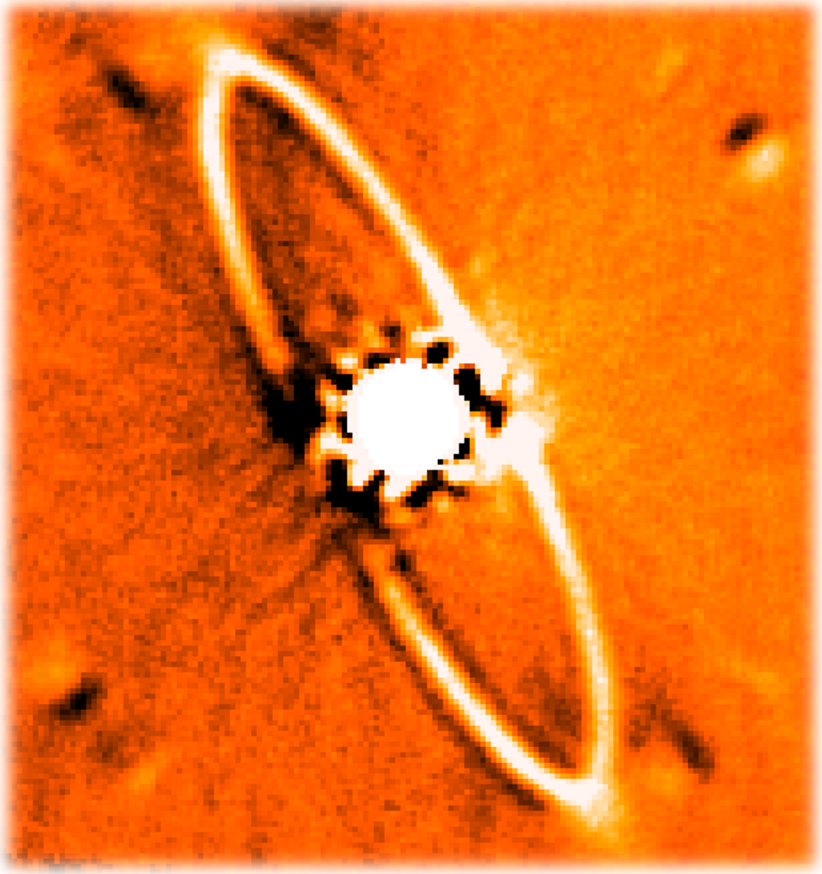
Jet Propulsion Laboratory
California Institute of Technology

The surprising scattering phase function of the HR 4796 debris disk



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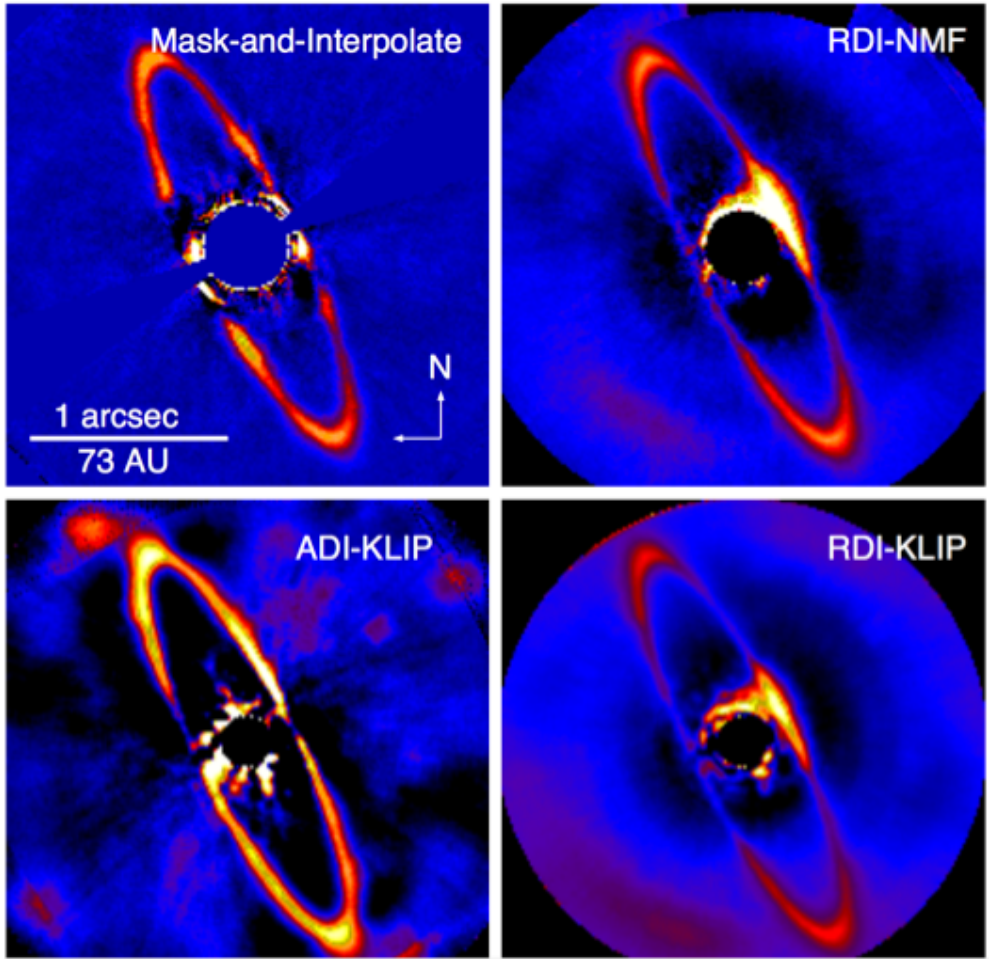
Mike Fitzgerald(UCLA); Thomas Esposito(Berkeley); Sasha Hinkley (Exeter); Dean Hines(STScI); A. Hughes(Wesleyan University); Paul Kalas(Berkeley); Ludmilla Kolokolova(UMD); Brenda Matthews(Victoria); Stanimir Metchev(University of Western Ontario); Jennifer Patience(ASU); Marshall Perrin(STScI); Fredrik Rantakyro(Gemini); Glenn Schneider(University of Arizona); Rémi Soummer(STScI); Christopher Stark(STScI); Alycia Weinberger(Carnegie DTM); David Wilner(Harvard); Laurent Pueyo(STScI)

Different types of algorithms

- Using ADI:
  - KLIP-ADI (Pueyo 2016)
  - Mask and Interpolate (Perrin, Duchene et al. 2015)

- Require a librairy of empty PSF (H band only for GPI):
  - Non-negative matrix factorization (Ren et al. 2018)
  - KLIP-RDI (see Justin Hom's conference)



Basically trading SNR and impact on the shape

Geometry

The exclusion angle increases a lot for the ADI-based methods due to self-subtraction

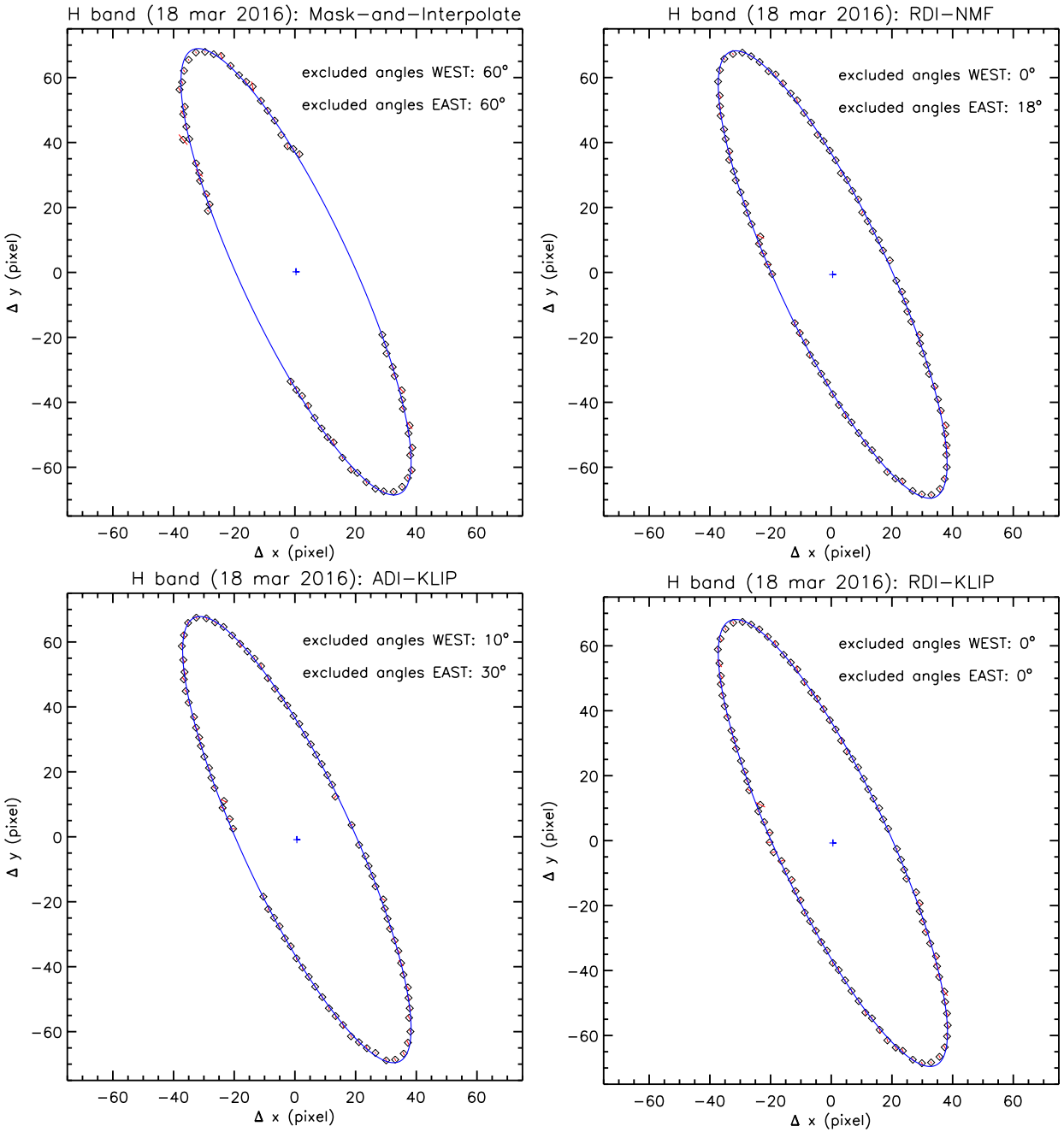
Geometrical parameters :

- R = 77 AU +/- 0.3 AU
- i = 76.0 ° +/- 0.15 °
- PA = 26.6 ° +/- 0.13 °

Offset are slighlty more important:

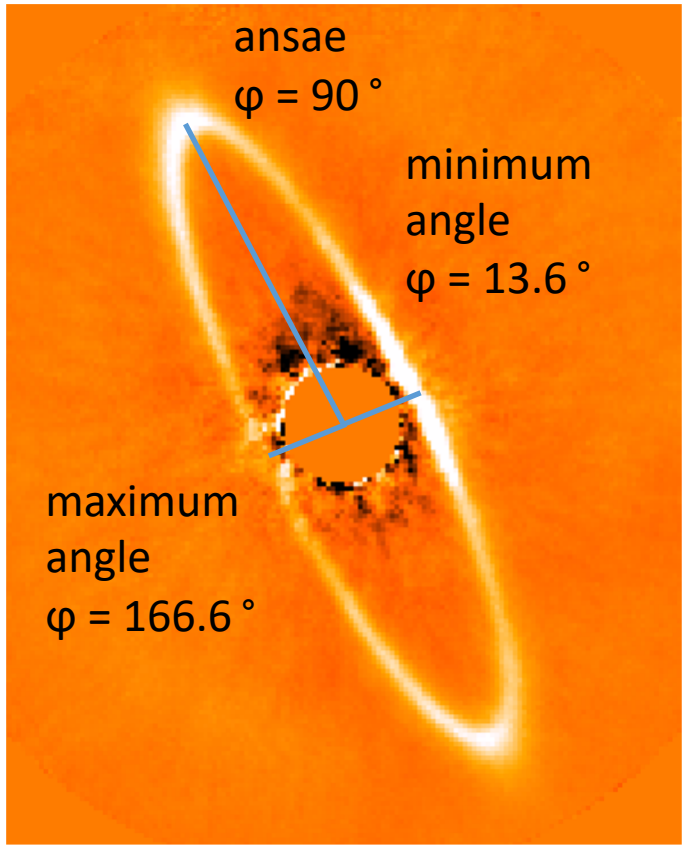
- Offset Major axis (toward SW) = 0.3 AU
- Offset Minor axis (toward NW)= -0.9 AU

In the disk plane



Scattering phase function

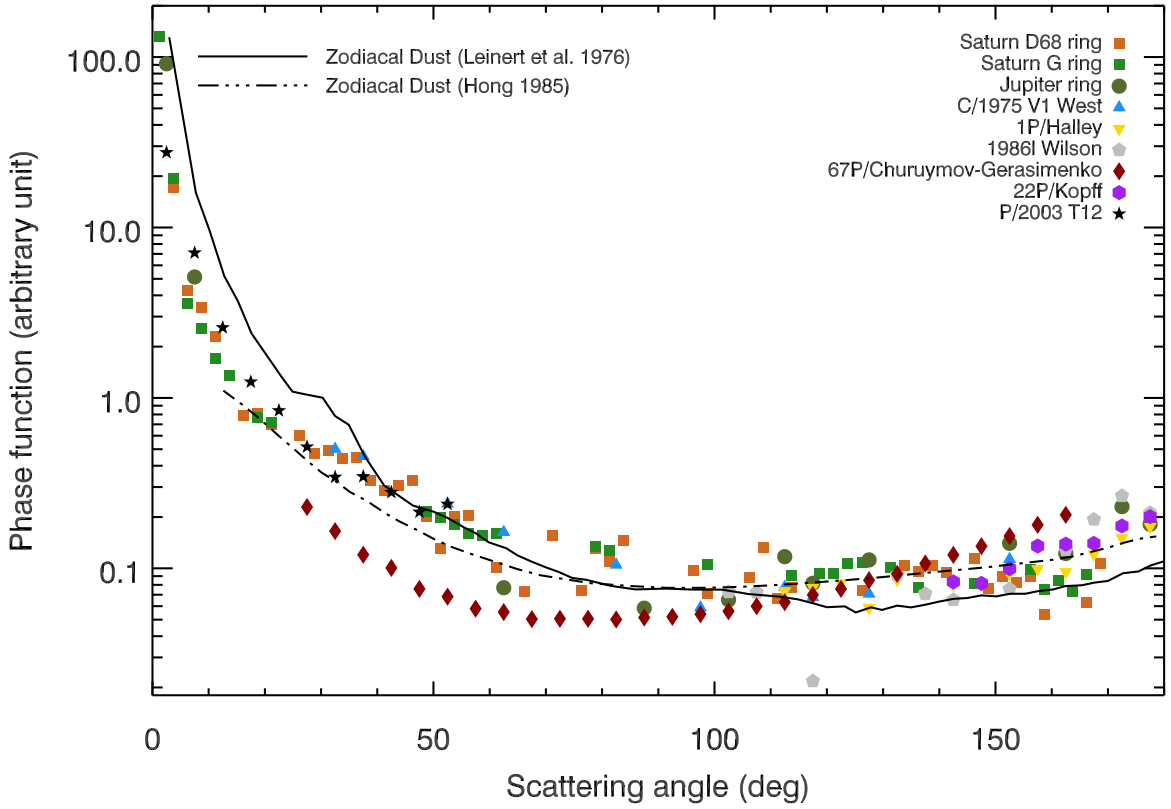
Amount of star light scattered at for each star – dust – observer angle



Scattering phase function

Amount of star light scattered at for each star – dust – observer angle

Well known in the solar system where you have probes (Rosetta, Cassini, …) that allows you to make these measurements at each angle



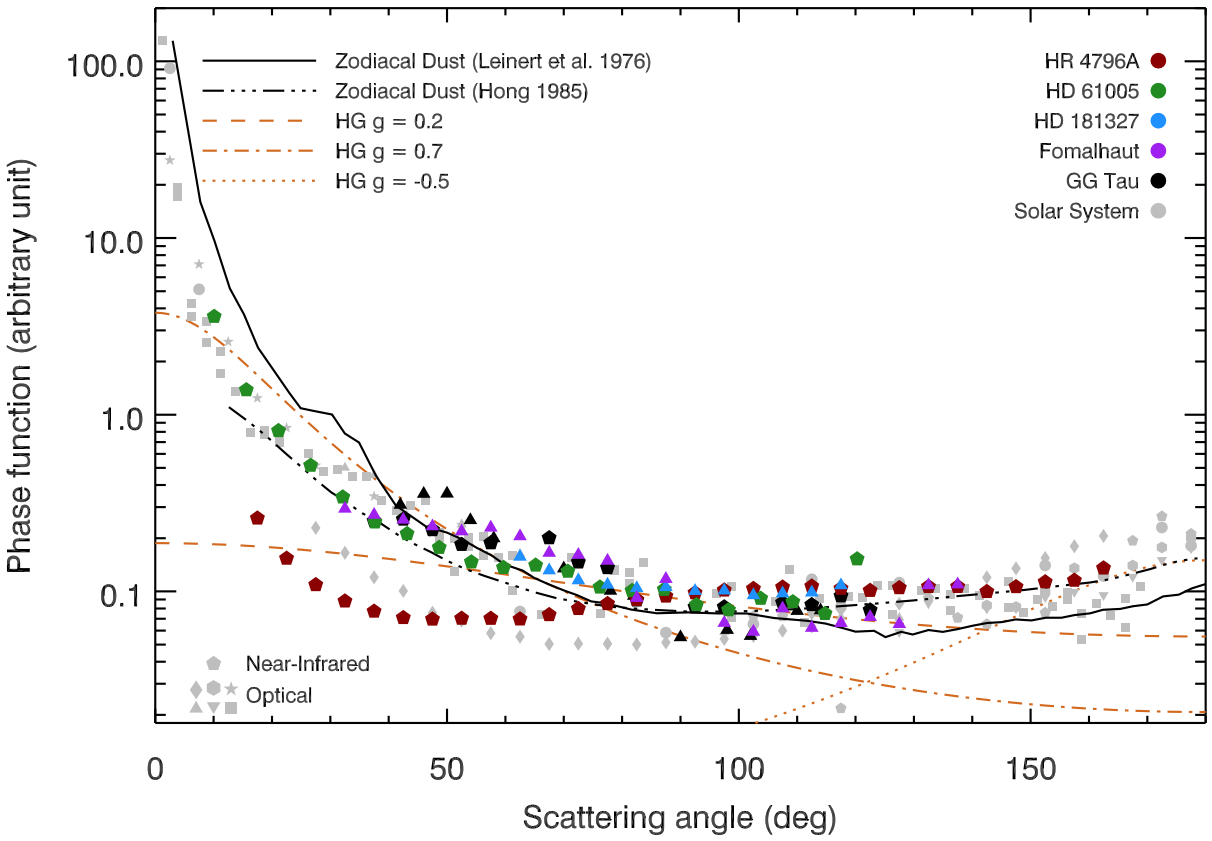
Hughes, Duchene, and Matthews (2108)

Scattering phase function

Amount of star light scattered at for each star – dust – observer angle

Harder for debris disk

Among the known SPFs for debris disks, HR 4796 is an outlier (SPHERE data : Milli et al. 2017)



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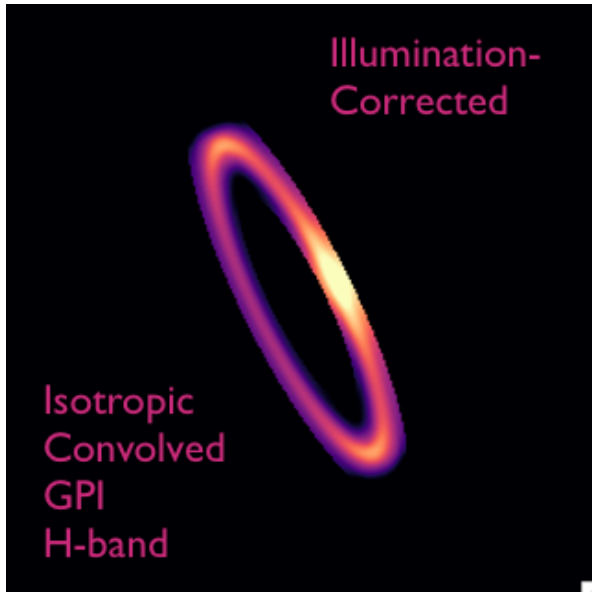
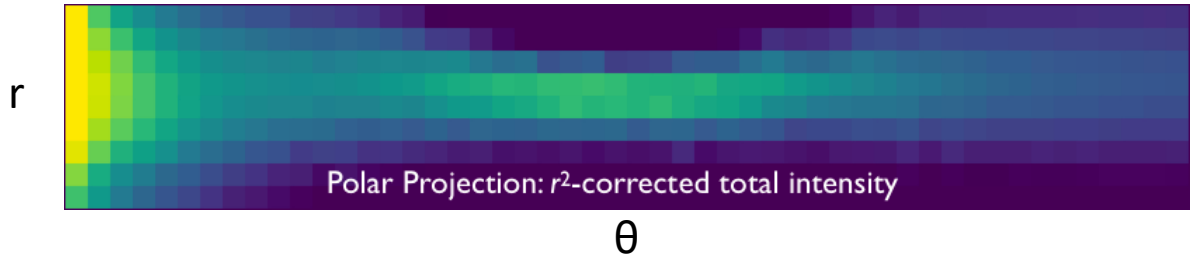
Empirical SPF Extraction Methodology



(I.) Calculate average SB within scattering angle wedge

(II.) Create a polar projection image of the average SPF

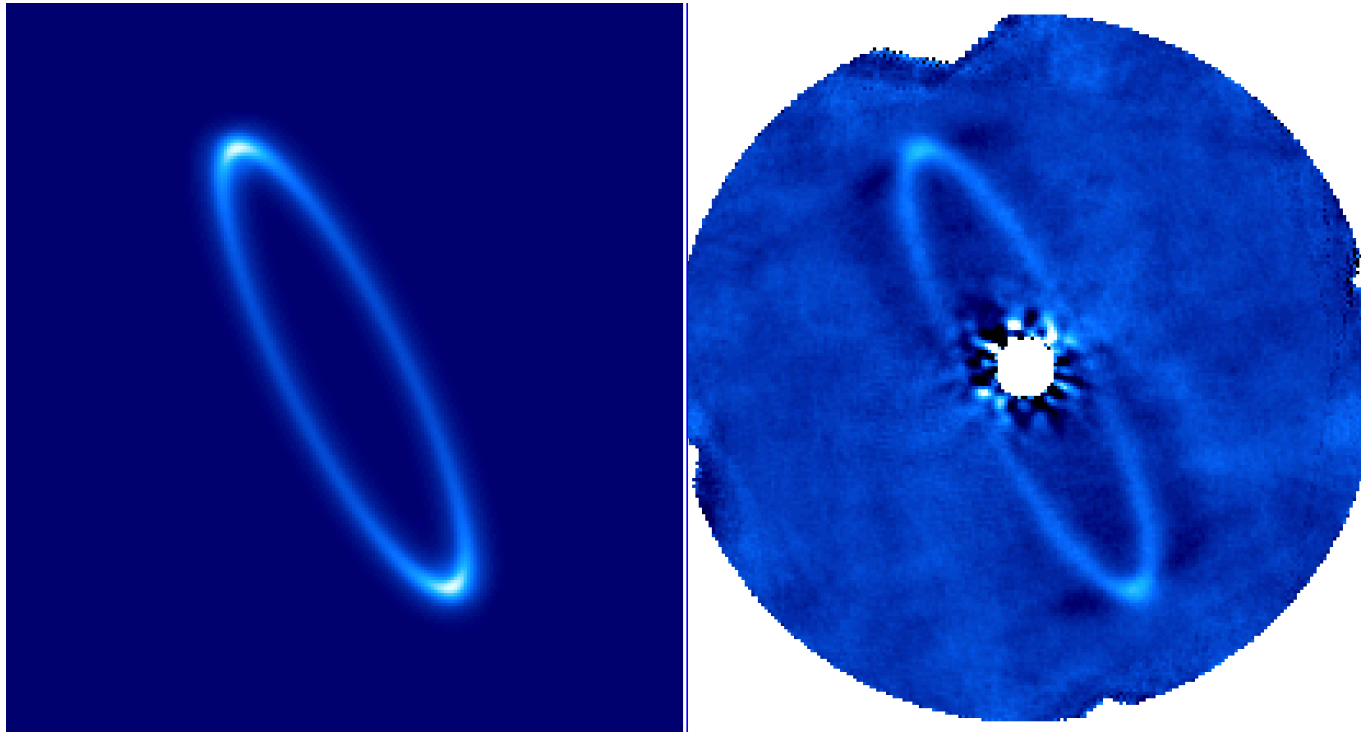
(III.) Sum radially the average SB across the disk



Empirical SPF Extraction Methodology

Isotropic SPF model
before KLIP-ADI

Isotropic SPF model
after injection and KLIP-ADI



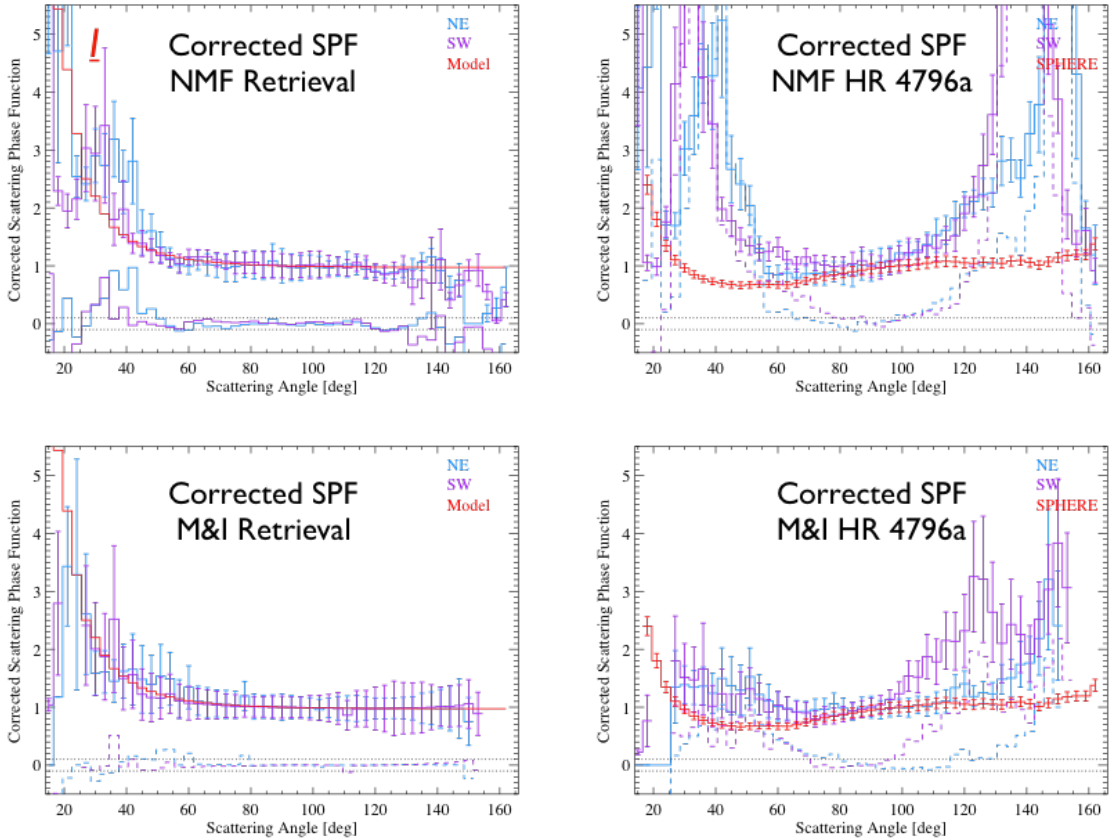
Correction of the effect of the reduction treatment:
inject a model of the disk in an empty data set (or with forward modelling) and then do the same treatment before and after to check the impact of your method

Empirical SPF Extraction:

Problem with this method:

- The model is not exactly the same as the data, which has a lot of impact on the self subtraction and over-subtraction

LEFT: with an injected fake disk for which we know the exact SPF and geometrical parameters

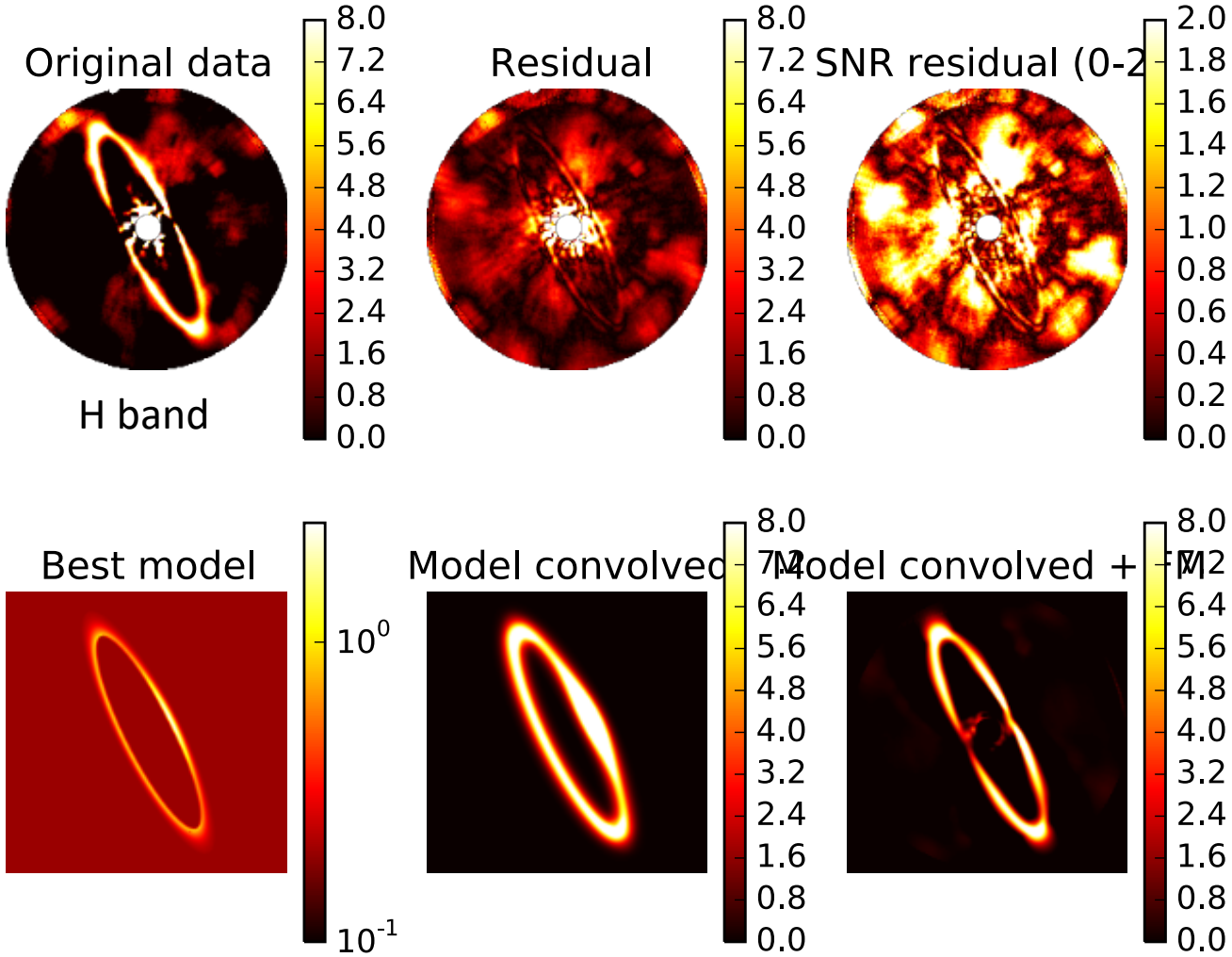


Right : with real data (exact geometrical parameters unknown)

SPF Retrieval possible

SPF retrieval not reproductible with different techniques and bandwidth

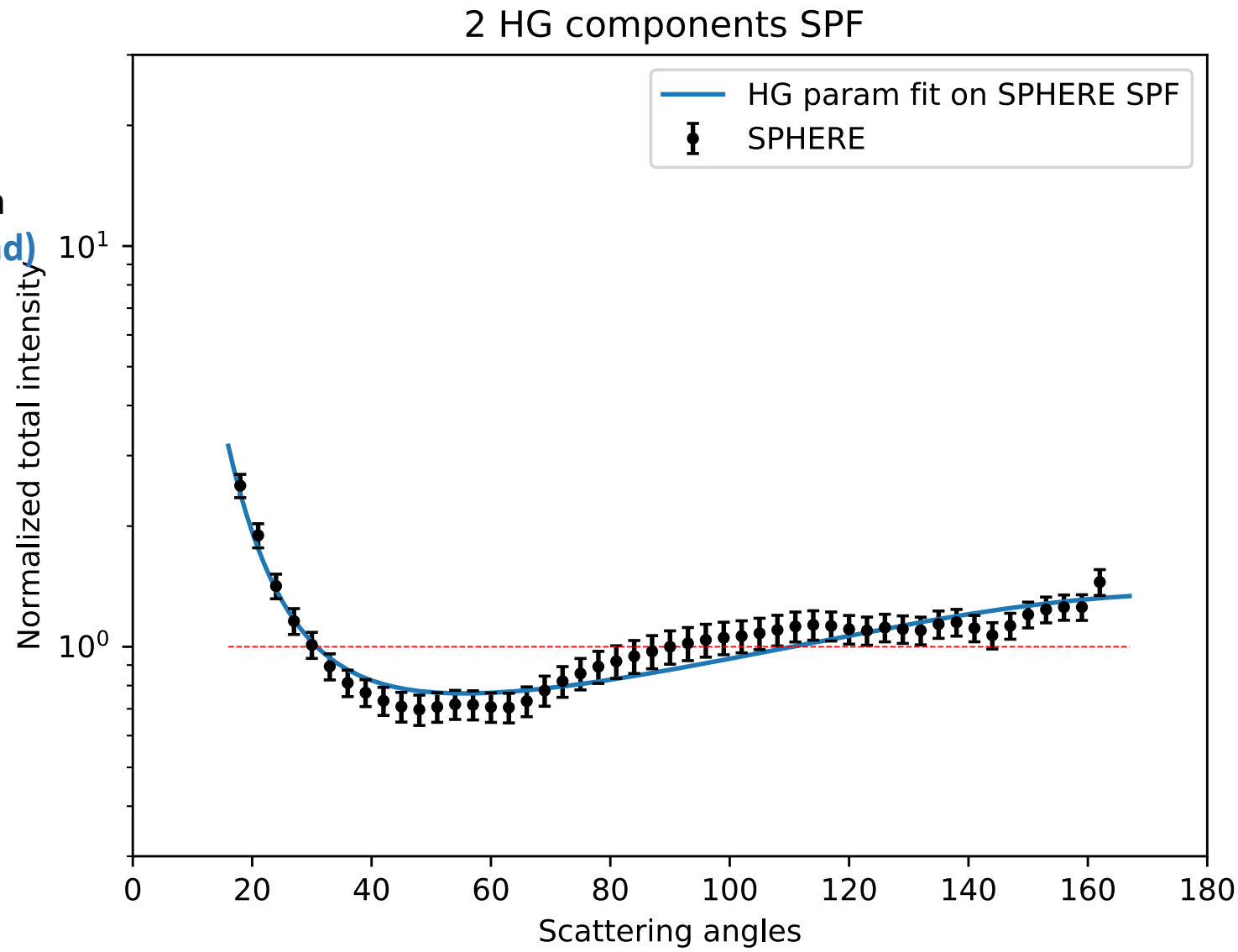
Full fit of the all the disks parameters including the SPF



Full fit of the all the disks parameters including the SPF

Two components Henyey-Greenstein function

- **fitted on the SPHERE extracted SPF (H band)**

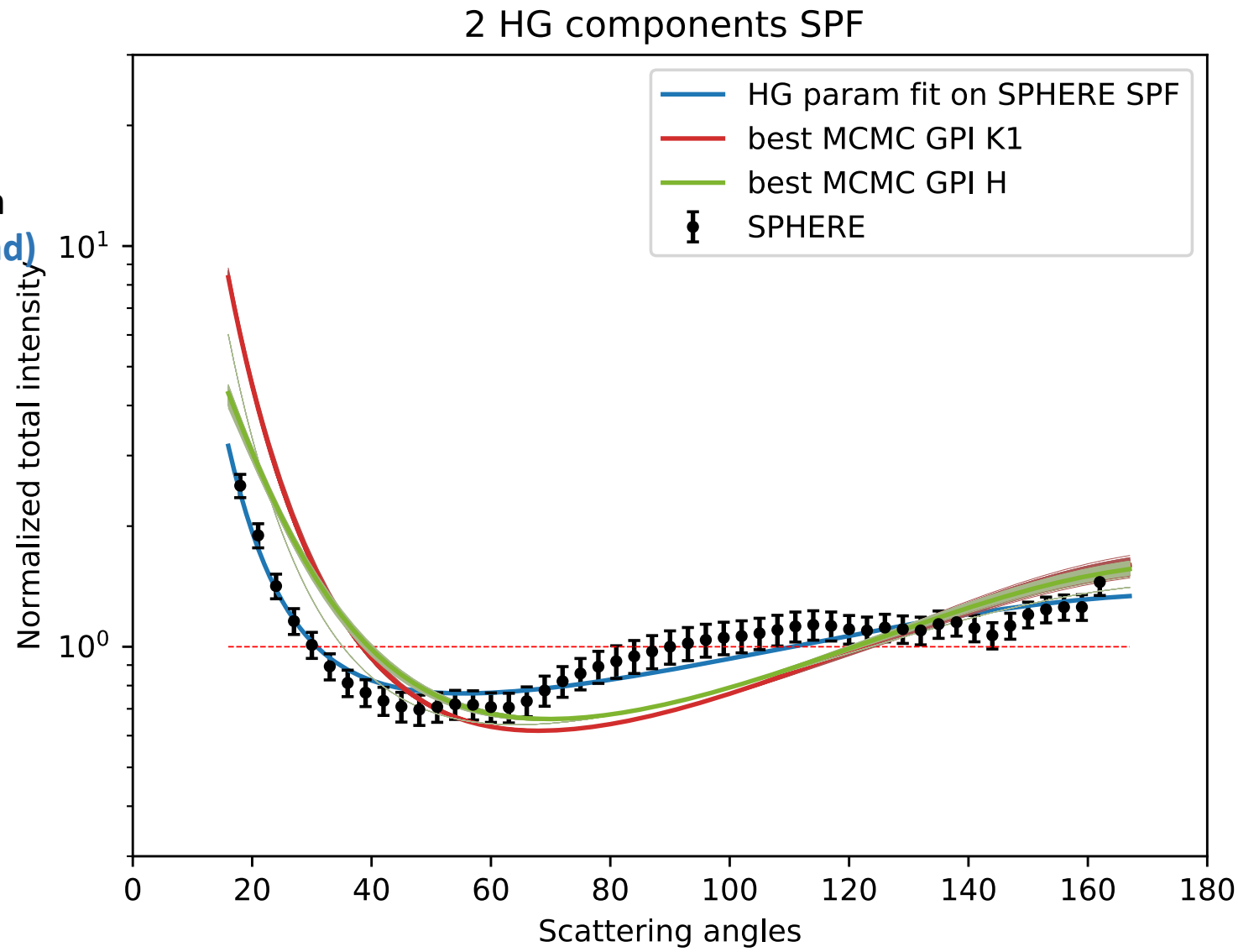
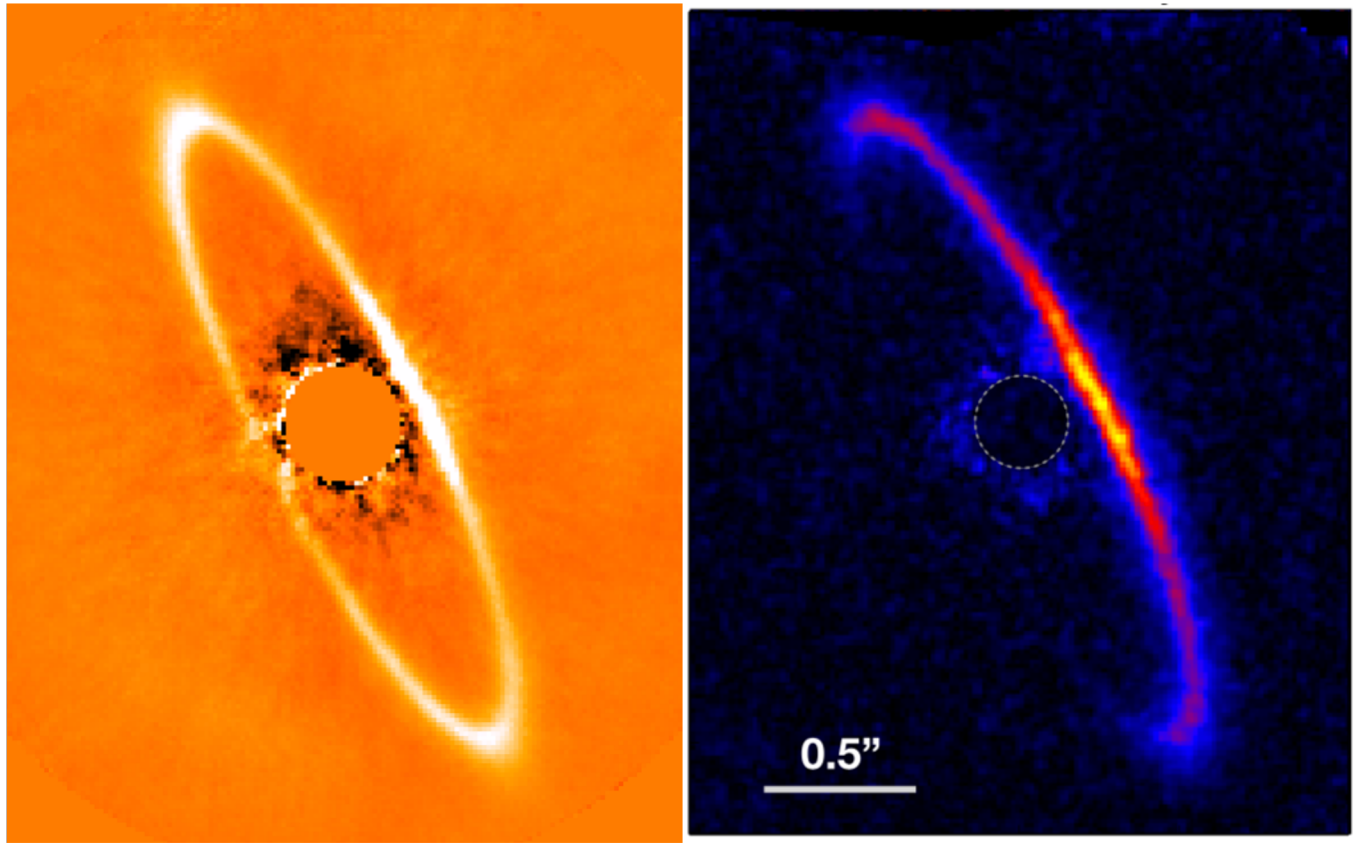


Full fit of the all the disks parameters including the SPF

Two components Henyey-Greenstein function

- **fitted on the SPHERE extracted SPF (H band)**

- **fitted directly on the GPI images**
  - **in K1 band**
  - **in H band**



Thank you !