Protostellar Outflows in L1448

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Abstract

Protostars are formed from molecular clouds and are at the forefront of star formation. Outflows within the L1448 region in the Perseus molecular cloud were observed using the Sub-Millimeter Telescope. We used the data from the protostars' spectra to determine the mass, momentum, and energy of the protostars systems. This allows us to see the effects on the molecular cloud and the protostar systems at a larger scale.

Introduction

- Protostars are very young stellar objects in the early phase of stellar evolution. There are multiple types of protostars that are based upon their ages. Those types are class 0, class 1, and class 2 (with class 0 being approximately 10^4 years). Outflows emitted by protostars can give us details about the protostars' outflows such as mass, momentum, and energy.
- The goal of this project is to observe region L1448's protostar systems and to get a better understanding of the outflows and their effects on other protostars and the molecular cloud. We can do this by observing ^{12}CO (J= 2 →1) and ^{13}CO (J= 2 →1) that trace the protostars' outflows.
- Data used was observed with the Arizona Submillimeter Telescope by Nick Reynolds, Rajeeb Sharma, Patrick Sheehan, and John Bieging.

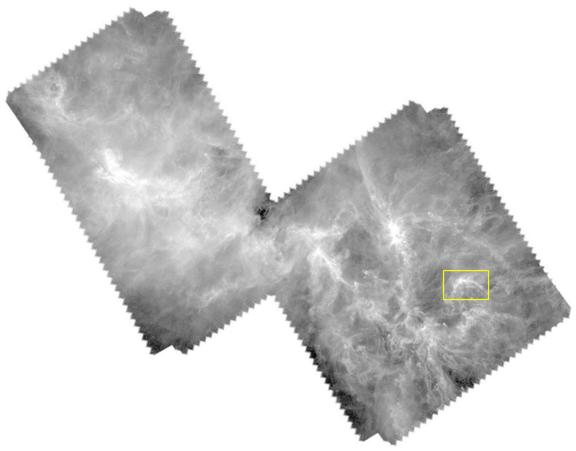


Figure 1: Perseus molecular cloud taken by SPIRE with region L1448 outlined

Methodology

- Using the observed data of ^{12}CO, contoured intensity maps were created to give a visual of different velocities relative to the molecular cloud's velocity and where they are being emitted from.

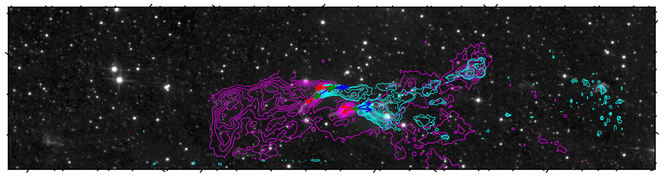


Figure 2: Moment 0 map of the low velocity outflows ($v_{sys} < 2\ km\ s^{-1}$) of ^{12}CO emitted from the three multiple-protostar systems in region L1448

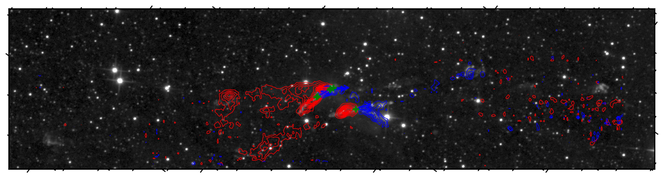


Figure 3: Moment 0 map of the high velocity outflows ($v_{sys} > 2\ km\ s^{-1}$) of ^{12}CO emitted from the three multiple-protostar systems in region L1448

- By using the spectral data, I was then able to use the intensity in each pixel to create column densities that could be used to create a lower limit mass, momentum, and energy maps for the outflows by using the following equations:

$$N_{12}(x,y,v) = (2.5 \times 10^{14})\ T_{ex}\ \frac{\tau_{12}(x,y,v)dv}{1-\exp(-T_0/T_{ex})}$$

Equation 1: Column density - by using optical depth of ^{12}CO,the excitation temperature of ^{12}CO in our data, and average temperature of ^{12}CO

$$M = \sum_{vel} M(x,y)$$

Equation 2: Mass of the outflows for each pixel - by using the density of H, area of a pixel, and the mass of H

$$P_{out} = \sum_{vel} M(v)|v - v\_cloud|$$

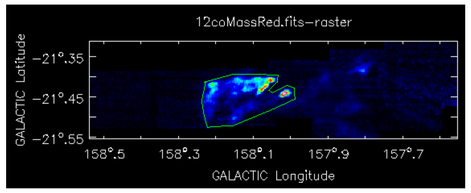
Equation 3: Momentum of the outflows - by using the calculated mass and outflow velocity with respect to the cloud's velocity

$$E_{out} = \frac{1}{2}\sum_{vel} M(v)|v - v_{cloud}|^2$$

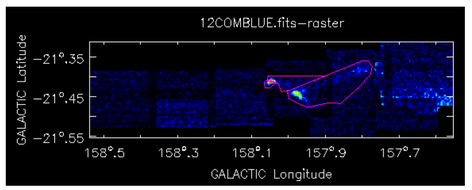
Equation 4: Kinetic energy of the outflows - by using the calculated mass and the velocity squared with respect to the cloud's velocity

Analysis

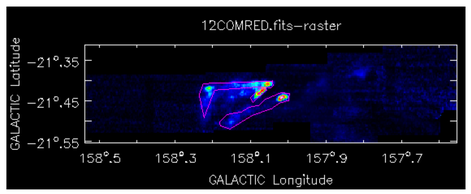
- I used the *Common Astronomy Software Application* (CASA) to create regions with the help of the initial contour maps that can then read in values for mass, momentum, and energy
- Three different types of regions for blue doppler shifted velocities and red doppler shifted velocities were overlaid and were created to extract from the observational data
  - All – a region that estimates all three protostar systems' outflows put together
  - Conservative –a region that estimates the maximum amount of outflow for each region
  - Liberal – a region that estimates the minimum amount of outflow for each region



- **Figure 4**: Red doppler shifted Map of Mass with All region around the three multi-protostar systems in region L1448



- **Figure 5**: Blue doppler shifted Map of Energy with Liberal regions around the three multi-protostar systems in region L1448



- **Figure 6**: Red doppler shifted Map of Momentum with Conservative regions around the three multi-protostar systems in region L1448

Conclusion

- Some notable data from the maps:
  - L1448NW, IRS3A, and Per 33 has the largest liberal mass with 0.143 $M_\odot$
  - L1448NW, IRS3A, and Per 33 has the largest liberal momentum with 0.704 $M_\odot$ km s^{-1}
  - IRS2 has the largest liberal energy with 2.53 10^{43} erg
- Due to the high optical depth of ^{12}CO, the results given are lower limit values and once ^{13}CO is included, then the mass, momentum, and energy will become more accurate

Future Work

- We will perform a similar analysis using ^{13}CO, an isotopologue of ^{12}CO that will better constrain the results derived to a more accurate value since ^{13}CO is less optically thick due to its lower abundance ratio
- By taking this numerical data, we can use it to compare to the gravitational energy of the cloud to see if the turbulence in the outflows cause the cloud to have turbulent motion

Citation

- McMullin, J. P., Waters, B., Schiebel, D., Young, W., & Golap, K. 2007, Astronomical Data Analysis Software and Systems XVI (ASP Conf. Ser. 376), ed. R. A. Shaw, F. Hill, & D. J. Bell (San Francisco, CA: ASP), 127
- Oswalt, Terry D., et al. *Planets, Stars and Stellar Systems*. Springer, 2013.
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