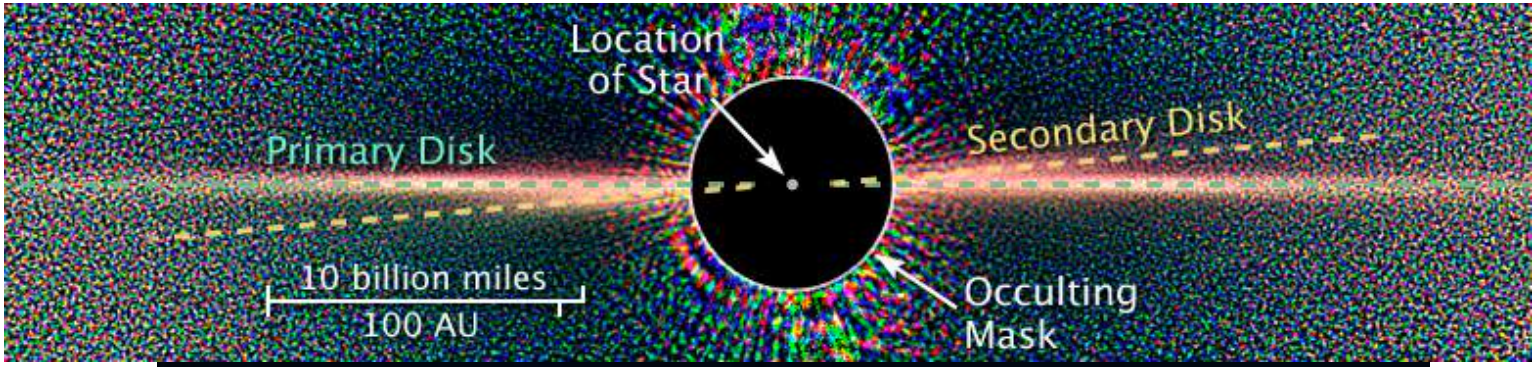
Characterizing Dusty Debris in Exoplanetary Systems

Christine Chen (STScI)

Reconstructing the β Pictoris Planetary System

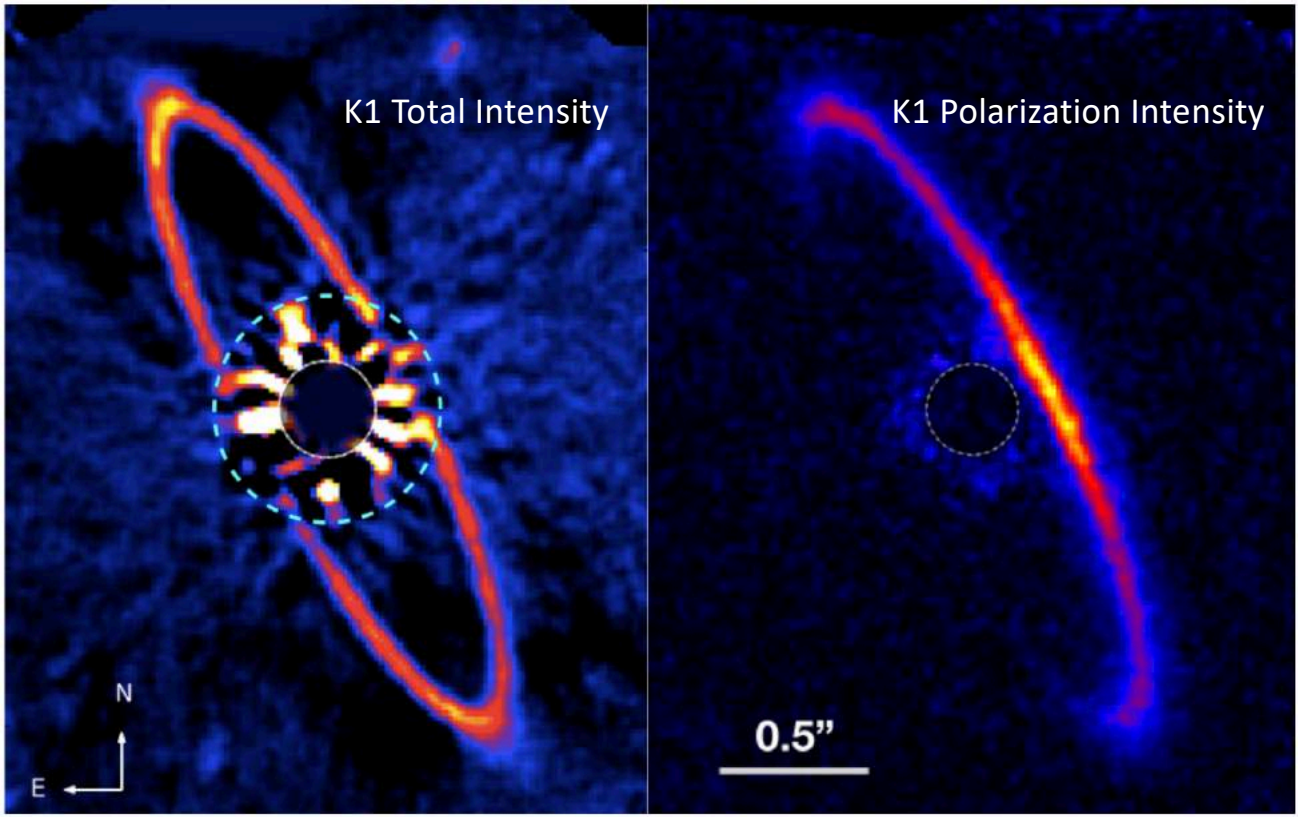
Extended disk of small grains up to ~1400 AU from the star (Golimowski et al. 2006)



“Characterizing Dusty Debris in Exoplanetary Systems”

- Approved Gemini 2015B Large and Long Program
- Allocation: 87 hours in Band 2
- Principal Investigator: Christine Chen (STScI)
- Co-Investtigators: John Debes, Dean Hines, Marshall Perrin, **Charles Poteet**, Laurent Pueyo, **Bin Ren**, Chris Stark (STScI/JHU), **Johan Mazoyer**, Max Millar-Blanchaer, Debbie Padgett (JPL), **Gaspard Duchene**, **Tom Esposito**, **Paul Kalas** (UC Berkeley), **Mike Fitzgerald**, **Pauline Arriaga**, Ronald Lopez (UCLA), Jennifer Patience, **Justin Hom** (ASU), Schuyler Wolff (Leiden), Brenda Matthews, Zack Draper (Victoria), Sally Dodson-Robinson, Inbok Yea (Delaware), Ludmilla Kolokolova (Maryland), Alycia Weinberger (Carnegie DTM)

GPI Observing Modes



Perrin et al. (2015)

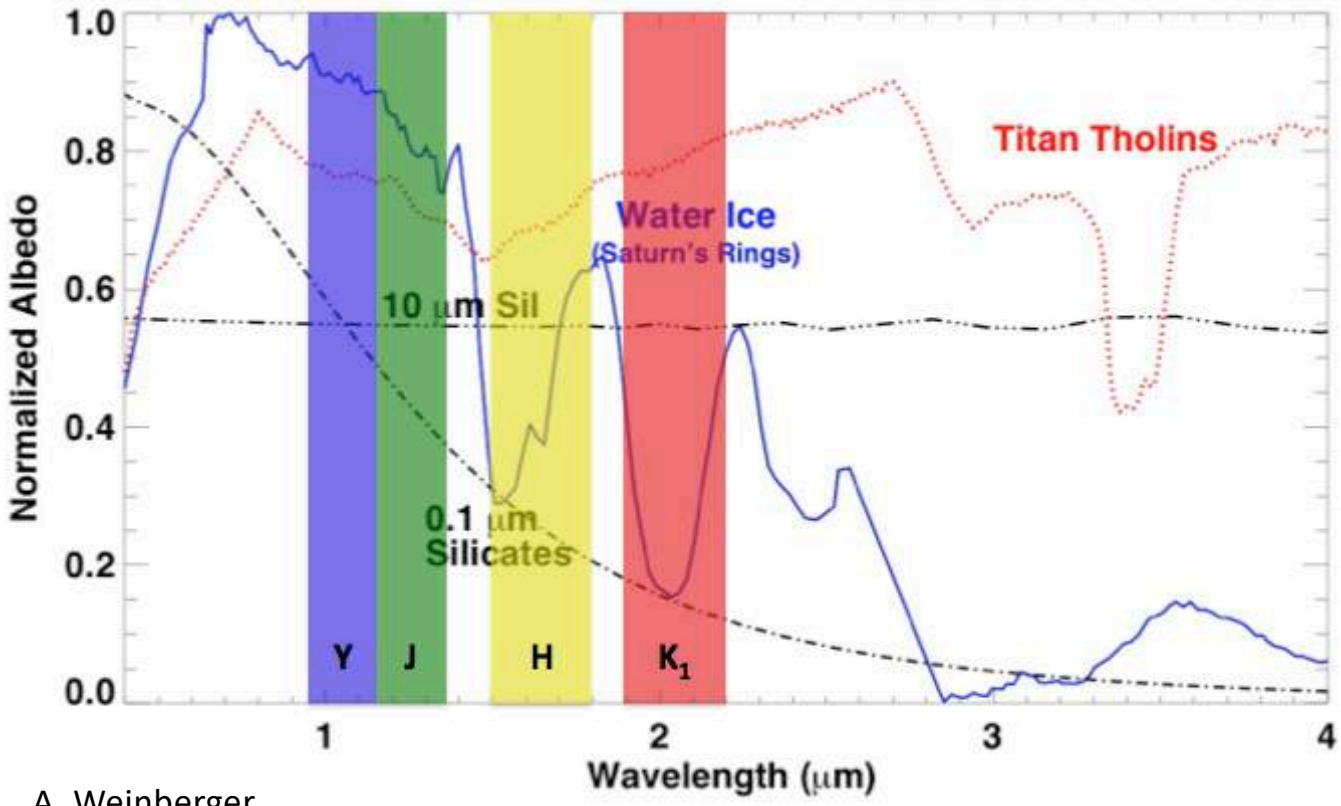
Spectroscopic

- Light is dispersed using a conventional prism
- Speckles from stellar point source must be subtracted or modeled

Polarimetric

- Light is divided in ordinary an extraordinary ray using a Wollaston prism
- The two beams can be simply differenced to produced a polarized intensity image
- Achieves an order of magnitude higher contrast performance

Science Goal 1: Constraining Dust Composition

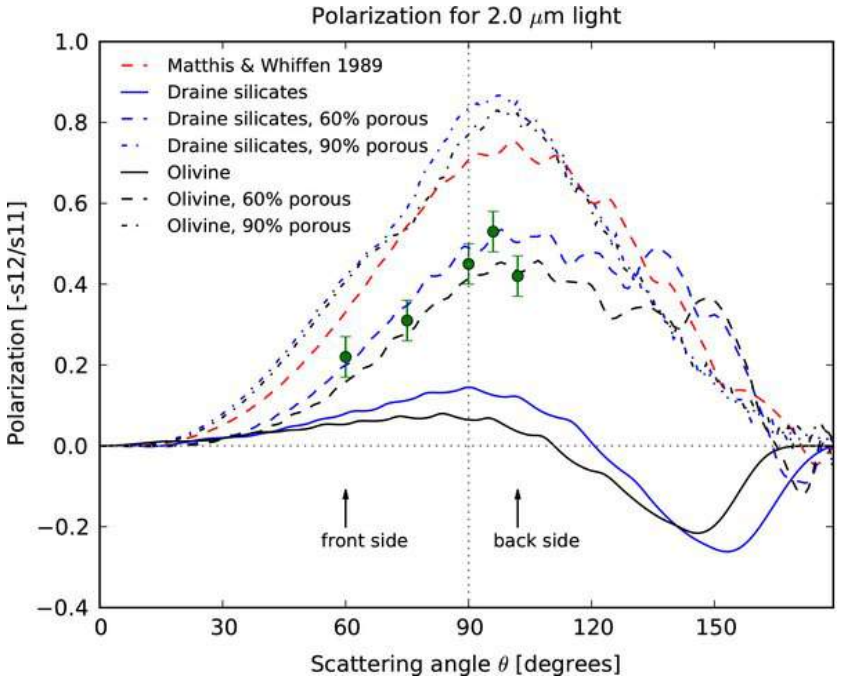


A. Weinberger

- The GPI IFS enabled high contrast spectroscopy in reflected light for debris disks
- The H and K-band filters provide access to water ice features
- Observations in multiple filters can be combined to provide reflected light color

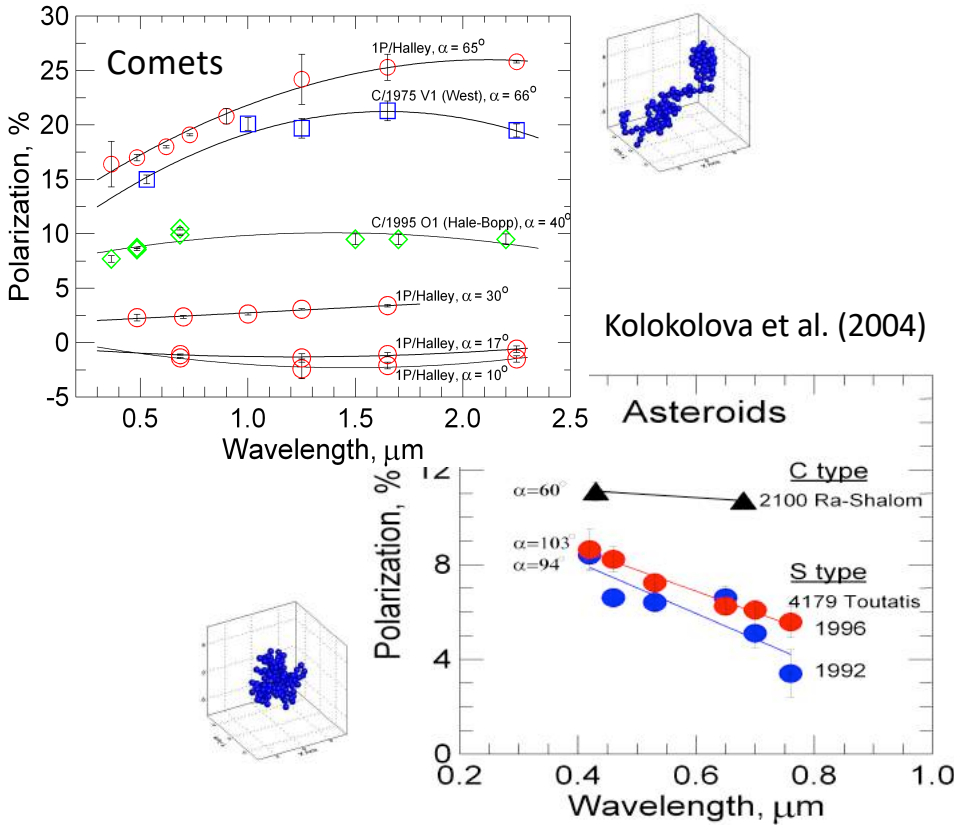
Science Goal 2: Constraining Dust Porosity

Polarization Fraction Phase Function



Perrin et al. (2009)

Polarization Fraction Color



Kolokolova et al. (2004)

Completed Observations

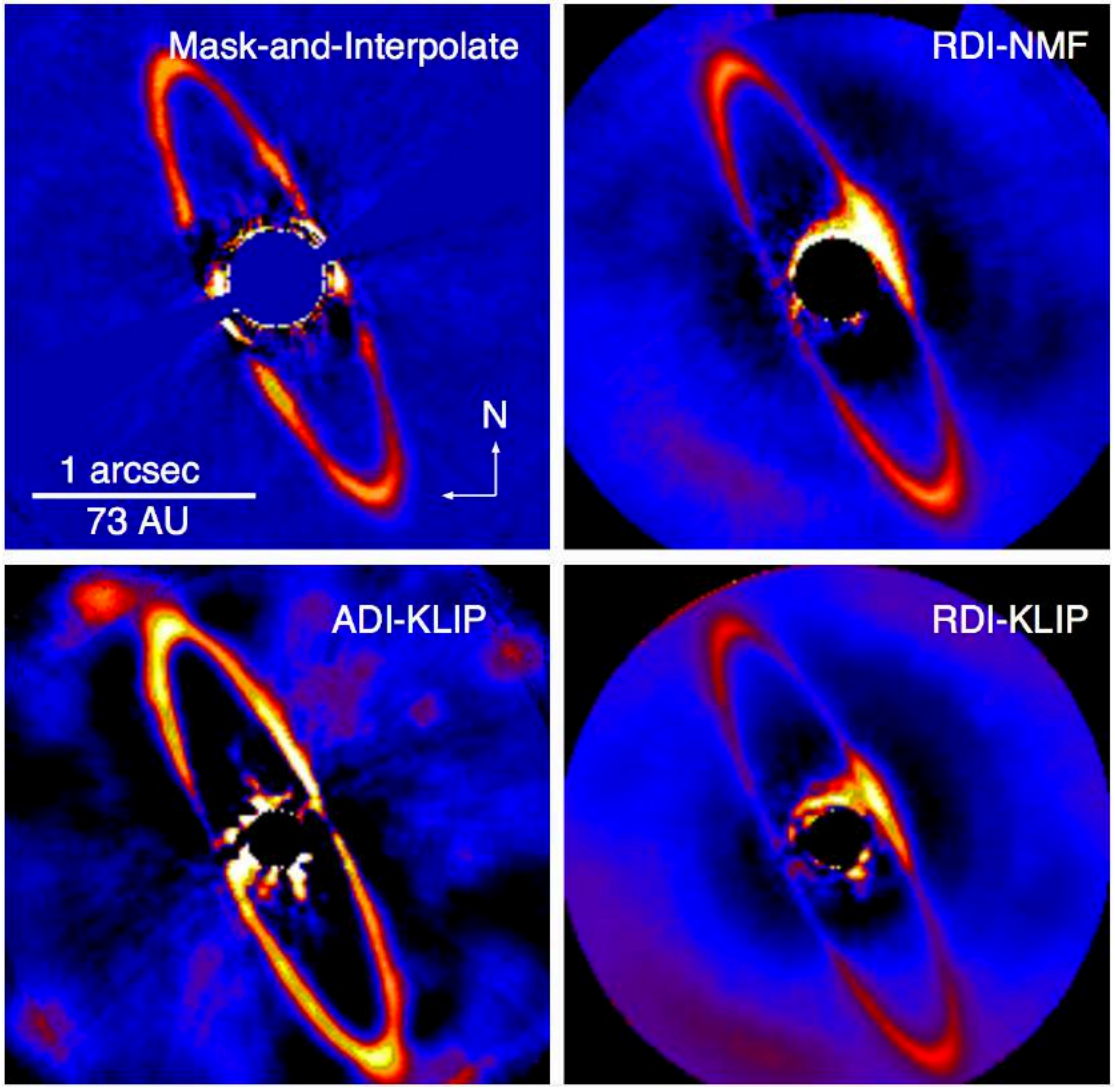
- *Y*, *J*, and K_1 Spec and Polarimetric characterization of ~one dozen debris disks already spatially resolved in scattered light
- Complementary to GPIES Debris Disk program to search for planetary mass companions and characterize dust using *H* Spec and Pol

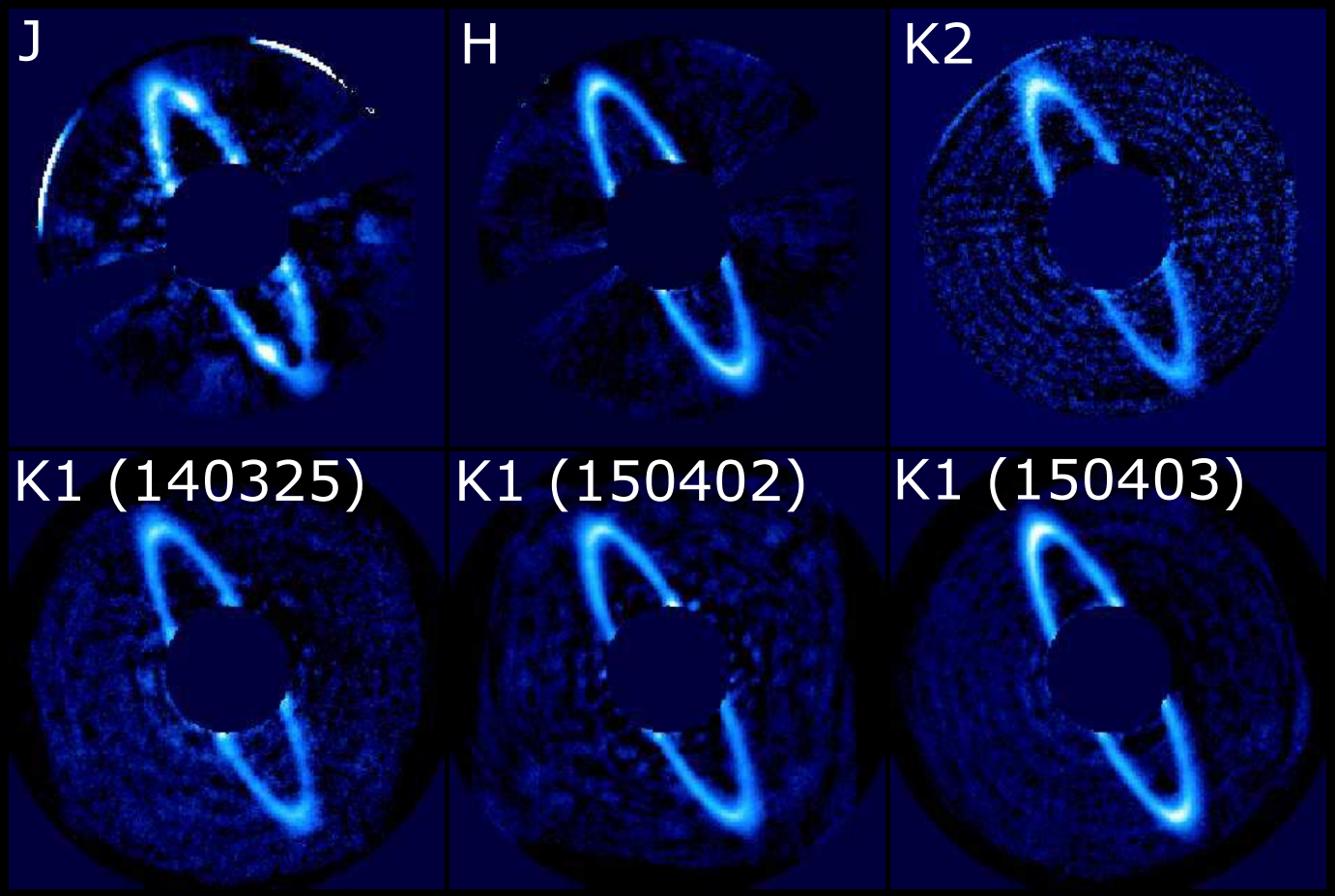
Name	Sp Type	Dist (pc)	Age (Myr)	D (AU)	i	Observations
HD 15115	F2	45	12	31-315	90°	Spec: J, K_1; Pol: J, H
HD 32297	A0V	112	30	50-1680	90°	Spec: J, K_1; Pol: J
HD 36546	B8	113	~10	50-1200	90°	Spec: H; Pol: H
HD 61005	G8V	18	45	62	85°	Spec: J, K_1; Pol: J
HD 106906	F5V	92	>16	50-500	85°	Spec: J, K_1; Pol: J, K_1
HR 4796A	A0V	72	8	60-87	73°	Spec: J, H, K_1, K_2; Pol: J, H, K_1
HD 110058	A0V	130	>16	32-65	90°	Spec: J, K_1; Pol: J, K_1
HD 111520	F5-6V	108	>16	35-650	87°	Spec: J, K_1; Pol: J, K_1
HD 114082	F3V	97	>16	28-	~83°	Pol: K_1
HD 115600	F2IV/V	110	>16	46	~80°	Spec: J, K_1; Pol: J, K_1
HD 129590	G3V	136	~16	60-70	75°	Spec: J; Pol: K_1
HD 146897	F2V	123	11	25-250	90°	Spec: J, K_1; Pol: J, K_1
HD 157587	F5V	107	?	80-500	70°	Spec: K_1, Pol: J, K_1

Primary Challenge: Recovering Accurate Total Intensity Images

PSF Subtraction Techniques

- **Mask and Interpolate** – For observations of bright disks, mask disk and interpolate PSF under the mask
- **RDI-NMF** – For H-band (with GPIES reference library), construct PSF from reference observations using NMF
- **RDI-KLIP** – For H-band (with GPIES reference library), construct PSF from reference observations using KLIP
- **ADI-KLIP** – Construct PSF from observational sequence using KLIP

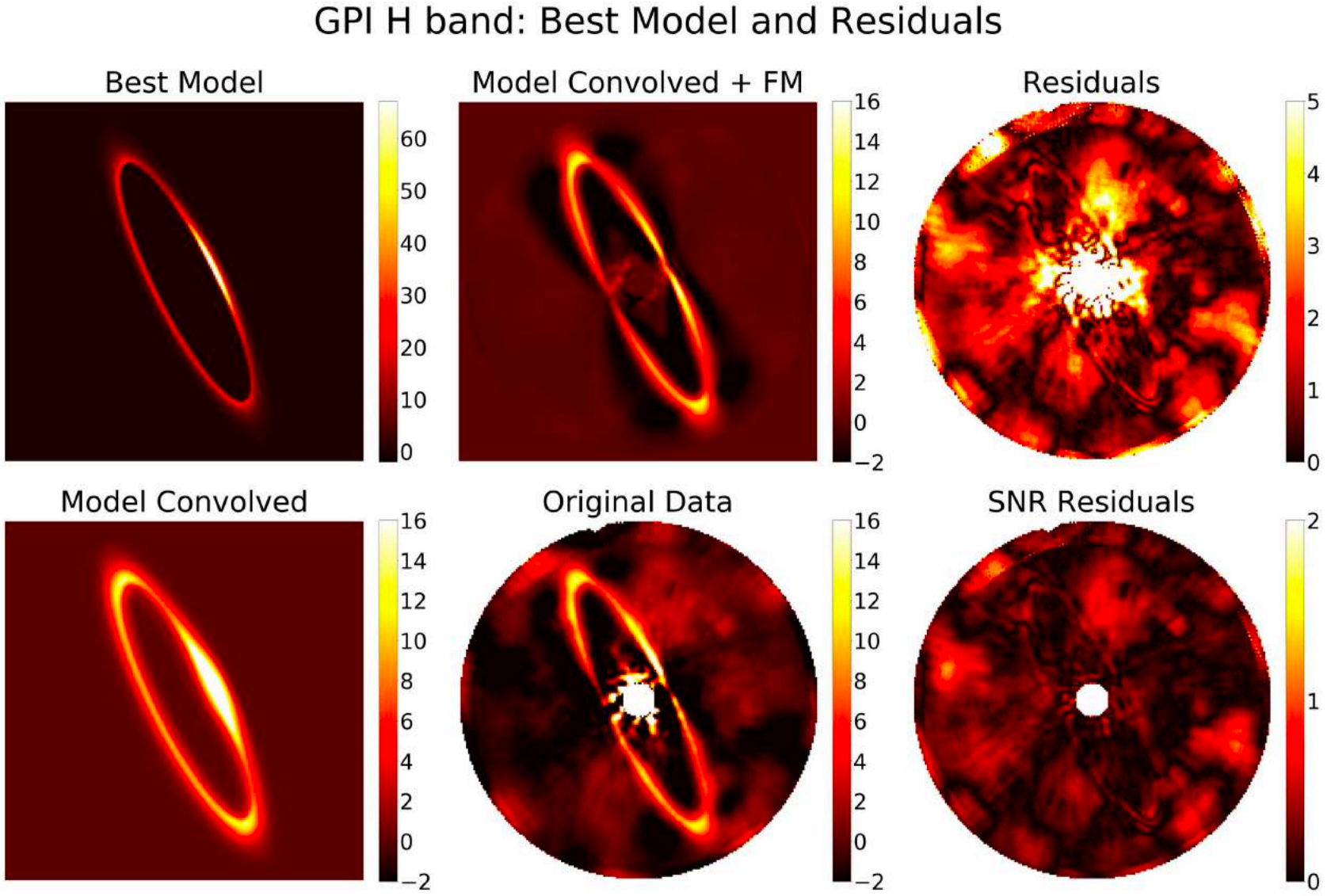




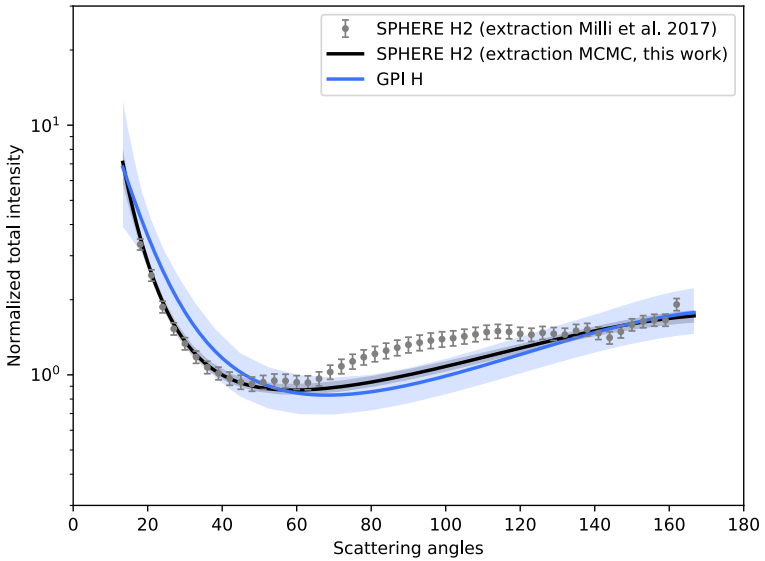
Gaspard Duchêne

Johan Mazoyer
NHFP Sagan Fellow @ JPL
Paris Observatory

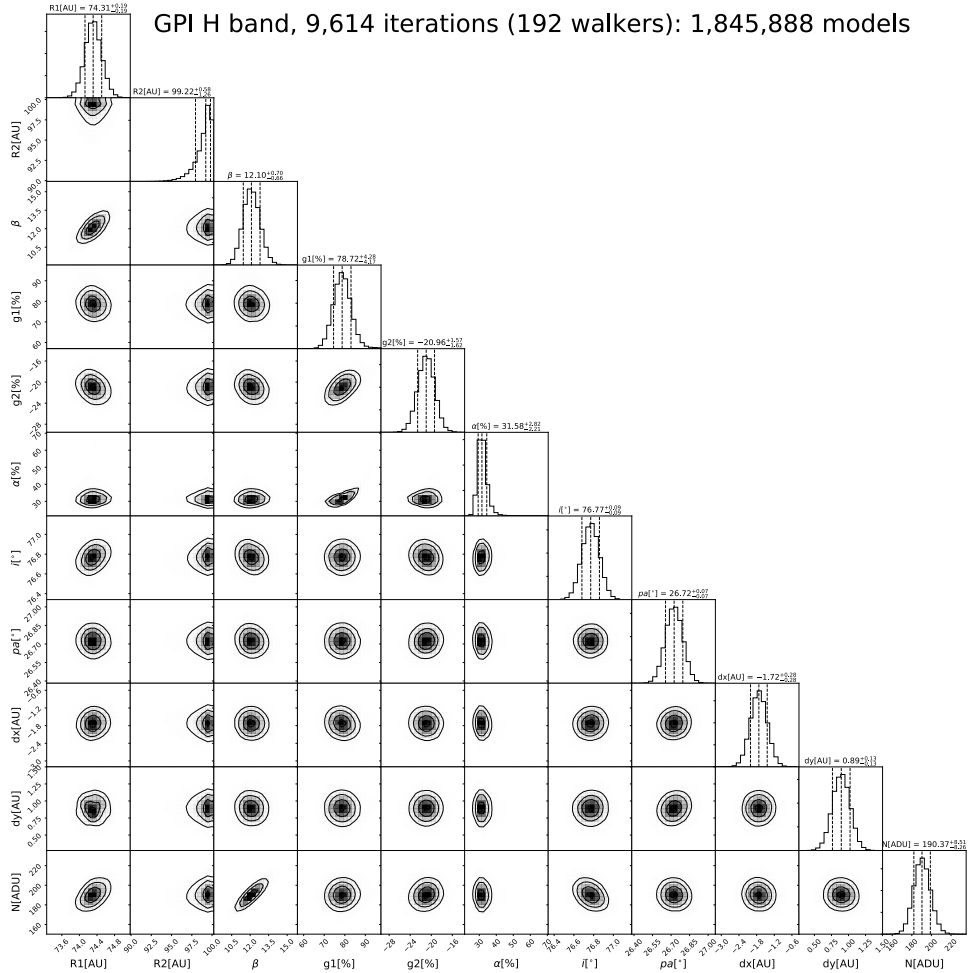
Forward Modeling GPI Spec Observations of the HR 4796A Debris Disk


GPI H band: Best Model and Residuals
Best Model
60
50
40
30
20
10
0
Model Convolved + FM
16
14
12
10
8
6
4
2
0
−2
Residuals
5
4
3
2
1
0
Model Convolved
16
14
12
10
8
6
4
2
0
−2
Original Data
16
14
12
10
8
6
4
2
0
−2
SNR Residuals
2
1
0

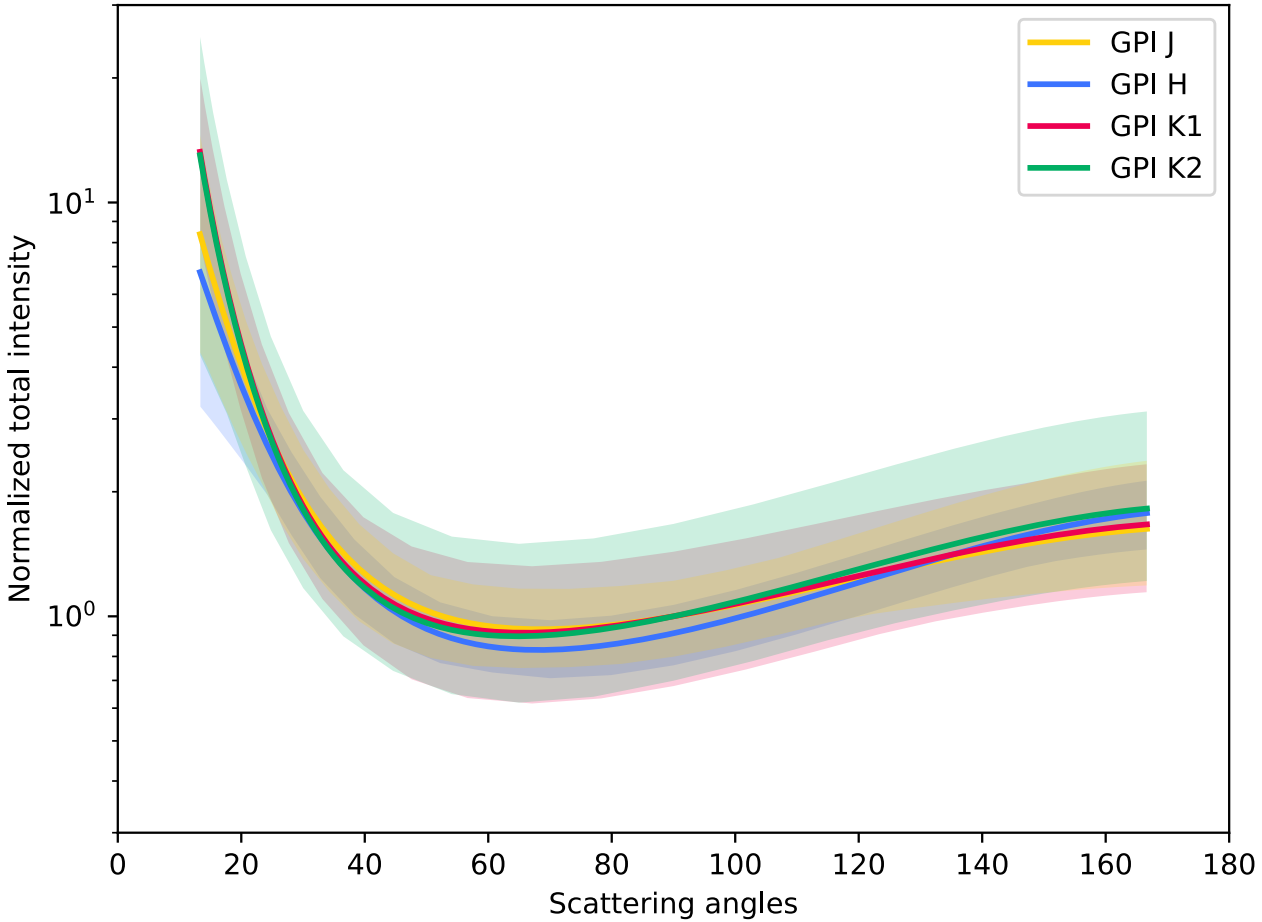
Estimated GPI H-Spec Scattering Phase Function



Disk modeling produces similar GPI H-Spec scattering phase function as previously reported; although, the minimum in the scattering phase function may be at slightly larger scattering angles

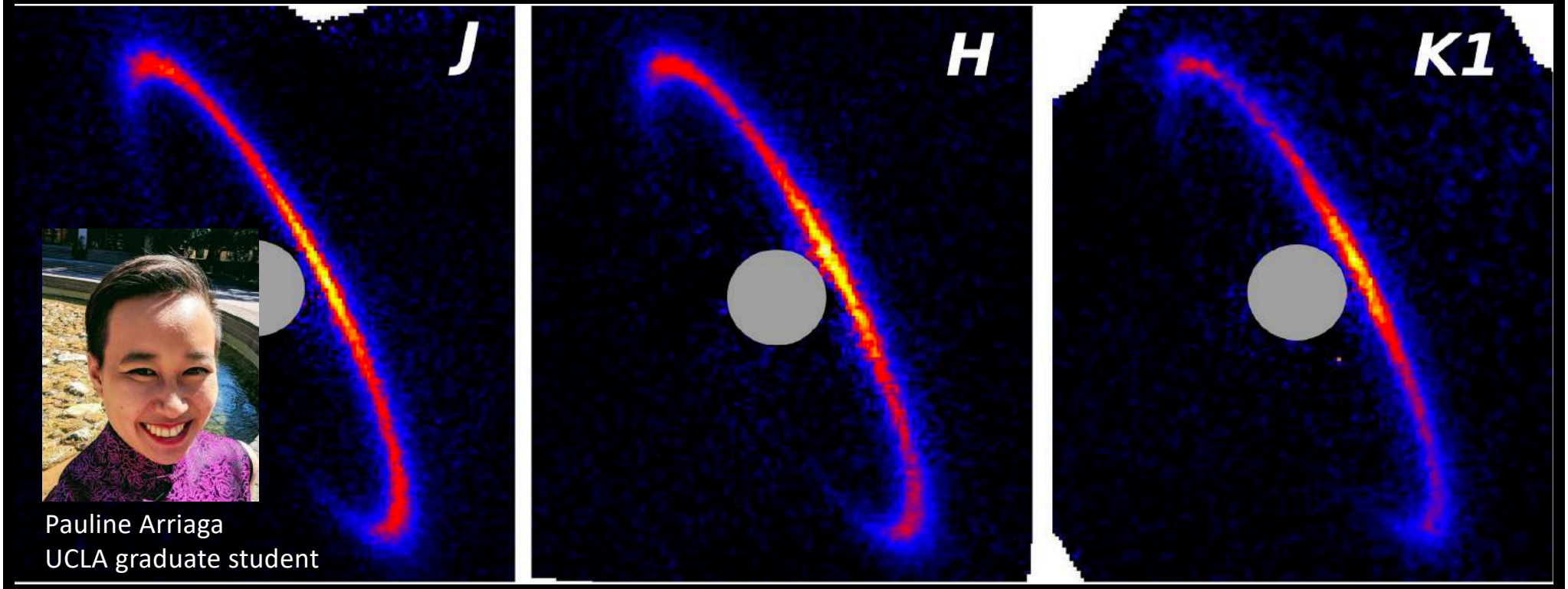


GPI Multiwavelength Scattering Phase Functions



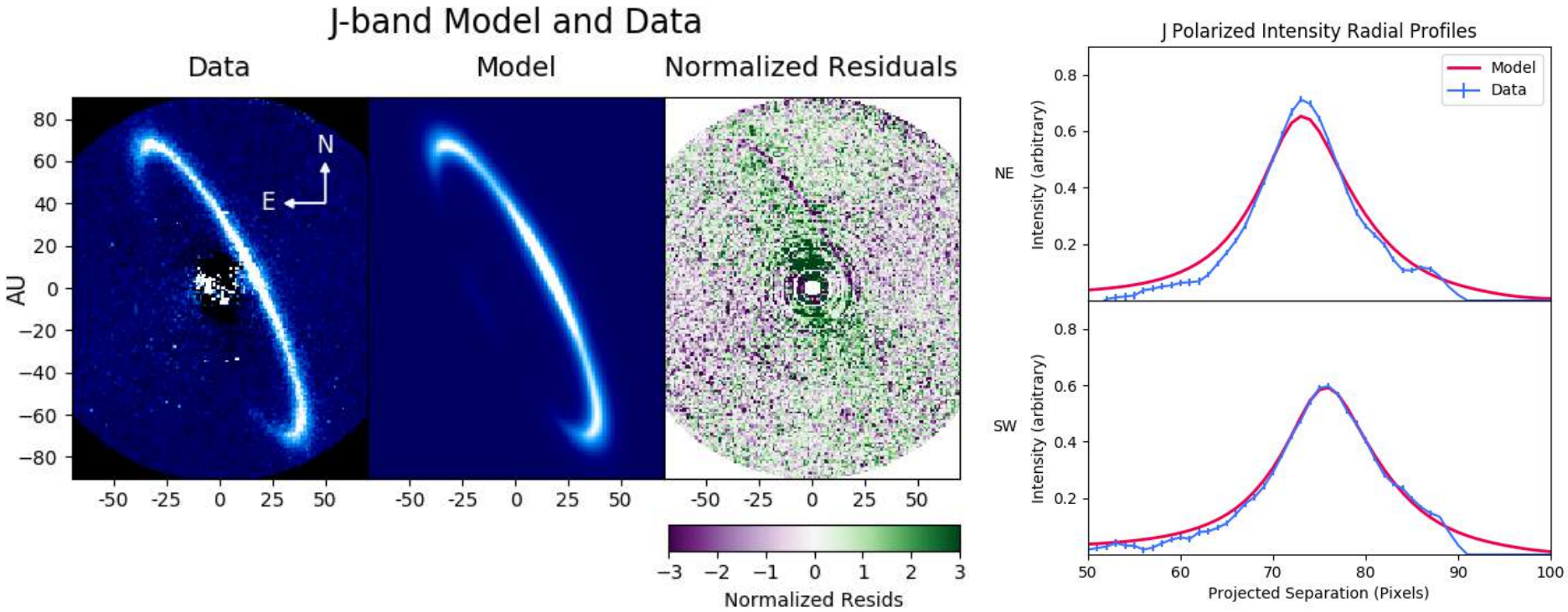
The GPI J, H, K_1, and K_2 scattering phase functions do not show any obvious wavelength dependence.

Multiband Polarimetric Imaging with the Gemini Planet Imager



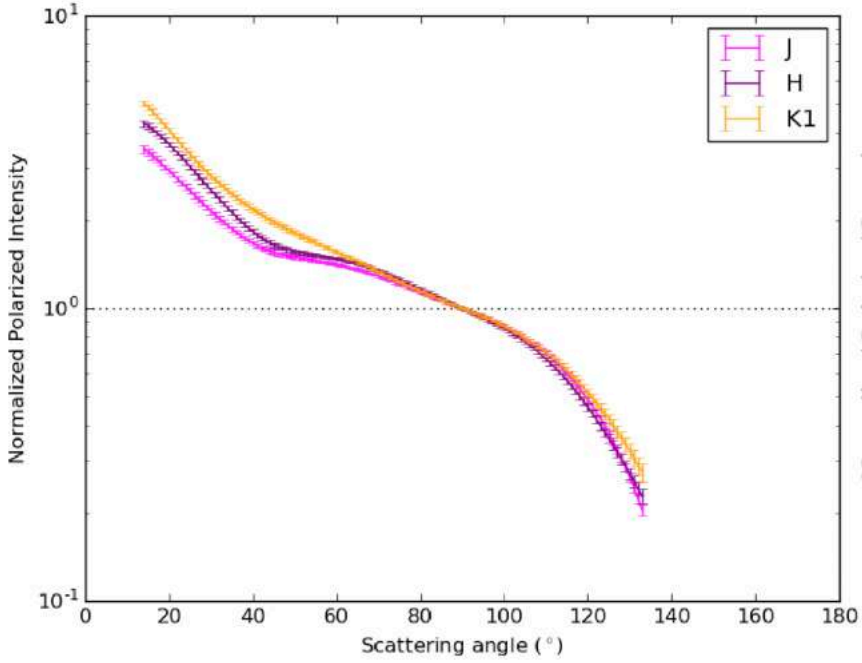
Pauline Arriaga
UCLA graduate student

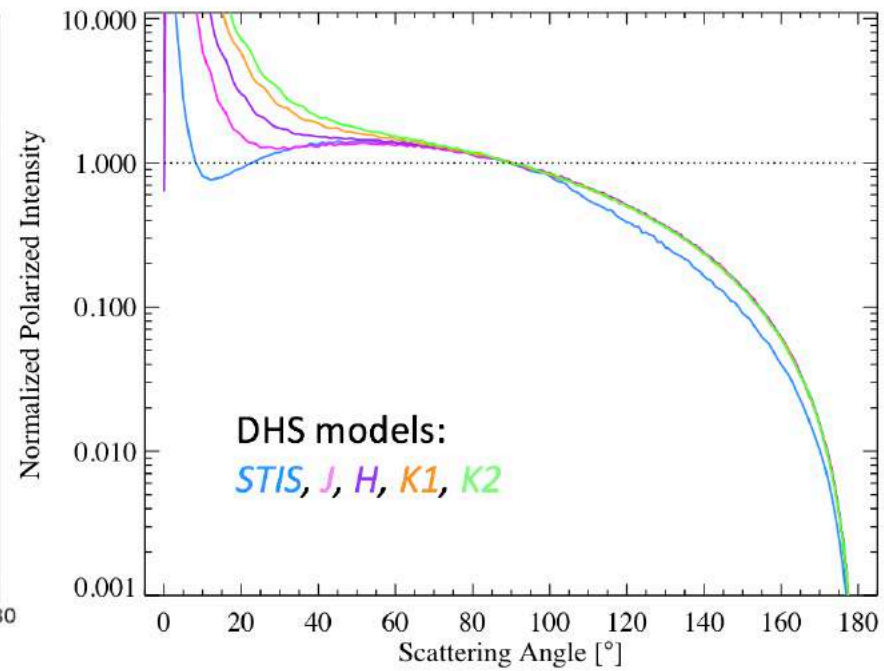
Apsidal Alignment of Circumstellar Dust



- The radial profile at pericenter (NE) appears sharper than at apocenter (SW)
- One explanation is that the parent bodies have conjunctions at pericenter where they are aligned

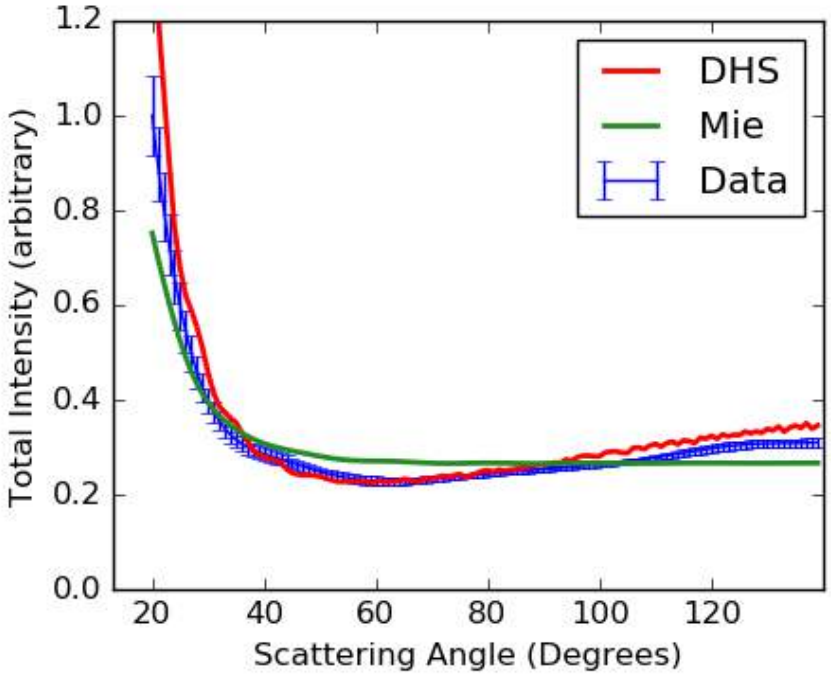
GPI Multiwavelength Polarization Intensity Phase Functions

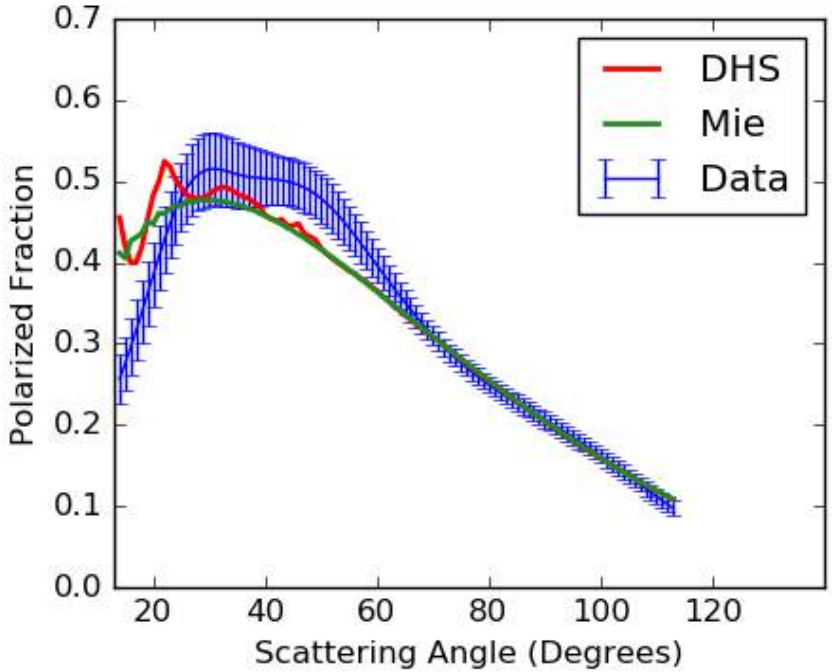




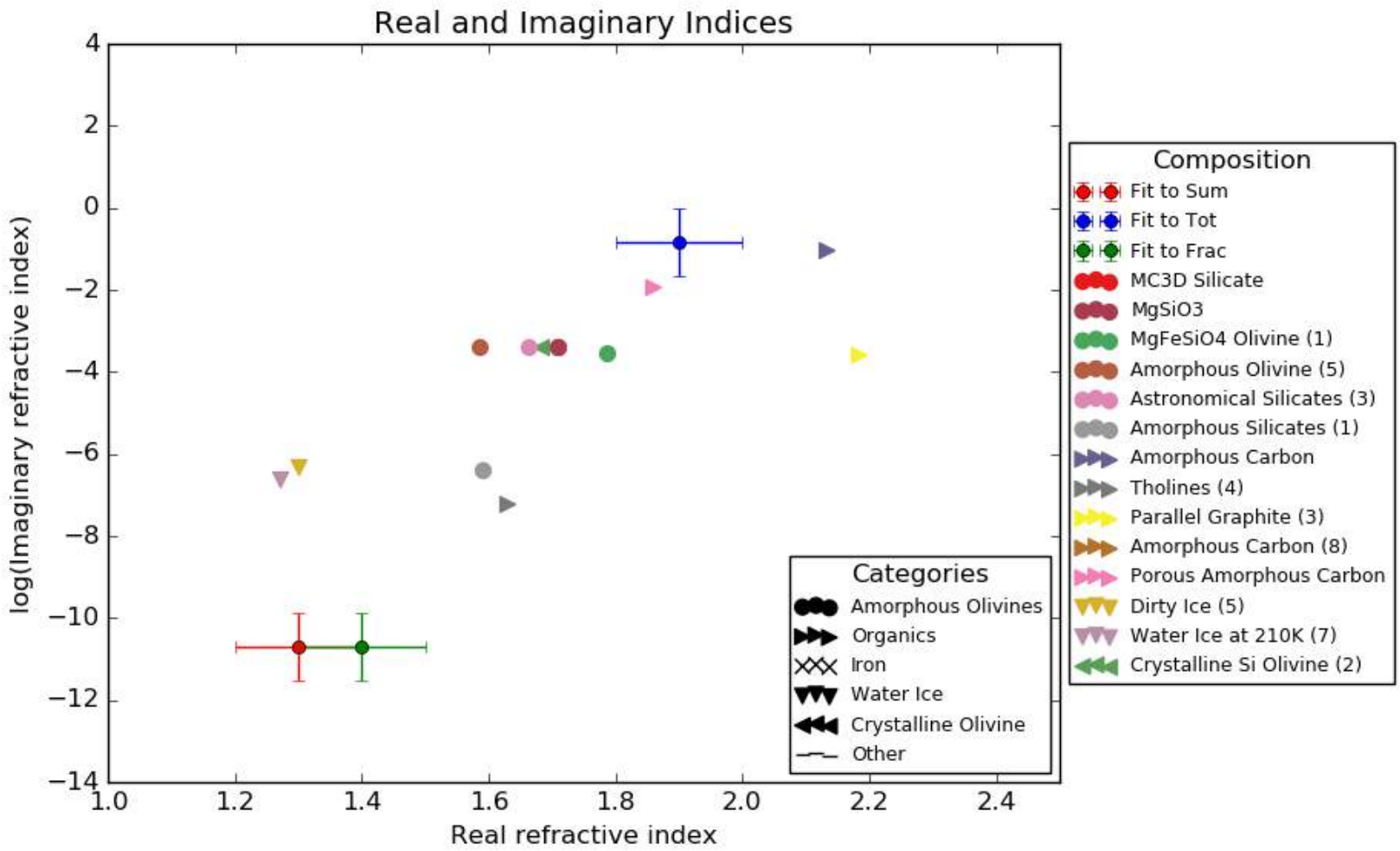
Both observations and models show that the brightest forward scattering occurs at the longest wavelengths and the largest region of forward scattering also occurs at the longest wavelengths

K1-band Phase Function Fitting





- Used MCFost to model the K1 band total intensity and fractional polarization phase functions
- The real and imaginary part of the index of refraction are left as a free parameter


Real and Imaginary Indices
log(Imaginary refractive index)
Real refractive index
4
2
0
−2
−4
−6
−8
−10
−12
−14
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
Composition
Fit to Sum
Fit to Tot
Fit to Frac
MC3D Silicate
MgSiO3
MgFeSiO4 Olivine (1)
Amorphous Olivine (5)
Astronomical Silicates (3)
Amorphous Silicates (1)
Amorphous Carbon
Tholines (4)
Parallel Graphite (3)
Amorphous Carbon (8)
Porous Amorphous Carbon
Dirty Ice (5)
Water Ice at 210K (7)
Crystalline Si Olivine (2)
Categories
Amorphous Olivines
Organics
Iron
Water Ice
Crystalline Olivine
Other

Advice to Prospective LLP Programs

- Be aware of challenging technical goals
  - Our team did not anticipate the difficulty in extracting multi-wavelength total intensity images and spent much effort trying to correct images before settling on forward modeling
- Include intermediate science goals
  - Our team is expanding our science goals for other systems to include high precision measurements disk geometry to determine whether the structures seen in debris disks are generated by planets or ISM-interaction
- Be aware of challenging scientific goals
  - Our team is continuing to work on our original science goals and is currently working on absolute calibration of extended source spectroscopic data. Once completed, we will be able to complete our project as originally envisioned.