Dust Entrainment in Externally Photo-Evaporated Proto-Planetary Discs

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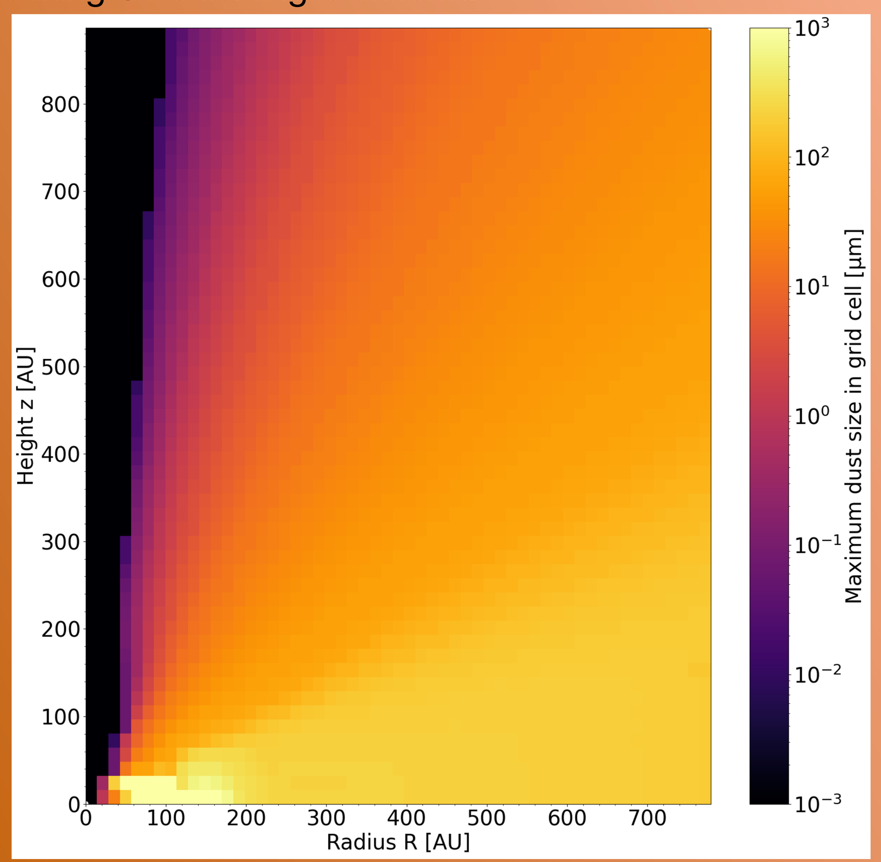
Abstract

- The environment in which proto-planetary discs evolve plays a crucial role in their evolution.
- Planets form in short-lived discs around young stars.
- One important mechanism for dispersing the disc is external photo-evaporation from nearby large stars.
- This heats the disc and entrains (carries out) dust, reducing the available mass for forming planets.
- The dust also shields the disc from further radiation, forming a feedback loop.
- External winds are able to entrain grains up to 100μm in the midplane, down to micron size in winds above the disc surface.
- Preliminary synthetic images and SEDs of the disc and wind.

Dust grain sizes in the wind

- Tracer dust particles are placed at the base of the wind, to set an upper bound on the maximum dust size entrained in the wind.
- The resulting dust sizes decreases with radius and polar angle, with a dust size gradient along the midplane (but no gradient along dust paths when launched from the disc surface).
- Since at least 0.1μm dust is entrained in most of the wind, the resulting UV shielding is uniform.

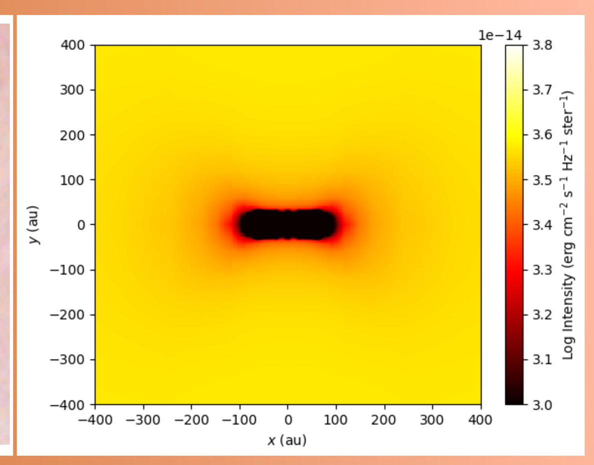


[Paine et al., 2025]

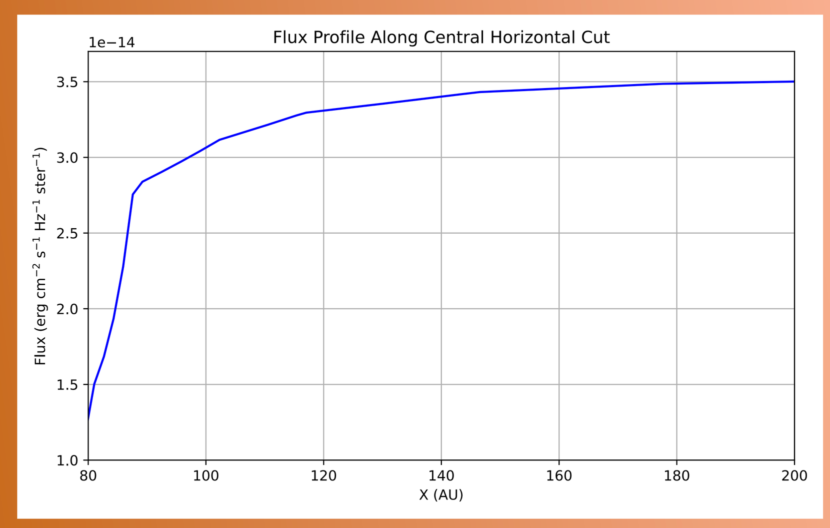
Images of disc winds

- Dust in discs can be observed through absorption in optical or emission in IR and mm.
- Dust sizes can be extracted from absorption in regions with a bright background source (e.g. [Miotello+2012]).
- Next steps are to apply this strategy to many more discs in UV/Visible/IR to extract dust sizes and properties in external winds.

[Ricci+2008]



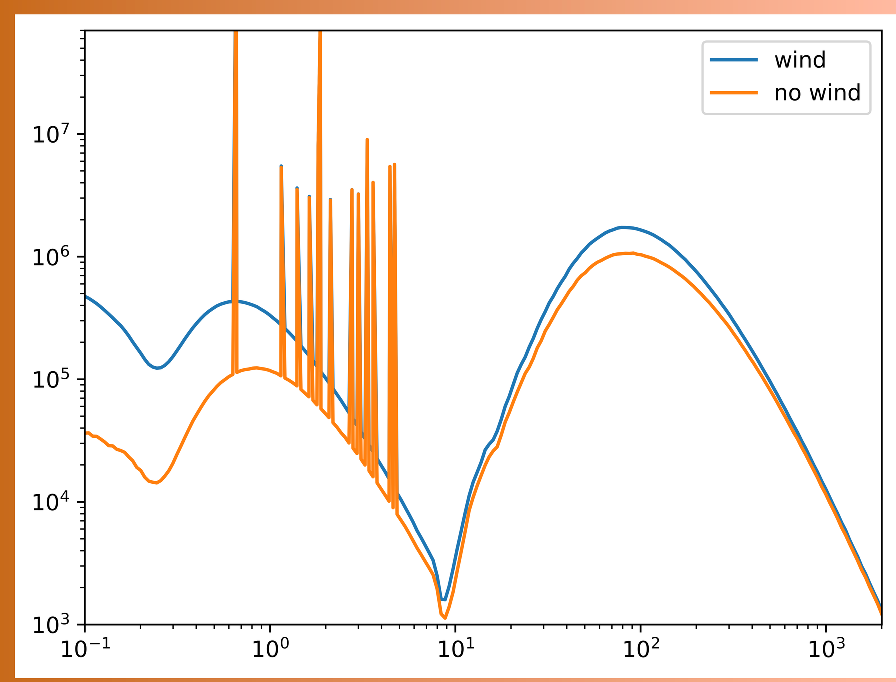
[Paine&Haworth, in prep.]



[Paine&Haworth, in prep.]

Disc wind SED

- Preliminary SEDs seem to show an excess in dust emissions across the infrared to the far-infrared (2~100μm).
- Emissions in the sub-mm and mm remain similar to discs without extended dusty winds, as these are due to cold dust within the disc.
- In future work, we will determine how this can be factored into SED modelling of irradiated discs.



[Paine&Haworth, in prep.]

EUV Radiation

FUV Radiation

Interstellar Medium

Ionised Gas

[OII], [OIII], [He I], ... lines

Photo-dissociated Gas

Proto-planetary Disc

[CO], ... lines and larger dust

Gas and Dust

- Gas orbits at sub-Keplerian velocities, supported by its outward pressure gradient.

$$\frac{v_{gas}^2}{r} = \frac{v_{kep}^2}{r} + \frac{1}{\rho}\frac{\partial P}{\partial r}$$

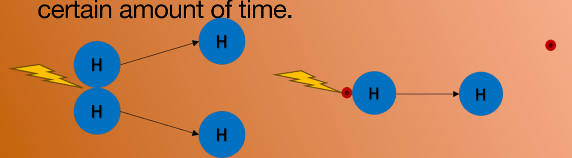
- Dust orbits at Keplerian velocity and will experience drag.
- Over time, drag slows down the dust and it will be captured by the central star.

Dust in the wind

- Photoevaporative winds drive gas mass loss from the disc.
- Dust up to a certain size is also entrained from the disc.
- Largest grains are entrained from the midplane and disc edge.
- Dust entrained from the disc surface is an order of magnitude smaller.
- Entrained dust from the disc surface *doesn't* settle back down to the midplane.

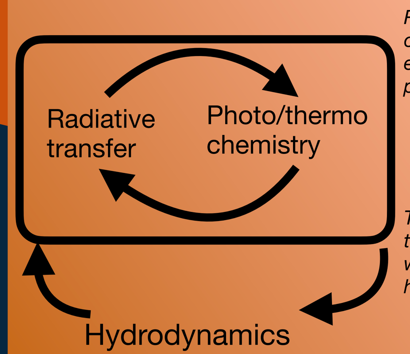
What is Photo-Evaporation?

- Far Ultraviolet (FUV) Radiation: 6-13.6eV, photo-dissociates Hydrogen (H_2 -> H + H).
- Extreme Ultraviolet (EUV) Radiation: 13.6eV-100eV, ionises Hydrogen (H -> H^+).
- X-Ray Radiation: 0.1-1keV, heats the disc and triggers chemical reactions.
- Gas is heated and expelled from the disc, dragging dust along with it.
- Internal photo-evaporation is due to the central star.
- External photo-evaporation is due to nearby stars, typically O and B-stars.
- Dust carried out to the edges of the disc will shield the interior of the disc from radiation, preventing further photo-evaporation.
- Creates feedback loop, where strong external photo-evaporation will protect a disc for a certain amount of time.



Why is modeling external photo-evaporation difficult?

It is technically challenging and computationally expensive!



It is computationally cheaper to add dust in pre-rendered models. This is justified since the dust feedback on the gas is expected to be negligible.

What is a proto-planetary disc?

- Stars form from collapsing gas clouds, leaving behind a disc of 99% H and He and 1% dust.
- The dust and gas becomes the mass reservoir from which planets are formed.
- Signatures of photo-evaporation are observed by looking at dust in the infrared and at specific chemical lines (e.g. CO, C[II], H_2).

What is dust?

- Small grains of silicates, metals and ices.
- Through collisions it can grow and fractionate.
- Can be sub-micron sized up to planet sized.

References

- Ricci et al. 2008, AJ, 136, 2136
- Miotello et al. 2012, APJ, 757:78
- Winter & Haworth 2022, EPJP, 137, 1132W
- Haworth et al. 2023, MNRAS, 526, 4315H
- Paine et al. 2025, MNRAS, 539, 1414