New results on the high-mass protostar NGC 7538S

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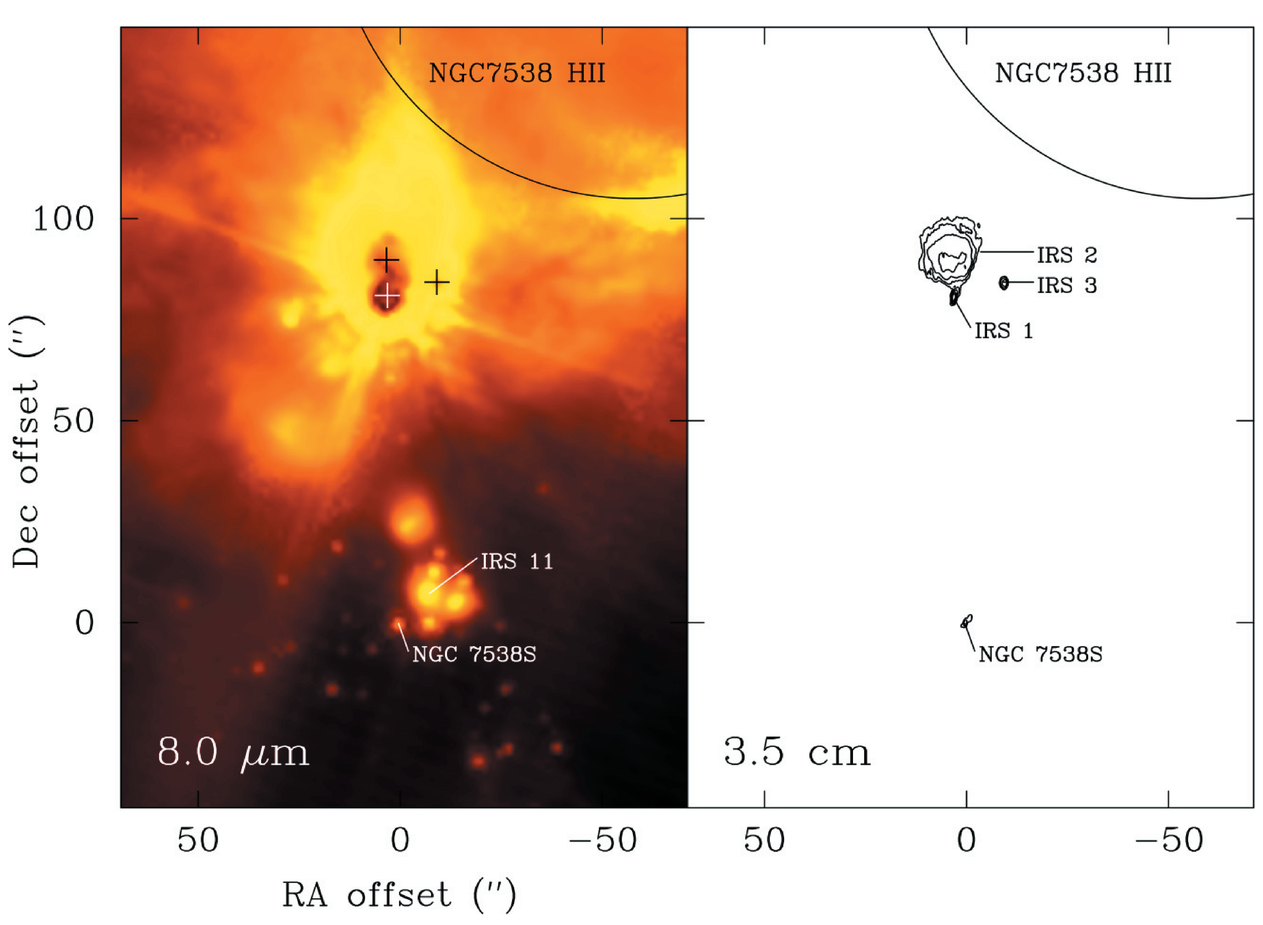
Abstract: New deep high angular resolution observations of the high-massprotostar NGC 7538 S with BIMA and the VLA confirms that the star is surrounded by a rotating accretion disk. The disk drives an ionized jet and a compact, hot molecular outflow approximately perpendicular to the rotating disk. The continuum emission observed with BIMA is dominated by dust emission at all observed frequencies (72 GHz - 220 GHz). The center of the accretion disk appears optically thick, even at mm-wavelengths. Spitzer observations with IRAC and IRS detect the central protostar and show a small cluster around the near-IR source IRS11, which dominates the emission at mid-IR wavelengths. The closest cluster member is 5″ away from our protostar, which allow us to study the protostar in relative isolation. NGC 7538S is detected with IRAC at 4.5, 5.8, and 8 μm, but does not appear very red. Spectral mapping with the IRS shows strong absorption bands in the Short-Low spectrograph (5.2 - 7.8 μm).The long wavelength spectrographs shows that the continuum is strongly absorbed at wavelengths shorter than 30 μm. At longer wavelengths the protostar becomes brighter than IRS11. The IRS data therefore confirm that NGC 7538S is the most luminous source in this region, but do not provide us with a reliable luminosity due to the strong absorption by the dense surrounding cloud core and probably from the accretion disk as well. The enclosed mass in the inner, rotationally supported part of the disk, D = 5″ (14,000 AU) is 14 - 24 $M_{\odot}$.

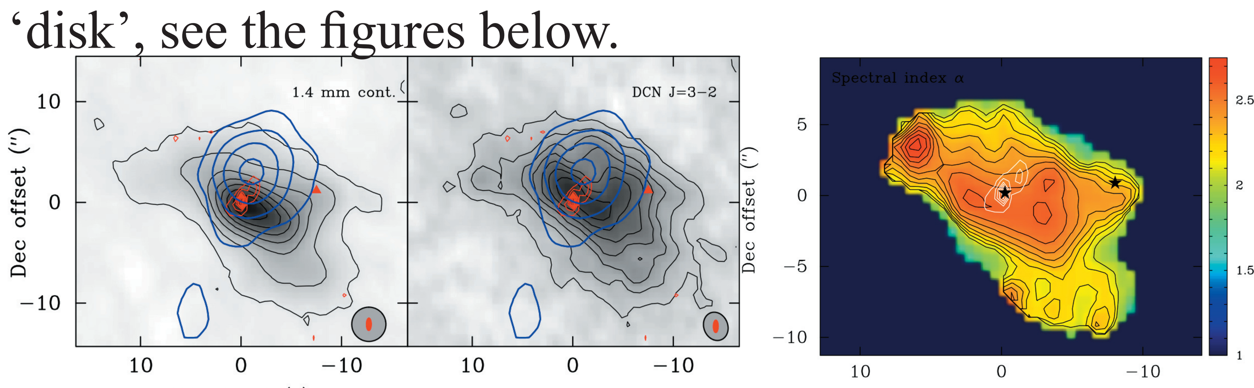
Overview

NGC 7538S is embedded in a cold massive molecular cloud core (D ~ 0.8 pc, M ~ 5,000 $M_{\odot}$) southeast of the optical HII region at a distance of ~ 2.8 kpc. It coincides with an OH maser and a cluster of H_2O masers, but has no near-IR counterpart. Sandell et al (2003) identified NGC 7538S as a high-mass protostar surrounded by a rotating accretion disk and driving a compact molecular outflow approximately perpendicular to the accretion disk. The figure below shows the location of NGC 7538S relative to the HII region and the more well known Ultra-Compact HII regions IRS1 - 3. The IRAC 8 μm image (left) shows the intense activity from IRS1 & 2 (both saturated), and reveals a small deeply embedded cluster centered around the near-IR source IRS11. NGC 7538S is in the outskirt of the cluster, ~ 10″ from IRS11. The deep 3.5 cm VLA image (right), plotted with logarithmic contours, shows strong emission from IRS1 - 3 and a faint (~ 6 mJy) jet-like source centered on the protostar.

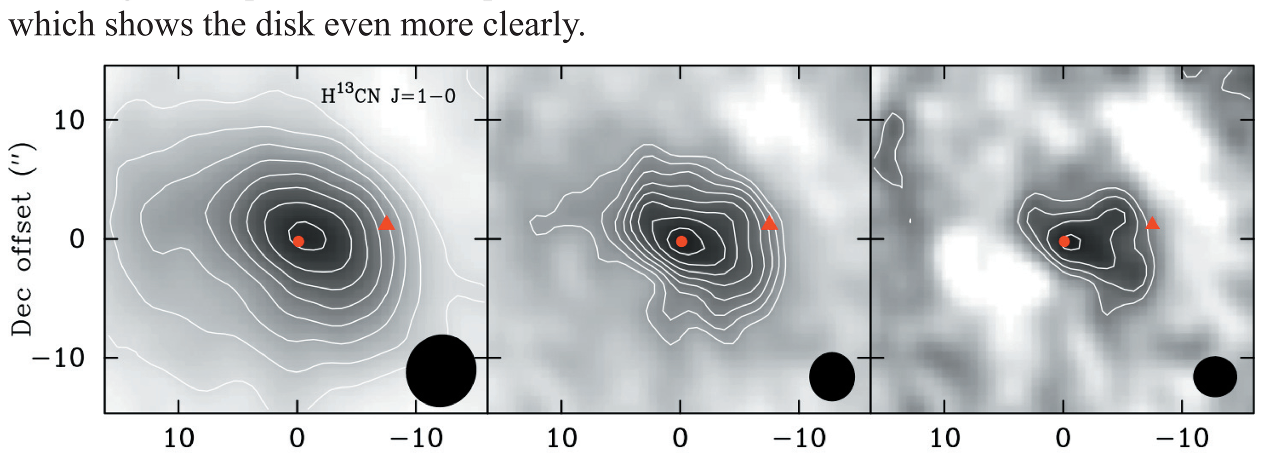


NGC 7538S

Imaging in dust continuum and molecules tracing high densities show a disk-like source centered on an OH/H_2O maser and FIR source with a luminosity of ~10^4 $L_{\odot}$. It powers a highly collimated ionized jet and drives a very young, compact, hot molecular outflow orthogonal to the 'disk', see the figures below.



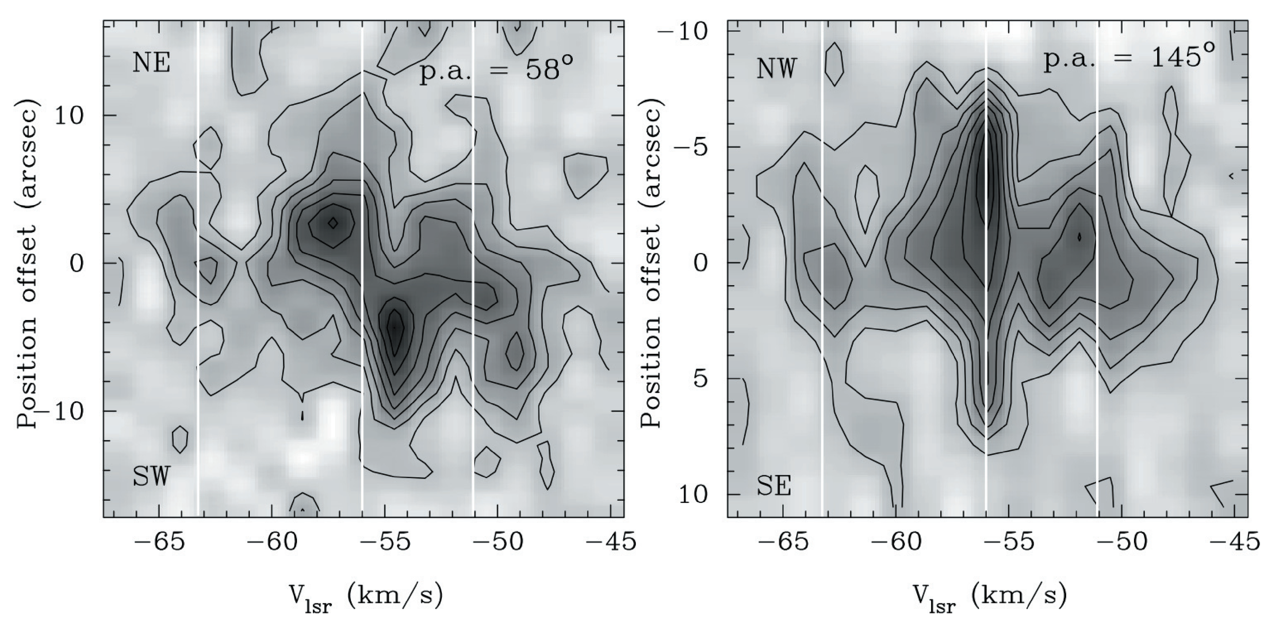
The NGC 7538S cloud core imaged in 1.4 mm continuum and DCN J=3-2 overlaid with the blue HCO+ J=1-0 high velocity outflow and the VLA source. The color imge to the right is a spectral index map of the dust continuum between 3 and 1.4 mm. which shows the disk even more clearly.



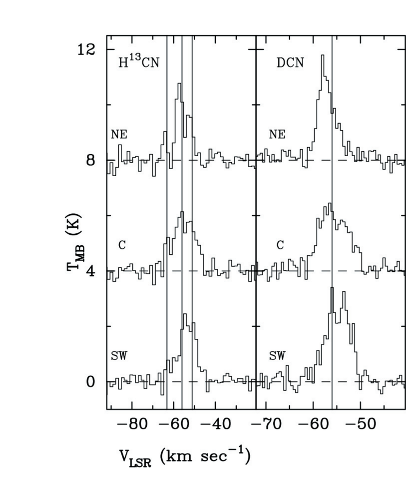
The same in $H^{13}CN$. The left image is produced by using all data and uniform weighting, the middle image with robust weighting and excluding uv-spacings shorter than 5 kλ. The one to the right is with uniform weighting and excluding all uv-spacings shorter than 10 kλ.

The accretion disk - do we see rotation?

Evidence for rotation is seen in all optically thin molecular tracers, $H^{13}CN$ J = 1-0, $HN^{13}C$ J = 1-0, $H^{13}CO+$ J = 1-0, and DCN J =3-2, although several molecules, particularly DCN and CH_3CN are affected by the hot molecular outflow. One therefore needs to examine the data with extreme care to ensure that the rotation signature is not caused by the outflow or by accretion from the massive infalling envelope. Below we show a position velocity plot of $H^{13}CN$ in the disk plane and in the outflow direction.

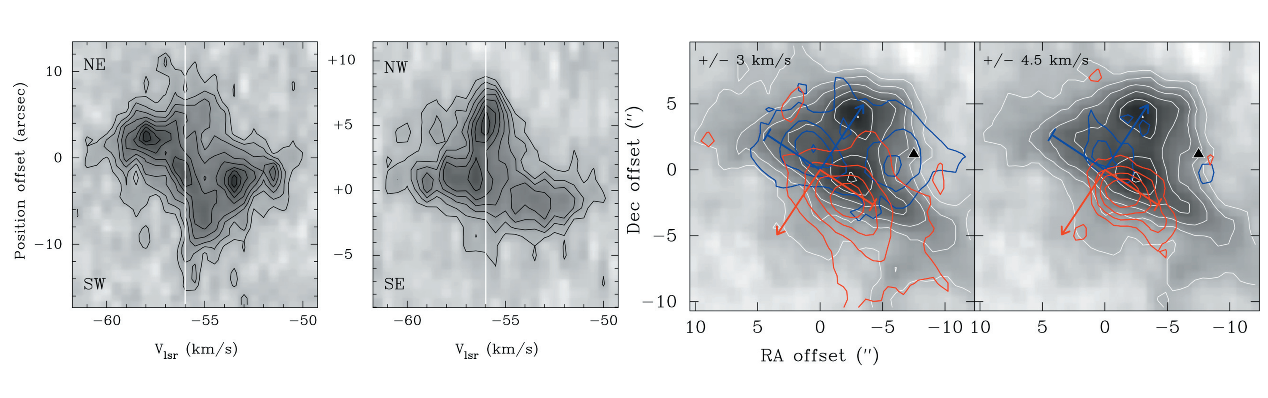


There is a clear velocity gradient along the disk plane, which appears to be Keplerian. No velocity gradient is seen in the outflow direction (pa ~ 145°). Note that even $H^{13}CN$ is self-absorbed towards the center of the accretion disk. The velocity gradient is seen very clearly in the spectra, see below,



Spectra from the blue-shifted edge (NE), center (C), and red-shifted edge (SW) of the disk in the robust weighted $H^{13}CN$ J=1-0 and in DCN J=3-2. The radius of the rotationally supported disk is 2.5″. For both molecules we indicate the systemic velocity with a vertical line. For $H^{13}CN$ we additionally also show the velocities of the two hyperfine lines relative to the main line, F=2-1.

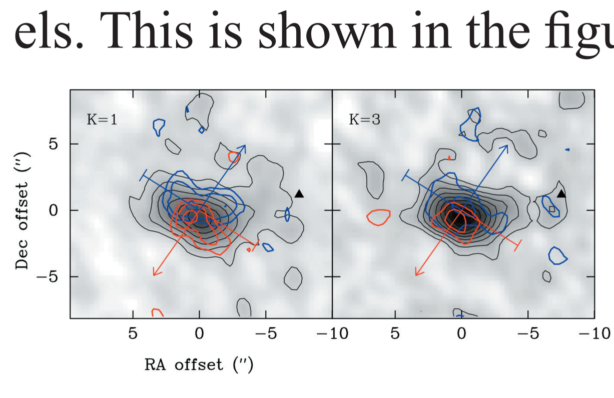
The deduced velocity gradient from $H^{13}CN$ J=1-0 is 3.4 km/s over 5″ (14,000 AU), i.e. the gravitationally supported part of the disk, corresponding to an enclosed mass of 14 - 24 $M_{\odot}$. DCN J=3-2 gives very similar results, but is definitely contaminated by the outflow, see below.



DCN shows a clear velocity gradient in the position velocity plot along the disk-plane, but one can clearly see high velocity gas along the cut in the out-flow direction. This is seen even more clearly in the right panel, which shows blue- and red-shifted gas overlaid on the integrated DCN emission from the cloud core. The arrows indicate the direction of the outflow and the blue- and red-shifted part of the disk.

CH_3CN J=12-11 traces the hot outflow, not the disk!

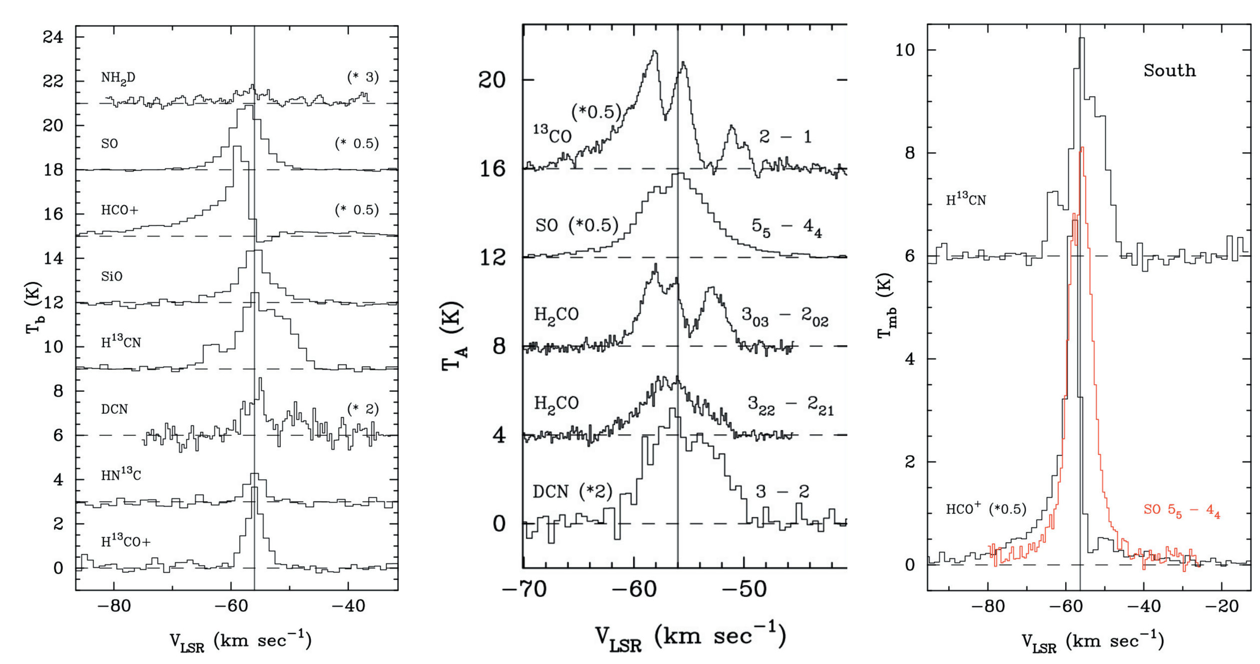
CH_3CN J = 11-10 shows a disk-like structure, but is severely affected by the outflow, especially at higher K-levels. This is shown in the figure below.



The integrated CH_3CN emission over the cloud core (grey scale) appears very disk-like and becomes more compact with higher K-levels indicating that the gas is hot near the center. However, when we show the distribution of the high velocity wings, the red- and blue- emission is clearly separated in the outflow direction.

What about accretion ?

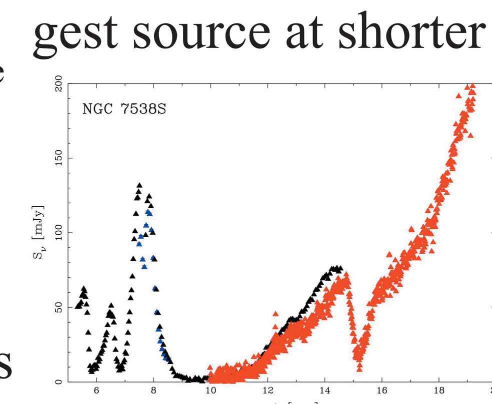
All optically thick lines show redshifted self-absorption from the cold infalling envelope. This self-absorption is particularly strong in HCO^+ and H_2CO, see selected spectra below. The self-absorption extends over ~ 0.1 pc and broadens towards the center of the disk, i.e. the infall is accelerating.



The first two panels show spectra towards NGC 7538S observed with BIMA at 3 & 1 mm. The redshifted self-absorption is quite striking in HCO^+ J=1-0 and H_2CO 3_{03} - 2_{02}. In ^{13}CO J=2-1 (not shown) most of the red-shifted wing is completely supressed, suggesting strong accretion onto the disk,whereas e.g. SO 5_5 - 4_4 exhibits symmetric line wings. In the right panel we have overlaid a scaled SO spectrum on the HCO^+ spectrum, which demonstrates that most of the redshifted wing of HCO^+ is supressed by absorption from the infalling envelope.

Spitzer IRS maps (preliminary)

We have mapped the NGC 7538S cloud core with IRS in short-low, SL (5-8 μm), short-high, SH (10-20 μm) and long-high, LH (20-38 μm). Examination of these data cubes show that the protostar is heavily absorbed by the surrounding cloud at λ < 30 μm. At 35 μm the protostar is ~ 10 - 15 Jy, and rising much faster than IRS11, the strongest source at shorter wavelengths.



Spectrum of NGC 7538S in the SL and SH modules of the IRS. The different orders are plotted with different colors. Note that the continuum level is almost down to zero over part of the spectrum, indicating that the emission from the protostar is completely absorbed by the surrounding dense cold molecular cloud and most likely by part of the disk as well.

Summary

Embedded in the NGC 7538S cloud core is a small cluster of young stars detected only in the mid-IR. The most extreme one of these stars coincides with an OH, H_2O, and CH_3OH class II maser, suggesting that it is a high-mass object. Observations with BIMA show that this high-mass protostar is surrounded by a disk-like structure >20,000 AU in diameter and with a mass of ~ 100 $M_{\odot}$. The inner part of the disk appears to be in Keplerian rotation, and drives a highly collimated ionized jet, and a compact molecular outflow. The disk is seen nearly edge-on and has a velocity gradient of 3.4 km/s across its diameter, corresponding to an enclosed mass of ~ 20 $M_{\odot}$. Infalling molecular gas is observed out to at least 0.1 pc from the disk, with an estimated accretion rate of ~ 8 10^{-3} $M_{\odot}$/yr. NGC 7538S appears to be a very young high-mass star. The large outer parts of the disk are probably unstable and unlikely to survive.

The NRAO is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.The BIMA array is operated by the Universities of California (Berkeley), Illinois, and Maryland with support from the National Science Foundation. This work was supported in part by NSF Grant AST 0228963 to the University of California.