High-Contrast LBTAO Images of Debris Disks at 2-4 μm

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+ Phil Hinz, Laird Close, Alycia Weinberger, Andy Skemer, Jared Males, Vanessa Bailey, Kate Follette, Katie Morzinski, Denis Defrere, & many, many Italians from Arcetri
Why image debris disks at 2-4 μm?

- Higher Strehl → higher contrast → clues to unseen planets
- Dust grain composition & size
  - water ice, organics, silicates (Inoue et al. 2008, Debes et al. 2009)
- 2-4 μm window also very sensitive to luminous exoplanets
How do you image debris disks at 2-4 μm?

- Everything glows in the infrared
- Minimize number of warm surfaces → minimize noise
- Need adaptive secondary mirror
  - e.g., LBTI (Phil Hinz), MagAO (Laird Close)

LBTI/LMIRcam, 4 μm
MagAO/Clio, 3.1 μm
LBTI: how it works

For more info: see posters by V. Bailey (1.07) & D. Defrere (6.13)
LBTI: how it works

“tomorrow’s resolution...today!”

HOSTS (Hinz)  LEECH (Skemer)

For more info: see posters by V. Bailey (1.07) & D. Defrere (6.13)
LBTI vs. MagAO

zero.as.arizona.edu/groups/lbti/blog/  visao.as.arizona.edu

and see talk by K. Morzinski on Wednesday!

Close et al. 2013
If the HD 15115 disk were a symmetric structure, then the east side of the disk would have been detected within the rectangular box, showing that the edge-on orientation to the line of sight. The image of the disk remains fixed and it is confirmed as real. However, whereas the residual diffraction pattern noise of the telescope rotates relative to the sky orientation over time, the east side of the disk is detected as far as the edge of the occulting spot at 1.5 mas fainter than 2006 October, suggesting that our frame average, the 2007 January disk photometry is 0.13 mag with effective filtering out nonphotometric data. The appearance of the disk is more symmetric in the second epoch agrees well with that of the first epoch (on average, the 2007 January data therefore yields a detection of the west edge of the field at 12.38 mas, with model fits of the spectral energy distribution that place the dominant emitting dust component at 35 AU radius (Zuckerman et al. 2006). The northern side of the west midplane is more vertically extended than the southern side. For example, the vertical cuts are not symmetric about the midplane when measuring the half-width at quarter-maximum (HWQM). The HWQM north of the west midplane is times greater than the midplane south of the west midplane (Kalas & Jewitt 1995). This may be an effect of asymmetry here.

Kalas et al. 2007
false-color, log scale images of the HD 15115 disk as originally discovered using the ACS/HRC F606W (nm, nm;).

Kalas et al. 2007
Debes et al. 2008
Kalas et al. 2007
Debes et al. 2008
Kalas et al. 2007
Rodigas et al. 2012
below the ACS/HRC occulting finger. The NIR data (HD 15115 itself. If the HD 15115 disk were a symmetric structure, then the east side of the disk would have been detected within the rectangular box, show exposures, the image of the disk remains fixed and it is confirmed as real.

However, whereas the residual diffraction pattern noise of the telescope rotates relative to the sky orientation over 7 o’clock relative to HD 15115). Furthermore, we find at 2.15 µm the uncertainty as being half the difference between the two measurements. Figure 2 shows the PA and FWHM of the west extension that indicates an edge of the field at 12.38

Kalas et al. 2007
Debes et al. 2008
Kalas et al. 2007
Rodigas et al. 2012
The disk is morphologically different between the visible & NIR.
The disk is bowed

Real

Model (87° inclined ring, forward-scattering grains)

Model reproduces PA well (though not unique)

PA vs. radius

Rodigas et al. 2012
Surface brightness asymmetries & a possible gap

2.15 µm

3.8 µm

Rodigas et al. 2012
Surface brightness asymmetries & a possible gap

2.15 μm

3.8 μm

Rodigas et al. 2012
Surface brightness asymmetries & a possible gap

2.15 µm

3.8 µm

West brighter than East

Rodigas et al. 2012
Surface brightness asymmetries & a possible gap

2.15 µm

3.8 µm

Rodigas et al. 2012

West brighter than East
Surface brightness asymmetries & a possible gap

2.15 \( \mu \text{m} \)

- Ks East
- Ks West

3.8 \( \mu \text{m} \)

- L' East
- L' West

Rodigas et al. 2012

West brighter than East

\( \rightarrow \) we are seeing different grain distributions at 2 & 4 \( \mu \text{m} \)
Surface brightness asymmetries & a possible gap

2.15 µm

- West brighter than East

3.8 µm

- ~ equal

→ we are seeing different grain distributions at 2 & 4 µm
The data also may suggest that the west side of the disk is composed of smaller grains than the east side. The disk has a gap interior to the large parent body dust grains in the disk. 

The SB profiles at Ks-L′(Hahn 2010), assuming gas telluric of 1.3 μm, are observed near 1.1′′. For an edge-on disk with no flattening, we can independently constrain the parent body dust grain size using estimates of the disk's equilibrium temperature as a function of distance from the star, for different silicate grain sizes. See text for methodology to calculate an independent estimate of the blowout grain size for this system.

Fig. 8.—Disk color vs. distance from the star, expressed as ∆(Ks-L′) (mags). For an edge-on disk with no flattening, we can independently constrain the parent body dust grain size using estimates of the disk's equilibrium temperature as a function of distance from the star. The SB should continue to increase closer to the inner edge of the gap, the SB should continue to increase closer to the inner edge of the gap. Because we do not see this in our data, this may be indicative of a central object whose semimajor axis = its projected separation from the central star. Large, gray dust grains in the range 10-30 μm are the best match to the observed SB near 1.1′′. If the system is young, we can say that the object must be less than a few M⊕. To constrain the parent body dust grain sizes, we also plot model colors from Inoue et al. (2008) (colored horizontal lines). The data suggest that the disk has a gap interior to the inner edge of the disk component (and hence the semimajor axis and mass of the planet, respectively), we can independently constrain the parent body dust grain sizes to be between 0.87-1.15 μm (dashed line in Fig. 10). The planet's semimajor axis is calculated by substituting this into Eq. 1 and solve for the planet mass, where ∆a/a = is the width of the chaotic zone, and a and p are the semimajor axis and mass of the planet, respectively. Rodigas et al. (2012) assumed a stellar temperature of 7000 K and a representative as the best-fit Kuiper belt object model with a stellar temperature of 179 K and 57 K from Moór et al. (2011b). Given that we have observationally detected the gap, we can independently constrain the blowout grain size for this system is expected to be ∼3-10 μm. Does the disk have a gap? Does the disk have a gap? Yes, the gap is expected to be ∼3-10 μm. 

Rodigas et al. 2012
HD 32297

- Young, bright, & edge-on
  - → easier to detect!
- Interesting morphological features

\[ \text{SB vs. distance} \]

Asymmetry & flattening!

\[ \text{Currie et al. 2012} \]

HST, JHK

Debes et al. 2009

Ks

HD 32297 at L’
HD 32297 at L’
Within the images to a fiducial pixel by calculating the center of data, images were averaged in sets of 4. We registered metric, so they could not be easily masked out and would not be caused by the spider arms, and were not symmetric with the raw data, out to several arcseconds. These streaks in the data suggest the quality of the PSFs was good, the second half of the data, and the entire set. We saw that though the data, we median-combined the first half of the data, in the same manner as for the profile of each image and subtracted it, also in the same way plus an offset of 0.0685/\(D\) and binned by a factor of 4 to bring out the disk. At this radius mask has been added in post-processing. The image has been smoothed with a Gaussian kernel with FWHM = 0.5 arcseconds.

Fig. 1.— HD 32297 at L’

Fig. 2.— Final PISCES image shown above. The disk is detected at SNRE \(\sim 0.5\) for the HD 15115 and at shorter wavelengths (Kalas et al. 2007; Debes 2009). The western side of the disk is equally bright on both sides. These features are nearly opposite to what is seen at shorter wavelengths. For display purposes a 0.5 magnitude/arcsecond slice was taken with LMIRcam the night before. The error was determined to be 1.81 \(\pm 0.0685\) arcseconds.

HD 32297

3 hour integration
80° rotation
new detector
400 modes AO

HD 15115

40 min integration
40° rotation
old detector
200 modes AO

Rodigas et al. 2013, in prep.
Preliminary dust modeling

models from John Debes

Rodigas et al. 2013, in prep.
Limits on planets

~3 MJ planets would have been recovered at >5σ confidence...outside of 0.45" (50 AU)

~1 MJ planets not detected
Summary

• HD 15115 (imaged at 2.15 & 3.8 μm)
  • bowed
  • might have gap
  • large grains
  • dynamically interacting with ISM
• HD 32297 (imaged at 3.8 μm)
  • Preliminary models: pure water ice or tholins/silicates preferred (so far)