VLTI/AMBER spectro-interferometry of the young Herbig Be star MWC 297 with a spectral resolution of 12 000: studies of its disk and disk wind

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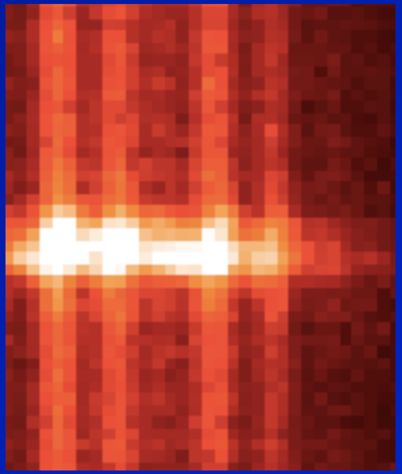
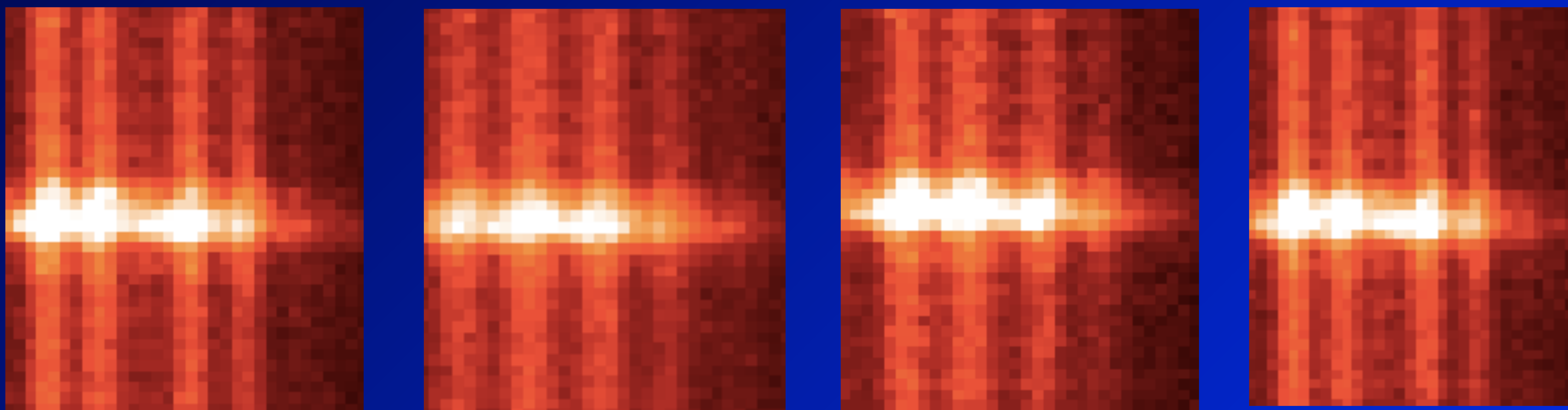
Disk-outflow connection



Infrared spectro-interferometric observations with milli-arcsecond spatial resolution and high spectral resolution (up to 12000) allow unprecedented studies of the inner accretion-ejection region, which hosts fascinating astrophysical objects such as inner gaseous accretion disks, dust disks, disk winds, jets, etc.

Questions: Disk structure? Structure and kinematics of wind launching region? Stellar wind, X-wind, or disk wind?

VLTI-AMBER-FINITO interferograms of MWC 297



MWC 297: spectral type of B1.5V, mass of ~10 solar masses, distance of 250 ± 50 pc, strong Br γ line.

AT configuration: E0-G0-H0
DIT: 4 s (FINITO fringe tracker); Seeing: 0.4”

Previous NIR interferometry: Millan-Gabet et al. 2001; Eisner et al. 2004; Monnier et al. 2006; Malbet et al. 2007; Acke et al. 2008; Kraus et al. 2008

MWC 297:

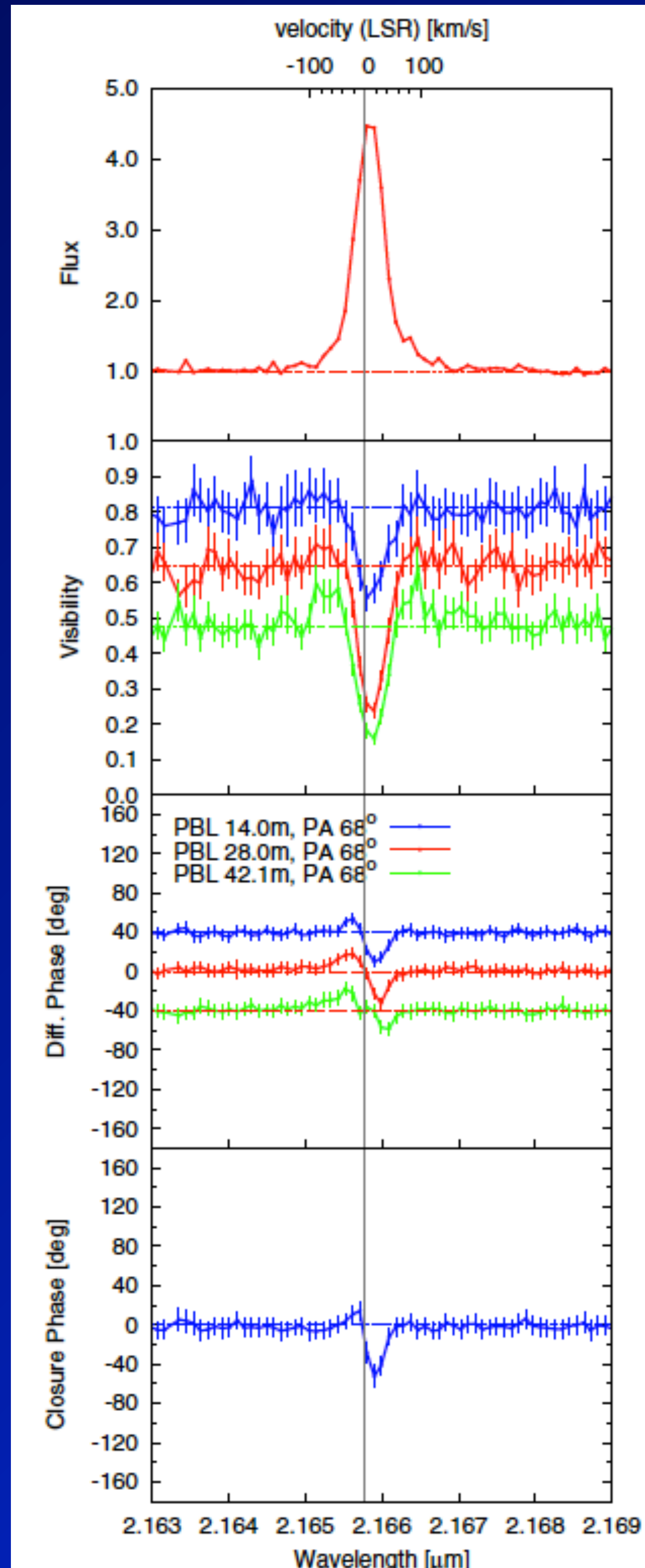
visibilities & phases; R = 12000

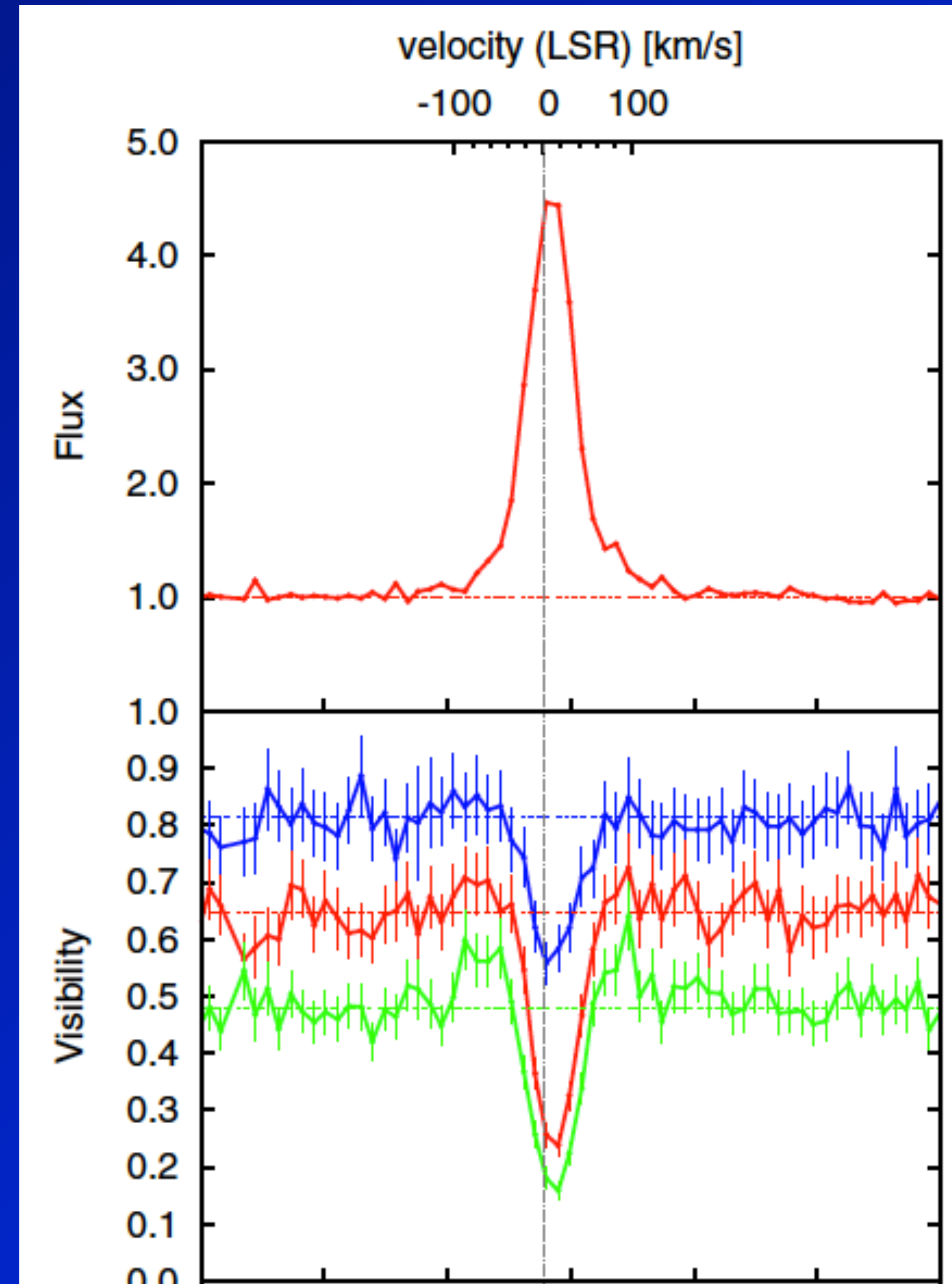
Visibilities at baselines 14, 28, and 42 m

wavelength-differential phases

Closure phase

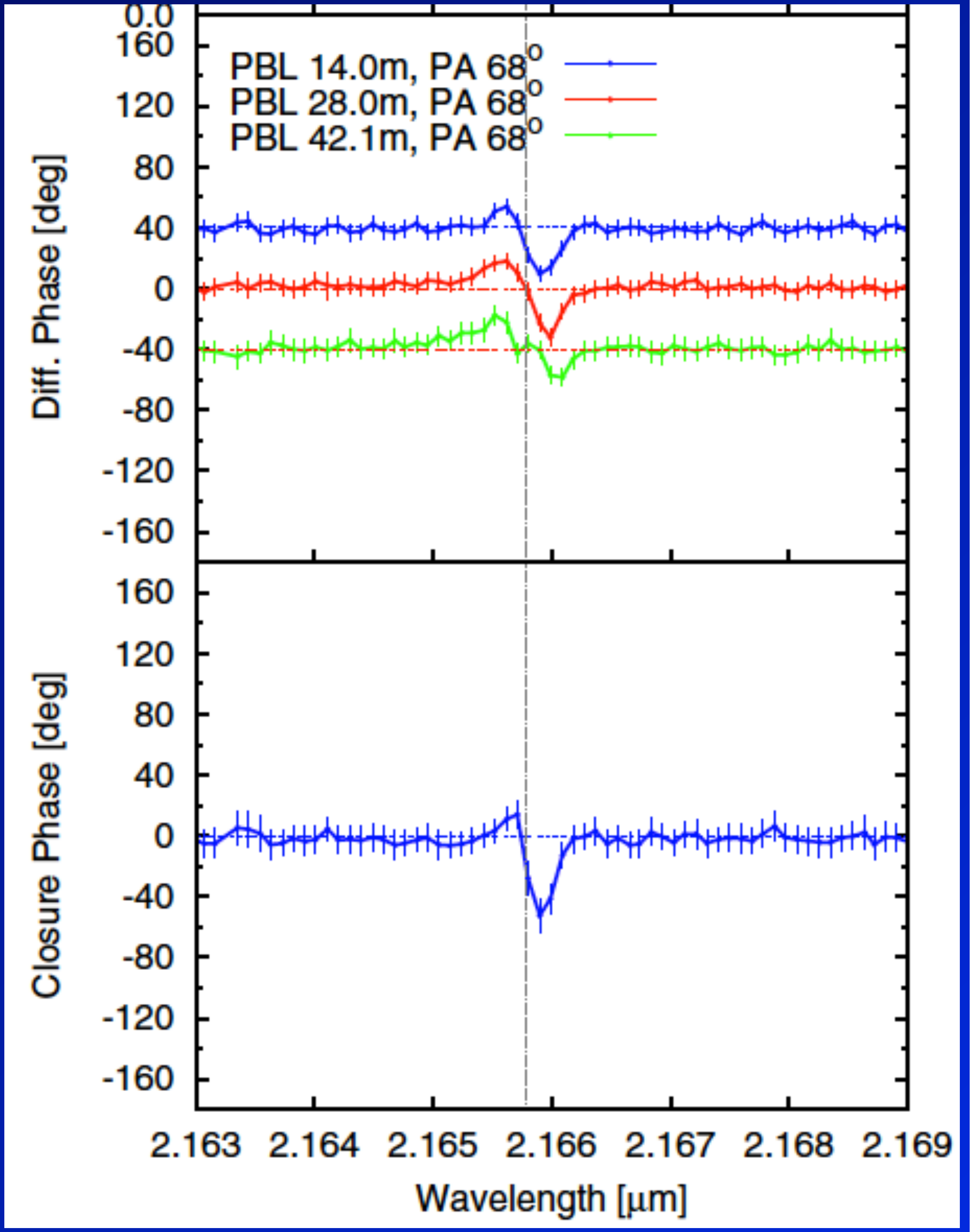
wavelength range 2.163 - 2.169 µm



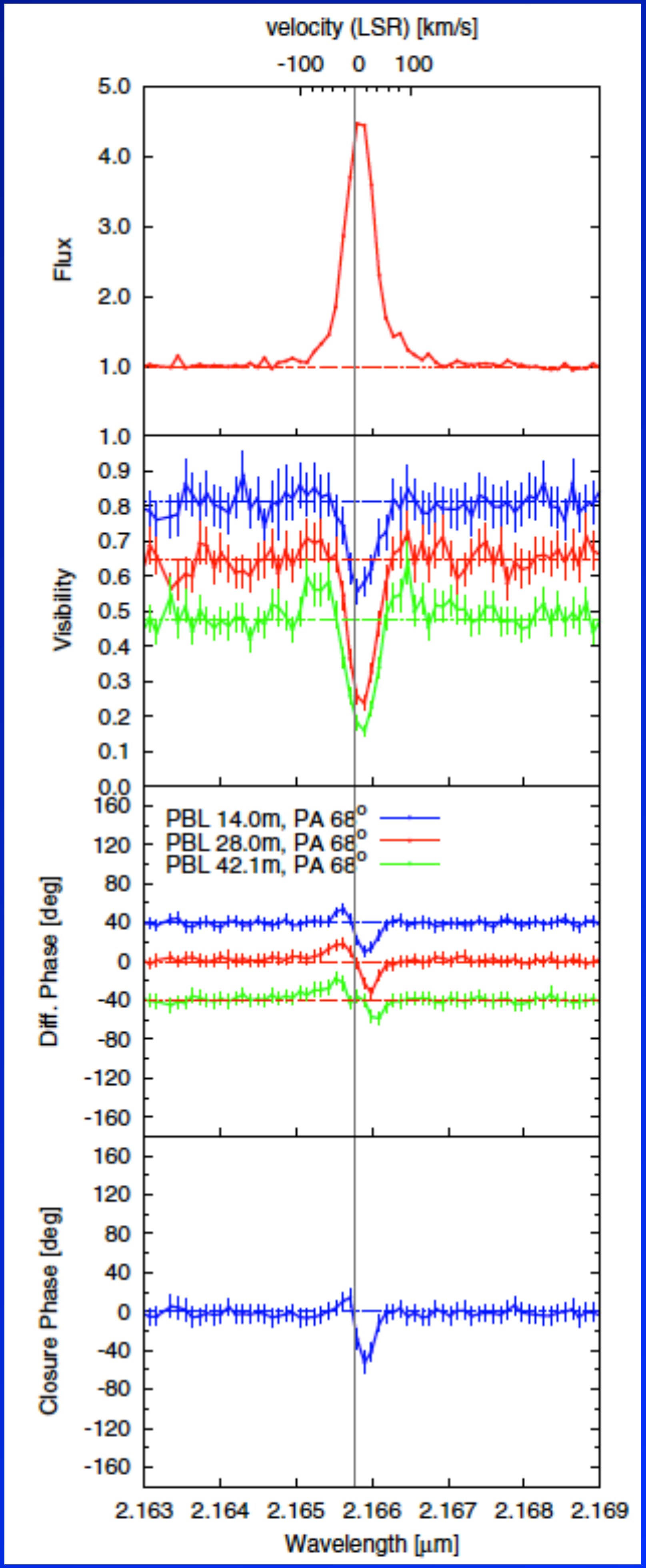


Weigelt et al. 2011 (A&A 527, A103)

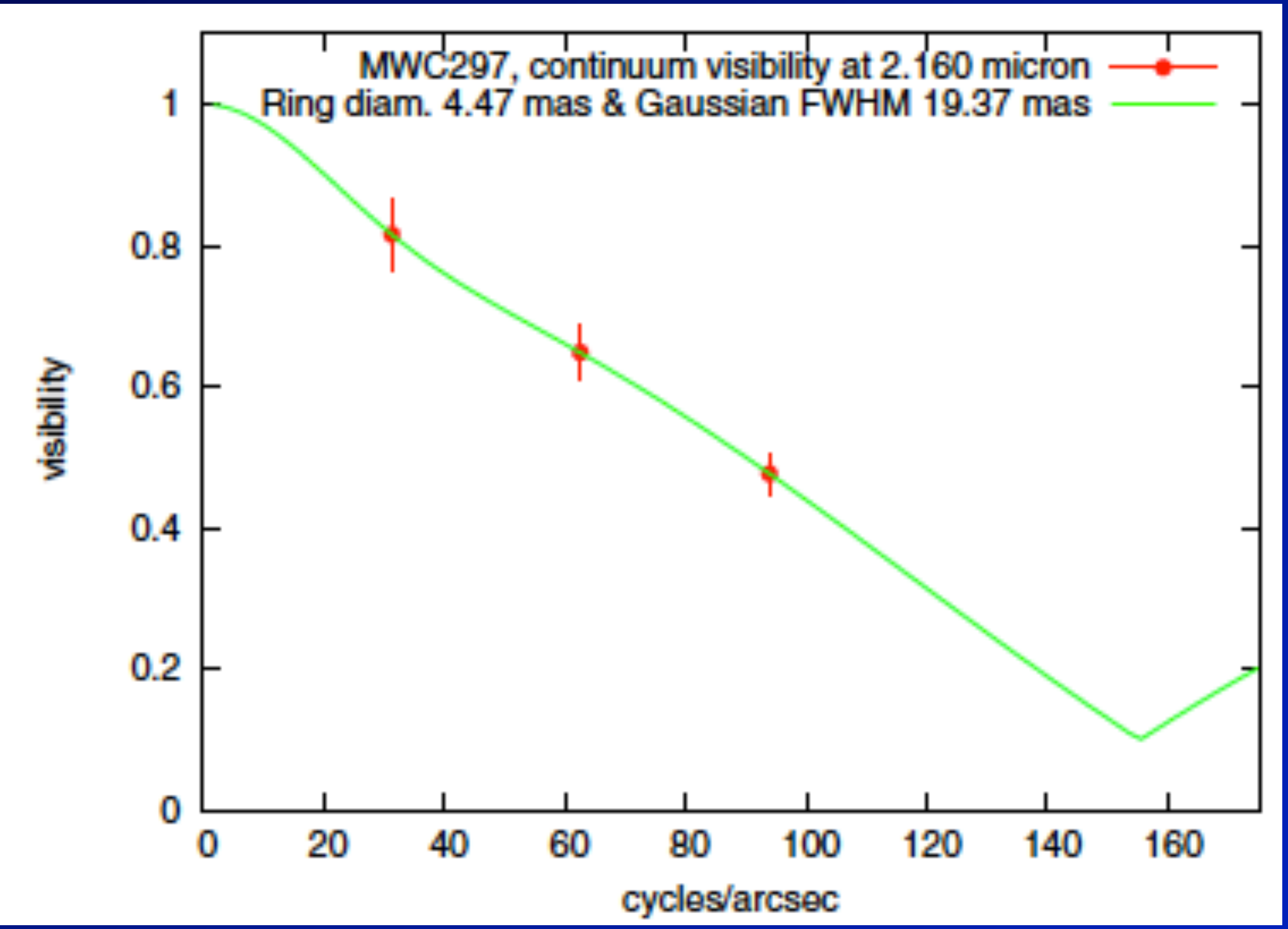
Wavelength-differential phases & closure phases



Br γ CP ~ - 40°



Visibilities in the K-band continuum



Continuum ring-fit radius:

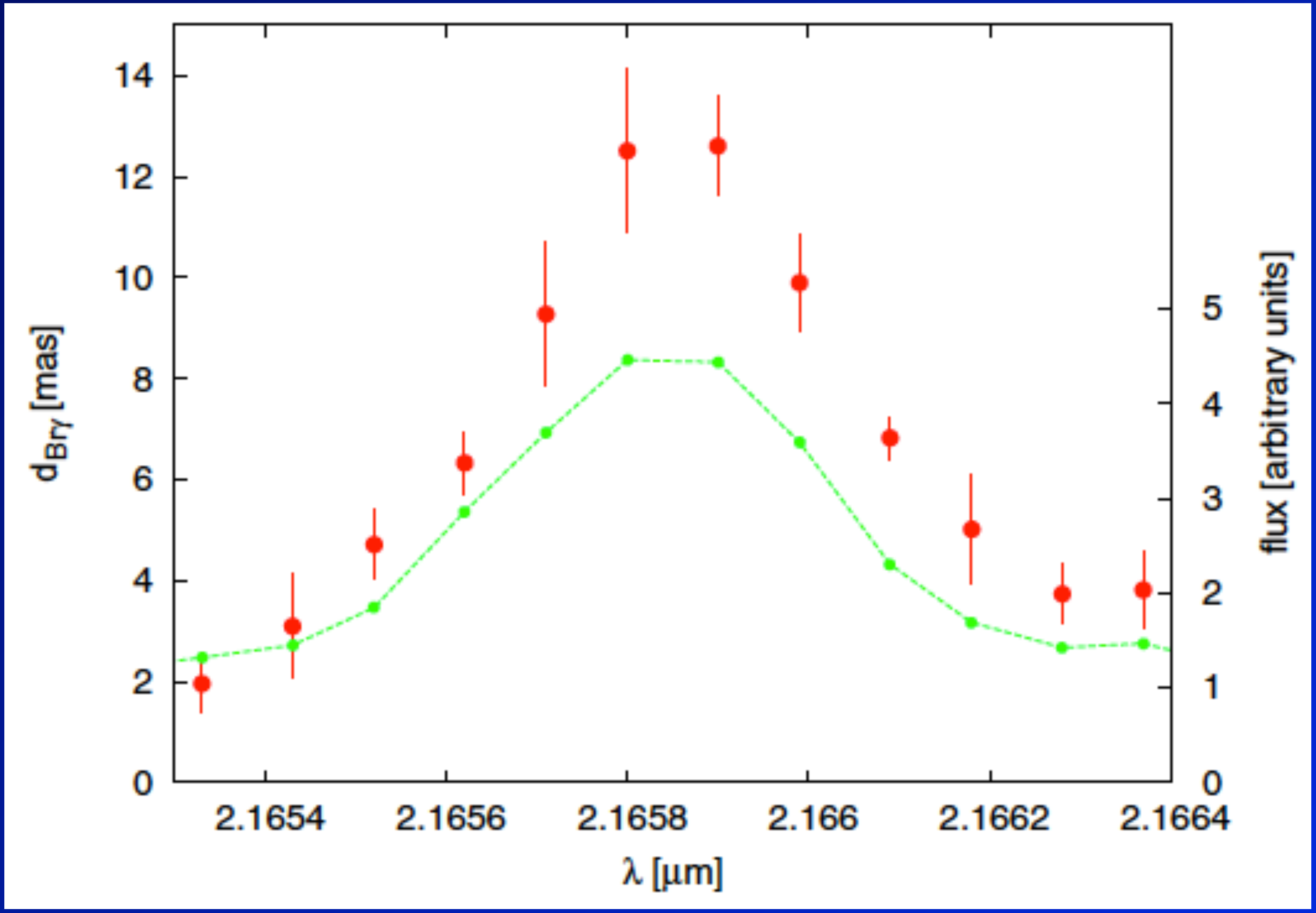
~2.2 mas or 0.56 AU,

which is ~5.4 times smaller than the 3 AU dust sublimation radius expected in the absence of radiation-shielding material.

Geometric model fit diameters (continuum & line):

Wavelength range	Component C1 (dominant compact core)	Diameter of C1	Component C2 (halo)	Diameter of C2	Flux ratio (C1/C2)
Continuum[a]	Gaussian	4.63 ± 0.21 mas	Gaussian	$\gtrsim 22$ mas[c]	4.6
Continuum[a]	Ring (20%)[b]	4.47 ± 0.20 mas	Gaussian	$\gtrsim 19$ mas[c]	3.6
Brγ center	Gaussian	12.6 ± 0.75 mas[d]	–	–	–

Wavelength dependence of the Br γ emission line region

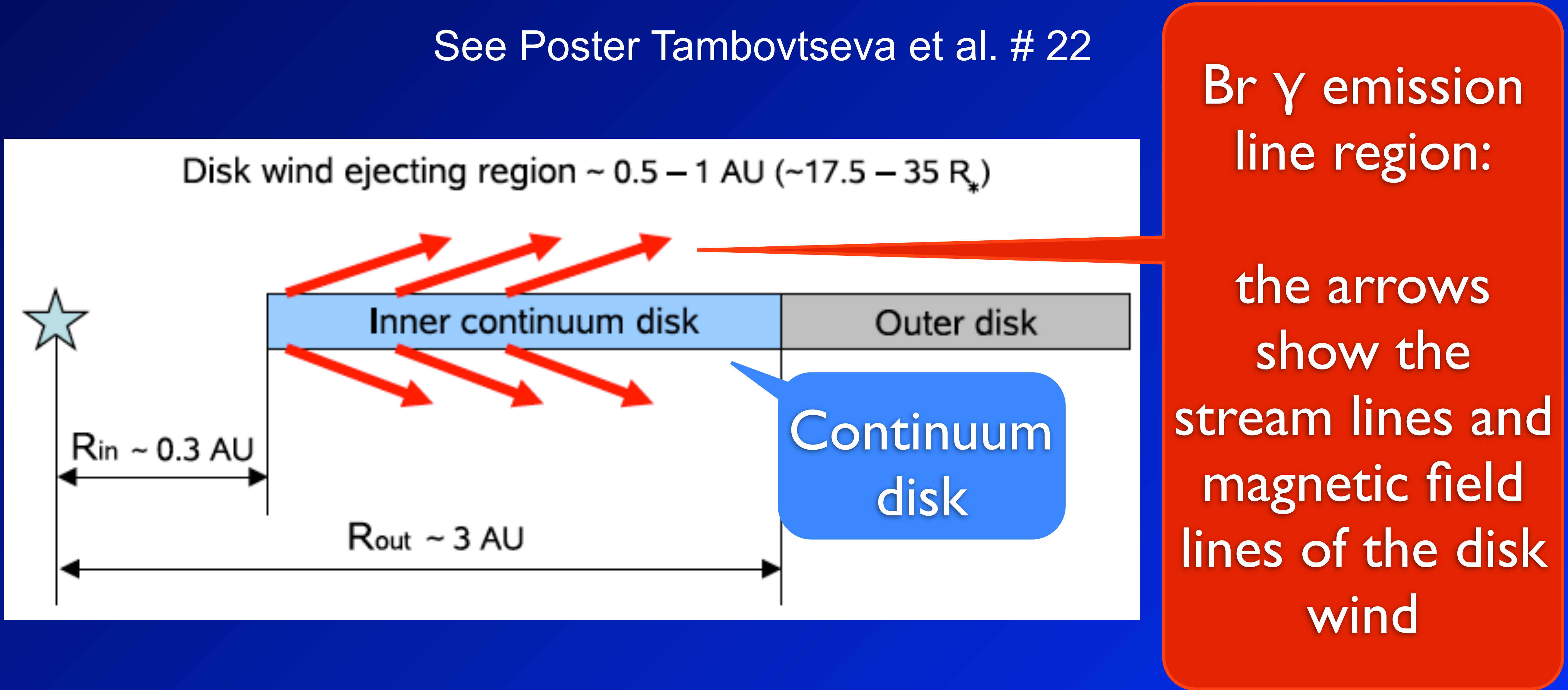


At the center of the Brγ line, we derive a Gaussian fit radius of ~6.3 mas (~1.6 AU), which is ~2.7 times larger than the 2.3 mas Gaussian-fit continuum radius.

Magneto-centrifugally driven disk-wind model

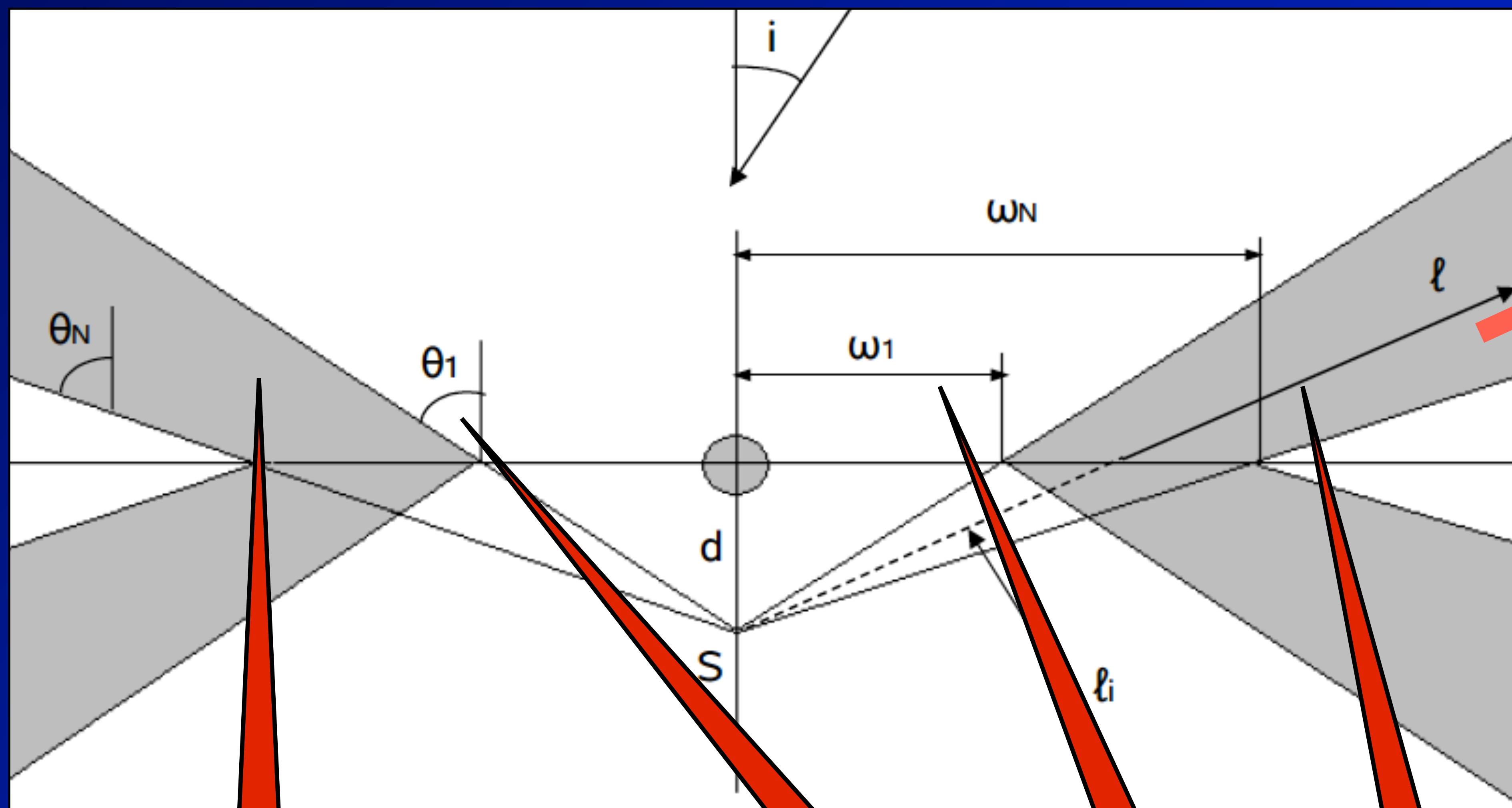
Theory: Blandford & Payne 1982, Pudritz & Norman 1983, Königl & Pudritz 2000, Pudritz 2000, Ferreira 2007, Grinin & Mitskevich 1990, Tambovtseva et al. 2001 etc.

See Poster Tambovtseva et al. # 22



Sketch of the MWC 297 disk-wind model adopted in this study (dust sublimation radius ~3 AU). Which disk+wind model parameters can be derived from the observations?

Geometry of the magneto-centrifugally driven disk-wind model



Br γ emitting disk-wind region:

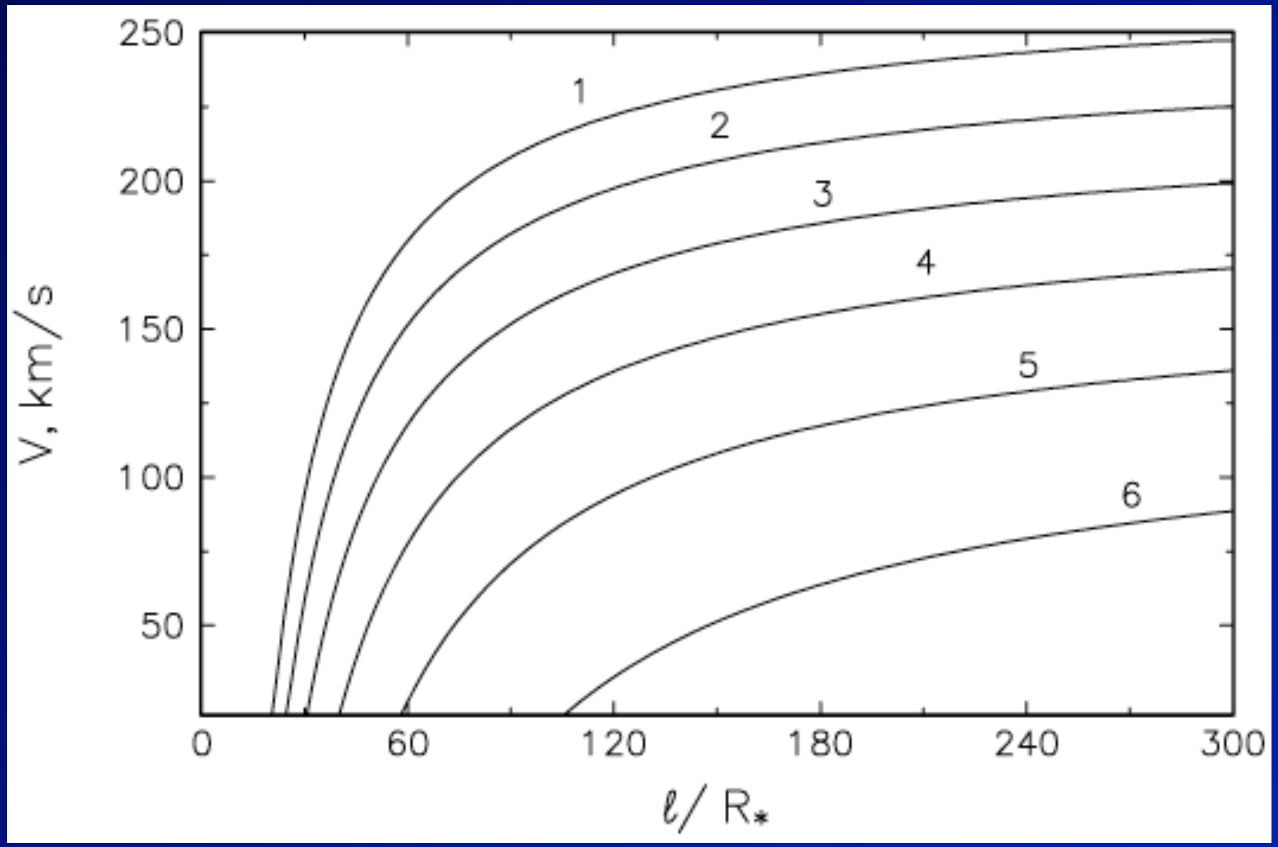
kinematics of the disk wind can be derived from the wavelength-dependent visibilities and phases within the Br γ line

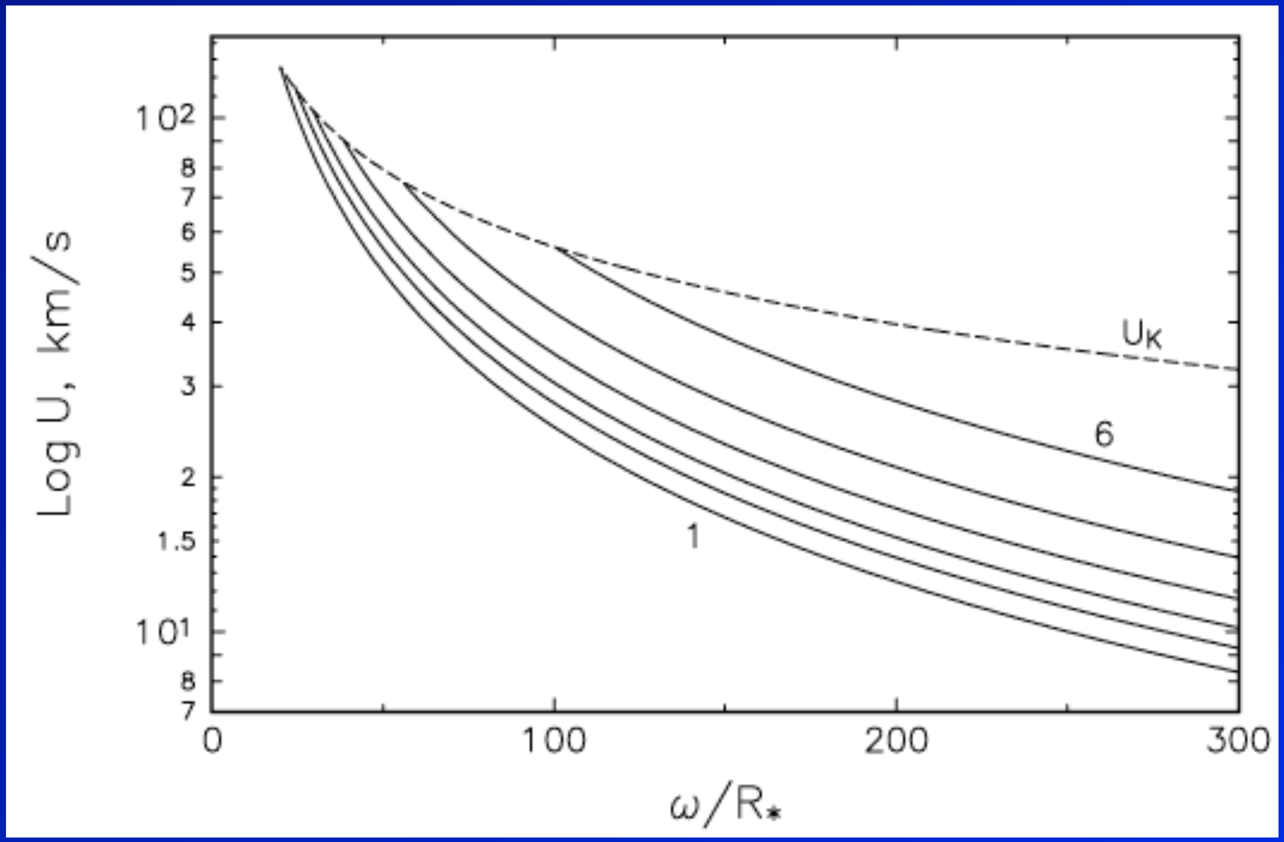
half opening angle

inner radius

one of the streamlines and magnetic field lines

Disk-wind kinematics of the model



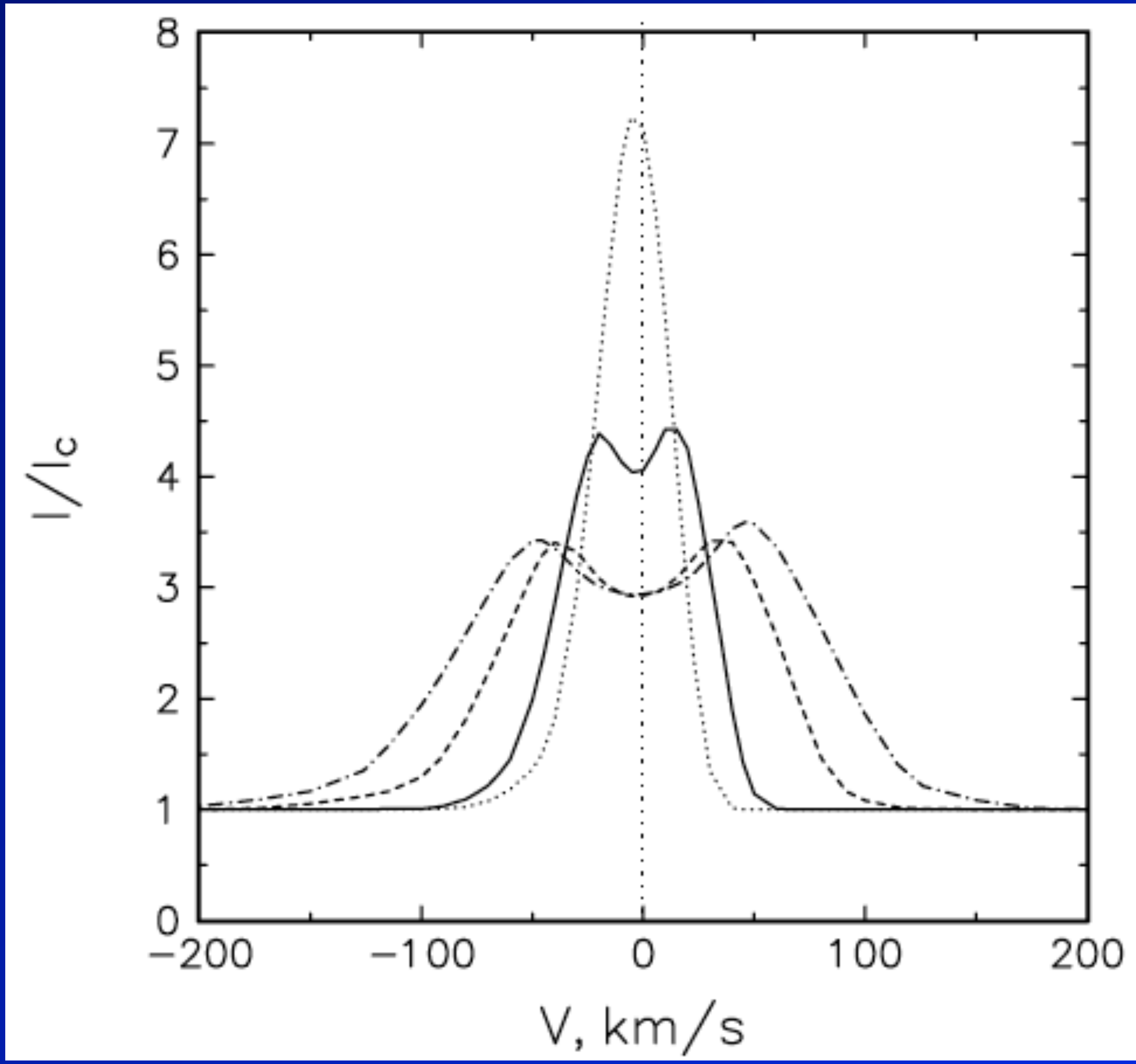


Radial velocity of the outflow along the different stream lines; numbers 1–6 denote the stream lines.

Rotational velocity: the dashed line shows the Keplerian velocity in the disk.

Normalized Brγ line profiles of our best disk-wind model:

(dotted line), 20° (solid), 40°
(dashed), and 60° (dashed-dotted; infinite spectral resolution!)



Dependence of the disk-wind model images on the radial velocity within the Br γ line

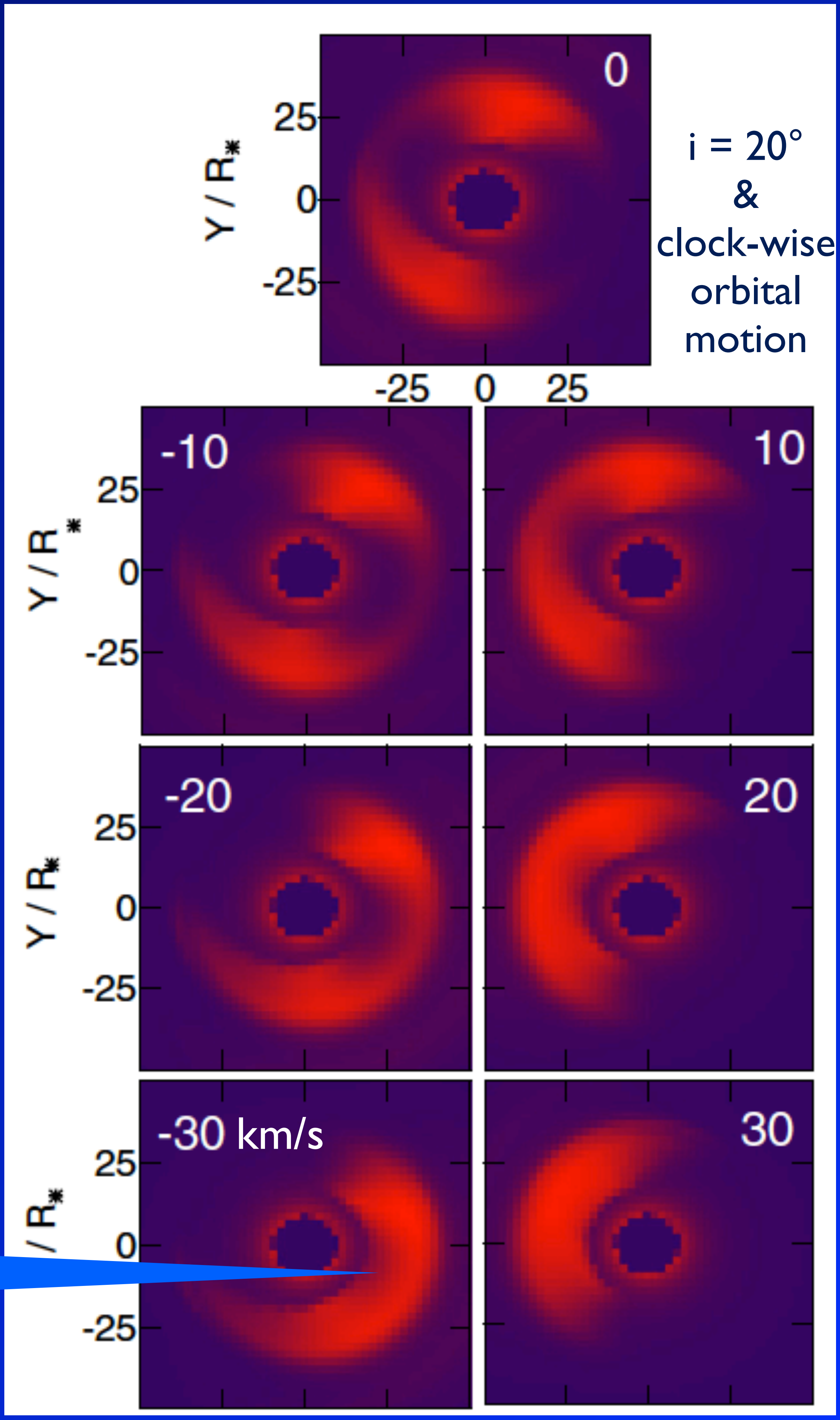
Model intensity distributions for radial velocity channels from 0 to ± 30 km/s.

The images show both the inner continuum disk & the Br γ emission region (*i* = 20°):

left: blue-shifted light, right: red-shifted

- Blue wing of Br γ line: -30 km/s
- i = 20°; clockwise orbital motion:

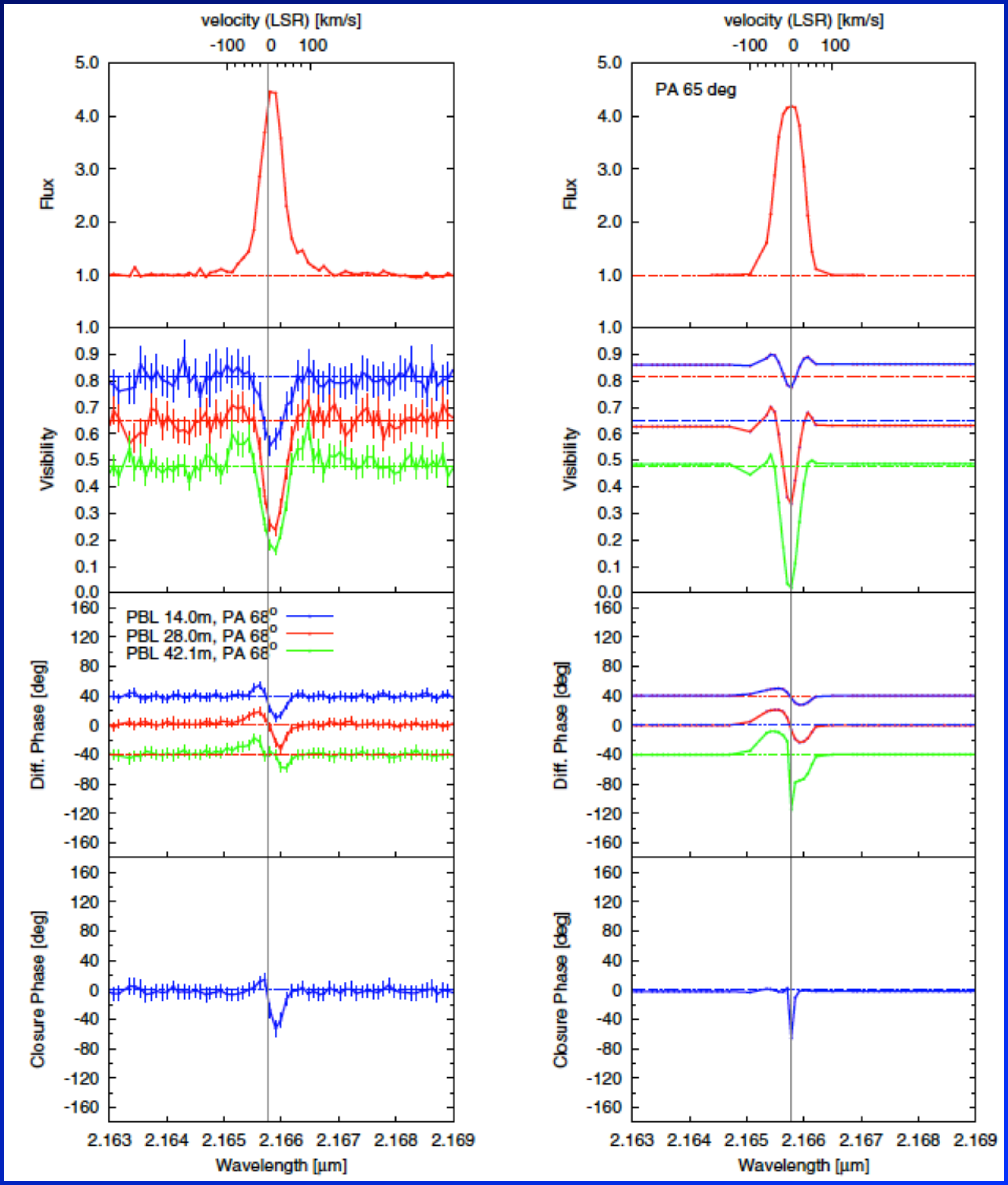
➜ right region of the wind zone is bright



Comparison of observation and model for all interferometric observables:

left: observation

right: disk-wind model

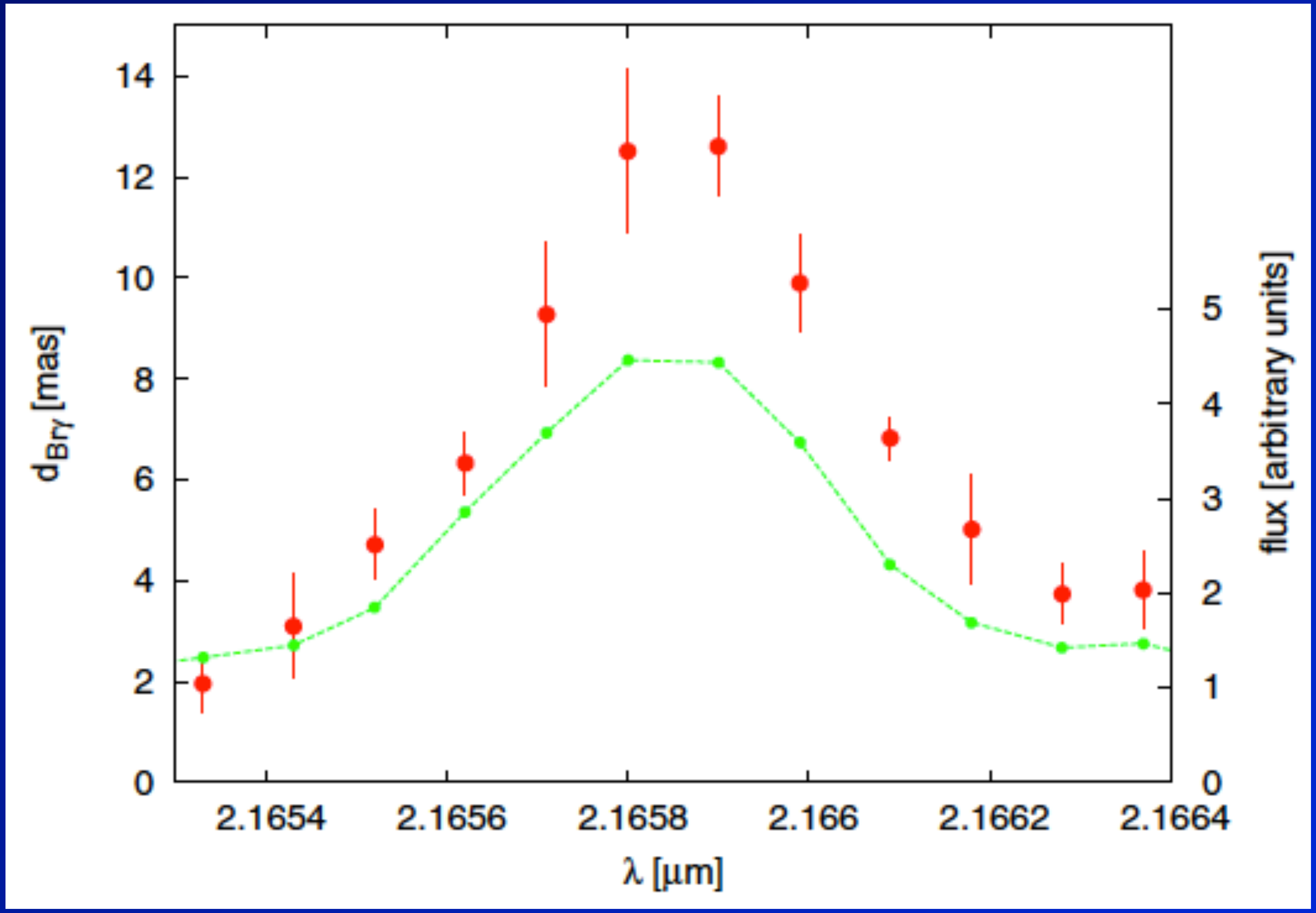


Range of parameter variations for our continuum-disk plus disk-wind model calculations

Parameters	Range	Model 5
Disk:		
R_{in}	0.25–3 AU (8.8–105 R_*)	0.3 AU (10.5 R_*)
R_{out}	1–5 AU (35–175 R_*)	3 AU (105 R_*)
R_s	0.85–1.25 AU (30–44 R_*)	0.9 AU (31.5 R_*)
α_1	−0.4– −0.75	−0.5
α_2	−0.34– −0.4	−0.33
T_{in}	1400–2000 K	1800 K
Disk wind:		
ω_1	0.1–3 AU (3.5–105 R_*)	0.5 AU (17.5 R_*)
ω_N	0.5–5.7 AU (17.5–200 R_*)	1 AU (35 R_*)
γ	−1–5	2
β	0.3–2	1
θ_1	10°–80°	80°
$\dot{M}_w$	10^{-9}–10^{-6} $M_\odot$ yr^{-1}	10^{-7} $M_\odot$ yr^{-1}

parameters of our closest fitting model

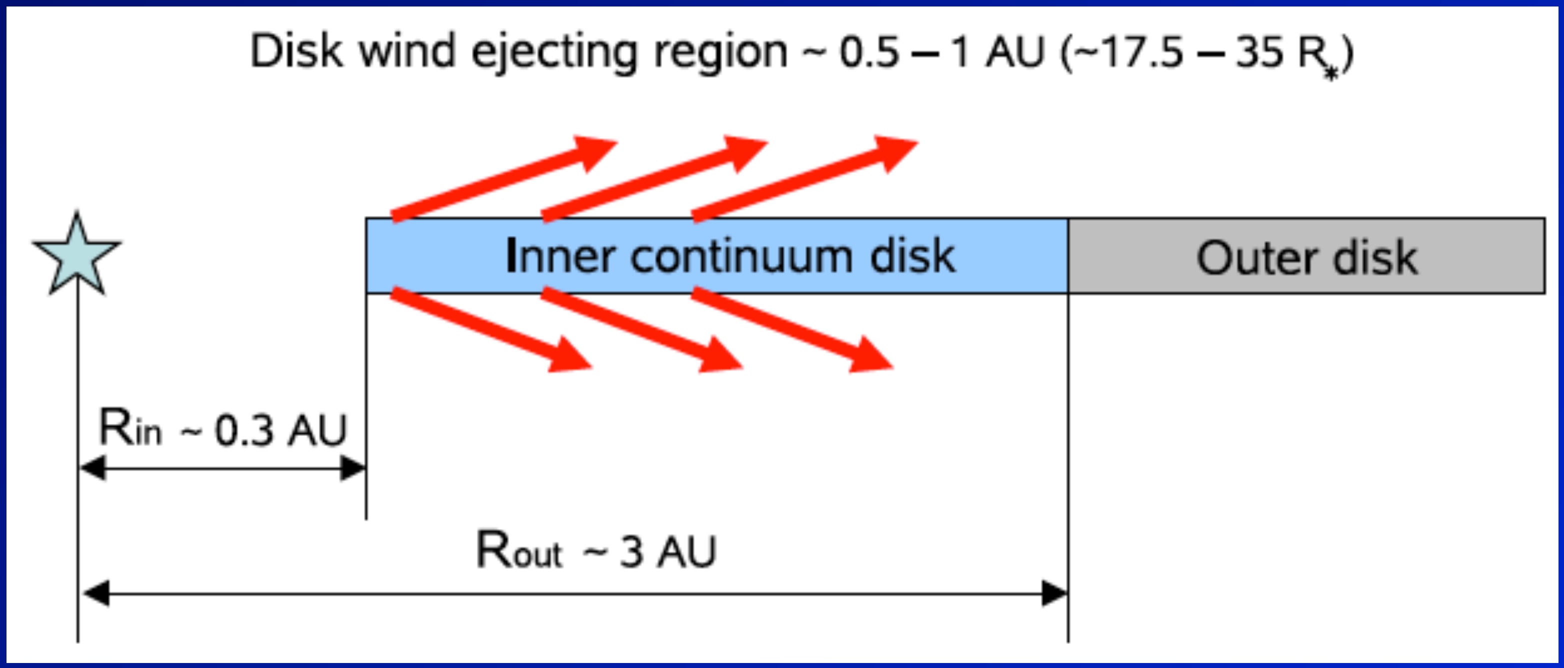
MWC 297 results: geometric model fits



(1) The **continuum** visibilities confirm previous results that the continuum-emitting region is remarkably compact:
continuum ring-fit radius **~2.2 mas (~0.56 AU)**, which is ~5.4 times smaller than the 3 AU dust sublimation radius expected in the absence of radiation-shielding material.

(2) At the center of the **Brγ line**, the Gaussian fit radius is **~6.3 mas (~1.6 AU)**, i.e., Br γ-emitting region is ~2.7 times larger than the continuum region.

Results: disk-wind model



(4) To interpret the observations, we employed a magneto-centrifugally driven disk-wind model consisting of an
- accretion disk, which emits the observed continuum radiation, and a
- disk wind, which emits the Brγ line.

(5) The *K*-band flux, line profile, visibilities, and remarkably strong phases can be explained by the employed driven disk-wind model.

(6) The closest fitting model predicts a
- continuum-emitting disk with an inner radius of ~0.3 AU,
- a disk-wind ejection region with an inner radius of ~0.5 AU (~17.5 stellar radii),
- a disk-wind half-opening angle of ~80° (the angle between the rotation axis and the innermost streamline of the disk wind), which is larger than in T Tau models,
- and a disk inclination angle of ~20 ± 10°(i.e., almost pole-on).

Disk-wind model ➜ inclination angle i ~ 20 ± 10°
— almost pole-on

However, spectroscopic observations suggested a much larger i.

Spectroscopic observations of photospheric absorption lines suggest a projected rotation velocity *v* sin i of about 350 ± 50 km/s (Drew et al. 1997) and a much larger inclination angle (otherwise the rotation velocity becomes larger than the critical rotation velocity of 450 km/s).

Puzzling .... Therefore, we performed new interferometric observations with the configuration D0-H0-G1 at many different hour angles (PAs) to measure elongation and inclination of the disk.

➜ **Result:** Range of diameters: 3.9-4.4 mas ➜ inclination *i* = 26 ±7°

Summary:

1) K-band continuum: ring-fit radius of ~2.2 mas (~0.56 AU) is ~5.4 times smaller than the 3 AU dust sublimation radius (confirmation of previous results).

(2) Brγ-emitting region: Gaussian fit radius of ~6.3 mas (~1.6 AU) is ~2.7 times larger than the continuum radius.

(4) Interpretation: We employed a **magneto-centrifugally driven disk-wind model** consisting of a continuum accretion disk & a Br γ disk-wind region.

(5) The *K*-band flux, line profile, visibilities, and remarkably strong phases can be explained by the employed disk-wind model.

(6) The closest fitting model predicts the following **disk-wind model parameters**:

- continuum-emitting disk with an inner radius of ~0.3 AU,
- disk-wind ejection region with an inner radius of ~0.5 AU (~17.5 stellar radii),
- a disk-wind half-opening angle of ~80°
- a disk inclination angle of 20 ± 10° (i.e., almost pole-on).

(7) New AMBER obs. at many PAs ➜ diameters 3.9-4.4 mas ➔ inclination i = 26 ±7°

See Weigelt et al. 2011 (A&A 527, A103) for more details.