Ionization of Infalling Gas


U. Wisconsin—Madison, U. Sydney

Abstract

Hα emission from neutral halo clouds probes the radiation and hydrodynamic conditions in the halo. Armed with such measurements, we can explore how radiation escapes from the Galactic plane and how infalling gas can survive a trip through the halo. The Wisconsin H-Alpha-Mapper (WHAM) is one of the most sensitive instruments for detecting and mapping optical emission from the ISM. Here, we present recent results exploring the ionization of two infalling high-velocity complexes. First, we turn our attention to the extended red tail of Hα emission toward one direction may indicate deceleration in the ionized component of the cloud.

Complex A

Introduction

HVC Complex A is a distant (~3-kpc, Walker et al. 2003), <1-kpc, van Woerden et al. (1999) collection of infalling neutral gas (ν~300–330 km s−1). Its metallicity and origin are still uncertain, although a detection of O I (by Kurth et al. [1994]) suggests neutral oxygen is a 0.1 solar (Walker et al. 2001). Figure 1 shows the 21 cm emission from the complex as well as related gas structures in the region. Tufte et al. (1998) provides the first measurement of Hα in the complex toward cores A#2 (90 mR) and A#1 (90 mR). Observations

In Figure 1, we present the first comprehensive map of Hα emission in the region. The map is composed of over 1600 WHAM one-degree beams and has been processed in a manner similar to that used for the WHAM/Northern Sky Survey (Haffner et al. 2003). The images are then constructed by integrating over velocities that sample Complex A (~300–330 km s−1). A first presented by Duncan et al. (2005), we have now doubled the total integration (to 120 s) for about half of the sightlines, mostly distributed along the Complex A chain. Due to considerable atmospheric line density at latitudes ~30–50 km s−1, base-line fitting is the major source of uncertainty. Combining cleaned spectra obtained on multiple nights lessens the impact of any systematic contaminations. Nonetheless, the resulting map still shows very close contrast compared to the 21 cm map of the region. The bulk of the detected components have intensities of 20–80 mR (EM = 0.04–0.18 pc cm−6). Figure 4 presents the Hα spectra.

To study the relationship between the ionized and neutral components throughout the region, we developed a simple, automated, Gaussian-fitting algorithm to characterize positive detections. The Hα detection toward the direction of Complex A (~300 km s−1) gives 35 mR (~6000 mR). Figure 1 shows the spectrum of a normal Hα detection (~300 km s−1). The complex as related gas structures in the region. Tufte et al. (1998) provides the first measurement of Hα in the complex toward cores A#2 (90 mR) and A#1 (90 mR).

Discussion

The correspondence between the neutral and ionized gas velocities seen in the selected spectra here continue in the larger statistical sample. The ionized and neutral components are strongly kinematically linked, as seen in other HVC and HII studies (see Haffner et al. 2001 and Haffner 2008). Our data shows that the ionized emission peaks on the other hand, does not correlate (or anti-correlate) with H I column density. As with other studied complexes, the column density exhibits much larger variations over the extent of the HVC than the Hα intensity. The neutral column spans about a factor of 10 to 20 while the emission measure exhibits much larger variations over the extent of the HVC than the Hα intensity.

On the other hand, the extended red tail of emission toward Direction #1 seems at odds with a head-tail structure expected for shielding due to drag. If the cloud is externally illuminated from the Galactic plane, enhanced density in the head should give rise to greater EM. Alternatively, if the ionization that gives rise to Hα in the complex is due to the dynamics, the most likely position for collisionally ionized gas or shock radiation is near the head.

Acknowledgements


References


Figure 1. 21 cm (left, LDS, 0°.5 beam) and Hα (right, WHAM, 1° beam) emission maps integrated between ν~220 and ~110 km s−1 toward the direction of HVC Complex A. Roman numerals denote the standard cloud core designations. Some emission associated with HVC Complex C (upper-right) and the Outer Arm (lower-right) is also present in the region at these velocities. Figure 2. Overlay of 21 cm contours (1, 3, and 7×104 mR) on the Hα map from Figure 1. While crosses show locations where measurable neutral and ionized spectral components are close in velocity (~< 10 km s−1). Spectra summarizing the map present examples from these locations. Hα spectra are displayed in black, while 21 cm spectra are shown on the same plot in blue.

Figure 2. 21 cm emission in the direction of a very high velocity (~300 km s−1) segment of the Anti-Center complex (see Figure 3). Based on the morphology of the main feature and several red-shifted (~30 km s−1) smaller clouds at slightly higher Galactic latitudes, they suggest that the gas is being dynamically shaped and stripped away by interaction with the halo. Weiner et al. (2001) report detecting Hα emission at about 40 mR toward another cloud in this subcomplex (HVC 165-43 280), as noted in the left-hand panel of Figure 3. Based on this evidence and a rough model of ionization that is consistent with the Hα locator, the HVC between about 10 and 20 km s−1 away. Figure 4 presents the Hα spectra.

Figure 3: 21 cm emission in the direction of a very high latitude Anti-Center HVC. Low-resolution (left), LSD and high-resolution (right; 3Å, GALFA, from Peek et al. 2007) maps are presented. The location of the WHAM observations (blue, “on”, green, “off”) are denoted by the crosses and numbers overplotted on the left map. The black “W” denotes the approximate location of the Hα detection (40 mR) reported by Weiner et al. (2001).

Anti-Center Clouds

Introduction

Peek et al. (2007) present 21 cm observations from Arecibo (~< 100 mR) but correlate on the sky and in velocity with 21 cm emission. Second, we follow up on high-resolution 21 cm observations by Peek et al. (2007) and their proposal that the clouds exhibit morphological features shaped by interaction with the halo. Initial measurements of deep Hα observations toward a few different regions in these Anti-Center clouds present a challenge to this scenario. To detect these clouds with WHAM. A~160 mR toward another cloud in this subcomplex (HVC 165-43 280), as noted in the left-hand panel of Figure 3. Based on this evidence and a rough model of ionization that is consistent with the Hα locator, the HVC between about 10 and 20 km s−1 away. Figure 4 presents the Hα spectra.

Figure 4: A (~< 100 mR) spectrum with velocity profiles similar to those of the 21 cm emission. Direction #1 shows no clear emission at the location of the Hα velocity. Although the baseline is far from flat, the range of intensities limits any possible emission to no more than one third of that of Direction #3 (~< 30 mR). Direction #3 hints at red-shifted emission or a second component. This asymmetry is present in both directions examined separately. Integrating over the whole velocity window gives a lower limit of 90 mR, while assuming a 30 km s−1. Figure 5 presents the Hα spectrum in black and the H I spectrum from LSD shown in blue.

Discussion

Hα emission is clearly detected in directions #1 (~< 100 mR) with velocity profiles similar to those of the 21 cm emission. Direction #1 shows no clear emission at the location of the Hα velocity. Although the baseline is far from flat, the range of intensities limits any possible emission to no more than one third of that of Direction #3 (~< 30 mR). Direction #3 hints at red-shifted emission or a second component. This asymmetry is present in both directions examined separately. Integrating over the whole velocity window gives a lower limit of 90 mR, while assuming a 30 km s−1. Figure 5 presents the Hα spectrum in black and the H I spectrum from LSD shown in blue.

There are various possible scenarios for the formation and evolution of these clouds. One possibility is that they are remnant gas that is still bound to the Galactic potential. Another possibility is that they are gas that has been stripped away from the Galaxy by the halo. The latter scenario is supported by the fact that the clouds are mostly located near the Galactic plane and how infalling gas can survive a trip through the halo.