Chemical signatures of a planet-induced warp in a protoplanetary disc

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Models

Physical model

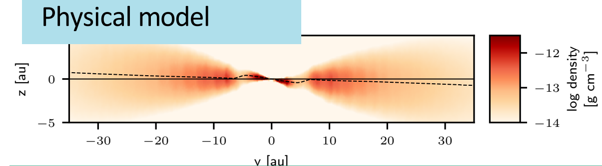


Fig. 1. Density cross-section of the hydrodynamical snapshot. The planet at 5 au breaks the disc into a misaligned inner disc and warped outer disc.

- **3D Phantom SPH simulation of 6.5 M_{Jup} planet misaligned 12° relative to the disc, at 5 au (see Nealon+2019).** Aligned planet modelled for comparison.
- 1 $M_{\odot}$ star at 1 Myr, 5×10^{-3} $M_{\odot}$ disc initially r_{in} = 0.1 au and r_{out} = 50 au, viscosity $\alpha = 10^{-3}$, $H/R = 0.05(R/R_0)^{1/4}$
- Gas phase and gas-grain chemistry including photoionization (Walsh+ 2015).
- Chemistry evolved in snapshot (Fig.1) for 10^6 yrs- equilibrium reached.
- MCFOST ray-tracing line radiative transfer.

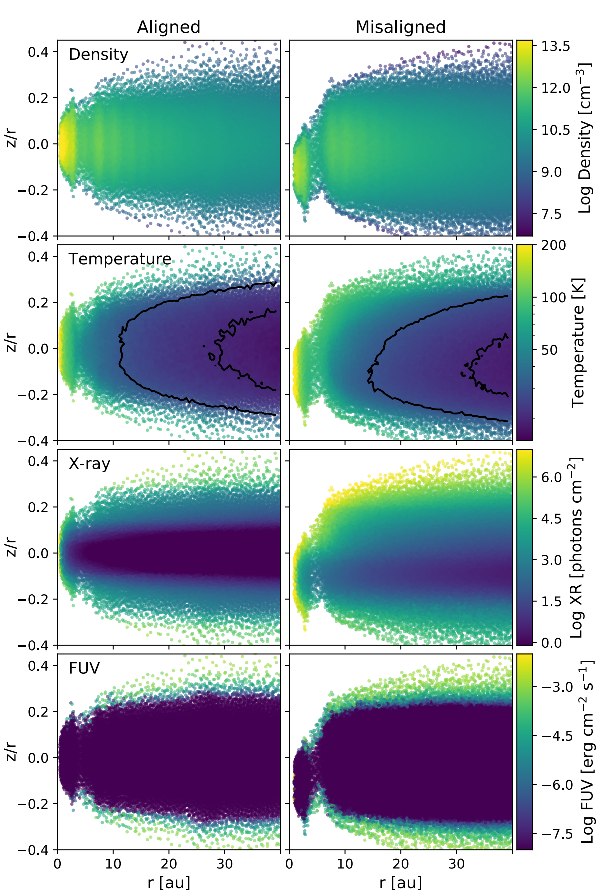


Fig. 2. Cross-sections of the disc along the y-axis, showing the physical properties for the aligned & misaligned cases.

The temperature of the upper side of the warped disc is higher than the unperturbed disc. The X-ray and FUV fields are also greater on upper side of the warp.

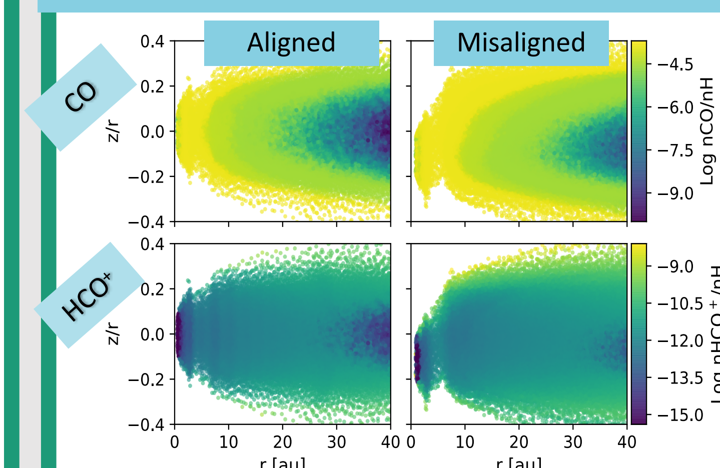
Introduction

- Planet-hosting discs can be warped by a misaligned embedded planet.
- High resolution observations of protoplanetary discs have revealed asymmetric structures and non-Keplerian motion, some consistent with a warped disc.
- **A warped disc surface leads to azimuthal temperature variation → how does this affect the chemistry?**
- **Could molecular lines provide a diagnostic of protoplanetary disc warps?**

Summary

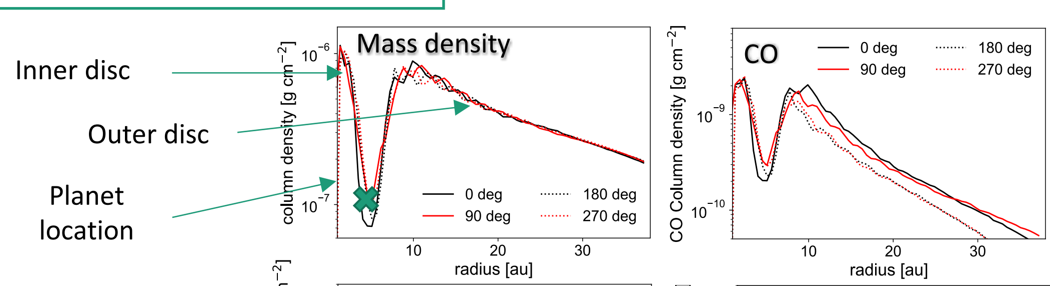
Chemical abundances in warped protoplanetary vary azimuthally.
Line emission from warped discs is asymmetric, though the exact morphology will depend on the relative orientations of the inner disc, outer disc and planet, and the molecular species.
A planet at ~au radii may cause measurable asymmetries in line emission at much greater radii.

Chemical abundance



There is a clear asymmetry in the abundances, primarily driven by the temperature differences. The CO abundances (Fig.3) follow the temperature structure shown in Fig.2. For HCO+ we see the influence of the enhanced X-ray irradiation on the upper side of the warp. The azimuthal temperature variation also causes asymmetric snowlines, for example in CO. From Fig.4, we see that for different azimuths the molecular column densities may vary by an order of magnitude at the same radius. The difference is particularly great in the case of SO.

Fig. 3. Slices through the warp showing the fractional abundances of CO and HCO⁺.



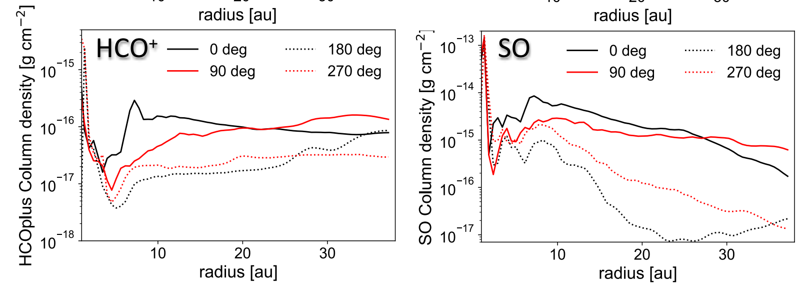


Fig. 4. Column density to the disc midplane for selected species for slices taken at 90° intervals around the disc.

Simulated line emission maps

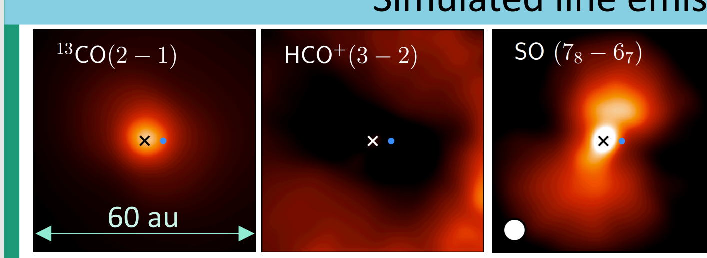


Fig. 5. Moment 0 (integrated intensity) maps smoothed with a 0.1 arcsec Gaussian beam. 'x' marks the star position, blue circle marks the planet position, white circle shows beam size.

We model line emission maps for a distance of 60 pc and smooth with a 0.1 arcsec Gaussian beam. The selected lines trace different disc regions and present different asymmetries. ^{13}CO emission shows a shift in the emission peak towards the upper side of the warp. Remarkably, a planet at 5 au causes asymmetries in HCO^+ emission on the scale of ~30 au.