

The Properties of Young Clusters in M82

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Abstract. We present a detailed study of two luminous super star clusters in the starburst galaxy M82. Spectra, covering 3250–8790 Å at a resolution of 1.6 Å, were obtained at the 4.2 m William Herschel Telescope (WHT) for cluster F and the highly reddened cluster L. We compare the strengths of the observed Balmer absorption lines and the Balmer jump in the blue spectrum of F with theoretical model cluster spectra using the PEGASE spectral synthesis code to derive an age of 60 ± 20 Myr. For cluster L, we find that the similarities in the strength of the Ca II triplet and overall spectral appearance with cluster F suggest a similar age. The brightness and compactness of cluster F make it an ideal candidate for determining its dynamical mass by measuring the velocity dispersion. We present the results of such an investigation based on echelle spectra at a resolution of 8 km s^{-1} obtained at the WHT from 5760–9140 Å. By cross-correlating various wavelength regions in the spectrum of cluster F with cool giant and supergiant template stars, we derive a velocity dispersion and, by application of the virial theorem, determine a dynamical mass of $2 \times 10^6 M_{\odot}$. We compare our derived mass with those determined for other young super star clusters and discuss whether our derived parameters are consistent with cluster F being able to survive to become a globular cluster.

1. Introduction

Observations with the *Hubble Space Telescope* (*HST*) have revealed that hundreds of super star clusters (SSCs) are present in the nearby starburst galaxy M82 (O’Connell et al. 1995). SSCs appear to be frequently associated with starbursts, and it has often been suggested that they represent young globular clusters. One critical aspect is whether they have enough mass to survive over long time-scales. In this paper, we present a detailed investigation of the luminous cluster F (O’Connell & Mangano 1978) and the nearby, highly reddened, cluster L (Kronberg, Pritchet, & van den Bergh 1972). They are located 440 pc south-west of the nucleus of M82.

Our study is based on optical spectroscopy obtained at the 4.2 m William Herschel Telescope (WHT) at resolutions of 1.6 \AA and 8 km s^{-1} . We use the intermediate dispersion spectra to obtain ages for the two clusters. The brightness and compactness of SSC F make it an ideal candidate for measuring the line of sight velocity dispersion, and hence obtaining the dynamical mass of the cluster. We use our recently obtained high dispersion red spectra to derive the mass and discuss whether our derived parameters are consistent with SSC F being able to survive to become a globular cluster.

2. The Ages of Clusters F and L

Observations of clusters F and L were obtained in 1997 March with the WHT on La Palma, Canary Islands, the double beam spectrograph ISIS and 1024×1024 TeK CCDs on the blue and red arms. The spectra, shown in Fig. 1, cover $3300\text{--}5500 \text{ \AA}$ and $5700\text{--}8800 \text{ \AA}$ for cluster F and $5700\text{--}8800 \text{ \AA}$ for cluster L. The resolution is 1.6 \AA with a S/N of 30–40 for a total exposure time of 100 min for each arm. We derive a V magnitude of 15.8 and $(B-V)=1.07$ for cluster F.

The blue spectrum of cluster F is dominated by broad Balmer absorption lines and a strong Balmer jump, indicative of a mid-B spectral type. The red spectrum shows strong absorption due to the Ca II triplet and many weak features attributable to F and G supergiants. The red spectrum of cluster L is very similar to that of F.

The quality of the WHT spectra allows us to considerably improve previous age estimates for cluster F. We have used the PEGASE spectral synthesis code (Fioc & Rocca-Volmerange 1997) to compute synthetic spectra for ages of 20, 40, 60, 80 and 100 Myr, using a Salpeter IMF, the Geneva evolutionary tracks and the Jacoby, Hunter, & Christian (1984) spectral library. The ratio of the observed to model spectra suggests a reddening $E(B - V) \approx 1.5$, although we find that a standard Galactic extinction law does not properly correct the data. The 40 Myr model gives the best fit to the $H\beta$, $H\gamma$ and $H\delta$ absorption lines but does not do as well for the Balmer jump region as the 60 and 80 Myr models. The 20 and 100 Myr models gave worse fits in all areas. We therefore adopt an age for cluster F of 60 ± 20 Myr. The ratio between the observed spectrum of cluster F and the 60 Myr model is shown in Fig. 2.

For cluster L, we find that similarities in the strength of the Ca II triplet and the overall spectral appearance with cluster F suggest a similar age. We conclude that M82 experienced an episode of intense star formation ≈ 60 Myr ago in the mid-disc region. In the central region, the age of the starburst is younger, at 20–30 Myr (Rieke et al. 1993). More details of this analysis can be found in Gallagher & Smith (1999).

3. The Mass of Cluster F

Cluster F was observed in 1999 February with the WHT and the Utrecht echelle spectrograph (UES). The detector used was a 2048×2048 SITe CCD and the wavelength range covered was $5760\text{--}9140 \text{ \AA}$ in a single exposure at a resolution

Figure 1. The WHT+ ISIS spectra of SSCs F and L (smoothed with $\sigma = 1.0 \text{ \AA}$ for presentation purposes). The y-axis is in units of $10^{-15} \text{ ergs s}^{-1} \text{ cm}^{-2} \text{ \AA}^{-1}$.

Figure 2. The ratio between the observed cluster F spectrum and the 60 Myr PEGASE model. The slope is caused by dust obscuration in M82.

of 8 km s^{-1} . We achieved a per pixel S/N of 15–25 in a total integration time of 6.4 hr.

We chose this spectral region because, as discussed by Ho & Filippenko (1996a,b), and demonstrated by our ISIS spectra, the wavelength region longward of 5000 \AA is dominated by the light of cool supergiants. Thus by cross-correlating the cluster spectrum with a suitable template spectrum of a cool supergiant, it is possible to recover the velocity dispersion of the cluster, and hence derive its mass by application of the virial theorem.

We obtained UES spectra of eight stars with spectral types from A7 III to M2 Iab for the purpose of providing a suitable template. Comparison of these spectra with that of cluster F shows that the best spectral match is between HR 6863 (F8 II) and HR 1529 (K1 III), as demonstrated in Fig. 3 for the region containing the Ca II triplet.

We have therefore used these two stars as templates and cross-correlated their spectra with that of cluster F. We chose four spectral regions which are free of telluric absorption lines: $6010\text{--}6275 \text{ \AA}$, $6320\text{--}6530 \text{ \AA}$, $7340\text{--}7590 \text{ \AA}$, and $7705\text{--}8132 \text{ \AA}$ for the analysis. We ignored the region containing the Ca II triplet because these lines are saturated in the template spectra and broad Paschen absorption lines from early-type stars are present in the cluster F spectrum.

For each cross-correlation function, we measured the FWHM by fitting a Gaussian profile. The relationship between the FWHM and the velocity dispersion was empirically calibrated by broadening the template spectra with Gaussians of different dispersions and cross-correlating with the original spectra.

Figure 3. WHT+UES spectra covering the Ca II triplet region at a resolution of 8 km s^{-1} for M82-F and the two template stars. The data for M82-F have been lightly smoothed for presentation purposes.

Using this approach, we find that relative to HR 6863 (F8 II) and HR 1529 (K1 III) the velocity dispersion of F is 13.2 ± 1.9 and $16.5 \pm 2.4 \text{ km s}^{-1}$ respectively. The latter value is larger because the dispersion due to macroturbulence is smaller in the K1 giant. The difference in the two values is consistent with the velocity dispersion derived by cross-correlating the two template stars. We adopt the lowest value as representing the velocity dispersion of F because we expect the spectrum to be dominated by cool supergiants, and the work of Gray & Toner (1986, 1987) indicates that the macroturbulence dispersion in an F8 bright giant is similar to that of cool supergiants.

To derive the dynamical mass of cluster F, we need its half-light radius. O’Connell et al. (1995) derive a radius of 1.9 pc from HST images taken with WFPC. We have searched the HST archive for images of cluster F taken with WFPC2 and have found two suitable images. We measure a half-light radius of 4.4 pc, uncorrected for the PSF which is likely to reduce it by $\sim 10\%$. We assume that this radius represents a good upper bound to the half-mass radius, and that the cluster is spherically symmetric with an isotropic velocity distribution. Application of the virial theorem then gives a mass of $1.8 \pm 0.5 \times 10^6 M_{\odot}$.

4. Is Cluster F a Young Globular Cluster?

In Table 1, we compare our derived properties of cluster F with those derived for the young super star clusters NGC 1569-A and NGC 1705-1 (Ho & Filippenko 1996a,b; Sternberg 1998). Cluster F appears to be more massive and luminous than both these clusters. To derive the value of M_V given in Table 1,

Table 1. Comparison of Properties of Super Star Clusters

Cluster	Age (Myr)	M_V (mag)	R_h (pc)	σ (km s ⁻¹)	Mass (M_\odot)
NGC 1569-A ^{a,c}	10–20	−14.1	1.9 ± 0.2	15.7 ± 1.5	$1.1 \pm 0.2 \times 10^6$
NGC 1705-1 ^{b,c}	10–20	−14.0	0.9 ± 0.2	11.4 ± 1.5	$2.7 \pm 0.8 \times 10^5$
M82-F	60 ± 20	−15.8	4.4	13.2 ± 1.9	$1.8 \pm 0.5 \times 10^6$

^aHo & Filippenko (1996a); ^bHo & Filippenko (1996b); ^cSternberg (1998).

we have measured a V magnitude of 16.5 from the WFPC2 image, and assumed a reddening of $E(B - V) = 1.5$ (Sect. 2).

Mandushev et al. (1991) provide measurements for 32 Galactic globular clusters. The mass of cluster F is a factor of ~ 9 higher than their mean mass of $1.9 \times 10^5 M_\odot$. From the PEGASE models, we expect cluster F to dim by 4.5 mag for an age of 15 Gyr, giving $M_V = -11.3$. This is higher than the mean value from Mandushev et al. (1991) of -8.1 ± 1.2 although the reddening towards F is uncertain. If we use $E(B - V) = 1.0$ (O’Connell et al. 1995) instead, then the predicted M_V at 15 Gyr of -9.8 agrees better with the mean value of Mandushev et al. (1991). The predicted mass-to-light ratio $(M/L_V)_\odot$ for cluster F of 0.6 or 2.5 (with $M_V = -11.3$ and -9.8 , respectively) agrees well with the range of 0.7–2.9 for Galactic globular clusters (Mandushev et al. 1991). This suggests that cluster F could survive to become a globular cluster. Although it would be considerably more massive than the average Galactic globular cluster, it still would have less mass than large globular clusters such as ω Cen (Merritt, Meylan, & Mayor 1997).

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