Cascaded Relay Requirement Flowdown and Open Issues

R. Dekany

NGAO Team Meeting #9

Cascaded Relay

- Preliminary design point choices
  - 1st stage relay
    - K-mirror
      - Rotating reconstructors to handle pupil rotation on DM's (as per Keck AO)
    - F/15 input and output
    - 20 x 20 actuator DM
      - 5 mm pitch; 100 mm pupil diameter
    - DNIRI
      - 6 IFU heads
        - » One may be usable as a PSF camera
      - 32 x 32 actuator MEMS DM used in MOAO mode
  - 2nd stage relay
    - F/15 input and F/45 output (tentative)
    - OAP mirror relay
    - 64 x 64 actuator DM
      - 400 micron pitch; 25.6 mm pupil diameter
    - Up to 5 narrow-field instruments
      - 'LEGO block' instrument stack
      - BFD from output fold mirror > 250 mm
  - Enclosure
    - Cooled to 259K (-16C below ambient at MK summit)
      - Background due to input window must be minimized

Error and performance budget flowdown:

Start with a set of design assumptions (based on NGAO KAON library & Sys Arch evaluations)

Then, iterate to reduce costs while building performance margin

Keck Wavefront Error Budget Summary

Mode: NGAO LGS

Instrument: TBD

Observation: KBO

Science Band	u'	g'	r'	i'	Z	Y	J	H	K
λ (μm)	0.36	0.47	0.62	0.75	0.88	1.03	1.25	1.64	2.20
δλ (μm)	0.06	0.14	0.14	0.15	0.12	0.12	0.16	0.29	0.34
λ/D (mas)	7	10	13	15	18	21	26	34	46

High-order Errors (LGS Mode)		Wavefront Error (rms)	Parameter	Strehl Ratio (%) u'	g'	r'	i'	Z	Y	J	H	K
Atmospheric Fitting Error		41 nm	64 Subaps	0.59	0.73	0.84	0.89	0.92	0.94	0.96	0.98	0.99
Bandwidth Error		31 nm	80 Hz (-3db)	0.74	0.84	0.91	0.94	0.95	0.97	0.98	0.99	0.99
High-order Measurement Error		42 nm	90 W	0.57	0.72	0.83	0.88	0.91	0.94	0.96	0.97	0.99
LGS Tomography Error		108 nm	6 beacon(s)	0.03	0.12	0.30	0.44	0.55	0.65	0.75	0.84	0.91
Asterism Deformation Error		17 nm	0.50 m LLT	0.92	0.95	0.97	0.98	0.99	0.99	0.99	1.00	1.00
Multispectral Error		20 nm	18 zenith angle, H band	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Scintillation Error		11 nm	0.27 Scint index, H-band	0.97	0.98	0.99	0.99	0.99	1.00	1.00	1.00	1.00
WFS Scintillation Error		10 nm	Alloc	0.97	0.98	0.99	0.99	0.99	1.00	1.00	1.00	1.00
	130 nm											
Uncorrectable Static Telescope Aberrations		43 nm	64 Acts	0.56	0.72	0.83	0.88	0.91	0.93	0.95	0.97	0.99
Uncorrectable Dynamic Telescope Aberrations		22 nm	Dekens Ph.D	0.86	0.92	0.95	0.97	0.98	0.98	0.99	0.99	1.00
Static WFS Zero-point Calibration Error		25 nm	Alloc	0.82	0.89	0.94	0.96	0.97	0.98	0.98	0.99	0.99
Dynamic WFS Zero-point Calibration Error		50 nm	Alloc	0.46	0.64	0.77	0.84	0.88	0.91	0.94	0.96	0.98
Leaky Integrator Zero-point Calibration Error		15 nm	Alloc									
Go-to Control Errors		43 nm	Alloc	0.56	0.71	0.82	0.88	0.91	0.93	0.95	0.97	0.98
Residual Na Layer Focus Change		20 nm	30 m/s Na layer vel	0.88	0.93	0.96	0.97	0.98	0.99	0.99	0.99	1.00
DM Finite Stroke Errors		0 nm	4.0 um P-P stroke	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
DM Hysteresis		13 nm	from TMT	0.95	0.97	0.98	0.99	0.99	0.99	1.00	1.00	1.00
High-Order Aliasing Error		14 nm	64 Subaps	0.94	0.97	0.98	0.99	0.99	0.99	1.00	1.00	1.00
DM Drive Digitization		1 nm	16 bits	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Uncorrectable AO System Aberrations		35 nm	Alloc	0.68	0.80	0.88	0.92	0.94	0.96	0.97	0.98	0.99
Uncorrectable Instrument Aberrations		32 nm	TBD Instrument	0.73	0.83	0.90	0.93	0.95	0.96	0.97	0.99	0.99
DM-to-lenslet Misregistration		15 nm	Alloc	0.93	0.96	0.98	0.98	0.99	0.99	0.99	1.00	1.00
DM-to-lenslet Pupil Scale Error		15 nm	Alloc	0.93	0.96	0.98	0.98	0.99	0.99	0.99	1.00	1.00
	105 nm											
Angular Anisoplanatism Error		52 nm	5 arcsec	0.43	0.61	0.76	0.83	0.87	0.91	0.93	0.96	0.98
Total High Order Wavefront Error	167 nm	**175 nm**	**High Order Strehl**	0.00	0.00	0.04	0.12	0.22	0.33	0.47	0.64	0.78

Tip/Tilt Errors	Sci Filter	Angular Error (rms)	Equivalent WFE (rms)	Parameter	Strehl ratios (%) u'	g'	r'	i'	Z	Y	J	H	K
Tilt Measurement Error (one-axis)		5.95 mas	98 nm	20.7 mag (mV)	0.24	0.35	0.48	0.58	0.66	0.72	0.79	0.87	0.92
Tilt Bandwidth Error (one-axis)		2.50 mas	42 nm	10.2 Hz	0.64	0.75	0.84	0.89	0.92	0.94	0.96	0.97	0.99
Tilt Anisoplanatism Error (one-axis)		6.90 mas	112 nm	87.3 arcsec	0.19	0.28	0.41	0.50	0.59	0.66	0.74	0.83	0.90
Residual Centroid Anisoplanatism		0.95 mas	16 nm	10 x reduction	0.92	0.95	0.97	0.98	0.99	0.99	0.99	1.00	1.00
Residual Atmospheric Dispersion	H	0.14 mas	3 nm	20 x reduction	0.45	0.59	0.94	0.98	1.00	1.00	1.00	1.00	1.00
Science Instrument Mechanical Drift		1.25 mas	36 nm	Alloc 0.25 mas / min	0.95	0.97	0.97	0.98	0.98	0.98	0.98	0.98	0.98
Long Exposure Field Rotation Errors		1.25 mas	36 nm	Alloc 0.25 mas / min	0.95	0.97	0.97	0.98	0.98	0.98	0.98	0.98	0.98
Residual Telescope Pointing Jitter (one-axis)		5.20 mas	86 nm	29 Hz input disturbance	0.29	0.41	0.55	0.64	0.71	0.77	0.83	0.90	0.94
Total Tip/Tilt Error (one-axis)		**11.0 mas**	181 nm	**Tip/Tilt Strehl**	0.07	0.12	0.18	0.25	0.32	0.39	0.48	0.61	0.74

Total Effective Wavefront Error	**251 nm**	**Total Strehl (%)**	0.00	0.00	0.01	0.03	0.07	0.13	0.23	0.39	0.58
		Spaxial Size (mas)	50	70	80	120	240	480	1000		280
Ensquared Energy	H		0.48	0.61	0.64	0.69	0.77	0.87	0.91		0.80

Sky Coverage Galactic Lat. 80 deg

Corresponding Sky Coverage **30.0%** This fraction of sky can be corrected to the Total Effective WFE shown

Assumptions / Parameters

r0	0.175 m	at this zenith	Wind Speed	9.99 m/s	Zenith Angle	18 deg			
Theta0_eff	2.68 arcsec	at this zenith	Outer Scale	50 m	HO WFS Rate	1603 Hz	SH	using	CCID56
Sodium Abund.	4 x 10^9	atoms/cm^2	LGS Ast. Rad.	1.18 arcmin	HO WFS Noise	2.1 e- rms			
Science Target:	MOAO				HOWFS anti-aliasing	NO			
LOWFS Target:	MOAO	Num TT 2	Num 3x3	0	LO WFS rate	256 Hz	SH	using	H2RG
LOWFS Star Type:	M	Num TTFA 1	Num HOWFS	0	LO WFS Noise	4.5 e- rms			
Max Exposure Time	300 sec				Max mechanical tip/tilt rejection bandwidth	50 Hz			

Cascaded Relay

- Preliminary design point choices (proposed)
  - LGS beacons
    - Science Asterism
      - Regular pentagon plus one central LGS
      - Variable radius from 11” to ~71” (TBD)
    - LOWFS NGS sharpening
      - ‘Point-and-shoot’
        - » One LGS pointed slightly (~11”) outside of NGS location for best tomography (TBC)
        - » 64 x 64 MEM’s DM in each LOWFS channel running MOAO (combination of science sexcunx and NGS LGS
      - Alternative is regular array of 9 beacons
        - » This forces degradation of on-axis tomography to sharpen LOWFS NGS
    - Center projected
    - Pulse format TBD
      - Options: CW, MM pulse, new format?
    - Number of lasers TBD
      - Return needed for science asterism is equivalent to ~90W of SOR CW return (6 x ~15 W in lab)
      - NGS LGS need ~ 15W on sky each (e.g. another 45 W, so 90+45 = 135W total in lab).
      - Degradation with lesser power TBD
    - No uplink compensation
      - But not precluded as future upgrade

Cascaded Relay

- Preliminary design point choices (proposed)
  - BTO
    - Design choice TBD
    - Maximizing transmission is paramount
      - Each 10% transmission loss requires = 13.5 W lost ~ $1.5M
  - LGS HOWFS
    - Radially scaling object selection mechanism (OSM)
    - Zoom optics for LGS aberration correction
    - Independent 'z-stage' for focus tracking (and asterism plane tilt changes)
    - Detector configuration TBD
      - Options: Square geometry, Radial geometry
      - Max rate, read noise, dark current, diffusion specs all TBC
  - NGS HOWFS
    - NGS requirements not well defined
  - Aircraft, Satellite, and Beam Collision Avoidance (not error budget flowdown)
    - Requirements not written down, but may be similar to Keck AO
    - Issues
      - Reuse of Keck AO subsystems, shared resources with Gemini, Subaru?

Cascaded Relay

- Preliminary design point choices (proposed)
  - NGS LOWFS
    - 2 IR TT trackers + 1 TTFA pyramid sensor
      - Diffraction-limited
        - » 32 x 32 MEMS DM in each channel
      - As much of Y+J+H band as possible (e.g. not being used for science)
      - One TT possibility is Hawaii RG in ROI mode with 0.05 arcsec/pixel
        - » Array detector provides self-acquisition for each (faint) NGS)
    - Alternatives
      - 1 TTFA SH sensor in lieu of TTFA pyramid sensor (TBC)
      - IR APD quad-cells (custom) in lieu of array trackers
        - » Transfer the ACQ problem elsewhere
    - Likely to need detailed physical optics modeling
  - Truth WFS
    - Visible light 6x6 SH WFS
      - Single stand-alone sensor
      - Alternative: Might be an On-Instrument WFS (OIWFS) internal to each instrument (?)
    - Alternatives
      - Low-order curvature or phase diversity techniques
      - NIR 6x6 SH WFS

Cascaded Relay

- Preliminary design point choices (proposed)
  - RTC
    - Requirements TBD
      - Rate, latency, matrix sizes and update rates, servo algorithms, and telemetry req's all TBD
    - Algorithm issues
      - Woofer / tweeter control
      - Robustness to WFS pupil misalignments (strong goal)
      - Upgrade path to MCAO?
        - » Algorithms or algorithms & hardware?
  - PSF estimation pipeline
    - We baseline a dedicated NGAO MASS/DIMM for $C_n^2(h,t)$ measurement
    - Other requirements TBD
    - Issues
      - Development of real astrometry and/or photometry error budgets?
  - Supervisory software (not error budget flowdown)
    - Requirements TBD
    - Issues
      - Extent of practical reuse of Keck AO software unknown
      - Telescope and Instrument interface changes may preclude reuse