RevMexAA (Serie de Conferencias), **35**, 72–73 (2009)

SPATIAL DISTRIBUTION OF THE HIGH-VELOCITY CLOUDS

C. A. Olano[1]

RESUMEN

Se desarrolla un método para determinar las distancias teóricas a las Nubes de Alta Velocidad (NAV), basado en la idea de que las NAV se expulsaron de las Nubes de Magallanes en un período de tiempo relativamente corto como consecuencia del choque entre las Nubes Mayor y Menor de Magallanes. La posición espacial actual para cada NAV se obtuvo calculando su órbita con la condición inicial de que cada NAV se lanzó simultaneamente desde la Nube Mayor en el tiempo y posición de la colisión entre las Nubes de Magallanes.

ABSTRACT

I developed a method to determine theoretical distances to the High-Velocity Clouds (HVCs), based on the idea that the HVCs were ejected from the Magellanic Clouds in a relatively short period of time as a consequence of the collision between the Large (LMC) and Small Magellanic Clouds (SMC). The present spatial position of each HVCs was obtained by calculating its orbit with the initial condition that the each HVCs was simultaneously launched from the LMC at the time and position of the LMC-SMC encounter.

Key Words: Galaxies: interactions — Galaxies: Magellanic Clouds — Galaxy: halo — ISM: clouds

1. INTRODUCTION

The anomalous velocity clouds of neutral hydrogen known as the high-velocity clouds (HVCs) were discovered in 1963 and their nature and origin are not yet well understood. We will show that the observational and theoretical evidences support the picture of a circum-Galactic origin for the HVCs. The distances to the majority of these clouds remains unknown. Therefore, the main goal of this work is to determine theoretical distances to the HVCs from their observational data: sky positions (l, b) and radial velocities ρ.

We will develop a method to determine distances to the HVCs based on a model for the origin and evolution of the HVC system (Olano 2004). According to this model, the majority of the HVCs had a common origin at the time when the the Large (LMC) and Small Magellanic Cloud (SMC) collided. The LMC-SMC encounter triggered a period of star formation bursts in the Magellanic Clouds (MCs), and the subsequent winds and explosions of massive stars ejected clouds at high velocities. This HVC system has evolved dynamically in the Galactic halo as a circum-Galactic stream of HVCs whose more conspicuous feature is the so-called Magellanic Stream.

2. METHOD

In order to obtain the present spatial positions of the HVCs, hence their distances from the Sun, we calculate the HVC orbits from their initial time and position. The initial time of the HVCs is the time in which the HVCs were simultaneously launched from the MCs and coincides with the encounter time T_e between the LMC and SMC. The initial position of all HVCs is the position of the MCs at T_e. Therefore, to obtain the initial conditions of the HVCs, the orbits of the LMC and SMC are traced back in time.

To determine the distance to an HVC, we first need to solve the inverse problem, that is if an HVC lies to an assumed distance d from the Sun in the direction (l, b), which radial velocity should this HVC have? Fixed the present position and initial conditions of the HVC, the motion equations are numerically solved for the present and initial spatial velocity of the HVC. Repeating the procedure for a set of distances regularly spaced along the line of sight, we construct a theoretical radial velocity-distance relationship for the HVC, $\rho = f(d)$. The observed radial velocity of the HVC determines its distance from the Sun.

To specify the equations of motion, we consider that the HVCs and MCs move under the Galactic potential given by a massive spherical halo of dark matter, whose density profile is

$$\rho_h(r) = \frac{M_h}{2\pi^{\frac{3}{2}}} \frac{\alpha}{r_h} \frac{\exp(-r^2/r_h^2)}{r^2 + \gamma^2}, \qquad (1)$$

(Hernquist 1993) where M_h is the halo mass, r_h is a scale radius, γ is a core radius and α is a normalization constant. For simplicity, we adopt $\gamma = 0$, and

[1]Facultad de Ciencias Astronómicas y Geofísicas, UNLP, Paseo del Bosque, 1900 La Plata, Argentina (colano@lilen.fcaglp.unlp.edu.ar).

consequently $\alpha = 1$. We can express M_h as a function of r_h, equating the circular velocity of Galactic rotation at the Sun's position (220 km s^{-1}) with the corresponding expression derived from equation (1). Thus the adopted Galactic potential is characterized by an unique free parameter: r_h.

We fit r_h, and observational parameters of uncertain values (the SMC proper motions), through the requirement that the model should reproduce known facts and data of the MCs and HVCs as (1) the MCs have collided, and (2) a component of HVC Complex A lies at ≈ 10 kpc from the Sun. In other words, we use the HVCs and the MCs as tracers of the Galactic gravitational potential. The rest of the parameters needed to trace the orbits of the MCs and HVCs are equal to those adopted by Olano (2004). To solve the equation of motion for an HVC, we have into account that the HVC is subject to the gravitational field of the Galaxy and the LMC, and a drag force, experienced by the HVC when moving through the gaseous disk of the Galaxy.

3. RESULTS

By means of the above described method, we obtain that the mass M_h and halo radius r_h of the Milky Way are $4.24 \times 10^{11}\ M_\odot$ and 42 kpc, respectively. Besides, we find that the time of the HVC ejections is ≈ 840 Myr ago, assumed equal to the time of the LMC-SMC encounter T_e. This time is coincident within the errors with the occurrence epoch of a major starburst that probably gave origin to a stellar component of the LMC bar (Elson et al. 1997).

For the position (l, b) of each HVC component, we construct a theoretical $\rho - d$ relation, from which and with the observed ρ of the HVC component we derive its distance. The observational data were taken from the HVC catalogue of Wakker (2004). The $\rho - d$ relations of the first and second Galactic quadrants are two-valued functions, i.e. there are two possible solutions for the distance. Figure 1 shows the probable spatial distribution of the HVCs.

In the light of our dynamic model, the HVCs can be grouped into three populations, that we call MS, W and A-C. All HVCs of the first and second Galactic quadrant belong to Population A-C, except the southern HVCs belonging to the Magellanic stream (MS). Population A-C is the only one that presents distance ambiguities. Indeed, the distance of this population have two possible solutions: the near distance of around 6 kpc or the far distances ranging from 5 to 250 kpc. Evidences that the HVCs of this population are likely interacting with the outer Galactic disk favor its near-distance solutions. Furthermore, some HVCs of this population have upper distance limits ≤ 10 kpc. Population W is a group of positive-velocity HVCs located in the Galactic periphery of the third and fourth quadrants at a mean distance of about 15 kpc. The HVCs of population W have been strongly braked by the interaction with the gas layer of the outer Galactic disk.

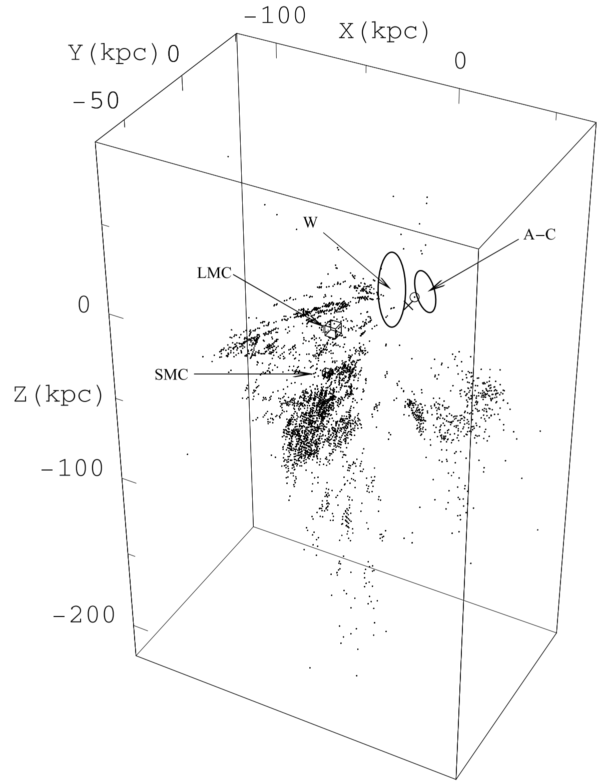

Fig. 1. Spatial distribution of the HVC populations. The dots represent the HVC-component positions of the main body of Population MS. The locations of Population W and Population A-C at its near distances are indicated schematically by ellipses. The positions of the LMC and SMC are represented. This Cartesian coordinate system (X,Y,Z) has the origin at the Galactic center, the X-axis pointing in the direction of the Sun's Galactic rotation, the Y-axis pointing in the direction from the Galactic center to the Sun, and the Z-axis pointing toward the Galactic north pole.

REFERENCES

Elson, R. A. W., Gilmore, G. F., & Santiago, B. X. 1997, MNRAS, 289, 157
Hernquist, L. 1993, ApJS, 86, 389
Olano, C. A. 2004, A&A, 423, 895
Wakker, B. P. 2004, in High Velocity Clouds, ed. H. van Woerden, B. P. Wakker, U. J. Schwarz, & K. S. de Boer (Dordrecht: Kluwer), 25