Disk Parameters from CO isotopologues: It's COmplicated

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Abstract

CO isotopologues are the most widely used molecules to observe protoplanetary disks and probe their physical structure. Using an astrochemical model ANDES and radiative transfer code RADMC-3D, we explore and analyze how CO isotopologue millimeter line fluxes (CO, ^{13}CO, C^{18}O J=2-1) depend on the model parameters of the protoplanetary disk of a T Tauri star.

We vary such parameters as disk mass, disk radius, stellar mass and inclination of the disk. We explain the nature of these dependences and draw conclusions on how single lines or their combinations can provide constraints on the disk parameters. While such parameter study is not new, our approach differs by the inclusion of a comprehensive chemical network with grain surface chemistry together with line radiative transfer.

Grid of model parameters:

Parameter	Values
$M_\star$	0.5, 1.0, 1.5, 2.0 $M_\odot$
M_d	0.001, 0.002, 0.005, 0.01, 0.02, 0.05, 0.1, 0.2 $M_\odot$
R_c	12.5, 25, 50, 100, 200 au
i	0°, 30°, 45°, 60°, 75°, 80°, 85°, 90°

Physics and chemistry of the disk:

ANDES
(Akimkin+2013)

↓

Radiative transfer:

RADMC-3D
(Dullemond+2012)

Fig. 1

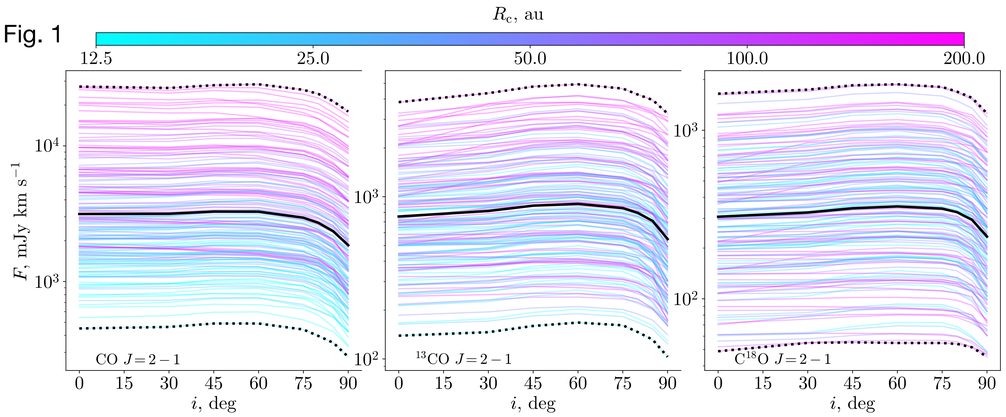


Fig. 2

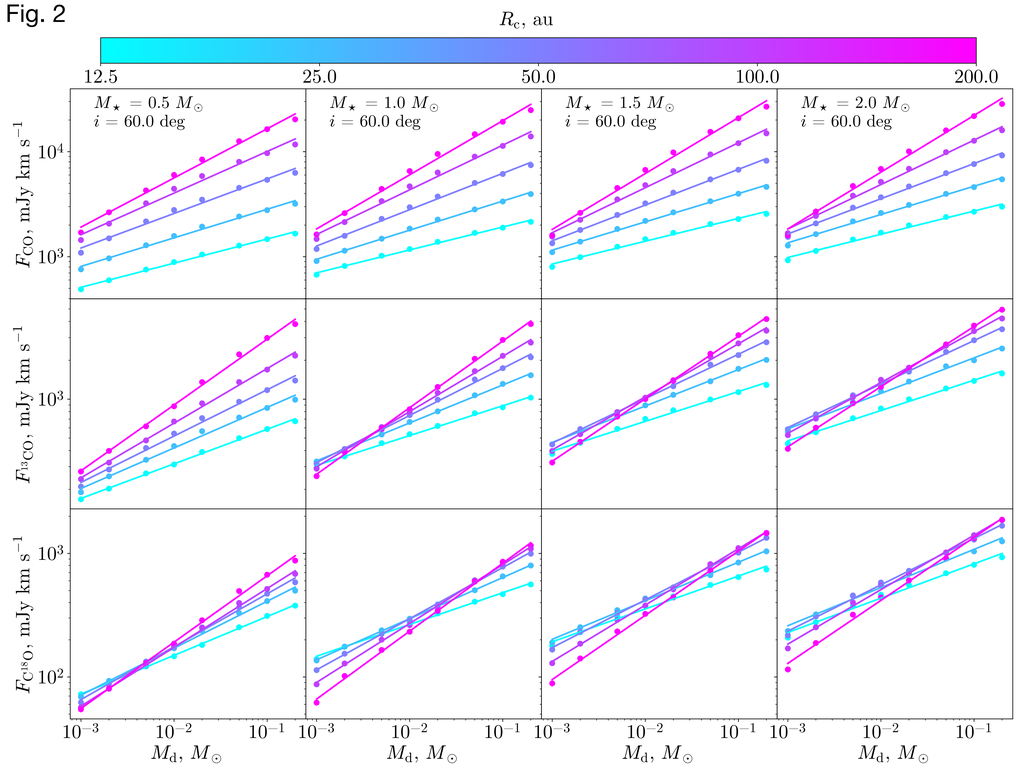
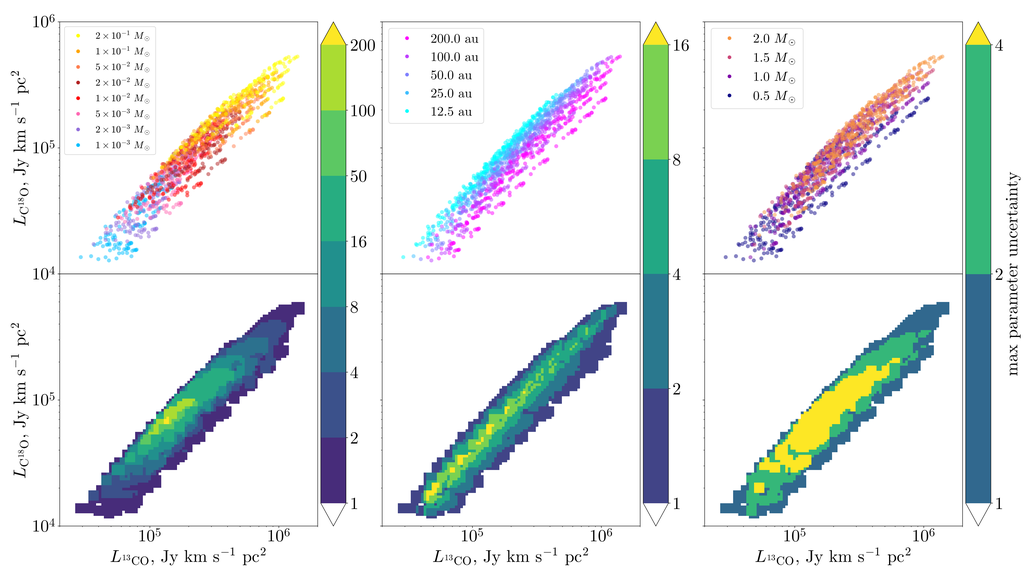


Fig. 3



Figures

1. Dependence of line flux on inclination
2. Dependence of line flux on disk mass, characteristic radius of the disk and stellar mass
3. Luminosity diagrams with model values grouped by disk mass (upper left), characteristic radius (upper middle), stellar mass (upper right). Lower panels show the parameter uncertainty within 10% of the luminosity of the point on the diagram.

Acknowledgements

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Conclusions

- CO isotopologue flux depends very weakly on inclination
- CO isotopologue flux always increases with disk mass
- How it increases with it depends on the disk radius, up to a factor of two
- CO flux increases with disk radius while ^{13}CO and C^{18}O flux dependence on it is more complex and depends both on disk and stellar mass.
- You cannot reliably estimate disk mass from ^{13}CO and C^{18}O flux combination (two orders of magnitude uncertainty)
- You can, however, estimate one parameter from any of the lines if you have independent constraints on other parameters.
- The inclusion of surface chemistry significantly reduces ^{13}CO and C^{18}O flux as their emission traces the region of chemical CO depletion. This reduction in flux is a major source of a systematic underestimation of disk mass in previous works. A structure from hydrostatic equilibrium also gives a lower ^{13}CO and C^{18}O flux compared to parametric prescription.