Opposite, top: *Globular cluster M13 in Hercules, dimly visible to the unaided eye, is revealed on this photograph as a dense ball of almost a million old stars.*

Opposite, bottom: *Clouds of dusty gas surround members of the Pleiades (or 'Seven Sisters'), revealed here as a cluster of over two hundred stars. The presence of gas and dust betrays the cluster's youth: it is thought to have been formed a mere sixty million years ago.*

Further collapse meant faster rotation, a more pronounced equatorial bulge, and an increased gas density. The atoms in the gas, once so dispersed, now became close enough to interact and collide with one another, a process which most efficiently removed energy from the gas. No longer able to support itself, the gas collapsed quickly into a very thin disc, rotating rapidly about the starry nuclear bulge of the Galaxy. The entire collapse process, from protogalaxy to disc system, probably took no longer than a few hundred million years – a mere one-hundredth of the Galaxy's present age.

Since then, the disc of our Galaxy has been in a perpetual state of change. Gas clouds continue to collapse, stars still form, while old stars die, returning their debt with interest to the ever-evolving interstellar medium. But all around, in the remote halo, are the faded relics of a bygone age. By studying the halo population, we learn of our Galaxy's past history; and we also unearth vital clues as to the formation of galaxies in general.

## The galactic halo

Of all the regions in our Galaxy, the halo is the most poorly understood. Its extent, mass and density are not known with any certainty, and there are even indications that our ideas of its contents are in need of a review. However, there is no dispute over its most prominent members: the 130 or so globular clusters which can be observed to distances approaching 100 kpc (Fig. 6·3).

Early in this century, the globular clusters played an important role in finally dethroning the Sun from its assumed position at the centre of the Galaxy. Using the newly discovered period-luminosity relationship (page 66) of Cepheid variable stars to measure the distances to these clusters, and thereby gauge the extent of the Galaxy, Harlow Shapley found that they were strongly concentrated towards the Milky Way in Sagittarius. He reasoned that this grouping reflected the underlying distribution of matter in the Galaxy and, consequently, that the massive central regions lay some 16 kpc away from the Sun. More recent investigations have modified this last figure to between 8–10 kpc, but Shapley's position has held remarkabiy well.

Despite their distance, globular clusters can still appear bright in our skies. Two clusters in the southern hemisphere – $\omega$ Centauri and 47 Tucanae – were originally catalogued as stars by mistake; and M13, the brightest globular cluster in the northern hemisphere, is visible as a small, misty patch in the constellation of Hercules. In long-exposure photographs they are revealed as tight balls of $10^4$–$10^6$ stars packed into a region averaging only 30 pc across. Despite appearances, the stars are far from touching one another – it is just that star images are spread out on photographs – but the stars in the central region of a globular cluster must still be extremely high; perhaps 1 000 times higher than in the neighbourhood of the Sun. Here the skies must be truly spectacular, with the closest stars outshining the planet Venus, and 1 000 other stars brighter than even Sirius.

The skies of a globular cluster would have none of the variety which we are accustomed to. As the first in our Galaxy to form, the stars in a globular cluster are all now in an evolved stage – red giants, or red and white dwarfs. This is strikingly revealed on globular cluster H–R diagrams where the luminous stars form a prominent **giant branch** in the red giant region.These H-R diagrams tell us how long ago the globular clusters came into being: around $1{\cdot}3 \times 10^{10}$ years ago.

Although most globular clusters superficially resemble one another, there are some significant differences. There is a factor of 100 between brightest and faintest, and a similar range in their star numbers. The most distant globular clusters are noticeably larger, because their outer regions are not stripped away by galactic tides to the same extent as those clusters closer in. Some astronomers have called these outermost systems 'Tramp' globular clusters, believing them to be moving freely in intergalactic space. It seems more likely that these clusters formed in the outermost halo and are now leaking away from the Galaxy, having perhaps suffered slight perturbations from passing galaxies far off in space.

Striking differences are found in the proportions of heavier elements ('metals') making up globular cluster stars. As would be expected from their great age, the stars in globular clusters are relatively metal-poor, but the range in this deficiency is surprisingly large. Stars in the cluster 47 Tucanae have metal abundances of about 25 per cent that of the Sun (about 0·6 per cent). This figure is down to 5 per cent in the case of M 5, and the stars in M 92 and M 15 have only 0·2 per cent of the solar metal abundance. A general trend in metallicity is observed, those globular clusters near the galactic disc having the highest abundances, while the clusters in the outer halo are very metal-poor. Differences such as these are believed to reflect the times and places at which globular clusters formed, and can tell us much about the collapse of our Galaxy. Information about the brightest globular clusters is summarized in Table 6·1.

Globular clusters travel about the Galaxy on long, highly-inclined orbits, another relic from the early days of the protogalaxy. Some clusters are observed to be slowly rotating, and all of them – although it may not be at all obvious – are slowly losing stars to the halo. Interactions between the closely-packed stars in globular clusters can speed up or slow down their motions; and some interactions are sufficiently energetic to eject completely a star from the cluster. It is unlikely that a globular cluster could be totally disrupted in this way, although these processes can speed the break-up of looser star clusters. Over their total lifetimes of $10^{10}$ years, it appears that the globular clusters have remained virtually intact.

The stars which do leak away become members of the general halo population, which appears to make up the greatest part of the halo's mass. What proportion of this population started off their lives as members of clusters is uncertain; it is currently estimated to be a few per cent. Individual halo stars can be identified readily by their high velocities (greater than 63 km per s) and steeply inclined orbits, which sometimes intersect the galactic plane. Although they