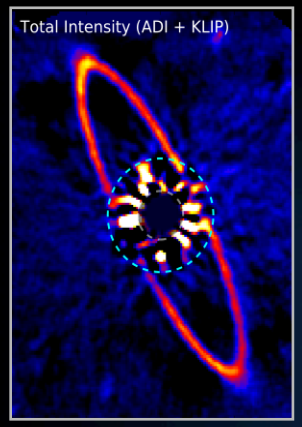
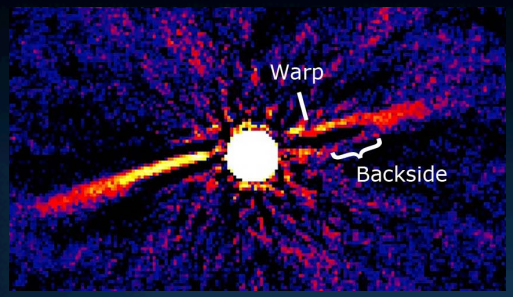
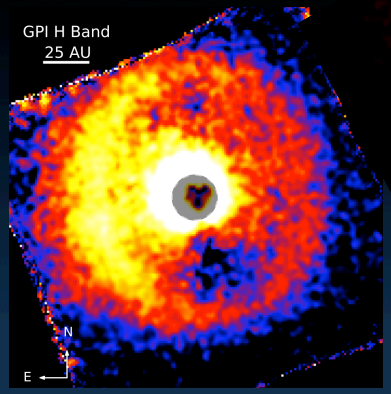
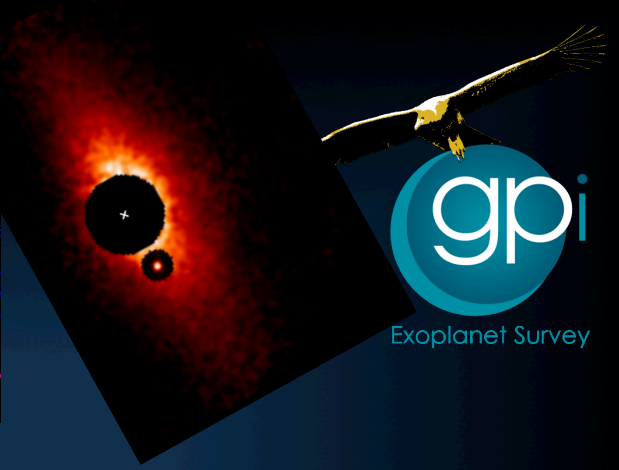




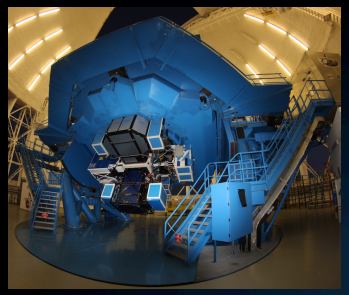




Revealing the structure and dust content of debris disks on solar system scales with GPI

Gaspard Duchêne (UC Berkeley)

Mike Fitzgerald, Paul Kalas, James Graham, ***Pauline Arriaga***, ***Sebastian Bruzzone***, Christine Chen, Bekki Dawson, Robin Dong, ***Zack Draper***, Tom Esposito, Kate Follette, ***Li-Wei Hung***, ***Samantha Lawler***, ***Max Millar-Blanchaer***, Ruth Murray-Clay, Marshall Perrin, Julien Rameau, ***Jason Wang***, ***Schuyler Wolff***, Bruce Macintosh, and the GPIES Team (PI Macintosh)



GPIES: GPI Exoplanet Survey

- 890h campaign for a direct imaging planet survey (2015 – 2017) *[see B. Macintosh's talk – 321.04]*
  - 600 young nearby stars
  - PI: Bruce Macintosh (Stanford)
  - Project Scientist: James Graham (UC Berkeley)
- Subset of 57 targets for debris disk characterization
  - Selected as previously resolved and/or large IR excess
  - GPI *H*-band "spectroscopy" + "polarimetry" modes
  - Group Lead: Mike Fitzgerald (UCLA) & Paul Kalas (UC Berkeley)

Exoplanet Survey

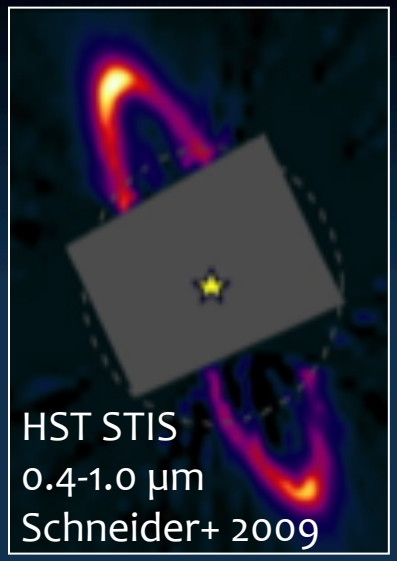
Key Science Goals

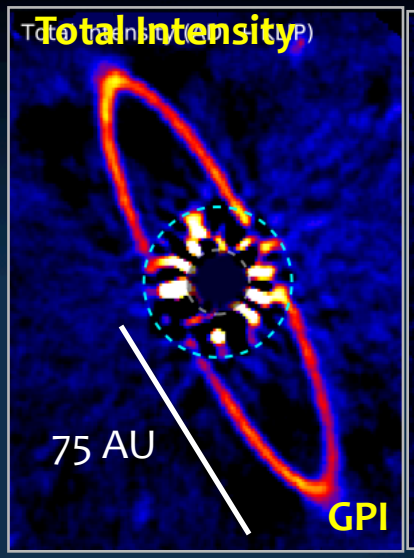
- Image disks much closer to their parent star
  - Inner working angle several times smaller than previous studies (HST, ground-based "regular" AO)
- Precisely assess the disk morphology
  - Substructures, offset from central star, …
  - Search for evidence of dynamical interaction with planet
- Characterize the dust content of disks (total mass, composition, grain size, …)
  - Scattering phase function
  - Polarization fraction

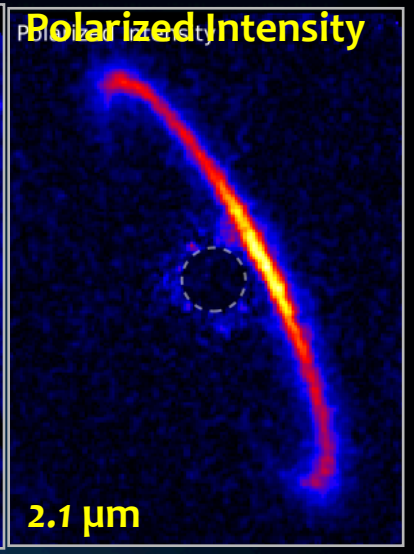
HR 4796A

A0V, 73 pc, 8±2 Myr

Perrin+ 2015







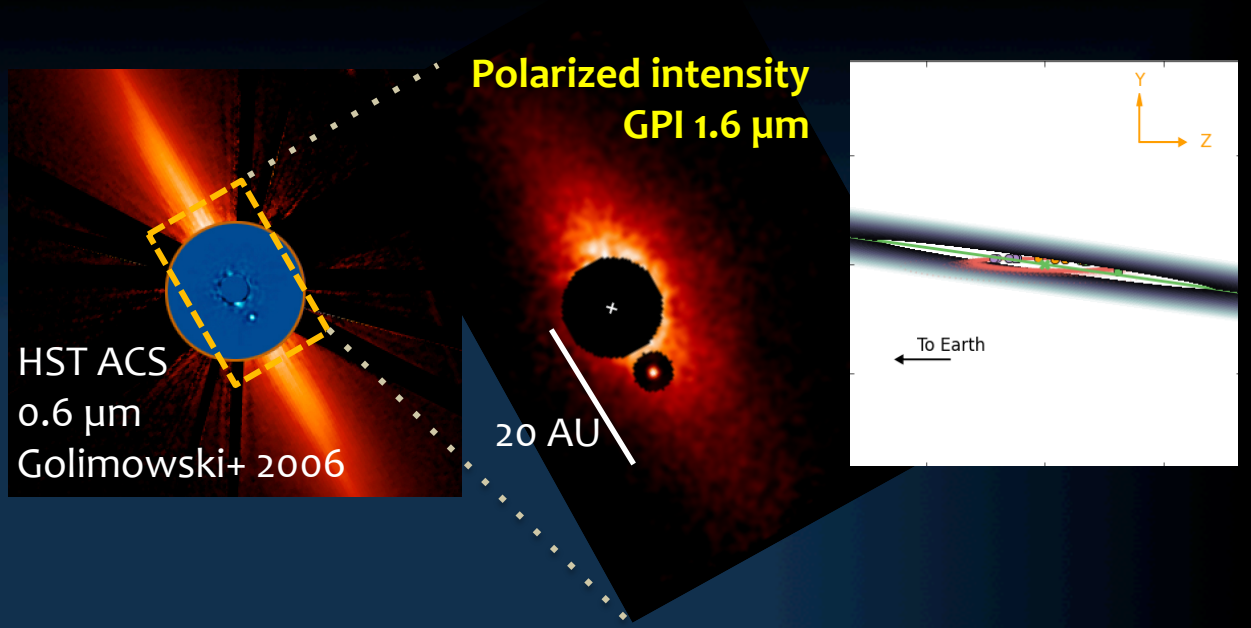
- Much more complete view of the ring than previous images
  - Very smooth azimuthally
  - Ring center is slightly offset from the star (corresponding to e = 0.02)
- Extreme asymmetry in polarized intensity revealed for the first time
  - West side is out of the plane of the sky
  - Dust grains scatter in the Fresnel regime ($a_{min} \geq 5$ μm)
  - Ring may be moderately optically thick

Exoplanet Survey

β Pic

A5V, 19 pc, 23 Myr

Millar-Blanchaer+ 2015



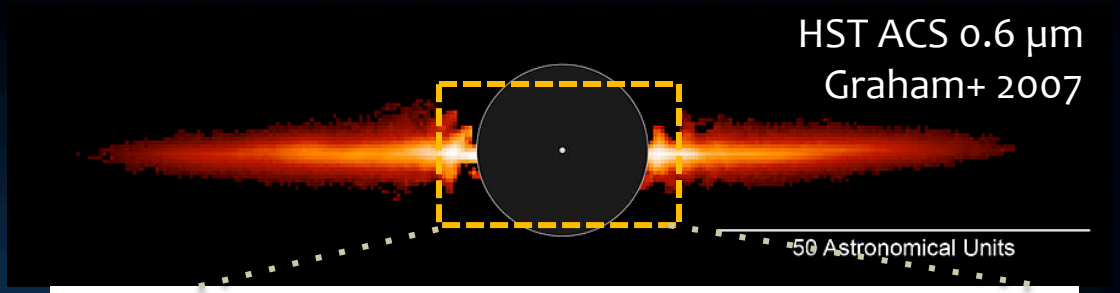
- GPI reveals disk structure as close as 0.3” from star
  - Inner radius of 24 AU, or ≈ 2.5 times planet’s semi-major axis
  - Significant vertical height (*H/r* ≈ 0.14)
  - Strong forward scattering *in polarized intensity* dust (large grains?)
- The planet’s orbit and the inner disk are misaligned by ≈ 4˚
  - Astrophysical effect (same instrument!)
- Is a second planet sculpting and warping the disk?

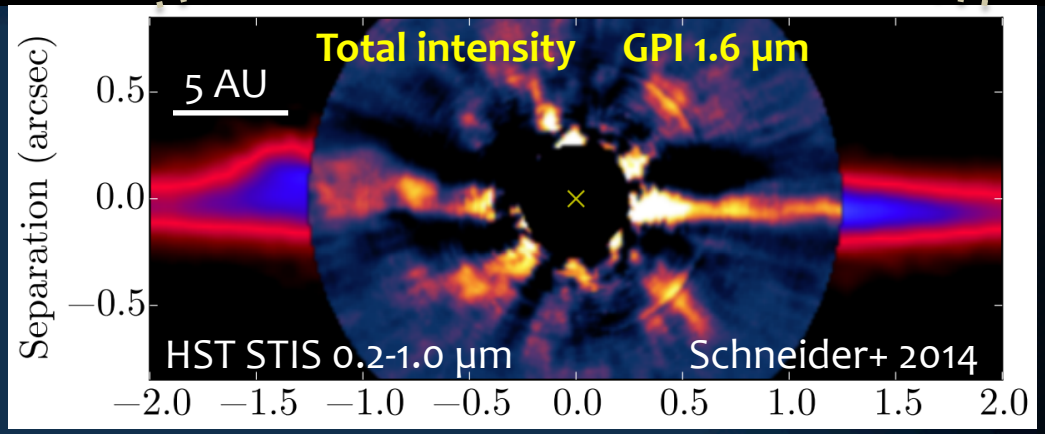
gpi Exoplanet Survey

AU Mic

M1Ve, 9.9 pc, 23 Myr

Wang+ 2015





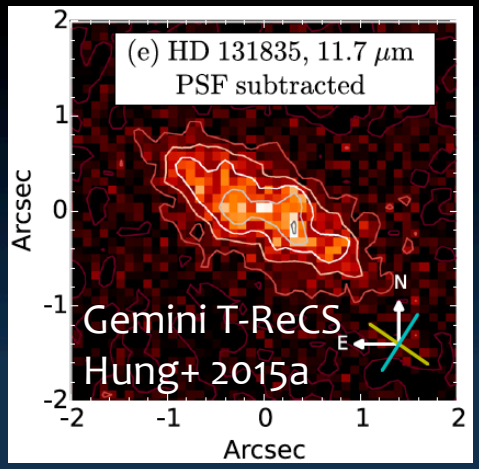
- GPI image reveals marked asymmetry between two sides
  - Also seen in ALMA data, HST and VLT/SPHERE (Boccaletti+ 2015)
  - Back side? Disk warp? Fast moving (high-eccentricity) particles?
- Undetected in polarized intensity (despite deep integration)
  - Disk too faint in the first place?
  - Low polarization fraction (small grains)?

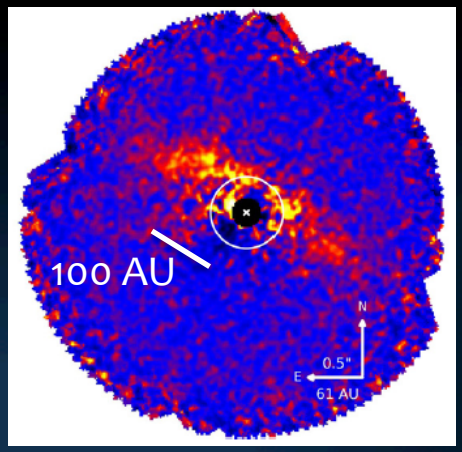
Exoplanet Survey

HD 131835

A2IV, 120 pc, 15 Myr

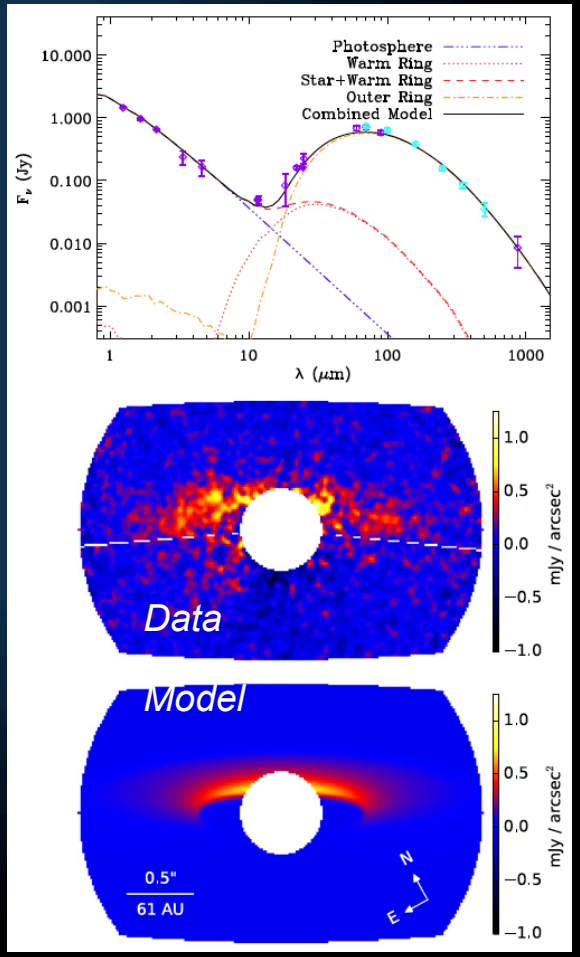
Hung+ 2015b





Polarized Intensity GPI 1.6 μm

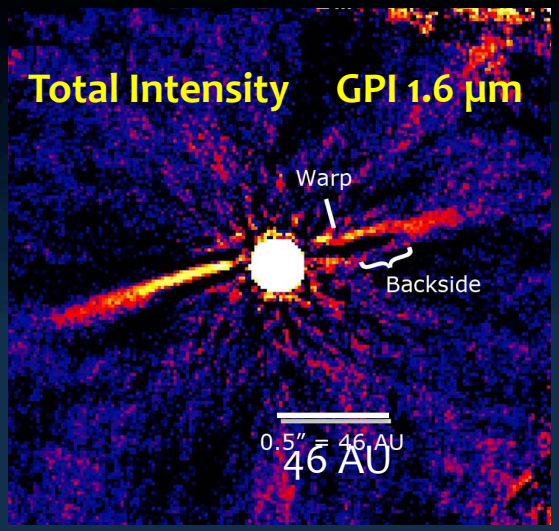
- A rare CO-rich disk (Moór+ 2015)
- First scattered light detection of the disk
  - Broad parent body belt (≈ 75 − 210 AU)
  - Nearly flat surface density profile ($\Sigma(r) \approx r^{-0.3}$)
  - Possible lateral asymmetry (≈ 3σ)
- Radiative transfer modeling constrains dust properties
  - Medium-sized grains (a_{min} ≈ 1.5 μm)
  - 50/50 silicates/carbon mixture

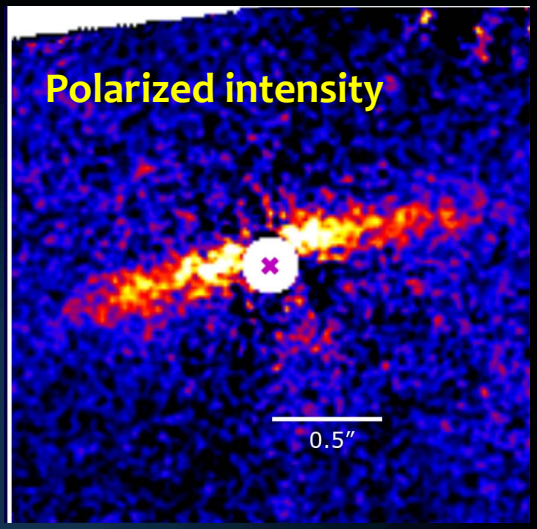


HD 106906

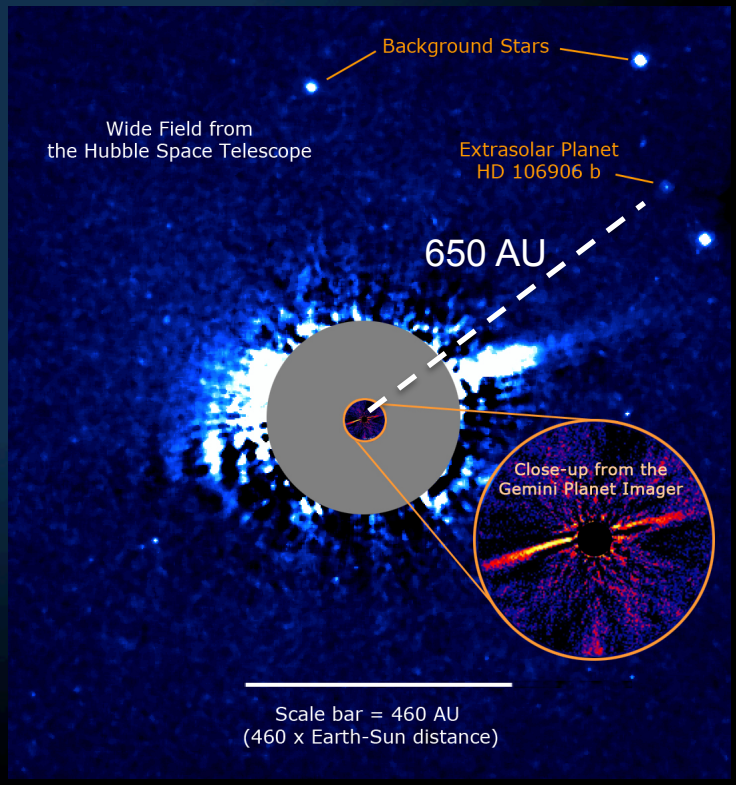
F5V, 92 pc, 13 Myr

Kalas+ 2015





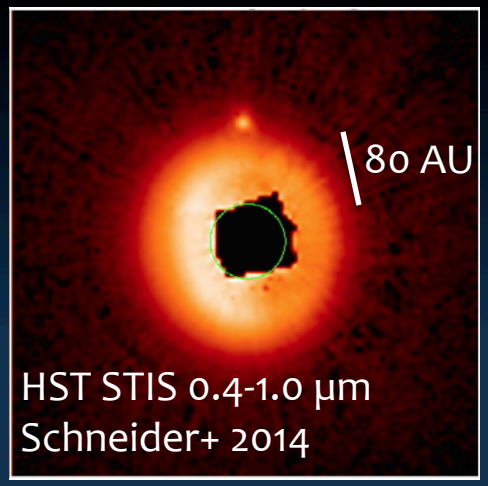
- GPI imaging resolves the disk for the first time
  - Nearly edge-on ring, possibly warped
  - Significant asymmetry between sides
- HST image reveals complex outer disk structure
  - Highly asymmetric (“fan” + “needle”)
- The planet is misaligned with the disk by ≈ 23°
  - Recent upheaval? (Jilkova+ 2015)
- Planet may host circumstellar material

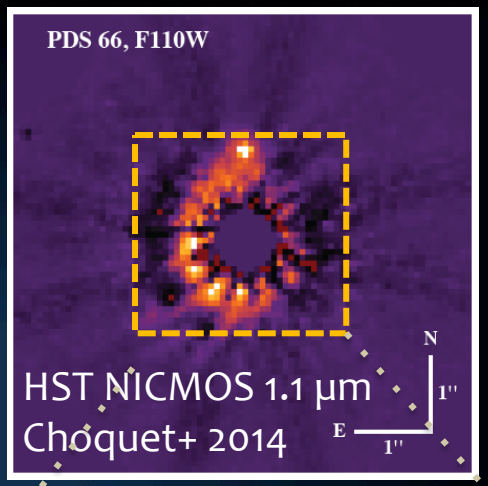


PDS 66 (MP Mus)

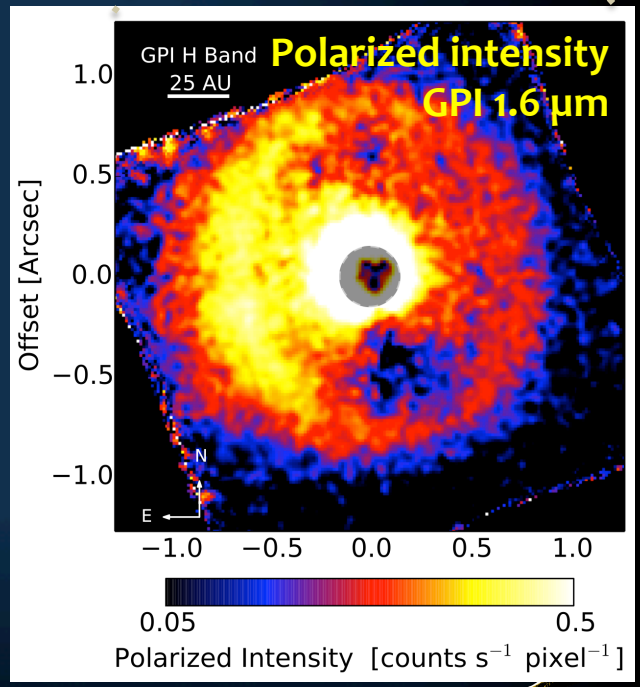
K1V, 101 pc, 5-7 Myr

Wolff+ 2016 (in prep.)





- A nearly face-on, evolved protoplanetary disk with a prominent 80 AU ring imaged with HST
- GPI imaging detects the region interior of the ring for the first time all the way down to ≈ 20 AU
  - Confirms the pre-transition disk categorization
- Small/negligible offset between ring and star
  - Small surface height ➔ dust settling?
- Deficit at Southern azimuths
  - Shadowing due to structure in inner disk?



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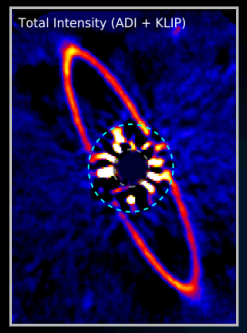
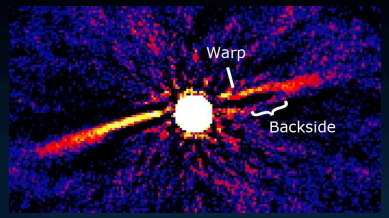
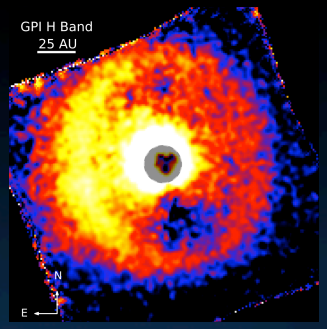
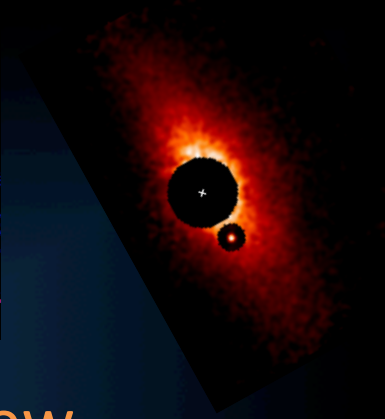




Summary





- GPI's high contrast and resolution enables new breakthroughs in imaging circumstellar disks
  - 10 papers published since the instrument came online
- Its polarization mode offers a double advantage
  - Naturally suppresses (unpolarized) starlight
  - Provides unprecedented insights on dust properties
- The GPIES survey has been very successful in Year 1
  - Stay tuned for Year 2 & 3, as well as for a multi-wavelength follow-up LLP program (PI: C. Chen, 87h, 2015B-2018A)!

Exoplanet Survey