The WFIRST Coronagraphic Instrument (CGI)

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WFIRST Pasadena Conference
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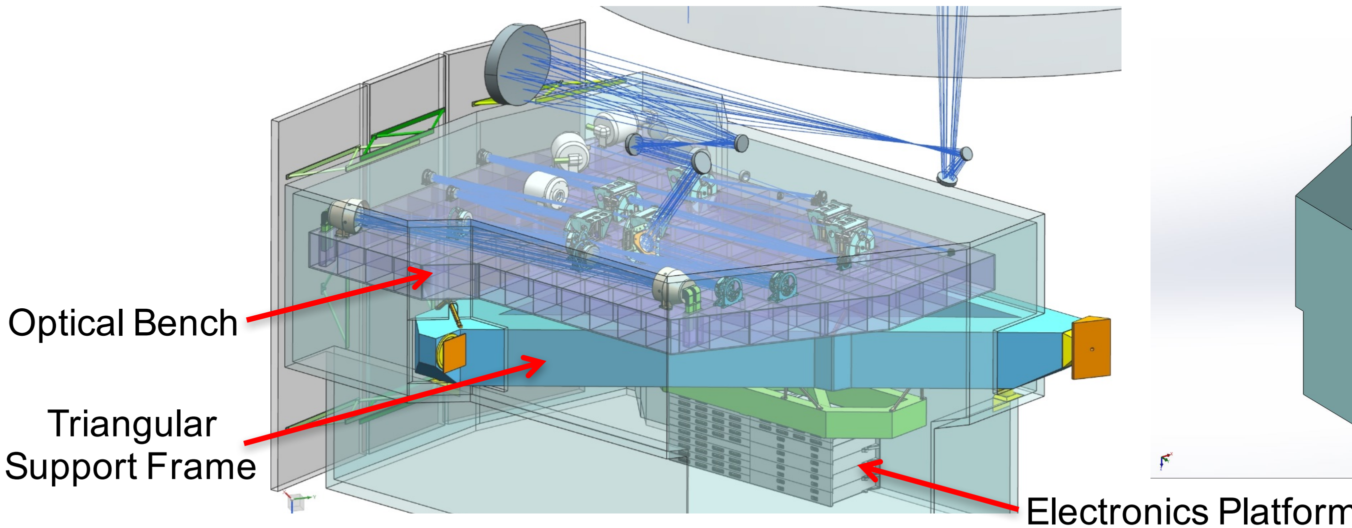
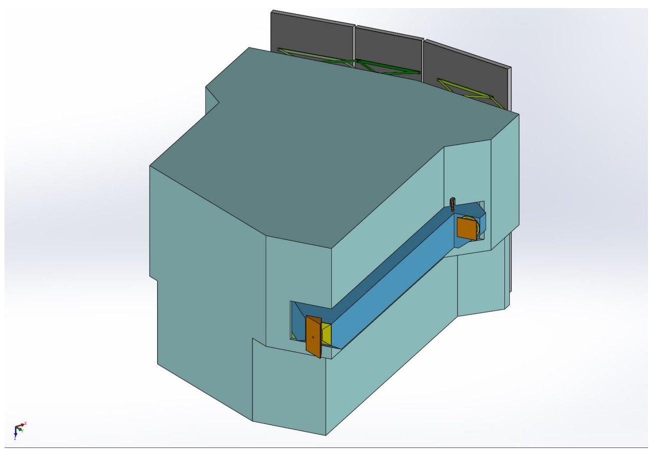
The Coronagraph Instrument





Imaging Camera

5 arcsec imaging FOV from 430 to 970 nm

4 filters for color photometry

Contrast better than 10^{-8} (raw)

Dark hole from 0.2 to 1 arcsec

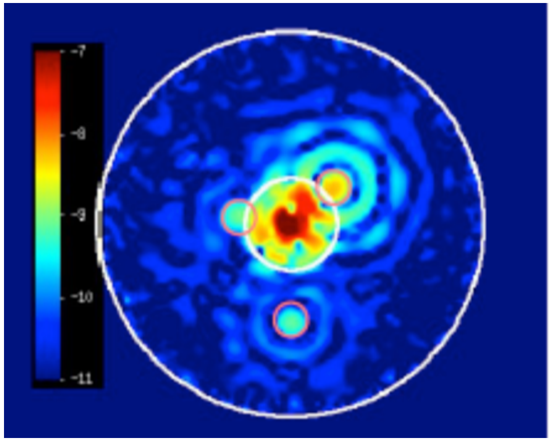
Dual polarizations

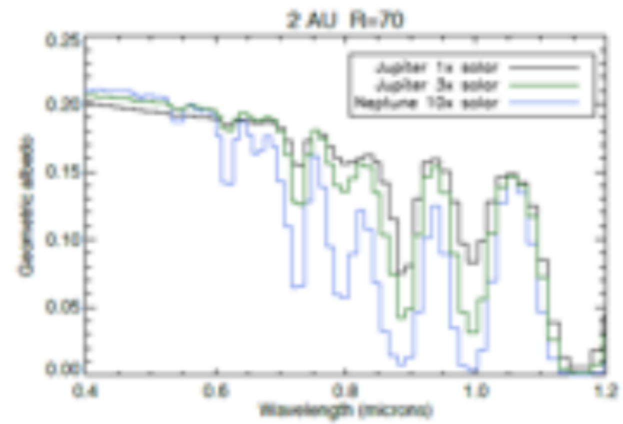
Integral Field Spectrograph

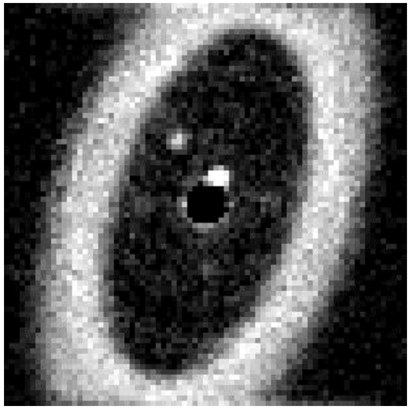
R70 Spectra in IFS 600 to 970 nm

0.5 arcsec FOV

High-Contrast Science with WFIRST







- Characterize Roughly a Dozen Known RV Planets
- Photometrically Discover New Planets Down to Mini-Neptunes
- Image Debris Disks and Exo-Zodi in Two Polarizations
- GO High-Contrast and Narrow Field Science
- Demonstrate technology for future Earth imager

Exoplanet Imaging Survey

- Encompasses 1 year of mission time
- Image previously discovered radial velocity planets in WFIRST CGI range
- Perform searches for new planets in range from Super-Earths to Jupiters
- Search for debris disks and characterize down to a few zodi levels
- Opportunities for general observer science using imager or IFS with our without the coronagraph

Current WFIRST Preparatory Science project and newly selected SITs will develop detailed DRM simulations to optimize distribution of mission time and observations.

The census of extrasolar planets

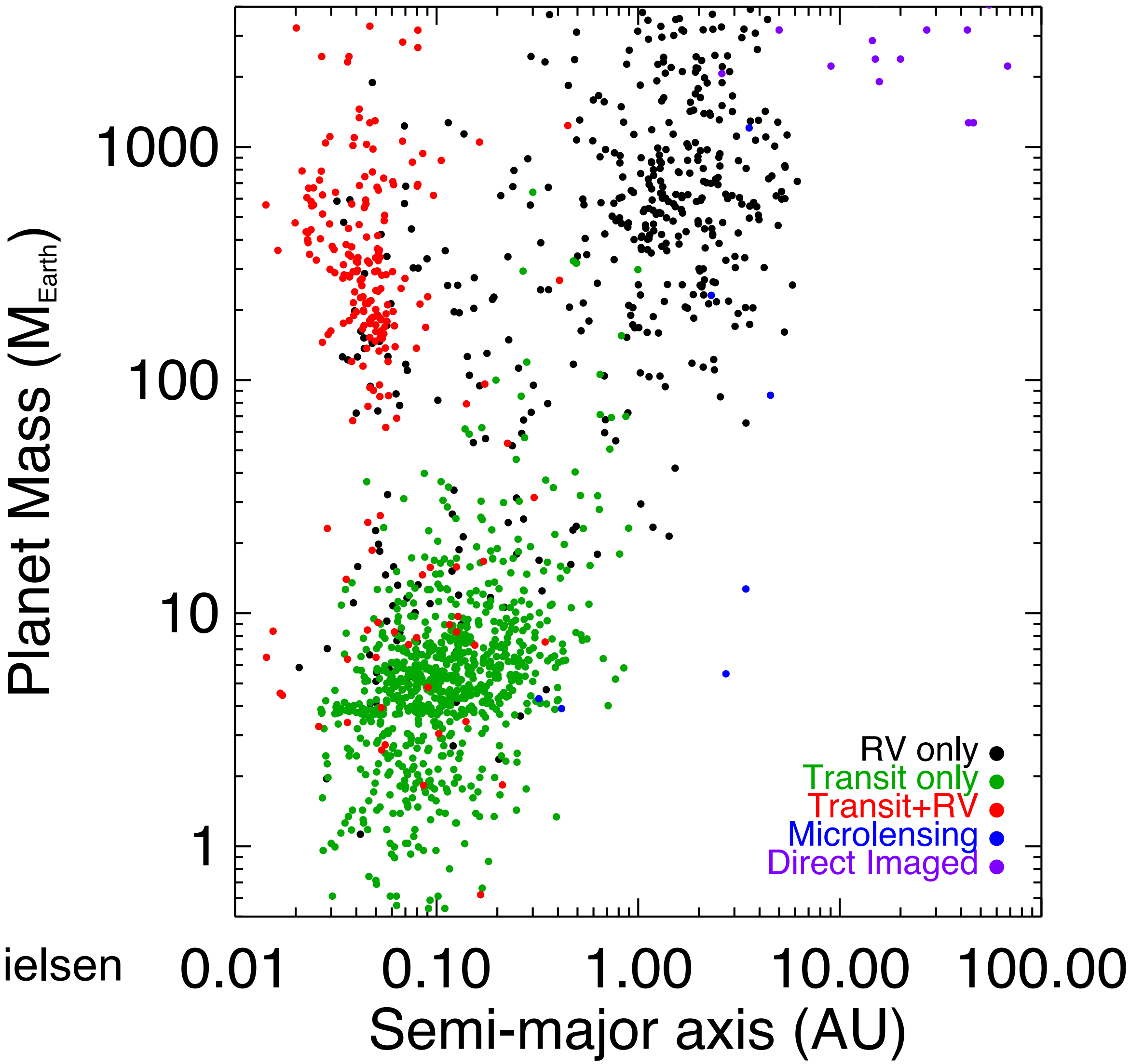
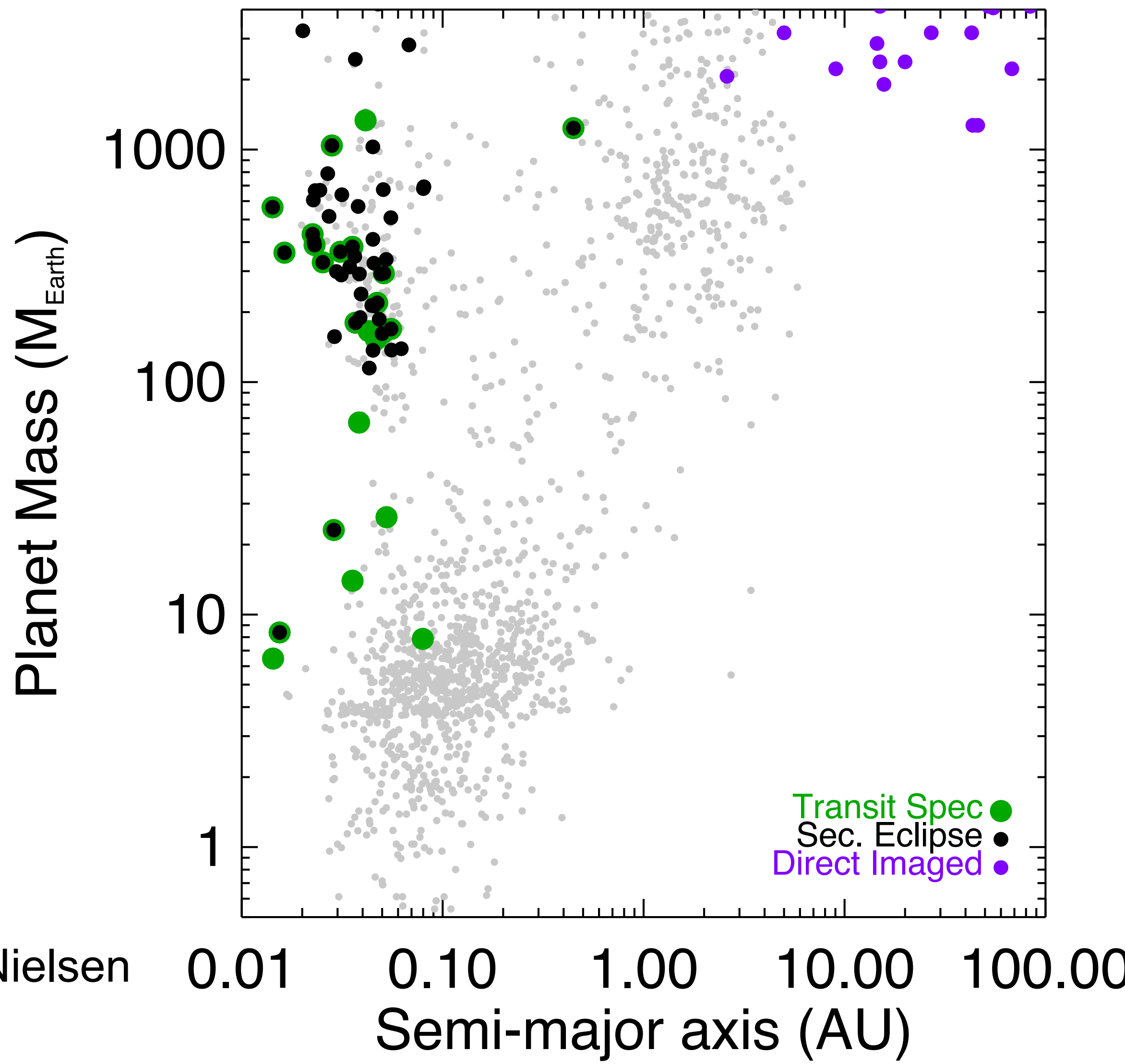


Figure by Eric Nielsen

Characterized extrasolar planets



“long-form”
census

Figure by Eric Nielsen

WFIRST

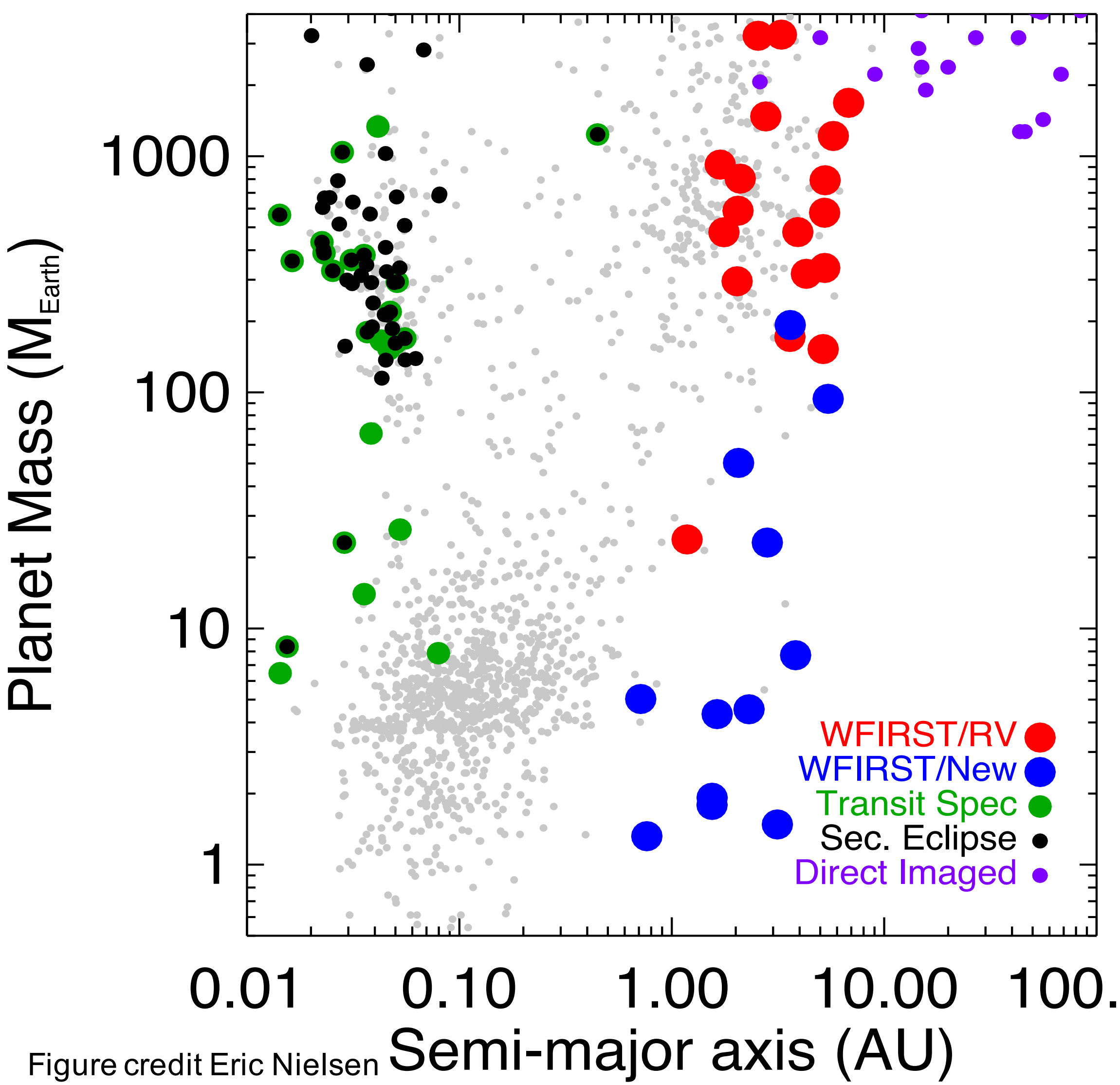
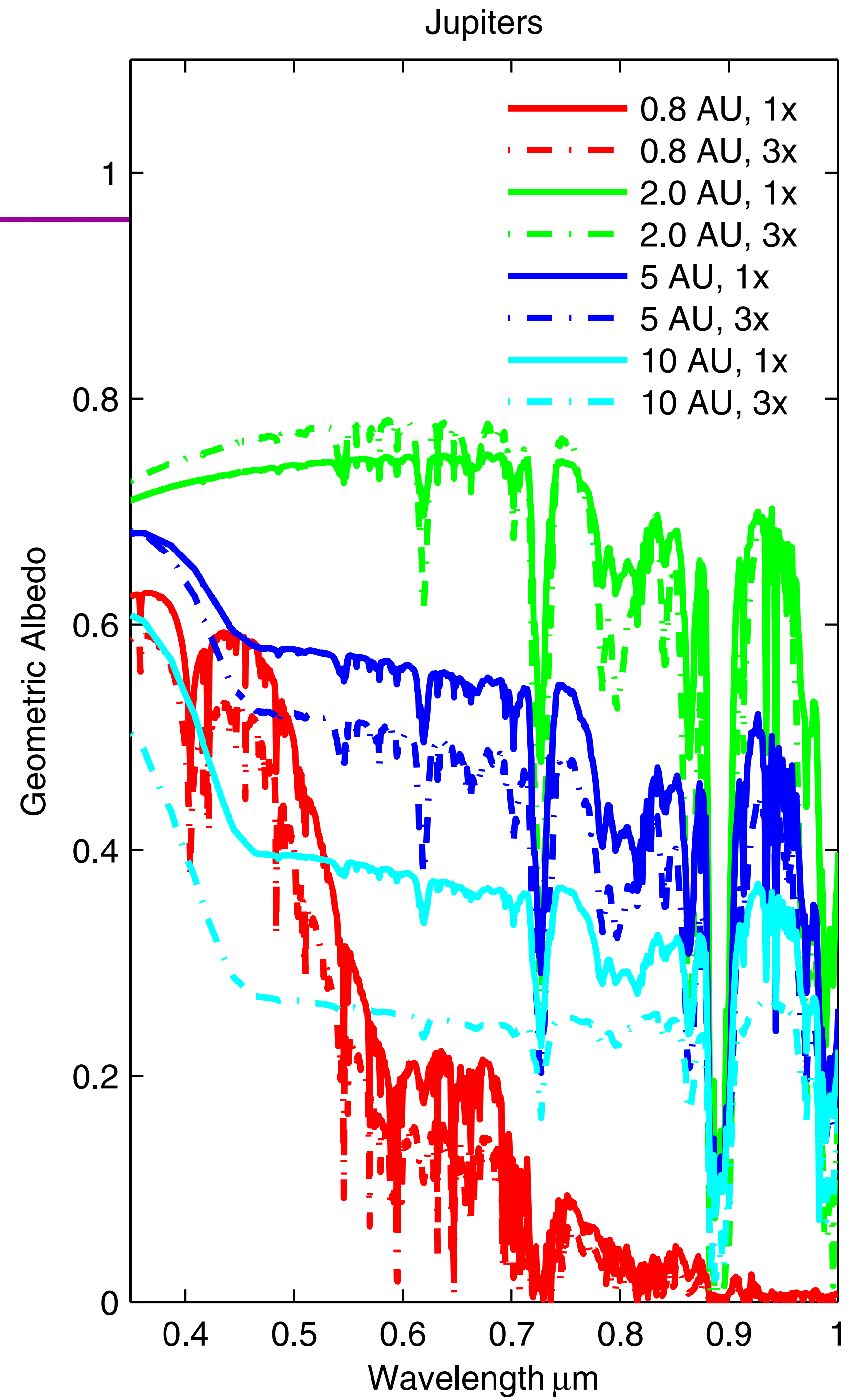


Figure credit Eric Nielsen

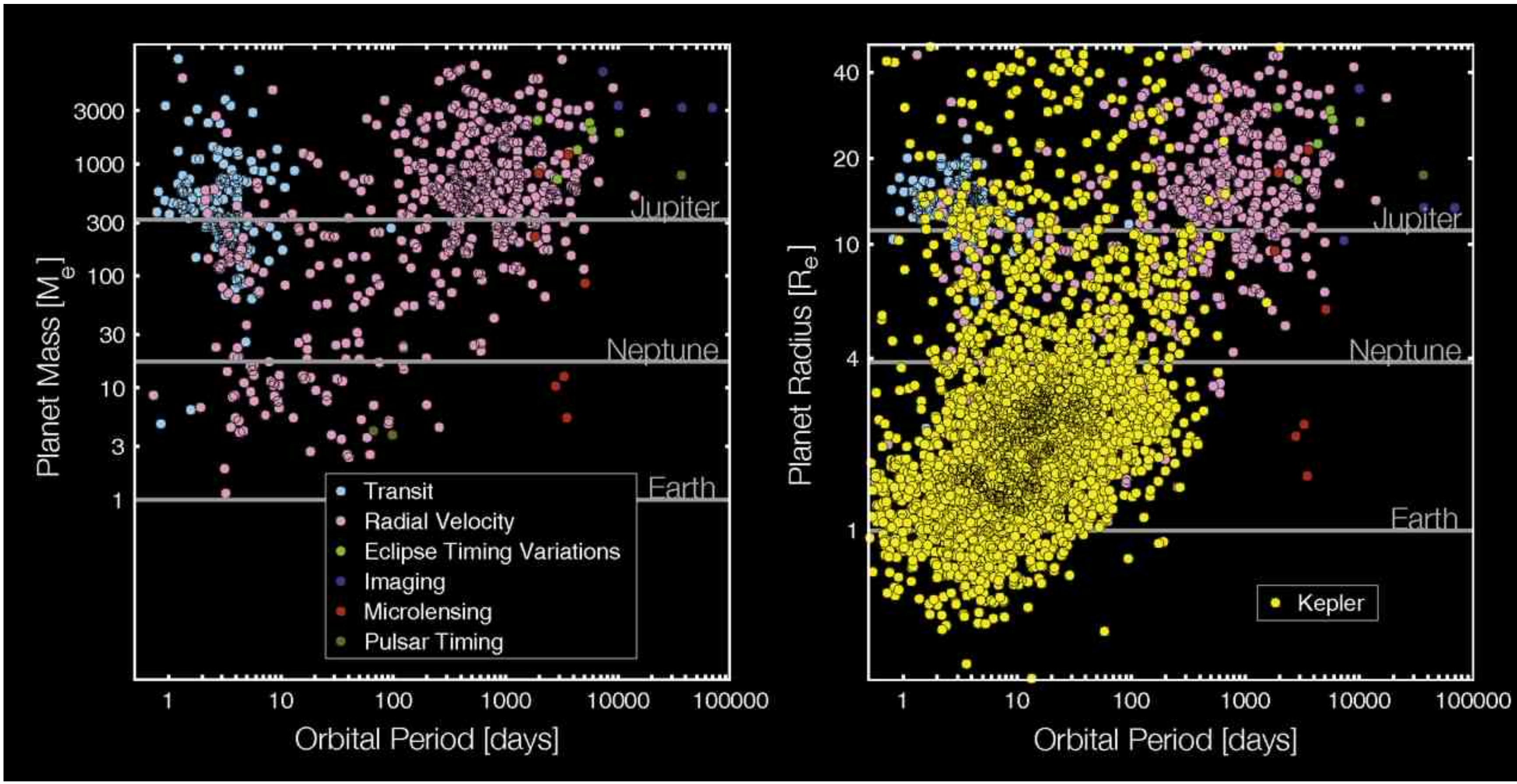
Planet models

- Full-physics planet models to generate input spectra
- Planets properties will be extremely diverse and different than our solar system
- Parameters including metallicity, clouds, chemistry
- Previous work produces many models; we will organize and curate



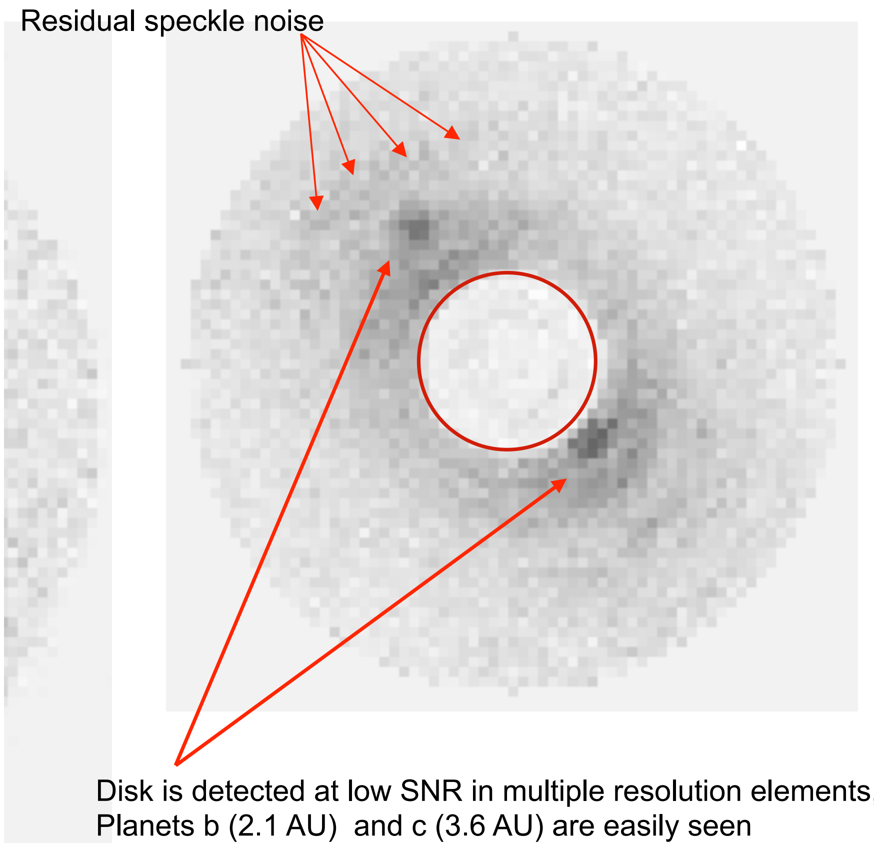
A New Population of Planets

Batalha PNAS 2104

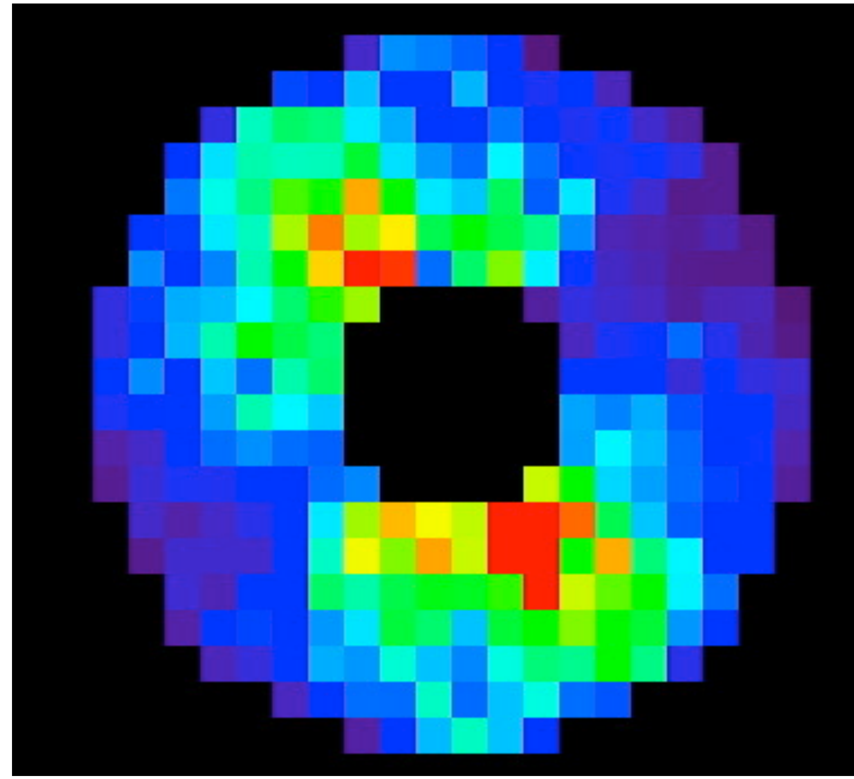


Kepler showed that most planets are small and there exists a large population of 2-4 Earth radii planets previously unknown.

Circumstellar dust
47 UMa + 30 Zodi disk



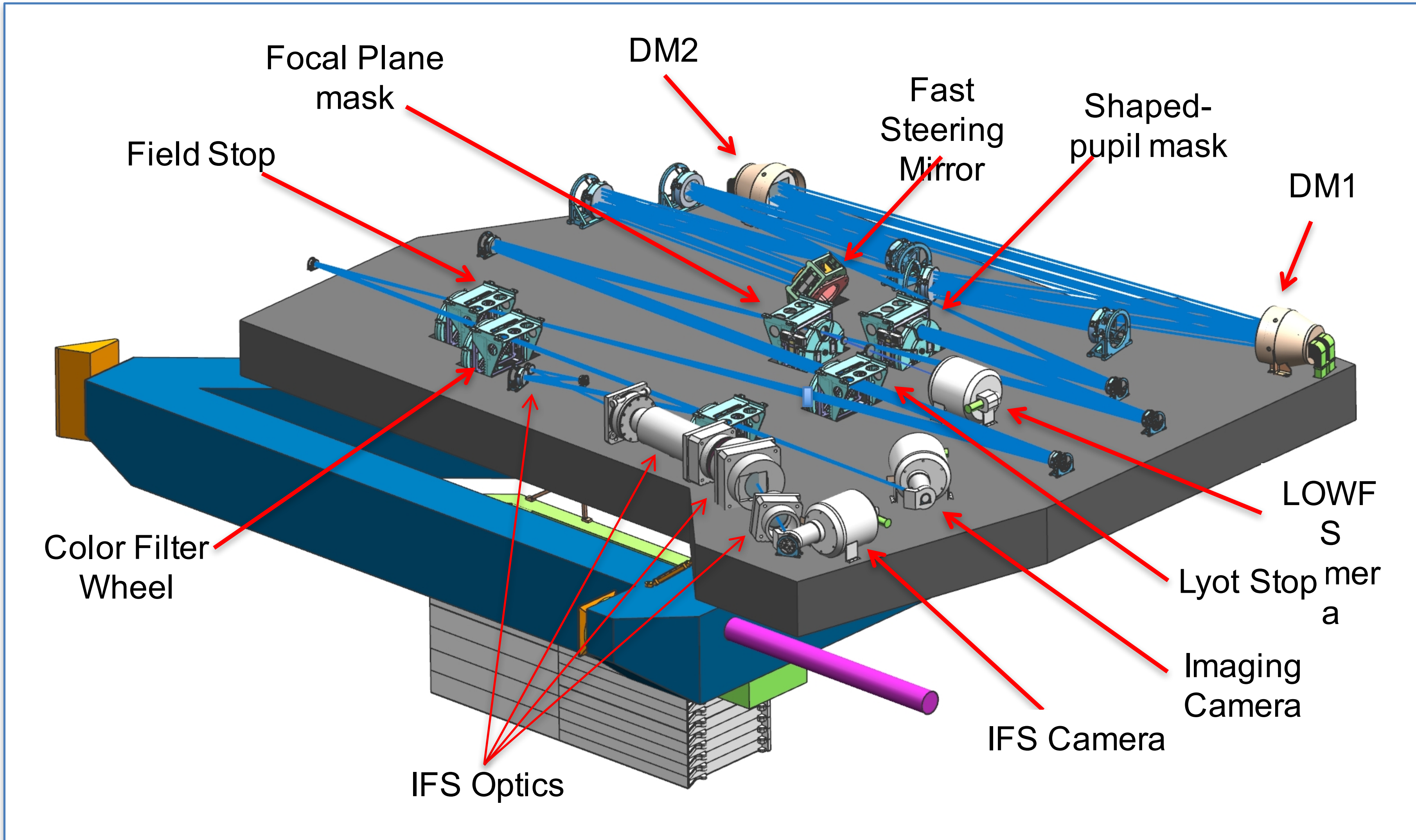
PSF-subtracted image



Binned SNR map of disk (peak SNR=15)

SDT report, Schneider & Greene

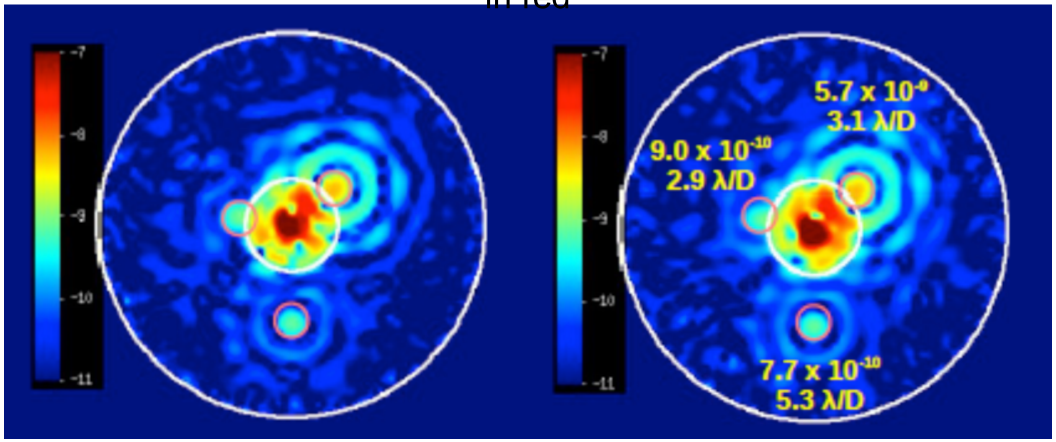
CGI Optical Layout

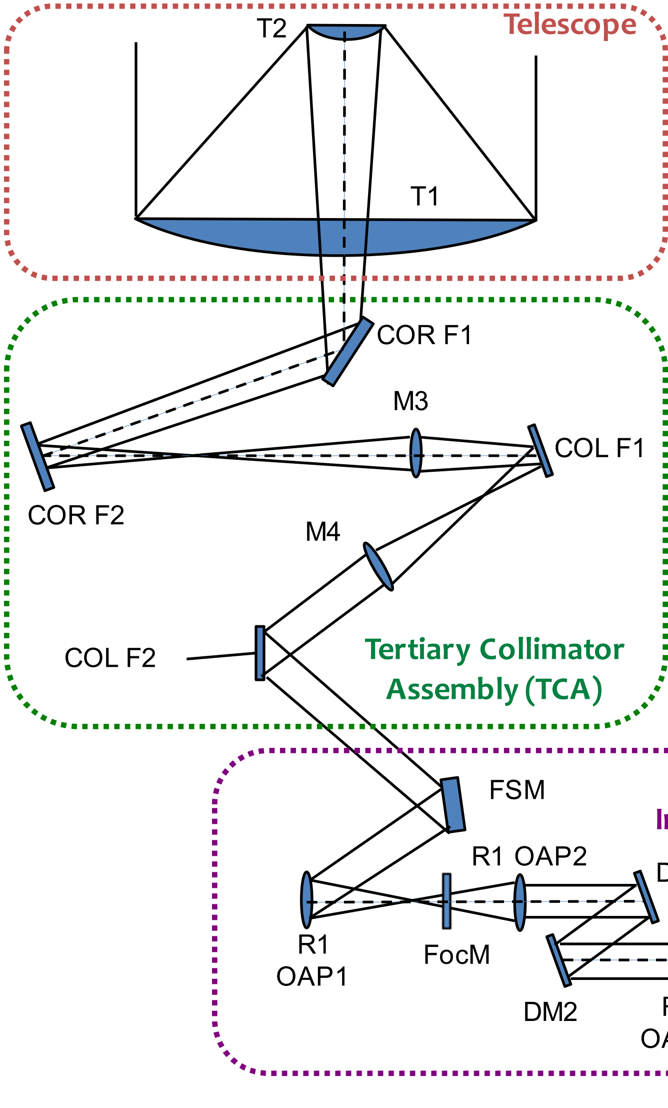
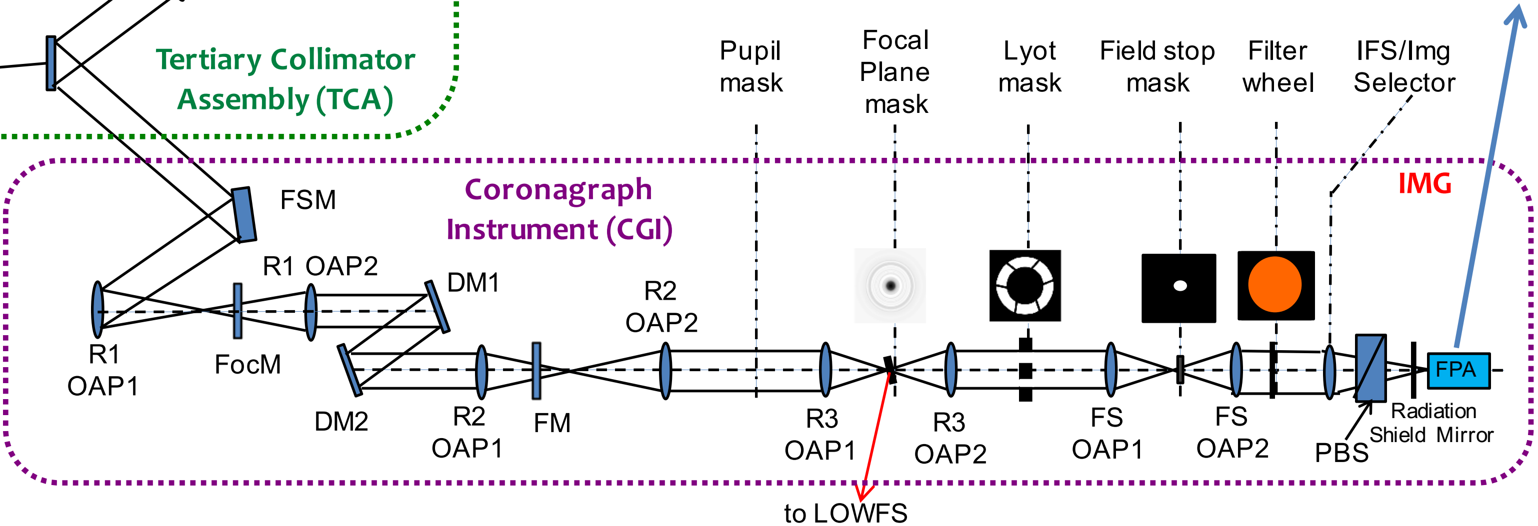


CGI Operational Modes

Hybrid Lyot Mode

Imaging in 2 simultaneous polarizations, simulated planets are circled in red

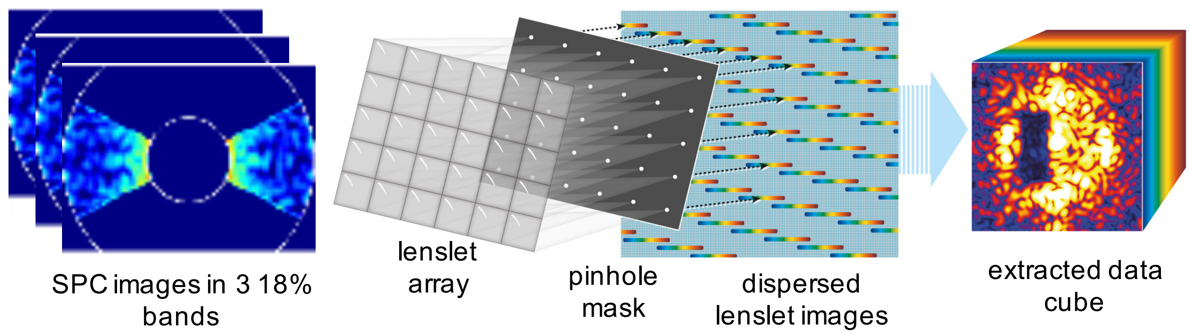


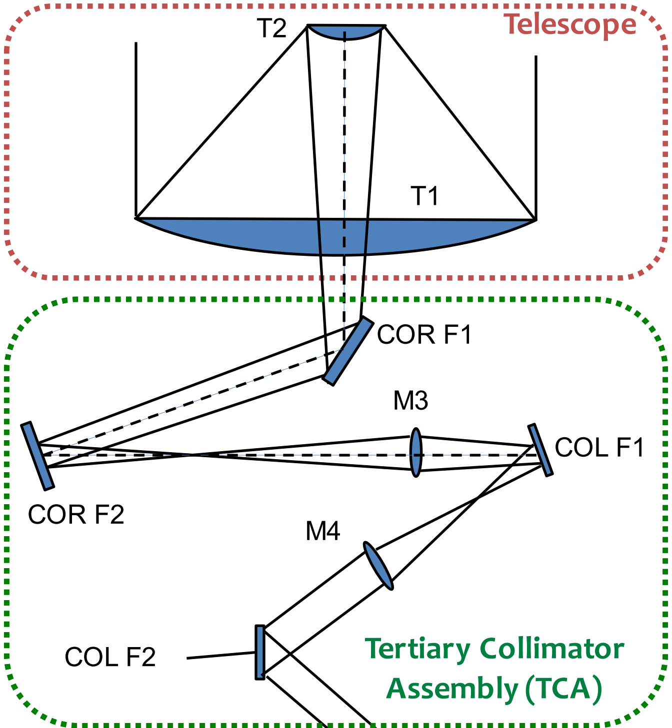



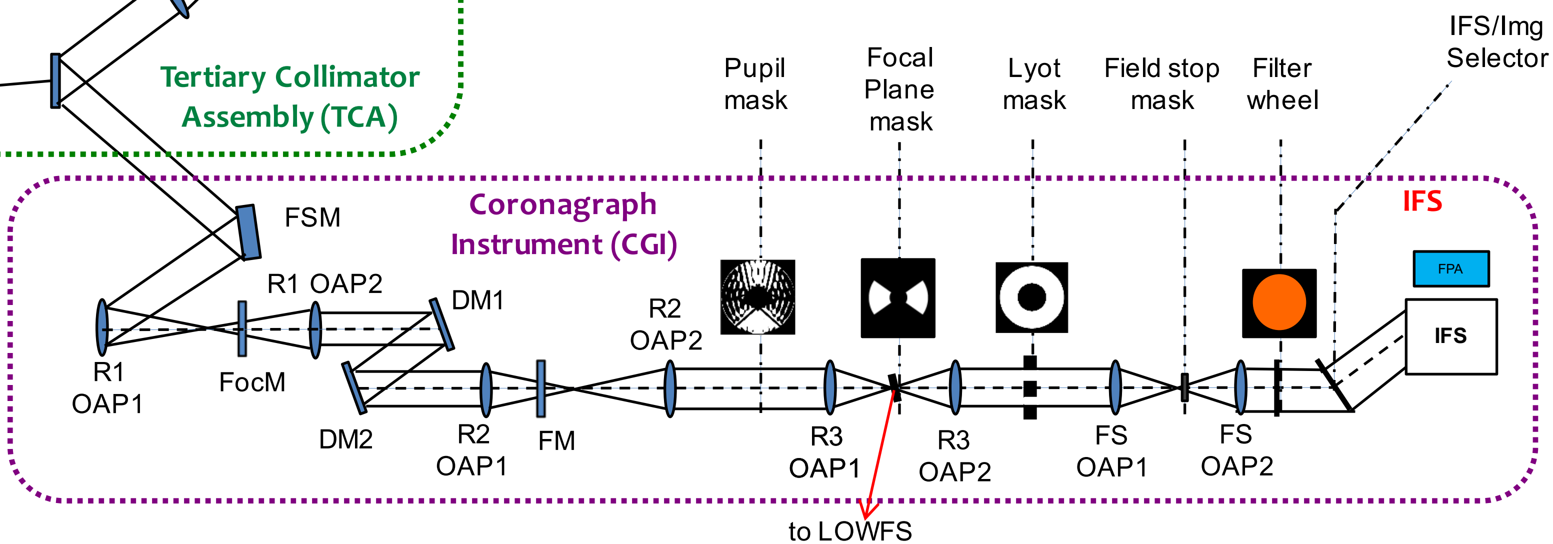
CGI Operational Modes

Shaped Pupil Spectroscopy Mode

The IFS uses 3 18% bands to produce an R=70 spectra from 600 to 970 nm







CGI Operational Modes

Shaped Pupil Disk Imaging Mode

Disk Imaging at wavelengths 465 and 890 nm, in 2 simultaneous polarizations

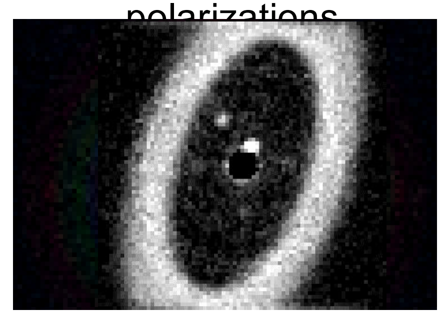
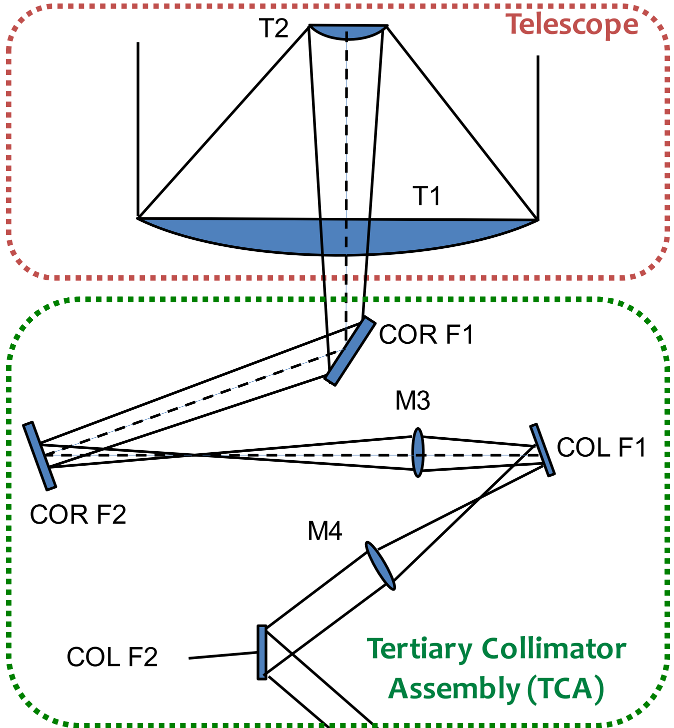
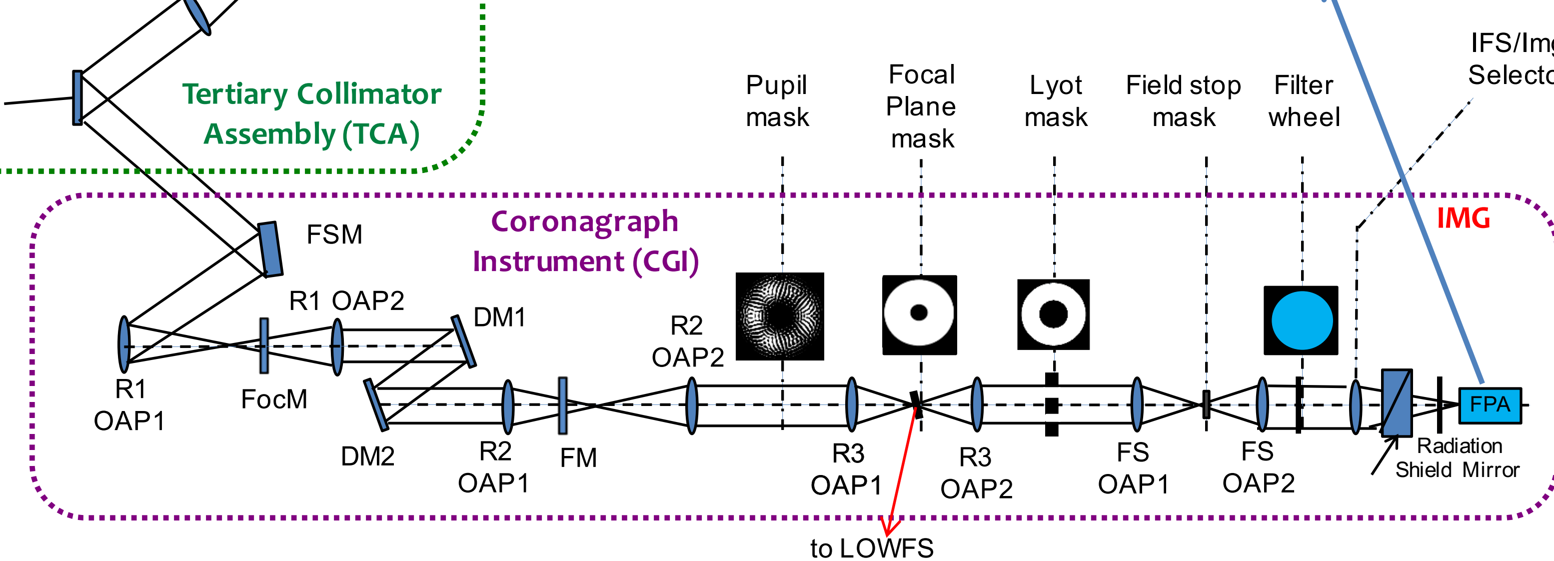
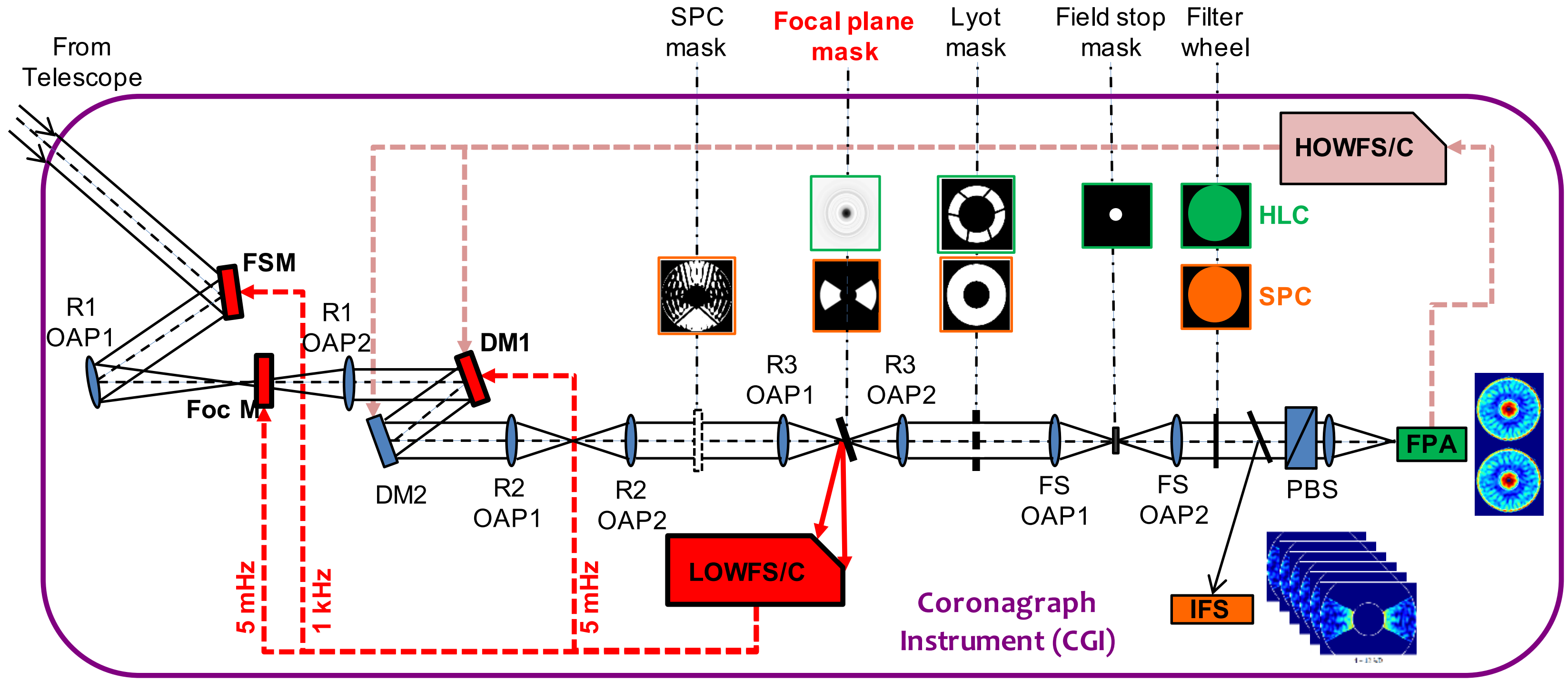


Image from 2015 Exo-C STDT Final Report





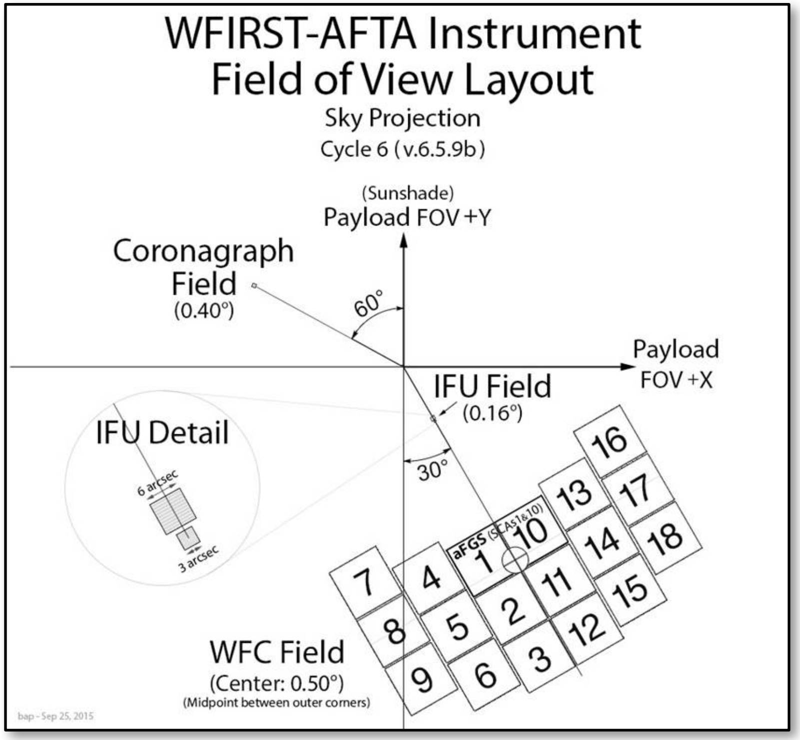
Low Order Wavefront Sensing and Control (LOWFS/C)



- LOWFS/C subsystem measures and controls line-of-sight (LoS) jitter/drift and low order wavefront drift (also measures low order wavefront jitter)
  - Differential sensor referenced to coronagraph wavefront control: maintains wavefront established for high contrast
  - Uses rejected starlight
  - Telemetry can be used for post-processing

CGI Performance Parameters

Design Implementation	Value	Comments
Bandpass	430 - 980 nm	Measured sequentially in 10% and 18% bands
Inner Working Angle [radial]	150 mas	at 550nm, 3λ/D driven by telescope pupil obscurations
	270 mas	at 1μm
Outer Working Angle [radial]	0.5 as	at 550nm, 10λ/D, for highest contrast
	0.9 as	at 1μm, 10λ/D
	0.95 as	at 550, 20λ/D, lower contrast
	1.7 as	At 1μm, 20λ/D, lower contrast
Detection Limit (Contrast after post-processing)	3×10^{-9}	Cold Jupiters; deeper contrast unlikely due to pupil shape & extreme stability requirements.
Imaging DL FOV [radius] w/o masks	2.9 as	Without masks in place
Imaging pixel plate scale	0.01 as	
Spectral Resolution	70	R = λ/δλ (IFS)
IFS Spatial Sampling	17 mas	3 lenslets per λ/D, better than Nyquist
As-designed Static WFE [rms]	13,570 nm	After M2
	4.0 nm	After M4
Dynamic WFE [rms] (for 14 mas LOS jitter variation)	400 pm	After M4
	16 pm	After M4, coma only
Throughput (excludes detector QE)	0.04	SPC (Spectroscopy)
	0.05	HLC (Imaging)



From Mission Concept Review (MCR), December, 2015.

https://wfirst.ipac.caltech.edu/sims/Param_db.html

Imager without Coronagraph

Without Coronagraphic masks					
	UNITS	**Eval point**	**Wavelength (nm)**		
			550	430	980
FOV (half)					
Vignetting free	as	TCA-ExPupil	36	36	36
Diffraction limited	as	TCA-ExPupil	3.4	2.7	6.1
Diffraction limited	as	CGI-Imgr	2.9	2.3	3.1
	as	CGI-Imgr	2.4	2.4	2.4
Sensor limited	pixels		194.0	194.0	194.0
Working F/#			90.64		
Effective f	mm		215723		
λ/D	mas		0.05		
fλ/D	mm		0.05		
Sampling	pixels/(fλ/D)		3.8		
Plate scale	mas/Pixel		0.012		

Technology Demonstration

Coronagraph Design, Masks and Hardware (varies by type)

– Shaped Pupil (SP), SPLC, Hybrid Lyot, APLC, Vector Vortex, PIAA, PIAA/CMC, 4QPM

– Large central obstruction, spiders, segmented mirrors

Wavefront Estimation and Control (common to all)

Probes and Field estimation, Control Algorithms (EFC & Stroke Minimization), Deformable Mirrors, Broadband control (with and without IFS), Low-Order Wavefront Sensing and Control (LOWFSC)

Data Analysis and Planet Identification

PFS Subtraction (LOCI, ADI, KLIP), IFS data cube, Spectral Characterization

Mission Modeling and DRMs

Operation scenarios, target stars, survey parameters, science yield

Engineering and Instrumentation

Optical design, low-noise detector, polarization, IFS, calibration and test, operations

Error Analysis

Polarization, finite stellar size, stability, thermal bending (low-order aberrations)

Demonstrated in Space by WFIRST

Coronagraph Design, Masks and Hardware (varies by type)

– Shaped Pupil (SP), SPLC, Hybrid Lyot, APLC, Vector Vortex, PIAA, PIAA/CMC, 4QPM

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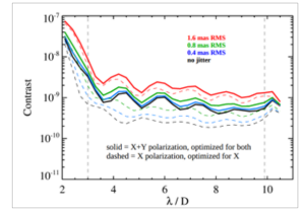
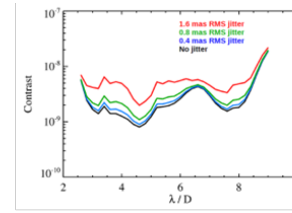
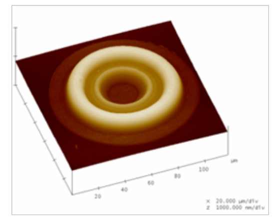
Technology Development

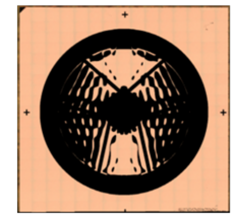
Coronagraph Designs Work with AFTA Telescope "as is" (Computer Model)



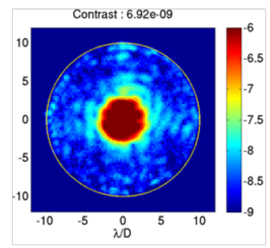


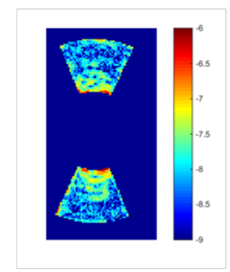
Demonstrate Fabrication of Key Starlight Suppression Components





Demonstrate Starlight Suppression in Narrowband Light

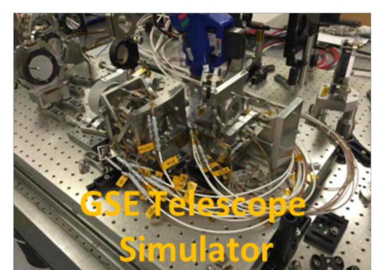




in progress

Demonstrate Starlight Suppression in Broadband Light

Demonstrate Starlight Suppression in Broadband Light, with Simulated Jitter and Drift from "as-is" Telescope



Ilya Proberezhskiy, JPL

Moving through Phase-A

- Continued technology development/demonstration, including control algorithms and post-processing
  - Strong project team at JPL
- Development of Level 2 systems requirements
- Two Science Investigation Teams Selected
  - PIs: Bruce Macintosh and Maggie Turnbull
  - Science Modeling
  - Integrated instrument modeling and simulation
  - Image post-processing and data extraction
  - Operating scenarios, Design Reference Mission and Science Yield
  - Target Selection
  - Community Data Challenges
- Workshop in Fall of 2016
- Special sessions at upcoming conferences

Now is time to identify impactful GO science and accompanying requirements.