Study of the radial and vertical structure of edge-on protoplanetary disks

Coralie Foucher, Anne Dutrey, Stephane Guilloteau, Vincent Piétu and Edwige Chapillon
Laboratoire d'Astrophysique de Bordeaux

How the complex molecules evolve and lead to the emergence of life is one of the fundamental questions in astrophysics. To answer this question, we must first understand where these molecules come from and how they are synthesized. A crucial stage in their formation takes place in protoplanetary disks, dense, rotating structures of gas and dust that surround young stars and where planets form.

Edge-on protoplanetary disks offer a unique opportunity to study this vertical distribution of gas and dust, providing direct insight into the processes that govern molecular stratification and planet formation. Using archival ALMA observations of CO isotopologues and continuum emission, together with new NOEMA HCO^+ (3-2) observations, we analyze the gas and dust properties of the disk around SSTTau042021. We use a tomographic method combined with the DiskFit model to extract vertical and radial temperature and density profiles.

Our results show that the CO emission extends significantly above the mid-plane, partially tracing the H_2 wind previously observed with JWST. The molecular layer, characterized by emissions of $C^{18}O$, ^{13}CO, and HCO^+, has temperatures around 16 K, while mid-plane temperatures range between 7 and 11 K. The thermalized nature of HCO^+ (3-2) allows us to derive a lower limit for the H_2 volume density of about 3×10^6 cm^{-3} at 100-200 au, between one and two scale heights. At 100 au, the disk atmosphere reaches temperatures of about 31 K. In particular, we detect CO and HCO^+ gas beyond the dust outer radius ($\geq$ 300 au), indicating that the molecular material extends further than the solid particles in the disk. The estimated total mass of gas and dust within 300 au is about 4.6×10^{-2} M⊙.

Thanks to the edge-on orientation of this disk, we present the quantitative evidence of vertical molecular stratification, directly observing CO and HCO^+ in the mid-plane. Our study provides critical constraints on the temperature and density structures within the disk, improving our understanding of how molecular material evolves in planet-forming environments.