Laboratory Astrophysics: from Observations to Interpretation
Proceedings IAU Symposium No. 350, 2019
F. Salama & H. Linnartz, eds.
doi:10.1017/S1743921319006367

The gas structure of the HD 163296 planet-forming disk - gas gaps or not?

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Abstract. HD 163296 is a young star surrounded by a planet-forming disk that shows clear signatures of dust gaps and rings; likely an indication of ongoing planet formation. We use the radiation thermochemical disk code ProDiMo to investigate the impact of dust/gas gaps on the temperature, chemistry and observables. Furthermore, we model high spatial resolution gas and dust observation of HD 163296 (ALMA/DSHARP). Our first results indicate that features in the observed radial intensity profile of the ^{12}CO line are a consequence of the dust gaps and do not require gas depletion. Those preliminary results indicate that self-consistent modelling of the gas (chemistry, heating/cooling) and dust is necessary to accurately infer the degree of gas depletion within dust gaps. Such information is crucial to understand the processes that generate the disk substructure and their relation to planet formation.

Keywords. stars: pre–main-sequence, (stars:) planetary systems: protoplanetary disks, astrochemistry, radiative transfer, methods: numerical

1. Introduction and Method

HD 163296 is a Herbig Ae/Be star surrounded by a planet-forming disk that shows clear signatures of dust gaps and rings (Isella *et al.* (2018)). The most intriguing theory for the origin of the dust gaps are embedded planets (e.g. Liu *et al.* (2018); Zhang *et al.* (2018)). However, also other theories have been proposed such as molecular ice lines (e.g. Pinilla *et al.* (2017)), dust evolution (Birnstiel *et al.* (2015)) or magnetized disks (e.g. Flock *et al.* (2015)). In the planet scenario, significant gas depletion within the dust gaps is predicted whereas for the other theories only shallow or no gas depletion at all is expected.

We use the radiation thermochemical disk code ProDiMo (PROtoplanetary DIsk MOdel, e.g. Woitke *et al.* (2016)) to self-consistently model the dust and gas component of HD 163296. We discuss two types of models; the first one is based on the dust disk model of Muro-Arena *et al.* (2018) which fits the ALMA mm image (pre DSHARP) and the SPHERE scattered light images; for the second one we focused on the recently published high spatial resolution DSHARP dataset (Andrews *et al.* (2018); Isella *et al.* (2018)). Both models are based on a model from the DIANA project (Woitke *et al.*

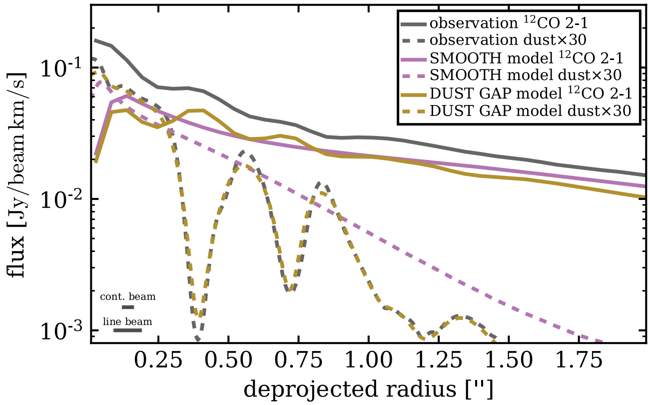

Figure 1. Radial intensity profiles of HD 163296 for the dust (*dashed lines*) and for ^{12}CO $J = 2-1$ (*solid lines*). The *black lines* show the observational data (DSHARP project). The SMOOTH model (*magenta*) has no gas or dust gaps, the DUST GAP model (*gold*) has dust gaps but *no* gas gaps.

(2019)) that fits the SED and CO line fluxes (mid/far infrared to mm) within a factor of two or better, but did not yet include any gap or ring structures. ProDiMo models allow to study the impact of the dust gaps/rings on the disk chemistry, temperature structure and gas observables.

2. Results and Conclusions

We match the observed radial intensity profiles of the continuum by varying the dust surface density. On top of this dust structure we either use a smooth gas surface density profile (no gas gaps) or a profile where we introduce gas gaps at the location of the dust gaps (constant gas to dust ratio). The resulting column density profiles for CO and CN show gaps/rings in both models. CO is more sensitive to gas depletion and less sensitive to dust depletion (self-shielding; Facchini *et al.* (2018)). CN seems to be a good dust gap tracer. The CN column density increases within the dust gaps (i.e. enhanced radiation field within the dust gaps), whereas in models with gas depletion within the dust gaps, this ring structure is washed out again. This indicates that observations of multiple molecules are a promising way to derive total gas surfaces density profiles in disks with dust gaps.

Fig. 1 shows our modelling results for the DSHARP data of HD 163296. Dust gaps can produce ring like features in the ^{12}CO line emission, with the enhanced CO emission at the location of the dust gaps (also visible in the observational data). ^{12}CO is highly optically thick and therefore sensitive to temperature changes within the dust gaps (van der Marel *et al.* (2018)). In the dust gaps the temperature increases as radiation can penetrate deeper into the disk (vertically). Although this preliminary model still needs to be improved, it indicates that self-consistent modelling of the dust and gas structure is required to interpret molecular line emission of disks with dust and possible gas gaps. Our models indicate that observations of multiple molecules and self-consistent modelling of the dust and gas is required to accurately derive gas surface density profiles for disks with dust gaps, information most relevant for gap and planet formation theories.

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