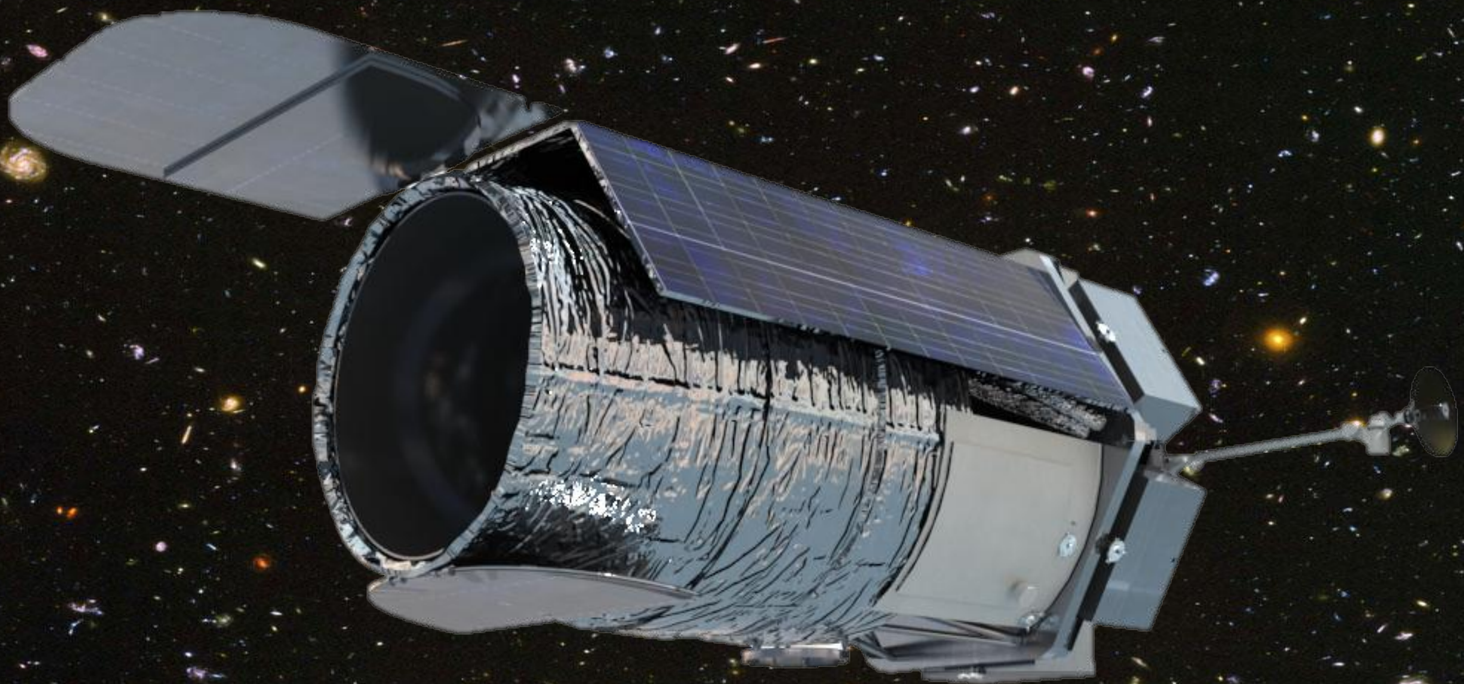


WFIRST-AFTA Presentation to the Committee on Astronomy & Astrophysics

March 4, 2014

Outline

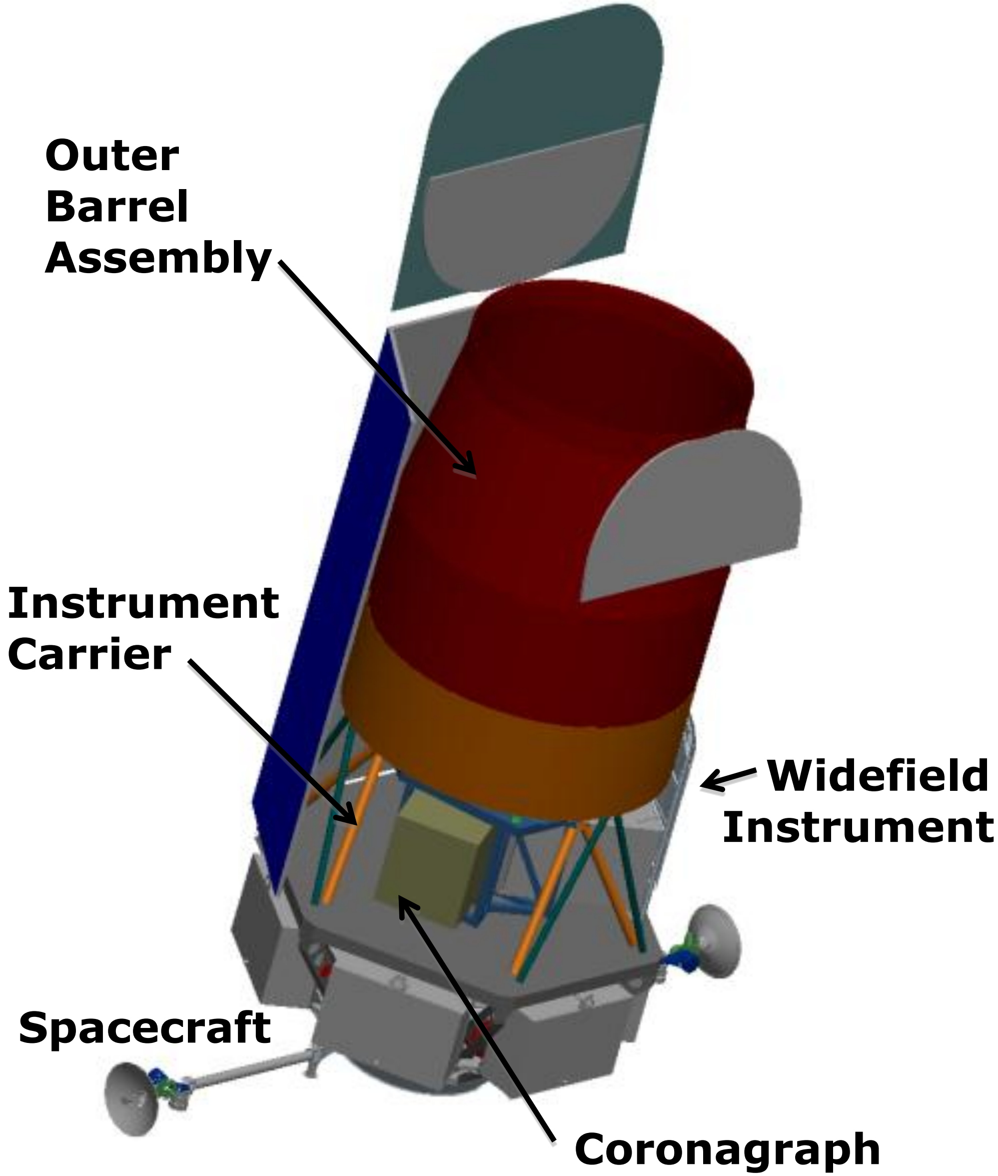
1. WFIRST-AFTA Overview
   – IDRM Comparison
2. IDRM & AFTA Cost Comparison, including CATE
3. Recent Technical Progress
   – Detector Status
   – Payload Design & Analyses Results
4. Summary

WFIRST-AFTA TECHNICAL OVERVIEW

WFIRST-AFTA Science Objectives

- ***Determine the expansion history of the Universe and the growth history of its largest structures*** in order to test explanations of its apparent accelerating expansion including Dark Energy and modifications to Einstein's gravity.
- ***Complete the statistical census of planetary systems*** in the Galaxy, from the outer habitable zone to free floating planets, including analogs of all of the planets in our Solar System with the mass of Mars or greater.
- ***Produce a deep map of the sky at NIR wavelengths***, enabling new and fundamental discoveries ranging from mapping the Galactic plane to probing the reionization epoch by finding bright quasars at z>10.
- ***Directly image giant planets and debris disks*** from habitable zones to beyond the ice lines, around nearby AFGK stars, at visible wavelengths, and characterize their physical properties by measuring brightness, color, spectra, and polarization while providing information to constrain their orbital elements.
- Provide a robust ***general observer program*** utilizing a significant portion of the mission minimum lifetime.

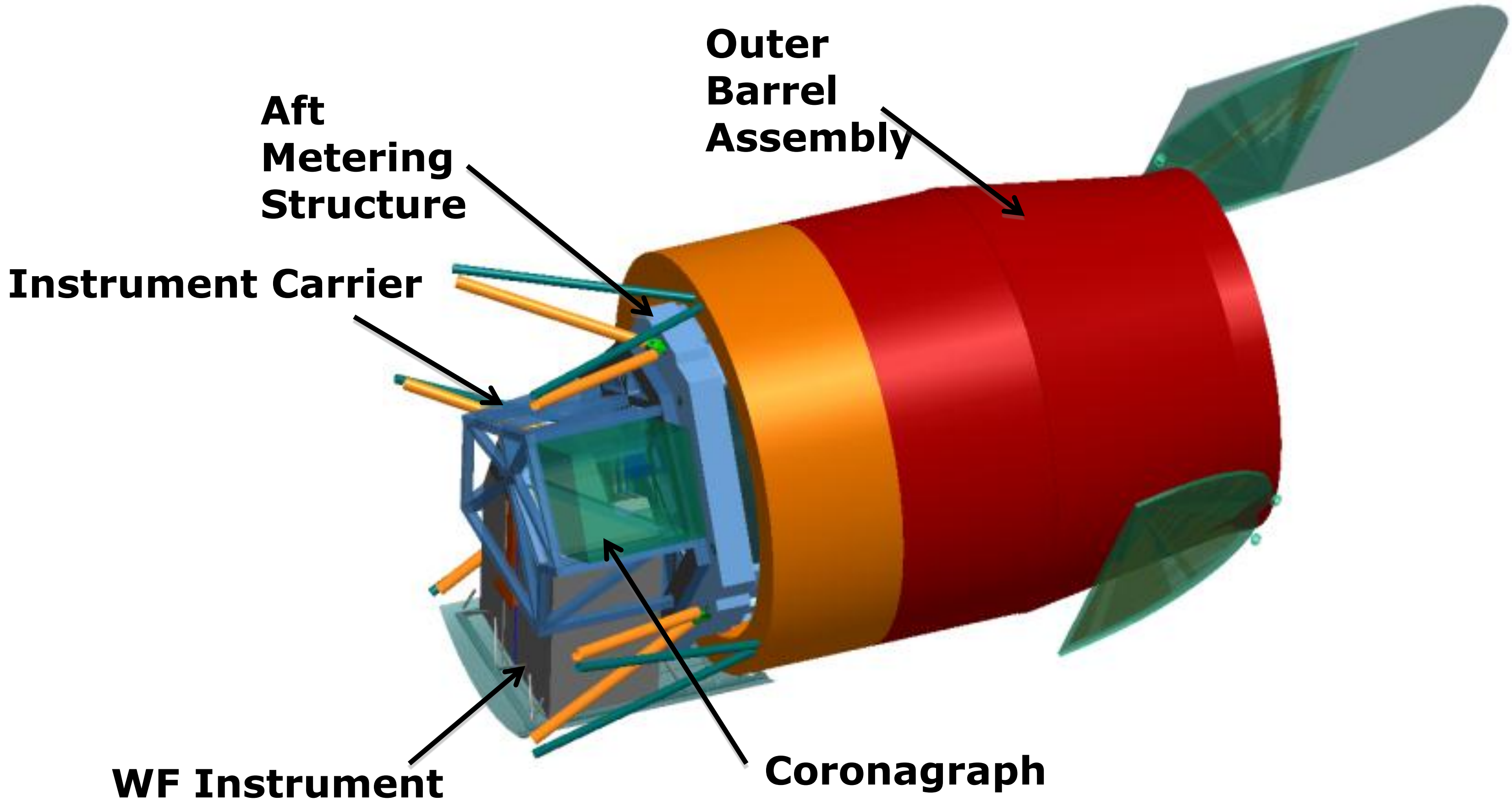
WFIRST-AFTA Observatory Concept



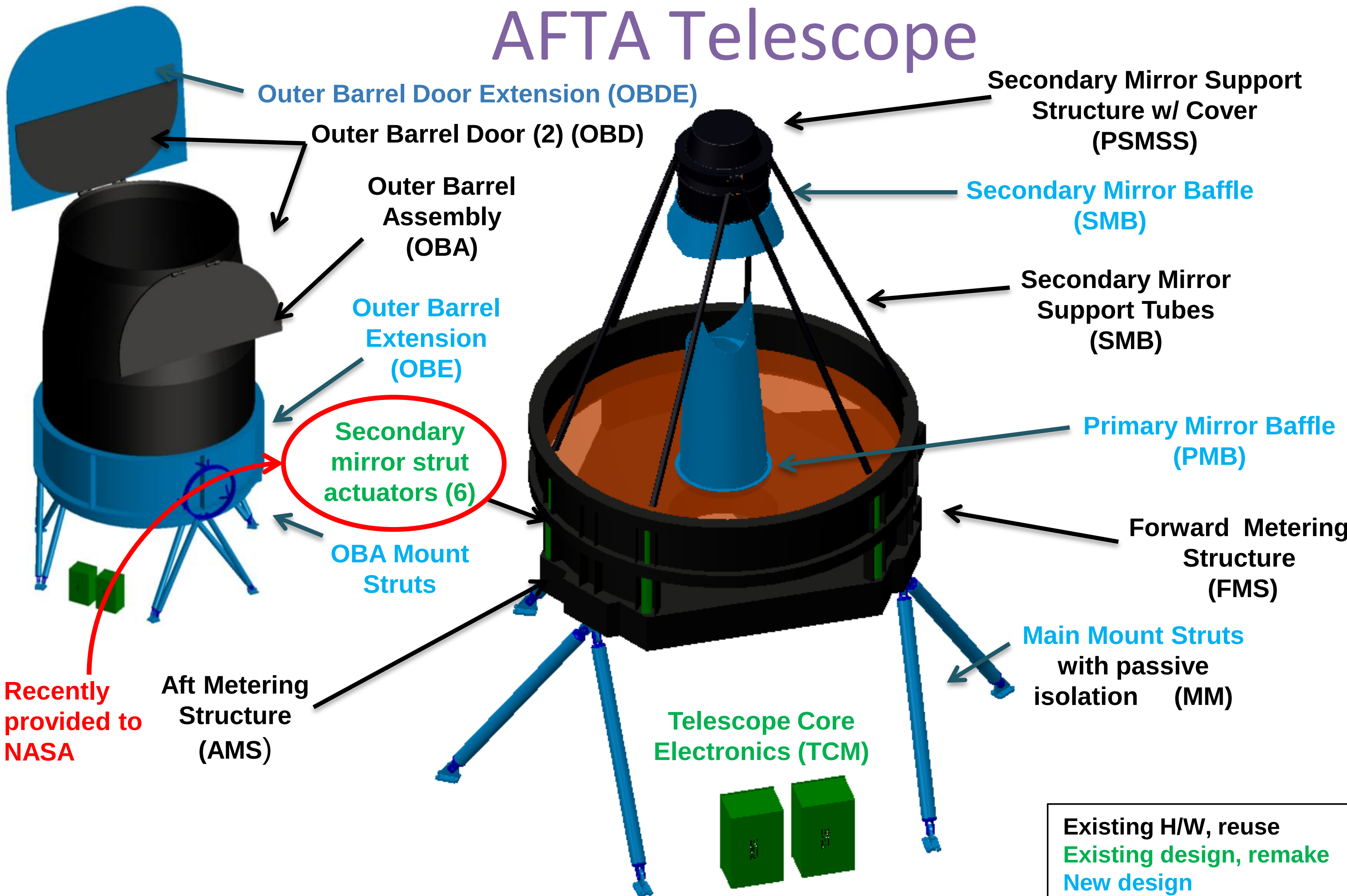
Key Features

- Telescope – 2.4m aperture primary
- Instruments
  - Single channel widefield instrument, 18 4k k 4k HgCdTe detectors; integral field unit spectrometer incorporated in wide field for SNe observing
  - Internal coronagraph technology demonstration with integral field spectrometer
- Overall Mass – ~6500 kg (CBE) with components assembled in modules; ~2600 kg propellant; ~3900 kg (CBE dry mass)
- Primary Structure – Graphite Epoxy
- Downlink Rate – Continuous 150 mbps Ka-band to Ground Station
- Thermal – passive radiator
- Power – 2100 W
- GN&C – reaction wheels & thruster unloading
- Propulsion – bipropellant
- GEO orbit
- Launch Vehicle – Atlas V 551

AFTA Payload Design Concept



AFTA Telescope



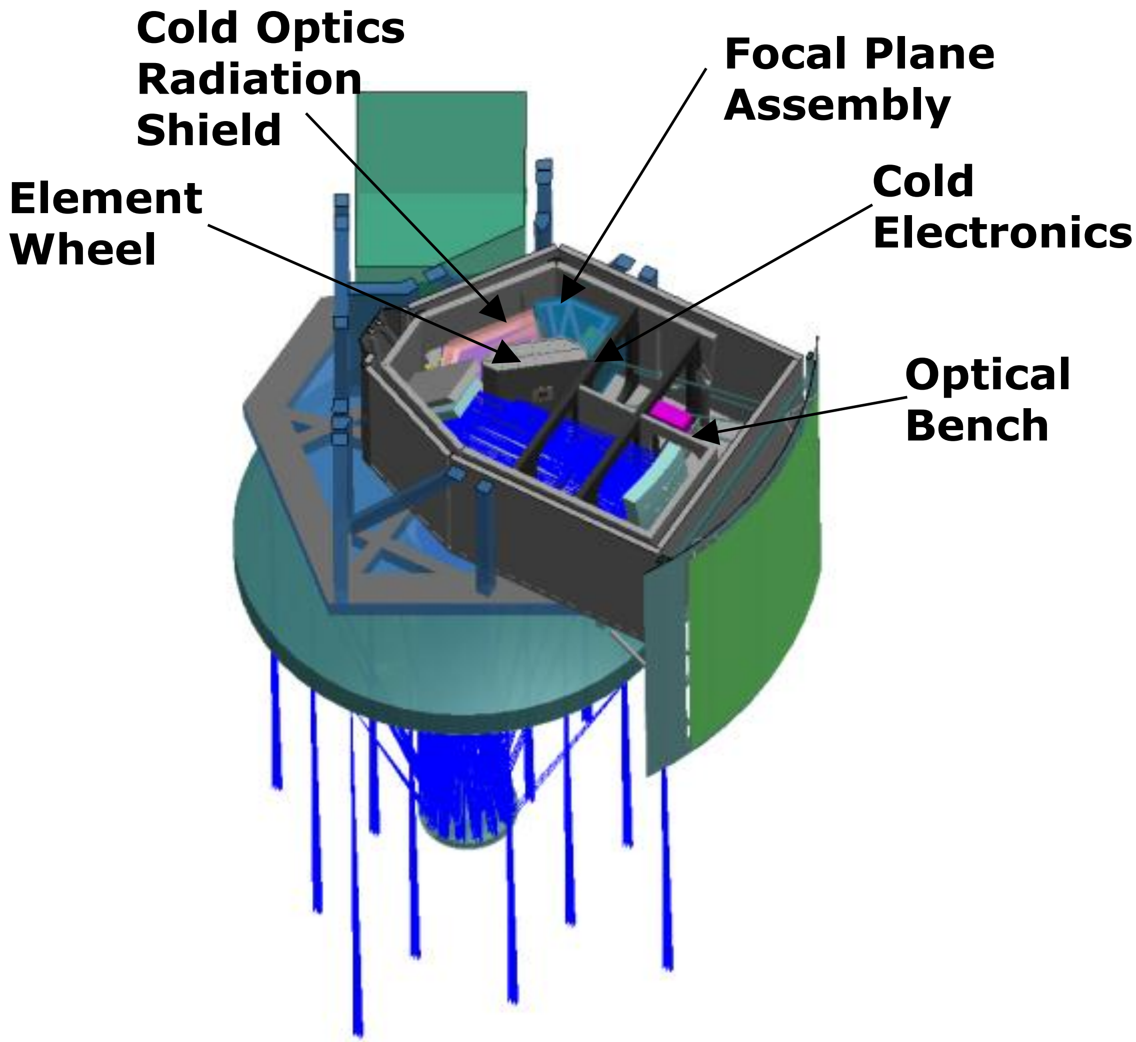
Existing H/W, reuse	1188 kg
Existing design, remake	153 kg
New design	254 kg
TOTAL:	1595 kg

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

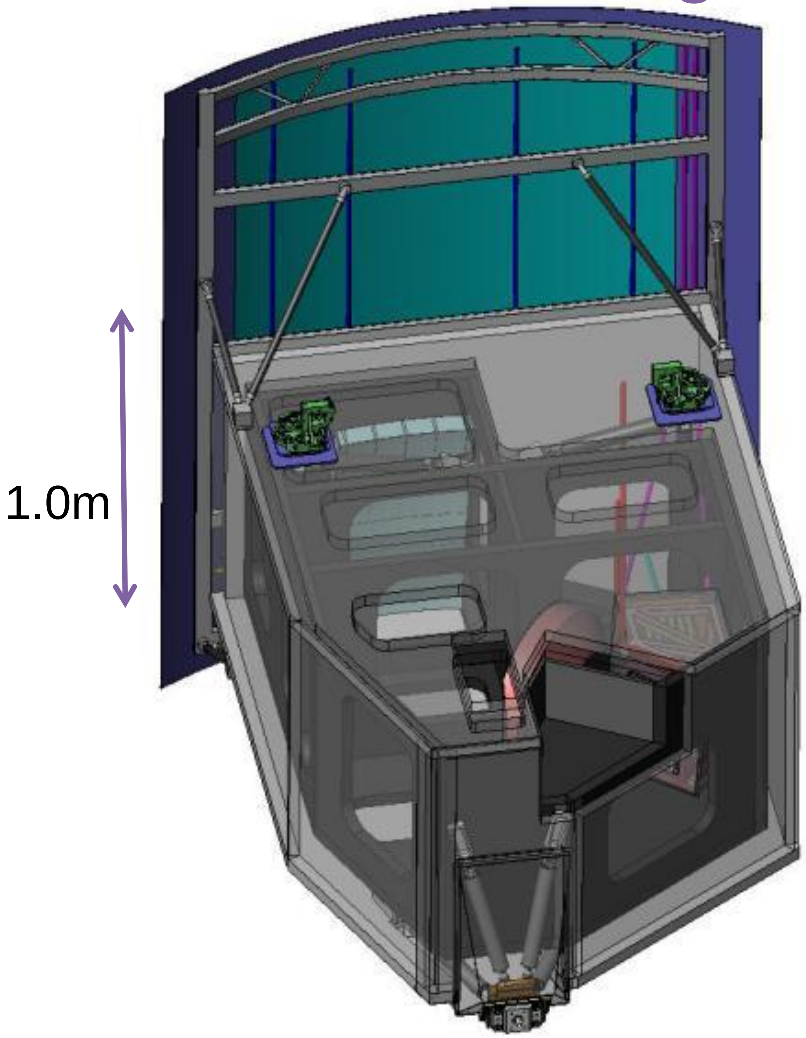
AFTA Wide field Instrument Layout

Key Features

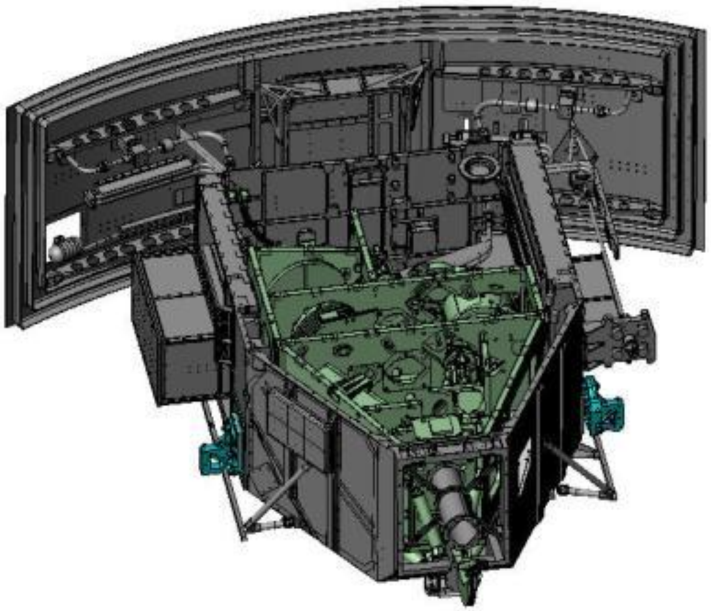
- Single wide field channel instrument
- 3 mirrors, 1 powered
- 18 4K x 4K HgCdTe detectors
- 0.11 arc-sec plate scale
- IFU for SNe spectra, single HgCdTe detector
- Single filter wheel
- Grism used for GRS survey
- Thermal control – passive radiator



Wide Field Instrument Shares Architecture and Heritage with HST/WFC3



WFIRST wide field

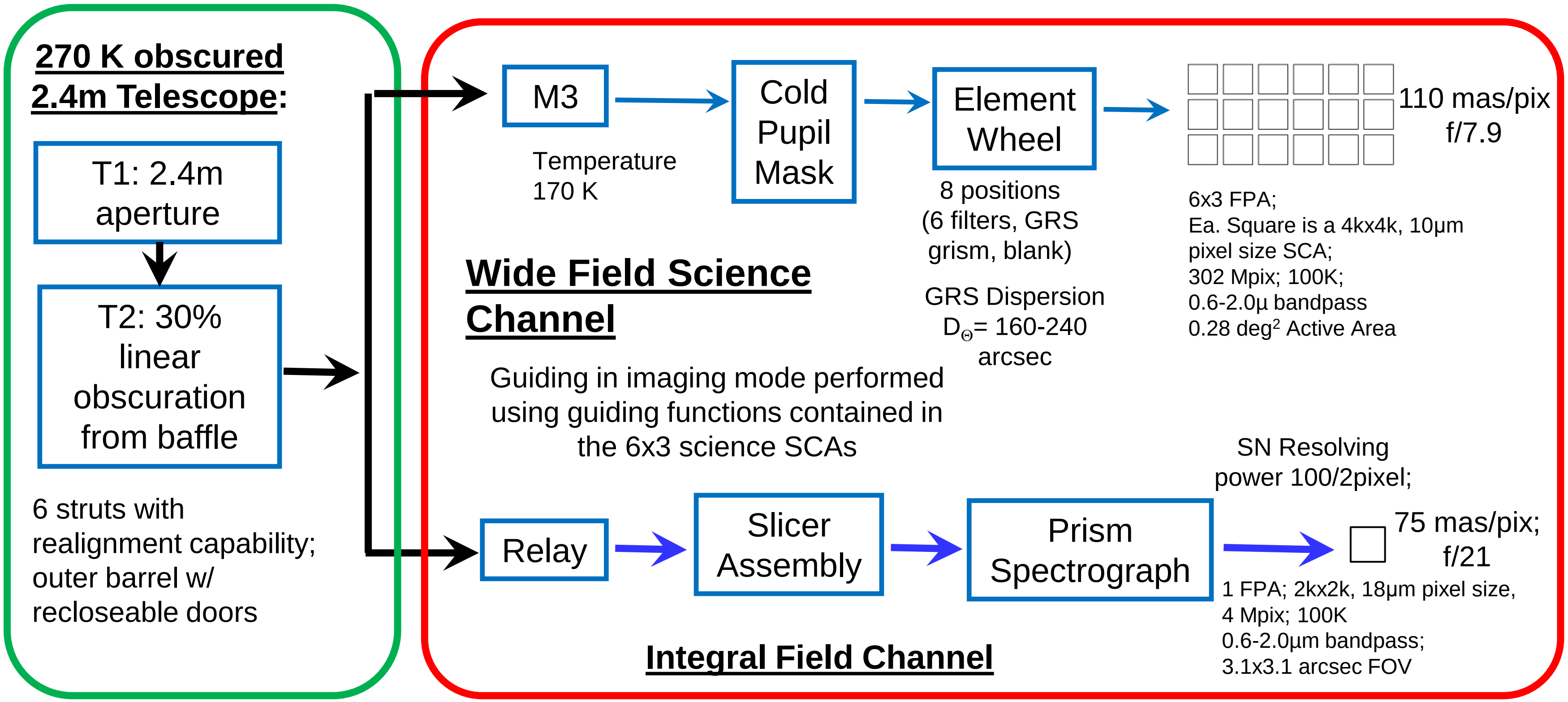


HST/WFC3

WFIRST-AFTA Payload Block Diagram

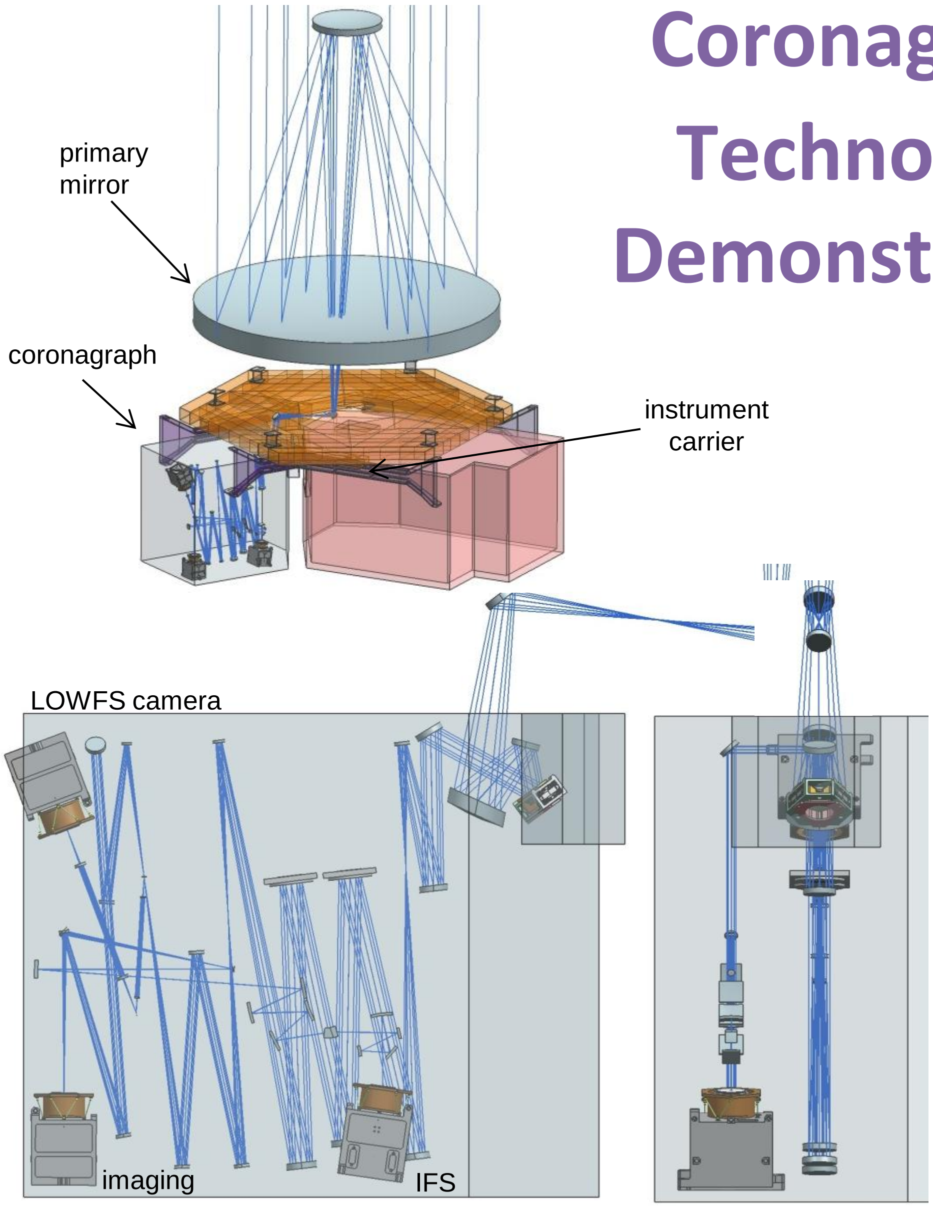
Telescope

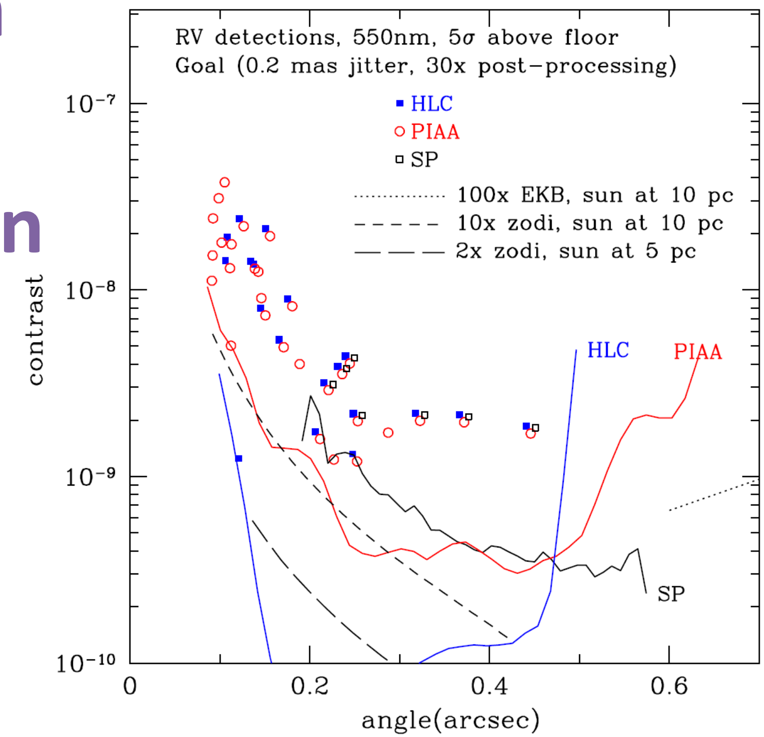
Wide Field Instrument



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

Coronagraph Technology Demonstration





Contrast (planet/star brightness ratio) of detectable known RV planets, vs distance from star

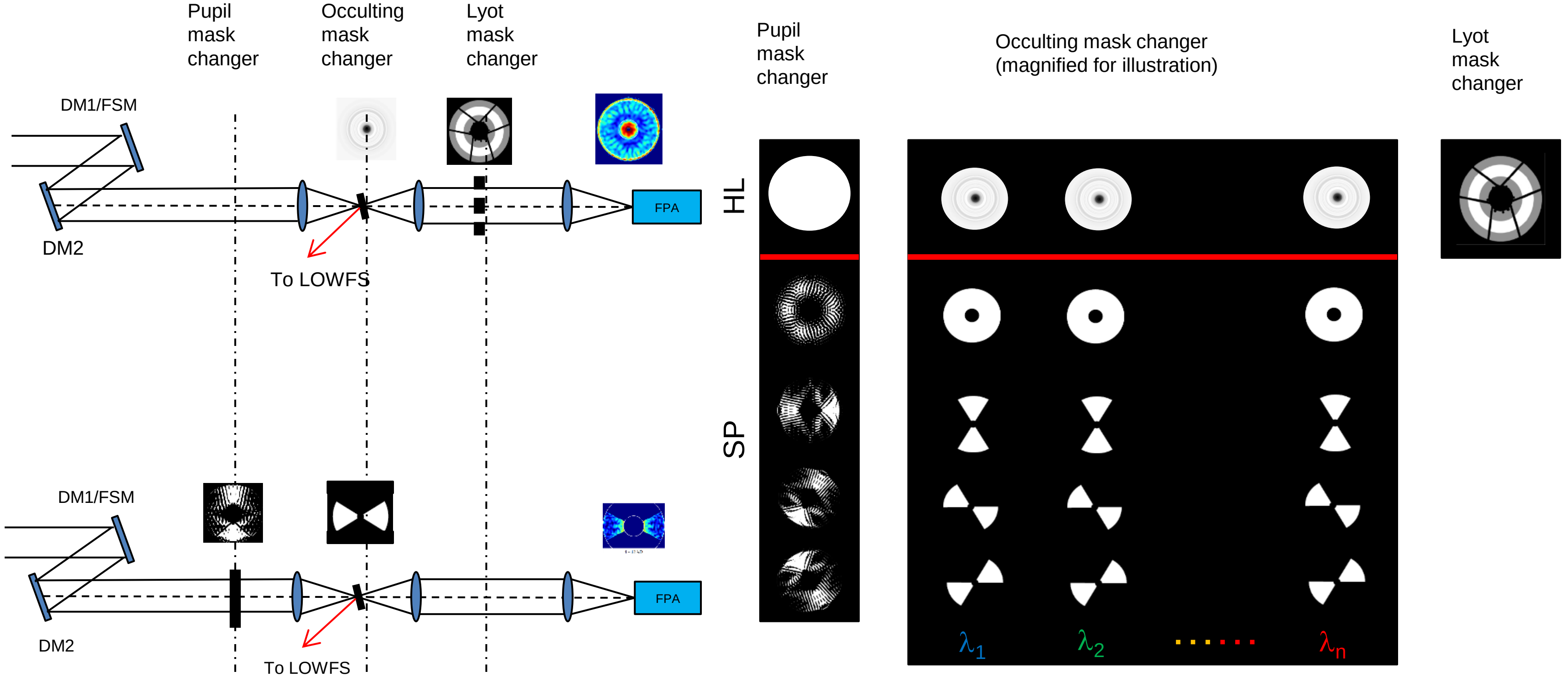
Occulting Mask Coronagraph (OMC) is the Hybrid Lyot Coronagraph (HLC) plus the Shaped Pupil (SP) combination

Solid lines: 5-σ detection limits

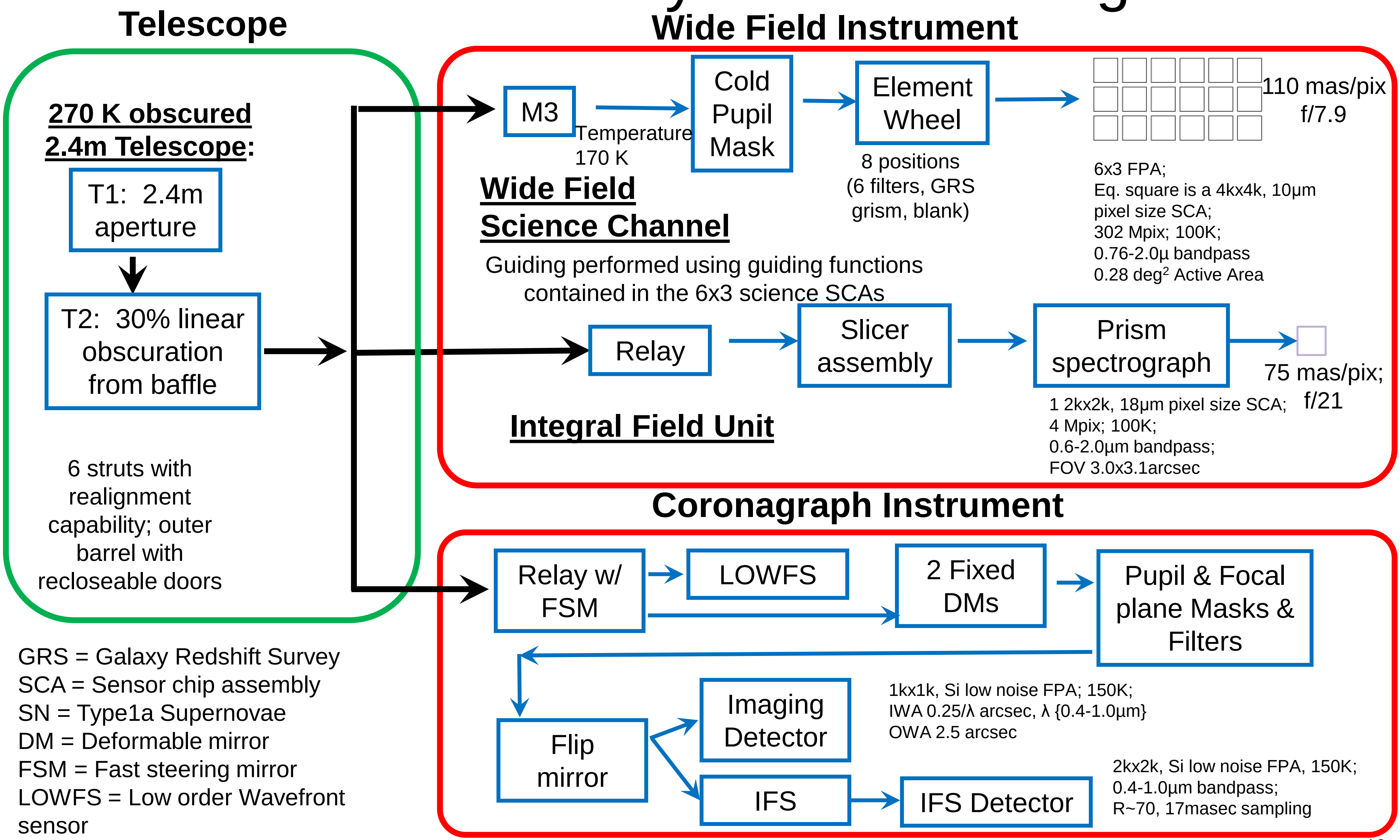
Points: detectable RV planets for each coronagraph

Occulting Mask Coronagraph Architecture: Shaped Pupil + Hybrid Lyot

- **SP and HL masks share common optical layout**
- **Straightforward SP design prevents coronagraph tech demo from driving WFIRST-AFTA development schedule.**



WFIRST-AFTA Payload Block Diagram



GRS = Galaxy Redshift Survey
SCA = Sensor chip assembly
SN = Type1a Supernovae
DM = Deformable mirror
FSM = Fast steering mirror
LOWFS = Low order Wavefront sensor
IFS = Integral field spectrograph

WFIRST-AFTA AND IDRM MISSION COST COMPARISON

WFIRST-AFTA Cost Assumptions

- Life-cycle cost developed assumes the use of an existing 2.4m aperture telescope.
- A 79 month development phase (B/C/D) is assumed for basic WFIRST mission. With the addition of the coronagraph, the payload and observatory I&T phases are increased a total of three months.
- Five year operational phase is baselined in the cost for the basic WFIRST mission. With the addition of the coronagraph, an additional year of operations is assumed and costed.
- Cost developed using a combination of grassroots and parametric modeling, along with historical analogous GSFC missions.
- Life-cycle costs are presented in fixed year 2014 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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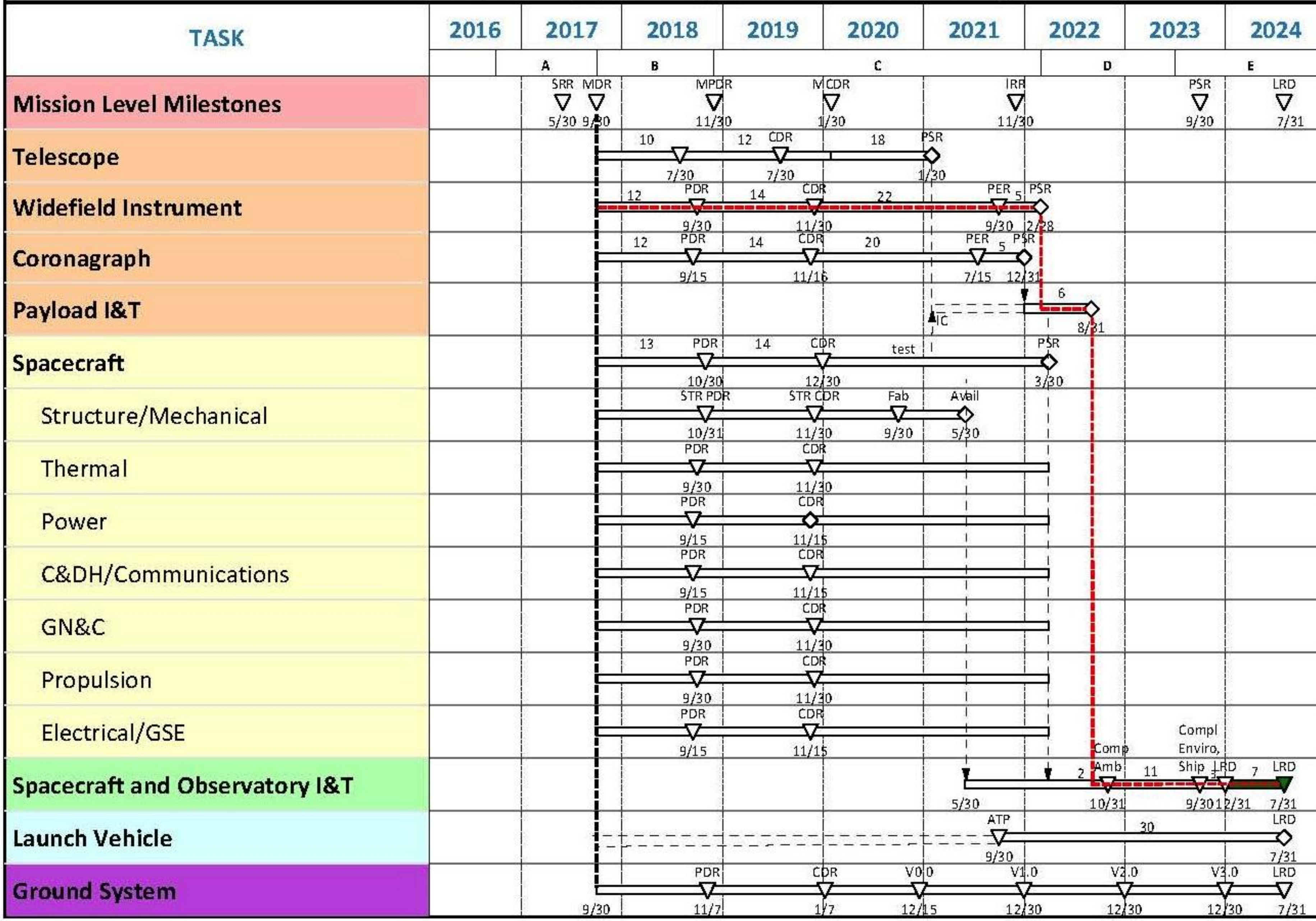
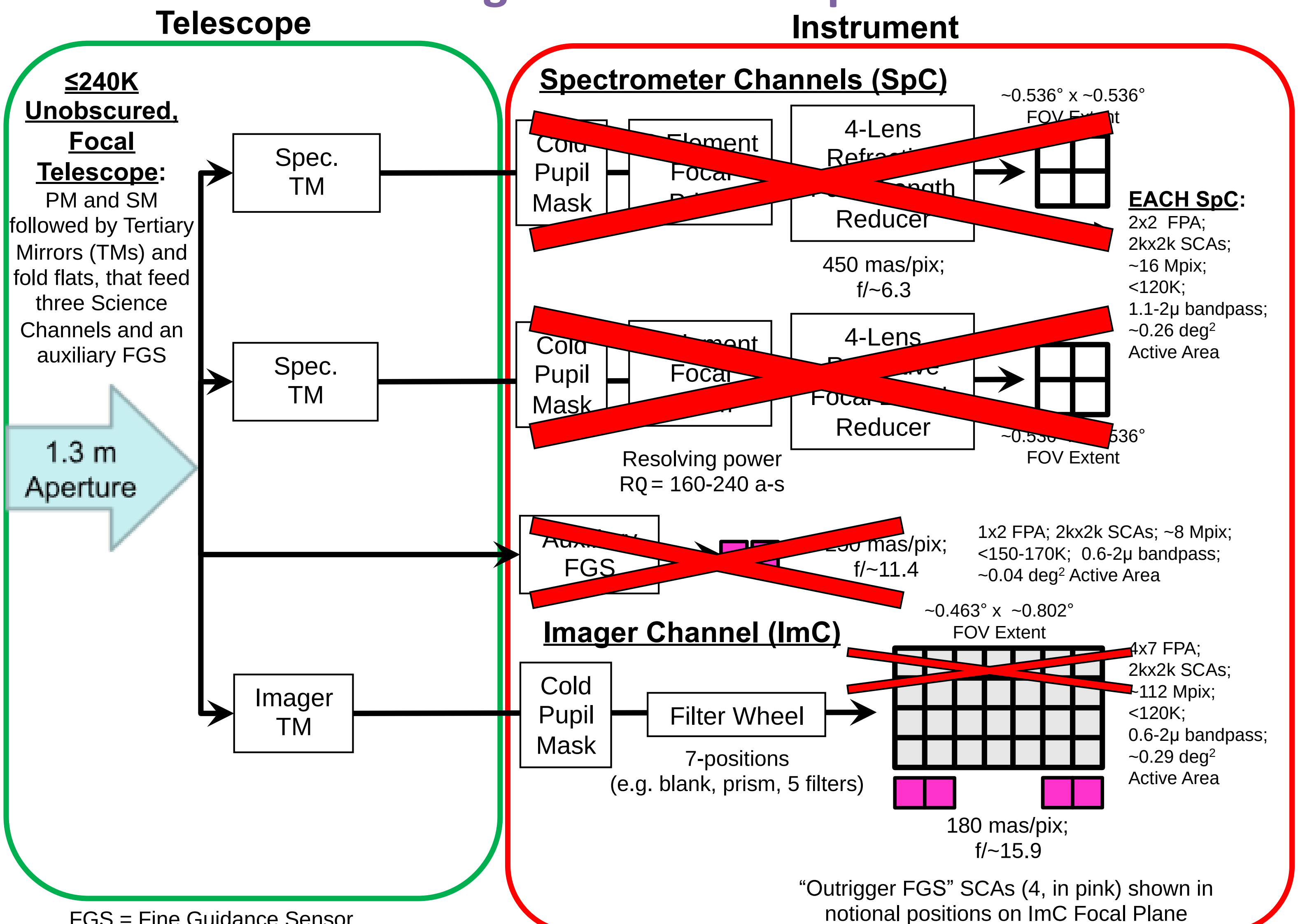
AFTA Development (w/Coronagraph Start Phase B FY18)



Critical Path

AFTA Instrument Deletions to IDRM Payload Block Design Result in simplification



FGS = Fine Guidance Sensor

Comparison of Complexity & Risk of AFTA to Previous IR Survey DRMs (1 of 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. 3 months added to overall I&T flow for coronagraph I&T.
- Operations are greatly simplified by eliminating DSN overhead and scheduling requirements. Transmitter operates under steady thermal conditions.

Comparison of Complexity & Risk of WFIRST AFTA to Previous IR Survey DRMs (2 of 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 cost was $1.44B (FY14$) without launch vehicle. CATE was 9% higher.*
- ***AFTA is heavier, primary contributors are: propellant (to circularize), heavy NRO telescope (existing) 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 & 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 Study Office and the Aerospace CATE concluded that the AFTA cost is in family with the IDRM cost.---

Cost Comparison Details (FY14 $M)

WBS Element	IDRM Study Estimate	IDRM CATE Estimate	AFTA Study Estimate	AFTA CATE Estimate
Pre-Phase A/Phase A	38	38	32	32
Mission PM/SE/MA	92	116	89	122
OTA and Wide Field	393	403	377	399
Flight System including I&T	295	253	342	338
Pre-launch Ground and Science	111	99	105	116
Phase A-D Reserves	274	339	252	249
Phase A-D Subtotal	**1202**	**1248**	**1197**	**1256**
Phase E Costs (w/Reserves)	242	256	222	251
Total Mission Cost w/o LV or coronagraph	**1444**	**1504**	**1419**	**1507**
Schedule Threats		-		21
Design Threats		74		172
Total Mission Cost + Threats w/o LV or coronagraph	**1444**	**1578**	**1419**	**1700**

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 ($FY14) 274M
  - 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”.

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 pilot lot of 4K x 4K, 10 μm pixel pitch, detectors; characterized during FY12.
  - 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.
    - 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.

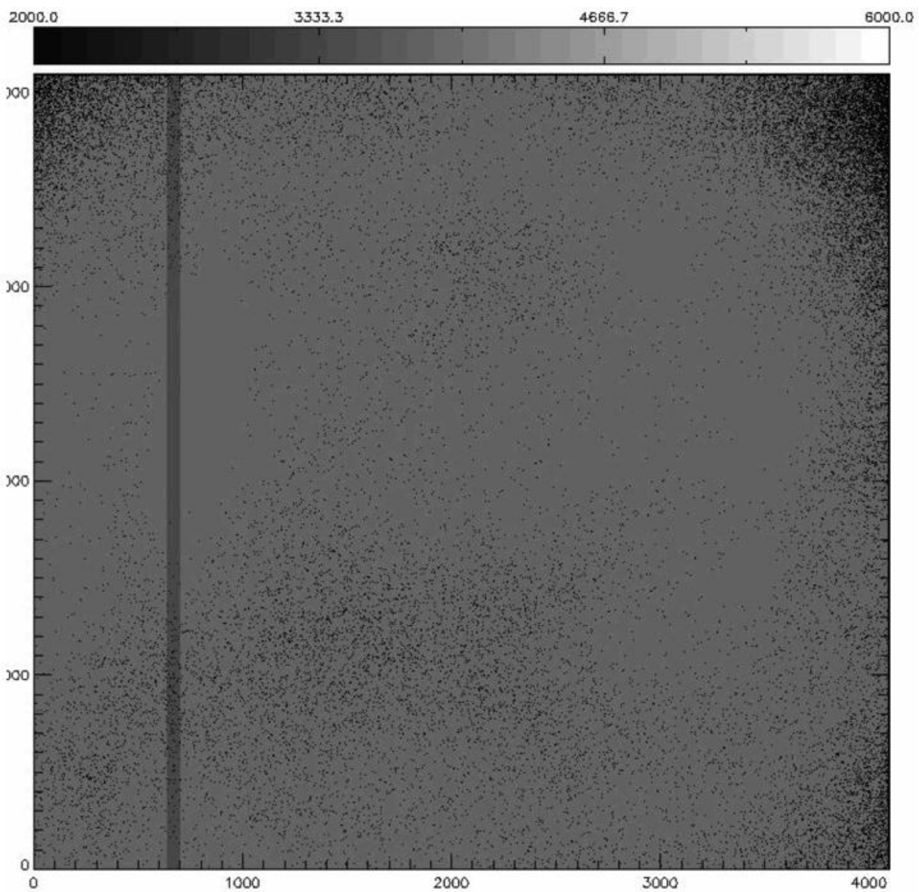
H4RG-10 Development Upcoming Work

- 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.
- 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. Thus, detectors for flight instrument build-up will be available quite early.
  - Completion of the Yield Demonstration Lot is planned to be in FY16, after which the flight build can be started.

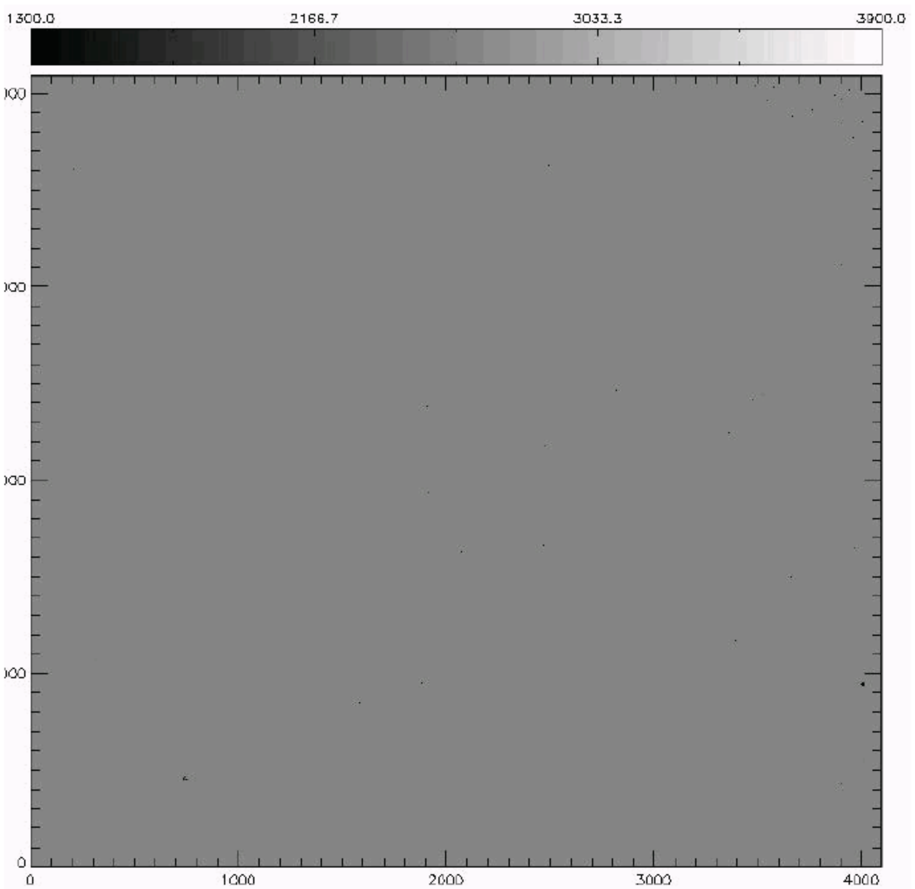
Current Results

- 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.*
    - *Basic parameters QE, dark current, noise, persistence, and intrapixel capacitance are consistent with notional requirements.*
- 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



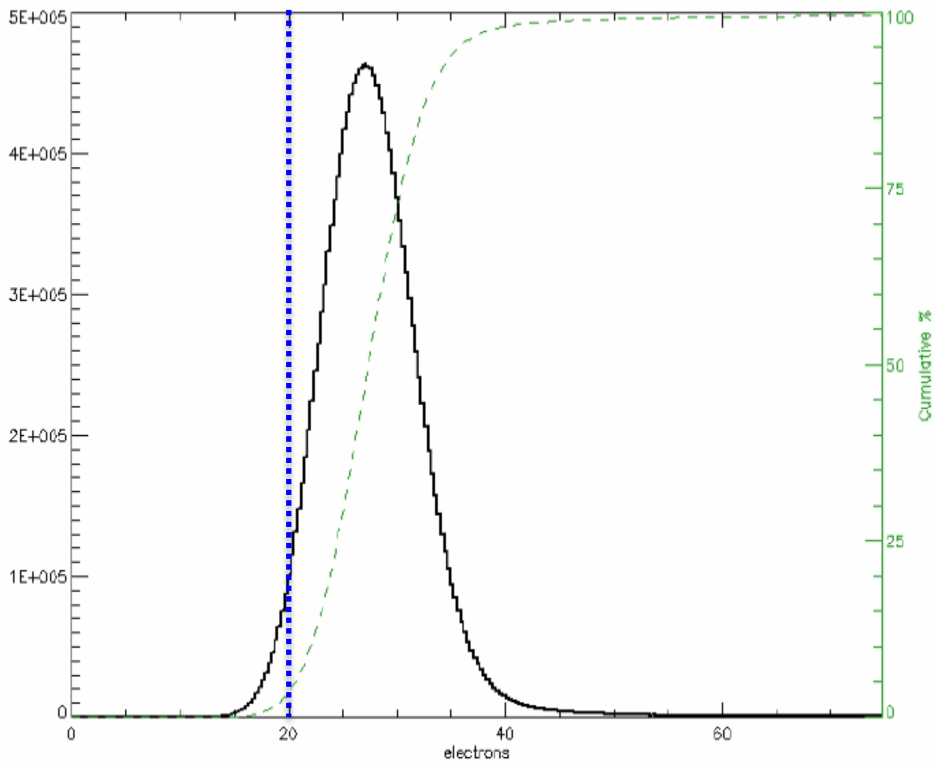
SCA 16361
Previous Pilot Run Lot
Black dots indicate interconnect failures, ~5%.



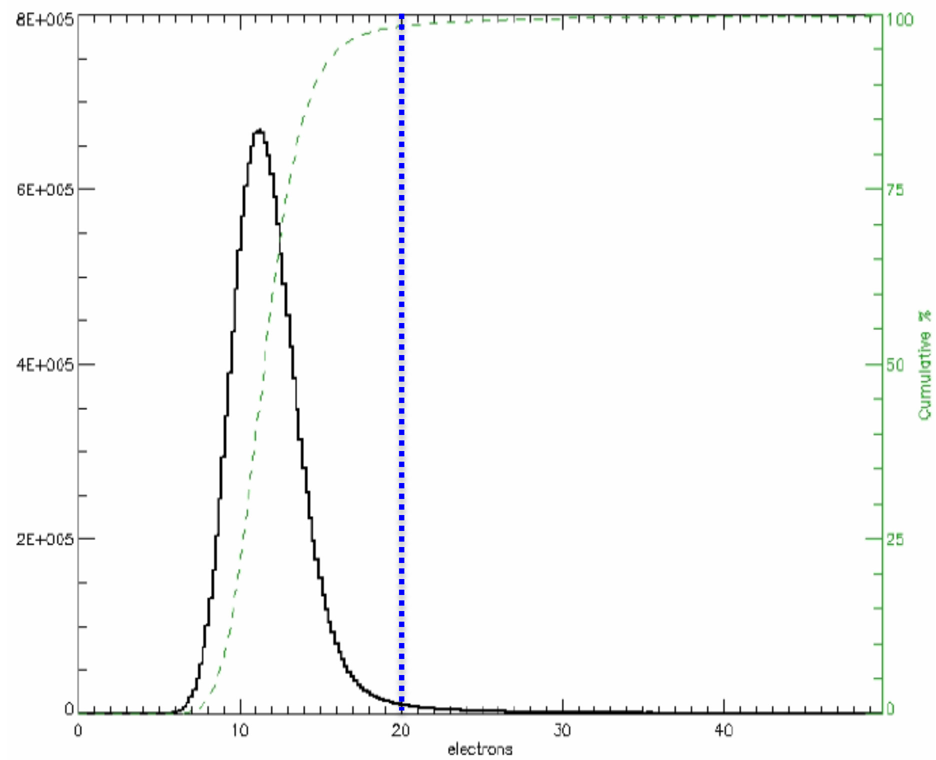
SCA 17429
Current Process Optimization Lot
< 0.5% interconnect failures

CDS Noise Is Much Improved

Blue line shows CDS noise target.



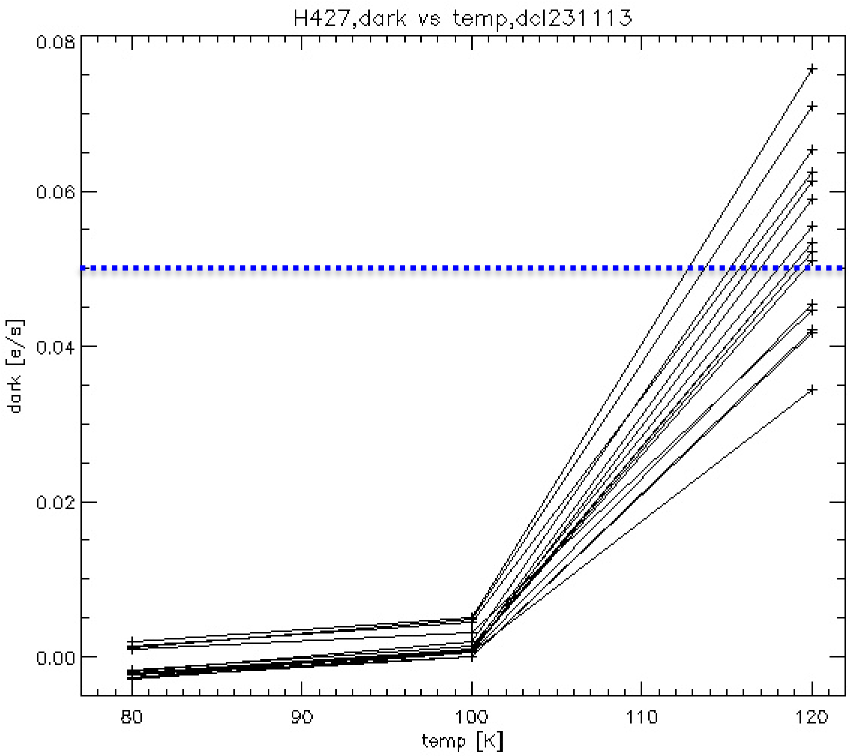
SCA 16360
(Previous Pilot Run Lot)

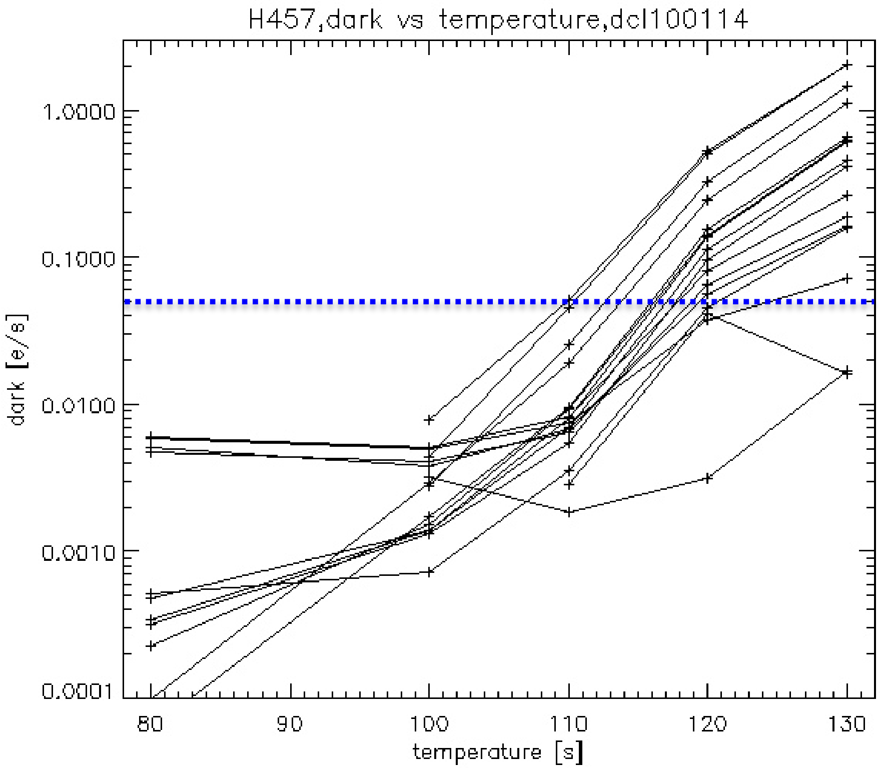


SCA 17427
(Current Process Optimization Lot)

Example Dark Current

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

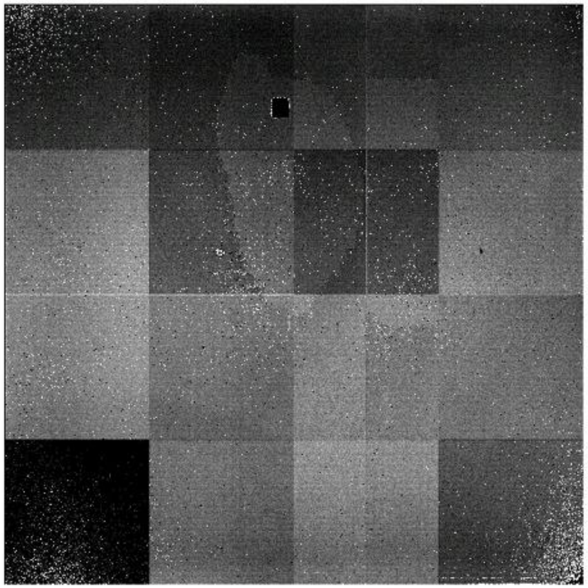




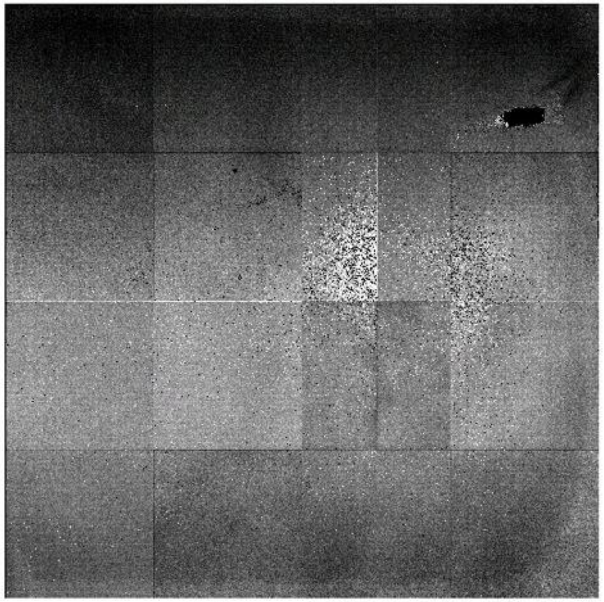
The lines are the different “bands.”
Results below 100K are limited by the data set (need longer integrations to detect smaller dark currents).

Example Flat Field Response

SCA 17427



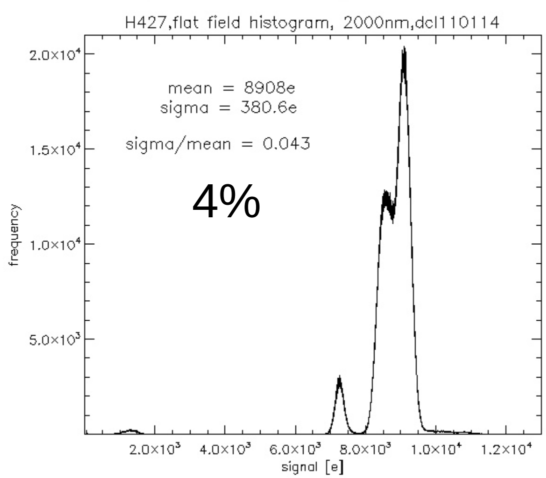
SCA 17457

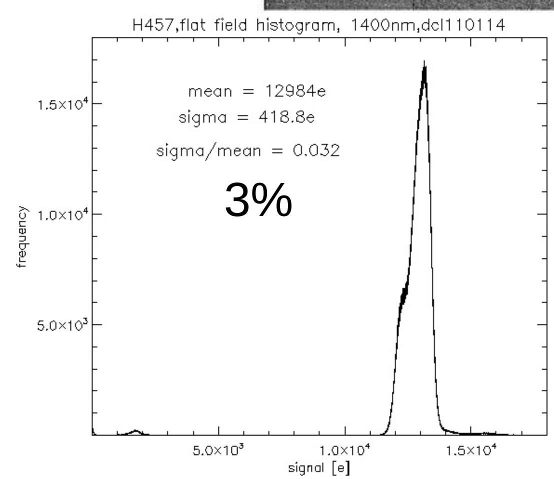


2000 nm exposures.

Scale is +/-10% of mean.

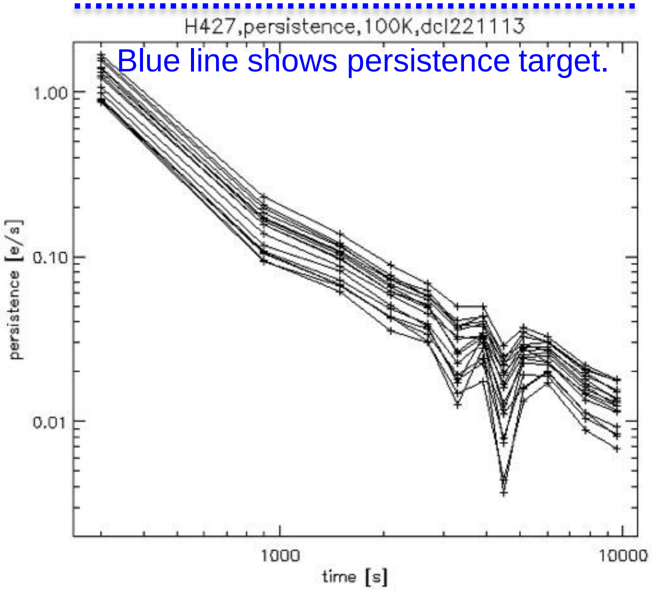
Sigma/mean is very good, especially since the arrays are banded and the non-uniformity of the Lambertian source is not corrected.





Example Persistence

SCA 17427

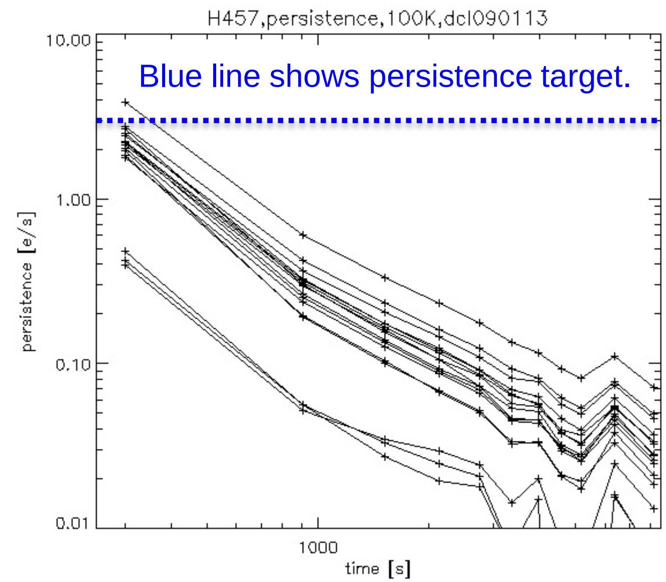


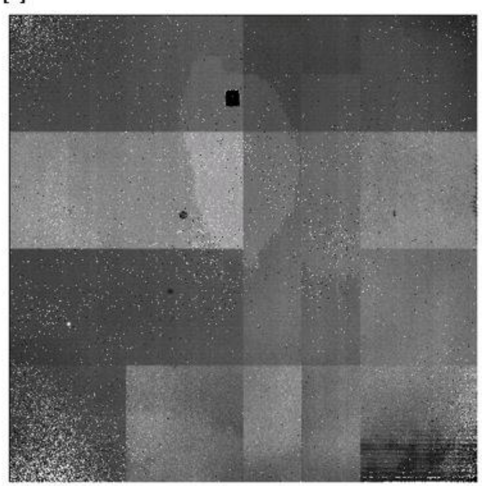
Measurements at 100 K with ~ 80000 e- illumination at t=0.

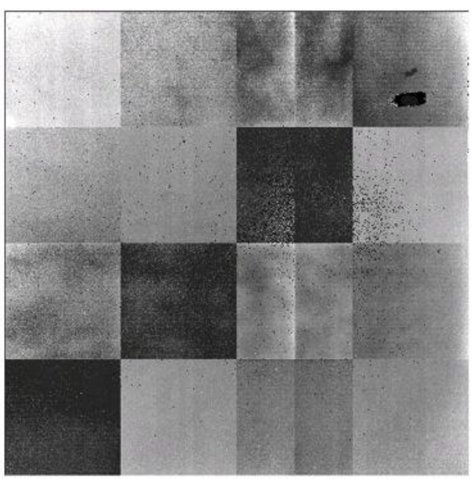
Low persistence at 100 K and below, increasing with temperature.

Images show effective dark current after 600 sec.

SCA 17457







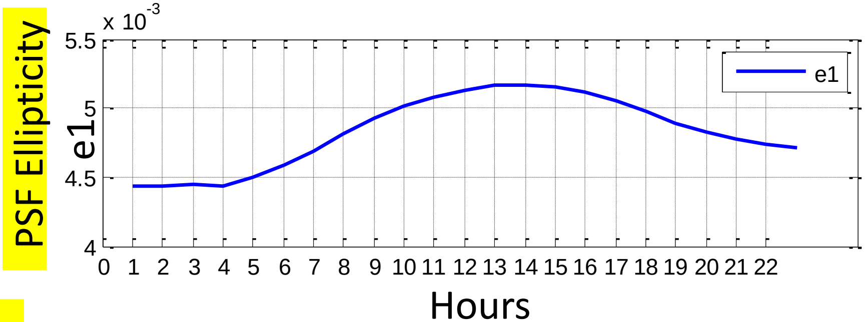
Detector Development Summary

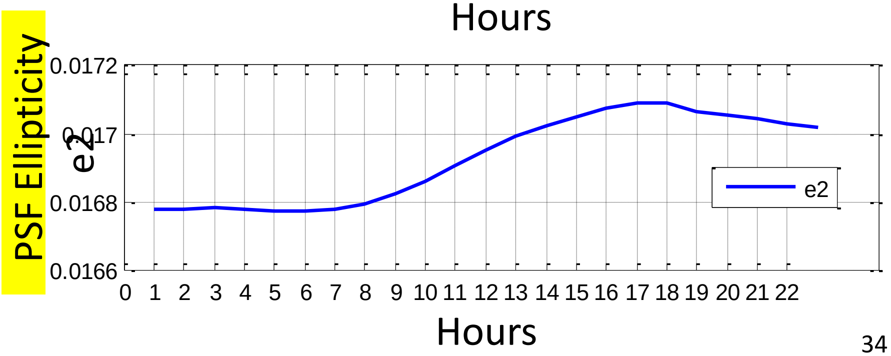
- The lot of H4RG detectors currently in process looks very promising.
- Initial results indicate most bands meeting or are very close to performance targets.
- These devices have demonstrated that the technology is capable of producing the required levels of performance.
- The remaining work will demonstrate achieving these performance levels with reasonable yields (and thus cost).
- Current trend indicates that flight detectors could be fabricated well in front of need date.

RECENT DESIGN REFERENCE MISSION TECHNICAL PROGRESS

Structural/ Thermal/Optical Performance (STOP) Assessment Summary

- Excellent WFI PSF Ellipticity stability and solid WFI WFE stability margins, the best results that we have seen (even for the worst-slew case)
  - x9 margins on WFI WFE drift stability requirement
    - 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





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 ≤ 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
- Telescope {existing} damping struts critical to Jitter performance

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; selected SP because it doesn't drive observatory pointing and pose a schedule threat.**
- **Cost:**
  - **Both the Study Office and Aerospace agree that the cost of AFTA is in family with IDRM.**