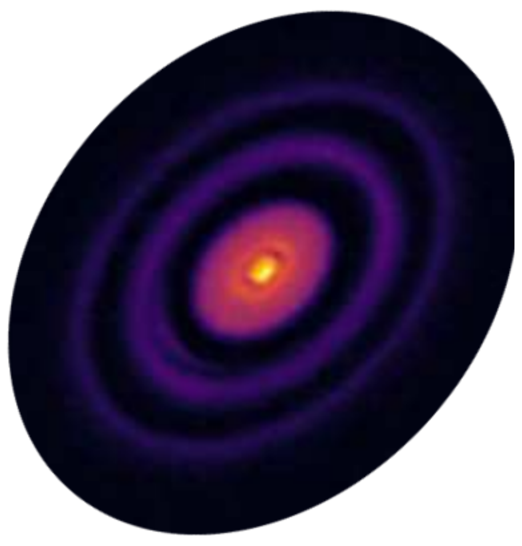


The planet-forming disk HD 163296
Gas gaps … or not?

Christian Rab[1], Muro-Arena G.A.[2], Kamp I.[1], Ginski C.[2], Dominik C.[2], Waters L.B.F.M.[2,3], Thi W.-F.[4], Woitke P.[5]

[1]Kapteyn Astronomical Institute, University of Groningen;[2]Anton Pannekoek Institute, University of Amsterdam; [3]SRON Netherlands Institute for Space and Research; [4]MPE ;[5]SUPA, School of Physics & Astronomy, University of St. Andrews

Contact: `rab@astro.rug.nl`

Abstract

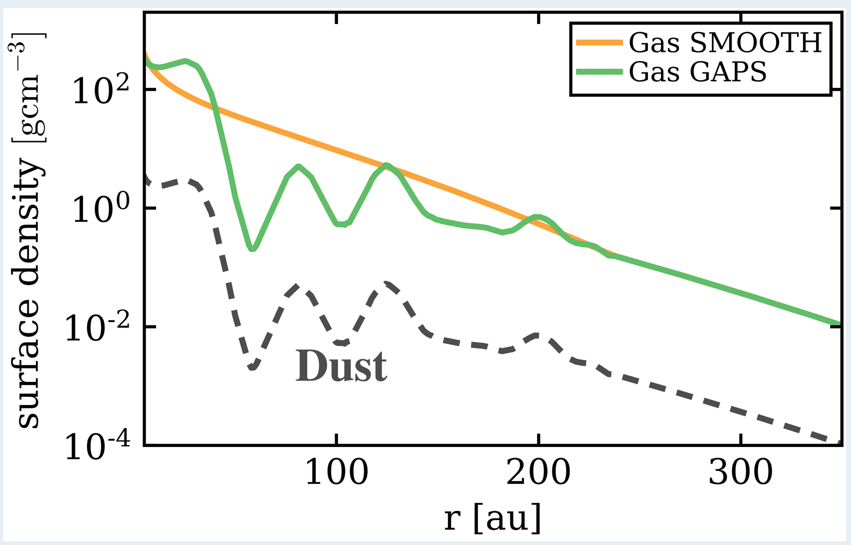
HD 163296 is a Herbig Ae/Be star surrounded by a planet-forming disk that shows clear signatures of dust gaps and rings (Isella et al. 2016, 2018, see top left image).
The most intriguing theory for the origin of the dust gaps are embedded planets (e.g. Isella et al. 2016; Liu et al. 2018; Zhang et al. 2018). However, also other theories have been proposed such as molecular ice lines (Zhang et al. 2015; Pinilla et al. 2017), dust evolution (Birnstiel et al. 2015) or magnetized disks (Flock et al. 2015; Pinilla et al. 2016). In the planet scenario, significant gas depletion within the dust gaps is predicted whereas for the other theories only shallow or no gas gaps at all are expected.
We present models which allow to investigate self-consistently the impact of dust/gas gaps on the temperature, chemistry and observables. Such models are crucial for deriving gas depletion factors from molecular line observations.

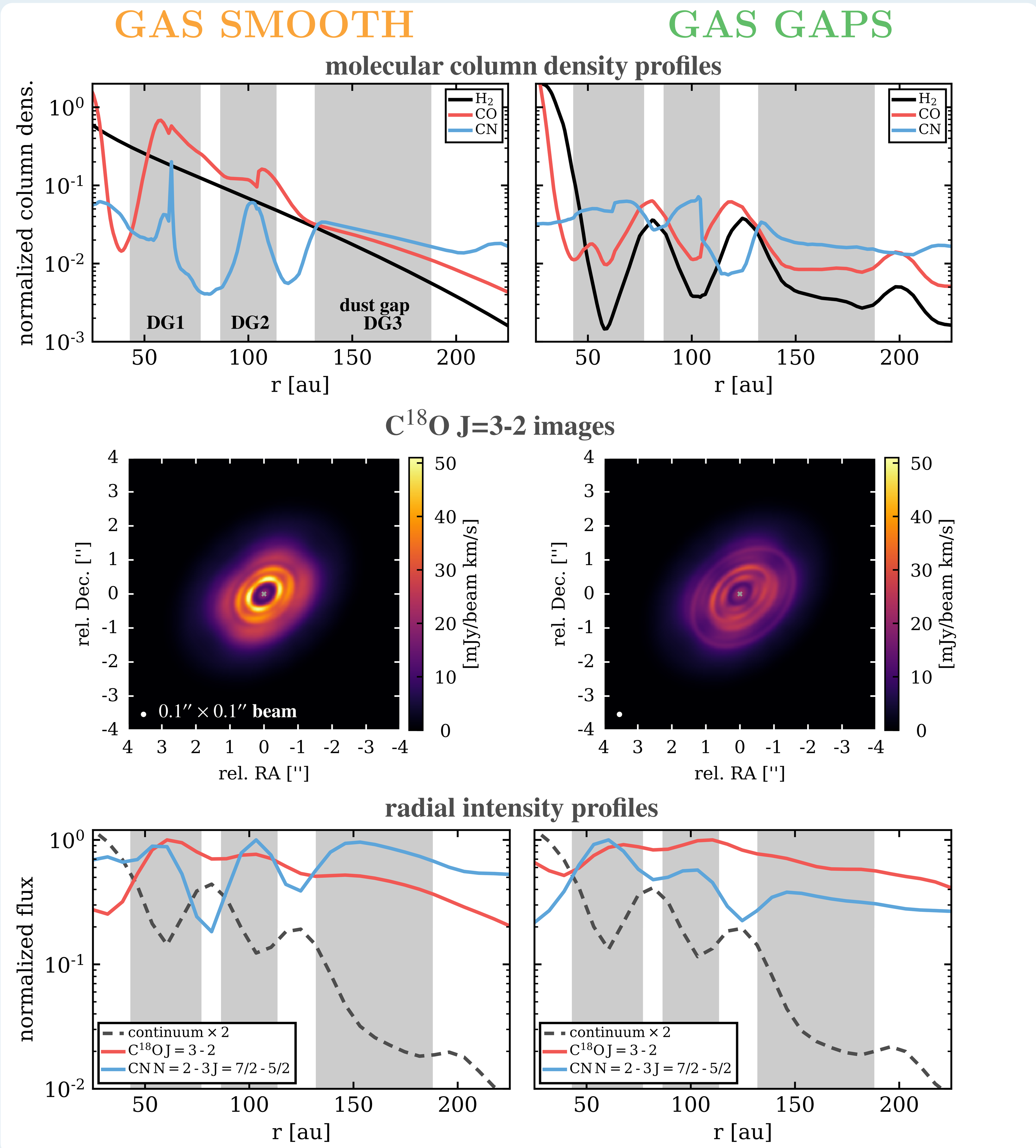
Method

We use the radiation thermochemical disk code ProDiMo (e.g. Woitke et al. 2016) to self-consistently model the dust and gas component of HD 163296. We present two 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 models from the DIANA project (Woitke et al. 2018) that fit the SED and CO line fluxes (mid/far infrared to mm) within a factor of 2 or better but did not include any gap or ring structures. This approach allows us to study the impact of the dust gaps/rings on the disk chemistry, temperature structure and gas observables.

Gap chemistry

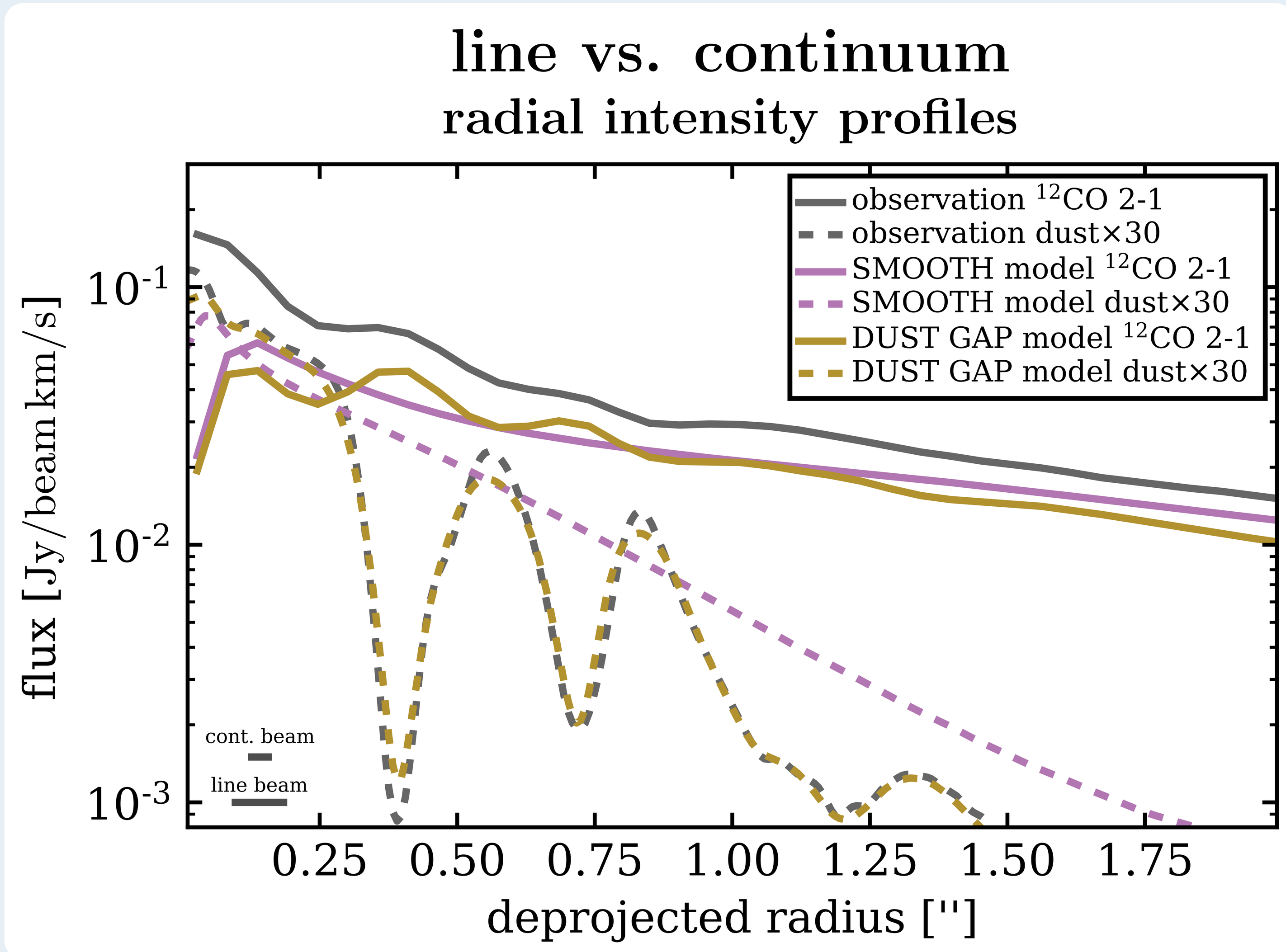
Here we show two ProDiMo models with different gas surface density profiles: one without gas gaps (GAS SMOOTH) and one with gas GAS GAPS (r.h.s Figure). In both models the underlying dust disk structure is identical to the detailed dust model (pre DSHARP) of Muro-Arena et al. (2018). With these two extreme cases we can study in detail the impact of dust and possible gas gaps on the chemistry and observables.





- the molecular column density profiles show gaps/rings in both models; in the GAS SMOOTH model this is solely due to the impact of dust gaps on the chemistry (e.g. temperature change, see also van der Marel et al. 2018)
- CO is sensitive to gas depletion and less sensitive to dust depletion (self-shielding; see also Facchini et al. 2018)
- CN gaps/rings appear due to dust depletion (enhanced radiation field, ice sublimation) but are somewhat washed out in the GAS GAPS model → CN possible dust gap tracer
- even in C^{18}O the gaps are only marginally visible (low contrast); the line is still partly optically thick (i.e. rings) → it traces temperature variations
- rings/gaps in the CN line images are actually more pronounced in the model without gas gaps

DSHARP modelling



- initial model with SMOOTH dust and gas surface densities; introduce dust gaps/rings by modulating the dust surface density according to the observed profile → DUST GAP model
- the gas surface density is identical in both models
- the SMOOTH DIANA model is in good agreement with the slope of the radial line profile; no attempt was made to fit the new line data; problems with the inner disk → additional adjustment required
- dust gaps seem to be the sole reason for the wavy pattern in the ^{12}CO $J = 2-1$ radial intensity profile (DUST GAP model)
- DSHARP line data has the sensitivity and spatial resolution to trace possible gas gaps; but optically thin tracers and multiple molecules are required to infer accurate gas column densities
- **THIS IS WORK IN PROGESS!**

Conclusions

- self-consistent dust&gas modelling including chemistry and gas thermal balance is required to accurately infer gas column densities (gas gaps) from molecular line observations
- with the here presented self-consistent dust&gas model predictions for other possible gas gap tracers can be made (e.g. CN, CS Teague et al. 2017, HCO^+ Yen et al. 2016)
- dedicated gas observations with ALMA of multiple molecules with the necessary spatial resolution and with high sensitivity (to trace low contrast features) are required to constrain possible gas gaps and derive accurate total gas column densities

Our first results suggest that no gas gaps are required for HD 163296, but high quality observational data of multiple molecules in combination with consistent dust&gas modelling is required to conclusively answer the question: "Are there gas gaps in HD 163296 … or not?"