MIDI's Interferometric View of Circumstellar Discs in Binary and Multiple Systems

LMU

USM

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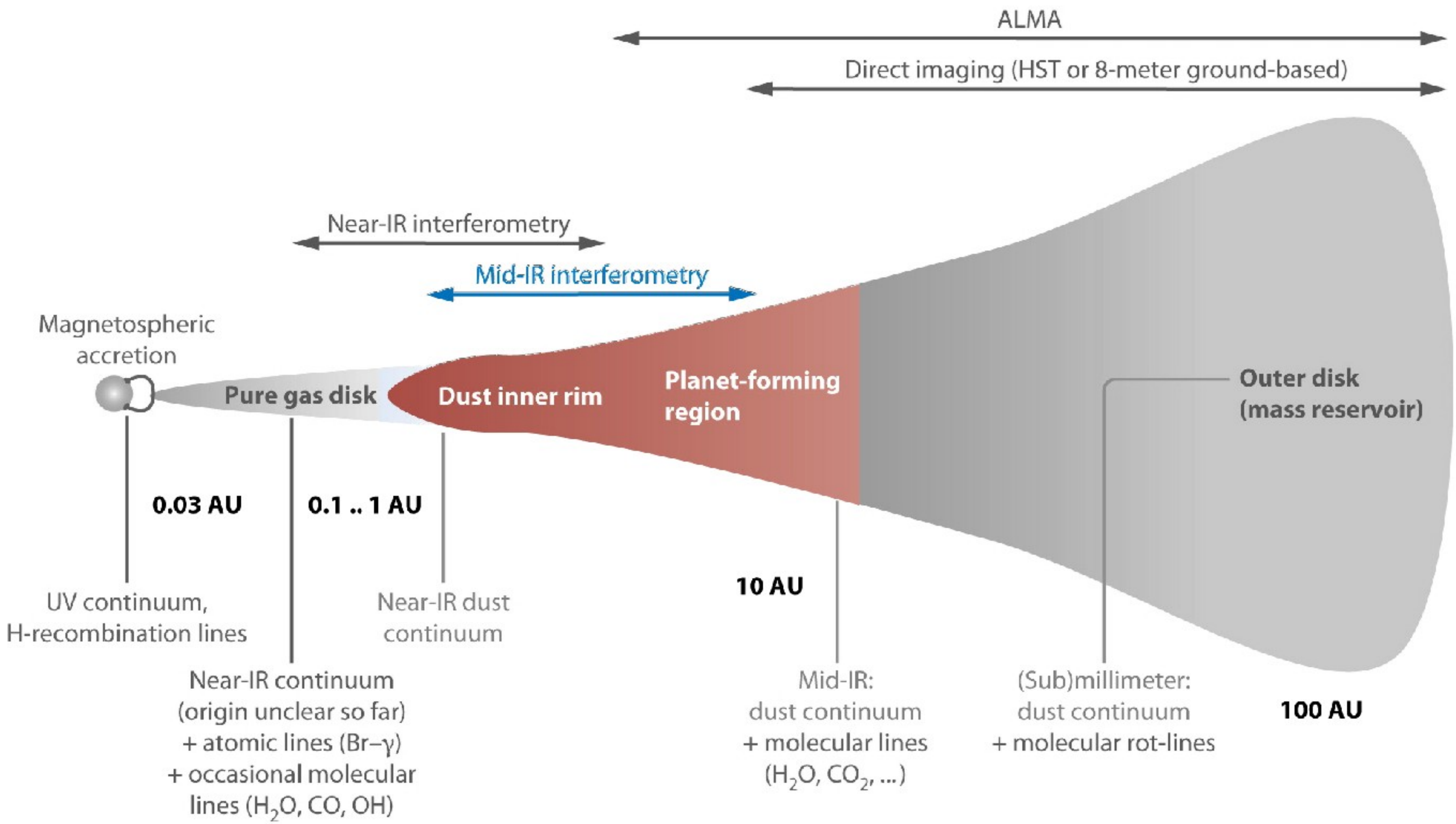
A "typical" circumstellar disc



100 pc	200 km	200 m	
↓	↓	↓	~ 0.01"
1 AU	1 cm	10 μm	

Dullemond & Monnier, ARAA 48, 2010

The VLT Interferometer

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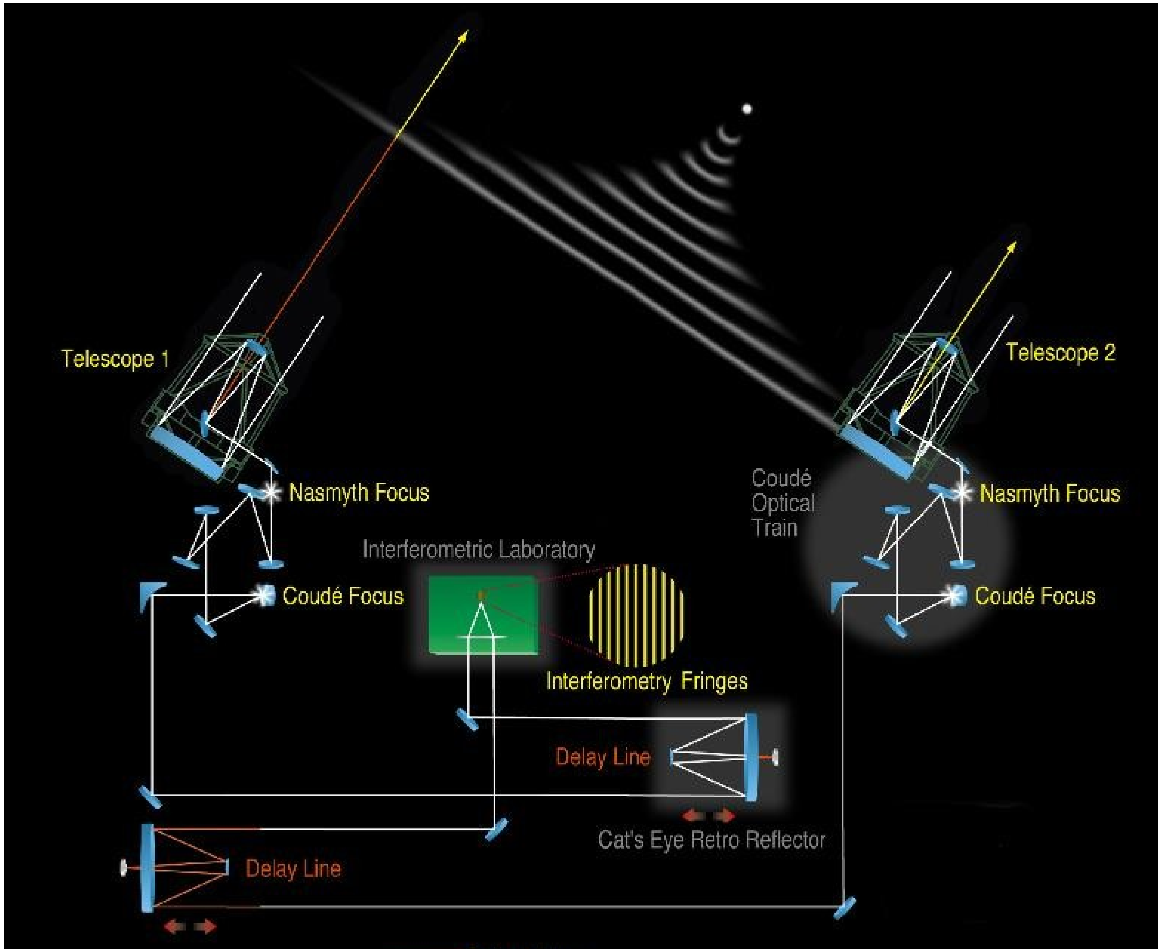
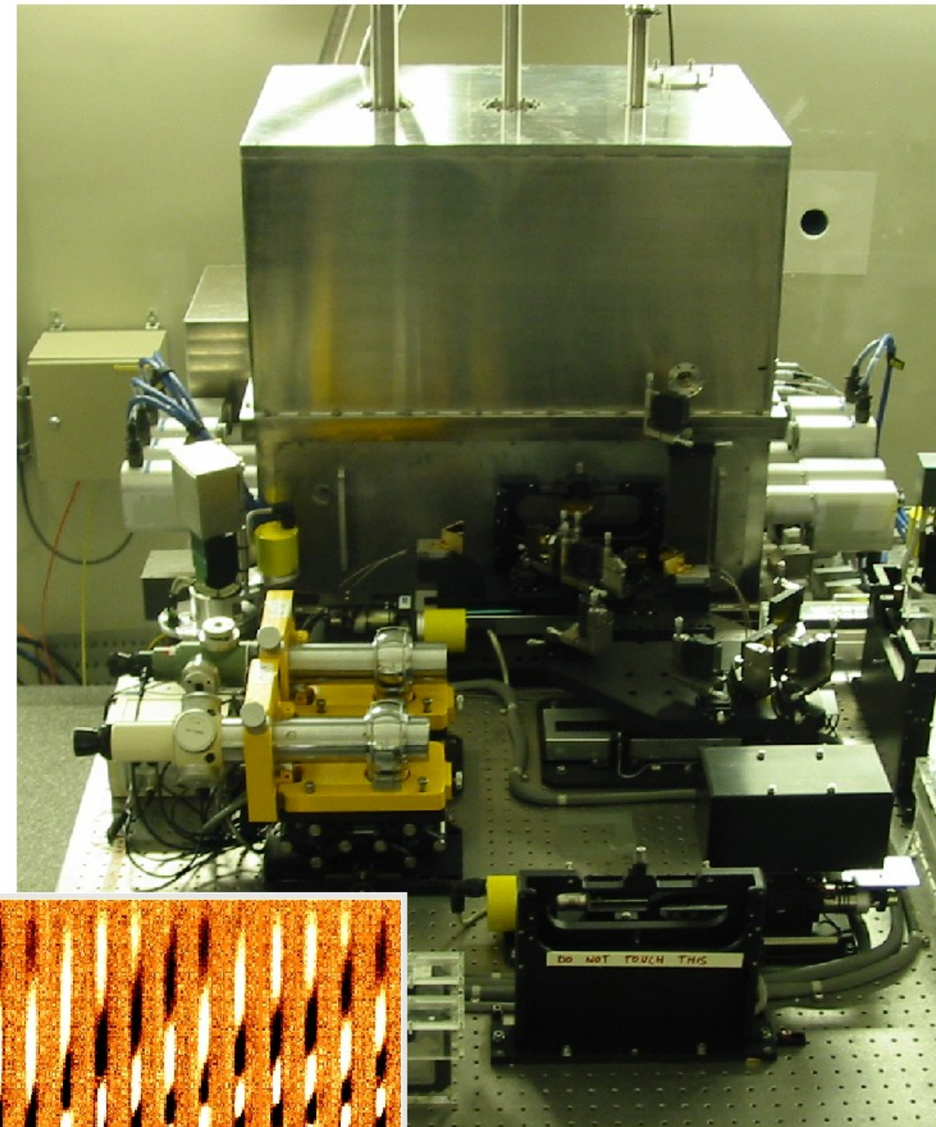
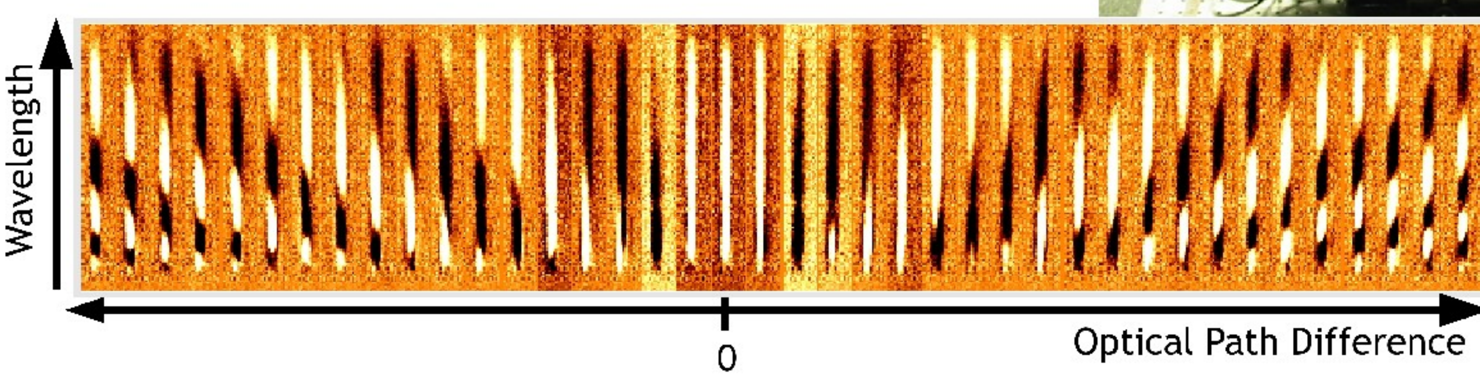


MIDI in a "Nutshell"

Name	**MID**-infrared Interferometric Instrument	
First Light	December 2002	
Type	Two-beam pupil-plane interferometer	
Wavelegths	N-band (8 … 13 µm)	
Telescopes	UTs (8.2 m)	ATs (1.8 m)
Baselines	47 … 130 m	8 … 200 m
FoV	2 arcsec	10 arcsec
Airy Disk	0.26 arcsec	1.14 arcsec
Resolution	≥ 15 mas	≥ 10 mas
Limit	1 Jy / 0.1 Jy	10 Jy / 0.5 Jy





Interferometric Observables

$$\langle E^*(\vec{r_1},t_1)\times E(\vec{r_2},t_2)\rangle = V(\vec{r_1}-\vec{r_2},t_1-t_2) = V(\vec{\rho},0)$$

$$\langle E^*(\vec{r_1},t_1)\times E(\vec{r_2},t_2)\rangle = V(\vec{r}_1-\vec{r}_2,t_1-t_2) = V(\vec{0},\tau)$$

»visibility«

»For sources in the far field the normalised value of the spatial coherence function is equal to the Fourier transform of the normalised brightness distribution *I*.« (van Cittert-Zernike Theorem)

$$\frac{V_r(\vec{\rho})}{V_r(0)} = \frac{\int I(\vec{\alpha})\exp(-i2\pi\frac{(\vec{\alpha}\cdot\vec{\rho})}{\lambda})\,d\alpha}{\int I(\vec{\alpha})\,d\alpha}$$

intensity

$$V_{r,\mathrm{norm}}(u,v) = \frac{\int\int I(\alpha,\beta)\exp(-i2\pi(u\alpha+v\beta))\,d\alpha\,d\beta}{\int\int I(\alpha,\beta)\,d\alpha\,d\beta}$$

sky coordinates

spatial frequencies in units of B/λ

A) Fringe Contrast

sometimes known as »Michelson visibility«, and related to the measured maximum and minimum intensities in the fringe pattern:

$$V_{\mathrm{Michelson}} = \frac{I_{\max}-I_{\min}}{I_{\max}+I_{\min}}$$

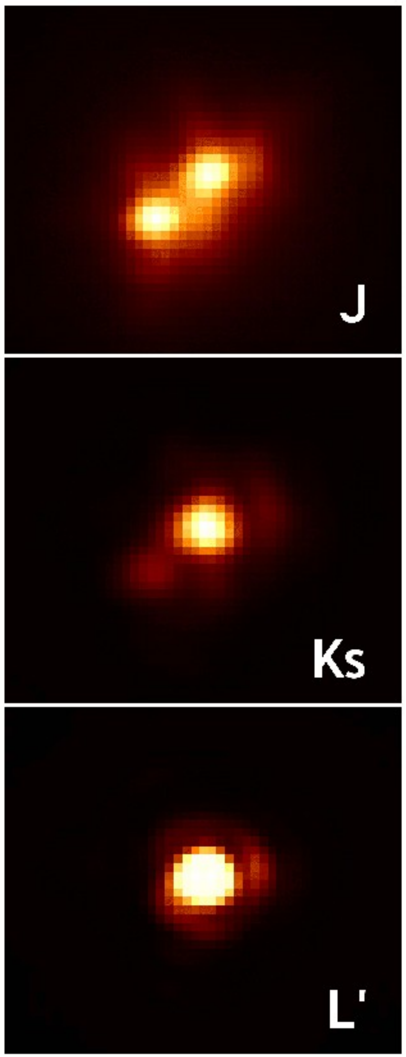
visibility varies between 0 ($I_{min} = I_{max}$) and 1 ($I_{min} = 0$)

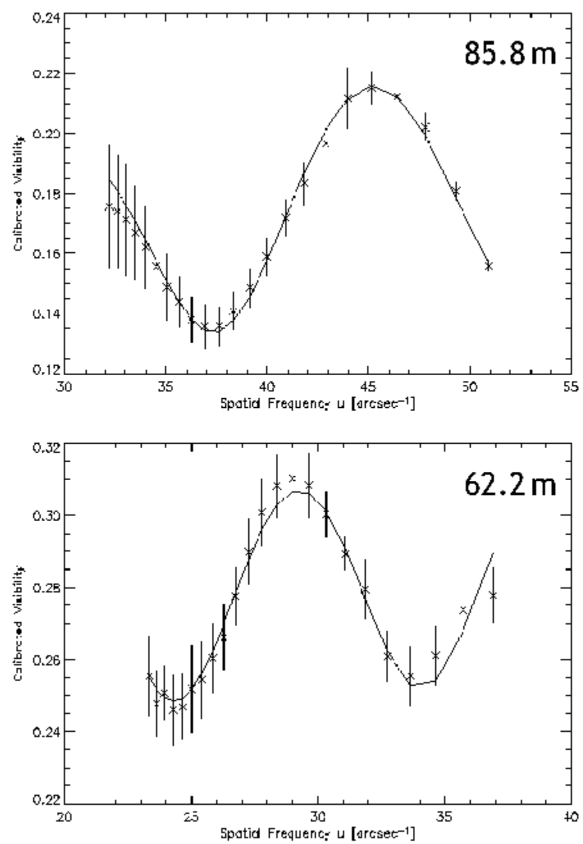
B) Fringe Phase

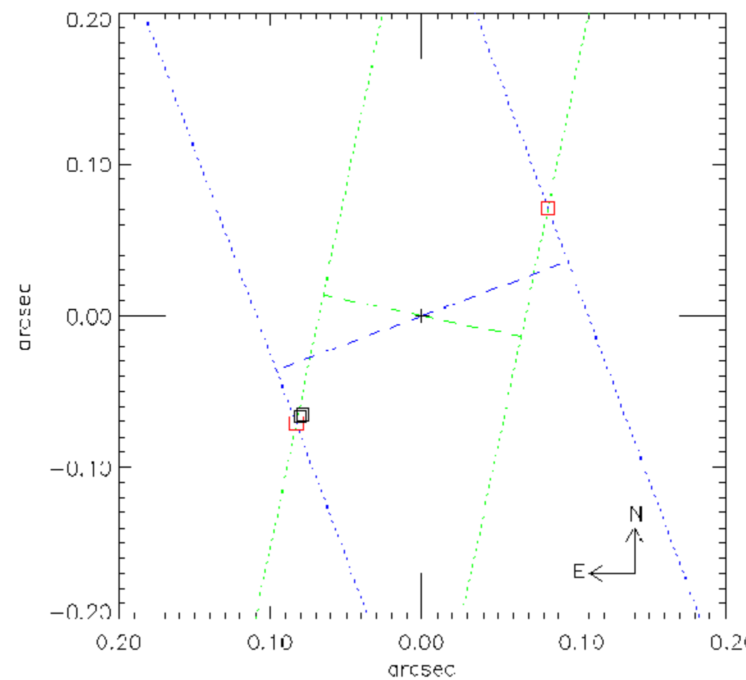
location of the central fringe with respect to the zero optical path difference

Z CMa – an unequal binary

consists of a FU Ori object (T Tau with a high accretion rate) and probably an embedded Herbig Be star that dominates the system at infrared wavelengths

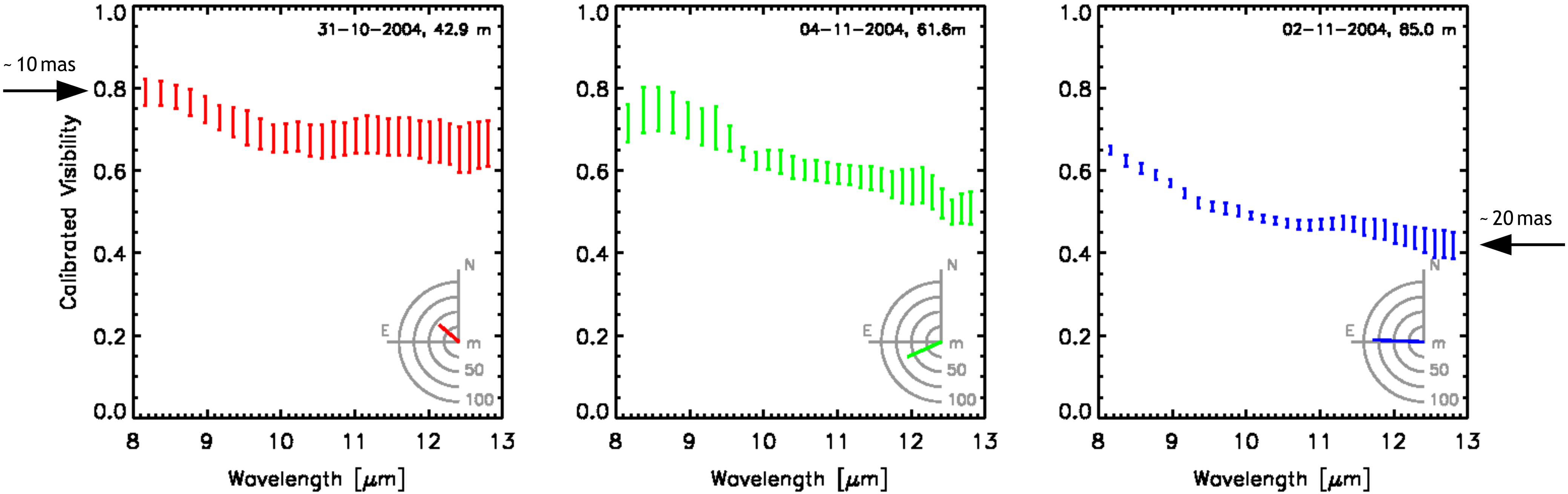






109 mas @ 131°, f = 0.16 ± 0.08

A typical circumstellar disk!

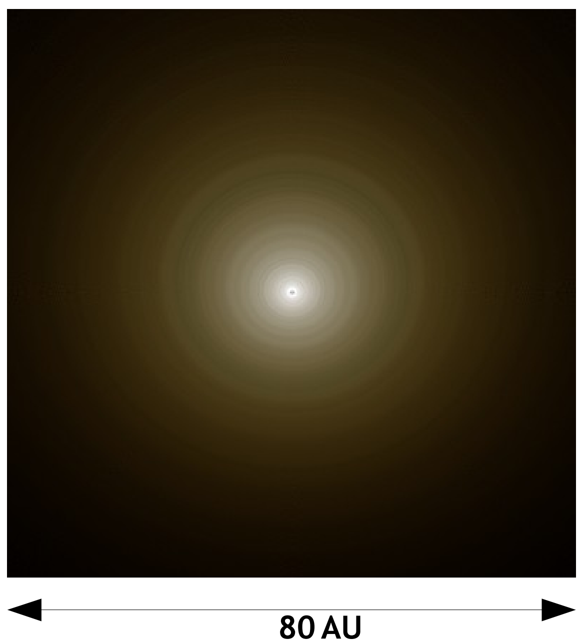


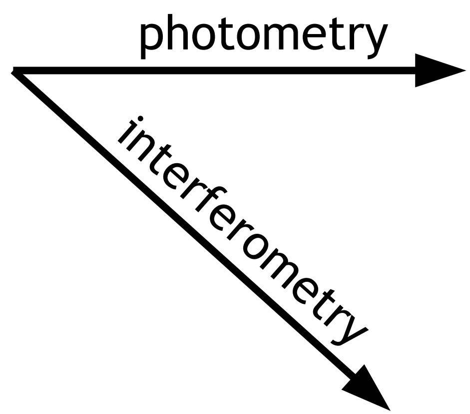
- the resolution of the interferometer decreases with wavelength
- the emitting region becomes larger due to the temperature gradient

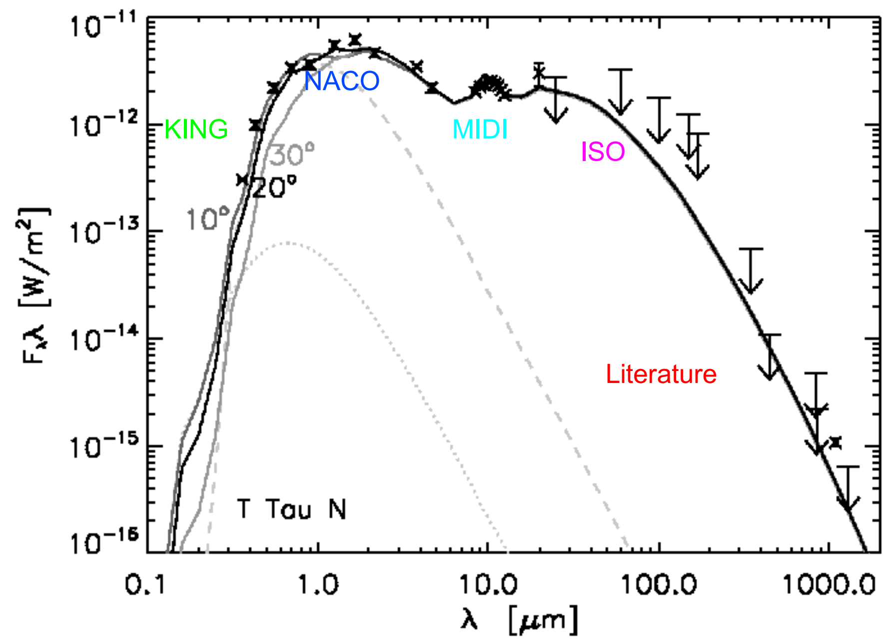
→ decreasing visibilities
→ direct size estimates

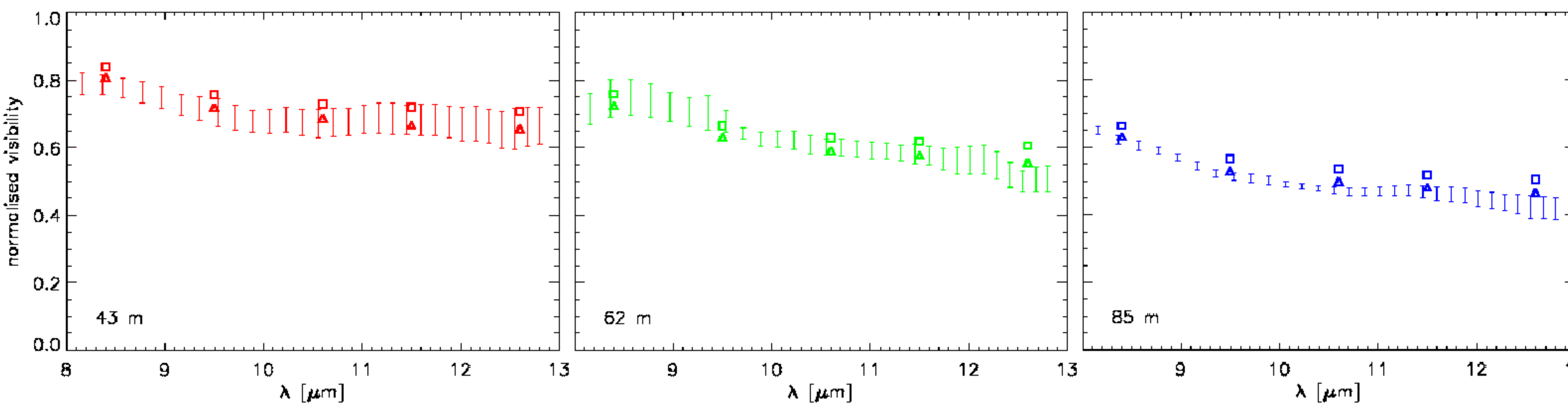
Ratzka et al., A&A, 502, 2009

Radiative transfer model T Tau N



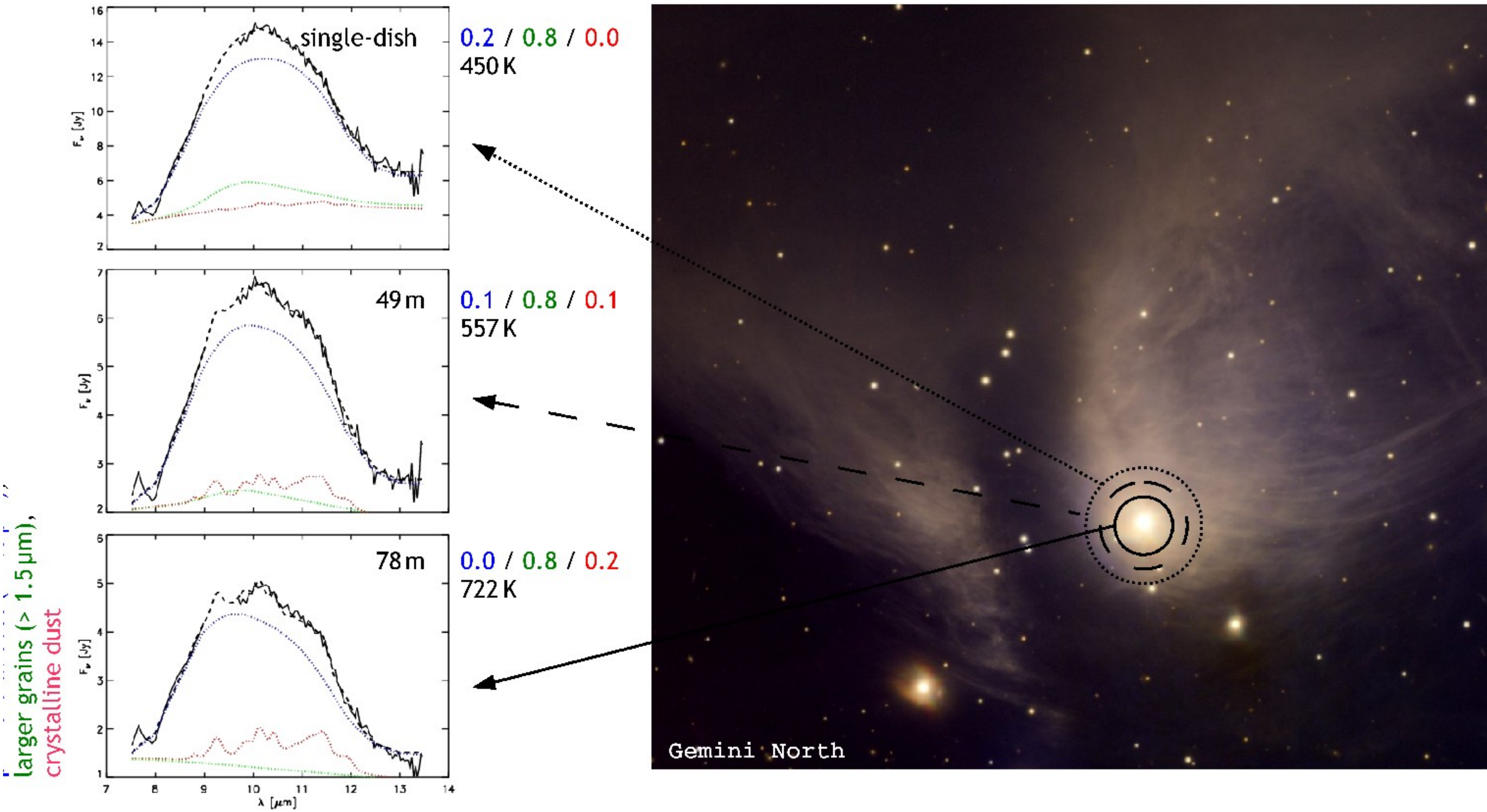




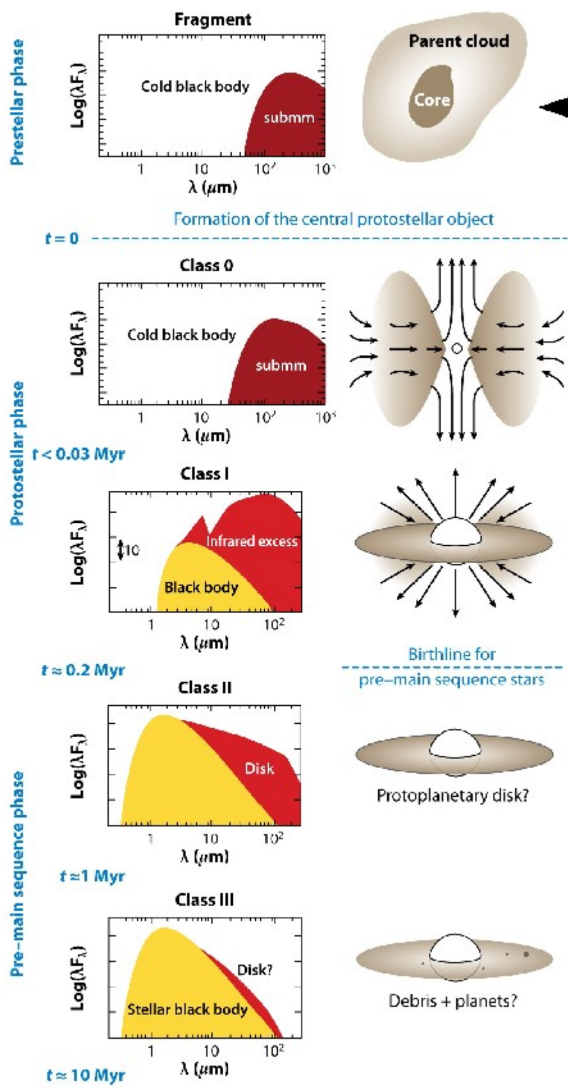


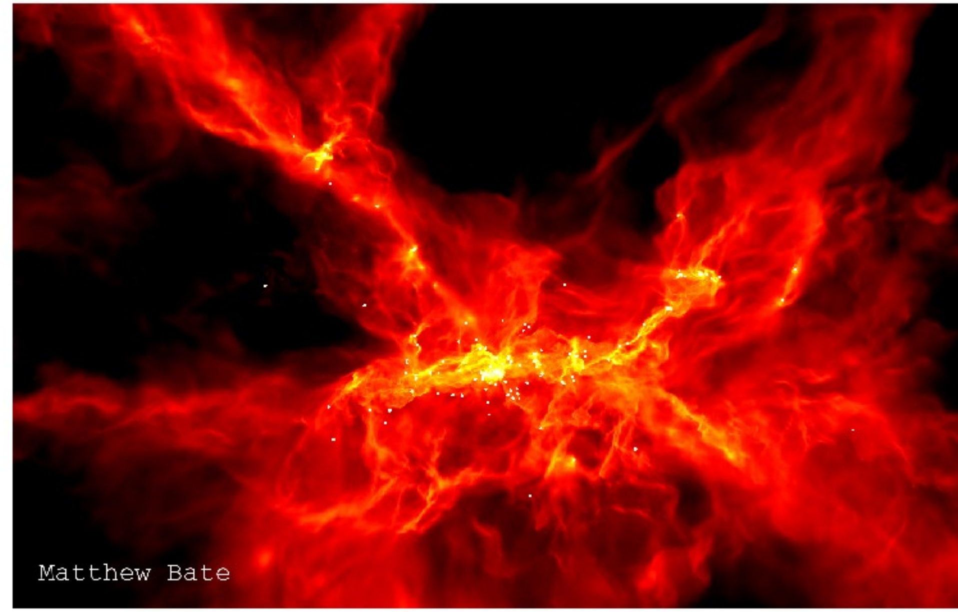
Ratzka et al., A&A, 502, 2009

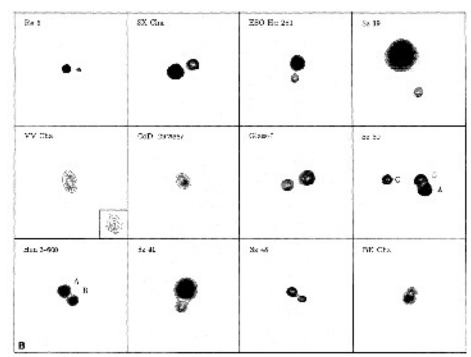
RY Tau – A case study

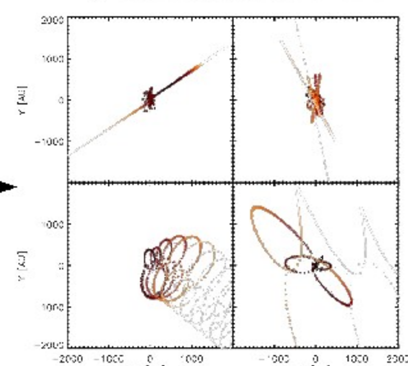


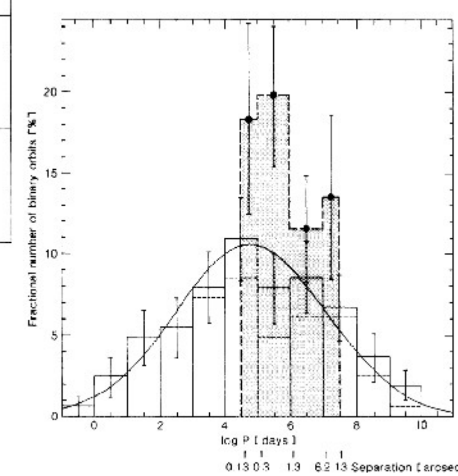
Schegerer et al., A&A, 478, 2008







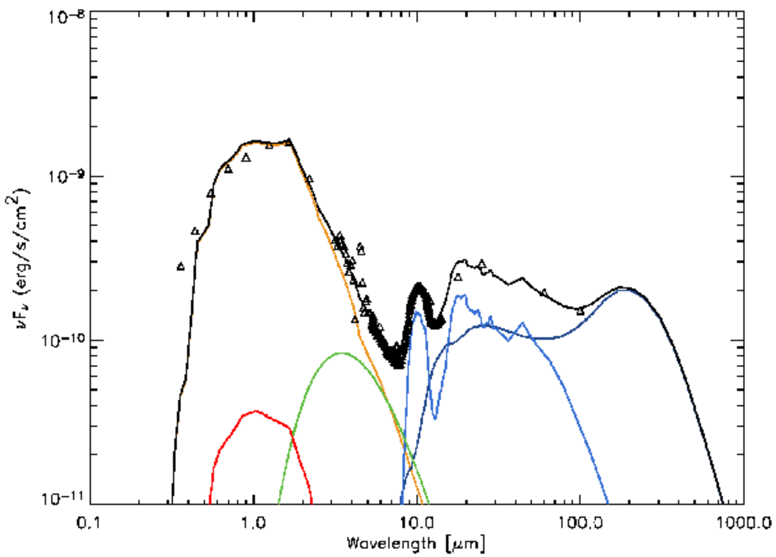


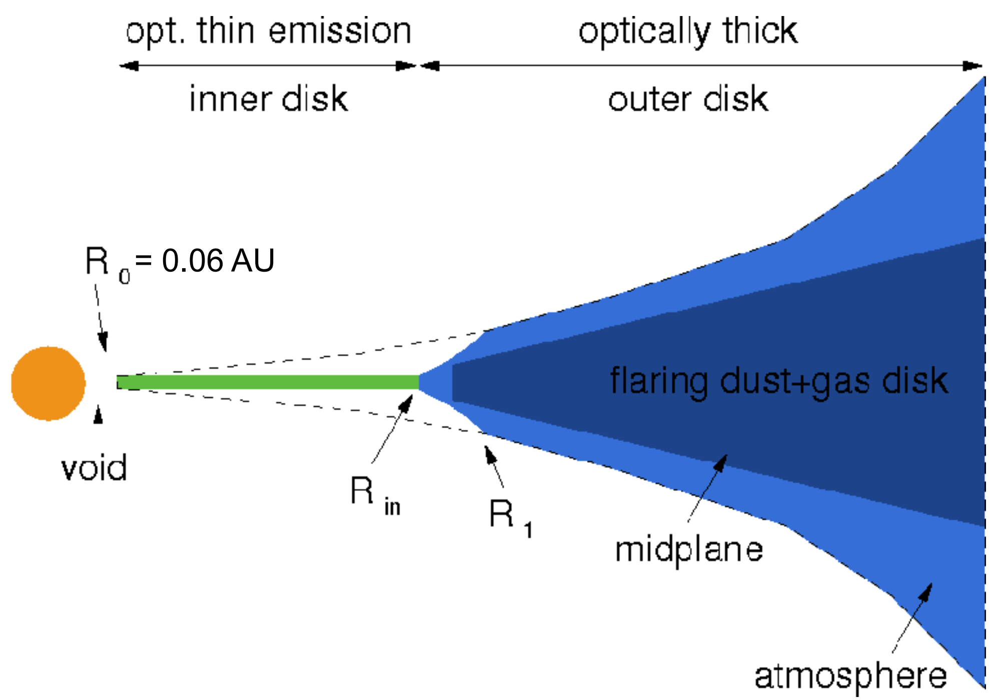


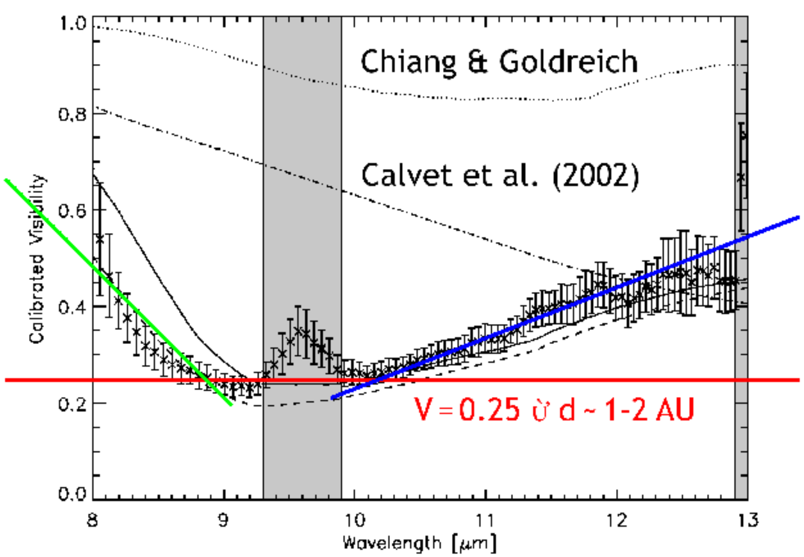
Dauphas & Chaussidon, AREPS, 39, 2011

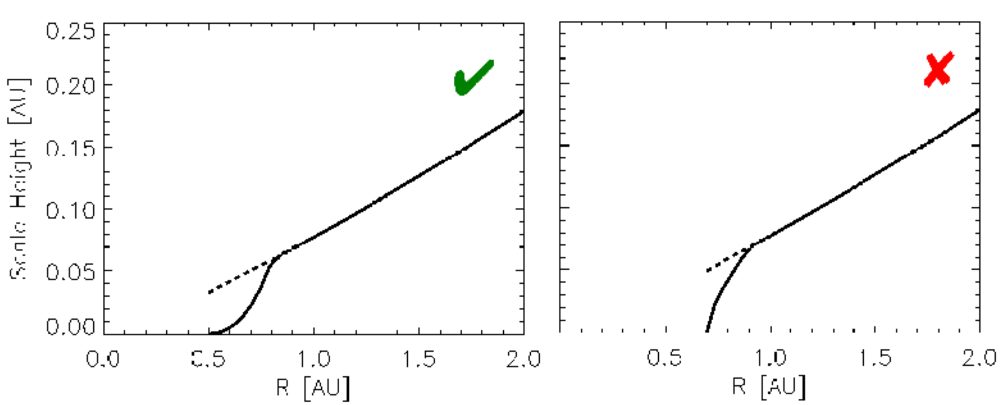
Reipurth & Zinnecker, A&A 278, 1993
Leinert et al., A&A 278, 1993
Reipurth et al., ApJ 725, 2010

The transitional disk of TW Hya



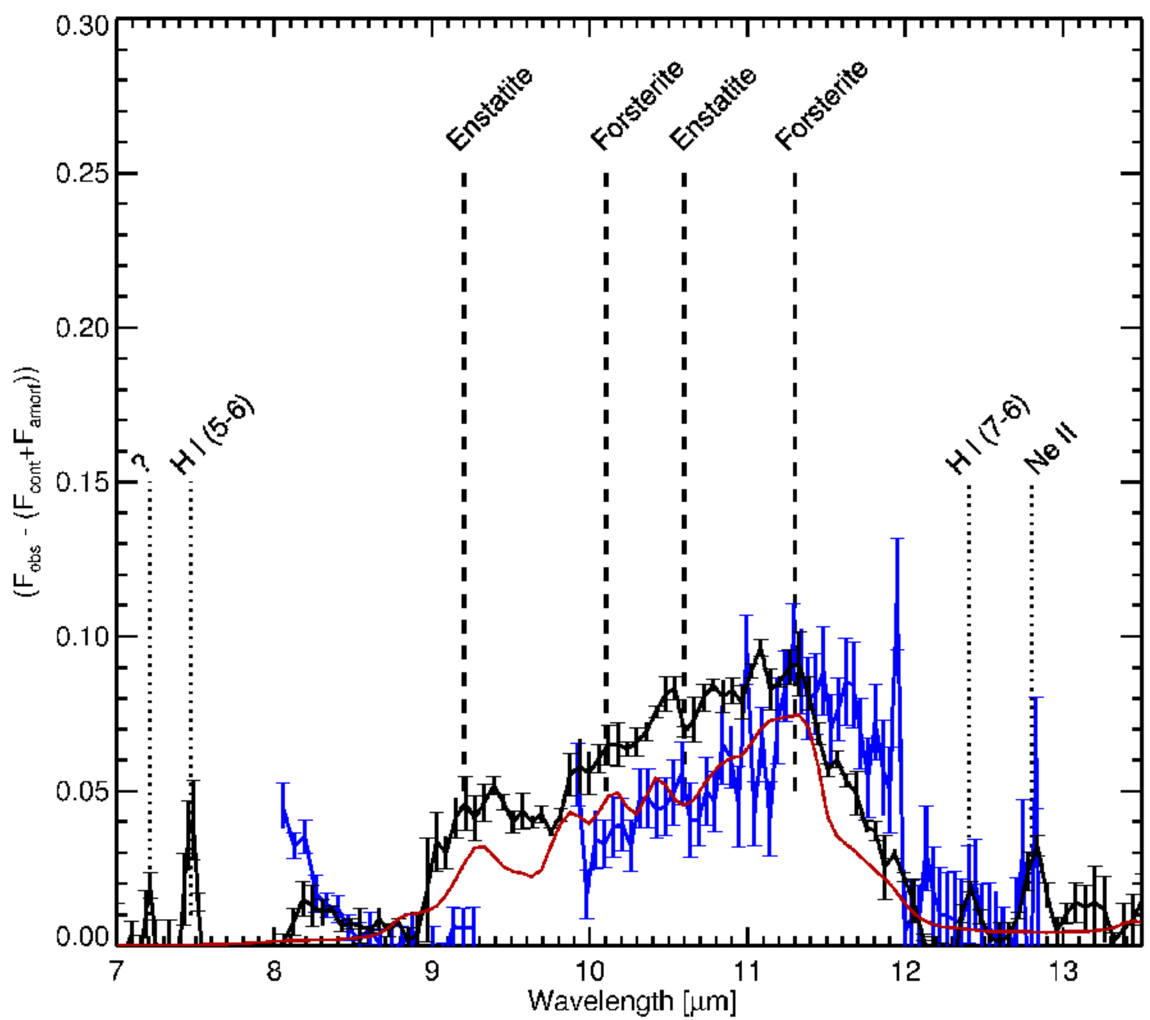






Ratzka et al., A&A, 328, 2007

Processed Dust around TW Hya

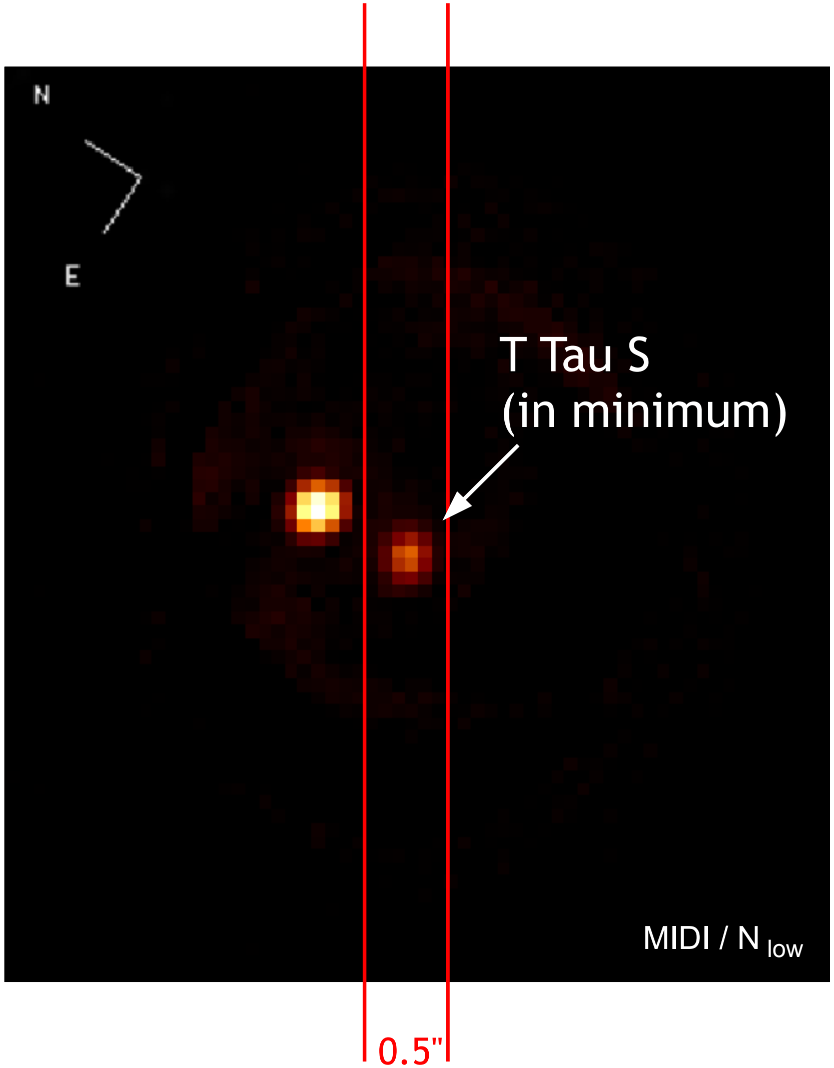


- ~ 8% of the mass is in sub-micron sized crystalline dust particles; ~83% of the mass is in sub-micron sized amorphous dust grains
- Comparison of the spectrally dispersed correlated flux with the dust model shows that most of the crystalline material is concentrated within 1 AU from the central star
- The disk of TW Hya is not well mixed

Ratzka et al., A&A, 328, 2007

A non-prototypical prototype

T. A. Rector (University of Alaska Anchorage) &
H. Schweiker (WIYN and NOAO/AURA/NSF)



Ratzka et al., A&A, 502, 2009

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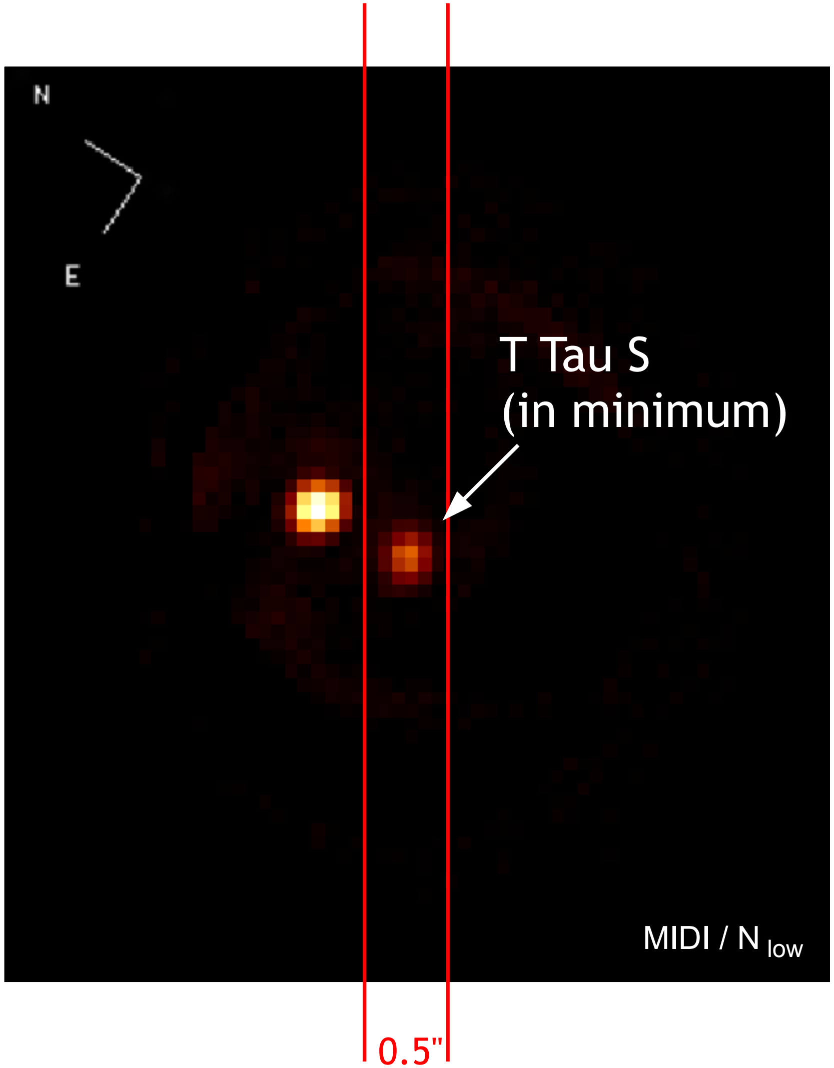
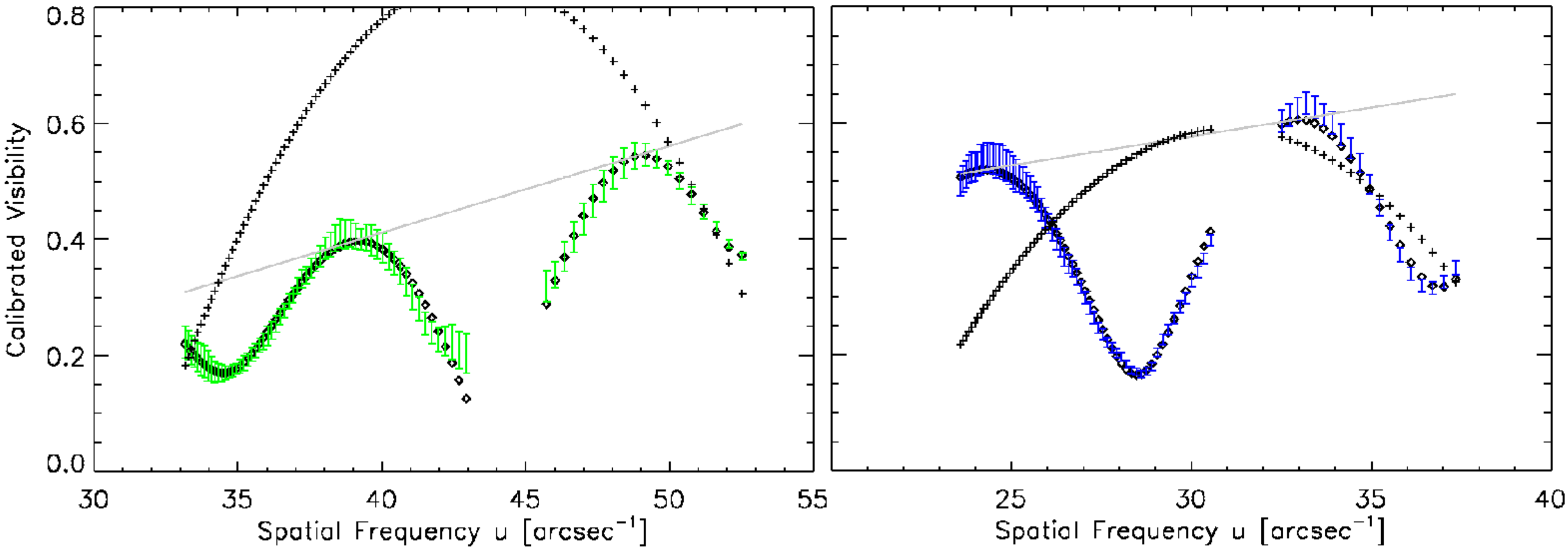


Ratzka et al., A&A, 502, 2009

Fitting the binary signal



$$V_{\mathrm{fit}}(u) = V_0(u) \cdot \frac{\sqrt{1 + f^2(u) + 2f(u)\cos\left[2\pi u s(u)\right]}}{1 + f(u)}$$

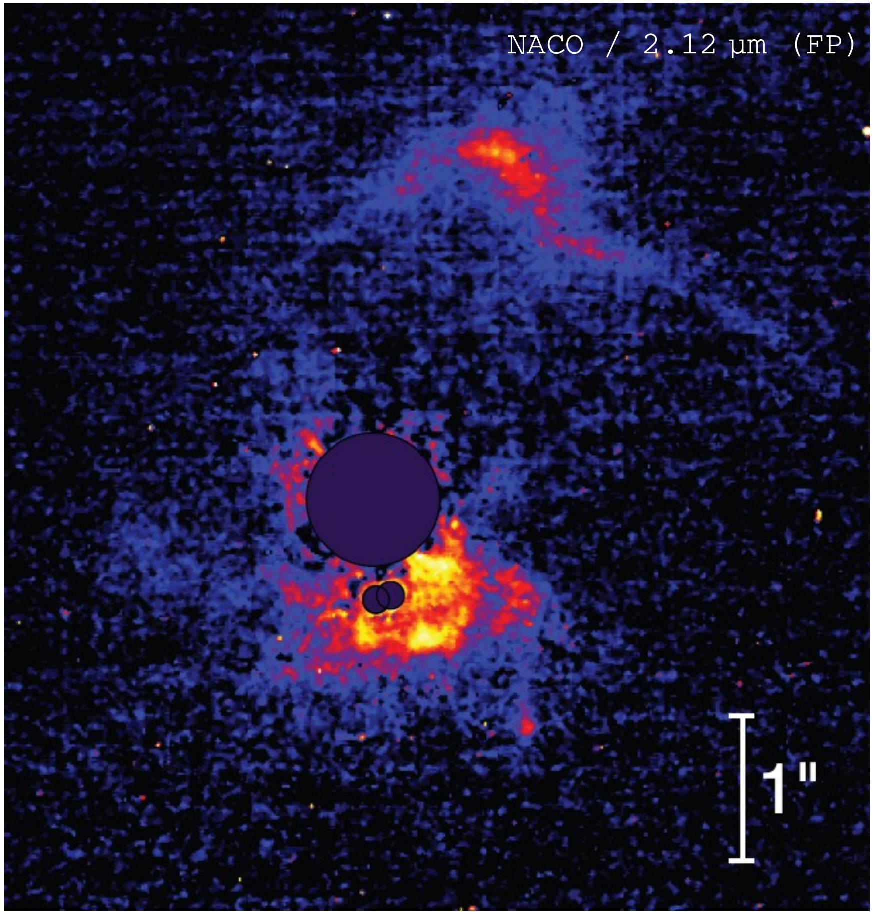
$$s(u) = s_0 + s_1 u$$

$$V_0(u) = a_0 + a_1 u$$

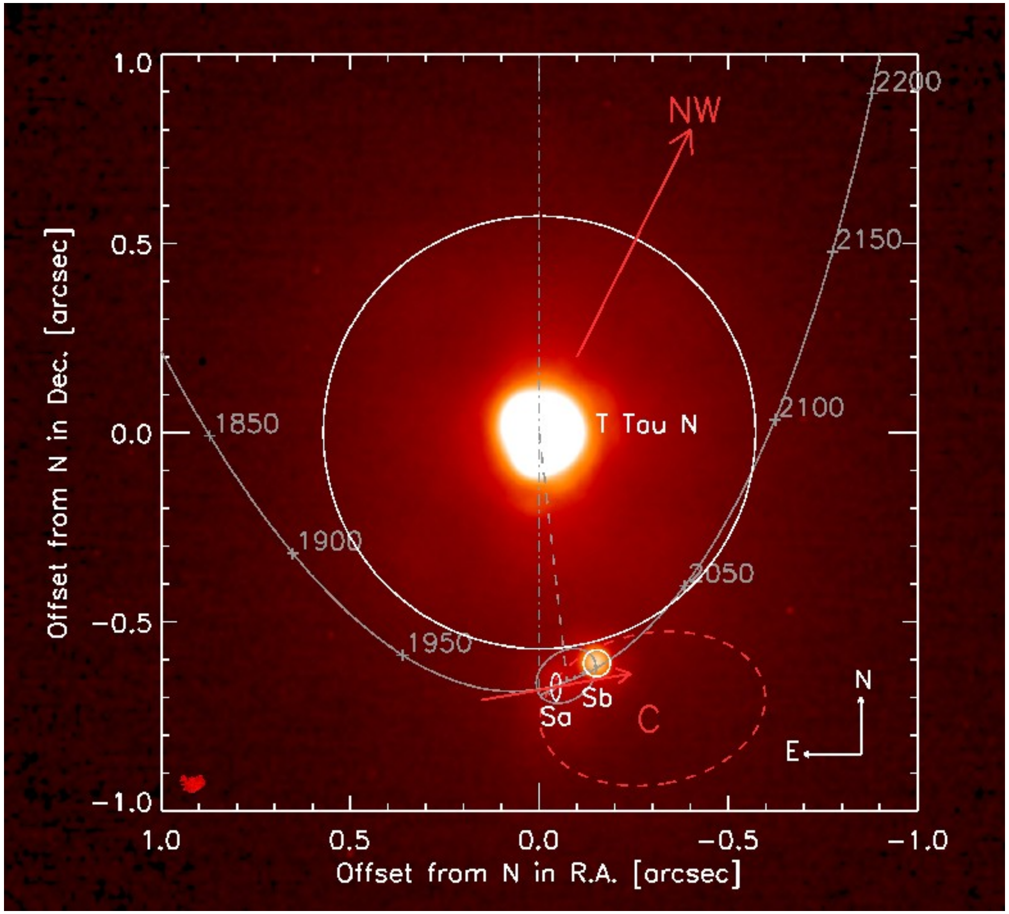
$$f(u) = f_0 + f_1 u + f_2 u^2, \;\; f(u) < 1$$

Ratzka et al., A&A, 502, 2009

Sketching the T Tau system



Herbst et al., AJ, 134, 359, 2007



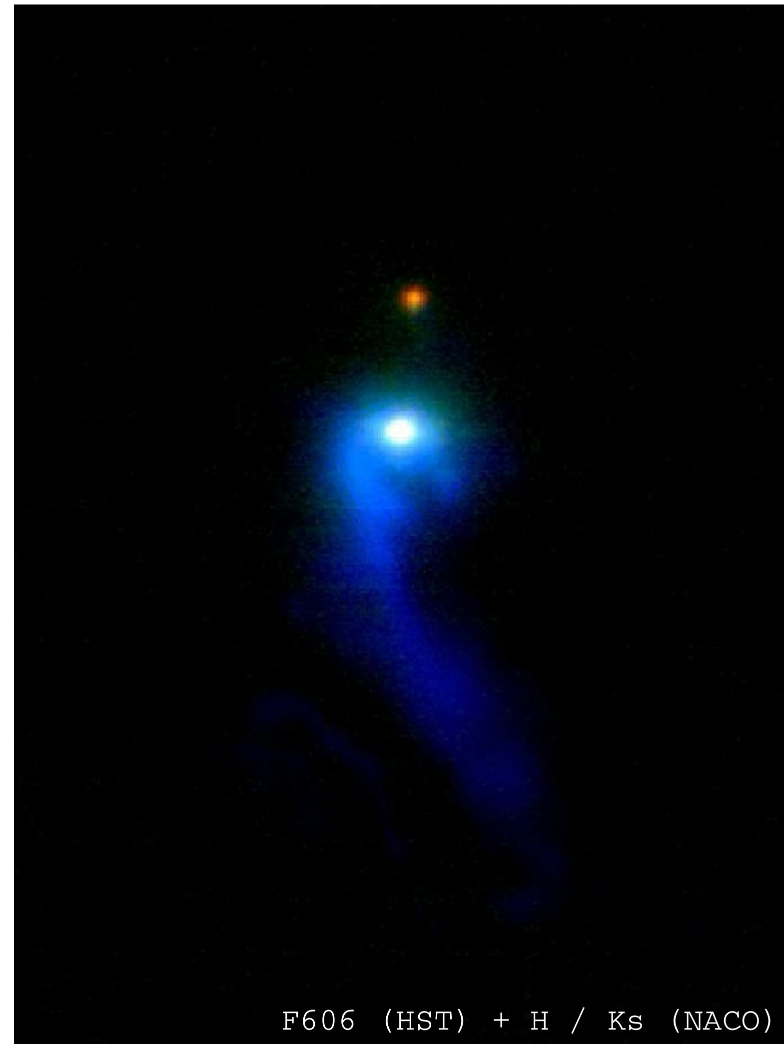
Th. Ratzka., A&A 502, 623, 2009 &
R. Köhler, A&A 482, 929, 2008

GV Tau – another IRC

- binary separated by 1.2“
- distance of ~ 140-160 pc
- variable on short timescales due to

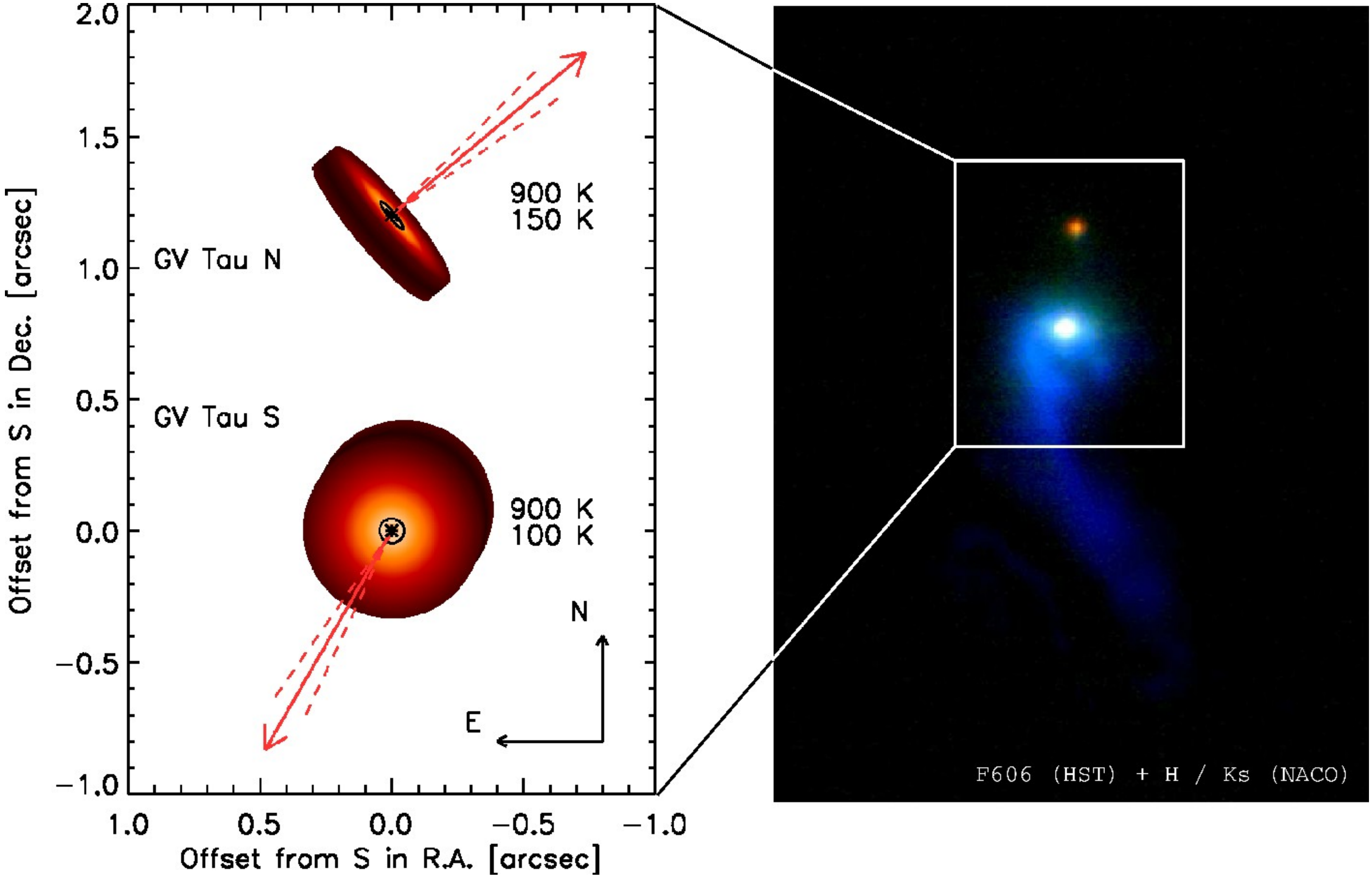
  inhomogeneities in the circumstellar material around the southern component?

  variable accretion of the northern component?
- presence of a circumbinary envelope suggested



Roccatagliata et al., A&A, 534, 2011

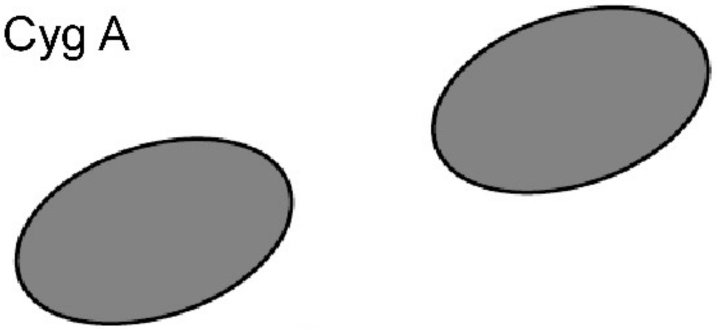
GV Tau – another IRC



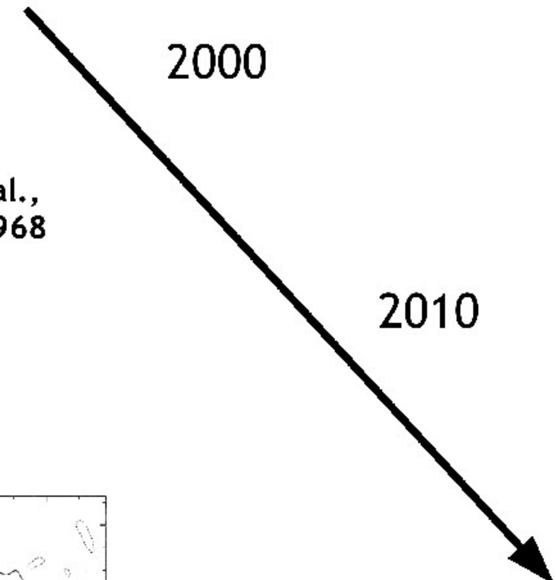
Roccatagliata et al., A&A, 534, 2011

Where do we stand?

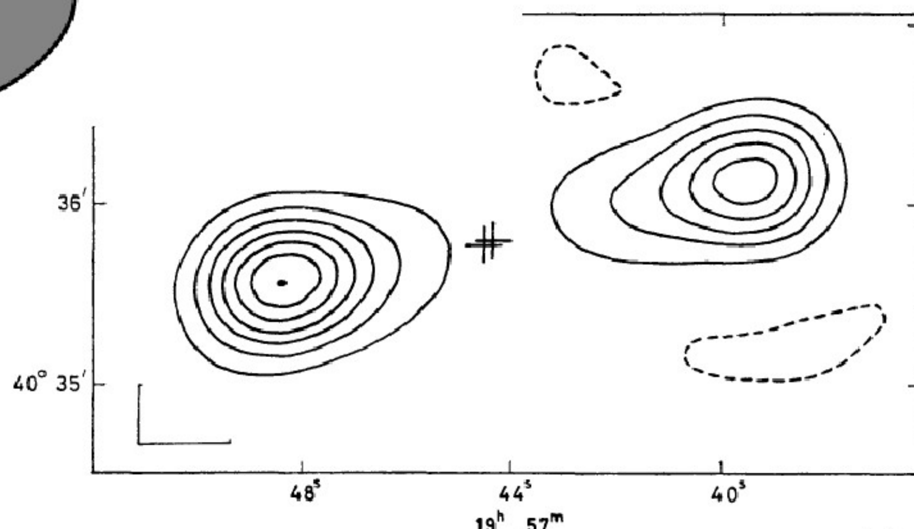
Cyg A

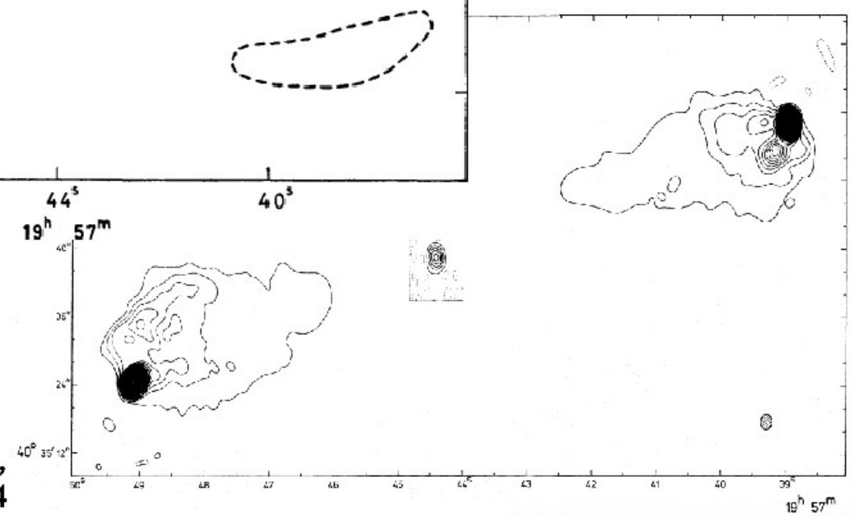


Jennison & Gupta,
Nature, 172, 1953

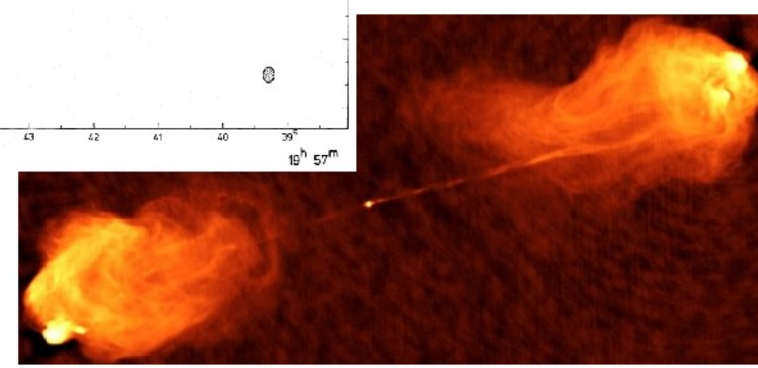


Mac Donald et al.,
MNRAS, 138, 1968





Hargrave & Ryle,
MNRAS, 166, 1974



Perley et al.,
ApJ, 285, 1984