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Deep Stellar Photometry of IC 10

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Abstract. Results of VRI photometry are presented, based on 1-m, 6-m and HST telescope frames taken in different parts of IC 10. From comparison of the location in CM diagrams of branches of blue supergiants it was found that $E(B-V) = 0.98$. The distance modulus estimation from TRGB is $(m-M)_I = 23.8 \pm 0.1$. The ages of brightest stars of the east star complex are derived from comparison with theoretical isochrones. It is possible that IC 10 is a galaxy with an extended red giant disk.

1. Introduction

The dwarf irregular galaxy IC 10 is located in the Milky Way region ($b = -3.3°$) and suffers strong light extinction. It has been found in papers of Massey et al. (1992), Massey & Armandroff (1995) that the number of WR stars is unexpectedly high in this galaxy, which is indicative of very active processes of star formation. Annually this galaxy is the subject of study of 10–15 papers in various journals, however, even now we can't say that we know all about it. I note only the results concerning our study. The distance to IC 10 has been measured repeatedly. Table 1 presents the results of many authors obtained in different years using different techniques. The results of measurements of extinction using different techniques can (or even must) yield different values since they refer to objects located in different places and conditions. So, it is desirable to use different techniques in order to specify the results being obtained. The purpose of our investigations was to obtain precise photometry of bright stars for determination of light extinction and for reaching the stars of the giant branch in order to measure the distance.

2. Observations

CCD observations of IC 10 have been carried out with the 1-m and 6-m telescopes of the Special Astrophysical Observatory of Russian Academy of Sciences. CCD images of some regions of the galaxy have been obtained in the VRI passband. Besides we used the images of HST archives, obtained in June 1997. Deep images of HST were obtained only in the I(F814) passband, which restricts their use for analysis of the stellar population. All CCD images have photometry using the DAOPHOT II programmes (Stetson 1993). Figure 1 shows the galaxy with the marked fields of observations. A stellar complex whose analogues can be found in other irregular and spiral galaxies (Massey et al. 1995) falls within

Table 1. The distance to IC 10

Authors	Year	D (Mpc)	$E(B-V)$	Method
Roberts	1962	1.3	—	HI extent
de Vaucouleurs & Ables	1965	1.3	0.87	HII rings
Sandage & Tammann	1974	3.0	0.74	HII regions
de Vaucouleurs	1978	2.0	0.40	HII rings
Jacoby & Lesser	1981	1.8	—	PN
Bottinelli at al.	1984	2.0	0.40	TF
Karachentsev & Tikhonov	1993	1.04	0.87	blue & red SG
Wilson	1995	0.24	1.55	Cep. ?
Massey & Armandroff	1995	0.95	0.80	WR
Wilson at al.	1996	0.82	0.80	Cep. in IR
Saha at al.	1996	0.83	0.94	Cep.
This paper	1998	0.58	0.98	TRGB

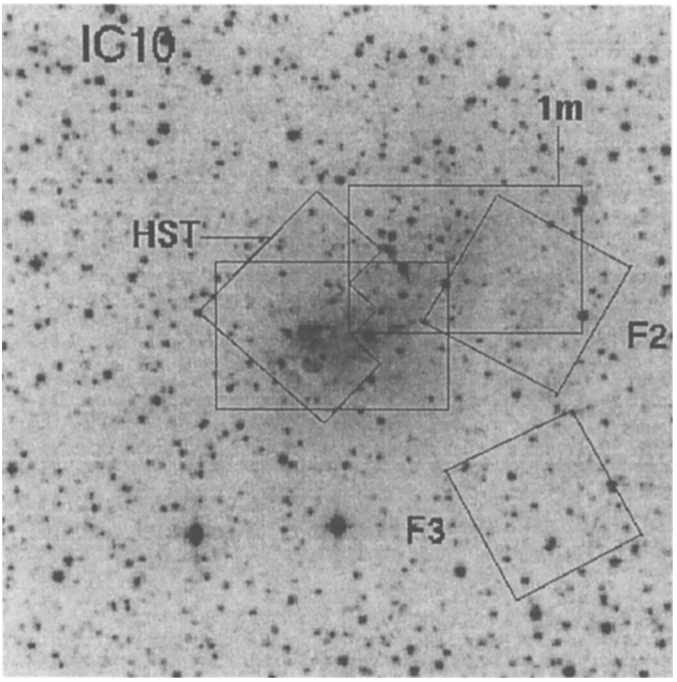

Figure 1. The view of IC 10 from the digital POSS. The fields of different telescopes are marked.

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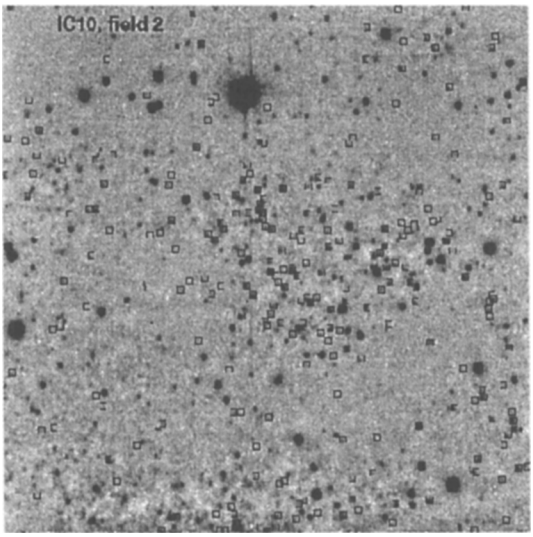

Figure 2. The view of the star complex "V" light. The blue stars are marked by squares.

field 2 (Fig. 2). Field 3 has been chosen so that bright stars of the galaxy do not interfere with photometry of faint stars — red giants.

3. Results and Conclusions

3.1. Light Extinction

Having compared the locations of branches of blue supergiants on colour-magnitude diagrams (CMDs) of IC 10 and galaxies with low extinction (DDO 190, GR 8, IC 2574) we found that $E(B-V) = 0.98$. This result is quite consistent with the mean extinction values derived earlier. It should be noted that the measures from the two different areas (1-m and F2) agree to an accuracy no worse than 0.05 mag. After this it is not difficult to determine the light extinction in any passband: $A_B = 4.12$, $A_V = 3.14$, $A_R = 2.66$, $A_I = 1.94$ mag.

3.2. The Distance

On the frames of field 3 many red giants can be seen. The results of the *RI* photometry of about 3000 stars, are presented in the CMD (Fig. 3).

The red giant branch forms a wide strip caused by photometry errors and a mixture of stars of different metallicities. Besides the giants, we can see a narrow strip of background stars and a small number of probable supergiants of IC 10. The application of the 'tip of the red giant branch' (TRGB) method, a detailed description of which is available in the paper by Lee et al. (1993), allows measurement of the distance to the galaxy and the average metallicity of old stars. We found that the TRGB is observed at $I = 21.68$. Assuming that

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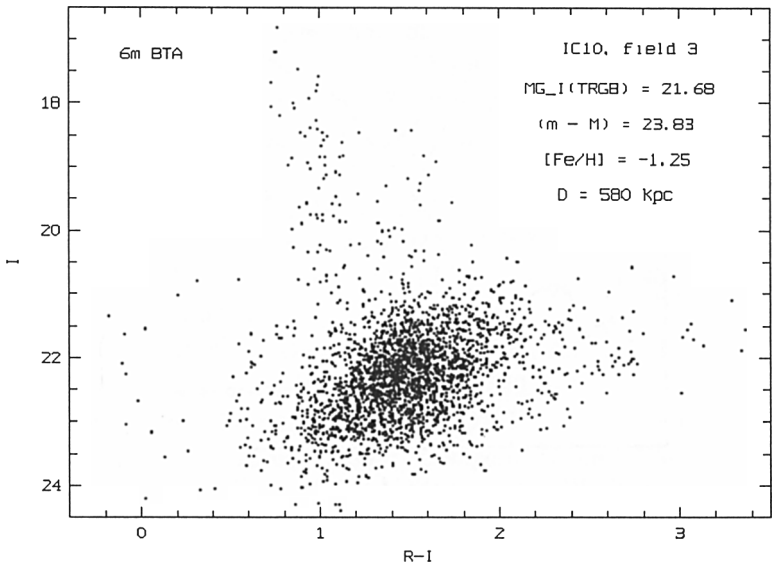

Figure 3. The CMD of all stars from field 3.

the colour excess $E(B-V) = 0.98$, and having determined the maximum of the distribution of stars in colour at a level of 0.5 mag below the TRGB at $(R-I) = 1.42$, we find that the giants of IC 10 have [Fe/H] $= -1.25$, and their luminosity $M(I) = -4.09$. Then the distance modulus to IC 10 $(m-M)_0 = 23.83$, which equals 580 kpc.

Since HST images were obtained in one colour we could study only the morphology of the galaxy and obtain the luminosity function (LF) for all stars of the image. It was expected that a large number of red giants would appear on the LF (Fig. 4). For comparison, beside the LF of IC 10 the LF of the galaxy DDO 210 is displayed, whose CMD is well known. All the details of the LF of the two galaxies are seen to be in a good agreement. For IC 10, $I_{\rm TRGB} = 21.75$, which is in a good consistent with our 6-m telescope measurements.

3.3. Stellar Complex

Knowing the distance and the light extinction in the direction of IC 10 we can use the theoretical isochrones. From the paper of Lequeux et al. (1979) it is known that metallicity of the galaxy is low. However, using the isochrones of Bertelli et al. (1994) we could plot in the CMD the isochrones with high metal abundance only, for both the whole galaxy and the stellar complex. The use of other isochrones leads to unsatisfactory results.

We should bear in mind the paper of Massey & Armandroff (1995) where they report that a great number of WR stars found in IC 10 are WC stars, that is possible at high metallicity. The inscribed isochrones indicate that the active

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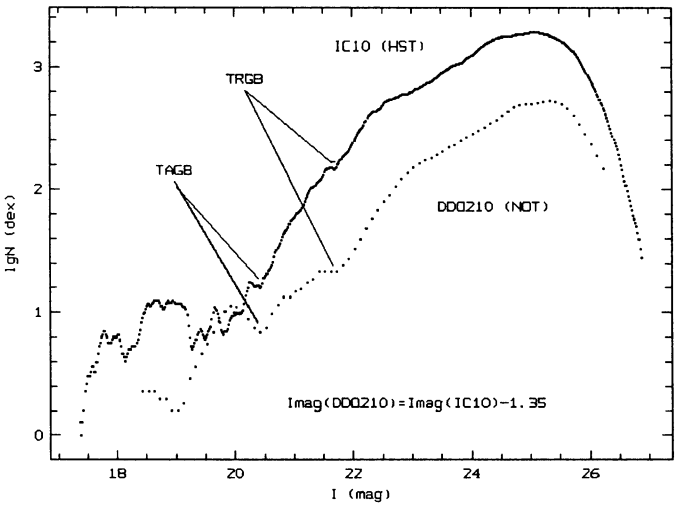

Figure 4. The luminosity function (LF) of IC 10 from HST data and LF of DDO 210 from Nordic telescope. On both LF are seen the same variations in number of stars near TAGB and TRGB.

star formation commenced 35 Myr ago and ended 9 Myr ago. The size of the complex is 200 pc, and its luminosity $M_V = -11.3$, which is typical of stellar complexes in other galaxies.

3.4. Science Speculations

The distribution of red giants from the centre towards the edge of the galaxy, as well as the morphology of its central regions, based on the HST data, suggests that the galaxy IC 10 is a disk galaxy about 18′ in size. The disk consists mainly of red giants, and it is only in the central region of about 6′ that active star formation is going on and almost all young supergiants are present. Since a similar structure has been revealed in the BCD galaxy NGC 6789 (Drozdovsky & Tikhonov, 1998) it is not unlikely that many, if not all, irregular galaxies have a disk consisting of old red stars. This is also corroborated by the reddening of quite a few Irr galaxies from the centre outward.

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Discussion

Armandroff: For two reasons I was interested in how confident you are in the identification of the giant branch tip. First, the TRGB distance deviates significantly from the Cepheid distance. Second, in a population with substantial recent star formation, it can be difficult to differentiate tip of the giant branch stars from stars evolving onto the extended giant branch. How did you convince yourself that the tip magnitude is not biased brightward by extended AGB stars?

Tikhonov: (a) On the red stars LF are two jumps of star density, corresponding to TAGB and TRGB. (b) The LF we obtain from our 6m IC 10 data is similar in shape and in many details to the LF of DDO 210 and to the LF obtained for IC 10 itself from HST data. This makes us confident in our conclusion concerning the position of the TRGB. Also, the difference between HST and 6m I band is 0.08 mag. (c) Concerning the Cepheid distance estimation of IC 10, may we remind you of the history of disagreement between distance estimations of M81 and Pegasus galaxies.

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