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The role of stellar cosmic rays in protoplanetary disk evolution

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The role of magnetic fields in the evolution and dispersal of protoplanetary disks remains unclear to date partially due to the uncertainty regarding the sources of ionisation present in protoplanetary disks. Magnetic fields can only influence protoplanetary disk dynamics if the disks are sufficiently ionised. Ionisation due to X-rays, FUV photons and radioactivity is well-studied and generally only leads to high levels of ionisation close to the young star and in the surface layers of protoplanetary disks due to high disk column densities. Here I will instead focus on the importance of stellar cosmic rays which may provide a source of ionisation for the outer regions, and closer to the midplane, of protoplanetary disks.

Young solar-type stars are very magnetically active and drive stronger stellar winds in comparison to the present day Sun. The increased magnetic activity of young solar-type stars suggests that they are efficient ~GeV particle accelerators producing so-called stellar cosmic rays. Thus, protoplanetary disks are likely to be bombarded by stellar cosmic rays, influencing their chemical and dynamic evolution. These incident particles are believed to trigger the formation of complex organic molecules. Thus, they are essential to advance our understanding of how organic molecules, the building blocks of life in the Universe, form.

Recent ALMA observations have provided a number of tantalising clues as to the possible importance of stellar cosmic rays in protoplanetary disks. On the one hand, chemical modelling of observations of TW Hya's protoplanetary disk suggest that the overall ionisation rate is remarkably low. While on the other hand, ALMA observations have been used to infer the presence of significant turbulent motion in DM Tau's protoplanetary disk. This turbulent motion is likely driven by the magneto-rotational instability which would require a much higher level of ionisation than was inferred in TW Hya's disk for instance. I will discuss the potential influence of stellar cosmic rays in these disks.

More generally, I will present recent results which investigated the propagation, and ionising effect, of stellar cosmic rays in protoplanetary disks around young solar-mass stars. Unlike X-rays and FUV photons, stellar cosmic rays may effectively avoid being attenuated by the high column densities in the inner regions of protoplanetary disks due to their diffusive transport. To construct our disk density profiles, we use observationally inferred values from nearby star-forming regions for the total disk mass and the radial density profile. By varying the disk mass within the observed scatter for a solar-mass star, we find for a large range of disk masses and density profiles that protoplanetary disks are "optically thin" to low energy stellar cosmic rays. I will describe how our results indicate, for a wide range of disk masses, that low energy stellar cosmic rays provide an

important source of ionisation at the disk midplane at large radii (□70 au). Finally, I will discuss the type of systems where we expect that stellar cosmic rays are likely to be most influential.