# ON THE DISTANCE OF THE MAGELLANIC STREAM

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Summary. If the HI clouds in the Magellanic Stream are in pressure equilibrium with the hot gaseous corona of our Galaxy, the distance of each cloud can be estimated from the observed properties of a cloud: position, angular dimensions, surface density of HI and the cloud temperature. Using a dynamical model with massive corona we have found distances of about 30 - 40 kpc for spherical condensations in the northern part of the Magellanic Stream.

## 1. INTRODUCTION

During the twenty-year history of the study of HI clouds, the determination of their distances has remained one of the central problems. The only physical method used has been the virial one. As we know (see e.g. Hulsbosch 1979), most clouds, except the smallest and coldest ones, have virial distances about a Megaparsec. Evidently some distance standard is needed to check these results.

The Magellanic Stream is the best cloud complex for the calibration of the distance estimates. It is evidently connected to the Magellanic Clouds, and its distance cannot differ much from the distance of the Clouds. The virial distances cannot be used for the Stream. Therefore, the Stream is not gravitationally bound and the observed concentrations of neutral hydrogen must be in pressure equilibrium with the hot gaseous component of the galactic corona. The short thermal expansion time ($3\times10^7$ y for a typical cloud) seems to exclude the possibility of non-equilibrium clouds. In case of pressure equilibrium we can find the distance of a nearly spherical cloud, using its parameters (coordinates, angular dimensions, surface density, and velocity dispersion in 21-cm line) and by making some assumptions on the gaseous corona of our Galaxy.

## 2. GASEOUS CORONA

Let us suppose that the coronal region of our Galaxy contains hot, fully-ionized, isothermal gas of primeval composition. All these assumptions are not unavoidable, and our method can also be applied to



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other models, as the adiabatic flow, the galactic fountain (Bregman 1980), etc. As an example the isothermal model serves well enough. We suppose that the coronal gas is in hydrostatic equilibrium:

$$\mathrm{grad}\ p = -\rho\ \mathrm{grad}\ \phi \tag{1}$$

(p is the pressure of the gas, its density and $\phi$ the full gravitational potential of our Galaxy that practically does not depend on the density of the coronal gas). The isothermal equation of state leads to a barometric law:

$$p = p_o \ \exp\left[-\mu m_H(\phi - \phi_o)/kT_c\right] \tag{2}$$

($\mu$ is the molecular weight and $T_c$ the temperature of the coronal gas). Any dynamical model of our Galaxy (e.g., Einasto et al 1976) can be used to calculate $\phi$ as a function of galactic coordinates and distance. To find the pressure we must know $\phi_o$, $p_o$ and $T_c$. If we choose $\phi_o$ to be the potential in the solar neighbourhood (given by the model), then $p_o$ is the pressure of the interstellar gas. It is a poorly determined parameter, the estimates ranging from $p/k = 2000\ K/cm^3$ (Field 1965) to 20000 (Shapiro and Field 1966). We choose the latter value and use $T_c = 10^6$ K. Now we have the coronal pressure as a function of the galactic coordinates and distance (with $R_{cl}$ the distance of the cloud):

$$p = p(l,b,R_{cl}) \tag{3}$$

## 3. METHOD

Consider now a spherical cloud of density

$$n_H = \sigma_H/D_{cl} = \sigma_H/\Theta R_{cl} \tag{4}$$

where $\sigma_H$ is the central surface density, $D_{cl}$ is the line-of-sight diameter of the cloud, and $\Theta$ its mean angular diameter. We suppose that the cloud is homogeneous; this is true if the temperature of the cloud is high enough compared to the virial temperature. The pressure in the cloud

$$p = n_H k T_{cl} \tag{5}$$

must be balanced by the external pressure of the coronal gas:

$$n_H k T_{cl} = p_o \cdot \ \exp\left[-\mu m_H(\phi - \phi_o)/kT_c\right], \quad \text{or} \tag{6}$$

using (4) $$\sigma_H T_{cl}/\Theta = R_{cl}\, p_o/k \ . \ \exp\left[-\mu m_H(\phi - \phi_o)/kT_c\right]. \tag{7}$$

Now we have a function of observed cloud parameters at the left-hand side ($T_{cl}$ can be found from the half-velocity width of the 21-cm line profile). The right-hand side is a function of the galactic coordinates and the distance; it varies slowly with l,b and for a single cloud it can be used as a function of distance only. Thus the cloud distance $R_{cl}$ can be found solving the last equation. To illustrate its properties we have drawn the rhs of eq. (7) as a function of $R_{cl}$ in Fig. 1. As every cloud defines a horizontal line in this figure, we see that the number of solutions of eq. (7) ranges from zero to three. In case of a multiple solution, additional information is needed to locate the cloud.

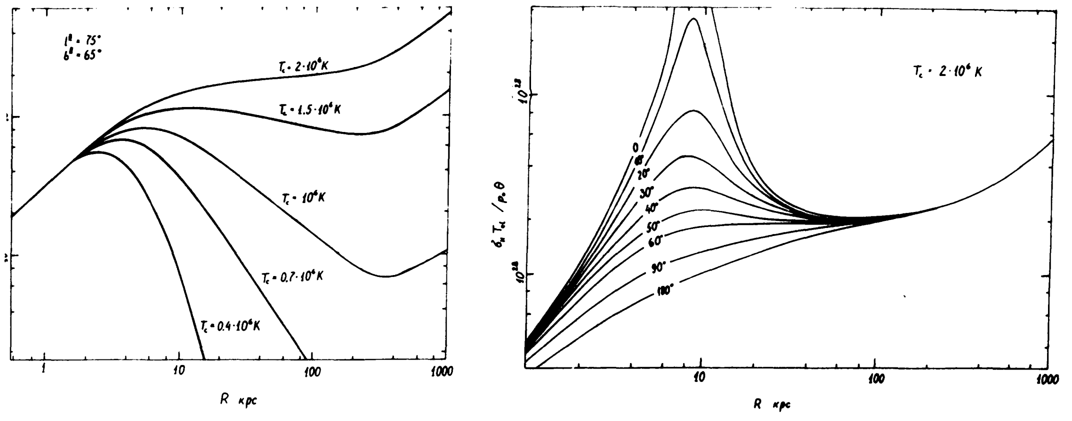


Figure 1. The observational combination $\sigma_H T_{cl} / \theta p_0$ versus cloud distance $R_{cl}$ for different temperatures of the coronal gas (left panel) and for different angular distances from the galactic center for l = 0, π (right panel).

## 4. APPLICATION TO THE MAGELLANIC STREAM

First we must choose suitable clouds in the Stream. The clouds must be spherical and as isolated as possible; the last condition is poorly satisfied in the Stream. The accuracy of our estimates depends strongly on that of the observational parameters, particularly of the half-width of the 21-cm line w (the lhs of (7) is a function of $w^2$ ). The best resolution, both angular and in velocity, have the observations of Mirabel (1981) with the Arecibo dish; unfortunately the cloud is not spherical enough. Some clouds in the Stream have been observed with the Mark IA telescope (Mirabel et al. 1979), but their angular resolution is not sufficient. Nevertheless, we chose a cloud from both observations as an example. Of course, there is no guarantee that they are not elongated or compressed along the line of sight; so the distances obtained correspond to the location where the clouds were most symmetrical.

**Table. Data and distances for two HI clouds.**

| No | R.A hms | δ d/m | σ* deg | $n_H$** $10^{19}$/cm² | $w_{1/2}$ Km/s | $T_3$ $10^3$K | $\sigma_H T_{cl}/\theta$ $10^{25}$K/cm² | $R_{cl}$ Kpc | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 23 05 30 | 12 48 | 0.09 | 1.2 | 19.2*** | 8.03 | 6.2 | 0.97 35 | M 1981 |
| 2 | 23 24 40 | -9 24 | 0.26 | 1.5 | 31 | 21.2 | 7.0 | 1.1 32 | M 1979 |

* Mean diameter of the last closed (compact) isophote.
** Central surface density, background subtracted.
*** Measured from Fig. 4 by Mirabel et al. 1981.

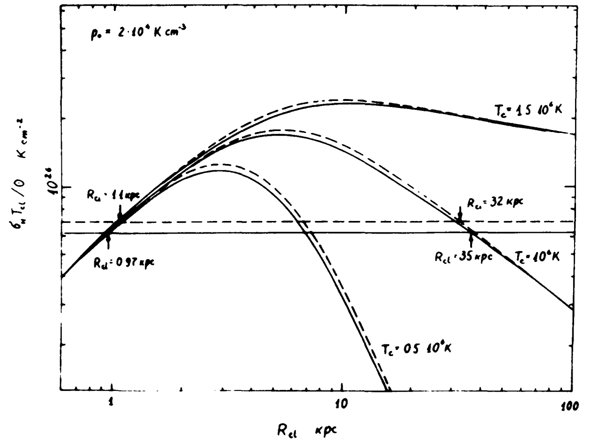


Figure 2. Determination of distances for the HI clouds in the northern part of the Magellanic Stream. Solid lines correspond to cloud 1 from the Table, dashed lines to cloud 2. Horizontal lines are determined by observations.

As you see, in both cases there are two solutions for each cloud, one about 1 kpc, the other 30 - 40 kpc from the Sun. So, our method does not completely solve the problem of the location of the clouds. Of course, for the Magellanic Stream the larger distances are more probable. And, as we have shown above (Fig. 1), the distances found depend strongly on the behaviour of the coronal pressure and especially on its temperature. This ties the problem of external HI clouds together with the problem of the gaseous corona - data on the corona can be used to derive the properties of the clouds and vice versa - cloud data can be used to restrict and verify coronal models.

In order to use this method high-resolution HI data, both in the coordinates and velocities, are badly needed. The two papers cited above show that such data could be obtained now, if the observers were interested in this task. With sufficient angular and velocity resolution it should be easy enough to choose spherical condensations with well-defined temperature as HI distance indicators.

The detailed description of the method will appear in a paper by Dr. E. Saar and me in the Publications of the Tartu Astrophysical Observatory (in Russian). An English version of the paper will be published as a preprint.

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