AFTA-WFIRST Coronagraph Instrument Status Report -- ExoPAG

Feng Zhao

AFTA Coronagraph Instrument Manager

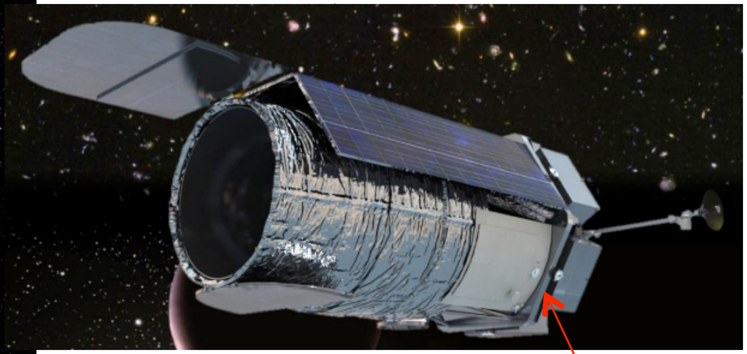
1/5 2014

Outline

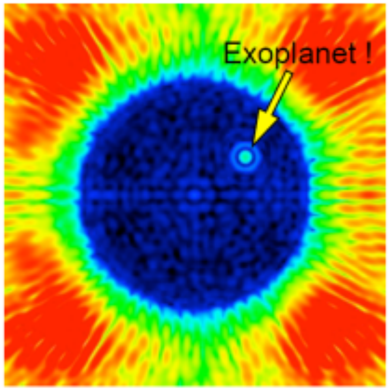
- Introduction
- Newly selected architecture description
- Status and next steps
- Summary

Exoplanet
Missions
JWST
AFTA
TESS
Kepler
New Worlds
Telescope
Spitzer
Hubble
Ground-based
Observatories
Astronomy and Astrophysics
in the New Millennium
2001
Decadal
Survey
New Worlds,
New Horizons
2010
Decadal
Survey

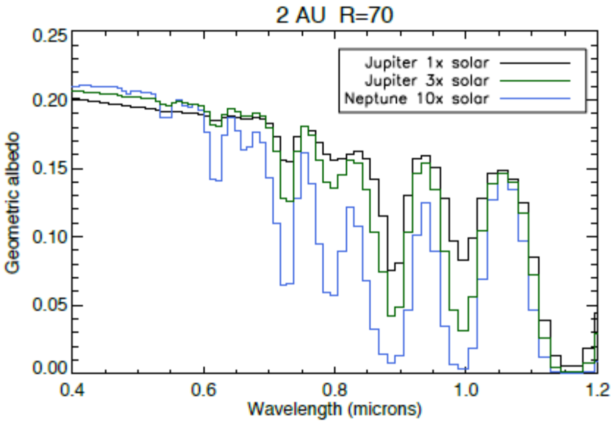
AFTA Coronagraph Instrument



Coronagraph Instrument



Exo-planet Direct imaging



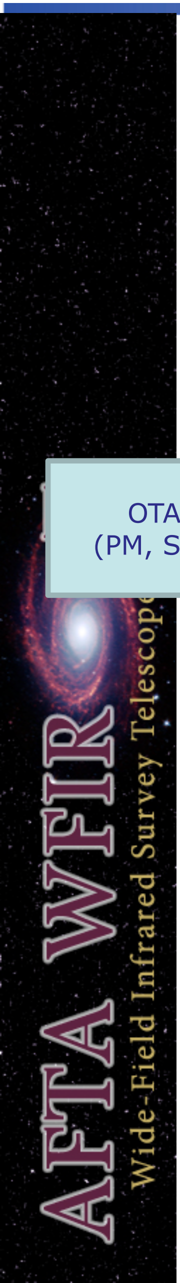
Exo-planet Spectroscopy

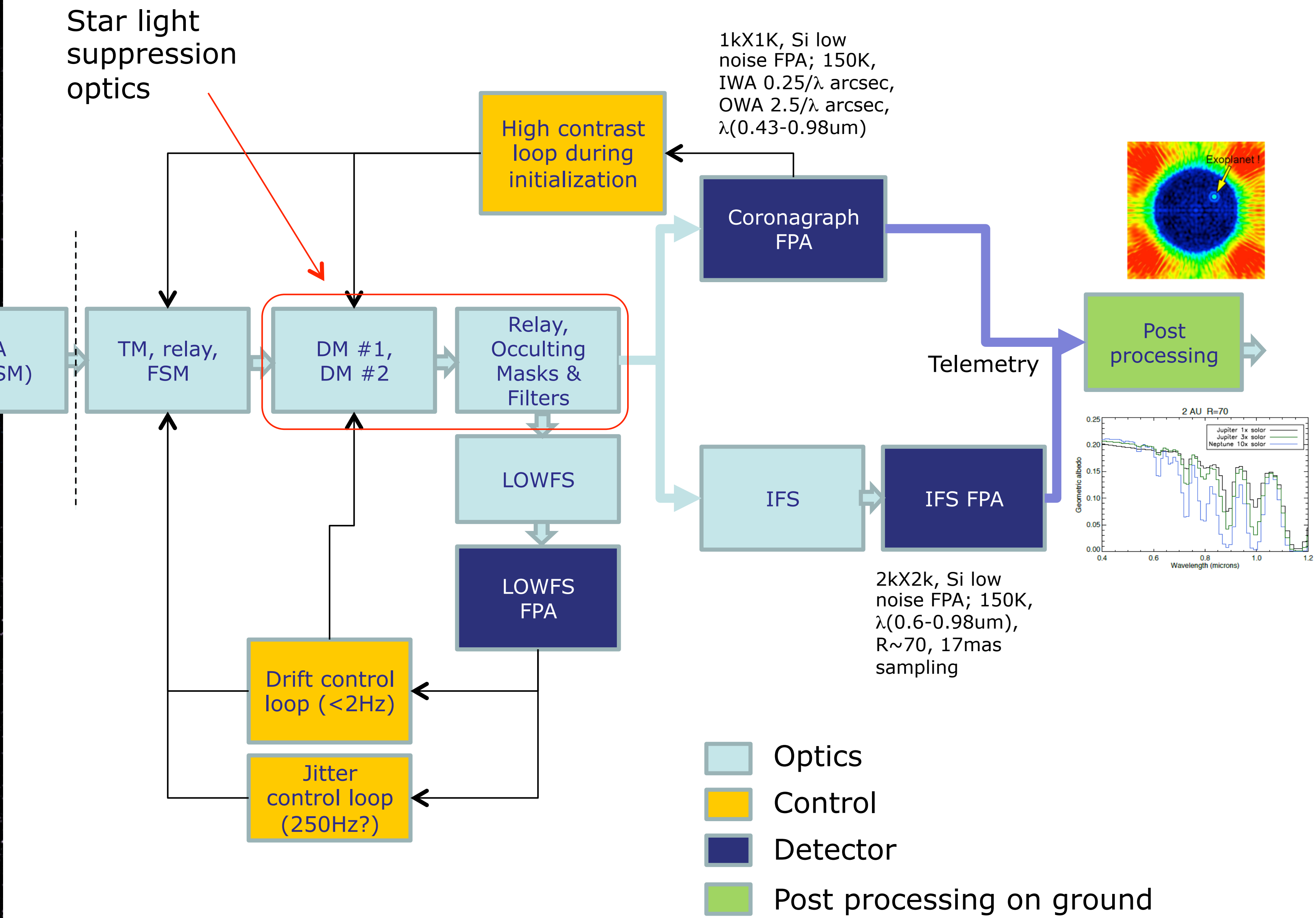
Bandpass	430 – 980nm	Measured sequentially in five ~10% bands
Inner working angle	100 – 250 mas	~3λ/D, driven by science
Outer working angle	0.75 – 1.8 arcsec	By 48X48 DM
Detection Limit	Contrast ≤ 10^{-9} After post processing)	Cold Jupiters, not exo-earths. Deeper contrast looks unlikely due to pupil shape and extreme stability requirements
Spectral Resolution	~70	With IFS, R~70 across 600 – 980 nm
IFS Spatial Sampling	17mas	Nyqust for λ~430nm

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.
- Provide crucial information on the physics of planetary atmospheres and clues to planet formation.
- Respond to decadal survey to mature coronagraph technologies, leading to first images of a nearby Earth.

Functional Block Diagram

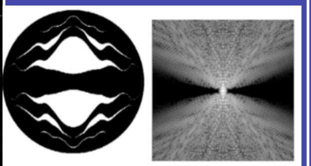




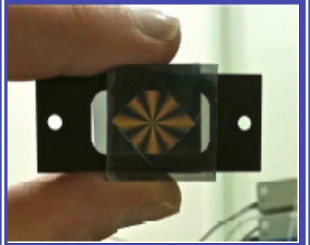
Star light suppression -- Technical Approach

AFTA WFIRST
Wide-Field Infrared Survey Telescope

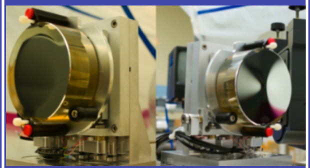
Six different concepts



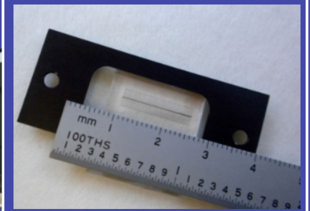
Shaped Pupil Mask Pupil Masking (Vanderbei & Kasdin, Princeton Univ.)



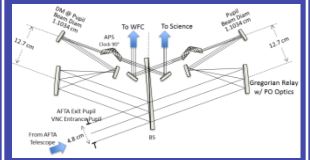
Vector Vortex Mask Image Plane (Serabyn, JPL)



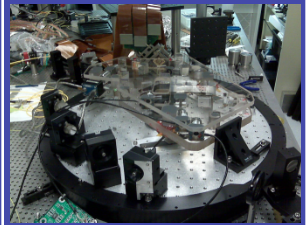
Phase Induced Amplitude Apodization (PIAA) Pupil Re-Mapping (Guyon, Univ. Arizona)



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



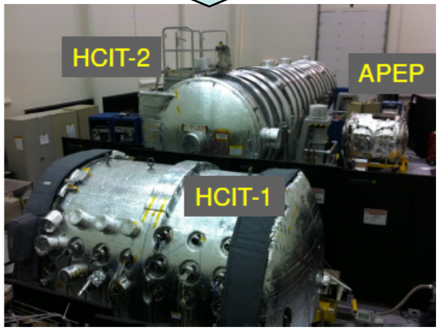
Visible Nuller Coronagraph: Phase-Occulting (Lyon, GSFC)



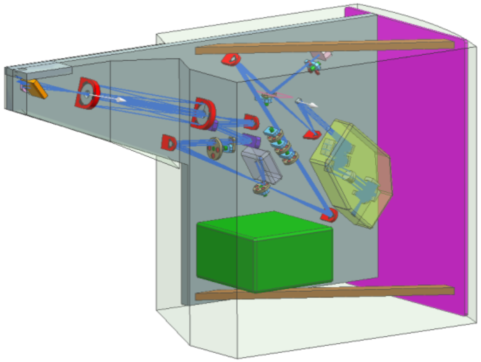
Visible Nuller Coronagraph: DaVinci (Shao, JPL)

Down select 12/15/2013
http://wfirst.gsfc.nasa.gov/

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



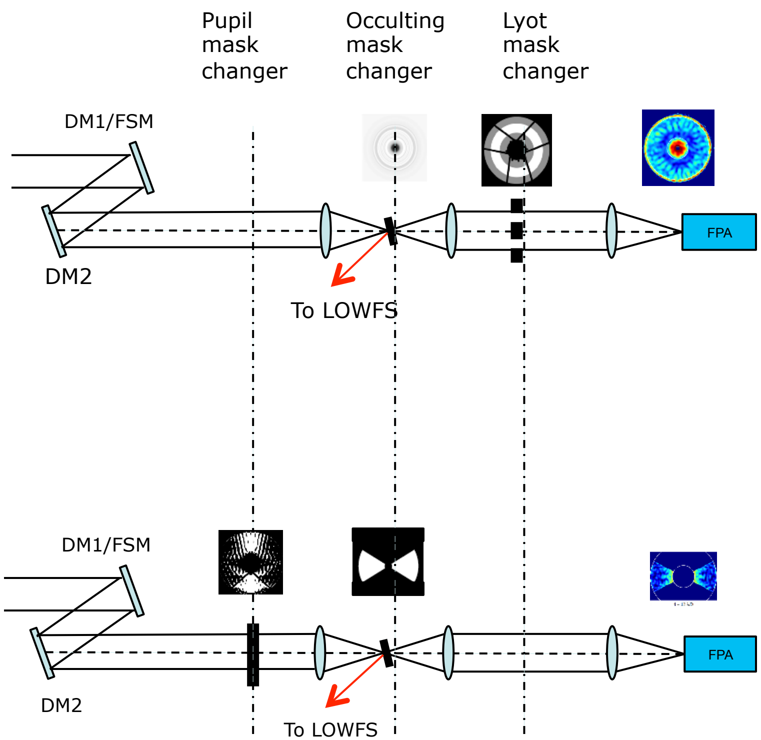
TRL-5 @ start of Phase A (10/2016)

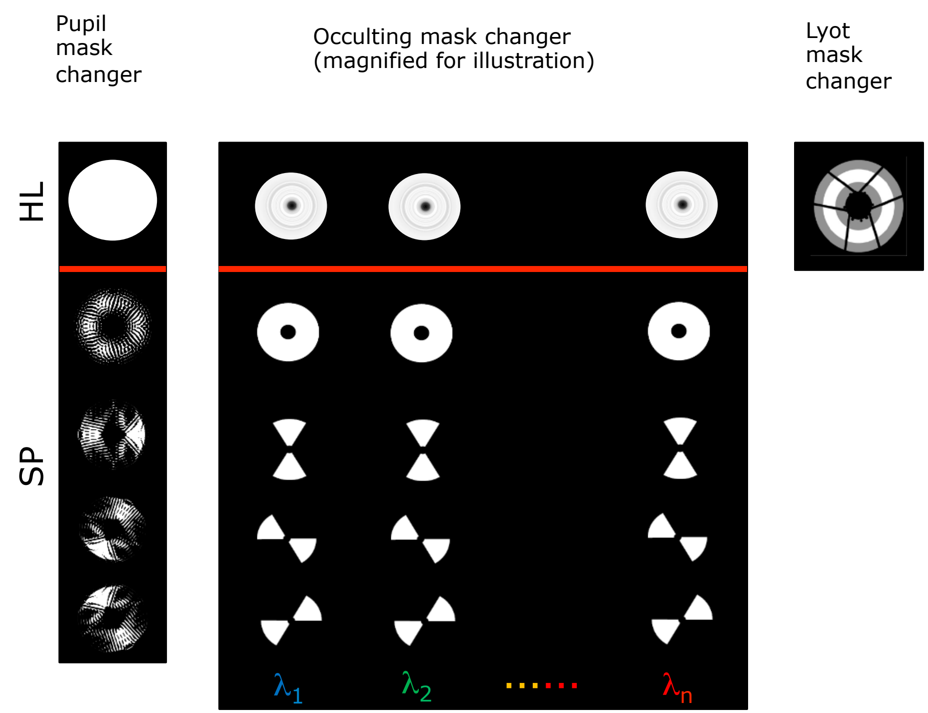


TRL-6 @ PDR (10/2018)

Primary Architecture: Occulting Mask Coronagraph = Shaped Pupil + Hybrid Lyot

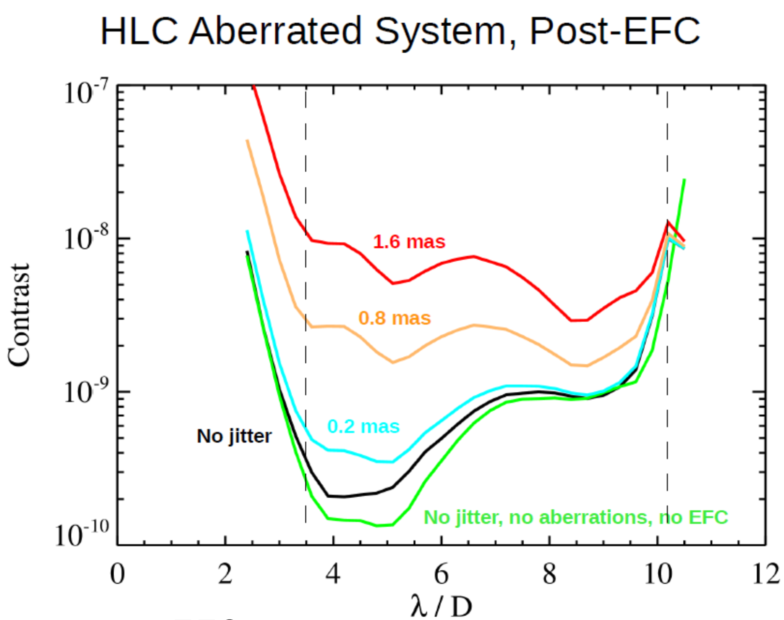
- SP and HL masks share very similar optical layouts
- Small increase in over all complexity compared with single mask implementation



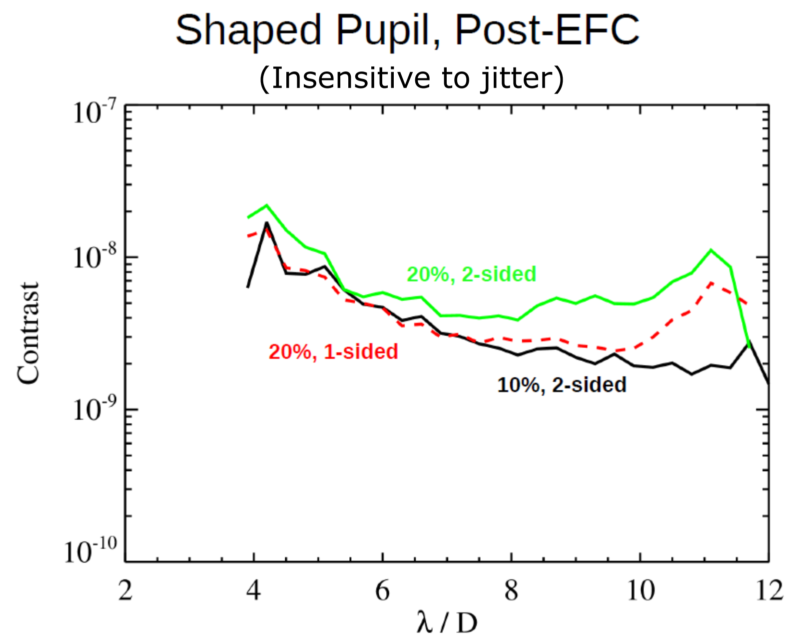


Contrast simulations with AFTA pupil, aberrations and expected range of telescope pointing jitter

- OMC in its "SP mode" provides the simplest design, lowest risk, easiest technology maturation, most benign set of requirements on the spacecraft and "use-as-is" telescope. This translates to low cost/schedule risk and a design that has a high probability to pass thru the CATE process.
- In its "HL mode", the OMC affords the potential for greater science, taking advantage of good thermal stability in GEO and low telescope jitter for most of the RAW speed



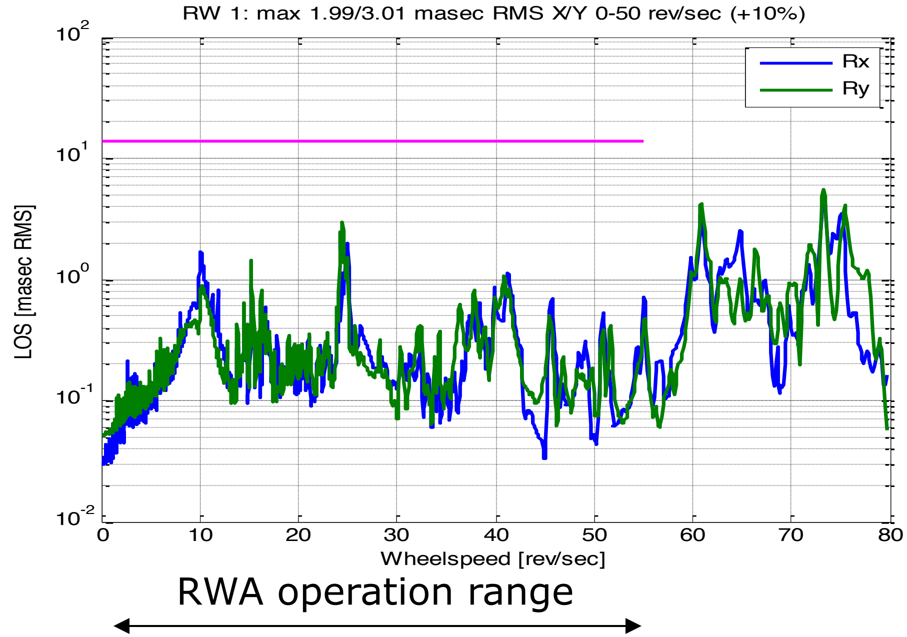
λ=550nm



Good balance of science yield and engineering risk

Observatory Pointing Jitter Estimate

- The results indicate telescope LOS jitter less than 1 mas over a wide range of wheel speeds, before LOWFS tip/tilt correction.
  - Except at wheel speed ~10 and 26 rps
- Numerous opportunities exist for further jitter optimization:
  - operational constraints,
  - momentum management strategies,
  - structural redesign,
  - LOWFS design optimization

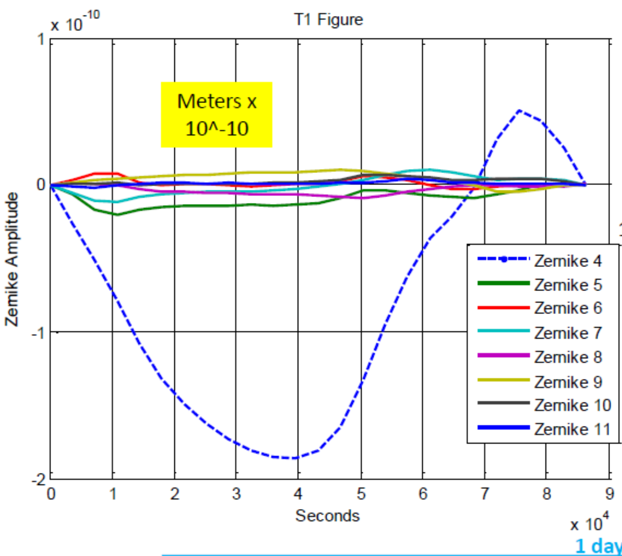


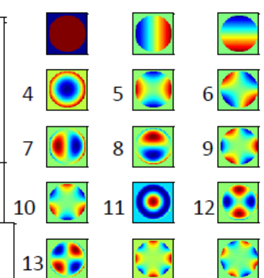
"Model uncertainty factor (MUF)" consistent with flight projects (MUF=2.5 for f<20Hz, and MUF=6 for f>40Hz, linear in between)

Telescope Thermal Stability Estimate

- Recent STOP model results indicate very stable telescope wavefront during operation
  - Dominant term is focus, ~2nm over 24 hrs
  - Other low-order WFE <20pm over 24 hrs

T1 Zernike Amplitudes over 24 Hours

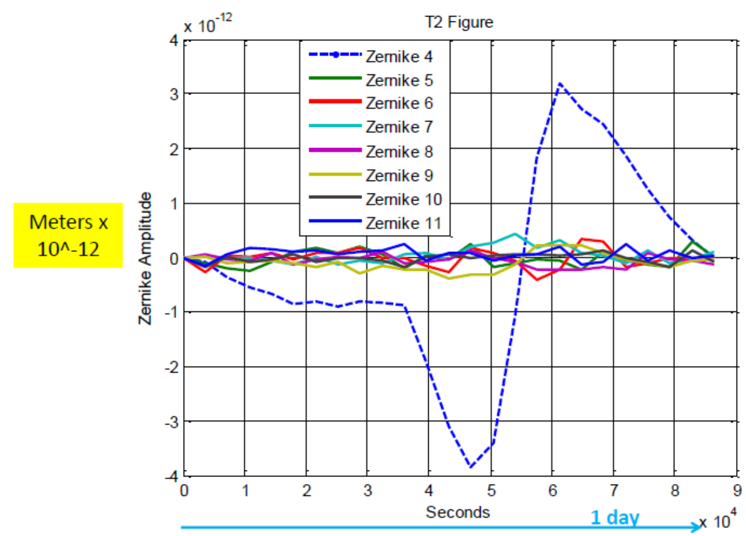




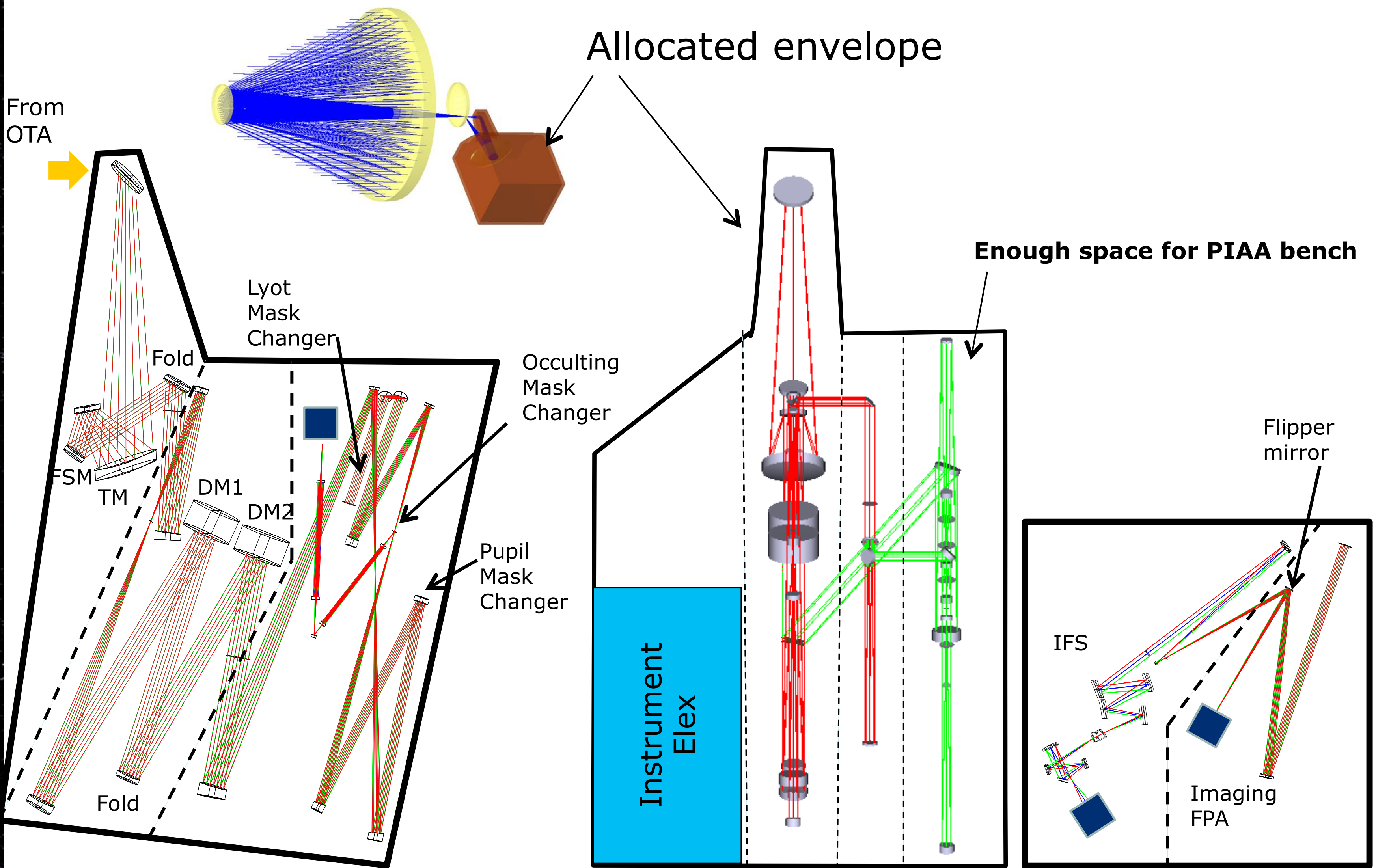
Zernike shapes

26

T2 Zernike Amplitudes over 24 Hours



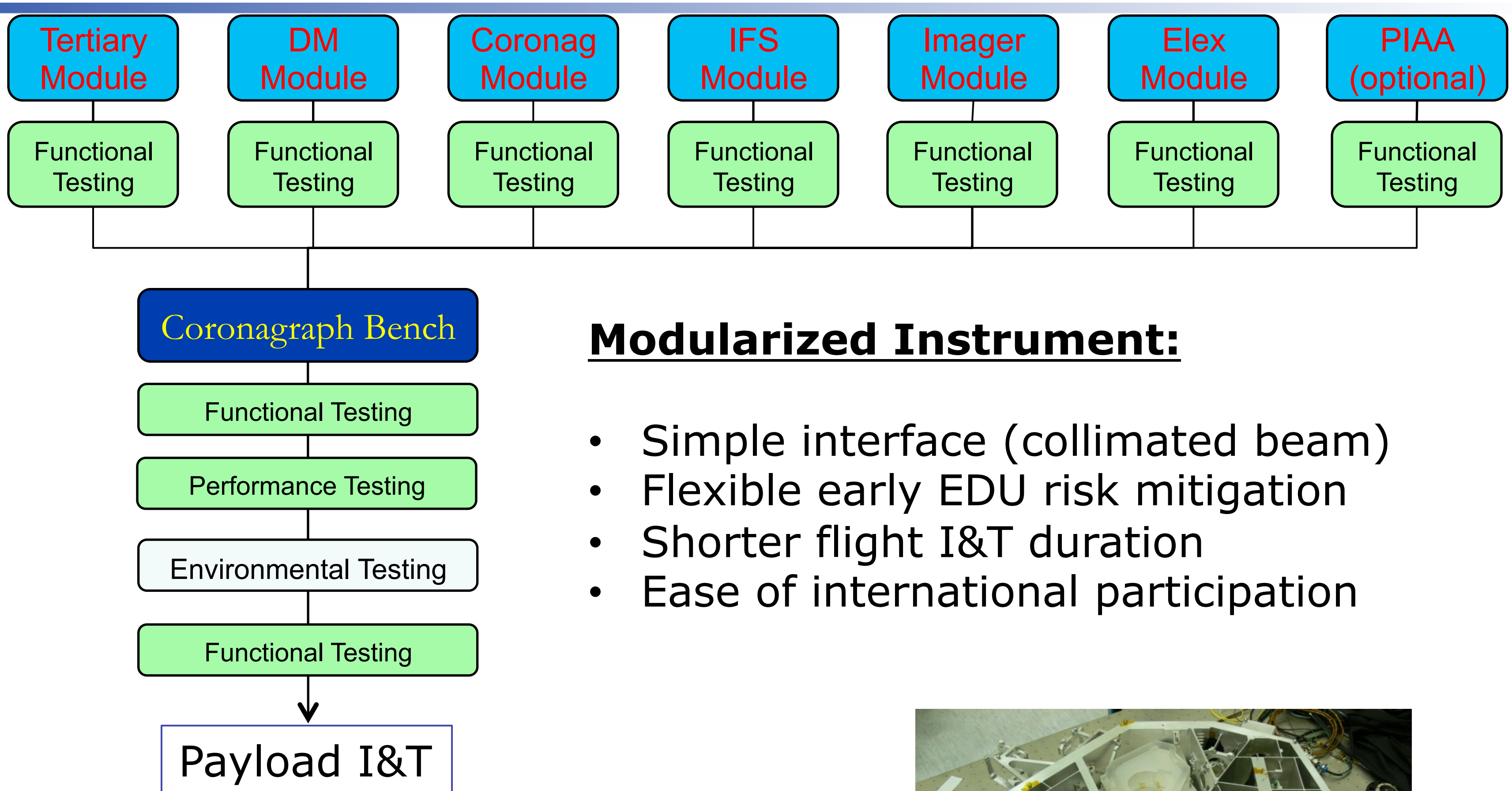
Instrument Layout within the Allocated Envelope



(1) Main OMC Bench

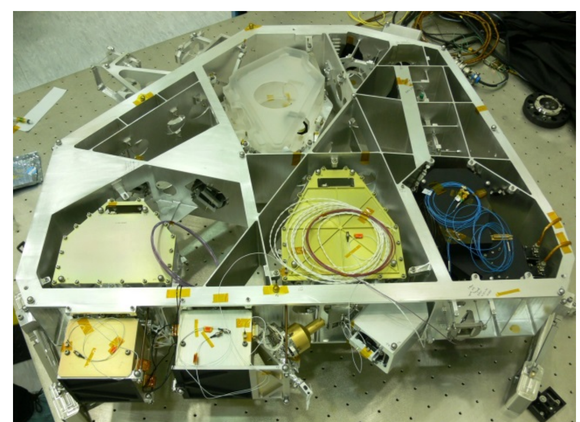
(2) Detector Bench

Functional Modularized Instrument



Modularized Instrument:

- Simple interface (collimated beam)
- Flexible early EDU risk mitigation
- Shorter flight I&T duration
- Ease of international participation



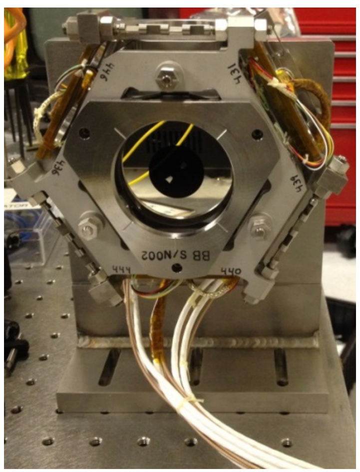
Modularized example (SIM ABC)

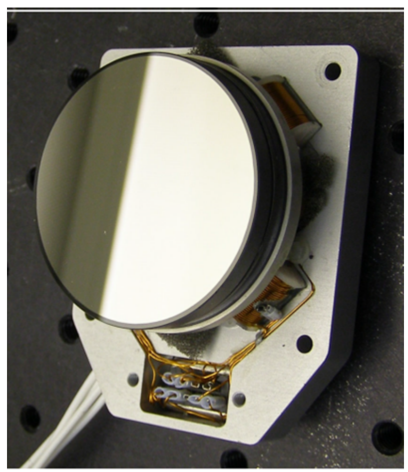
AFTA WFIRST Wide-Field Infrared Survey Telescope

Active Optics

Fine Steering Mirror (FSM)

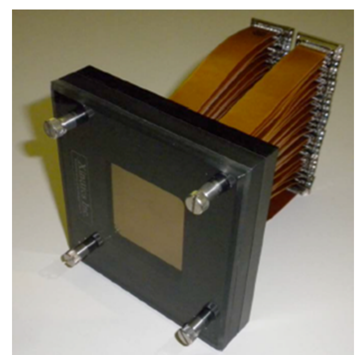
- To correct telescope line-of-sight (wavefront tip/tilt) error
- Low risk with rich flight heritage

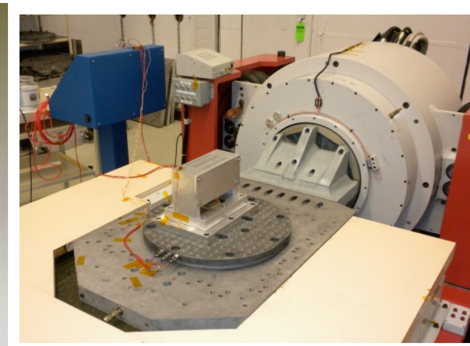




Deformable Mirror (DM)

- To correct telescope & instrument optical WFE (static and drift)
- Low risk with good heritage:
  - Flight PMN actuators, driver electronics
  - HCIT contrast demonstration to 10^{-10}
  - Assembly passed random vibe test (2012)



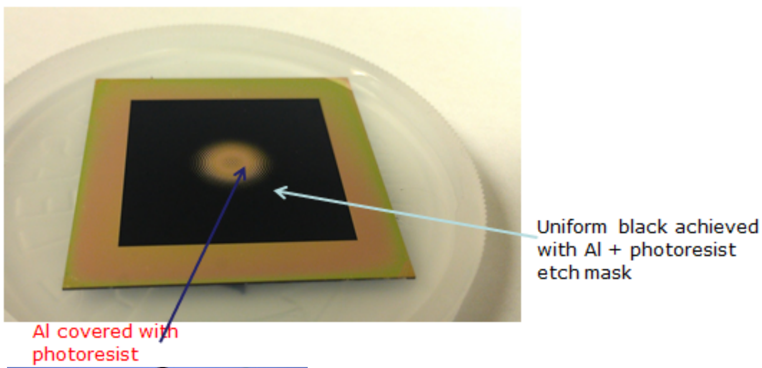


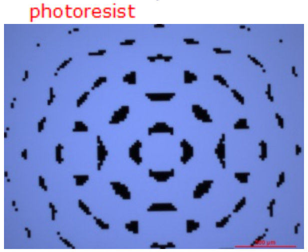
Low risk for flight implementation

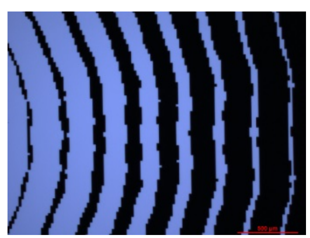
Coronagraph Masks

Reflective shaped pupil masks

- Black Si on Al mirror coating demonstrated at JPL/MDL and Caltech/KNI

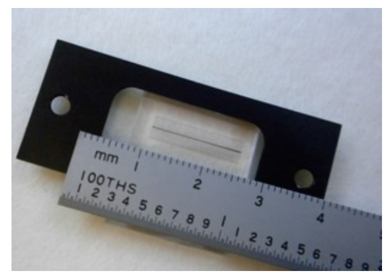


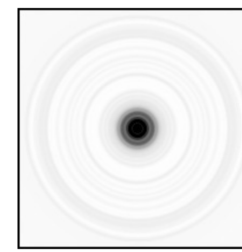




Transmissive hybrid Lyot mask

- Profiled Ni layer (amplitude) over-coated with profiled MgF2 layer (phase) at JPL Trauger's lab
- Linear mask fabricated and demonstrated 10^{-10} in HCIT for un-obscured pupil





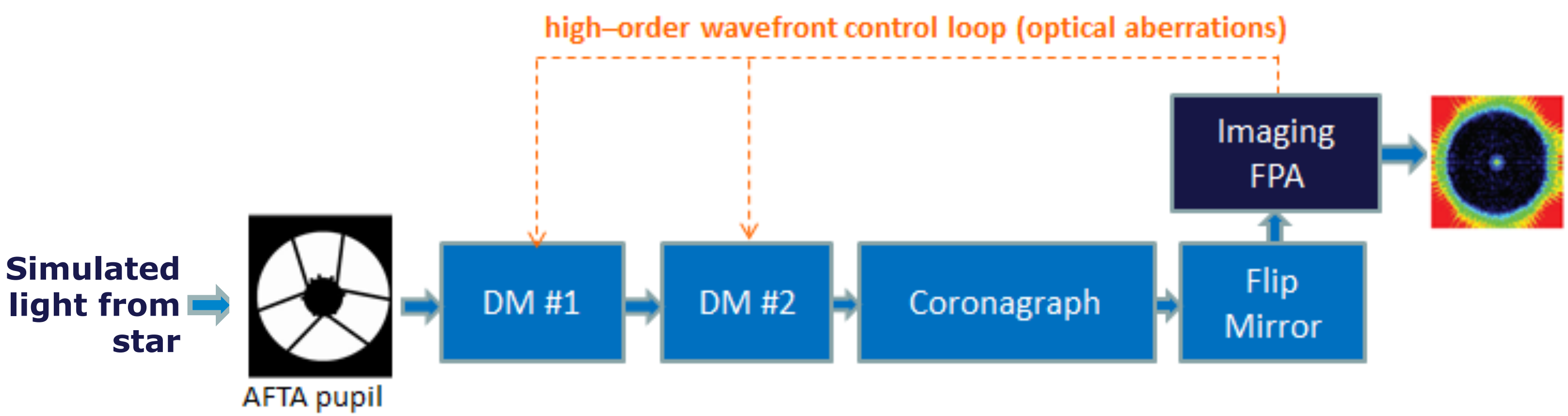
AFTA

Both masks have credible plan for FY14 delivery to HCIT

System-Level Testbed Demonstration Phase 1: Static Wavefront

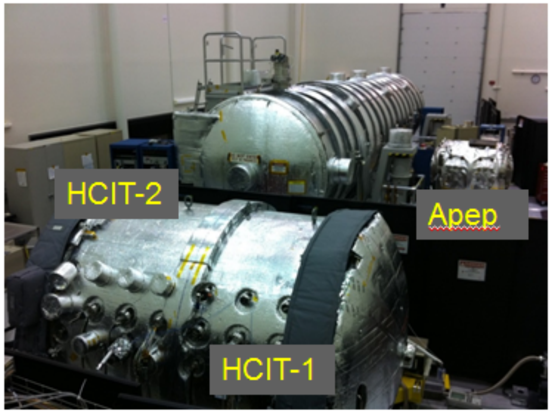
Possible Path to Closing Gap

Demonstrate static wavefront performance in fully-assembled coronagraph vacuum testbed with simulated AFTA-WFIRST telescope pupil.



Key Demonstration Objectives

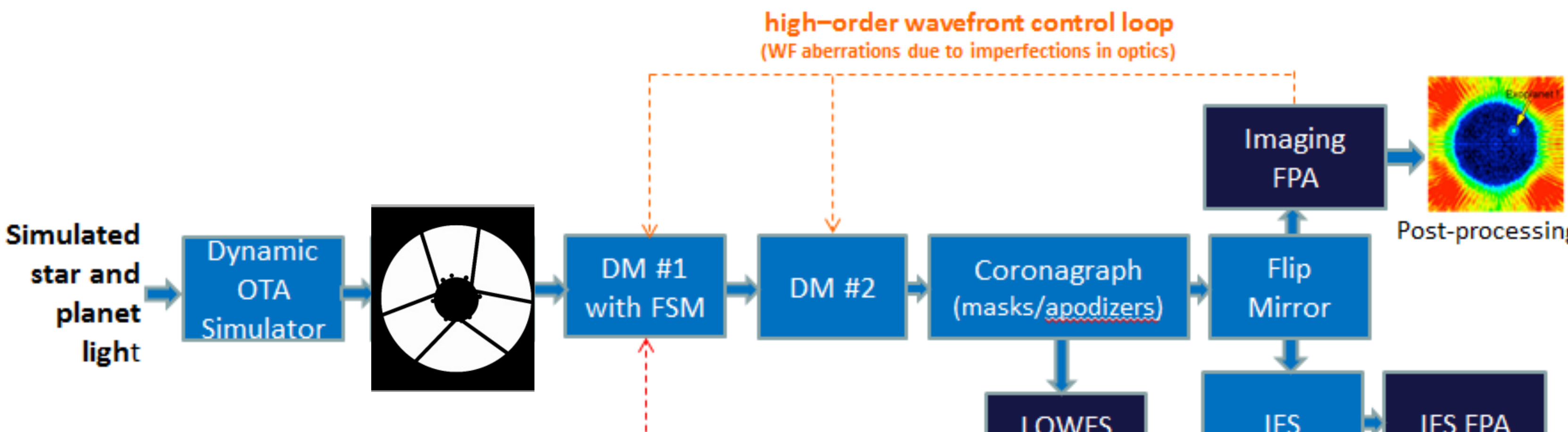
- **Coronagraph masks/apodizers for AFTA-WFIRST obscured pupil**
- **Two-DM configuration**
- **Wavefront control algorithms developed**
- **Static wavefront performance:**
  - 1e-8 contrast
  - 2% → 10% BW (in 500-600 nm window)

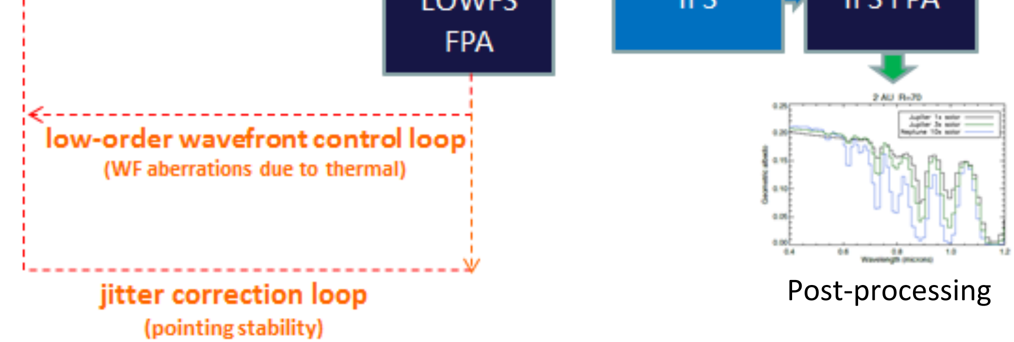


System-Level Testbed Demonstration Phase 2: Dynamic Wavefront

Possible Path to Closing Gap

Demonstrate dynamic wavefront performance in fully-assembled coronagraph vacuum testbed with simulated AFTA-WFIRST telescope pupil in a dynamic env't.



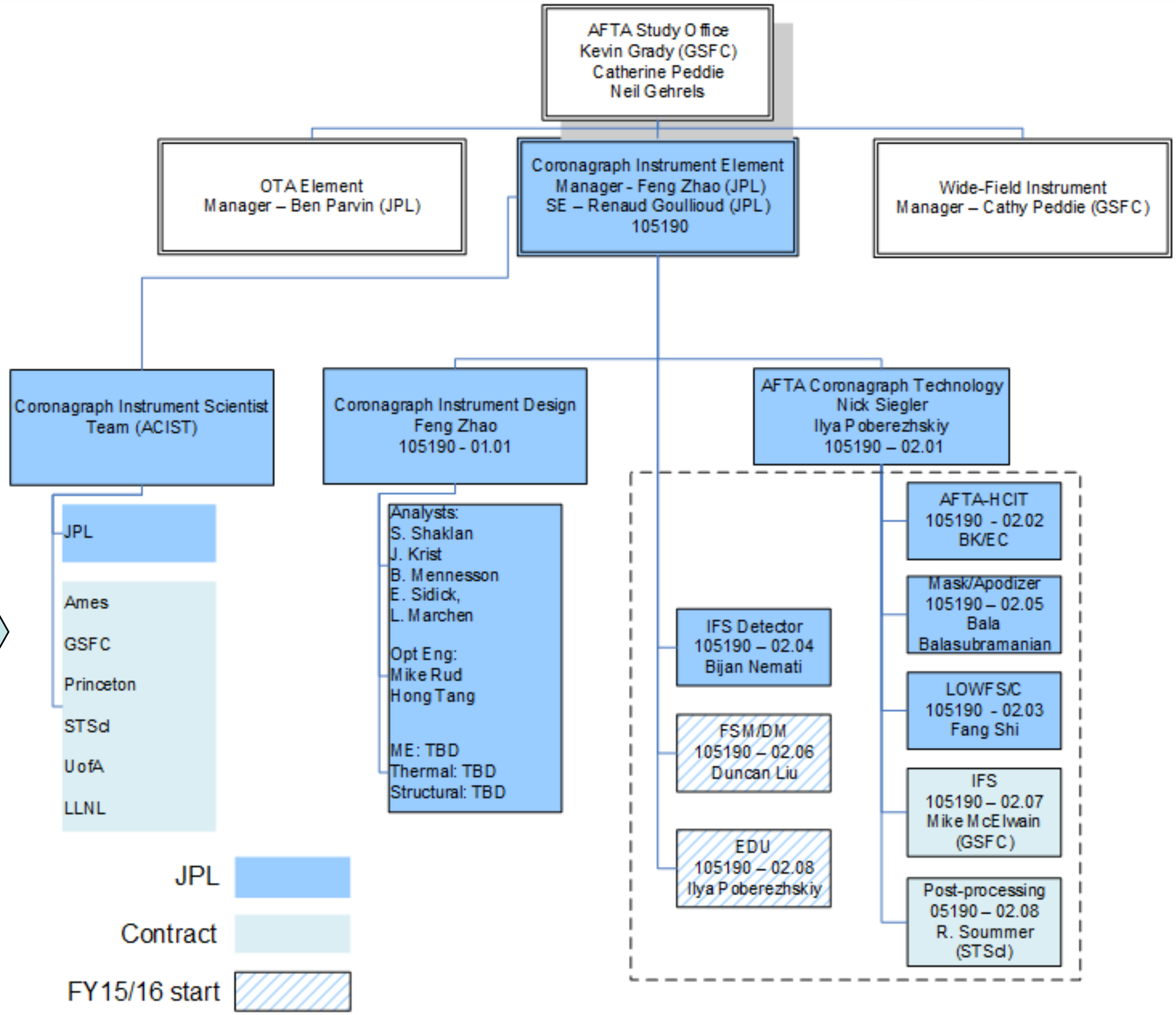


Key Demonstration Objectives (TRL 5)

- **Dynamic OTA simulator**
- **DM/FSM integrated assembly**
- **LOWFS/C and algorithms developed**
- **Dynamic wavefront performance:**
  - 1e-8 raw contrast
  - 1e-9 detection contrast
  - 2% → 10% BW (central wavelength of 550 nm)
  - IFS (R~70 TBD) separately
- **Planet simulation and extraction**

Org Chart

Negotiation with instrument scientist underway



Next Steps

- Technology Maturation:
  - Submit technology maturation plan to HQ with milestones FY14-FY16 (TRL-5 demonstration by 10/2016)
- AFTA-WFIRST DRM:
  - SDT interim report 4/2014
  - SDT final report 1/2015
  - CATE 2/2015
- Wider community participation
  - ACIST
  - International partnership

Summary

- Exciting coronagraph technology maturation for a generic telescope (such as AFTA)
  - Benefit future exo-Earth imaging missions using a generic telescope (such as ATLAST)
- AFTA-WFIRST Occulting Mask Coronagraph offers balanced science returns and engineering risks
- Strong interest from community and international partners, modularized instrument design offers simple interface and flexible contributions

Acknowledgement

- Contributions from team members from JPL, GSFC, Princeton, Univ of Arizona, Ames, LLNL, STScI, Caltech

AFTA WFIRST
Wide-Field Infrared Survey Telescope