High Velocity Cloud Analysis in HI4PI Data

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***Abstract*—This practical work aims to study some physical properties of a High Velocity Cloud (HVC) HVC125+41-207 by analyzing its neutral hydrogen HI spectrum. Its temperature, HI density, thermal pressure and distant are the parameters of interest.**

I. Introduction

A High Velocity Cloud (HVC) is a clump of gas that spans the halo region. It is abundant in neutral hydrogen and is moving with a very high velocity ranging from around 1 to several hundred kpc.s^{-1}. It was discovered through a 21-cm line measurement, which is the spectrum of hyperfine structure.

As HVCs falls in to the galactic plane, it adds the source of materials to form new stars in the galaxy. This process is what compensates the density of elements in the galaxy, since a large number of stars are always forming. The HVCs then helps to maintain the star formation rate. The origin of HVCs is still unclear. However, as it plays an important role for the evolution of a star and a galaxy, it is a fascinating object to be studied.

II. Data manipulation

The data is stored in the form of the brightness temperature (T_b) at each point of the observation field (x,y) at a certain velocity. Thus, the data is a rank-3 tensor that can be visualized as a 3-dimension cube, so-called a *hyperspectral cube* as shown in Fig. 1.

In order to have a rough approximation of the location of the HVC, only one position on the xy plane of the cube was selected. By doing so, a spectrum, which is a plot of the brightness temperature as a function of the velocity, can be constructed. Fig. 2 shows the spectrum at latitude 119° and longitude 19° (correspond to x = 0, y = 0 in the detector coordinates) over the whole range of velocity. It is noted that there are two significant peaks in the plot. The larger peak at the center represents the neutral hydrogen (HI) in the galactic plane and the smaller one represents that of the HVC. Since the solar system is also in the galactic plane, this peak can be inferred as the spectrum of HI measured in the rest frame and, therefore, it displays no Doppler shift. In contrary, the HI spectrum of the HVC is altered by the Doppler shift due to its motion towards the galactic plane.

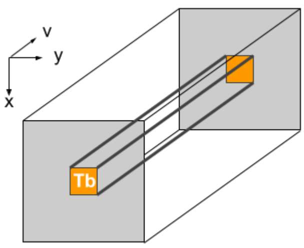

Fig. 1. A visualization of a hyperspectral cube. The cross section (xy plane) of the cube represents the observation field. Each point on the plane is the brightness temperature at a certain radial velocity.

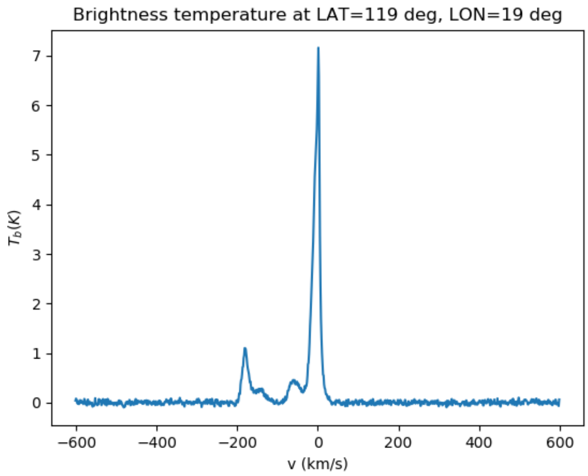

Fig. 2. The velocity spectrum of a specific position. HI of the galactic plane is shown at the center and HI of the HVC is shifted to the left from the center.

According to Fig. 2, the velocity range of the HVC can be estimated to fall in the range of -200 to -180 km.s^{-1}. In fact, previous studies show that HVC125+41-207 is located within the range of $v_{rad}\ (km.s^-1) = [-225, -185]$. In the following parts of this report, this selected range is referred to as v$_{sel}$ range.

The mean density of HI $\langle N_{HI}\rangle$ can be evaluated by integrating the brightness temperature over velocity domain as shown in the following equation:

$$\langle N_{HI}\rangle = 1.82243\times 10^{18}\int_{-\infty}^{\infty} T_b(v)d(v)\ \ \text{cm}^{-2}, \quad (1)$$

where T_b is in K and dv is the spectral resolution of the detector and is in the unit of km.s$^-1$. Thus, the density map of HI can be built by performing a summation of T_b data array over the velocity axis. Fig. 3 shows the density of HI integrated over the velocity range [-600, 600]. In this figure, there is no clear verification of the HVC, since the high density region seems to be randomly distributed. Furthermore, As described

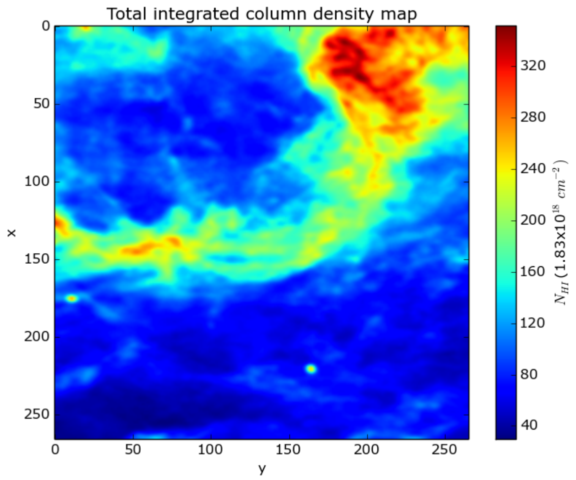

Fig. 3. The density map of HI over the whole velocity range. The vertical and the horizontal axes values are shown in detector coordinates.

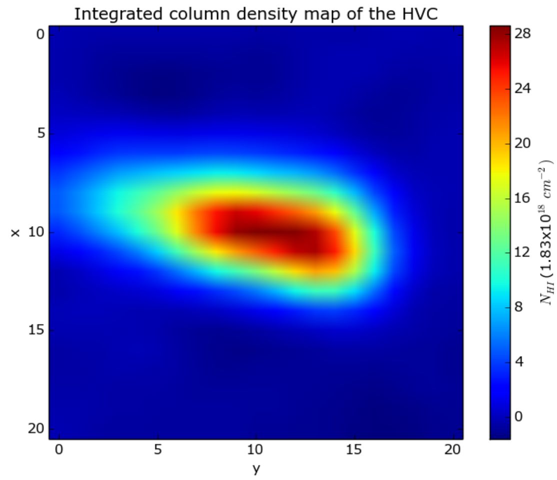

Fig. 5. The density map of HI of the HVC. The vertical and the horizontal axes values are shown in detector coordinates.

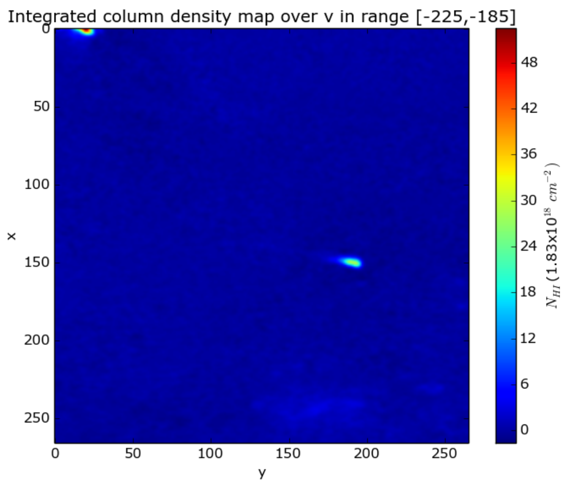

Fig. 4. The density map of HI over the velocity range [-225, -185]. The vertical and the horizontal axes values are shown in detector coordinates.

before, the dominant HIs are the ones that are located in the galactic plane. So, this density map is also dominated by those local HIs.

By performing a summation of T_b only over the v$_s el$ range, the influence of the galactic plane HI is expected to be eliminated. Figure. 4 shows the density over the v$_s el$ range. As expected, the HVC, which is the bright spot at the middle right, is clearly displayed. The region in which the HVC is located is shown in Fig. 5. Remind that, up to this step, the hyperspectral cube has been reduced to contain only the data of the HVC.

III. HVC Spectral Analysis

A. Mean Spectrum

The spectrum studied in this part has to be the mean spectrum of the entire HVC and not only one specific position on the xy plane anymore. Thus, it is necessary to sum T_b over the x and y axes before plotting against the velocity. The mean spectrum of the HVC is depicted in Fig. 6 as the dark blue line. It is noted that this spectrum can not be fit by a single Gaussian curve, since the base of the spectrum exhibits an asymmetry. However, a superposition of two Gaussian functions with different widths and heights can represent the spectrum very well.

According to the kinetic theory, the velocity of gas particles obey a Maxwellian distribution which is characterized by kinetic temperature T_k. The width of a Gaussian due to this thermal effect is given by

$$\sigma_{th} = \sqrt{\frac{2kT_k}{m_H}}, \tag{2}$$

where σ_{th} is the standard deviation, k is the Boltzmann constant and m is the mass of hydrogen. Consequently, Eq. (2) indicates that the HVC is composed of two thermal distinct phase, one is hot (broad spectrum) and the other one is cold (narrow spectrum). The σ_{th} of the cold spectrum and the hot spectrum are 2.24 and 2.92 km/s, respectively. Consequently, the kinetic temperature of the hot phase is 4281 K, while that of the cold phase is 753.6 K.

B. Thermal Pressure and Distance of HVC

It is assumed that the HVC is a spherical cloud with a cold core surrounded by a hot gas. Then, by applying the Virial Theorem, the pressure outside the cloud can be obtained by a balance between the kinetic pressure of the hot gas and the gravitational pressure. The equation can be written as

$$\frac{P_s}{k} = \frac{\langle N_{HI}\rangle T_k}{d\theta} - \frac{\mu^2 G\pi \langle N_{HI}\rangle^2}{15k}, \tag{3}$$

where P_s is the pressure outside the cloud, d is the distance from Sun to the cloud, θ is the angular size of the cloud, and μ is the mean molecular mass $\simeq 1.25m_H$. The $\langle N_{HI}\rangle$ of the hot phase is $1.67\times10^{18}\text{cm}^{-2}$. It is calculated by using Eq. (1) with $T_b(v)$ is the optimized Gaussian function obtained from

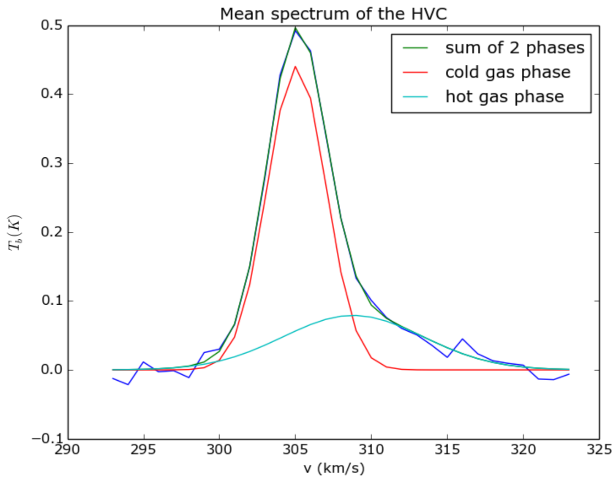

Fig. 6. The mean spectrum (dark blue line) of the HVC can be represented by a superposition of two Gaussian functions shown in orange and light blue lines. The result of the super position is shown as the green line.

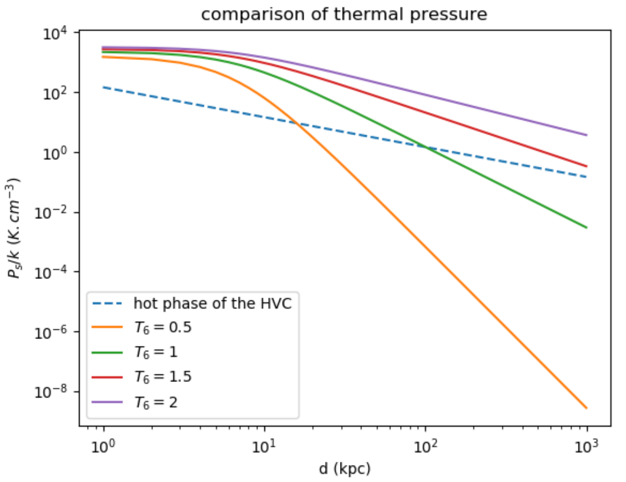

Fig. 7. A Comparison of the thermal pressure calculated from Eq. (3) (dashed line) and from Eq. (4) (solid lines).

the last section IIIA and it has the value of $1.67 \times 10^{18}\mathrm{cm}^{-2}$. The calculated value of P_s/k as a function of the distance is shown in Fig. 7. Here, the thermal pressure of the cold phase is neglected and is not shown.

The study by Wolfire (1995) [1] provides the calculation of the thermal pressure of a hot corana in the halo region as a function of distance. The equation takes the form

$$\frac{P_s}{k} = 2250 T_6^{1/2} \big(1.0 + \frac{z^2}{19.6}\big)^{-1.35/T_6} \quad \mathrm{K.cm}^{-3}, \qquad (4)$$

where z is the distance of an object perpendicular to the galactic plane and $T_6 = n$ corresponds to the isothermal halo temperature of $n \times 10^6$ K. The thermal pressure at some values of T_6 are shown in Fig. 7. The crossing points between the dashed and the solid lines indicate the possible values of the distance of the HVC, since they represent the equilibrium of the cloud and the surrounding corona. It can be seen that within the distance of 1 Mpc, there are two location at which the HVC can exist depending on the temperature of the corona. If the temperature of the corona is 5×10^5 K ($T_6 = 0.5$), the HVC is located at about 20 kpc. Nevertheless, the HVC is likely to be found at 100 kpc for the corona temperature of 10^6 K ($T_6 = 1$).

IV. Conclusion

The spectrum of neutral hydrogen showed that the HVC125+41-207 is moving towards the galactic plane with the radial velocity of about 300 km/s. It was evidently presented that the HVC is composed of two phases that have a great distinct in temperature. In the end, the distance of the HVC was determined to be 20 kpc for the corona temperature of 5×10^5 K and 100 kpc for the temperature of 1×10^6 K.

References

[1] M. G. Wolfire *et al.* 1995, *The multi phase structure of the galactic halo : high-velocity clouds in a hot corona*, ApJ. 453 673W