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Letter to the Editor

The globular cluster system of NGC 1316

II. The extraordinary object SH2*

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ABSTRACT

Context. SH2 has been described as an isolated HII-region, located about 6.5′ south of the nucleus of NGC 1316 (Fornax A), a merger remnant in the the outskirts of the Fornax cluster of galaxies.
Aims. We give a first, preliminary description of the stellar content and environment of this remarkable object.
Methods. We used photometric data in the Washington system and HST photometry from the *Hubble* Legacy Archive for a morphological description and preliminary aperture photometry. Low-resolution spectroscopy provides radial velocities of the brightest star cluster in SH2 and a nearby intermediate-age cluster.
Results. SH2 is not a normal HII-region, ionized by very young stars. It contains a multitude of star clusters with ages of approximately 10^8 yr. A ring-like morphology is striking. SH2 seems to be connected to an intermediate-age massive globular cluster with a similar radial velocity, which itself is the main object of a group of fainter clusters. Metallicity estimates from emission lines remain ambiguous.
Conclusions. The present data do not yet allow firm conclusions about the nature or origin of SH2. It might be a dwarf galaxy that has experienced a burst of extremely clustered star formation. We may witness how globular clusters are donated to a parent galaxy.

Key words. galaxies: star clusters: general – galaxies: clusters: individual: NGC 1316 – galaxies: peculiar – galaxies: ISM

1. Introduction

NGC 1316 (Fornax A) is a merger remnant in the outskirts of the Fornax cluster. Starting with the classical work of Schweizer (1980), it has been intensively investigated from X-rays to the radio regime (D'Onofrio et al. 1995; Shaya et al. 1996; Mackie & Fabbiano 1998; Arnaboldi et al. 1998; Longhetti et al. 1998; Kuntschner 2000; Horellou et al. 2001; Goudfrooij et al. 2001b,a; Gómez et al. 2001; Kim & Fabbiano 2003; Bedregal et al. 2006; Nowak et al. 2008; Lanz et al. 2010; McNeil-Moylan et al. 2012).

Morphologically, it is characterized by an inner bulge with extensive dust fine structure and a number of shells, ripples and tidal structures at larger radii. Intermediate-age stellar populations of about 2 Gyr and younger contribute significantly to the total luminosity (e.g. Kuntschner 2000; Richtler et al. 2012, hereafter Paper I).

Regarding young populations, one may suspect star formation to be still ongoing in the central regions, as indicated by the dust and the presence of dense molecular gas (Horellou et al. 2001). At larger radii, there is no evidence for really young populations, with one exception: an HII-region located about 6.5′ south of the nucleus, which has been discovered by Schweizer (1980) and was labeled SH2 (southern HII-region) by Mackie & Fabbiano (1998). Its diameter is about 10″ or 860 pc.

Schweizer described the main H_α-emission as coming "...from a banana-shaped...region along the south-western edge of a blue round fuzz..." SH2 is one of the few places in NGC 1316 where atomic hydrogen has been detected. Horellou et al. (2001) quote an HI-mass of $2 \times 10^7\ M_\odot$. The center of the HI-emission appears to be displaced from the center of SH2 by about 10″ to the northeast. Molecules have not been detected. Horellou et al. give an upper limit of $7 \times 10^6\ M_\odot$ for the H_2-mass.

In the framework of a kinematic investigation of the globular cluster system of NGC 1316, we also obtained spectra for the brightest object in SH2. Moreover, HST/WFPC2 imaging and photometry in the Washington system is available. The aim of this contribution is to give a first preliminary description of this remarkable object, which may be an example for a way, how globular clusters are donated to a parent galaxy.

We adopt the supernovae Ia distance of 17.8 Mpc quoted by Stritzinger et al. (2010) (distance modulus 31.25). One arcsec corresponds to 86.3 pc.

* Based on observations taken at the European Southern Observatory, Cerro Paranal, Chile, under the programmes 082.B-0680, on observations taken at the Interamerican Observatory, Cerro Tololo, Chile. Furthermore based on observations made with the NASA/ESA *Hubble* Space Telescope (HST, PI: A. Sandage, Prop.ID: 7504), and obtained from the *Hubble* Legacy Archive, which is a collaboration between the Space Telescope Science Institute (STScI/NASA), the Space Telescope European Coordinating Facility (ST-ECF/ESA) and the Canadian Astronomy Data Centre (CADC/NRC/CSA).

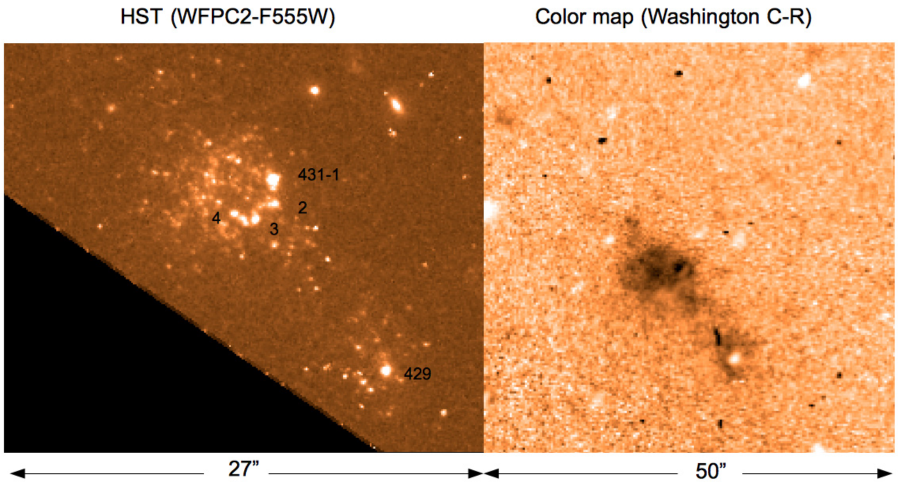

Fig. 1. *Left panel*: the region of SH2 as seen on a WFPC2 exposure of 5000 s (filter $F555W$). The objects for which photometric values are given are indicated. Object 429 is a globular cluster. The other objects in the field are either foreground stars or background galaxies. *Right panel*: color map in C-R of the same region, constructed from MOSAIC images with lower spatial resolution. Bright is red, dark is blue with a dynamical range $0 < C - R < 2$ mag. The background color is typically $C - R = 1.3$, the darkest spots have $C - R = 0.2$. The color map is shown with a larger scale to better demonstrate the color homogeneity of the surrounding and the blueish envelope of SH2.

2. Observations

We found SH2 on archival HST/WFPC2-images, taken on August 8, 1999 (PI: A. Sandage, proposal ID: 7504), at the image border of exposures in $F555W$ and $F814W$. The ground-based photometric and spectroscopic data are presented in detail in other contributions (Paper I and Kumar et al., in prep.), therefore we give some basic information only. The ground-based photometry uses wide-field imaging in the Washington system with the MOSAIC-camera at the 4 m-Blanco telescope at Cerro Tololo, Chile. The reduction was performed as described in Dirsch et al. (2003) and Paper I. Within a program aiming at measuring radial velocities of globular clusters we obtained spectra using FORS2/MXU at the VLT. The spectral resolution is 5 Å, using the grism 600B.

3. Morphology

One look at Fig. 1 is sufficient to convince any spectator of the extraordinary nature of this object. We see a multitude of sources, the brightest of them arranged in a ring-like fashion. The brighter objects are marginally resolved. At least the brightest object shows a young stellar spectral continuum, therefore we assume that the sources are star clusters and not compact HII-regions or even extremely bright OB-stars. That these star clusters are young, but not extremely young, is suggested by their colors. The distribution of point sources is extended toward the south-west, pointing toward another assembly of sources at a distance of 13″ (1120 pc). This second group is dominated by a bright globular cluster. See more remarks below. We point out that there is no indication that any other object is connected to SH2. The bright source at a distance of 7″ and a position angle of −35° is a background galaxy at $z = 0.54$.

4. Photometric properties of SH2

4.1. HST-imaging and Washington color map

We name the relevant objects according to our spectral scheme. The brightest source in SH2 is object 431-1 (mask 4, slit 31, and object Nr. 1 as the brightest). The two other sources for which brightnesses and colors in the Washington system were measured are indicated by numbers 2 and 3 and the values are given in Table 1.

Table 1. Washington and HST photometry of sources in SH2.

Object	mag(R)	$C - R$	$F555$	$F555 - F814$
429	20.83	1.52	21.73	0.92
431-1	20.88	0.20	21.28	0.13
431-2	21.71	0.25	23.56	–0.21
431-3	21.19	0.37	23.30	–0.24
431-4	–	–	23.54	–0.10
SH2	18.4	0.06	–	–

Notes. The HST magnitudes are in the ABMAG-system (Sirianni et al. 2005). The total magnitude and color of SH2 was measured through an aperture of 12″ diameter.

Owing to the lower resolution of the MOSAIC image, we were unable to measure more sources. The magnitudes result from PSF-fitting. It is clear from the comparison with the HST-image that the photometry is approximate because of the immense crowding, but nevertheless the results are good indications. The colors do not indicate superbright OB stars or groups of OB stars, but rather star clusters.

The right-hand side of Fig. 1 is the color map of the surroundings in lower resolution (seeing 1.1″), which we constructed from the C- and R MOSAIC images. The dynamical range is $0 < C - R < 2$. Here we also see the background stellar population of NGC 1316, which was subtracted from the HST-image. Bright is red, dark is blue. The color of the background stellar population is typically $C - R = 1.3$. One recognizes that both SH2 and the associated object are surrounded by a region distinctly bluer than the background with a typical color of $C - R = 0.9$. The O-II 3727 emission roughly coincides with the maximum transmission of the C-filter, but we cannot easily distinguish between a gaseous emission and a blue stellar population. However, the HST-image suggests that the bluer colors represent the unresolved stellar population. The color around SH2 is about 0.5 and the two dark spots show a color of 0.2. There is no indication for the presence of dust.

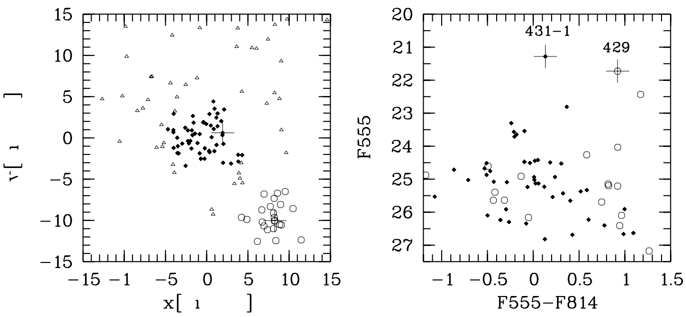

Fig. 2. *Left panel*: the locations of objects with available aperture photometry. Symbols are according to their proximity either to 431 (filled circles), 429 (open circles) or the "field" (triangles). *Right panel*: CMD for the sources from the left panel, using the same symbol coding. The magnitudes are on the ABMAG system and the colors can be approximately transformed into $V - I$ by adding 0.4 mag.

The color of object 429 is surprisingly red and could indicate a globular cluster of age 2 Gyr, if solar metallicity as the typical metallicity for younger populations in NGC 1316 were assumed (of course, we cannot exclude an old cluster of intermediate metallicity, in which case it would be an ω-Centauri-like cluster). Object 429 is embedded in some blue fuzz, which may be an unresolved stellar population, but a group of sources with colors similar to 429 can also be identified in the CMD (see next section).

One might doubt a physical connection with SH2, but the morphological indications (the common blueish envelope, the extension of SH2 toward 429) are puzzling. Moreover, the radial velocities are similar (Sect. 5).

4.2. Aperture photometry from HST images

We used the source catalogs extracted with Daophot and SExtractor, available in the *Hubble* Legacy Archive. This photometry can perhaps be improved by future ACS observations. The objects 429 and 431 are not in the Daophot source list, which otherwise lists many more objects in the most crowded region around 431 than does the SExtractor source list. We therefore used the Daophot aperture magnitudes and the SExtractor magnitudes only for 429 and 431. In both cases, the magnitudes were measured through apertures with radii of 3 pixels.

The magnitudes may not be precise because of the extreme crowding, but the colors are sufficiently accurate to distinguish objects that are as different as 431-1 and 429.

The left panel of Fig. 2 shows the locations (relative to an approximate center of SH2) of all 127 objects within a 30″ by 30″ region, for which photometry in both filters ($F555$ and $F814$) are available. The sources belonging to SH2 (defined by a radius of 5″) are denoted by filled circled, the objects belonging to the 429-group by open circles. The objects 429 and 431 themselves are crosses. The right panel shows the CMD, using the same symbol coding. Magnitudes are given in the ABMAG-system (Sirianni et al. 2005).

The color can be approximately transformed into Cousins $V - I$ by adding 0.4 mag. The large scatter for fainter objects may not be real, but produced by the extreme crowding. The colors are quite blue, but do not indicate extremely young objects. It is striking that the faint sources around 429 also fit to the redder color of 429, which suggests a generically connected ensemble. The nature of these sources is not known, but one may suspect that many of them are fainter GCs somehow related to 429.

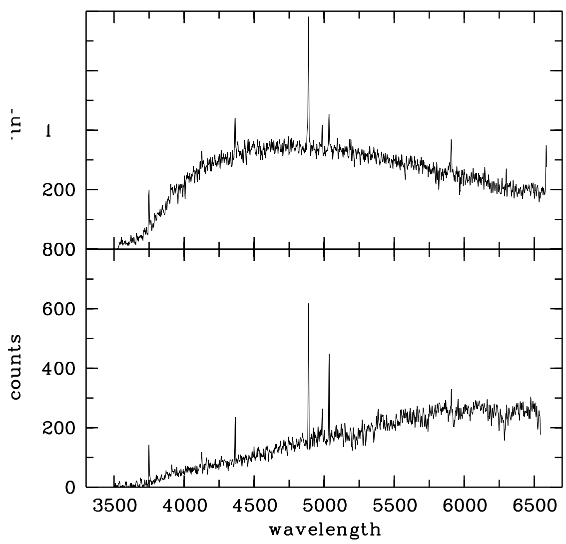

Fig. 3. *Upper panel*: spectrum of 431-1. *Lower panel*: spectrum of 429. The spectra are not flux-calibrated, but the hotter continuum of 431-1 is striking.

4.3. Stellar masses

We can roughly estimate stellar masses by comparing magnitudes and colors with theoretical values. Doing that we assume solar metallicity and use the $C - R$ color as an age indicator. A comparison of ground-based and HST photometry in Table 1 shows brighter R-magnitudes, as expected from the extreme crowding. Employing the models of Marigo et al. (2008), one finds an age of 0.16 Gyr for a color $C - R = 0.2$ (the models use the IMF of Chabrier 2001). The mass-to-light ratio in the R-band is 0.24 (adopting 4.45 as the absolute solar R-magnitude). We find then for 431-1 a mass of $1.9 \times 10^5\ M_\odot$, using the R-magnitude. The true brightness and mass are somewhat lower. At these blue colors, metallicity is not a critical parameter for the age.

The total absolute R-brightness of SH2 is -12.9, corresponds to about $8 \times 10^7\ L_\odot$. For a single stellar population and attributing the entire luminosity to stellar emission, one would assign an age of about 0.1 Gyr and a mass of $1.6 \times 10^6\ M_\odot$.

For 429, one finds an age of 2 Gyr, $M/L_R = 1.1$, and a mass of $0.9 \times 10^6\ M_\odot$ at solar metallicity.

5. Spectral information

Slits were centered on 429 and 431-1. The resulting spectra are shown in Fig. 3. Our spectra are not flux-calibrated but it is clear that the continuum of 431-1 is much bluer than that of 429, as one expects from the photometry. This also shows that at least this object is not a compact HII, but a star cluster. For measuring velocities from emission lines, we used the following lines: OII-3727, HI-4101,HI-4340, HI-4861, OIII-4959, OIII-5007, HeI-5876. The resulting heliocentric velocities are listed in Table 2. Strikingly, the two bluest lines (3727 and 4101) are offset from the others, which agree well. Within the wavelength calibration, the bluest line was 3888, so some extrapolation is necessary to include 3727. It is not clear why H_δ deviates. Skipping OII-3727 and H_δ, we obtain 1709 ± 12 km s^{-1} as the mean velocity of the emission lines in 429 and 1660 ± 11 km s^{-1} as the corresponding velocity for 431.

To measure the radial velocity of the stellar absorption spectrum for 429, we removed the emission lines in the region

Table 2. Velocities of spectral lines and equivalent widths for 431-1 and 429.

Line	Rest wavelength	429	431-1	*EW*(429)	*EW*(431)
OII	3727.32	1745	1737	37	18.5
H_δ	4101.73	1779	1769	–	–
H_γ	4340.47	1721	1645	–	–
H_β	4861.33	1698	1674	16	8.1
OIII	4958.91	1716	1665	2.8	2.0
OIII	5006.84	1717	1663	9.5	2.3
HeI	5875.69	1691	1651	–	–

Notes. The equivalent widths are rough estimates only.

4800–5400 for 429 and cross-correlated this spectral region with a template spectrum, obtained with the same instrumentation that was already used in Schuberth et al. (2010).

We measure a velocity of 1685 ± 20 km s^{-1}. The difference of 24 km s^{-1} to the line velocities is hardly significant. Certainty will only come from spectroscopy of higher spectral resolution.

The color of 431-1 indicates a spectral type of about early A. The strong hydrogen absorption lines which we would expect are filled up by emissions. CaII H+K as well as molecular bands (G-band at 4300 Å and the CN-band at 3883 Å) are weak, but visible. One can conclude at least that the spectrum is not of O-type or early B-type and that it shows a velocity very similar to that of the emitting gas. Taking the mean of CaII H+K, we obtain a radial velocity of 1670 ± 20 km s^{-1}.

Schweizer (1980) quotes a velocity of SH2 relative to the core of NGC 1316 of -101 ± 8 km s^{-1}. That leads to 1760 km s^{-1} for the radial velocity of NGC 1316 and agrees well with all previous measurements. The HI-velocity of SH2 is 1690 km s^{-1} (Horellou et al. 2001) and fits excellently.

The metallicity of SH2 obviously is a key parameter: for a dwarf galaxy, one would expect an abundance distinctly lower than solar. As Kobulnicky & Phillips (2003) showed, simple diagnostics based on the equivalent widths of H_β and the [OIII], [OII]-lines (the R_{23}-parameter) lead to good results for HII regions. Unfortunately, our spectra miss the quality for such work and the quoted equivalent widths in Table 2 are only rough estimates. Moreover, the continuum contamination of H_β in 431 is unknown. However, it is striking that the OIII-line 5007 is much weaker with respect to H_β than in typical HII-regions. The R_{23}-parameter is defined as $R_{23} = \log\left((EW(3727) + EW(4958) + EW(5007))/EW(H_\beta)\right)$. A calibration in terms of oxygen abundance is given by Kobulnicky et al. (1999, their Fig. 8). The R_{23}-values for 431-1 and 429 are 0.24 and 0.49, respectively. They indicate either a super-solar or a very low metallicity due to the ambiguity of R_{23} without other diagnostic parameters.

6. Discussion and conclusions

This is a contribution where questions are mainly posed, not answered. The morphology of SH2 gives the impression of a region of recent star-formation (the only one outside the nucleus of NGC 1316) with extreme clustering. The colors of the star clusters indicate an age of about 0.1 Gyr, thus SH2 is not a typical HII-region, where star formation is ongoing and the ionization sources are UV-photons from very young stars. Very puzzling is its apparent association with a star cluster that is much older. This is hard to understand, even if one speculates that SH2 is the debris of a dwarf galaxy and the cluster 429 one of its globular clusters, which dynamically survived the disruption process. Such a massive object should not come without a field population.

On the other hand, the similarity of the radial velocities can be understood if both SH2 and 429 are moving within a disk with only a low velocity dispersion along the line of sight. But if one excludes 429 itself as the ionizing source, what ionizes the gas around 429?

The grouping of fainter sources with similar colors around 429 is another puzzling finding.

What is the dynamical state and fate of SH2? If it disperses, it may donate a significant number of star clusters to the cluster system of NGC 1316. Why the ring-like structure? How high is the metallicity? What ionizes the gas? Is the connection with 429 real? Is there a faint older population? These questions may find answers after a thorough investigation with integral field spectroscopy and high-resolution space-based and ground-based adaptive optics imaging.

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References

Arnaboldi, M., Freeman, K. C., Gerhard, O., et al. 1998, ApJ, 507, 759
Bedregal, A. G., Aragón-Salamanca, A., Merrifield, M. R., & Milvang-Jensen, B. 2006, MNRAS, 371, 1912
Chabrier, G. 2001, ApJ, 554, 1274
Dirsch, B., Richtler, T., Geisler, D., et al. 2003, AJ, 125, 1908
D'Onofrio, M., Zaggia, S. R., Longo, G., Caon, N., & Capaccioli, M. 1995, A&A, 296, 319
Gómez, M., Richtler, T., Infante, L., & Drenkhahn, G. 2001, A&A, 371, 875
Goudfrooij, P., Alonso, M. V., Maraston, C., & Minniti, D. 2001a, MNRAS, 328, 237
Goudfrooij, P., Mack, J., Kissler-Patig, M., Meylan, G., & Minniti, D. 2001b, MNRAS, 322, 643
Horellou, C., Black, J. H., van Gorkom, J. H., et al. 2001, A&A, 376, 837
Kim, D.-W., & Fabbiano, G. 2003, ApJ, 586, 826
Kobulnicky, H. A., & Phillips, A. C. 2003, ApJ, 599, 1031
Kobulnicky, H. A., Kennicutt, Jr., R. C., & Pizagno, J. L. 1999, ApJ, 514, 544
Kuntschner, H. 2000, MNRAS, 315, 184
Lanz, L., Jones, C., Forman, W. R., et al. 2010, ApJ, 721, 1702
Longhetti, M., Rampazzo, R., Bressan, A., & Chiosi, C. 1998, A&AS, 130, 267
Mackie, G., & Fabbiano, G. 1998, AJ, 115, 514
Marigo, P., Girardi, L., Bressan, A., et al. 2008, A&A, 482, 883
McNeil-Moylan, E. K., Freeman, K. C., Arnaboldi, M., & Gerhard, O. E. 2012, A&A, 539, A11
Nowak, N., Saglia, R. P., Thomas, J., et al. 2008, MNRAS, 391, 1629
Richtler, T., Bassino, L. P., Dirsch, B., & Kumar, B. 2012, A&A, 543, A131 (Paper I)
Schuberth, Y., Richtler, T., Hilker, M., et al. 2010, A&A, 513, A52
Schweizer, F. 1980, ApJ, 237, 303
Shaya, E. J., Dowling, D. M., Currie, D. G., et al. 1996, AJ, 111, 2212
Sirianni, M., Jee, M. J., Benítez, N., et al. 2005, PASP, 117, 1049
Stritzinger, M., Burns, C. R., Phillips, M. M., et al. 2010, AJ, 140, 2036