An EVLA Continuum Search for Ionized Jets Toward Massive Protostars : Preliminary Results at K-Band

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We have observed 28 regions of massive star formation using the EVLA with two 1 GHz wide bands at 1.3 cm (K-band). 50 % of the targets are hot molecular core candidates, which were selected from Sridharan et al. (2002). The rest came from Rathborne et al. (2006) plus a small number of specially selected sources. Typically, the sample is characterized by having high FIR luminosity, dense molecular and dust condensations, and massive CO flows. All of these regions are non-detections in the CORNISH survey with a 6 cm flux density < 1 mJy (radio quiet). The absence of strong cm emission in these regions suggests that they contain massive stars in an evolutionary phase prior to ultra- or hypercompact H II regions. Of the 18 targets reduced, we present the detections of cm continuum emission in these regions as well as the in-band spectral index between 21.0 GHz and 25.5 GHz for the brightest sources. The morphological features of these sources are also discussed.

Introduction

One competing theory for massive star formation is the accretion scenario. The model predicts that during the early phases of massive star formation, the protostar will have a disk/jet system as it is accreting mass. So far, only a small number of such jets are known (e.g. Garay et al. 2003).

Radio Observations of high resolution and high sensitivity are required in order to probe the environments very near the massive protostar. In the past decades the Very Large Array established two late phases of massive star formation : ultracompact (UC) and hypercompact (HC) HII regions. Stars in these regions are thought to be on or near the main sequence.

In order to observe evolutionary phases prior to that of UC/HC regions, deeper observations are required. In the early phases, the radio continuum is very weak requiring μJy sensitivity. The newly upgraded EVLA can reach this sensitivity in about an hour. This means that the EVLA will allow us to observe new stages in the process of massive star formation.

Observations

The observations were performed in the EVLA K-band (18.0~26.5 GHz) with two sub bands, 1 GHz in width, centered at 21.0 GHz and 25.5 GHz. The synthesized beam of these observations is ~0.3 arcsec. Each target was observed with around 40 minutes on-source to reach a rms noise of about 8.5 μJy.

Data Reduction

The data reduction for these sources was performed using the Common Astronomy Software Applications (CASA). All images were made in CASA using the clean task with natural weighting.

Spectral Information

In the table below, the spectral indices are shown for the brightest of the sources in the target list between the two sub band frequencies (21.0 GHz and 25.5 GHz). The in-band spectral index is unreliable for weak sources, hence these sources were chosen because they have a peak intensity greater than 100 μJy/beam.

	Target Name	S_ν (μJy)	I_ν (μJy/beam)	Int. α
1	IRAS 18089-1732	1720	1010	1.7
2	IRAS 18151-1208	595	555	0.8
3	IRAS 18182-1433	639	347	2.2
4	IRAS 18264-1752	631	427	1.7
5	IRAS 18345-0641	320	189	1.8
6	IRAS 18440-0148	382	374	-1.4
7	IRAS 18470-0044B	3670	237	0.6
8	IRAS 18470-0044C	125	134	-1.7
9	IRAS 18470-0044D	3310	129	0.3
10	g15.05-mm1	184	190	0.6

For most of the sources, the spectral index is between 0.6 and 2.0 indicating thermal free-free emission. Two sources have steep negative spectral indices indicating non-thermal emission, possibly due to a synchrotron jet.

	Target Name	RA (J2000)	Dec. (J2000)	Target Type	Point Source Detections	Extended Detections
1	IRAS 18089-1732	18 11 51.3	-17 31 29	HMC	4	2
2	IRAS 18151-1208	18 17 57.1	-12 07 22	HMC	3	0
3	IRAS 18182-1433	18 21 07.9	-14 31 53	HMC	0	2
4	IRAS 18264-1152	18 29 14.3	-11 50 26	HMC	7	1
5	IRAS 18345-0641	18 37 16.8	-06 38 32	HMC	1	1
6	IRAS 18437-0216	18 46 22.7	-02 13 24	HMC	0	1
7	IRAS 18440-0148	18 46 36.3	-01 45 23	HMC	1	0
8	IRAS 18470-0044	18 49 36.7	-00 41 05	HMC	1	3
9	g15.05-mm1	18 17 50.4	-15 53 38	CMC	2	0
10	g15.31-mm3	18 18 45.3	-15 41 58	CMC	0	0
11	g25.04-mm3	18 38 10.2	-07 02 44	CMC	0	0
12	g27.75-mm2	18 41 33.0	-04 33 44	CMC	1	1
13	g28.23-mm1	18 43 30.7	-04 13 12	CMC	0	0
14	g28.53-mm1	18 44 18.0	-03 59 34	CMC	0	0
15	g30.97-mm2	18 48 22.0	-01 47 42	CMC	2	0
16	G11.11-P1	18 10 28.4	-19 22 29	CMC-IR	3	0
17	IRDC18222-3	18 25 08.5	-12 45 23	CMC-IR	1	1
18	g18.82-mm3	18 25 52.6	-12 44 37	CMC-IR	1	1

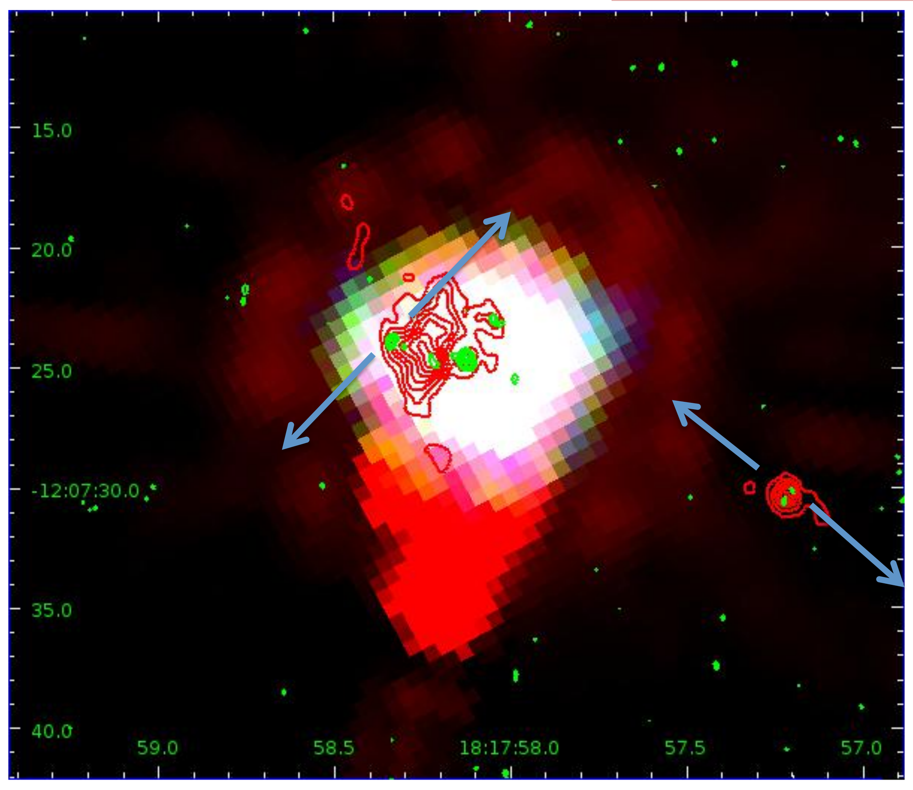
HMC – Hot molecular cores candidate, denoted in all tables by a red background.

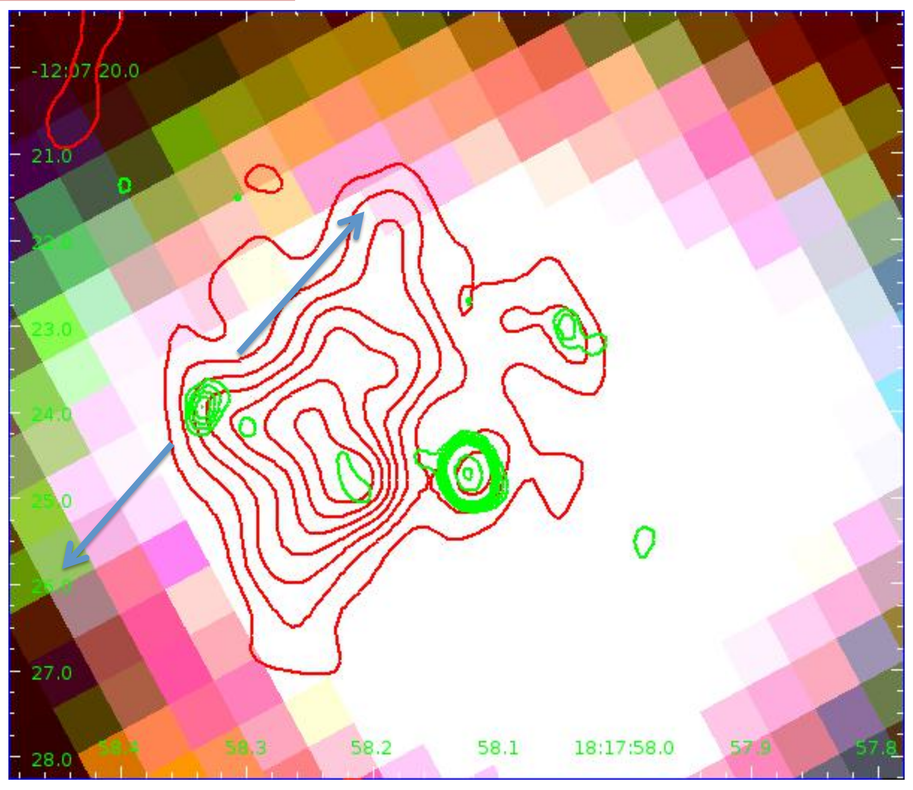
CMC – Cold molecular cores, denoted by a blue background.

CMC-IR – Cold molecular cores with an infrared counterpart, denoted by a purple background.

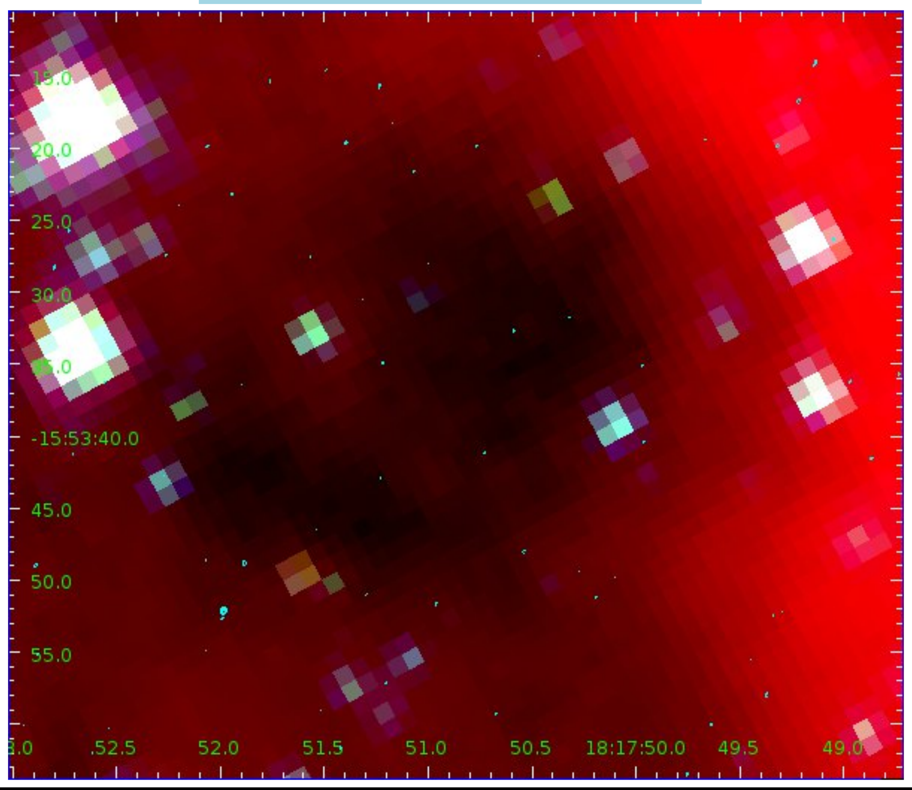
Example Sources

HMC : IRAS 18151-1208

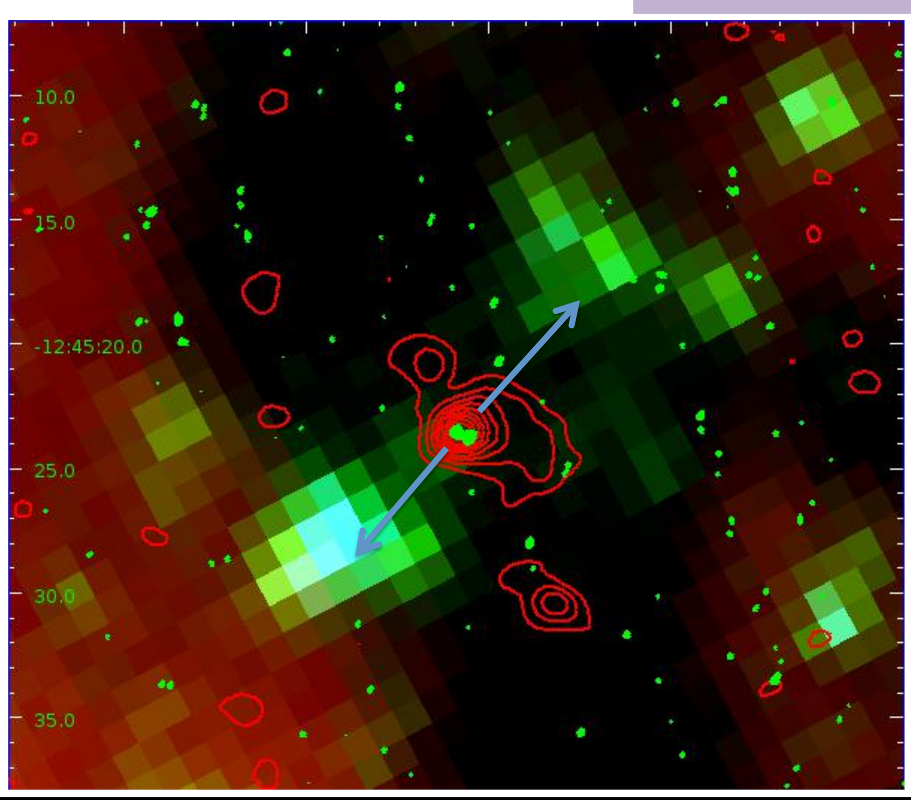


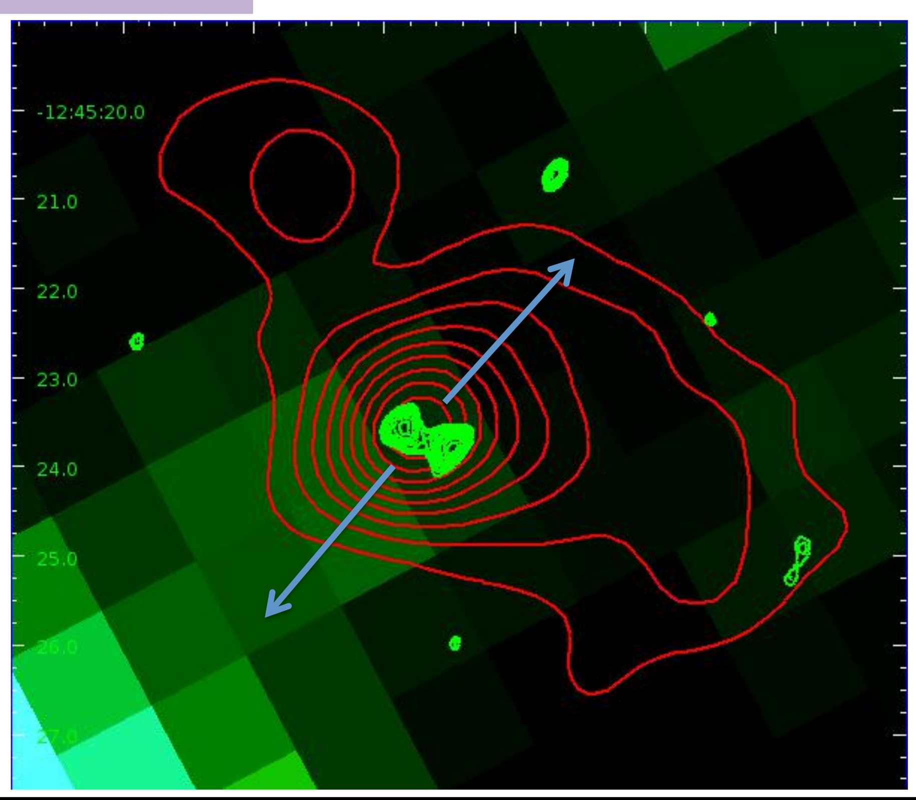


CMC : g15.05-mm1



CMC-IR: IRDC18222-3





The Sample

Our sample was split into two categories: Hot Molecular Cores Candidates (HMCs) and Cold Molecular Cores (CMCs).

HMCs are defined to be regions with sizes of ~0.1 pc, densities ~10^7 cm^{-3}, and temperatures of ≥ 100 K. Our list of candidates came from Sridharan et al. (2002).

CMCs are defined as regions with T < 25K, M > 100 $M_\odot$, and can appear as infrared dark clouds. Chambers et al. (2009) found that about half of the CMCs had an extended 4.5 μm infrared 'green' excess and/or 24 μm emission. These sources are identified as CMC-IR (Cold Molecular Cores with Infrared Counterparts).

Detection Statistics

Out of the 18 target fields that we have reduced, 14 contain 1.3 cm continuum emission. A detection rate of 100% was achieved toward the HMC candidates and CMC-IRs. A detection rate of < 40% was achieved toward the CMC targets.

Discussion

HMC : IRAS 18151-1208

Top top set of images is an example of one of the HMC candidates. The Spitzer three color image on the left shows the HMC candidate with the 1.3 cm (green) and 1.3 mm (red) contours. The blue arrows indicate the direction of the CO outflows centered on two radio continuum sources. We have detected cm sources located at the center of the CO flow and elongated in the direction of the flow. This suggests that these may be the ionized jets that are driving the flows.

CMC : g15.05-mm1

The center figure is and example of one of the cold molecular cores. The figure shows a three color image created from the Spitzer Glimpse survey. There is no detection of a radio source in the dark cloud. The only radio detection is located south of the dark cloud and probably is not related to the cloud.

CMC-IR : IRDC18222-3

The bottom set of images show an example of one of the CMC-IRs. Here, we detect a 1.3 cm continuum source (green contours) that is elongated perpendicular to the outflow of this system. The outflow is shown very clearly in the Spitzer three color image and arrows are shown to emphasize the direction of the flow. The red contours show the 1.3 mm continuum emission due to dust. Here, we seem to be detecting the disk of the massive protostellar system.

Preliminary Results

- We have a 100% detection rate at 1.3 cm toward the HMC candidates as well as toward the CMC-IR targets. Most of these are new detections.
- In most cases the detected cm sources are located near the center of massive molecular flows, which suggests that we detect the ionized jets at the base of the flows.
- In some cases, we appear to detect the disks of the protostellar systems.
- Our findings suggest that disks and jets are common in massive star formation phases prior to HC/UC phases, thus supporting the idea that massive stars are formed via disk accretion.

Acknowledgements

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References

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