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Tracing the early planet formation with molecular lines: chemistry of vortex in the protoplanetary disks

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Abstract. The millimeter observations of dust in protoplanetary disks show us spectacular structures like numerous gaps, vortices and spirals. In particular, IRS 48 disk demonstrates a large vortex-like structure. Molecular lines provide information about disks that is complementary to dust continuum observations: formaldehyde was found on the inner edge of the IRS 48 vortex, along with detections of SO_2 and CS isotopes.

We use a reduced chemical network containing main carbon- and sulfur-bearing species to find the molecular species which can be sensitive to the gaps in dust, as well as to accumulation of the dust grains in the vortex. We find that SO molecule is the main reservoir for sulfur in IRS 48, for adopted disk model as in Bruderer *et al.* 2014. While SO is very sensitive to the gap edge, it cannot trace the vortex as it is weakly responding to the local increase in dust. Instead, SO_2 molecule abundance can be expected to drop quickly within the vortex, making it an interesting tracer of dust-trapping structure.

Keywords. Astrochemistry, protoplanetary systems: protoplanetary disks

1. Introduction

The transitional disk IRS 48 is very low in mass, only $5.5{\cdot}10^{-4}M_\odot$ in gas and $1.5{\cdot}10^{-5}M_\odot$ in dust mass, and displaying a grand vortex-like asymmetry visible both in dust emission and in molecular lines (Van der Marel *et al.* 2013, van der Marel *et al.* 2014). The presence of the gas in the inner cavity inside of 60 AU is debated (Bruderer *et al.* 2014, van der Marel *et al.* 2016b). Because of the prominence of the vortex, IRS 48 is an ideal laboratory to study how the chemistry is altered locally in the vortex. We propose here that the sulfur-bearing molecules might be useful to detect and to characterize the vortices, which could be potentially applyed for more the disks where vortices are undetectable in millimeter dust emission.

2. Overview

Vortex causes an increase up to 100% in local gas density, and accumulates dust of of sizes for the Stokes numbers between 0.01 and 100. We use compact chemical network as in Dzyurkevich *et al.* (2017), extended to S-bearing species. The abundance of sulfur available for gas-reactions is $n_{S_{\rm init}}/n_{H2} = 7.99\cdot 10^{-8}$. Fig. 1 shows the most abundant

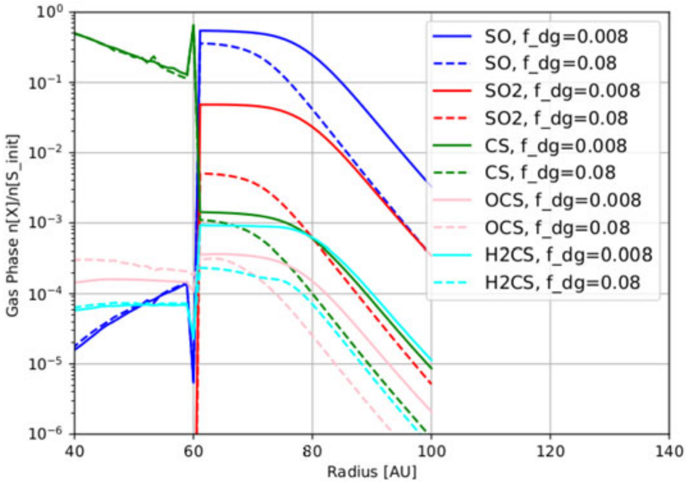

Figure 1. Sulfur-bearing species along radius in IRS 48, relative to the total sulfur abundance.

S-bearing species along the midplane of IRS 48 disk, age 5 Myrs, where solid lines correspond to the plain or opposite-to-vortex part of the disk. Inside 60 AU, all species are in the gas phase because of high temperatures and absence of the dust. Effect of increased dust-to-gas mass ratio on the abundance of S-bearing molecules is shown with dashed lines, as vortex is expected to accumulate dust. Whereas SO is the most abundant molecule, only SO_2 is strongly sensitive to the amount of dust. Species OCS, H_2CS, CS are not tracing the vortex for the gas densities as in IRS 48.

3. Implications

We have performed 1-D chemical modelling of the IRS 48 disk, with the focus on sulfur bearing molecules. We can show that *SO molecule is an efficient tracer of the gas cavity* and is quite abundant, (n[SO]/n[H] from 1.e-9 to 1.e-10). SO molecule will not be able to trace vortex, as it's abundance increases proportionally to gas, and only weakly drops with increased dust-to-gas ratio. *SO_2 is more promising to detect the vortex*, inspite that it is less abundant. SO_2 abundance drops very quickly with increased dust-to-gas mass ratio. In future, we plan to include the formation of H_2S on dust surface. The moleculaes like formaldehide and H_2S can be sensitive the the rotation of the vortex.

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