MIDI observations of T Tauri stars and their companions

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Concluding MIDI Science Group Meeting

Introduction

Observables

The VLT Interferometer

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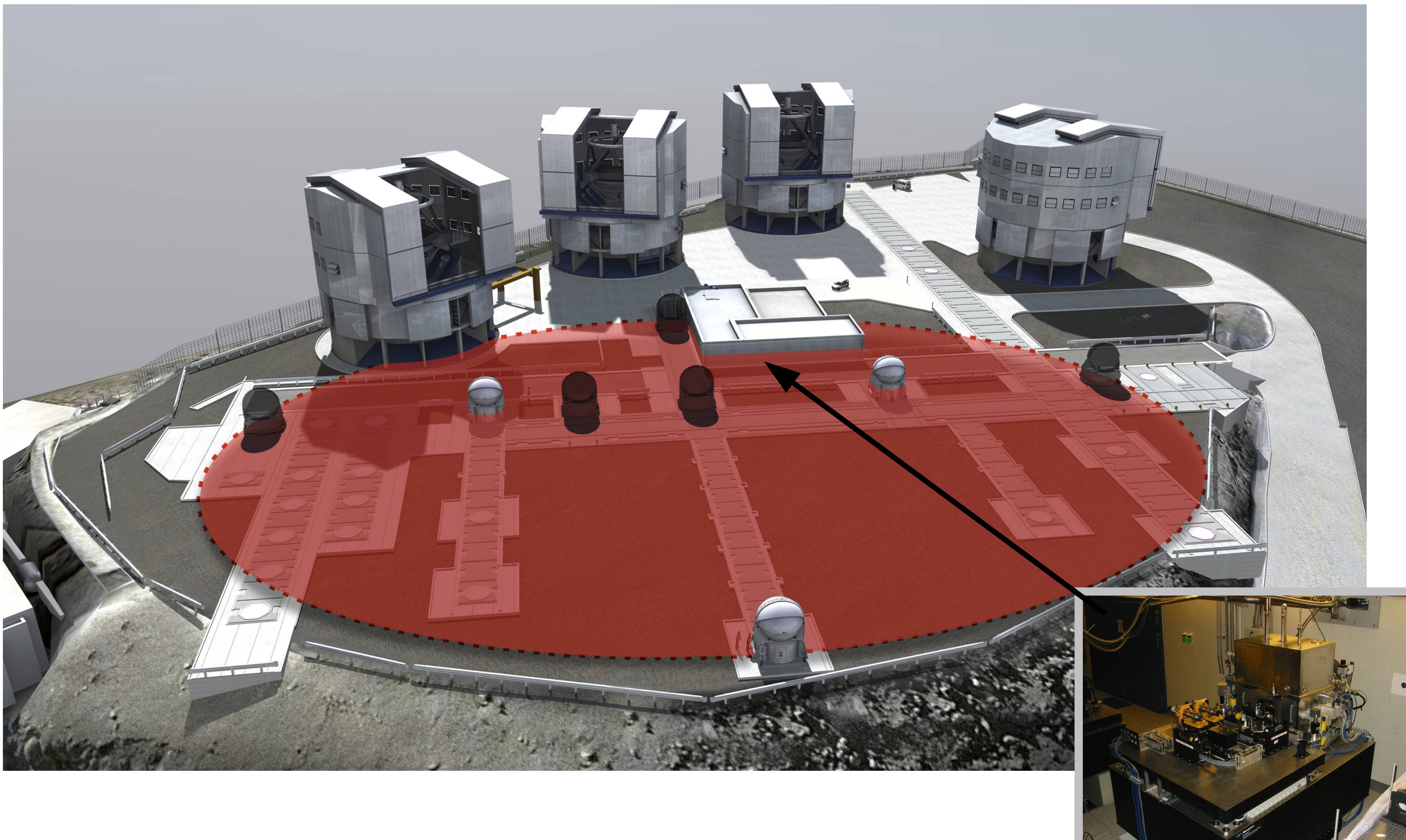


Interferometric Observables

$$\frac{V_r(\vec{\rho})}{V_r(0)} = \frac{\int I(\vec{\alpha}) \exp(-\mathrm{i}2\pi \frac{(\vec{\alpha}\cdot\vec{\rho})}{\lambda})\, \mathrm{d}\alpha}{\int I(\vec{\alpha})\, \mathrm{d}\alpha}$$

intensity

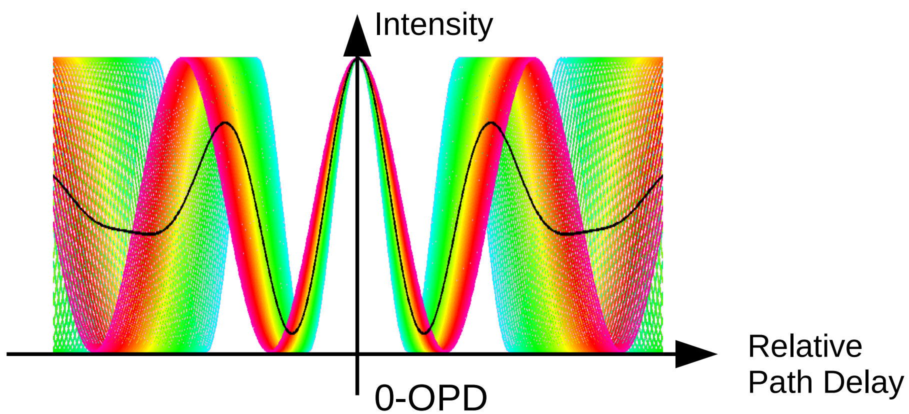
$$V_{r,\mathrm{norm}}(u,v) = \frac{\int\int I(\alpha,\beta) \exp(-\mathrm{i}2\pi(u\alpha + v\beta))\, \mathrm{d}\alpha\, \mathrm{d}\beta}{\int\int I(\alpha,\beta)\, \mathrm{d}\alpha\, \mathrm{d}\beta}$$

»visibility«

sky coordinates

spatial frequencies
in units of B/λ

»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)



A) Fringe Contrast

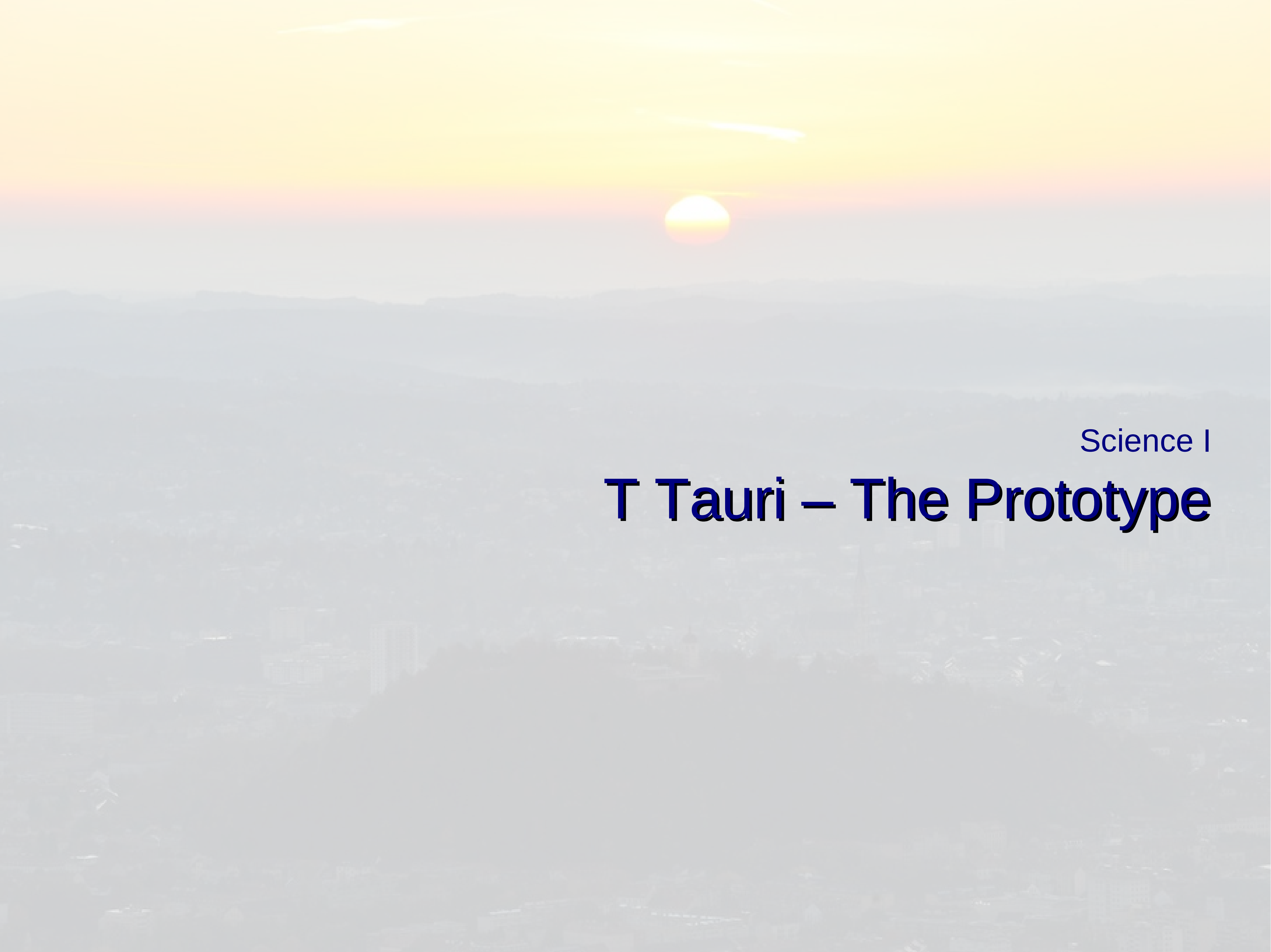
sometimes known as **»Michelson visibility«**, and related to the measured maximum and minimum intensities in the fringe pattern:

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

visibility varies between 0 ($I_{min} = I_{max}$) and 1 ($I_{min} = 0$); indicates **»compactness«** of the source

B) Fringe Phase

location of the central fringe with respect to the zero optical path difference; indicates **»asymmetry«** of the source

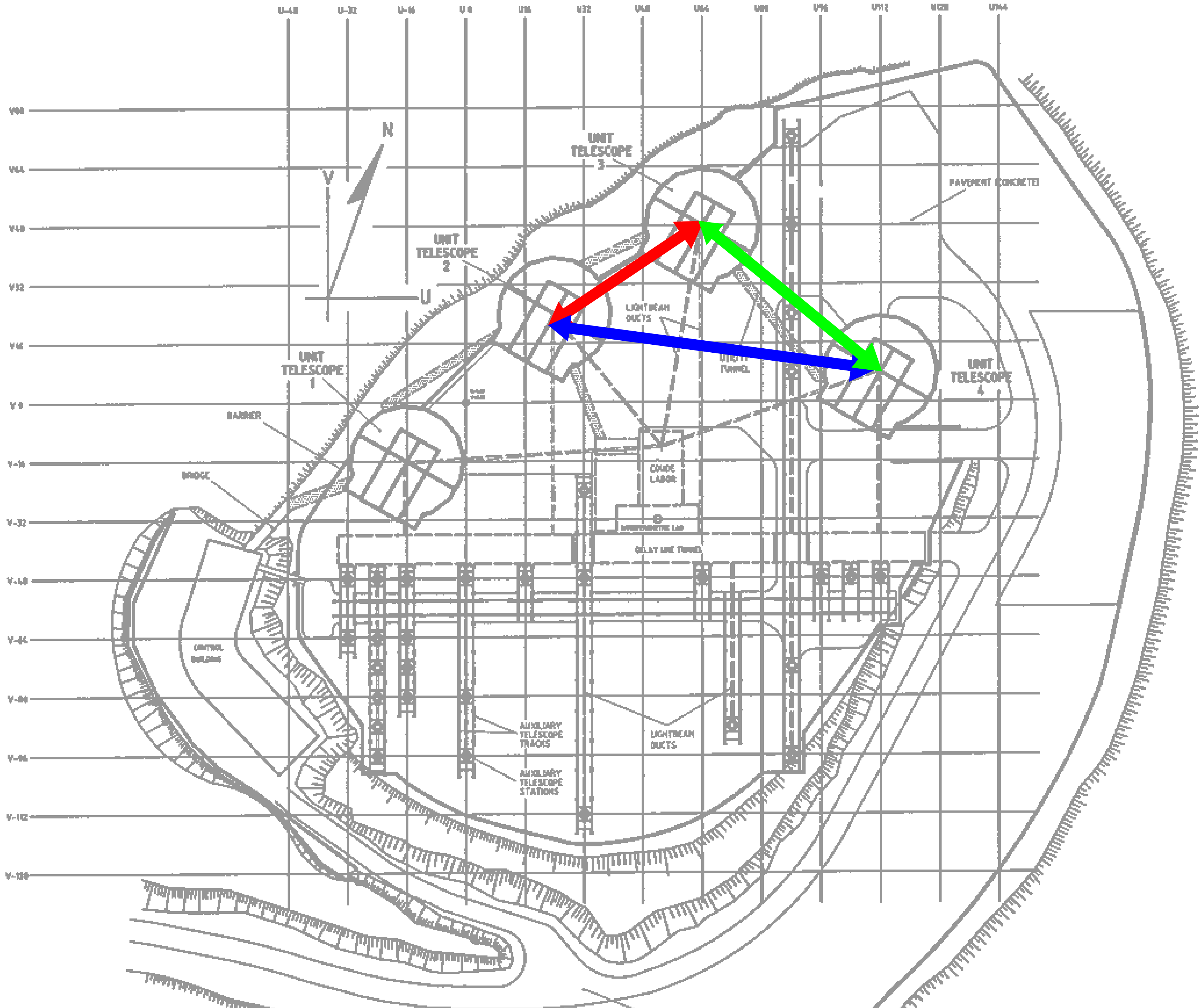


Science I

T Tauri – The Prototype

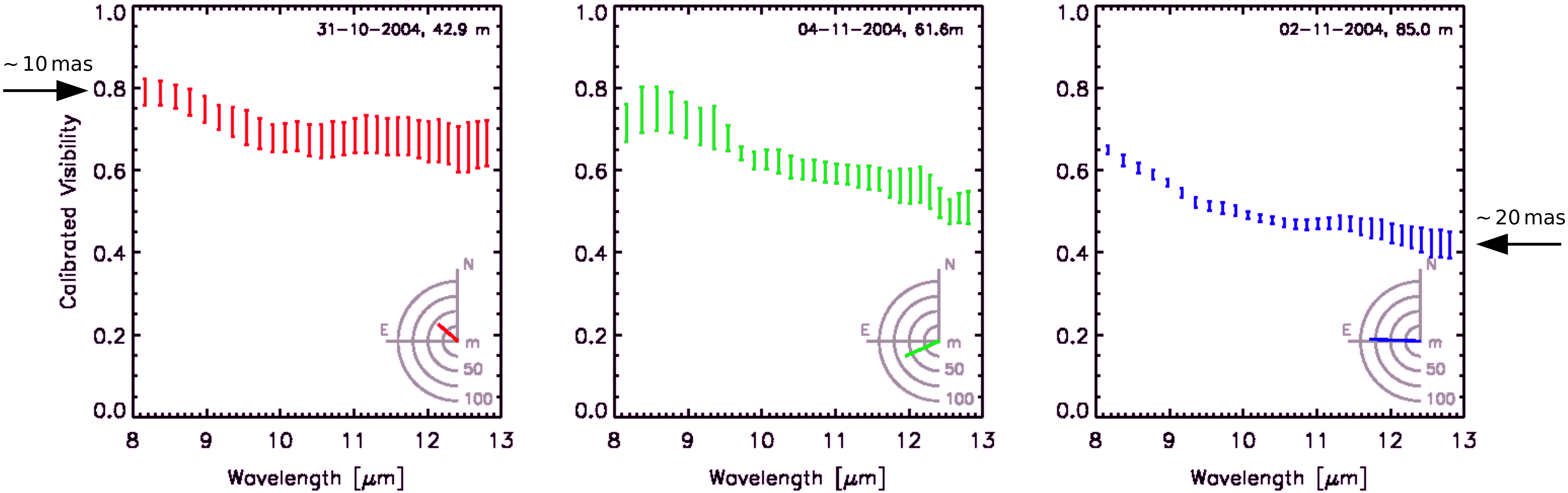
T Tauri – The Prototype

The Grid



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

The Visibilities ...

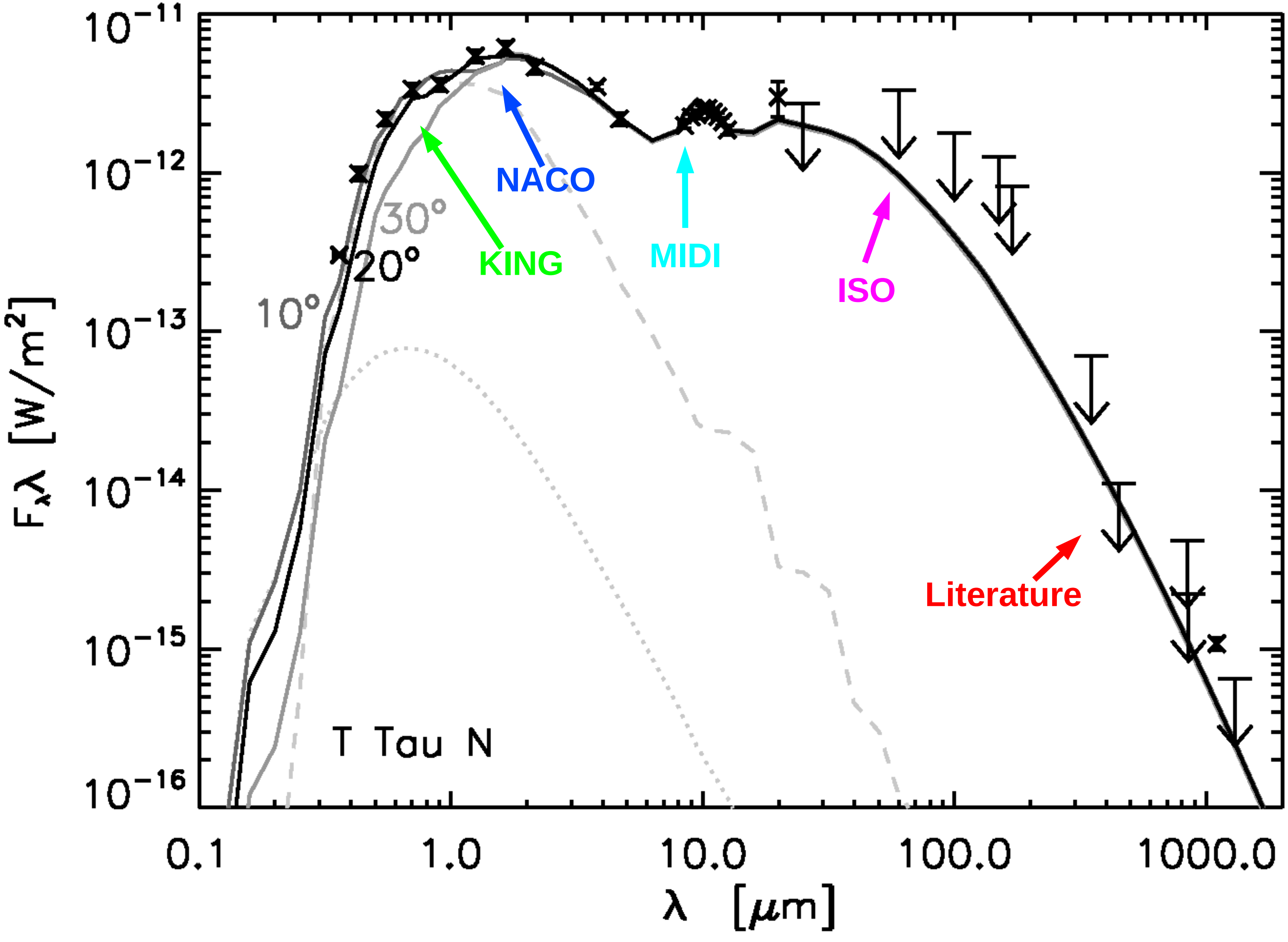


the resolution of the interferometer decreases with wavelength
the emitting region becomes larger due to the temperature gradient

⇒ decreasing visibilities
⇒ direct size estimates

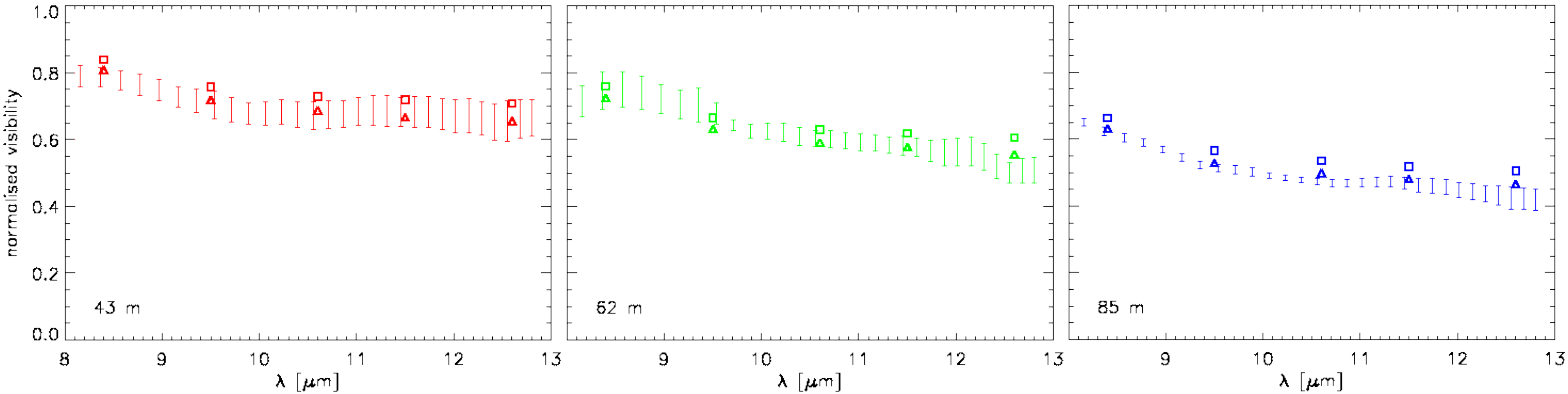
Ratzka et al., A&A, 502, 2009

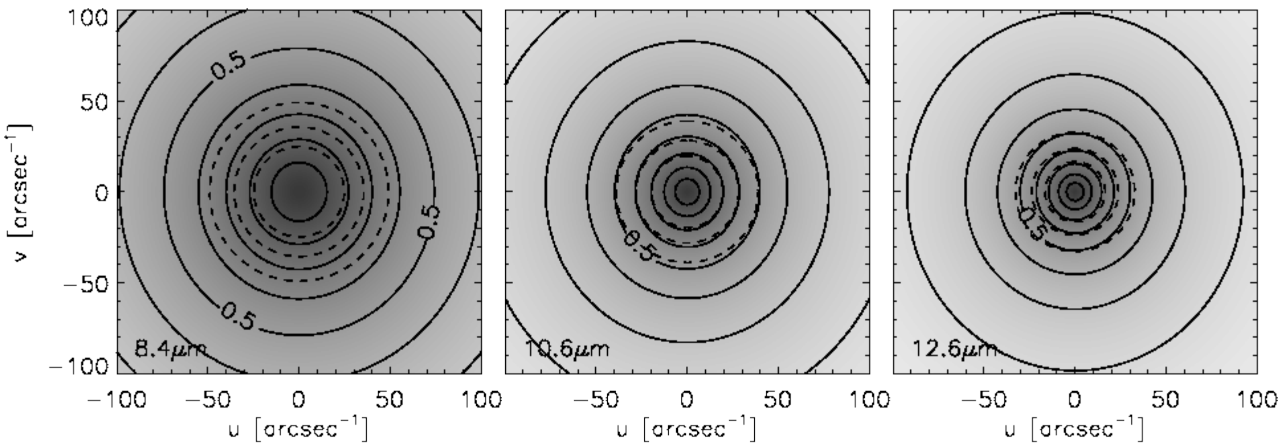
The Spectral Energy Distribution ...

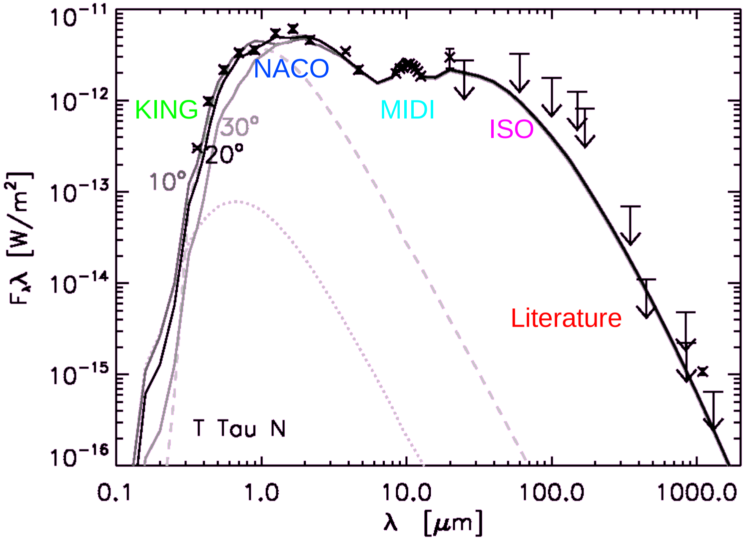


Ratzka et al., A&A, 502, 2009

The Radiative Transfer Model ...

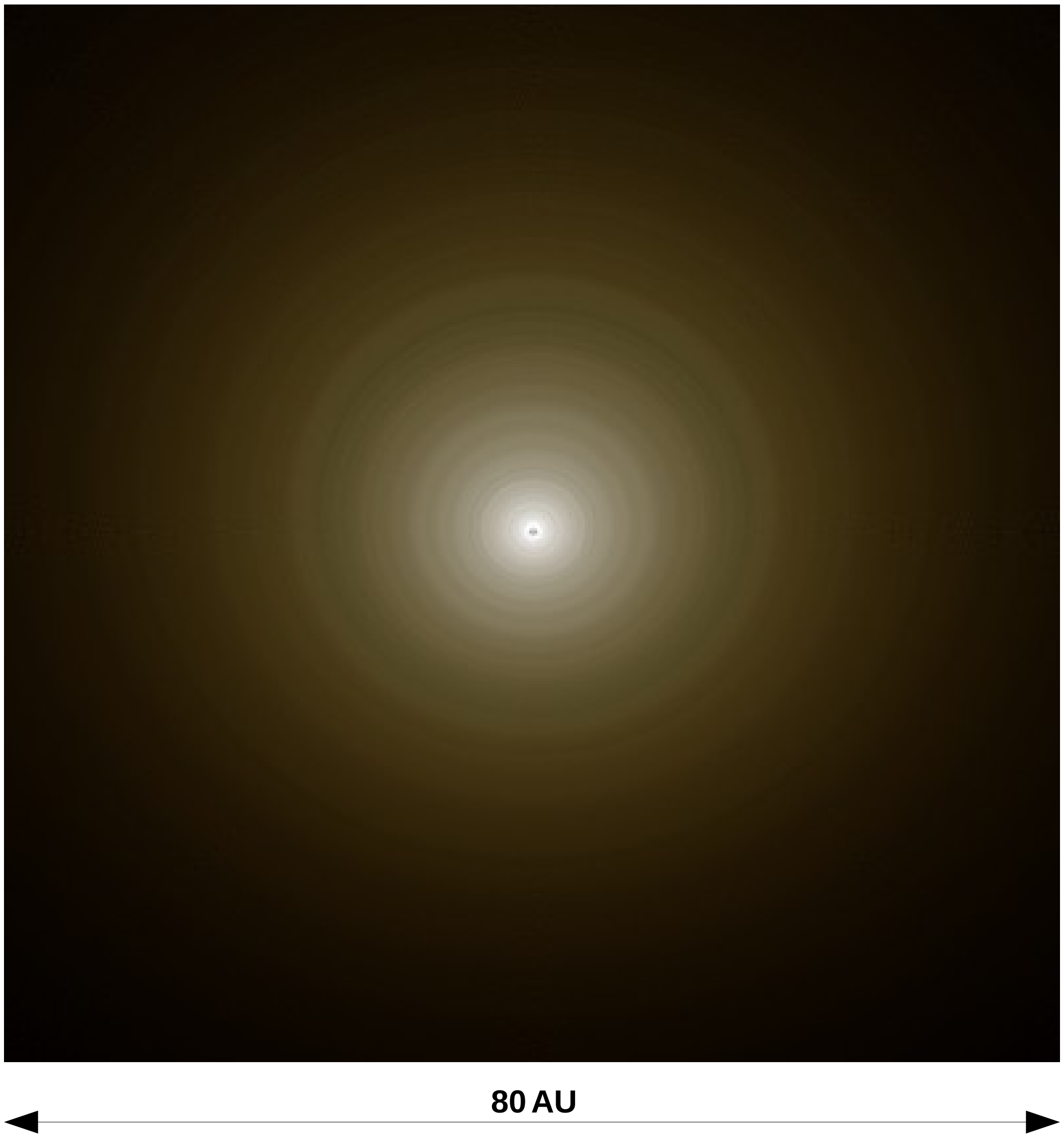






Ratzka et al., A&A, 502, 2009

The Radiative Transfer Model ...



star

$M_* = 2.1\,M_\odot$
$T_* = 5250\,K$
$L_* = 7.3\,R_\odot$
$R_* = 3.3\,R_\odot$

disk

$M_d = 0.04\,M_\odot$
$r_d = 0.1 \ldots 80\,AU$
$i < 30^o$
$h_{100} = 18\,AU$
$\beta = 1.25$

envelope

$c_1 = 1 \cdot 10^{-5}$
$c_2 = -5.0$

accretion

$dM/dt = 3 \cdot 10^{-8}\,M_\odot yr^{-1}$

extinction (foreground)

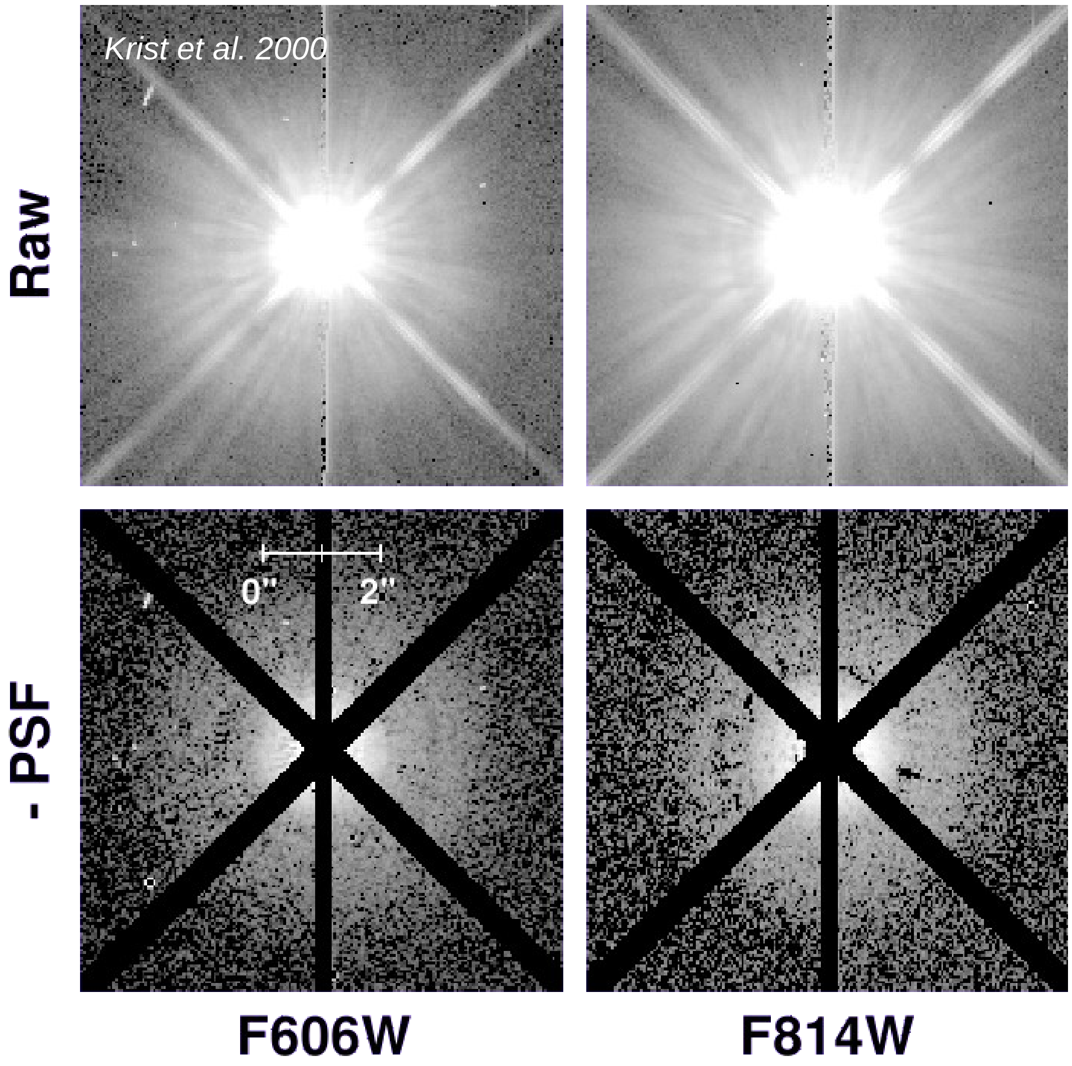
$A_V = 1.5\,mag$

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

Science II

Structure of Transitional Disks

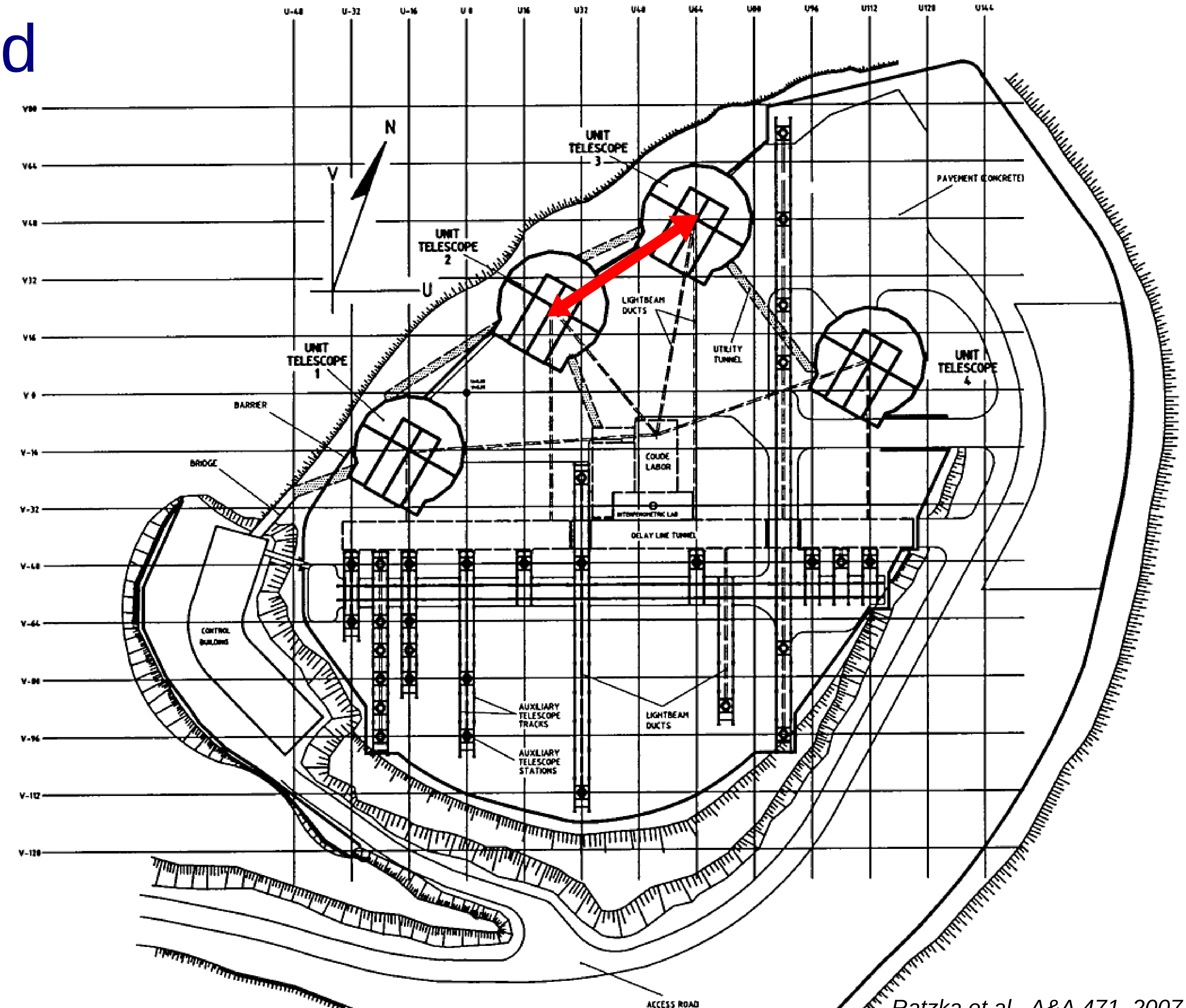
TW Hya - The Prototypical Transitional Disk



- classical T Tauri star
- distance of 51 ± 4 pc
- age of 5 - 15 Myr
- K7V (T ~ 4000 K, 0.19 $L_{\odot}$)
- actively accreting at a low rate: 4 x $10^{-10} M_{\odot}$/yr
- images taken at various wavelengths reveal a dust disk:
  - nearly face-on
  - diameter: ~ 300 AU

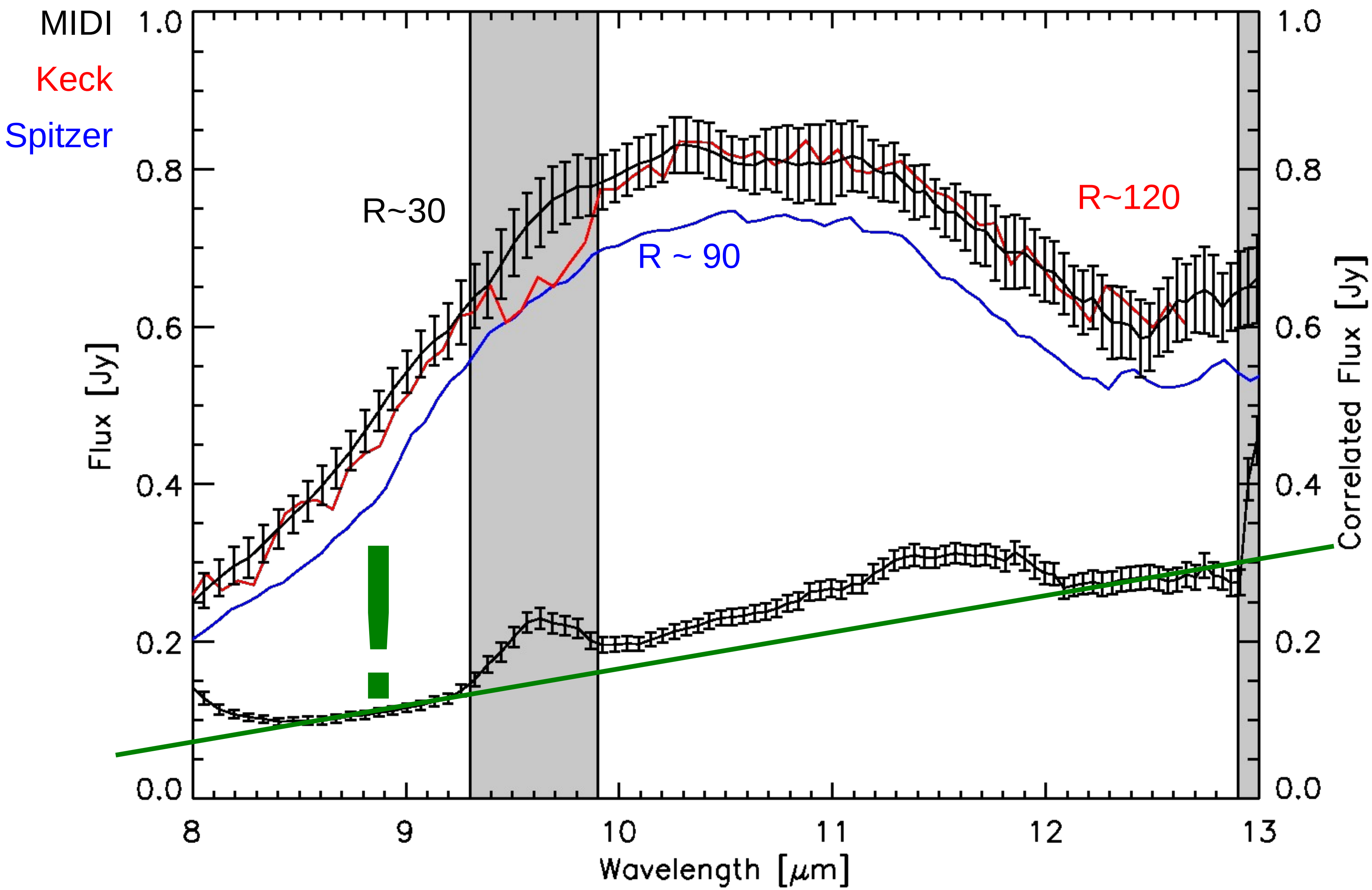
Ratzka et al., A&A 471, 2007

The Grid



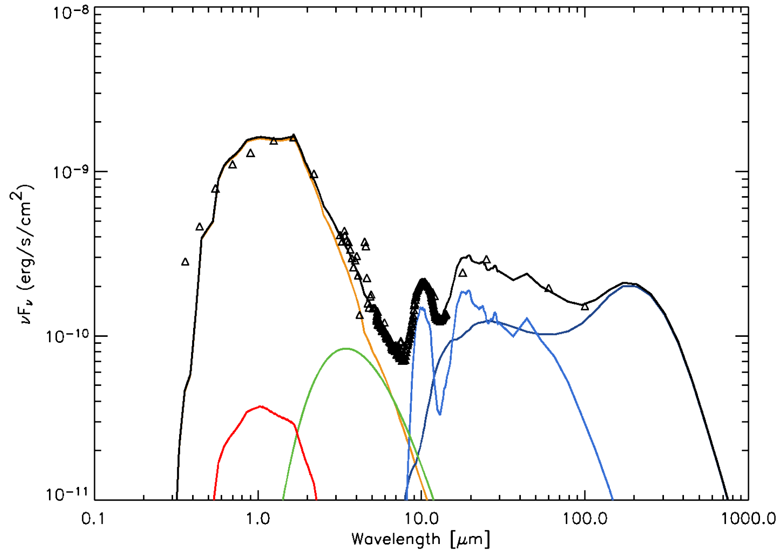
Ratzka et al., A&A 471, 2007

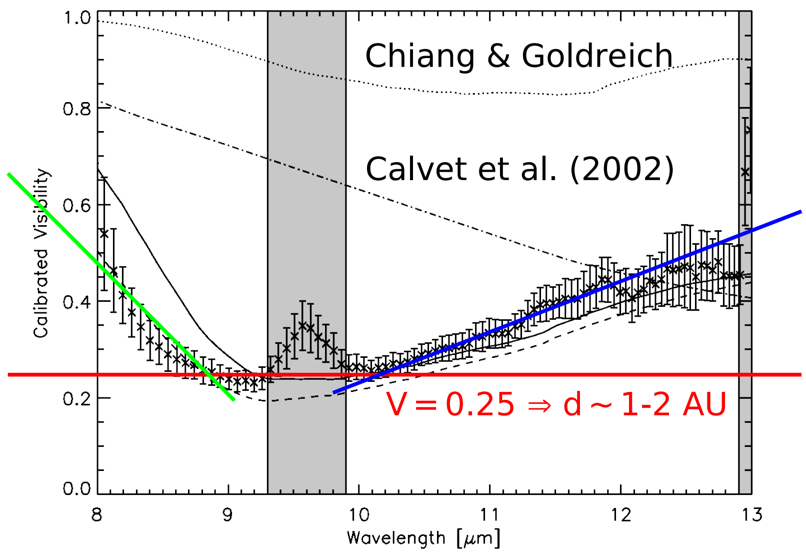
The Total and the Correlated Flux

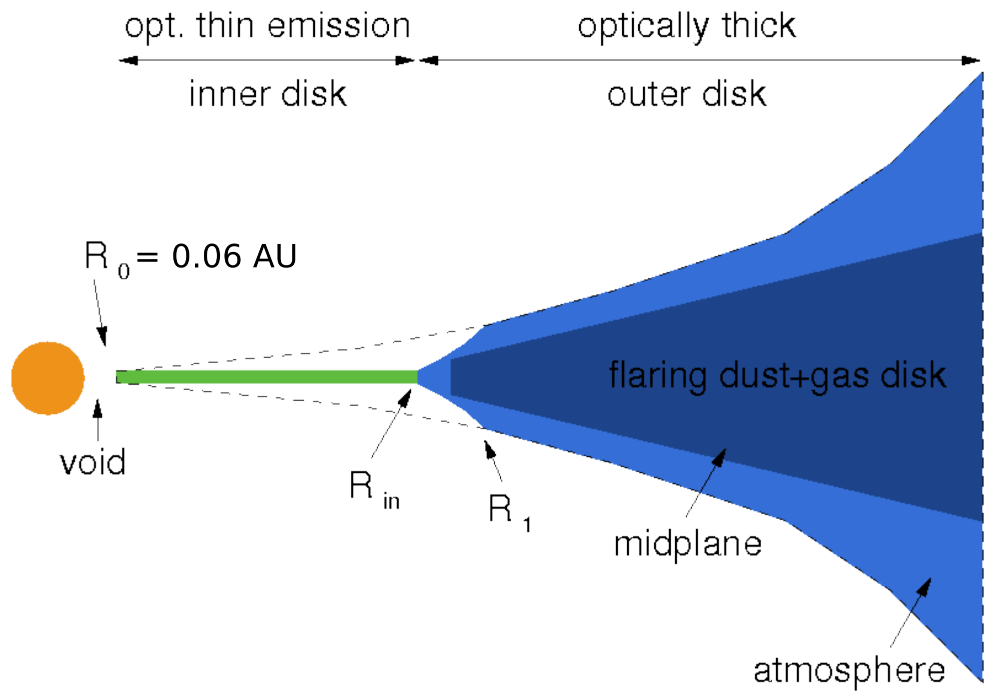


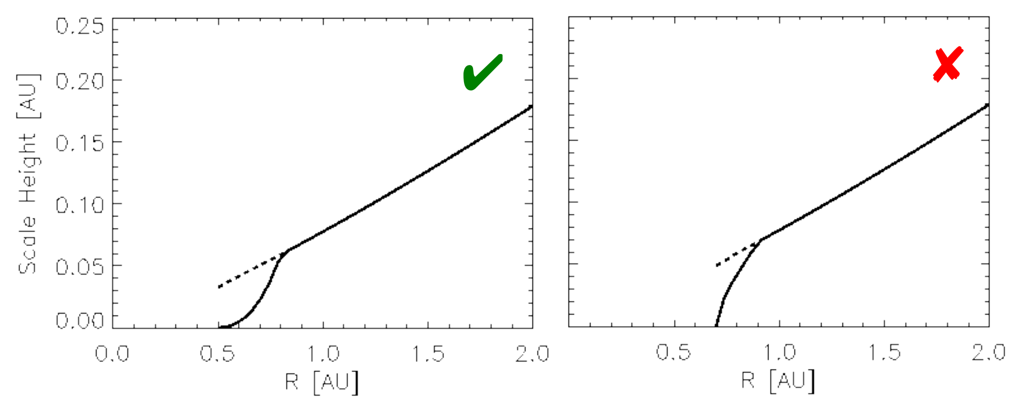
Ratzka et al., A&A 471, 2007

Modified Chiang & Goldreich Model



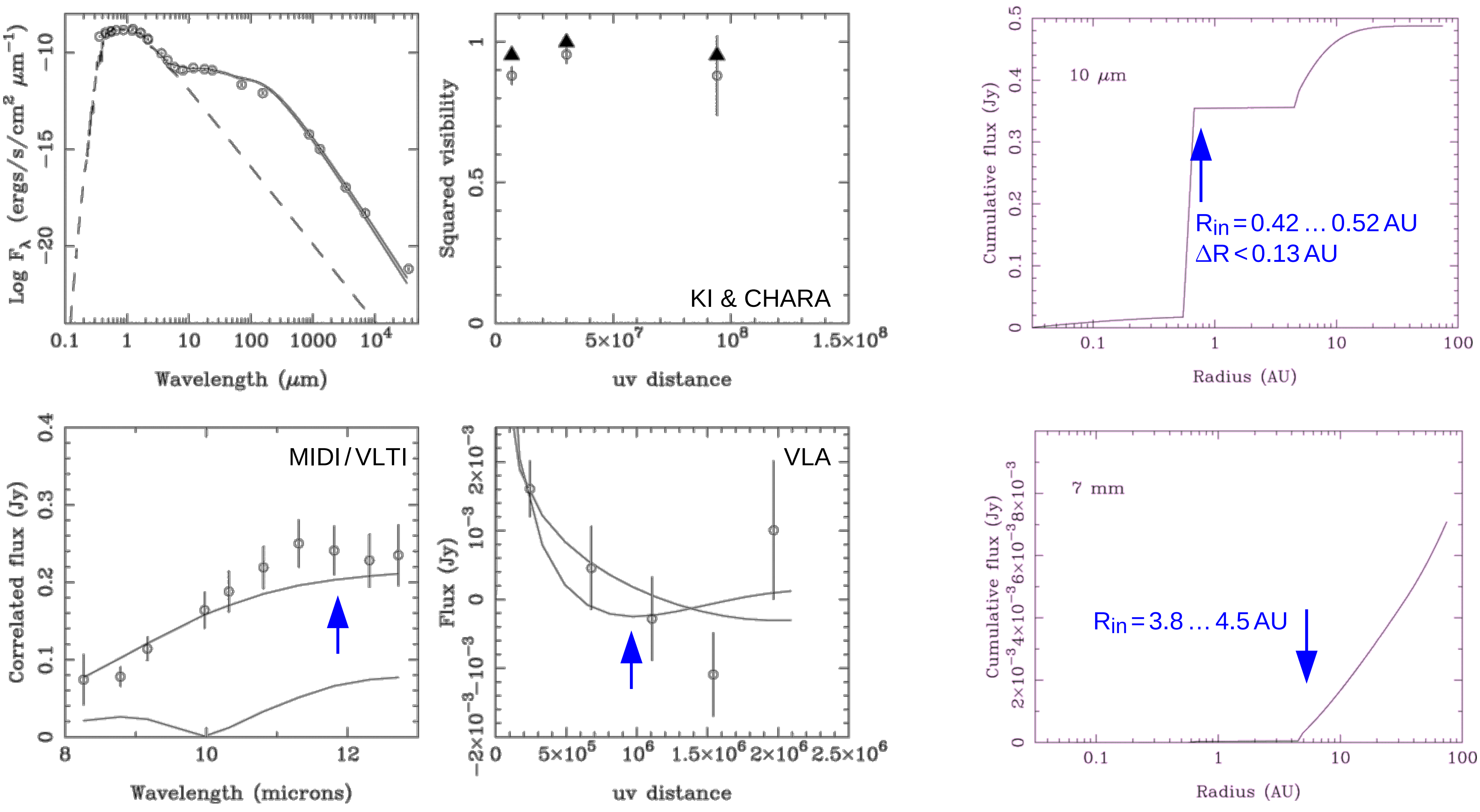






Ratzka et al., A&A 471, 2007

The Transitional Disk of TW Hya



Akeson et al., ApJ 728, 2011

Science III

The Dust Composition and Distribution

Dust Species and Properties

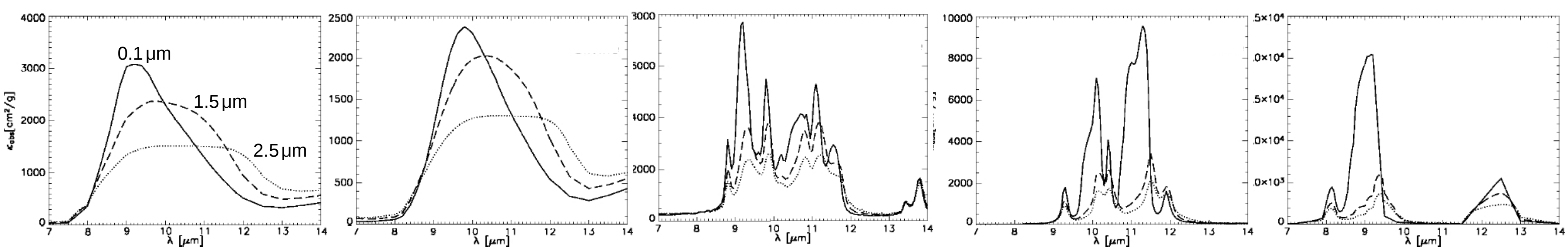
Pyroxene Group	**Olivine Group**	**Enstatite**	**Forsterite**	**Quartz**
$Mg_nFe_{n-1}Si_2O_6$	$Mg_nFe_{n-1}SiO_4$	$Mg_2Si_2O_6$	Mg_2SiO_4	SiO_2

← SiO_2

amorph

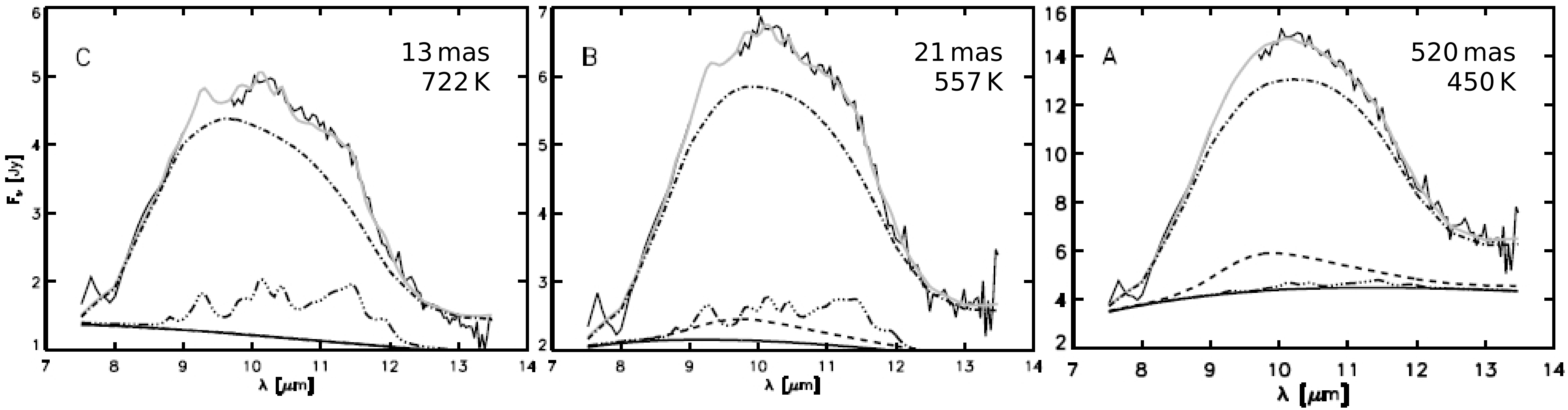
amorph

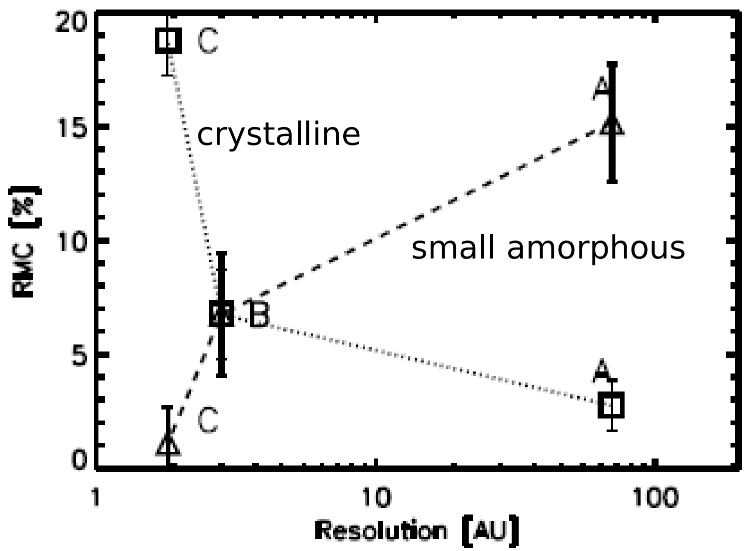
→ processing / thermal stability



Schegerer et al., A&A 456, 2006

Dust Processing in the RY Tau Disc!



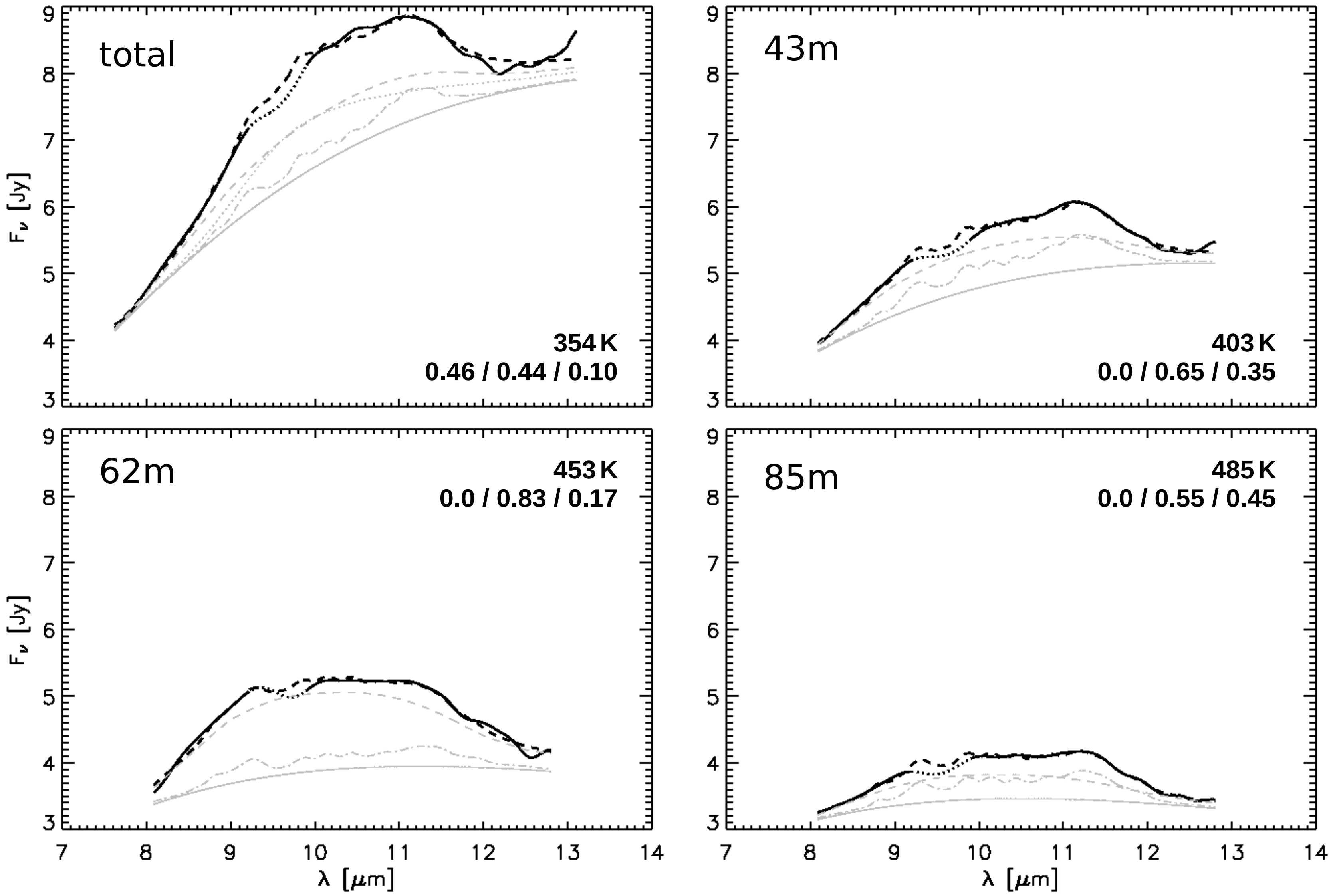


$$F_\nu = B_\nu(T_{\rm cont})\,C_0 + B_\nu(T_{\rm dust})\left(\sum_{i=1}^{3}\sum_{j=1}^{6} C_{i,j}\,\kappa_\nu^{i,j}\right)$$

Comparison of interferometric and single-dish observations shows for the first time dust evolution in a T Tauri star with a reduced fraction of small amorphous and an increased fraction of crystalline particles closer to the star.

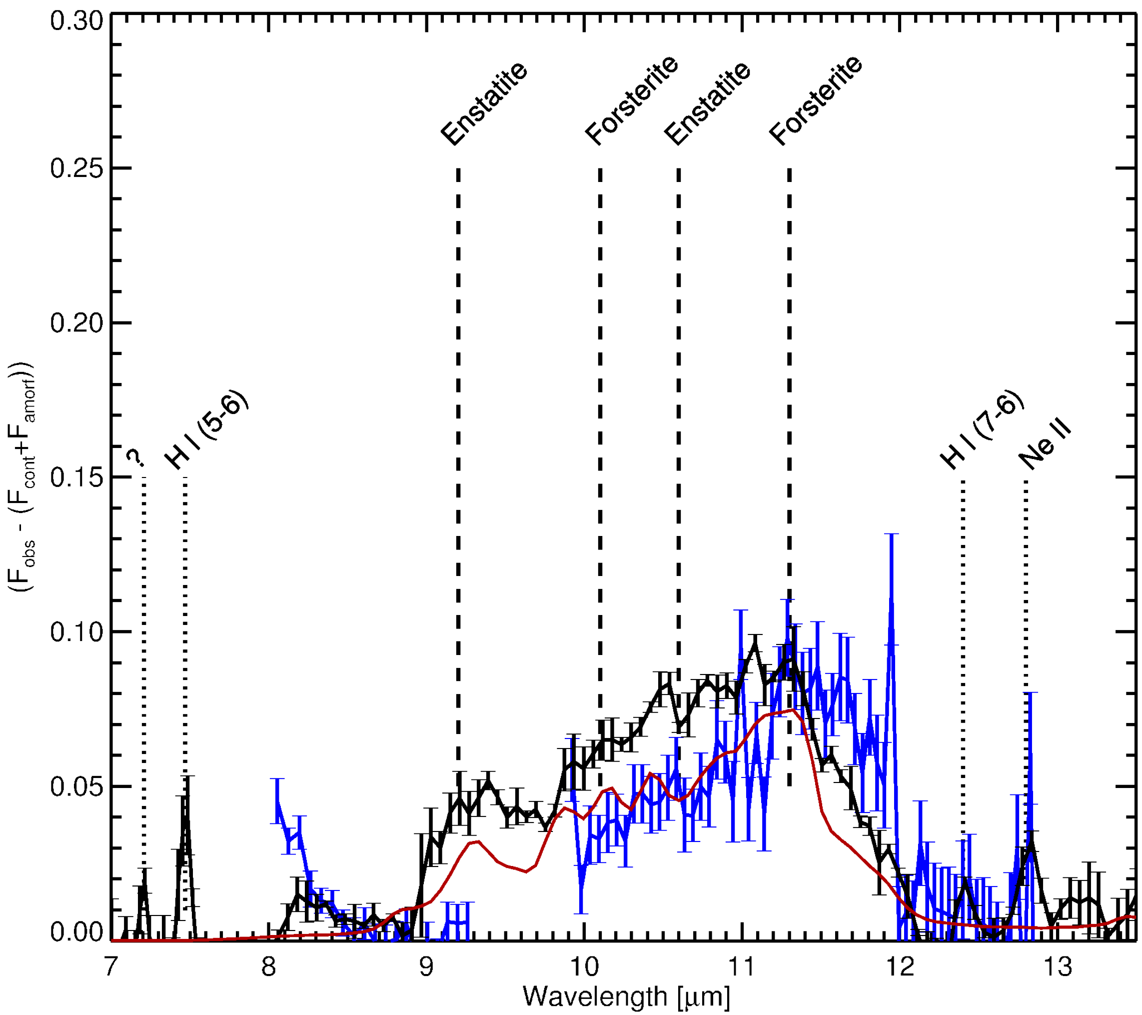
Schegerer et al., A&A 456, 2006

Dust Processing around T Tau?



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

Where is the Processed Dust in TW Hya?



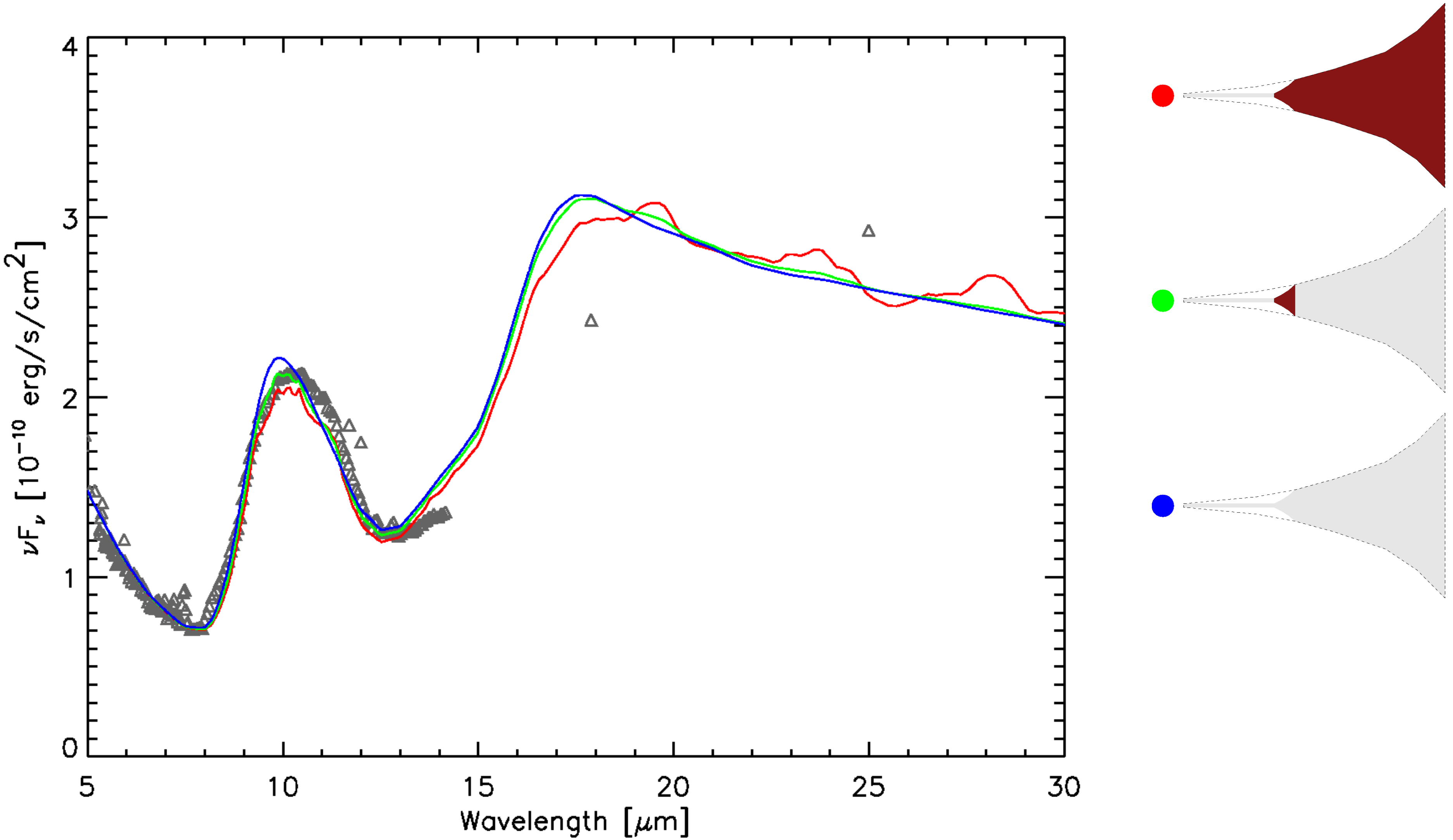
~ 8 % of the mass is in sub-micron sized crystalline dust particles; ~83 % of the mass is in sub-micron sized amorphous dust grains

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, 471, 2007

Where is the Processed Dust in TW Hya?



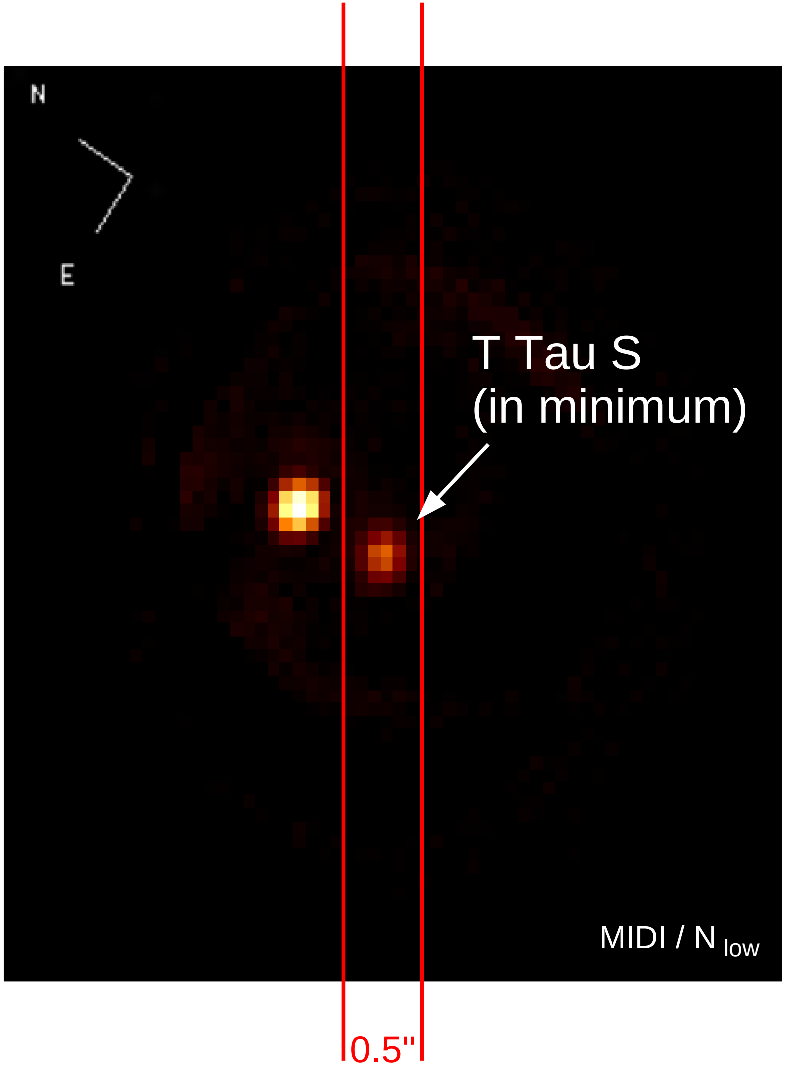
Ratzka et al., A&A 471, 2007

Science IV

T Tauri – N + S = N + Sa + Sb ≠ Prototype

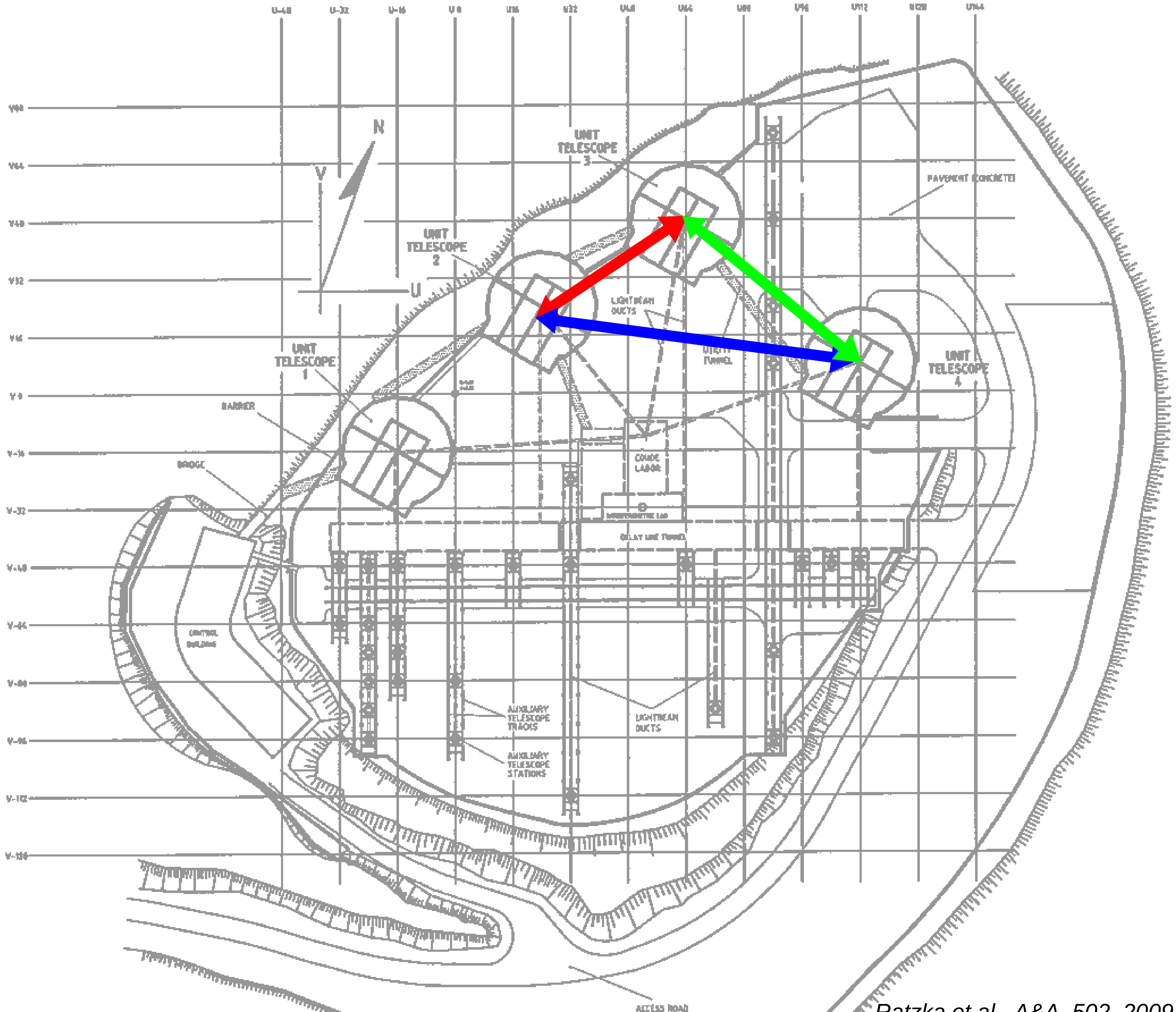
A Non-Prototypical Prototype

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



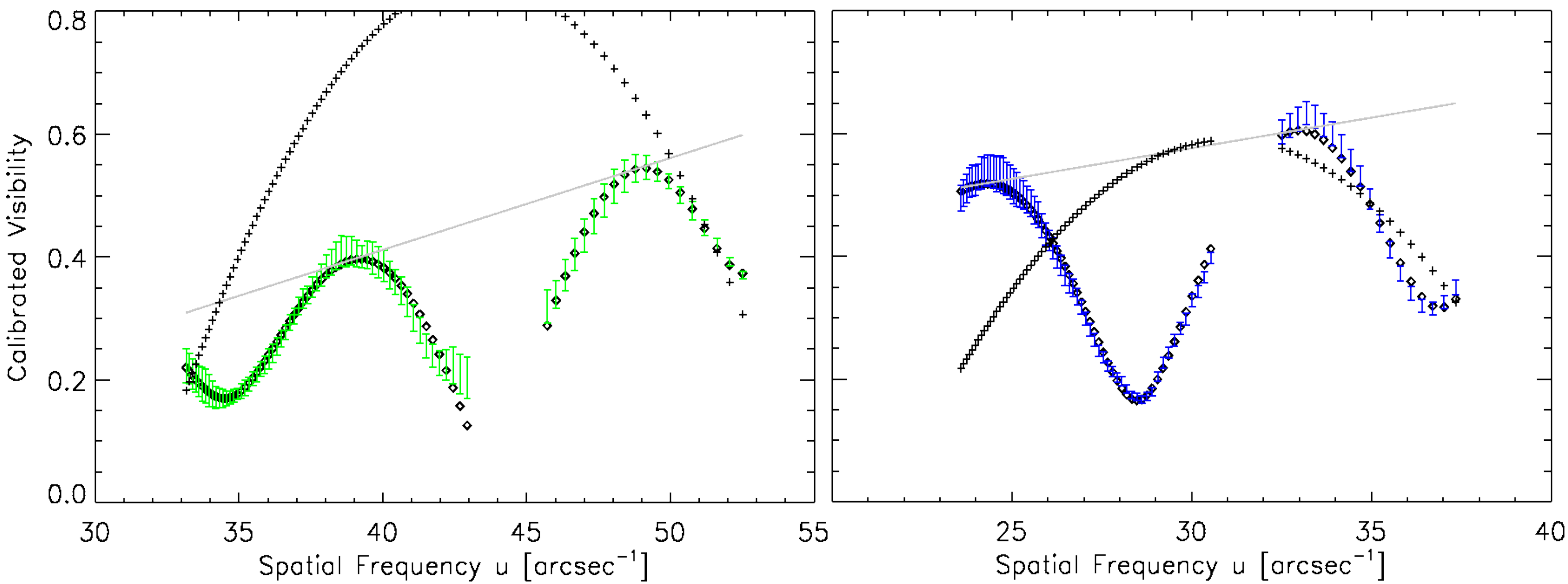
Ratzka et al., A&A, 502, 2009

The Grid



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

The Binary Signal



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

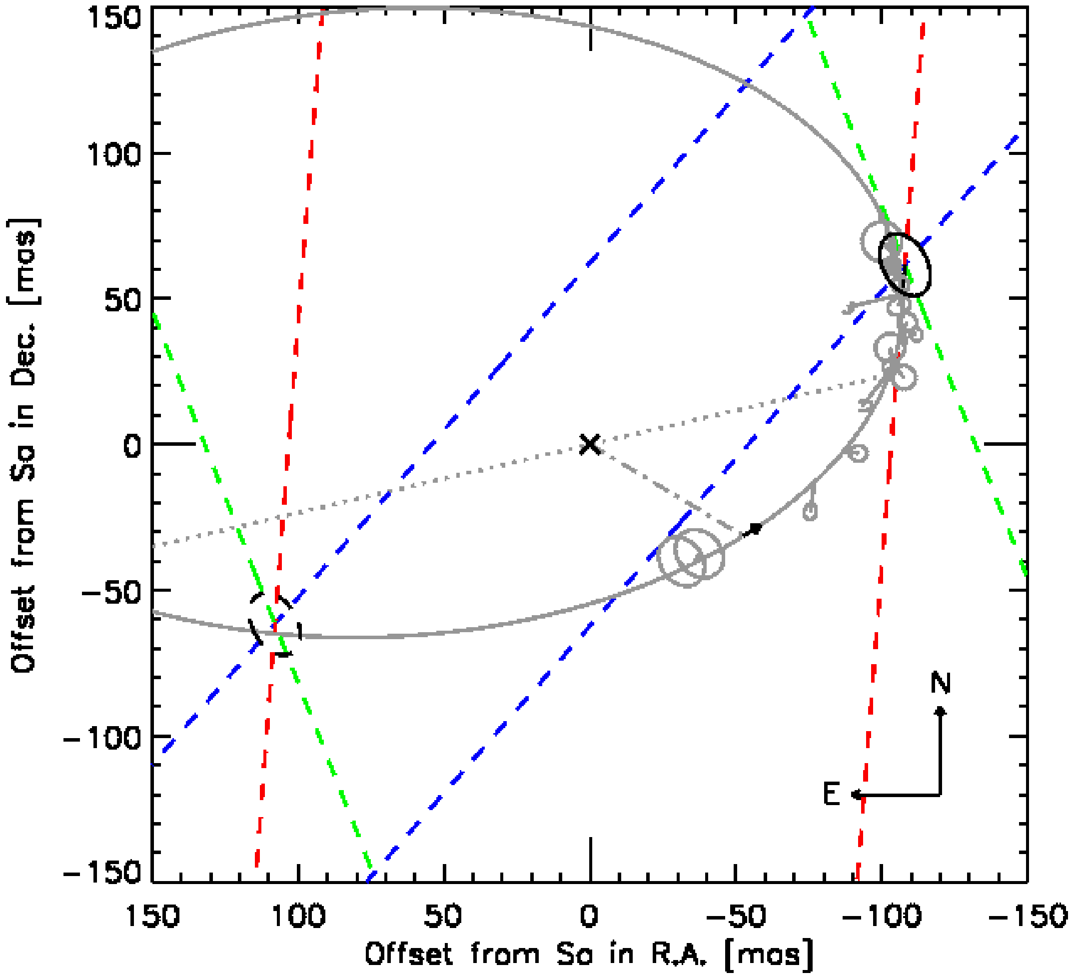
$$s(u) = s_0 + s_1 u$$

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

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

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

The Relative Position of T Tau Sb



s ≈ 103.0 ± 1.2 mas (87.6°)

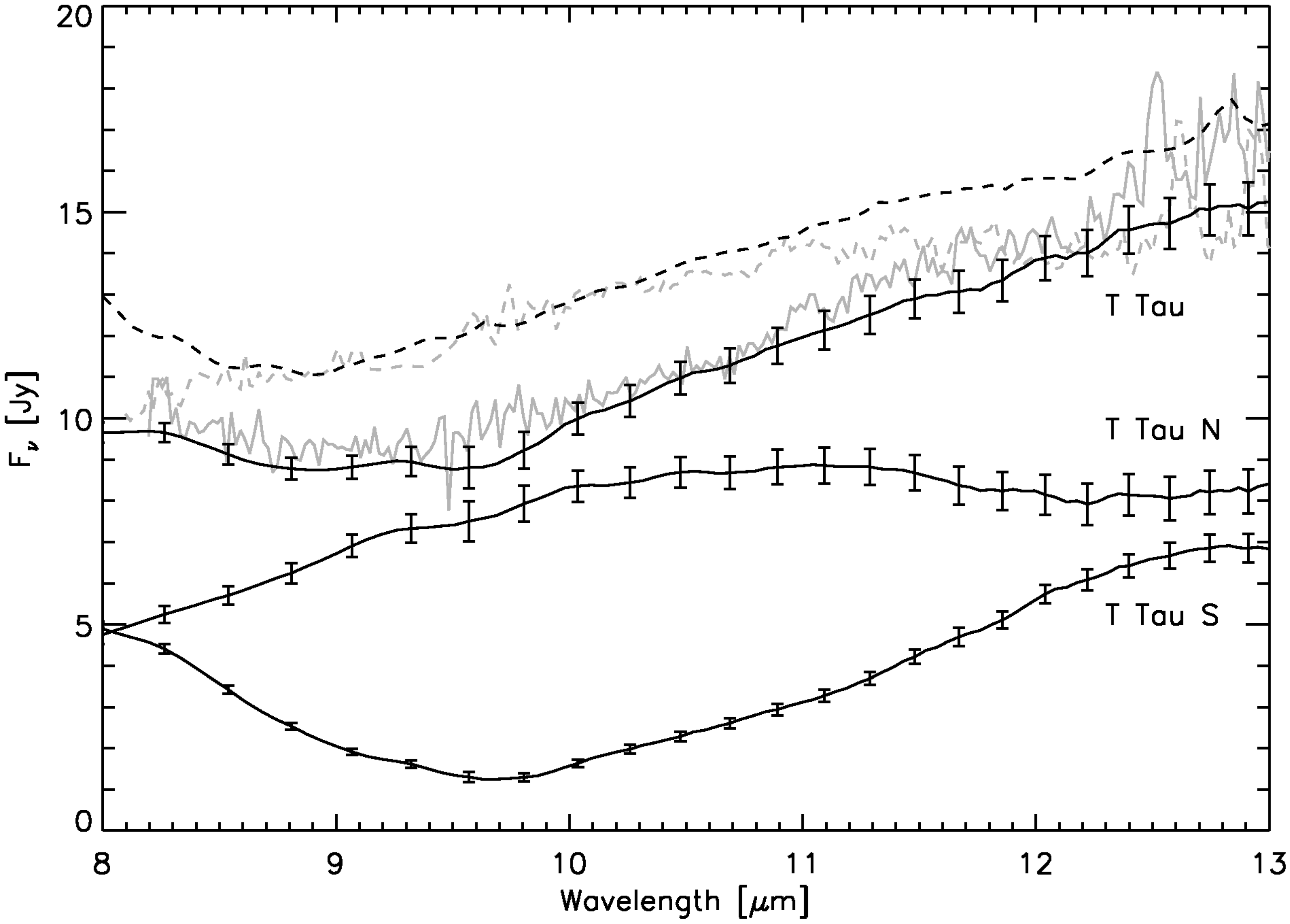
s ≈ 123.0 ± 5.9 mas (111.4°)

⇒ **124.3 ± 7.6 mas @ 299.7 ± 5.3°**

Köhler et al., A&A, 482, 2008

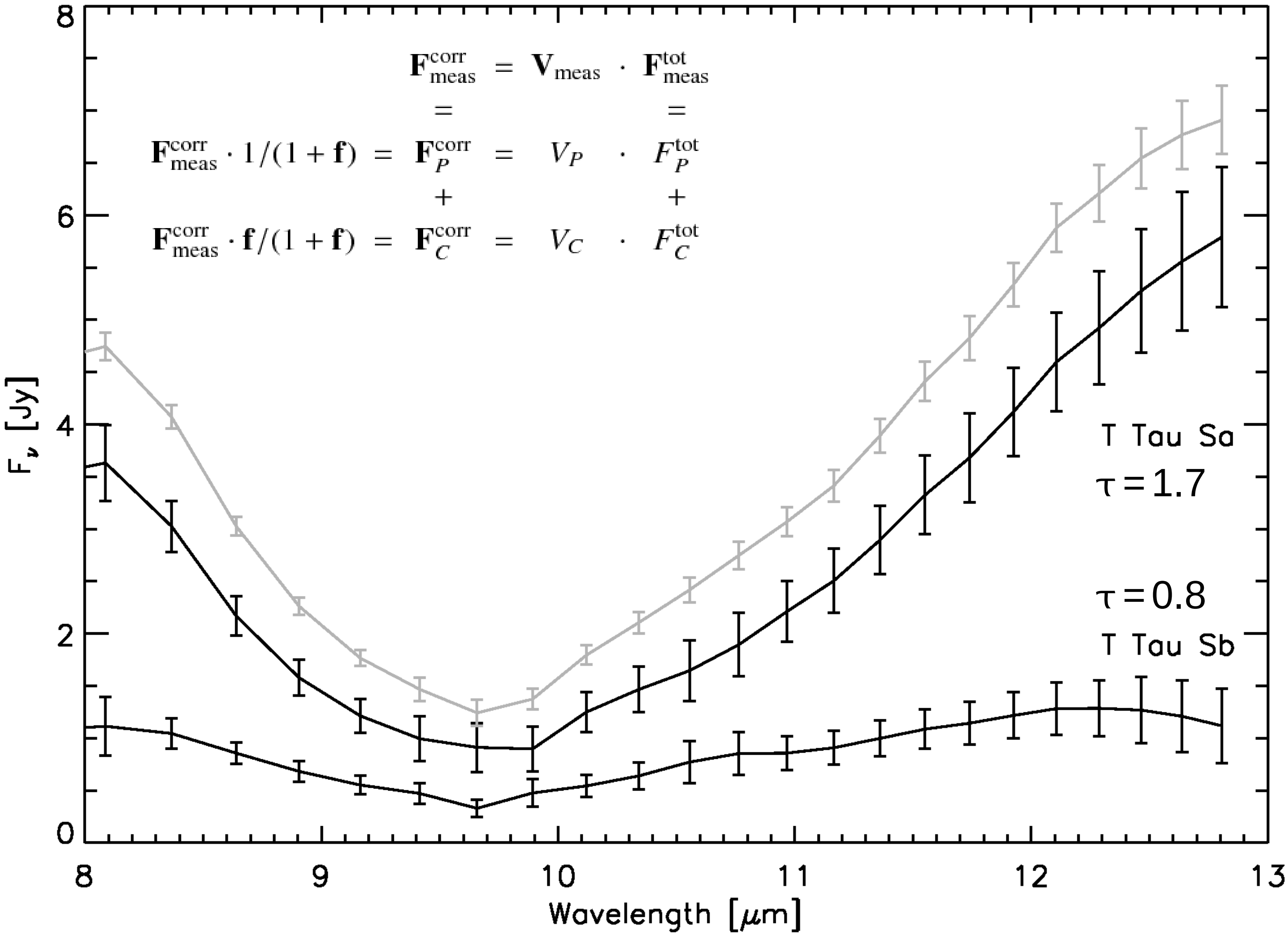
Ratzka et al., A&A, 502, 2009

Separating the Spectra



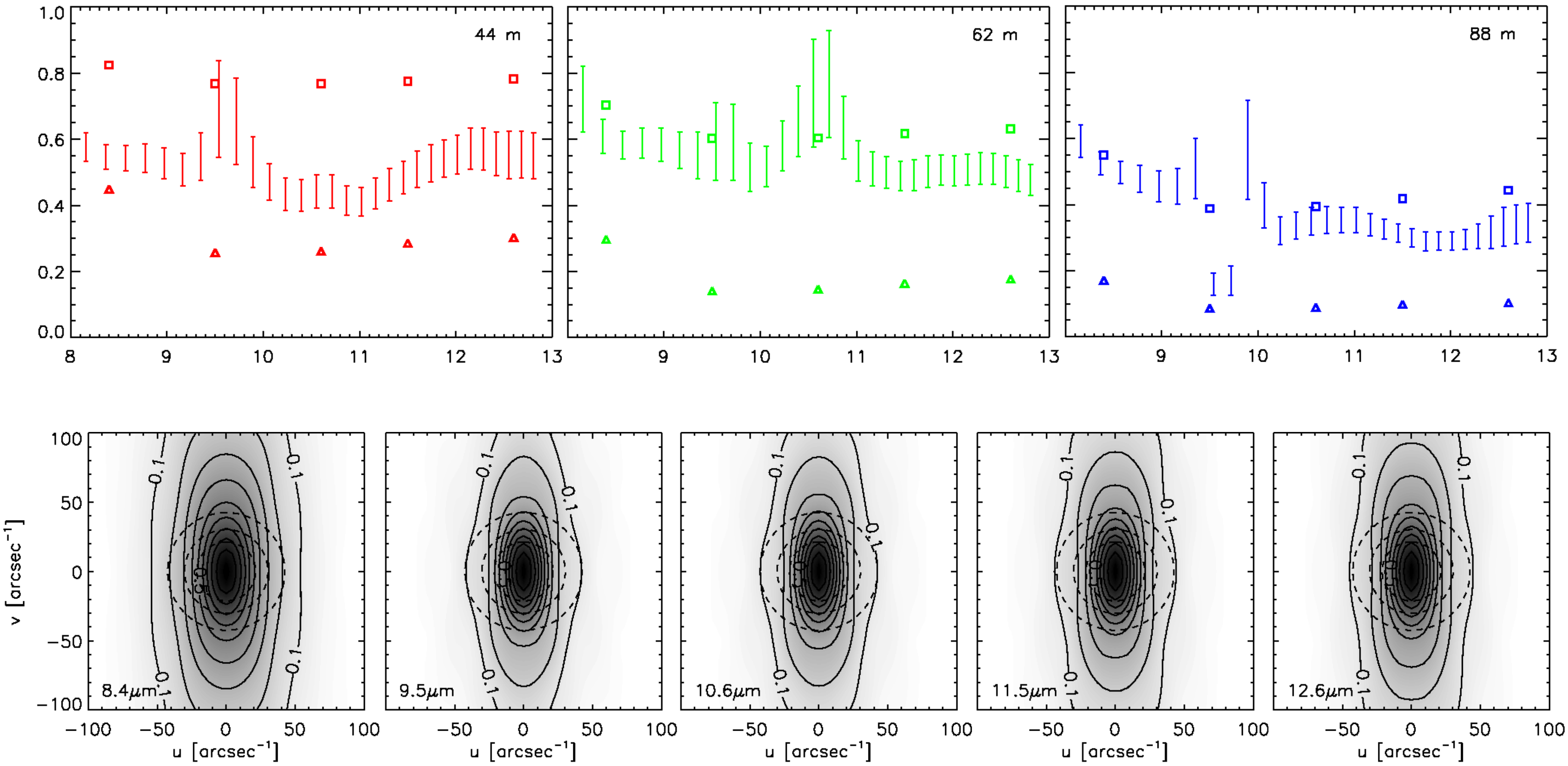
Ratzka et al., A&A, 502, 2009

Separating the Spectra



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

Model for T Tau Sa

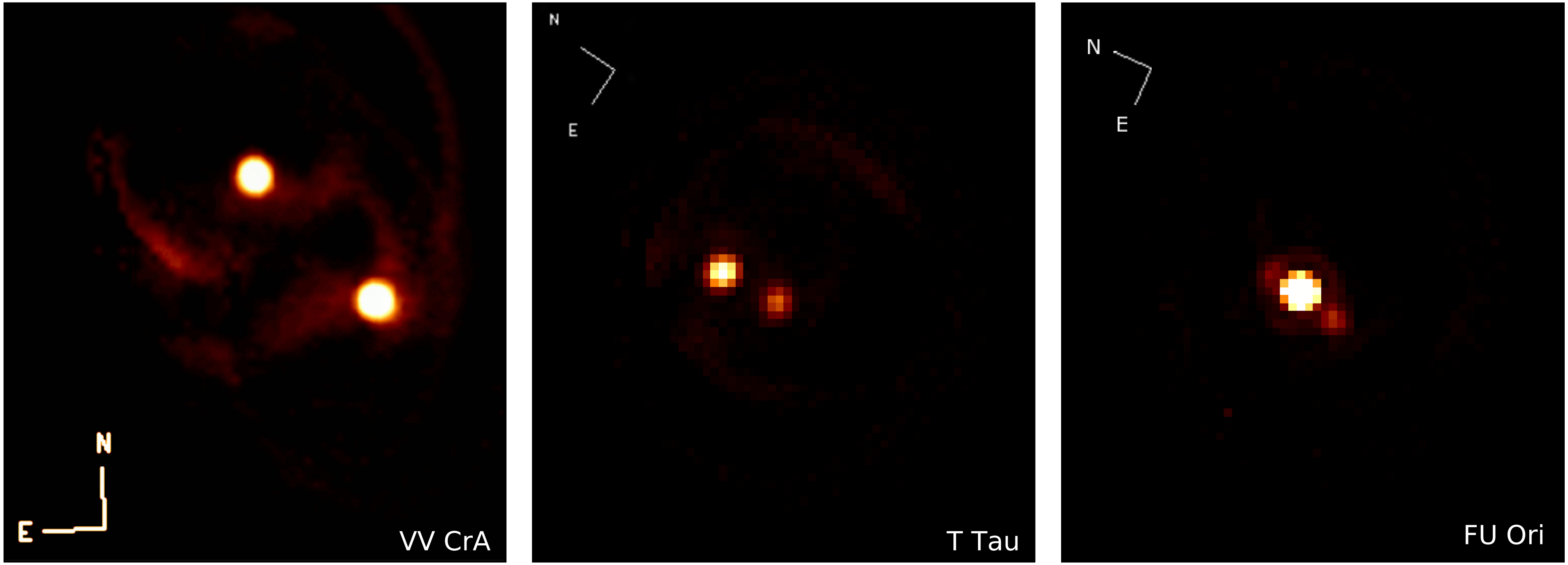


Ratzka et al., A&A, 502, 2009

Science V

Binaries in the Mid-Infrared

“Family Portraits”



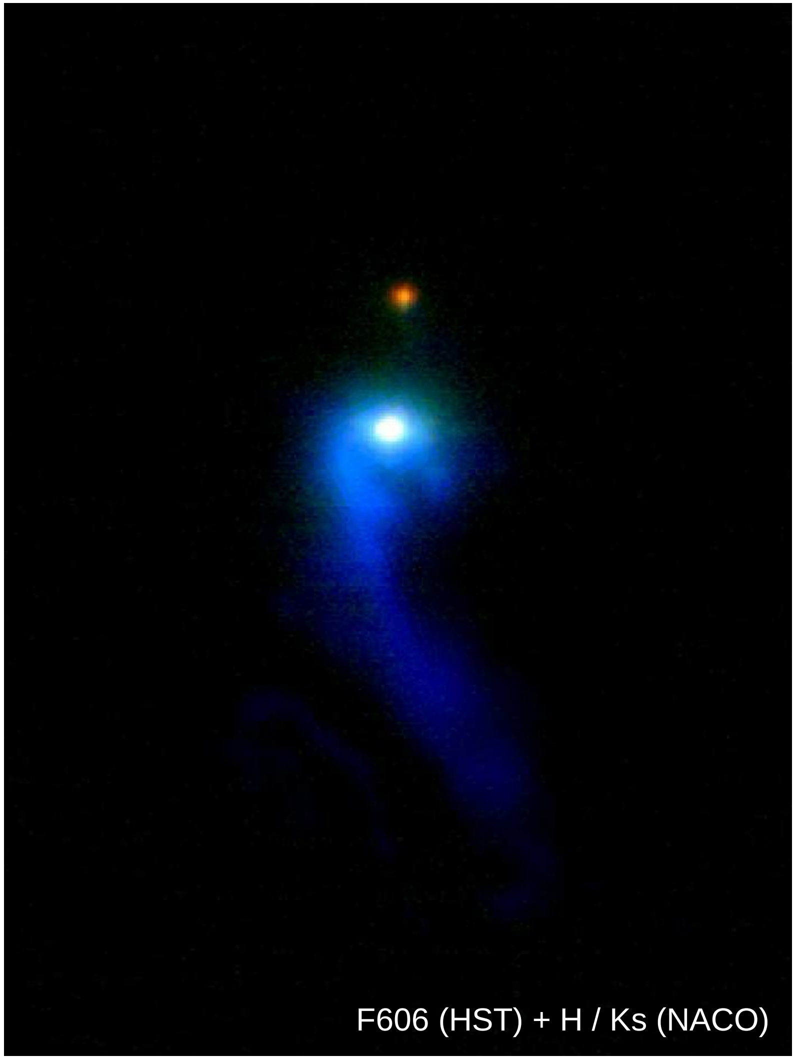
GV Tau – Another Infrared Companion

- binary separated by 1.2“

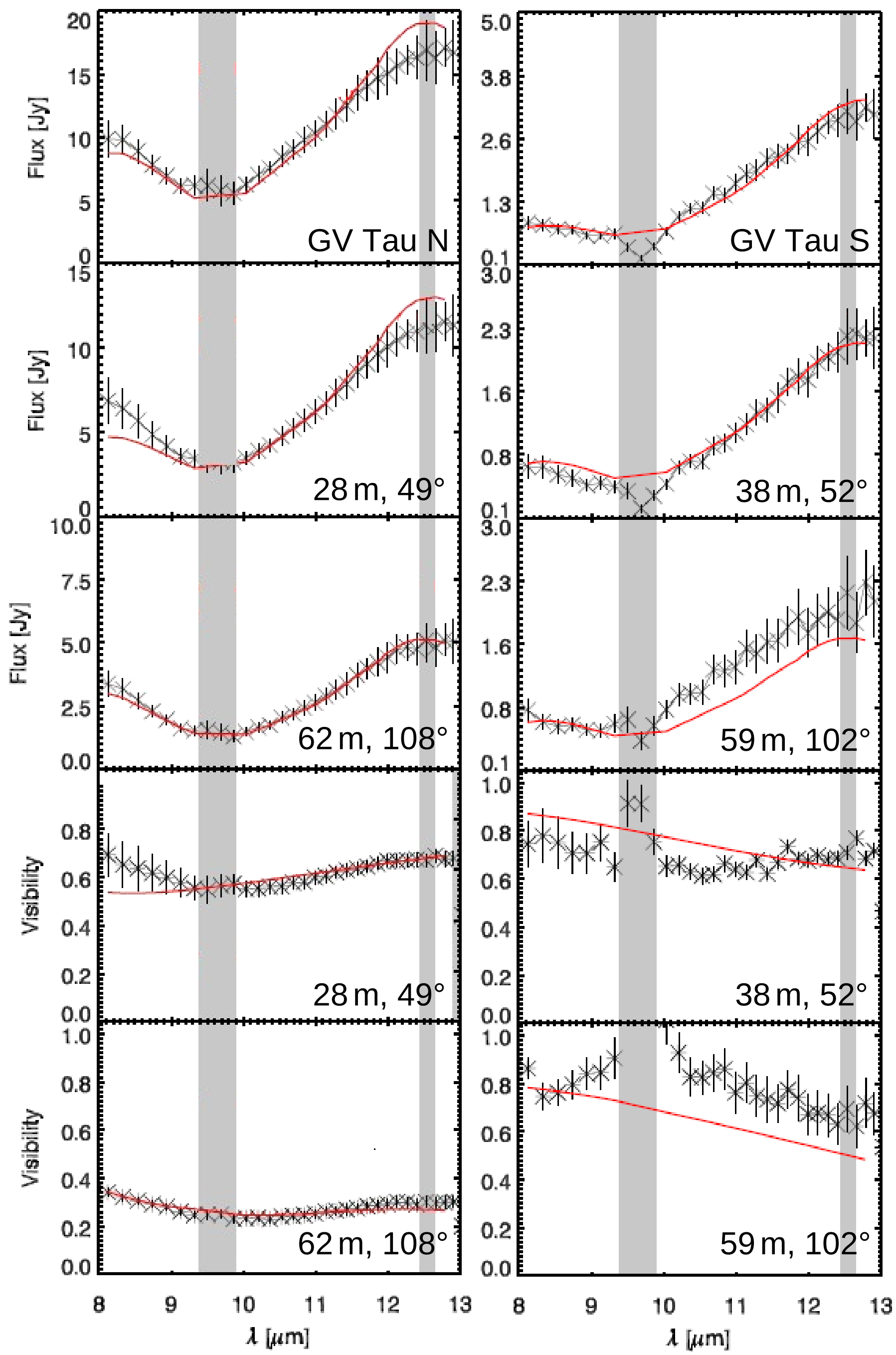
- distance of 140-160 pc

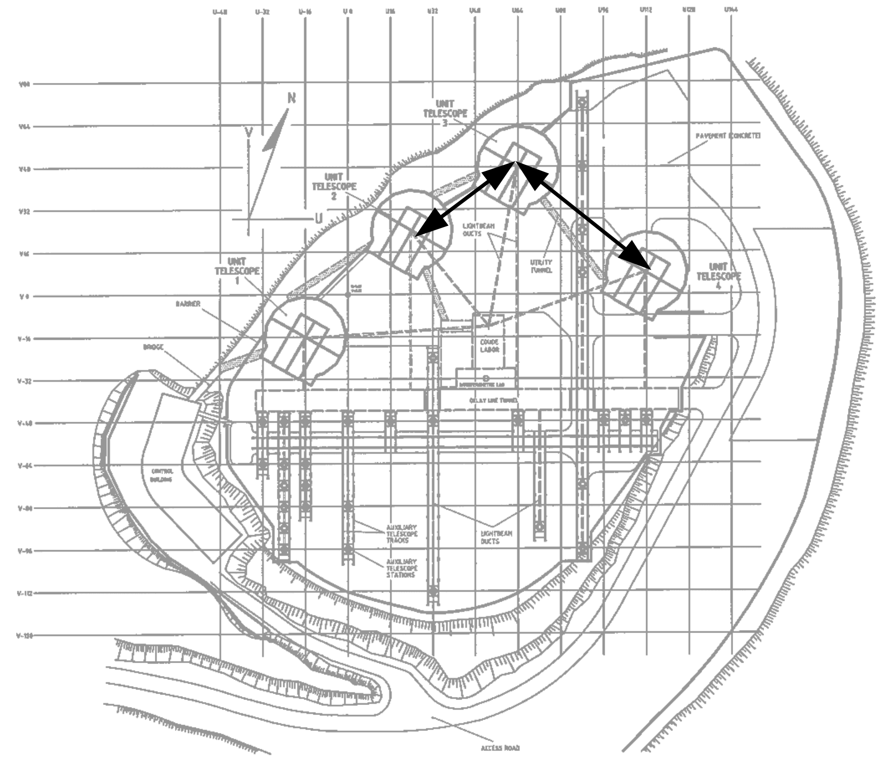
- variable on short timescales due to
  - inhomogeneities in the cir-cumstellar material around the southern component?
  - variable accretion of the northern component?

- presence of a circumbinary enve-lope suggested



Roccatagliata et al., A&A 534, 2011

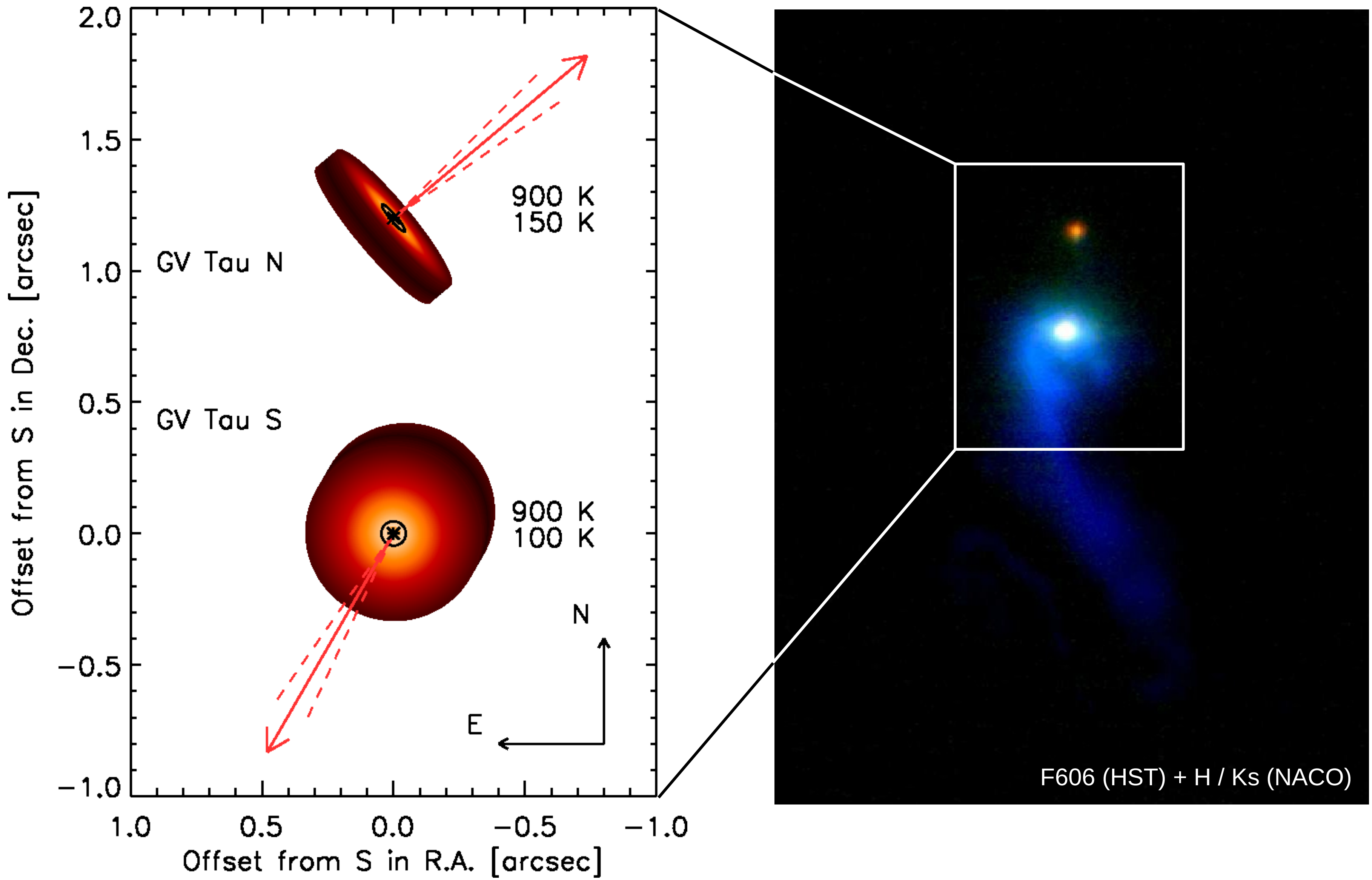




	GV Tau N	GV Tau S
r_1 [AU]	1.5 ± 0.5	1.0 ± 0.5
T_1 [K]	900 ± 100	900 ± 300
r_2 [AU]	10 ± 2	7 ± 3
T_2 [K]	150 ± 50	100 ± 50
i [deg]	**80 ± 10**	**10 ± 5**
PA [deg]	50 ± 20	50 ± 20
A_V [mag]	13 ± 4	19 ± 4

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

GV Tau – Another Infrared Companion



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

SVS 20 – In the Core of Serpens

- binary separated by 1.5"
  (actually a triple system!)

- distance of about 250 AU

SVS 20 N

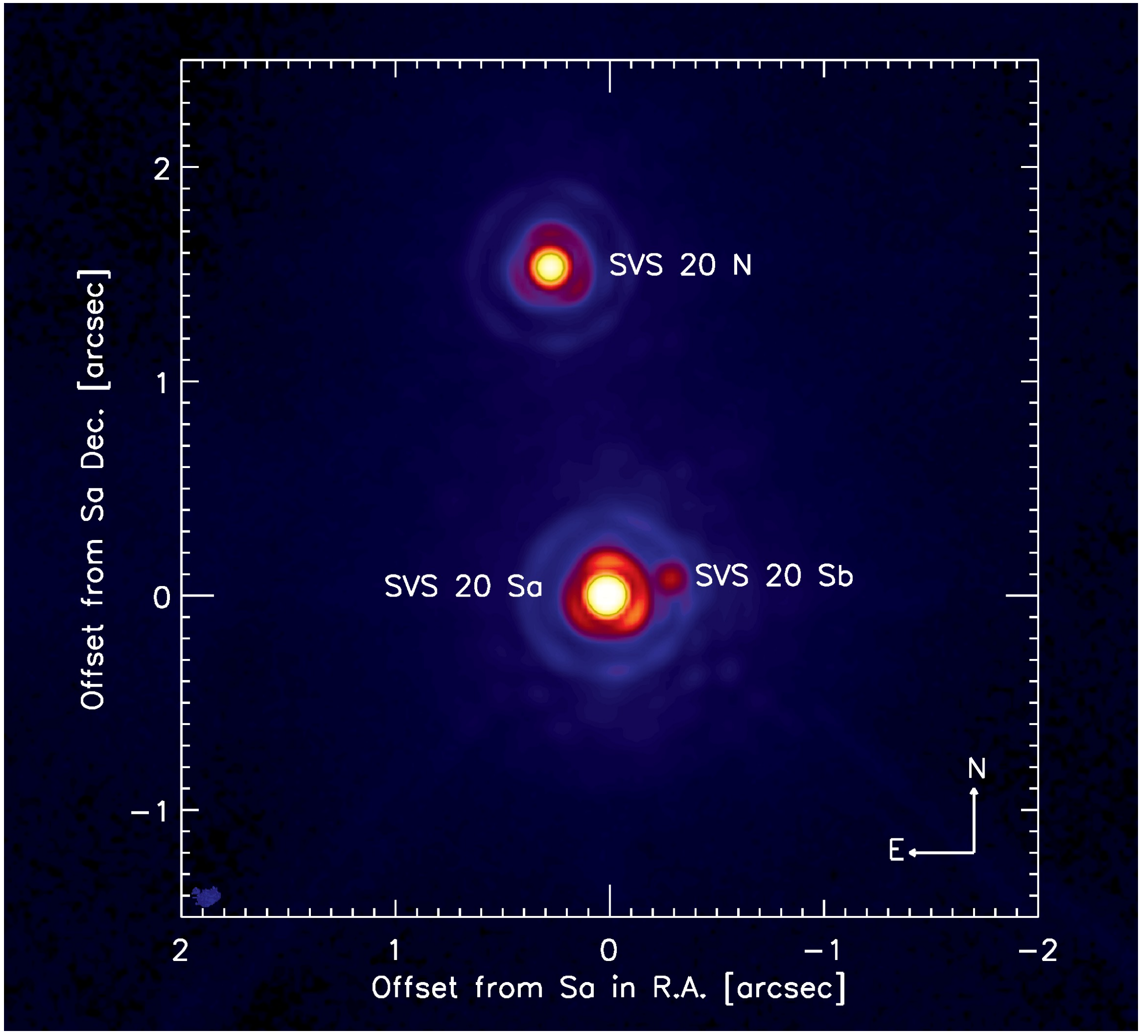
$T = 3300$ K

$L = 0.9\ L_\odot$

SVS 20 S

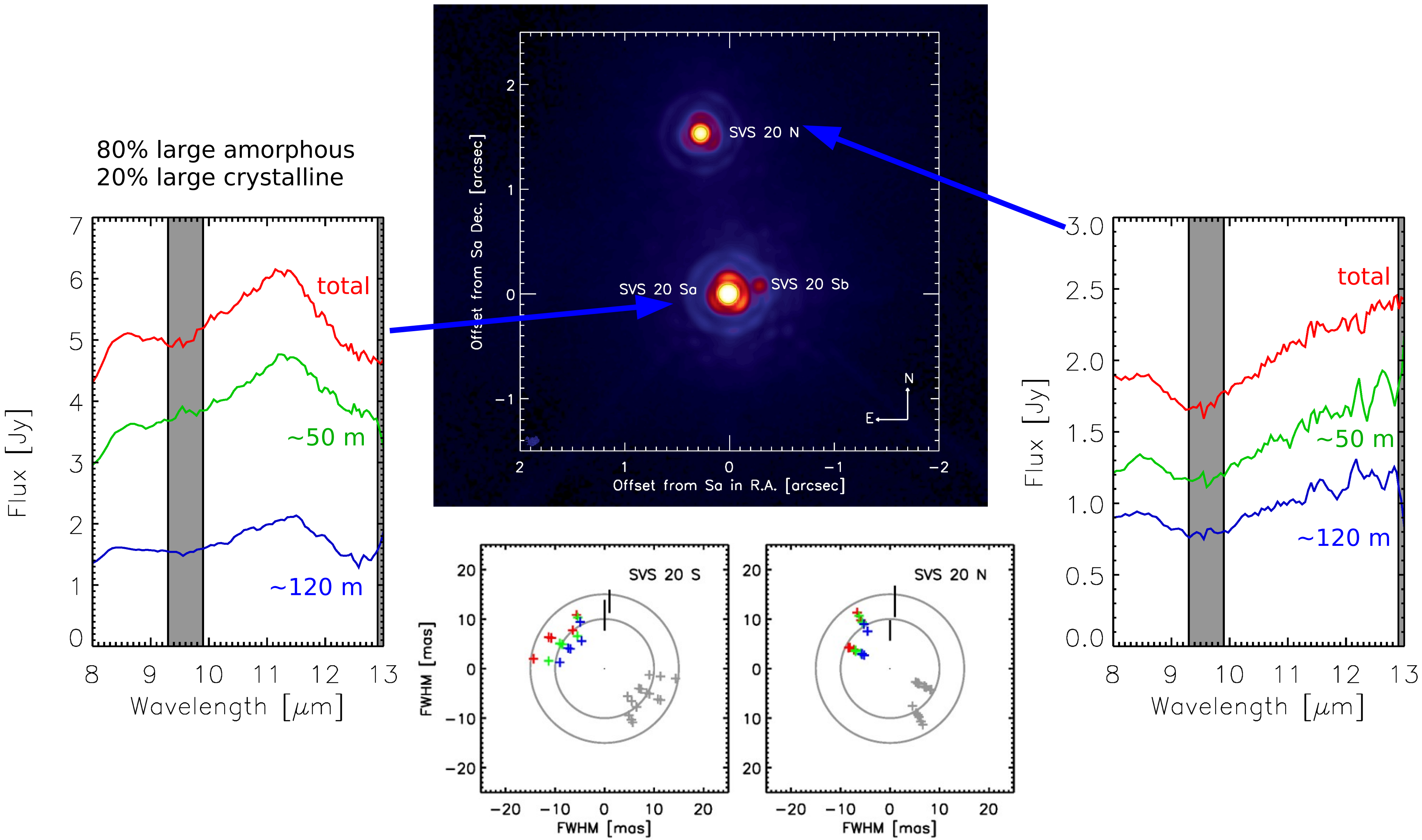
$T = 6000 – 10000$ K

$L = 20 – 80\ L_\odot$



Ratzka et al., A&A, in prep.

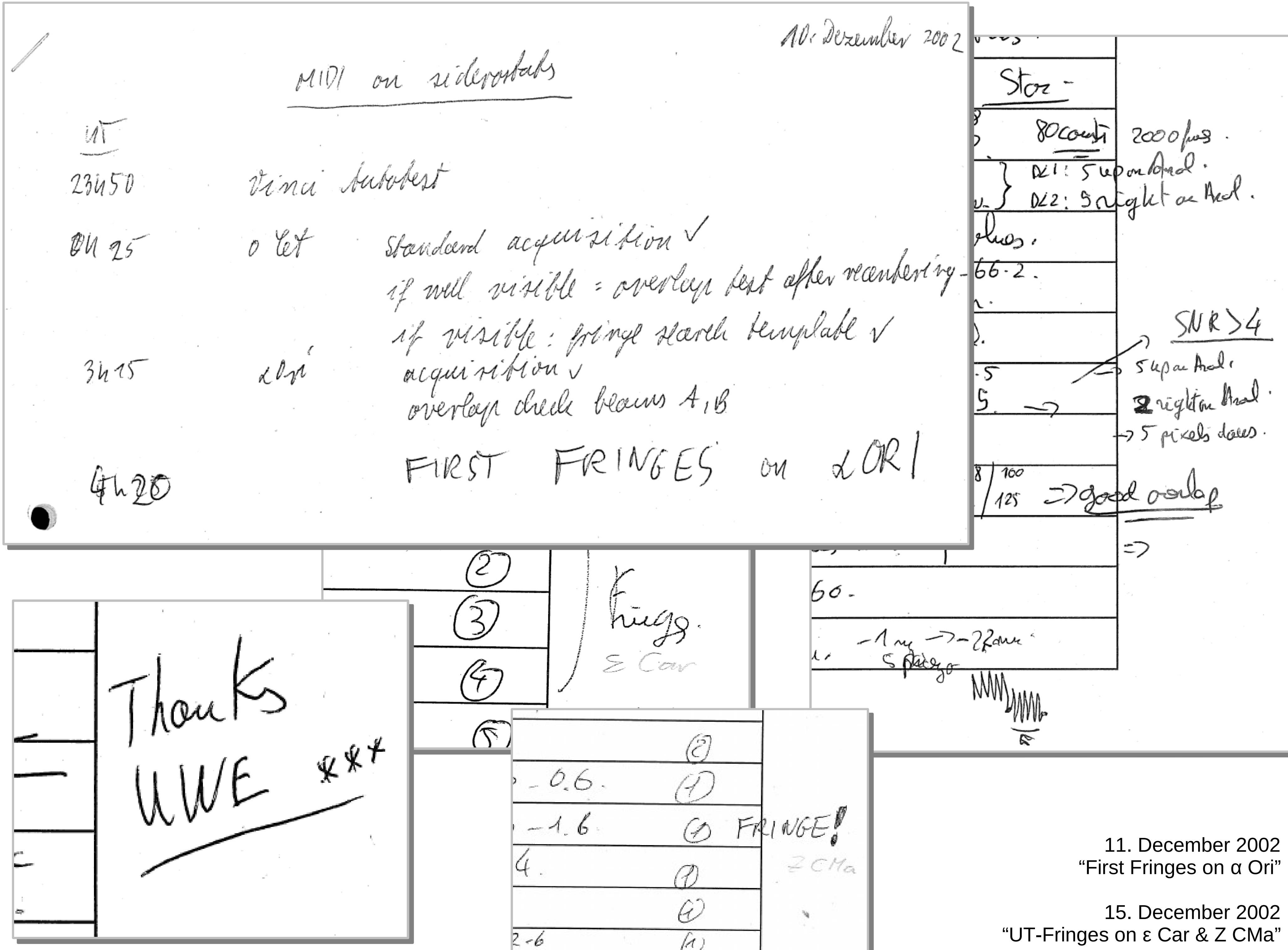
SVS 20 – In the Core of Serpens



Ratzka et al., A&A, in prep.

Epilog

Beyond Science



11. December 2002
“First Fringes on α Ori”

15. December 2002
“UT-Fringes on ε Car & Z CMa”

Epilog

Beyond Science