HST Pixel Analysis of the Interacting Galaxy System M51

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ABSTRACT

A pixel analysis is carried out on the interacting galaxy system M51 (NGC 5194 + 5195), using the HST/ACS images in the F435W, F555W and F814W (BVI) bands. After 4 x 4 binning of the HST/ACS images to secure a sufficient signal-to-noise ratio for each pixel, we derive several quantities describing the pixel color-magnitude diagram (pCMD) of M51: blue/red color cut, red pixel sequence parameters, blue pixel sequence parameters and blue-to-red pixel ratio. For NGC 5194 (Sbc type), the red sequence pixels (corresponding to the bulge or dusty area) are mostly older than 1 Gyr, while the blue sequence pixels (corresponding to the disk or spiral arms) are mostly younger than 1 Gyr, in their luminosity-weighted mean stellar ages. For NGC 5195 (SB0 type), most pixels form a red pixel sequence and only a very small fraction of pixels form blue pixel sequences. The blue pixel sequences of NGC 5195 seem to originate from the tidal interaction between the two galaxies, whereas almost all pixels in the NGC 5195 main body form the red pixel sequence. The pixels corresponding to the central AGN area of NGC 5194 show a tight sequence at the bright-end of the pCMD, of which spatial extent is R~100 pc.

Introduction

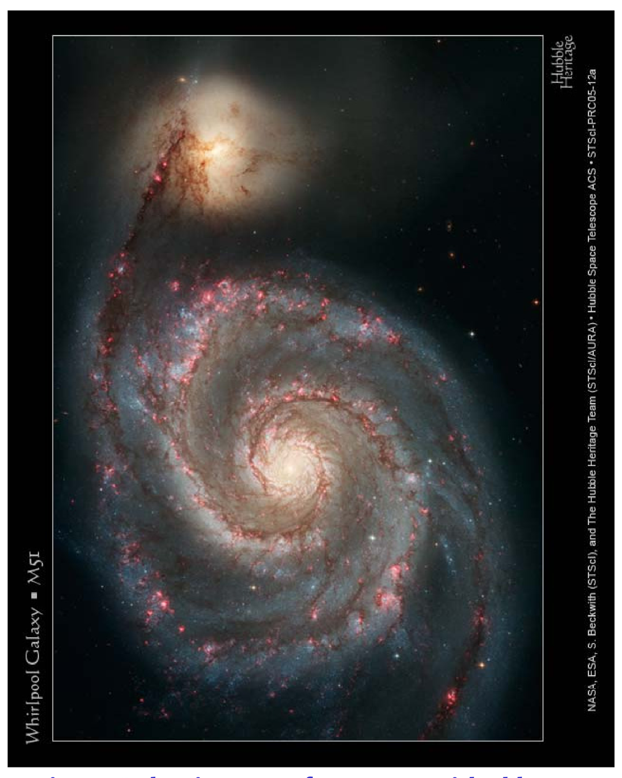

Fig. 1. Color image of M51, provided by the Hubble Heritage Team.

M51 (NGC 5194 + NGC 5195)

M51 is one of the nearest interacitng galaxy system and consists of NGC 5194 (Sbc type) and NGC 5195 (SB0 type). Since this system provides a very close view of an interaction between a face-on late-type galaxy with grand design spiral arms and a dusty barred lensicular galaxy, M51 is a very good target to study the effect of a galaxy interaction on the stellar populations in detail.

Pixel Analysis

Extended sources with sufficient angular size but not nearby enough to resolve their stars can be investigated using the pixel analysis methods (e.g. Conti et al. 2003; de Grijs et al. 2003; Lanyon-Foster et al. 2007).

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We present a pixel analysis of M51. The main goals are 1) to improve our understanding of M51 properties and 2) to establish the pixel color-magnitude diagram (pCMD) analysis methods for future photometric studies of galaxies.

Data and Analysis

Hubble Heritage Data of M51

The Hubble Heritage Team observed M51 using the HST/ACS with F435W, F555W, F814 and F658N filters. The observation was completed in January 2005 and the data were publicly released in April 2005, covering about a 6.8'x10.5' field centered on M51. Here, we use F435W (B), F555W (V) and F814W (I) images.

Pixel Binning and Area Division

We binned the image pixels by a factor of 4 (4x4 binning) to ensure that each pixel is statistically independent of the surrounding pixels and to improve the S/N. We divide the entire area into the NGC 5194 and NGC 5195 areas, using a line that is vertical to the line connecting the centers of the two galaxies and the ratio between its distances to the NGC 5194 center and to the NGC 5195 center is 7:3.

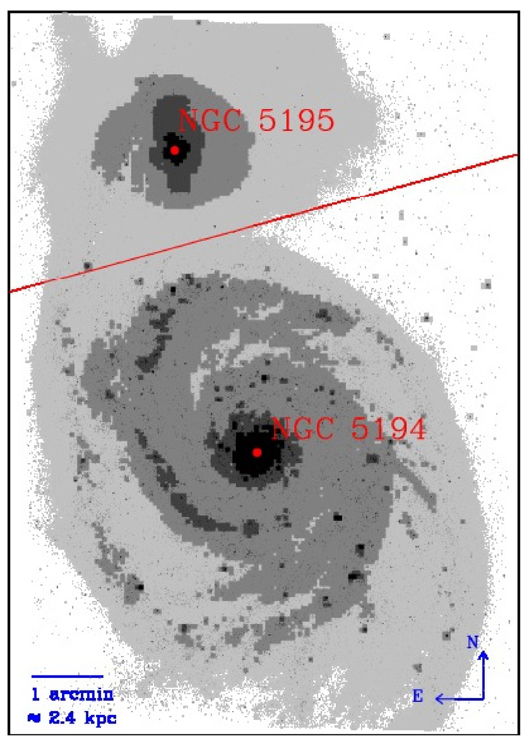


Fig. 2. Area division between NGC 5194 and NGC 5195.

NGC 5194 pCMDs

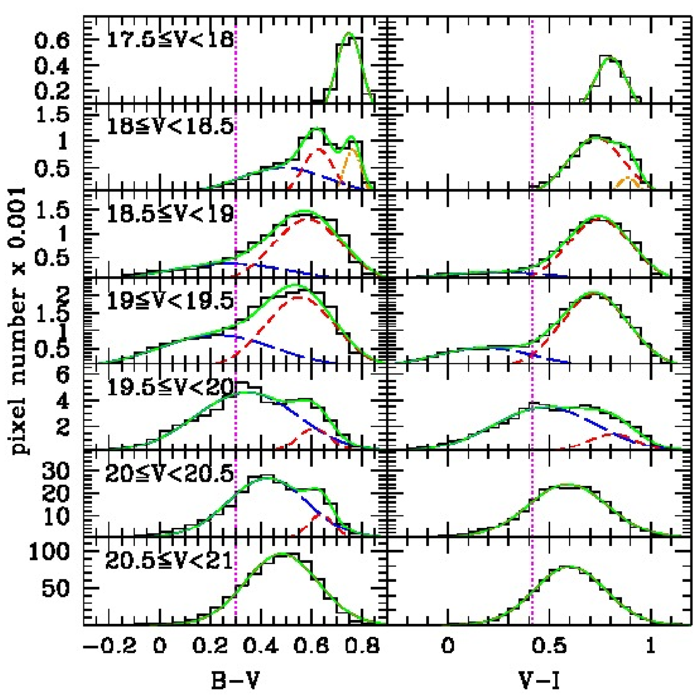


Fig. 3. Color distributions as a function of pixel surface brightness with Gausian fits for NGC 5194.

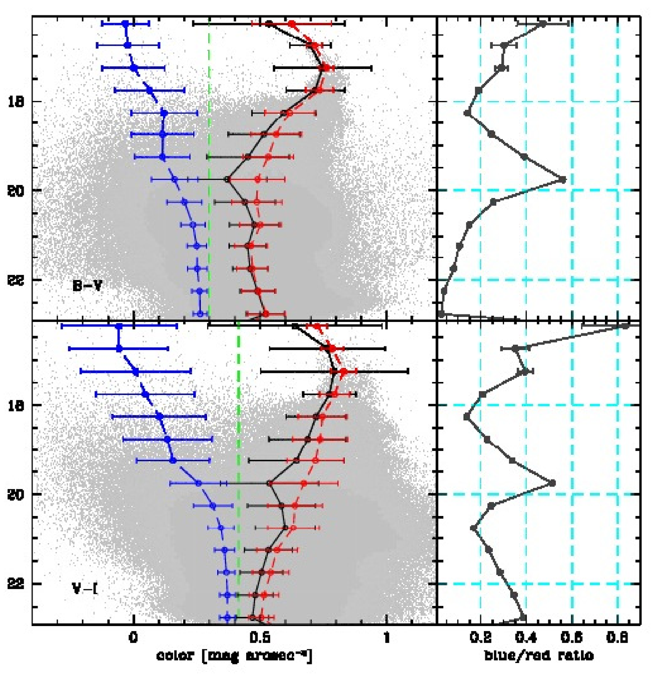


Fig.4. Blue, red and total pixel sequences, and blue-to-red pixel number ratio in the pixel color-magnitude diagrams (pCMDs) for NGC 5194.

From the Gaussian fits to the color distributions of the NGC 5194 pixels (Fig. 3), we selected B–V=0.299 and V–I=0.416 as the color cuts between blue pixels and red pixels. The spatial distributions of the blue and red pixels approximately correspond to the disk/spiral arm area and bulge/dusty disk area, respectively. If solar metallicity and moderate dust extinction are supposed, the luminosity-weighted mean stellar ages of the blue sequence pixels are mostly < 1 Gyr and the median colors of the blue pixel sequence correspond to the SSP-equivalent ages of 5 Myr – 300 Myr, which agrees with the result of Hwang & Lee (2010) that the star cluster fomration rate in M51 increased significantly during the period of 100 – 250 Myr ago. The median colors of the red pixel sequence can be due to either metallicity variation of Δ[Fe/H] ~ 2 or dust variation of $\Delta\tau_V \sim 4$ (ΔE(B-V) ~ 0.2). However, the actual red pixel sequence does not exactly agree with either the metallicity or dust effects. Thus, the red pixel sequence is thought to be affected by both metallicity and dust, and possibly also by age.

NGC 5195 pCMDs

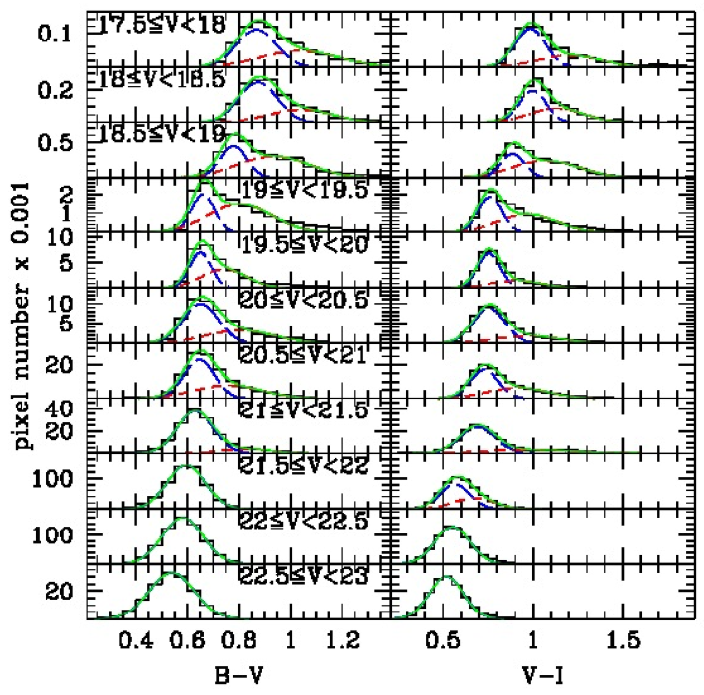


Fig. 5. Color distributions as a function of pixel surface brightness with Gausian fits for NGC 5195.

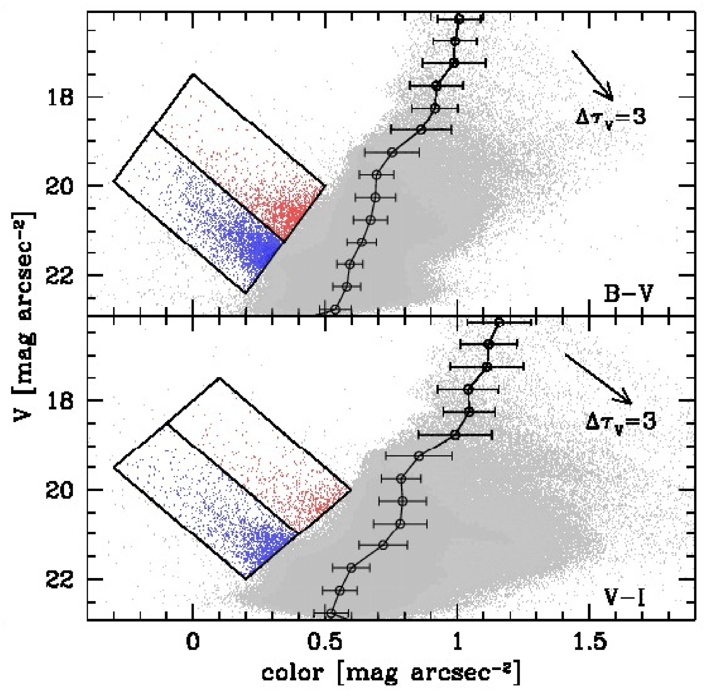
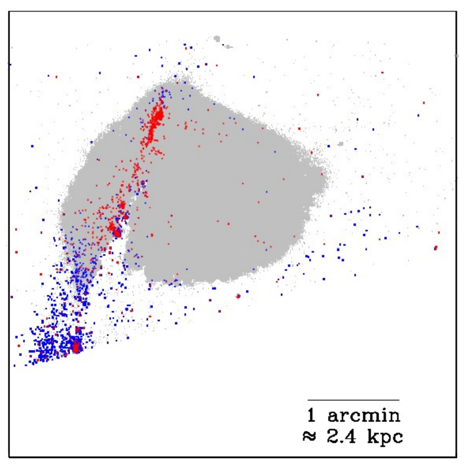


Fig.46 Blue and red pixel sequences, in the pCMDs for NGC 5195. The arrows show the extinction vectors.

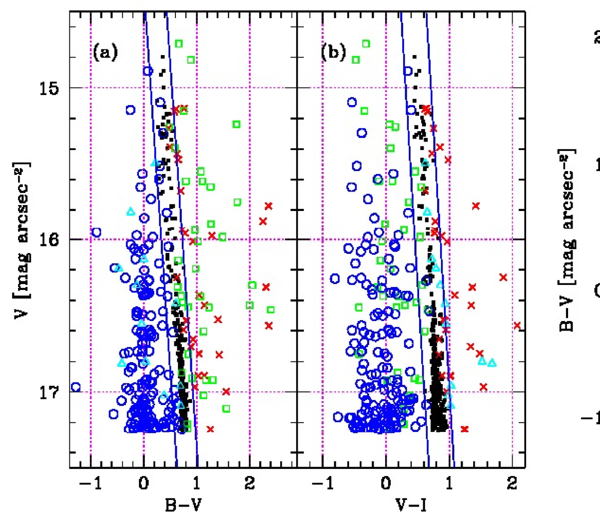
Unlike NGC 5194, NGC 5195 has very weak blue pixel sequences, which are hardly found in the color distribution plots (Fig. 5). Thus, we manually selected two blue pixel sequences in the NGC 5195 pCMDs and regarded all pixels except for those blue sequence pixels as red sequence pixels (Fig. 6). The red pixel sequence of NGC 5195 is redder than that of NGC 5194 and has larger color dispersions, which seem to be the results of heavy dust extinction, as large as $\Delta\tau_V \sim 6$.

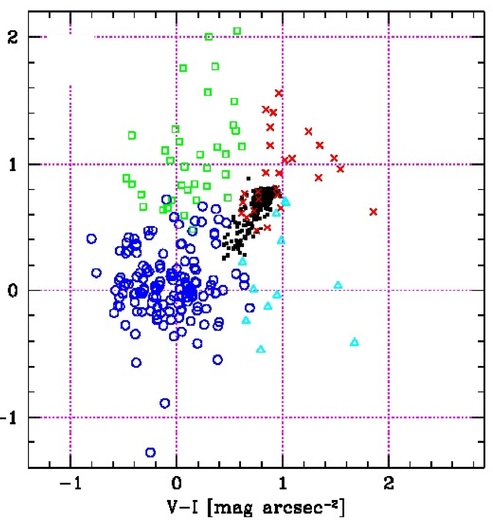


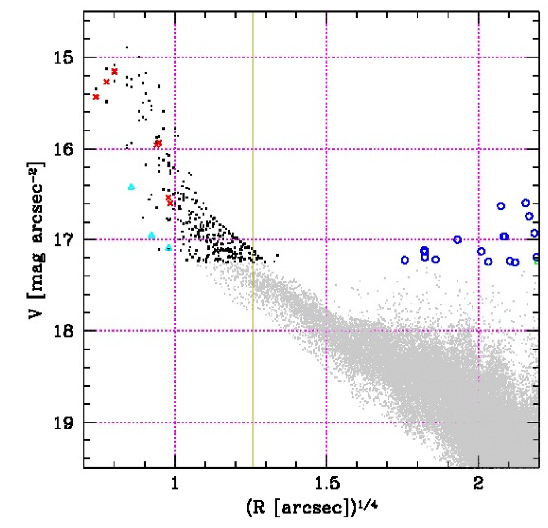
While the red sequence pixels are almost evenly distributed over NGC 5195, the blue sequence pixels are tightly gathered along the tidal bridge between NGC 5194 and NGC 5195 (Fig. 7). This 'blue pixel stream' seems to be the inflow of young stars from NGC 5194 or the star formation regions along the inflow of cold gas from NGC 5194. In other words, if there were no tidal interaction with NGC 5194, NGC 5195 would have only a single red pixel sequence.

Fig. 7. Spatial distribution of the blue sequence pixels in NGC 5195.

Bright-end Pixels in the NGC 5194 pCMDs







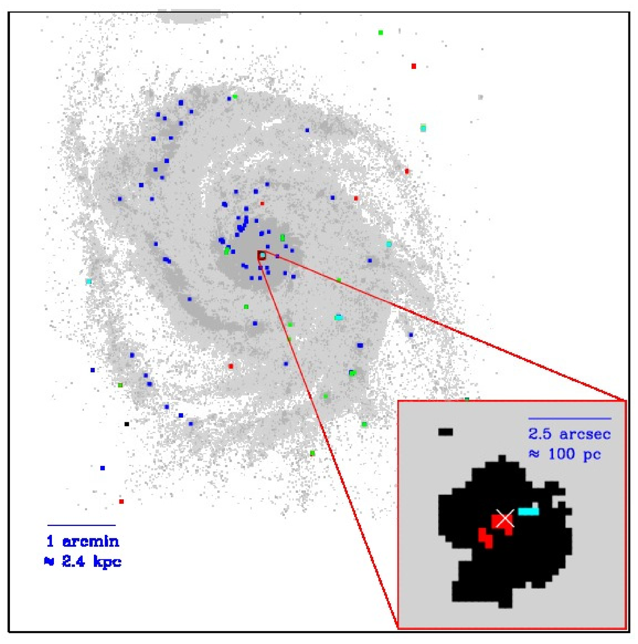


Fig. 8. Bright-end pixels of NGC 5194 in the pCMDs. The bright-end sequence population (BSP; black dots) is defined as the pixels within a narrow cylinder in the V - (B–V) - (V–I) domain, with a 0.2 radius of the color indices (solid lines).

Fig. 9. Bright-end pixels of NGC 5194 in the pixel color-color diagram.

Fig. 10. Pixel surface brightness versus $R^{1/4}$ in the central region of NGC 5194. The vertical yellow line is drawn at R = 2.5" (~ 100 pc).

Fig. 11. Spatial distribution of the bright-end pixels of NGC 5194. The center of NGC 5194 is marked as a white cross (RA = 13h 29m 52.72s, Dec = +47d 11m 43.4s).

The bright-end of the NGC 5194 pCMD has a `reverse' slope: brighter pixels are bluer unlike typical red sequence pixels. The pixels forming the tight sequence at the bright-end of the pCMD are within ~ 100 pc from the NGC 5194 center. Since NGC 5194 hosts an AGN (Ford et al. 1985; Terashima & Wilson 2001), the AGN may significatly affect the photometric properties of the central area of NGC 5194. It is interesting that the size of the area occupied by the bright-end sequence population (BSP) is approximately consistent with the estimated size of the AGN torus in the AGN unification model (Pier & Krolik 1993). However, such an agreement does not explain the origin of the tight and reverse sequence. If the light from those central pixels were stellar light, the obscuring torus would make those pixels redder, rather than bluer. In short, the BSP may be a photometric indicator of the central AGN properties, but its physical origin is an open question for now.

Two papers with more details are coming soon (hopefully).

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