HIGH VELOCITY CLOUDS : GALACTIC OR EXTRAGALACTIC ?

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While most of the sky has been surveyed in the 21 cm line at velocities within a few hundred km/s with respect to the LSR, the coverage is highly inhomogeneous in sensitivity, angular and spectral resolution and velocity extent. As interesting information has recently become available on the structure of the clouds, however, inferences on the dynamical and thermal state of the gas have become possible. Here, we shall concentrate on the direction in which this structural information influences the dichotomy stated in the title of this paper.

EXTRAGALACTIC MODELS

Verschuur(1969) first proposed that High velocity clouds (HVC's) may be primordial intergalactic clouds. Since then, two facts have contributed most to reactivate interest in extragalactic interpretations of the HVC phenomenon: (a) the discovery of the Magellanic Stream (MS)(Wannier and Wrixon 1972; Mathewson et al. 1974), and (b) the discovery of the clouds apparently associated with the Sculptor group of galaxies (Mathewson et al. 1975). A number of authors (Lynden-Bell 1976; Kunkel and Demers 1976; Mathewson 1976; de Vaucouleurs and Corwin 1975; Einasto et al. 1976) have claimed that HVC's, distant globular clusters and nearby dwarf galaxies describe some or another great circle. In some models, the implication of such an alignment is that the HVC's form tails of tidal debris in the orbits of nearby dwarf galaxies undergoing tight pericenter transits with the Galaxy; in others, the clouds are primordial inhabitants of intergalactic space. While the MS stretches close to a great circle, the other HVC's do not. Actually, the various great circles proposed by those authors are quite different. The statistical samples used in the above-mentioned studies were not complete: (a) no a priori reasons exist for excluding from the sample the so-called "intermediate" velocity clouds (IVC's) at high galactic latitude (particularly since the differentiation of the IVC's from the HVC's was not based on any physical grounds, and in fact, arose from their LSR rather than GSR velocities), while (b) a number of clouds with very high velocities have been recently found far from the proposed great circles (Shostak 1977; Greisen, private

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communication; Giovanelli, in preparation; Hulsbosch, communication by Prof. Oort).

The parameters of most HVC's when assumed to be at distances comparable with those of other galaxies in the Local Group, are similar to the ones of the Sculptor clouds (if those are indeed within the Sculptor group) : sizes of several tens of kpc, HI masses between 10^8 and 10^9 $M_{\odot}$, HI densities on the order of 5 10^{-4} cm^{-3}. However, as pointed out by Giovanelli (1977), there is substantial evidence indicating that the northern galactic hemisphere HVC's are rather different objects than either the Sculptor clouds or the clouds in the MS. Fine spectral and morphological structure as well as very strong velocity and brightness gradients characterize the northern HVC complexes. The large and disordered velocity gradients coupled with the angular extent of the features infer that the HVC's are transient. The narrow components in the line profiles indicate that a large fraction of the gas is at low kinetic temperature and cannot be supported in steady-state conditions in intergalactic space. The severe brightness gradients along cloud peripheries suggest that effective compression mechanisms are at work. Moreover, very low brightness emission has been detected in some fields between complexes, implying that the gas distribution may be far from patchy. A distribution of primordial intergalactic clouds, as proposed by Mathewson (1976), de Vaucouleurs and Corwin (1975) and Eichler (1976), cannot explain the dynamical unrest of the clouds, their low brightness connections, or the low temperature inferred from their line profiles. The idea that HVC's form tidal streams in the wakes of nearby dwarf galactic systems, as proposed by Lynden-Bell (1976), leaves, on the other hand, the majority of the HV material unexplained, since no obvious association with globular clusters or dwarf galaxies exists for most complexes.

GALACTIC MODELS

Two scenarios that put the HVC's within the Galaxy have dominated: Oort's infall model and the Verschuur-Davies distant spiral arm model. The merits and pitfalls of both have been illustrated in review papers (Hulsbosch 1975; Verschuur 1975); both meet with considerable difficulties in trying to incorporate parts of the observational data. Clouds at high galactic latitude, near l = 180°, cannot be interpreted as parts of distant spiral arms; the general velocity field of the HVC's shows a large anisotropy, if they are to be interpreted as an infall phenomenon; while the very high velocity clouds recently discovered present additional problems. And the MS cannot of course be accounted for as either infalling or spiral arm material. On the other hand, galactic interpretations can more flexibly adapt themselves to the transient character and the occurrence of condensations of cold material in the northern HVC's.

SO, WHAT THEN ?

The panoramic view of models is then not particularly satisfying.

A combination of several of them could possibly leave no major piece of information unexplained, at the price, however, of a very poor balance in the economy of the hypotheses. For example, the gas at not too high galactic latitude with intermediate or moderately high velocities may be distant spiral arms; the high northern latitude gas, the shell of an old nearby supernova remnant; the MS, the tidal debris of the Magellanic Clouds (MC); and the very high velocity clouds, primordial intergalactic objects. The number of degrees of freedom of such a "model" is large enough that it can probably accomodate all of the known phenomenology and, presumably, observational data acquired for some time ahead. However, to understate the problem, this approach utterly lacks simplicity. Hopefully, it should be possible to do better than explaining the whole picture by means of proposing one model per phenomenological item.

Possibly, all the observations can be incorporated in a unified picture. Tidal interaction between neighboring galaxies is known to severely distort the gas within the system, as in the cases of the Leo triplet and NGC 4631/56. The Galaxy/MC system may suffer analogous distortion, yielding the MS as the most prominent evidence. Earlier numerical models of the tidal interaction between the Galaxy and the MC met difficulties in describing the large negative velocities at the northernmost tip of the MS. They may be overcome if orbits with relatively small pericenter distances are assumed, which allow for capture of Magellanic material by the Galaxy. Angular momentum conservation will then yield high orbital velocities. Davies and Wright (1977) obtain a numerical solution of that type, which reproduces the velocity field along the MS by locating its tip at less than 10 kpc from the galactic center. It is clear that orbiting material with a galactocentric distance smaller than the radius of the galactic disk will eventually collide with galactic gas in a time smaller than its orbital period. Such collision processes may indeed have already started; we propose that the northern HVC's may be their conspicuous result. As the infalling Magellanic material approaches the galactic disk, its evolution will be similar to the one predicted within the framework of Oort's model, with the notable advantage that here a large "fly-by" component of motion and the high velocities beyond the tip of the MS come naturally, in addition to the infall. Savedoff et al. (1967) and Chow and Savedoff (1972) elaborated the hydrodynamical and thermal evolution details of the infall model. Their guidelines are still applicable: northern HVC's would then be high z galactic material, accelerated by the infalling flux, as seen after undergoing shock compression and subsequent cooling. The fine structure and the disordered velocity field present in this material may be easily accounted to density or phase inhomogeneities of the high z galactic gas. The large, quasi-continuous distribution of HV material in the northern hemisphere reflects the nearness of this material, probably located in the high z extension of our spiral arm. Supersonic impact between infalling and galactic gas will produce temperatures in excess of 10^6 K. For temperatures of that order, thermal emission peaks in the 0.25 keV (44-70 Å) X-ray domain. An external test of the scheme being proposed is possible, by comparing the expected soft X-ray flux that would be produced by the infall, with the observed high latitude background. This test applies equally well to Oort's model. The emission measure EM (cm^{-6} pc), the emissivity J (erg cm^3 s^{-1}) and the photon flux F (cm^2 s sterad keV)$^{-1}$ in the 44 to 70 Å energy range, are related according to $F = 2\ 10^{27}$ J EM (Silk 1973). Using Chow and Savedoff's (1972) density and temperature profiles of the post-shock gas, the EM of the infalling gas in the specified energy range is on the order of 0.013. By assuming an emissivity of 10^{-23} (Tucker and Koren 1971), one gets F = 260, which compares well with the value of 300 observed at high galactic latitudes. This hypothesis also accomodates well the observed enhancement in flux and the softening of the spectrum observed toward high northern galactic latitudes (Levine et al. 1976). Although this hypothesis seems capable of encompassing all the known observational information, further numerical tests of Magellanic passages and revision of the calculations of Chow and Savedoff are needed.

In conclusion, observational evidence indicates structural differences between the MS and the rest of the HVC gas. Existing extragalactic or galactic models cannot interpret consistently all of the data. It is proposed that the northern hemisphere HVC's are the result of Magellanic material infalling on the galactic disk after a close pericenter passage of the MC. The high latitude enhancement of the soft X-ray flux and the softening of its spectrum may be partly produced as a consequence of this infall.

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DISCUSSION FOLLOWING PAPER V.6 GIVEN BY R. GIOVANELLI

WRIGHT: Isn't the infall theory for HVCs in serious trouble for velocities as high as -400 to -500 km/s?

GIOVANELLI: According to the infall theory of Professor Oort such clouds would still be Galactic clouds. If they were material broken off the Magellanic Stream then it has not collided with Galactic material.

WRIGHT: But you would then expect the velocity profiles to look similar in the Magellanic Stream and in the HVCs — which they don't!

OORT: It is somewhat surprising that one does find such a preponderance of negative velocities in these high velocity objects. In part, of course, these can be explained by the fact that velocities are relative to the Local Standard of Rest, and part of them can be ascribed to rotation of the Galaxy. But even if you subtract that you are left with a great majority of negative velocities, also in the other regions near the anticenter where rotation of the Galaxy does not play any role. It is probably too early to speculate about this until we get data on the whole sky with the same completeness.

EINASTO: HIGH VELOCITY CLOUDS AND WARPING OF THE GALACTIC PLANE

We have collected available data on the kinematics and distribution of high velocity clouds. The data show that HVCs can be divided into two populations. One population is concentrated towards the Galactic plane and takes part in Galactic rotation. The other population is concentrated towards a plane perpendicular to the Galactic plane. Southern HVCs of this population form the Magellanic Stream, northern HVCs form three shorter streams. The kinematics of both stream systems is similar: near $\ell = 90^o$ the southern stream is approaching the Galaxy and the northern stream is receding it, while near $\ell = 270^o$ the situation is vice versa.

Numerical calculations carried out by Mr. Haud (Astr. Circ. USSR No. 958, 1977) indicate that the infall of HVCs to the Galactic gas from opposite directions to opposite Galactic sides can give rise to the warping of gas in the outskirts of the Galaxy.

A similar mechanism may act also in companions of massive galaxies. Suppose that a small galaxy like M33 is circulating around a massive one (M31) and that there is some extragalactic gas in the system. The circulation of the small galaxy in the extragalactic medium is equivalent to the rotation of this medium around the galaxy and the warping of the gas disk of the galaxy is a natural consequence.

DAVIES: What intergalactic density do you require for the intergalactic wind?

EINASTO: A density of about 0.001 cm^{-3}.

OORT: Your plot showing the far "streams" of HVCs seems to me oversimplified. There are important groups of clouds lying outside these streams. I find it difficult to imagine a rotation between the two streams. The one lies outside the Galaxy and has clearly been tidally drawn out from the Magellanic Clouds. The other lies in a rather different part of space and seems actually to be falling into the halo of the Galaxy.

MIRABEL: FINE STRUCTURE IN THE MAGELLANIC STREAM

In order to study the small-scale structure of the Magellanic Stream, high resolution and high sensitivity neutral hydrogen observations have been carried out on selected areas of the sky (in cooperation with R.J. Cohen and R.D. Davies). The 250 foot Mk IA radio telescope (beamwidth 12' x 12' at 21 cm) has been used with receiver channel spacings of 2.06 and 1.03 km/s.

The gas has a hierarchical structure in which small bright clouds are distributed along narrow filaments embedded in larger areas of low emissivity. These bright clouds have elongated shapes with major axes generally aligned parallel to the great circle described by the large scale distribution of the Magellanic Stream. Their typical minor axis diameters are $0\overset{\circ}{.}4$ to $0\overset{\circ}{.}6$, with masses in the range $10-20\ D^2$ (kpc^2) solar masses. Although there are velocity differences up to 30 km/s between adjacent clouds, there are no velocity gradients within the clouds themselves. The spectra show no evidence for two phases in the gas. Typical half-power widths are in the range 25-30 km/s; any component narrower than 16 km/s is less than 5 per cent of the HI column density observed.

The differences in spectral properties between bright clouds in the Magellanic Stream and high velocity clouds in the northern galactic hemisphere (where two phases were found by Cram and Giovanelli (1976, A.A. 48, 39)) provide a clue for the understanding of their different origin and nature.

The lifetime of the large-scale features in the Stream is consistent with tidal models. However, the present observations show that small-scale features have much shorter lifetimes and require a containment mechanism to explain their continued existence.