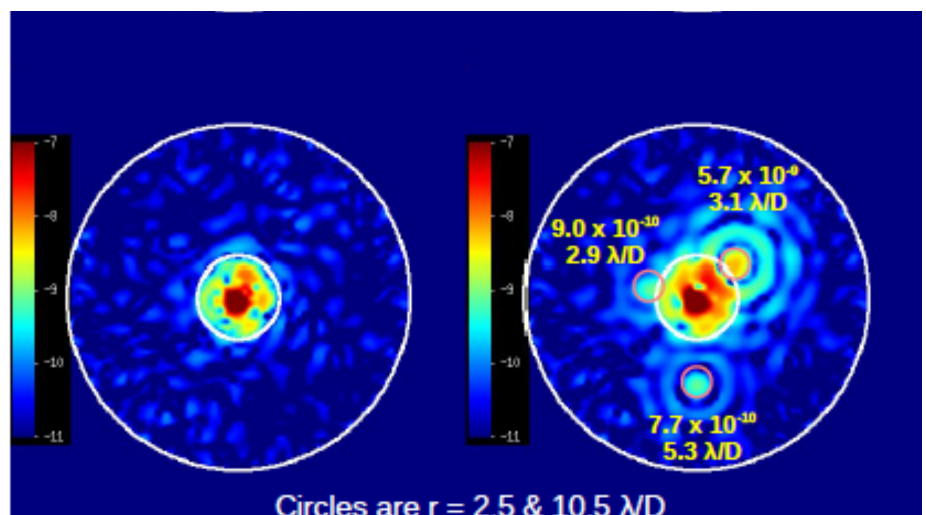
Optimizing WFIRST Coronagraph Science

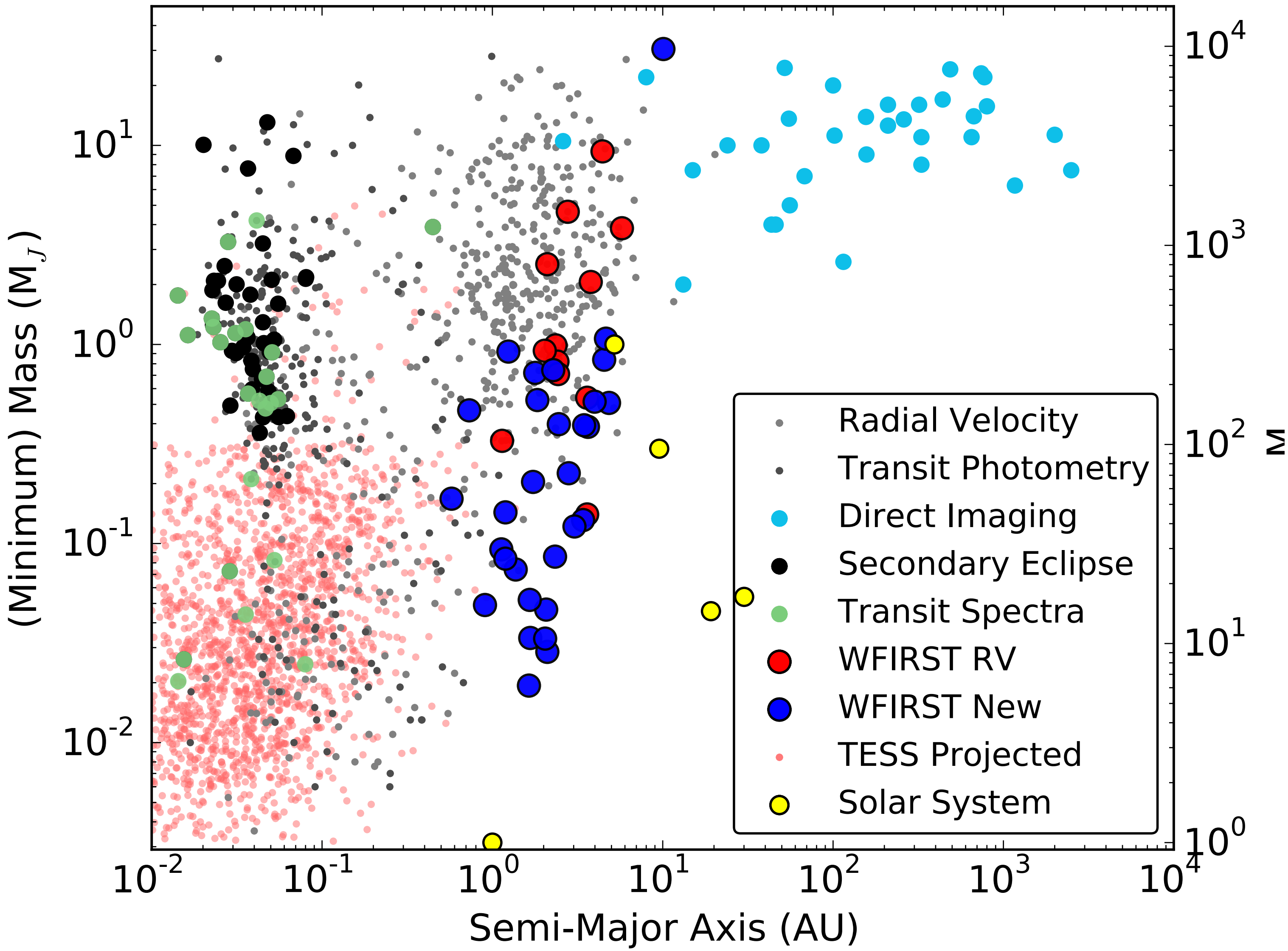
Laurent Pueyo
For Macintosh (PI) WFIRST SIT Team

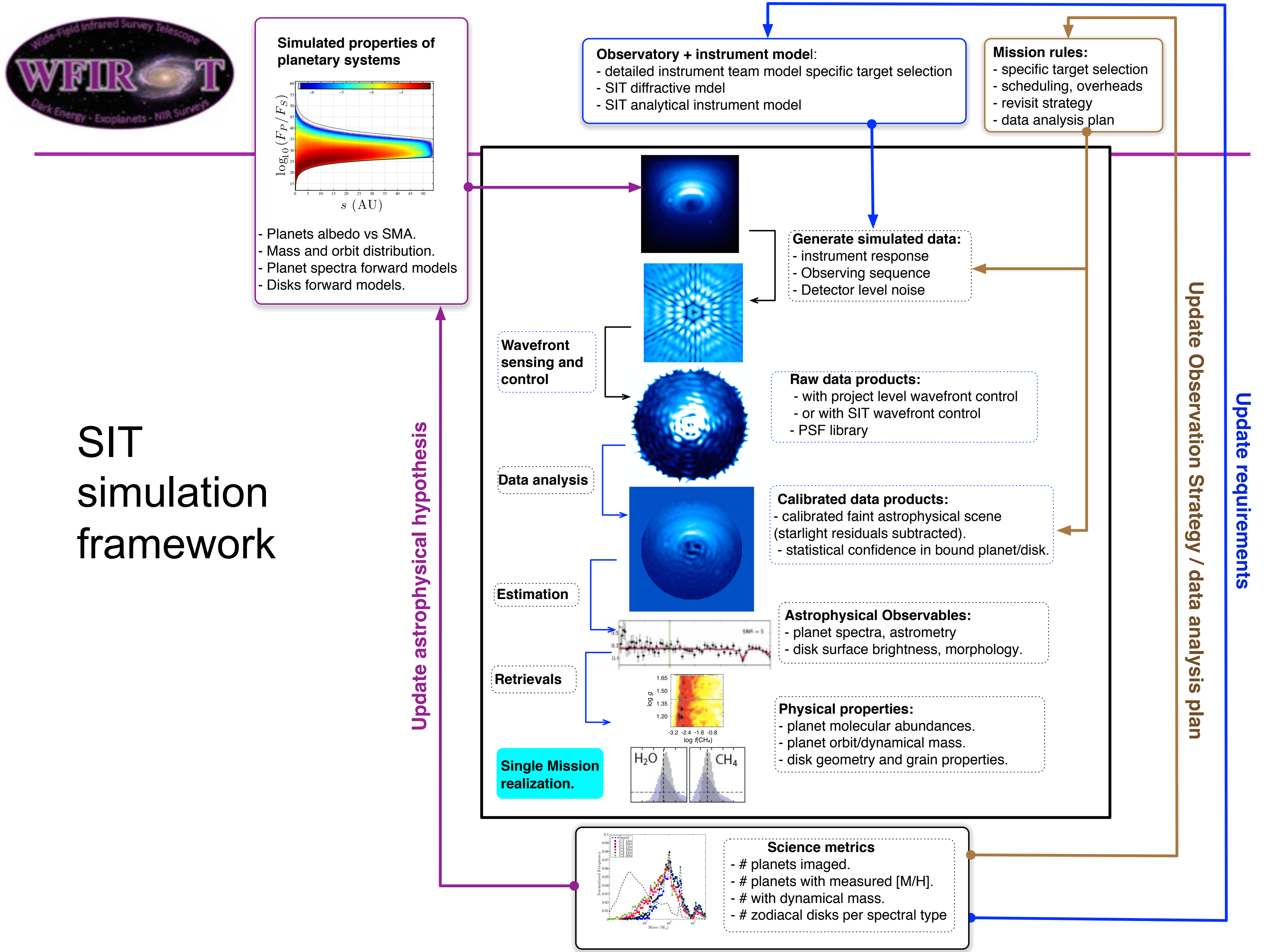
03-01-16

|47 Uma - 61 Uma|



The Potential of the WFIRST CGI





Wide-Field Infrared Survey Telescope
WFIRST
Dark Energy - Exoplanets - NIR Surveys
Simulated properties of planetary systems
$\log_{10}(F_P/F_S)$
s (AU)
- Planets albedo vs SMA.
- Mass and orbit distribution.
- Planet spectra forward models
- Disks forward models.
Observatory + instrument model:
- detailed instrument team model specific target selection
- SIT diffractive mdel
- SIT analytical instrument model
Mission rules:
- specific target selection
- scheduling, overheads
- revisit strategy
- data analysis plan
Generate simulated data:
- instrument response
- Observing sequence
- Detector level noise
Wavefront sensing and control
Raw data products:
- with project level wavefront control
- or with SIT wavefront control
- PSF library
Data analysis
Calibrated data products:
- calibrated faint astrophysical scene (starlight residuals subtracted).
- statistical confidence in bound planet/disk.
Estimation
Astrophysical Observables:
- planet spectra, astrometry
- disk surface brightness, morphology.
Retrievals
log g
log f(CH4)
Physical properties:
- planet molecular abundances.
- planet orbit/dynamical mass.
- disk geometry and grain properties.
Single Mission realization.
H_2O
CH_4
SIT simulation framework
Update astrophysical hypothesis
Update Observation Strategy / data analysis plan
Update requirements
Science metrics
- # planets imaged.
- # planets with measured [M/H].
- # with dynamical mass.
- # zodiacal disks per spectral type

Team Structure

Bruce Macintosh (PI)

Nikole Lewis (Deputy PI)

Science Modeling	Instrument	Simulations	Strategy & DRM	Data analysis
Lewis, Debes	Cahoy	Macintosh	Savransky	Pueyo

Science Modeling – Co-Is:
- Nikole Lewis
- Mark Marley
- Roxana Lupu
- Adam Burrows
- Renyu Hu
- John Debes
- Tom Greene
- Marshall Perrin

Instrument – Co-Is:
- Jeremy Kasdin
- Tom Greene
- John Trauger
- Mike McElwain
- Tyler Groff
- Laurent Pueyo
- Marshall Perrin

Simulations – Co-Is:
- Bruce Macintosh
- Jeremy Kasdin
- Dmitry Savransky
- John Trauger
- Mike McElwain

Strategy & DRM – Co-Is:
- Dmitry Savransky
- Nikole Lewis
- Bruce Macintosh

Data analysis – Co-Is:
- Laurent Pueyo
- John Debes
- Mike McElwain
- Marshall Perrin

Team Structure

Collaborators:

- Rafael Millan-Gabet
- Christian Marois
- Andrew Howard
- Leslie Rogers
- Michael Line
- Natalie Batalha
- Jonathan Fortney
- Amy Simon
- Colin Goldblatt
- Rebekah Dawson
- Gaspard Duchene
- Remi Soummer
- Tyler Robinson
- Caroline Morley

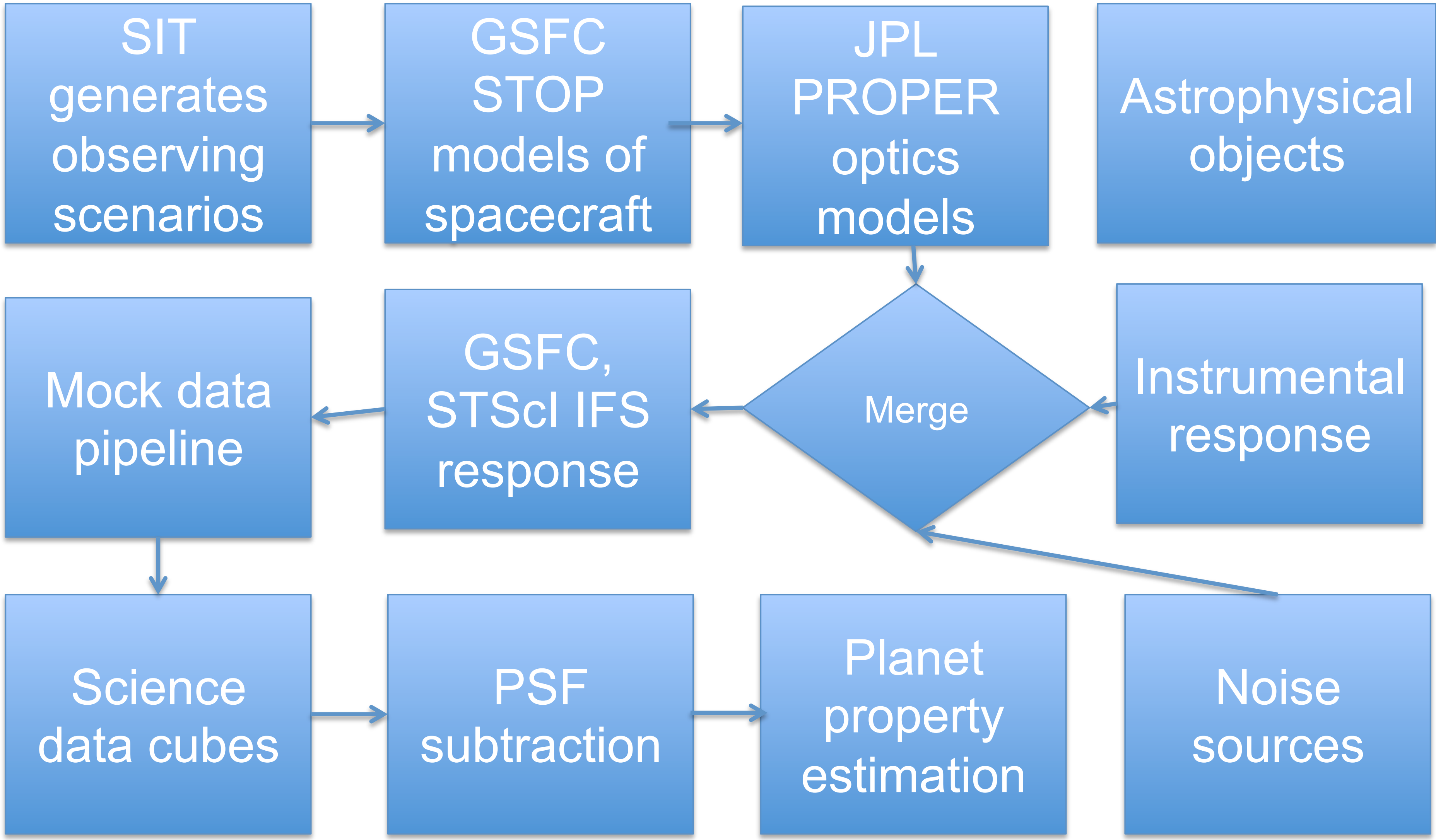
Simulations

- Lead: Bruce Macintosh

Co-Is

- Jeremy Kasdin
- Dmitry Savransky
- John Trauger
- Mike McElwain

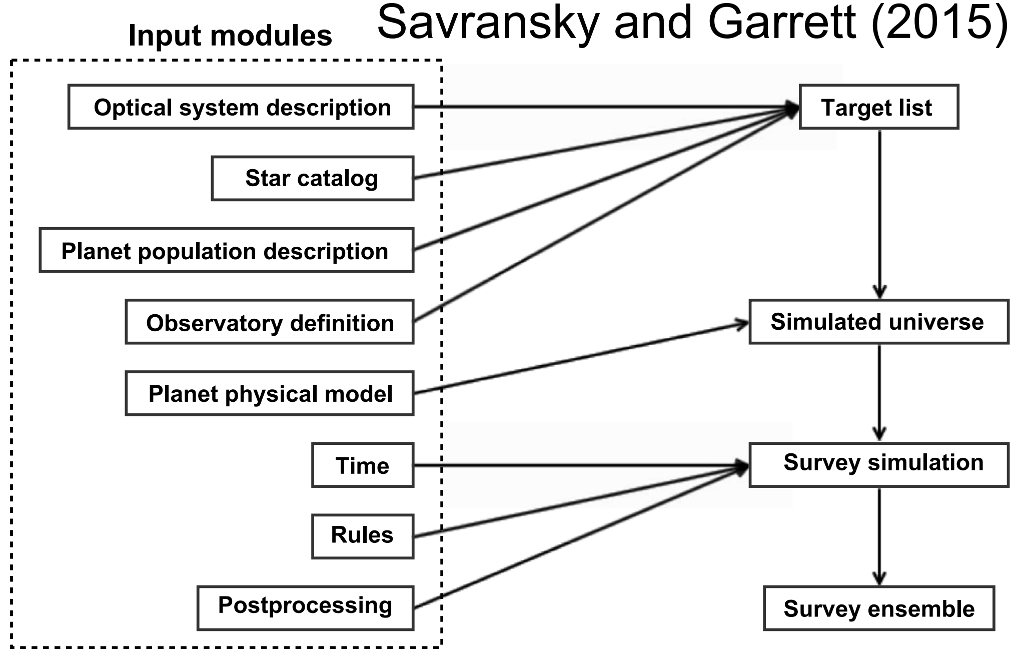
Full-physics simulation flow



Key Simulation tasks

- Develop faster simulation approaches
- Develop open framework to merge astrophysics from other groups.
- Support Turnbull SIT

EXOSIMS
Savransky and Garrett (2015)



We will provide a public release of our simulations framework that can be used to evaluate GO/GI science opportunities.

Science modeling

- Lead: Nikole Lewis

Co-Is:

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- Adam Burrows
- Renyu Hu
- John Debes
- Tom Greene
- Marshall Perrin

Collaborators

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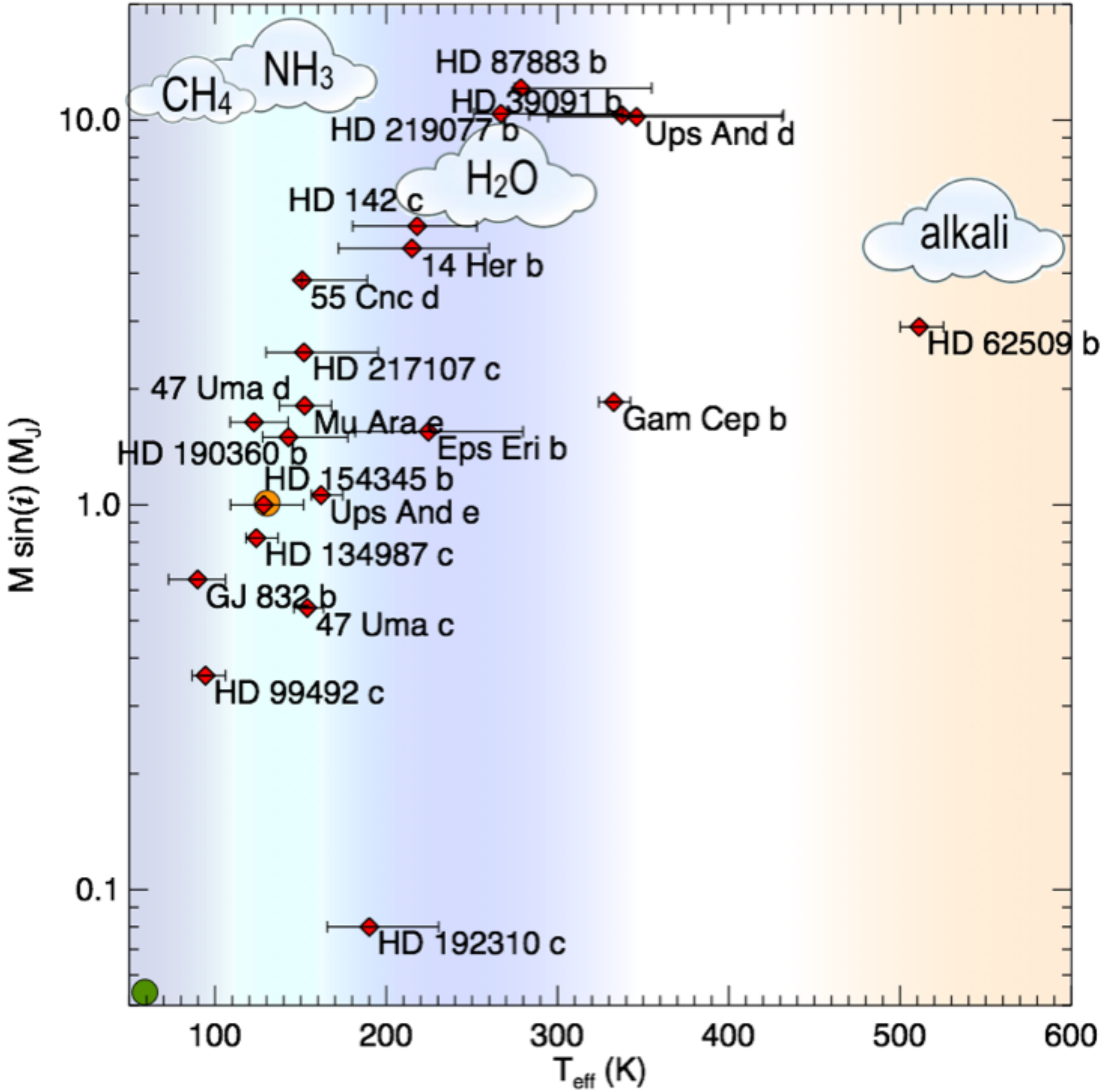
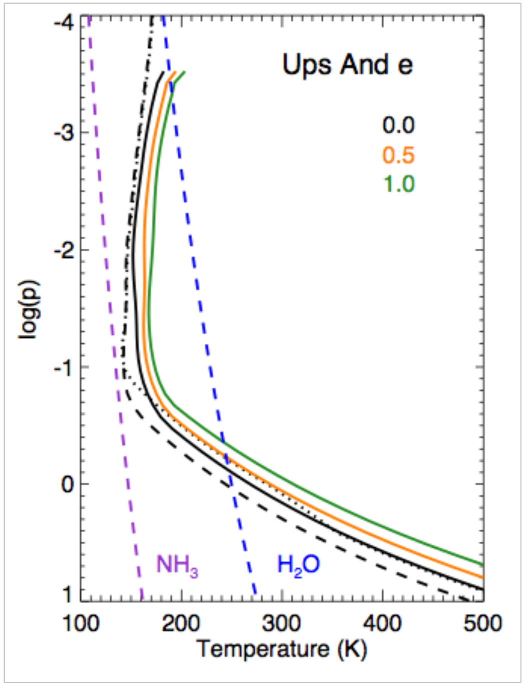
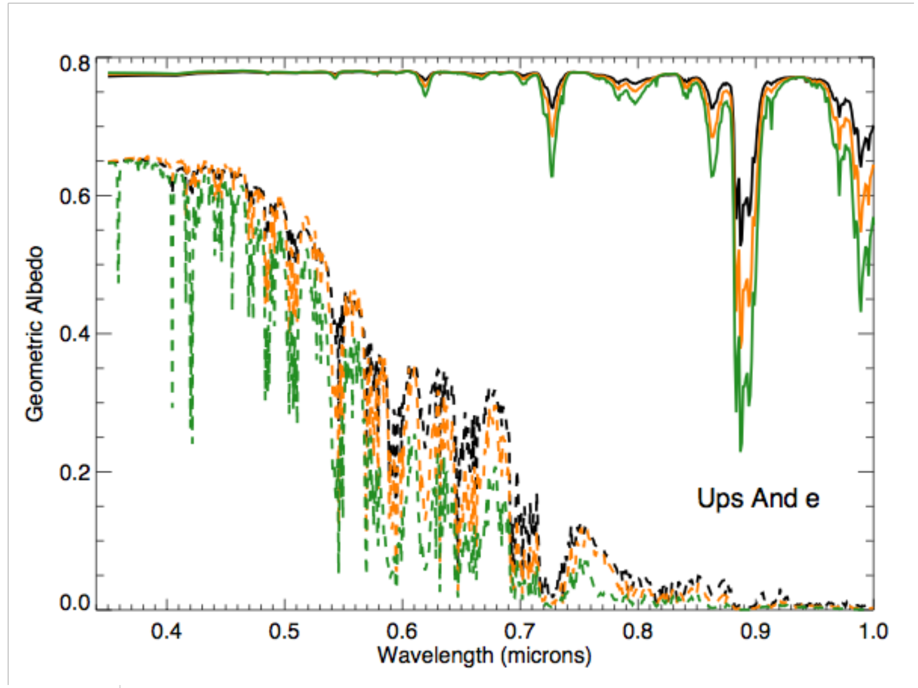
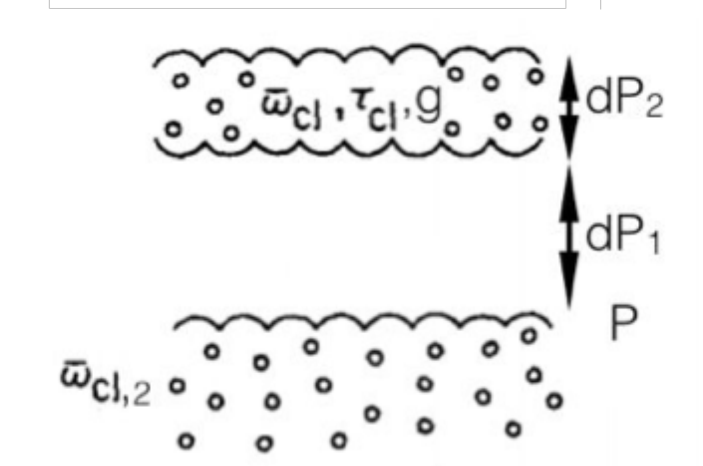
WFIRST-accessible known RV planets span a range of properties



Step 1: Albedo spectra generation with full-physics models



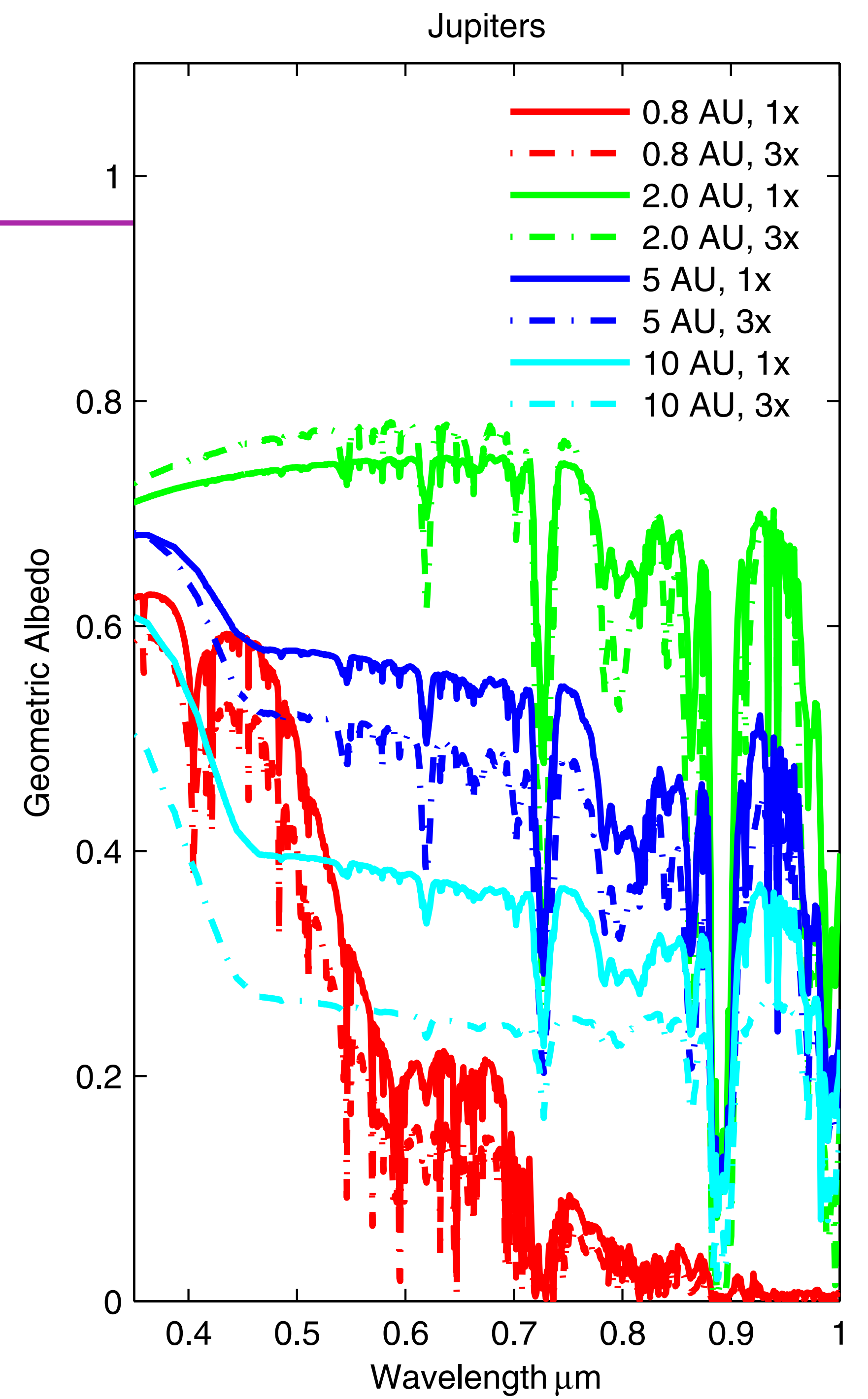




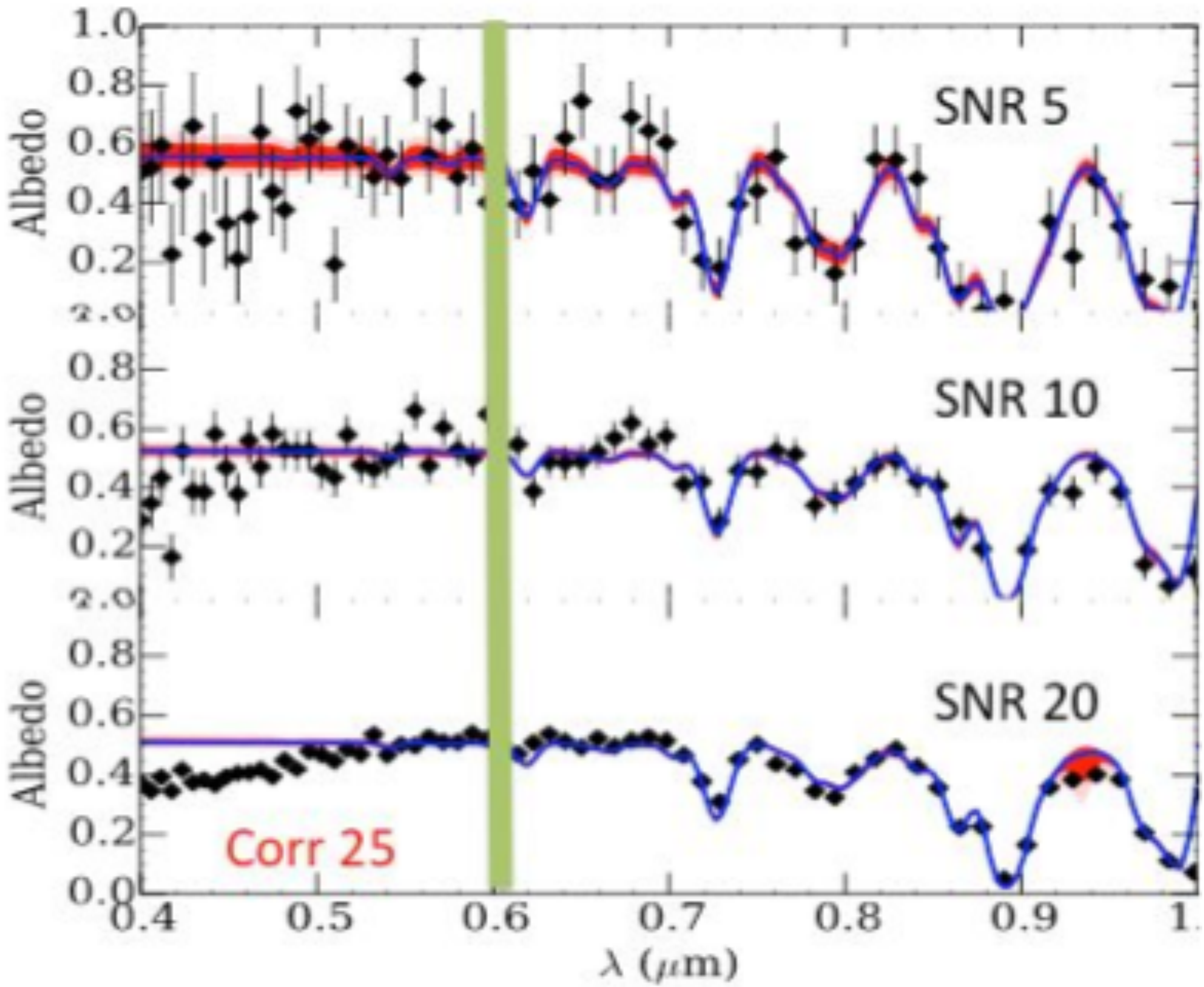
- Methane Abundance (fCH4)
- Surface Gravity (g)
- Cloud Properties
  - Single Scattering Albedo (ϖ)
  - Asymmetry factor (ğ)
  - Optical Depth (τ)
  - Cloud Top Pressure (P)

Planet models

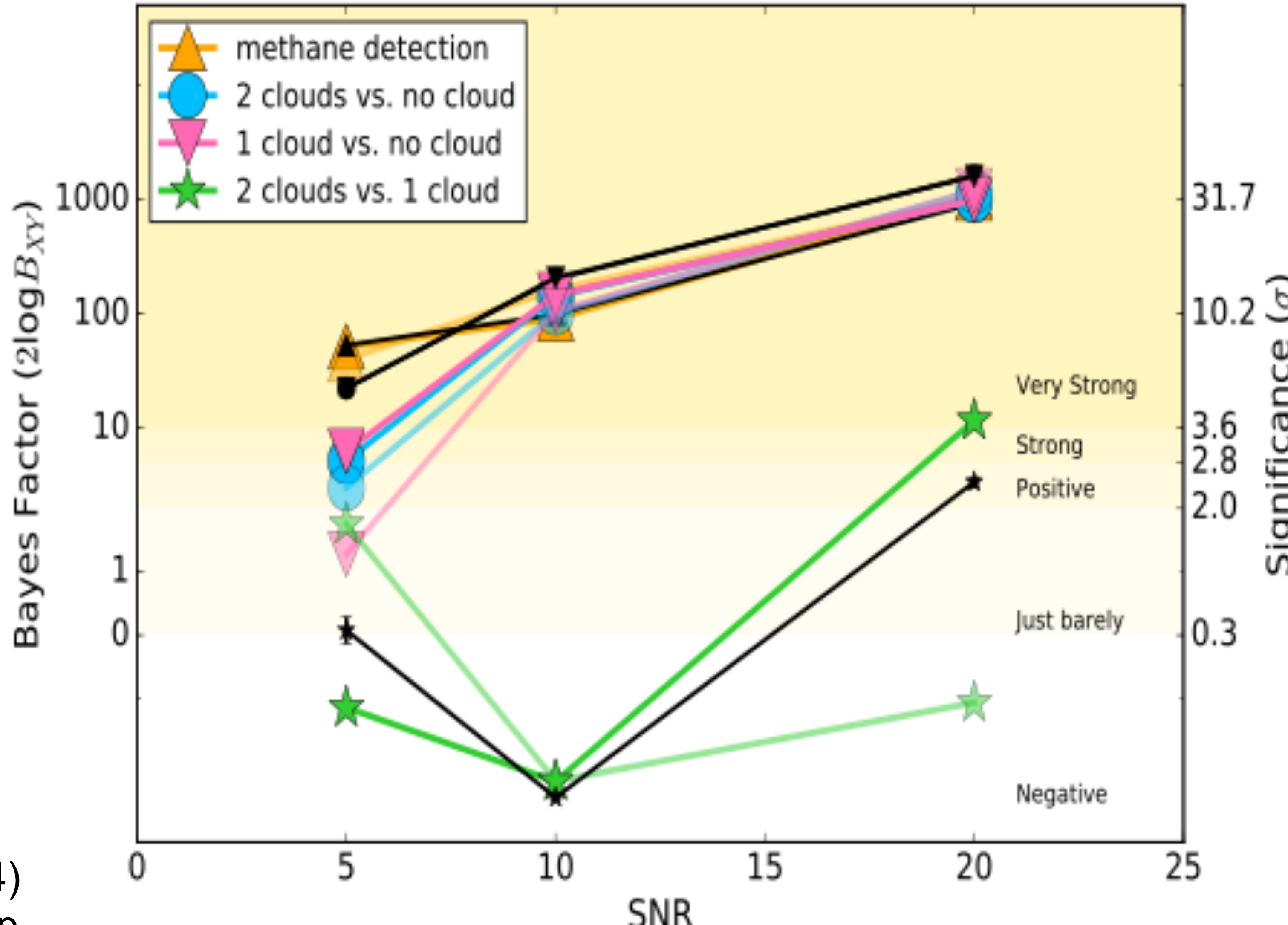
- Full-physics planet models to generate input spectra
- Planets properties will be extremely diverse and different than our solar system
- Parameters including metallicity, clouds, chemistry
- Previous work produces many models; we will organize and curate



Step 2: Propagate through CGI models (analytic or full)

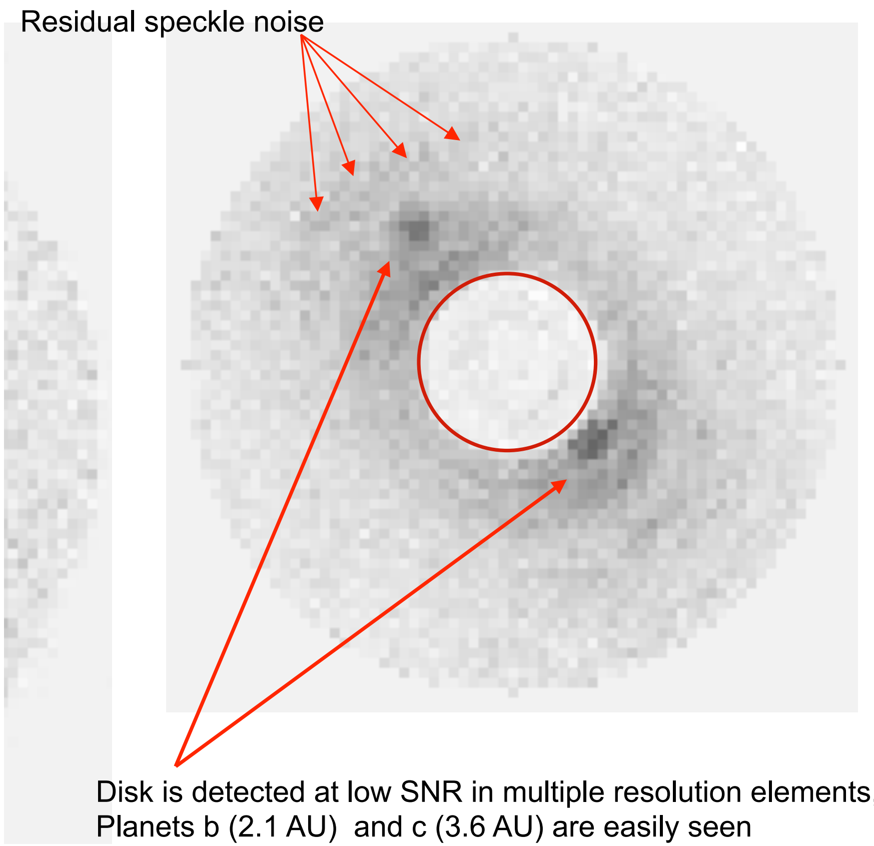


Step 3: Use MCMC inversion to recover parameters

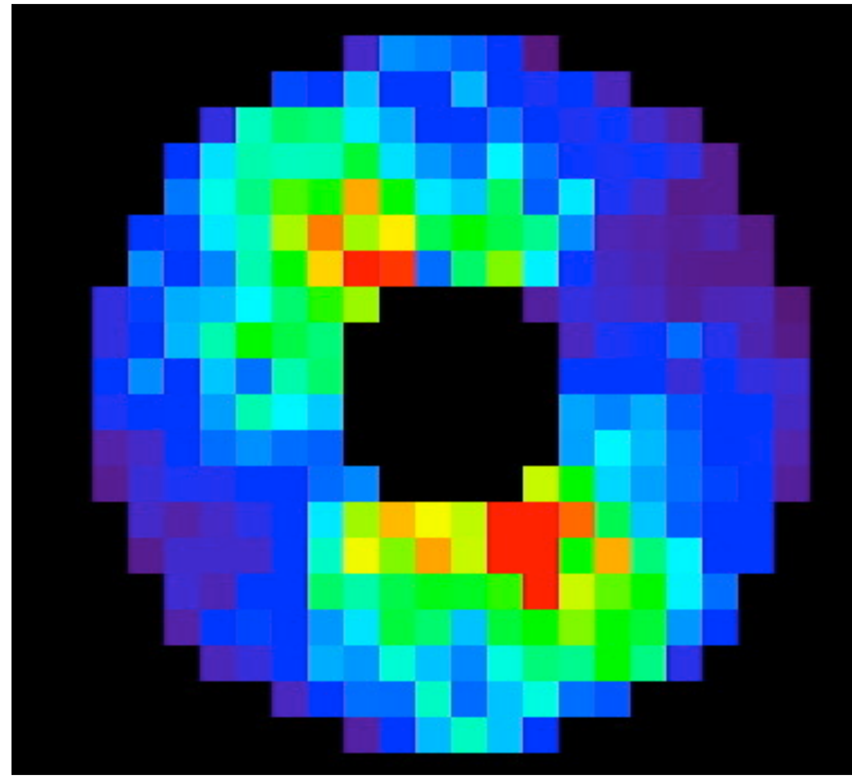


Marley et al (2014)
Lupu et al., in prep

Circumstellar dust
47 UMa + 30 Zodi disk



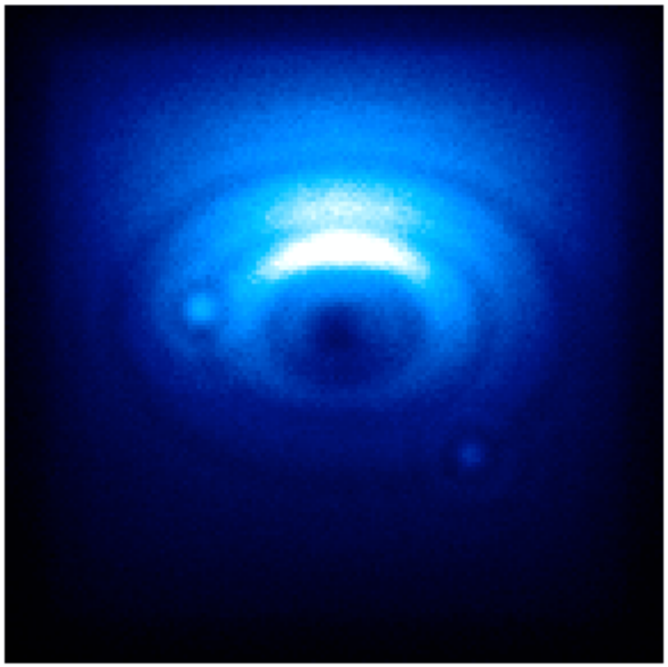
PSF-subtracted image



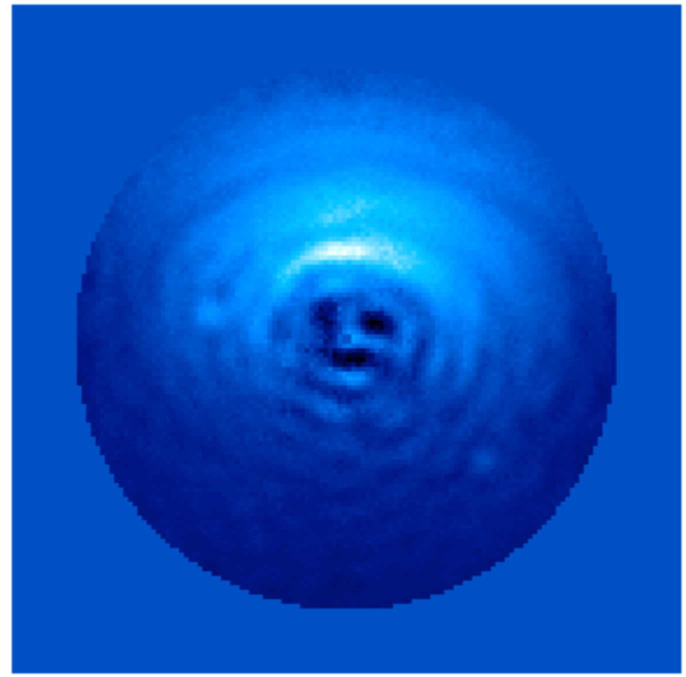
Binned SNR map of disk (peak SNR=15)

SDT report, Schneider & Greene

Disk (Debes et al) flowing through simulation and data pipeline



Simulated astrophysical scene

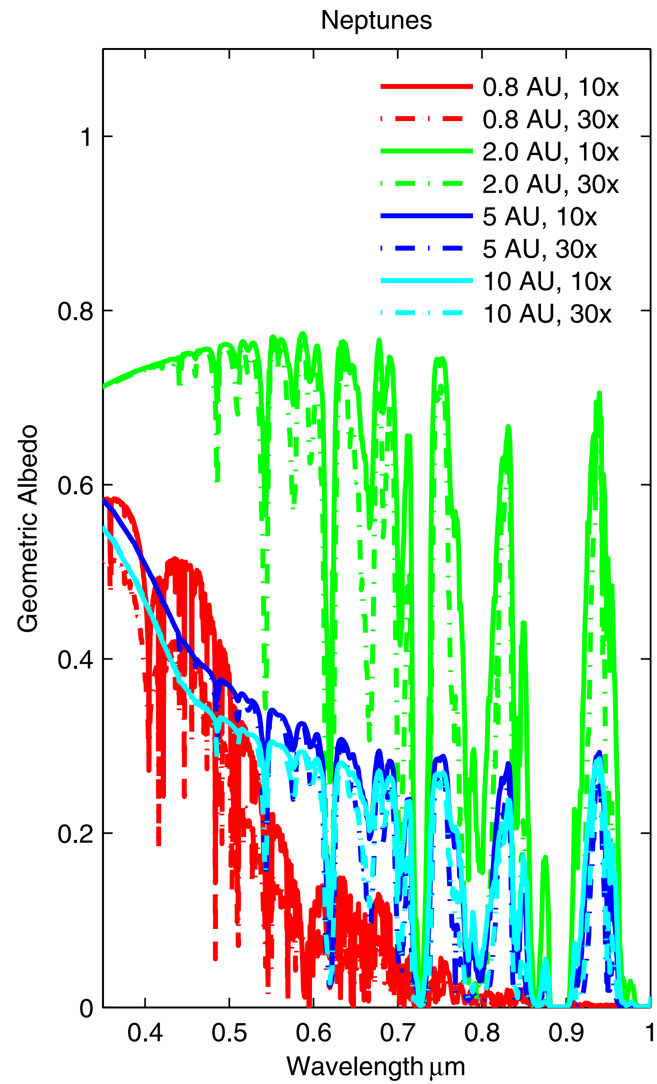


Recovered astrophysical scene

Model a range of disks (mature zodiacal disks, young debris disks, transitional disks…). Collaboration with Turnbull SIT
We will also use MCMC inversion to retrieve the disk parameters.

Key Science Modeling tasks

- Plan to collate library of theoretical planet and disk spectra/models that will be made available online and identify critical areas on which to focus our modeling efforts (e.g. mini neptunes and super earths)
- Evaluate importance of polarization measurements for planets and disks
- Model orbit-fitting



Instrument operations, requirements

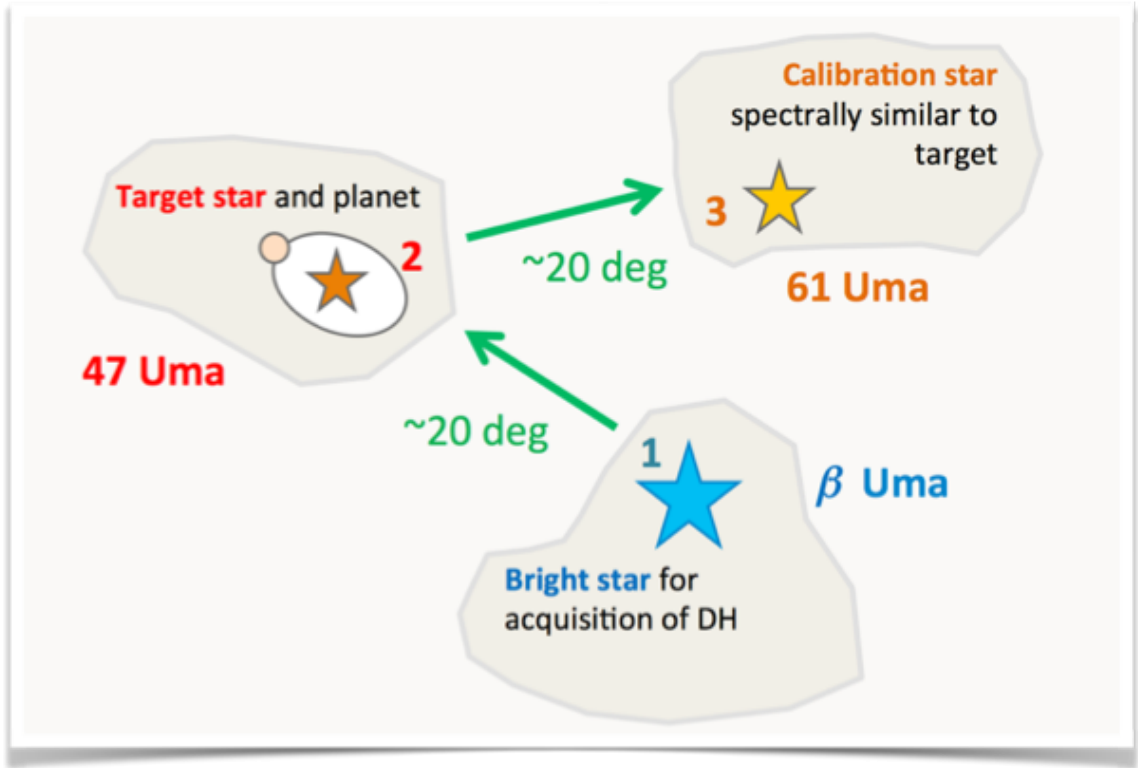
- Lead: Kerri Cahoy

Co-Is:

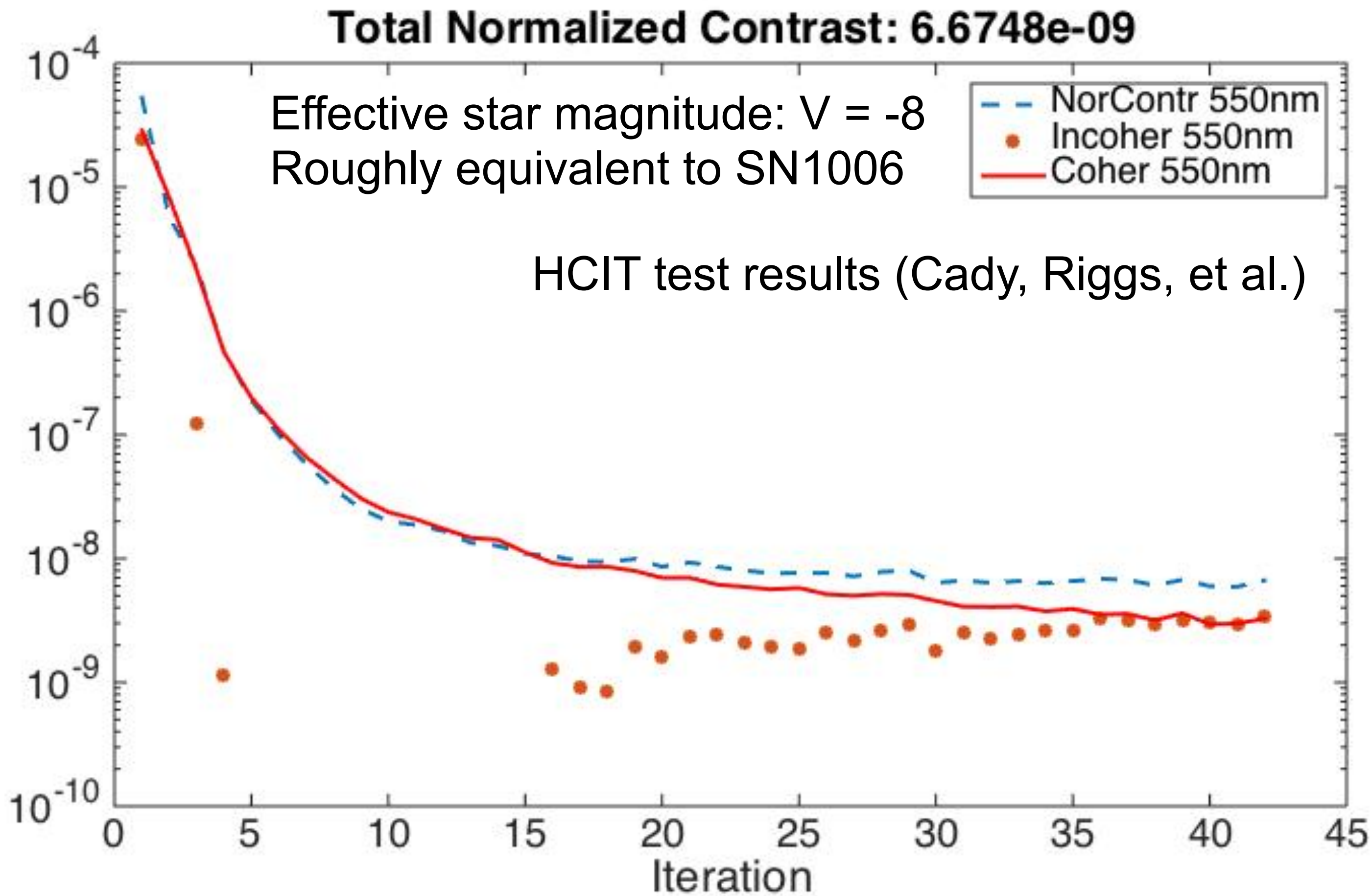
- Jeremy Kasdin
- Tom Greene
- John Trauger
- Mike McElwain
- Tyler Groff
- Laurent Pueyo
- Marshall Perrin

Development of operating scenarios

- Observing scenarios involve three stars per target
- Wavefront reference star (bright)
- Science target
- PSF reference star (matching science target)
- Are all three necessary? How close to a match does it need to be?



Wavefront control convergence



Need to include wavefront control overheads in DRMs. Should wavefront control continue during science?

Can science images generated in wavefront control distinguish speckles and planets?

Key instrument tasks

- Work to push wavefront control algorithms within ExEP / WFIRST
- Co-organize “Stanford meetings” with instrument team
- Setting level 2 requirements
  - Define spatial and spectral sampling
  - Current design overampled spatially and undersampled spectrally
  - Explore dark current vs readnoise
  - Maximize throughput

- Explore polarimetry modes
  - Polarization-dependent aberrations in beam
  - DM can only correct one polarization state for some modes
  - How to split, modulate polarization
  - Scientific value?

DRM and exoplanet strategy

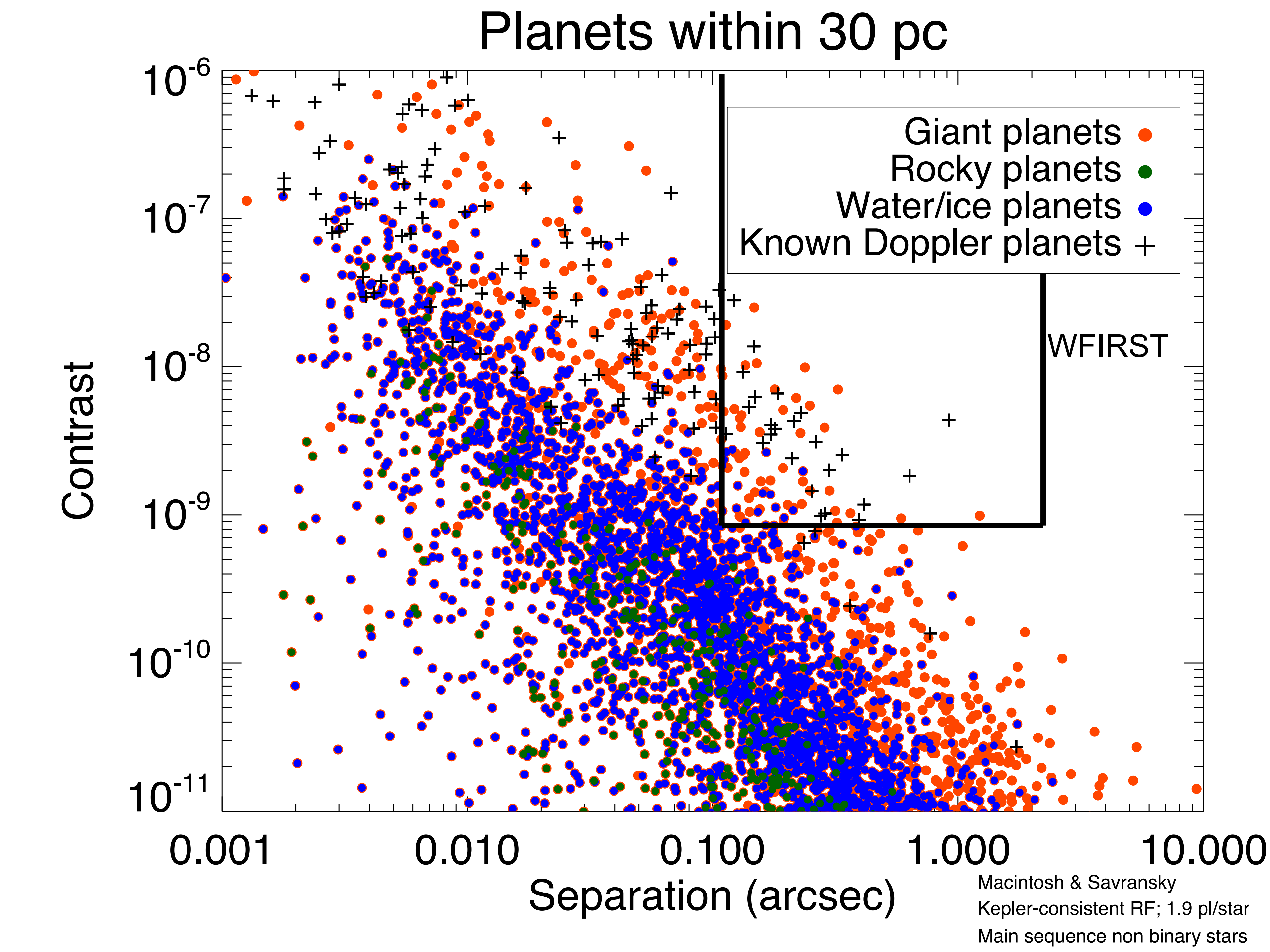
- Lead: Dmitry Savransky

Co-Is

- Nikole Lewis
- Bruce Macintosh

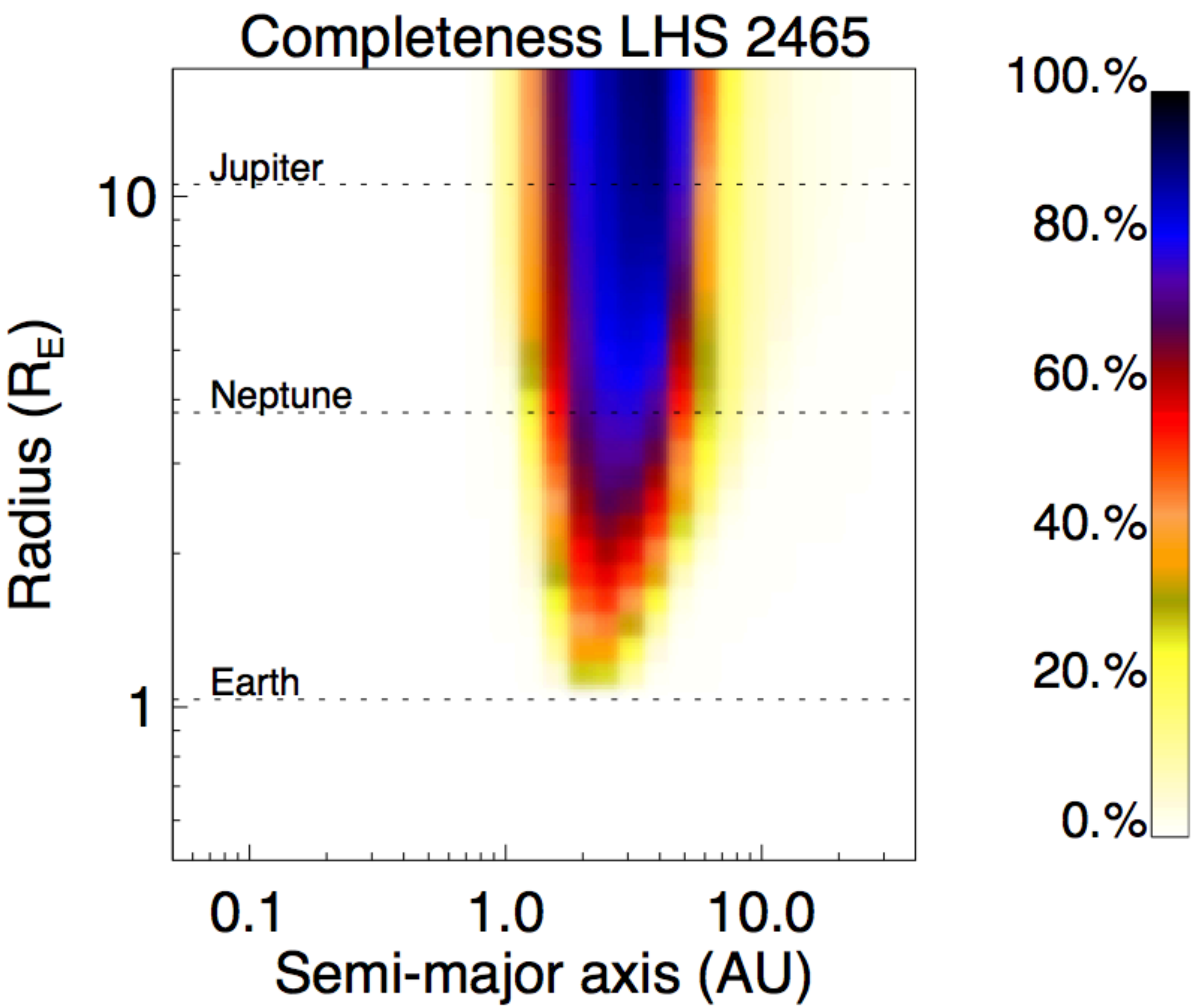
Collaborators

- Leslie Rogers
- Andrew Howard
- Natalie Batalha
- Rafael Millan-Gabet



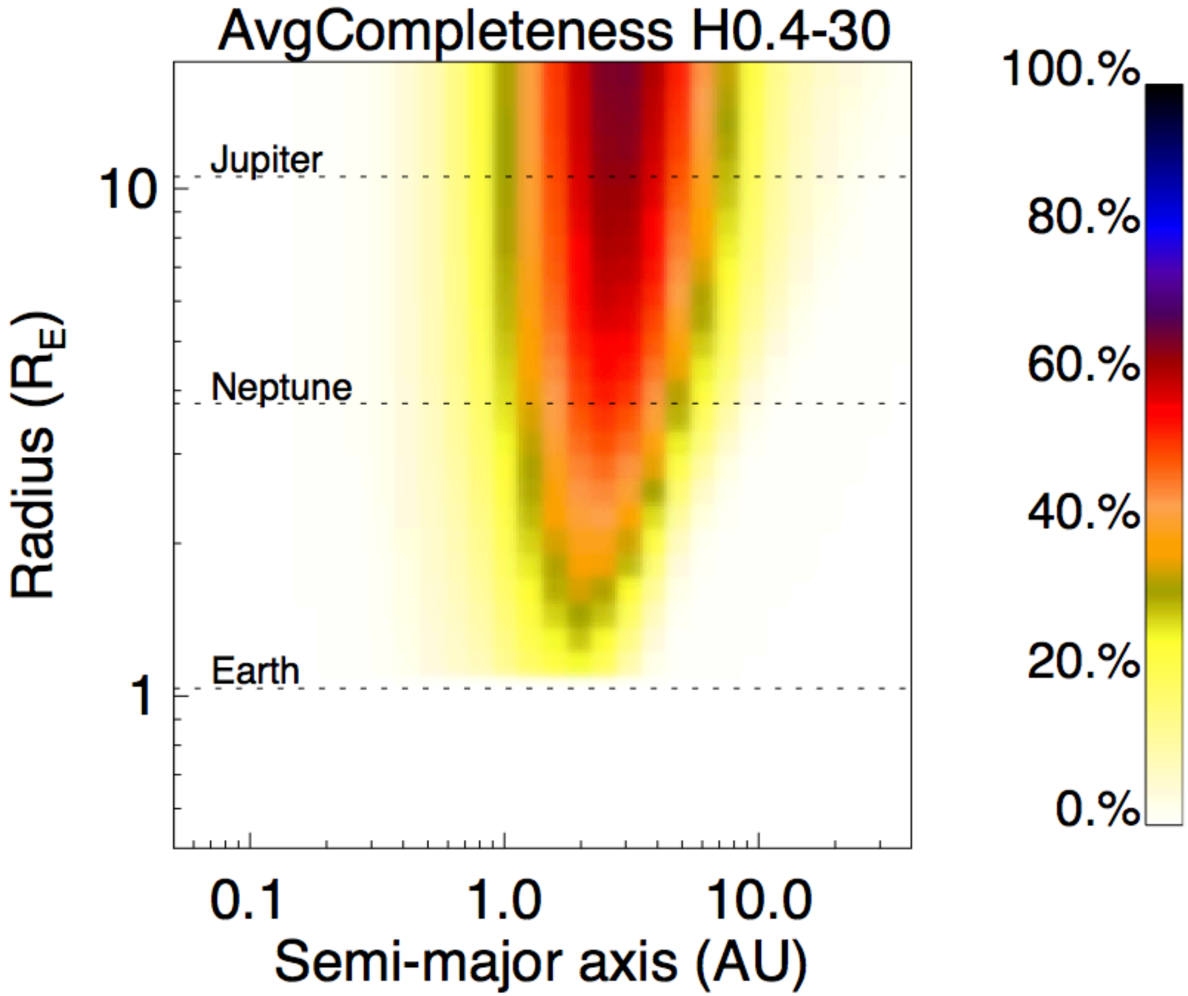
Planets within 30 pc
Giant planets
Rocky planets
Water/ice planets
Known Doppler planets +
WFIRST
Contrast
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
0.001
0.010
0.100
1.000
10.000
Separation (arcsec)
Macintosh & Savransky
Kepler-consistent RF; 1.9 pl/star
Main sequence non binary stars

WFIRST sensitivity space



Single-star completeness

WFIRST sensitivity space



Average completeness
6 month / 46 star

Exoplanet Yield Estimates

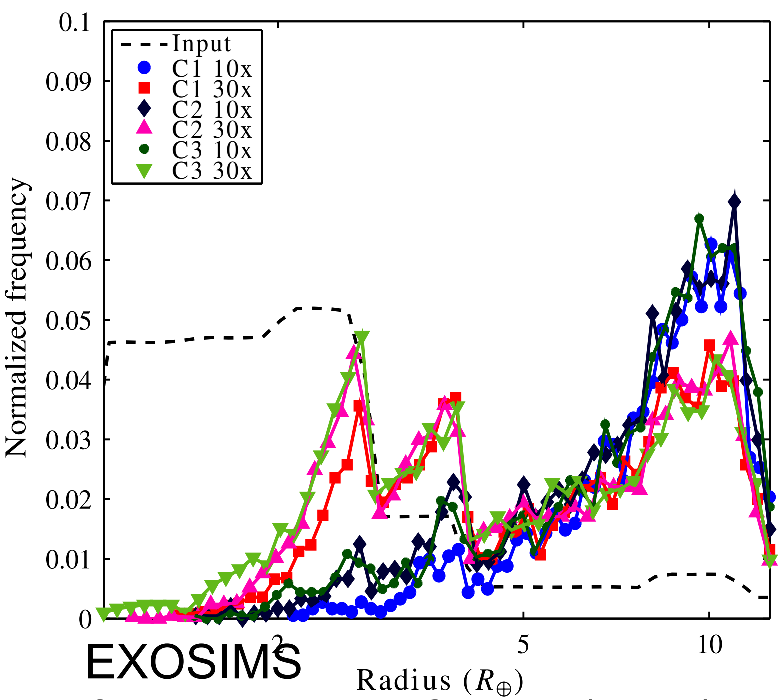
	Giants (4-15 R_E)	Sub-Neptunes (2-4 R_E)	Super-Earths (1-2 R_E)	Total
Known RV Studies*	16	0	0	16
180-day Blind Search	2	6	4	12
Total**	18	6	4	28

- RV yield could be augmented by the WIYN program for future RV observations; see poster by Chontos et al

** Yield assumes 0.4 jitter and 30x speckle attenuation

DRM optimization

- Add to models
  - Target ID by GAIA, WIYN precision RV
  - RV planet recovery and full characterization
  - Blind search optimization including recovery and orbits
  - Extrasolar zodiacal dust models with varying properties and higher fidelity



EXOSIMS
Savransky and Garrett (2015)

Long term: evaluate a range of possible planet populations:

- Model multiplanet correlations,
- Bimodal planet formation (Kepler-blind solar analogs)

Image processing

- Lead: Laurent Pueyo

Co-Is

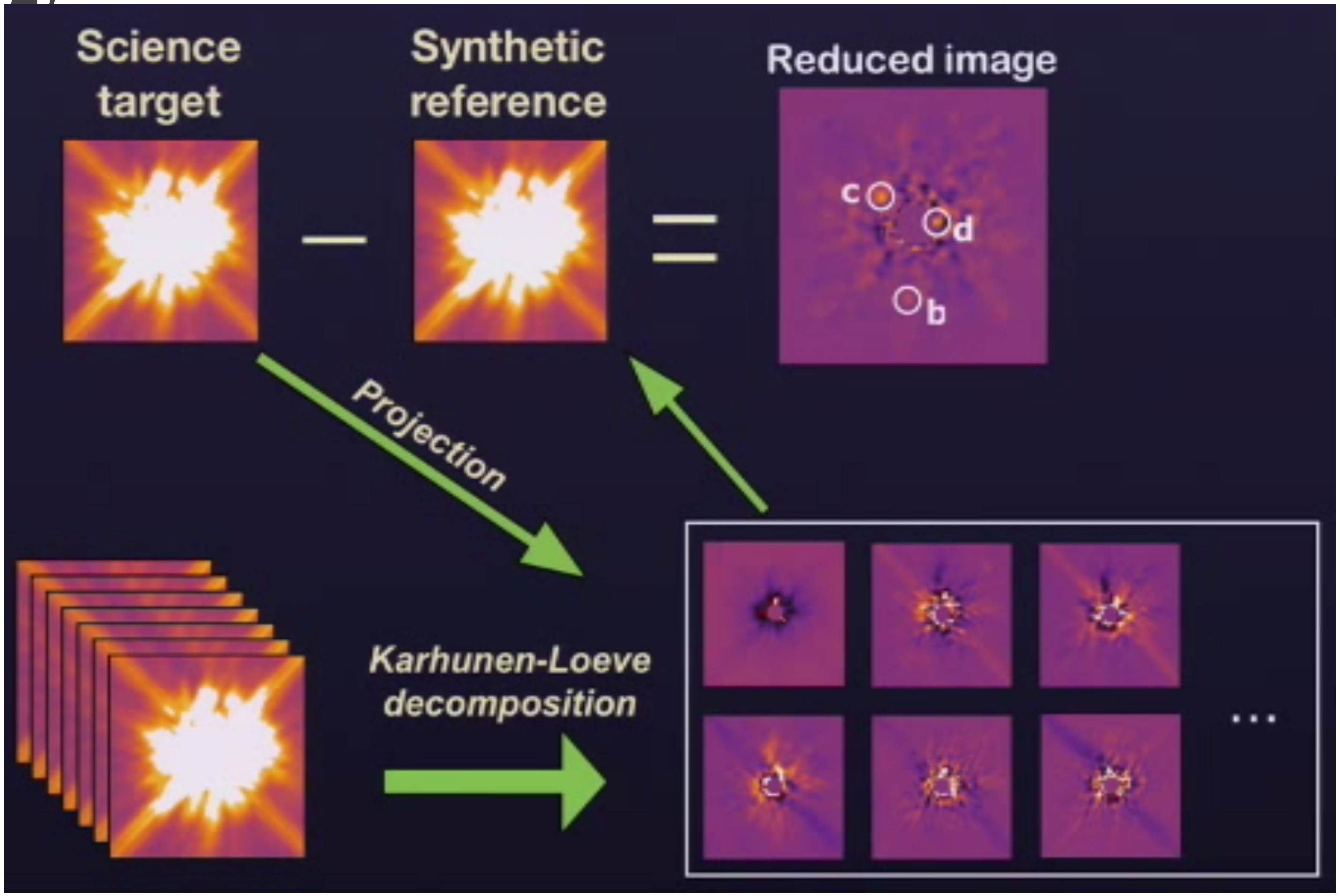
- Laurent Pueyo
- John Debes
- Mike McElwain
- Marshall Perrin

Collaborators

- Remi Soummer
- Christian Marois

PSF subtraction and image processing

Karhunen-Loève Image Processing (Soummer et al 2012)

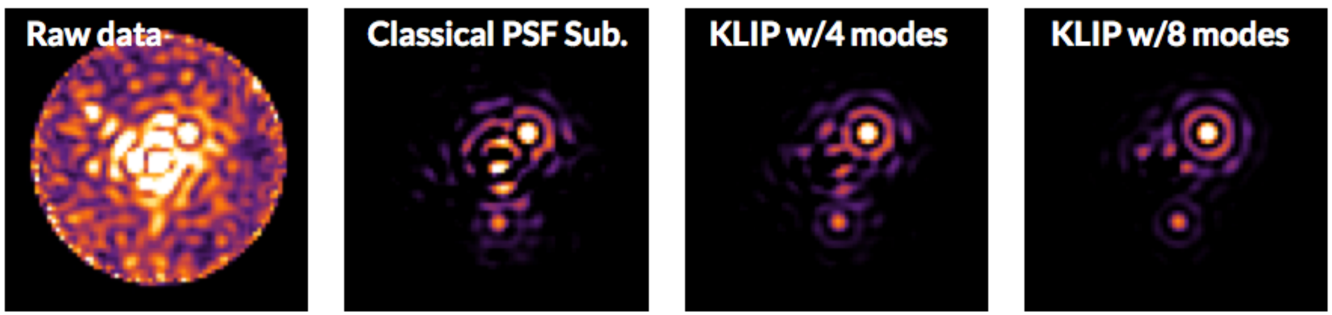


Slide by M. Ygouf

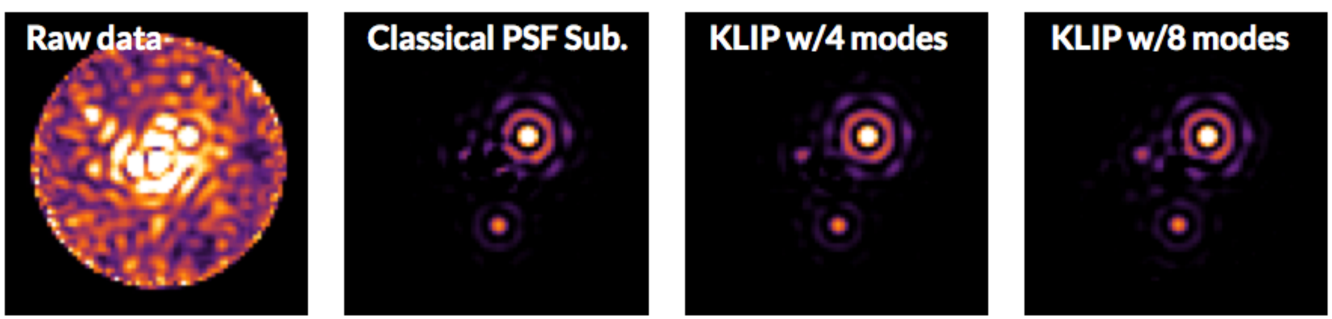
PSF subtraction and data processing

- Ongoing STScI project uses standard algorithms (KL mode / PCA base) against project data.

HBLC OS3 distribution



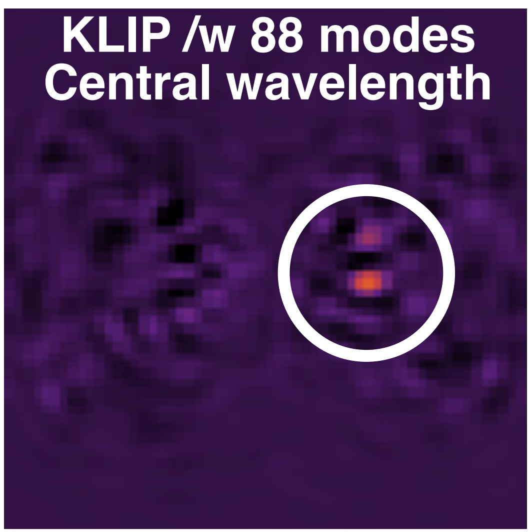
(a) Without LOWFC

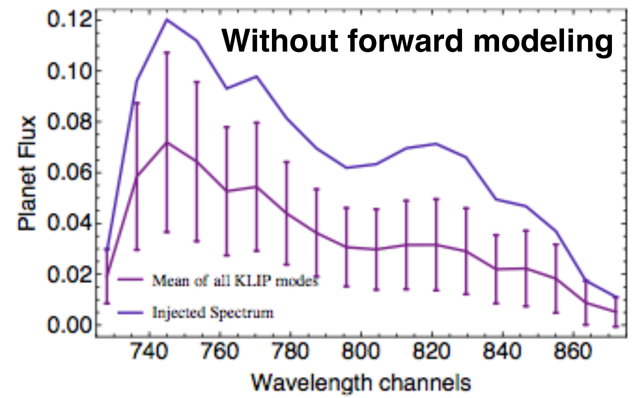


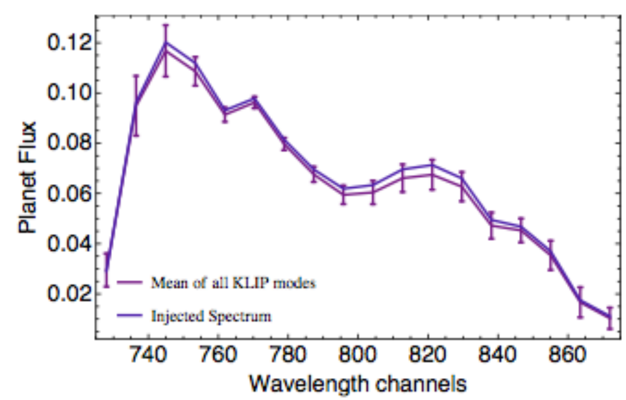
(b) With LOWFC

Estimation of spectrum

- Optimal estimation of recovered planet properties
  - Algorithmic self-subtraction biases
- Properly asses probabilities (false positive and missed-planet) for blind surveys







Team Structure

Bruce Macintosh (PI)

Nikole Lewis (Deputy PI)

Science Modeling
Lewis, Debes

Co-Is:
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Instrument
Cahoy

Co-Is:
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- Tyler Groff
- Laurent Pueyo
- Marshall Perrin

Simulations
Macintosh

Co-Is:
- Bruce Macintosh
- Jeremy Kasdin
- Dmitry Savransky
- John Trauger
- Mike McElwain

Strategy & DRM
Savransky

Co-Is:
- Dmitry Savransky
- Nikole Lewis
- Bruce Macintosh

Data analysis
Pueyo

Co-Is:
- Laurent Pueyo
- John Debes
- Mike McElwain
- Marshall Perrin

Long-term tasks that will enable GO/GI science

- Iterative cycles of simulated high-fidelity data
  - This will include public data releases
- Refined science models
  - Improved disk models with consistency with planet models, observations
  - Mini-Neptune and Super-Earth atmospheric models
  - Public releases of models developed in support of SIT effort
- DRM cycles
  - Public release of yield analysis code via github
- GO coronagraph science collaboration
  - Exoplanet topics – young planets and planet-forming disks, self-luminous planets
  - Non-exoplanet science