AFTA-WFIRST Exoplanet Science Capabilities

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1/7/ 2014

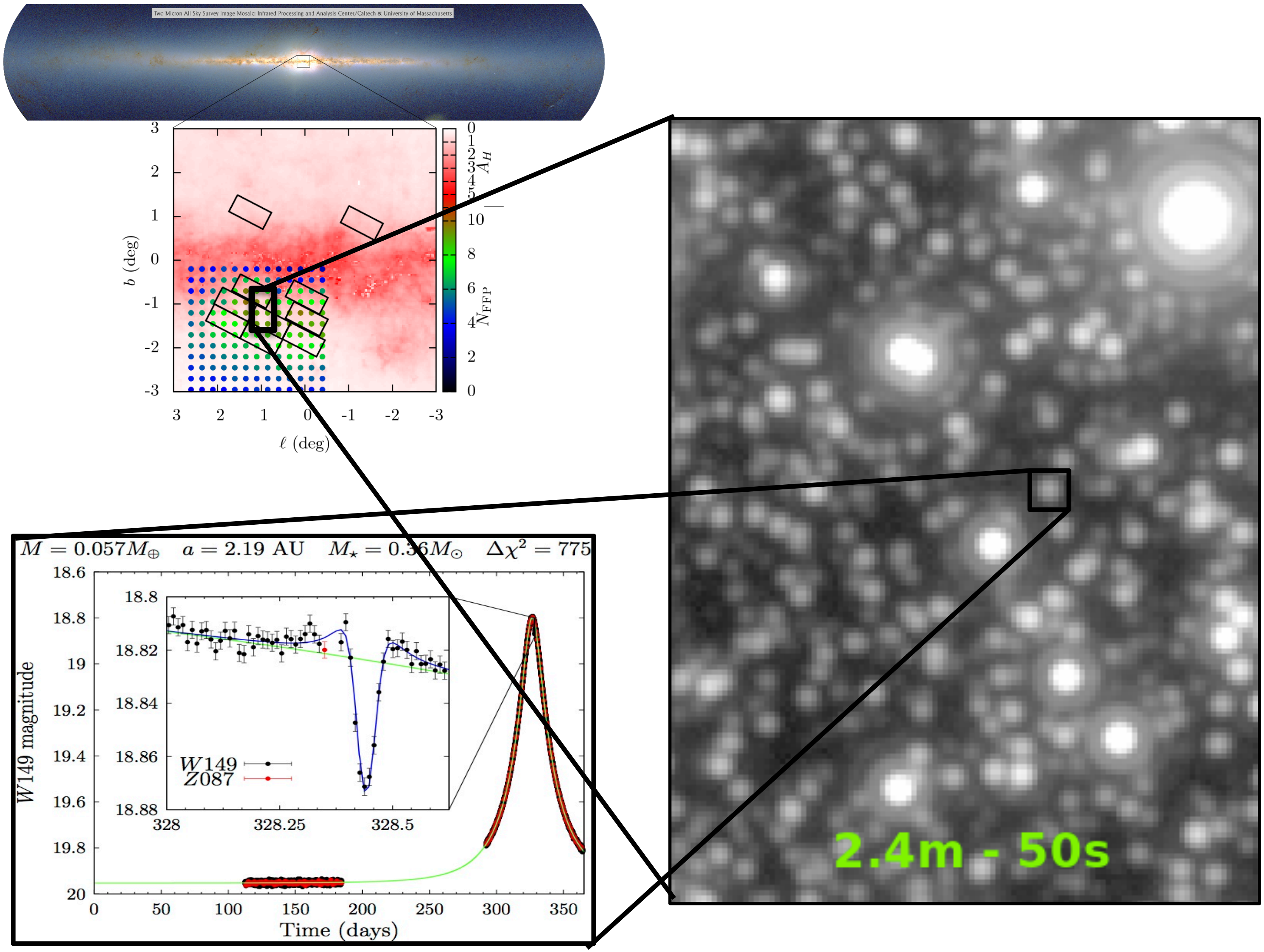
Outline

- Introduction
- AFTA overview & microlensing
- Science goals
- Coronagraph architecture
- Initial evaluation of exoplanet coronagraph capabilities
- Status and next steps

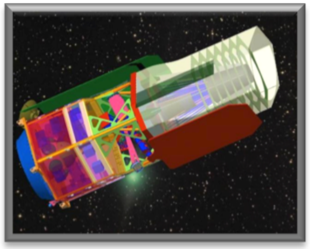
WFIRST Microlensing Survey

AFTA WFIRST

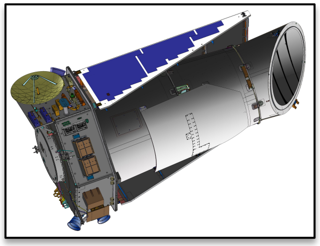
Wide-Field Infrared Survey Telescope



A Complete Statistical Census.

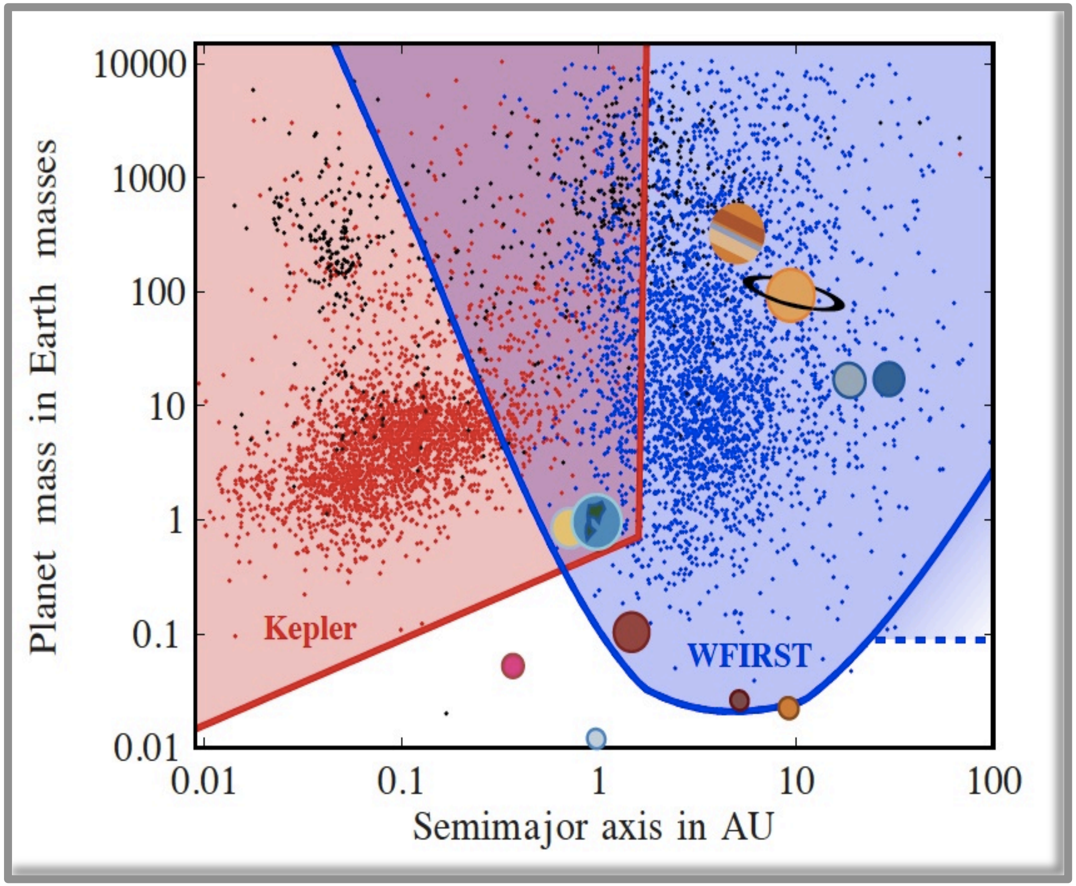


Together, Kepler and WFIRST complete the statistical census of planetary systems in the Galaxy.



WFIRST will:

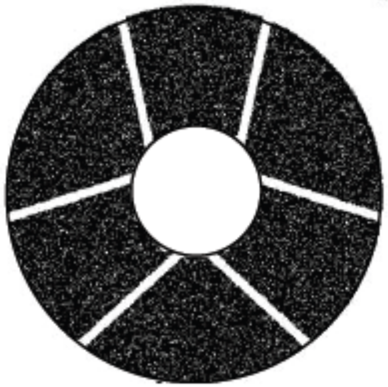
- Detect 2800 planets, with orbits from the habitable zone outward, and masses down to a few times the mass of the Moon.
- Have some sensitivity to "outer" habitable zone planets (Mars-like orbits).
- Be sensitive to analogs of all the solar systems planets except Mercury.
- Measure the abundance of free-floating planets in the Galaxy with masses down to the mass of Mars
- Characterize the majority of host systems.



AFTA Telescope

- 2.4 m
- Inclined geosynchronous orbit
- 5 year mission
- Wide-field near-IR imager
- Coronagraphic imager&IFS

- Pupil:



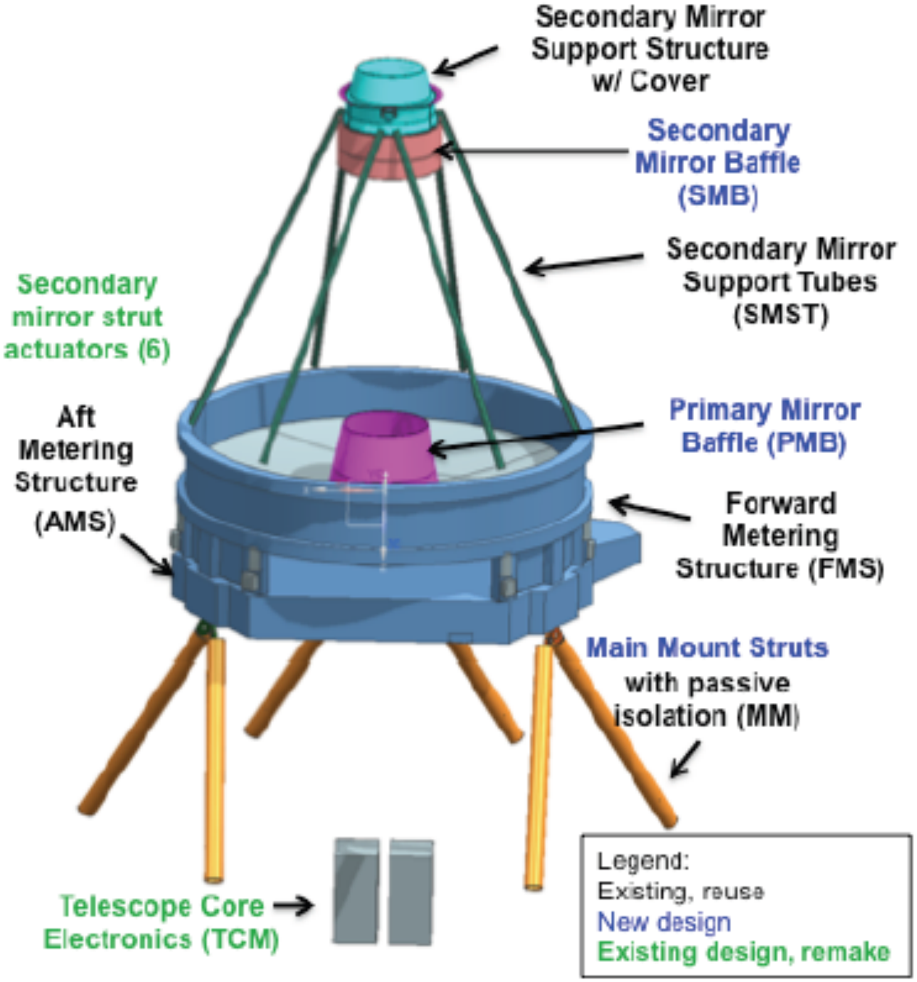


Figure 3-4: The telescope components without the outer barrel assembly.

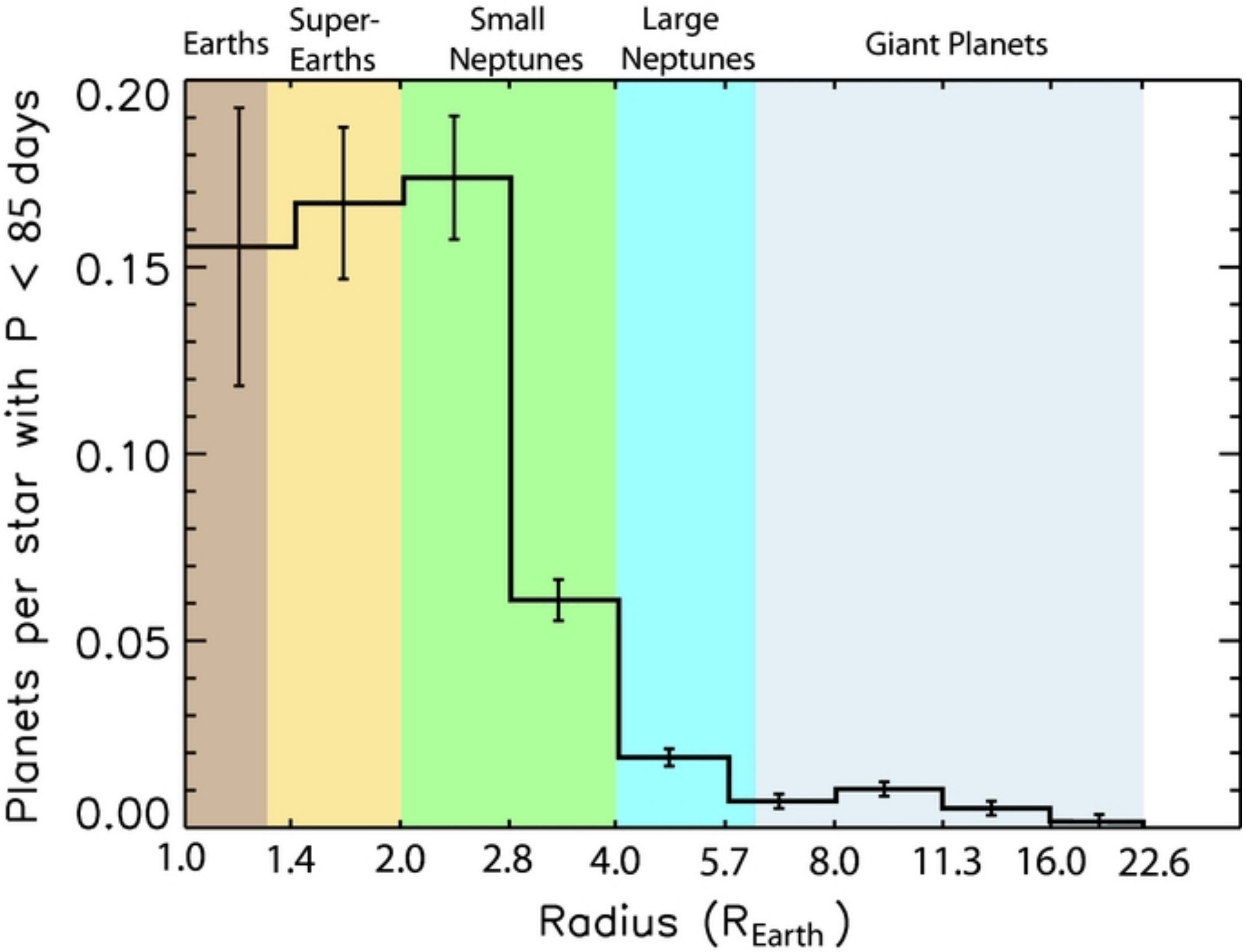
AFTA coronagraph goals

1) Measure and understand the composition and nature of a diverse sample of extrasolar planets orbiting nearby stars
2) Illuminate the process through which planetary systems form
3) Determine which stars have dusty remnant or debris disks, measure their disk properties, and observe how their disks and planets interact
4) Determine which systems (statistically or individually) in the solar neighborhood are suitable targets for future terrestrial-planet characterization
5) Demonstrate and validate coronagraph technology useable for a future habitable-planet-detecting mission

AFTA exoplanet science objectives

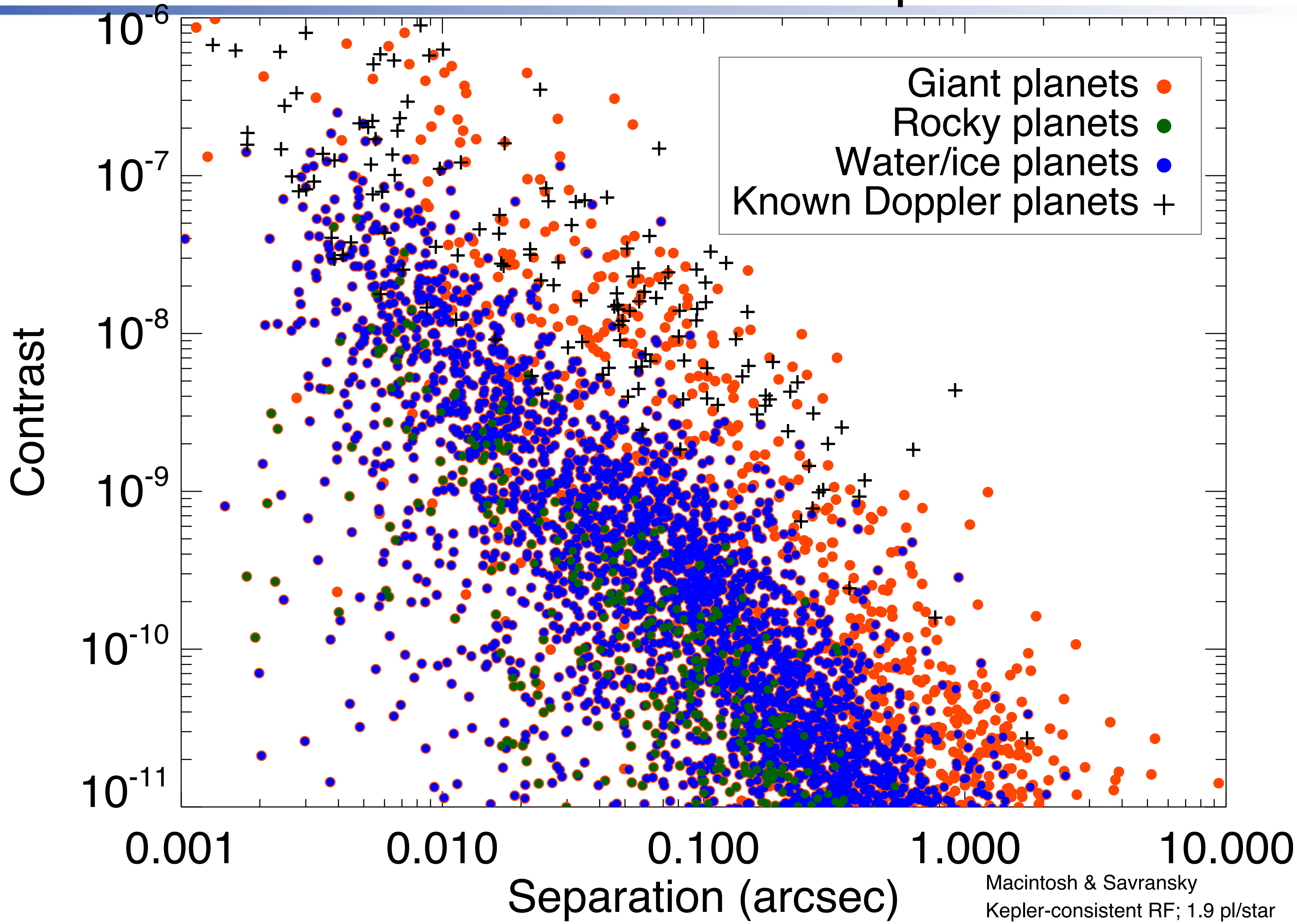
1) Survey 200 nearby stars including both those with known extrasolar planets and those for which no constraints will exist (e.g. A stars) spanning the range of spectral types
2) Characterize a significant sample (10-20) of giant planets in broadband reflected-light photometry with an accuracy of 0.03 in albedo, spanning a ~5 bands that are sensitive from Rayleigh scattering to methane absorption
3) Spectroscopically characterize a subset (6-10) of giant planets spanning a range of irradiances and determine the depth of methane, water, and other features
    - Detect a sample (~2-4) of planets of less than 3 RE in broadband photometry of at least 3 bands with an accuracy of 0.05 in albedo
4) Characterize the orbital semi-major-axis (within 20%) and eccentricity (within 0.2) of these planets, in conjunction with Doppler or astrometric measurements

Kepler radius distribution



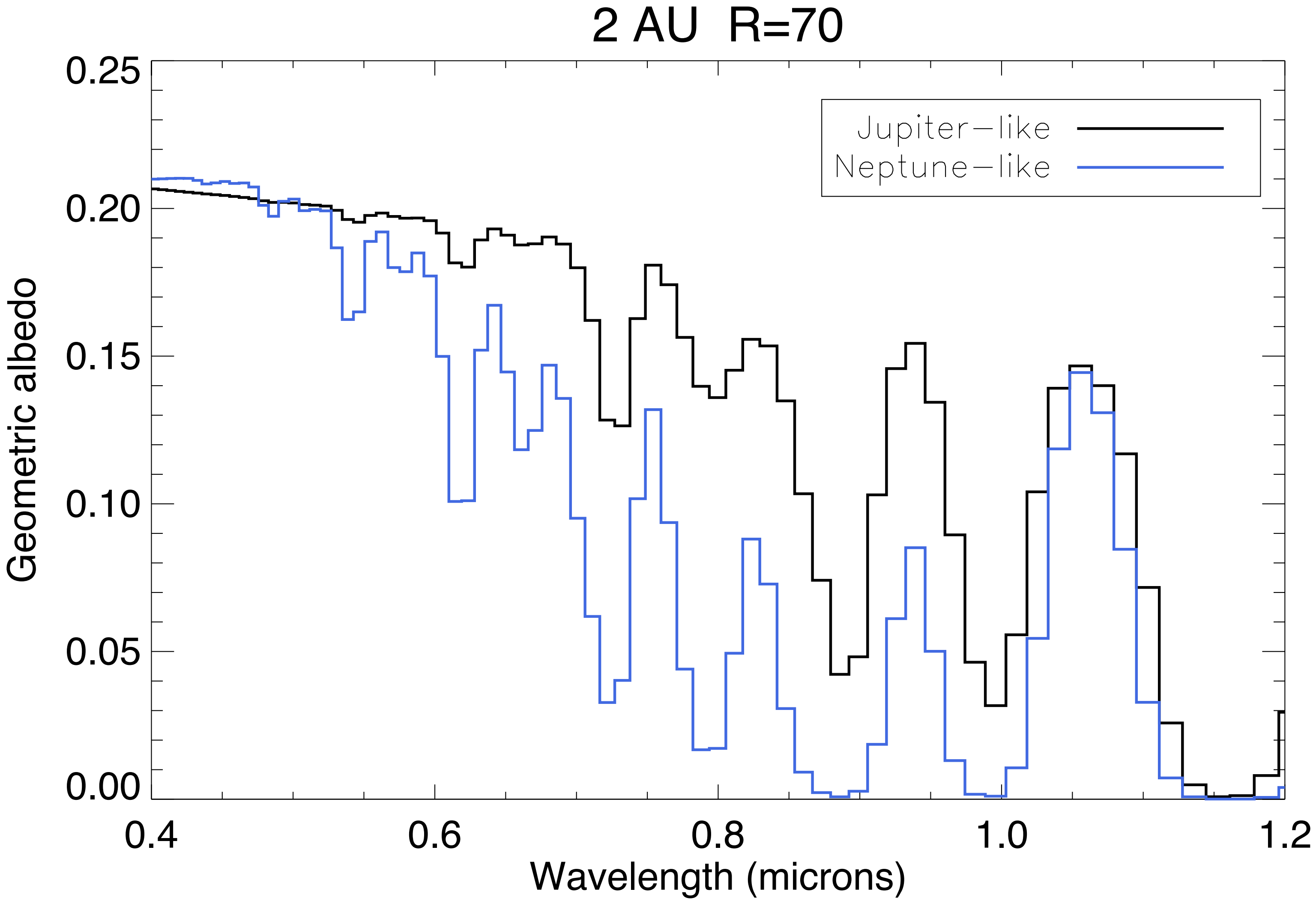
Fressin et al 2013; Kepler FGKM stars P<85 days

Planets within 30 pc



Macintosh & Savransky
Kepler-consistent RF; 1.9 pl/star
Main sequence non binary stars

R~70 spectra can determine planet properties



7) Search for low surface density circumstellar disks around a sample of several dozen nearby stars.

8) Measure the location, surface density and extents of dust particles around nearby stars from habitable zones to beyond ice lines to understand delivery of materials to inner solar systems

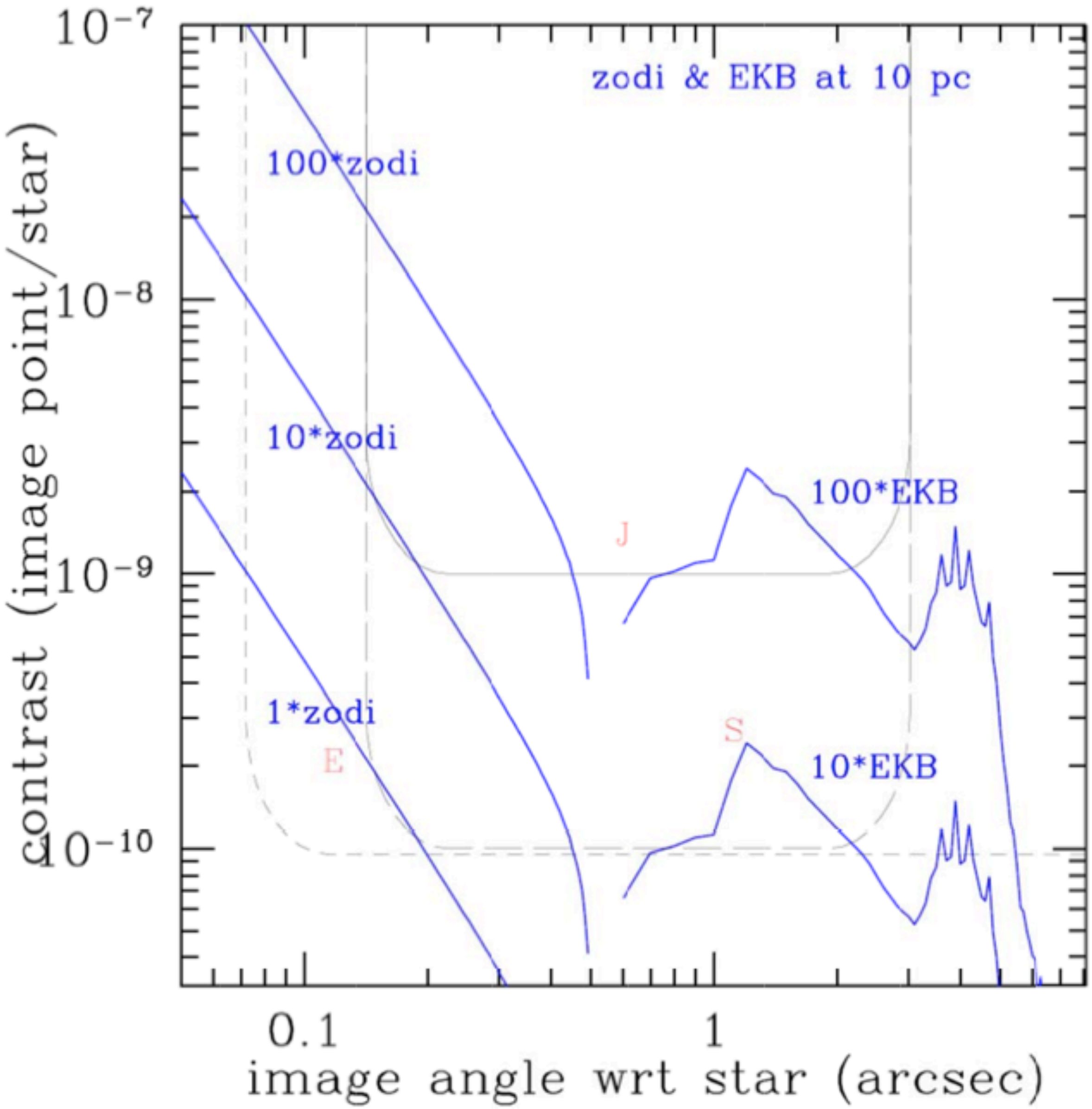
9) Constrain dust grain compositions and sizes

10) Detect and measure substructures within dusty debris that can be used to understand the locations of parent bodies (asteroids, comets) and influences of seen and unseen planets

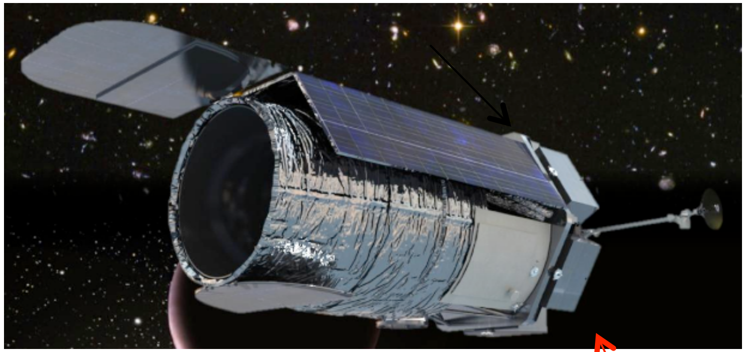
11) Identify what nearby stars have zodiacal dust levels indicating they may be poor candidates for future terrestrial planet imaging

12) Understand the time evolution of circumstellar disk properties around a broad star sample

Disk densities of 10-100 Zodi should be detectable in inner system



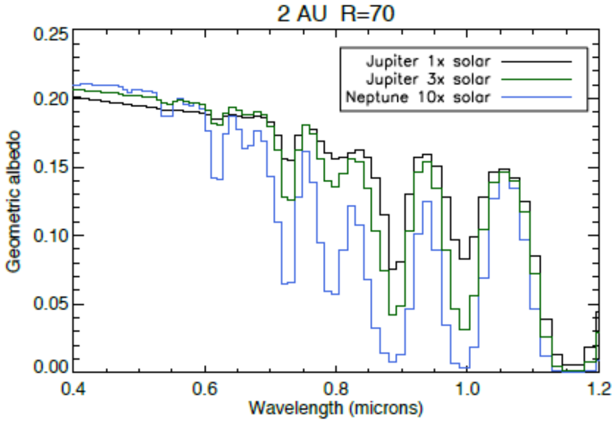
AFTA Coronagraph Instrument



Coronagraph Architecture:

Primary: OMC
Backup: PIAA

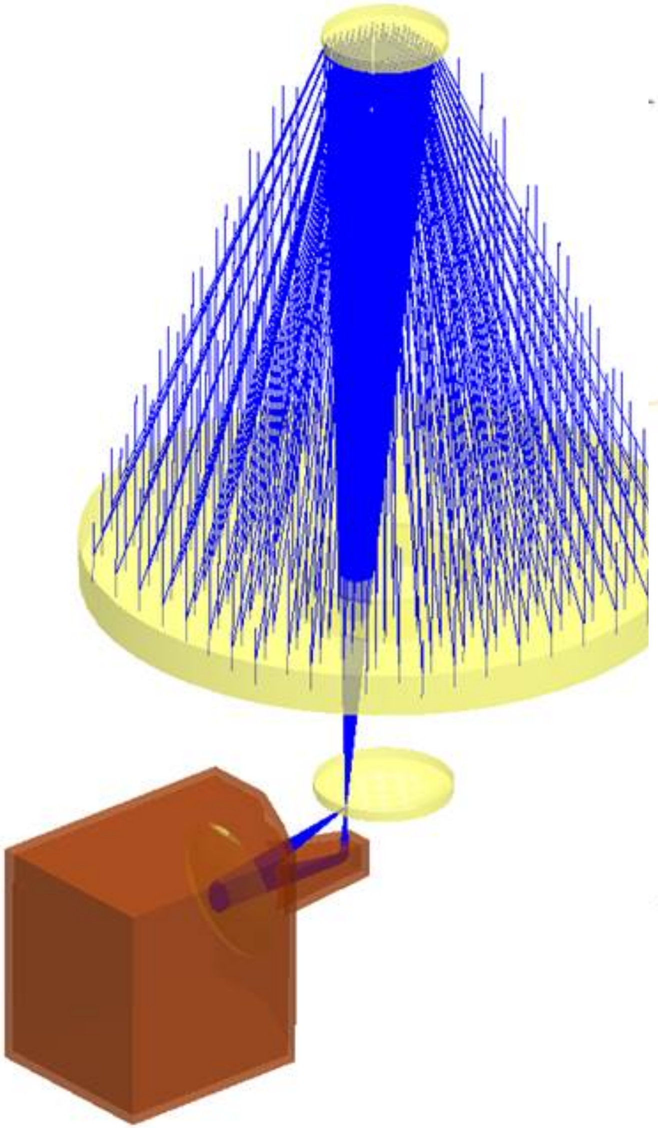
Coronagraph Instrument

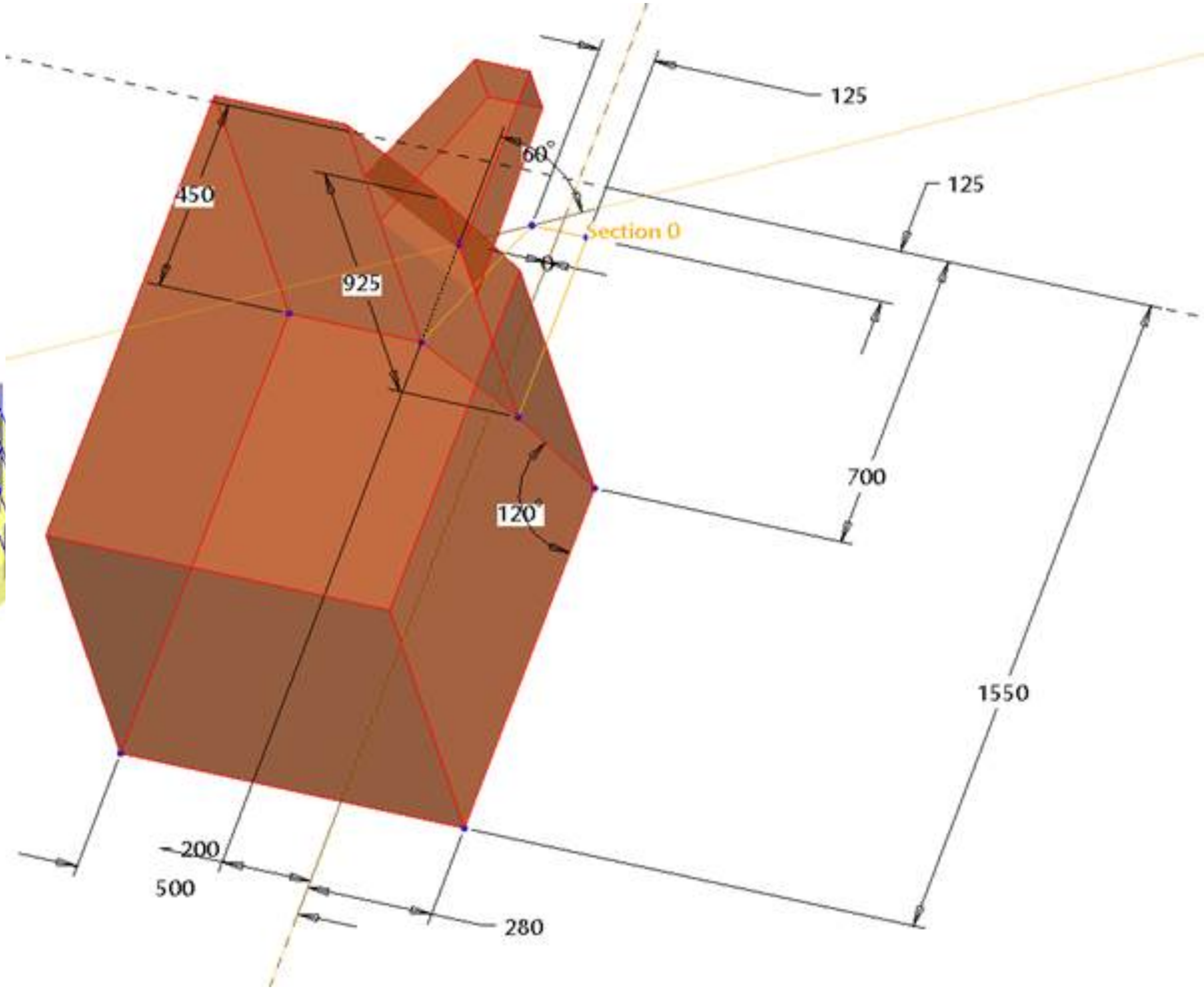


Exo-planet
[Spectroscopy

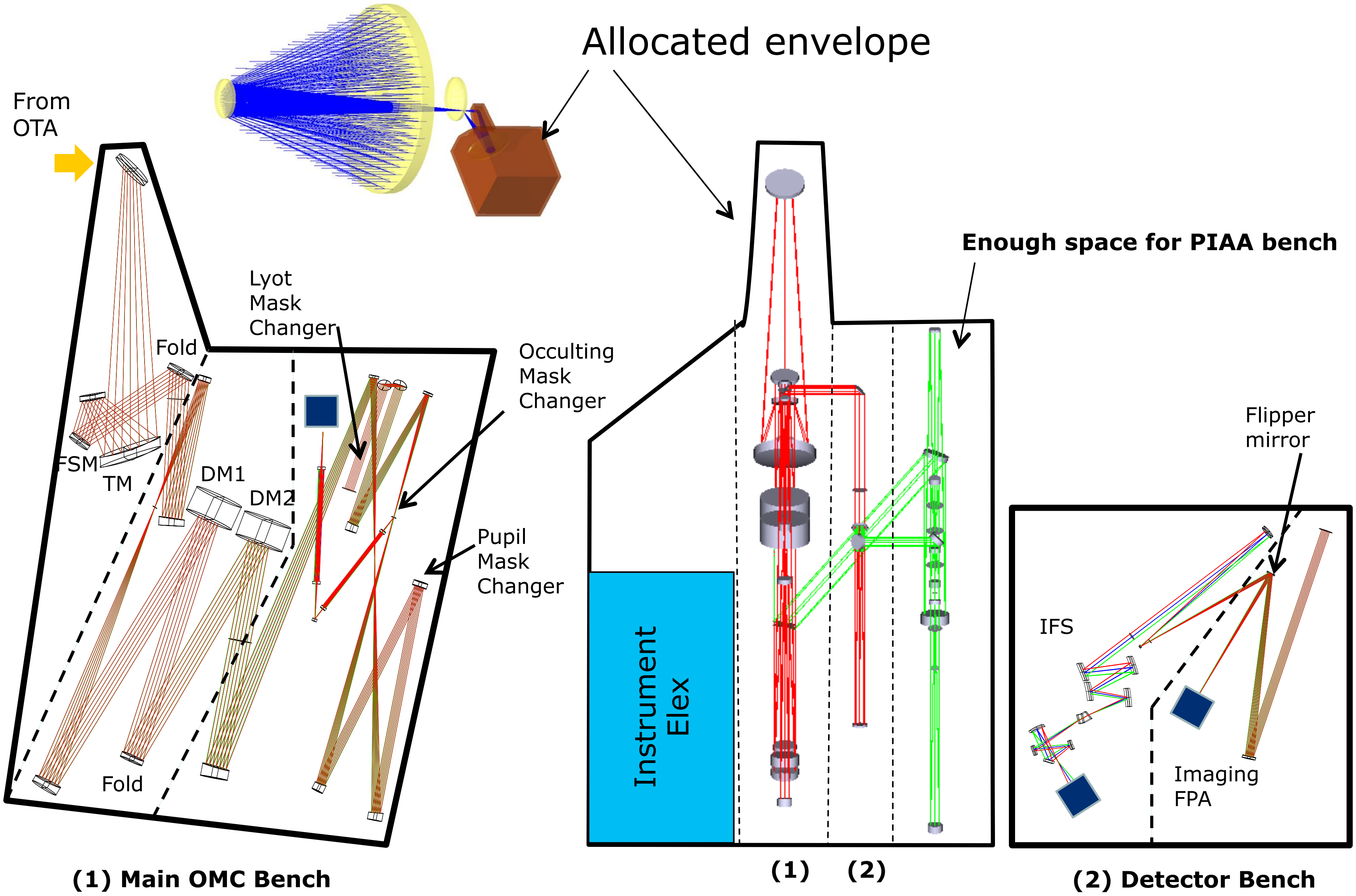
Bandpass	430 – 980nm	Measured sequentially in five ~10% bands
Inner working angle	100 – 250 mas	~3λ/D, driven by science
Outer working angle	0.75 – 1.8 arcsec	By 48X48 DM
Detection Limit	Contrast ≤ 10^{-9} After post processing)	Cold Jupiters, Neptunes, down to ~2 RE
Spectral Res.	~70	With IFS, R~70 across 600 – 980 nm
IFS Spatial Sampling	17mas	Nyqust for λ~430nm

Cycle 4 Configuration (July 2013)

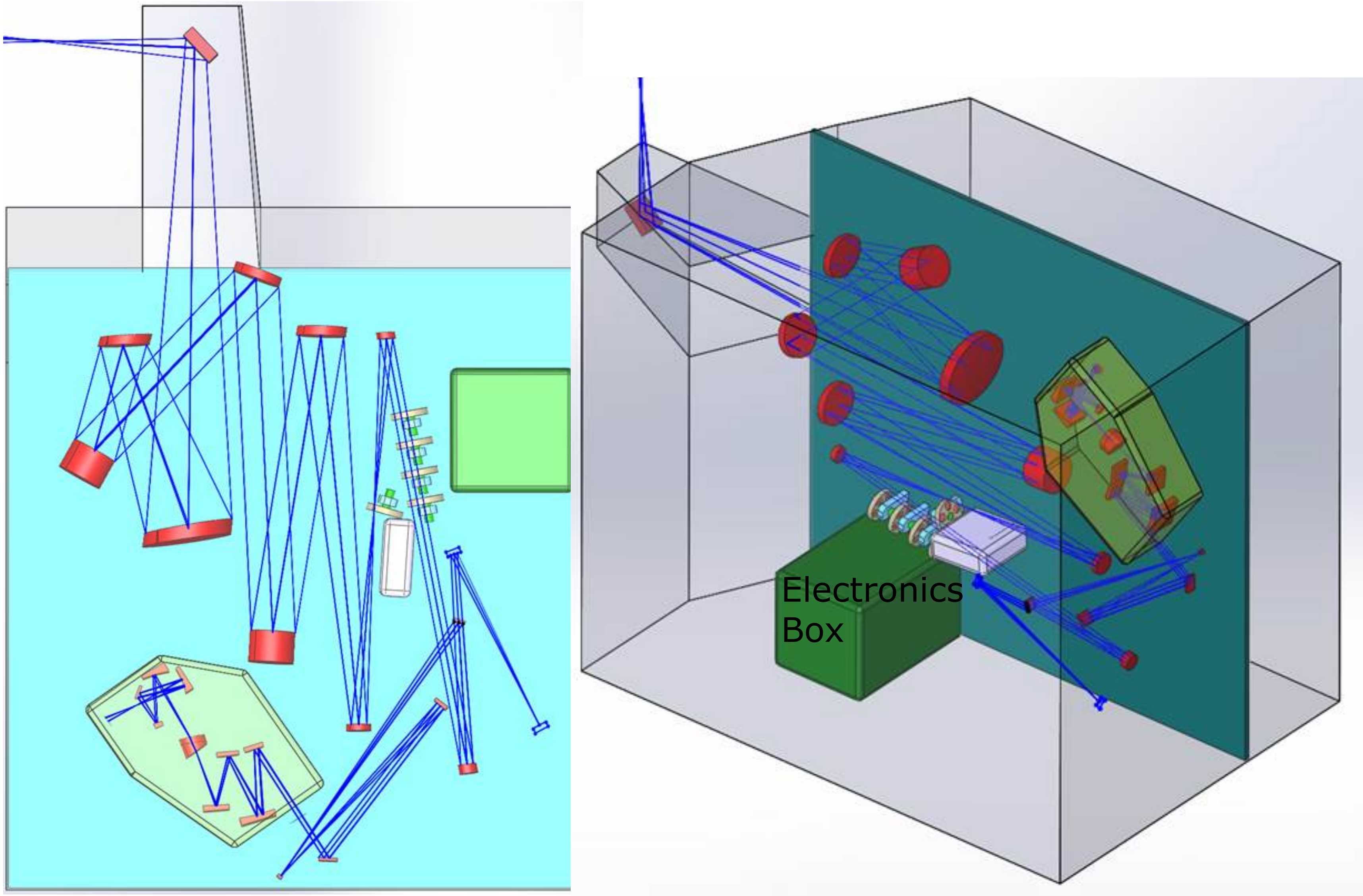




Instrument Layout within the Allocated Envelope



Coronagraph within Allocated Volume

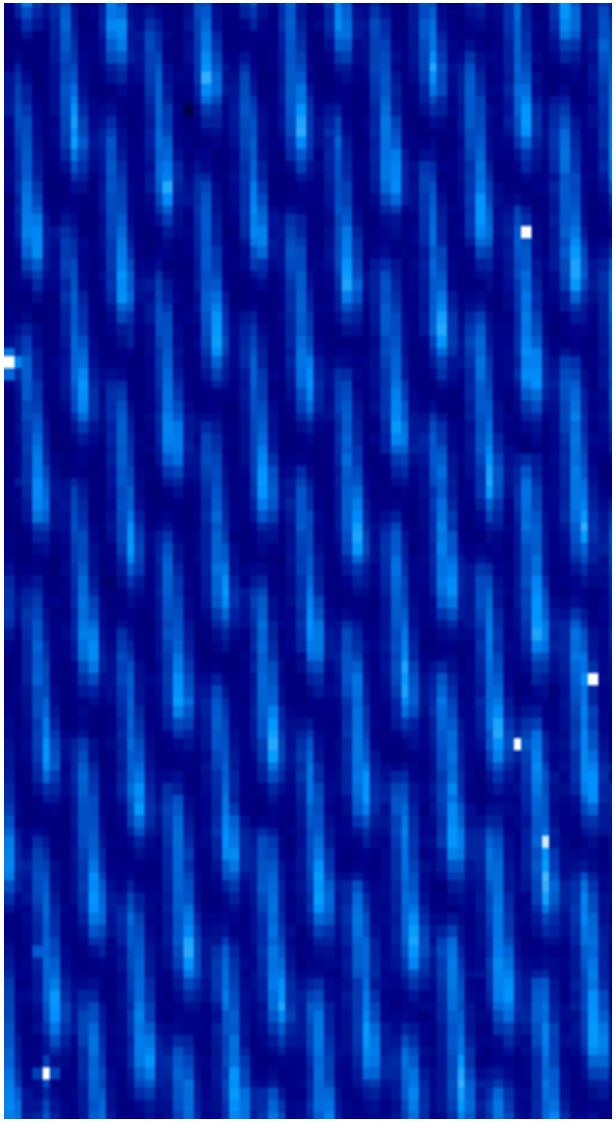


Integral Field Spectrograph

Follows design principles of ground-based IFS instruments, e.g. CHARIS (Princeton), GPI, SPHERE. OSIRIS

140 x 140 lenslet array. Designed to disperse 20% band over 24 detector pixels (SR ~70).

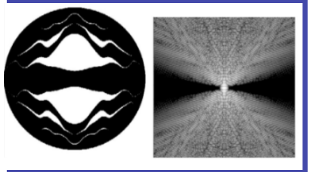
- Accommodates 0.5 – 1 um range using 4 bandpass filters (one at a time)
- 17 mas ‘spaxel’ pitch.



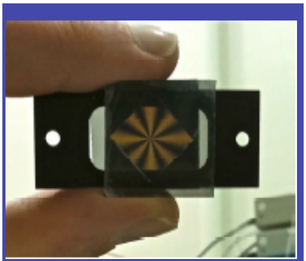
GPI IFS microspectra

Star light suppression -- Technical Approach

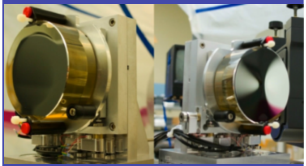
Six different concepts spanning range of performance and risk



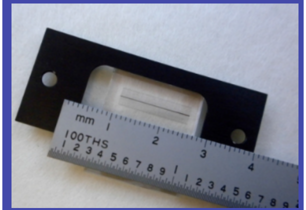
Shaped Pupil Mask Pupil Masking (Vanderbei & Kasdin, Princeton Univ.)



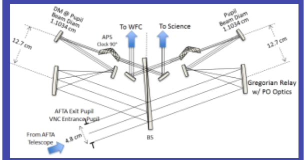
Vector Vortex Mask Image Plane (Serabyn, JPL)



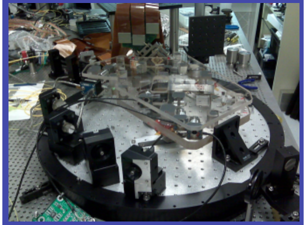
Phase Induced Amplitude Apodization (PIAA) Pupil Re-Mapping (Guyon, Univ. Arizona)



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



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

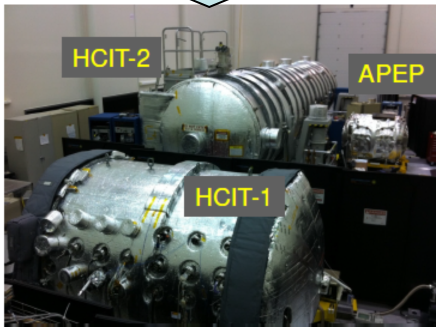


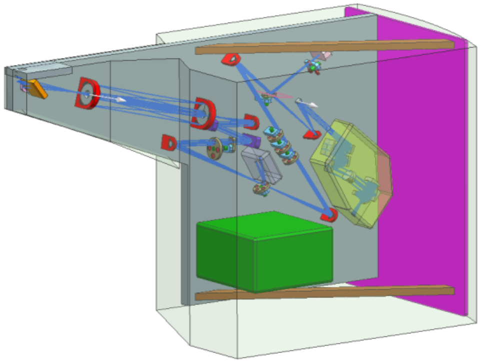
Visible Nuller Coronagraph: DaVinci (Shao, JPL)

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

Primary Architecture (OMC)

Back-up Architecture (PIAACMC)



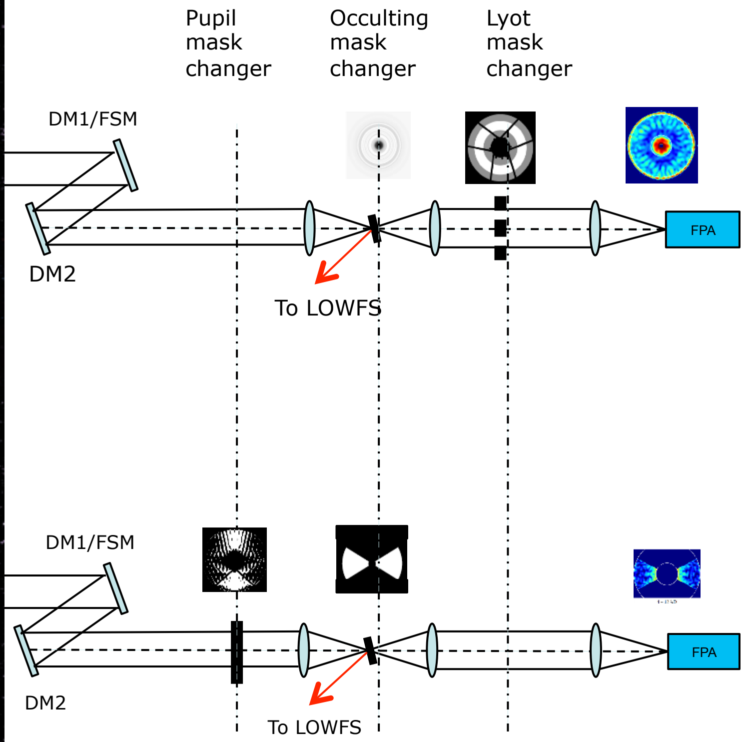


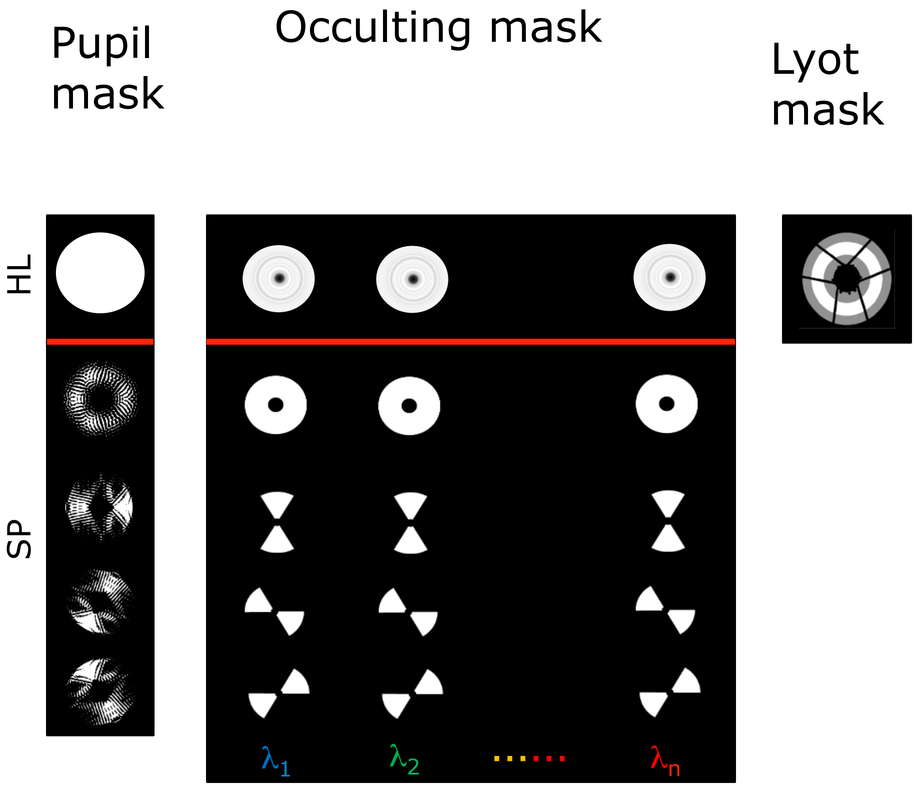
TRL-5 @ start of Phase A (10/2016)

TRL-6 @ PDR (10/2018)

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

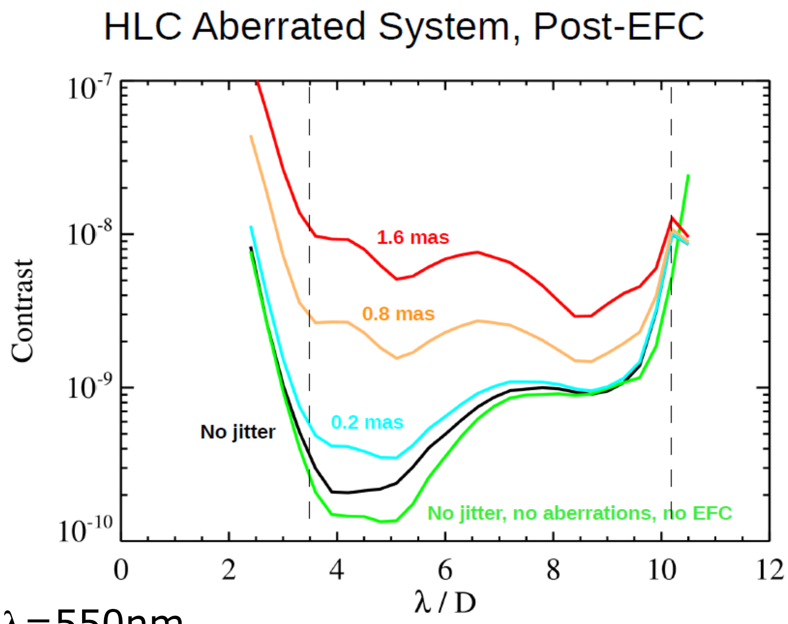
- SP and HL masks share very similar optical layouts
- Small increase in over all complexity compared with single mask implementation



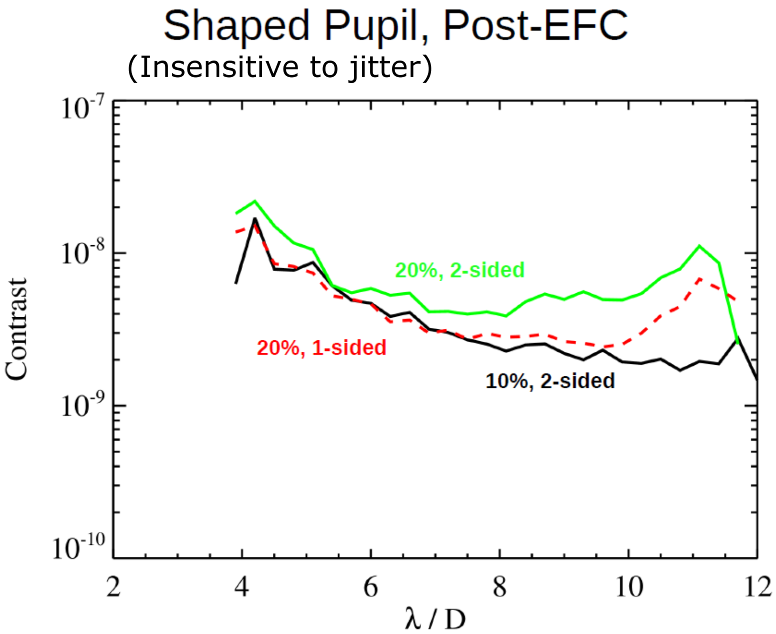


Contrast simulations with AFTA pupil, aberrations and expected range of telescope pointing jitter

- 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



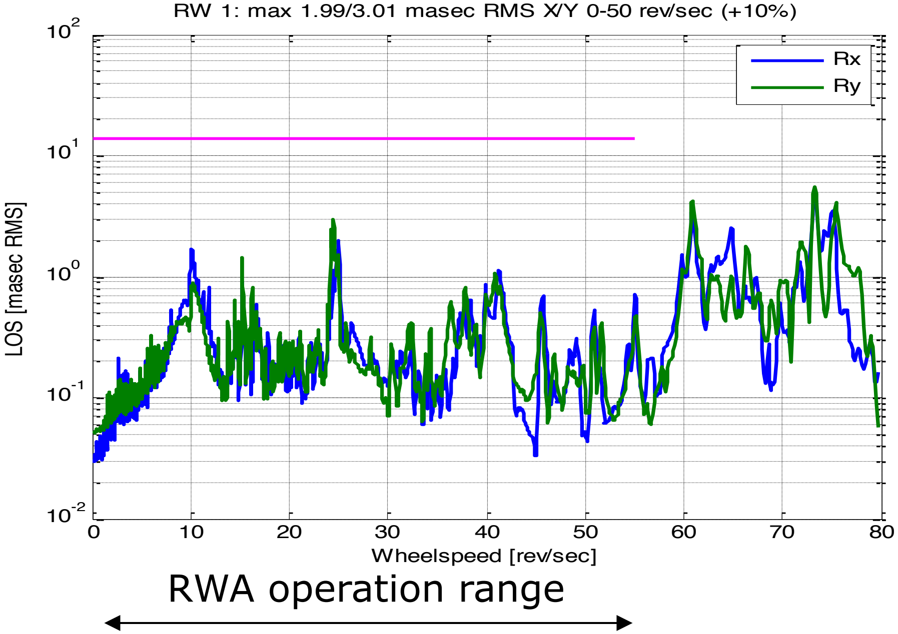
λ=550nm



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



RWA operation range

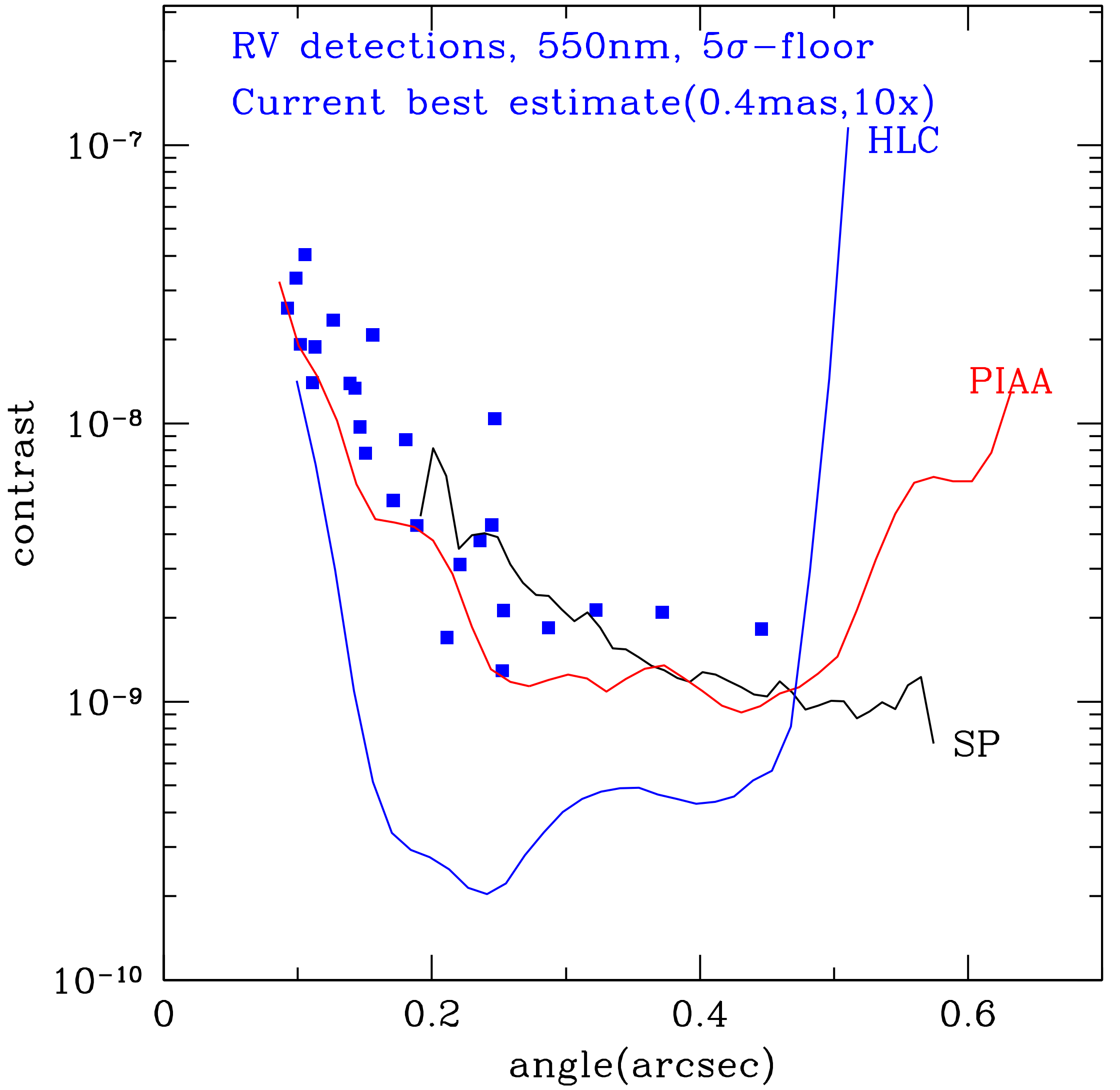
"Model uncertainty factor (MUF)" consistent with flight projects (MUF=2.5 for f<20Hz, and MUF=6 for f>40Hz, linear in between)

Science modeling (Wes Traub)

- Science yield modeling focusing on ability to study Doppler planets
- Contrast curves generated from John Krist PROPER models
- Model residual speckle noise, photon noise from halo, photon noise from foreground and background zodiacal light, detector noise sources
- Significant uncertainty in removal of speckles through post-processing and PSF subtraction

Contrast vs Angle from Star

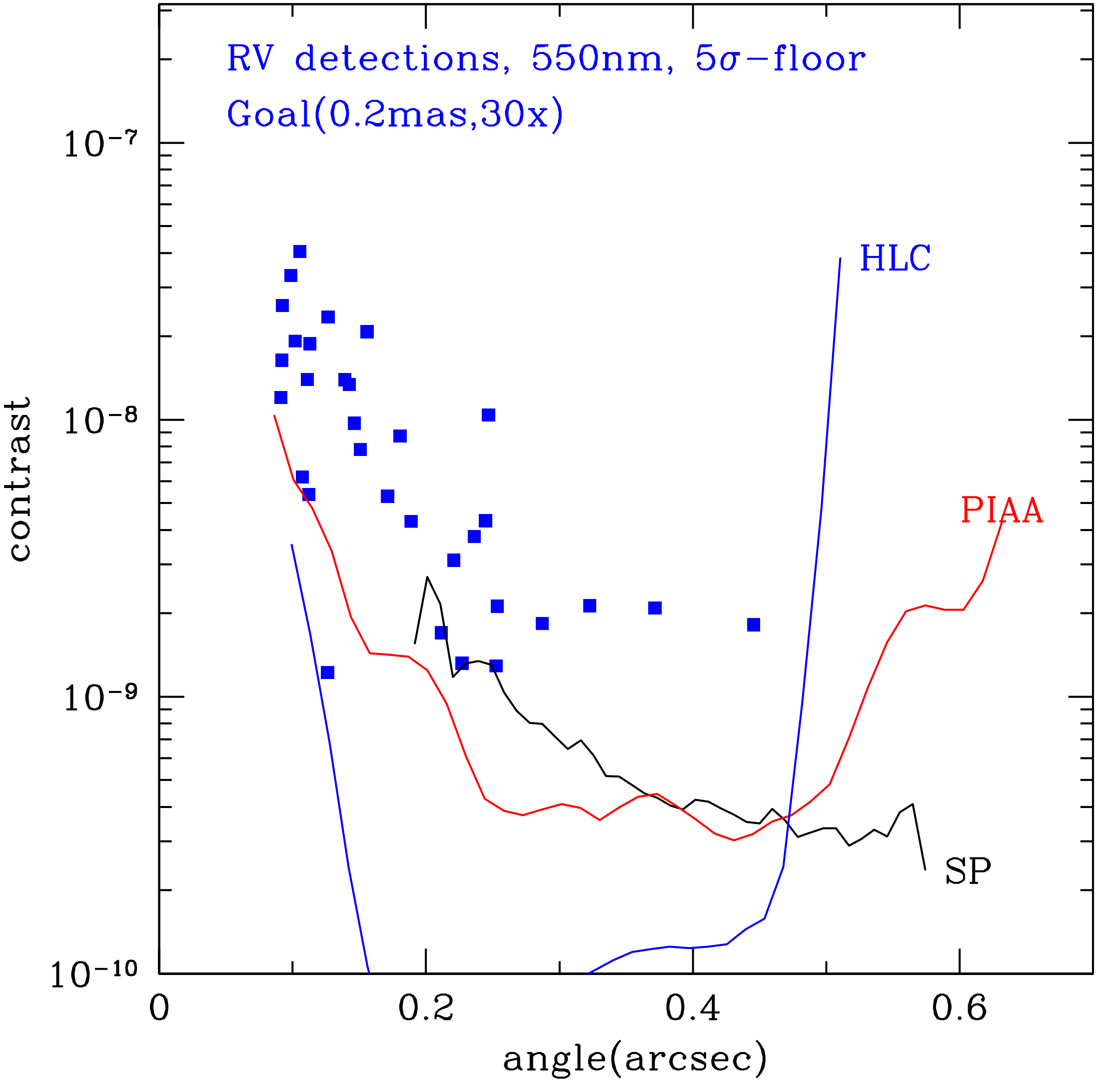
Current best estimate jitter & post-processing factor



Contrast floors here are upper limit for long exposure/very bright star

Contrast vs Angle from Star

Goal jitter & post-processing factor



Contrast floors here are upper limit for long exposure/very bright star

AFTA RV Exoplanet Detection Estimates

- RV exoplanet detections are estimated based on imaging of radial velocity planets from the current RV catalog

Configuration	Design	Inner working angle	# RV planets, 550nm band, 6-month campaign	# spectral bands per target, 6-month campaign
Prime (OMC: Occulting Mask Coron.)	**SP**	0.19	4 7	4.3 4.9
	HL	0.10	18 19	4.3 4.2
Backup	**PIAA**	0.09	23 30	3.2 4.3

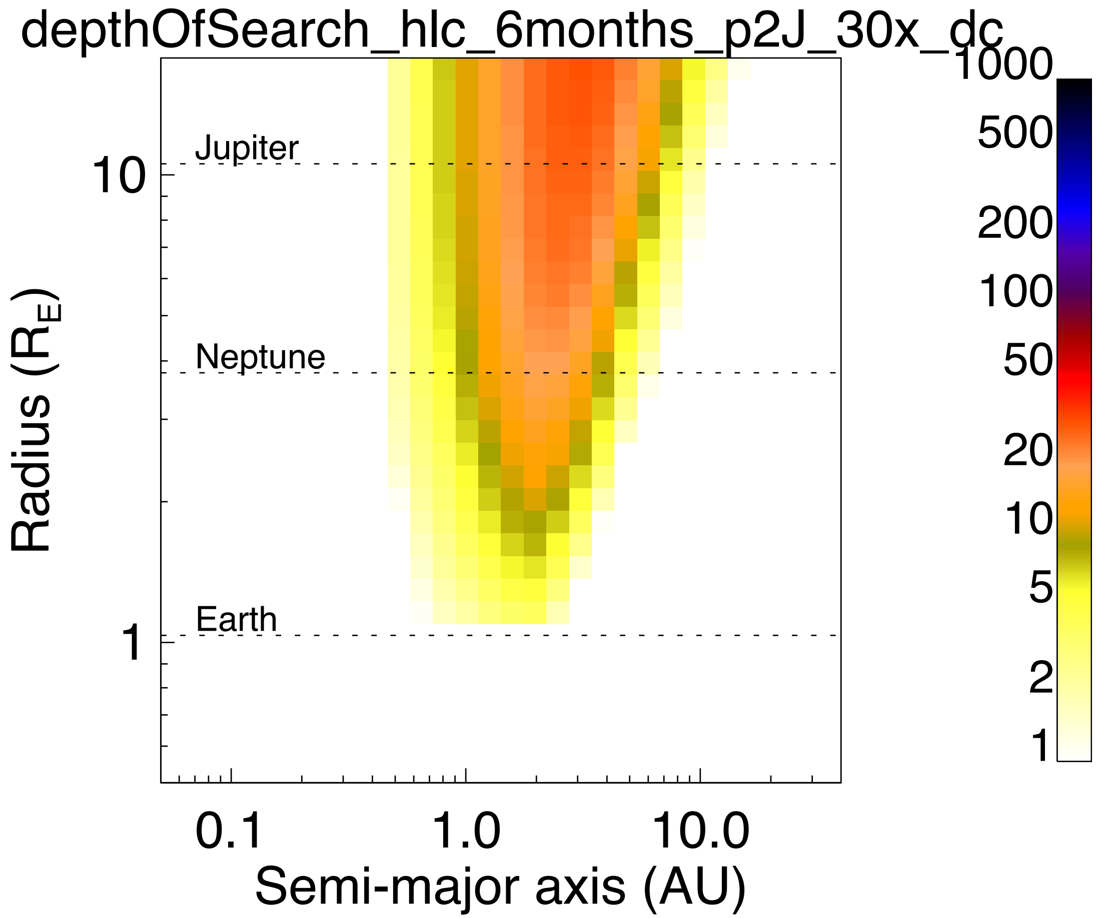
Note 1. Two rows for contrast and # RV images columns are for cases of

- Current Best Estimate: 0.4 mas RMS jitter & 1 mas star, 10x post-processing factor (slide 4)
- Goal: 0.2 mas RMS jitter & 1 mas star, 30x post-processing factor (slide 5)

Note 2. Spectral bands are 10% wide, centered at 450, 550, 650, 800, 950 nm

Other science figures of merit

- Earlier simulations with previous coronagraph generation show 5-12 planets available for 550 nm spectra
  - 800 nm spectra, improved coronagraphs to be modeled



- Blind search models (Savransky & Macintosh) show discovery and photometric characterization of 3-6 planets of <4 RE in a 3 month survey

Future science tasks

- Evaluate spectroscopic capabilities of new designs
  - Requires coronagraph modeling at 800 nm
- Evaluate capabilities for 1-4 RE planets
- Assess Doppler completeness of likely target sample
- Additional integrated modeling of coronagraph
- Assess likely disk imaging science using refined coronagraphic capabilities and integrated simulations
- Evaluate speckle removal requirements and capabilities
- Develop mission scenarios

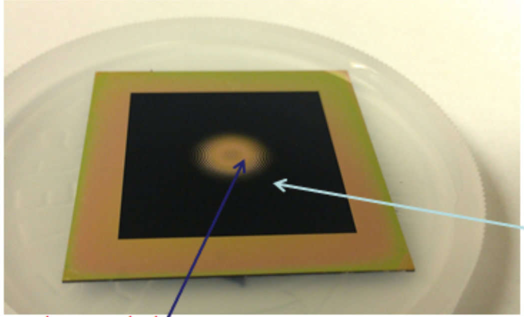
Coronagraph technology development

- Finalize designs for testing
- Manufacture masks and stops Winter/Spring 2014
- Begin HCIT vacuum facility testing Spring/Summer 2014
- Perform static wavefront control tests followed by dynamic tests with jitter through Summer 2016.
- Goal of TRL 5 by October, 2016.

Coronagraph Masks

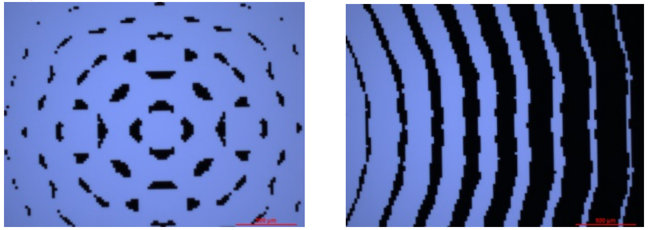
Reflective shaped pupil masks

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



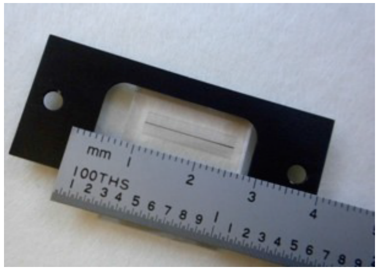
Uniform black achieved with Al + photoresist etch mask

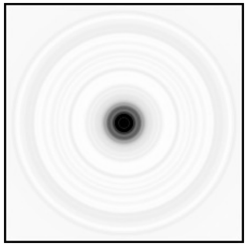
Al covered with photoresist



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





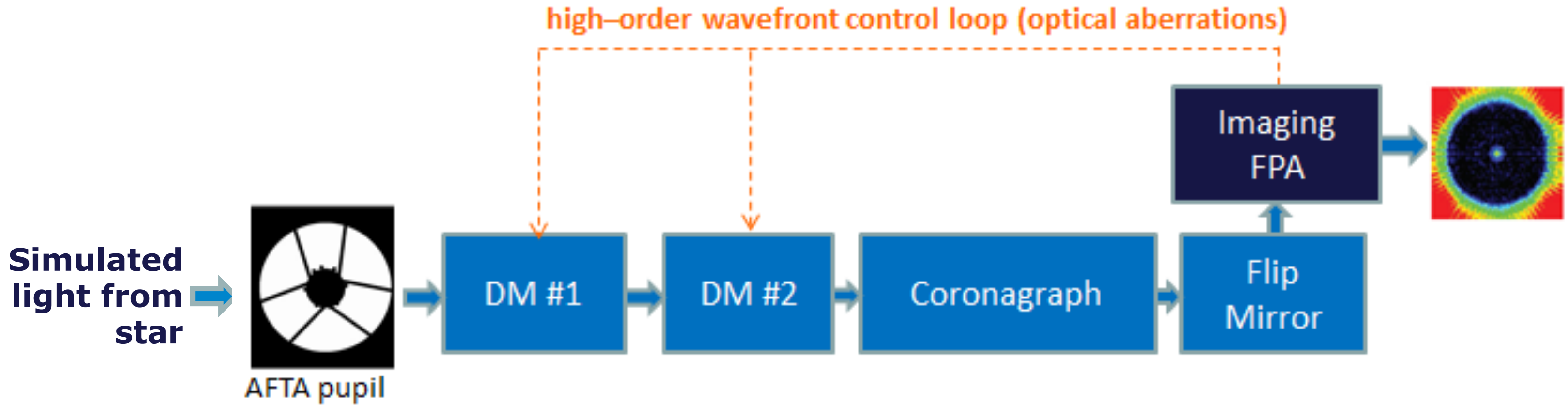
AFTA

Both masks have credible plan for FY14 delivery to HCIT

System-Level Testbed Demonstration Phase 1: Static Wavefront

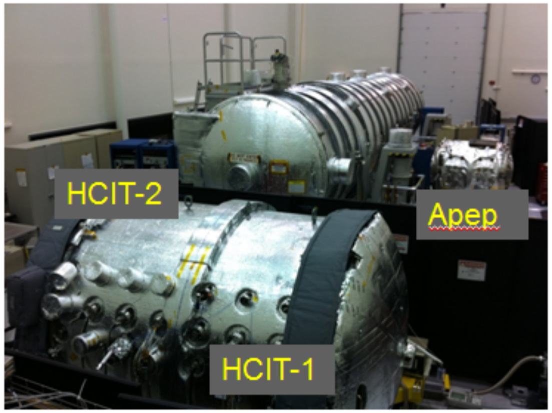
Possible Path to Closing Gap

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



Key Demonstration Objectives

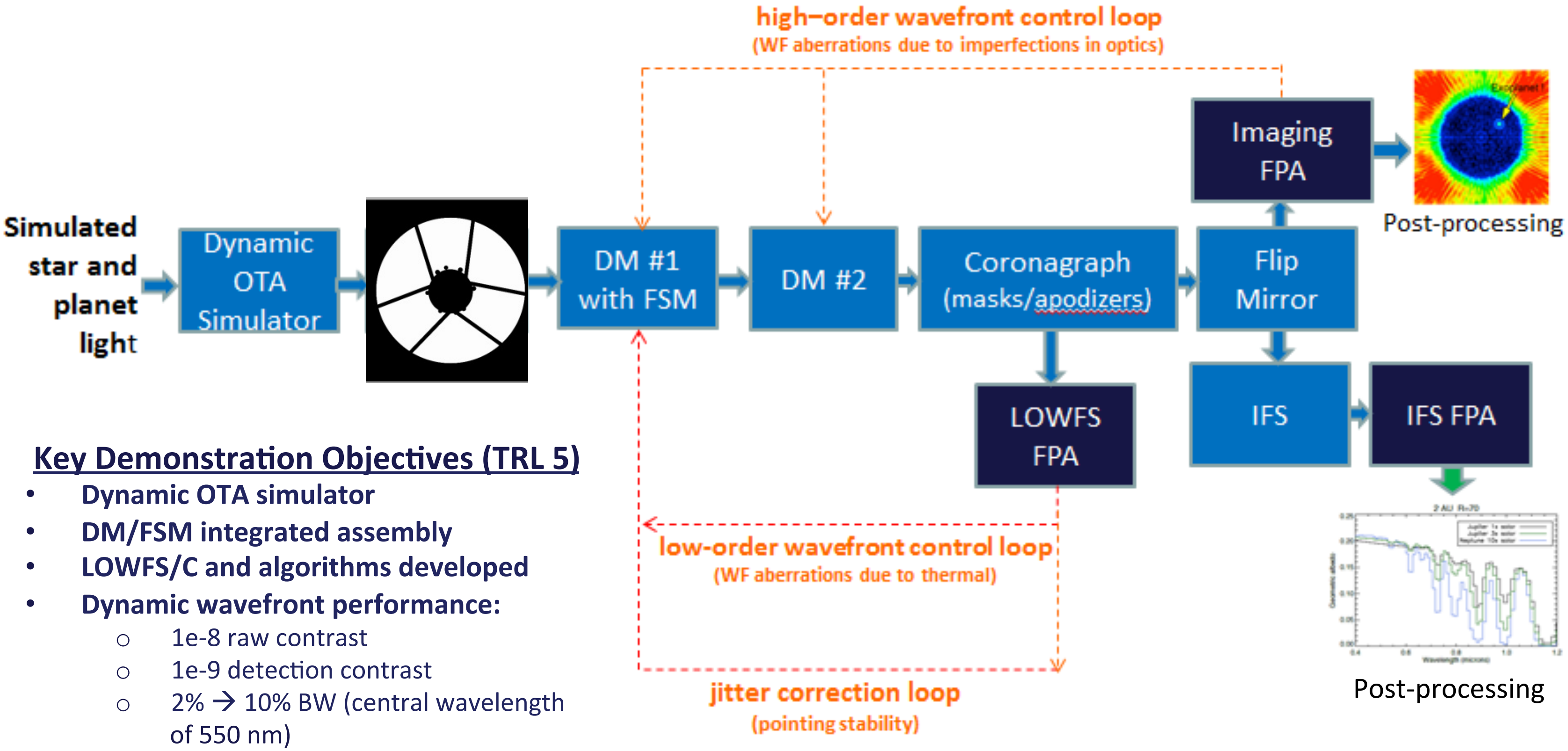
- Coronagraph masks/apodizers for AFTA-WFIRST obscured pupil
- Two-DM configuration
- Wavefront control algorithms developed
- Static wavefront performance:
  - 1e-8 contrast
  - 2% → 10% BW (in 500-600 nm window)



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.



high–order wavefront control loop
(WF aberrations due to imperfections in optics)

Simulated star and planet light

Dynamic OTA Simulator

DM #1 with FSM

DM #2

Coronagraph (masks/apodizers)

Flip Mirror

Imaging FPA

Post-processing

LOWFS FPA

IFS

IFS FPA

low-order wavefront control loop
(WF aberrations due to thermal)

jitter correction loop
(pointing stability)

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**

Conclusions

AFTA-WFIRST with a coronagraph will be the first high-contrast, small inner working angle instrument in space with wavefront correction capability. It is an important first step to a future large mission capable of detecting and characterizing Earth-size rocky planets in the habitable zone of nearby stars.

Acknowledgements

This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

JPL

NASA Goddard

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