Impacts of Exozodi on Measurements

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Exozodi gives noise and confusion

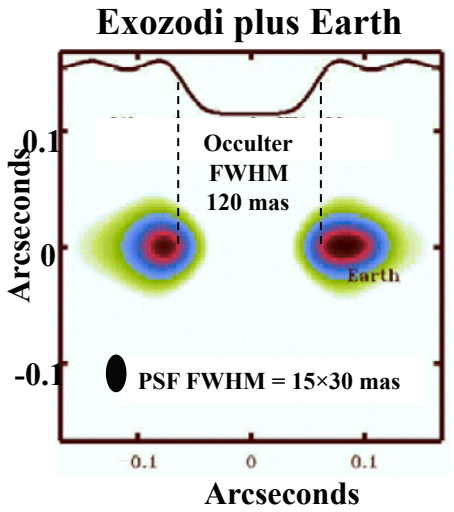
- Exozodi distribution has often been treated as a shot noise source only, even uniform
- Following shows that we can have trouble distinguishing exozodi features from point sources
- Consequently, we will have to limit how small a planet we can pull out of a given exozodi cloud, depending on how well we can discriminate blobs and decentering from point sources

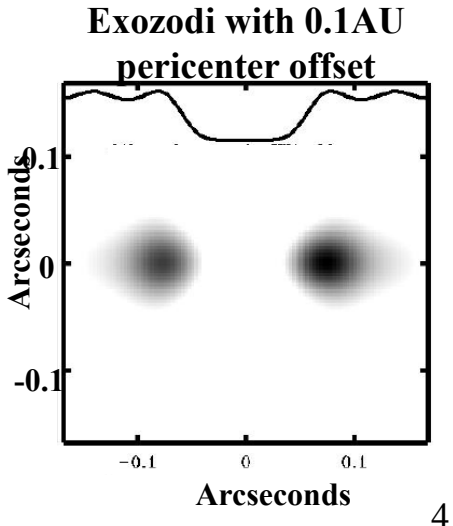
Challenges of exozodi

- Exozodi increases integration times
- Exozodi profile features can mimic small exoplanets
  - Exozodi profile traditionally assumed symmetric and/or uniform
    - Neglects difficulties in fitting exozodi and isolating the planet
  - Asymmetry in the image can be caused by
    - Dynamics of the planetary system (giant planets → pericenter shift)
    - Occulter decenter and asymmetry
    - Requires a more general exozodi profile model for planet detection analysis
  - Broad PSF (small telescope) leaves ambiguity between point sources and exozodi features

Terrestrial Planet detection requires fitting a fully general exozodi model

- From panchromatic camera or integral field spectrograph data
- Fit exozodi shape and brightness, coronagraph suppression, and exoplanet position
- Correct for expected exozodi profile features, based on measurements
- Uncertainty in exozodi profile increases uncertainties in exoplanet position, brightness, and spectrum

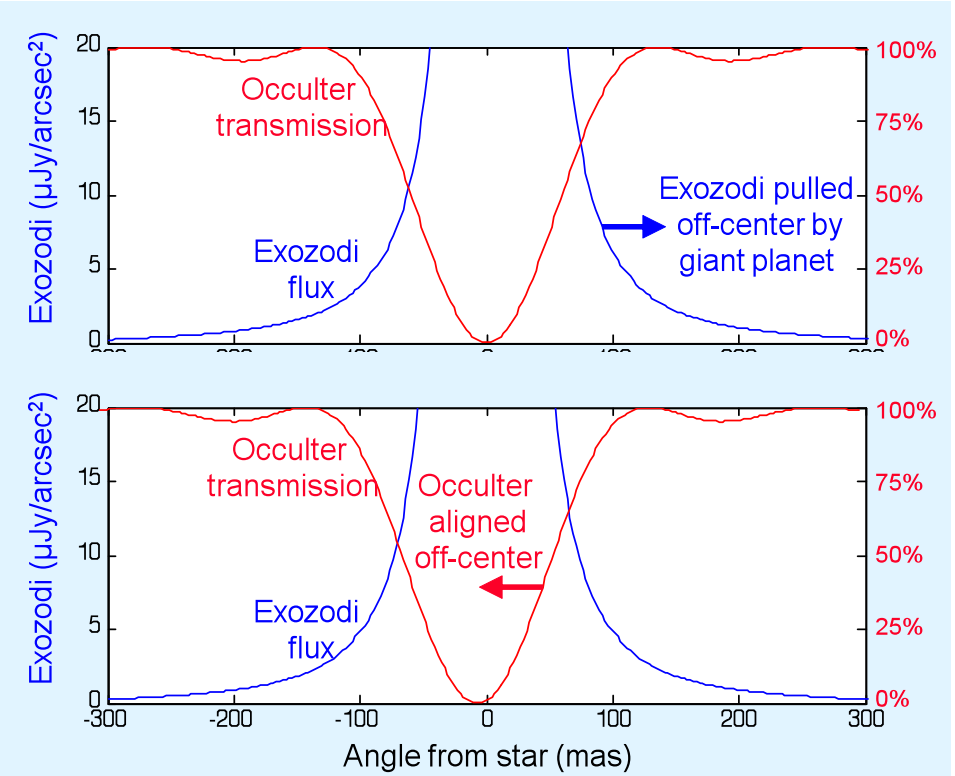




Causes of exozodi asymmetry

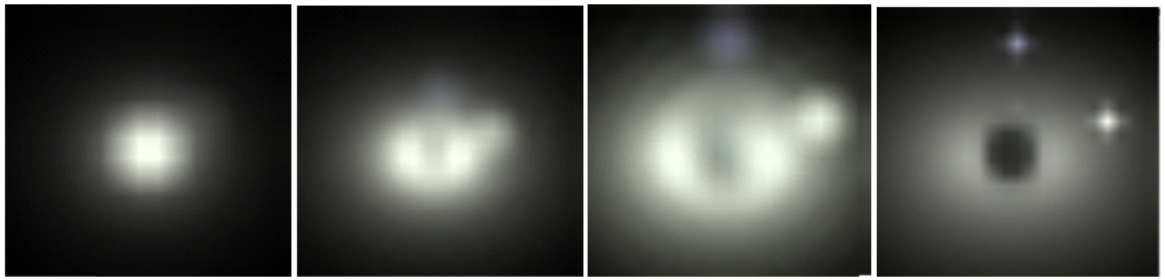
- Planetary dynamics causes real exozodi asymmetry
  - Gravitational influence of giant planet(s) causes exozodi pericenter offset
  - Offset is locked to the giant planet's axis of orbital symmetry (periastron-apastron)
  - Precise knowledge of giant planet orbits might allow estimates of the asymmetry

- Occulter decentering causes apparent exozodi asymmetry
  - Exozodi brightness profile is sharply peaked near center
  - Decentered occulter (internal/external) asymmetrically blocks the exozodi cloud
  - Precise knowledge of the offset vs. the star would allow estimates of the apparent asymmetry



Measurement limitations

- Broad PSF (small telescope) exacerbates the ambiguity problem
  - Makes point sources (exoplanets) difficult to distinguish from exozodi features
  - Features of exozodi clouds are ~0.1-1 AU in size;
  - Coronagraph with IWA = 2λ/D has PSF FWHM ≈ 0.5 AU
  - A broad PSF washes out details and spreads point sources



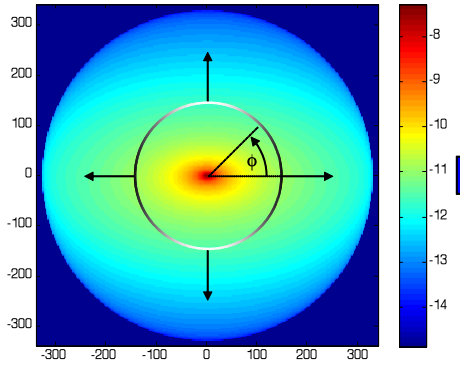
Cash et.al., Proc. SPIE **7010**, p. 70101Q (Marseille, 2008)

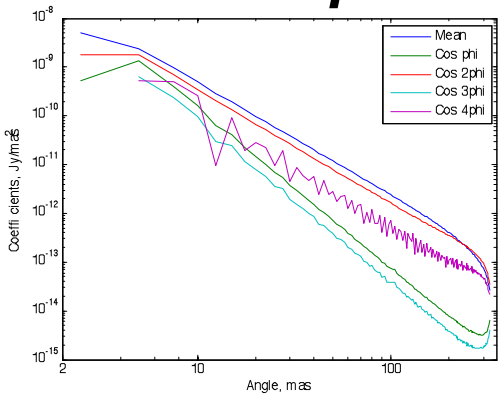
A starting point for analyzing exozodi clouds

R-ϕ components of exozodi profiles

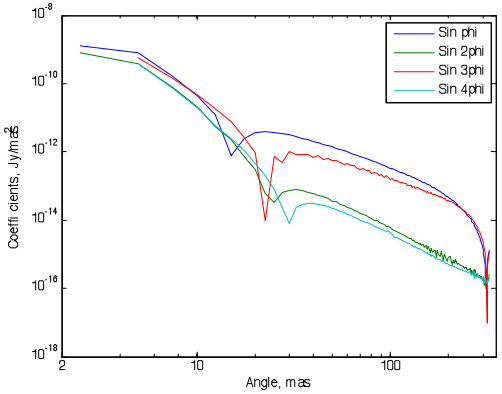
Exozodi at 10pc, 10× brighter than Solar zodi, no Sun and no planets, λ=0.5 μm, 60° inclination

Log_{10} contours, jansky/(2.5mas)²





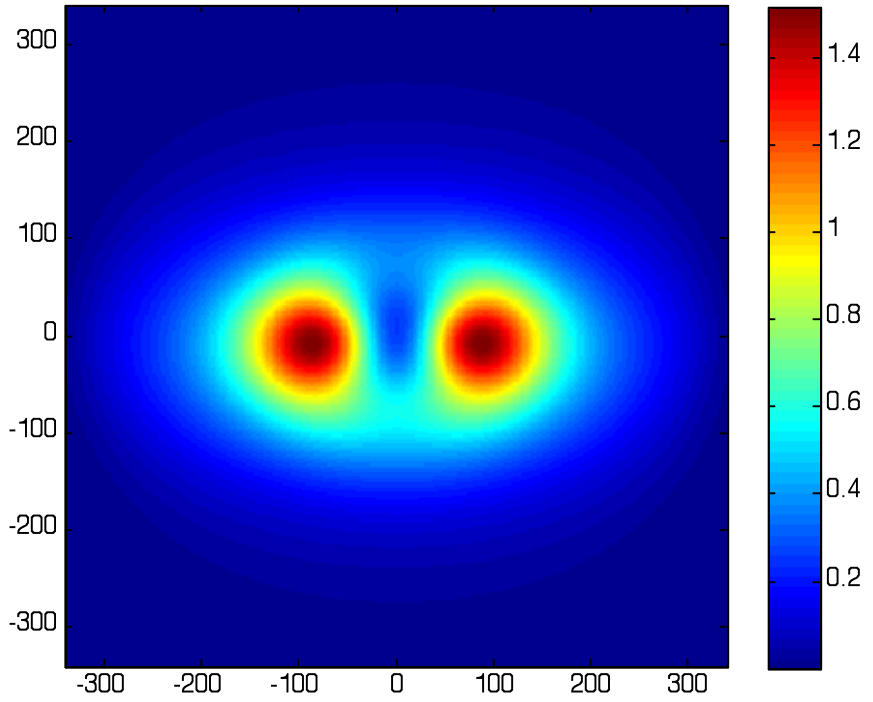
Cosines (x): Even harmonics dominate (→ symmetric left-right)



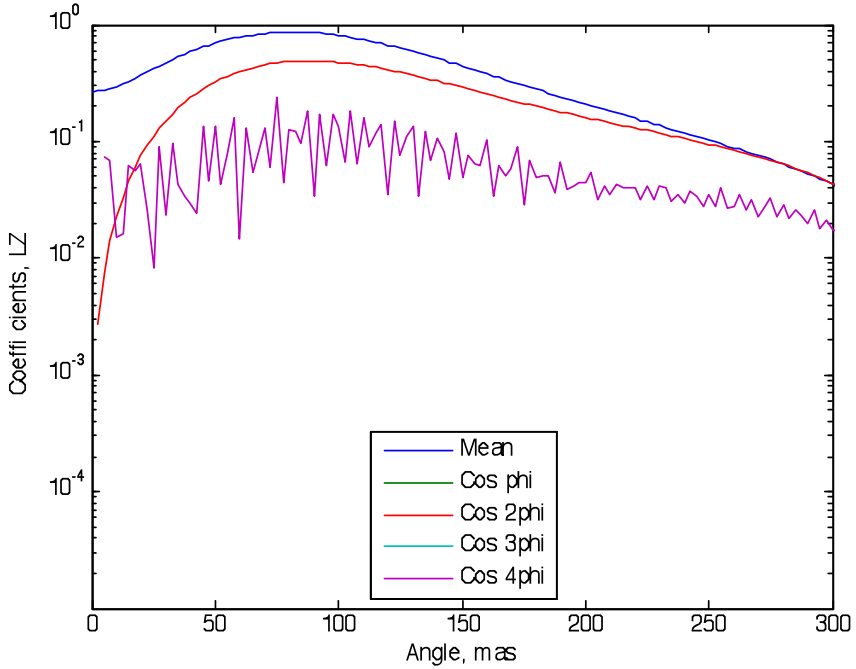
Sines (y): Odd harmonics dominate (asymmetric top-bottom)

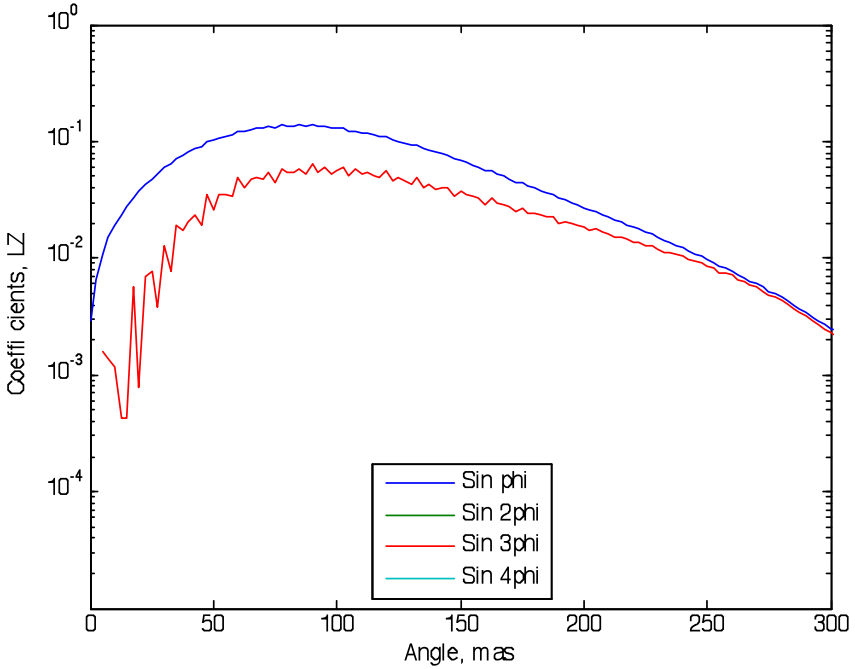
Baseline case
Symmetric exozodi, No planets

- Same zodi seen through a 4m diam Lyot coronagraph, jinc^2 mask (circular)
  IWA = 3.1 λ/D = 80mas
  Linear contours



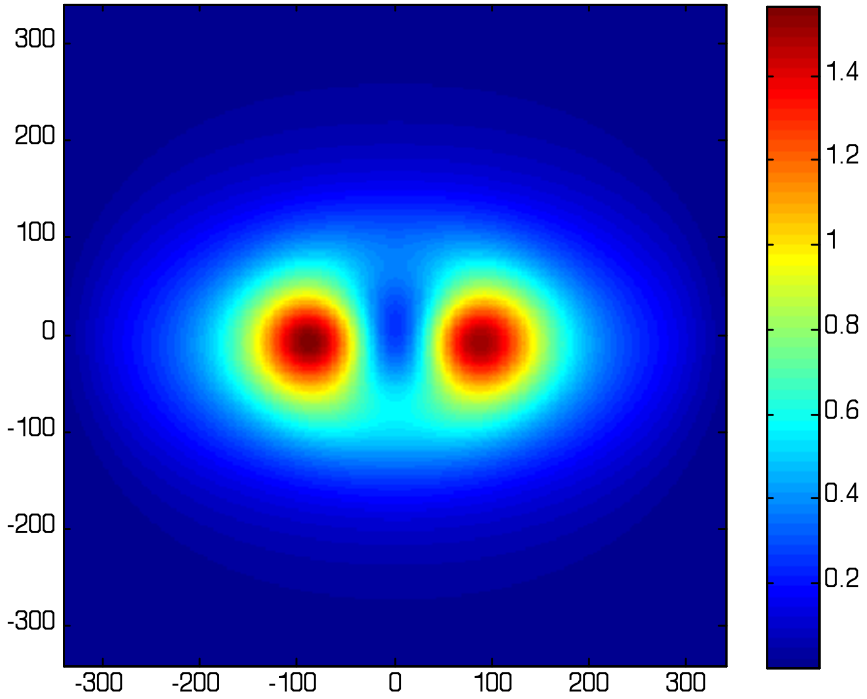
Resulting angular decomposition





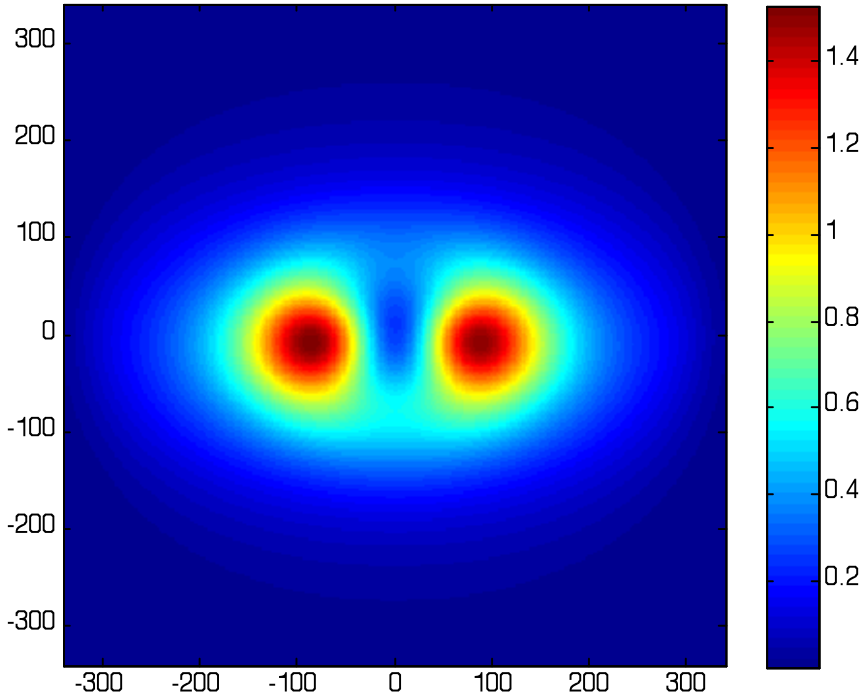
With Earthlike exoplanet and Symmetric exozodi

- Same zodi with Earth-like planet (on the left side),
- Seen through the same coronagraph
- Linear contours



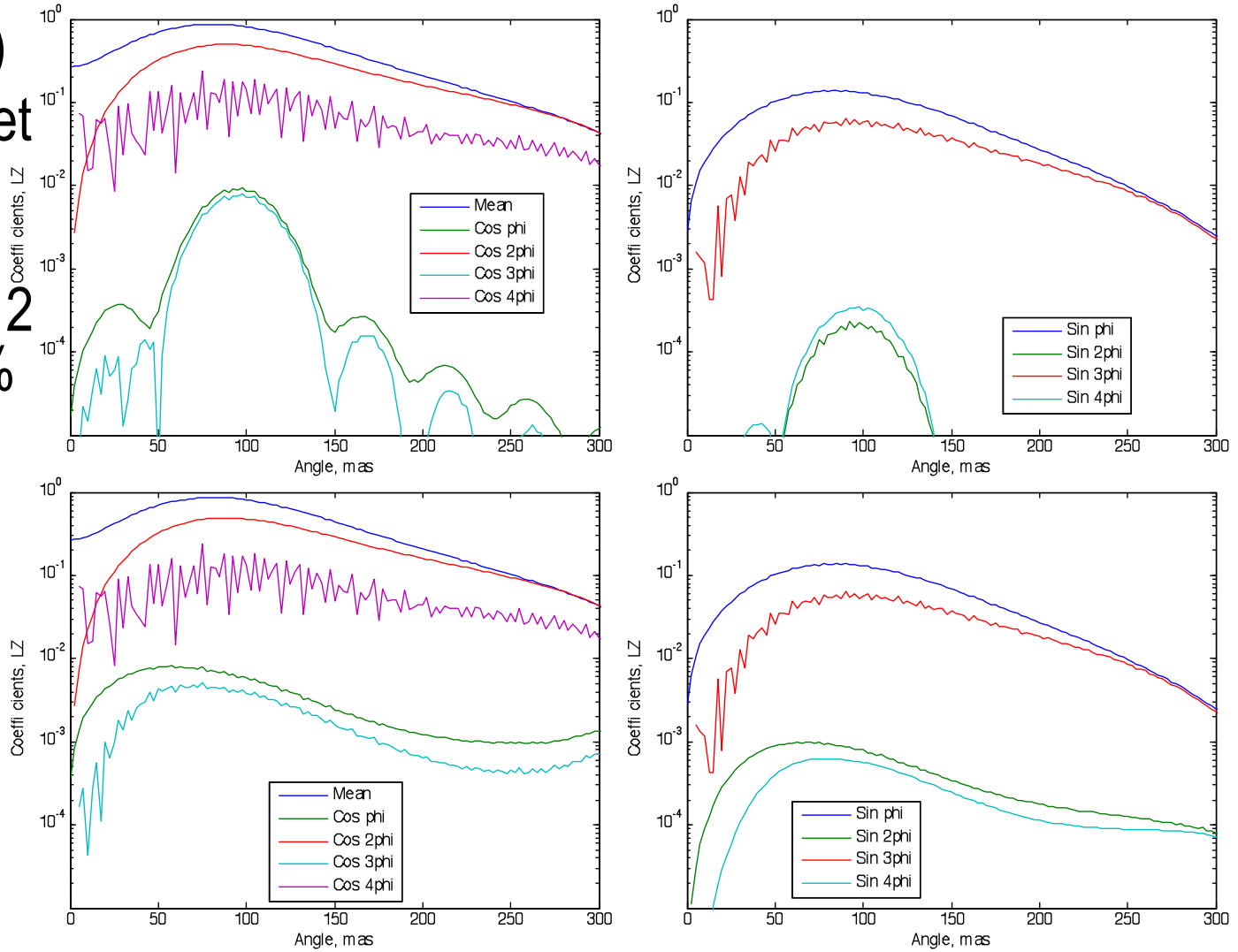
With pericenter offset: Asymmetric exozodi, no planets

- Same zodi with pericenter offset of 0.0131 AU,
- Seen through the same coronagraph
- Linear contours



Compare them in angular decomposition

- Exoplanet (top)
- Pericenter offset (bottom)
- Differences between these 2 curves are <1% of average EZ flux
- Demands greater measurement sensitivity to distinguish the 2 possibilities



The example pericenter offset is comparable to

- Dynamical effect of our Jupiter on our local zodi
- One Earth signature in the coronagraph
- 2% (TBR) skew asymmetry in internal occulter attenuation profile
- 1.3 mas offset of occulter from star (0.5 m for external occulter)
- 1.3 mas error in locating the star on the detector
- 10× smaller pericenter offset for 10× brighter exozodi

Exozodi modeling uncertainty

- Exozodi modeling could become the dominant uncertainty / ambiguity in finding exoplanets
- Small telescopes (fat PSFs) make it more difficult
- Brighter exozodis make it more difficult

Possible mitigation strategies

- Increase the telescope size to sharpen the PSF
- Increase SNR to aid in distinguishing subtle shape variations
- Multiple revisits to same target star to observe exoplanet orbital motion
- Advanced exozodi models supported by calibration measurements

Conclusion: Exozodi gives noise and confusion

- Faint-planet detection requires careful modeling of exozodi asymmetry
- Uncertainty in faint-planet detection can be limited by uncertainty in modeling the exozodi asymmetry
  - Or possible driver for integration times
- Consequently, we will have to limit how small a planet we can pull out of a given exozodi cloud, depending on how well we can discriminate blobs and decentering from point sources