Astron. & Astrophys. 30, 365—368 (1974)

A High Velocity H I Cloud near the Galactic Center

M. J. M. Saraber and W. W. Shane

Leiden Observatory, Leiden, The Netherlands

Received August 8, 1974

Summary. Twenty-one centimeter line observations of a high velocity H I cloud near $l=+8°$, $b=-4°$ are discussed and interpreted. The cloud is approximately 3° in extent and has a mean line-of-sight velocity of $-212.8\ \mathrm{km\,s^{-1}}$; the velocity dispersion is $15\ \mathrm{km\,s^{-1}}$. Three possible interpretations are considered: that the object may be a nearby external galaxy, that it may be an infalling high velocity H I cloud, or that it may be a cloud which has been ejected from the galactic nucleus. Of these three, the last appears most plausible on account of the close agreement with predictions based upon previously proposed models of gas ejection from the galactic nucleus.

Key words: high velocity cloud — galactic H I — galactic nucleus

---

Observations and Reductions

In the course of a survey of high velocity H I in the neighbourhood of the galactic center (Oort, 1968), Shane noted a high velocity H I cloud at $l=+8°$, $b=-4°$ (Hulsbosch, 1968, Fig. 1). This paper presents and discusses observations of the region made by Shane and van der Kruit between June 1967 and November 1968.

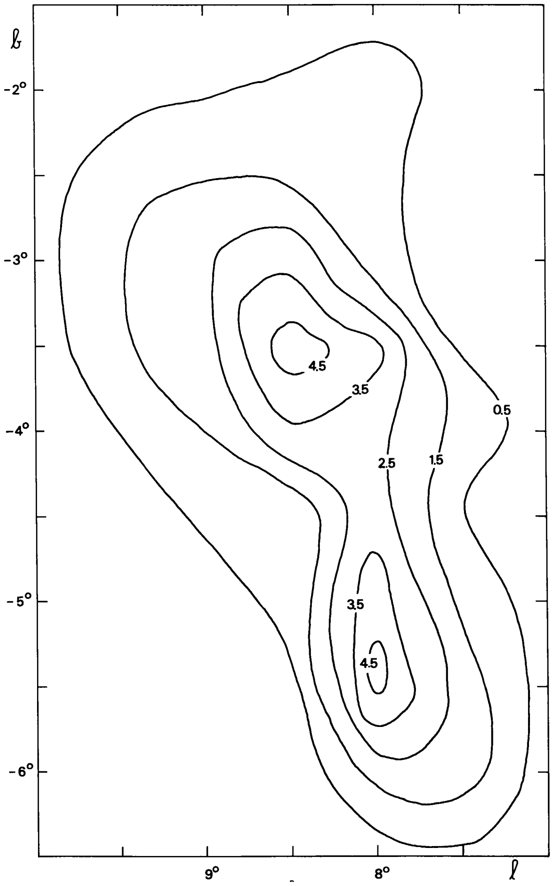

Fig. 1. The contour map of the integrated H I column density, neglecting self-absorption. Contour units are 10^{19} atoms $\mathrm{cm^{-2}}$

The observations were obtained with the 25 metre radiotelescope at Dwingeloo. The beamwidth at 21 cm was $0\overset{\circ}{.}61 \times 0\overset{\circ}{.}66$. For these observations the instrument was equipped with a 20 channel line receiver with a quasi-degenerate parametric amplifier, which has been described by Muller *et al.* (1966). The noise temperature of the system was 180 K.

For nearly every position Shane obtained four observations covering the velocity range of $-70\ \mathrm{km\,s^{-1}}$ to $-300\ \mathrm{km\,s^{-1}}$ with a bandwidth of 16 kHz. Observing each position only once, van der Kruit covered the velocity range $-30\ \mathrm{km\,s^{-1}}$ to $-250\ \mathrm{km\,s^{-1}}$ and used a bandwidth of 50 kHz. After averaging the observations for each of the 54 positions there remained 26 positions in which line radiation was detected. The resulting r.m.s. noise in brightness temperature is of the order of 0.2 K for both sets of observations.

For purposes of analyses, gaussian functions were fitted to the observed profiles using a least-squares method.

Figure 1 shows the contour map of the integrated brightness temperature in units of H I column density, assuming small optical depths; in Fig. 2 the contour map of the weighted mean radial velocities for the gas columns in the line of sight is shown. The observed and derived parameters of the feature are listed in Table 1.

Interpretation

In Fig. 3 the density of the object, which is here assumed roughly spherical, is plotted as a function of the assumed

1974A&A....36..365S

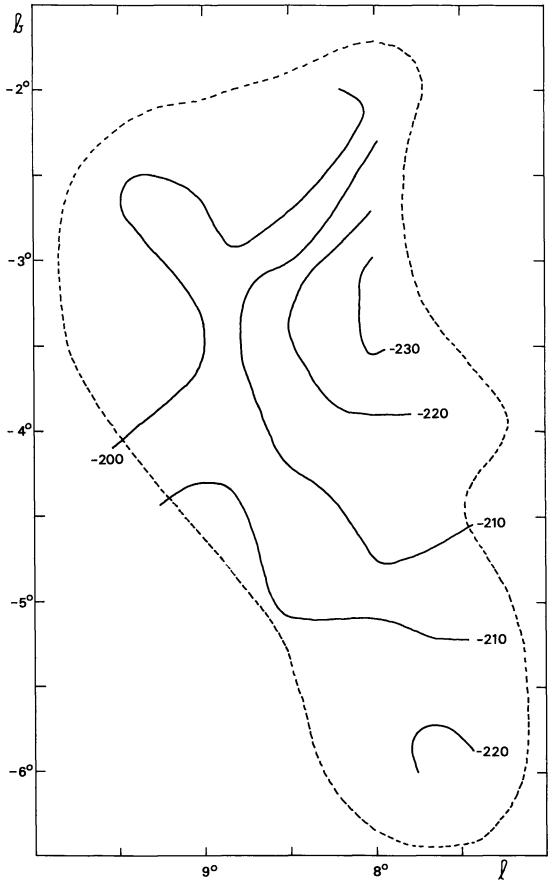

Fig. 2. Contour map of the weighted mean radial velocities for the gas columns in the line of sight. Contour values are in km s^{-1}. The lowest contour from Fig. 1 is shown as a broken line for reference

Table 1. The parameters of the feature. The distance D of the object from the Sun is expressed in kiloparsec

Position	$l = +8.^{\circ}3$ $b = -4.^{\circ}3$
Size[a]	Geometric mean angular radius = 1°
	Linear radius = $17D$ pc
Radial velocity	Center of mass = -212.8 km s^{-1}
	Dispersion = 15 km s^{-1}
H I mass	$M_H = 307 D^2$ solar masses
H I density[a]	$\varrho_H = 0.90 D^{-1}$ atoms cm^{-3}

[a] Assuming a roughly spherical form.

distance from the Sun, together with several models for the interstellar medium. It is evident that for any distance, except, possibly, around 2 kpc, the object will be more dense than its surroundings. The Palomar Sky Survey revealed large clouds of gas and dust in the direction of the object, so that identification of the cloud with an optical object, which might be helpful in the interpretation, is impossible.

It is unlikely that the object consists of two unrelated clouds since the clouds are close together on the sky and all measured parameters (velocity, column density, angular size and dispersion) are very similar. The following discussion is based on the assumption that the two parts are physically related. Possible interpretations of the cloud discussed in this paper are 1) an extragalactic object, 2) a high velocity cloud penetrating the galactic disk, and 3) a cloud expelled from the galactic nucleus. The possibility that we may be seeing a nearby feature accelerated by an explosion, as in the case of a supernova shell, is rejected on account of the low velocity dispersion and the small velocity difference between the two concentrations.

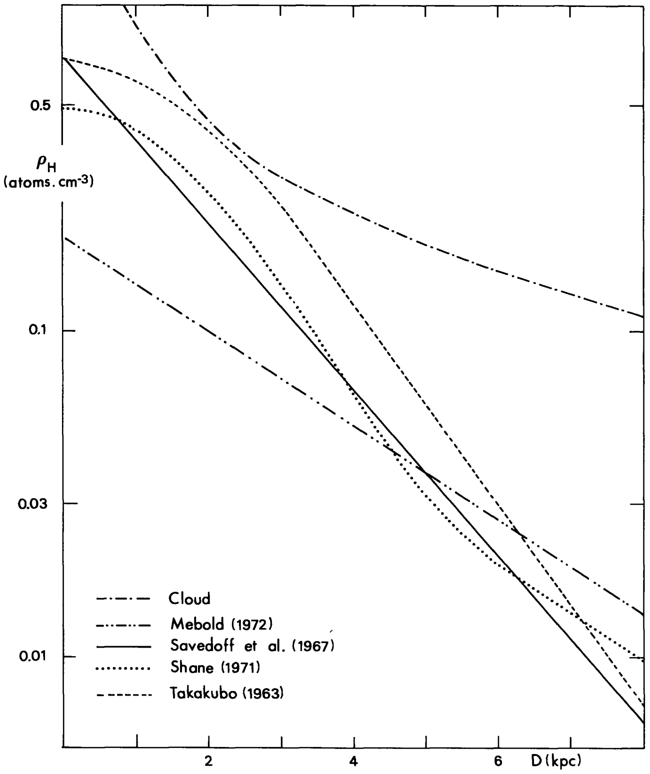

Fig. 3. The density of the object, which is assumed roughly spherical, plotted as a function of the assumed distance from the Sun. Several models for the local density of the interstellar medium are also plotted

Extragalactic Object

If the cloud is an extragalactic object it is reasonable to assume that it is isolated and in equilibrium so that the distance can be estimated from the virial theorem. Following the discussion of Prata (1964), a value of $2.7 \times 10^{48} D^2 q^{-1}$ erg is found for the contribution of the internal motion of gas in the observed elements to the kinetic term, where D is the distance of the cloud from the Sun in kiloparsec and q is the ratio of the neutral hydrogen mass to the total mass of the object. As it is clear from Fig. 2 that the run of velocity across the feature is not systematic enough to be explained by rotation or transverse motion of the cloud alone, it is assumed that the velocity gradient is caused mainly by

1974A&A....36..365S

Table 2. Comparison with known extragalactic objects. For q (the ratio of H I to total mass) a value of 0.1 is assumed

	LMC[a])	SMC[a])	Fornax[a])	Sculptor[a])	NGC-1058[b])	Observed feature[c])
D (kpc)	55	63	190	85	6300	1100
M_H/M_{sun}	5.4×10^8	4×10^8	—	—	2×10^9	3.7×10^8
M_t/M_{sun}	5×10^9	1.5×10^9	2×10^7	2×10^7	10^{11}	3.7×10^9
r_0 (kpc)	6	2.5	3.1	1.2	50	39
σ (km s^{-1})	11.5	—	—	—	15	15

a) S. van den Bergh, 1968, *J. Roy. Astron. Soc. Can.* **62**, No. 4, 145.

b) B. M. Lewis (private communication).

c) The derived parameters for the feature are based upon the equilibrium conditions discussed in the text. For comparison with NGC 1058 the additional rotation term in the virial theorem will require an equilibrium distance, several times larger.

large scale turbulent motions, resulting in a contribution of $1.7 \times 10^{48} D^2 q^{-1}$ erg to the kinetic term. The resulting value for the kinetic term in the virial theorem is $4.4 \times 10^{48} D^2 q^{-1}$ erg. For estimation of the gravitational term it is assumed that the hydrogen density ϱ_H is constant throughout the feature; this results in a value of $-3.9 \times 10^{44} D^3 q^{-2}$ erg for the self-gravitational contribution. For an angular diameter of 2° of the cloud and B expressed in microgauss, the net magnetic term becomes $8.6 \times 10^{46} D^3 \Delta \langle B^2 \rangle q$ erg, where Δ denotes the difference between the volume and surface averages. For a magnetic field decreasing from 1 μG at the center to 0 at the boundary and a value for $q \leqq 0.2$ the magnetic term may be neglected.

The above argument indicates an equilibrium distance of $11\,q$ Mpc. This distance in turn gives a total mass of $3.7 \times 10^{10} q$ solar masses and a distance between the two concentrations of $380 q$ kpc. The projected velocity with respect to the galactic center is about -230 km.s^{-1}, which is greater than the velocity of escape from the local group.

If the object is a face-on galaxy the kinetic term in the virial theorem has to be corrected to include the rotational energy, resulting in a larger equilibrium distance, which in turn gives a larger radius and mass.

In Table 2 a few representative quantities for the Magellanic Clouds, for two dwarf galaxies, for a nearly face-on galaxy and for the object are listed; for q a value of 0.1 was used, corresponding to the Magellanic Clouds. The object bears no particular resemblance to the objects listed in the table, except perhaps to the nearly face-on galaxy in the case the parameters are corrected for the rotation. Though the larger mass would be in agreement with the mass of the face-on galaxy, the large radius and the shape of the object, in particular its double appearance, argue against this interpretation.

High Velocity Cloud Penetrating the Galactic Disk

If the cloud comes from the galactic halo or intergalactic space and penetrates the galactic disk its motion is influenced by the interstellar medium, which puts a lower limit on the distance of the cloud from the Sun.

Orbit calculations have been made for a cloud penetrating the galactic disk taking into account attraction by the disk and braking by the interstellar medium, adopting the model of Savedoff *et al.* (1967). The present distance D of the cloud from the Sun and the angle α between the present velocity vector of the cloud and the z-axis are used as parameters in the calculations. In all calculations it has been assumed that the present velocity vector of the cloud lies in a plane through the Sun and perpendicular to the galactic plane; this configuration permits the lowest space velocity. It is assumed, following Savedoff *et al.* (1967), that the radius of the cloud remains constant. The calculations show that the mass fraction swept up during the motion decreases with increasing assumed distance of the cloud from the Sun; for a distance of about 3 kpc it is of the order of the original mass while it is only a small fraction thereof for distances of 6 kpc or more. The velocity required of the cloud at 2 kpc from the plane decreases from about 1000 km s^{-1} for $D = 3$ kpc to about 400 km s^{-1} for $D = 6$ kpc. In Table 3 the results of the calculations are presented for $D = 6$ kpc.

This model can account for the observed properties of the cloud, provided the present distance from the Sun is at least 5 kpc. However for such large distances the density of the cloud is very small and the radius very large compared to other known high velocity clouds.

Table 3. Orbit calculations for a cloud penetrating the galactic disk at a distance of 6 kpc from the Sun

α	M_0/M_{Sun}	ϱ_0 atoms cm^{-3}	V_{orbit} km s^{-1}	$V_{rad.}$ km s^{-1}	$t \times 10^6$ years
10°	9500	.13	850	-420	4
30°	9260	.12	405	-330	8
50°	8540	.11	370	-350	15
70°	5660	.08	550	-495	24

α is the angle between the present velocity vector and the z-axis, M_0 is the H I mass of the cloud when it was 2 kpc from the plane, ϱ_0 is the H I density of the cloud at the same point, V_{orbit} is the orbital velocity and $V_{rad.}$ the radial velocity at this point and t the elapsed time. Assuming a distance of 6 kpc the present radius of the cloud is 100 pc and the H I mass is 1.1×10^4 solar masses.

Cloud Expelled from the Galactic Nucleus

According to van der Kruit [1971, Eq. (20)] the orbital velocity of a non-selfgravitating cloud is governed by the equation:

$$\frac{d}{dt}\left(\frac{ds}{dt}\right) = -\frac{d\phi}{ds} - \frac{1}{m(s)} \cdot \left(\frac{dm(s)}{dt}\right) \cdot \left(\frac{ds}{dt}\right)$$

where s is the position of the cloud in its orbit, ϕ the gravitational potential of the Galaxy (for which van der Kruit's model is used) and $dm(s)/dt$ the mass-accretion rate, which in the case of a non-selfgravitating cloud is proportional to s^2.

Boundary conditions for the solution of the equation are the observed radial velocity, the galactic latitude and the present mass. Numeric solution of the above equation leads to the following model for the cloud. The cloud has an initial velocity of 675 km s^{-1} at a distance of 125 pc from the center, an initial mass of 2.2×10^4 solar masses, while the angle between the initial velocity and the galactic plane is 30°. At the present time, 5×10^6 years after expulsion, the distance of the cloud from the galactic plane is 650 pc and from the galactic center 1.9 kpc. The orbital velocity of the cloud is 280 km s^{-1} and the mass swept up during the motion is about 2.5×10^3 solar masses.

The calculated expulsion velocity and the angle between the initial velocity and the galactic plane agree very well with the values given by van der Kruit for gas expelled from the galactic nucleus. The age of the cloud also agrees well with the age calculated by van der Kruit for the features observed outside the plane.

Conclusions

Although none of the three interpretations discussed above can be excluded, the fact that the model in which the cloud is expelled from the galactic nucleus agrees very well with van der Kruit's model, argues in favour of this last interpretation. In order to interpret the observed feature in terms of the other models, we would have to postulate the existence of types of objects not hitherto observed.

Acknowledgement. The Radio Observatory at Dwingeloo is operated by the Netherlands Foundation for Radio Astronomy with the financial support of the Netherlands Organization for the Advancement of Pure Research (Z.W.O.).

References

Bergh, S. van den 1968, *J. Roy. Astron. Soc. Canada* **62**, No. 4, 145
Hulsbosch, A. N. M. 1968, *Bull. Astron. Inst. Neth.* **20**, 33
Kruit, P. C. van der 1970, *Astron. & Astrophys.* **4**, 462
Kruit, P. C. van der 1971, *Astron. & Astrophys.* **13**, 405
Mebold, U. 1972, *Astron. & Astrophys.* **19**, 13
Muller, C. A., Raimond, E., Schwarz, U. J., Tolbert, C. R. 1966, *Bull. Astron. Inst. Neth. Suppl.* **1**, 23
Oort, J. H. 1968, IAU *Symp.* **29**, 41
Prata, S. W. 1964, *Bull. Astron. Inst. Neth.* **17**, 511
Savedoff, M. P., Hovenier, J. W., Leer, B. van 1967, *Bull. Astron. Inst. Neth.* **19**, 107
Shane, W. W. 1971, *Astron. & Astrophys. Suppl.* **4**, 315
Takakubo, K. 1963, *Sci. Rep. Tôhoku Univ. Ser.* I, **47**, No. 2, 85

M. J. M. Saraber
W. W. Shane
Sterrewacht
Huygens Laboratorium
Wassenaarseweg 78
Leiden-2405, The Netherlands