The circumstellar disk of AB Aurigae: evidence for envelope accretion at late stages of star formation?

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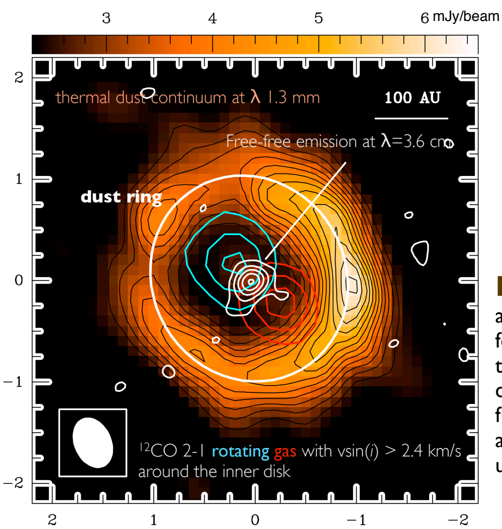
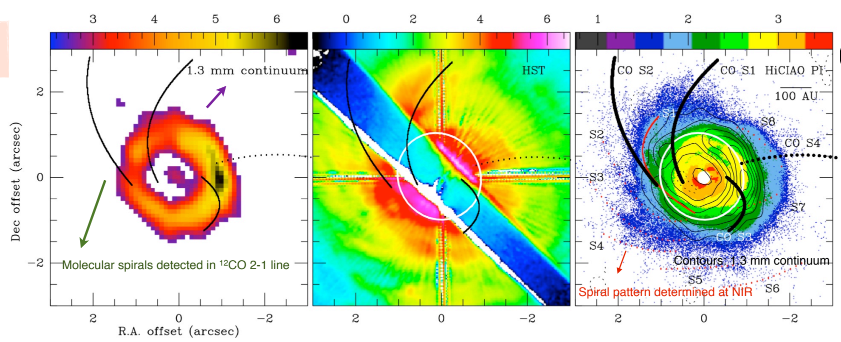
ABSTRACT: More and more circumstellar discs around pre-main-sequence stars are found to have complex structures, such as great cavities seen in thermal dust emission and spiral-like features seen in the optical near-infrared images. Among them, AB Aurigae exhibits a spectacular spiral pattern. One popular formation mechanism often invoked for these two structures is the gravitational perturbation created by embedded companion/ brown dwarf in the discs. However, the explanations of the spiral formations are purely based on the morphologies due to the lack of the kinematic information.

We have made the combined Submillimeter Array (SMA), IRAM 30-m and the Plateau de Bure Interferometer (PdBI) observations toward AB Aurigae with high sensitivity and high angular resolution to trace the kinematics of the spirals using CO lines. Using the ^{12}CO 2-1 images with 0.5" resolution of AB Aurigae, we found the "spiral" like features appear counter-rotating with respect to the circumstellar disc. Late accretion from the envelope above and below the disc plane is the simplest explanation for this. Dense disk surrounding AB Aurigae is resolved into an inner disk and an outer dust ring as traced with the thermal dust continuum emission at 1.3 mm. The dust ring is highly asymmetric as a function of azimuth, suggesting that the disk is perturbed.

Circumstellar disk of AB Aur seen at various λ

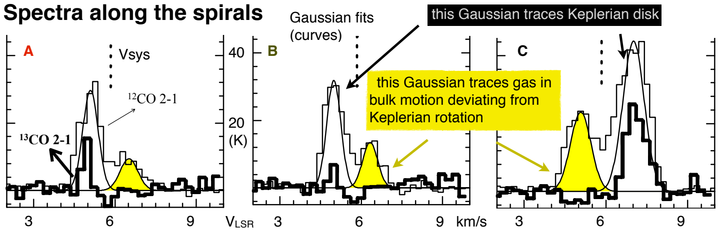


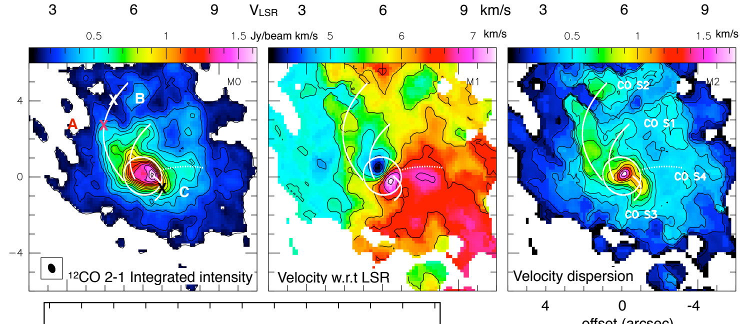


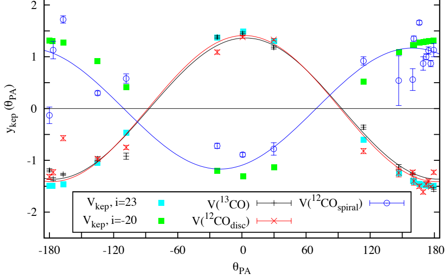
Polarization intensity image at 1.6μm by Subaru telescope (color scale; Hashimoto et al. 2011). Red solid and dotted arcs mark the near infrared spirals. Among them, only S1 has a molecular spiral detected in CO.

RESULT: At 1.3 mm, this disk is resolved into an inner disk and an outer ring, which has a radius of 90 AU. The most striking features are the large scale spirals within the circumstellar matter traced in the ^{12}CO J=2-1 line. Spectra at these spiral locations suggest that the excess gas components on the spirals are in bulk motion with velocity deviating from the rotating disk. We further studied the kinematics of these spiral-like features. Surprisingly, the excess of CO gas along the spirals is apparently counter-rotating with respect to the gaseous disk. This behavior is unexpected from standard disk and accretion models.

Spectra along the spirals







Consider only the rotation

$$V_{obs} = V_{sys} + V_{kep}\cos(\theta_{PA})\sin(\theta_{incli})$$

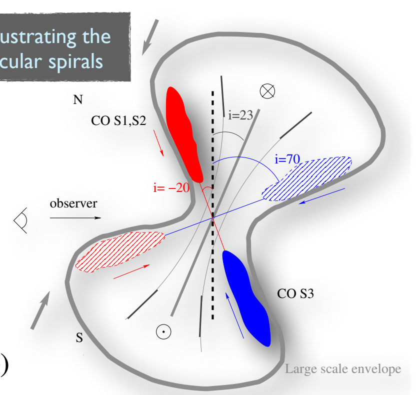
$$y_{kep} \equiv (V_{obs} - V_{sys}) \cdot \sqrt{r} = \sqrt{GM}\cos(\theta_{PA})\sin(\theta_{incli})$$

$$V_{kep} = \sqrt{\frac{GM}{r}}$$

The CO spiral gas has a different sign in y_{kep} => this gas is either counter rotating on the disk, which is very unlikely, or it is at different θ_{incli}

CONCLUSION: The wide dust gap, the warped disk, and the asymmetric dust ring (intensity contrast is up to 3 on the ring), suggest the existence of, at least, one undetected companion with a mass of 0.03 M☉ at a radius of 45 AU. The different spirals would likely require multiple perturbing bodies. Tidal interactions can explain the inner disturbances of the disk but cannot explain the apparent counter-rotation of the gas in the outer spirals. A better explanation is that these motions are due to very small amounts (10^{-6} M☉) of inhomogenously accreting gas infalling preferentially well above/or below the main disc plane from the surrounding remnant envelope along quasi parabolic/spiral like trajectories. Our study indicates that accretion can play a role in shaping the disk even at rather late stages as the age of AB Aur is estimated to be ~4 Myr.

Cartoon image illustrating the origin of the molecular spirals



The excess emission seen in the ^{12}CO 2-1 line is most likely from the gas well above and below the disk plane (solid filaments; i=~-20°). If the gas is at the same sign of inclination angle (shown in hatched filaments), the deviation of the velocity will not be well separated from the Keplerian disk. The accreting gas is therefore not easily seen in the spectrum.

Tang et al. 2012, AA, 547, A84