New Observations of Fomalhaut, Beta Pic and HR 4796A with HST and GPI

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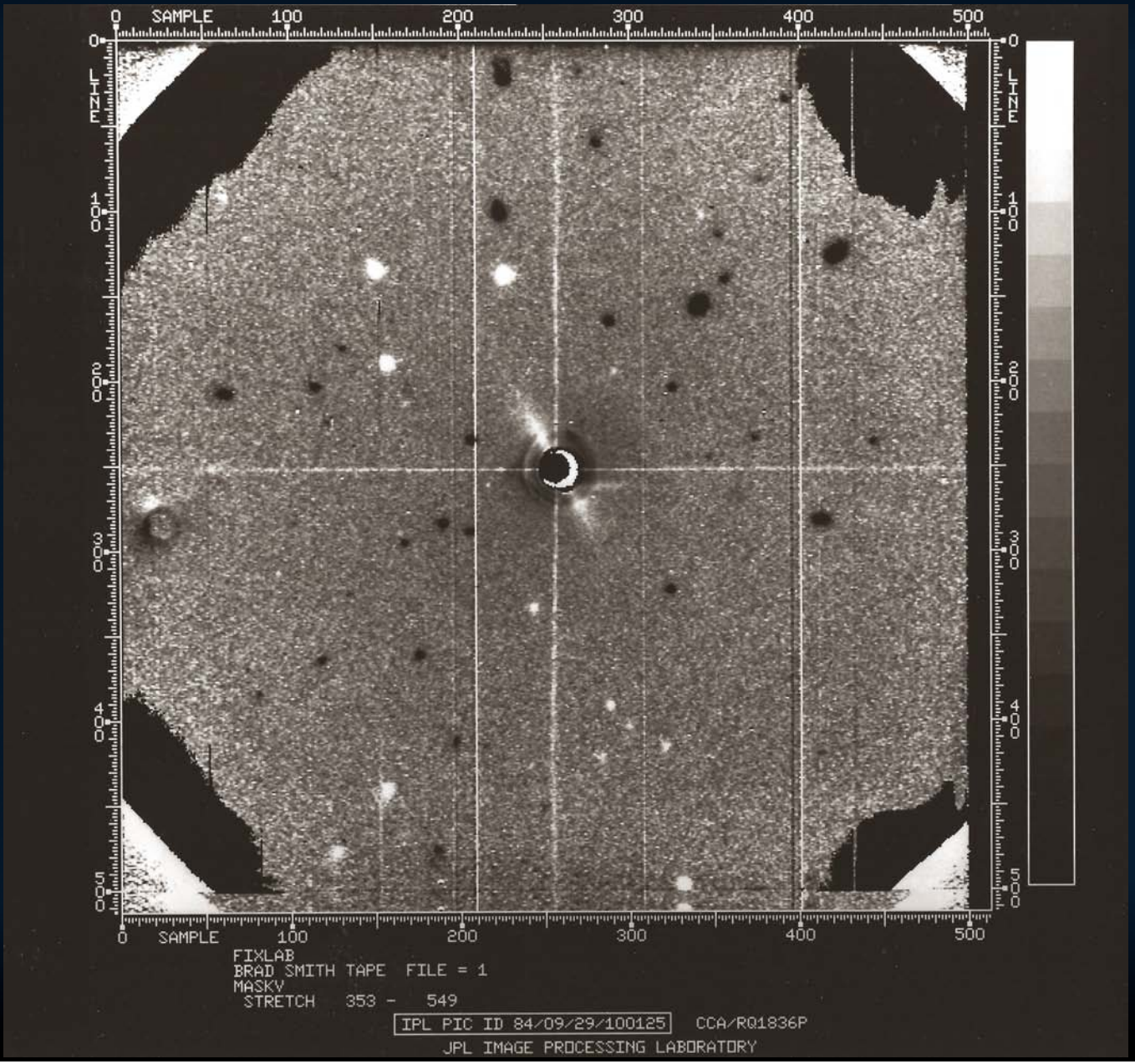
Observatoire de Paris

Collaborators:

James Graham (UC Berkeley), Mike Fitzgerald (UCLA), Gaspard Duchene (UC Berkeley), Max Millar-Blanchaer (Toronto), Marshall Perrin (STScI), Bruce Macintosh (Stanford), Mark Clampin (NASA GSFC), and the GPI Instrument and Science Teams

NASA NNX11AD21G, NSF AST-0909188, University of California LFRP-118057, GO-11818, GO-12576, GO-13037

Knowledge of Beta Pic is born September 1984



10-year anniversary

CIRCUMSTELLAR DUST DISKS AND PLANET FORMATION

PROCEEDINGS OF THE 10TH IAP ASTROPHYSICS MEETING

INSTITUT D'ASTROPHYSIQUE DE PARIS

JULY 4 - 8, 1994

ASSYMETRIES IN THE BETA PICTORIS DUST DISK

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Reports of asymmetry in the Beta Pictoris dust disk have been inconsistent and rarely discussed. On 10 and 12 October, 1993, we obtained coronagraphic R-band images at the UH 2.2 m telescope on Mauna Kea with the goal of identifying and interpreting the disk asymmetries. After careful data reduction, 5 types of asymmetry are evident in the β Pic disk:

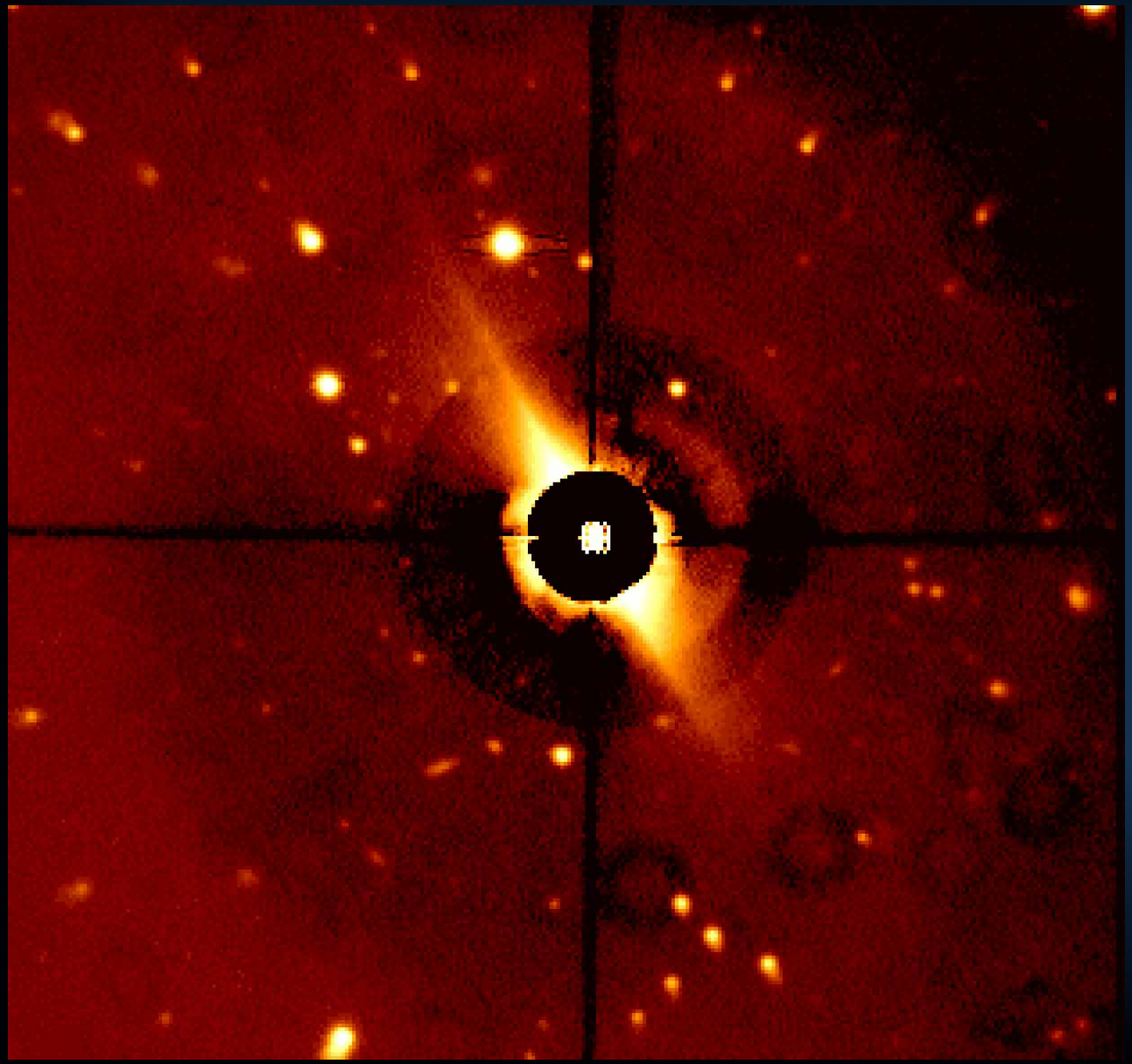
Size Asymmetry: The NE extension is detected out to a radius of 48" (790 AU), while the SW extension cannot be traced beyond 40" (650 AU). This asymmetry can be measured in raw, unreduced images of β Pic and is related to the next two types of asymmetry.

Brightness Asymmetry: Beyond approximately 20" radius, the midplane surface brightness of the NE extension is about 0.5 mag arcsec^{-2} brighter than the SW extension at a given radius. A corollary is that the radial gradient in surface brightness is steeper in the SW extension than for the NE extension.

Width Asymmetry: At approximately 10" radius, the FWHM of the disk perpendicular to the midplane becomes significantly larger in the SW extension than in the NE extension.

Butterfly Asymmetry: There is a subtle shape asymmetry which reflects diagonally across the star in each extension. This asymmetry is present in both nights of our data and in the surface brightness maps of previously published data [1,2,3, and 5] (Fig. 1).

The Wing-Tilt: The position angle of the NE midplane differs from the position angle of the SW midplane by approximately $1.5^{\circ} \pm 0.5^{\circ}$ (Fig. 1).



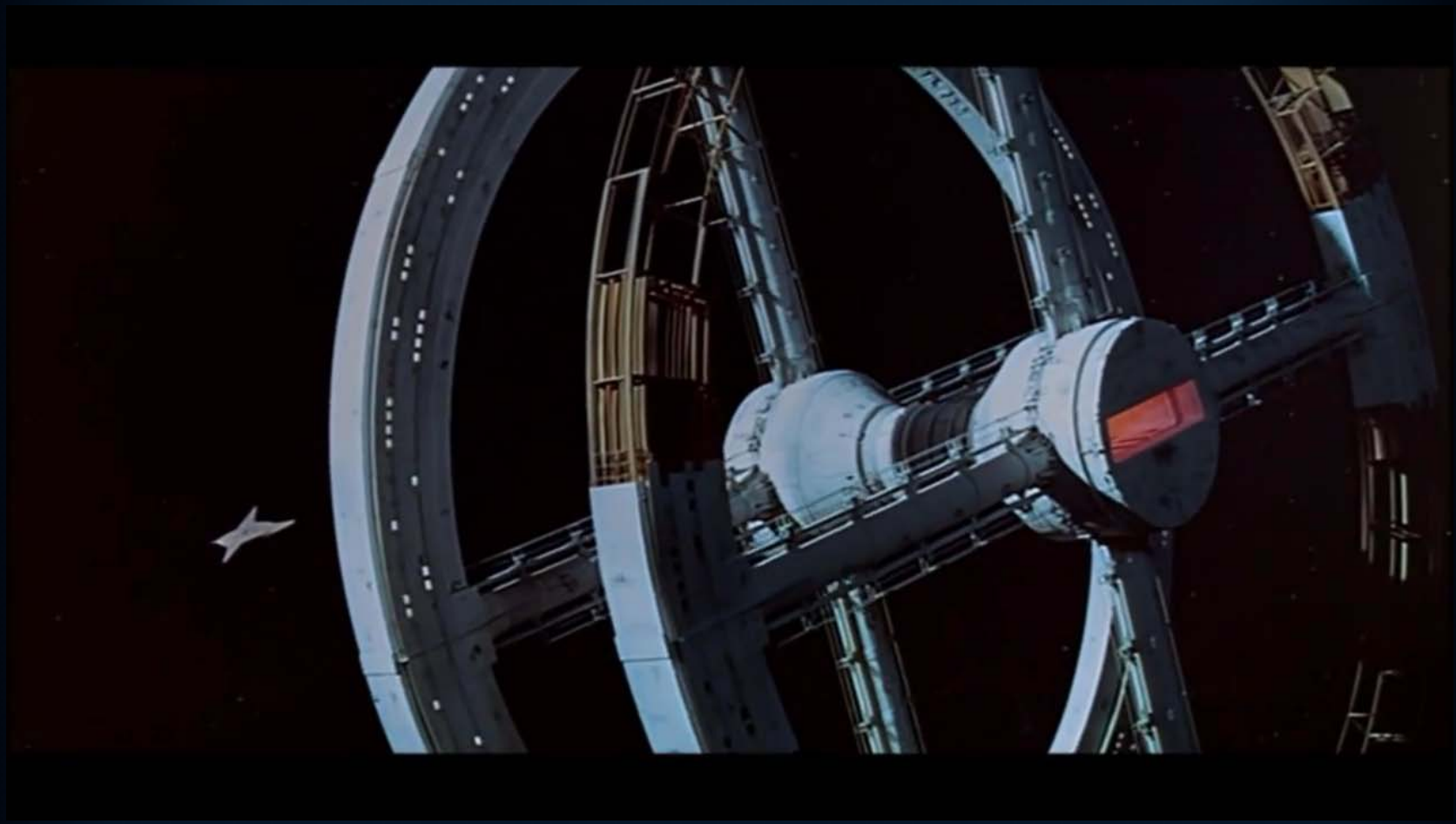
First deep coronagraphic image of Beta Pic from 1987.

Smith & Terrile.

Never published or seen before

30-year anniversary in 2014

Should have been held in low-earth orbit, above Paris

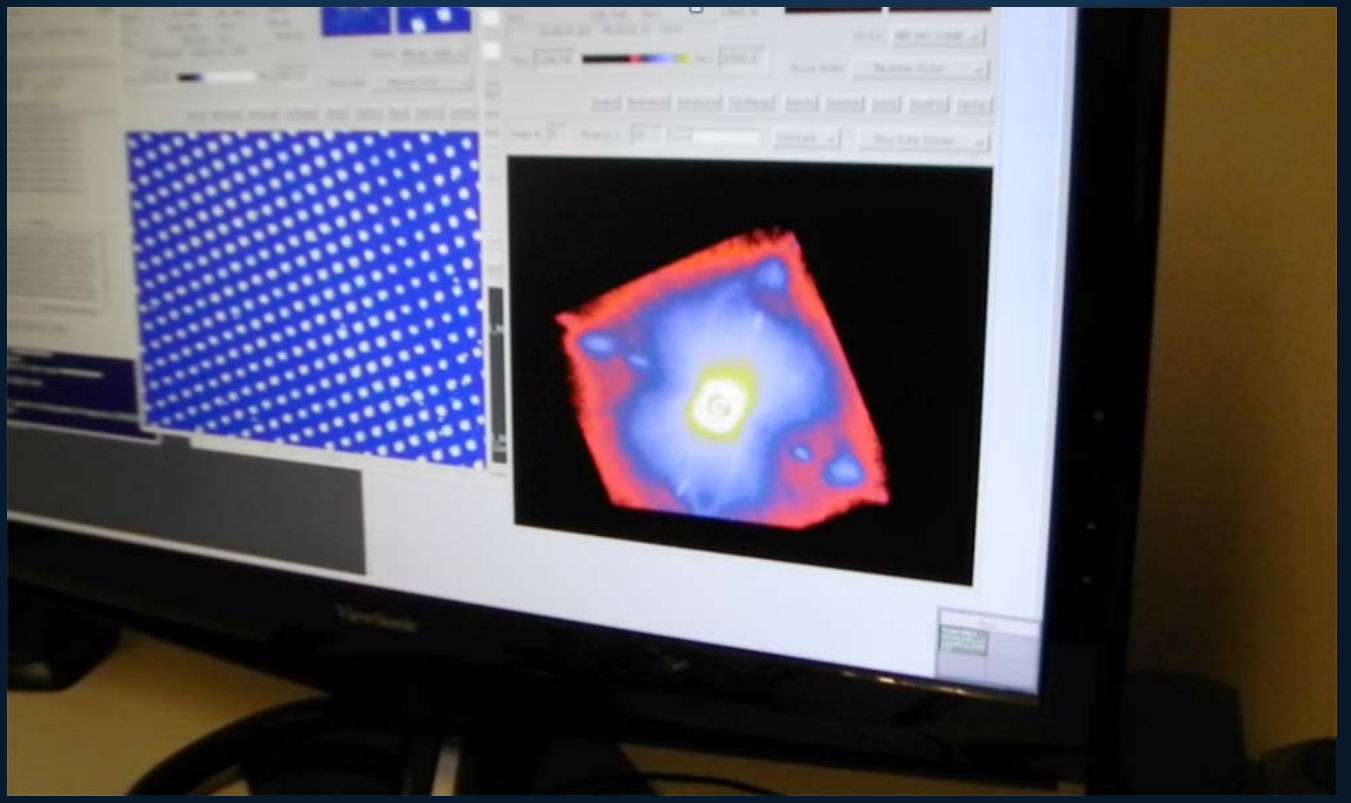


30-year anniversary in 2014

- That space station = *still science fiction*
- Real time imaging of exoplanetary systems = *science fact*

GPI First Light

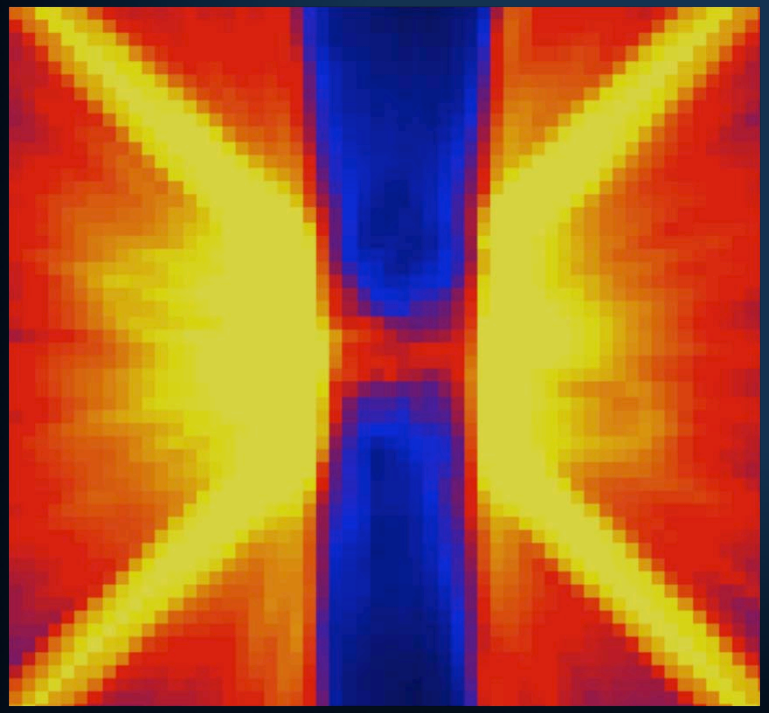
the HR 4796A planetary system is detected in real time



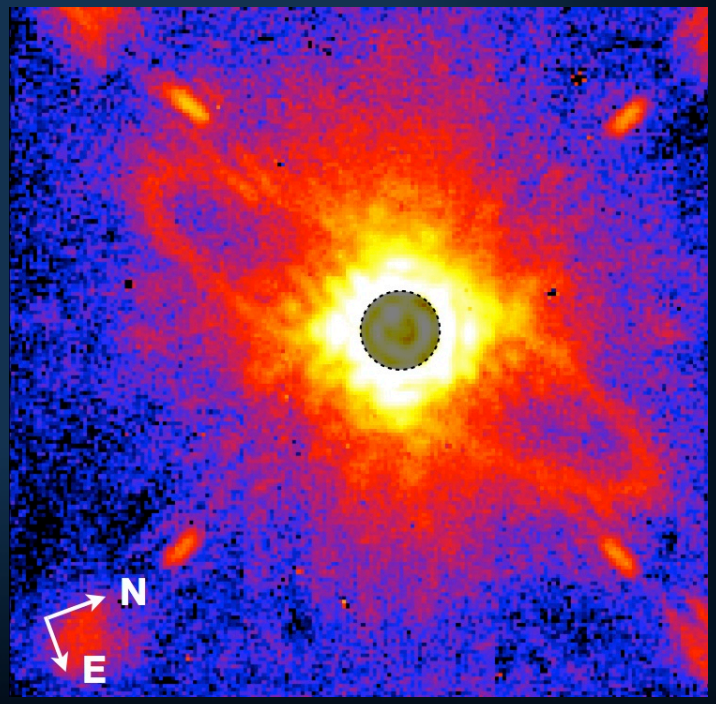
A remarkable achievement

Raw images in ~60 seconds integration.
No data processing.
No PSF subtraction.

Space: HST/STIS



Ground: Gemini Planet Imager



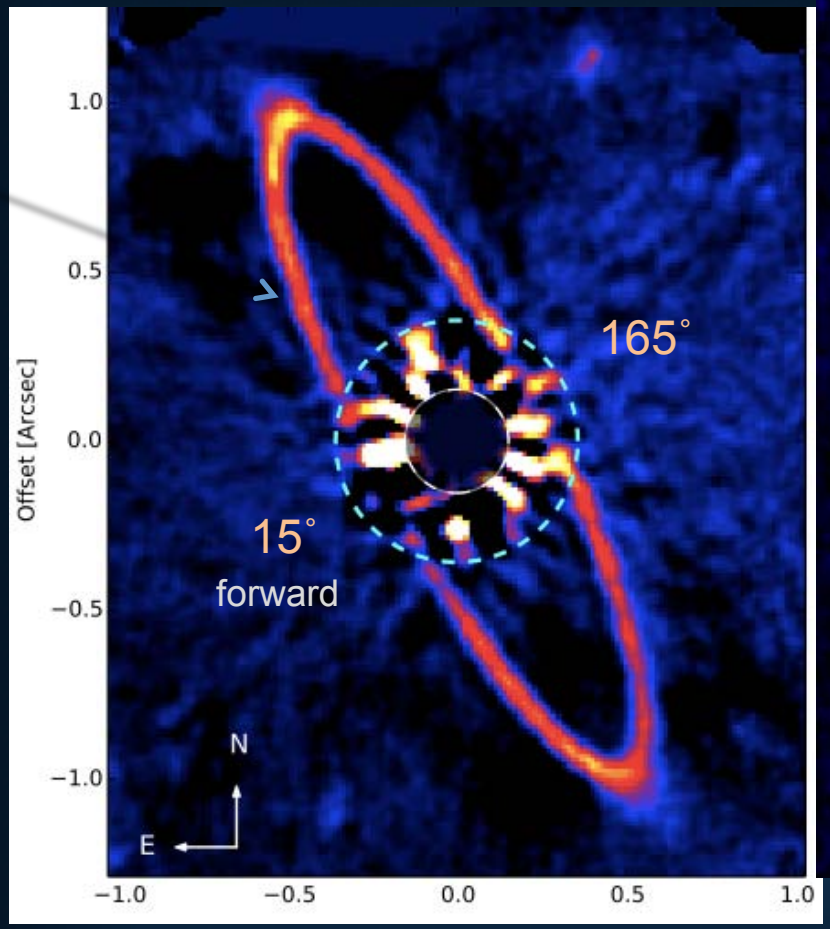
Perrin et al. 2014, in press

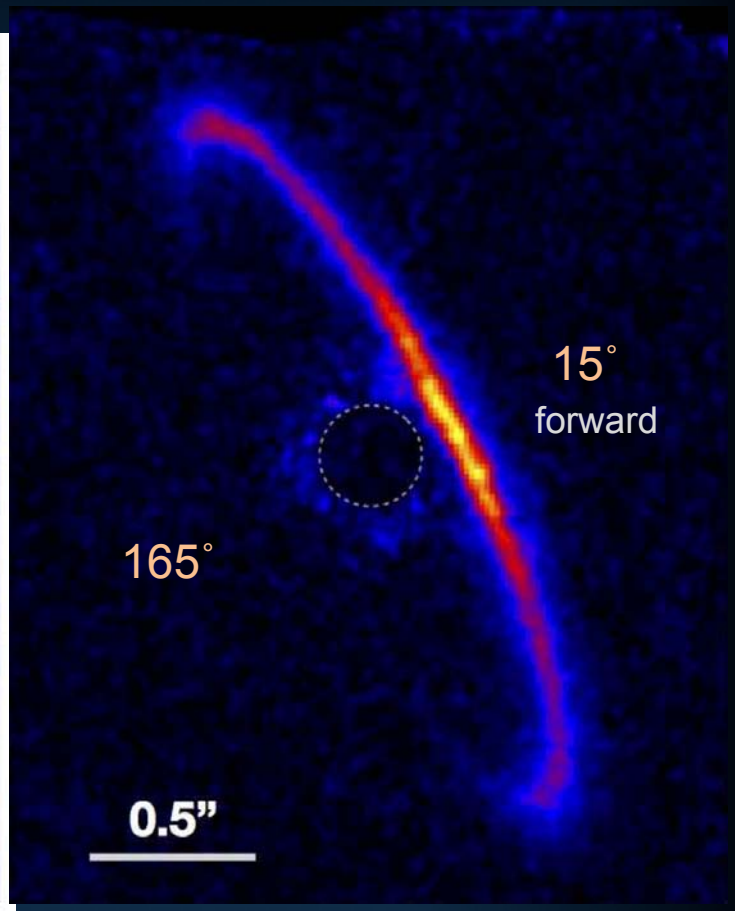
Total Intensity

K-band

Polarized Intensity

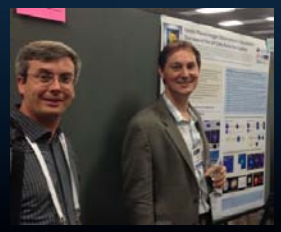
Brighter side in both optical and NIR data. Forward scattering direction.





offsets of the ring center relative to the star 0.56 ± 0.06 AU west, and 1.33 ± 0.13 AU south, consistent with previous estimates (Schneider et al. 2009; Thalmann et al. 2011)

Fitzgerald et al. 2014, in prep.



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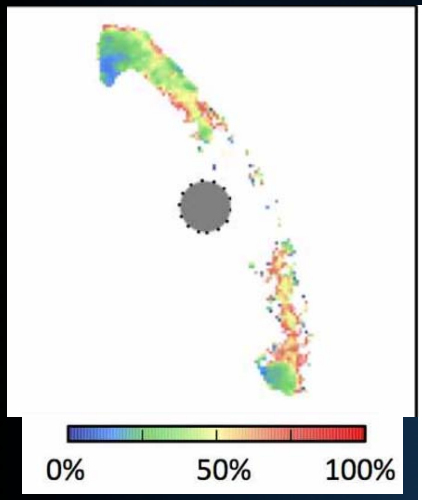
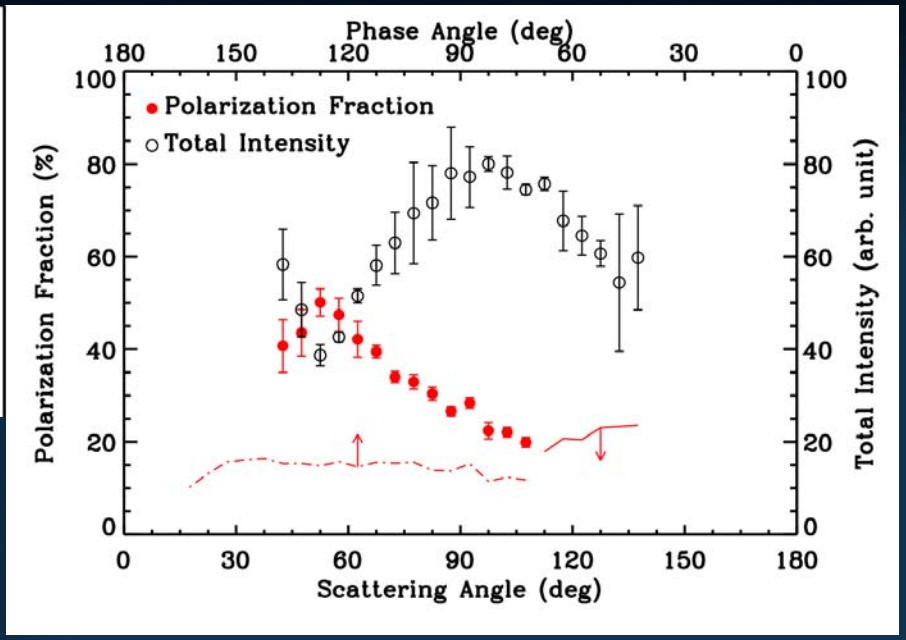


PoI Fraction

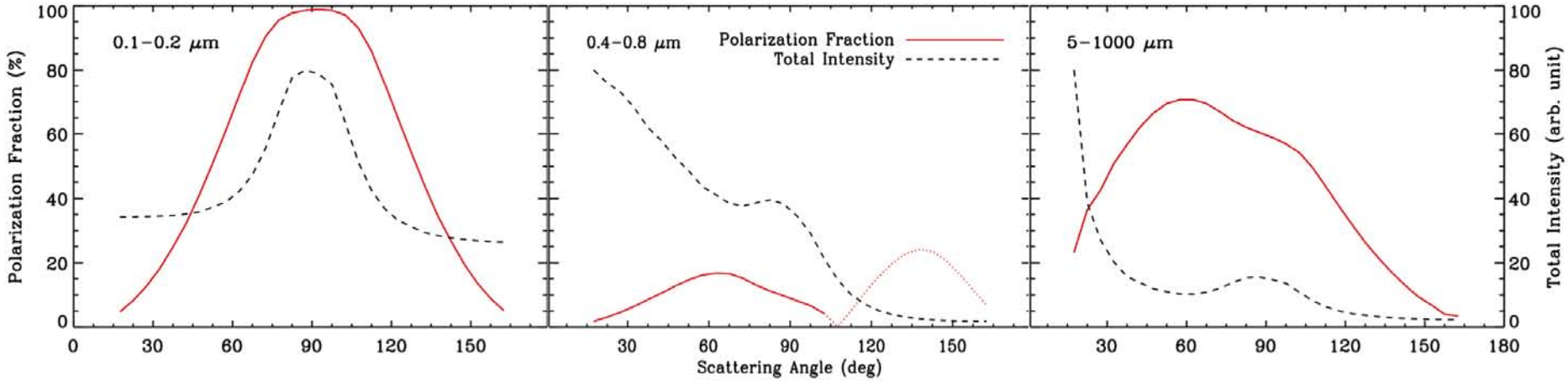
K-band



The scattering properties of the HR 4796A ring are more complex than expected: Large particles?
Not optically thin?

Perrin, Duchene, Millar-Blanchaer, et al. 2014 (arXiv:1407.2495)

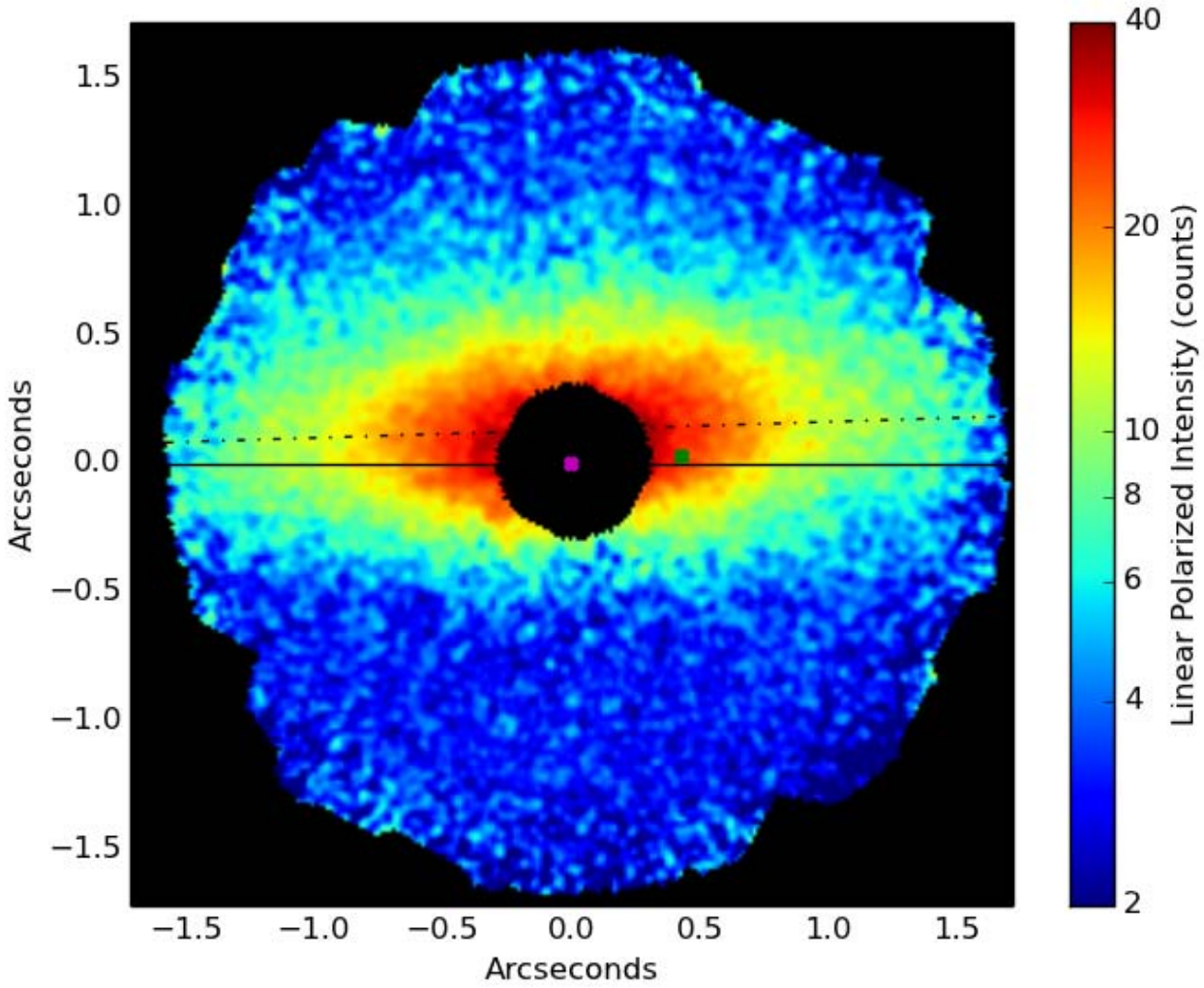
Optically thin Mie scattering model for astronomical silicates



MCFOST models by Gaspard Duchene

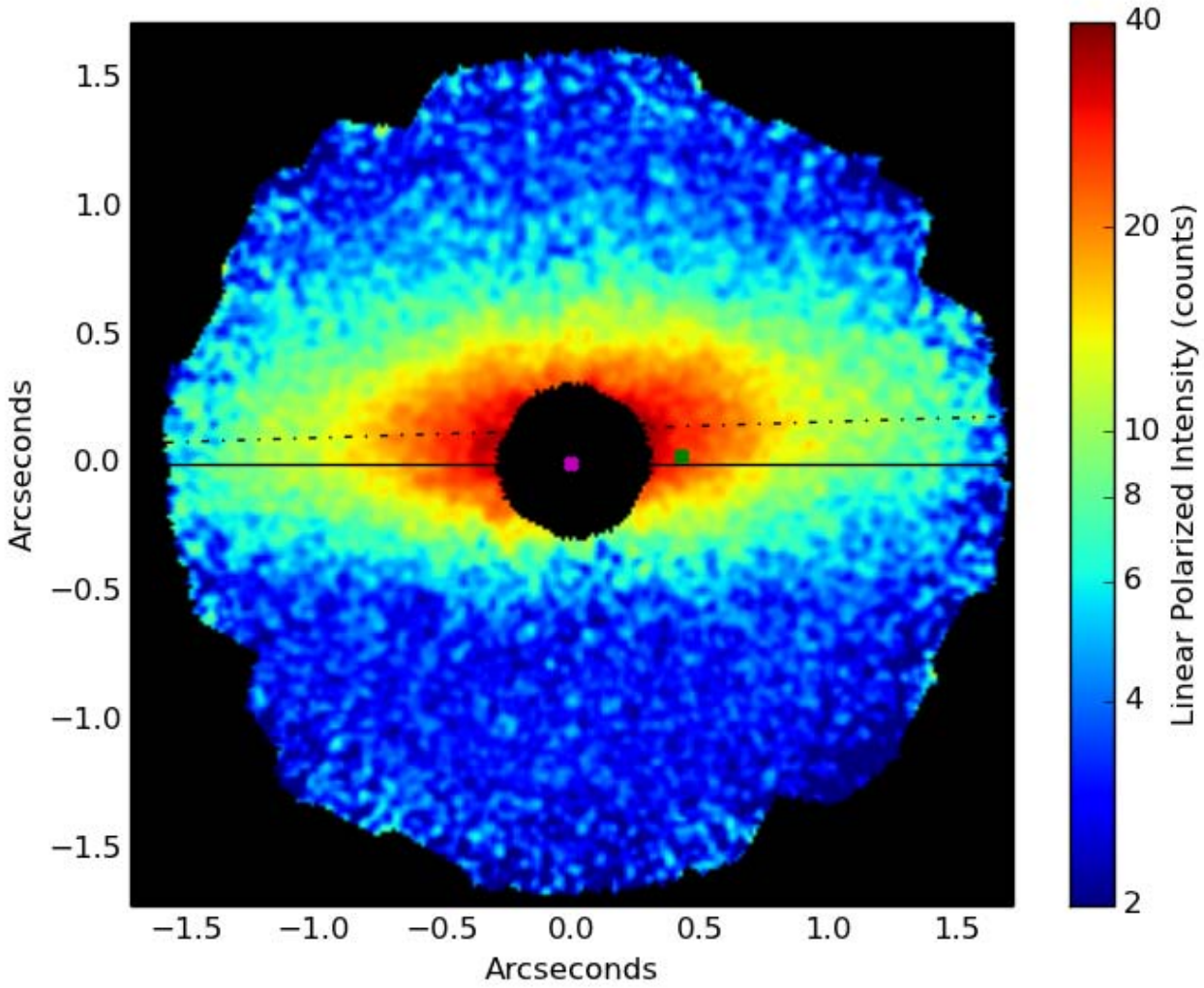
What is the morphology of the β Pic disk with GPI's inner working angle and image fidelity?

[Max Millar-Blanchaer et al., in prep.]



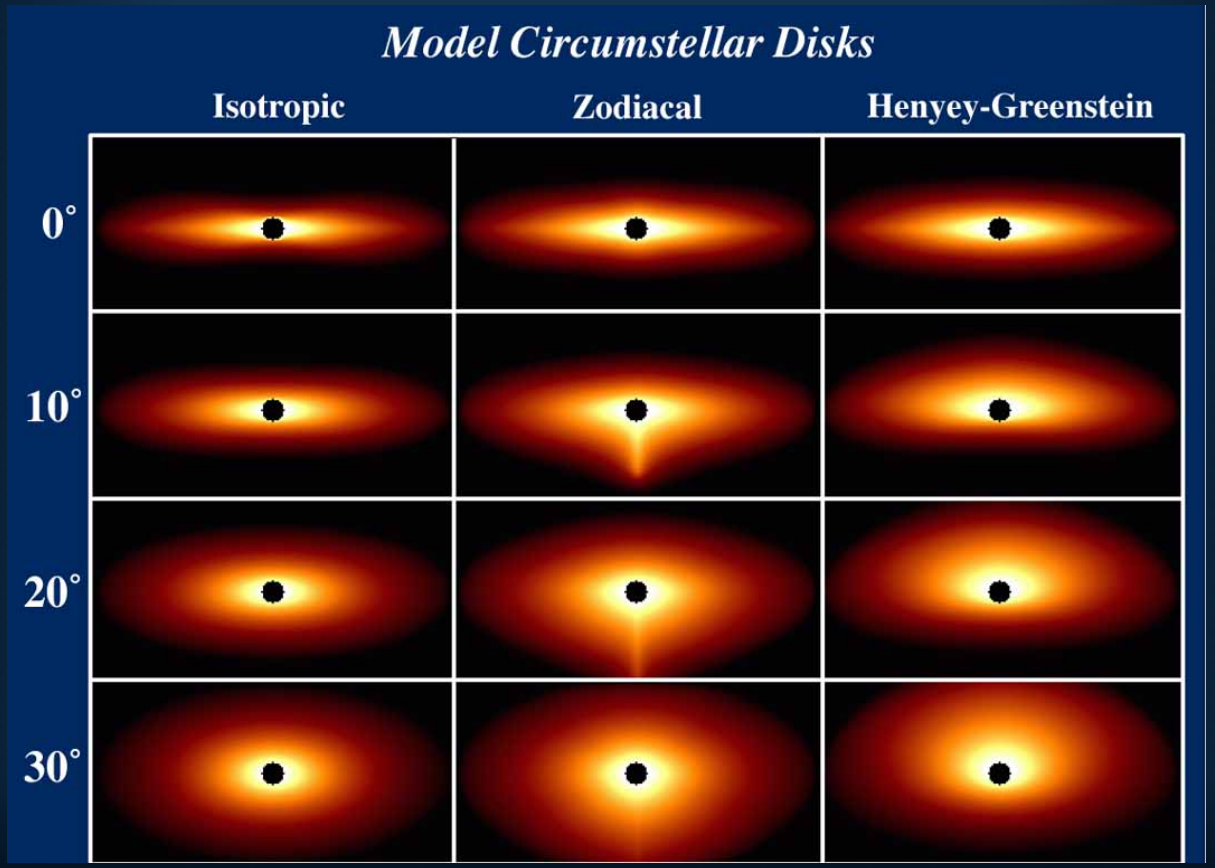
GPI Discovery of vertical asymmetry along minor axis. NOT edge-on.

[Max Millar-Blanchaer et al., in prep.]



From Kalas & Jewitt 1996

A dust disk can have a symmetric structure, but isophotes will appear to curve due to the phase function effect when the disk is not edge-on



Kalas & Jewitt 1996, ApJ, 111, 1347

20 yrs ago…

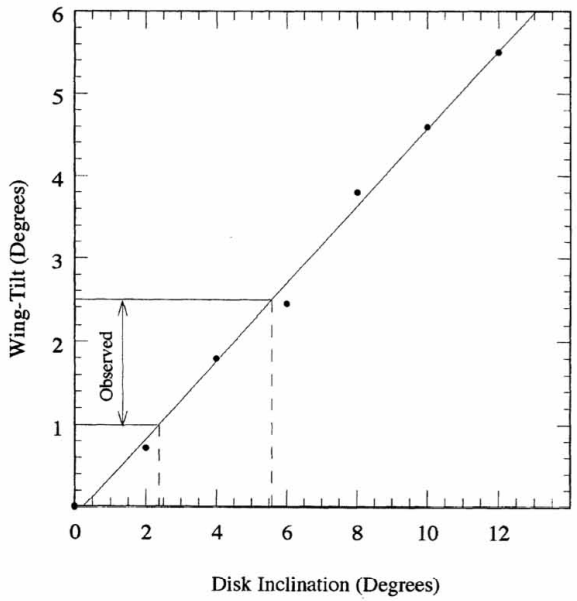
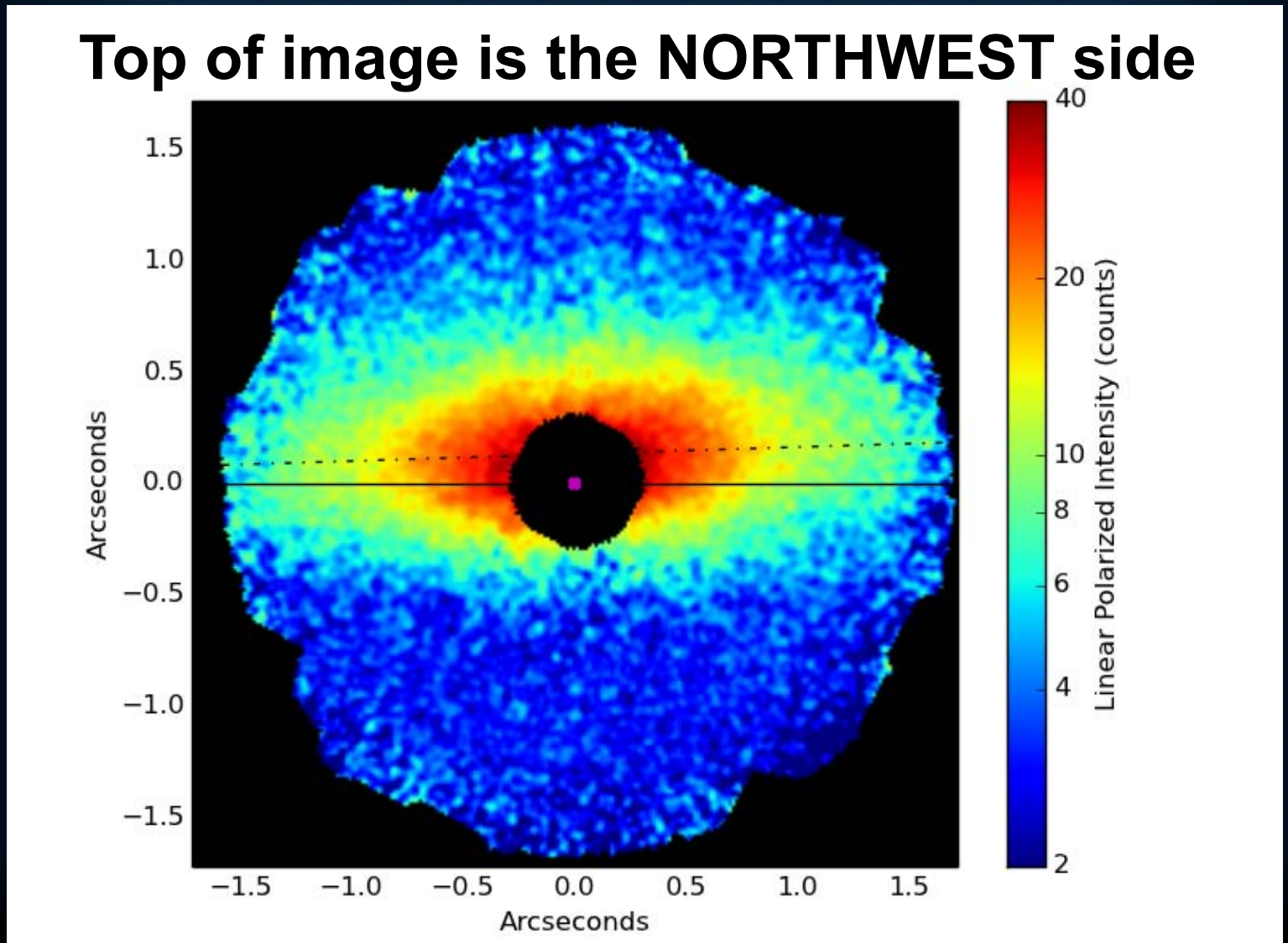


FIG. 12. Disk wing tilt as a function of disk inclination is plotted and shows an approximately linear relationship from $i=0°-12°$. The models used for this figure employed parameters listed for the NE extension model of Fig. 11, but with 2° increments of i. The wing tilts were then measured using the same method employed for data (Fig. 8), and the departures from a perfect straight-line fit indicate the uncertainties due to the measuring and fitting process. The observed range of angles for the wing tilt (Fig. 8) constrains the disk inclination to $2°<i<6°$. However, as reported in the text, $i>5°$ produces poor fits to the curvature of isophotes at the midplane.

If indeed disk inclination and the phase function are responsible for generating the apparent wing-tilt, then the direction of enhanced scattering leads to the prediction that the portion of the disk along the projected minor axis should be brighter to the northwest than to the southeast. There are at least three obstacles to observing this asymmetry. First, the regions near the star and along the polar axis of the disk are used to determine the registration and scaling of a comparison star for the subtraction of scattered light. Any subtle brightness asymmetries will be eliminated by this subtraction process. Second, such an observed asymmetry could also be produced by a systematic misalignment of the star with the occulting spot. Third, the occulting spot blocks the area very near the star where this asymmetry would be most evident.

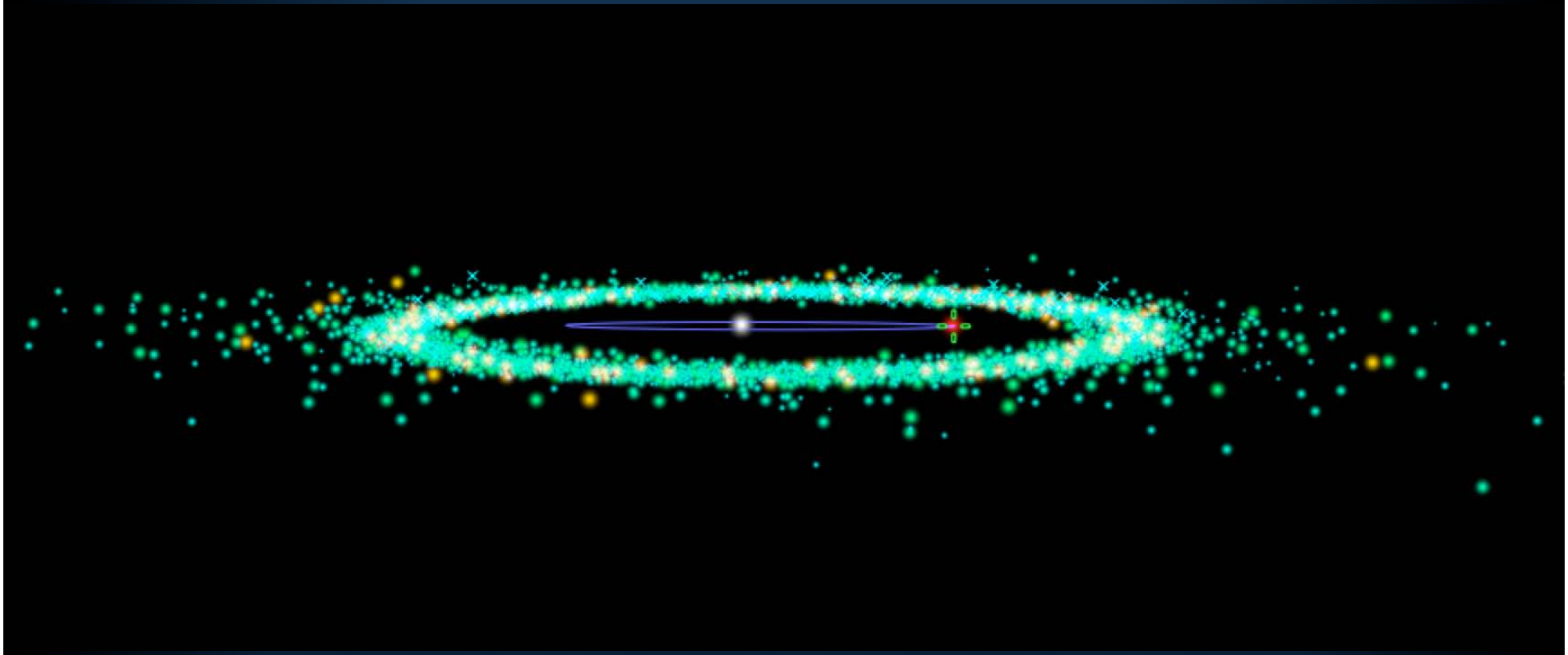
Kalas & Jewitt 1995, ApJ, 110, 794

GPI Discovery of vertical asymmetry along minor axis. NOT edge-on.
[Max Millar-Blanchaer et al., in prep.]



What exactly are the consequences?

Degeneracies between PA and mutual inclination depends on line of sight relative to line of nodes



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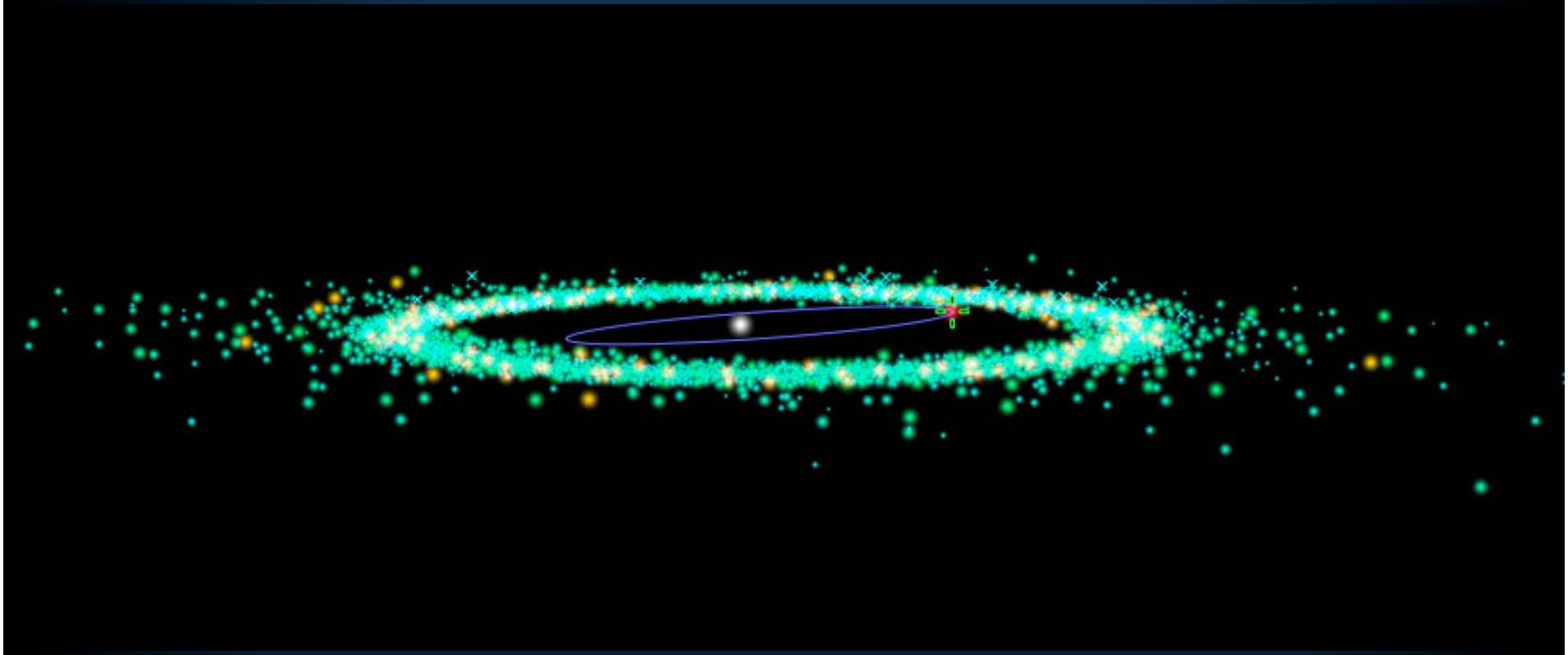
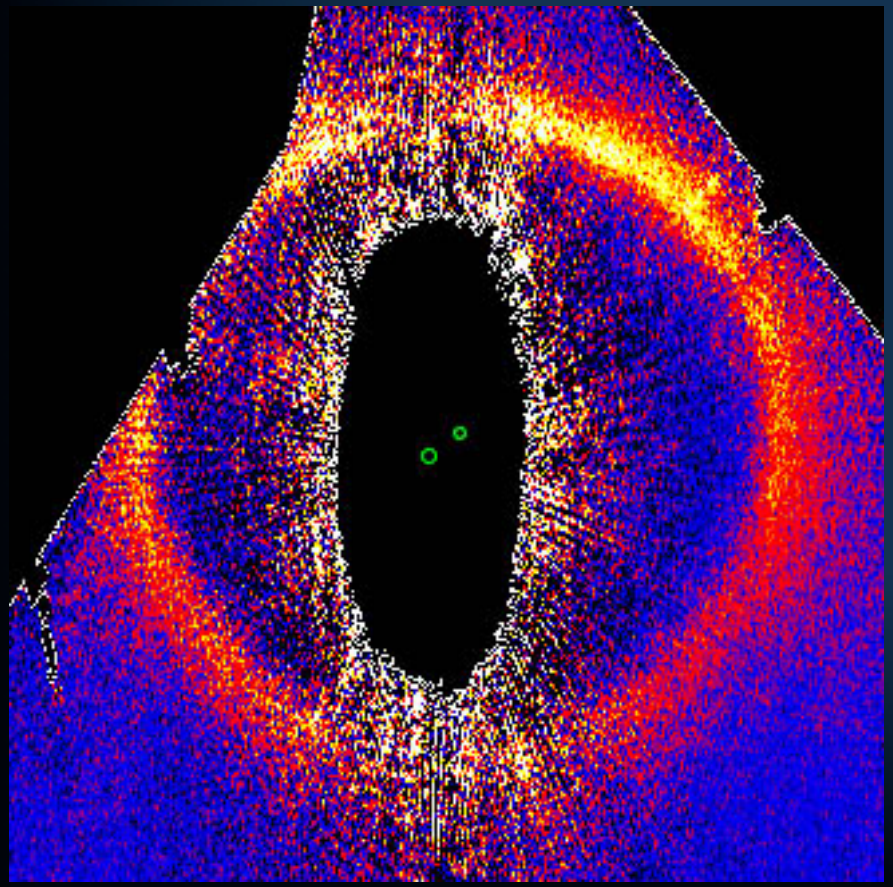


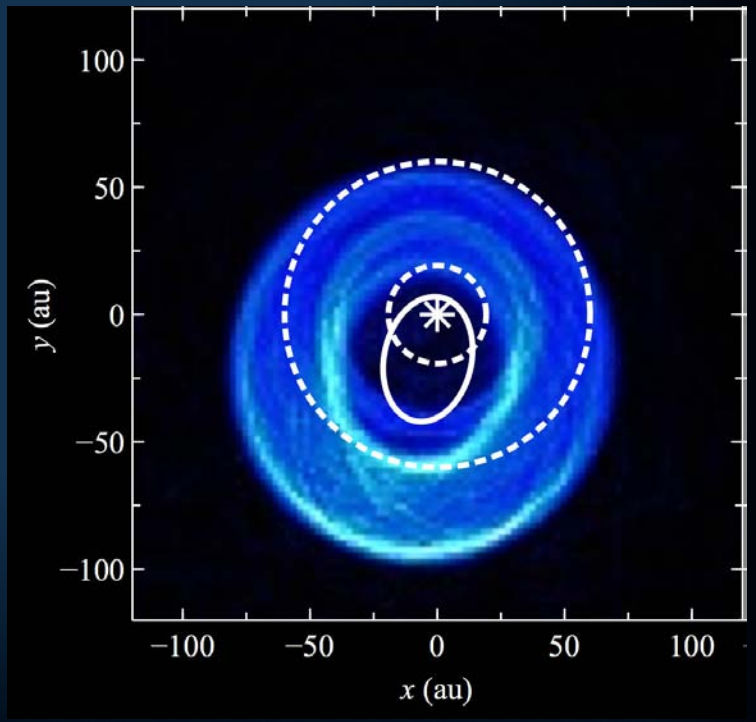
Fomalhaut

New HST/STIS observations Sept. 27, 2014, to resolve the 10 AU "ice-line" belt in scattered light

undisturbed or disturbed?



Pearce & Wyatt 2014



See also Faramaz et al. 2014

Summary

- HR 4796A with GPI (Perrin et al. 2014, Fitzgerald et al. 2014): Very unexpected ~40% polarization on what was previously thought to be the back-scattering side of the belt. *Large grains? Optically thick?*

- Beta Pic with GPI (Millar-Blanchaer et al. 2014): New GPI polarimetry gives unprecedented view of the minor axis direction. Asymmetry discovered. Suggests that the inner dust disk is not edge-on by a few degrees. *Implications for planet-disk relative geometries?*

- Fomalhaut with HST (Kalas et al. 2014): New HST observations planned to map the morphology of Fomalhaut A's inner belt. *Is it dynamically disturbed?*