

## Detection of a Disk Surrounding the Variably Accreting Young Star HBC722

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### ABSTRACT

We present new ALMA 233 GHz continuum observations of the FU Orionis Object HBC722. With these data we detect HBC722 at millimeter wavelengths for the first time, use this detection to calculate a circumstellar disk mass of  $0.024 M_{\odot}$ , and discuss implications for the burst triggering mechanism.

### 1. INTRODUCTION

FU Orionis objects (hereafter FUors) are a group of pre-main-sequence stars that abruptly increase in brightness by several magnitudes, lasting decades or longer. There are about 10 – 20 FUors confirmed by direct observation of their bursts, along with an approximately equal number of candidates found to display similar spectral characteristics (e.g., ?). The FUors’ large amplitude bursts are credited to enhanced mass accretion from the surrounding circumstellar disk, with various triggering mechanisms being proposed over the years, e.g. gravitational and/or magnetorotational instabilities, thermal instabilities, or interactions with binary companions (e.g., ???). FUors may represent the late stages of a cycle of episodic accretion bursts and luminosity flares during the embedded phase (?). Thus, studying and characterizing each FUor is important for understanding how they fit into the general star formation process.

In this paper, we present new 1 mm continuum observations of the FUor HBC722 obtained with the Atacama Large Millimeter/Submillimeter Array (ALMA). HBC722, located in the North American/Pelican Nebula Complex ( $d \sim 800$  pc; ?), was undetected in previous 1 mm continuum data from the Submillimeter Array (SMA), setting an upper limit for the disk mass of  $0.05 M_{\odot}$  (after rescaling to the current distance; ?). With our new ALMA data we present the first millimeter continuum detection of this object, and use our data to calculate the mass of its circumstellar disk.

### 2. OBSERVATIONS & RESULTS

We obtained ALMA Cycle 2, Band 6, 12-m array observations of HBC722 on 2014 May 01 and 2015 May 03, with 34 – 36 operational antennas. The array configuration provided projected baseline lengths of 12–450 m and a synthesized beam size (assuming natural weighting) of  $1.67'' \times 0.89''$  at a position angle of  $5.82^{\circ}$  (measured east of north). To measure the continuum with the widest possible bandwidth while avoiding contamination from bright lines, the four spectral windows were centered at 224, 226, 240, and 242 GHz, and were configured to provide 128 channels over 1.875 GHz bandwidth. The resulting continuum image is centered at 233 GHz (1.29 mm) and has a total bandwidth of 7.5 GHz.

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**Figure 1.** ALMA 233 GHz continuum image of HBC722. The yellow circle shows the ALMA primary beam. The black contours show the ALMA continuum data at levels of 5, 20, 50, and 100 times the  $1\sigma$  rms noise, whereas the gray contours show the SMA continuum data at approximately the same frequency from ?, starting at  $3\sigma$  and increasing in steps of  $5\sigma$ . The ALMA and SMA synthesized beams are shown as the black and gray ellipses, respectively. Detections from ? are labeled, with annotations reporting their integrated flux densities from the primary beam corrected ALMA data. MMS3 from ? is resolved as two sources in our higher-resolution ALMA data, MMS5, MMS6, and MMS7 from ? are too far outside the ALMA primary beam to be robustly detected, and MMS8 is a new ALMA detection that was only marginally detected in the SMA data.

Calibration was performed using the Common Astronomy Software Applications (CASA) package<sup>1</sup>, following the standard techniques described in ? and ?. We then applied two rounds of phase self-calibration, followed by one round of amplitude self-calibration. The effective solutions intervals used for self-calibration were 390 s (first round of phase calibration), 30 s (second round of phase calibration), and 900 s (amplitude calibration). After applying the amplitude self-calibration we verified that the noise in the image decreased while the total fluxes of the detected objects did not change. The self-calibrated image has a  $1\sigma$  rms of  $0.057 \text{ mJy beam}^{-1}$ .

In Figure 1, which displays the self-calibrated ALMA 233 GHz continuum image, HBC722 is detected with a peak signal-to-noise ratio of 51. With a peak intensity of  $2.9 \text{ mJy beam}^{-1}$ , the ALMA detection of HBC722 is consistent with the previous SMA non-detection from ? at approximately the same frequency.

### 3. ANALYSIS & CONCLUSIONS

We used the CASA tool GAUSSFIT to fit an elliptical Gaussian in the image plane to all of the detected sources in the ALMA continuum image. The resulting integrated flux densities are included as annotations in Figure 1. For

<sup>1</sup> Available at <http://casa.nrao.edu>

HBC722, we then calculated the total circumstellar disk mass  $M$  as:

$$M = 100 \frac{d^2 S_\nu}{B_\nu(T_D) \kappa_\nu} \quad (1)$$

where  $d = 800$  pc,  $S_\nu$  is the measured integrated flux density,  $B_\nu(T_D)$  is the Planck function at the isothermal dust temperature  $T_D$ ,  $\kappa_\nu$  is the opacity of the dust, and the factor of 100 is the assumed gas-to-dust ratio. We adopt the dust opacities of ? for thin ice mantles after  $10^5$  yrs of coagulation at a gas density of  $10^6$  cm $^{-3}$ , giving  $\kappa_\nu = 0.901$  cm $^2$  g $^{-1}$  at 233 GHz. Assuming  $T_D = 30$  K, Equation ?? gives a total circumstellar disk mass for HBC722 of  $0.024 M_\odot$ . With typical uncertainties of a factor of a few (?), this result is in good agreement with the total gas mass of  $0.03 M_\odot$  found by ?.

With a burst accretion rate of  $10^{-6} M_\odot \text{ yr}^{-1}$  (?), it would take 24,000 yr to drain a  $0.024 M_\odot$  disk. Thus this disk mass is sufficient to power the current accretion burst. With a known stellar mass of approximately  $0.5 M_\odot$  (?), our calculated disk mass implies that HBC722 has a disk-to-star mass ratio of approximately 5%. While this is a factor of ten higher than the median disk-to-star mass ratio for T Tauri stars (?), it is still marginally too low for gravitational instabilities to serve as the burst triggering mechanism, as such instabilities likely require disk-to-star mass ratios of 10% or higher. However, given the uncertainties in the calculated mass, and the possibility that the ALMA continuum detection is optically thick, gravitational instabilities remain a possible triggering mechanism for this object. Future analysis using radiative transfer modeling is required to better determine the true mass of the HBC722 disk.

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