Massive Young Stellar Clusters in the Milky Way

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Abstract Compact young open clusters with very high masses ($M_{\rm cl} \gtrsim 10^5\, M_\odot$) have been observed in many galaxies, and their connection to globular clusters is a matter of discussion. However, until very recently, no clusters with masses $M_{\rm cl} \gtrsim 10^4\, M_\odot$ were known in the Milky Way. Their absence was considered a natural consequence of the mild star formation rate in the Milky Way. The development of new infrared observational techniques has completely changed our perception. At present, almost a dozen young massive clusters are known in the Milky Way, and there are reasons to believe that many more wait to be found. In this paper, I briefly review our knowledge of some of these objects: the extended star-forming region Cygnus OB2, the compact young massive cluster Westerlund 1, currently believed to be the most massive young cluster in the Galaxy, and the new massive clusters hosting a large population of red supergiants found at the base of the Scutum Arm.

1 Introduction

The development of infrared detectors has allowed us to realise that the majority of stars form in clusters inside giant molecular clouds, even if many of these clusters disperse before becoming visible (24). Clusters in the solar neighbourhood are typically small, with masses up to $\sim 10^3\, M_\odot$ (4), though perhaps their natal masses are somewhat higher (39). More massive clusters were thought scarce in the Milky Way. The double cluster in Perseus (h & χ Per) is a good example of rather young (double) cluster, with a combined initial mass $M_{\rm cl} \gtrsim 10^4\, M_\odot$ (40). Another example is the very young and compact cluster NGC 3603, which has a large population of very massive stars (32) and $M_{\rm cl} \gtrsim 10^4\, M_\odot$ (20).

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In contrast, globular clusters are testimony to an earlier epoch when enormous clusters were formed. Low-mass stars lost in the course of their dynamical evolution could explain the majority of Population II field stars found in galaxy halos (30). The formation of massive cluster, however, is not restricted to the distant past. Indeed, hundreds of young clusters with estimated masses comparable to or greater than Galactic globular clusters ($\geq 10^5\,M_\odot$) have been identified in starburst galaxies like, e.g., the Antennae galaxies (e.g., 41). Since the size of the clusters formed seems to be correlated to the intensity of the starburst and star formation was more intense in the past, these Young Massive Clusters (YMCs) might represent the dominant mode of star formation in the Universe.

Unfortunately, at extragalactic distances, even the brightest individual cluster members are unresolved. The physical properties of YMCs must be estimated from their integrated spectra and photometry, dominated by the most massive and luminous stars, or from their dynamical masses, estimated from their half mass radius and velocity dispersion. These methods require strong assumptions, which may or not be justified (e.g., 7; 2). We do not know if the observed YMCs will evolve into globular clusters. The fate of a cluster depends on how much mass is contributed by low-mass stars (14), i.e., on the initial mass function (IMF), and the low-mass portion of the IMF cannot be observed in YMCs. Studies of YMCs by different groups have come to entirely contradictory conclusions about the shape of their IMF. Some find a truncation of the IMF towards lower stellar masses (e.g., 33). Others find that a standard (29) IMF describes well the whole range of stellar masses (e.g., 31). Because of the complications involved in studying unresolved populations (e.g., 1), the study of the most massive young clusters in the Milky Way provides a useful testbed for comparison, at a distance where individual stars may be observed. In recent years, important efforts have been carried out to locate the most massive clusters in the Galaxy (e.g., 15). The presence of a population of YMCs with $M_{\rm cl} \gtrsim 10^5\,M_\odot$ in the Milky Way had not been considered until recently, but is not ruled out at present (19; 39).

2 Cygnus OB2

Cyg OB2 was considered an interesting target since a population of very massive stars was discovered, but early studies were hampered by high obscuration (22). Advances in detector technology allowed comprehensive investigations, which identified ~ 60 stars more massive than $15M_\odot$ (34). Cyg OB2 is very compact for an OB association and seems to occupy a more or less unique position somewhat intermediate between an open cluster and a normal OB association (cf. 26). The central region contains two cluster-like stellar concentrations (5). They form an elongated figure $\sim 4' \times 10'$ ($\sim 2 \times 5$ pc at the distance of Cyg OB2) and contain 18 O-type stars (not counting binaries, which could perhaps almost double this figure).

Star counts in the 2MASS observations of this region suggested a much richer population of early type stars, leading to the proposal that the number of O-type stars in Cyg OB2 could exceed 100 (26). Several studies have followed (10; 18; 38), resulting in the discovery of many new members (see Figure 1). The whole association contains > 50 (and likely $\sim$ 70–80) O-type stars (27; 38), including another small cluster (38). The exact mass of the association is very difficult to determine. The number of O-type stars is highly uncertain due to their propensity to appear in binaries or groups. A high binary fraction in Cyg OB2 has been confirmed observationally (28). In addition, Cyg OB2 is projected along the line of sight spanning the Local Spur and so suffers from high fore- and background contamination, especially stars connected with the Cygnus Superbubble (9).

The properties of Cyg OB2 represent clear demonstration that massive star clusters can exist without being conspicuous. It is unlikely that Cyg OB2 would stand out if it were at 5 kpc or projected against a denser background. Another region which may contain a very high number of massive stars spread over a moderately wide area, resulting in a low apparent density, is the massive star forming region W49A (21). Subclustering is seen in both Cyg OB2 and W49A, as well as in other large Galactic star forming regions, such as W51 (36). Study of large stellar complexes in M51 (3) shows that the age spread within different clusters is $\lesssim 10$ Myr. It is thus possible that the largest stellar aggregates in the Galaxy have escaped detection until now.

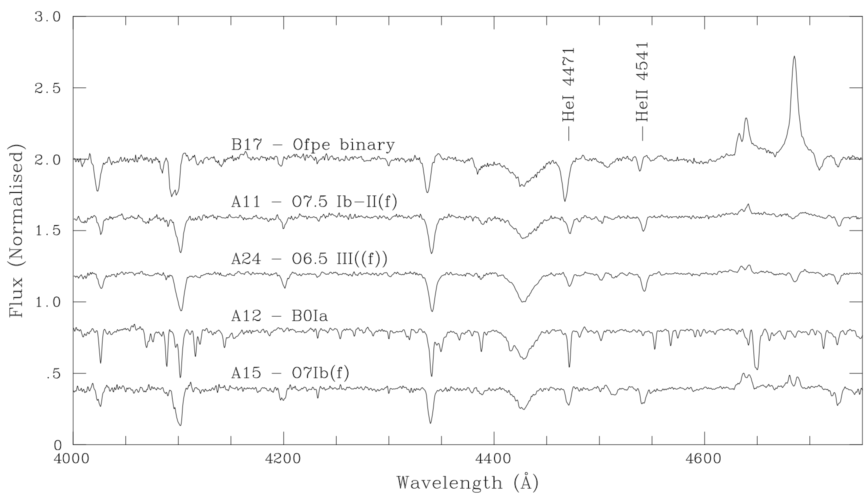

Fig. 1 New evolved very massive stars in Cyg OB2 found by (38) amongst the candidates of (10).

3 Westerlund 1

Our perception of the cluster population in the Milky Way has changed since the discovery that Westerlund 1 (Wd 1) is much more massive than other Galactic clusters (8). Three independent mass estimates place its mass around $10^5 M_\odot$ (8; 35; 6), making it the only Galactic young cluster approaching the size of YMCs in starburst regions. With a half-mass radius of ~ 0.5 pc, it is as dense and compact as extragalactic YMCs (8). These properties provide us with an excellent opportunity to measure the physical properties of a YMC at a distance that allows the observation of individual stars down to subsolar masses. Direct measurement of its stellar content finds an IMF consistent with standard down to $\sim 2\,M_\odot$ (6).

Moreover, at an age ~ 4.5 Myr, Wd 1 is an ideal laboratory to study the post-MS evolution of massive stars. The cluster contains 23 Wolf-Rayet stars (11) and a large ($\gtrsim 100$) population of luminous supergiants with spectral types from O to M (8; 37). This huge population of evolved massive stars contains several examples of rare evolutionary phases and peculiar objects, such as the strange sgB[e] star 9, which may be a common envelope binary, or the red supergiant stars 20 & 26, which show bipolar nebulae in radio and Hα. Such rare stars are frequent in Wd 1 simply because of the size of the population. A recent report on the state of the study of this population is presented in Negueruela et al. (37). A detailed investigation of its evolutionary context will be crucial to understand the evolutionary paths of massive stars and the way in which they lose a significant fraction of their masses before becoming Wolf-Rayet stars. The exact physical processes producing this mass loss will determine the nature of the final remnant left by a massive star and the contribution made by such stars to the enrichment of the ISM.

Wd 1 provides us with a wonderful example of a compact cluster, most likely formed monolithically, and so an excellent analogue to the huge young globular clusters seen in external galaxies.

4 The red supergiant clusters

The realisation that Wd 1 is a YMC has led to a search for further examples of very massive young open clusters (19; 15). As they are likely to be very reddened, a sensible strategy may be looking for them in the near-infrared. The brightest massive stars in the near-infrared will be those in the red supergiant (RSG) phase. A very obscured cluster containing many luminous red stars was found by Figer et al. (16). Further work suggests that this cluster (known as Red Supergiant Cluster 1; RSGC1) contains at least 15 yellow and red supergiants and has a mass $M_{\rm cl} \approx 3 \times 10^4\,M_\odot$ at an age of ~ 12 Myr (13). Its dynamical distance is 6.6 ± 0.6 kpc. RSGC1 is located only $\sim 1^\circ$ away from Stephenson 2 (= RSGC2). This cluster contains ~ 25 RSGs and has a mass estimate $M_{\rm cl} \approx 4 \times 10^4\,M_\odot$ at an age in the $10-17$ Myr range (12). Its distance is estimated at 6 ± 2 kpc.

The presence of these two clusters in a small area is unlikely to be a coincidence. As a matter of fact, a third RSG cluster candidate is being investigated by our group in the neighbourhood of the other two. The three clusters are located in a region (around Galactic latitude $l = 26^{\circ}$) where Garzón et al. (17) had already discovered a very high density of field RSGs. This overdensity had been attributed to a concentration of sources at distances ~ 6.5 kpc in an area of only a couple of squared degrees, and interpreted as evidence for the presence of a prominent star formation region possibly associated with the end of the Galactic Bar, where it meets the Scutum spiral arm (25).

This area may represent the first fully blown starburst region discovered in the Milky Way. Its location close to the base of the Scutum Arm is almost certainly not casual and suggests that this region may be almost unique in the Galaxy.

5 Future work

In order to check the possibility that more RSG clusters may exist outside the region at the base of the Scutum Arm, we have made a shallow survey of optically visible

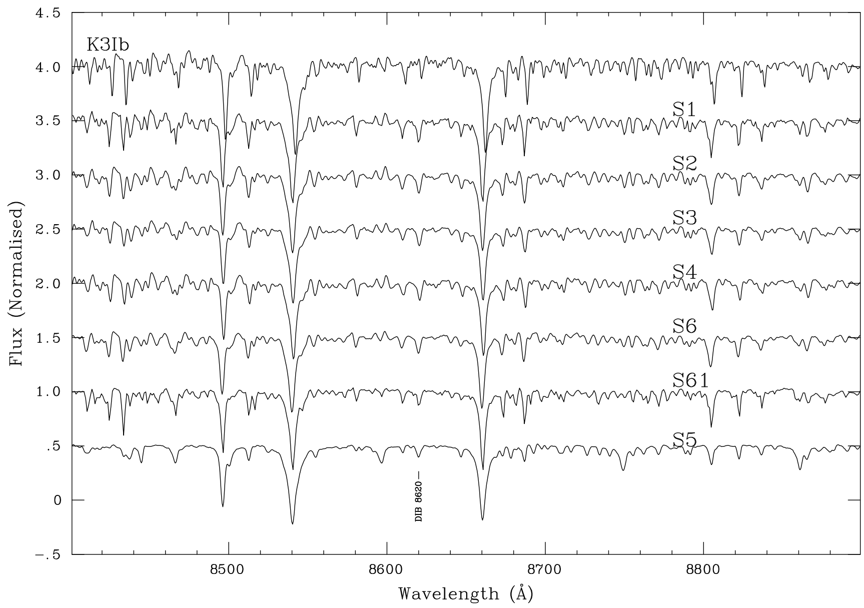

Fig. 2 Seven low-luminosity supergiants in the previously unstudied cluster Berkeley 55. The top spectrum is a K3 Ib supergiant used as comparison. The six stars immediately below are luminosity class Ib or II K-type members of Berkeley 55. The bottom spectrum corresponds to a late-F supergiant member.

clusters in the $l = 30^\circ - 100^\circ$ range, using 2MASS photometry. We have searched for the presence of a large number of RSGs, which should be seen in the $K_S/(J-K_S)$ diagrams as a clump of very bright stars with high $(J-K_S)$ and values of the Q_{IR} parameter clearly separating them from field red giants. We have not found any cluster resembling the known RSGCs, but we have come across some interesting cases.

A good example is the open cluster Berkeley 55. *I*-band spectra of its brightest members (Figure 2) reveal a population of K–M stars with luminosities close to the borderline between Ib supergiants and II bright giants and suggest a moderately massive cluster with an age ~ 50 Myr. Therefore this method looks a very effective way of finding obscured compact clusters with masses above the average.

If we take into account that the area that we have surveyed is unlikely to be the richest in obscured clusters (most lines-of-sight are towards the outer reaches of the Galaxy and extinction is much lower than along line of sights towards the Galactic Bulge), we expect many more interesting clusters to lie hidden in other regions of the Galaxy. Given its closeness to the Sun, ~ 4 kpc (23), it is unlikely that Wd 1 will turn out to be unique. Very young massive clusters may, however, be relatively inconspicuous. Only clusters older than ~ 4 Myr will have a population of yellow and red supergiants that will make them stand out in infrared surveys. Likewise, less compact clusters, like Cyg OB2 may be more difficult to detect. Therefore future detections may be biased towards compact, moderately evolved massive clusters. Current and future wide-field surveys will provide the mining ground for our searches.

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