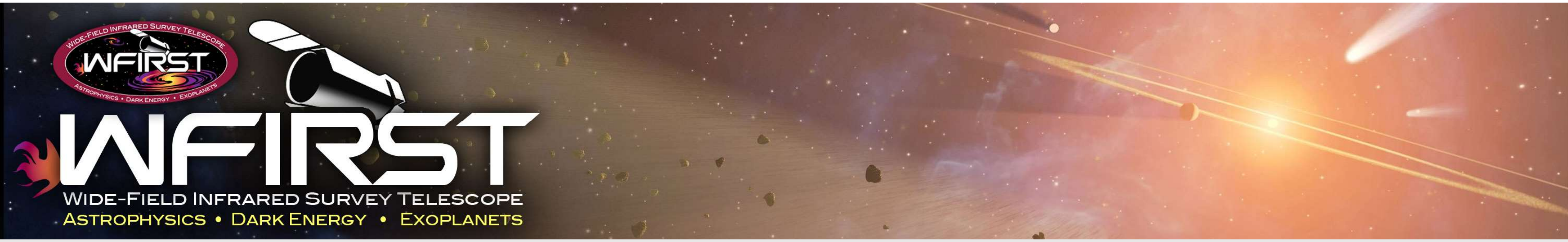


WFIRST Coronagraph Instrument: Science Activities

John Debes
Bruce Macintosh, Nikole Lewis, Maggie Turnbull
on behalf of the WFIRST CGI SITs

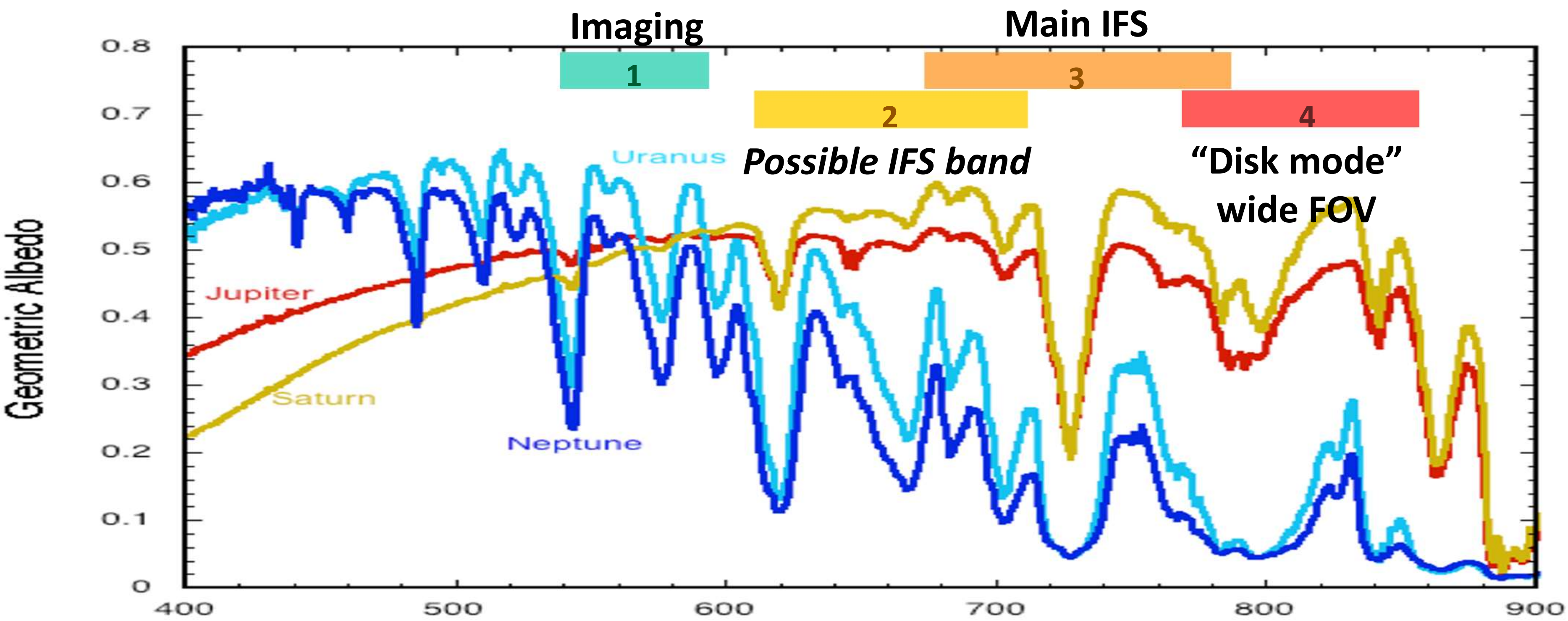
WFIRST CGI project / SIT status

- WFIRST project past SRR, approaching mission PDR in 2019 for nominal 2025 launch
- Coronagraph currently defined as a technology demonstration with *potential* future GO-like program
- Design requirements set by tech demo
  - Good performance on V~5 mag stars
  - Limited filter sets
- Coronagraph Science Investigation Teams (SITs) still operational
  - Helping define requirements and plans for tech demo phase
  - Advocating for maximizing science potential within realistic constraints
- Coronagraph SITs will conclude their service in two years
  - To be replaced by a "participating science program" (see later slides)

Mission plan

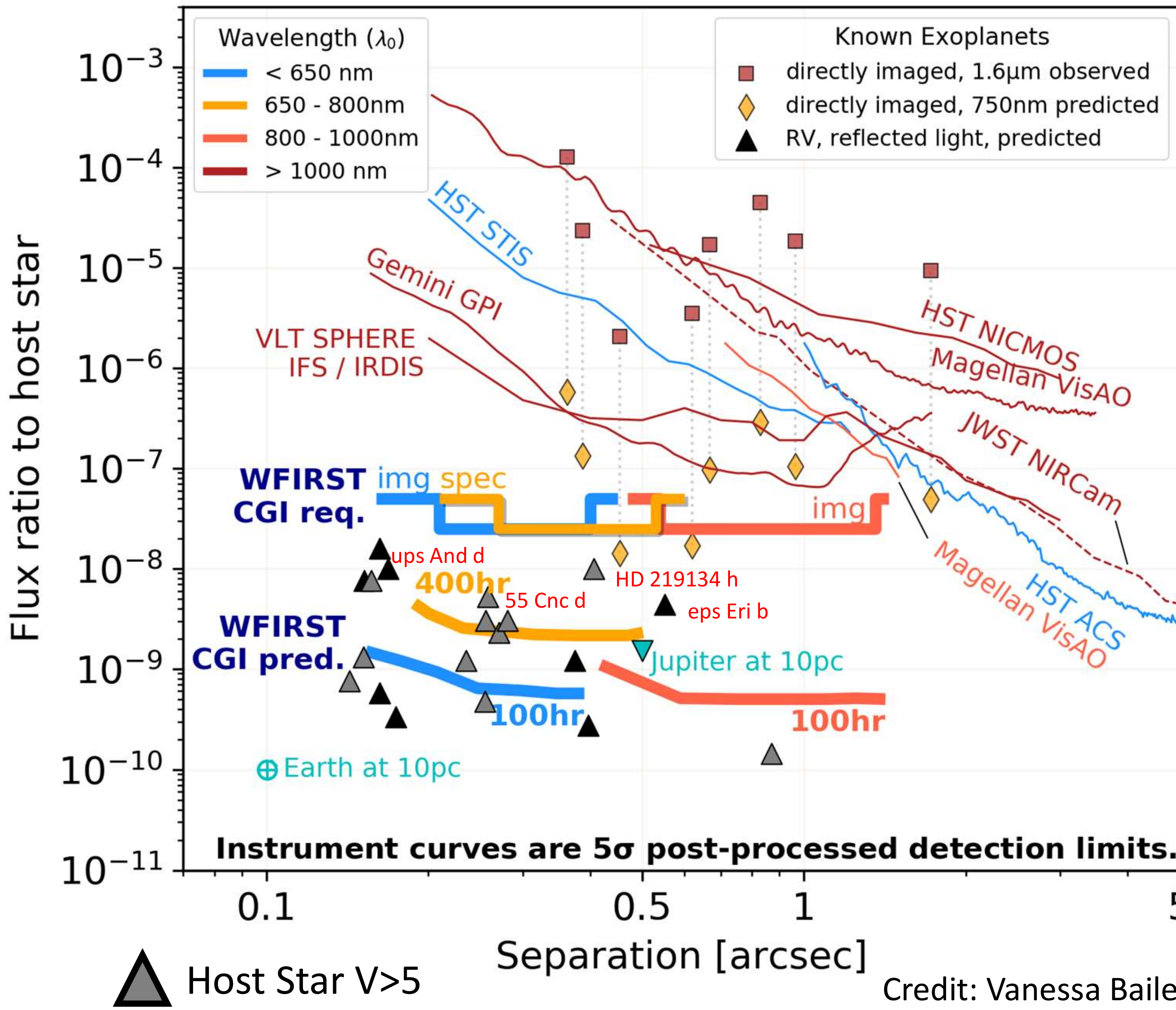
- **Primary objective**: validate coronagraph techniques and technology for future visible-light exoplanet imaging/characterization missions
- 2000 hour technology demonstration/validation observations in first 1.5 years of mission
  - Imaging / photometric observations of multiple known planets
  - SNR=10 spectrum of at least one known planet
  - Observations of known (cold) debris disks and warm zodiacal disks
  - Performance characterization and model validation
  - Led by instrument team with support from participating scientists
- If science capabilities are compelling
  - ~25% of remaining mission time available for PI-led projects, through the framework of the Participating Scientist Program and perhaps general GO calls

Baseline Science Filters



λ_1 = 575 nm, 10% λ_2 = 660 nm, 15% λ_3 = 730 nm, 15% λ_4 = 825 nm, 10%

Predicted CGI contrast for V=5 Star



Credit: Vanessa Bailey

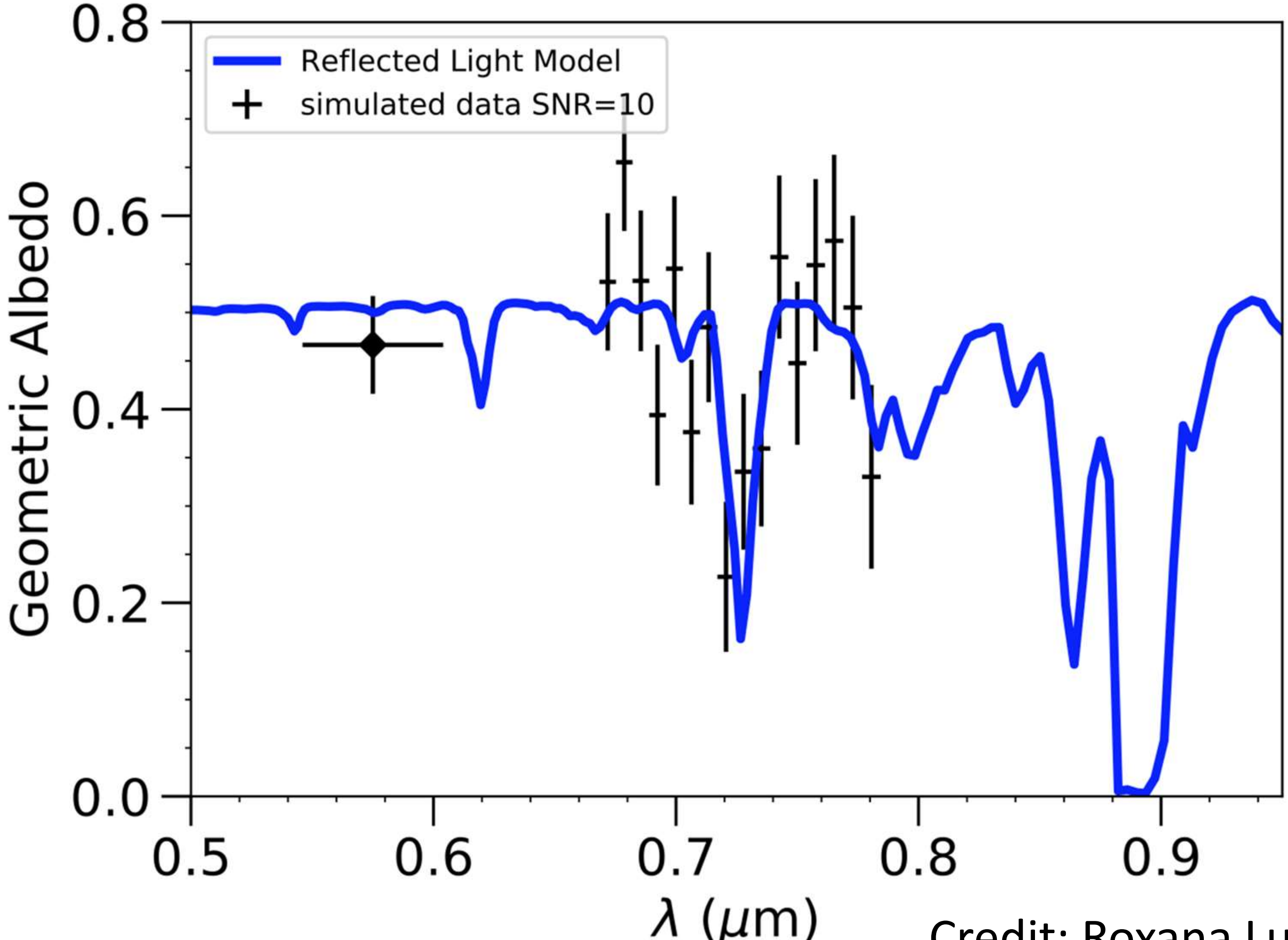
SIT science aspirations for the mission

- Demonstrate the techniques of high-contrast exoplanet reflected-light spectroscopy from raw pixels to planetary atmospheric parameters
- Demonstrate high-contrast astrometry and orbit determination
- Measure scattered-light brightness, polarimetry, and morphology of zodiacal dust to ~10 times solar
- Photometrically characterize a large sample of giant planets to determine bulk properties such as clouds
- Spectroscopically characterize a few planets to coarsely constrain C/H ratio
- Study protoplanetary systems in visible light (including H-alpha accretion)
- Photometrically characterize a small sample of Neptune-sized planets (new discoveries by GAIA+RV or WFIRST-CGI)

SIT activities: Macintosh & Lewis SIT

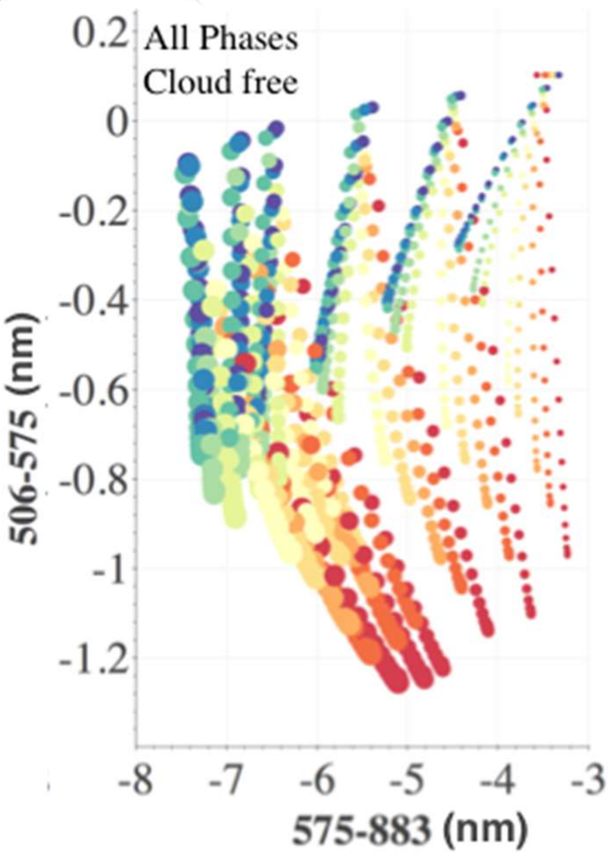
- Develop and make available a comprehensive list of reflected-light giant planet models
- Develop a database of potential targets including orbital predictions, stellar properties, disk properties, and predicted planetary properties
- Develop quantitative predictions and metrics for disk science
- Collaborate with JPL on requirements, DRM, design trades, calibration
- Collaborate with science center (IPAC) on data requirements/processing
- Coordinate precursor observations (imaging) with project and Turnbull SIT
- Develop notional GO programs

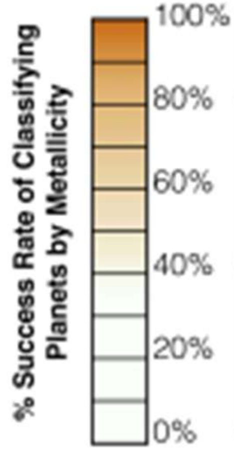
SNR=10 IFS spectra can detect CH_4 and measure EW



Credit: Roxana Lupu & Mark Marley

Power of WFIRST CGI Photometry





Sample Used	Algorithm Used	2 Filters (nm)	3 Filters (nm)	4 Filters (nm)	5 Filters (nm)	All Filters
Cloud-free Sample	LDA	506,883	506,575,883	All but 721,940	All but 721	
	CART	506,883	506,661,883	All but 721,949	All but 940	
Full Sample	LDA	661,883	575,661,883	All but 506,883	All but 506	
	CART	721,883	506,883,940	All but 575,721	All but 721	

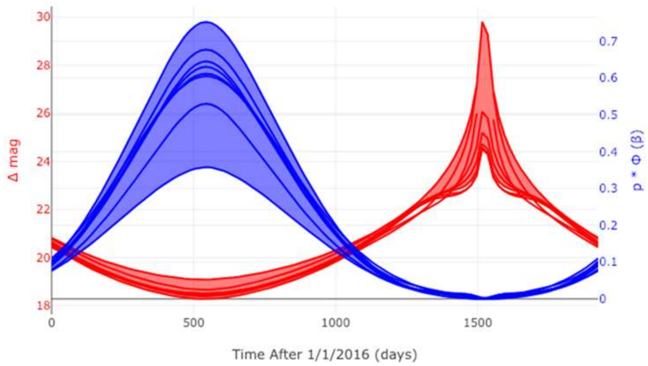
Addition of 3rd filter gives largest gain in success rate

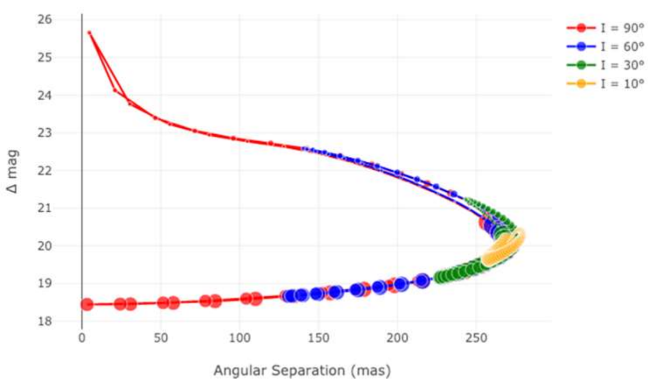
Strong science benefits if WFIRST CGI can add 1-2 additional imaging filters)

Batalha et al. (2018)

Imaging Mission Database (plandb.sioslab.com)

Talk #402.04 (Savransky)

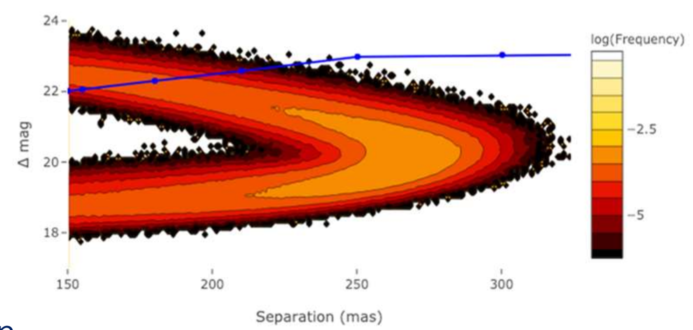


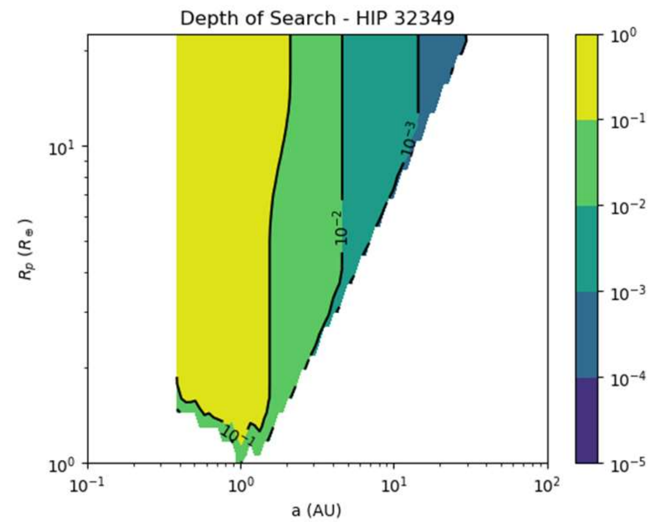


Includes (partial) orbital fits combined with photometric models for 3852 known exoplanets

- Photometric variability in multiple filters available as functions of time for planets with known time of periastron passage
- Multiple inclination models for planets with unknown orbital inclinations
- Full 2D Δmag – Angular Separation density functions for 56 highest priority WFIRST targets

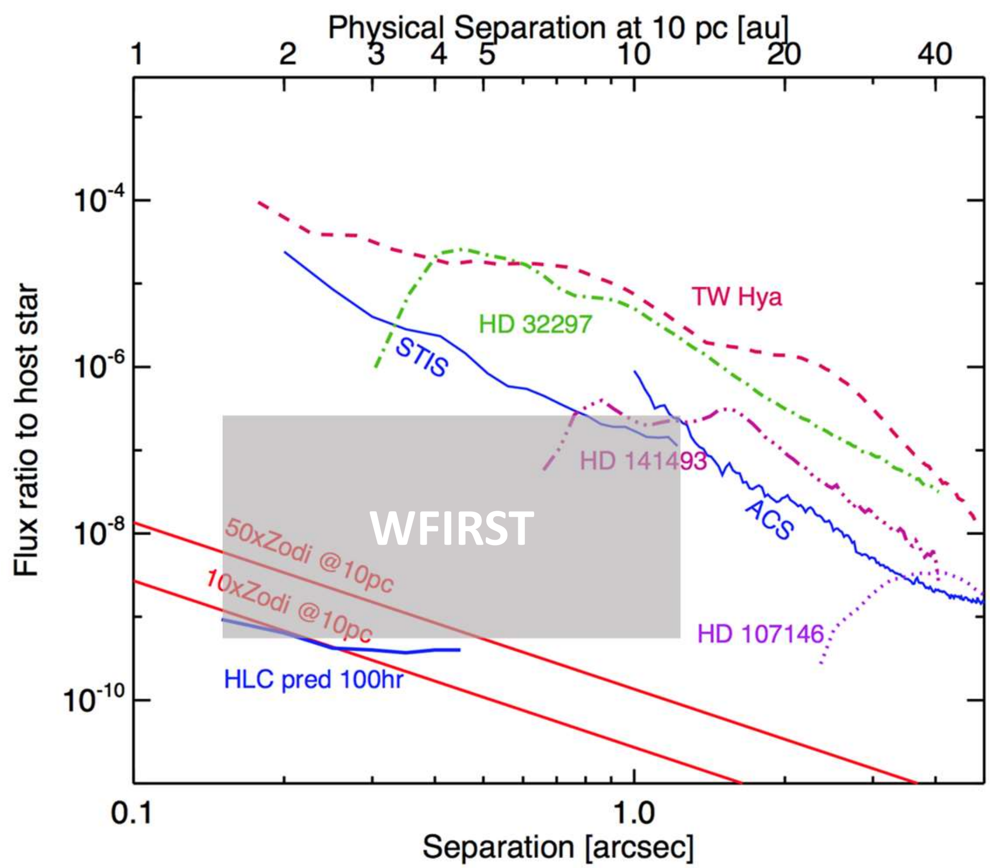
Full completeness values for 125 highest priority blind search targets





Science opportunity: Exozodis and Faint Disks

- WFIRST/CGI predicted performance will be sensitive to dust that may impact future direct imaging missions
- Visible linear polarizing filters will provide constraints on grain properties
- Reconnoiter nearest exo-Earth systems to determine exo-zodi levels

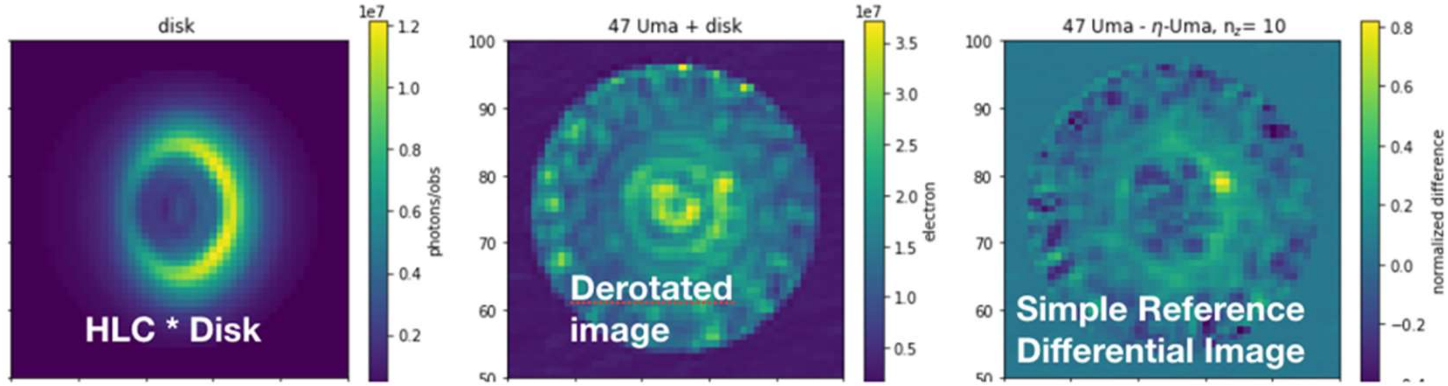


Modeling Disks to Predict Performance

Talks:
#340.01 (Debes)
#340.03 (Douglas)

Accounting for Zodis

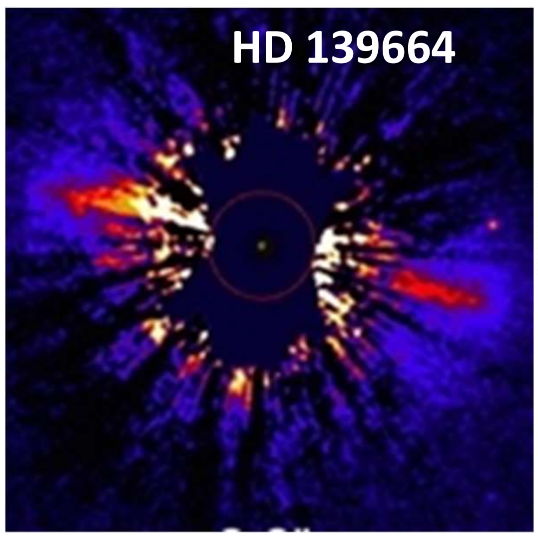
- Toy Model Disks
- ***Field Dependent PSF***
- Implant into OS6

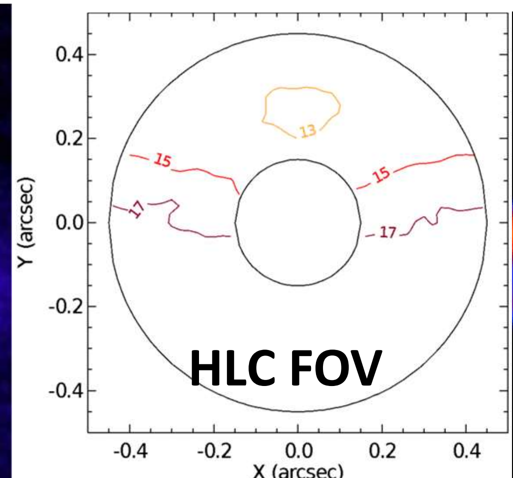


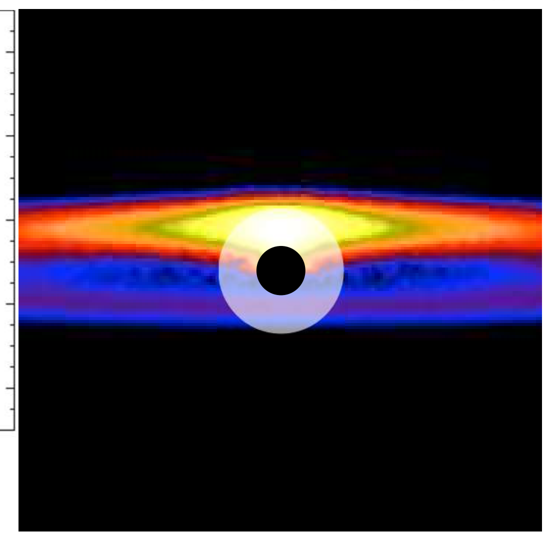
Douglas, E., Debes, J., et al, *in prep*

Tech Demo Disks

- Use modeling to predict peformance
- ***Important for DRM Target Selection***







Modeling Known Planet+Disk Systems

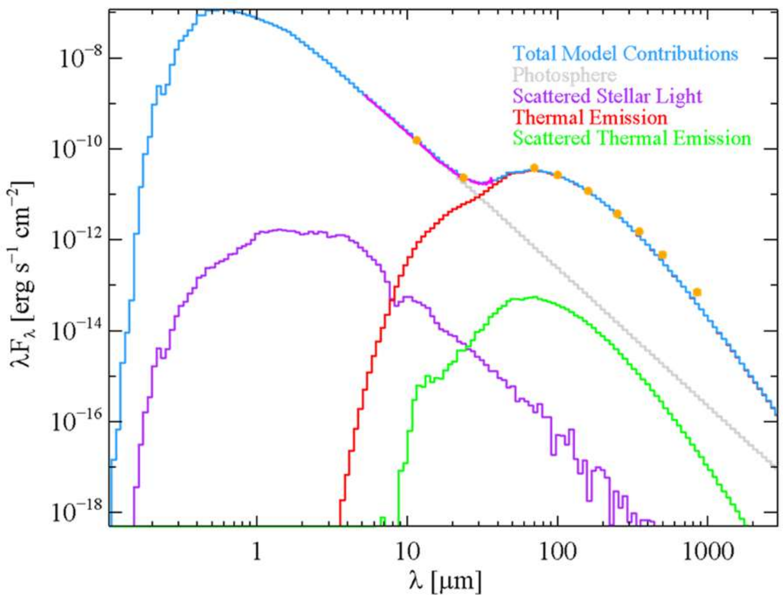
7 Disk+Planet Systems available on IPAC WFIRST site (https://wfirst.ipac.caltech.edu/sims/Chen_WPS.html)

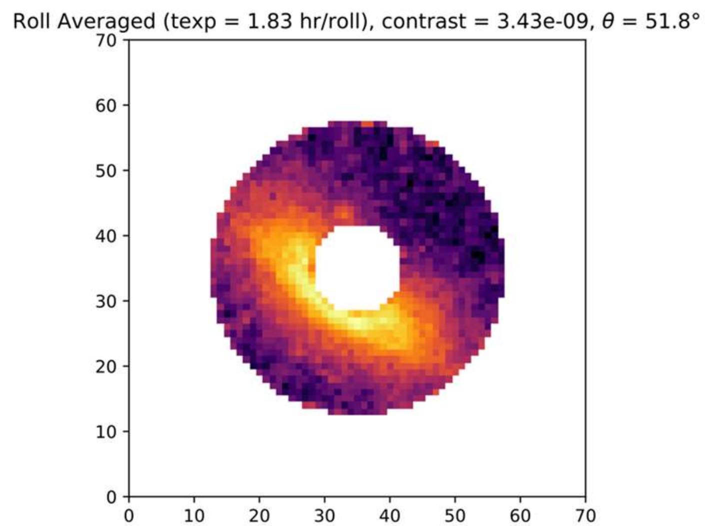
Model Disks constrained by observed IR SED

Model HLC images simulated with planets+OS6 scenario

Useful for DRM/Tech Demo studies (i.e., Tau Ceti)

HD 10647





credit: Charles Poteet and Christine Chen

Turnbull SIT Activities and AAS Posters

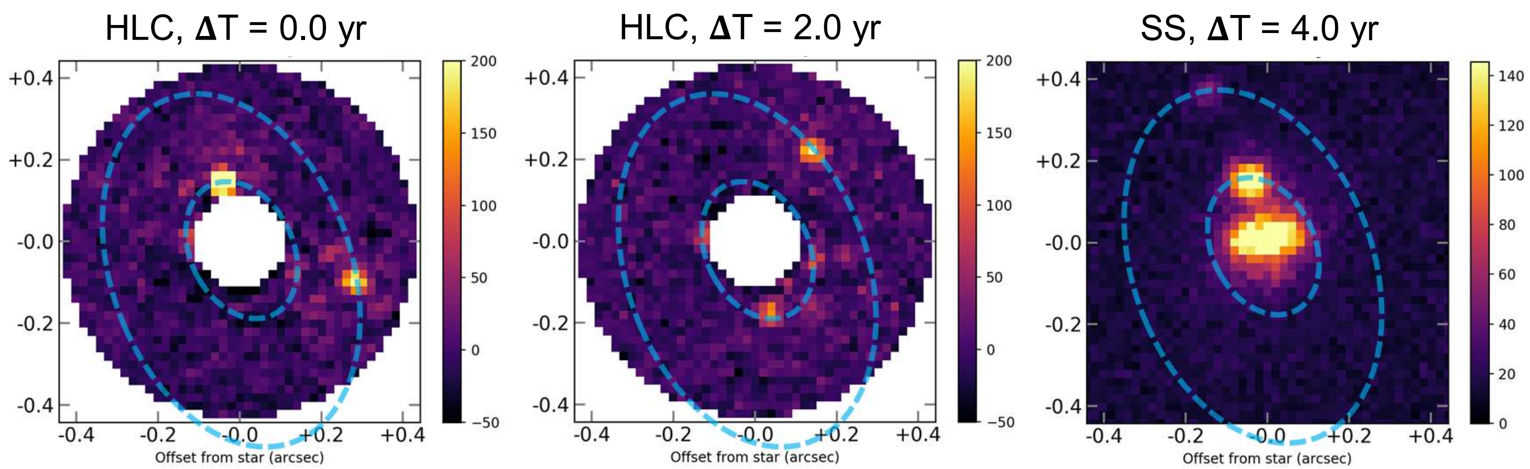
- Maggie Turnbull (PI, SETI Institute), with Co-Is…
- Neil Zimmerman and Avi Mandell (GSFC, CGI Image Simulations and Data Challenge) → #140.44
- Stephen Kane and Zhexing Li (UC-Riverside, RV Precursor Observations, Target Characterization) → #140.42, #140.43
- Sergi Hildebrandt and Stuart Shaklan (JPL, Starshade Image Simulations) → #140.48
- Aronne Merrelli and Tristan L'Ecuyer (UW, Planetary Spectral Simulations) → #140.31

(All posters in Monday's Exoplanet session.)

WFIRST CGI Imaging Data Challenge

- AAS Poster on MONDAY: #140.44 (Mandell et al., CGI) and #140.48 (Turnbull et al., Starshade images)
- The Turnbull SIT is organizing the second community data challenge for the WFIRST Coronagraph Instrument.
- Beginning February 2019, release simulated WFIRST datasets of exoplanetary systems imaged at multiple epochs over a 6-year baseline, including images taken with a starshade rendezvous probe at later epochs.
- Participants will be asked to post-process the images, discriminate planet candidates from noise and background objects, and fit their orbits using relative astrometry.
- All experience levels are welcome to participate, with plans for hack days and tutorial sessions. Contact Turnbull for signup.

Simulated, processed images for example system



- These are co-added images from 3 sample observing epochs; in the case of HLC, this includes reference differential imaging post-processing. Dashed ellipses trace the respective orbits of the two planets.
- The CGI HLC data simulations (**left** and **middle**) are based on WFIRST OS6 STOP model time series; these include various sources of time-varying wavefront errors and spacecraft jitter.
- Starshade data simulations (**right**) based on JPL's model for a starshade design with 26-m diameter, 24 petals (spinning), stationed 37,000 km from the WFIRST spacecraft, including effects of line-of-sight jitter and solar glint.
- Detector model is a photon-counting EMCCD with lifetime degradation.

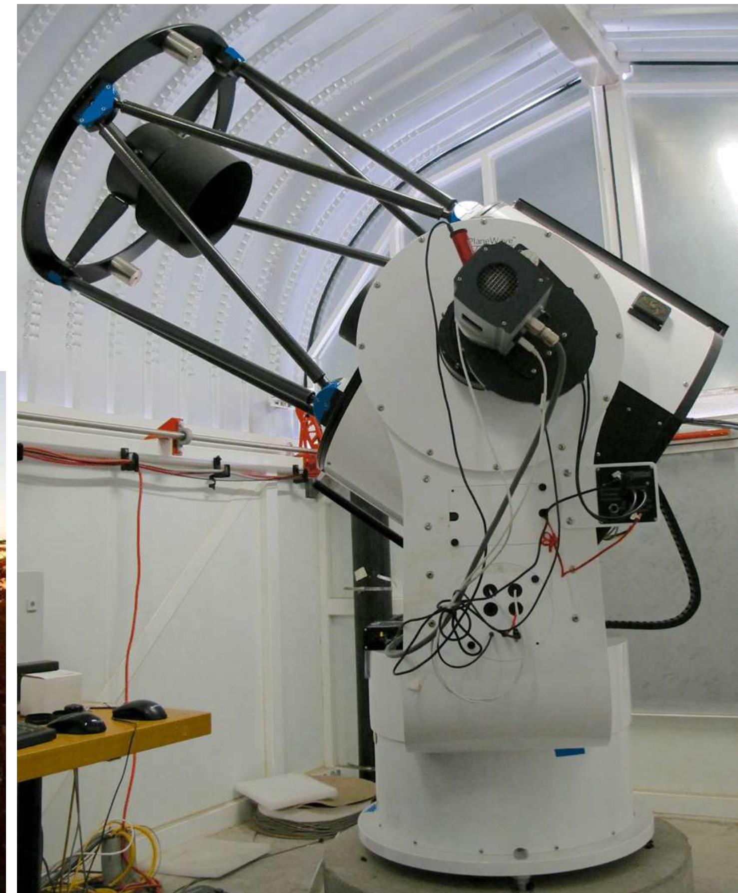
Radial Velocity Pre-Cursor Observations: Known RV Targets+Blind Search

NASA Keck time & Key Projects

NASA NEID time

NASA time on southern facilities (MINERVA, CHIRON)

Automated Planet Finder

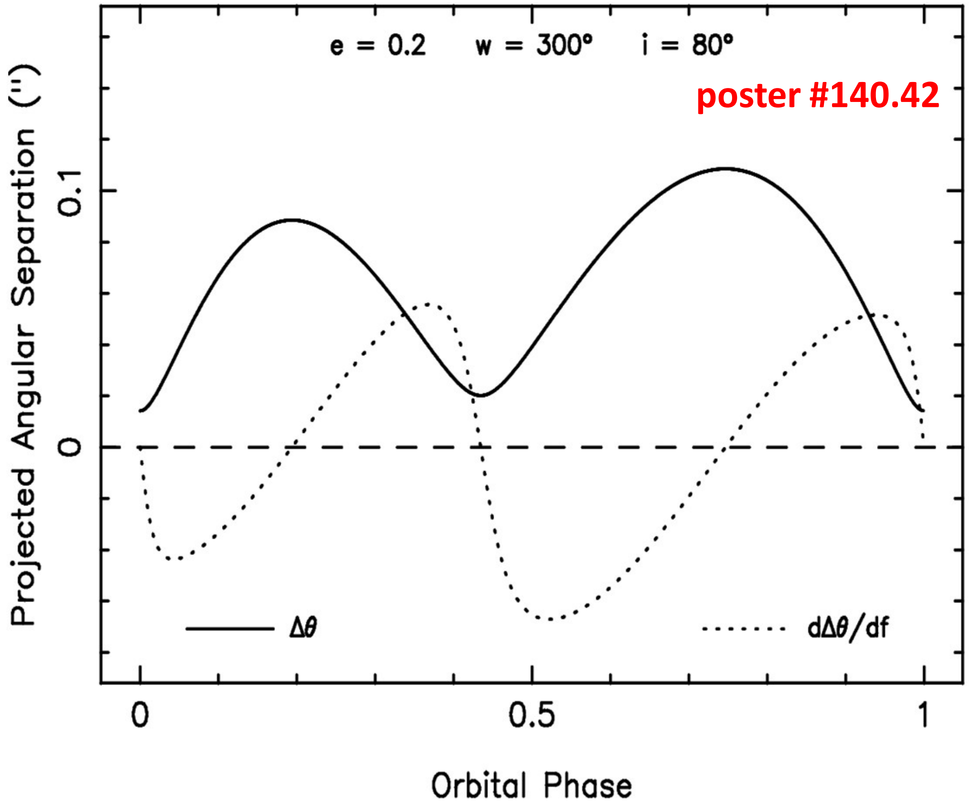


Blind Search:

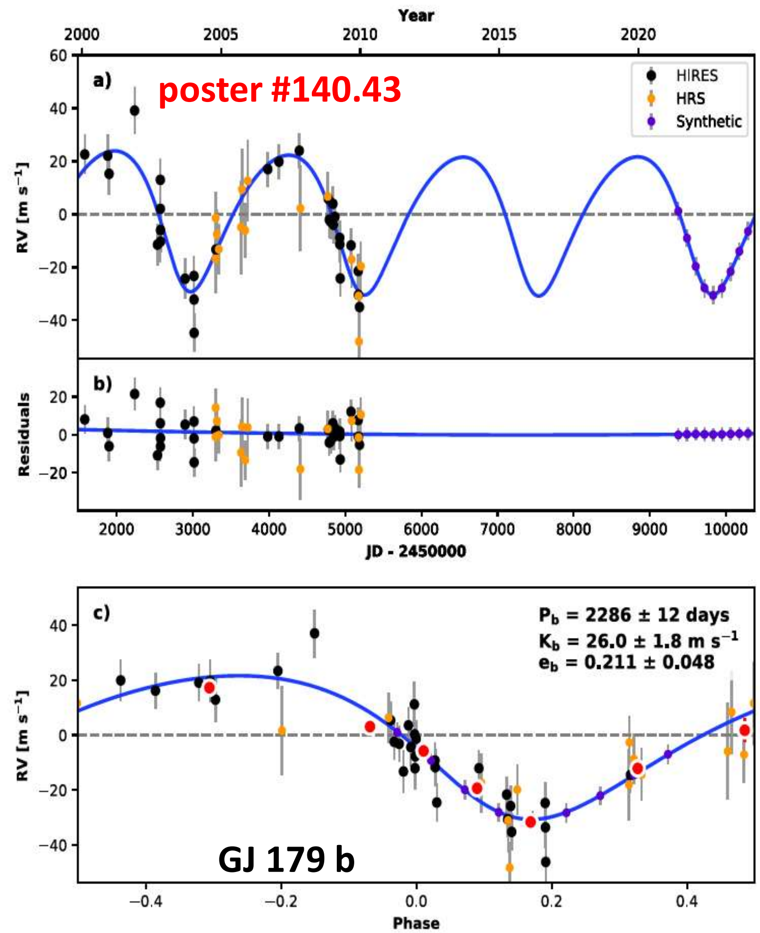
- Instrumental error: 27 cm/s
- 45 FGK stars, 150 nights over 5 years will sample terrestrial planets to P~100 days

Determining Optimal Timing of NEID Observations

Predicting Maximum Angular Separation



Kane, Meshkat, Turnbull. 2018, AJ, 156, 267



Li, Kane, Turnbull. 2019, AJ, in prep

Participating Scientists Program (PSP)

#247.37 (Rhodes)

Notional PSP Program, to be confirmed by HQ and project in Phase B

- Core PSP members selected via peer review well before launch
- Makeup of PSP informed by CGI team needs
- PSP fully partners with CGI team during 'tech demo' phase (first 1.5 years of mission)

➢ Proposed PSP Stages:

➢ **Stage 1:** Pre- PSP: Keep current SITs through ~2021

➢ **Stage 2:** Compete for small PSP in ~2021 that will be in place through first 18 months of mission; must justify selection 5 years ahead of launch

➢ **Stage 3:** If warranted, augment the PSP for years 1.5-2.5

➢ **Stage 4:** If warranted, augment the PSP or open CGI to GO science (or both) for 2.5-end of mission

*warranted → CGI can do compelling science; PSP will be critical in helping demonstrate this

Conclusions

- WFIRST coronagraph still has an important science role to play
- Learning how to do reflected-light spectroscopy will lay groundwork for later imaging missions
- Measuring zodiacal scattered light at ~5-10x solar levels
- Science Investigation Teams are working to maximize the utility of the mission both as a technology demonstration and for science
- Science capability could be enhanced by strategically targeted investments

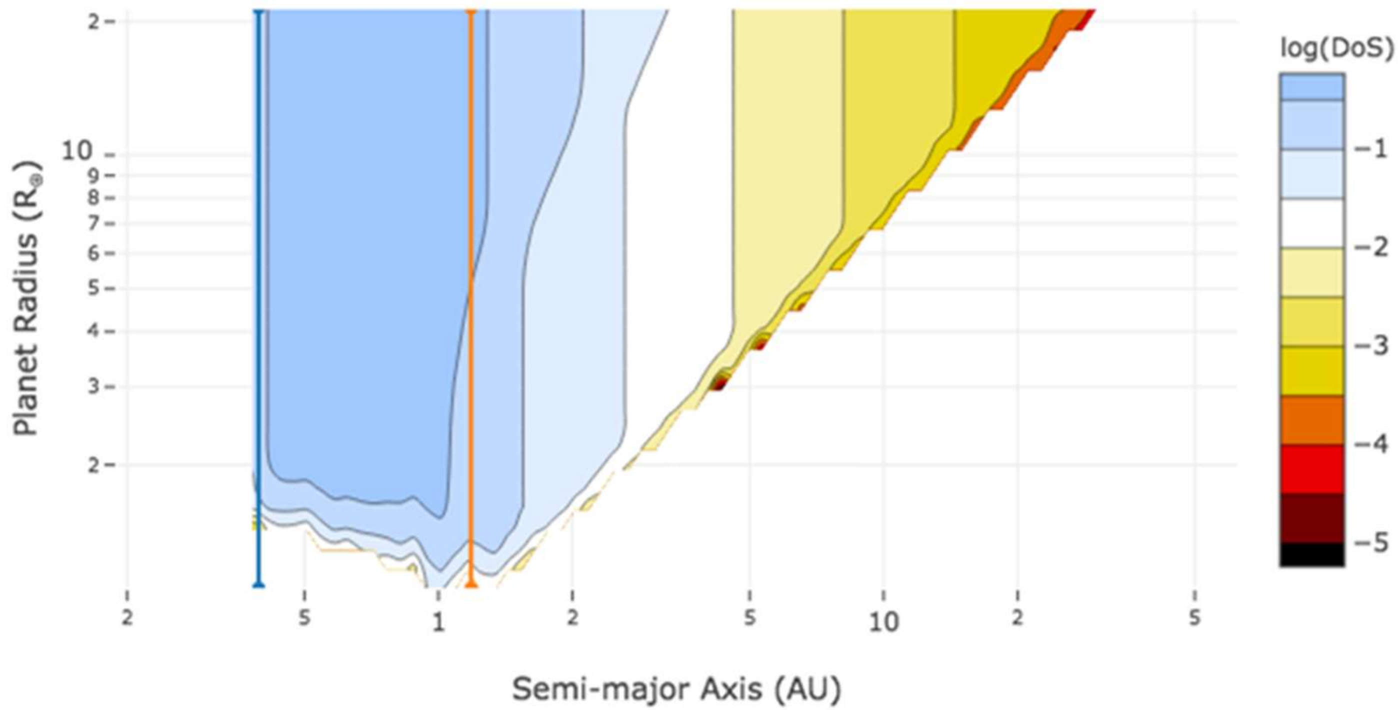
Grab this presentation at: https://goo.gl/1hj2Bg

Backup Slides

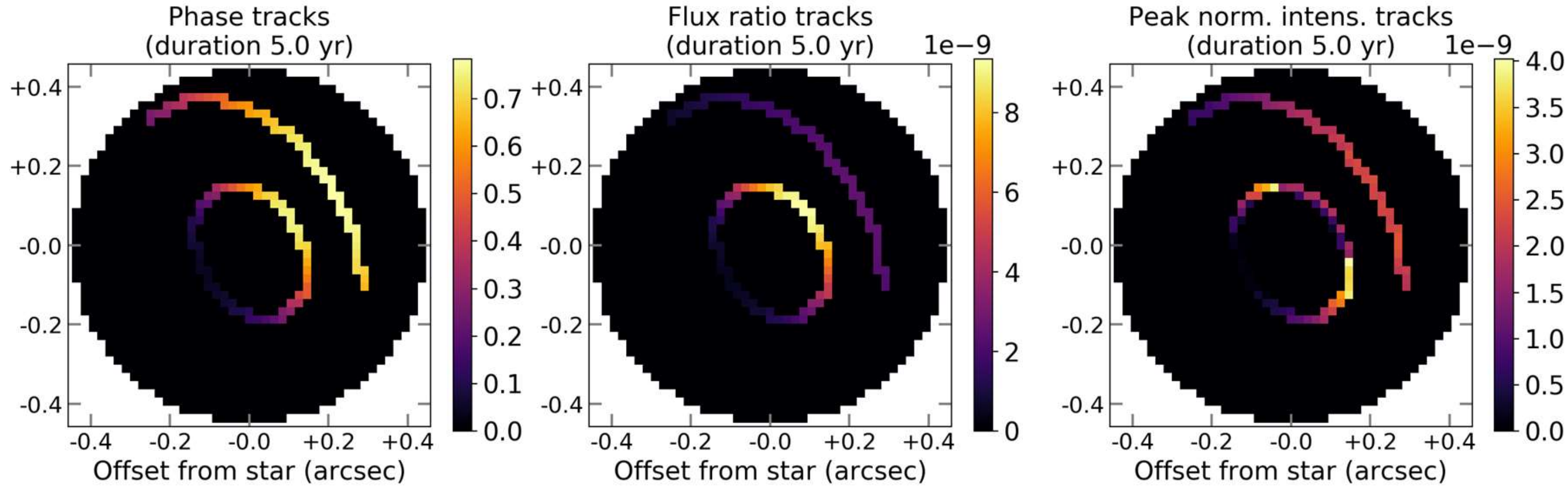
Science Opportunity: Small Exoplanets in Blind Searches

Log Completeness for Sirius

Discovery potential for Neptune and super-Earth planets in inner solar systems



Example CGI Imaging Challenge Planet Parameters



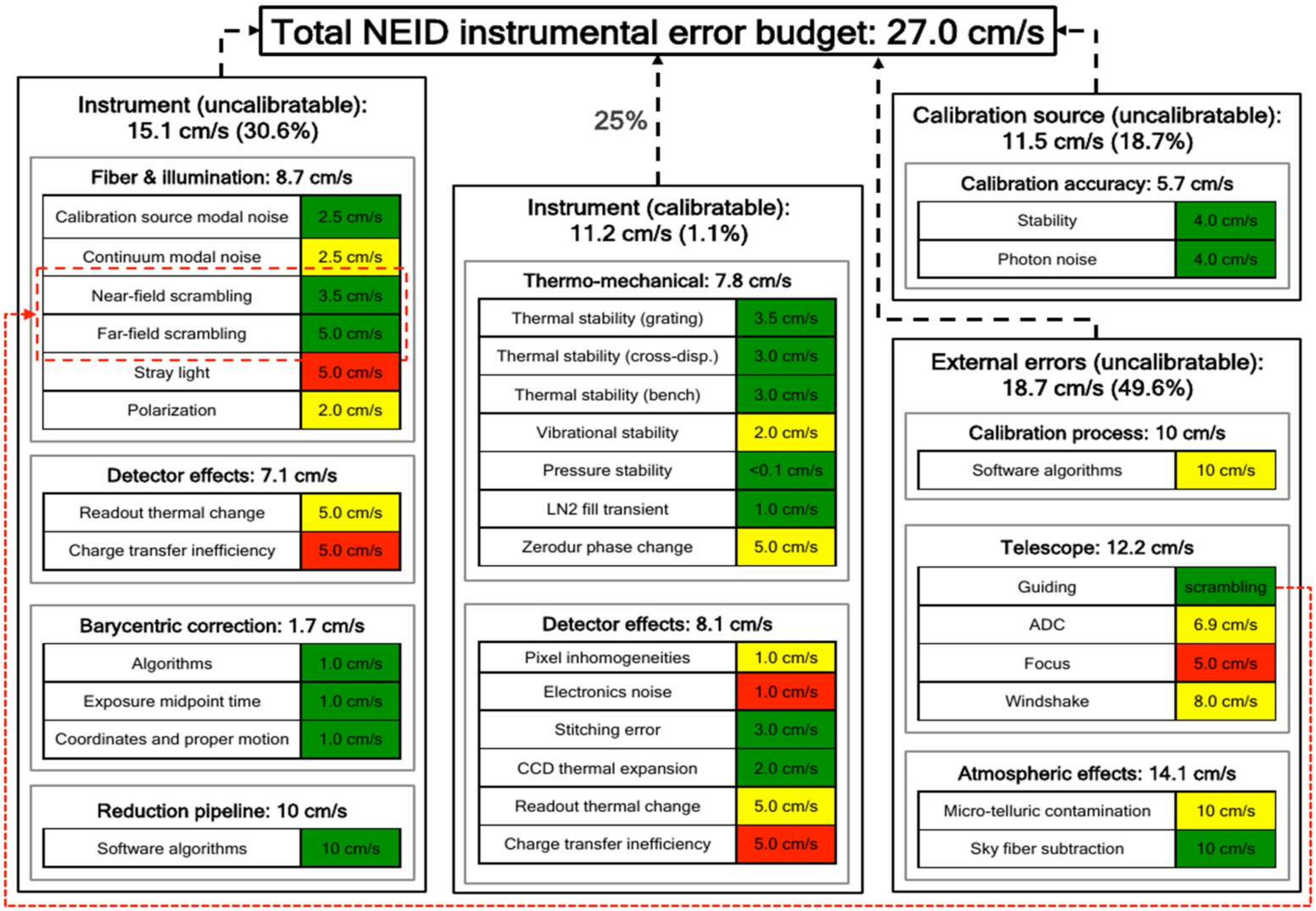
Star (47 UMa-like)

mass	1.0 solar mass
spec type	G0V
distance	14.0 pc
apparent V mag	5.0

Planets (fictitious)

	b	c
semi-major axis	2.5 AU	5.5 AU
period	3.95 yr	12.89 yr
radius	1.0 jupiterRad	1.0 jupiterRad
albedo	0.3	0.4
wavelength	575 nm	575 nm
eccentricity	0.10	0.05
arg periastron	155.0 deg	50.0 deg
inclination	45.0 deg	48.0 deg
long. ascending node	300.0 deg	300.0 deg

RV Precursor Observations: Error Budget with NEID



Halverson et al. 2016, SPIE, 9908, 99086P