

Young Star Clusters in Spiral Galaxies

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Abstract. We present the methodology and some preliminary results of a new study of cluster populations in spiral galaxies. For three galaxies that have been studied so far, we find that blue clusters trace the spiral patterns of their galaxies (while red clusters do not) and that their cluster luminosity functions are in agreement within the uncertainties.

1. Introduction

Young star clusters, dense concentrations of young stars roughly resembling globular clusters, represent a relatively extreme mode of star formation. We can observe these objects easily in the LMC, where they appear as blue globular clusters (Gascoigne & Kron 1952). At this distance, a typical size of 3 pc corresponds to ~ 12 arcsec, allowing their profiles and integrated properties to be studied from the ground. Their profiles are well-fit by a $(1 + (r/a)^2)^{-\gamma/2}$ modified power law, with typical core radii of 1 – 3 pc (Elson, Fall, & Freeman 1987). The ages, determined from studies of their stellar content, are mostly under 3 Gyr, with a typical age of $\sim 30 - 100$ Myr (Olszewski, Suntzeff, & Mateo 1996 and references therein). Despite having similar luminosities as the LMC's old globular clusters ($M_V \approx -9$), these objects are much too faint to be their evolutionary precursors because of fading. However, we do see that the cluster age distribution qualitatively mirrors the star formation history of LMC field stars (Holtzman et al. 1999; Dolphin 2000a), implying a link between cluster formation and overall star formation.

To find a statistically significant number of spiral galaxies, one must observe at ~ 20 Mpc – a factor of 400 times the LMC distance, where the study of cluster populations becomes much more difficult. At this distance, 3 pc corresponds to ~ 0.03 arcsec, making these objects essentially unresolved even at the resolution of the Hubble Space Telescope. However, HII regions and OB associations of spiral galaxies have been studied, showing that HII regions are more numerous and have shallower luminosity function in late-type spirals compared with early-type spirals (Kennicutt, Edgar, & Hodge 1989) and that trends in OB associations consistent with those in HII regions (Bresolin et al. 1998). However, compact star clusters have a longer lifetime than HII regions and OB associations, and

thus trace a longer period of the galaxy’s history. Additionally, because HII regions, OB associations, and clusters do not necessarily come from the same types of star-forming events, they may be tracers of different modes of star formation and thus contain different information.

Because of the difficulty in studying young clusters, some very fundamental questions remain unanswered. (1) What does any difference between a galaxy’s cluster and OB association/HII region populations tell us? (2) Are trends of the cluster populations along the Hubble sequence similar to those of OB associations and giant HII regions? (3) Is the preponderance of young clusters in interacting and starburst galaxies a product of the unique dynamical environment in mergers, or are similar populations of star clusters present in all star-forming galaxies? This paper describes the method and preliminary results of a project aimed at answering these questions.

2. Technique

2.1. Target Selection and Reduction

Because we are attempting to resolve objects of size 0.03 arcsec, we have stringent requirements on the type and quality of data we are using. Namely, we are restricted to high signal-to-noise HST-based observations of galaxies in the 10 – 20 Mpc distance range. Fortunately, the WFPC2 Cepheid projects, for which full-orbit images were taken over many epochs, provide exactly what is required: typical total integration times of 40000s in V and 20000s in I , and galaxies at optimal distances with a range of Hubble types.

Once the targets are selected, a key question will be the photometry method. PSF-fitting packages are advantageous because of better handling of variable backgrounds and extreme crowding (both severe problems in these data), but will clearly run into problems when attempting to fit a stellar PSF to extended objects. However, this problem can be solved because while variable background and crowding cause random errors, PSF-fitting errors are systematic and thus correctable. Therefore, we will use HSTphot (Dolphin 2000b), a stellar photometry package that is optimized for WFPC2 data. HSTphot produces a sharpness parameter that is zero for a perfect star, positive for an overly sharp object (such as a cosmic ray), and negative for an extended object.

Because of the choice of PSF-fitting photometry, the first stage of the reductions is the determination of the stellar PSF for the image – a step necessary both for measuring accurate photometry and for discriminating stars from clusters. It should be noted that the more common approach – using a template PSF for all images and using aperture corrections to correct for PSF variations – produces incorrect photometry of the faint stars because the photometry error caused by an incorrect PSF is a function of magnitude. (This is also the case in our photometry of clusters, as noted above, but we are applying a correction.)

In measuring the stellar PSF, the largest difficulty is caused by the fact that the brightest “stars” in the images are actually clusters. A prime example of this is NGC 3627, one of the galaxies examined by the Supernova Ia calibration team (Saha et al. 1999) and later by the H_0 Key Project (Gibson et al. 2000). Both studies found the stellar PSF to be broader than in the other galaxies studied. However, by plotting the HSTphot sharpness parameter against magnitude, we

find that NGC 3627 contains a very large number of marginally-resolved objects, with the sharpest bright objects (stars) having comparable sizes as those of the other target galaxies. To compensate, we model the PSF as a position-dependent Tiny Tim (Krist 1995) PSF plus a residual image (constant for each chip), with the residual image chosen to produce a mean sharpness value of zero.

2.2. Distance and Extinction

A side benefit of the use of Cepheid targets is that it is possible to compare our photometry with that of the previous H_0 studies. As noted above, the photometry accuracy is expected to be higher in the present study because of the careful attention to the PSF, but such a comparison still provides a useful check. After attempting to locate the previously-measured Cepheids, we measure the period and mean V and I magnitudes. These values can be used to calculate true and apparent V distance moduli for each Cepheid, using the V and I period-luminosity relations from Madore & Freedman (1991). For NGC 3627, for example, the apparent V distance moduli for the Cepheids are consistent with $\mu_V = 30.46$ ($\chi^2 = 1.04$), implying that differential reddening is not severe. We also find a true distance modulus of $\mu_0 = 30.35 \pm 0.18$, consistent with previous measurements based on these data.

2.3. Cluster Candidates

Cluster/star discrimination is made by examining sharpness values and V magnitudes. On a plot of the two variables, stars fall within an envelope of $|\text{sharp}| < 0.05 + 10^{0.2(V-29)}$, with possible cluster candidates falling below $\text{sharp} = -0.05 - 10^{0.2(V-29)}$. Additionally, because of the diminished photometry quality below $V = 26$, we require possible cluster candidates to have $V < 26$.

As noted above, cluster photometry is subject to a systematic error, a result of use of a stellar PSF. This error, a function of cluster size, brightness, and color, can be calculated via artificial cluster tests analogous to artificial star tests in stellar photometry. Artificial clusters are generated by placing many stars on the image based on an input IMF and profile. The strength of this approach is that it can be used to reproduce either resolved LMC clusters or unresolved distant clusters. To test this procedure, we reproduced four LMC clusters, both in terms of stellar photometry and cluster profile, providing confidence that the routine would also create realistic distant clusters.

The routine was then applied to the distant spiral galaxies, building many thousands of artificial clusters with a range of position, age, initial mass, and core radius (closely related to the a parameter). Each is photometered using the same HSTphot algorithms, producing a library of the expected observed quantities (V , I , and sharpness) as a function of the input parameters. By comparing input and output values for the artificial clusters, it is possible to estimate photometry errors (and thus corrections) of the observed cluster candidates (δV , δI , and $\delta(V - I)$) as a function of their observed quantities. After completing this process, we find that the ability to measure cluster photometry diminishes significantly for clusters with a core radius near or greater than 1 pixel, so these objects are eliminated from the list of cluster candidates. Fortunately this is not a problem in our search for clusters, as the 1 pixel limit corresponds to a radius of ~ 10 pc, much larger than the typical nearby cluster.

3. Preliminary Results

Studies have so far been made for three galaxies, NGC 3627, NGC 4527, and NGC 4639, with results summarized in Table 1.

Table 1. Preliminary Results

Quantity	NGC 3627	NGC 4527	NGC 4639
class	Sb	Sbc	SBb
V time	35000s	55000s	60000s
I time	15000s	25000s	12500s
μ_0	30.35 ± 0.18	30.81 ± 0.14	31.81 ± 0.10
μ_0^1	30.28 ± 0.15	30.74 ± 0.12	32.03 ± 0.22
μ_0^2	30.06 ± 0.17	30.67 ± 0.15	31.80 ± 0.09
A_V	0.11	0.40	0.09
cluster LF, $M_V < -10$	-2.5 ± 0.8	n/a	n/a
cluster LF, $-10 < M_V < -8$	-1.0 ± 0.3	-1.0 ± 0.2	-1.0 ± 0.2
stellar LF, $-10 < M_V < -8$	-3.4 ± 0.5	-2.2 ± 0.6	-2.2 ± 0.3

¹SN Ia project distance moduli: NGC 3627 (Saha et al. 1999), NGC 4527 (Saha et al. 2001), and NGC 4639 (Saha et al. 1997).

²H₀ Key Project distance moduli: NGC 3627 and NGC 4639 (Gibson et al. 2000) and NGC 4527 (Calculated from the Gibson & Stetson 2001 photometry, using the Madore & Freedman 1991 P-L relations)

NGC 3627 is the only of the galaxies with a large number of very bright ($M_V < -8$) cluster candidates. Based on the PC data (which has greater spatial resolution), we find that these objects have core radii of ~ 1 pc and colors of $(V - I) < 0.5$ – parameters comparable to young LMC clusters. There also appears to be a population of bright cluster candidates that is larger and redder (probably older), with core radii of ~ 2 pc and colors of $(V - I) > 0.5$, corresponding to parameters we would expect for old globular clusters. Finally, the fainter ($-8 < M_V < -6$) cluster candidates have a broad range of colors and core radii of 1.5 – 3 pc. Overall, the cluster candidates are rather blue ($V - I < 1$) and trace the galaxy’s spiral structure.

The second galaxy, in order of distance, is NGC 4527. As with NGC 3627, its bright cluster candidates ($M_V < -8$) tend to be blue, but they appear to be somewhat larger (1.5 – 3 pc). Also along with NGC 3627, the fainter cluster candidates have mixed colors and core radii of 1.5–3 pc. The color differentiation is not as strong as in NGC 3627, partially because of internal reddening; some, though not all, of the red ($V - I > 1$) cluster candidates are found in the dust lanes. Most of the remaining red cluster candidates are found beyond the visual extent of the disk, likely indicators of a population of old globular clusters.

The final galaxy in this preliminary work is NGC 4639, the most distant of the three and the only one for which most of the galaxy falls within the WFPC2 field of view. NGC 4639 is also a barred spiral (the only of the three), and shows a blue cluster candidate population tracing the ring and arms. This galaxy shows the largest cluster candidates, with many of the bright blue objects

showing core radii of $4 - 8$ pc. We also find smaller ($1 - 3$ pc) candidates, which have a range of colors, although at its distance we don't expect to resolve as many of the smallest objects as were seen in the NGC 3627 and NGC 4527.

4. Summary

To summarize, we are measuring the properties of cluster populations of spiral galaxies, in order to answer the questions listed in the first section. This paper describes some of the techniques developed for this project, and some preliminary results. HSTphot is used to photometer the stars and clusters, with its sharpness parameter used to discriminate between the two. An artificial cluster routine then creates and photometers (using HSTphot algorithms) clusters with ranges of age, size, and initial mass, allowing the estimation of physical parameters. Although we only have data on three galaxies at this point, we find that blue clusters trace the spiral patterns of their galaxies (while red clusters do not) and that the cluster luminosity functions are in agreement.

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