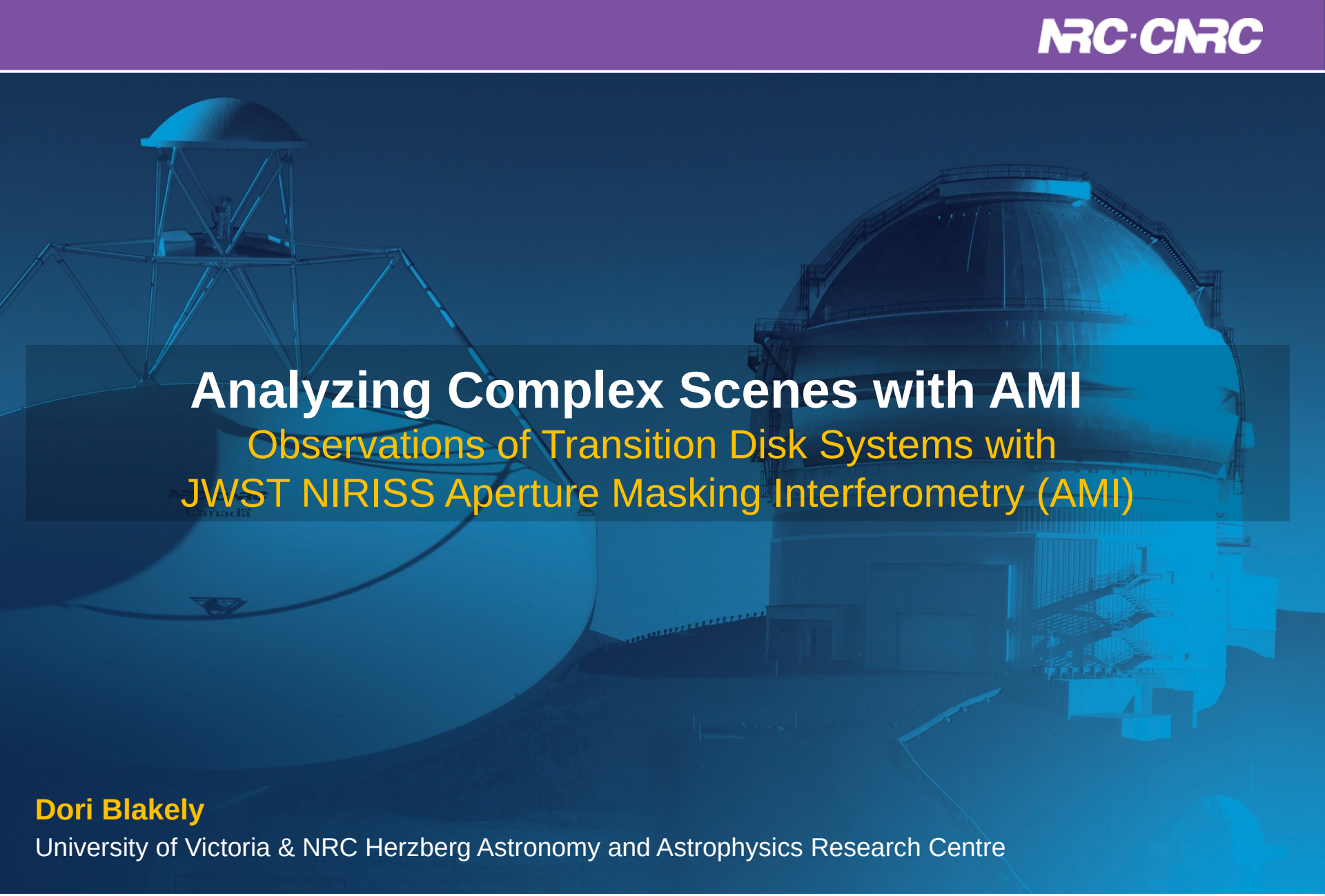


Analyzing Complex Scenes with AMI

Observations of Transition Disk Systems with JWST NIRISS Aperture Masking Interferometry (AMI)

Dori Blakely
University of Victoria & NRC Herzberg Astronomy and Astrophysics Research Centre

National Research Council Canada | Conseil national de recherches Canada
Canada

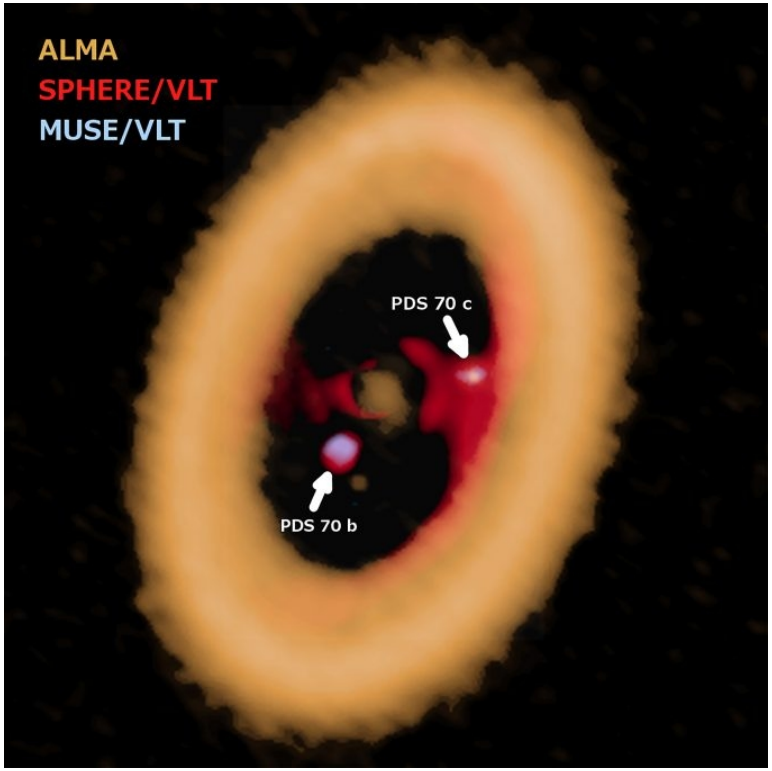
Target – PDS70

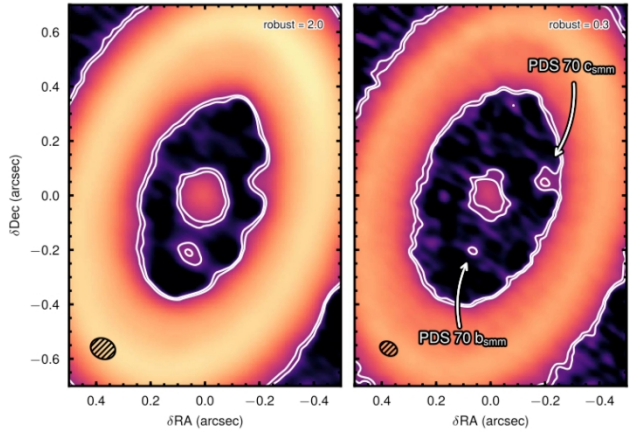
Detection of Continuum Submillimeter Emission Associated with Candidate Protoplanets

Andrea Isella[1], Myriam Benisty[2,3,4], Richard Teague[5], Jaehan Bae[6], Miriam Keppler[7], Stefano Facchini[8], and Laura Pérez[2]

Two accreting proto-planets around the young star PDS 70

S. Y. Haffert[1], A. J. Bohn[1], J. de Boer[1], I. A. G. Snellen[1], J. Brinchmann[1,2], J. H. Girard[3,4], C. U. Keller[1], F Bacon[5]*



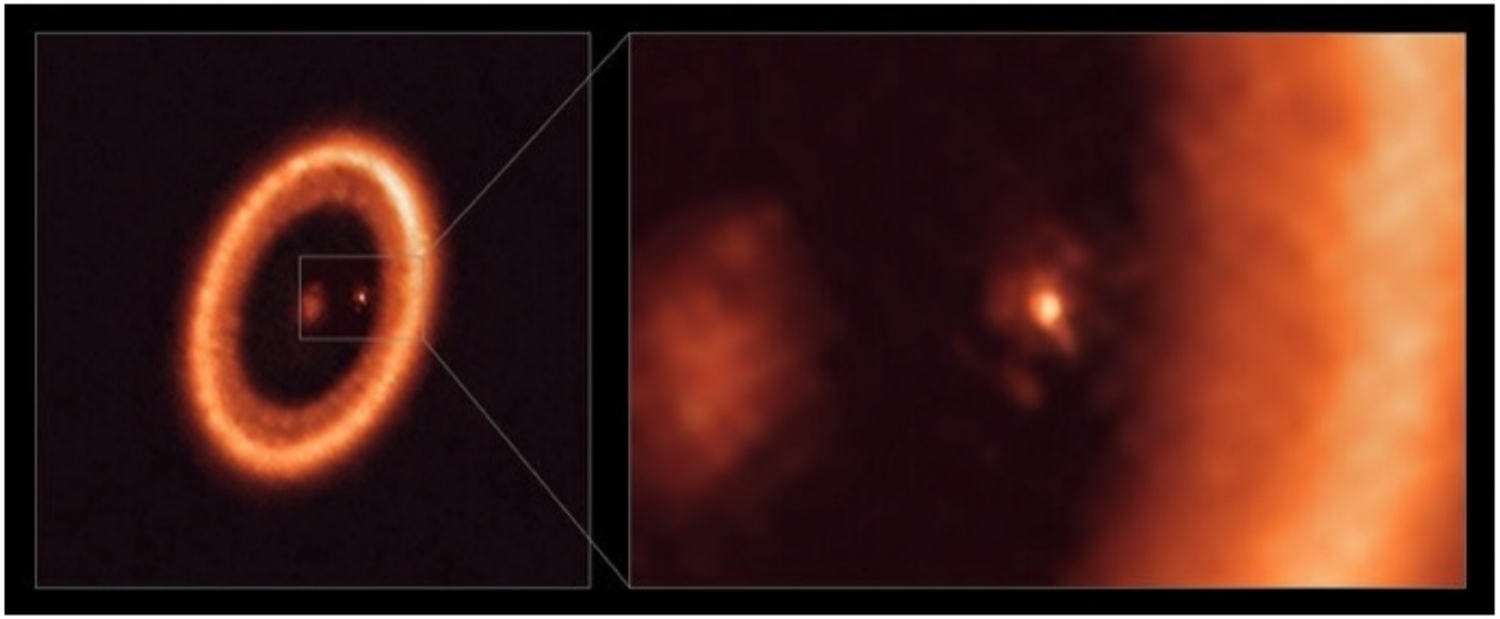


- T Tauri star, 113 pc, 5.4 Myrs old
- 20-40 au inner hole (0.2-0.4”)
  - Larger in sub-mm (dust segregation)
  - Inner sub-mm disk ~10au (0.1”)
- Disk looks like donut
- Well observed candidate planets
  - b ~ 22 au (0.195”) has Halpha !!
  - c ~ 30 au (0.24”) seen in Halpha!

Planets In Formation – PDS 70 Planet(s) in the Disk

Astronomers make first clear detection of a moon-forming disc around an exoplanet

22 July 2021



Using the Atacama Large Millimetre/submillimeter Array (ALMA), in which the European Southern Observatory (ESO) is a partner, astronomers have unambiguously detected the presence of a disc around a planet outside our Solar System for the first time. The observations will shed new light on how moons and planets form in young stellar systems.

Target – HD 100546

SPHERE/ZIMPOL

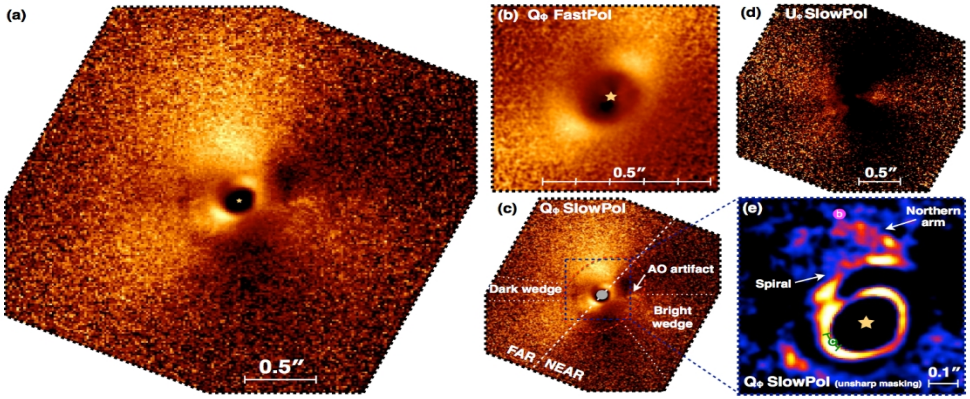
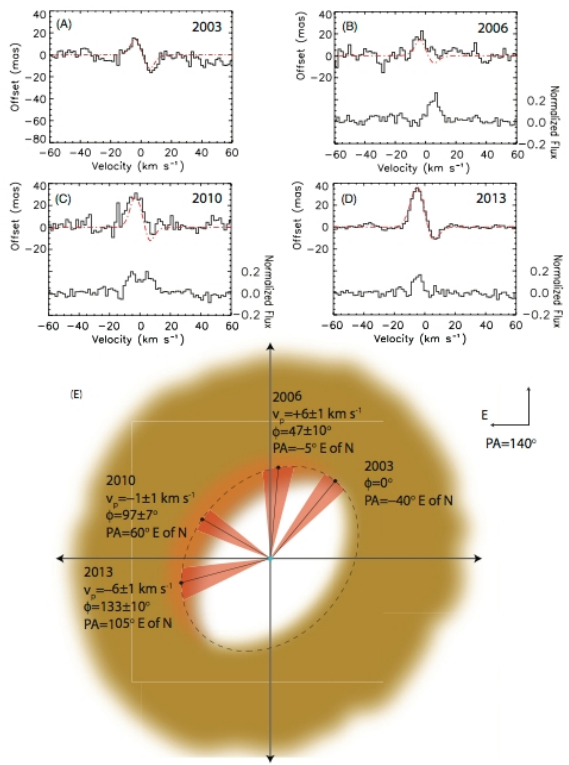


Fig. 1. SPHERE/ZIMPOL polarized light imagery of HD100546. **(a)**: Q_ϕ images in coronagraphic SlowPol mode. **(b)**: Q_ϕ images in FastPol mode. **(c)**: same as (a) with labels, where the white dashed line indicates the disk major axis and the inner grey spot the coronagraph size. **(d)**: U_ϕ images in SlowPol mode, with color stretch twice as hard as in (a). **(e)**: Unsharp masking of the Q_ϕ image (see Sect. 3.1.3). The predicted locations of *b* (Quanz et al. 2015) and of *c* in May 2015 with relative azimuthal uncertainty (Brittain S., private comm.) are shown in purple and green. All images except (e) are scaled by the squared distance from the star and are shown with linear stretch. North is up, East is left.

NIR SPECTROSCOPY OF THE HAeBe STAR HD 100546. III. FURTHER EVIDENCE OF AN ORBITING COMPANION?

Sean D. Brittain[1], John S. Carr[2], Joan R. Najita[3,4], Sascha P. Quanz[5], and Michael R. Meyer[5]



- B9Vne star, 97 pc
- 11 AU inner hole (0.1”)
- Disk shows spiral structure
- Well observed candidate planet at 50 au
- Indirect evidence for inner planet ~15 au

Target– HD 135344B

Shadows cast on the transition disk of HD 135344B ⋆

Multiwavelength VLT/SPHERE polarimetric differential imaging

T. Stolker[1], C. Dominik[1], H. Avenhaus[2,21], M. Min[3,1], J. de Boer[4,5], C. Ginski[4], H. M. Schmid[6], A. Juhasz[7], A. Bazzon[6], L. B. F. M. Waters[3,1], A. Garufi[6], J.-C. Augereau[8,9], M. Benisty[8,9], A. Boccaletti[10], Th. Henning[11], M. Langlois[13,14], A.-L. Maire[11], F. Ménard[12,2], M. R. Meyer[6], C. Pinte[12,2], S. P. Quanz[6], C. Thalmann[6], J.-L. Beuzit[8,9], M. Carbillet[15], A. Costille[14], K. Dohlen[14], M. Feldt[11], D. Gisler[6], D. Mouillet[8,9], A. Pavlov[11], D. Perret[10], C. Petit[16], J. Pragt[17], S. Rochat[8,9], R. Roelfsema[17], B. Salasnich[18], C. Soenke[19], and F. Wildi[20]

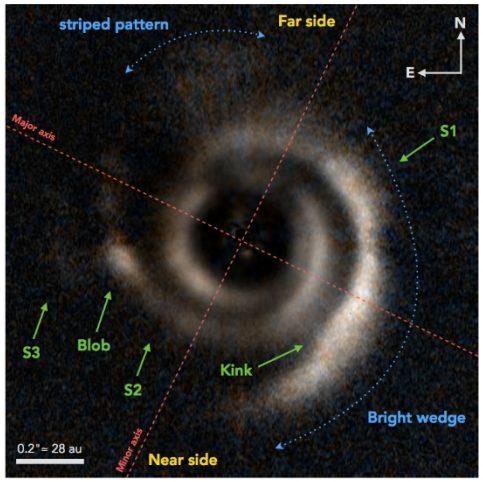


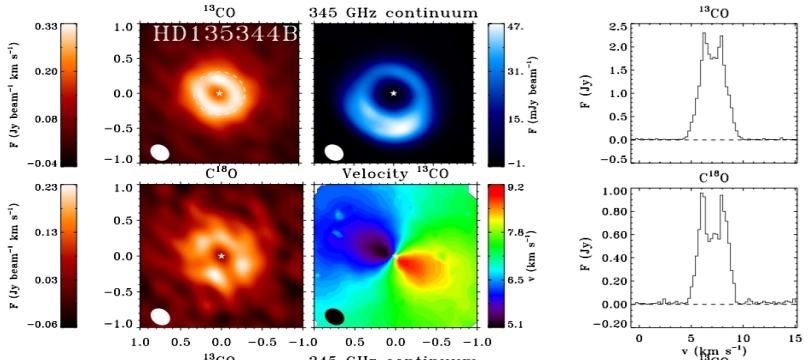
Fig. 4. Color composite RGB image of ZIMPOL *R*-band (blue), ZIMPOL *I*-band (red), and the average of *R*- and *I*-band (green). The field of view is 1.″4 × 1.″4 and the main features that have been identified are labeled.

- F4V star, ~140 pc
- 25 au inner hole (0.2”)
- Modest accretion onto central star
- Disk shows spiral structure and cavity
- Multiple shadows seen in outer disk
- Sub-mm hole observed by SMA & ALMA

Resolved gas cavities in transitional disks inferred from CO isotopologs with ALMA

N. van der Marel[1], E. F. van Dishoeck[1,2], S. Bruderer[2], S. M. Andrews[3], K. M. Pontoppidan[4], G. J. Herczeg[5], T. van Kempen[1], and A. Miotello[1]

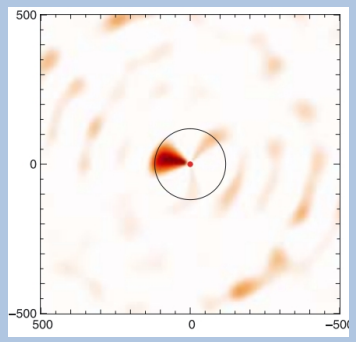
A&A 585, A58 (2016)



NRC·CNRC

Problem:
Differentiating extended disk and point-like planet

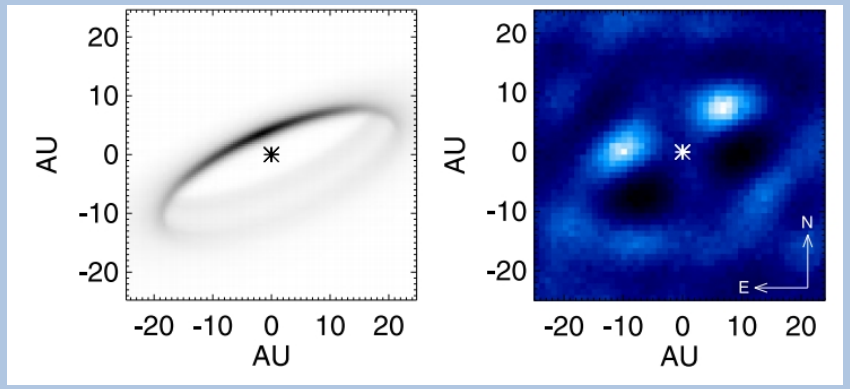
This?



Huelamo+ 2011

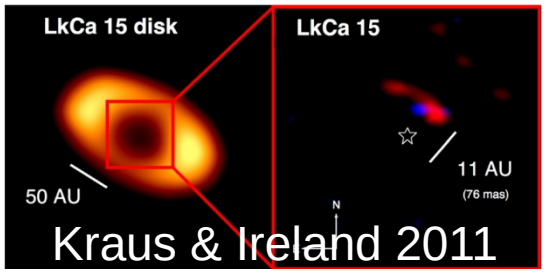
Binary
(point source
companion)

Or this?

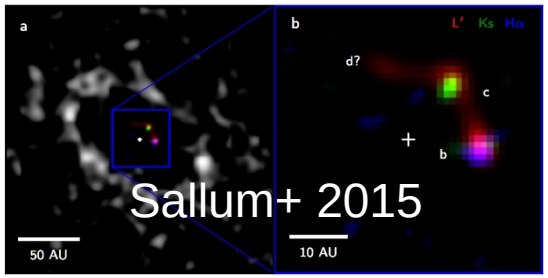


Olofsson+ 2012, Cheetham+ 2015

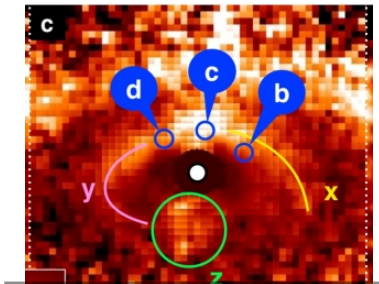
LkCa 15



Kraus & Ireland 2011



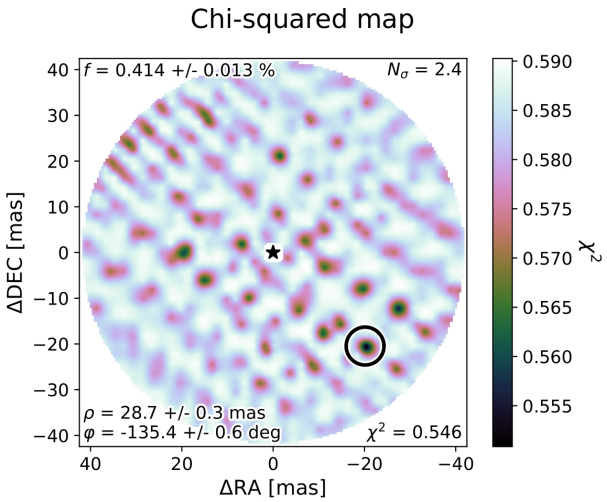
Sallum+ 2015



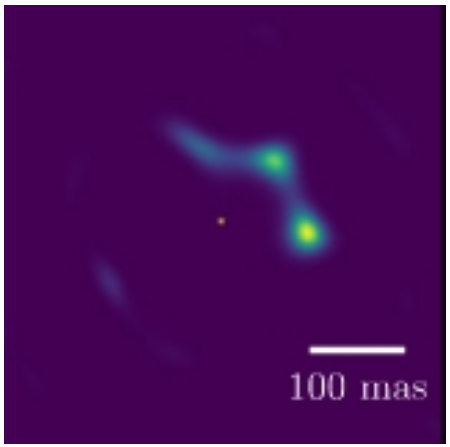
Thalmann+2016

How can we separate planets from inner disk emission in these observations using AMI?

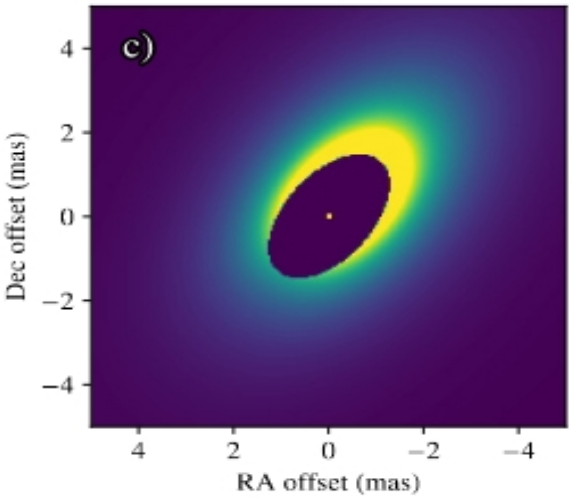
- Binary fitting methods.
- Image reconstruction.
- **Model disk + binary fitting methods.**



Fouriever binary chi-squared map (Kammerer+ 2020)

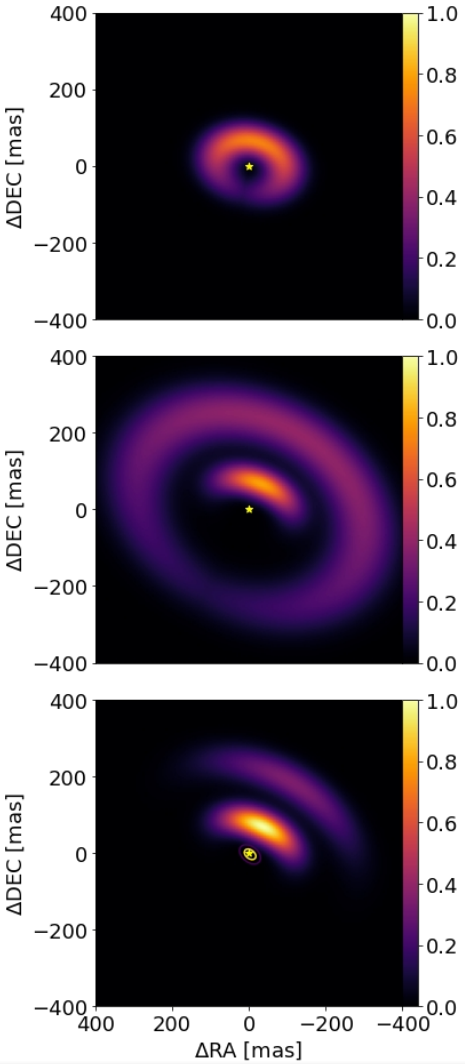


Reconstructed image of LkCa 15 from LBT SAM data (Sallum+ 2017)

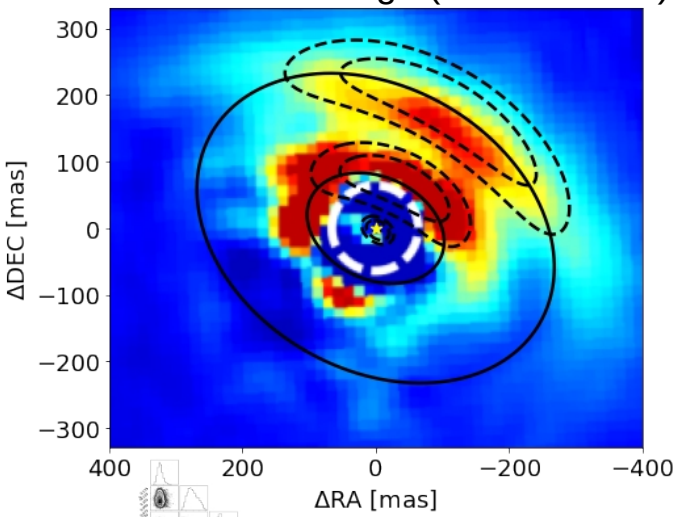


Geometrical model fit of HD 163296 from VLTI (Varga+ 2020)

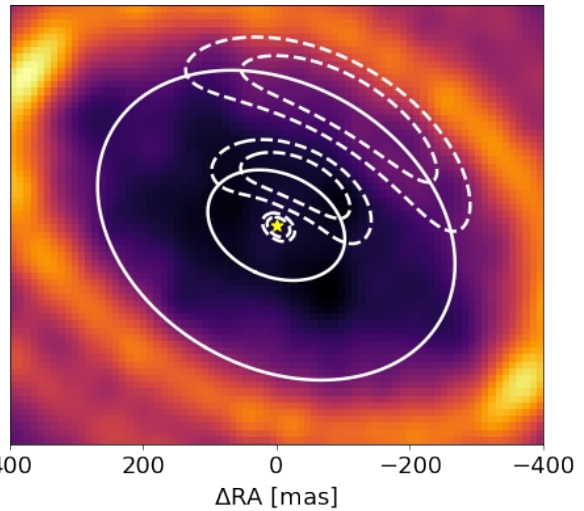
Model Fitting with Visibility Amplitudes and Closure Phases

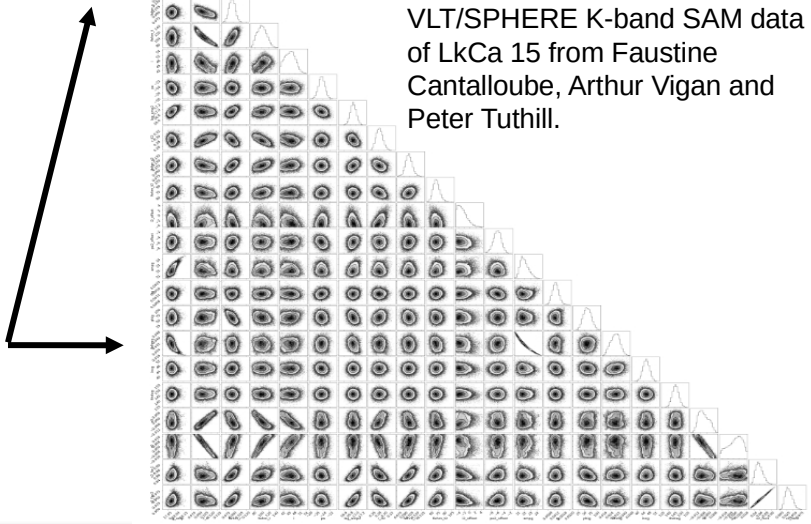


K-band direct image (Currie+ 2019)



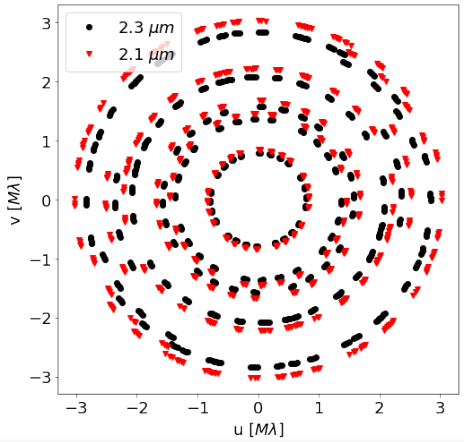
ALMA image (Facchini+ 2020)





VLT/SPHERE K-band SAM data of LkCa 15 from Faustine Cantalloube, Arthur Vigan and Peter Tuthill.

Spatial scales: ~30-300 mas

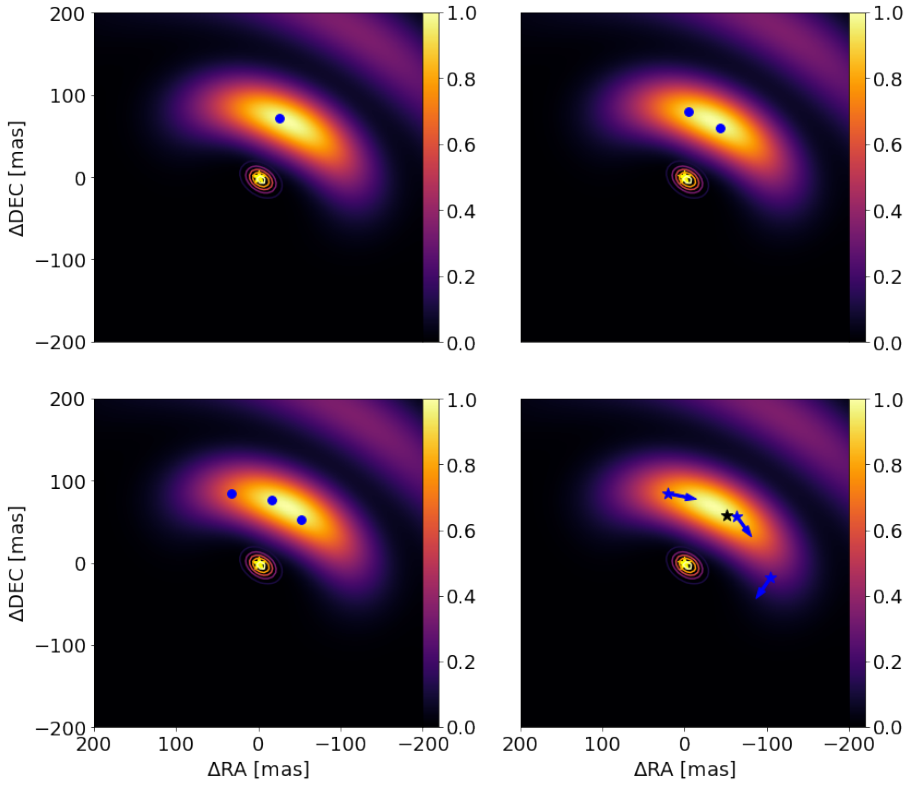


(Blakely+ 2022)

Searching for Point-Like Objects with and without Considering Extended Emission

WITHOUT

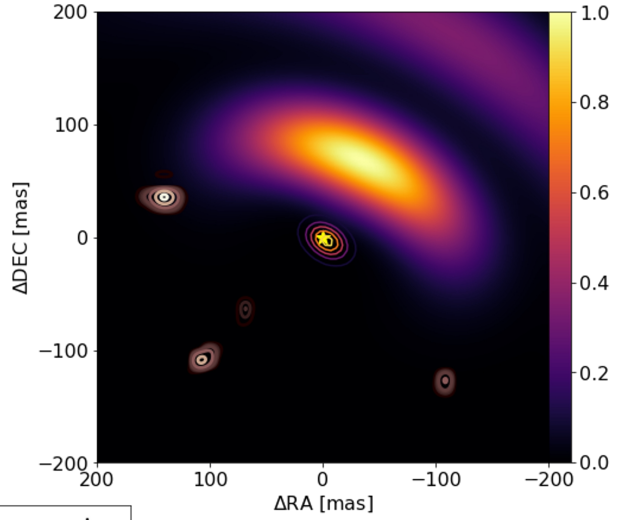
Found bright planets tracing inner disk.

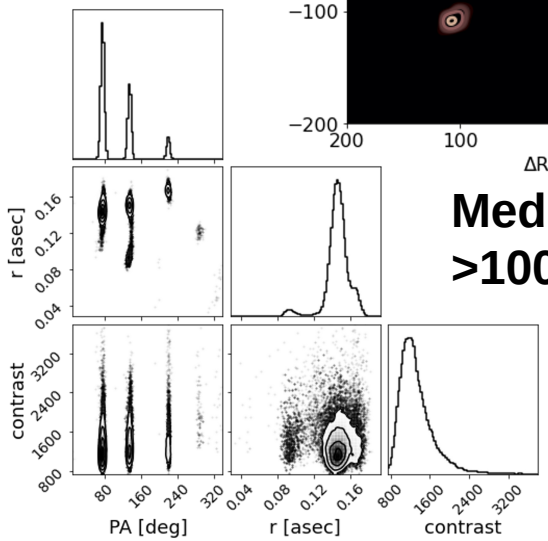


Contrasts of a few 100

WITH

Found faint candidate solutions away from peak disk emission.

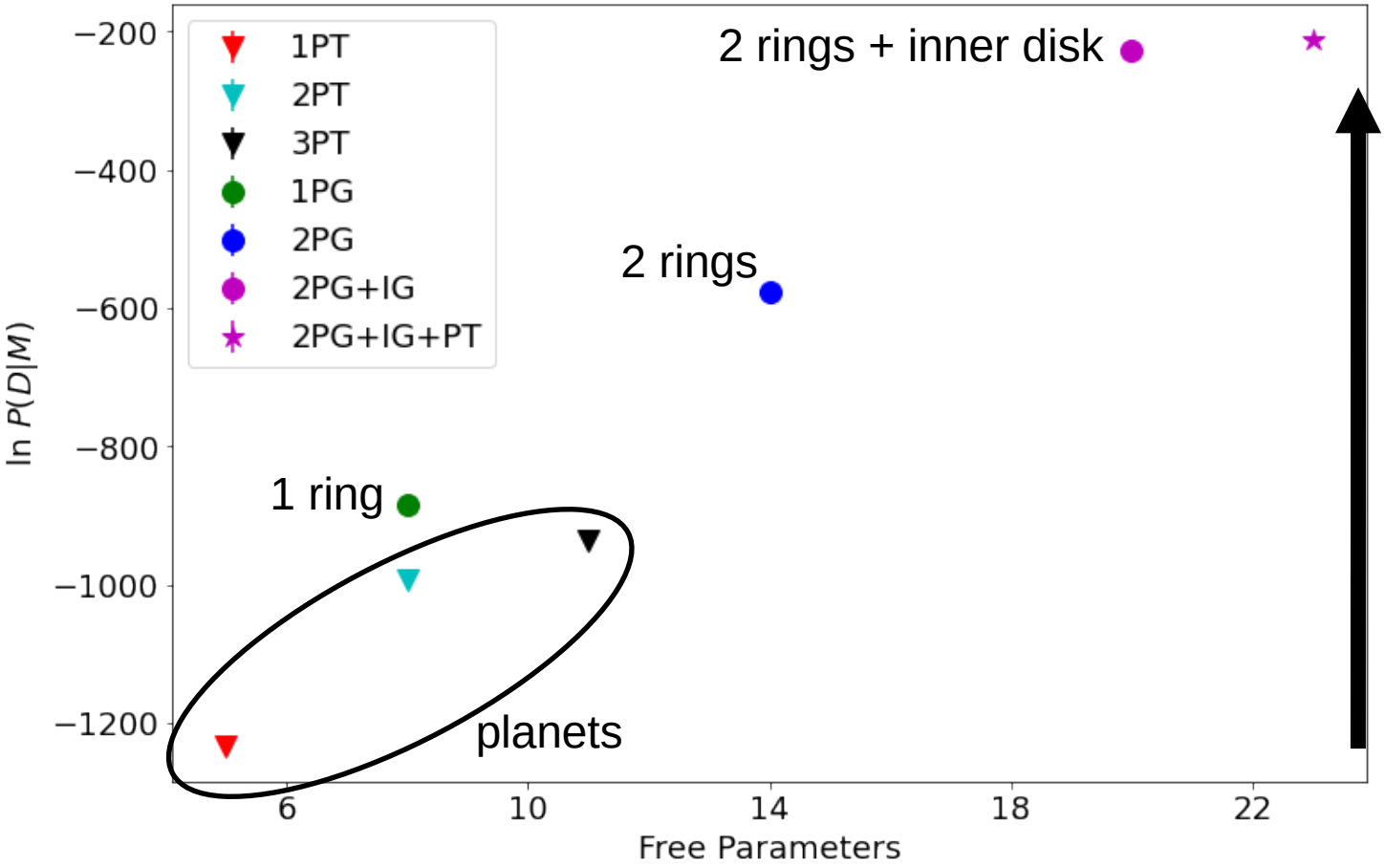




Median Contrast >1000

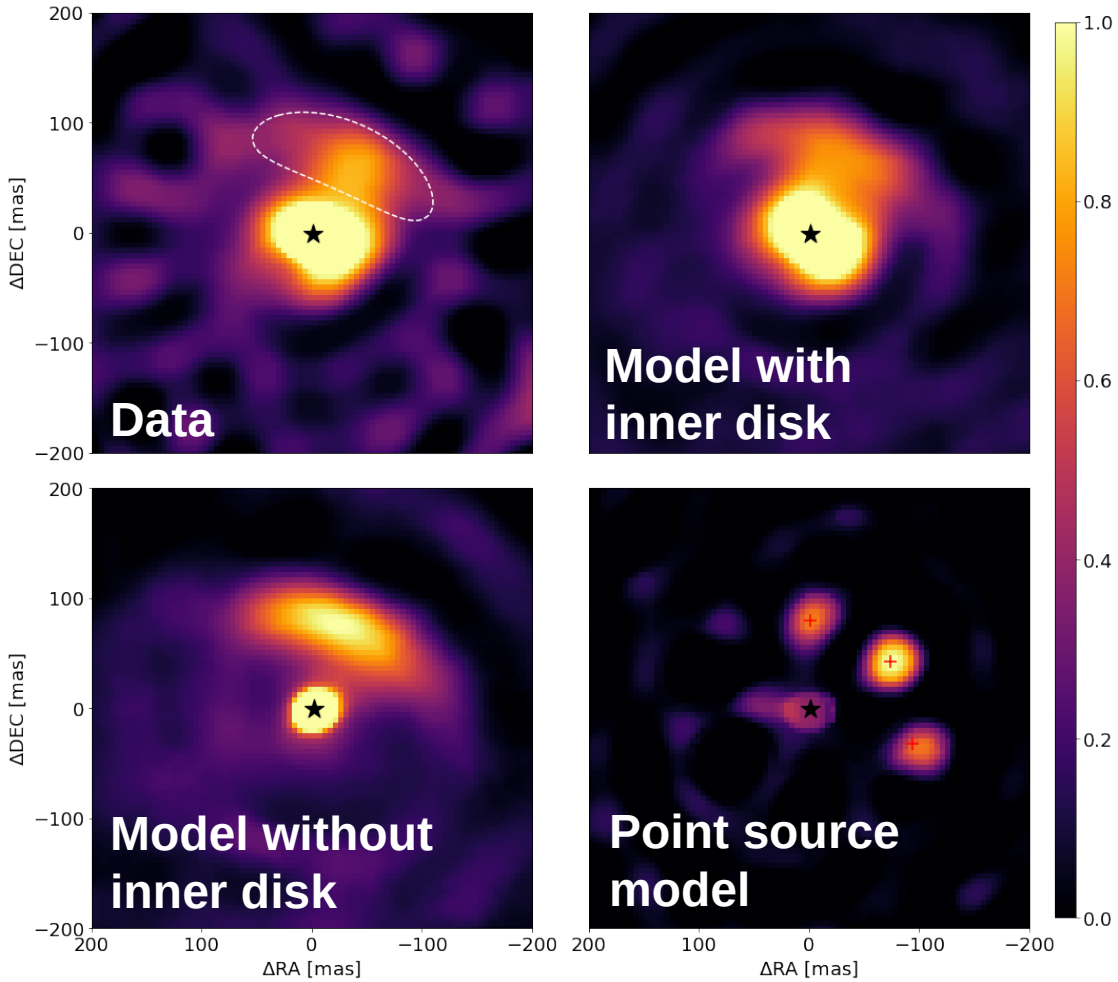
(Blakely+ 2022)

Model Comparison - Evidences



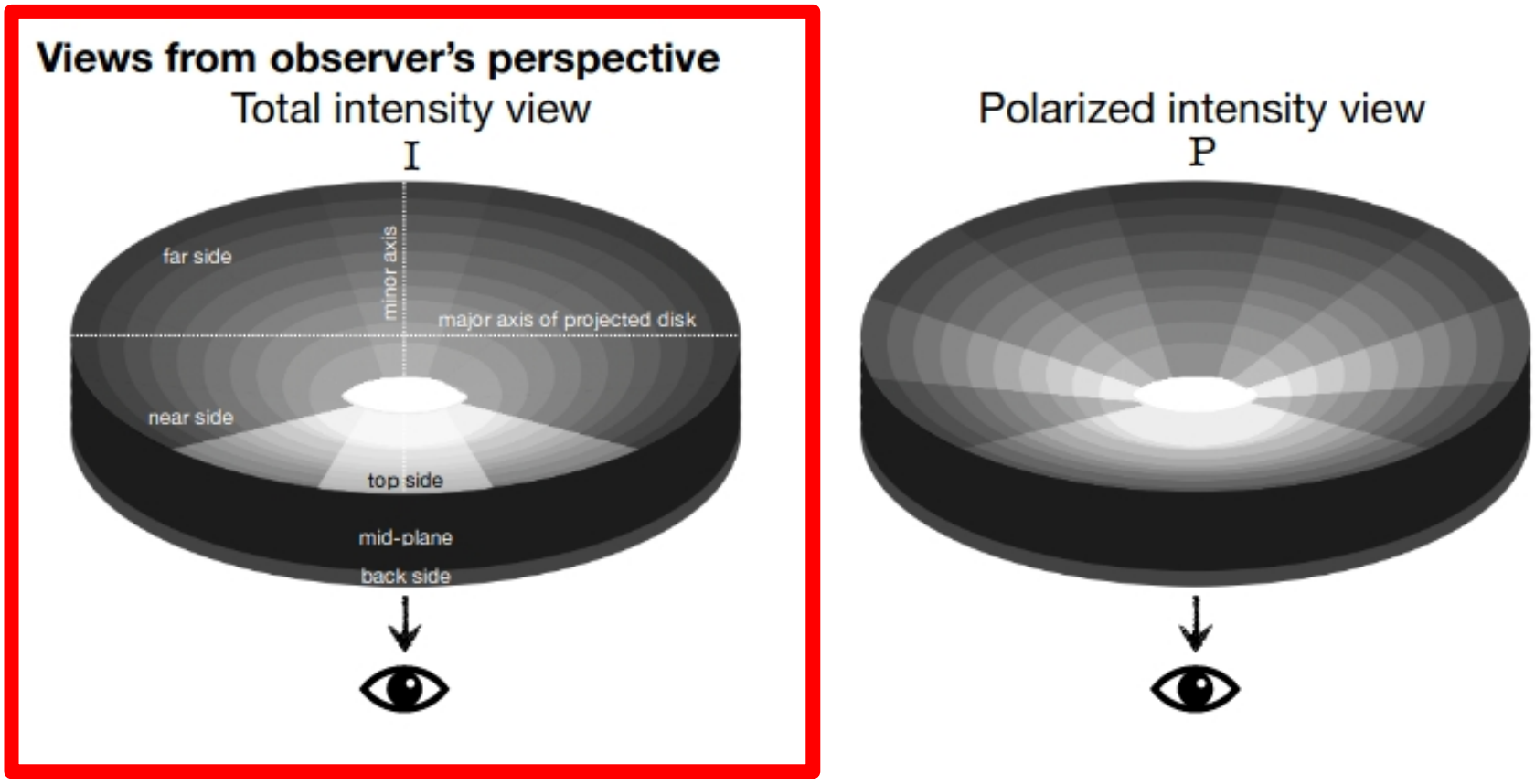
(Blakely+ 2022)

Image Reconstruction – LkCa 15



(Blakely+ 2022)

Components of a Geometrical Model for Transition Disks



Benisty+ 2022

Modeling of Systems with Ground-Based SAM Data + Simulated Observations of Radiative Transfer Models

VLT/SPHERE H-band SAM data

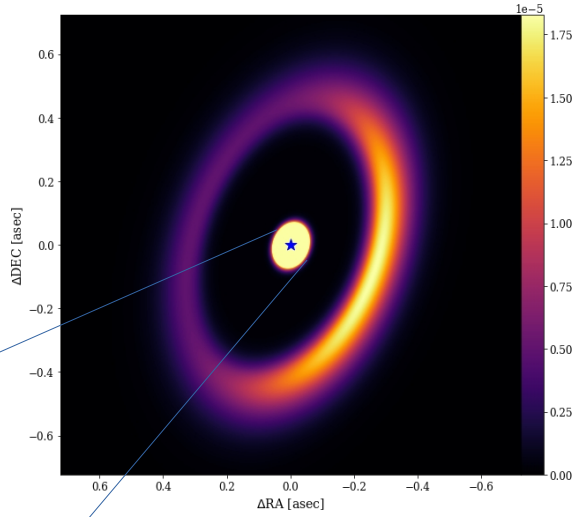
from Stolker et al. in prep. (PI Benisty)

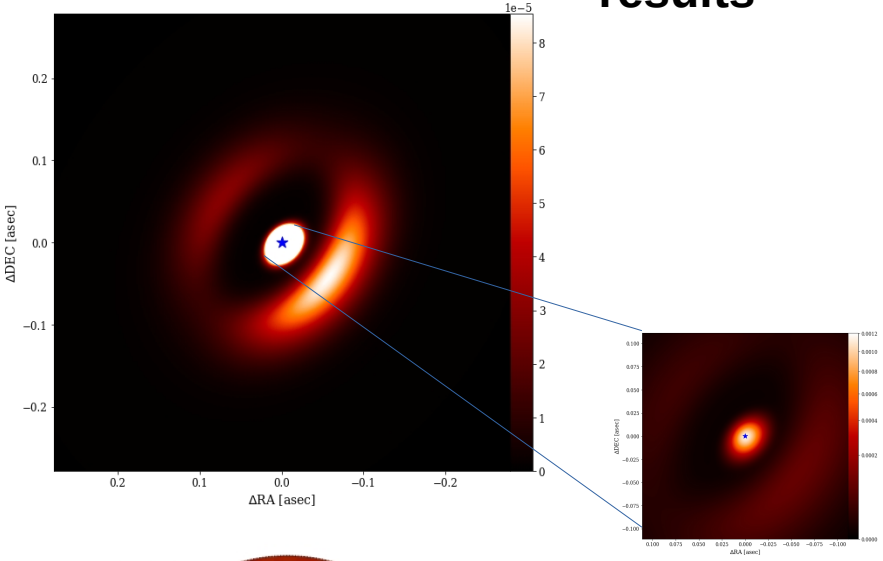
PDS 70

HD 100546

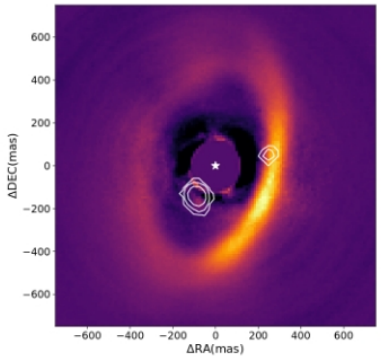
***preliminary results**

Model

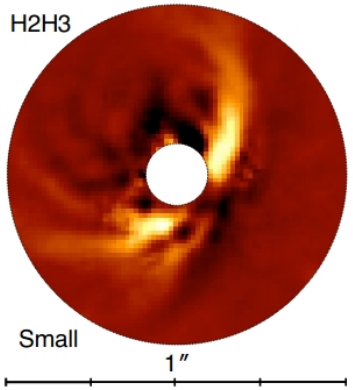




Direct Image



Haffert+ 2019



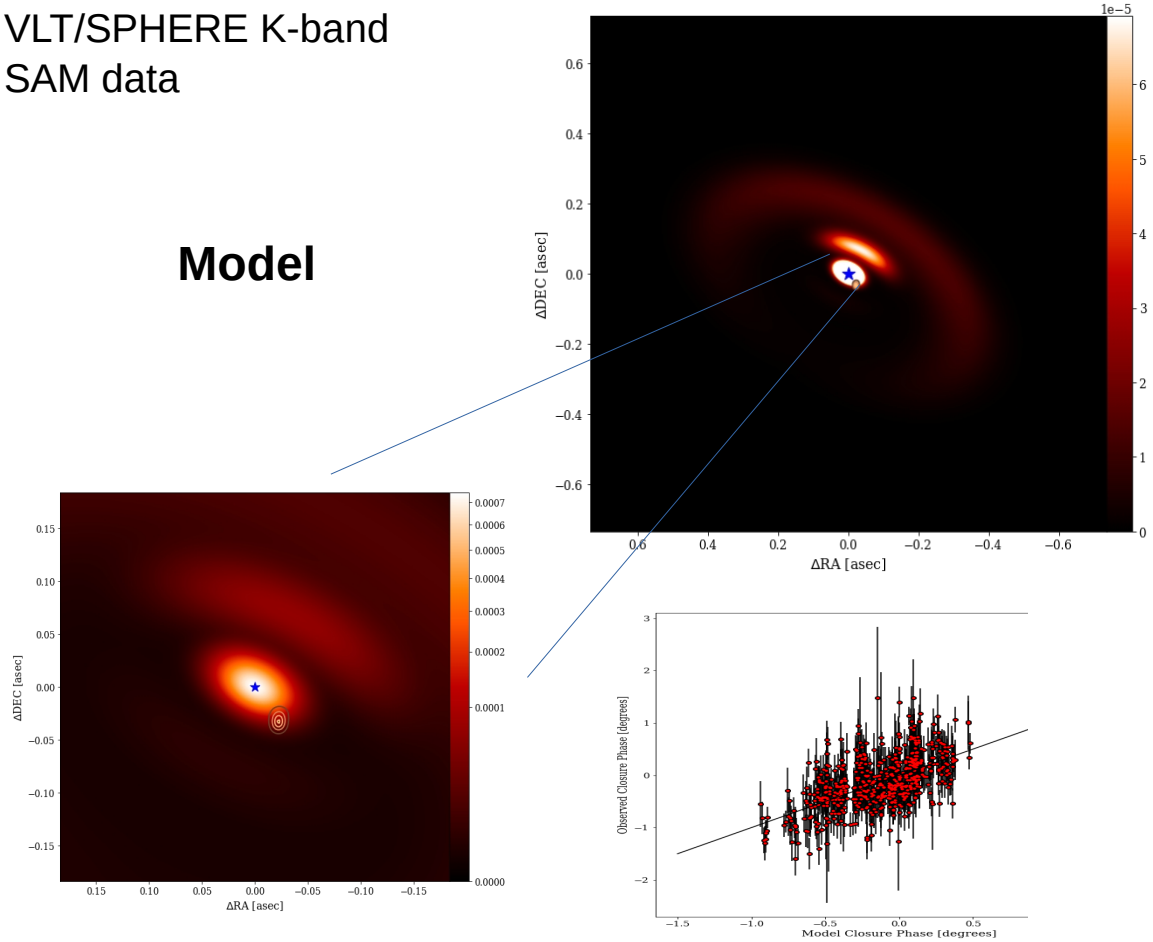
Garufi+ 2016

Modeling of Systems with Ground-Based SAM Data + Simulated Observations of Radiative Transfer Models

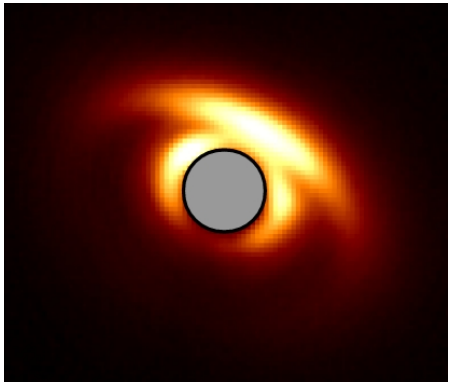
LkCa 15

VLT/SPHERE K-band
SAM data

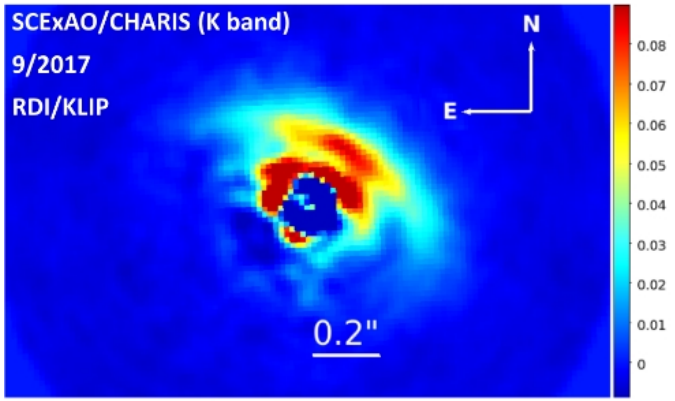
Model



Direct Images

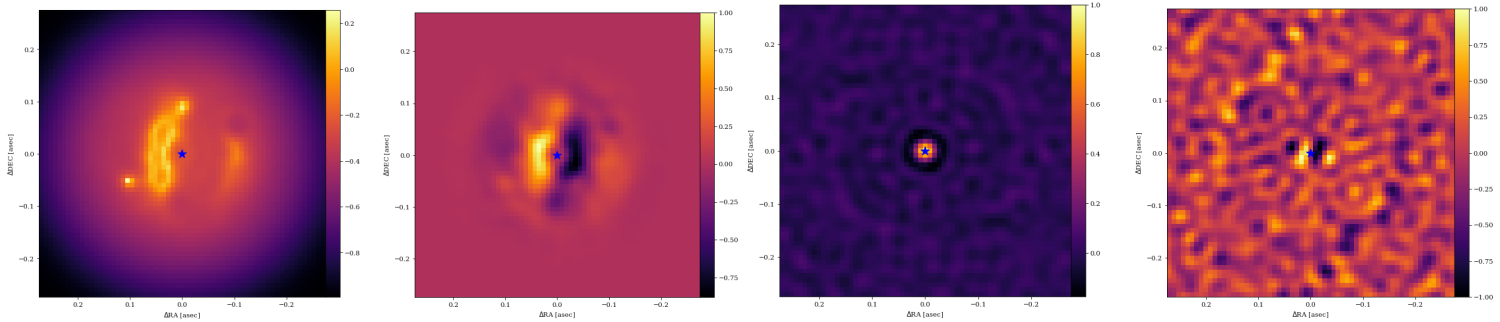


Benisty+ 2022



Currie+ 2019

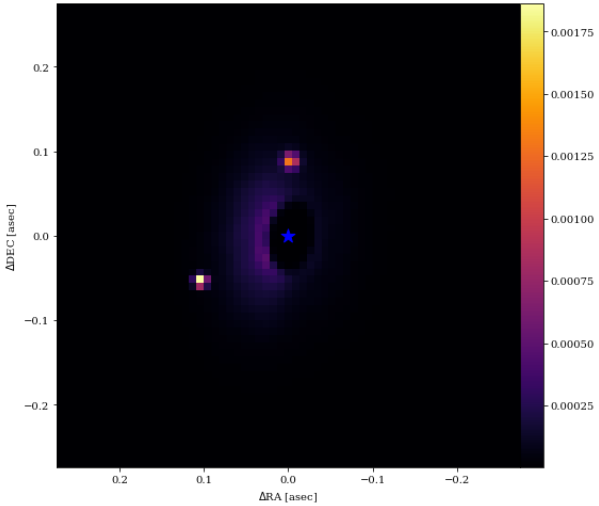
Beyond Geometrical Modeling: Denoising Diffusion Probabilistic Models for Constrained Image Reconstruction



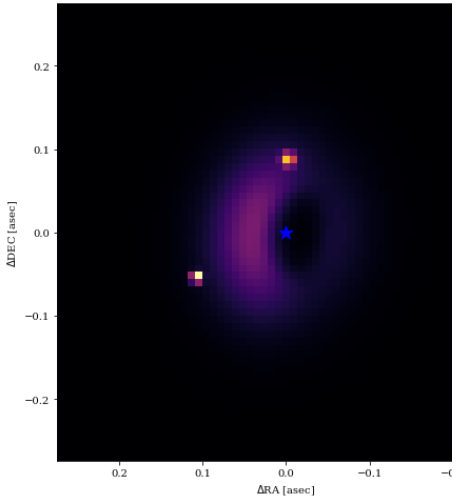
Inputs

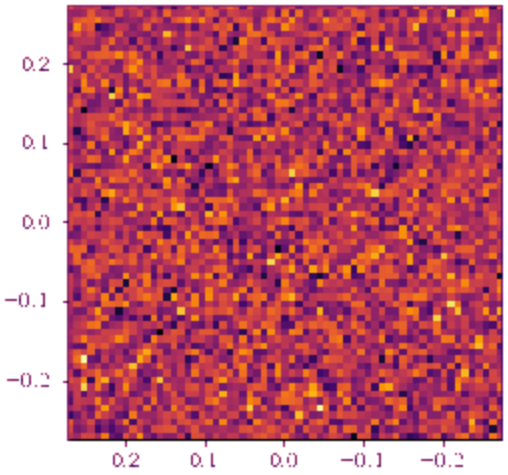
Simulated Data

Reconstruction



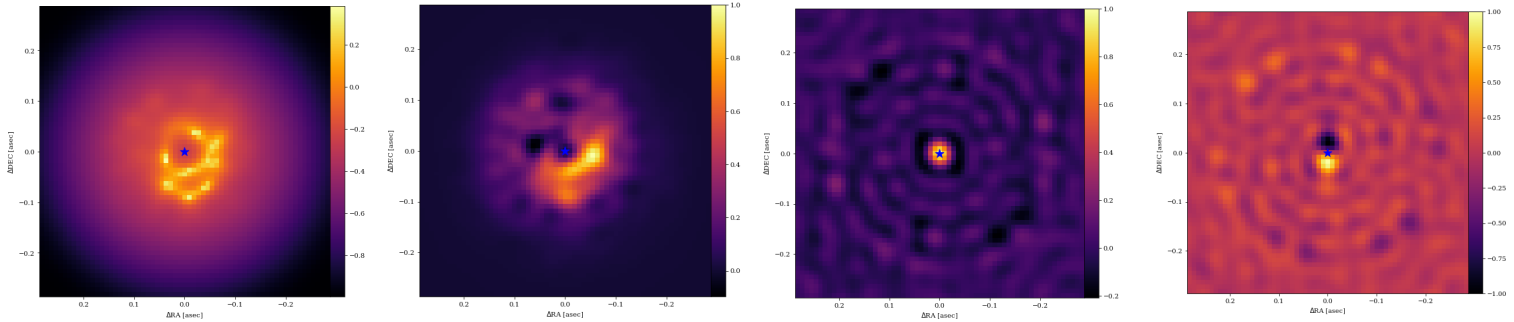
Ground Truth





***preliminary results**

Beyond Geometrical Modeling: Denoising Diffusion Probabilistic Models for Constrained Image Reconstruction

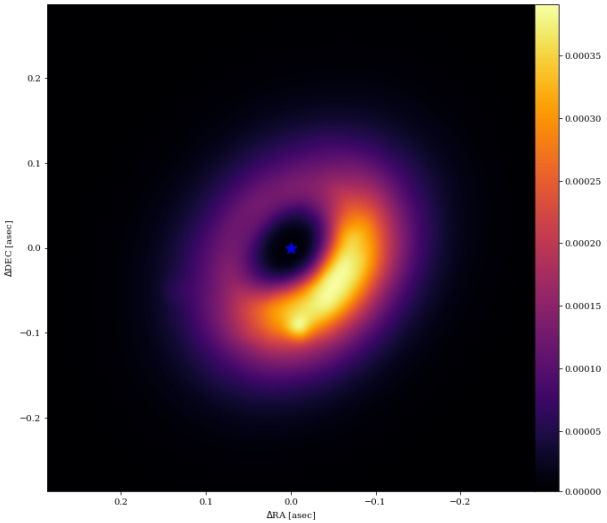


Inputs

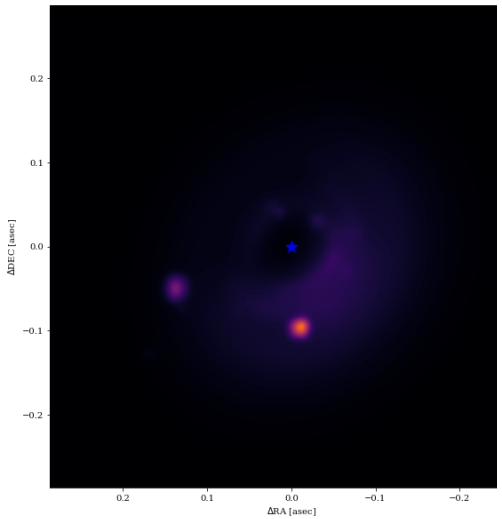
VLT/SPHERE H-band SAM data of HD100546

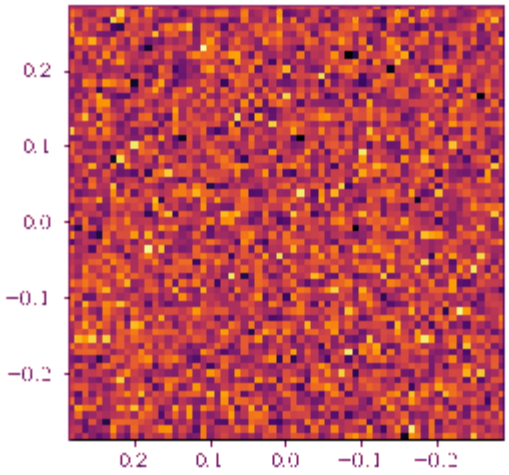
from Stolker et al. in prep. (PI Benisty)

Median



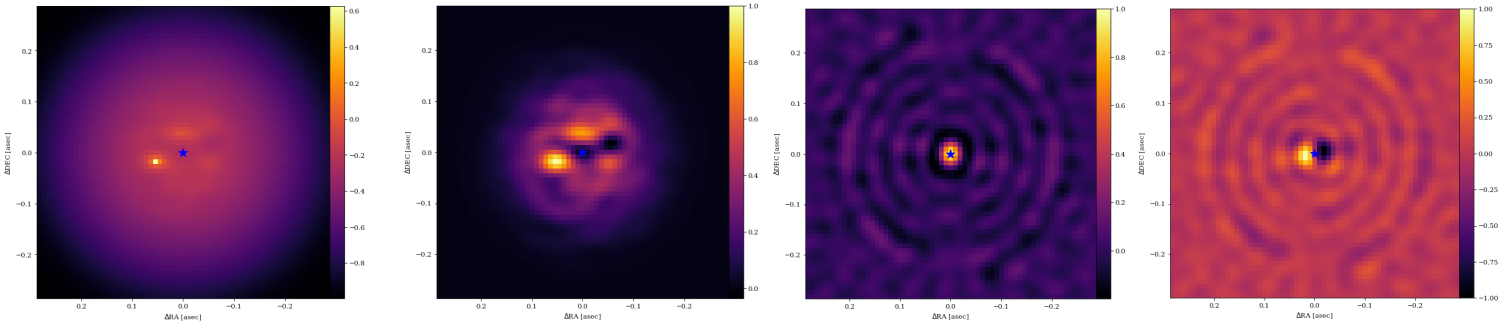
Standard Deviatio





***preliminary results**

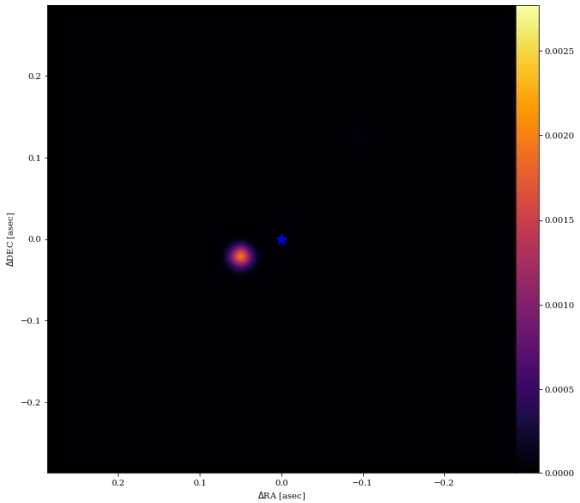
Beyond Geometrical Modeling: Denoising Diffusion Probabilistic Models for Constrained Image Reconstruction



Inputs

VLT/SPHERE H-band SAM data of HD142527

Median



Standard Deviation

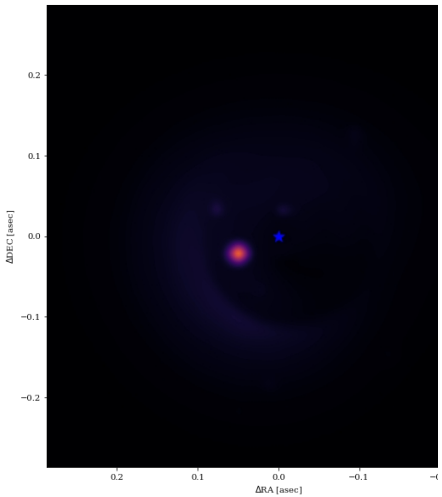
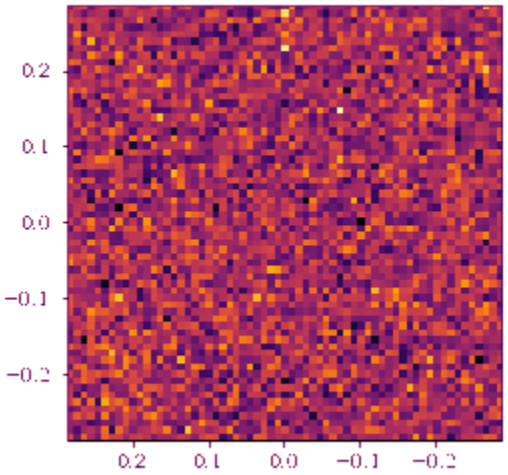


Image Generation



Final Comments: Image Reconstruction and Extended Emission Modeling for NIRISS-AMI

- Implemented geometrical modeling tools in Jax (+ Tensorflow + PyTorch):
  - FFT + interpolation and exact DFT based observable calculation.
  - Differentiable (+ GPU compatible + easily vectorized) geometrical models + analytic binary models.
  - Nested sampling based Bayesian model comparison.
  - Normalizing flow + Hamiltonian Monte Carlo accelerated posterior exploration.
  - Compatible with covariance matrices from Fouriever.
- Our work on VLT/SPHERE SAM data of LkCa 15 demonstrated:
  - Simple geometrical models can be used to fit for extended emission with SAM/AMI data of transition disk systems.
  - By modeling the extended emission, significantly higher planet contrasts can be probed.
- Currently we are testing/developing methods using ground based VLT/SPHERE data of PDS 70, HD100546 and HD135344B.
  - Using this data + radiative transfer simulations we will be informing the priors used when analyzing JWST NIRISS-AMI data.
- Future work: developing and testing image reconstruction and radiative transfer modeling techniques.
  - DDPM image reconstruction model architecture optimization, expanding training set + extensive testing.
  - MCMC with radiative transfer models.
  - Develop best practices for working with AMI + KPI data simultaneously.