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. I used the data from the protostars' spectra to determine the mass, momentum, and energy of the protostars systems. This allows me to see the effects on the molecular cloud and the protostar systems at a larger scale.

1 Introduction

Protostars are young stellar objects in the early phase of stellar evolution. Protostar types are determined by age. Those types are class 0, class 1, and class 2 with class 0 being approximately 10^4 years old. L1448 is a region that is within the Perseus molecular cloud, which is a star nursery. The goal of this project is to observe region L1448's, mostly class 0, protostar systems and to get a better understanding of the outflows and their effects on the molecular cloud. We can do this by observing ^{12}CO ($J = 2 \rightarrow 1$) and ^{13}CO ($J = 2 \rightarrow 1$), which trace the protostars' outflows. ^{12}CO is observed because it is the second most abundant molecule in the molecular cloud, but tracing this molecule comes with a cost. The cost being that at lower velocities, close to the molecular cloud's velocity, ^{12}CO becomes optically thick. ^{13}CO is observed because it is less abundant and it is easy to see the outflow movement around and lower than the cloud's velocity. By observing the protostars' outflows, I are able to calculate the mass, momentum, and energy of the outflows themselves.

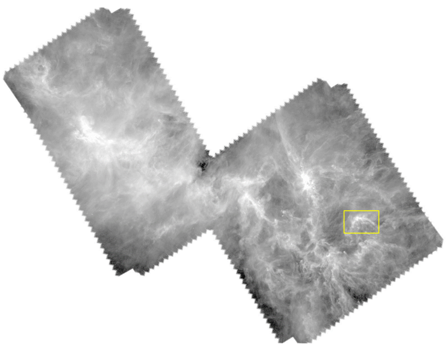

Figure 1: Perseus molecular cloud taken by SPIRE with region L1448 outlined.

2 Methodology

2.1 Contoured Intensity Maps

The first step is taking the observed data and creating contoured intensity maps. These maps will help give a visualization of how the protostellar outflows are flowing. These maps also show red and blue doppler shifted velocities and with this information two maps were created. One map (Figure 2) is depicting lower outflow velocities where the velocities are less than $2kms^{-1}$ and another map (Figure 3) for high outflow velocities where the velocities are greater than $2kms^{-1}$. I used past data to verify that particular protostellar outflows were flowing in the correct directions that are depicted on the contoured maps.

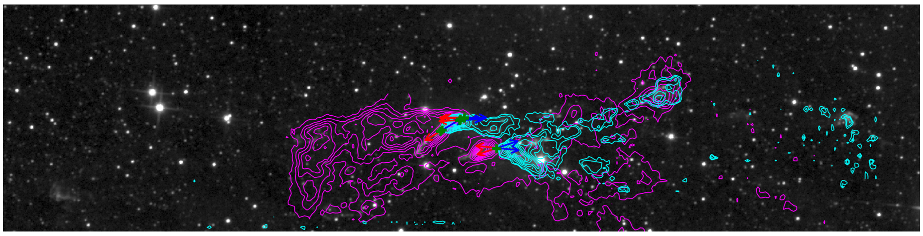

Figure 2: Contour map of low velocity outflows ($V_{sys} < 2kms^{-1}$) of ^{12}CO emitted from the triple-protostar systems in region L1448.

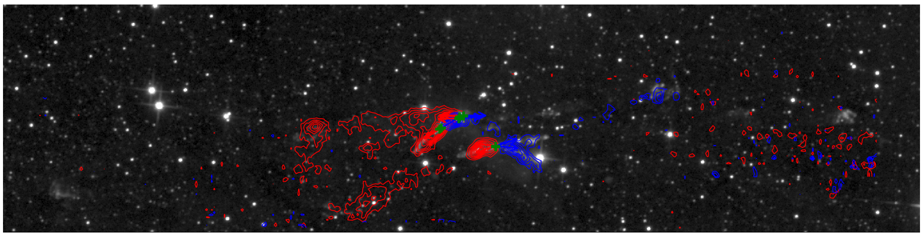

Figure 3: Contour map of high velocity outflows ($V_{sys} > 2kms^{-1}$) of ^{12}CO emitted from the triple-protostar systems in region L1448.

2.2 Calculations

For the first calculations that I used in this project, I used the assumption that ^{12}CO was optically thin and I only used the intensities of ^{12}CO, $I_{12}(x_i, y_i, v_i)$. By doing this, when I calculated mass, momentum, and energy I obtained only lower limits of what the true calculation will be. This was due the short amount of time that I had left at the University of Oklahoma's Research Experience for Undergraduates. I used ^{12}CO to calculate an optical depth of ^{12}CO intensities, τ_{12}. By using this approximated column density, I was able to calculated column densities summed over all velocities by using this equation: $N_{12}(x,y) = \sum_{vel}(2.5 \cdot 10^{14})T_{ex}\frac{\tau_{12}(x,y,v)dv}{1-\exp -T_0/T_{ex}}$ where T_{ex} is the excitation temperature of ^{12}CO and $T_0 = 5.29$. I then took that column density and calculated mass by this equation: $M(x, y) = m_{H_2}(7 \cdot 10^5)N_{12}A$ where A is the total area and m_{H_2} is the mean molecular mass of hydrogen. The mass over the outflow area is calculated by $M = \sum_{area} M(x, y)$, then momentum is calculated by $P = \sum_{vel} M(v) \, |v - v_{cloud}|$ and finally kinetic energy is calculated by $E = \frac{1}{2} \sum_{vel} M(v) \, |v - v_{cloud}|$.

My next step on calculating mass, momentum, and energy was to incorporate ^{13}CO data. The difference between the calculations talked about earlier is to use ^{13}CO intensities, unless the intensities are less than three times the rms noise. Then I also used ^{12}CO intensities and then calculated the new mass, momentum, and energy.

3 Analysis and Results

Once the mass, momentum, and energy was numerically calculated, I then created maps of each kinematic. This gives a good visualization and conformation that the structure looks just like the contour maps. I then needed a way to calculate the mass, momentum, and energy from the maps that I created. I used the Common Astronomy Software Application (CASA) to create region files that could read in the data that I was able to select. I then created three different types of regions. I first created an 'All' region that estimates the total outflow coming from all three protostar systems' outflows put together. Then I created a 'conservative' region that estimates the minimum amount of outflows for each protostar system. Finally I created a 'liberal' region that estimates the maximum amount of outflows for each protostar system.

To calculate mass, momentum, and energy with ^{13}CO incorporated, new maps were created and had CASA read in the data. Once the new maps were created, there was a problem where the outflow characteristics were not the same or even similar to the contour intensity maps. Due to this problem, and lack of time, there will need to be further work to calculate proper mass, momentum, and energy maps. Once that is done, I can then compare the kinetic energy and the Perseus molecular cloud's.

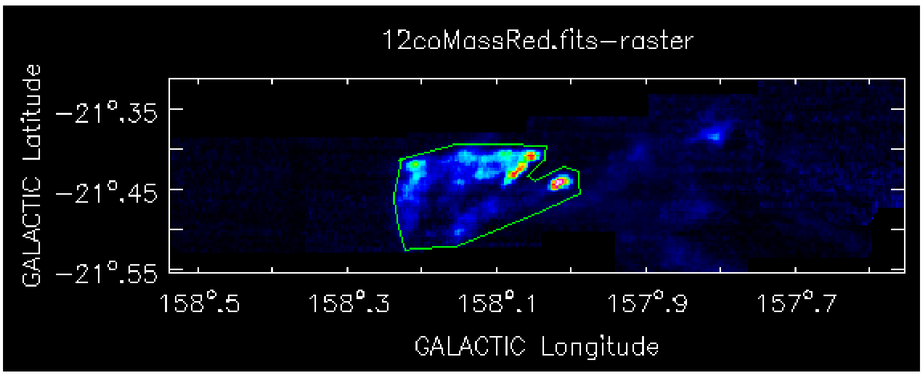

Figure 4: Red doppler shifted map of Mass with All region around the three multi-protostar systems in region L1448.

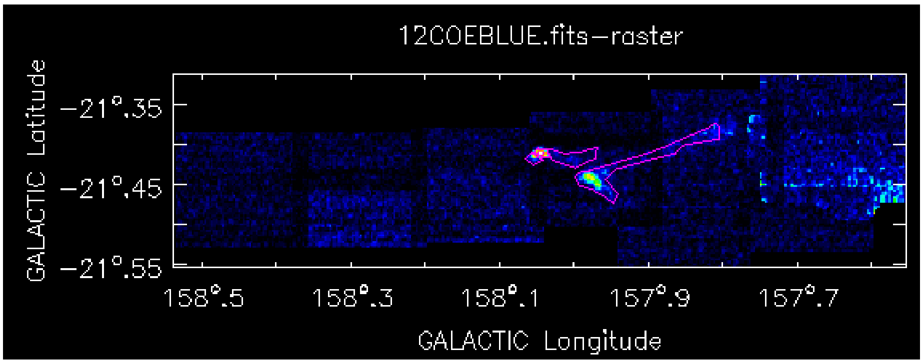

Figure 5: Blue doppler shifted map of Energy with Conservative region around the three multi-protostar systems in region L1448.

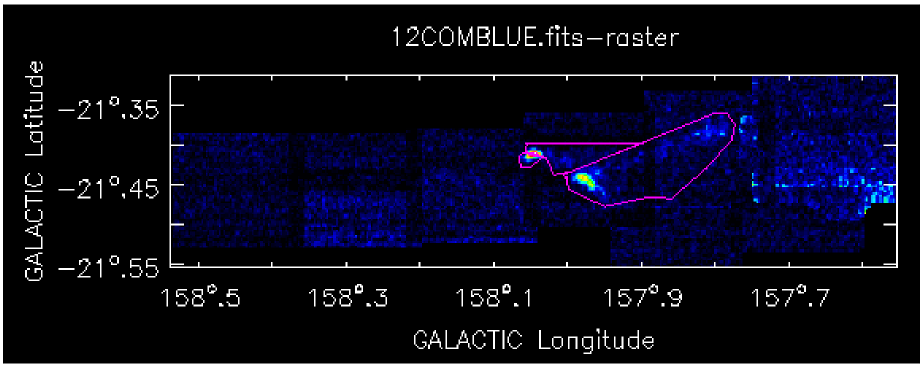

Figure 6: Boue doppler shifted map of Momentum with Liberal region around the three multi-protostar systems in region L1448.

4 Conclusion

In conclusion, I created contour intensity outflow maps to visualize the structure of the outflows coming from the triple-protostar systems. I have calculated lower limits of mass, momentum, and energy and created region files that can give readings to each specific protostar system's outflows. I also created mass, momentum, and energy maps that incorporate ^{13}CO with ^{12}CO to be able to have better protostellar outflow readings.

5 Future Work

I will need to fix my python program so that the mass, momentum, and energy maps that use ^{13}CO have the same outflow visual characteristics that the other maps I created have. Once I have obtain that new kinetic energy, I can compare it with the Perseus molecular cloud's gravitational potential energy and see if the protostars are maintaining turbulence in the molecular cloud. I will also need to calculated the uncertainty for my calculations.

6 References

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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