1. Science aim/goal

The Solar System in context: what is the frequency of true Kuiper belt analogues?

2. (i) Scientific Importance:

The Asteroids and Comets in the Solar System (i.e. our "debris disk") are an integral part of our Solar System. These small bodies give life by delivering water, and take it away with occasional extinction events. Their locations and orbital structure provide strong constraints on the Solar System's history, a story that includes Neptune's outward migration, capture of Jupiter's Trojans, and the Late Heavy Bombardment of the terrestrial planets.

However, this story lacks context because true analogues of our Asteroid and Kuiper belts remain invisible. While all other stars must host debris disks at some level, only the brightest 20% are currently detectable, and we know neither our rank in the remaining 80%, nor how this rank is related to the Solar System's history. A decade from now we will have detected or set stringent limits on planets around most nearby stars, but the limits on small body populations will be as poor as they are now (see Figure). A Far-IR Surveyor can be designed to image true Kuiper belt analogues, completing the planetary system inventory around nearby stars to the extent that we can place our own in context.

(ii) Measurements Required:

True Kuiper Belt (KB) analogues can only be detected by imaging, as they are too faint relative to the host star (1%) to detect as an IR excess. A reference KB model (Vitense+2012) has peak emission near 60μm, which drives the choice of wavelength. We assume that to be well-resolved a 45au radius KB must have an angular separation from the host star of $>2\lambda/D$. Aperture size is then driven by the targets; to ensure robust results when the sample is split by spectral type or planetary system architecture requires searching for KBs around $O(100)$ targets, here roughly equal numbers of F, G, and K stars. The sample size demands an 8.5m aperture (see Figure). To access more targets (e.g. 100 G-types) requires either a larger aperture or less well resolved disks.

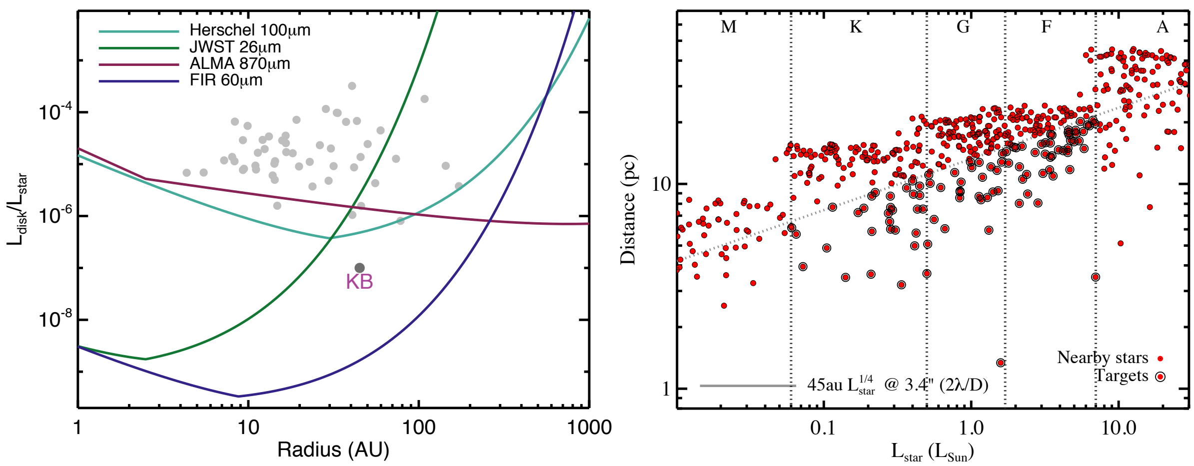
A KB is about 10x fainter than the star's Airy disk at $2\lambda/D$. Thus, to detect disks at 10σ the PSF wings must be stable at <1% levels, which is equivalent to a contrast better than 10^{-4} (1σ). The disk must be above the photon noise from the stellar PSF, mitigation of which will probably require coronagraphy. This seems feasible as similar or better contrast levels (10^{-5}-10^{-4}) are expected at a few λ/D for the Vortex AGPM on VLT/VISIR at 13μm and the 4PQM MIRI on JWST at 16μm. Contrast can be improved by imaging at more than $2\lambda/D$, i.e. by requiring disk radii of $3\lambda/D$ and thus a 13m aperture.

(iii) Uniqueness to 10μm to few mm wavelength facility:

Far-IR wavelengths are needed to detect the cool KB emission near the thermal peak (see left panel of Figure); disks 1000x times brighter than KBs are detected with only 10% success by HST/VLT so scattered light detection is not considered feasible.

(iv) Longevity/Durability:

No expected future facility has the sensitivity or resolution needed to achieve the science goals outlined above. If SPICA launches with a 60μm imaging capability it may achieve some of the science here, but is limited to a few tens of targets by the 3m aperture because high proper motion targets are needed to mitigate confusion noise.



<u>3. Figure</u> (***left***) Sensitivity to Kuiper belt analogues at 10pc. Grey dots are known disks around nearby stars. Disks that lie above a given instrument's line are detectable. Only a Far-IR Surveyor can detect debris disks at Kuiper belt (and fainter) levels. (***right***) 100-star sample. These targets have resolvable KBs at >2λ/D with an 8.5m aperture (or equivalently at >3λ/D with a 13m aperture). This sample assumes a KB-size vs. L_{star} relation that yields roughly equal numbers of resolved disks around F, G, and K stars (solid line). Alternatively, assuming constant KB size yields more K-types, while constant KB temperature yields more F-types.

<u>4. Table:</u>

Parameter	Unit	Desired Value	Comments
Wavelength/band	μm	60	
Number of targets		100	
Survey area	deg.^{2}	n/a	
Angular resolution	arcsec	1.7	Depends on achievable contrast
Spectral resolution	Δλ/λ	n/a	
Bandwidth		n/a	
Continuum Sensitivity (1 σ)	μJy	1	per square arcsec
Spectral line sensitivity (1 σ)	W m^{-2}	n/a	
Signal-to-noise		10	per beam
Dynamic range			Depends on how contrast is achieved.
Field of Regard		few arcmin	(per-source FOV), targets are all-sky
Cadence		n/a	
Other requirements		10^{-4} contrast at 2λ/D	Very well characterized and stable beam. Otherwise coronagraph.

<u>5. Key references</u>:

Vitense, Krivov, Kobayashi, & Löhne 2012, A&A 540 30, *An improved model of the Edgeworth-Kuiper debris disk*