Star Clusters in the Interacting Spiral Galaxy M51

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M51 Star Cluster Survey with HST ACS

(For details, please refer to Hwang & Lee 2008 AJ, 135, 1567; HL08)

1. Introduction

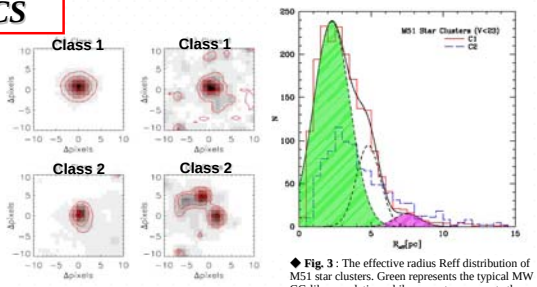
- M51 is a system consisting of two interacting galaxies: NGC 5194 (grand design spiral Sbc) & NGC 5195 (SB0), located at D=8.4±0.6 Mpc (Feldmeier et al. 1997)
- Observed by Hubble Heritage program (PI: S.V.W. Beckwith) and released to the public in May 2005 (Mutchler et al. 2005).
- ACS/WFC in F435W (B), F555W (V), F814W (I), F658N (Hα) bands

2. Star Cluster Survey

- Detection and photometry with SExtractor.
- Star cluster selection and classification using the structural parameters by SExtractor and the visual inspection.
- A 'clean' sample of about 3,600 star clusters with V<23 mag, including ~ 2,200 Class 1 clusters (circular shape without neighbor) and ~ 1,400 Class 2 clusters (non-circular shape and/or with neighbors).

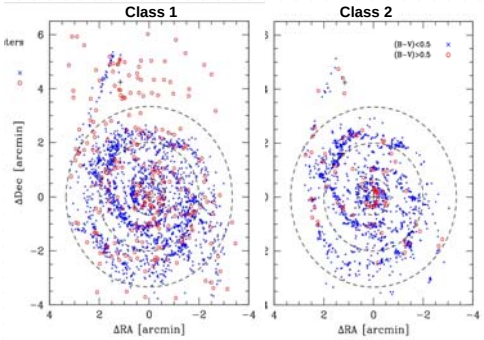
3. Star Cluster Spatial Distribution

- Most star clusters in M51 are bluer than (B-V)=0.5 & (V-I)=0.8 and are mostly distributed along the distinguishable spiral structures of M51.
- Class 2 star clusters appear to be more tightly bound along the spiral arms, compared with Class 1 clusters.
- However, spatial distribution also depends on the color of star clusters: blue clusters with (B-V)<0.5 appear mostly associated with spiral arms while red clusters with (B-V)>0.5 appear more widely scattered.



◆ **Fig. 1** : 2D contour map of Class 1 and Class 2 star clusters (Fig. 2 of HL08).

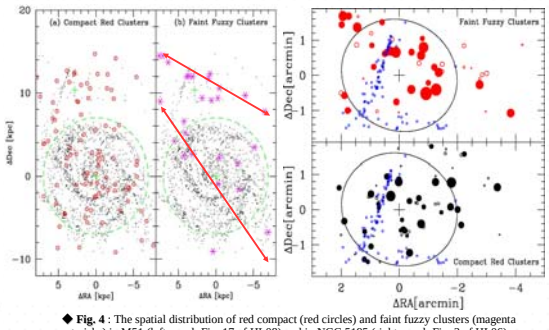
◆ **Fig. 3** : The effective radius Reff distribution of M51 star clusters. Green represents the typical MW GC-like population while magenta represents the large FF population.



◆ **Fig. 2** : The spatial distribution of Class 1 (left) and Class 2 (right) star clusters. Clusters with (B-V)<0.5 are marked in crosses and those with (B-V)>0.5 marked in circles (Figs. 9 & 10 of HL08).

4. Compact Clusters vs. Faint Fuzzy Clusters

- At least more than two components in the size distribution : one with Reff ~ 3pc and the other with Reff > 7pc.
- Faint Fuzzy clusters are found to distribute around NGC 5195 (Hwang & Lee 2006; HL06).
- Spatial distribution of faint fuzzy clusters is different from that of compact red clusters (Fig. 4)
- It seems that faint fuzzy clusters are not distributed in random but rather in a certain direction.
- Different spatial distribution and size implies different origin of FF clusters than other typical compact red clusters.



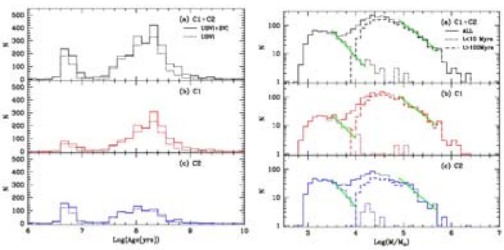
◆ **Fig. 4** : The spatial distribution of red compact (red circles) and faint fuzzy clusters (magenta asterisks) in M51 (left panel: Fig. 17 of HL08) and in NGC 5195 (right panel: Fig. 3 of HL06). These faint fuzzy star clusters are concentrated around NGC 5195 and their distribution is different from that of compact red star clusters.

Tracing the Star Cluster Formation in M51

(Hwang & Lee 2009 ApJ, submitted)

5. Star Cluster Age & Mass Distribution

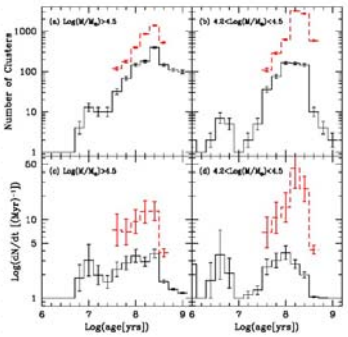
- Used ACS/WFC BVI(Hα) + WFPC2 U(F336W) band data.
- SED fitting using the Bruzual & Charlot (2003) model.
- We have derived age and mass of about 2,600 star clusters with V<23 mag
- Age distribution displays two peaks at ~ 100 Myrs and ~ 250 Myrs in addition to a peak at ~ 60 Myrs.
- Mass distribution ranges from 10^3 to 10^6 $M_\odot$ and is composed of old (t>100 Myr) and young (t<10 Myr) components.
- Power law slope for old component is α = -1.35 +- 0.07 while that of young component if α = -1.87 +- 0.10.



◆ **Fig. 5** : The age distribution (left panel) and mass distribution (right panel) of M51 star clusters. There are two prominent age peaks at about 100 Myrs and 250 Myrs. The slope of mass distribution of old component is relatively shallow compared with that of young component.

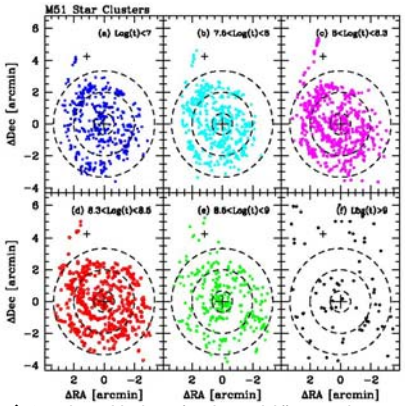
6. Evolution of Cluster Formation Rate

- Cluster formation rate reveals significant increase around 250 Myrs.
- However, the theoretical models of M51 system (Toomre & Toomre 1972; Salo & Laurikainen 2000; Durrel et al. 2003) expect the passage of NGC5195 to have taken place at about 300-500 Myrs ago.
- The theoretically expected interaction epoch is roughly consistent with the epoch of cluster formation rate increase.



◆ **Fig. 6** : Cluster formation rate for clusters with Log(M/$M_\odot$) > 4.5 (left panels) and clusters with 4.2 < Log(M/$M_\odot$) < 4.5 (right panels). Black solid line shows the observed data while red dashed line shows the extrapolated data from the best fit mass distribution in the corresponding age bin.

- Star clusters with Log(t)<8.5 display mostly similar spatial distribution, showing well defined spiral arms
- Star clusters with Log(t)>9 appear widely scattered, suggesting that they may be halo population.
- Spiral arm seems to be developed around Log(t)=8.5 or later, when the cluster formation rate was increased.

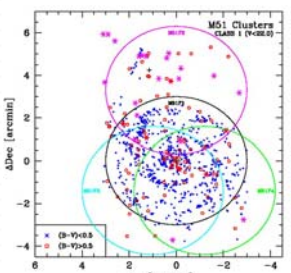


◆ **Fig. 7** : The spatial distribution of star clusters with different ages. The age range is indicated in each panel. Spiral arm structure appears after Log(t) = 8.5, i.e. t = 250~300 Myrs, which is just around the significant increase of cluster formation rate.

Spectroscopy Survey of M51 Star Clusters

7. Next Step – Spectroscopy Campaign

- Very Important Role of Ground-based Telescopes
- Major purposes of this 'proposed' campaign:
  - To determine the kinematical properties of star clusters in M51
  - To separate the halo population from the disk population of clusters
  - To compare the kinematical properties of Faint Fuzzy clusters with Compact Red clusters.
  - To determine the age and metallicity of star clusters.
  - To reconstruct the star cluster formation history in the context of the dynamical evolution of M51.
  - To test theoretical models for dynamical evolution of M51 – single passage model or multiple passage model.



◆ **Fig. 8** : A proposed FOV map for M51 star cluster spectroscopy observation. A FOV of FOCAS/MOS is used for this. Blue clusters are marked in crosses and red clusters are in circle, while faint fuzzy clusters are plotted in asterisks.

10. Summary

- We have detected and visually classified about 3,600 star clusters with V < 23 in the entire HST/ACS field of M51.
- Most star clusters are bluer than (B-V)=0.5 and (V-I)=1.0 but some clusters are as red as (V-I)>1.0.
- Some of these red clusters are faint fuzzy clusters mostly around NGC 5195.
- Faint fuzzy clusters display a different spatial distribution than compac red clusters, implying different origin.
- Cluster age distribution shows two peaks at about 100 Myrs and 250 Myrs. And the cluster formation rate appears to be increased around 250 Myrs, which is roughly coincide with the dynamical encounter epoch of NGC 5195 and NGC 5194 expected by the theoretical models.

9. Tentative Proposed Setup

- For Subaru/FOCAS:
  A combination of 300B grating and L600 filter to cover 3500 – 6000 A with 4800 sec accumulated exposure time, which returns 1.34 A/pixel spectra for V< 22 mag clusters.
- For Gemini/GMOS:
  B600 or R600 grating with 7200 sec accumulated exposure, which returns 0.45 ~ 0.47 A/pixel spectra for V<22 mag clusters.

11. References

- Durrel et al. 2003, ApJ, 582, 170
- Hwang & Lee 2006, ApJ, 638, L79
- Hwang & Lee 2008, AJ, 135, 1567
- Hwang & Lee 2009, ApJ, submitted
- Mutchler et al. 2005, BAAS, 37, 2
- Salo & Laurikainen 2000, MNRAS, 319, 377
- Toomre & Toomre 1972, ApJ, 178, 623