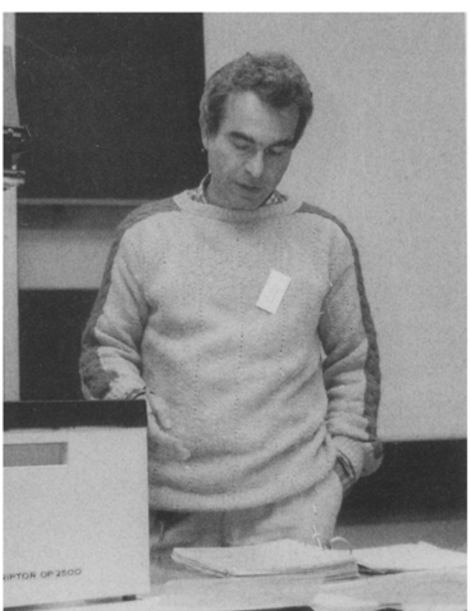
Part III

Clusters of Galaxies

Piotr Flin

Gabor Tóth



Guido Chincarini

Konrad Rudnicki

A Study of Nearby Clusters of Galaxies

Piotr Flin
Jagiellonian University Observatory
Kraków, Poland

Paul Hickson
Department of Geophysics and Astronomy
University of British Columbia
Vancouver, B.C., Canada

Giancarlo Pittella
Osservatorio Astronomico di Roma, sede Monte Porzio
Roma, Italy

Abstract

The paper describes a study, presently underway, of a sample of 150 nearby clusters of galaxies. We discuss the selection criteria, observational data, and methods of analysis, and present some illustrative results.

1 Introduction

In recent years much progress hass been made toward the understanding of nearby rich clusters of galaxies (Dressler 1984). In addition, studies of more distant clusters (Butcher and Oemler 1985) have revealed important differences between high-redshift clusters and nearby rich clusters. Despite this activity, we still know little about the nature of typical nearby clusters. As yet, there is no large well studied sample of typical low-redshift clusters, although some progress is being made toward this goal (Oegerle *et al.* 1986).

The lack of good published data for nearby clusters prompted PH to obtain photographic plates of a large sample of nearby clusters in the course of a study of structural properties of clusters (Hickson 1977a, b). These plates form the basis for the present study. Our primary objectives are to extend this previous work by including photometric and morphological properties of cluster galaxies, obtained by microdensitometer scanning and digitization of the plates. The resulting large homogeneous data set will allow us to examine statistical properties of clusters with accuracy. Such data are important, not only for the understanding of nearby clusters and the galaxies that they contain, but also to provide a firm basis for comparison with distant clusters.

In this paper, we discuss the observational data and selection criteria for the sample, the methods of analysis, and the present status of the project.

2 Observational data and sample selection

The observational material consists of 10-inch plates taken by PH with the 48 inch Palomar Schmidt telescope. Two emulsions were employed: Kodak 127-02 (a fine grain red-sensitive emulsion which preceded the more recent IIIa-F) was used for more distant clusters, and Kodak 098-04 (a more sensitive coarse grain emulsion) was used for nearby clusters. Both emulsions were used with 2 mm of Schott RG-1 glass, corresponding to the red photographic F-band of Oemler (1974). This band is centered at 6500Åand is almost identical to the r-band of Thuan and Gunn (1976). Plates were developed for eight minutes in MWP-2. Each plate was calibrated with the Palomar spot sensitometer, which exposes a corner of the plate to spots of increasing (by $\sqrt{2}$) intensities.

These plates are centred on clusters in Hickson's "nearby" sample (1977a), but their large format results in other clusters being serendipitously included. In addition to the central cluster, all Abell clusters also on the plate were included, if their galaxies were clearly visible. This resulted in a sample of 150 clusters, which forms the basis for our study.

3 Image analysis

Each selected field containing clusters as well as the sensitometer spots, was scanned at the Rome Observatory at Monte Porzio with a PDS 1010 G microdensitometer. The measurements were made in the transparency mode.

The plate scanning procedure produced a huge set of data recorded on magnetic tapes and to these data image processing software developed at the Rome Observatory was applied (Nanni *et al.* 1980, Pittella 1987). This software includes automatic object detection and identification, plate calibration and photometry, star-galaxy separation, and the determination of object shapes.

3.1 Object detection procedure

Object detection is the most essential procedure in the automatic image analysis. Its purpose is to build up a catalogue containing data on each of the objects detected. Objects were identified using the algorithm of Pittella and Vignato (1979), which operates in a line-by-line single pass mode (the image is read sequentially from mass memory only once with one line in the memory at a time). The algorithm is based on an image segmentation criterion which detects all sets of connected pixels above a suitable threshold level. To account for background variation, the local threshold level is defined using a smoothed surface derived from the original image by local averaging. A pixel is selected as part of an object if its transparency is lower than x % of the threshold value. In order to be accepted, an object must contain at least n pixels, where n is large enough to reject most random noise. The best values of x and n were determined by running the program interactively and displaying graphically the output from a region of the image.

This procedure produces the following data for each object: coordinates of the centroid, extent of the object (above threshold) in the coordinate directions, number of pixels n, maximum intensity, and threshold intensity.

3.2 Plate calibration and photometry

The calibration is obtained by fitting measured spot densities with a Fermi function of the form:

$$D = DF + \frac{DS - DF}{1 + Ae^{-\log \frac{I}{P}}}\,, \tag{1}$$

where DF, DS, A and P are free parameters. A typical calibration curve is shown in *Fig. 1.* The calibration curve serves to construct the look-up table.

Photometry is carried out as follows. First, a series of integrated flux measurements is made. These measurements integrate over pixels through diaphragms of increasing diameter to give the integrated object intensity profile. Then the local background intensity I_b is estimated by averaging five values nearest to the profile minimum. The intensity profile is converted to magnitudes according to the relation $m = -2.5\log(I/I_b)$. By using local background measurements we avoid errors associated with plate nonuniformity. The total magnitude of an object is computed as that corresponding to the largest diaphragm which does not include the background level.

3.3 Star-galaxy separation

Stars are distinguished from galaxies by comparing the magnitudes of all objects in diaphragms of two different sizes (Di Chio *et al.* 1983). In the present study, the diaphragm radii were 2.5 and 5 arcsec. Denoting the corresponding magnitudes by m_3 and m_5, respectively, the discriminating parameter between stars and galaxies

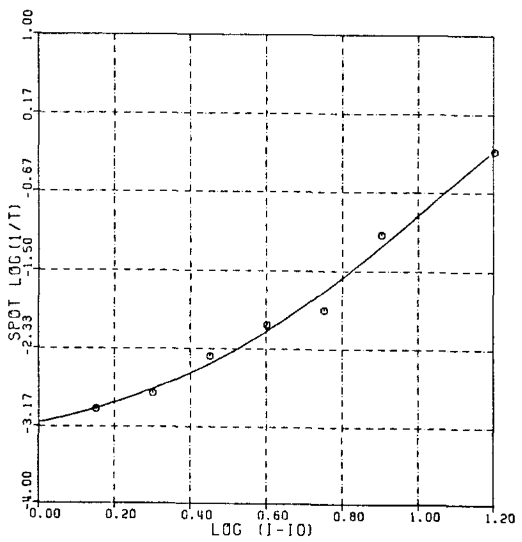


Fig. 1. Calibration curve (cluster A1661).

is: $\Delta m = m_3 - m_5$. Calculating the magnitude of a star with the intensity profile $I = I_0 f(r)$ as:

$$m = -2.5 \log \int_0^R I_0 f(r)\, r\, dr \,, \tag{2}$$

the discriminating parameter is:

$$\Delta m = 2.5 \log \frac{\int_0^5 f(r)\, r\, dr}{\int_0^3 f(r)\, r\, dr} \,. \tag{3}$$

Thus Δm is independent of magnitude, and assumes a minimum value for stars (*Fig. 2*).

3.4 Object description

The objects detected are structureless and small. Their shapes can be described by the values of their major and minor axes, their orientation is given through the position angle. These parameters are readily determined (Stobie 1980, Pittella 1987) from the computed second-order moments of an image.

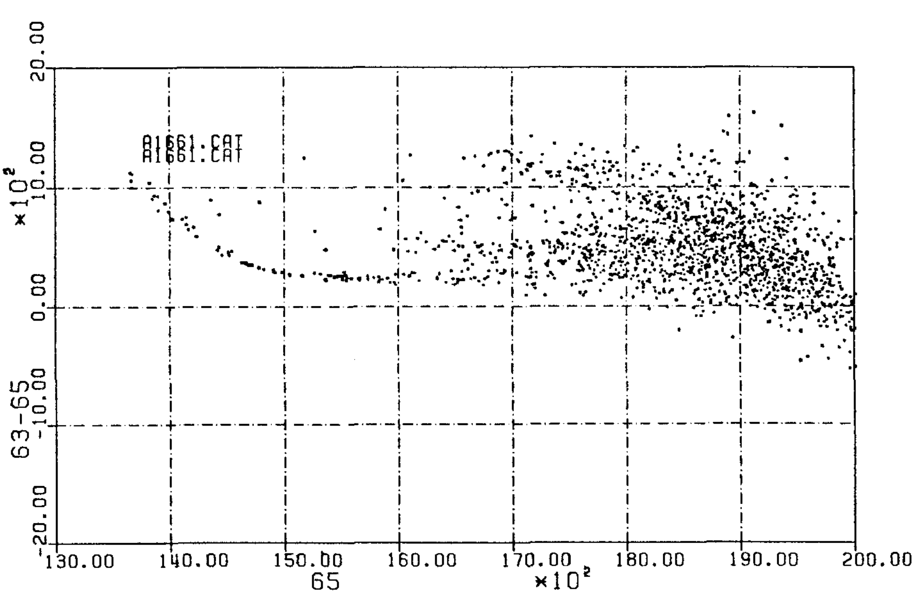


Fig. 2. Star-galaxy separation.

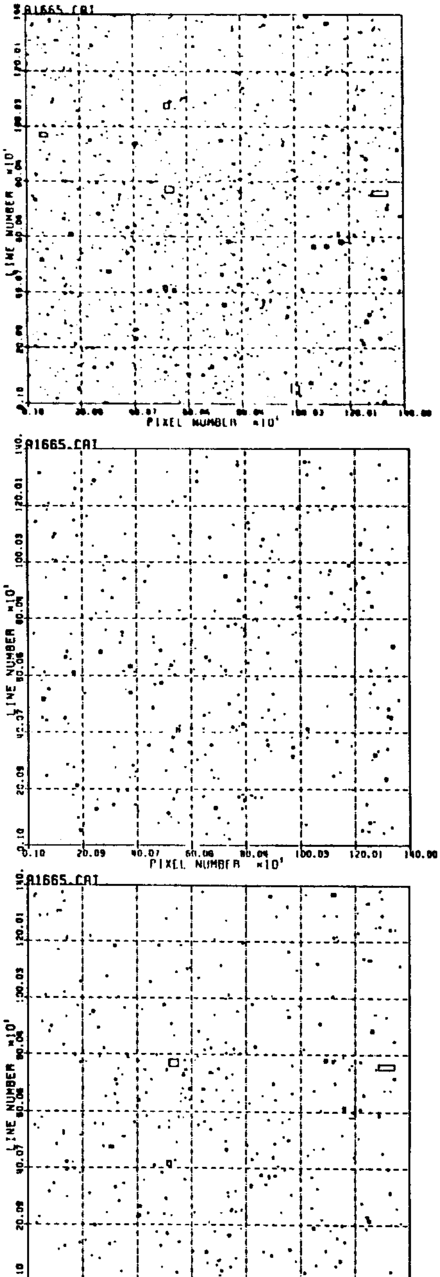


Fig. 3. Maps of the investigated clusters of galaxies. (a) all detected objects, (b) stars, (c) galaxies.

4 Present status

The project began in 1984, shortly after the PDS 1010 G microdensitometer in Monte Porzio started operation. After inspection of the plates and selection of the clusters to be studied, initial trials were made to determine the optimal values of spot size and step size for scanning. Spot sizes of 20 μm and 15 μm were chosen for the 098-04 and 127-02 emulsions, respectively. The scan step size was chosen to be equal to the spot size. The Rome Observatory software was updated and adapted to this program, then all plates were scanned.

The accuracy of the object detection procedure and the star-galaxy separation was checked by comparison between the object list and visual inspection of both the original plates and digitized images displayed on a video terminal.

So far, catalogues have been generated for 16 clusters. Each catalogue contains the following data for each galaxy: Coordinates, total magnitude, intensity profile, number of pixels in the object, sizes of major and minor axis, position angle and object classification (star or galaxy).

For illustration, we present here data on two clusters, A 1661 and A 1665. These are both distant clusters (distance class 6) of richness class 2 and 3, respectively. Abell (1980) gave diameters of 12' and 13', respectively, for these clusters. Both appear on one 127-02 plate (PS 9985) of 120 min exposure.

In *Fig. 2* we plot Δm *vs.* magnitude for all objects in the field of A 1661. As the figure shows, there is a clear separation between stars and galaxies over an interval of two magnitudes, even for such a distant cluster. *Fig. 3* presents maps of detected objects in the field of the cluster A 1665.

The magnitudes appearing in the figures, as well as those in the final catalogues, are the machine magnitudes. To obtain proper magnitudes, we need zero points for calibration. In order to do this, at least one galaxy with known magnitude in the F-band (or r-band) measured through a known aperture is required. The literature search resulted in some data, usually photometry of the brightest cluster members. For some other bright cluster members, good measurements are available in different photometric systems. We hope that these data will be also useful for our purposes. We plan to make observations of selected galaxies in those clusters, where no data are available so far.

Acknowledgments

PF is greatly indebted to the Institute of Astronomy of the University of Rome "La Sapienza" and the Vatican Observatory for their hospitality and support, enabling him to carry out the present project. PH is supported by the Natural Sciences and Engineering Research Council of Canada. GP thanks the Jagiellonian University Observatory for its hospitality during his stay there. We are grateful to the Mt. Wilson and Palomar Observatories for providing observing time and the loan of plate material.

References

Abell, G.O., 1980. Preprint.
Butcher, H., Oemler, A., 1985. *Astrophys. J. Suppl.*, **57**, 665.
Di Chio, P., Nanni, D., Pittella, G., Trevese, D., Vignato, A., 1983. In *Clustering in the Universe*, ed. Gerbal, D., Mazure, A., Éditions Frontières, Gif-sur-Yvette, p. 145.
Dressler, A., 1984. *Ann. Rev. Astr. Astrophys.*, **22**, 185.
Hickson, P., 1977a. *Astrophys. J.*, **217**, 16.
Hickson, P., 1977b. *Astrophys. J.*, **217**, 964.
Nanni, D., Pittella, G., Trevese, D., Vignato, A., 1980. *SPIE*, **264**, 48.
Oegerle, W.R., Hoessel, J.C., Ernst, R.M., 1986. *Astr. J.*, **91**, 697.
Oemler, A., 1974. *Astrophys. J.*, **194**, 1.
Pittella, G., 1987. *Acta Cosmologica*, **15**, 119.
Pittella, G., Vignato, A., 1979. *Mem. Soc. astr. Ital.*, **50**, 537.
Stobie, R.S., 1980. *SPIE*, **264**, 208.
Thuan, T.X., Gunn, J.E., 1976. *Publ. astr. Soc. Pacific*, **88**, 543.