

The Kinematics of Warm Ionized Gas in the Fourth Galactic Quadrant

Martin C. Gostisha, Robert A. Benjamin (University of Wisconsin-Whitewater), L.M. Haffner (University of Wisconsin-Madison), Alex Hill (CSIRO), and Kat Barger (University of Notre Dame)



Abstract: We present an preliminary analysis of an on-going Wisconsin H-Alpha Mapper (WHAM) survey of the fourth quadrant of the Galactic plane in diffuse emission from [S II] 6716 Å, covering the fourth galactic quadrant (Galactic longitude = 270-360 degrees) and Galactic latitude $|b| < 12$ degrees. Because of the high atomic mass and narrow thermal line widths of sulfur (as compared to hydrogen or nitrogen), this emission line serves as the best tracer of the kinematics of the warm ionized medium in the mid plane of the Galaxy. We detect extensive emission at velocities as negative as -100 km/s indicating that we are seeing much further into the center of the Milky Way than was found for the first quadrant. We discuss constraints on the velocity and vertical density structure of this gas, and compare this distribution with what is observed in CO and HI surveys. This work was partially supported by the National Science Foundation's REU program through NSF award AST-1004881.

[SII] provides better velocity resolution than H-Alpha

The equation,

$$\Delta v = \sqrt{\frac{2KT}{M_a}}$$

gives us a physical value for the line widths of both H-Alpha and [SII], varying only by the mass of the individual atoms. Assuming that the gas is at a temperature of $T=10^4$ K, the velocity widths of H-Alpha and [SII], respectively, are

$$\Delta v_H = 12.8 \text{ km} \cdot \text{s}^{-1} \quad \Delta v_{[SII]} = 2.27 \text{ km} \cdot \text{s}^{-1}$$

Figure 2 - H-Alpha vs. [S II] Spectra – This is a spectrum from $l = 305$ degrees and $b = -7.6$ degrees showing the difference between the line profiles of H-Alpha (black) and the [S II] (red). Two velocity components can easily be seen in the [S II] spectrum, where as the wide line width of the H-Alpha blends the two components together.

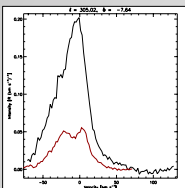


Figure 4 - Galactic Rotation Curve Map – The fourth quadrant of an artist's conception of the Milky Way Galaxy is shown with contours of the LSR (radial) velocity as a function of position in the Galaxy assuming a flat rotation curve with $\Theta_0 = 220$ km/s. Each circle is 2 kpc from the Sun. We are able to determine how far WHAM "sees" by measuring the maximum speed along a line of sight ("the terminal velocity"). WHAM detects gas much further into the center of the Galaxy in the 4th quadrant than in the 1st quadrant!

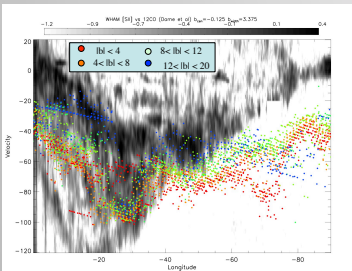
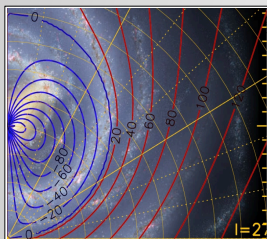


Figure 6 - Longitude-Velocity Diagrams – The [S II] terminal velocities (marked in the Latitude-Velocity Diagrams) are compared to the CO LV diagram for the midplane. Symbol colors show different latitude ranges. In the inner Galaxy we find that we detect [SII] emission almost to the same terminal velocity as the CO. The high velocity excursion at $L=70^\circ-290^\circ$ is due to the extremely bright, broad emission from the Carina Nebula. The offset between the CO and [S II] terminal velocities for $L < 40^\circ$ is puzzling, but probably indicates that the inclusion of non-thermal broadening will be necessary to interpret the velocity structure of the [SII] emission.



Acknowledgements: We would like to thank Nick Pingel for his work in reducing H-alpha data, which was also used in our studies. This work was supported by the National Science Foundation's REU program through NSF Award AST-1004881.

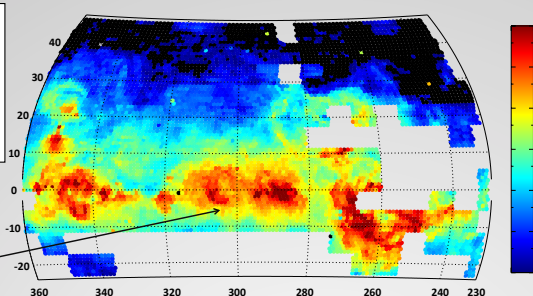


Figure 1. WHAM Full [S II] Map – This map displays all of the data reduced in [S II] so far. The plot ranges from $l = 230 - 360$ degrees and $b = -35 - 50$ degrees. There are numerous interesting features, such as a dust lane from $l = 320 - 340$ degrees that rises in latitude, and a bubble at $l = 320$ degrees, $b = -5$ degrees.

WHAM South Sky Survey

The Wisconsin H-Alpha Mapper (WHAM) was first located at Kitt Peak National Observatory in Arizona, where it covered about two-thirds of the sky in the WHAM Northern Sky Survey. Then, to gather data on the remaining third of the sky, WHAM was moved to Chile. This is where the [SII] data we present was taken from. Although WHAM mainly gathers H-alpha data, it is capable of gathering spectra in a wide range of wavelengths, from 4800 Å to 7400 Å. We used [SII] in our work because it is heavier than H-alpha, making for more narrow line widths and better intrinsic velocity resolution. WHAM has a 1 degree angular resolution to accompany a 12 km/s velocity resolution. The beams are taken for either 60 second intervals, then moved to a new spot in the sky.

Each beam results in a ~100 element spectrum. I have reduced 9410 of these spectra, which includes subtracting a baseline, fitting Gaussians to the spectra, and fitting an atmospheric template for subtraction. Once everything is fit and subtracted, maps like the one shown above are made by integrating over the whole beam and plotting the total intensity. We are continuing to take data to fill in this map, as well as retaking some parts of the sky to expand the velocity coverage at negative velocities. We plan to fill in the data at lower latitudes to search for symmetries about the galactic plane. Such symmetries would be due to Galactic structure and not the effects of individual regions of emission or absorption.

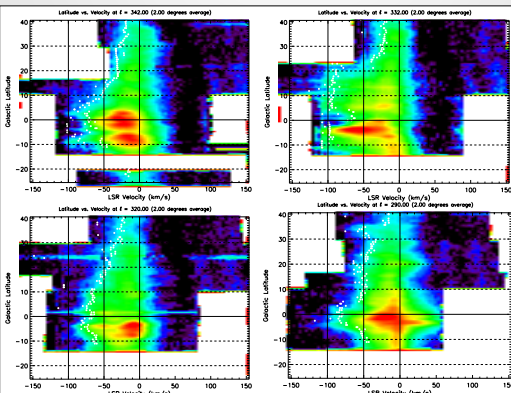


Figure 5 - Latitude-Velocity Diagrams – Two of the principal goals of this project are (1) to look at the vertical scale-height of emission as a function of distance (which here is proportional to velocity; for gas at high latitudes, we can safely assume the gas is at the near kinematic distance), and (2) determine whether there is a gradient in the rotation velocity as a function of height. The latitude-velocity diagrams shown here are useful for investigating these questions. The terminal velocity (maximum velocity along the line sight) is determined using an intensity threshold and are marked with white points. These diagrams show a remarkable amount of structure which we are still working on interpreting. Some feature of note:

- (1) In the inner Galaxy detect emission to very negative velocities, ~ -100 km/s. This indicates for much of the 4th quadrant we can see much further into the Galaxy than the 1st quadrant.
- (2) There is a pronounced dust lane in the midplane (Scutum-Centaurus arm) that puts a "divot" in the terminal velocity for $|b| < 4^\circ$ (upper two plots). Individual HII regions/bubbles show up as bright red spots in the figures above. In the lower right plot, the line width of the Carina Nebula produces a negative velocity excursion in the terminal velocity curve.
- (3) The drop in terminal velocity with height can be very complex, either indicating a lack of emission in certain latitude/distance ranges, or an extreme drop in rotation speed vs. height. We hope to see soon whether these patterns are symmetric about the midplane of the Galaxy.

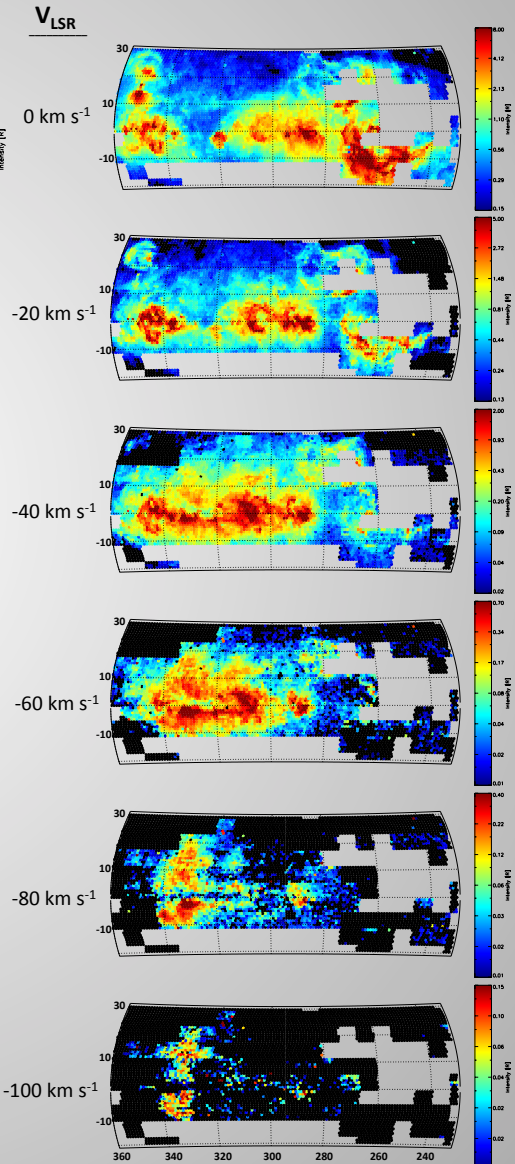


Figure 3. Channel Maps – Shown above are channel maps of the fourth quadrant. The maps show velocities of ± 10 km/s around the central velocity to the left of the map. The lower maps show that we are still getting great coverage at very negative velocities, meaning that we are seeing further into the Galaxy than we previously thought we were. Particularly noteworthy is the absorption lane right in the midplane from $l=340-320^\circ$ presumably due to the Scutum-Centaurus Arm (also referred to as the Molecular Ring).