Disrupted Beginnings: How the Environment Shapes Planetary Birthplaces

Impact of External Factors on the Evolution and Structure of Planet-Forming Disks

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In Short

- Gravitational perturbances due to stellar flybys on disks.
- Interaction of interstellar gas clouds with disks.
- External UV radiation field modulated disk winds.
- Radioactive interstellar contaminants and their effect on disks.

In the past few years, our understanding of how planets are born around young stars has grown rapidly, thanks to major breakthroughs in astronomical observations. Cutting-edge instruments like the VLT/SPHERE and the powerful ALMA telescope array have opened a new window into the dusty, gas-rich disks that surround young stars—known as protoplanetary disks. These disks are the cradles where planets form, and with better and more observations, we are now able to study them in unprecedented detail during their early stages, known as the Class I and Class II phases.

Until recently, most theoretical studies focused on individual disks in ideal, relatively calm and isolated environments, especially during the T Tauri phase, when the central star is stable and the disk is evolving over viscous timescales. But real star formation and disk evolution doesn't happen in isolation. Stars are born in dense stellar nurseries like the Taurus, Orion, and Lupus regions, where many young stars and their disks are packed close together. In such crowded environments, the disks can be influenced by their neighbors and by their surrounding environment in dramatic ways.

One major factor we are beginning to understand is the role of gravitational flybys—close tidal encounters between stars that can pull on each other's disks. These interactions may trigger spiral arms in the disk, which play a key role in redistributing material and angular momentum (Lesur et al., 2015 2; Hennebelle et al., 2016, 2017 3). Another newly observed phenomenon includes large arcs of gas, so called streamers, seen at distances of up to a few 1000 AU from the disk, see Fig.(1) for example. These structures may be the result of interactions with streams of interstellar gas, suggesting a dynamic link between the disk and its broader cosmic environment (Pineda et.al., 2023)4.

External influences don't just come from gravity. Radiation from nearby stars, especially high-energy ultraviolet (UV) light, can heat and erode the outer parts of a disk, changing its chemistry and possibly affecting where and how planets form. These UV rays may also help drive the powerful winds that blow gas away from the disk, shaping its final structure (Adams et al., 2004)5.

Even more intriguingly, massive stars in these stellar neighborhoods can go supernova, scattering radioactive elements like aluminum-26 (^{2}Al) and iron-60 (Fe) into the surrounding space. These materials are thought to have been present in our own Solar System early on and may have contributed to heating and melting processes that formed the cores of early planetesimals. But while these elements can mix into the general interstellar medium (e.g., de Avillez Mac Low, 2002; Schulreich et al., 2017) 6, it's still an open question how they end up in the densely packed disks—which are much denser than the surrounding gas by several orders of magnitude.

This project seeks to explore these external influences on planet-forming disks through three main questions:

How does infalling interstellar gas affect the structure, dynamics, and long-term evolution of the disk?

What is the role of stellar flybys and external UV radiation in creating disk substructures, and in truncating or eroding the outer disk?

Once these external effects are accounted for, can we still see the signatures of viscous spreading—the slow spreading of the disk material outward—predicted by models of isolated disk evolution?

To answer these questions, we need to bring together all the key physical ingredients: gravity, radiation, hydrodynamics, and magnetic fields. The complex interplay of these processes cannot be studied through theory alone—they require detailed, high-resolution numerical simulations. In this project, we will run advanced magnetohydrodynamic (MHD) simulations, using the publicly available astrophysical gas dynamics code Nirvana, that can realistically capture the non-linear interaction between a disk and its environment. This will help us better understand how protoplanetary disks evolve over secular timescales and consequently how planets are shaped not just by their parent star, but by the dynamic, often chaotic, environments in which stars themselves are born.

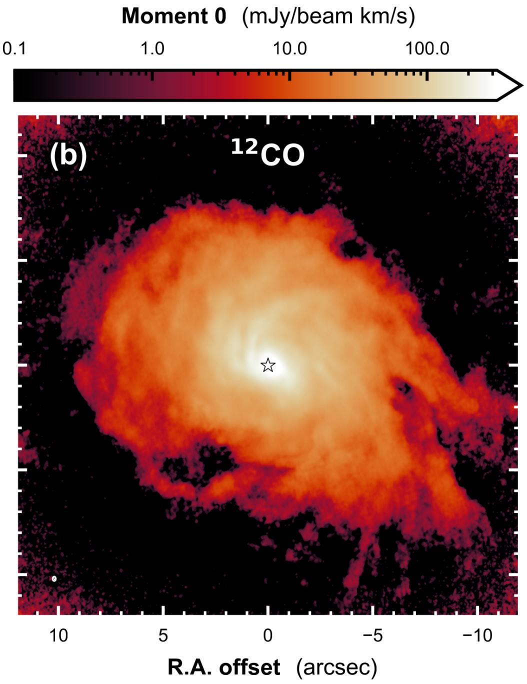

Figure 1: *Observation of a proto-planetary disk (PPD) using the chemical tracer ^{12}CO. The image shows a lopsided PPD possibly created by infalling interstellar gas. Credit [1]*

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More Information

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[4] Pineda, J. E. et. al. From Bubbles and Filaments to Cores and Disks: Gas Gathering and Growth of Structure Leading to the Formation of Stellar Systems. `doi: 10.48550/arXiv.2205.03935`

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