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HOW DO MASSIVE STARS FORM? INFALL & OUTFLOW IN DENSE CORES IN THE MILKY WAY

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ABSTRACT

Massive stars are some of the most influential objects in the Universe, shaping the evolution of galaxies, creating chemical elements and hence shaping the evolution of the Universe. However, the processes by which they form and how they shape their environment during their birth processes are not well understood. We use NH_3 data from "The H_2O Southern Galactic Plane Survey" (HOPS) survey to define the positions of dense cores/clumps of gas in the southern Galactic plane that are likely to form stars. Then, using data from "The Millimetre Astronomy Legacy Team 90 GHz" (MALT90) survey, we search for the presence of infall and outflow associated with these cores. We subsequently use the "3D Molecular Line Radiative Transfer Code" (MOLLIE) to constrain properties of the infall and outflow, such as velocity and mass flow. The aim of the project is to determine how common infall and outflow are in star forming cores, and therefore to provide valuable constraints on the timescales and physical process involved in massive star formation. Preliminary results are presented here.

Key words: star formation, interstellar medium, HOPS, MALT90, molecular transition line

1. INTRODUCTION

Infall and outflow are processes intimately associated with the formation of stars and may provide valuable insights into how stars accrete mass through infall and lose it through outflow. Things that we do not yet know about accretion include how much of the mass of the final star is accreted during this stage, how much of this accreted mass goes into the outflow and how this scenario changes for stars forming in clusters, the dominant mode for star formation in the Galactic plane. Our main aim is to quantify infall and outflow of massive star formating cores. Characterising how much of the mass of the final star is accreted (i.e., infall) during star formation, and how much of this accreted mass goes into the outflow, will help us advance our knowledge of massive star formation. Our current study will help us to understand: a) how important infall to star forming cores is in influencing the star formation occurring within, b) how common are infall and outflow in dense star forming cores, c) do they occur together or separately and how often, d) is the infall turbulent and how much energy does this inject at small scales, e) how much outflow contributes to turbulence in interstellar gas. To achieve our goals, we are starting with the HOPS survey (see below) to select dense gas likely to be taking part in star formation.

2. HOPS: TEST REGION

The HOPS project[1] covers 100 square degrees of the sky. The width of the survey is $|b| \leq 0.50^{o}$, centred on the Galactic plane. For our current project, we are using the NH_3 (1,1);(2,2) molecular transition lines. We have selected a test region (Figure 1) that is 1/10th of the HOPS survey area in the NH_3 (1,1) molecular transition lines in the 12mm window taken with the 22m Mopra Radio Telescope (Walsh A. J. et al., 2011).

For this project, we need to identify star forming regions throughout the southern Galactic plane. The star formation rate is controlled by the fraction of gas that is greater than the critical density threshold of 10^4 cm^{-3} (Lada et al., 2012). The multiple inversion transition lines of NH_3 (1,1) and (2,2) are among the primary thermal lines surveyed by HOPS and trace the densest regions of molecular clouds (n$> 10^4$ cm^{-3}).

3. FINDING CLUMPS

An essential part of this project is identifying dense clumps from the HOPS data. We found that the Fellwalker algorithm implemented by CUPID [2] was the best way to find the 2D distribution of clumps presented in integrated emission images. Figure 2 is the result of applying the Fellwalker algorithm to the data presented in Figure 1. We found 90 clumps in the test region and we

[1]http://awalsh.ivec.org/hops/public/index.php
[2]http://docs.jach.hawaii.edu/star/sun255.htx/node4.html

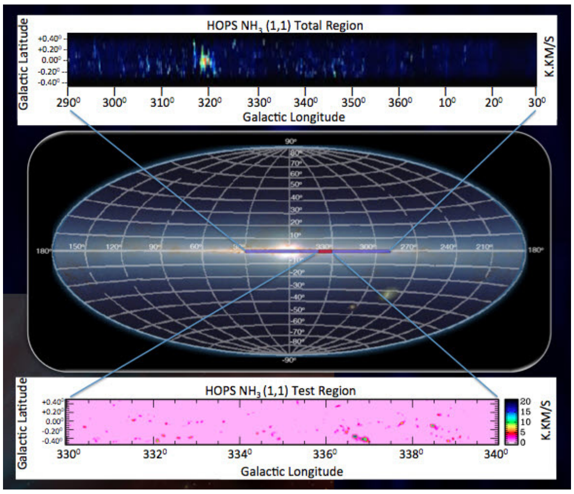

Figure 1. Integrated HOPS NH_3 (1,1) emission for total and test regions.

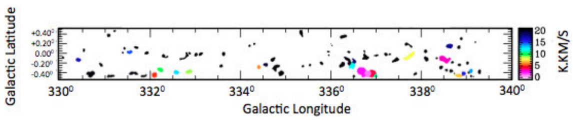

Figure 2. The 90 clumps found in the test region using 2D Fellwalker.

expect to find $\sim$ 900 clumps in the entire HOPS survey region for NH_3 (1,1) .

4. SPECTRAL ANALYSIS

For the clumps identified in the test region we look at the corresponding spectra extracted from the 3D position-position-velocity cubes to confirm whether there are likely to be multiple velocity components along the line of sight.

5. FURTHER ANALYSIS: MALT90

Figure 3 shows a spectrum with likely one component, where the central component and the four satellite lines all have the same FWHM and have relative height ratios of 0.26, 0.26, 1, 0.26, 0.26, (Park Y. -S., 2001) which is expected from this transition of NH_3. In Figure 4, however, the measured ratios are consistent with more than one physical component, with an offset in velocities among the components. Preliminary analysis indicates that $\sim$ 10% of 90 clumps show line profiles with multiple components at the resolution of the Mopra beam.

Once we have identified dense cores from HOPS, we match these 90 clumps with the MALT90 data. MALT90 is a large international project, using the capability of the ATNF Mopra-22m telescope, combined with the broadband MOPS correlator. The survey simultaneously maps 16 molecular lines near 90 GHz of over 2,000 dense molecular cores (hosting the early stages of high-mass star formation and a range of evolutionary states) in the Galactic plane. These molecular lines will probe the physical conditions, chemical states and evolutionary states of the target cores (Jackson et al., 2013).

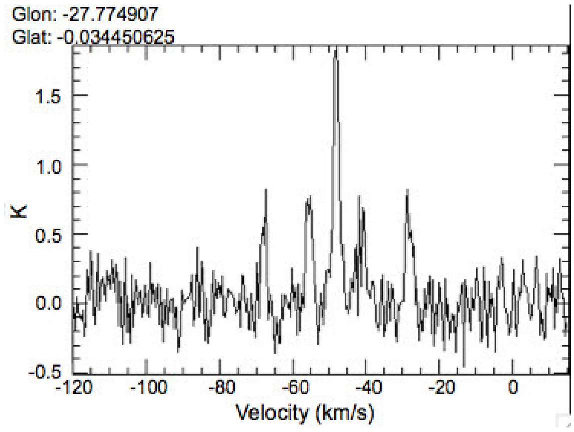

Figure 3. Simple component along the line of sight.

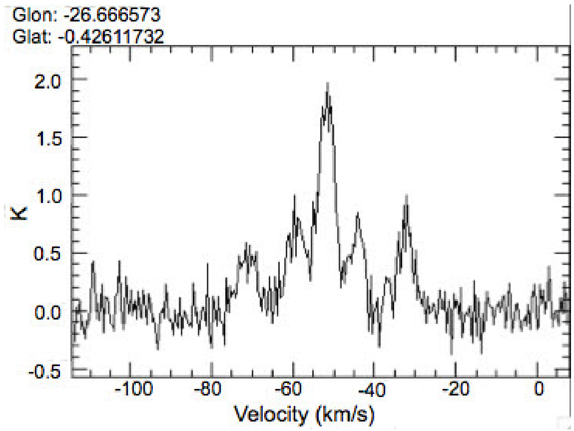

Figure 4. Multiple components along the line of sight.

For our project, we will use molecules from MALT90 that are useful for constraining infall and outflow, such as HCO+ and SiO.

6. MOLLIE: DETECTING INFALL & OUTFLOW

The spectra of several molecules can be used to constrain the MOLLIE radiative transfer code to detect turbulent infall and outflow. The inputs to MOLLIE describe a continuum source and its radius, a hot molecular core and its radius and the surrounding sphere of molecular gas. We need to specify the abundances of particular molecules, an asymmetrical infall velocity and a bipolar outflow velocity. The output of the radiative transfer code is a position-position-velocity cube. We can then compare a line profile in the simulated cube to the observed line profile in different molecules (e.g. Figure 9 of Lo et al. (2011)). This will help determine the physical properties of the star-forming cores that we are observing (Lo et al. (2011) and references there in).

In this way, NH_3 emission lines from HOPS will help us to identify dense gas in the ISM in our southern galactic sky that hosts the earliest stages of high-mass star formation (Purcell et al., 2009).

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