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TOWARDS A STUDY OF SOUTHERN DISTANT CLUSTERS OF GALAXIES

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RESUMEN

Se hace una breve descripción de un proyecto de investigación cuya meta es la identificación de cúmulos de galaxias lejanos en placas rojas (IIIa-F + RG 630) obtenidas con el telescopio Schmidt de 1 m de ESO, así como un estudio detallado de la morfología, la fotometría y la espectroscopía de objetos selectos. El cúmulo más débil encontrado con este método puede tener un corrimiento al rojo ~ 1, pero hasta el momento las observaciones espectroscópicas sólo se han llevado a cabo para cúmulos con $z < 0.4$.

ABSTRACT

A brief description is given of a collaborative research project, which aims at the identification of distant clusters of galaxies on red plates (IIIa-F + RG 630) obtained with the ESO 1-m Schmidt telescope, as well as a detailed morphological, photometric and spectroscopic study of selected objects. The faintest clusters found this way may have red-shifts ~ 1, but so far spectroscopic observations have only been made of clusters with $z < 0.4$.

Key words: GALAXIES-CLUSTERS OF – COSMOLOGY

I. INTRODUCTION

With the advent of large-scale photographic surveys of the southern sky, various research projects have been started at the European Southern Observatory. These surveys are similar to and complement the Palomar/National Geographical Society Sky Survey (POSS) which was made with the 48″ Palomar Schmidt telescope in the 1950s. The POSS covers the sky down to -33° and has a limiting magnitude of approximately 21^m in *B* and 20^m in *R*.

The ESO (B) survey was made with the ESO 1 m Schmidt telescope at La Silla from 1973 to 1977. It consists of 606 plates, each covering $5.^\circ5 \times 5.^\circ5$, with a scale of 67.5 arcsec/mm, and covers the sky from -90° to -17.5° declination. The 60^m exposures were obtained on IIa-O plates behind a GG385 filter (3900-4800 A); they reach approximately $21^m.5$ *B*. Copies of these plates were published on glass and on transparent films as the ESO (B) Atlas of the Southern Sky (also known as the ESO Quick Blue Atlas). Further details have been given by West (1974).

This survey is now being followed by a two-colour atlas covering the same area, but produced in a joint venture by the European Southern Observatory and the Science Research Council of the United Kingdom. IIIa-J + GG 395 plates (4000-5400 A) are exposed with the SRC 48″ Schmidt telescope at Siding Spring to the sky limit and reach approximately 23^m. The red plates are taken with the ESO Schmidt telescope (IIIa-F + RG 630, 6300-7000 A). They are exposed during 120 minutes and reach ~ 22^m in *R*. Most of the SRC (J) plates have now been taken , whereas good red plates of somewhat less than one third of the fields were procured by early 1981. From these plates the ESO/SRC Atlas of the Southern Sky is produced on-film and on-glass. It is expected that the first edition will be ready by 1985.

Among the several projects which have been undertaken at ESO on the basis of these atlases, one may here mention the ESO/Uppsala Survey of the ESO (B) Atlas of the Southern Sky which has resulted in a catalogue of approximately 18500 objects, mainly galaxies many of which are peculiar or interacting (Holmberg *et al.* 1974 to 1980; Lauberts *et al.* 1981).

Due to the extended green sensitivity of the J emulsion, the SRC (J) part of the ESO/SRC Atlas is particularly suited for the detection of very faint objects and objects with [O III] emission, as well as relatively blue objects. The spectral region of the ESO (R) plates includes the emission lines of Hα, [N II] and [S II] and is therefore very useful for the detection of nebulae as well as other emission objects and, in general, of red objects. They include late-type stars (M, carbon stars) and, not the least, very faint red objects, e.g. very distant galaxies.

A search for distant clusters of galaxies on the ESO (R) plates and follow-up observations are now underway at the European Southern Observatory in collaboration with some other observatories in Europe. The ultimate aim is to study clusters at various distances and of different types, in order to detect possible evolutionary effects. The programme is similar to studies currently being carried out in the North at the Palomar and Kitt Peak Observatories.

The ESO study includes the *identification* (detection)

of distant clusters on ESO (R) plates, the morphological *classification* of these clusters (qualitative and quantitative), photometry of the individual galaxies and *slit spectroscopy*. Various people have contributed to this programme at different stages: Drs. J. Semeniuk, O. Kurtanidze, M. Tarenghi, S. Frandsen, B. Thomsen and A. Kruszewski and the author.

In what follows, we describe briefly the status of this programme as of January 1981. It should be stressed that, until now, most of the effort has gone into establishing the optimal way to proceed and that the project is only now leaving the pilot phase.

II. IDENTIFICATION OF CLUSTERS OF GALAXIES

The ESO (R) atlas is particularly well suited for the identification of hitherto unknown, very faint clusters of galaxies, because of the combination of high angular resolution, faint limiting magnitude and optimum use of the K-effect. Very distant galaxies are comparatively red (e.g. 3C 343.1 at $z = 0.75$ has $(B\text{-}R) = 2^{m}.3$, Kristian *et al.* 1978) and it is therefore to be expected that such galaxies are better visible on the ESO (R) than on the SRC (J) plates. The experience shows that this is indeed the case. The actual limiting magnitude for detection of clusters is somewhat above the plate limit, because it is necessary to see several member galaxies in order to recognize the cluster. In practice, this means that the upper two magnitudes ought to be visible; i.e. clusters in which the brightest member has an apparent magnitude $R \sim 20$ can be detected, corresponding to a redshift $z \gtrsim 1$.

In a pilot survey, more than one hundred very distant and in most cases compact clusters were identified in five atlas fields for which at least two ESO (R) plates were available. This work is now being carried out by Dr. A. Kruszewski at ESO. The coordinates are measured to an accuracy of $\lesssim 1''$ on the ESO S-3000 two-dimensional microphotometer and areas around each cluster are scanned. It is the intention to quantify the cluster parameters (morphology, magnitudes) by means of further treatment of the image arrays. The exact criteria still have to be decided upon, but the basic software frame is available at ESO within the IHAP image processing system, supplemented by a number of routines written by Dr. P. Grosbøl. Until now, most studies of clusters have employed visual classification criteria, we hope to determine the parameters in a fully objective way. An example of a very faint and distant cluster, found at ESO, is shown in Figure 1.

III. PHOTOMETRY

So far, direct images have been obtained by means of the Danish 1.5-m and the ESO 3.6-m telescopes at La Silla for about 10 of the clusters found by the procedure described above. The observations at the Danish telescope are carried out with the McMullan electrographic cameras (4 cm and 8 cm field diameter) at the Cassegrain focus (18 arcsec/mm) and include exposures in B and V to the sky limit (S. Frandsen and B. Thomsen). At the 3.6-m telescope, photographic plates were obtained with the Gascoigne corrector in the prime focus (plate scale 19 arsec/mm, limiting magnitude $\sim$ 24 on IIIa-J) and electrographs with a McMullan camera in the same focus. In addition, some IIIa-J and IV-N plates have been taken with the triplet adaptor (1° circular field). The measurements of the electrographs are carried out with the Lund Observatory PDS measuring machine (S. Frandsen and B. Thomsen) and include surface photometry (magnitude, colour and size). Furthermore, it has been shown that the application of advanced deconvolution techniques may result in the assignment of morphological type and shape to even very faint objects. At the same time, the distribution of the objects within the cluster is obtained. Similar measurements will be carried out at ESO with the S-3000 and PDS measuring machines.

In order to calibrate the electrographic and photographic plates, photoelectric (B,V) photometry has been made of some galaxies around 18^{m} in some of the nearer clusters.

IV. SPECTROSCOPY

Digital spectra have been obtained of approximately 60 galaxies in the above mentioned clusters. The observations were made with the ESO 3.6 m telescope equipped with an image dissector scanner at the Cassegrain focus (Boller & Chivens spectrograph, 170 A/mm, resolution $\sim$ 6 A, spectral range 3700-6200 A or 4300-7000 A) and the Las Campanas 2.5 m Irenée Du Pont telescope equipped with a Shechtman Reticon spectrograph (120 A/mm, resolution 5 A, spectral range 4000-7200 A). Some redshifts resulting from these spectra have been published by West and Frandsen (1981).

In addition to the determination of redshifts, these spectra also allow a more detailed analysis in terms of line strengths etc. With integrations of up to 2 hours it has been possible to obtain spectra of galaxies in the redshift interval $0.1 - 0.4$ with reasonable S/N-ratios. An example is shown in Figure 2. If possible, it is the intention to establish "standard" spectra of galaxies of various morphological types and at various distances in order to facilitate the determination of z in fainter objects and also to study the stellar content in galaxies at different distances and of various morphological types.

V. CONCLUSION

The project described in this paper concerns the identification and detailed study of distant to extremely distant clusters of galaxies in the southern sky. The

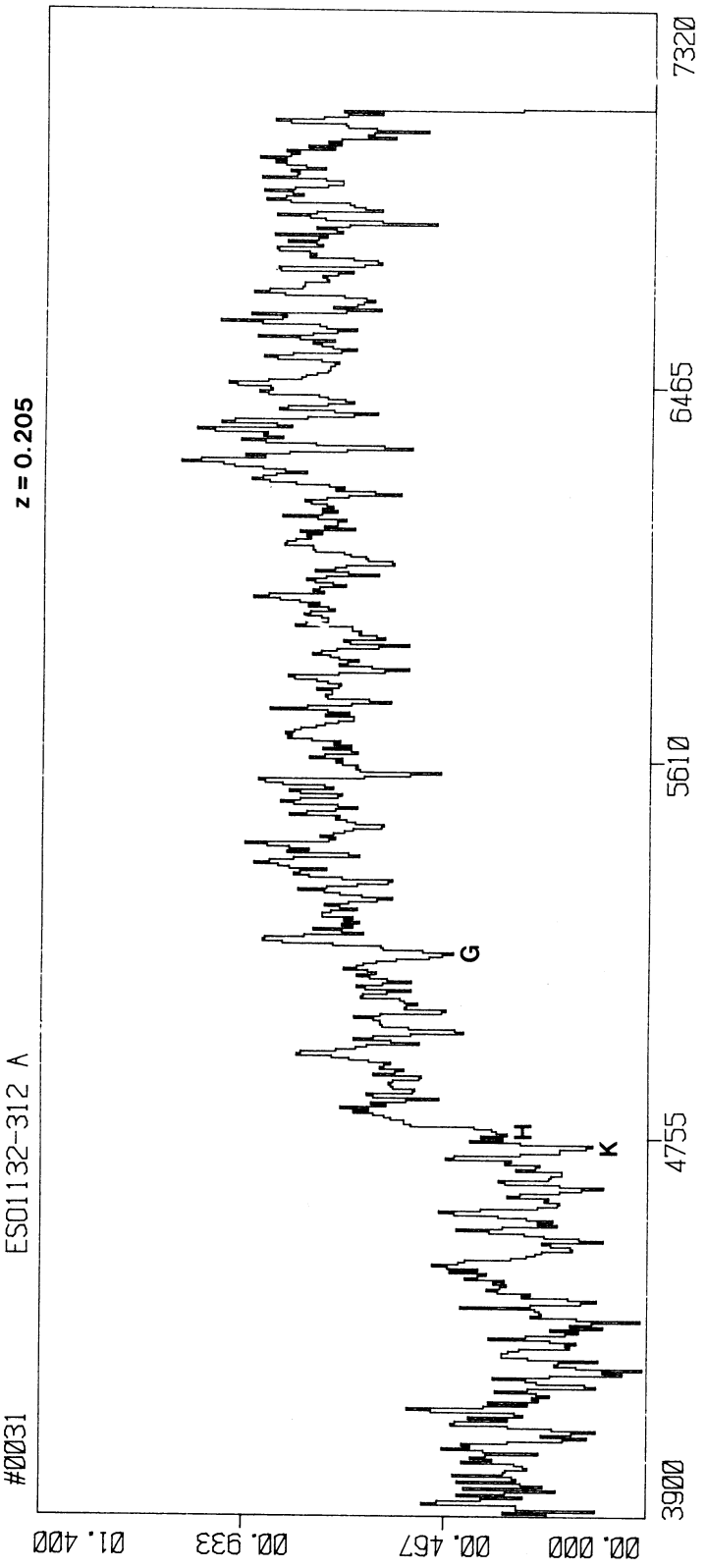

Fig. 2. A tracing of the spectrum of the brightest galaxy in the cluster, 1132-312, as observed with the IDS at the ESO 3.6-m telescope, in the observer rest frame. Resolution approximately 6 A. This tracing has been smoothed with a sliding mean of 5 pixels ~ 5 A. Note the strong 4000 A break. The ordinate unit is 10^{-16} erg cm^{-2} s^{-1} A^{-1} (through a 2".5 x 4" slot).

clusters are identified on ESO (R) plates and observed photometrically and spectroscopically with large telescopes. Until now, several hundred clusters have been found and good spectra have been obtained for galaxies up to $z = 0.4$. Photometry is made by means of electrographic and photographic plates with high angular resolution.

This project has now passed the pilot stage and most of the optimal procedures have been established. In the future, we shall continue to identify clusters in a large number of fields, but restrict ourselves to the detailed study of certain clusters selected by morphological type and distance.

It is expected that our cluster sample will provide important objects for further observation with the Space Telescope. At the same time, our main restriction is that the spectrographs and detectors at ESO do not allow spectral observation of the faintest clusters without excessive observing time. It is hoped that this situation will soon be changed when CCD's are introduced at ESO.

This research project obviously depends on the work of many people. Among these, Drs. S. Frandsen, A. Kruszewski, O. Kurtanidze, J. Semeniuk, M.Tarenghi and B. Thomsen have made major contributions. Special thanks are due to H.-E. Schuster, Guido Pizarro and Oscar Pizzaro at the ESO 1 m Schmidt telescope who are responsible for taking of the ESO (R) atlas plates and without whose dedication this and many other projects would not have been possible.

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DISCUSSION

Mendoza, E.: Have you found any quasars? What is your technique to sensitize the IV-N plates?
West: No quasars were found so far in our sample, but are watching for blue objects within the cluster areas. The IV-N plates are sensitized by immersion in an $AgNO_3$-solution.
Bruzual: Can you detect any differences between your spectrum of the $z = 0.57$ cluster and the $z = 0.11$ one? In particular, can you say anything about the amplitude of the 4000 A discontinuity? What criteria were used to determine the $z = 0.57$?
West: The S/N-ratio of the one spectrum at $z = 0.57$ is too low to make a reliable comparison with spectra of lower redshifts. The criteria are the strongest features (e.g., H&K) and are described in the paper by West and Frandsen (1981).

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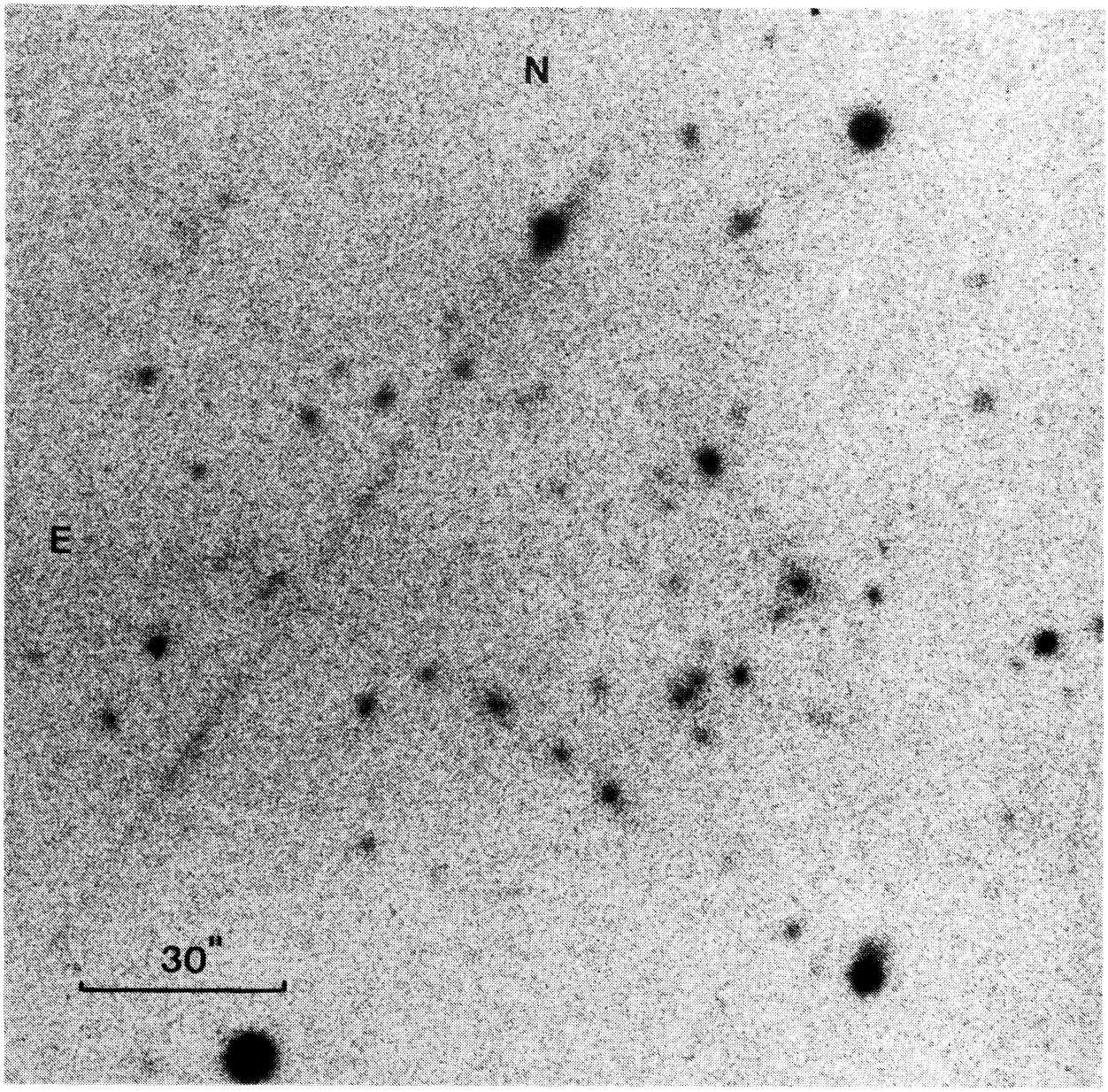

Fig 1. The cluster of galaxies 0346-454, found on an ESO plate and here photographed with the ESO 3.6-m telescope (IIIa-J + GG 385, 60 minutes, mediocre seeing). The redshift of this cluster was measured at the Las Campanas 2.5-m telescope as z = 0.325.

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