Exoplanet Direct Imaging: Coronagraph Probe Mission Study “EXO-C”

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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 $3\lambda/D$ 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 $3\lambda/D$ (already demonstrated in lab) and $\sim1.5m$ 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

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## JPL Engineering Design Team

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## ExEP Office

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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, cost
• 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$_2$O, Rayleigh scat. Fix orbit inclination $\rightarrow$ 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

Known RV planets vs. $2 \lambda/D @ \lambda = 0.8 \mu m$

![Graph showing cumulative number vs. planet elongation (arcsec) with vertical lines at different wavelengths (1.1m, 1.3m, 1.5m, 1.8m).]
α Cen binary orbit:

- 8.5″ separation in 2025, growing to 10.5″ a few years later
- Need coronagraph mask that covers both stars and can accommodate the variable 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 $1 \times 10^{-09}$ contrast at quadrature
Planet detectability placeholder from the Trauger et al. ACCESS study

![Graph showing planet detectability](image)
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

• 800 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.