Near-Infrared Tip-Tilt Sensor System Design Review

Peter Wizinowich, Richard Dekany, Ean James,
Sudha LaVen, Chris Neyman, Roger Smith,
Thomas Stalcup, Marcos van Dam, Ed Wetherell

December 7, 2010

Agenda

- 12:30 PST. Introductions
- 12:40. Requirements
- 13:10. Design
- *14:10. Break*
- 14:30. Performance
- 15:00. Project Management
- 15:50. Discussion & Q&A
- *16:20. Break*
- 16:30. Reviewer Discussion
- 17:30. Reviewer Report
- *17:50. End*

Introductions

Reviewers:

- Sean Adkins (WMKO Instrument Program Manager)
- Antonin Bouchez (GMT AO Lead)
- Corinne Boyer (TMT AO Lead – chair)
- Randy Campbell (WMKO AO Operations Manager)

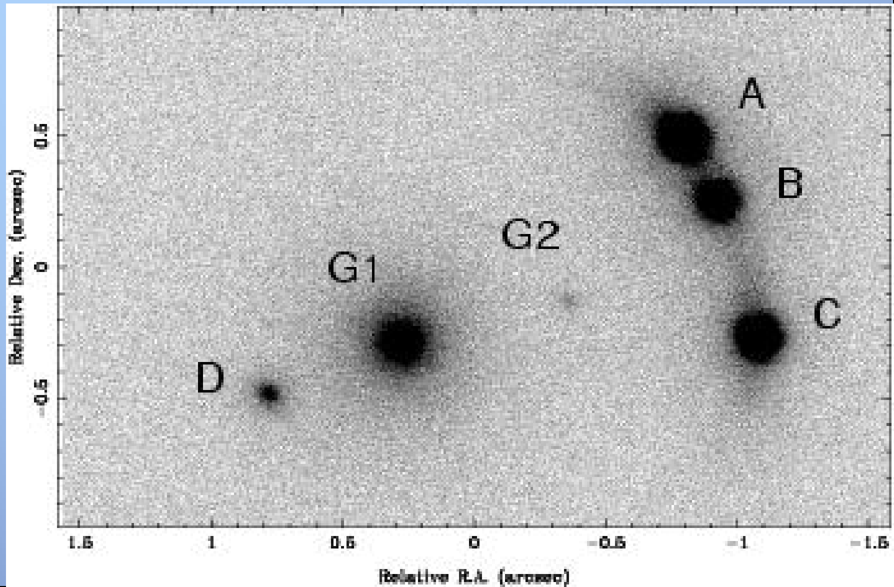
Team & Contributors (to date)

- PI: Peter Wizinowich (WMKO)
- Project Scientist & Team: Tommaso Treu (UCSB), Mark Morris (UCLA), Liz McGrath (UCSC)
- Project Manager: Wizinowich → Thomas Stalcup (after PDR)
- Camera Lead: Roger Smith (COO)
- Performance Analysis: Richard Dekany (COO), Marcos van Dam (Flat Wavefronts)
- WMKO Engineers: Ean James (ME), Sudha LaVen (SE), Chris Neyman (systems engineering), Thomas Stalcup (OE), Ed Wetherell (EE)
- Microgate: Roberto Biasi

Requirements

System Requirements: Proposal

- “This proposal is for the design, construction and implementation of a near-infrared (NIR) tip-tilt sensor (TTS) with the Keck I laser guide star (LGS) adaptive optics (AO) system and the integral field spectrograph OSIRIS, to dramatically increase the sky coverage and faint tip-tilt star performance.”
- 3 limitations of Keck LGS AO that the proposal was intended to alleviate:
  - Improve the sky coverage for intrinsically rare science objects
  - Allow LGS AO science in heavily dust obscured regions (e.g. star forming regions)
  - Improve astrometric precision & spatial resolution currently limited by residual tip-tilt errors
- A few key science areas that would benefit from the performance improvements were identified:
  - Galaxy morphology & supernovae
  - Dark matter in galaxies
  - Science of dust obscured objects



System Requirements: Science

- Sky coverage.
  - Limiting magnitude for usable tip-tilt stars (#13, 14, 33)
  - Field of view for usable tip-tilt stars (#32)
  - Acquisition (#8, 32, 33)
- Tip-tilt residuals for short and long exposures
  - Residuals versus tip-tilt star magnitude and off-axis distance (#4)
  - Residuals versus exposure time.
    - Vibrations (#36), stability (#26) & differential atmospheric refraction correction (#22)

Error Term	High-Redshift Galaxies (r0 = 14.7 cm @ 30° zenith angle; wind 9.5 m/s)		
	K2 2009	K1 2010	K1 2013 (w/ new TTS)
Atmospheric Fitting	126	126	126
Telescope Fitting	66	66	66
Science Camera	30	30	30
DM Bandwidth	108	55	55
DM Measurement	146	71	71
Tip-tilt Bandwidth	145	145	89
Tip-tilt Measurement	191	192	95
Tip-tilt Anisoplanatism	190	190	111
LGS Focus Error	34	34	34
Focal Anisoplanatism	187	187	187
LGS High Order Error	50	50	50
Calibration Errors	29	29	29
Miscellaneous	90	36	101
Total Wavefront Error	442	405	329
Science Wavelength	2.2 μm		
Strehl Ratio	20%	26%	41%
Ensquared Energy (50 mas)	18%	23%	32%

System Requirements: Science

- Wavelengths at which science can be performed with the NIR TTS (#34, 35)
- Wavelengths at which tip-tilt sensing can be performed (#13, 14, 33)
- Throughput and emissivity (#34, 35)
- Field of view over which science can be performed with the NIR TTS (#15)
- Observing modes (#46)
  - Refocus (#16); dithering, nodding, offsetting (#23)
  - Non-sidereal tracking (#28, goal only), use of non-point sources (#10, 11)
- Positioning accuracy and repeatability (#24, 25, 27)
- Observing efficiency (#18, 20, 21)
- Higher bandwidth focus measurements (#5, goal only)
- Performance monitoring (#29)
- Observation planning (#46, 63, 64)

Functional Requirements & Interfaces

- Functional requirements generated for each of 5 major subsystems
- Flow down from system requirements indicated
- Camera system interfaces defined in KAON 836
- RTC requirements & interfaces defined in KAON 824

- Compliance of both system & functional requirements, at SDR, provided in KAON 838
  - No requirements are expected not to be met, but many will require further compliance assessment during remaining design phases

Reviewer Topics

1a) Wavefront error budget (Table 1 of KAON 823)

- Clarify range of conditions over which system will meet the requirements in Table 1.
- Derive sub-system requirements from Table 1 early in PD

Response:

- The system only needs to meet the Table 1 requirements for the NGAO high redshift galaxy case which is defined as 30% sky coverage at 60° galactic latitude, 30° zenith angle & median seeing conditions (r0 = 14.7 cm, wind speed = 9.5 m/s) for an 1800 sec integration. As stated in SR-4 the performance is allowed to degrade with respect to Table 1 as conditions worsen.
- The tip-tilt bandwidth, measurement & anisoplanatism terms will need to be flowed down. Need to show we can reduce these errors to the requirement levels while not degrading any of the other error terms.
  - Effects opto-mechanical system throughput & emissivity, opto-mechanical & camera stability & vibrations, camera & RTC system latency, RTC algorithm performance, controls DAR & focus performance, observing software calibrations & optimization parameters.

Reviewer Topics

1b) Motivations for simultaneous NIR TTS & STRAP not convincing (concerns about additional complexity). Consider this option as a possible descope.

Response: Agreed. We will consider this as a descope.

Would like to include the RTC mods to allow this to be a future option. Need interface mods anyhow to allow choice of TT sensor.

RIX

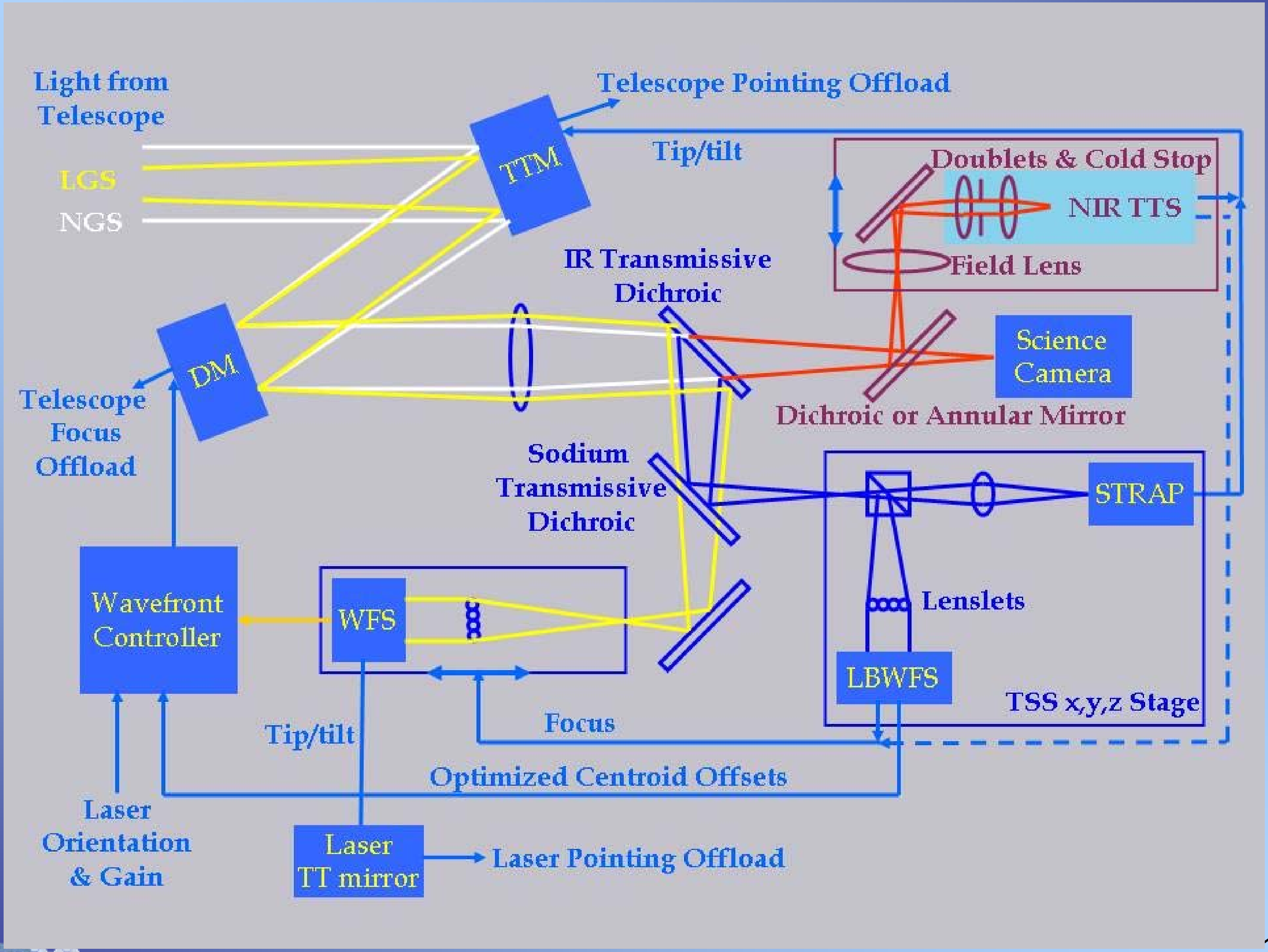
- RIQ-ABO-1. Why does the miscellaneous wfe term increase so much for the IR TTS case?
  - Miscellaneous term used as a free parameter to match on-sky or simulation results. The K1 2013 case includes 45 nm rms of high order wfe not assumed in the earlier columns.
- RIQ-ABO-2. SR-4 must have an integration time associated with it.
  - High redshift galaxy case assumes 1800 sec.
- RIQ-ABO-3. Does SR-51 imply that there will no longer be a spare K2 wavefront controller?
  - All 3 units will be upgraded, so a common spare remains.
- RIQ-ABO-4. What is the justification for SR-12 simultaneous STRAP & NIR TTS operation? Concern about significant complexity.
  - Motivation is to use all available information. STRAP & NIR TTS performance comparable for low sky coverage cases.
  - Asynchronous operation & DAR divergence could be issues.
  - May want to reduce to a goal (due to low contingency) but keep the hooks in to add later.

RIX

- RID-RDC-4. Several references in ICD to cameras, LOWFS, etc. that don't pertain to this system
  - Will correct outdated language. LOWFS is NGAO version of NIR TTS.

Design

Design Overview – Control Schematic



Design Overview - Subsystems

Operations Software System

- Pre-Observing Tools
- Observation Setup
- Calibration
- User Interface
- Observing Tools

Controls System

- Pickoff & Focus Motion Control
- Camera Device Control
- Supervisory Controller Modifications

Camera System

- NIR Camera
- Internal Camera Optics
- Camera Controller
- Filter Changer
- Cryo-cooler
- Host Computer

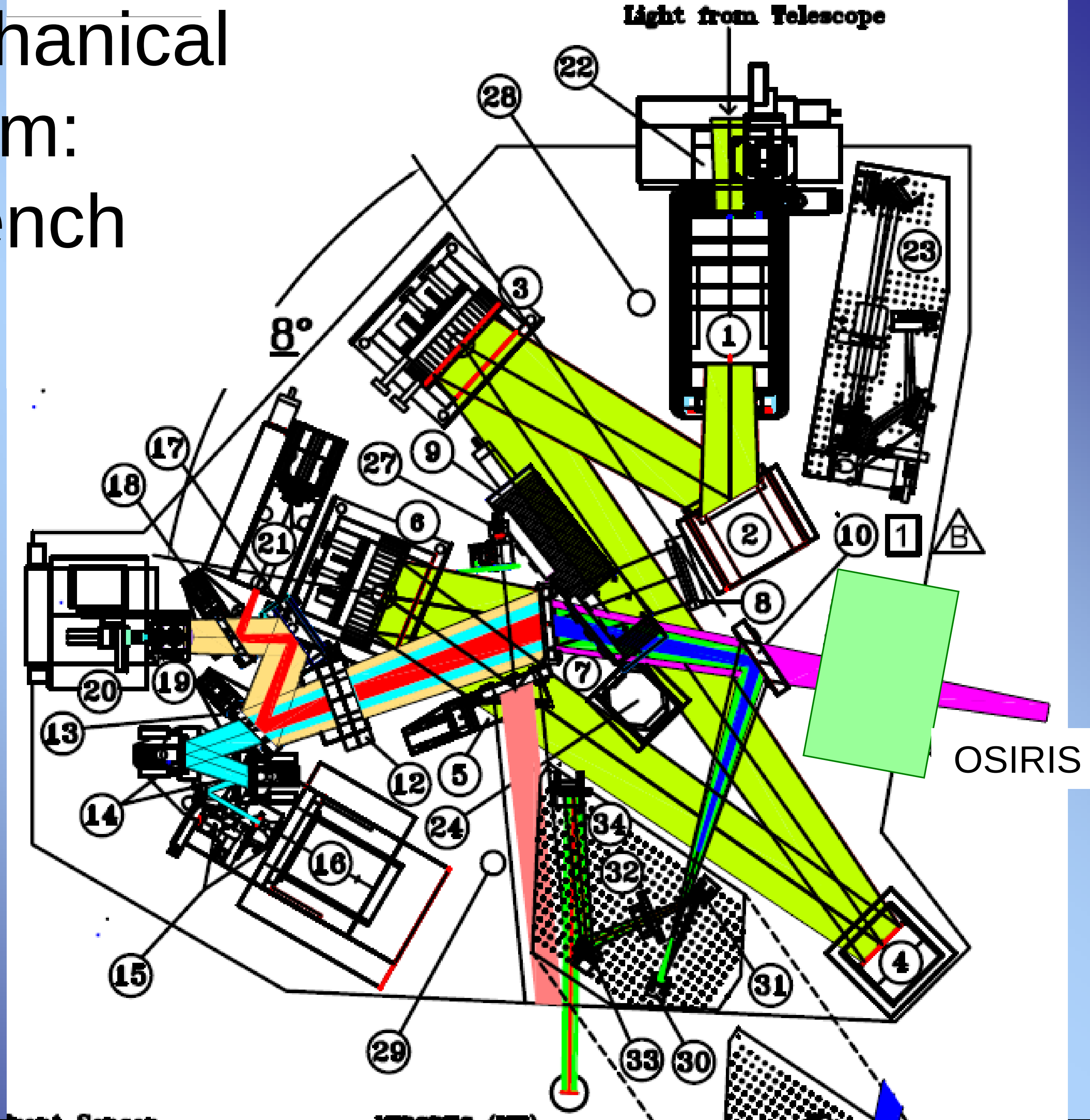
Real-Time Control System

- Camera Data Processing
- TT Determination
- Telemetry Input Mods

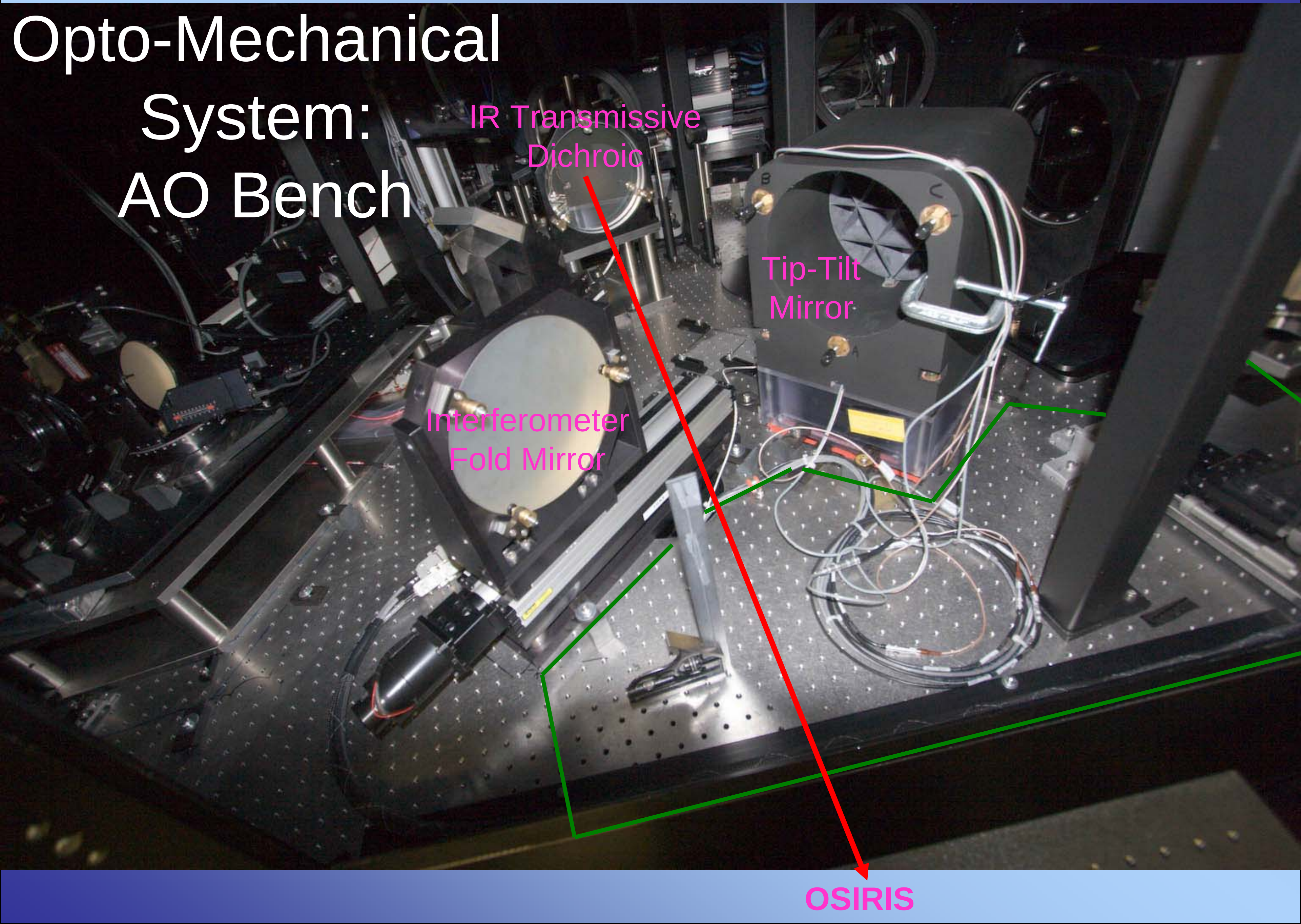
Opto-Mechanical System

- Pickoff Exchange Mechanism
- External Camera Optics
- Focus Mechanism

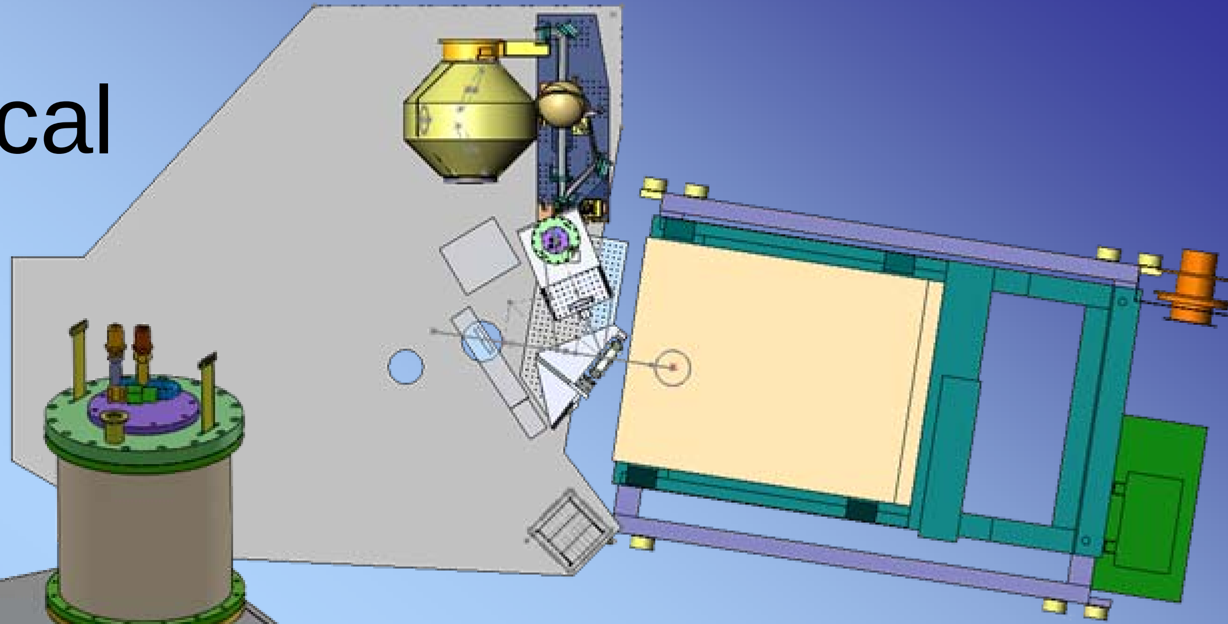
Opto-Mechanical System: AO Bench

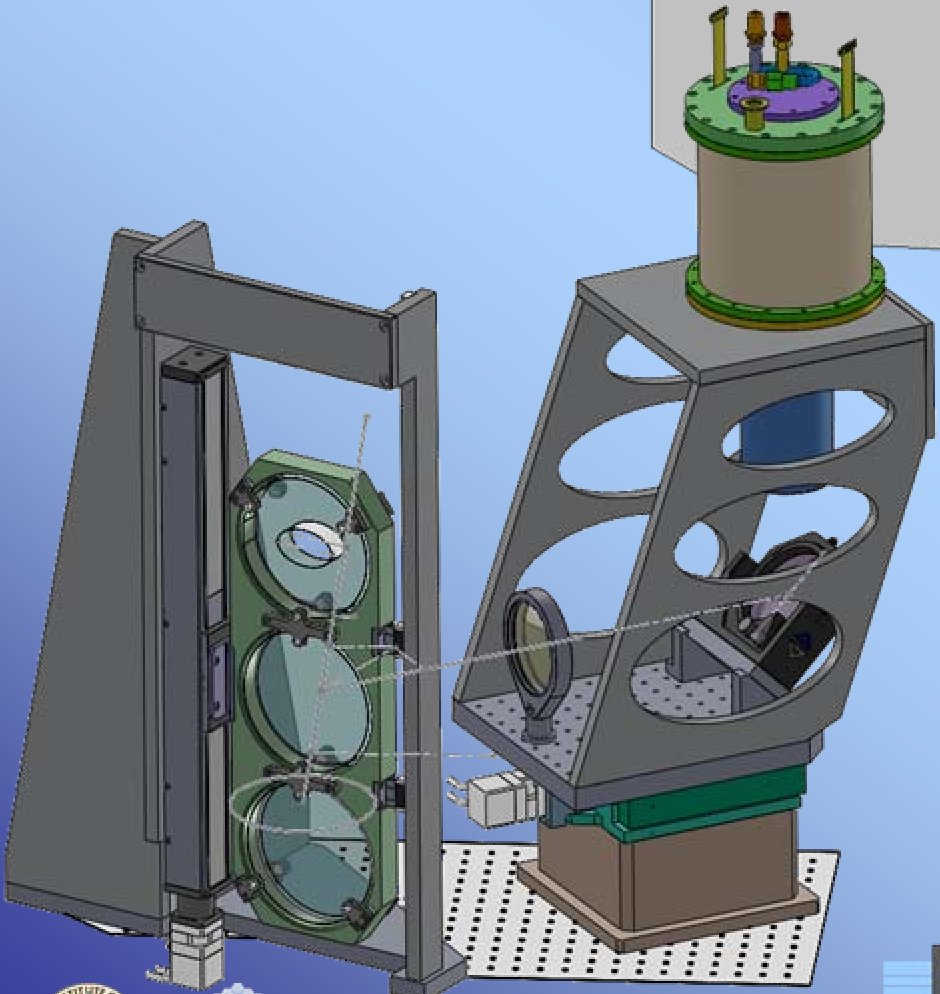


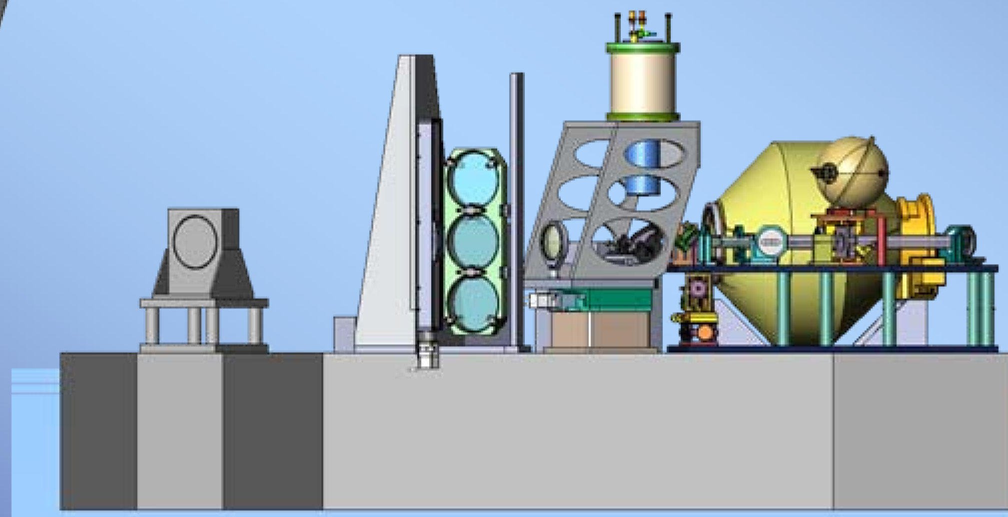
Opto-Mechanical System: AO Bench



Opto-Mechanical System







Reviewer Topics

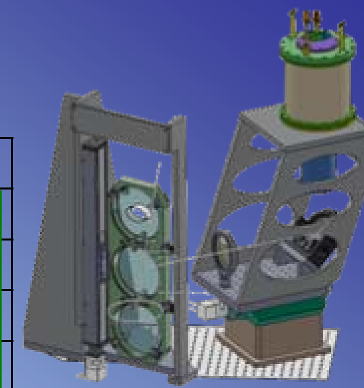
2c) Review alternatives of NIR TTS location on AO bench

- Proposed location is small & difficult to access
- Not demonstrated that the proposed design fits the envelope
- Not clear if alternatives have been considered, for example can the pupil simulator be moved or redesigned to provide more room?

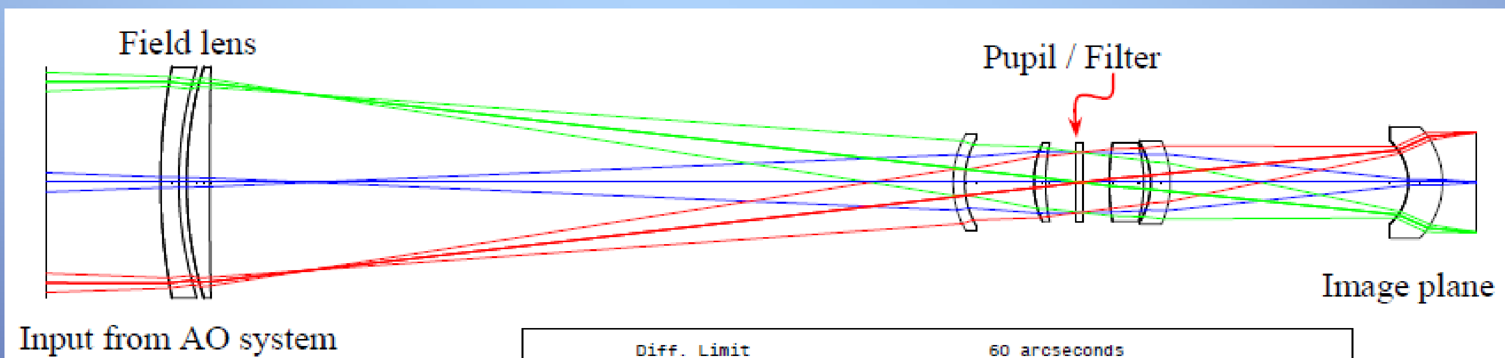
Response:

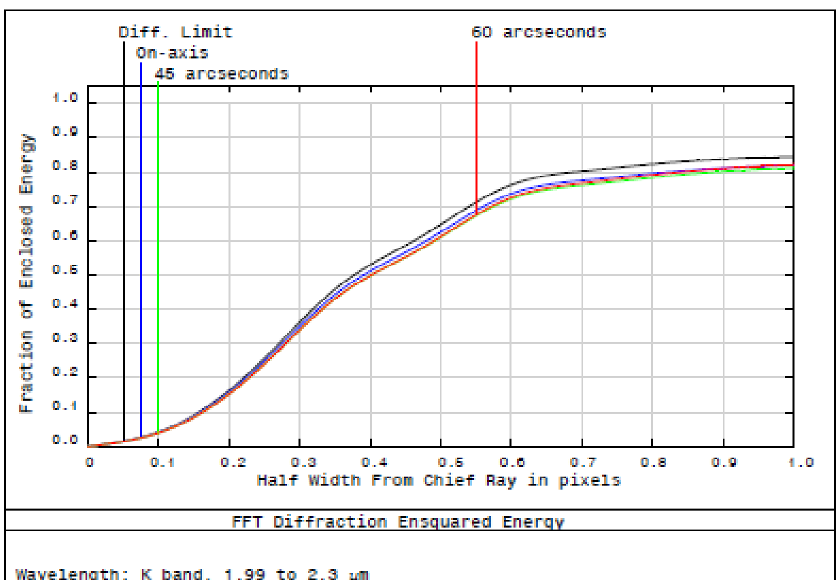
- A location between the IR transmissive dichroic & OSIRIS is strongly preferred. System size depends on proximity to focus.
- This is the only viable location we could identify. The current design does fit into this location (tightly), including some extension off the AO bench.
- We did include modifications to the pupil simulator in the proposal budget, but our current design does not seem to require this.
- An updated SolidWorks model fully consistent with the design & existing bench will be produced for PDR.

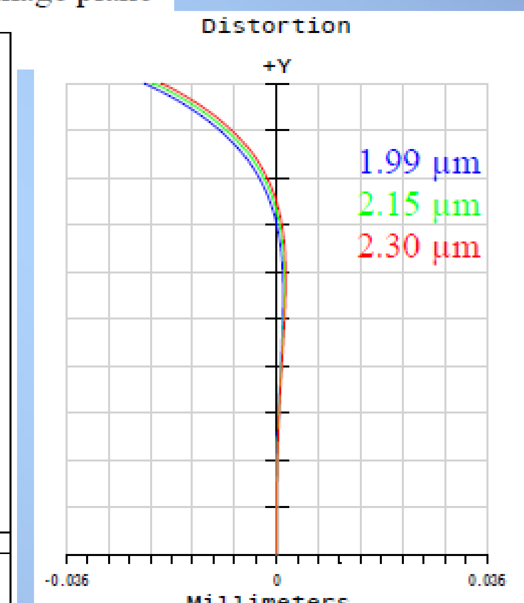
Opto-Mechanical System



Case	Science λ	IFU	Imager	NGS location	Tip-tilt λ	NIR fold
1	JHK	Yes	Yes	0-60" off-axis	Vis	n/a
2	JHK	Yes	No	35-60" off-axis	K (or H)	annular mirror
3	JH	Yes	Yes	0-60" off-axis	K	K-dichroic
4	K	Yes	Yes	0-60" off-axis	H	H-dichroic
5	K	Yes	No	<35" off-axis	H	H annular mirr
6	K	Yes	No	35-60" off-axis	K (or H)	H annular mirr







Reviewer Topics

2b) Reconsider design to better use NIR TTS as a NGAO pathfinder

- In particular review possibility to include TT mirror &/or MEMS

Response: We did consider this extensively during the SD.

- Proposed an AO-corrected NIR TTS upgrade for $2.6M of TSIP funding (not approved by SSC). In addition to MEMS requires a 2nd movable laser beacon & WFS, & mods to RTC, controls & observing SW.
- We did consider a TT mirror but rejected this for cost & complexity reasons.
  - Cold TT mirror in a tight space or a 2nd pupil location required.
- Breaking news: the current fold mirror could provide benefits as an affordable TT mirror option. Will pursue in PD.
  - The pupil shift is 0.9% per arcsec of tilt.
  - The effect on image quality is negligible for 1" & only changes the ensquared energy by a few % for shifts up to 2".
  - DAR is only 16 mas between science at J & TT sensing at K for a zenith angle change from 45° to 50° (~20 min exposure).
  - Could offer focus benefit by allowing us to keep 1 TT star at 4 pixel intersection.
- Current design offers multiple benefits to NGAO: Tests LOWFS dewar, demos use of 1 & 3 NIR TT stars, tests TT performance benefits, able to check focus benefit, + overall controls & operations.

RIX

- RIQ-TT-1. More about TT mirror option, costs, impact of performance & pros & cons from an observer point of view.
  - Primary con is cost & complexity. Hence not included.
    - For significant stroke needs to be at a pupil plane which requires a more complicated optical system with a pupil outside the dewar or a TT mirror at the existing pupil in the dewar.
    - Another control loop.
    - Already need to work off 4 pixel intersection with 3 stars.
  - TT mirror could deal with DAR and offsets (so no moving ROIs) plus needed for focus sensing.
  - Fold mirror as TT mirror now being considered.
- RIQ-TT-2. Same question for focus.
  - Not investigated enough to fully understand pros.
    - Potential performance & observing efficiency improvements (vs LBWFS).
  - Not included for cost reasons
  - Hooks left in for a future upgrade & will be able to test utility on-sky.

Design Overview - Subsystems

Operations Software System
- Pre-Observing Tools
- Observation Setup
- Calibration
- User Interface
- Observing Tools

Controls System
- Pickoff & Focus Motion Control
- Camera Device Control
- Supervisory Controller Modifications

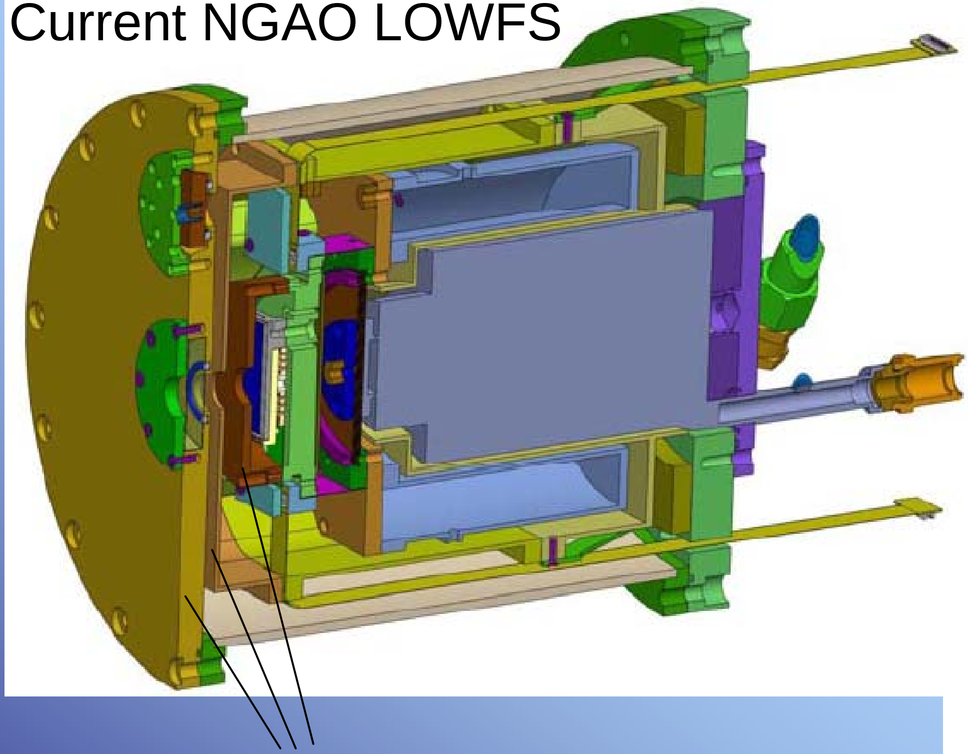
Camera System
- NIR Camera
- Internal Camera Optics
- Camera Controller
- Filter Changer
- Cryo-cooler
- Host Computer

Real-Time Control System
- Camera Data Processing
- TT Determination
- Telemetry Input Mods

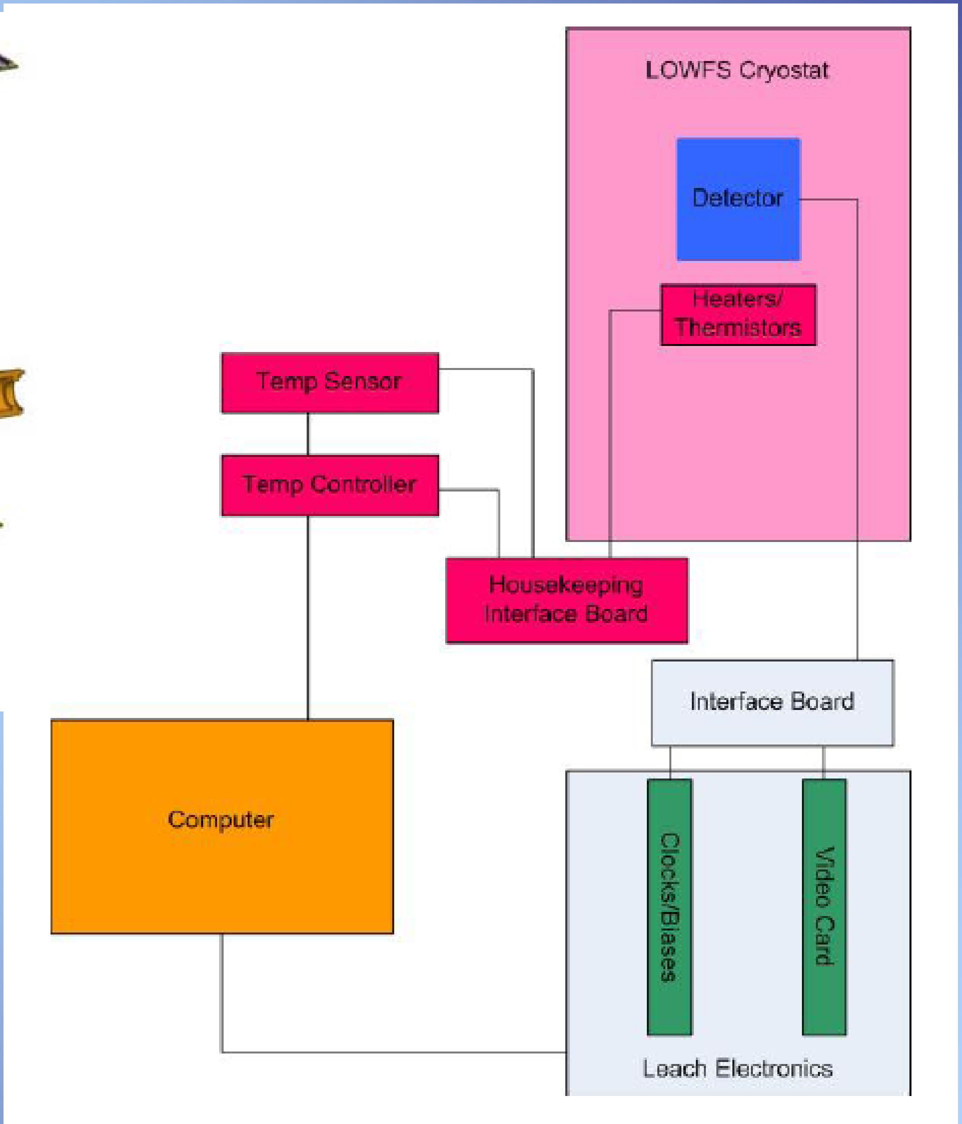
Opto-Mechanical System
- Pickoff Exchange Mechanism
- External Camera Optics
- Focus Mechanism

Camera System

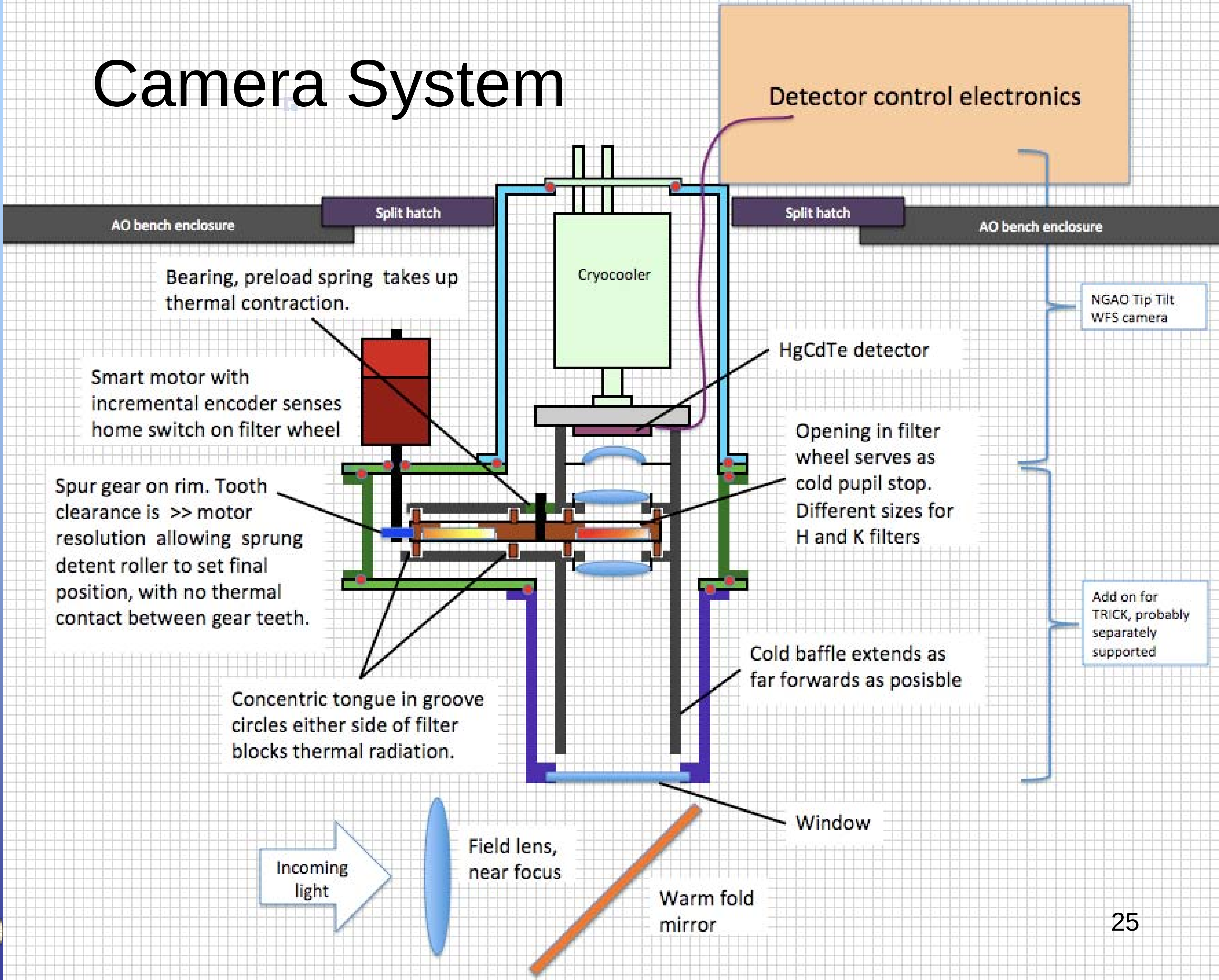
Current NGAO LOWFS



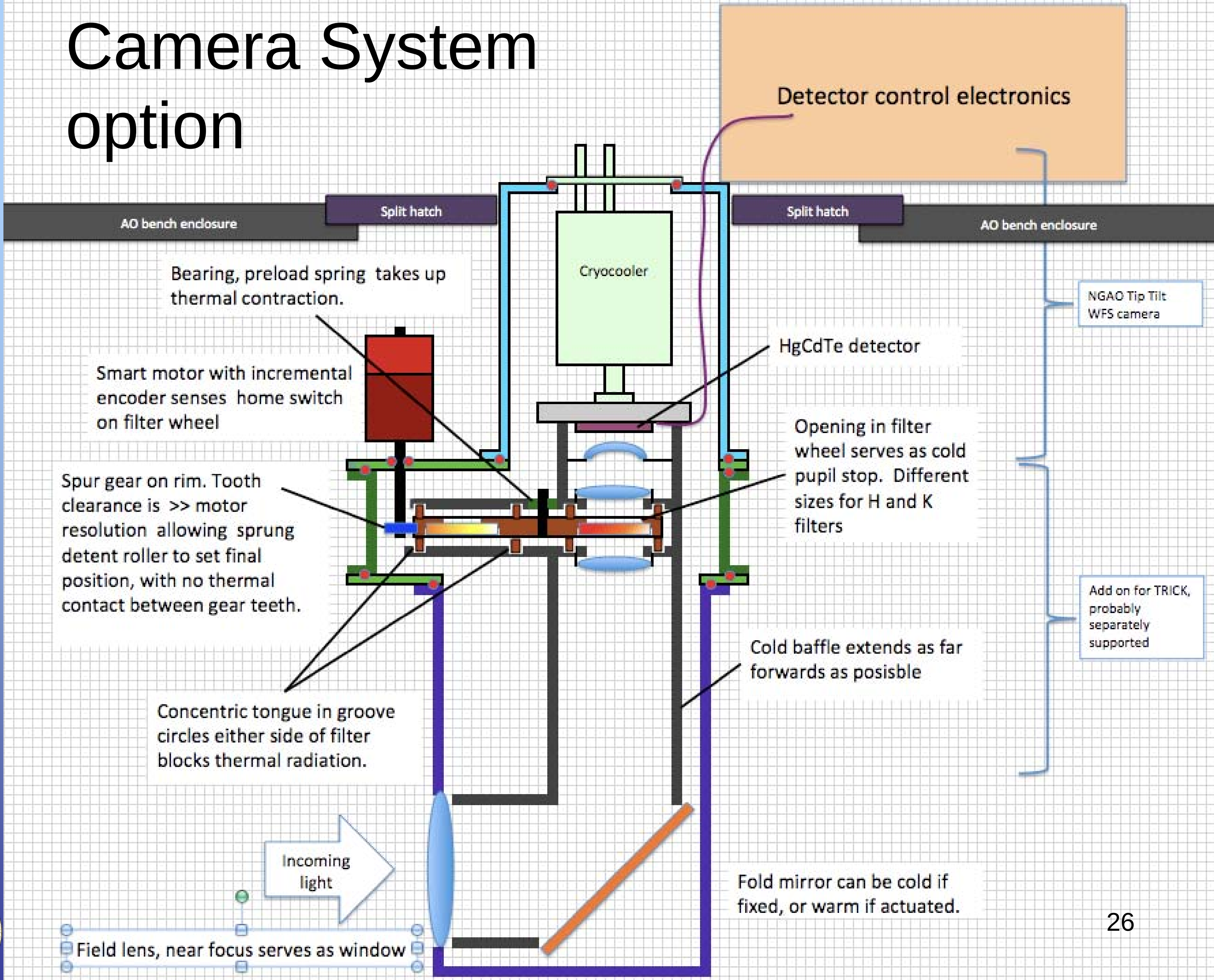
Replace covers with extension carrying cold optics, filter and baffles



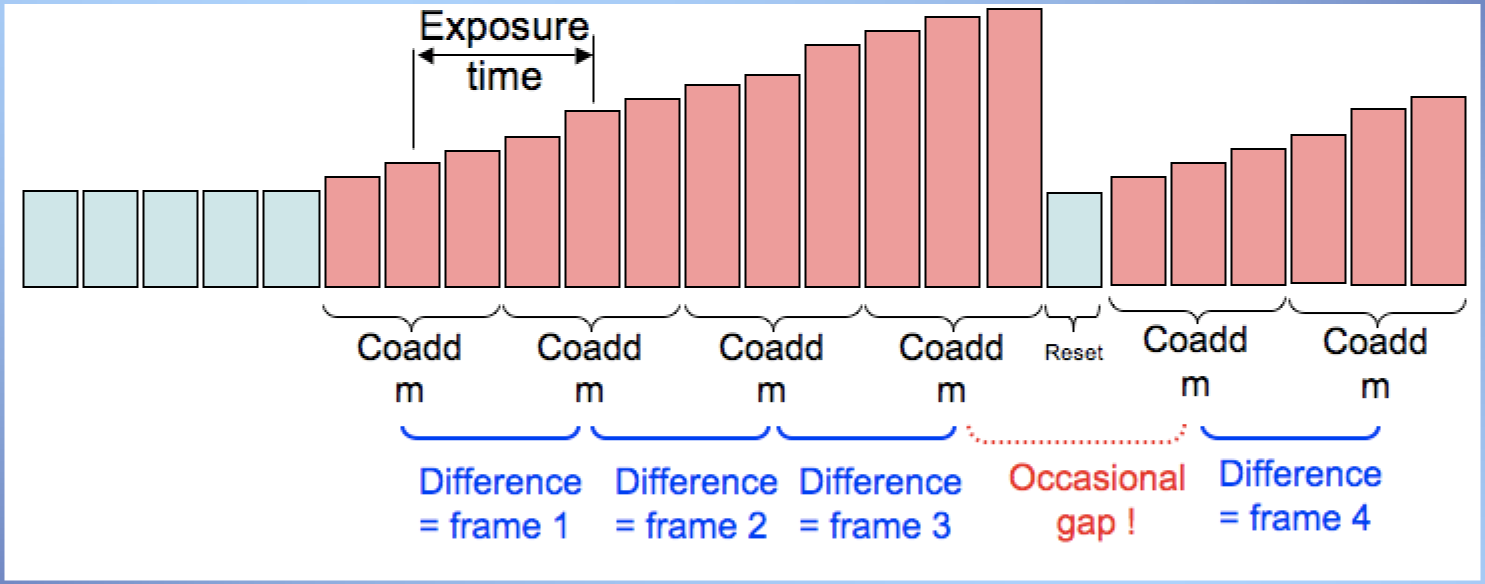
Camera System



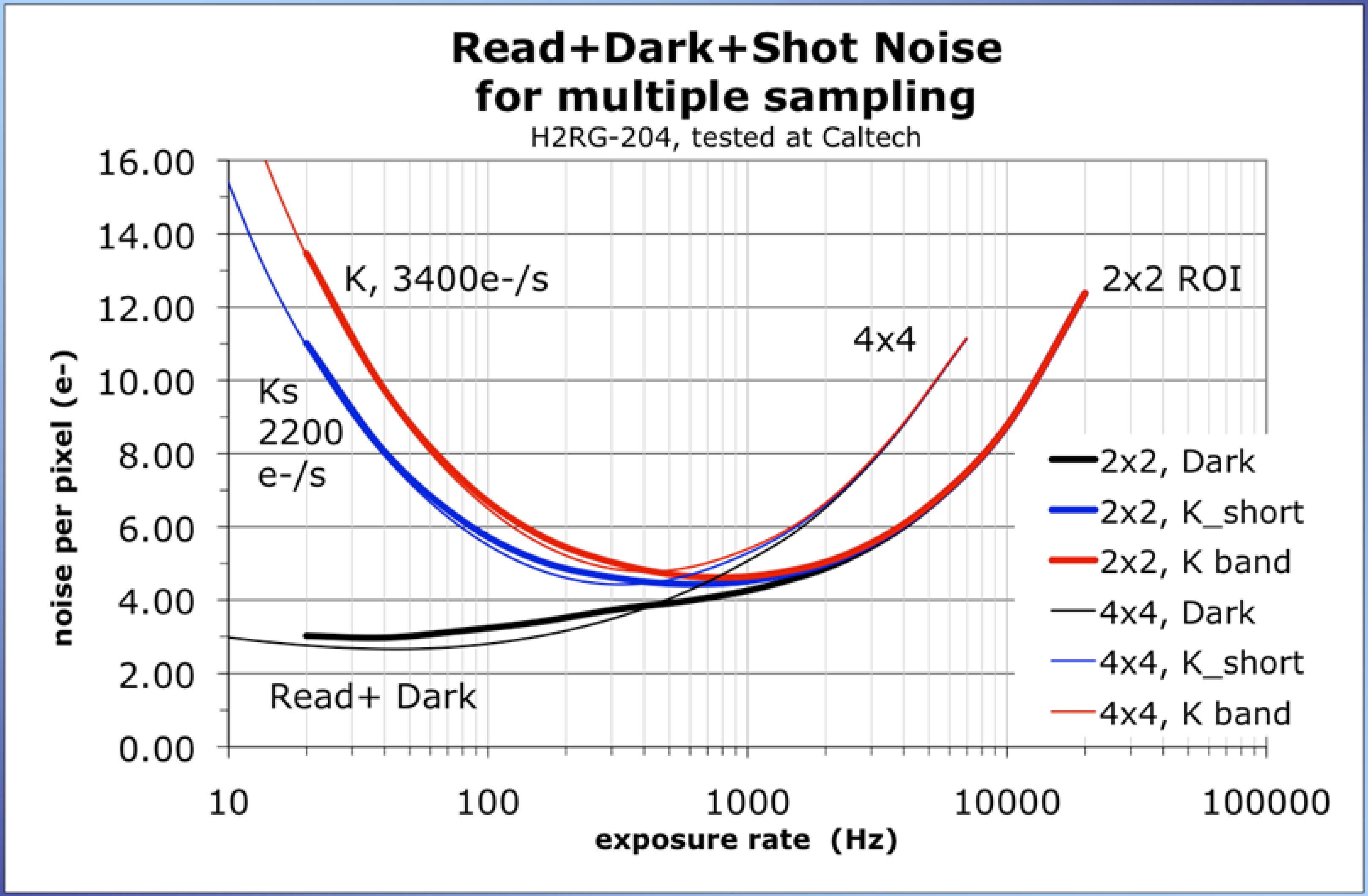
Camera System option



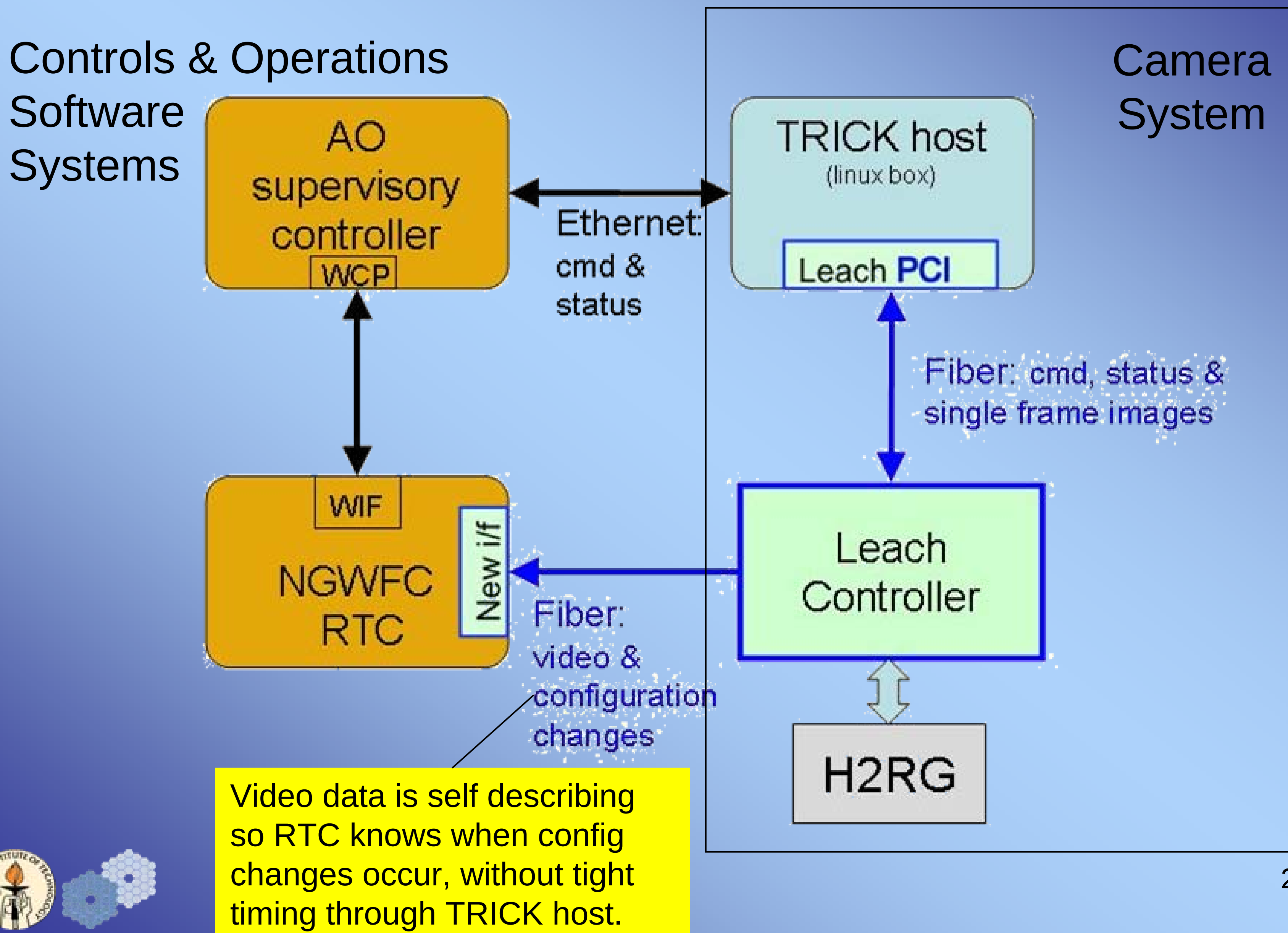
Camera System - Readout



Camera System - Noise

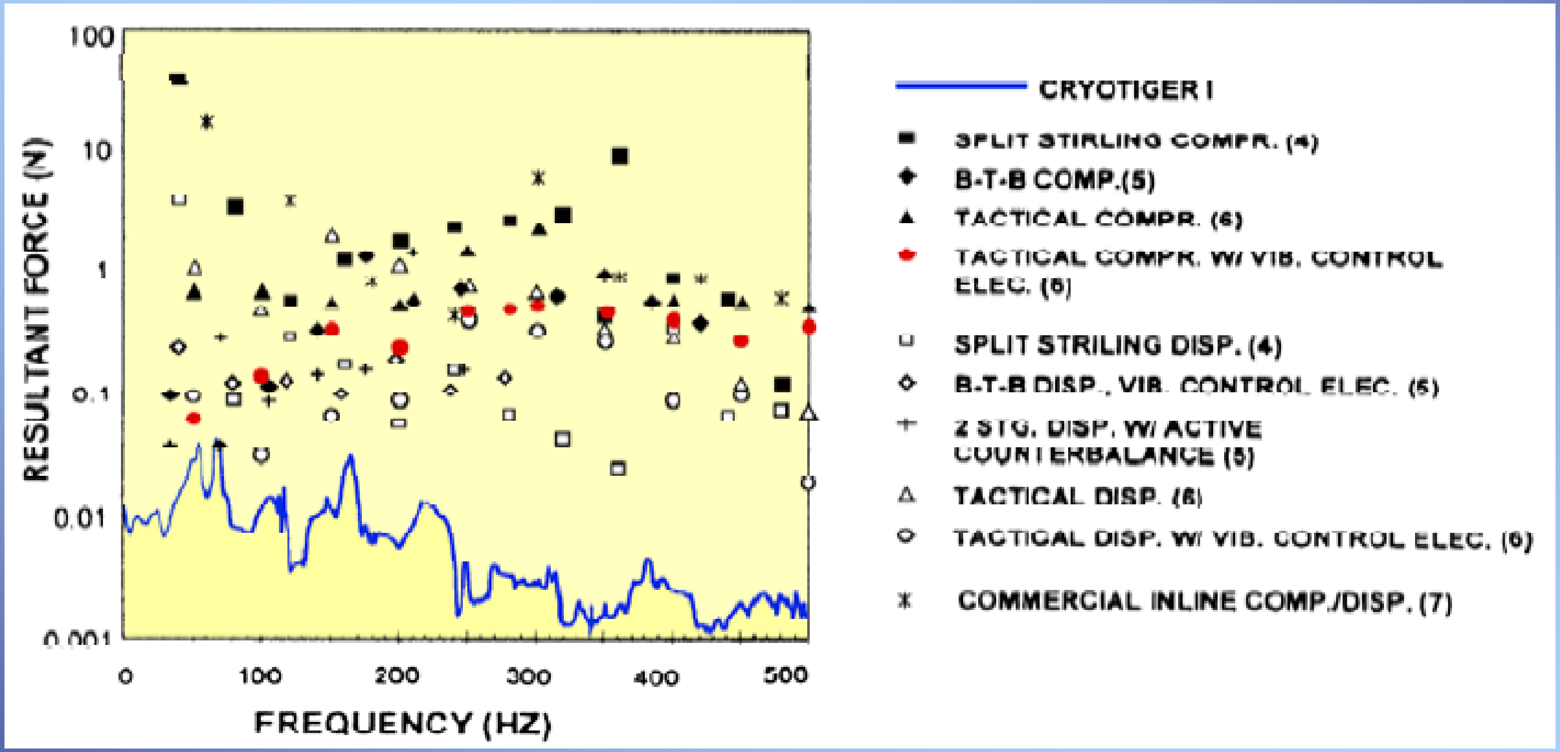


Communication Interfaces



RIX

- RIQ-RDC-1. Vibration specs for CryoTiger?
  - Negligible vibrations



RIX

- RIQ-RDC-2. Will the synthetic exposure / continuous readout mode work with dithering? Any penalties, noise, timing overheads, etc. associated with changing ROIs?
  – Should work once star is on new ROI after 1st frame needed for subtraction. Will perform lab tests of changing ROIs with existing Caltech camera. Will test for self heating.
- RIQ-RDC-5. Will access to vacuum port be available when on bench?
  – Yes.

Design Overview - Subsystems

Operations Software System
- Pre-Observing Tools
- Observation Setup
- Calibration
- User Interface
- Observing Tools

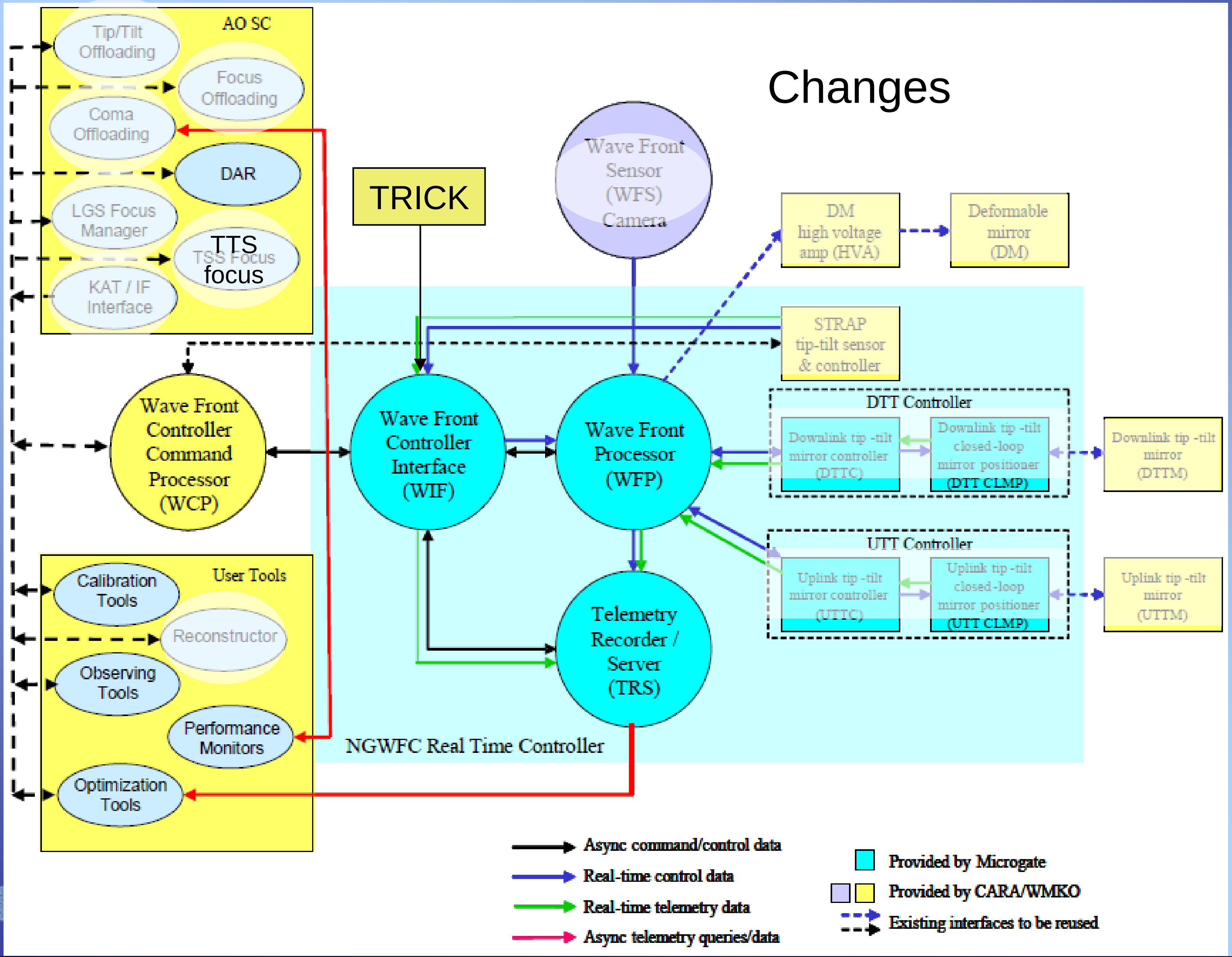
Controls System
- Pickoff & Focus Motion Control
- Camera Device Control
- Supervisory Controller Modifications

Camera System
- NIR Camera
- Internal Camera Optics
- Camera Controller
- Filter Changer
- Cryo-cooler
- Host Computer

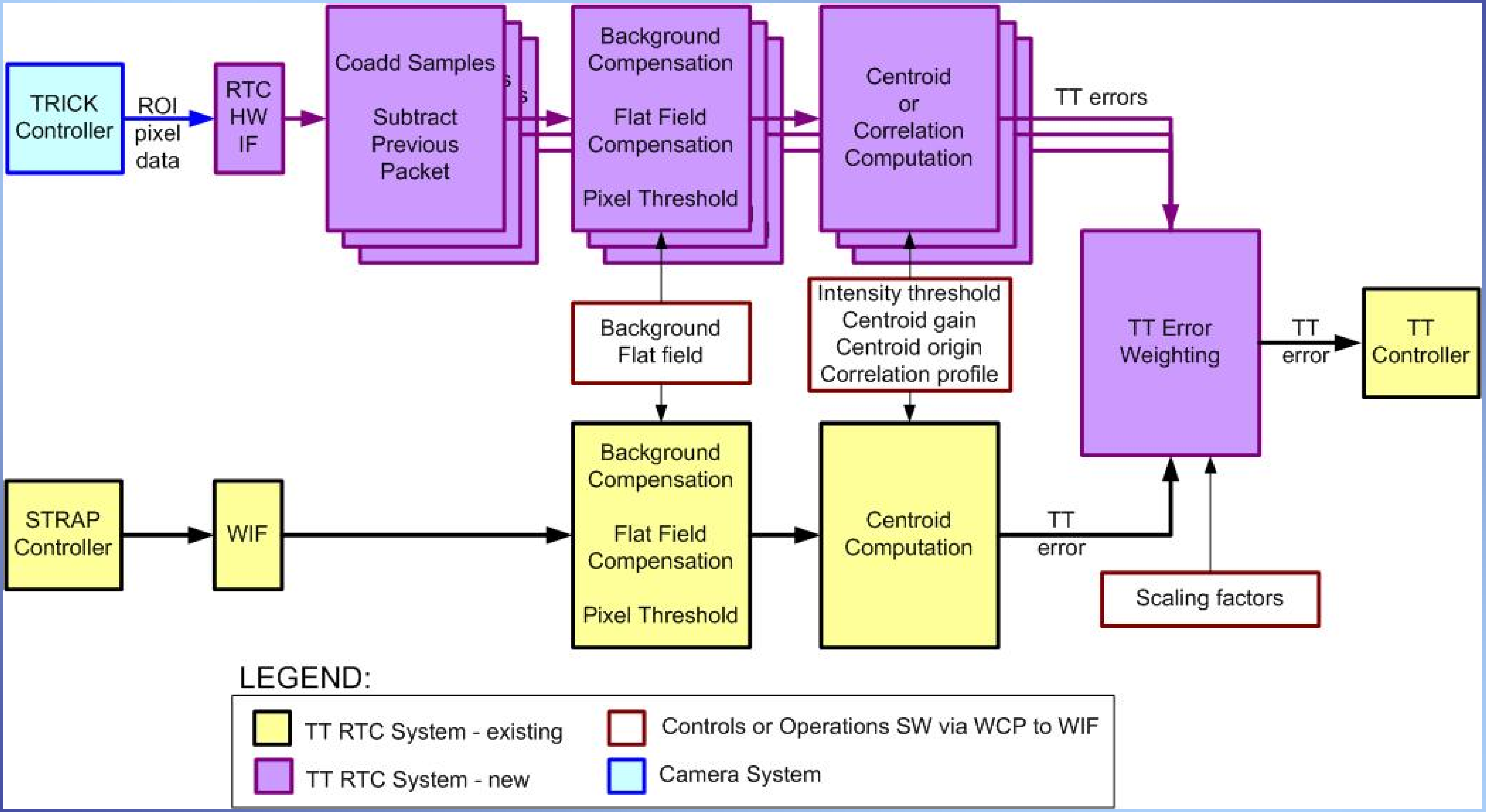
Real-Time Control System
- Camera Data Processing
- TT Determination
- Telemetry Input Mods

Opto-Mechanical System
- Pickoff Exchange Mechanism
- External Camera Optics
- Focus Mechanism

RTC – Existing & Modified System



RTC – Control Loop



RIX

- RIX-CBO-1. How is the seeing disk background measured & used?
  - Use seeing disk in outer 8x8 pixels to extrapolate seeing disk in 4x4; provide this info to RTC for subtraction. May not be useful as discussed in RIQ-ABO-5.
- RIQ-ABO-5. Subtracting the time averaged seeing disk will not stabilize the centroid gain due to speckles.
  - Agreed. Could potentially reduce the sensitivity to gain.
  - Reinforces the need to focus on the correlation algorithm with a backup of a centroid algorithm using a Strehl estimate to optimize gain.
- RIX-ABO-6. A 1.3" region can be read at 1kHz with 12e- read noise. However, SOW only mentions 16x16 pixels (0.8").
  - Illustrative example only.
- RIQ-ABO-7. How will processing of asynchronous tip-tilt residuals be performed.
  - Needs more careful thought. Multiples of shortest integration time will be used. For STRAP had just thought to use most recent result when applying NIR TTS result.

RIX

- RIQ-ABO-9. Current AO centroid gain optimization method will only work with 1 star. Getting centroid gain correct could be a big problem.
  - Agreed. Only important for centroiding not correlation. Will focus on Strehl estimate approach. High priority for PD.
- RIQ-CBO-4. How do you decide which algorithm to apply?
  - Baseline to use correlation algorithm all the time.
  - Centroid algorithm primarily a backup.
- RIQ-CBO-5. Do you have information on how Microgate will implement the modifications required to process the IR TT pixels?
  - An existing interface board will be modified.

Design Overview - Subsystems

Operations Software System

- Pre-Observing Tools
- Observation Setup
- Calibration
- User Interface
- Observing Tools

Controls System

- Pickoff & Focus Motion Control
- Camera Device Control
- Supervisory Controller Modifications

Camera System

- NIR Camera
- Internal Camera Optics
- Camera Controller
- Filter Changer
- Cryo-cooler
- Host Computer

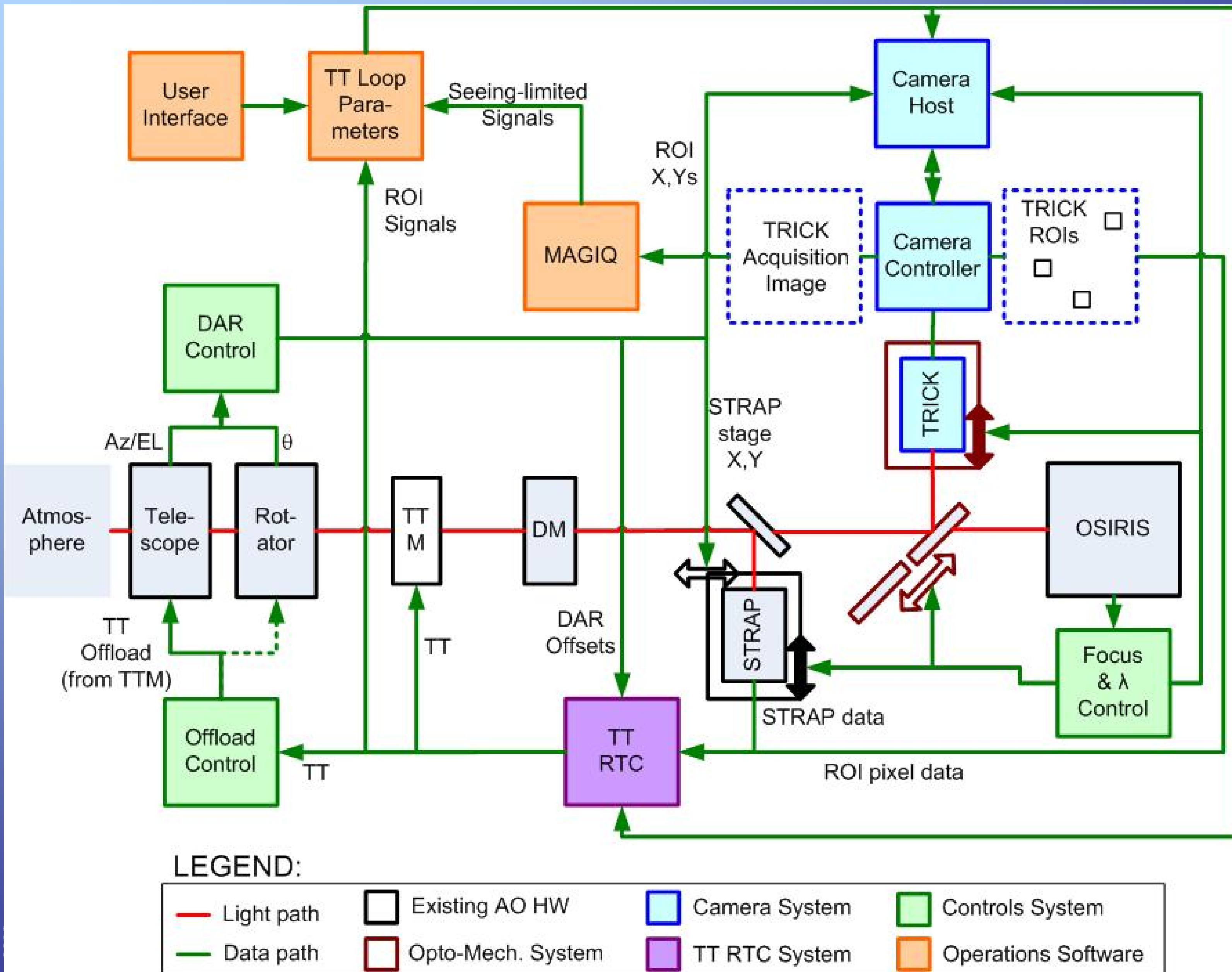
Real-Time Control System

- Camera Data Processing
- TT Determination
- Telemetry Input Mods

Opto-Mechanical System

- Pickoff Exchange Mechanism
- External Camera Optics
- Focus Mechanism

Controls



User Interface
TT Loop Para- meters
Seeing-limited Signals
ROI X,Ys
Camera Host
ROI Signals
MAGIQ
TRICK Acquisition Image
Camera Controller
TRICK ROIs
DAR Control
TRICK
STRAP stage X,Y
Az/EL
θ
Atmos- phere
Tele- scope
Rot- ator
TT M
DM
OSIRIS
STRAP
TT Offload (from TTM)
TT
DAR Offsets
Focus & λ Control
STRAP data
Offload Control
TT
TT RTC
ROI pixel data
LEGEND:
Light path
Data path
Existing AO HW
Opto-Mech. System
Camera System
TT RTC System
Controls System
Operations Software

Design Overview - Subsystems

Operations Software System

- Pre-Observing Tools
- Observation Setup
- Calibration
- User Interface
- Observing Tools

Controls System

- Pickoff & Focus Motion Control
- Camera Device Control
- Supervisory Controller Modifications

Camera System

- NIR Camera
- Internal Camera Optics
- Camera Controller
- Filter Changer
- Cryo-cooler
- Host Computer

Real-Time Control System

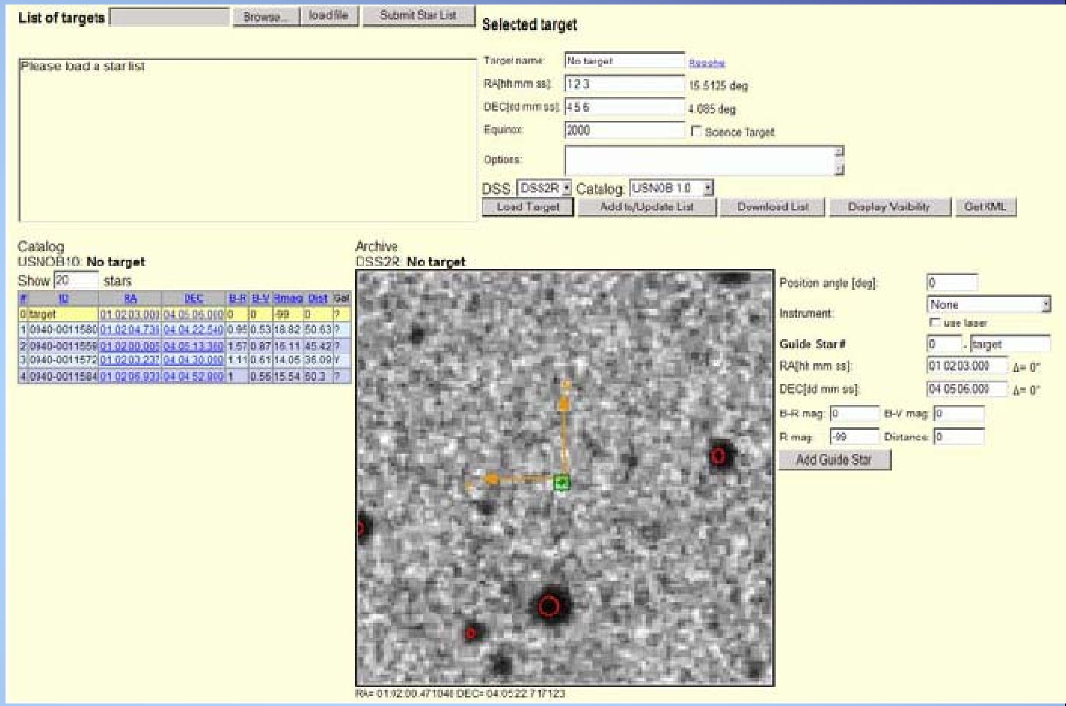
- Camera Data Processing
- TT Determination
- Telemetry Input Mods

Opto-Mechanical System

- Pickoff Exchange Mechanism
- External Camera Optics
- Focus Mechanism

Operations Software

- Pre-Observing
  - Acquisition planning
  - Performance estimation
- Observation Setup
- Calibrations
  - Camera, focus & distortion
- User Interfaces
- Observing Tools
  - Acquisition
  - TT parameter optimization
  - Nodding, dithering & repositioning
  - Seeing disk & sky background subtraction
  - Strehl determination
  - Science image FITS header
  - Telemetry recorder system



Reviewer Topics

2e) Acquisition & dithering

- Not well defined. Will need to be better defined early in PD.

Response:

- Agreed that this needs to be better defined for PD; one of the early PD tasks will be development of the observing operations concept document.
- We thought that this was at a SD level especially for acquisition.
- For acquisition the pre-observing process is defined (SDM 8.1.1) based on the existing acquisition planning tool & the acquisition steps are defined (8.5.1).
- For dithering a brief procedure is provided (8.5.3). This process should be very similar to STRAP where instead of moving the STRAP stage we move the ROIs. Since the LGS loop remains locked the PSF will stay small. The telescope positioning error should be small enough that a 200x200 mas ROI can still find & pull in the star; if not we can briefly use a larger ROI for re-acquisition.

RIX

- RIQ-ABO-8. Strategy for tip-tilt star reacquisition after dither will depend on telescope offset precision.
  - A 200x200 mas region should be sufficient to reacquire star.
  - If not then can briefly use a 400x400 mas region & window down.
- RID-RDC-2 &3. Not enough presented on dithering to confirm this requirement has been met.
  - Will evaluate further in PD.
  - Similar to dithering with STRAP where instead of moving the sensor we move the ROIs.
- RIQ-TT-3. Is it possible to design SW to optimize subpixel position of all 3 stars?
  - We intend to have an algorithm to optimize the positions. May not be all that useful given DAR.

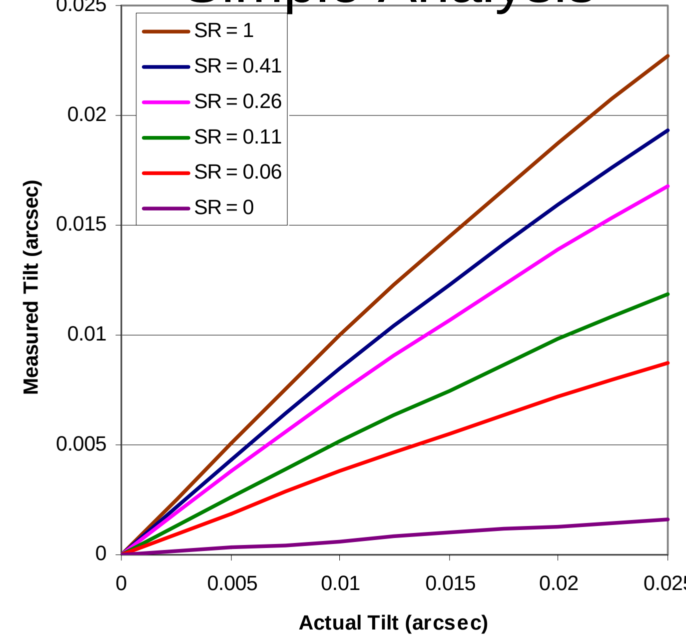
RIX

- RIQ-TT-4. Appreciate plan to create a performance simulator & strongly support a PSF simulator. In addition to Strehl, magnitude of TT stars & seeing disk (2-component gaussian?) useful to estimate performance & to adjust exposure times.
  - Magnitude straightforward from acquisition camera & is planned.
  - Reminder that performance simulator is a goal.

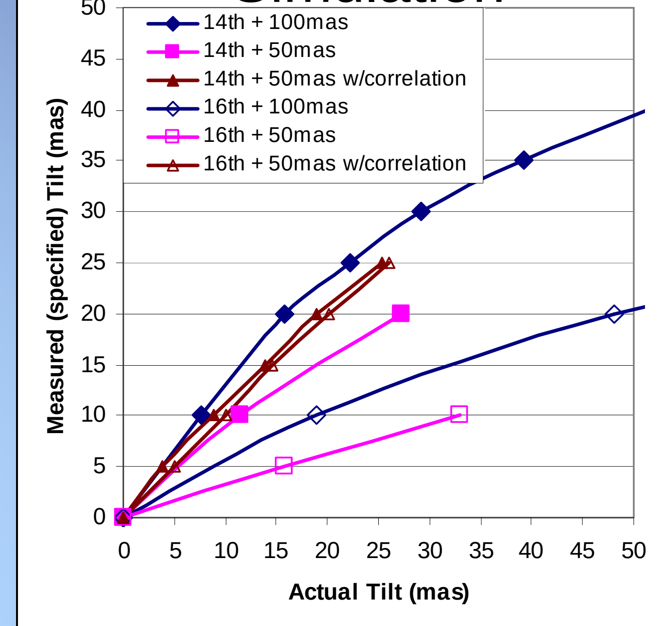
Performance

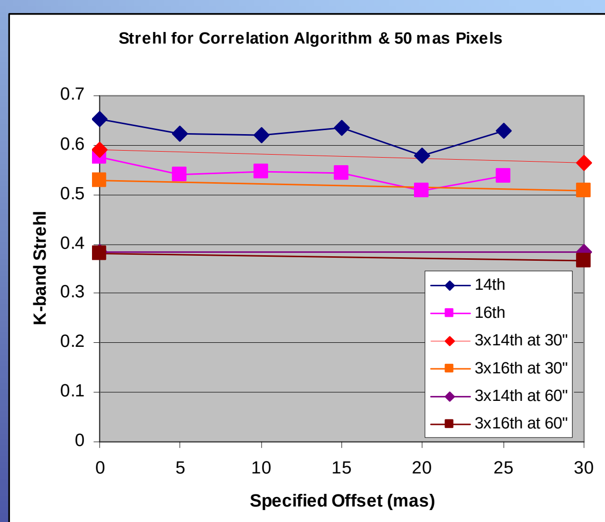
Performance Analysis – Plate Scale & Algorithm

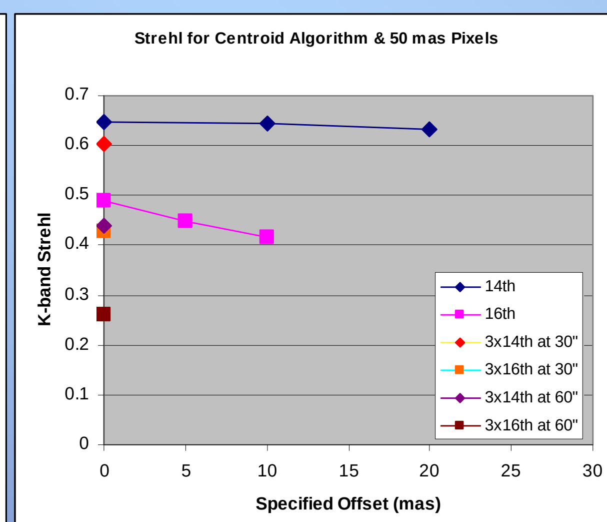
Simple Analysis



Simulation







Reviewer Topics

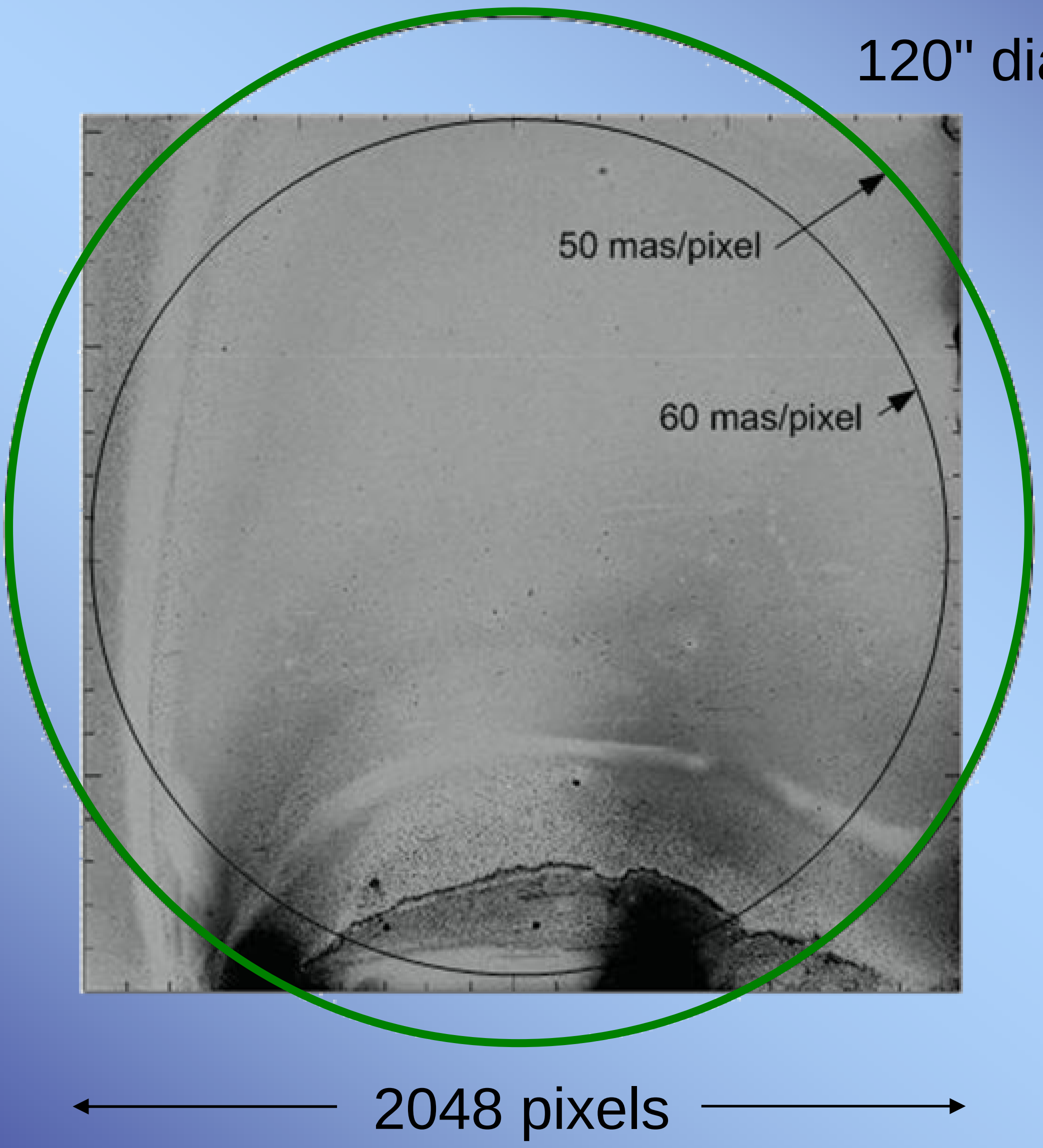
2a) Detector plate scale & algorithm

- Additional simulations to confirm the choice of plate scale & algorithm during PD
- How to estimate centroids gain when using multiple guide stars?
- How correlation algorithm works with changing ROIs?

Response:

- Additional simulations will be performed during PD.
- Current baseline approach is to use Strehl to estimate centroid gain for each guide star. Get Strehl from signal in 2x2 pixels divided by total flux from acquisition image.
- Unclear why correlation algorithm would have a problem with changing ROIs. Could use a larger correlation region if necessary not to have to move the ROI at the expense of noise.

Performance Analysis – H2RG & Field



Reviewer Topics

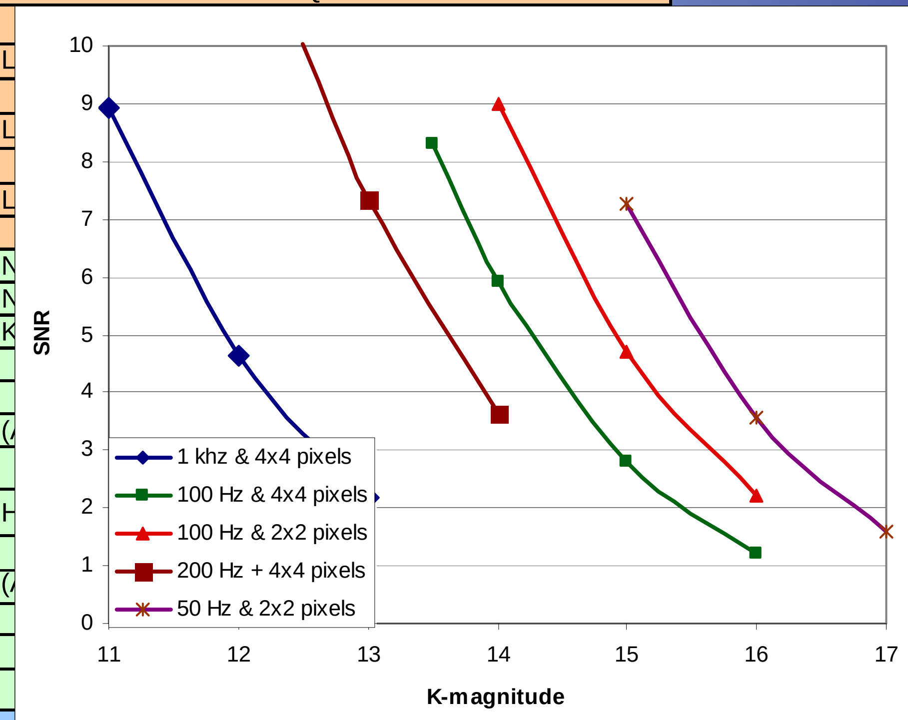
2f) Detector performance

- Concern that procured H2RG not as good as expected; what are the impacts on system performance?

Response: The detector is much better than anticipated (we only paid for 1 good quadrant). This has allowed us to go to 50 mas pixels while still maintaining a ~120” field.

Performance Analysis - SNR

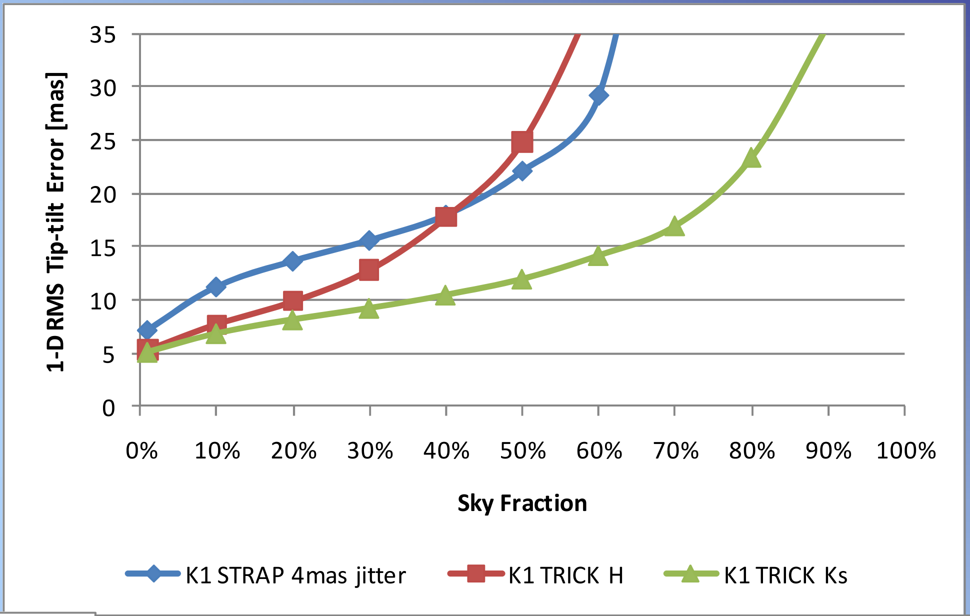
Quantity	Units	H-band	Ks-band	Notes
Telescope throughput		0.92	0.92	
AO system throughput to TRICK		0.50	0.51	
Detector QE		0.75	0.84	Measured H2RG median QE
Telescope + AO Throughput		***34.4%***	***39.7%***	
Strehl at zenith		0.12	0.30	L
Zenith angle		45	45	
Strehl at zenith angle		0.08	0.21	L
Tip-Tilt star off-axis distance	arcsec	30	45	
Isokinetic angle	arcsec	55	70	L
Tip-Tilt Star Strehl		***6%***	***13%***	
Wavelength	nm	1633	2124	N
Filter Bandwidth	nm	300	336	N
log f (in W/cm2/um) at zero mag		-13	-13.4	K
Telescope diameter	cm	1000	1000	
Flux (above atmosphere for 0 mag)	W	2.36E-08	1.05E-08	
Photon energy	J/photon	1.22E-19	9.35E-20	(
Flux (above atmosphere for 0 mag)	photon/sec	1.94E+11	1.12E+11	
Magnitude		14.5	14.0	H
Flux (above atmosphere for mag)	photon/sec	3.07E+05	2.82E+05	
Atmospheric Transmission		0.989	0.989	(
Photons on telescope	photon/sec	3.04E+05	2.79E+05	
Integration time	s	0.01	0.01	
Total signal in AO-corrected core	**electron**	***60***	***146***	
Background (sky + thermal)	mag/arcsec^2	13.6	12.56	K -band background measured on NIRC2
Zero point magnitude		25.44	24.74	NIRC2 sensitivity manual
Number of pixels		16	16	
Arcsec/pixel		0.05	0.05	
Total background	***electron***	87	119	
Background noise	**electron**	**9**	**11**	
Seeing disk photon noise	**electron**	**12**	**12**	Assumes 15% of total seeing disk energy in 4x4 pixels
Readout + dark noise	**electron**	**3.5**	**3.5**	Lab noise measurements
Photon noise	**electron**	**8**	**12**	
Noise	**electrons**	**22**	**25**	
SNR		***2.7***	***5.9***	

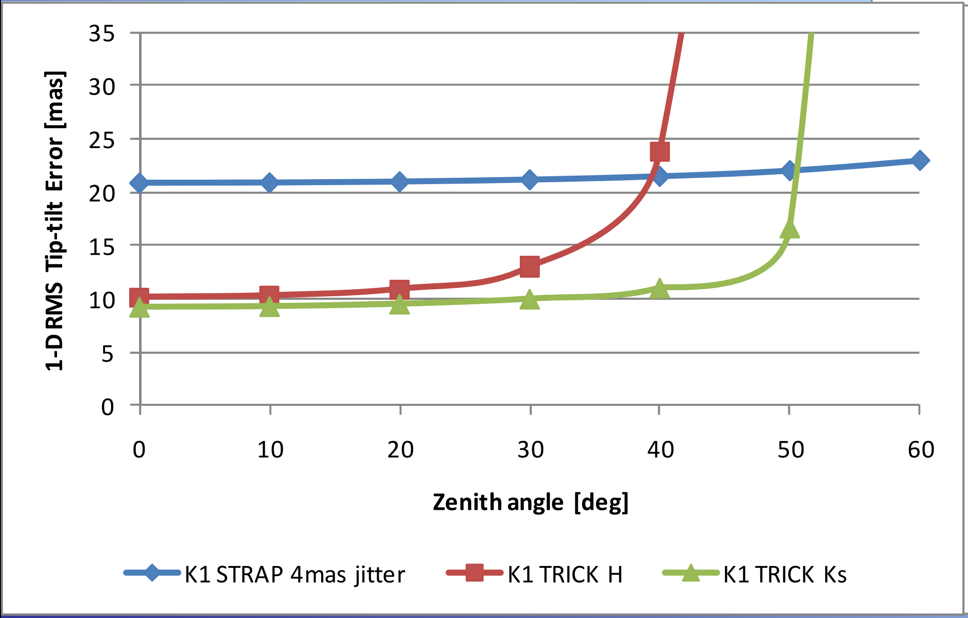


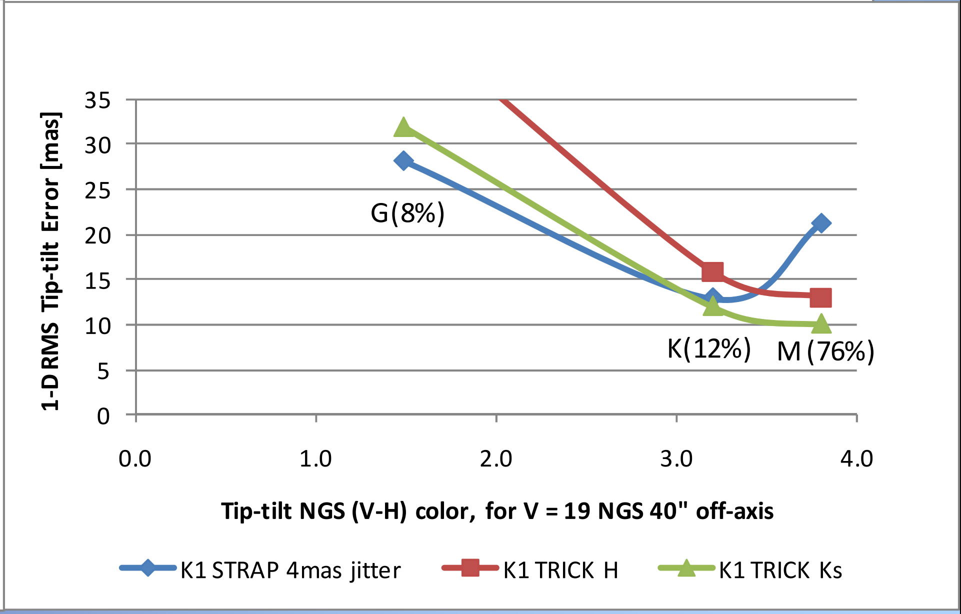
Performance Analysis – Tip-Tilt Error

Galaxy assembly science case

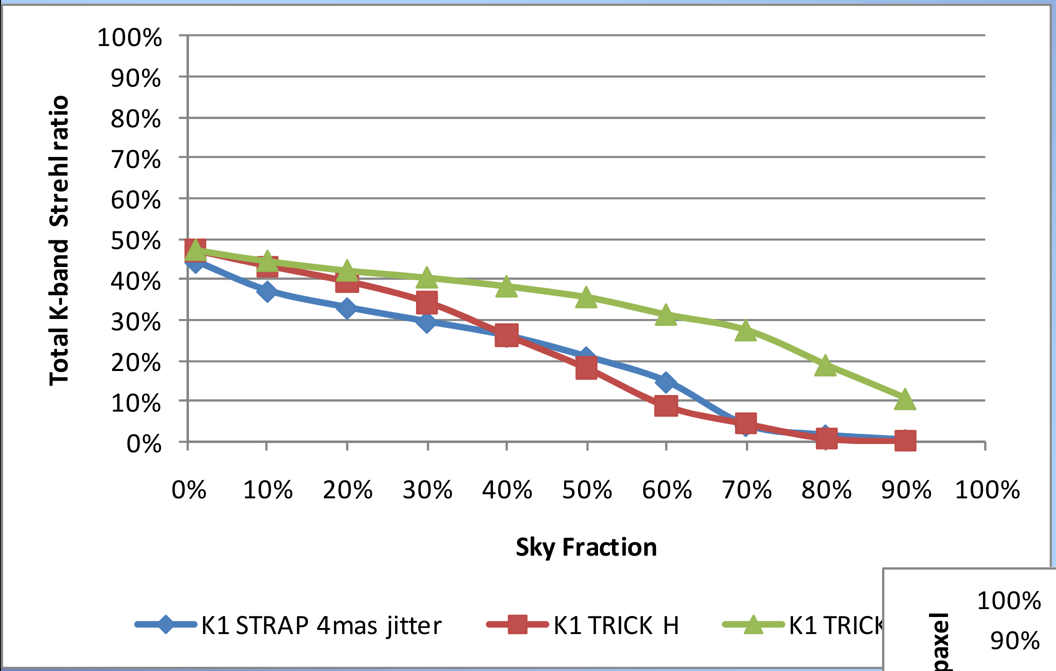
- Median seeing
- 60° galactic latitude
- 30° zenith angle
- 30 minute integration

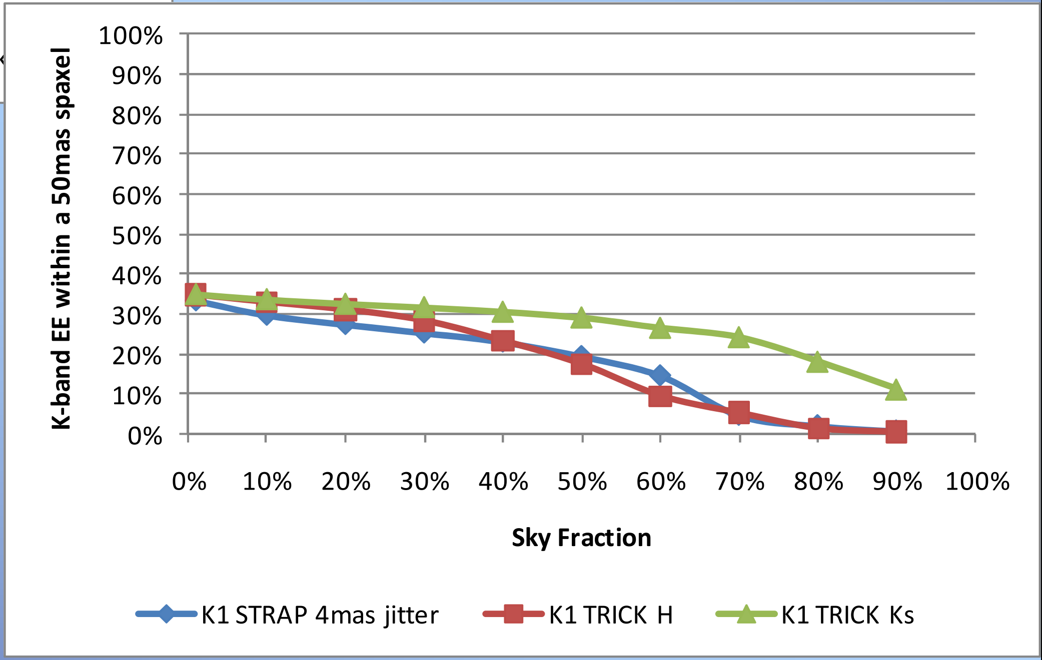






Performance Analysis – SR & EE





Reviewer Topics

2d) LBWFS

- Proposed system does not solve the sky coverage limitations with the LBWFS. Consider solutions to increase sky coverage for this system such as sending all the light to the LBWFS (requires an additional mechanism). May still be an issue in dust obscured regions.

Response:

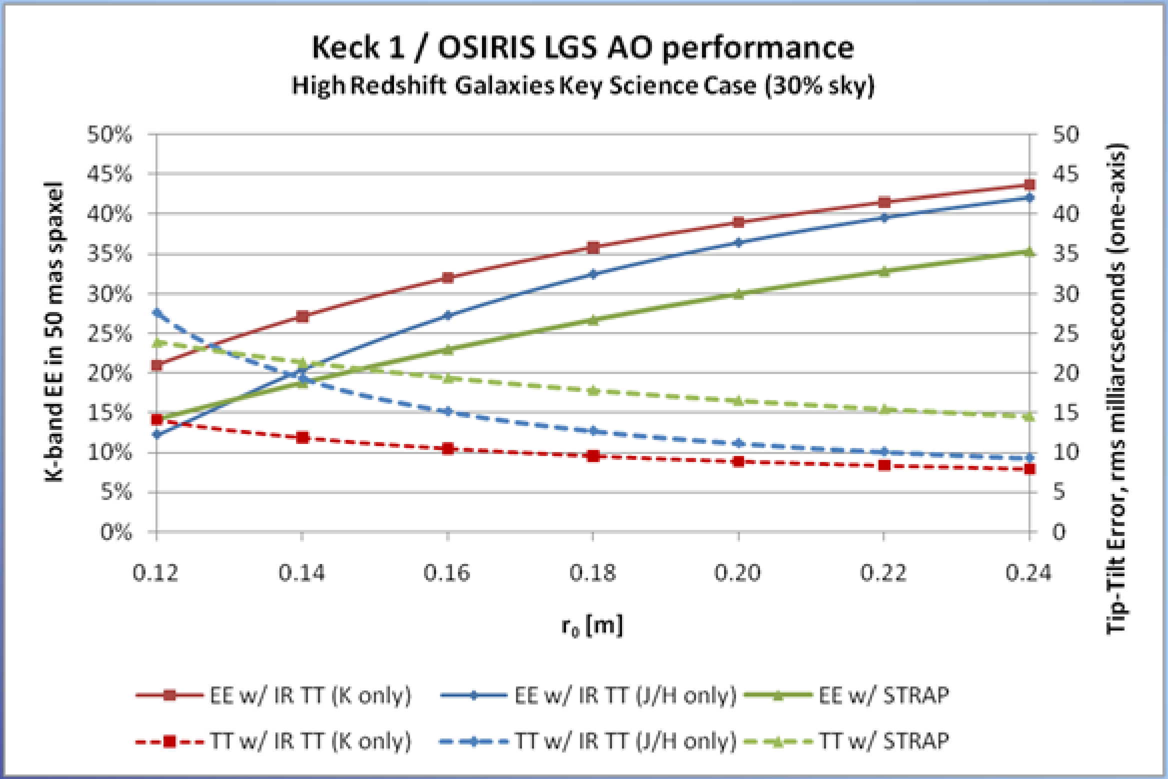
- NIR TTS performance model has LBWFS (Truth) WFS in error budget spreadsheet with assumptions consistent with 5x5 mode of current LBWFS
- Same tool/assumption used for NIR TTS sky coverage calculations
- Center launch reduces need to measure centroid offsets (mostly Na focus & Na profile (spherical ab.) changes; elongation effects greatly reduced)
- LBWFS must integrate long enough to average atmospheric effects including off-axis anisoplanatism
- In dust obscured regions probably have to take performance penalty
  - For dust obscured regions like the GC can use the currently used NGS for the LBWFS while using IRS-7 for H-band TT sensing.
  - If necessary, could move to nearby visible band star, update LBWFS measurement, leave fixed for integrations, & return to visible star periodically

RIX

- RIQ-CBO-2. How will 50 mas/pixel be re-assessed in PD?
  - Not anticipating significant changes. Understand sensitivity to plate scale choice in larger field vs smaller pixels.
- RIQ-CBO-3. Are inoperable pixels taken into account when defining ROI locations?
  - Not yet considered. PD task.
- RIQ-ABO-10. Are the performance plots using 1 or more star?
  - 1 star.

RIX

- RIQ-ABO-11. Not demonstrated that NIR TTS will function in 80th percentile seeing (SR-6). Performance in low Strehl regime important to understand.
  - Agreed. Loosely extrapolated from Fig. 49 (below) which shows reasonable performance at r0=12 cm. Low Strehl performance important to understand in PD.

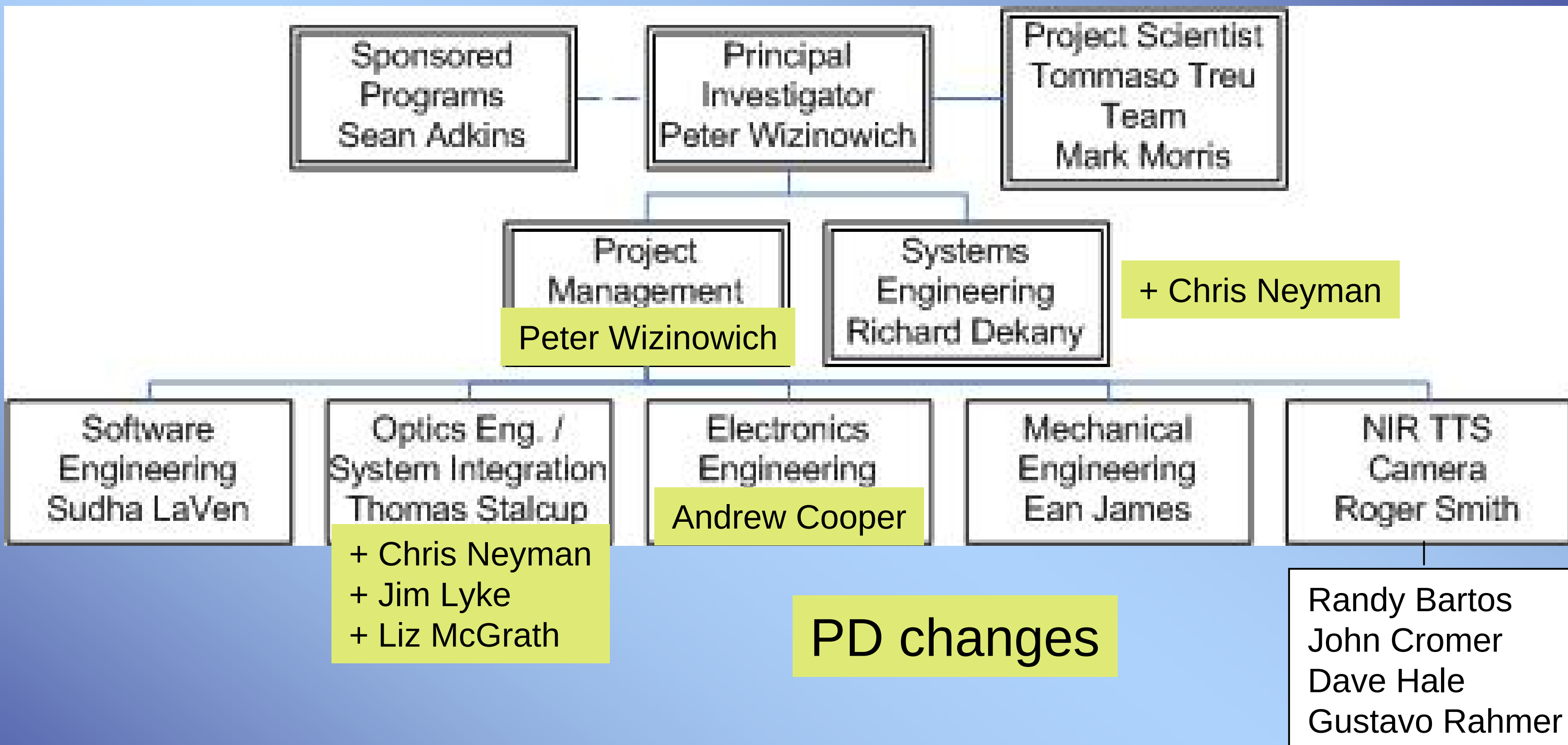


RIX

- RIQ-RDC-3. Effects of pixel/pixel charge dispersion taken into account?
  - No, but small. Diffusion length, σ = 1.87 $\pm$ 0.02 μm = 0.104 pixels.
  - 1% electrical crosstalk between pixels.
- RID-RDC-1. SR calculation appears to only use 1-pixel read noise.
  - Corrected in this presentation. Also corrected read-noise to 3.5e-.
- RIQ-RDC-4. Are SR-13 & 14 met if SNR calculation recomputed using total read noise?
  - SNR spreadsheet a sanity check. Simulations by van Dam & analysis by Dekany more rigorous. Van Dam simulation indicated good performance for K=16 using correlation algorithm. During PD will compare assumptions & results in these 3 tools.
  - K-band SNR = 3.6 for K=16, 2x2 pixels & 50 Hz.
  - H-band SNR =1.2 for H=16. May need to relax SR-14 to H=15.

Project Management

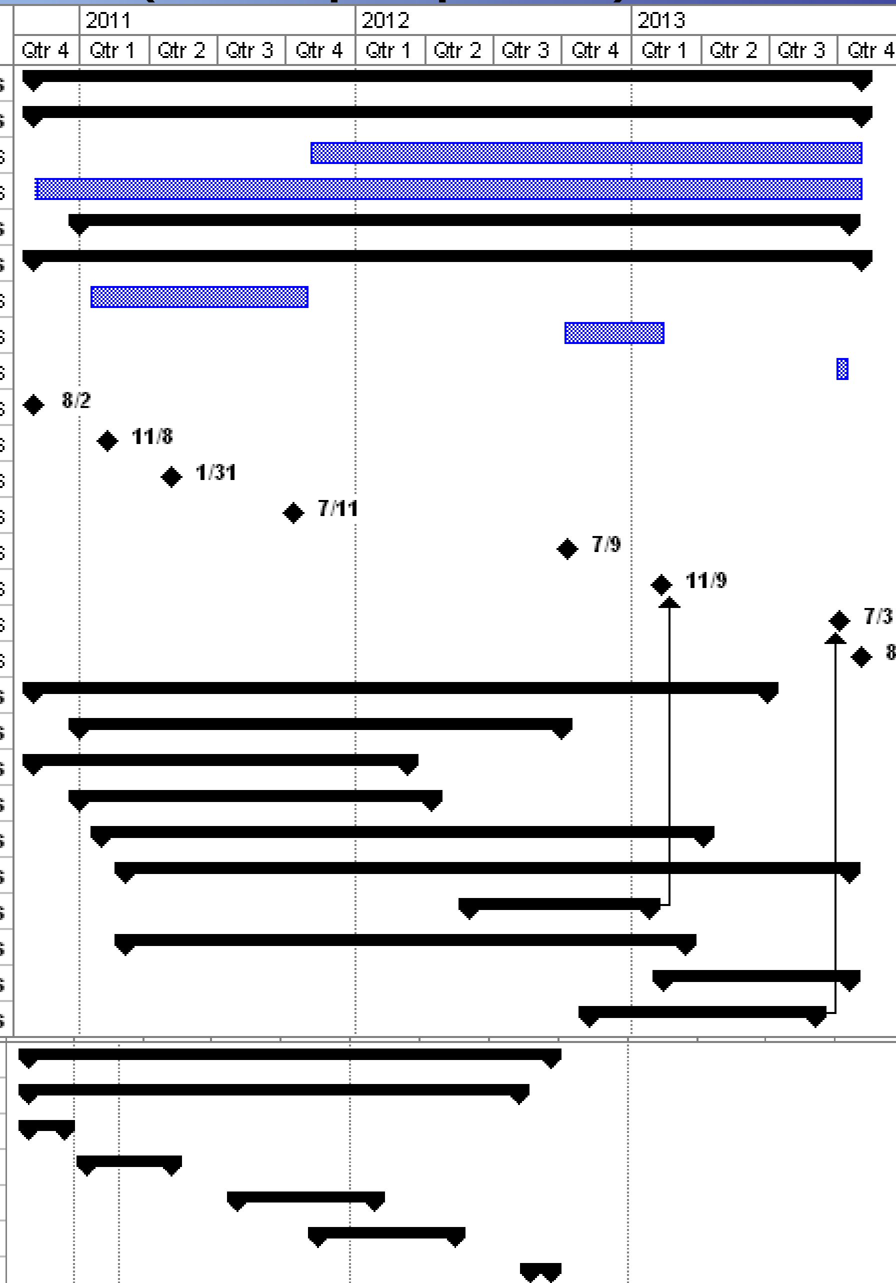
Project Organization



Full Project Plan (from proposal)

ID	WBS	Task Name	Work
1	1	**Keck I TTS Facility**	**7,210 hrs**
2	**1.1**	**Project Management**	**1,650 hrs**
3	1.1.1	Planning	280 hrs
4	1.1.2	Management & Reporting	500 hrs
5	**1.1.3**	**Travel**	**120 hrs**
9	**1.1.4**	**Milestones & Design Reviews**	**750 hrs**
10	1.1.4.1	Design Review Support	350 hrs
11	1.1.4.2	Pre-Ship Review Support	300 hrs
12	1.1.4.3	Handover Review Support	100 hrs
13	1.1.4.4	Project Start	0 hrs
14	1.1.4.5	System Design Review	0 hrs
15	1.1.4.6	Preliminary Design Review	0 hrs
16	1.1.4.7	Detailed Design Review	0 hrs
17	1.1.4.8	TTF Sensor Pre-Ship Review	0 hrs
18	1.1.4.9	Pre-Summit Review	0 hrs
19	.1.4.10	Handover Review	0 hrs
20	.1.4.11	TAC-allocated Science Starts	0 hrs
21	**1.2**	**Systems Engineering**	**600 hrs**
26	**1.3**	**NIR TT Sensor Camera**	**0 hrs**
40	**1.4**	**Opto-mechanics**	**890 hrs**
57	**1.5**	**Controls**	**760 hrs**
76	**1.6**	**Operations Software**	**960 hrs**
86	**1.7**	**Integration, Test & Commissioning**	**2,030 hrs**
87	**1.7.1**	**Laboratory I&T**	**570 hrs**
100	**1.7.2**	**AO Facility Modifications**	**300 hrs**
106	**1.7.3**	**Telescope I&T**	**1,160 hrs**
119	**1.8**	**Operations Handover**	**320 hrs**

1	**1.3**	**NIR TT Sensor Camera**	**6,022.4 hrs**
2	**1.3.1**	**Project management, meetings & reviews**	**834 hrs**
54	**1.3.2**	**Systems engineering**	**128 hrs**
64	**1.3.3**	**Design**	**1,012 hrs**
95	**1.3.4**	**Procurement and Fabrication**	**2,684.4 hrs**
155	**1.3.5**	**System integration and test at Caltech**	**1,060 hrs**
178	**1.3.6**	**Commisioning support at Keck**	**304 hrs**



Project Budget

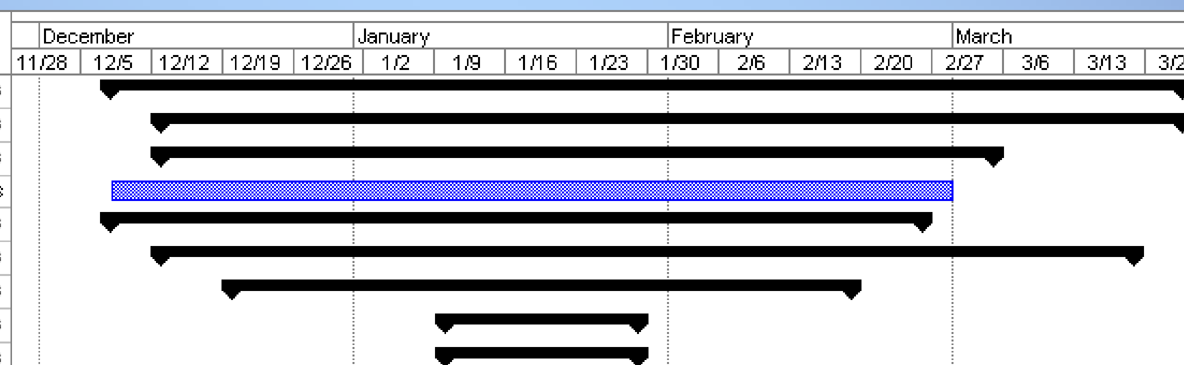
Expenses		Person Months	Notes	Year One ACTUAL 8/1/10 9/30/10	Year Two ACTUAL 10/01/10 11/21/10	Year Two 11/22/10 09/30/11	Year Three 10/01/11 09/30/12	Year Four 10/01/12 09/30/13	Total Revised Budget
A. Senior Personnel	**Title**								
P. Wizinowich	Principal Investigat	2.4		$ 4,239	$ 8,145	$ 15,809	$ 7,830	$ 8,717	$ 44,740
T. Stalcup	Project Manager	15		$ 670	$ 6,258	$ 26,201	$ 35,702	$ 47,555	$ 116,386
(2) Total Senior Personnel		18	1	**$ 4,909**	**$ 14,403**	**$ 42,010**	**$ 43,532**	**$ 56,272**	**$ 161,126**
B. Other Personnel									
(0) Post Doctoral Associates				$ -		$ -	$ -	$ -	$ -
(9) Other Professionals		23	1	$ 4,922	$ 5,995	$ 88,192	$ 66,630	$ 35,339	$ 201,078
(0) Graduate Students				$ -		$ -			$ -
(0) Undergraduate Students				$ -		$ -			$ -
(1) Secretarial - Clerical (If Charged Directly)			1	$ -		$ -	$ -	$ -	$ -
(0) Other				$ -					$ -
Total Salaries and Wages				**$ 9,831**	**$ 20,398**	**$ 130,202**	**$ 110,162**	**$ 91,611**	**$ 362,204**
C. Fringe Benefits			2	$ 2,320	$ 5,263	$ 33,592	$ 28,091	$ 23,332	$ 92,599
Total Salaries, Wages and Fringe Benefits				**$ 12,151**	**$ 25,661**	**$ 163,794**	**$ 138,253**	**$ 114,943**	**$ 454,803**
D. Equipment									
H2RG detector				$ -	$ 250,000			$ -	$ 250,000
ARC SDSU-III readout electronics				$ -	$ 6,000				$ 6,000
Microgate RTC modifications				$ -		$ 27,120	$ 40,680		$ 67,800
Dewar optics				$ -		$ 10,000	$ 13,000		$ 23,000
Dichroic beamsplitter				$ -		$ -	$ 11,000		$ 11,000
Host computer				$ -		$ 5,500	$ -		$ 5,500
Single board computer				$ -		$ 5,500	$ -		$ 5,500
Focus stage				$ -		$ -	$ 6,600	$ -	$ 6,600
Total Equipment				**$ -**	**$ 256,000**	**$ 48,120**	**$ 71,280**	**$ -**	**$ 375,400**
E. Travel									
Domestic			3	$ -		$ 2,066	$ 4,000	$ -	$ 6,066
Foreign				$ -		$ -	$ -	$ -	$ -
F. Other Supplies				$ -		$ -	$ -	$ -	$ -
G. Other Direct Costs									
1. Materials and Supplies				$ 331	$ 44	$ 13,375	$ 14,300	$ 2,200	$ 30,250
2. Publication Costs/Documentation/Dissemination				$ -		$ -	$ -	$ -	$ -
3. Consultant Services				$ -		$ -	$ -	$ -	$ -
4. Computer Services				$ -		$ -	$ -	$ -	$ -
5. Subawards	CIT		4	$ -	$ -	$ 405,105	$ 149,730	$ -	$ 554,835
6. Other				$ -		$ -	$ -	$ -	$ -
Total Other Direct Costs				**$ 331**	**$ 44**	**$ 418,480**	**$ 164,030**	**$ 2,200**	**$ 585,085**
H. Total Direct Costs				**$ 12,482**	**$ 281,705**	**$ 632,460**	**$ 377,563**	**$ 117,143**	**$ 1,421,354**
I. Indirect Costs (F&A)									
Modified total direct costs (Base)			5	$ 12,482	$ 25,705	$ 179,236	$ 156,553	$ 117,143	$ 491,119
Rate		60.00%		$ 6,865	$ 17,438	$ 106,150	$ 93,932	$ 70,286	$ 294,671
Total Indirect Costs				**$ 6,865**	**$ 17,438**	**$ 107,541**	**$ 93,932**	**$ 70,286**	**$ 296,062**
J. Total Direct and Indirect Costs				**$ 19,347**	**$ 299,143**	**$ 740,002**	**$ 471,495**	**$ 187,429**	**$ 1,717,417**
WMKO cost share							$ 15,000	$ 28,000	$ 43,000
Revised Proposal Funding Profile				$ 314,511		$ 715,613	$ 498,447	$ 187,429	$ 1,716,000
Budget (Proposal + WMKO) - Plan				$ 295,164	$ (299,143)	$ (24,389)	$ 41,952	$ 28,000	**$ 41,583**

Preliminary Design Budget & Schedule

	WMKO										COO						
	EJ	**SK**	**SL**	**JL**	**CN**	**TS**	**PS**	**CT**	**PW**	**AC**	**RB**	**JC**	**RD**	**DH**	**GR**	**RS**	**Total**
Total (hrs) =	136	10	287	79	215	107	32	34	218	109	252	60	84	186	40	164	2013
Total (wks) =	3.4	0.3	7.2	2.0	5.4	2.7	0.8	0.9	5.5	2.7	6.3	1.5	2.1	4.7	1.0	4.1	50.3
12 work weeks (14 calendar) % =	28%	2%	60%	16%	45%	22%	7%	7%	45%	23%	53%	13%	18%	39%	8%	34%	
SD estimate total (hrs) =	158	0	44	4	40	92	0	8	201	20	10	10	58	4	0	73	721

	WMKO	**COO**
Proposal est.	2257	1478
SD estimate	25%	10%
PD plan	54%	53%
DD remainder	21%	36%

ID	WBS	Task Name	Work
1	**1**	**NIR TTS Preliminary Design**	**1,227 hrs**
2	**1.1**	**Project Management**	**229 hrs**
11	**1.2**	**Systems Engineering**	**210 hrs**
30	1.3	Camera System	0 hrs
31	**1.4**	**Opto-mechanical System**	**248 hrs**
40	**1.5**	**Controls System**	**326 hrs**
49	**1.6**	**Operations Software System**	**190 hrs**
62	**1.7**	**Integration, Test & Commissioning**	**16 hrs**
64	**1.8**	**Operations Handover**	**8 hrs**



Risk Assessment

SDR Likelihood \ SDR Consequences	1	2	3	4	5
5					
4		3			
3		6	1,4		
2			5	2	
1					

#	Conse-quence	Like-lihood	Description	SDR Status	PDR Proposed Mitigation
1	3	3	Tip-Tilt measurement accuracy requirement not achieved working off null	The selected approach (to allow the use of 3 stars, & to compensate for differential atmospheric refraction & to allow small positional adjustments) requires good tip-tilt performance even when the tip-tilt star is located up to 25 mas in x & y from the intersection of 4 pixels. The proposed correlation algorithm achieves the required performance.	a) Do additional analysis of the correlation algorithm approach to ensure it will meet the requirements. b) Further develop the backup centroiding approach, also being implemented, which would require seeing disk background subtraction &/or Strehl estimation. c) Ensure that the fold mirror in the tip-tilt sensor path could be upgraded with a tracking device to keep 1 star positioned on a quad cell.
2	4	2	Advantages of NIR tip-tilt sensing not achieved	Many groups have predicted improvements with this technique but this is an unproven concept on the sky.	Perform additional checks on performance analysis.
3	2	4	Schedule delays due to personnel non-availability	The SDR is 1 month late, & the PDR will likely be ~ 6-8 weeks late, due to personnel still being involved in other projects. Caltech involvement in preparing SDR has been limited. At WMKO issue will extend through ~ Feb/11.	a) At WMKO, more PI involvement & bringing in Neyman. b) At WMKO project priority will significantly increase as K1 free space transport & center launch system are completed in FY11. c) Collaborate with GMT for analysis
4	3	3	Inadequate contingency (project requires more resources than budgeted)	Project already had effectively a \$160k reduction. Microgate fixed price quote assumes modification of an existing interface.	a) Perform a more careful cost evaluation for PDR. b) Only accept goals after sufficient budget clearly identified. c) Ensure PD phase stays in budget. d) Test out Microgate interface during PD. e) Review COO SW estimate by mid-Jan.
5	3	2	Detector failure	We rely on 1 key & expensive (\$250k) component.	a) Smith has a spare detector that could be used as a backup
6	2	3	Conflicts with observing schedule impact delivery schedule	The observing schedule is defined in 6 month increments with some TBD engineering.	Not an issue to be addressed in PDR. Longer term we will request adequate implementation gaps & engineering nights. A quick switch back to the operational system is practical.

Reviewer Topics

3a) Current contingency of 3% is a concern. Recommend to propose some descope (requirements &/or goals) to save up to 20-25% of contingency or be ready to come up with amount if necessary.

- Possible descope to be considered: 1 star instead of 3.

Response: We had intended to work on getting the contingency to 10% by PDR. We will look at additional contingency, however 20-25% seems high for a project of this scope.

3b) Availability of key people is a concern. People may not be available when needed. Recommend to develop a backup plan.

Response: We did demonstrate flexibility in order to complete the SDR with only a 1 month delay despite personnel unavailability at COO & WMKO.

Near-term issue is for the PD phase. COO has said the identified people are available (this was an issue during SD). WMKO people have been identified to fill the roles of people that were originally planned for this phase but who are not available.

The WMKO situation will improve after the PDR as the K1 LGS FST project is completed & the K2 CLS project completes DD.

Beyond remaining flexible, a PDR schedule delay may be the only option.

RIX

- RIQ-TT-5. Contingency seems really low. Pity if follow-up calibration & user support software/tools were to suffer as a result.
  - Contingency is too low (forced into this by NSF budget reduction). To deliver on all requirements (as opposed to goals) will need to get back up to at least 10% contingency by PDR. Choices will need to be made.

Reviewer Topics

4a) Project management now performed by Peter to solve Observatory staff availability issue. How will NGAO impact Peter's availability to this project?

Response: NGAO is currently on-hold pending funding. Peter will be involved in fund raising.

Peter has been able to make time to lead the SD phase.

Peter's availability & those of others could potentially delay the PDR.

4b) Upgrade of the 3 RTC will have to be well coordinated as to not impact observatory operations (in particular K2).

Response: Agreed. We do have considerable experience in doing upgrades so as not to impact ops, including CCB review. The modifications will be fully tested prior to summit installation, & will be tested on K1 prior to K2.

In Conclusion

- We feel that we are ready to move into the PD phase of this project.
- The reviewer input (topics & RIX) has already proven to be helpful, as doubtlessly will be the reviewer report. We will make use of these in the PD.
- Thanks to all involved. Reviewers & contributors.