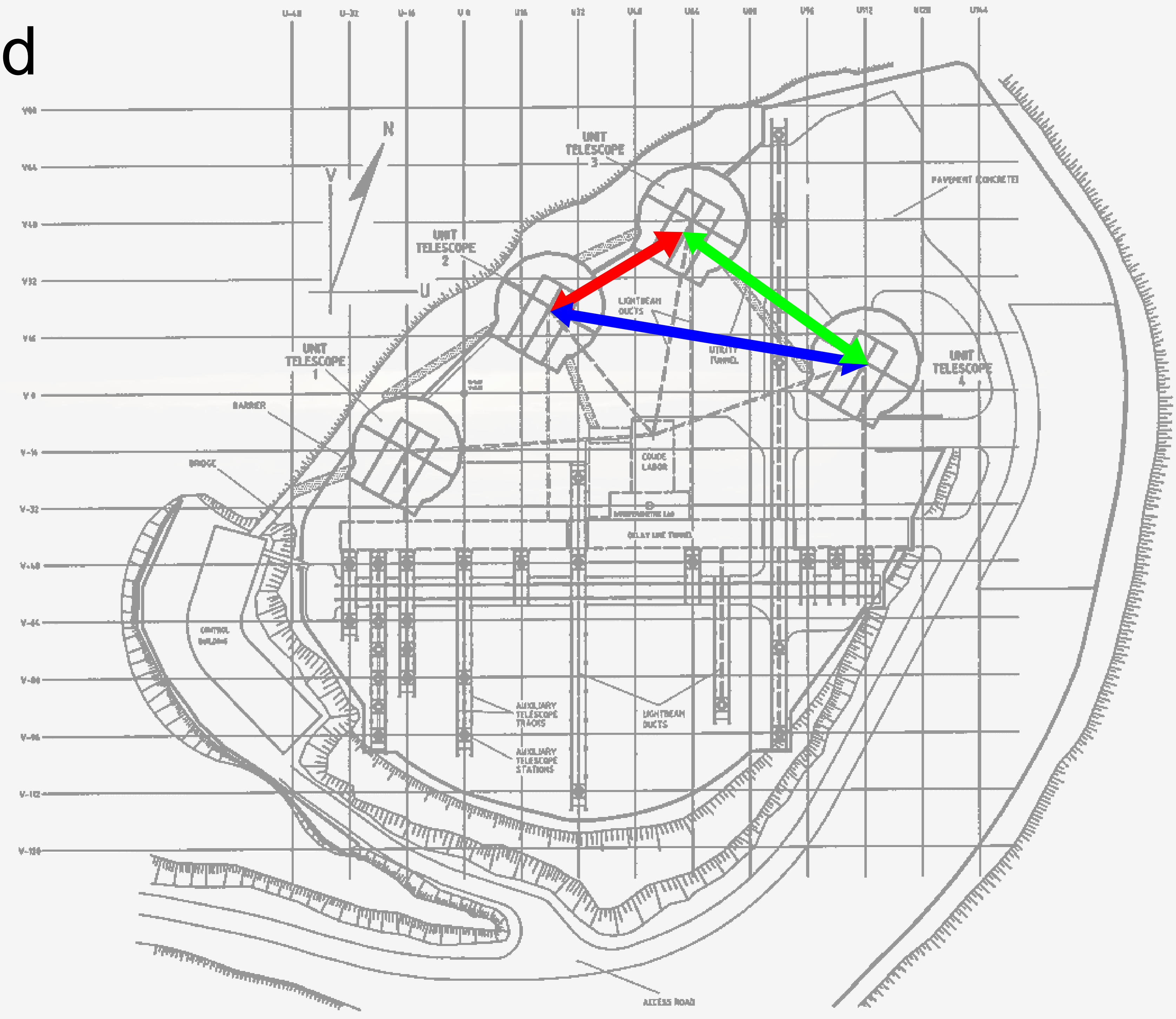
MIDI's view on circumstellar discs around young, solar-mass stars

Thorsten Ratzka (Universitäts-Sternwarte München)
»The Origin and Fate of the Sun: Evolution of Solar-mass Stars Observed with High Angular Resolution«
ESO-Workshop, 2.-5. May 2010, Garching

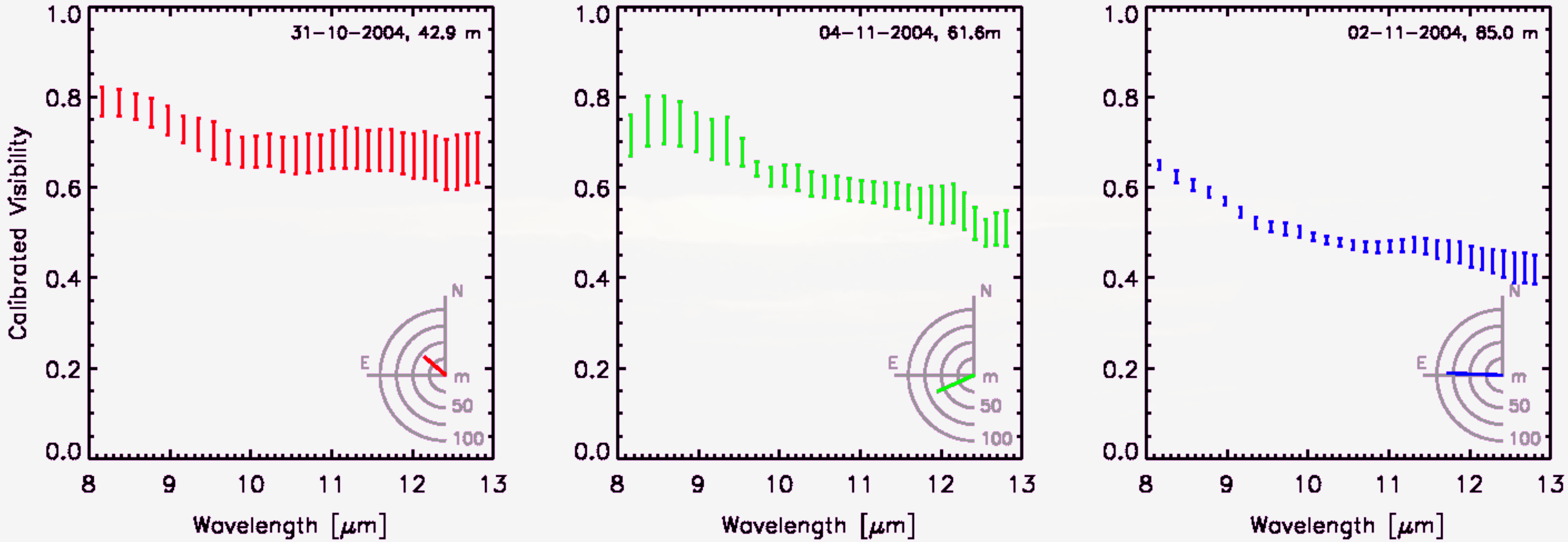
T Tau – A prototypical star

- prototype for low-mass pre-main-sequence stars
- variable source
- still surrounded by an accretion disc and thus exhibiting a large infrared excess
- number of nebulous patches detected in the vicinity
- distance of ~140 pc

The Grid


N
V
U
UNIT TELESCOPE 3
UNIT TELESCOPE 2
UNIT TELESCOPE 1
UNIT TELESCOPE 4
PAVEMENT (CONCRETE)
LIGHTBEAM DUCTS
UTILITY TUNNEL
BARRIER
BRIDGE
COUDE LABOR
AUXILIARY TELESCOPE TRACKS
AUXILIARY TELESCOPE STATIONS
LIGHTBEAM DUCTS
ACCESS ROAD

The Visibilities



- the visibilties decrease with wavelength
- the visibilities decreases with the projected length of the baseline
- the „length-corrected“ visibilties are almost independent of the position angle

⇒ face-on circumstellar disc

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

Modelling with MC3D

I. disk with two layers:

$$\rho_{\text{disk}}(r,z) = \rho_0 \left(\frac{R_\star}{r}\right)^{3\left(\beta-\frac{1}{2}\right)} \exp\left(-\frac{1}{2}\left[\frac{z}{h(r)}\right]\right)$$

$$h(r) = h_{100}\left(\frac{r}{100\,\text{AU}}\right)^{\beta}$$

II. envelope:

$$\rho_{\text{env}}(\boldsymbol{r}) = c_1 \cdot \rho_{\text{disk}}(R_{\text{in}}) \cdot \left(\frac{|\boldsymbol{r}|}{R_{\text{in}}}\right)^{c_2}$$

with $c_1 \ll 1$ and $c_2 < 0$

$$\rho_{\text{env}}(\boldsymbol{r}) = \begin{cases} \rho_{\text{disk}}(\boldsymbol{r}) & \text{for } \rho_{\text{env}}(\boldsymbol{r}) \lesssim \rho_{\text{disk}}(\boldsymbol{r}) \\ \rho_{\text{env}}(\boldsymbol{r}) & \text{for } \rho_{\text{env}}(\boldsymbol{r}) > \rho_{\text{disk}}(\boldsymbol{r}) \end{cases}$$

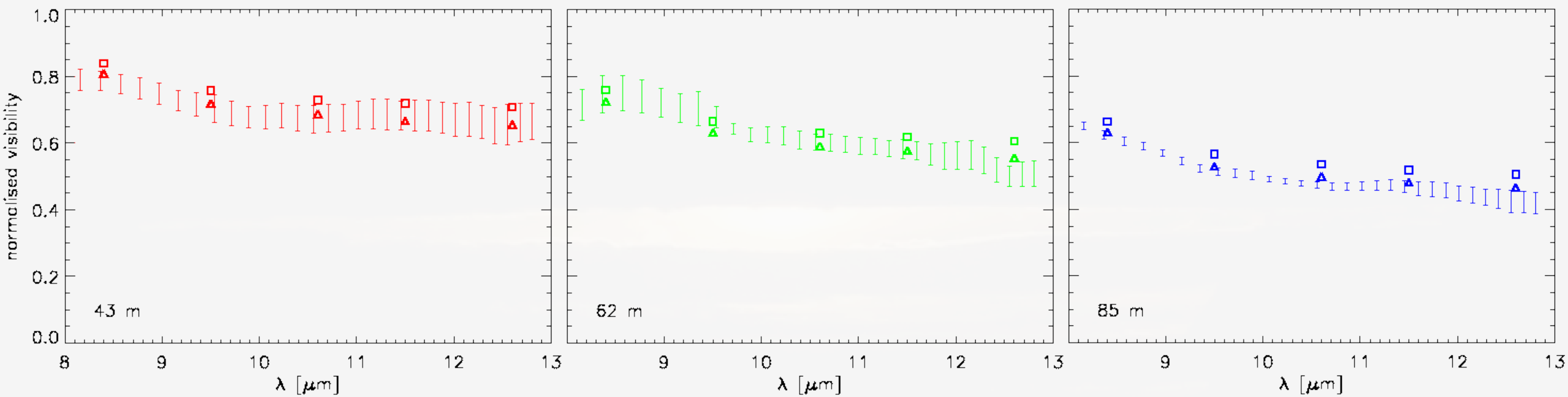
(prevents illumination/heating of outer disk regions
→ increase of IR flux in the SED and an additional increase of MIR visibilities)

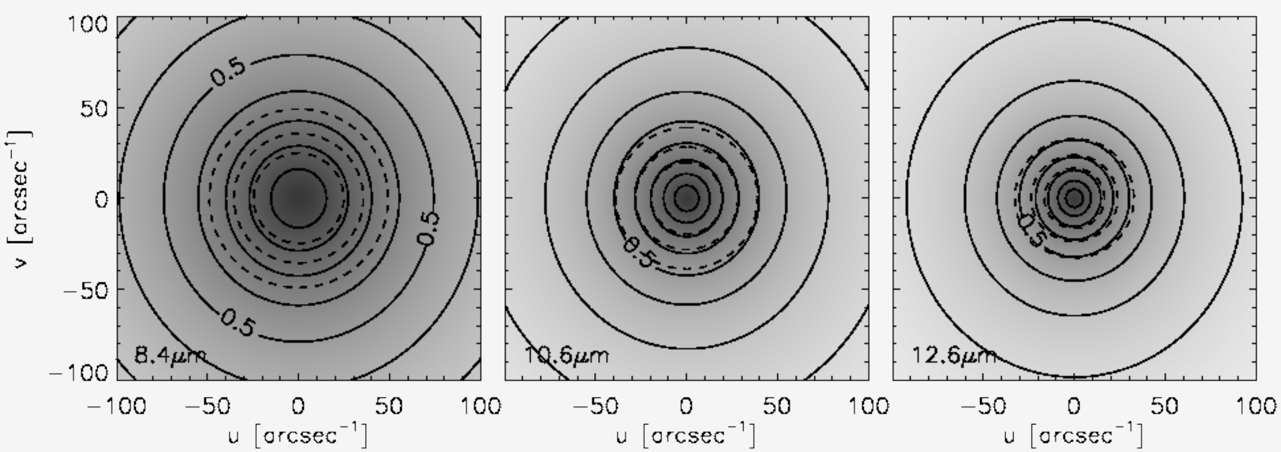
III. accretion

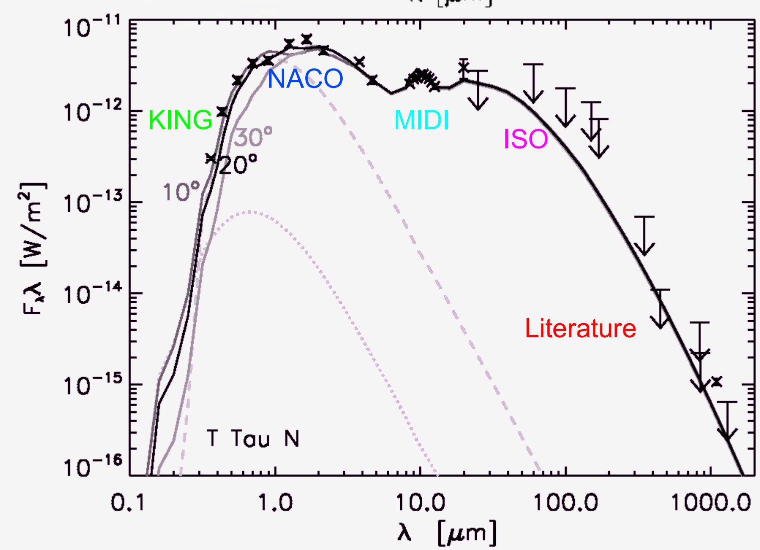
(production of IR flux in the innermost region
→ increase of NIR/MIR visibilities)

Schegerer et al., A&A, 479, 2008

Radiative transfer model for T Tau

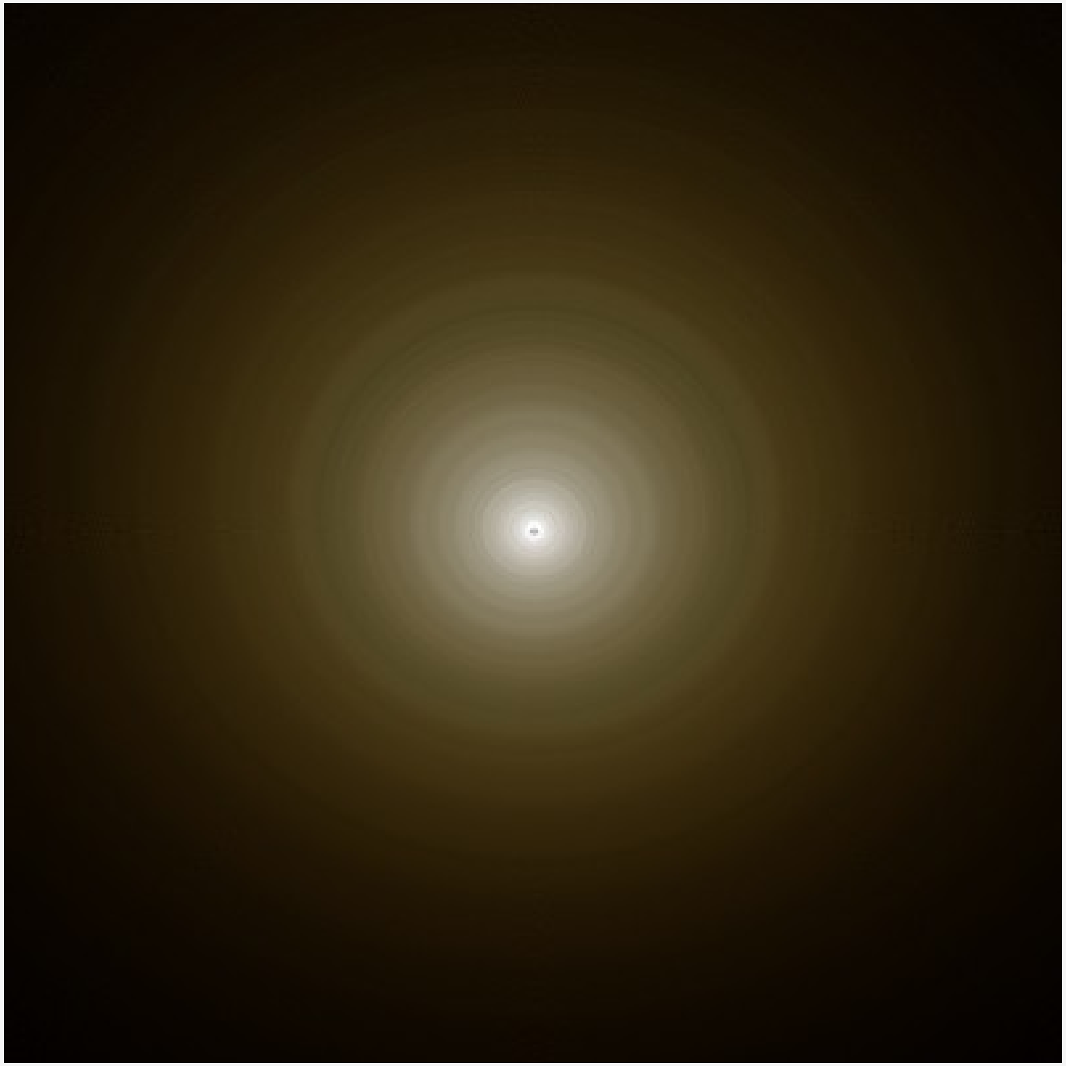






✔ model is also in agreement with the near-infrared PTI data (Akeson et al., 2000)

How does T Tau look?



80 AU

star

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

disk

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

envelope

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

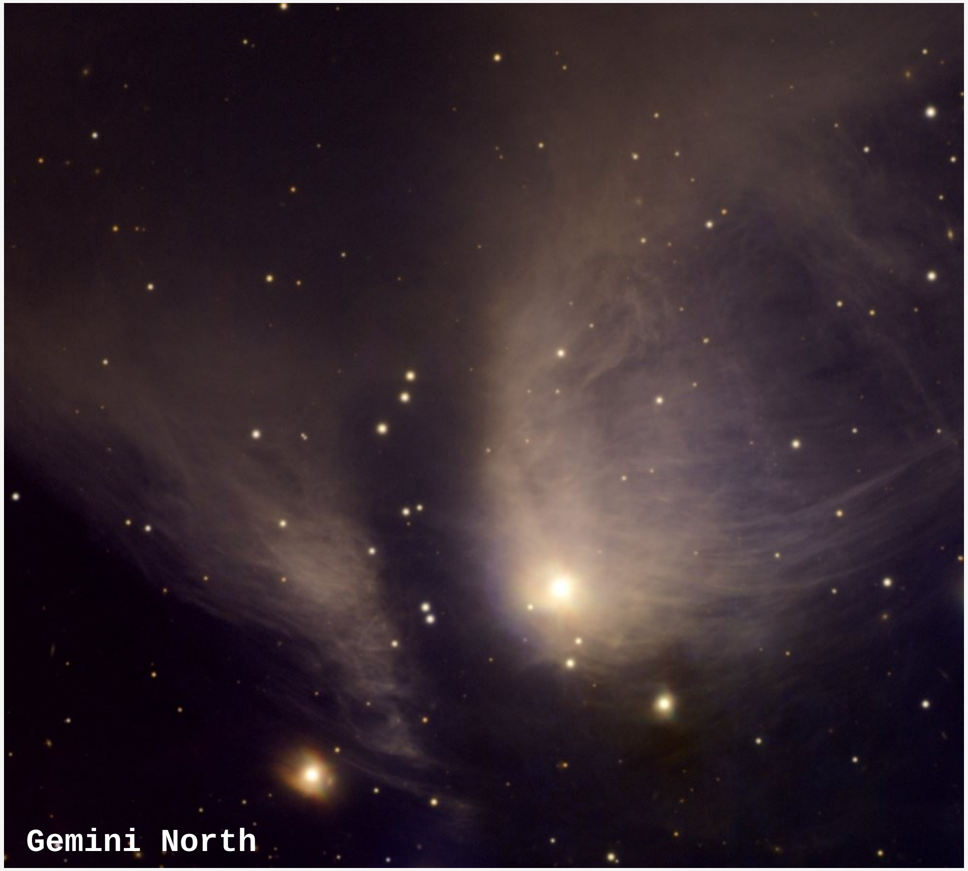
accretion

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

extinction (foreground)

- $A_V = 1.5\,mag$

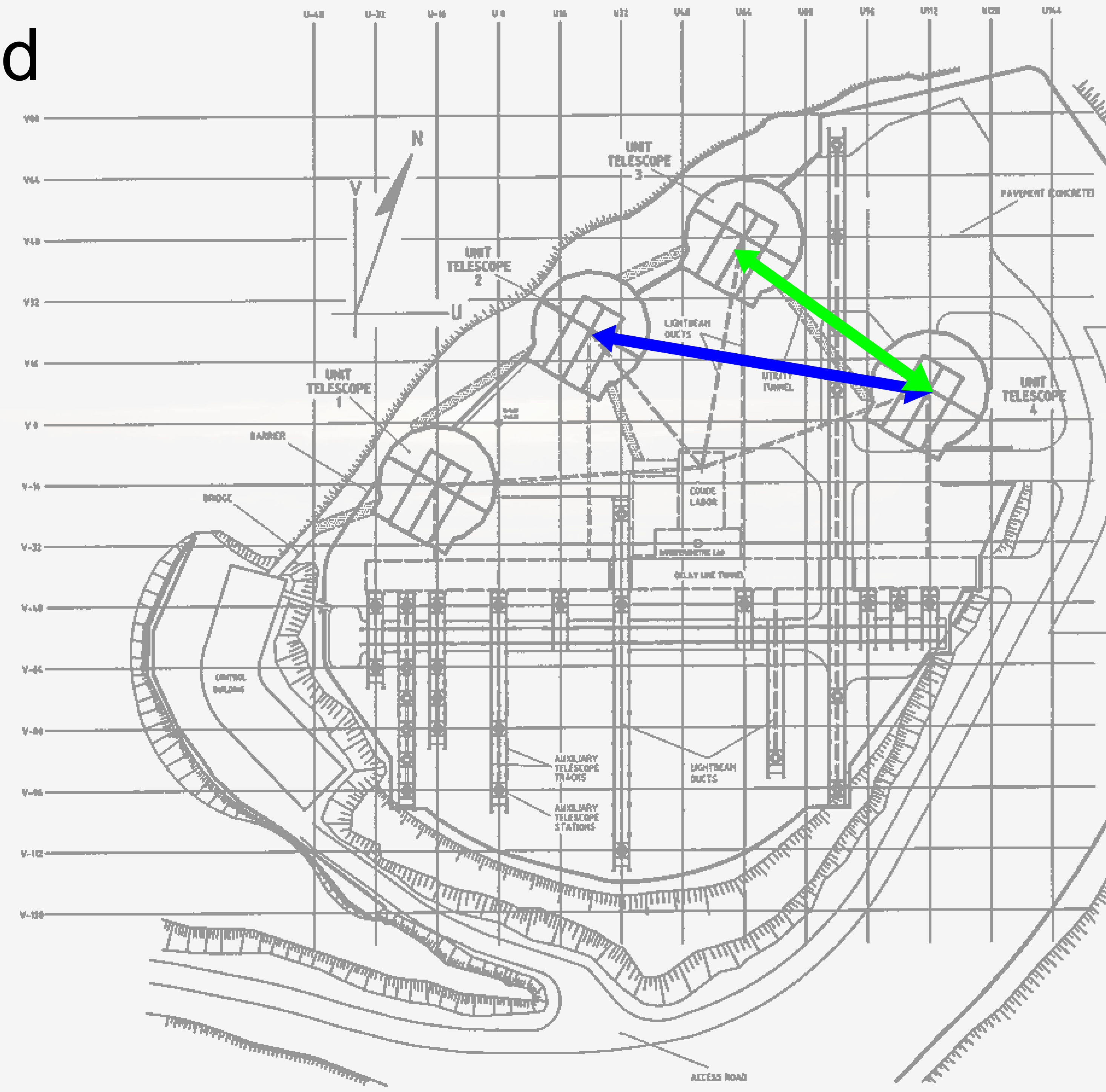
RY Tau – A case study



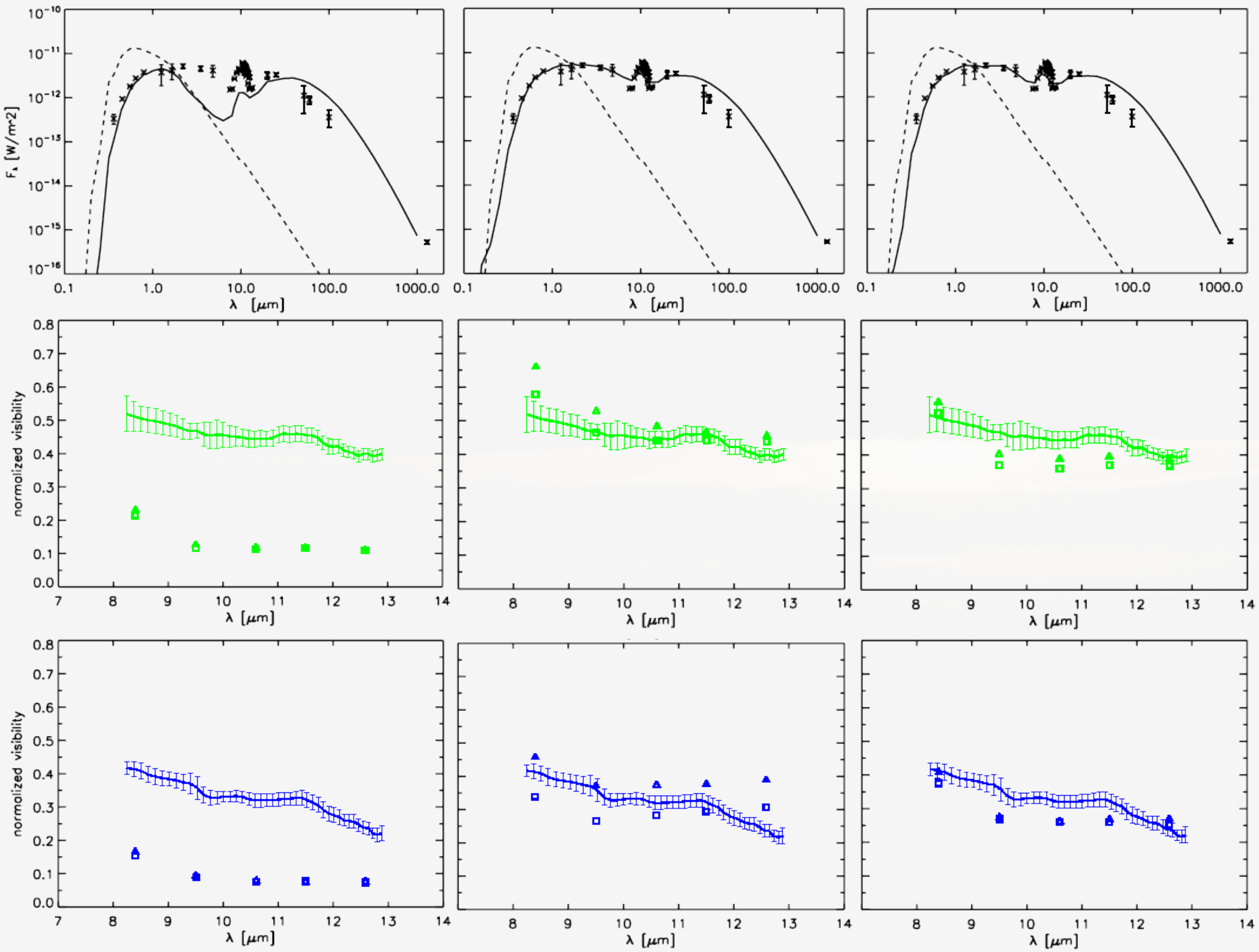
- classical T Tauri star
- UX Ori-type variable
- distance of ~140 pc
- age of 6.5±0.9 Myr
- F8III (T~5560 K, 1.7 $M_\odot$)
- actively accreting at a rate of $7.8 \times 10^{-8} M_\odot$/yr

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

The Grid

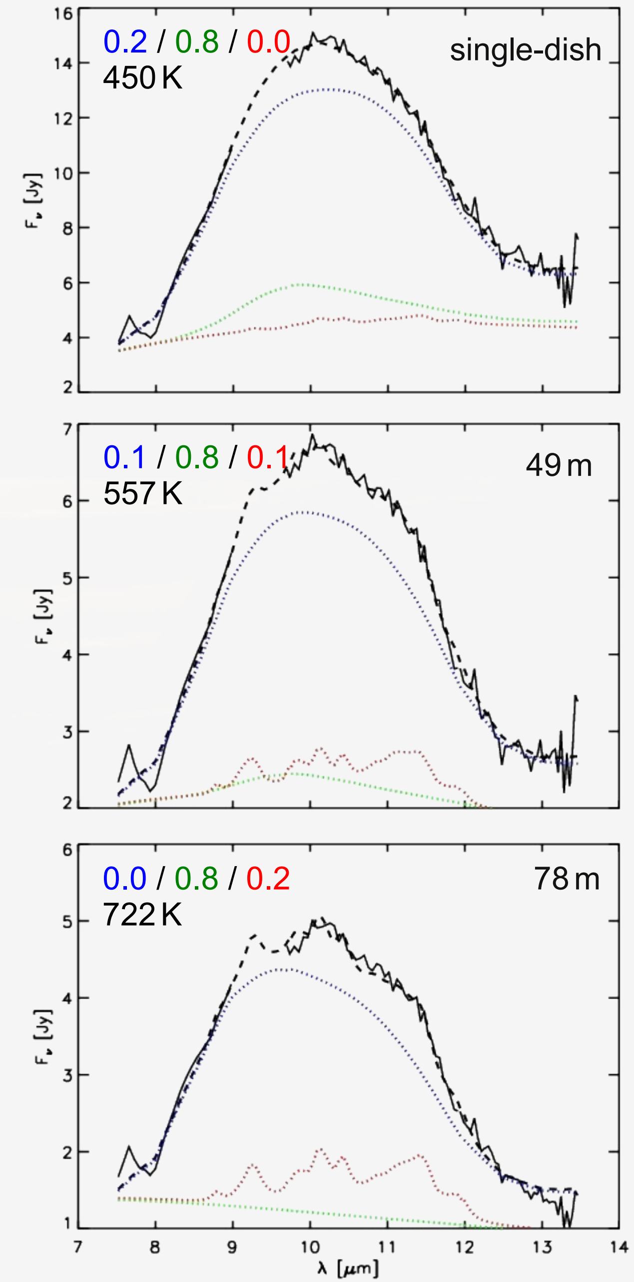

UNIT TELESCOPE 3
UNIT TELESCOPE 2
UNIT TELESCOPE 1
UNIT TELESCOPE 4
N
V
U
PAVEMENT (CONCRETE)
LIGHTBEAM DUCTS
UTILITY TUNNEL
BARRIER
BRIDGE
COUDE LABOR
DELAY LINE TUNNEL
CONTROL BUILDING
AUXILIARY TELESCOPE TRACKS
AUXILIARY TELESCOPE STATIONS
LIGHTBEAM DUCTS
ACCESS ROAD

passive disc	active disc withouth envelope	active disc with envelope



passive disc	active disc withouth envelope	active disc with envelope
$L_* = 10\,L_\odot$	$L_* = 10\,L_\odot$	$L_* = 10\,L_\odot$
$A_V = 2.2$ mag	$A_V = 2.2$ mag	$A_V = 2.2$ mag
$M_d = 0.02\,M_\odot$	$M_d = 0.004\,M_\odot$	$M_d = 0.004\,M_\odot$
$r_d = 0.3 \ldots 270$ AU	$r_d = 0.3 \ldots 270$ AU	$r_d = 0.3 \ldots 270$ AU
$p = 1.3$, $i \leq 70°$	$p = 1.3$, $i \leq 70°$	$p = 1.3$, $i \leq 65°$
–	$dM/dt = 9.1\cdot10^{-8}\ M_\odot yr^{-1}$	$dM/dt = 2.5\cdot10^{-8}\ M_\odot yr^{-1}$
–	–	$c_1 = 5\cdot10^{-5}$, $c_2 = -1.0$

primordial dust (< 1.5 µm), larger grains (> 1.5 µm), crystalline dust



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

Dust species and properties

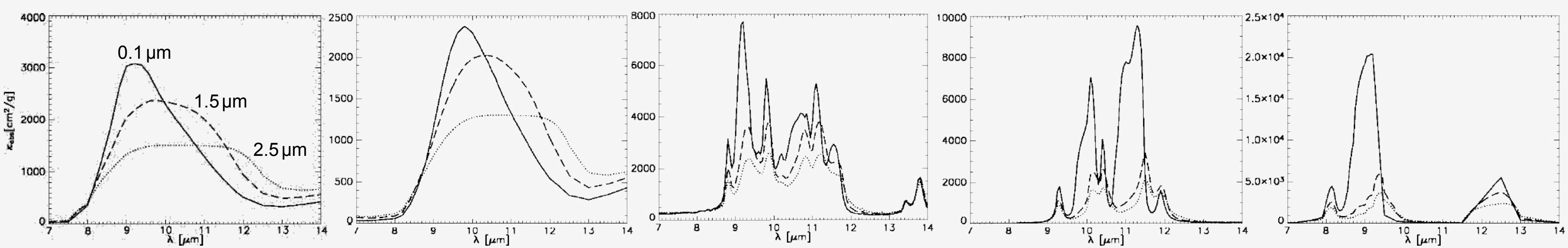
Pyroxene Group	**Olivine Group**	**Enstatite**	**Forsterite**	**Quartz**
$Mg_nFe_{n-1}Si_2O_6$	$Mg_nFe_{n-1}SiO_4$	$Mg_2Si_2O_6$	Mg_2SiO_4	SiO_2

← SiO_2

amorph

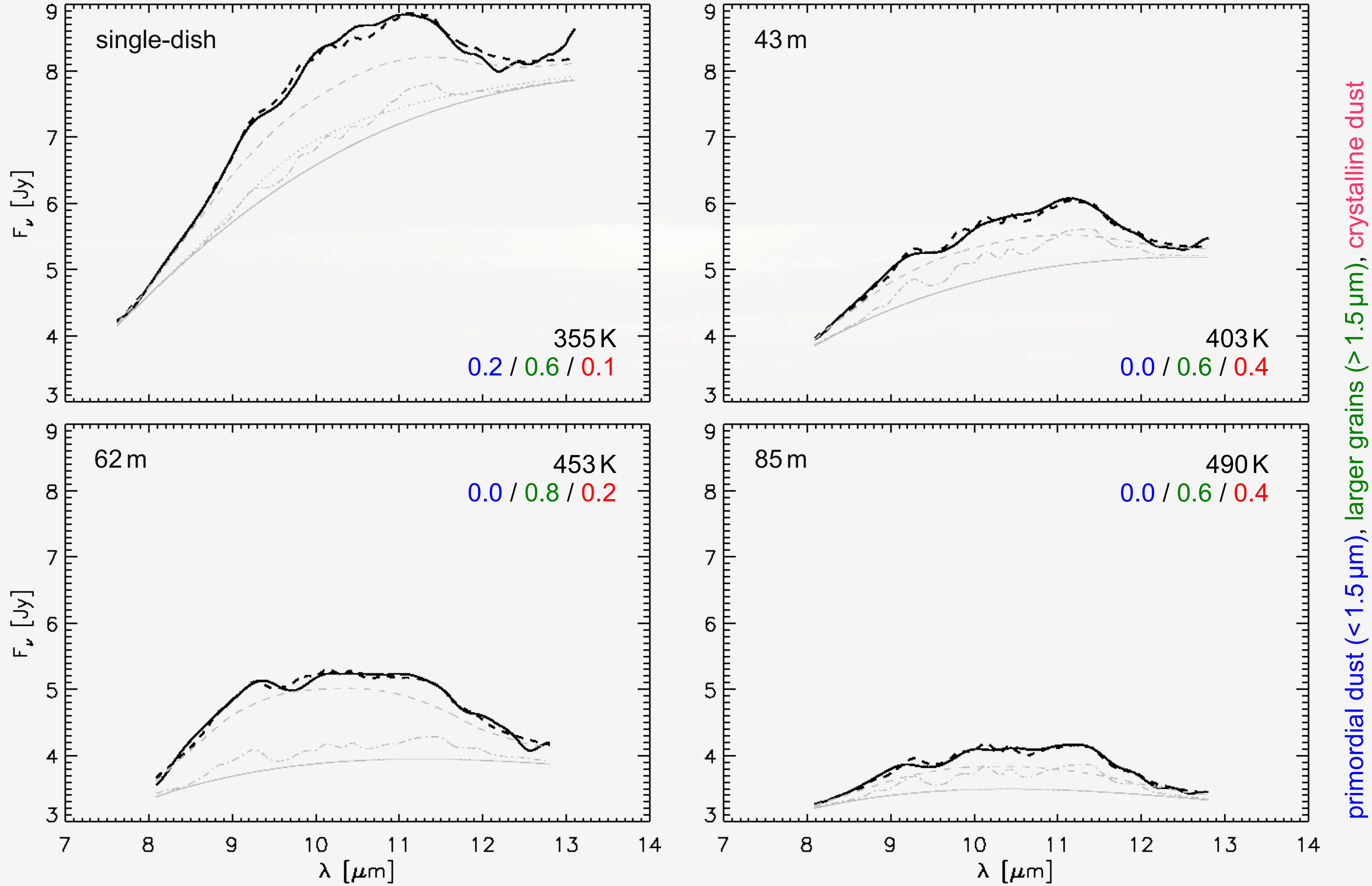
amorph

processing / thermal stability →

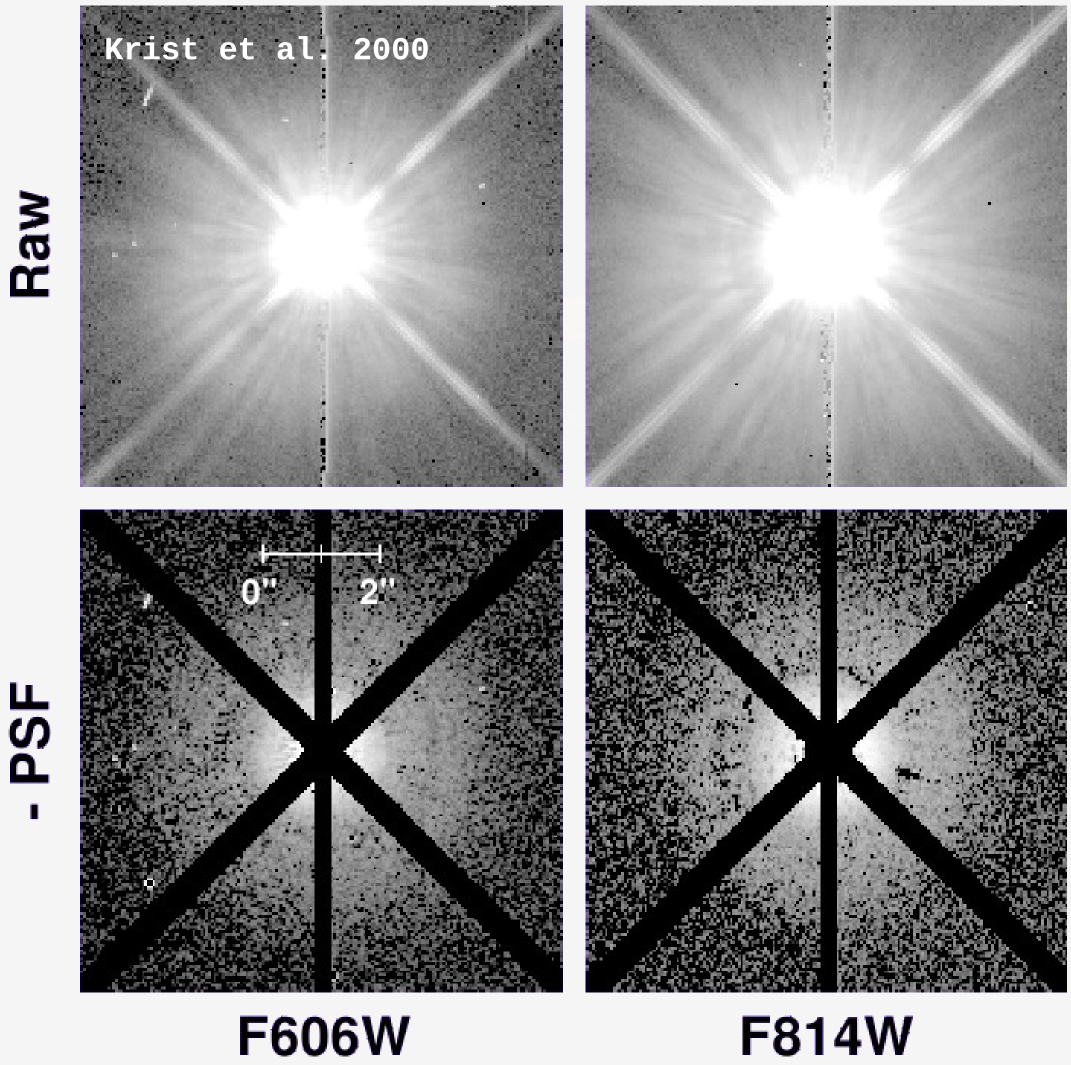


Schegerer et al., A&A, 456, 2006

Dust processing around T Tau?

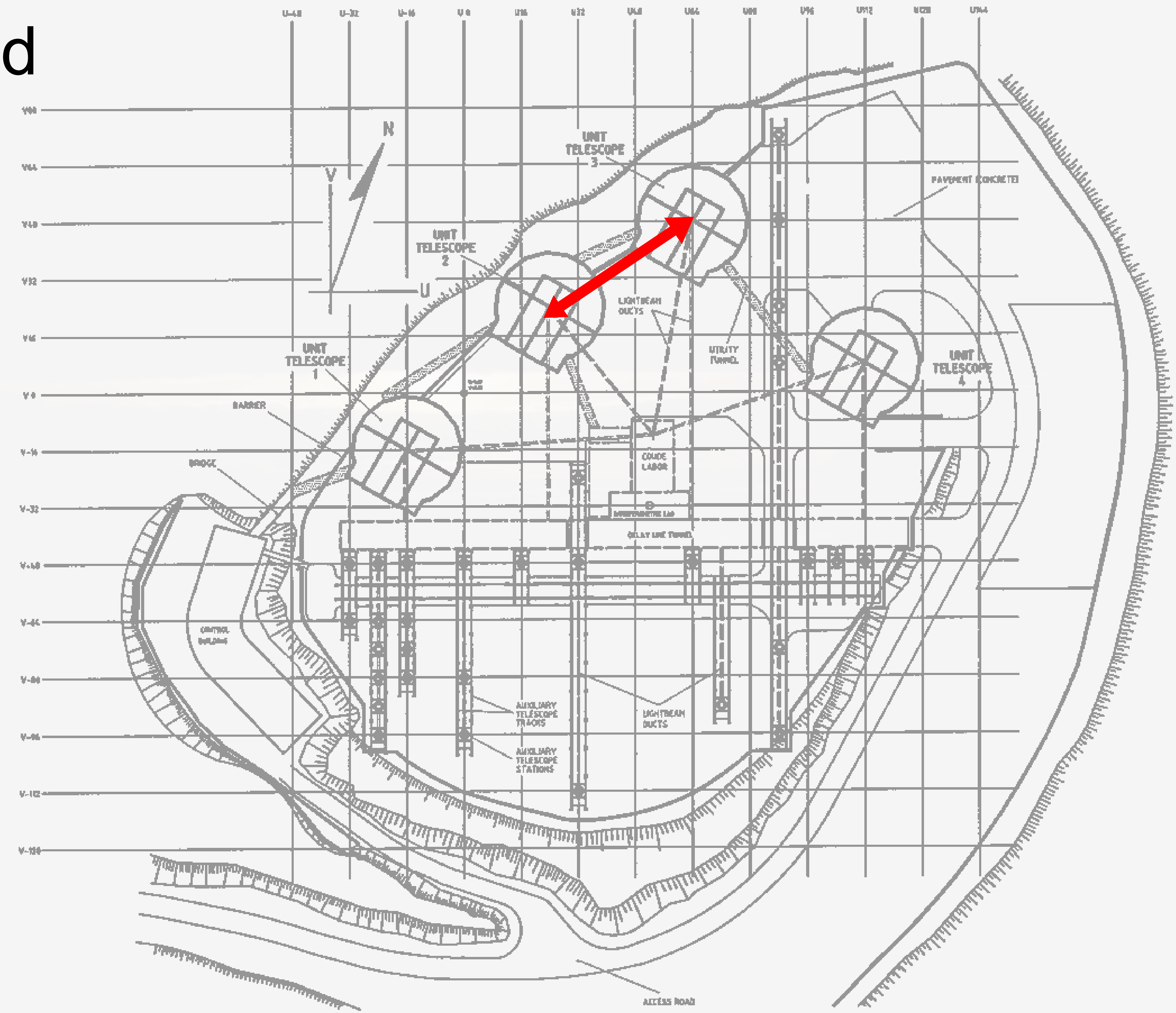


TW Hya - A prototypical transition disc

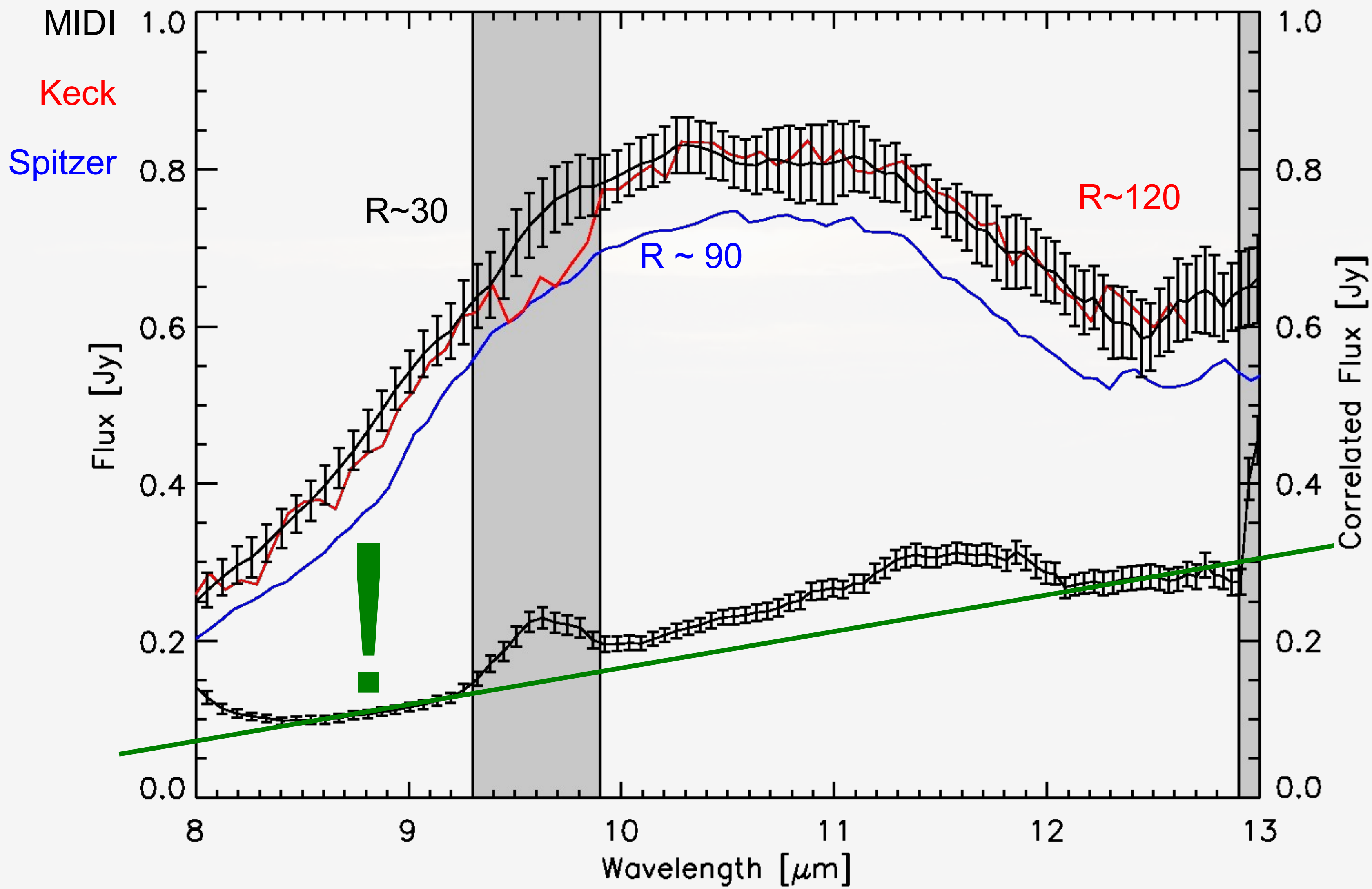


- classical T Tauri star
- distance of 51±4 pc
- age of 5-15 Myr
- K7V (T~4000 K, 0.19 $L_\odot$)
- actively accreting at a low rate: 4×10^{-10} $M_\odot$/yr
- images taken at various wavelengths reveal a dust disk:
  - nearly face-on
  - diameter: ~300 AU

The Grid

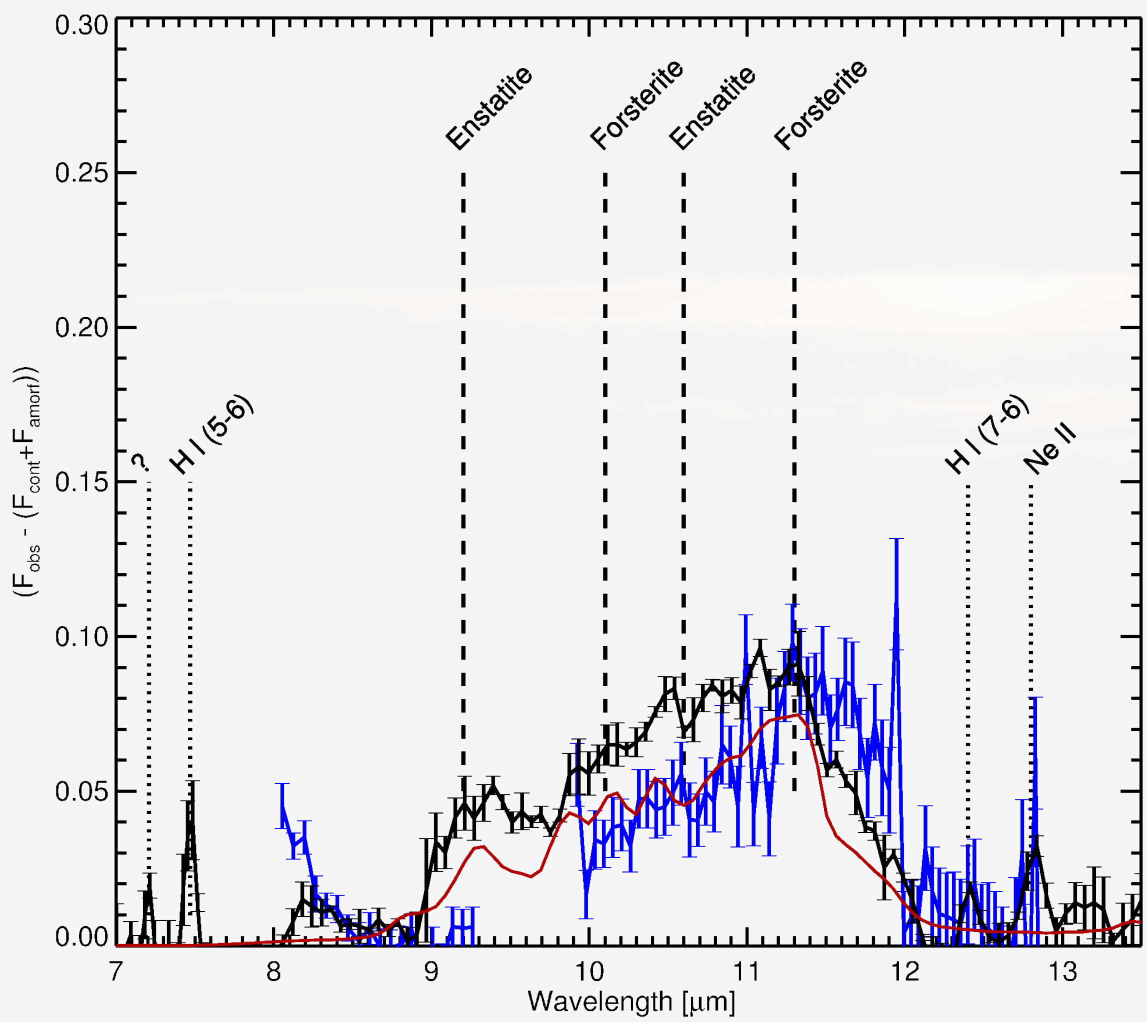

N
V
U
UNIT TELESCOPE 1
UNIT TELESCOPE 2
UNIT TELESCOPE 3
UNIT TELESCOPE 4
BARRIER
BRIDGE
LIGHTBEAM DUCTS
UTILITY TUNNEL
PAVEMENT (CONCRETE)
COUDE LABOR
DELAY LINE TUNNEL
AUXILIARY TELESCOPE TRACKS
AUXILIARY TELESCOPE STATIONS
LIGHTBEAM DUCTS
ACCESS ROAD

The total and the correlated flux



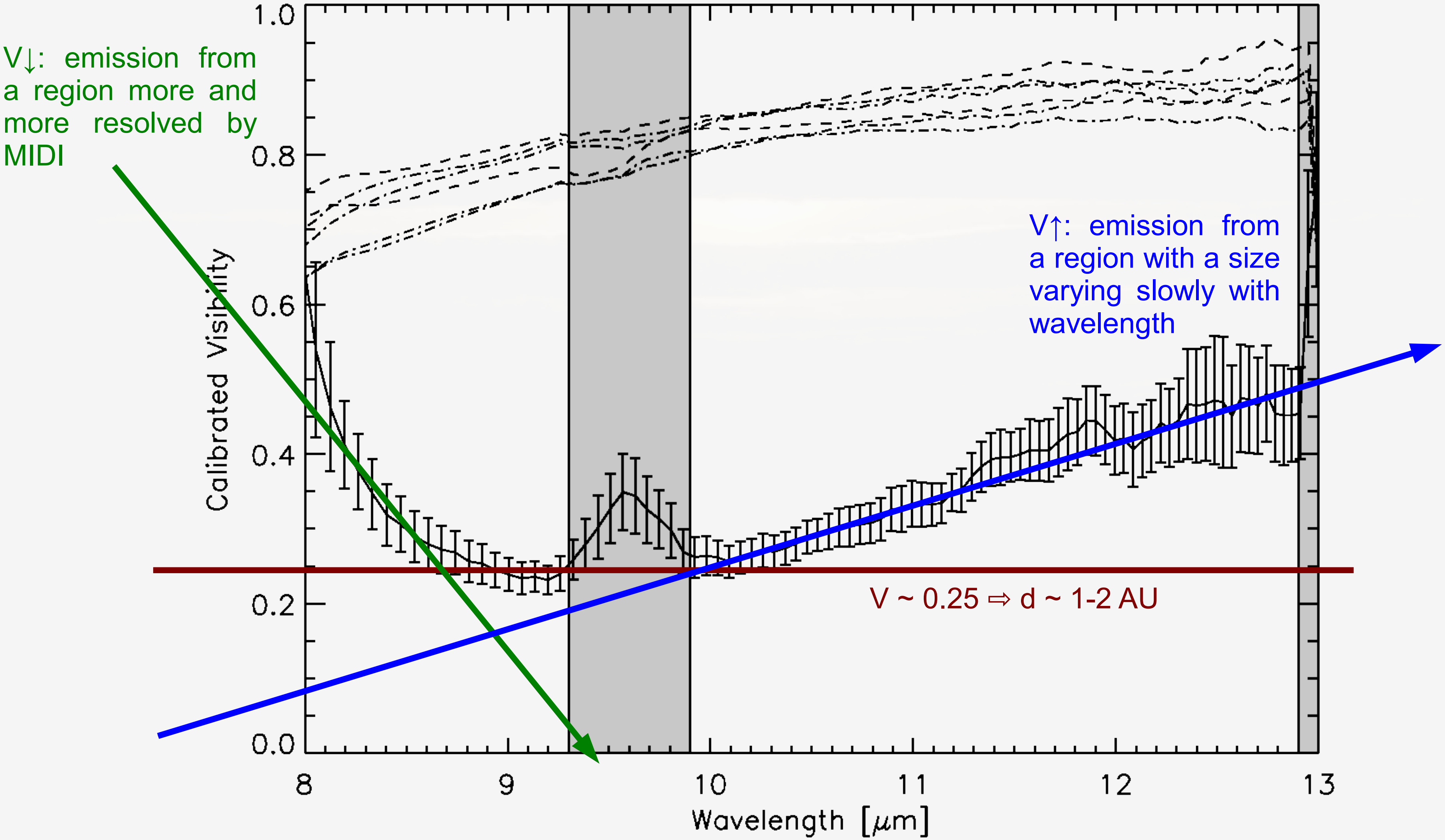
Ratzka et al., A&A, 471, 2007

Where is the processed dust?

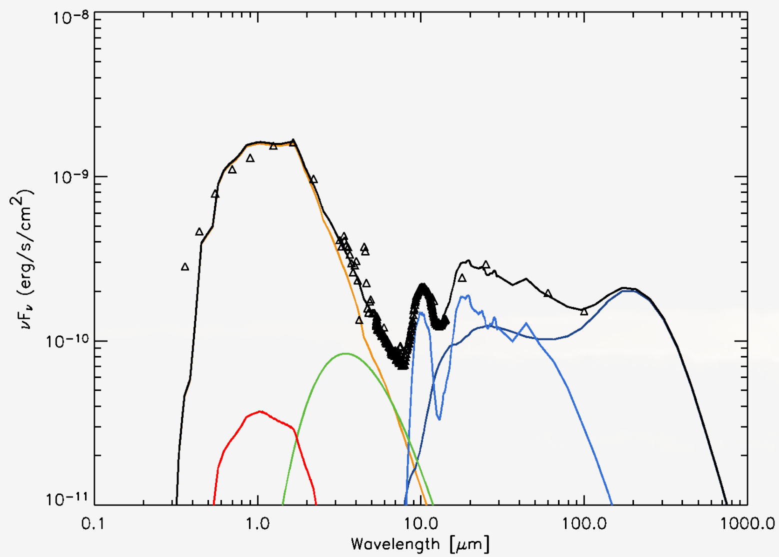


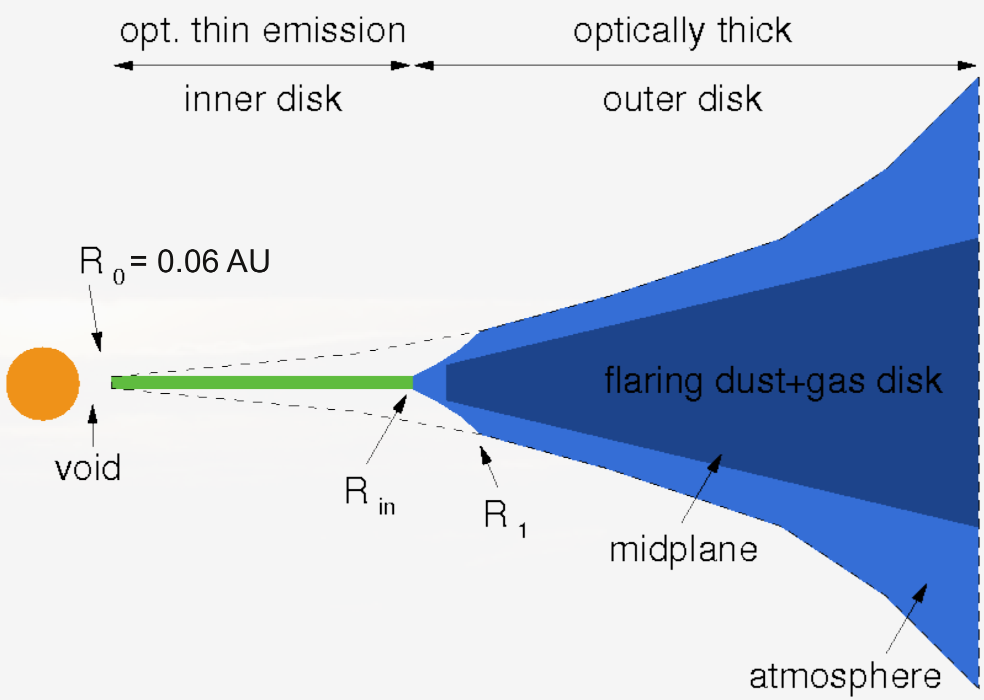
- ~ 8 % of the mass is in sub-micron sized crystalline dust particles; ~83 % of the mass is in sub-micron sized amorphous dust grains
- Comparison of the spectrally dispersed correlated flux with the dust model shows that most of the crystalline material is concentrated within 1 AU from the central star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

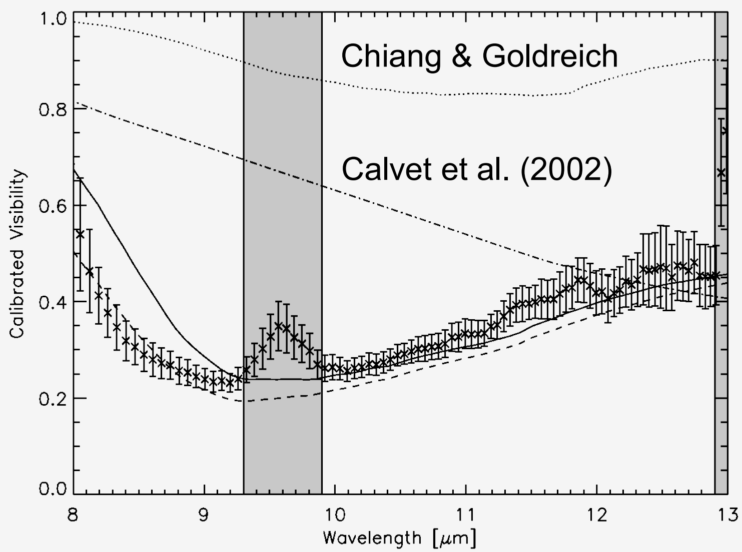
Geometrical constraints

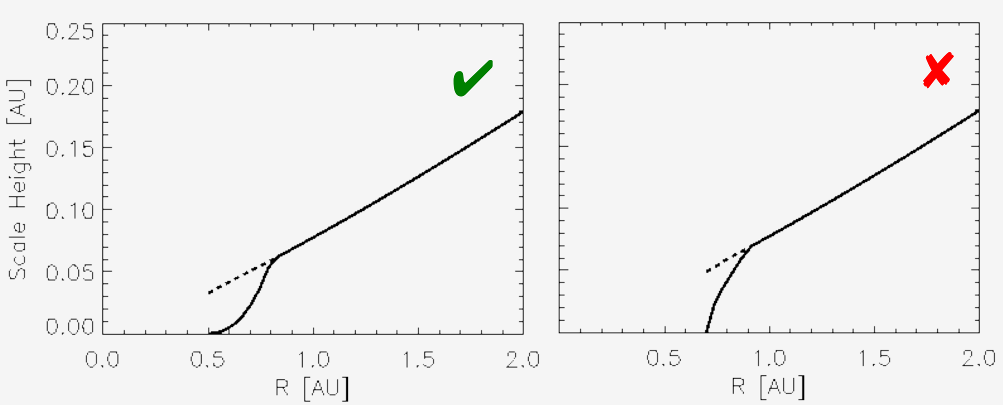


Modified Chiang & Goldreich model







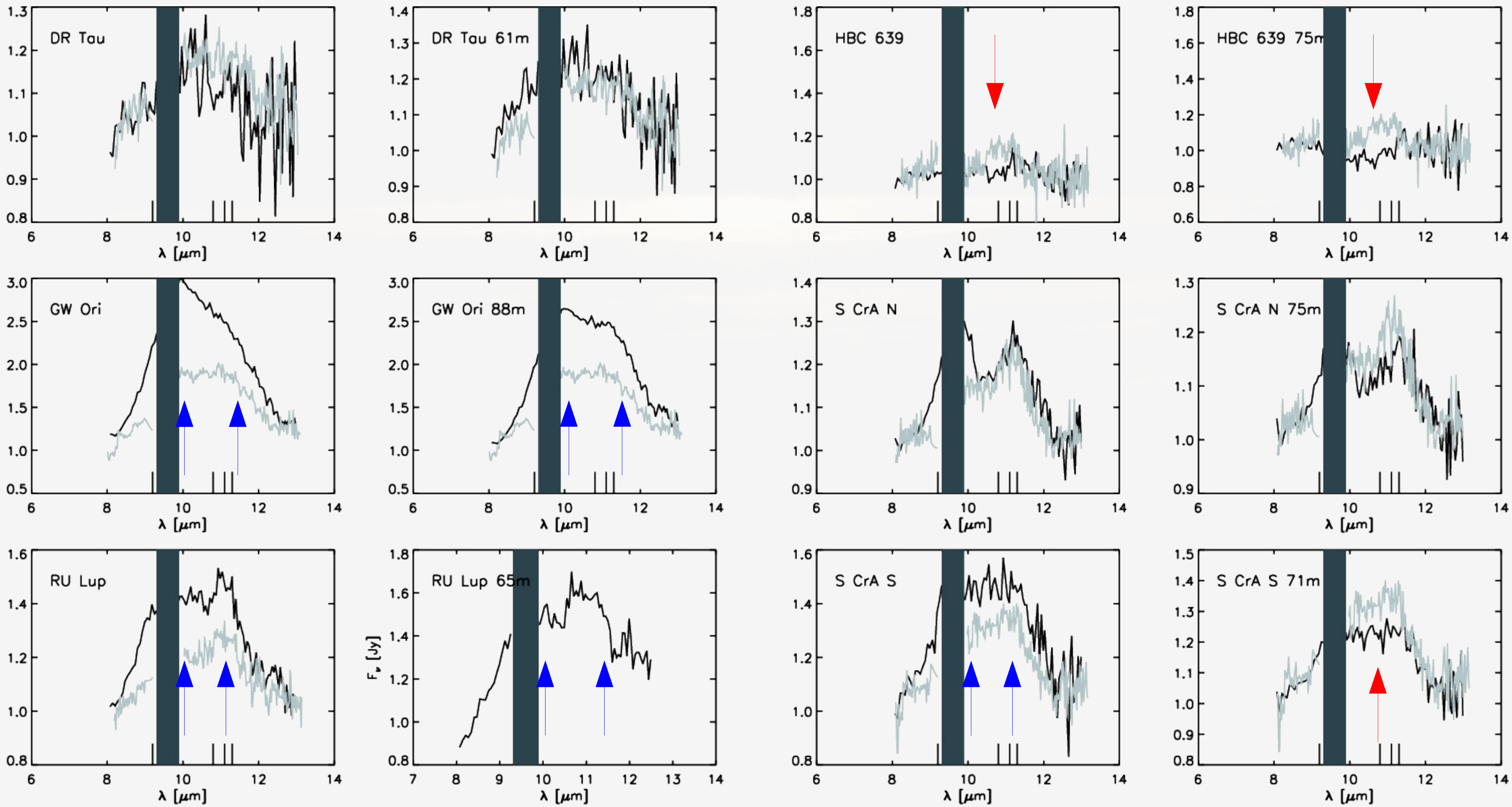


Seven more young stars

DR Tau	K7 (T_*~4000 K, L_*~1.7 $L_\odot$)	M_*~0.8 $M_\odot$	3 Myr
	m_d~0.1 $M_\odot$, r_d~0.10...90 AU, β~0.75, h_{100} ~15 AU, i~20°, 2.0·10^{-8} $M_\odot$/yr		
GW Ori	G0 (T_*~6000 K, L_*~40 $L_\odot$)	M_*~3.7 $M_\odot$	1 Myr
	m_d~1.0 $M_\odot$, r_d~0.35...360 AU, β~1.10, h_{100} ~22 AU, i~10°, 2.5·10^{-7} $M_\odot$/yr		
HD 72106B	A0 (T_*~9500 K, L_*~28 $L_\odot$)	M_*~1.8 $M_\odot$	10 Myr
	m_d~0.005 $M_\odot$, r_d~0.50...40 AU, β~1.30, h_{100} ~8 AU, i~60°, no accretion		
RU Lup	K8 (T_*~4000 K, L_*~1.3 $L_\odot$)	M_*~0.8 $M_\odot$	1 Myr
	m_d~0.1 $M_\odot$, r_d~0.10...100 AU, β~0.90, h_{100} ~20 AU, i~28°, 1·10^{-8} $M_\odot$/yr		
HBC 639	K0 (T_*~4800 K, L_*~8.5 $L_\odot$)	M_*~2.0 $M_\odot$	2 Myr
	m_d~0.1 $M_\odot$, r_d~0.10...120 AU, β~1.00, h_{100} ~10 AU, i~65°, no accretion		
S CrA N	K3 (T_*~4400 K, L_*~2.3 $L_\odot$)	M_*~1.5 $M_\odot$	3 Myr
	m_d~0.03 $M_\odot$, r_d~0.05...120 AU, β~1.10, h_{100} ~9 AU, i~10°, 4·10^{-8} $M_\odot$/yr		
S CrA S	M0 (T_*~3800 K, L_*~1.0 $L_\odot$)	M_*~0.6 $M_\odot$	1 Myr
	m_d~0.03 $M_\odot$, r_d~0.10...100 AU, β~1.05, h_{100} ~8 AU, i~30°, 4·10^{-8} $M_\odot$/yr		

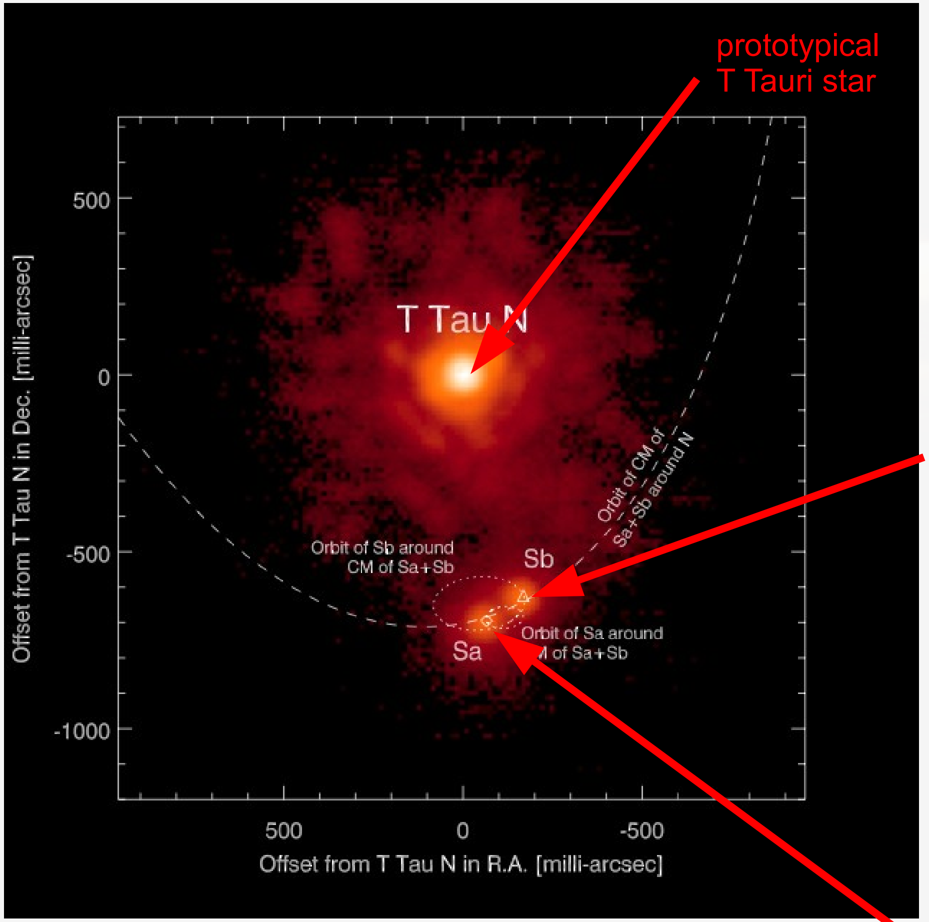
Schegerer et al., A&A, 502, 2009

Dust processing?



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

The T Tau triple system



yet another
T Tauri star

Köhler et al., A&A, 482, 2008

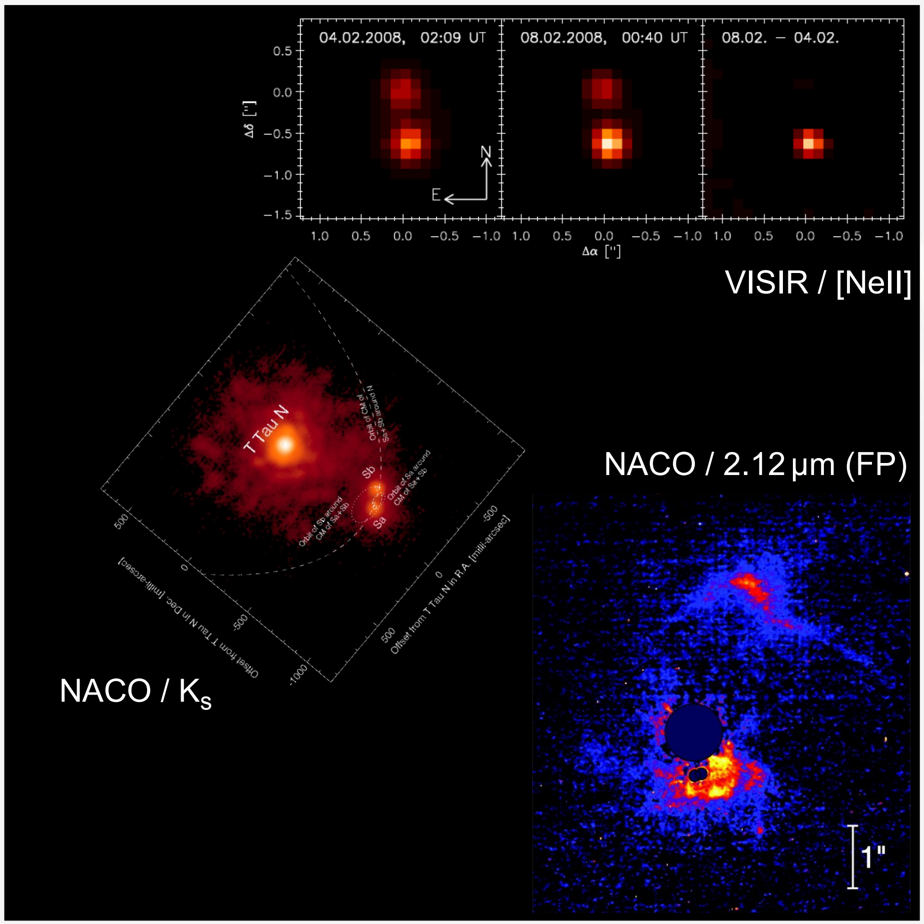
»intermediate mass«
infrared companion
strongly variable!

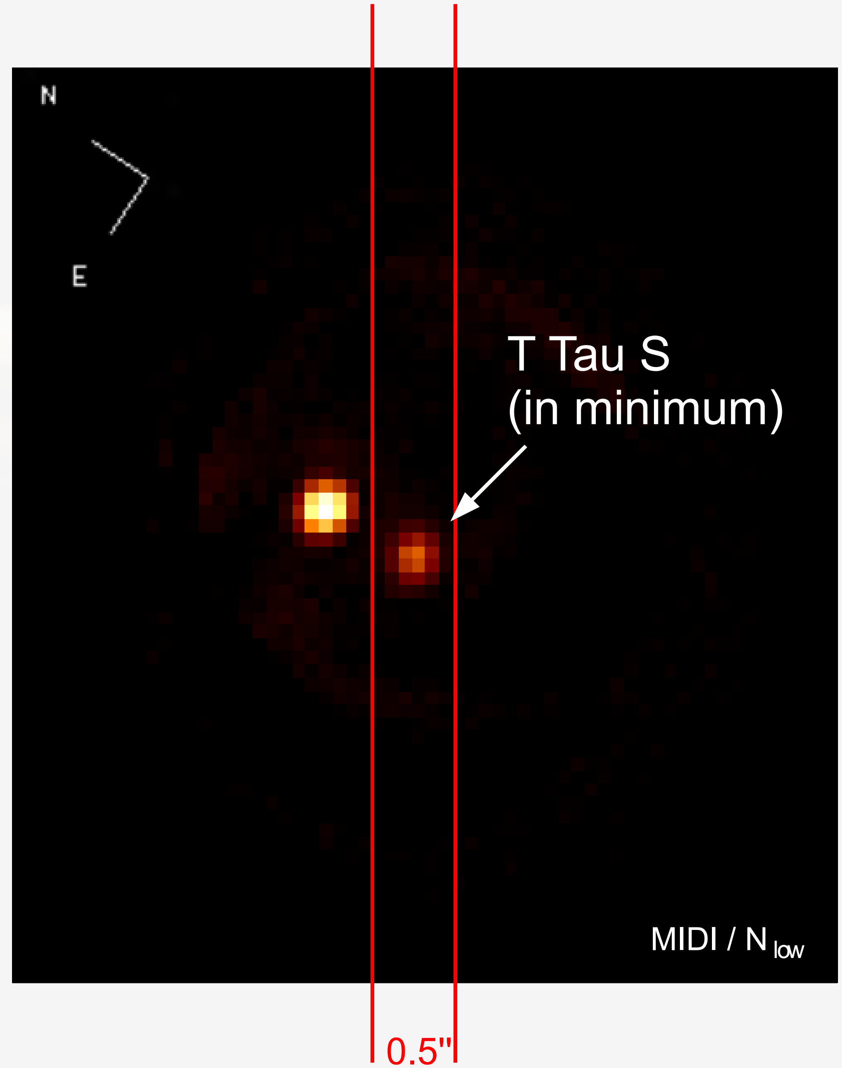
T Tauri became more and more complex as the observational techniques were improved:

- three stars
- two jets (E-W, NW-SE)
- a number of nebulous patches similar to Herbig Haro objects on scales of arcsec
- many interlocking loops and filaments of H_2

T Tauri is the best characterised triple system of pre-main sequence stars. It allows to investigate the <u>mass and dynamics of the stellar components</u> as well as the <u>structure and geometry of the discs</u> in an interacting system.

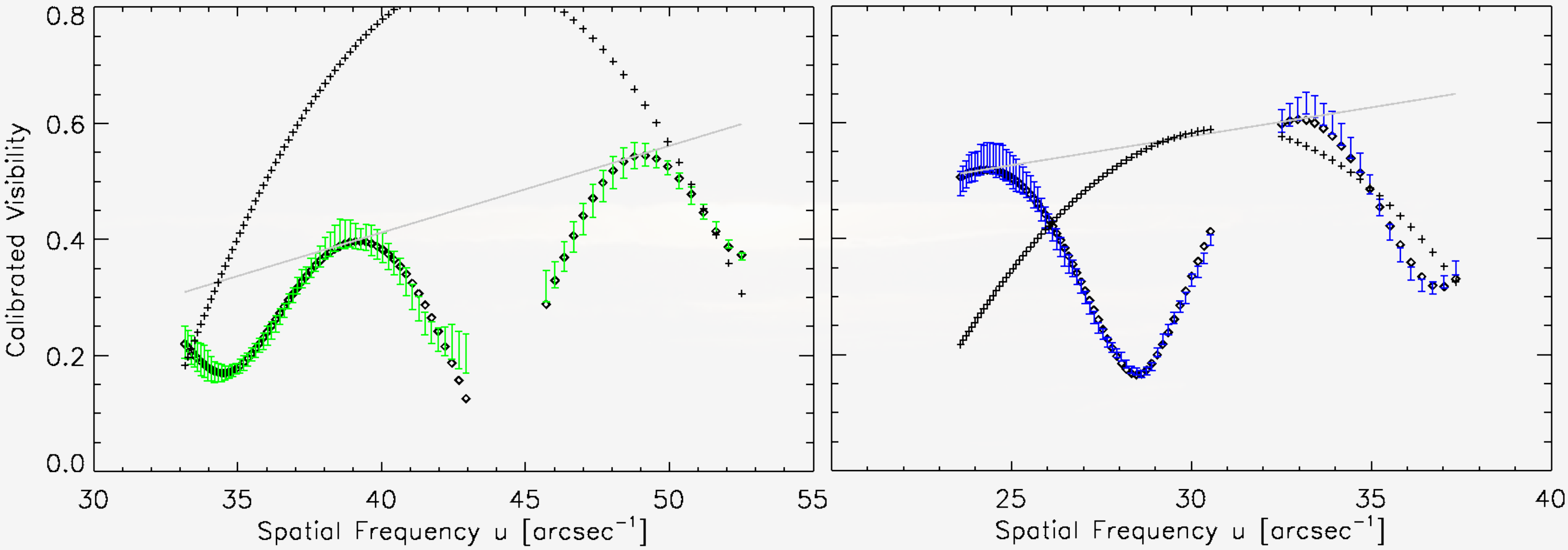
Resolving T Tau with a single UT





van Boekel et al., A&A, submitted
Köhler et al., A&A, 482, 2008
Herbst et al., ApJ, 134, 2007

Fitting the binary signal



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

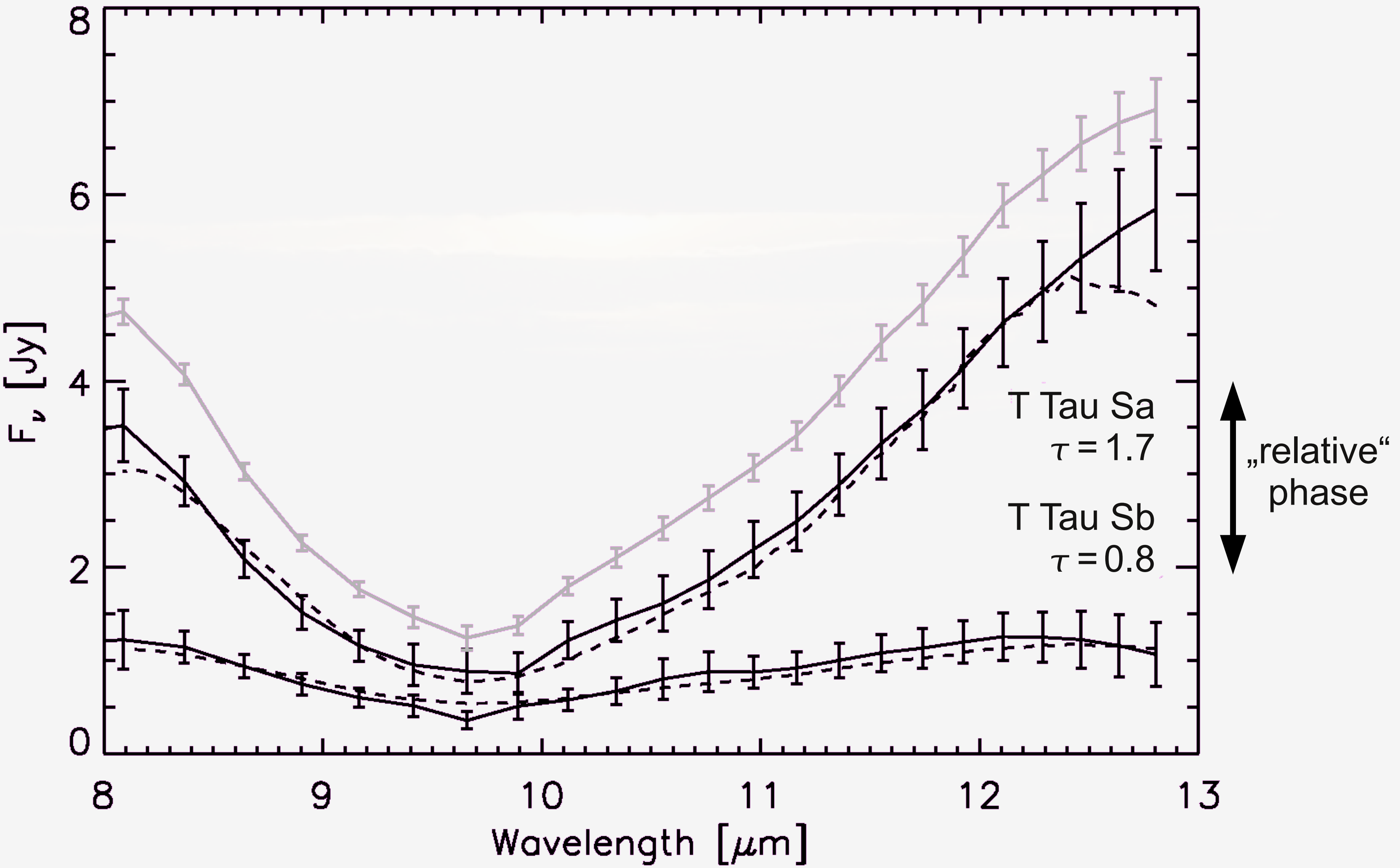
$$s(u) = s_0 + s_1 u$$

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

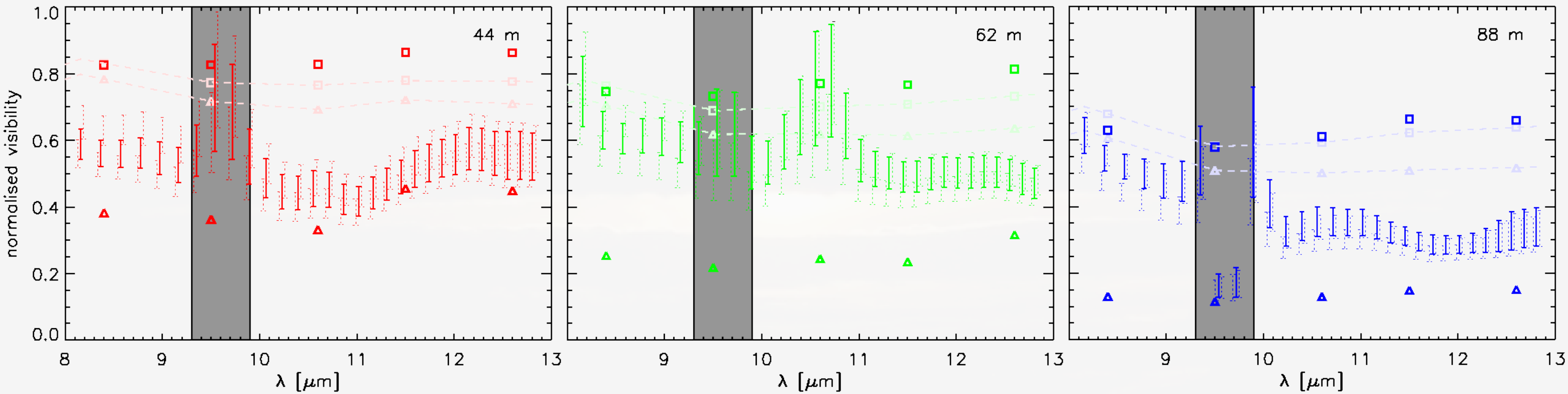
$$f(u) = f_0 + f_1 u + f_2 u^2, \ \ f(u) < 1$$

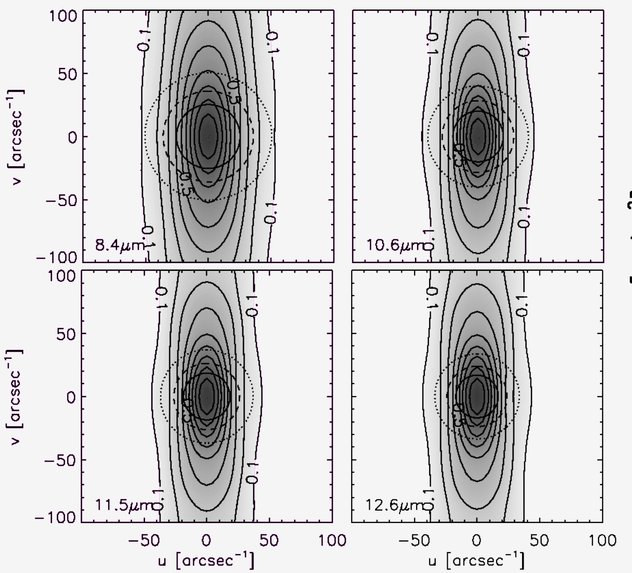
Ratzka et al., A&A, 502, 2009

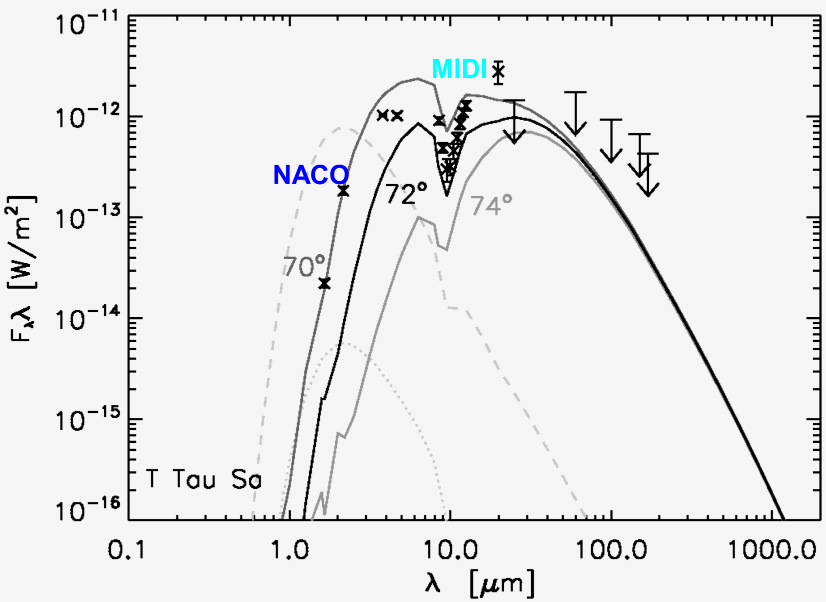
Separating the spectra



Model for T Tau Sa







star

$M_* = 2.3\ M_\odot$

$T_* = 9000$ K, $R_* = 2.6\ R_\odot$

$L_* = 40\ L_\odot$

disc

$M_d = 3 \cdot 10^{-3}\ M_\odot$

$r_d = 0.5 \ldots 5.0$ AU

$i \sim 72^\circ$

$h_{100} = 10$ AU

$\beta = 1.00$

env.

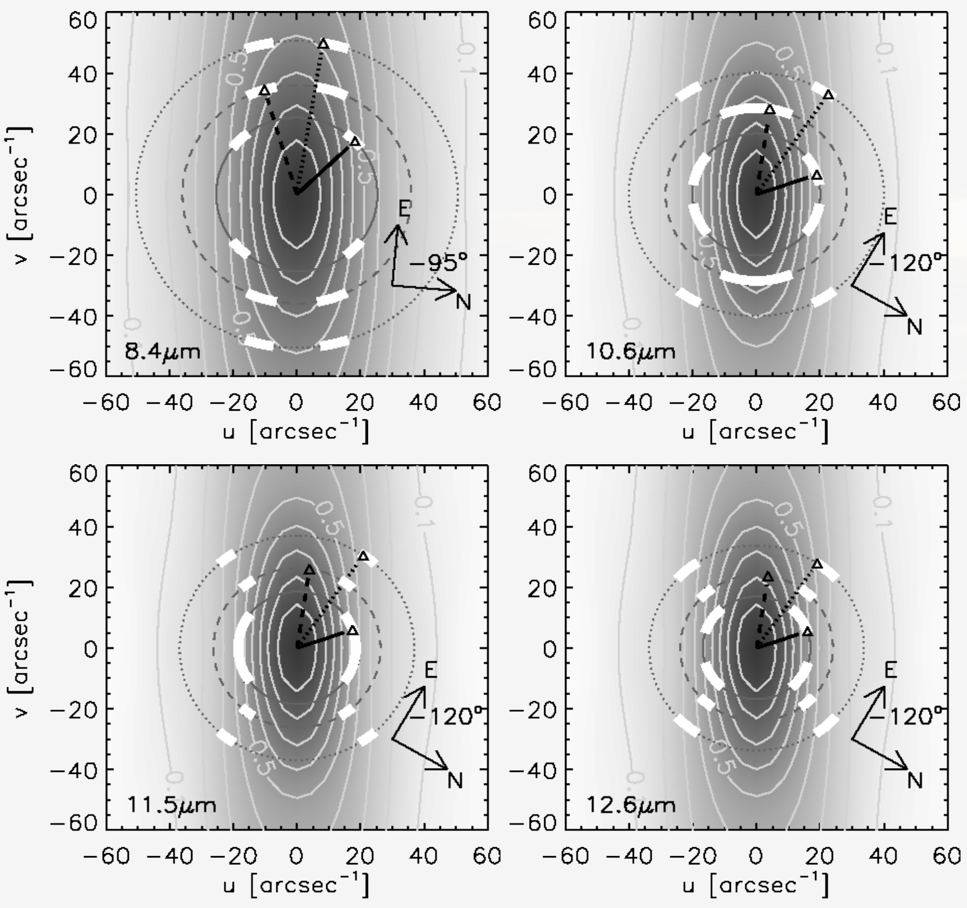
$c_1 = 1 \cdot 10^{-5}$

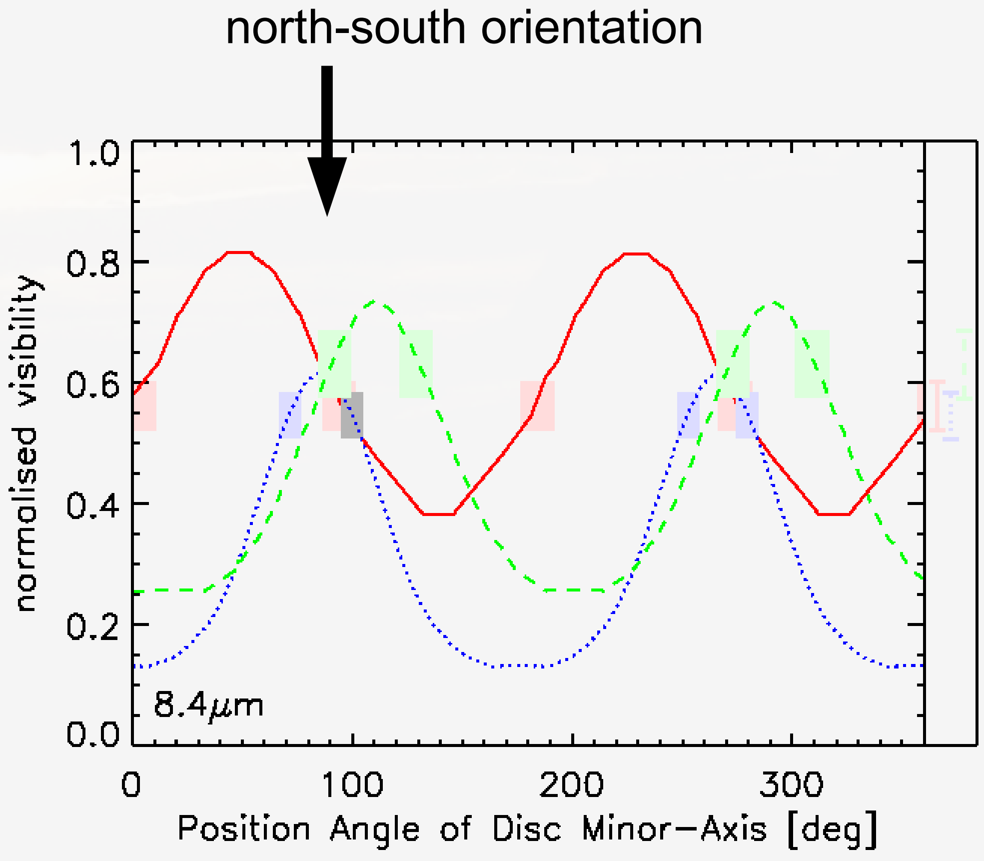
$c_2 = -5.0$

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

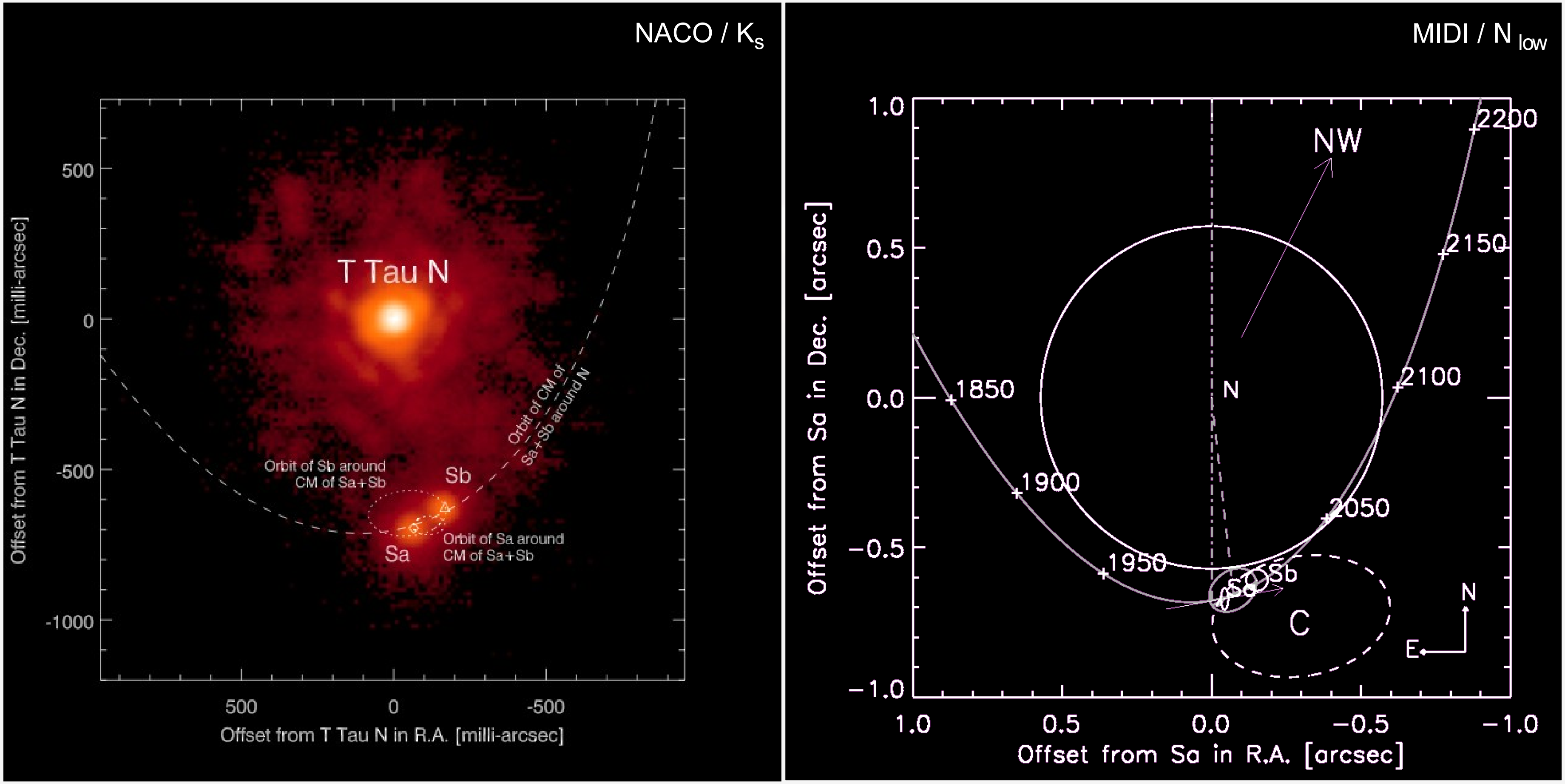
$A_V = 30$ mag

Position angle of the T Tau Sa disc



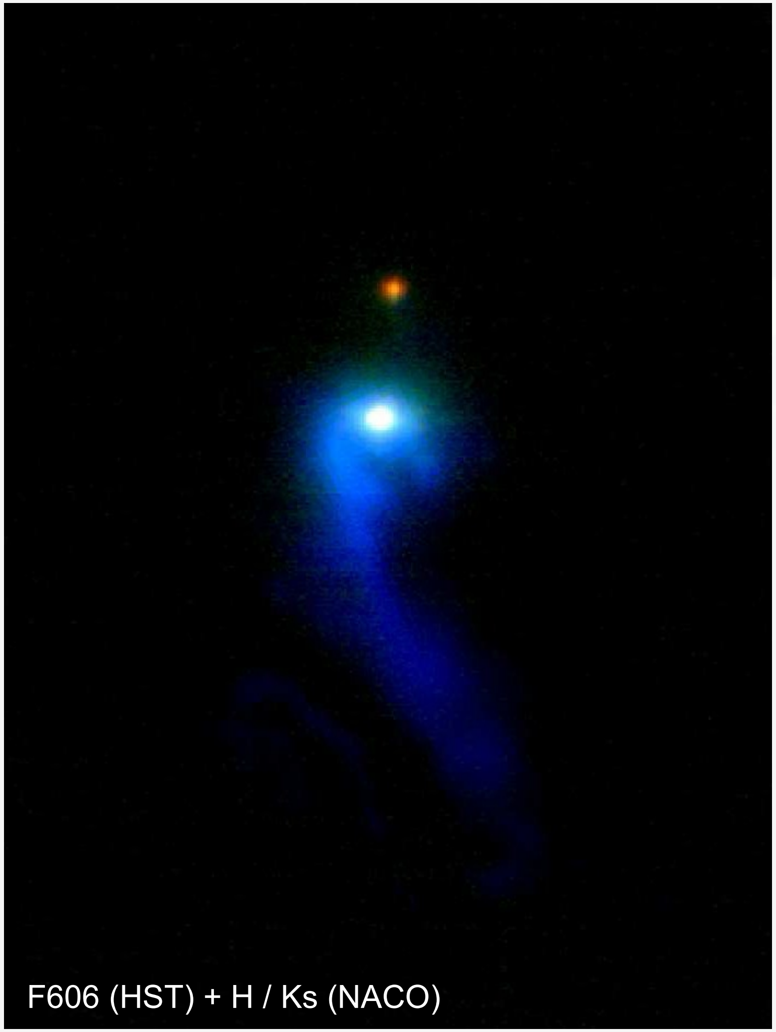


Sketching the T Tau system



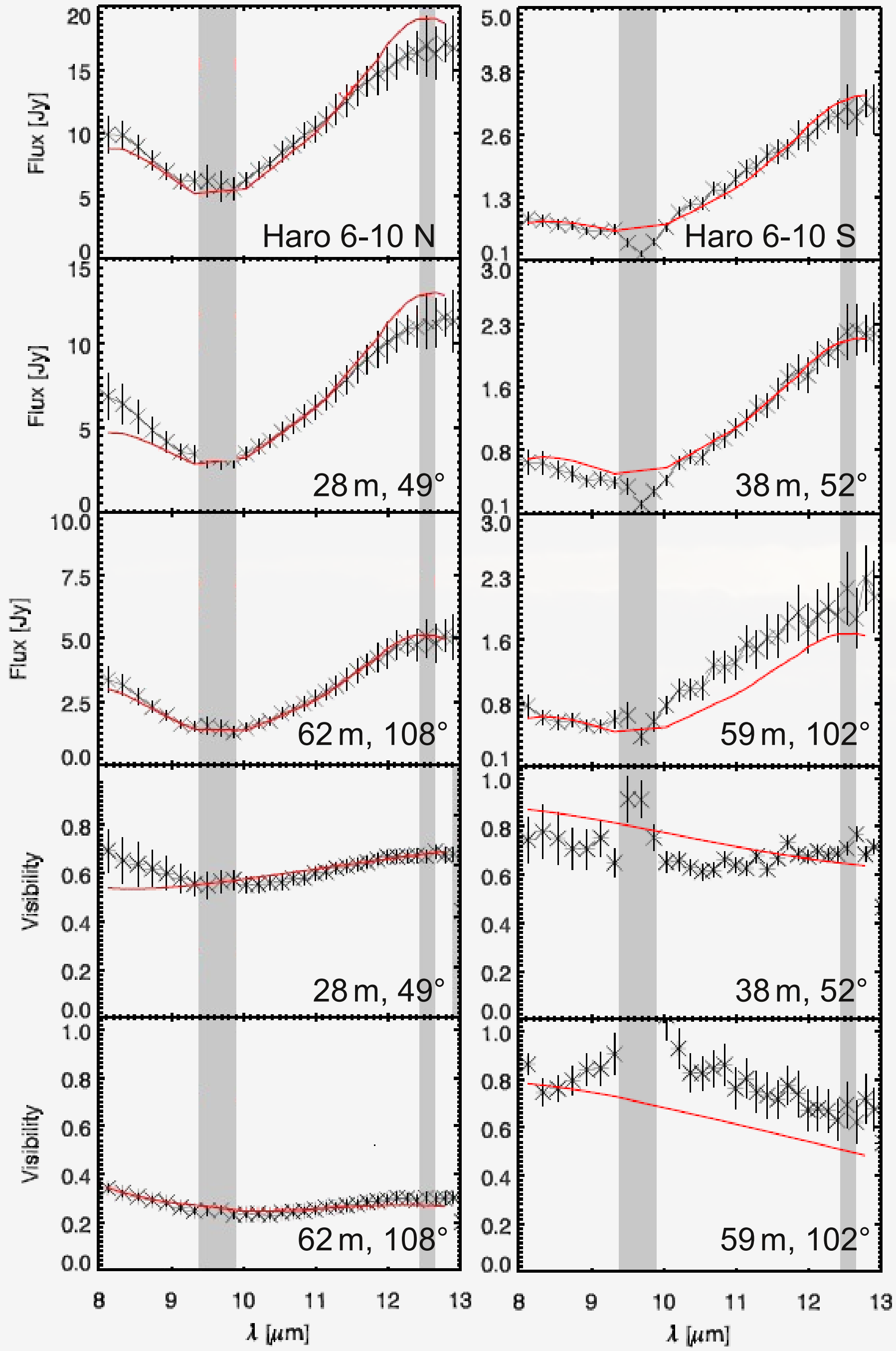
Köhler et al., A&A, 482, 2008

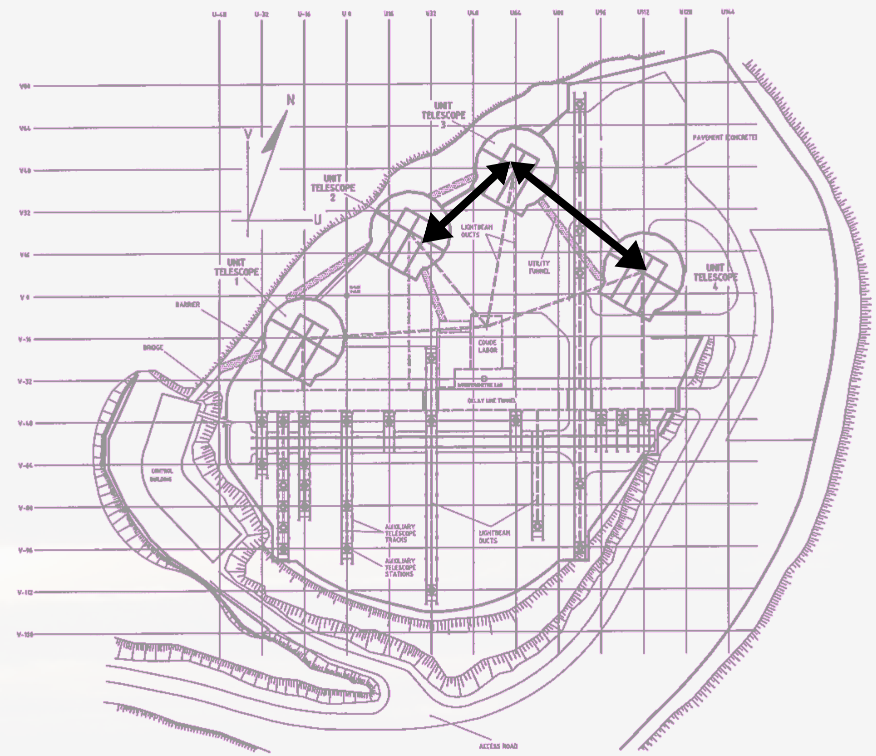
GV Tau – another IRC



- 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, submitted





	Haro 6-10 N	Haro 6-10 S
r_1 [AU]	1.0 ± 0.5	1.5 ± 0.5
T_1 [K]	900 ± 300	900 ± 100
r_2 [AU]	7 ± 3	10 ± 2
T_2 [K]	100 ± 50	150 ± 50
i [deg]	10 ± 5	80 ± 10
PA [deg]	50 ± 20	50 ± 20
A_V [mag]	19 ± 4	13 ± 4

Roccatagliata et al., A&A, submitted

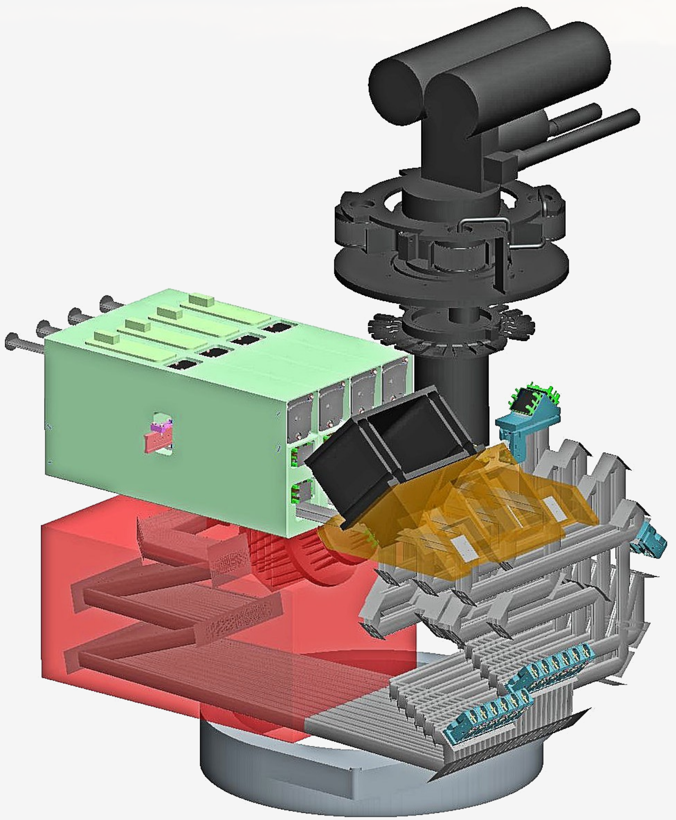
MATISSE – A mid-IR imager

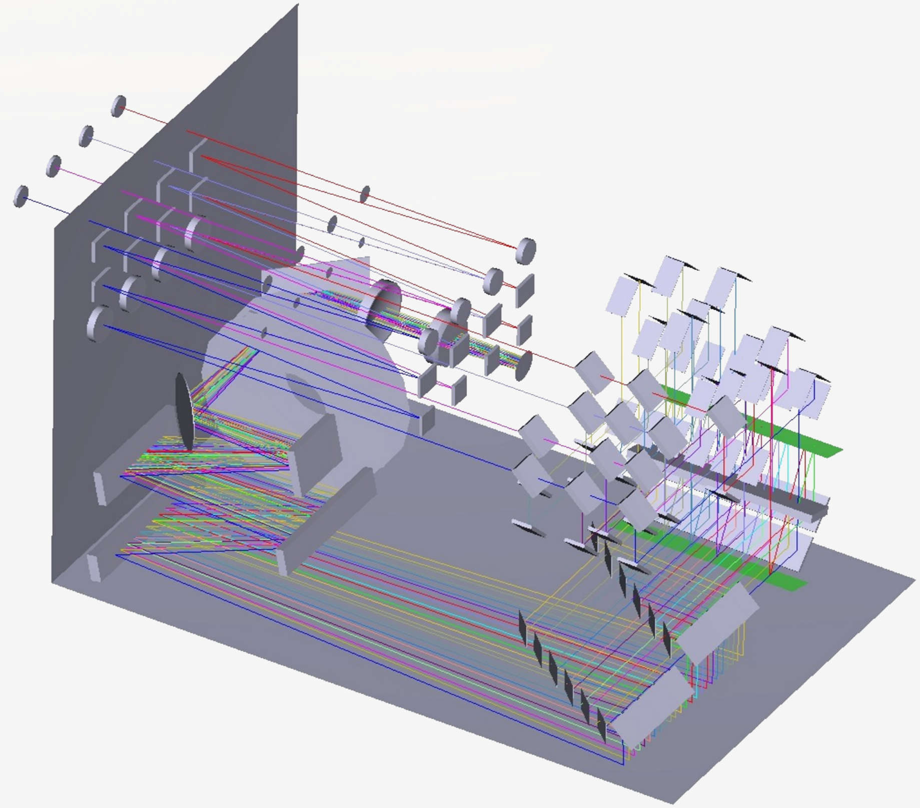
Multi-AperTure mid-Infrared SpectroScopic Imager

2nd Generation VLTI Instrument

Principal Investigator: Lopez (OCA,Nice)

Co-PI & Proj.Scient: S. Wolf (ITAP, University of Kiel)





MATISSE – A mid-IR imager

Multi-wavelength approach in the mid-infrared

- L, M, N band: ~ 2.7 – 13 µm
- 2 new mid-IR observing windows for interferometry (L,M)
- simultaneous observations in 2 spectral bands

Improved Spectroscopic Capabilities

- spectral resolutions: 30 / 100-300 / 500-1000

Image reconstruction

- on size scales of **3** / 6 mas (L-band) **10** / 20mas (N-band)
- using **ATs** / UTs