Exo-Zodi modeling for LBTI

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The Hunt for Observable Signatures of Terrestrial planetary Systems (HOSTS) is a survey using mid-IR nulling interferometry with LBTI to detect exo-Zodi a few times brighter than Zodiacal dust near the Earth in the Solar System. This poster describes a parametric exo-Zodi model, how this model is being used to simulate LBTI observations and derive the survey's sensitivity to exo-Zodi. The transparent assumptions of this model make it easy to understand the dependence of exo-Zodi sensitivity on stellar luminosity, as well as implications for a mission to detect exo-Earths.

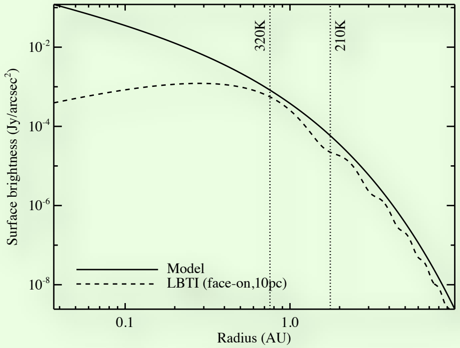
Disk model

$$S_{\rm disk} = 2.35 \times 10^{-11} \Sigma_{\rm m} B_\nu(\lambda, T_{\rm BB})$$

$$T_{\rm BB}(r) = 278.3\, L_{\rm star}^{0.25}\, r^{-0.5}\,{\rm K}$$

$$\Sigma_{\rm m} = z \Sigma_{\rm m,0} (r/r_0)^{-\alpha}$$

The equations above describe a parametric exo-Zodi model that is defined by its surface brightness, $S_{\rm disk}$ (vertical structure is less important here). It assumes power-law distributions of temperature ($T_{\rm BB}$) and dust surface density ($\Sigma_{\rm m}$). The radial (r) temperature depends on the stellar luminosity ($L_{\rm star}$). The reference surface density ($\Sigma_{\rm m,0}$) at the reference radius (r_0) defines a "1 zodi" disk. The surface density variation with radius is set by α. Disk brightness (in units of zodi) is set by z.

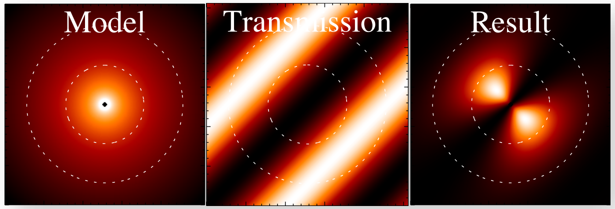


What is 1 zodi?

The Solar System's Zodiacal cloud level defines a disk with "1 zodi" brightness for a Solar-mass star. When $L_{\rm star}$=1$L_{\rm sun}$, z=1, $\Sigma_{\rm m,0}$=7.12e-8, and r_0=1AU, our parametric model is almost identical to the ZODIPIC model of our Zodiacal cloud for LBTI purposes, but is much simpler. For more or less luminous stars, the dust surface density is constant where a planet has the same temperature as the Earth (i.e. r_0=sqrt[$L_{\rm star}/L_{\rm sun}$]AU). With this definition, all 1 zodi disks have the same thermal surface brightness in the habitable zone. Imaged exo-Earths will be unresolved, so the impact of a 1 zodi disk on future exo-Earth imaging missions varies with system distance, but is the same for stars of different luminosities at fixed distance.

LBTI Transmission

Transmission through LBTI can be derived using the projection of the nulling interferometric transmission pattern onto the sky. Observing at ~10μm with a baseline of 14.4m, LBTI is most sensitive at ~70mas separations (i.e. 0.7AU at 10pc), so is ideally suited for probing habitable regions around nearby stars.



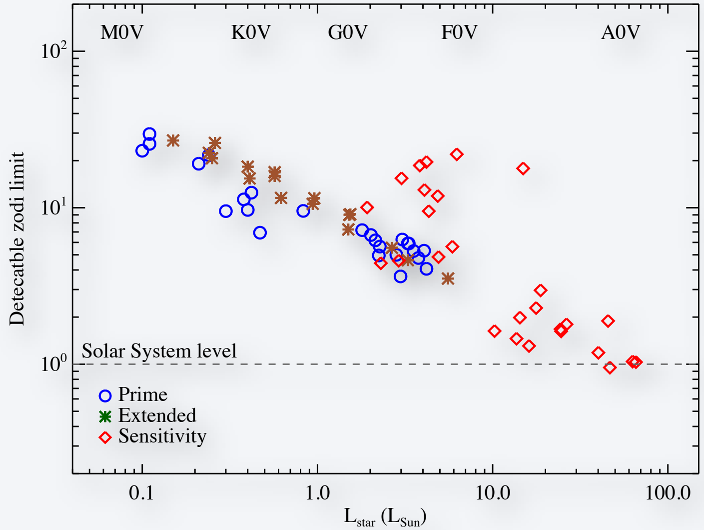
(left panel) Face-on disk model for $L_{\rm star}$=1$L_{\rm sun}$ and z=1 at 10pc, *(middle panel)* null transmission pattern, *(right panel)* transmitted flux. The dotted circles are at radii of 0.5 and 1AU. LBTI is insensitive to hot dust near to the star because it is unresolved, and cool dust far from the star because it is faint. LBTI is most sensitive to warm dust near the habitable zone just inside 1AU.

To show the left and right panels in another way, the plot to the left shows the azimuthally averaged surface brightness of the $L_{\rm star}$=1$L_{\rm sun}$, z=1 model, and the model transmitted through LBTI.

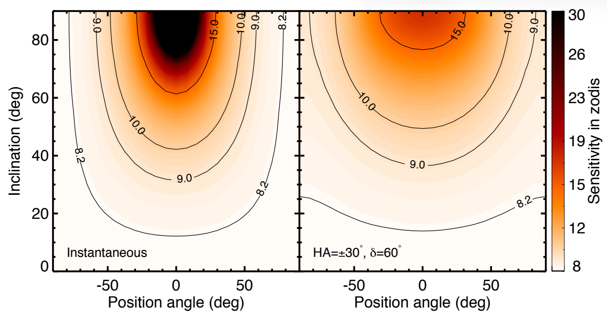
The sum of the right panel above is the flux observed when the star is nulled. The instrument sensitivity is characterized by the fraction of flux transmitted relative to the stellar brightness (the "leak"), predicted to be ~10^{-4} for stars with no disk. The sensitivity is the number of zodis that can be detected above this level, which is 10^{-4} divided by the leak for a 1 zodi disk.

The HOSTS survey

HOSTS will observe a sample of ~50 nearby stars within ~20pc (see Alycia Weinberger's poster #XXX for details). Stars are grouped into several sub-samples, and the zodi sensitivity for these stars is simulated assuming the predicted LBTI null sensitivity of 10^{-4}. For each star, the sensitivity to many disks with random orientations is calculated because in general the orientation of any exo-Zodi is unknown, and the final sensitivity is the average of these. The zodi sensitivity for survey stars is shown below, with the strong luminosity variation due to the larger total disk area at greater habitable-zone distances around more luminous stars (see "What is 1 zodi?").



Disk orientation and sensitivity



Example of LBTI sensitivity as a function of disk position angle and inclination, assuming a disk around a Sun-like star at δ=60° and a distance of 10pc. *(left panel)* Instantaneous sensitivity (i.e. assuming observations take negligible time), showing that bright face-on disks brighter than 8 zodi can always be seen (see also figure above), but edge-on disks aligned with the transmission pattern can be instantaneously invisible unless they are extremely bright (black region). *(right panel)* Real observations take finite time so cover a range of hour angles, allowing the disk to rotate w.r.t. the LBTI transmission pattern. For this declination, averaging the zodi sensitivity across the range of observed hour angles shows that even edge-on disks can be detected, to within a factor of ~2 of the best zodi sensitivity for observing over 4h (this 4h is simply assumed, and not related to the required integration time).