How to form a $200M_{\odot}$ star

Hans Zinnecker,
Royal Observatory,
Edinburgh,
Scotland

ABSTRACT
Stellar coalescence is suggested as a possible mechanism for doubling the upper stellar mass limit from $\sim 100M_{\odot}$ to $\sim 200M_{\odot}$ in a moderately dense cluster of a few hundred young massive stars ($\sim 10^5 M_{\odot} pc^{-3}$). The merger will be between the two components of the dominant central tight binary formed in the core of the cluster by the N-body evolution. This process may occur in some giant extragalactic HII regions.

1. Introduction

Theoretical work on star formation by accretion suggests an upper stellar mass limit of the order of 100 $M_{\odot}$ (Larson and Starrfield 1971, Appenzeller and Tscharnuter 1974, Kahn 1974, Yorke 1979) in agreement with observations (Humphreys 1982), barring possible exceptions. Formation of an HII region and the reversal of the accretion process due to the radiation pressure on the dust grains (which transfer their momentum to the infalling gas) are thought to stop the growth of stellar masses beyond $\sim 100M_{\odot}$. One possible means of exceeding this limit may be a reduction of the dust-to-gas ratio and alteration of the dust properties (Wolfire and Cassinelli 1985). Here I suggest another possibility: a collisional merger between the two most massive stars in the core of a compact cluster of young OB stars. The original motivation for investigating this possibility came from the debate about the object R136a in the core of the central cluster in the 30 Doradus Nebula (see the review by Walborn 1984 and the panel discussion following his paper; see also Walborn 1986 and Moffat et al. 1985). Furthermore, a recent numerical simulation of the collision of two identical massive stars with various non-zero impact parameters has shown stellar coalescence to be quite effective (Benz and Hills 1985).

2. The Physical Idea

Consider a superdense cluster of massive stars which (for simplicity) are assumed to be coeval and of the same mass M (say $100M_{\odot}$). A necessary condition for star-star collisions to occur in such a cluster

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is that the cluster evolution becomes faster than the stellar evolution. In other words: the timescale for cluster core contraction (30-40 initial crossing times), after which a central dominant binary is formed, must be less than the main sequence lifetime of the massive stars (a few times 10^6 yr). The former timescale is based on Aarseth's (1974) numerical simulation of the N-body evolution of isolated star clusters (N=250). The crossing time in a virialized cluster is $t_{cr} \approx (G\rho)^{-\frac{1}{2}}$ where ρ is the mean stellar mass density and G is the gravitational constant. It follows that $\rho \geq 10^5 M_\odot pc^{-3}$.

As a criterion for collision I adopt the condition that the semimajor axis (a) of the central binary be as small as 10 times the stellar radius (r) or less. In that case the numerical calculations of Benz and Hills (1985) predict that merging between the two binary components is inevitable after several orbits, especially if the binary has a sizable excentricity (as predicted by the N-body simulations). Moreover, the presence of a captured third body generates repeated perturbations of the eccentricity of the binary orbit so that nearly head-on collisions and hence merging will occur. The key point is that the central binary absorbs practically all the energy of the cluster (Aarseth 1974), thus $a=R_o N^{-2}$ for an initial cluster radius R_o and N cluster members of equal mass. Since $r/a \leq 1/10$ (as discussed above) and $r \sim 0.1$AU for O-stars, $a \leq 1$AU is required for the merging of the binary. Thus, if $R_o=0.2$pc, N~200 follows from $a = R_o N^{-2}$; if $R_o=0.5$pc, N~300; but for larger R_o (and larger N) the above limit $\rho = NM/4R_o^3 \gtrsim 10^5 M_\odot pc^{-3}$ is violated and the cluster evolution is not fast enough.

3. Discussion

The main, perhaps surprising conclusion is that two massive stars may merge in moderately compact, young clusters. It remains to be shown that the result is valid in more general cases. Use of a realistic stellar mass spectrum at a fixed number N of stars would speed up cluster evolution by a factor ~3 (Aarseth 1974), but extension of the mass spectrum to lower mass stars (B-stars), that is increasing N to ∿4N as well as decreasing the mean stellar mass, would slow down cluster evolution by a factor 3-4. Therefore, as long as the mass spectrum terminates at ∿B5 stars, both effects will cancel, and the timescale for cluster evolution as given remains correct. Note that the basic event of stellar coagulation requires the presence of a mass spectrum otherwise the central binary would not become tight enough (Aarseth 1974). In fact, the speckle data on R136a (Weigelt and Baier 1985) do suggest that the central binary a1/a2 is not tight at all (sep. ∿0″.1 or 6000 AU) which in turn may indicate that the mass distribution in 30 Dor is quite narrow indeed, i.e. WR and O-stars only (cf. Melnick 1986). The large spatial extent of 30 Dor is consistent with the N-body relaxation of a cluster born in a small volume.

At present the only known remaining candidate for a very massive star (∿ $2000 M_\odot$) is (was!) the progenitor of the unique supernova SN 1961v in the galaxy NGC 1058 (Utrobin 1984).

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