THE ORIGIN AND STRUCTURE OF MOLECULAR CLOUDS

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Although we have known about giant molecular clouds (GMCs) for nearly 25 years, their origin, evolution, and destruction is still poorly understood. Formation mechanisms can be grouped into two general categories; *galactic scale processes* including global gravitational instabilities of the galactic disk, Jeans-Parker type magnetically regulated instabilities, and spiral density waves, and *local processes* based on self-propagating star formation or supershell fragmentation (cf. Elmegreen 1994).

The Solar vicinity lying within about 0.5 to 1 kpc is the only place where we have reasonably complete knowledge of the location and motion of stars and associated gas. The radial velocities and proper motions of stars, their locations in 3 dimensions, and association with gas, make it possible to reconstruct the history of recent (< 60 Myr) star formation. HII regions and low mass T-Tauri stars trace the youngest (< 3 Myr old) massive stars and sites of on-going star formation. Nearby OB associations (Orion OB1, Per OB2, Sco-Cen, and Lac OB1) trace sites of star formation active within the last 15 Myr. GMCs and giant shells of expanding HI are associated with these OB associations. Late B and A stars and proper motion groups, such as the Cas-Tau "fossil" OB association, trace star formation over the last 60 Myr (Blaauw 1991).

After correction for the effect of Galactic differential rotation, most of the ISM in the Solar vicinity (GMCs and HI) is found to be expanding with a mean velocity of about 5 km s^{-1} from a point located near $l = 150$, $d = 200$ pc, the approximate centroid of the Cas-Tau group. This is the 'Lindblad ring' recognized in early 21 cm maps and is traced by local molecular gas (see Dame et al. 1987; Poppel et al. 1994). Associated B and A stars trace Gould's Belt of nearby intermediate age and young stars.

The Lindblad ring appears to be a 30 to 60 Myr old fossil supershell driven into the local ISM by a massive OB association whose remnants

are recognized as the Cas-Tau group. Support for this view comes from the agreement between the observed radial velocity of HI and nearby CO clouds with models of an expanding and tidally shearing 30 to 60 Myr old superbubble (see Poppel et al. 1994). The location of holes in the distribution of high galactic latitude HI (the Lockman Hole) and dust (Baade's Hole) above and below the Cas-Tau group centroid indicates that the ancient bubble burst out of the Galactic plane. Excess low negative velocity HI at high latitudes indicates that dense clumps accelerated out of the plane 25 to 50 million years ago are now falling back due to the gravity of the disk.

Most nearby molecular clouds may have formed by gravitational fragmentation of the Cas-Tau fossil supershell. Gravitational instabilities in a swept-up shell lead to a fragment mass of order $10^5 M_\odot$, and to a global velocity structure similar to what is observed in the local ISM.

Massive stars in OB associations dominate the energy injected into the ISM. Over the 5 to 15 Myr formation time of an OB association, between 10 to 100 stars with masses in excess of $8 M_\odot$ are produced (in addition to more than 10^4 lower mass stars). Their Lyman continuum (LyC) radiation dissociates and ionizes surrounding molecular gas, their powerful winds shock and expel this plasma, and their demise in supernova (SN) explosions contribute to the 10^{52} to 10^{54} ergs of energy available to inflate superbubbles in the ISM.

The energy injected into the ISM by OB stars can be approximately represented as a time variable OB association driven wind with $L_w \approx 10^{38}$ erg s^{-1} that first evolves through an adiabatic (energy conserving) phase, which after a bubble cooling time or after the bubble blows out of the Galactic disk and loses pressure, enters an isothermal (momentum conserving) phase. In the first phase ($t < 1$ to 10 Myr), the shell radius evolves according to $R_s = 70(pc) L_{38}^{1/5} n_0^{-1/5} t^{3/5}$ where L_{38} is the wind mechanical luminosity in 10^{38} erg s^{-1}, n_0 is the mean ISM density, and t_6 is the bubble age in Myr. In the second phase, $R_s = (L_w/\alpha V_0 n_0)^{1/4} t^{1/2}$ where α is of order unity and V_0 is the shell velocity when it enters the isothermal phase. After the last massive star dies (at $t > 30$ Myr), the shell coasts, with $R_s = (E_0/\alpha' V_0 n_0)^{1/4} t^{1/4}$ where E_0 is the shell kinetic energy when the shell enters this third phase.

Bubble evolution is modified (with respect to uniform density, spherical models) by *non-coeval star formation*; by *poisoning* resulting from the evaporation of clumps that have been over run, adding coolants to the bubble; *blowout* when the bubble bursts out of the galactic disk; *shear* induced by galactic differential rotation; *magnetic fields*; *clumps* in the ISM; *density waves* which modulate the ISM pressure; and *gravitational instabilities*.

Gravitational instabilities cause the shell walls to *curdle* when the escape velocity from a piece of the shell exceeds the effective velocity dispersion

($v_{\rm eff}$) in the same volume ($v_{\rm eff}$ is the sum in quadrature of the sound speed, turbulent velocity, alfven speed, and shell divergence velocity). As shown by McCray & Kafatos (1987), supershells tend to fragment into $10^5 M_\odot$ clumps at a characteristic shell radius of 200 pc and a shell age of about 30 Myr. Condensation on this mass, size, and time scale is enhanced in the Solar vicinity by the blowout scale and the time taken for ballistic objects to start to fall back onto the plane (1/4 to 1/2 of the z-oscillation time scale of 80 Myr). Galactic differential rotation (shear) elongates fragmenting fossil supershells into ovoids with a major axis of about 500 - 800 pc and a minor axis of about 200 - 400 pc in this time scale.

The above model and data can be used to reconstruct the 30 to 60 Myr history of the Solar vicinity. A large OB association formed between 30 and 60 Myr ago at the present location of the Cas-Tau group, possibly triggered by the previous passage of the Sun through a major spiral arm. The resulting superbubble overran preexisting clouds, swept-up low density ISM into a $10^6 M_\odot$ supershell, and blew out of the disk. About 15 to 25 Myr ago, the first GMC-sized condensations formed near the center of the present day Sco-Cen, Orion, Lac OB1, and Per OB2 associations. These associations started forming about 15 Myr ago, and are presently driving their own superbubbles into the remnants of the ancient Cas-Tau fossil supershell. The expansion velocity of the Cas-Tau fossil shell is imprinted on the currently forming OB groups, the Great Rift clouds, the Lindblad ring, and other clouds lying within 500 pc of the Sun.

The model is self-sustaining. The nearby younger supershells will in turn fossilize, and curdle into new GMCs that will produce future generations of OB associations. In this model, the nearby 'hot cavity' may be an outlying portion of the Sco-Cen superbubble which is presently over-running the Solar system as evidenced by Solar Lyman-α back-scatter and the streaming of the ISM through the Solar system (Crutcher 1982) which indicates outflow from the general direction of the Sco-Cen OB association.

References

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