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A RED ENVELOPE AROUND A DOMINANT ELLIPTICAL GALAXY IN AN X-RAY SELECTED POOR CLUSTER[1]

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ABSTRACT

A photometric and spectroscopic study of the optical counterpart of the X-ray source 1E 1111.9−3754 has revealed a poor cluster of galaxies dominated by a very luminous giant elliptical. Three-color surface photometry of this galaxy shows that the elliptical body is surrounded by a large envelope with colors redder than the galaxy. The formation of this system in a high velocity dispersion poor cluster is briefly discussed.

Subject headings: galaxies: clustering — X-rays: sources

I. INTRODUCTION

In the process of identifying X-ray sources from the *Einstein Observatory* Extended Medium Sensitivity Survey (Gioia, Maccacaro, and Wolter 1987; Gioia *et al.* 1988) we have observed the field of 1E 1111.9−3754, which contains a poor cluster or group of galaxies. The brightest member of 1E 1111.9−3754 is a giant elliptical galaxy sitting at the bottom of the potential well described by the X-ray emitting gas, similar to the Albert/Morgan groups studied in the X-rays by Kriss, Cioffi, and Canizares (1983). D or cD galaxies in clusters and groups have been studied in detail by, e.g., Oemler (1976) and Thuan and Romanishin (1981), as they are useful objects for cosmological tests and provide information on galaxy formation and cannibalism. In particular it was found that the D galaxies in poor clusters lack the large envelopes defining their counterparts in rich galaxy environments.

In this *Letter* we report on photometric and spectroscopic observations of the brightest cluster member of 1E 1111.9−3754, which we have nicknamed GREG (Giant Red Envelope Galaxy).

Throughout this *Letter* we used a Hubble constant of 50 km $\mathrm{Mpc}^{-1}\ \mathrm{s}^{-1}$ and $q_0 = 0$, implying a scale of 3.17 kpc arcsec^{-1} at $z = 0.1312$.

II. OBSERVATIONS

a) X-Rays

The X-ray source 1E 1111.9−3754 has been found analyzing the Image Proportional Counter (IPC) image with sequence number 4923. The image was centered on a cataclysmic variable; the observation was carried out on 1980 January 9 and lasted 1600 s. 1E 1111.9−3754 is detected in the area between the IPC window support structure and the edge of the detector. We have reprocessed the data to obtain an "unmasked" image. This procedure allows us to recover the information contained in the outer region of the IPC field of view (see Harnden *et al.* 1984 for details). The position of the source and the small number of net counts (∼100) prevents us from studying the surface brightness distribution and thus determining the source core radius. We can only say that the source is extended and that it is elongated in the NE–SW direction, as indicated by the isointensity contours. These are shown in Figure 1 (Plate L1) superposed onto a reproduction of the ESO/SRC J sky survey plate of the same area. The edge of the IPC image is indicated. The proximity of 1E 1111.9−3754 to this edge causes the X-ray contours to appear compressed, thus underestimating the size of the X-ray source. The dominant cluster galaxy is found at the centroid of the X-ray position. The hydrogen column density in the direction of 1E 1111.9−3754 is 9.0×10^{20} atoms cm^{-2} (Stark *et al.* 1999). This, combined with the assumption of a temperature of ∼4 keV for the X-ray emitting gas, allows us to convert the detected counts into a flux (corrected for galactic absorption) of $(5.1 \pm 0.6) \times 10^{-12}$ ergs $\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$ (0.3–3.5 keV). The quoted error only reflects the uncertainty due to the photon counting statistics.

b) Optical

i) *Environment*

Galaxy counts were measured on a film copy of the ESO/SRC J sky survey plate. Galaxies were counted down to the plate limit in seven concentric annuli centered on GREG, reaching a maximum radius of 1.3 Mpc at the distance of the galaxy. The galaxy density enhancement at the position of 1E 1111.9−3754 characterizes a rather poor cluster of galaxies. We estimate a richness between 0 and −1 and a central galaxy density $N_0 \sim 10$. This estimate results from a visual inspection of the small-scale SRC plate. It should therefore be confirmed through automated galaxy counts on a large scale direct plate.

ii) *Spectroscopy*

Spectra of nine galaxies in 1E 1111.9−3754 were obtained at the ESO 3.6 m telescope equipped with EFOSC (Dekker and D'Odorico 1985) in the Multi Object Spectroscopy (MOS) Mode (Dekker and D'Odorico 1986) on 1987 May 1. Circular holes with a diameter of 2″.1 were drilled in a mask placed in front of a grism with a dispersion of 230 Å mm^{-1}. The wavelength coverage is 3600–7200 Å. We used ESO CCD No. 11 (RCA 1024 × 640 pixels) with a pixel size of 0″.34, which was read in binned (2 × 2) mode. The spectral resolution was 20 Å. Twin 50 minute exposures were obtained in order to facilitate the identification of cosmic-ray events. A He-Ar lamp served as wavelength calibration.

The velocity dispersion of the cluster, computed using the method of Danese, De Zotti, and di Tullio (1980) is 1226 (+515, −286) km s^{-1}. GREG's spectrum clearly shows the Ca II H and K, the G band, Hβ, Mg I, and Na D absorption

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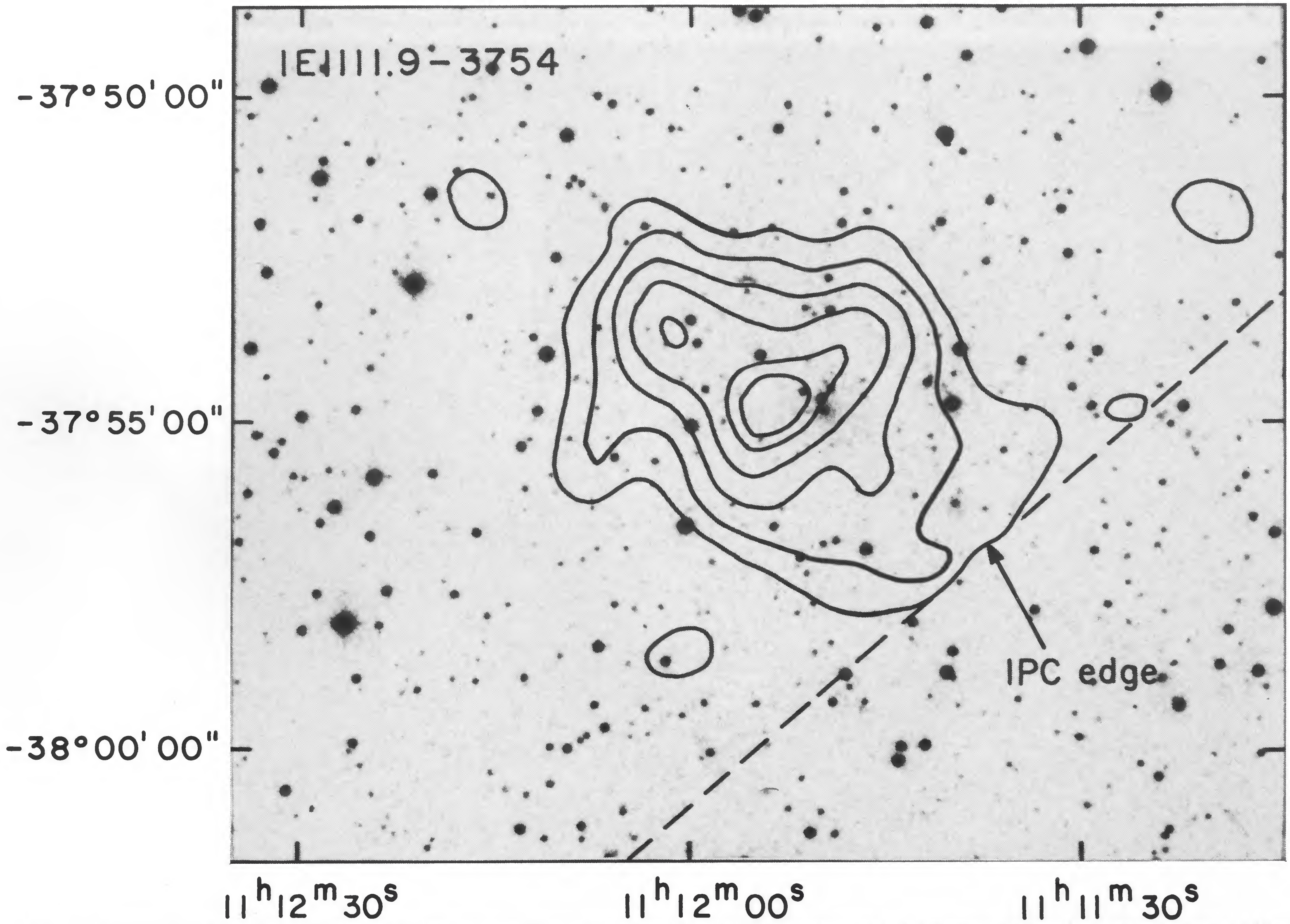

FIG. 1.—X-ray contours from the *Einstein Observatory* IPC observation superposed on the ESO/SRC J sky survey plate. The X-ray emitting region has an extent of about 1.3 Mpc at 5 σ above the background. The innermost contour is 12 σ above the background. The contours are elongated in the NE–SW direction, the same direction as that shown by the isophotes of the dominant galaxy.

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lines at a redshift $z = 0.1312$, corresponding to an (uncorrected) radial velocity $V = 39340 \pm 153$ km s^{-1}. No emission lines are present. We note, however, that the redshifted position of Hα falls outside the observed range.

iii) *Photometry*

Three pairs of slightly offset images of a region centered on GREG were obtained on 1987 April 29, using the EFOSC in direct imaging mode. EFOSC field of view is about $3' \times 5'$. Each image was exposed for 8 minutes in the Gunn, g, r, and i filters (Thuan and Gunn 1976; Wade, Hoessel, and Elias 1979). This time the CCD was read at its full resolution. The images were bias subtracted and flat-fielded following the usual procedures. Each pair was then summed after being aligned by measuring the coordinates of 10 stellar objects in each frame. Flat-fielding provides a correction accurate to within 1%. Our photometry was calibrated by observing three standard stars in the E-regions (Graham 1982), one at the beginning, one in the middle, and one at the end of the night. The zero point we obtain is correct within 0.1 mag. The average seeing during the night was $1\farcs6$.

Figure 2 (Plate L2) shows a false color image in the i filter of GREG and its immediate surroundings. GREG appears elongated in the direction NE–SW, i.e., aligned with the X-ray contours. The surface brightness profiles of GREG were obtained in each filter by integrating the counts within concentric ellipses with position angle 65° and a ratio of minor to major axis of 0.77. An iterative sigma-clipping procedure was used to remove extraneous objects and chip defects from the integrations. We first removed the sky level which was determined by inspecting selected regions around the galaxy. Sky brightness was 21.92, 20.97, and 19.97 mag arcsec^{-2} in the g, r, and i filters, respectively. Corrections for atmospheric extinction were applied. The resulting surface brightness profiles are shown in Figure 3, where magnitudes arcsec^{-2} are plotted against the $R^{1/4}$ (kpc) down to a surface brightness level 2.5 times above the sky noise.

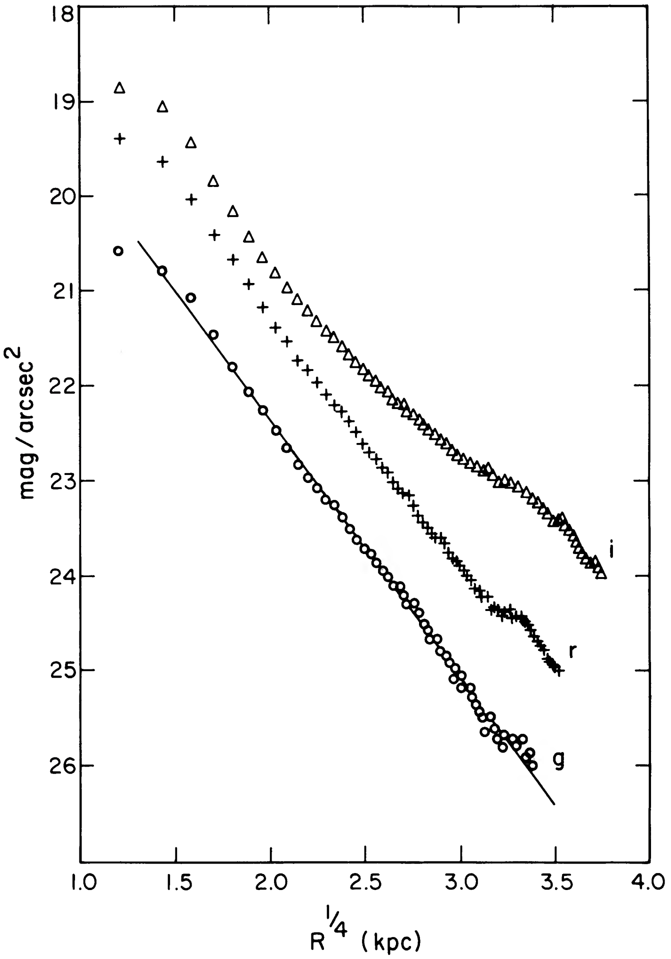

FIG. 3.—Surface brightness profiles of GREG in the three g, r, and i Gunn filters. The straight line is a fit with a de Vaucouleurs law to the central part of the galaxy.

III. RESULTS AND DISCUSSION

Table 1 gives the de Vaucouleurs and Oemler parameters of GREG as well as other basic quantities. The parameters have been K-corrected after Schneider, Gunn, and Hoessel (1983) and reduced to the B, V system by applying the transformations given by Cohen (1985) and the corrections for galactic absorption as given in Sandage (1973).

The X-ray luminosity of 1E 1111.9−3754 is 3.6×10^{44} ergs s^{-1} (0.3–3.5 keV). When compared with the Albert-Morgan groups studied by Kriss, Cioffi, and Canizares (1983), our poor cluster of galaxies is among the most luminous ones. As shown by Bahcall (1980, 1981), the central galaxy density correlates with the X-ray luminosity and with the velocity dispersion of the cluster, which are also correlated between themselves (Quintana and Melnick 1982). In the case of 1E 1111.9−3754, this last correlation holds well, while the central galaxy density is small with respect to both the X-ray luminosity and the velocity dispersion. This could be an indication that in this poor cluster the dynamical evolution has abnormally advanced and that the "missing galaxies" are to be looked for in the giant structure of GREG.

GREG is extremely bright for the environment in which it is found, and its absolute magnitude $M_V = -25.23$ (as derived from the g filter growth curve) makes it comparable to the cD galaxies in rich Abell clusters like A2670 and A1413 (Oemler 1976). Its extreme luminosity (about 1 mag brighter than the brightest of the galaxies in poor clusters) can be tied to the high velocity dispersion of 1E 1111.9−3754, since the total accretion rate onto the central region is about twice that in poor clusters. If we consider only the g (and partly the r) filter observations, GREG has the dynamical structure of a normal elliptical galaxy, even though it is extremely large and luminous. This can be seen by plotting both the visual absolute

TABLE 1

MAIN CHARACTERISTICS OF GREG

Characteristic	Value
Redshift (z)	0.1312 ± 0.0005
Total visual absolute magnitude (M_v)	−25.23
de Vaucouleurs's parameters:	
Blue effective surface brightness ($B_{e,B}$)	25.51
Logarithm effective radius (r_e)	1.95
Oemler's parameters:	
Visual absolute reduced magnitude $M_{V,\mathrm{rd}}$	−22.62
log α	>2.5
log β	0.93

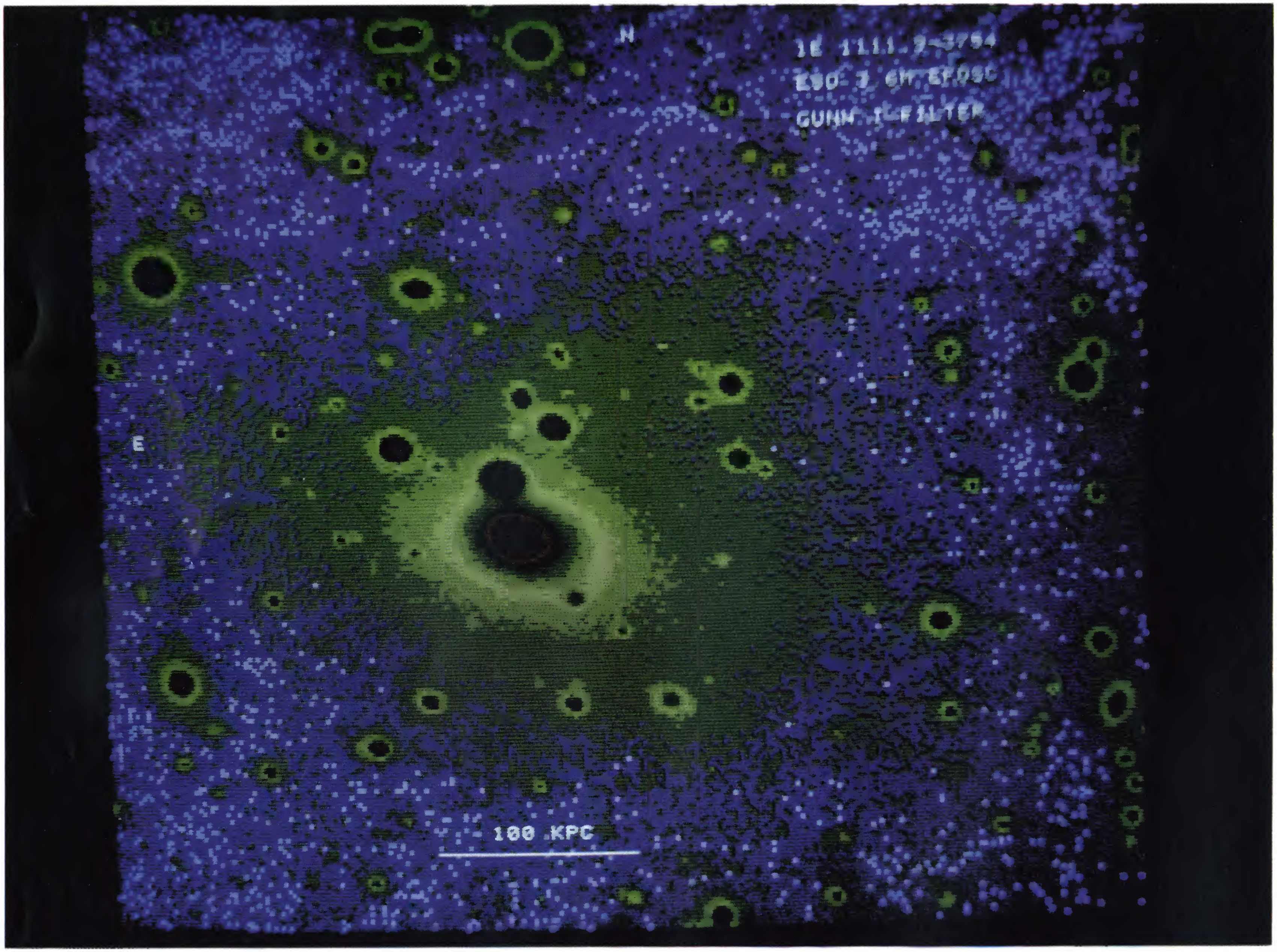

FIG. 2.—False color image of GREG obtained by summing the two 8 minute exposures in the Gunn *i* filter, after bias correction and flat-fielding. The large envelope (~250 kpc radius) is clearly visible. North is at the top, and east is on the left.

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reduced magnitude versus the total visual absolute magnitude (Fig. 9 of Thuan and Romanishin 1981) and the de Vaucouleurs blue effective surface brightness versus the logarithm of the effective radius (in kpc) (Fig. 10 of Thuan and Romanishin 1981). In both cases GREG's points fall on the extrapolations of the relations given by Oemler (1976) and Kormendy (1980), respectively, for normal ellipticals. This means that even in extreme cases like this, brightest cluster galaxies can be a useful cosmological tool.

Where GREG's properties deviate from normal ellipticals and from the brightest members in poor clusters is in the presence of an envelope redder than the galaxy. Inspection of Figure 3 reveals that, while the *g* filter surface brightness profile can be represented by a de Vaucouleurs law out to a radius of about 130 kpc, at about 100 kpc radius in the *r* filter profile and even from about 50–80 kpc radius in the *i* filter, an excess surface brightness with respect to the de Vaucouleurs law is clearly visible. This is the signature of the envelope found in cD galaxies in rich clusters, but in this case the envelope has extremely red colors and would have escaped detection if our photometry had not included the *i* (and *r*) filter. In order to be certain that no instrumental effects are responsible for *i* band envelope we detected around the galaxy, we made a check on a field star which showed identically shaped profiles in the three filters; that is, there was no halo-like emission present in the *i* band.

Therefore GREG is characterized by a very luminous elliptical core and by an envelope much redder than the galaxy. Furthermore, it is located at the center of a deep potential well, and it is the brightest member of a poor cluster with rather high velocity dispersion. By taking into account both merging and stripping processes after cluster virialization. Malamuth and Richstone (1984) succeed in simulating a brightest galaxy of a luminosity comparable with that of GREG only in a rich environment. Merritt (1984) argues that cD's in cases when the velocity dispersion is high must be the product of special initial conditions and that their formation and properties are determined not later than cluster collapse. A case similar to that of GREG, but not so extreme, has been simulated by Carnevali, Cavaliere, and Santangelo (1981). However, no one seems to have considered in detail the case of a final poor cluster environment with rather high velocity dispersion.

The colors of GREG's envelope could find an explanation either in a peculiar initial mass function with a large excess of very low mass stars or in an intermediate age population (a few Gyr old) where cool AGB stars contribute a large fraction of the total luminosity (Renzini and Buzzoni 1986). In this second, more plausible hypothesis, the collisions responsible for GREG's formation should have occurred a few billion years ago and little or no dynamical evolution must have occurred since then. Stripping is generally very effective at high encounter velocities, but the envelope colors perhaps hint to an epoch of formation of this giant elliptical either during or before cluster collapse.

Cooling flows have also been proposed to explain the formation of cD galaxies at the center of X-ray clusters. GREG's colors seem not to conform to the expectations of such models, since the low-mass stars formed by the flow (Fabian, Nulsen, and Canizares 1982; Sarazin and O'Connell 1983) should concentrate in the central parts of the galaxy. Furthermore, there is no evidence of emission lines in GREG's spectrum, nor is GREG a radio source (the 5 σ upper limit at 5 GHz is 0.7 mJy; our data, unpublished).

However, for a better understanding of GREG's properties, we lack morphological information as to the presence of multiple nuclei to probe merging processes since cluster collapse. H and K photometry of the envelope is needed to discriminate its stellar population (Renzini and Buzzoni 1986). Measurements of the velocity dispersion in the elliptical body and in the envelope should be obtained to better characterize the dynamical properties of GREG's constituents with respect to its environment. Finally, *i* band surface photometry of other brightest members in poor and rich clusters is necessary to appreciate the frequency of occurrence of envelopes with colors redder than the galaxies.

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