Infrared Interferometric Studies of Protoplanetary Accretion Disks

Thomas Preibisch
University Observatory Munich

Stefan Kraus & Gerd Weigelt
Max Planck Institute for Radio Astronomy, Bonn

Thorsten Ratzka
& Rebekka Grellmann
University Observatory Munich
Near-infrared emission from young stellar objects is usually assumed to be dominated by emission from hot dust at the dust sublimation radius.

Simple geometric ring-model fits to (single) visibility measurements

→ ring radii

→ looks like a simple ring
In most objects, the ring model radii agree well with the expected dust sublimation radii.
Some intermediate / high - mass objects deviate from the relation

\[ R_{\text{subl}} \propto L^{1/2} \]
A closer look at the inner disk regions

Fraction of accretion energy released: 2% 32% 66%

MWC 147: 7 M⊙, D = 800 pc

R* ~ 0.03 AU ~ 0.04 mas

Gas disk produces near-infrared emission

2000 K

3000 K

T ≤ 1000 K

1500 K

Rsub ~ log r

Racc ~ 2.5 AU

~ 0.09 AU

~ 3.1 mas

~ 0.1 mas
A closer look at the inner disk regions

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Fraction of accretion energy released</th>
</tr>
</thead>
<tbody>
<tr>
<td>T ≤ 1000 K</td>
<td>2%</td>
</tr>
<tr>
<td>peak(λF_λ) ≥ 4 μm</td>
<td>32%</td>
</tr>
<tr>
<td>1500 K: 2.5 μm</td>
<td>66%</td>
</tr>
<tr>
<td>2000 K: 1.5 μm</td>
<td></td>
</tr>
<tr>
<td>3000 K: 1.2 μm</td>
<td></td>
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</tbody>
</table>

**Emission from dust disk** predominantly at λ ≥ 2.5 μm

**Combination of near- + mid-infrared data** is important for the determination of physical conditions in the inner disk, e.g. radial temperature profile
Monoceros OB1.
(D=800 pc)

AMBER & MIDI study of
MWC 147 = HD 259431
Kraus, Preibisch, Ohnaka

Hernandez et al (2004): $\text{SpT} = \text{B6}$, $M = 7 M_\odot$, $L=1550 L_\odot$, $T=14,000 \text{ K}$, $t\sim 0.3 \text{ Myr}$

- near-infrared interferometry
- mid-infrared interferometry
- multiple baselines
- radiative transfer modeling
Dusty circumstellar disk model

\[ \chi_r^2 = 42 \]

Model image 2.25 \( \mu m \)

15 AU = 12 mas

MIR visibilities

NIR visibilities
Dusty disk + inner gas disk: $\chi_r^2 = 1.28$

Inclination: 60º, $\dot{M}_{\text{acc}} = 9 \times 10^{-6} \, \text{M}_\odot/\text{yr}$

Model image 2.25 $\mu$m

SED

MIR visibilities

NIR visibilities

15 AU = 12 mas

SED visibilities

91.4m/82º
49.5m/45º
102.0m/37º
88.4m/35º
Best-fit radiative transfer model images

NIR emission mainly from hot inner gas disk

MIR emission also from warm dust disk

Applications 1: gas luminosity $\propto$ accretion rate

$\Rightarrow$ $dM/dt = 6 \cdot 10^{-6} \, M_\odot/yr$
Applications 2:
Variations in accretion rate

→ variations in strength of gas emission

→ variations in sizes measured by infrared interferometry
Applications 3:
Spatially resolved spectroscopy of gas accretion disks

inner part
φ < λ/B
unresolved

F_λ (in) ~ F_λ (tot) × V_λ

outer part
φ > λ/B
resolved

F_λ (out) = F_λ (tot) - F_λ (in)

φ = 1 mas ~ 4 R_i at 140 pc
φ = 1 mas ~ 12 R_i at 500 pc

Model spectra of different annuli in an accretion disk

R_i ~ 5 R_⊙
Is Br$\gamma$ emission a good accretion tracer?

For low / intermediate mass stars ($\leq 4 \, M_\odot$), Br$\gamma$ emission is often assumed to originate from accretion funnels: $\rightarrow L_{\text{acc}} \propto L_{\text{Br}\gamma}^{0.9}$

If true, Br$\gamma$ emission should be **unresolved**.

\[ R_{\text{acc}} \sim 3 \, R_\star \leq 0.2 \text{ mas} \quad \text{for} \, D \geq 500 \text{ pc} \]

**Spectro-Interferometry** with $R > 1000$

$\rightarrow$ measure size of line emission regions

**Result:** In only two out of 5 objects the Br$\gamma$ emission zone is compact enough to be related to accretion funnels.

Kraus et al., 2008, A&A 489, 1157
MIDI Interferometry of T Tauri

Ratzka et al. 2009
A&A 502, 623

Koehler et al. 2008
NACO

T Tau N 100 AU
Sa 17 AU
Sb

[Image of a star field with labeled components and distances]
Binary Sa-Sb: $r, PA = 125.9 \pm 2.9 \text{ mas}, \ 301.4 \pm 4.5^\circ$

Ratzka et al. 2009
A&A 502, 623
T Tau N
G5

$M_\ast = 2.1 \ M_\odot$

$M_d = 0.04 \ M_\odot$

$r_d = 80 \ AU$

$i < 30^\circ$

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

T Tau Sa
A3e

$M_\ast = 2.4 \ M_\odot$

$M_d = 0.003 \ M_\odot$

$r_d = 5 \ AU$

$i \sim 72^\circ \ \tau_v(l.o.s) \sim 15$

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

T Tau Sb
M1

$M_\ast = 0.4 \ M_\odot$

$M_d = 0.0003 \ M_\odot$

$r_d = 5 \ AU$

$i < 60^\circ$

dM/dt = $1 \cdot 10^{-7} \ M_\odot$/yr

• Orbit Sa – Sb: periastron distance ~ 10 AU, disk radii ~ 5 AU: → strong tidal interactions

• Disk planes of Sa and Sb are tilted by > 45 degrees

• Warning: for D > 1 kpc, Sa-Sb would remain unresolved
THE END