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Tracing the Galactic bar through dense molecular cores with broad emission spectra

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Abstract. We find 14 dense molecular regions with $NH_3(1,1)$ transition line from the H_2O Southern Galactic Plane Survey (HOPS) exhibiting broad emission spectra (with observed velocity widths between 19.8 and 47.6 km/s). These clumps are clustered at $l \approx 5.4°, -5.4°$ and $-10°$. Cluster-1 and Cluster-2 have inverse symmetry with respect to the Galactic centre and are rotating in a non-circular x-1 orbit. We predict them as the indicator of Galactic Bar potential. Cluster-3 with 2 clumps are undergoing high-mass star formation.

Resumo. Encontramos 14 regioes moleculares densas com linha de transicão $NH_3(1,1)$ do H_2O Southern Galactic Plane Survey (HOPS) exibindo amplos espectros de emissão (com larguras de velocidade observadas entre 19,8 e 47,6 km/s). Esses aglomerados são agrupados em $l \approx 5.4°, -5.4°$ e $-10°$. Cluster-1 e Cluster-2 tem simetria inversa em relacão ao centro galactico e estão rolando em uma orbita x-1 não-circular. Nos os predizemos como o indicador do potencial da Barra Galãctica. Cluster-3 com 2 aglomerados estão passando por formacão de estrelas de alta massa.

Keywords. Stars: formation – ISM: clouds – Galaxy: kinematics and dynamics

1. Introduction

Study of high-mass star formation helps us to understand the evolution of our Galaxy, its surrounding ISM and shape of the Universe. From literature we know that our Galaxy has a central rotating bar (e.g., Sormani & Magorrian 2015). This has been suggested since the 1970's, from the large non-circular kinematics of HI and CO lines in the inner Galaxy (e.g., Peters 1975) and was confirmed two decades later with evidences (e.g., Binney et al. 1997). The understanding of the formation of this bar can help us to solve the mystery of star formation, evolution of the Galaxy, gas infall in the vicinity of the Galactic centre, disk accretion and the non-circular motion of the gases near the Galactic centre.

In this research, we used $NH_3(1,1)$ from the HOPS as the primary tracer of dense molecular cores. NH_3 is a very good tracer for colder and denser gas (Walsh et al. 2011) because: 1) it has a high critical density ($\rho_c \sim 10^4 cm^{-3}$, Ho & Townes 1983) and 2) unlike many other tracers, it is protected from being frozen out to dust in the cold temperature (Bergin & Langer 1997). We then compared NH_3 spectra with other tracers available from the HOPS. This study will aid in the understanding of the dynamics of the molecular clouds in the Galactic bar. All the results, analysis and discussion of this proceeding are in Akhter et al. (2018).

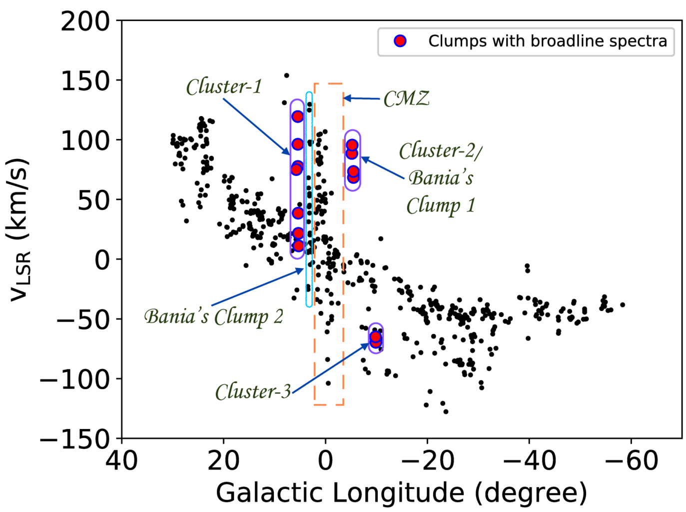

FIGURE 1. The $l - v$ diagram of all the clumps found in the entire HOPS region with $NH_3(1,1)$ transition line. The three clusters of 14 clumps with broad emission spectra are shown with 'red solid circles with blue edge'. The 'orange dotted box' shows the CMZ and the 'sky-blue oval box' shows *Bania's Clump 2* (Bania 1977) to put all these features into perspective.

2. Data

We used data from HOPS (Walsh et al. 2011) - a survey of selected frequencies between 19.5−27.5 GHz with the 22 m Mopra Radio Telescope. The survey covered one third of the Galactic plane, 100° in Galactic longitude $30° \leqslant l \leqslant 290°$ (through $l = 0°$) and 1° in Galactic latitude $|b| \leqslant 0.5°$. The average beam size was $\sim$ 2 arc-min (2.4′ to 1.7′) with a velocity coverage of ± 200 kms^{-1}. We used the 3D position-position-velocity data cubes of the molecular transition lines $NH_3(1,1)$, (2,2), (3,3),

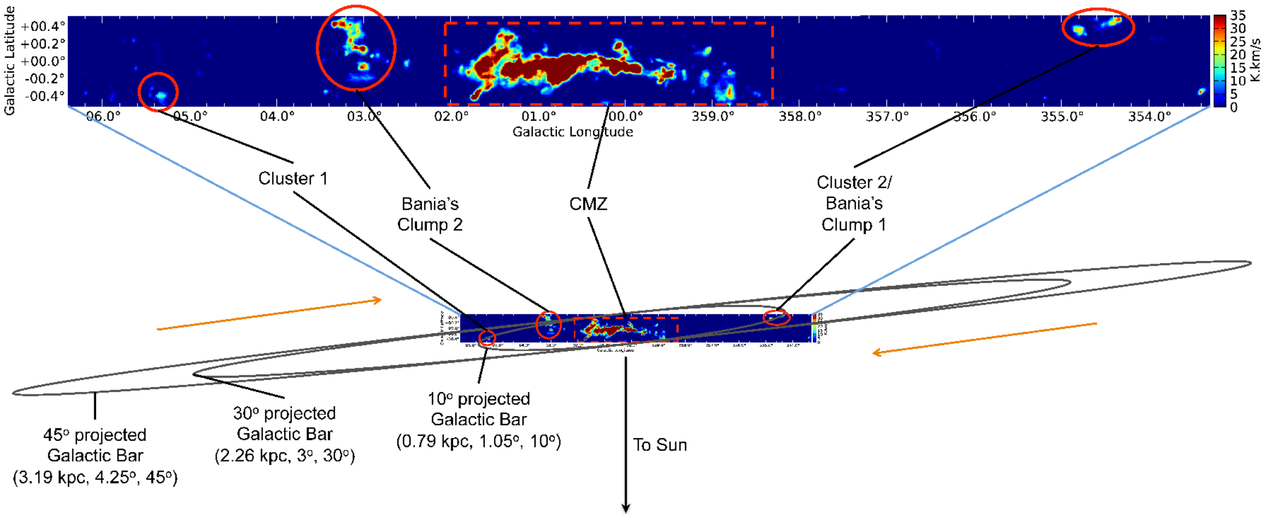

Figure 2. *Top:* NH_3(1,1) integrated emission data from the HOPS; *Bottom:* A geometrical Galactic model showing Cluster-1 and Cluster-2 in relation to the Galactic bar potential. Three apparent projected galactic bars with respect to different bar parameters are shown ('black outlined' ellipses). This Figure is adapted from Akhter et al. (2018).

(6,6), HC_3N(3−2), H_2O maser emission and the radio recombination line H69α. Because the CMZ is dominated by dense molecular gas with large velocity dispersion and high temperatures (Morris & Serabyn 1996), to avoid inexplicability, we did not use the data from the HOPS region $-2.7° < l < 3.9°$ that contains the CMZ.

3. Analysis and Results

To find clumps (regions of dense molecular gas which may form stars), we used FELLWALKER, a clump finding algorithm from the STARLINK-CUPID package (Berry 2015) on 2D position-position images (integrated over velocity) of the NH_3(1,1) line. We identified 496 candidate star forming clumps in $-60° \leqslant l \leqslant -2.7°$ & $3.9° \leqslant l \leqslant 30°$. We then used 3D data cubes to find averaged spectra over each clump. Among these, 14 clumps exhibit broad observed linewidths (~19.8 – 47.6 $\mathrm{km s^{-1}}$) with all five hyperfine components blended. Here, we analyse these clumps.

Figure 1 shows $l - v$ diagram of these broad emission line clumps. These clumps are clustered in three positions and we refer them as Cluster-1, Cluster-2 and Cluster-3. A multimolecular line comparison exhibits the same line broadening for other tracers as well (where detected emission). We did not detect any NH_3(6,6) emission in the current working region of HOPS. *Cluster-1 and Cluster-2:* Clumps in these clusters have anomalous and positive central velocities with large velocity dispersion (Figure 1) and approximately equal angular distance from the Galactic centre (i.e., $|l| = 5.5° \pm 0.1°$). We detect NH_3(1,1), (2,2), (3,3), and HC_3N(3−2) lines in the clumps and no H_2O maser emission and H69α. *Cluster-3* is quite different from Cluster-1 and Cluster-2. The clumps in the Cluster-3 have negative velocities and are at $l \approx -10°$. Other than detecting NH_3(1,1), (2,2), (3,3), and HC_3N(3−2) lines in the two clumps, we also detect H_2O maser emission and H69α in one of the clumps.

We measured observed velocity widths, velocity center and antenna temperature for all the clumps with Gaussian model fitting. We also performed Ammonia model fitting on these clumps for NH_3(1,1), (2,2), (3,3) lines, measured their intrinsic velocity widths and estimated their rotational temperature using equation from Menten & Alcolea (1995) considering the system is optically thin and in LTE.

4. Discussion and Conclusion

We found that Cluster-1 and Cluster-2 have: **a)** No visible sign of star formation; **b)** High rotational temperatures for NH_3 (2,2)/(1,1) and (3,3)/(1,1); **c)** High Spearman's rank-order correlation between cloud positions and their spectral parameters; **d)** Relative positions w.r.t. the Galactic Bar (Figure 2); **e)** Appear as two vertical features (i.e., regions with a large velocity range within a small longitude range, indicating clumps lying on the dust lane shocks Sormani & Magorrian 2015) in the $l - v$ diagram. We suggest that *these two clusters are associated with the shocked dust-lane and are affected by dynamics of the Galactic bar potential.* This scenario gives explanation for their line broadening and high velocity dispersion.

Clumps in Cluster-3 are undergoing high-mass star formation. The clumpiness in the three clusters might result from molecular clouds undergoing heating & cooling processes (Baba et al. 2010).

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