Performance Budget Development

Team Meeting #2

Caltech
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NGAO Observing Modes

- Proposed definitions
  - An observing mode is a particular choice of AO and instrument settings selected to optimize a kind of science observation
    - Examples could include
      - Deployable faint-object spectroscopy; Contiguous-field astrometry; High-contrast; Polarimetry
    - Different observing modes are usually characterized by different division of collected light, both spatially and spectrally, into arms feeding different photosensors
  - A system configuration is the snapshot of all system operational parameters and subsystems states
    - Examples could include
      - Non-sidereal target / bright star appulse with HO WFS'ing using the appulse star, LO WFS'ing using the target, automatic reconstruction generation, active HO gain curve measurement, full telemetry recording, medium IFU spaxial scale, Fowler-8 readout, etc.
    - Different configurations are usually characterized by different active control loops and diagnostics states.

NGAO Wavefront Sensing Modes

- Guide star modes
  - Fast high-order guide star
    - Visible NGS, Sodium LGS, IR NGS (goal)
  - Fast low-order guide star
    - IR NGS, Visible NGS (goal, if WFE ~ 170nm or better)
  - Slow high-order guide star
    - Visible NGS
- LGS Projection modes
  - Narrow-field optimized
  - Wide-field optimized

Performance Budget (PB) Integrated Product Team (IPT) common goals

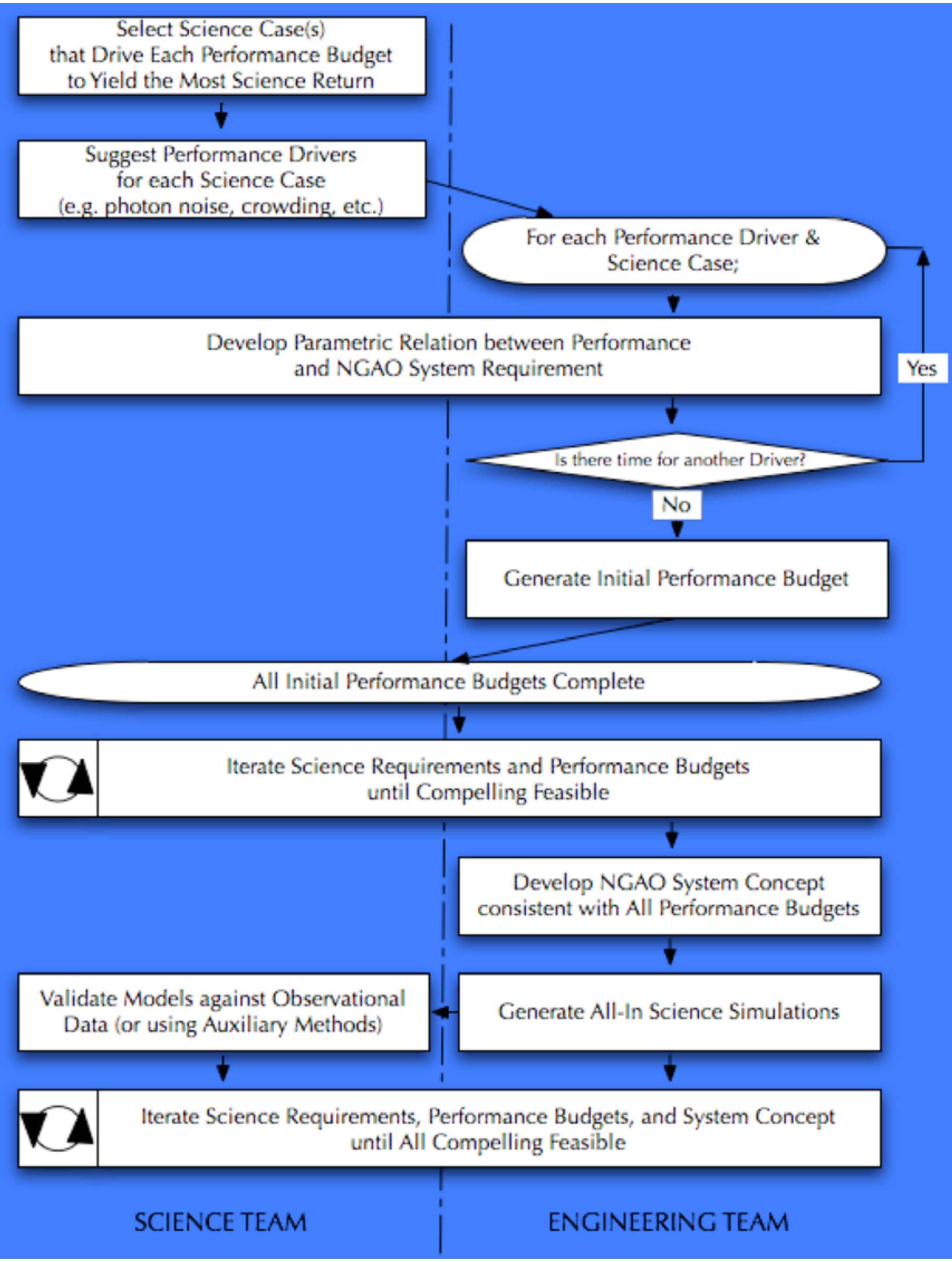
- Produce a technical report
  - Describing the major PB drivers, including experimentally supportive information, quantitative background, and potential simulation results
- Produce a numerical engineering tool to support future design iterations
  - Emphasizing abstracted quantitative scaling laws and interdependencies (if unavoidable.)
    - Based upon Excel file template or utilizing existing tools
    - Traceable to, but independent of, any Monte Carlo simulation, covariance code, or similar machinery.
- Support science requirements development
  - Capturing the experience of the science team and reflecting quantitative underpinning to current limitations

PB IPT common assumptions

- Common model assumptions captured in performance budget spreadsheet template (to be posted to TWiki)
  - Telescope parameters
  - Photometric Band definitions
  - Atmospheric turbulence model
  - Meteorology model
  - Detector model
- Notional NGAO performance estimates from June ‘06 proposal
  - Estimates to be augmented and updated as part of the WFE PB IPT (due Jan 22, 2007)

Keck NGAO

NGAO SD Phase:
Science Requirements & Performance Budget Process



Performance Budget (PB) Integrated Product Team (IPT) Overview

Team	Status	Notes
Astrometric Accuracy	Initiated	240 hr, Very active research area
Background and Sensitivity	Initiated	82 hr, Combine due to small time allocation
Encircled Energy	To convene 12/06	110 hr
High-Contrast	To convene 11/21/06	240 hr, Mature tools available
Photometric Precision	Initiated	240 hr, Active research area
Polarimetric Precision	Initiated	40 hr
Wavefront Error	Initiated	110 hr
Observing Efficiency	Initiated	100 hr; possibly combine w/ Uptime?
System Uptime	Initiated	80 hr

Photometric Precision

- Science cases
  - Photometry in disks and bulges of high-z galaxies
    - Claire to provide Observing Scenario for TM #3
  - Stellar populations in crowded fields
    - Knut to provide Observing Scenario for TM #3
- Key Drivers for initial Budget
  - Crowding
    - Knut to parameterize
  - Sky background
  - Photon noise
    - Rich to parameterize
- Both science cases are limited by imperfect knowledge of the system PSF
    - Claire to comment on the relevant time scales for PSF estimation
- The IPT agreed to divide the problem into two flavors
  - Determining the on-axis PSF
  - Determining the off-axis PSF

Sources of PSF Knowledge

	On-axis	Off-axis
Data-based ↑ ↓ Model-based	Direct measurement of isolated point source [e.g. de Pater] Calibration star PSF [many examples] ADI (Telescope Roll) [e.g. Marois] AO system telemetry [e.g. Veran]	Calibration star cluster PSF [e.g. Steinbring] Dedicated concurrent PSF camera [e.g. COO TMT IRMOS concept] Self-consistent solution of multiple sources [e.g. Christou, *StarFinder*] Auxiliary information from $C_n^2(h)$ [e.g. Britton]

Determining the on-axis PSF

- Techniques
  - Use the PSF of an on-axis star in the science field
    - – Ultimately limited by SNR or sampling
  - Estimate the science PSF from a self-consistent solution among many (supposed) point sources in the science field
    - – Ultimately limited by SNR
  - Estimate the science PSF from a similar isolated PSF calibration star
    - – Limits are based on atmospheric stability between calibrations
  - Estimate the science PSF from AO system telemetry
    - Chris N. to canvass practitioners for current limitations

Determining the off-axis PSF

- Techniques
  - Estimate the science PSF from a self-consistent solution among many (supposed) point sources in the science field
    - Two common techniques
      - Local techniques solve for PSF independently in each local subregion of an observation (e.g. Christou, Drummond, *StarFinder)*
      - Global solutions solve for PSF based upon some overall model for anisoplanatic fall-off (e.g. Britton, Cameron, Diolaiti
    - Ultimately limited by SNR
  - Dedicate a PSF monitoring camera, which could raster among field points during deep exposures (TMT IRMOS concept)
      - Rich to advise Instrument WG of such desirability
  - Assume knowledge of the on-axis PSF (measured or estimated); Augment off-axis model using auxiliary concurrent $C_n^2(h)$ measurements
      - Matt to evaluate how imperfect knowledge of $C_n^2(h)$ maps into PSF uncertainties

Astrometric Accuracy

- Science cases
  - Astrometry of the Galactic Center
    - Jessica to provide Observing Scenario for TM #3
  - Faint target astrometric in isolated fields
    - Brian to provide Observing Scenario for TM #3
- Key Drivers for initial Budget
  - Atmospheric tilt anisoplanatism
    - Matt to parameterize
  - Imperfect knowledge of geometric distortions
    - Jessica to consider time variability
  - Stellar Confusion
    - Andrea to study via parametric simulations for differing WFE (provided by Chris) - TBC
  - SNR for isolated stars
    - Brian to parameterize and confirm precision based on SNR and PSF FWHM
  - Differential atmospheric refraction (as well as achromatic refraction)
    - Brian to consider limits to calibration (e.g. meteorological calibrations)

Wavefront Error and Encircled Energy

- Science Cases
  - Maintain all cases from the June ‘06 NGAO proposal
      - Rich to confirm parameters with Science Team
- Key Drivers for initial Budget
  - Uncertainty in tomographic reconstruction error
      - Modeling tool validation IPT to investigate
      - Don to validate in LAO testbed
  - Uncertainty in sodium laser photoreturn from the mesosphere
    - Per delivered Watt, as a function of different pulse formats
    - Requires 50W class lasers to investigate non-linear optical pumping effects
      - Mitigation plan TBD
  - Uncertainty in multi-NGS tilt tomography efficacy
    - Not included in original budget development
      - Mitigation plan TBD

Sensitivity Budget

- Primary drivers (ignoring thermal background):
  - Local background and noise sources
    - Optical metrology systems and optical encoders.
    - All sources of electronic noise in science detectors (issue typically handed off to instruments, but should be considered.)
  - Variable transmission vs. field position.
    - K mirror near a focal plane.
    - Beam wander on tertiary mirror.
  - Architecture decisions determine the number of surfaces.
    - Adaptive secondary vs. pupil relay.
    - Inclusion of a K mirror.
    - Inclusion on an ADC in the science path.
    - Wavelength splitting architecture.
  - Optimized coatings become more difficult and expensive as bandpass increases.

Thermal Background Budget

- Primary drivers
  - Minimizing number of surfaces becomes crucial for reducing the thermal background.
    - Adaptive secondary vs. pupil relay.
    - Inclusion of a K mirror.
    - Inclusion on an ADC in the science path.
    - Wavelength splitting architecture (dichroics reflecting warm surfaces.)
  - Optimized coatings become more difficult and expensive as bandpass increases.
  - Reducing the temperature of the most emissive optics (pupil relay and beams splitters) has expensive repercussions.
    - Access becomes more difficult.
    - Humidity control is crucial.
    - PZT and PNM hysteresis increases.

Architecture and Technology Drivers for Polarimetry

- The key technology drivers for high-contrast imaging polarimetry are instrumental
  - Need rapid polarization modulation (e.g. with a Liquid-Crystal Variable Retarder)
  - Need simultaneous channels (e.g. by using a Wollaston prism).
- Imaging polarimetry is different from absolute polarimetry
  - It is OK to polarize the entire field (e.g. by a 60 degree AOI mirror in a collimated beam) and calibrate later.
- A Nasmyth focus is certainly possible if the instrument rotates (e.g. VLT http://www.eso.org/projects/vlt/unit-tel/nasmyth.html)
- A K-mirror in a converging beam likely kills any kind of precision polarimetry mode
  - PSF's will be different enough in orthogonal polarization states. A way around this is an LCVR placed before the K-mirror - but readily available LCVR's only go to 1.6” clear-aperture…

Architecture and Technology Drivers for Thermal Background Budget

Primary drivers

1. Minimizing number of surfaces becomes crucial for reducing the thermal background.
   - Adaptive secondary vs. pupil relay.
   - Inclusion of a K mirror.
   - Inclusion on an ADC in the science path.
   - Wavelength splitting architecture (dichroics reflecting warm surfaces.)
2. Optimized coatings become more difficult and expensive as bandpass increases.
3. Reducing the temperature of the most emissive optics (pupil relay and beams splitters) has expensive repercussions.
   - Access becomes more difficult.
   - Humidity control is crucial.
   - PZT and PNM hysteresis increases.

High-Contrast Budget

- Science Cases
  - TBD (but likely…)
    - Planets around low-mass stars and brown dwarfs
    - Debris disks, protostellar envelopes and outflows
- Key Drivers for initial Budget
  - TBD (Many, but dependent on Science Requirements and specific coronagraphy / nulling technique)
    - Known biggies may include
      - Static, uncalibrated telescope and NGAO wavefront errors
      - Residual tip/tilt jitter
      - Chromatism and other non-common-path chromatic effects
- Mature contrast estimation tools have been previously developed for Keck high-contrast scenarios

Observing efficiency for NGAO

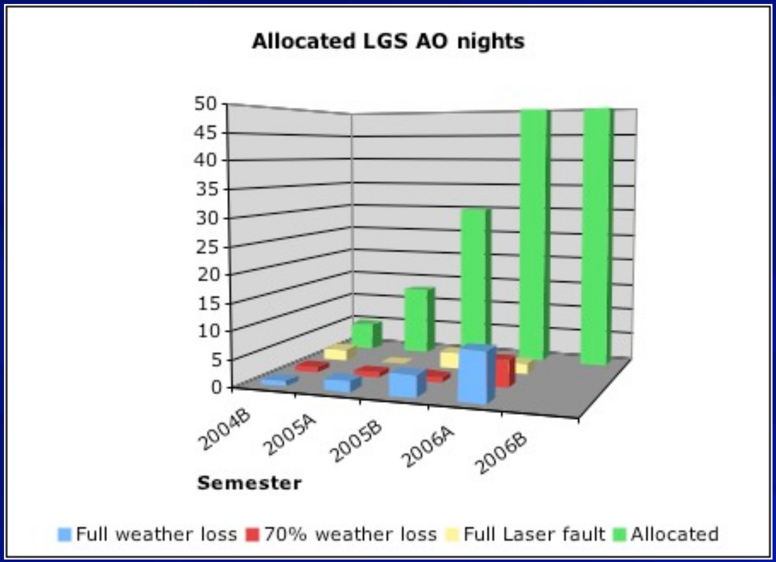
1. Definitions
2. Lessons learned
   a) Keck LGS AO “efficiency”
   b) Keck AO brute conclusion
3. Observing efficiency *budget*
4. Observing efficiency *work plan*

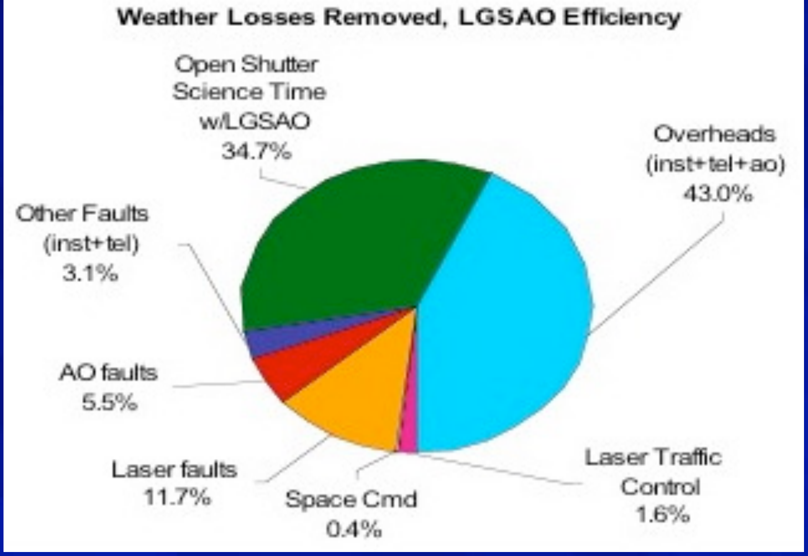
Definitions for <u>Observing Efficiency</u>

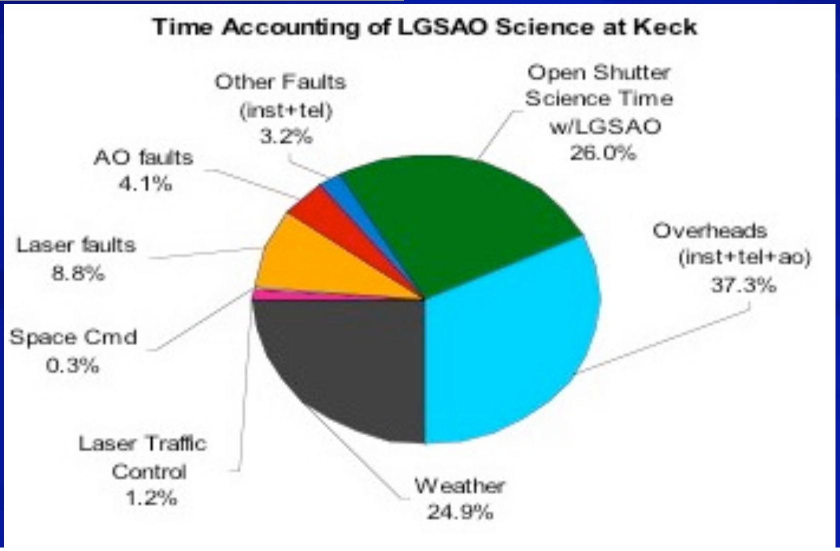
(what are we talking about?)

- Currently
  - Science instrument open shutter time during dark time, including science data and calibrations (sky, telluric, photometric, PSF, astrometry, wavelength) / dark time
    - Does not take into account any metric science-data quality -> very difficult to understand how “observing efficient” an instrument is.
- A future definition for NGAO?
  - Science instrument open shutter(s) time during dark time delivering science-quality data
    - Each data set is flagged with a science-quality idx
    - Good understanding of the “observing efficiency” for each type of science

101 nights of Keck II LGS AO ops since Nov. 04 till Jul. 06

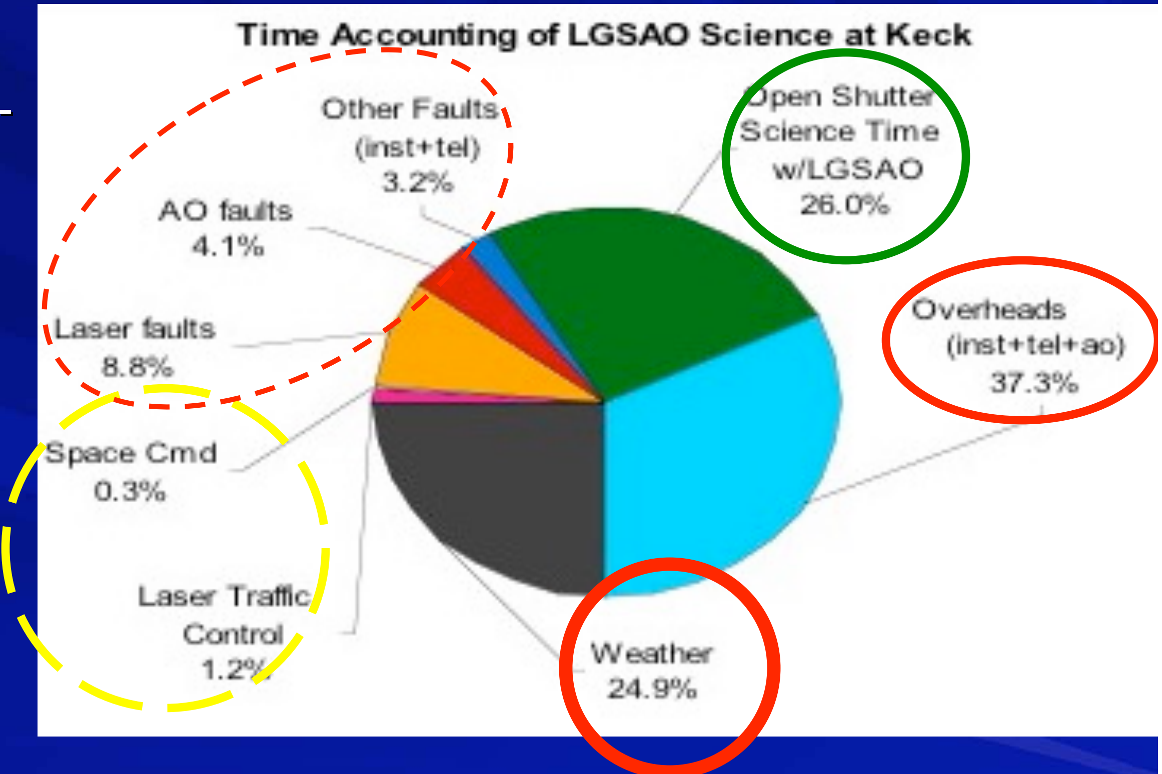




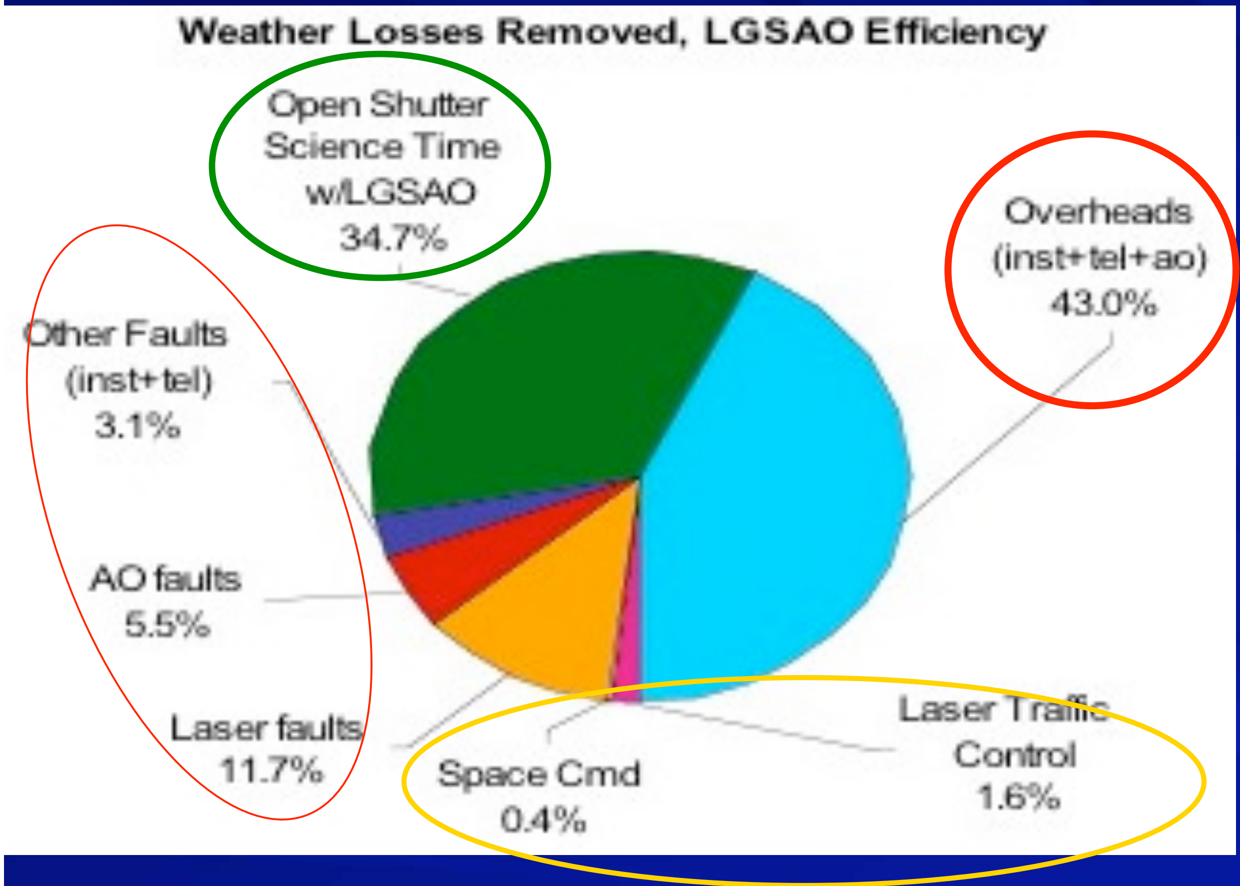


Overall Efficiency: **101 nights**

- Bad weather impact:
  - a) ~17% nights dome closed - winter weather
  - b) ~21% nights impacted by marginal weather
- Laser faults
  - a) Lost: 2 full and 5 1/2-nights
  - b) 9 nights with ~ 1h lost
- AO faults
  - – Minor time lost yet present for 50% of nights
- Laser Traffic
  - ~ 2% impact
- Overheads
  - – A BIG chunk!



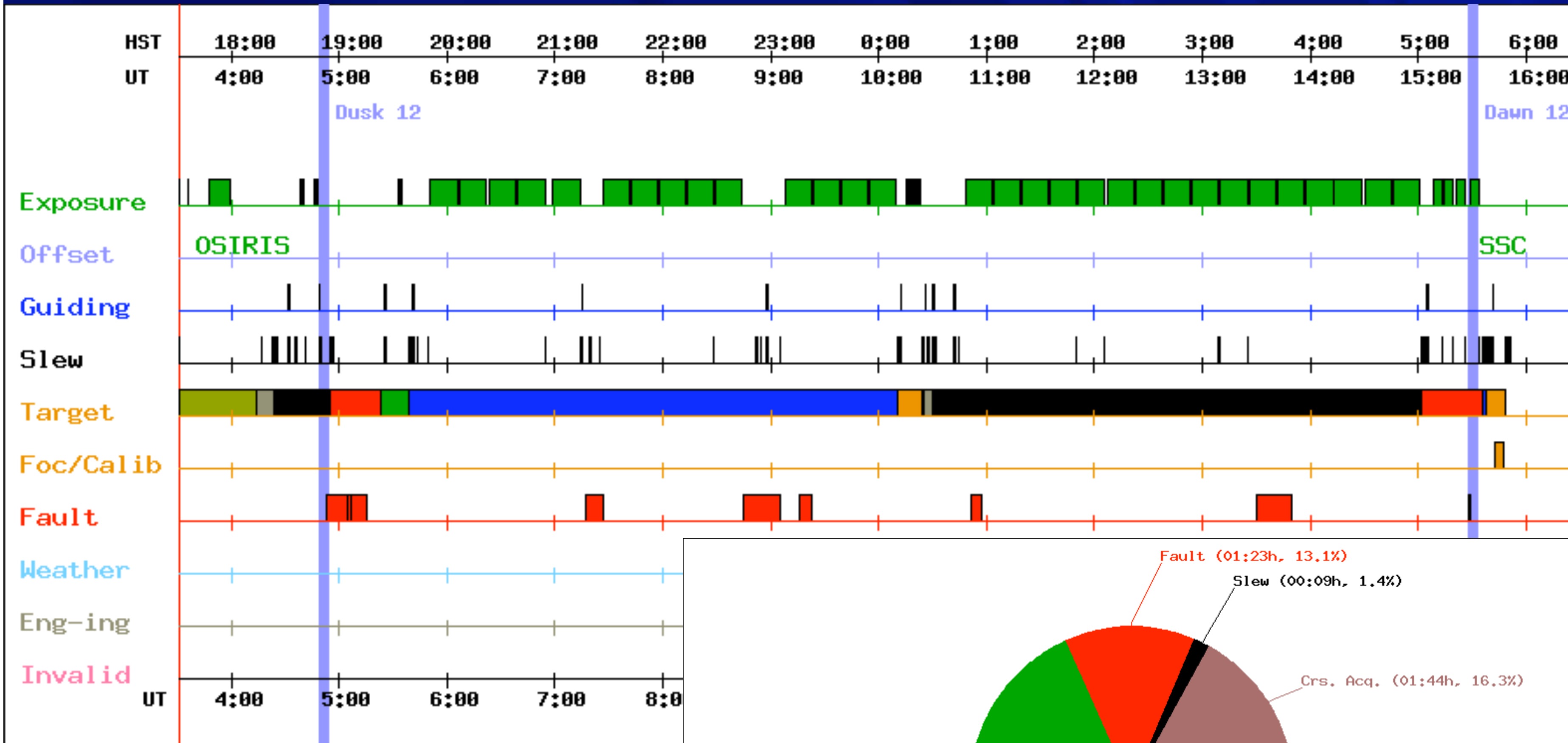
Overall Efficiency: overheads

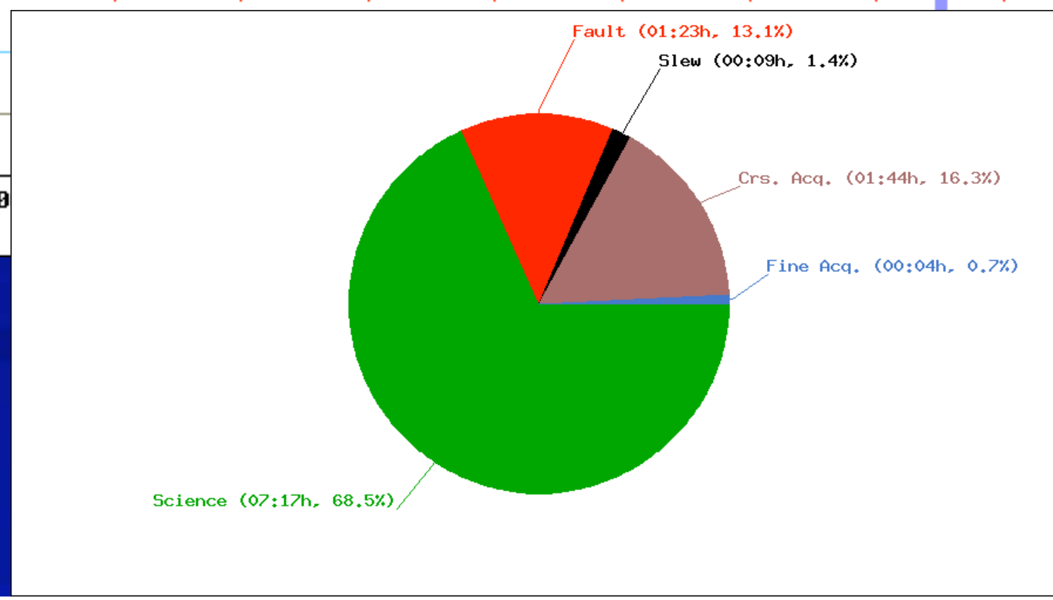


1. LGS AO checkout 30min/night ✔
2. Telescope slew and pointing ✔
3. Target ID and centering
4. LGS AO readiness 5 - 10 min/target
5. LGS AO optimization 2min per hour on target
6. Telescope/AO handshakes ✔ 30+ sec per dither
7. Scientific instrument setup and readout ✔ Observing strategy

Ref: 2006 SPIE papers and some Keck internal discussion for K1 LGS AO

Efficiency example: OSIRIS





Lessons learned

- Keck NGSAO observing efficiency for nights w/o weather or technical problems *at best* vary from 25% (snapshot surveys, Lp and Ms obs) to 60-80% for deep-exposure science programs.
- LGSAO shows roughly the same values, except that it is *more* impacted by weather and technical problems

DLM's conclusions: For a reliable system in good weather conditions, we are currently mostly limited by

1. Serial (vs parallel) algorithms (DCS /inst/AO) during observations
2. Under-designed telescope pointing and acquisition systems
3. Under-designed AO nodding/dithering hardware and software
4. Under-designed science instrument readout

Observing efficiency *budget*

- Built for each science use case
  - Include all observing steps: target acquisition, ID & centering; dithering; science readout and reductions; dithering; command parsing and decision making process; calibrations; etc
- Should assume a 100% core hardware/software reliability? Why separate Uptime and Obs. Efficiency?
- Should look into other lost-time statistics (weather, technical, laser traffic)
- Should look into benefits of:
  - Observing planning GUI and simulation tools
  - Calibration units and auxiliary systems/data during observing (seeing, photometry, air-glow monitoring?)
  - Other possible impact on science-quality data (cirrus, centering stability)
  - System monitoring and recovery to optimize system uptime?
  - etc

Observing efficiency *work plan*

- Lessons learned
  - Collect experience from other LGS AO systems (Palomar, Gemini, Lick, ESO) and a complex non-AO MOS instrument
  - Summarize, analyze and understand main factors
- Provide spreadsheet to science and technical team to help build the efficiency budget
  - Look into big terms per science per sub-system
  - Circulate a first phase of requirements
- Anyone welcome to work on this
  - Need observing experience with other AO/instrument
  - Need experience with high-level software
  - Need new ideas to break limitations of current observing paradigms
  - All need to work fast and efficiently (100 hours total!!)

Backup Slides

Keck NGAO

Team Meeting Calendar

Date	#	Venue	Major Meeting Goal	Science/Management Milestone	Systems Engineering Milestone	Optics/Mechanics Milestone	Electronics/Software Milestone	WFS/WFP Milestone	Laser/DM Milestone	Instrument/Observatory Milestone
14-Sep-06	1	UCI	Kickoff	NGAO SD Plan	Model/Tool Validation					
			Sci. Case I							
14-Nov-06	**2**	**CIT**	Performance Drivers		Identify Perf. Drivers			Var/Fixed LGS Ast		Interfer. Requirements
			SRD I		SRD I			LGS Ast Geom & Sz		Instr. Study Strategy
13-Dec-06	3	Video	Various TS's		Obs. Effic. Budget	Rayleigh Rejection				Sci. Instr Reuse
					Site Monitoring Update	Tip/Tilt Stage v. DM				Instrument Balance
					MCAO/MOAO					
22-Jan-07	**4**	**Keck**	Performance Budgets	Continuous Sci. Field	Photometric Budget	Tel Wavefr Errors		LOWFS Num & Type		
				Operations Arch. I	Astrometric Budget			HOWFS Num & Type		
					High-contrast Budget					
					Polarimetric Budget					
					Throughput Budget					
7-Mar-07	5	Video	SRD II	K- & L-band Science	SRD II	AM2	NGAO vs Upgrades			Interfer. Support
			Various TS's	GLAO for non-AO	Subsys Funct Req I	Optical Relay				
18-Apr-07	**6**	**UCSC**	Various TS's	d-IFU Opt Sampling		Field Rotat. Strategy		Focus Compens.	DM Stroke Req	Dichroics
				Risk Analysis I		Encl/Relay Temp.			Laser Pulse Format	
30-May-07	7	Video	Software Review I	Operations Tools I		Laser Enclosure	Software Architecture	Slow WFS	Free/Fiber BTO	Obs. Interfaces I
								Centroid Anisoplan	DM RfI	Instrument Interfaces
9-Jul-07	**8**	**UCSC**	5-day Retreat		SRD III	Sci Path Opt Des I	Non-real-time Softwr I	HOWFS I	Laser RfI	Calibr. Stimulus I
						Mech Structure I		LOWFS II		
22-Aug-07	9	Video	Cost Review I	Cost Estimate I	Subsystem Test Plans		Electronics I	Real-time Control I		
					SDM I					
11-Sep-07	**10**	**CIT**	Infrastructure I		Science Verification	Sci Path Opt Des II			LGS Delivery I	Obs. Interfaces II
						Mech Structure II				
5-Nov-07	11	Video	Software Review II	Operations Tools II	SDM II		Non-real-time Softwr II			Instrument #1 I
12-Dec-07	**12**	**Keck**	3-day Meeting	Risk Analysis II	Integr. & Test Plan I		Electronics II	HOWFS II		
			Cost Review II	Cost Estimate II	Subsys Funct Req I			LOWFS II		
9-Jan-08	13	Video	SDR Preparation	SDR Prep	SDR Prep	SDR Prep	SDR Prep	SDR Prep	SDR Prep	SDR Prep
			Prelim. Design Prop.		SRD IV					
31-Mar-08	**14**	**Keck**	**SDR**	SDR						

Keck NGAO 2a. K2 LGS AO Efficiency: NIRC2 survey