The inner disk of RY Tau observed with MATISSE

Johannes S. Martin,

J. Kobus, J. Varga, A. Matter, S. Wolf and MATISSE Collaboration

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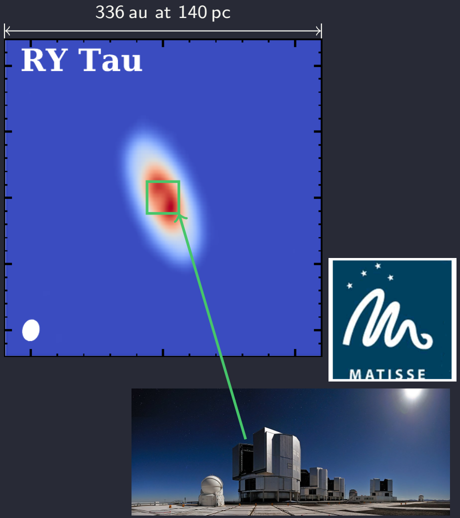
Christian-Albrechts-Universität zu Kiel
Mathematisch-
Naturwissenschaftliche Fakultät

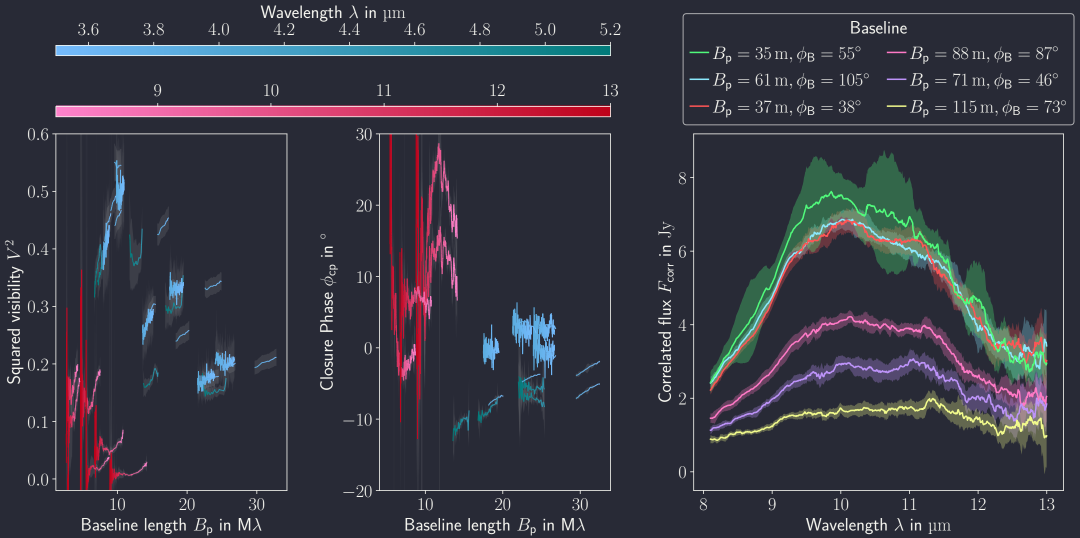
Agenda

- MATISSE GTO observations
- Compositional analysis of silicates
  - Single temperature approximation
  - Crystallinity and grain sizes
- Model-based imaging
  - Temperature gradient model
  - Best fit
- Radiative transfer simulations
  - Modeling approach
  - Best fit
- Conclusion



Credit: Long et al. (2019) and G.Hüdepohl (atacamaphoto.com)/ESO

MATISSE GTO Observations



Compositional analysis of silicates – Single temperature approximation

Single temperature approximation of correlated fluxes per baseline k

(Schegerer et al. 2008)

$$F_{\mathrm{corr},k}(\lambda) = B_\lambda(T_{\mathrm{eff}}) \sum_i c_{i,k} \varkappa_i(\lambda)$$

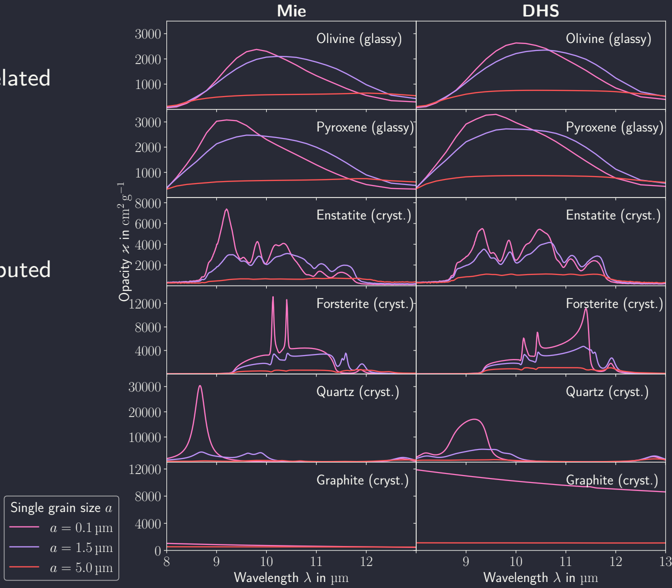
with opacities $\varkappa_i(\lambda)$ of silicate species i computed via `optool`:

(Dominik et al. 2021)

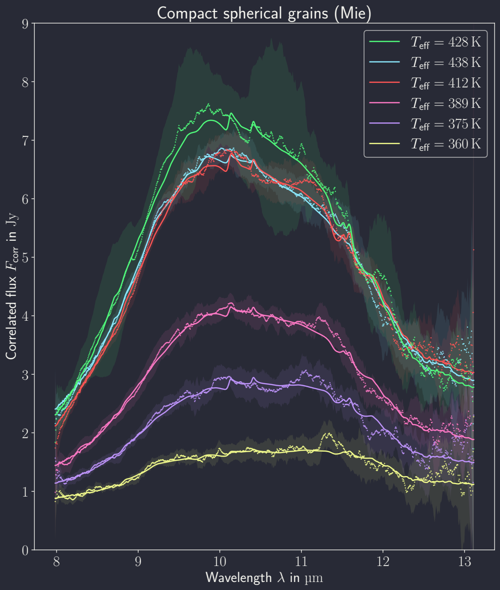
i) Spherical compact grains (Mie)

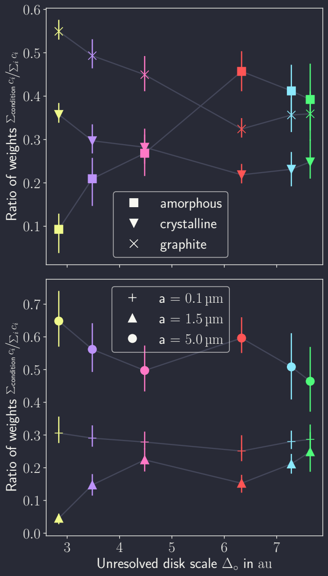
ii) Distribution of hollow spheres (DHS)

with different grain sizes a.



Compositional analysis of silicates – Crystallinity and grain sizes





$\Delta_\circ$	χ^2_{red} Mie	χ^2_{red} DHS
7.6 au	0.089	0.370
7.3 au	0.162	0.523
6.3 au	0.243	0.526
4.5 au	0.195	0.697
3.5 au	0.207	0.478
2.8 au	0.200	0.439

Dominant silicate species

- Olivine $a = 1.5\,\mu\mathrm{m}$
- Pyroxene $a = \{1.5, 5\}\mu\mathrm{m}$
- Enstatite $a = 5\,\mu\mathrm{m}$

Model-based imaging – Temperature gradient model

Temperature gradient model:

(Menu et al. 2015; Varga et al. 2017, 2018)

$$I_{\mathrm{disk},\nu}(r) \propto B_\nu\left(T_{\mathrm{sub}}\left(\frac{r}{R_{\mathrm{sub}}}\right)^q\right), \quad R_{\mathrm{sub}} = \sqrt{\frac{L_\star}{4\pi\sigma_{\mathrm{SB}}T_{\mathrm{sub}}^4}}$$

Fitting the observed visibilities V^2 with `emcee`:

(Foreman-Mackey et al. 2013)

- Free parameters: ι, PA, q and T_{sub}
- Fixed parameters:

$L_\star$	T_{eff}	A_V	d	$f_\circ$
$11.6\,\mathrm{L}_\odot$	5945 K	1.6	140 pc	$\rightarrow$

Stellar properties (Davies et al. 2020)

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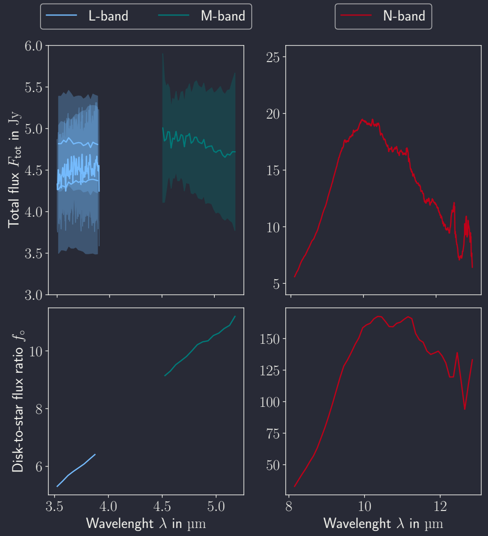
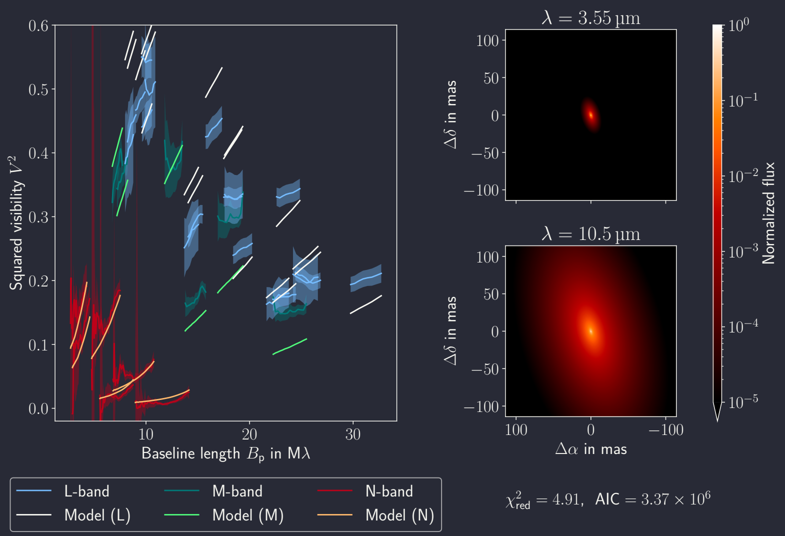


Total flux measurements F_{tot} and derived disk-to-star flux ratio $f_\circ$.

Model-based imaging – Best fit



$\chi^2_\mathrm{red} = 4.91$, AIC $= 3.37 \times 10^6$

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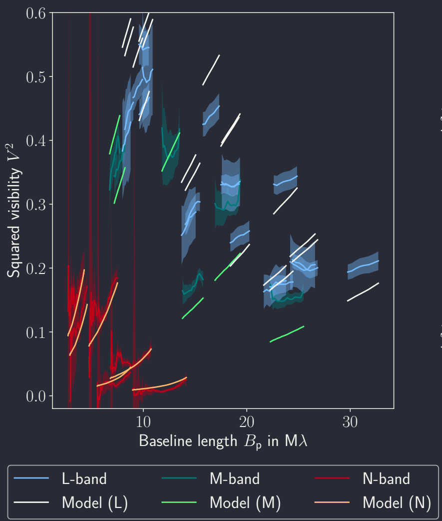

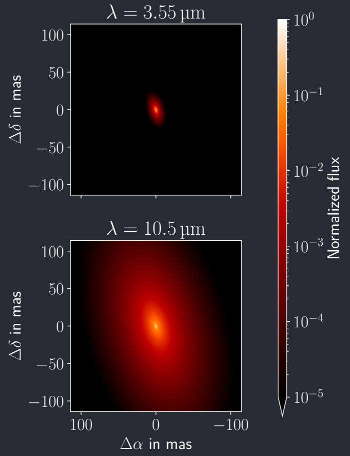

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Best fit parameters

PA	$\left(14.97^{+0.68}_{-0.57}\right)\,^\circ$
ι	$\left(59.55^{+0.37}_{-0.34}\right)\,^\circ$
q	$0.5088^{+0.0009}_{-0.0010}$
T_{sub}	$\left(2865^{+444}_{-172}\right)$ K

- *No inner rim?*

Radiative transfer simulations – Modeling approach

Viscous accretion disk

- Gas density distribution

$$\varrho_{\mathrm{disk}}(r,z) = \varrho_{0,\mathrm{disk}} \left(\frac{R_{\mathrm{ref}}}{r}\right)^{\alpha} \exp\left[-\frac{1}{2}\left(\frac{z}{h(r)}\right)^2\right]$$

$$h(r) = h_{\mathrm{ref}} \left(\frac{r}{R_{\mathrm{ref}}}\right)^{\beta}, \quad R_{\mathrm{ref}} = 100\,\mathrm{au}$$

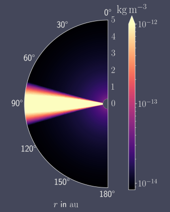
- MRN grain size distribution (Mathis et al. 1977)
- $\iota = 61^\circ$ (temperature gradient modeling)
- $PA = 23^\circ$ (Davies et al. 2020)
- Olivine and Graphite as dust material

M_{disk}? h_{ref}? α? β? →

Monte Carlo radiative transfer

POLARIS (Reissl et al. 2016)

- 3D geometry
- Passively heated disk
- Scattering



↓ galario (Tazzari et al. 2018)

Synthetic observables

- V^2, ϕ_{cp}, F_{corr} and F_{tot}

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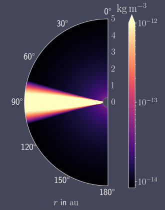
$>$ 1000 simulations

$\Rightarrow$ F_{tot} *underestimated*



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constrain

Synthetic observables

- V^2, ϕ_{cp}, F_{corr} and F_{tot}
- $\chi^2_{\mathrm{red}}(V^2, F_{\mathrm{tot}})$

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Viscous accretion disk

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- Olivine and Graphite as dust material

+

Envelope

$$\varrho_{\mathrm{env}}(r) = \varrho_{0,\mathrm{env}} \left(\frac{r}{1\,\mathrm{au}}\right)^{\gamma}, \gamma \leq 0$$

$$\varrho(r,z) = \begin{cases} \varrho_{\mathrm{disk}}(r,z) & \text{if } \varrho_{\mathrm{disk}}(r,z) \geq \varrho_{\mathrm{env}}(r) \\ \varrho_{\mathrm{env}}(r) & \text{else} \end{cases}$$

M_{disk}? h_{ref}? α? β?

$\varrho_{0,\mathrm{env}}$? γ?

constrain

constrain

Monte Carlo radiative transfer

POLARIS (Reissl et al. 2016)

- 3D geometry
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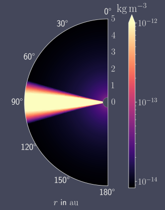
$\Rightarrow$ best fit

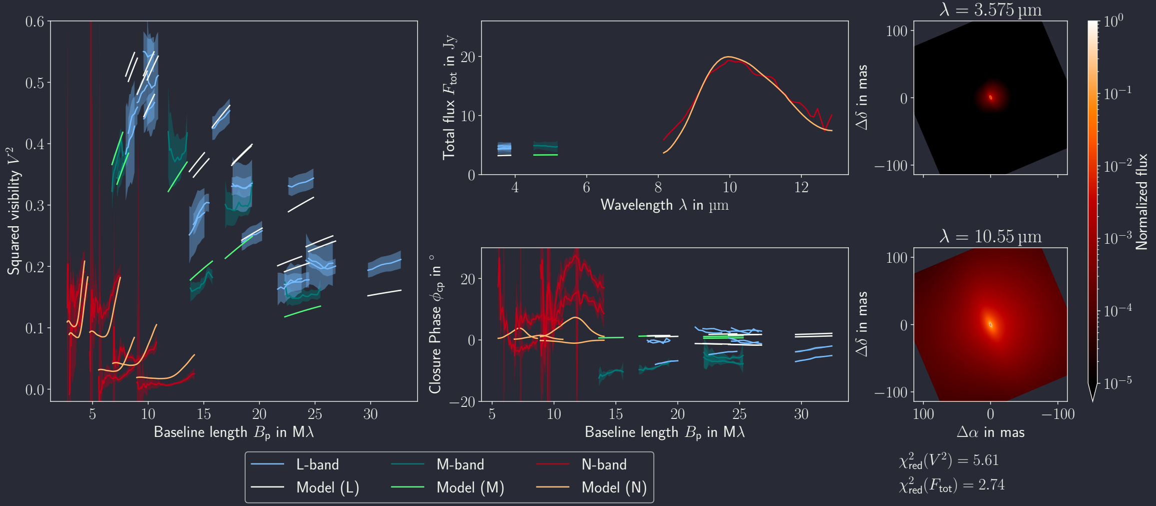


galario (Tazzari et al. 2018)

Synthetic observables

- V^2, ϕ_{cp}, F_{corr} and F_{tot}
- $\chi^2_{\mathrm{red}}(V^2, F_{\mathrm{tot}}) = 8.34$

Radiative transfer simulations – Best fit



$\chi^2_{red}(V^2) = 5.61$
$\chi^2_{red}(F_{tot}) = 2.74$

Conclusion

Compositional analysis of silicates

- Spherical compact grains model observations well
- Trends for unresolved disk scale $\Delta_\circ \downarrow$: grain size $\uparrow$, crystallinity $\uparrow$, continuum $\uparrow$

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Model-based imaging and MCRT simulations

- Evidence for envelope or disk wind (Valegård et al. 2022):
  - Temperature gradient model without a visible inner rim fits observations best
  - Total flux cannot be modeled with only an accretion disk
- Physically consistent disk and envelope 3D radiative transfer model fits observations well

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Paper in preparation ...

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Institut für Theoretische Physik und Astrophysik, Christian-Albrechts-Universität zu Kiel, Leibnizstraße 15, 24118 Kiel, Germany
e-mail: jmartin@astrophysik.uni-kiel.de

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