

## Letter to the Editor

# Detection and photometry of a complex system in the center of the A 2218 cluster of galaxies

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### Summary:

During a photometric survey of rich clusters of galaxies, we took several deep, high resolution, g and r exposures on Abell 2218. We confirm the probable existence in the core of peculiar structures, elongated and curved around the central cD galaxy and another giant galaxy. We provide photometric and geometric data on the cluster core in the hope to constrain the various possible models. One of these “arcs” is very blue, but faint, fragmentary, and of questionable significance. The other ones, redder and smaller, are similar to background galaxies lensed by a cluster core, which may be more or less elongated and distorted depending on their position with respect to the lens caustic.

**Keywords :** Clusters of galaxies – Arcs – Gravitational lensing

### 1. Introduction

In the past few months, several papers have appeared concerning the discovery of luminous arcs lying in the center of a few clusters of galaxies. The first arc was discovered by a team from Toulouse Observatory (France) in the distant cluster A 370 (Soucail *et al.*, 1987a), of redshift  $z=0.374$ . The second one has been discovered by Lynds and Petrosian (1986) in the center of the cluster Cl 2244-02 ( $z=0.33$ ). In addition, the possible presence of a similar but fragmentary structure around A 2218 was reported (Petrosian 1987). A 2218 being one of the objects selected in our program of photometric survey of very rich clusters, we tried to obtain a deep detection of faint features in the field. So, we present our multicolor photometry of the central structure, confirming the existence of a complex system around the central cD galaxy.

### 2. Observations and data reduction

The observations were made on the night of May 21, 1987, at the 3.50 m telescope of the Centro Astronomico Hispano Aleman de Calar Alto (Almeria, Spain). We used an RCA 006 EX CCD camera at the F/3.4 prime focus with an equivalent pixel size of 0.516 arcsec. The angular size of the CCD frame is  $4.4 \times 2.8$  arcmin<sup>2</sup>. Two frames were obtained using the g and r

filters of the Thuan-Gunn system (Thuan and Gunn, 1976), with exposure times of 1800 and 1500 sec., respectively. Observing conditions were excellent: the night was photometric throughout and seeing was 1 arcsec or better. These images were of very good quality.

During the run several flat fields, either on g and r filters, and dark current frames were obtained. Standard stars for photometrical calibration were mainly picked in the field near M92, which has been formerly photometrized in the Thuan-Gunn system by Kent (1985). Furthermore, we used several of the standard stars that define this photometric system. The photometry of those objects which are not strongly blended was performed with an automatic package developed by Le fèvre (1986) and implemented on the VAX 750 of Observatoire Midi- Pyrénées (Toulouse, France). Its main specificity is to integrate the light inside elliptical annuli, so it is well suited to the photometry of extended objects such as galaxies in clusters.

### 3. Description and photometry

#### 3.1. Main properties of the cluster A2218

This cluster of redshift  $z=0.171$  (Kristian *et al.*, 1978), intensively observed in many spectral ranges, shows some spectacular properties. First, with a richness class 4, it is one of the richest clusters of the Abell catalog. It contains a large cD galaxy in its center, with a very low central surface brightness and an envelope extending over more than 180 kpc ( $H_0 = 50$  km/s/Mpc), and several other bright galaxies. An analysis of the detailed photometry published by Butcher *et al.* (1983, hereafter BOW) gives a concentration parameter  $C_{30} = 0.59$  (Butcher and Oemler 1984, hereafter BO), one of the largest in their sample. An Einstein Observatory high-resolution X-ray map is available (Boyton *et al.*, 1982). The profile is smooth and the image is circularly symmetric, except for a small contribution from the cD galaxy, possibly due to a cooling flow. The X-ray luminosity is  $6.5 \cdot 10^{44}$  ergs/s in the range 0.5-4.5 KeV (Perrenod *et al.*, 1981).

In connection with the X-ray luminosity, the Sunyaev-Zel'dovich effect has been detected with millimetric observations of the cluster (Birkinshaw *et al.*, 1981,1984, Partridge *et al.*, 1987). Moreover, the map at 11.1 cm (Schallwisch *et al.*, 1978) shows the presence of an extended radio halo with an intensity peak centered on the cluster.

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### 3.2. Description of the arcs

Looking at a deep CCD frame, one can see several elongated faint objects (Fig. 1) that we shall call "arcs" for convenience, even if they appear somewhat different from the giant luminous arcs detected in some other distant clusters.

In particular, two arcs extend roughly in the East-West direction around the cD galaxy, close to both extremities of its major axis and perpendicular to it. Both are resolved, with a width of 8 to 10 kpc, and curved.

These arcs show very different shapes (Fig. 2). The brightest one, southward (H on Figs. 1 and 2), extends through a bright galaxy (BO # 24) over about 70 kpc. Its radius of curvature is  $130 \pm 20$  kpc and the angle subtended is approximately  $30^\circ$ . Its actual center is 51 kpc in the North-West direction from the cD center. The northern arc is fragmentary and quite fainter in comparison. It consists of a bright part (A on Figs. 1 and 2) which has a faint extension eastward. A is perhaps connected to a second portion A' but the connection appearing around B (a superimposed object?) is just above the noise and hardly significant. A' also shows a faint extension toward South-West. On the isophote map (Fig. 2), the global AA' system appears as a segment of a roughly circular ring, spanning about a quarter of a circle. Its radius of curvature, about 100 kpc, is smaller

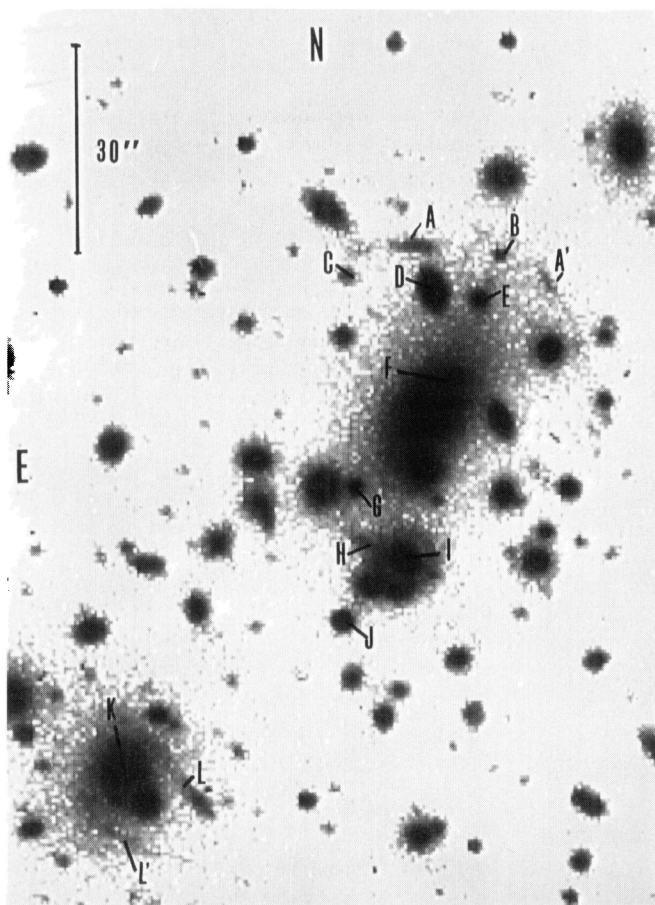


Fig. 1: CCD image of the center of the A2218 cluster, in a logarithmic scale. The exposure time is 25 minutes, taken with a g filter at the prime focus of the 3.5 m telescope at Calar Alto (Spain).

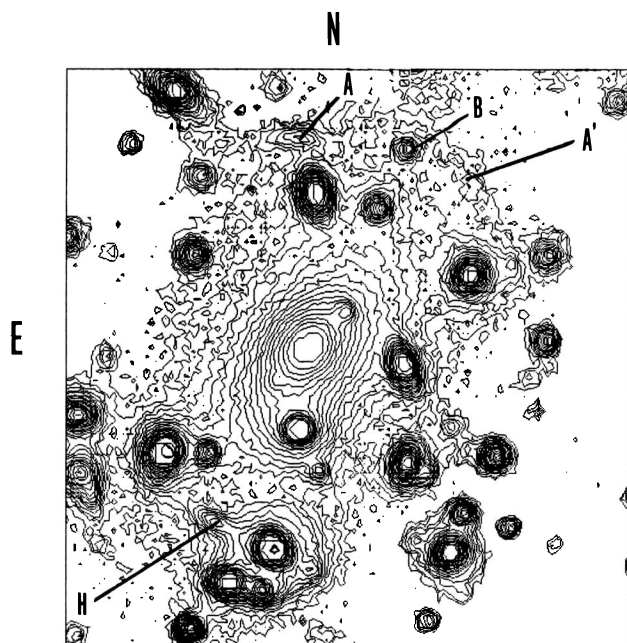


Fig. 2: Isophotal picture of the system near the cD galaxy, showing the northern and southern arcs. The image is presented in a logarithmic scale.

than that of H, and its extent about 160 kpc. Its center is approximately 20 kpc South-Eastward from the cD center. In fact, this arc lies close to the limit of the cD envelope but seems to be relatively distinct from it, even if this remains questionable due to the low S/N ratio.

South-Eastward from the cluster center, another large and bright galaxy (K on Fig. 1) retained our attention. Indeed, it seems to be surrounded by at least two other arcs (L and L'). Both are diffuse and resolved. L, by far brighter than L', somewhat resembles H. But these arcs L and L' appear to be different from H and from the A system, being larger in width, centered far from the cluster center, and not so symmetric around galaxy K. In fact, the lack of redshifts prevents us from interpreting all these objects as cluster members.

### 3.3. Photometry

As the main results of the photometry were published elsewhere (Butcher *et al.*, 1983), we do focus essentially on some new results concerning the colour index (g-r) and the r-magnitude of objects dealing with the arcs. We may stress that the center of A 2218 is very rich and confused, so a lot of galaxies are rather blended.

First, we compared our r photometry with the BOW F photometry for about 25 galaxies (Fig.3) as the spectral range of the two filters are similar. The correlation is quite good except for the brightest galaxies ( $r \leq 18$ ) where the magnitudes were integrated in a larger aperture in our data (the radius corresponds to a surface brightness  $r = 25$  mag/sq.arcsec.), and for the faintest ones where the uncertainties become predominant. We can estimate the accuracy of this photometry as 0.08 on magnitudes, being  $\sigma_{g-r}$  about 0.1.

We have reported the magnitudes of some selected objects of the field in Table I, with the identification number from BOW

ID	BO n°	r <sub>25</sub>	g <sub>26</sub>	g-r <sub>25</sub>
A	293	22.50	22.55	0.19
B	369	21.52	22.32	0.92
C	–	21.63	22.41	0.73
D	48	18.74	19.16	0.43
E	126	20.13	21.18	0.95
F	8	16.63	17.59	0.95
G	–	20.46	21.66	1.26
H	–	21.57	22.85	1.28
I	24	17.21	17.87	0.94
J	135	19.86	20.03	0.19
K	3	17.13	18.14	1.05
L	–	22.20	21.90	0.56

**Table I** : Successive columns are : identification , Butcher-Oemler n°, r magnitude (inside the r<sub>25</sub> radius), g magnitude (inside the g<sub>26</sub> radius) and g-r color index (inside the r<sub>25</sub> radius)

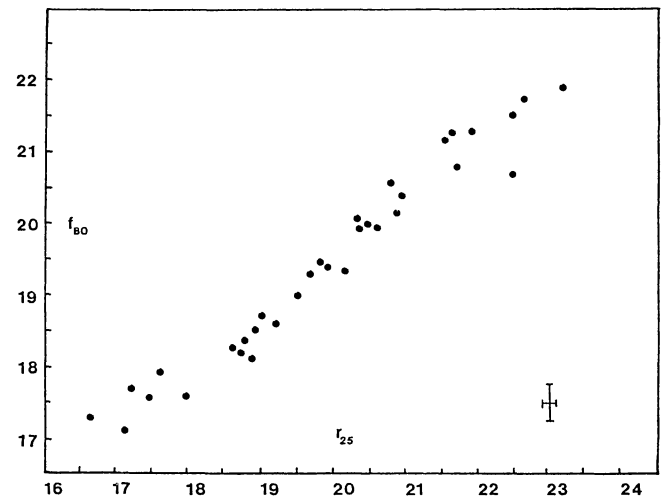
when it exists. The northern arc is by far bluer than most cluster galaxies. Note that there are nevertheless a few objects lying in the same zone, that present very blue color indices. On the contrary, the southern arc seems to be redder, but this result must be taken with caution because of the possible contamination by the red cD envelope.

A special comment can be done about the cD galaxy of A2218. Its total integrated magnitude is difficult to measure, because of the contamination by many superimposed objects and because of the huge extent of an envelope which is strikingly flat in surface brightness. Probably one of the flattest ever seen in a rich cluster, this cD should deserve a study for itself. However the colour index of the center can be evaluated with a good accuracy. We have measured  $g-r=0.95$ , corresponding to the colour predicted by the evolutionary model of Guiderdoni and Rocca-Volmerange (1987) for an elliptical galaxy at redshift  $z=0.171$ . On the contrary, the colour indices of the northern and southern arcs are, respectively, bluer and redder than those predicted for galaxies at the cluster redshift (whatever their morphological type) and observed for all objects in the field.

#### 4. Discussion

The arcs in A2218 present striking differences with those observed in A370 and Cl 2244-02. They are several, irregular, well resolved, instead of a single per cluster, faint, blue, regular, not at all or hardly resolved and flat in surface brightness. Nevertheless all these structures show common properties : more or less circular, they lie in the core of rich clusters. More precisely, they surround a cD galaxy or a giant galaxy very close to the edge of its envelope. H in A2218 is the only exception, being rather bright, red and broad, and showing a central intensity peak.

In A370 and Cl 2244-02, the last data seem to be consistent with the gravitational lensing hypothesis. Indeed, the spectrum of the eastern end of the A370 arc (Soucail *et al.*, 1987b) is very flat and could be similar to the large scale energy distribution of a spiral at  $z=0.6$ , while the integrated spectrum of the Cl 2244-02 arc (Soucail *et al.*, 1987c), also quite flat, is non stellar in appearance. Unfortunately, due to their poor S/N ratio, neither



**Fig. 3** : Comparison of our r magnitudes with the F magnitudes of Butcher *et al.* (1983) for 33 objects in the center of A2218

of these spectra does show any undeniable signature of high redshift.

In A2218, very few spectroscopic data are presently available and we may be dealing with a superimposed cluster. Among the objects appearing on Fig. 1 only the large cD has a measured redshift ( $z=0.171$ ). A priori, neither the difference in colour between A and H nor the morphology of H does support the hypothesis of gravitational lensing of some background object. The three systems (AA', H and LL'), quite different from one another, might have different origins. On the basis of its appearance in Fig. 2, the northern arc is a possible candidate as image of a distant object gravitationally lensed. In this case, A, A' and/or B can or not be superimposed galaxies (A somewhat resembles an edge-on spiral). The southern arc H and L, redder, broader and showing a central intensity peak, might be an edge-on galaxies, L being a chance projection on the galaxy BO # 24. Alternately, LL' might be an interacting system (Toomre and Toomre, 1972) or belong to a shell system around galaxy K. Nevertheless, as noted above, A2218 is a quite rich cluster and it would not be surprising that atypical phenomena occur there. No information is available neither on the dynamical stage nor on the mass of the cluster, but remember that A2218, a relatively strong X-ray emitter, is dominated by an extended cD galaxy. All these properties suggest that a lot of dark matter could lie in the center of the cluster, which then could act as a very massive deflector.

Grossman and Narayan (1987) performed simulations of gravitational lensing of background field galaxies by realistic dense cluster cores. In particular they show that background galaxies crossing the lens cusp caustic can be simultaneously lensed and distorted into several small pieces of arcs. Kovner (1987a) derived similar images in the case where most of the lensed galaxy is outside the caustic. There are a few similarities between one of the 101 Grossman and Narayan simulations (their Fig. 2) with the core of A2218, both showing several elongated objects. They made use of a somewhat enhanced background density, but an overdensity can be found behind A2218 due to statistical fluctuations. The colour difference between A and H cannot be taken as a definitive argument against the lensing hypothesis

since Guiderdoni and Rocca (1987) predict that the g-r color index of all galaxies increases with increasing redshift in the range  $z < 0.3$  and decreases at larger  $z$ . So, H could be a lensed elliptical of redshift about 0.5 while A could be a lensed spiral of larger  $z$ .

Many models have been proposed to explain the nature of the arcs in the center of rich clusters of galaxies, namely the light echo (Katz 1987, Milgrom 1987), the double torch (Kovner 1987b) or a shell of stellar formation (Braun and Dekel 1987). Understanding the origin of these structures will come from spectroscopic, photometric and eventually polarimetric observations. The arcs of A2218 appear so faint that they first need to be confirmed. It will be difficult to obtain conclusive data from observations with a 4 m telescope. The clue for the origin of giant arcs should come from data on the arcs in Cl 2244-02, A370, or in other clusters which still remain to be discovered.

The cluster A2218 is undoubtedly quite interesting and deserves a complete spectroscopic survey, including the huge, flat diffuse component. It contains some arc-like structures whose nature and origin remain to clarify and whose similarity with the giant arcs in A370 and Cl 2244-02 is still questionable.

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