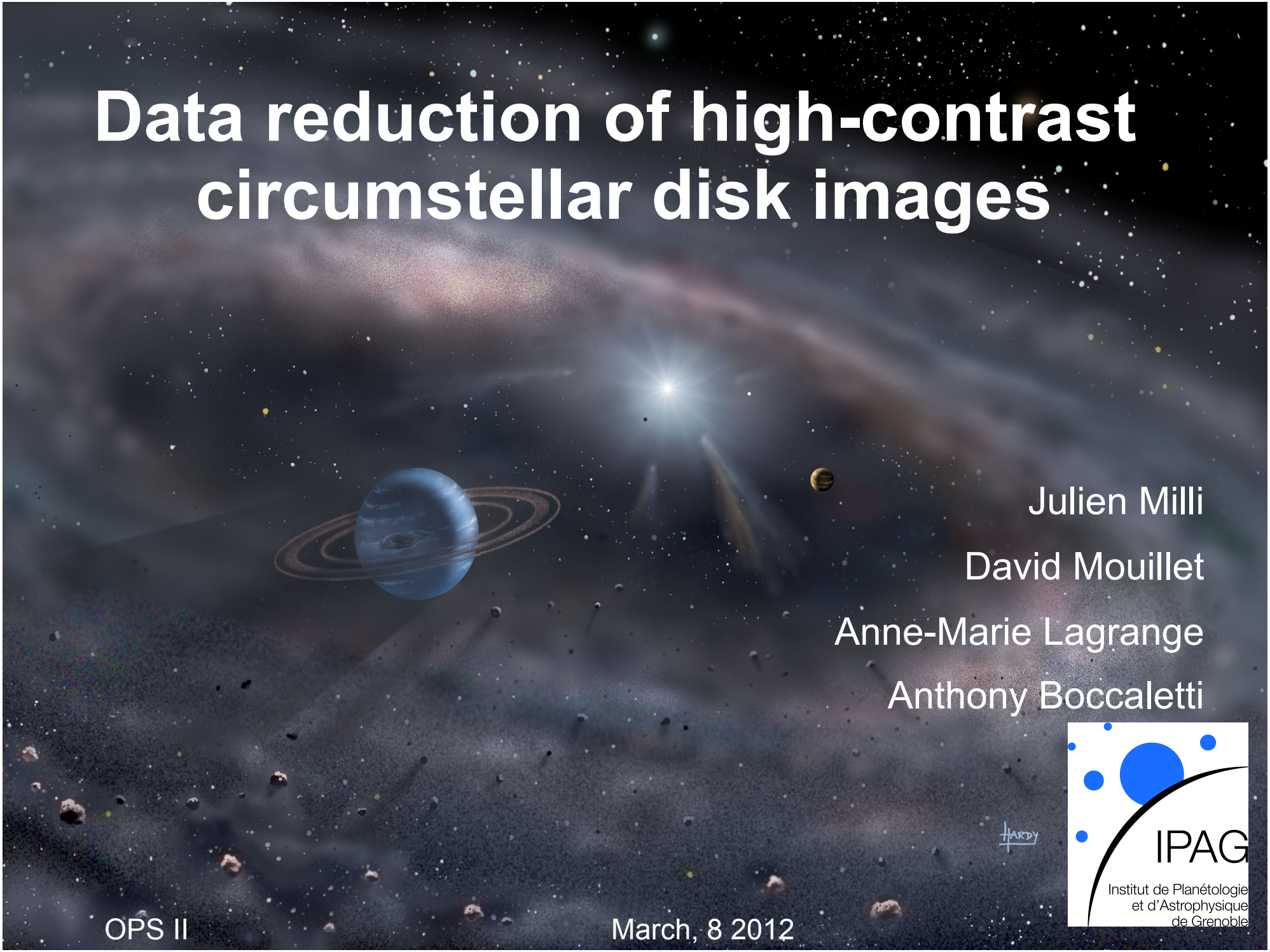
Data reduction of high-contrast circumstellar disk images



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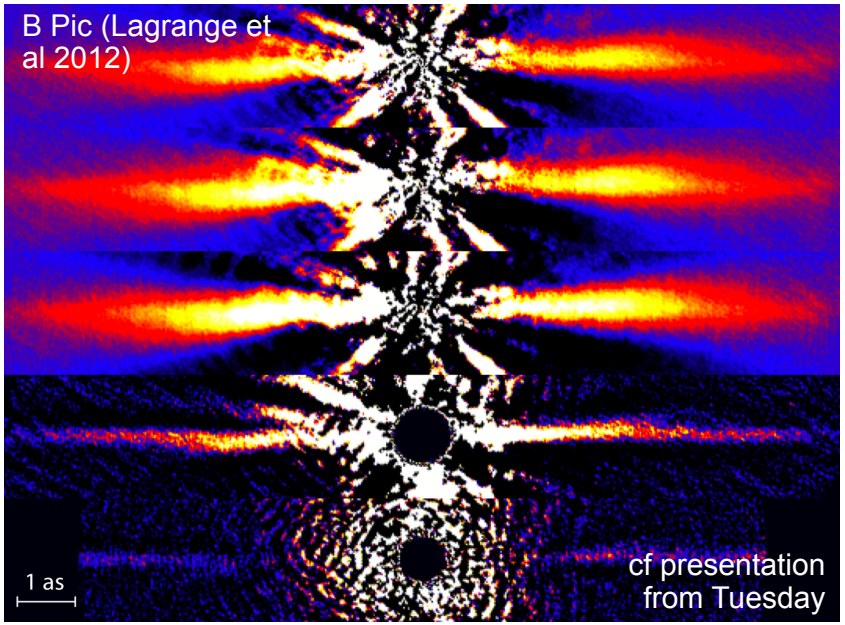
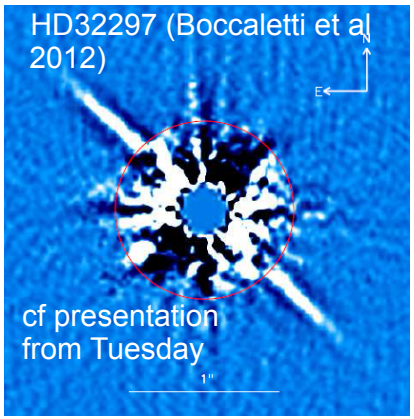
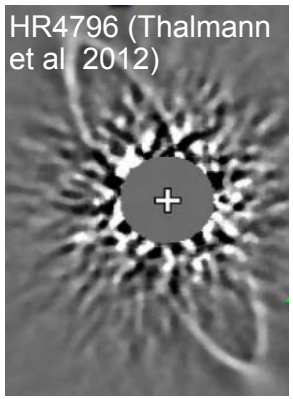
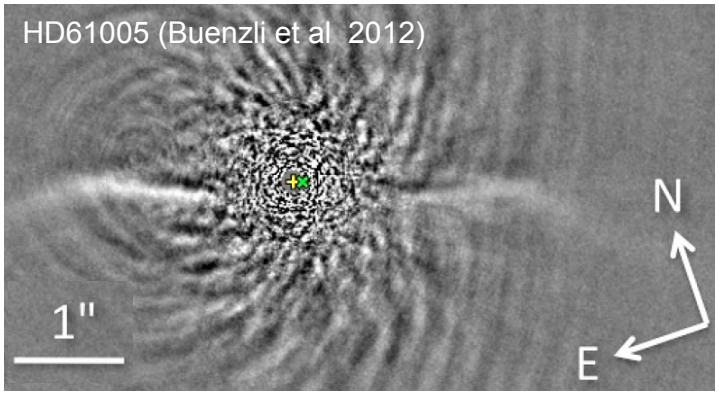
Introduction: disk imaging



- Objective: reach a high contrast, close to the star
- Difficulties: quasi-static speckles
- ADI: a successful technique for ground-based observations





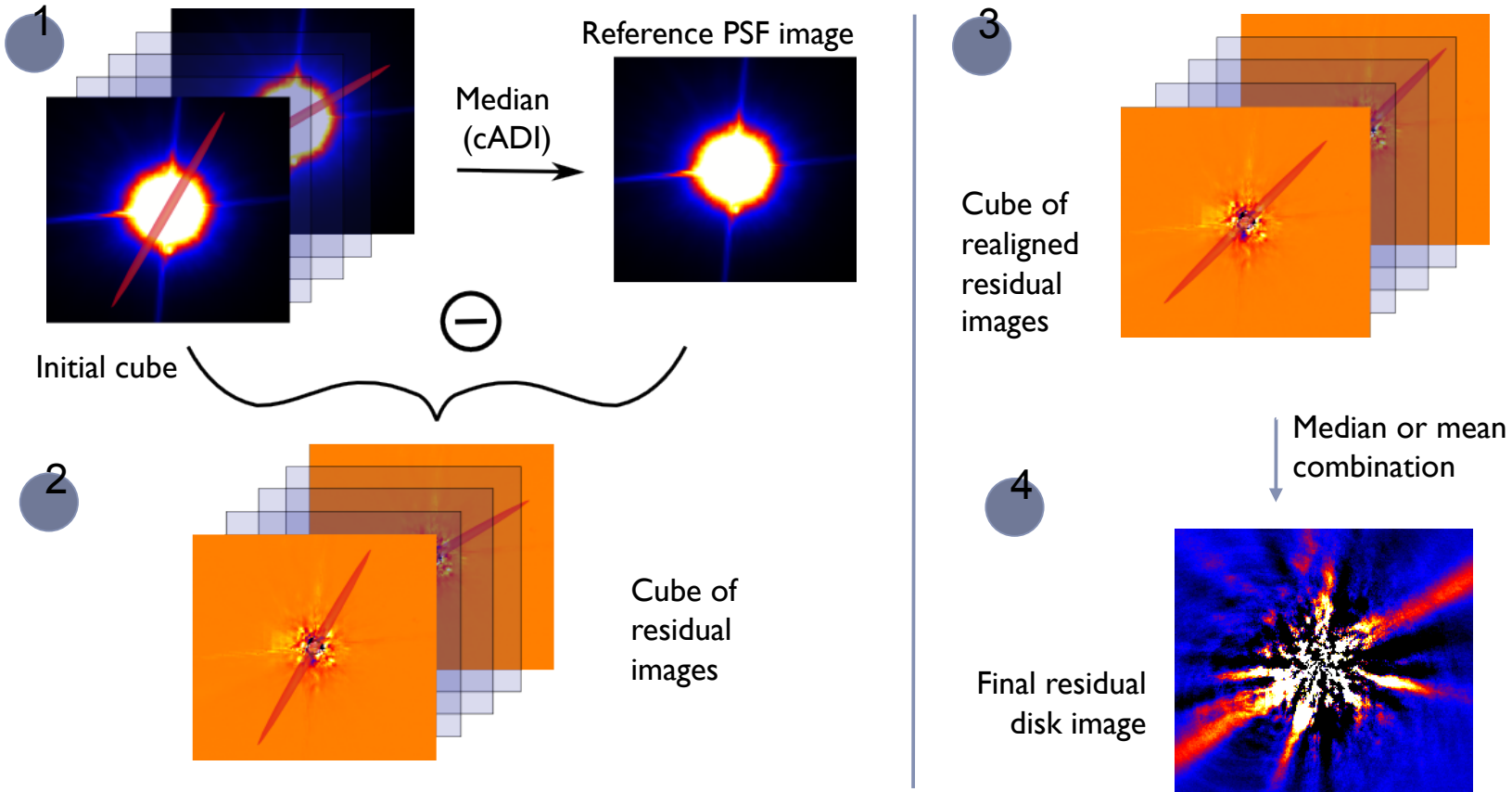


Outline

I. Angular Differential Imaging (ADI) applied to disks

II. Application to the HR4796 debris disk

I. Angular Differential Imaging

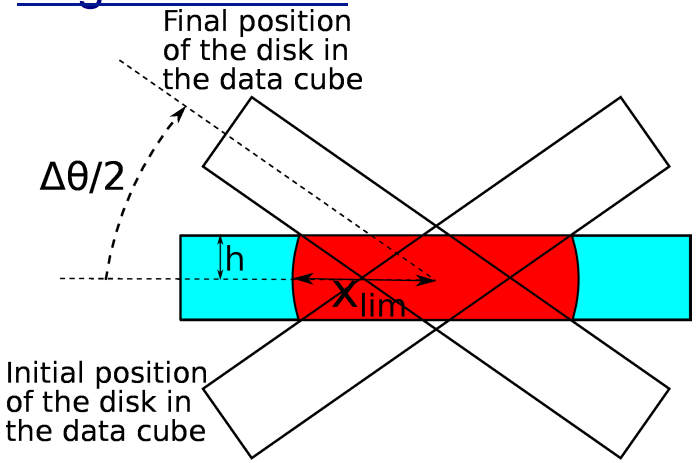


Disk self-subtraction can occur

Marois et al 2006

ADI applicability

- Edge-on disks: flux losses can be predicted theoretically

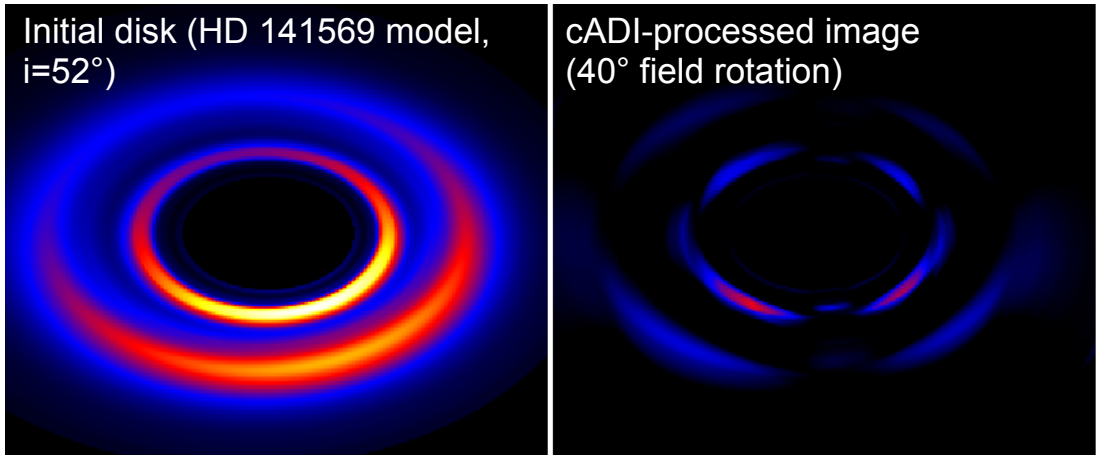


Self-subtracted region

Preserved region

Key parameter: ratio Δθ/h

- Nearly pole-on disks or i<50°: ADI inappropriate

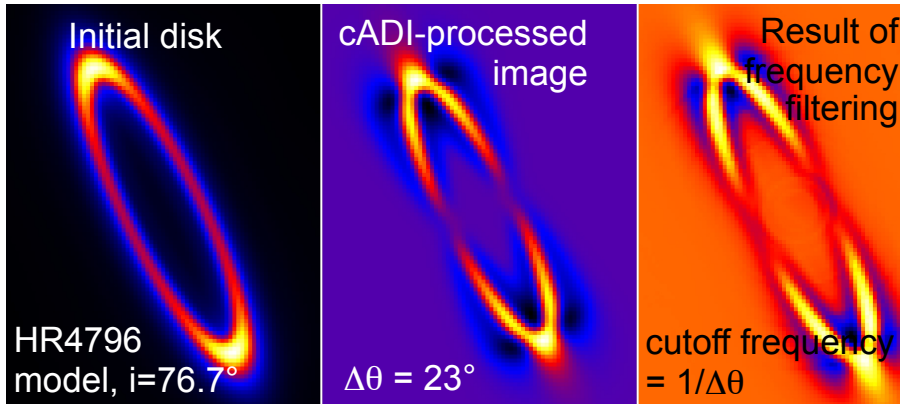


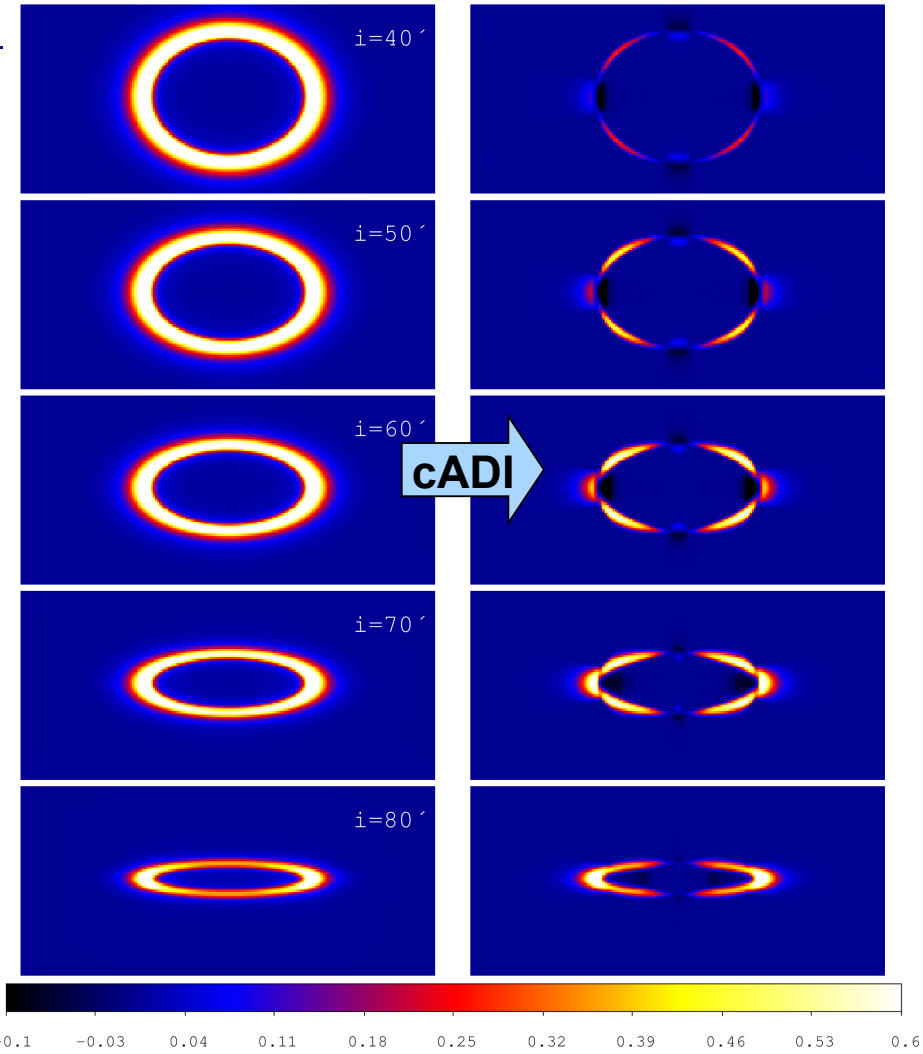
ADI applicability

- General case of an inclined ring:
  - Flux losses
  - Negative regions
  - Streamers
  - Extinctions

How do we understand those features?

- ADI ~ high pass frequency filter along azimuthal profiles

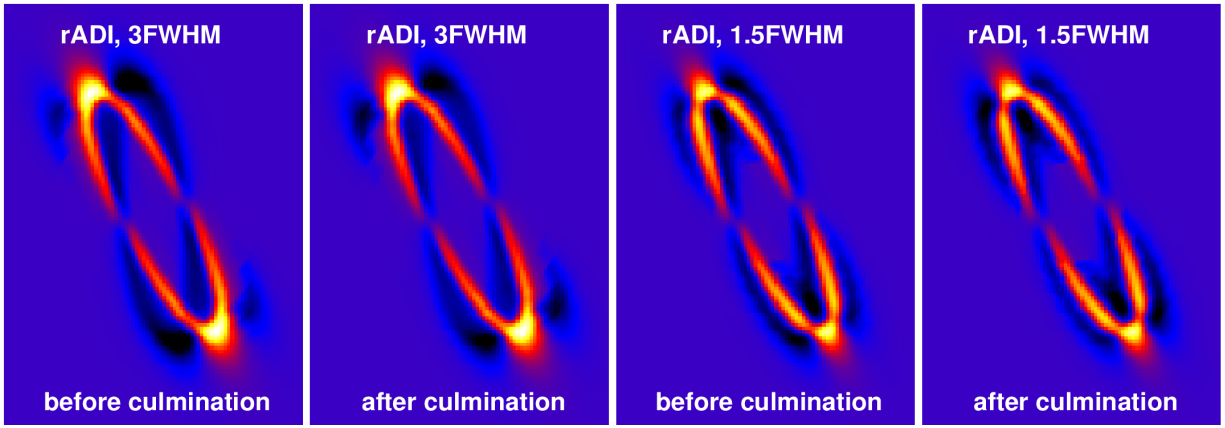




Variations from classic ADI

- Radial ADI:
  (Marois et al 2006)
  separation criteria N_δ

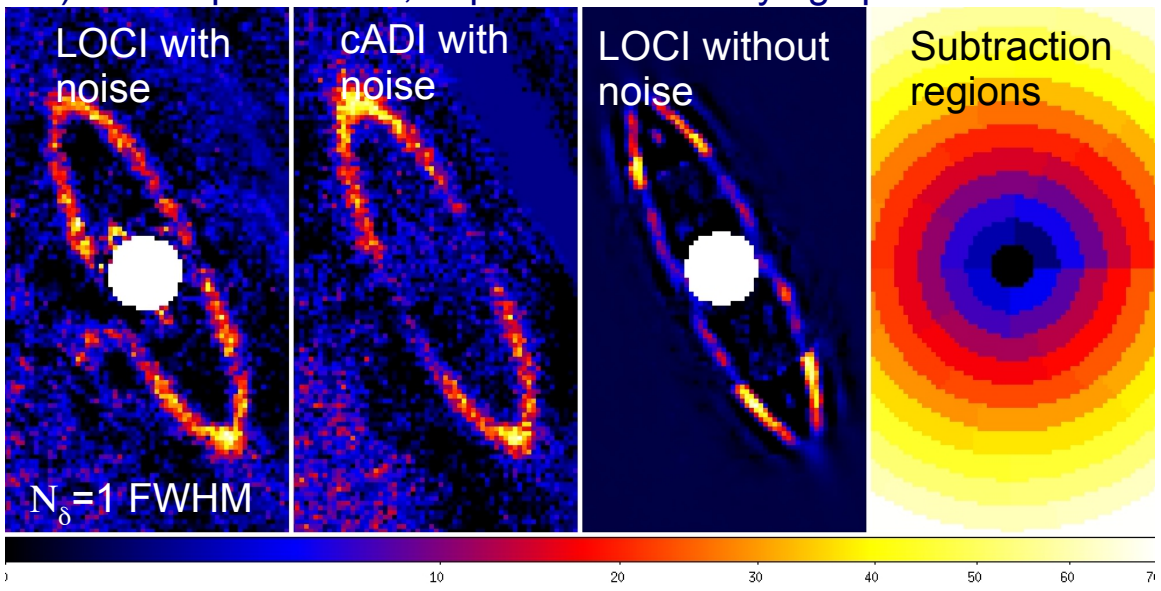
Key parameter: N_δ instead of $\Delta\theta$



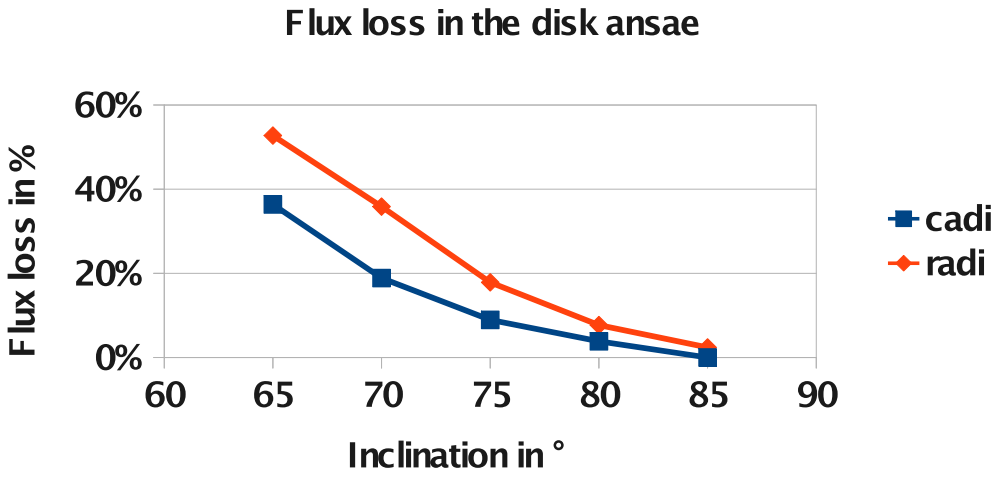
- LOCI (Lafrenière et al 2008): local optimization, depends on underlying speckle noise

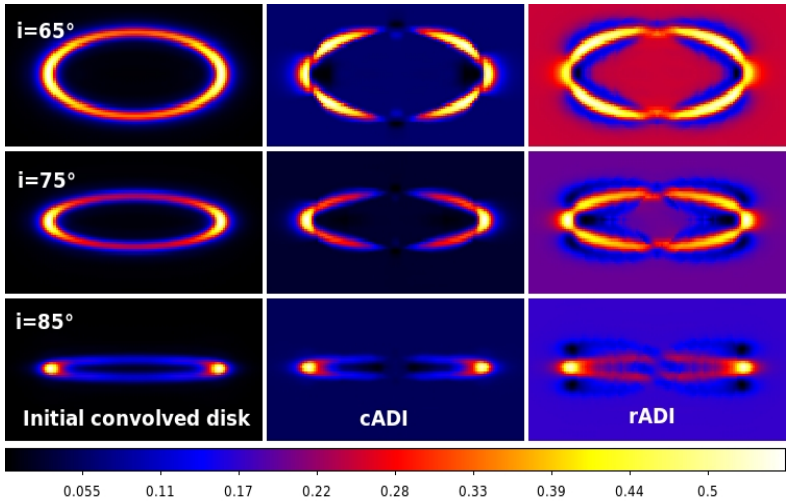
Be very careful with LOCI !

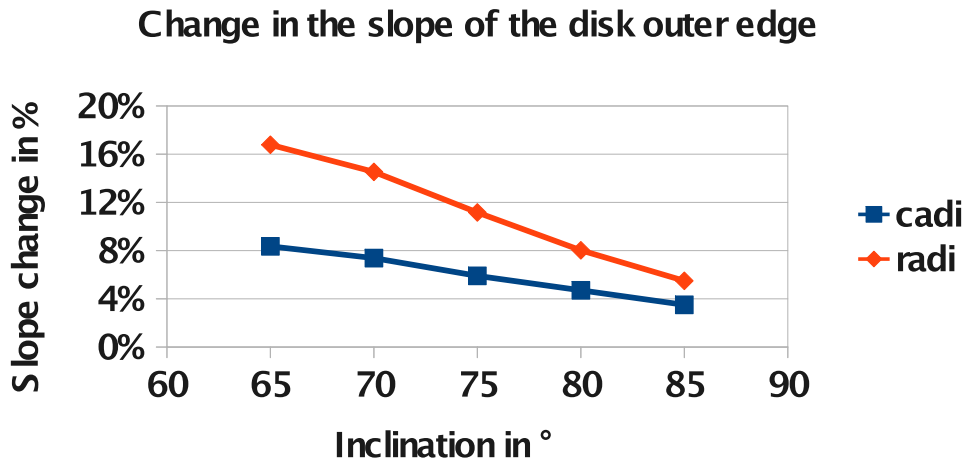
- Enhancements masking, iterating



ADI measurable effects







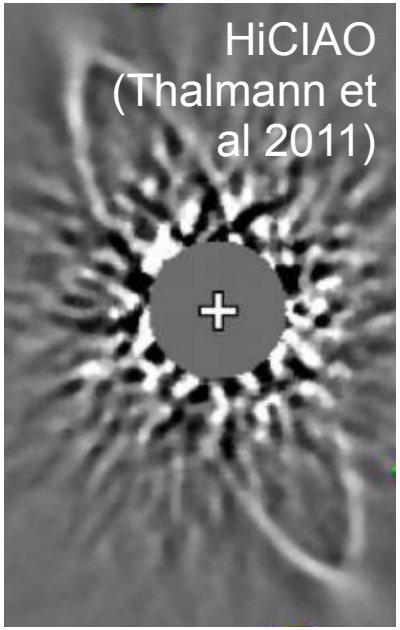
The smaller the inclination, the larger the changes in the disk properties

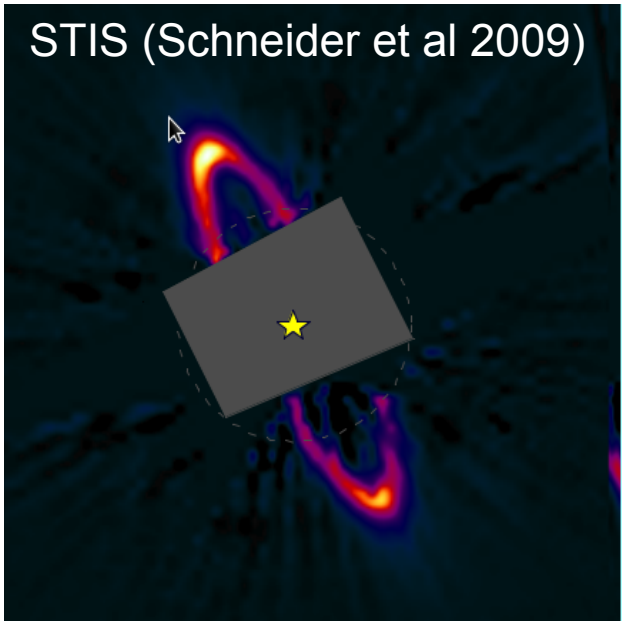
(Milli et al in preparation)

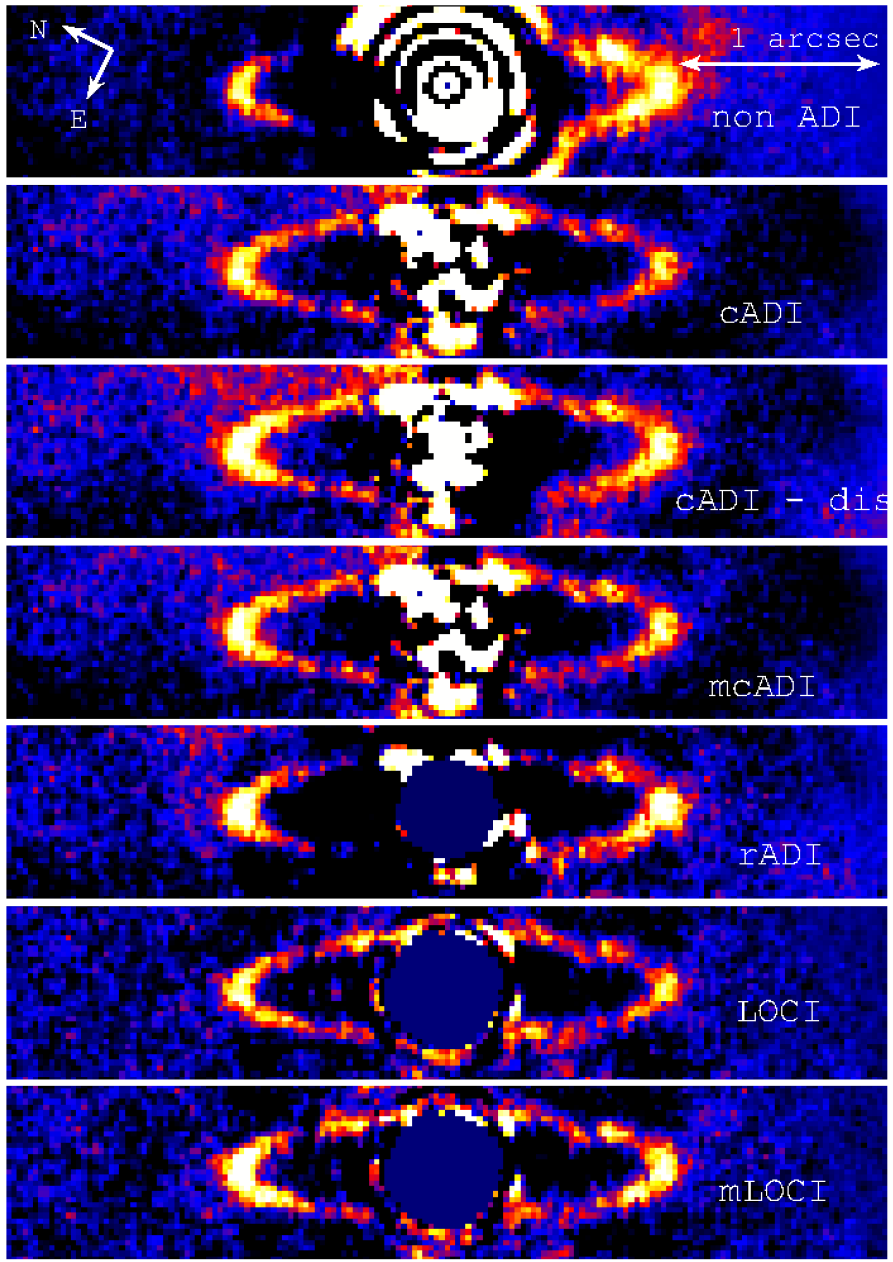
II. Application to HR4796

- A0 star, 8 Myr, d=73pc
- Resolved in mid-IR, in near-IR with NICMOS/HST (Schneider et al. 1999) and HiCIAO/Subaru (Thalmann et al 2011), and in visible with STIS/HST (Schneider et al 2009)

- Narrow cold ring at ~77 AU
- M-type stellar companion at 7.7”







New images and their peculiarities

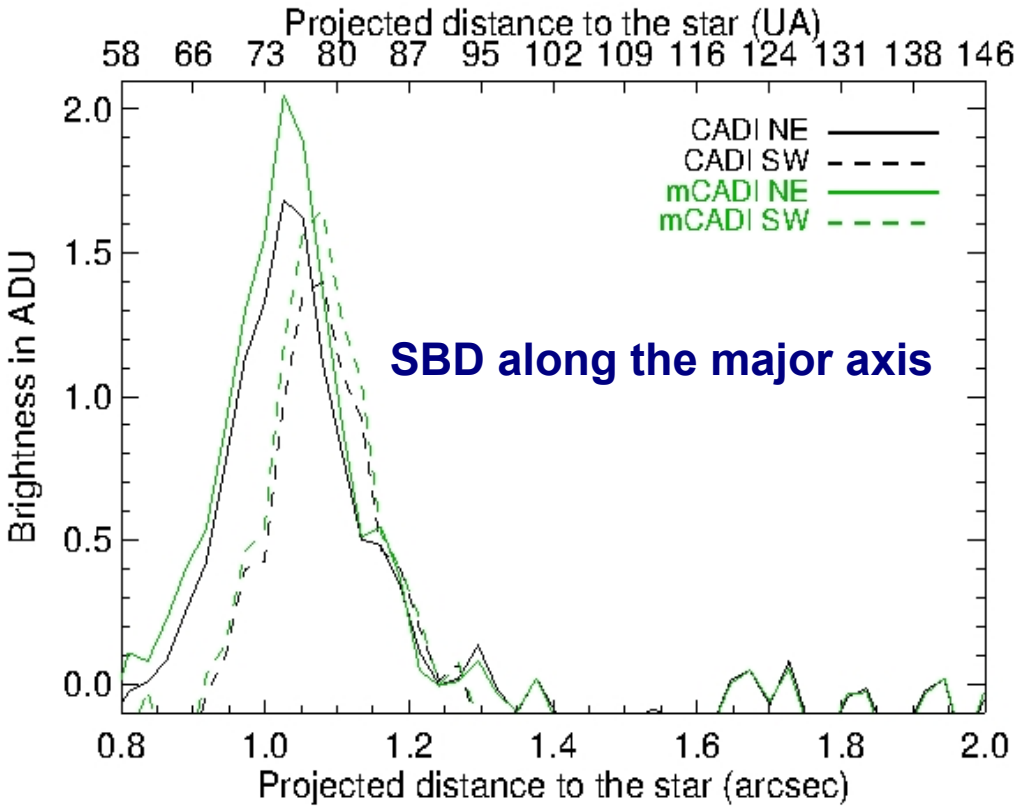
NaCO L' band (3.8μm)
combination 6/7 April 2010
ADI with 77° and 83° FoV rotation
(Lagrange et al 2012 submitted)

Observed peculiarities

- Offset of the ring and asymmetries
- Very narrow disk
- Steep inner and outer slopes
- Features in the disk

Are they reflecting real structures or are they ADI artefacts ?

Offset and asymmetry



- Offset of 20 mas +/-7 along major axis in cADI

  Not due to ADI (imperfect knowledge of PSF center in the saturated images)

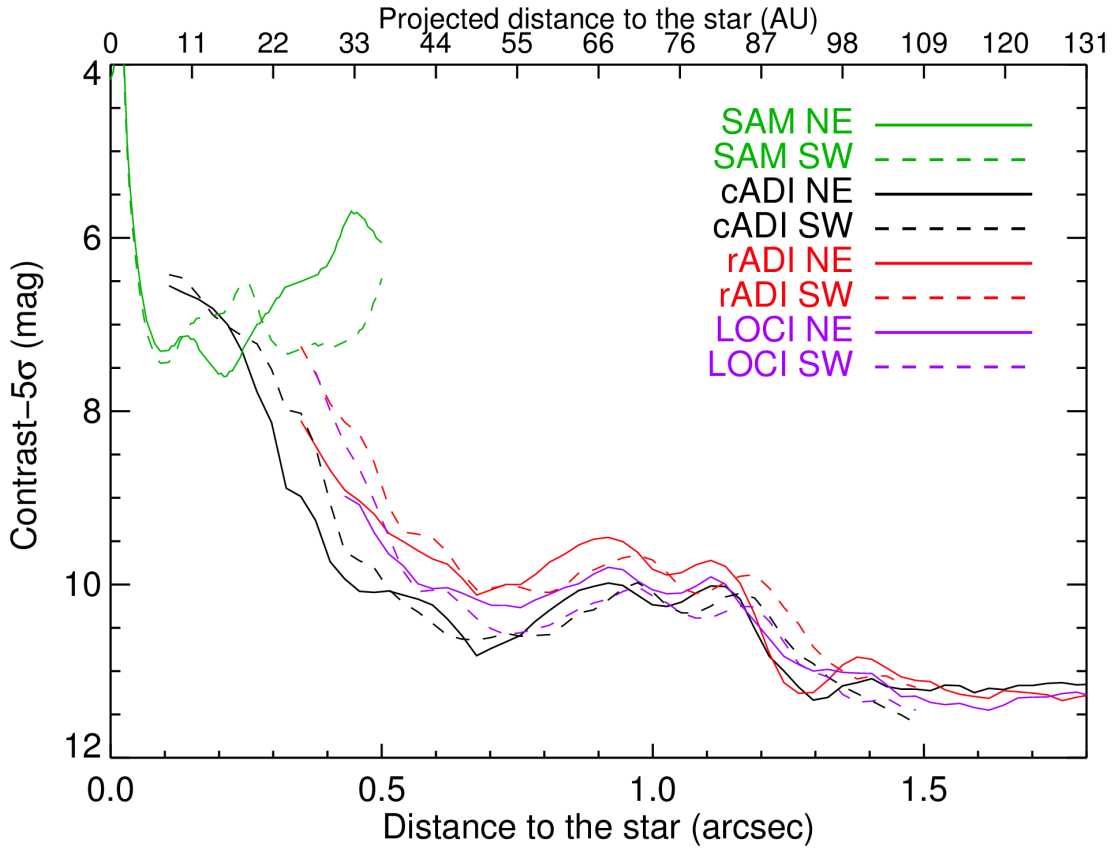
- Asymmetry NE/SW of ~20%

  Uncertain origin:
  Non-uniform background
  Pericenter glow

2 scenarii: 1) close faint companion and circumbinary disk
2) companion on a slightly eccentric orbit close to the disk inner edge

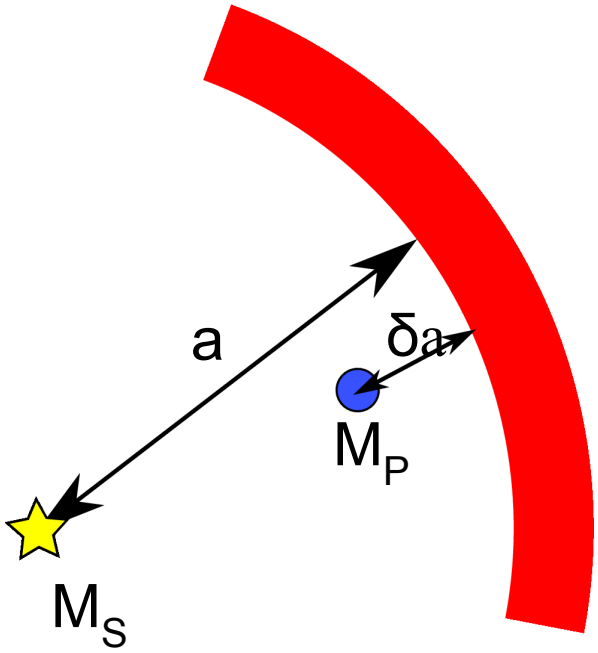
Planet detection limits

- The presence of the disk impacts the detection limits inside the ring due to negative flux regions



Scenario 1 ruled out with SAM data

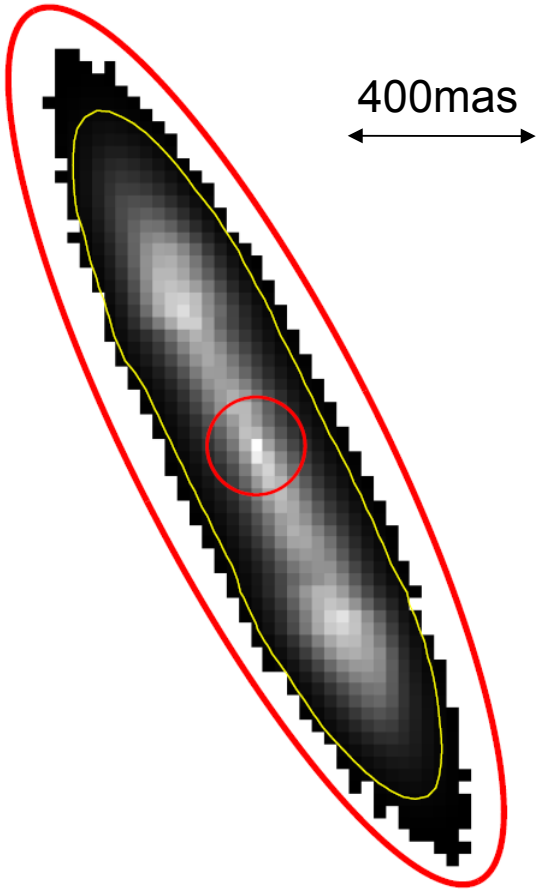
Inner edge sculpted by an inner planet ?



Overlap of the mean motion resonance

$\delta a/a = 1.3(M_P/M_S)^{2/7}$

(Wisdom 1980)



2D detection limits map

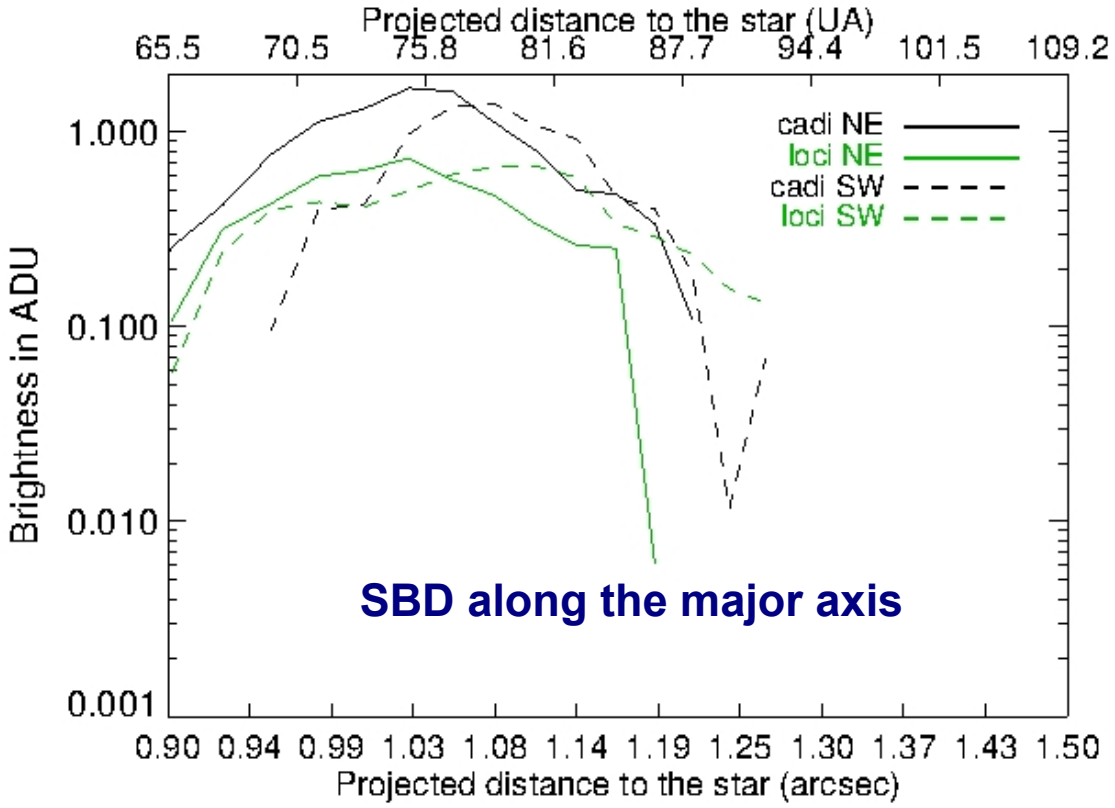
Disk inner edge

If a planet sculpts the inner edge:

$\delta a < 15$ AU along the major axis

$\delta a < 26$ AU along the minor axis

Width and outer slope of the disk



SBD along the major axis

How can the disk be so narrow ?

Does the disk SBD follow the -3.5 power law ? (Thebault et al 2008)

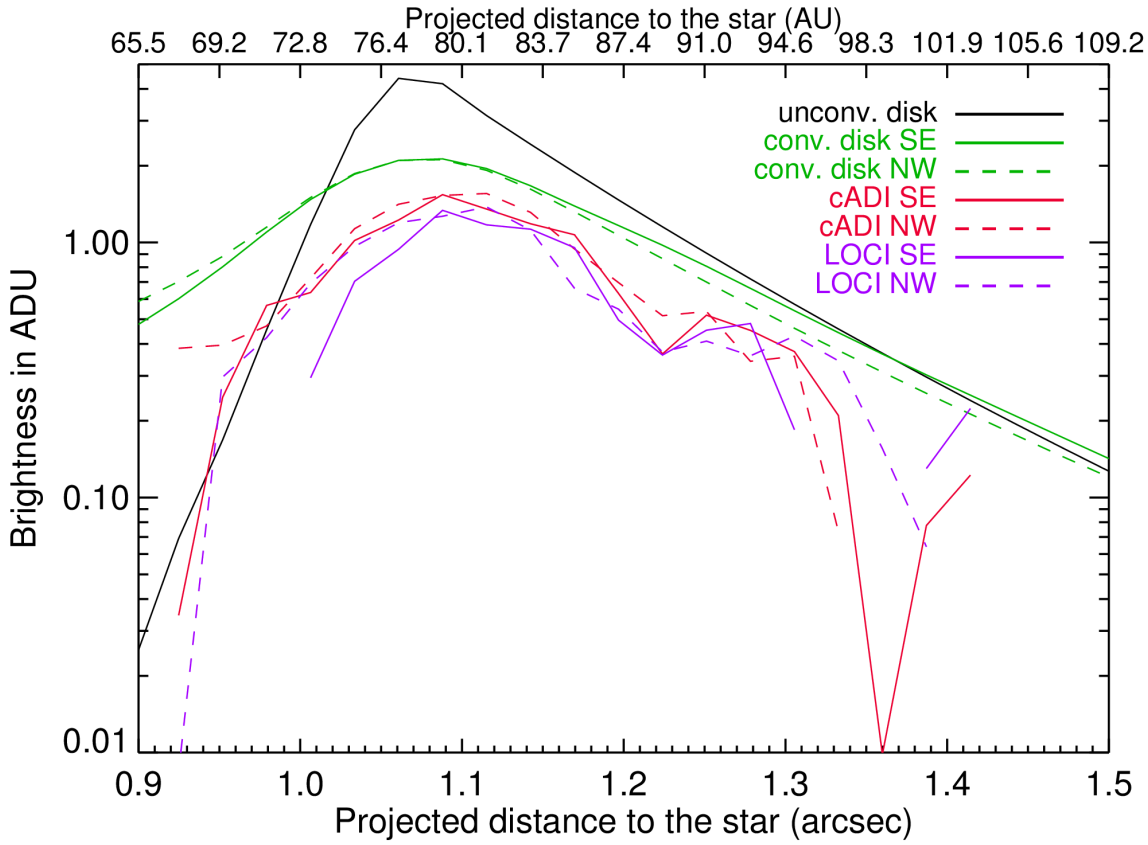
Accurate slope measurement not possible due to the noise level and poor image dynamic

Simulation:

Initial disk with volumetric dust number density parametrized by the radial exponents

α_{out}=-10
α_{out}=-4

Simulations performed

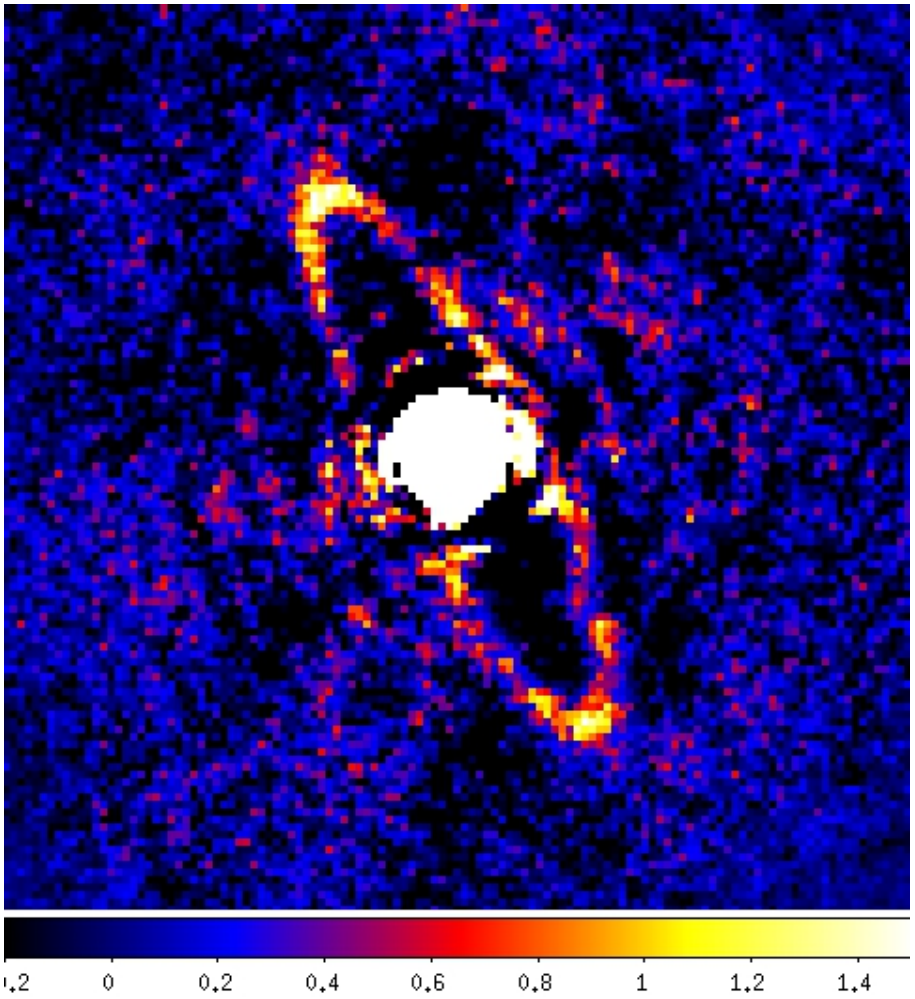


Slopes impacted by:

- PSF convolution
- Noise
- ADI procedure
- Binning used to extract the radial SBD

The case of a -3.5 slope can be ruled out.

Interpretation

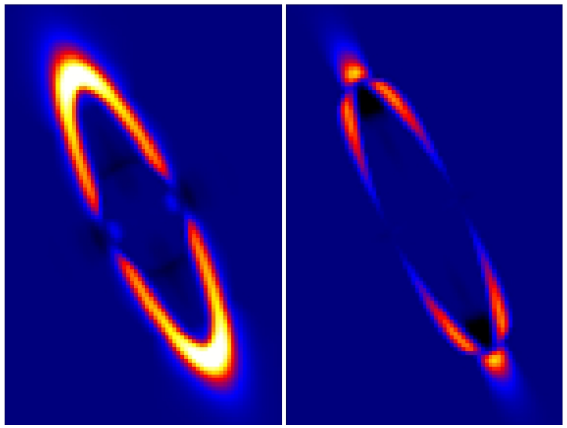


1) Disk dynamically cold
2) Presence of gas
3) Outer edge sculpted by a massive body

N-body simulations and current detection limits are compatible with the 3rd scenario

Conclusion

- ADI yields strong constraints on disks morphology and its relation to planets, as shown with HR4796



- Keep in mind some artefacts !

- Many optimization techniques already exist to limit those biases: masking, iterating, damped-LOCI (Puyeo et al 2010)

- ADI techniques are now also applied for space-based observations (eg Fomalhaut b, Janson et al 2012)


Questions ?
HARDY