# Coronagraphic Imaging with WFIRST

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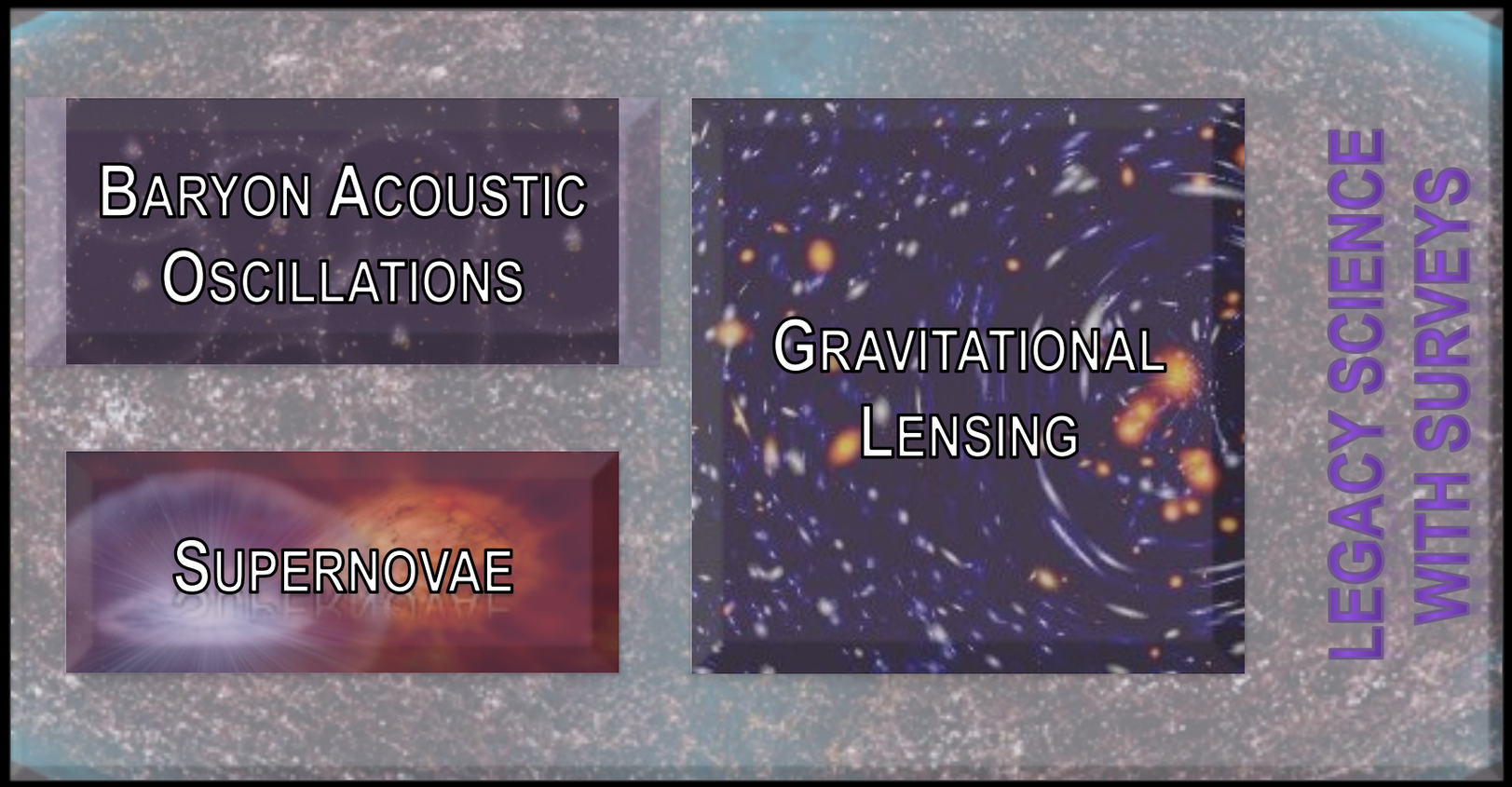
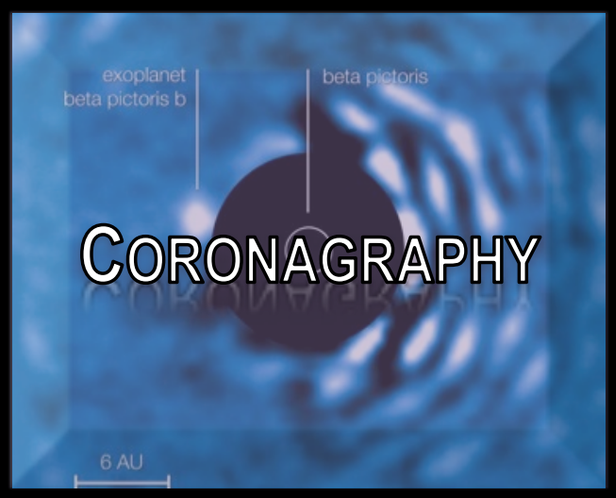
Space Telescope Science Institute

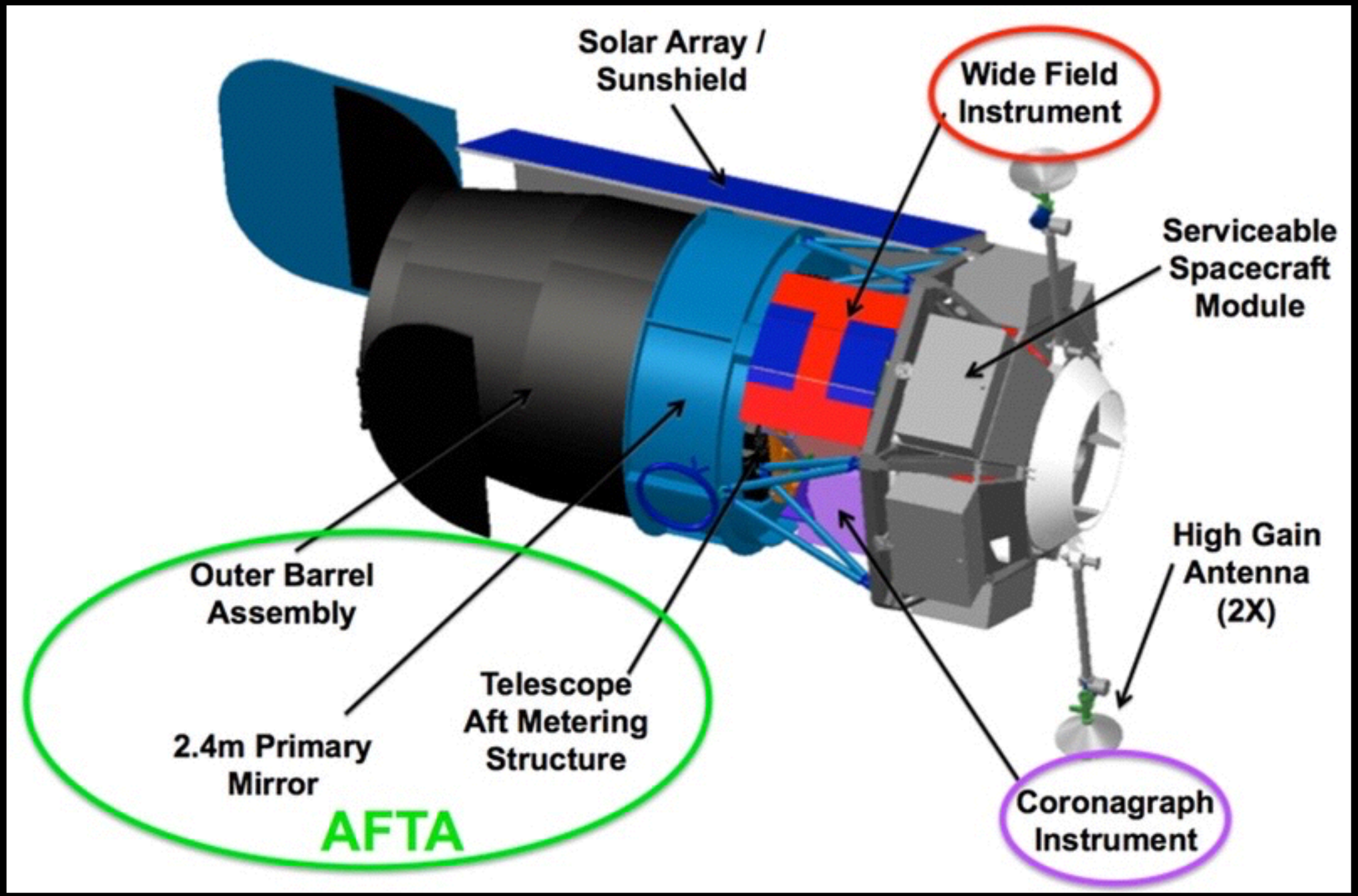
http://wfirst.gsfc.nasa.gov/gallery-movies.html

# WFIRST Science







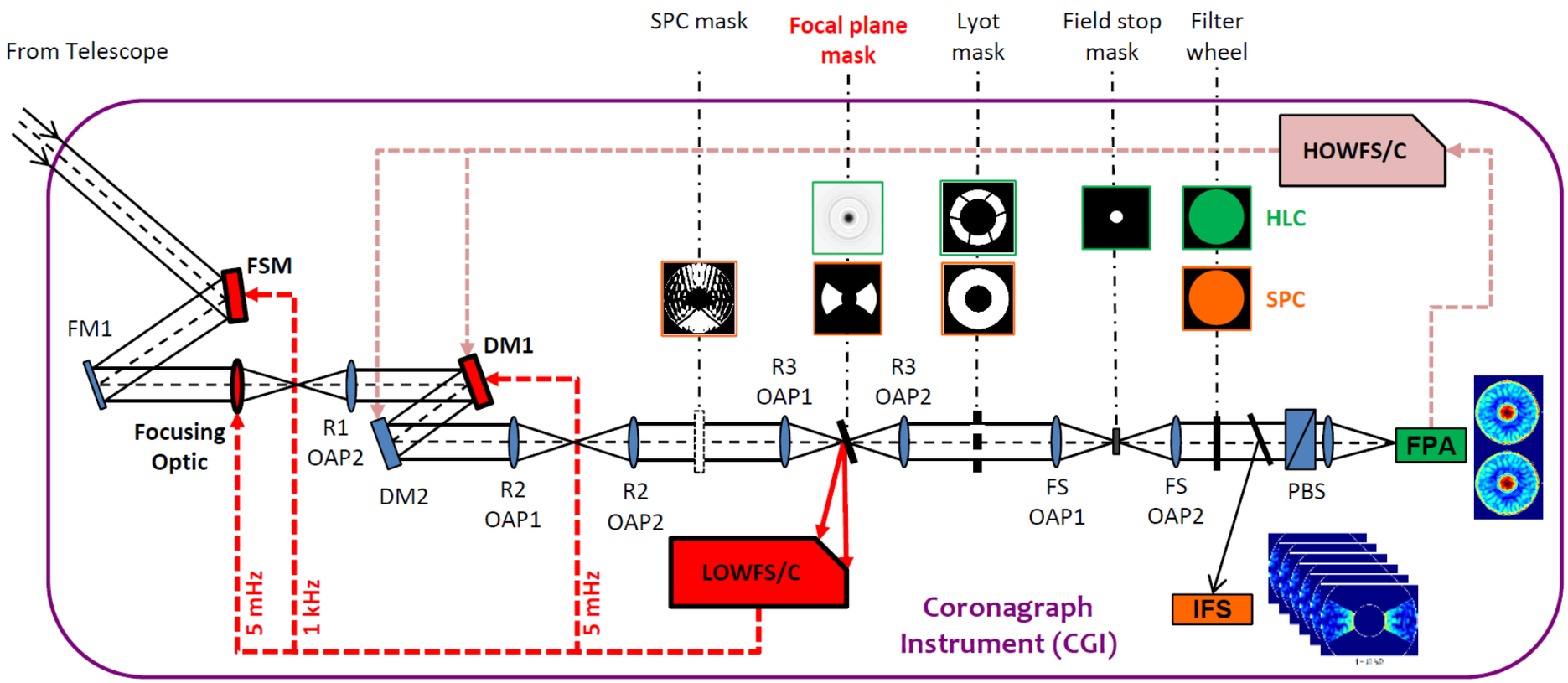


Solar Array /
Sunshield
Wide Field
Instrument
Serviceable
Spacecraft
Module
High Gain
Antenna
(2X)
Outer Barrel
Assembly
2.4m Primary
Mirror
Telescope
Aft Metering
Structure
AFTA
Coronagraph
Instrument

# Internal Coronagraph Basics

# WFIRST CGI

JPL

- Brown lines in upper right: Speckle Control via deformable mirrors
- Red lines in lower left: Low Order WaveFront Sensor (LOWFS) and control of tip-tilt, focus, astigmatism, and coma
- Select combinations of masks to make an SPC or HLC coronagraph for various wavelength bands

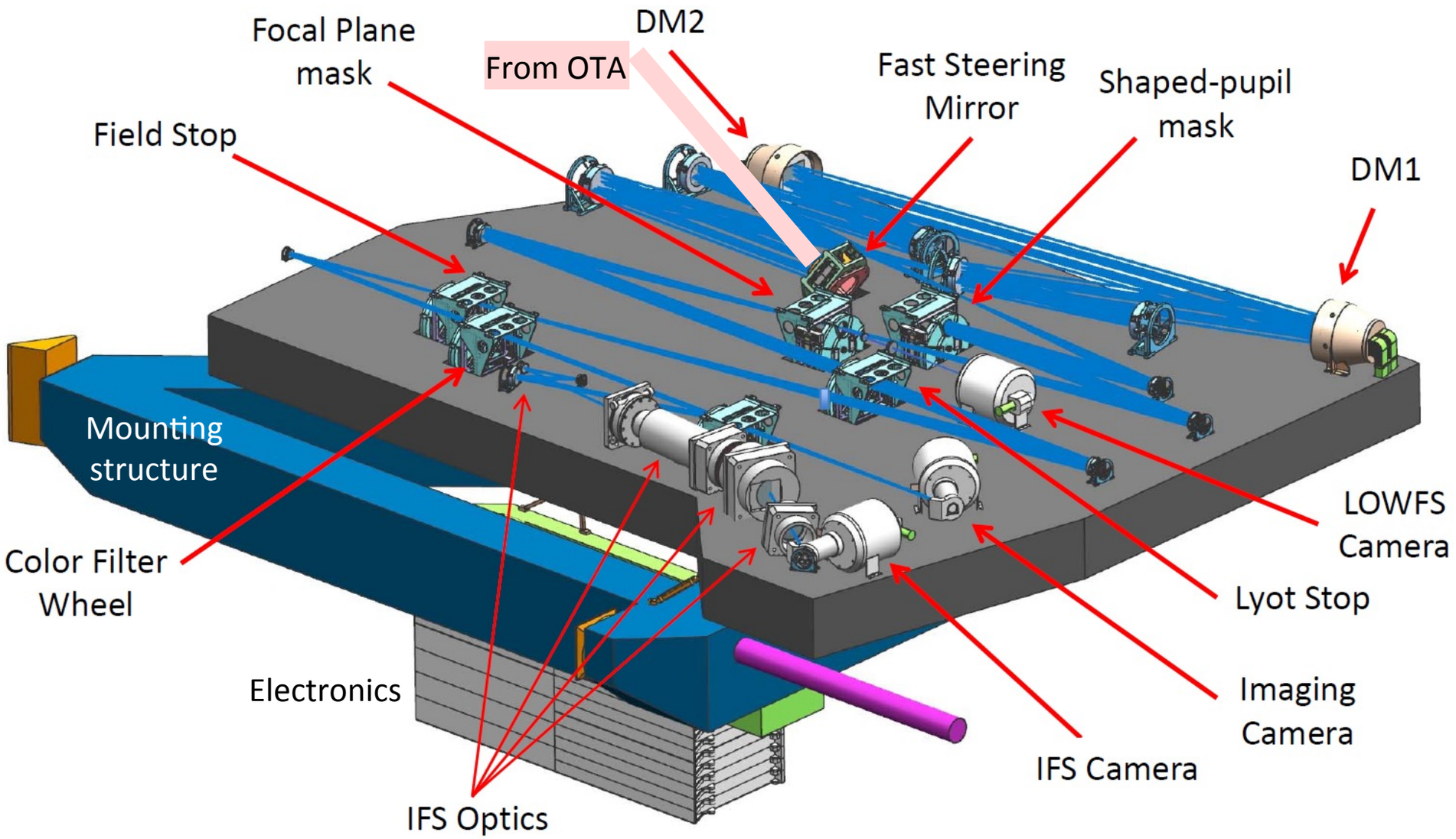



Credit: JPL WFIRST CGI Team

# WFIRST CGI

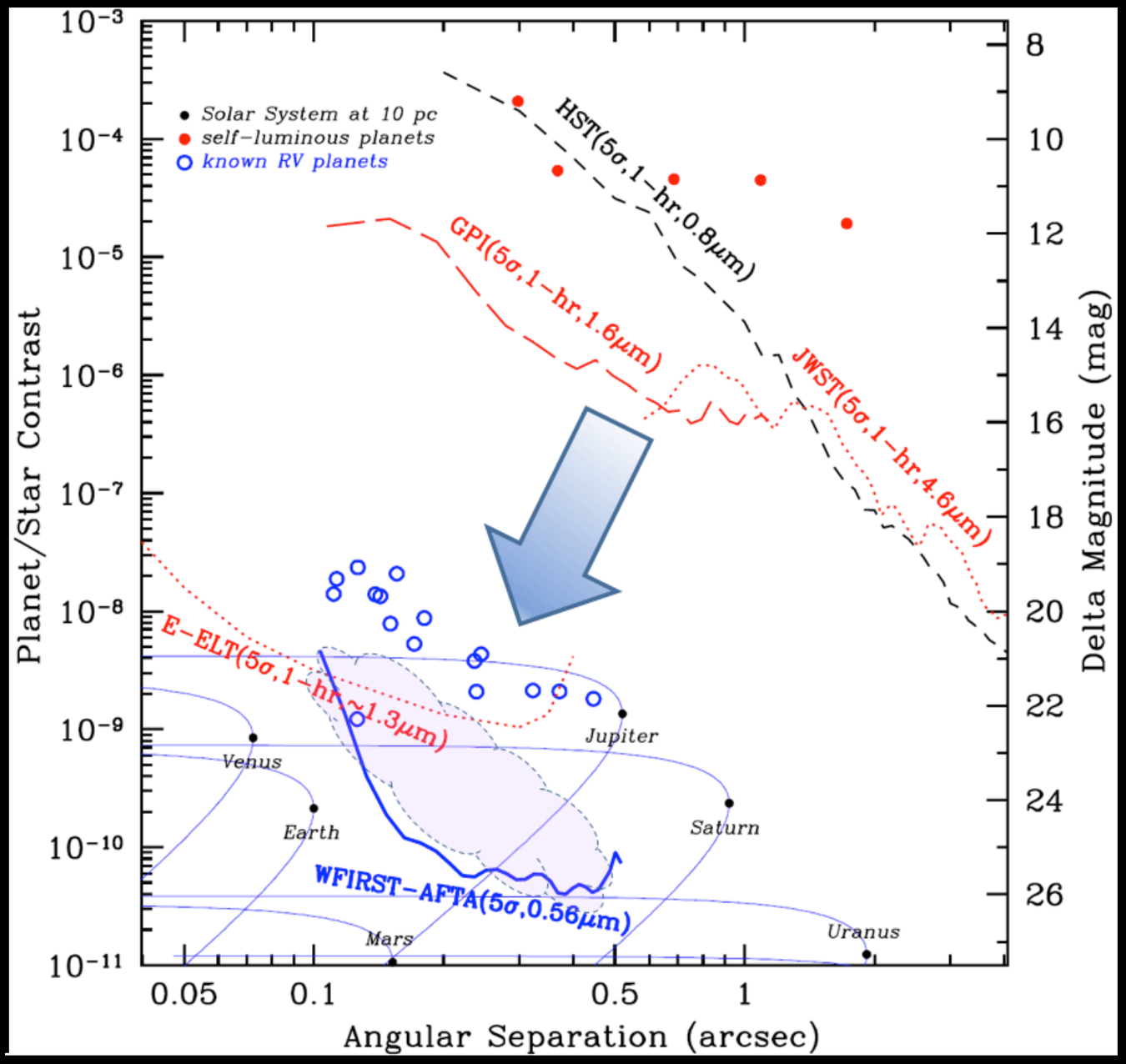
JPL

- Drawing of the coronagraph optical bench layout
  - Beam from telescope enters in the middle of the table




Credit: JPL WFIRST CGI Team

# CGI Performance




- Technology Demonstration
- Broadband Imaging (430-970 nm)
- R~70 spectroscopy (600-970 nm)
- Polarimetric Capabilities

Spergel et al (2015), WFIRST-AFTA 2015 Report

# High-Level Science Goals: Planets

- Detect planets spanning a range of physical properties, probing populations beyond the limits of current surveys
- Use photometry to provide initial discriminators for the nature of the planet and explore planetary diversity
- Use spectroscopy to explore mass-metallicity relationship and cloud/haze formation

# High-Level Science Goals: Disks

- Directly image and resolve scattered light from exo-zodi
- Measure optical properties of disk/zodi to put constraints on grain properties
- Determine spatial disk structure and link to planet formation
- Understand diversity of disk/zodi systems through multi-band photometry


# Planet Detection:

# Is There a Planet in My Data?

# Planet Search Mode

## Hybrid Lyot Mode

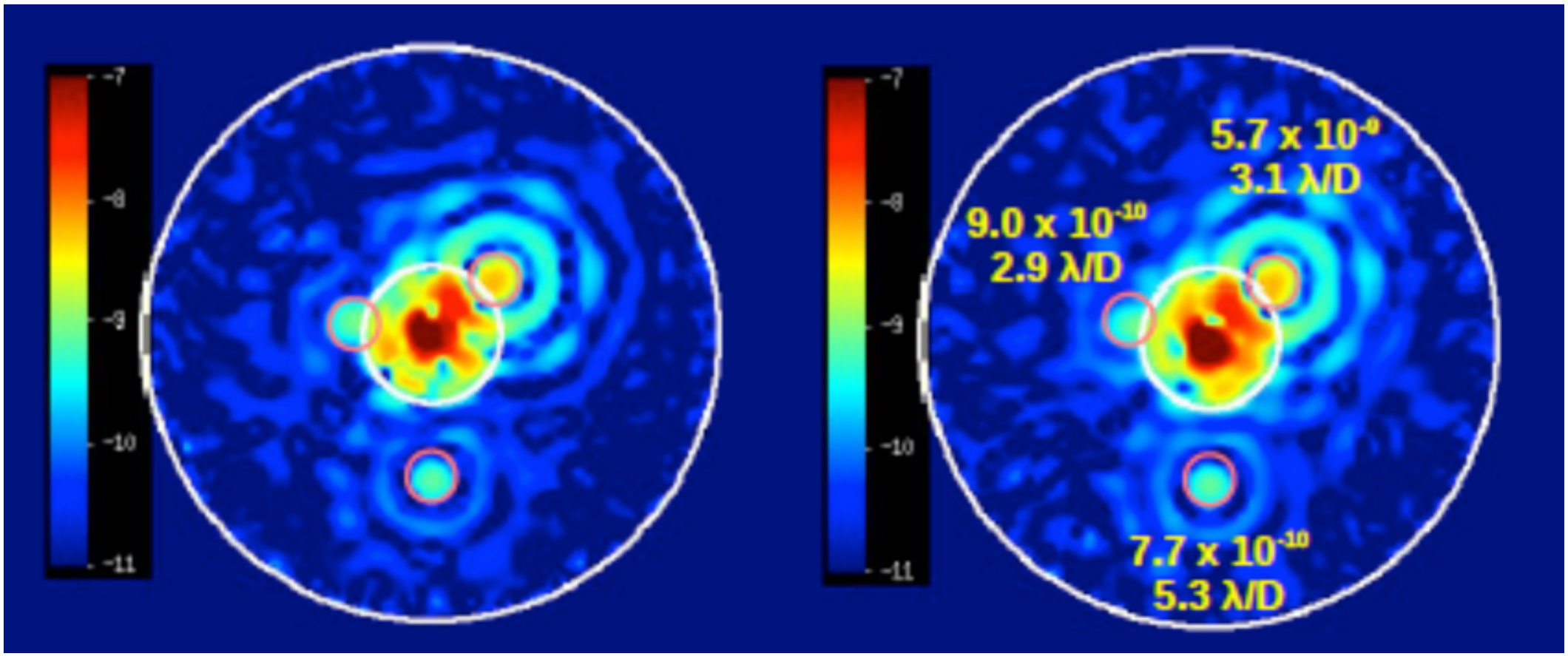



Figure Credit: JPL WFIRST CGI Team

# Post Processing

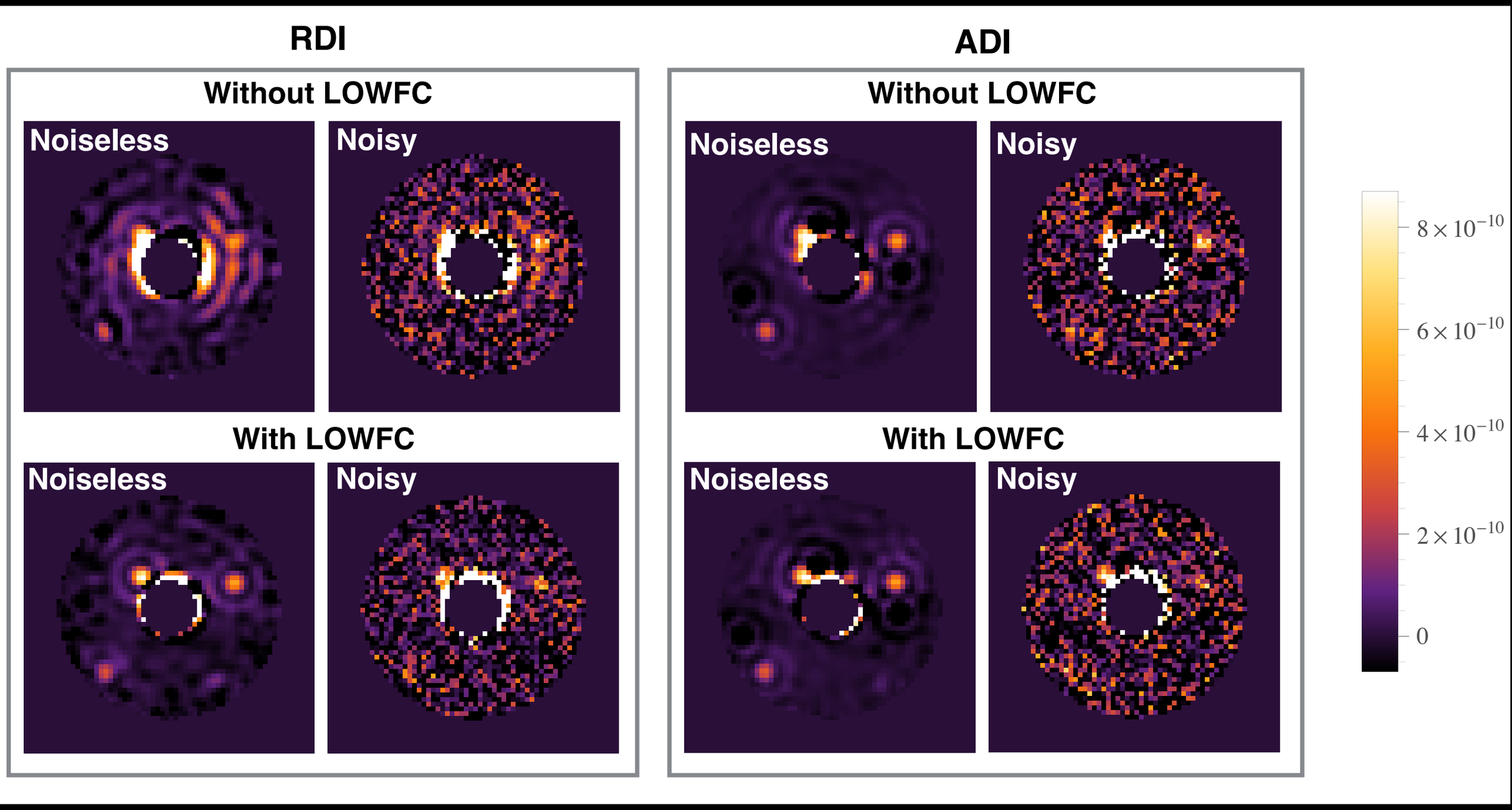



Figure from L. Pueyo (STScI)


# Techniques and Lessons Learned From Ground and Space

- See Talk by Mawet:

http://nexsci.caltech.edu/workshop/2016/Sagan2016_mawet_v2.pdf

- See Talk by Pueyo:

http://nexsci.caltech.edu/workshop/2016/Sagan2016Pueyo2.pdf


# Planet Characterization:

# What Kind of Planet is in My Data?

# WFIRST CGI Exoplanet Yields

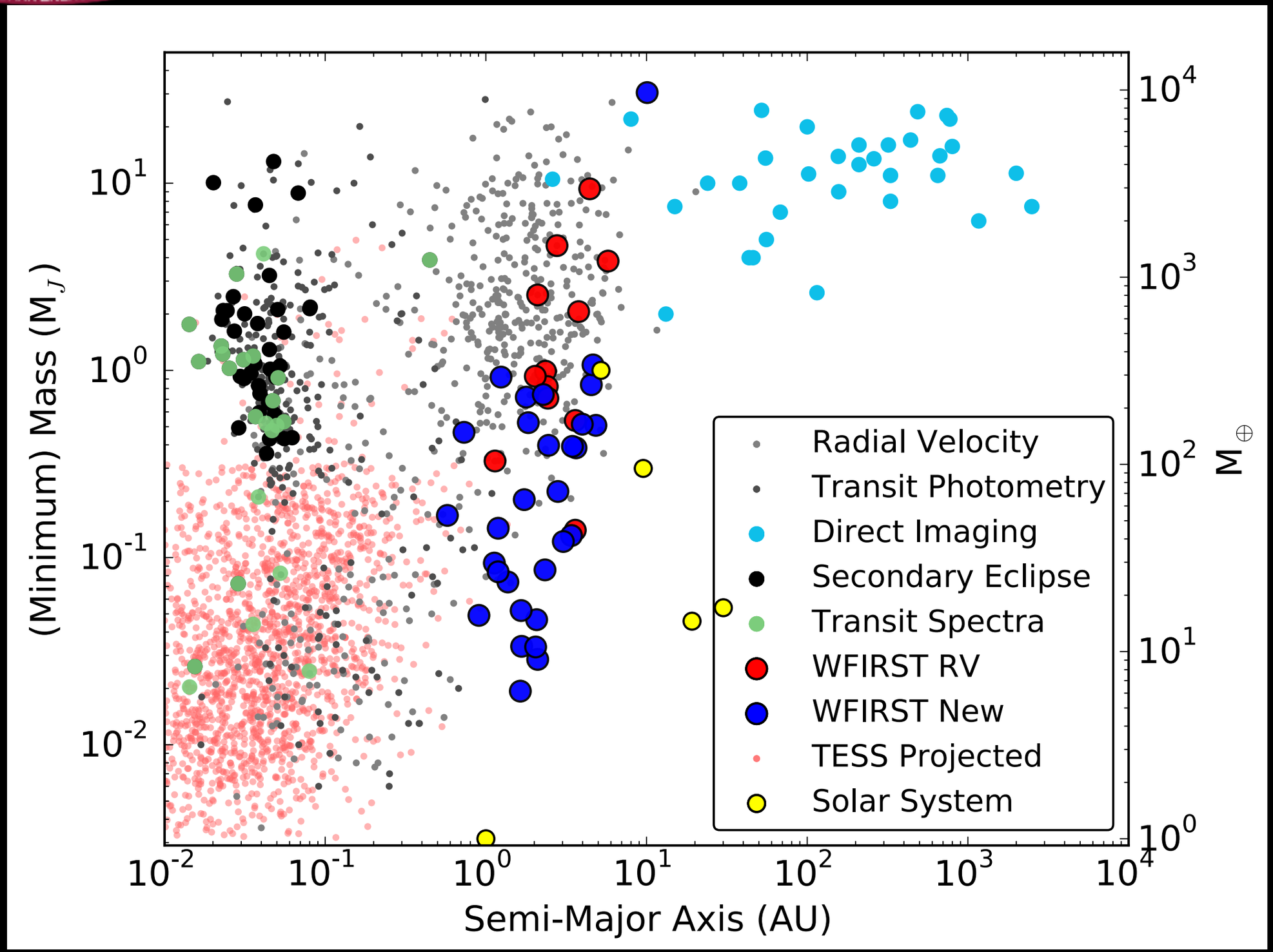



Figure Credit: D. Savransky/Eric Neilsen

# Planets Around Other Targets: WFIRST Bands

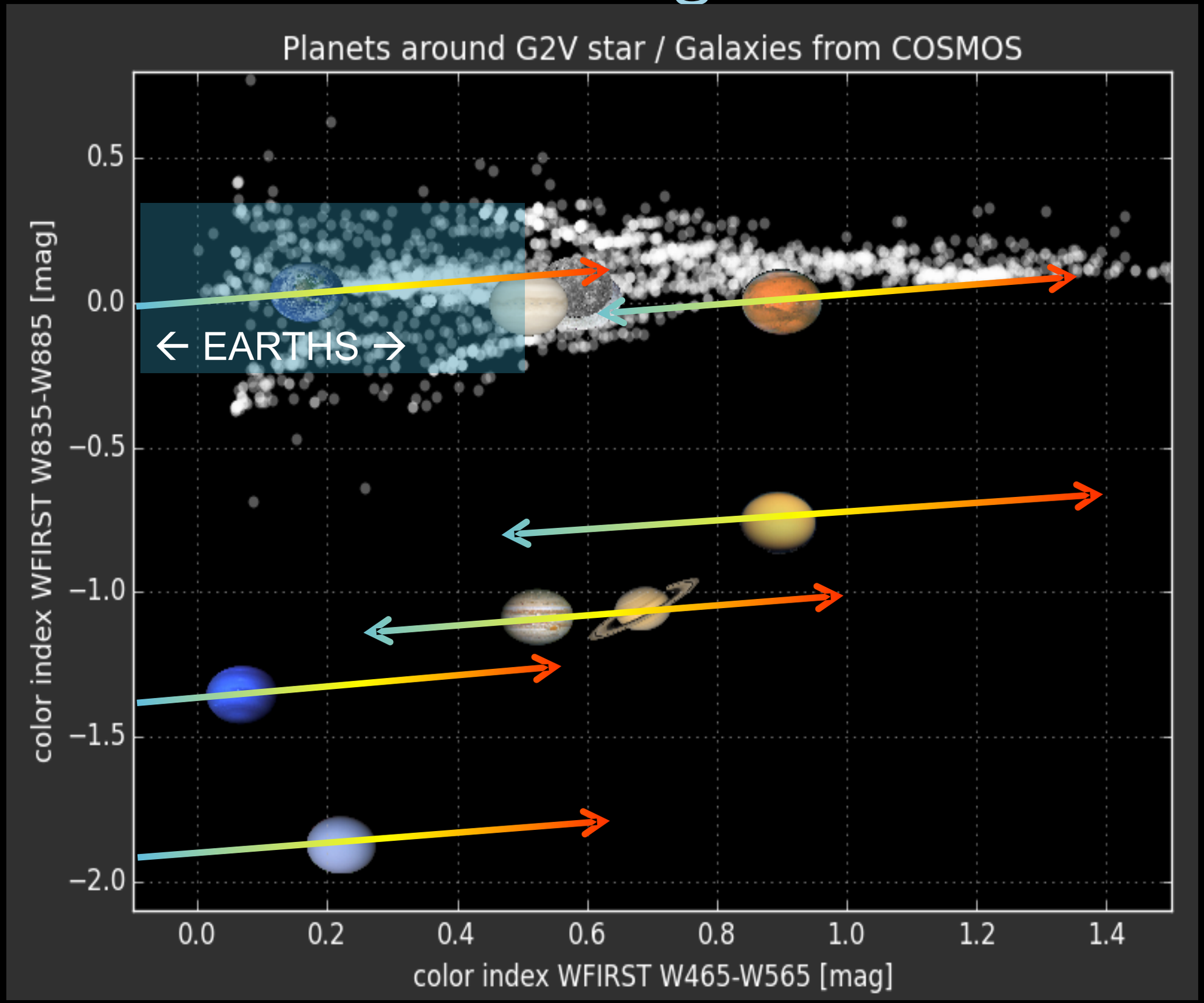
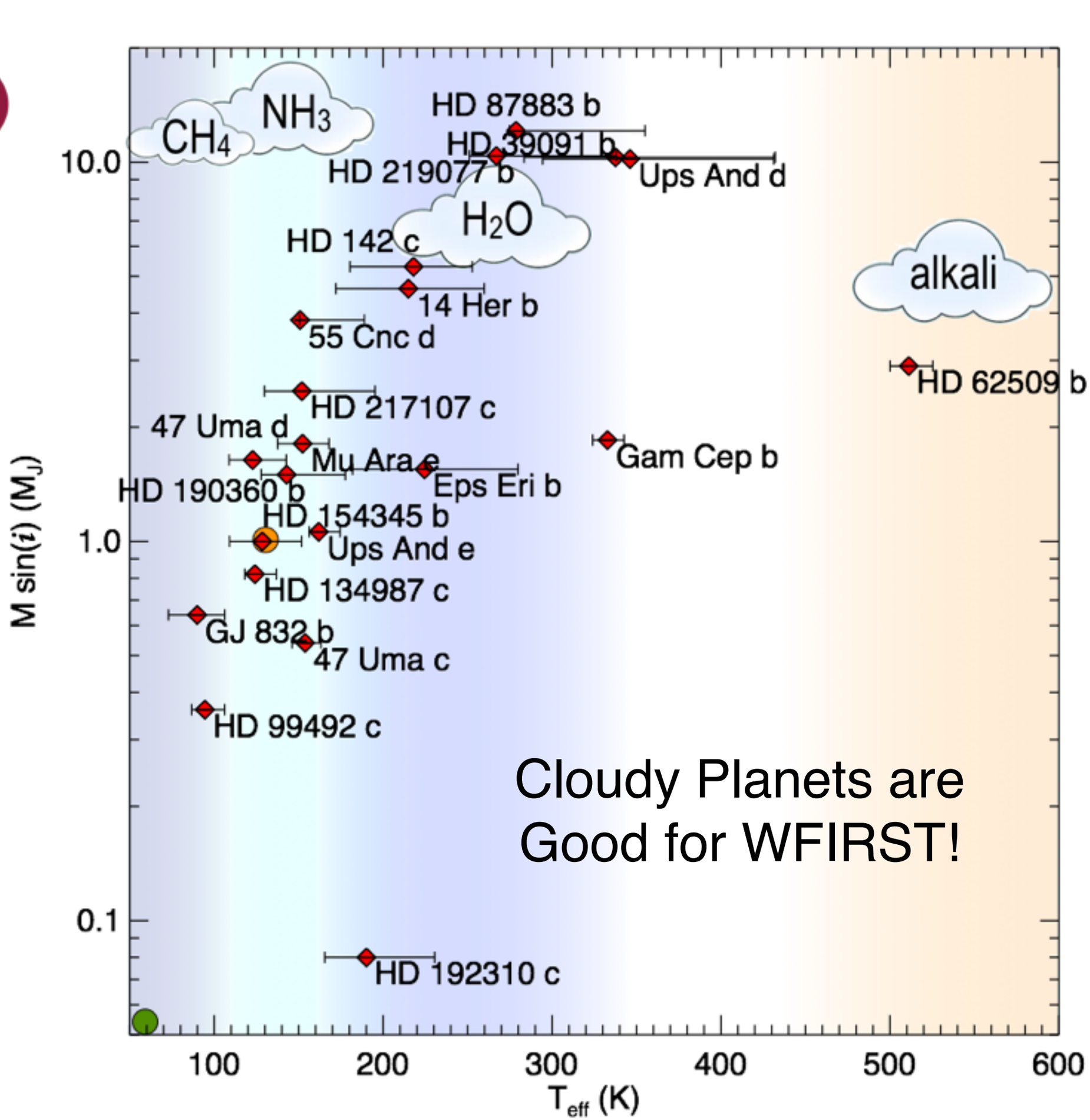
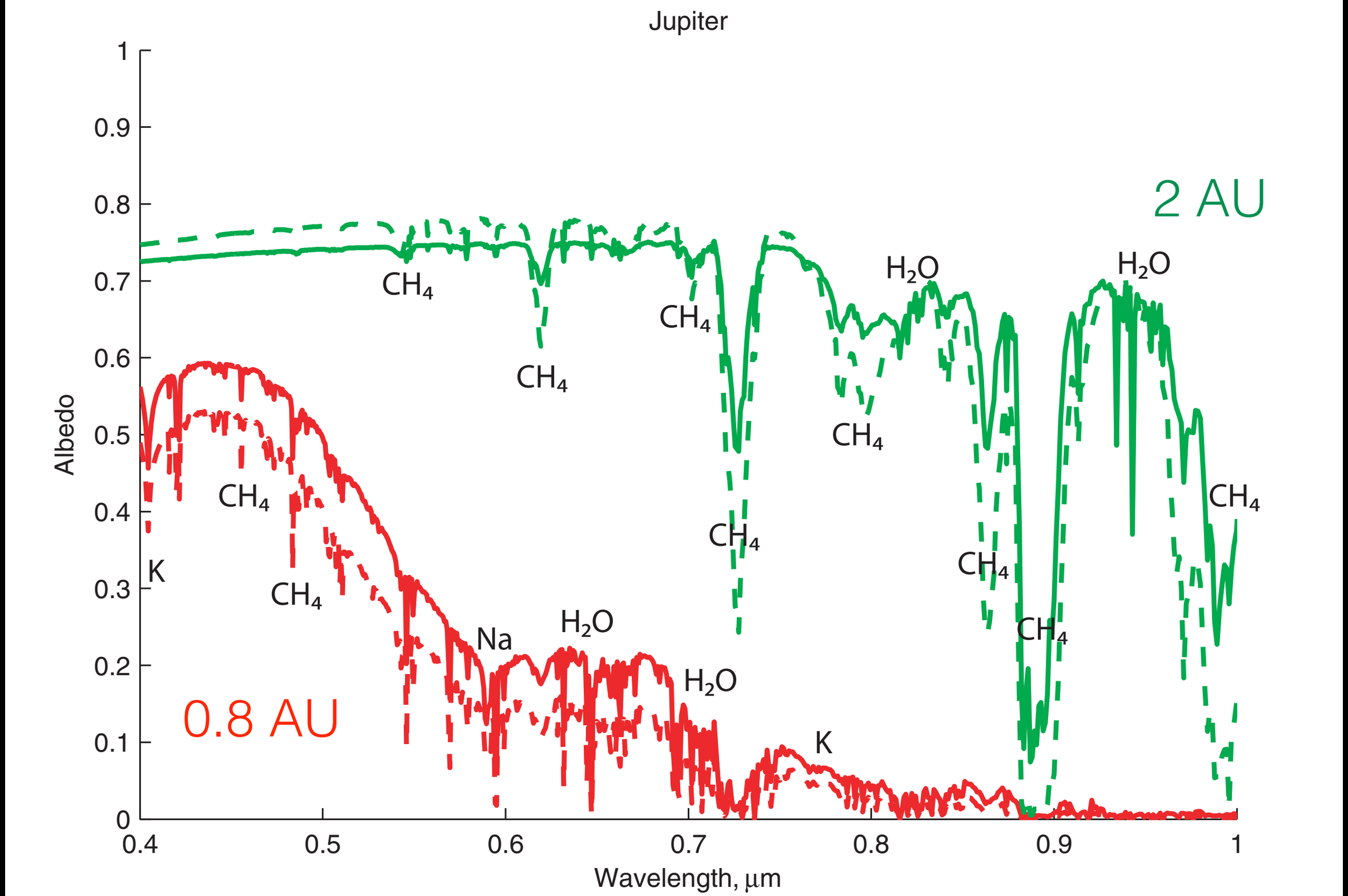



Figure by M. Turnbull

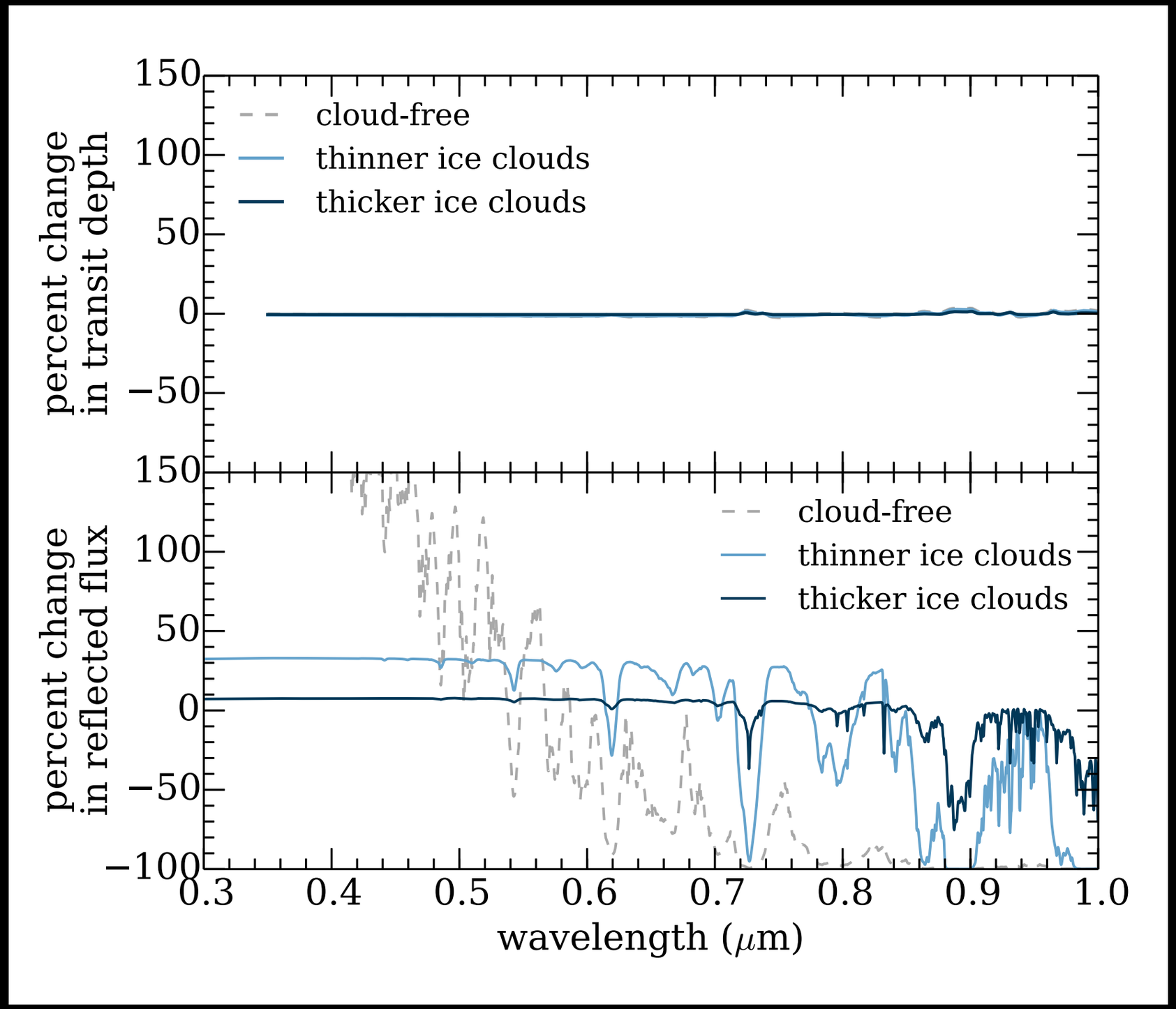

WIDE-FIELD INFRARED SURVEY TELESCOPE
WFIRST
ASTROPHYSICS • DARK ENERGY • EXOPLANETS


CH4
NH3
H2O
alkali
HD 87883 b
HD 39091 b
HD 219077 b
Ups And d
HD 142 c
14 Her b
55 Cnc d
HD 62509 b
HD 217107 c
47 Uma d
Mu Ara e
Gam Cep b
Eps Eri b
HD 190360 b
HD 154345 b
Ups And e
HD 134987 c
GJ 832 b
47 Uma c
HD 99492 c
HD 192310 c
Cloudy Planets are
Good for WFIRST!
10.0
1.0
0.1
100
200
300
400
500
600
M sin(i) (MJ)
Teff (K)




Cahoy et al (2010)

# Super-Earths in Reflected Light

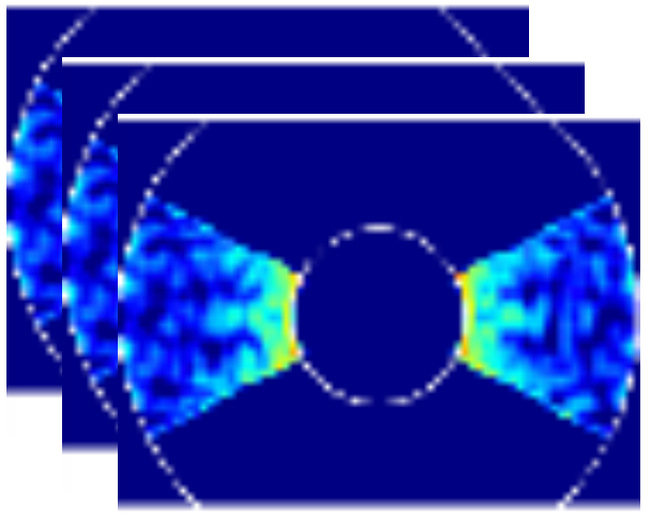



Morley et al. (2015)

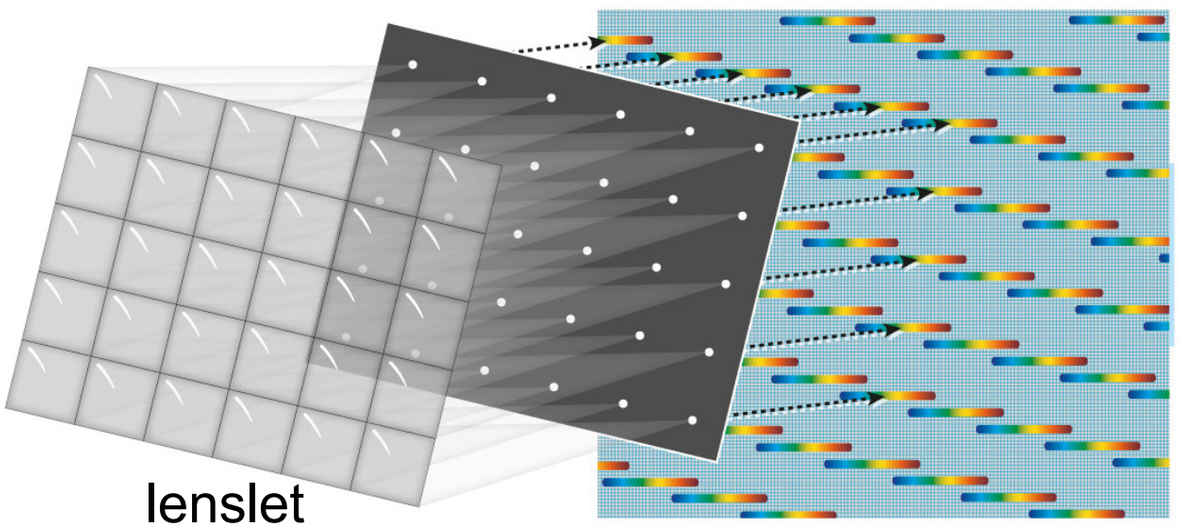
# Planet Spectroscopy Mode

## Shaped Pupil Spectroscopy Mode

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



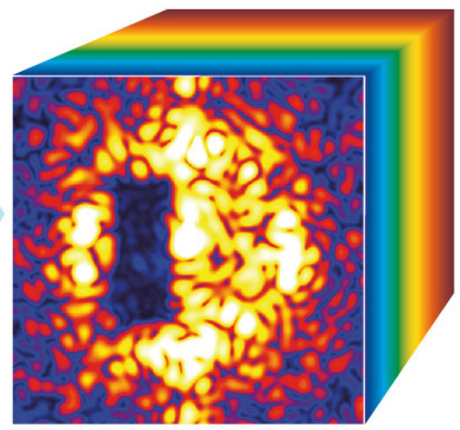
SPC images in 3 18% bands



lenslet array

pinhole mask

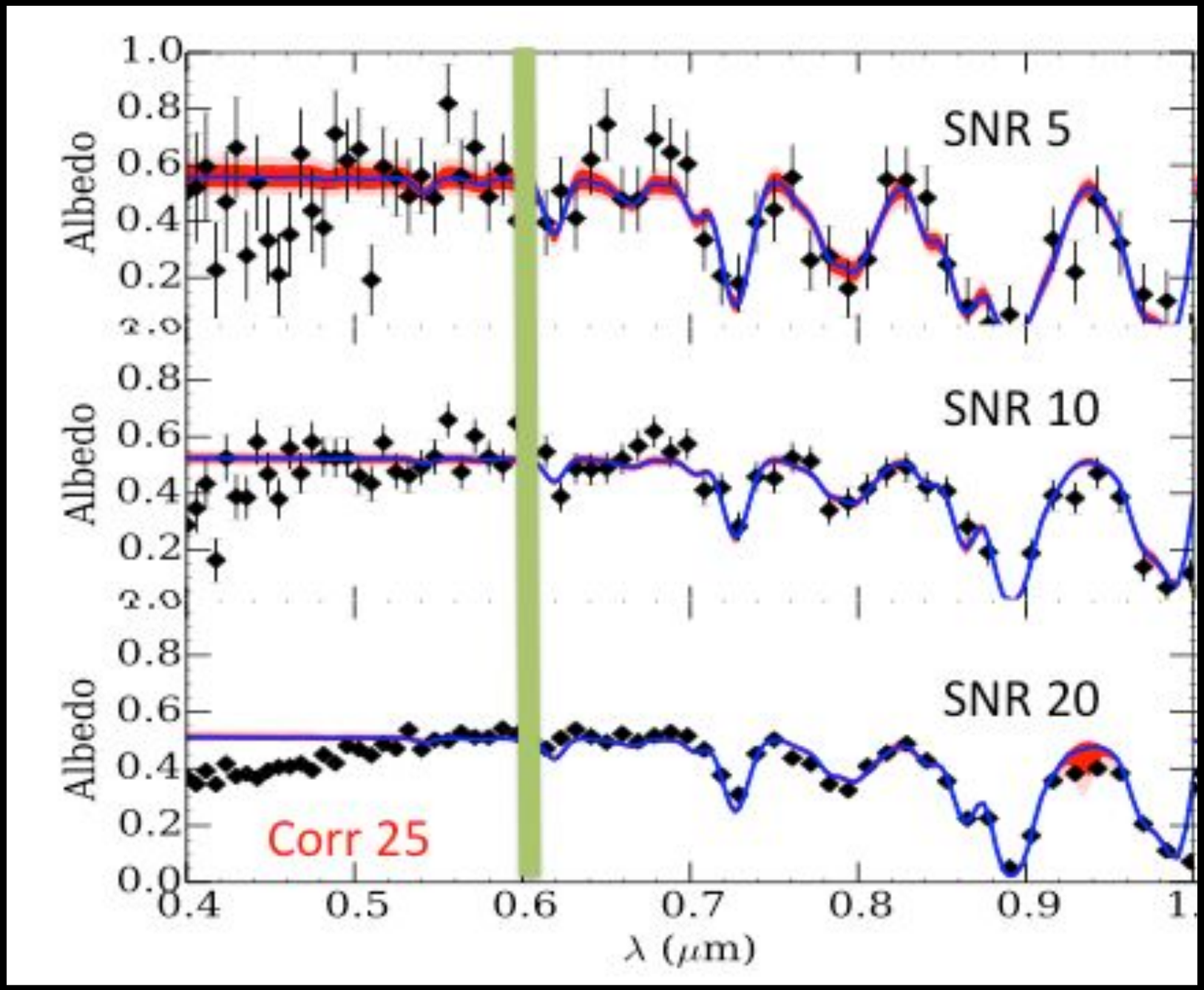
dispersed lenslet images



extracted data cube

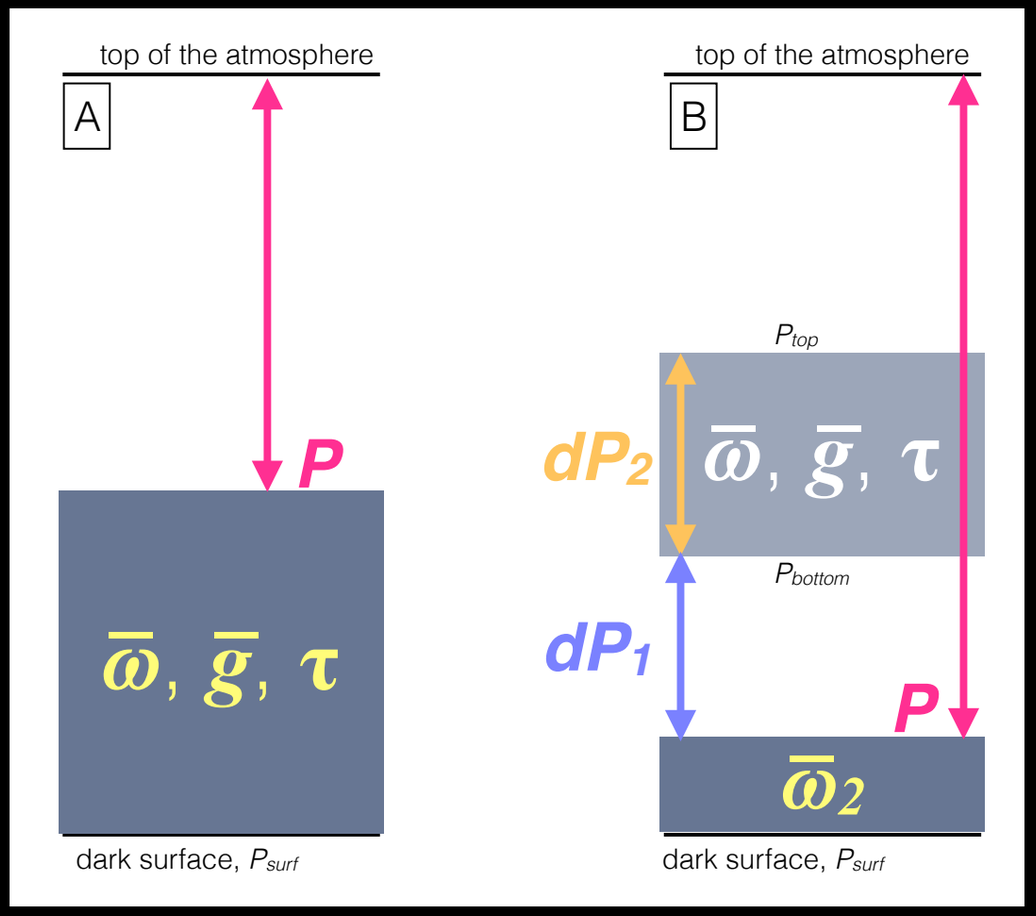
Figure Credit: JPL WFIRST CGI Team

# WFIRST CGI Spectra

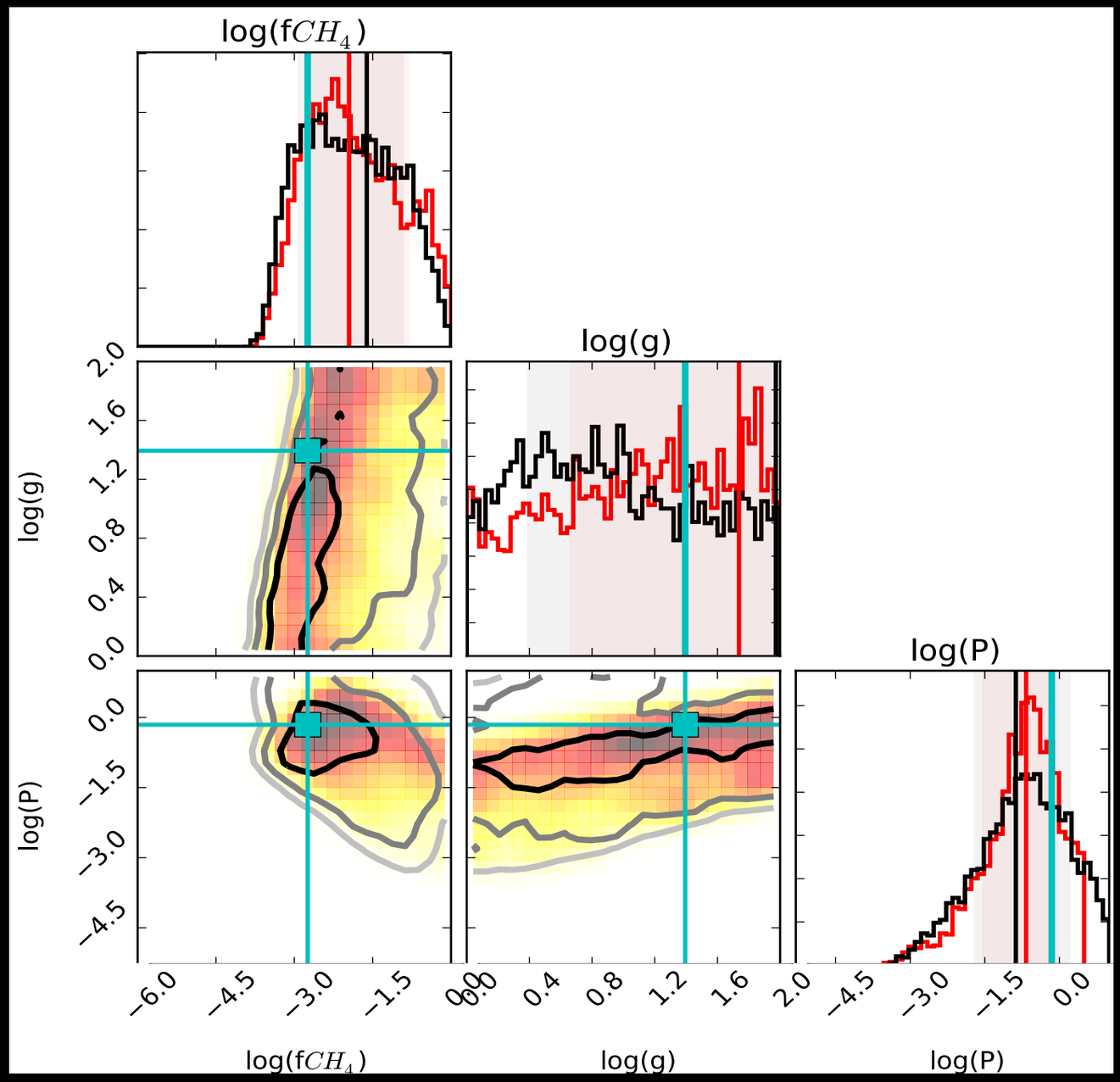



Lupu et al. (2016)

# Atmospheric Retrieval Studies

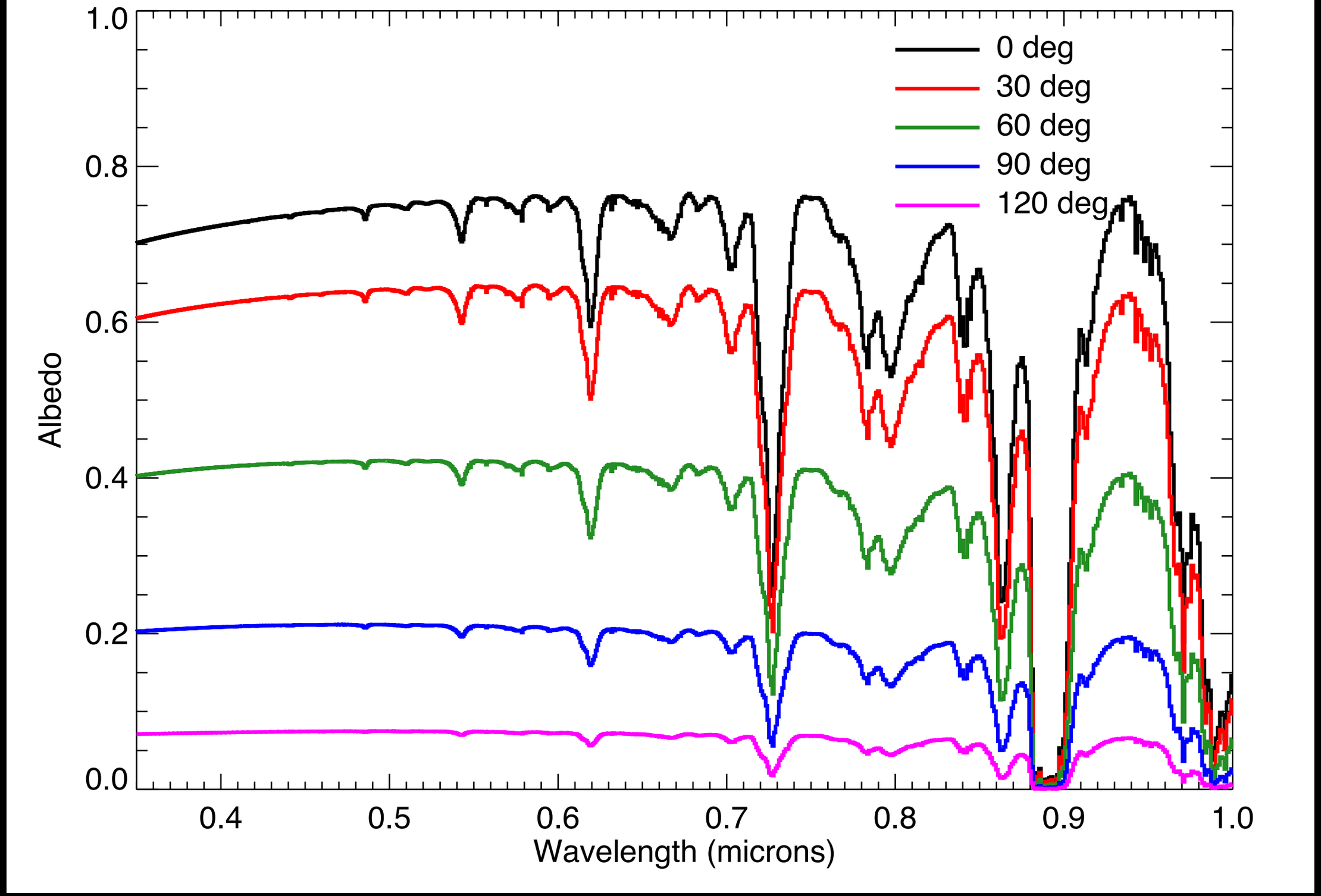



- Methane Abundance
- Surface Gravity
- Cloud/Haze Properties



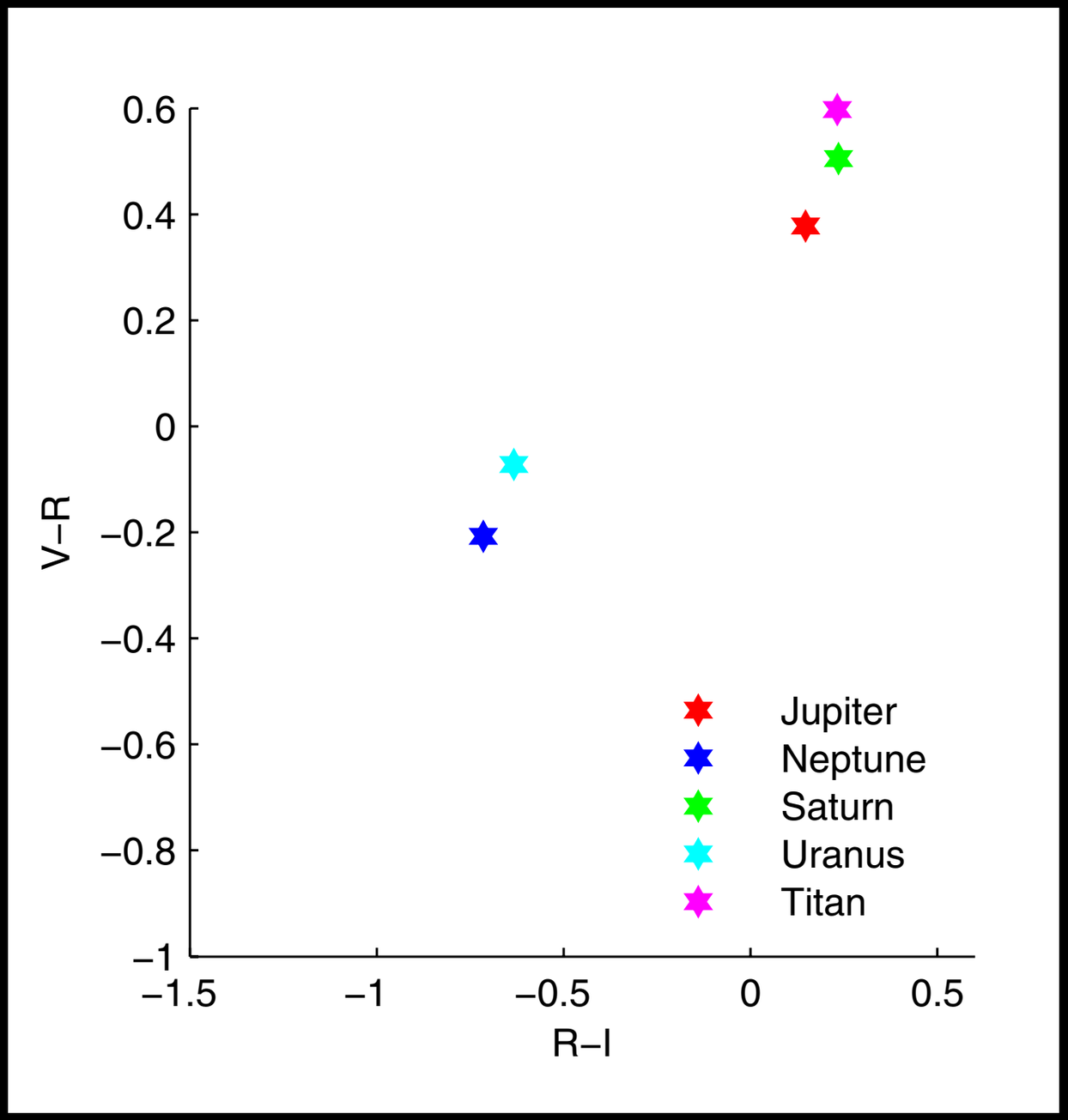

Lupu et al. (2016)

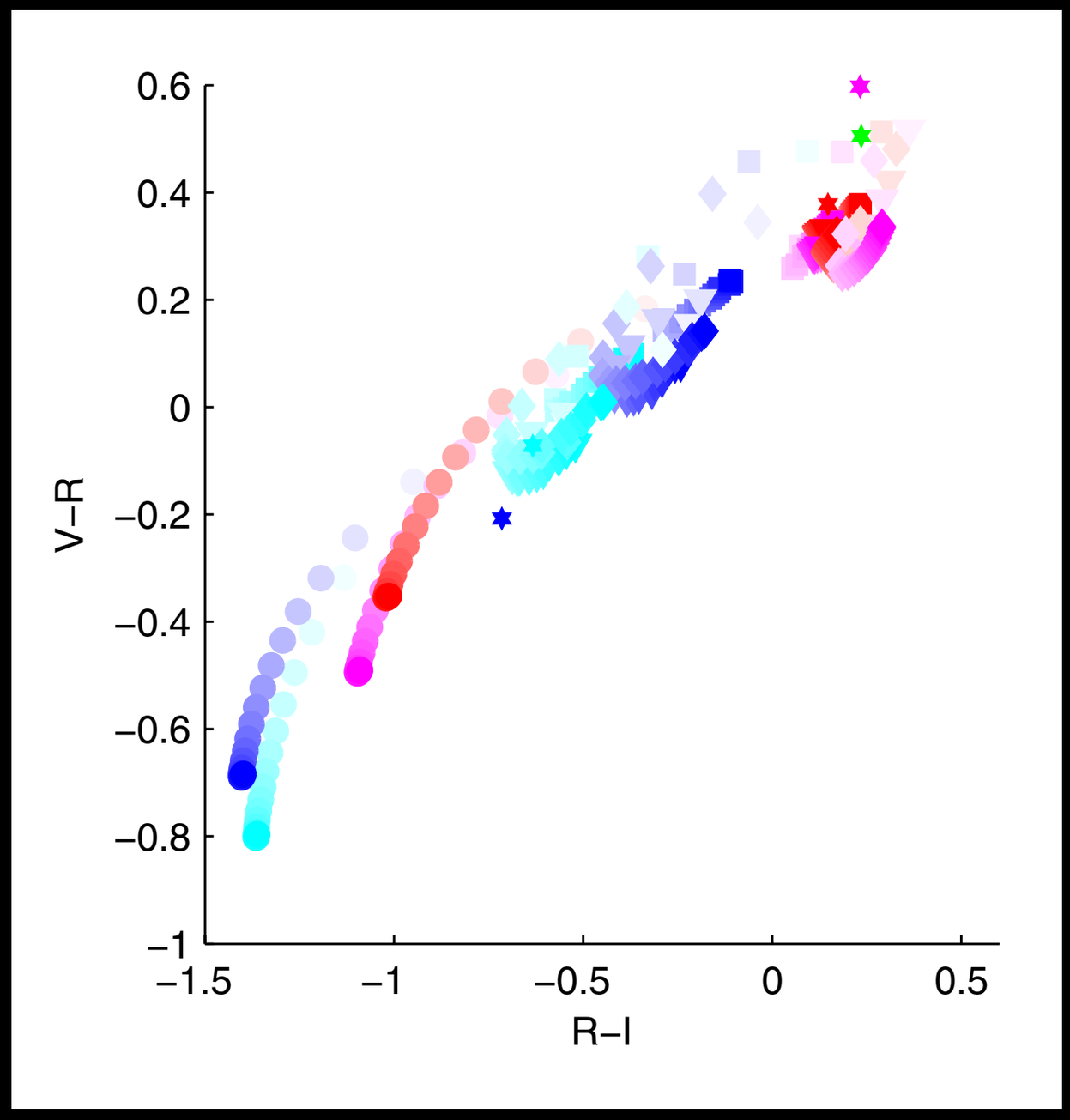
# Orbital Phase Matters!!!




Lewis et al, in prep

# Orbital Phase Matters

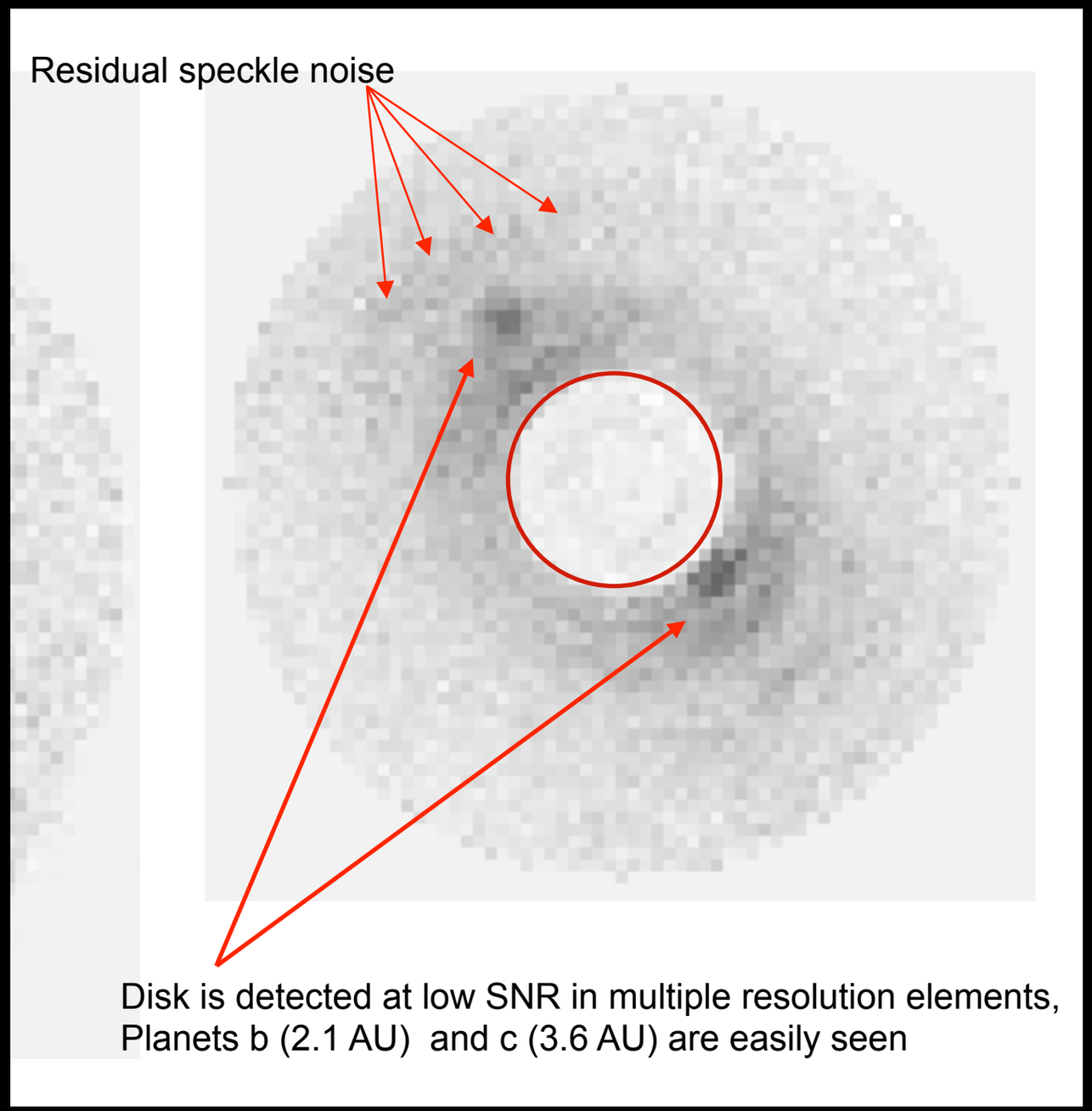


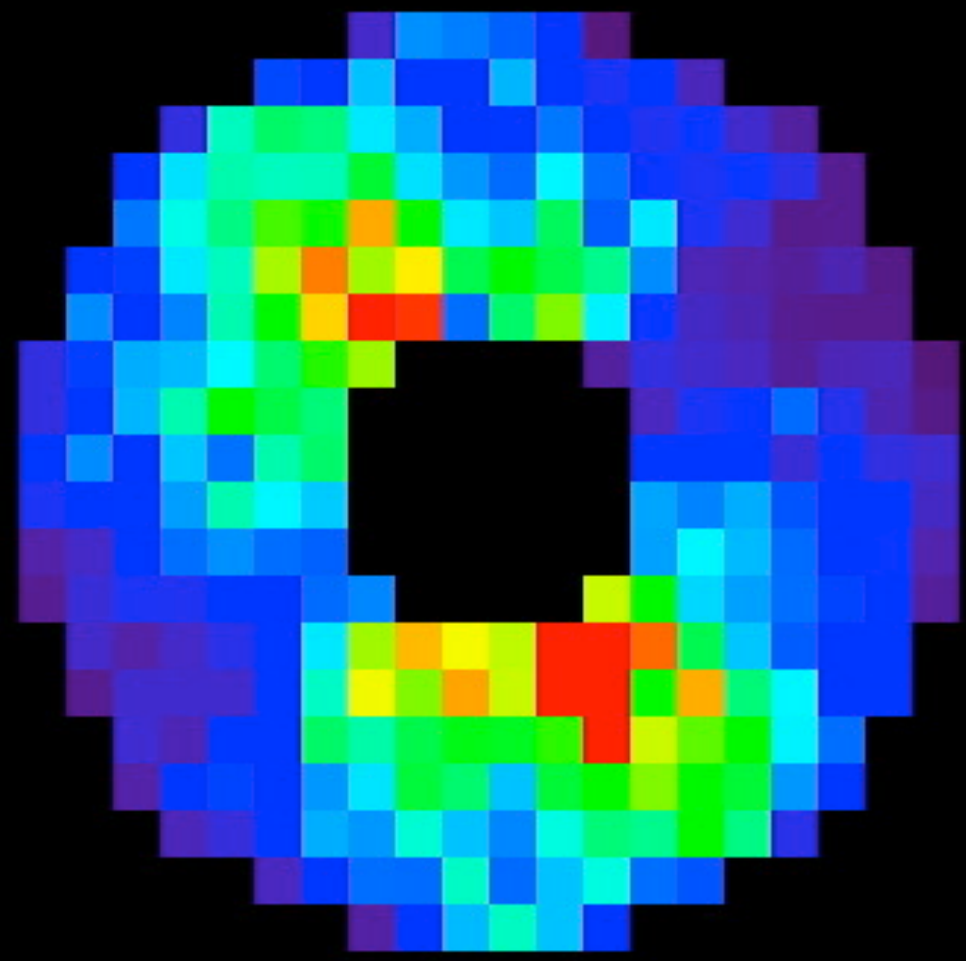

Cahoy et al (2010)

# Disk Detection and Characterization

# Exozodi

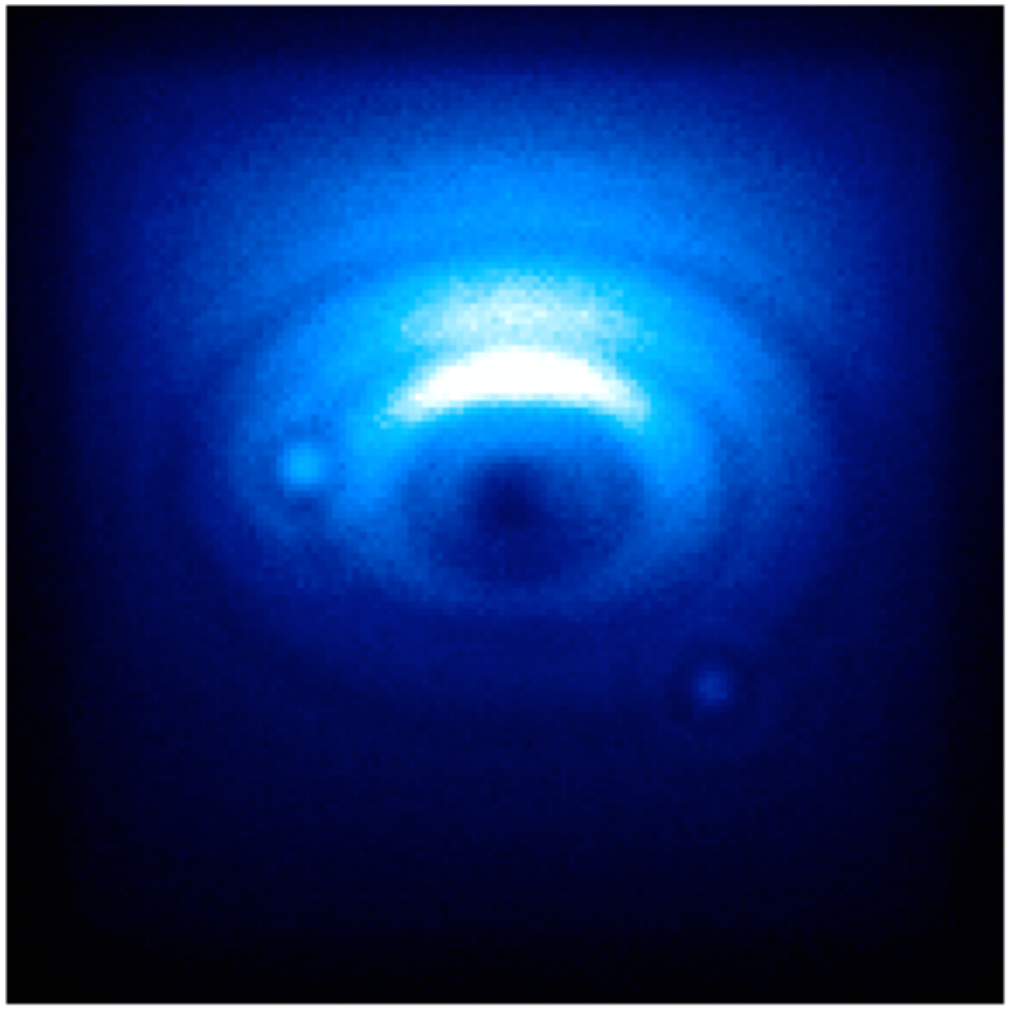



47 UMa + 30 zodi

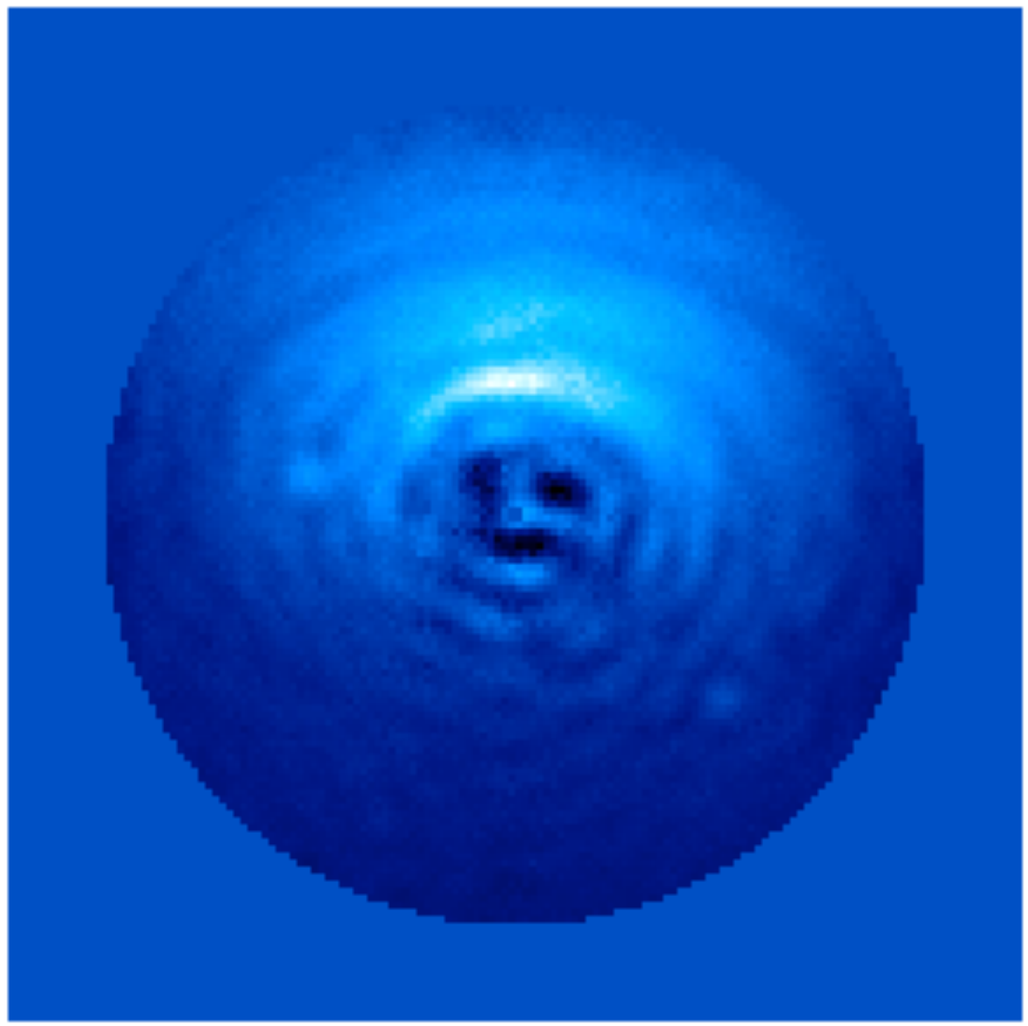


Binned SNR map
(peak SNR=15)

# Gaps in Disks



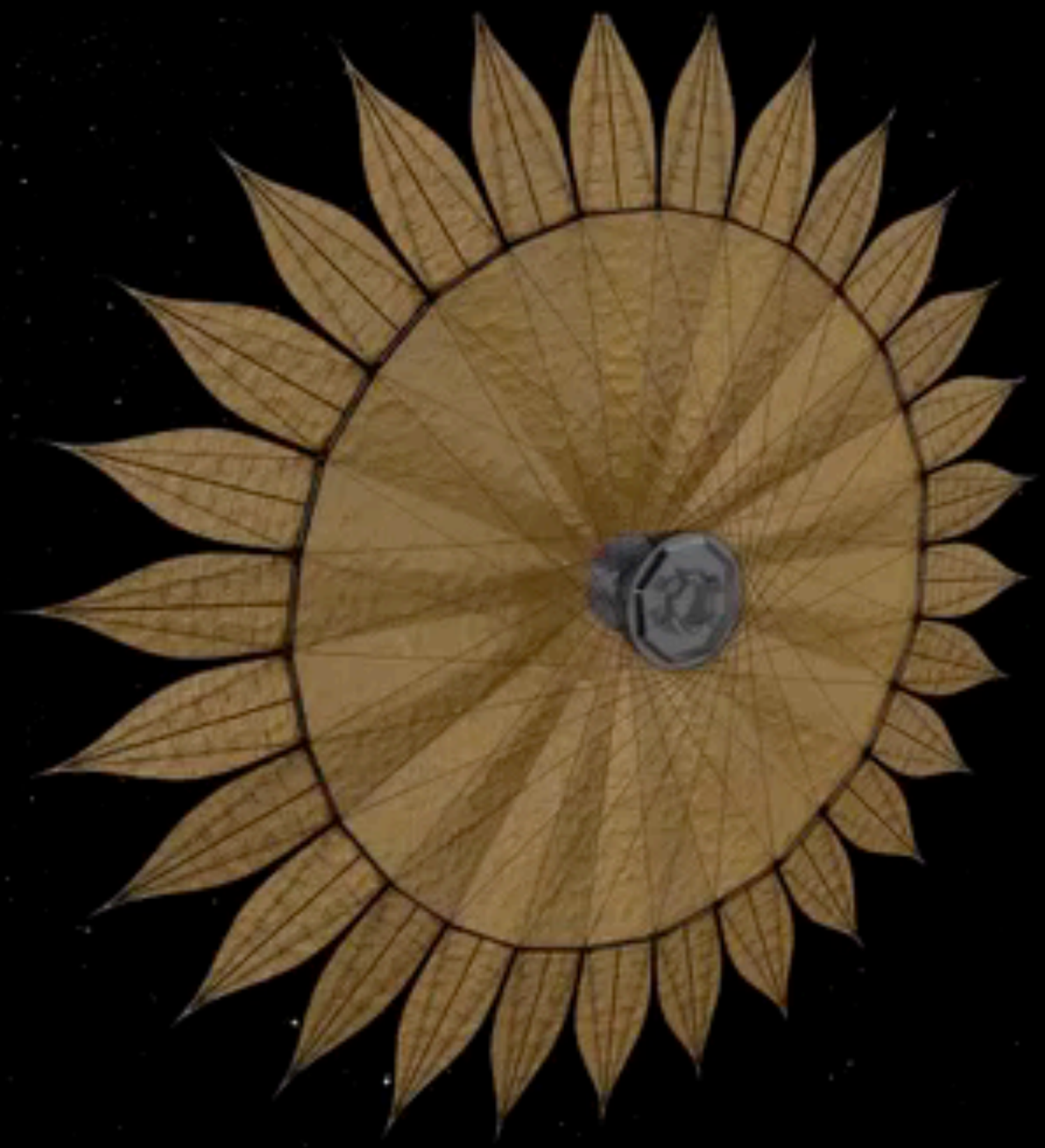
Original Scene



Original Scene as Viewed with WFIRST CGI

Figures from John Debes (STScI)

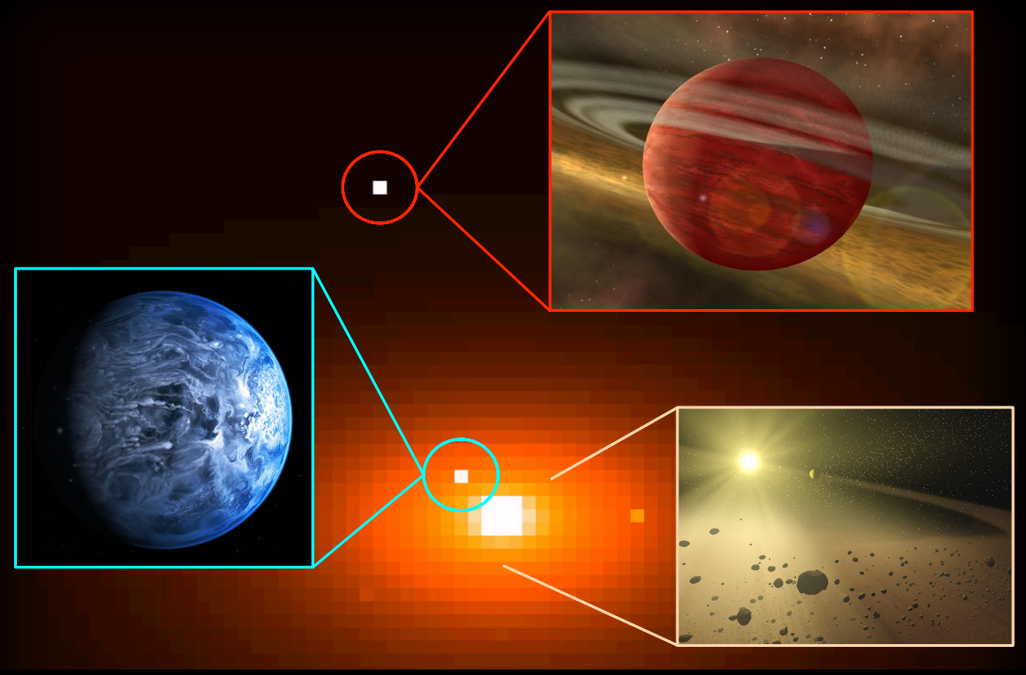
# WFIRST+Starshade



## Studying Other Worlds with the Help of a Starshade

# Opportunities


## Turnbull SIT Data Challenges



*Dr. Margaret Turnbull, SETI Institute*
*mturnbull@seti.org*
*Carl Sagan Center for the Study of Life in the Universe*

# WFIRST Exoplanet Data Challenge 2016

*Goal is to Conduct "Blind" Spectral Retrieval Studies*, including In-House and Community Data Challenges.

- use assembled spectra and cubes for "blind" studies
- test extraction algorithms to find everything
- test modelers' ability to retrieve own models
- test inter-team differences
- include placebos and non-planets
- map science yield vs spectral resolution and SNR
- start with noisey spectra and add complexity gradually
- FIRST DATA CHALLENGE: AUGUST 2016

# First Spectral Retrieval Challenge

1. Opening/Closing Dates: August 15 – November 15, 2016

   Informational Telecons:

   Monday July 25, at 3PM EDT = 2pm CDT = 1pm MDT = 12pm PDT

   and

   Thursday July 28, at 2PM EDT = 1PM CDT = 12pm MDT = 11am PDT

2. Distribute several planet spectra with range of possible planet parameters (temperature, clouds, $H_2O$, $CH_4$, $NH_4$) – both for known RV systems and discovery planets (Hu, Cahoy, Lewis)
3. Include appropriate stellar spectra for division
4. Add instrumental noise
5. Explore SNR at 5-20, R from 25 - 70
6. Distribute via IPAC
7. Interpret findings in terms of parameters relevant to the SRD

# Online Resources


http://wfirst.gsfc.nasa.gov


http://www.stsci.edu/wfirst


https://wfirst.ipac.caltech.edu