Exozodiacal Dust & Planet Imaging

NASA Exoplanet Program Analysis Group
Food for Thought

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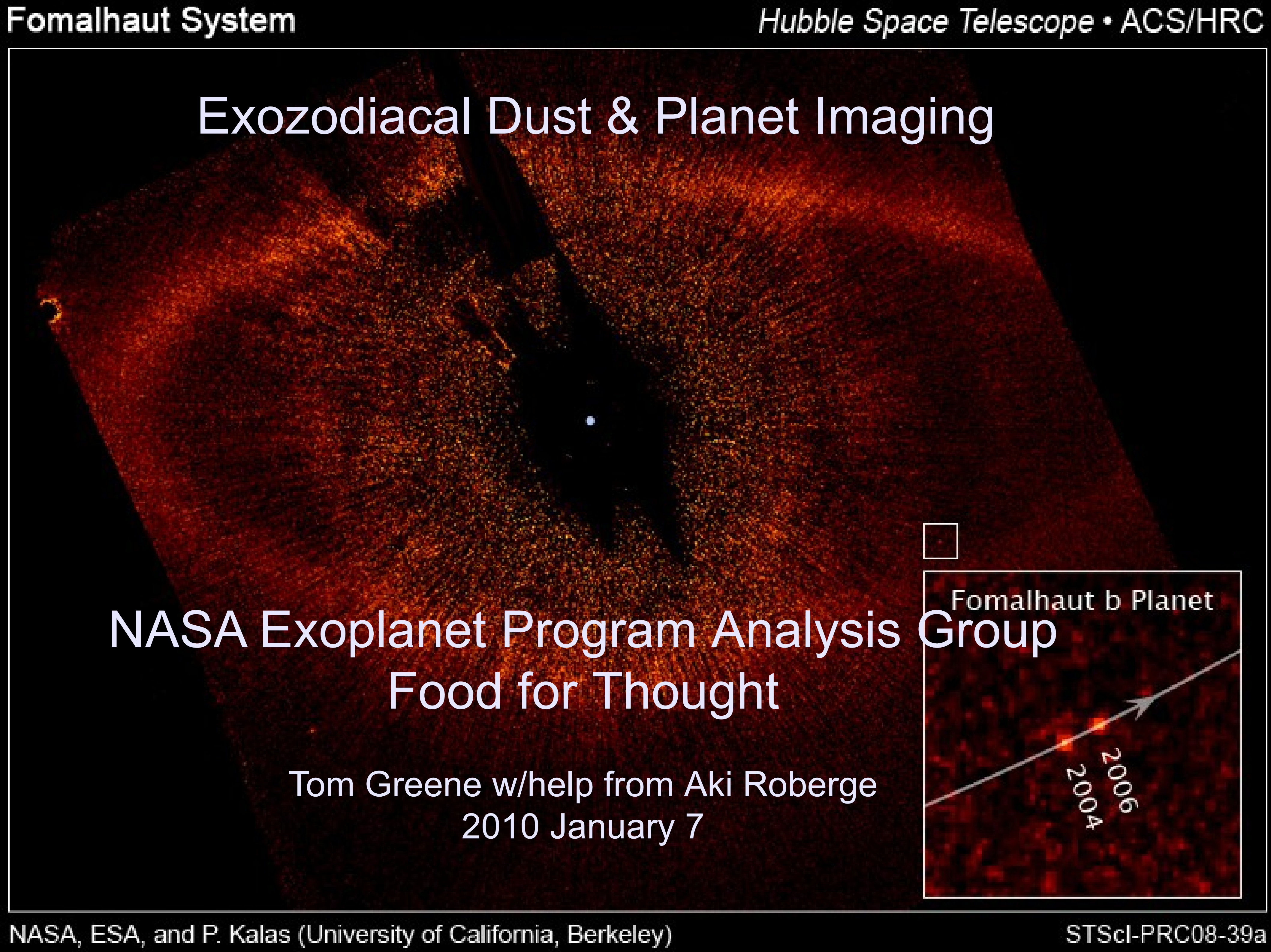


Exozodiacal Dust & Planet Imaging

- Exozodiacal dust disks will add noise to both single aperture and interferometric exoplanet imaging observations
  - *Symmetric disks* add photon noise (minimum impact)
  - *Asymmetric disk structure* → large systematic noise
  - *Clumps in disks* difficult to distinguish from planets
- Small optical telescopes and IR interferometers are impacted more greatly by exozodi flux noise than large ones:
  - Lower spatial resolution includes more dust flux per resolution element
  - New, high efficiency, small inner working angle imaging systems (PIAA, optical vortex, Occulter) and limited budgets are driving down apertures of future imaging missions
- Exozodi impact on interferometers is more complex; trades off with stellar leakage and other terms (more later)
- We must carefully consider the impact of noise from exozodiacal dust in evaluating mission concepts for both detecting and characterizing small exoplanets & atmospheres.

Exozodi vs telescope aperture (visible)

- Angular extent of exozodi flux within a PSF increases as D^{-2} but flux from an exoplanet is always within 1 PSF
  - For a given number of photons, SNR ~ D^1 and t_{int} ~ D^{-2}
  - For real telescopes, SNR ~ D^2 and t_{int} ~ D^{-4} (like bkg noise limited)
- Useful to consider 1 zodi Exozodi to 1 Earth flux for different apertures
  - Assume exozodiacal disk is inclined 60 deg with V =22 mag / sq as

d (pc)	Dtel (m)	Flux (Exozodi / Earth)
5	1.5	7
5	2.5	3
5	4.0	1
10	4.0	4
15	1.5	64
15	2.5	23
15	4.0	9

Implications for visible Imaging

- Exozodi > 1 zodi will significantly impact the SNR and integration times for ***broadband detections*** of terrestrial planets greater than 5 pc away for telescopes with D < 4m
  - Many stars greater than 10 pc away will have prohibitively long integration times for planet searches even with large telescopes if Exozodi > 10 zodi (depends on both star and distance)
  - Modest D < 2.5-m telescopes are more severely impacted; can only tolerate up to a few zodi at 10 pc distance
- Spectroscopic characterization of detected planets can be impacted more severely:
  - More integration time is required for each planet, so even a modest increase can eliminate a planet or greatly limit the number studied
  - Measuring deep absorption bands like O2 will be very difficult because of the low signal from the planet coupled with the full noise of the exozodi
  - Even a 4-m telescope may be limited to characterizing planets (good SNR spectra) with less than a few zodi exozodi for stars at d > 10 pc.

Simulation: α Cen w/10 zodi & D=1.5-m tel.

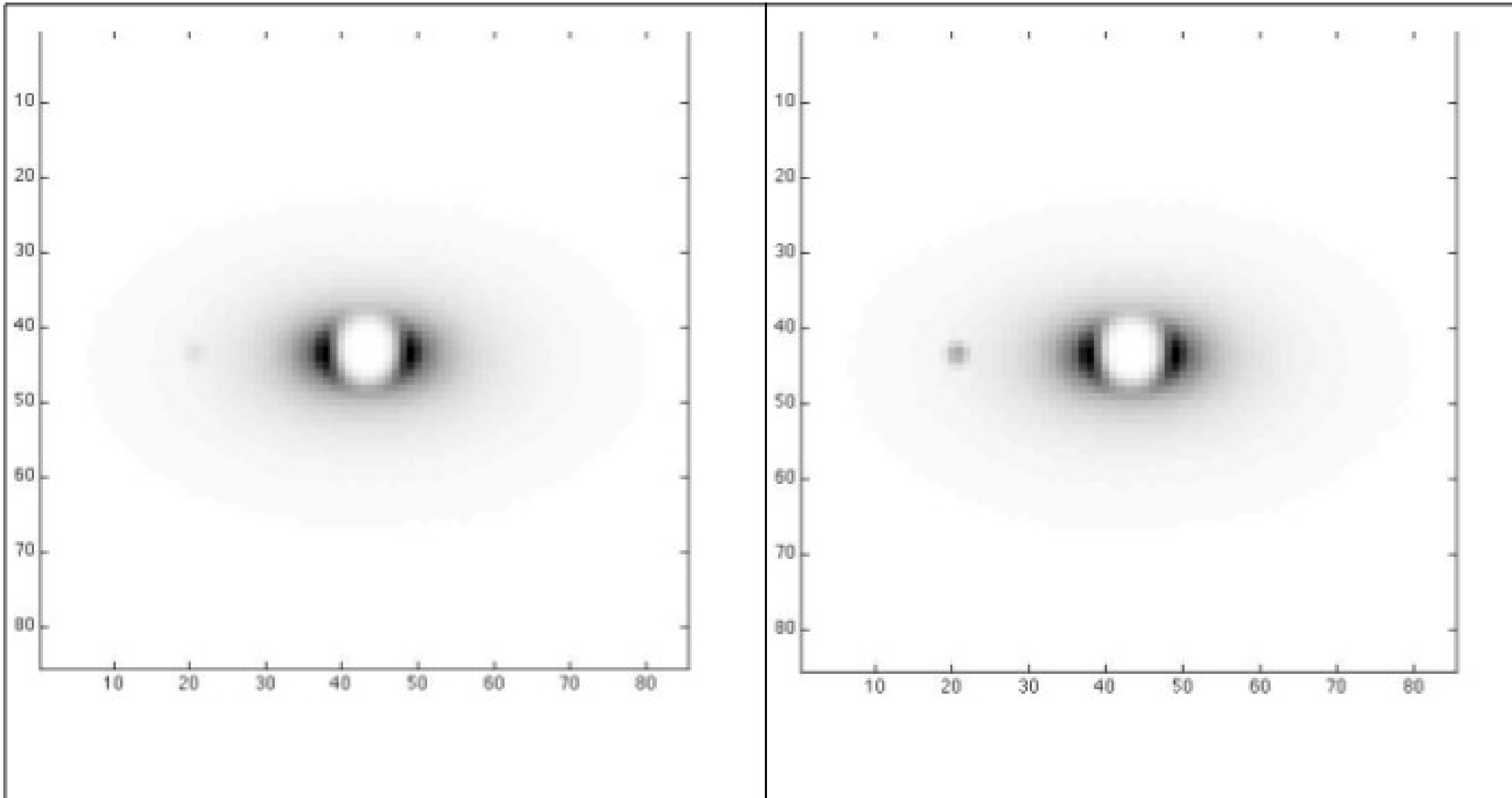


Figure 7-3: Alp Cen A with 10 zodi disk i = 59 deg with Earth (L) and Super-Earth (right), both 1 AU from the G2 V star and easily detectable in these 1E4 second exposures.

Simulations by K. Cahoy & O. Guyon (PECO study report)

Simulation: Sun @ 10pc w/10 zodi & D=1.5-m

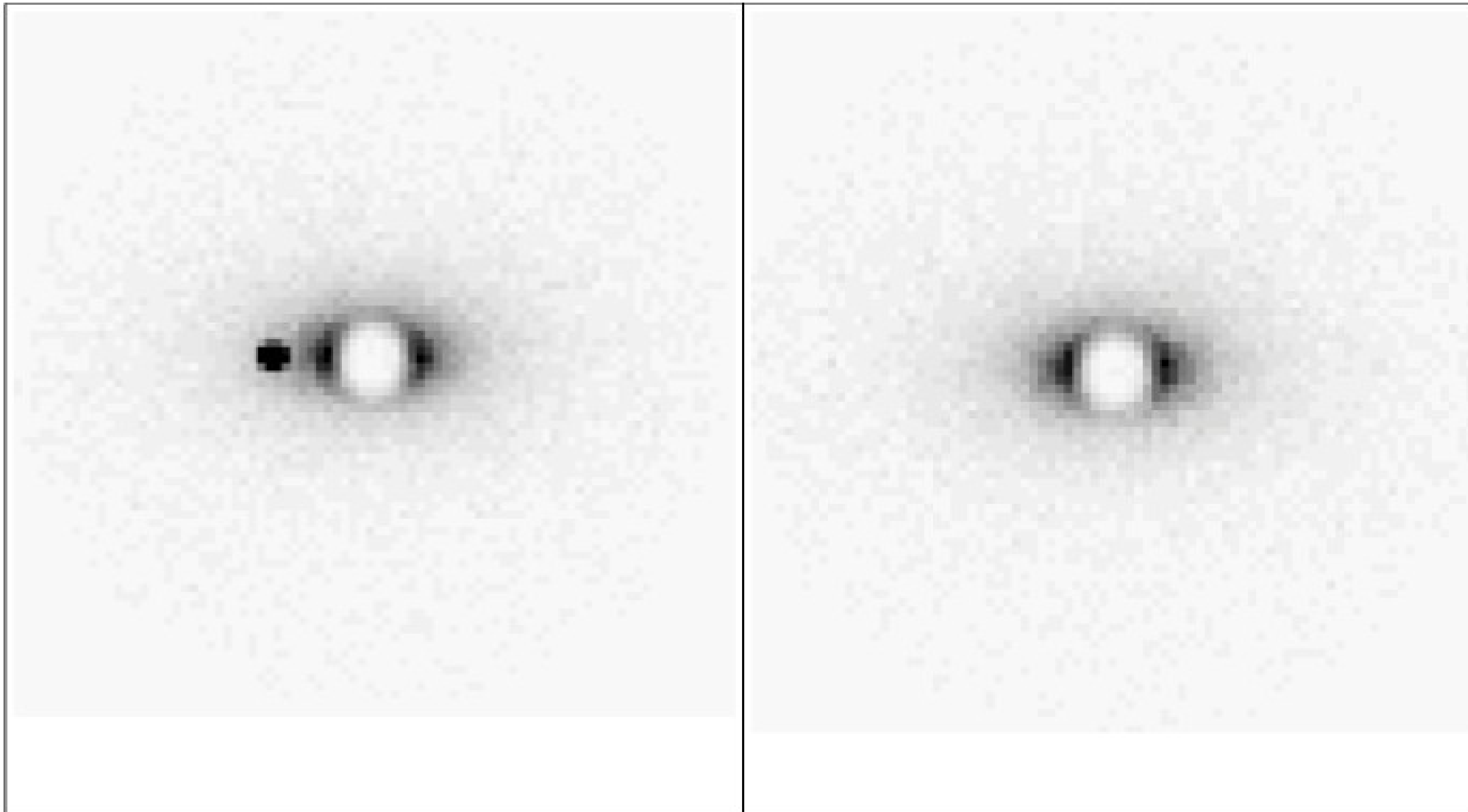
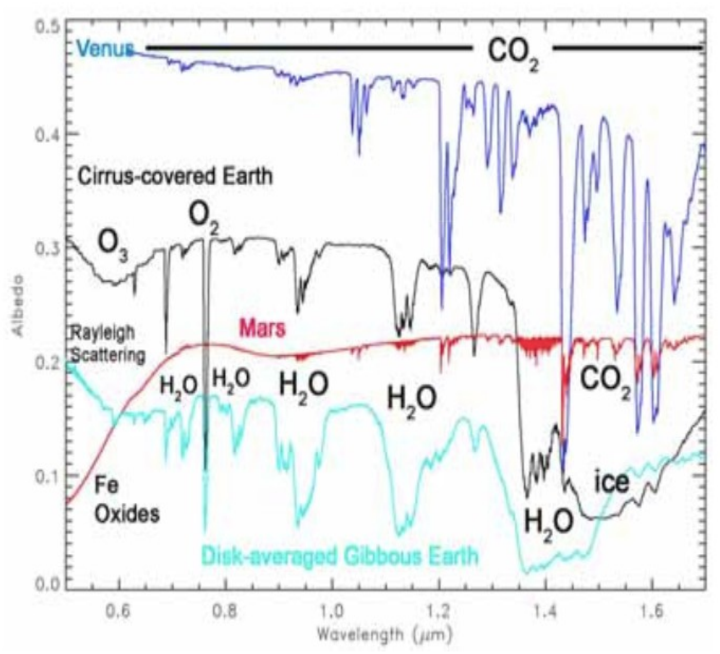


Figure 7-4: Sun at 10 pc with a circumstellar disk and Jupiter (left) and with Earth (right), each 86,400 sec (10 days) integration time. The 10 zodi disk has inclination i = 59 degrees in each image. Jupiter is clearly visible at high signal-to-noise because it is far outside the IWA where the disk surface brightness is low. The Earth has disappeared within the IWA and is drowned by the disk flux.

Simulations by K. Cahoy & O. Guyon (PECO study report)

Impact on Characterization Spectroscopy

- Exozodi adds substantial noise to deep absorption lines like O_2 A
  - A 66% deep line has its SNR degraded by an factor of ~sqrt 2 or its integration time increased by ~2x over a continuum point in presence of substantial exozodi.
  - Need to observe lines with at least modest SNR to determine abundances



Adding 1 continuum level of exozodi increases photon noise by sqrt(2) in continuum and sqrt(1.33/.33) = 2 in a line that is 66% deep

Exozodi impact on interferometers

- Large baseline IR interferometers can operate at good resolution and low IWA and can tolerate some exozodi because:
  - Increasing stellar leakage as baseline / resolution increases
  - Local zodi is fairly high for mid-IR interferometers
- Darwin / TPF in Emma X-array can tolerate ~10 zodi before exozodi signal exceeds local zodi or stellar leakage (Defrere et al. 2009 error budget) – can operate with still higher levels
- Spectroscopic observations will be similarly limited: stellar leakage and local zodi will dominate noise in planetary atmosphere features until exozodi exceeds ~10 zodi (unlike optical imaging)
- Dust asymmetries will limit similar interferometers to ~10 zodi (more limiting than exozodi photon noise)