

Study of the young and old compact stellar cluster population in M81

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ABSTRACT

We study the population of compact stellar clusters in M81, using the HST/ACS images in the filters F435W, F606W and F814W that cover a total field of view of approximately 340 square arcmin, the largest area covered until now for this galaxy. We present details about the selection criteria, which were based both on morphological and photometrical features. The extracted sample of compact stellar clusters shows the presence of two cluster populations, a blue cluster group (young) with more than 300 objects, and a red cluster group (old) with 138 objects. Surprisingly, the young group lacks clusters more massive than 10000 solar masses, that are present in large numbers in its neighbor M82. The luminosity function of the young group follows a power-law distribution with an index of 2.0. The luminosity function for the red group resembles very much that of the globular clusters in the Milky Way. Assuming an age of 5 Gyr, these red clusters have masses between 0.1 to 10 million solar masses.

INTRODUCTION

With the advent of the HST (Hubble Space Telescope) a new class of clusters have been identified: the Compact Star Clusters (CSCs) with typical masses of $\sim 3 \times 10^4$ to 10^6 solar masses and sizes between 1 and 6 pc (Meurer et al. 1995). CSCs have been found in several environments, including violent star formation regions within interacting galaxies (Whitmore et al. 1999). M81 (NGC 3031) is a large Sab spiral galaxy at 3.63 Mpc (Freedman et al. 1994) and it belongs to the M81 Group which includes the prototype starburst galaxy M82. Recent observations of M82 show that it has a large number of CSCs, with young clusters (age < 10 Myr) concentrated towards the center and old clusters (> 100 Myr) homogeneously distributed across the disk (Mayya et al. 2008). Almost all the stars in the disk of M82 were formed in a violent disk-wide burst about 100–500 Myr ago, following the interaction of M82 with M81 (Mayya et al. 2006). The cluster population of M81 has been studied previously -- Chandar et al. (2001) using data from the WFPC2/HST camera discovered 114 compact star clusters. The analysis found two different cluster populations, red clusters similar to globular clusters observed in our Galaxy and a young population with ages (< 600 Myr) that support a recent star formation epoch in M81 related with the interaction between M81 and M82.

OBSERVATIONS

The observations used in this work were taken with the ACS on board the HST. In Figure 1, we show the locations of the fields overlaid on a GALEX Image. There are 29 adjacent fields that cover a total area of ~ 340 square arcmin, with a resolution of $0.05'' \text{pix}^{-1}$ (0.88 pc pix^{-1}). The area covered in our search is 8.5 times larger than the previous search by Chandar et al. (2001). The F435W (B), F606W (R) and F814W (I) filters were used on each field.

CSCs DETECTION AND SELECTION

We used the automatic detection code SExtractor (Bertin & Arnouts 1996) to select an unbiased sample of cluster candidates. The B band was used for the first selection of candidates and we carried out photometry in each of the B, R and I images. This resulted in 656,438 objects in the 29 fields analyzed.

The preliminary list of candidates contain unresolved (stellar-like) and resolved (extended) objects. Among the resolved objects we have the compact stellar clusters, but also we find two kinds of contaminating sources: 1) Sources formed by improper subtraction of the background due to the presence of dust and 2) Sources formed by the superposition of several point sources mainly due to blended stars. In order to reject the contaminating sources we applied the following criteria:

Selection Filter 1:

1) Because the point sources (stellar-like) have a size distribution that peaks at a FWHM of 2.1 pixels, we considered those sources with a FWHM greater than 2.4 as cluster candidates. In order to avoid extreme extended objects such as large stellar groups and artificial sources created by residual background we impose a FWHM < 10 pixels and an area greater than 50 pix (Figure 2).

Selection Filter 2:

2) All sources with ellipticity < 0.1 are compatible with being bound systems and are automatically accepted. 3) More sources with ellipticities greater than 0.1 are in general not clusters. However, we found that some genuine sources are slightly elongated, and such sources have a bright central concentration of light. In order to rescue these sources, we compared the magnitudes inside aperture diameters of 2 and 4 pixels ($dmag$).

CONCLUSIONS

Thanks to the superb spatial resolution of the ACS camera on board the HST, we were able to study the largest sample of compact stellar clusters in M81 until now. We found a total population of 905 Compact Stellar Clusters, more than 300 of them brighter than $B=22$ mag. The sample is divided into two well-defined populations – a young group with ages less than 500 Myr, masses around 10^4 solar masses and distributed along the spiral arms of M81, and a group of globular clusters with masses between 10^5 – 10^7 solar masses which are uniformly distributed across the face of M81. It may be noted that the inferred ages are in agreement with the time of the encounter of M82 with M81. The luminosity function of young clusters follows a power law distribution with $\alpha=2.0$, with a clear deficit of high-mass clusters as compared with the number of massive stellar clusters observed in M82 (Mayya et al. 2008). Perhaps massive cluster formation requires an extreme burst mode of star formation such as seen in M82. The luminosity function for the M81 globular clusters has the same distribution as the Milky Way globular clusters with a peak at $M_B=-6.7$ mag ($M_V=-7.5$ mag). The result confirms the similarities between M81 and the Milky Way but also makes our complex selection method very trustworthy. The close encounter of M82 with M81 created a new generation of compact clusters (those with ages less than 500 Myr) but did not affect the distribution of old clusters that were in place at the time of the encounter.

ANALYSIS

In Figure 3, we present the Color-Magnitude Diagram (CMD) of the selected candidates. They have a range of colors between $-0.55 < B-I < 4.29$. It can be seen that there are clearly two families of clusters. Following this visual trend, we separated them into two groups, a blue stellar cluster group with $B-I < 1.7$ (blue rhombus) and a red group with $B-I > 1.7$ (red circles). There are 767 stellar clusters in the former group and 138 in the latter group. The reddening vector for a visual extinction of 1 mag is shown (Kong et al. 2000, schlegel et al. 1998). It is very unlikely that the two families are produced by just the effect of dust.

An evolutionary track for an SSP for a cluster mass of 10^4 solar masses ranging from 8 Myr to 1 Gyr is superposed to explain the colors of the blue group (Girardi et al. 2002). It can be easily seen that there are no clusters above the brightest point in the track, indicating the lack of massive clusters. The track reproduces the observed colors of the brightest clusters ($B < 22$ mag). At fainter magnitudes there are several clusters bluer than the SSP which share the same color range as that for individual stars (green small rhombus). Many of these sources may not be clusters and instead blended stars and hence we exclude them from detailed analysis. Therefore, most genuine clusters are consistent with ages younger than 500 Myr and have masses less than 10^4 solar masses. In the unlikely case of clusters being older than 1 Gyr the mass can be $\sim 10^5$ solar masses.

The red clusters have colors expected for galactic globular clusters. We hence assumed a constant age of 5 Gyr for this group, and estimated their masses. The resulting masses are in the range of 10^5 – 10^7 solar masses.

Figure 4 shows the luminosity function (LF) for the young clusters that in the magnitude range $19 < B < 22$ mag is consistent with a power law index of $\alpha = 2.0$ (dotted line), similar to that found for the young stellar cluster systems in other galaxies (de Grijs et al. 2003).

The LF for the old group is plotted in Figure 5, where we also plotted the distribution for the Milky Way globular clusters. Both agree very well up to around $M_B = -4$ mag ($B=24$ mag), which is the completeness limit for the red objects of our sample. Notice that, the red group contains 138 clusters, which compares well with the 146 globular clusters in the Milky Way (Harris 1996). It is heartening to find that the numbers and the LF between M81 and the Milky Way coincide, in spite of the complexity involved in the selection process.

In Figure 6, the spatial distribution of young (blue squares) and old clusters (red circles) are presented over a GALEX near UV image. The young clusters are located mainly on top of the spiral arms, where star formation is taking place currently and reinforces the idea that the blue clusters have ages of a few hundred million years.

On the other hand, the old clusters are distributed homogeneously over the face of M81 which is compatible with these clusters being located in the halo of M81.

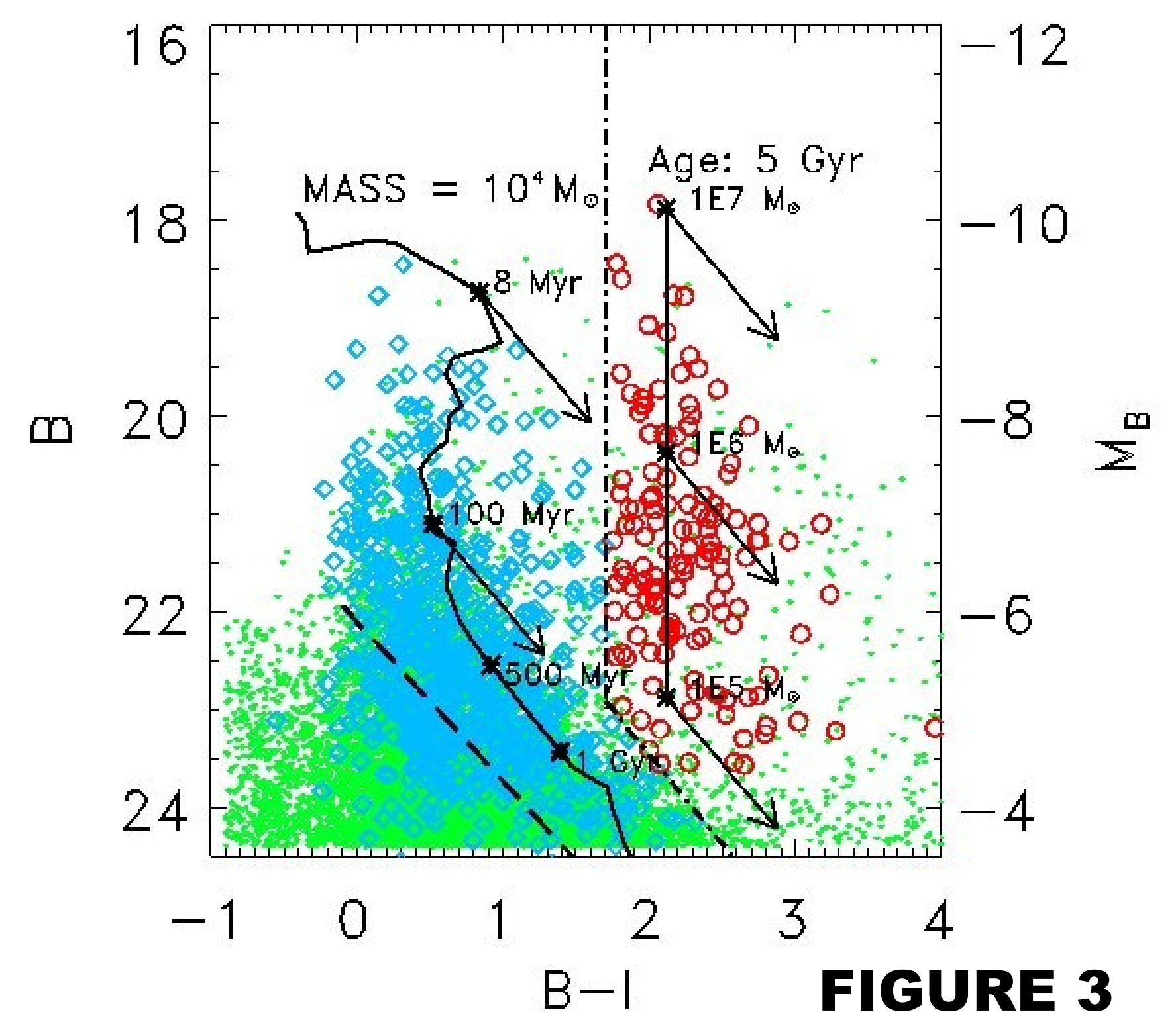


FIGURE 3

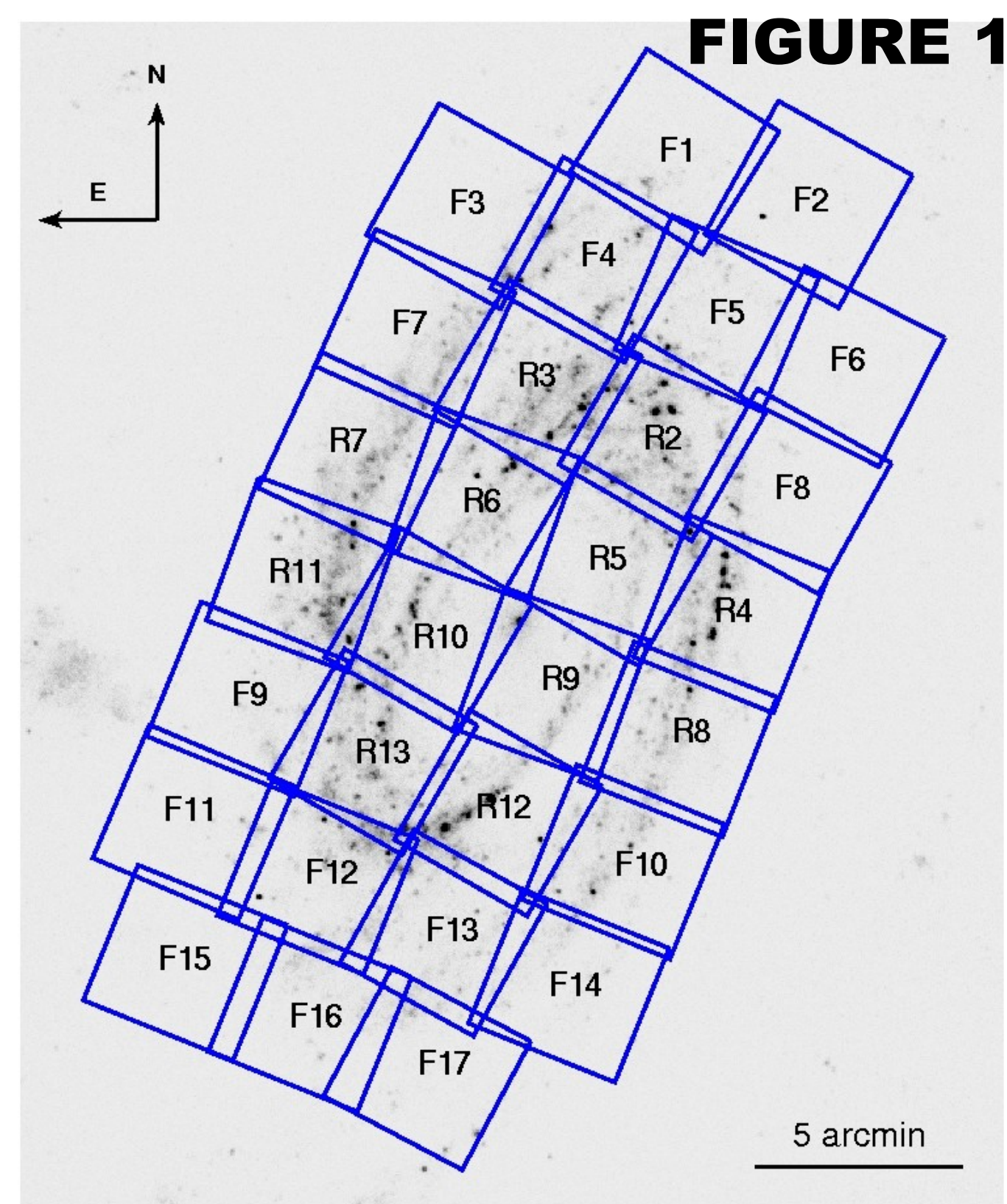


FIGURE 1

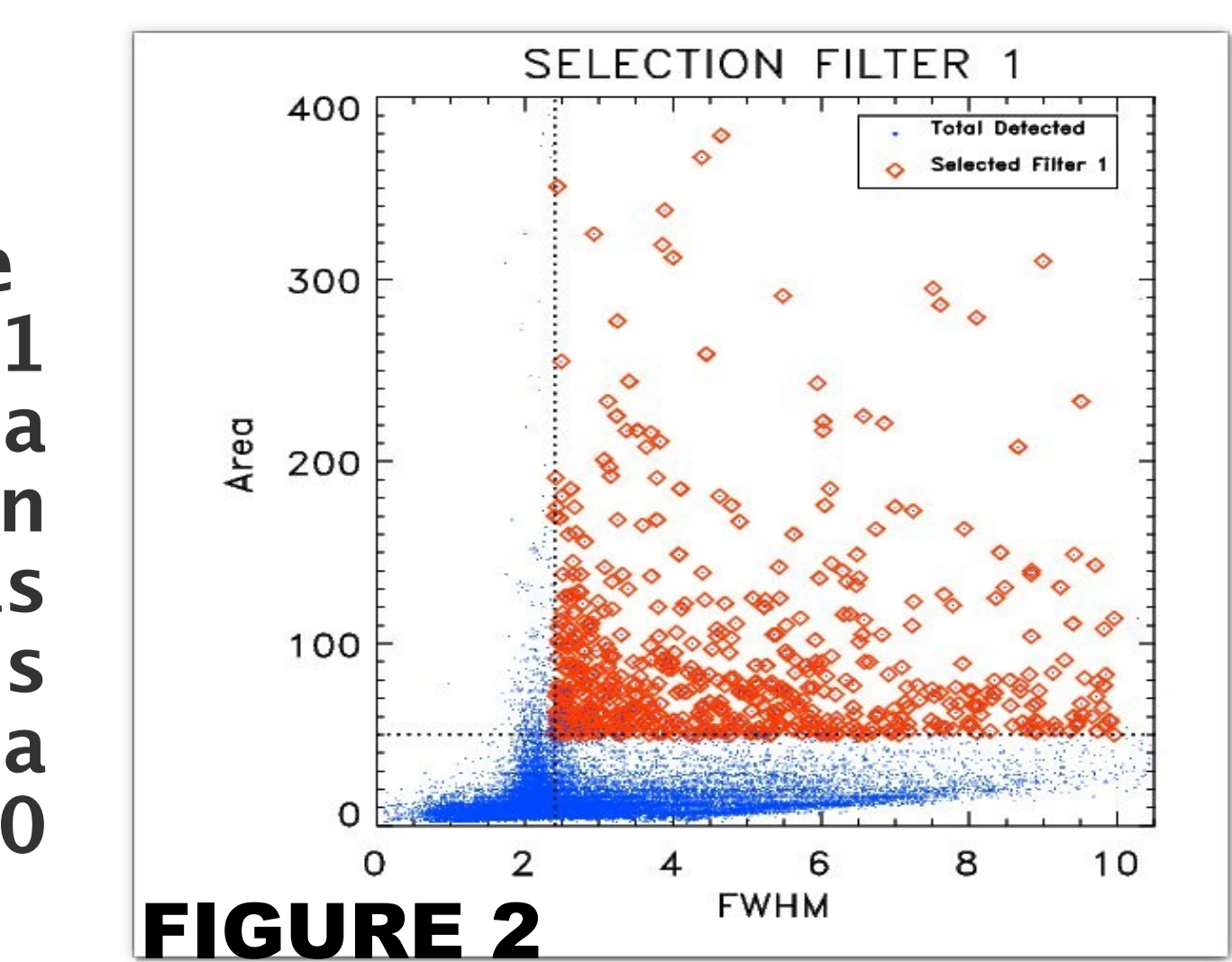


FIGURE 2

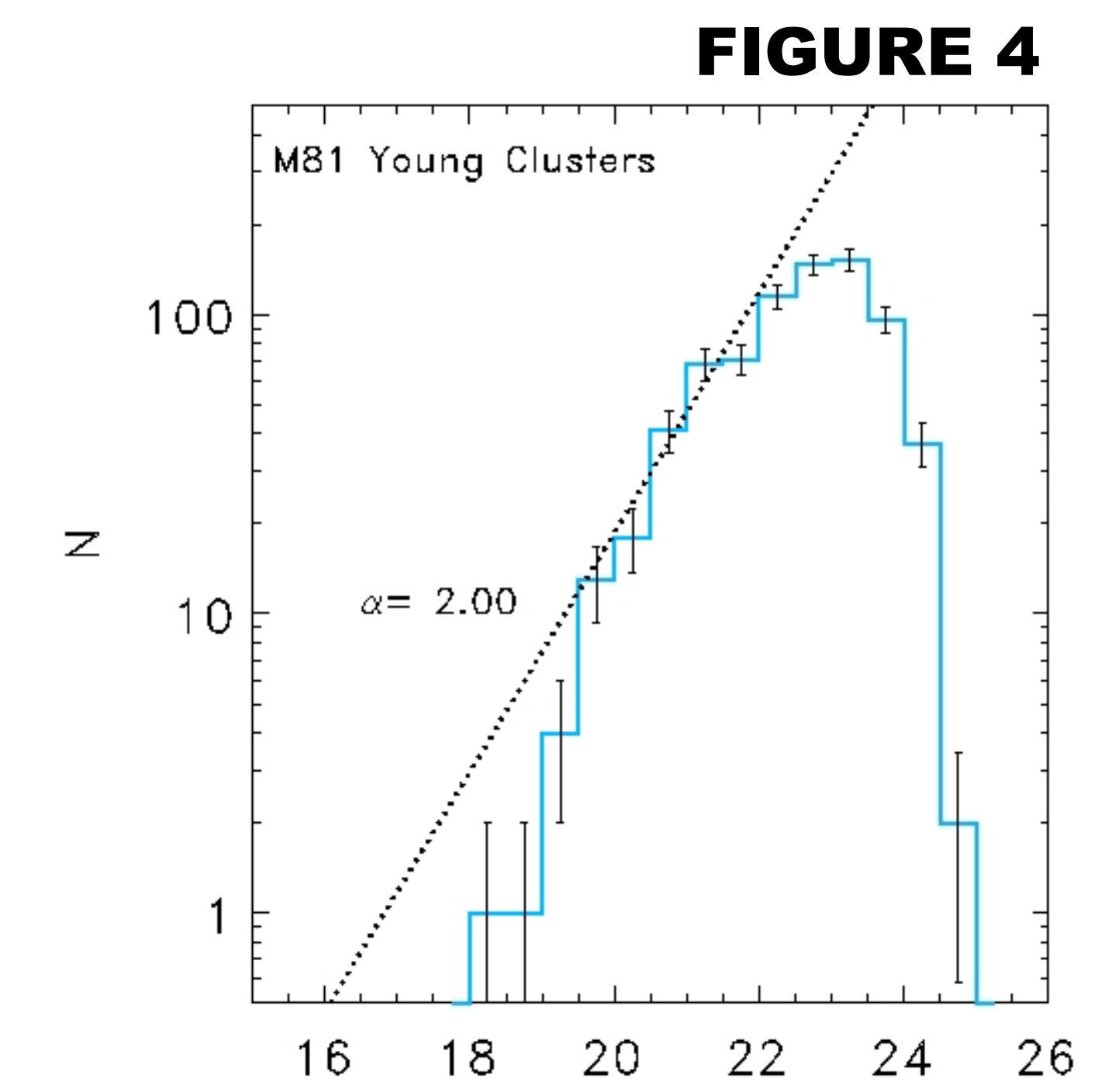


FIGURE 4

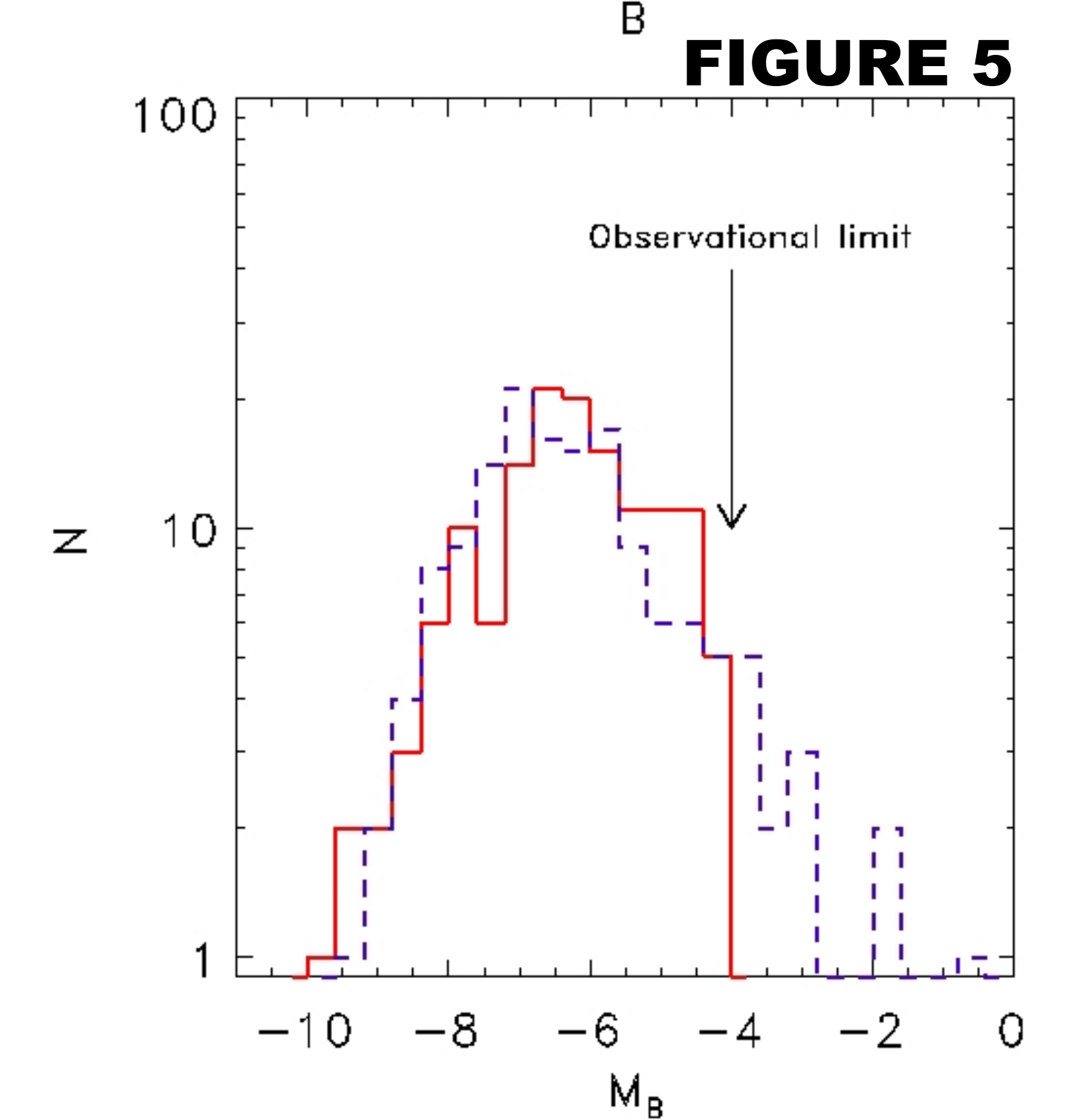


FIGURE 5

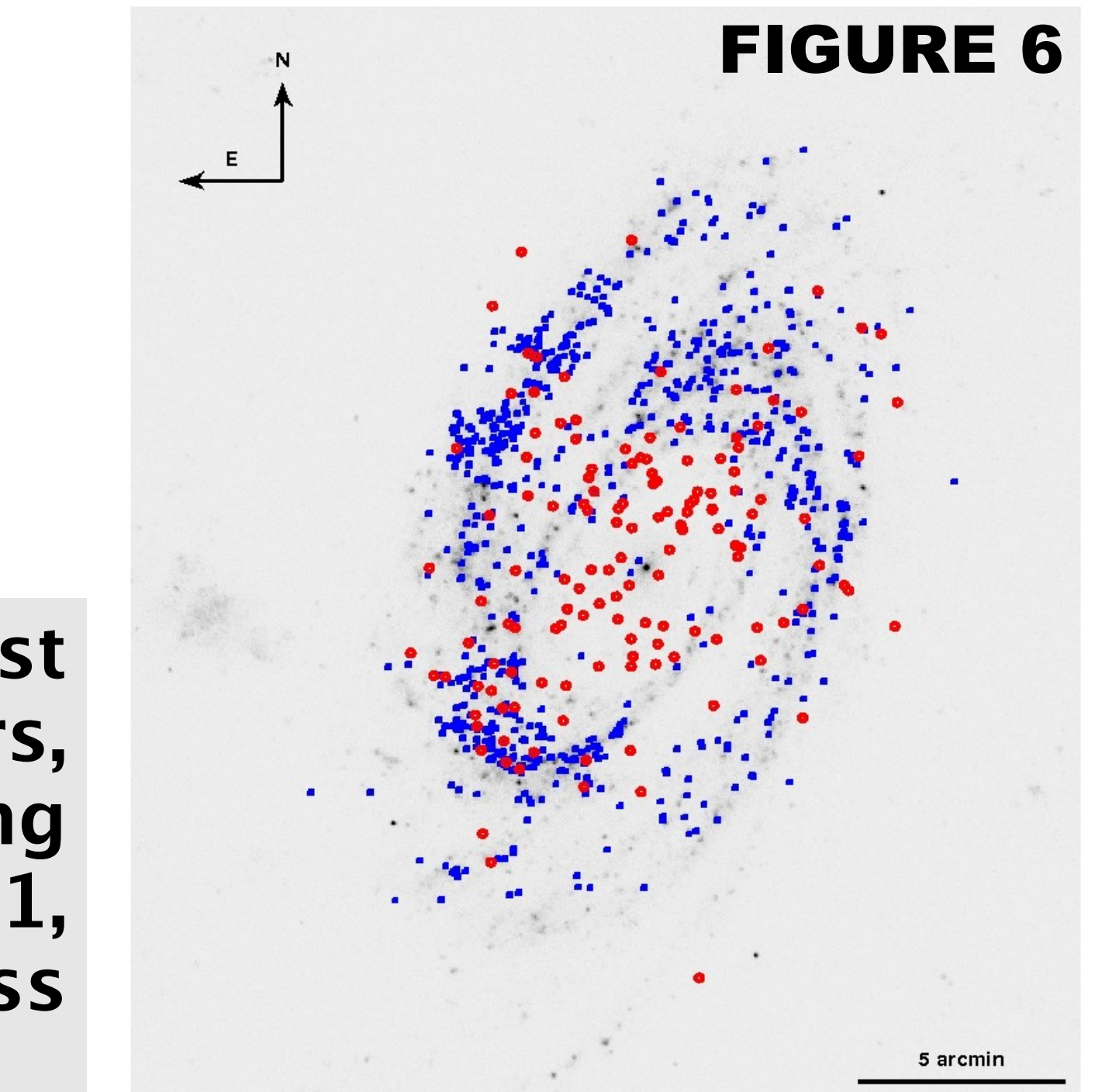


FIGURE 6

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