Modeling self-subtraction of extended emission in angular differential imaging: Application to the HD 32297 debris disk

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Abstract: We have spatially resolved the debris disk around the A star HD 32297 in scattered light using Keck NIRC2 coronagraphic imaging with adaptive optics in the H and K bands. We used angular differential imaging and the LOCI algorithm to suppress the stellar PSF and reveal the nearly edge-on disk. Although LOCI is effective in subtracting quasistatic speckles in the stellar PSF, its application can result in self-subtraction of the disk signal due to its finite spatial extent. The degree of self-subtraction varies with radius, which would preclude accurate measurement of the surface brightness profile and compromise our inferences regarding the physical processes responsible for the dust distribution. We have developed a new technique to model the effects of self-subtraction on spatially extended emission introduced by the LOCI-processed angular differential imaging. Our method accounts for both the self-subtraction kernel's dependence on LOCI parameters and spatial location. We forward model the 2-D structure of the disk and compute the form of the self-subtraction at each radius, and then use this to jointly extract the disk surface brightness, scale height, and midplane location as functions of radius. Our preliminary investigation into the inner structure of the disk recovers a previously reported brightness asymmetry.

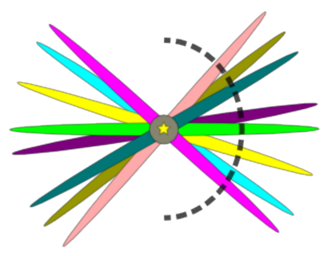
Observations: All images were acquired with the Keck NIRC2 narrow-field camera with coronagraph and adaptive optics. The observations were made using angular differential imaging, in which the orientation of the telescope's optics remains fixed while the field of view rotates on the camera. HD 32297 is an A star at a distance of $\sim 112^{+15}_{-12}$ pc[1].

Wavelength	**H (λ_{cen}= 1.63 μm)**	**K_S (λ_{cen}= 2.15 μm)**
Exposure number & duration	30 exposures, 30 seconds each	48 exposures, 60 seconds each
Dataset total angular rotation	30.5°	82.2°
Observation date	2007/09/22	2006/02/12

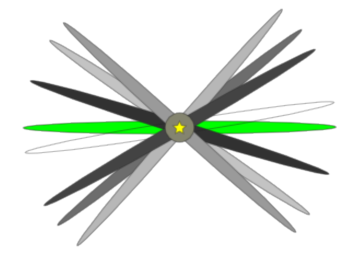
LOCI Self-Subtraction Modeling

For each exposure in a set of angular differential imaging data, the LOCI algorithm constructs a unique optimized reference PSF image. This image is divided into subsections, with each subsection an optimized linear combination of available exposures. For further details, see Lafrenière et al.[2]

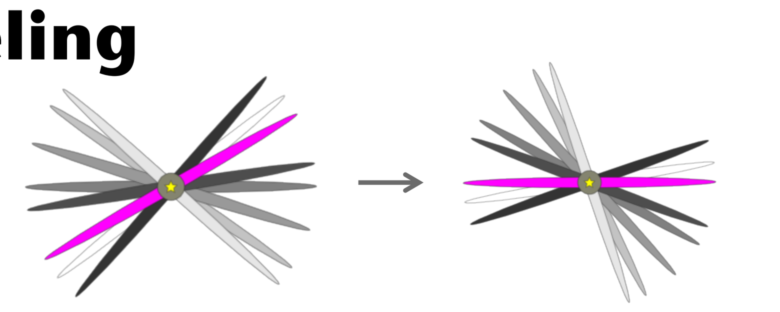
It is straightforward to prevent self-subtraction of point sources by carefully selecting the reference images. In the case of extended emission, the restriction on the set of reference images is often too severe. The resulting self-subtraction biases surface brightness measurements and compromises our inferences regarding the physical properties of the system. Here, we discuss our efforts to model that self-subtraction in order to extract accurate surface brightness profiles.



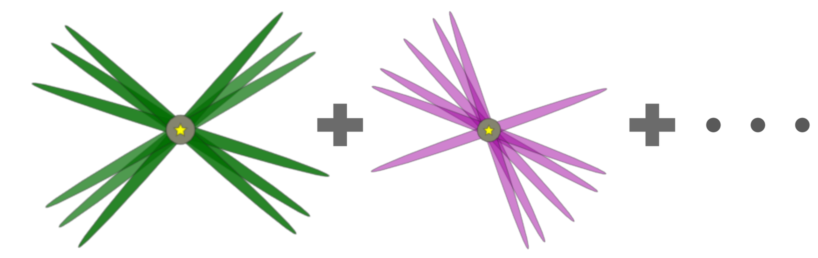
We model the vertical extent of the **reference image disks** as mean-subtracted Lorentzian distributions, positioned according to each image's degree of angular rotation. Below are plots showing the vertical profile along an azimuthal slice (dashed line in cartoon).



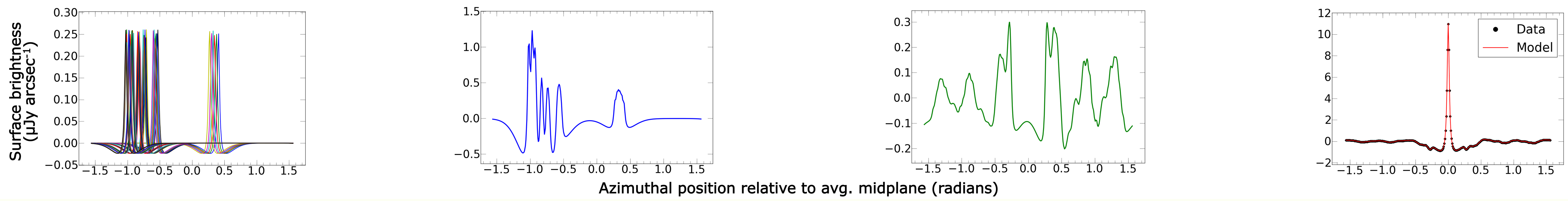
For one target image out of the 48 total, we weight each reference image disk by the appropriate LOCI coefficient and sum them together to create the **reference PSF image** for that target image.



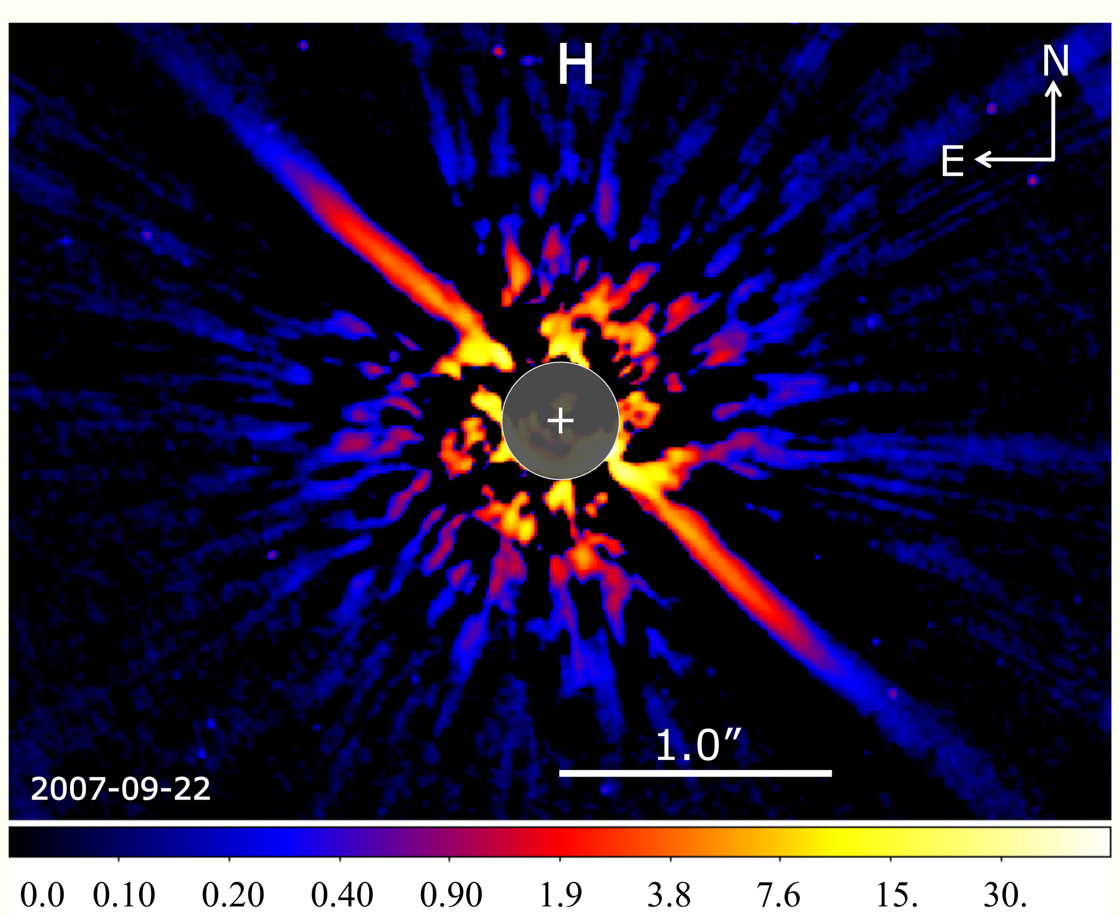
We rotate all reference PSF images so their target disks are aligned, then average them. This creates a **self-subtraction function** that represents the position and amplitude of self-subtraction for a given radius in the final LOCI-processed image.

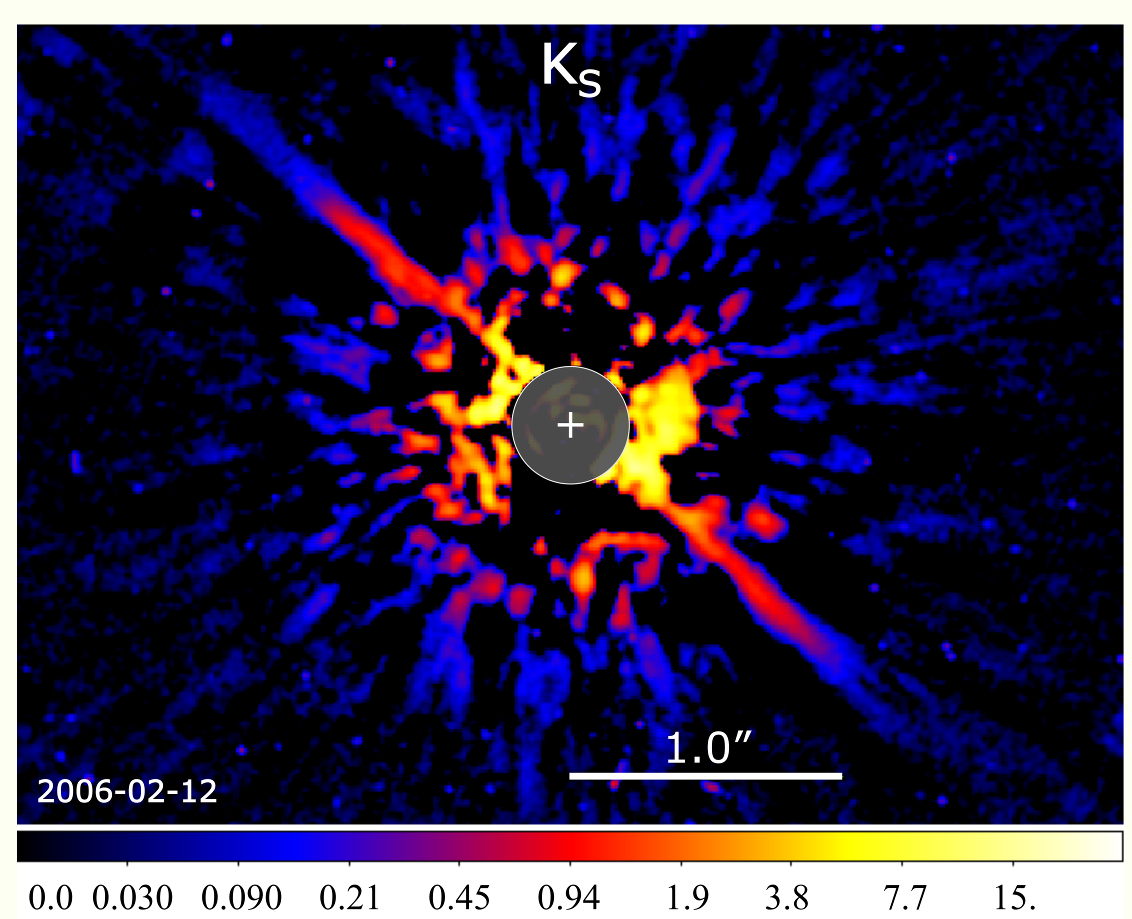


Finally, we subtract the self-subtraction function from a model disk function to produce our **model vertical profile**. Below, we compare our model (red) to the measured vertical profile (black) of a fake dataset at a given radius.

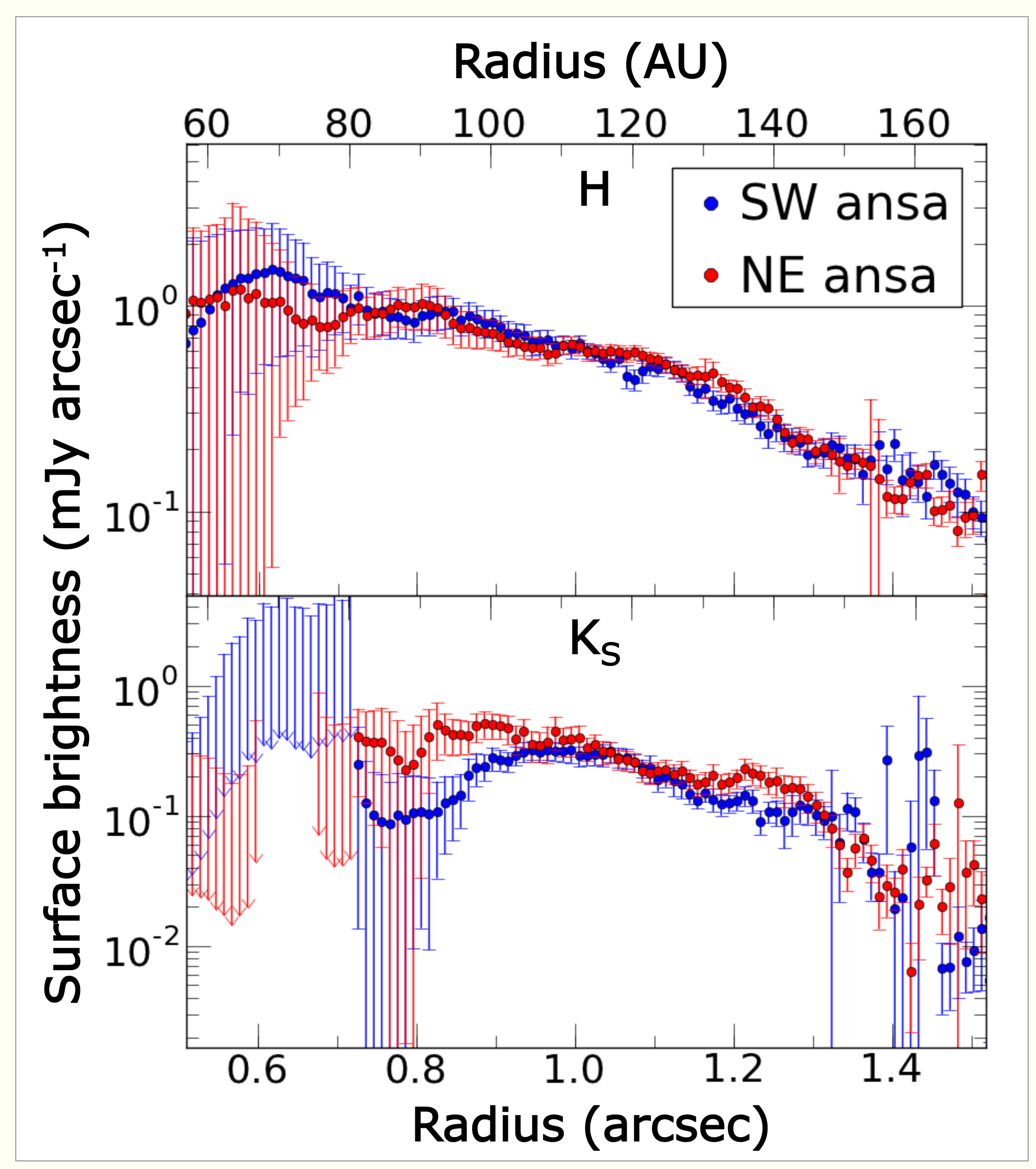


Results





Our final images of the HD 32297 debris disk. Individual images in each dataset underwent radial profile subtraction, an unsharp mask, and LOCI PSF subtraction. All individual images were then rotated to the same orientation and averaged to create the above images. (left) Final *H* band image. (right) Final K_S band image. The disk is detected in both bands from an inner working angle of ~0.6″ (70 AU) to ~1.5″ (170 AU). The images' color scales are logarithmic with units of mJy arcsec^{-2}.



One-dimensional surface brightness profiles produced by LOCI self-subtraction modeling of our final images in H (top) and K_S (bottom).

We present the following preliminary results:

- **A spatially resolved edge-on debris disk at 1.6 and 2.2 μm at projected separations of 70-170 AU.**
- **An apparent surface brightness asymmetry detected at ~70-110 AU in *H* band, in which the disk's southwest ansa is brighter than its northeast ansa. This is consistent with reports of a SW-NE asymmetry seen at near-IR[3,4,5], optical[6], and millimeter[7] wavelengths.**
- **An apparent surface brightness asymmetry detected at ~80-145 AU in K_S band, in which the disk's northeast ansa is brighter than its southwest ansa.**

Discussion

Our new technique for modeling the self-subtraction of extended emission allows us to extract unbiased disk surface brightness profiles from LOCI-processed images. Preliminary results are encouraging, as the apparent brightness asymmetries imply that the southwest side of the disk is relatively blue in the 80-110 AU range. This may indicate an enhanced population of micron-sized dust grains in that region. Improved fitting of the vertical profile, particularly at small separations, would allow us to better probe the inner region of the disk where planets may play a key role in the disk's structure.

Future Work

Future work will include improving our fitting routine to reduce the surface brightness uncertainties so we can use our multi-wavelength observations to investigate disk colors and potential gradients. Additionally, our modeling technique estimates the disk scale height and midplane position as functions of radius, which could inform us about the disk's morphology and deserves further analysis. We also plan to construct a 3-D scattered light model of the disk in order to investigate dust distribution and grain properties. Greater understanding of the self-subtraction in our images will aid our comparisons of data and models.

References

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