M31 and Beyond: Poster Papers

https://doi.org/10.1017/S0074180900204191 Published online by Cambridge University Press

The Stellar Content of Local Group Galaxies
IAU Symposium, Vol. 192, 1999
Patricia Whitelock and Russell Cannon, eds.

Nearby Blue Compact Dwarf Galaxy NGC 6789

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Abstract.
We present the results of a detailed *BVRI* and Hα study of the isolated nearby blue compact dwarf (BCD) galaxy NGC 6789. Judging from the literature the observed galaxy has not yet been resolved into stars up to now. On CCD frames obtained with 6m BTA telescope and 2.5m Nordic telescope the galaxy is well resolved. Its colour-magnitude diagram confirms the two component (core-halo) galaxy morphology, which consists of two stellar populations distinct in structure and colour: an inner high surface-brightness young population within 150 pc from the center of the galaxy, and a relatively low surface-brightness intermediate-age population extending out to at least 600 pc. The distance to the galaxy, estimated from the tip of the red giant branch (TRGB) is 2.1 Mpc which places NGC 6789 close to the Local Group. From the mean colour of the RGB, the mean metal abundance of the halo population is estimated as [Fe/H] $\simeq -1$ dex.

1. Introduction

Blue Dwarf Galaxies are objects of low luminosity ($M_V \geq -18$ mag) and very blue visible colours. Both the colours and the presence of narrow emission lines in their spectra are usually interpreted to result from intensive episodes of star formation. Different morphologies are found among BDG including compact elliptical, irregular, magellanic and interacting.

NGC 6789 belongs to the group of blue compact dwarf (BCD) galaxies, which have an irregular patchy blue central part with large H II regions and bright blue stars. They show no prominent nucleus while their outer regions have a smooth spheroidal shape and an old red stellar population, as dwarf ellipticals. According to the classification scheme of Loose & Thuan (1985), NGC 6789 may be classified of the "iE" type, comprising $\sim 70\%$ of BCD, which combines irregular inner isophotes with accurately elliptical outer isophotes. The intensive star formation observed in the central region of NGC 6789 contrasts with the absence of a significant young population in the outer regions and

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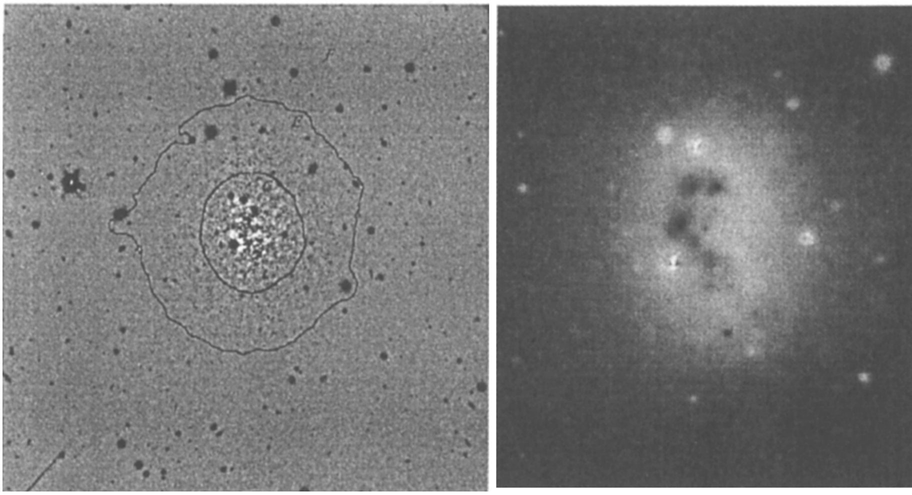

Figure 1. NGC 6789 in the I band after subtracting the median, smoothed with a window of $10 \times (FWHM)$. The size of the CCD frame is 3.7 by 3.7 arcmin. The Isophotes correspond to 22.5 mag arcsec^{-2} and 24.2 mag arcsec^{-2}. They are used to define the central region (**C**) the periphery (**E**), and the foreground stars (**F**). North left, East top.

suggests a two-component (core-halo or disk-halo) structure of the galaxy. This seems to be common not only in large spirals but also in dwarfs.

The current stage of investigation of NGC 6789 has started with the search for new Local Volume galaxies by Karachentseva & Karachentsev (1998), who compiled the list of 260 dwarf galaxies on the basis of the POSS-II and ESO-SERC surveys. The NGC 6789 galaxy is outstanding by its high surface brightness in central regions, small radial velocity ($V_0 = -157$ km s^{-1}: Huchra et al. 1995), and spatial isolation. But, in spite of its optical high surface brightness, it was undetected in H I with the Effelsberg 100m radiotelescope (Huchtmeier et al. 1997).

We resolved this galaxy into stars with the 6m telescope in April 1996 under rather poor seeing conditions. In a July 1996 run with the 6m telescope we have constructed a colour-magnitude diagram (CMD) of NGC 6789, which shows the existence of two distinct groups of stellar population placed within different radii from the galaxy's optical center. The photometric limit in the red frames did not allow to locate the RGB.

Later optical spectral observations with the 6m-telescope long slit spectrometer UAGS revealed H II gas in NGC 6789 (Karachentsev & Makarov 1998). The Hα radial velocity is -141 ± 8 km s^{-1}, close to the value of Huchra et al. (1995).

Deep photometric observations with the Nordic 2.5m telescope with better seeing revealed the RGB, while Hα frames have shown large H II regions in the central region and three compact objects in the outer region.

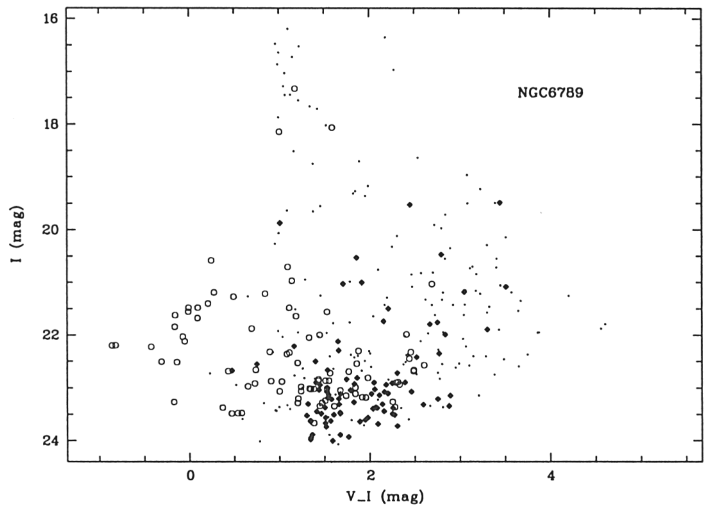

Figure 2. Colour-Magnitude diagram for 337 stars in NGC 6789. The circles correspond to stars measured in the central region (C), the filled diamonds indicate stars in the periphery (E), and dots are stars outside the galaxy (F).

After dark subtraction, flat-fielding and cleaning for cosmic-ray events, the photometric processing of the frames was performed with DAOPHOT and ALLSTAR packages (Stetson 1987) running within MIDAS.

Figure 1 shows the images of NGC 6789 obtained with the 6m-telescope and the NOT. For the analysis of stellar content, the observed field has been divided into several parts, as indicated in the figure caption.

2. The Results

2.1. Colour-magnitude diagram

The $[(V-I), I]$ CMD of NGC 6789 (Fig. 2) shows characteristics typical of the CMDs of other dwarf galaxies, with evidence for both old and young populations. The main feature of the central stars of the NGC 6789 CMD is the concentration that extends between $1.2 \lesssim (V-I) \lesssim 2.4$ and $I \gtrsim 21.5$ mag, which corresponds to RGB and asymptotic giant branch (AGB) old and intermediate-age stars. There is also a considerable population of blue stars ($(V-I) \lesssim 0.7$) in the CMD of the central region. It is remarkable that these blue stars are entirely absent in the outer part of the galaxy. The presence of these stars in the central region, as well as candidate H II regions in the Hα image, shows that NGC 6789 is a BCD galaxy rather than a dE. Most of the bright stars ($I \lesssim 20.5$ mag) are likely foreground stars. According to our our spectral long slit observations the brightest foreground star near the center of the galaxy is an F star.

The galactic latitude of NGC 6789 is $b_{II} \simeq 21°$. Following the extinction maps of Burstein & Heiles (1984) and using the extinction law by Cardelli et al.

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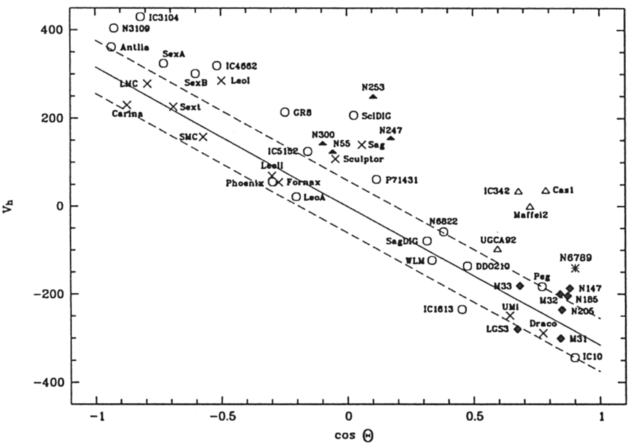

Figure 3. Heliocentric velocity versus cos Θ for nearby galaxies closer than 2.5 Mpc. Θ is the angle between the center of the galaxy and the solar apex. The crosses represent the satellites of the Milky Way Galaxy, the solid diamonds represent the satellites of M31, the solid triangles are for members of the Sculptor group, and the open triangles are for members of the IC 342/Maffei complex. The open circles are for galaxies not members of these subgroups. The Local Group is defined as within the dashed lines at ± 60 km s^{-1} from the center line with $V_{\odot} = -316 \cos \Theta$. The star symbol represents the location of the NGC 6789.

(1989) with $R_V = 3.3$, the extinction is: $A_B = 0.32$, $A_V = 0.24$, $A_R = 0.21$ and $A_I = 0.15$ mag.

The average stellar metallicity can be obtained from the index $(V - I)_{-3.5}$, which is the colour index of the RGB half a magnitude below the TRGB (see Da Costa & Armandroff 1990; Lee, Freedman, & Madore 1993). We believe that the TRGB is at $I_{\rm TRGB} = 22.7$ mag (see next Section). The median colour between $I = 23.4$ and $I = 24.0$ mag, that we take as $(V - I)_{-3.5}$, is 1.7 ± 0.2.

The corresponding dereddened value is $(V - I)_{-3.5,0} = 1.6 \pm 0.2$. Using the calibration by Lee et al. (1993), we obtain a metallicity [Fe/H] $\simeq -1$ dex.

2.2. Distance

We estimated the distance to NGC 6789 based on the magnitude of the tip of the RGB (TRGB) (Lee et al. 1993). It is slightly dependent on the metallicity. To obtain the magnitude of the TRGB we have used the luminosity function (LF) of the stars in the colour interval $1.0 < (V - I) \leq 3.0$ for the external ring part of the galaxy (region E). Finally, an edge detecting Sobel filter $[-1, 0, +1]$ (Sakai et al. 1996) has been applied to the LF. This produces a sharp peak at the TRGB corresponding to $I_{\rm TRGB} = 22.7$ mag. The resulting dereddened value is $I_{\rm TRGB,0} = 22.55$ mag. Using the colour index of the TRGB and the bolometric correction from Lee et al. (1993), we obtain a value of $M_{I,\rm TRGB} = -4.10 \pm 0.01$.

We then derive a distance modulus $(m - M)_0 = 26.65$ mag, corresponding to 2.1 Mpc. The intrinsic error of the method is about ± 0.1 (see Lee et al. 1993). Our estimate of the stellar photometry errors is ± 0.2 due to severe crowding and high surface brightness in this galaxy. We adopt a total error of 0.3.

To see how near NGC 6789 is to the Local Group we construct the $V_\odot$ versus $\cos\Theta$ diagram (Fig. 3) for nearby galaxies closer than 2.5 Mpc, follow the work of van den Bergh (1994) on the basis the data tabulated by Lee (1995), Karachentsev & Makarov (1996) and our compilation. Θ is the angle between the center of the galaxy and the solar apex. We adopt a solar motion with respect to the Local Group members of 316 km s^{-1} toward the solar apex ($l_\odot = 93°$, $b_\odot = -4°$) given by Karachentsev & Makarov (1996).

We see that NGC 6789 is probably not far from the Local Group. Note that NGC 6789 is a very isolated galaxy situated inside the *Local Void* described by Tully (1988).

2.3. Integrated Light

The equivalent V band surface brightness distribution can be well fitted by a Gaussian with a central surface brightness $\mu_0(V) = 21.7$ mag arcsec^{-2} and a standard deviation $\sigma_V = 15.9''$ in the inner regions, and exponential profile with central surface brightness $\mu_0(V) = 21.7$ mag arcsec^{-2} and exponential scale length $\alpha = 16.2''$ at larger radii. Given the distance of the galaxy, the break in the surface brightness profile occurs at $r_{\rm equiv} \approx$ 600 pc.

Integrating the surface brightness profiles within the V and I bands out to the $\mu_V = 25$ mag arcsec^{-2} isophote, we find $m_V = 13.63 \pm 0.15$, and $m_I = 14.62 \pm 0.15$, not corrected for internal or galactic extinction. After correction for extinction (see §2.1.) and considering the error in the distance modulus, the total absolute magnitude of NGC 6789 is $M_{V,0} = -13.26 \pm 0.35$ and $M_{I,0} = -12.36 \pm 0.35$. The integrated colour index $(V - I)_0$ increases smoothly from 0.67 in the center of NGC 6789 up to 0.90 within the largest visible radii. This is comparable to the colours of Scd & Im galaxies ($(V - I) = 0.82$) for the Coleman et al. (1980) composite spectral energy distributions.

3. Concluding Remarks

We have presented the B, V, R and I photometry of 337 resolved stars in the blue compact dwarf galaxy NGC 6789. The CMD shows two stellar populations distinct in structure and colour: an underlying older low-surface-brightness stellar population formed previously to the present burst, and an inner high-surface-brightness young and intermediate age population within 150 pc from the center of the galaxy.

The tip of the first ascent RGB is used to estimate a metallicity ([Fe/H] ~ -1 dex) and distance of NGC 6789 (about 2.1 Mpc).

NGC 6789 has a light distribution which is well described by combination of the Gaussian and exponential laws. Its central surface brightness is $\mu_0(V) = 21.1$ mag arcsec^{-2}, and its isophotal equivalent diameter is $\theta_{26,\rm equiv} = 2\farcm1$ or $D_{26,\rm equiv} = 1.2$ kpc, making it an intrinsically small high surface brightness galaxy. NGC 6789's integrated absolute magnitude within $\mu_V = 25$ mag arcsec^{-2} is $M_{V,0} = -13.26 \pm 0.25$. It is also quite blue: ($(V - I) = 0.67$) in its central region, but its halo is much redder, so the total colour index of NGC 6789 inside the $\mu_V = 25$ mag arcsec^{-2} isophote is $(V - I) = 0.90$.

Acknowledgements. We are grateful to Dr. A. Aparicio for his participation in the observations with NOT and basic CCD frames reduction from this run. This work is partially supported by RFBR grant N 97-02-17163 and INTAS-RFBR grant N 95-IN-RU-1390. ID thanks the Special Astrophysical Observatory for its hospitality. This research has made use of the NASA/IPAC extragalactic database (NED) which is operated by the Jet Propulsion Laboratory, Caltech, under contract with the National Aeronautics and Space Administration. We are grateful to the organizers and sponsors of the IAU Symposium 192 for partial support to attend this meeting.

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