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INTERACTION BETWEEN HIGH-VELOCITY CLOUDS AND THE GALAXY: THE CASE OF THE ORION MOLECULAR CLOUD COMPLEX

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RESUMEN: Discutimos la posición del Complejo Molecular de Orión, a unos 150 pc del plano galáctico y de varias de las peculiaridades de la región. Analizamos dos posibles mecanismos de formación: i) "Cáscaras" en expansión generadas por asociaciones OB, y ii) la interacción entre nubes de alta velocidad y el disco. Favorecemos la segunda alternativa como la explicación más "natural".

ABSTRACT: The location of the Orion Molecular Complex, about 150 pc away from the galactic plane,and some of the features of the region are discussed. Two possible origins are analyzed: i) expanding shells from OB associations, and ii) a collision between the disk and a high-velocity cloud. We favour the latter as the most natural explanation.

Key words:

I. INTRODUCTION

The Orion molecular cloud complex is one of the most active star formation regions in our Galaxy. It is located some 500 pc away from the sun and it has a large extension with a complex filamentary structure (see Figure 1). The total gaseous mass in the region is about 1-5× 10^5 $M_\odot$, but most of this mass is concentrated in clouds situated some 150 pc out of the plane (see Kutner *et al.* 1977; Thaddeus 1982).

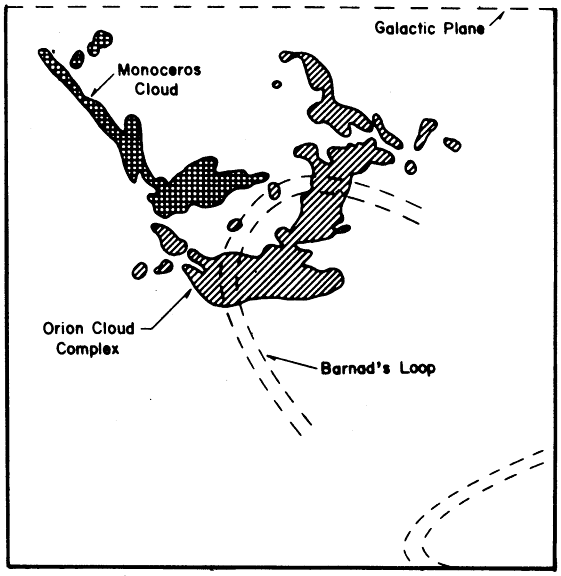

Fig. 1. Orion's main gaseous features. Broken lines indicate the Hα emission.

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The cloud complex has several OB subgroups associated with it (see Blaaw 1964) and large scale gaseous features that have been ascribed to supernova explosions (Sivan 1974; Cowie, Songaila and York 1979; Reynolds and Ogden 1979; Cowie 1982). The region has many interesting peculiarities and it has been the target of several studies related to the properties of recently formed objects (e.g., Cohen and Kuhi 1979; Herbig 1982; Werner 1982; Moran *et al.* 1982), the possible modes of star formation (Elmegreen and Lada 1977; Larson 1982; Zinnecker 1982; Franco 1984), and the properties of young H II regions (Peimbert 1982; Franco and Savage 1982). Unfortunately, little attention has been paid to the location of the molecular clouds and their associated atomic gas features that extend even further away from the plane (see Reynolds and Ogden 1979).

The one-dimensional velocity dispersion among molecular clouds with masses $10^3 \leq M_C/M_\odot \leq 3\times10^5$ in the solar neighborhood is roughly constant at about 7 km s^{-1}, and for giant cloud complexes the dispersion decreases as $M_C^{-1/2}$ (see Stark 1984). This translates into a scale height smaller than 70 pc and it is consistent with the position of most known complexes (see Stark and Blitz 1978). Orion's location is certainly peculiar and requires a minimum velocity of 15 km s^{-1} perpendicular to the plane. The corresponding cloud kinetic energy is equivalent to at least one supernova explosion while the linear momentum is equivalent to ten supernova events. These energy and momentum requirements can easily be obtained from OB associations, and from the interaction between high velocity clouds (HVCs) and the galactic disk. In this communication we explore the main aspects of these two possible origins and favour the collision of a HVC as the most natural generator.

II. SHELLS FROM OB ASSOCIATIONS

The combined action of stellar *UV* radiation, winds, and supernova explosions from OB associations can destroy their parental clouds in relatively short timescales and generate large expanding shells (e.g., Bruhweiler *et al.* 1980). The material pilled-up in the shells can eventually form new molecular clouds which in turn will give birth to new generations of stars (i.e., Elmegreen 1984; Franco and Shore 1984). Thus, one can envisage the production of successive generations of clouds and stars as a result of long range self-propagated and self-regulated star formation.

The late-time evolution of the shell radius can be approximated by (Franco and Shore 1984)

$$R_s(t) \cong 129 \langle n\rangle^{-1/5} N_{OB}^{1/5} L_{36}^{1/5} \tau_7^{7/20} \beta^{1/4} t_7^{1/4} \text{ pc}, \qquad (1)$$

where $\langle n\rangle$ is the average gas number density in cm^{-3}, N_{OB} is the number of OB stars in the association, L_{36} is the average wind luminosity per massive star in units of 10^{36} erg s^{-1}, τ_7 is the main-sequence lifetime of an "average" OB star in units of 10^7 yr, t_7 is the age of the shell in units of 10^7 yr, and β is the shell momentum normalized at $t = \tau$. The appropriate parameters for an "average" galactic OB association, weighted over the initial mass function, are: $N_{OB} \geq 20$, $L_{36} = \tau_7 = 0.6$, and $\beta = 1.2$ (Franco and Shore 1984). This specific choice is not crucial due to the weak parameter dependence, and actually, any other "reasonable" set of values will yield similar results. Also, notice that the evolution of the radius does not include the initial thermal expansion of the H II region (see Tenorio-Tagle 1984), nor the effects of the disk density gradient and the gravitational deceleration of the shell. These effects do not produce dramatic changes in the situation considered here but equation (1) should be considered just as a rough approximation.

With these restrictions in mind, Orion's origin can be explored by assuming that the cloud complex is part of a large shell that was generated near the plane by an "average" OB association. For an average ambient density $n = 1$ cm^{-3}, a radius $R_S \sim 150$-200 pc is reached in a timescale of $t_7 \sim 1$-2. The corresponding expansion velocity is $v_S \sim 3$-5 km s^{-1} and the collected mass amounts to $M_S \sim 5$-$15\times10^5 M_\odot$. All these values, eventhough they are rough estimates, are certainly consistent with the features observed in the region; the older OB subgroup, I Oria, has an estimated age of 1.2×10^7 yr (i.e., Blaaw 1964), the total gaseous mass is 1-5×10^5 $M_\odot$ (i.e., Thaddeus 1982), and the nearby stellar groups seem to be moving away from the plane at speeds of 5-10 km s^{-1} (i.e., Lesh 1968).

At first sight the model is very attractive and may deserve a more careful analysis. Unfortunately, the main problem with this idea is the absence of the rest of the shell. Actually, not only the expected counterpart of the shell is lacking but also no gas features or stellar groups are present at the other side of the plane (see Figure 2). One could explore different configurations, but the main problem seems to remain; the pressure inside the cavity is inefficient in accelerating highly asymmetric and massive shells. The real question, then, is how the energy and momentum can be funneled to accelerate the cloud complex in a single direction.

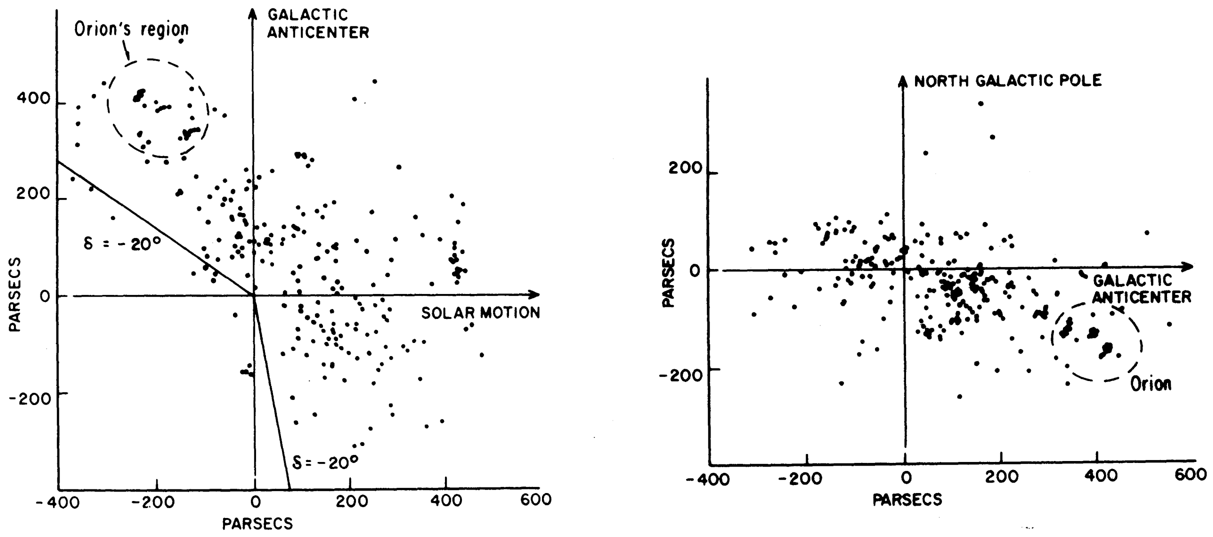

Fig. 2. The location of stars with known distances less than 600 pc (adapted from Lesh 1968).

III. HIGH VELOCITY CLOUDS

HVCs are neutral hydrogen clouds probably located outside the galactic disk and moving with radial velocities $|V_{LSR}| \geq 100$ km s^{-1}. They are usually found in groups of several clouds. Most of these groups display negative velocities and seem to be directed towards the disk (see Giovanelli 1980). Relative to the galactic standard of rest, some of them reach an approach velocity in excess of 200 km s^{-1} (see Mirabel 1981*a*, 1982). Their masses are not known but rough estimates indicate that these groups can have masses in the range of 10^4 to 10^5 $M_\odot$.

Their origin is also uncertain but the best known group of HVCs, the Magellanic Stream, seems to be falling from the Magellanic Clouds into the Milky Way (i.e., Mirabel 1981*b*, and references therein). Thus, one is led to infer that at least some of the observed HVCs can be of extragalactic origin. In any case, whatever their fountainhead might be, the collisions between HVCs and the disk are a rich potential source of energy and momentum.

Infalling clouds inject energy at a rate

$$\dot{E} = \tfrac{1}{2}\,\dot{M}\,v^2 = 10^{47}\,\dot{M}_1 v_7^2 \text{ erg yr}^{-1} , \qquad (2)$$

where $\dot{M}_1$ is the mass rate falling into the disk in solar masses per year, and v_7 is the shock velocity in units of 100 km s^{-1}. This energy injection rate is similar to the ones ascribed to supernova activity and stellar winds from massive stars, and HVCs may be responsible for some of the observed large scale HI structures (see Heiles 1984). Unlike stellar winds and supernovae, however, the momentum injected by HVCs is directed in a single direction and the corresponding cavities are asymmetrical (see Tenorio-Tagle 1980, 1981). An example of a numerical simulation for a cavity evolution in a constant density disk is shown in Figure 3.

If Orion was generated by a collision that took place at the other side of the plane, a cylindrical cavity with a radius of about 100 pc is required in order to collect the observed gaseous mass in the cloud complex. The mass of the infalling cloud, on the other hand, is de-

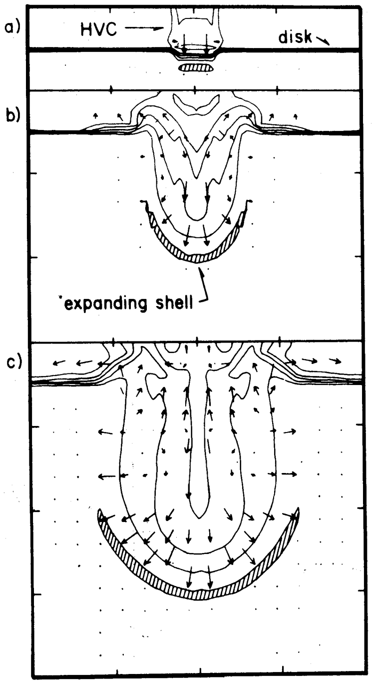

Fig. 3. Numerical simulation for the collision of a HVC and the plane. Arrows indicate the velocity field (units are arbitrary; adapted from Tenorio-Tagle *et al.* 1985)

termined by momentum conservation

$$M_{HVC} \sim 2\text{-}8\times10^{4}\ v_7^{-1}\ M_\odot \ , \qquad (3)$$

and the resulting column density for the center of a spherical cloud is

$$N_{HVC} \sim 1\text{-}5\times10^{20}\ v_7^{-1}\ \mathrm{cm}^{-2} \ . \qquad (4)$$

All these values are within the estimated range of parameters of known HVCs (Giovanelli 1980; Mirabel 1982).

The age of the cavity should be several times 10^7 yr, which is sufficient for the shell to cool down and to develop gravitational instabilities. The cloud complex was formed when the shell column density reached a value $N_S \sim 10^{21}$ cm^{-2}, and this corresponds to the momentum when the shell has decelerated to, roughly, one tenth of its initial velocity. Star formation probably began a few free-fall times later. The first generations of stars maintained their original motion whereas the shell keeps decelerating, and these stars have already moved out of their parental cloud. Hence, the formation of the Orion cloud complex and the kinematics of the stellar groups in the region could be contemplated as a natural by-product of the interaction between a "normal" HVC and the galactic disk.

The ideas sketched in this section suggest a plausible mechanism to explain the features observed in Orion. A detailed modeling of the collision, shell evolution and cloud formation is in progress in collaboration with G. Tenorio-Tagle and F.I. Mirabel, and the final results will be presented elsewhere.

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