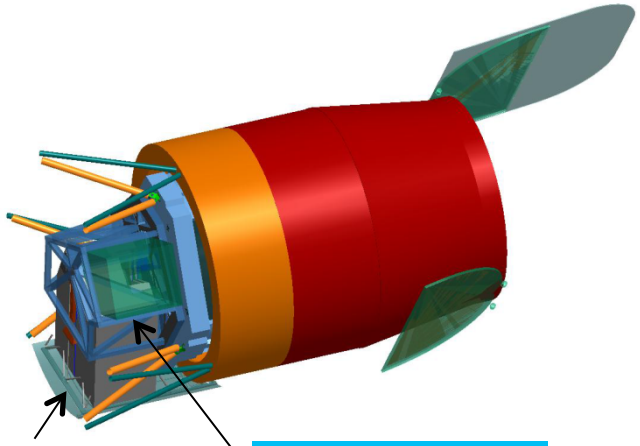
Exoplanet Imaging Science with the WFIRST Coronagraph

N. Jeremy Kasdin

Bruce Macintosh, Olivier Guyon, Tom Green, Wes Traub, Jim Breckinridge
and
The WFIRST/AFTA Coronagraph Engineering team

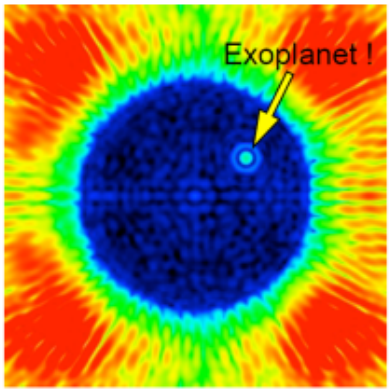
AAS Conference 2015

WFIRST-AFTA Coronagraph Specs

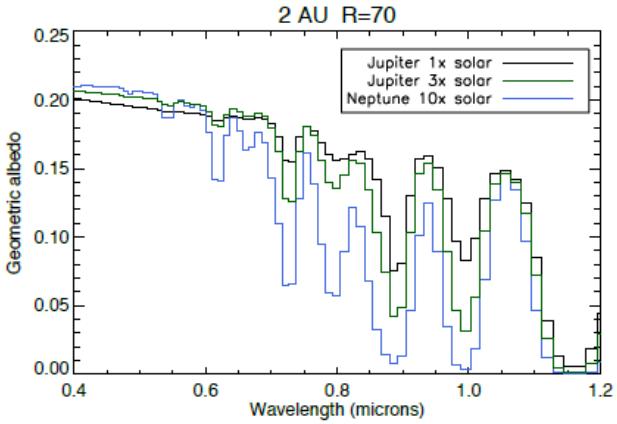


Wide field instrument

Coronagraph Instrument



Exoplanet Direct imaging



Exoplanet Spectroscopy

Bandpass	400-1000 nm	Measured sequentially in five bands, 10% each
Inner Working Angle	0.10 arcsec	At 400 nm, driven by challenging pupil
Outer Working Angle	0.80 arcsec	At 400 nm, driven by 48x48 DM
Detection Limit	Contrast = 10^{-9}	Cold Jupiters, not exo-Earths
Spectral Resolution	70	With IFS, from 600 to 1000 nm

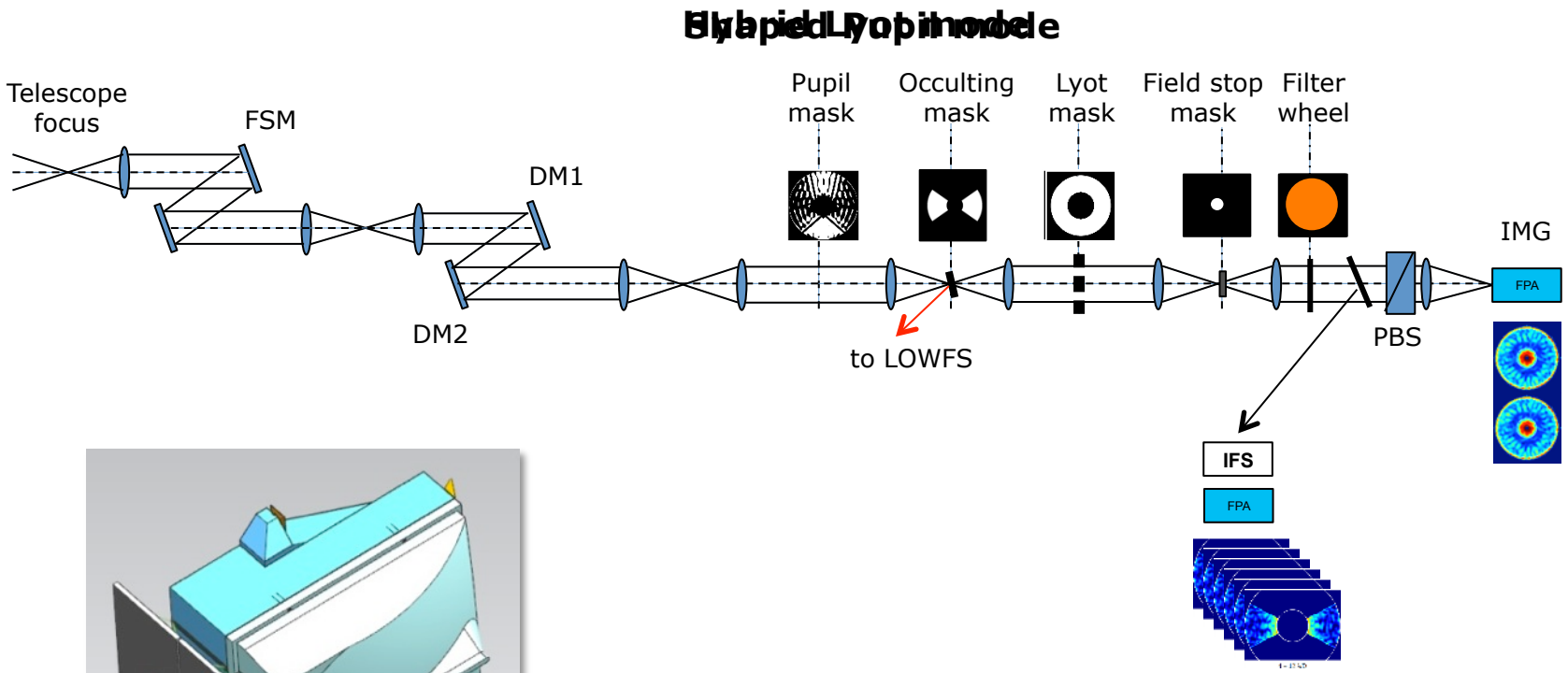
Ref.: Feng Zhao, 13 Nov. 2013, revised

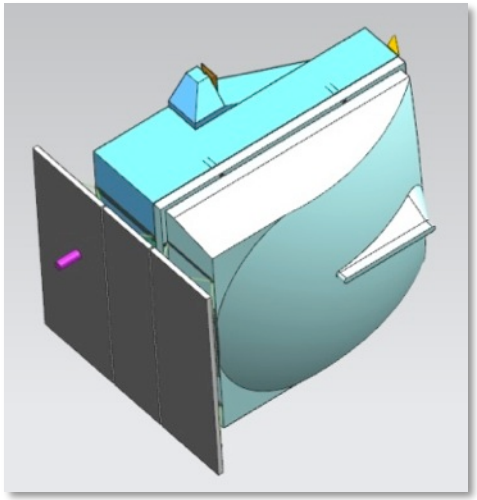
AFTA Coronagraph Instrument will:

- Characterize with spectroscopy 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.
- Image disks around nearby stars to ~ 10 zodi

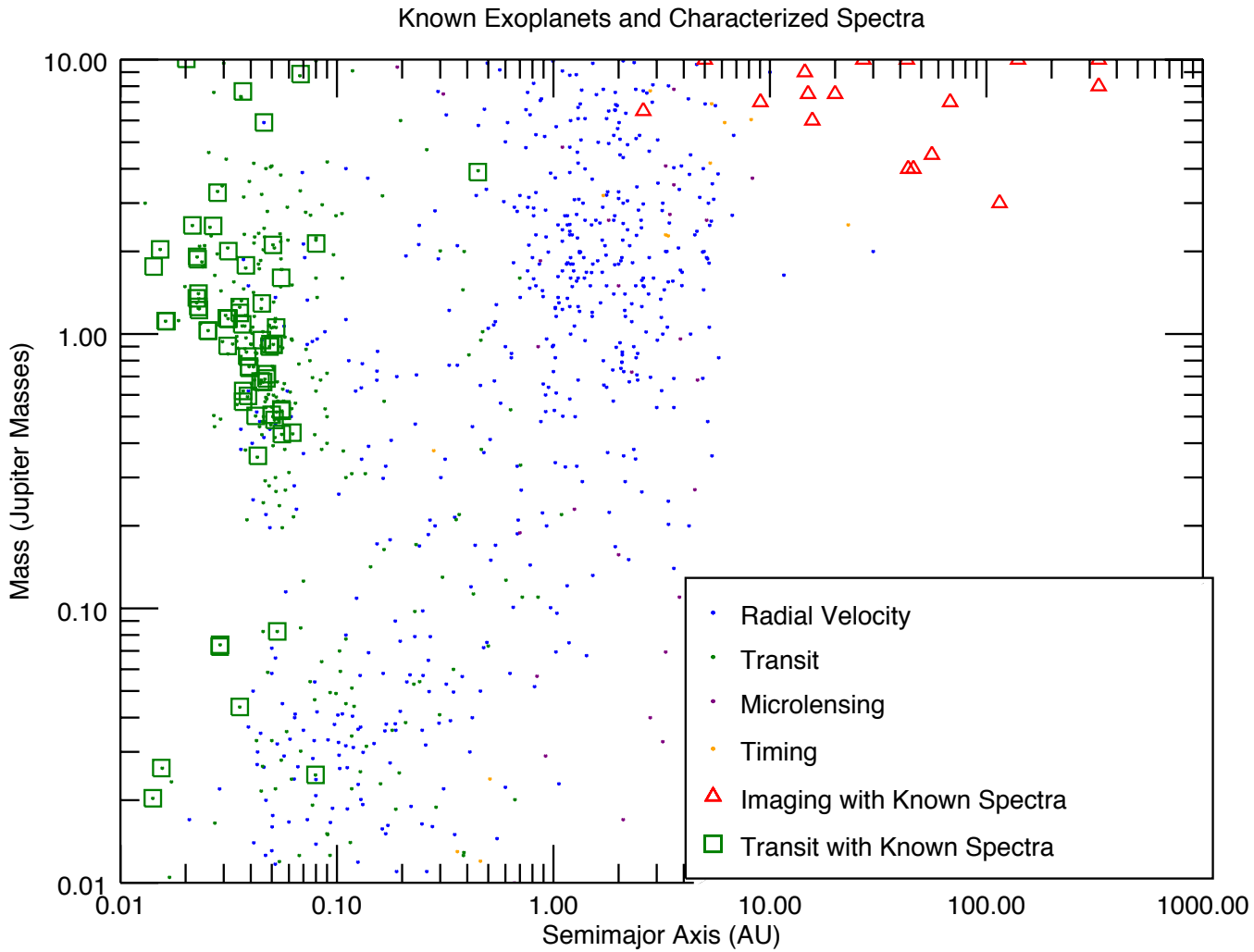
Coronagraph architecture

Baseline coronagraph architecture is flexible combination of hybrid Lyot coronagraph and shaped-pupil apodizer

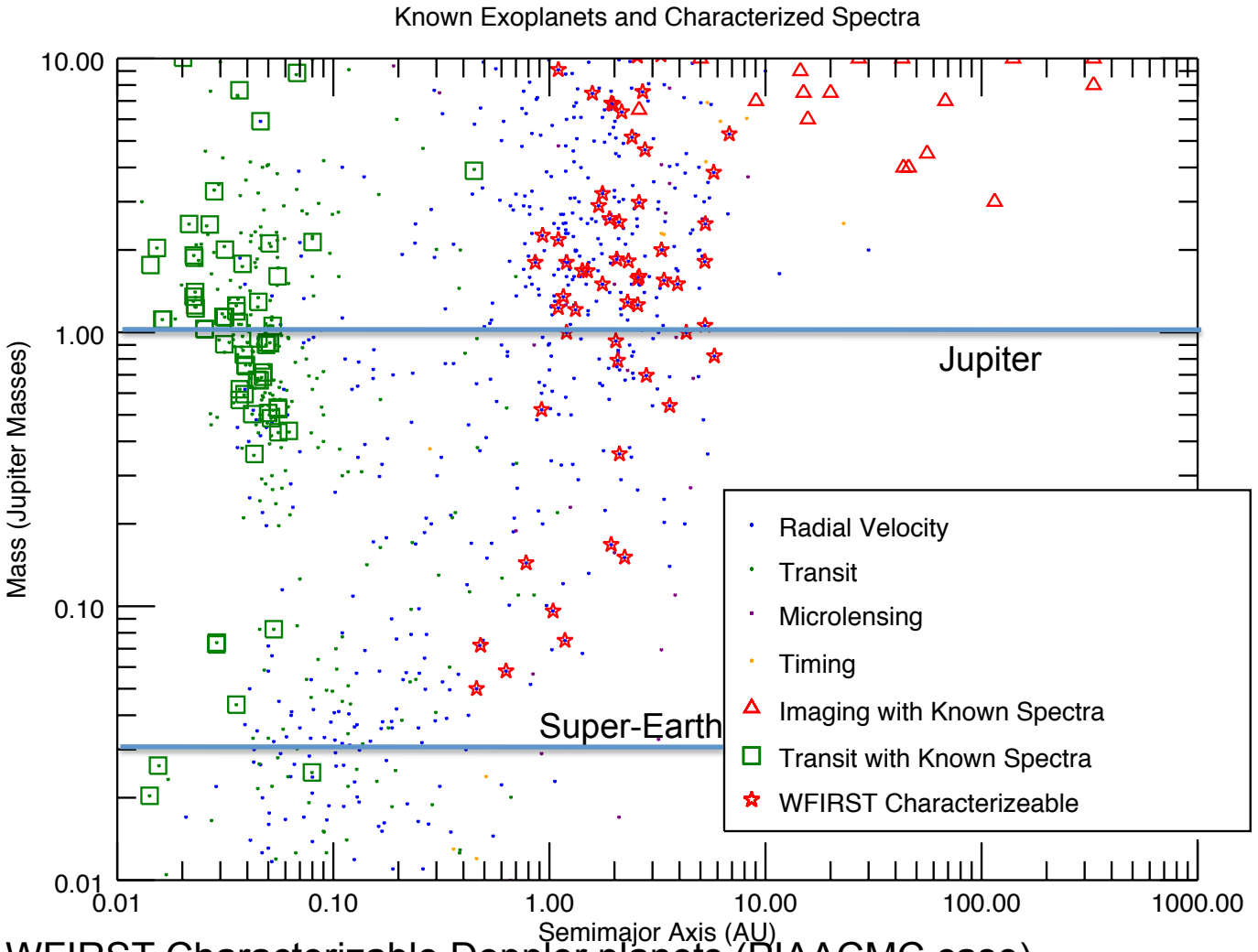




Many planets are known, few have been characterized

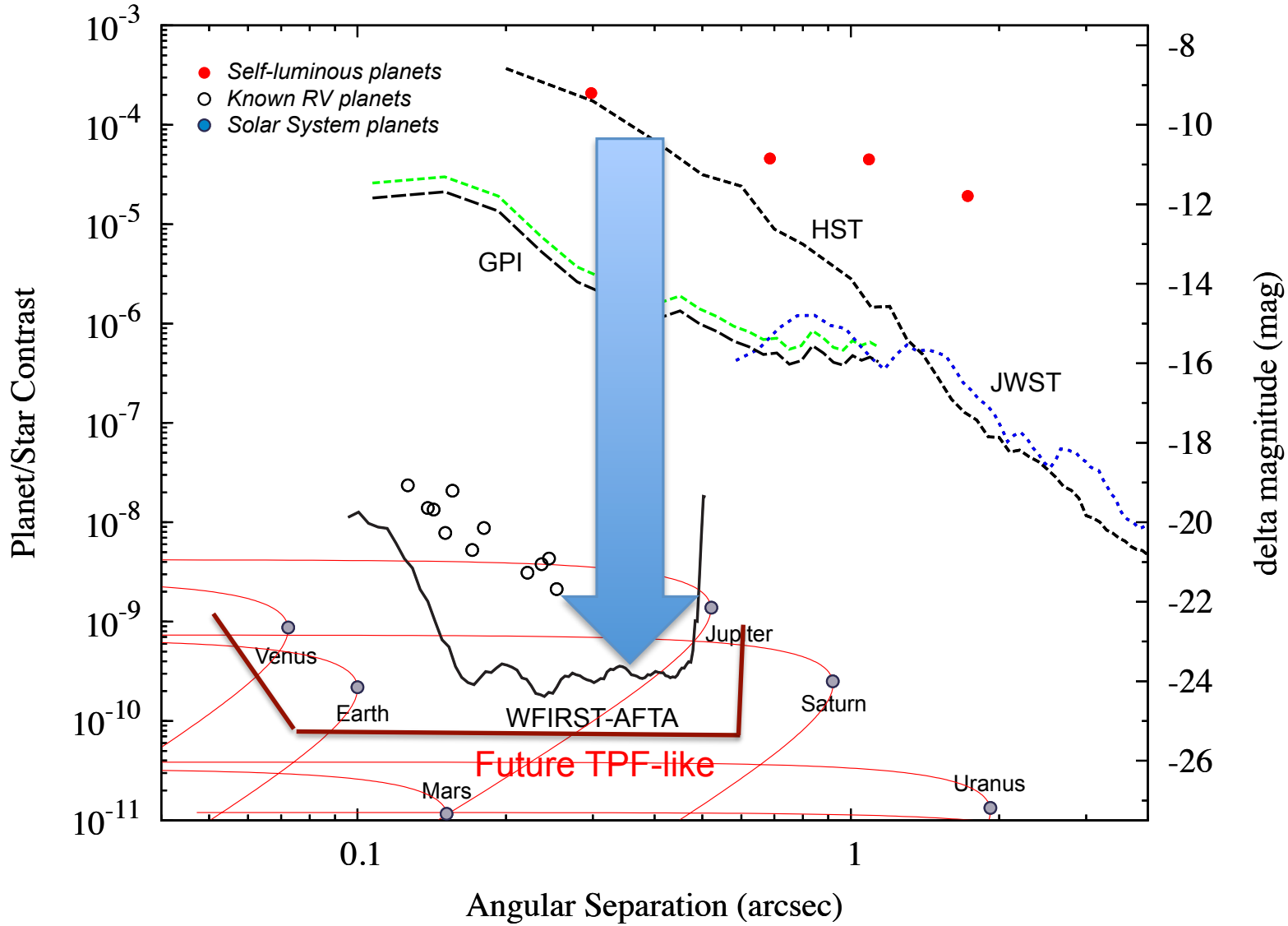


AFTA will characterize planets in completely new regime

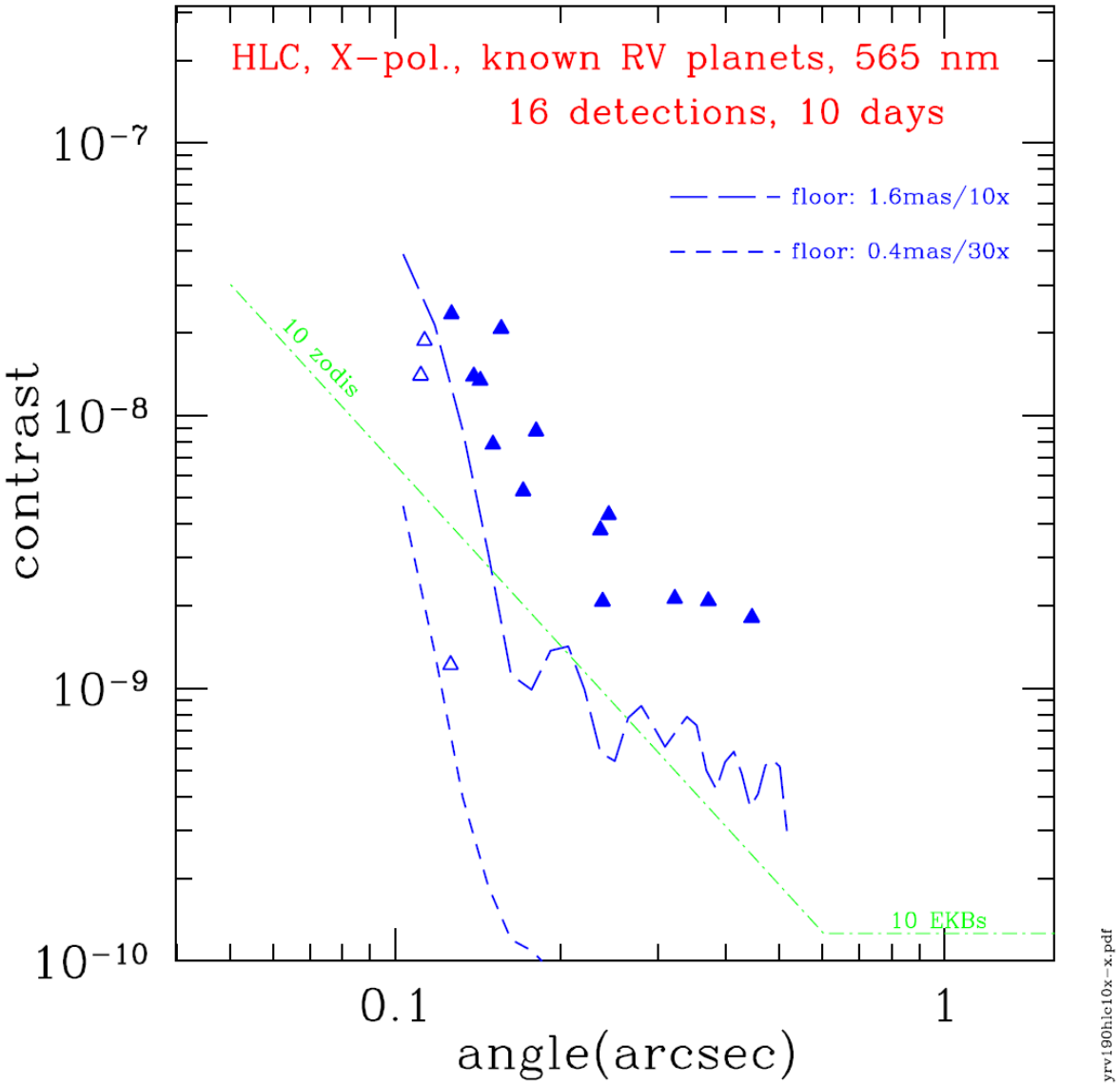


WFIRST Characterizable Doppler planets (PIAACMC case)

AFTA bridges the gap to future Earth-finding missions

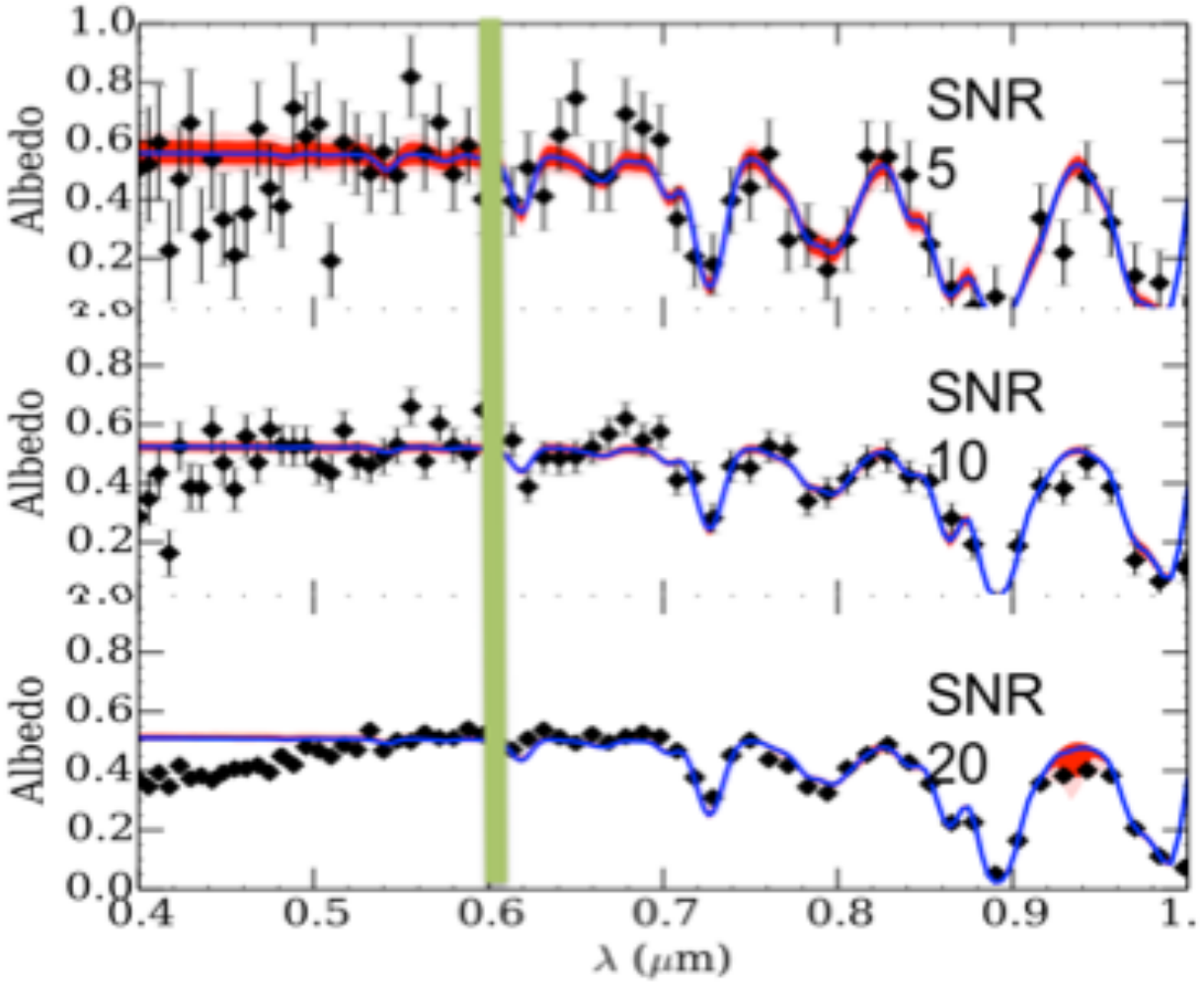


Typical contrast-angle plot

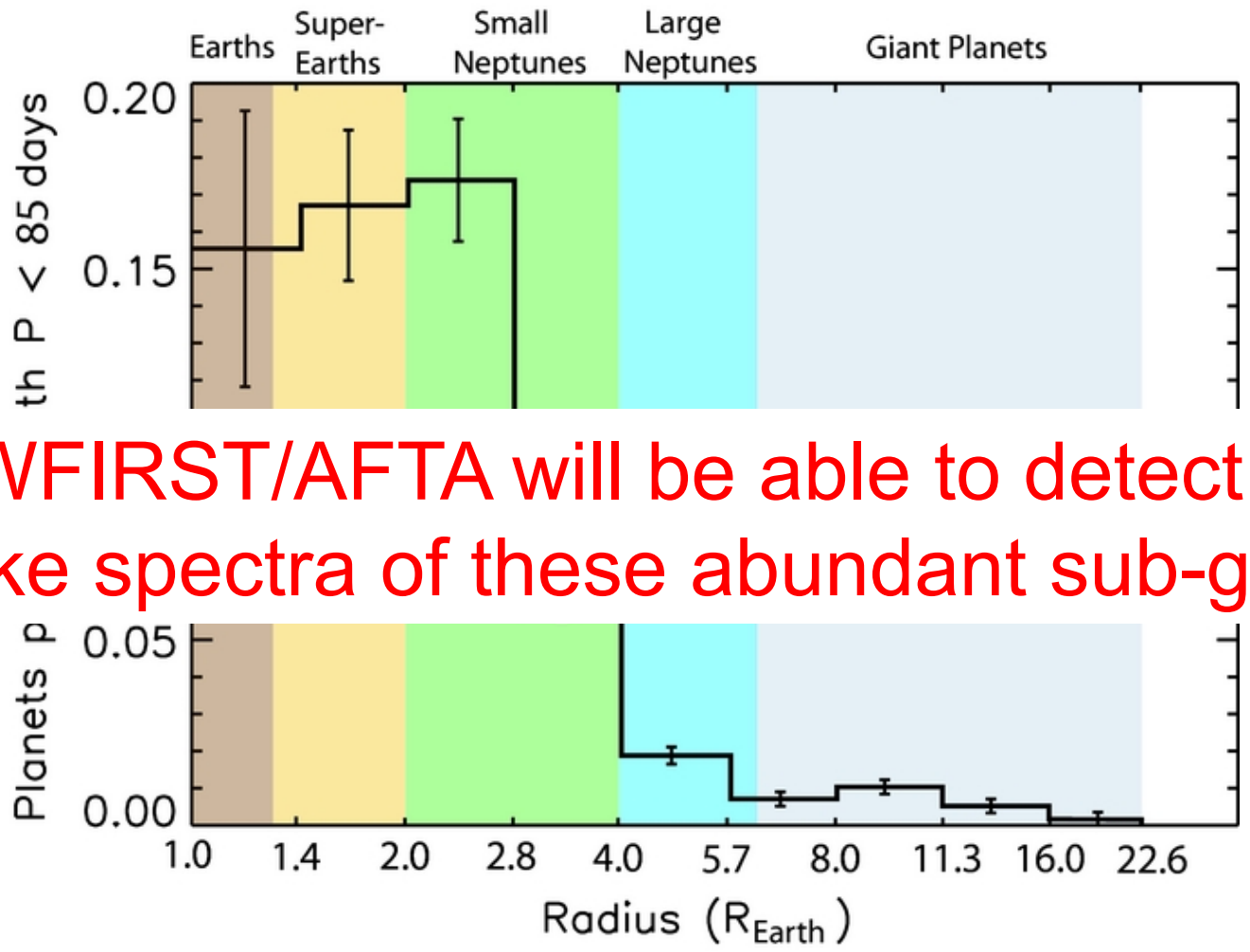


Simulated Spectra

Simulated WFIRST/ AFTA CGI spectra of a Jupiter-like planet at SNR = 5 – 20. Multiple methane absorption features are detectable over 600 – 970 nm, and the blue continuum slope is measurable (Marley et al. 2014)



The most common planets have no equivalent in our solar system

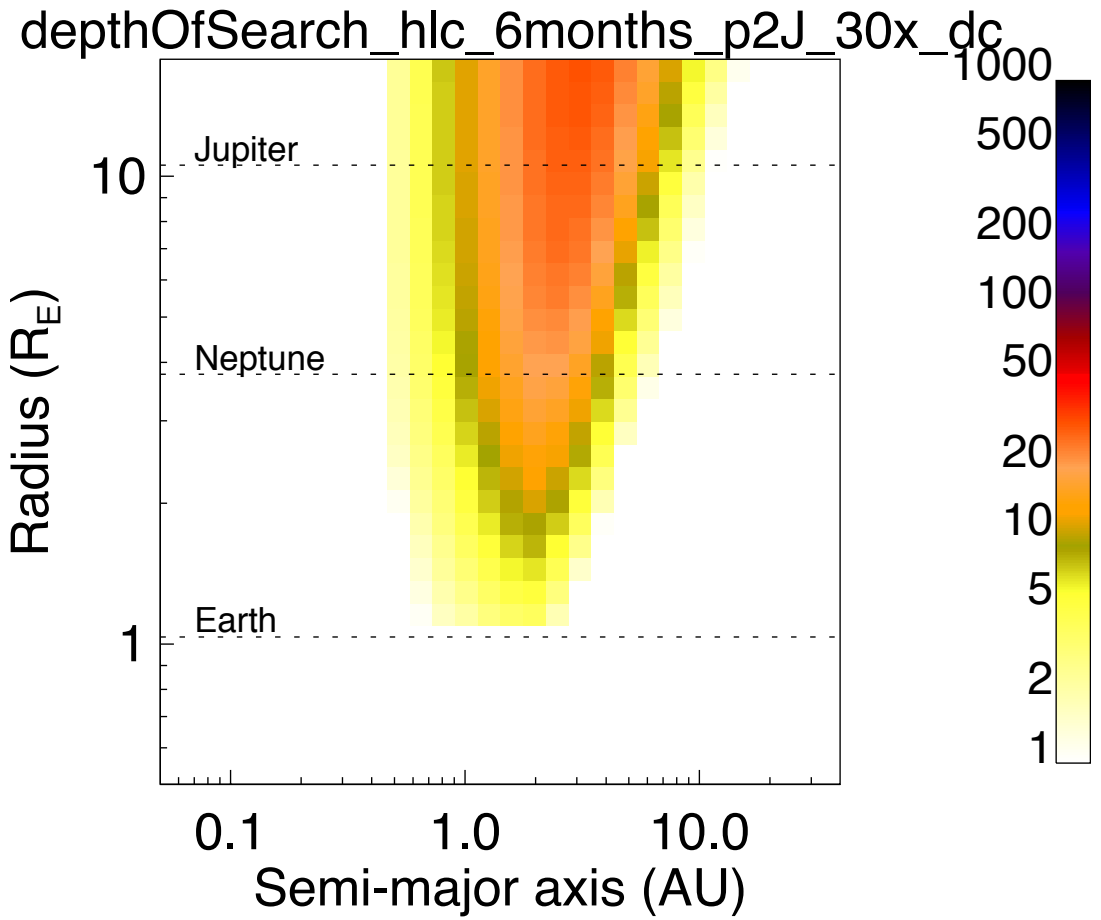


WFIRST/AFTA will be able to detect and take spectra of these abundant sub-giants.

Kepler exoplanet distribution from Fressen et al 2013

AFTA is sensitive into Super-Earth regime

- Blind search models show that surveys discovers 3-6 planets of <4 RE
- Blind search discovery rate enhanced by Doppler pre-survey



Summed completeness for 3-month AFTA ≈100 star survey

WFIRST/AFTA Coronagraph Key Milestones

MS #	Milestone	Date
1	First-generation reflective Shaped Pupil apodizing mask has been fabricated with black silicon specular reflectivity of less than 10^{-4} and 20 µm pixel size.	7/21/14
2	Shaped Pupil Coronagraph in the High Contrast Imaging Testbed demonstrates 10^{-8} raw contrast with narrowband light at 550 nm in a static environment.	9/30/14
3	First-generation PIAACMC focal plane phase mask with at least 12 concentric rings has been fabricated and characterized; results are consistent with model predictions of 10^{-8} raw contrast with 10% broadband light centered at 550 nm.	12/15/14
4	Hybrid Lyot Coronagraph in the High Contrast Imaging Testbed demonstrates 10^{-8} raw contrast with narrowband light at 550 nm in a static environment.	2/28/15
5	Occulting Mask Coronagraph in the High Contrast Imaging Testbed demonstrates 10^{-8} raw contrast with 10% broadband light centered at 550 nm in a static environment.	9/15/15
6	Low Order Wavefront Sensing and Control subsystem provides pointing jitter sensing better than 0.4 mas and meets pointing and low order wavefront drift control requirements.	9/30/15
7	Spectrograph detector and read-out electronics are demonstrated to have dark current less than 0.001 e/pix/s and read noise less than 1 e/pix/frame.	8/25/16
8	PIAACMC coronagraph in the High Contrast Imaging Testbed demonstrates 10^{-8} raw contrast with 10% broadband light centered at 550 nm in a static environment; contrast sensitivity to pointing and focus is characterized.	9/30/16
9	Occulting Mask Coronagraph in the High Contrast Imaging Testbed demonstrates 10^{-8} raw contrast with 10% broadband light centered at 550 nm in a simulated dynamic environment.	9/30/16

Coronagraph Summary

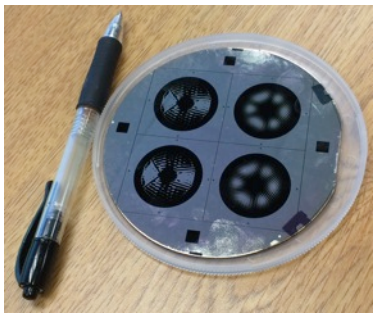
- AFTA coronagraph addresses key NWNH and post-NWNH science goals
  - As Kepler and microlensing complete exoplanet census, we move into the era of characterization
- AFTA coronagraph brings wavefront-controlled coronagraphy to flight levels on the path to future Earth-finding missions
  - Not just hardware, but algorithms and science
- Well-developed technology program to achieve appropriate TRL by Phase A
- System design is advanced and detailed
- Rigorous simulation program shows coronagraph performs well with the real telescope and will impose no new requirements

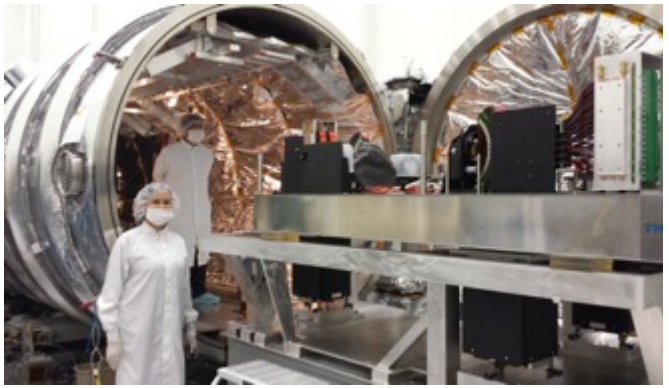
Backup Slides

Coronagraph Technology Development Highlights

Reflective shaped pupil mask

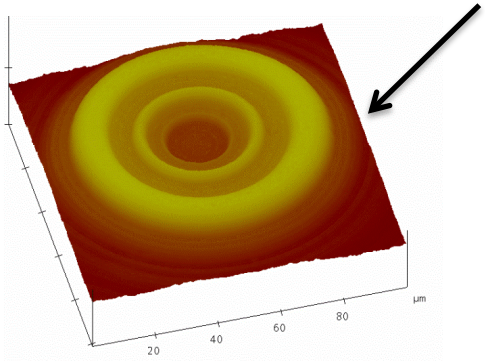
- Black Si on Al mirror coating demonstrated at JPL/MDL and Caltech/KNI
- High contrast demonstrated at HCIT



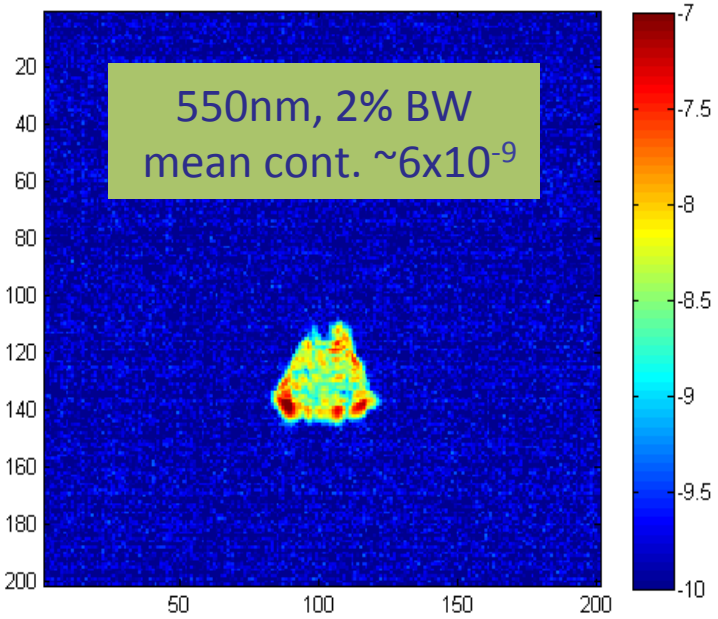


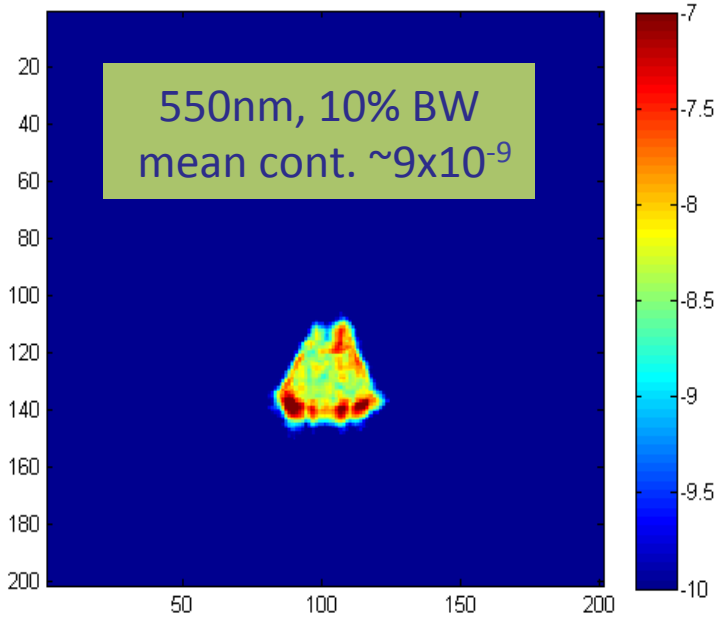
Transmissive hybrid Lyot mask

- Circular mask fabricated and measured
- Testbed commissioned on 8/15/2014



Shaped Pupil Coronagraph Testbed Demonstration





- Narrowband results and early broadband results were submitted to TAC on 9/17/2014
- Milestone 2 approved during review with TAC on 10/8/2014
- Early broadband result meets Milestone 5 success criterion (for shaped pupil)
- **Retired our biggest risk, proving that high contrast is achievable with AFTA telescope pupil**

Albedo Spectra

Giant planet albedo spectra for homogenous model atmospheres at T=200K as a function of atmospheric metallicity. These models are cloud-free. From Burrows (2014).