Stellar population of the interacting galaxies M 51.

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Abstract. Stellar photometry of about one million stars in the system of the interacting galaxies M 51 (NGC 5194/NGC 5195) has been carried out on the basis of the ACS/WFC images of the Hubble Space telescope. The distance to the system has been determined by TRGB method and metallicity of red supergiants along the NGC 5194 radius has been measured. A comparison of the spacial distribution of stars in the main galaxy NGC 5194 with our empirical model of spiral galaxies showed their similarity, in spite of interaction in system M 51. It has been discovered that the ”feathers”, arising as a result of the interaction of galaxies, mainly consist of stars of intermediate age.

Introduction

The spiral galaxy M 51 (NGC 5194/5195 ore VV 001) discovered in 1773 by Charles Messier is of great interest because it is a nearby system of two interacting galaxies (Fig. 1). Therefore Vorontsov-Vel’yaminov et al. (1959) put it first in their list of interacting galaxies. M 51 system is not far from the Local Group and it is convenient for checking of theoretical simulation of galaxy interaction. At present there exist two models of galaxy interaction which describe morphology and dynamics of M 51:

1) A model with a single parabolic approach (Toomre & Toomre, 1972)

2) A model of the related system with repeated passing of the companion (Salo & Laurikainen, 2000).

In the model of Toomre and Toomre (1972) the galaxy-companion NGC 5195 crossed the south area of the main galaxy disk NGC 5194 at a distance of 25 − 30 kpc approximately 300 − 500 million years ago. NGC 5195 is located now at a distance of 50 kpc behind M 51 disk and it moves away. This model is confirmed by the observations of kinematics of the planetary nebulae (Durrell et al., 2003).
In the model with the repeated approaches NGC 5195 crossed first NGC 5194 disk towards an observer, then it crossed NGC 5194 once more in the north about 100 million years ago. Now NGC 5195 is situated within a distance of about 20 kpc behind the main galaxy NGC 5194. This model is confirmed by radio observations of the detailed kinematics of HI (Salo & Laurikainen, 2000).

**Investigation of M 51 stellar population**

Images received at the Hubble Space Telescope with ACS/WFC in 2005 (ID 10452) give a possibility to study the population of the galaxies directly. We investigated 6 fields which cover both galaxies of system M 51 (Fig. 2). Exposure durations are 1360 seconds in F555W and F814W filters. The results of stellar photometry for almost a million stars obtained with DAOPHOT are represented as colour — magnitude diagram (CMD) in Fig.3a. The obtained CMD is similar to the diagrams of normal spiral galaxies. It shows a wide branch of blue supergiants, a branch of red supergiants and many stars of intermediate age and red giants unresolved on the diagram. Determinations of the distance to M 51 have been carried out many times. The distance values obtained by different techniques are presented in the Table 1.

| Year | Authors            | Method                  | (m-M) | σ   |
|------|--------------------|-------------------------|-------|-----|
| 1974 | Sandage & Tammann  | H II regions            | 29.91 |  |
| 1990 | Georgiev et al.    | Stellar association sizes | 29.2  | 0.2 |
| 1994 | Iwamoto et al.     | SN 1994Ic+O stars       | 29.2  | 0.2 |
| 1996 | Baron et al.       | SN 1994                 | 28.9  | 0.6 |
| 1996 | Feldmeier          | PNLF                    | 29.62 | 0.15|
| 2006 | Takats & Vitko     | SN 2005cs               | 29.25 | 0.34|
| 2007 | This paper         | TRGB                    | 29.98 | 0.15|

Using the photometry results we found the distance to M 51 by determining the location of the tip of the red giant branch (TRGB method, Lee et al., 1993). In order to decrease the influence of brighter AGB stars on the accuracy of TRGB determination, we used three distant periphery galaxy regions, where red giants predominate (Fig. 4). Fig. 5 shows the luminosity function of the red giants and the jump in luminosity function computed with the Sobel filter determines the tip of the giant branch. Using equations of Lee et al. (1993) we have obtained: $[\text{Fe/H}] = -0.65$ and $(m - M) = 29.98$, that corresponds to the distance $D = 9.9 \pm 0.7$ Mpc.

**Metallicity distribution in the galaxy disk**
Since the location of the red supergiant branch at CMD depends on their metallicity which can be well seen in the theoretical isochrones (Bertelli et al., 1994), we used this effect for studying metallicity distribution of stars along the radius of NGC 5194. For relative measurement of red supergiants metallicity we use average colour indices relative to the colour index of the blue supergiants branch. Such approach makes the transition to absolute measurements of metallicity unnecessary.

Red supergiants colour indices have been obtained in seven ring-shaped regions (Fig. 6), the stars being selected in the band $I = 23.0 \pm 0.25(M_I = -7)$. Variation of the average colour value along the galaxy radius is shown in Fig. 7. A sharp drop of metallicity in the central galaxy region, slow variation in spiral arms and the second sharp drop in the periphery of the thin disk can be well seen in this figure. The obtained results are in agreement with the metallicity variations of the young stars of our Galaxy (Shaver et al., 1983) and other galaxies (Marquez et al., 2002).

**Distribution of stellar number density along the galaxy radius**

Having picked out young supergiants and the stars of intermediate age (AGB) on CM diagram (Fig. 3), we have built of stellar number density along the radius of NGC 5194 (Fig. 8). In spite of some fluctuation, the distribution of stellar number density of supergiants corresponds to the empirical model of the stellar structure of the spiral galaxies (Tikhonov et al., 2005), i.e. a small gradient of the number density is observed in the thin disk (up to Radious = of 8 kpc) and a sharp drop out of it. The AGB stars are distributed in the disk more evenly and they stretch along the radius further than supergiants, which also corresponds to the model of stellar structure of galaxies (Galazutdinova, 2005). A disagreement with the model is observed in the central galaxy region, where AGB number density decreases although according to the model it must increase. Probably, the AGB stars deficiency in the central galaxy regions may be a result of interaction of galaxies.

**Stellar content of the tidal formations of NGC 5195**

In the interaction of galaxies tidal formations called "feathers" have been formed around NGC 5195. A question about their nature had been raised long ago (Toomre & Toomre, 1972), but only deep ACS/WFC images helped us to clarify this problem. By choosing different age stars and drawing their spatial distribution, we have found that young supergiants are seen in the tidal arm and in star formation regions of NGC 5194. The red giants are evenly distributed around both galaxies and AGB stars are concentrated in "feathers" (Fig. 9). Having chosen the region of maximum concentration of AGB stars closed to NGC 5195, we have constructed CM diagram for this region and imposed isochrones Bertelly et al.
(1994) with $z = 0.02$ on it. The age of the youngest AGB stars is equal to 80 million years, which agrees with the model of repeated approaches of galaxies (Salo & Laurikainen, 2000), but age distribution of AGB stars has maximum at 400–500 Myr, which agrees with model of Toomre & Toomre (1972).

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Figure 2:
3 periphery regions

$I(\text{TRGB}) = 25.99$

Figure 4:
Figure 5:
Figure 6:

Figure 7:
Figure 8:
Figure 9: