MAD workshop - November 4th, 2014

The synergy between optical interferometry and imaging

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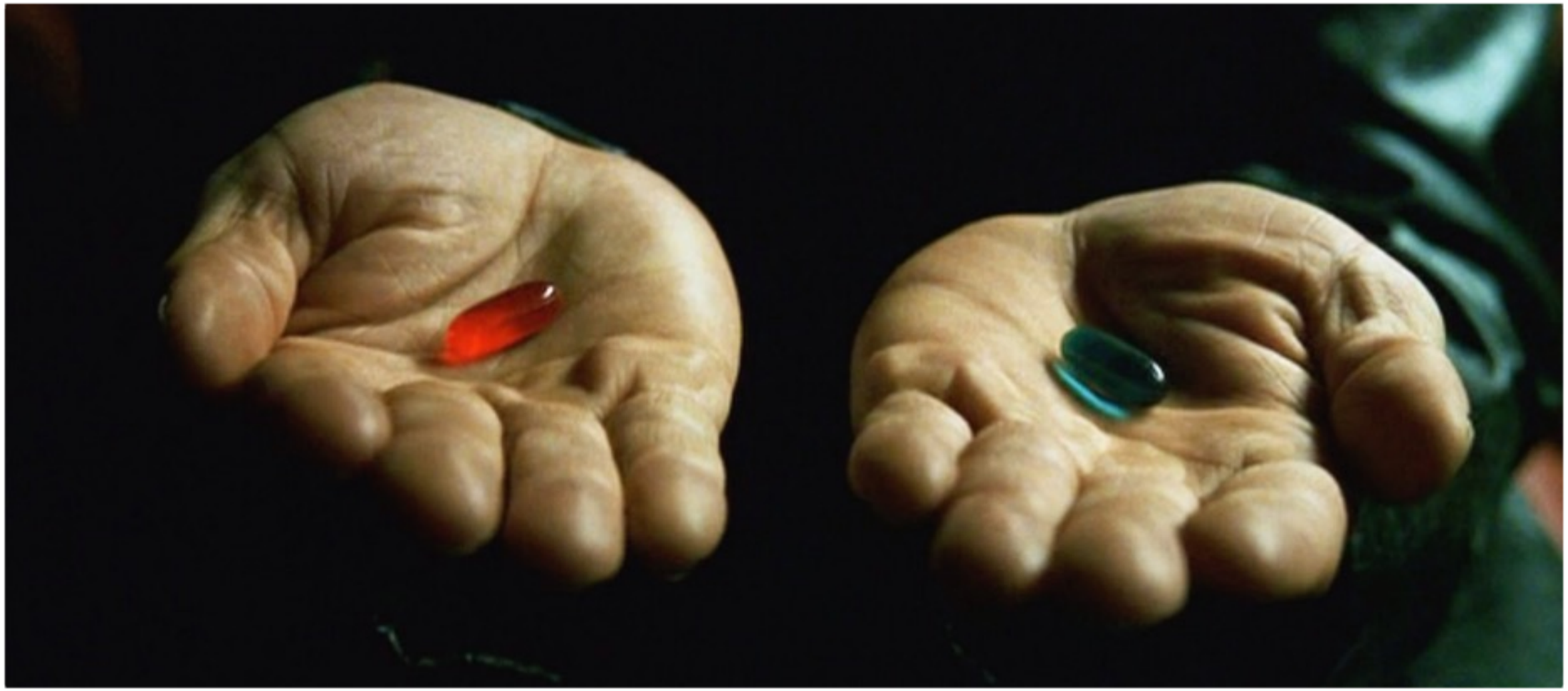
Outline

- Imaging vs. interferometry
  - Similarities, differences
- Synergy: illustrations
  - Protoplanetary disks
  - Debris disks
  - Extrasolar planets



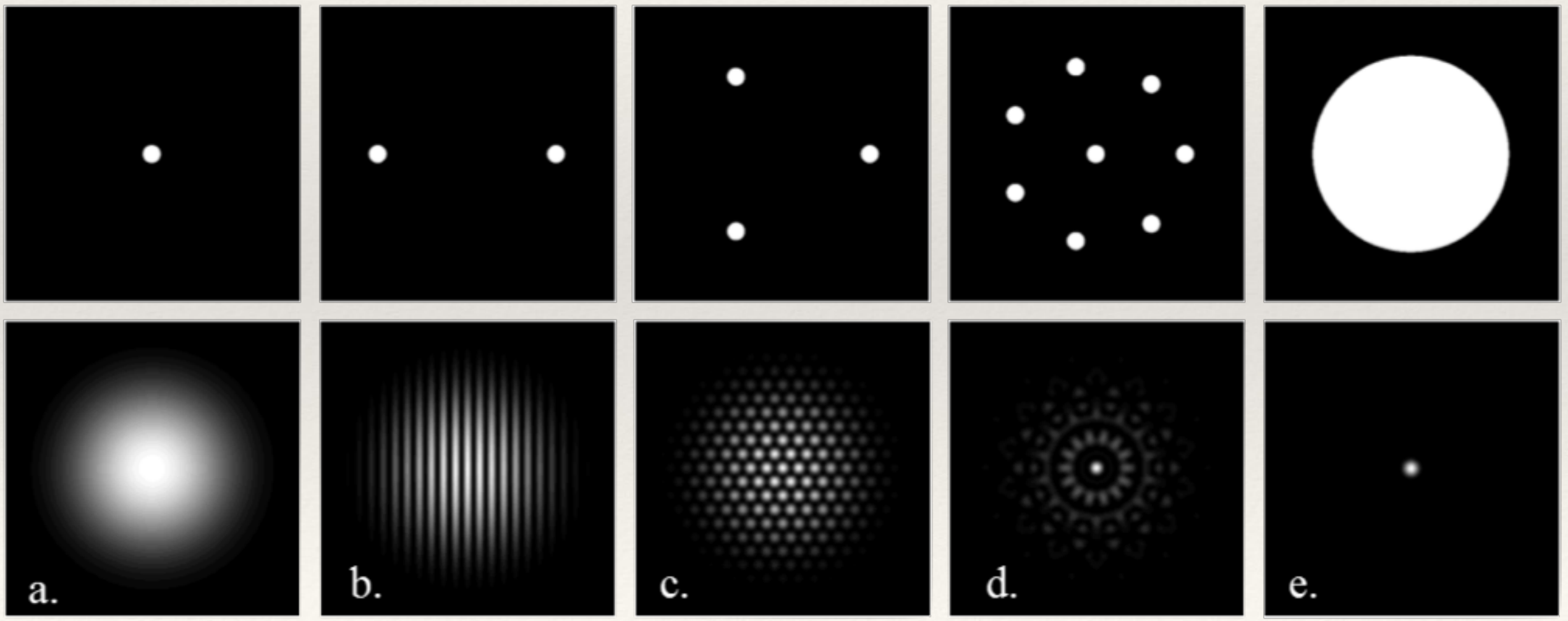
Wachowski & Wachowski 1999

Imaging vs. interferometry

One challenge, two cures

Two names for one phenomenon

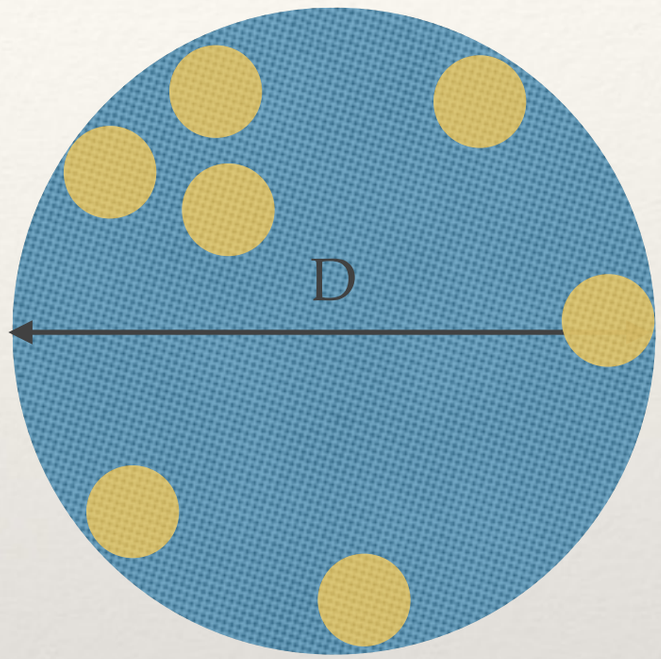
- Diffraction+interference at the root of image formation



Patru 2009

The borders of their realms

- Angular resolution: $\lambda/2B$
- Field-of-view limited by bandwidth smearing and/or use of fibers



- Angular resolution: $1.22\ \lambda/D$

Where's the limit?

A continuum of angular resolution

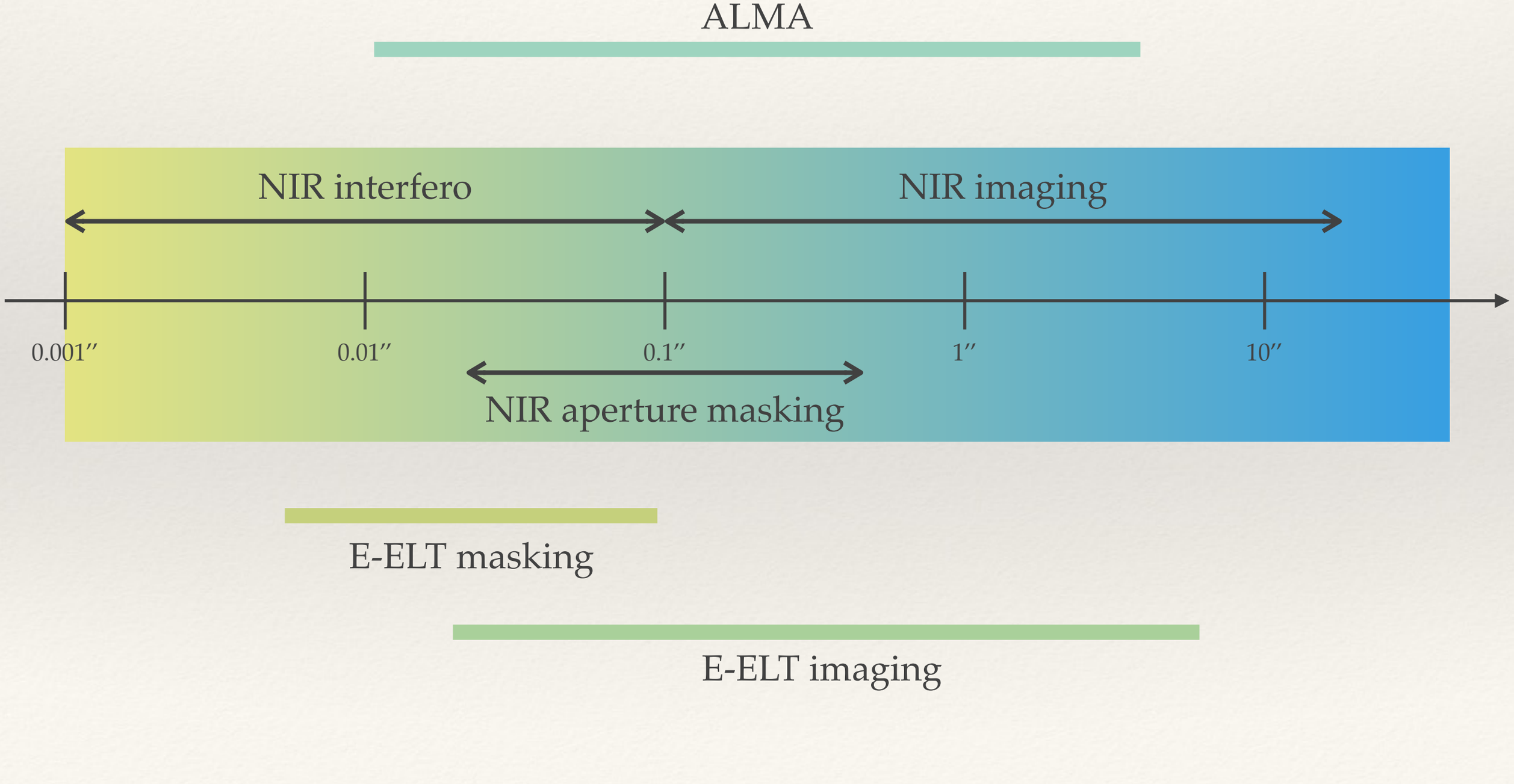
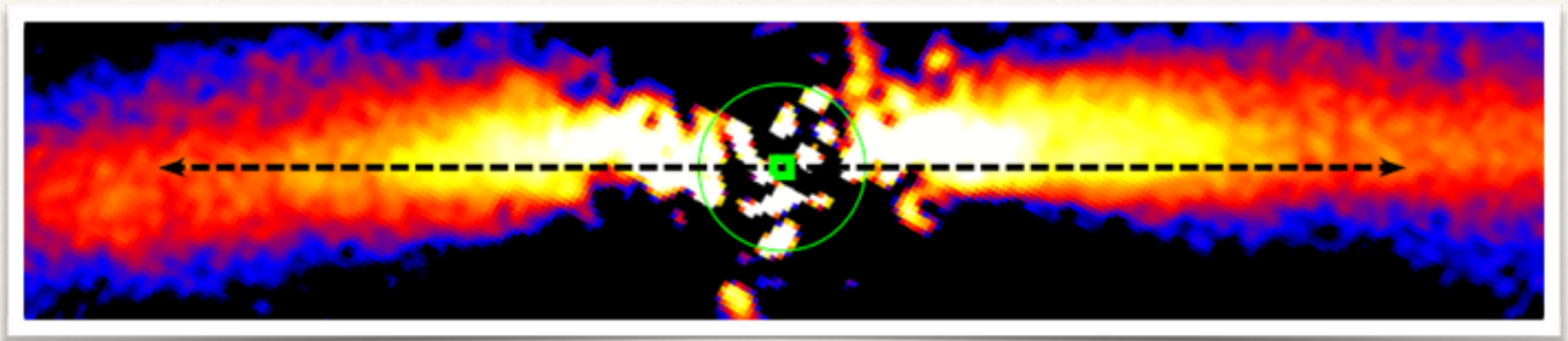
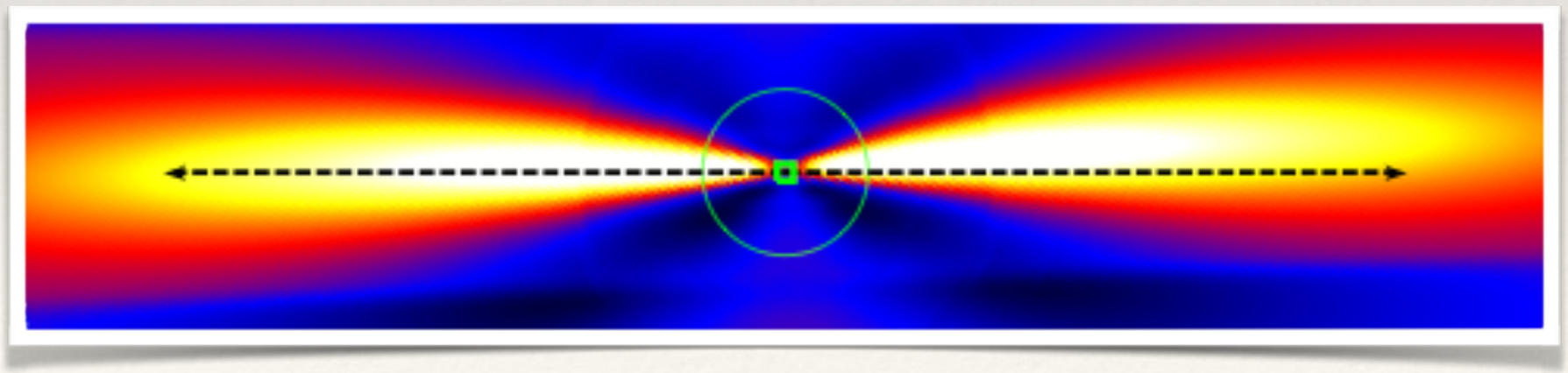


Image or model?

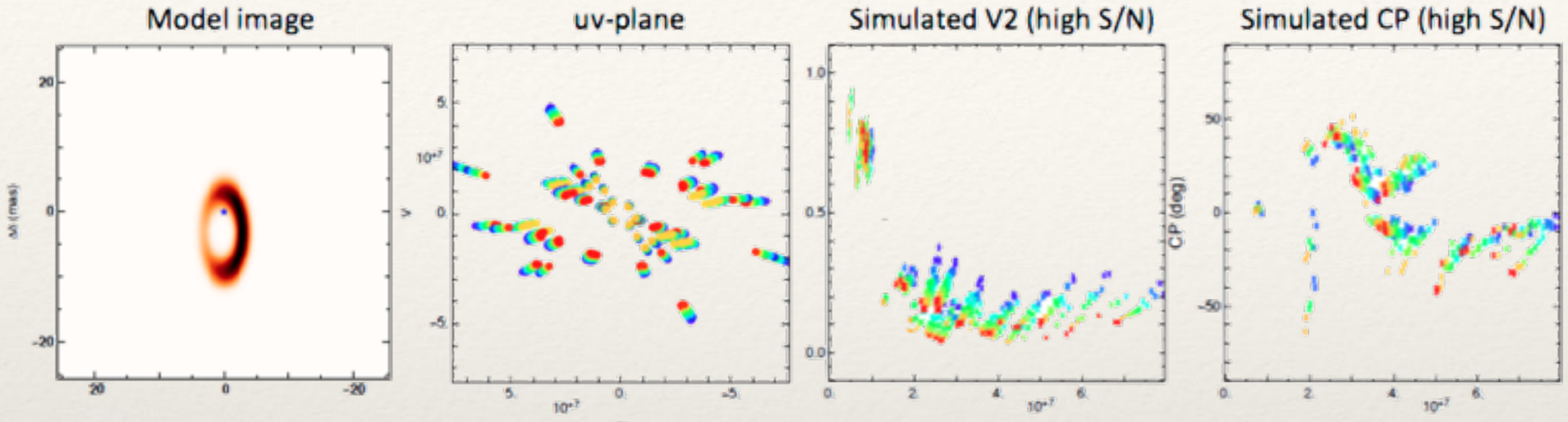


- Image: constrains the surface brightness
- Forward modelling: constrains model parameters

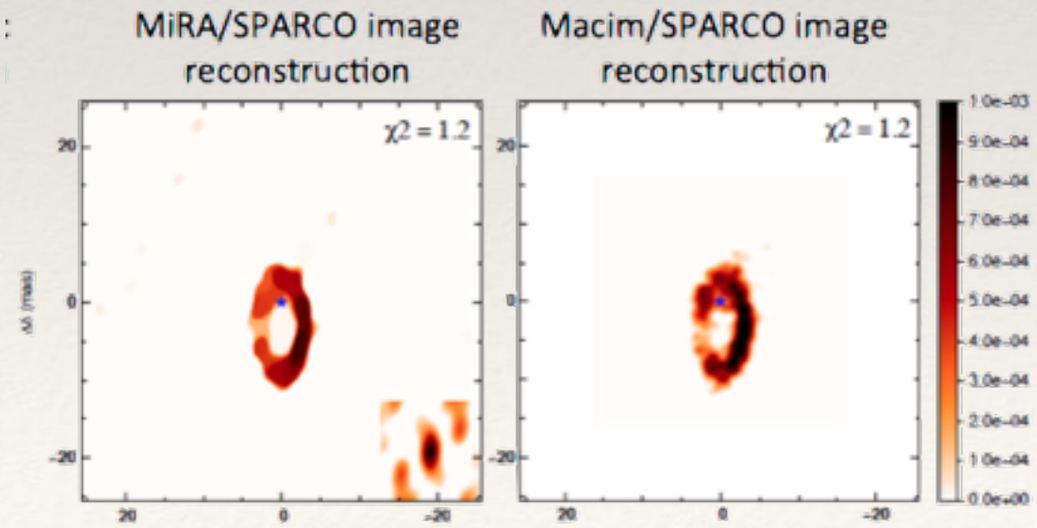


Milli et al. 2014

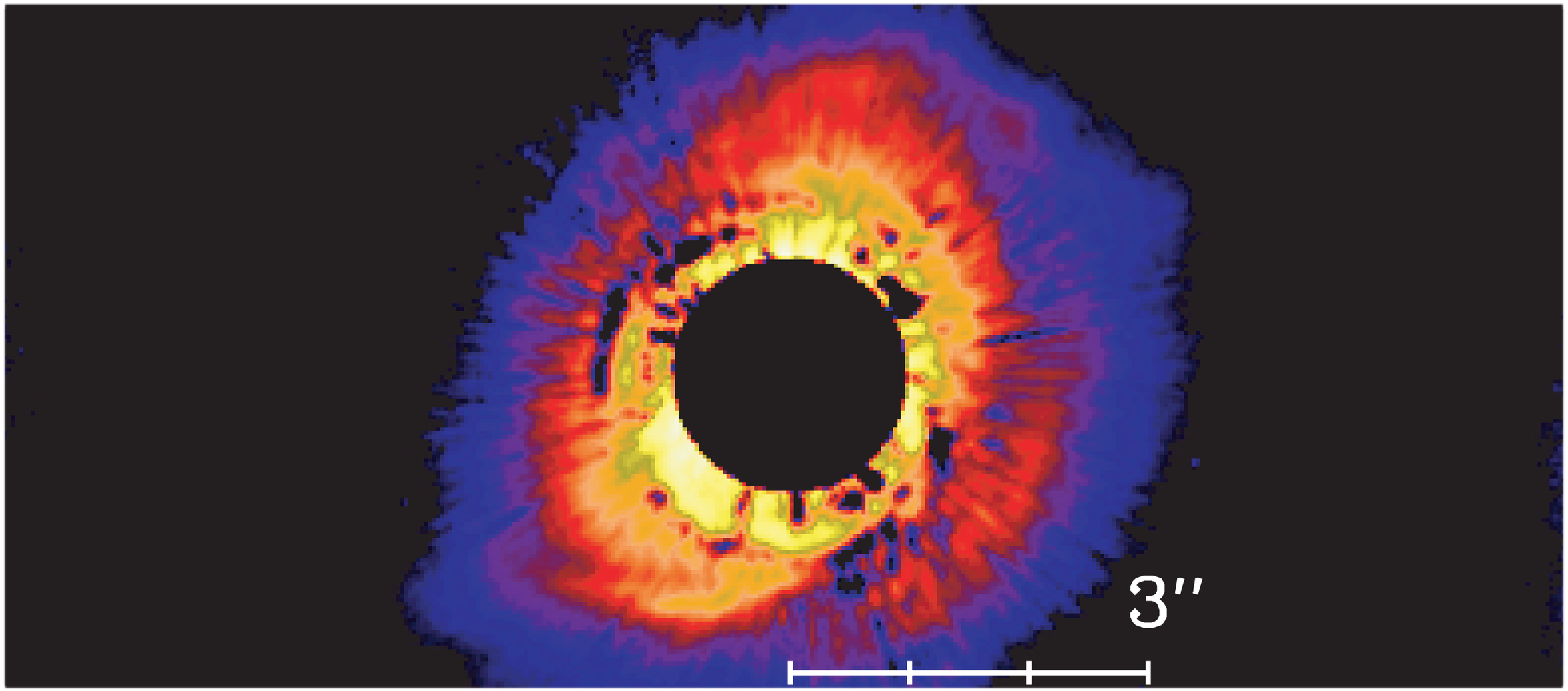
Model or image?



- Model-fitting interferometric observables (V2, CP)
- Image reconstruction: surf. bright. / forward modeling



Kluska et al. 2014

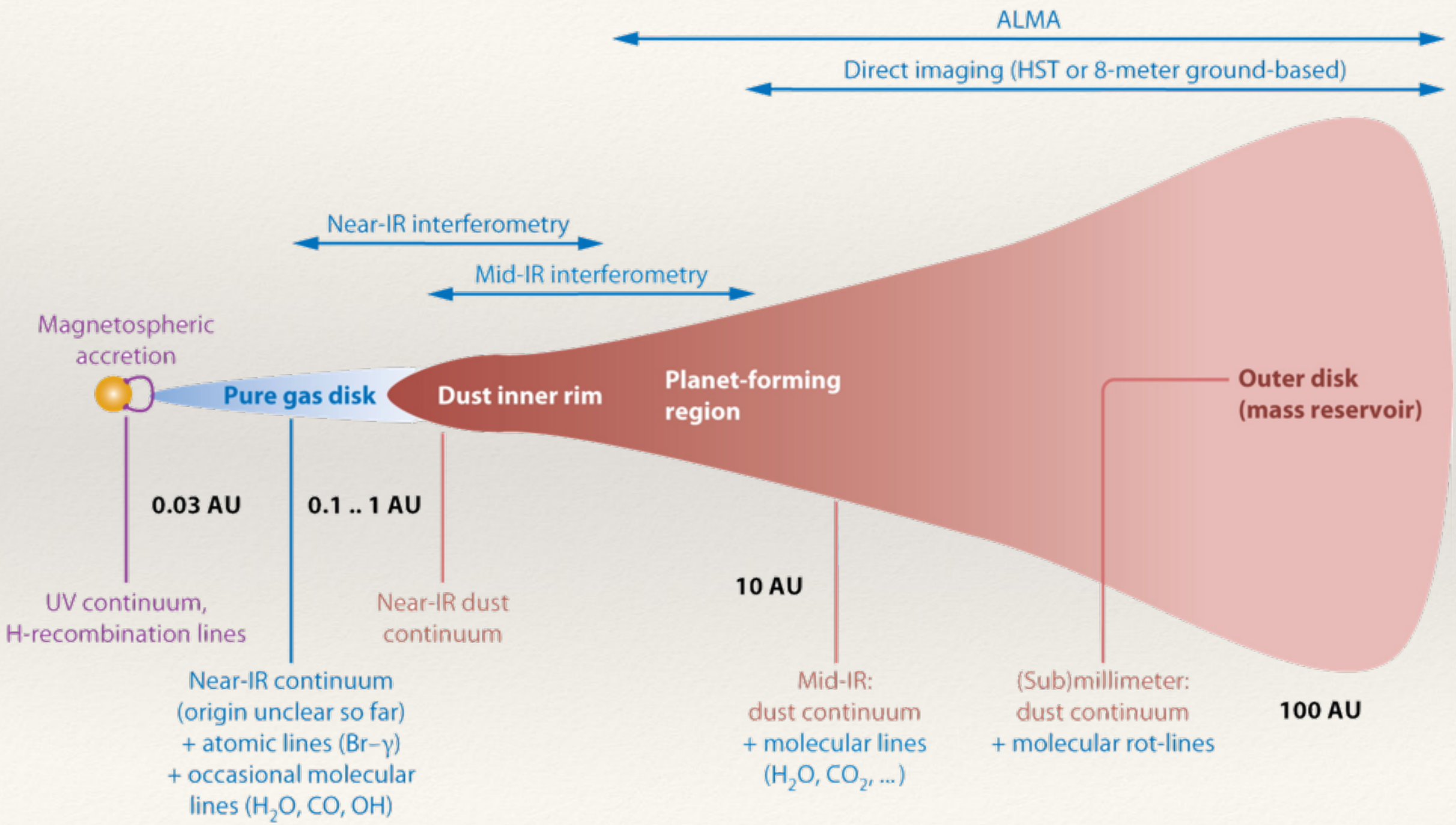


HD100546 — Ardila et al. 2007

Protoplanetary disks

Planetary formation at all scales

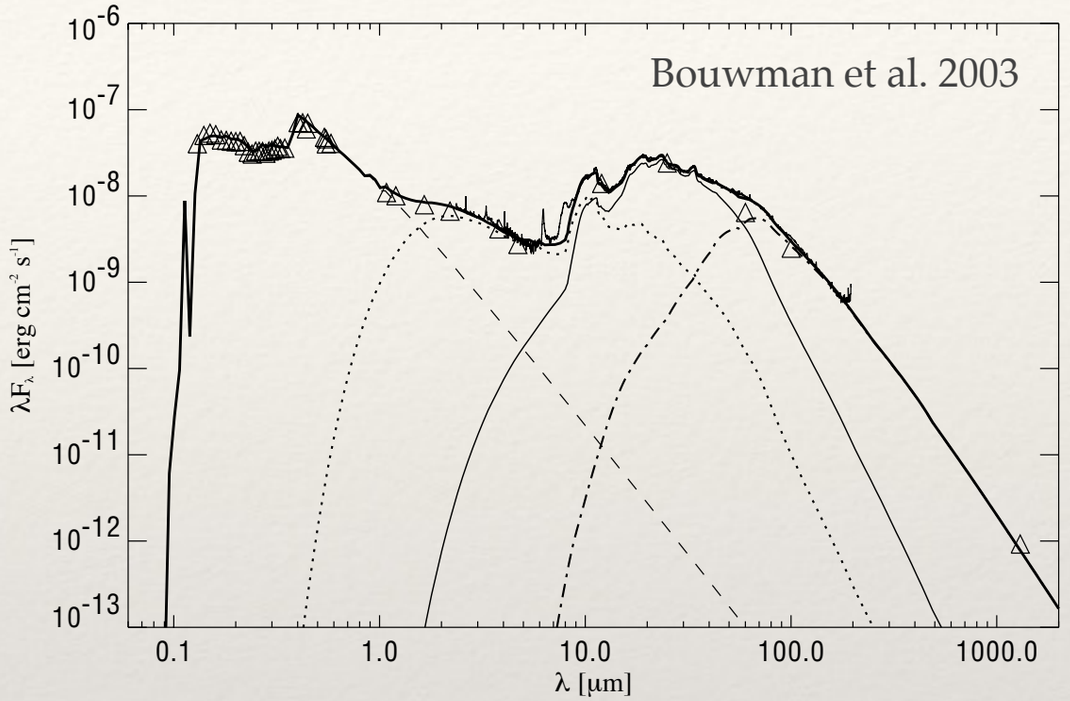
Synergy in a nutshell

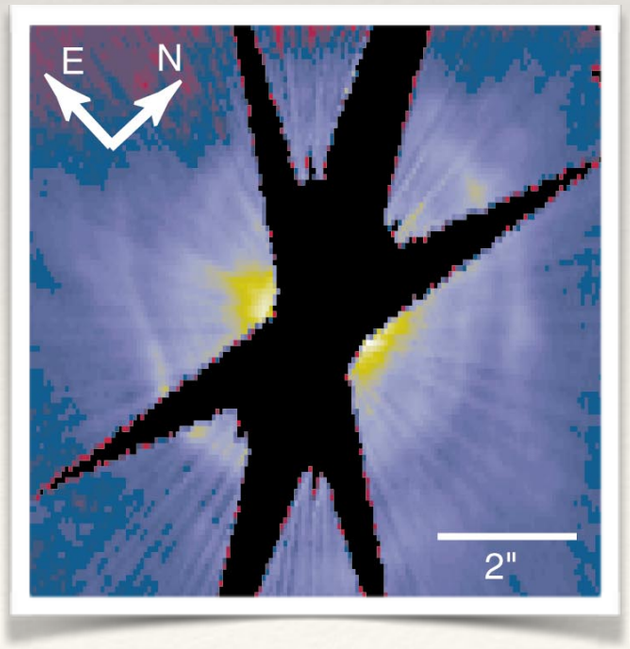


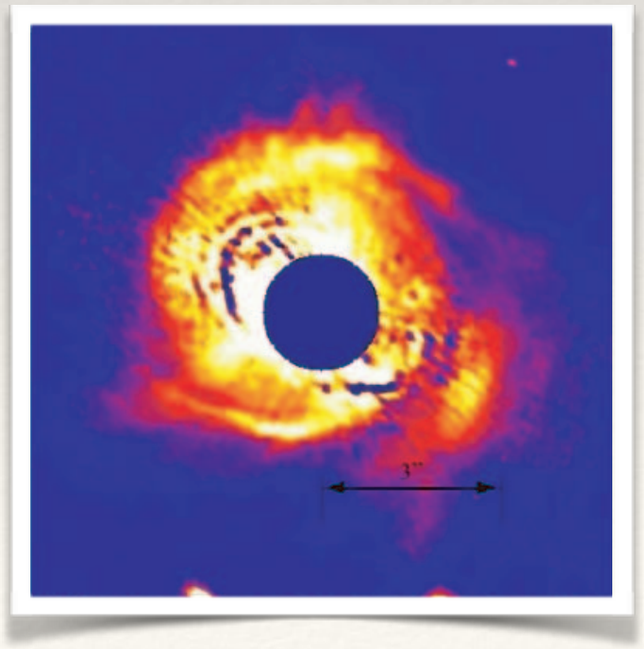
Dullemond & Monnier 2010

The case of HD100546

- Herbig Be star at 97pc
- One of the first « transition » disks
  - Gap suspected (1-10 AU)
- Spiral arms detected in visible and near-IR images of the outer disk



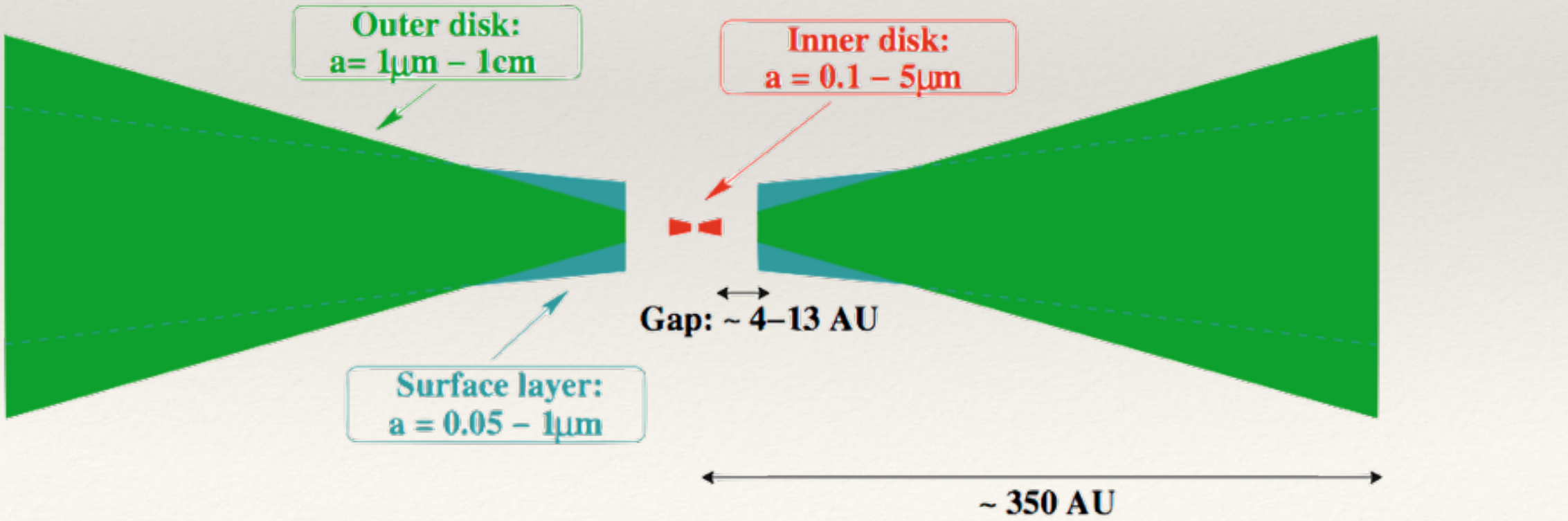




Grady et al. 2001, Ardila et al. 2004 (deprojected)

NIR interferometry

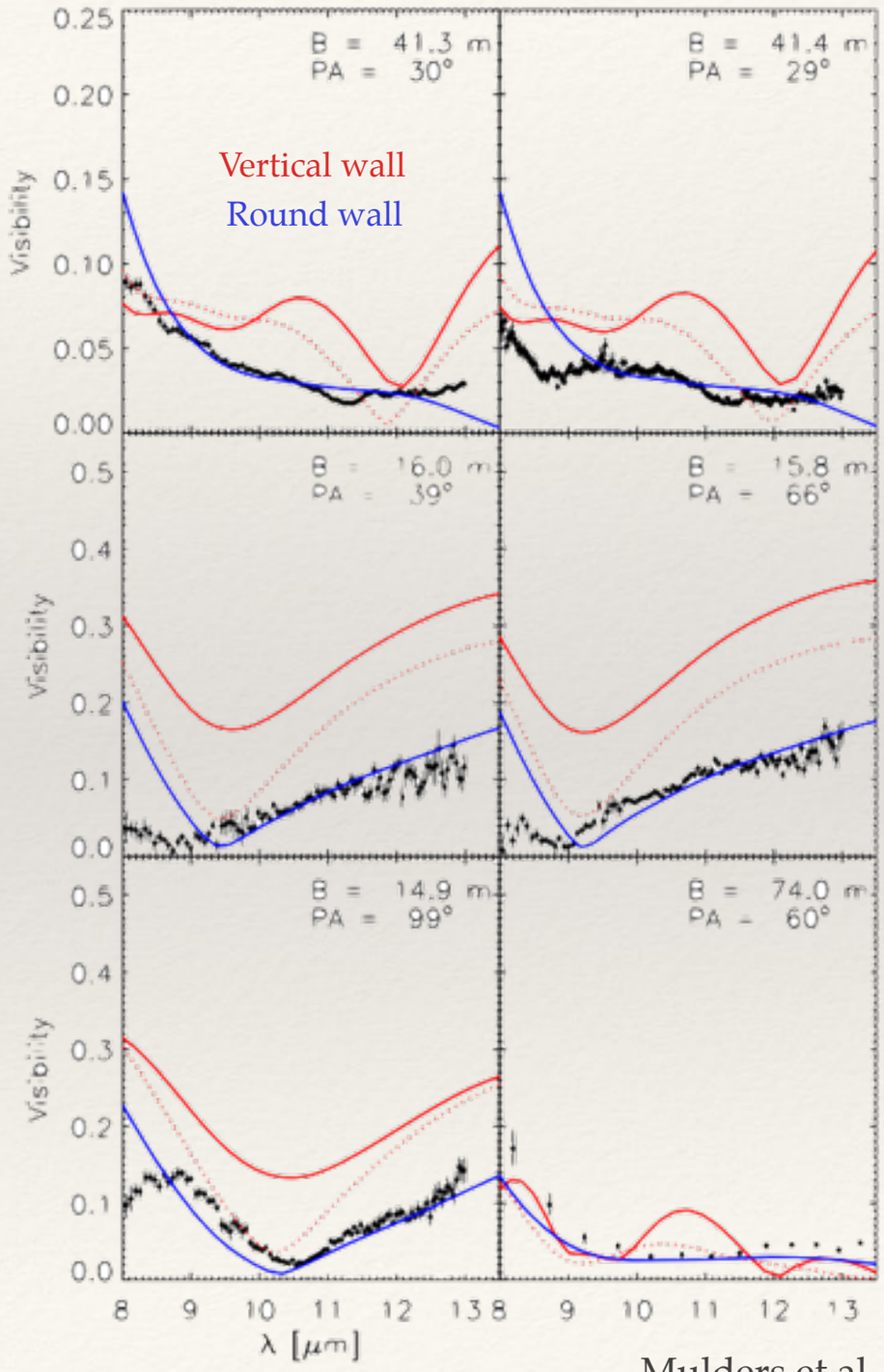
- Tenuous inner disk of small grains, peaking at 0.25 AU, coplanar with outer disk
- Gap confirmed up to 13 AU, possibly opened by planet
- Inner disk rim probably not puffed up



Benisty et al. 2010

MIR interferometry

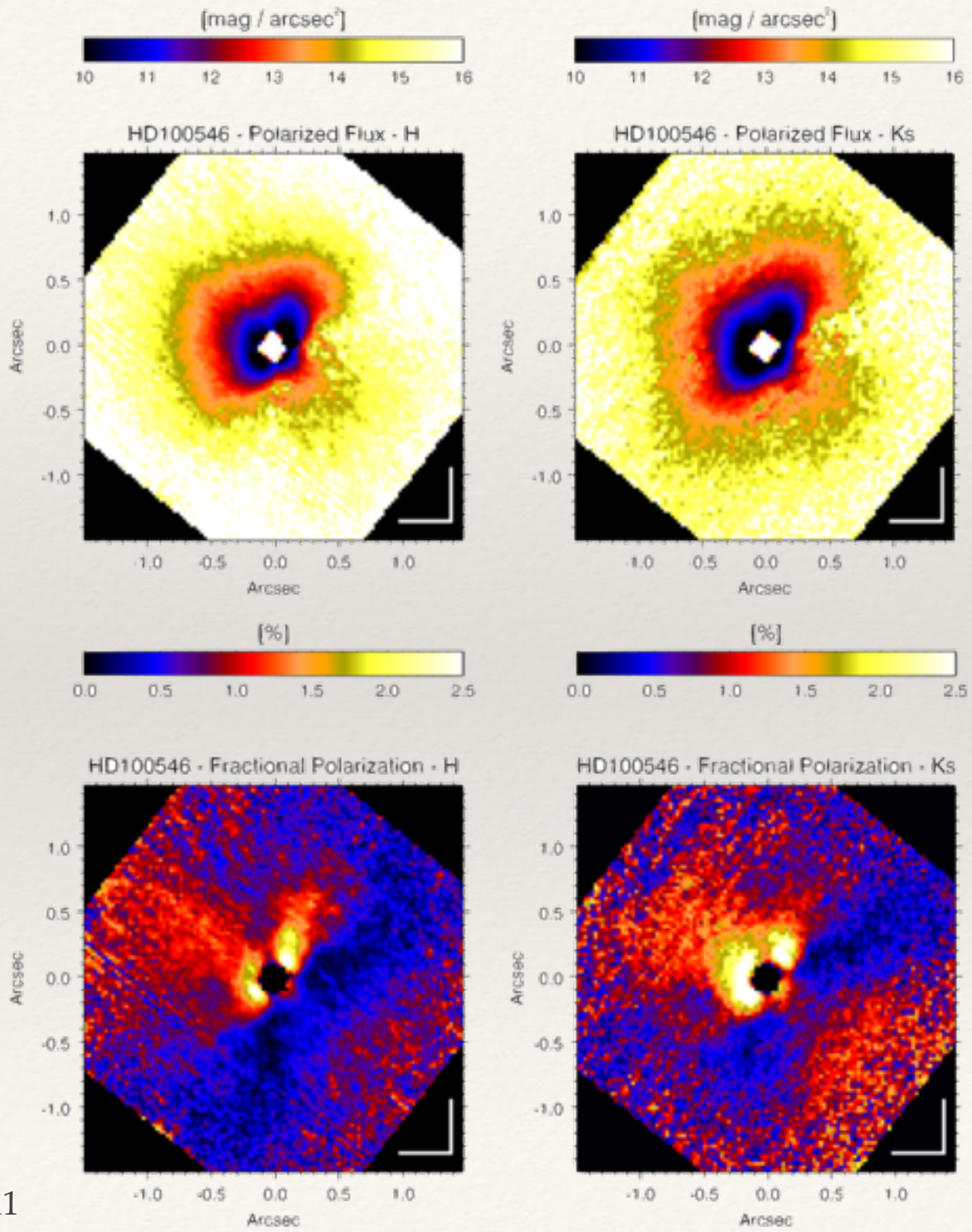
- Sensitive to warm dust, including inner rim of outer disk
- Inner rim = (asymmetric) bright ring at 11±1 AU
- Curvature of inner wall constrained
  - Hydro simulations suggest massive gap-clearing BD
- Upper limit of 0.7 AU for innermost disk



Mulders et al. 2013

Polarimetric differential imaging

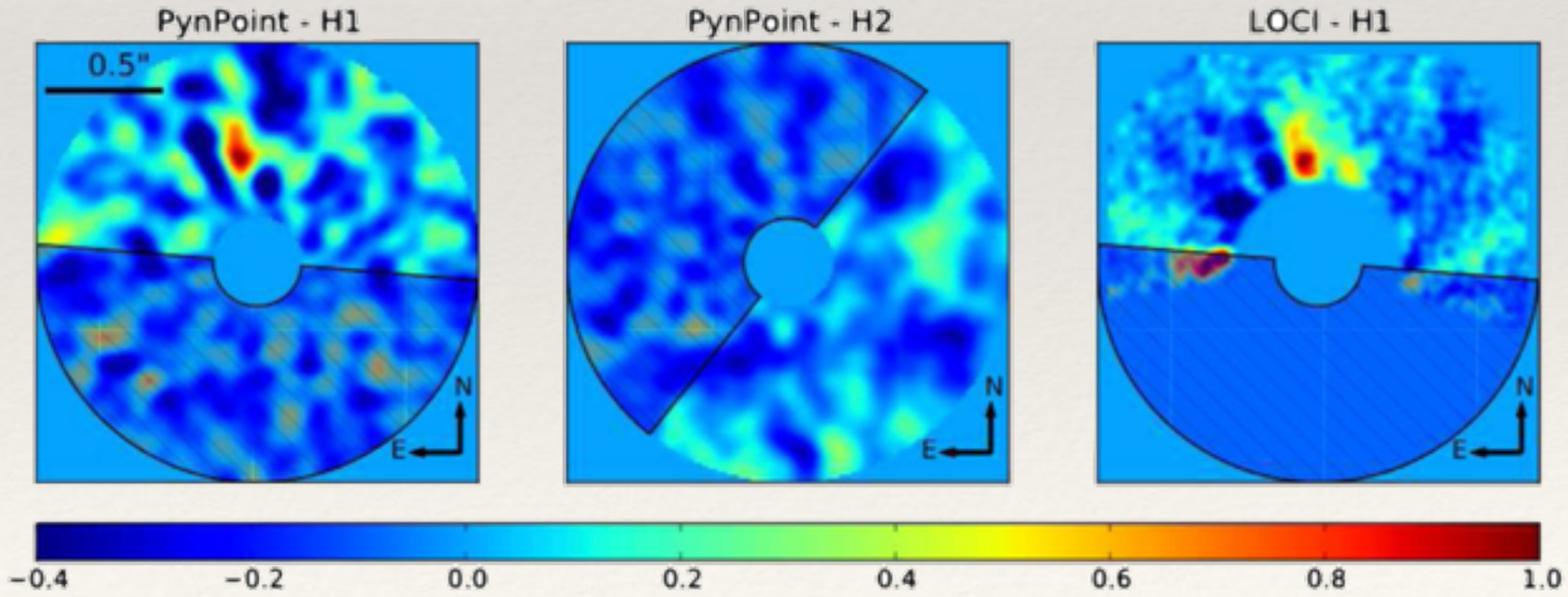
- Disk resolved down to 0.1″ (10AU) with NACO
- Outer radius of inner gap constrained to 14±2 AU
- Asymmetric brightness profile along minor axis (preferential backward scattering)
- Polarization degree suggests grains larger than ISM grains
- Possible hole



Quanz et al. 2011

High contrast imaging

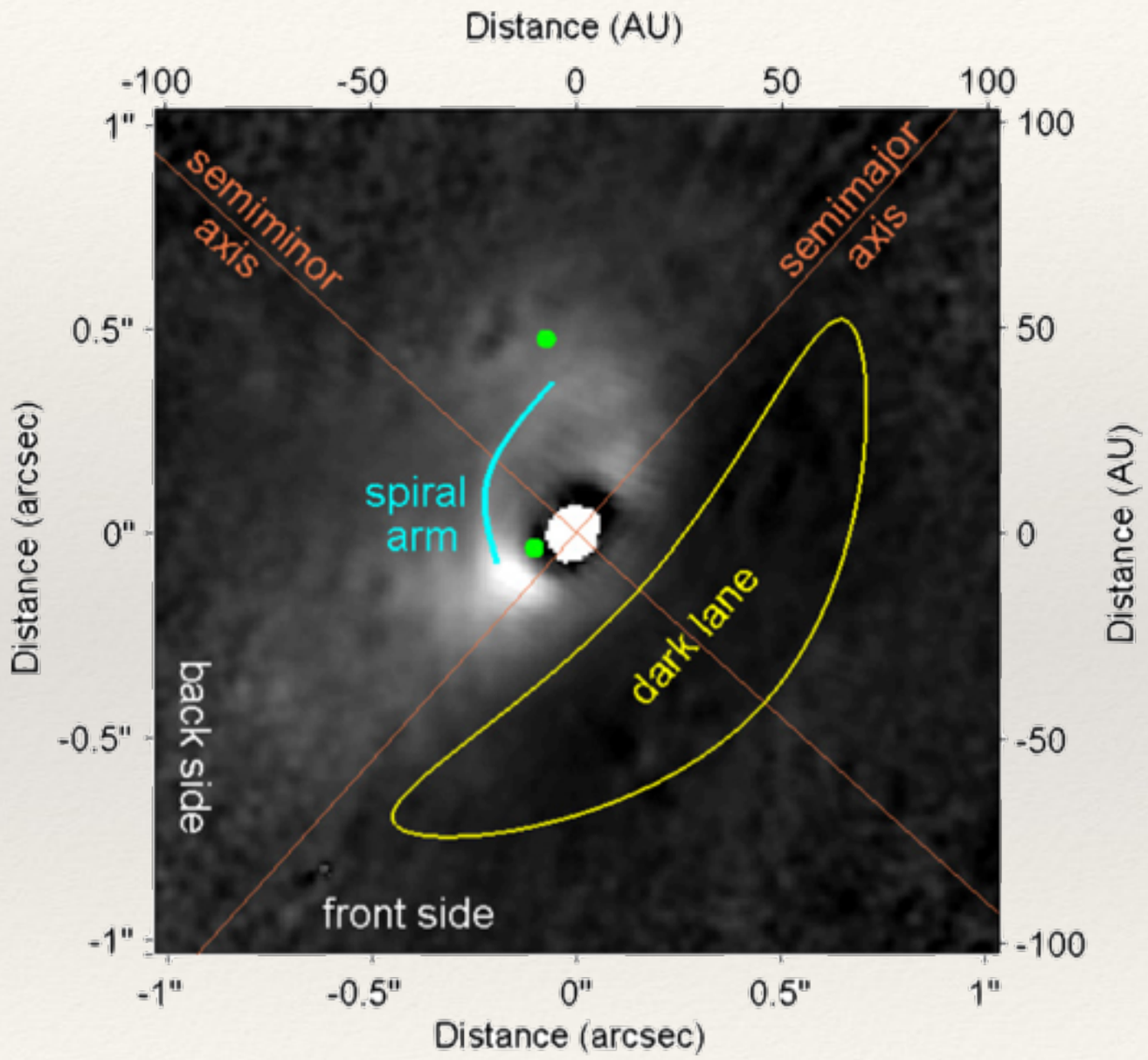
- L-band coronagraphy reveals compact emission at 0.48”
  - Deprojected separation ~ 68 AU
  - Position corresponds to polarimetric hole
  - Contrast ~ 9 mag
  - Slightly extended
- Possible forming planet?

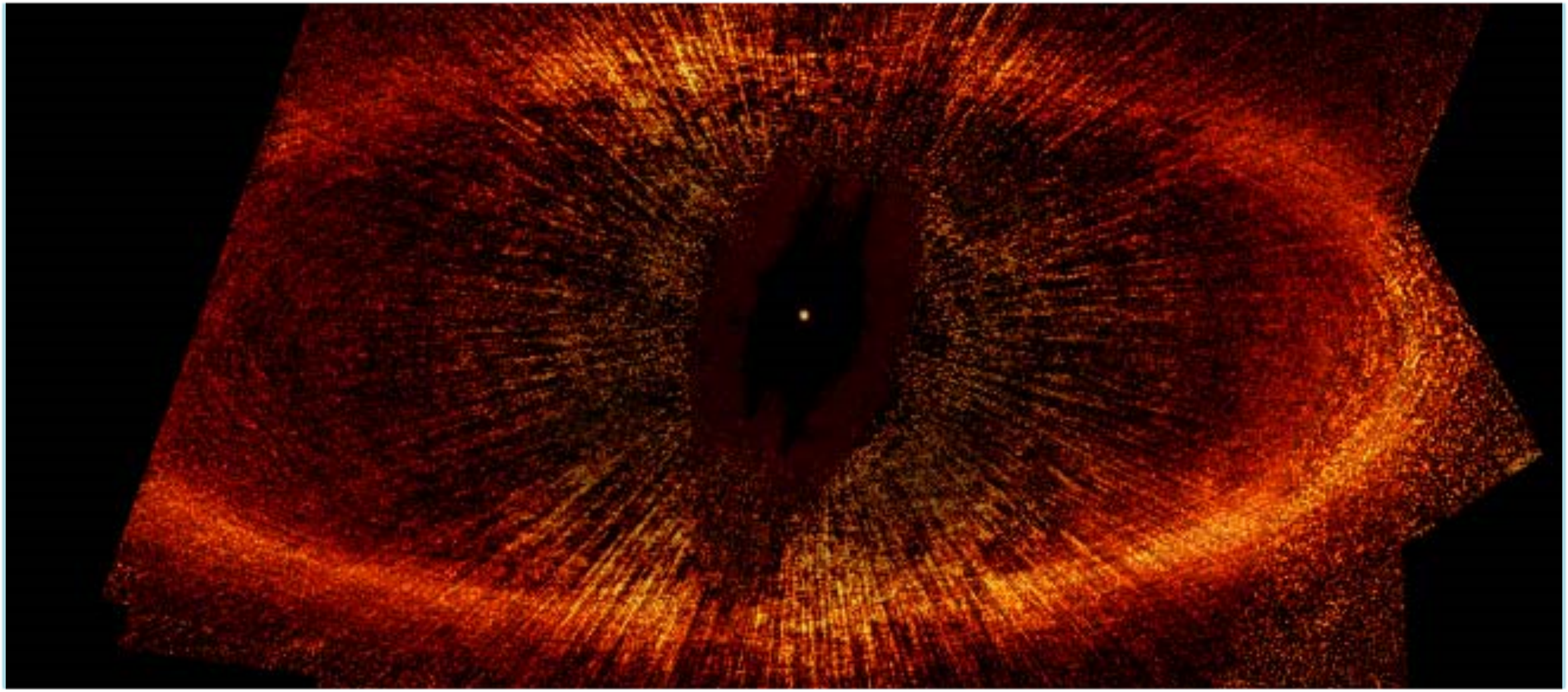


Quanz et al. 2013

Big picture

Avenhaus et al. 2014



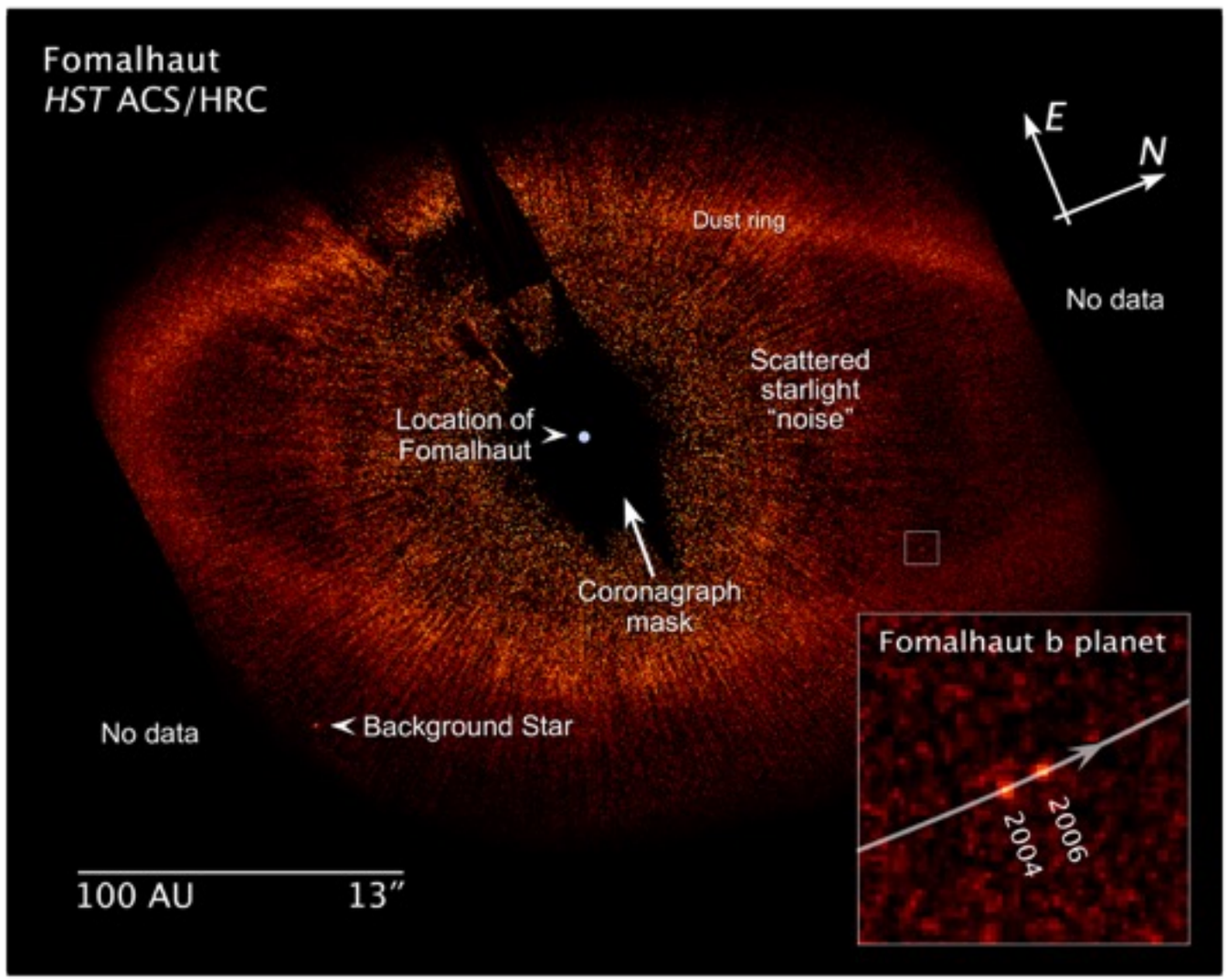


Fomalhaut — Kalas et al. 2005

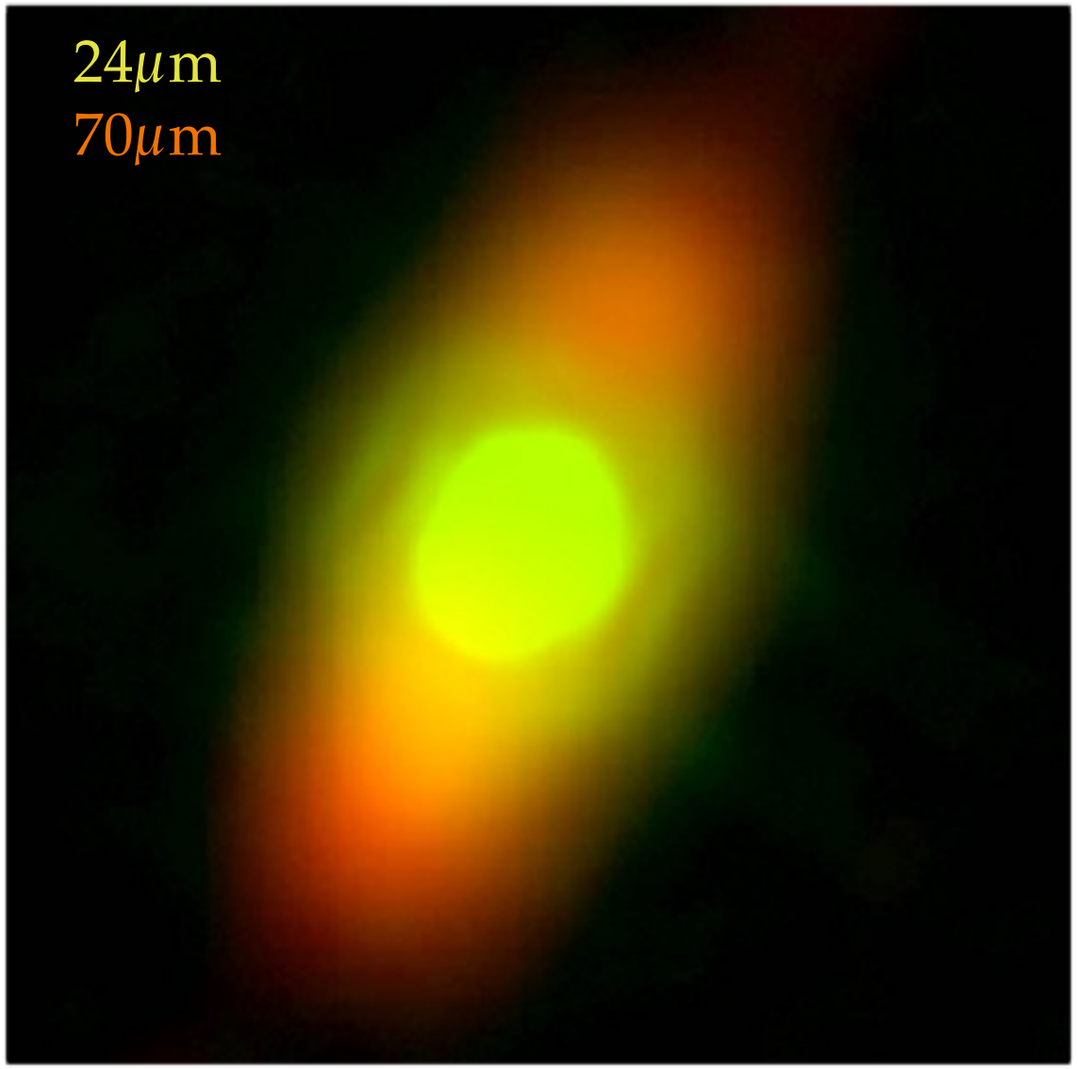
Debris disks

Faint disks around bright stars

Outer disk



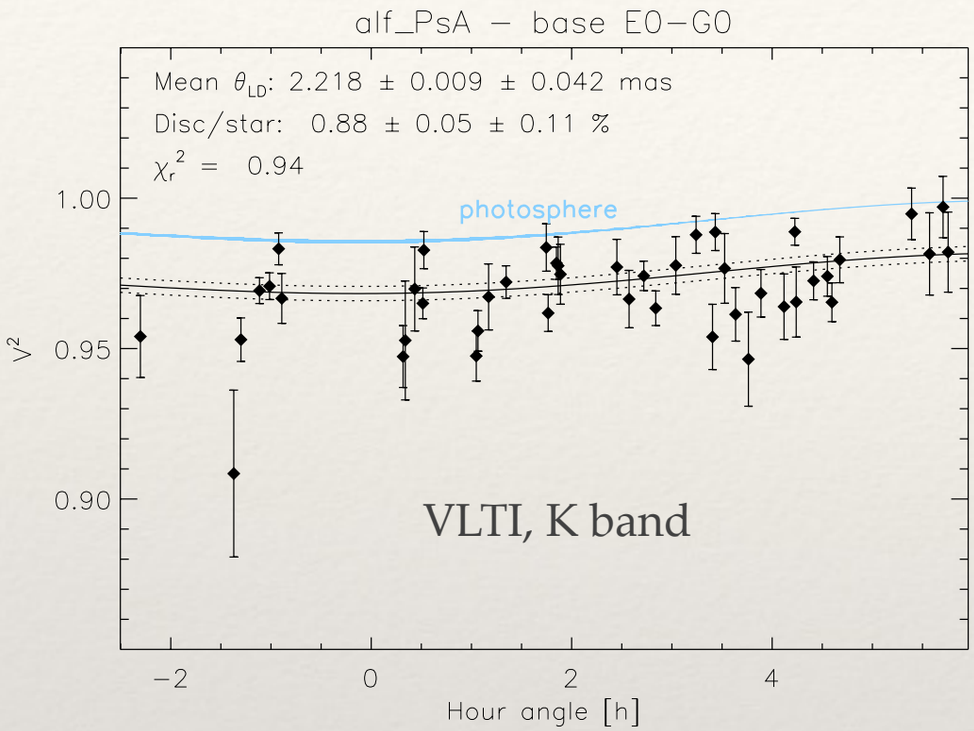
Kalas et al. 2008

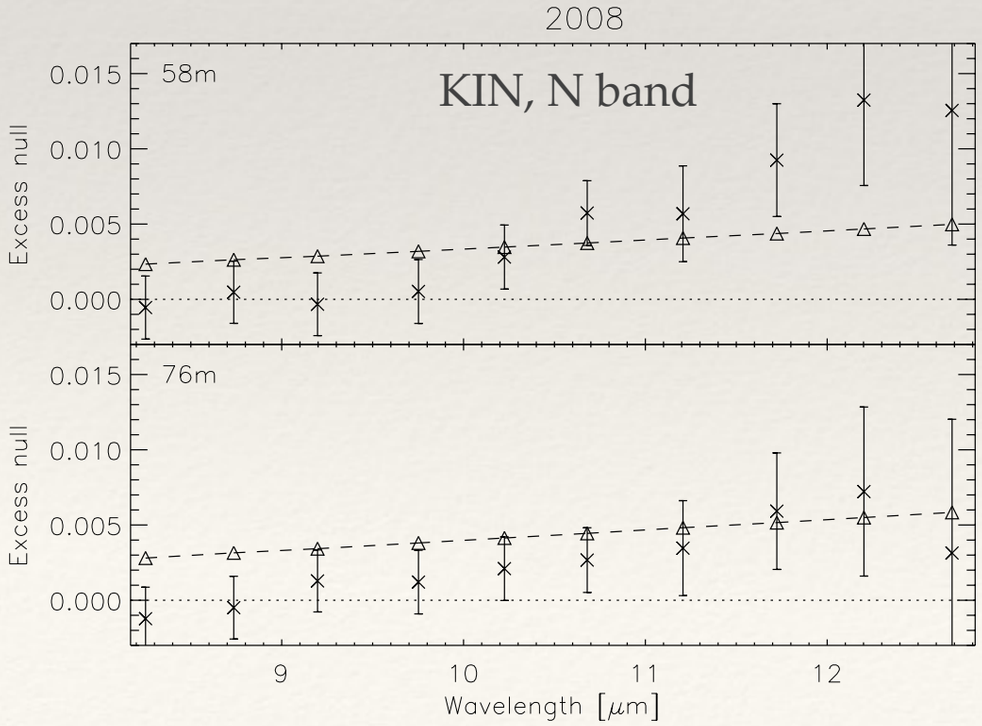


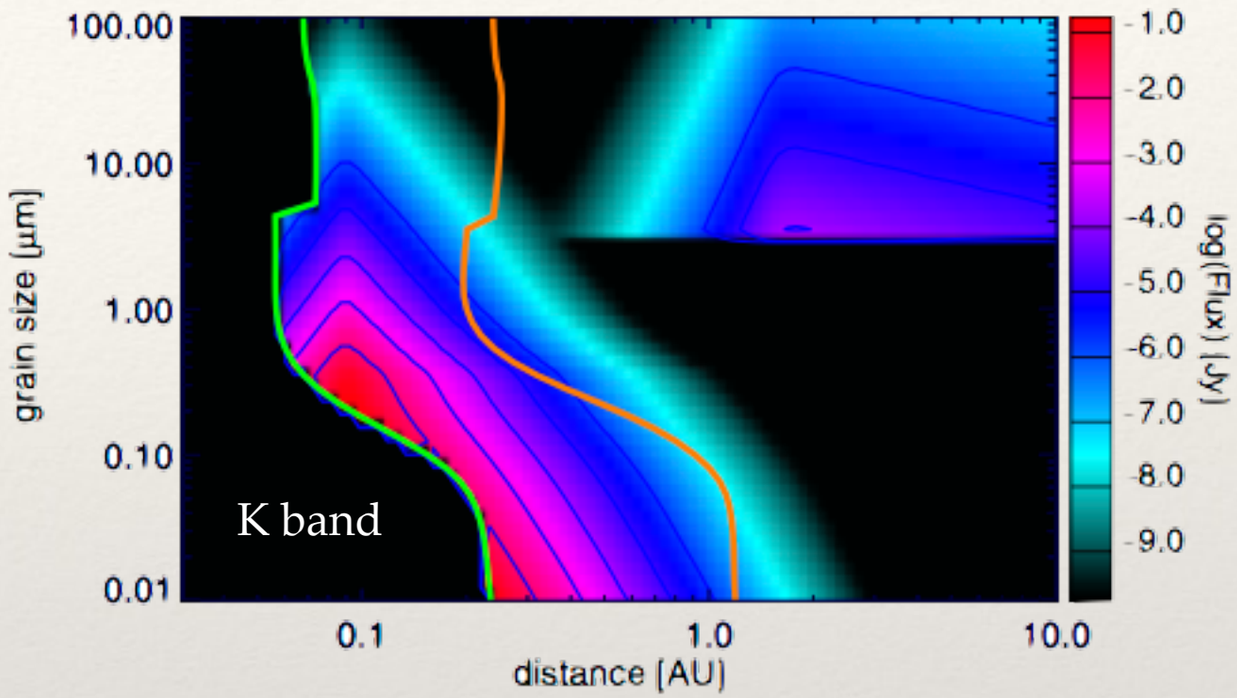
Stapelfeldt et al. 2004

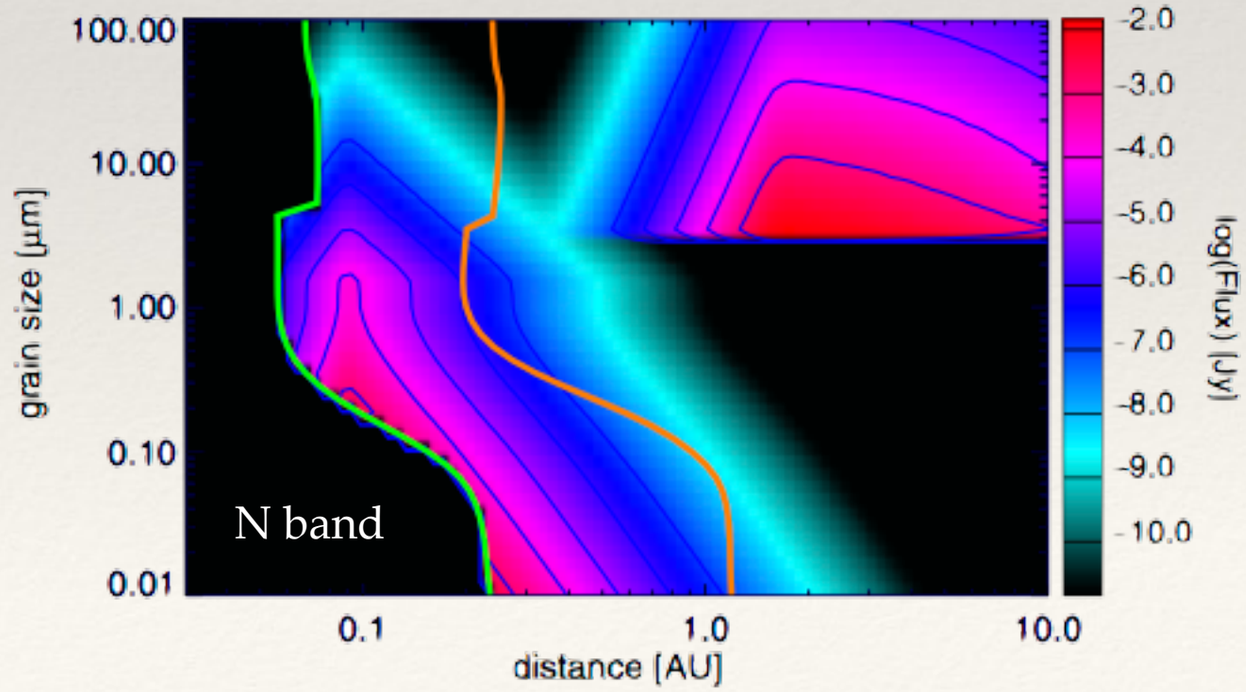
A double inner disk

Absil et al. 2009
Mennesson et al. 2013
Lebreton et al. 2013



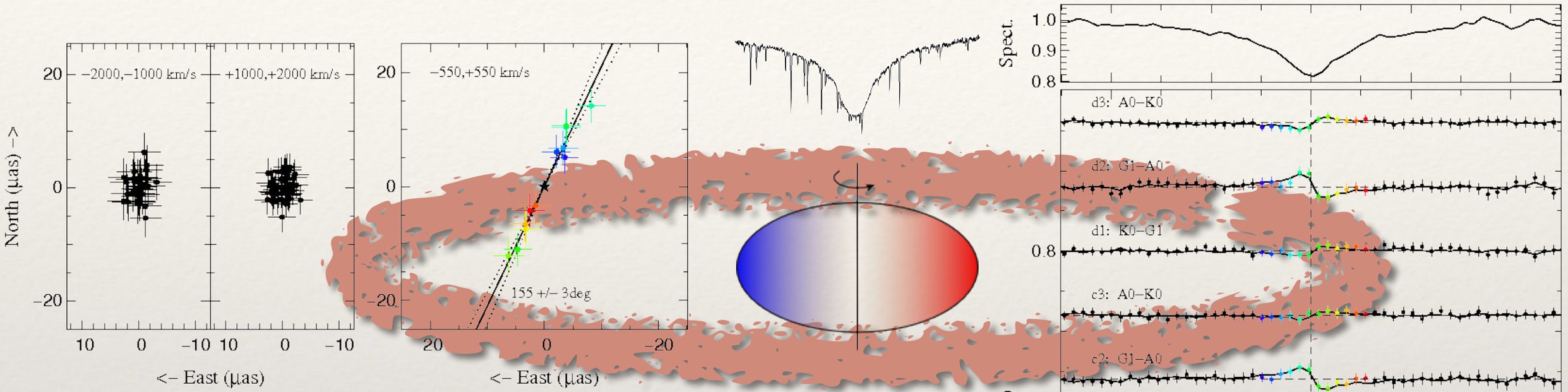


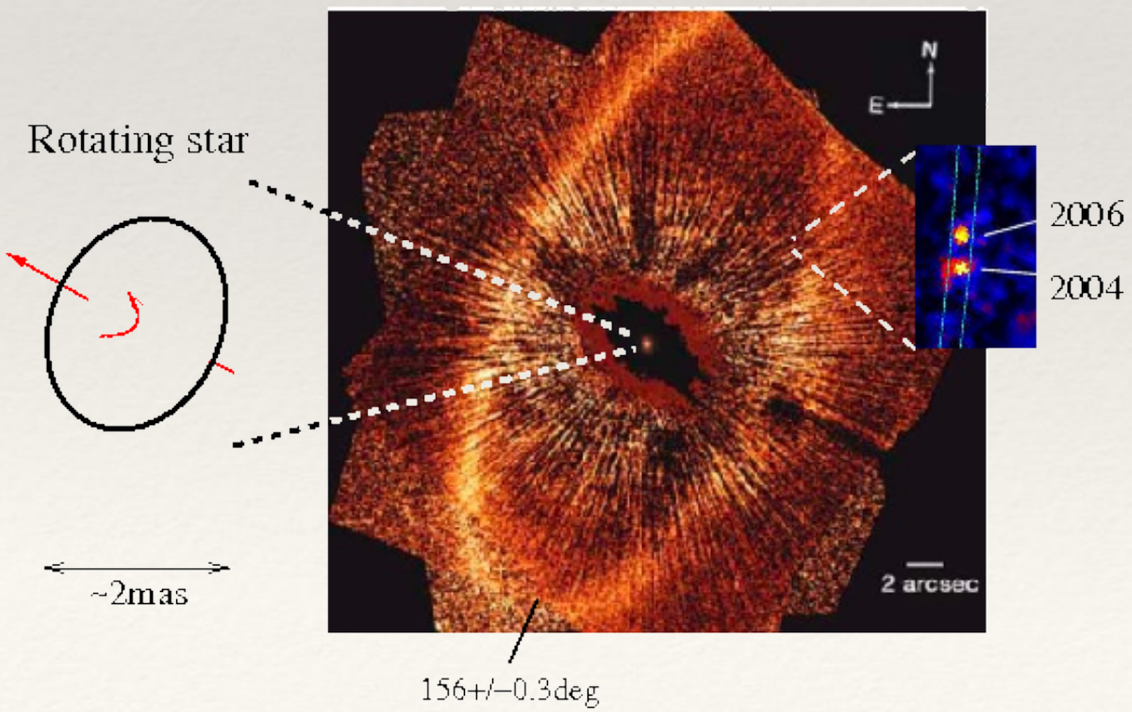




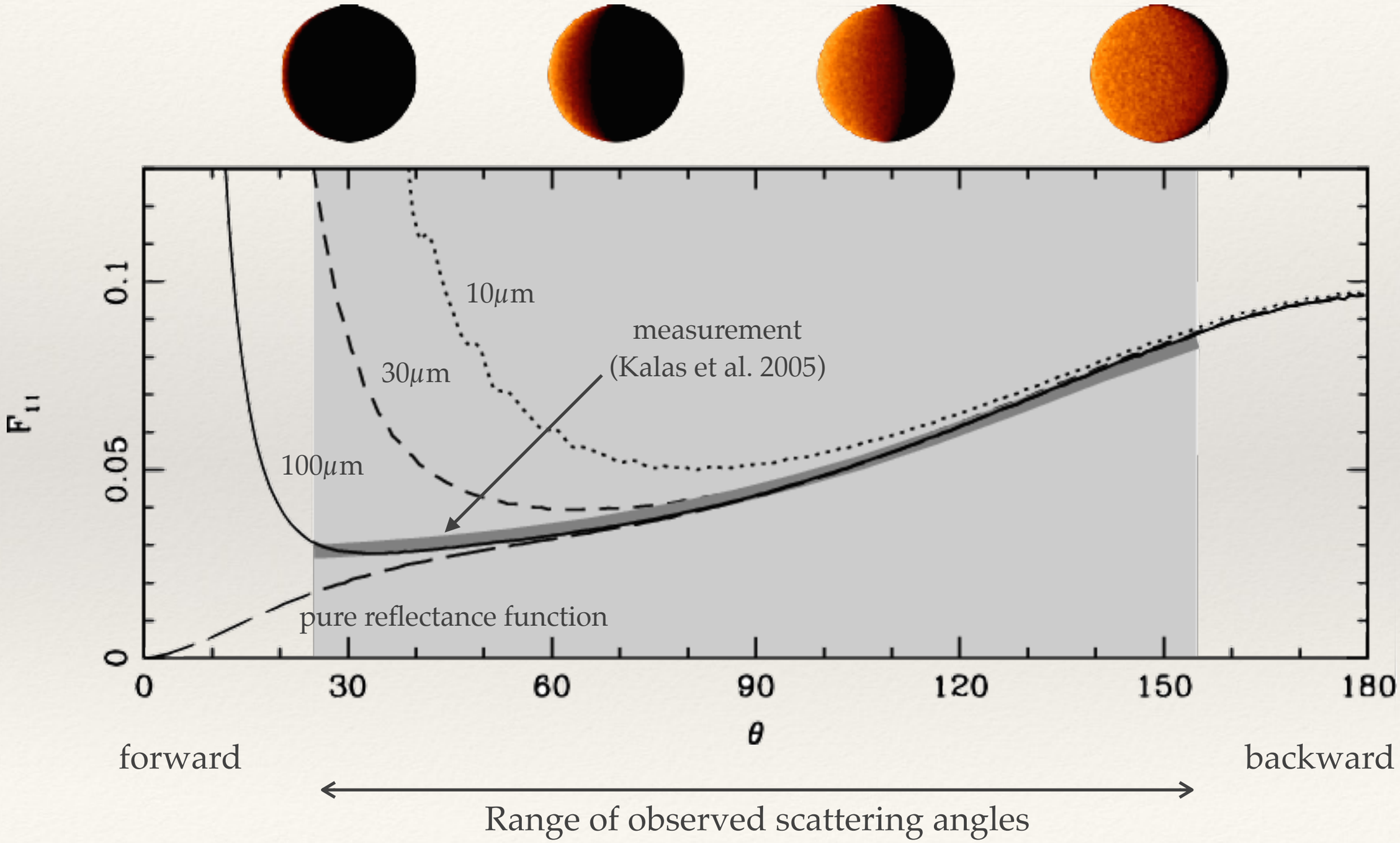
Spin-orbit alignment

Le Bouquin et al. 2009

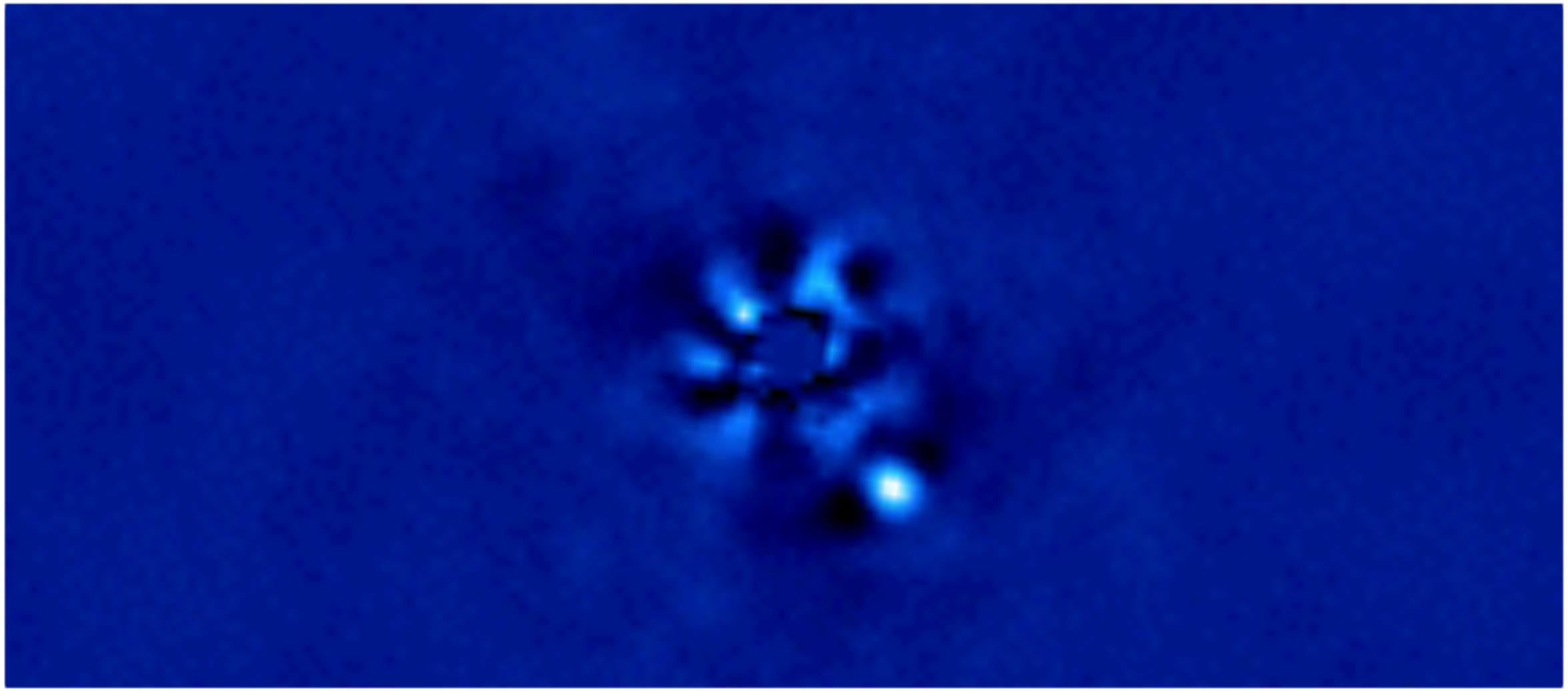




Consequence on the grains



Min et al. 2010



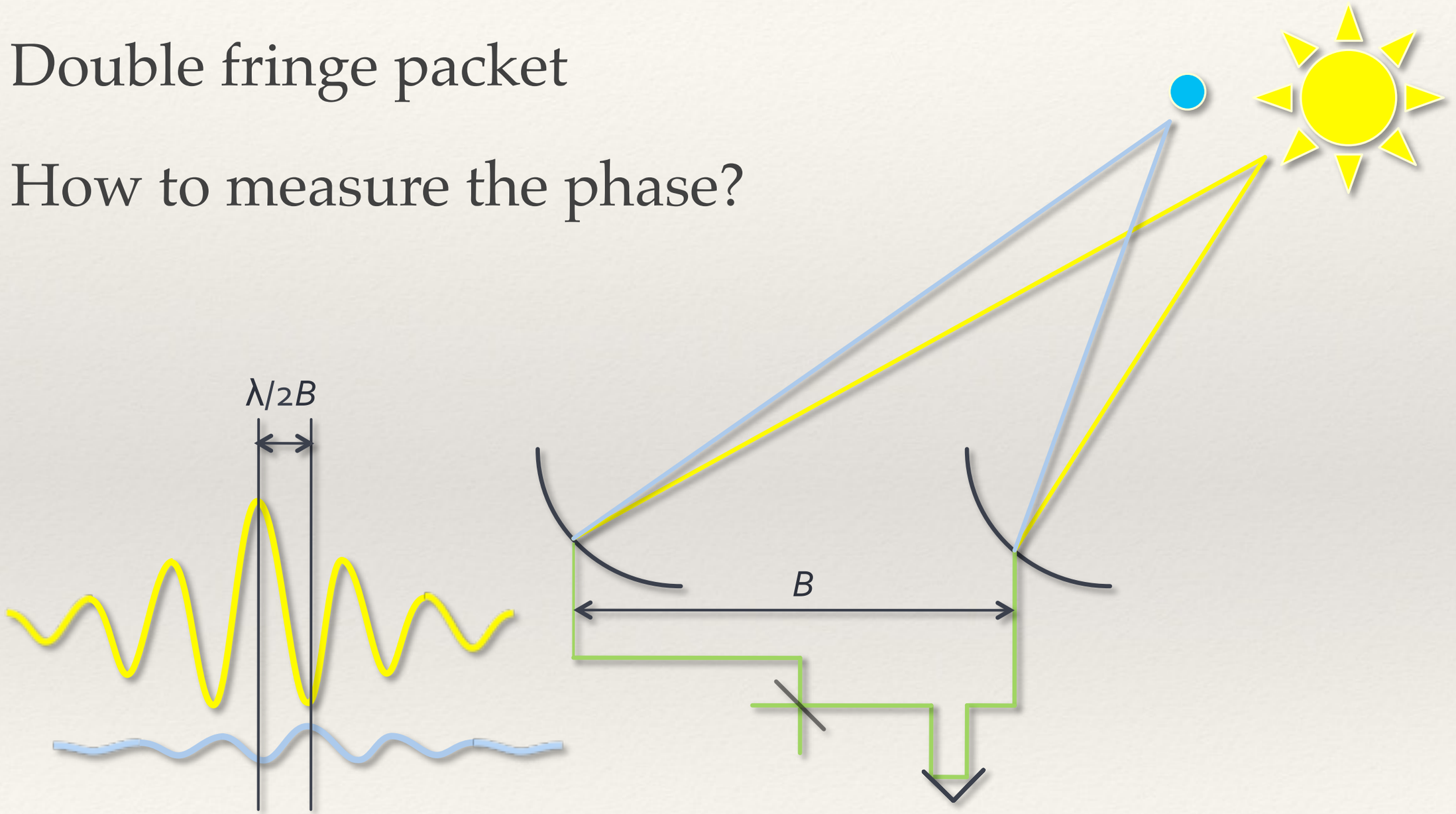
beta Pic — Absil et al. 2013

Substellar / planetary companions

Reaching the highest contrasts

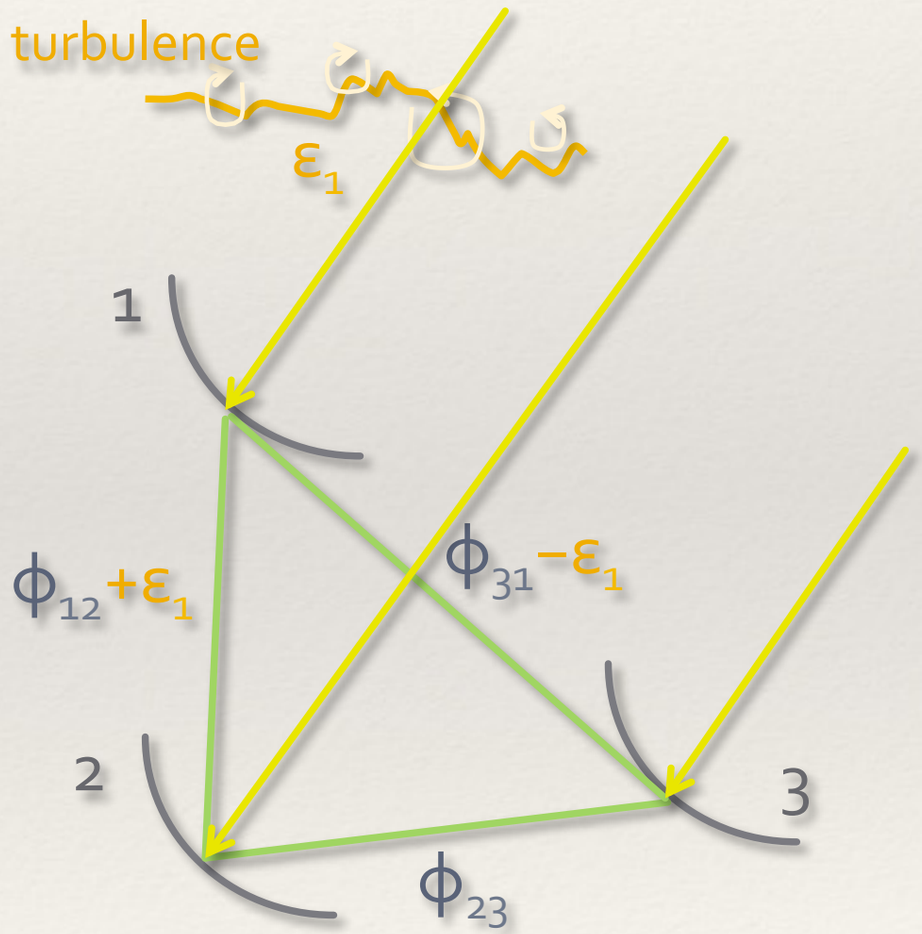
The interferometric view

- Double fringe packet
- How to measure the phase?

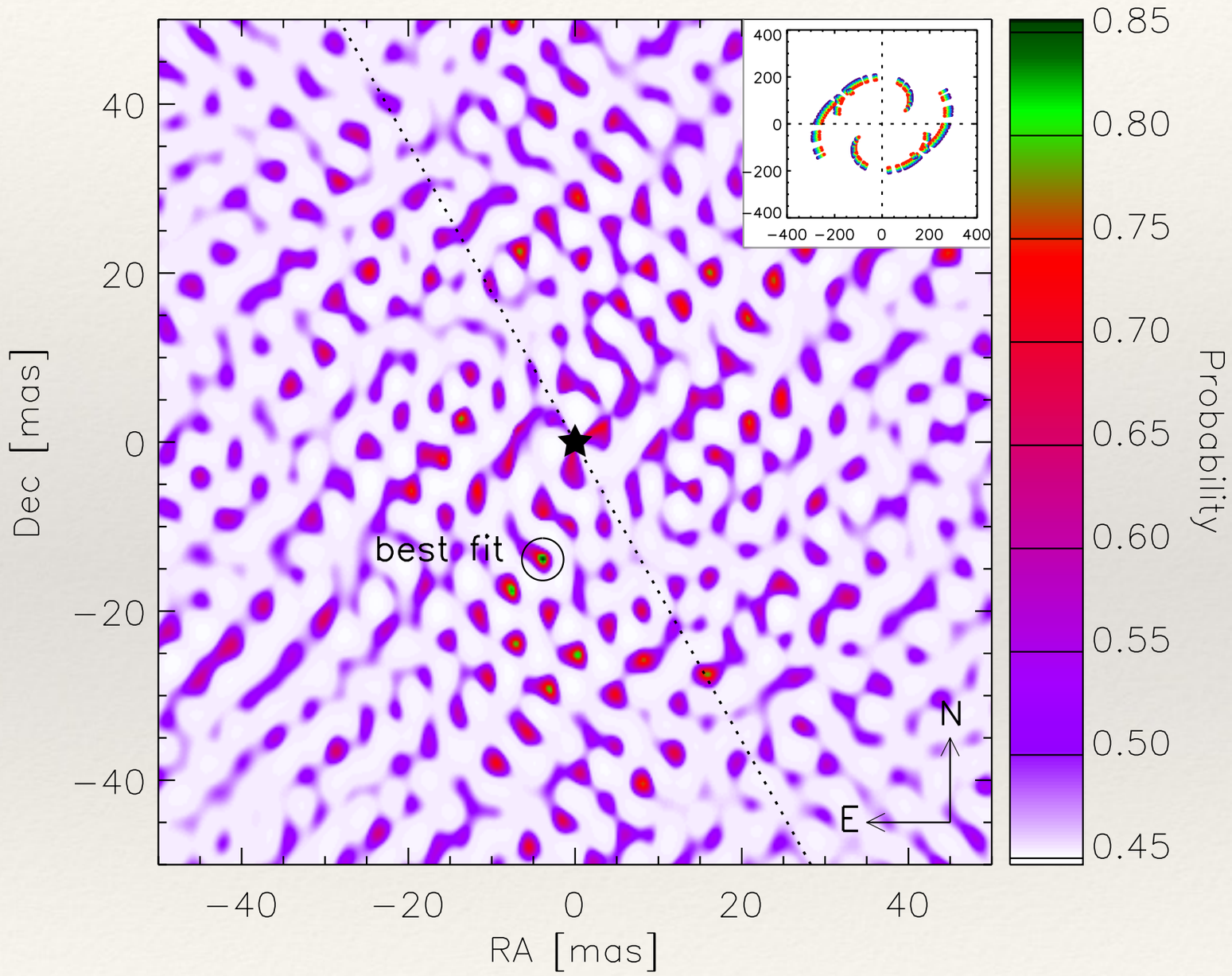


The closure phase

- Closure phase not affected by telescope-specific errors
  - $\psi_{123} = \phi_{12}{+\varepsilon_1} + \phi_{23} + \phi_{31}{-\varepsilon_1}$
  - Not biased by turbulence
- Asymmetric objects: $\psi_{123} \neq 0$
  - Sensitive to companions
  - $\psi_{123} = \varrho\ (\sin \alpha_{12} + \sin \alpha_{23} + \sin \alpha_{31})$
    - proportional to flux ratio
    - $\varrho = 1\%$ —> $\psi_{123} \sim 1°$



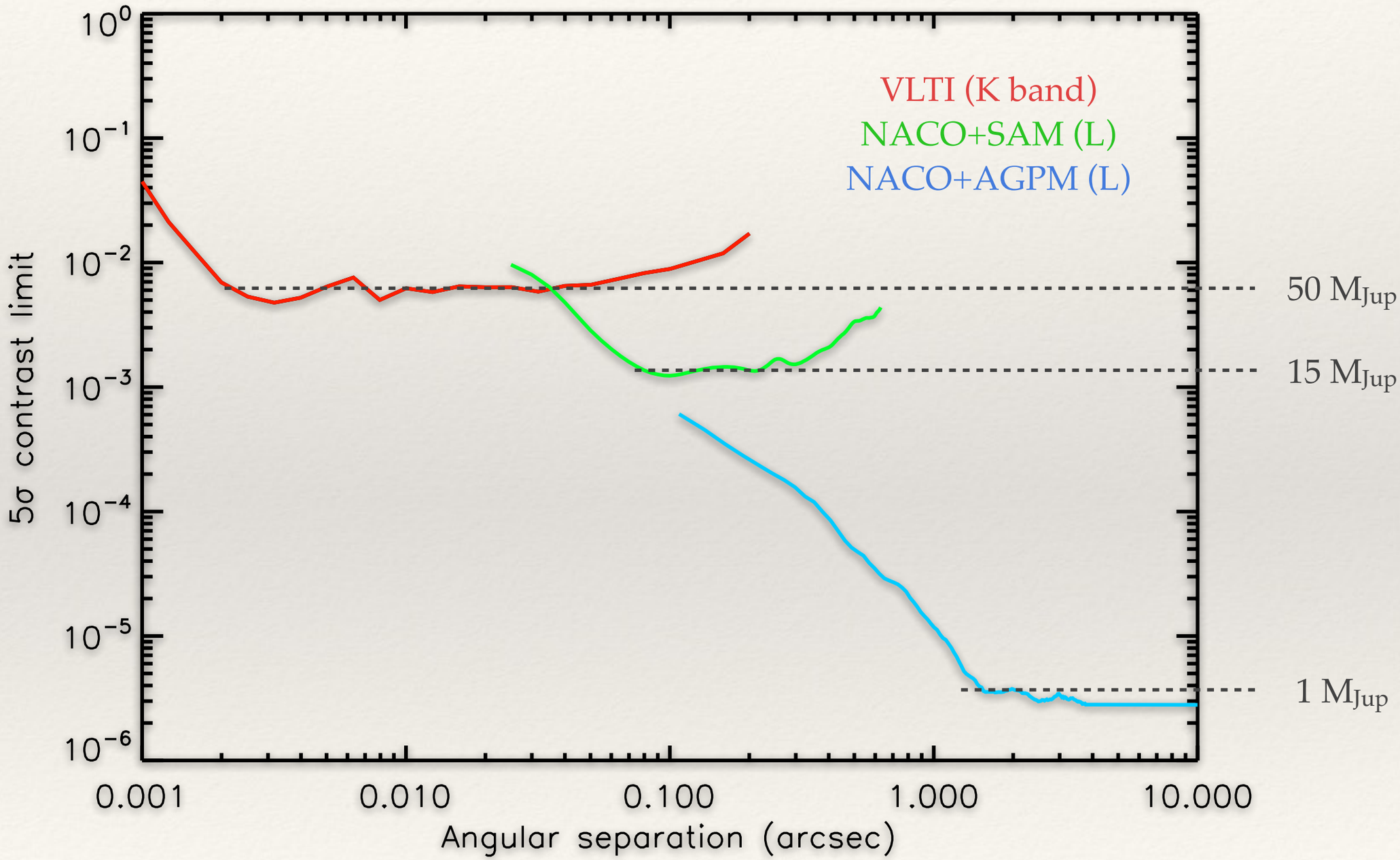
Result: χ^2 map



Best fit: $1.8\times10^{-3} \pm 1.1\times10^{-3}$ at 14 mas

Absil et al. 2010

Detection limits



Conclusion: I'll have both!