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Environs and Formation of Massive Stars

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1. Introduction

Massive stars in our Galaxy are born predominantly within the dense cores of giant molecular clouds. They affect their environment very soon after a stellar core has formed through their large rate of ionizing photons and their strong stellar winds. Massive stars are formed in clusters with stellar densities $n_* \sim 10^4$ stars/pc^3 and sizes 0.2 – 0.4 pc, and seem to preferentially form near the central region of the cores. Disks have been found in several sources (see Cesaroni, this volume). Associated with massive stars also are bipolar molecular outflows, which have masses, mass loss rates, and energies that are factors of $\sim$ 100 larger than those of low mass stars (see review of Churchwell 1999).

An understanding of the physical processes that dominate during the early stages of formation of massive stars and their influence back on the molecular gas from which they formed requires a detailed knowledge of the physical conditions of the environment prior to and after the formation of the star. Here we present an abstract of an extensive review on this subject by Garay & Lizano (1999). For compactness, most of the references have been omitted.

2. Compact HII Regions

Regions of ionized gas around recently formed massive stars have sizes $L \sim 0.005 - 0.5$ pc, emission measures $EM \sim 2 \times 10^6 - 10^9$pc cm^{-6}, electron densities $n_e \sim 2 \times 10^3 - 3 \times 10^5$cm^{-3}, and are often found in clusters. The observations show that the width of the recombination lines from HII regions decreases as size increase, Δv_{obs}(compact)>>Δv_{obs}(extended), the non-thermal part of the line width being the dominant component.

Wood & Churchwell (1989) noted that the short dynamical ages of UCHII regions, derived assuming a classical expansion into a constant density medium, implies a too high present star formation rate. Different models have been proposed to extend the time scale in the compact phase: *i)* in the champagne flow model, the HII region is confined in the direction of the high density region; *ii)* in the bow-shock model, the ram pressure of a stellar wind balances the hydrodynamic pressure of the cloud material entering a static bow shock structure as the star moves through a dense core; *iii)* in the photoevaporating disk model, the ionizing photons of the star evaporate the surface of a circumstellar disk producing a slow and dense photoevaporated disk wind which lasts as long as the reservoir of gas in the disk is avalaible; *iv)* HII regions can achieve pressure equilibrium at small radii if they are expanding in a warm and high density environment; *v)* mass loading of stellar winds via hydrodynamical ablation or photoevaporation of clumps inside the HII region can increase the density of stellar winds producing a recombination front at a small radius.

3. Molecular environment

The presence of dense, hot, molecular gas toward regions of newly formed stars is quite common. High resolution observations yield information of the structure, physical properties and kinematics of hot molecular cores (HMCs) (see review of Kurtz et al. 2000). HMCs have sizes $L < 0.1$ pc, densities $n(H_2) \sim 10^4 - 7 \times 10^7 \mathrm{cm}^{-3}$, masses $M \sim 10 - 3 \times 10^2\ M_\odot$, temperatures $T > 100\,K$, and velocity dispersions $\Delta v \sim 4 - 10$ km s^{-1} . HMCs are found in the vicinity of UCHII regions, thus they can be internally or externally heated: the densest and more massive cores could be the cradles of massive stars while the less dense and less massive hot cores would just be remnant molecular core material that has survived the powerful effects of the formation of massive stars.

HMCs and compact HII regions are immersed in massive molecular cores with sizes $L \sim 0.3 - 1$ pc, densities $n(H_2) \sim 2 \times 10^4 - 3 \times 10^6 \mathrm{cm}^{-3}$, masses $M \sim 10^3 - 3 \times 10^4 M_\odot$, temperatures $T \sim 25 - 50K$, and velocity dispersions, $\Delta v \sim 2 - 3$ km s^{-1} . Massive cores are highly inhomogeneous and contain $\sim 20\%$ of the total gas in Giant Molecular Clouds.

4. HMCs and the Formation of Massive Stars

Some luminous HMCs are not associated with an UCHII region. Walmsley (1995) proposed that these cores host a young massive OB-type star (or stars) undergoing an intense accretion, which quenches the development of a detectable UCHII region. Kaufman, Hollenbach & Tielens (1998) calculated the temperature structure of dense hot cores with either internal or external illumination. They found that internally heated cores can more easily produce large column densities ($N_{H_2} \geq 10^{23}$ cm^{-2}) of hot ($T > 100$ K) gas than externally heated cores.

Recently, Osorio et al. (1999) modeled the dust thermal spectrum of several HMCs as massive envelopes accreting onto young massive central B-type stars. This model can reproduce the observed spectra of several HMCs. In order to fit the available data, one requires central early B-type stars, and mass accretion rates $\dot{M} \gtrsim 6 \times 10^{-4}\ M_\odot$ yr^{-1}. These objects are young, $t_{\mathrm{age}} \sim 6 \times 10^4$ yr, and the accretion luminosity is larger than the stellar luminosity, $\mathrm{L_{acc}} > L_*$. Also, the mass weighted velocity dispersion is large, compatible with the line widths observed in $\mathrm{NH_3}$ inversion transition lines.

What is the fate of these objects undergoing this intense accretion phase? In a short timescale, $\Delta t \lesssim 0.5\ t_{\mathrm{age}}$, the increasing stellar luminosity will stop the accretion of matter onto the central star. As the accretion is shut off, so is the accretion luminosity, an important contributor to the total luminosity. Thus, accretion will start again, and this cycle will repeat until a stellar wind can also turn on, which can help to clear out the accreting flow. An HII region can then be produced, although in this scenario, its evolution would be governed by the reversal of the accretion flow, a problem we are currently studying.

The total number of this type of collapsing HMCs is unknown, so we are unable to determine if the statistics of these type of cores are consistent with the birth rate of massive stars. All of the luminous hot cores without radio emission reported so far have been found in the neighbourhood of HII regions, and is not clear how much of their heating is due to an internal or an external source of energy.

Another mechanism that has been recently proposed to form massive stars is the coalescence of already existing stars of lower mass in dense clusters. Since the cross section for these type of encounters is too small for naked stars, Stahler et al. (2000) suggested that the coagulation occurs when the low-mass stars are still surrounded by dense molecular cores which increases the effective cross sections. It is unclear if in such a collision the core will be disrupted, or will merge, or if the central low mass protostars will be ejected from the cores. Another issue is how do these objects lose energy and angular momentum to finally coalesce. Models of this complex hydrodynamical problem have yet to be constructed.

5. Conclusions

The observational evidence gathered during the last decade suggests that the formation of stellar clusters and OB associations becomes favored in molecular cores with large densities and masses. The new observations show the presence of circumstellar disks around young massive stars, collimated bipolar flows, both in molecular gas and ionized gas, and hot and dense molecular structures undergoing high mass accretion rates. This evidence suggests that the formation of massive stars has similar characteristics than that of low-mass stars.

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