NGC6789: The closest BCD galaxy resolved with HST*

I.O. Drozdovsky[1,2], R.E. Schulte-Ladbeck[1], U. Hopp[3], L. Greggio[3,4], M. Crone[5]

[1]University of Pittsburgh, Pittsburgh, PA 15260, USA
[2]Astronomical Institute, St.Petersburg University, Russia
[3]Universitätssternwarte München, München, FRG
[4]Osservatorio Astronomico di Bologna, Bologna, Italy
[5]Skidmore College, Saratoga Springs, NY 12866, USA

1 Introduction

NGC 6789 is the most nearby example of an unevolved Blue Compact Galaxy (BCD) known to date. Being in the direction of the Local Void in Hercules-Aquila this galaxy is extremely isolated. Galaxies in voids are interesting for their potential use as probes of Cold Dark Matter (CDM) cosmogonies (Dekel & Silk 1986). In general, these models predict that isolated galaxies are less evolved than those in denser environments. For example, N-body simulations show that dark matter halos in lower-density regions tend to have lower masses (e.g. Lemson & Kauffmann 1999), making them more susceptible to negative feedback from ionizing radiation and stellar winds (Ferrara & Tolstoy 2000). Indeed, recent high-resolution simulations which incorporate a semi-analytic prescription for star formation specifically predict that star formation is inhibited in voids (White & Springel 2000). Clearly, these models should be tested against the observed star-formation history of void galaxies.

The most straightforward way to observe the star-formation history of galaxies is through deep single-star photometry, which can directly identify stars in various evolutionary phases through their positions on a color-magnitude diagram (CMD). While observations of chemical abundances can be performed for more distant star-forming galaxies, the validity of age-dating from certain element abundance ratios has been challenged by recent chemical evolution models, which indicate that even extremely low-metallicity galaxies can have formed many Gyr ago (Henry, Edmunds & Köppen 2000).

NGC 6789 was resolved into stars for the first time by Drozdovsky & Tikhonov (2000, hereafter DT) from the ground. They found that it belongs to the iE subtype, which exhibits the morphology most characteristic of BCDs. In this work we show that NGC 6789 is the most nearby BCD on record; and the presence of RGB stars allows us to ascertain that it is at least about 1 Gyr old. We conclude that despite its isolated location in the Local Void, its low metallicity, and its active star formation, the properties of NGC 6789 are clearly not those of a galaxy in formation.

*Based on observations made with the NASA/ESA *Hubble Space Telescope*, obtained at the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Inc., Under NASA contract NAS 5-26555.

"Dwarf Galaxies and their Environment"; Bad Honnef, Germany, 23-27 January 2001; Eds. K.S. de Boer, R.-J.Dettmar, U. Klein; Shaker Verlag

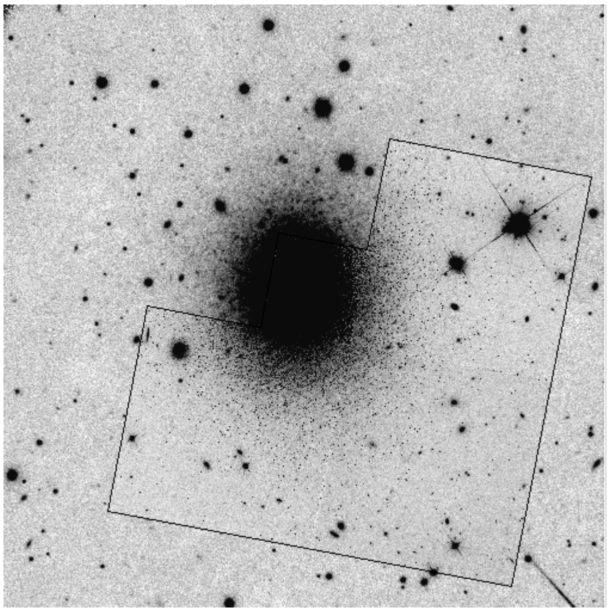

Figure 1: I-band picture of the WFPC2-resolved stars from program 8122 overlaid onto the NOT ground-based image of DT. N is up and E is to the left. The size of the image is $3\farcm7 \times 3\farcm7$, which corresponds to $\sim 4 \times 4$ kpc.

2 Results

With the help of WFPC2 aboard the Hubble Space Telescope (GO program 8122), we resolve NGC 6789 into over 15,000 point sources in the F555W (V) and F814W (I) bands. In Fig. 1, we overlay deep WFPC2 photometry on the Nordic Optical Telescope (NOT) image of DT. The PC chip has a very high stellar density. The CMD of the of the PC (Fig. 2a) exhibits a stellar mix which is characteristic of the superposition of many stellar generations, including both the old and young stars. On the contrary, the WF chips have a low stellar density and lack blue stars down to the detection limit (see Fig. 2b). This suggest that the average population age is higher in the halo than it is in the core.

We used the WF data to find the TRGB, and to determine the distance and metallicity of NGC 6789 (following Lee, Freedman & Madore 1993). The location of the TRGB occurs at the same magnitude in all three chips. The final TRGB magnitude was derived from the combined I-band luminosity function of about 7,000 stars selected to have $0.7 < (V-I)_0 < 2.0$. The TRGB was found by applying a Sobel filter; it occurs at $I_0 = 23.82 \pm 0.05$. In order to derive the metallicity of the RGB stars we measure the $(V-I)_0$ color both at half a magnitude below the TRGB and, owing to the high quality of the data, also at one magnitude below the TRGB. We consistently find a low metallicity, which, at 0.5 mag below the TRGB, is $[\mathrm{Fe/H}] = -1.92 \pm 0.03 \pm 0.15$, where the first error is the uncertainty in the mean and the second is the systematic error. With the appropriate bolometric correction, the absolute magnitude of the TRGB is -4.0, yielding a distance modulus of $27\overset{\mathrm{m}}{.}80 \pm 0\overset{\mathrm{m}}{.}13 \pm 0\overset{\mathrm{m}}{.}18$, or a distance of $3.6 \pm 0.2 \pm 0.3$ Mpc. This location of the TRGB is indicated in Fig. 2a and 2b by a dashed line.

NGC 6789 is about 70% more distant than was derived by DT. At this new distance, an angular scale of $1'$ corresponds to a physical scale of 1.05 kpc. The star-formation rate derived by DT from the H_α luminosity increases to 0.04 $\mathrm{M}_\odot \mathrm{yr}^{-1}$ (for a Salpeter initial mass function ranging from 0.1–100 $\mathrm{M}_\odot$, i.e., Hunter & Gallagher 1986). The integrated total magnitudes of NGC 6789 within the $\mu_\mathrm{V} = 25$ mag/$\square''$ isophote of DT, $m_\mathrm{I} = 13\overset{\mathrm{m}}{.}63 \pm 0\overset{\mathrm{m}}{.}15$ and $m_\mathrm{V} = 14\overset{\mathrm{m}}{.}62 \pm 0\overset{\mathrm{m}}{.}15$, correspond to absolute magnitudes of $M_{\mathrm{I},0} = -14\overset{\mathrm{m}}{.}31 \pm 0\overset{\mathrm{m}}{.}20$ and $M_{\mathrm{V},0} = -13\overset{\mathrm{m}}{.}41 \pm 0\overset{\mathrm{m}}{.}20$. DT show that the outer regions of NGC 6789 exhibit the exponential surface brightness profile of a disk galaxy. The scale length correponds to 280 pc, much smaller than that of VII Zw 403 ($\approx$600 pc, Schulte-Ladbeck et al. 1999).

NGC 6789 is undetected in HI (Huchtmeier et al. 2000). Possible reasons given are confusion

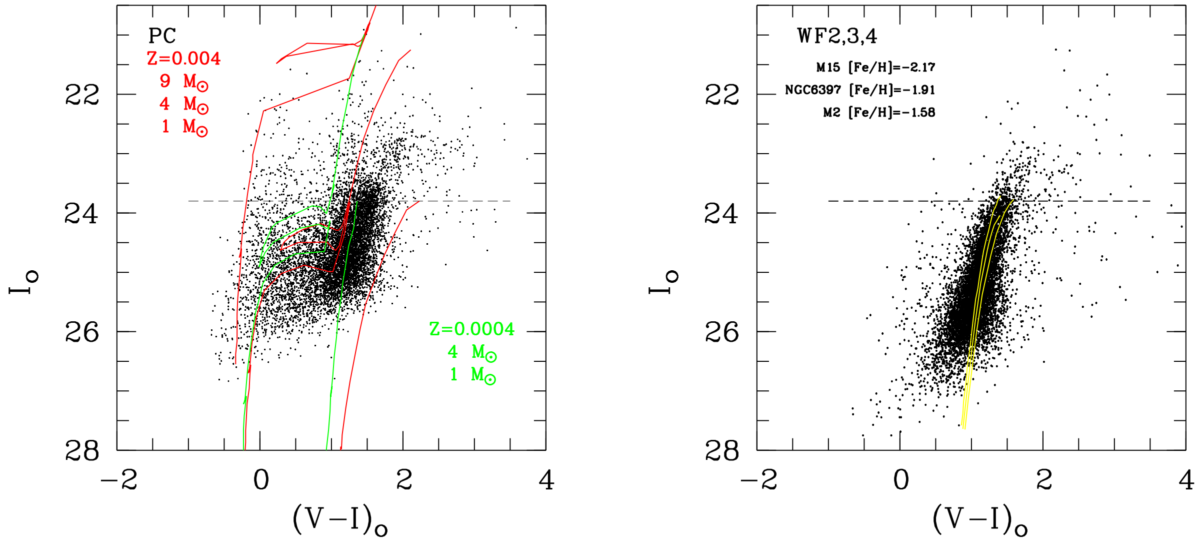

Figure 2: *Left* is the CMD of the PC chip with a range of stellar tracks overlayed for two metallicities, Z=0.004 and 0.0004. *Right* is the CMD of the WF chips with low Fe/H Globular Cluster ridge lines overlayed. The dashed line on both images indicates the position of the TRGB.

with local HI or lack of sensitivity for very weak emission. If NGC 6789 could indeed be shown to possess very little neutral gas, it could be interpreted as a BCD near the end of its life.

3 Discussion

We start by comparing the properties of NGC 6789 to those of the other four BCDs which are resolved with HST to magnitudes below the TRGB. NGC 6789, at a mere 3.6 Mpc, is the most nearby BCD resolved to date. Ordered by increasing distance we have: Mrk 178 ($\geq$4.2$\pm$0.5 Mpc, Schulte-Ladbeck et al. 2000), VII Zw 403 (4.4$\pm$0.2 Mpc, Schulte-Ladbeck et al. 1999), I Zw 36 ($\geq$5.8$\pm$0.4 Mpc, Schulte-Ladbeck et al. 2001), and UGCA 290 (6.7$\pm$0.4 Mpc, Crone et al. 2000). NGC 6789, situated in the Local Void, is the BCD in the most underdense region. VII Zw 403 is on the line of sight to M 81 but at least a Mpc behind the center of the group. Mrk 178, I Zw 36 and UGCA 290 all lie in the direction of the Canes Venatici Cloud.

The stellar population in NGC 6789 exhibits several features typical of the other resolved BCDs. For example, the CMD of the star-forming core of NGC 6789 exhibits a prominent population of luminous AGB stars. This serves to indicate that star formation in the centers of BCDs (at the bottom of the gravitational well) has continued to be active over the past several hundred Myr. All of the nearby BCDs resolve into red giants, which in all but UGCA 290, are much more extended spatially than the young, main sequence and AGB stars. We have termed these halos "Baade's red sheets" (Schulte-Ladbeck, Crone & Hopp 1998). Because stars of a wide range of ages overlap on the RGB, we can only be sure that these stars are at least 1 Gyr old, while they could in principle be as old as the oldest stars in the Universe. Whenever optical photometry is available we find that the halo populations of BCDs exhibit blue RGBs, which can be interpreted to indicate low mean stellar [Fe/H] ratios of about -2 (for VII Zw 403, -1.92 ± 0.04, for UGCA 290, -2.0 ± 0.1), as low as those of the most metal poor galactic Globular Clusters.

The current star-formation rate of NGC 6789 is not particularly high. The rates are never exceptionally high in the cases we have investigated, only of order a few times 10^{-3} - 10^{-2} $M_{\odot}yr^{-1}$, from either or both, H_{α} luminosity and CMD modeling. They are orders of magnitude below the high rates, 10^{0} - 10^{2} $M_{\odot}yr^{-1}$, determined for a sample of 27 BCDs in the Second Byurakan Survey

(Izotova, Parnovsky & Izotov 2000).

The question of whether BCDs in voids are statistically different from those in the field is an area of active research. Vílchez (1995) compared BCDs in the Virgo cluster with isolated BCDs. He found that BCDs in low density environments are likely to exhibit their first major episode of star formation. More recently, however, Popescu, Hopp & Rosa (1999) investigated a sample of BCDs in voids and in the field, and found no differences between their star-formation rates or metallicities. Moreover, Vennik, Hopp, & Popescu (2000) performed B and R surface photometry on the above galaxy sample, and found that field and void BCDs are indistinguishable in terms of luminosity and color. They also noted that more than half of their void BCDs show indications for low surface-brightness red disks, possibly due to an older stellar population.

Our results for the most nearby BCDs support the idea that void and field BCDs are similar, in terms of resolved stellar content, star-formation rate, Fe/H ratio, and morphology. In particular, they support the hypothesis that void BCDs have stellar background sheets that pre-date the on-going starburst.

The ubiquity of Baade's sheet in *every* galaxy resolved deeply enough to detect red giants — including isolated and low-metallicity star-forming dwarfs — imposes significant constraints on models of galaxy formation and chemical evolution.

Work on this project was supported through HST grants to RSL and MMC (project 8122). UH acknowledges financial support from SFB 375. LG acknowledges support from the Alexander von Humboldt Stiftung. We made extensive use of the SIMBAD and NED data bases.

References

Crone, M., Schulte-Ladbeck, R.E., Hopp, U., & Greggio, L. 2000, ApJL, 545, 31
Dekel, A., Silk, J. 1986, ApJ, 303, 39
Drozdovsky, I., & Tikhonov, N. 2000, A&AS, 142, 347 (DT)
Ferrara, A., & Tolstoy, E. 2000, MNRAS, 313, 291
Henry, R.B.C., Edmunds, M.G., Köppen, J. 2000, ApJ, 541, 660
Huchtmeier, W.K., Karachentsev, I.D., Karachentseva, V.E., & Ehle, M. 2000, A&AS, 141, 469
Hunter, D. A., Gallagher, J. S. 1986, PASP, 98, 5
Izotova, Parnovskya, S., & Izotov, Y. 2000, NewAR, 44, 283
Lee, M.G., Freedman, W.L., & Madore, B.F., 1993, ApJ, 417, 553
Lemson, G., & Kauffmann, G. 1999, MNRAS, 302, 111
Popescu, C.C, Hopp, U., & Rosa, M.R. 1999, A&A, 350, 414
Schulte-Ladbeck, R.E., Crone, M.M., & Hopp, U. 1998, ApJ, 493, L23
Schulte-Ladbeck, R.E., Hopp, U., Crone, M.M. & Greggio, L. 1999, ApJ, 525, 709
Schulte-Ladbeck, R.E., Hopp, U., Greggio, L., & Crone, M.M. 2000, AJ, 120, 1713
Schulte-Ladbeck, R.E., Hopp, U., Greggio, L., Crone, M.M., & Drozdovsky, I.O., 2001, AJ, accepted
Vennik, J., Hopp, U., & Popescu C.C., 2000, A&AS, 142, 399
Vílchez, J.M. 1995, AJ, 110, 1090
White, S.D.M., & Springel, V. 2000, in "The First Stars", ESO Astrophysics Symposia, eds. A. Weiss, T. Abel, & V. Hill (Springer), 327