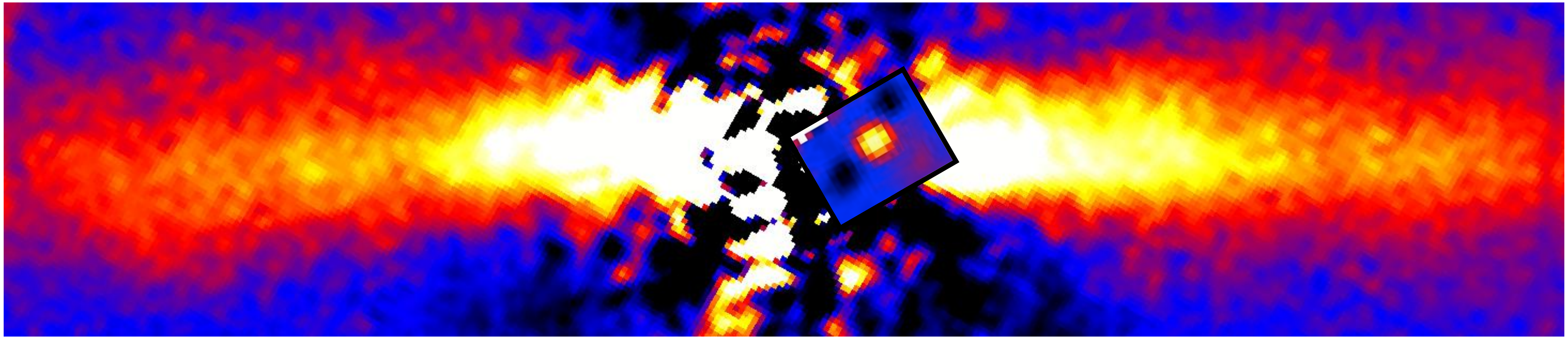

High-contrast imaging of debris discs

Julien Milli

11 June 2015

Work in collaboration with David Mouillet, Dimitri Mawet, Anne-Marie Lagrange, Jean-Charles Augereau, Olivier Absil

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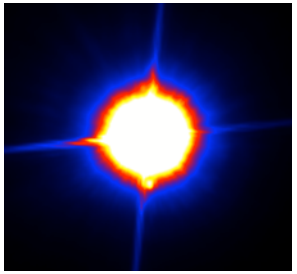
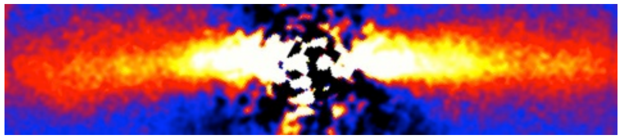
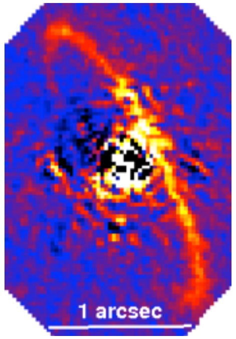
II. Characterising the stellar halo
III. Asymmetries in the β Pictoris disc
IV. The dust properties of HR 4796
V. Early science results from SPHERE

Conclusions







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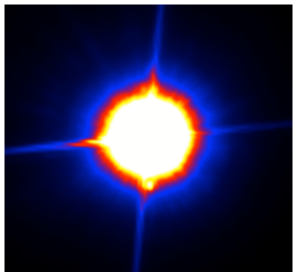
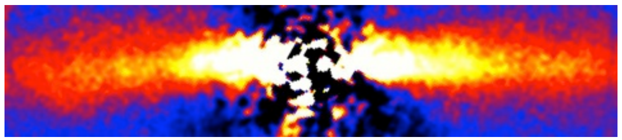
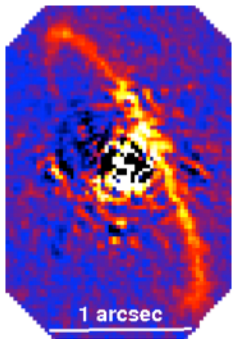
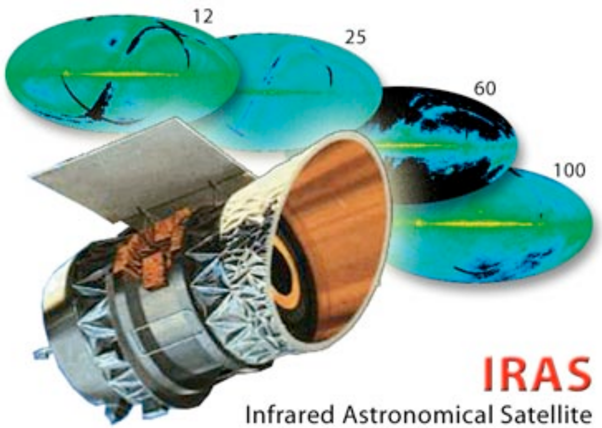


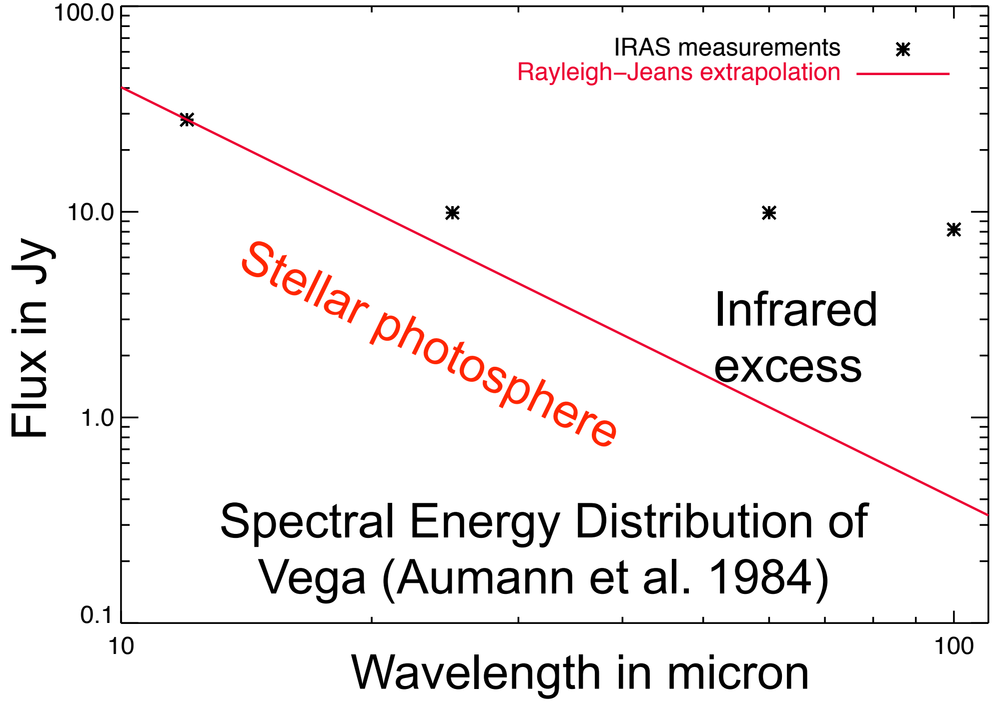




What is a debris disc ?

First detection in 1983 with the infrared satellite IRAS

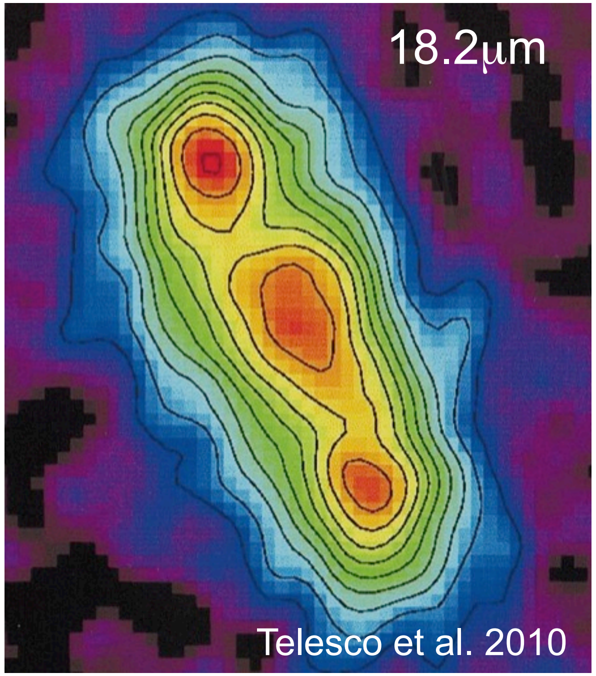


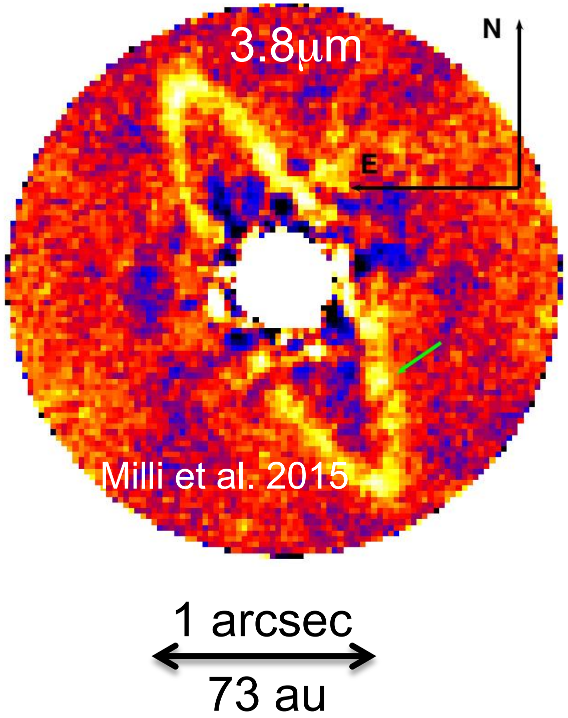


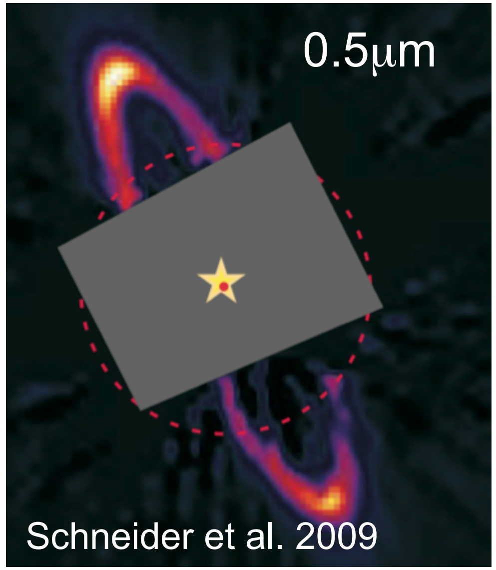
Spectral Energy Distribution of Vega (Aumann et al. 1984)

Resolved imaging

HR 4796

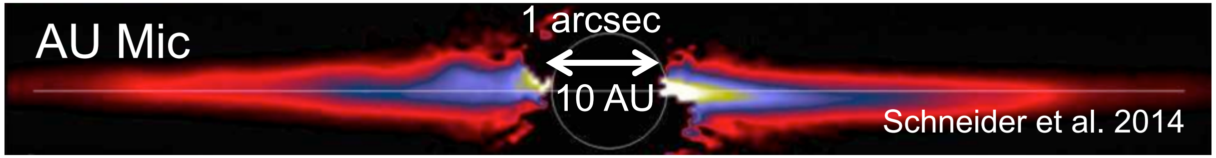


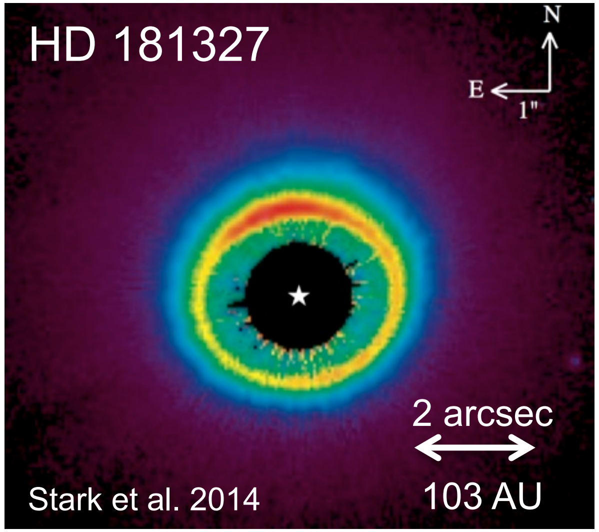


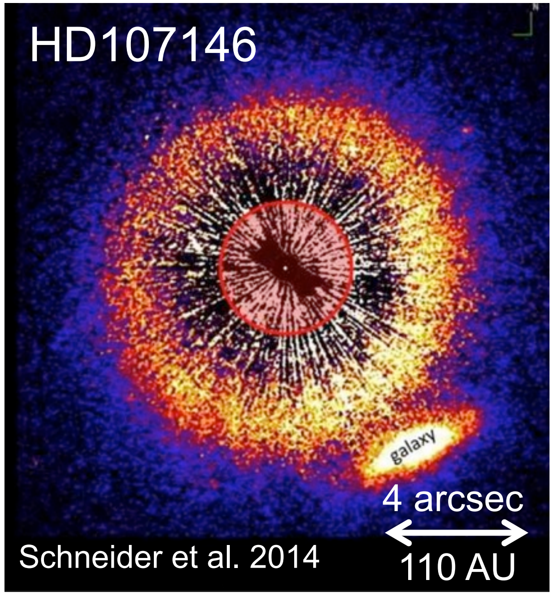


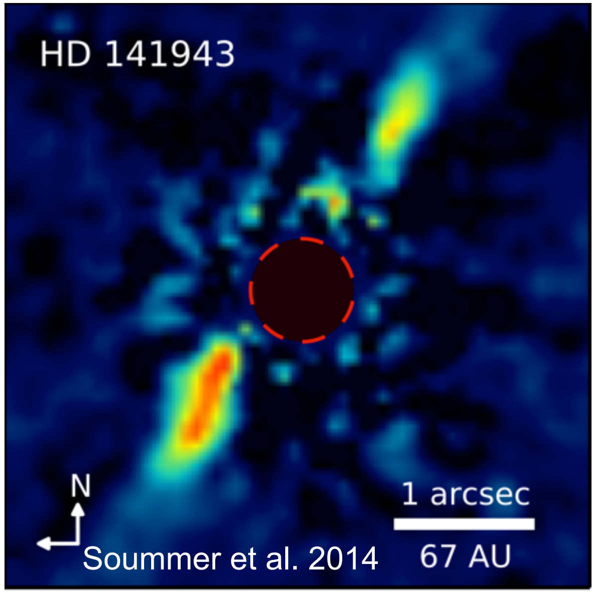
Imaging brings a additional information: the localisation of the dust

High-contrast imaging



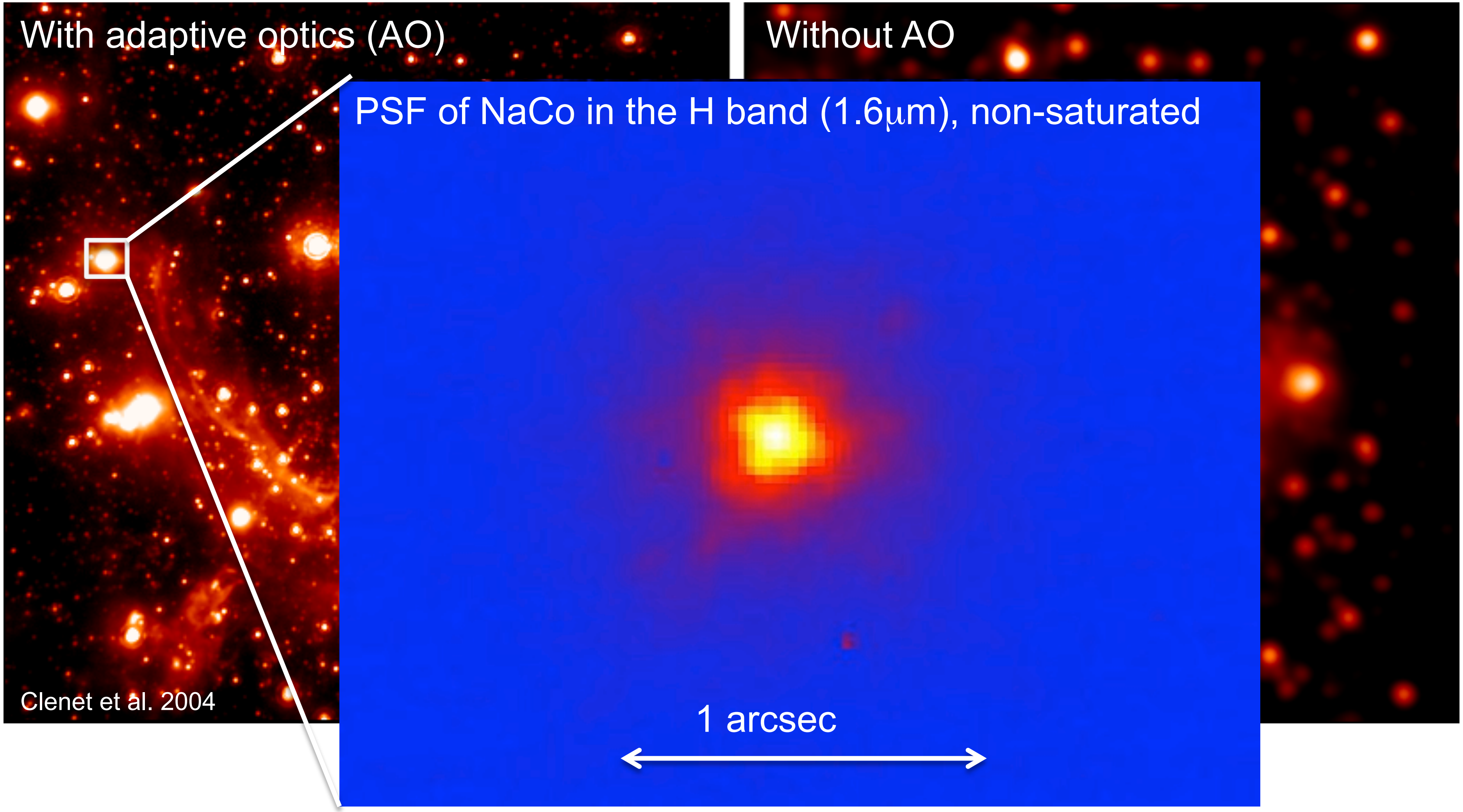




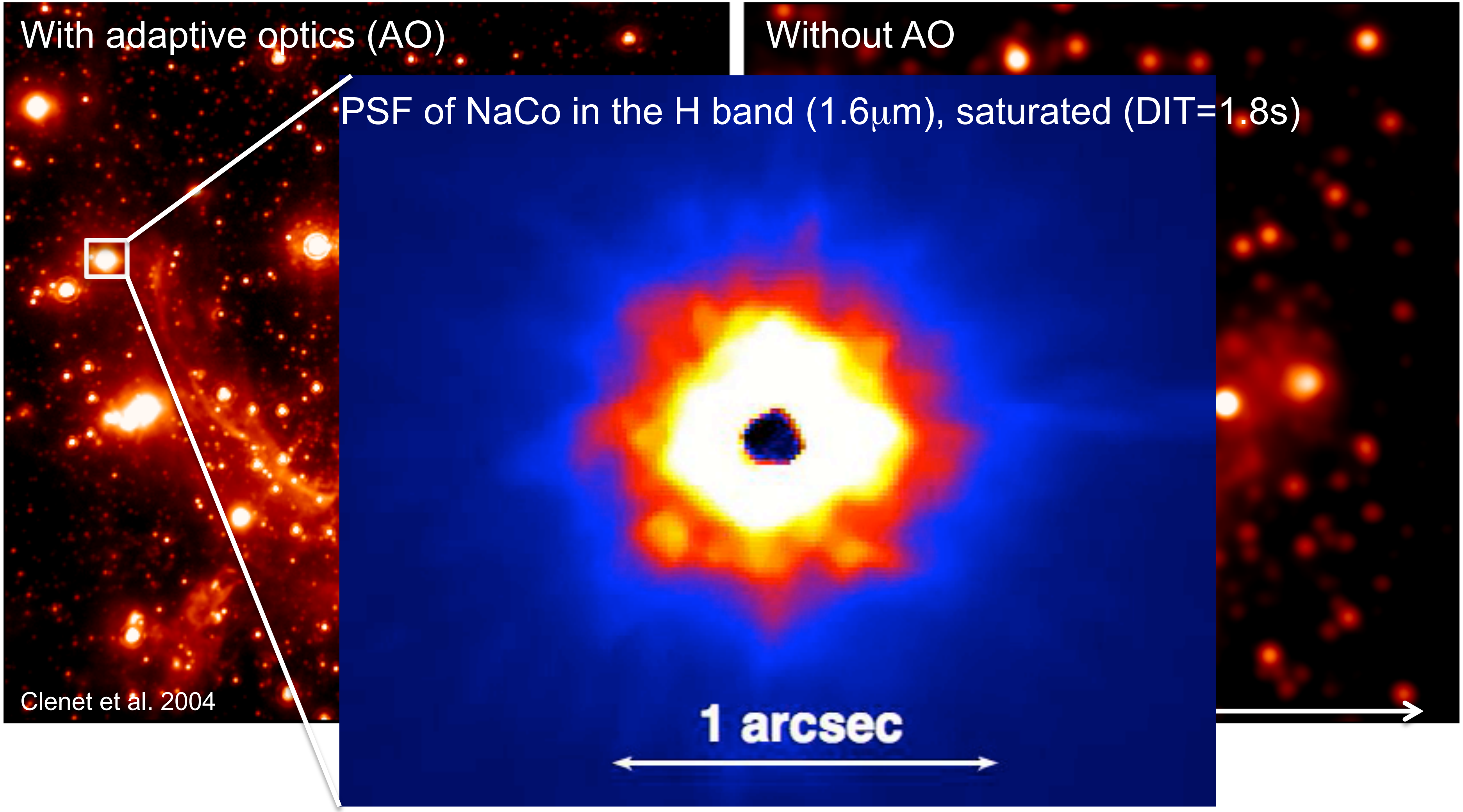


Two prerequisites: high contrast and high-angular resolution

High contrast



High contrast



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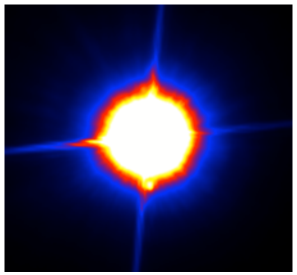
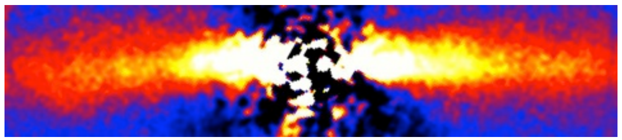
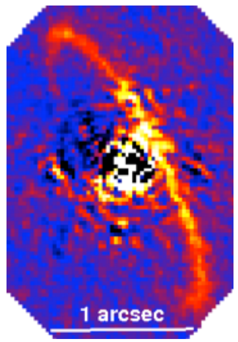




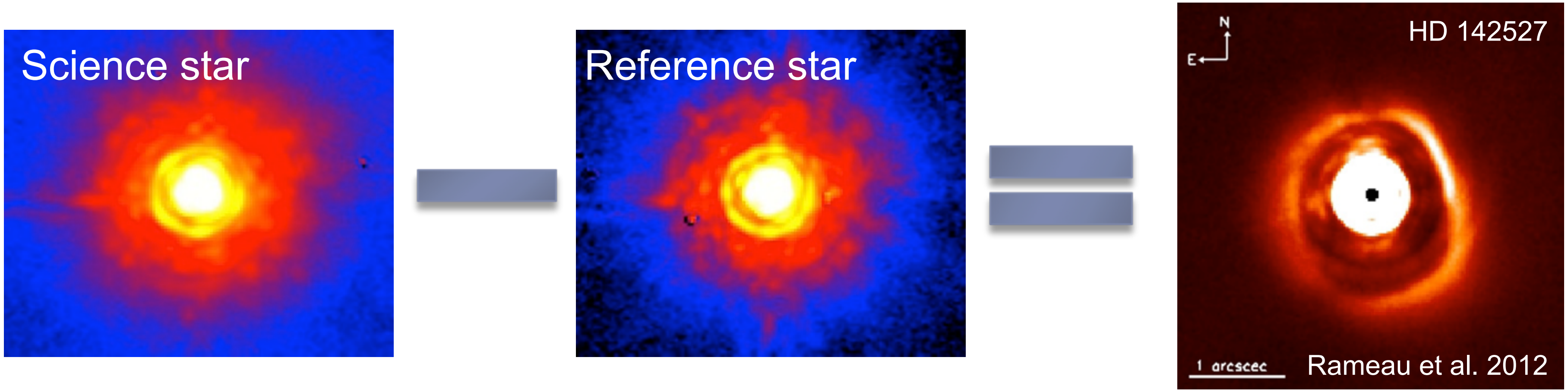


II. Characterisation of the stellar halo

How to decouple the stellar halo from an astrophysical object ?

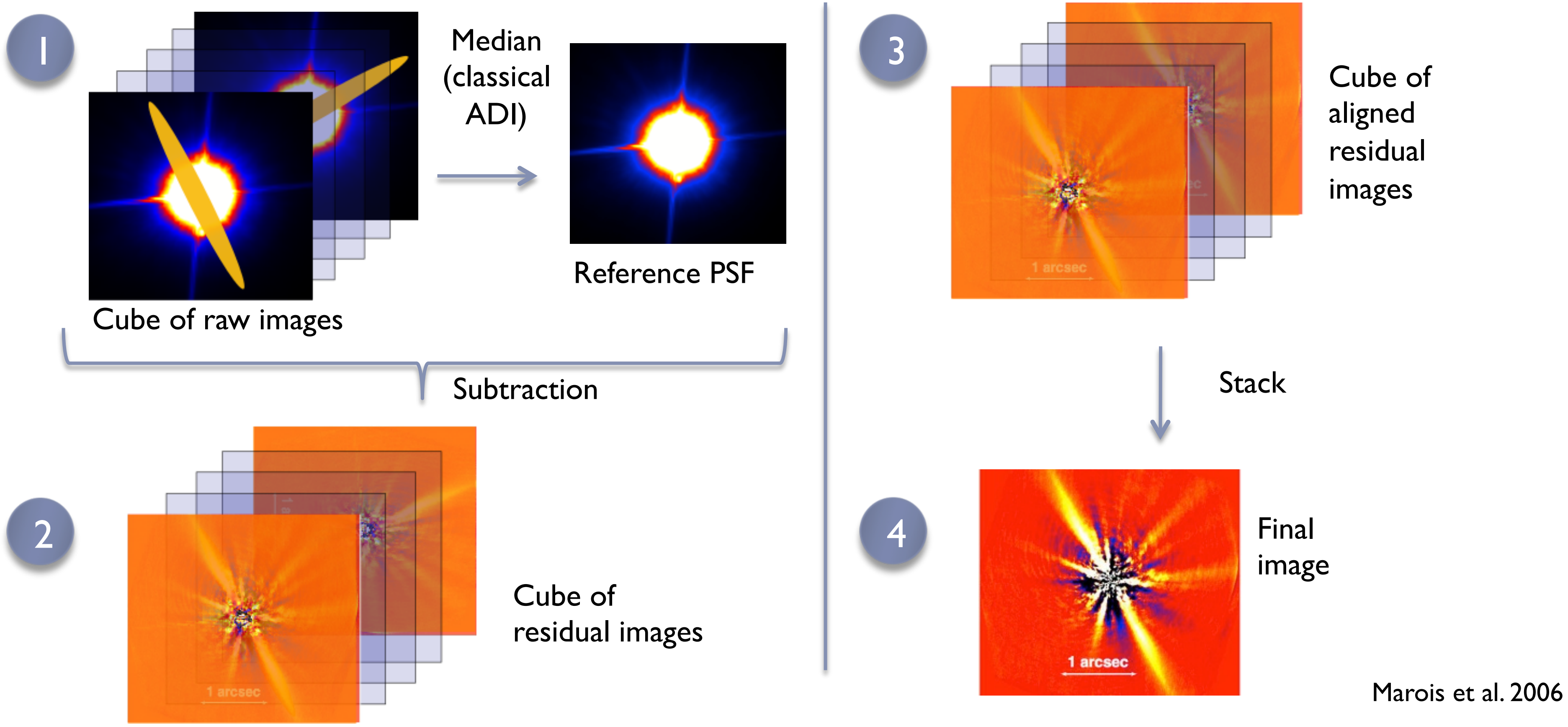
Reference star differential imaging (RDI)	Angular differential imaging (ADI)	Polarimetric differential imaging (PDI)

Decoupling the stellar halo from an astrophysical signal



Reference star differential imaging (RDI)	Angular differential imaging (ADI)	Polarimetric differential imaging (PDI)

Decoupling the stellar halo from an astrophysical signal



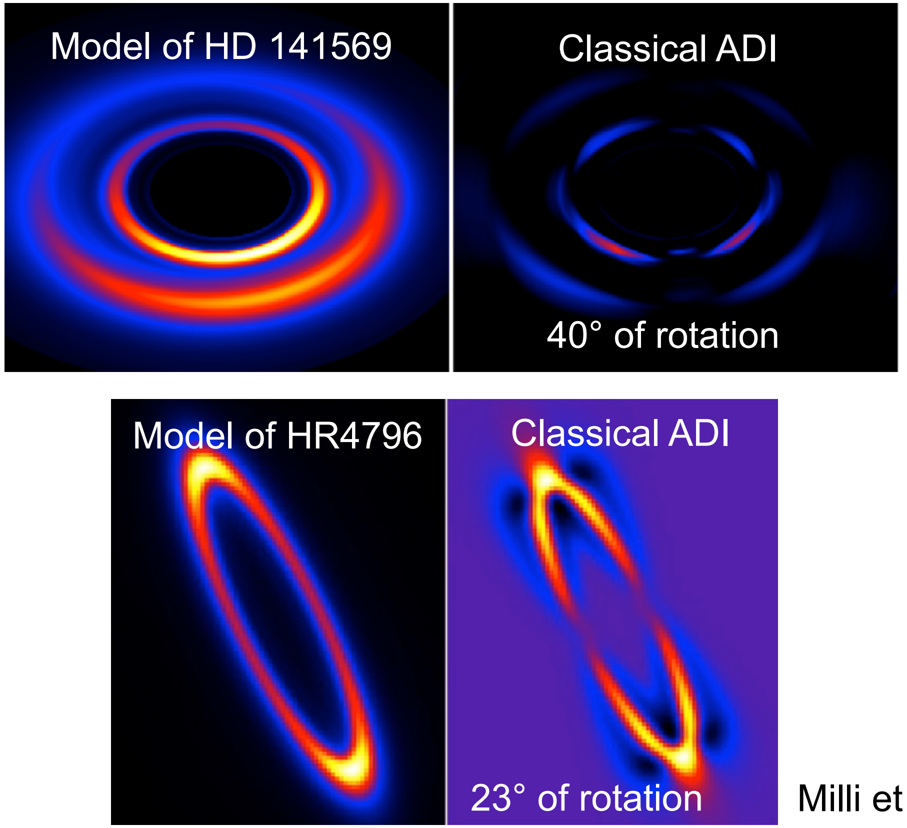
Reference star differential imaging (RDI)	Angular differential imaging (ADI)	Polarimetric differential imaging (PDI)

Decoupling the stellar halo from an astrophysical signal

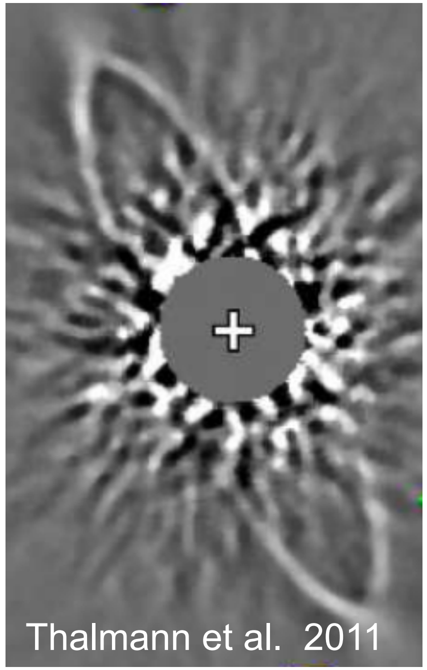
a) Quantify and correct for the biases on discs
b) Build a reference PSF
c) Understand the temporal evolution of the PSF

Reference star differential imaging (RDI)	Angular differential imaging (ADI)	Polarimetric differential imaging (PDI)

The biases of ADI on discs

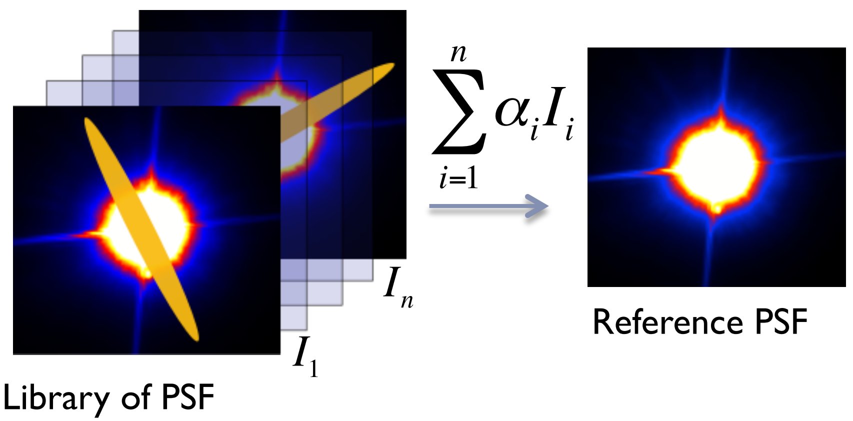


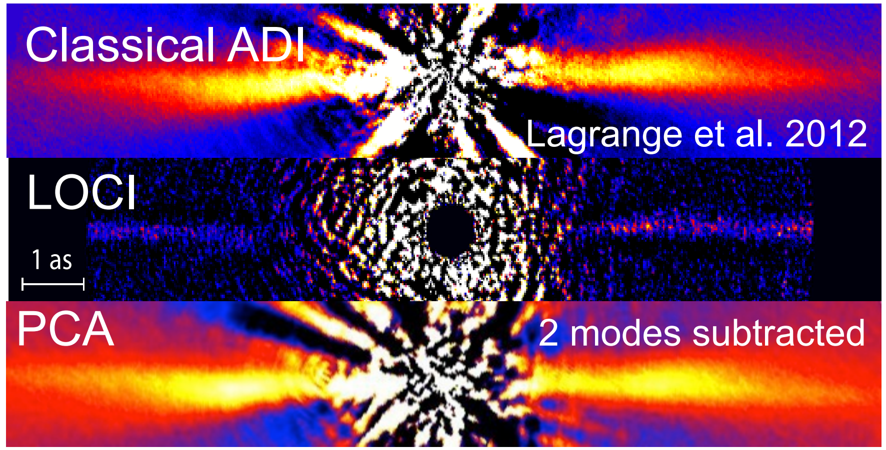
Milli et al. 2012



Reference star differential imaging (RDI)	Angular differential imaging (ADI)	Polarimetric differential imaging (PDI)

How to best combine the data to build the reference PSF ?

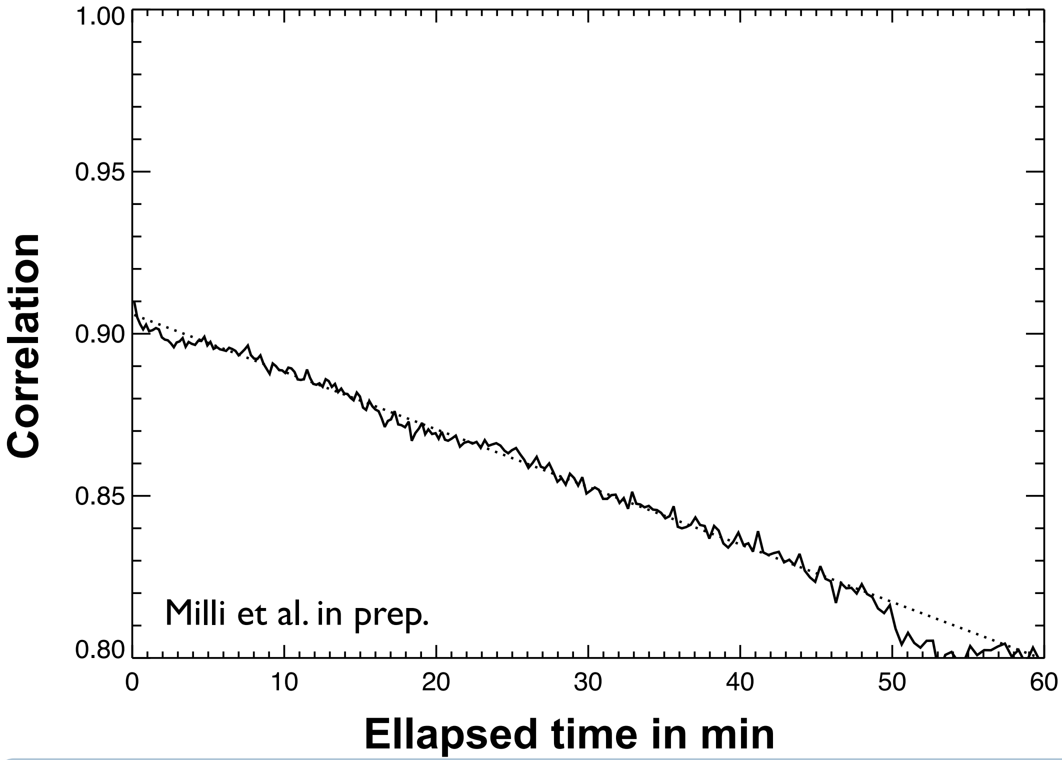




- LOCI: linear combination of images to minimise the noise (Lafrenière et al. 2007)
- PCA: orthogonalisation of a library of PSF, clipped to the first modes (Soummer et al 2012, Amara et al. 2012)

Reference star differential imaging (RDI)	Angular differential imaging (ADI)	Polarimetric differential imaging (PDI)

The temporal evolution of the PSF



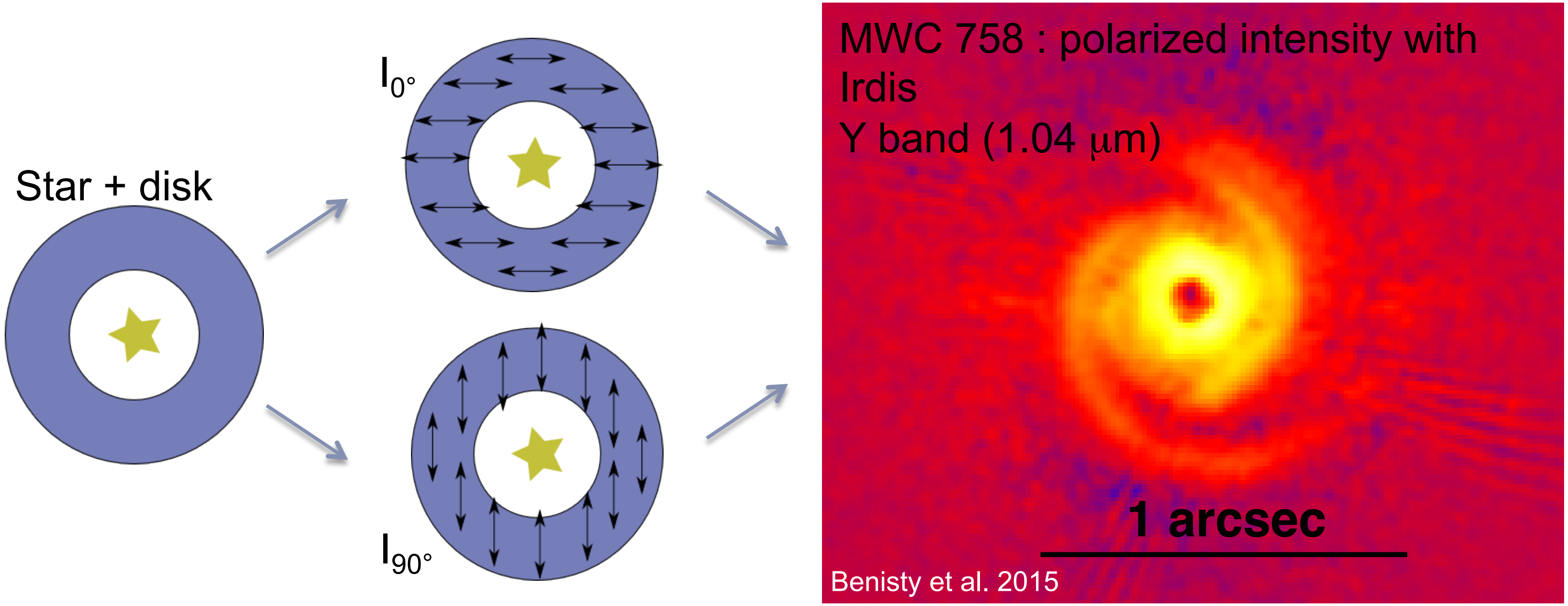
- Linear decorrelation from 10 to 50min
- Fast decorrelation over the first seconds

Reference star differential imaging (RDI)	Angular differential imaging (ADI)	Polarimetric differential imaging (PDI)

Decoupling the stellar halo from an astrophysical signal

Reference star differential imaging (RDI)	Angular differential imaging (ADI)	Polarimetric differential imaging (PDI)

Decoupling the stellar halo from an astrophysical signal



- Instantaneous subtraction
- Calibration of instrumental polarisation and differential aberrations

Reference star differential imaging (RDI)	Angular differential imaging (ADI)	Polarimetric differential imaging (PDI)

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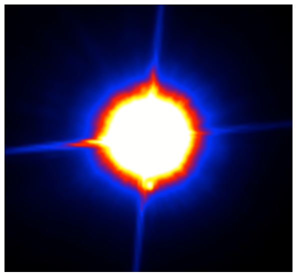
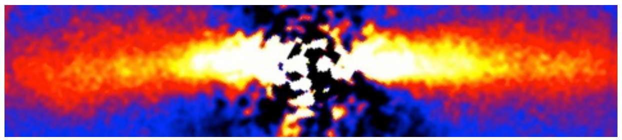
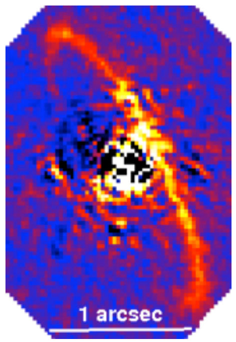
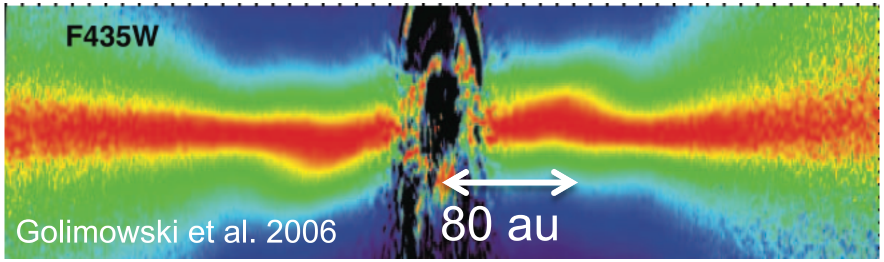




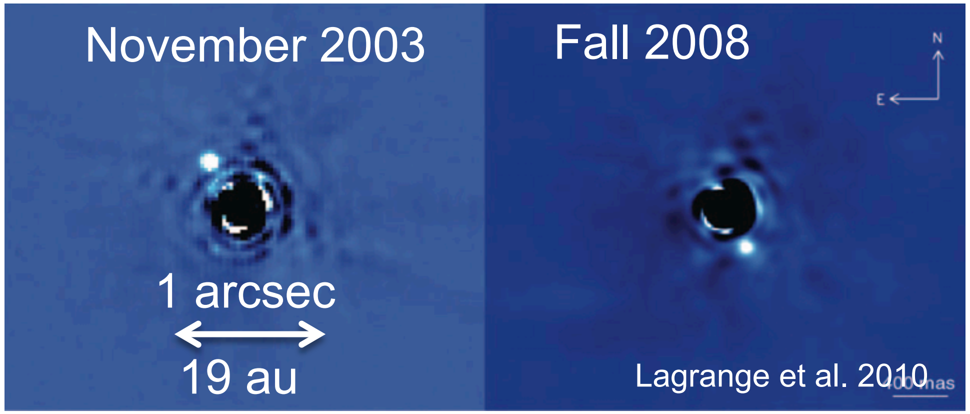


An emblematic case of disc/planet interaction

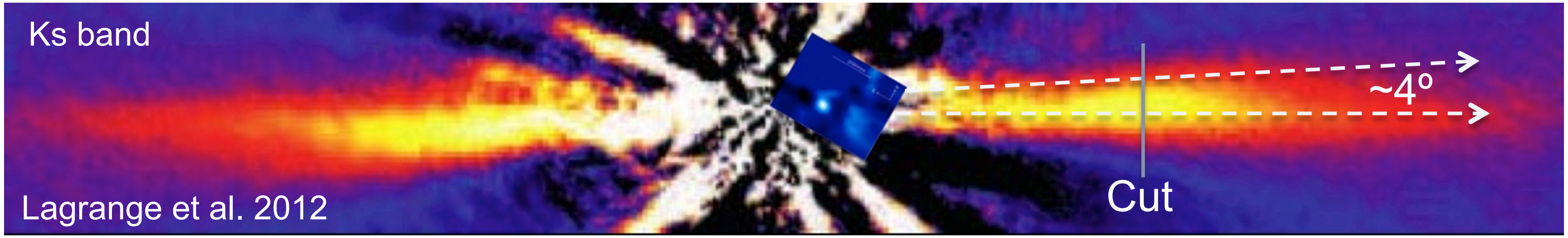
- The disc warped by an unseen gravitational perturber
  (Mouillet et al. 1997, Augereau et al. 2001)



- The planet discovered in 2008 with VLT/NaCo

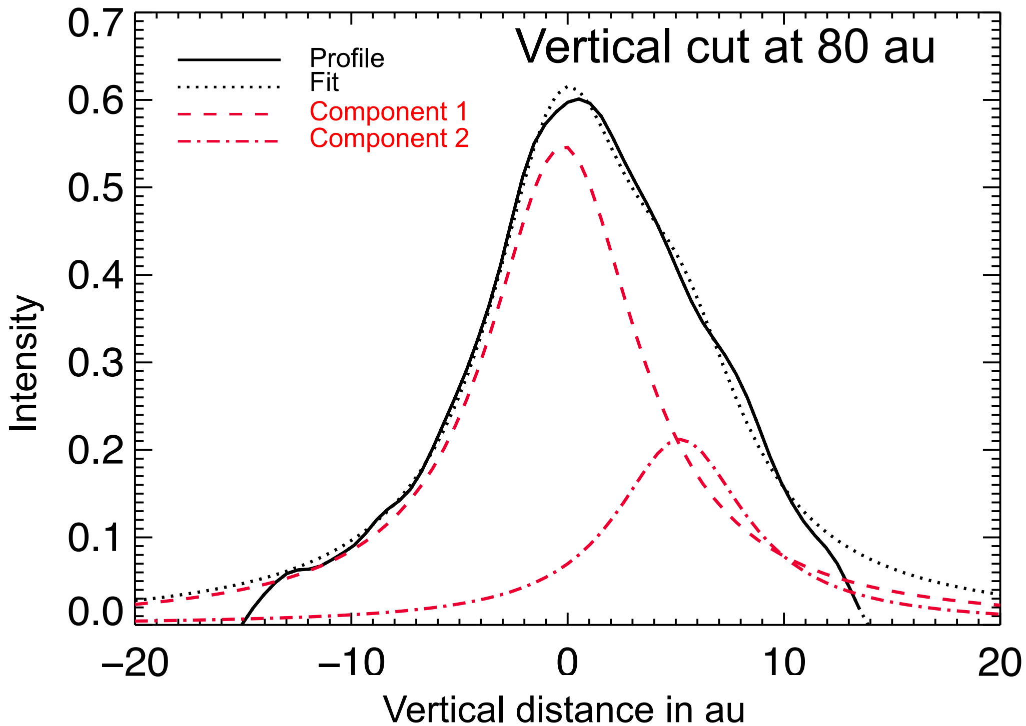


Simultaneously measure the disc and planet orientation



Simultaneous measurement of the position angle

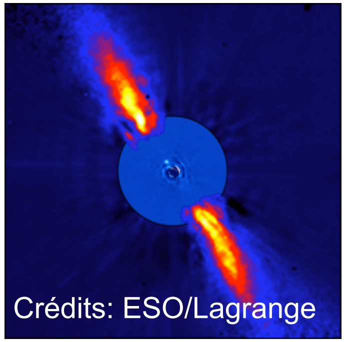
- of the planet
- of the outer disc
- of the inner warped disc

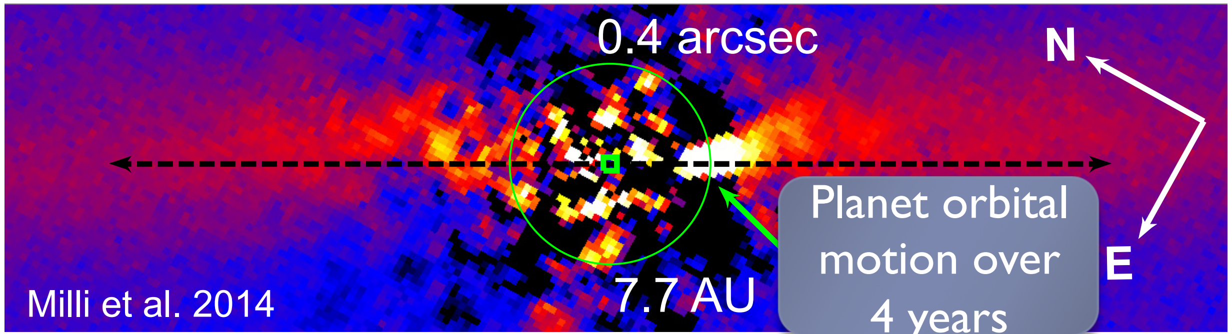


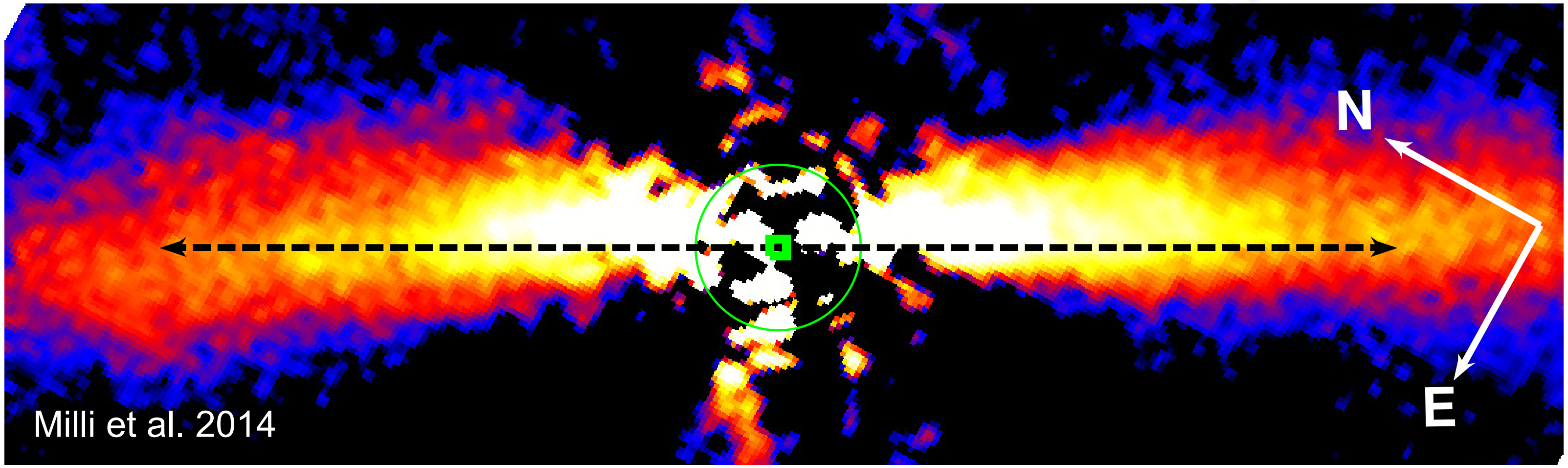
The planet is aligned with the warped inner disc

The internal parts of the disc

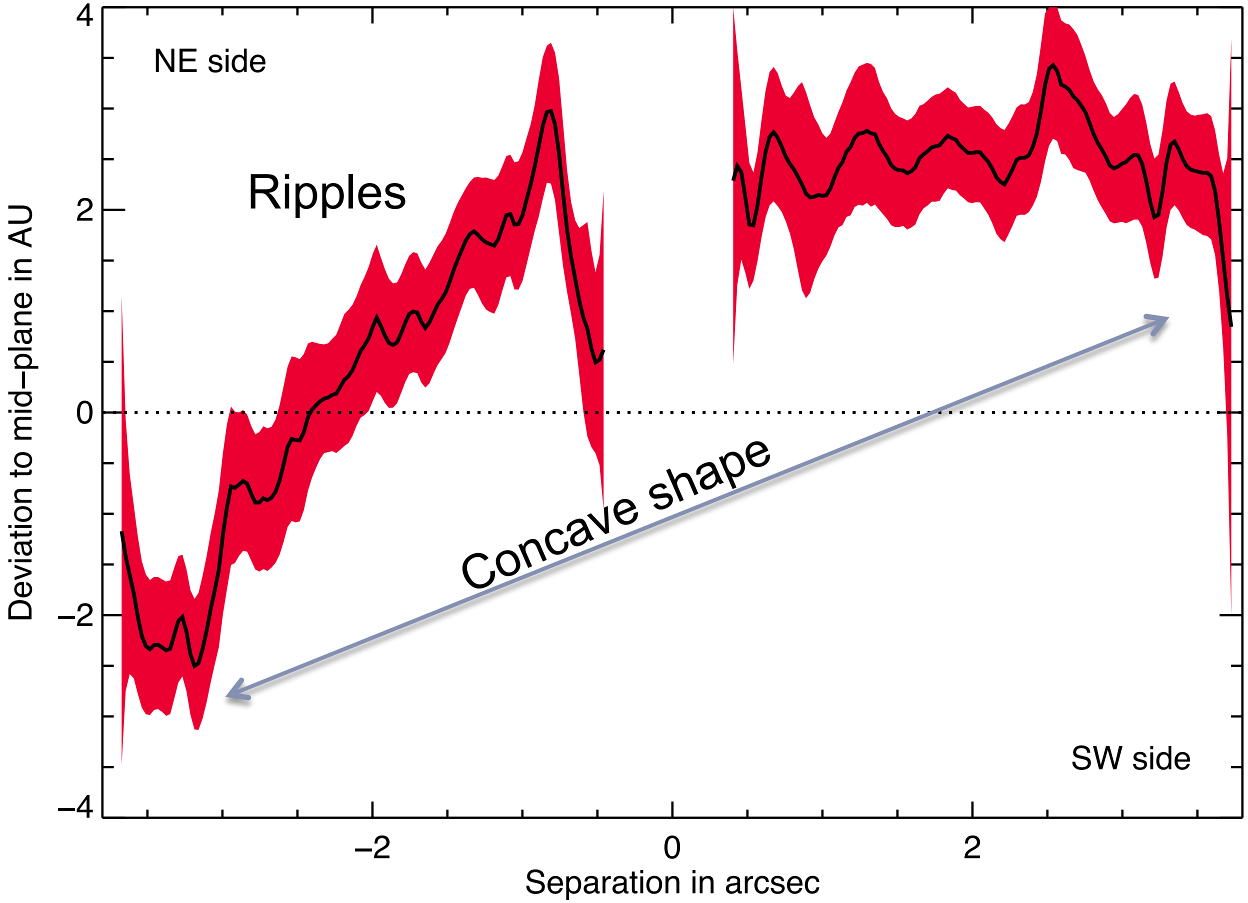
- L band (3.8μm) : resolution of 0.09 arcsec and good AO correction
- Combination of 7 deep datasets from 2009 to 2013







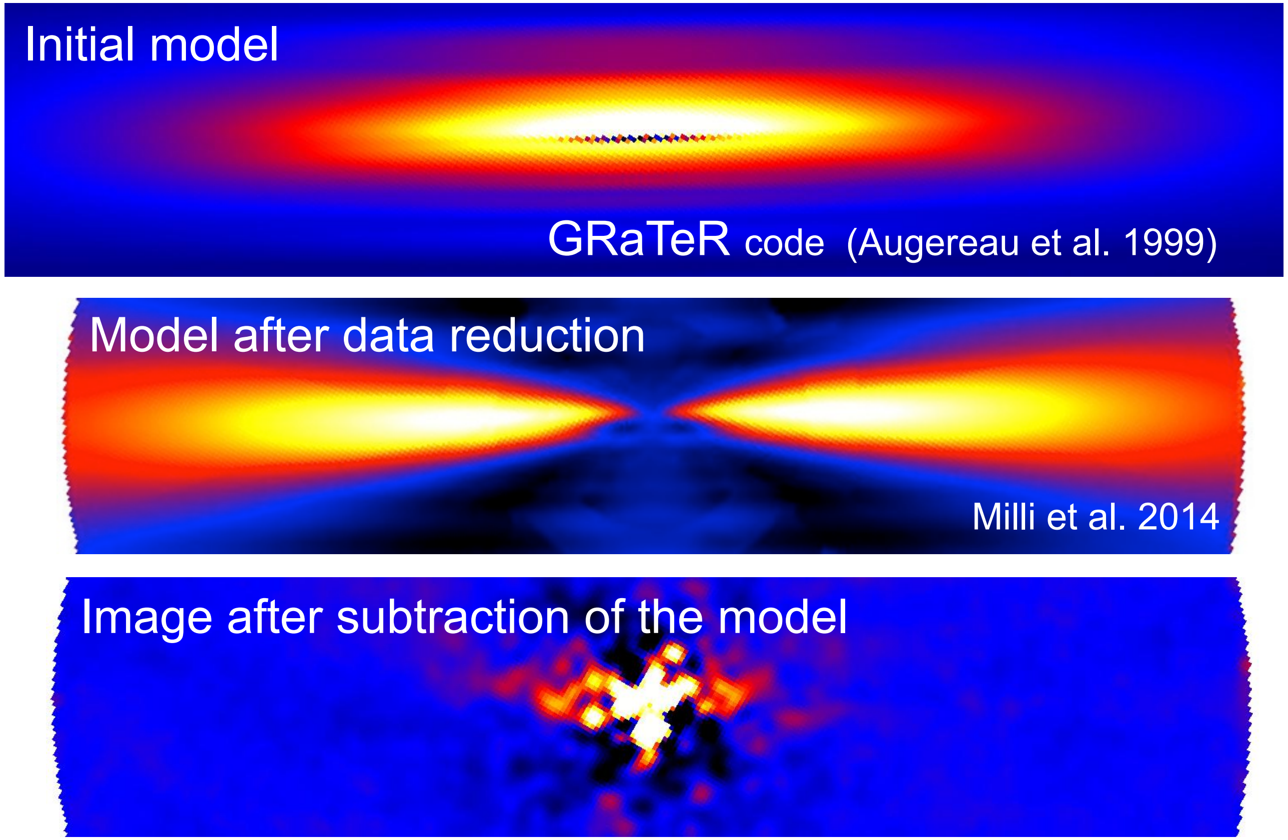
Morphology of the disc: the position of the spine



Morphology compatible with an inclined disc by a few degrees combined with anisotropy of scattering.

Modelisation

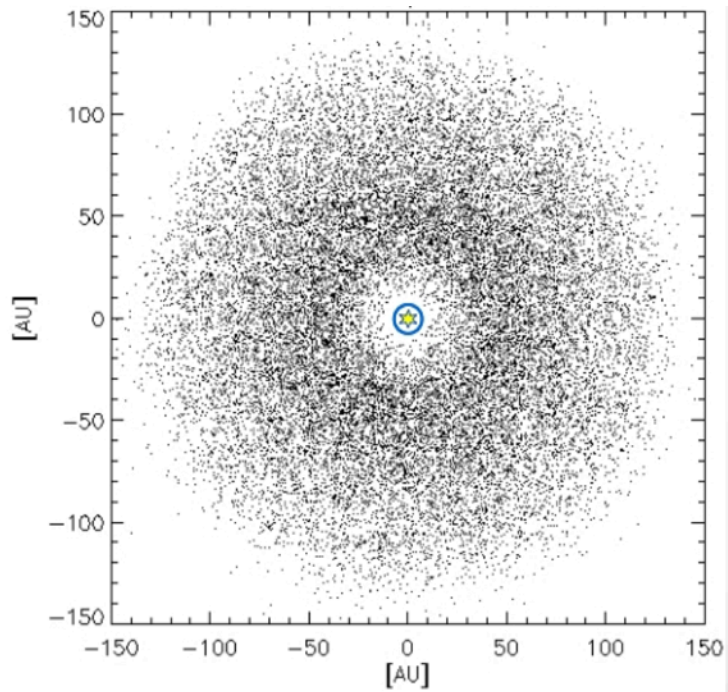
Optically thin ring of dust, scattering stellar light anisotropically.

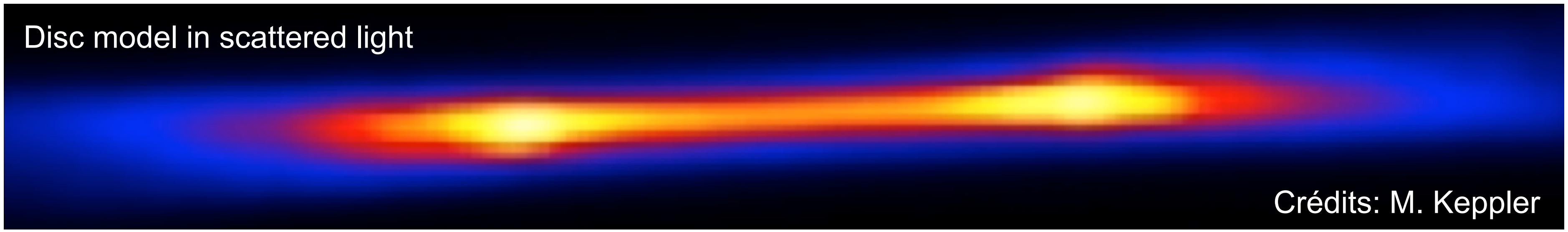


Comparison with a dynamical model

- Can the planet explain the warp and spine position ?
- Model simulating the dynamical evolution of planetesimals over 20Myrs perturbed by a planet on an inclined orbit.

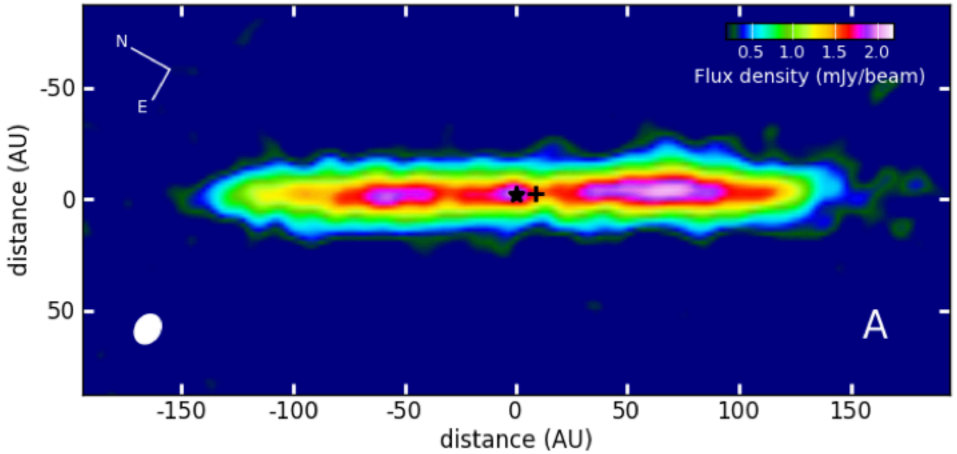
Initial population of planetesimals



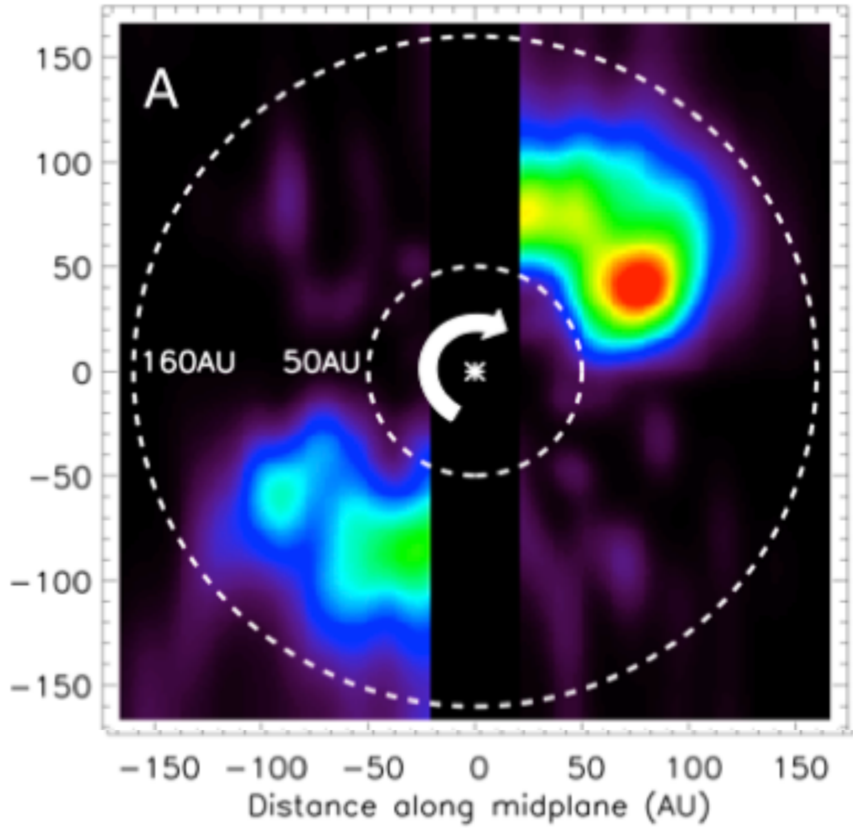


Many opened questions remaining

Image with the same resolution (0.1arcsec) obtained with ALMA



ALMA continuum, 870µm (Dent et al. 2014)



Deprojected distribution of CO

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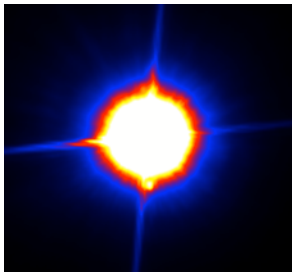
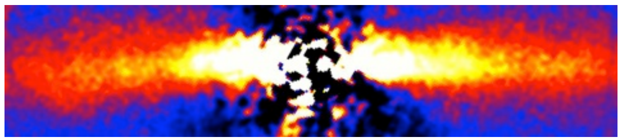
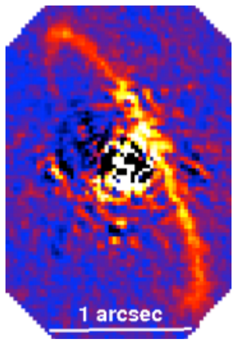
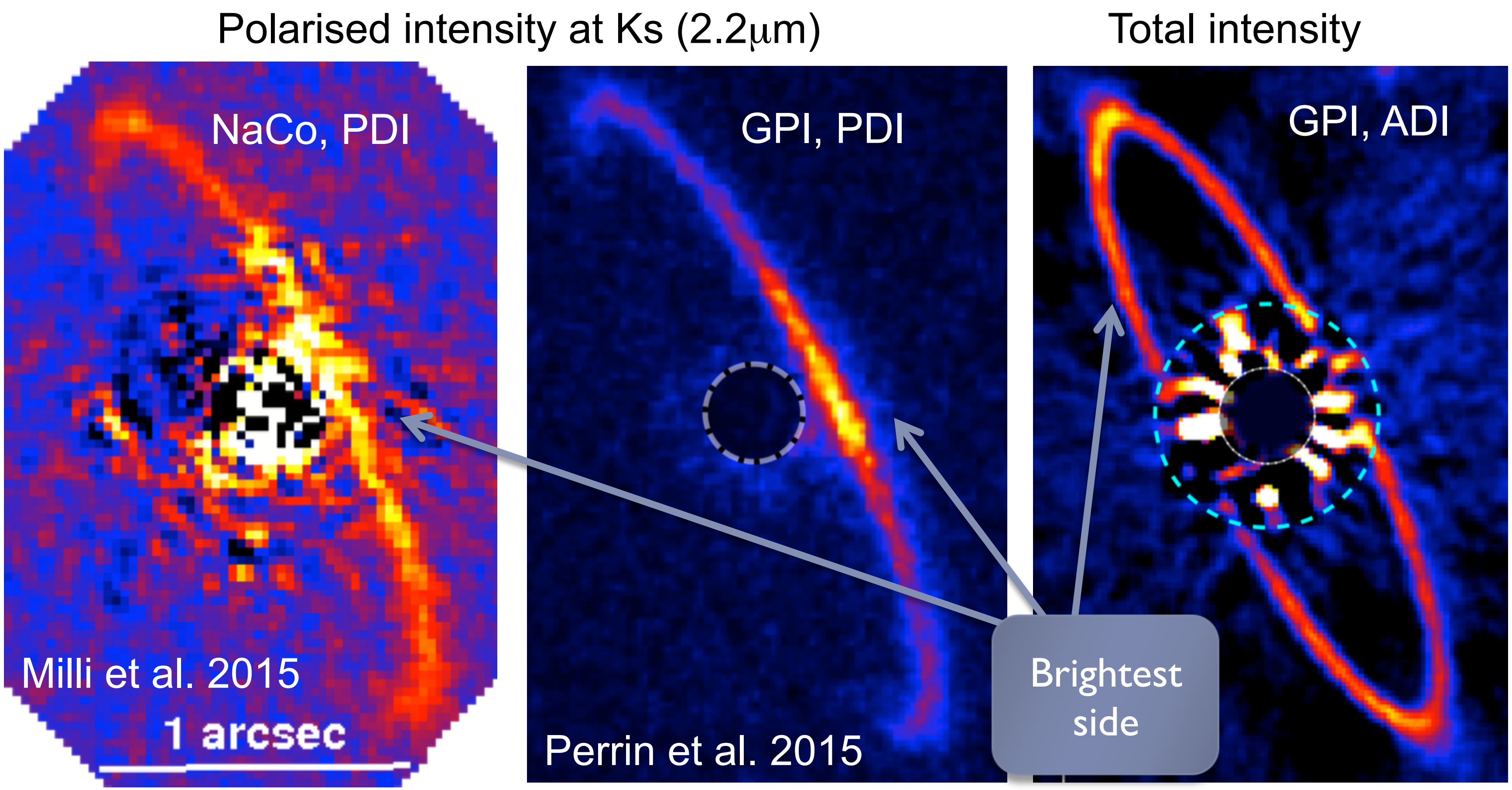






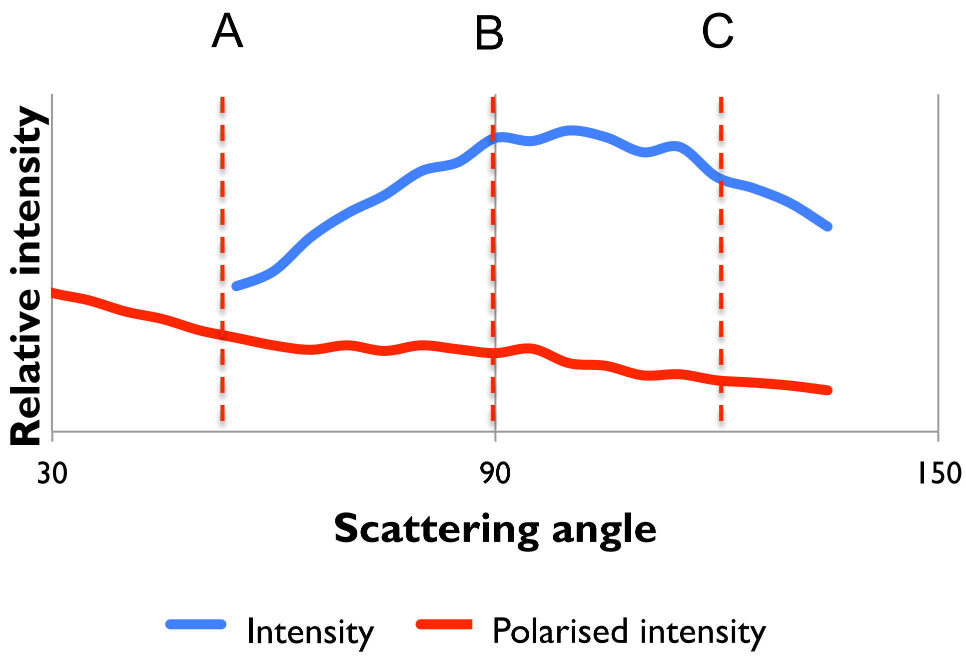
IV. The dust properties of HR4796

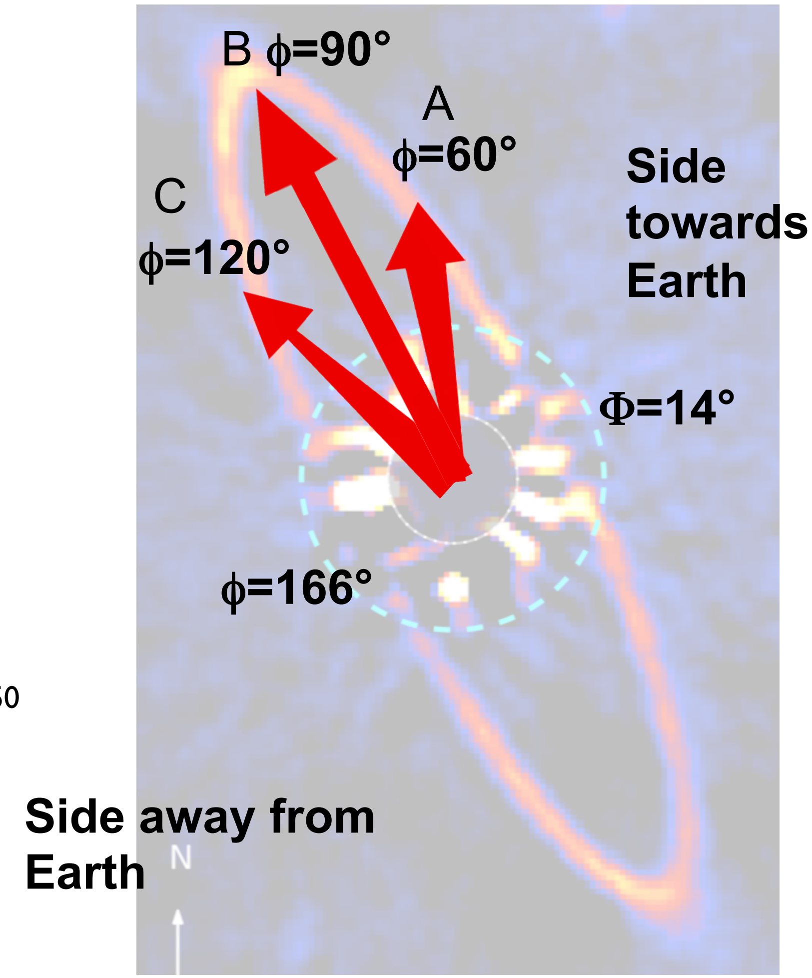


A brightness inversion occurs between polarised and unpolarised light.

Two scenarios possible

Scenario 1



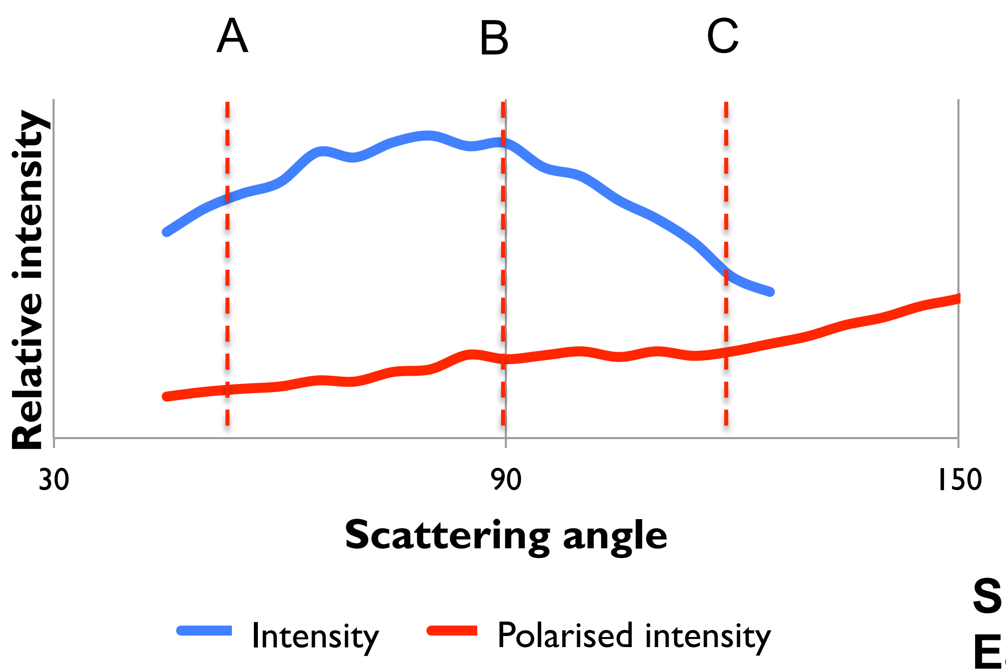


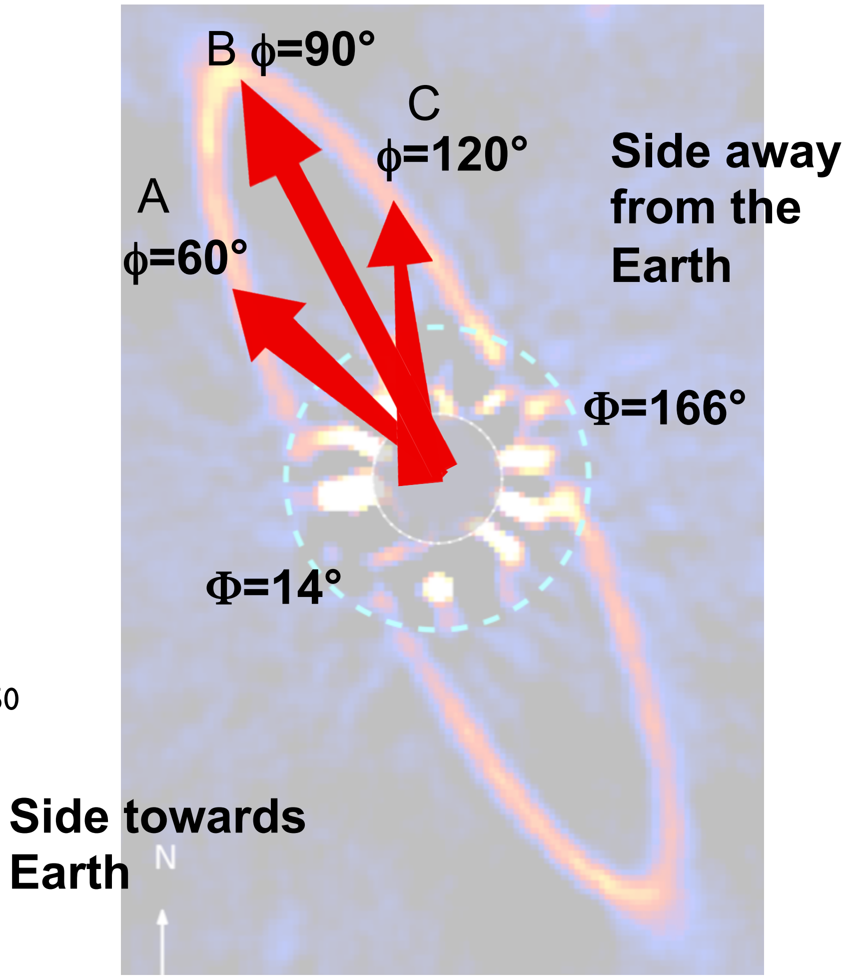
$pI_A > pI_C$

$I_A < I_C$

Two scenarios possible

Scenario 2



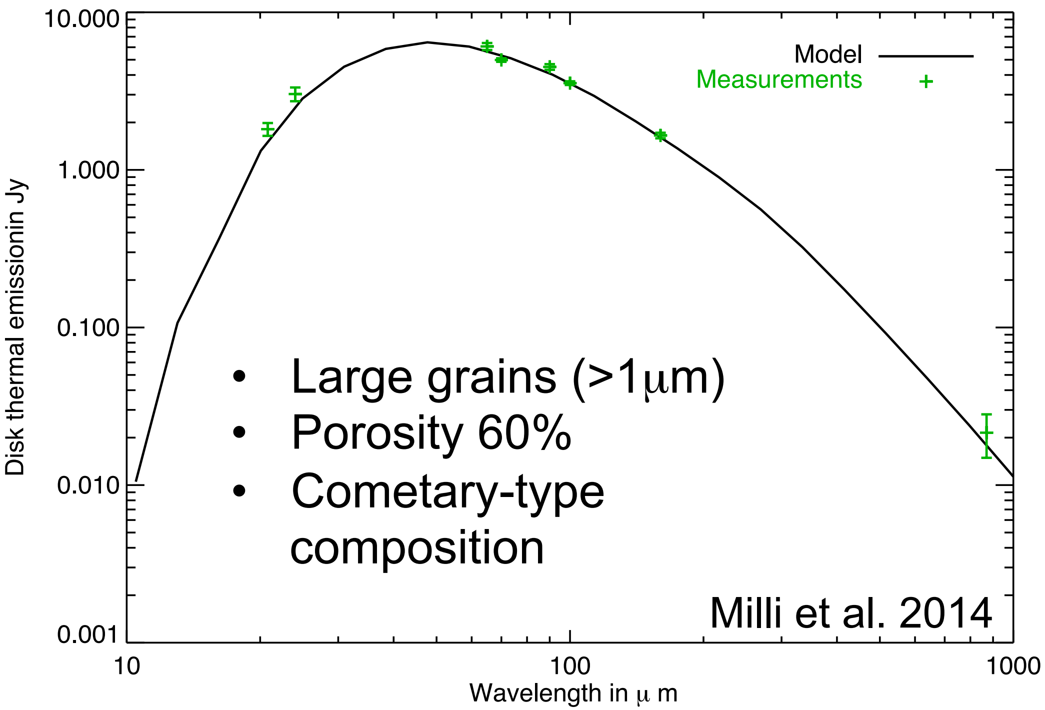


$pI_A < pI_C$

$I_A > I_C$

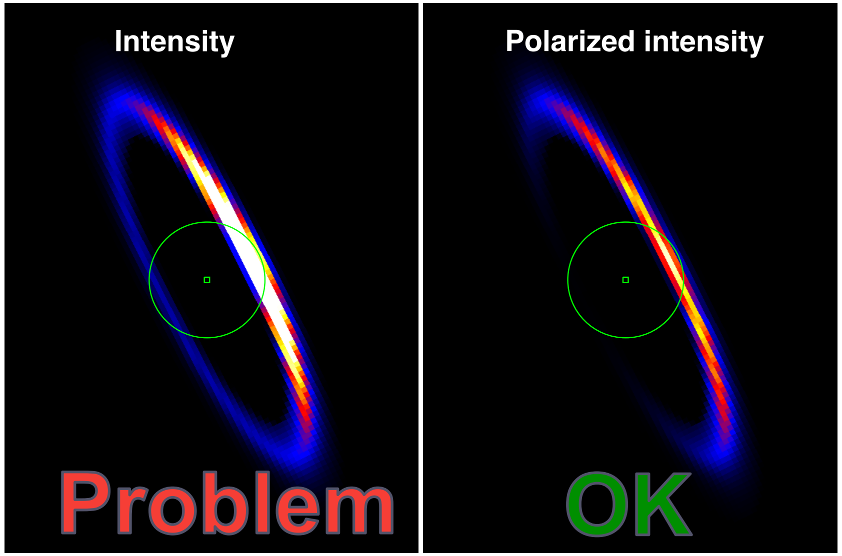
What does the theory say?

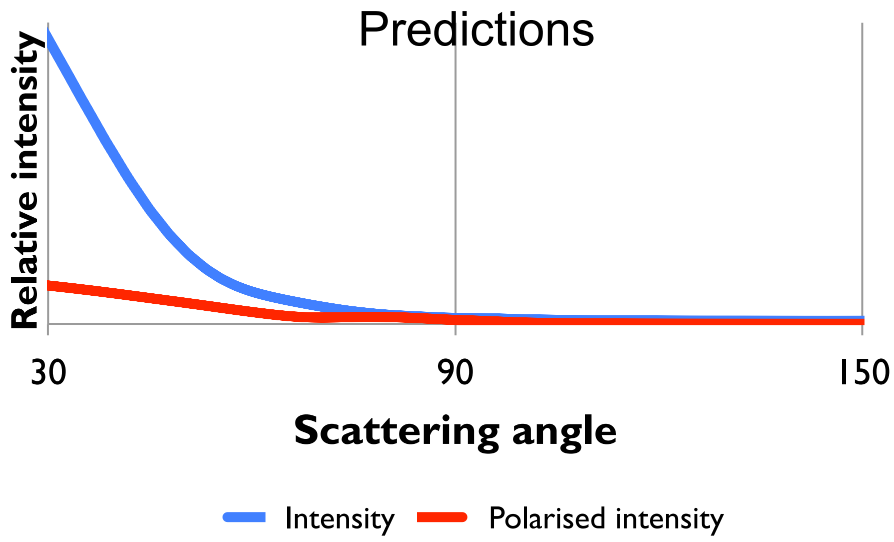
- Constraints from the Spectral Energy Distribution
  - Free parameters: size, distribution and composition of the grains

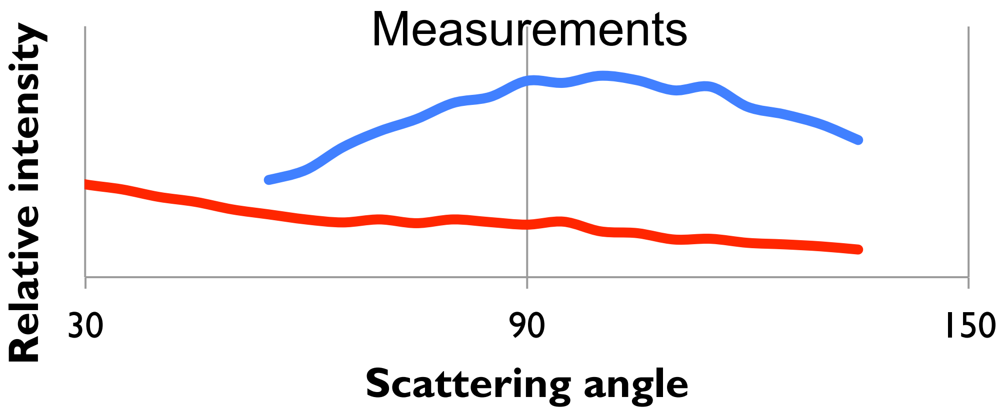


- Modelling the scattering
  - Mie (1908) and Distribution of Hollow Spheres (DHS, Min et al. 2005)
  - Fundamental assumption: spherical grains

Incompatibility between theory and observations

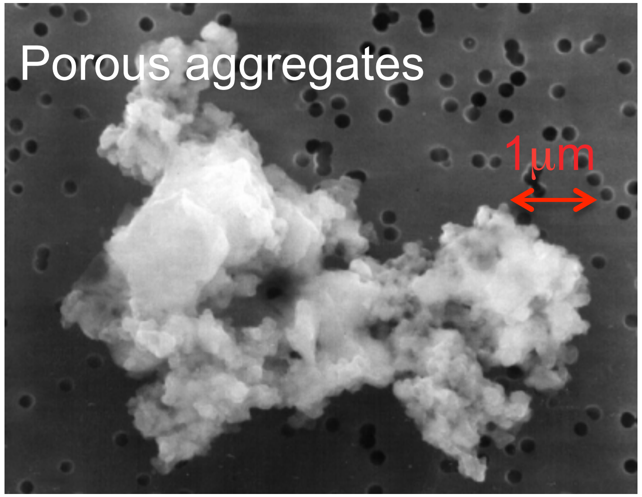






Incompatibility with the scattering phase function

Discussion on the assumption of spherical grains



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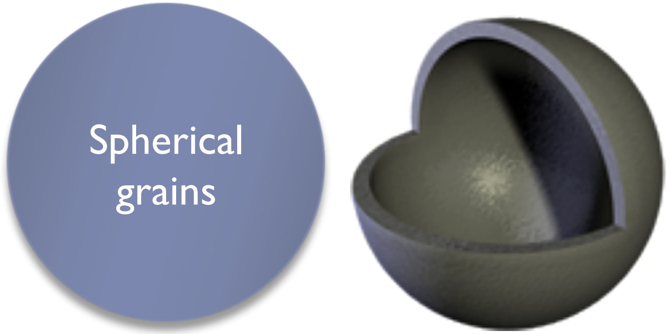
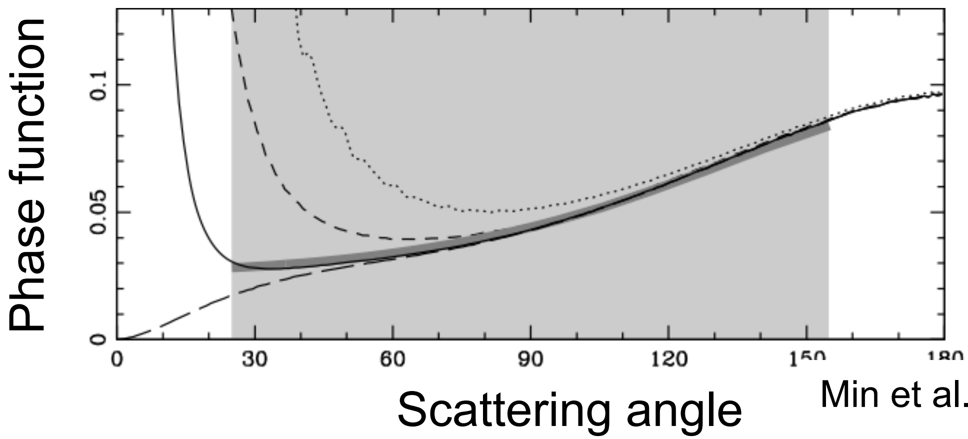


Mie

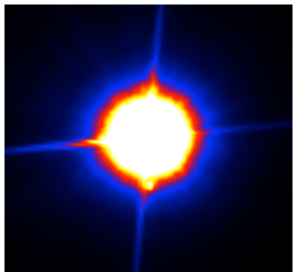
DHS

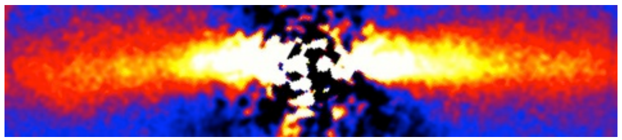
Possible solution
1) Porous aggregates with a phase function increasing beyond ~70º
2) Optical depth close to 1, proposed by Perrin et al. 2015.

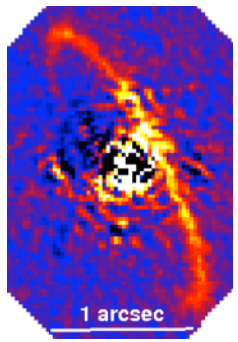


Min et al. 2010

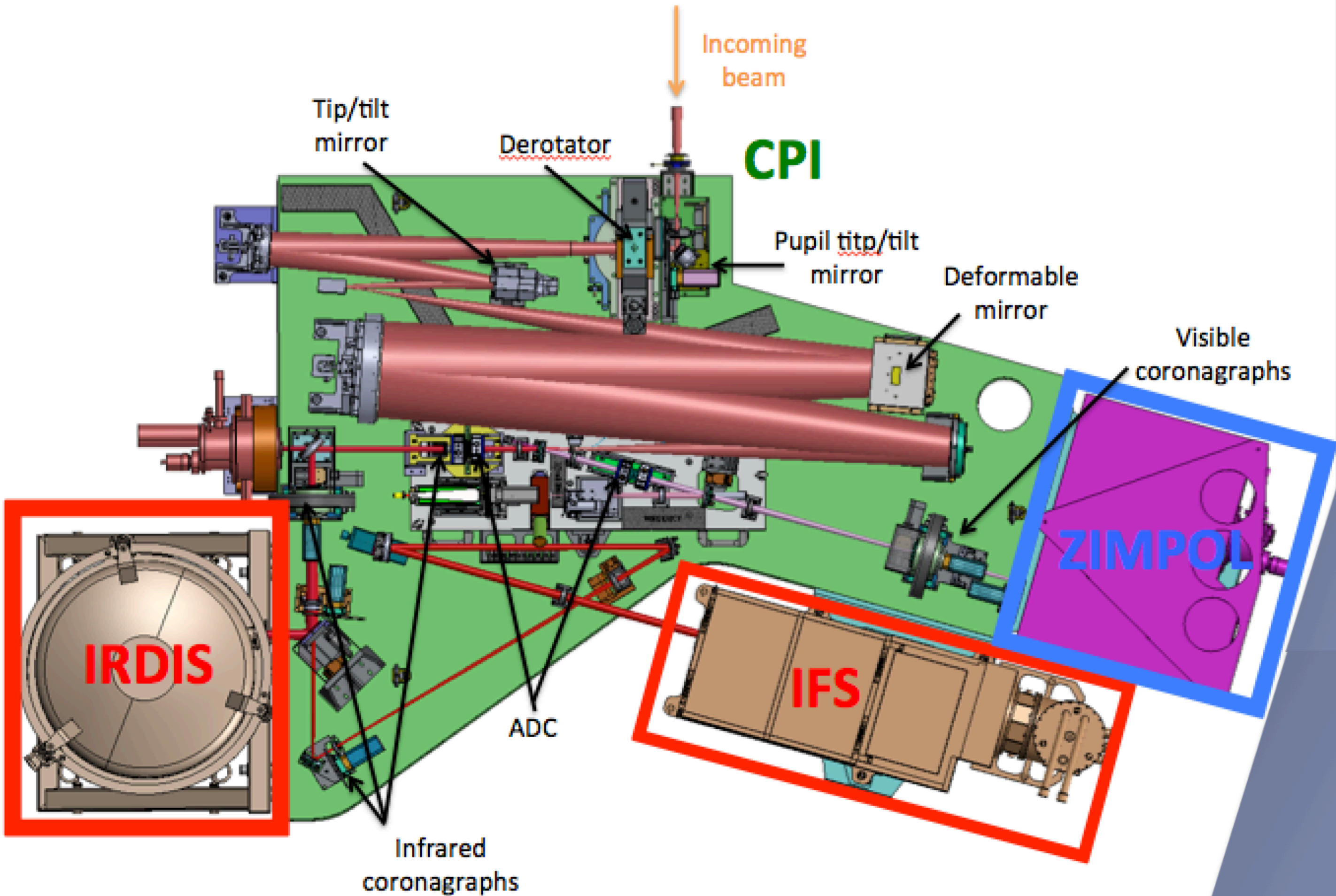
Content

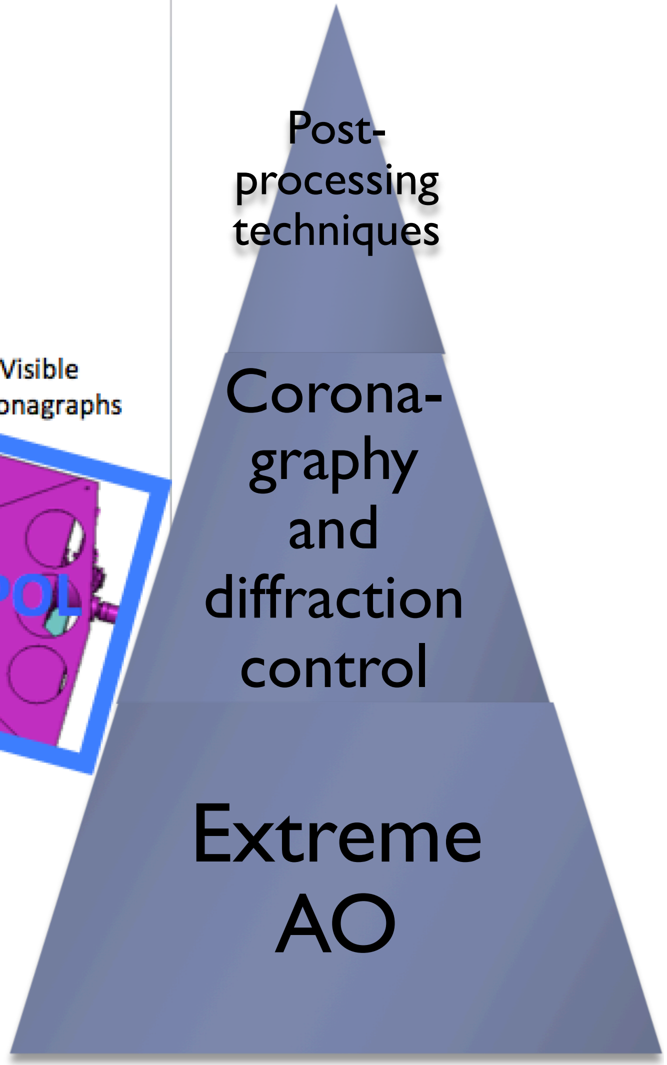




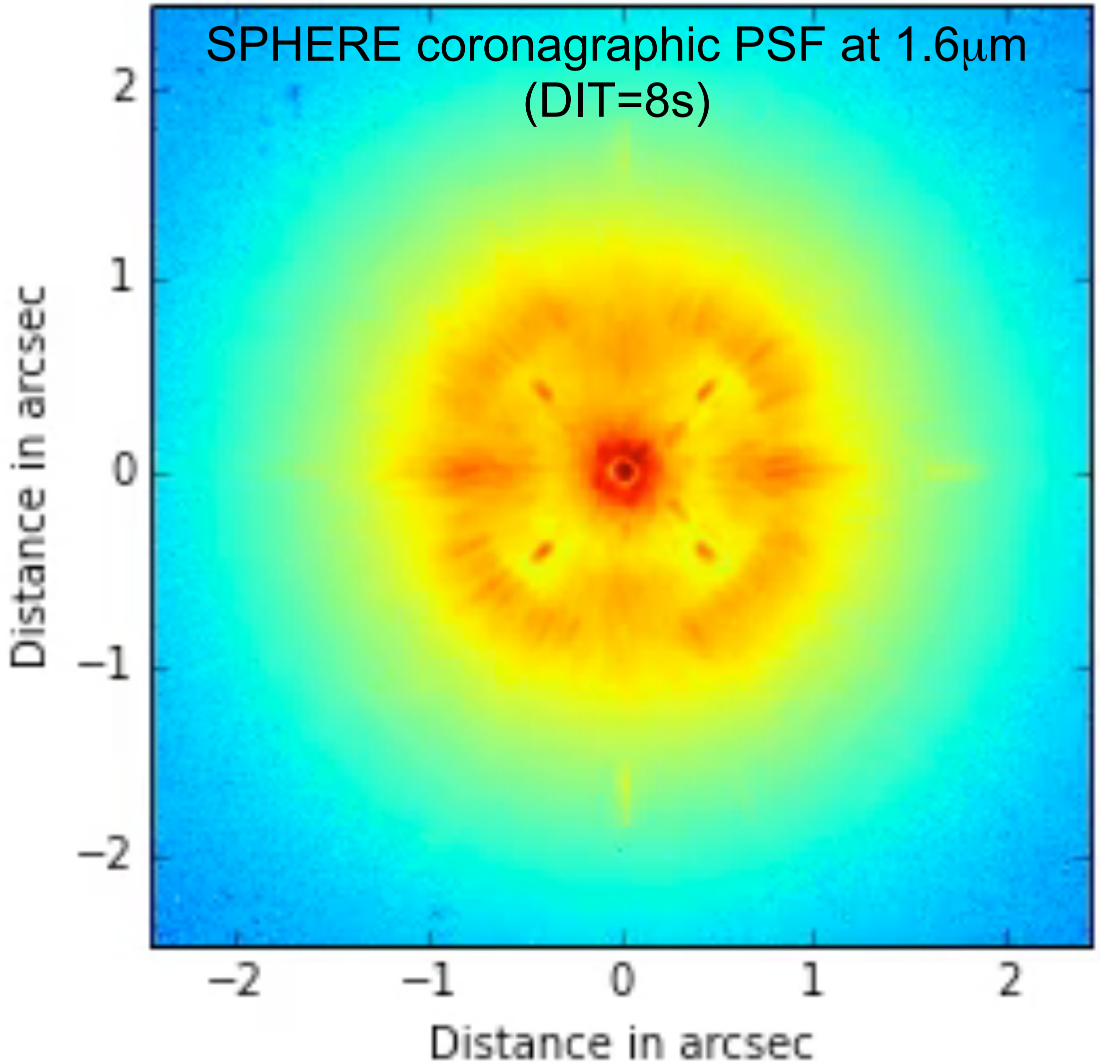


V. SPHERE in a nutshell

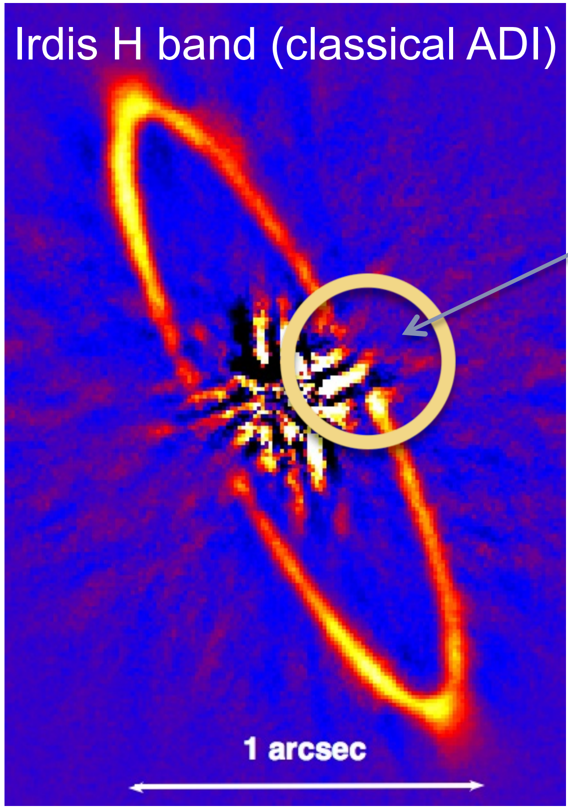




SPHERE secrets: stability, high Strehl, and diffraction control



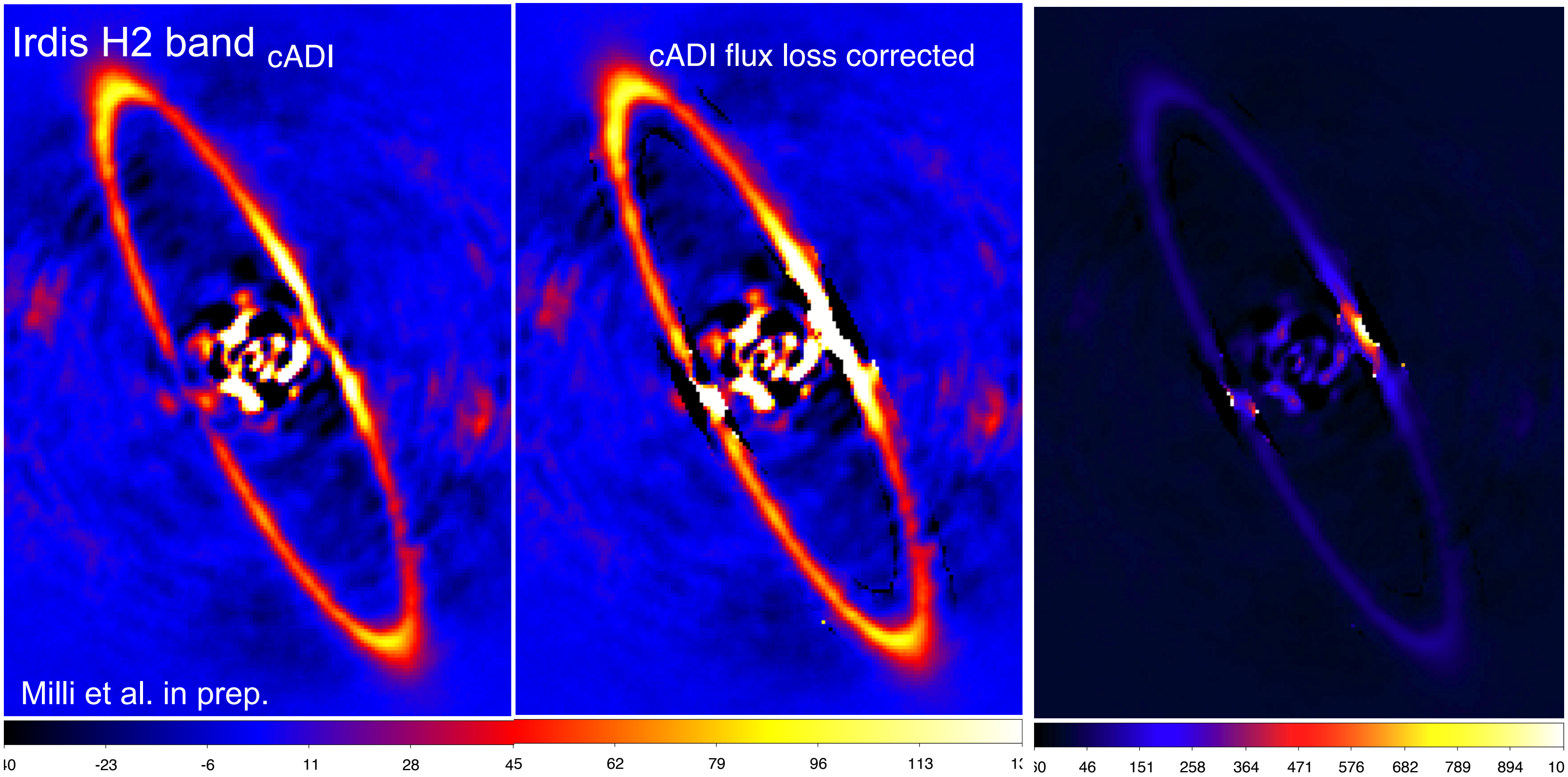
Final say for HR4796 with IRDIS



Critical region

Still strong residuals along the semi-minor axis preventing a clear-cut statement

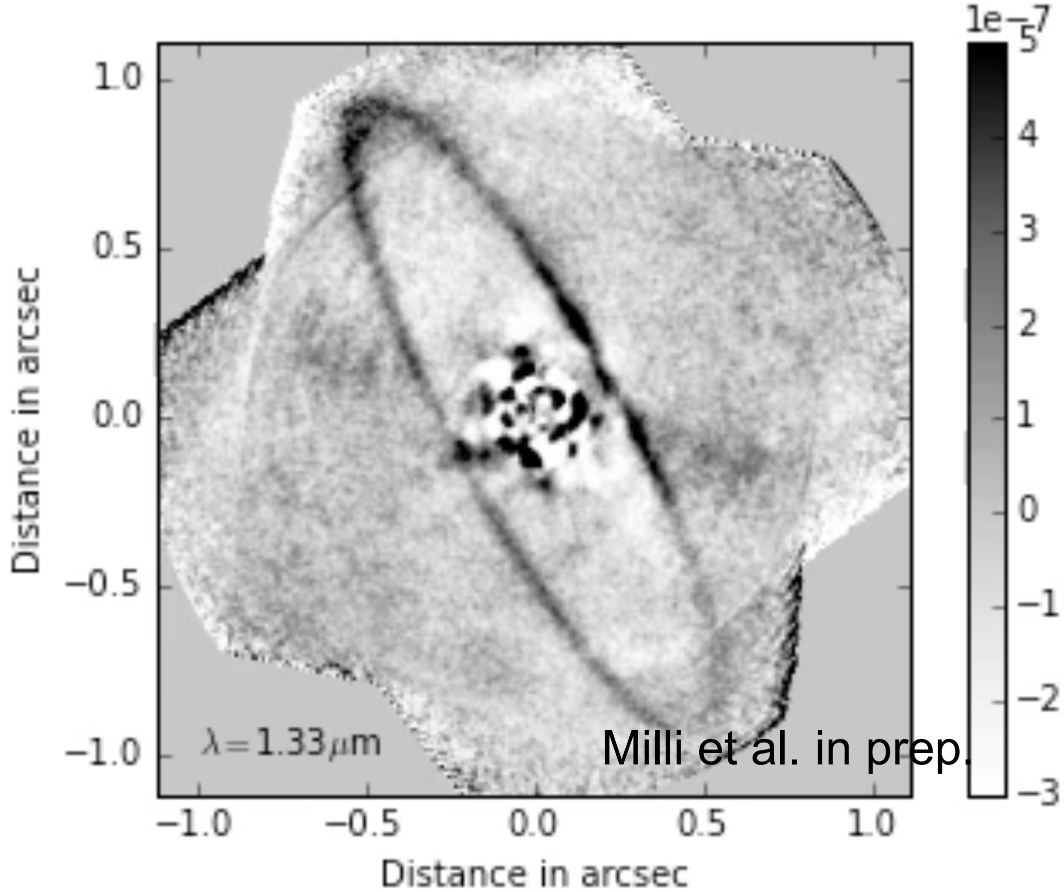
Final say for HR4796: second chance with IRDIFS

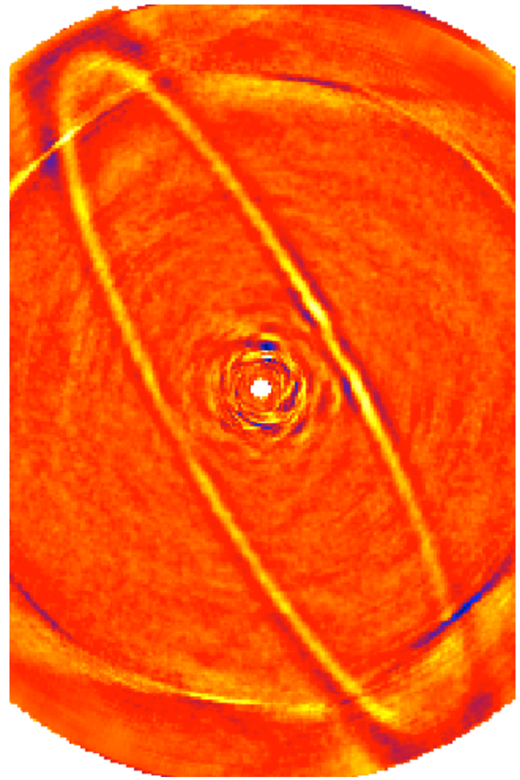


Disk detected entirely, even along the semi-minor axis (0.3")

Final say for HR4796: second chance with IRDIFS

The IFS reveals the dust properties from 0.95μm to 1.3μm





Exploiting the spectral dependance of speckles

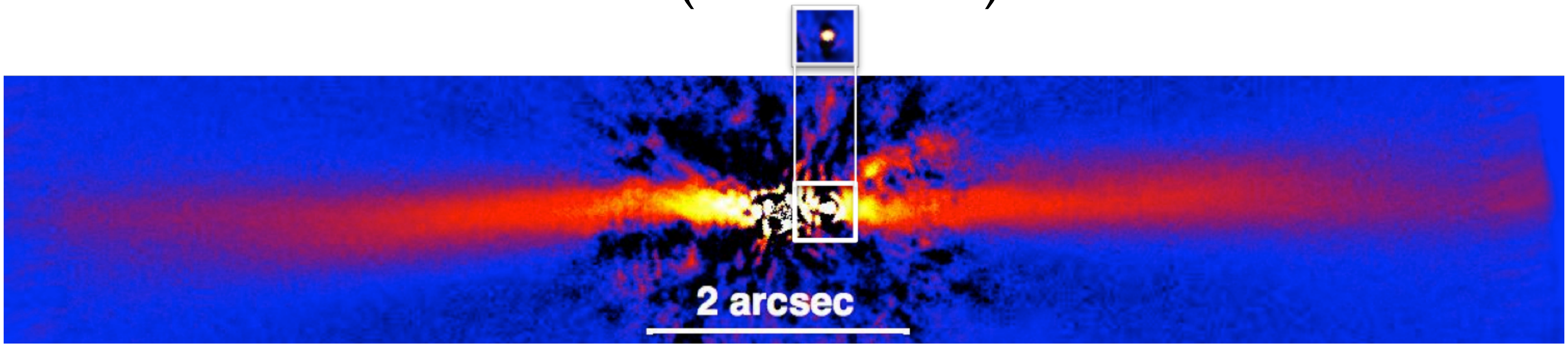
Wavelength dependance of the albedo and phase function

Dust albedo (integrated along the disc)

The dust has a red color, as previously reported by HST
(Debes et al. 2008)

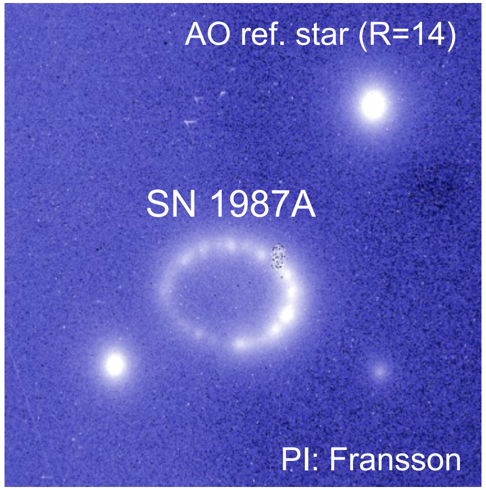
Conclusions

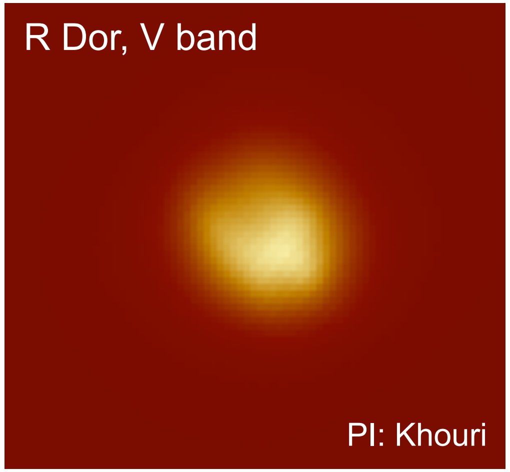
- This work, at the frontier between instrumentation and interpretation enabled to:
  - Investigate optimal data reduction strategies
  - Apply them to two famous examples to study the dust properties (HR4796) and dust morphology (β Pic)
- Next challenge: access very short separations (warm dust, planet/disc interactions) with multi-wavelength, multi-technique approaches, combining all available high-angular resolution instruments (ALMA / VLTI)

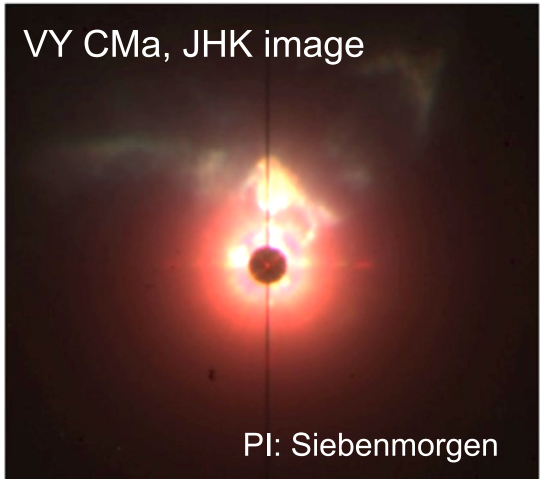


Nasmith plateform, UT3

Evolved star science with SPHERE (Science Verification results)







Planet search around the young (125Myr), nearby (31pc) white dwarf GD50

Xu et al. accepted in A&A
Today on astro-ph