Scattering and sublimation: A multi-scale view of μm-sized dust in the inclined disc of HD 145718

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Star Formation: From Clouds to Discs – A Tribute to the Career of Lee Hartmann

October 20th 2021
G-LIGHTS: $Q_\phi$ gallery

- Gemini Large Imaging with Gpi: Herbig/T-Tauri Survey

Non-detections not shown - see Rich et al. (2021b, in prep) for details

- Monnier et al. (2017, ApJ, 838, 20); Monnier et al. (2019, ApJ, 872, 122); Laws et al. (2020, ApJ, 888, 7); Rich et al. (2021a, ApJ, 913, 138); Kraus et al. (2020, Science, 369, 1233)
Inspecting HD 145718

\[ Q_\phi = -U \sin(2\phi) - Q \cos(2\phi) \]

\[ U_\phi = Q \sin(2\phi) - U \cos(2\phi) \]

where

\[ \phi = \tan^{-1} \left( \frac{Y - Y_0}{X - X_0} \right) + \gamma \]

Davies et al. (2021, submitted)
Inspecting HD 145718: $U_\phi$ image
Inspecting HD 145718: $Q_\phi$ image
Study motivation: HD 145718

Previous H-band VLTI/PIONIER images (reconstructed from interferometry)

Lazareff et al. (2017, A&A, 599, 85)

Kluska et al. (2020, A&A, 636, 116)

Previous ALMA band 6 ($\lambda = 1.3$mm) image (reconstructed from interferometric observations)

Ansdell et al. (2020, MNRAS 492, 572)
Study motivation: disc structure

Illuminated edge of the “rear” side of the disc (faces away from observer)

Illuminated surface of the “front” side of the disc (faces toward observer)

Image centre (at star’s position)

Radial extent of the dusty disc

Height of scattering surface above disc midplane at disc outer edge
**Qϕ Surface Brightness Isophote fitting**

\[
\begin{align*}
\text{PA} &= \tan^{-1} \left( \frac{\delta \text{RA}}{\delta \text{Dec}} \right) + \frac{\pi}{2} \\
h_{\text{scat}}(r) &= d \left( (\delta \text{RA})^2 + (\delta \text{Dec})^2 \right)^{1/2}
\end{align*}
\]

\[
0.13 \leq \frac{h_{\text{scat}}(r)}{r} \leq 0.16
\]

Aspect ratios consistent with findings for “gapped” discs (0.09-0.25):

- Avenhaus et al. (2018, ApJ, 863, 44)
- Ginski et al. (2016, A&A, 595, 112)

Davies et al. (2021, submitted)
Monte Carlo Radiative Transfer modelling

TORUS (Harries 2000, MNRAS, 315, 722; Harries et al. 2019, A&C, 27, 63)

\[ \rho_{\text{gas}}(r, z) = \frac{\Sigma_{\text{gas}}(r)}{h_{\text{gas}}(r) \sqrt{2\pi}} \exp \left\{ -\frac{1}{2} \left( \frac{z}{h_{\text{gas}}(r)} \right)^2 \right\} \]

\[ h_{\text{gas}}(r) = h_{0,\text{gas}} \left( \frac{r}{r_0} \right)^\beta \quad ; \quad \Sigma_{\text{gas}}(r) = \Sigma_{0,\text{gas}} \left( \frac{r}{r_0} \right)^{-p} \]

see Shakura & Sunyaev (1973, A&A, 24, 337)

Small grains:
\[ T_{\text{sub},1} = G \rho_{\text{gas}}^2 (r, z) \]
see Pollack et al. (1994, ApJ, 421, 615)
\[ n(a) \propto a^{-3.5} \]
\[ a_{\text{min}} = 0.01 \mu m \]
\[ 0.14 \leq a_{\text{max}} \leq 1.30 \mu m \]
see Isella & Natta (2005, A&A, 438, 899); Davies et al. (2020, ApJ, 897, 31); Davies & Harries (in prep)

\[ M_{\text{disc}} = \frac{F_v d^2}{\kappa_v B_v (T_{\text{dust}})} = 0.0097 M_\odot \]

Davies et al. (2021, submitted)
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see Shakura & Sunyaev (1973, A&A, 24, 337)

\[ T_{\text{eff}} = 8000 \text{ K} \] (Fairlamb et al. 2015, MNRAS, 453, 976); \( d = 152.5 \text{ pc} \) (Gaia eDR3)

\[ \dot{L}_{\text{disc}} = \frac{F_v d^2}{\kappa_v B_v (T_{\text{dust}})} = 0.0097 \text{ M}_\odot \]

Large grains:

\[ T_{\text{sub},2} = 1200 \text{ K} \]
\[ h_2 = f \ h_{\text{gas}} \]
\[ n(a) \propto a^{-3.5} \]

Based on \( BVRI \) photometry from Lazareff et al. (2017, A&A, 599, 85) with \( R_v = 3.1 \)

\[ L_* = 14.3L_\odot \]
\[ A_V = 0.89 \text{ mag} \]
\[ R_* = 1.97R_\odot \]

\[ \text{consistent } L_* \text{ found when using faint epoch photometry & } R_v = 5.0 \]

suggests a > \( \lambda/2\pi \) in occulting medium

Davies et al. (2021, submitted)
Complementary observational data

Davies (2021, SoftwareX, 14, 100687)
TORUS model fitting

| Parameter       | Model value |
|-----------------|-------------|
| $h_{0\text{,gas}}$ (au) | 10          |
| $f(h_{0\text{,gas}})$        | 0.1         |
| $\beta$         | 1.15        |
| $a_{\text{max}}$ (μm)       | 0.50        |
| $R_{\text{out}}$ (au)       | 75          |
| $i$ (°)         | 72          |
| $\text{PA}$ (°)   | 0           |

Davies et al. (2021, submitted)
### TORUS model fitting

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Location and extent of sublimation rim controlled by size of largest grains present:

- Isella & Natta (2005, A&A, 438, 899),
- Tannirkulam et al. (2007, ApJ, 661, 374)

Davies et al. (2021, submitted)
Tests of the isophote fitting with TORUS

Scattering surface flaring from GPI data isophote fit

Scattering height, $h_R = h_{65} \left( \frac{r}{65 \text{ au}} \right)^\beta$

Scattering surface flaring from TORUS model and its isophotes

Davies et al. (2021, submitted)
Tests of the isophote fitting with TORUS

Stretched to the east close to the edge of the disc

Squashed in the west due to the relative back-scattering inefficiency

Davies et al. (2021, submitted)
Summary

- G-LIGHTS observations of HD 145718, complemented with new and archival IR interferometry (CHARA+ VLTI) and archival spectro-photometry (use SEDBYS!)

- \( i = 67-71^\circ \), major axis PA = -1.0 – +0.6\(^\circ\), \( R_{\text{out}} \approx 75 \) au, \( h_{\text{scat}}(r)/r = 0.13 – 0.16 \) (J-band) and 0.10 – 0.13 (H-band)

- Apparent evidence that grains > \( \lambda/2\pi \) are present in the surface layers of the disc and grains > 0.50 \( \mu \)m have settled:
  - Scattering phase function (``pacman-like” feature in the \( Q_\phi \) images)
  - Shape of the sublimation rim
  - Consistent values of \( L_\star \) found when using \( R_v = 3.1 \) with bright-epoch and \( R_v = 5.0 \) with faint-epoch photometry

- If the inclination can be independently constrained (using e.g. ALMA), can use isophote fitting method on similarly inclined, apparently full discs to probe the flaring of the scattering surface.

Davies et al. (2021, submitted)