CALTECH OPTICAL OBSERVATORIES / NASA JET PROPULSION LABORATORY PALM-3000 PROJECT

PALM-3000 Error Budget Summary (EBS)

CIN #626

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Revision Sheet

Revision No.	Date	Revision Description
Rev. 0.1	11/07/07	Initial draft based on the spreadsheet file "Wavefront Error Budget Tool v1.30"
Rev. 0.2	11/09/07	Updated Appendix tables and added Performance Summary section

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1 GENERAL INFORMATION

1.1 Purpose

This document is intended to outline the top-level wavefront error budget and associated detailed error budget flow-downs for the PALM-3000 system at different stages of its deployment (particularly for different TT WFS and guide star laser phases.)

1.2 Acronyms and Abbreviations

888Cam	The COO-built visible photon-counting camera (R. Dekany, PI) (named in honor of the successful June 2007 PALMAO + Cambridge LuckyCam experiments and a nod to the 2008 Beijing Olympic Summer Games)
AMNH	American Museum of Natural History
AO	Adaptive Optics
BTO	Beam transfer optics (for laser beam transport from Coude to Prime focus)
BVRIZ'YJHK	Johnson-Glass spectral bands (see table of definitions)
CCD50	E2V CCD model selected for PALM-3000 HO WFS
COO	Caltech Optical Observatories
CSFL	(University of) Chicago Sum-Frequency Laser
CW	Continuous Wave
CY	Calendar Year
DM	Deformable Mirror
EE	Ensquared Energy (never encircled energy in this document)
FoR	Field of Regard (usually the accessible sky patrol field of a sensor)
FoV	Field of View (usually the instantaneous field of view of a detector)
GS	Guide Star
HOWFS	High-order Wavefront Sensor
IAD	Instrument Architecture Document
IRD	Instrument Requirements Document
IRTT	Infrared Tip/Tilt Sensor
JPL	Jet Propulsion Laboratory
KBO	Kuiper Belt Object
LGS	Laser Guide Star
LOWFS	Low-Order Wavefront Sensor (for PALM-3000 indicating tip/tilt/focus sensing)
MASS/DIMM	A $C_n^2(h,t)$ profile and seeing measurement apparatus
MM	Macropulse/Micropulse
Na	Sodium
NGS	Natural Guide Star
NIR	Near Infrared (typically 0.9 to 2.5 microns)
P1640	The AMNH-built speckle-supression NIR integral field spectrograph (B. R. Oppenheimer, PI)
P18	The 18" telescope at Palomar, site of the P18 MASS/DIMM unit
РЗК	An abbreviation of PALM-3000

PALAO	The original NGS AO system at Palomar commissioned in December 1999
PALM-3000	The visible light AO upgrade to PALMAO
PALMAO	Upgrades to PALAO, particularly after the April 2003 upgrade
PALM LGS	The LGS upgrade to PALMAO, with first science in Summer 2007
PALM LGS+	The (potential) PALM LGS sodium laser upgrade from 6-8 W to 20-50 W or more via new technologies
PHARO	The Cornell-built NIR imager/slit spectrograph/coronagraph (T. Hayward and B. Brandl, PI's)
PMP	PALM-3000 Management Plan
PSF	Point Spread Function
QE	Quantum Efficiency
SR	Strehl Ratio
SRD	Science Requirements Document
SoAD	Software Architecture Document
SOR	Starfire Optical Range (Kirtland Air Force Base, Albuquerque, NM)
SoRD	Software Requirements Document
SWIFT	The Oxford-built visible integral field spectrograph (N. Thatte, PI)
TT	Tip/Tilt
TTF	Tip/Tilt/Focus
TTFA	Tip/Tilt/Focus/Astigmatism (often synonymous with TTF when describing LOWFS)
TTWFS	Tip/Tilt Wavefront Sensor
TWFS	Truth Wavefront Sensor
u'g'r'i'Z'YJHK	SDSS spectral bands
VIS	Visible (typically 0.38 to 1.0 microns)
WFE	Wavefront Error

1.3 Definitions

$C_n^2(h,t)$	Index of refraction structure function constant, a function of height, h, and time, t, describing the strength of atmospheric turbulence at differing heights in the atmosphere.
Equivalent 12W MM Laser Return	Based upon our experience with the 5-8W macropulse/micropulse Chicago Sum Frequency Laser, which has demonstrated to date a yearly average \sim 50 photons/sec/cm ² /W unadulterated sodium return, we assume that a 12W MM laser would return a total of 600 photons/sec/cm ² . (This is believed to correspond to \sim 4e9 atoms/cm ² sodium column density.) For total transmission to HOWFS = 0.28 (Section 2.2) and our CCD50 QE of 0.88, resulting in 148 e ⁻ /sec/cm ² in the HOWFS.
Equivalent 50W CW Laser Return	Based upon reported returns from the 50W-class SOR sum- frequency laser, yearly average ~100 photons/sec/cm ² /W unadulterated sodium return, we assume that a 50W CW laser would return a total of 5000 photons/sec/cm ² , where we assume no saturation, even for a small (1.7 arcsec FWHM) diameter sodium beacon. (This is believed to correspond to ~4e9 atoms/cm ² sodium column density.) For total transmission to HOWFS = 0.28 (Section 2.2) and our CCD50 QE of 0.88, resulting in 1,232 e ⁻ /sec/cm ² in the HOWFS.
r ₀	Fried's parameter, having median value at Palomar of 9.2 cm (based on CY2007 P18 DIMM data)
spaxel	An integral field spectrograph spatial element (analogous to a imaging pixel)
Unadulterated sodium return	The return from the sodium laser in photons/sec/cm ² /W where Watts are laser Watts reaching the mesospheric sodium layer, and photons are photons just departing the sodium layer, and cm ² are cm ² at the entrance pupil of the telescope.
1.4 Point of Contact	
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2 AO SYSTEM ASSUMPTIONS

2.1 PALM-3000 Implementation Stages

2.1.1 Interim Layout (April 2008 – December 2009)

As described in the P3K IAD, PALM-3000 will during this period work with all the existing PALM-LGS hardware, but will be realigned to allow for inclusion of SWIFT and P1640 (one at a time) onto the PALM optical bench.

In this phase, we assume a 12W current equivalent MM pulse laser return (Section 1.3)

2.1.2 PALM-3000 Phase I (May 2010 – December 2010)

During this period, PALM-3000 will operate with upgraded deformable mirror(s), new control computer, new RTC, and some other improvements. However, the LOWFS at this time will be the existing LOWFS, perhaps improved slightly (by reducing dark current via better heat management). For this EBS, we do *not* assume a reduction from 3x3 subaperture sampling to 2x2 subaperture sampling in the LOWFS.

In this phase, we assume a 12W current equivalent MM pulse laser return (Section 1.3).

2.1.3 PALM-3000 Phase II (May 2011 – Onward)

In this final phase, the visible light LOWFS will be augmented (or perhaps replaced) by a NIR tip/tilt sensor which will allow guiding on AO-sharpened tip/tilt stars to improve sky coverage for a given WFE or EE specification.

In this phase, we assume two different possible laser situations, one in which a 12W current equivalent MM pulse laser return is obtained, and another using a current equivalent return of the SOR 50W CW laser return (Section 1.3).

2.2 Optical Transmission

We assume the following transmission values for PALM-3000:

0.67 (assumes laser in Upper Coude Lab)
0.92
0.95
0.86 at 5 deg zenith angle
0.50 (half the power out of the laser itself)
0.86 at 5 deg zenith angle
0.64 (0.80 for both M1 and M2)
0.51 to CCD50
0.28
0.86 at 5 deg zenith angle
0.64 (0.80 for both M1 and M2)
0.55 to IRTT sensor
0.30

3 SCIENCE CASES

We elect to report our summary of error budget breakdown and performance predictions for a set of specific science programs that will be undertaken by the PALM-3000 system. We believe this is informative in identifying the individual limitations to science performance and provides guidance for particular cost/benefit decisions both in the implementation of the system and the long-term facility system maintenance and potential upgrade paths.

The key parameters for each of the considered science cases are shown in Table 1.

	Io surface geology	Hot, young exo-Jupiter NGS	Faint NGS science	Hot, young exo-Jupiter LGS	Dynamics of z = 1-2 galaxies	30% sky coverage science
HO GS Type	NGS	NGS	NGS	LGS	LGS	LGS
HO GS Brightness	m _V 5.0	m _V 7.0	m _V 16.0	12 W MM (50 W CW)	12 W MM (50 W CW)	12 W MM (50 W CW)
TT GS Distance (")				On-axis	16.8 (19.1)	38.6 (38.5)
TT GS Brightness (m _H)				9.2	14.6 (14.2)	16.9 (16.9)
Zenith Angle (degrees)	33	30	10	10	5	5
Galactic Latitude				30	30	60
NGS Color	G	М	K	М	М	М
NGS WFS Bands	g'r'i'Z	g'r'i'Z	g'r'i'Z	YJH	YJH	YJH
HO GS Intrinsic Diameter (")	1.1			1.0 Projection only ¹	1.0 Projection only	1.0 Projection only
HO WFS Spot Diameter for Centroiding (")	2.27	1.97	0.73	1.71	1.70	1.70
Field of View (evaluated at FoV edge)	0.5 arcsec	1.0 arcsec	5 arcsec	1.0 arcsec	4.0 arcsec	5.0 arcsec
Instrument	888Cam	P1640	PHARO	P1640	SWIFT	PHARO
Science Band	g'	Н	K	Н	Z	Н
Max Exposure Time (sec)	10	2	30	300	1800	300
Optimizations	HO Int Time	HO Int Time	HO Int Time	HO Int Time TT Int Time	HO Int Time TT Int Time TT GS Brightness TT GS Distance (maximize EE _z)	HO Int Time TT Int Time TT GS Brightness TT GS Distance to (maximize SR _H)

Table 1. Science case and observation parameters. For a list of acronyms, see Section 1.2.

¹ This size represents the combination of the intrinsic laser beam quality, beam transfer and launch telescope aberrations. It does not include atmospheric aberrations on the uplink or downlink, WFS subaperture diffraction, or charge diffusion (these are included in the subsequent table row "Spot Diameter for Centroiding"

4 PERFORMANCE SUMMARY

	Io surface geology	Hot, young exo-Jupiter NGS	Faint NGS science	Hot, young exo-Jupiter LGS	Dynar z = 1-2	nics of galaxies	30% sky cov (galactio	erage science c b = 60)		
Science Band (nm)	g'	Н	K	Н	Z 88	2 nm	Н			
Number of Subapertures per Pupil	64	64	8	16 (32)	16	16 (32)				
TT WFS Type	HOWFS	HOWFS	HOWFS	IRTT	IRTT	Visible LOWFS	IRTT	Visible LOWFS		
			Optimal	Frame Rates (2000 Max)					
HO WFS	2000	1755 ²	182	437 (826)	434 (815)	430 (796)	446 (894)	443 (839)		
TT WFS	2000	1755	182	500 (500)	184 (234)	82 (86)	25 (32)	12 (12)		
				Strehl Ratio						
g' 467 nm	22	23								
r' 616 nm	41	42								
i' 747 nm	55	56		(06)						
Y 1031 nm	72	73		13 (37)	(12)					
J 1250 nm	80	81		25 (51)	11 (22)	(06)				
H 1635 nm	87	88	8	45 (67)	25 (39)	09 (13)	(09)			
K 2200 nm	92	93	23	64 (80)	45 (58)	20 (24)	11 (18)			
			Ensquared	Energy (EE) in	Science Band					
80 mas	48	63	13	33 (49)	05 (16)	(06)	05 (10)			
160 mas	49	88	28	48 (70)	08 (24)	06 (17)	19 (33)	06 (07)		
240 mas	50	89	34	50 (73)	12 (27)	11 (25)	33 (53)	12 (15)		
Optimizations	HO Int Time (Maximize SR _{g'})	HO Int Time (Maximize SR _H)	HO Int Time (Maximize SR _H)	HO Int Time TT Int Time (Maximize SR _H)	HO & TT TT GS Brightn (Maxim	Int Time ess & Distance ize EE _z)	HO & TT TT GS Brightn (Maxim	Tht Time ess & Distance ize SR _H)		

Table 2. PALM-3000 Performance Summary. Table values for LGS cases are for 12W MM equivalent return³ laser and for 50W CW equivalent return⁴ laser guide star (results in parentheses). The rightmost column shows that 30% sky coverage is not obtained with equivalent 12W MM laser return and the interim LOWFS. For a full list of acronyms, see Section 1.2.

³ Unadulterated sodium return of 600 photons/sec/cm²; 148 e⁻/sec/cm² detected in HOWFS.

 $^{^{2}}$ System settings that optimize contrast will differ from those that minimize residual wavefront error (shown here). PALM-3000 has set an IRD goal of 3,000 Hz operation because it is believed this will help mitigate relatively long-lived 'system latency speckles' that evolve only with wind-crossing time.

⁴ Unadulterated sodium return of 5,000 photons/sec/cm²; 1,232 e⁻/sec/cm² detected in HOWFS (see Sections 1.3 and 2.2.)

5 PARAMETRIC STUDIES

5.1 Performance vs. r₀

One of the features of LGS AO systems that surprise astronomers familiar with NGS AO systems is the stronger dependency of performance on seeing. To first order, because the LGS spot size is degraded in poor seeing conditions, wavefront sensing quality degrades with seeing, leading to a double degradation of the wavefront correction (which itself degrades with seeing, even given perfect wavefront information.) For a sufficiently large surface brightness beacon, some robustness of performance can be achieved, but for a 12 W equivalent MM laser return performance degrades rapidly at worse than median seeing conditions at Palomar, as shown in Figure 1.



Figure 1. Ensquared Energy vs. r_0 for the science case 'Dynamics of Z=1 Galaxies w/ Equivalent 12 W MM Laser Return & Interim LOWFS', as will be seen in the Interim Layout phase of PALM-3000. Three curves show the EE for The descending curve (associated with the right axis) shows the residual RMS tip/tilt error in millarcseconds, which is seen to be generally small compared to SWIFT's set of spaxial sizes. As seeing improves, benefit to EE comes from both lower tip/tilt error and improved concentration of higher-order wavefront errors.

5.2 Performance vs. Month for CY 2007 Conditions

Given the careful recording of photometric and environmental conditions at Palomar during calendar year (CY) 2007, it is interesting to ask what PALM-3000 performance might have been expected to be obtained during each of the CY2007 LGS science and engineering runs. Similar to the result in Section 5.1, we find in Figure 2 that the PALM-3000 ensquared energy in a 240 mas spaxel with 12W equivalent MM laser return is largely insufficient for reliable science use in winter conditions, when seeing is typically worse than median (1.1 arcsec FWHM).



Figure 2. Example PALM-3000 + SWIFT Z-Band (882 nm) Performance vs. Month based upon CY2007 MASS/DIMM seeing and Na abundance estimated from measured CSFL mesospheric photoreturn⁵. The bottommost (dashed) curve represents the 240 mas spaxel EE for seeing-limited PSF. The middle (solid) curve represents what might have been seen in the same spaxel with PALM-3000 (interim LOWFS) with

⁵ A. Bouchez, private communication – seeing estimates based on P18 DIMM data.

an equivalent 12W MM laser return. The topmost (dotted) curve represents what might have been seen with PALM-3000 (interim LOWFS) with an equivalent 50W CW laser return. Notice that even though P3K is laser photon starved with 12W MM laser return, expected performance depend more strongly upon the natural seeing than sodium abundance (Not only is AO NGS performance a strong function of seeing, but so is LGS spot size, making LGS performance particularly sensitive to seeing). In this simulation, there is no (optical pumping-based) spot-size dependency on photoreturn from the mesosphere.



Figure 3. Example PALM-3000 + SWIFT Z-Band (882 nm) Performance vs. Month under the same scenario as in Figure 2, but describing the Ensquared Energy in a 80 mas diameter spaxel.

5.3 Performance vs. Sky Fraction

PALM-3000 will be usable to some performance level over the entire viewable sky. However, the delivered performanced will be a function of the availability of sufficiently bright TT guide stars. A prediction of performance vs. sky fraction, along with the associated TT guide star parameters, is shown in Figure 4 using the planned IRTT sensor. The corresponding (lesser) performance curve using the interim LOWFS in shown in Figure 5.



Figure 4. PALM-3000 performance vs. sky fraction r_0 for the science case 'Dynamics of Z=1 Galaxies w/ Equivalent 12 W MM Laser Return' using the IRTT sensor. The three horizontal lines represent the seeing-limited EE for 240 mas, 160 mas, and 80 mas spaxels (top to bottom).



Figure 5. PALM-3000 performance vs. sky fraction r_0 for the science case 'Dynamics of Z=1 Galaxies w/ Equivalent 12W MM Laser Return' using the interim LOWFS sensor. The three horizontal lines represent the seeing-limited EE for 240 mas, 160 mas, and 80 mas spaxels (top to bottom).

6 APPENDIX: DETAILED ERROR BUDGETS

6.1 Near-IR TT WFS Budgets

6.1.1 Io surface geology with P3K NGS

Palomar Wavefront Error Budget Su	mmary	Version 1.30					Scie	ence E	Band			
Mode: P3K NGS	-			u'	q'	r'	i'	Ζ	Y	J	Н	К
Instrument: 888Cam			λ (μ m)	0.36	0.47	0.62	0.75	0.88	1.03	1.25	1.64	2.20
Observation: Io			δλ (μm)	0.06	0.14	0.14	0.15	0.12	0.12	0.16	0.29	0.34
			λ/D (mas)	15	20	27	32	38	45	54	71	95
		Wavefront					Stret	nl Rati	io (%)			
High-order Errors (NGS Mode)		Error (rms)	Parameter				•		• (/0)			
Atmospheric Fitting Error		41 nm	64 Subaps									
Bandwidth Error		32 nm	133 Hz (-3db)									
High-order Measurement Error		31 nm	5 mV 1 patural guido star									
Asterism Deformation Error		0 nm	0.50 m LLT									
Multispectral Error		22 nm	33 zenith angle, H band									
Scintillation Error		18 nm	0.46 Scint index, H-band									
WES Scintillation Error	68 nm	10 nm	Alloc									
Uncorrectable Static Telescope Aberrations	001	14 nm	64 Acts									
Uncorrectable Dynamic Telescope Aberrations		0 nm	Dekens Ph.D									
Static WFS Zero-point Calibration Error		25 nm	Alloc									
Leaky Integrator Zero-point Calibration Error		20 nm 15 nm	Alloc									
Go-to Control Errors		0 nm	Alloc									
Residual Na Layer Focus Change		0 nm	30 m/s Na layer vel									
DM Finite Stroke Errors		29 nm	5.5 um P-P stroke									
DM Hysteresis High-Order Aliasing Error		7 nm 9 nm	from TMT 64 Subaps									
DM Drive Digitization		1 nm	16 bits									
Uncorrectable AO System Aberrations		20 nm	Alloc									
Uncorrectable Instrument Aberrations		20 nm	888Cam Instrument									
DM-to-lenslet Misregistration		15 nm	Alloc									
Division april ocale Error	60 nm	10 1111	Alloc									
Angular Anisoplanatism Error		12 nm	0.5 arcsec									
Total High Order Wavefront Error	91 nm	92 nm	High Order Strehl	0.11	0.28	0.47	0.60	0.69	0.76	0.83	0.89	0.93
	Angular	Equivalent	Doromotor				Streh	I ratio	os (%)			
Tip/Tilt Errors	Angular Error (rms)	Equivalent WFE (rms)	Parameter				Streh	I ratio	os (%)			
Tip/Tilt Errors	Angular Error (rms)	Equivalent WFE (rms)	Parameter				Streh	nl ratio	os (%)			
Tip/Tilt Errors Sci Filt Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis)	Angular Error (rms) er 0.60 mas 2.26 mas	Equivalent WFE (rms) 5 nm 18 nm	Parameter 3.5 mag (mH) 36 4 Hz (-3db)				Streh	I ratio	os (%)			
Tip/Tilt Errors Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis)	Angular Error (rms) er 0.60 mas 2.26 mas 0.00 mas	Equivalent WFE (rms) 5 nm 18 nm 0 nm	Parameter 3.5 mag (mH) 36.4 Hz (-3db) 0.0 arcsec				Streh	nl ratio	os (%)			
Tip/Tilt Errors Sci Filt Tilt Measurement Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism	Angular Error (rms) er 0.60 mas 2.26 mas 0.00 mas 0.00 mas	Equivalent WFE (rms) 5 nm 18 nm 0 nm	Parameter 3.5 mag (mH) 36.4 Hz (-3db) 0.0 arcsec NGS x reduction				Streh	I ratio	os (%)			
Tip/Tilt Errors Sci Filt Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion Residual Atmospheric Dispersion Indruced Data Scale Deformations	Angular Error (rms) er 0.60 mas 2.26 mas 0.00 mas 3.58 mas 0.28 mas	Equivalent WFE (rms) 5 nm 18 nm 0 nm 0 nm 31 nm 2 nm	Parameter 3.5 mag (mH) 36.4 Hz (-3db) 0.0 arcsec NGS x reduction 20 x reduction -1500 m coni beint				Streh	I ratio	os (%)			
Tip/Tilt Errors Sci Filt Tilt Bandwidth Error (one-axis) Tilt Bandwidth Error (one-axis) Titt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion Induced Plate Scale Deformations Science Instrument Mechanical Drift	Angular Error (rms) er 0.60 mas 2.26 mas 0.00 mas 0.00 mas 3.58 mas 0.28 mas 0.28 mas	Equivalent WFE (rms) 5 nm 18 nm 0 nm 0 nm 31 nm 2 nm 1 nm	Parameter 3.5 mag (mH) 36.4 Hz (-3db) 0.0 arcsec NGS x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min				Streh	I ratio	os (%)			
Tip/Tilt Errors Sci Filt Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisopilanatism Error (one-axis) Residual Centroid Anisopilanatism Residual Atmospheric Dispersion Residual Atmospheric Dispersion Science Instrument Mechanical Drift Long Exposure Field Rotation Errors	Angular Error (rms) er 0.60 mas 2.26 mas 0.00 mas 3.58 mas 0.28 mas 0.08 mas 0.08 mas	Equivalent WFE (rms) 5 nm 18 nm 0 nm 0 nm 31 nm 2 nm 1 nm 0 nm	Parameter 3.5 mag (mH) 36.4 Hz (-3db) 0.0 arcsec NGS x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min				Streh	nl ratio	os (%)			
Tip/Tilt Errors Sci Filt Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion r' Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis)	Angular Error (rms) er 0.60 mas 2.26 mas 0.00 mas 0.00 mas 3.58 mas 0.28 mas 0.08 mas 0.08 mas 0.08 mas 0.016 mas	Equivalent WFE (rms) 5 nm 18 nm 0 nm 0 nm 31 nm 2 nm 1 nm 1 nm	Parameter 3.5 mag (mH) 36.4 Hz (-3db) 0.0 arcsec NGS x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance				Stref	Il ratio	os (%)			
Tip/Tilt Errors Sci Filt Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Centroid Anisoplanatism Residual Atmospheric Dispersion r' Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis)	Angular Error (rms) er 0.60 mas 2.26 mas 0.00 mas 0.00 mas 0.28 mas 0.28 mas 0.08 mas 0.08 mas 0.08 mas 0.00 mas 0.36 mas 0.28 mas 0.00 mas 0.16 mas	Equivalent WFE (rms) 5 nm 18 nm 0 nm 31 nm 2 nm 1 nm 1 nm 36 nm	Parameter 3.5 mag (mH) 36.4 Hz (-3db) 0.0 arcsec NGS x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tin/Tilt Strehl	0.69	0.80	0.87	Streh	0.93	0.95	0.97	0.98	0.99
Tip/Tilt Errors Sci Fill Tilt Bandwidth Error (one-axis) Sci Fill Tilt Andwidth Error (one-axis) Residual Centroid Anisoplanatism Error (one-axis) Residual Atmospheric Dispersion r' Induced Plate Scale Deformations science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Tip/Tilt Error (one-axis)	Angular Error (rms) er 0.60 mas 2.26 mas 0.00 mas 0.00 mas 0.28 mas 0.28 mas 0.28 mas 0.28 mas 0.00 mas 0.16 mas 0.16 mas 0.16 mas	Equivalent WFE (rms) 5 nm 18 nm 0 nm 0 nm 2 nm 1 nm 1 nm 1 nm 36 nm	Parameter 3.5 mag (mH) 3.6.4 Hz (-3db) 0.0 arcsec NGS x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl	0.69	0.80	0.87	Streh 0.91	0.93	os (%) 0.95	0.97	0.98	0.99
Tip/Tilt Errors Sci Fill Tilt Bandwidth Error (one-axis) Sci Fill Tilt Andwidth Error (one-axis) Residual Centroid Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism (r) Residual Centroid Anisoplanatism (r) Induced Plate Scale Deformations r' Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis)	Angular Error (rms) er 0.60 mas 2.26 mas 0.00 mas 0.00 mas 0.28 mas 0.28 mas 0.28 mas 0.08 mas 0.16 mas 4.3 mas	Equivalent WFE (rms) 5 nm 18 nm 0 nm 2 nm 2 nm 1 nm 1 nm 36 nm	Parameter 3.5 mag (mH) 36.4 Hz (-3db) 0.0 arcsec NGS x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strohl (%)	0.69	0.80	0.87	Streh	0.93	0.95 0.72	0.97	0.98	0.99
Tip/Tilt Errors Sci Fill Tilt Bandwidth Error (one-axis) Sci Fill Tilt Andwidth Error (one-axis) Residual Centroid Anisoplanatism Error (one-axis) Residual Atmospheric Dispersion r' Induced Plate Scale Deformations science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error	Angular Error (rms) er 0.60 mas 2.26 mas 0.00 mas 0.00 mas 0.28 mas 0.28 mas 0.28 mas 0.08 mas 0.16 mas 4.3 mas	Equivalent WFE (rms) 5 nm 18 nm 0 nm 0 nm 2 nm 1 nm 1 nm 36 nm 36 nm	Parameter 3.5 mag (mH) 36.4 Hz (-3db) 0.0 arcsec NGS x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%)	0.69	0.80	0.87	Streh 0.91 0.55	0.93 0.64	0.95 0.72	0.97	0.98	0.99
Tip/Tilt Errors Sci Filt Tilt Bandwidth Error (one-axis) Sci Filt Tilt Andwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism For (one-axis) Residual Centroid Anisoplanatism Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error	Angular Error (rms) er 0.60 mas 2.26 mas 0.00 mas 0.00 mas 0.28 mas 0.28 mas 0.28 mas 0.28 mas 0.00 mas 0.16 mas 4.3 mas	Equivalent WFE (rms) 5 nm 18 nm 0 nm 0 nm 2 nm 1 nm 1 nm 1 nm 36 nm 92 nm	Parameter 3.5 mag (mH) 3.6.4 Hz (-3db) 0.0 arcsec NGS x reduction 2.0 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%)	0.69	0.80	0.87	Streh 0.91 0.55	0.93 0.64	0.95 0.72	0.97	0.98	0.99
Tip/Tilt Errors Sci Filt Tilt Bandwidth Error (one-axis) Sci Filt Tilt Bandwidth Error (one-axis) Residual Centroid Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism (Provided Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error	Angular Error (rms) er 0.60 mas 2.26 mas 0.00 mas 0.00 mas 0.00 mas 0.28 mas 0.28 mas 0.08 mas 0.01 mas 0.16 mas 0.43 mas	Equivalent WFE (rms) 5 nm 18 nm 0 nm 0 nm 2 nm 1 nm 1 nm 36 nm 36 nm	Parameter 3.5 mag (mH) 3.6.4 Hz (-3db) 0.0 arcsec NGS x reduction 2.0 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%)	0.69	0.80	0.87 0.41 80 0.48	0.91 0.55 160 0.49	0.93 0.64 240 0.50	0.95 0.72 480 0.57	0.97 0.80 1000	0.98	0.99 0.92 880 0.80
Tip/Tilt Errors Sci Filt Tilt Bandwidth Error (one-axis) Sci Filt Tilt Bandwidth Error (one-axis) Residual Centroid Anisopianatism Error (one-axis) Residual Atmospheric Dispersion r' Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy r'	Angular Error (rms) er 0.60 mas 2.26 mas 0.00 mas 0.00 mas 0.00 mas 0.28 mas 0.28 mas 0.28 mas 0.00 mas 0.16 mas 4.3 mas	Equivalent WFE (rms) 5 nm 18 nm 0 nm 0 nm 2 nm 1 nm 0 nm 1 nm 36 nm 36 nm	Parameter 3.5 mag (mH) 3.6.4 Hz (-3db) 0.0 arcsec NGS x reduction 2.0 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.69 0.08 50 0.45	0.80 0.22 70 0.48	0.87 0.41 80 0.48	Stref 0.91 0.55 160 0.49	0.93 0.64 240 0.50	0.95 0.72 480 0.57	0.97 0.80 1000	0.98	0.99 0.92 880 0.80
Tip/Tilt Errors Sci Filt Tilt Bandwidth Error (one-axis) Sci Filt Tilt Bandwidth Error (one-axis) Residual Centroid Anisopianatism Error (one-axis) Residual Atmospheric Dispersion r' Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy r' Sky Coverage Galactic Lat.	Angular Error (rms) er 0.60 mas 2.26 mas 0.00 mas 0.28 mas 0.28 mas 0.28 mas 0.08 mas 0.08 mas 0.08 mas 0.016 mas 1.16 mas	Equivalent WFE (rms) 5 nm 18 nm 0 nm 2 nm 2 nm 1 nm 0 nm 1 nm 36 nm 36 nm	Parameter 3.5 mag (mH) 3.6.4 Hz (-3db) 0.0 arcsec NGS x reduction 2.0 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.69 0.08 50 0.45	0.80 0.22 70 0.48	0.87 0.41 80 0.48	0.91 0.55 160 0.49	0.93 0.64 240 0.50	0.95 0.72 480 0.57	0.97 0.80 1000 #####	0.98	0.99 0.92 880 0.80
Tip/Tilt Errors Sci Fill Tilt Madix Error (one-axis) Sci Fill Tilt Andividit Error (one-axis) Residual Centroid Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism (Provide Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy r Sky Coverage Galactic Lat. Corresponding Sky Coverage	Angular Error (rms) er 0.60 mas 2.26 mas 0.00 mas 0.08 mas 0.28 mas 0.28 mas 0.28 mas 0.00 mas 0.16 mas 4.3 mas	Equivalent WFE (rms) 5 nm 18 nm 0 nm 2 nm 2 nm 1 nm 1 nm 36 nm 92 nm	Parameter 3.5 mag (mH) 36.4 Hz (-3db) 0.0 arcsec NGS x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the	0.69 0.08 50 0.45	0.80 0.22 70 0.48	0.87 0.41 80 0.48	Streh 0.91 0.55 160 0.49	0.93 0.64 240 0.50	0.95 0.72 480 0.57	0.97 0.80 1000	0.98	0.99 0.92 880 0.80
Tip/Tilt Errors Sci Fill Tilt Bandwidth Error (one-axis) Sci Fill Tilt Bandwidth Error (one-axis) Residual Centroid Anisoplanatism Error (one-axis) Residual Atmospheric Dispersion r' Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy r Sky Coverage Gelactic Lat. Corresponding Sky Coverage Assumptions / Parameters	Angular Error (rms) er 0.60 mas 2.26 mas 0.00 mas 0.28 mas 0.28 mas 0.28 mas 0.28 mas 0.08 mas 0.00 mas 0.16 mas 4.3 mas	Equivalent WFE (rms) 5 nm 18 nm 0 nm 2 nm 2 nm 1 nm 1 nm 36 nm 36 nm 92 nm	Parameter 3.5 mag (mH) 36.4 Hz (-3db) 0.0 arcsec NGS x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the	0.69 0.08 0.45	0.80 0.22 70 0.48	0.87 0.41 0.48 WFE sho	Streh 0.91 0.55 160 0.49	0.93 0.64 240 0.50	0.95 0.72 480 0.57	0.97	0.98	0.99 0.92 880 0.80
Tip/Tilt Errors Sci Filt Tilt Bandwidth Error (one-axis) Sci Filt Tilt Bandwidth Error (one-axis) Residual Centroid Anisopianatism Error (one-axis) Residual Atmospheric Dispersion r' Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy r' Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters	Angular Error (rms) er 0.60 mas 2.26 mas 0.00 mas 0.28 mas 0.28 mas 0.28 mas 0.28 mas 0.08 mas 0.08 mas 0.16 mas 1.16 mas 3.0 deg	Equivalent WFE (rms) 5 nm 18 nm 0 nm 2 nm 1 nm 1 nm 36 nm 36 nm 92 nm	Parameter 3.5 mag (mH) 3.6.4 Hz (-3db) 0.0 arcsec NGS x reduction 2.0 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the	0.69 0.08 50 0.45 ∍ Total E	0.80 0.22 70 0.48	0.87 0.41 80 0.48 WFE sho	0.91 0.55 160 0.49	0.93 0.64 240 0.50	0.95 0.72 480 0.57	0.97	0.98	0.99 0.92 880 0.80
Tip/Tilt Errors Sci Fill Tilt Measurement Error (one-axis) Sci Fill Tilt Analogital Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion r' Induced Plate Scale Deformations science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy r' Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters 10 0.083 m	Angular Error (rms) er 0.60 mas 2.26 mas 0.00 mas 0.00 mas 0.28 mas 0.28 mas 0.28 mas 0.28 mas 0.16 mas 0.16 mas 0.16 mas 3.0 deg	Equivalent WFE (rms) 5 nm 18 nm 0 nm 0 nm 1 nm 1 nm 1 nm 36 nm 36 nm 92 nm 92 nm	Parameter 3.5 mag (mH) 3.6.4 Hz (-3db) 0.0 arcsec NGS x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.69 0.08 50 0.45 * Total E	0.80 0.22 70 0.48	0.87 0.41 80 0.48 WFE sho	0.91 0.55 160 0.49	0.93 0.64 240 0.50	0.95 0.72 480 0.57	0.97	0.98	0.99 0.92 880 0.80
Tip/Tilt Errors Sci Fill Tilt Measurement Error (one-axis) Sci Fill Tilt Bandwidth Error (one-axis) Residual Centroid Anisoplanatism Error (one-axis) Residual Atmospheric Dispersion r' Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy r' Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.083 m Theta0_eff 1.49 arcse0	Angular Error (rms) er 0.60 mas 2.26 mas 0.00 mas 0.00 mas 0.28 mas 0.28 mas 0.28 mas 0.08 mas 0.16 mas 0.16 mas 0.16 mas 3.0 deg 30 deg	Equivalent WFE (rms) 5 nm 18 nm 0 nm 2 nm 1 nm 1 nm 1 nm 36 nm 92 nm 92 nm Und Speed 9.54 004er Scale 165 Ad Perd 0 00%	Parameter 3.5 mag (mH) 3.6.4 Hz (-3db) 0.0 arcsec NGS x reduction 2.0 x reduction -1500 m conj height Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle m HO WFS Rate arromin HO WFS Rate	0.69 0.08 50 0.45	0.80 0.22 70 0.48	0.87 0.41 80 0.48 WFE sho	Streh 0.91 0.55 160 0.49 wm	0.93 0.64 240 0.50	0.95 0.72 480 0.57	0.97	0.98	0.99 0.92 880 0.80
Tip/Tilt Errors Sci Filt Tilt Bandwidth Error (one-axis) Sci Filt Tilt Bandwidth Error (one-axis) Residual Centroid Anisoplanatism Error (one-axis) Residual Atmospheric Dispersion r' Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy r' Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.083 m Theta0_eff 1.49 arcsec Science Target: SCA0	Angular Error (rms) er 0.60 mas 2.26 mas 0.00 mas 0.28 mas 0.28 mas 0.28 mas 0.28 mas 0.28 mas 0.28 mas 0.16 mas 1.16 mas 3.0 deg	Equivalent WFE (rms) 5 nm 18 nm 0 nm 0 nm 1 nm 2 nm 1 nm 36 nm 92 nm 0 nm 0 nm 0 nm 1 nm 36 nm 92 nm Und Speed 9.54 Outer Scale 75 LGS Ast. Rad. 0.00%	Parameter 3.5 mag (mH) 3.6.4 Hz (-3db) 0.0 arcsec NGS x reduction 2.0 x reduction -1500 m conj height Alloc 0.25 mas / min Spaxel Diameter (mas) This fraction of sky can be corrected to the mis Zenith Angle m HO WFS Rate arcmin HO WFS Rate arcmin HO WFS Rate	0.69 0.08 50 0.45 33 2000 6.5. YES	0.80 0.22 70 0.48 ffective V deg Hz e-rms	0.87 0.41 80 0.48 WFE sho	0.91 0.55 160 0.49 wm	0.93 0.64 240 0.50	0.95 0.72 480 0.57	0.97 0.80 1000 #####	0.98	0.99 0.92 880 0.80
Tip/Tilt Errors Sci Filt Tilt Bandwidth Error (one-axis) Sci Filt Titt Bandwidth Error (one-axis) Residual Centroid Anisoplanatism Error (one-axis) Residual Atmospheric Dispersion r' Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy r' Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.083 m Theta0_eff 1.49 arcsec Sodium Abund. 4 x 10" Science Target: NGS	Angular Error (rms) er 0.60 mas 2.26 mas 0.00 mas 0.00 mas 0.28 mas 0.28 mas 0.08 mas 0.08 mas 0.00 mas 0.16 mas 4.3 mas 30 deg	Equivalent WFE (rms) 5 nm 18 nm 0 nm 0 nm 1 nm 1 nm 1 nm 36 nm 92 nm 92 nm 0.0% Vind Speed 9.54 Outer Scale 75 LGS Ast. Rad. 0.00 HOWFS Trans 0.23	Parameter 3.5 mag (mH) 3.6.4 Hz (-3db) 0.0 arcsec NGS x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m's Zenith Angle m HO WFS Rate arcmin HO WFS Noise HO WFS Noise HO WFS Noise HO WFS Noise HO WFS Noise	0.69 0.08 50 0.45 * Total E 2000 6.5 2000	0.80 0.22 70 0.48 ffective V Hz e - rms	0.87 0.41 0.48 0.48 WFE sho	0.91 0.55 160 0.49 wm using using	0.93 0.64 240 0.50 ccD50 ccD50	0.95 0.72 480 0.57	0.97	0.98	0.99 0.92 880 0.80
Tip/Tilt Errors Sci Fill Tilt Measurement Error (one-axis) Sci Fill Tilt Bandwidth Error (one-axis) Residual Centroid Anisoplanatism Error (one-axis) Residual Atmospheric Dispersion r' Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy r' Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.083 m Theta0_eff 1.49 arcsec Socience Target: SCAO LOWFS Star Type: G	Angular Error (rms) er 0.60 mas 2.26 mas 0.00 mas 0.00 mas 0.28 mas 0.28 mas 0.28 mas 0.28 mas 0.16 mas 0.03 mas 0.16 mas 0.16 mas 3.0 deg 30 deg	Equivalent WFE (rms) 5 nm 18 nm 0 nm 0 nm 1 nm 2 nm 36 nm 36 nm 92 nm Und Speed 9.54 Outer Scale 9.54 USS Ast Rad. 0.00 HOWFS Trans 0.23 Num 3x3 0	Parameter 36.4 (Hz (-3db) 0.0 arcsec NGS x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min 3 Hz input disturbuance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle m HO WFS Noise HOWFS sant-aliasing LO WFS Noise LO WFS Noise HOWFS noise	0.69 0.08 50 0.45 • Total E 33 2000 6.5 YES 2000 6.5	0.80 0.22 70 0.48 ffective V deg Hz e - rms	0.87 0.41 80 0.48 WFE sho	Streth 0.91 0.55 160 0.49 wm using using	0.93 0.64 240 0.50 CCD50	0.95 0.72 480 0.57	0.97	0.98	0.99 0.92 880 0.80

Table 3. Error budget performance prediction for Io surface geology science case. This budget is dominated by the many uncorrectable internal aberration and calibration error terms, which might be reduced with optimized algorithms or calibration techniques.

6.1.2 Hot, Young Exo-Jupiters (NGS mode) with P3K NGS

Palomar W	Vavefront Error Budget Sun	nmary	Version 1.30					Scie	ence E	Band			
Mode:	P3K NGS				u'	g'	r'	i'	Ζ	Y	J	Н	Κ
Instrument:	P1640			λ (μ m)	0.36	0.47	0.62	0.75	0.88	1.03	1.25	1.64	2.20
Observation:	Exo Jup NGS			δλ (μm)	0.06	0.14	0.14	0.15	0.12	0.12	0.16	0.29	0.34
				λ/D (mas)	15	20	27	32	38	45	54	71	95
			Wavefront					Stret	nl Rati	o (%)			
High-order E	Errors (NGS Mode)		Error (rms)	Parameter				•		• (/0)			
Atmospheri	ic Fitting Error		40 nm	64 Subaps									
Bandwidth B	Error		35 nm	117 Hz (-3db)									
High-order I	Measurement Error		37 nm	6 mV									
Asterism De	eformation Error		0 nm	0.50 m LLT									
Multispectra	al Error		22 nm	30 zenith angle, H band									
Scintillation	Error		17 nm	0.44 Scint index, H-band									
WFS Scintil	llation Error	71 nm	10 nm	Alloc									
Uncorrectat	ble Static Telescope Aberrations	7.1.1011	14 nm	64 Acts									
Uncorrectat	ble Dynamic Telescope Aberrations		0 nm	Dekens Ph.D									
Static WFS	Zero-point Calibration Error		25 nm	Alloc									
Dynamic W	FS Zero-point Calibration Error		20 nm	Alloc									
Go-to Contr	rol Errors		0 nm	Alloc									
Residual Na	a Layer Focus Change		0 nm	30 m/s Na layer vel									
DM Finite S	Stroke Errors		29 nm	5.5 um P-P stroke									
DM Hystere	esis		7 nm	from TMT									
High-Order	Allasing Error		9 nm 1 nm	64 Subaps 16 bits									
Uncorrectat	ble AO System Aberrations		20 nm	Alloc									
Uncorrectat	ble Instrument Aberrations		2 nm	P1640 Instrument									
DM-to-lensl	let Misregistration		15 nm	Alloc									
DM-to-lensl	let Pupil Scale Error	57 nm	15 nm	Alloc									
Angular Ani	isoplanatism Error	57 1111	21 nm	1 arcsec									
Total Hi	igh Order Wavefront Error	91 nm	94 nm	High Order Strehl	0.10	0.26	0.45	0.58	0.68	0.75	0.82	0.88	0.93
	20	Angular	Equivalent	Paramotor				Streh	I ratio	os (%)			
				E AL ALLIGION									
Tip/Tilt Erro	15	Error (rms)	WFE (rms)	T arameter									
	Sci Filter	Error (rms)	WFE (rms)										
Tilt Measure	Sci Filter ement Error (one-axis) dth Error (one-axis)	0.69 mas	WFE (rms) 6 nm 19 nm	2.2 mag (mH)									
Tilt Measure Tilt Bandwid Tilt Anisopla	Sci Filter ement Error (one-axis) dth Error (one-axis) anatism Error (one-axis)	0.69 mas 2.39 mas 0.00 mas	WFE (rms) 6 nm 19 nm 0 nm	2.2 mag (mH) 35.0 Hz (-3db) 0.0 arcsec									
Tilt Measure Tilt Bandwic Tilt Anisopla Residual Ce	Sci Filter ement Error (one-axis) dth Error (one-axis) anatism Error (one-axis) entroid Anisoplanatism	0.69 mas 2.39 mas 0.00 mas 0.00 mas	WFE (rms) 6 nm 19 nm 0 nm 0 nm	2.2 mag (mH) 35.0 Hz (-3db) 0.0 arcsec NGS x reduction									
Tilt Measure Tilt Bandwid Tilt Anisopla Residual Ce Residual At	Sci Filter ement Error (one-axis) dth Error (one-axis) anatism Error (one-axis) entroid Anisophanatism tmospheric Dispersion H	Error (rms) 0.69 mas 2.39 mas 0.00 mas 0.00 mas 0.34 mas	WFE (rms) 6 nm 19 nm 0 nm 0 nm 3 nm	2.2 mag (mH) 35.0 Hz (-3db) 0.0 arcsec NGS x reduction 20 x reduction									
Tilt Measure Tilt Bandwid Tilt Anisople Residual Ce Residual At Induced Pla	so Sci Filter ement Error (one-axis) dth Error (one-axis) anatism Error (one-axis) entroid Anisoplanatism imospheric Dispersion H ate Scale Deformations trument Mechanical Drift	Error (rms) 0.69 mas 2.39 mas 0.00 mas 0.00 mas 0.34 mas 0.57 mas 0.02 mas	WFE (rms) 6 nm 19 nm 0 nm 3 nm 5 nm 0 nm	2.2 mag (mH) 3.5.0 Hz (-3db) 0.0 arcsec NGS x reduction 20 x reduction -1500 m conj height Alloc 0.25 mag / min									
Tilt Measure Tilt Measure Tilt Ansopla Residual Ce Residual At Induced Pla Science Ins Long Expos	Sci Filter ement Error (one-axis) dth Error (one-axis) anatism Error (one-axis) entroid Anisoplanatism mrospheric Dispersion H ate Scale Deformations strument Mechanical Drift ure Field Rolation Errors	Error (rms) 0.69 mas 2.39 mas 0.00 mas 0.00 mas 0.34 mas 0.57 mas 0.02 mas 0.00 mas	WFE (rms) 6 nm 19 nm 0 nm 3 nm 5 nm 0 nm	2.2 mag (mH) 3.5.0 Hz (-3db) 0.0 arcsec NGS x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min									
Tilt Measure Tilt Measure Tilt Bandwid Tilt Anisopla Residual At Induced Pla Science Ins Long Expos Residual Te	s Sci Filter ement Error (one-axis) dth Error (one-axis) antism Error (one-axis) entroid Anisopianatism mospheric Dispersion H dte Scale Deformations firument Mechanical Drift sure Field Rotation Errors bescope Pointing Jitter (one-axis)	Error (rms) 0.69 mas 2.39 mas 0.00 mas 0.34 mas 0.57 mas 0.02 mas 0.00 mas 0.16 mas	WFE (rms) 6 nm 19 nm 0 nm 3 nm 5 nm 0 nm 0 nm 1 nm	2.2 mag (mH) 3.5 0 Hz (-3db) 0.0 arcsec NGS x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance									
Tilt Measure Tilt Measure Tilt Bandwid Tilt Anisople Residual At Induced Pla Science Induced Pla Science Induced Pla Science Induced Pla Science Induced Pla Science Induced Pla	Sci Filter ement Error (one-axis) dth Error (one-axis) anatism Error (one-axis) entroid Anisopianatism imospheric Dispersion H ate Scale Deformations trument Mechanical Drift sure Field Rotation Errors elescope Pointing Jitter (one-axis)	Error (rms) 0.69 mas 2.39 mas 0.00 mas 0.00 mas 0.34 mas 0.57 mas 0.02 mas 0.00 mas 0.16 mas 2.6 mas	WFE (rms) 6 nm 19 nm 0 nm 3 nm 5 nm 0 nm 1 nm 22 nm	2.2 mag (mH) 35.0 Hz (-3db) 0.0 arcsec NGS x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tin/Tiit Strabl	0.86	0.92	0.95	0.97	0.97	0.98	0.99	0.99	1.00
Tip/Titt Error Titt Measure Titt Bandwic Residual CC Residual XL Induced Pla Science Ins Long Expos Residual Te Total Ti	Sci Filter ement Error (one-axis) dth Error (one-axis) anatism Error (one-axis) entroid Anisopianatism imospheric Dispersion H ate Scale Deformations trument Mechanical Drift sure Field Rotation Errors elescope Pointing Jitter (one-axis) p/Tilt Error (one-axis)	Error (rms) 0.69 mas 2.39 mas 0.00 mas 0.00 mas 0.34 mas 0.67 mas 0.02 mas 0.00 mas 0.16 mas 2.6 mas	WFE (rms) 6 nm 9 nm 0 nm 3 nm 5 nm 0 nm 1 nm 1 nm 22 nm	2.2 mag (mH) 35.0 Hz (-3db) 0.0 arcsec NGS x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl	0.86	0.92	0.95	0.97	0.97	0.98	0.99	0.99	1.00
Tith Measure Titt Bandwir Titt Bandwir Residual Cr Residual Ar Induced Pia Science Ins Long Expos Residual Te Total Tit	Sci Filter ement Error (one-axis) dh Error (one-axis) anatism Error (one-axis) enroid Anisopianatism imospheric Dispersion H ate Scale Deformations trument Mechanical Drift sure Field Rotation Errors alescope Pointing Jitter (one-axis) p/Tilt Error (one-axis) ive Wavefront Error	Error (rms) 0.69 mas 0.39 mas 0.00 mas 0.00 mas 0.44 mas 0.57 mas 0.02 mas 0.00 mas 0.16 mas 2.6 mas	WFE (rms) 6 nm 0 nm 0 nm 3 nm 5 nm 0 nm 1 nm 2 nm 22 nm 94 nm	2.2 mag (mH) 35.0 Hz (-3db) 0.0 arcsec NGS x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%)	0.86	0.92	0.95	0.97	0.97	0.98	0.99	0.99	1.00
Titl Measure Titl Bandwin Titl Bandwin Titl Bandwin Titl Bandwin Titl Bandwin Residual At Induced Pia Science Ins Long Expos Residual Te Total Titl Total Effecti	Sci Filter ement Error (one-axis) dth Error (one-axis) anatism Error (one-axis) entroid Anisopianatism imospheric Dispersion H ate Scale Deformations trument Mechanical Drift sure Field Rotation Errors eleescope Pointing Jitter (one-axis) p/Tilt Error (one-axis) ive Wavefront Error	Error (rms) 0.69 mas 0.09 mas 0.00 mas 0.00 mas 0.07 mas 0.57 mas 0.02 mas 0.00 mas 0.16 mas 2.6 mas	WFE (rms) 6 nm 0 nm 0 nm 3 nm 5 nm 0 nm 0 nm 1 nm 22 nm 94 nm	2.2 mag (mH) 3.5.0 Hz (-3db) 0.0 arcsec NGS x reduction 2.0 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%)	0.86	0.92	0.95	0.97	0.97	0.98	0.99	0.99	1.00
Titl Measure Titl Bandwir Titl Bandwir Titl Anisopie Residual At Induced Pia Science Ins Cong Expos Residual Te Total Effecti	Sci Filter ement Error (one-axis) dth Error (one-axis) anatism Error (one-axis) entroid Anisoplanatism imospheric Dispersion H ate Scale Deformations trument Mechanical Drift sure Field Rotation Errors eleescope Pointing Jitter (one-axis) p/Tilt Error (one-axis) ive Wavefront Error	Error (rms) 0.69 mas 2.39 mas 0.00 mas 0.00 mas 0.07 mas 0.57 mas 0.02 mas 0.07 mas 0.16 mas 2.6 mas	WFE (rms) 6 nm 19 nm 0 nm 3 nm 5 nm 0 nm 0 nm 1 nm 22 nm 94 nm	2.2 mag (mH) 3.5.0 Hz (-3db) 0.0 arcsec NGS x reduction 2.0 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.86	0.92	0.95	0.97	0.97	0.98	0.99	0.99	1.00
Tip/Tilt Error Tilt Measur Tilt Bandwi Tilt Anisopi Residual 74 Science Ins Long Expos Residual 75 Total Effecti	Sci Filter ement Error (one-axis) antism Error (one-axis) entroid Anisoplanatism imospheric Dispersion H ate Scale Deformations strument Mechanical Drift sure Field Rotation Errors eleescope Pointing Jitter (one-axis) p/Tilt Error (one-axis) ive Wavefront Error Energy H	Error (rms) 0.69 mas 2.39 mas 0.00 mas 0.00 mas 0.07 mas 0.57 mas 0.02 mas 0.02 mas 0.00 mas 0.16 mas 2.6 mas	WFE (rms) 6 nm 19 nm 0 nm 3 nm 5 nm 0 nm 0 nm 1 nm 22 nm 94 nm	2.2 mag (mH) 3.5.0 Hz (-33b) 0.0 arcsec NGS x reduction 2.0 x reduction -1500 m conj height Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.86 0.08 50 0.34	0.92 0.23 70 0.54	0.95 0.43 80 0.63	0.97 0.56 160 0.88	0.97 0.66 240 0.89	0.98 0.73 480 0.91	0.99 0.81 1000 0.94	0.99	1.00 0.93 110 0.80
Tip/ Tilt Error Tilt Measure Tilt Bandwir Residual CA Residual At Residual At Residual At Induce Pia Science Ins Long Expos Residual At Total Effecti Ensquared I	Sci Filter ement Error (one-axis) antism Error (one-axis) entroid Anisoplanatism imospheric Dispersion H ate Scale Deformations strument Mechanical Drift sure Field Rotation Errors eleescope Pointing Jitter (one-axis) p/Tilt Error (one-axis) ive Wavefront Error Energy H	Error (rms) 0.69 mas 2.39 mas 0.00 mas 0.00 mas 0.07 mas 0.57 mas 0.02 mas 0.02 mas 0.16 mas 2.6 mas	WFE (rms) 6 nm 19 nm 0 nm 3 nm 5 nm 0 nm 0 nm 1 nm 22 nm 94 nm	2.2 mag (mH) 3.5.0 Hz (-33b) 0.0 arcsec NGS x reduction 2.0 x reduction -1500 m conj height Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.86 0.08 50 0.34	0.92 0.23 70 0.54	0.95 0.43 80 0.63	0.97 0.56 160 0.88	0.97 0.66 240 0.89	0.98 0.73 480 0.91	0.99 0.81 1000 0.94	0.99	1.00 0.93 110 0.80
Titl Measure Titl Bandwir Titl Bandwir Titl Anisopie Residual CA Residual At Induced Pia Science Ins Long Expos Residual Te Total Effecti Ensquared I Sky Coverage	Sci Filter ement Error (one-axis) dth Error (one-axis) anatism Error (one-axis) entroid Anisoplanatism imospheric Dispersion H ate Scale Deformations trument Mechanical Drift sure Field Rotation Errors eleescope Pointing Jitter (one-axis) p/Tilt Error (one-axis) ive Wavefront Error Energy H ge Galactic Lat.	Error (rms) 0.69 mas 2.39 mas 0.00 mas 0.00 mas 0.57 mas 0.57 mas 0.02 mas 0.78 mas 0.28 mas 0.28 mas 0.26 mas 2.6 mas 30 deg	WFE (rms) 6 nm 19 nm 0 nm 1 nm 22 nm 94 nm	2.2 mag (mH) 3.5.0 Hz (-3db) 0.0 arcsec NGS x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.86 0.08 50 0.34	0.92 0.23 70 0.54	0.95 0.43 80 0.63	0.97 0.56 160 0.88	0.97 0.66 240 0.89	0.98 0.73 480 0.91	0.99 0.81 1000 0.94	0.99	1.00 0.93 110 0.80
Tip/ Tit Error Tit Measure Tit Bandwir Residual CA Residual CA Residual CA Residual A Science Ins Long Expos Residual Te Total Effecti Ensquared I Sky Coverag Corresp	Sci Filter ement Error (one-axis) dth Error (one-axis) antism Error (one-axis) entroid Anisoplanatism imospheric Dispersion H ate Scale Deformations trument Mechanical Drift sure Field Rotation Errors eleescope Pointing Jitter (one-axis) p/Tilt Error (one-axis) ive Wavefront Error Energy H ge Galactic Lat. bonding Sky Coverage	Error (rms) 0.69 mas 2.39 mas 0.00 mas 0.00 mas 0.07 mas 0.57 mas 0.07 mas 0.07 mas 0.16 mas 0.16 mas 2.6 mas 30 deg	WFE (rms) 6 nm 0 nm 0 nm 3 nm 5 nm 0 nm 0 nm 1 nm 22 nm 94 nm 0.0%	2.2 mag (mH) 3.5.0 Hz (-3db) 0.0 arcsec NGS x reduction 2.0 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the	0.86 0.08 50 0.34	0.92 0.23 70 0.54	0.95 0.43 80 0.63	0.97 0.56 160 0.88	0.97 0.66 240 0.89	0.98 0.73 480 0.91	0.99 0.81 1000 0.94	0.99	1.00 0.93 110 0.80
Tip/ Tit Error Tit Measur Tit Bandwi Tit Anisopic Residual At Induced Pia Science Ins Long Expos Residual Te Total Effecti Ensquared I Sky Coverag Corresp Assumption	Sci Filter ement Error (one-axis) dth Error (one-axis) anatism Error (one-axis) entroid Anisopianatism imospheric Dispersion H ate Scale Deformations attrument Mechanical Drift sure Field Rotation Errors aleascope Pointing Jitter (one-axis) p/Titt Error (one-axis) p/Titt Error (one-axis) ive Wavefront Error Energy H ge Galactic Lat. boonding Sky Coverage as / Parameters	Error (rms) 0.69 mas 0.00 mas 0.00 mas 0.04 mas 0.57 mas 0.02 mas 0.07 mas 0.07 mas 0.02 mas 0.08 mas 2.6 mas 30 deg	WFE (rms) 6 nm 0 nm 0 nm 3 nm 5 nm 0 nm 0 nm 1 nm 22 nm 94 nm 0.0%	2.2 mag (mH) 350 Hz (-3db) 0.0 arcsec NGS x reduction 20 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.86 0.08 50 0.34	0.92 0.23 70 0.54	0.95 0.43 80 0.63	0.97 0.56 160 0.88	0.97 0.66 240 0.89	0.98 0.73 480 0.91	0.99	0.99	1.00 0.93 110 0.80
Titl Measure Titl Measure Titl Bandwit Residual CA Residual At Residual At Residual At Residual At Residual At Residual At Total Effecti Ensquared I Sky Coverag Corresp Assumption	Sci Filter ement Error (one-axis) antism Error (one-axis) entroid Anisopianatism imospheric Dispersion H ate Scale Deformations trument Mechanical Drift sure Field Rotation Errors eleescope Pointing Jitter (one-axis) p/Tilt Error (one-axis) p/Tilt Error (one-axis) ive Wavefront Error Energy H ge Galactic Lat. boonding Sky Coverage is / Parameters r0 0.084 m	Error (rms) 0.69 mas 2.39 mas 0.00 mas 0.00 mas 0.07 mas 0.57 mas 0.02 mas 0.07 mas 0.16 mas 0.16 mas 2.6 mas 30 deg at this zenith	WFE (rms) 6 nm 0 nm 1 nm 22 nm 94 nm	2.2 mag (mH) 35.0 Hz (-3db) 0.2 arcsec NGS x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the	0.86 0.08 50 0.34	0.92 0.23 70 0.54	0.95 0.43 80 0.63	0.97 0.56 160 0.88	0.97 0.66 240 0.89	0.98 0.73 480 0.91	0.99 0.81 1000 0.94	0.99	1.00 0.93 110 0.80
Titl Measure Titl Bandwir Titl Bandwir Titl Bandwir Residual At Residual At Residual At Residual Te Total Effecti Ensquared B Sky Coverag Corresp Assumption	Sci Filter ement Error (one-axis) anatism Error (one-axis) anatism Error (one-axis) entroid Anisoplanatism imospheric Dispersion H ate Scale Deformations trument Mechanical Drift sure Field Rotation Errors aleascope Pointing Jitter (one-axis) p/Tilt Error (one-axis) p/Tilt Error (one-axis) ive Wavefront Error Energy H ge Galactic Lat. boonding Sky Coverage is / Parameters r0 0.084 m Theta0 eff 1.57 arrsee	Error (rms) 0.69 mas 2.39 mas 0.00 mas 0.00 mas 0.57 mas 0.57 mas 0.22 mas 0.00 mas 0.16 mas 2.6 mas 30 deg 30 deg at this zenith at this zenith	WFE (rms) 6 nm 19 nm 0 nm 1 nm 22 nm 94 nm 0.0%	2.2 mag (mH) 35.0 Hz (-330b) 0.0 arcsec NGS x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m	0.86 0.08 50 0.34	0.92 0.23 70 0.54	0.95 0.43 80 0.63	0.97 0.56 160 0.88	0.97 0.66 240 0.89	0.98 0.73 480 0.91	0.99 0.81 1000 0.94	0.99	1.00 0.93 110 0.80
Titl Measure Titl Bandwir Titl Bandwir Residual CR Residual At Induced Pia Science Ins Long Expos Residual Te Total Effecti Total Effecti Sky Coverag Corresp Assumption	Sci Filter ement Error (one-axis) dth Error (one-axis) anatism Error (one-axis) enroid Anisopianatism imospheric Dispersion H ate Scale Deformations attrument Mechanical Drift sure Field Rotation Errors alesscope Pointing Jitter (one-axis) p/Tilt Error (one-axis) p/Tilt Error (one-axis) ive Wavefront Error Energy H ge Galactic Lat. bonding Sky Coverage is / Parameters r0 0.084 m Theta0_eff 1.57 arcsec Sodium Abund. 4 x 10 ⁹	Error (rms) 0.69 mas 0.09 mas 0.00 mas 0.00 mas 0.44 mas 0.57 mas 0.02 mas 0.00 mas 0.66 mas 0.16 mas	WFE (rms) 6 nm 9 nm 0 nm 1 nm 22 nm 94 nm 0.0%	2.2 mag (mH) 35.0 Hz (-3db) 0.0 arcsec NGS x reduction 20 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas 7 min Alloc 0.25 mas 7 min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle m HO WFS Rate arcmin HO WFS Rate arcmin HO WFS Noise	0.86 0.08 50 0.34	0.92 0.23 70 0.54 ffective V deg Hz e-rms	0.95 0.43 80 0.63 VFE sho	0.97 0.56 160 0.88 wn	0.97 0.66 240 0.89	0.98 0.73 480 0.91	0.99 0.81 1000 0.94	0.99	1.00 0.93 110 0.80
Tip/ Tilt Error Tilt Measur Tilt Bandwi Tilt Anisopic Residual At Residual At Residual At Science Ins Long Expos Residual At Total Effecti Ensquared I Sky Coverag Corresp Assumption	Sci Filter ement Error (one-axis) antism Error (one-axis) antism Error (one-axis) entroid Anisopianatism imospheric Dispersion H ate Scale Deformations trument Mechanical Drift sure Field Rotation Errors eleescope Pointing Jitter (one-axis) p/Tilt Error (one-axis) p/Tilt Error (one-axis) ive Wavefront Error Energy H ge Galactic Lat. bonding Sky Coverage is / Parameters r0 0.084 m Theta0_eff 1.57 arcsec Sodium Abund. 4 x 10 ⁶ Science Target: SCAO	Error (rms) 0.69 mas 2.39 mas 0.00 mas 0.00 mas 0.07 mas 0.57 mas 0.02 mas 0.16 mas 0.16 mas 2.6 mas 30 deg 30 deg at this zenith at this zenith at oms/cm ²	WFE (rms) 6 nm 19 nm 0 nm 1 nm 22 nm 94 nm 0.0%	2.2 mag (mH) 35.0 Hz (-3db) 0.2 arcsec NGS x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle m H0 WFS Rate arcmin H0 WFS Noise	0.86 0.08 50 0.34 Total El 30 1755 6.2 YES	0.92 0.23 70 0.54 ffective V deg Hz e-rms	0.95 0.43 80 0.63 VFE shor	0.97 0.56 160 0.88 wm	0.97 0.66 240 0.89	0.98 0.73 480 0.91	0.99	0.99	1.00 0.93 110 0.80
Titl Measur Titl Bandwi Titl Bandwi Titl Bandwi Titl Bandwi Residual At Residual At Residual At Residual Te Science Ins Long Expos Residual Te Total Effecti Ensquared I Sky Coverag Corresp Assumption	Sci Filter ement Error (one-axis) anatism Error (one-axis) anatism Error (one-axis) entroid Anisoplanatism imospheric Dispersion H ate Scale Deformations strument Mechanical Drift sure Field Rotation Errors eleescope Pointing Jitter (one-axis) p/Tilt Error (one-axis) p/Tilt Error (one-axis) ive Wavefront Error Energy H ge Galactic Lat. bonding Sky Coverage is / Parameters r0 0.084 m Theta0_eff 1.57 arcsec Sodium Abund. 4 x 10 ⁹ Science Target: SCAO LOWFS Target: NGS	Error (rms) 0.69 mas 2.39 mas 0.00 mas 0.00 mas 0.00 mas 0.77 mas 0.27 mas 0.27 mas 0.27 mas 0.26 mas 2.6 mas 30 deg 30 deg at this zenith at this zenith at mas	WFE (rms) 6 nm 19 nm 0 nm 1 nm 22 nm 94 nm 94 nm Uter Scale 75 LGS Ast. Rad. 0.24 HOWFS Trans 0.24	2.2 mag (mH) 35.0 Hz (-3db) 0.0 arcsec NGS x reduction 2.0 x reduction -1500 m conj height Alloc 0.25 mas / min A	0.86 0.08 50 0.34 Total Ef 300 1755 6.2.2 YES 1755 50 50	0.92 0.23 70 0.54 ffective V deg Hz e-rms Hz	0.95 0.43 80 0.63 VFE sho	0.97 0.56 0.88 wn using using	0.97 0.66 240 0.89 CCD50	0.98 0.73 480 0.91	0.99	0.99	1.00 0.93 110 0.80
Tip/ Tilt Error Tilt Measur Tilt Bandwi Tilt Bandwi Tilt Bandwi Tilt Bandwi Tilt Bandwi Tilt Bandwi Residual A Residual A Total Effecti Ensquared I Sky Coverag Corresp	Sci Filter ement Error (one-axis) antism Error (one-axis) antism Error (one-axis) entroid Anisoplanatism imospheric Dispersion the Scale Deformations strument Mechanical Drift sure Field Rotation Errors elescope Pointing Jitter (one-axis) p/Tilt Error (one-axis) p/Tilt Error (one-axis) ge Gelactic Lat. conding Sky Coverage is / Parameters r0 0.084 m Theta0_eff 1.57 arcsec Sodium Abund. 4 x 10° Science Target: SCAO LOWFS Star Type: M Max Exposure Time 2 sec	Error (rms) 0.69 mas 2.39 mas 0.00 mas 0.00 mas 0.00 mas 0.34 mas 0.27 mas 0.02 mas 0.00 mas 0.66 mas 2.6 mas 30 deg 30 deg 30 deg 30 deg Num TTF 0 Num TTF 0 Num TTF 0	WFE (rms) 6 nm 0 nm 0 nm 0 nm 3 nm 5 nm 0 nm 0 nm 0 nm 0 nm 1 nm 22 nm 94 nm 0uter Scale 75 LGS Ast. Red. 0.00% Num 3x3 0.xum HOWFS 1	22 mag (mH) 35.0 H2 (-3db) 0.0 arcsec NGS x reduction 20 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Ho WFS Rate arcmin HO WFS Rate HOWFS notise HOWFS notise HOWFS notise LO WFS Notise Max mechanical tiotith m	0.86 0.08 50 0.34 Total El 755 6.2 YES 1755 6.2 YES 1755 6.2 YES	0.92 0.23 70 0.54 ffective V deg Hz e-rms Hz e-rms	0.95 0.43 80 0.63 VFE sho SH NGS h	0.97 0.56 160 0.88 wn using using 50	0.97 0.66 240 0.89 CCD50 CCD50	0.98 0.73 480 0.91	0.99	0.99	1.00 0.93 110 0.80

Table 4. Error budget performance prediction for hot, young exo-Jupiters (NGS mode) science case. Here, we do include the potential calibration benefit of the JPL-built P1640 calibration unit, which could reduce all calibration errors (within frequencies of interest) to a few nm rms.

6.1.3 Faint NGS with P3K NGS

Paiomar Wavefront Error Budget Sun	nmary	Version 1.30					Scie	nce E	Band			
Mode: P3K NGS	-			u'	g'	r'	i'	Ζ	Y	J	Н	K
Instrument: PHARO			λ (μm)	0.36	0.47	0.62	0.75	0.88	1.03	1.25	1.64	2.20
Observation: Faint NGS			δλ (μm)	0.06	0.14	0.14	0.15	0.12	0.12	0.16	0.29	0.34
			λ/D (mas)	15	20	27	32	38	45	54	71	95
									(0/)			
High-order Errors (NGS Mode)		Wavefront	Parameter				Streh	il Rati	o (%)			
		Error (rms)										
Atmospheric Fitting Error		213 nm	8 Subaps									
High-order Measurement Error		202 nm	12 Hz (-500)									
LGS Tomography Error		0 nm	1 natural guide star									
Asterism Deformation Error		0 nm	0.50 m LLT									
Multispectral Error		19 nm	10 zenith angle, H band									
WES Scintillation Error		14 nm 10 nm	0.34 Scint Index, H-band									
	368 nm	10 1111	Alloc									
Uncorrectable Static Telescope Aberrations		14 nm	64 Acts									
Uncorrectable Dynamic Telescope Aberrations		0 nm	Dekens Ph.D									
Static WFS Zero-point Calibration Error		25 nm	Alloc									
Leaky Integrator Zero-point Calibration Error		20 nm 15 nm	Alloc									
Go-to Control Errors		0 nm	Alloc									
Residual Na Layer Focus Change		0 nm	30 m/s Na layer vel									
DM Finite Stroke Errors		19 nm	5.5 um P-P stroke									
UM Hysteresis High Order Aliacing Error		7 nm	Trom TMT									
DM Drive Digitization		4/ nm 1 nm	8 Subaps 16 hits									
Uncorrectable AO System Aberrations		20 nm	Alloc									
Uncorrectable Instrument Aberrations		38 nm	PHARO Instrument									
DM-to-lenslet Misregistration		15 nm	Alloc									
DM-to-lenslet Pupil Scale Error	90 nm	15 nm	Alloc									
Angular Anisoplanatism Error	00 1111	68 nm	5 arcsec									
Total High Order Wavefront Error	276 nm	202 nm	Link Orden Ctaski	0.00	0.00		0.00	0.00	0.00	0.03	0 12	0.00
Total high order wavenont Ellor	370 1111	302 1111	High Order Streni	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.12	0.30
	Angular	502 min	High Order Streni	0.00	0.00	0.00	0.00	l ratio	0.00 s (%)	0.05	0.12	0.30
Tip/Tilt Errors	Angular Error (rms)	Equivalent WFE (rms)	Parameter	0.00	0.00	0.00	Streh	l ratic	os (%)	0.00	0.12	0.30
Tip/Tilt Errors	Angular Error (rms)	Equivalent WFE (rms)	Parameter	0.00	0.00	0.00	Streh	l ratic	os (%)	0.05	0.12	0.30
Tip/Tilt Errors Till Measurement Error (one-axis) Till Beadwidth Error (one-axis)	Angular Error (rms)	Equivalent WFE (rms)	Parameter	0.00	0.00	0.00	Streh	l ratio	os (%)	0.00	0.12	0.30
Tip/Tilt Errors Sci Filter Tilt Bandwidt Error (one-axis) Tilt Bandwidt Error (one-axis) Tilt Bandwidt Error (one-axis) Tilt Anisonlanatism Error (one-axis)	Angular Error (rms) 19.49 mas 9.27 mas 0.00 mas	Equivalent WFE (rms)	Parameter 12.8 mag (mH) 9.8 Hz (-3db) 0.0 arcsec	0.00	0.00	0.00	Streh	l ratio	0.00 ps (%)	0.03	0.12	0.30
Tip/Tilt Errors Sci Filter Till Measurement Error (one-axis) Till Bandwidth Error (one-axis) Till Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism	Angular Error (rms) 19.49 mas 9.27 mas 0.00 mas 0.00 mas	Equivalent WFE (rms) 151 nm 75 nm 0 nm	Parameter 12.8 mag (mH) 9.8 Hz (-3db) 0.0 arcsec NGS x reduction	0.00	0.00	0.00	Streh	l ratio	os (%)	0.03	0.12	0.30
Tip/Tilt Errors Till Measurement Error (one-axis) Till Bandwidth Error (one-axis) Till Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion K	Angular Error (rms) 19.49 mas 9.27 mas 0.00 mas 0.00 mas 0.05 mas	Equivalent WFE (rms) 151 nm 75 nm 0 nm 0 nm 0 nm	Parameter 12.8 mag (mH) 9.8 Hz (-3db) 0.0 arcsec NGS x reduction 20 x reduction	0.00	0.00	0.00	Streh	l ratio	os (%)	0.03	0.12	0.30
Tip/Tilt Errors Sci Filter Tilt Beadwidth Error (one-axis) Tilt Ansoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion Induced Plate Scale Deformations	Angular Error (rms) 19.49 mas 9.27 mas 0.00 mas 0.00 mas 0.05 mas 2.84 mas	Equivalent WFE (rms) 151 nm 75 nm 0 nm 0 nm 0 nm 23 nm	Parameter 12.8 mag (mH) 9.8 Hz (-3db) 0.0 arcsec NGS x reduction 20 x reduction -1500 m conj height	0.00	0.00	0.00	Streh	l ratic	os (%)	0.03	0.12	0.30
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Atmospheric Dispersion Residual Atmospheric Dispersion Science Instrument Mechanical Drift Science Instrument Mechanical Drift	Angular Error (rms) 19.49 mas 9.27 mas 0.00 mas 0.05 mas 0.28 mas 0.25 mas	Equivalent WFE (rms) 151 nm 75 nm 0 nm 0 nm 0 nm 2 nm 2 nm 2 nm	Parameter 12.8 mag (mH) 9.8 Hz (-3db) 0.0 arcsec NGS x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min	0.00	0.00	0.00	Streh	l ratic	os (%)	0.03	0.12	0.30
Tip/Tilt Errors Till Measurement Error (one-axis) Till Anisoplanatism Error (one-axis) Till Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion K Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescore Pointing. Jitter (one-axis)	Angular Error (rms) 19.49 mas 9.27 mas 0.00 mas 0.00 mas 0.05 mas 2.84 mas 0.25 mas 0.00 mas	Equivalent WFE (rms) 151 nm 0 nm 0 nm 0 nm 23 nm 2 nm 0 nm 5 nm	Parameter 12.8 mag (mH) 9.8 Hz (-3db) 0.0 arcsec NGS x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz innut disturbance	0.00	0.00	0.00	Streh	l ratic	os (%)	0.03	0.12	0.30
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Anadwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion K Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Filed Rotation Errors Residual Telescope Pointing Jitter (one-axis)	Angular Error (rms) 19.49 mas 0.00 mas 0.00 mas 0.05 mas 0.25 mas 0.00 mas 0.00 mas	Equivalent WFE (rms) 151 nm 75 nm 0 nm 0 nm 23 nm 2 nm 0 nm 5 nm	Parameter 12.8 mag (mH) 9.8 Hz (-3db) 0.0 arcsec NGS x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min 3 Hz input disturbance		0.00	0.00	Streh	l ratic	os (%)	0.03	0.12	0.30
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion K Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis)	Angular Error (rms) 19.49 mas 9.27 mas 0.00 mas 0.05 mas 0.25 mas 0.25 mas 0.59 mas 2.18 mas	302 mm Equivalent WFE (rms) 151 nm 0 nm 0 nm 0 nm 2 nm 2 nm 5 nm	Parameter 12.8 mag (mH) 9.8 Hz (-3db) 0.0 arcsec NGS x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl	0.00	0.13	0.00	0.00 Streh	0.35	0.43	0.52	0.65	0.30
Tip/Tilt Errors Til Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Residual Centroid Anisoplanatism Residual Atmospheric Dispersion K Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis)	Angular Error (ms) 19.49 mas 9.27 mas 0.00 mas 0.05 mas 2.24 mas 0.25 mas 0.25 mas 0.59 mas 21.8 mas	362 mm Equivalent WFE (rms) 151 nm 0 nm 0 nm 23 nm 2 nm 5 nm 178 nm	Parameter 12.8 mag (mH) 9.8 Hz (-3db) 0.0 arcsec NGS x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl	0.00	0.00	0.00	0.00 Streh	0.35	0.43	0.52	0.65	0.30
Tip/Tilt Errors Sci Filter Til Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion K Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis)	Angular Error (rms) 19.49 mas 0.00 mas 0.00 mas 0.05 mas 0.25 mas 0.59 mas 21.8 mas	Soz min Equivalent WFE (rms) 151 nm 0 nm 0 nm 0 nm 23 nm 0 nm 5 nm 151 nm 151 nm 0 nm 10 nm 2 nm 0 nm 178 nm	Parameter 12.8 mag (mH) 9.8 Hz (-3db) 0.0 arcsec NGS x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl	0.00	0.13	0.00	0.00 Streh	0.00 I ratic	0.43	0.52	0.65	0.30
Tip/Tilt Errors Til Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Centroid Anisoplanatism Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis)	Angular Error (rms) 19.49 mas 9.27 mas 0.00 mas 0.05 mas 0.25 mas 0.25 mas 0.00 mas 0.25 mas 0.25 mas 0.25 mas 2.1.8 mas	362 mm Equivalent WFE (rms) 151 nm 0 nm 0 nm 0 nm 23 nm 2 nm 5 nm 178 nm 422 nm	Parameter 12.8 mag (mH) 9.8 H2 (-3db) 0.0 arcsec NGS x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%)	0.00	0.00	0.00	0.00 Streh	0.00 I ratic	0.43 0.00	0.52	0.65	0.77
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Residual Atmospheric Dispersion K Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis)	Angular Error (ms) 19.49 mas 9.27 mas 0.00 mas 0.05 mas 2.24 mas 0.25 mas 0.59 mas 21.8 mas	362 mm Equivalent WFE (rms) 151 nm 75 nm 0 nm 0 nm 2 nm 2 nm 5 nm 178 nm 422 nm	Parameter 12.8 mag (mH) 9.8 Hz (-3db) 0.0 arcsec NGS x reduction 20 x reduction -1500 m corj height Allec 0.25 mas / min Allec 0.25 mas / min Allec 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%)	0.00	0.13	0.00	0.00 Streh 0.28	0.35 0.00	0.43 0.00	0.52	0.65	0.30
Tip/Tilt Errors Sci Filter Tit Measurement Error (one-axis) Titt Bandwidth Error (one-axis) Titt Bandwidth Error (one-axis) Titt Anisoplanatism Residual Atmospheric Dispersion K Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error	Angular Error (rms) 19.49 mas 9.27 mas 0.00 mas 0.05 mas 0.25 mas 0.26 mas 0.26 mas 0.39 mas 21.8 mas	362 mm Equivalent WFE (rms) 151 nm 75 nm 0 nm 0 nm 2 nm 2 nm 5 nm 178 nm 422 nm	Parameter 12.8 mag (mH) 9.8 Hz (-3db) 0.0 arcsec NGS x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min All	0.00	0.13	0.00	0.00 Streh 0.28 0.00	0.00 I ratic 0.35 0.00	0.43 0.00 480	0.52	0.65	0.30
Tip/Tilt Errors Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Residual Atmospheric Dispersion K Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy	Angular Error (rms) 19.49 mas 9.27 mas 0.00 mas 0.05 mas 0.25 mas 0.25 mas 0.59 mas 21.8 mas	362 mm Equivalent WFE (rms) 151 nm 75 nm 0 nm 0 nm 2 nm 5 nm 178 nm 422 nm	Parameter 12.8 mag (mH) 9.8 Hz (-3db) 0.0 arcsec NGS x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min All	0.00 0.08 0.00 50 0.06	0.13 0.00 70 0.10	0.00 0.21 0.00 80 0.13	0.00 Streh 0.28 0.00 160 0.28	0.35 0.00 240 0.34	0.43 0.00 480 0.45	0.52 0.01 1000 0.72	0.65	0.30 0.77 0.23 1180 0.80
Tip/Tilt Errors Sci Filter Till Measurement Error (one-axis) Sci Filter Till Bandwidth Error (one-axis) Till Bandwidth Error (one-axis) Residual Centroid Ansoplanatism Residual Centroid Ansoplanatism Residual Atmospheric Dispersion K Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy κ Sky Coverage Galactic Lat.	Angular Error (rms) 19.49 mas 9.27 mas 0.00 mas 0.05 mas 0.25 mas 0.25 mas 0.59 mas 21.8 mas 21.8 mas	362 mm Equivalent WFE (rms) 151 nm 75 nm 0 nm 0 nm 2 nm 2 nm 5 nm 178 nm 422 nm	Parameter 12.8 mag (mH) 9.8 Hz (-3db) 0.0 arcsec NGS x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.00	0.13 0.00 70 0.10	0.21 0.00 80 0.13	0.00 Streh 0.28 0.00 160 0.28	0.00 I ratic 0.35 0.00 240 0.34	0.43 0.00 480 0.45	0.52 0.01 1000 0.72	0.65	0.30 0.77 0.23 1180 0.80
Tip/Tilt Errors Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Residual Centroid Anisoplanatism Residual Atmospheric Dispersion K Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy κ Sky Coverage Galactic Lat. Corresponding Sky Coverage Galactic Lat.	Angular Error (rms) 19.49 mas 9.27 mas 0.00 mas 0.05 mas 0.25 mas 0.59 mas 21.8 mas 21.8 mas 30 deg	362 mm Equivalent WFE (rms) 151 nm 0 nm 0 nm 0 nm 2 nm 2 nm 178 nm 178 nm 422 nm	Parameter 12.8 mag (mH) 9.8 Hz (-3db) 0.0 arcsec NGS x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.08 0.08 0.00 50 0.06	0.13 0.00 70 0.10	0.21 0.00 80 0.13	0.28 0.00 160 0.28	0.00 I ratic 0.35 0.00 240 0.34	0.43 0.43 0.00 480 0.45	0.52 0.01 1000 0.72	0.65	0.77 0.23 1180 0.80
Tip/Tilt Errors Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Residual Atmospheric Dispersion K Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy K Sky Coverage Galactic Lat. Corresponding Sky Coverage Galactic Lat.	Angular Error (rms) 19.49 mas 9.27 mas 0.00 mas 0.05 mas 0.25 mas 0.25 mas 0.59 mas 21.8 mas 21.8 mas	382 mm Equivalent WFE (rms) 151 nm 0 nm 0 nm 2 nm 2 nm 2 nm 5 nm 178 nm 422 nm	Parameter 12.8 mag (mH) 9.8 Hz (-3db) 0.0 arcsec NGS x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 ma	0.08 0.00 0.00 0.00	0.13 0.00 70 0.10	0.21 0.00 80 0.13	0.28 0.00 0.28 0.00 160 0.28	0.35 0.35 0.00	0.43 0.43 0.00 480 0.45	0.52 0.01 1000 0.72	0.65	0.77 0.23 1180 0.80
Tip/Tilt Errors Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Residual Centroid Anisoplanatism Residual Atmospheric Dispersion K Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy κ Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters	Angular Error (rms) 19.49 mas 9.27 mas 0.00 mas 0.05 mas 0.25 mas 0.25 mas 0.59 mas 21.8 mas 21.8 mas	382 mm Equivalent WFE (rms) 151 nm 75 nm 0 nm 0 nm 2 nm 5 nm 178 nm 422 nm 0.0%	Parameter 12.8 mag (mH) 9.8 Hz (-3db) 0.0 arcsec NGS x reduction -1500 m conj height Alico 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the	0.00 0.08 0.00 50 0.06	0.13 0.00 70 0.10	0.21 0.00 80 0.13	0.28 0.00 160 0.28	0.35 0.35 0.00 0.34	0.43 0.00 480 0.45	0.52	0.65	0.77 0.23 1180 0.80
Tip/Tilt Errors Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Residual Atmospheric Dispersion K Induced Plate Scale Deforming Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Tip/Tilt Error (one-axis) Total Tip/Tilt Error (one-axis) Ensquared Energy K Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.001 m	Angular Error (rms) 19.49 mas 9.27 mas 0.00 mas 0.05 mas 0.25 mas 0.25 mas 0.25 mas 0.29 mas 21.8 mas 30 deg	362 mm Equivalent WFE (rms) 151 nm 75 nm 0 nm 0 nm 2 nm 0 nm 178 nm 178 nm 0.0%	High Order Streni Parameter 12.8 mag (mH) 9.8 Hz (-3db) 9.8 Hz (-3db) 0.0 arcsec NGS x reduction -20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the	0.00 0.08 0.00 50 0.00	0.13 0.00 70 0.10	0.21 0.00 80 0.13	0.28 0.28 0.00 160 0.28	0.35 0.35 0.00 240 0.34	0.00 0.43 0.00 480 0.45	0.52 0.01 1000 0.72	0.65	0.77 0.23 1180 0.80
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Sci Filter Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Residual Atmospheric Dispersion K Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy κ Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.091 m Thetal off 1.92 arcsec	Angular Error (ms) 19.49 mas 9.27 mas 0.00 mas 0.05 mas 2.24 mas 0.25 mas 0.25 mas 0.59 mas 21.8 mas 21.8 mas 30 deg 30 deg	362 mm Equivalent WFE (rms) 151 nm 75 nm 0 nm 0 nm 2 nm 2 nm 178 nm 178 nm 422 nm 0.0%	Parameter Parameter 12.8 mag (mH) 9.8 Hz (-3db) 0.0 arcsec NGS x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle m H0 WES Rate	0.00 0.08 0.00 50 0.06 Total El	0.13 0.00 70 0.10 fective V deg Hz	0.21 0.21 0.00 vFE sho	0.28 0.28 0.00 160 0.28	0.00 I ratic 0.35 0.00 240 0.34 	0.43 0.43 0.00 480 0.45	0.52 0.01 1000 0.72	0.65	0.77 0.23 1180 0.80
Tip/Tilt Errors Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Residual Atmospheric Dispersion K Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy κ Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.091 m Theta0_eff 1.92 arcsec Sodium Abund. 4 x 10°	Angular Error (rms) 19.49 mas 9.27 mas 0.00 mas 0.05 mas 0.25 mas 0.25 mas 0.59 mas 21.8 mas 21.8 mas 30 deg 30 deg	362 mm Equivalent WFE (rms) 151 nm 75 nm 0 nm 0 nm 0 nm 2 nm 0 nm 178 nm 178 nm 422 nm 0.0% 0.0%	High Order Streni Parameter 12.8 mag (mH) 9.8 Hz (-3db) 9.8 Hz (-3db) 0.0 arcsec NGS x reduction -250 m conj height Alloc 0.25 mas / min -3 Hz (-sput disturbance Tip/Tilt Strehl - Total Strehl (%) - Spaxel Diameter (mas) - This fraction of sky can be corrected to the m/s Zenith Angle m HO WFS Rate arcmin HO WFS Noise	0.00 0.08 0.00 50 0.06 Total El 10 182 4.0	0.13 0.00 70 0.10 ffective V deg Hz e - rms	0.00 0.21 0.00 80 0.13 VFE sho	0.00 Streh 0.28 0.00 160 0.28 wn	0.00 I ratic 0.35 0.00 240 0.34 CCD50	0.00 0.43 0.00 480 0.45	0.52	0.65	0.77 0.23 1180 0.80
Tip/Tilt Errors Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Residual Centrol Anisoplanatism Residual Centrol Anisoplanatism Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Interfective Wavefront Error Ensquared Energy κ Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.091 m Theta0_eff 1.92 arcsec Sodium Abund. 4 × 10°	Angular Error (rms) 19.49 mas 9.27 mas 0.00 mas 0.05 mas 0.25 mas 0.25 mas 0.25 mas 0.29 mas 2.24 mas 0.29 mas 2.24 mas 0.29 mas 2.24 mas 0.30 deg 30 deg at this zenith at this zenith at this zenith	362 mm Equivalent WFE (rms) 151 nm 75 nm 0 nm 23 nm 0 nm 2 nm 0 nm 151 nm 75 nm 0 nm 2 nm 0 nm 178 nm 422 nm 0.0%	High Order Streni Parameter 12.8 mag (mH) 9.8 Hz (-3db) 9.8 Hz (-3db) 0.0 arcsec NGS x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle m HO WFS Rate arcmin HO WFS Rate	0.00 0.08 0.00 50 0.06 0.06 10 182 4.0.0 YES	0.13 0.00 70 0.10 fective V deg Hz e-rms	0.21 0.21 0.00 80 0.13 VFE shor	0.28 0.28 0.00 160 0.28 wm	0.00 I ratic 0.35 0.00 240 0.34 CCD50	0.43 0.43 0.00 0.45	0.52 0.01 1000 0.72	0.65	0.77 0.23 1180 0.80
Tip/Tilt Errors Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Atmospheric Dispersion K Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Trip/Tilt Error (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy κ Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.091 m Theta0_eff 1.92 arcsec Science Target: SCAO LOWF2 Target: NGS	Angular Error (ms) 19.49 mas 9.27 mas 0.00 mas 0.05 mas 2.24 mas 0.25 mas 0.25 mas 0.59 mas 21.8 mas 21.8 mas 30 deg 30 deg	362 mm Equivalent WFE (rms) 151 nm 0 nm 0 nm 0 nm 0 nm 2 nm 2 nm 0 nm 5 nm 178 nm 178 nm 422 nm Uter Scale 15 LGS Ast. Rad. 0.00 HOWFS Trans 0.28	High Order Streni Parameter 12.8 mag (mH) 9.8 Hz (-3db) 9.8 Hz (-3db) 0.0 arcsec NGS x reduction 20 x reduction -1500 m conj height Allec 0.25 mas / min Allec 0.25 mas / min Allec 0.25 mas / min Allec 0.25 mas / min Allec 0.25 mas / min Allec 0.25 mas / min Allec 0.25 mas / min Allec 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) Spaxel Diameter (mas) This fraction of sky can be corrected to the HO WFS Rate arcmin HO WFS Rate HO WFS rate HO WFS rate HO WFS rate HO WFS rate	0.00 0.08 0.00 50 0.06 	0.13 0.00 70 0.10 fective V deg Hz e-rms Hz	0.00 0.21 0.00 80 0.13 VFE sho	0.28 0.28 0.00 160 0.28 wn using using	0.00 I ratic 0.35 0.00 240 0.34 CCD50 CCD50	0.43 0.43 0.00 480 0.45	0.52	0.65	0.77
Tip/Tilt Errors Til Measurement Error (one-axis) Tilt Missoplanatism Error (one-axis) Tilt Anisoplanatism Residual Centroid Anisoplanatism Residual Telescope Polinting Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy κ Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.091 m Theta_eff 1.92 arcsec Sodiom Abund. 4 × 10° Science Target: NGS LOWFS Star Type: K	Angular Error (rms) 19.49 mas 9.27 mas 0.00 mas 0.05 mas 2.24 mas 0.05 mas 0.59 mas 21.8 mas 21.8 mas 30 deg 30 deg	362 mm Equivalent WFE (rms) 151 nm 75 nm 0 nm 0 nm 0 nm 2 nm 2 nm 151 nm 178 nm 100 nm 178 nm 178 nm 422 nm 100 nm 0.0% 0.0%	High Order Streni Parameter 12.8 mag (mH) 9.8 Hz (-3db) 9.8 Hz (-3db) 0.0 arcsec NGS x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle m HO WFS Rate arcmin HO WFS Noise HOWFS rate LO WFS Noise LO WFS Noise LO WFS Noise	0.08 0.00 50 0.00 10 10 122 142 142 142 142 142 142 142 142 142	0.13 0.00 70 0.10 ffective V deg Hz e-rms Hz e-rms	0.21 0.00 80 0.13 VFE shoo	0.28 0.00 160 0.28 wn using using	0.00 I ratic 0.35 0.00 240 0.34 CCD50 CCD50	0.43 0.00 480 0.45	0.52	0.65	0.77

Table 5. Error budget performance prediction for faint NGS science case. This case may be overly pessimistic in bandwidth error as the WFE budget tool overestimates bandwidth error at low HOWFS frame rates. In practice, the existing PALMAO system with N=16 subapertures can provide, in median conditions with an $m_V = 15$ (not 16) star, $SR_K \sim 15\%$ and $EE_{K, 240 \text{ mas}} \sim 30\%$, even with a guide star some 10-20 arcsec off-axis⁶.

⁶ R. Dekany, private communication.

6.1.4 Hot, Young Exo-Jupiters (LGS mode) w/ Equivalent 12 W MM Laser Return

Palomar Wavefront Error Budget Sur	nmary	Version 1.30					Scie	ence E	Band			
Mode: P3K LGS				u'	g'	r'	i'	Ζ	Y	J	Н	Κ
Instrument: P1640			λ (μ m)	0.36	0.47	0.62	0.75	0.88	1.03	1.25	1.64	2.20
Observation: Exo Jup LGS			δλ (μm)	0.06	0.14	0.14	0.15	0.12	0.12	0.16	0.29	0.34
			λ/D (mas)	15	20	27	32	38	45	54	71	95
		Wayofront					Strok	l Dati	o (%)			
High-order Errors (LGS Mode)		Error (rms)	Parameter				Strei	ii ixau	0(%)			
Atmospheric Fitting Error		119 nm	16 Subaps									
Bandwidth Error		106 nm	29 Hz (-3db)									
High-order Measurement Error		118 nm	12 W									
Asterism Deformation Error		0 nm	0.50 m LLT									
Multispectral Error		19 nm	10 zenith angle, H band									
Scintillation Error		14 nm	0.34 Scint index, H-band									
WES Scintillation Error	218 nm	10 nm	Alloc									
Uncorrectable Static Telescope Aberrations	21011	14 nm	64 Acts									
Uncorrectable Dynamic Telescope Aberrations		0 nm	Dekens Ph.D									
Static WFS Zero-point Calibration Error		25 nm	Alloc									
Dynamic WFS Zero-point Calibration Error		30 nm	Alloc									
Go-to Control Errors		0 nm	Alloc									
Residual Na Layer Focus Change		4 nm	30 m/s Na layer vel									
DM Finite Stroke Errors		19 nm	5.5 um P-P stroke									
DM Hysteresis High Order Aliaging Error		/ nm 40 nm	from IMI 16 Subaas									
DM Drive Digitization		1 nm	16 bits									
Uncorrectable AO System Aberrations		20 nm	Alloc									
Uncorrectable Instrument Aberrations		2 nm	P1640 Instrument									
DM-to-lenslet Misregistration		15 nm	Alloc									
Divisionensier Pupil Scale Error	69 nm	13 1111	Alloc									
Angular Anisoplanatism Error		18 nm	1 arcsec									
Total High Order Wavefront Error	229 nm	230 nm	High Order Strehl	0.00	0.00	0.00	0.03	0.07	0.14	0.27	0.46	0.65
Tip/Tilt Errors	Angular	Equivalent	Parameter				Streh	I ratio	os (%)			
Tip/Tilt Errors	Angular Error (rms)	Equivalent WFE (rms)	Parameter				Streh	I ratio	os (%)			
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis)	Angular Error (rms)	Equivalent WFE (rms)	Parameter				Streh	I ratio	os (%)			
Tip/Tilt Errors Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis)	Angular Error (rms)	Equivalent WFE (rms) ^{5 nm} 37 nm	Parameter 9.2 mag (mH) 20.0 Hz (-3db)				Streh	I ratio	os (%)			
Tip/Tilt Errors Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis)	Angular Error (rms)	Equivalent WFE (rms)	Parameter 9.2 mag (mH) 20.0 Hz (-3db) 0.0 arcsec 0.0 triangle the second				Streh	I ratio	os (%)			
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Besidual Atmospheric Dispersion H	Angular Error (rms) 0.60 mas 4.54 mas 0.00 mas 1.63 mas 0.10 mas	Equivalent WFE (rms) 5 nm 37 nm 0 nm 13 nm	9.2 mag (mH) 9.2 mag (mH) 20.0 Hz (-3db) 0.0 arcsec 10 x reduction 20 x reduction				Streh	I ratio	os (%)			
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion Induced Plate Scale Deformations	Angular Error (rms) 0.60 mas 4.54 mas 0.00 mas 1.63 mas 0.10 mas 0.57 mas	Equivalent WFE (rms) 5 nm 37 nm 0 nm 13 nm 1 nm 5 nm	Parameter 9.2 mag (mH) 20.0 Hz (-3db) 0.0 arcsec 10 x reduction 20 x reduction -1500 m coni height				Streh	I ratio	os (%)			
Tip/Tilt Errors Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Andwidth Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift	Angular Error (rms) 0.60 mas 4.54 mas 0.00 mas 1.63 mas 0.10 mas 0.57 mas 2.50 mas	Equivalent WFE (rms) 5 nm 37 nm 0 nm 13 nm 1 nm 5 nm 20 nm	Parameter 9.2 mag (mH) 20.0 Hz (-3db) 0.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min				Streh	I ratio	os (%)			
Tip/Tilt Errors Sci Filter Tilt Bandwidth Error (one-axis) Tilt Anioplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors	Angular Error (rms) 0.60 mas 4.54 mas 0.00 mas 0.67 mas 0.57 mas 2.50 mas 0.00 mas	Equivalent WFE (rms) 5 nm 37 nm 0 nm 13 nm 1 nm 5 nm 20 nm 0 nm	9.2 mag (mH) 20.0 Hz (-3db) 0.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min				Streh	I ratio	os (%)			
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion H Induced Plate Scale Deformations in Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis)	Angular Error (rms) 0.60 mas 4.54 mas 0.00 mas 1.63 mas 0.57 mas 2.50 mas 0.00 mas 0.29 mas	Equivalent WFE (rms) 5 nm 37 nm 13 nm 1 nm 5 nm 20 nm 2 nm 2 nm	9.2 mag (mH) 20.0 Hz (-3db) 0.0 arcsec 10 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance				Streh	I ratic	os (%)			
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Filed Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis)	Angular Error (rms) 0.60 mas 4.54 mas 0.00 mas 1.63 mas 0.57 mas 0.29 mas 0.29 mas 5.5 mas	Equivalent WFE (rms) 5 nm 37 nm 13 nm 1 nm 5 nm 20 nm 0 nm 2 nm 48 nm	9.2 mag (mH) 20.0 Hz (-3db) 0.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl	0.58	0.71	0.81	Streh 0.86	0.90	0.92	0.94	0.97	0.98
Tip/Tilt Errors Sci Filter Tilt Bandwidth Error (one-axis) Tilt Anioplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Fild Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis)	Angular Error (rms) 0.60 mas 4.54 mas 0.00 mas 1.63 mas 0.57 mas 0.57 mas 0.29 mas 0.29 mas 5.5 mas	Equivalent WFE (rms) 5 nm 37 nm 1 nm 1 nm 5 nm 20 nm 2 nm 2 nm 48 nm	Parameter 9.2 mag (mH) 20.0 Hz (-3db) 0.0 arcsec 10 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl	0.58	0.71	0.81	Streh	0.90	0.92	0.94	0.97	0.98
Tip/Tilt Errors Sci Filter Tilt Bandwidth Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Herror (one-axis) Residual Centroid Anisoplanatism Exposure Field Rotation Errors H Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Total Effective Wavefront Error	Angular Error (rms) 0.60 mas 0.00 mas 0.10 mas 0.57 mas 0.00 mas 0.250 mas 0.00 mas 0.29 mas 5.5 mas	Equivalent WFE (rms) 5 nm 37 nm 0 nm 1 nm 1 nm 20 nm 2 nm 2 nm 48 nm	Parameter 9.2 mag (mH) 20.0 H2 (-3db) 0.0 arcsec 10 arcsec 10 arcsec 20 x reduction -1560 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 H2 input disturbance Tip/Tilt Strehl Total Strehl (%)	0.58	0.71	0.81	Streh 0.86 0.02	0.90 0.06	0.92 0.13	0.94	0.97	0.98
Tip/Tilt Errors Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Ansoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis)	Angular Error (rms) 0.60 mas 4.54 mas 0.00 mas 1.63 mas 0.57 mas 0.57 mas 0.29 mas 5.5 mas	Equivalent WFE (rms) 5 nm 37 nm 0 nm 13 nm 5 nm 2 nm 2 nm 48 nm	Parameter 9.2 mag (mH) 20.0 Hz (-3db) 0.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%)	0.58	0.71	0.81	Streh 0.86 0.02	0.90 0.06	0.92 0.13	0.94	0.97	0.98
Tip/Tilt Errors Sci Filter Tilt Bandwidth Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Error Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error	Angular Error (rms) 0.60 mas 4.54 mas 0.00 mas 1.63 mas 0.57 mas 2.50 mas 0.29 mas 5.5 mas	Equivalent WFE (rms) 5 nm 37 nm 13 nm 1 nm 5 nm 2 0 nm 2 nm 2 nm 48 nm 234 nm	Parameter 9.2 mag (mH) 20.0 Hz (-3db) 0.0 arcsec 10 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%)	0.58	0.71	0.81	0.86 0.02	0.90 0.06	0.92 0.13	0.94	0.97	0.98
Tip/Tilt Errors Sci Filter Tilt Bandwidth Error (one-axis) Sci Filter Tilt Andwidth Error (one-axis) Residual Centroid Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Mechanical Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error	Angular Error (rms) 0.60 mas 4.54 mas 0.00 mas 1.63 mas 0.57 mas 0.57 mas 0.29 mas 0.29 mas 5.5 mas	Equivalent WFE (rms) 5 nm 37 nm 13 nm 1 nm 5 nm 20 nm 2 nm 2 nm 48 nm	Parameter 9.2 mag (mH) 20.0 Hz (-3db) 0.0 arcsec 10 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.58	0.71	0.81 0.00 80 0.32	0.86 0.02	0.90 0.06	0.92 0.13 480 0.60	0.94	0.97	0.98
Tip/Tilt Errors Sci Filter Tilt Bandwidth Error (one-axis) Sci Filter Tilt Andwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Hechanical Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy H	Angular Error (rms) 0.60 mas 4.54 mas 0.00 mas 1.63 mas 0.10 mas 0.57 mas 0.29 mas 0.29 mas 5.5 mas	Equivalent WFE (rms) 5 nm 37 nm 13 nm 1 nm 5 nm 20 nm 2 nm 2 nm 48 nm	Parameter 9.2 mag (mH) 20.0 Hz (-3db) 0.0 arcsec 10 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.58 0.00 50 0.18	0.71 0.00 70 0.28	0.81 0.00 80 0.33	Stref 0.86 0.02 160 0.48	0.90 0.06 240 0.50	0.92 0.13 480 0.60	0.94 0.25 1000 0.78	0.97	0.98 0.64 1080 0.80
Tip/Tilt Errors Sci Filter Tilt Bandwidth Error (one-axis) Sci Filter Tilt Andwidth Error (one-axis) Residual Centroid Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Mechanical Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy H Sky Coverage Galactic Lat.	Angular Error (rms) 0.60 mas 4.54 mas 0.00 mas 0.10 mas 0.57 mas 0.25 mas 0.29 mas 5.5 mas	Equivalent WFE (rms) 5 nm 37 nm 13 nm 1 nm 5 nm 20 nm 2 nm 2 nm 48 nm	Parameter 9.2 mag (mH) 20.0 Hz (-3db) 0.0 arcsec 10 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.58 0.00 50 0.18	0.71 0.00 70 0.28	0.81 0.00 80 0.33	0.86 0.02 160 0.48	0.90 0.06 240 0.50	0.92 0.13 480 0.60	0.94 0.25 1000 0.78	0.97	0.98 0.64 1080 0.80
Tip/Tilt Errors Sci Filter Tilt Bandwidth Error (one-axis) Sci Filter Tilt Andwidth Error (one-axis) Residual Centroid Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Mechanical Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy H Sky Coverage Galactic Lat. Corresponding Sky Coverage Sciactic Lat.	Angular Error (rms) 0.60 mas 4.54 mas 0.00 mas 1.63 mas 0.57 mas 0.57 mas 0.29 mas 5.5 mas 30 deg	Equivalent WFE (rms) 5 nm 0 nm 13 nm 5 nm 2 nm 2 nm 48 nm 234 nm	Parameter 9.2 mag (mH) 20.0 Hz (-3db) 0.0 arcsec 10 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the	0.58 0.00 50 0.18	0.71 0.00 70 0.28	0.81 0.00 80 0.33	0.86 0.02 160 0.48	0.90 0.06 240 0.50	0.92 0.13 480 0.60	0.94 0.25 1000 0.78	0.97	0.98 0.64 1080 0.80
Tip/Tilt Errors Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Sandwidth Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy H Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters	Angular Error (rms) 0.60 mas 4.54 mas 0.00 mas 1.63 mas 0.57 mas 0.57 mas 0.29 mas 5.5 mas 30 deg	Equivalent WFE (rms) 5 nm 37 nm 0 nm 13 nm 5 nm 2 nm 2 nm 2 nm 2 nm 2 nm 0 nm 2 nm 0 nm 0 nm 13 nm 13 nm 10 nm 10 nm 13 nm 10 nm 2 nm 2 nm 2 nm 0 nm 2 nm 2 nm 0 nm 2 n	Parameter 9.2 mag (mH) 20.0 Hz (-3db) 0.0 arcsec 10 x reduction 20 X reduction -1500 m conj height Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the	0.58 0.00 50 0.18	0.71 0.00 70 0.28	0.81 0.00 80 0.33	0.86 0.02 160 0.48	0.90 0.06 240 0.50	0.92 0.13 480 0.60	0.94	0.97	0.98 0.64 1080 0.80
Tip/Tilt Errors Sci Filter Tilt Bandwidth Error (one-axis) Sci Filter Tilt Bandwidth Error (one-axis) Residual Centroid Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Mechanical Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Dift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy H Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters	Angular Error (rms) 0.60 mas 4.54 mas 0.00 mas 1.63 mas 0.57 mas 0.57 mas 0.29 mas 5.5 mas 30 deg	Equivalent WFE (rms) 5 nm 37 nm 0 nm 13 nm 5 nm 2 nm 2 nm 48 nm 234 nm	Parameter 9.2 mag (mH) 20.0 Hz (-3db) 0.0 arcsec 10 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the	0.58 0.00 50 0.18	0.71 0.00 70 0.28	0.81 0.00 80 0.33	0.86 0.02 160 0.48	0.90 0.06 240 0.50	0.92 0.13 480 0.60	0.94	0.97	0.98 0.64 1080 0.80
Tip/Tilt Errors Sci Filter Tilt Bandwidth Error (one-axis) Sci Filter Tilt Bandwidth Error (one-axis) Residual Centroid Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Mechanical Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy H Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters Total Context Science Scien	Angular Error (rms) 0.60 mas 4.54 mas 0.00 mas 0.10 mas 0.57 mas 0.00 mas 0.25 mas 0.20 mas 0.29 mas 5.5 mas 30 deg	Equivalent WFE (rms) 5 nm 37 nm 0 nm 1 nm 20 nm 20 nm 2 nm 48 nm 234 nm 0.0% 8.12 0.0%	Parameter 9.2 mag (mH) 20.0 H2 (-3db) 0.0 arcsacc 10 x reduction 20x reduction -1500 m conj height Alloc 0.25 mas/ min Strip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle m/s Zenith Angle	0.58 0.00 0.18 Total E	0.71 0.00 70 0.28	0.81 0.00 0.33	0.86 0.02 160 0.48	0.90 0.06 0.50	0.92 0.13 480 0.60	0.94 0.25 1000 0.78	0.97	0.98 0.64 1080 0.80
Tip/Tilt Errors Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Ansoplanatism Error (one-axis) Residual Centroid Anisoplanatism (Proceeding) Residual Atmospheric Dispersion Hodital Atmospheric Dispersion Hodital Atmospheric Dispersion Cong Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy H Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.091 m Theta0_eff 1.92 arcsec Softim Ahund 4 × 10°	Angular Error (rms) 0.60 mas 4.54 mas 0.00 mas 1.63 mas 0.57 mas 0.57 mas 0.29 mas 5.5 mas 30 deg 30 deg	Equivalent WFE (rms) 5 nm 37 nm 0 nm 13 nm 5 nm 2 nm 2 nm 48 nm 234 nm 0.0% 0.0% 0.0%	Parameter 9.2 mag (mH) 20.0 Hz (-3db) 0.0 arcsec 10 x reduction 20 X reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbuance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m HO WFS Rate armin HO WFS Rate m HO WFS Rate	0.58 0.000 50 0.18	0.71 0.00 70 0.28 ffective V deg Hz e. (me	0.81 0.00 0.33 VFE sho	0.86 0.02 160 0.48	0.90 0.06 240 0.50	0.92 0.13 480 0.60	0.94	0.97	0.98
Tip/Tilt Errors Sci Filter Tilt Bandwidth Error (one-axis) Sci Filter Tilt Bandwidth Error (one-axis) Residual Centroid Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Mechanical Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy H Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.091 m Theta_eff 1.92 arcsec Sodium Abund. 4 x 10° Science Target: SCAO	Angular Error (rms) 0.60 mas 4.54 mas 0.00 mas 1.63 mas 0.57 mas 2.50 mas 0.29 mas 5.5 mas 30 deg 30 deg	Equivalent WFE (rms) 5 nm 37 nm 0 nm 13 nm 5 nm 2 nm 2 nm 48 nm 234 nm 0.0% Wind Speed 8.12 Outer Scale 75 LGS Ast. Rad. 0.0WFS Trans 0.28 0.0%	Parameter 9.2 (mag (mH)) 20.0 Hz (-3db) 0.0 arcsec 10 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.40 ms Spaxel Diameter (mas) This fraction of sky can be corrected to the m HO WFS Rate arcmin HO WFS Rate arcmin HO WFS Rate	0.58 0.00 50 0.18 10 437 4.3 NO	0.71 0.00 70 0.28 ffective W deg Hz e-rms	0.81 0.00 80 0.33 VFE sho	0.86 0.02 160 0.48	0.90 0.06 240 0.50	0.92 0.13 480 0.60	0.94	0.97	0.98 0.64 1080 0.80
Tip/Tilt Errors Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Residual Centroid Anisoplanatism Residual Centroid Anisoplanatism Residual Atmosphere Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) H Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy H Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.091 m Theta_eff 1.92 arcsec Sodium Abund. 4 × 10° Science Target: SCA0	Angular Error (rms) 0.60 mas 0.00 mas 0.10 mas 0.57 mas 0.00 mas 0.25 mas 0.20 mas 0.29 mas 5.5 mas 30 deg 30 deg	Equivalent WFE (rms) 5 nm 37 nm 0 nm 1 nm 20 nm 20 nm 2 nm 20 nm 2 nm 48 nm 234 nm Und Speed 8.12 Outer Scale 75 LOS Ast. Rad. 0.00 HOWFS Trans 0.28	Parameter 9.2 mag (mH) 20.0 H2 (-3db) 0.0 arcsec 10 arcsec Alloc 0.25 mas / min Alloc 0.25 mas / min 3 H2 input disturbance 3 H2 input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle m HO WFS Rate arcmin HO WFS rate HO WFS rate	0.58 0.00 50 0.18 * Total E	0.71 0.00 70 0.28 ffective w Hz e-rms Hz	0.81 0.00 80 0.33 VFE show SH	0.86 0.02 160 0.48 wn using using	0.90 0.06 240 0.50 CCD50	0.92 0.13 480 0.60	0.94	0.97	0.98 0.64 1080 0.80
Tip/Tilt Errors Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Bandwidth Error (one-axis) Residual Centroid Anisoplanatism Residual Centroid Anisoplanatism Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy H Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.091 m Theta0_eff 1.92 arcsec Science Target: SCA0 LOWFS Star Type: M	Angular Error (rms) 0.60 mas 4.54 mas 0.00 mas 1.63 mas 0.10 mas 0.57 mas 2.50 mas 0.29 mas 5.5 mas 30 deg 30 deg	Equivalent WFE (rms) 5 nm 37 nm 0 nm 1 nm 5 nm 2 nm 2 nm 1 nm 2 nm 2 nm 48 nm 234 nm Und Speed 8.12 0uter Scale UGS Ast Rad. 0.00% Wind Speed 8.12 0.00% Num Scale 0.02 0.02	Parameter 9.2 mag (mH) 200 Hz (-3db) 0.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m HO WFS Rate aromin HO WFS rate LO WFS Noise HOWFS Noise	0.58 0.00 50 0.18 10 4377 4.3 NO 500 64.5	0.71 0.00 70 0.28 ffective V deg Hz e-rms Hz e-rms	0.81 0.00 80 0.33 VFE sho	0.86 0.02 160 0.48 wn using	0.90 0.06 240 0.50 	0.92 0.13 480 0.60	0.94	0.97	0.98 0.64 1080 0.80

Table 6. Error budget performance prediction for hot, young exo-Jupiters (LGS mode) 12 W MM laser science case.

6.1.5 Hot, Young Exo-Jupiters (LGS mode) w/ Equivalent 50 W CW Laser Return

Palomar Wavefront Error Budget Sur	nmarv	Version 1.30					Scie	ence E	Band			
Mode: P3K LGS	,			u'	q'	r'	i'	Z	Y	J	Н	К
Instrument: P1640			λ (μ m)	0.36	0.47	0.62	0.75	0.88	1.03	1.25	1.64	2.20
Observation: Exo Jup LGS			δλ (μm)	0.06	0.14	0.14	0.15	0.12	0.12	0.16	0.29	0.34
			λ/D (mas)	15	20	27	32	38	45	54	71	95
		Wavefront					Streb	nl Rati	o (%)			
High-order Errors (LGS Mode)		Error (rms)	Parameter				••		• (/0)			
Atmospheric Fitting Error		67 nm	32 Subaps									
Bandwidth Error		63 nm	55 Hz (-3db)									
LGS Focal Anisoplanatism Error		87 nm	1 beacon(s)									
Asterism Deformation Error		0 nm	0.50 m LLT									
Multispectral Error		19 nm	10 zenith angle, H band									
WES Scintillation Error		14 nm 10 nm	0.34 Scint Index, H-band									
WI O OGINAIIZION EITO	145 nm	10 1111	Alloc									
Uncorrectable Static Telescope Aberrations		14 nm	64 Acts									
Uncorrectable Dynamic Telescope Aberrations Static WES Zoro point Calibration Error		0 nm 25 nm	Dekens Ph.D									
Dynamic WES Zero-point Calibration Error		30 nm	Alloc									
Leaky Integrator Zero-point Calibration Error		15 nm	Alloc									
Go-to Control Errors		0 nm	Alloc									
DM Finite Stroke Errors		4 nm 27 nm	30 m/s Na layer vel 5.5 um P-P stroke									
DM Hysteresis		7 nm	from TMT									
High-Order Aliasing Error		22 nm	32 Subaps									
DM Drive Digitization		1 nm	16 bits									
Uncorrectable Instrument Aberrations		20 nm	P1640 Instrument									
DM-to-lenslet Misregistration		15 nm	Alloc									
DM-to-lenslet Pupil Scale Error	64 nm	15 nm	Alloc									
Angular Anisoplanatism Error	04 1111	18 nm	1 arcsec									
Total High Order Wavefront Error	159 nm	160 nm	High Order Strehl	0.00	0.01	0.08	0.18	0.29	0.40	0.53	0.69	0.81
							Ctrob	Irotic	o (%)			
Tin/Tilt Erroro	Angular	Equivalent	Doromotor				Stren	ii rauc	/ (//)			
Tip/Tilt Errors	Angular Error (rms)	Equivalent WFE (rms)	Parameter				Stren	ii rauc	5 (/0)			
Tip/Tilt Errors Tilt Messurgment Error (one-avis)	Angular Error (rms)	Equivalent WFE (rms)	Parameter				Stren	ii rauc	5 (/0)			
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis)	Angular Error (rms)	Equivalent WFE (rms) 4 nm 37 nm	9.2 mag (mH) 20.0 Hz (-3db)				Stren		JS (70)			
Tip/Tilt Errors Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis)	Angular Error (rms)	Equivalent WFE (rms) 4 nm 37 nm 0 nm	9.2 mag (mH) 20.0 Hz (-3db) 0.0 arcsec				Stren		JS (70)			
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Ansoplanatism Error (one-axis) Residual Centroid Anisoplanatism Besidual Atmospheric Disparcing	Angular Error (rms) 0.44 mas 4.54 mas 0.00 mas 1.63 mas 0.10 mas	Equivalent WFE (rms) 4 nm 37 nm 0 nm 13 nm	9.2 mag (mH) 20.0 Hz (-3db) 0.0 arcsec 10 x reduction 20 x orduction				Stren		JS (/6)			
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Atmospheric Dispersion Residual Atmospheric Dispersion H Induced Plate Scale Deformations	Angular Error (rms) 0.44 mas 4.54 mas 0.00 mas 1.63 mas 0.10 mas 0.57 mas	Equivalent WFE (rms) 4 nm 37 nm 0 nm 13 nm 1 nm 5 nm	Parameter 9.2 mag (mH) 20.0 Hz (-3db) 0.0 arcsec 10 x reduction 20 x reduction -1500 m coni height				Stren	ii rauc	JS (/6)			
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift	Angular Error (rms) 0.44 mas 4.54 mas 0.00 mas 1.63 mas 0.57 mas 2.50 mas	Equivalent WFE (rms) 4 nm 37 nm 0 nm 13 nm 1 nm 5 nm 20 nm	Parameter 9.2 mag (mH) 20.0 Hz (-3db) 0.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min				Stren					
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Measurement Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Deschild Telesrope Spoilton Litter (one-axis)	Angular Error (rms) 0.44 mas 4.54 mas 0.00 mas 0.57 mas 2.50 mas 0.20 mas 0.20 mas	Equivalent WFE (rms) 4 nm 37 nm 0 nm 13 nm 1 nm 5 nm 20 nm 0 nm 2 nm	9.2 mag (mH) 20.0 Hz (-3db) 0.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min 3 Hz ingrid (Highthappe)				Stren					
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis)	Angular Error (rms) 0.44 mas 4.54 mas 0.00 mas 0.10 mas 0.57 mas 2.50 mas 0.00 mas 0.29 mas	Equivalent WFE (rms) 4 nm 37 nm 0 nm 13 nm 1 nm 5 nm 20 nm 0 nm 2 nm	Parameter 9.2 mag (mH) 20.0 Hz (-3db) 0.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance				Stren		JS (70)			
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis)	Angular Error (rms) 0.44 mas 4.54 mas 0.00 mas 0.10 mas 0.57 mas 0.29 mas 0.29 mas 5.5 mas	Equivalent WFE (rms) 4 nm 37 nm 0 nm 1 nm 1 nm 20 nm 2 nm 2 nm 48 nm	Parameter 9.2 mag (mH) 20.0 Hz (-30b) 0.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tiit Strehl	0.58	0.71	0.81	0.86	0.90	0.92	0.95	0.97	0.98
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Atmospheric Dispersion Residual Atmospheric Dispersion Residual Atmospheric Dispersion Residual Atmospheric Dispersion Kesidual Atmospheric Dispersion H Induced Pitale Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis)	Angular Error (rms) 0.44 mas 4.54 mas 0.00 mas 0.67 mas 2.50 mas 0.29 mas 5.5 mas	Equivalent WFE (rms) 4 nm 37 nm 0 nm 1 nm 1 nm 20 nm 2 nm 2 nm	Parameter 9.2 mag (mH) 20.0 Hz (-3db) 0.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl	0.58	0.71	0.81	0.86	0.90	0.92	0.95	0.97	0.98
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error	Angular Error (rms) 0.44 mas 4.54 mas 0.00 mas 0.67 mas 2.50 mas 0.29 mas 5.5 mas	Equivalent WFE (rms) 4 nm 37 nm 0 nm 1 nm 1 nm 20 nm 2 nm 2 nm 48 nm	Parameter 9.2 mag (mH) 20.0 Hz (-3db) 0.0 arcsec 10 x reduction 20 x reduction 20 x reduction Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%)	0.58	0.71	0.81	0.86	0.90	0.92	0.95	0.97	0.98
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion H Induced Pilate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error	Angular Error (rms) 0.44 mas 4.54 mas 0.00 mas 0.67 mas 2.50 mas 0.29 mas 5.5 mas	Equivalent WFE (rms) 4 nm 37 nm 0 nm 1 nm 1 nm 20 nm 2 nm 2 nm 48 nm	Parameter 9.2 mag (mH) 20.0 Hz (-3db) 0.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%)	0.58	0.71	0.81	0.86 0.15	0.90	0.92	0.95	0.97	0.98
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error	Angular Error (rms) 0.44 mas 4.54 mas 0.00 mas 0.67 mas 2.50 mas 0.00 mas 0.00 mas 0.29 mas 5.5 mas	Equivalent WFE (rms) 4 nm 37 nm 0 nm 1 nm 1 nm 20 nm 2 nm 2 nm 2 nm 48 nm	Parameter 9.2 mag (mH) 20.0 Hz (-3db) 0.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.58	0.71	0.81	0.86 0.15	0.90	0.92	0.95	0.97	0.98
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Sci Filter Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy H	Angular Error (rms) 0.44 mas 4.54 mas 0.00 mas 0.67 mas 2.50 mas 0.00 mas 0.29 mas 5.5 mas	Equivalent WFE (rms) 4 nm 37 nm 0 nm 1 nm 1 nm 2 nm 2 nm 2 nm 48 nm 165 nm	Parameter 9.2 mag (mH) 20.0 Hz (-3db) 0.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.58 0.00 50 0.26	0.71 0.01 70 0.42	0.81 0.06 80 0.49	0.86 0.15 160 0.70	0.90 0.26 240 0.73	0.92 0.37 480 0.79	0.95	0.97	0.98 0.80 500 0.80
Sci Filter Sci Filter Tilt Measurement Error (one-axis) Tilt Analysidh Error (one-axis) Tilt Anisoplanatism Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy H Sky Coverage Galactic Lat.	Angular Error (rms) 0.44 mas 4.54 mas 0.00 mas 0.67 mas 2.50 mas 0.29 mas 5.5 mas 5.5 mas	Equivalent WFE (rms) 4 nm 37 nm 0 nm 1 nm 1 nm 20 nm 2 nm 2 nm 48 nm	Parameter 9.2 mag (mH) 20.0 Hz (-3db) 0.0 arcsec 10 x reduction 20 x reduction 20 S mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.58 0.00 50 0.26	0.71 0.01 70 0.42	0.81 0.06 80 0.49	0.86 0.15 160 0.70	0.90 0.26 240 0.73	0.92 0.37 480 0.79	0.95	0.97	0.98 0.80 500 0.80
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Analydidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Atmospheric Dispersion Handwidt Error Deformations Science Instrument Mechanical Drift Long Exposure Field Rolation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy H Sky Coverage Galactic Lat.	Angular Error (rms) 0.44 mas 4.54 mas 0.00 mas 0.67 mas 2.50 mas 0.29 mas 5.5 mas 5.5 mas	Equivalent WFE (rms) 4 nm 37 nm 0 nm 1 nm 1 nm 20 nm 2 nm 2 nm 48 nm 165 nm	Parameter 9.2 mag (mH) 20.0 Hz (-3db) 0.0 arcsec 10 x reduction 20 x reduction 20 S mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.58 0.00 50 0.26	0.71 0.01 70 0.42	0.81 0.06 80 0.49	0.86 0.15 160 0.70	0.90 0.26 240 0.73	0.92 0.37 480 0.79	0.95	0.97	0.98 0.80 500 0.80
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Analydidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Atmospheric Dispersion Handword Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rolation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy H Sky Coverage Galactic Lat. Corresponding Sky Coverage Indicate Lat.	Angular Error (rms) 0.44 mas 4.54 mas 0.00 mas 0.07 mas 2.50 mas 0.29 mas 5.5 mas 30 deg	Equivalent WFE (rms) 4 nm 3 7 nm 0 nm 1 nm 1 nm 2 nm 2 nm 2 nm 48 nm 165 nm	Parameter 9.2 mag (mH) 20.0 Hz (-3db) 0.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the	0.58 0.00 50 0.26	0.71 0.01 70 0.42	0.81 0.06 80 0.49	0.86 0.15 160 0.70	0.90 0.26 0.73	0.92 0.37 480 0.79	0.95	0.97	0.98 0.80 500 0.80
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Atmospheric Dispersion Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Tip/Tilt Error (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy H Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters	Angular Error (rms) 0.44 mas 4.54 mas 0.00 mas 0.67 mas 2.50 mas 0.29 mas 5.5 mas 30 deg	Equivalent WFE (rms) 4 nm 37 nm 0 nm 1 nm 20 nm 2 nm 2 nm 48 nm 165 nm	Parameter 9.2 mag (mH) 20.0 Hz (-3db) 0.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the	0.58 0.00 50 0.26	0.71 0.01 70 0.42	0.81 0.06 0.49	0.86 0.15 160 0.70	0.90 0.26 240 0.73	0.92 0.37 480 0.79	0.95	0.97	0.98 0.80 500 0.80
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Tilt Anisoplanatism Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy H Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.091 m	Angular Error (rms) 0.44 mas 4.54 mas 0.00 mas 0.67 mas 2.50 mas 0.29 mas 5.5 mas 30 deg at this zenith	Equivalent WFE (rms) 4 nm 37 nm 0 nm 1 nm 2 nm 2 nm 2 nm 48 nm 165 nm 165 nm	Parameter 9.2 mag (mH) 20.0 Hz (-3db) 0.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle	0.58 0.00 50 0.26	0.71 0.01 70 0.42	0.81 0.06 0.49	0.86 0.15 160 0.70	0.90 0.26 240 0.73	0.92 0.37 480 0.79	0.95	0.97	0.98 0.80 500 0.80
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Sci Filter Tilt Analydidh Error (one-axis) Tilt Anisoplanatism Residual Atmospheric Dispersion H Induced Plate Scale Deformations H Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy Kky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.091 m Theta0_eff 1.92 arcsec	Angular Error (rms) 0.44 mas 4.54 mas 0.00 mas 0.07 mas 2.50 mas 0.07 mas 0.29 mas 5.5 mas 30 deg 30 deg	Equivalent WFE (rms) 4 nm 37 nm 0 nm 1 nm 20 nm 2 nm 2 nm 48 nm 165 nm 0.0% Wind Speed 8.12 Outer Scale 75	Parameter 9.2 mag (mH) 20.0 Hz (-3db) 0.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle m HO WFS Rate	0.58 0.00 50 0.26 € Total El	0.71 0.01 70 0.42	0.81 0.06 80 0.49 VFE shor	0.86 0.15 160 0.70 wm	0.90 0.26 240 0.73	0.92 0.37 480 0.79	0.95	0.97	0.98 0.80 500 0.80
Sci Filter Sci Filter Till Measurement Error (one-axis) Till Landwidth Error (one-axis) Tilt Anisoplanatism Residual Atmospheric Dispersion H Nesidual Atmospheric Dispersion H Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy Ky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.091 m Theta0_eff 1.92 arcsec Sodum Abund. 1.42 arcsec	Angular Error (rms) 0.44 mas 4.54 mas 0.00 mas 0.67 mas 2.50 mas 0.29 mas 5.5 mas 30 deg 30 deg	Equivalent WFE (rms) 4 nm 37 nm 0 nm 1 nm 1 nm 2 nm 2 nm 48 nm 48 nm 165 nm 0.0% Wind Speed 8.12 Outer Scale 75 LGS Ast. Rad. 0.00	Parameter 9.2 mag (mH) 20.0 Hz (-3db) 0.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle m H0 WFS Rate arcmin H0 WFS Noise	0.58 0.00 50 0.26 * Total El	0.71 0.01 70 0.42 ffective V deg Hz e-rms	0.81 0.06 80 0.49 VFE show	0.86 0.15 160 0.70 wn	0.90 0.26 240 0.73	0.92 0.37 480 0.79	0.95	0.97	0.98 0.80 500 0.80
Sci Filter Tilt Measurement Error (one-axis) Tilt Mandwidth Error (one-axis) Tilt Anisoplanatism Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy H Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.091 m Theta0_eff 1.92 arcsec Science Target: SCA0 LOWES Target: SCA0	Angular Error (rms) 0.44 mas 4.54 mas 0.00 mas 0.67 mas 2.50 mas 0.29 mas 0.29 mas 5.5 mas 30 deg 30 deg	Equivalent WFE (rms) 4 nm 37 nm 0 nm 1 nm 1 nm 2 nm 1 nm 2 nm 2 nm 48 nm 165 nm 0.0% Under Scale 0.0% Udd Speed 8.12 Outer Scale 0.05 Ast. Rad. 0.00 HOWFS Trans 0.28	Parameter 9.2 mag (mH) 20.0 Hz (-3db) 0.0 arcsec 10 x reduction -1500 m conj height Allco 0.25 mas / min Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle m HO WFS Rate arcmin HO WFS Noise HOWFS rate HOWFS rate	0.58 0.00 50 0.26 * Total Ef	0.71 0.01 70 0.42 fective V deg Hz e - rms	0.81 0.06 80 0.49 VFE sho	0.86 0.15 160 0.70 wn	0.90 0.26 240 0.73	0.92 0.37 480 0.79	0.95	0.97	0.98 0.80 500 0.80
Sci Filter Sci Filter Tilt Measurement Error (one-axis) Tilt Mansoplanatism Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rolation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy M Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.091 m Theta0_eff 1.92 arcsec Scdoium Abund. 4 x 10 ^o Scale Erget: SCAO LOWFS Target: SCAO LOWFS Target: SCAO	Angular Error (rms) 0.44 mas 4.54 mas 0.00 mas 0.00 mas 0.29 mas 0.29 mas 0.29 mas 30 deg 30 deg 30 deg	Equivalent WFE (rms) 4 nm 37 nm 0 nm 1 nm 2 nm 2 nm 2 nm 48 nm 48 nm 165 nm 0.0% 0.0%	Parameter 9.2 mag (mH) 20.0 Hz (-3db) 0.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle m H0 WFS Rate arcmin H0 WFS noise H0WFS noise L0 WFS noise L0 WFS Noise	0.58 0.00 50 0.26 * Total El * Total El * NO 500 * NO 500	0.71 0.01 70 0.42 fective V deg Hz e-rms Hz e-rms	0.81 0.06 80 0.49 VFE shor SH	0.86 0.15 160 0.70 wm	0.90 0.26 240 0.73 CCD50	0.92 0.37 480 0.79	0.95	0.97	0.98 0.80 500 0.80

Table 7. Error budget performance prediction for the hot, young exo-Jupiters (LGS mode) science case. The benefit of more LGS return compared to 12W MM is to achieve 165 nm WFE, compared to 234 nm, delivering between 4x - 8x higher Strehl ratio in Z-band (882 nm).

6.1.6 Dynamics of Z = 1 Galaxies w/ Equivalent 12 W MM Laser Return

Palomar Wavefront Error Budget Sur	nmary	Version 1.30					Scie	ence E	Band			
Mode: P3K LGS	•			u'	g'	r'	i'	Ζ	Y	J	Н	Κ
Instrument: SWIFT			λ (μ m)	0.36	0.47	0.62	0.75	0.88	1.03	1.25	1.64	2.20
Observation: Z = 1 Galaxies			δλ (μm)	0.06	0.14	0.14	0.15	0.12	0.12	0.16	0.29	0.34
			λ/D (mas)	15	20	27	32	38	45	54	71	95
									(0/)			
High-order Errors (LGS Mode)		Wavefront	Parameter				Stref	n Rati	0 (%)			
		Error (rms)										
Atmospheric Fitting Error		119 nm 107 nm	16 Subaps									
High-order Measurement Error		115 nm	12 W									
LGS Focal Anisoplanatism Error		86 nm	1 beacon(s)									
Asterism Deformation Error		0 nm	0.50 m LLT									
Scintillation Error		19 nm 13 nm	0.34 Scint index, H-band									
WFS Scintillation Error		10 nm	Alloc									
	216 nm											
Uncorrectable Static Telescope Aberrations		14 nm	64 Acts Dekens Ph D									
Static WFS Zero-point Calibration Error		25 nm	Alloc									
Dynamic WFS Zero-point Calibration Error		30 nm	Alloc									
Leaky Integrator Zero-point Calibration Error		15 nm	Alloc									
Go-to Control Errors Residual Na Laver Focus Change		0 nm 4 nm	Alloc 30 m/s Na laver vel									
DM Finite Stroke Errors		19 nm	5.5 um P-P stroke									
DM Hysteresis		7 nm	from TMT									
High-Order Aliasing Error		40 nm	16 Subaps									
Uncorrectable AO System Aberrations		20 nm	Alloc									
Uncorrectable Instrument Aberrations		62 nm	SWIFT Instrument									
DM-to-lenslet Misregistration		15 nm	Alloc									
DM-to-lenslet Pupil Scale Error	93 nm	15 nm	Alloc									
Angular Anisoplanatism Error	55 1111	56 nm	4 arcsec									
Total High Order Wavefront Error	235 nm	242 nm	High Order Strehl	0.00	0.00	0.00	0.02	0.05	0.12	0.23	0.43	0.62
	Angular	Equivalent	Baramatar				Streh	I ratio	os (%)			
Tip/Tilt Errors	Angular Error (rms)	Equivalent WFE (rms)	Parameter				Streh	I ratio	os (%)			
Tip/Tilt Errors Sci Filter	Angular Error (rms)	Equivalent WFE (rms)	Parameter				Streh	I ratio	os (%)			
Tip/Tilt Errors Tilt Measurement Error (one-axis) Sci Filter Till Bandwidth Error (one-axis)	Angular Error (rms)	Equivalent WFE (rms) 83 nm 71 nm	Parameter				Streh	I ratio	os (%)			
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis)	Angular Error (rms) 11.13 mas 9.32 mas 12.41 mas	Equivalent WFE (rms) 83 nm 71 nm 91 nm	Parameter 14.6 mag (mH) 9.9 Hz (-3db) 16.8 arcsec				Streh	I ratio	os (%)			
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Anisoplanatism Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism	Angular Error (rms) 11.13 mas 9.32 mas 12.41 mas 1.62 mas	Equivalent WFE (rms) 83 nm 71 nm 91 nm 13 nm	Parameter 14.6 mag (mH) 9.9 Hz (-3db) 16.8 arcsec 10 x reduction				Streh	I ratio	os (%)			
Tip/Tilt Errors Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion Z	Angular Error (rms) 11.13 mas 9.32 mas 12.41 mas 1.62 mas 0.14 mas	Equivalent WFE (rms) 83 nm 71 nm 91 nm 13 nm 1 nm 10 nm	Parameter 14.6 mag (mH) 9.9 Hz (-3db) 16.8 arcsec 10 x reduction 20 x reduction				Streh	I ratio	os (%)			
Sci Filte Tilt Keasurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Drift	Angular Error (rms) 11.13 mas 9.32 mas 12.41 mas 1.62 mas 0.14 mas 2.27 mas 15.00 mas	Equivalent WFE (rms) 83 nm 71 nm 91 nm 13 nm 1 nm 18 nm 105 nm	Parameter 14.6 mag (mH) 9.9 H2 (-3db) 16.8 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas/min				Streh	I ratio	os (%)			
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Centroid Anisoplanatism Residual Atmospheric Dispersion Z Induced Plate Scale Deformations is Science Instrument Mechanical Drift Long Exposure Field Rotation Errors	Angular Error (rms) 11.13 mas 9.32 mas 12.41 mas 1.62 mas 0.14 mas 2.27 mas 15.00 mas 0.00 mas	Equivalent WFE (rms) 83 nm 71 nm 91 nm 13 nm 1 nm 18 nm 105 nm 0 nm	Parameter 14.6 mag (mH) 9.9 Hz (-3db) 16.8 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min				Streh	I ratio	os (%)			
Tip/Tilt Errors Till Measurement Error (one-axis) Sci Filter Till Bandwidth Error (one-axis) Till Anisoplanatism Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis)	Angular Error (rms) 11.13 mas 9.32 mas 9.32 mas 12.41 mas 1.62 mas 0.14 mas 2.27 mas 15.00 mas 0.00 mas 0.58 mas	Equivalent WFE (rms) 83 nm 71 nm 13 nm 1 nm 18 nm 105 nm 5 nm	Parameter 14.6 mag (mH) 9.9 Hz (-3db) 16.8 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance				Streh	I ratio	os (%)			
Tip/Tilt Errors Tilt Measurement Error (one-axis) Sci Filter Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Tilt Anisoplanatism Residual Centroid Anisoplanatism Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Tip/Tilt Error (one-axis)	Angular Error (rms) 11.13 mas 9.32 mas 12.41 mas 1.62 mas 0.14 mas 2.27 mas 15.00 mas 0.58 mas 24.5 mas	Equivalent WFE (rms) 83 nm 71 nm 91 nm 13 nm 18 nm 105 nm 0 nm 5 nm	Parameter 14.6 mag (mH) 9.9 Hz (-3db) 16.8 arcsec 10 x reduction -20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tin/Tilt Strehl	0.07	0.11	0.17	Streh	0.30	0.37	0.46	0.60	0.73
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Sci Filter Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Residual Centrol Anisoplanatism Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Tip/Tilt Error (one-axis)	Angular Error (rms) 11.13 mas 9.32 mas 1.241 mas 1.62 mas 0.14 mas 2.27 mas 15.00 mas 0.00 mas 0.00 mas 0.58 mas	Equivalent WFE (rms) 83 nm 71 nm 91 nm 13 nm 18 nm 105 nm 0 nm 5 nm	Parameter 14.6 mag (mH) 9.9 Hz (-3db) 16.8 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl	0.07	0.11	0.17	Streh	0.30	0.37	0.46	0.60	0.73
Tip/Tilt Errors Till Measurement Error (one-axis) Till Bandwidth Error (one-axis) Till Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis)	Angular Error (rms) 11.13 mas 9.32 mas 1.241 mas 1.62 mas 0.14 mas 2.27 mas 0.00 mas 0.00 mas 0.58 mas 24.5 mas	Equivalent WFE (rms) 83 nm 91 nm 13 nm 13 nm 18 nm 105 nm 5 nm 154 nm	Parameter 14.6 mag (mH) 9.9 H2 (-3db) 16.8 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Titt Strehl	0.07	0.11	0.17	0.24	0.30	0.37	0.46	0.60	0.73
Tip/Tilt Errors Till Measurement Error (one-axis) Till Bandwidth Error (one-axis) Till Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error	Angular Error (rms) 11.13 mas 9.32 mas 1.62 mas 0.14 mas 2.27 mas 15.00 mas 0.00 mas 0.58 mas 24.5 mas	Equivalent WFE (rms) 83 nm 91 nm 13 nm 13 nm 18 nm 5 nm 5 nm 154 nm	Parameter 14.6 mag (mH) 9.9 Hz (-3db) 16.8 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%)	0.07	0.11	0.17	0.24 0.00	0.30 0.02	0.37 0.04	0.46	0.60	0.73
Tip/Tilt Errors Tilt Bandwith Error (one-axis) Tilt Bandwith Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis)	Angular Error (rms) 11.13 mas 9.32 mas 1.241 mas 1.62 mas 0.14 mas 2.27 mas 1.500 mas 0.00 mas 0.58 mas 24.5 mas	Equivalent WFE (rms) 83 nm 91 nm 13 nm 13 nm 18 nm 5 nm 5 nm 154 nm	Parameter 14.6 mag (mH) 9.9 Hz (-3db) 16.8 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spored Diameter (pace)	0.07	0.11	0.17	0.24 0.00	0.30 0.02	0.37 0.04	0.46	0.60	0.73
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Sci Filter Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Centroid Anisoplanatism Aresidual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error	Angular Error (rms) 11.13 mas 9.22 mas 1.62 mas 1.62 mas 0.14 mas 2.27 mas 0.50 mas 0.58 mas 24.5 mas	Equivalent WFE (rms) 83 nm 71 nm 13 nm 13 nm 18 nm 0 nm 5 nm 154 nm 285 nm	Parameter 14.6 mag (mH) 9.9 Hz (-3db) 16.8 arcsec 10 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.07	0.11	0.17 0.00 80	0.24 0.00	0.30 0.02 240	0.37 0.04 480 0.27	0.46	0.60	0.73
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Sci Filter Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism (Anisoplanatism Residual Centroid Anisoplanatism (Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy z	Angular Error (rms) 11.13 mas 9.32 mas 1.62 mas 1.62 mas 2.27 mas 2.27 mas 0.00 mas 0.00 mas 0.58 mas 24.5 mas	Equivalent WFE (rms) 83 nm 71 nm 13 nm 13 nm 18 nm 0 nm 5 nm 154 nm 285 nm	Parameter 14.6 mag (mH) 9.9 Hz (-3db) 16.8 arcsec 10 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.07 0.00 50 0.02	0.11 0.00 70 0.04	0.17 0.00 80 0.05	0.24 0.00 160 0.08	0.30 0.02 240 0.12	0.37 0.04 480 0.27	0.46 0.11 1000 0.63	0.60	0.73 0.45 1330 0.80
Tip/Tilt Errors Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy z Sky Coverage Gelactic Lat.	Angular Error (rms) 11.13 mas 9.32 mas 1.62 mas 0.14 mas 2.27 mas 1.500 mas 0.00 mas 0.58 mas 24.5 mas 30 deg	Equivalent WFE (rms) 83 nm 91 nm 13 nm 13 nm 18 nm 05 nm 5 nm 154 nm	Parameter 14.6 imag (mH) 9.9 Hz (-3db) 16.8 arcsec 10 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.07 0.00 50 0.02	0.11 0.00 70 0.04	0.17 0.00 80 0.05	0.24 0.00 160 0.08	0.30 0.02 240 0.12	0.37 0.04 480 0.27	0.46 0.11 1000 0.63	0.60	0.73 0.45 1330 0.80
Tip/Tilt Errors Til: Measurement Error (one-axis) Til: Bandwidth Error (one-axis) Til: Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy z Sky Coverage Galactic Lat. Corresponding Sky Coverage	Angular Error (rms) 11.13 mas 9.32 mas 1.62 mas 0.14 mas 2.27 mas 1.500 mas 0.00 mas 0.58 mas 24.5 mas 30 deg	Equivalent WFE (rms) 83 nm 91 nm 13 nm 13 nm 18 nm 5 nm 5 nm 154 nm 285 nm	Parameter 14.6 imag (mH) 9.9 Hz (-3db) 16.8 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the	0.07 0.00 50 0.02	0.11 0.00 70 0.04	0.17 0.00 80 0.05	0.24 0.00 160 0.08	0.30 0.02 240 0.12	0.37 0.04 480 0.27	0.46 0.11 1000 0.63	0.60	0.73 0.45 1330 0.80
Tip/Tilt Errors Till Measurement Error (one-axis) Till Bandwidth Error (one-axis) Till Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy z Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters	Angular Error (rms) 11.13 mas 9.32 mas 1.241 mas 0.14 mas 2.27 mas 0.00 mas 0.00 mas 0.58 mas 24.5 mas 30 deg	Equivalent WFE (rms) 83 nm 91 nm 13 nm 18 nm 105 nm 0 nm 5 nm 154 nm 285 nm	Parameter 14.6 imag (mH) 9.9 H2 (-3db) 16.8 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 H2 input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the	0.07 0.00 50 0.02	0.11 0.00 70 0.04	0.17 0.00 80 0.05	0.24 0.00 160 0.08	0.30 0.02 240 0.12	0.37 0.04 480 0.27	0.46	0.60	0.73 0.45 1330 0.80
Tip/Tilt Errors Til: Measurement Error (one-axis) Til: Bandwidth Error (one-axis) Til: Anadwidth Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy z Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters	Angular Error (rms) 11.13 mas 9.32 mas 1.62 mas 0.14 mas 2.27 mas 1.500 mas 0.00 mas 0.58 mas 24.5 mas 30 deg	Equivalent WFE (rms) 83 nm 91 nm 13 nm 13 nm 18 nm 5 nm 5 nm 154 nm 285 nm	Parameter 14.6 imag (mH) 9.9 Hz (-3db) 16.8 arcsec 10 X reduction 20 X reduction -1500 m conj height Alloc 0.25 mas / min 3 HZ input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the	0.07 0.00 50 0.02	0.11 0.00 70 0.04	0.17 0.00 80 0.05	0.24 0.00 160 0.08	0.30 0.02 240 0.12	0.37 0.04 480 0.27	0.46 0.11 1000 0.63	0.60	0.73 0.45 1330 0.80
Tip/Tilt Errors Till Measurement Error (one-axis) Till Bandwidth Error (one-axis) Till Anisoplanatism Error (one-axis) Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy z Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.092 m Topic of 100 meters	Angular Error (rms) 11.13 mas 9.32 mas 12.41 mas 12.41 mas 12.62 mas 0.14 mas 0.00 mas 0.00 mas 0.00 mas 0.05 m	Equivalent WFE (rms) 83 nm 91 nm 91 nm 105 nm 0 nm 5 nm 154 nm 285 nm 285 nm	Parameter 14.6 imag (mH) 9.9 Hz (-3db) 16.8 arcsec 10 x reduction -1500 m conj height Alloc 0.25 mas / min Charlet Control Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle m HO WTS Date	0.07 0.00 50 0.02	0.11 0.00 70 0.04	0.17 0.00 0.05	0.24 0.00 160 0.08	0.30 0.02 240 0.12	0.37 0.04 480 0.27	0.46 0.11 1000 0.63	0.60	0.73 0.45 1330 0.80
Tip/Tilt Errors Till Measurement Error (one-axis) Till Anisoplanatism Error (one-axis) Till Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Centroid Anisoplanatism Residual Centroid Anisoplanatism Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy z Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.092 m Theta0_eff 1.96 arcsec Sodium Abund 4 x 10 ⁹	Angular Error (rms) 11.13 mas 9.32 mas 12.41 mas 1.62 mas 0.14 mas 2.27 mas 0.00 mas 0.00 mas 0.00 mas 0.58 mas 24.5 mas 30 deg 30 deg	Equivalent WFE (rms) 83 nm 91 nm 91 nm 13 nm 10 nm 0 nm 5 nm 154 nm 285 nm Vind Speed 5.0% Vind Speed 8.03 Outer Scale 76 8.03 0 nm	Parameter 14.6 mag (mH) 9.9 Hz (-3db) 9.8 Hz (-3db) 16.8 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle m HO WFS Rate arcmin HO WFS Noise	0.07 0.00 50 0.02 • Total Ef	0.11 0.00 70 0.04 ffective V deg Hz e-rms	0.17 0.00 80 0.05	0.24 0.00 160 0.08 wm	0.30 0.02 240 0.12	0.37 0.04 480 0.27	0.46	0.60	0.73 0.45 1330 0.80
Tip/Tilt Errors Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy Z Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.092 m Theta0_eff 1.96 arcsec Science Target: SCAO	Angular Error (rms) 11.13 mas 9.32 mas 1.241 mas 1.62 mas 0.14 mas 2.27 mas 0.00 mas 0.00 mas 0.58 mas 24.5 mas 30 deg 30 deg	Equivalent WFE (rms) 83 nm 91 nm 13 nm 13 nm 105 nm 0 nm 5 nm 154 nm 285 nm 285 nm Wind Speed 8.03 Outer Scale 75 LGS Ast. Rad. 0.028 0.28	Parameter 14.6 mag (mH) 9.9 H2 (-3db) 16.8 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 HZ input disturbuance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle m HO WFS Rate arcmin HO WFS Rate arcmin HO WFS Rate	0.07 0.00 50 0.02 Total El 434 4.3 NO	0.11 0.00 70 0.04 ffective V deg Hz e-rms	0.17 0.00 80 0.05 VFE show	0.24 0.00 160 0.08 wm	0.30 0.02 240 0.12	0.37 0.04 480 0.27	0.46	0.60	0.73 0.45 1330 0.80
Tip/Tilt Errors Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rolation Errors Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy z Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.092 m Thela_eff 1.96 arcsec Science Target: SCAO LOWFS Target: SCAO	Angular Error (rms) 11.13 mas 9.32 mas 12.41 mas 12.41 mas 12.41 mas 0.58 mas 0.00 mas 0.00 mas 0.00 mas 0.05 m	Equivalent WFE (rms) 83 nm 91 nm 91 nm 105 nm 0 nm 5 nm 154 nm 285 nm 285 nm Und Speed 5.0% 0.00 0.0	Parameter 14.6 imag (mH) 9.9 Hz (-3db) 16.8 arcsec 10 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disurbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m m MO WFS Rate arcmin HO WFS Rate arcmin HO WFS rate UO WFS rate	0.07 0.00 50 0.02 Total El 434 4.3 NO 184	0.11 0.00 70 0.04 ffective V deg Hz e-rms Hz	0.17 0.00 80 0.05 VFE show SH SH	0.24 0.00 160 0.08 wn using using	0.30 0.02 240 0.12 CCD50 H2RG	0.37 0.04 480 0.27	0.46	0.60	0.73 0.45 1330 0.80
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Sci Filter Tilt Mandwidth Error (one-axis) Tilt Anisoplanatism Residual Centroid Anisoplanatism Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy z Sky Coverage Galactic Lat. Corresponding Sky Coverage Solence Target: Assumptions / Parameters r0 0.092 m Theta0_eff 1.96 arcsec Science Target: SCAO LOWFS Star Type: M How Enverse 10000 Fire	Angular Error (rms) 11.13 mas 9.32 mas 12.41 mas 1.62 mas 0.14 mas 2.27 mas 0.00 mas	Equivalent WFE (rms) 83 nm 71 nm 91 nm 13 nm 1 nm 18 nm 0 nm 5 nm 154 nm 285 nm 285 nm Und Speed 6.0% Vind Speed 0.046 X cale 0.046 X cale	Parameter 14.6 mag (mH) 9.9 Hz (-3db) 16.8 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle m HO WFS Rate arcmin HO WFS Noise HOWFS rate LO WFS Noise LO WFS Noise How restraining	0.07 0.00 50 0.02 • Total Ef	0.11 0.00 70 0.04 ffective V deg Hz e-rms Hz e-rms	0.17 0.00 80 0.05 VFE show SH SH	0.24 0.00 160 0.08 wn using using	0.30 0.02 240 0.12 ccd50	0.37 0.04 480 0.27	0.46	0.60	0.73 0.45 1330 0.80

Table 8. Error budget performance prediction for dynamics of Z = 1 galaxies w/ equivalent 12 W MM laser return science case, optimized for Z-band ensquared energy.

6.1.7 Dynamics of Z = 1 Galaxies w/ Equivalent 50W CW Laser Return

Palomar Wavefront Error Budget Sur	nmary	Version 1.30					Scie	ence E	Band			
Mode: P3K LGS				u'	a'	r'	i'	Z	Y	J	Н	К
Instrument: SWIFT			λ (μ m)	0.36	0.47	0.62	0.75	0.88	1.03	1.25	1.64	2.20
Observation: Z = 1 Galaxies			δλ (μ m)	0.06	0.14	0.14	0.15	0.12	0.12	0.16	0.29	0.34
			λ/D (mas)	15	20	27	32	38	45	54	71	95
High-order Errors (LGS Mode)		Wavefront	Parameter				Streh	nl Rati	io (%)			
g. 0.40		Error (rms)										
Atmospheric Fitting Error Bandwidth Error		67 nm 63 nm	32 Subaps 54 Hz (-3db)									
High-order Measurement Error		65 nm	54 HZ (-500) 50 W									
LGS Focal Anisoplanatism Error		86 nm	1 beacon(s)									
Asterism Deformation Error		0 nm	0.50 m LLT									
Multispectral Error		19 nm	5 zenith angle, H band									
Scintillation Error		13 nm 10 nm	0.34 Scint Index, H-band									
WI 3 Schulaton Error	144 nm	10 1111	Alloc									
Uncorrectable Static Telescope Aberrations		14 nm	64 Acts									
Uncorrectable Dynamic Telescope Aberrations		0 nm	Dekens Ph.D									
Static WFS Zero-point Calibration Error		25 nm	Alloc									
Dynamic WFS Zero-point Calibration Error		30 nm	Alloc									
Go-to Control Errors		0 nm	Alloc									
Residual Na Layer Focus Change		4 nm	30 m/s Na layer vel									
DM Finite Stroke Errors		27 nm	5.5 um P-P stroke									
DM Hysteresis		7 nm	from TMT									
High-Order Aliasing Error		22 nm	32 Subaps									
Uncorrectable AO System Aborrations		1 nm 20 nm	16 DIts									
Uncorrectable Instrument Aberrations		62 nm	SWIFT Instrument									
DM-to-lenslet Misregistration		15 nm	Alloc									
DM-to-lenslet Pupil Scale Error		15 nm	Alloc									
Angular Anisoplanatism Error	89 nm	56 nm	4 arcsec									
Total High Order Wavefront Error	169 nm	178 nm	High Order Strehl	0.00	0.00	0.04	0.11	0.21	0.32	0.46	0.63	0.77
							I.		- /0/ \			
Tip/Tilt Errors	Angular Error (rms)	Equivalent WFE (rms)	Parameter				Stren	ii ratio	os (%)			
Tip/Tilt Errors	Angular Error (rms)	Equivalent WFE (rms)	Parameter				Stren	ii ratio	DS (%)			
Tip/Tilt Errors Sci Filte Tilt Measurement Error (one-axis)	Angular Error (rms)	Equivalent WFE (rms) 59 nm	Parameter				Stren	ii ratio	os (%)			
Tip/Tilt Errors Sci Filte Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis)	Angular Error (rms)	Equivalent WFE (rms) 59 nm 60 nm	Parameter 14.2 mag (mH) 11.9 Hz (-3db)				Stren		os (%)			
Tip/Tilt Errors Sci Filte Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Pacificual Controit Aniconglanatism	Angular Error (rms) 7.61 mas 7.73 mas 14.04 mas 162 mas	Equivalent WFE (rms) 59 nm 60 nm 100 nm 13 nm	Parameter 14.2 mag (mH) 11.9 Hz (-3db) 19.1 arcsec 10 v reduction				Stren		os (%)			
Tip/Tilt Errors Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion Z	Angular Error (rms) 7.61 mas 7.73 mas 14.04 mas 1.62 mas 0.14 mas	Equivalent WFE (rms) 59 nm 60 nm 100 nm 13 nm 1 nm	Parameter 14.2 mag (mH) 11.9 Hz (-3db) 19.1 arcsec 10 x reduction 20 x reduction				Stren		os (%)			
Tip/Tilt Errors Sci Filte Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion Z Induced Plate Scale Deformations	Angular Error (rms) 7.61 mas 7.73 mas 14.04 mas 1.62 mas 0.14 mas 2.27 mas	Equivalent WFE (rms) 59 nm 60 nm 100 nm 13 nm 1 nm 1 nm 18 nm	Parameter 14.2 mag (mH) 11.9 Hz (-3db) 19.1 arcsec 10 x reduction 20 x reduction -1500 m conj height				Stren		os (%)			
Tip/Tilt Errors Sci Filte Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Centroid Anisoplanatism Residual Atmospheric Dispersion Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Difft	Angular Error (rms) 7.61 mas 7.73 mas 14.04 mas 1.62 mas 0.14 mas 2.27 mas 15.00 mas	Equivalent WFE (rms) 59 nm 60 nm 100 nm 1 3 nm 1 nm 18 nm 105 nm	Parameter 14.2 mag (mH) 11.9 Hz (-3db) 19.1 arcsec 10 x reduction 20 x reduction -1500 m conj height Allco 0.25 mas' min				Stren		95 (%)			
Tip/Tilt Errors Sci Filte Tilt Measurement Error (one-axis) Tilt Anadwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Tenor (one-axis) Residual Centroid Anisoplanatism Tenor (one-axis) Residual Centroid Anisoplanatism Tenor (one-axis) Residual Centroid Anisoplanatism Tenor (one-axis) Z Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Long	Angular Error (rms) 7.61 mas 7.73 mas 14.04 mas 16.2 mas 0.14 mas 2.27 mas 15.00 mas 0.00 mas	Equivalent WFE (rms) 59 nm 60 nm 100 nm 13 nm 1 nm 18 nm 105 nm 0 nm	Parameter 14.2 mag (mH) 11.9 Hz (-3db) 19.1 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min				Stren		DS (%)			
Sci Filte Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Ansoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Centroid Anisoplanatism Residual Centroid Anisoplanatism Errors Science Instrument Mechanical Drift Long Exposure Fild Rotation Errors Residual Telescope Pointing Jitter (one-axis)	Angular Error (rms) 7.3 mas 14.04 mas 1.62 mas 0.14 mas 2.27 mas 15.00 mas 0.048 mas	Equivalent WFE (rms) 59 nm 60 nm 13 nm 1 nm 18 nm 105 nm 0 nm 4 nm	Parameter 14.2 mag (mH) 11.9 Hz (-3db) 19.1 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance				Stren		JS (%)			
Tip/Tilt Errors Till Measurement Error (one-axis) Sci Filte Till Bandwidth Error (one-axis) Tilt Anisoplanatism Till Anisoplanatism Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Tip/Tilt Error (one-axis)	Angular Error (rms) 7.61 mas 7.73 mas 14.04 mas 162 mas 0.14 mas 2.27 mas 15.00 mas 0.48 mas 23.4 mas	Equivalent WFE (rms) 59 nm 60 nm 100 nm 1 nm 1 nm 1 nm 1 nm 1 nm 4 nm 4 nm	Parameter 14.2 mag (mH) 11.9 Hz (-3db) 19.1 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl	0.07	0.12	0.19	0.25	0.32	0.39	0.49	0.62	0.75
Tip/Tilt Errors Sci Filte Tilt Measurement Error (one-axis) Sci Filte Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Residual Centroid Anisoplanatism Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Tip/Tilt Error (one-axis)	Angular Error (rms) 7.61 mas 7.73 mas 14.04 mas 14.04 mas 0.44 mas 2.27 mas 15.00 mas 0.00 mas 0.00 mas 0.00 mas 0.48 mas	Equivalent WFE (rms) 59 nm 60 nm 100 nm 1 nm 1 nm 1 nm 105 nm 0 nm 4 nm 150 nm	Parameter 14.2 mag (mH) 11.9 Hz (-3db) 19.1 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl	0.07	0.12	0.19	0.25	0.32	0.39	0.49	0.62	0.75
Tip/Tilt Errors Sci Filte Tilt Measurement Error (one-axis) Sci Filte Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Centroid Anisoplanatism Z Induced Plate Scale Deformations Z Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis)	Angular Error (rms) 7.61 mas 14.04 mas 14.04 mas 2.27 mas 15.00 mas 0.00 mas 0.48 mas 23.4 mas	Equivalent WFE (rms) 59 nm 60 nm 100 nm 1 nm 18 nm 105 nm 0 nm 4 nm 150 nm	Parameter 14.2 mag (mH) 11.9 Hz (-3db) 19.1 arcsec 10 x reduction 20 x reduction -1500 m conj height Allco 0.25 mas / min Allco 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl	0.07	0.12	0.19	0.25	0.32	0.39	0.49	0.62	0.75
Tip/Tilt Errors Tilt Measurement Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Centroid Anisoplanatism Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error	Angular Error (rms) 7.61 mas 7.73 mas 14.04 mas 1.62 mas 0.14 mas 2.27 mas 15.00 mas 0.00 mas 0.48 mas 2.3.4 mas	Equivalent WFE (rms) 59 nm 60 nm 100 nm 1 nm 18 nm 105 nm 4 nm 150 nm 231 nm	Parameter 14.2 mag (mH) 11.9 Hz (-3db) 19.1 arcsec 10 x reduction 20 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%)	0.07	0.12	0.19	0.25 0.03	0.32 0.07	0.39	0.49	0.62	0.75
Tip/Tilt Errors Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis)	Angular Error (rms) 7.61 mas 7.73 mas 1.4.04 mas 1.62 mas 0.14 mas 2.27 mas 15.00 mas 0.00 mas 0.48 mas 23.4 mas	Equivalent WFE (rms) 59 nm 60 nm 13 nm 13 nm 18 nm 105 nm 0 nm 4 nm 150 nm	Parameter 14.2 mag (mH) 11.9 Hz (-3db) 19.1 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%)	0.07	0.12	0.19	0.25 0.03	0.32	0.39	0.49	0.62	0.75
Tip/Tilt Errors Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion z Induced Pilate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rolation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error	Angular Error (rms) 7.81 mas 7.73 mas 14.04 mas 14.04 mas 0.44 mas 2.27 mas 15.00 mas 0.48 mas 23.4 mas	Equivalent WFE (rms) 59 nm 100 nm 1 nm 1 nm 1 8 nm 105 nm 0 nm 4 nm 150 nm 231 nm	Parameter 14.2 mag (mH) 11.9 Hz (-3db) 19.1 arcsec 10 x reduction 20 x reduction 20 Z reduction Allec 0.25 mas / min Allec 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.07	0.12	0.19	0.25 0.03	0.32 0.07	0.39 0.12 480	0.49	0.62	0.75
Tip/Tilt Errors Sci Filte Tilt Measurement Error (one-axis) Sci Filte Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rolation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy Z	Angular Error (rms) 7.81 mas 7.73 mas 14.04 mas 14.04 mas 0.44 mas 2.27 mas 15.00 mas 0.48 mas 23.4 mas	Equivalent WFE (rms) 59 nm 60 nm 100 nm 1 nm 1 nm 1 8 nm 105 nm 0 nm 4 nm 150 nm 231 nm	Parameter 14.2 mag (mH) 11.9 Hz (-3db) 19.1 arcsec 10 x reduction 20 x reduction -1500 m conj height Allec 0.25 mas / min Allec 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.07 0.00 50 0.09	0.12 0.00 70 0.14	0.19 0.01 80 0.16	0.25 0.03 160 0.24	0.32 0.07 240 0.27	0.39 0.12 480 0.41	0.49 0.22 1000 0.66	0.62	0.75 0.58 1540 0.80
Tip/Tilt Errors Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Ansolvatile Error (one-axis) Tilt Ansolvatile Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy Z Sky Coverage Galactic Lat.	Angular Error (rms) 7.81 mas 14.04 mas 14.04 mas 1.62 mas 0.14 mas 2.27 mas 15.00 mas 0.48 mas 2.3.4 mas 2.3.4 mas	Equivalent WFE (rms) 59 nm 100 nm 1 nm 1 nm 1 8 nm 105 nm 0 nm 4 nm 150 nm 231 nm	Parameter 14.2 mag (mH) 11.9 Hz (-3db) 19.1 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.07 0.00 50 0.09	0.12 0.00 70 0.14	0.19 0.01 80 0.16	0.25 0.03 160 0.24	0.32 0.07 240 0.27	0.39 0.12 480 0.41	0.49 0.22 1000 0.66	0.62	0.75 0.58 1540 0.80
Tip/Tilt Errors Tilt Masurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy z Sky Coverage Galactic Lat. Corresponding Sky Coverage	Angular Error (rms) 7.81 mas 14.04 mas 14.04 mas 1.62 mas 0.14 mas 2.27 mas 15.00 mas 0.48 mas 23.4 mas 30 deg	Equivalent WFE (rms) 59 nm 100 nm 1 nm 1 nm 105 nm 0 nm 4 nm 150 nm 231 nm	Parameter 14.2 mag (mH) 11.9 Hz (-3db) 19.1 arcsec 10 x reduction 20 x reduction 20 Z reduction Alloc 0.25 mas / min Alloc 0	0.07 0.00 50 0.09	0.12 0.00 70 0.14	0.19 0.01 80 0.16	0.25 0.03 160 0.24	0.32 0.07 240 0.27	0.39 0.12 480 0.41	0.49 0.22 1000 0.66	0.62	0.75 0.58 1540 0.80
Tip/Tilt Errors Sci Filte Tilt Measurement Error (one-axis) Sci Filte Tilt Ansoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy Z Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters	Angular Error (rms) 7.61 mas 14.04 mas 14.04 mas 2.27 mas 0.00 mas 0.00 mas 0.48 mas 23.4 mas 30 deg	Equivalent WFE (rms) 59 nm 60 nm 100 nm 1 nm 18 nm 0 nm 4 nm 150 nm 231 nm 5.0%	Parameter 14.2 mag (mH) 11.9 Hz (-3db) 19.1 arcsec 10 x reduction -1500 m conj height Alico 0.25 mas / min Alico 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the	0.07 0.00 50 0.09	0.12 0.00 70 0.14	0.19 0.01 80 0.16	0.25 0.03 160 0.24	0.32 0.07 240 0.27	0.39 0.12 480 0.41	0.49 0.22 1000 0.66	0.62	0.75 0.58 1540 0.80
Tip/Tilt Errors Tilt Measurement Error (one-axis) Tilt Mandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy z Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters	Angular Error (rms) 7.81 mas 14.04 mas 14.04 mas 1.62 mas 0.14 mas 2.27 mas 15.00 mas 0.48 mas 2.3.4 mas 23.4 mas 30 deg	Equivalent WFE (rms) 59 nm 100 nm 1 nm 1 nm 1 8 nm 105 nm 0 nm 4 nm 150 nm 231 nm	Parameter 14.2 mag (mH) 11.9 Hz (-3db) 19.1 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the	0.07 0.00 50 0.09	0.12 0.00 70 0.14	0.19 0.01 80 0.16	0.25 0.03 160 0.24	0.32 0.07 240 0.27	0.39 0.12 480 0.41	0.49 0.22 1000 0.66	0.62	0.75 0.58 1540 0.80
Tip/Tilt Errors Till Measurement Error (one-axis) Till Analyddh Error (one-axis) Till Anisoplanatism Residual Centrold Anisoplanatism Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy z Sky Coverage Gelactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.092 m	Angular Error (rms) 7.61 mas 7.73 mas 14.04 mas 16.26 mas 0.14 mas 2.27 mas 15.00 mas 0.00 mas 0.48 mas 23.4 mas 30 deg 30 deg	Equivalent WFE (rms) 59 nm 60 nm 100 nm 1 nm 1 nm 1 nm 4 nm 150 nm 231 nm 5.0% Wind Speed 8.03	Parameter 14.2 mag (mH) 11.9 Hz (-3db) 19.1 arcsec 10 X reduction 20 X reduction -1500 m conj height Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle	0.07 0.00 50 0.09	0.12 0.00 70 0.14	0.19 0.01 80 0.16	0.25 0.03 160 0.24	0.32 0.07 240 0.27	0.39 0.12 480 0.41	0.49 0.22 1000 0.66	0.62	0.75 0.58 1540 0.80
Tip/Tilt Errors Tilt Measurement Error (one-axis) Tilt Ansoplanatism Error (one-axis) Residual Centroid Anisoplanatism Comparison Residual Centroid Anisoplanatism Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy z Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.092 m Theta0_eff 1.96 arcsec	Angular Error (rms) 7.61 ms 7.73 ms 14.04 mas 14.04 mas 2.27 mas 2.27 mas 0.00 mas 0.00 mas 0.08 mas 23.4 mas 30 deg 30 deg	Equivalent WFE (rms) 59 nm 60 nm 100 nm 1 nm 1 nm 105 nm 0 nm 4 nm 150 nm 231 nm 5.0% Wind Speed 8.03 Outer Scale 75	Parameter 14.2 mag (mH) 11.9 Hz (-3db) 19.1 arcsec 10 X reduction 20 X reduction -1500 m conj height Alice 0.25 mas / min Alice 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle m H0 WFS Rate	0.07 0.00 50 0.09	0.12 0.00 70 0.14	0.19 0.01 80 0.16	0.25 0.03 160 0.24	0.32 0.07 240 0.27	0.39 0.12 480 0.41	0.49 0.22 1000 0.66	0.62	0.75 0.58 1540 0.80
Tip/Tilt Errors Sci Filte Tilt Measurement Error (one-axis) Sci Filte Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rolation Errors Residual Atmospheric Dispersion Total Tip/Tilt Error (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy Z Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.092 m Theta0_eff 1.96 acrsec Solum Abund. 2.4 x 10°	Angular Error (rms) 7.81 mas 14.04 mas 14.04 mas 1.62 mas 0.14 mas 2.27 mas 15.00 mas 0.48 mas 23.4 mas 30 deg	Equivalent WFE (rms) 59 nm 60 nm 100 nm 1 nm 1 nm 1 8 nm 105 nm 0 nm 4 nm 150 nm 231 nm 231 nm 5.0%	Parameter 14.2 mag (mH) 11.9 Hz (-3db) 19.1 arcsec 10 x reduction 20 x reduction 20 x reduction Alloc 0.25 mas / min Alloc 0.25 mas	0.07 0.00 50 0.09 • Total E1	0.12 0.00 70 0.14 ffective V deg Hz e-rms	0.19 0.01 80 0.16 V/FE shor	0.25 0.03 160 0.24 wn	0.32 0.07 240 0.27	0.39 0.12 480 0.41	0.49 0.22 1000 0.66	0.62	0.75 0.58 1540 0.80
Tip/Tilt Errors Tilt Measurement Error (one-axis) Tilt Massurement Error (one-axis) Tilt Anisoplanatism Residual Centrold Anisoplanatism Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy Z Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.092 m Theta0_eff 1.96 arcsec Science Target: SCA0 Science Target: SCA0	Angular Error (rms) 7.61 ms 7.73 ms 14.04 mas 1.62 mas 0.14 mas 2.27 mas 15.00 mas 0.00 mas 0.00 mas 0.00 mas 0.48 mas 23.4 mas 30 deg	Equivalent WFE (rms) 59 nm 60 nm 100 nm 1 nm 1 nm 1 nm 0 nm 4 nm 150 nm 231 nm 231 nm Un Constant Con	Parameter 14.2 mag (mH) 11.9 Hz (-3db) 19.1 arcsec 10 X reduction 20 X reduction -1500 m conj height Alice 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle m HO WFS Rate arcmin HO WFS Noise HOWFS enti-aliasing UC WFS reduction	0.07 0.00 50 0.09 • Total El 815 4.8 NO	0.12 0.00 70 0.14 ffective V deg Hz e-rms	0.19 0.01 80 0.16 V/FE show	0.25 0.03 160 0.24 wn	0.32 0.07 240 0.27 CCD50	0.39 0.12 480 0.41	0.49 0.22 1000 0.66	0.62	0.75 0.58 1540 0.80
Tip/Tilt Errors Sci Filte Tilt Measurement Error (one-axis) Tilt Madwidth Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy Z Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.092 m Theta0_eff 1.96 arcsec Sodium Abund. 4 x 10° Science Target: SCAO LOWFS Target: SCAO	Angular Error (rms) 7.61 mas 7.73 mas 14.04 mas 14.04 mas 2.27 mas 0.14 mas 2.27 mas 0.00 mas 0.00 mas 0.48 mas 23.4 mas 30 deg 30 deg	Equivalent WFE (rms) 59 nm 60 nm 100 nm 1 nm 1 nm 105 nm 0 nm 4 nm 150 nm 231 nm 231 nm Uter Scale 75 LGS Ast. Rad. 0.00 HOWFS Trans 0.28 Num 3x3 0	Parameter 14.2 mag (mH) 11.9 Hz (-3db) 19.1 arcsec 10 X reduction 20 X reduction -1500 m conj height Alice 0.25 mas / min Alice 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle m H0 WFS Rate arcmin H0 WFS Rate arcmin H0 WFS Rate IO WFS rate [0 WFS rate [0 WFS rate [0 WFS rate][0 WFS ra	0.07 0.00 50 0.09 Total El 8155 8155 8155 8155 8155 8155 8155 815	0.12 0.000 70 0.14 ffective V deg Hz e-rms Hz e-rms	0.19 0.01 80 0.16 V/FE shoo	0.25 0.03 160 0.24 wn using using	0.32 0.07 240 0.27 CCD50	0.39 0.12 480 0.41	0.49 0.22 1000 0.66	0.62	0.75
Tip/Tilt Errors Sci Filte Tilt Measurement Error (one-axis) Sci Filte Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Z Science Instrument Mechanical Drift Long Exposure Field Rolation Errors Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rolation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy Z Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.092 m Theta0_eff 1.96 arcsecc Science Target: SCA0 LOWFS Star Type: Mo Max Exposure Time 1800 sec	Angular Error (rms) 7.81 mas 14.04 mas 1.62 mas 0.14 mas 2.27 mas 15.00 mas 0.48 mas 0.48 mas 23.4 mas 30 deg 30 deg	Equivalent WFE (rms) 59 nm 60 nm 100 nm 1 nm 1 nm 1 nm 1 nm 1 nm 1 nm 1 nm 231 nm 231 nm 231 nm 0 uter Scale 5.0% Wind Speed 8.03 0.04 Nove 5.0%	Parameter 14.2 mag (mH) 11.9 Hz (-3db) 19.1 arcsec 10 x reduction 20 x reduction 20 x reduction Allce 0.25 mas / min Allce 0.25 mas / min Allce 0.	0.07 0.00 50 0.09 * Total El * 15 * 4.8 * NO 234 4.5 * 234 * 4.5	0.12 0.00 70 0.14 ffective V deg Hz e-rms Hz e-rms	0.19 0.01 80 0.16 VFE shoo SH SH SH	0.25 0.03 160 0.24 wn using using 50	0.32 0.07 240 0.27 CCD50 H2RG	0.39 0.12 480 0.41	0.49 0.22 1000 0.66	0.62	0.75 0.58 1540 0.80

Table 9. Error budget performance prediction for dynamics of Z = 1 galaxies w/ equivalent 50 W CW laser return science case, optimized for Z-band ensquared energy.

6.1.8 30% Sky Coverage w/ Equivalent 12 W MM Laser Return

Palomar V	Vavefront Error Budget Sur	mmary	Version 1.30					Scie	ence E	Band			
Mode:	P3K LGS				u'	g'	r'	i'	Ζ	Y	J	Н	К
Instrument:	PHARO			λ (μ m)	0.36	0.47	0.62	0.75	0.88	1.03	1.25	1.64	2.20
Observation:	30% Sky			δλ (μΜ)	0.06	0.14	0.14	0.15	0.12	0.12	0.16	0.29	0.34
				λ/D (mas)	15	20	27	32	38	45	54	71	95
			Wavefront					Stre	nl Rati	io (%)			
High-order	Errors (LGS Mode)		Error (rms)	Parameter						- (/-/			
Atmospheri	ric Fitting Error		119 nm	16 Subaps									
High-order	Measurement Error		104 nm	30 Hz (-3db) 12 W									
LGS Focal	Anisoplanatism Error		86 nm	1 beacon(s)									
Asterism D	Deformation Error		0 nm	0.50 m LLT									
Scintillation	n Error		13 nm	0.34 Scint index. H-band									
WFS Scinti	illation Error		10 nm	Alloc									
Uncorrecta	able Static Telescone Aberrations	216 nm	14 nm	64 Acts									
Uncorrecta	able Dynamic Telescope Aberrations		0 nm	Dekens Ph.D									
Static WFS	S Zero-point Calibration Error		25 nm	Alloc									
Dynamic W	VFS Zero-point Calibration Error		30 nm	Alloc									
Go-to Cont	trol Errors		0 nm	Alloc									
Residual N	la Layer Focus Change		4 nm	30 m/s Na layer vel									
DM Finite S	Stroke Errors		19 nm	5.5 um P-P stroke									
High-Order	r Aliasing Error		40 nm	16 Subaps									
DM Drive D	Digitization		1 nm	16 bits									
Uncorrecta	able AO System Aberrations		20 nm 38 nm	Alloc PHARO Instrument									
DM-to-lens	slet Misregistration		15 nm	Alloc									
DM-to-lens	slet Pupil Scale Error		15 nm	Alloc									
Angular An	nisoplanatism Error	79 nm	67 nm	5 arcsec									
						0.00		0.00		0.10		0.40	
I otal H	Ign Order Wavefront Error	230 nm	240 nm	High Order Strehl	0.00	0.00	0.00	0.02	0.06	0.12	0.24	0.43	0.63
	20	Angular	Equivalent	Damana atau				Streh	nl ratio	os (%)			
Tin/Tilt Erro		-	-	Daramotor									
Tip/Tilt Erro	, , , , , , , , , , , , , , , , , , ,	Error (rms)	WFE (rms)	Parameter									
Tip/Tilt Erro	Sci Filte	Error (rms)	WFE (rms)	16.9 mag (mH)									
Tip/Tilt Erro Tilt Measur Tilt Bandwi	rement Error (one-axis) idth Error (one-axis)	Error (rms) r 59.35 mas 56.00 mas	WFE (rms) 318 nm 308 nm	16.9 mag (mH) 1.6 Hz (-3db)									
Tip/Tilt Erro Tilt Measur Tilt Bandwi Tilt Anisopl	Sci Filte rement Error (one-axis) idth Error (one-axis) lanatism Error (one-axis)	Error (rms) r 59.35 mas 56.00 mas 28.49 mas	WFE (rms) 318 nm 308 nm 199 nm	16.9 mag (mH) 1.6 Hz (-3db) 38.7 arcsec									
Tip/Tilt Erro Tilt Measur Tilt Bandwi Tilt Anisopl Residual C Besidual C	rement Error (one-axis) idth Error (one-axis) ianalism Error (one-axis) Pantroid Anisoplanatism tropenbeir Diserscion H	Error (rms) r 59.35 mas 56.00 mas 28.49 mas 1.62 mas 0.05 mas	WFE (rms) 318 nm 308 nm 199 nm 13 nm 0 nm	Parameter 16.9 mag (mH) 1.6 Hz (-3db) 38.7 arcsec 10 x reduction 20 x reduction									
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Tip/Tilt Erro Tilt Measur Tilt Bandwi Tilt Anisopi Residual C Residual X Residual X Science Ins Long Expor Residual Tr Total Ti	Sci Fitte rement Error (one-axis) idth Error (one-axis) lanatism Error (one-axis) entroid Anisoplanatism timospheric Dispersion H ate Scale Deformations strument Mechanical Drift isure Field Rotation Errors elescope Pointing Jitter (one-axis) ip/Tilt Error (one-axis)	Error (rms) r 59.35 mas 56.00 mas 28.49 mas 1.62 mas 0.05 mas 2.54 mas 0.00 mas 3.50 mas 86.6 mas	WFE (rms) 318 nm 308 nm 139 nm 13 nm 0 nm 23 nm 0 nm 28 nm 390 nm	Parameter 16.9 mag (mH) 1.6 Hz (-3db) 38.7 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl	0.01	0.01	0.02	0.02	0.03	0.04	0.06	0.11	0.18
Tip/Tilt Erro Tilt Measur Tilt Bandwi Tilt Anisopi Residual O Residual O Residual O Residual T Total Til Total Effect	Sci Filte rement Error (one-axis) idth Error (one-axis) lanatism Error (one-axis) entroid Anisoplanatism throspheric Dispersion H ate Scale Deformations strument Mechanical Drift sure Field Rotation Errors elescope Pointing Jitter (one-axis) ip/Titt Error (one-axis) ive Wavefront Error	Error (rms) r 59.35 mas 56.00 mas 28.49 mas 1.62 mas 0.05 mas 2.50 mas 0.00 mas 3.50 mas 86.6 mas	WFE (rms) 318 nm 308 nm 139 nm 13 nm 0 nm 23 nm 0 nm 28 nm 390 nm 457 nm	16.9 mag (mH) 1.6 Hz (-3db) 38.7 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%)	0.01	0.01	0.02	0.02	0.03	0.04	0.06	0.11	0.18
Tip/Tilt Erro Tilt Measur Tilt Bandwi Tilt Ansopi Residual A Induced Pir Science Ins Long Expor- Residual T Total Ti Total Effect	Sci Filte rement Error (one-axis) idth Error (one-axis) lanatism Error (one-axis) Pentroid Anisoplanatism tmospheric Dispersion H iate Scale Deformations strument Mechanical Drift sure Field Rotation Errors ip/Tilt Error (one-axis) iip/Tilt Error (one-axis) iive Wavefront Error	Error (rms) r 59.35 mas 56.00 mas 28.49 mas 1.62 mas 2.84 mas 2.50 mas 3.50 mas 86.6 mas	WFE (rms) 318 nm 308 nm 199 nm 13 nm 0 nm 23 nm 20 nm 38m 390 nm 390 nm	16.9 mag (mH) 1.6 Hz (-3db) 38.7 arcsec 10 x reduction 20 x reduction 10 to 25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%)	0.01	0.01	0.02	0.02	0.03	0.04	0.06	0.11	0.18
Tip/Tilt Erro Tilt Measur Tilt Bandwi Tilt Anisopi Residual C Residual C Residual T Long Expor Residual T Total Til Total Effect	Sci Filte rement Error (one-axis) idfli Error (one-axis) ianatism Error (one-axis) ianatism Error (one-axis) introspheric Dispersion H ate Scale Deformations strument Mechanical Drift sure Filed Rotation Errors elescope Pointing Jitter (one-axis) ip/Tilt Error (one-axis) ive Wavefront Error	Error (rms) f 59.35 mas 56.00 mas 28.49 mas 1.62 mas 2.50 mas 2.50 mas 3.50 mas 86.6 mas	WFE (rms) 318 nm 308 nm 199 nm 13 nm 23 nm 20 nm 28 nm 390 nm 390 nm	16.9 mag (mH) 1.6 Hz (-3db) 38.7 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.01	0.01	0.02	0.02	0.03	0.04 0.01 480	0.06	0.11	0.18
Tip/Tilt Erro Tilt Measur Tilt Bandwi Tilt Anisopi Residual C Residual C Residual T Science In Long Expor Residual T Total Til Total Effect	Sci Filte rement Error (one-axis) dith Error (one-axis) inardism Error (one-axis) inardism Error (one-axis) introspheric Dispersion H ate Scale Deformations strument Mechanical Drift ssure Filed Rotation Errors eleescope Pointing Jitter (one-axis) intro (one-axis) intro (one-axis) itive Wavefront Error Energy H	Error (rms) r 59.35 mas 56.00 mas 28.49 mas 1.62 mas 2.56 mas 2.56 mas 3.50 mas 86.6 mas	WFE (rms) 318 nm 308 nm 139 nm 13 nm 23 nm 20 nm 0 nm 28 nm 390 nm 457 nm	16.9 mag (mH) 1.6 Hz (-3db) 38.7 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.01 0.00 50 0.02	0.01 0.00 70 0.04	0.02 0.00 80 0.05	0.02 0.00 160 0.19	0.03 0.00 240 0.33	0.04 0.01 480 0.56	0.06	0.11	0.18 0.11 1140 0.80
Tip/Tilt Erro Tilt Measur Tilt Bandwi Tilt Anisopi Residual C Residual A Residual T Science Ins Long Expor Residual T Total Effect Ensquared Sky Covera	Sci Filte rement Error (one-axis) dith Error (one-axis) inardism Error (one-axis) inardism Error (one-axis) introspheric Dispersion H ate Scale Deformations strument Mechanical Drift sure Filed Rotation Errors eleescope Pointing Jitter (one-axis) intro (one-axi	Error (rms) r 59.35 mas 56.00 mas 28.49 mas 1.62 mas 0.05 mas 2.54 mas 2.54 mas 3.50 mas 86.6 mas	WFE (rms) 318 nm 308 nm 139 nm 13 nm 23 nm 20 nm 0 nm 28 nm 390 nm 457 nm	16.9 mag (mH) 1.6 Hz (-3db) 38.7 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.01 0.00 50 0.02	0.01 0.00 70 0.04	0.02 0.00 80 0.05	0.02 0.00 160 0.19	0.03 0.00 240 0.33	0.04 0.01 480 0.56	0.06 0.02 1000 0.76	0.11	0.18 0.11 1140 0.80
Tip/Tilt Erro Tilt Measur Tilt Bandwi Tilt Anisopi Residual C Residual A Science Ins Long Expor Residual T Total Effect Ensquared Sky Covera	Sci Filte rement Error (one-axis) (iditi Error (one-axis)) inantism Error (one-axis)) inantism Error (one-axis) introspheric Dispersion H ate Scale Deformations strument Mechanical Drift usure Field Rotation Errors eleescope Pointing Jitter (one-axis) Image: Comparison of the sure Field Rotation Errors ip/Till Error (one-axis) Image: Comparison of the sure Field Rotation Errors ip/Energy H Ige Galactic Lat.	Error (rms) r 59.35 mas 56.00 mas 28.49 mas 1.62 mas 0.05 mas 2.54 mas 2.50 mas 0.00 mas 3.50 mas 86.6 mas 60 deg	WFE (rms) 318 nm 308 nm 130 nm 0 nm 23 nm 0 nm 28 nm 390 nm 457 nm	16.9 mag (mH) 1.6 Hz (-3db) 38.7 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.01 0.00 50 0.02	0.01 0.00 70 0.04	0.02 0.00 80 0.05	0.02 0.00 160 0.19	0.03 0.00 240 0.33	0.04 0.01 480 0.56	0.06 0.02 1000 0.76	0.11	0.18 0.11 1140 0.80
Tip/Tilt Erro Tilt Measur Tilt Bandwi Tilt Anisopi Residual A Residual A Residual Ti Total Effecti Ensquared Sky Covera Corresp	Sci Filte rement Error (one-axis) (idth Error (one-axis)) inantism Error (one-axis)) entroid Anisoplanatism throspheric Dispersion H ate Scale Deformations strument Mechanical Drift sure Field Rotation Errors elescope Pointing Jitter (one-axis) Image: Comparison of the sure Field Rotation Errors ig/Tilt Error (one-axis) Image: Comparison of the sure Field Rotation Errors ig/Energy H igge Galactic Lat. ponding Sky Coverage	Error (rms) r 59.35 mas 56.00 mas 28.49 mas 1.62 mas 0.05 mas 2.56 mas 0.00 mas 3.50 mas 86.6 mas 60 deg	WFE (rms) 318 nm 308 nm 130 nm 13 nm 23 nm 20 nm 0 nm 28 nm 390 nm 457 nm 30.0%	Parameter 16.9 mag (mH) 1.6 Hz (-3db) 38.7 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the	0.01 0.00 50 0.02	0.01 0.00 70 0.04	0.02 0.00 80 0.05	0.02 0.00 160 0.19	0.03 0.00 240 0.33	0.04 0.01 480 0.56	0.06 0.02 1000 0.76	0.11	0.18 0.11 1140 0.80
Tip/Tilt Erro Tilt Measur Tilt Bandwi Tilt Anisopi Residual C Residual A Science In Long Expor Residual T Total Effecti Ensquared Sky Covera Corresp Assumptior	Sci Filte rement Error (one-axis) idth Error (one-axis) inardism Error (one-axis) inartism Error (one-axis) introdyter Dispersion ate Scale Deformations strument Mechanical Drift sure Field Rotation Errors elescope Pointing Jitter (one-axis) ip/Tilt Error (one-axis) tive Wavefront Error Energy H ige Galactic Lat. ponding Sky Coverage ns / Parameters	Error (rms) r 59.35 mas 56.00 mas 28.49 mas 1.62 mas 0.05 mas 2.54 mas 2.50 mas 0.00 mas 3.50 mas 86.6 mas 60 deg	WFE (rms) 318 nm 308 nm 130 nm 13 nm 23 nm 20 nm 0 nm 28 nm 390 nm 457 nm 30.0%	Parameter 16.9 mag (mH) 1.6 Hz (-3db) 38.7 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the	0.01 0.00 50 0.02	0.01 0.00 70 0.04	0.02 0.00 0.05	0.02 0.00 160 0.19	0.03 0.00 240 0.33	0.04 0.01 480 0.56	0.06 0.02 1000 0.76	0.11	0.18 0.11 1140 0.80
Tip/Tilt Erro Tilt Measur Tilt Bandwi Tilt Anisopi Residual A Residual A Residual Ti Total Effecti Ensquared Sky Covera: Corresp Assumptior	Sci Filte rement Error (one-axis) idth Error (one-axis) inardism Error (one-axis) inardism Error (one-axis) strument Mechanical Drift ssure Field Rotation Errors relescope Pointing Jitter (one-axis) tip/Tilt Error (one-axis) tive Wavefront Error Energy H tige Galactic Lat. ponding Sky Coverage ms / Parameters to ponding Sky Coverage	Error (rms) f 59.35 mas 56.00 mas 28.49 mas 1.62 mas 0.05 mas 2.54 mas 2.50 mas 0.00 mas 3.50 mas 86.6 mas 60 deg	WFE (rms) 318 nm 308 nm 199 nm 13 nm 23 nm 20 nm 0 nm 28 nm 390 nm 457 nm 30.0%	Parameter 16.9 mag (mH) 1.6 Hz (-3db) 38.7 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the	0.01 0.00 50 0.02	0.01 0.00 70 0.04	0.02 0.00 80 0.05	0.02 0.00 160 0.19	0.03 0.00 240 0.33	0.04 0.01 480 0.56	0.06 0.02 1000 0.76	0.11	0.18 0.11 1140 0.80
Tip/Tilt Erro Tilt Measur Tilt Bandwi Tilt Anisopi Residual A Induced Plu Science Ins Long Expor- Residual T Total Effecti Ensquared Sky Coveran Corresp Assumptior	Sci Filte rement Error (one-axis) idth Error (one-axis) ianatism Error (one-axis) ianatism Error (one-axis) iantom Error biopersion ide Scale Deformations strument Mechanical Drift isure Field Rotation Errors ielescope Pointing Jitter (one-axis) ip/Tilt Error (one-axis) iive Wavefront Error ge Galactic Lat. ponding Sky Coverage ns / Parameters r0 0.092 m Thelad eff 196 erreen	Error (rms) r 59.35 mas 56.00 mas 28.49 mas 1.62 mas 0.05 mas 2.54 mas 2.54 mas 3.50 mas 0.00 mas 3.50 mas 86.6 mas 60 deg 60 deg	WFE (rms) 318 nm 308 nm 308 nm 13 nm 20 nm 20 nm 20 nm 390 nm 390 nm 457 nm 30.0%	Parameter 16.9 mag (mH) 1.6 Hz (-3db) 38.7 arcsec 10 x reduction 20 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt StrehI Total StrehI (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle m H0 WES Rate	0.01 0.00 50 0.02 • Total Ef	0.01 0.00 70 0.04 fective V	0.02 0.00 80 0.05	0.02 0.00 160 0.19 wn	0.03 0.00 240 0.33	0.04 0.01 480 0.56	0.06 0.02 1000 0.76	0.11	0.18 0.11 1140 0.80
Tip/Tilt Erro Tilt Measur Tilt Bandwi Tilt Anisopi Residual C Residual C Residual C C Residual T C Residual T Total Effect Ensquared Sky Covera; Corres; Assumptior	Sci Filte rement Error (one-axis) idith Error (one-axis) ianatism Error (one-axis) ianatism Error (one-axis) iantors far (one-axis) istruent Mechanical Drift sure Filed Rotation Errors elescope Pointing Jitter (one-axis) ip/Tilt Error (one-axis) iive Wavefront Error Energy H Ige Galactic Lat. ponding Sky Coverage In Jea Ganseec Sodum Abund. 4 x 10 ⁹	Error (rms) r 59.35 mas 56.00 mas 28.49 mas 1.62 mas 0.05 mas 2.54 mas 2.50 mas 0.00 mas 3.50 mas 86.6 mas 60 deg 60 deg	WFE (rms) 318 nm 308 nm 308 nm 13 nm 23 nm 20 nm 0 nm 28 nm 390 nm 457 nm 30.0%	Parameter 16.9 mag (mH) 1.6 Hz (-3db) 38.7 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle m HO WFS Rate arcmin HO WFS Noise	0.01 0.00 50 0.02 * Total Ef	0.01 0.00 70 0.04 fective V deg Hz e-rms	0.02 0.00 80 0.05	0.02 0.00 160 0.19 wm	0.03 0.00 240 0.33	0.04 0.01 480 0.56	0.06 0.02 1000 0.76	0.11	0.18 0.11 1140 0.80
Tip/Tilt Erro Tilt Measur Tilt Bandwi Tilt Anisopi Residual C Residual A Science In Long Expor Residual T Total Effecti Ensquared Sky Covera Corresp Assumptior	Sci Filte rement Error (one-axis) idth Error (one-axis) iaratism Error (one-axis) iaratism Error (one-axis) struent Mechanical Drift sure Field Rotation Errors eleescope Pointing Jitter (one-axis) iip/Tilt Error (one-axis) iive Wavefront Error Energy H ige Galactic Lat. ponding Sky Coverage ns / Parameters r0 0.092 m Theta0_eff 1.96 arcsec Sodum Abund. 4 x 10° Science Target: SCAO	Error (rms) r 59.35 mas 56.00 mas 28.49 mas 1.62 mas 0.05 mas 2.54 mas 2.50 mas 0.00 mas 3.50 mas 86.6 mas 60 deg 60 deg	WFE (rms) 318 nm 308 nm 199 nm 13 nm 23 nm 20 nm 0 nm 28 nm 390 nm 390 nm 457 nm 457 nm Und Speed 8.03 Outer Scale 5.05 LGS Ast. Rad. 0.00 HOWFS Trans 0.28	Parameter 16.9 mag (mH) 1.6 Hz (-3db) 38.7 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 ma	0.01 0.00 50 0.02 * Total Ef	0.01 0.00 70 0.04 fective V deg Hz e-rms	0.02 0.00 80 0.05 VFE sho	0.02 0.00 160 0.19 wm	0.03 0.00 240 0.33	0.04 0.01 480 0.56	0.06	0.11	0.18 0.11 1140 0.80
Tip/Tilt Erro Tilt Measur Tilt Bandwi Tilt Ansopl Residual A Solence In Long Expor Residual Ti Total Effecti Ensquared Sky Covera: Corresg Assumptior	Sci Filte rement Error (one-axis) idth Error (one-axis) inartism Error (one-axis) inartism Error (one-axis) inartism Error (one-axis) strument Mechanical Drift ssure Field Rotation Errors relescope Pointing Jitter (one-axis) ip/Tilt Error (one-axis) tive Wavefront Error Energy H ige Galactic Lat. ponding Sky Coverage ms / Parameters r0 0.092 m Theta0_eff 1.96 arcsec Science Target: SCAO LOWFS Target: SCAO LOWFS Target: SCAO	Error (rms) T 59.35 mas 56.00 mas 28.49 mas 1.62 mas 0.05 mas 2.54 mas 2.54 mas 2.54 mas 3.50 mas 3.50 mas 86.6 mas 60 deg 60 deg	WFE (rms) 318 nm 308 nm 199 nm 13 nm 23 nm 20 nm 0 nm 28 nm 390 nm 457 nm 457 nm 0uter Scale 75 LGS Ast. Rad. 0.028 HOWE Strans 0.28	Parameter 16.9 mag (mH) 1.6 Hz (-3db) 38.7 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle m HO WFS Rate arcmin HO WFS Rate arcmin HO WFS rate LO WFS rate LO WFS rate LO WFS rate	0.01 0.00 50 0.02 • Total Ef	0.01 0.00 70 0.04 fective V deg Hz e-rms Hz	0.02 0.00 80 0.05 VFE sho	0.02 0.00 160 0.19 wm using using	0.03 0.00 240 0.33 CCD50	0.04 0.01 480 0.56	0.06 0.02 1000 0.76	0.11	0.18 0.11 1140 0.80
Tip/Tilt Erro Tilt Measur Tilt Bandwi Tilt Ansopi Residual C Residual A Induced Pin Science Ins Long Expo- Residual T Total Effect Ensquared Sky Coverage Corresp Assumptior	Sci Filte rement Error (one-axis) idth Error (one-axis) ianatism Error (one-axis) ianatism Error (one-axis) ianatism Error (one-axis) strument Mechanical Drift isure Field Rotation Errors ielescope Pointing Jitter (one-axis) ip/Tilt Error (one-axis) ip/Tilt Error (one-axis) ig/ Gege Galactic Lat. ponding Sky Coverage ns / Parameters r0 0.092 m Theta0_eff 1.96 arcsec Solence Target: SCAO LOWFS Target: SCAO LOWFS Star Type: M Max Exposure Time 300 sec	Error (rms) r 59.35 mas 56.00 mas 28.49 mas 1.62 mas 0.05 mas 2.56 mas 2.56 mas 0.00 mas 3.50 mas 86.6 mas 60 deg 60 deg Num TT 1 Num TT 1 Num TT 1	WFE (rms) 318 nm 308 nm 199 nm 13 nm 23 nm 20 nm 0 nm 28 nm 390 nm 390 nm 457 nm 457 nm Uter Scale 75 LGS Ast. Rad. Num 30X5 Num 30X5	Parameter 16.9 mag (mH) 1.6 Hz (-3db) 38.7 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m's Zenith Angle m HO WFS Rate arcmin HO WFS Rate arcmin HO WFS Rate LO WFS Noise HOWFS Rate LO WFS Noise HOWFS Rate Advect the stress of the stre	0.01 0.00 50 0.02 * Total Ef	0.01 0.00 70 0.04 fective V deg Hz e-rms Hz e-rms	0.02 0.00 80 0.05 VFE sho SH SH SH	0.02 0.00 160 0.19 wn using using 50	0.03 0.00 240 0.33 ccd50 H2RG Hz	0.04 0.01 480 0.56	0.06	0.11	0.18 0.11 1140 0.80

Table 10. Error budget performance prediction for 30% sky coverage w/ equivalent 12 W MM laser return science case, optimized for H-band Strehl ratio.

6.1.9 30% Sky Coverage w/ Equivalent 50 W CW Laser Return

Palomar W	Vavefront Error Budget Sun	nmarv	Version 1.30					Scie	nce E	Band			
Mode:	P3K LGS				u'	q'	r'	i'	Ζ	Y	J	Н	к
Instrument:	PHARO			λ (μ m)	0.36	0.47	0.62	0.75	0.88	1.03	1.25	1.64	2.20
Observation:	30% Sky			δλ (μm)	0.06	0.14	0.14	0.15	0.12	0.12	0.16	0.29	0.34
				λ/D (mas)	15	20	27	32	38	45	54	71	95
			Wayofront					Strok	I Dati	o (%)			
High-order E	Errors (LGS Mode)		Error (rms)	Parameter				Sue	ii rau	0(%)			
Atmospheri	ic Fitting Error		67 nm	32 Subaps									
Bandwidth I	Error		58 nm	60 Hz (-3db)									
High-order	Measurement Error		69 nm	50 W									
Asterism De	eformation Error		0 nm	0.50 m L L T									
Multispectra	al Error		19 nm	5 zenith angle, H band									
Scintillation	Error		13 nm	0.34 Scint index, H-band									
WFS Scintil	Illation Error	144 pm	10 nm	Alloc									
Uncorrectat	ble Static Telescope Aberrations	144 100	14 nm	64 Acts									
Uncorrectat	ble Dynamic Telescope Aberrations		0 nm	Dekens Ph.D									
Static WFS	Zero-point Calibration Error		25 nm	Alloc									
Dynamic W	/FS Zero-point Calibration Error		30 nm	Alloc									
Go-to Contr	rol Errors		0 nm	Alloc									
Residual Na	a Layer Focus Change		4 nm	30 m/s Na layer vel									
DM Finite S	Stroke Errors		27 nm	5.5 um P-P stroke									
DM Hystere	esis		7 nm	from TMT									
DM Drive D	Digitization		22 nm 1 nm	32 Subaps 16 hits									
Uncorrectat	ble AO System Aberrations		20 nm	Alloc									
Uncorrectat	ble Instrument Aberrations		38 nm	PHARO Instrument									
DM-to-lensl	let Misregistration		15 nm	Alloc									
Divi-to-iensi	let Pupil Scale Error	74 nm	15 nm	Alloc									
Angular Ani	isoplanatism Error		67 nm	5 arcsec									
Total Hi	igh Order Wavefront Error	162 nm	175 nm	High Order Strehl	0.00	0.00	0.05	0.12	0.22	0.33	0.47	0.64	0.78
		Angular	Equivalent					Streh	I ratio	os (%)			
Tip/Tilt Erro				Doromotor									
Tip/Tilt Erro	ors	Error (rms)	WFE (rms)	Parameter									
Tip/Tilt Erro	Sci Filter	Error (rms)	WFE (rms)										
Tip/Tilt Erro	rement Error (one-axis)	Error (rms) 48.53 mas 44.82 mas	285 nm 271 nm	16.9 mag (mH)									
Tip/Tilt Erro Tilt Measure Tilt Bandwid Tilt Anisopla	VIS Sci Filter rement Error (one-axis) dth Error (one-axis) analism Error (one-axis)	Error (rms) 48.53 mas 44.82 mas 28.37 mas	WFE (rms) 285 nm 271 nm 198 nm	Parameter 16.9 mag (mH) 2.0 Hz (-3db) 38.5 arcsec									
Tip/Tilt Erro Tilt Measuri Tilt Bandwid Tilt Anisopla Residual Ce	rrs sci Filter rement Error (one-axis) dth Error (one-axis) anatism Error (one-axis) entroid Anisoplanatism	Error (rms) 48.53 mas 44.82 mas 28.37 mas 1.62 mas	WFE (rms) 285 nm 271 nm 198 nm 13 nm	Parameter 16.9 mag (mH) 2.0 Hz (-3db) 38.5 arcsec 10 x reduction									
Tip/Tilt Erro Tilt Measurd Tilt Bandwid Tilt Anisopla Residual At Residual At	ITS Sci Filter wenent Error (one-axis) dth Error (one-axis) anatism Error (one-axis) entroid Anisoplanatism tmospheric Dispersion H cb Borde Defermentiona	Error (rms) 48.53 mas 44.82 mas 28.37 mas 1.62 mas 0.05 mas	WFE (rms) 285 nm 271 nm 198 nm 13 nm 0 nm 22 nm	Parameter 16.9 mag (mH) 2.0 Hz (-3db) 38.5 arcsec 10 x reduction 20 x reduction 1500 m acqui balabl									
Tip/Tilt Erro Tilt Measurd Tilt Bandwid Tilt Anisopla Residual CC Residual At Induced Pla Science Ins	ITS Sci Filter rement Error (one-axis) dth Error (one-axis) anatism Error (one-axis) entroid Anisopianatism tmospheric Dispersion H ate Scale Deformations strument Mechanical Drift	Error (rms) 48.53 mas 44.82 mas 28.37 mas 1.62 mas 0.05 mas 2.84 mas 2.50 mas	WFE (rms) 285 nm 271 nm 198 nm 13 nm 0 nm 23 nm 20 nm	Parameter 16.9 mag (mH) 2.0 Hz (-3db) 38.5 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 max (min									
Tilt/Tilt Erro Tilt Measun Tilt Bandwi Residual Ct Residual At Induced Pla Science Ins Long Expos	ITS Sci Filter wenent Error (one-axis) dth Error (one-axis) analsm Error (one-axis) entroid Anisoplanatism tmospheric Dispersion ate Scale Deformations strument Mechanical Drift sure Field Rotation Errors	Error (rms) 48.53 mas 44.82 mas 28.37 mas 1.62 mas 0.05 mas 2.84 mas 2.50 mas 0.00 mas	WFE (rms) 285 nm 271 nm 198 nm 13 nm 0 nm 20 nm 0 nm	Parameter 16.9 mag (mH) 2.0 Hz (-3db) 38.5 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min									
Tilt Measuri Tilt Measuri Tilt Anisopi Residual At Induced Pla Science Ins Long Expos Residual Te	ITS Sci Filter wenent Error (one-axis) dth Error (one-axis) anatism Error (one-axis) entroid Anisoplanatism tmospheric Dispersion the Scale Deformations strument Mechanical Drift sure Field Rotation Errors elescope Pointing últter (one-axis)	Error (rms) 48.53 mas 44.82 mas 28.37 mas 1.62 mas 0.05 mas 2.84 mas 2.50 mas 0.00 mas 2.80 mas	WFE (rms) 285 nm 271 nm 198 nm 13 nm 0 nm 20 nm 20 nm 0 nm 23 nm	Parameter 16.9 mag (mH) 2.0 Hz (-3db) 38.5 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min 3 Hz input disturbance									
Tip/Tilt Erro Tilt Measur Tilt Bandwid Tilt Anisopia Residual At Induced Pla Science Ins Long Expos Residual Te	Sci Filter rement Error (one-axis) dth Error (one-axis) anatism Error (one-axis) entroid Anisoplanatism tmospheric Dispersion H ate Scale Deformations strument Mechanical Drift sure Field Rotation Errors elescope Pointing Jitter (one-axis) in/Tilt Error (one-axis)	Error (rms) 48.53 mas 44.82 mas 28.37 mas 1.62 mas 0.05 mas 2.50 mas 2.60 mas 2.80 mas 72.1 mas	WFE (rms) 285 nm 271 nm 198 nm 0 nm 23 nm 20 nm 0 nm 23 nm 23 nm 23 nm	Parameter 16.9 mag (mH) 2.0 Hz (-3db) 38.5 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strobl	0.01	0.01	0.02	0.03	0.05	0.06	0.09	0.15	0.24
Tip/Tilt Erro Tilt Measun Tilt Bandwir Tilt Anisople Residual At Induced Pie Science Ins Long Expos Residual Te Total Tij	Sci Filter rement Error (one-axis) dth Error (one-axis) anatism Error (one-axis) entroid Anisoplanatism tmospheric Dispersion H ate Scale Deformations strument Mechanical Drift sure Field Rotation Errors eleescope Pointing Jitter (one-axis)	Error (rms) 48.53 mas 44.82 mas 28.37 mas 1.62 mas 0.05 mas 2.50 mas 2.80 mas 2.80 mas 72.1 mas	WFE (rms) 285 nm 271 nm 138 nm 13 nm 23 nm 20 nm 0 nm 23 nm 361 nm	Parameter 16.9 mag (mH) 2.0 Hz (-3db) 38.5 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl	0.01	0.01	0.02	0.03	0.05	0.06	0.09	0.15	0.24
Tip/Tilt Erro Tilt Measun Tilt Bandwit Tilt Anisoph Residual At Residual At Residual At Induced Pie Science Ins Long Expos Residual Te Total Ti	Sci Filter Filter (one-axis) Sci Filter Filter Finandism Error (one-axis) Finandism Error (one-axis) Finandism Error (one-axis) Filter Filter (one-axis) Filter Error (one-axis) Filter Error (one-axis) Filter Error (one-axis)	Error (rms) 48.53 mas 44.82 mas 28.37 mas 1.62 mas 0.05 mas 2.84 mas 2.50 mas 0.00 mas 2.80 mas 72.1 mas	WFE (rms) 285 nm 271 nm 188 nm 13 nm 0 nm 23 nm 0 nm 23 nm 361 nm	Parameter 16.9 mag (mH) 2.0 Hz (-3db) 38.5 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl	0.01	0.01	0.02	0.03	0.05	0.06	0.09	0.15	0.24
Tip/Tilt Erro Tilt Measur Tilt Bandwi Tilt Bandwi Residual Cr Residual Cr Residual Cr Science Ins Long Expos Residual Te Total Effecti	Sci Filter rement Error (one-axis) dth Error (one-axis) dth Error (one-axis) entroid Anisoplanatism tmospheric Dispersion H ate Scale Deformations strument Mechanical Drift sure Field Rotation Errors ip/Tillt Error (one-axis) ive Wavefront Error	Error (rms) 48.53 mas 44.82 mas 28.37 mas 1.62 mas 0.05 mas 2.84 mas 2.80 mas 0.00 mas 2.80 mas 72.1 mas	WFE (rms) 285 nm 271 nm 188 nm 13 nm 0 nm 20 nm 0 nm 23 nm 3 nm 3 61 nm 401 nm	Parameter 16.9 mag (mH) 2.0 Hz (-3db) 38.5 arcsec 10 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%)	0.01	0.01	0.02	0.03	0.05	0.06	0.09	0.15	0.24
Tip/Tilt Erro Tilt Measur Tilt Bandwi Residual Cr Residual Cr Residual Ar Induced Pie Science Ins Long Expos Residual Te Total Ti Total Effecti	Sci Filter rement Error (one-axis) dth Error (one-axis) entroid Anisoplanatism tmospheric Dispersion H at Scale Deformations strument Mechanical Drift surure Field Rotation Errors elescope Pointing Jitter (one-axis) ip/Tilt Error (one-axis) ive Wavefront Error	Error (rms) 48.53 mas 44.82 mas 28.37 mas 1.62 mas 2.84 mas 2.50 mas 2.60 mas 2.80 mas 72.1 mas	WFE (rms) 285 nm 271 nm 188 nm 13 nm 23 nm 20 nm 23 nm 3 nm 3 nm 20 nm 3 nm 401 nm	Parameter 16.9 mag (mH) 2.0 Hz (-3db) 38.5 arcsec 10 x reduction -1500 m conj height Alloc 0.25 mas/ min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%)	0.01	0.01	0.02	0.03	0.05	0.06	0.09	0.15	0.24
Tip/Tilt Erro Tilt Massur Tilt Anisopia Residual Cr Residual Ar Induced Pia Science Ins Long Expos Residual Te Total Ti Total Effecti	Sci Filter rement Error (one-axis) dith Error (one-axis) anatism Error (one-axis) entroid Anisoplanatism tmospheric Dispersion ate Scale Deformations strument Mechanical Drift sure Field Rotation Errors elescope Pointing Jitter (one-axis) ip/Tilt Error (one-axis) ive Wavefront Error	Error (rms) 48.53 mas 44.82 mas 28.37 mas 1.62 mas 0.05 mas 2.44 mas 2.50 mas 2.60 mas 2.80 mas 72.1 mas	WFE (rms) 285 nm 271 nm 198 nm 13 nm 0 nm 20 nm 23 nm 20 nm 361 nm 401 nm	Parameter 16.9 mag (mH) 2.0 Hz (-3db) 38.5 arcsec 10 x reduction 20 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min Alloc 0.25 mas / min Alloc 0.25 mas / min Alloc 1.5 mas / min Alloc 1.	0.01	0.01	0.02	0.03	0.05	0.06	0.09	0.15	0.24
Tip/Tilt Erro Tilt Measur Tilt Anisopi Residual Cr Residual Cr Residual Ar Induced Pie Science Ins Long Expos Residual Te Total Effecti Ensquared I	Sci Filter rement Error (one-axis) dth Error (one-axis) entroid Anisoplanatism tmospheric Dispersion H ate Scale Deformations strument Mechanical Drift sure Field Rotation Errors elescope Pointing Jitter (one-axis) ive Wavefront Error Energy H	Error (rms) 48.53 mas 44.82 mas 28.37 mas 1.62 mas 2.64 mas 2.50 mas 2.60 mas 2.80 mas 72.1 mas	WFE (rms) 285 nm 271 nm 198 nm 13 nm 0 nm 20 nm 23 nm 20 nm 361 nm 401 nm	Parameter 16.9 mag (mH) 2.0 Hz (-3db) 38.5 arcsec 10 x reduction 20 x reduction 21 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.01 0.00 50 0.04	0.01 0.00 70 0.08	0.02 0.00 80 0.10	0.03 0.00 160 0.33	0.05 0.01 240 0.53	0.06 0.02 480 0.75	0.09	0.15	0.24 0.18 670 0.80
Tip/Tilt Erro Tilt Measur Tilt Bandwik Tilt Anisopi Residual Cr Residual Cr Residual Cr Residual Ar Induced Pie Science Ins Long Expos Residual Te Total Til Total Effecti Ensquared I Sky Coverage	Sci Filter rement Error (one-axis) dth Error (one-axis) entroid Anisoplanatism tmospheric Dispersion H ate Scale Deformations strument Mechanical Drift sure Field Rotation Errors elescope Pointing Jitter (one-axis) ive Wavefront Error Energy H ge Galactic Lat.	Error (rms) 48.53 mas 44.82 mas 28.37 mas 1.62 mas 2.50 mas 2.50 mas 2.60 mas 2.80 mas 72.1 mas 60 deg	WFE (rms) 285 nm 271 nm 188 nm 13 nm 23 nm 20 nm 23 nm 361 nm 401 nm	Parameter 16.9 mag (mH) 2.0 Hz (-3db) 38.5 arcsec 10 x reduction -1500 m conj height Alloc 0.25 mas/ min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.01 0.00 50 0.04	0.01 0.00 70 0.08	0.02 0.00 80 0.10	0.03 0.00 160 0.33	0.05 0.01 240 0.53	0.06 0.02 480 0.75	0.09	0.15	0.24 0.18 670 0.80
Tip/Tilt Erro Tilt Measur Tilt Bandwi Residual Cr Residual Cr Residual Cr Residual Cr Residual Cr Science Ins Long Expos Residual Te Total Effecti Ensquared I Sky Coverage Correst	Sci Filter rement Error (one-axis) dth Error (one-axis) dth Error (one-axis) entroid Anisoplanatism tmospheric Dispersion H ale Scale Deformations strument Mechanical Drift sure Field Rotation Errors elescope Pointing Jitter (one-axis) ive Wavefront Error Energy H ge Galactic Lat. coonding Sky Coverage	Error (rms) 48.53 mas 44.82 mas 28.37 mas 1.62 mas 0.05 mas 2.24 mas 2.50 mas 0.00 mas 2.80 mas 72.1 mas 60 deg	WFE (rms) 285 nm 271 nm 188 nm 13 nm 20 nm 23 nm 20 nm 23 nm 361 nm 401 nm 401 nm	Parameter 16.9 mag (mH) 2.0 Hz (-3db) 38.5 arcsec 10 x reduction -1500 m conj height Alice 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the	0.01 0.00 50 0.04	0.01 0.00 70 0.08	0.02 0.00 80 0.10	0.03 0.00 160 0.33	0.05 0.01 240 0.53	0.06 0.02 480 0.75	0.09	0.15	0.24 0.18 670 0.80
Tip/Tilt Erro Tilt Madwin Tilt Bandwin Residual Cr Residual Cr Residual Cr Residual Cr Science Ins Long Expos Residual Te Total Effecti Ensquared I Sky Coverag Corresp Assumption	Ins Signature Science	Error (rms) 48.53 mas 44.82 mas 28.37 mas 1.62 mas 0.05 mas 2.80 mas 0.00 mas 2.80 mas 72.1 mas 60 deg	WFE (rms) 285 nm 271 nm 188 nm 13 nm 20 nm 20 nm 20 nm 20 nm 361 nm 401 nm 401 nm	Parameter 16.9 mag (mH) 2.0 Hz (-3db) 38.5 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas/ min Alloc 0.25 mas/ min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the	0.01 0.00 50 0.04	0.01 0.00 70 0.08	0.02 0.00 80 0.10	0.03 0.00 160 0.33	0.05	0.06 0.02 480 0.75	0.09	0.15	0.24 0.18 670 0.80
Tip/Tilt Erro Tilt Measur Tilt Bandwi Residual Cr Residual Cr Residual At Induced Pie Science Ins Long Expos Residual Te Total Effecti Ensquared I Sky Coverage Corresp Assumption	Sci Filter rement Error (one-axis) dth Error (one-axis) dth Error (one-axis) entroid Anisoplanatism tmospheric Dispersion H ate Scale Deformations strument Mechanical Drift sure Field Rotation Errors elescope Pointing Jitter (one-axis) ive Wavefront Error Energy H ge Galactic Lat. coonding Sky Coverage ts / Parameters	Error (rms) 48.53 mas 44.82 mas 28.37 mas 1.62 mas 0.05 mas 2.50 mas 0.00 mas 2.80 mas 72.1 mas 60 deg	WFE (rms) 285 nm 271 nm 188 nm 13 nm 20 nm 20 nm 20 nm 23 nm 361 nm 401 nm 401 nm	Parameter 16.9 mag (mH) 2.0 Hz (-3db) 38.5 arcsec 10 x reduction 20 x reduction -1500 m conj height Alice 0.25 mas/min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the	0.01 0.00 50 0.04	0.01 0.00 70 0.08	0.02 0.00 80 0.10	0.03 0.00 160 0.33	0.05	0.06 0.02 480 0.75	0.09	0.15	0.24 0.18 670 0.80
Tip/Tilt Erro Tilt Measur Tilt Maisoph Residual Cr Residual Cr Residual Cr Residual Ar Induced Pie Science Ins Long Expos Residual Te Total Effecti Ensquared I Sky Coverag Corresp Assumption	Ins Sci Filter Firement Error (one-axis) Ght Error (one-axis) Ght Error (one-axis) Filter Ght Error (one-axis) Filter Ght Error (one-axis) Filter (one-axis)	Error (rms) 48.53 mas 44.82 mas 28.37 mas 1.62 mas 0.05 mas 2.84 mas 2.80 mas 2.80 mas 72.1 mas 60 deg 60 deg	WFE (rms) 285 nm 271 nm 13 nm 23 nm 23 nm 23 nm 23 nm 361 nm 401 nm 401 nm 401 nm 80.0%	Parameter 16.9 mag (mH) 2.0 Hz (-3db) 38.5 arcsec 10 x reduction 20 X reduction -1500 m conj height Alloc 0.25 mas/min Alloc 0.25 mas/min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle	0.01 0.00 50 0.04	0.01 0.00 70 0.08	0.02 0.00 80 0.10	0.03 0.00 160 0.33	0.05	0.06 0.02 480 0.75	0.09	0.15	0.24 0.18 670 0.80
Tip/Tilt Erro Tilt Measur Tilt Bandwi Tilt Bandwi Tilt Bandwi Tilt Bandwi Tilt Bandwi Residual A Residual A Residual A Total Effecti Ensquared I Sky Coverag Corresp Assumption	Interpretation of the second s	Error (rms) 48.53 mas 44.82 mas 28.37 mas 1.62 mas 0.05 mas 2.80 mas 2.80 mas 2.80 mas 72.1 mas 60 deg 60 deg	WFE (rms) 285 nm 271 nm 138 nm 13 nm 0 nm 23 nm 20 nm 0 nm 23 nm 361 nm 401 nm 30.0% Wind Speed 8.03 Outer Scale 75	Parameter 16.9 mag (mH) 2.0 Hz (-3db) 38.5 arcsec 10 X reduction 20 X reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle m H0 WFS Rate	0.01 0.00 50 0.04	0.01 0.00 70 0.08 ffective V	0.02 0.00 80 0.10 VFE show	0.03 0.00 160 0.33	0.05 0.01 240 0.53	0.06 0.02 480 0.75	0.09	0.15	0.24 0.18 670 0.80
Tip/Tilt Erro Tilt Measur Tilt Bandwi Residual Ar Residual Ar Residual Ar Residual Ar Science Ins Long Expos Residual Te Total Effecti Sky Coverag Corresp Assumption	rs Sci Filter rement Error (one-axis) dth Error (one-axis) anatism Error (one-axis) entroid Anisoplanatism trospheric Dispersion H ate Scale Deformations strument Mechanical Drift sure Field Actation Errors ive Wavefront Error Energy H ge Galactic Lat. conding Sky Coverage r0 0.092 m Theta0_eff 1.96 arcsec Sodium Abund. 0.002 m	Error (rms) 48.53 mas 44.82 mas 44.82 mas 28.37 mas 1.62 mas 0.05 mas 2.84 mas 2.80 mas 2.80 mas 72.1 mas 60 deg 60 deg at this zenith at this zenith at max	WFE (rms) 285 nm 271 nm 138 nm 13 nm 0 nm 23 nm 20 nm 0 nm 361 nm 401 nm 30.0%	Parameter 16.9 mag (mH) 2.0 Hz (-3db) 38.5 arcsec 10 x reduction 20 x reduction -1500 m conj height Alico 0.25 mas / min Alico 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle m HO WFS Rate arcmin HO WFS Noise	0.01 0.00 50 0.04	0.01 70 0.08 fective V deg Hz e- rms	0.02 0.00 80 0.10 VFE show	0.03 0.00 160 0.33 wwn	0.05 0.01 240 0.53	0.06 0.02 480 0.75	0.09	0.15	0.24 0.18 670 0.80
Tip/Tilt Erro Tilt Measur Tilt Maison Residual Cr Residual Cr Residual Cr Residual Cr Residual Cr Science Ins Long Expos Residual Te Total Effecti Ensquared I Sky Coverag Corresp Assumption	Ins Sci Filter rement Error (one-axis) dth Error (one-axis) entroid Anisoplanatism throspheric Dispersion H ate Scale Deformations strument Mechanical Drift sure Field Rotation Errors eleescope Pointing Jitter (one-axis) ip/Tilt Error (one-axis) ive Wavefront Error Energy H ge Galactic Lat. conding Sky Coverage Ins / Parameters r0 0.092 m Theta0_eff 1.96 arcsec Sodium Abund. 4 x 10° Science Target: SCAO	Error (rms) 48.53 mas 44.82 mas 28.37 mas 1.62 mas 0.05 mas 2.84 mas 2.80 mas 2.80 mas 72.1 mas 60 deg 60 deg at this zenith at this zenith at oms/cm ²	WFE (rms) 285 nm 271 nm 138 nm 13 nm 0 nm 23 nm 361 nm 401 nm 401 nm Los Ast Rad. 0.00%	Parameter 16.9 mag (mH) 2.0 Hz (-3db) 38.5 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas/min Alloc 0.25 mas/min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle m HO WFS Rate arcmin HO WFS Noise HOWFS anti-aliasing LOWFS anti-aliasing LOWFS anti-aliasing LOWFS anti-aliasing LOWFS anti-aliasing LOWFS anti-aliasing	0.01 0.00 50 0.04 Total El	0.01 70 0.08 fective V deg Hz e - rms Hz	0.02 0.00 80 0.10 VFE show	0.03 0.00 160 0.33 wn	0.05 0.01 240 0.53	0.06 0.02 480 0.75	0.09	0.15	0.24 0.18 670 0.80
Tip/Tilt Erro Tilt Measur Tilt Bandwi Tilt Bandwi Tilt Bandwi Tilt Bandwi Tilt Bandwi Tit Bandwi Residual A Residual A Residual Te Total Effecti Ensquared I Sky Coverag Corresp Assumption	rs rement Error (one-axis) dth Error (one-axis) entroid Anisopianatism thospheric Dispersion H ate Scale Deformations strument Mechanical Drift sure Field Rotation Errors elescope Pointing Jitter (one-axis) ive Wavefront Error Energy H ge Galactic Lat. ponding Sky Coverage the Scale off 1.96 arcsec solum Abund. 4 x 10 ² Science Target: SCAO LOWFS Target: SCAO LOWFS Target: M	Error (rms) 48.53 mas 44.82 mas 28.37 mas 1.62 mas 0.05 mas 2.80 mas 2.80 mas 2.80 mas 72.1 mas 60 deg 60 deg 60 deg	WFE (rms) 285 nm 271 nm 138 nm 13 nm 0 nm 23 nm 20 nm 0 nm 23 nm 361 nm 401 nm 401 nm Under Scale 75 LGS Ast. Rad. 0.08 Num 3x3 0	Parameter 16.9 mag (mH) 2.0 Hz (-3db) 38.5 arcsec 10 X reduction 20 X reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Termin H0 WFS Rate arcmin H0 WFS Rate L0 WFS Noise L0 WFS Noise L0 WFS Noise L0 WFS Noise	0.01 0.00 50 0.04 50 0.04	0.01 0.00 70 0.08 ^T fective V deg Hz e - rms Hz e - rms	0.02 0.00 80 0.10 VFE show	0.03 0.00 160 0.33 wn using using	0.05 0.01 240 0.53 CCD50 H2RG	0.06 0.02 480 0.75	0.09	0.15	0.24 0.18 670 0.80
Tip/Tilt Erro Tilt Measur Tilt Bandwi Residual Cr Residual Cr Residual Cr Residual Tilt Long Expos Residual Te Total Effecti Sky Coverage Corresp Assumption	rement Error (one-axis) terment Error (one-axis) terment Error (one-axis) entroid Anisopianatism trospheric Dispersion H ate Scale Deformations strument Mechanical Drift sure Field Rotation Errors elescope Pointing Jitter (one-axis) ive Wavefront Error Energy H ge Galactic Lat. conding Sky Coverage r0 0.092 m Theta0_eff 1.96 arcsec Sodium Abund. 4 x 10° Science Target: SCAO LOWFS Target: SCAO LOWFS Target: M Max Exposure Time 300 sec	Error (rms) 48.53 mas 44.82 mas 24.42 mas 28.37 mas 1.62 mas 0.05 mas 2.80 mas 2.80 mas 2.80 mas 2.80 mas 72.1 mas 60 deg 60 deg at this zenith at this zenith at mis zeni	WFE (rms) 285 nm 271 nm 138 nm 13 nm 0 nm 23 nm 20 nm 361 nm 401 nm 401 nm Understand 1000000000000000000000000000000000000	Parameter 16.9 mag (mH) 2.0 Hz (-3db) 38.5 arcsec 10 X reduction 20 X reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle m HO WFS Rate arcmin HO WFS Rate arcmin HO WFS Rate LO WFS noise Max mechanical tip/tilt rt	0.01 0.00 50 0.04 5894 5.0 NO 32 2.5 5450 10 10 10 10 10 10 10 10 10 10 10 10 10	0.01 70 0.08 fective V deg Hz e-rms Hz e-rms andwidt	0.02 0.00 80 0.10 VFE show	0.03 0.00 160 0.33 wn using using 50	0.05 0.01 240 0.53 CCD50 H2RG Hz	0.06 0.02 480 0.75	0.09	0.15	0.24 0.18 670 0.80

Table 11. Error budget performance prediction for 30% sky coverage w/ equivalent 50 W CW laserreturn science case, optimized for H-band Strehl ratio.

6.2 Visible Interim LOWFS Budgets

6.2.1 Dynamics of Z = 1 Galaxies w/ Equivalent 12 W MM Laser Return & Interim LOWFS

Palomar W	Vavefront Error Budget Sun	nmary	Version 1.30					Scie	ence E	Band			
Mode:	P3K LGS	-			u'	g'	r'	i'	Ζ	Y	J	Н	К
Instrument:	SWIFT			λ (μm)	0.36	0.47	0.62	0.75	0.88	1.03	1.25	1.64	2.20
Observation:	Z = 1 Galaxies			δλ (μm)	0.06	0.14	0.14	0.15	0.12	0.12	0.16	0.29	0.34
				λ/D (mas)	15	20	27	32	38	45	54	71	95
··· · · ·			Wavefront					Stret	nl Rati	io (%)			
High-order E	Errors (LGS Mode)		Error (rms)	Parameter						,			
Atmospheri	ic Fitting Error		119 nm	16 Subaps									
High-order	Error Measurement Error		107 nm 114 nm	29 Hz (-3db) 12 W									
LGS Focal	Anisoplanatism Error		86 nm	1 beacon(s)									
Asterism De	eformation Error		0 nm	0.50 m LLT									
Multispectra	al Error		19 nm	5 zenith angle, H band									
WFS Scintil	Ilation Error		10 nm	Alloc									
		216 nm											
Uncorrectat	ble Static Telescope Aberrations		14 nm	64 Acts									
Static WES	Zero-point Calibration Error		25 nm	Alloc									
Dynamic W	FS Zero-point Calibration Error		30 nm	Alloc									
Leaky Integ	grator Zero-point Calibration Error		15 nm	Alloc									
Go-to Contr Residual Na	rol Errors		0 nm 4 nm	Alloc 30 m/s Na laver vel									
DM Finite S	Stroke Errors		19 nm	5.5 um P-P stroke									
DM Hystere	esis		7 nm	from TMT									
High-Order	Aliasing Error		40 nm	16 Subaps									
Uncorrectat	ble AO System Aberrations		20 nm	Alloc									
Uncorrectat	ble Instrument Aberrations		62 nm	SWIFT Instrument									
DM-to-lensl	let Misregistration		15 nm	Alloc									
Divi-to-iensi	let Pupil Scale Error	93 nm	mn cr	Alloc									
Angular Ani	isoplanatism Error		56 nm	4 arcsec									
Total Hi	igh Order Wavefront Error	235 nm	242 nm	High Order Strehl	0.00	0.00	0.00	0.02	0.05	0.12	0.23	0.43	0.62
		Angular	Equivalant					Streb	nl ratio	os (%)			
		Alluulai						0.00					
Tip/Tilt Erro	rs	Error (rms)	WFE (rms)	Parameter				01101					
Tip/Tilt Error	Sci Filter	Error (rms)	WFE (rms)	Parameter				0.101					
Tip/Tilt Error	rs Sci Filter rement Error (one-axis) dth Error (one-axis)	Error (rms)	WFE (rms)	Parameter 14.9 mag (mV) 4.9 Hz (-3db)									
Tip/Tilt Error Tilt Measure Tilt Bandwid Tilt Anisopla	rs Sci Filter ement Error (one-axis) dth Error (one-axis) anatism Error (one-axis)	31.15 mas 18.60 mas 44.22 mas	169 nm 200 nm	Parameter 14.9 mag (mV) 4.9 Hz (-3db) 60.0 arcsec									
Tip/Tilt Error Tilt Measure Tilt Bandwid Tilt Anisopla Residual Ce	ITS Sci Filter ment Error (one-axis) dth Error (one-axis) anatism Error (one-axis) entroid Anisoplanatism _	Angular Error (rms) 31.15 mas 18.60 mas 44.22 mas 1.62 mas	169 nm 123 nm 200 nm 13 nm	Parameter 14.9 mag (mV) 4.9 Hz (-3db) 60.0 arcsec 10 x reduction									
Tip/Tilt Error Tilt Measure Tilt Bandwid Tilt Anisopla Residual At Induced Pla	IFS Sci Filter ement Error (one-axis) dth Error (one-axis) anatism Error (one-axis) enroid Anisophanatism tmospheric Dispersion Z e Scale Deformations	31.15 mas 18.60 mas 44.22 mas 0.14 mas 2 27 mas	WFE (rms) 169 nm 123 nm 200 nm 13 nm 1 nm 18 nm	Parameter 14.9 mag (mV) 4.9 Hz (-3db) 60.0 arcsec 10 x reduction 20 x reduction 20 x reduction									
Tip/Tilt Error Tilt Measure Tilt Bandwid Tilt Anisople Residual Ce Residual At Induced Pla Science Ins	rs Sci Filter ement Error (one-axis) th Error (one-axis) anatism Error (one-axis) entroid Anisopianatism throspheric Dispersion Z tate Scale Deformations trument Mechanical Drift	Angular Error (rms) 31.15 mas 18.60 mas 44.22 mas 1.62 mas 0.14 mas 2.27 mas 15.00 mas	169 nm 123 nm 200 nm 1 nm 1 nm 1 nm 18 nm 105 nm	Parameter 14.9 mag (mV) 4.9 Hz (-3db) 60.0 arcsec 10 x reduction 20 x reduction 20 x reduction 1500 m conj height Alloc 0.25 mas / min									
Tip/Tilt Error Tilt Measure Tilt Bandwic Tilt Anisopie Residual Ct Residual At Induced Pla Science Ins Long Expos	ITS Sci Filter ement Error (one-axis) dth Error (one-axis) analism Error (one-axis) entroid Anisoplanatism tmospheric Dispersion at Scate Deformations strument Mechanical Drift sure Field Rotation Errors	Angular Error (rms) 31.15 mas 18.60 mas 44.22 mas 1.62 mas 0.14 mas 2.27 mas 15.00 mas 0.00 mas	Equivalent WFE (rms) 169 nm 123 nm 200 nm 1 nm 1 nm 105 nm 0 nm	Parameter 14.9 mag (mV) 4.9 Hz (-3db) 60.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min									
Tip/Tilt Error Tilt Measur Tilt Bandwic Tilt Anisopie Residual Ct Residual At Induced Pla Science Ins Long Expos Residual Te	ITS Sci Filter ment Error (one-axis) dth Error (one-axis) analism Error (one-axis) entroid Anisopianalism tmospheric Dispersion Z strument Mechanical Drift ure Field Rotation Errors elescope Pointing Jitter (one-axis)	Argular Error (rms) 31.15 mas 18.60 mas 44.22 mas 0.14 mas 2.27 mas 15.00 mas 0.00 mas 1.16 mas	WFE (rms) 169 nm 123 nm 200 nm 1 nm 1 nm 18 nm 105 nm 0 nm 9 nm	Parameter 14.9 mag (mV) 4.9 Hz (-3db) 60.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance									
Tip/Tilt Error Tilt Measurt Tilt Bandwid Tilt Anisopia Residual At Induced Pla Science Ins Long Expos Residual Te Total Tij	rs ment Error (one-axis) dth Error (one-axis) anatism Error (one-axis) enroid Anisopianatism tmospheric Dispersion Z at Scate Deformations strument Mechanical Drift ure Field Rotation Errors elescope Pointing Jitter (one-axis) p/Tilt Error (one-axis)	Angular Error (rms) 31.15 mas 18.60 mas 44.22 mas 0.14 mas 2.27 mas 15.00 mas 0.00 mas 1.16 mas 59.2 mas	Equivalent WFE (rms) 169 nm 123 nm 200 nm 1 nm 1 nm 1 nm 1 nm 105 nm 0 nm 9 nm 230 nm	Parameter 14.9 mag (mV) 4.9 Hz (-3db) 60.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl	0.01	0.02	0.03	0.05	0.07	0.09	0.13	0.20	0.31
Tip/Tilt Error Tilt Measur Tilt Bandwid Tilt Anisopi Residual At Induced Pia Science Ins Long Expos Residual Te Total Tip	rs ment Error (one-axis) dth Error (one-axis) anatism Error (one-axis) entroid Anisopianatism tmospheric Dispersion Z at Scate Deformations strument Mechanical Drift ure Field Rotation Errors elescope Pointing Jitter (one-axis) p/Tilt Error (one-axis)	Angular Error (ms) 31.15 mas 18.60 mas 44.22 mas 1.62 mas 0.14 mas 2.27 mas 15.00 mas 0.00 mas 1.16 mas 59.2 mas	WFE (rms) 169 nm 123 nm 200 nm 13 nm 1 nm 105 nm 005 nm 9 nm	Parameter 14.9 mag (mV) 4.9 Hz (-3db) 60.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tiit Strehl	0.01	0.02	0.03	0.05	0.07	0.09	0.13	0.20	0.31
Tip/Tilt Error Tilt Measur Tilt Bandwir Residual Cc Residual Ta Science Ins Long Expos Residual Ta Total Tip	ITS Sci Filter ement Error (one-axis) dth Error (one-axis) anatism Error (one-axis) anatism Error (one-axis) enroid Anisophanatism tmospheric Dispersion Z ats Scate Deformations strument Mechanical Drift sure Field Rolation Errors p/Tilt Error (one-axis) ive Wavefront Error	Angular Error (rms) 31.15 mas 18.60 mas 4.4.22 mas 1.62 mas 0.74 mas 2.27 mas 15.00 mas 1.16 mas 59.2 mas	United and the second s	Parameter 14.9 mag (mV) 4.9 Hz (-3db) 60.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%)	0.01	0.02	0.03	0.05	0.07	0.09	0.13	0.20	0.31
Tip/Tilt Error Tilt Measur Tilt Andwir Residual Cc Residual At Induced Pla Science Ins Long Expos Residual Te Total Til	ITS Sci Filter ement Error (one-axis) dth Error (one-axis) anatism Error (one-axis) anatism Error (one-axis) enroid Anisophanatism tmospheric Dispersion Z ats Scate Deformations strument Mechanical Drift sure Field Rolation Error p/Tilt Error (one-axis) ive Wavefront Error	Angular Error (rms) 31.15 mas 18.60 mas 4.422 mas 1.62 mas 0.14 mas 2.27 mas 1.500 mas 1.16 mas 59.2 mas	Equivalent WFE (rms) 189 nm 123 nm 200 nm 1 nm 1 nm 1 nm 105 nm 9 nm 230 nm 332 nm	Parameter 14.9 mag (mV) 4.9 Hz (-3db) 60.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%)	0.01	0.02	0.03	0.05	0.07	0.09	0.13	0.20	0.31
Tip/Tilt Error Tilt Measur Tilt Bandwir Residual Cr Residual Ar Residual Ar Residual Ar Residual Ar Science Ins Long Expos Residual To Total Tip	ITS Sci Filter ement Error (one-axis) dth Error (one-axis) anatism Error (one-axis) anatism Error (one-axis) mrospheric Dispersion Z strument Mechanical Drift sure Field Rotation Errors p/Tilt Error (one-axis) ive Wavefront Error	Angulai Error (rms) 31.15 mas 18.60 mas 44.22 mas 1.62 mas 0.14 mas 2.27 mas 15.00 mas 1.16 mas 59.2 mas	Equivalent WFE (rms) 169 nm 123 nm 200 nm 1 nm 1 nm 1 nm 0 nm 9 nm 230 nm 332 nm	Parameter 14.9 mag (mV) 4.9 Hz (-3db) 60.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.01	0.02	0.03	0.05	0.07	0.09	0.13	0.20	0.31
Tip/Tilt Error Tilt Measur Tilt Bandwir Residual A Residual A Residual A Science Ins Long Expos Residual Te Total Effecti Ensquared B	rs Sci Filter ement Error (one-axis) dth Error (one-axis) anatism Error (one-axis) anatism Error (one-axis) mrospheric Dispersion Z ate Scale Déromations strument Mechanical Drift sure Field Rotation Errors p/Tilt Error (one-axis) ive Wavefront Error Energy z	Angulai Error (rms) 31.15 mas 18.60 mas 44.22 mas 1.62 mas 0.14 mas 2.27 mas 15.00 mas 1.16 mas 59.2 mas	Equivalent WFE (rms) 169 nm 123 nm 200 nm 1 nm 1 nm 1 nm 105 nm 9 nm 230 nm 332 nm	Parameter 14.9 mag (mV) 4.9 Hz (-3db) 60.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.01 0.00 50 0.01	0.02 0.00 70 0.02	0.03 0.00 80 0.02	0.05 0.00 160 0.06	0.07 0.00 240 0.11	0.09 0.01 480 0.27	0.13 0.03 1000 0.63	0.20	0.31 0.20 1330 0.80
Tip/Tilt Error Tilt Measur Tilt Bandwir Residual A Residual A Residual A Residual A Science Ins Long Expos Residual Te Total Tip Total Effecti Ensquared I	Irs Sci Filter ment Error (one-axis) dth Error (one-axis) antism Error (one-axis) antism Error (one-axis) entroid Anisoplanatism tmospheric Dispersion z ate Scale Deformations ater Field Rolation Errors p/Tilt Error (one-axis) p/Tilt Error (one-axis) ive Wavefront Error Energy z	Angular Error (ms) 31.15 mas 18.60 mas 44.22 mas 162 mas 0.27 mas 2.27 mas 15.00 mas 0.00 mas 1.16 mas 59.2 mas	Equivalent WFE (rms) 169 nm 123 nm 200 nm 1 nm 1 nm 1 nm 105 nm 0 nm 9 nm 230 nm 332 nm	Parameter 14.9 mag (mV) 4.9 Hz (-3db) 60.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.01 0.00 50 0.01	0.02 0.00 70 0.02	0.03 0.00 80 0.02	0.05 0.00 160 0.06	0.07 0.00 240 0.11	0.09 0.01 480 0.27	0.13 0.03 1000 0.63	0.20	0.31 0.20 1330 0.80
Tip/Tilt Error Tilt Measur Tilt Bandwir Residual A Residual A Residual A Residual T Science Ins Long Expos Residual Te Total Effecti Ensquared I Sky Coverag	Irs Sci Filter ment Error (one-axis) dth Error (one-axis) analism Error (one-axis) analism Error (one-axis) ate Scale Deformations ate Scale Deformations ater Field Rolation Errors p/Tilt Error (one-axis) p/Tilt Error (one-axis)	Angular Error (ms) 31.15 mas 18.60 mas 44.22 mas 16.20 mas 2.27 mas 2.27 mas 15.00 mas 0.00 mas 1.16 mas 59.2 mas 30 deg	Equivalent WFE (rms) 189 nm 130 nm 13 nm 105 nm 105 nm 0 nm 9 nm 230 nm 332 nm	Parameter 14.9 mag (mV) 4.9 Hz (-3db) 60.0 arcsec 10 x reduction 20 x reduction -1500 m con height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.01 0.00 50 0.01	0.02 0.00 70 0.02	0.03 0.00 80 0.02	0.05 0.00 160 0.06	0.07 0.00 240 0.11	0.09 0.01 480 0.27	0.13 0.03 1000 0.63	0.20	0.31 0.20 1330 0.80
Tip/Tilt Error Tilt Measur Tilt Andwir Residual Cc Residual At Induced Pia Science Ins Long Expos Residual Te Total Effecti Ensquared I Sky Coverag Corresp	Irs Sci Filter ement Error (one-axis) dth Error (one-axis) anatism Error (one-axis) anatism Error (one-axis) entroid Anisophanatism tmospheric Dispersion z strument Mechanical Drift sure Field Rolation Errors elescope Pointing Jitter (one-axis) p/Tilt Error (one-axis) ive Wavefront Error Energy z ge Galactic Lat. coonding Sky Coverage	Angular Error (rms) 31.15 mas 18.60 mas 44.22 mas 0.62 mas 0.27 mas 15.00 mas 0.00 mas 1.16 mas 59.2 mas 30 deg	Equivalent WFE (rms) 189 nm 123 nm 200 nm 1 nm 1 nm 105 nm 0 nm 9 nm 230 nm 332 nm 5.0%	Parameter 14.9 mag (mV) 4.9 Hz (-3db) 60.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the	0.01 0.00 50 0.01	0.02 0.00 70 0.02	0.03 0.00 80 0.02	0.05 0.00 160 0.06	0.07 0.00 240 0.11	0.09 0.01 480 0.27	0.13 0.03 1000 0.63	0.20	0.31 0.20 1330 0.80
Tip/Tilt Error Tilt Measur Tilt Mandwit Residual Cc Residual Tc Residual Tc Residual Tc Total Effecti Total Effecti Sky Coverag Corresp Assumption	rrs Sci Filter ement Error (one-axis) dth Error (one-axis) anatism Error (one-axis) anatism Error (one-axis) entroid Anisopianatism tmospheric Dispersion z at scale Deformations strument Mechanical Drift usure Field Rolation Errors elescope Pointing Jitter (one-axis) p/Tilt Error (one-axis) ive Wavefront Error Energy z ge Galactic Lat. coonding Sky Coverage ts / Parameters	Angular Error (ms) 31.15 mas 18.60 mas 44.22 mas 0.14 mas 2.27 mas 15.00 mas 0.00 mas 1.16 mas 59.2 mas 30 deg	Equivalent WFE (rms) 169 nm 123 nm 200 nm 1 nm 1 nm 105 nm 9 nm 203 nm 203 nm 203 nm 332 nm	Parameter 14.9 mag (mV) 4.9 Hz (-3db) 60.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the	0.01 0.00 50 0.01	0.02 70 0.02 ffective V	0.03 0.00 80 0.02	0.05 0.00 160 0.06	0.07 0.00 240 0.11	0.09 0.01 480 0.27	0.13 0.03 1000 0.63	0.20	0.31 0.20 1330 0.80
Tip/Tilt Error Tilt Measur Tilt Mandwit Residual Cc Residual Cc Residual Til Science Ins Long Expos Residual Te Total Effecti Ensquared I Sky Coverag Corresp Assumption	Insignment Error (one-axis) analism Error (one-axis) analism Error (one-axis) analism Error (one-axis) entroid Anisoplanatism twospheric Dispersion z tes Scale Deformations aturument Mechanical Drift sure Field Rotation Errors Insignment State	Angular Error (ms) 31.15 mas 18.60 mas 14.42 mas 16.20 mas 2.27 mas 15.00 mas 2.27 mas 15.00 mas 1.16 mas 59.2 mas 30 deg	Equivalent WFE (rms) 189 nm 130 nm 100 nm 100 nm 100 nm 0 nm 9 nm 230 nm 332 nm 5.0%	Parameter 14.9 mag (mV) 4.9 Hz (-3db) 60.0 arcsec 10 × reduction 20 ar eduction 20 ar eduction 10 × reduction Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle	0.01 0.00 50 0.01	0.02 0.00 70 0.02	0.03 0.00 80 0.02	0.05 0.00 160 0.06	0.07 0.00 240 0.11	0.09 0.01 480 0.27	0.13 0.03 1000 0.63	0.20	0.31 0.20 1330 0.80
Tip/Tilt Error Tilt Measur Tilt Anisopic Residual Cr Residual Cr Residual At Induced Pia Science Ins Long Expos Residual Te Total Effecti Ensquared I Sky Coverage Corresp Assumption	ITS Sci Filter ment Error (one-axis) analism Error (one-axis) entroid Anisoplanatism tmospheric Dispersion Z at Scate Deformations strument Mechanical Drift sure Field Rotation Errors elescope Pointing Jitter (one-axis) p/Tilt Error (one-axis) ive Wavefront Error Energy Z ge Galactic Lat. conding Sky Coverage is / Parameters 10 0.092 m Theta0 eff 1.96 arcsec.	Angular Error (rms) 31.15 mas 18.60 mas 1.62 mas 0.14 mas 0.27 mas 1.60 mas 1.60 mas 1.60 mas 1.60 mas 1.16 mas 59.2 mas 30 deg 30 deg	Equivalent WFE (rms) 169 nm 123 nm 200 nm 13 nm 1 nm 105 nm 0 nm 9 nm 230 nm 332 nm 332 nm 5.0%	Parameter 14.9 mag (mV) 4.9 Hz (-3db) 60.0 arcsec 10 x reduction 20 x reduction 20 x reduction Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m's Zenith Angle m H0 WFS Rate	0.01 0.00 50 0.01 • Total El	0.02 0.00 70 0.02	0.03 0.00 80 0.02 //FE shor	0.05 0.00 160 0.06 wm	0.07 0.00 240 0.11	0.09 0.01 480 0.27	0.13	0.20	0.31 0.20 1330 0.80
Tip/Tilt Error Tilt Measur Tilt Bandwir Residual Cr Residual Cr Residual At Induced Pia Science Ins Long Expos Residual Te Total Effecti Ensquared I Sky Coverag Corresp Assumption	rss Sci Filter ment Error (one-axis) dth Error (one-axis) analism Error (one-axis) analism Error (one-axis) mrospheric Dispersion z eta Scate Deformations strument Mechanical Drift sure Field Rolation Errors p/Tilt Error (one-axis) p/Tilt Error (one-axis) p/Tilt Error (one-axis) p/Tilt Error (one-axis) p/Tilt Error	Arigulai Error (ms) 31.15 mas 18.60 mas 44.22 mas 0.14 mas 2.27 mas 15.00 mas 0.00 mas 1.16 mas 59.2 mas 30 deg 30 deg	Equivalent WFE (rms) 169 nm 123 nm 200 nm 1 nm 1 nm 0 nm 9 nm 180 nm 105 nm 9 nm 230 nm 332 nm 332 nm Use Sate 75.0%	Parameter 14.9 mag (mV) 4.9 Hz (-3db) 60.0 arcsec 10 X reduction 20 X reduction 20 X reduction -1500 m conj height Alloc 0.25 mas / min Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle m HO WFS Rate arcmin HO WFS Noise	0.01 0.00 50 0.01 • Total El 430 4.3	0.02 0.00 70 0.02 ffective V deg Hz e - rms	0.03 0.00 80 0.02 VFE sho	0.05 0.00 160 0.06 wn	0.07 0.00 240 0.11	0.09 0.01 480 0.27	0.13	0.20	0.31 0.20 1330 0.80
Tip/Tilt Error Tilt Measur Tilt Mandwit Residual Ce Residual Te Residual Te Residual Te Science Ins Long Expos Residual Te Total Effecti Ensquared I Sky Coverag Corresp Assumption	rs Sci Filter ment Error (one-axis) dth Error (one-axis) antism Error (one-axis) antism Error (one-axis) entroid Anisoplanatism tropspheric Dispersion Z ate Scale Deformations ter Field Rolation Errors p/Tilt Error (one-axis) p/Tilt Error (one-axis) p/Tilt Error (one-axis) tive Wavefront Error Energy Z ge Galactic Lat. conding Sky Coverage ts / Parameters f0 0.092 m Theto, eff 1.06 arcsecc Sodium Abund. 4 x 10 ⁹ Science Target: SCAO	Arigural Error (ms) 31.15 mas 18.60 mas 44.22 mas 1.62 mas 0.00 mas 0.00 mas 0.00 mas 0.00 mas 1.16 mas 59.2 mas 30 deg 30 deg	Equivalent WFE (rms) 169 nm 123 nm 200 nm 1 nm 1 nm 1 8 nm 105 nm 9 nm 2030 nm 230 nm 332 nm 332 nm Und Speed 8.03 00ter Scale 75 LGS Ast. Rad. 0.00 000WFS trans	Parameter 14.9 mag (mV) 4.9 Hz (-3db) 60.0 arcsec 10 X reduction 20 X reduction -1500 m conj height Alloc 0.25 mas / min Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle m HO WFS Rate arcmin HO WFS Noise HOWFS anti-aliasing	0.01 0.00 50 0.01 • Total El	0.02 0.00 70 0.02 ffective V deg Hz e-rms	0.03 0.00 80 0.02 VFE sho	0.05 0.00 160 0.06 wm	0.07 0.00 240 0.11	0.09 0.01 480 0.27	0.13 0.03 1000 0.63	0.20	0.31 0.20 1330 0.80
Tip/Tilt Error Tilt Measur Tilt Ansolg Residual Cr Residual Ar Induced Pia Science Ins Long Expos Residual Te Total Effecti Ensquared I Sky Coverag Corresp Assumption	rs Sci Filter ment Error (one-axis) dth Error (one-axis) analism Error (one-axis) entroid Anisoplanatism tmospheric Dispersion z et Scate Deformations zure Field Rotation Errors p/Tilt Error (one-axis) p/Tilt Error (one-axis) p/Tilt Error (one-axis) ge Galactic Lat. conding Sky Coverage rs / Parameters r0 0.092 m Theta0_eff 1.96 arcsec Sodium Abund. 4 x 10° Science Target: SCAO LOWFS Target: SCAO LOWFS Target: SCAO	Arigular Error (rms) 31.15 mas 18.60 mas 44.22 mas 1.62 mas 0.14 mas 2.27 mas 15.00 mas 1.16 mas 59.2 mas 30 deg 30 deg	Equivalent WFE (rms) 169 nm 123 nm 13 nm 1 nm 169 nm 9 nm 13 nm 1 nm 105 nm 9 nm 230 nm 332 nm 332 nm Under Scale 75 LGS Ast. Rad. 0.00 0.028 HOWES Trans. 0.28 Num 3/3 1	Parameter 14.9 imag (mV) 4.9 Hz (-3db) 60.0 arsec 10 x reduction 20 X reduction 20 X reduction Alloc 0.25 mas / min Alloc 0.25 mas / m	0.01 0.00 50 0.01 • Total El 430 43 3.00 822 43	0.02 70 0.02 ffective V deg Hz e-rms Hz e-rms	0.03 0.00 80 0.02 //FE sho SH	0.05 0.00 160 0.06 wm using using	0.07 0.00 240 0.11 CCD50 CCD59	0.09 0.01 480 0.27	0.13	0.20	0.31 0.20 1330 0.80
Tip/Tilt Error Tilt Measur Tilt Bandwir Residual Cc Residual Tc Residual Tc Science Ins Long Expos Residual Tc Total Effecti Total Effecti Sky Coverag Corresp Assumption	rss Sci Filter ment Error (one-axis) dth Error (one-axis) analism Error (one-axis) analism Error (one-axis) analism Error (one-axis) antroid Anisoplanatism theospheric Dispersion Z trument Mechanical Drift sure Field Rotation Errors ite Wavefront Error Energy Z ge Galactic Lat. Donding Sky Coverage ts / Parameters f0 0.092 m Theta0_eff 1.96 arcsec Sodium Abund. 4 × 10° Science Target: SCAO LOWFS Star Type: M Max Exposure Time 1800 sec	Aliguial Error (ms) 31.15 mas 18.60 mas 1.62 mas 0.14 mas 2.27 mas 1.60 mas 0.00 mas 1.16 mas 59.2 mas 30 deg 30 deg 30 deg	Equivalent WFE (rms) 189 nm 123 nm 200 nm 13 nm 1 nm 105 nm 9 nm 2332 nm 2332 nm 332 nm 332 nm Urier Scale 75 LGS Ast, Rad. 0.00 0.00WFS Trans 0.0WFS Trans 0.28 Num HOWFS 0	Parameter 14.9 mag (mV) 4.9 Hz (-3db) 60.0 arcsec 10 × reduction 20 ar exduction 20 ar exduction 10 × reduction 10 × reduction 20 ar exduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle m HO WFS Rate LO WFS Noise Max mechanical tip/tilt r	0.01 0.00 50 0.01 • Total Ef 430 423 NO 82 4.3 ***********************************	0.02 0.00 70 0.02 ffective V deg Hz e - rms Hz e - rms	0.03 0.00 80 0.02 VFE sho SH SH SH	0.05 0.00 160 0.06 wm using using 50	0.07 0.00 240 0.11 CCD50 CCD50 CCD59 Hz	0.09 0.01 480 0.27	0.13 0.03 1000 0.63	0.20	0.31 0.20 1330 0.80

Table 12. Error budget performance prediction for dynamics of Z = 1 galaxies w/ equivalent 12 W MM laser return & interim LOWFS science case. Through comparison with the nearly equivalent EE per spaxial seen with the NIR TT sensor in Table 8, we see that the interim LOWFS does not degrade this science case (which benefits most from more laser power). We do note, however, that using the interim visible LOWFS, the optimal TT GS will typically be found further away from the science object (compare 59 arcsec distance here with 38 arcsec distance in Table 8.)

6.2.2 Dynamics of Z = 1 Galaxies w/ Equivalent 50W CW Laser Return & Interim LOWFS

Palomar Wavefront Error Budget Sur	nmarv	Version 1.30					Scie	ence E	Band			
Mode: P3K LGS	,			u'	q'	r'	i'	Z	Y	J	Н	Κ
Instrument: SWIFT			λ (μ m)	0.36	0.47	0.62	0.75	0.88	1.03	1.25	1.64	2.20
Observation: Z = 1 Galaxies			δλ (μm)	0.06	0.14	0.14	0.15	0.12	0.12	0.16	0.29	0.34
			λ/D (mas)	15	20	27	32	38	45	54	71	95
		Wavefront					Stre	h Rati	io (%)			
High-order Errors (LGS Mode)		Error (rms)	Parameter				01101	ii i tat	0 (70)			
		,										
Atmospheric Fitting Error		67 nm	32 Subaps									
Bandwidth Error		64 nm	53 Hz (-3db)									
LGS Focal Anisoplanatism Error		86 nm	1 beacon(s)									
Asterism Deformation Error		0 nm	0.50 m LLT									
Multispectral Error		19 nm	5 zenith angle, H band									
Scintillation Error		13 nm	0.34 Scint index, H-band									
WI 3 SCITULIZION ETO	144 nm	10 1111	Alloc									
Uncorrectable Static Telescope Aberrations		14 nm	64 Acts									
Uncorrectable Dynamic Telescope Aberrations		0 nm	Dekens Ph.D									
Static WFS Zero-point Calibration Error		25 nm	Alloc									
Leaky Integrator Zero-point Calibration Error		15 nm	Alloc									
Go-to Control Errors		0 nm	Alloc									
Residual Na Layer Focus Change		4 nm	30 m/s Na layer vel									
DM Finite Stroke Errors		27 nm	5.5 um P-P stroke									
High-Order Aliasing Error		22 nm	32 Subans									
DM Drive Digitization		1 nm	16 bits									
Uncorrectable AO System Aberrations		20 nm	Alloc									
Uncorrectable Instrument Aberrations		62 nm	SWIFT Instrument									
DM-to-lenslet Misregistration		15 nm 15 nm	Alloc									
Bin to folio of 1 oprio dale Error	89 nm	10 1111	74100									
Angular Anisoplanatism Error		56 nm	4 arcsec									
Total High Order Wavefront Error	169 nm	178 nm	High Order Strehl	0.00	0.00	0.04	0.11	0.21	0.32	0.46	0.63	0.77
	Angular	Equivalent	Deservedes				Streh	nl ratio	os (%)			
Tip/Tilt Errors	Angular Error (rms)	Equivalent WFE (rms)	Parameter				Streh	nl ratio	os (%)			
Tip/Tilt Errors	Angular Error (rms)	Equivalent WFE (rms)	Parameter				Stref	nl ratio	os (%)			
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis)	Angular Error (rms)	Equivalent WFE (rms)	Parameter				Streh	nl ratio	os (%)			
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis)	Angular Error (rms) 31.88 mas 17.87 mas 44.22 mas	Equivalent WFE (rms) 171 nm 120 nm 200 nm	Parameter 14.9 mag (mV) 5.1 Hz (-3db) 60.0 arcsec				Streh	nl ratio	os (%)			
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism	Angular Error (rms) 31.88 mas 17.87 mas 44.22 mas 1.62 mas	Equivalent WFE (rms) 171 nm 120 nm 200 nm 13 nm	Parameter 14.9 mag (mV) 5.1 Hz (-3db) 60.0 arcsec 10 x reduction				Stref	nl ratio	os (%)			
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion Z	Angular Error (rms) 31.88 mas 17.87 mas 44.22 mas 1.62 mas 0.14 mas	Equivalent WFE (rms) 171 nm 120 nm 200 nm 13 nm 1 nm 1 nm	Parameter 14.9 mag (mV) 5.1 Hz (-3db) 60.0 arcsec 10 x reduction 20 x reduction				Stref	nl ratio	os (%)			
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmosphere Dispersion z Induced Plate Scale Deformations Schere Jorder Mark Medmonical Drift	Angular Error (rms) 31.88 mas 17.87 mas 44.22 mas 1.62 mas 0.14 mas 2.27 mas 150 mas	Equivalent WFE (rms) 171 nm 120 nm 200 nm 13 nm 1 nm 18 nm 18 nm	Parameter 14.9 mag (mV) 5.1 Hz (-3db) 60.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.05 mcc / min				Stref	nl ratio	os (%)			
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Centroid Anisoplanatism Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors	Angular Error (rms) 31.88 mas 17.87 mas 44.22 mas 1.62 mas 0.14 mas 2.27 mas 15.00 mas 0.00 mas	Equivalent WFE (rms) 171 nm 120 nm 200 nm 13 nm 1 nm 1 nm 18 nm 105 nm 0 nm	Parameter 14.9 mag (mV) 5.1 Hz (-3db) 60.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min				Stref	nl ratio	os (%)			
Tip/Tilt Errors Sci Filter Tilt Massurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisopianatism Error (one-axis) Residual Centroid Anisopianatism Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis)	Angular Error (rms) 31.88 mas 17.87 mas 44.22 mas 1.62 mas 0.14 mas 2.27 mas 15.00 mas 1.12 mas	Equivalent WFE (rms) 171 nm 120 nm 200 nm 1 nm 1 nm 1 nm 1 8 nm 105 nm 9 nm	Parameter 14.9 mag (mV) 5.1 Hz (-3db) 60.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance				Stref	hl ratio	os (%)			
Tip/Tilt Errors Sci Filte Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Error (one-axis) Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tin/Tilt Error (one axis)	Angular Error (rms) 31.88 mas 17.87 mas 44.22 mas 1.62 mas 0.14 mas 2.27 mas 15.00 mas 0.00 mas 1.12 mas	Equivalent WFE (rms) 171 nm 120 nm 13 nm 1 nm 18 nm 0 nm 9 nm	Parameter 14.9 mag (mV) 5.1 Hz (-3db) 60.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance	0.01	0.02	0.03	Stref		os (%)	0.12	0.20	0.21
Sci Filte Tip/Tilt Errors Sci Filter Tilt Bandwidth Error (one-axis) Tilt Anolyadatis Titt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Error Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Tip/Tilt Error (one-axis)	Angular Error (rms) 31.88 mas 17.87 mas 44.22 mas 1.62 mas 2.27 mas 2.27 mas 15.00 mas 0.00 mas 1.12 mas 59.4 mas	Equivalent WFE (rms) 171 nm 120 nm 13 nm 13 nm 18 nm 105 nm 9 nm 230 nm	Parameter 14.9 mag (mV) 5.1 Hz (-3db) 60.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl	0.01	0.02	0.03	Stref 0.05	0.07	os (%) 0.09	0.13	0.20	0.31
Tip/Tilt Errors Sci Filte Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Error (one-axis) Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis)	Angular Error (rms) 31.88 mas 17.87 mas 44.22 mas 1.62 mas 0.14 mas 2.27 mas 15.00 mas 0.00 mas 1.12 mas 59.4 mas	Equivalent WFE (rms) 171 nm 120 nm 200 nm 13 nm 18 nm 0 nm 9 nm 230 nm	Parameter 14.9 mag (mV) 5.1 Hz (-3db) 60.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl	0.01	0.02	0.03	Stref	0.07	os (%)	0.13	0.20	0.31
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Andwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Error (one-axis) Residual Cantroid Anisoplanatism Error Z Induced Plate Scale Deformations Z Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis)	Angular Error (rms) 31.88 mas 17.87 mas 44.22 mas 1.62 mas 0.14 mas 2.27 mas 15.00 mas 0.00 mas 1.12 mas 59.4 mas	Equivalent WFE (rms) 171 nm 120 nm 13 nm 13 nm 18 nm 0 nm 9 nm 230 nm 230 nm	Parameter 14.9 mag (mV) 5.1 Hz (-3db) 60.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%)	0.01	0.02	0.03	Stref 0.05 0.01	0.07	0.09 0.03	0.13	0.20	0.31
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Centroid Anisoplanatism Categories and the second seco	Angular Error (rms) 31.88 mas 17.87 mas 14.22 mas 1.62 mas 0.14 mas 2.27 mas 15.00 mas 0.00 mas 1.12 mas 59.4 mas	Equivalent WFE (rms) 171 nm 120 nm 13 nm 1 nm 18 nm 105 nm 9 nm 230 nm 230 nm	Parameter 14.9 mag (mV) 5.1 Hz (-3db) 60.0 arcsec 10 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%)	0.01	0.02	0.03	0.05 0.01	0.07	0.09 0.03	0.13	0.20	0.31
Tip/Tilt Errors Sci Filter Tilt Bandwidth Error (one-axis) Tilt Andwidth Error (one-axis) Tilt Ansoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Centroid Anisoplanatism Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis)	Angular Error (rms) 31.88 mas 17.87 mas 44.22 mas 1.62 mas 2.27 mas 15.00 mas 0.00 mas 1.12 mas 59.4 mas	Equivalent WFE (rms) 171 nm 200 nm 13 nm 1 nm 18 nm 105 nm 9 nm 230 nm 230 nm	Parameter 14.9 mag (mV) 5.1 Hz (-3db) 60.0 arcsec 10 x reduction -1500 m con) height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.01	0.02	0.03	0.05 0.01	0.07 0.01 240	0.09 0.03 480	0.13	0.20	0.31 0.24 1530
Tip/Tilt Errors Sci Filter Tilt Bandwidth Error (one-axis) Tilt Andwidth Error (one-axis) Tilt Ansoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy Z	Angular Error (rms) 31.88 mas 17.87 mas 44.22 mas 1.62 mas 2.27 mas 15.00 mas 0.00 mas 1.12 mas 59.4 mas	Equivalent WFE (rms) 171 nm 200 nm 13 nm 1 nm 18 nm 105 nm 9 nm 230 nm 230 nm	Parameter 14.9 mag (mV) 5.1 Hz (-3db) 60.0 arcsec 10 x reduction 20 x reduction -1500 m con) height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.01 0.00 50 0.02	0.02 0.00 70 0.04	0.03 0.00 80 0.06	0.05 0.01 160 0.17	0.07 0.01 240 0.25	0.09 0.03 480 0.41	0.13 0.06 1000 0.66	0.20	0.31 0.24 1530 0.80
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Error Residual Centroid Anisoplanatism Error Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy z Sky Coverage Galactic Lat.	Angular Error (rms) 31.88 mas 17.87 mas 14.22 mas 1.62 mas 0.14 mas 2.27 mas 1.500 mas 0.00 mas 1.12 mas 59.4 mas	Equivalent WFE (rms) 171 nm 120 nm 13 nm 1 nm 18 nm 0 nm 9 nm 230 nm 230 nm	Parameter 14.9 mag (mV) 5.1 Hz (-3db) 60.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alioc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.01 0.00 50 0.02	0.02 0.00 70 0.04	0.03 0.00 80 0.06	Stref 0.05 0.01 160 0.17	0.07 0.01 240 0.25	0.09 0.03 480 0.41	0.13 0.06 1000 0.66	0.20	0.31 0.24 1530 0.80
Tip/Tilt Errors Sci Filter Tilt Bandwidth Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Ansoplanatism Error (one-axis) Residual Centroid Anisoplanatism Error Residual Centroid Anisoplanatism Error Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy z Sky Coverage Galactic Lat. Corresponding Sky Coverage Calactic Lat.	Angular Error (rms) 31.88 mas 17.87 mas 44.22 mas 1.62 mas 0.14 mas 2.27 mas 0.00 mas 1.12 mas 59.4 mas 30 deg	Equivalent WFE (rms) 171 nm 120 nm 13 nm 18 nm 0 nm 9 nm 230 nm 230 nm 239 nm	Parameter 14.9 mag (mV) 5.1 Hz (-3db) 60.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the	0.01 0.00 50 0.02	0.02 0.00 70 0.04	0.03 0.00 80 0.06	0.05 0.01 160 0.17	0.07 0.01 240 0.25	0.09 0.03 480 0.41	0.13 0.06 1000 0.66	0.20	0.31 0.24 1530 0.80
Tip/Tilt Errors Sci Filter Tilt Bandwidth Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Ansoplanatism Error (one-axis) Residual Centroid Anisoplanatism Terror (one-axis) Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy z Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters	Angular Error (rms) 31.88 mas 17.87 mas 44.22 mas 1.62 mas 2.27 mas 1.60 mas 0.00 mas 0.00 mas 1.12 mas 59.4 mas 30 deg	Equivalent WFE (rms) 171 nm 120 nm 13 nm 18 nm 105 nm 0 nm 9 nm 230 nm 289 nm	Parameter 14.9 mag (mV) 5.1 Hz (-3db) 60.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the	0.01 0.00 50 0.02	0.02 0.00 70 0.04	0.03 0.00 0.06 VFE sho	Stref 0.05 0.01 160 0.17	0.07 0.01 240 0.25	0.09 0.03 480 0.41	0.13 0.06 1000 0.66	0.20	0.31 0.24 1530 0.80
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anadwidth Error (one-axis) Residual Centroid Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Error Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy z Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters	Angular Error (rms) 31.88 mas 17.87 mas 44.22 mas 1.62 mas 2.27 mas 2.27 mas 0.00 mas 1.12 mas 59.4 mas 30 deg	Equivalent WFE (rms) 171 nm 120 nm 13 nm 18 nm 0 nm 9 nm 230 nm 230 nm 230 nm	Parameter 14.9 mag (mV) 5.1 Hz (-3db) 60.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the	0.01 0.00 50 0.02	0.02 0.00 70 0.04	0.03 0.00 80 0.06	0.05 0.01 160 0.17	0.07 0.01 240 0.25	0.09 0.03 480 0.41	0.13 0.06 1000 0.66	0.20	0.31 0.24 1530 0.80
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anophantism Error (one-axis) Residual Centroid Anisoplanatism Error Residual Centroid Anisoplanatism Error Residual Centroid Anisoplanatism Error Science Instrument Mechanical Drift Long Exposure Field Rolation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy z Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters To 0.092 m Total Diff 0.092 m	Angular Error (rms) 31.88 mas 17.87 mas 14.22 mas 162 mas 0.14 mas 2.27 mas 1.60 mas 0.00 mas 0.00 mas 0.00 mas 1.12 mas 59.4 mas 30 deg	Equivalent WFE (rms) 171 nm 120 nm 13 nm 18 nm 0 nm 9 nm 230 nm 230 nm 230 nm 230 nm 230 nm	Parameter 14.9 mag (mV) 5.1 Hz (-3db) 60.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz Input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle m/s	0.01 0.00 50 0.02 * Total Ef	0.02 0.00 70 0.04	0.03 0.00 80 0.06	Stref 0.05 0.01 160 0.17	0.07 0.01 240 0.25	0.09 0.03 480 0.41	0.13 0.06 1000 0.66	0.20	0.31 0.24 1530 0.80
Tip/Tilt Errors Sci Filter Tilt Bandwidth Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Error (one-axis) Residual Atmospheric Dispersion Z Induced Piate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy z Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.092 m Theta0_eff 1.96 arcsec Sodium Ahund 4 × 10 ⁶	Angular Error (rms) 31.88 mas 17.87 mas 44.22 mas 1.62 mas 0.14 mas 2.27 mas 1.60 mas 0.00 mas 0.00 mas 1.12 mas 59.4 mas 30 deg at this zenith at this zenith at this zenith	Equivalent WFE (rms) 171 nm 120 nm 13 nm 18 nm 105 nm 0 nm 9 nm 230 nm 230 nm 230 nm 289 nm	Parameter 14.9 mag (mV) 5.1 H2 (-3db) 60.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle m HO WFS Rate arromin HO WFS Rate	0.01 0.00 50 0.02 * Total Ef	0.02 0.00 70 0.04 fective V deg Hz e, ms	0.03 0.00 80 0.06 VFE sho	Stref 0.05 0.01 160 0.17 wm	0.07 0.01 240 0.25	0.09 0.03 480 0.41	0.13 0.06 1000 0.66	0.20	0.31 0.24 1530 0.80
Tip/Tilt Errors Sci Filte Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Ansoplanatism Error (one-axis) Residual Centroid Anisoplanatism Error (one-axis) Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy z Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.092 m Theta0_eff 1.96 arcsec Sodium Abund. 4 x 10°	Angular Error (rms) 31.88 mas 17.87 mas 44.22 mas 1.62 mas 0.14 mas 2.27 mas 0.00 mas 1.12 mas 59.4 mas 30 deg 30 deg	Equivalent WFE (rms) 171 nm 120 nm 200 nm 13 nm 18 nm 0 nm 9 nm 230 nm 230 nm 230 nm 230 nm 230 nm	Parameter 14.9 mag (mV) 5.1 Hz (-3db) 60.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle m HO WFS Rate arcmin HO WFS Rate	0.01 0.00 50 0.02 • Total Ef	0.02 0.00 70 0.04 fective V deg Hz e- rms	0.03 0.00 80 0.06 VFE sho	0.05 0.01 160 0.17 wm	0.07 0.01 240 0.25	0.09 0.03 480 0.41	0.13 0.06 1000 0.66	0.20	0.31 0.24 1530 0.80
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Error Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy Z Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.092 m The act off 1.96 arcsec Sodium Abund. 4 x 10° Solence Target: SCAO	Angular Error (rms) 31.88 mas 17.87 mas 14.22 mas 1.62 mas 0.14 mas 2.27 mas 1.60 mas 0.00 mas 0.00 mas 0.00 mas 1.12 mas 59.4 mas 30 deg 30 deg	Equivalent WFE (rms) 171 nm 120 nm 13 nm 1 m 18 nm 0 nm 9 nm 230 nm 230 nm 230 nm 230 nm 230 nm 0 un 9 nm 230 nm	Parameter 14.9 mag (mV) 5.1 Hz (-3db) 60.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the arcmin HO WFS Rate arcmin HO WFS Noise HOWFS Noise HOWFS notise HOWFS notise	0.01 0.00 50 0.02 * Total Ef * Total Ef * 796 4.8 NO 86	0.02 0.00 70 0.04 fective V deg Hz e-rms Hz	0.03 0.00 80 0.06 VFE sho SH	0.05 0.01 160 0.17 wm using using	0.07 0.01 240 0.25 CCD50 CCD50	0.09 0.03 480 0.41	0.13	0.20	0.31 0.24 1530 0.80
Tip/Tilt Errors Sci Filter Tilt Bandwidth Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Error (one-axis) Residual Atmospheric Dispersion Z Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy Z Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.092 m Theta0_eff 1.96 arcsec Solience Target: SCA0 LOWFS Star Type: M	Angular Error (rms) 31.88 mas 17.87 mas 44.22 mas 1.62 mas 0.14 mas 2.27 mas 2.77 mas 0.00 mas 0.00 mas 0.00 mas 1.12 mas 59.4 mas 30 deg 30 deg	Equivalent WFE (rms) 171 nm 120 nm 13 nm 13 nm 105 nm 0 nm 9 nm 230 nm 230 nm 230 nm 230 nm 5.0%	Parameter 14.9 mag (mV) 5.1 H2 (-3db) 60.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle m HO WFS Rate arcmin HO WFS rate LO WFS Noise HOWFS rate LO WFS Noise HOWFS and ansing	0.01 0.00 50 0.02 • Total Ef 7966 4.8 NO 8	0.02 0.00 70 0.04 fective V deg Hz e-rms Hz e-rms	0.03 0.00 80 0.06 VFE sho SH SH	0.05 0.01 160 0.17 using	0.07 0.01 240 0.25 CCD50 CCD59	0.09 0.03 480 0.41	0.13 0.06 1000 0.66	0.20	0.31 0.24 1530 0.80

Table 13. Error budget performance prediction for dynamics of Z = 1 galaxies w/ equivalent 50W CW laser return & interim LOWFS science case.

6.2.3 30% Sky Coverage w/ Equivalent 12 W MM Laser Return & Interim LOWFS

Palomar Wavefront Error Budget Sun	nmarv	Version 1.30					Scie	ence E	Band			
Mode: P3K LGS	,, ,			u'	g'	r'	i'	Z	Y	J	Н	К
Instrument: PHARO			λ (μ m)	0.36	0.47	0.62	0.75	0.88	1.03	1.25	1.64	2.20
Observation: 30% Sky			δλ (μm)	0.06	0.14	0.14	0.15	0.12	0.12	0.16	0.29	0.34
			λ/D (mas)	15	20	27	32	38	45	54	71	95
		Wavefront					Stret	n Rati	in (%)			
High-order Errors (LGS Mode)		Error (rms)	Parameter				01101	ii i tuti	0 (70)			
Atmospheric Fitting Error		119 nm	16 Subaps									
Bandwidth Error		105 nm	30 Hz (-3db)									
L GS Focal Anisoplanatism Error		86 nm	12 w 1 beacon(s)									
Asterism Deformation Error		0 nm	0.50 m LLT									
Multispectral Error		19 nm	5 zenith angle, H band									
Scintillation Error		13 nm	0.34 Scint index, H-band									
WI S SCITULIZION ENO	216 nm	10 1111	Alloc									
Uncorrectable Static Telescope Aberrations		14 nm	64 Acts									
Uncorrectable Dynamic Telescope Aberrations		0 nm	Dekens Ph.D									
Dynamic WES Zero-point Calibration Error		25 nm 30 nm	Alloc									
Leaky Integrator Zero-point Calibration Error		15 nm	Alloc									
Go-to Control Errors		0 nm	Alloc									
Residual Na Layer Focus Change		4 nm	30 m/s Na layer vel									
DM Finite Stroke Errors		19 nm 7 nm	5.5 um P-P stroke from TMT									
High-Order Aliasing Error		40 nm	16 Subaps									
DM Drive Digitization		1 nm	16 bits									
Uncorrectable AO System Aberrations		20 nm	Alloc									
DM-to-lenslet Misregistration		38 nm 15 nm	Alloc									
DM-to-lenslet Pupil Scale Error		15 nm	Alloc									
	79 nm		-									
Angular Anisoplanatism Error		67 nm	5 arcsec									
Total High Order Wavefront Error	230 nm	240 nm	High Order Strehl	0.00	0.00	0.00	0.02	0.06	0.12	0.24	0.43	0.63
Tip/Tilt Errors	Angular	Equivalent	Parameter				Streh	I ratio	os (%)			
Tip/Tilt Errors	Angular Error (rms)	Equivalent WFE (rms)	Parameter				Streh	I ratio	os (%)			
Tip/Tilt Errors Sci Filter	Angular Error (rms)	Equivalent WFE (rms)	Parameter				Streh	l ratio	os (%)			
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis)	Angular Error (rms) 162.01 mas 114.30 mas	Equivalent WFE (rms) 472 nm 422 nm	Parameter 17.6 mag (mV) 0.8 Hz (-3db)				Streh	nl ratio	os (%)			
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Anadwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis)	Angular Error (rms) 162.01 mas 114.30 mas 66.33 mas	Equivalent WFE (rms) 472 nm 422 nm 336 nm	Parameter 17.6 mag (mV) 0.8 Hz (-3db) 90.0 arcsec				Streh	I ratio	os (%)			
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Anisoplanatism Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism	Angular Error (rms) 162.01 mas 114.30 mas 66.33 mas 1.62 mas	Equivalent WFE (rms) 472 nm 422 nm 336 nm 13 nm	Parameter 17.6 mag (mV) 0.8 Hz (-3ab) 90.0 arcsec 10 x reduction				Streh	I ratio	os (%)			
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Anisoplanatism Error (one-axis) Tilt Anisoplanatism Residual Centroid Anisoplanatism Residual Atmospheric Dispersion H Induced Plate Scale Deformations	Angular Error (rms) 162.01 mas 114.30 mas 66.33 mas 1.62 mas 0.05 mas 2 84 mas	Equivalent WFE (rms) 472 nm 422 nm 336 nm 13 nm 0 nm 23 nm	Parameter 17.6 mag (mV) 0.8 Hz (-3db) 90.0 arcsec 10 x reduction 20 x reduction 1500 m cosi beipt				Streh	nl ratio	os (%)			
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Anodwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift	Angular Error (rms) 162.01 mas 114.30 mas 66.33 mas 1.62 mas 0.05 mas 2.84 mas 2.50 mas	Equivalent WFE (rms) 472 nm 422 nm 336 nm 13 nm 23 nm 23 nm	Parameter 17.6 mag (mV) 0.8 Hz (-3db) 90.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min				Streh	nl ratio	os (%)			
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Anadwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Antospheric Dispersion Hinduced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors	Angular Error (rms) 162.01 mas 114.30 mas 66.33 mas 0.05 mas 2.84 mas 2.50 mas 0.00 mas	Equivalent WFE (rms) 472 nm 422 nm 336 nm 13 nm 0 nm 23 nm 0 nm	Parameter 17.6 mag (mV) 0.8 Hz (-3db) 90.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min				Streh	I ratio	os (%)			
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion Hindraced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Fild Rotation Errors Residual Telescope Pointing Jitter (one-axis)	Angular Error (rms) 162.01 mas 114.30 mas 66.33 mas 6.62 mas 0.05 mas 2.84 mas 2.50 mas 0.00 mas 7.15 mas	Equivalent WFE (rms) 472 nm 422 nm 13 nm 0 nm 23 nm 20 nm 58 nm	Parameter 17.6 mag (mV) 0.8 Hz (-3db) 90.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance				Stref	I ratio	os (%)			
Tip/Tilt Errors Sci Filter Tit Measurement Error (one-axis) Tit Bandwidth Error (one-axis) Tit Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion Haduced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis)	Angular Error (rms) 162.01 mas 114.30 mas 66.33 mas 1.62 mas 0.05 mas 2.84 mas 2.50 mas 0.00 mas 7.15 mas 209.2 mas	Equivalent WFE (rms) 472 nm 422 nm 13 nm 0 nm 23 nm 20 nm 58 nm	Parameter 17.6 mag (mV) 0.8 H2 (-3db) 90.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl	0.00	0.00	0.00	Streh	0.01	os (%)	0.01	0.02	0.04
Tip/Tilt Errors Sci Filter Tilt Bendwidth Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion Hindraced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Fild Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis)	Angular Error (rms) 162.01 mas 114.30 mas 66.33 mas 1.62 mas 2.64 mas 2.50 mas 0.00 mas 7.15 mas 209.2 mas	Equivalent WFE (rms) 472 nm 422 nm 336 nm 13 nm 0 nm 23 nm 20 nm 58 nm 515 nm	Parameter 17.6 mag (mV) 0.8 Hz (-3db) 90.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl	0.00	0.00	0.00	Streh	0.01	os (%) 0.01	0.01	0.02	0.04
Tip/Tilt Errors Sci Filter Tit Measurement Error (one-axis) Titt Bandwidth Error (one-axis) Titt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error	Angular Error (rms) 162.01 mas 114.30 mas 66.33 mas 66.33 mas 0.05 mas 2.26 mas 2.50 mas 0.00 mas 7.15 mas 209.2 mas	Equivalent WFE (rms) 472 nm 422 nm 336 nm 0 nm 23 nm 20 nm 58 nm 5115 nm	Parameter 17.6 mag (mV) 0.8 Hz (-3db) 90.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%)	0.00	0.00	0.00	Streh 0.00	0.01	0.01	0.01	0.02	0.04
Tip/Tilt Errors Sci Filter Tit Measurement Error (one-axis) Titt Bandwidth Error (one-axis) Titt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Error Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error	Angular Error (rms) 162.01 mas 114.30 mas 66.33 mas 66.33 mas 0.05 mas 2.26 mas 2.50 mas 0.00 mas 7.15 mas 209.2 mas	Equivalent WFE (rms) 472 nm 422 nm 336 nm 0 nm 23 nm 20 nm 58 nm 515 nm	Parameter 17.6 mag (mV) 0.8 H2 (-3db) 90.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%)	0.00	0.00	0.00	Streh 0.00 0.00	0.01 0.00	0.01 0.00	0.01	0.02	0.04
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Anadwidth Error (one-axis) Tilt Anajoplanatism Error (one-axis) Residual Centroid Anisoplanatism Error (one-axis) Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error	Angular Error (rms) 162.01 mas 114.30 mas 66.33 mas 1.62 mas 0.05 mas 2.84 mas 2.84 mas 2.90 mas 7.15 mas 209.2 mas	Equivalent WFE (rms) 472 nm 422 nm 336 nm 13 nm 23 nm 20 nm 0 nm 58 nm 515 nm 568 nm	Parameter 17.6 mag (mV) 0.8 Hz (-3db) 90.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.00	0.00	0.00	Streh 0.00 0.00	0.01 0.00	0.01 0.00 480	0.01	0.02	0.04
Tip/Tilt Errors Sci Filter Tilt Beadwidth Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Ansopheric Dispersion H Nesidual Centroid Anisoplanatism Error (one-axis) Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy H	Angular Error (rms) 162.01 mas 114.30 mas 66.33 mas 1.62 mas 0.05 mas 2.84 mas 2.84 mas 2.95 mas 7.15 mas 209.2 mas	Equivalent WFE (rms) 472 nm 422 nm 336 nm 13 nm 23 nm 20 nm 0 nm 58 nm 515 nm 568 nm	Parameter 17.6 mag (mV) 0.8 Hz (-3db) 90.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.00 0.00 50 0.01	0.00 0.00 70 0.01	0.00 0.00 80 0.01	Streh 0.00 0.00 160 0.06	0.01 0.00 240 0.12	0.01 0.00 480 0.38	0.01 0.00 1000 0.75	0.02	0.04 0.02 1160 0.80
Tip/Tilt Errors Sci Filter Tilt Bandwidth Error (one-axis) Sci Filter Tilt Bandwidth Error (one-axis) Tilt Ansopheric Dispersion Residual Centroid Anisoplanatism Error (one-axis) H Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy H Sky Coverage Colorid Lt	Angular Error (rms) 162.01 mas 114.30 mas 66.33 mas 1.62 mas 0.05 mas 2.84 mas 2.84 mas 2.84 mas 7.15 mas 7.15 mas 209.2 mas	Equivalent WFE (rms) 472 nm 422 nm 336 nm 13 nm 23 nm 20 nm 0 nm 58 nm 515 nm 568 nm	Parameter 17.6 mag (mV) 0.8 Hz (-3db) 90.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.00 0.00 50 0.01	0.00 0.00 70 0.01	0.00 0.00 80 0.01	0.00 0.00 160 0.06	0.01 0.00 240 0.12	0.01 0.00 480 0.38	0.01 0.00 1000 0.75	0.02	0.04 0.02 1160 0.80
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Anadwidth Error (one-axis) Tilt Analoginatism Error (one-axis) Residual Centroid Anisopianatism Error (one-axis) Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy H Sky Coverage Galactic Lat.	Angular Error (rms) 162.01 mas 114.30 mas 66.33 mas 1.62 mas 0.05 mas 2.84 mas 2.84 mas 2.84 mas 7.15 mas 209.2 mas 209.2 mas 60 deg	Equivalent WFE (rms) 472 nm 422 nm 336 nm 13 nm 23 nm 20 nm 58 nm 515 nm 568 nm	Parameter 17.6 mag (mV) 0.8 Hz (-3db) 90.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alioc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.00 0.00 50 0.01	0.00 0.00 70 0.01	0.00 0.00 80 0.01	0.00 0.00 160 0.06	0.01 0.00 240 0.12	0.01 0.00 480 0.38	0.01 0.00 1000 0.75	0.02	0.04 0.02 1160 0.80
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Anadwidth Error (one-axis) Tilt Anajoplanatism Error (one-axis) Residual Centroid Anisoplanatism Error Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy H Sky Coverage Galactic Lat. Corresponding Sky Coverage Intercenter	Angular Error (rms) 162.01 mas 114.30 mas 66.33 mas 1.62 mas 0.05 mas 2.84 mas 2.84 mas 2.85 mas 7.15 mas 209.2 mas 60 deg	Equivalent WFE (rms) 472 nm 422 nm 336 nm 13 nm 23 nm 20 nm 58 nm 515 nm 568 nm 30.0%	Parameter 17.6 mag (mV) 0.8 Hz (-3db) 90.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the	0.00 0.00 50 0.01	0.00 0.00 70 0.01	0.00 0.00 80 0.01	Streh 0.00 0.00 160 0.06	0.01 0.00 240 0.12	0.01 0.00 480 0.38	0.01 0.00 1000 0.75	0.02	0.04
Tip/Tilt Errors Sci Filter Tilt Bandwidth Error (one-axis) Sci Filter Tilt Bandwidth Error (one-axis) Tilt Ansopharitism Error (one-axis) Residual Centroid Anisoplanatism Merchanical Dift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy Kky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters	Angular Error (rms) 162.01 mas 114.30 mas 66.33 mas 1.62 mas 0.05 mas 2.84 mas 2.84 mas 2.80 mas 7.15 mas 209.2 mas 60 deg	Equivalent WFE (rms) 472 nm 422 nm 336 nm 13 nm 23 nm 20 nm 58 nm 515 nm 568 nm 30.0%	Parameter 17.6 mag (mV) 0.8 Hz (-3db) 90.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the	0.00 0.00 50 0.01	0.00 0.00 70 0.01	0.00 0.00 80 0.01	Streh 0.00 0.00 160 0.06	0.01 0.00 240 0.12	0.01 0.00 480 0.38	0.01 0.00 1000 0.75	0.02	0.04 0.02 1160 0.80
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Sci Filter Tilt Bandwidth Error (one-axis) Tilt Ansophenic Dispersion Residual Centroid Anisopianatism Error (one-axis) Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy H Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters	Angular Error (rms) 162.01 mas 114.30 mas 66.33 mas 1.62 mas 0.05 mas 2.84 mas 2.84 mas 2.84 mas 2.84 mas 2.85 mas 0.00 mas 7.15 mas 209.2 mas	Equivalent WFE (rms) 472 nm 422 nm 336 nm 13 nm 20 nm 20 nm 58 nm 515 nm 568 nm 30.0%	Parameter 17.6 mag (mV) 0.8 Hz (-3db) 90.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the	0.00 0.00 50 0.01	0.00 70 0.01	0.00 0.00 80 0.01	Streh 0.00 160 0.06	0.01 0.00 240 0.12	0.01 0.00 480 0.38	0.01 0.00 1000 0.75	0.02	0.04 0.02 1160 0.80
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Sci Filter Tilt Bandwidth Error (one-axis) Tilt Ansophenic Dispersion Residual Centroid Anisoplanatism Error (one-axis) House Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Filed Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Interfective Wavefront Error Ensquared Energy H Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters Total Content Filter 0.092 m	Angular Error (rms) 162.01 mas 114.30 mas 66.33 mas 1.62 mas 2.84 mas 2.50 mas 0.00 mas 0.00 mas 7.15 mas 209.2 mas 209.2 mas 60 deg	Equivalent WFE (rms) 472 nm 422 nm 386 nm 3 nm 20 nm 23 nm 20 nm 58 nm 515 nm 568 nm 568 nm 30.0%	Parameter 17.6 mag (mV) 0.8 Hz (-33b) 90.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alico 0.25 mas 7 min Alico 0.25 mas 7 min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle	0.00 0.00 50 0.01	0.00 0.00 70 0.01	0.00 0.00 80 0.01	Streh 0.00 0.00 160 0.06	0.01 0.00 240 0.12	0.01 0.00 480 0.38	0.01	0.02	0.04 0.02 1160 0.80
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Sci Filter Tilt Bandwidth Error (one-axis) Tilt Ansophenic Dispersion H Residual Centroid Anisoplanatism Error (one-axis) Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy H Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.092 m Theta0_eff 1.96 arcsec Sodium Ahund 4.107	Angular Error (rms) 162.01 mas 114.30 mas 66.33 mas 1.62 mas 0.05 mas 2.84 mas 2.84 mas 2.80 mas 0.00 mas 7.15 mas 209.2 mas 60 deg 60 deg	Equivalent WFE (rms) 472 nm 422 nm 336 nm 13 nm 23 nm 20 nm 0 nm 58 nm 515 nm 568 nm 30.0%	Parameter 17.6 mag (mV) 0.8 Hz (-3db) 90.0 arcsec 10 x reduction 20 x reduction 10 x reduction -1500 m conj height Alloc 0.25 mas / min Total Strehl (%) Strekt Angle min HO WFS Rate Alloc WFS Neise </td <td>0.00 0.00 50 0.01</td> <td>0.00 0.00 70 0.01 ffective V deg Hz e. (ms</td> <td>0.00 0.00 80 0.01 VFE sho</td> <td>Stref-</td> <td>0.01 0.00 240 0.12</td> <td>0.01 0.00 480 0.38</td> <td>0.01</td> <td>0.02</td> <td>0.04 0.02 1160 0.80</td>	0.00 0.00 50 0.01	0.00 0.00 70 0.01 ffective V deg Hz e. (ms	0.00 0.00 80 0.01 VFE sho	Stref-	0.01 0.00 240 0.12	0.01 0.00 480 0.38	0.01	0.02	0.04 0.02 1160 0.80
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Ansophentis Error (one-axis) Residual Centroid Anisopianatism Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rolation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy H Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.092 m Theta0_eff 1.96 arcsec Sodium Abund. 4 × 10° Science Target: SCAO	Angular Error (rms) 162.01 mas 114.30 mas 66.33 mas 1.62 mas 2.66 mas 2.84 mas 2.84 mas 2.85 mas 0.00 mas 7.15 mas 209.2 mas 60 deg 60 deg	Equivalent WFE (rms) 472 nm 422 nm 336 nm 13 nm 20 nm 20 nm 58 nm 5115 nm 568 nm 568 nm 30.0%	Parameter 17.6 mag (mV) 0.8 Hz (-3db) 90.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alice 0.25 mas / min Alice 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle m HO WFS Rate arcmin HO WFS Rate arcmin HO WFS Noise HO WFS Noise	0.00 0.00 50 0.01 Total Ef 443 4.3 NO	0.00 70 0.01 ffective V deg Hz e-rms	0.00 0.00 80 0.01 VFE shor SH	Streh 0.00 0.00 160 0.06	0.01 0.00 240 0.12 CCD50	0.01 0.00 480 0.38	0.01 0.00 1000 0.75	0.02	0.04
Tip/Tilt Errors Sci Filter Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Ansophents Residual Centroid Anisopianatism Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Filed Notation Errors Residual Telescope Pointing Jitter (one-axis) Total Effective Wavefront Error Ensquared Energy Ky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.092 m Theta0_eff 1.96 arcsec Socience Target: SCA0 LOWFS Target: SCA0	Angular Error (rms) 162.01 mas 114.30 mas 66.33 mas 1.62 mas 2.50 mas 2.50 mas 2.50 mas 7.15 mas 209.2 mas 209.2 mas 60 deg	Equivalent WFE (rms) 472 nm 422 nm 336 nm 3 nm 20 nm 53 nm 515 nm 515 nm 568 nm 568 nm 30.0%	Parameter 17.6 mag (mV) 0.8 Hz (-3db) 90.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m HO WFS Rate arcmin HO WFS Rate arcmin HO WFS rate HOWFS notice HOWFS rate	0.00 50 0.01 Total El 433 43 NO 0 12	0.00 70 0.01 ffective V deg Hz e - rms Hz	0.00 0.00 80 0.01 VFE sho SH SH	Streh	0.01 0.00 240 0.12 CCD50 CCD50	0.01 0.00 480 0.38	0.01	0.02	0.04 0.02 1160 0.80
Tip/Tilt Errors Sci Filter Tilt Bandwidth Error (one-axis) Sci Filter Tilt Bandwidth Error (one-axis) Residual Centroid Anisoplanatism Error (one-axis) Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy H Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.092 m Theta0_eff 1.96 arcsec Science Target: SCAO LOWFF Star Type: M	Angular Error (rms) 162.01 mas 114.30 mas 66.33 mas 1.62 mas 0.05 mas 2.84 mas 2.80 mas 0.00 mas 7.15 mas 209.2 mas 209.2 mas 60 deg 60 deg	Equivalent WFE (rms) 472 nm 422 nm 336 nm 13 nm 23 nm 20 nm 0 nm 58 nm 515 nm 568 nm 568 nm 30.0%	Parameter 17.6 mag (mV) 0.8 Hz (-3db) 90.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle m HO WFS Rate arcmin HO WFS rate UO WFS rate UO WFS Noise HOWFS Noise HO WFS Noise	0.00 0.00 50 0.01 Total El 443 43 43 43 43 43	0.00 70 0.01 ffective V deg Hz e-rms Hz e-rms	0.00 0.00 80 0.01 VFE sho SH SH	Streth 0.00 0.00 0.00 0.00 using using	0.01 0.00 240 0.12 CCD50 CCD59	0.01 0.00 480 0.38	0.01	0.02	0.04 0.02 1160 0.80

Table 14. Error budget performance prediction for 30% sky coverage w/ equivalent 12 W MM laser return & interim LOWFS science case. For this case, we have expanded the search radius for visible TT GS out to 90 arcsec radius (the P3K goal specification), which dramatically improves TT error.

6.2.4 30% Sky Coverage w/ Equivalent 50W CW Laser Return & Interim LOWFS

Palomar Wavefront Error Budget Sun	nmarv	Version 1.30					Scie	ence E	Band			
Mode: P3K LGS				u'	g'	r'	i'	Ζ	Y	J	Н	Κ
Instrument: PHARO			λ (μ m)	0.36	0.47	0.62	0.75	0.88	1.03	1.25	1.64	2.20
Observation: 30% Sky			δλ (μm)	0.06	0.14	0.14	0.15	0.12	0.12	0.16	0.29	0.34
			λ/D (mas)	15	20	27	32	38	45	54	71	95
		Marriefmant					Ofmak	I Det	- (0/)			
High-order Errors (LGS Mode)		wavefront	Parameter				Strer	ni kati	0 (%)			
		Error (rms)										
Atmosphoria Eitting Error		67 nm	22 Subanc									
Bandwidth Error		62 nm	56 Hz (-3db)									
High-order Measurement Error		66 nm	50 W									
LGS Focal Anisoplanatism Error		86 nm	1 beacon(s)									
Asterism Deformation Error Multispectral Error		19 nm	5 zenith angle H hand									
Scintillation Error		13 nm	0.34 Scint index, H-band									
WFS Scintillation Error		10 nm	Alloc									
Lincorroctable Static Telescone Aborrations	144 nm	14 nm	64 Acto									
Uncorrectable Dynamic Telescope Aberrations		0 nm	Dekens Ph.D									
Static WFS Zero-point Calibration Error		25 nm	Alloc									
Dynamic WFS Zero-point Calibration Error		30 nm	Alloc									
Leaky Integrator Zero-point Calibration Error		15 nm	Alloc									
Residual Na Layer Focus Change		4 nm	30 m/s Na layer vel									
DM Finite Stroke Errors		27 nm	5.5 um P-P stroke									
DM Hysteresis		7 nm	from TMT									
High-Order Allasing Error		22 nm 1 nm	32 Subaps 16 bits									
Uncorrectable AO System Aberrations		20 nm	Alloc									
Uncorrectable Instrument Aberrations		38 nm	PHARO Instrument									
DM-to-lenslet Misregistration		15 nm	Alloc									
DM-to-lensiet Pupil Scale Error	74 nm	15 nm	Alloc									
Angular Anisoplanatism Error		67 nm	5 arcsec									
Total High Order Wavefront Error	162 nm	175 nm	High Order Strehl	0.00	0.00	0.05	0.12	0.22	0.33	0.47	0.64	0.78
	Angular	Equivalent	Devementer				Streh	I ratio	os (%)			
I ID/I IIT Errors			Parameter									
	Error (rms)	WFE (rms)										
Sci Filter	Error (rms)	WFE (rms)										
Sci Filter	Error (rms) 162.22 mas 114.03 mas	472 nm 421 nm	17.6 mag (mV)									
Sci Filter Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) TiltAnisoolanatism Error (one-axis)	Error (rms) 162.22 mas 114.03 mas 66.33 mas	472 nm 421 nm 336 nm	17.6 <mark>mag (mV)</mark> 0.8 Hz (-3db) 90.0 arcsec									
Sci Filter Tilt Measurement Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism	Error (rms) 162.22 mas 114.03 mas 66.33 mas 1.62 mas	₩FE (rms) 472 nm 421 nm 336 nm 13 nm	17.6 mag (mV) 0.8 Hz (-3db) 90.0 arcsec 10 x reduction									
Till Measurement Error (one-axis) Till Bandwidth Error (one-axis) Till Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion H	Error (rms) 162.22 mas 114.03 mas 66.33 mas 1.62 mas 0.05 mas	WFE (rms) 472 nm 421 nm 336 nm 13 nm 0 nm	17.6 mag (mV) 0.8 Hz (-3db) 90.0 arcsec 10 x reduction 20 x reduction									
Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift	Error (rms) 162.22 mas 114.03 mas 66.33 mas 1.62 mas 0.05 mas 2.84 mas 2.50 mas	WFE (rms) 472 nm 421 nm 336 nm 13 nm 0 nm 23 nm 20 nm	17.6 mag (mV) 0.8 Hz (-3db) 90.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mag /min									
Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Ansophanatism Error (one-axis) Residual Centroid Anisopianatism Residual Centroid Anisopianatism Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exosure Field Rotation Errors	Error (rms) 162.22 mas 114.03 mas 66.33 mas 1.62 mas 0.05 mas 2.84 mas 2.50 mas 0.00 mas	WFE (rms) 472 nm 421 nm 336 nm 13 nm 0 nm 23 nm 20 nm 0 nm	17.6 mag (mV) 0.8 Hz (-3db) 90.0 arcsec 10 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min									
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Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis)	Error (rms) 162.22 mas 114.03 mas 1.62 mas 0.05 mas 2.84 mas 2.50 mas 0.00 mas 7.13 mas 209.3 mas	WFE (rms) 472 nm 421 nm 336 nm 0 nm 20 nm 0 nm 57 nm 515 nm	17.6 mag (mV) 0.8 Hz (-3db) 90.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.02	0.04
Sci Filter Titt Measurement Error (one-axis) Titt Bandwidth Error (one-axis) Titt Anisoplanatism Teror (one-axis) Tet Anisoplanatism Residual Centroid Anisoplanatism Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error	Error (rms) 162.22 mas 164.03 mas 66.33 mas 0.65 mas 0.05 mas 0.00 mas 7.13 mas 209.3 mas	WFE (rms) 472 nm 421 nm 336 nm 0 nm 20 nm 0 nm 57 nm 515 nm	17.6 mag (mV) 0.8 Hz (-3db) 90.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%)	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.02	0.04
Titl Measurement Error (one-axis) Scl Filter Titl Bandwidth Error (one-axis) Titl Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Centroid Anisoplanatism Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error	Error (rms) 162.22 mas 114.03 mas 66.33 mas 0.05 mas 2.84 mas 2.80 mas 0.00 mas 7.13 mas 209.3 mas	WFE (rms) 472 nm 421 nm 336 nm 0 nm 23 nm 0 nm 20 nm 0 nm 57 nm 515 nm 544 nm	17.6 mag (mV) 0.8 Hz (-3db) 90.0 arcsec 10 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%)	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.02	0.04
Till Measurement Error (one-axis) Till Mandwidth Error (one-axis) Till Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis)	Error (rms) 162.22 mas 164.03 mas 66.33 mas 1.62 mas 0.05 mas 2.84 mas 2.80 mas 0.00 mas 7.13 mas 209.3 mas	WFE (rms) 472 nm 421 nm 336 nm 13 nm 0 nm 23 nm 0 nm 57 nm 515 nm 544 nm	17.6 mag (mV) 0.8 Hz (-3db) 90.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%)	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.02	0.04
Sci Filter Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Aniosplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error	Error (rms) 162.22 mas 114.03 mas 66.33 mas 1.62 mas 0.05 mas 2.84 mas 2.80 mas 0.00 mas 7.13 mas 209.3 mas	WFE (rms) 472 nm 421 nm 336 nm 0 nm 20 nm 0 nm 57 nm 515 nm	17.6 mag (mV) 0.8 Hz (-3db) 90.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.00	0.00	0.00	0.00	0.01 0.00 240	0.01 0.00 480	0.01	0.02	0.04 0.03 880
Titt Measurement Error (one-axis) Sci Filter Titt Bandwidth Error (one-axis) Titt Anisoplanatism Titt Bandwidth Error (one-axis) Residual Atmospheric Dispersion Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy H	Error (rms) 162.22 mas 164.03 mas 66.33 mas 162.26 mas 0.05 mas 2.24 mas 2.50 mas 0.00 mas 0.00 mas 7.13 mas 209.3 mas	WFE (rms) 472 nm 421 nm 336 nm 13 nm 0 nm 20 nm 0 nm 57 nm 5715 nm 544 nm	17.6 mag (mV) 0.8 Hz (-3db) 90.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.00 0.00 50 0.01	0.00 0.00 70 0.01	0.00 0.00 80 0.02	0.00 0.00 160 0.07	0.01 0.00 240 0.15	0.01 0.00 480 0.46	0.01 0.01 1000 0.84	0.02	0.04 0.03 880 0.80
Sci Filter Till Measurement Error (one-axis) Till Andwidth Error (one-axis) Till Aniosphantism Error (one-axis) Residual Centroid Anisoplanatism Terror (one-axis) H Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy H Sky Coverage Galactic Lat.	Error (rms) 162.22 mas 114.03 mas 66.33 mas 1.62 mas 0.05 mas 2.84 mas 2.84 mas 2.80 mas 0.00 mas 7.13 mas 209.3 mas 60 deg	WFE (rms) 472 nm 421 nm 336 nm 0 nm 20 nm 0 nm 57 nm 515 nm	17.6 mag (mV) 0.8 Hz (-3db) 90.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas)	0.00 0.00 50 0.01	0.00 0.00 70 0.01	0.00 0.00 80 0.02	0.00 0.00 160 0.07	0.01 0.00 240 0.15	0.01 0.00 480 0.46	0.01 0.01 1000 0.84	0.02	0.04 0.03 880 0.80
Till Measurement Error (one-axis) Till Measurement Error (one-axis) Till Bandwidth Error (one-axis) Residual Centroid Anisoplanatism Residual Centroid Anisoplanatism Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy H Sky Coverage Galactic Lat. Corresponding Sky Coverage Inductic Lat.	Error (rms) 162.22 mas 164.03 mas 66.33 mas 1.62 mas 0.05 mas 2.84 mas 2.84 mas 2.80 mas 0.00 mas 7.13 mas 209.3 mas 60 deg	WFE (rms) 472 nm 421 nm 336 nm 13 nm 23 nm 20 nm 0 nm 57 nm 515 nm 544 nm 30.0%	17.6 mag (mV) 0.8 Hz (-3db) 90.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the	0.00 0.00 50 0.01	0.00 0.00 70 0.01	0.00 0.00 80 0.02	0.00 0.00 160 0.07	0.01 0.00 240 0.15	0.01 0.00 480 0.46	0.01	0.02	0.04 0.03 880 0.80
Titt Measurement Error (one-axis) Titt Measurement Error (one-axis) Titt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy H Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters	Error (rms) 162.22 mas 114.03 mas 66.33 mas 0.05 mas 2.24 mas 2.264 mas 0.00 mas 7.13 mas 209.3 mas 60 deg	WFE (rms) 472 nm 421 nm 336 nm 0 nm 23 nm 0 nm 20 nm 0 nm 57 nm 515 nm 544 nm 30.0%	17.6 mag (mV) 0.8 Hz (-3db) 90.0 arcsec 10 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the	0.00 0.00 50 0.01	0.00 0.00 70 0.01	0.00 0.00 0.02	0.00 0.00 160 0.07	0.01 0.00 240 0.15	0.01 0.00 480 0.46	0.01	0.02	0.04 0.03 880 0.80
Till Measurement Error (one-axis) Till Mandwidth Error (one-axis) Till Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Centroid Anisoplanatism Residual Centroid Anisoplanatism Residual Centroid Anisoplanatism Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy H Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters	Error (rms) 162.22 mas 14.03 mas 162 mas 0.05 mas 2.84 mas 2.84 mas 2.80 mas 0.00 mas 7.13 mas 209.3 mas 60 deg	WFE (rms) 472 nm 421 nm 336 nm 13 nm 13 nm 23 nm 20 nm 0 nm 57 nm 515 nm 544 nm 30.0%	17.6 mag (mV) 0.8 Hz (-3db) 90.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the	0.00 0.00 50 0.01	0.00 0.00 70 0.01	0.00 0.00 80 0.02	0.00 0.00 160 0.07	0.01 0.00 240 0.15	0.01 0.00 480 0.46	0.01	0.02	0.04 0.03 880 0.80
Titl Measurement Error (one-axis) Titl Bandwidth Error (one-axis) Titl Anisoplanatism Error (one-axis) Testidual Atmospheric Dispersion House Centroid Anisoplanatism Residual Centroid Anisoplanatism Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy H Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.092 m	Error (rms) 162.22 mas 164.03 mas 66.33 mas 2.84 mas 2.84 mas 2.80 mas 0.00 mas 2.80 mas 0.00 mas 7.13 mas 209.3 mas 60 deg 60 deg at this zenith	WFE (rms) 472 nm 421 nm 336 nm 336 nm 0 nm 20 nm 20 nm 0 nm 57 nm 5715 nm 544 nm 30.0%	17.6 mag (mV) 0.8 Hz (-3db) 90.0 arcsec 10 x reduction 20 x reduction 20 z reduction 1500 m conj height Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle	0.00 0.00 50 0.01 Total El	0.00 0.00 70 0.01	0.00 0.00 80 0.02	0.00 0.00 160 0.07	0.01 0.00 240 0.15	0.01 0.00 480 0.46	0.01	0.02	0.04 0.03 880 0.80
Sci Filter Till Bandwidth Error (one-axis) Till Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Centroid Anisoplanatism Residual Centroid Anisoplanatism Residual Centroid Anisoplanatism Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Intelement Total Effective Wavefront Error Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.092 m Theta0_eff 1.96 arcsec	Error (rms) 162.22 mas 114.03 mas 66.33 mas 0.05 mas 0.05 mas 0.00 mas 7.13 mas 209.3 mas 60 deg 60 deg at this zenith at this zenith	WFE (rms) 472 nm 421 nm 336 nm 0 nm 23 nm 0 nm 20 nm 0 nm 515 nm 515 nm 544 nm 30.0%	17.6 mag (mV) 0.8 Hz (-3db) 90.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas' min Alloc 0.25 mas' min 3 Hz iput distubance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle m H0 WFS Rate	0.00 0.00 50 0.01 Total Ef	0.00 70 0.01 ffective V deg Hz	0.00 0.00 80 0.02 //FE shot	0.00 0.00 160 0.07	0.01 0.00 240 0.15	0.01 0.00 0.46	0.01	0.02	0.04 0.03 880 0.80
Sci Filter Till Measurement Error (one-axis) Till Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Effective Wavefront Error Ensquared Energy H Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.092 m Thetalo_eff 1.96 arcsec Sciden Turot	Error (rms) 162.22 mas 162.03 mas 66.33 mas 1.62 mas 0.05 mas 2.24 mas 2.26 mas 0.00 mas 7.13 mas 209.3 mas 60 deg 60 deg at this zenith at this zenith at mas zenith	WFE (rms) 472 nm 421 nm 336 nm 336 nm 0 nm 20 nm 57 nm 515 nm 544 nm 30.0%	17.6 mag (mV) 0.8 Hz (-3db) 90.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle m HO WFS Rate arcmin HO WFS Rate arcmin HO WFS Rate	0.00 0.00 50 0.01	0.00 70 0.01 ffective V deg Hz e-rms	0.00 0.00 80 0.02 VFE shor	0.00 0.00 160 0.07 wm	0.01 0.00 240 0.15	0.01 0.00 480 0.46	0.01	0.02	0.04 0.03 880 0.80
Titt Measurement Error (one-axis) Titt Measurement Error (one-axis) Titt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy H Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.092 m Theta0_eff 1.96 arcsec Science Target: SCAO LOWES Tarreet: SCAO	Error (rms) 162.22 mas 164.03 mas 66.33 mas 2.84 mas 2.84 mas 2.00 mas 2.00 mas 2.00 mas 7.13 mas 209.3 mas 60 deg 60 deg at this zenith at this zenith at oms/cm ²	WFE (rms) 472 nm 421 nm 336 nm 336 nm 0 nm 20 nm 0 nm 57 nm 5715 nm 544 nm 30.0% Wind Speed 8.03 Outer Scale 7.03 LGS Ast. Rad. 0.00 HOWFS Trans 0.28	17.6 mag (mV) 0.8 Hz (-3db) 90.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle m HO WFS Rate arcmin HO WFS Noise HOWFS rate	0.00 0.00 50 0.01 Total El 55839 4.9 NO 12	0.00 0.00 70 0.01 ffective V Hz e - rms Hz	0.00 0.00 80 0.02 //FE sho SH	0.00 0.00 160 0.07 wn using using	0.01 0.00 240 0.15 CCD50	0.01 0.00 480 0.46	0.01	0.02	0.04 0.03 880 0.80
Titt Measurement Error (one-axis) Titt Measurement Error (one-axis) Titt Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy H Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.092 m Theta0_eff 1.96 arcsec Sodium Abund. 4 × 10° Science Target: SCAO LOWFS Target: SCAO LOWFS Start Type: M	Error (rms) 162.22 mas 164.03 mas 66.33 mas 0.05 mas 0.00 mas 7.13 mas 209.3 mas 60 deg 60 deg 60 deg 114.05 mas 114.05 mas 1	WFE (rms) 472 nm 421 nm 336 nm 0 nm 23 nm 0 nm 20 nm 0 nm 515 nm 515 nm 544 nm 000kg Speed 8.03 Outer Scale 51GS Ast. Rad. 0.028 Num 3x3 1	17.6 mag (mV) 0.8 Hz (-3db) 90.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/s Zenith Angle m H0 WFS Rate arcmin H0 WFS Noise H0WFS anti-aliasing L0 WFS rate L0 WFS rate L0 WFS Noise	0.00 0.00 50 0.01 Total Ef 8399 4.9 NO 12 4.9	0.00 70 0.01 ffective V deg Hz e-rms Hz e-rms	0.00 0.00 80 0.02 //FE shot	0.00 0.00 160 0.07 wn using using	0.01 0.00 240 0.15 CCD50 CCD50	0.01 0.00 480 0.46	0.01	0.02	0.04 0.03 880 0.80
Titl Measurement Error (one-axis) Titl Bandwidth Error (one-axis) Titl Anisoplanatism Error (one-axis) Residual Centroid Anisoplanatism Residual Atmospheric Dispersion H Induced Plate Scale Deformations Science Instrument Mechanical Drift Long Exposure Field Rotation Errors Residual Telescope Pointing Jitter (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefront Error Ensquared Energy H Sky Coverage Galactic Lat. Corresponding Sky Coverage Assumptions / Parameters r0 0.092 m Theta0_eff 1.96 arcsec Sodium Abund. 4 × 10° Science Target: SCAO LOWFS Target: M Max Exposure Time 300 sec	Error (rms) 162.22 mas 114.03 mas 66.33 mas 0.05 mas 0.26 mas 0.26 mas 0.00 mas 7.13 mas 209.3 mas 60 deg 60 deg 60 deg Num TT 0 Num TT 0 Num TT 0	WFE (rms) 472 nm 421 nm 336 nm 0 nm 23 nm 0 nm 23 nm 0 nm 515 nm 515 nm 544 nm 0 544 nm 0 0 0 0 0 544 nm 0 0 0 0 0 0 0 0 0 0 0 400% 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	17.6 mag (mV) 0.8 Hz (-3db) 90.0 arcsec 10 x reduction 20 x reduction -1500 m conj height Alloc 0.25 mas / min Alloc 0.25 mas / min 3 Hz input disturbance Tip/Tilt Strehl Total Strehl (%) Spaxel Diameter (mas) This fraction of sky can be corrected to the m/S Zenith Angle m H0 WFS Rate arcmin H0 WFS Rate LO WFS rate LO WFS Noise Max mechanical tip/tit m	0.00 50 0.01 Total El 839 4.9 NO 12 4.9 9 Solution 1	0.00 70 0.01 ffective V deg Hz e-rms bandwidt	0.00 0.00 80 0.02 VFE sho SH SH SH	0.00 0.00 160 0.07 wm using using 50	0.01 0.00 240 0.15 CCD50 CCD50 CCD39 Hz	0.01 0.00 480 0.46	0.01	0.02	0.04 0.03 880 0.80

Table 15. Error budget performance prediction for 30% sky coverage w/ equivalent 50W CW laser return & interim LOWFS science case. For this case, we have expanded the search radius for visible TT GS out to 90 arcsec radius (the P3K goal specification), which dramatically improves TT error. Through comparison with Table 10, we see the tip/tilt error associated with 30% sky coverage is much worse with the interim LOWFS than with the IRTT.