High Velocity Cloud Analysis in HI4PI Data

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***Abstract*—We study the properties of high velocity clouds by analyzing data from the HI4PI survey. We calculated a value of $\langle N_{HI} \rangle \approx 1.4 \times 10^{18} cm^{-2}$ for the mean value of the column density of the HVC. We observed the multiphase structure of the HVC, obtaining a kinetic temperature of $T_H \approx 4000K$ for the hot phase and $T_C \approx 8000K$ for the cold phase. We calculated the thermal pressure of both phases of the cloud and found that this coincides with the thermal pressure of the Hot Ionized Medium. Moreover, plotting the thermal pressure of the HVC as a function of the distance from the observer and comparing this to the plot for the thermal pressure of the Hot Ionized Medium we found that the HVC could exist at a distance of $2.08kpc$ from us.**

I. Introduction

The Milky Way is the galaxy that contains our solar system. It consists of a bar-shaped core surrounded by a disk of dust, gas and stars. This disk is surrounded by a halo of old stars and globular clusters and it is known as the Milky Way Halo. It also constitutes an important reservoir of gas; most of which is neutral hydrogen (HI).

Inside the Milky Way halo exist high velocity clouds (HVCs), which are of great interest in understanding the evolution of our galaxy, for they contain a large amount of the baryonic matter in the Halo and they play an important role in the formation of stars.

High velocity clouds are defined as neutral atomic hydrogen gas traveling with radial velocity of about $200km.s^{-1}$ and their motion cannot be explained by the rotation of the Milky Way. Being composed of hydrogen, they are very well observed through the $21cm$ hyperfine structure line.

The objective of this practical work is to study the properties of a high velocity cloud in the interstellar medium. The data we analyze comes from the HI4PI survey.

II. Physical Properties of the HVC

One of the main properties we would like to study is the temperature density of the HVC. At first approximation, we can assume Virial equilibrium in order to obtain the temperature density inside the cloud as a function of the distance d. In this approximation the cloud is taken to have a spherical shape.

$$\frac{P_s}{k} = \frac{\langle N_{HI} \rangle T_k}{d\theta} - \frac{\mu^2 G\pi \langle N_{HI} \rangle^2}{15k} \tag{1}$$

where θ is the observed angular diameter of the sphere, T_k is the kinetic temperature of the gas, G and k are respectively the gravitational and the Boltzmann constant, $\langle N_{HI} \rangle$ is the mean value of the column density and μ is the mean mass per particle within the sphere.

In order to obtain $\langle N_{HI} \rangle$, we first calculate the mean spectra of the cloud. The purpose of this is to obtain the mean temperature brightness as a function of the velocity. Then, we integrate the temperature brightness to obtain $\langle N_{HI} \rangle$.

$$\frac{\langle N_{HI} \rangle}{cm^{-2}} = 1.82243 \times 10^{18} \times \int_{-\infty}^{\infty} \left(\frac{T_b(v)}{K} \right) d\left(\frac{v}{km.s^{-1}} \right) \tag{2}$$

where T_b is the mean brightness temperature and v is the radial velocity of the cloud.

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Considering only temperature caused by the kinetic temperature of the particles in the cloud, T_k can be written as:

$$T_k = \frac{m_H \sigma_v^2}{k}(K) \tag{3}$$

where m_H is the mass of Hydrogen and σ_v is obtained as the half-width when we fit a Gaussian in to the mean spectra previously calculated.

The temperature density of the cloud will be compared to that of the Halo. The thermal pressure of the Halo will be calculated using the following analytic fit, extracted from [1].

$$\frac{P}{k} = 2250 T_6^{1/2} \left(1 + \frac{z^2}{19.6}\right)^{-1.35/T_6} Kcm^{-3} \tag{4}$$

where z is the vertical distance of the cloud from the plane of the galaxy in kpc, T_6 is the isothermal temperature of the Halo and k is the Boltzmann constant.

III. Analysis and Results

We work in Python to read and analyze the data. This work makes use of hyperspectral imaging. The data is provided in the FITS format as a hyperspectral cube with two dimensions of space and one dimension of velocity.

Each element of the cube contains a value of temperature brightness and is identified by three indexes. The first two indexes are the spacial indexes and they have a one to one correspondence longitude and latitude respectively. The third index corresponds to the radial velocity of the matter emitting radiation with said temperature brightness.

By stacking all layers of velocity, we can create an integrated column density map. This was done for the whole spectrum of velocities, as shown in Fig. 1 and for the range of velocities corresponding to the HVCs, as shown in Fig. 2.

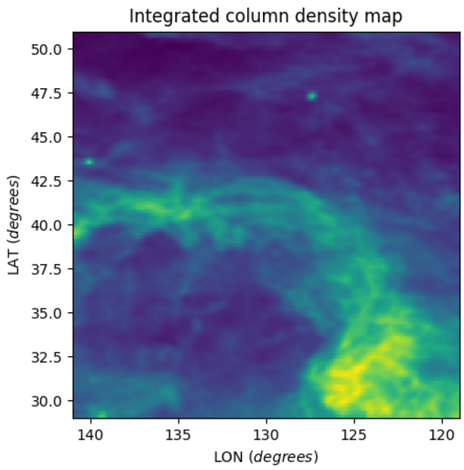

Fig. 1. Integrated column density map.

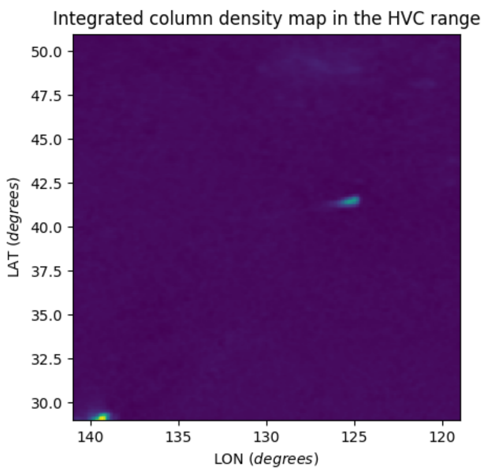

Fig. 2. Integrated column density map in the HVC range.

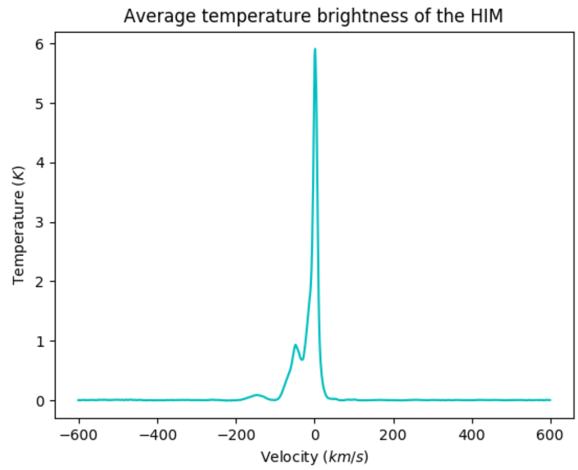

Fig. 3. Average temperature brightness of the hot ionized medium.

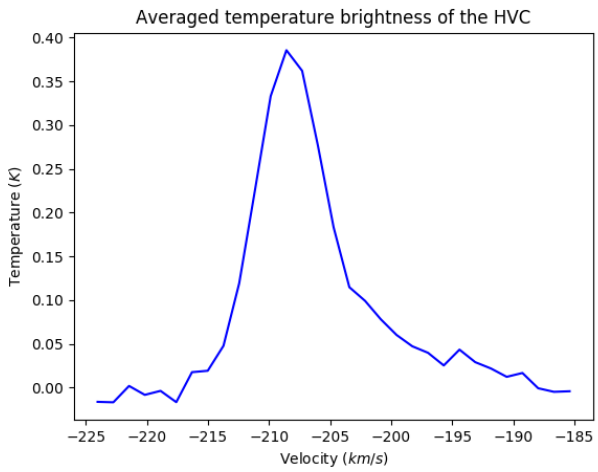

Fig. 4. Average temperature brightness of the HVC.

This map gives us a view of the actual High Velocity Cloud, which can be seen as the bright spot. From here we can move on to study various properties of the HVC.

As mentioned before, we need to compute the mean spectra in order to be able to calculate $\langle N_{HI} \rangle$. We do this by averaging the Column Density over the spacial dimensions. We plot the averaged temperature brightness for the whole spectrum of velocities, this is shown in Fig. 3.

From Fig. 2 we can obtain the region where the HVC is located. So we calculate the average temperature brightness only in the region where the HVC is located. Having the temperature brightness of the HVC as a function of velocity, we integrated to obtain $\langle N_{HI} \rangle$, making use of equation (2). The obtained value was $\langle N_{HI} \rangle \approx 1.4 \times 10^{18} cm^{-2}$. Additionally, using this criteria, we plotted the average temperature brightness versus velocity in the velocity range of the HVC. This is shown in Fig. 4.

From previous observations we know that HVCs have a multiphase nature possessing a cold core and a warm envelope [1]. For a particular pressure we observe this multiphase nature of density. From the phase diagrams of HVCs (Fig. 5), we clearly see two critical points which bridge the interaction between the warm and cold phases of the cloud. The gas oscillates between the two temperatures in this region.

In order to distinguish between the two phases of the cloud, we can fit the temperature brightness plot to a sum of two Gaussian functions. One for the warm phase and the other for the cold phase. These Gaussian fits are presented in Fig. 6.

From these individual Gaussian functions of the warm and cold phases, we obtain the values of σ_H and σ_C. These can then be used to calculate the kinetic temperatures T_H and T_C for the two phases of the cloud using equation (3). The obtained values were $T_C \approx 800K$ and $T_H \approx 4000K$.

Having the values for $\langle N_{HI} \rangle$, T_H and T_C, we can estimate

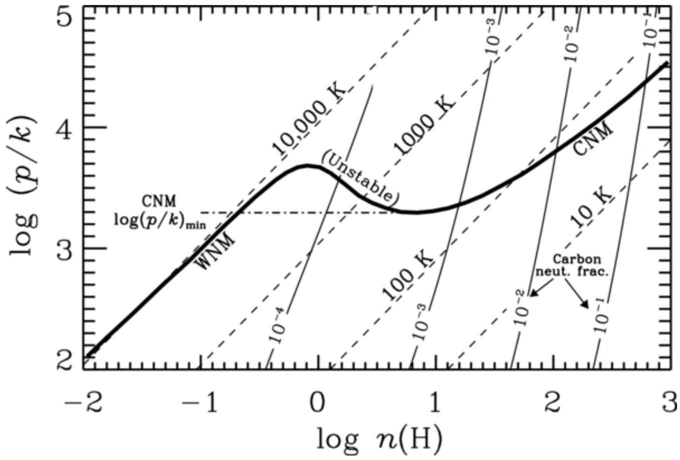

Fig. 5. Phase diagram of the HVC showing the variation of density n with thermal pressure P at different temperatures.

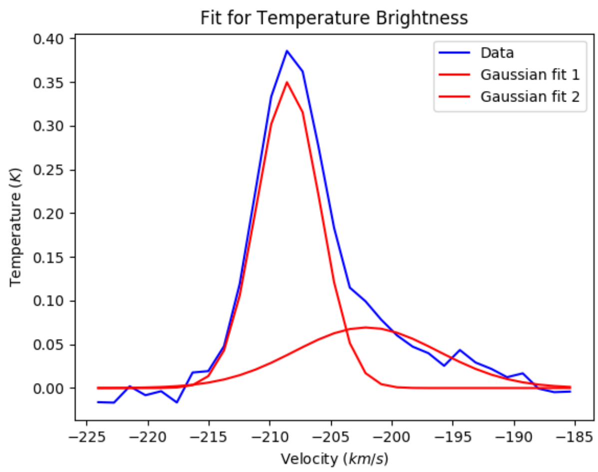

Fig. 6. Gaussian fit for the temperature brightness of the HVC.

the pressure at the surface of the HVC as a function of distance using the Virial equilibrium approximation from equation (1). In this equation, the variable $d\theta$ is calculated by using the value of the spatial resolution in radians and then multiplying it by the number of pixels from the integrated column density map (Fig.2) that highlight the HVC.

Simply put, this is the equilibrium pressure between the inside and outside medium. This means that in theory this should be equal to the pressure outside the HVC, which is estimated using equation (4) [1]. Here, z is the height of the HVC above the horizontal plane of the observer and T_6 is the isothermal halo temperature. For this experiment we make use of $T_6 = 1$ and $T_6 = 2$.

Finally, we compare the two pressure values from equation (1) and equation (4) and plot the temperature density variation with distance (Fig. 7) for the warm phase, cold phase, $T_6 = 1$ and $T_6 = 2$.

The intersection points in this plot clearly show that the hypothesis about the surface pressure or the equilibrium pressure being equal to the outside pressure is correct. It also enables us to estimate the distance of the cloud from us (the observer).

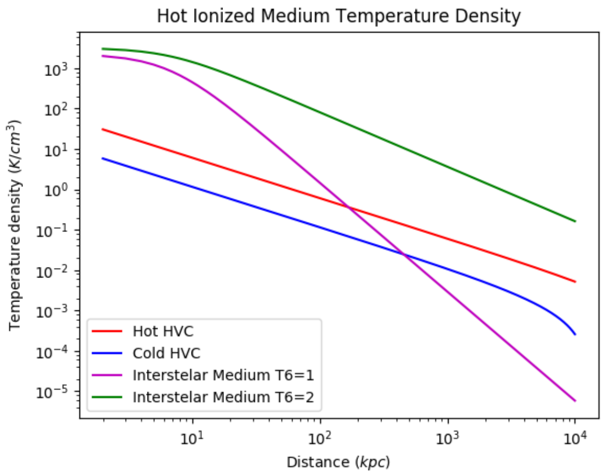

Fig. 7. Hot Ionized Medium temperature density.

IV. Conclusion

The averaged temperature brightness for the HVC makes evident its multiphase structure. We conclude this because of how accurately we can fit the sum of the two Gaussian functions, one corresponding to each phase, to the averaged temperature brightness. Through this fit, we were able to calculate the kinetic temperature of both phases of the cloud, obtaining values of $T_H \approx 4000K$ and $T_C \approx 800K$ for the hot and cold phases respectively.

By plotting the thermal pressure of the cloud as a function of distance and comparing it to the thermal pressure of the Hot Ionized Medium, we were able to find a distance at which both thermal pressures coincide. This means that the HVC can exist in equilibrium within this medium. Furthermore, we were able to estimate the distance at which the HVC should exist. We estimate it to be of approximately $2.08kpc$.

References

[1] Wolfire, M. G. and McKee, C. F. and Hollenbach, D. and Tielens, A. G. G. M. "The Multiphase Structure of the Galactic Halo: High-Velocity Clouds in a Hot Corona". Astrophysical Journal v.453, p.673. November, 1995.

[2] Edward B. Jenkins and Todd M. Tripp 2011 ApJ 734 65