Stellar Energetic Particles, a significant source of ionization for protoplanetary disks

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Ionization within protoplanetary disks is a fundamental driver of complex chemistry, particularly in the formation of complex organic molecules. The ionization rate in the upper layers of the protoplanetary disks of DM Tau, TW Hya, and IM Lup was recently inferred indirectly via chemical modeling of spatially resolved Atacama Large Millimeter Array (ALMA) line observations of the molecules N_2H^+ and HCO^+. Additionally, JWST/MIRI spectroscopic observations of TW Hya's inner disk (<1 AU) were able to detect HCO^+ lines in its inner regions.

These new observations show that the ionization rates in the inner region of DM Tau cannot be reproduced with the current disk composition model ionization prescription, requiring an artificially higher ionization rate from galactic cosmic rays in the inner region (within 100 AU) than in the outer region.

Young T-Tauri stars are highly magnetic and produce a stronger stellar wind than the present-day Sun. Their larger magnetic fields and greater activity suggest that they are efficient accelerators of energetic particles, propelling them to energies of several GeV. Therefore, we propose that these stellar energetic particles (SEPs) are the missing source of ionization in the inner region of DM Tau.

Using an energetic particle transport model, we demonstrate that the diffusion of particles through turbulent magnetic fields allows for the necessary ionization rate in the inner region of DM Tau up to 30 AU in the midplane with a disk magnetic field of 1 mG. These diffusing particles are less absorbed by the disk gas than FUV and X-ray stellar irradiation, which increases ionization within the midplane and has potential implications for the production of organic matter.