MIDI observations of T Tauri stars and their companions
Introduction

Observables
The VLT Interferometer
The VLT Interferometer
Interferometric Observables

\[
\frac{V_r(\vec{p})}{V_r(0)} = \frac{\int I(\vec{x}) \exp\left(-i2\pi \frac{\vec{x} \cdot \vec{p}}{\lambda}\right) \, d\vec{x}}{\int I(\vec{x}) \, d\vec{x}}
\]

\[
V_{r,\text{norm}}(u, v) = \frac{\int \int I(\alpha, \beta) \exp\left(-i2\pi (u\alpha + v\beta)\right) \, d\alpha \, d\beta}{\int \int I(\alpha, \beta) \, d\alpha \, d\beta}
\]

A) Fringe Contrast

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

\[
V_{\text{Michelson}} = \frac{I_{\text{max}} - I_{\text{min}}}{I_{\text{max}} + I_{\text{min}}}
\]

visibility varies between 0 (I_{\text{min}} = I_{\text{max}}) and 1 (I_{\text{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
T Tauri – The Prototype
T Tauri – The Prototype
The Grid
The resolution of the interferometer decreases with wavelength, the emitting region becomes larger due to the temperature gradient.

$\Rightarrow$ decreasing visibilities
$\Rightarrow$ direct size estimates

The Spectral Energy Distribution ...
The Radiative Transfer Model ...
The Radiative Transfer Model ...

star

\begin{align*}
M_* &= 2.1 M_\odot \\
T_* &= 5250 \text{ K} \\
L_* &= 7.3 R_\odot \\
R_* &= 3.3 R_\odot
\end{align*}

disk

\begin{align*}
M_d &= 0.04 M_\odot \\
r_d &= 0.1 \text{ ... } 80 \text{ AU} \\
i &< 30^\circ \\
h_{100} &= 18 \text{ AU} \\
\beta &= 1.25
\end{align*}

everenlope

\begin{align*}
c_1 &= 1 \cdot 10^{-5} \\
c_2 &= -5.0
\end{align*}

accretion

\[ \frac{dM}{dt} = 3 \cdot 10^{-8} M_\odot \text{yr}^{-1} \]

extinction (foreground)

\[ A_V = 1.5 \text{ mag} \]
Structure of Transitional Disks
**TW Hya - The Prototypical Transitional Disk**

**classical T Tauri star**

distance of $51 \pm 4$ pc

age of $5\text{-}15\text{ Myr}$

**K7V ($T \sim 4000\text{ K, } 0.19L_\odot$)**

actively accreting at a low rate: $4 \times 10^{-10} M_\odot/\text{yr}$

images taken at various wavelengths reveal a dust disk:

- nearly face-on
- diameter: $\sim 300\text{ AU}$

*Ratzka et al., A&A 471, 2007*
The Grid
The Total and the Correlated Flux

Ratzka et al., A&A 471, 2007
Modified Chiang & Goldreich Model

\[ \dot{V} = 0.25 \Rightarrow d \sim 1-2 \text{ AU} \]
The Transitional Disk of TW Hya

KI & CHARA

\[ R_{\text{in}} = 0.42 \ldots 0.52 \text{AU} \]
\[ \Delta R < 0.13 \text{AU} \]

The Dust Composition and Distribution
Dust Species and Properties

**Pyroxene Group**

\[ \text{Mg}_{n-1}\text{Fe}_n\text{Si}_2\text{O}_6 \]

**Olivine Group**

\[ \text{Mg}_{n}\text{Fe}_{n-1}\text{SiO}_4 \]

**Enstatite**

\[ \text{Mg}_2\text{Si}_2\text{O}_6 \]

**Forsterite**

\[ \text{Mg}_2\text{SiO}_4 \]

**Quartz**

\[ \text{SiO}_2 \]

Processing / thermal stability

Schegerer et al., A&A 456, 2006
Dust Processing in the RY Tau Disc!

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.

\[ F_\nu = B_\nu(T_{\text{cold}})C_0 + B_\nu(T_{\text{dust}}) \left( \sum_{i=1}^{3} \sum_{j=1}^{6} C_{i,j} \kappa_{\nu,i,j} \right) \]

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.
Dust Processing around T Tau?

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.

Where is the Processed Dust in TW Hya?
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)

The Grid
The Binary Signal

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

\[ s(u) = s_0 + s_1 u \]

\[ V_0(u) = a_0 + a_1 u \]

\[ f(u) = f_0 + f_1 u + f_2 u^2, \quad f(u) < 1 \]
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°
Separating the Spectra

![Graph showing spectral separations for different astronomical sources.](image-url)
Separating the Spectra

\[ F_{\text{meas}}^{\text{corr}} \cdot \frac{1}{1 + f} = F_{P}^{\text{corr}} = V_P \cdot F_{P}^{\text{tot}} + \]
\[ F_{\text{meas}}^{\text{corr}} \cdot \frac{f}{1 + f} = F_{C}^{\text{corr}} = V_C \cdot F_{C}^{\text{tot}} \]

\[ \tau = 1.7 \]
\[ \tau = 0.8 \]

Model for T Tau Sa

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 circumstellar material around the southern component?
  - variable accretion of the northern component?

- presence of a circumbinary envelope suggested

F606 (HST) + H / Ks (NACO)
<table>
<thead>
<tr>
<th></th>
<th>GV Tau N</th>
<th>GV Tau S</th>
</tr>
</thead>
<tbody>
<tr>
<td>( r_1 ) [AU]</td>
<td>1.5 ± 0.5</td>
<td>1.0 ± 0.5</td>
</tr>
<tr>
<td>( T_1 ) [K]</td>
<td>900 ± 100</td>
<td>900 ± 300</td>
</tr>
<tr>
<td>( r_2 ) [AU]</td>
<td>10 ± 2</td>
<td>7 ± 3</td>
</tr>
<tr>
<td>( T_2 ) [K]</td>
<td>150 ± 50</td>
<td>100 ± 50</td>
</tr>
<tr>
<td>( i ) [deg]</td>
<td>80 ± 10</td>
<td>10 ± 5</td>
</tr>
<tr>
<td>( \text{PA} ) [deg]</td>
<td>50 ± 20</td>
<td>50 ± 20</td>
</tr>
<tr>
<td>( A_V ) [mag]</td>
<td>13 ± 4</td>
<td>19 ± 4</td>
</tr>
</tbody>
</table>

GV Tau – Another Infrared Companion

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
- $L = 20 - 80 \, L_{\odot}$

SVS 20 – In the Core of Serpens

80% large amorphous
20% large crystalline

~50 m
~120 m

Beyond Science
Mid on vibroplate

- 11. December 2002
  - UT 23:50
    - 0.70 standard acquisition
    - if will visible = overlay test after reverberation
  - 3h 15
    - check acquisition
    - overlay check beams A and B

- 15. December 2002
  - UT 22:00
    - SNR > 4
    - 8 and 22 mm
    - 8/100 = good overlap

Thanks UWE

11. December 2002
  “First Fringes on α Ori”

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

Beyond Science