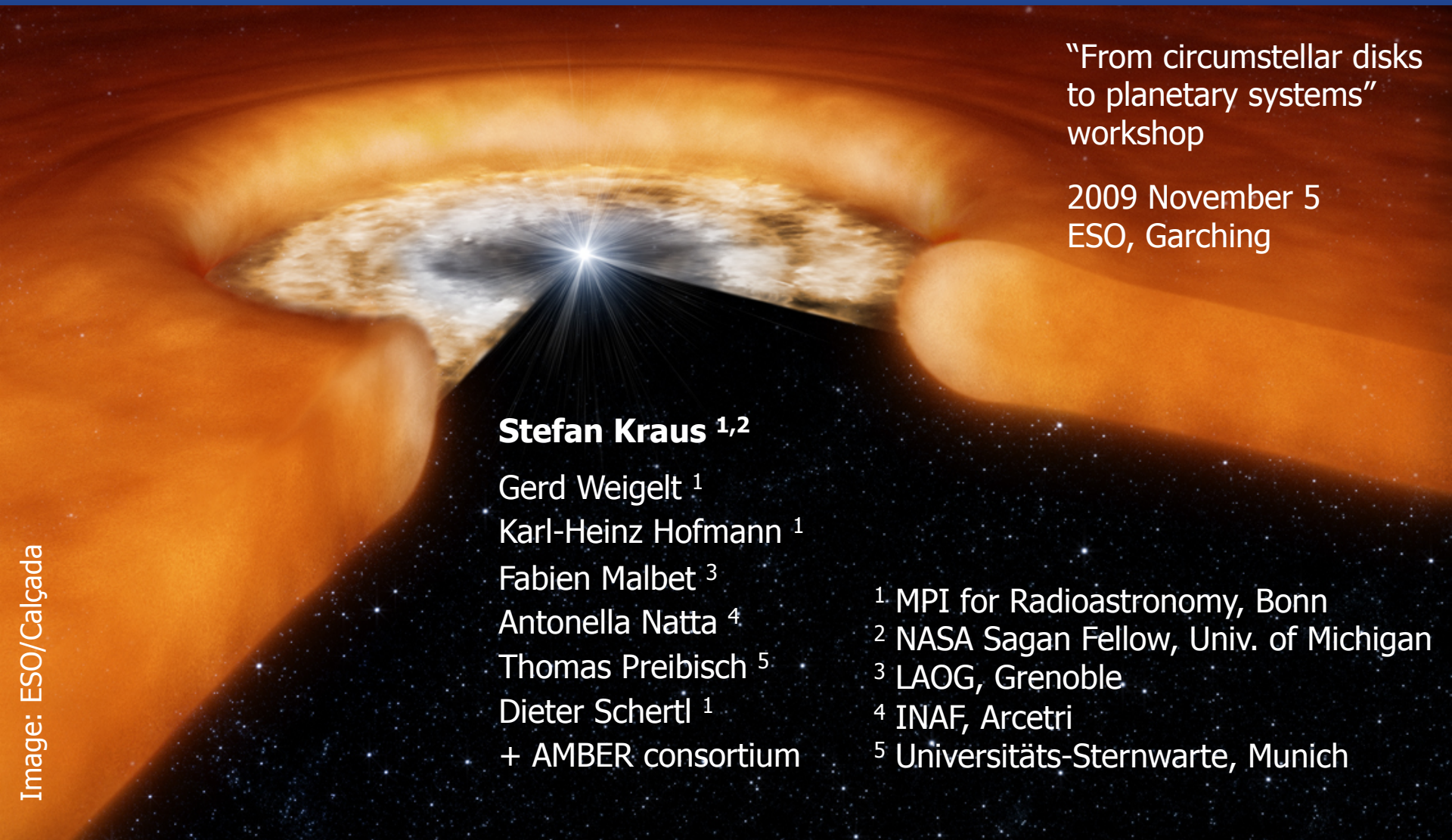
Studying the sub-AU structure of protoplanetary disks and YSO accretion-/outflow-processes with VLTI spectro-interferometry



"From circumstellar disks to planetary systems" workshop

2009 November 5
ESO, Garching

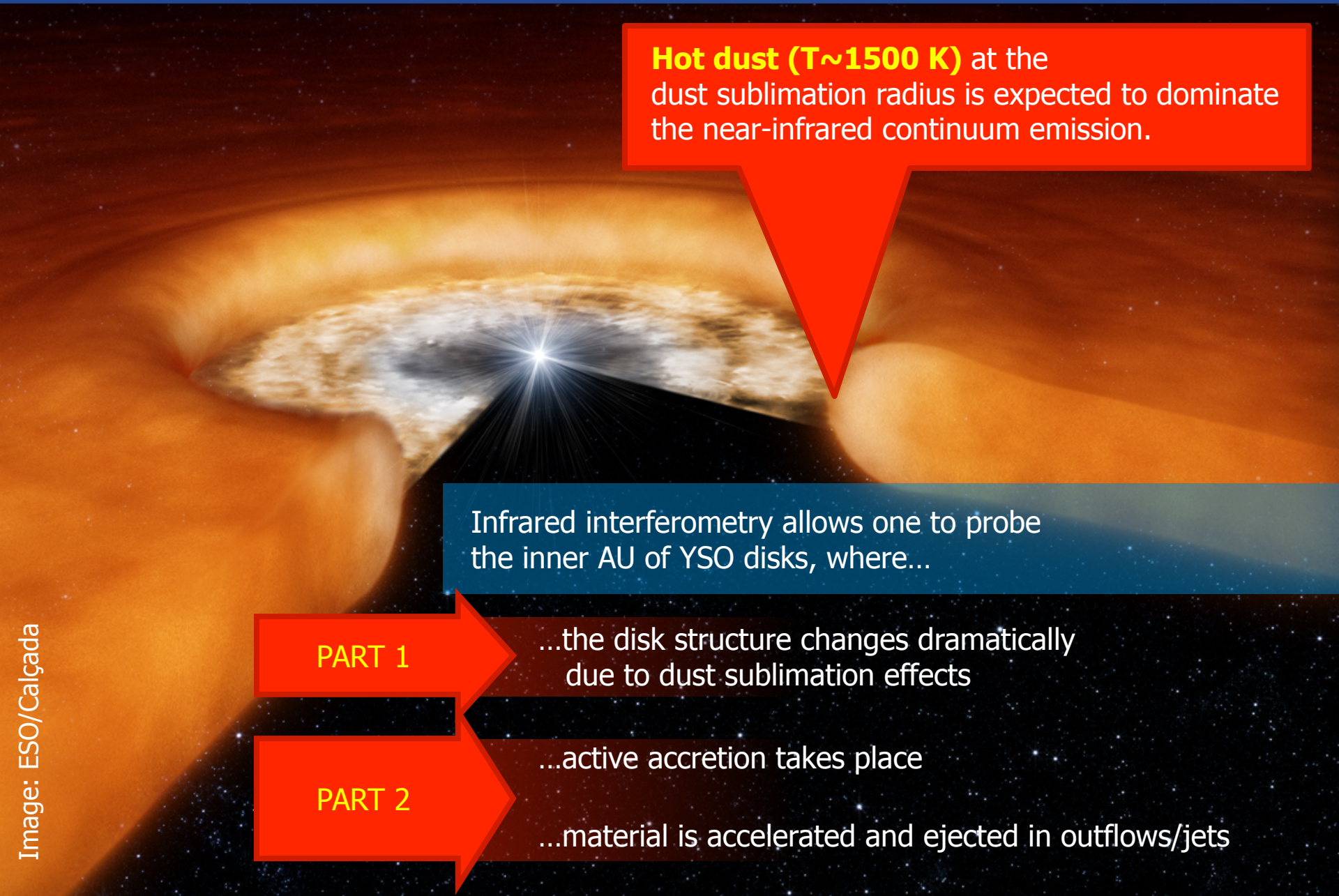
Stefan Kraus [1,2]

Gerd Weigelt [1]
Karl-Heinz Hofmann [1]
Fabien Malbet [3]
Antonella Natta [4]
Thomas Preibisch [5]
Dieter Schertl [1]
+ AMBER consortium

[1] MPI for Radioastronomy, Bonn
[2] NASA Sagan Fellow, Univ. of Michigan
[3] LAOG, Grenoble
[4] INAF, Arcetri
[5] Universitäts-Sternwarte, Munich

Image: ESO/Calçada

Exploring the inner-most AU of YSO disks



Hot dust (T~1500 K) at the dust sublimation radius is expected to dominate the near-infrared continuum emission.

Infrared interferometry allows one to probe the inner AU of YSO disks, where…

PART 1

…the disk structure changes dramatically due to dust sublimation effects

PART 2

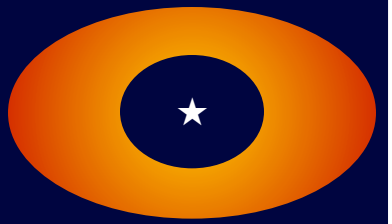
…active accretion takes place

…material is accelerated and ejected in outflows/jets

Image: ESO/Calçada

Constraints on the inner disk structure

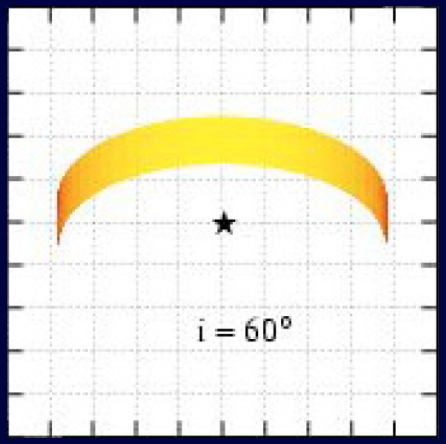
GEOM. FLAT DISK



e.g. temperature gradient models

No asymmetries (CP ≡ ZERO!)

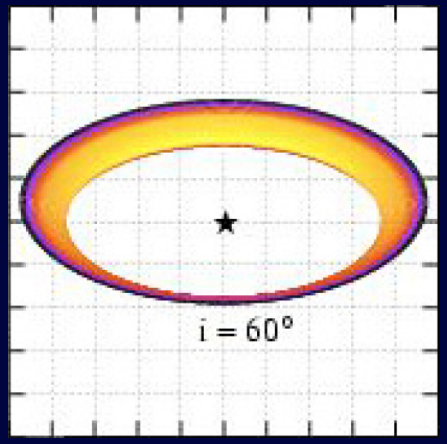
VERTICAL RIM



Natta et al. 2001
Dullemond et al. 2001

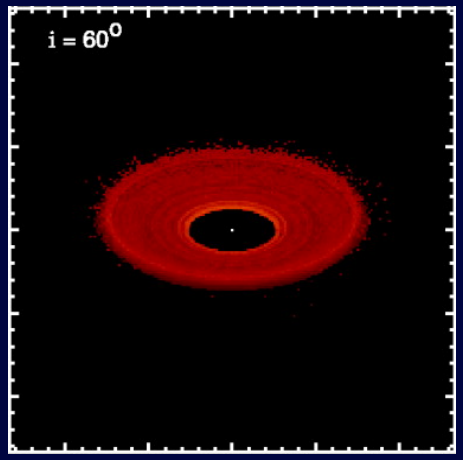
Strong asymmetries (strong CP signal)

CURVED RIM



Isella & Natta 2005

VERY CURVED RIM

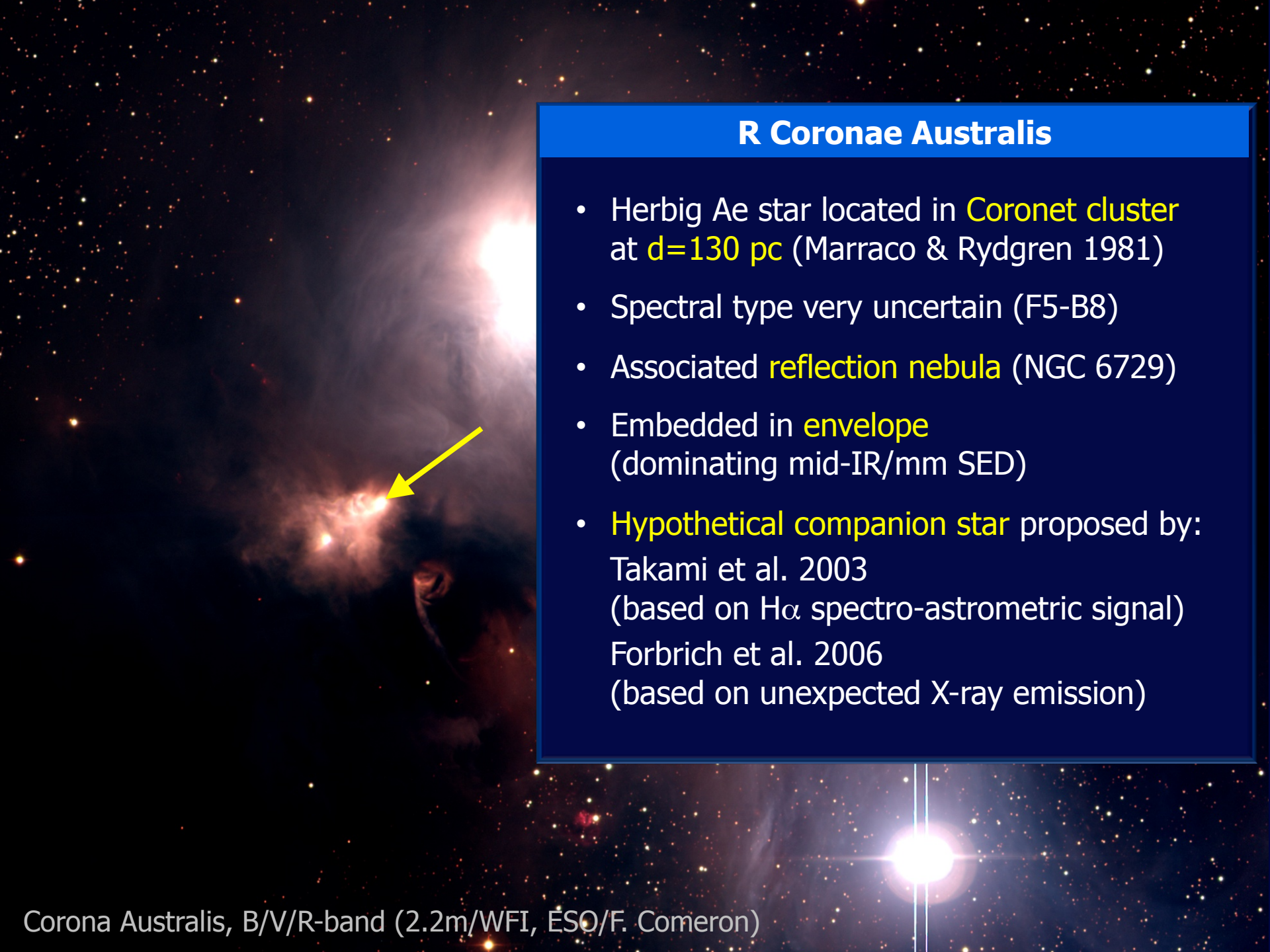


Tannirkulam et al. 2007
Kama et al. 2009

Weak asymmetries (weak CP signal)

Interferometric observables:

Visibilities ➜ measures object extension (in first order)
Closure Phases (CPs) ➜ measures deviations from point-symmetry



R Coronae Australis

- Herbig Ae star located in Coronet cluster at d=130 pc (Marraco & Rydgren 1981)
- Spectral type very uncertain (F5-B8)
- Associated reflection nebula (NGC 6729)
- Embedded in envelope (dominating mid-IR/mm SED)
- Hypothetical companion star proposed by:
  Takami et al. 2003
  (based on Hα spectro-astrometric signal)
  Forbrich et al. 2006
  (based on unexpected X-ray emission)

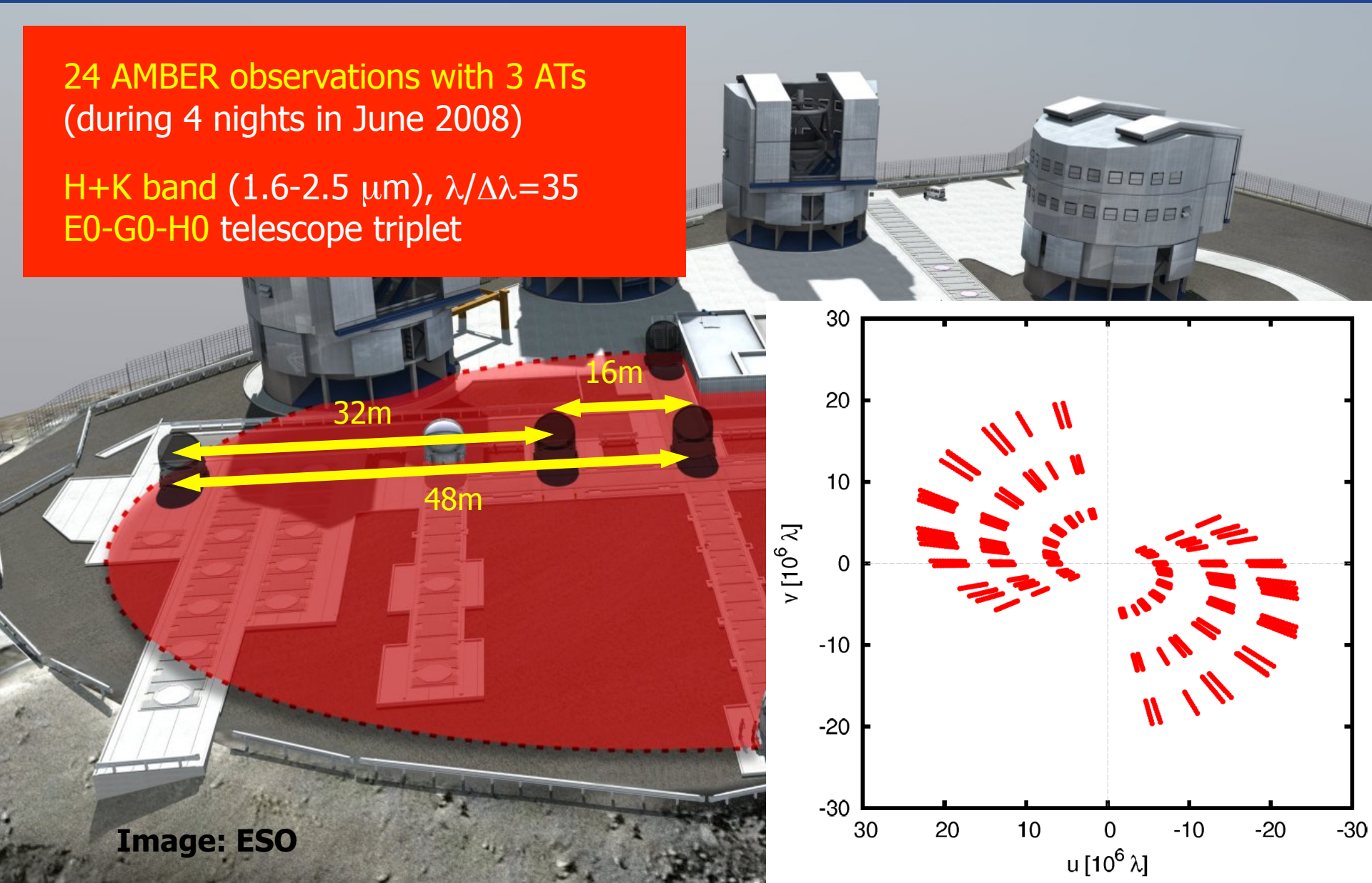
Corona Australis, B/V/R-band (2.2m/WFI, ESO/F. Comeron)

Revealing the asymmetries of the inner dust rim

VLTI/AMBER observations on R CrA

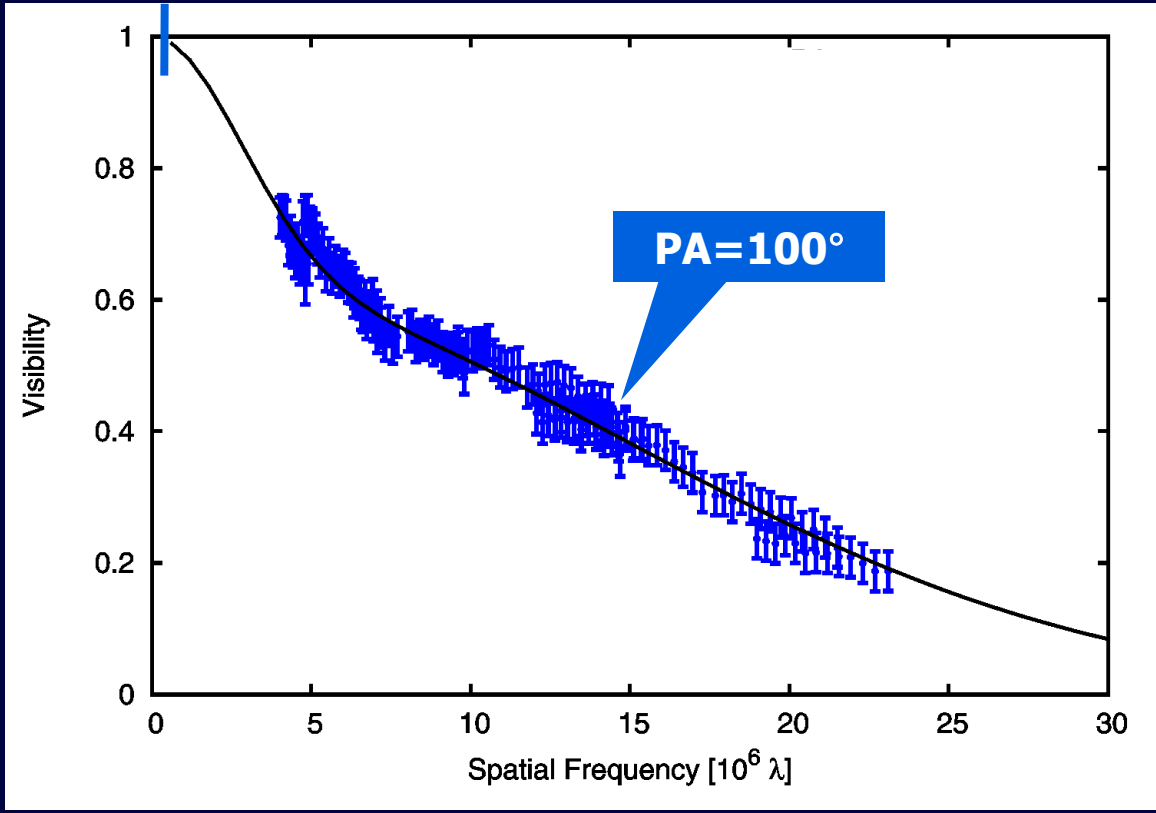
24 AMBER observations with 3 ATs
(during 4 nights in June 2008)

H+K band (1.6-2.5 μm), λ/Δλ=35
E0-G0-H0 telescope triplet



Revealing the asymmetries of the inner dust rim

Indications for a disk + envelope geometry

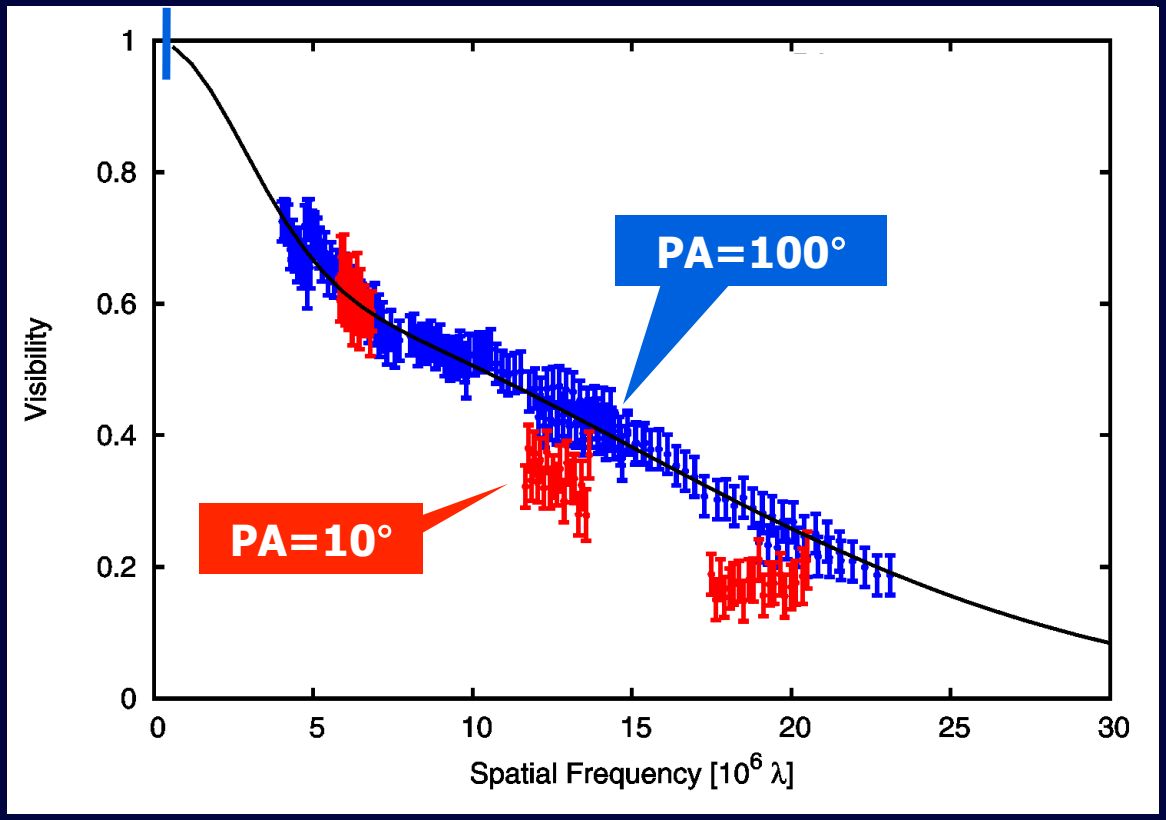


(1) Pronounced change in slope in visibility function indicates 2 spatial components:

Extended component (~30 mas) "Envelope" & Compact component (~5 mas) "Disk"

Revealing the asymmetries of the inner dust rim

Indications for a disk + envelope geometry



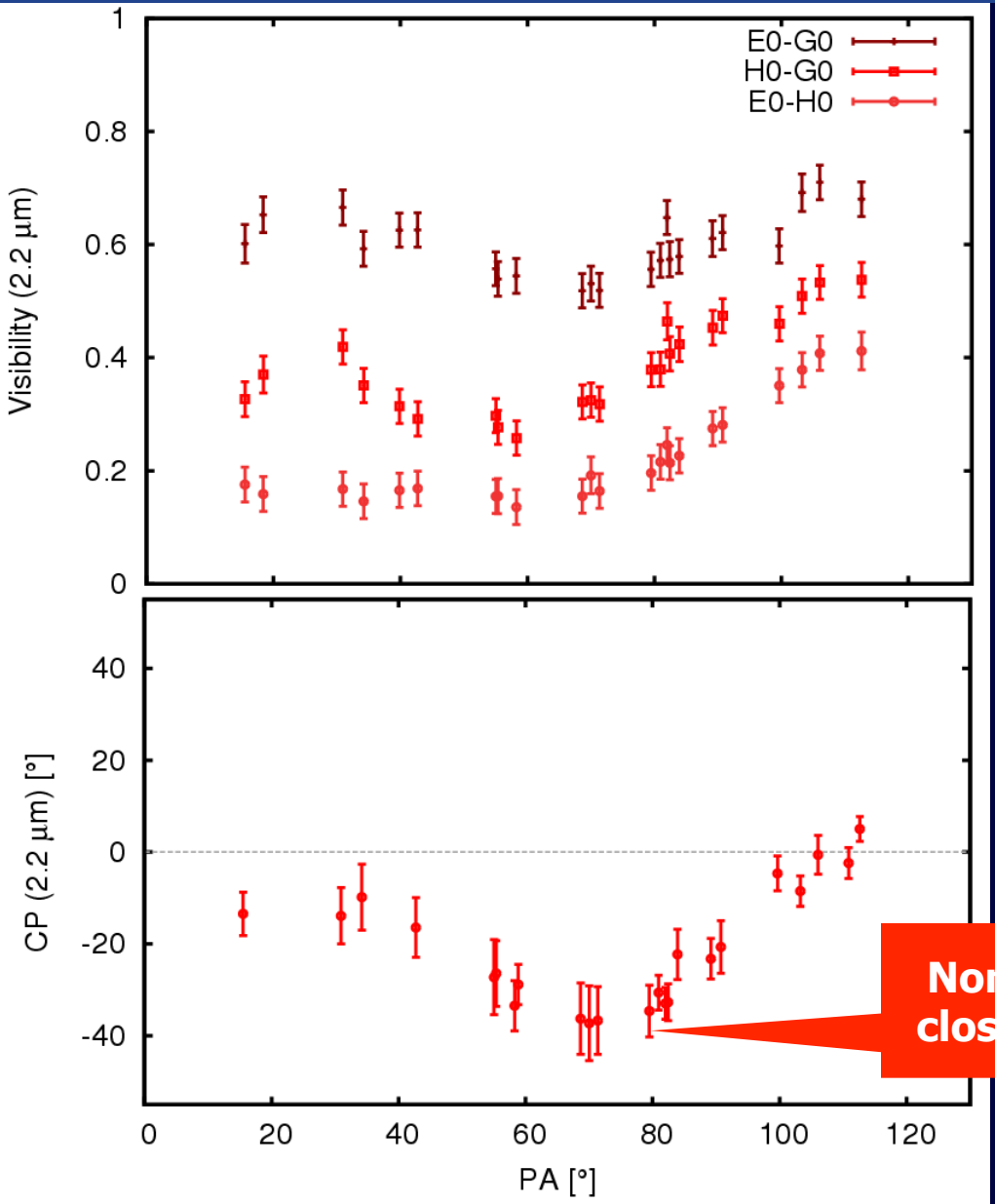
(1) Pronounced change in slope in visibility function indicates 2 spatial components:

Extended component (~30 mas) "Envelope" & Compact component (~5 mas) "Disk"

(2) Visibility profile changes with position angle

Revealing the asymmetries of the inner dust rim

Position-angle dependence of visibilities & CPs



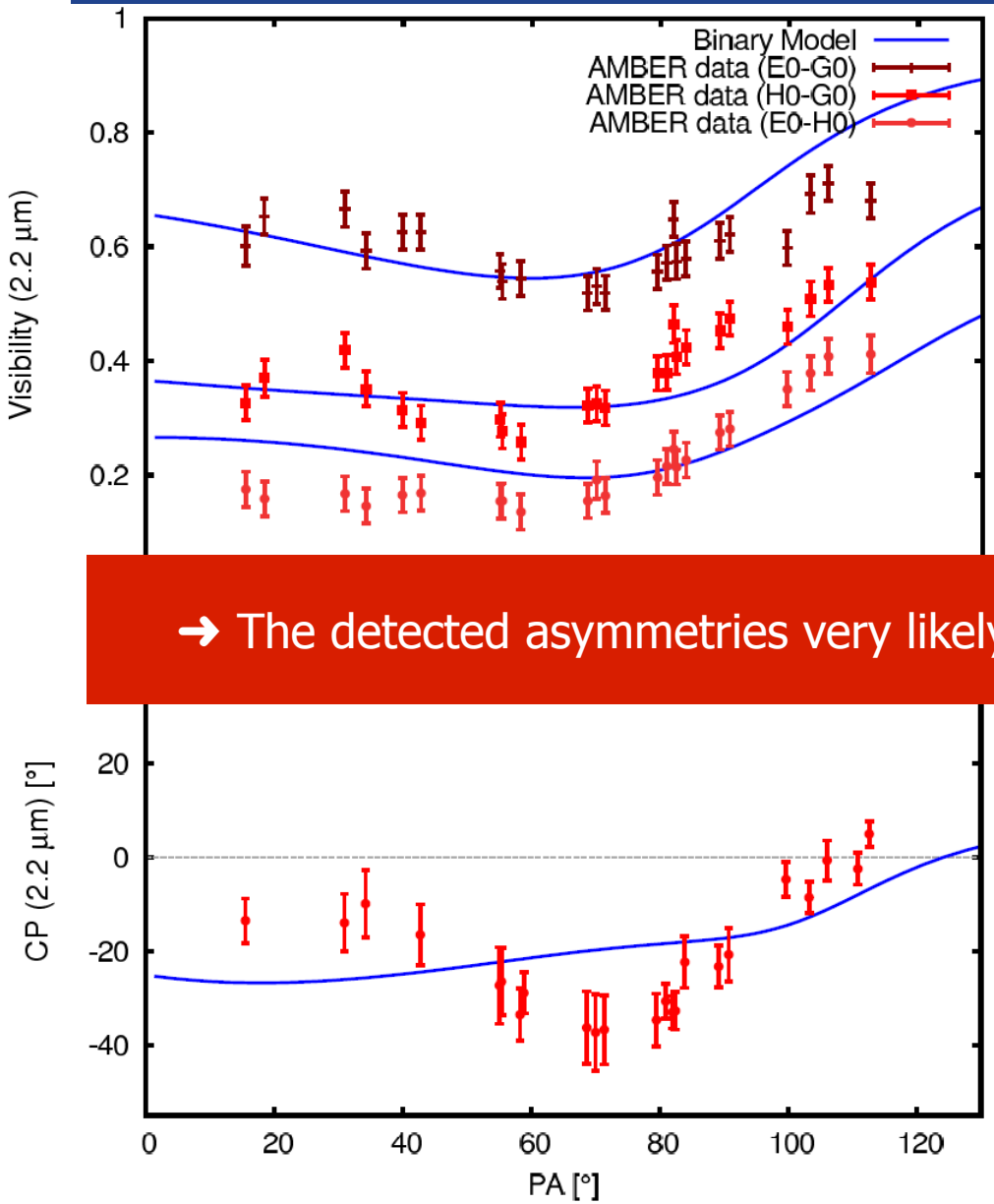
The visibility function and the measured non-zero closure phases are strongly position angle-dependent!

➜ Brightness distribution is highly asymmetric on sub-AU scales!

Non-zero (-40°) closure phases!!!

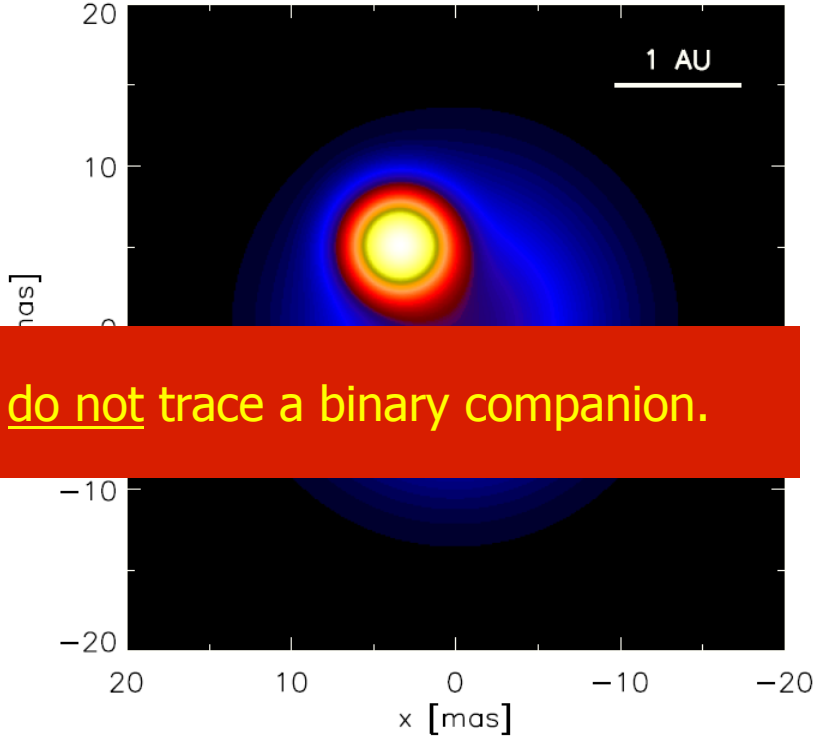
Revealing the asymmetries of the inner dust rim

BINARY STAR model



Scenario:

Close binary system (possibly with resolved disks)

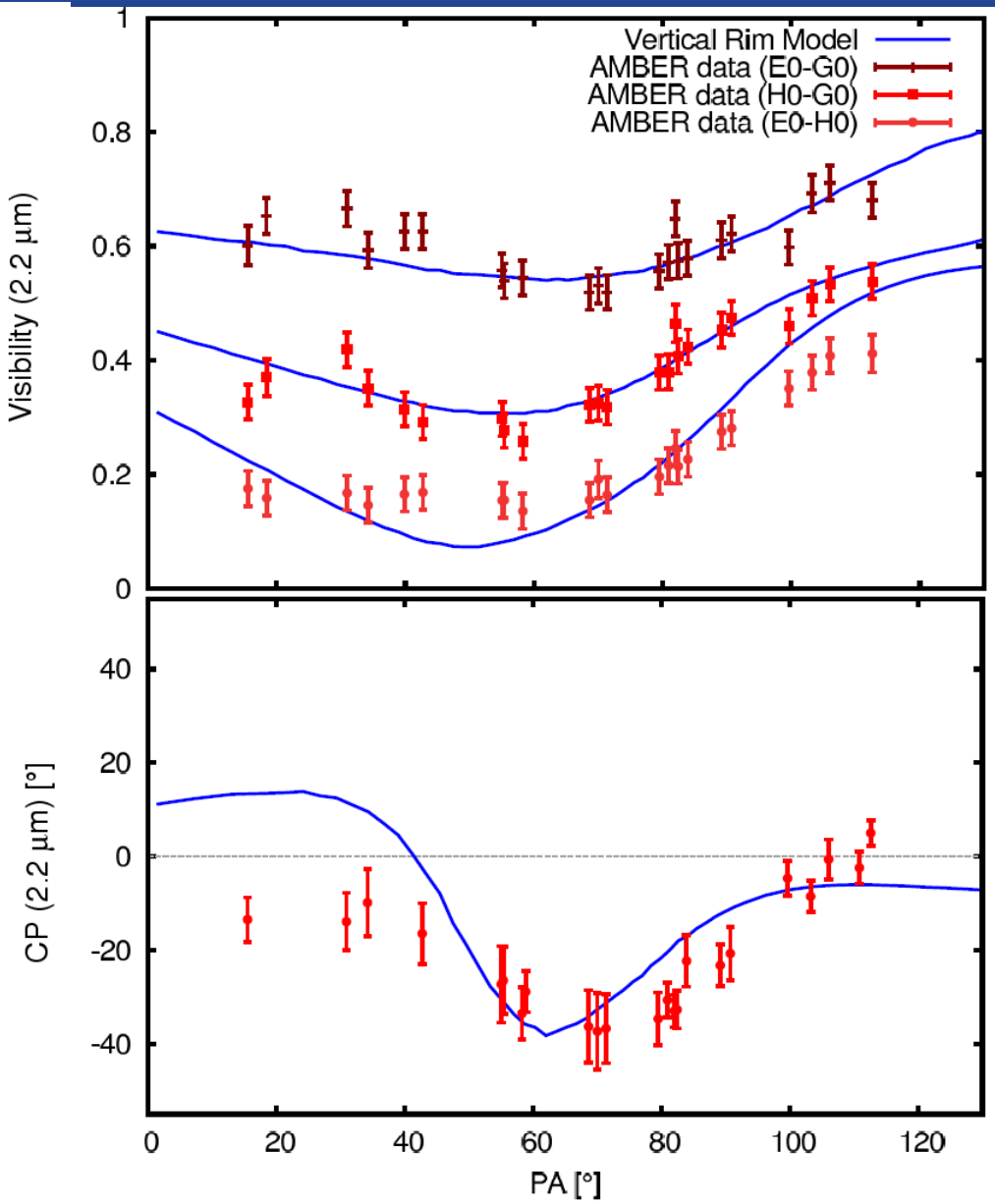


➜ The detected asymmetries very likely do not trace a binary companion.

$\chi^2 = 3.9$

Revealing the asymmetries of the inner dust rim

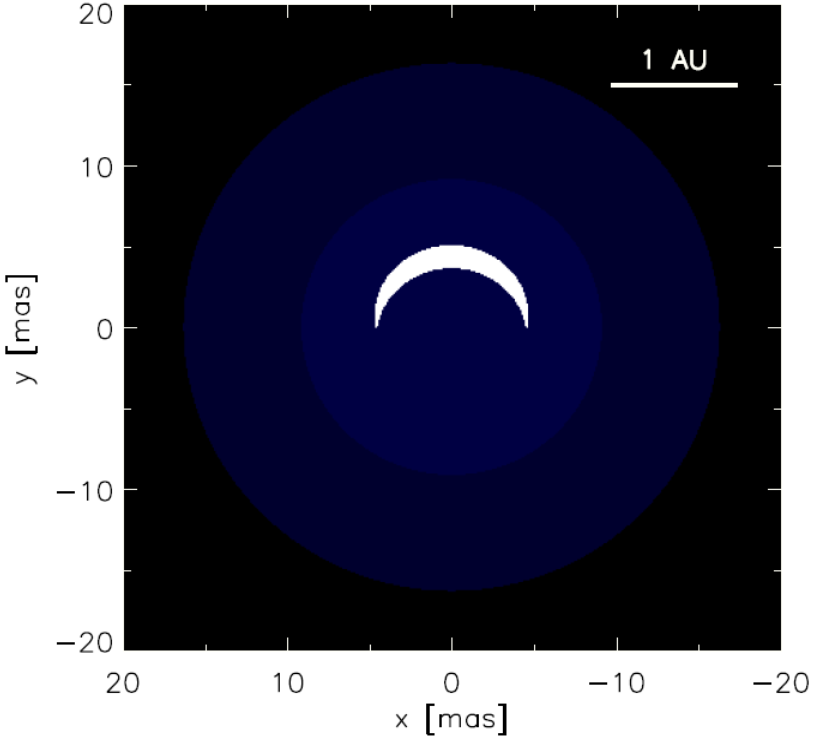
VERTICAL RIM model



Scenario:

Vertical puffed-up inner rim

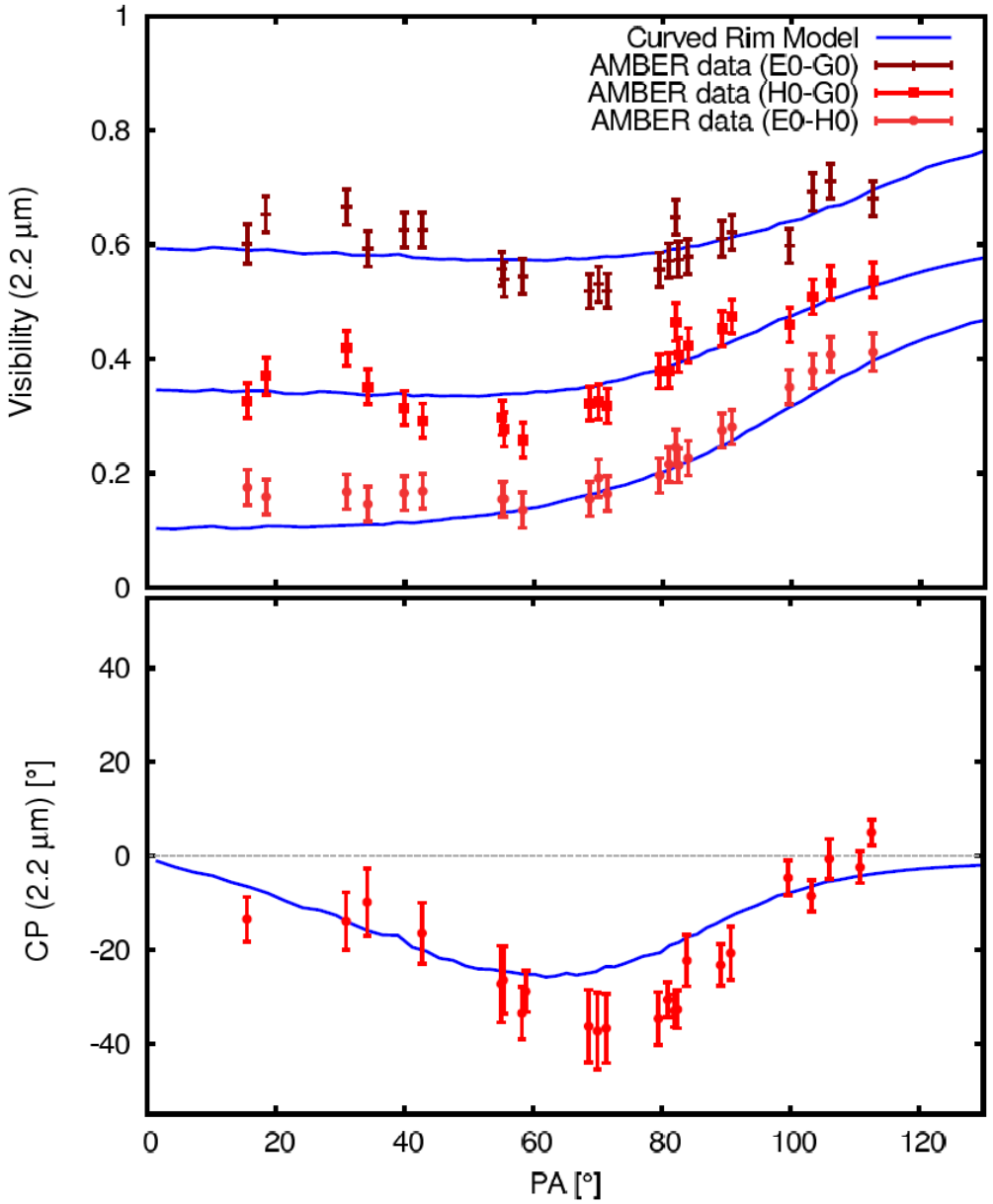
(motivated by Dullemond et al. 2001)



$\chi^2 = 3.3$

Revealing the asymmetries of the inner dust rim

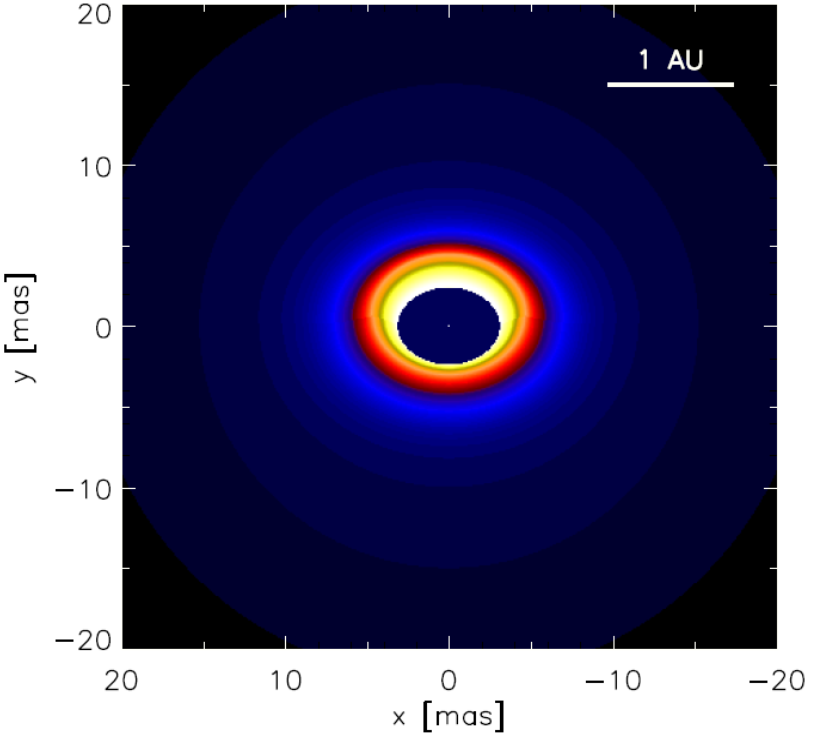
CURVED RIM model (1/2)



Scenario:

Curved puffed-up inner rim

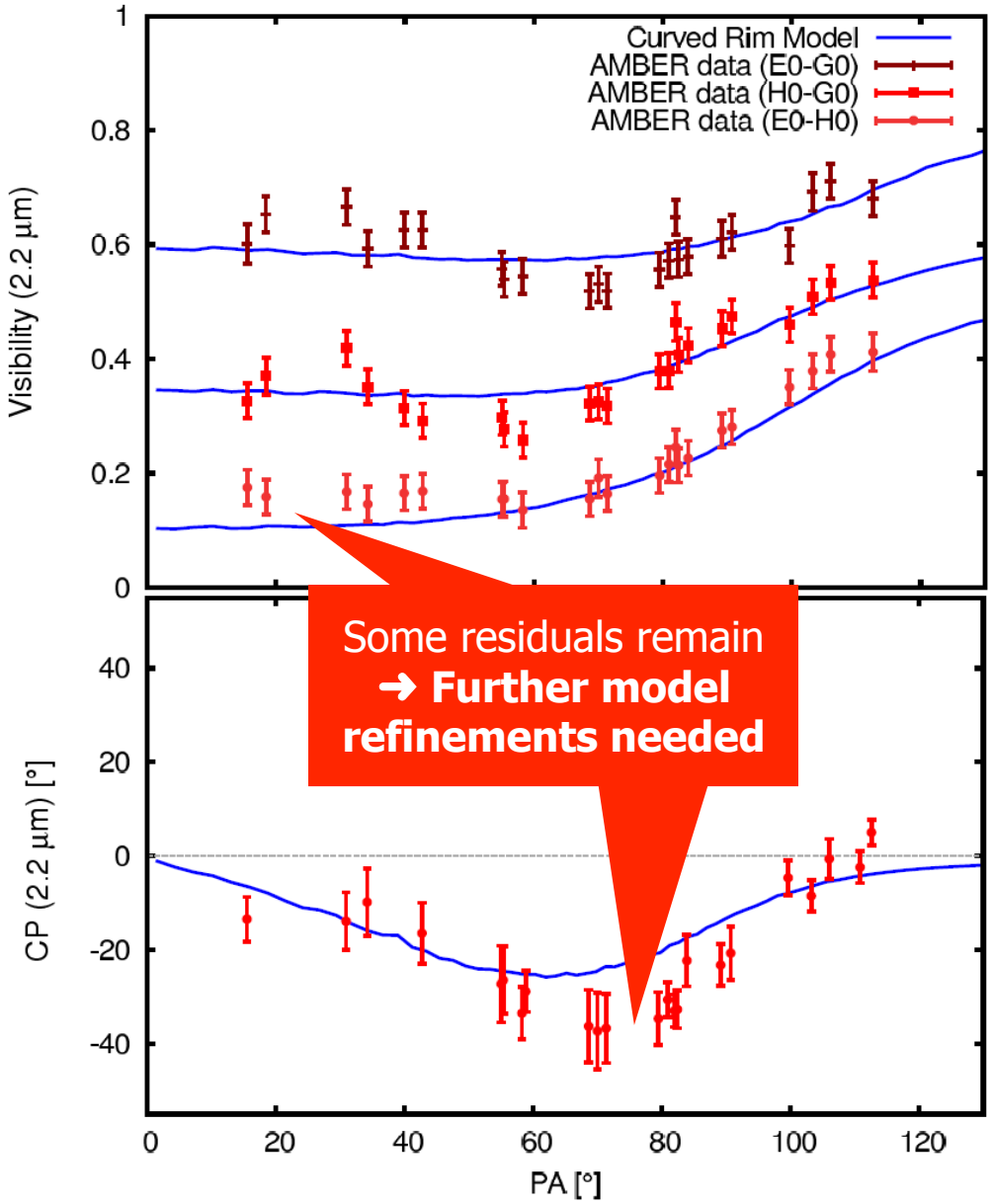
(following Isella & Natta 2005)



$\chi^2 = 2.1$

Revealing the asymmetries of the inner dust rim

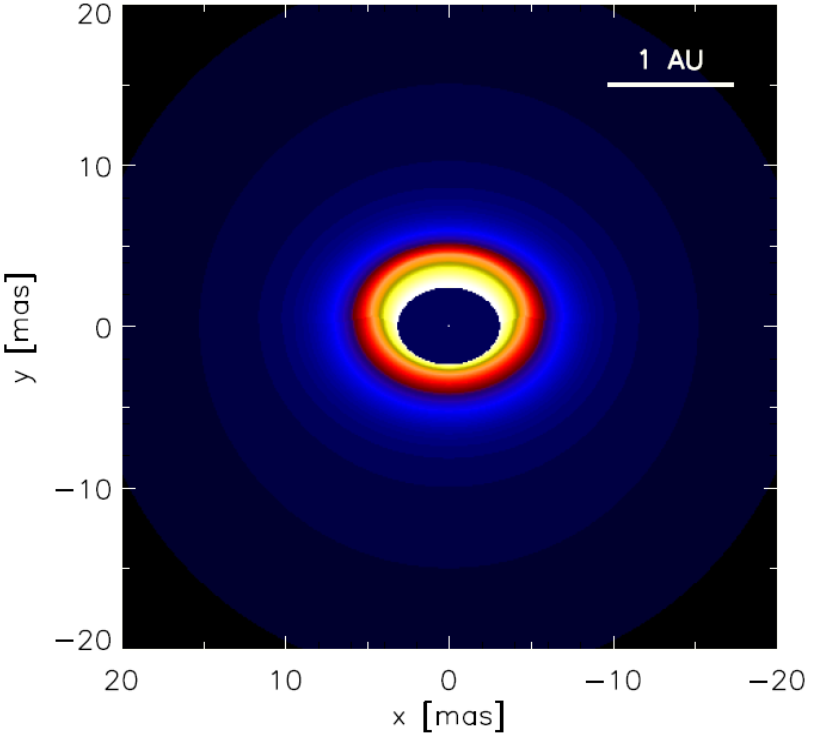
CURVED RIM model (1/2)



Scenario:

Curved puffed-up inner rim

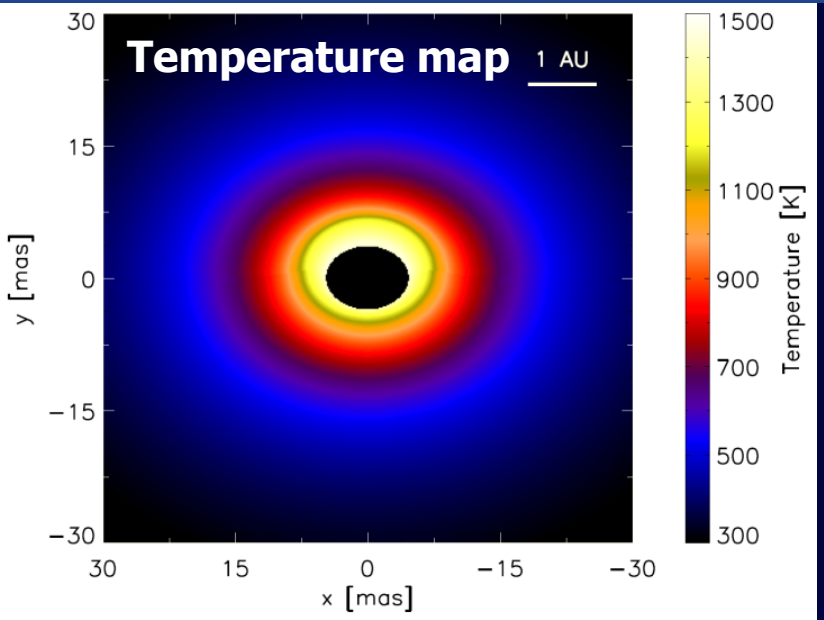
(following Isella & Natta 2005)

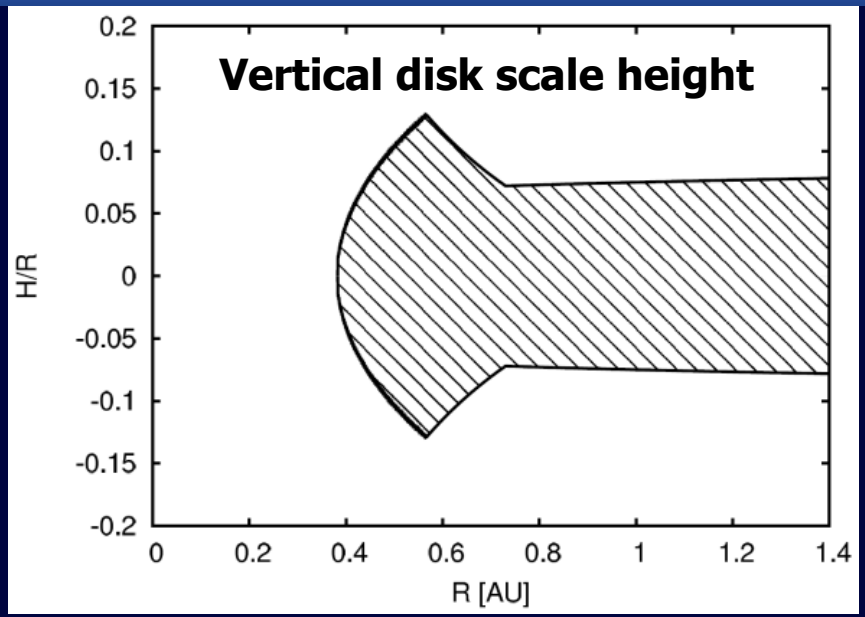


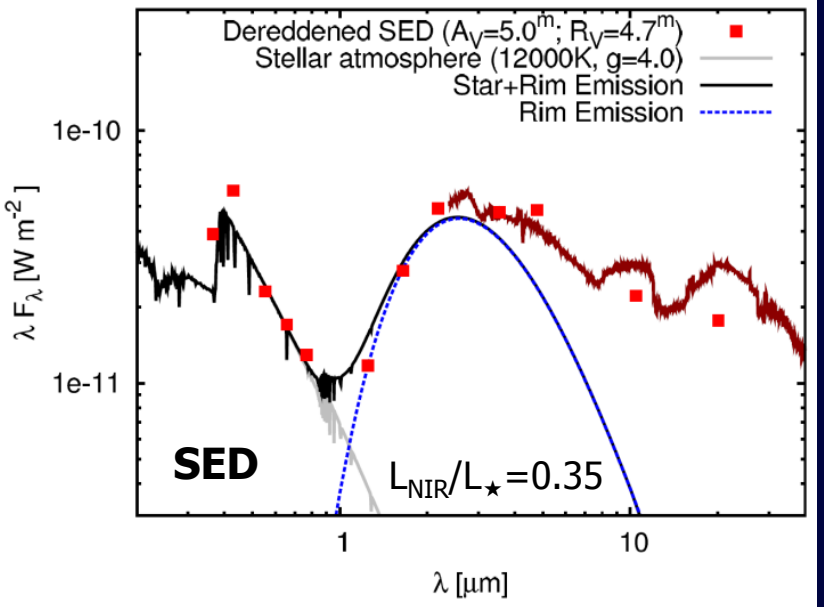
$\chi^2 = 2.1$

Revealing the asymmetries of the inner dust rim

CURVED RIM model (2/2)







STAR:

Luminosity: 29 $L_\odot$

DISK:

Inclination: $i = 35°$

Disk orientation: $\phi = 90°$ (N-S)

Dust cooling efficiency: $\varepsilon \geq \varepsilon_{cr}$ (large grains)

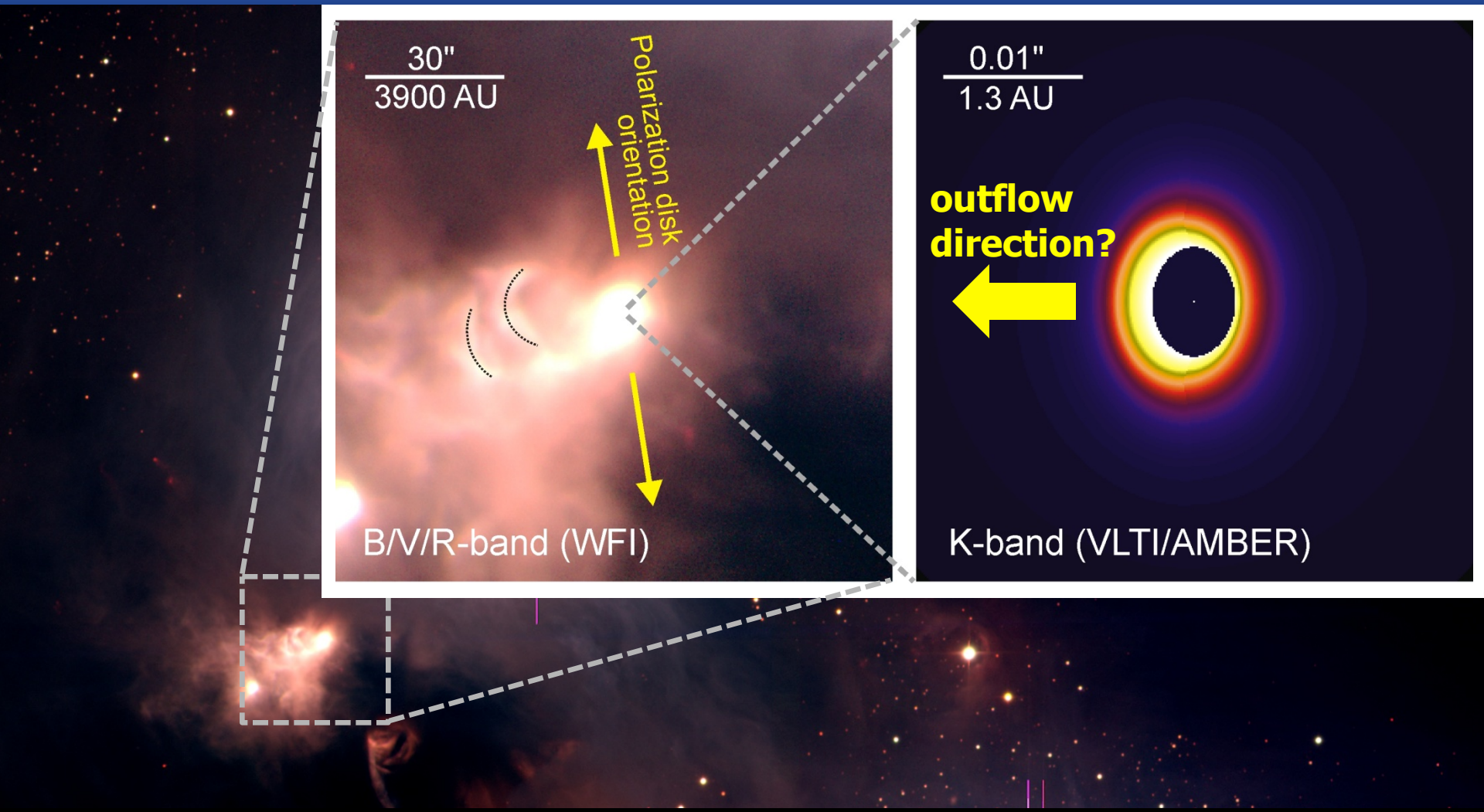
ENVELOPE:

Gauss FWHM: 32 mas

I_{env}/I_{disk} 0.5

Revealing the asymmetries of the inner dust rim

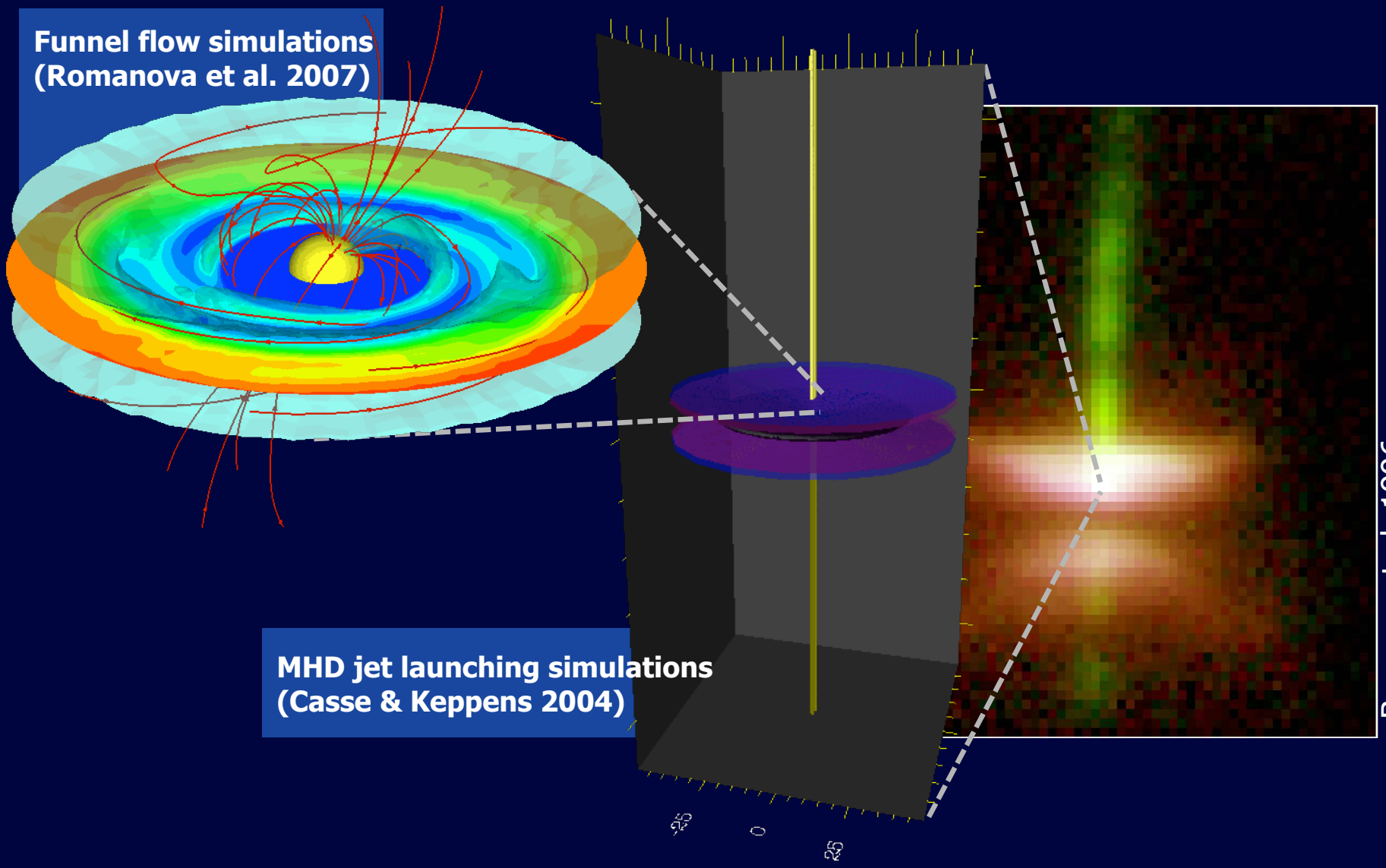
Comparison with large-scale structure



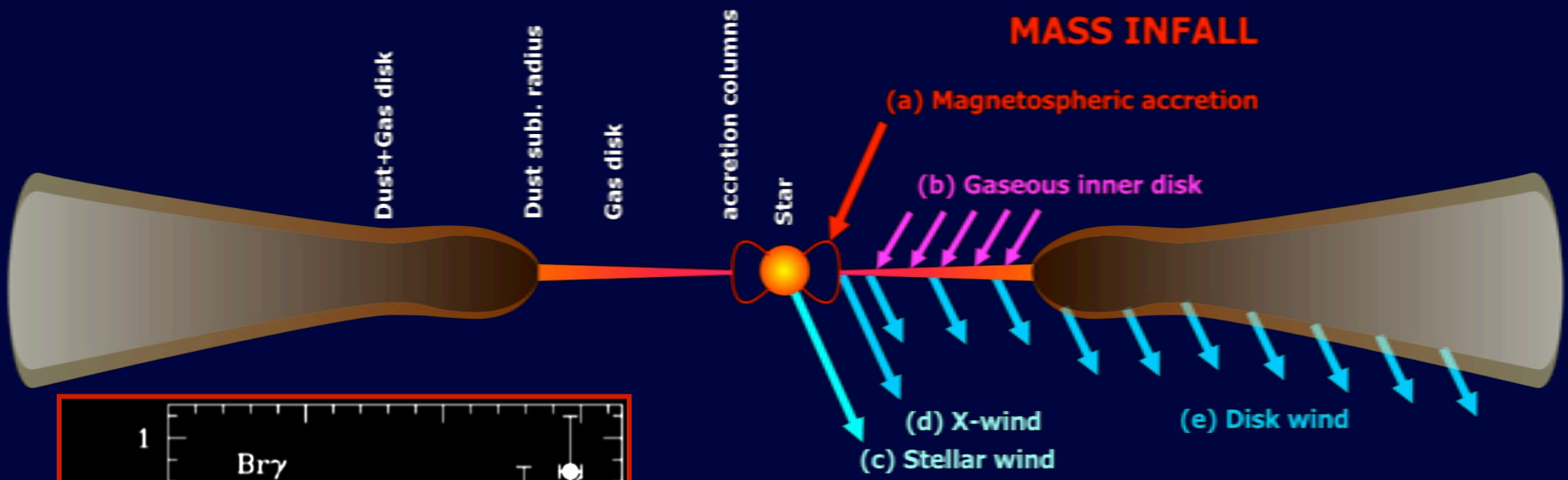
- Derived disk orientation is consistent with polarization disk (Ward-Thompson et al. 1985)
- Bow shock-like features appear roughly perpendicular to disk plane

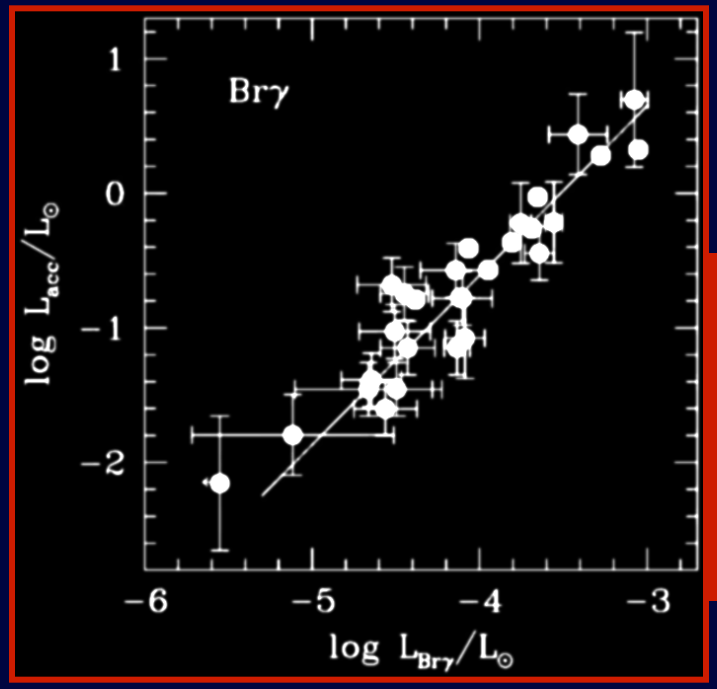
Origin of hydrogen line emission in YSOs

Besides the dust continuum emission, YSOs exhibit also gas-tracing emission lines, tracing the accretion & outflow processes in YSOs.



Origin of hydrogen line emission in YSOs





van den Ancker 2005

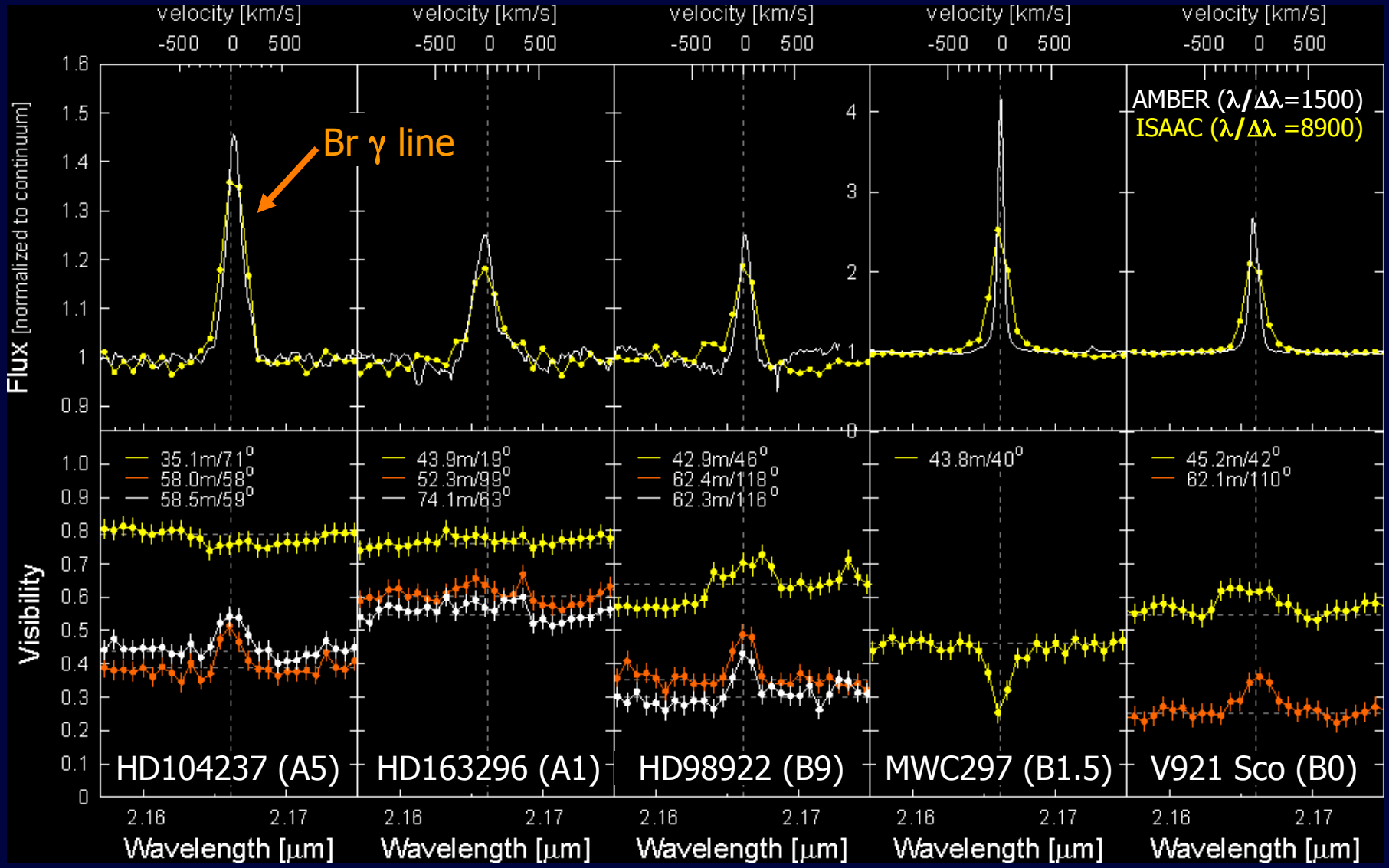
Br γ 2.16 μm hydrogen line:

- Often found in emission
- Line luminosity correlates with accretion luminosity
  (empirical correlation, established for pre-main-seq. stars 0.01 … 4 $M_\odot$)
  ➜ important diagnostic line for mass accretion rate
- Involved physical mechanism not yet identified

Origin of hydrogen line emission in YSOs

VLTI/AMBER observations on 5 Herbig Ae/Be stars

Our sample includes 5 YSOs, including archival data from Malbet et al. 2007 & Tatulli et al. 2007



Origin of hydrogen line emission in YSOs

Evidence for magnetospheric accretion & mass outflow

very compact Br γ-region (unresolved, $R_{Br\,\gamma} < 0.2\ R_{cont}$)

➜ consistent with magnetospheric accretion

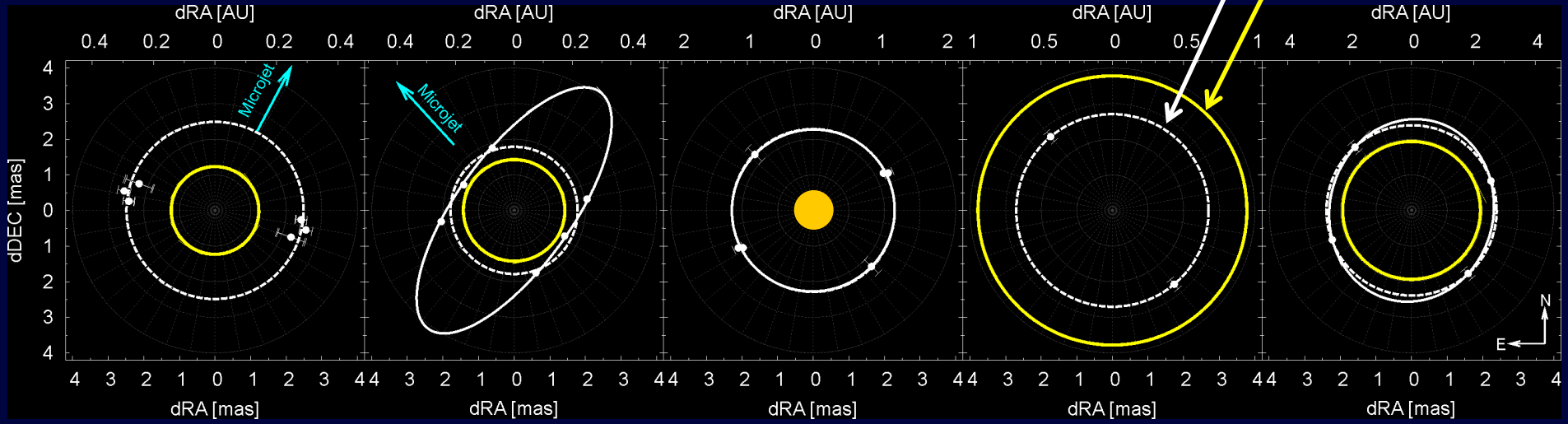
circumbinary disk

microjet (Lyα)

mircojet (Lyα/Hα)

continuum ring/ellipse

Br γ-line ring



HD 104237 (A5) HD 163296 (A1) HD 98922 (B9) MWC 297 (B1.5) V921 Sco (B0)

extended Br γ-region ($0.6 < R_{Br\,\gamma}/R_{cont} < 1.4$)

➜ consistent with disk wind or stellar wind

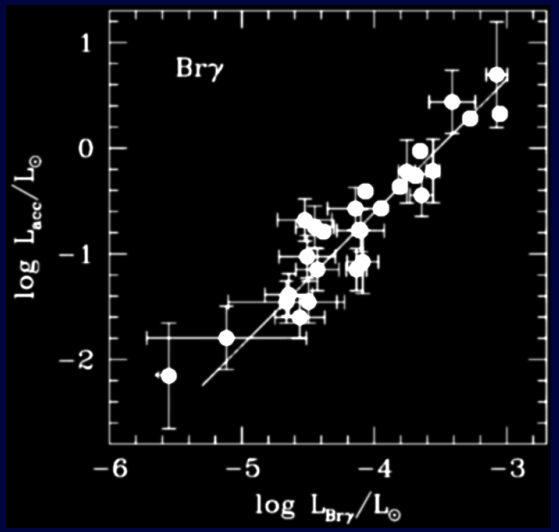
Origin of hydrogen line emission in YSOs

Evidence for magnetospheric accretion & mass outflow

What do we know about the Br γ-emitting mechanism?

(1) spectro-interferometry:
Br γ can trace both mass infall and mass outflow

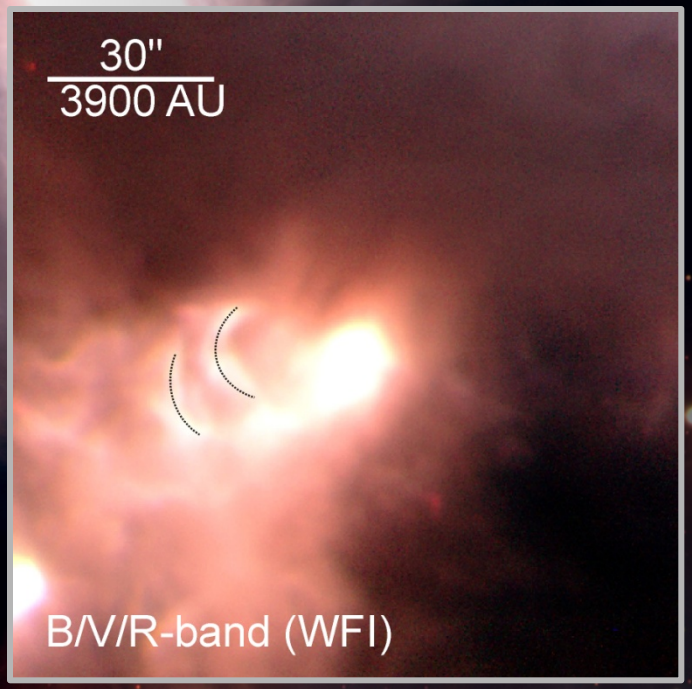
(2) empirical relation:
Br γ luminosity correlates with mass accretion rate
(as determined from UV veiling, e.g. Muzerolle et al. 1998)

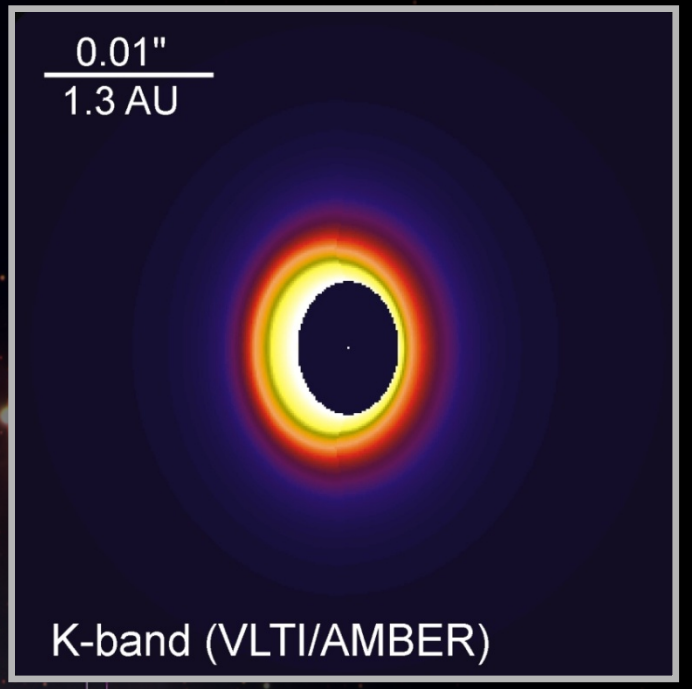


van den Ancker 2005

➜ Br γ *indirect tracer* of mass accretion rate

(suggests tight quantitative connection between accretion- & outflow processes)
(cf. spectroscopic studies, e.g. Cabrit et al. 1990: $\dot{M}_{eject}/\dot{M}_{acc} \approx 0.1$)





Revealing sub-AU asymmetries around R CrA: (Kraus et al., A&A accepted)

- Closure phases can measure sub-AU asymmetries & constrain inner rim models
- For R CrA, detected asymmetries cannot be explained with companion star scenario
- Visibilities, CPs & SED can be reasonably well reproduced with curved puffed-up inner rim + envelope model

Origin of line emission in Herbig Ae/Be stars: (Kraus et al. 2008)

- Spectro-interferometry allows one to trace gas in the inner disk
- Br γ traces *both* magnetospheric accretion and outflow processes
- Br γ *indirect* tracer of mass accretion rate