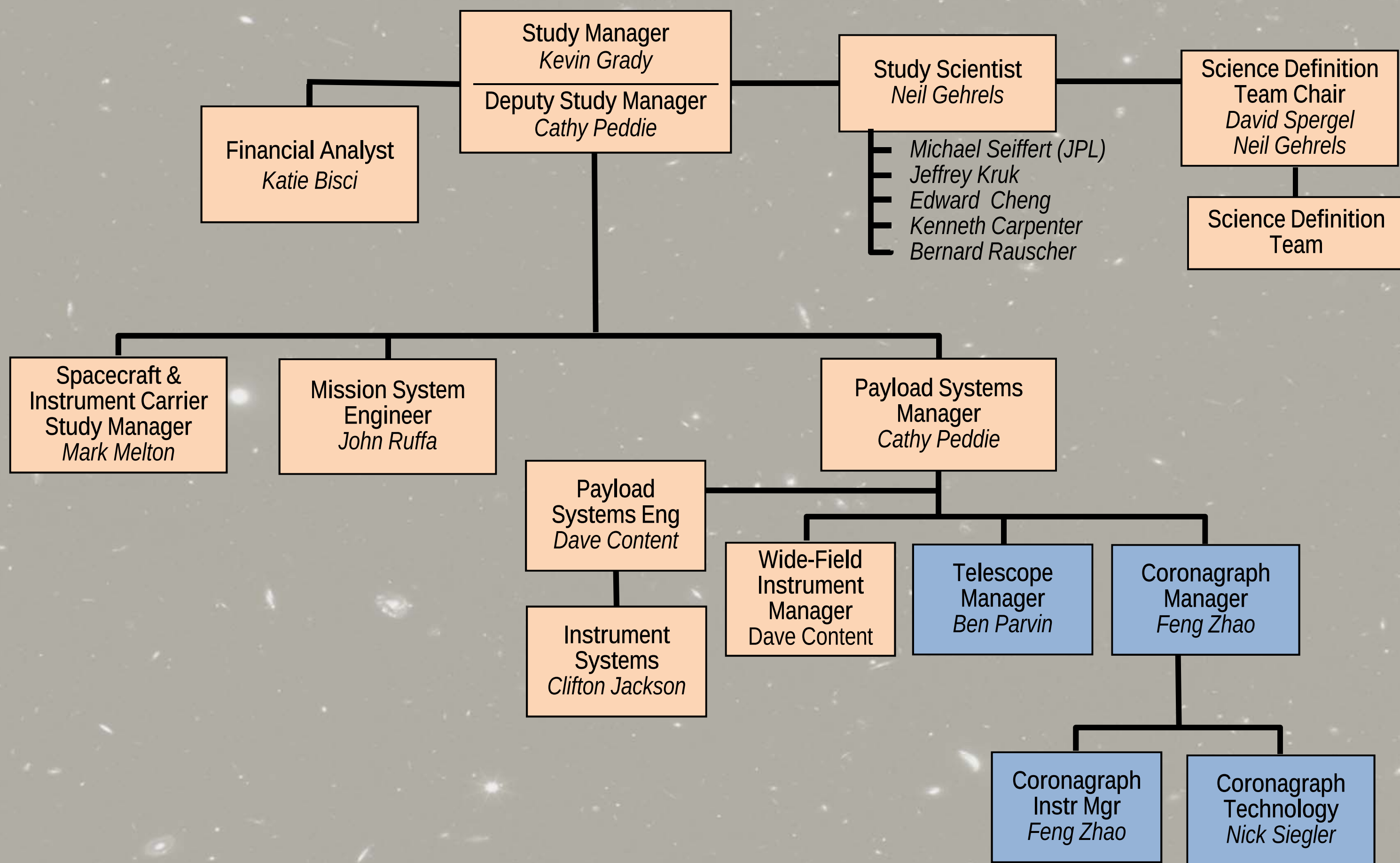
WFIRST-AFTA Presentation to the NRC

January 13, 2014

Outline

1. WFIRST-AFTA Overview
2. IDRM Overview
3. Spacecraft Overview
4. IDRM & AFTA Cost Comparison, including CATE
5. Detector Status
6. Recent Technical Progress
   - Payload Design & Analyses Results
   - Spacecraft Trades
7. Risks
8. Summary

Astrophysics Focused Telescope Assets (AFTA)
Study Team Organization



GSFC provided   JPL provided

NASA Goddard SPACE FLIGHT CENTER

November 5, 2013

WFIRST-AFTA SCIENCE DEFINITION TEAM

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- Wes Traub, JPL , ex-officio

EXECUTIVE SUMMARY

Executive Summary (1/2)

- Science
  - Dark energy: comparable to or better than IDRM science; better systematics
  - Microlensing: exoplanet yields are 1.6x that of IDRM for a fixed observing time; complete the planetary census started by Kelper
  - Coronagraphy: maturing critical coronagraph technologies to enable future earth-like planet finding mission; deliver precursor exoplanet science with full support of exo-planet community
  - Guest Observer: expanded time allocation & capability; broad community engagement; address diverse set of astrophysical questions; x 100 the capability of HST WFC-3
- Risk:
  - IR Detectors: existence proof fabricated for AFTA; yield to be addressed after we select final recipe
  - Coronagraph: is a tech demo - not allowed to drive mission requirements; SP doesn't drive observatory pointing

Executive Summary (2/2)

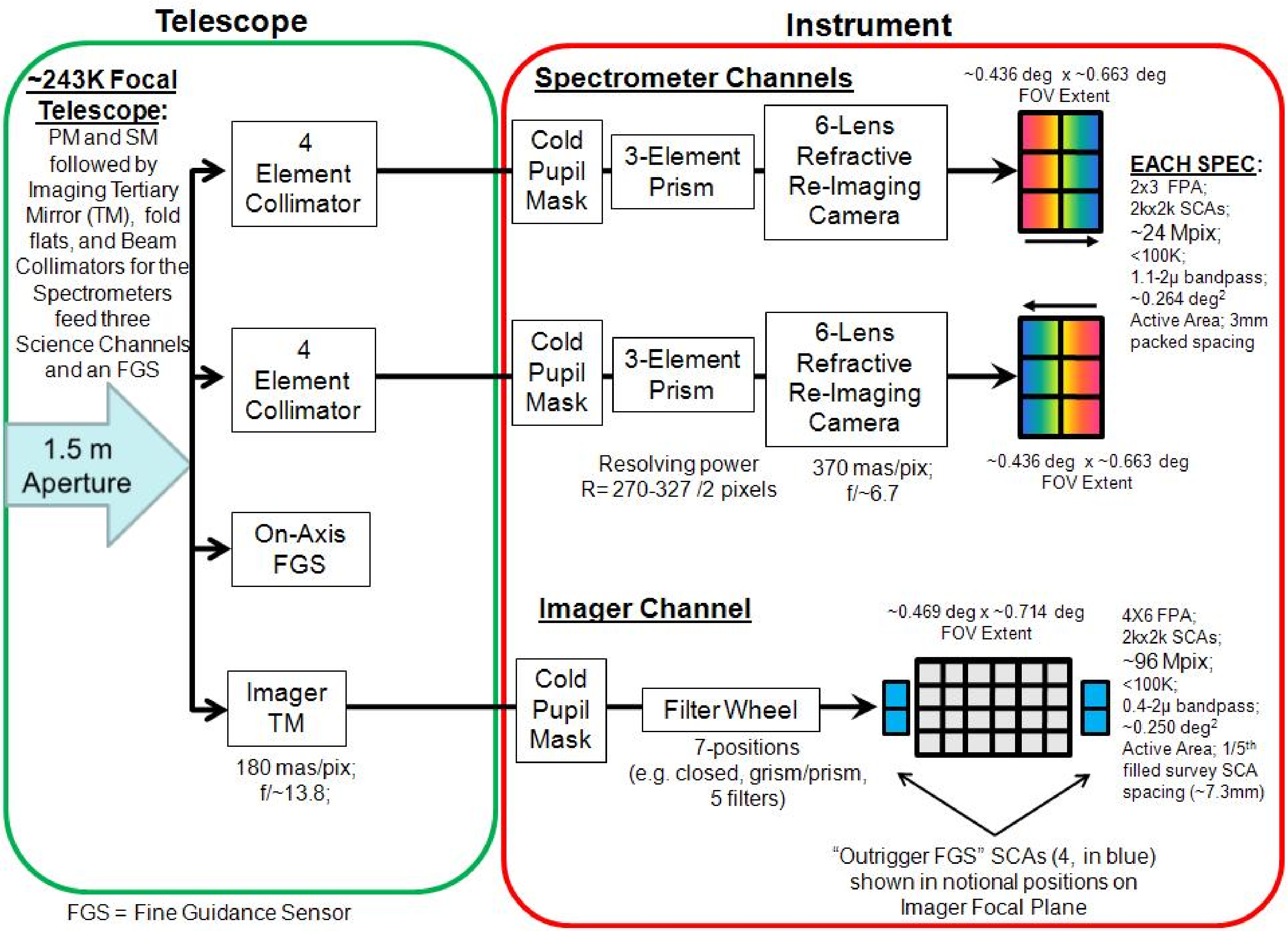
- Risk (cont.):
  - Primary optics: built; off of critical path, interfaces defined, less design iteration; early telescope: allows extended testing with wide field instrument significantly reducing risk and simplifies instrument/payload I&T requirements
- Cost
  - AFTA Project estimates (without launch vehicle, $FY12) are in very good agreement (20%) with the CATE estimate.

AFTA Project Estimate = **1347**   AFTA CATE Estimate = **1613**

  - Launch vehicle environment is dynamic (e.g. Falcon Heavy) that could potentially impact the AFTA launch vehicle costs: range 244M to 418M in RY dollars
  - Coronagraph costs address Decadal recommendation to mature high contrast imaging technologies and precursor science.
- Both the Project and Aerospace agree that the cost of AFTA is in family with IDRM; launch vehicle costs are expected to be dynamic over the decade and this should provide AFTA with other design and cost opportunities.

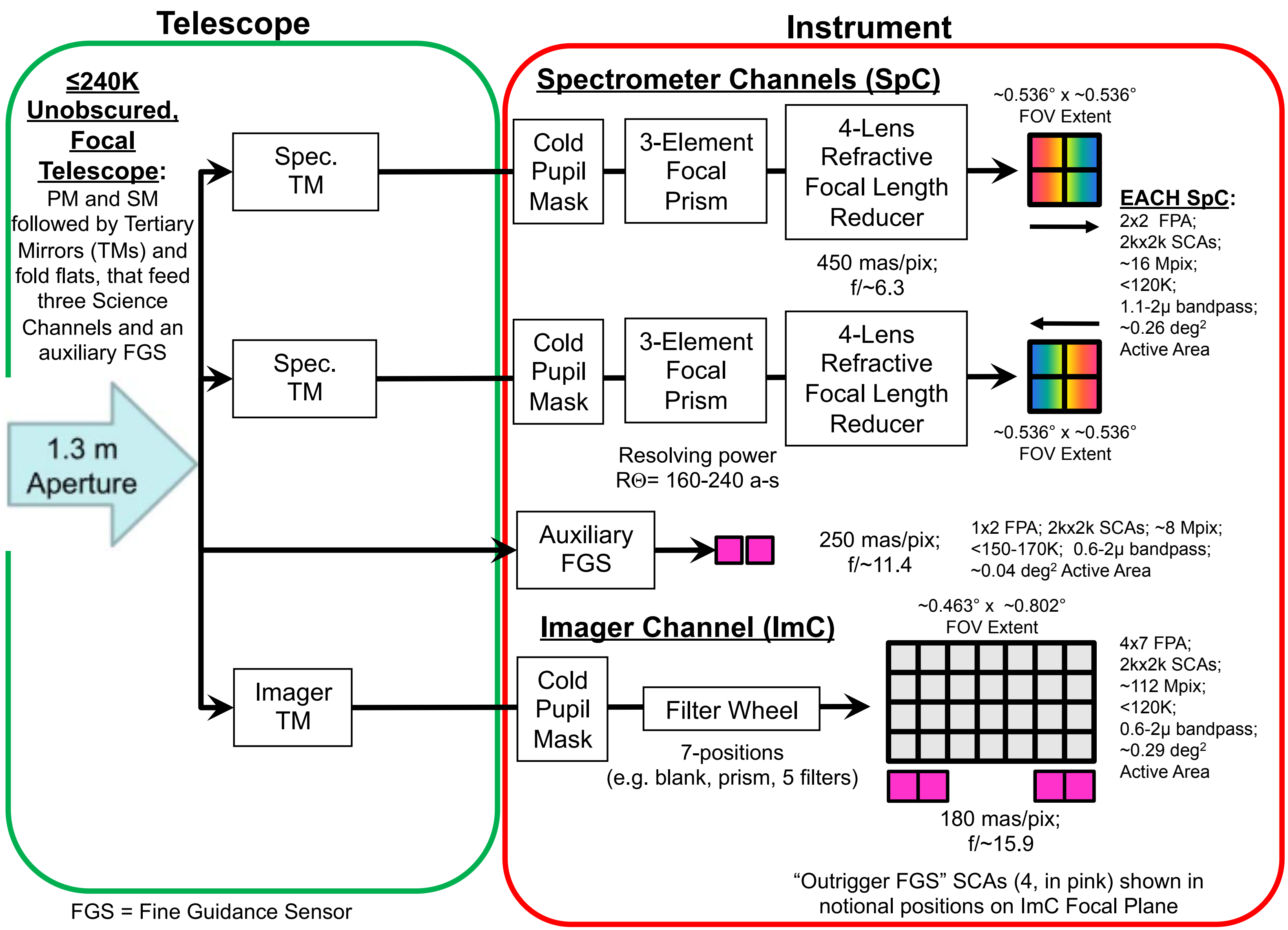
FOLLOW-UP DISCUSSION FROM YESTERDAY

JDEM-Omega Payload Block Diagram



FGS = Fine Guidance Sensor

IDRM Payload Block Diagram



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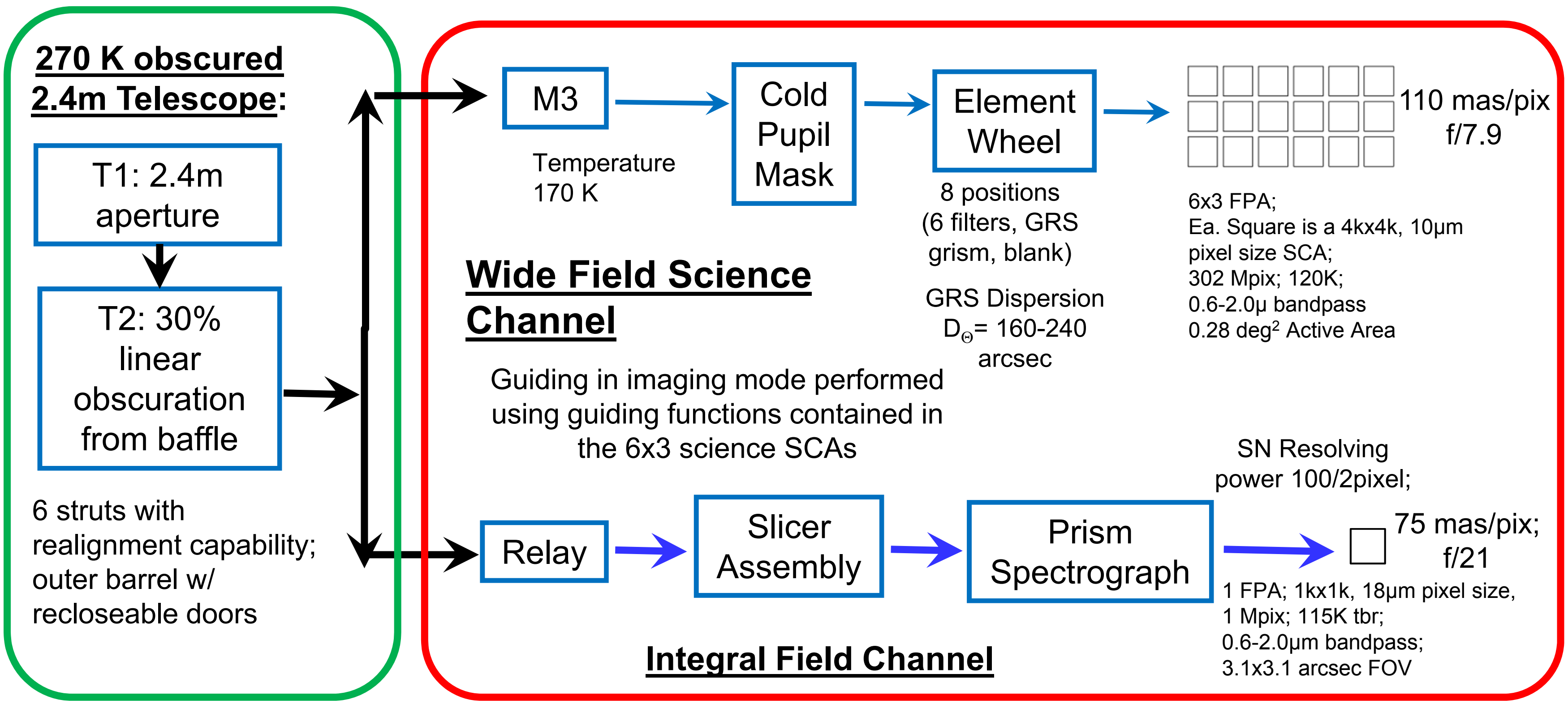
AFTA Payload Block Diagram

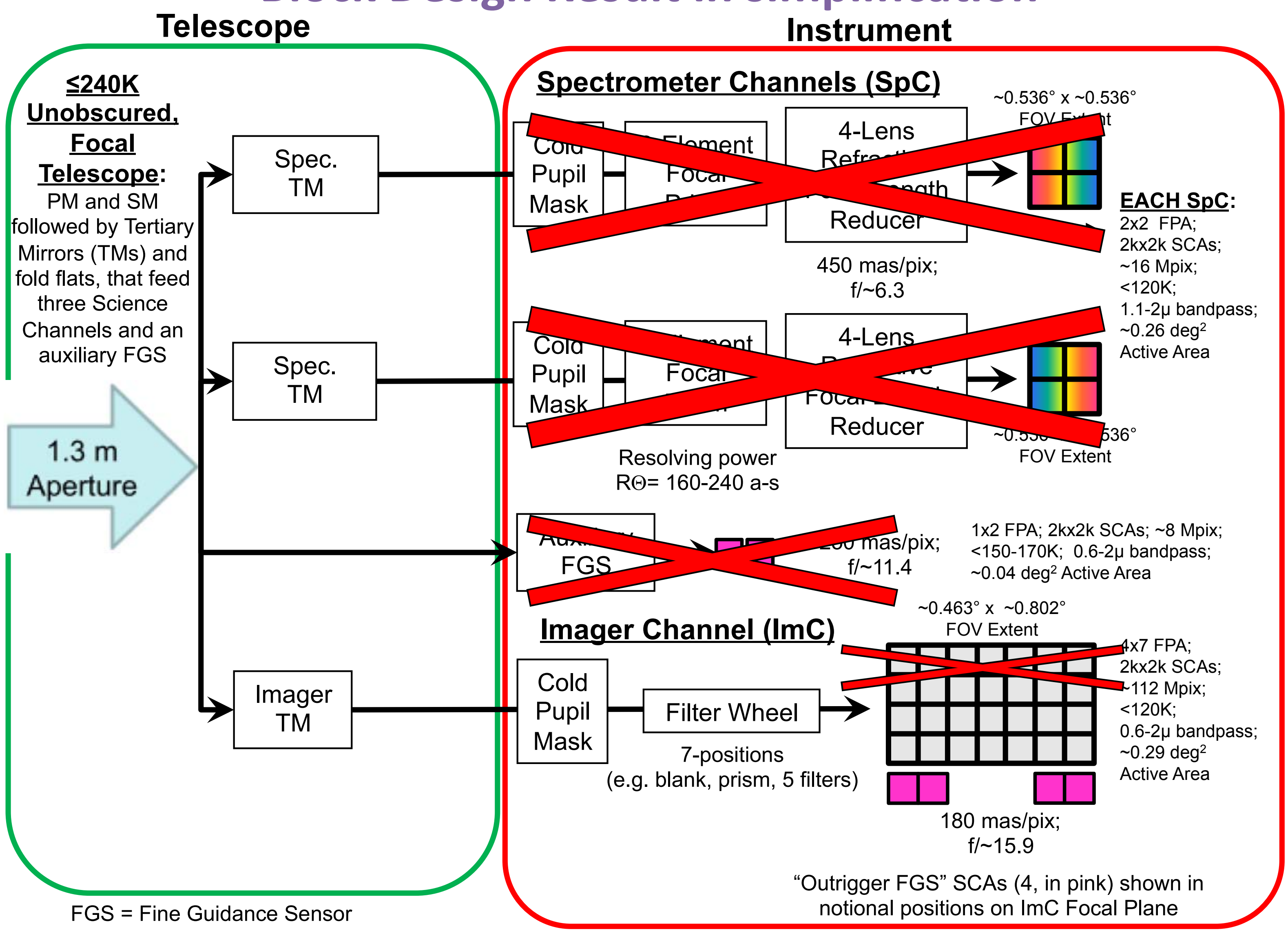
Telescope

Wide Field Instrument



GRS = Galaxy Redshift Survey
SCA = Sensor Chip Assembly
SN = Type1a Supernovae

AFTA Instrument Deletions to IDRM Payload Block Design Result in simplification



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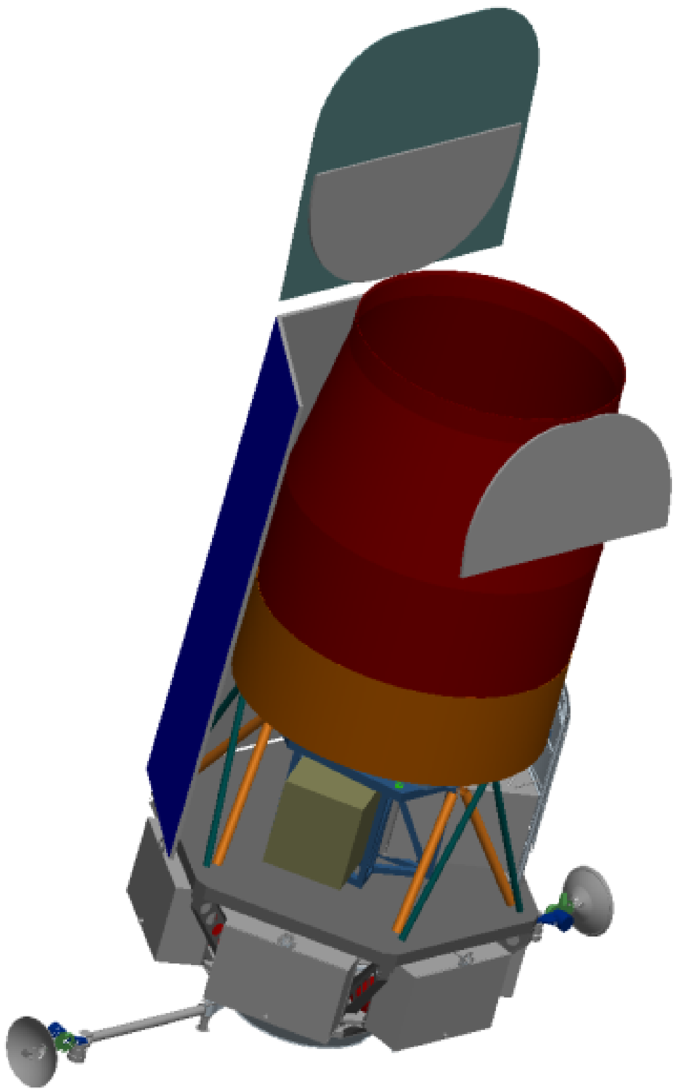
AFTA TECHNICAL OVERVIEW

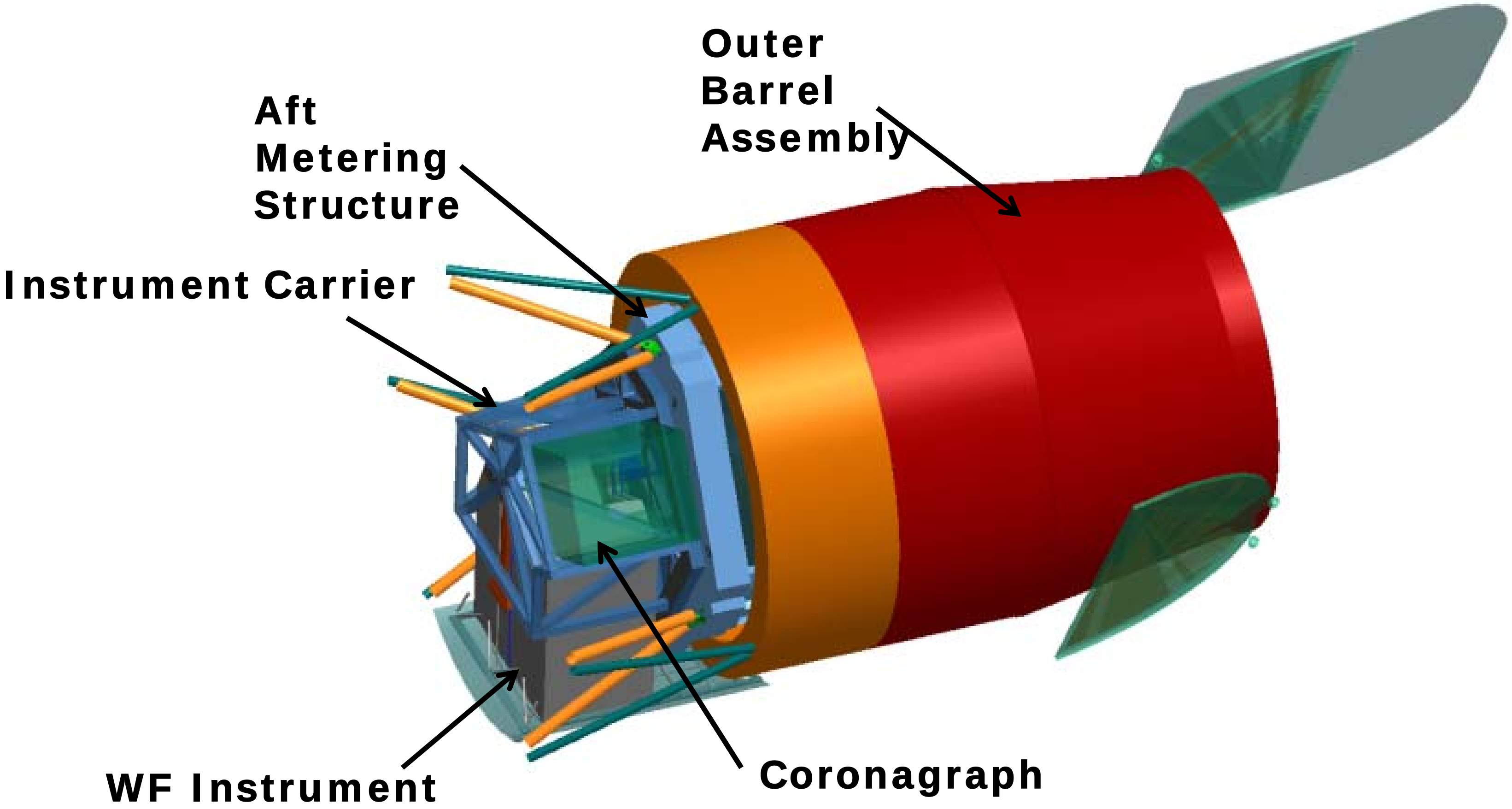
AFTA Observatory Concept



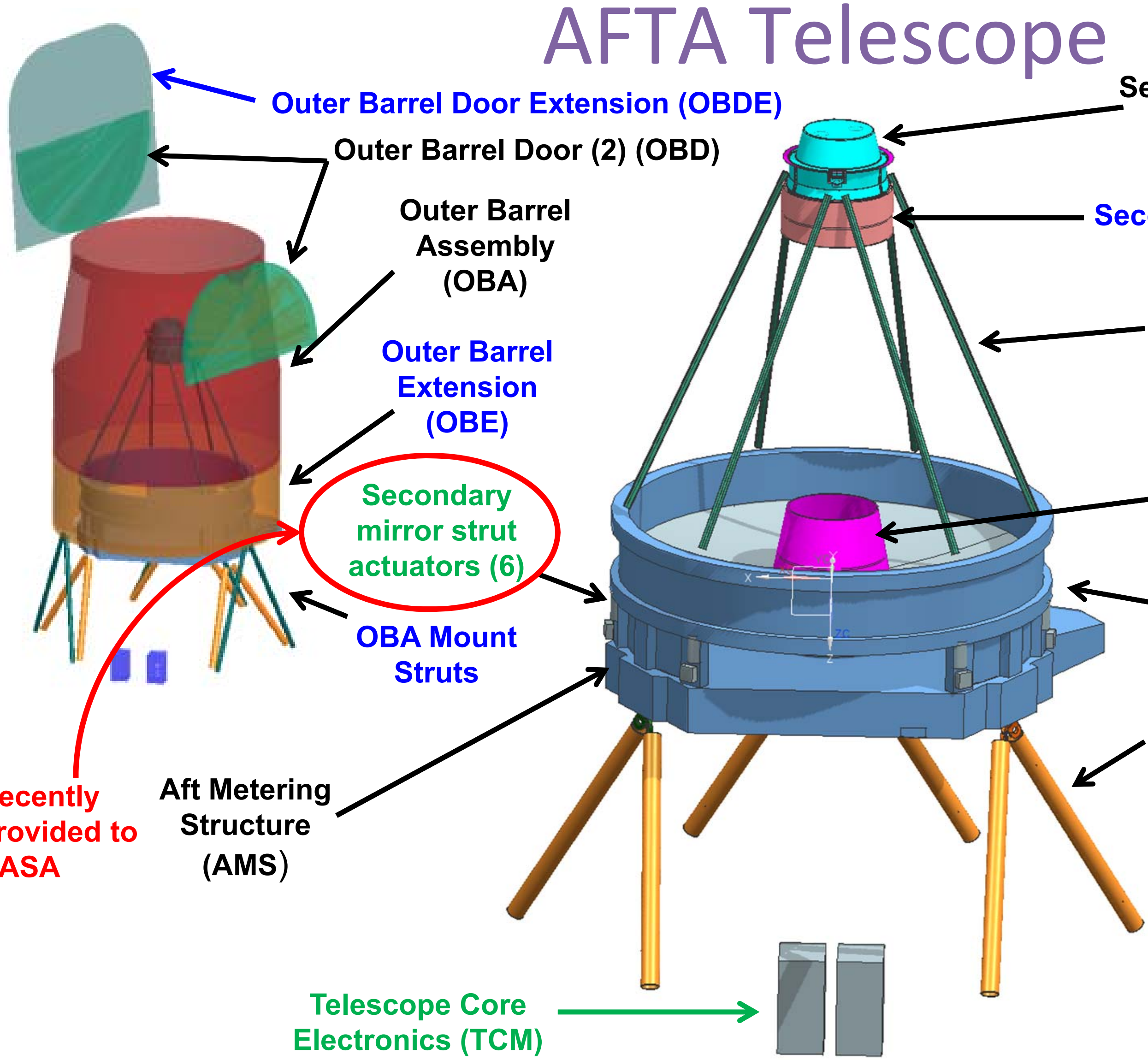
Key Features

- Telescope – 2.4m aperture primary
- Instrument – Single channel wide field, 18 4k x 4k HgCdTe detectors; integral field unit spectrometer incorporated in wide field for SNe observing
- Overall Mass – ~6300 kg (CBE) with components assembled in modules; ~2550 kg propellant; ~3750 kg (CBE dry mass), ~7700 kg (MEV) wet mass
- Primary Structure – Graphite Epoxy
- Downlink Rate – Continuous 150 Mbps Ka-band to dedicated ground station
- Thermal – passive radiator
- Power – 2000 W
- GN&C – reaction wheels & thruster unloading
- Propulsion – bipropellant
- GEO orbit
- Launch Vehicle – Atlas V 541

AFTA Payload Design Concept



AFTA Telescope



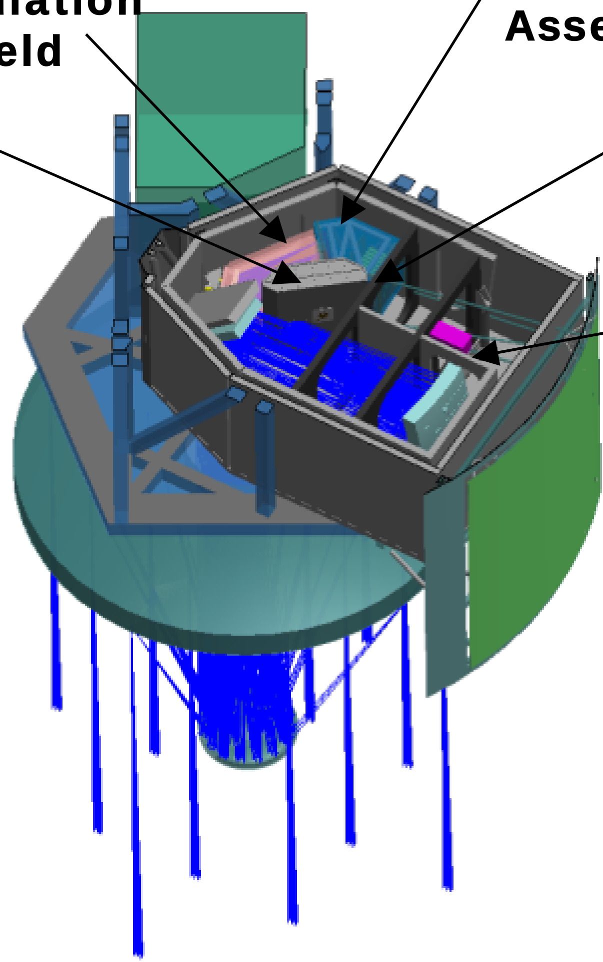
Existing H/W, reuse	1188 kg
Not available, existing design, remake	153 kg
New design	254 kg
TOTAL:	1595 kg

100% of the existing telescope hardware is being re-used.
Actuators, electronics and baffles not available and must be replaced.

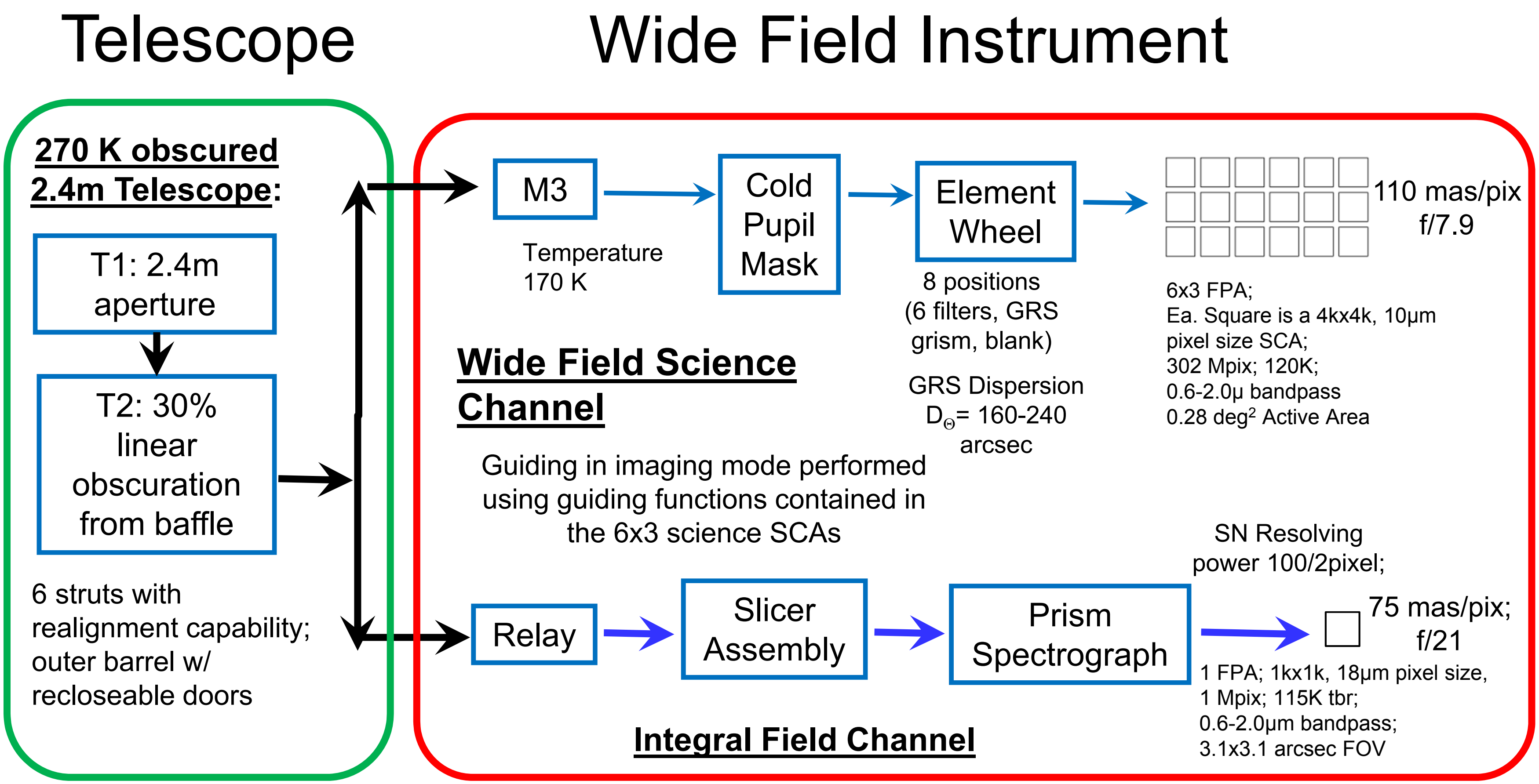
AFTA Wide field Instrument Layout

Key Features

- Single wide field channel instrument
- 3 mirrors, 1 powered
- 18 4K x 4K HgCdTe detectors
- 0.11 arc-sec plate scale
- IFU for SNe spectra, single HgCdTe detector
- Single filter wheel
- Grism used for GRS survey
- Thermal control – passive radiator



AFTA Payload Block Diagram



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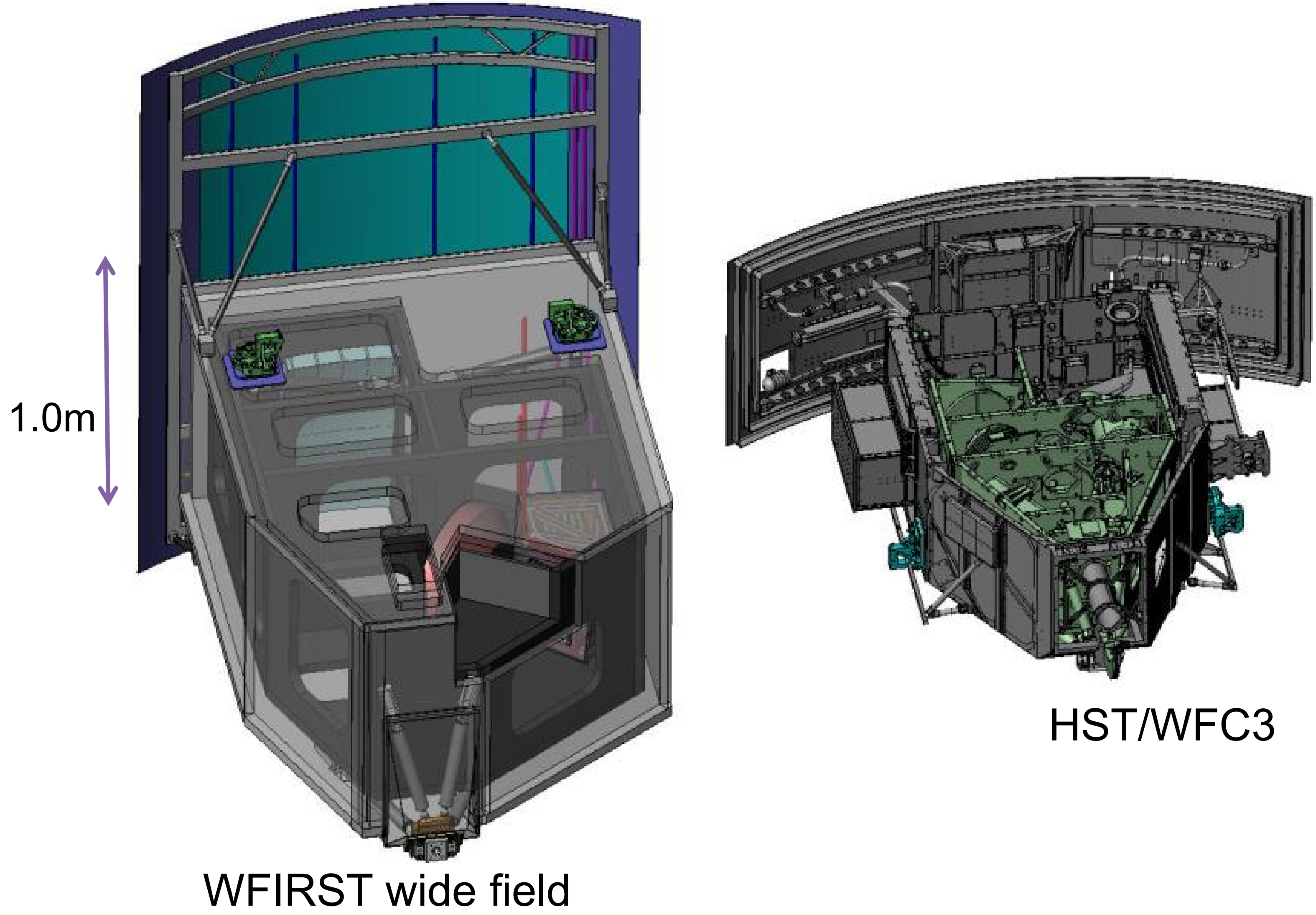
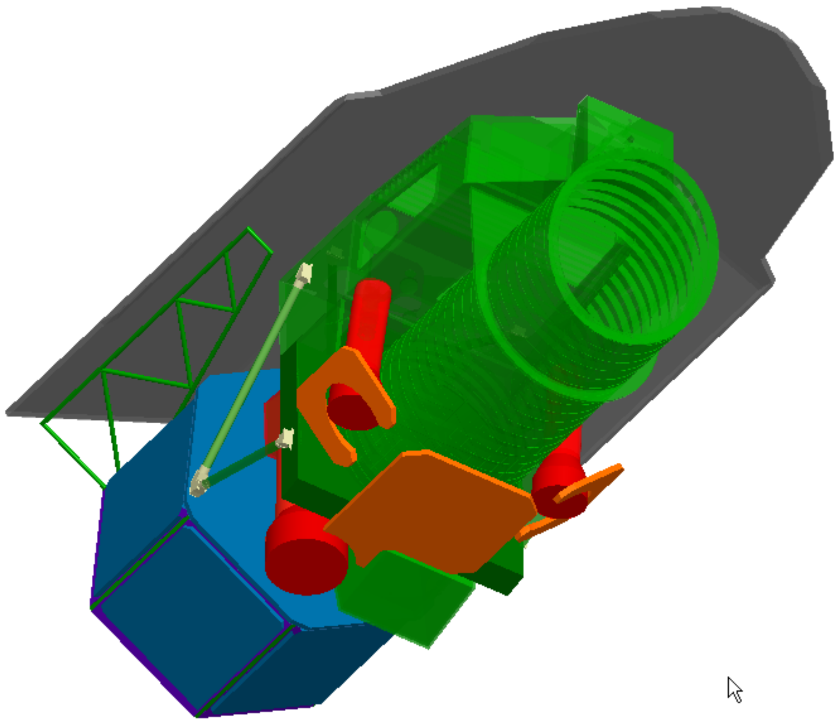
Wide Field Instrument Shares Architecture and Heritage with HST/WFC3



IDRM TECHNICAL OVERVIEW

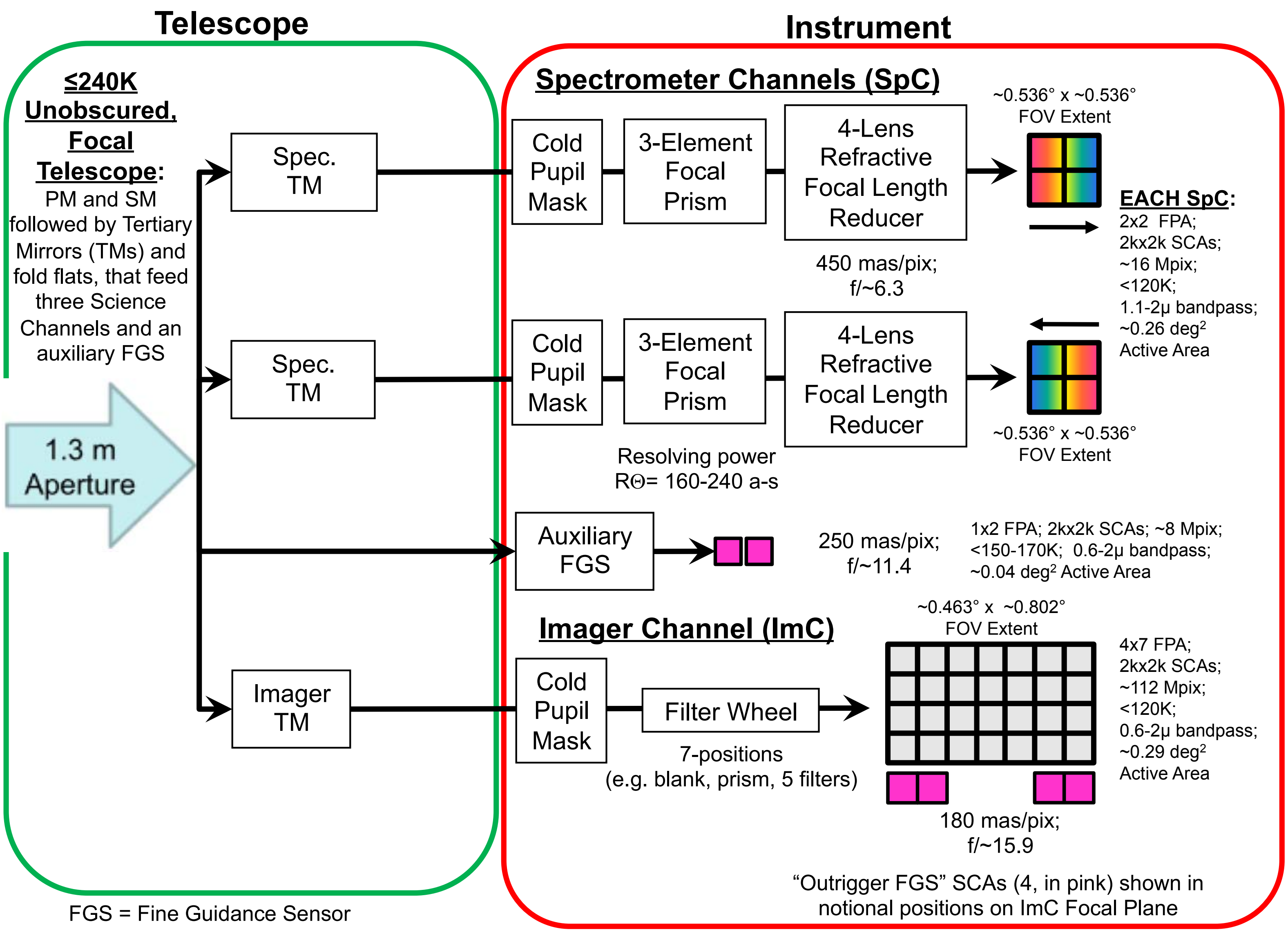
IDRM Observatory Concept



Key Features

- Telescope – 1.3m aperture primary, unobscured
- Instrument – 3 channel wide field (2 spectrometers and an imager), 36 2k x 2k HgCdTe detectors
- Overall Mass – ~2000 kg (CBE); ~150 kg propellant; ~1850 kg (CBE) dry mass, ~2500 kg (MEV) wet mass
- Primary Structure – Graphite Epoxy
- Downlink Rate –150 Mbps Ka-band to DSN
- Thermal – passive radiator
- Power – 1400 W
- GN&C – reaction wheels & thruster unloading
- Propulsion – monopropellant
- Earth-Sun L2 orbit
- Launch Vehicle – Atlas V 511

IDRM Payload Block Diagram



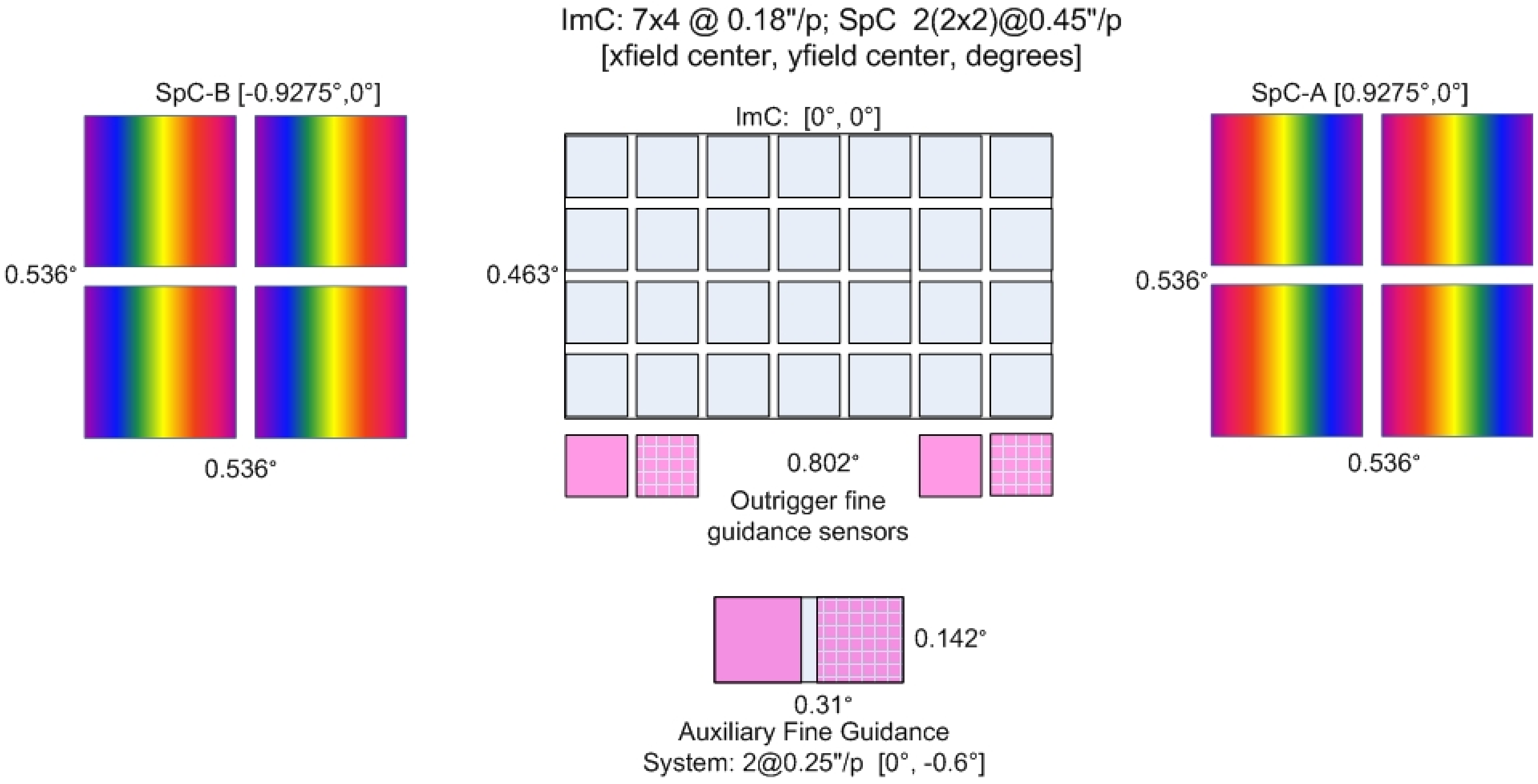
FGS = Fine Guidance Sensor

JDEM-Omega vs. IDRM

	JDEM-Omega	IDRM
Telescope	1.5m obscured	1.3m unobscured
Imager Channel		
Number of detectors	24	28
Active Area	0.25 deg^2	0.29 deg^2
Plate Scale	180 mas/pix	180 mas/pix
Spectrometer Channels (per channel)		
Number of detectors	6	4
Active Area	0.26 deg^2	0.26 deg^2
Plate Scale	370 mas/pix	450 mas/pix

Both Omega and IDRM had an optical cutoff of 2.0 μm; however, Omega used 2.5 μm detectors while IDRM used 2.1 μm detectors.

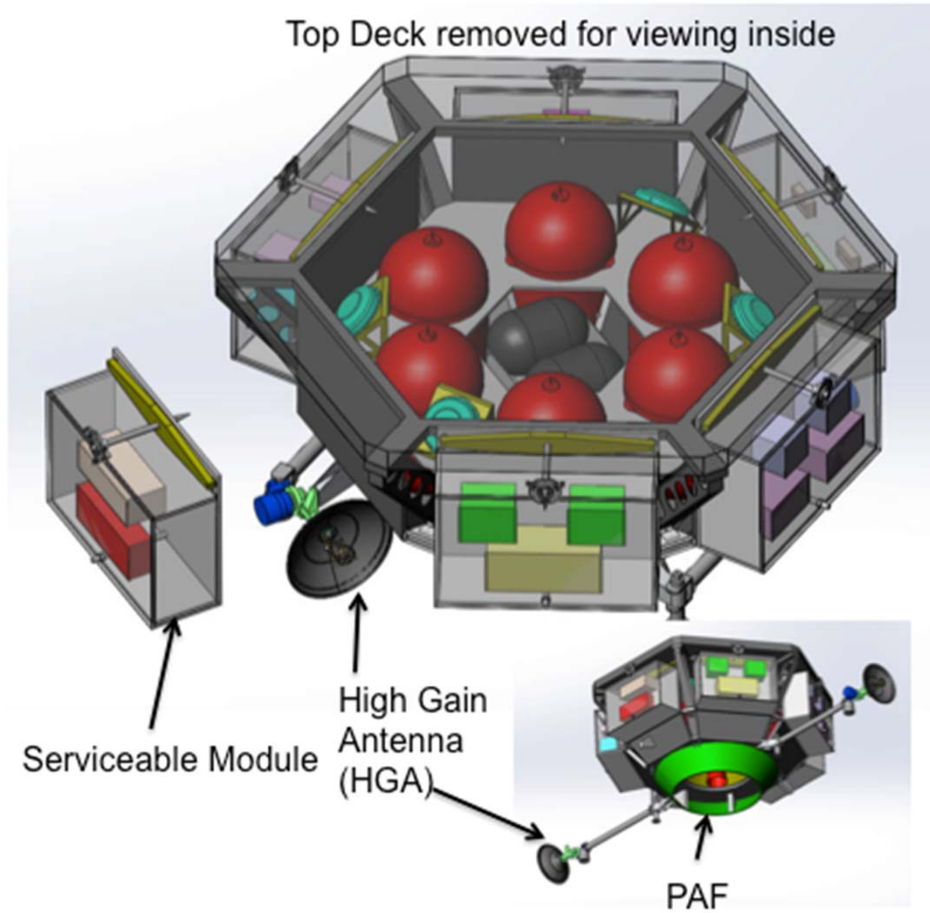
IDRM Instrument Field Layout



AFTA AND IDRM SPACECRAFT OVERVIEW

AFTA & IDRM Spacecraft Comparison

- Both S/C bus designs rely on recent GSFC in-house spacecraft electronics designs, primarily SDO and GPM
- AFTA S/C bus uses robotically serviceable/removable modules, design reused from Multimission Modular Spacecraft (MMS), while IDRM S/C bus had boxes mounted on bus panels
- IDRM uses single HGA and SSR to DSN, AFTA uses 2 deployable HGAs with continuous downlink to ground
- AFTA uses 6 bi-propellant tanks to circularize from GTO and stationkeeping, IDRM uses 1 mono-prop tank for orbit insertion and stationkeeping
- AFTA bus structure heavier due to larger payload mass and larger fuel load.



AFTA serviceable bus concept

AFTA Mass Comparison

	Wide Field Only			Wide Field + Coronagraph		
	CBE Mass (kg)	Cont. (%)	CBE + Cont. (kg)	CBE Mass (kg)	Cont. (%)	CBE + Cont. (kg)
Wide Field Inst.	421	30	547	421	30	547
Coronagraph	-	-	-	111	35	150
Instrument Carrier	208	30	270	208	30	270
Telescope	1595	11	1773	1595	11	1773
Spacecraft	1528	30	1987	1528	30	1987
Observatory (dry)	3752	22	4577	3863	22	4727
Propellant	2544		3095	2618		3196
Observatory (wet)	6296		7672	6481		7923

Lift Capacity to GTO: Atlas V 541: 7915 kg Atlas V 551: 8530 kg

AFTA AND IDRM MISSION COST COMPARISON

AFTA Cost Assumptions

- Life-cycle cost developed assumes the use of an existing 2.4m aperture telescope.
- Six and one-half year development phase is assumed. In the coronagraph option, the payload and observatory I&T phases are increased a total of three months.
- Five year operational phase baselined in cost. For the coronagraph option, an additional year of operations is assumed.
- Cost developed using a combination of grassroots and parametric modeling, along with historical analogous GSFC missions.
- Life-cycle costs are presented in fixed year 2012 dollars.
- Ground system costs include the build of one ground antenna, with an existing antenna used as the back-up.
- Separate costs developed for the addition of the coronagraph.

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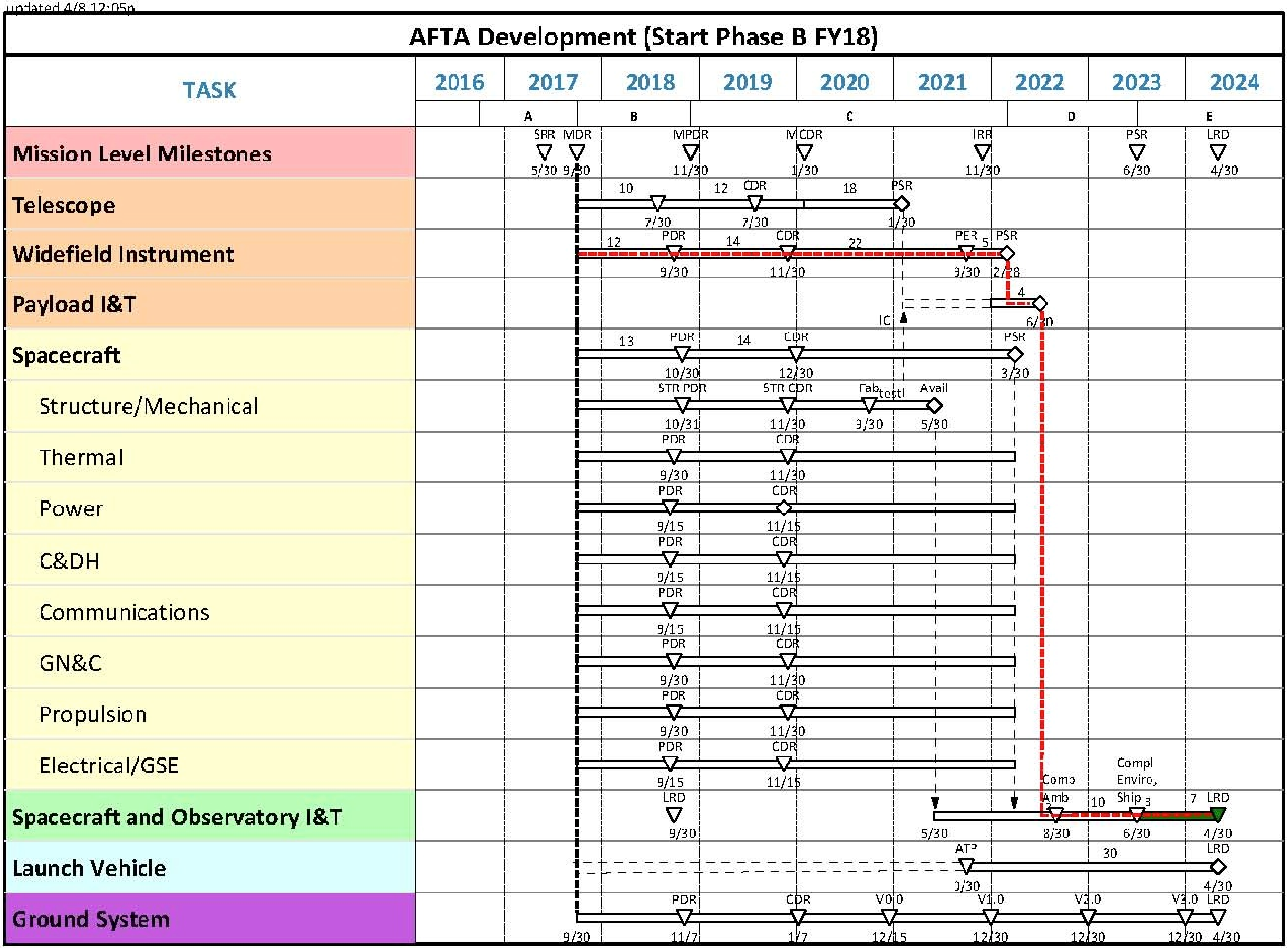

Critical Path

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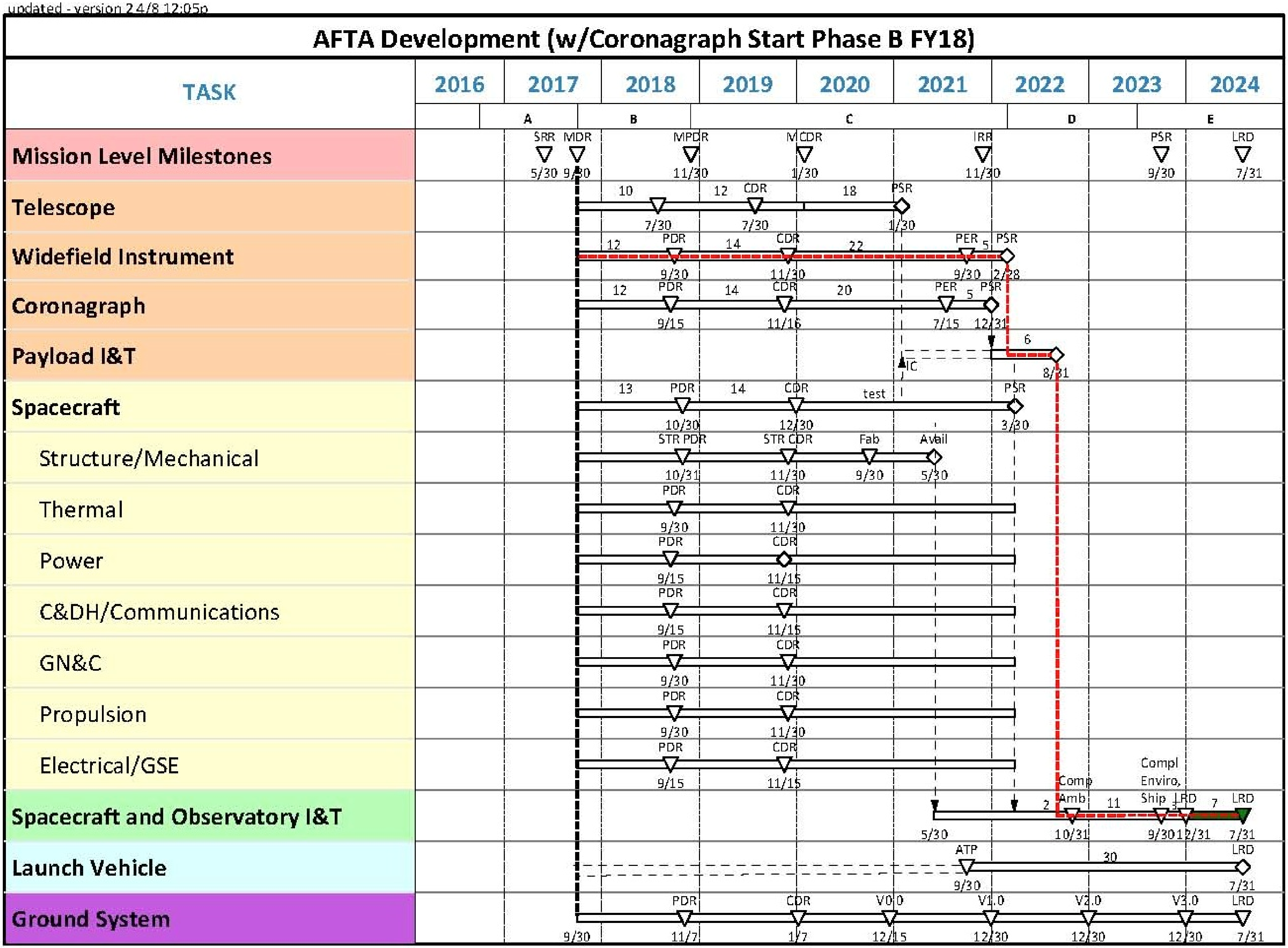


Critical Path

Comparison of Complexity & Risk of AFTA to Previous IR Survey DRMs (1/2)

- AFTA incorporates existing telescope - ensures optics not on critical path. Interfaces established, less design iteration.
- Early delivery of AFTA telescope allows for extended testing with wide field instrument (15 months). Early testing of wide field instrument (with EDU focal plane) and telescope significantly reduces risk and simplifies instrument/payload GSE requirements.
- AFTA contains a single wide field channel, IDRM had 3 wide field channels.
- AFTA contains ½ the total number of science HgCdTe detectors, reducing instrument integration time on the critical path.
- IFU channel adds a 19th detector and electronics chain to the instrument. Additional IFU optics are small and high TRL. R=75 SNe disperser eliminated. IFU allows simplification of spacecraft design due to decreased roll angle pointing requirement and relaxed revisit pointing requirements. This addition is offset by the deletion of the Aux Guider.
- Retained conservative 79 month development schedule, same as IDRM, in spite of all of the above simplifications.
- Operations are greatly simplified by eliminating DSN overhead and scheduling requirements. Transmitter operates under steady thermal conditions.

Comparison of Complexity & Risk of AFTA to Previous IR Survey DRMs (2/2)

Conclusion:

- *The AFTA DRM has a comparable overall complexity & development risk to the IDRM. (Fewer focal planes, fewer number detectors & telescope optics built are offset by a larger wide field instrument and H4RG development).*
- *The IDRM was costed at approximately $1.4B (FY12) without launch vehicle. CATE was 9% higher.*
- *AFTA is heavier, primary contributors are: propellant (to circularize), heavy NRO telescope and larger structure to support the large telescope.*
  - *Neither propellant or structure drive mission cost.*
- *The GSFC in-house GEO SDO spacecraft has been used as an analog for the WFIRST and JDEM DRMs. Very appropriate now given GEO orbit.*
- *I&T operations moving 2.4m telescope, only slightly more difficult than operations with a 1.5m telescope.*
- *Summary – the savings due to the available telescope and the simplifications to the functionality of the wide field instrument should, to first order, offset the cost increase of larger structural mass. AFTA should be in family with previous IR survey DRM estimates.*

AFTA Mission Functional Elements

AFTA System

Flight Segment

- Spacecraft
- Telescope
- Instruments
- Launch Vehicle

Ground Segment

- Space Network (USN, TDRSS)
- AFTA Ground Station & Data Storage/Distribution
- Mission Operations Center
- Science Operations Center & Data Archive/Analysis

Science

- AO Selected Science Team
- GO Science Program
- GI Archival Program
- EPO

Launch Vehicle Cost Considerations

- The following cost comparisons presented by the Study Office do not include the launch vehicle costs. Launch vehicle costs are provided to the Study Office by KSC and are specified as Sensitive But Unclassified (SBU) and can't be discussed in an open forum.
- The launch vehicle environment is dynamic with new vehicles expected to be available in the near future (e.g. Falcon Heavy) that could potentially impact the AFTA launch vehicle cost.
- While not on the NLS contract now, KSC has provided the Study Office with a range of estimates for a heavy launch vehicle in the 2021 timeframe; that range is $244 to $418M in RY dollars ($199 to $340 in FY12). Note the Study Office did not require the use of a Heavy Lift launch vehicle in its mission concept, however Aerospace recommended the switch to the more conservative launch vehicle, but at a much higher cost than the KSC estimate.
- Coronagraph was not part of the CATE process for AFTA and will be not be included in the comparisons between the CATE and the Study Office's estimates. Coronagraph costs will be discussed separately.

AFTA & IDRM Cost Estimate Comparisons

(without launch vehicle)

- IDRM Study vs. IDRM CATE
  - The Study Office and Aerospace CATE estimates were in good agreement. The CATE estimate was 9% higher than the Study Office's estimate.
- AFTA Study vs. AFTA CATE
  - The CATE estimate was 20% higher than the Study Office estimate; still quite reasonable agreement. The larger difference is attributed to the mass increase which the CATE utilizes to cost additional design threats. This is conservative given the telescope is built. Mass threats would be expected to be primarily structural mass increases.
- IDRM CATE vs. AFTA CATE
  - The AFTA CATE is 8% higher than the IDRM CATE.

SUMMARY: *The Study Office concluded that the simplifications to the wide field and telescope, and the fact the telescope was already built, offset the increased size of the observatory, whereas the CATE judged AFTA to be slightly more costly than IDRM. The AFTA cost is in family with the IDRM cost.*

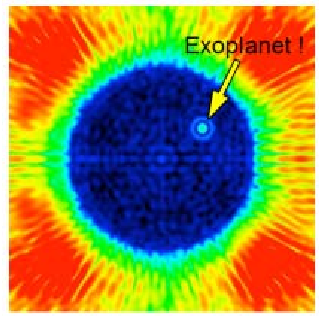
Note: The NWNH JDEM-Omega estimate of $1.6B is in $FY10. This is approximately $1.7B in $FY12.

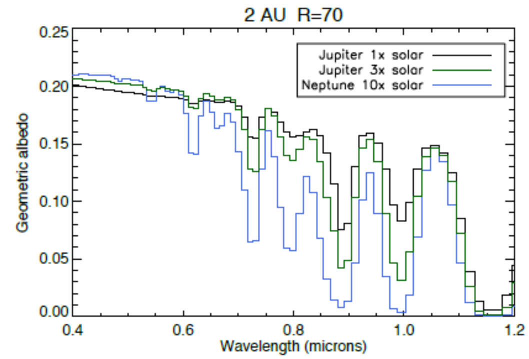
Cost of Serviceability

- The AFTA DRM arranges spacecraft and instrument hardware in robotically removable modules.
- In a conventional non-serviceable spacecraft, components are typically mounted on secondary structure, commonly panels, SDO for example.
- The change for AFTA is to make those panels readily removable. The spacecraft reference concept utilizes the attachment approach developed in the 1970's for the Multi-Mission Modular Spacecraft (MMS), and the instrument utilizes the mounting approach developed for HST in the 1980's.
  - Thus both approaches are low risk and high TRL (TRL-9).
- Spacecraft integration would proceed exactly as it would for a traditional "non-serviceable" spacecraft.
  - No unique GSE requirements.
- The estimate of the costs to incorporate serviceability included in the LCC is 18M. Based on both parametric and bottoms-up estimates.
- The cost of a servicing mission or the infrastructure to execute a servicing mission is not included in this LCC.

AFTA CORONAGRAPH OVERVIEW

AFTA Coronagraph Instrument





Coronagraph Instrument → Exoplanet Direct imaging — Exoplanet Spectroscopy

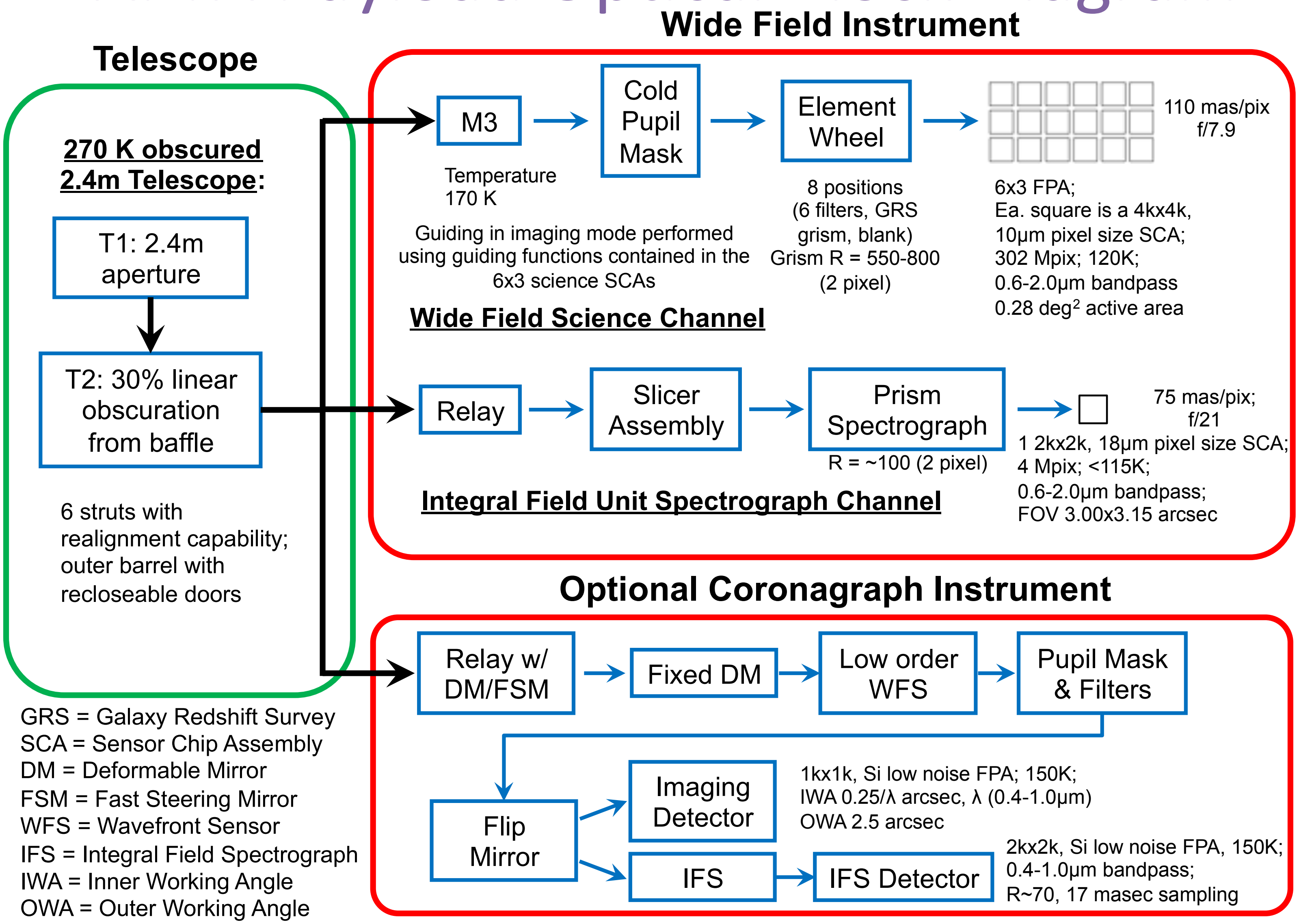
Bandpass	430 – 980nm	Measured sequentially in nine ~10% bands
Inner working angle	100 – 250 mas	$\sim 3\lambda/D$
Outer working angle	0.75 – 1.8 arcsec	By 48X48 DM
Detection Limit	Contrast $\leq 10^{-9}$ After post processing)	Ice and gas giants such as cold Jupiters
Spectral Resolution	R~70	With IFS, R~70 across 600 – 980 nm
IFS Spatial Sampling	17mas	Nyqust for $\lambda \sim 430$nm

AFTA Coronagraph Instrument will:

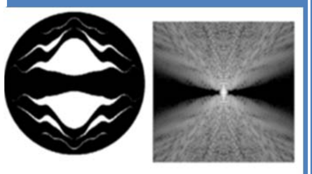
- Characterize the spectra of over a dozen radial velocity planets.
- Discover and characterize up to a dozen more ice and gas giants.
- Image and survey over a dozen exo-zodiacal disks
- Provide crucial information on the physics of planetary atmospheres and clues to planet formation.

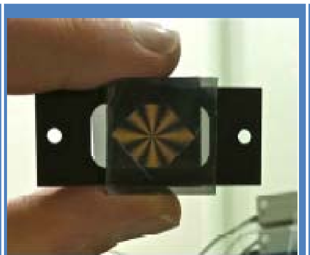
AFTA-WFIRST responds to decadal survey to mature exoplanet technologies, precursor science for study of earth-like planets

AFTA Payload Optical Block Diagram



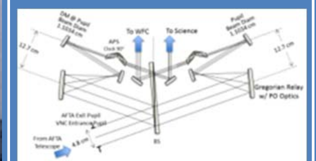
Star light suppression -- Technical Approach

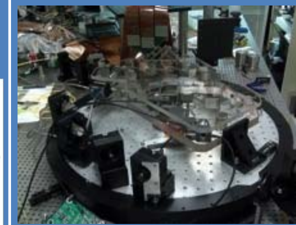

Shaped Pupil Mask Pupil Masking (Vanderbei & Kasdin, Princeton Univ.)


Vector Vortex Mask Image Plane (Serabyn, JPL)


Phase Induced Amplitude Apodization (PIAA) Pupil Re-Mapping (Guyon, Univ. Arizona)


Hybrid / Band-Limited Lyot Mask Image Plane Amplitude & Phase (Trauger, JPL)


Visible Nuller Coronagraph: Phase-Occulting (Lyon, GSFC)


Visible Nuller Coronagraph: DaVinci (Shao, JPL)

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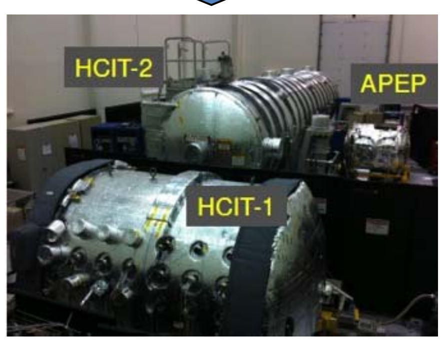
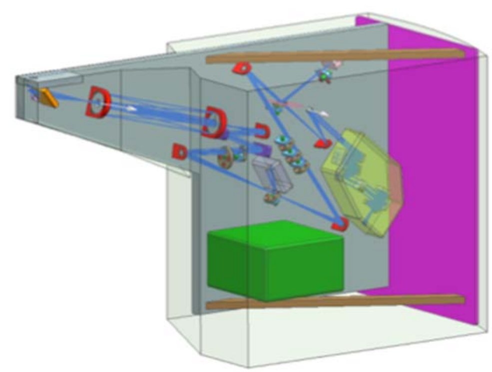
http://wfirst.gsfc.nasa.gov/

Six different concepts

Primary Architecture (OMC)	Back-up Architecture (PIAACMC)

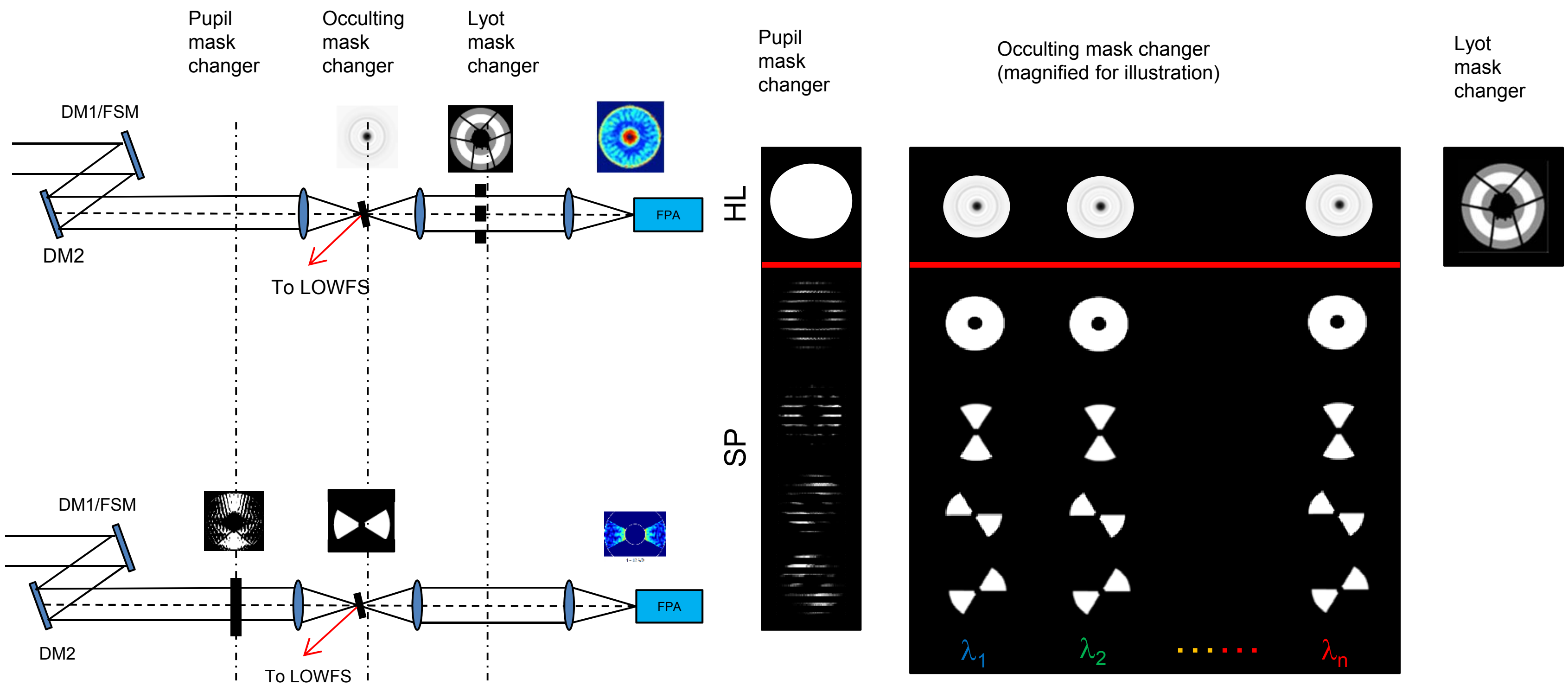


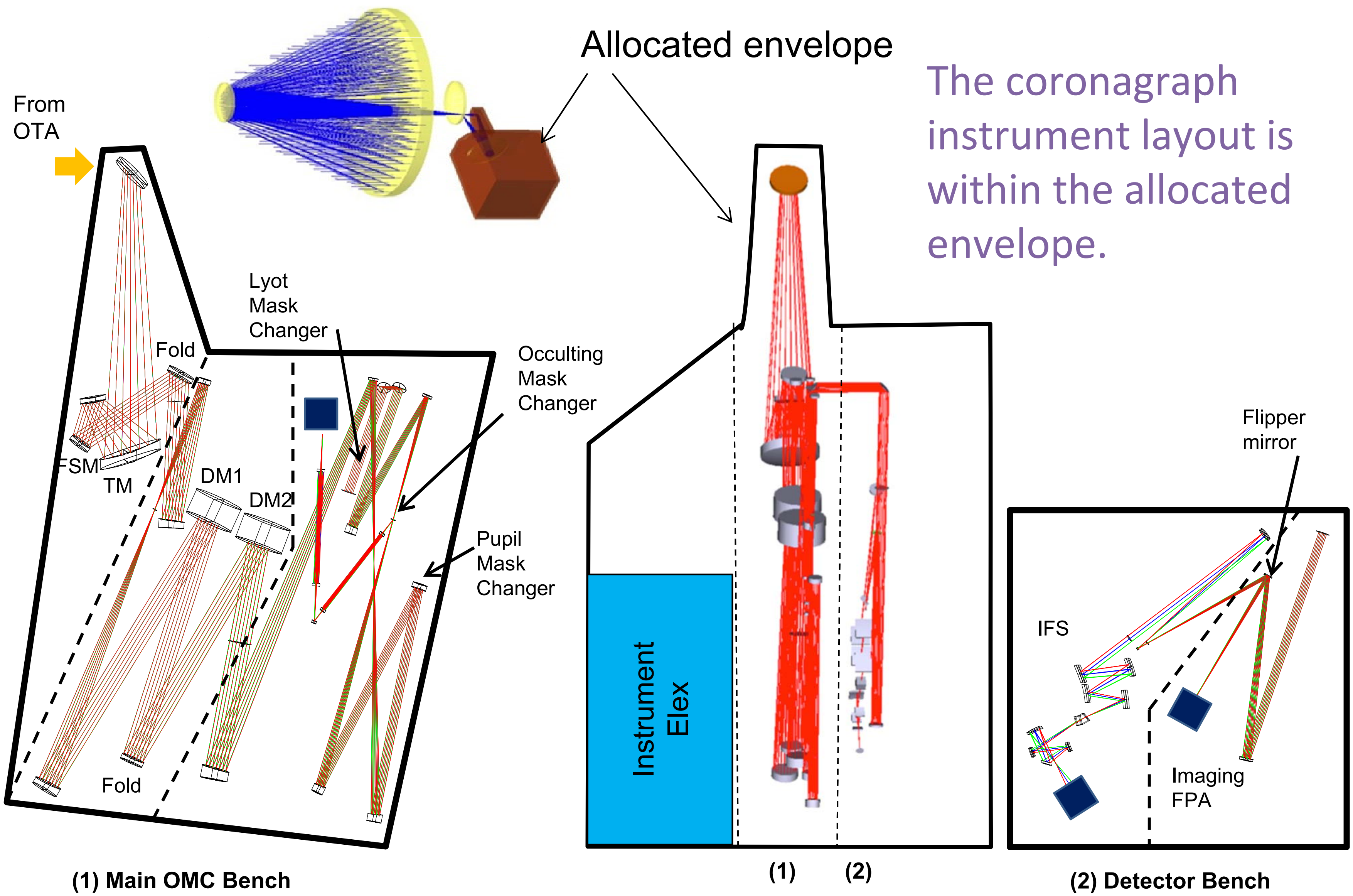


Primary Architecture:

Occulting Mask Coronagraph = Shaped Pupil + Hybrid Lyot

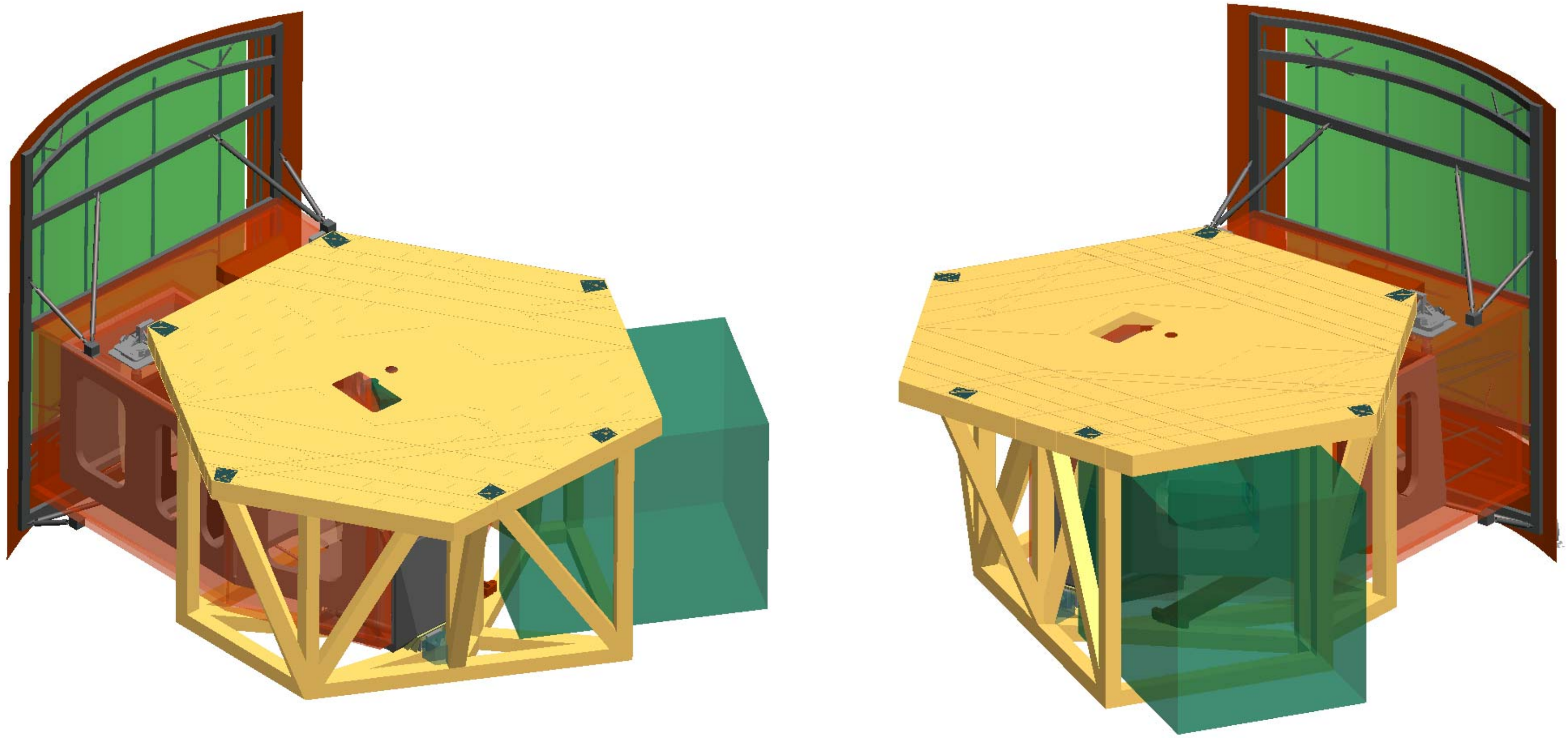
- SP and HL masks share very similar optical layouts
- Small increase in overall complexity compared with single mask implementation





The coronagraph instrument layout is within the allocated envelope.

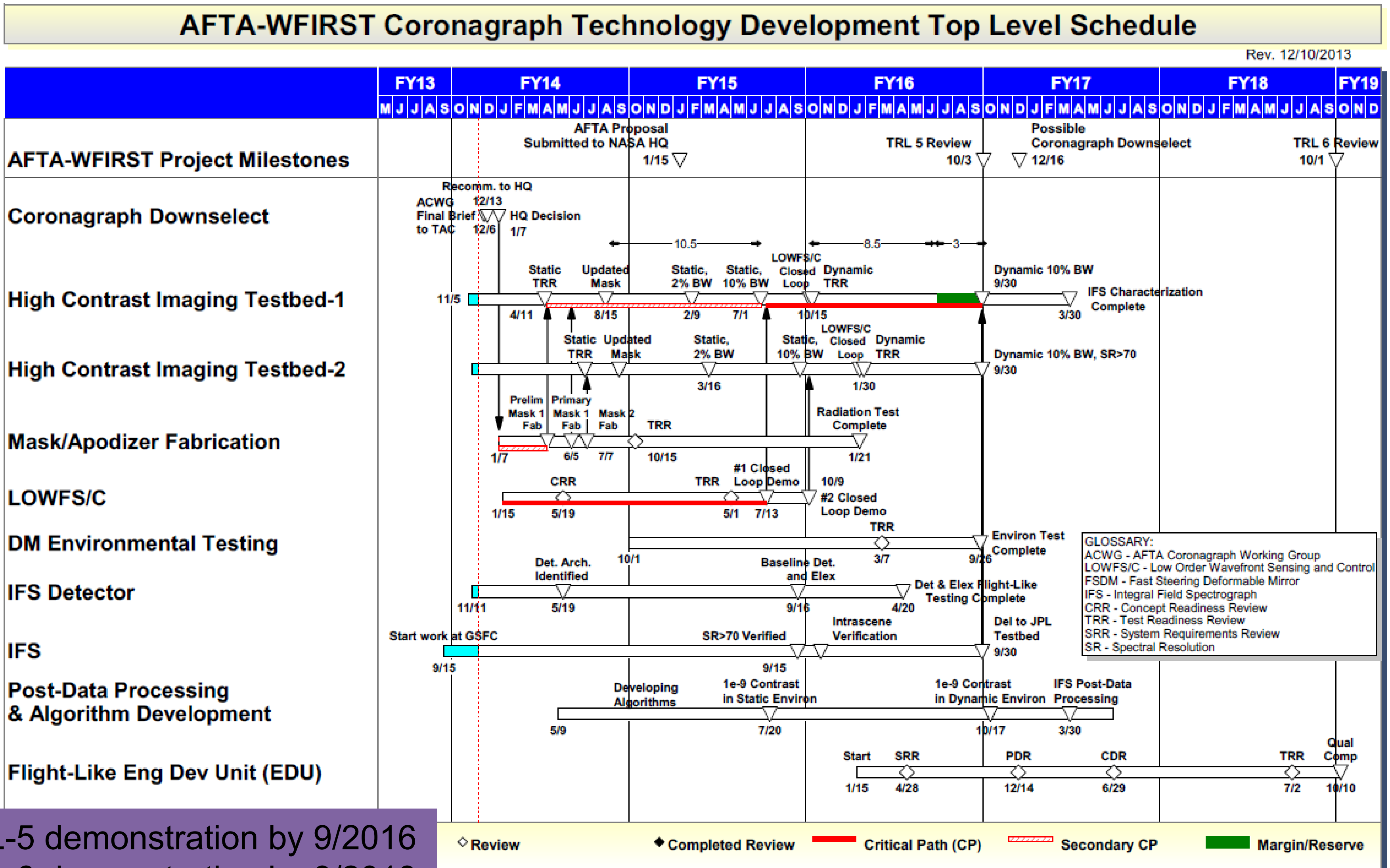
Coronagraph in Instrument Carrier



Coronagraph Cost

- Instrument Cost Basis
  - Coronagraph instrument costs were estimated with 4 independent models, all in agreement:
    - NICM System, NICM Sub-System, PRICE, SEER
  - Assumes additional 35% mass contingency above current best estimate.
  - Science costed at additional 15% of instrument development
  - Allocated additional 30% cost reserve on total
  - Assumes Technology matured to TRL 6 by PDR:
    - Technology development costed separately
    - STMD committed to provide significant funding to the coronagraph technology development effort in FY14-17.
- Coronagraph Cost Impact 260M ($FY12)
  - Instrument
  - Integration/I&T/launch vehicle/reserve
  - 6th year of operations
- The coronagraph development satisfies another Decadal Survey requirement “to lay the technical and scientific foundations for a future space imaging and spectroscopy mission”.

Coronagraph Technology Development Schedule



TRL-5 demonstration by 9/2016
TRL-6 demonstration by 9/2018

DETECTOR STATUS

H4RG-10 Detector Development Summary

- The current AFTA-WFIRST Wide-Field Imager configuration is based on a mosaic of 4K x 4K near-infrared detectors.
- The Project initiated detector development in FY11 with a successful Pilot Run Lot of detectors at Teledyne Imaging Sensors that were then characterized during FY12.
  - 4K x 4K, 10 μm pixel pitch, H4RG-10 ROIC, 2.1 μm cutoff.
  - The results were very encouraging and pointed to the need for some minor process improvements.
- A series of small process development experiments were completed to address the issues identified during the Pilot Run.
- In FY13, the Project started a Process Optimization Lot to optimize the potential flight recipes.
  - 4K x 4K, 10 μm pixel pitch, H4RG-10 ROIC, 2.5 μm cutoff.
    - The growth and processing of the detector material is varied (among different devices).
  - "Banded" arrays with spatially dependent recipe for efficiently spanning parameters.
  - These devices are currently being delivered, with the final device characterized by the end of FY14.

H4RG-10 Development Upcoming Work

- Towards the end of FY14, a Full Array Lot will be started to focus on producing full arrays of the selected recipe.
  - Downselected to one or potentially two possible variants.
  - Will confirm that the selected recipe(s) scale to the entire array and provide better full array uniformity and yield information.
  - Analysis will be complete by mid-FY15.
    - Assuming the planned testing infrastructure improvements are realized in FY14.
- The final pre-flight lot will be the Yield Demonstration Lot.
  - Anticipated start at the end of FY15.
  - A single flight candidate recipe will be used.
  - These detectors are expected to be of fairly high quality, and will be using during instrument development as engineering devices, for qualification testing, and for detailed performance characterization.
  - Completion of the Yield Demonstration Lot is planned to be in FY16, after which the flight build can be started.

Notional Detector Performance Targets

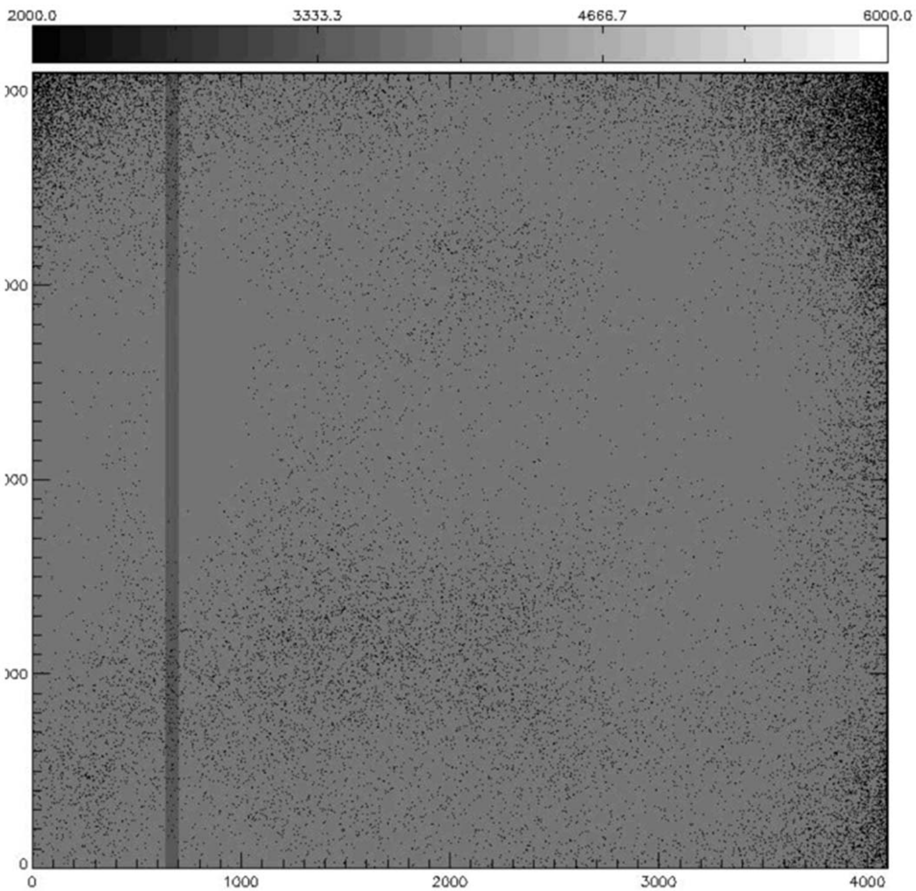
- Detailed flowdown of scientific requirements is in progress, including key simulations using the planned observation strategies.
- Until these detailed requirements are completed, a notional set of performance targets are used.
- Operating temperature is still an open trade, but is expected to be in the 80-100K range.
- Dark Current: < 0.05 e-/sec
- CDS Readout Noise: < 20 e-
- Total Noise: < 5 e- (in 150 sec)
- Quantum Efficiency: > 70%
- Persistence: < 0.01% (after 150 sec)
- Inter-Pixel Crosstalk: < 8% (total)
- Interconnect: > 98%

DRAFT: actual values pending SDT inputs.

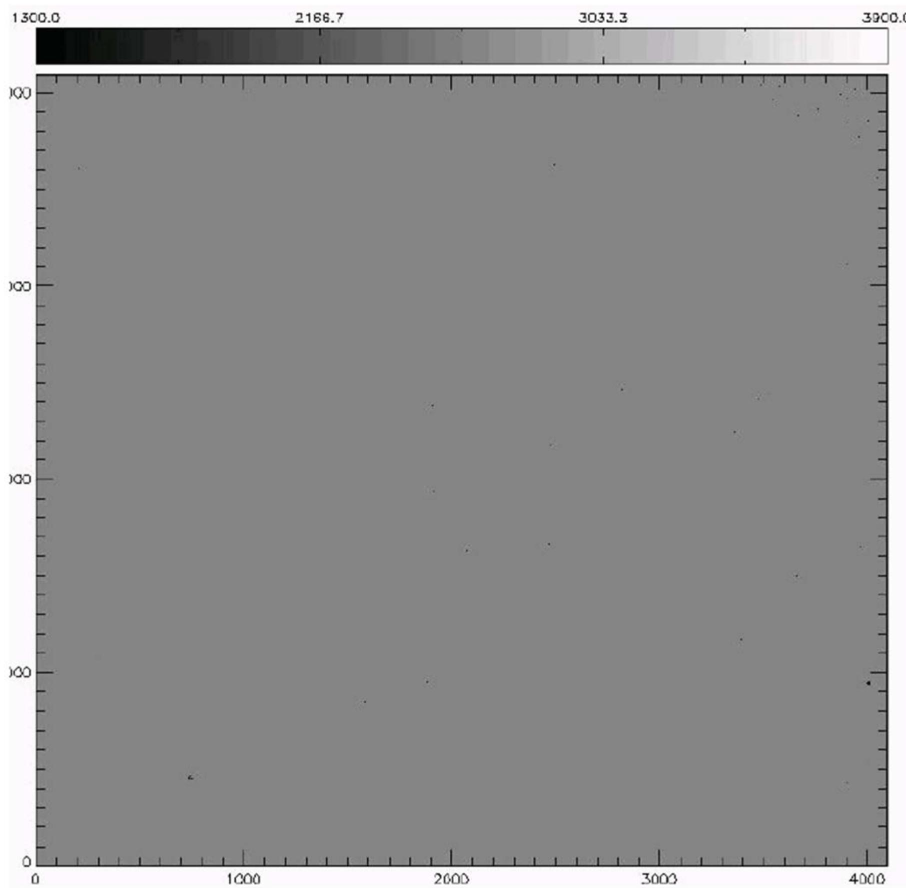
Current Results

- Results are preliminary, based on testing a small sample of variants and the parallel development/debugging of test procedures.
- Main points:
  - *Previously discovered interconnect issue appears to be resolved.*
  - *Previously discovered high CDS noise appears to be resolved.*
  - *Two very high quality devices have been produced to date.*
- Elevated dark current on the readout edge is noted in some devices.
  - The level is very low and still meets the performance target, but the effect is real (and may cause calibration complications).
  - The cause is under investigation, including contributions from the detector itself as well as potential ROIC sources.

Interconnect Issues Appear To Be Resolved



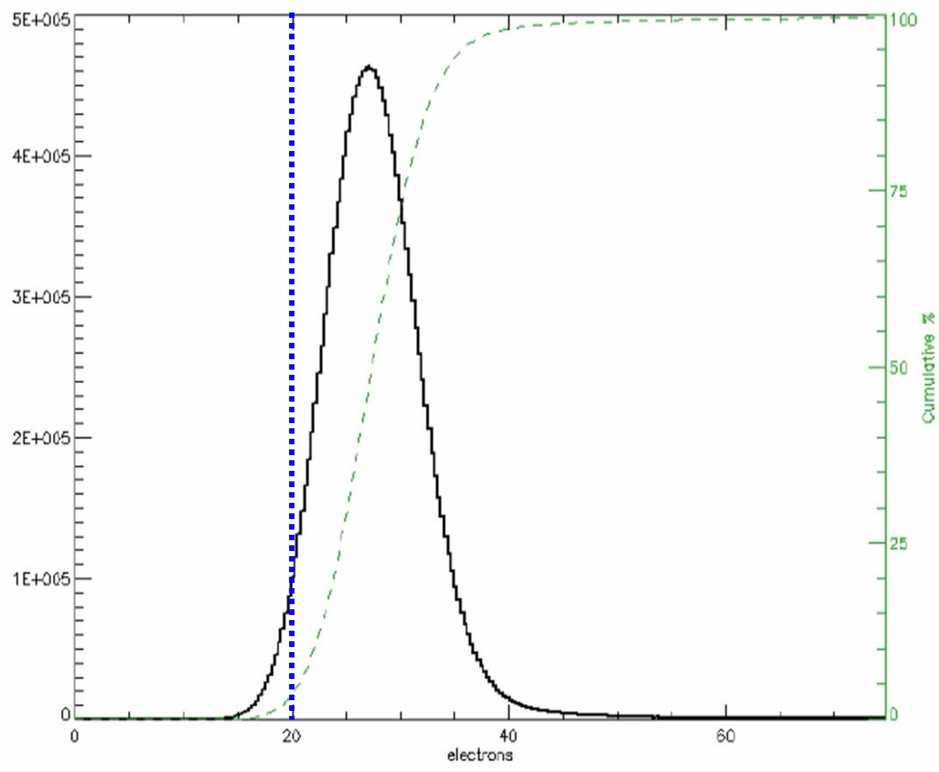
SCA 16361
Previous Pilot Run Lot
Black dots indicate interconnect failures, ~5%.



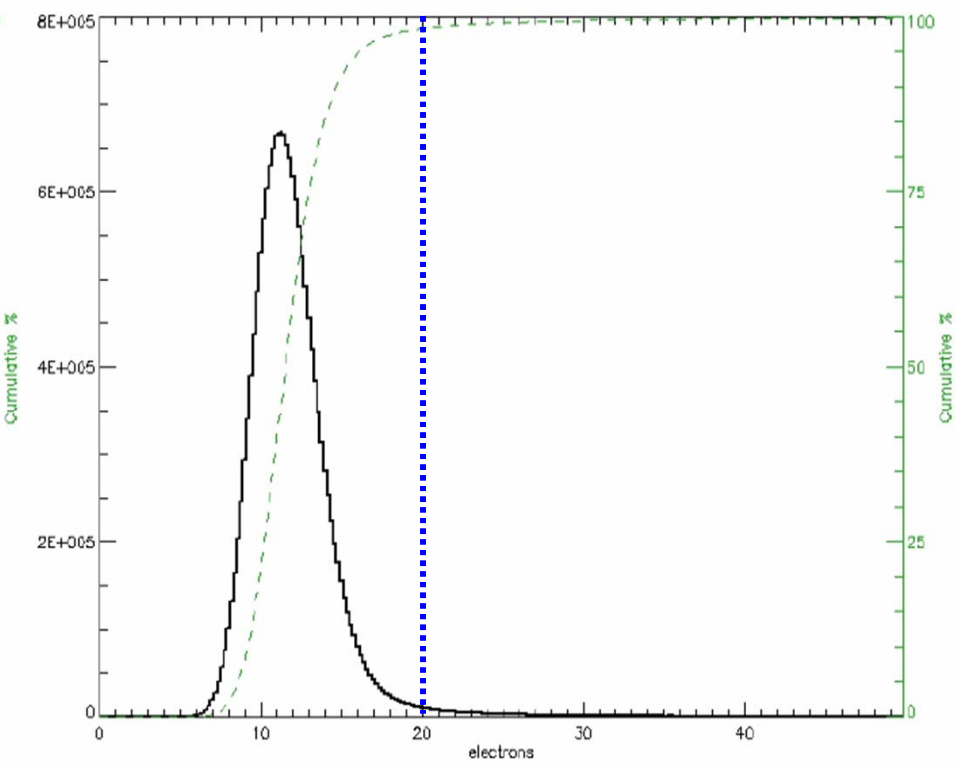
SCA 17429
Current Process Optimization Lot
< 0.5% interconnect failures

CDS Noise Is Much Improved

Blue line shows CDS noise target.



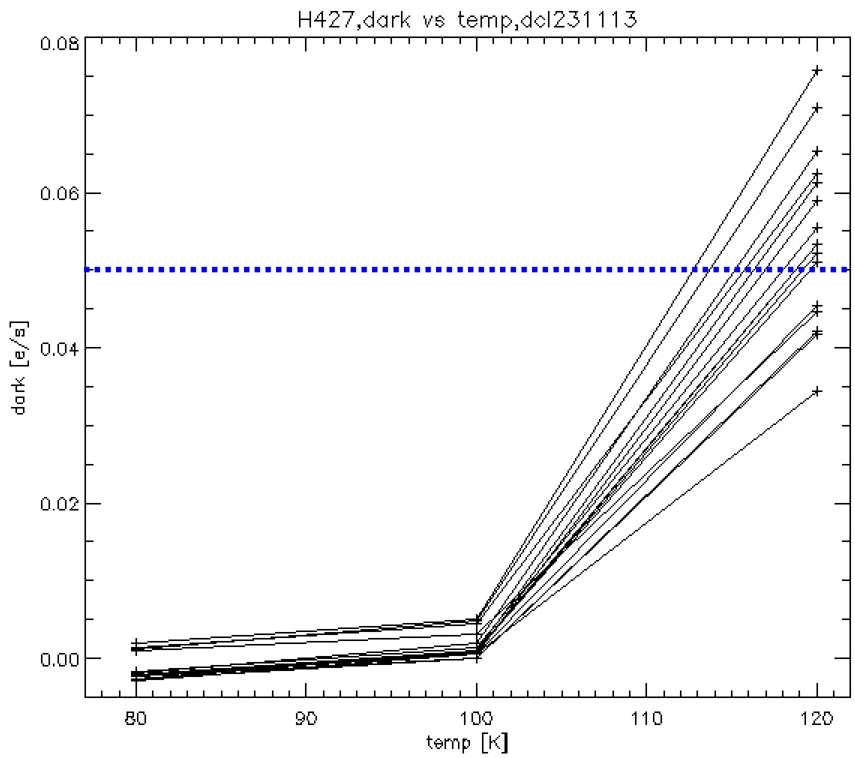
SCA 16360
(Previous Pilot Run Lot)

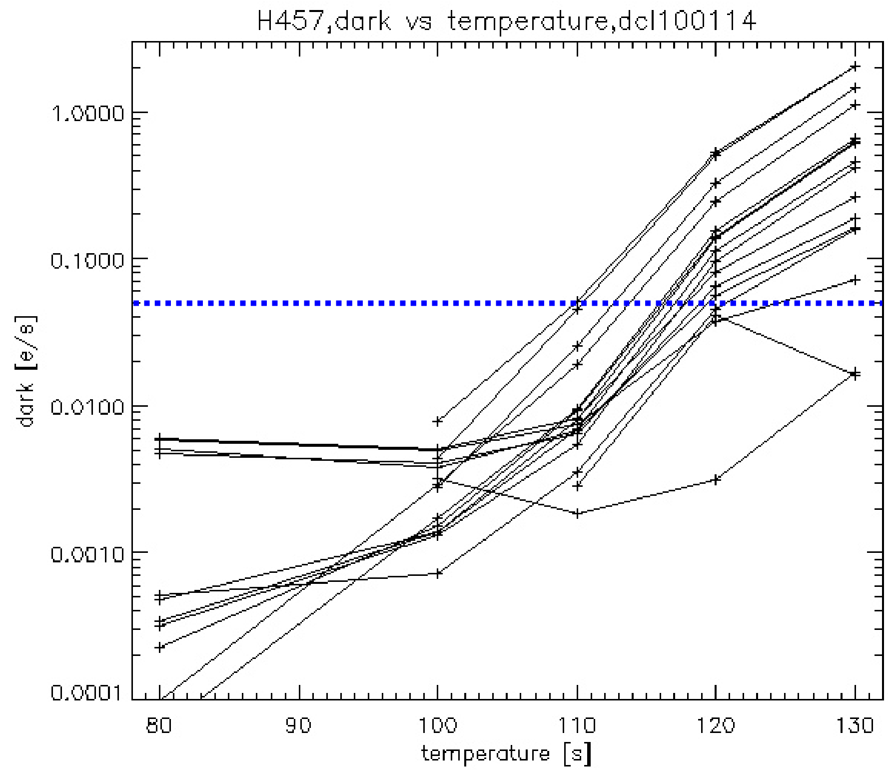


SCA 17427
(Current Process Optimization Lot)

Example Dark Current

Blue line shows dark current target.
Cycle 4 baseline FPA temperature of 90K provides margin.

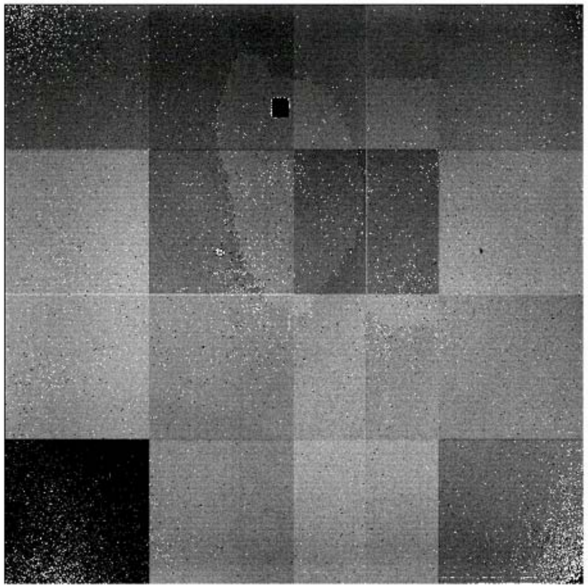




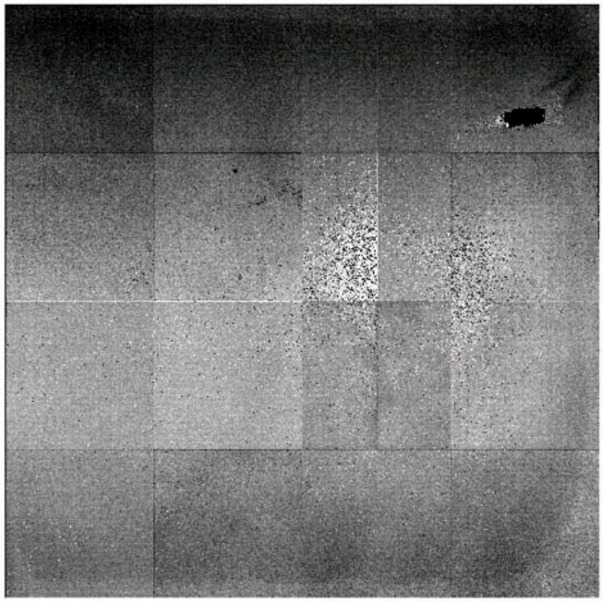
The lines are the different “bands.”
Results below 100K are limited by the data set (need longer integrations to detect smaller dark currents).

Example Flat Field Response

SCA 17427



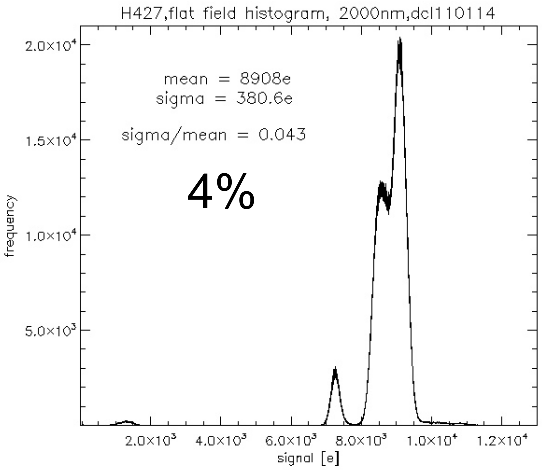
SCA 17457

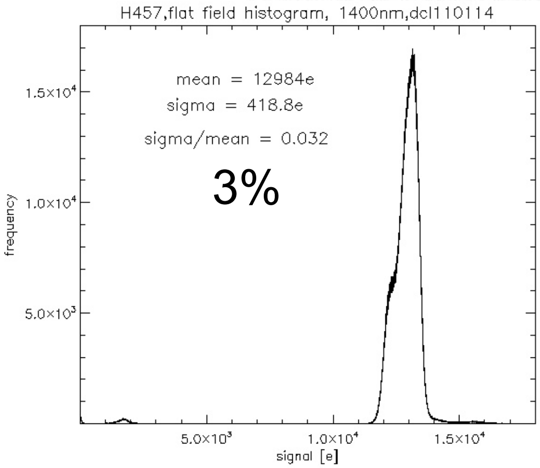


2000 nm exposures.

Scale is +/-10% of mean.

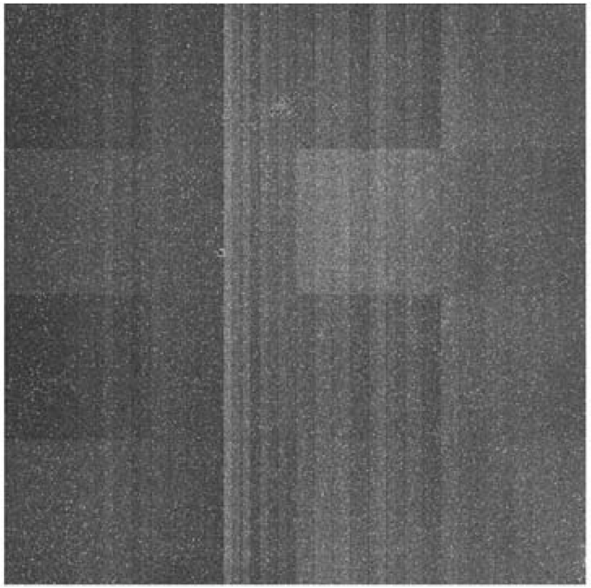
Sigma/mean is very good, especially since the arrays are banded and the non-uniformity of the Lambertian source is not corrected.





Example CDS Noise

SCA 17427

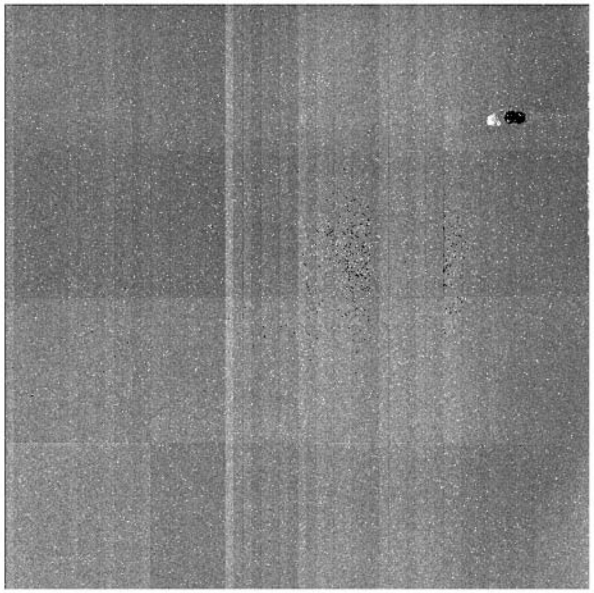


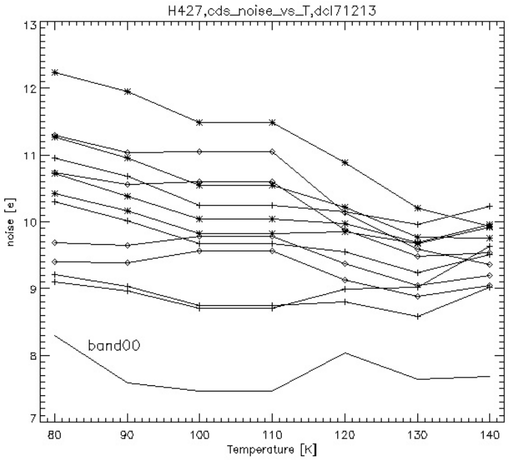
Measurements at 100 K.

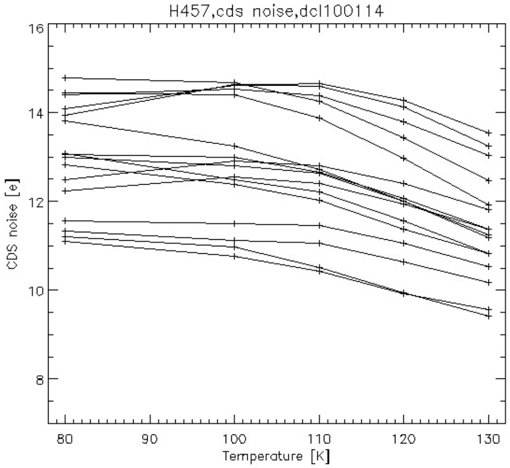
All variants meet the performance noise target of < 20 e- CDS.

Investigating why CDS noise is weakly decreasing with temperature.

SCA 17457

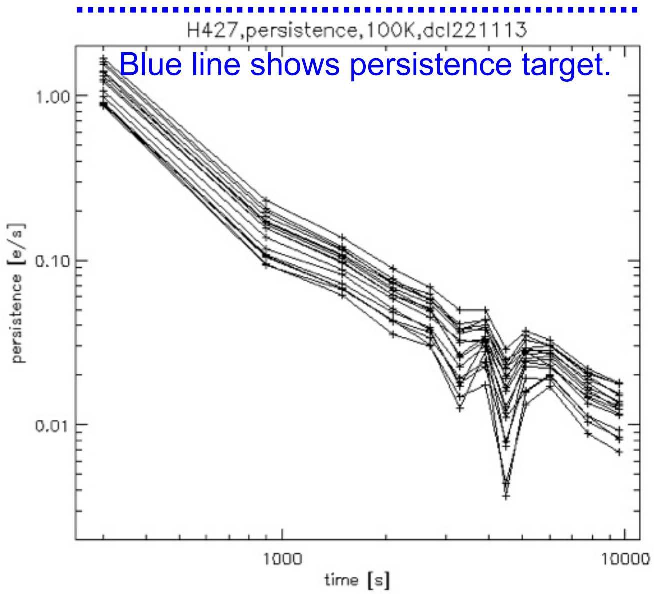






Example Persistence

SCA 17427

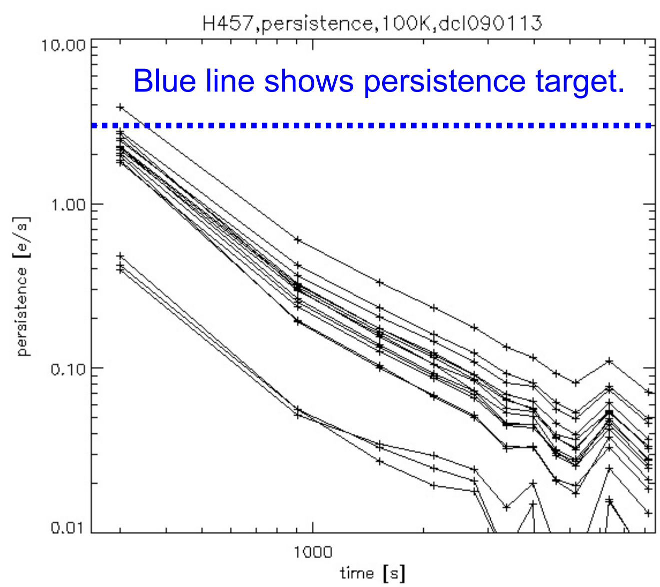


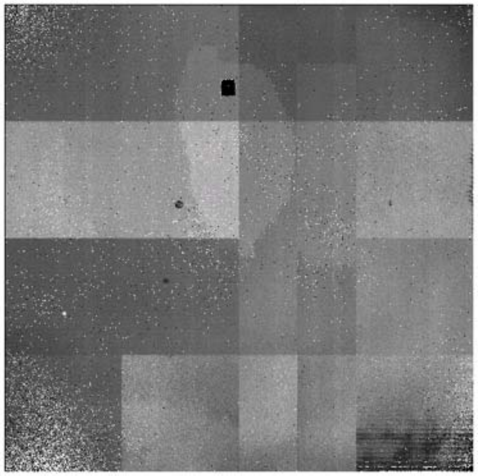
Measurements at 100 K with ~ 80000 e- illumination at t=0.

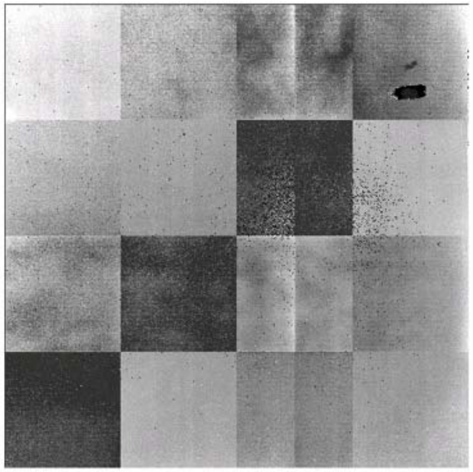
Low persistence at 100 K and below, increasing with temperature.

Images show effective dark current after 600 sec.

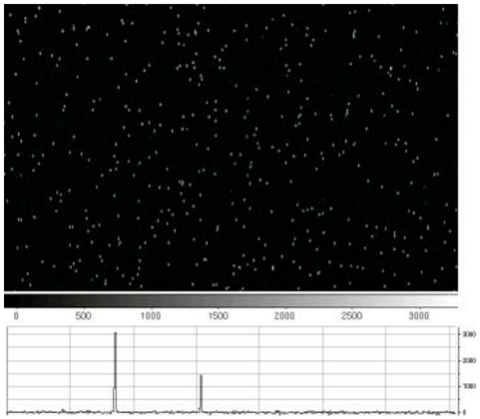
SCA 17457







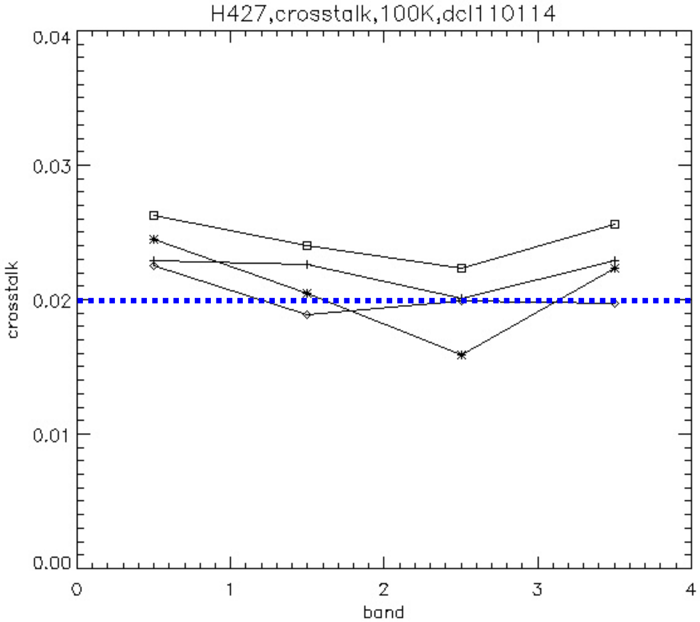
Example Inter-Pixel Capacitance Crosstalk



Measurements at 100 K using selected ^{55}Fe single pixel hits.

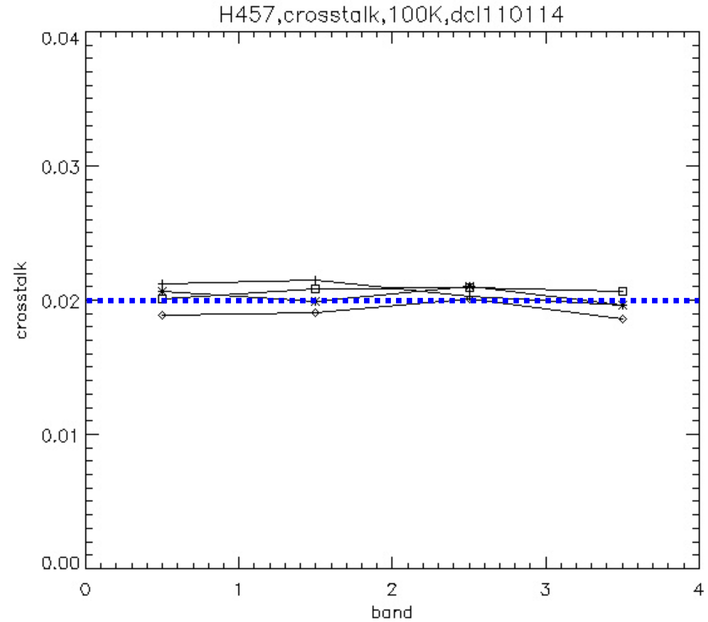
Plot on left shows an example raw image.

SCA 17427



Blue line shows IPC target.

SCA 17457



Detector Development Summary

- A plan is being executed for early development work to minimize the risk of using the H4RG-10 detectors.
- Initial results for the current Process Optimization Lot look very promising.
  - Two devices tested to date have most bands meeting or are very close to performance targets.
- These devices have demonstrated that the technology is *capable* of producing the required levels of performance.
- The remaining work will demonstrate achieving these performance levels *with reasonable yields* (and thus cost).
- Successful execution depends on consistent effort and funding over the next two to three years.

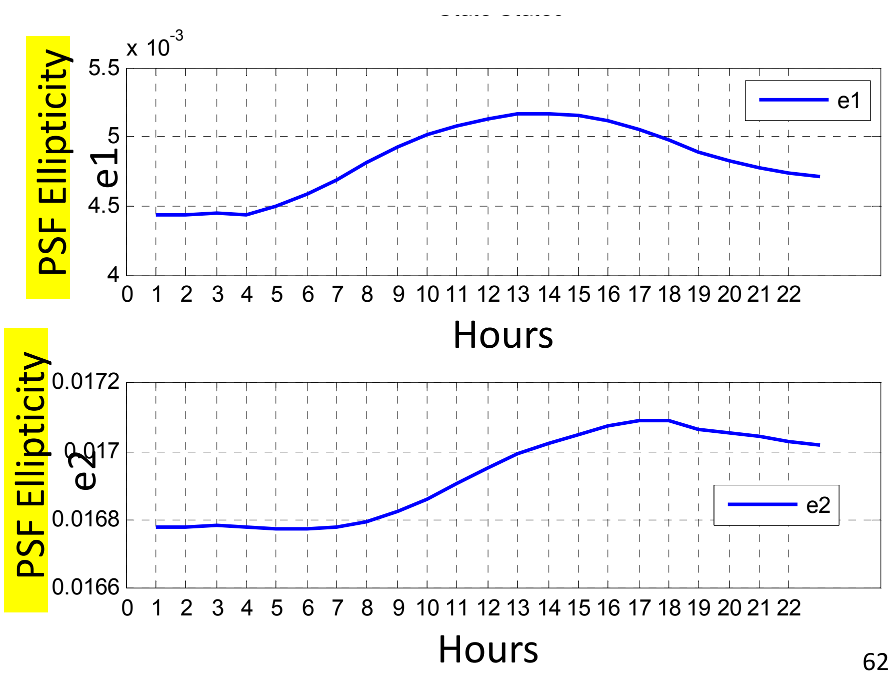
RECENT TECHNICAL PROGRESS

Wide Field Instrument Update [Cycle4]

- Optics:
  - Improved grism & IFU designs
  - Telescope error budget well along; WFI Error budget detail started
  - Early discussion of next iteration of optical design
  - Looking mainly for improved coronagraph interfaces, possible 'more rectangular' WFI layout
- Overall:
  - Instrument packaging well along
  - I&T discussion started; included is modeling of 'half pass test' which allows
    - Instrument only test w/out costly GSE

STOP Assessment Summary

- Excellent WFI PSF Ellipticity stability and solid WFI WFE stability margins, the best DRM results that we have seen (even for the worst-slew case)
  - x9 margins on WFI WFE drift stability rqt
    - x25 better than HST WFE variations, which can be ±30 nm over an orbit
  - x108 margins on WFI PSF Ellipticity total stability rqt
- The T1/T2 Shape/Position Stabilities, from fixed-attitude case, are viewed positively by the Coronagraph Team
  - Zernike instability dominated by focus at a fraction of a nanometer to a few picometers range over 24 hours
  - Sub-micron rigid body motion ranges over 24 hours
- MUF (Model Uncertainty Factor) x3 included in all above



Jitter Assessment Summary

- Significant margins on RWA-induced Jitter are predicted:
  - Peak LOS Jitter ≤ 4 masec rms/axis, x3.6 margin on 14 mas rms/axis LOS jitter rqt
  - Peak WFE jitter {not shown} ≤ 0.114 nm, x 6.2 margin on 0.707 nm WFE jitter rqt
    - But only evaluated at Telescope Intermediate Focus
  - Margins almost x2 better at all other speeds out to 50 Hz
- D-struts critical to Jitter performance
- MUF of 2.48(<20Hz) to 5.86 (>40 Hz) is included in all results

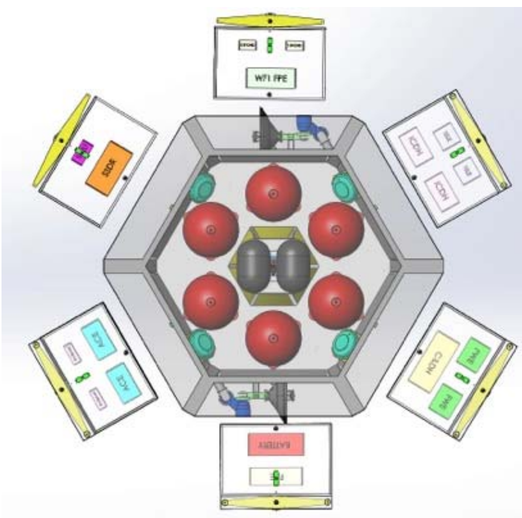
Recent AFTA Spacecraft Studies

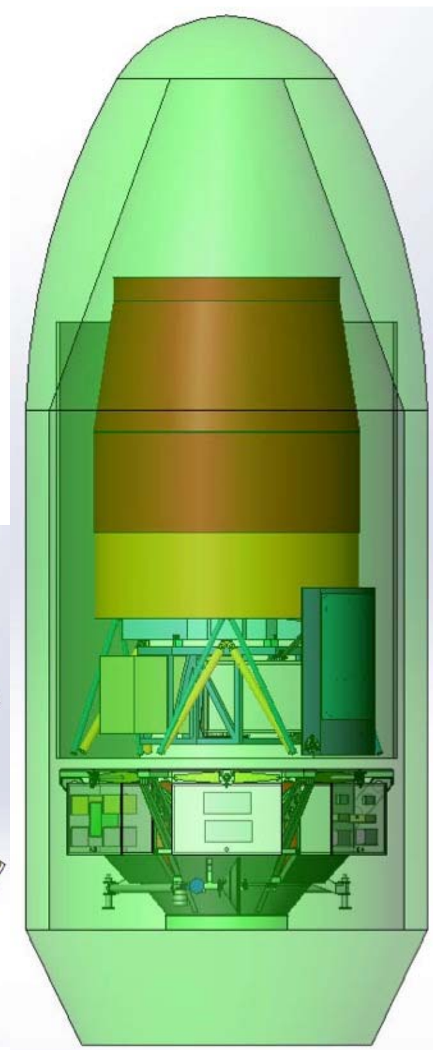
- The Study Office has been developing an alternate spacecraft configuration over the last couple of months
  - The alternate configuration would eliminate the bi-prop system, significantly simplifying the spacecraft and reducing overall mass, but requires the launch vehicle to circularize the orbit at GEO.
- SpaceX is planning on launching a test flight of the Falcon Heavy late 2014/early 2015 year and has an Air Force contract for the Falcon Heavy for 2015.
  - SpaceX is planning on starting the “on-ramp” process this year to make the Falcon Heavy available to NASA missions.
  - Potential cost savings.

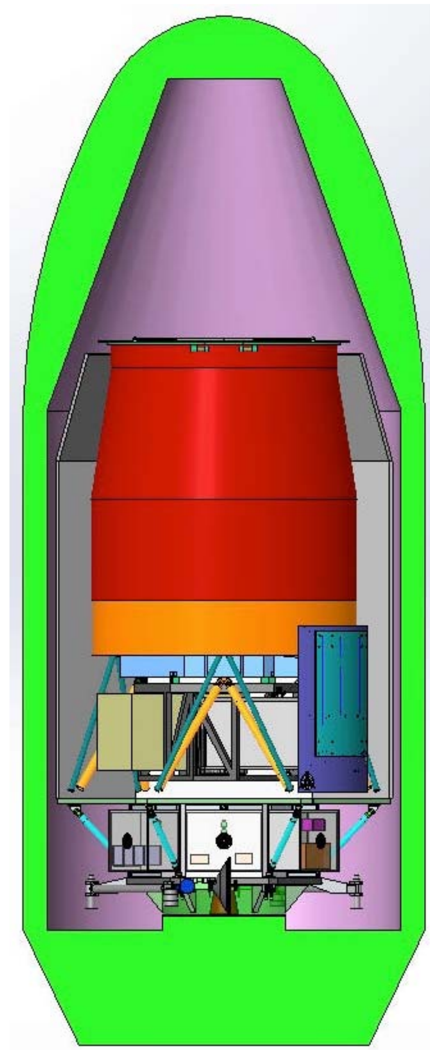
AFTA Spacecraft Configurations

Baseline Configuration

- 6 prop tanks carry >3000 kg of bi-prop to circularize orbit from GTO and for station keeping
- Taller S/C to accommodate tanks pushes higher into fairing
- Atlas V 551

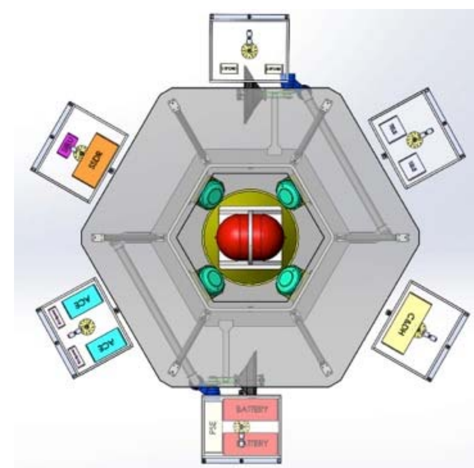






Alternate Configuration

- 1 prop tank carries <100 kg of mono prop for station keeping
- Shorter S/C is lower in fairing
- Falcon Heavy (or Delta IV Heavy)



Top View and View in Fairing of Baseline Configuration

Top View and View in Fairing of Alternate Configuration

RISKS

Candidate AFTA Risks

Risk Summary	Proposed Mitigations	Status
Detector Performance Given that initial detector fabrication resulted in some performance issues there is some possibility that future yields may also incur similar performance issues, affecting mission performance	a) Establish by modeling that the limitations experienced are the result of tunable manufacturing parameters and not due to fundamental device physics. b) Run early test lots to demonstrate detector performance	- Detector process optimization lot results are demonstrating ability to make and test arrays that meet WFIRST early draft requirements.
Wide Field Instrument Focal Plane Thermal Design Given that the instrument performance is sensitive to thermal stability there is the possibility that the current thermal design performance will produce unacceptable thermally induced noise, impacting scientific performance	a) Test the prototype detectors and ASICs over an expected range of thermal transients to verify any noise is within the overall noise budget. b) Develop more detailed thermal models and temperature transient mitigation strategies to minimize the temperature transients.	- WFI Cycle 3 results provide preliminary indication orbital temperature variation within preliminary reqs. Detector testing during FY14 will further refine SCA thermal stability reqs on various time scales.
Payload I&T and Verification Given that payload I&T and verification is critical to meeting mission requirements there is a possibility that poor definition and execution in these areas could impact payload testing and/or on-orbit performance	a) Parallel development of I&T and verification plan along with WFI design (verification approach and what level of assembly) b) Independent review of I&T and verification approach concurrently with design effort	- Ongoing risk reduction activity as part of system design work. Identified potential low-cost GSE for instrument level testing. Exelis funded to examine IV&V this FY.

Candidate AFTA Risks

Risk Summary	Proposed Mitigations	Status
Coronagraph Requirements Driver Given that the coronagraph is a lower TRL tech demo there is a possibility that coronagraph requirements growth may occur, potentially impacting overall WFIRST mission requirements and driving mission complexity and cost	a) HQ direction that coronagraph will not drive mission requirements b) Monitor key coronagraph driving requirements (thermal, pointing, jitter, etc) throughout early coronagraph requirements definition and development effort	- Early telescope STOP and jitter results recently completed compare well with draft coronagraph requirements. Detailed coronagraph STOP & jitter analysis planned for next WFIRST design iteration (Cycle5). HQ direction that coronagraph is a tech demo instrument and will not drive mission requirements.
Telescope Thermal Design Given that the telescope was designed for room temperature there is the possibility that it will not perform as required, requiring science compromises	a) Telescope coupon testing to evaluate thermal performance and reliability b) Analysis of telescope components (structures, bonded joints, outer barrel, etc) to colder WFIRST flight environment c) Cold testing of flight telescope to verify performance, reliability	- Completed initial AFTA subassembly thermal test in FY13. Coupon thermal measurements to occur Q2FY14 with model updates Q3FY14.
Payload Jitter and Thermal Stability Given that there are mechanical and thermal instabilities that may degrade science image quality, there is a possibility that optical and science performance requirements may not be met	a) Perform STOP analysis early, and include high-fidelity model of the attitude control system. b) Evaluate operations concept trades that may alleviate jitter and stability issues	- Design Cycle3 assessments provide early indication that preliminary jitter and thermal reqs can be met for both instruments. Continuing early life cycle STOP and Jitter assessments to verify design.

Candidate AFTA Risks

Risk Summary	Proposed Mitigations	Status
Wide Field Tertiary Mirror Given that the wide field tertiary mirror (M3) is a large, lightweight, optical precision mirror operated at a novel temperature (170K) there is a possibility that meeting the optical performance of the mirror when mounted, aligned, and cooled will delay the TRL 6 milestone.	1) Perform mirror material trade study 2) Procure prototype mirror and mount 3) Perform figure test of mirror before and after each environmental test to validate mirror/mount design.	- Trade study to start this quarter. Planning for prototype availability by FY15.
Assessment of Original Telescope Capabilities Given that the AFTA system being utilized on WFIRST was part of a program with a unique set of system requirements and operational constraints differing from those on WFIRST, there is a possibility that incompatibilities between the original design requirements and the current system implementation could impact flight system performance and life.	1) Incompatibilities between original design reqs and current system implementation need to be identified so mitigations can be developed. a) Systematic review of the previous program telescope requirements and capabilities b) Compare to existing design assumptions/requirements and develop planned mitigation strategies, including targeted testing of existing telescope assets	- JPL working with Exelis on telescope ICD that provides data in a open format for delivery this FY. Preliminary loads information delivered from Exelis

Candidate AFTA Risks

Risk Summary	Proposed Mitigations	Status
<u>Availability of Telescope Actuator Motors</u> Given that the original telescope focus/alignment actuator motors may not be available and commercial replacements may not be available there is a possibility that there will be a availability gap in obtaining this essential telescope flight hardware	1) Investigate availability and flight use of any original remaining actuator motors 2) Investigate availability of commercial motors to replace any missing actuator motors 3) Design and qualify alternative focus/alignment actuator motors if necessary	- Recent development- DOD transferred existing motors and additional materials to NASA.

SUMMARY

Summary of Key AFTA Considerations

- Science
  - Dark energy: comparable to or better than IDRM science; better systematics
  - Microlensing: exoplanet yields are 1.6x that of IDRM for a fixed observing time
  - Coronagraphy: maturing critical coronagraph technologies to enable future earth-like planet finding mission; deliver precursor exoplanet science
  - Guest Observer: expanded time allocation & capability; broad community engagement; address diverse set of astrophysical questions
- Risk:
  - IR Detectors: existence proof fabricated for AFTA; yield to be addressed after recipe selected
  - Primary optics: built; off of critical path; interfaces defined
  - Coronagraph: is a tech demo - not allowed to drive mission requirements; SP doesn't drive observatory pointing
- Cost:
  - Both the Study Office and Aerospace agree that the cost of AFTA is in family with IDRM.