ALMA observations of the envelope-to-disk mass transport in the FU Orionis-type young eruptive star V346 Normae

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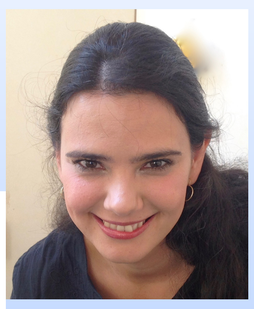

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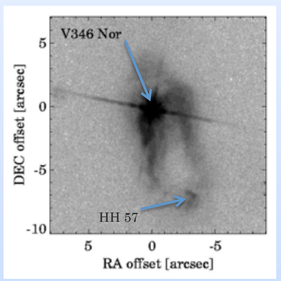
Abstract

Having disk-to-star accretion rates on the order of 10^{-4} $M_\odot$/yr, FU Orionis-type stars (FUors) are thought to be the visible examples for episodic accretion. FUors are often surrounded by massive envelopes, which replenish the disk material and enable the disk to produce accretion outbursts. Here we present ALMA observations of the FUor-type star V346 Nor at 1.3 mm continuum and in different CO rotational lines. We mapped the density and velocity structure of its envelope and analyzed the results using channel maps, position-velocity diagrams, and spectro-astrometric methods. We report the discovery of a pseudo-disk and a Keplerian disk around a 0.1 $M_\odot$ central star. We determined an infall rate from the envelope onto the disk of 6×10^{-6} $M_\odot$/yr, a factor of few higher than the quiescent accretion rate from the disk onto the star, hinting for a mismatch between the infall and accretion rates as the cause of the eruption.

Episodic accretion

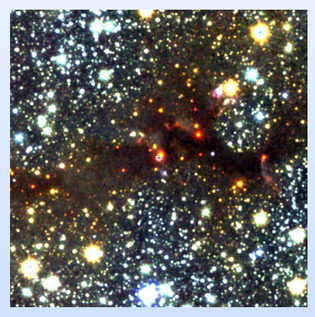
- A long-standing open issue of the paradigm of low-mass star formation is that most protostars are less luminous than theoretically predicted.
- One possible solution is that the accretion process is episodic. The young outbursting FU Ori-type stars (FUors) are thought to be the visible examples for objects in the high accretion state.
- Mass infall from FUor envelopes may play a fundamental role in refilling the disk, and triggering instabilities causing accretion outbursts. However, our knowledge on the envelope dynamics and on the envelope-to-disk mass transfer is still very limited.

Our target: V346 Normae



HST/WFPC2 optical image of V346 Nor

- Embedded FUor in the Sandqvist 187 dark cloud, at a distance of 700 pc.
- Erupted between 1976 and 1980, plateau until 2008, rapid fading in 2010, partial re-brightening since then.

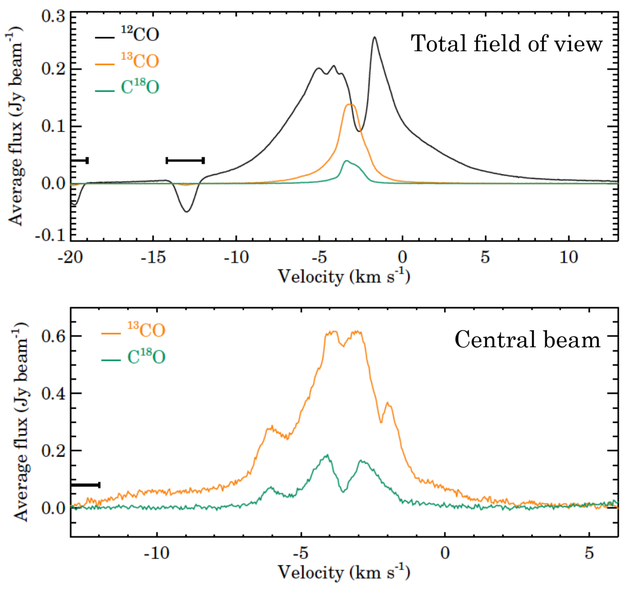


The S87 region in the near-infrared; V346 Nor is at the center

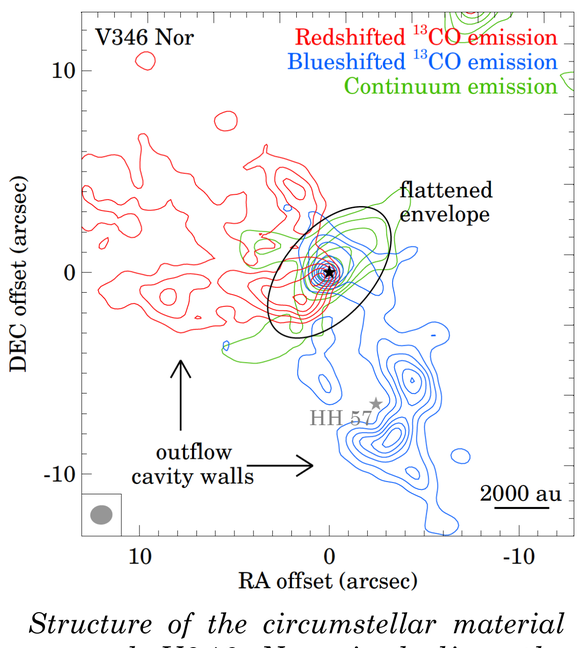
- Modeling of multi-epoch optical-infrared spectral energy distributions: peak accretion rate of 10^{-4} $M_\odot$/yr in 1992, drop of accretion by at least a factor of 100, meaning < 10^{-7} – 10^{-6} $M_\odot$/yr quiescent accretion rate.

Our ALMA observations

- J = 2 – 1 line of ^{12}CO, ^{13}CO, C^{18}O, and 1.32 mm continuum in one single setting in Band 6 (Cycle 2, PI: Á. Kóspál).
- Combination of 12 m array (2 h on-source time with 37 antennas) + 7 m array (5 h on-source time with 9 – 11 antennas) + Total Power (with 3 antennas) data.
- Baseline coverage: 8.3 – 349 m (6 – 268 k λ), beam size: 0.9″×1.1″.



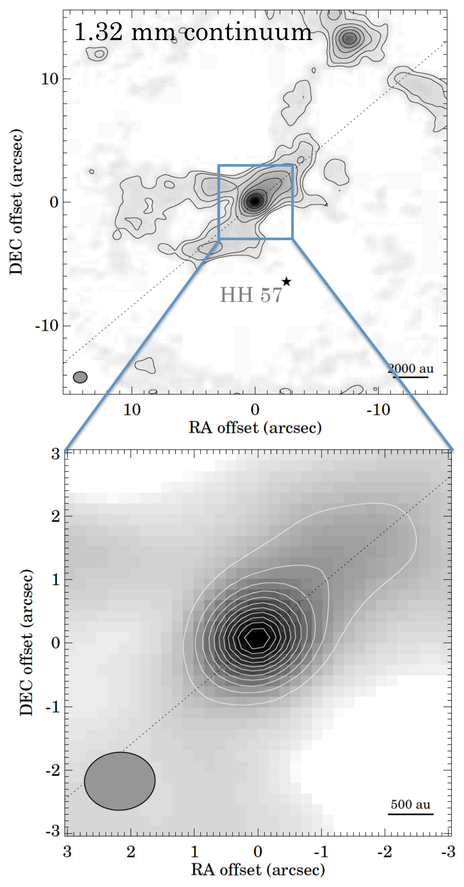
Spectra of different CO isotopologues for the total field of view (14 000 au radius, top), showing a typical infalling envelope profile, and for the central beam (700 au, bottom), displaying a double-peaked profile indicative of rotation.



Structure of the circumstellar material around V346 Nor, including the flattened envelope, and the red- and blueshifted emission from the material entrained in the walls of the outflow cavity.

Continuum results

- We detected a fairly compact continuum source coinciding with the near-infrared stellar location (see figures to the right).
- The source is marginally resolved, with a deconvolved FWHM of 0.46″× 0.60″. We interpret this as an inclined disk-like object, with a radius of 210 au.
- The position angle is NW-SE, same as the CO rotating disk.
- The central source is surrounded by more extended, fainter emission out to 6300 au.
- The dust mass in the compact source within 210 au is 7×10^{-4} $M_\odot$.

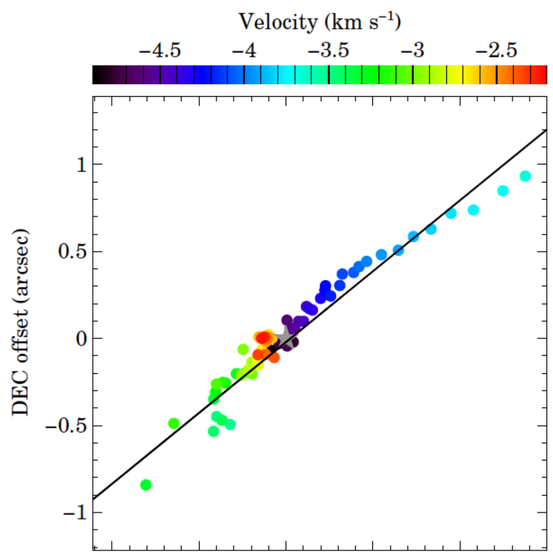


The outflow cavity

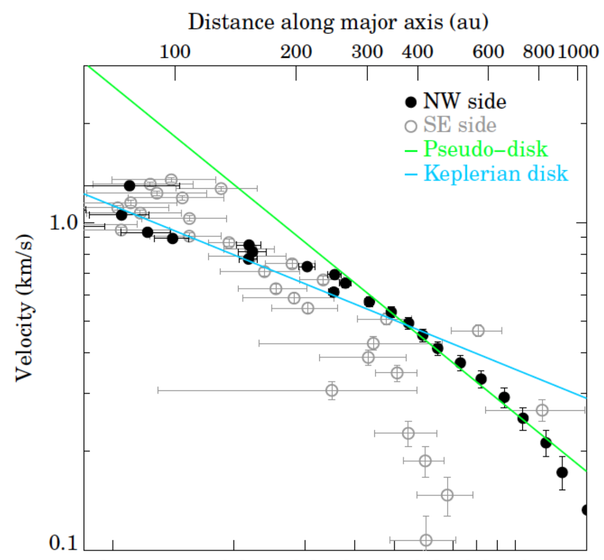
- Both the ^{12}CO and ^{13}CO profiles exhibit high-velocity line wings (see figures above).
- The redshifted emission shows a parabola opening towards the northeast with a relatively wide opening angle of about 80°.
- The blueshifted emission forms a narrower ellipse extending towards the southwest with an opening angle of about 40°.
- The geometry is reminiscent of an outflow cavity, where emission is coming from the swept-up material in the cavity walls.
- The Herbig-Haro object HH 57 is situated along the axis of the southwestern CO-emitting ellipse, close to its farther edge.

The pseudo-disk and the disk

- Results from a spectro-astrometric analysis of the C^{18}O data cube:
- From 350 to 700 au, the radial velocity profile is consistent with a pseudo-disk (infalling-rotating motion with angular momentum conservation).
- The inner 350 au resembles a Keplerian disk around a 0.1 $M_\odot$ central star. (see figures below).
- The total gas mass within 350/700 au is 0.01/0.03 $M_\odot$.



Spectro-astrometric signal (centroid position for the different channels) for the C^{18}O data cube. The black line is a fit to the points, while the gray asterisk marks the location of the continuum peak.



Velocity shift as a function of distance from the star for the C^{18}O data cube. The green curve is the velocity profile of a pseudo-disk (~r^{-1}), while the blue curve is a Keplerian profile (~$r^{-0.5}$).

The infall-accretion mismatch

- We calculated the infall rate using the following analytic formula:

$$\dot{M}_{\rm infall} = \frac{3}{2}\left(\frac{M_{\rm env}}{R_{\rm env}}\right)\left(\frac{2GM_*}{R_{\rm env}}\right)^{1/2}$$

- The resulting infall rate from the envelope onto the disk is 6×10^{-6} $M_\odot$/yr, which is a factor of few higher than the quiescent accretion rate from the disk onto the star (< 10^{-7} – 10^{-6} $M_\odot$/yr).
- It is a hint for a mismatch between the infall and accretion rates.
- **This is the first observational support for such mismatch in a FUor, previously invoked to explain FUor outbursts.**

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