A new and robust method to determine the abundance of ices in edge-on protoplanetary disks

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Ices form in the cold regions of protoplanetary disks and are involved in many processes leading to planetary formation. They can facilitate the formation of complex organic molecules and are the reservoir of volatile species, playing a key role in the chemical evolution from the molecular cloud to the protoplanets. In particular, water ice plays a crucial role in the growth of grains and in planetary formation. However, its spatial distribution in protoplanetary disks is still poorly constrained. The James Webb Space Telescope now enables the spectral study of ices with unprecedented sensitivity and angular resolution.

Past studies investigated ices through the analysis of spectra. The shape, the location of the minimum position, as well as the depth of the ice bands were used to provide information about the properties and abundances of the main ice species. However, recent studies have shown that the interpretation of ice bands is more complex than it seems because the shape and location of the minimum depend on i) the inclination of the system and ii) the location within the disk from which the spectra are extracted. These dependencies stem from a balance between absorption and scattering and are due to a shift in wavelength between the absorption and scattering opacity curves. They must be taken into account in detailed radiative transfer modeling of spatially resolved infrared spectroscopy of ices. Moreover, it has been demonstrated that the ice bands reach a saturation for the main ice species (H_2O, CO_2, CO) when the amount of ice is too high and when the inclination of the disk is too high, precluding the quantification of ice abundances from spectra only.

To overcome the problem of ice band saturation for highly inclined disks, we developed a method to determine the abundance of the main ice species using JWST/NIRSpec observations of edge-on disks, without using ice spectra. This method relies on the measure of the disk thickness as a function of wavelength. Indeed, the disk thickness is proportional to the disk mass as well as to the opacity of the dust+ice mixture. Thus, we showed that outside of ice bands, the disk thickness decreases with wavelength as the opacity drops, while it increases across ice bands due to the additional ice opacity on top of the continuum opacity. We used the radiative transfer code MCFOST to build a toy model showing that the increase of disk thickness increases linearly with ice abundance, indicating that this method is not affected by saturation. Thanks to this method, it is possible to determine the ice abundances in edge-on disks by building radiative transfer models tailored to each disks, and adjust the ice abundance as a free parameter to reproduce the observed thickness. In this contribution, we applied the method to a sample of edge-on disks by building models tailored to the observations, along with their corresponding ice abundances.

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