# AFTA-WFIRST Coronagraph Instrument Status Report -- ExoPAG

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AFTA Coronagraph Instrument Manager

1/5 2014

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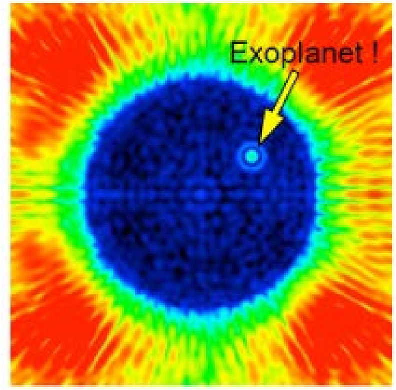
# Outline

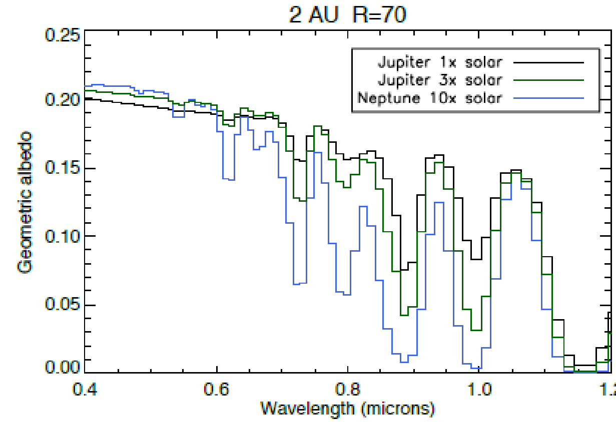
- Introduction
- Newly selected architecture description
- Status and next steps
- Summary


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

AFTA WFIRST
Wide-Field Infrared Survey Telescope




Coronagraph Instrument → Exo-planet Direct imaging

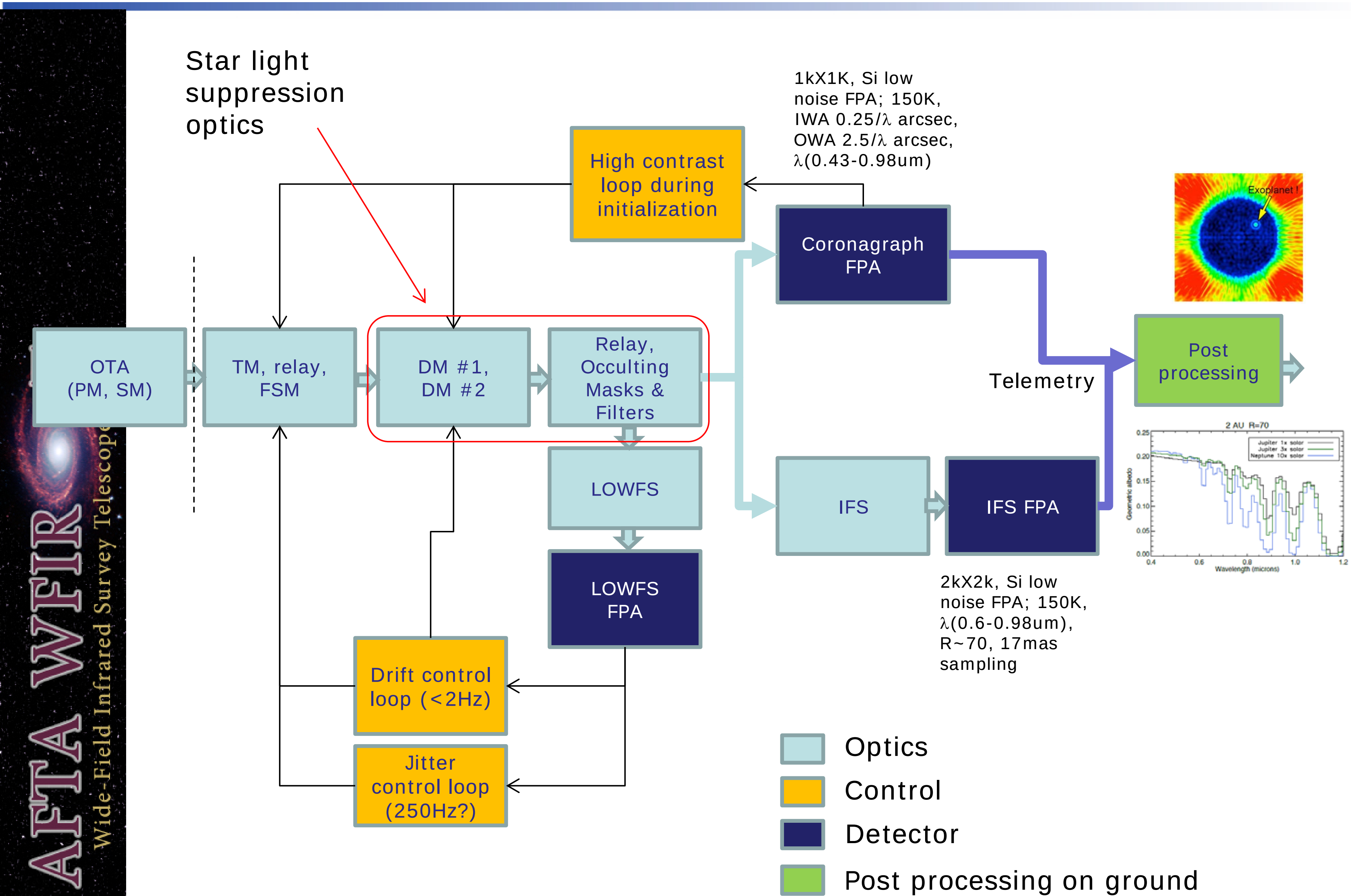
Exo-planet Spectroscopy

| | | |
|---|---|---|
| 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 | Nyquist 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.

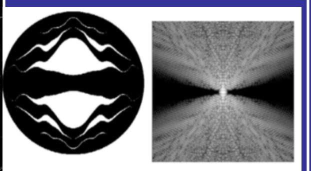
# Functional Block Diagram

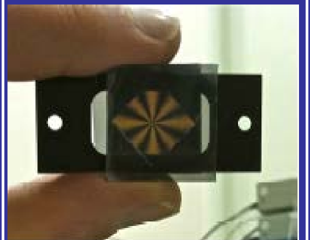


# Star light suppression -- Technical Approach



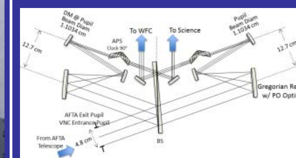
## Six different concepts

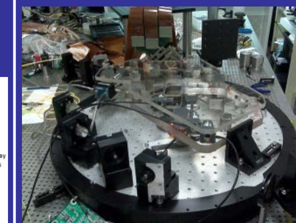

Shaped Pupil Mask Pupil Masking (Vanderbei & Kasdin, Princeton Univ. )


Vector Vortex Mask Image Plane (Serabyn, JPL)


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

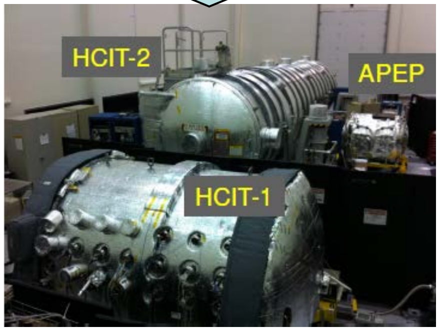

Hybrid / Band-Limited Lyot Mask Image Plane Amplitude & Phase (Trauger, JPL)

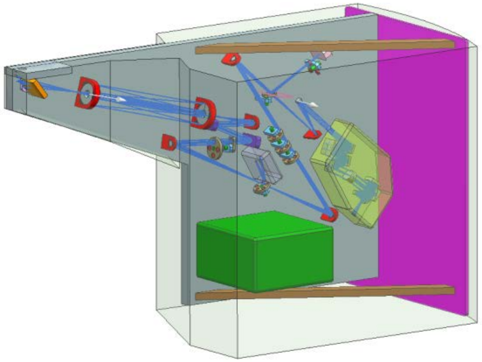

Visible Nuller Coronagraph: Phase-Occulting (Lyon, GSFC)


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)

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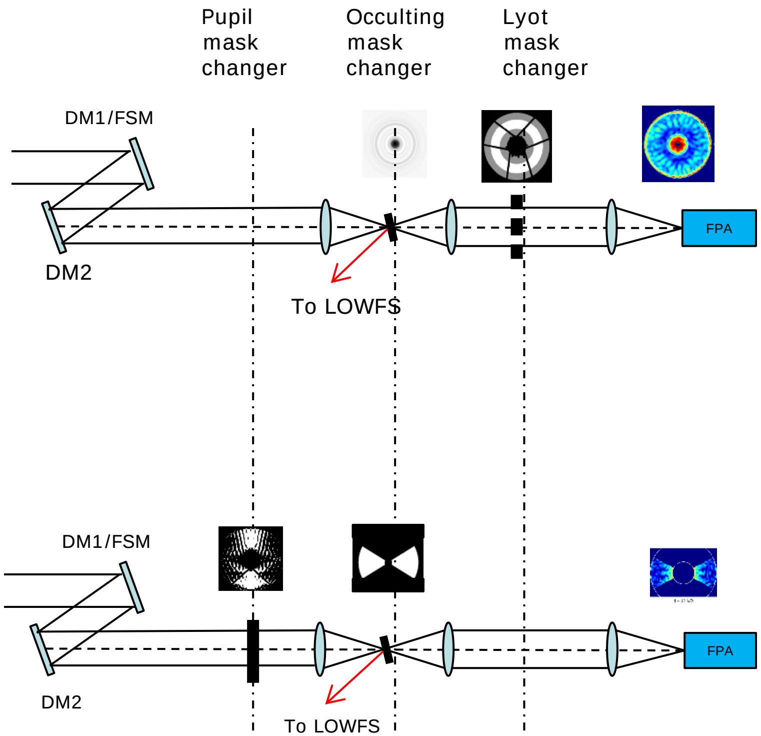
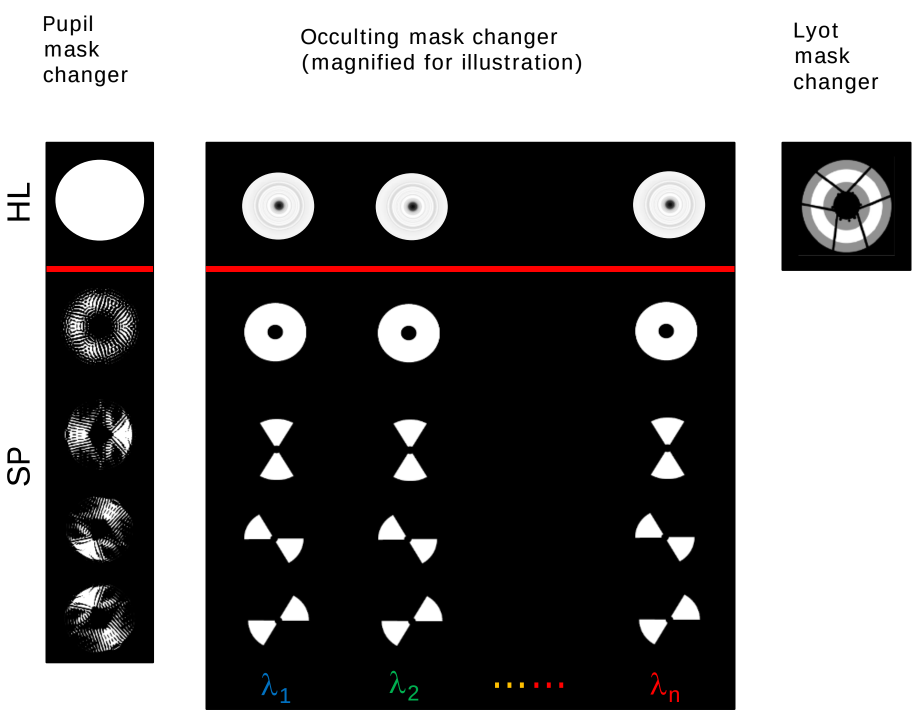
# Primary Architecture: Occulting Mask Coronagraph = Shaped Pupil + Hybrid Lyot

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



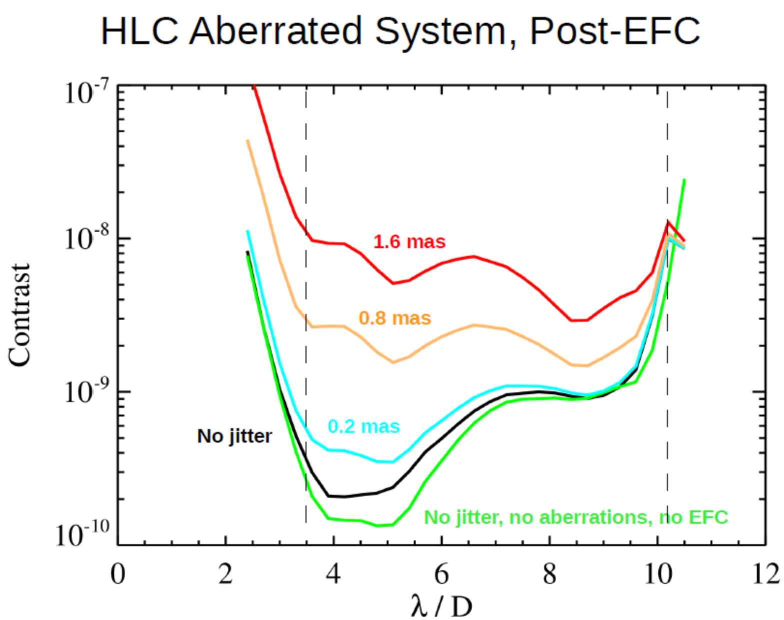




AFTA WFIRST
Wide-Field Infrared Survey Telescope

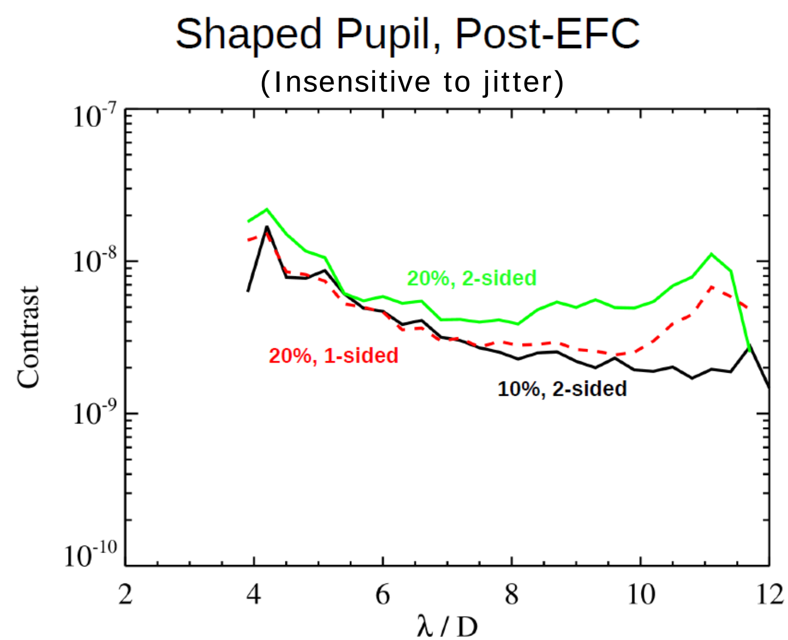
# Contrast simulations with AFTA pupil, aberrations and expected range of telescope pointing jitter



- 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



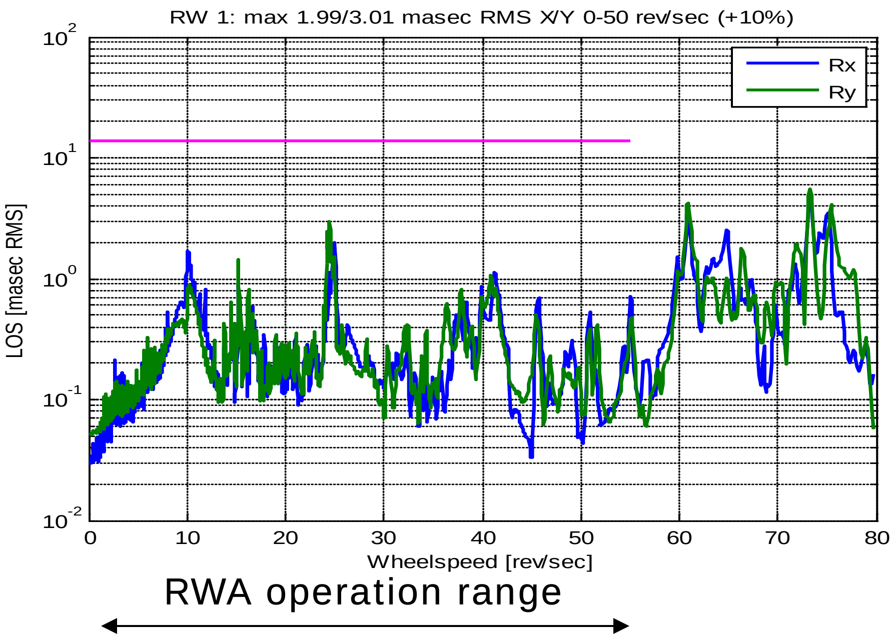

λ=550nm




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

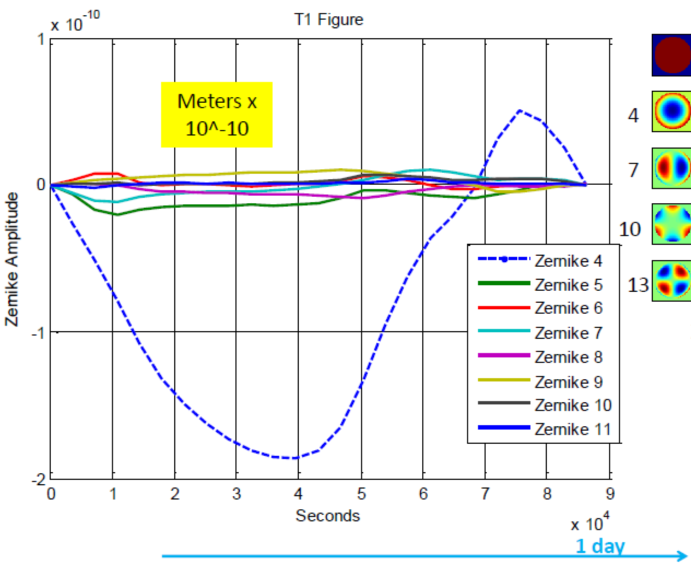


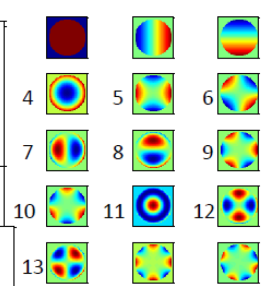

"Model uncertainty factor (MUF)" consistent with flight projects (MUF=2.5 for f<20Hz, and MUF=6 for f>40Hz, linear in between)

# 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

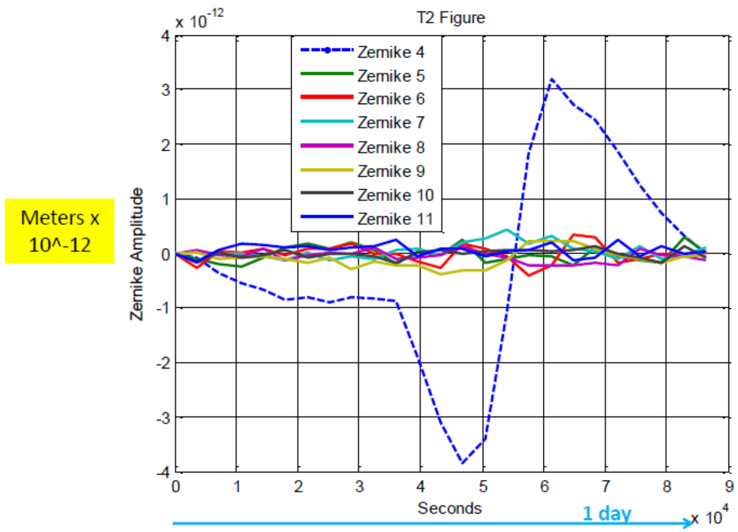
T1 Zernike Amplitudes over 24 Hours




Zernike shapes

T2 Zernike Amplitudes over 24 Hours

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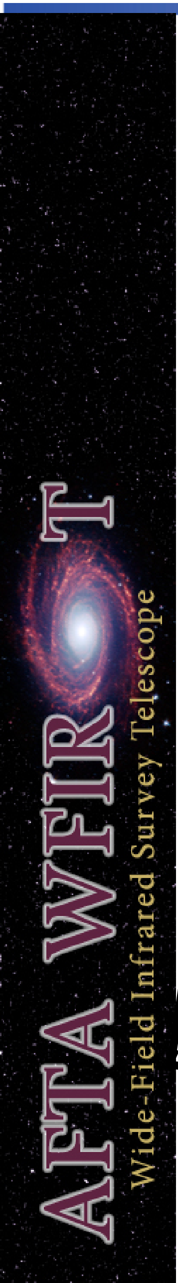
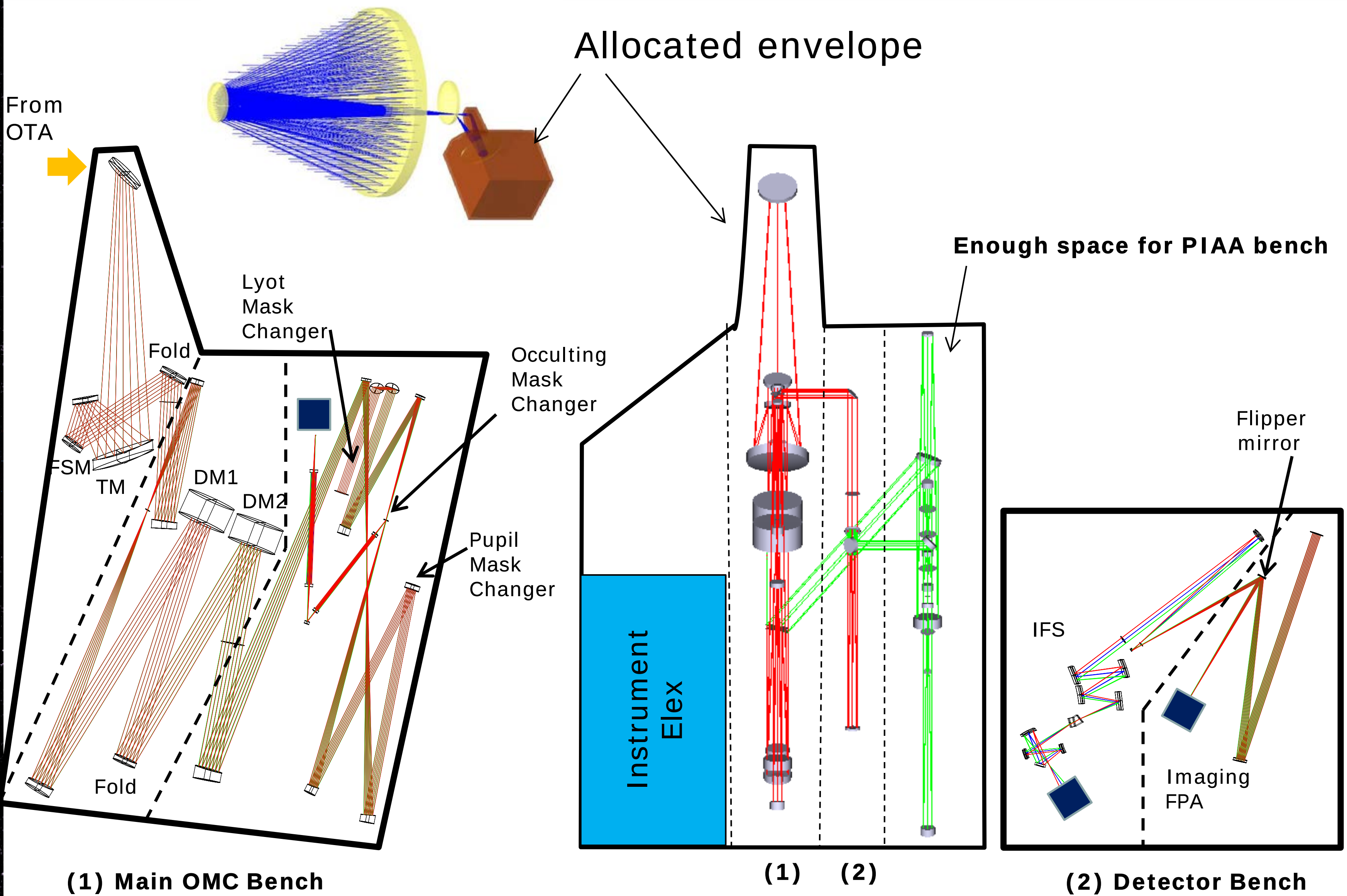
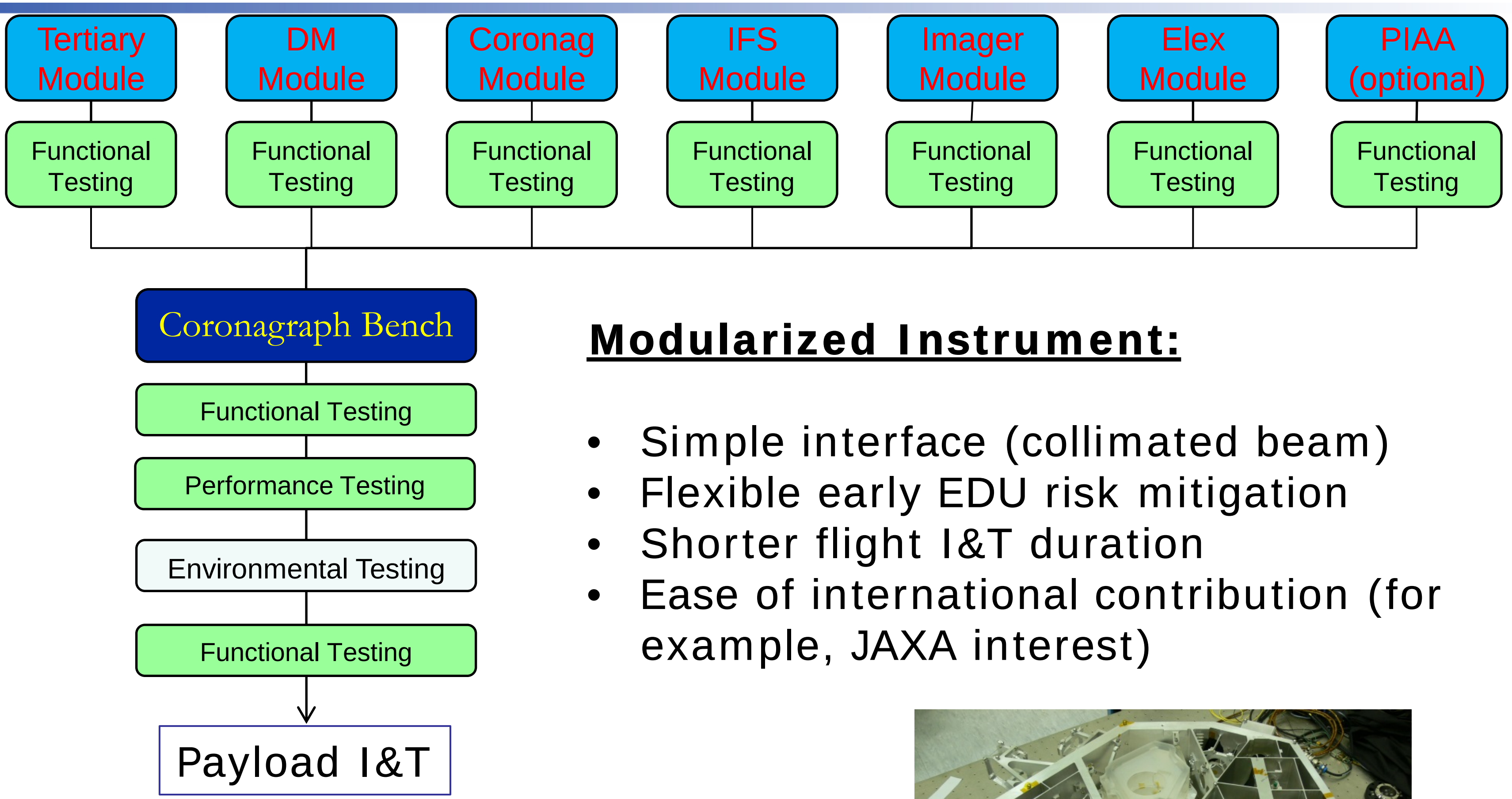
# Instrument Layout within the Allocated Envelope



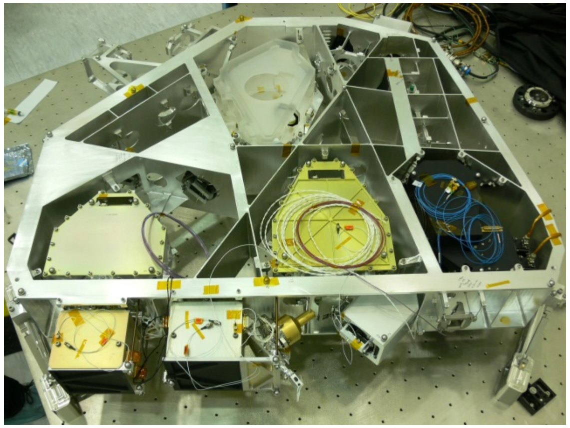



# Functional Modularized Instrument




## Modularized Instrument:

- Simple interface (collimated beam)
- Flexible early EDU risk mitigation
- Shorter flight I&T duration
- Ease of international contribution (for example, JAXA interest)



Modularized example (SIM ABC)

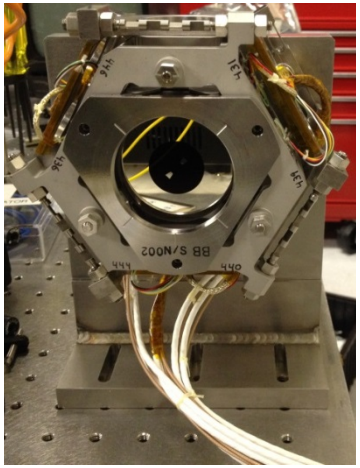
AFTA WFIRST Wide-Field Infrared Survey Telescope

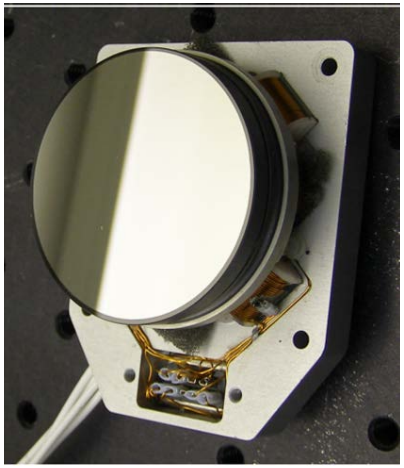
# Active Optics



## Fine Steering Mirror (FSM)

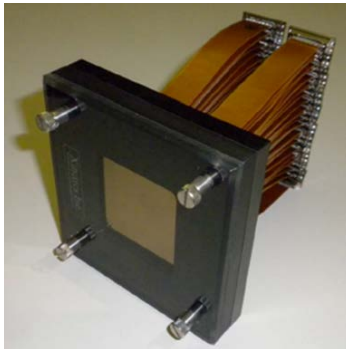
- To correct telescope line-of-sight (wavefront tip/tilt) error
- Low risk with rich flight heritage

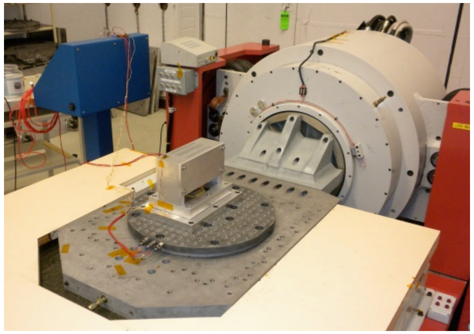




## Deformable Mirror (DM)

- 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)



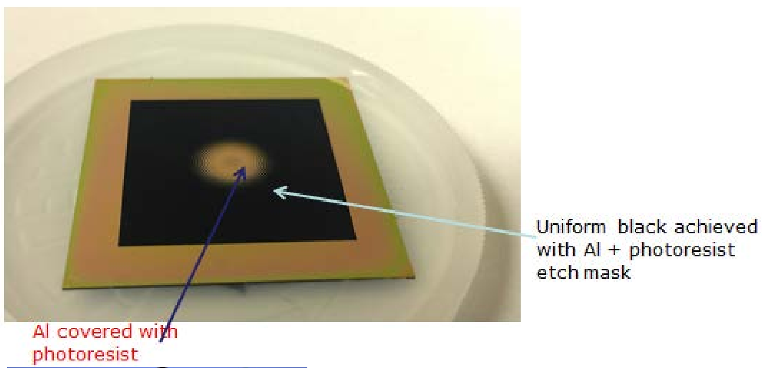


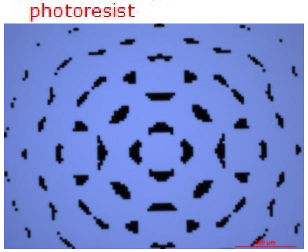
**Low risk for flight implementation**

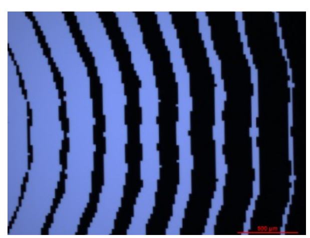
# Coronagraph Masks

## Reflective shaped pupil masks

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

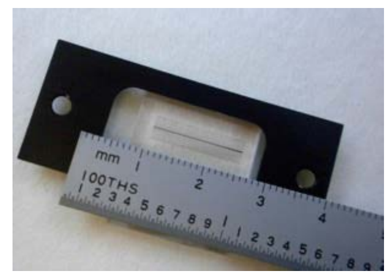


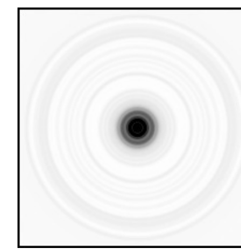





## Transmissive hybrid Lyot mask

- 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



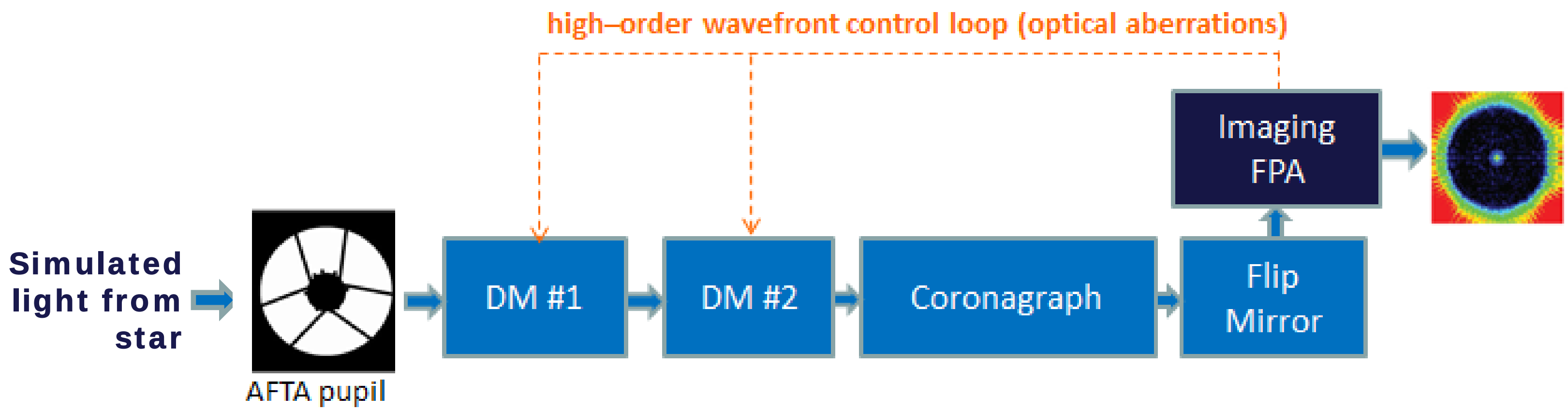
AFTA

**Both masks have credible plan for FY14 delivery to HCIT**

# System-Level Testbed Demonstration Phase 1: Static Wavefront

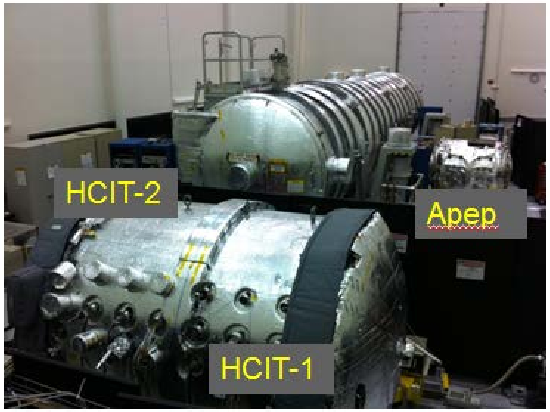

## Possible Path to Closing Gap

**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)

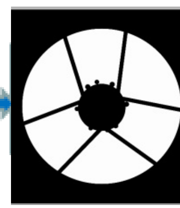


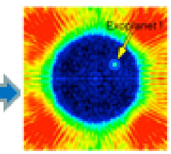
# System-Level Testbed Demonstration Phase 2: Dynamic Wavefront



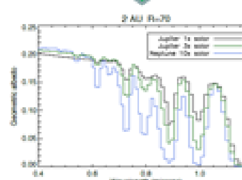
## Possible Path to Closing Gap

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




Post-processing



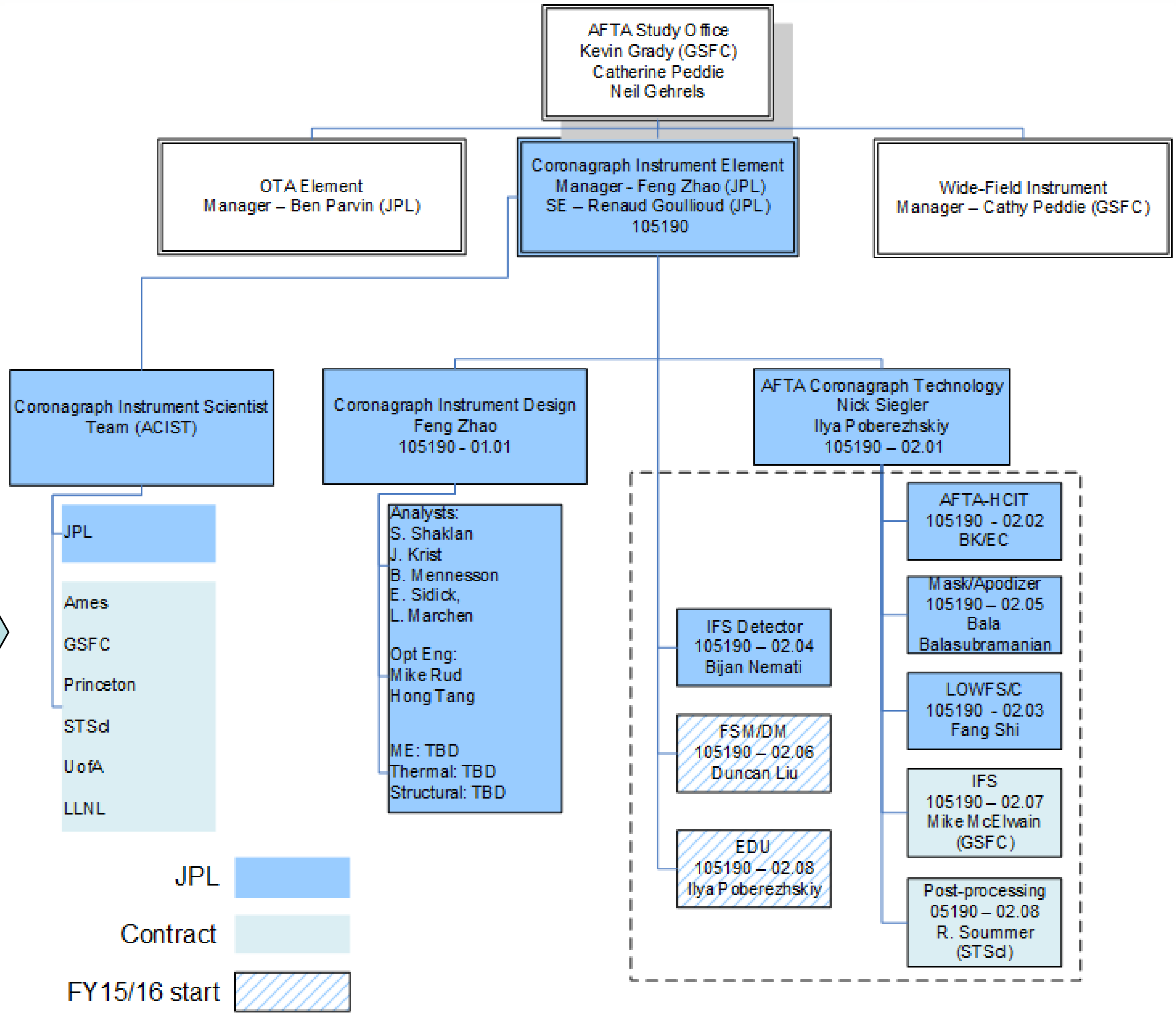
Post-processing

### 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 (such as JAXA)

# 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