Characterizing a Young Protoplanetary Disk in the Orion Nebula Cluster

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Background

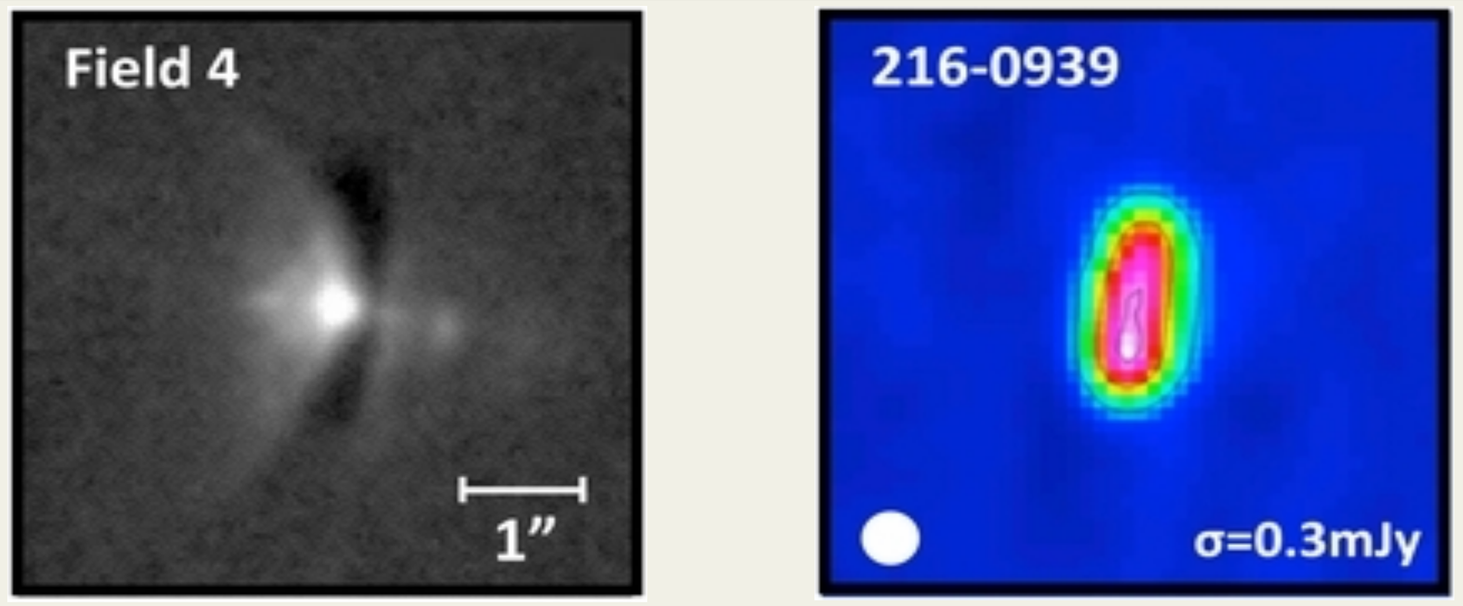

Figure 1: (left) HST (Hα) observation from Smith et al. 2004. (right) ALMA 856 μm continuum observation from Mann et al. 2014 with a FWHM resolution of 0.5”. Image sizes are 5”×5”.

Spatially resolved submillimeter observations of dust and gas in protoplanetary disks provide insight into the location and amount of material available for planet formation. By necessity, most such studies have focused on resolving disks in nearby, low-mass star forming regions, due to the limited sensitivity and angular resolution of submillimeter interferometers. However most stars, likely including our Sun, form in denser environments near O-type stars, such as the Orion Nebula. Previous submillimeter studies of disks in Orion have yielded marginally resolved observations of continuum emission only. For the first time, using ALMA, we have significantly detected and resolved gas emission from disks in Orion.

Observations

We present ALMA observations of d216-0939, a Solar-type star surrounded by the largest, most distant disk imaged in Orion. Observations are at wavelengths of 840 and 867 μm, corresponding to the HCO^+(4-3) and CO(3-2) rotational transitions, with spatial resolution of 0.5”, and velocity resolution of 0.4 km/s. The observations represent 22 min on source as part of a Cycle 0 survey by Mann et al. (2014). Baselines shorter than 70 kλ were excluded to minimize large-angular-scale cloud contamination. Channel maps for HCO^+(4-3) are shown in Figure 3. CO(3-2) emission is still dominated by background cloud emission and is not presented here.

Smith et al. noted significant asymmetry, with the northern portion being ~50% larger than the southern portion. In contrast, the 856μm continuum map shows the southern portion of the disk to be brighter. We also note high relative velocity emission coming from near the star shown in Figure 2. This could be a signature of an outflow or other complicated dynamics. Note that the emission matches the profile for a 2 $M_\odot$ central star, a factor of 2 larger than the predicted mass based on the spectrum of the scattered light.

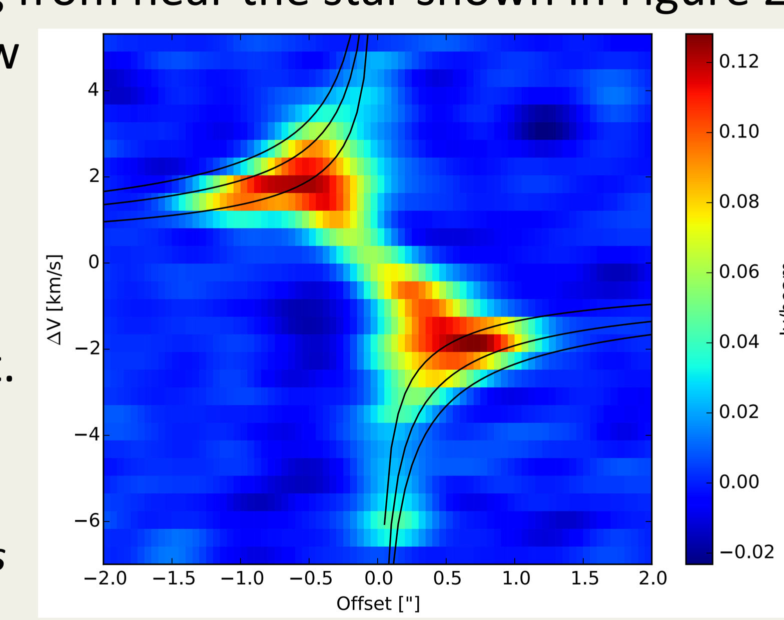

Figure 2: position-velocity diagram for HCO^+(4-3) emission. Black curves are Keplerian velocity profiles for stellar masses of 1, 2, and 3 $M_\odot$.

Modeling

We fit the data using a ray tracing code assuming local thermodynamic equilibrium (LTE). Position offset and systemic velocity were fitted using a simple grid search and a typical model disk. We then fit the model using an affine invariant Markov Chain Monte Carlo (MCMC) algorithm (Foreman-Mackey et al. 2013). This fitting method works particularly well with multidimensional degenerate parameter space and also allows us to characterize the uncertainty on our best fit parameters.

We only fit the HCO^+(4-3) emission since the CO(3-2) emission is highly contaminated. The wings of the CO(3-2) line are clear of contamination and will be used in the future to constrain the temperature profile. We chose to exclude the 8 most blue-shifted channels in our fitting to avoid the excess high-velocity emission close to the star, as seen in Figures 2 & 3. We did not fit the SED, as spectral data was either not available or contaminated by background emission.

Table 1: Best fit and fixed parameters. Uncertainties are relative and based solely on the fits; they do not reflect systemic uncertainties such as flux or distance. q and γ are the power law indices for temperature and density respectively. Z_q and R_c are the truncation distance for the vertical temperature and surface density respectively.

Best Fit Parameters		Fixed Parameters	
q	-0.01 ± 0.02	γ	-1
$M_{\rm disk}[M_\odot]$	$0.09^{+0.03}_{-0.05}$	$X_{\rm HCO+}$	10^{-10}
R_c[AU]	210^{+30}_{-20}	$V_{\rm turb}$[km/s]	0.01
$M_{\rm star}[M_\odot]$	2.09 ± 0.05	$T_{\rm mid,150}$[K]	19
$T_{\rm atm,150}$[K]	21^{+3}_{-1}	Z_q[AU]	29
$i[°]$	-67.7 ± 0.8	$D_{\rm Orion}$[pc]	414
$PA[°]$	-7.1 ± 0.8		
$V_{\rm sys}$[km/s]	8.1 ± 0.1		

Results: Planet Forming Potential and a Possible Binary

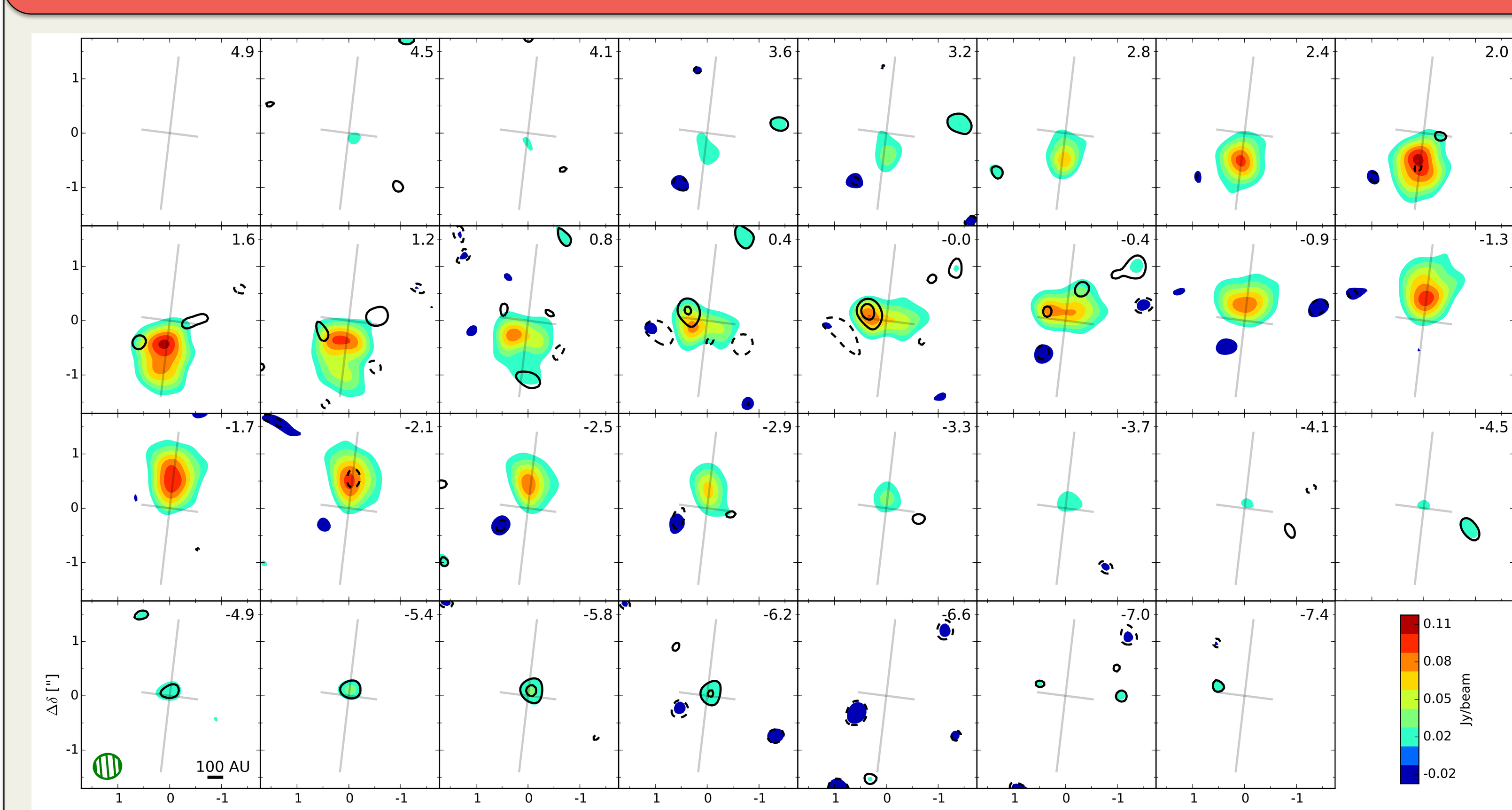

Figure 3: (left) Naturally weighted channel maps of HCO^+(4-3) emission. ΔV from line center is given in the upper right corner. Color map and contours start at 0.022 Jy/beam (3σ) with increments of 0.015 Jy/beam (2σ). Synthesized beam is marked in the bottom left corner. Contours are residuals from the best fit model given in Table 1.

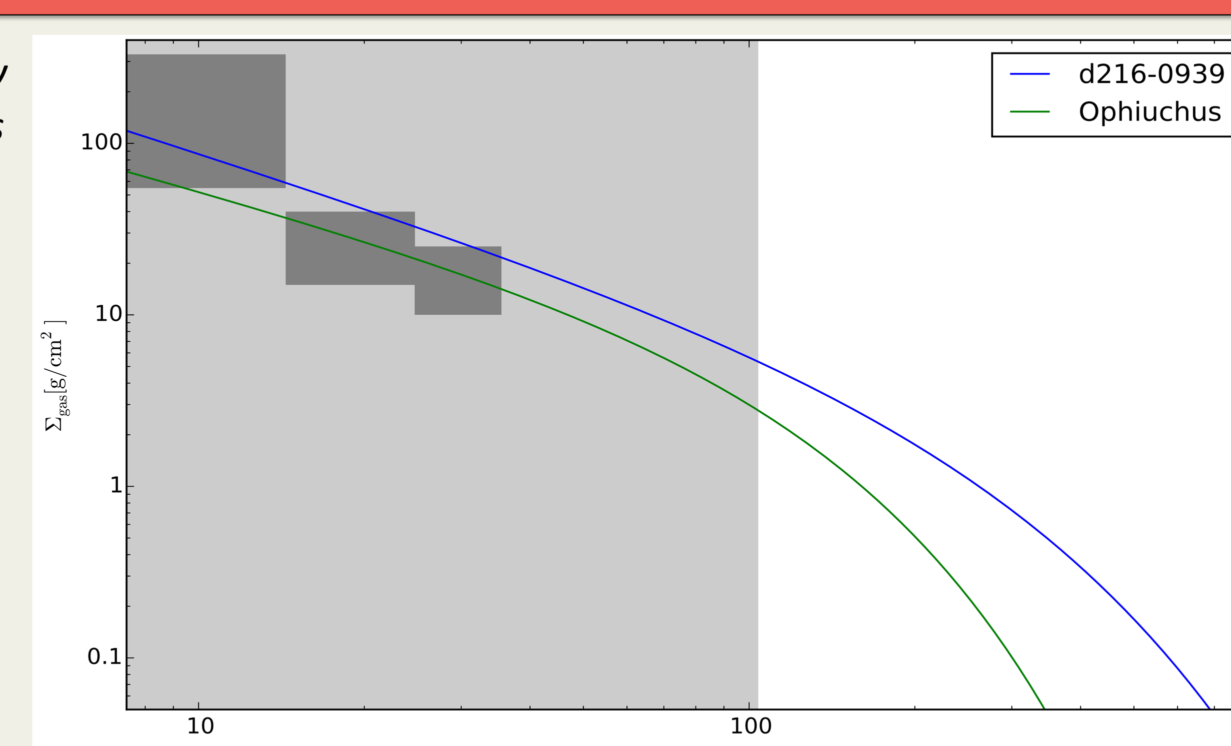

Figure 4: Radial surface density derived for d216-0939 alongside the median profile for disks in Ophiuchus given by Andrews et al. 2009 (M_{disk}=0.05 $M_\odot$, γ=0.9, R_c=100 AU). Dark gray rectangular regions mark the surface densities for Saturn, Uranus, and Neptune in the Minimum Mass Solar Nebula (MMSN; Weidenschilling 1977). Light gray region marks the resolution limit of the ALMA observations.

Our best fit disk mass is consistent with continuum measurements made by Mann & Williams 2009 and is similar to masses derived for disks in Ophiuchus. On the other hand, our best fit stellar mass, 2.09±0.0.05 $M_\odot$, is more than a factor of 2 higher than the predicted mass based on the spectral type, K5, suggesting a possible binary. There is no significant North-South asymmetry in HCO^+(4-3), in contrast to previous dust continuum imaging. The surface density profile is similar to the MMSN and disks in the Ophiuchus low-mass star forming region, with sufficient mass to represent significant planet forming potential.

References & Contact

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