Keck NGAO

Systems Engineering Status 2007 Mar 07

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Systems Engineering Status

- Overview
  - Performance Budgets
  - Trade Studies
  - System Architecture
- Updates from Performance Budget Teams

Performance Budgets

- Overall ~50% complete
  - Good progress on
    - Refining WFE budget & high-contrast budget tools
    - Identifying photometric, astrometric, and polarimetric drivers
      - Some IPT's investigating limiting factors using real Keck data (not yet understood)
      - Will have to draw a line and write these reports 'as are'
    - Understanding current limits to observing efficiency / uptime
  - Need to improve
    - Documentation efficiency
      - Only draft report to date: photometric precision
    - Some progress being limited by inter-project dependencies
      - E.g. Not having definitive observing scenarios, instrument requirements, etc.

Trade Studies

- Overall ~30% complete
- Good progress on
  - Digging into difficult technical issues
  - Collecting and understanding previous analyses
  - Teamwork
- Need to improve
  - Setting priorities
    - Spirit of the SD phase was to pass through *all* major issues (as understood in Aug 2006) in a timely fashion to identify the major drivers
      - Then, based on a preliminary architecture downselect, revisit the important issues in more detail
      - Iterate with the science team
    - Several TS's have gone 5x their budgeted scope
  - Documentation efficiency
    - More report drafts; more comments

System Architecture

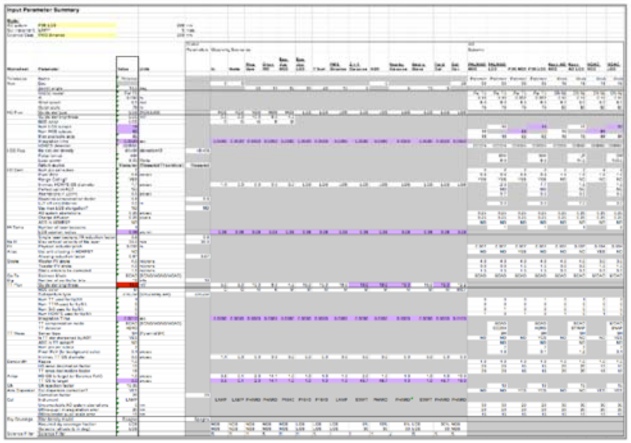
- Initial ideas being explored in several activities
  - 3.1.1 Performance Budget - update today (R. Dekany)
  - 3.1.2.1.1 MOAO v. MCAO - update today (D. Gavel)
  - 3.1.2.1.2 NGAO vs. Keck Upgrades - update today (P. Wizinowich)
  - 3.1.2.1.3 AM2
  - 3.1.2.1.4 K & L Band Science
  - 3.1.2.1.5 Keck Interferometer Support - update today (C. Neyman)
  - 3.1.2.1.6 Instrument Balance
  - 3.1.2.1.7 GLAO for non-NGAO - update today (R. Flicker)
  - 3.1.2.1.8 Instrument Reuse
  - 3.1.2.2.2 Optical Relay - update today (B. Bauman)
  - 3.1.2.2.3 Field Rotation Strategy - update today (B. Bauman)

- Synthesis methodology pending WBS 3.1.3 Work Scope Planning Sheet (R. Dekany)
  - Goal is adoption of NGAO Baseline Architecture at July 2007 NGAO retreat

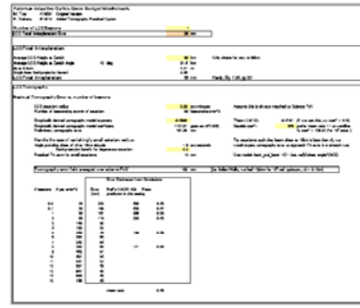
Wavefront Error and Ensquared Energy IPT Status

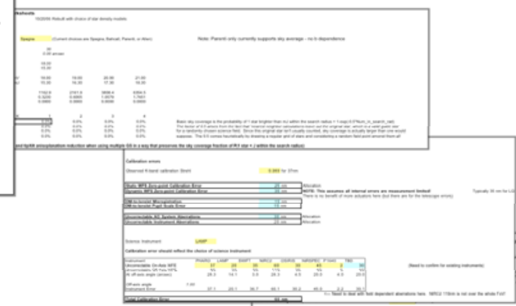
Richard Dekany (IPT Lead)
Don Gavel, Ralf Flicker, Claire Max,
Peter Wizinowich

Wavefront Error Budget

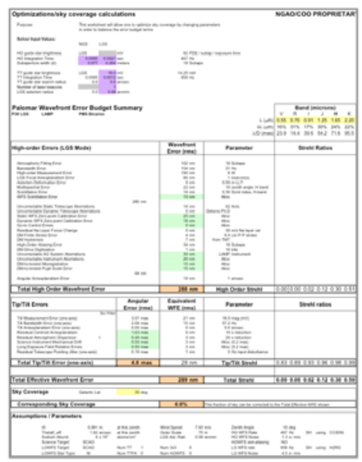


Input AO System and Observing Scenarios

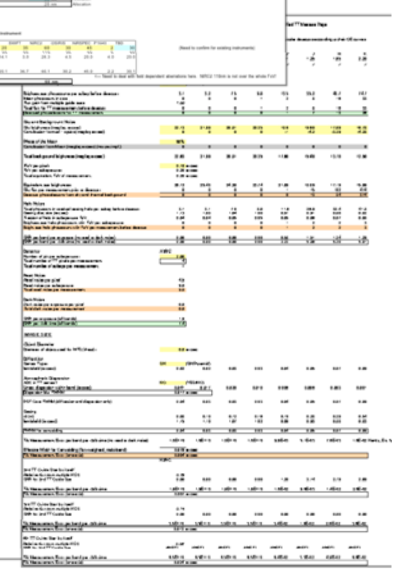


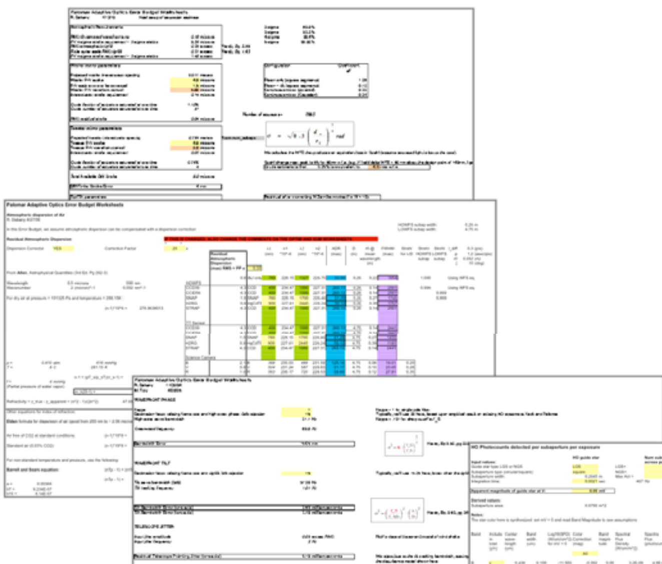


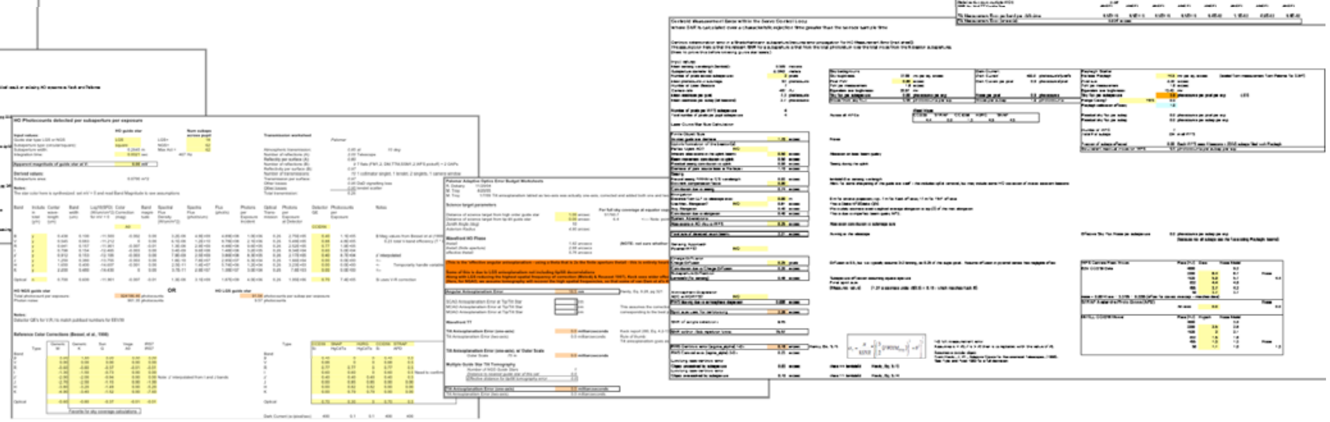
30+ Supporting Technical Worksheets



Error Budget Summary







Improvements tracked using 'punch list'

(about 30 implemented since 1/16/07)

Major items:

Observing scenarios
Improved Rayleigh contamination model
Measured LGS return
Better SNR model through servo loop
Benefit of single-laser tomography
Separate transmission models for Keck AO and Keck NGAO (LGS & NGS)
Truth WFS now has own bandwidth
Total WFE now calc directly from HO+TT Strehl

Topic	Worksheet Name	Inputs	Outputs	To Do	Comments
Input Summary	Input Summary	This sheet collects the major system parameters for several AO systems and many key observing scenarios	Many outputs are linked to the Optimization worksheet		
Optimization	Optim	Results wavelengths WFS integration times TT guide star search radius LGS asterism radius	RMS WFS Strehl ratio TT errors Sky coverage Assumptions and parameters Publishable summary table	Add MCAO blind mode error terms to spreadsheet Add TT multispectral error Add generalized anisoplanatism to handle MCAO architectures	
Telescope	Tel	Telescope name (some values are picked up from this) Telescope diameter Obscuration diameter (equivalent circular obscuration) Focal ratio Static aberration information Dynamic aberration information	Uncorrectable static errors Uncorrectable dynamic errors	Check Keck equivalent circular obscuration value For uncorrectable telescope errors, the number of available actuators is currently being drawn from the HO Flux page, but this link isn't obvious - should probably separate num acts (Fitting?) and num subaps (HO Flux)	
• Atmosphere	Atm	Cn^2(h) model Wind model r0 Turbulence-weighted wind Outer scale Atmospheric pressure model Atmospheric extinction model Zenith angle of observation	Theta0 Theta0 (finite aperture) Greenwood frequency tau0 Tilt isoplanatic angle Tilt tracking frequency d0 (Hardy) d0 (KAON 208) Scintillation index Effective turbulence height Global one-axis tilt Peak tilt	Currently atmospheric extinction is monochromatic, based on UKIRT data - update to have spectral information from various sites (if available) Obtain better(?) estimates of outer scale from various sites (at least document source of assumed values).	
High order WFS Flux	HO Flux	Guide star type (NGS/LGS) Subaperture geometry (square/circ) Subaperture width Integration time Apparent mag of GS (mV) Choice of spectral bands Transmission model QE model	Subaperture area Photodetections per subap per exposure Shot noise	Add ADC transmission losses where appropriate (should this be per AO system mode or by Observing scenario?)	
LGS Return Flux	LGS Flux	Laser power Laser pulse format Transmission model Slope efficiencies Na density Measured vs. Theoretical return estimates	Transmitted power Na layer distance Delivered power Na return flux per subap per exposure time	Need to include saturation effects in the theoretical photoreturn estimates for different pulse formats	
High order Centroiding Error	HO Cent	Sensing wavelength Pixel sampling per subap Intrinsic GS diameter LGS beam aberrations Uplink correction? Rayleigh gating? Off-axis launch distance Sensor type (SH/Pyr) Downlink residual aberrations Charge diffusion CCD read noise model Sky background flux Dark current model Rayleigh scatter model	Total number of pixels per measurement Max LGS elongation Mean LGS elongation Delivered Na spot size WFS optical spot size Subap diffraction Spot size for centroiding SNR of detection RMS centroid error	Verify values in Rayleigh scatter model Consider the impact on PSF shape arising from DM saturation (the effect is not simply to scatter light our of the core) Need to include SNR reduction due to fratricide in CW multi-laser scenario - start with single value global degradation (modal analysis will have to come from all-in simulations.) Add 'no elongation' option to model tracking of short-pulse lasers (with or without uplink AO) Add techniques for handling other centroiding algorithms (e.g. matched filters), not just the Hardy 5.14 implementation	
High order Measurement Error	HO Meas	Error propagator model (Hardy)	Estimate of measurement error		
Focal Anisoplanatism / Tomography Error	FA Tomog	Number of LGS beacons LGS height at zenith Model of Tomography error based on simulations Special case of small quincunx? (Yes/No)	Estimate of focal anisoplanatism error for 1 LGS beacon, or tomography error for multiple beacons	Update tomography error using Ralf's latest values Only valid beam height currently is 90km - need to make dependent upon zenith angle Small quincunx case is probably now superceded by more detailed results	
Asterism Deformation Error	Ast Def	Vertical velocity model for the Earth's sodium layer	Physical focus shift P-V nm of focus shift RMS tilt difference between uplink and down beams Estimate of wavefront error due to asterism deformation		
Sodium Layer Height Focus Error	Na H	Model of focus correction factor coming from LOWFS or Slow WFS	Estimate of error due to unpredictable Na layer height	Make LOWFS or Slow WFS distinct options	
Fitting Error	Fit	Fitting error coefficient, aF	Approximate total number of actuators Estimate of fitting error	See To Do item under 'Tel' worksheet Note, multiple LGS can in theory better sample the atmosphere than the 'classical' fitting error - consider dividing into sampling error and DM fitting error	

Latest NGAO wavefront error estimates

Science Target	Guide Star Mag (mV)	HO Err (nm)	TT Err (mas)	Total Err (nm)	N_subap_ optimal	Band	Strehl
Io	5	119	2.1	121	64	R	31%
Vesta	8	134	2.9	139	47	R	21%
Exo Jup NGS	8	136	2.6	139	51	H	75%
Mira Vars	10	170	3.8	177	33	H	62%
Orion IMF	13	338	7.8	351	15	K	34%
Gal Cen	12.2 @ 5.5"	258	1.7	258	64	K	58%
Exo Jup LGS	13 on-axis	146	1.5	147	64	H	73%
T Tauri	15 on-axis	149	1.5	150	64	K	83%
Debris Disks	16 on-axis	146	1.7	146	64	R	18%
Quasar Host Galaxies	19 on-axis	146	12.8	157	64	H	44%
KBO	10% sky (18 @ 60")	146	9.6	208	64	H	53%
Extended Groth Strip	30% sky (19 @ 75")	188	46.0	505	64	K	75% / 12%

- Many parameters set by observing scenario
  - Zenith angle
  - Guide star brightness *and color*
  - Required sky coverage
- Global Assumptions:
  - Median r_0 = 18 cm
    - Turbulence-weighted wind speed = 8 m/s
    - CN N2 $C_n^2(h)$ model
    - 50 m outer scale

- Sodium laser guide star FWHM = 1.47 arcsec
  - *150 W CW w/ measured SOR return*
  - 4 x 10^9 atoms/cm^2 abundance
  - Transmission to WFS ~23%
  - Single laser tomography FA reduction = 0.8
- Vis HOWFS
  - CCID56
    - 2.4 e- read noise (max; varies)
  - 4 x 4 pixels per subaperture
  - 6.4 arcsec diam field stop
  - *Optimize for N_{subaps}*
  - *Optimize for $t_{integration}$*

- IR TT sensors (x2) + IR TTFA (x1)
  - Distinction of TTFA v. TT *not* made
  - H2RG
    - MOAO compensated IR guide stars
    - 4.5e- IR read noise (fixed)
  - 2 x 2 pixels per subaperture
  - 0.1 x 0.1 arcsec field stop
  - *Measured NIRC2 thermal background*
  - ADC in sensor
  - *Optimize for off-axis TT guide star distance*
- Vis TWFS sensor
  - CCD39

Transmission & Emissivity

SEE PRESENTATION BY A. BOUCHEZ

Antonin Bouchez (IPT Lead)
Brian Bauman, Richard Dekany

Photometric Precision IPT Status

Matthew Britton (IPT Lead)
Richard Dekany, Ralf Flicker, Knut Olsen

Photometric Precision

- Matthew Britton posted v0.2 of the IPT technical report
  - February 15, 2007
    - 22 pages contains technical descriptions of key drivers
  - Awaiting comments from the IPT, including details from L. Olsen
  - Excellent collection of references
    - PSF estimation
    - PSF reconstruction and star-finding codes

- Concise numerical tool for rapid re-evaluation of quantitative precision budget proving elusive
  - Likely to rely on systems engineering team understanding content of this report

Astrometric Accuracy IPT Status

Brian Cameron (IPT Lead)
Matthew Britton, Richard Dekany, Andrea Ghez,
Jessica Lu

Astrometric Accuracy

- Brian Cameron at Keck this week
  - Working on distortion solutions and NIRC2 characterization with Keck staff
- Jessica Lu, et al., cranking away on Gal Cen data
  - Rank order of limitations to astrometric accuracy not yet settled
  - No obvious NGAO design drivers yet identified except:
    - Better Strehl and Strehl stability are good in crowded fields
    - The most sensitive TT sensors probably allow most flexibility for crafting strategies that minimize tip/tilt anisoplanatism over moderate FoV's
  - Will remain research area for periods long relative to SD Phase
- Concise numerical tool for rapid re-evaluation of quantitative precision budget proving elusive
  - Likely to rely on systems engineering team understanding content of the astrometric accuracy technical report

High-Contrast IPT Status

Ralf Flicker (IPT Lead)
Richard Dekany, Mike Liu, Bruce Macintosh, Chris Neyman

Companion Sensitivity

- IPT members: R. Dekany, R. Flicker (lead), M. Liu, B. Macintosh, C. Neyman
- Status of work:
  - Have initial performance budget spread sheet tool
  - Still needs improvement in a few areas
    - segment aberration/vibration PSD's, LGS specific errors, coronagraph details
  - Draft report in embryonic state
    - most of the mathematical analysis, some technical description, written up
    - science & observing scenarios, method description, results (etc) yet to be written

	Speckle time (sec)	PSF intensity Normalized peak=1	Photon noise	Long-exposure speckle noise	Post-SSDI speckle noise	SSDI factor
Atmosphere fitting error	0.4	2.2E-11	3.00E-09	3.2E-13	1.6E-13	2
Aliasing error	0.4	3.9E-05	4.04E-06	5.8E-07	2.9E-07	2
WFS measurement	0.01	3.6E-05	3.90E-06	8.6E-08	4.3E-08	2
Servo lag	0.4	4.4E-05	4.30E-06	6.6E-07	3.3E-07	2
Tomography	0.4	3.2E-05	3.65E-06	4.7E-07	2.4E-07	2
Calibration and static errors	600	4.8E-06	1.42E-06	2.8E-06	5.6E-07	**5**
LGS quasi-static errors	600	4.1E-05	4.15E-06	2.4E-05	1.2E-05	2
Telescope	600	2.6E-05	3.30E-06	1.5E-05	7.5E-06	2
Total		2.2E-04	9.67E-06	4.3E-05	2.1E-05	
Total speckle+photon final contrast					2.30E-05	

Sample (typical) contrast performance budget

Polarimetric Accuracy IPT Status

Mike Ireland (IPT Lead)
Richard Dekany

Polarimetric Accuracy Performance Budget

- Key science metric is polarimetric accuracy as a function of distance from the PSF core
  - E.g. 10^{-4} at 100 mas means the ability to detect a blob of dust 100 mas from a central source at 10-σ that scatters 1% of the incident radiation with 10% fractional polarization.
- Two different kinds of performance budgets, depending on polarimeter architecture
  - "Back-end" polarimeter
    - The entire polarimetry instrument is behind the entire NGAO system.
  - "Split" polarimeter
    - The polarization is modulated by an element (waveplate or variable retarder) downstream of only the primary, secondary and tertiary mirrors.

Polarimetric Accuracy Performance Budget

- "Back-end" polarimeter budget :
  - How does the differential wavefront between different polarization states translate to a difference in PSF between polarization states?
    - Differential wavefront error is due primarily to reflections off flat optics in converging beams and is mainly astigmatic.
    - With no (quasi-) static aberrations, a pure astigmatism differential aberration translates to zero PSF difference. The PSF difference is dominated by a cross-term that is linearly proportional to (quasi-) static aberrations and linearly proportional to the differential wavefront
      - E.g. 0.1 radians static astigmatism and 0.1 radians differential wavefront gives PSF difference which is 10^{-2} of the diffraction-limited PSF: better than10^{-4} at 2nd Airy ring or beyond. Math to come in report…
  - At what level can an observer calibrate the PSF difference using a standard star and how does this relate to quasi-static aberrations?
    - It is difficult (impossible?) to completely correct for static aberrations if a standard star is observed after a K-mirror rotation or telescope elevation change.
      - Obviously, quasi-static aberrations that change between observations can not be corrected.
- "Split" polarimeter budget:
  - More complex
  - Will only be examined if the "back-end" budget can not deliver adequate performance for primary science goals.