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Polar Alignment and Vortices in Circumbinary Disks

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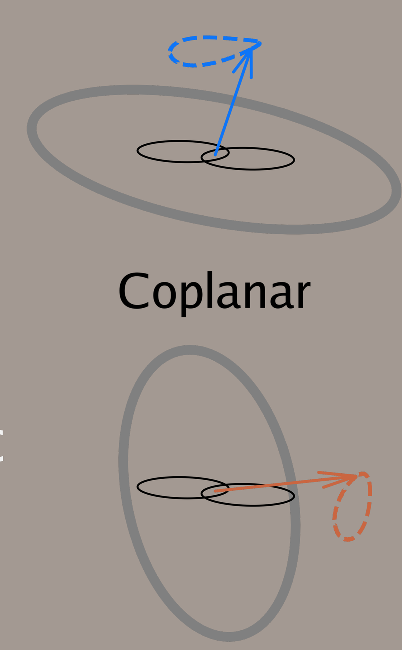
Overview — How do planets form?

Planets are thought to form in *protoplanetary disks*, the gas and dust orbiting around a young star. Binary stars are thought to be easily created during star formation (Kouwenhoven+ 2007), which can lead to *circumbinary disks* — protoplanetary disks encircling both stars.

Circumbinary disks can create the exoplanets observed around binary systems such as Kepler-16b. However, planet formation in a circumbinary disk is altered by the effects of the binary stars in the center, leading to unique scenarios compared to single-star planets.

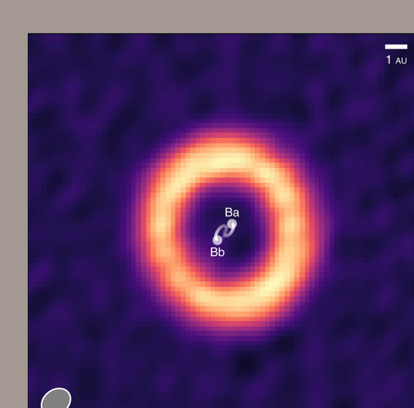
Introduction — What is a Polar Disk?

A *polar disk* is a protoplanetary disk that orbits at 90° to the rotation of the central object(s). In binary star systems, a *circumbinary polar disk* is a disk that orbits perpendicular to the binary orbital plane.



There are two different stable orbits around an eccentric binary system. Orbits can be coplanar (precessing around 0°) or polar (precessing around 90°) (Farago & Laskar 2010). Disks around binary stars will stabilize at 0° or 90° inclination - coplanar or perpendicular to the binary.

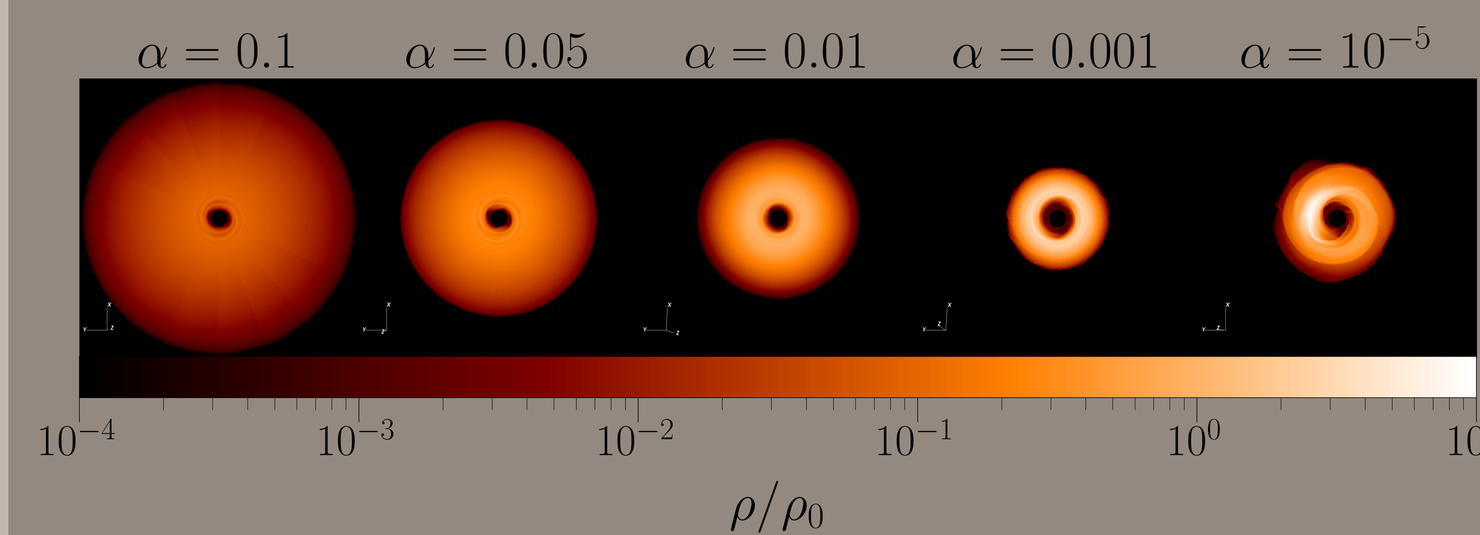
Some circumbinary disks have been imaged with orientations nearly perpendicular to their central binaries, such as HD 98800 (Kennedy+ 2019, right).

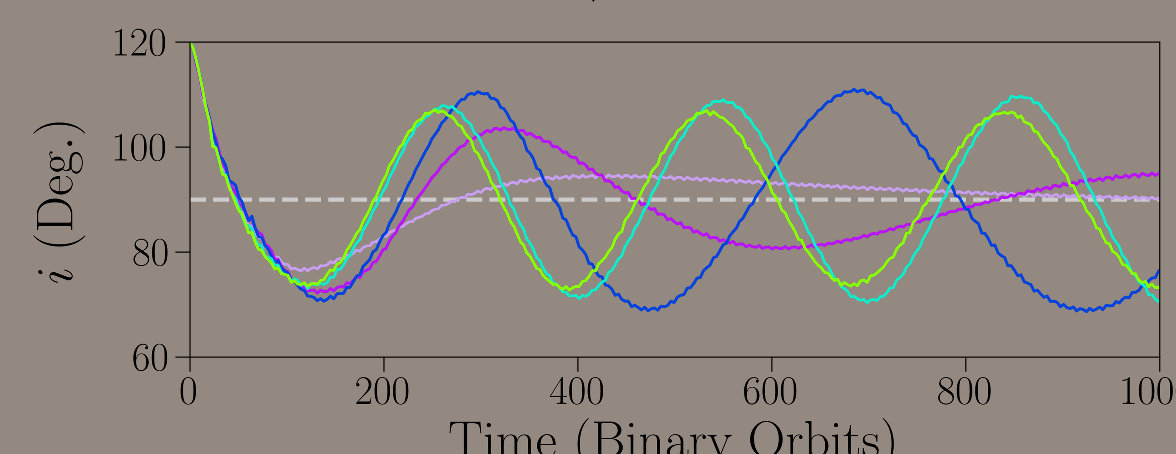

HD 98800

Results — How do the disks evolve to a polar orientation?

A Polar Alignment

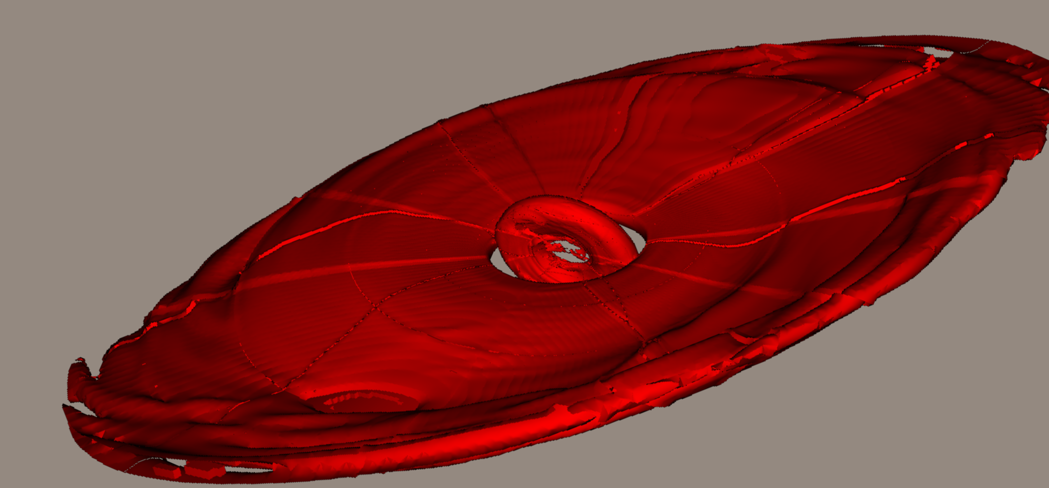
The disks precess from the binary torque, spiraling in towards 90° inclination. The different viscosities result in different disk sizes, precession rates, and polar alignment time scales.

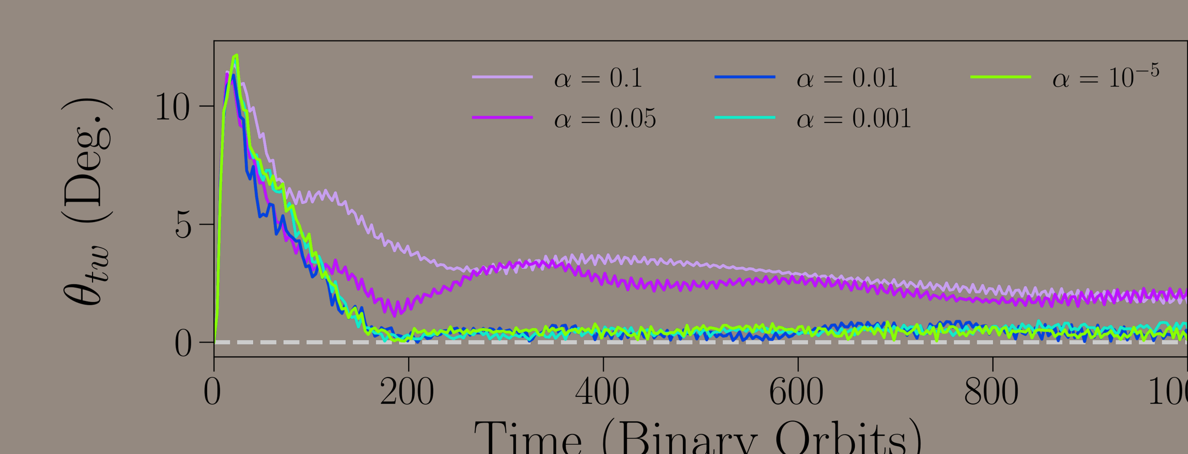




B Disk Warping and Tearing

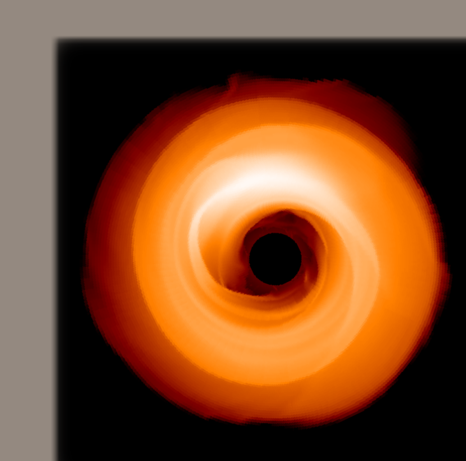
The binary stars provide a torque on the disk, which is propagated outwards through viscous forces. Depending on the strength of the viscosity, the disk can become warped or even break into multiple rings!

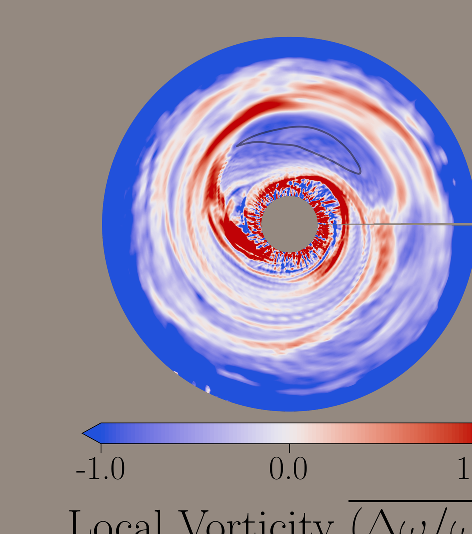




C Vortices

In disks with low viscosity, the Rossby Wave Instability can generate anticyclonic vortices, which creates a localized arc-shaped region of high density and a single-armed spiral.

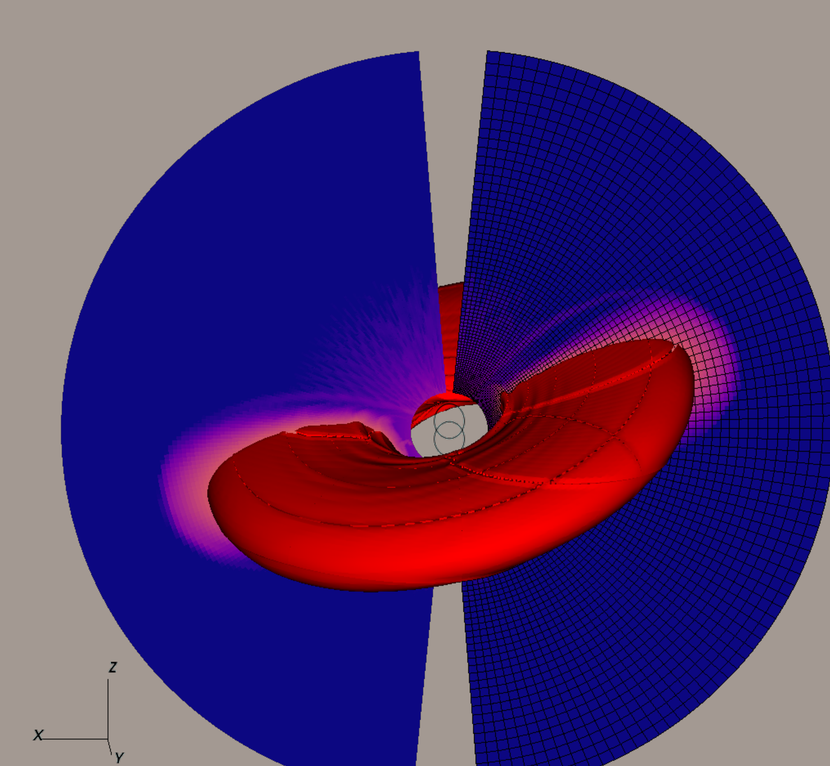




Methods — How do we simulate a polar disk?

We use ATHENA++, a grid-based hydrodynamic code, to simulate a polar disk, starting with a highly inclined disk around an eccentric binary. Using a grid-based code allow us to test a larger range of disk viscosities compared to previous studies (Martin+ 2017).

An example of a polar disk simulation is shown at right, with the eccentric binary visible in the center.



Conclusion — What does this mean for planet formation?

Polar circumbinary disks can allow for the possibility of a circumbinary planet forming *in situ* with a polar orbit. The vortices that form in the disk can gather up solids towards the center of the vortex, which can accelerate the growth of planets. A planetary system like this would result in a new, currently undiscovered class of circumbinary planets.

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