# Systematic Evolutions of CO Gas Abundance in Protoplanetary Disks

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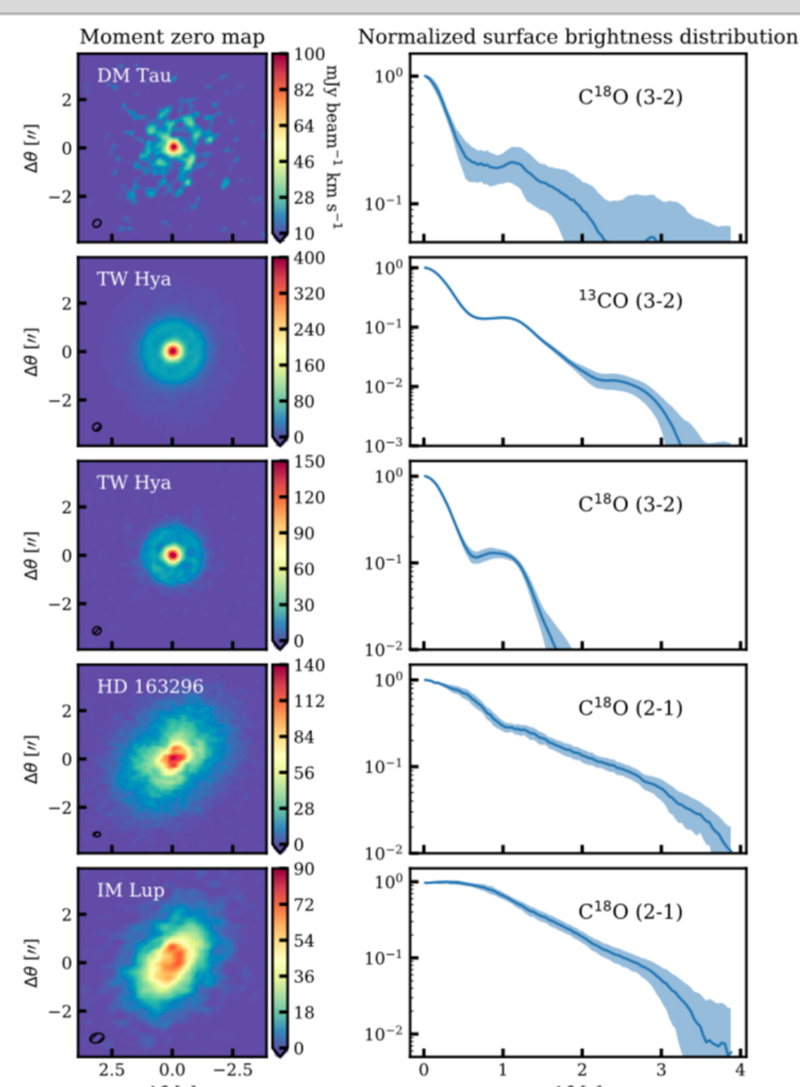
**Abstract:** CO is the most widely used gas tracer of protoplanetary disks. Its abundance is usually assumed to be an interstellar ratio throughout the warm molecular layer of disks. But recent surveys of Class II protoplanetary disks (1-10Myr) showed that the CO gas-to-dust mass ratios in the majority of disks are at least an order of magnitude lower than expectations, which arises challenges to our understanding of physical and chemical evolutions in disks. Here we investigate the spatial variation and time evolution of CO abundance in proplanetary disks. By comparing observations with detailed thermo-chemical models of four well-studied Class II disks, we find that their CO gas abundances vary with radius by an order of magnitude. These radial variations are qualitatively consistent with predictions of pebble formation, settling, and drifting in disks. To trace the evolution of CO abundance, we measure the CO gas abundance in the young HL Tau disk (Class I, <1Myr) using its $^{13}C^{18}O$ (2-1) line emission. We find that its CO gas abundance of this young disk is still comparable to the ISM ratio. These results suggest that the CO abundance likely evolves both with location and with time in protoplanetary disks.

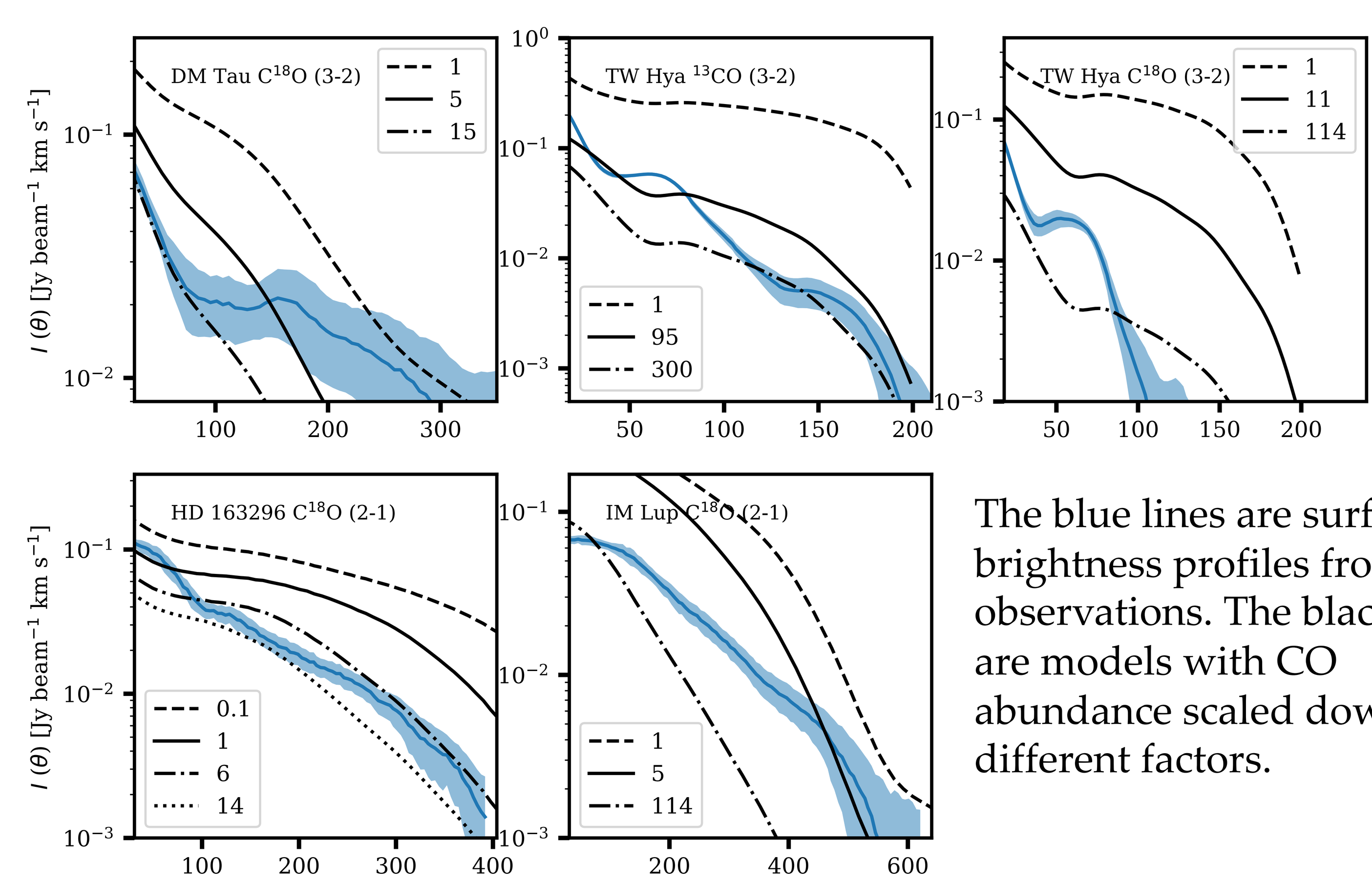
## I. Is the CO gas abundance constant inside the warm molecular layer of a disk? (Zhang et al. 2019a)

**Observations**: Spatially resolved $C^{18}O$/$^{13}CO$ line images of four Class II disks ( DM Tau, TW Hya, HD 163296, IM Lup). The ages of the disks are between 2-10 Myr.

ALMA observations, Beam size: 0.2-0.5”

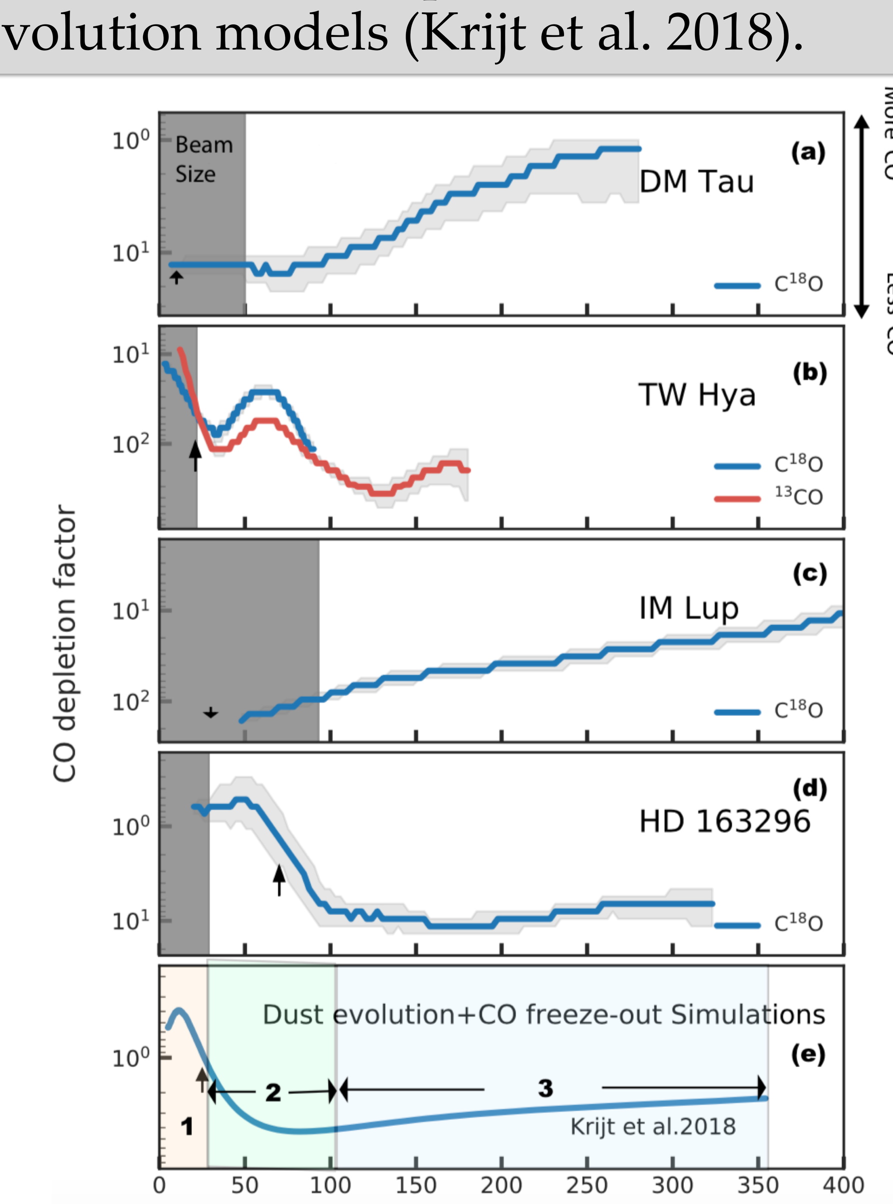



**Modeling**: we build detailed models of these four disks using the thermo-chemical code RAC2D (Du et al. 2014). We then scale the initial CO abundance (1e-4) by a constant factor across these disks to compare with observations. We then derive a best-fitting radial profile of CO abundance for each source.



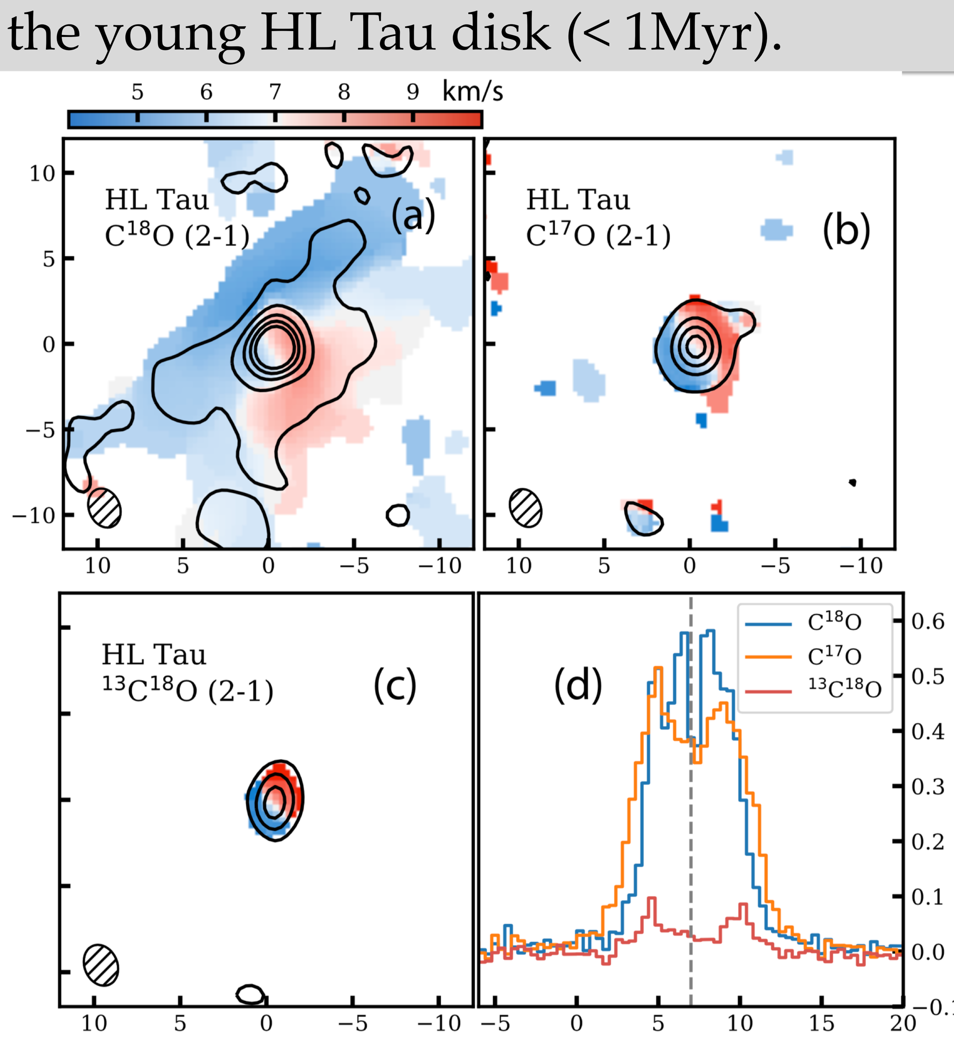

The blue lines are surface brightness profiles from observations. The black lines are models with CO abundance scaled down by different factors.

**Results**: The CO gas abundances in these disks vary significantly with radius. The general trend of the radial profiles of CO depletion in three disks (except for TW Hya) is qualitatively consistent with predictions of dust evolution models (Krijt et al. 2018).

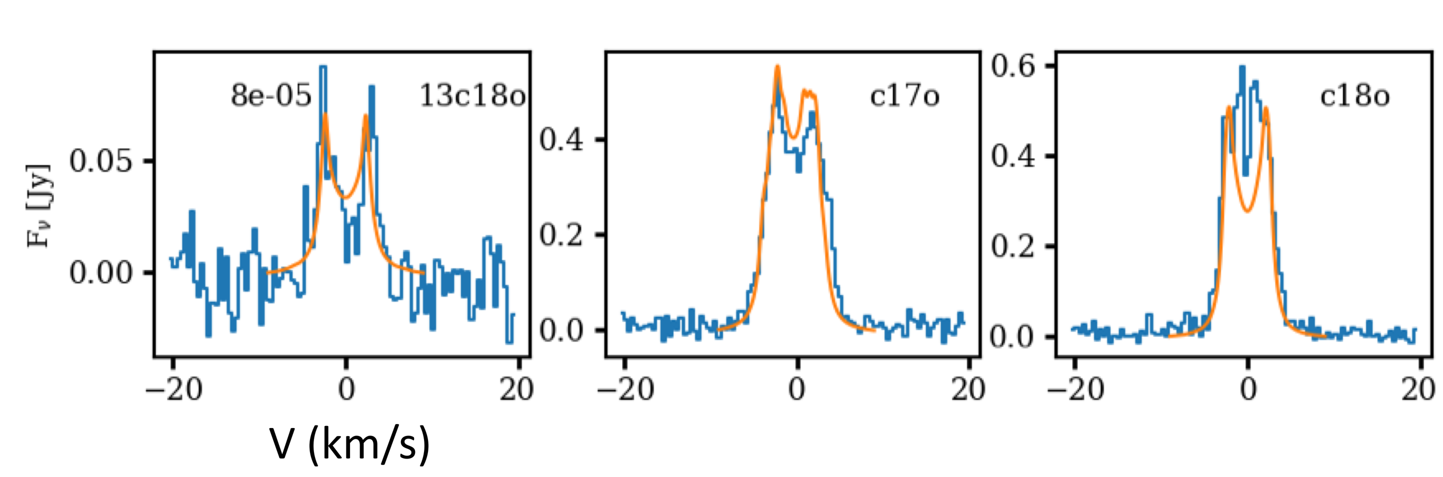



## II: Does the disk-averaged CO gas abundance evolve with time? (Zhang et al. 2019b)

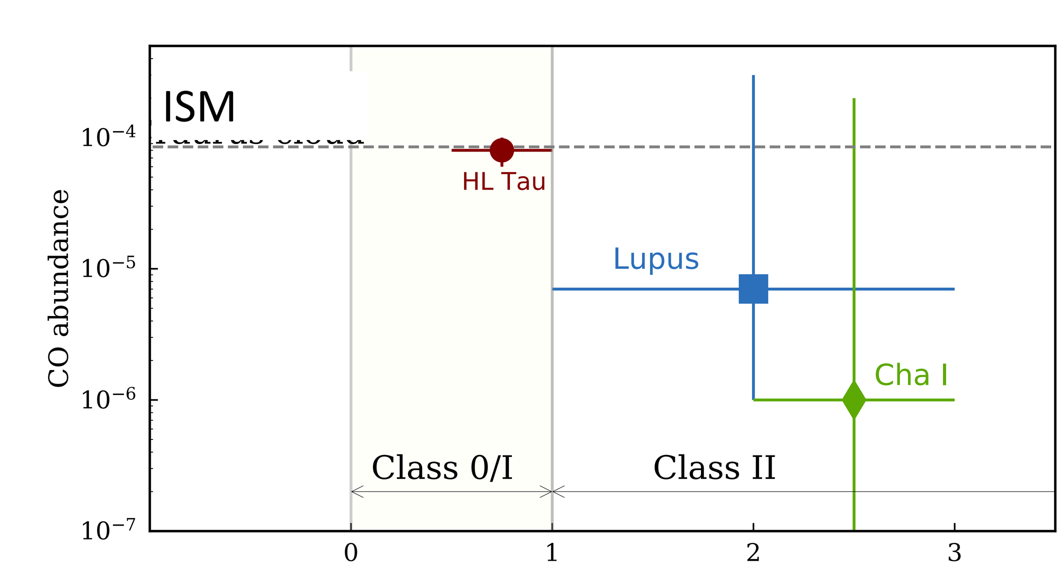
**Observations**: NOEMA observations of $C^{18}O$, $C^{17}O$, $^{13}C^{18}O$ (2-1) line emission from the young HL Tau disk (< 1Myr).




**Modeling**: we use the HL Tau model by Pinte et al. 2016, which matches the continuum emission of the HL Tau disk at 0.87, 1, and 3 mm. We find a disk-averaged CO gas abundance of 8e-5 gives the best match to observations.




**Results**: CO gas abundance in the young HL Tau disk is still close to the ISM, which is one to two orders of magnitude higher than that of the majority of older Class II disks (Ansdell et al. 2016, Long et al. 2017).




## Summary:

- We find that the CO gas abundances in four protoplanetary disks vary with radius by an order of magnitude. The radial variations are qualitatively consistent with models of dust evolution. These results suggest that dust evolution may play a significant role in transporting volatile materials (Zhang et al. 2019a, submitted).
- The CO gas abundance in the young HL Tau disk (<1Myr) is orders of magnitude higher than that of the majority of Class II disks. These results suggest that the chemical compositions in protoplanetary disks may evolve at a comparable timescale as planet formation (Zhang et al. 2019b, in prep).

**References:**

Du, F., et al. 2014, ApJ, 792,2
Krijt , S., et al. 2018, ApJ, 864,78
Pinte, C., et al. 2016, 816,25
Ansdell, M., et al.2016, ApJ, 828,46
Long, F., et al. 2017, ApJ, 844,99