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Searching for chemical signatures of planet formation

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Abstract. High spatial resolution observations with ALMA and VLT/SPHERE show gaps and rings in continuum emission of protoplanetary disks, possibly indicating ongoing planet formation. However, it is still unclear if the gas follows the dust distribution. We present radiation thermo-chemical models for the disk of HD 163296 to study the impact of dust and gas gaps on the chemistry and molecular line emission. We compare a model with only dust gaps to a model that also has gas gaps. In both models, rings and gaps are visible in (sub)mm molecular line emission. Due to chemistry, certain molecules are sensitive to dust gaps where others are more sensitive to gas depletion. Observations of multiple molecules might allow to accurately determine the degree of gas depletion within the dust gaps, information crucial to discriminate between gap formation theories (e.g. planets, ice lines).

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

1. Introduction & Methods

High spatial resolution observations with ALMA and VLT/SPHERE reveal gaps and rings in dust continuum images of protoplanetary disks (e.g. Andrews *et al.* 2016, Avenhaus *et al.* 2018). Although those gaps and rings are very prominent in dust observations, they are not yet clearly detected in the gas. An accurate measurement of the gas column densities and the possible gas depletion within the dust gaps is crucial to discriminate between different gap formation scenarios. If planets produced the gaps, one would expect strong gas depletion and gas gaps, other formation scenarios such as dust evolution, molecular ice lines or deadzones predict no or only shallow gas gaps (e.g. Isella *et al.* 2016, Birnstiel *et al.* 2015, Zhang *et al.* 2015, Pinilla *et al.* 2016).

Here we present a model for the HD 163296 protoplanetary disk to study in detail the impact of the observed dust gaps and possible gas gaps on the chemistry and on molecular line emission. We used the radiation thermo-chemical disk model ProDiMo (PROtoplanetary DIsk MOdel, e.g. Woitke *et al.* 2009, Kamp *et al.* 2017) to self-consistently calculate dust and gas temperatures, molecular abundances and synthetic observables. The models are based on the HD 163296 ProDiMo model presented in Woitke *et al.* (2019),

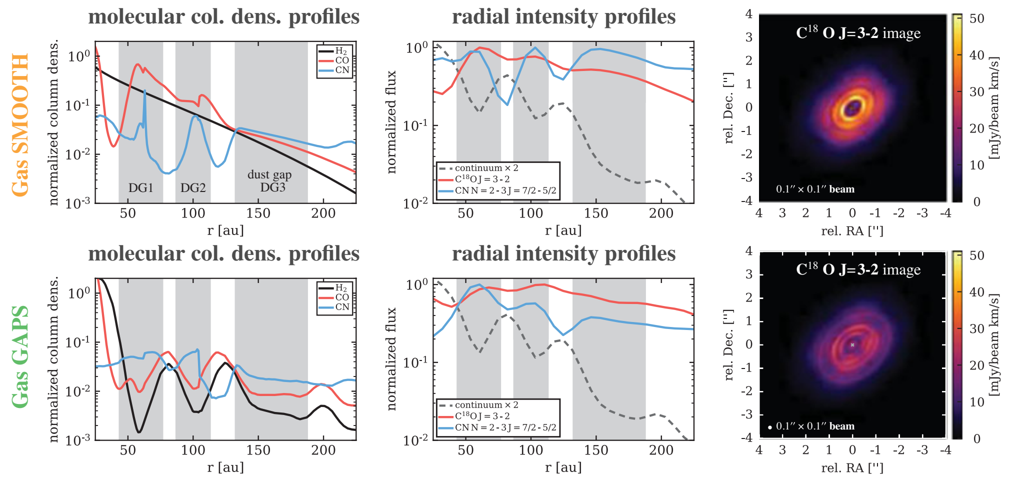

Figure 1. Two models for the HD 163296 disk, one without gas gaps (SMOOTH, *top row*) and one with gas gaps (GAPS, *bottom row*). The gray boxes mark the dust gaps present in both models. *First column:* normalized radial molecular column density profiles (H_2 traces the total gas column); *second column:* the corresponding radial intensity profiles (normalized to the peak intensity); *third column:* integrated intensity map for $C^{18}O$ $J = 3 - 2$.

but was refined by Muro-Arena *et al.* (2018) to fit new VLT/SPHERE and ALMA continuum observations that show prominent dust gaps and rings.

2. Results & Conclusions

In Fig. 1, we compare two models, one with a smooth gas surface density profile (SMOOTH) and one with gas gaps (GAPS). As an example, we show the column densities and observables for the molecules CO and CN. The molecular column density profiles show gaps and rings in both models. In the SMOOTH model this is solely due to the impact of dust gaps on the chemistry (e.g. temperature, radiation field). In the models CO quite nicely follows the total gas surface density (see also Facchini *et al.* 2018), but also in the SMOOTH model gaps are seen in the $C^{18}O$ line image. The $C^{18}O$ line is optically thick and therefore sensitive to temperature changes caused by the dust gaps (see also van der Marel *et al.* 2018). In the SMOOTH model, CN gaps and rings appear due to dust depletion and the column density actually peaks within the dust gaps, but in the gas GAPS model these peaks are washed out, making CN a good tracer of dust gaps without gas depletion. This example shows that self-consistent dust and gas modeling including chemistry is required to accurately infer gas column densities (gas gaps) from molecular line observations and that observations of multiple molecules will allow for a more accurate measurement of gas depletion within dust gaps.

References

Andrews, S. M.,Wilner, D. J., Zhu, Z., Birnstiel, T. *et al.* 2016, *ApJ* (Letters), 820, L40
Avenhaus, H., Quanz, S. P.,Garufi, A., Perez, S., Casassus, S. *et al.* 2018, *ApJ*, 863, 44
Birnstiel, T., Andrews, Sean M., Pinilla, P., & Kama, M. 2015, *ApJ*, 813
Facchini, S., Pinilla, P., van Dishoeck, E. F. & de Juan Ovelar, M. 2018, *A&A*, 612
Isella, A., Guidi, G., Testi, L., Liu, S., Li, H., Li, S. *et al.* 2016, *Phys. Rev. Lett.*, 117, 251101
Kamp, I., Thi, W.-F., Woitke, P., Rab, C., Bouma, S., & Ménard, F. 2017, *A&A*, 607, A41
Muro-Arena, G. A., Dominik, C., Waters, L. B. F. M., Min, M. *et al.* 2018, *A&A*, 614, A24
Pinilla, P., Flock, M., Ovelar, M. de Juan & Birnstiel, T. 2016, *A&A*, 596
van der Marel, N., Williams, J. P., & Bruderer, S. 2018, *ApJ* (Letters), 867, L14

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Woitke, P., Kamp, I., & Thi, W.-F. 2009, *A&A*, 501, 383
Woitke, P., Kamp, I., Antonellini, S., Anthonioz, F., *et al.*, 2019, *PASP*, 131, 064301
Zhang, K., Blake, G. A., & Bergin, E. A. 2015, *ApJ* (Letters), 806, L7

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