FTT/NAS & FLC Conceptual Design Review

14th September 2010

Introduction

Reviewing conceptual design of two systems:

- FTT/NAS
  - For science operations
  - Target acquisition (NAS)
  - Correction of atmospheric tip-tilt variations (FTT)
- FLC
  - For commissioning and integration
    - Ready in time for 1st Unit Telescope
  - NAS-like functions
  - Standalone capability

Outline of this Presentation

- Topic-by-topic presentation, **questions** after each topic:
  - All FTT/NAS topics (including “system design” and “interfaces” for FLC)
    - Derived Requirements
    - System Design (also for FLC)
    - Optical Layouts
    - Camera Selection
    - Conceptual Opto-Mechanical Design
    - Conceptual Thermal Design
    - Conceptual Electronics Design
    - Conceptual Software Design
    - Lifetime and Maintenance
    - Interfaces (also for FLC)
    - Summary and path forward
  - FLC topics, only where design differs from FTT/NAS

FTT/NAS Top-level Requirements (i)

- See INT-403-ENG-0003
- Key requirements:
  - Acquisition and fast-guiding modes
  - Limiting sensitivity ≥ 16^{th} magnitude
  - Zero-point stability ≤ 0.060″ for $\Delta T = 5$ °C
  - $T - T_{ambient} \leq 2$ °C for components on Nasmyth optical table; power consumption (dissipation?) < 250 W
  - Space constraints on Nasmyth optical table

FTT/NAS Top-level Requirements (ii)

- Key requirements (cont.):
  - Time-varying objective point for dispersion compensation and/or off-axis reference star
  - Streaming of diagnostic data to ISS
  - Dither function synchronised to UTC

FLC Top-level Requirements

- See INT-403-TSP-0107
- Key requirements:
  - Operating roles with or without ISS
  - All FTT/NAS operating modes except FTT mode
  - FOV ≥ 60″
  - Limiting sensitivity ≥ 10th magnitude
  - Stability ≤ 1″ for ΔT = 5 °C
  - Operation down to $T_{ambient}$ ≥ -15°C
  - Streaming of diagnostic data to ISS

FTT/NAS Derived Requirements

FTT/NAS Derived Requirements: Assumptions

- Single camera for acquisition and fast tip-tilt sensing; same focusing optics for all modes
- Use of EMCCD with:
  - Format 512 × 512 pixels
  - Read noise 50 electrons RMS

FTT/NAS Derived Requirements

- Pixel scale between 0.12 and 0.2 arcsec/pixel
  - Lower limit set by FOV requirement
  - Upper limit for centroiding accuracy
- FTT mode sub-frame size $\geq 3.6'' \times 3.6''$
  - i.e. 18 to 30 pixels square
  - Allows for worst-case field rotation over 300 second observation when using an off-axis reference at 10″ separation

FTT/NAS Derived Requirements: Image Quality

Element	Degree of freedom	Tolerance
Dichroic	δx	
"	δy	
"	δz	> 5 mm
"	$\delta \theta_x$	0.37°
"	$\delta \theta_y$	0.37°
"	$\delta \theta_z$	
Focusing lens	δx	> 5 mm
"	δy	> 5 mm
"	δz	0.35 mm
"	$\delta \theta_x$	0.93°
"	$\delta \theta_y$	0.93°
"	$\delta \theta_z$	
Fold mirror #1	δx	
"	δy	
"	δz	0.17 mm
"	$\delta \theta_x$	0.65°
"	$\delta \theta_y$	1.9°
"	$\delta \theta_z$	
Fold mirror #2	δx	
"	δy	
"	δz	0.22 mm
"	$\delta \theta_x$	0.77°
"	$\delta \theta_y$	1.2°
"	$\delta \theta_z$	
FTT/NAS sensor	δx	
"	δy	
"	δz	0.35 mm
"	$\delta \theta_x$	> 5°
"	$\delta \theta_y$	> 5°
"	$\delta \theta_z$	

FTT/NAS Derived Requirements: Stability

Element	Degree of freedom	Budget allocation	Element	Degree of freedom	Budget allocation
Dichroic	δx		Focusing lens	δx	0.47 μm
"	δy		"	δy	0.35 μm
"	δz		"	δz	250 μm
"	$\delta \theta_x$	0.047″	"	$\delta \theta_x$	0.75″
"	$\delta \theta_y$	0.045″	"	$\delta \theta_y$	0.70″
"	$\delta \theta_z$		"	$\delta \theta_z$	n/a
Fold mirror #1	δx		Fold mirror #2	δx	
"	δy		"	δy	
"	δz	0.59 μm	"	δz	0.31 μm
"	$\delta \theta_x$	0.090″	"	$\delta \theta_x$	0.064″
"	$\delta \theta_y$	0.049″	"	$\delta \theta_y$	0.074″
"	$\delta \theta_z$		"	$\delta \theta_z$	
FTT/NAS sensor	δx	0.47 μm			
"	δy	0.35 μm			
"	δz	250 μm			
"	$\delta \theta_x$				
"	$\delta \theta_y$				
"	$\delta \theta_z$	2.32″			

FTT/NAS Derived Requirements: Thermal Management (i)

- Assumptions:
  - EMCCD camera in environmentally-controlled enclosure:
    - Camera enclosure temperature is controlled to ensure exterior surface within 2 °C of ambient
    - Camera environment controlled at all times, so always ready to be switched on
    - Heat removed from camera head and enclosure by fluid and exchanged into one of telescope coolant loops

FTT/NAS Derived Requirements: Thermal Management (ii)

- Derived requirements from thermal modelling:
  - Max. enclosure internal air temperature: 30 °C
  - Min. enclosure internal air temperature: 0 °C
  - Min. internal air/external surface temperature differential: 3 °C (goal 8 °C)
  - Enclosure air dew point: coldest internal component -5 °C
  - Enclosure residual heat 5 W
  - Emissivity of enclosure outer surface > 0.7
  - Residual camera heat 20 W [TBC]
  - Camera enclosure space envelope: 340 mm × 300 mm × 350 mm max.
  - CPU and interface electronics power dissipation allowance 180 W
  - Camera interface and controller power dissipation allowance 70 W
  - Power consumption 350 W

FTT/NAS Derived Requirements: Closed-loop Bandwidth

- Assumptions:
  - Frame rate 1 kHz
  - Compute latency 100 μs
- Derived requirements:
  - Readout latency req. 1130 μs (for 40 Hz 3dB b/w)
  - Readout latency goal 790 μs (for 50 Hz 3dB b/w)

FTT/NAS Derived Requirements: Limiting Sensitivity (i)

- Adopted tip-tilt residual error budget for observation of 16th magnitude AGN in 0.7″ seeing (15 Hz b/w):

Tilt error	RMS error /milliarcsec
UT residual mount error	20
UT residual wind shake	30
Residual seeing tilt	30
Speckle noise centroiding error	15
Detection noise centroiding error	34
Total	**60**

FTT/NAS Derived Requirements: Limiting Sensitivity (ii)

- Would require 102% throughput for FTT optics (dichroic, focusing optic, fold mirrors) to meet budget, assuming readout noise negligible
- If we assume (conservatively) 85% throughput, tip-tilt residual is 2% over budget
  - Corresponds to extra 0.5% visibility loss in H band
  - Budget is satisfied at magnitude 15.8
- Need EMCCD gain ≥ 250 for 50e^- readout noise to be negligible

FTT/NAS Derived Requirements: Dynamic Range

- Assumptions:
  - FTT mode frame rate 1 kHz (except for faintest objects)
  - NAS mode: exposure time independent of frame rate; minimum exposure 1 ms
- Derived requirements:
  - Two EMCCD gain settings needed to allow observations spanning magnitudes 3.3–16 in good seeing
  - 2-magnitude overlap between settings allows for target and calibrator to be observed with same gain setting

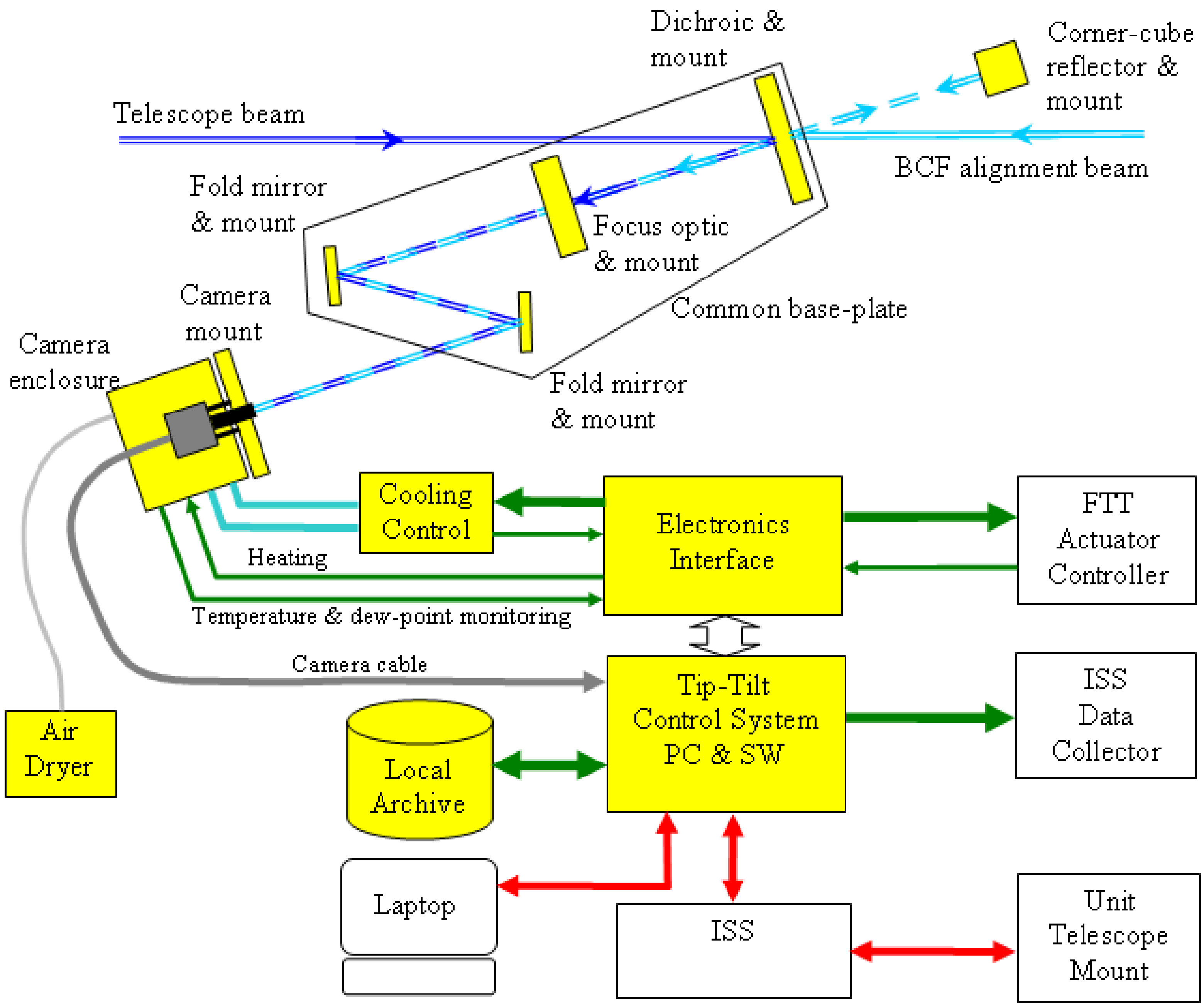
FTT/NAS Derived Requirements

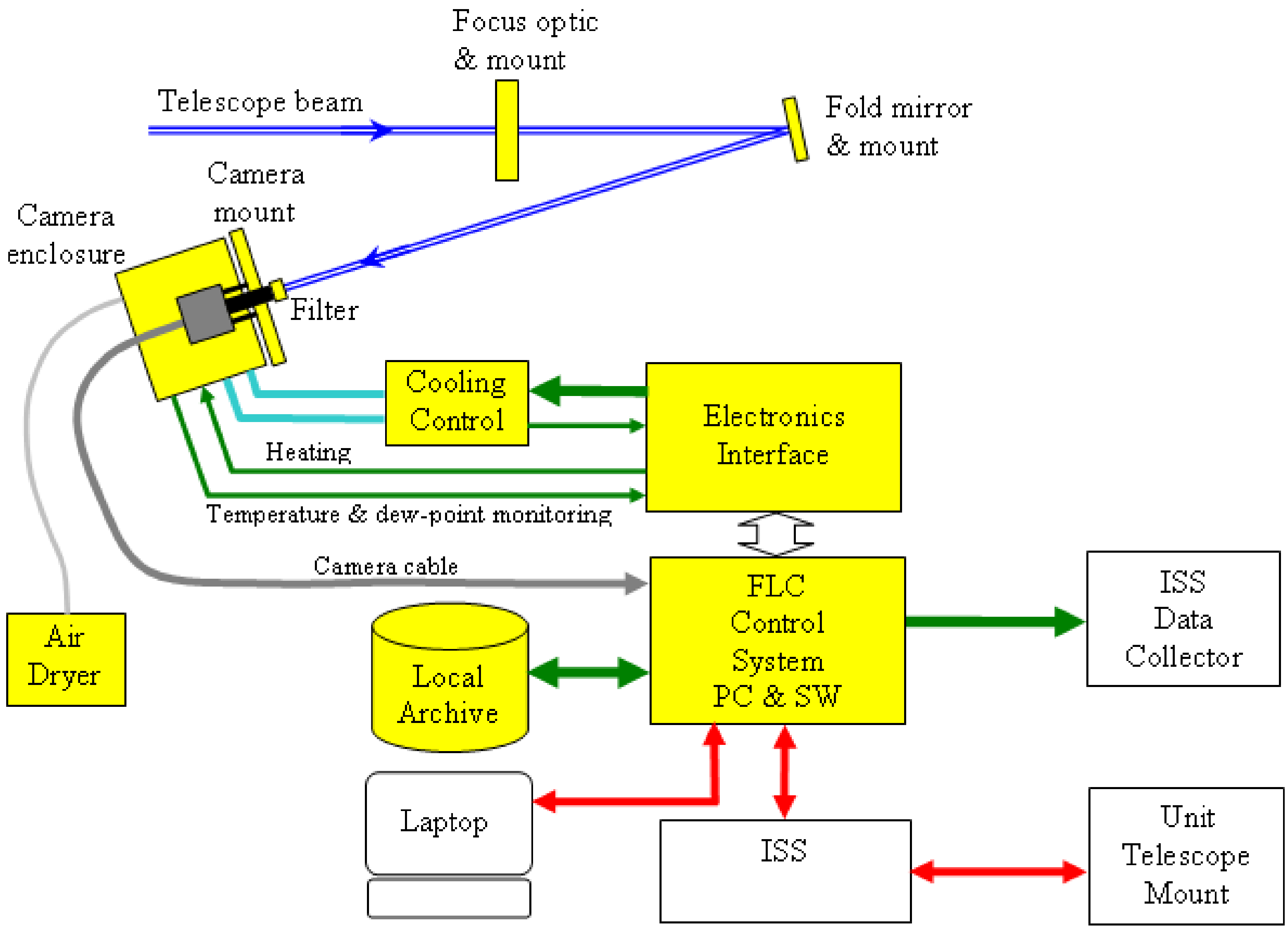
Questions?

System Design: FTT/NAS & FLC

System Design

- Electron-Multiplying CCD needed to meet FTT closed-loop bandwidth and limiting sensitivity requirements
- Chosen to use same camera for target acquisition (NAS mode) and fast tip-tilt correction, with fixed pixel scale
  - Need 2.5 pixels across short-exposure FWHM for accurate centroiding
  - Hence minimum CCD format 500 × 500 pix. for NAS FOV
  - Custom 23 × 23 pixel subframe readout for FTT mode ⇒ pixel scale > 0.15″/pix
- EMCCDs must be operated above 0 °C, non-condensing
  - Hence camera enclosed in a thermally-controlled environment, controlled at all times
- Opto-mechanical design driven by requirement to maintain image position stable to 0.5 μm over ΔT = 5 °C
  - Optical mounts without adjusters
  - Aluminium mounts with symmetric designs


Dichroic & mount
Corner-cube reflector & mount
Telescope beam
BCF alignment beam
Fold mirror & mount
Focus optic & mount
Camera mount
Camera enclosure
Common base-plate
Fold mirror & mount
Cooling Control
Electronics Interface
FTT Actuator Controller
Heating
Temperature & dew-point monitoring
Camera cable
Tip-Tilt Control System PC & SW
ISS Data Collector
Air Dryer
Local Archive
Laptop
ISS
Unit Telescope Mount


Focus optic
& mount
Telescope beam
Fold mirror
& mount
Camera
mount
Camera
enclosure
Filter
Cooling
Control
Electronics
Interface
Heating
Temperature & dew-point monitoring
Camera cable
FLC
Control
System
PC & SW
ISS
Data
Collector
Air
Dryer
Local
Archive
Laptop
ISS
Unit
Telescope
Mount

Relationship between FTT/NAS & FLC

- FLC delivered end July 2011 vs. ~Feb 2012
- Common aspects:
  - EMCCD camera
    - Allows interchange of camera and software
  - Thermally-controlled camera enclosure
  - Camera mount
  - Computer and interface electronics
  - FLC software is subset of FTT/NAS software
    - Except for additional functionality specified by UTM vendor

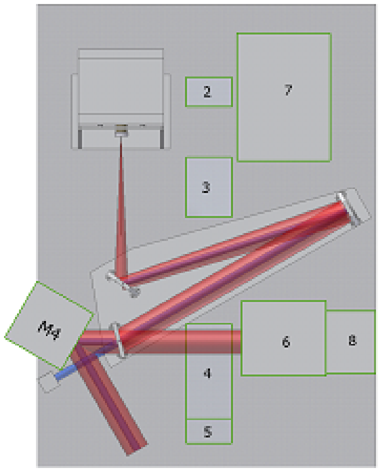
System Design

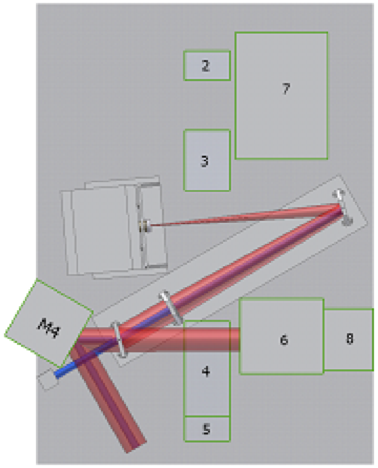
Questions?

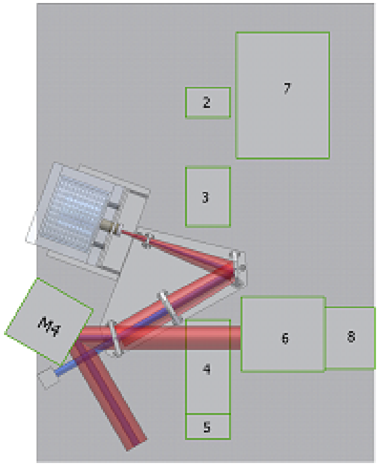
FTT/NAS Optical Layouts

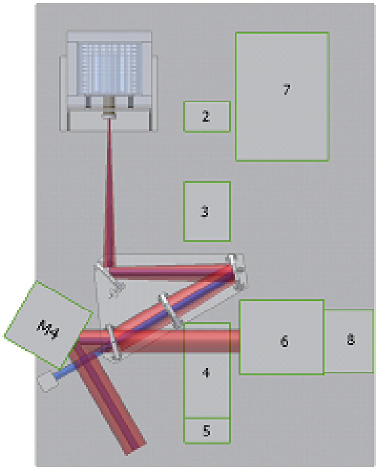
Four Candidate Layouts

- **Off-Axis Paraboloid** (top left)
- **Direct Transmissive** (top right)
- **Dog-Leg Transmissive** (bottom right)
  - Extra fold mirror for compact baseplate
- **Zoom Transmissive** (bottom left)
  - Negative lens allows camera adjacent to baseplate









Notes on Candidate Layouts

- All layouts use a common baseplate for the dichroic, focusing optic, and fold mirror(s)
  - Mitigates local tilts or deformations of Nasmyth table due to temperature changes
  - Camera not mounted on baseplate to isolate optics from heat and vibration
- AO, ADC envelopes respected
- AAS components have been moved as permitted by the Technical Requirements
- We have allowed space for the dichroic mount to be replaced in Phase II with a customer-supplied mount that switches between two dichroics (space envelope from MRO)

Preferred Layout

- OAP, DT have long baseplates which are insufficiently stiff
  - First resonance ~40 Hz
- Transmissive layouts have 20 $\times$ looser tolerance on angular stability of focusing optic
- No success yet in designing lenses for Zoom layout that work over required bandpasses and temperatures
- Hence preferred layout is DLT
  - Most compact feasible layout
  - Less or equally sensitive to misalignment compared with other layouts
- Will continue to investigate lens design for Zoom layout

FTT/NAS Optical Layouts

Questions?

Camera Selection: FTT/NAS & FLC

Candidate Cameras

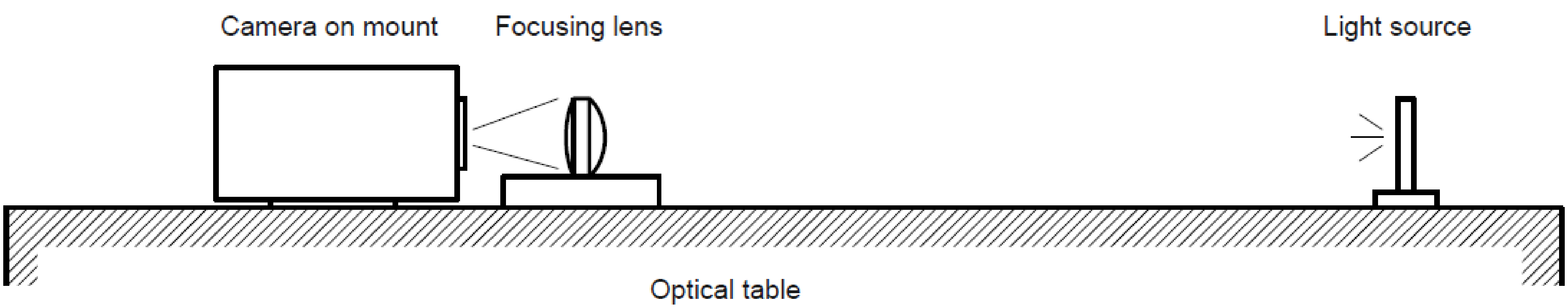
- Selection criteria:
  - Back-illuminated EMCCD sensor
  - Format at least 500 × 500 pixels
  - Likelihood of low readout latency
  - Water-cooling option
  - Vendor presence in UK and US
- Candidate cameras evaluated in lab:
  - Andor iXon^{EM}+ 897
  - Princeton Instruments ProEM 512B
- Reserve, evaluated from documentation and vendor queries:
  - Hamamatsu ImagEM C9100-13
- All three cameras use the same e2v EMCCD chip

Camera Evaluation Criteria

- Price
- Hardware considerations:
  - Packaging, cabling requirements, mounting arrangement
- CCD clocking
  - Clocking speed, readout noise
- Power, environment, cooling
  - Power dissipation, temperature and humidity ranges, cooling arrangements
- Latency and programming considerations
  - Readout latency, Linux support, source code availability

Camera Laboratory Tests

- Measured readout latency
- (Measured noise performance)
- Measured power dissipation
  - Voltage and current
  - Temperature rise of fan-forced air
- Measured mechanical stability of CCD chip



Camera Evaluation Conclusions

- Andor iXon^{EM}+ 897
  - ✓ Latency in spec.
  - ✓ Power dissipation in spec.
  - ✓ Linux support, real-time driver proof-of-concept
  - Need to pay for development of custom subframe readout (max. 23 × 23 pix. for all cameras)
- Princeton Instruments ProEM 512B
  - Latency 1000–1300 μs (requirement 1130 μs)
  - ✗ Head power dissipation 30 W (requirement 20 W)
  - Linux support “soon”
- Hamamatsu ImagEM C9100-13
  - Latency untested
  - ✓ Linux support, real-time driver should be straightforward
  - Survival temperature -10 °C (warranty implications only)

Camera Selection

Questions?

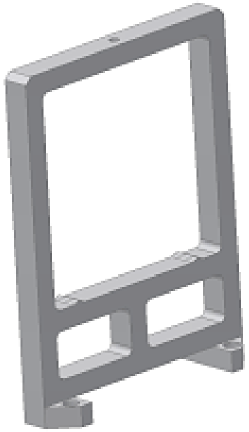
FTT/NAS Conceptual Opto-Mechanical Design

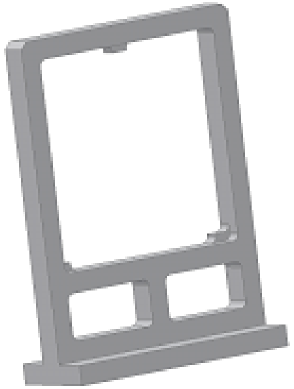
Opto-Mechanical Concept

- Common baseplate for dichroic mount, focusing optic and fold mirror(s)
  - Kinematic three-point support
- No adjusters (avoids many stability problems)
  - Seasonal focus adjustment **may** be required, compensation by lens design is possible
- Mounts and baseplate made from aluminium
  - Invar also suitable, but is much more expensive

Dichroic Mount

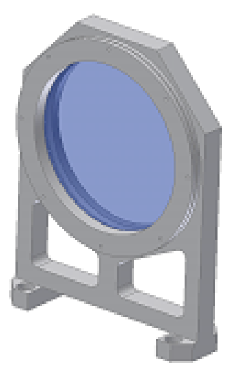
- Two alternative clamping methods:
  - Left panel: 2 point/line contacts support lower edge, spring load from top
  - Right panel: 3 point/small area contacts on one face
    - Contacting areas in central plane of mount
- Retaining shoulder/tabs to prevent excessive motion in earthquake

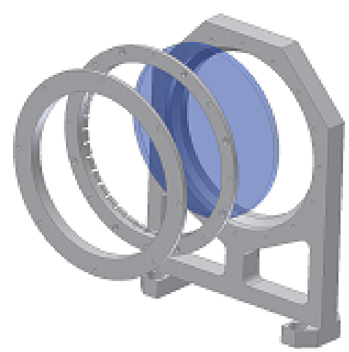




Lens Mount

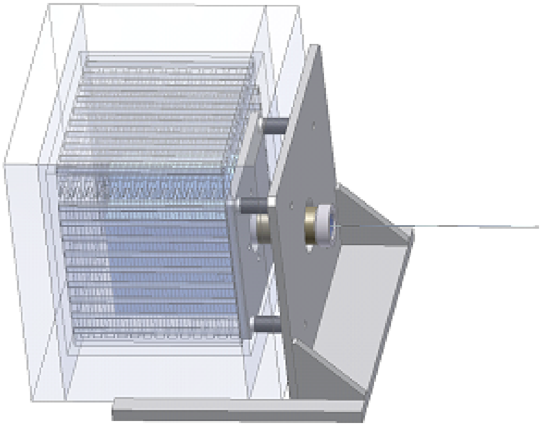
- Lens held circumferentially at edge by compliant Al fingers projecting from Al centering ring
- Retaining ring pre-loaded against lens by compression springs
- Contacting surfaces precision machined

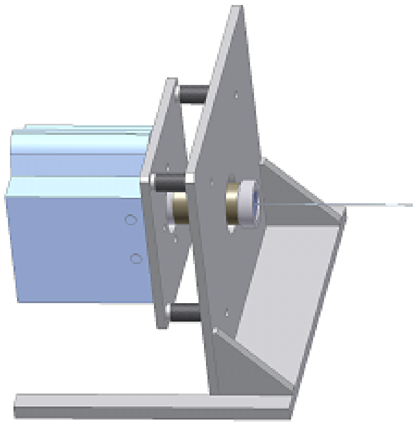




Camera Mount

- Camera mount outside thermal enclosure so it experiences ambient conditions
- Connection to camera via carbon fibre tubes
  - Stiff connection with thermal isolation
- Provision to avoid over-constraint at interface with table





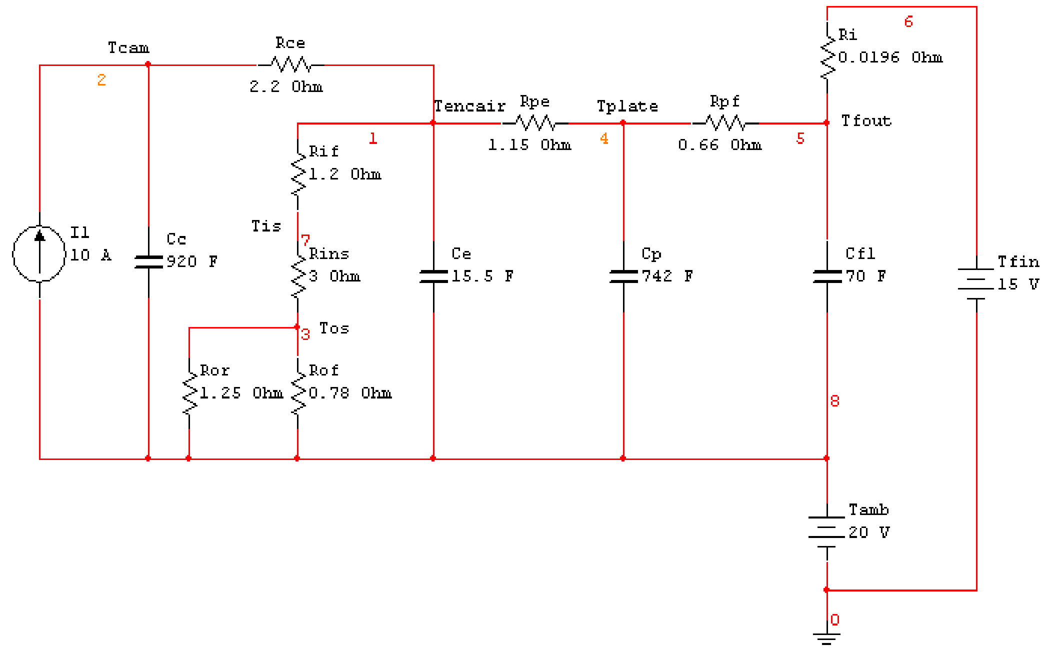
FTT/NAS Conceptual Opto-Mechanical Design

Questions?

Conceptual Thermal Design: FTT/NAS & FLC

Thermal Modelling

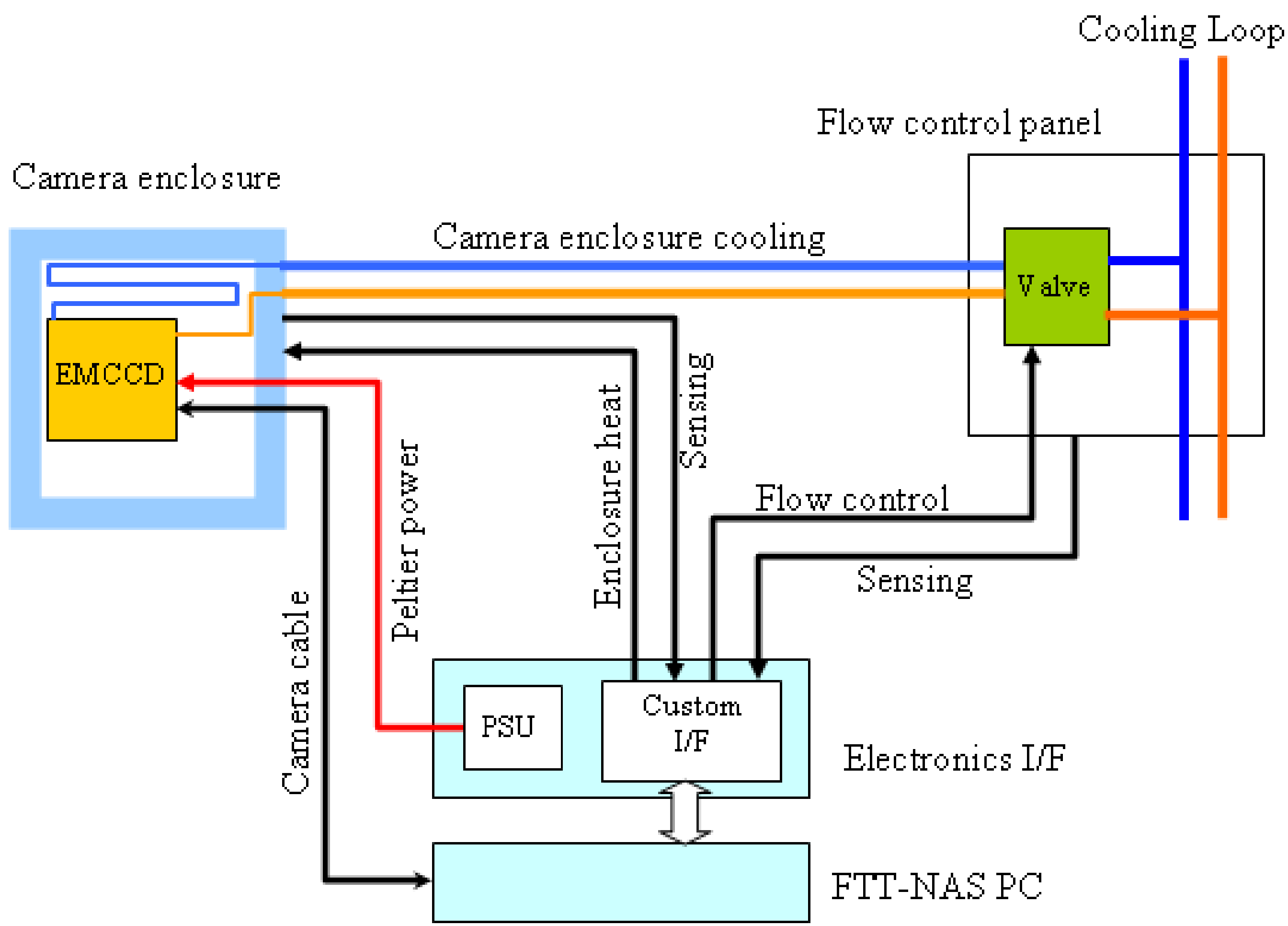
- Simple lumped parameter model
  - Andor camera parameters
  - Heat transfer coefficients calculated at operating temps
  - Radiation included
  - Matlab model next
  - Thermal testing
  - Refined Model



Baseline Thermal Design

- Use electronics housing cooling loop ("Loop 1")
  - Flow valve to camera controlled by FTT/NAS computer
- Camera enclosure:
  - Temperature and dew point sensors inside
  - Temperature sensors on external surface
  - Heating element
  - Dry air feed (< 1 litre/min)
- UTE temperature and dew point from ISS

Baseline Thermal Control System

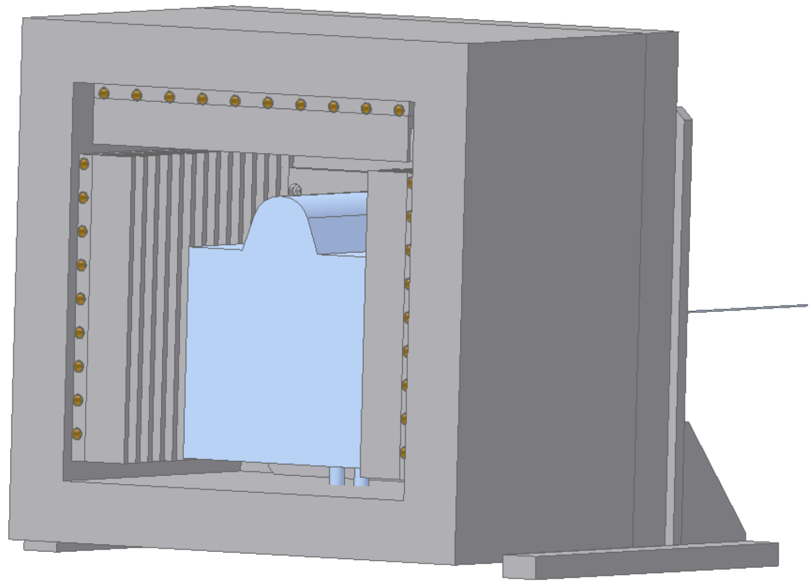


Alternative Thermal Design

- Dedicated cooling loop for camera enclosure
  - Exchanges heat to UT motor/enclosure cooling loop ("Loop 2")
- Interface to Loop 2 in insulated housing mounted to UTE structure under Nasmyth table, containing:
  - Peltier liquid-liquid heat exchanger
  - Circulating pump
  - Expansion tank
  - Flow control
- Camera enclosure as baseline design
- UTE temperature and dew point from ISS

Camera Enclosure

- External dimensions
  340 × 340 × 300 mm
- 40 mm Aerogel insulation in aluminium casing
- Heat sinks bonded to cold plates
- Camera cooling in series with cold plates
- Thermally managed



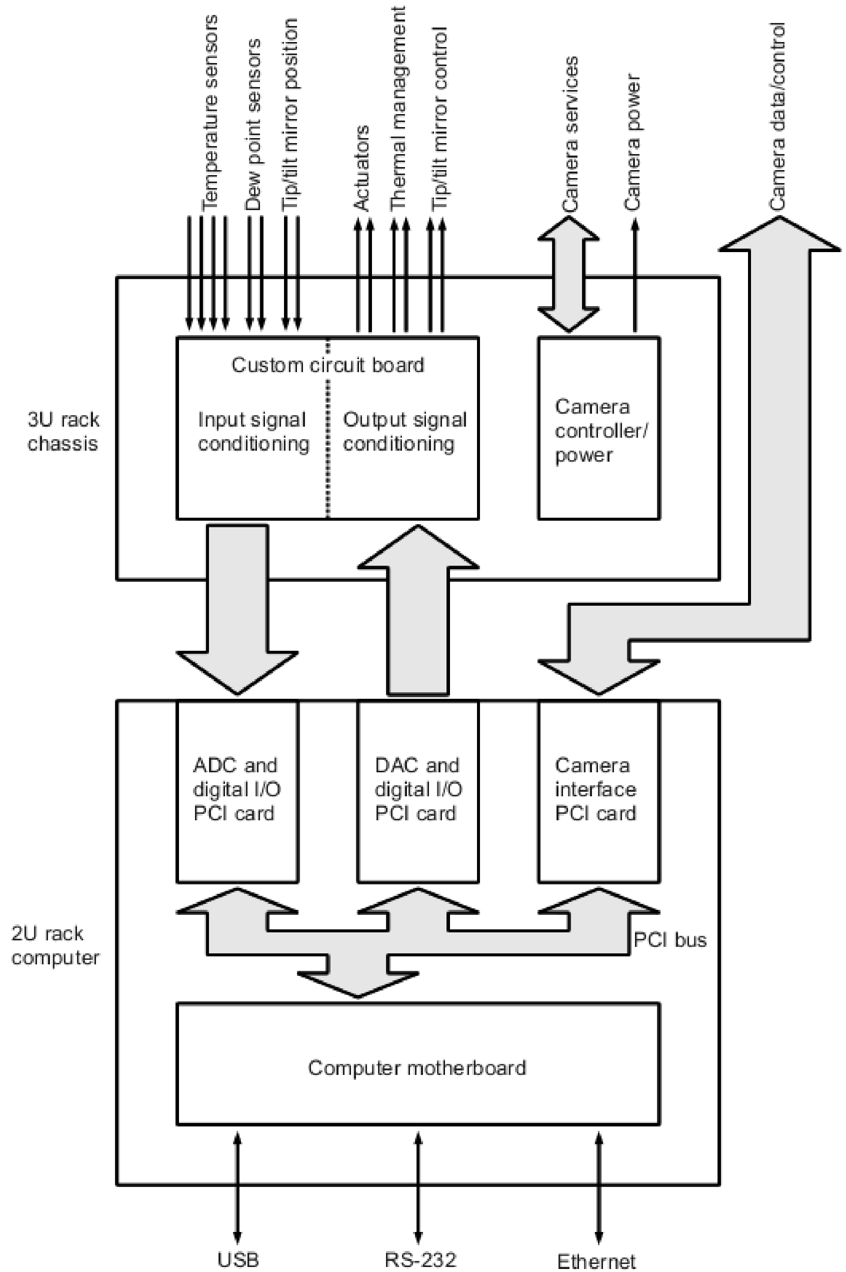
Conceptual Thermal Design

Questions?

Conceptual Electronics Design

Electronics Requirements

- Allocated 5U of rack space in electronics housing Q5
- Control computer (2U)
- Interfaces (3U):
  - Interface to EMCCD camera (PCI or Ethernet)
  - Interface to FTTA
    - Control and monitoring of tip-tilt mirror position
  - Thermal control:
    - Read temperature and dew point sensors
    - Coolant flow control

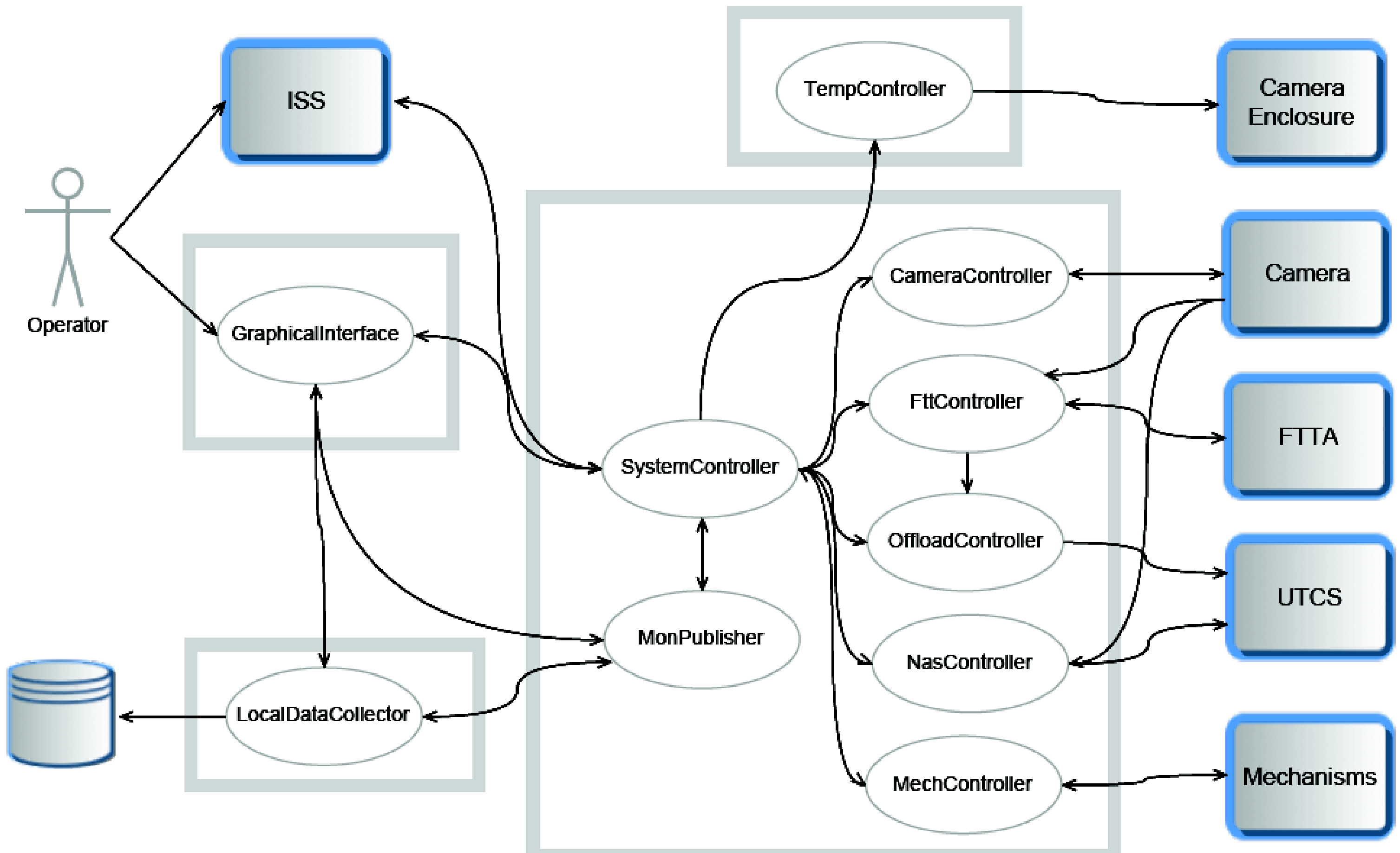

Temperature sensors
Dew point sensors
Tip/tilt mirror position
Actuators
Thermal management
Tip/tilt mirror control
Camera services
Camera power
Camera data/control
3U rack chassis
Custom circuit board
Input signal conditioning
Output signal conditioning
Camera controller/ power
ADC and digital I/O PCI card
DAC and digital I/O PCI card
Camera interface PCI card
2U rack computer
PCI bus
Computer motherboard
USB
RS-232
Ethernet

Conceptual Electronics Design

Questions?

FTT/NAS Conceptual Software Design

FTT/NAS Software: Tasks and Processes



Software Processes

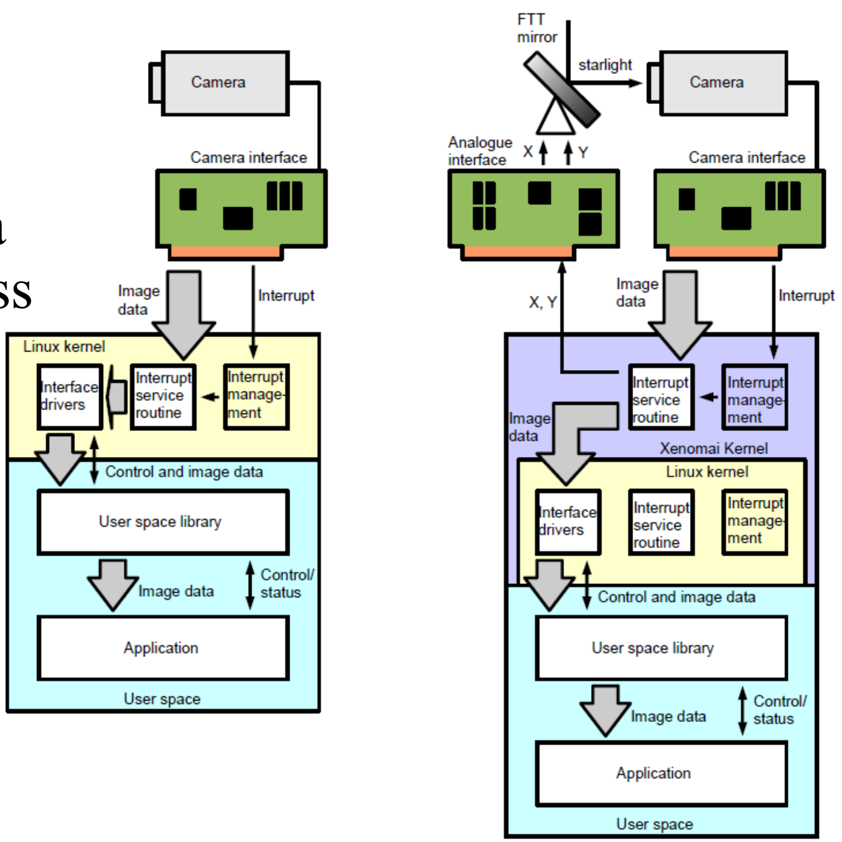
- Definition of processes follows from host, lifetime and programming language considerations:
  - GraphicalInterface may be run on laptop or control room computer for fastest video (C or Java)
  - TempController must be running at all times (C)
  - LocalDataCollector may be local copy of ISS Data Collector (Java)
  - Master process: all remaining tasks (C)

Software Tasks and ISS Interface

- Master process comprises multiple concurrent tasks
- Possible implementation is threads:
  - SystemController and MonPublisher use C with-threads ISS API
  - Need to see more details of ISS API to decide whether "actor model" with message-passing (e.g. using ZeroMQ) between threads is best way of achieving thread-safety
- Alternative implementation is event-driven:
  - Single thread switches between tasks based on "events" such as periodic timers and availability of data – as in DL software
  - SystemController and MonPublisher use C no-threads API

RT Camera Driver

- Closed-loop b/w requirement imposes hard deadline of 100 µs from receipt of camera data to output of FTTA control voltage
- Hence need a real-time operating system and camera driver
- Porting of vendor-supplied driver from vanilla Linux to Xenomai straightforward given access to source code for interrupt service routine
  - Have demonstrated this for the Andor camera



FTT/NAS Conceptual Software Design

Questions?

Lifetime and Maintenance: FTT/NAS (& FLC)

Lifetime and Maintenance

- No moving parts on optical table
- Cooling fluid flow control valve will be selected to suit 10-year lifetime requirement
- Optics will be suitably overcoated
  - But may need recoating after several years
- Electronics modularised, selected with lifetime in mind
  - Risk that replacement parts won't be available
- No issues with EMCCD camera
  - Gain ageing not an issue for the expected pixel rate and gain settings

Lifetime and Maintenance

Questions?

Interfaces: FTT/NAS & FLC

Proposed ICDs

ICD reference number	Owner	Description
MRO-ICD-CAM-1100-0108 **FTT/NAS-FTTA** MRO-ICD-AMO-6000-025 FTTA-FTT	CAM AMOS	Specific FTTA-FTT interface General UT electrical ICD
MRO-ICD-CAM-1000-0109 **FTT/NAS,FLC-UTE** MRO-ICD-EIE-0032 UTE-FTT	CAM EIE	FTT/NAS & FLC to Enclosure ICD Enclosure to FTT system ICD
MRO-ICD-CAM-1000-0110 **FTT/NAS,FLC-NOT**	CAM	FTT/NAS & FLC to optical table ICD
MRO-ICD-CAM-1000-0111 **FTT/NAS,FLC-UT**	CAM	FTT/NAS & FLC to UT optical ICD
MRO-ICD-CAM-1100-0112 **FTT/NAS-ISS**	CAM	FTT/NAS to ISS ICD
MRO-ICD-CAM-1200-0113 **FLC-ISS**	CAM	FLC to ISS ICD

Interface Issues

- **Stability of the Nasmyth optical table**. This has potential system-wide impact;
- **Cooling**: we request that cooling loop 1 (EIE electronics housing) rather than loop 2 be routed to Nasmyth optical table [TBC];
- **Dry air**: we request that air be supplied to the Nasmyth optical table and understand that we should include suitable drying equipment as part of our system;
- **Cable route** from the FTT/NAS sensor on the optical table to controller in electronics housing: The camera cable is 6 m maximum and the latest calculation of the route it must take is approximately 5.3 m. This should be sufficient margin;
- **FTT/NAS space envelope**: we request that parts of AAS be separated to allow a common base-plate to be used for FTT/NAS components;
- **Power consumption**: we request an increase in FTT/NAS power consumption allowance and a potential increase in power dissipation if an alternative candidate camera must be chosen.

Interfaces

Questions?

FTT/NAS: Summary and path forward

FTT/NAS Summary (i)

- Optical layout:
  - Preferred DLT layout satisfies all constraints
  - Will continue to investigate lens design for Zoom layout
- Camera selection:
  - Andor iXon^{EM}+ 897 is lowest-risk choice
  - Plan to pay for development of custom subframe readout ASAP
- Opto-mechanical design:
  - Expect to meet specification using common baseplate and non-adjustable Al mounts, within factor 2 uncertainty
  - High risk that stability will be compromised by tilt and deformation of Nasmyth optical table

FTT/NAS Summary (ii)

- Thermal design:
  - Baseline design using Loop 1 directly will meet all requirements for Andor camera
  - Extra design and implementation effort would be required to accommodate an alternative camera
- Electronics design:
  - Straightforward to implement using available rack space
- Software design:
  - No critical issues foreseen unless Princeton ProEM camera is used
  - Multi-tasking implementation and inter-task communication scheme will be decided in PDR phase once full details of ISS API are known

FTT/NAS Risk Areas (i)

- **Camera selection:**
  - Risk of schedule delays if Andor iXon^{EM}+897 cannot be used
- **Opto-mechanical stability:**
  - We are confident of meeting specification to within factor 2 uncertainty in modelling
  - Plan to test prototype dichroic mount early in PDR phase
  - Fallback is use of Invar (implies cost increase)
- **Nasmyth optical table stability:**
  - Recommend that MROI Project Office assess this system-level risk ASAP

FTT/NAS Risk Areas (ii)

- **Impact of speckle noise:**
  - Impact on centroid accuracy not yet fully assessed
  - We are developing a numerical simulation to verify our initial estimates
- **Limiting sensitvity:**
  - Derived requirement calculations suggest limiting sensitivity $m_V = 16$ under the assumptions defined in the Technical Requirements Document is impossible
  - We believe a more realistic sensitivity limit is $m_V = 15.8$
  - The system will work at $m_V = 16$ but with tip-tilt residuals 2% over-budget, leading to an additional 0.5% visibility loss in the H band
- **Dynamic range:**
  - Current design can accommodate targets as bright as magnitude 3
  - If capability to observe brighter targets is desired, additional hardware to attenuate the starlight will need to be designed and installed

FTT/NAS: Summary and path forward

Questions?

FLC Derived Requirements

FLC Derived Requirements: Thermal Management (i)

- Assumptions:
  - EMCCD camera in environmentally-controlled enclosure:
    - Camera enclosure temperature is controlled to protect camera and reduce heat dissipation (no requirement for exterior surface to be within 2 °C of ambient)
    - Camera environment controlled at all times, so always ready to be switched on
    - Heat removed from camera head and enclosure by fluid and exchanged into one of telescope coolant loops

FLC Derived Requirements: Thermal Management (ii)

- Derived requirements from thermal modelling:
  - Max. enclosure internal air temperature: 30 °C
  - Min. enclosure internal air temperature: 0 °C
  - Enclosure air dew point: coldest internal component -5 °C
  - Emissivity of enclosure outer surface > 0.7
  - Residual camera heat 20 W [TBC]
  - Camera enclosure space envelope: 340 mm × 300 mm × 350 mm max.
  - CPU and interface electronics power dissipation allowance 180 W
  - Camera interface and controller power dissipation allowance 70 W
  - Power consumption 350 W

FLC Derived Requirements: Dynamic Range

- Assumptions:
  - EMCCD read noise 50 electrons RMS
  - Exposure time independent of frame rate; minimum exposure 1 ms; maximum exposure 1 s
  - Cousins R-band filter 570–730 nm
- Derived requirements:
  - With unity EMCCD gain, magnitude range is 2.5 to 16.2 in ~0.6″ seeing (1.0 to 14.8 in ~1.2″ seeing)
  - Hence could use permanent 1–2 magnitude attenuation

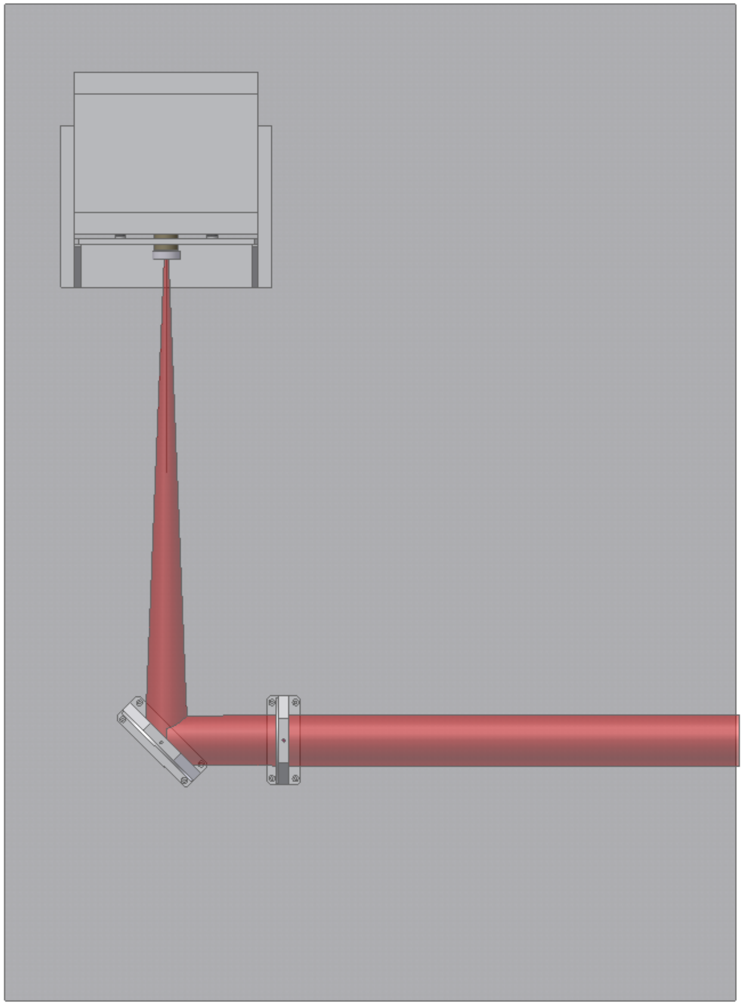
FLC Derived Requirements

Questions?

FLC Optical Layouts

FLC Layout

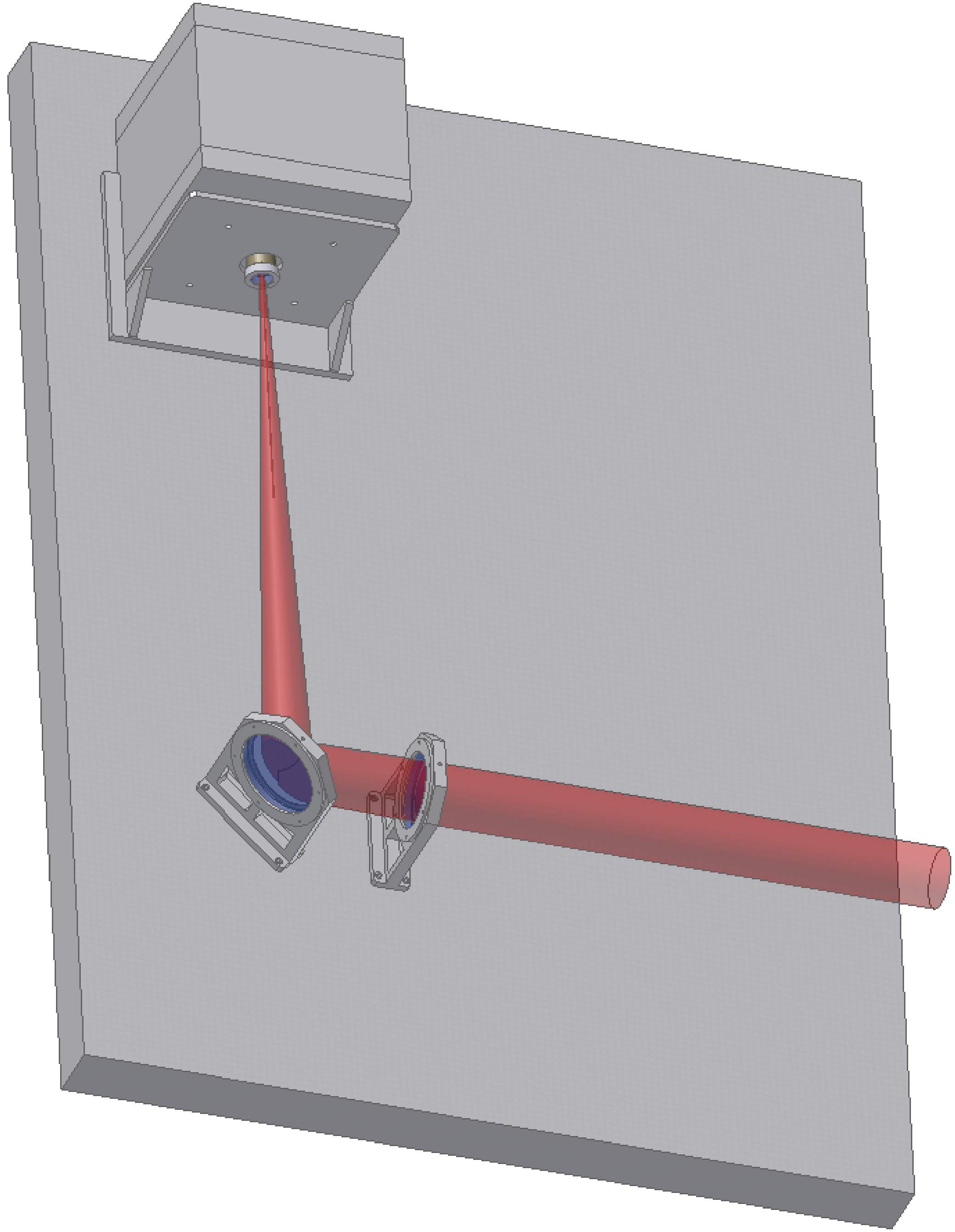
- COTS doublet lens → 0.18″/pix
- FTT/NAS camera mount
- Width of table ⇒ fold mirror
- Yet to optimize relative distances between components
- Could move left or right to accommodate other equipment



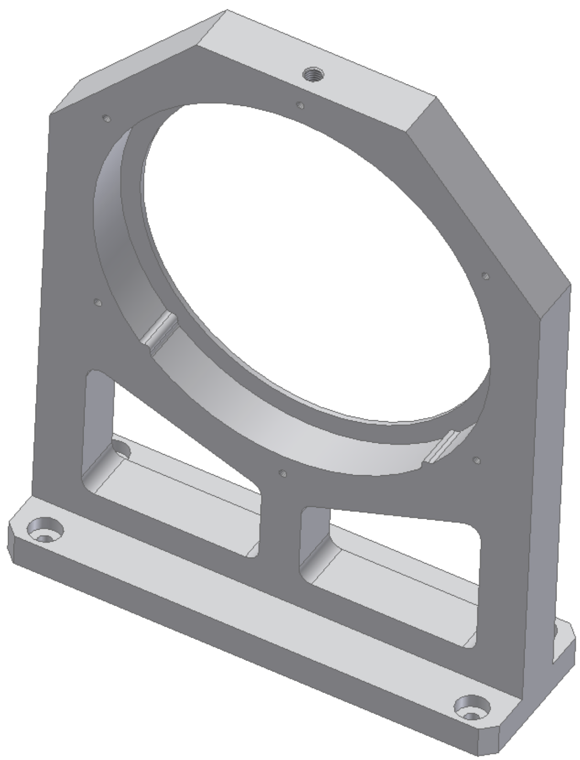
FLC Optical Layouts

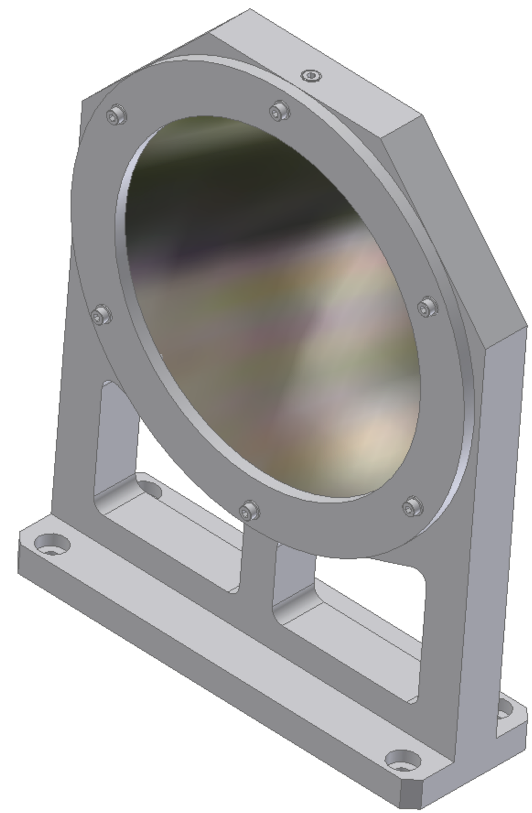
Questions?

FLC Conceptual Opto-Mechanical Design



Lens/Fold Mirror Mount





Lens Mount

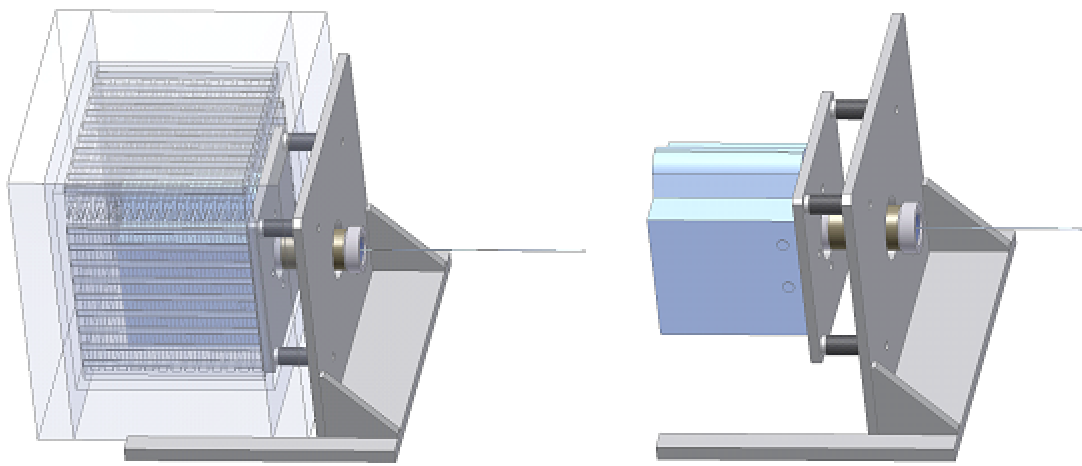
- Designed so lens centred to 0.2 mm and stable to 50 μm
- Lens held against reference face by compliant ring, backed by retaining ring screwed into mount
- Contacting surface machined tangent to lens surface
- Lens held radially using 2 compliant locating surfaces and a compliant pre-load screw
- Mount will be bolted directly to table; no adjustments needed

Fold Mirror Mount

- Mirror held against axial reference face by compliant ring, backed by retaining ring screwed into mount
- Mirror held radially using 2 reference surfaces and a compliant pre-load surface
- Mount will be bolted directly to table; no adjustments needed

Camera Mount

- Same design as FTT/NAS

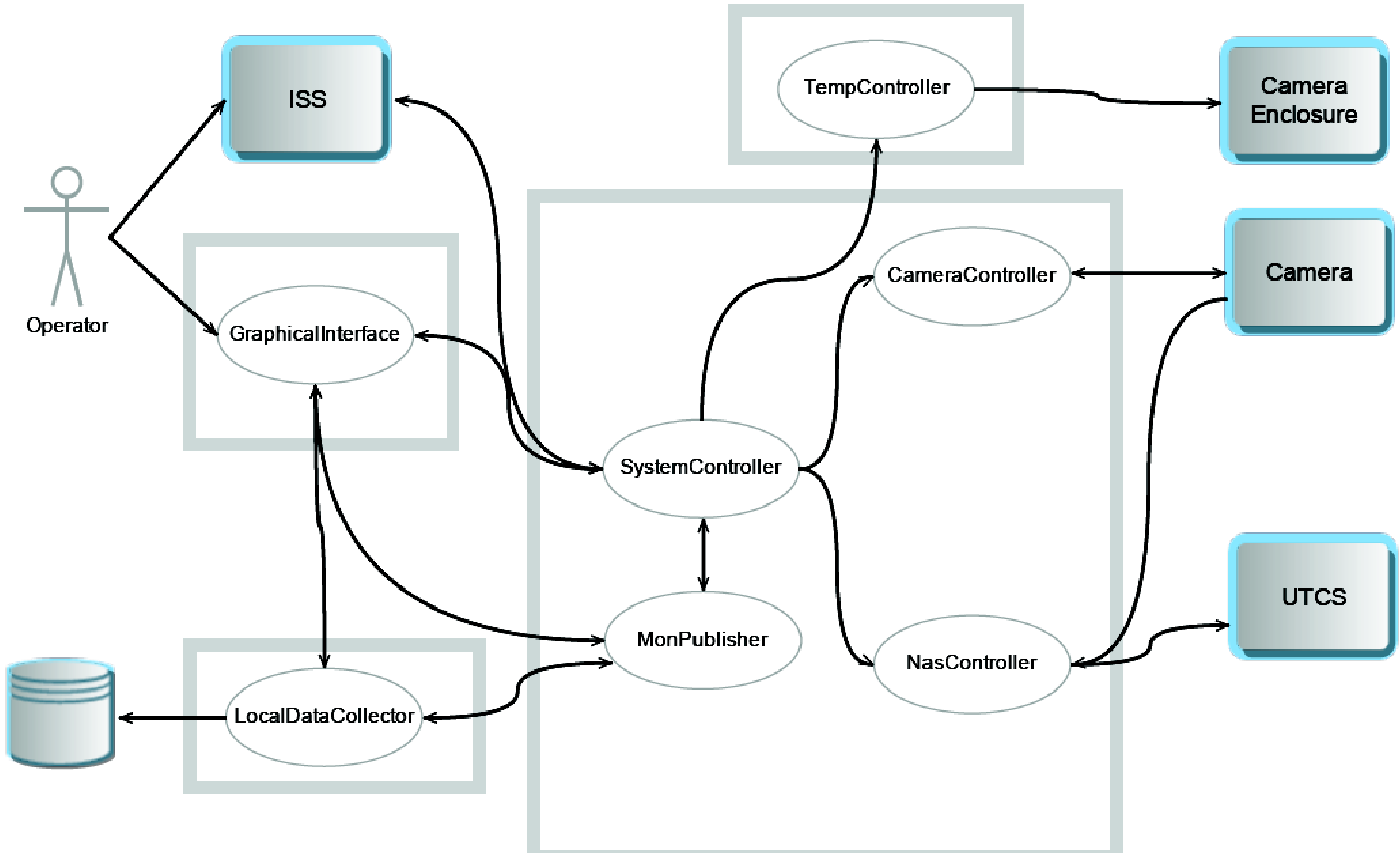


FLC Conceptual Opto-Mechanical Design

Questions?

FLC Conceptual Software Design

FLC Software: Tasks and Processes



FLC Software

- Standalone and integrated roles
  - Standalone role may use ISS code but will not require a running ISS
- Will be as far as possible strict subset of FTT/NAS software
  - Except for UTM vendor-requested functionality, which is mostly in GUI
  - Implies dependence on Xenomai real-time Linux

FLC Conceptual Software Design

Questions?

FLC: Summary and path forward

FLC Summary (i)

- Optical layout:
  - Straightforward
  - To be optimised very soon
- Camera selection – depends on FTT/NAS camera choice:
  - Andor iXon^{EM}+ 897 is lowest-risk choice for FTT/NAS
  - Plan to pay for development of FTT custom subframe readout ASAP
- Opto-mechanical design:
  - Not challenging
  - Potential impact of Nasmyth table instability – will optimise layout to mitigate

FLC Summary (ii)

- Thermal design:
  - Baseline design using Loop 1 directly will meet all requirements for Andor camera
  - Extra design and implementation effort would be required to accommodate an alternative camera
- Electronics design:
  - Straightforward to implement using available rack space
- Software design:
  - No critical issues forseen unless Princeton ProEM camera is used
  - Multi-tasking implementation and inter-task communication scheme will be decided in PDR phase once full details of ISS API are known

FLC: Summary and path forward

Questions?