The Circulation of Ionized Gas in the Milky Way Galaxy

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Abstract

We use the Wisconsin H-alpha Mapper (WHAM) all sky survey to observe kinematic properties of ionized interstellar gas in the Galaxy. WHAM's survey is a velocity resolved map of the H-alpha emission from the Milky Way with a one-degree spatial resolution and 12.8 km s-1 velocity resolution. Using this data the first and second moments are calculated and mapped to provide insight on the kinematic properties of the Galaxy. This research was funded by the Wisconsin Space Grant Consortium and supported by the NSF REU site grant to the University of Wisconsin-Madison

Background

Gas makes up 99% of the Milky Way Galaxy and plays a major role in our understanding of the structure of the Galaxy. This gas is in constant motion around the center of the Milky Way. Understanding the velocity structure of the ionized regions of this gas in the Milky Way provides valuable insight about the Galaxy. Velocity structure provides input on the ionized gas' distance not only from the Sun, but from the center of the Milky Way. This insight opens up the study of galactic structure through the use of a longitude-velocity (L-V) diagram or through the use of a rotation curve map. An L-V diagram is used to identify spiral arms or other prominent features in the Galaxy however this is not the main focus of this study. Wisconsin H-alpha Mapper (WHAM) spectra's mean velocities can be compared to a galactic rotation map (figure 3) to place a distance to given objects or dense clouds of ionized gas. As mentioned earlier using data from WHAM it is possible to characterize the structure of the ionized regions.

The WHAM survey contains 49607 spectra each representing the spatially integrated emission of a one-degree patch in the sky. The data was taken in two sky surveys to complete the all-sky survey. Two-thirds of the sky was completed at Kitt Peak Observatory for the WHAM Northern Sky Survey, the mapper was then moved to Chile to complete the WHAM All-Sky Survey. One of the benefits to this data is it provides insight on velocity information of each WHAM pointing. This survey was used to create a variety of all-sky maps based on this velocity information.

In the past many ionized regions have been discovered most of which have no velocity information to go with them. The WHAM survey provides velocity information in an all-sky map. This means that a lot of the discovered regions will have velocities placed to them for the first time. I worked this summer to create a system to analyze the WHAM survey to characterize the velocity information of each pointing. A visualization of WHAM pointing size can be seen in a comparison of figure 1 to figure 2.

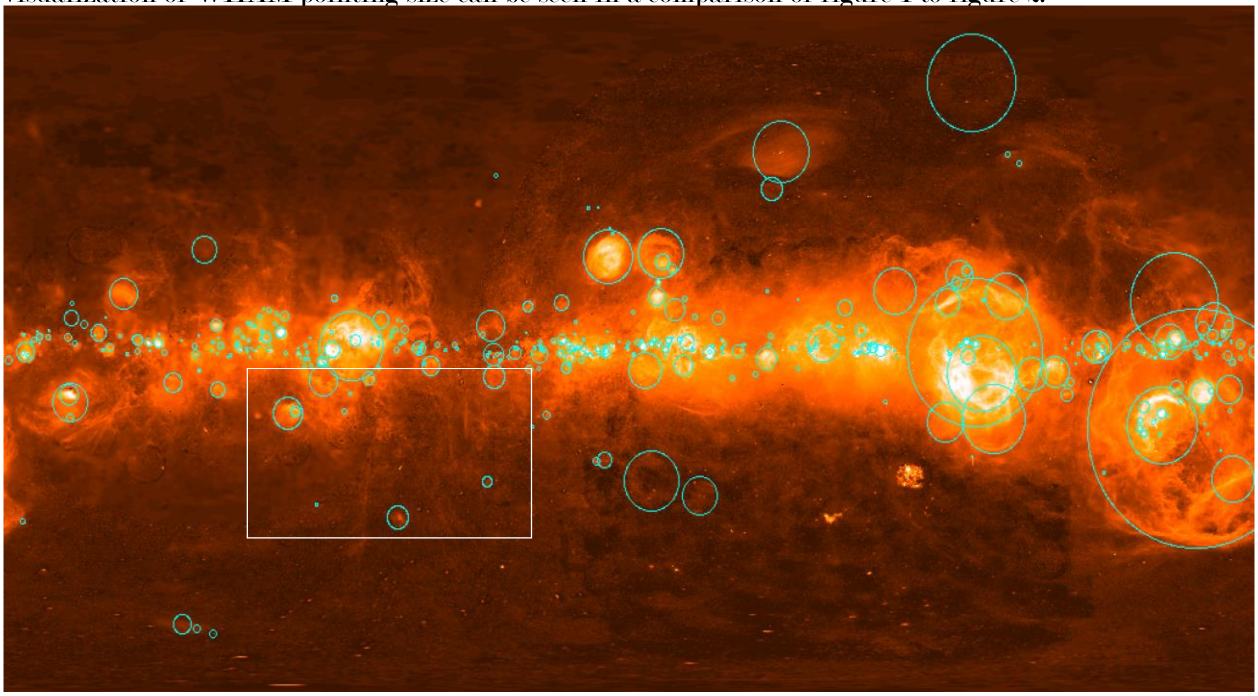

Figure 1: Finkbeiner all sky map of H-alpha emmission showing newly discovered regions from the efforts of the REU program at University of Wisconsin-Madison, 2015. The white box can be seen below zoomed in.

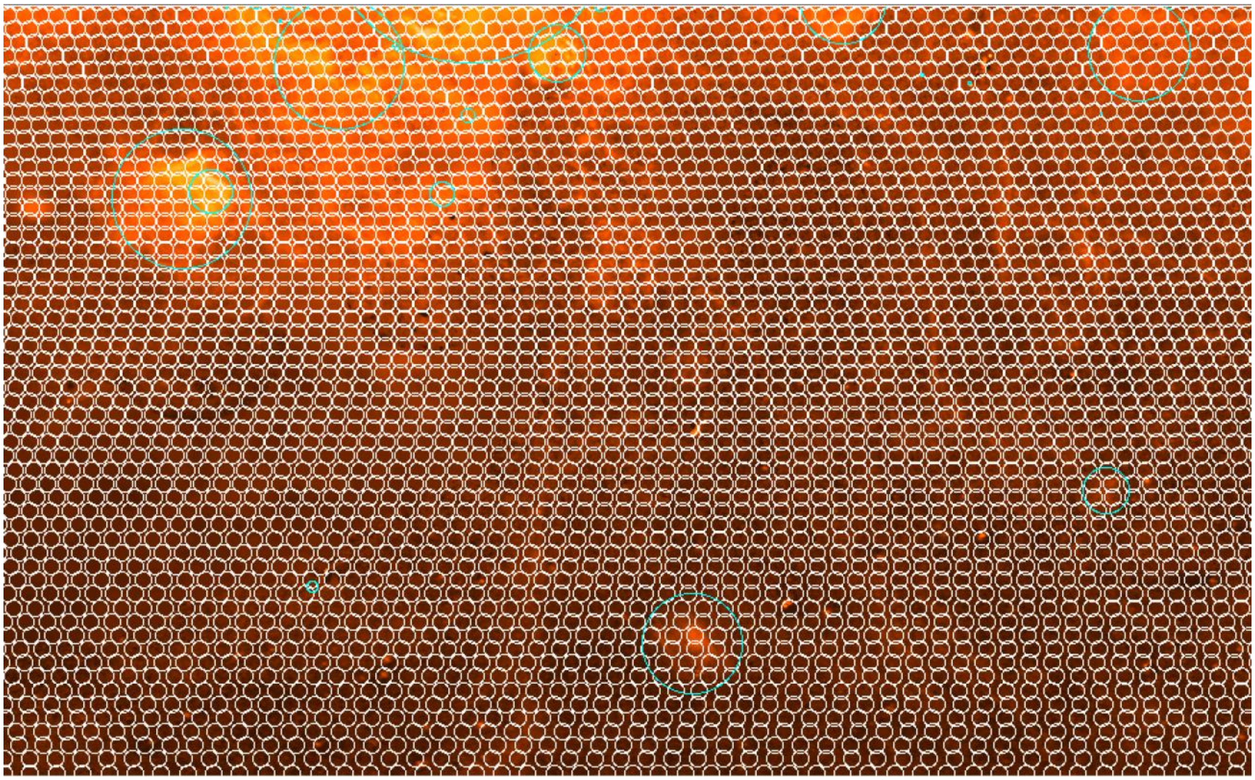
Figure 2: This image gives an example of the size of each WHAM pointing's size.

Each spectra's overall intensity, mean velocity, standard deviation, skew and kurtosis were calculated. These values characterize the spectra of the WHAM data making it easier to interpret. With these values new sky maps were created to help identify patterns in the data.

Procedure

The extensive data collected by the WHAM was simplified and characterized by the use of moment calculations. The moment calculations take a probability, like a spectral power distribution, and put a value to characteristics like size (zeroth moment), position (first moment) and width (second moment). Other values like the skew and kurtosis were mentioned but are not the main focus of this study. An example WHAM spectra can be seen in Figure 3, their Gaussian like properties allow us to apply the moments to them.

The zeroth moments were calculated algebraically by "adding" up the total intensity (area under the spectra). The first and second moment calculation can be seen below. These calculations were also done algebraically using a computer program based on equation 1 and equation 2.

$$\bar{v} = \frac{\int vI(v)dv}{\int I(v)dv} \qquad SD = \sqrt{\frac{\int (v-\bar{v})^2 I(v)dv}{\int I(v)dv}}$$

Eqn. 1 **Eqn. 2**

The first moment, in this situation, gives the intensity weighted velocity average of a spectrum which means we can place a velocity center to each spectrum. This is useful in placing a distance to the objects in the WHAM pointing corresponding to that spectrum. This is made possible by comparing the average velocity of the pointing to a galactic rotation map.

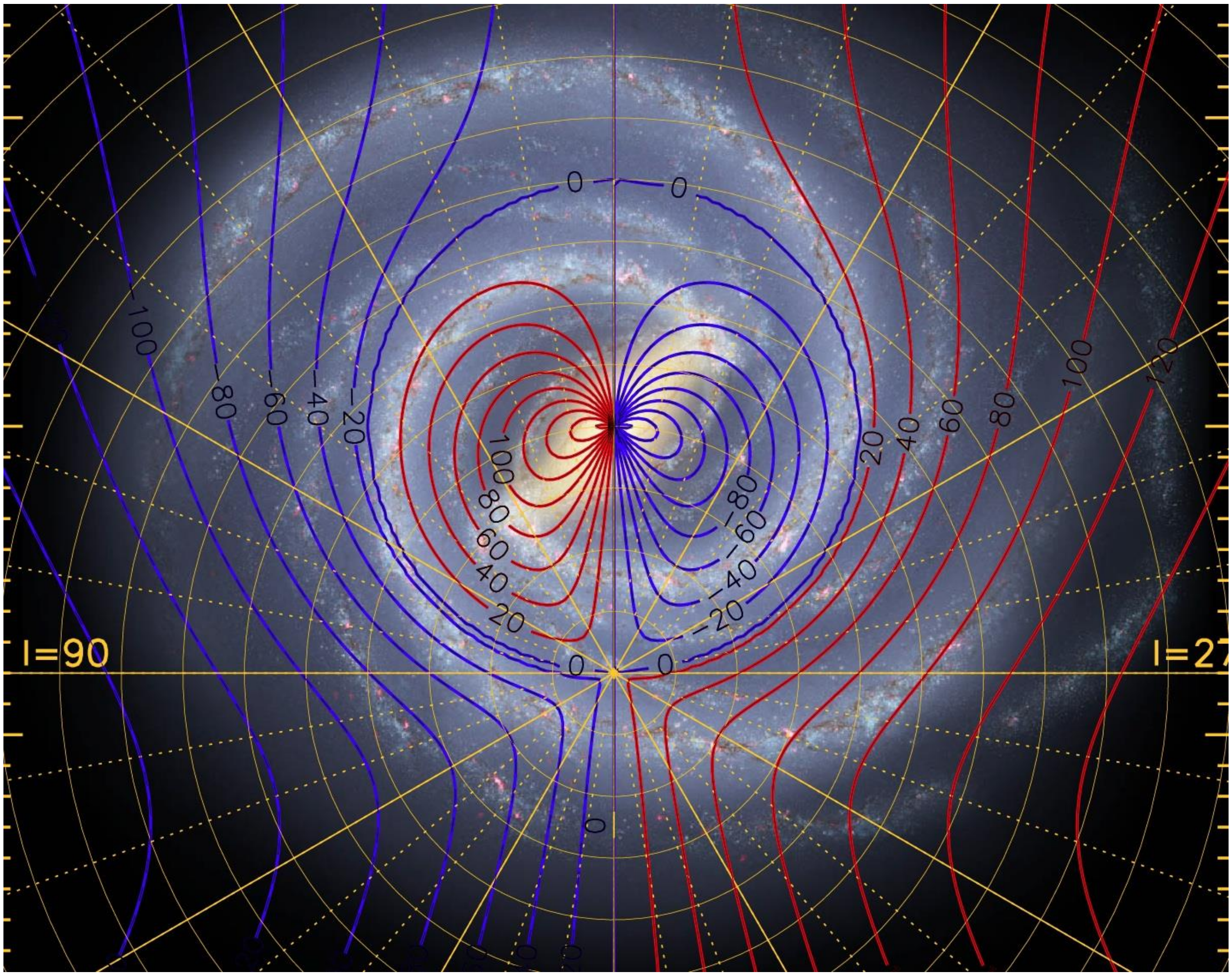

Figure 3: Hurt-McClure rotation map. This "artist's conception" image of the Milky Way Galaxy by Robert Hurt (Spitzer Science Center/IPAC/JPL) shows most of the claimed structures in the Galaxy, where the Sun, located at the center of the polar grid, is assumed to be Ro=8 kpc from Galactic center. Superimposed is the line-of-sight velocity that would be measured from gas at a given position, assuming the rotation curve obtained by McClure-Griffiths and Dickey (2007, ApJ 671, 427). The Galaxy is divided into four quadrants. Galactic longitude l=0 to 90 deg (where longitude runs counter-clockwise) is the 1st quadrant, l=90-180 deg is the 2nd quadrant, etc. (Description Courtesy of University of Wisconsin-Madison)

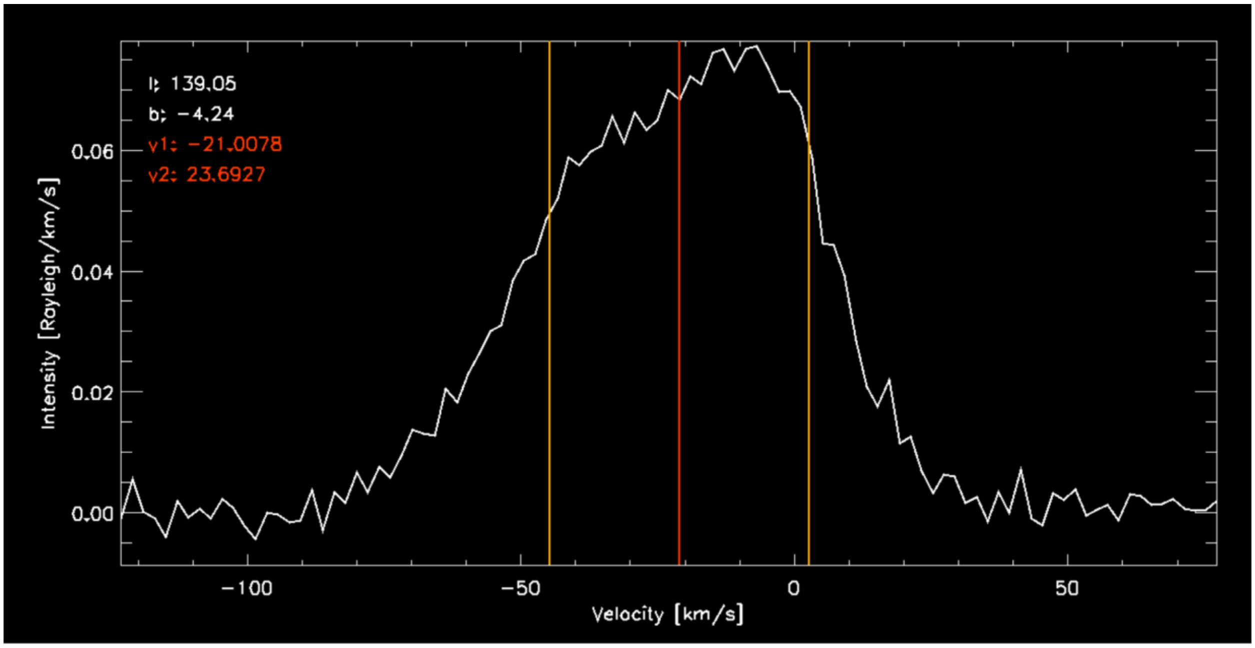

Figure 4: This shows an example WHAM spectra with velocity on the x-axis in km/s and intensity on the y-axis in Rayleigh per km/s with first (v1) and second (v2) moment calculations displayed on the plot. The second moment, in yellow, shows the standard deviation or variance from the mean velocity.

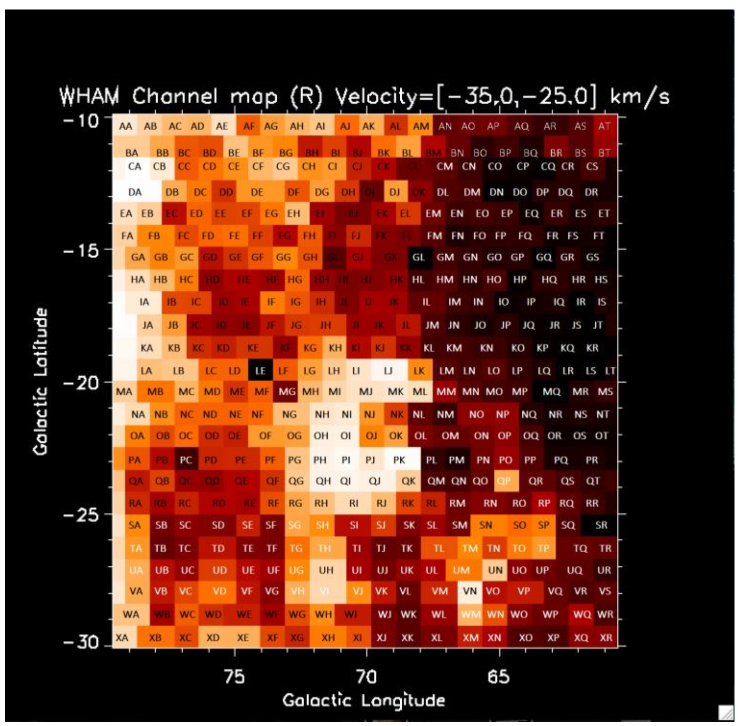

Figure 5: Pixel per Spectra map. Once the moments were calculated, each WHAM pointing was then converted to a pixel on a longitude vs. latitude all sky map that could then be observed to look for patterns in the survey. Above is an example of a section of the zeroth moment map. Each pixel is labeled and has a corresponding spectra.

Results

The results of this project are two new all sky maps from the WHAM data which allow for a better understanding of the kinematic properties of structures in the Milky Way Galaxy.

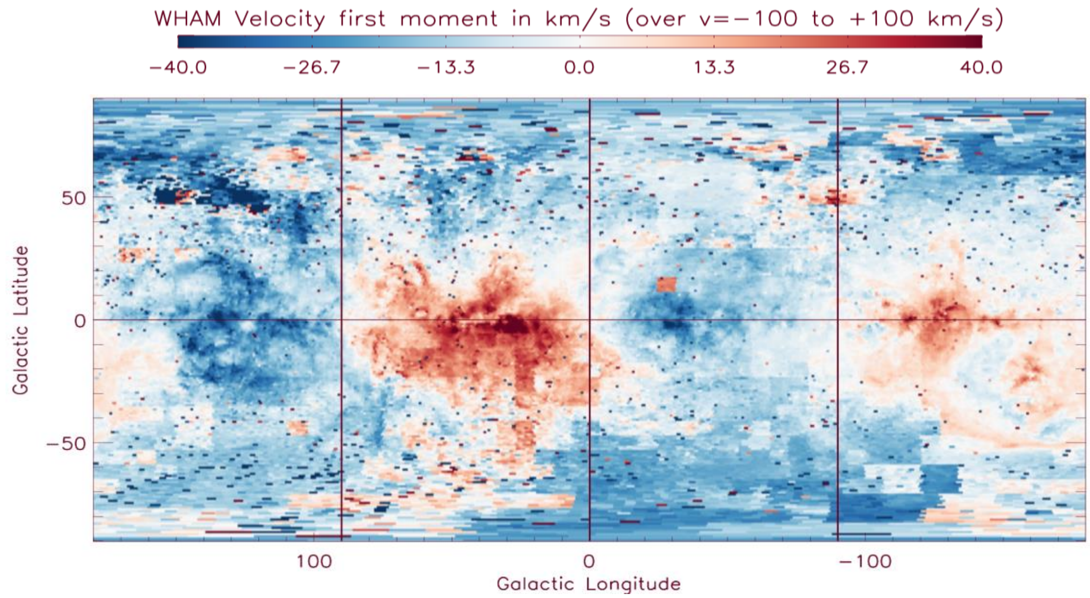

Figure 6: (Above) This map shows the all-sky survey with the calculated intensity weighted velocities for each pointing. The intensity weighted velocities of the ionized gas in the Milky Way shows alternating direction for each quadrant due to galactic rotation.

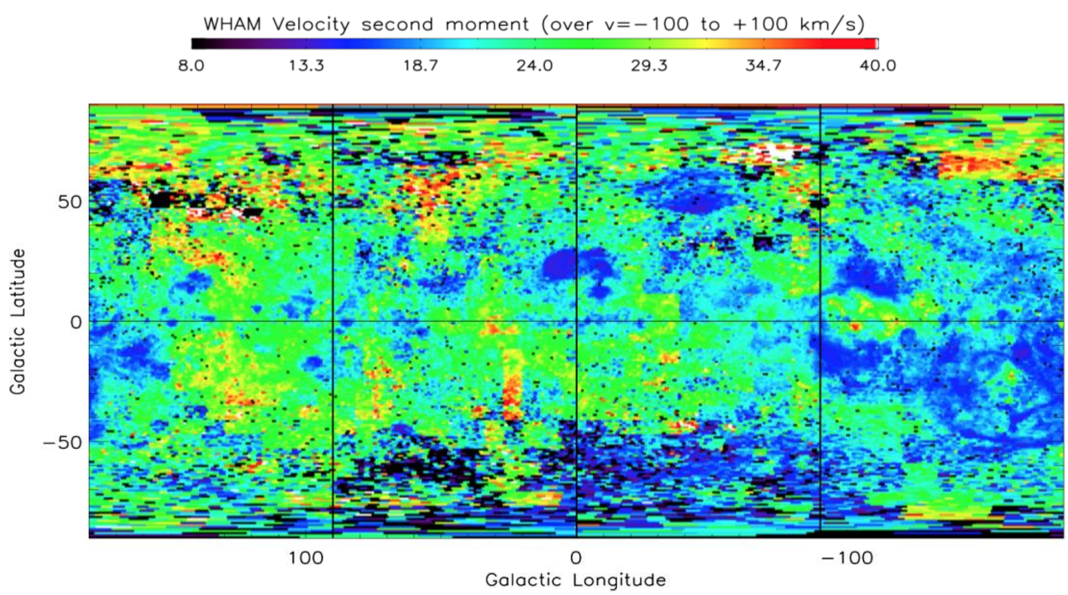

Figure 7: This map shows the all-sky survey with the calculated standard deviation of the intensity weighted velocity for each pointing. The standard deviation (or "width") of the spectra is low in the direction of bright ionized nebulae due to the fact that gas at one single velocity dominates the spectrum. Areas of large second moment indicate either intrinsically wide lines or multiple components, widely separated in velocity. These latter regions have been targeted for future study.

Conclusion

The first moment map highlights the effects of galactic rotation which we expect to see based on the Hurt-McClure rotation map in figure 3. Another interesting finding in the first moment is the lack of galactic rotation at higher latitudes. It can be seen that above the plane galactic rotation peters of at about 25º and below the plane galactic rotation peters out at about -38º at which point the direction of the gas seems to be mostly blue shifted. This overall blue shift, at higher latitudes, tells us that the majority of ionized gas above and below the disk of the Galaxy is coming in towards the plane of the Galaxy.

The second moment map highlights properties of bubbles (regions of gas being ionized by a source such as an O star or by a supernovae remnant). It can be seen that, on the second moment map, familiar regions such as the Orion-Eridanus and the Spica H-II region have a low second moment. This is a characteristic that comes out due to intensity weighted calculations; bright regions with single peaks will tend to lower the width of a given spectra. However, towards the centers of some bubbles such as the gum nebula, a wider second moment is observed. This tendency for bubbles to have a wider second moment in their centers is due to the intensity weighting as well; widely separated (in velocity) equally bright peaks will produce a wider second moment. The equally bright peaks are indicative of the front and back side of the bubbles as they expand, this interesting characteristics of bubbles can be used to help find bubbles in the WHAM data in the future.

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