Exoplanet Direct Imaging: Coronagraph Probe Mission Study "EXO-C"

Karl Stapelfeldt

Affiliate Scientist, JPL/Caltech

For the EXO-C STDT and Design Team

Context for Study

- Flagship mission for spectroscopy of ExoEarths is a long-term priority for space astrophysics (Astro2010).
- Requires 10^{-10} contrast at 3 λ/D separation, (>10,000 times beyond HST performance) and large telescope > 4m aperture. Big step.
- Mission for spectroscopy of giant planets and imaging of disks requires 10^{-9} contrast at 3 λ/D (already demonstrated in lab) and ~1.5m telescope. Should be much more affordable, good intermediate step.
- Various PIs have proposed many versions of the latter mission 17 times since 1999; no unified approach.

NASA HQ Astrophysics Implementation Plan

- New strategic mission expected to start in FY 17. It will be AFTA/WFIRST if budget allows. If not, need less expensive “probe” mission options as backups. Four to choose from: WFIRST, 2 exoplanet, and X-ray.
- Probe mission terms:
  - cost ~ $1B
  - technical readiness (TRL 5) by 2017
- EXO-C is an 18 month HQ-funded study of an internal coronagraph probe mission
  - Science & Technology Definition Team selected May 2013. *Previous competitors now working together.*
  - Engineering Design Team in place at Jet Propulsion Laboratory, July 2013
  - Interim report for March 2014, Final report due Jan 2015

EXO-C Key People

Science and Technology Definition Team

Karl Stapelfeldt (Chair)

Rus Belikov (NASA/Ames)

Geoff Bryden (JPL/Caltech)

Kerri Cahoy (MIT)

Supriya Chakrabarti (UMass Lowell)

Mark Marley (NASA/Ames)

Michael McElwain (NASA/GSFC)

Vikki Meadows (U. Wash)

Gene Serabyn (JPL/Caltech)

John Trauger (JPL/Caltech)

JPL Engineering Design Team

Keith Warfield	Michael Brenner
Ron Bauman	John Krist
Paul Brugarolas	Jared Lang
Frank Dekens	Joel Nissen
Serge Dubovitsky	Jeff Oseas
Bobby Effinger	Otto Polanco
Andy Kissel	Eric Sunada

ExEP Office

Gary Blackwood	Wes Traub
Peter Lawson	Steve Unwin

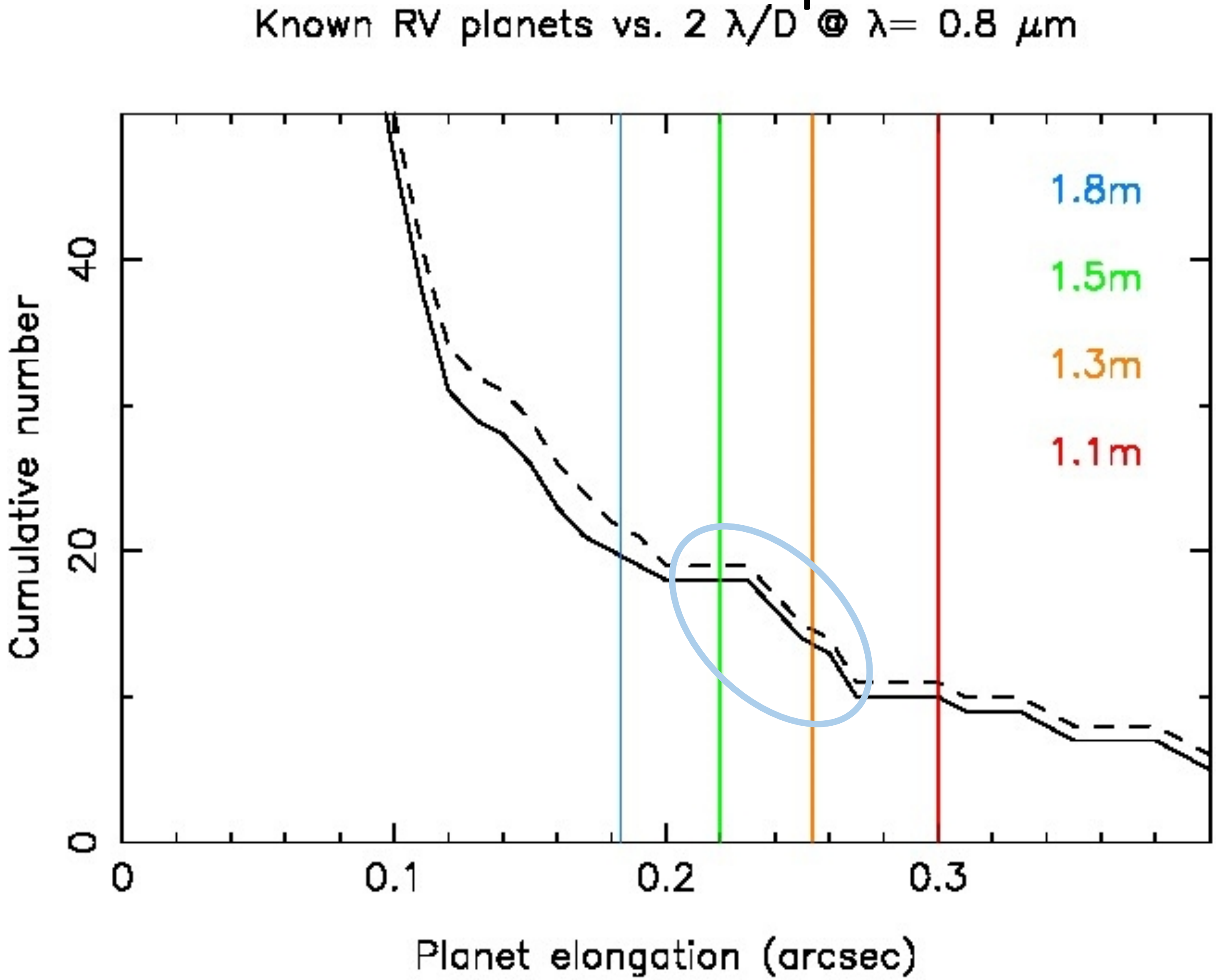
Approach to the Study

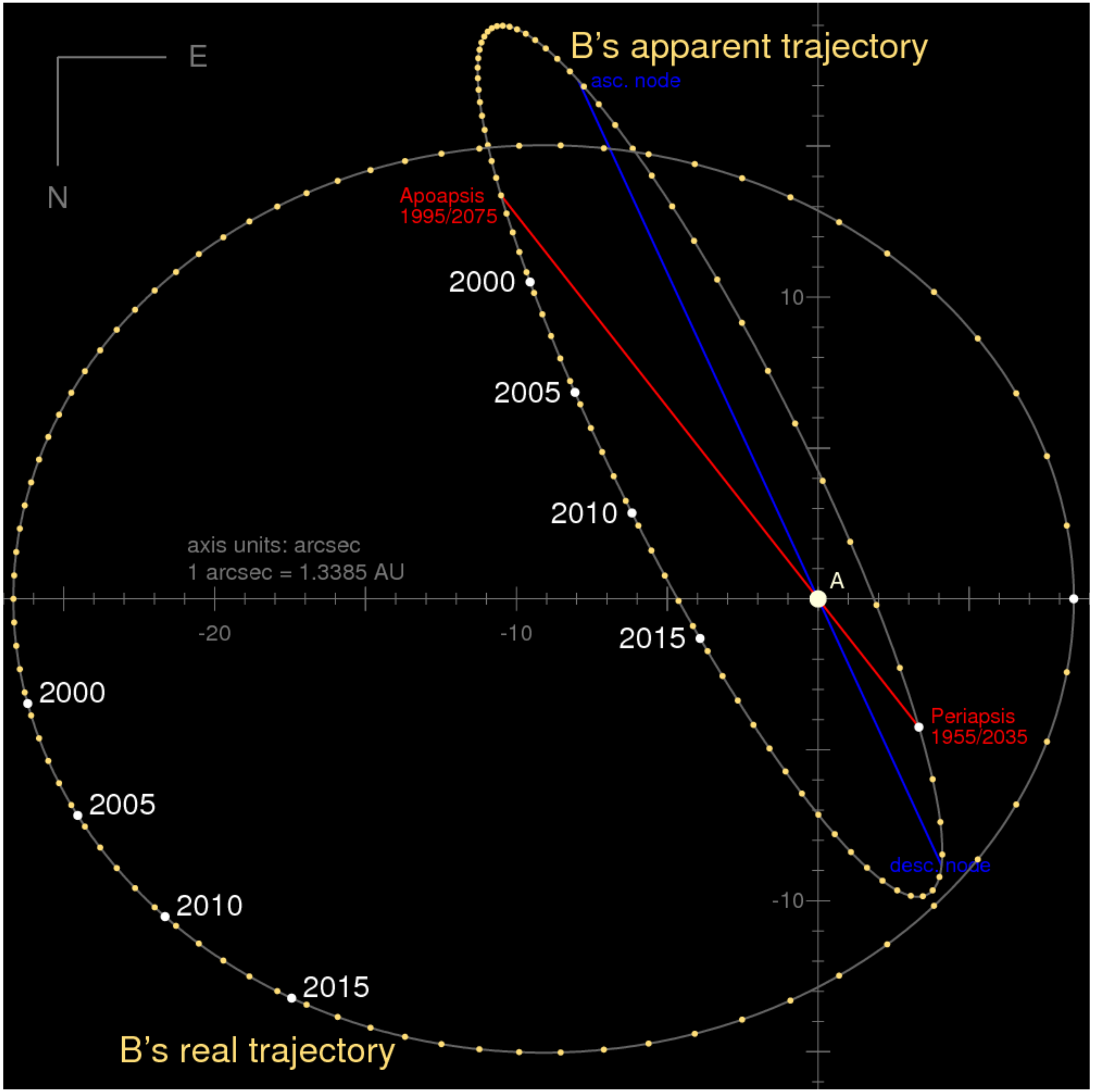
- Build on previous work (ACCESS, PECO, ...)
- Begin with science goals and trade studies of system-level issues: telescope design, orbit selection, pointing control, wavefront stability and control, <u>cost</u>
- Evaluate coronagraph options in the context of achievable system performance
- Engage Aerospace Corp. early in the study for cost feedback
- Innovate

Science Goals

- Obtain optical spectra of the nearest RV planets: measure CH_4, H_2O, Rayleigh scat. Fix orbit inclination → planet mass.
- Search for planets beyond RV limits (Neptunes, super-Earths) in a TBD nearby star sample. Measure their orbits, carry out follow-on spectroscopy of the brightest ones
  - alpha Centauri system is a particularly important case
- Optical spectra of planets discovered by near-IR ground AO
- Image circumstellar disks beyond HST, AO, and ALMA limits:
  - Resolve disk structures: Size, extent, rings/gaps/asymmetries as evidence for planetary perturbations
  - Dust properties: diagnose via albedo, color, and phase function
  - Time evolution of the above from protoplanetary to debris disks
  - Assess dust content near HZ in maybe a dozen nearby sunlike stars

Accessible RV planets



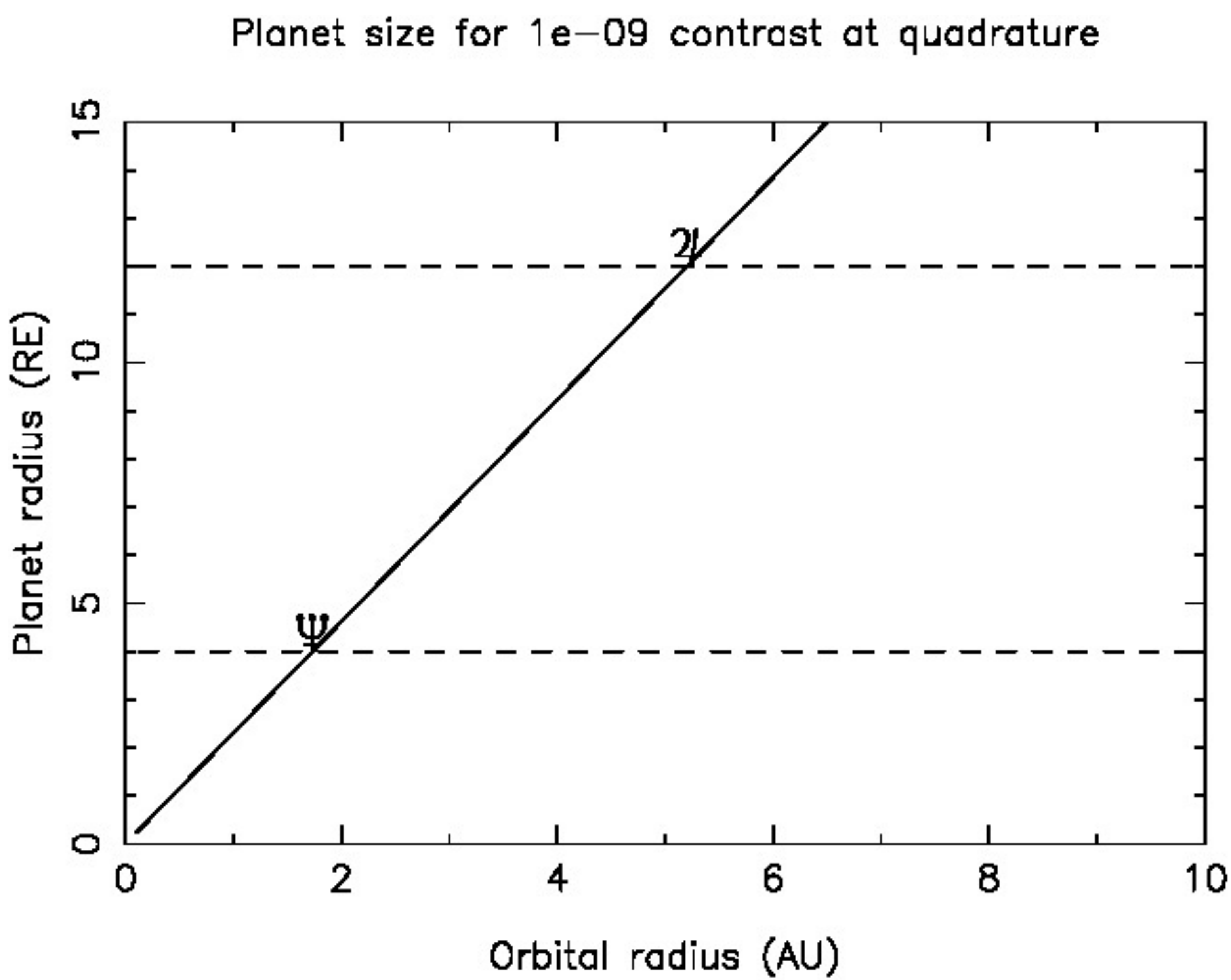


α Cen binary orbit:

- 8.5″ separation in 2025, growing to 10.5″ a few years later
- Need corona-graph mask that covers both stars and can accom-modate the vari-able separation
- HZs at 0.5″

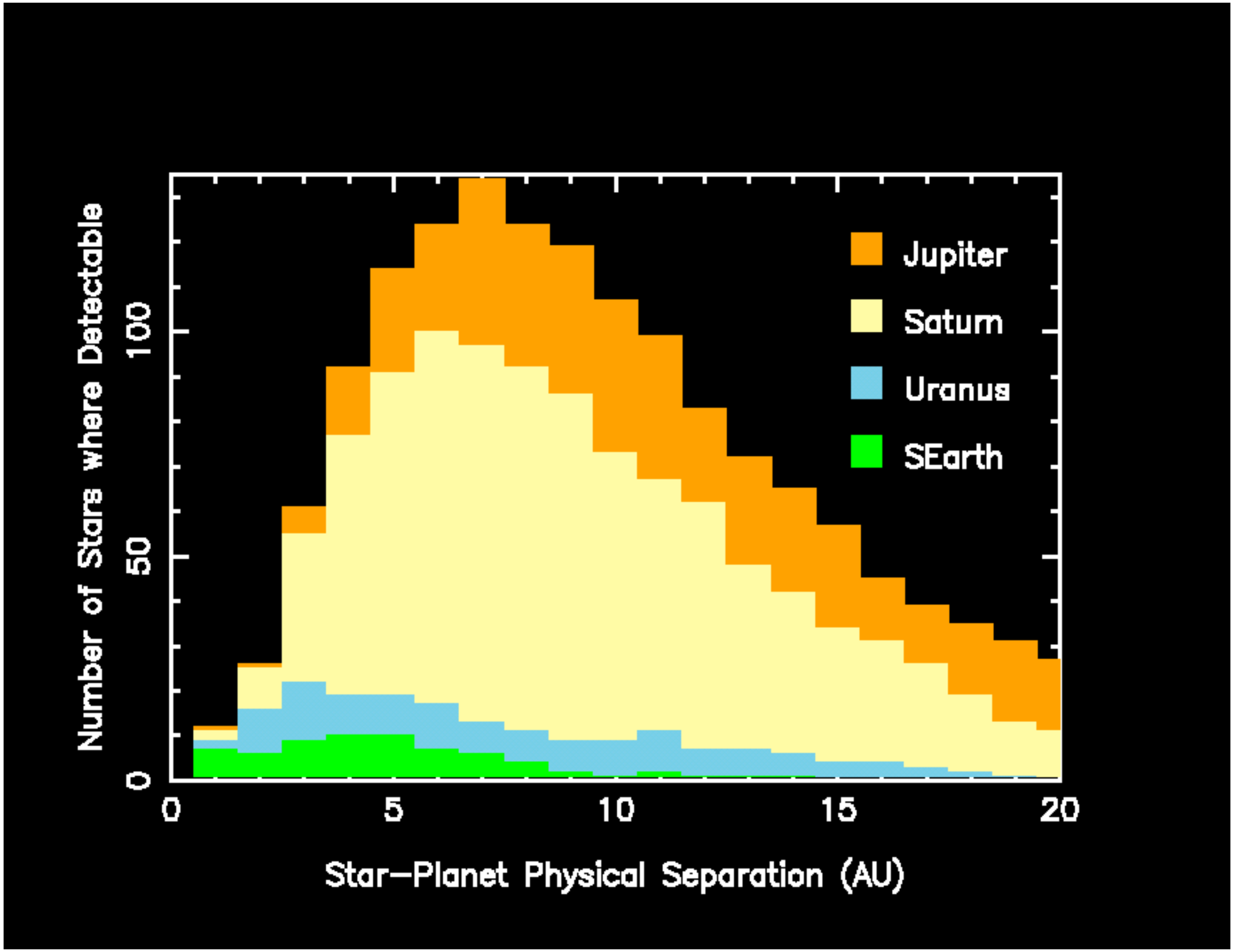
Current working science requirements

- Residual uncontrolled speckle contrast:
  - DC level ≤ 1e-09, stability over 48 hours ≤ 1e-10, stray/scattered light from binary companion ≤ 1e-09 @ 8″ sep
- Pointing performance
  - 0.1 mas accuracy, 0.5 mas stability per 1000s (to be achieved with fine steering mirror)
  - Telescope/spacecraft requirements still under evaluation
- Spectroscopy: 450 nm < λ < 1000 nm range desired
  - R~25 at short wavelengths, R~50 at long wavelengths
- Astrometric precision 30 mas
- Mission lifetime >= 3 yrs


Planet size for 1e−09 contrast at quadrature
Planet radius (RE)
Orbital radius (AU)
0
5
10
15
0
2
4
6
8
10
♃
Ψ

Planet detectability placeholder

from the Trauger et al. ACCESS study



Engineering Trades

- Unanimous decision for unobscured telescope
  - Better throughput, resolution, stiffness, coronagraph TRL. Slightly higher cost
- Telescope aperture of 1.3-1.5m appears to be affordable
- Nearly decided on Earth-trailing orbit
  - Better thermal stability & sky visibility than EO. No propulsion needed. Acceptable data rates.
- Integral Field Spectrograph in addition to filter imaging
  - Simultaneous measurements over ~> 20% bandpass
  - Supports speckle rejection as well as planet spectra

Choosing a coronagraph

- Pre-requisite is having some understanding of likely pointing performance, thermal stability, and control authority over time-variable low order aberrations.
- Six concepts to be evaluated: hybrid Lyot, PIAA, shaped pupils, vector vortex, two visible nuller variants.
- Process will begin at our Nov. meeting. Optical simulations, science yield estimates. Demonstrated lab performance will be highly weighted. Will take our time.
- EXO-C decision will be totally independent of AFTA choices.

Thoughts on 3 year Design Reference Mission

- Very preliminary: don't yet understand our overheads, and throughput varies across coronagraph types
- 850 days of integration time would support:
  - Spectra of ~ dozen known RV planets (100 days)
  - Planet searches in 250 stars (250 days), followup spectroscopy of another ~ dozen objects (100 days)
  - Disk imaging surveys
    - Detection survey in 500 RV planet systems (200 days)
    - 120 known debris disks within 40 pc (60 days)
    - 180 young debris disks from WISE (100 days)
    - 100 nearby protoplanetary disks (40 days)

Conclusions

- EXO-C Study is well underway. We will show what an affordable, optimal, high TRL exoplanet direct imaging mission could do.
- We are eager to get our first Structural-Thermal-OPtical (STOP) models to assess telescope stability
- Capability to search alpha Cen system may be key to selling the mission
- Please send me your suggestions for things we should look into, or how you'd like to help: kstapelf@gmail.com.