A NEW ULTRADENSE GROUP OF OBSCURED EMISSION-LINE GALAXIES

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ABSTRACT

We present the discovery of an isolated compact group of galaxies that is extremely dense (median projected galaxy separation: 6.9 kpc), that has a very low velocity dispersion ($\sigma_{2D} = 67$ km $\cdot$ s$^{-1}$), and in which all observed members show emission lines and are morphologically disturbed. These properties, together with the lack of spiral galaxies and the presence of a prominent tidal tail, make this group one of the most evolved compact groups.

Subject headings: galaxies: compact — galaxies: evolution — galaxies: interactions — galaxies: starburst

1. INTRODUCTION

Recent works support the hierarchical galaxy formation theory, in which massive galaxies form by subsequent mergers of smaller systems (Larson 1990; Rauch, Haehnelt, & Steinmetz 1997). In the context of understanding the formation and evolution of galaxies, compact groups (CGs) play an eminent role and can be regarded as a unique laboratory for the study of galaxy interactions, tidally triggered starburst or active galactic nucleus (AGN) activity, and the merging of galaxies.

CGs combine low velocity dispersions (compared to galaxy clusters), small size, and high spatial density. This combination suggests that interactions and mergers should occur frequently in these groups. Details of these processes are, however, under lively discussion and, particularly, the latest stages of the evolution of CGs are widely unknown. The reason is that known high-density CGs are scarce; however, there are examples such as parts of HCG 94 (Pildis 1995) and of HCG 95 (Iglesias-Páramo & Völchez 1998; Rodrigue et al. 1995).

As to remnants of CGs, results are even more meager: only two fossil CGs have been found, and the coalescence processes that lead to the expected bright field elliptical galaxies appear to proceed much slower than anticipated (Ponman 1995; Mulchaey & Zabludoff 1999).

To find the most promising candidate yet. It was recognized by us as a morphologically unusual object (Weinberger 1995) and will be called CG 1720—67.8.

2. OBSERVATIONS AND DATA REDUCTION

For the study in this Letter, we used both imaging and spectroscopic data. A 900 s $V$ frame (centered at $\lambda = 5610$ Å; seeing 1''8) was obtained at the Du Pont 2.5 m telescope of Las Campanas Observatory, equipped with a 2048$^2$ pixel$^2$ Tek5 CCD having a pixel size of 24 $\mu$m and giving a resolution of 0'259 pixel$^{-1}$ in an 8' $\times$ 8' field of view. The frame was processed by means of the Potsdam Image Processing System. This package includes both a standard reduction procedure and a Laplacian adaptive filtering procedure. This adaptive filtering method, developed to suppress the background noise and to distinctly enhance faint structures hidden in strong long-scale luminosity variations (Richter et al. 1991; Lorenz et al. 1993), allows one to put in evidence details of extended objects as well as faint objects otherwise not clearly visible on an image.

Two long-slit spectra (1800 and 1500 s), taken under good seeing conditions (<1'' in the second case), were obtained in 1997 May at the MPI 2.2 m telescope in La Silla and in 1998 February at the Du Pont 2.5 m telescope of Las Campanas Observatory, respectively. For the former spectrum we had a spatial resolution of 0'26 pixel$^{-1}$ and a dispersion of 2 Å pixel$^{-1}$ over the range 3850–8000 Å; the spectral resolution was ~12 Å. For the latter spectrum the spatial resolution was 0'56 pixel$^{-1}$ and the dispersion 2 Å pixel$^{-1}$ over the range 3770–7180 Å; the spectral resolution was ~4 Å. The standard stars LTT 7379 and CD $-$329927 were used to perform the flux calibration.

The standard reduction steps (mean bias subtraction, flat-field correction, wavelength calibration, and atmospheric extinction correction) as well as line flux and position measurements were carried out by means of the IRAF packages. The spectra of all the galaxies of the group show emission lines and, in two cases, pronounced absorption lines too. Emission-line fluxes were measured after a template spectrum of the underlying stellar component, which was obtained from a composition of elliptical galaxy spectra and conveniently diluted to best fit the absorption features, had been subtracted from the spectra, following Ho, Filippenko, & Sargent (1993). Particular care was taken to uncover the H$\beta$ emission line, which is embedded in the corresponding Balmer absorption-line feature. A further correction was applied to eliminate the telluric atmospheric absorption bands falling at the wavelength of H$\alpha$.

3. THE IMAGES

In Figure 1, we present the CCD $V$ frame: the image as reduced in the standard way is shown in Figure 1a; its filtered counterpart, displayed with contour lines and with spectral slit positions superimposed (see below), is presented in Figure 1b and as a color image in Figure 1c.

A wealth of details is visible: the brightest object is an elliptical galaxy (object 2); the next brightest galaxy (object 4)
also appears to be of elliptical type in Figure 1a, but shows a more complicated structure in Figures 1b and 1c, where one notices an elongated (double?) nucleus and outer contours that are reminiscent of two (disk) galaxies that have almost merged. Object 1, the third brightest galaxy, is disturbed by object 2, appears elliptical (Fig. 1a), but shows some internal structure in Figure 1c. Most spectacular is the arc: at both ends there are distinct brightness enhancements; the northern one (the fourth brightest object) is number 3, and the other 7. Object 5, halfway between object 4 and a star, either is the end of a tail connected to object 4 (see Fig. 1c) or is an individual object. A faint diffuse extended object is seen southwest of the star just mentioned, close to the western rim of Figure 1c. Finally, number 6 was assigned to a location at which one slit position crossed the arc. CG 1720–67.8 is very isolated: there is no obvious other galaxy within 11 times the diameter (ca. 30′′) of this ensemble of galaxies; the next cataloged galaxy is about 1° away. The group shows a strikingly high degree of interactions between its member candidates.

Although the V frame was uncaliibrated, comparison with the images on the SERC J and ESO R film copies allowed an estimate of the V-magnitudes of the brightest member candidates (±0.5 mag): we estimate that the objects range from 17.5 (object 2) to 20.5 (object 3). That is, the four brightest member candidates are within 3 mag, and the group is compact and isolated—it thus fulfills the criteria of Hickson (1982) compact groups.

4. THE SPECTRA

We found emission lines in all the objects (objects 1–6) of CG 1720–67.8 covered by the slits and absorption lines in objects 2, 4, 5, and 6. The emission-line fluxes for the four brightest galaxies are listed in Table 1; objects 5 and 6 showed Hα and [N II] λ6583 only.

Heliocentric radial velocities were determined from the emission lines; they are in accord with the otherwise less accurate velocities derived from absorption lines. The calibration error, estimated from the mean deviation of the measured skyline positions from the predicted ones, is ~14 km s⁻¹ for the spectrum taken at Las Campanas and ~30 km s⁻¹ for the one taken.

The spectra are available on astro.uiuc.ac.at (anonymous ftp) in the directory /pub/weinberger/.

TABLE 1

| Line       | Object 1 (±0.15) | Object 2 (±0.15) | Object 3 (±0.15) | Object 4 (±0.15) |
|------------|------------------|------------------|------------------|------------------|
| [O II] λ3727 | 1.79 ± 0.29; 2.28 | 2.02 ± 1.43; 3.28 | ...              | ...              |
| Hα         | 0.42 ± 0.14; 0.49 | ...              | ...              | ...              |
| [O II] λ4959 | 0.63 ± 0.04; 0.62 | 0.27 ± 0.21; 0.26 | 0.98 ± 0.95; 0.92 | 0.07 ± 0.06; 0.07 |
| [O III] λ5007 | 1.89 ± 0.08; 1.84 | 0.53 ± 0.33; 0.50 | 1.51 ± 1.07; 1.62 | 0.53 ± 0.12; 0.23 |
| He λ5876   | ...              | ...              | ...              | ...              |
| [O I] λ6300 | 0.09 ± 0.03; 0.07 | 1.07 ± 0.61; 0.64 | ...              | ...              |
| [N II] λ6548 | 0.33 ± 0.06; 0.25 | 0.36 ± 0.38; 0.20 | 0.96 ± 1.07; 0.31 | 0.49 ± 0.20; 0.24 |
| Hα         | 3.80 ± 0.15; 2.85 | 5.09 ± 2.14; 2.85 | 8.78 ± 4.21; 2.85 | 5.76 ± 0.86; 2.85 |
| [N II] λ6583 | 0.67 ± 0.06; 0.50 | 1.09 ± 0.69; 0.61 | 3.07 ± 1.87; 0.99 | 1.86 ± 0.35; 0.91 |
| [S II] λ6716 | 0.44 ± 0.07; 0.32 | 1.64 ± 1.13; 0.88 | 3.63 ± 3.16; 1.09 | 1.00 ± 0.28; 0.47 |
| [S II] λ6731 | 0.35 ± 0.06; 0.26 | 1.65 ± 0.74; 0.56 | 1.54 ± 2.51; 0.46 | 0.73 ± 0.22; 0.34 |
| F(Hβ)      | 62.7 ± 2.0; 16.06 | 14.36 ± 5.03; 8.32 | 3.22 ± 1.81; 13.05 | 16.3 ± 2.1; 13.74 |
| Vint       | 13430 ± 1        | 13558 ± 4        | 13523 ± 4        | 13427 ± 10       |

Note.—Bold numbers are extinction-corrected intensities. F(Hβ) is in units of 10⁻¹⁶ ergs s⁻¹ cm⁻². Heliocentric radial velocities are given in the last line; for objects 5 and 6 they are 13,547 ± 45 and 13,639 ± 88 km s⁻¹, respectively.
for galaxies 1–4, respectively. In all four cases a non-LTE Mihalas stellar continuum with $T = 42,000$ K was assumed (Mihalas 1972). Since we could not properly fit the observed emission-line ratios assuming solar abundances for objects 2 and 4, we tried to vary the nitrogen (N) and sulfur (S) abundances. A best fit to the data was obtained assuming an N abundance of 0.5 (solar units) for object 2 and both N and S abundances of 0.5 for object 4. Some deviations of $[O II]/H\alpha$ and $[S II]/H\alpha$ line ratios from typical H II galaxies suggest that photoionization is not the only ionization mechanism acting in these galaxies; a possible interpretation would be the presence of shocks generated from stellar winds as a consequence of bursts of star formation (Dopita & Sutherland 1995). Better spectroscopic data are needed to firmly establish the nature of the ionization mechanism.

To obtain an estimate of the star formation rates (SFRs) in the four most luminous objects, the $H\alpha$ luminosity has been calculated from $H\alpha$ fluxes using the radial velocities listed in Table 1. According to Hunter & Gallagher (1986), $SFR = 7.07 \times 10^{-42} L(H\alpha) M_\odot$ yr$^{-1}$, taking into account all stars from 0.1 to 100 $M_\odot$ and providing a measure of the current SFR.

Since the luminosity calculated refers to only to the portion of the galaxies sampled by the long-slit spectra, the SFR values have been divided by the corresponding areas occupied by the single galaxies in the slit (not taking into account the effects of seeing). Anyway, it should be considered that if the SF processes are concentrated in restricted regions of a galaxy, the SFR per unit area declines with the size of the sampled region.

We found values (Table 2) up to 1 order of magnitude greater than those for interacting spirals (Bushouse 1987). This means that all four galaxies are experiencing a clear enhancement of star formation.

An estimate of the number of ionizing photons required to produce the observed $L(H\alpha)$ is given by $Q_{\text{ion}} = 7.3 \times 10^{53} [L(H\alpha)/10^{40}$ ergs s$^{-1}]$. This quantity can be expressed in equivalents of the number of O5 stars, $N(05)$, assuming that each O5 star emits $\sim 5 \times 10^{40}$ ionizing photons s$^{-1}$ (Osterbrock 1989). The values obtained by us (Table 2) are comparable to or even higher than those found in “giant” or “supergiant” extragalactic H II regions, whose $L(H\alpha)$s are in the range $10^{39}$–$10^{40}$ ergs s$^{-1}$ (Kennicutt, Edgar, & Hodge 1989).

5.2. Comparison with Hickson Compact Groups

Hickson compact groups (HCGs) prove to be of great significance for the understanding of interactions between galaxies and appear to be of key interest for studying the formation of new, bright field elliptical galaxies. Our data allow, e.g., the determination of two very important parameters to characterize CGs, namely the median projected galaxy separation (MPS) and the velocity dispersion ($\sigma$): from our four brightest galaxies we found an MPS of 6.9 kpc, much lower than 9.1 kpc for Seyfert’s Sextet (HCG 79), which is reported to be the most compact group (Hickson 1993), and velocity dispersions

| Object | $L(H\alpha)$ ($10^{40}$ ergs s$^{-1}$) | SFR ($M_\odot$ yr$^{-1}$) | Area ($10^4$ pc$^2$) | SFR ($10^4$ $M_\odot$ yr$^{-1}$ pc$^{-2}$) | $Q_{\text{ion}}$ (photons s$^{-1}$) | $N(05)$ |
|--------|----------------|----------------|----------------|----------------|----------------------------|--------|
| 1 ......| 17.6          | 1.24           | 8.26           | 15.0           | 12.8                       | 2560   |
| 2 ......| 9.30          | 0.66           | 9.06           | 7.3            | 6.79                       | 1358   |
| 3 ......| 1.45          | 0.1            | 8.38           | 1.2            | 1.06                       | 212    |
| 4 ......| 15.0          | 1.06           | 10.7           | 9.9            | 10.9                       | 2190   |
\[ \sigma_{2D} = 67 \text{ km s}^{-1} \text{ and } \sigma_{1D} = 99 \text{ km s}^{-1} \]. Median values for the HCGs are MPS = 52 kpc, \( \sigma_{1D} = 200 \text{ km s}^{-1} \), and \( \sigma_{1D} = 331 \text{ km s}^{-1} \) (Hickson et al. 1992). The comparison thus convincingly shows that CG 1720–67.8 is extreme with respect to these quantities.

The fact that we found activity in all our hitherto observed member galaxies is, even if taken alone, remarkable and reminds one of HCG 16 (Mendes de Oliveira et al. 1998). Such a wide-spread activity underlines the prevalence of interaction and merger processes in CG 1720–67.8. In addition, the prominent tail—obviously a tidal tail—that dominates the optical appearance of CG 1720–67.8 is further proof of the ongoing interaction in this group.

5.3. The Dust Puzzle

From H\(_{i}\)/H\(_{\alpha}\), after carefully having taken hydrogen absorption features into account, we found visual extinctions (\( A_v = 3.1E_{B-V} \)) that are variable across the field and are partly astonishingly high: we found \( A_v \) values of \( 0.8 \pm 0.1 \), \( 1.6 \pm 1.2 \), \( 3.2 \pm 1.4 \), and \( 2.0 \pm 0.4 \) mag for objects 1–4, respectively. The Galactic foreground extinction is small: the remote (>7 kpc) globular cluster NGC 6362 (\( \ell = 325^\circ, b = -17^\circ \)), only about 1.3 away from CG 1720–67.8, has a color excess of only \( E_{B-V} = 0.11 \) (Zinn 1985). Provided that the derived extinctions represent the foreground obscuration of the respective galaxies, estimates of the absolute magnitudes of these galaxies are possible and the combined brightness of all these four galaxies (together with a rough estimate of the remaining objects) results in a total absolute magnitude of not more than \(-21.5 \) mag for CG 1720–67.8. Strangely enough, there is no counterpart in the IRAS catalogs but a very vague hint for 60 \( \mu \text{m} \) emission in IRAS maps (by the way, CG 1720–67.8 also has no counterpart in radio or X-ray catalogs).

Why does the abundance of dust, which is responsible for the pronounced extinction, not emit in the IRAS bands? We suggest that it might be very cool dust that mainly radiates beyond 100 \( \mu \text{m} \). If true, this may be due to dust in the group’s halo, perhaps blown off by strong galactic winds.

From all pieces of evidence, taken together, we conclude that CG 1720–67.8 is in all probability a group of galaxies on the verge of coalescence. If we assume that the group will evolve into an elliptical galaxy, as is generally believed for compact groups (Mulchaey & Zabludoff 1999), the end-product may hardly be a very bright field elliptical galaxy, but rather a moderately bright one. This ultradense compact group deserves thorough future studies.

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