# Science yield modeling with the Exoplanet Open-Source Imaging Mission Simulator (EXOSIMS)

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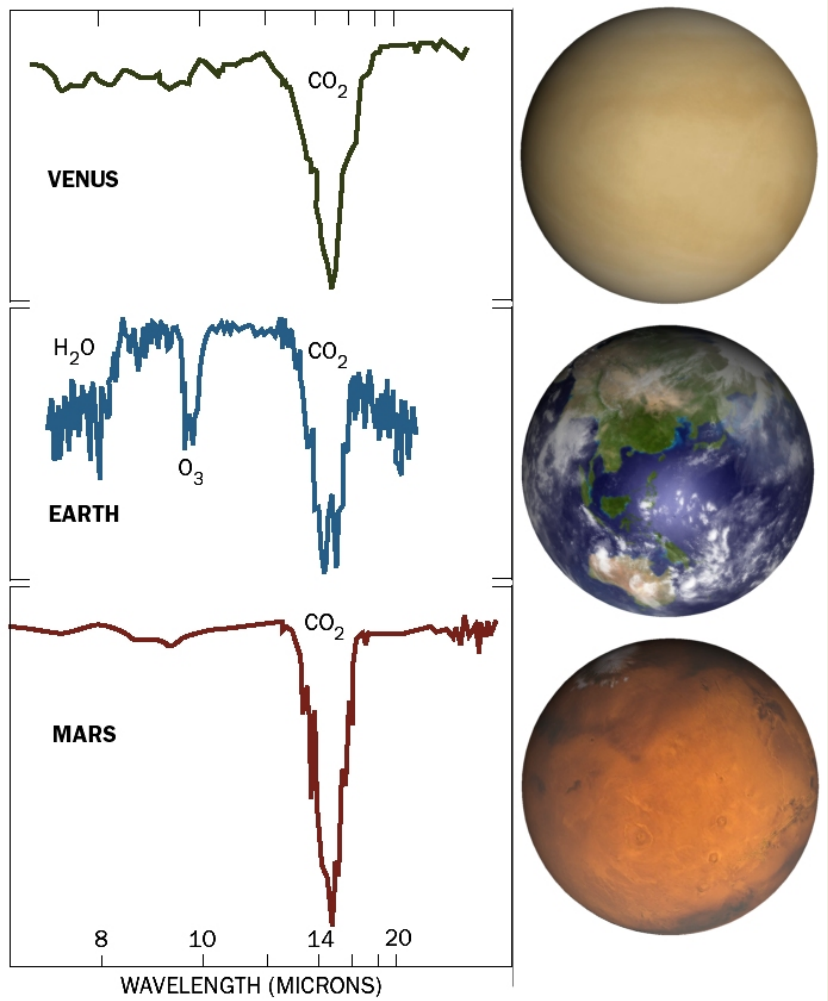
# Direct imaging: motivations and challenges

- Pure detection
- Astrometry, orbital parameters
- Photometry, spectroscopy
- Detection of life

But…

- Small angular separation:
  1AU @ 10pc = 0.1arcsec
- High contrast scenes:
  $10^6$ (IR) – $10^9$ (visible)
- **Speckle noise** due to wavefront deformation (atmosphere, optics)



# High contrast and resolution speckle discrimination and control

Direct imaging requires:

- Coronagraphy
- Wavefront sensing and control
- Pointing jitter control
- Post-processing algorithms

Need to extend parameter space
→ **space observatories**
e.g. WFIRST (launch ~2024)

Ultimate goal: Earth-like planets



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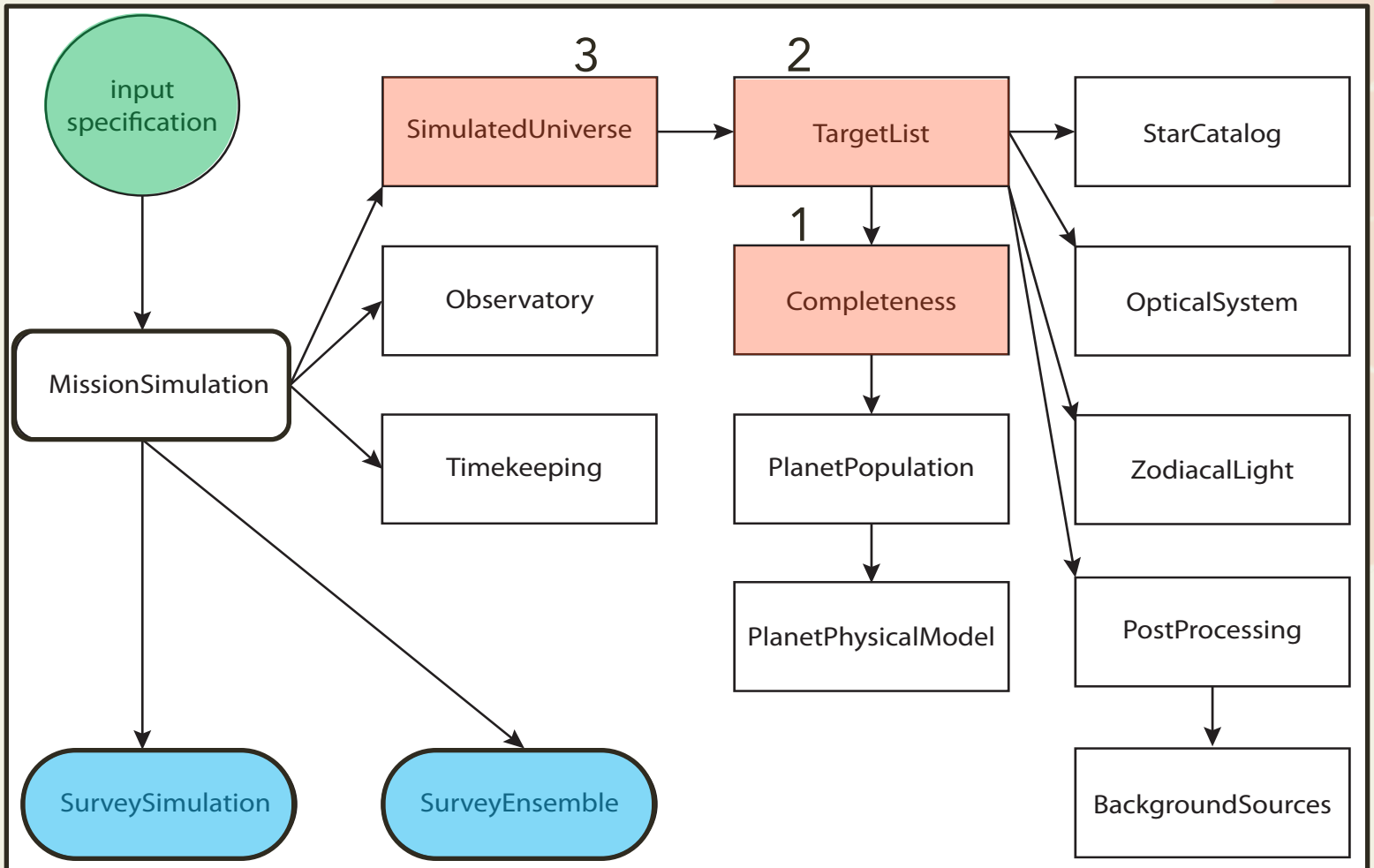
# EXoplanet Open-Source Imaging Mission Simulator

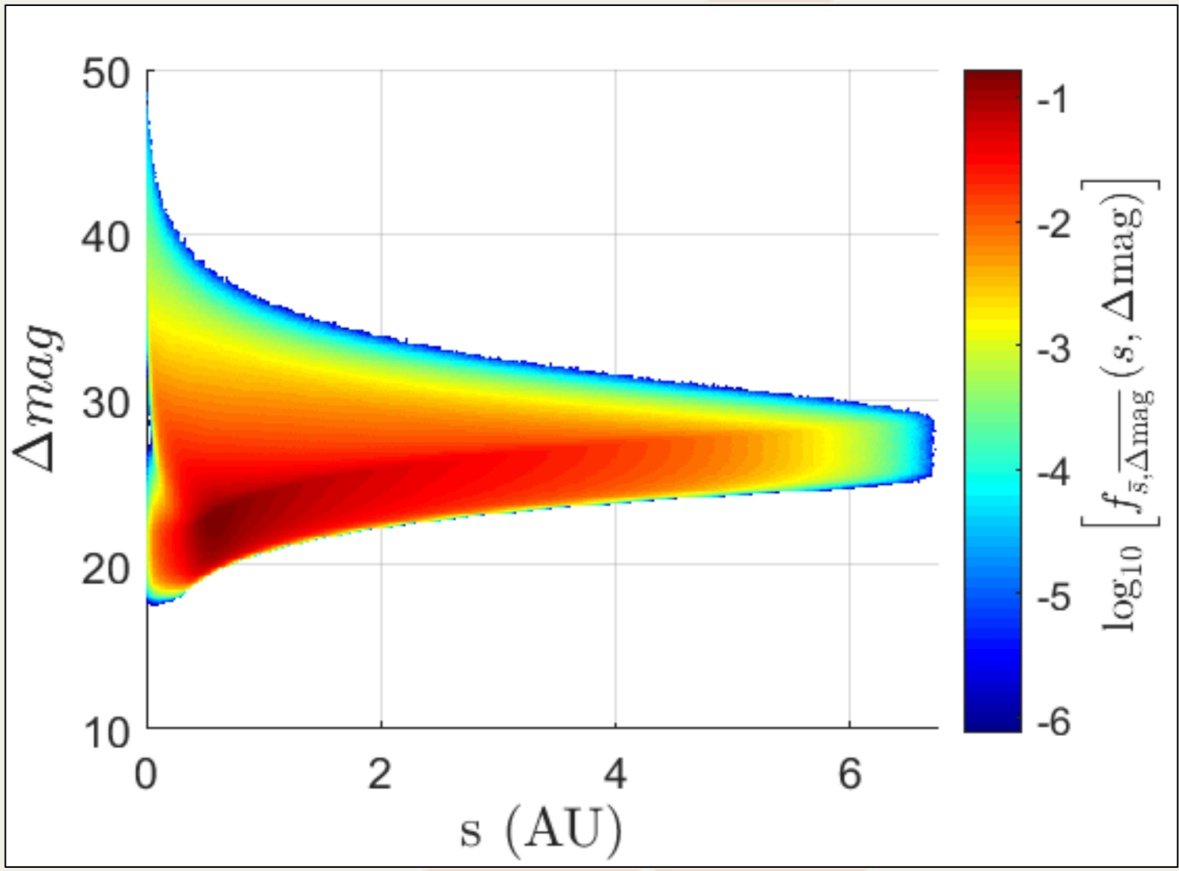
- EXOSIMS - developed as part of WFIRST Preparatory Science
- Performs ensembles of simulations to determine science yield distributions
- Modular architecture, allows multiple mission designs
- https://github.com/dsavransky/EXOSIMS



# Example of joint probability density function

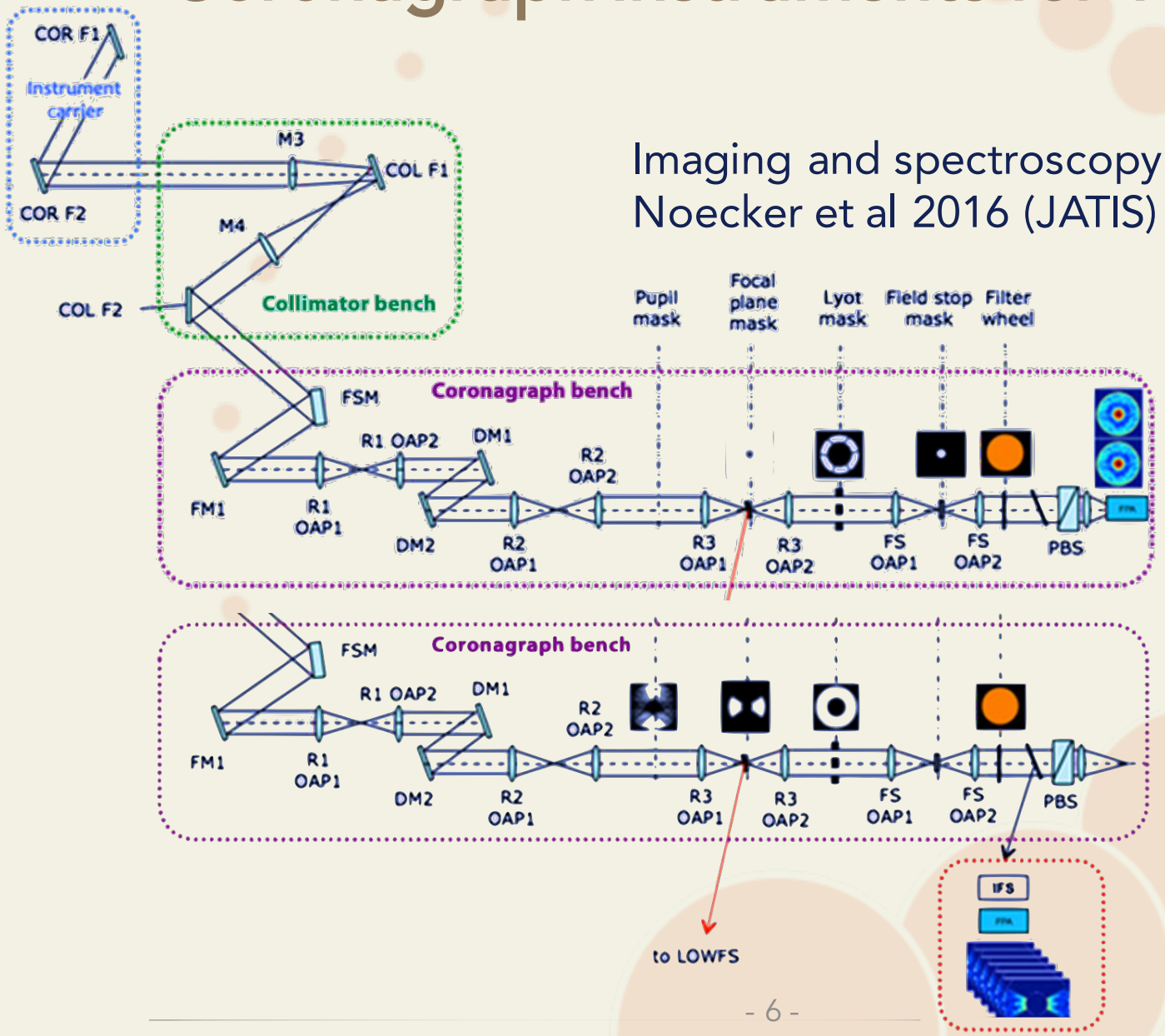
- PDF of planet orbital and physical properties
- Completeness = CDF (cf. Brown 2005)
- Probability to detect a planet
- Updates completeness values for systems previously observed

Garrett and Savransky 2016, ApJ (accepted)



# Optical System Module
# Coronagraph instruments for WFIRST

Imaging and spectroscopy modes
Noecker et al 2016 (JATIS)




Hybrid Lyot Coronagraph

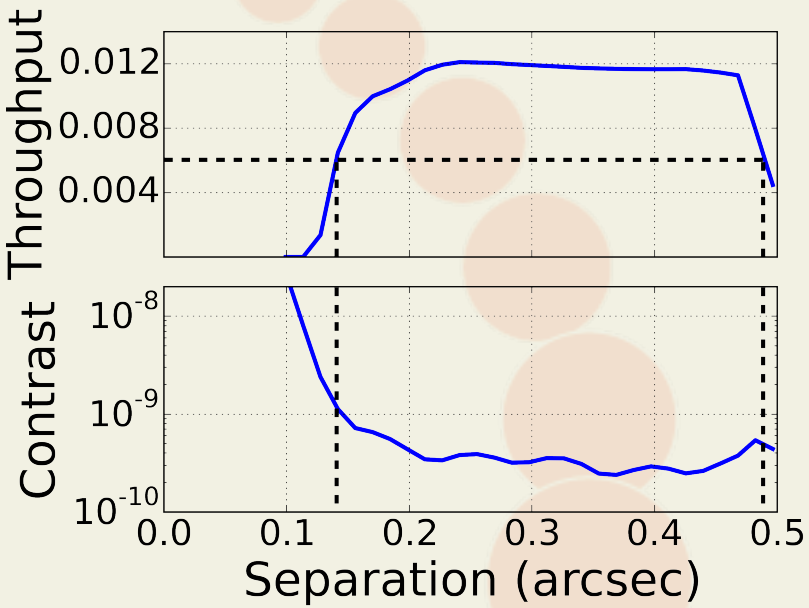
Shaped Pupil Coronagraph

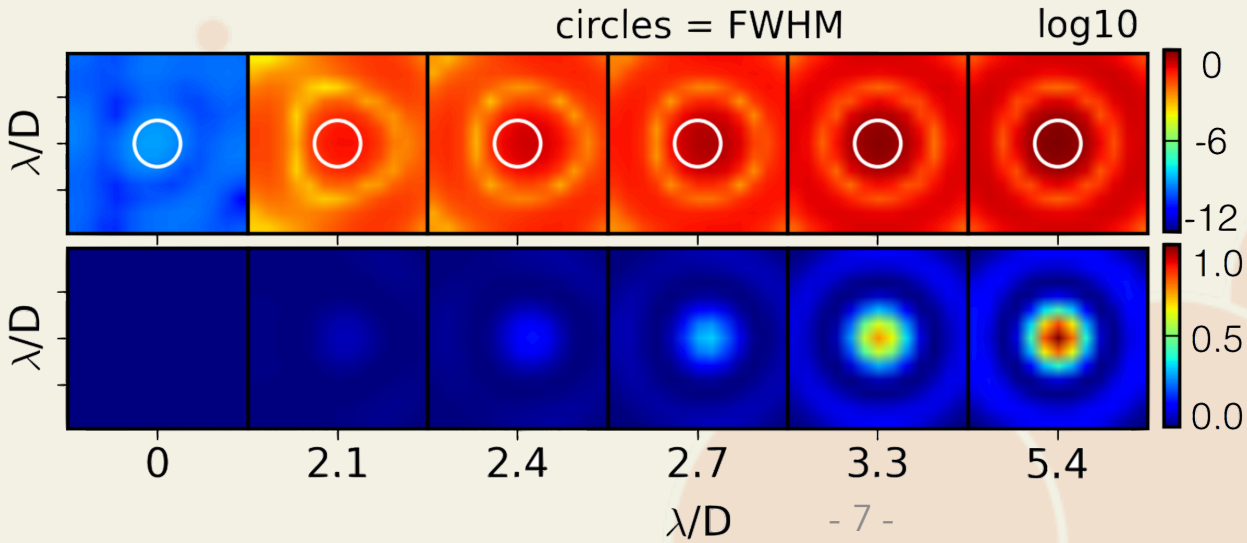
# Target List Module Filtering

Filters out (from star catalog):

- Binary stars
- Too long integration times
- Unreached completeness threshold
- **Stars with planets within the IWA** → calculated based on throughput, contrast, and off-axis PSF

data from Traub 2016 JATIS



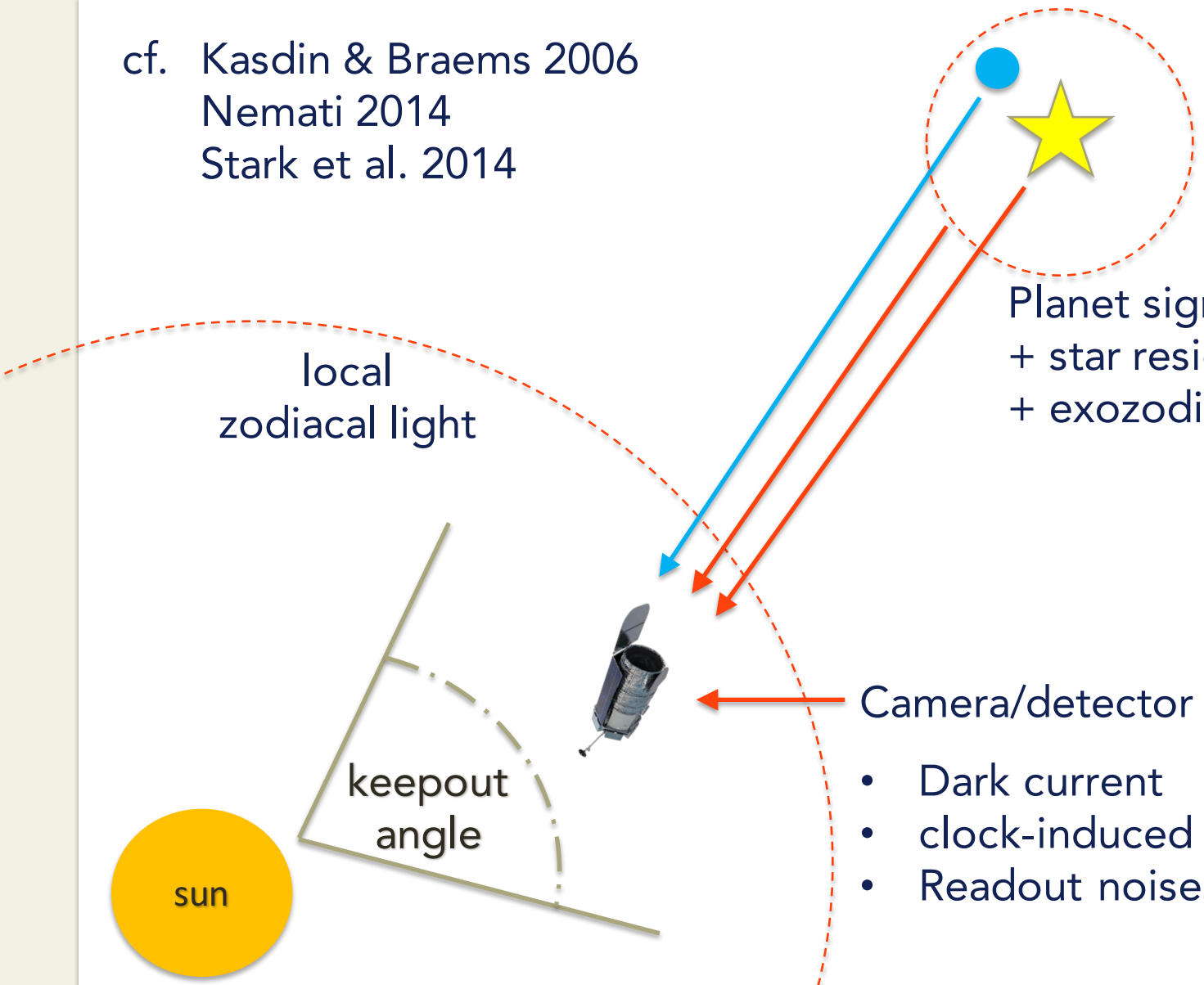




← log scale

← linear scale

# Planet integration time – noise budget

cf. Kasdin & Braems 2006
Nemati 2014
Stark et al. 2014




Camera/detector noise:

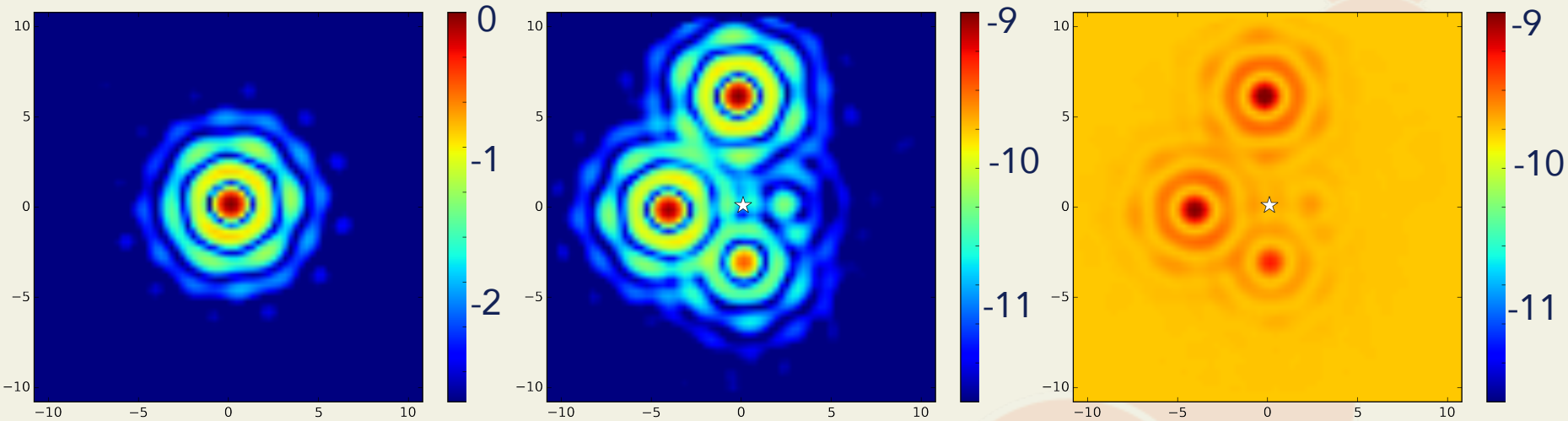
- Dark current
- clock-induced charge
- Readout noise

# Planet integration time – noise budget (cont'd)

normalized star PSF

planets (star cancelled)

+ local zodi
+ exozodi



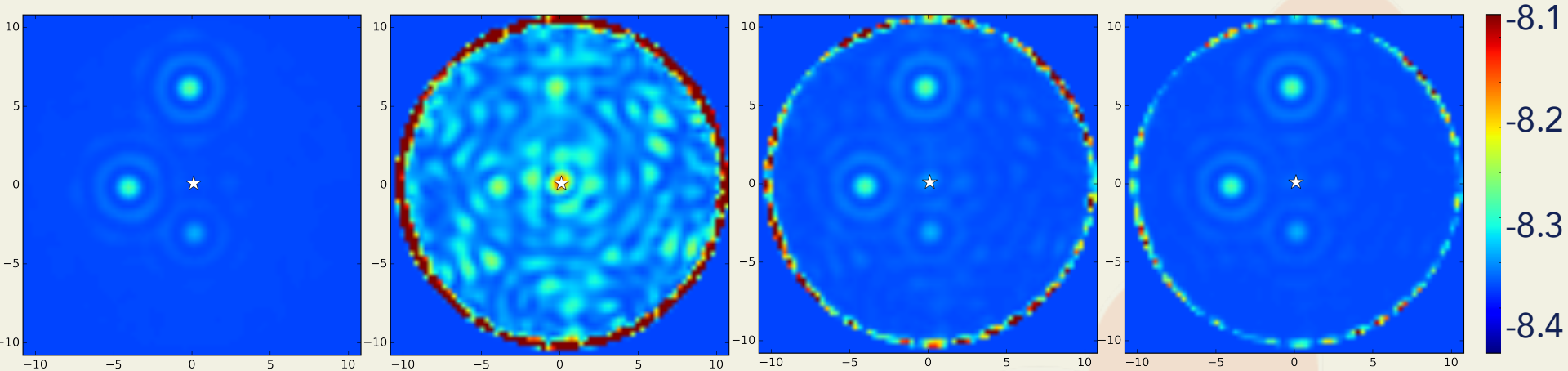
# Planet integration time – noise budget (cont'd)

+ detector noise

+ residual speckles

post-processing 10x gain

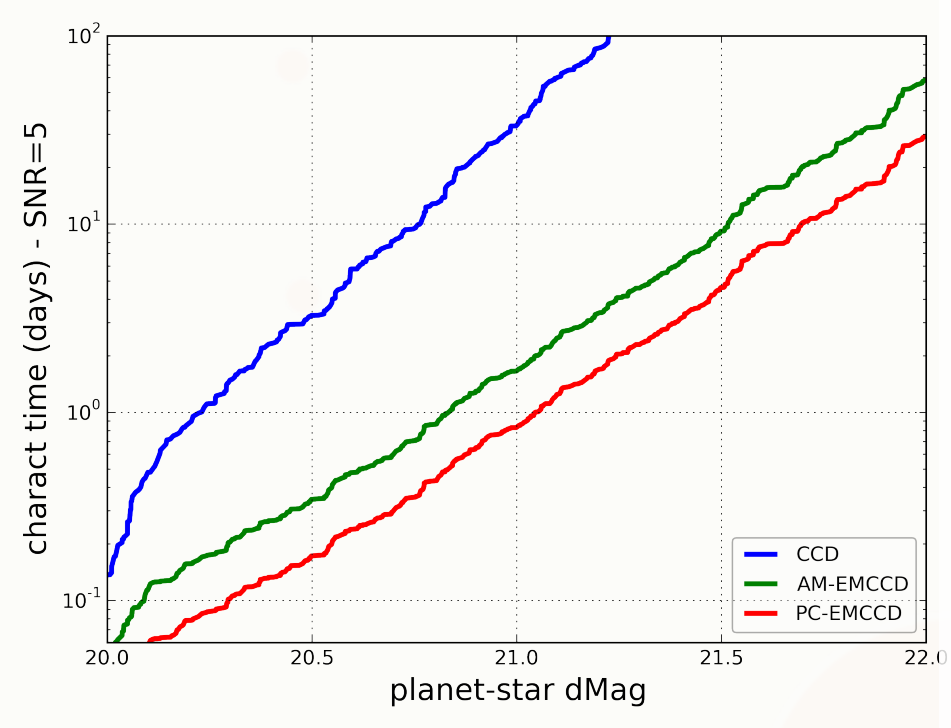
post-processing 30x gain

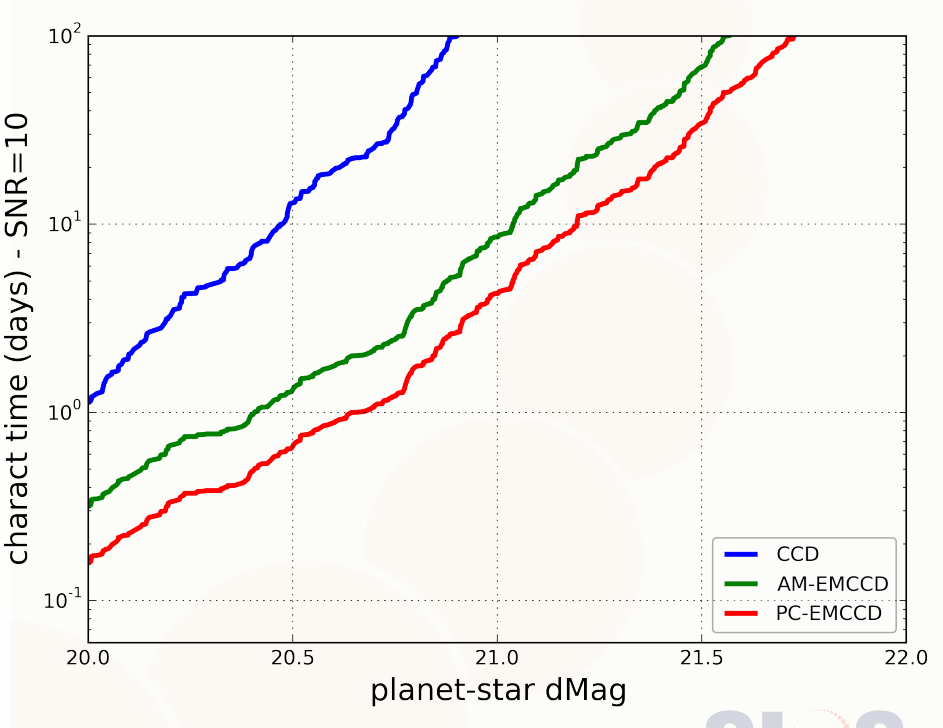


# Comparison of different science instruments (cameras)

Detector performance parameters taken from Nemati 2014 (SPIE)

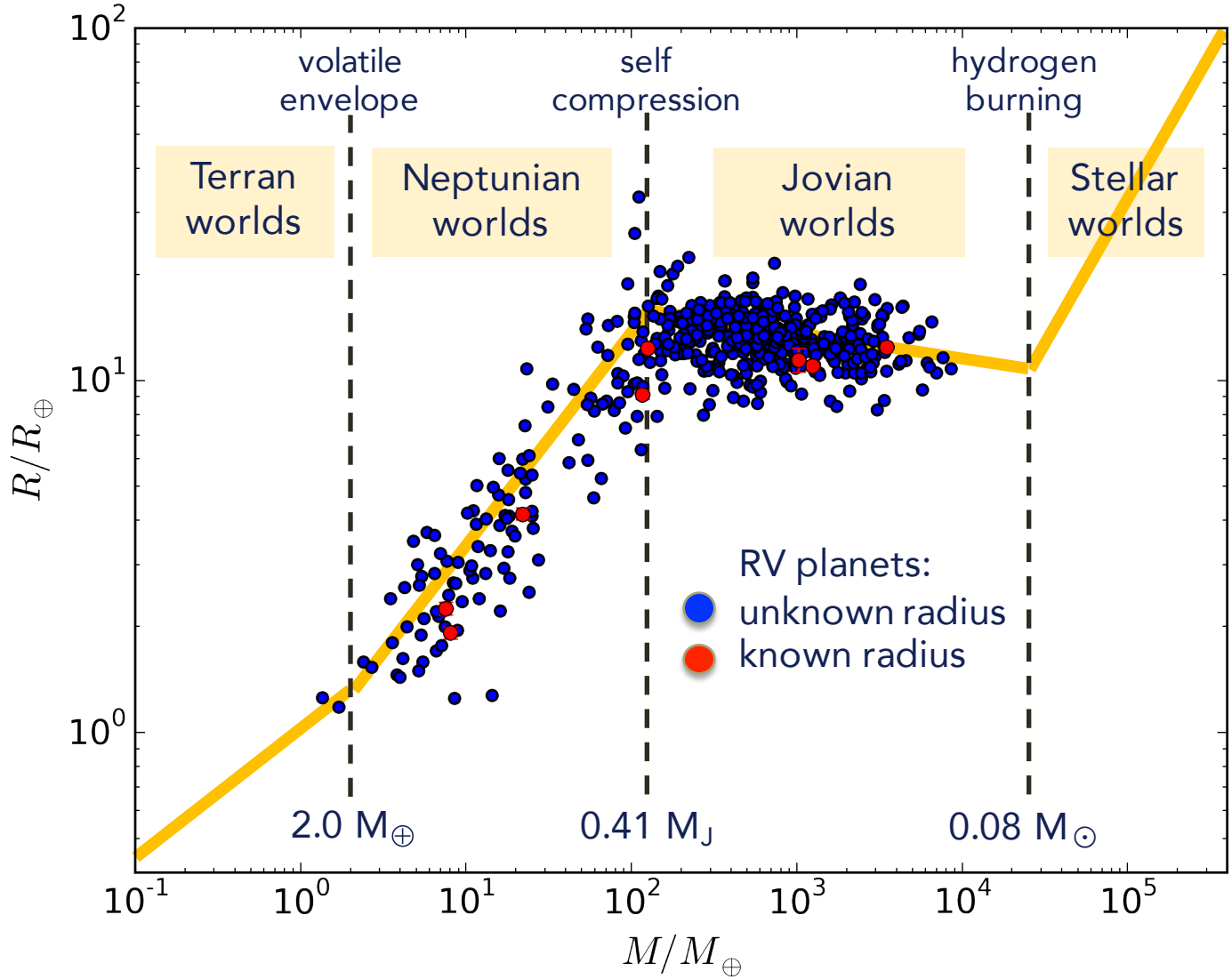
| | CCD | Analog EMCCD | PC-EMCCD |
|---|---|---|---|
| Dark current | 1E-4 e-/pix/s | | |
| Read noise | 3 e- | 16 e- | 16 e- |
| EM gain | 1 | 500 | 500 |
| CIC | 1E-3 e-/pix/frame | | |



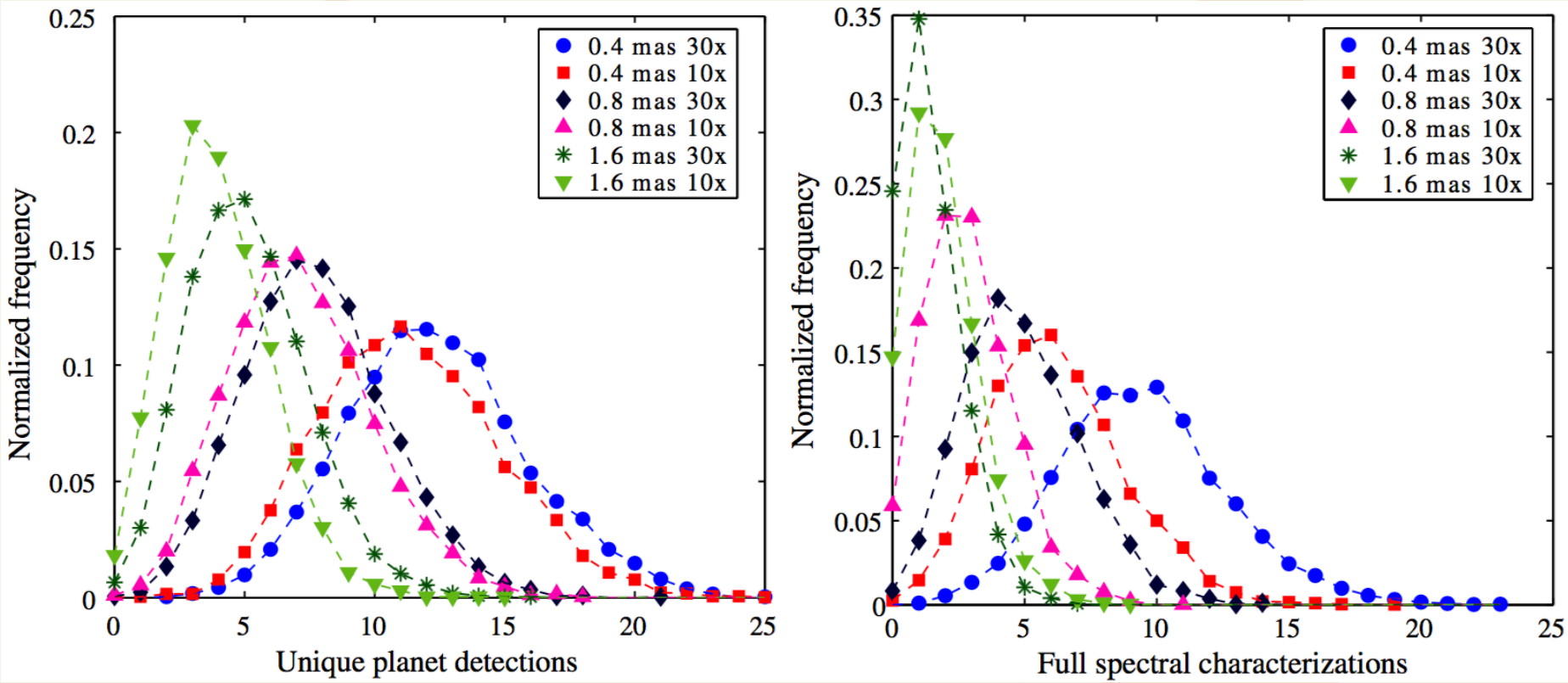
# Simulated Universe: Mass-radius relation

Model from FORECASTER software (Chen and Kippling 2016)
available at github.com/chenjj2/forecaster



# Comparison of post-processing gains and telescope jitter values

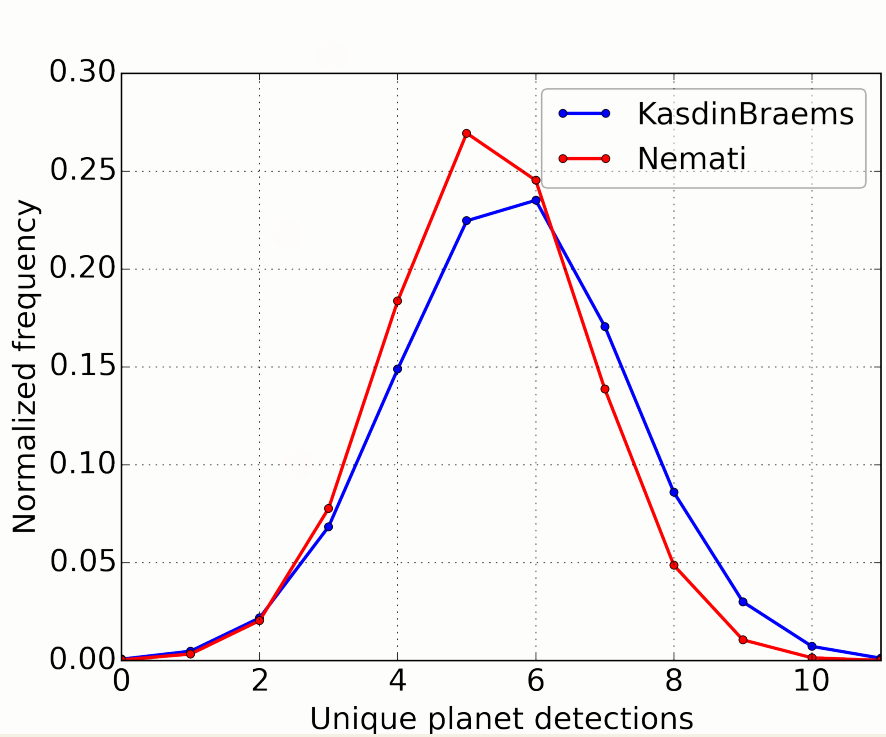
PDF obtained from mission ensemble simulation (~5000)

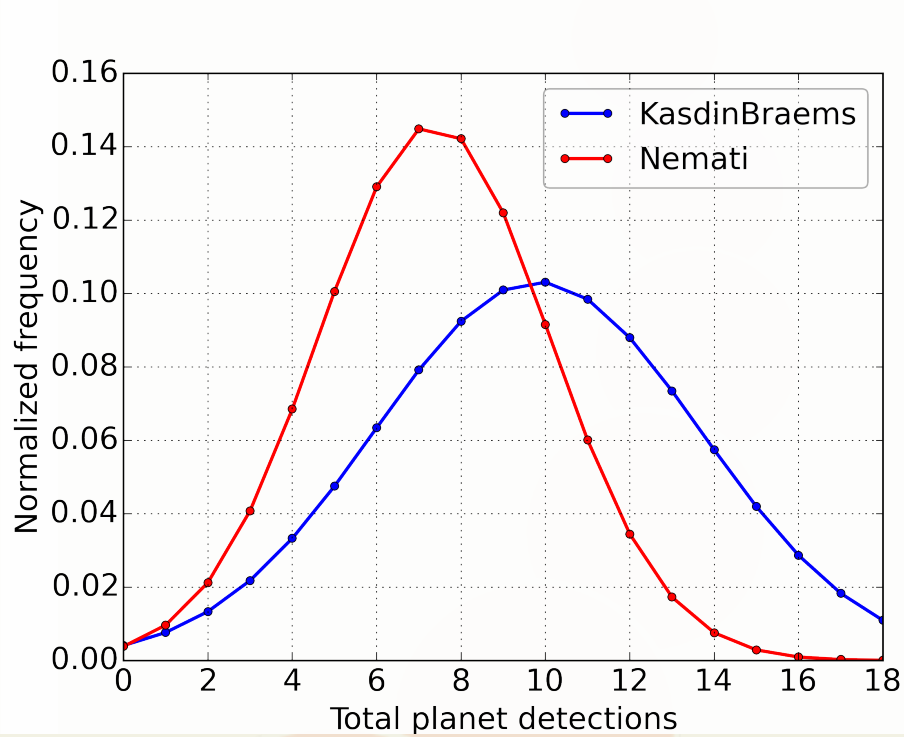



Savransky et al 2016 (JATIS)

# Comparison of detection criteria

- method 1, Kasdin 2006: FAP = 3E-5 and MDP = 1E-3
- method 2, Nemati 2014: setting a SNR = 5



# Conclusions and future development

- EXOSIMS — a modular, open-source software
- Compare different cameras, coronagraphs, post-processing gains, jitter values, etc.
- Alpha release: February 2016
- Continued updates through 2017, as a community-driven project
- Code and documentation publicly available: https://github.com/dsavransky/EXOSIMS



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