Understanding the Evolution of the Magellanic System

A Survey of the Ionized Gas in the Magellanic Bridge using WHAM

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The Magellanic System exhibits some of the nearest examples of interactions affecting galaxy evolution with extended gaseous structures strewn throughout the halos of the Milky Way and the Magellanic Clouds. Models shown that tidal forces can partly – if not dominantly – produce this stripped material as the Clouds encounter each other and the Milky Way. Interaction with halo gas and exposure to radiation from all three galaxies shapes their extended structures, their evolution, and their ability to form stars. In this work, we use the Wisconsin Hα Mapper to study the faint, warm ionized gas in the Magellanic Bridge, a structure between the Clouds. H I studies have extensively mapped the neutral gas in this region, but the amount and extent of the ionized gas remains uncertain. A census of the material allows us to ask questions addressing the evolution of this system: How much gas have the galaxies lost to this structure? How does the gas loss affect future star formation? Is this environment conducive to star formation?

Introduction:

Galaxy interactions have influenced the evolution of many galaxies. Understanding how these interactions disturb their gas is essential to unraveling the evolution of these galaxies. Unfortunately the great distances to most galaxies makes investigating this gas difficult. The nearby Magellanic Clouds offer a unique opportunity to study the evolution of two richly interacting galaxies.

These interactions can greatly alter the morphology of galaxies. In the case of the Magellanic System, the Small Magellanic Cloud has a gravitational binding force ten times less than the Large Magellanic Cloud. This makes the Small Magellanic Cloud much more susceptible to ram pressure and to tidal stripping, especially at the halo and the outer arms regions with lower gravitational force and column density.[1] Most studies suggest that recent tidal interactions from a nearby encounter between the Milky Way and the Magellanic Clouds created the Magellanic Bridge and other prominent tidal features,[e.g.,2] although there are other studies that suggest alternate formation mechanisms.[e.g., 3]

Though this interaction has caused a burst of star formation at the tidally disturbed Small Magellanic Cloud tail – the portion of the Magellanic Bridge that interfaces with the Small Magellanic Cloud – the gas loss will ultimately cause a reduction in star formation. The Hα and the HI emission from the Bridge traces the changing star formation rate and gas density of the Small Magellanic Cloud. This study explores the warm ionized gas in the Magellanic Bridge to gain insight on how this system is evolving.

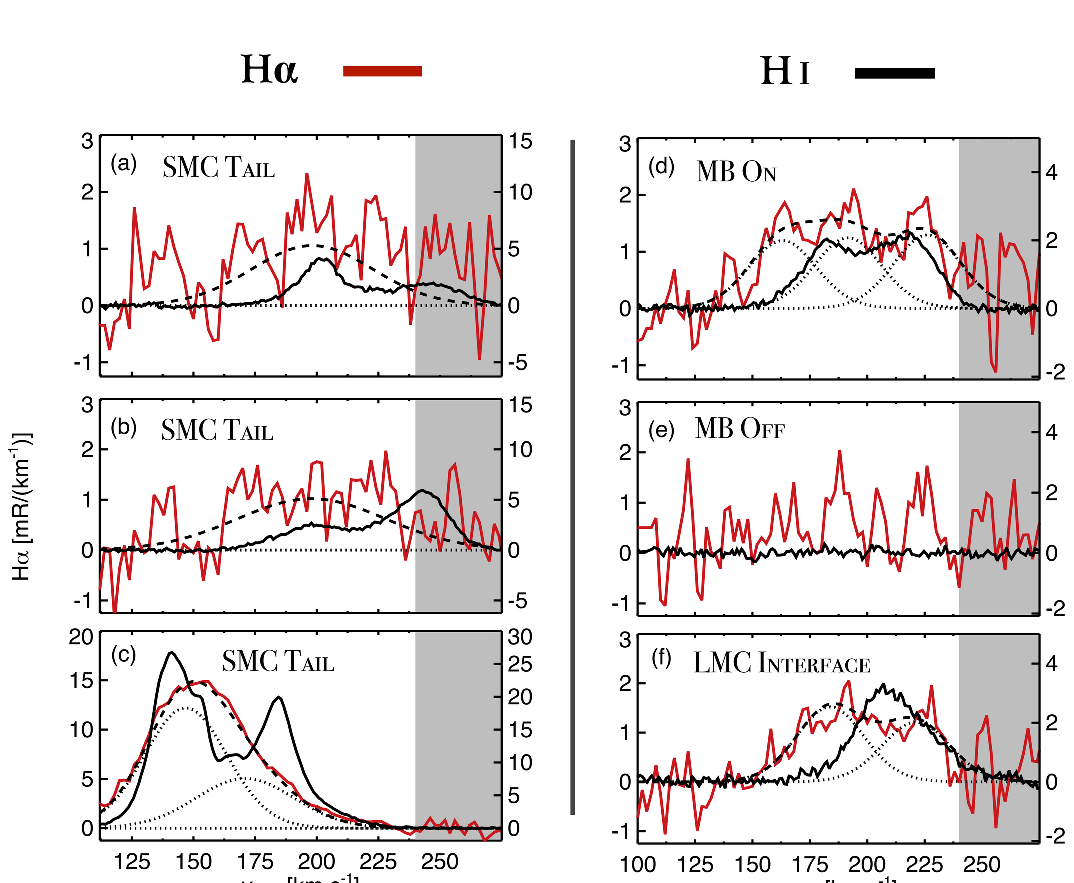

Figure 1: Hα (red) and H I[4,5] (black) emission. Most of the Magellanic Bridge sightlines have a complex, multi-peaked, velocity distribution. In many regions, the bright Hα feature corresponds to the fainter H I feature. Panel(e) represents a typical observation off the Bridge; this flat spectra indicates that most of the atmospheric emission has been adequately removed. The region highlighted in gray represents the location that the bright OH line, marked as (ii) in panel (a) of Figure 3, was removed; unfortunately, this study is insensitive to faint Hα emission in this gray region because this emission could easily be subtracted during the OH line removal.

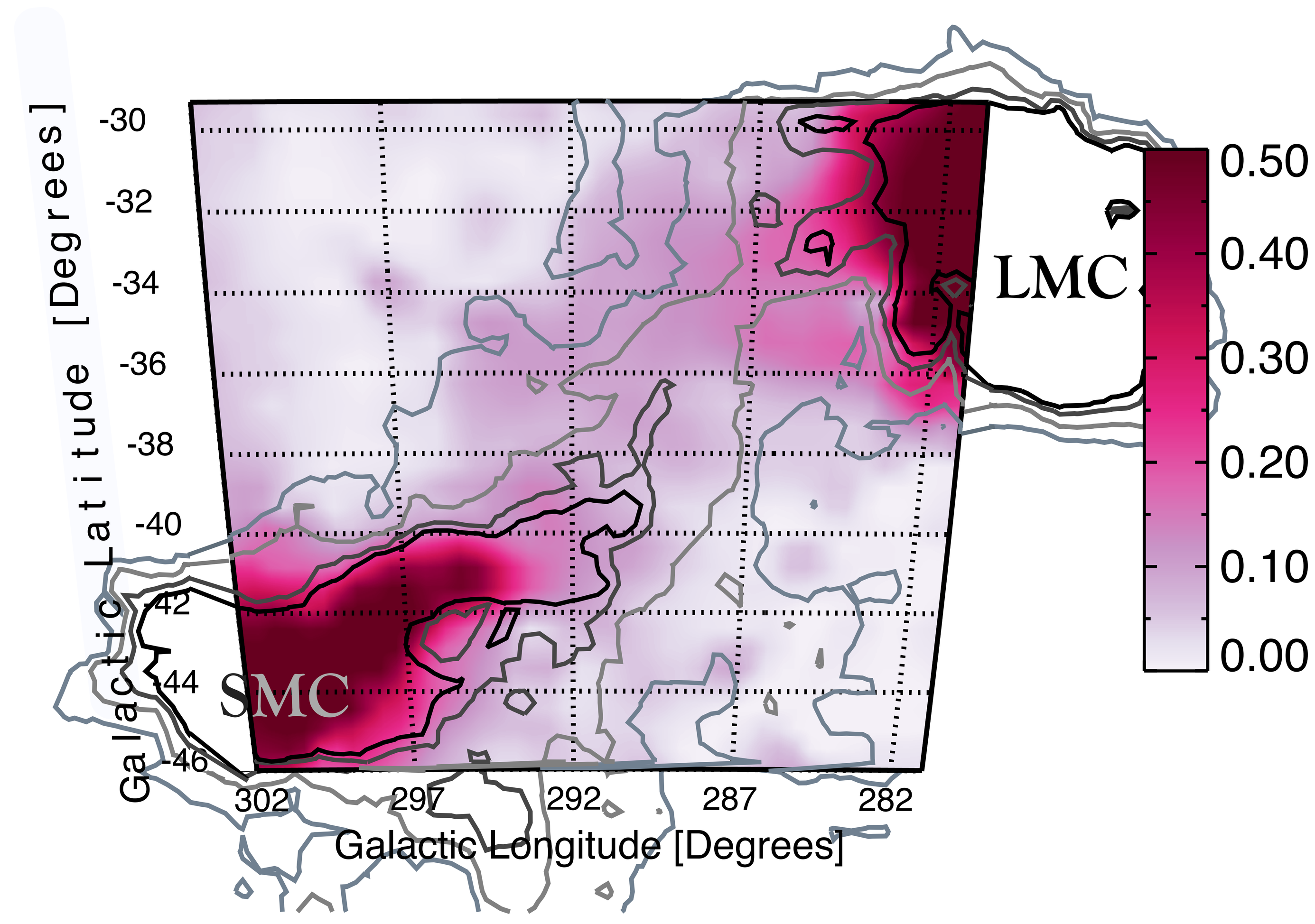

Figure 2: This Hα Magellanic Bridge map features emission over the +100 to +350 km s^{-1} local standard of rest velocity range. These observation were taken over three months span and total 24 hours of observations. The atmosphere was subtracted using the atmospheric template shown as black line in panel (b) of Figure 3. The contour lines trace the 10^{19} cm^{-2} H I[4,5] column density at increments of 10, 20, 35, and 50. The brightest Hα emission follows the high density H I gas in the Small Magellanic Cloud Tail (lower left) and the Large Magellanic Cloud (upper right). We fully sampled this region with a half-beam step pattern to completely observe the large scale structure of the ionized gas.

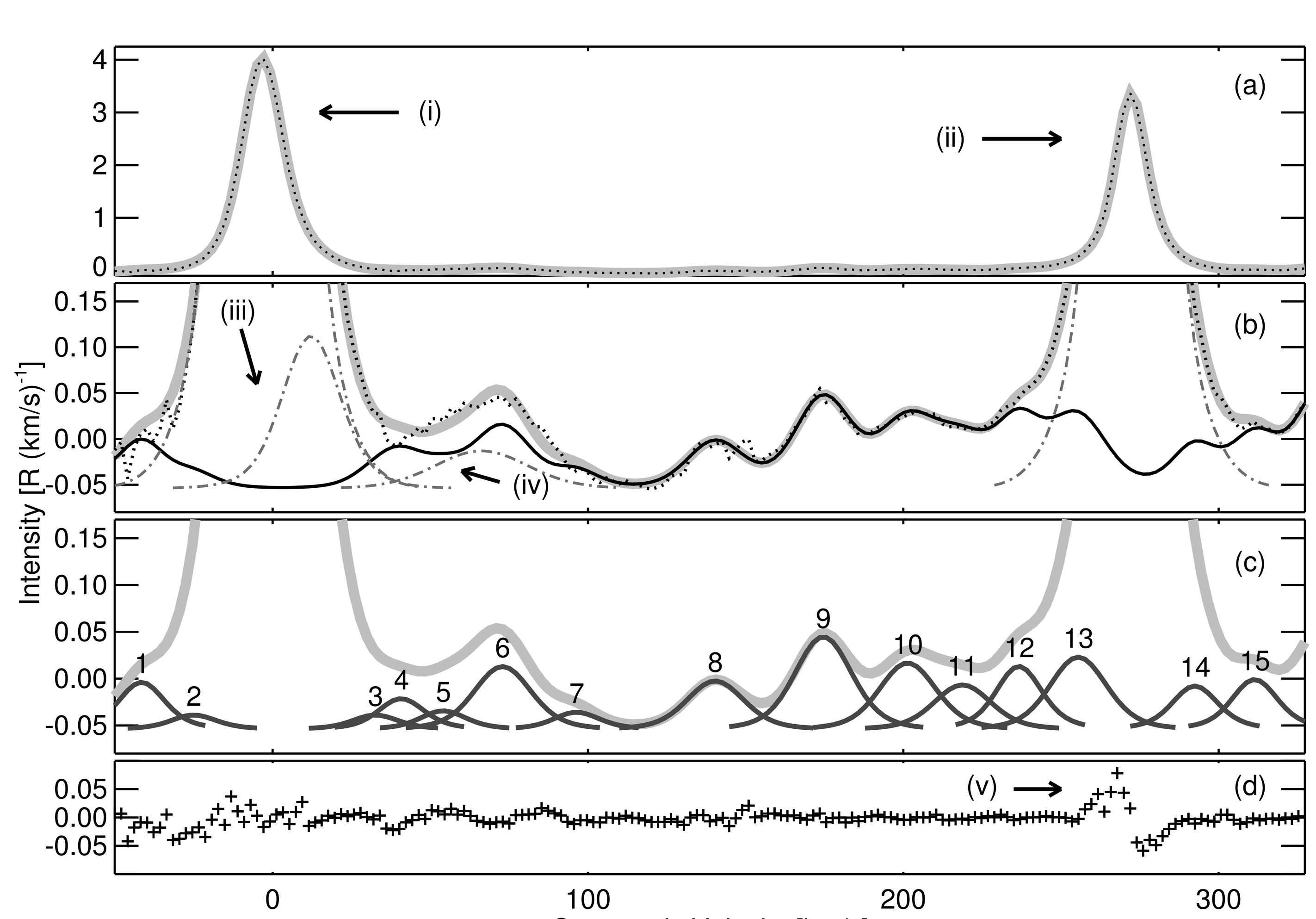

Figure 3: The average Hα emission, towards two directions faint in Hα, established a model used to construct a synthetic atmospheric template. This template was used to remove the atmospheric emission in the Bridge observations. This averaged spectra consist of more than 4.5 hours of observations taken over 10 days towards (l,b) = (60.0, −67.0) and (89.0, −71.0). The (a) and (b) panels show this average spectra as a dotted line and the corresponding fit in gray. The (b) panel emphasizes the faint emission in panel (a) and displays the constructed atmospheric template as a black solid line. Panel (c) illustrates the faint atmospheric lines in dark gray against the fit for the averaged spectra. Panel (d) displays the residuals between the average spectra and the total fit. The (i) marker indicates the geocoronal line at −2.3 km s^{-1} and the (ii) marker denotes a bright OH line at 272.44 km s^{-1} in the geocentric velocity frame. Galactic emission is labeled by markers (iii) and (iv). The (v) marker indicates residuals from the OH line subtraction caused by a slight mismatch in instrument profile.

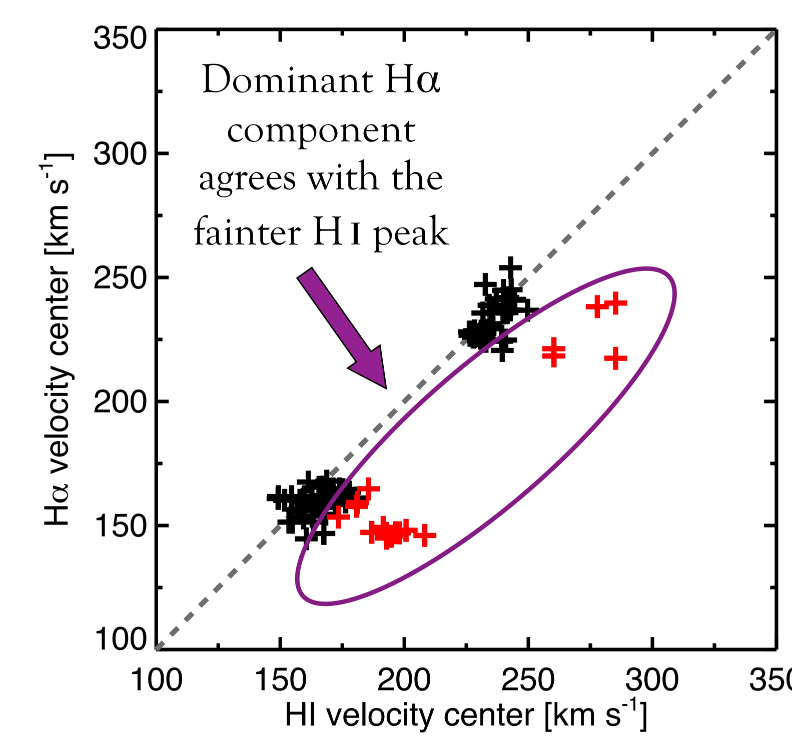

Figure 4: The dominant Hα and H I peak position. The large separation in Hα and H I peak position at the red crosses stems from a complex multi-peak distribution, as seen in Figure 1, where the dominant Hα component agrees with the fainter H I peak. The ratios of the Hα and H I emission vary considerably. The intricate two and three peak distribution exists throughout the Bridge, including at the interfaces with the Magellanic Clouds.

The interaction with the Large Magellanic Cloud and the Milky Way has caused the Small Magellanic Cloud to lose gas. This loss affects the star forming potential of this galaxy. The Magellanic Bridge accounts for much of this mass loss. This study shows that ionized gas exists throughout the Bridge. Quantifying how much ionized and neutral gas exists within the Bridge is necessary to interpreting how the Small Magellanic Cloud, and similarly interacting galaxies, will evolve.

The MB has a complex distribution with multi-peak spectral features. Often the dominant Hα peak corresponds with a weaker H I peak, suggesting that some of these components have a higher ionization fraction. These regions could indicate active local star formation, more exposure of the gas to radiation from the galaxies, or perhaps an interface between the neutral portion of the Bridge and hot halo gas.

The Magellanic Bridge has a lower metallicity than both the Magellanic Clouds. This bridge gas could originate from the lower metallicity halo and outer disk regions – regions also more susceptible to tidal forces – of the Small Magellanic Cloud. Understanding the complex velocity distribution of the Magellanic Bridge is necessary to unraveling where this gas originates and the fate of this gas.

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