interesting way for the comprehension of the intrinsic structure of elliptical galaxies.

References

(1) Bertola, F., Bettoni, D., Rusconi, L. and Sedmak, G., 1984, *A. J.*, **89**, 356.
(2) Ulrich, M. H., Butcher, H. and Boksenberg, A., 1984, ESO Preprint No. 327.
(3) de Vaucouleurs, G., de Vaucouleurs, A. and Corwin, H. G., 1976, *Second Reference Catalogue of Bright Galaxies* (University of Texas Press).
(4) Faber, S. M. and Jackson, R. E., 1976, *Ap. J.*, **204**, 668.
(5) Davies, R. L., Efstathiou, G., Fall, S. M., Illingworth, G. and Schechter, P. L., 1983, *Ap. J.*, **266**, 41.
(6) Graham, J. A., 1979, *Ap. J.*, **232**, 60.
(7) Peterson, C. J., 1978, *Ap. J.*, **222**, 84.
(8) Caldwell, N., 1984, Ph. D. Thesis Yale University.

Suspected Rotation of an X-ray Cluster of Galaxies

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Introduction

The universe as we observe it shows structure on many scale lengths. They start probably with the sizes of quarks having an extent of maybe 10^{-18} m and increase up to at least superclusters of galaxies with sizes of 10^{24} m. The building blocks of the large scale structure of the universe are, however, the largest gravitationally bound stellar systems, the galaxies. They are the largest systems we can observe relatively easily as whole objects.

The distribution of galaxies in the universe, that is in space, is difficult to determine. We can observe directly only very limited properties: distribution on the sky and, with a great effort, radial velocities. The third dimension, the distance, is normally lacking. Generally we replace it by the radial velocity. If we assume that the universe is expanding homogeneously – and there is no reason not to believe in this – we can convert radial velocities into distances using the Hubble law, radial velocities v_{rad} being proportional to distances D:

$$V_{rad} = H_o D.$$

But there is a problem. Clusters of galaxies are gravitationally bound and probably relaxed. Consequently, the internal motion of the galaxies relative to the cluster centre is superimposed onto the receding motion due to the expanding universe. The Hubble flow appears distorted in the direction of clusters.

Cluster Kinematics and Dynamics

This seeming disadvantage can also be turned into an advantage. If we have some coarse ideas about the distribution of galaxies in clusters we can identify the member galaxies using a distribution function. The simplest approach is density enhancement relative to the neighbourhood and clustering in velocity distribution. Then we can define the cluster averages and investigate the behaviour of the member galaxies relative to the cluster mean. Of course, this is an iterative process and we hope that it converges to the right model.

Apart from the galaxy distribution, the X-ray emission provides an independent way of studying cluster properties. One of our main goals is to unify observations in the optical regime with the ones in the X-ray regime. The spatial form and the gravitational potential of a cluster are very well given by the X-ray emission, the dynamics can be studied best with the galaxy velocities. A simple first step is to look for correlations of the X-ray emission with other properties: total luminosity, total mass (which should be correlated to the luminosity via a mass-to-light ratio), velocity dispersion (which should be governed by the mass distribution), content in types, or cluster classification.

Therefore, many astronomers started to observe in more detail clusters which were detected by the satellites Uhuru or Ariel as X-ray sources.

An ultimate aim is to understand the phase space distribution function of the galaxies in clusters. Then we would know at each place the density of galaxies and their velocities. When using the galaxy distribution combined with the X-ray emission distribution, we have to be very careful because the dynamical age of these components may be different. An important question is whether the galaxies and the hot gas are formed together or if the galaxies have shed the gas during their lifetime into the intracluster space. The latter assumption is more plausible because the X-ray emitting gas seems to be processed material, matter which has gone through stars already and which is enriched with heavy elements.

The Cluster SC 0316-44

One of the galaxy clusters discovered with the Ariel satellite is in the southern hemisphere (03^h16^m–44°). One of the first investigations of this cluster was done by the two former ESO members J. Melnick and H. Quintana. They noted some curious properties of the cluster:

(i) SC 0316-44 has a very large velocity dispersion. The radial velocities scatter over a broad range.

(ii) It belongs to the few clusters in which the central dominant cD galaxy (number 18 in the figures) is neither at the dynamical centre of the cluster nor at the bottom of the potential well. In the present case the most massive galaxy does not have the mean radial velocity though it is roughly in the geometrical centre.

(iii) It has a dominant cD galaxy. But there is also a galaxy nearly as big as the central one, far offset from the centre (number 8 in the figures). One might speculate that we have in reality two clusters centred on these two dominant galaxies.

This made the cluster interesting enough to investigate it again. We counted and determined the positions of all the galaxies with a major diameter larger than 14 kpc in the region of the cluster. For comparison, our Galaxy has a major diameter of some 30 kpc. The measurements were done with the ESO Optronics machine in Garching. The positions were measured manually but the software available made these measurements very efficient. There were nearly 1,100 galaxies. Their spatial density distribution projected on the sky reveals another remarkable fact:

(iv) The central part of the cluster is elongated in the NE-SW direction. The outer regions indicate, however, an elongation in the NW-SE direction though this is still a matter under discussion. Elongation of clusters is not so unusual. The Basel

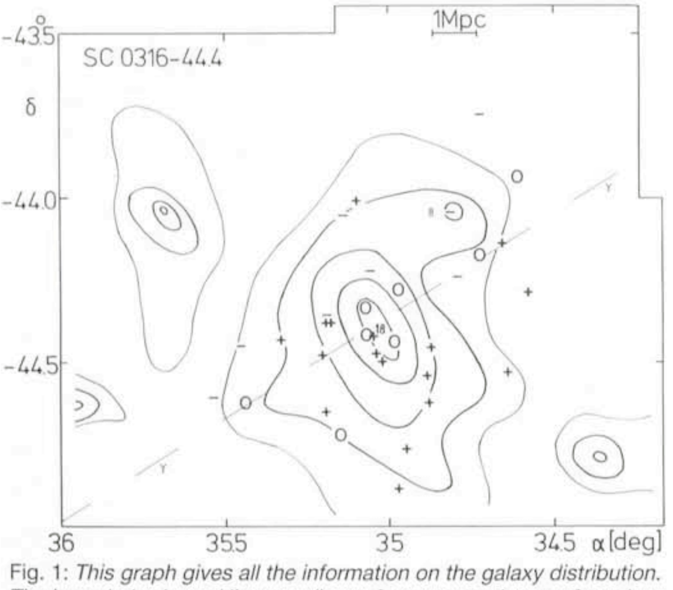

Fig. 1: *This graph gives all the information on the galaxy distribution. The irregularly shaped lines are lines of constant galaxy surface density. The levels are 8, 10, 16, 21, and 26 galaxies/Mpc². In the centre the cluster has a density of approximately 35 galaxies/Mpc². The most prominent galaxies, number 18 and number 8, are also indicated. The broken line called Y is the axis of rotation. The galaxies with measured radial velocities are marked:*

–: $v_{rad} < 20{,}000$ km s^{-1}
O: 20,000 km s$^{-1} \leq v_{rad} < 22{,}000$ km s^{-1}
+: 22,000 km s$^{-1} \leq v_{rad}$.

astronomer B. Binggeli has shown that it is a rather common fact. To illustrate this for SC 0316-44 we have plotted in Fig. 1 contours of equal galaxy number densities (so-called isopleths). The elongated central part can clearly be seen. B. Binggeli has also found that the long axis of an elongated cluster points to its neighbours. If we accept this as a general rule, the twists of the outer isopleths should have no relevance because two adjacent clusters can be seen NE and SW. The reader should be cautioned, however, that no radial velocities are available for the two neighbouring clusters, they may be just chance projections.

New Measurements

An increase of the number of radial velocities compared with those available to Melnick and Quintana seemed to be necessary. Therefore we reobserved the cluster and took more spectra with the ESO 1.52 m telescope equipped with the Boller & Chivens spectrograph and an image tube. This "oldtimer" of ESO can be a very efficient telescope for this kind of work, securing spectra of moderately faint galaxies. We now know radial velocities for 39 galaxies. Of these, four are foreground objects and three are in the background.

A table with these velocities is not very illustrative. Therefore, the description in form of a histogram is given in Fig. 2 in which the foreground galaxies are omitted. Most of the galaxies cluster around 22,000 km s^{-1}. To be precise, the mean velocity of the cluster is 21,400 km s^{-1}. This puts the cluster at a distance of 1,200 million light-years. Its velocity dispersion, that is the spread in velocities, is 1,500 km s^{-1}, which is high. But we can give a possible reason for this below.

In a first step we wanted to see how the galaxies for which radial velocities are available are distributed in the cluster. Therefore, we plotted these galaxies in Fig. 1. We not only marked their position but also tried to indicate their radial velocities. The small bars represent galaxies with radial velocities lower than 20,000 km s^{-1}, the circles are for galaxies in the range 20,000 to 22,000 km s^{-1}, while the crosses are taken for galaxies with velocities larger than 22,000 km s^{-1}.

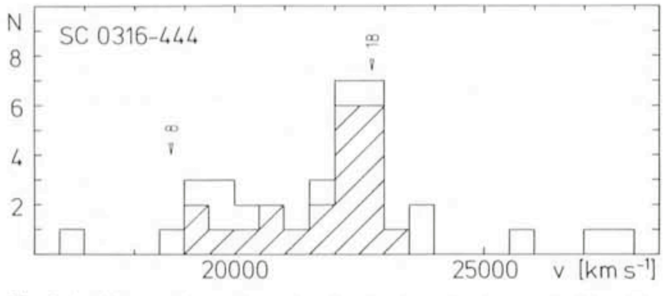

Fig. 2: *In this graph we show the distribution of galaxy velocities. The two most prominent galaxies, number 18 and number 8, are marked. They are near the edges of the velocity range spanned by the cluster and not at the centre.*

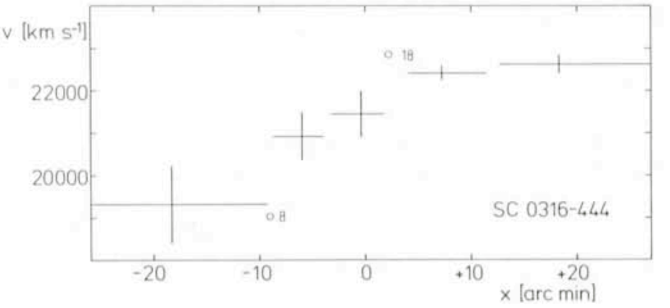

Fig. 3: *In this final figure we plot the radial velocities of the galaxies versus their distance to the axis of rotation. We have averaged over several galaxies. The horizontal bars show the averaged range in distance from the rotation axis, the vertical bars the velocity errors in these ranges.*

The Asymmetric Velocity Distribution

When looking at Fig. 1, one has the impression that there are more crosses in the lower right part, the circles are on a strip from the lower left to the upper right, and the bars are in the upper left corner. In fact, we used a much more refined colour coding to visualize this. But this cannot be reproduced here.

In the NE the velocities are generally lower than in the SW. We looked for a method to make this effect more clearly visible. The broken inclined line called "Y" in Fig. 1 was chosen so that it separates most efficiently the low velocity galaxies from the high velocity ones. Then we plotted the radial velocities of the galaxies versus their distance from this line Y. The result can be seen in Fig. 3. There we have binned the galaxies to decrease the noise. The trend for the galaxy velocities shows up clearly. Fig. 3 displays something like a rotation curve of a disk galaxy.

We have presently two possible explanations for the effect if it is real and not an artefact of poor statistics caused by too few radial velocities:

(i) Fig. 3 can be interpreted as a rotation curve indeed. Then the axis Y is the rotation axis of the cluster.

(ii) We see two clusters partially overlapping, collapsing or expanding. The decision which of these two possibilities may be the right one is difficult to make.

Discussion

Generally, one believes that clusters of galaxies do not rotate. Dressler, for example, found no rotation for the very elongated cluster Abell 2029. This is analogous to the case of the elliptical galaxies which rotate, if at all, only very slowly though they are elongated. The gravitational force of the mass of the member galaxies is balanced by their kinetic energy – the velocity dispersion. The motion of the galaxies is not typically in circular orbits. Nevertheless, the asperical shape can be maintained by an anisotropic distribution of the velocities as has been shown, for instance, by Binney.

One should keep in mind, however, that Gregory and Tifft thought they had detected some rotation for the Coma cluster which is also elongated. But these authors were careful not to exclude an anisotropic expansion.

Generally one can say that there is always a residual angular momentum for any isolated bound object in the universe. Therefore, the elongated shape of the inner part of the cluster may be caused indeed by rotation, the outer isopleths appearing distorted only because of the noise in the galaxy counts. And the dominant galaxy number 18 is not at the dynamical centre but it is roughly where one would expect it to be from the rotation curve. Also the radial velocity of the second most prominent galaxy number 8 is approximately predicted by the rotation curve.

The two massive galaxies number 8 and number 18 are not likely the centres of two clusters being projected onto each other because the line connecting them is far away of being perpendicular to the proposed line separating high velocity galaxies from low velocity ones.

Conclusion

We have probably detected a rotating cluster of galaxies though we cannot exclude that we just observe two clusters partially overlapping. To decide on the correct answer, we have to collect much more information. We should try to determine the luminosity functions of the two possible clusters given by the low and high velocity parts and see if they are shifted, or we should try to look for different contents of types. But this is an ambitious programme.

We (Ulrich Hopp took part in this investigation) would not have been able to pursue this programme without the support by ESO. It is not only the telescope time which counts but also the possibility to reduce observations in Garching or do plate measurements there.

Wolf-Rayet Stars in "Lazy" Galaxies

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We are all very familiar with the concept of "active galaxies" but have you ever heard about "lazy galaxies"? We shall stress that they are the ones which have been recognized as a class by Sargent and Searle (1970: *Astrophysical Journal,* **162,** 455) under the generic name of "extragalactic" H II regions. They are dwarf objects, compact on photographic atlasses such as the Palomar Sky Survey or the ESO Quick Blue Survey. They have low masses but, strikingly, they are blue and their spectra resemble those of Giant H II regions. Therefore, one of us (DK) in his Ph. D., regarding as most probable the current view that these galaxies now experience star formation after a long period of quiescence, suggested they might be regarded as "lazy". Indeed, on average they have not done much: little stellar nucleosynthesis, thus showing marked deficiencies in heavy elements, and containing large quantities of unprocessed neutral hydrogen.

Since their discovery, these unevolved objects have been very much studied. They are especially important for galactic evolution models and in various occasions were chosen for their low metallicities to study the primordial helium abundance. Along these studies—spectroscopic for most of them—a few galaxies have shown the presence of a very large number of Wolf-Rayet stars!

A Huge Number of Wolf-Rayet Stars?

André Maeder has emphasized that WR stars are "much more than a mere curiosity in the zoological garden of spectral peculiarities" (ESO Workshop: The Most Massive Stars, 1981, p. 173) and pointed out a few facts contributing to make their study a fascinating one: they power giant H II regions with large mass losses, may be useful indicators of metallicities in galaxies, contribute to eject processed material into the interstellar medium and are supernova progenitors.

In our Galaxy, WR stars have been discovered individually in young clusters and stellar associations and their number—relative to that of the blue supergiants—is small. Should one not find them in lazy galaxies with active sites of star formation? Of course, one cannot expect to detect individual WR stars in such distant galaxies but one can detect the strongest broad emission lines formed in their atmospheres, for instance the He II 4686 Å emission.

In most of the past spectroscopic observations of giant H II regions and emission line galaxies, WR stars have been overlooked merely because observers have focussed on the intensities of the nebular emission lines for abundance determinations in the gas. As a result, very few cases were found. The broad emission waveband 4600–4700 Å around the He II line remained unnoticed until its first discovery in the emission line galaxy He 2–10 by Allen et al. (1976: *Monthly Notices of the Royal Astronomical Society,* **177,** 91). Since then, spectra of several clusters in H II regions in external galaxies have also been found to exhibit the same WR features (e.g. in NGC 604 and 30 Dor) but only a few lazy galaxies are known to share these properties: Tololo 3, Mkn 750 and other peculiar galaxies such as Mkn 309, NGC 6764 and Tololo 89.

All these observations led to one surprising fact: WR stars largely outnumber the blue supergiants in number in both giant H II regions and lazy galaxies! This can be understood if one picks out objects during a very evolutionary point at which most of the massive stars in the range 25–60 $M_\odot$ have entered a post-red-supergiant stage on which they exhibit WR activity in their He-burning phase. Another way of explaining the data requires that the observed broad-band emission is due to a very small number of WR stars more massive than 60 $M_\odot$