Data analysis of the High-Velocity Cloud HVC 125+41-207

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***Abstract*—This data analysis studies the High-Velocity Cloud HVC 125+41-207. We analyze the data of 21 cm line and identify the HVC among the spectrum of a general area. By using different fitting techniques, the cloud was separated into two parts: a cold and a warm shell. We then estimated the distance to the cloud estimating its pressure through a pair of different techniques.**

I. Introduction.

High-Velocity clouds (HVCs) are neutral atomic hydrogen clouds with velocities more than 100 km/s and cannot be explained by the simple Galactic rotation. They are important for our Galaxy because they thought to be clouds of material falling into our Galaxy from the outside. There are multiple hypotheses for the origin of the HVC, but it is not fixed yet. The main reason is that the distance to the many HVCs are unknown. In this data analysis, we start from looking for the HVC from the data of the 21 cm line, then we try to find the characteristic structures of the HVC and to derive the distance to the HVC in the end.

II. General description and initial treatment

In this data analysis, we are given data of a spectral observation of the 21 cm line as FITS files. The data cube consist of 266 × 266 × 933 elements with values of the brightness temperature. Here the surface of 266×266 elements correspond to the location in the sky (latitude and longitude), while 933 elements in the other direction, namely "depth" of the hyper-spectral cube, correspond to the velocity measured through the Doppler effect in each pixel.

The brightness temperature itself does not carry a physical meaning. However, we can estimate the mean integrated column density from the brightness temperature with the Equation 1.

$$\frac{\langle N_{HI}\rangle}{\mathrm{cm}^{-2}} = 1.822 \times 10^{18} \int_{-\infty}^{\infty} \left(\frac{T_b(v)}{K}\right) \mathrm{d}\left(\frac{v}{\mathrm{km}\cdot\mathrm{s}^{-1}}\right), \quad (1)$$

where T_b is the mean brightness temperature, and $\mathrm{d}v$ is the spectral resolution.

As the first step, we calculated the total integrated column density for each space element and plotted the result in the Figure 1. Since we look at the 21 cm line from all over the Milky Way, we take into account that the emission generated all over the observed solid angle, making it difficult to discriminate between the Galaxy and other objects moving out/towards it. The plot shown was obtained using the data as it is.

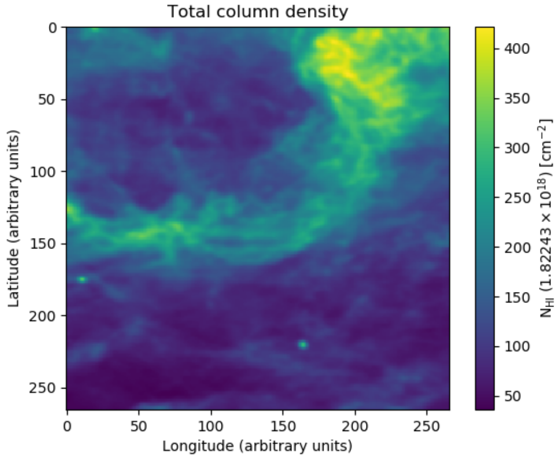

Fig. 1. Total integrated column density map, from -580 to 580 $\mathrm{km}\cdot\mathrm{s}^{-1}$

If we were to check the value of T_b along all of the pixels, we would always find a big peak centered at 0 km/s, and since we are measuring only the speed with which the objects move along our axis of sight, we can assume that it corresponds to everything moving along the Galactic disk, just like us. However, a second peak would appear at around -200 km/s, like shown in Figure 2.

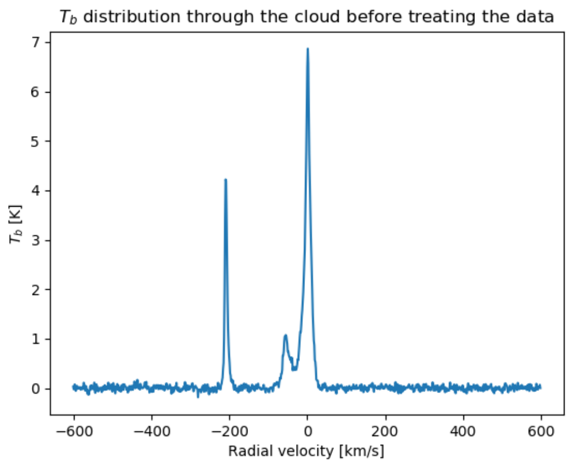

Fig. 2. Relation between the velocity and the brightness temperature

Considering this two peaks located only on specific parts of the spectrum, and a few other approximations due to the nature of the cloud, we can say that such object is moving ”independently” of the rotation of the Galaxy, and thus we assume that everything between a range, from -225 to -185 km/s, in this case, is enough to separate such anomalous object from the background, which will turn out to be our High Velocity Cloud (henceforward, HVC). By doing such and re-calculating the column density for each pixel, we obtain the mapping shown in Figure 3.

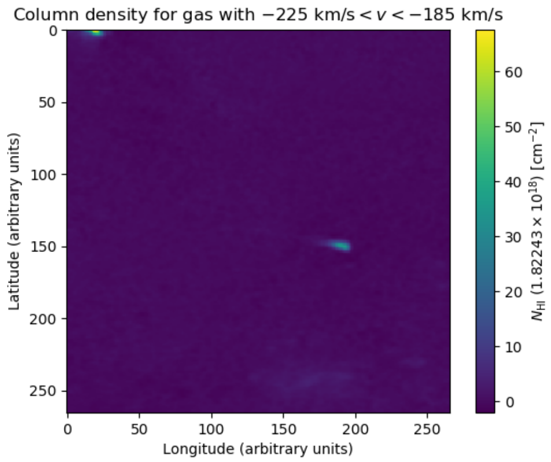

Fig. 3. Integrated column density map, from -225 to -185 $\mathrm{km \cdot s^{-1}}$

This allows us to not only work with such object alone, but to concentrate on the specific area of the measurements corresponding to it. Hence, we concentrated narrowing the analysis area to a small rectangle around the HVC, as shown in Figure 4.

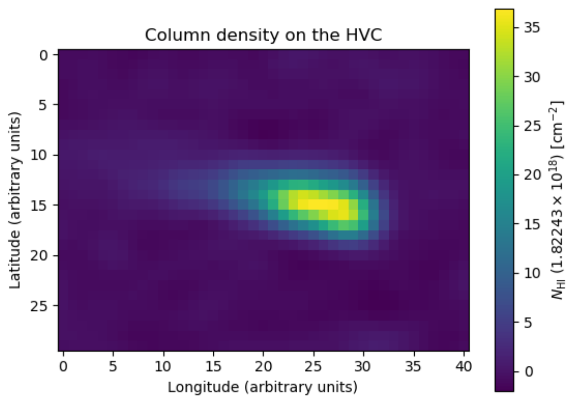

Fig. 4. Integrated column density map of HVC 125+41-20

As the object area has been narrowed, we would like to have as clean as possible set of data, i.e. to remove the background noise in it. We set this way a threshold on the column density i.e. we made a mask locating all the pixels with a value smaller than $10 \cdot dv \cdot \sigma_{rms} = 0.516$ with $\sigma_{rms} = 0.043$ K [1]. Assisted of this mask, we obtained a ”cleaner” map, as shown plotted in Figure 5. By this point, our data is good enough to be analyzed.

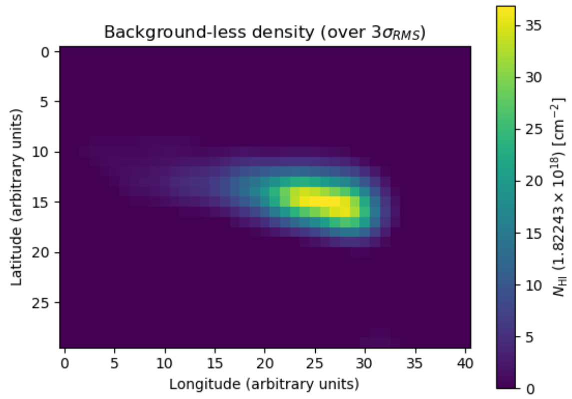

Fig. 5. Integrated column density map of HVC 125+41-20 without the noise

Since we do not know yet the exact size of the cloud, we studied first the values of T_b after taking the average at each speed (and considering the mask described in the previous paragraph). Plotting the average values gives a curve like the one shown in Figure 6, which despite looking like a Gaussian, shows an asymmetrical behaviour. This way, we fitted the curve using a double Gaussian over the averaged data. The results of the fitting are shown in the same plot. Several remarks can be made here. First of all, the presence of two Gaussian distributions hints about two different parts of the cloud living along each-other, and moving *towards us* with slightly different velocities. Considering that for higher temperatures we expect a wider distribution of the kinetic energy for the particles inside the cloud (and thus, a larger standard deviation), we can easily assume that the both functions correspond to different shells of the cloud, a hot and warm one, whose sigmas are respectively 7.110 and 2.495 km/s, the second getting closer to us faster than the first.

Now that we have a general description of the area for the spatially averaged spectrum, we are interested in finding those values for each of the pixels, as it would allow us to find the real extension of each shell, and moreover, to separate both of them. To do that, we started fitting from the very center of the cloud, using as initial parameters the ones found for the average (6). Then, we jumped to the immediate neighbour to the left of it, and fitted using as initial parameters the ones obtained for the previous pixel. We repeated the process until reaching the edge, and then came back to the centre, but one pixel higher, and fitted using the values of the fitting for the pixel right beneath it. This was followed by the same horizontal fitting described before, and then reset to fitting in the centre (one pixel higher than the last time) using again as initial values the ones obtained for the pixel right beneath it. This procedure (going to the left, and then up) was done until reaching the corner, and repeated 3 more times (left-down,

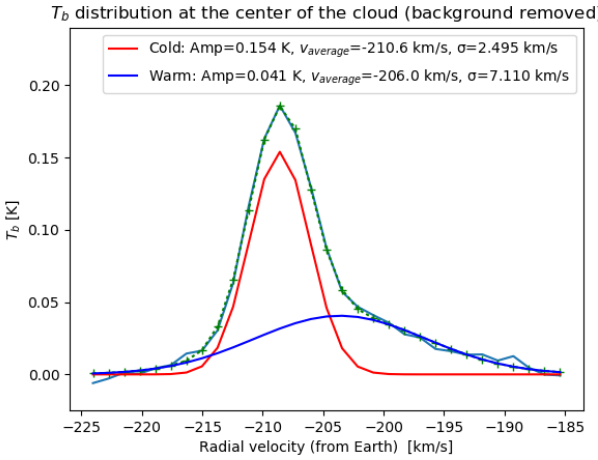

Fig. 6. Gaussian curves for the two different temperatures

right-up and right-down) to cover the whole image.

Once we obtained fitting values for each of the pixels, and remembering that the area under a Gaussian (from ∞ to $-\infty$) depends only on its standard deviation and amplitude, we can recreate the contributions to the column density of each cloud. This way, considering each Gaussian is pretty well centered on the range of velocities studied, we can neglect the contribution of the tails on infinity, so that it's integral (multiplied by a factor) will give information similar to 1. This way, we define a column density from the fitting given by

$$\frac{\langle N_{HI}\rangle}{\mathrm{cm}^{-2}} = 1.822 \times 10^{18} \cdot \sqrt{2\pi}\sigma A \cdot \mathrm{d}\left(\frac{v}{\mathrm{km}\cdot\mathrm{s}^{-1}}\right), \qquad (2)$$

where σ and A are, respectively, the standard deviation and the amplitude of each Gaussian.

Using the values obtained for the hot and warm cloud separately, we can simulate the column density of each shell. The result of such calculation is shown in Figure 7. Moreover, being interested in the amounts of hot and cold gas in the cloud, we show in Figure 8 the proportion of cold gas in terms of the total (calculated) densities i.e. cold/(cold+hot).

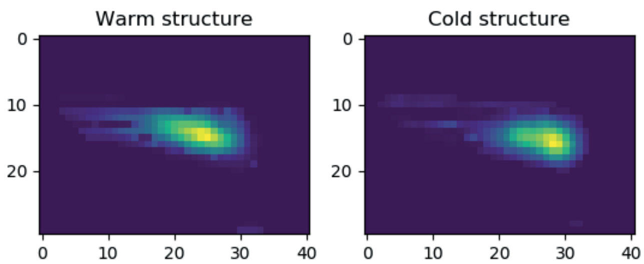

Fig. 7. Column density from the two different temperatures

From these plots, we can easily see that the cold structure is more dominant around the head region, whereas the warm structure is found to be prevailing near the tail region. Not only that, but a shell-like structure can be appreciated, having the cold and hot phases somehow separated.

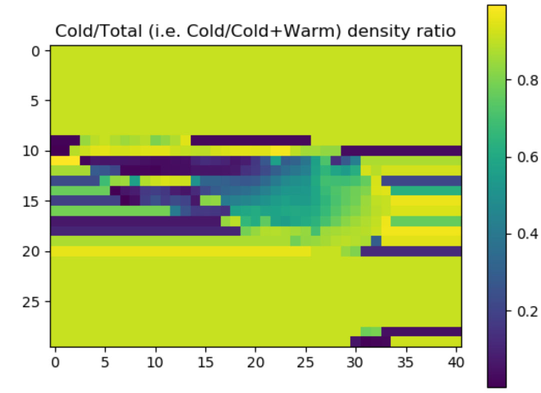

Fig. 8. Ratio of the cold gas to the total gas

Now that the HVC itself has been generally characterized, we would like to estimate the distance at which it is located from us. To evaluate the distance, and consequence of the Virial equilibrium between the shells of gas, the expression

$$\frac{P}{k} = \frac{\langle N_{HI}\rangle T_k}{d\theta} - \frac{\mu^2 G\pi\langle N_{HI}\rangle^2}{15k}, \qquad (3)$$

describes the thermal pressure at equilibrium relative to the Boltzmann constant k, for a gas kinetic temperature T_k of a cloud located at a distance d and with angular diameter θ, where G is the gravitational constant and μ is the mean mass particle within the sphere.

However, we can estimate the same pressure using the equation proposed by Wolfire [3] based on equilibrium of the outer shell and the interstellar medium,

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

where z is the vertical height over the galactic plane ($z = d\sin(\mathrm{L_{atitude}})$), and T_6 a parameter between 0.5 and 2.0.

Assuming that both expressions describe the pressure in the cloud well enough, we can determine the distance of the HVC by solving this two expressions, i.e. by solving Equation 3 = Equation 4 for the distance, for a particular T_6 value.

By plotting the both pressure functions, we obtained the behaviour shown in Figure 9. Thus, for different values of T_6, we expect to find different distances to the cloud. For instance, if we set $T_6 = 1$, we found a solution for both equations at a P_s/k value of about 9.5 $\mathrm{K}\cdot\mathrm{cm}^{-3}$, for a distance of 50 kpc.

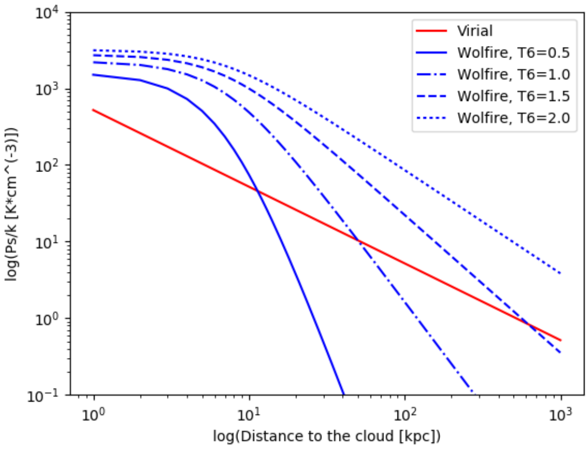

Fig. 9. Distance (cloud-observer) dependence of the external cloud pressure, as estimated from the Theorem of the Virial and from the function proposed by Wolfire [3] for different values of T_6.

III. Conclusions.

From the general hyper-spectrum of a section of the sky, we were able to find and analyze a High Velocity Cloud falling towards us. Additionally, we were able to separate the two different temperature structures inside the cloud, giving a first analysis of its composition and mechanics on it. We discovered that, on average, the colder cloud is moving at 206 km/s towards us, while the hotter one does the same at 210 km/s. Furthermore, it was possible to bind the distance at which the HVC is by comparing different descriptions of its pressure, concluding its located around 50 kpc away from us.

References

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