



Ionization of Infalling Gas

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Abstract

H α 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 report on our progress mapping H α emission covering the full extent of the HVC Complex A. Intensities are faint (< 100 mR; EM < 0.2 pc cm⁻⁶) 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 H α observations toward a few directions in these Anti-Center clouds present a challenge to this scenario: H α is detected quite definitively in the “tail”, but not the “head” of the main HVC cloud. Yet, a red-shifted tail of H α emission toward one direction may indicate deceleration in the ionized component of the cloud.

Complex A

HVC Complex A is a distant (>8 kpc, Wakker et al. 2003; <10 kpc, van Woerden et al. 1999) collection of infalling neutral gas ($v_{\text{LSR}} \sim -200$ to -130 km s⁻¹). Its metallicity and origin are still uncertain, although a detection of O I by Kunth et al. (1994) suggests *neutral* oxygen is ≤ 0.1 solar (Wakker 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 H α in the complex toward cores AIII (80 mR) and AIV (90 mR).

Introduction

Observations

In Figure 1, we present the first comprehensive map of H α 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 image is then constructed by integrating over velocities that sample Complex A (-220 to -110 km s⁻¹). First presented by Duncan et al. (2005), we have since 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 intensities ~ 10 –100 mR, baseline fitting is the major source of uncertainty. Combining cleaned spectra obtained on multiple nights lessens the impact of any systematic contaminants. Nonetheless, the resulting map still shows very low contrast compared to the 21-cm map of the region. The bulk of the detected components have H α intensities of 20–80 mR (EM ~ 0.04 –0.18 pc cm⁻⁶, if $T_e = 8,000$ K).

Discussion

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 in H α and 21 cm spectra. Focusing on lines of sight that show a strong kinematic relationship between the two gas components, we identify directions in Figure 2 (white crosses) where the fitted mean velocity of the H α and 21 cm component differ by less than 10 km s⁻¹. Plots comparing the two emission spectra toward a representative sample of these directions are also shown. Exploring the data in the spectral domain adds considerable confidence that the WHAM data is tracing high-velocity gas especially toward directions with measurable H I column density. Since the H α map is created completely independently from the 21-cm map, it is tempting to extrapolate that features in the H α map *not* associated with 21-cm emission (at LDS sensitivities) are also real Galactic emission. However, we have not yet studied those locations in enough detail to make any definitive conclusions.

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 IVC and HVC studies (see Haffner et al. 2003 and Haffner 2005). H α intensity, 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 H α intensity. Here, the neutral column spans about a factor of 10 to 20 while the emission measure varies by a factor of 3 to 5.

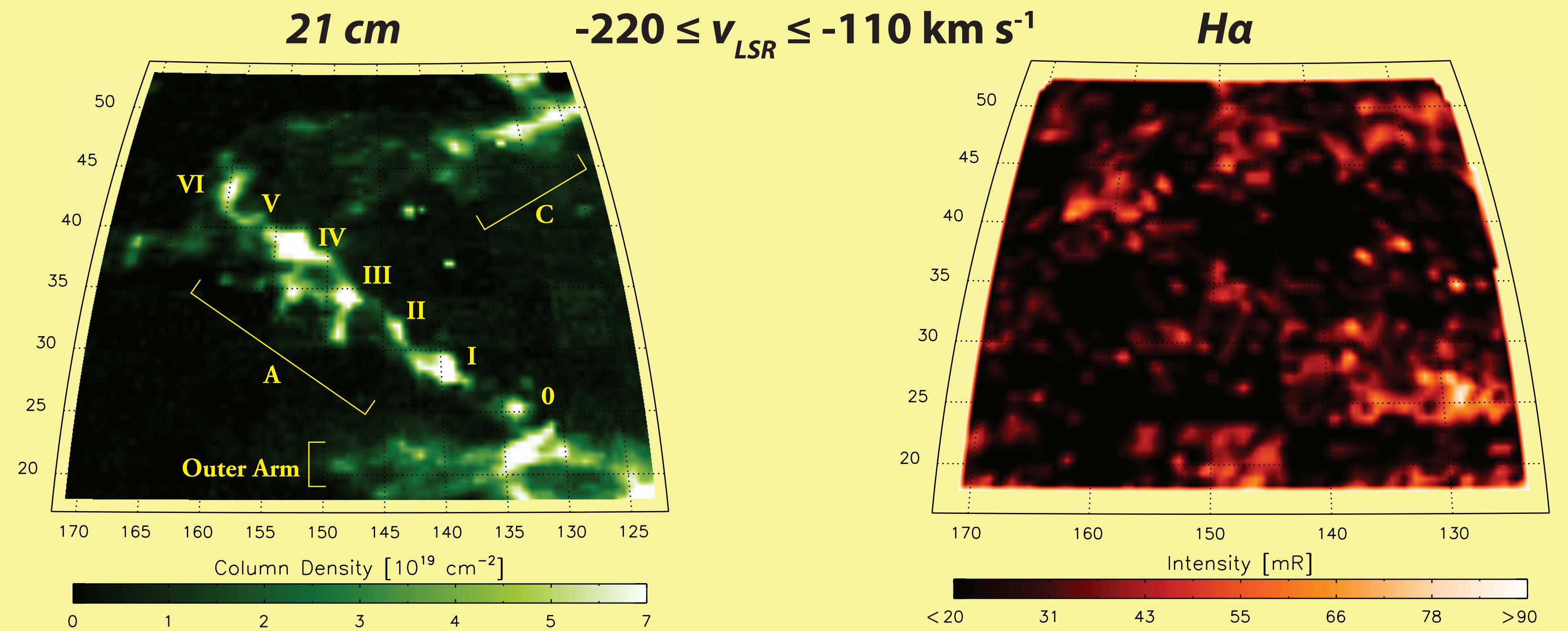


Figure 1: 21-cm (left; LDS, 0°.5 beam) and H α (right; WHAM, 1° beam) emission maps integrated between $v_{\text{LSR}} = -220$ and -110 km s⁻¹ toward the direction of HVC Complex A. Roman numerals denote the standard cloud core designations. Some emission associated with HVC Complex C (upper-right) and the Outer Arm (lower-right) is also present in the region at these velocities.

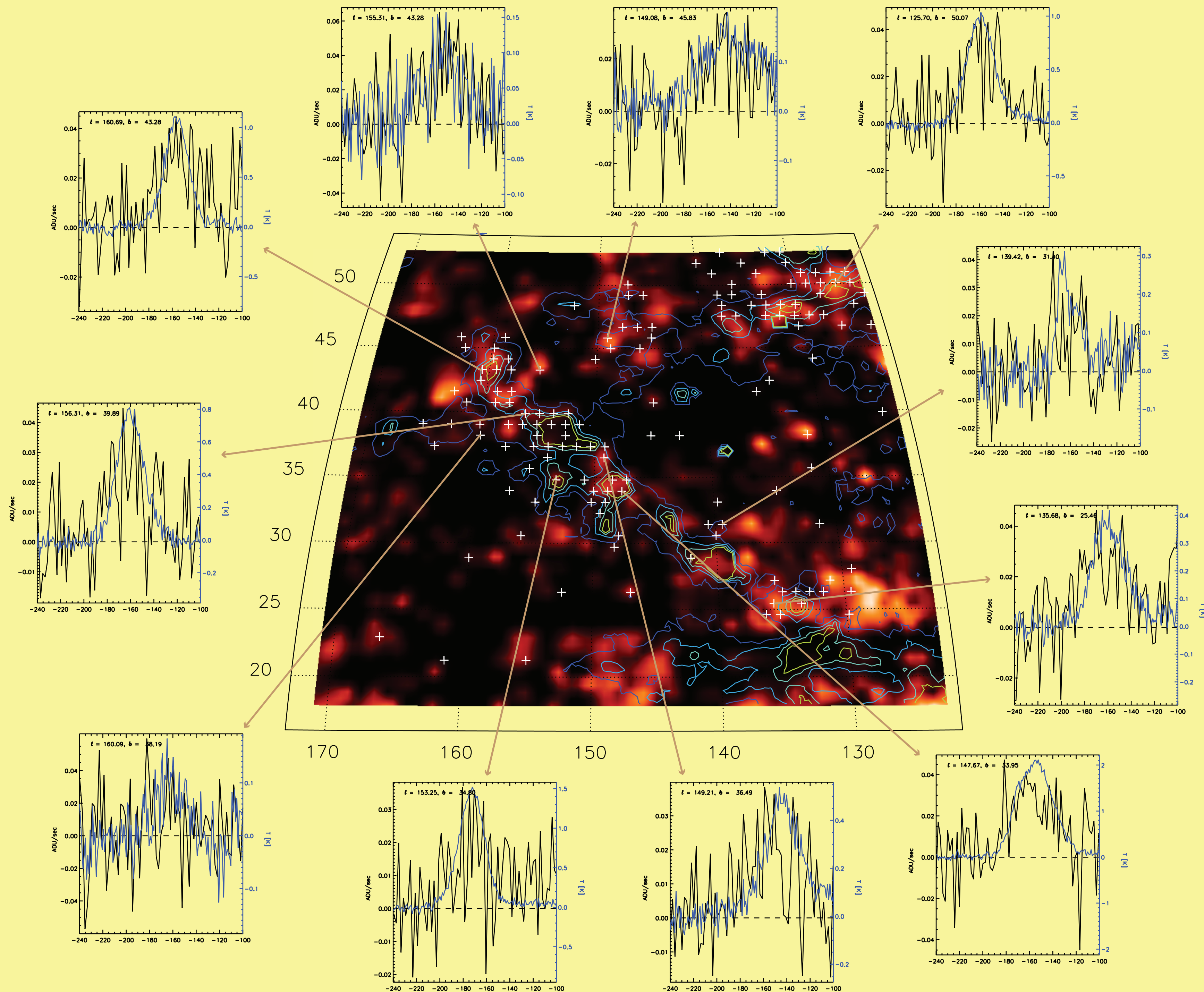


Figure 2: Overlay of 21-cm contours (1, 3, 5, and 7×10^{19} cm⁻²) on the H α map from Figure 1. White crosses show locations where measurable neutral and ionized spectral components are close in velocity ($\Delta v < 10$ km s⁻¹). Spectra surrounding the map present examples from these locations. H α spectra are displayed in black, while 21 cm spectra are shown on the same plot in blue.

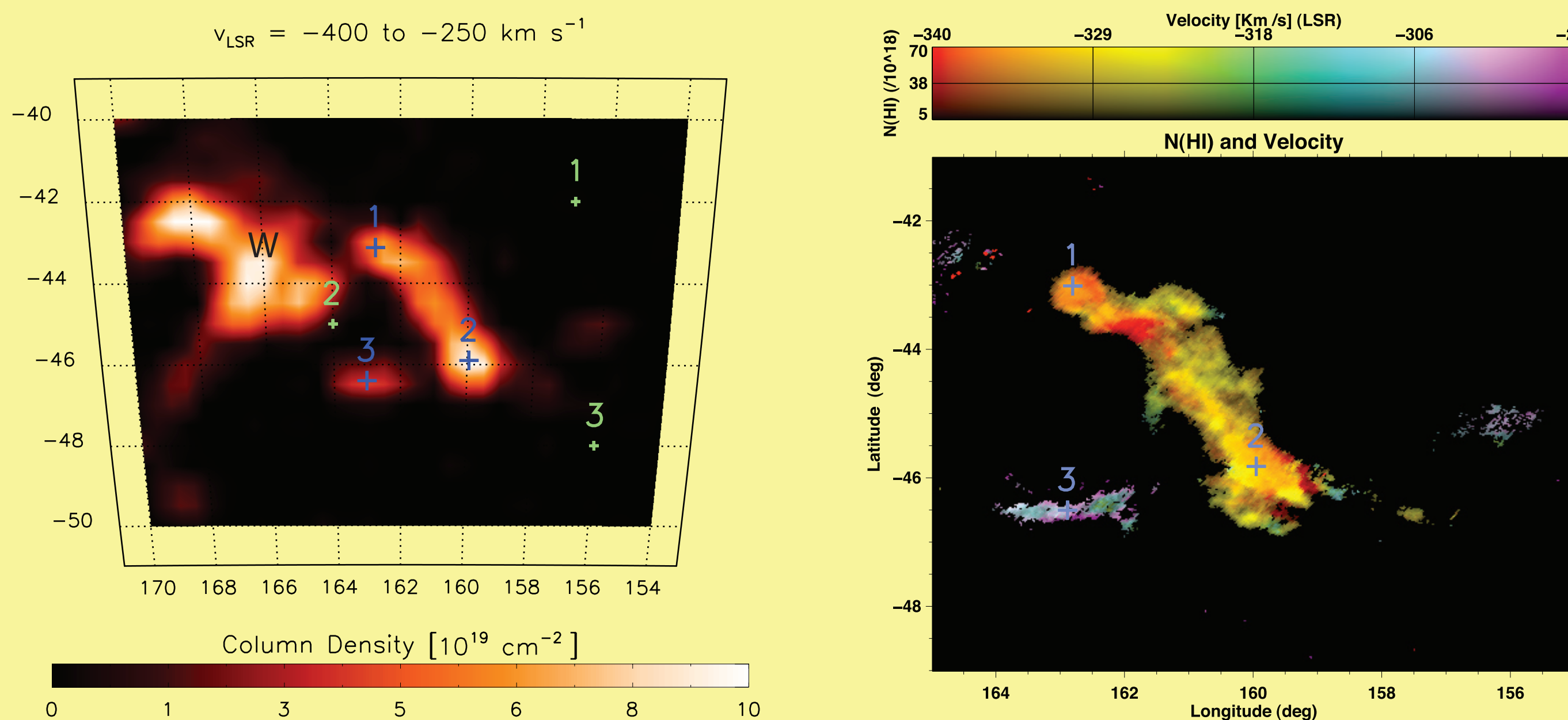


Figure 3: 21-cm emission in the direction of a few high-latitude Anti-Center HVCs. Low-resolution (left; 0°.5, LDS) and high-resolution (right; 3'/4, GALFA, from Peek et al. 2007) maps are presented. The location of the WHAM observations (blue, “on”; green, “off”) are denoted by the crosses and numerals overplotted on the left map. The black “W” denotes the approximate location of the H α detection (40 mR) reported by Weiner et al. (2001).

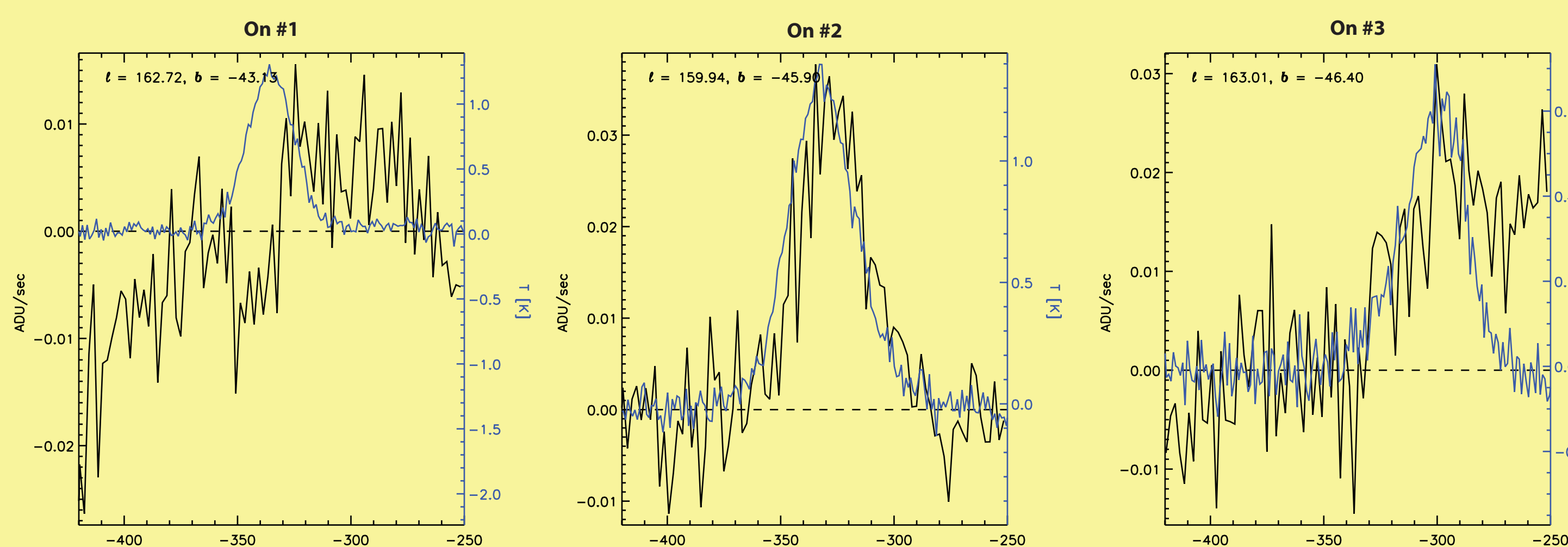


Figure 4: H α (“on”–“off”) spectra (black) towards three Anti-Center HVC lines of sight (see Figure 3). The corresponding average 21 cm spectrum from LDS within the WHAM one-degree beam is overplotted (blue).

Anti-Center Clouds

Introduction

Peek et al. (2007) present 21-cm observations from Arecibo ($\sim 3'$) of a very high-velocity ($v_{\text{LSR}} \sim -330$ km s⁻¹) segment of the Anti-Center complex (see Figure 3). Based on the morphology of the main feature and several red-shifted ($\Delta v \sim 30$ 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 H α 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 emission and a rough model of ionizing flux in the halo, they locate the HVC between about 10 and 20 kpc away. Peek et al. find that their drag model predicts a consistent distance. At their suggestion, we began a more comprehensive study of the ionized gas associated with these clouds with WHAM.

Observations

Three “on” and three “off” directions (labeled in Figure 3) were identified as the initial WHAM targets. Each location was observed for 120 s per exposure, with “on” and “off” targets interleaved to aid atmospheric line removal. Each target was observed 10 times during the first night and 4 times during the second night, about one month later. The total exposure time per direction is then 1680 s. Since there is a 10 km s⁻¹ shift in the location of the LSR relative to the geocentric rest frame between the two nights, each data set is reduced separately until we combine the “clean” Galactic emission with the data registered to the LSR velocity frame. None of the “off” directions appeared to contain Galactic emission, so a single, very high signal-to-noise “off” was created for each night and subtracted from each “on” direction. Results are shown in Figure 4 with the WHAM

spectrum in black and the H I spectrum from LDS shown in blue.

Discussion

H α emission is clearly detected in directions #2 (60 mR) and #3 (35–90 mR) with velocity profiles similar to those of the 21-cm emission. Direction #1 shows no clear emission at the location of the H I velocity. Although the baseline is far from flat, the range of intensities limits any possible emission to no more than one-third that of Direction #2 (< 20 mR). Direction #3 hints at red-shifted emission or a second component. This asymmetry is present in both nights when examined separately. Integrating over the whole velocity window gives a lower limit of 90 mR, while assuming a 30 km s⁻¹ FWHM as measured in Direction #2 gives 35 mR for a component centered near $v_{\text{LSR}} = -290$ km s⁻¹.

Although this is a very sparse initial sample, the lack of emission toward Direction #1 seems at odds with a head-tail structure expected for shaping 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 H α in the complex is due to the dynamics, the most likely position for collisionally ionized gas or shock radiation is near the head.

On the other hand, the extended red tail of emission toward Direction #3 may lend additional support to the proposal. Peek et al. suggest the velocity difference in this small cloud compared to the main structure is due to the effects of drag. Material shed from this cloud will also decelerate, but may be of low enough density that it is unable to self-shield from the general ionizing field in the halo and becomes completely ionized.

References

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