OBSERVING REQUEST
University of Arizona Observatories

Year: 2015 **Term:** Jan–Jun **Proposal type:** short-term

Characterizing hot dust populations around nearby main sequence stars with LBTI/LMIRCAM

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Abstract of Scientific Justification

The inner solar system, where the terrestrial planets formed and evolve, contains a cloud of small dust grains produced by collisions of asteroids and outgassing comets. This dust cloud – the zodiacal disk – has long been suspected to have extrasolar analogs (exozodiacal disks), the first of which were detected recently in the near- and mid-infrared regimes long-baseline interferometry and $Spitzer$. The near-infrared excesses detected by long-baseline interferometry are however quite intriguing, as they point toward very high dust replenishment rates, high cometary activity or unlikely major collisional events. With this proposal, we envision to use LBTI/LMIRCAM in dual-aperture mode to obtain for the first time L-band interferometric observations of two of the largest near-infrared excesses detected so far around two nearby main-sequence stars (namely Vega and Altair). These observations would provide crucial information to study the possible link with the outer warm dust probed by nulling interferometry at 10 μm (HOSTS survey) and to constrain the nature of the hot dust, which is nowadays still speculative.

This proposal was already accepted twice but not executed because of the DX secondary mirror failure (2013A) and bad weather conditions (2014A).

Summary of observing runs requested for this project

								Scheduling		Sharing	
Run	Telescope	Cage	Instrument	PI	AO	Nights	Moon	Optimal	Acceptable	Poss.	Adv.
1	LBT	LBTI	LMIRCAM	*		1.0	bright	May–May	May–Jun	yes	yes

Scheduling constraints and unusable dates *(up to 4 lines)*: For practical reasons, we would like the proposed observations to be scheduled with other LBTI observations.

no text past this line

A ⋆ appended to the proposal type indicates a continuation proposal; a ⋆ appended to the name of a proposer indicates the proposer is a (graduate) student; a proposer whose name is underlined is certified on the proposed telescope/instrument combination; if a * appears within the PI or AO box in the observations summary table, the instrument is a PI instrument and/or Adaptive Optics are requested – signatures are required on the next page.

Target list (attach list if longer than 26 objects)

#	Object	RA	Dec	mag / color / type / redshift / comment / etc.
1	Vega	18:36:56.34	+38:47:01.28	A0V, V=0.1, R=0.1, L=0.1
2	Altair	19:05:24.61	+13:51:48.52	A7V, V=0.8, R=0.8, L=0.1

Approval for Instrument Use from PI: See general e-mail sent separately by P. Hinz to the TAC.

Graduate students *(provide the following information for* ***each*** *student named as PI or CoI on the cover page. Have the advisor's signature(s) appear on* ***all*** *submitted copies)*

Student's Name	Advisor's Name	Advisor's Signature	2nd-yr	Thesis

Scientific Justification

The inner solar system, where the terrestrial planets formed and evolve, is populated by small (1-100 μm) grains of dust produced by collisions of asteroids and outgassing comets. This dust cloud – the zodiacal cloud, also called debris disk – fills the ecliptic plane within the asteroid belt and can be clearly seen from Earth as a diffuse glow in the night sky. At visible and infrared wavelengths, it is in fact the most luminous component in the solar system after the Sun itself, and the Earth might clearly appear as an embedded clump in it for an external observer (Kelsall et al. 1998). Hence, the possible presence of dust in the habitable zone around nearby main-sequence stars is considered as a major hurdle toward the direct imaging of Earth-like extrasolar planets (exo-Earths) with future dedicated space-based telescopes (e.g., Beichman et al. 2006, Defrère et al. 2010, Chen et al. 2012). Unfortunately, very little is known about the presence of dust in the terrestrial planet region of nearby planetary systems. So far, debris disks have mostly been observed on relatively large spatial scales, corresponding to material located tens to hundreds of AU from their host star. Whether exozodiacal dust is actually present in observable quantities in these systems has been an important question for several years. Mid-infrared surveys (e.g., IRAS, ISO, *Spitzer*) addressed this issue and reported the detection of warm dust (at $\sim$10 μm) around a handful of candidates with an occurrence rate lower than 1% for nearby main-sequence stars (Lawler et al. 2009). However, single-dish telescopes do not provide the required spatial resolution to localize the grains in the region where physical and dynamical processes need to be studied (<5-10AU).

With an angular resolution reaching the milli-arcsecond (mas) level, near-infrared interferometry has the potential to get around this issue and resolve the innermost regions of planetary systems from the glare of their parent star. The first convincing detection has been obtained around Vega in 2005 at the CHARA array (Absil et al. 2006). Following this result, more detections have been reported with CHARA/FLUOR (di Folco et al. 2007; Absil et al. 2008; Akeson et al. 2009; Absil et al. 2013), VLTI/VINCI (Absil et al. 2009), VLTI/MIDI (Smith et al. 2009), VLTI/PIONIER (Defrère et al. 2012), IOTA/IONIC (Defrère et al. 2011), MMT/BLINC (Stock et al. 2010), and the Keck Interferometer Nuller (Millan-Gabet et al. 2011, Mennesson et al. 2012). In most cases, the detected infrared excesses are interpreted as the signature of abundant (but optically thin) circumstellar dust located in the first inner AU around the target star. This dust is thought to be produced by collisions between larger rocky bodies and/or by the evaporation of comets as in the solar zodiacal disk. The origin of this phenomenon is however largely unclear. Indeed, the inferred dust populations are much hotter, more massive, and composed of much smaller grains than the zodiacal cloud. Such grains would be expected to be expelled from the inner planetary system by radiation pressure within only a few years, which indicates inordinate replenishment rates that challenge the current view of debris disks. In practice, the steady state collisional grinding of a massive asteroid belt is difficult to reconcile with such massive and hot populations, which are most likely produced by isolated catastrophic events (collision, comet break-up), or by major dynamical perturbations such as the Falling Evaporating Bodies (FEB) phenomenon in the β Pic inner disk (Beust et al. 2000) or the Late Heavy Bombardment (LHB) that happened early in the history of the solar system (Gomes et al. 2005). Scattering of cold bodies from the outer disk by multiple planets is also a possibility discussed recently by Bonsor et al. (2012).

In this context, LBTI/LMIRCAM has a major role to play, as it is currently the only instrument world-wide capable of performing interferometry in the L-band, a key wavelength range to constrain the spatial distribution of the detected dust populations by multi-wavelength SED modelization. In fact, the LBTI was precisely built to detect and characterize exozodiacal disks, providing an ideal combination of spatial resolution and dynamic range in both the near- and the mid-infrared. While mid-infrared observations will be performed under NASA protected time, near-infrared observations can already provide information about the hot inner part of known exozodiacal dust disks. In this context, modeling L-band LBTI observations in conjunction with our K and N band data will not only provide spatial constraints on the dust population but also indicate how compare to our own solar zodiacal cloud. To achieve these goals, we will model LBTI/LMIRCAM observations with the 3D radiative transfer code originally developed by Augereau et al. (1999) for cold debris disks, and adapted to the case of exozodiacal disks (e.g., Absil et al. 2006, Defrère et al. 2011 and 2012, Mennesson et al. 2012). The model considers a population of dust grains with a parametric surface density profile and size distribution, and calculates the thermal equilibrium temperature of the grains exposed to the stellar radiation. The code handles complex chemical compositions for the grains in order to discuss for instance the fraction of carbonaceous or silicate material contributing to the observed emission. A specific attention is given in the model to the treatment of the exozodiacal disk close to the sublimation radius, to account for the size-dependent position of this radius. The model calculates the thermal and scattered light emissions, and produces both images and spectral energy distributions to combine observations from different instruments (CHARA/FLUOR, Spitzer/IRS, broadband fluxes). Our fitting approach is based on a full Bayesian exploration of a large χ^2 hypercube, including all relevant disk and grain parameters (e.g., radial profile, grain size distribution, optical properties, etc). This fitting method is particularly robust and gives a comprehensive view of all possible families of plausible models and of the uniqueness of the best fit parameters (Lebreton et al. 2012). This approach allows to go beyond a blackbody approach that poorly constrains the actual location of the dust, and does not permit any discussion of the dust mass nor of the grains properties and dynamics. Our team has performed such analyses on a representative targets like Vega (Defrère et al. 2011) and Fomalhaut (Mennesson et al., 2012) proving the feasibility of this multi-wavelength high visibility accuracy interferometric approach. With this proposal, our goal is to observe two of the brightest hot exozodiacal disks detected so far:

- *Vega* (A0V, HD 172167, 7.8 pc) is known to harbor hot dust since the initial discovery in 2005 with K-band interferometric observations at the CHARA array (Absil et al. 2006), a result confirmed one year later with the IOTA interferometer in the H band (see Fig. 1 left, Defrère et al. 2011). The detected hot dust population is thought to consist in a compact dust disk producing a thermal emission that is largely dominated by small grains located between 0.1 and 0.3 AU from Vega (see Fig. 2) and accounting for a relative flux with respect to the stellar photosphere of approximately 1%. Interestingly, no excess emission has been detected in the N band with MMT (Liu et al. 2009) nor in the K-band with the Palomar fiber nuller (Mennession et al. 2011), which are both not sensitive to the inner hot dust. Obtaining L-band interferometric observations would therefore be crucial in order to constrain the spatial distribution of the disk and, hence, the grain properties.
- *Altair* (A7V, HD 187642, 5.1 pc) is one of the three targets out of 25 around which exozodiacal dust has been detected very recently by the Keck interferometer nuller in the N band (Millan-Gabet et al. 2011). Following this discovery, Altair was observed with the CHARA array which revealed a K-band excess emission of approximately 3% (the largest among our exozodiacal target sample, Absil et al. in prep). As in the case of Vega, getting L-band interferometric data of Altair is crucial in order to constrain the spatial distribution of the disk and, hence, the grain properties.

In summary, we intend to answer the following question with the proposed L-band observations: **What is the morphology and nature of bright hot exozodiacal disks?** Thanks to the resolved L-band observations provided by the LBTI, we will directly constrain the spatial distribution and temperature of the dust grains, by comparing the size and brightness of the disk in H, K, N, and L bands. Furthermore, these observations align perfectly with NASA's strategic goals in the area of Exoplanet Exploration science and Cosmic Origin. It is long known that exozodiacal disks can be a major threat to the capability of directly imaging Earth-like exoplanets and strongly impact the design of such missions. LBTI observations will provide the necessary keys to evaluate the actual impact of hot debris disks on exoplanet imaging. Our observations will unveil the stellar environment where terrestrial planets are thought to be formed and evolve, and investigate the relationship between cometary systems, asteroid belts and zodiacal clouds. In the particular case of Vega, possible connections between the large reservoirs of cold dust detected in the outer debris disks and the innermost parts of the disk will shed a new light on the large-scale dynamical evolution of planetary systems.

References

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Millan-Gabet R. et al. 2011, ApJ 734, 67
Skemer A. et al. 2012, ApJ 753, 14
Stock N. et al. 2010, ApJ 724, 1238

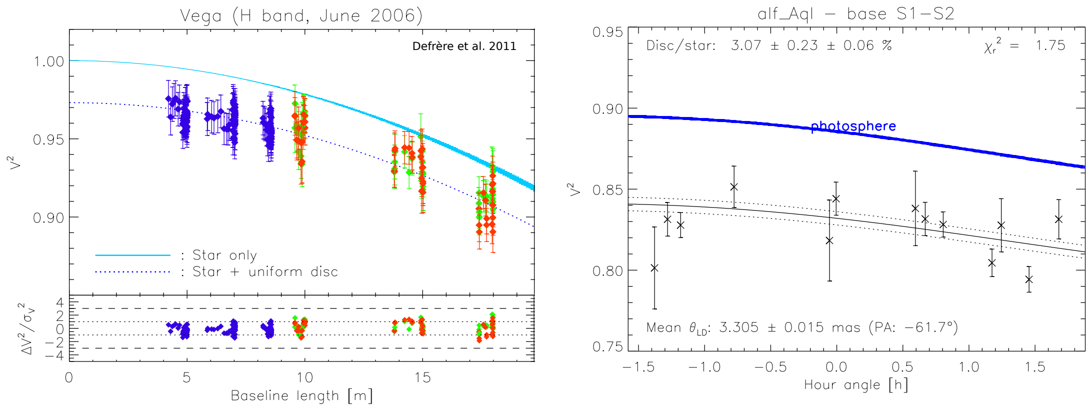

Figure 1: *Left,* Detection of a circumstellar emission around Vega, based on IOTA/IONIC H-band data (Defrère et al. 2011). This plot illustrates the principle of the detection method, which relies on the accurate measurement of short-baseline visibilities (diamonds with error bars) and on the comparison with the expected stellar photospheric visibility (blue solid line). The thickness of the blue solid line corresponds to the 5-σ uncertainty related to the uncertainty on the stellar diameter. A significant offset is seen between the model and the data, which can only be reconciled by adding a resolved circumstellar emission to the photospheric model. *Right,* Detection of a circumstellar K-band excess around Altair with CHARA/FLUOR (Absil et al., 2013).

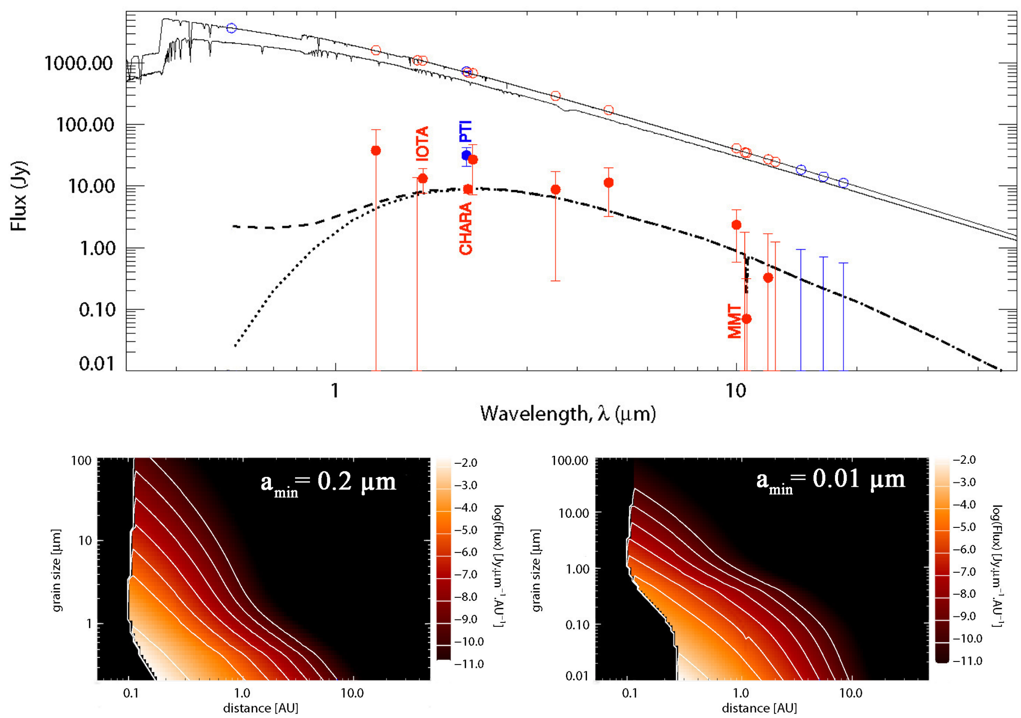

Figure 2: *Top,* SED for a good fit of our debris disk model to H, K, and N band interferometric data of Vega (Defrère et al. 2011). The dashed and dotted lines represent the total emission from the disk on a 6 AU field-of-view, respectively with and without the scattered emission. The photospheric SED, simulated by a NextGen model atmosphere, is represented by the two solid lines as seen pole-on (upper curve) and from the equatorial plane (lower curve). *Bottom*, Flux density maps given as a function of grain size and distance to the star computed for two possible minimum grain sizes ($a_{\rm min}$ = 0.2 μm and $a_{\rm min}$ = 0.01 μm).

Experimental Design & Technical Description *Describe your overall observational program. How will these observations contribute toward the accomplishment of the goals outlined in the science justification? If you've requested long-term status, justify why this is necessary for successful completion of the science. (**up to one page**)*

The observing strategy is based on the fact that the stellar photospheres are completely unresolved at short baselines, while circumstellar disks, which have much larger angular diameters, are almost completely resolved and therefore contribute mostly as incoherent sources of emission. The presence of incoherent emission within the field-of-view of the interferometer produces a decrease of the observed squared visibility with respect to the expected visibility of the stellar photosphere (see Fig. 1). This deficit is equal to twice the flux ratio between the circumstellar disk and the star. Hence, the identification of a circumstellar excess requires to precisely know the visibility level of the sole photosphere, to which the actual visibility measurements will be compared. This can be achieved either by using surface-brightness relationships (Kervella et al. 2004) to derive the expected angular diameters of the target stars from visible and near-infrared photometry, or by obtaining long-baseline interferometric measurements. Based on our experience, the first option is generally sufficient to reach the required accuracy although, in this case, the angular diameter of Vega and Altair is already well constrained by long-baseline infrared interferometric measurements (see for instance Aufdenberg et al. 2006 for Vega and Monnier et al. 2007 for Altair).

The LBTI is particularly well adapted to the above strategy as it provides a relatively short baseline length that is ideal to resolve the inner planetary region while not resolving the central star. In the L band, LBTI/LMIRCAM has a resolution of 40 mas, corresponding to separations of 0.2 AU and 0.3 AU respectively at the distance of Altair and Vega. This is ideal to probe the hot dust content around these systems and constrain the spatial distribution of the disks. For instance, two of our current best models for Vega (see Fig. 2 bottom) present different locations for the bulk of the exozodiacal emission. One model is dominated by small grains located at 0.3 AU and beyond while the other is dominated by larger grains located closer than 0.3 AU. This is precisely the region probed by LBTI/LMRICAM so that it will be straightforward to constrain the spatial distribution of the disk and, hence, the grain properties.

In order to reach the accuracy required by our program (1% to 2% on individual visibility measurements), we plan to use fringe tracking which is currently under commissioning and should be operational to work with LMIRCAM early in the next few months. Vega and Altair are very bright nearby stars that are also part of the NASA LBTI/HOSTS survey performed in the N band in nulling mode and will likely be observed very early in the survey. These observations will not be sensitive to the hot inner part of the exozodiacal disks described in this proposal and for which L-band interferometric observations with LMIRCAM are required. They might however bring interesting complementary information about the structure of the hot inner planetary system around Vega and Altair.

Summary of Time Requested and Awarded *The TAC needs to understand the scope of this project — (1) tell us how many UAO nights you've already had for this project, how many you request this time, and (a good guess of) how many you need to complete the project; (2) if a substantial amount of observing for this project comes from non-UAO telescopes, tell us about that observing, and how the UAO part fits in; (3) if you are collaborating with people who have telescopes, especially if you are part of a large collaboration, tell us who is leading the project, and how UAO time and your participation fit in. (**up to one page**)*

This proposal was already accepted twice but not executed because of the DX secondary mirror failure (2013A) and bad weather conditions (2014A). LBTI/LMIRCAM is a key instrument to understand the hot dust phenomenon. In this context, we propose to observe two stars showing two of the largest K-band excesses detected so far around main-sequence stars (namely Vega and Altair). The addition of L-band interferometric data to our previous (and published) H, K, and N band observations is expected to bring crucial information about the nature of the detected excesses and, hence, would be sufficient to produce one or two publications. Following these first observations, we plan to start a survey to follow-up in the L band all hot exozodiacal disks detected so far with other interferometric facilities ($\sim$10 objects accessible from the LBT).

In order to detect circumstellar emission down to a significant level of about 1% of the stellar flux, we need to achieve a final precision of 0.4% on the squared visibility. Assuming an accuracy of about 1-2% on individual measurements (depending on seeing conditions and target magnitude), we plan to obtain 10 calibrated visibility measurements per target to reach of typical accuracy of 0.3% to 0.6% on the final squared visibility, i.e., of 0.15% to 0.3% on the disk/star contrast (at 1 sigma). Considering that each observation will take 15 min and that we need 21 data points (science star + calibrators) per target, a total of 21x15x2=630 minutes (or $\sim$1 night) are necessary to achieve the proposed program. The right ascensions of both target stars is appropriate for spring observations, typically in May or June, when the fringe tracker will be operational.

Previous Use of Steward Facilities *List **all** allocations of telescope time for the present project and allocations for other projects on facilities available through UAO during the past 2 years, together with the current status of the data (cite publications where appropriate). Mark those allocations related to the present proposal (i.e, precede text with* `\related` *command). **(up to one page)***

The PI and co-Is whose name is underlined on the first page have all been using Steward facilities (and particularly the LBTI) on a regular basis over the last few years. In particular, several papers using LBTI/NOMIC and LBTI/LMIRCAM observations have been published recently (e.g., Rodigas et al. 2012, Skemer et al. 2012, Bailey et al. 2013, Bonnefoy et al., 2013, Skemer et al. 2014, Defrère et al. submitted) and many other are under preparation. In addition to the allocated time listed in the previous section, the PI of this proposal has also been allocated 1.5 nights for L-band coronagraphic imaging of nearby planetary systems. The results of these observations were published recently (Defrère et al. 2014).

LaTeX 2ε UAO Observing Proposal class, 'soprop.cls' v1.3 (2007 Aug 01 [RAJ]).