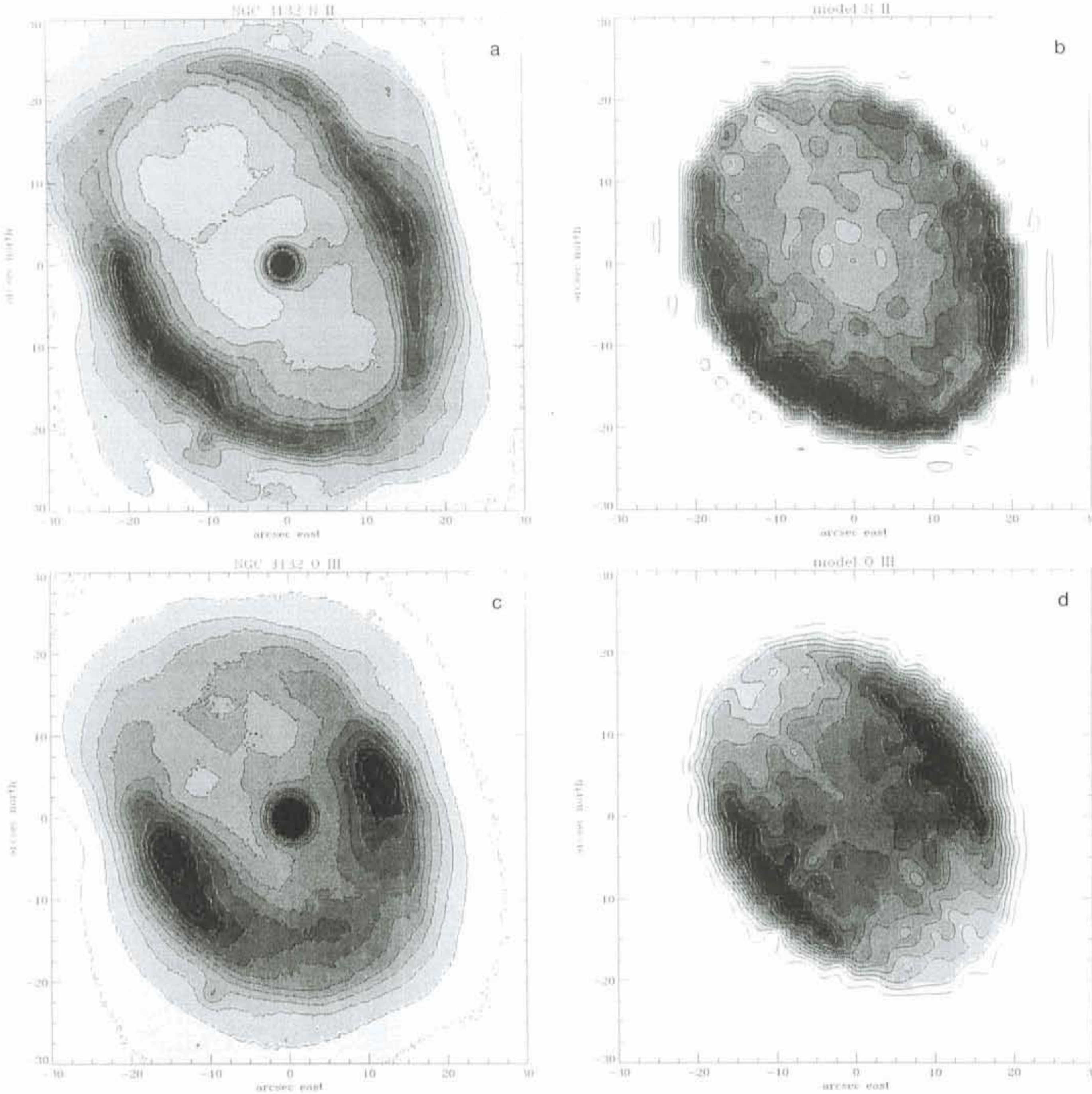

Figure 2 a–d: *Observed and calculated monochromatic OIII and NII images. The calculated images have been extended to a higher pixel number to allow direct comparison.*

be caused be shadowing effects combined with ionization by diffuse radiation of the neighbouring volume elements. It would also be possible to study the ionization structure of knots and so-called ansae. With the improved observing possibilities those features seem to be common in a lot of PNe.

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Peculiar Kinematics in Interacting Elliptical Galaxies

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Introduction

The investigation of galaxy encounters is important to understand the dynamical processes of tidal interaction between galaxies and to probe the internal dynamics of galaxies. Encounters between galaxies are not extremely rare and they cannot be neglected in the evolution of galaxies because even one efficient encounter may substantially alter their internal structures. Efficient interaction can lead to merging of galaxies.

Interactions between galaxies in the

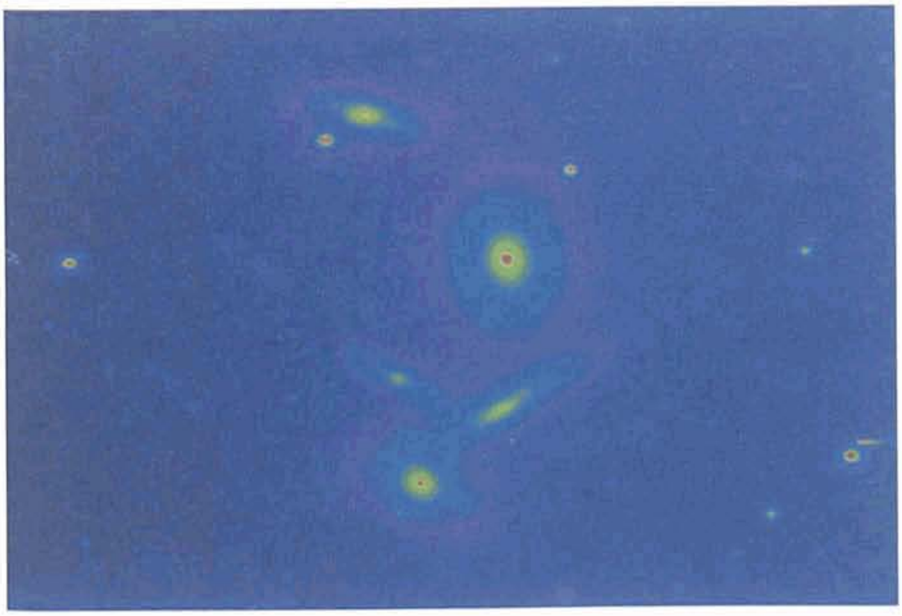

Figure 1: *Arp 321 is a group of five galaxies, which all have redshifts between 6400 and 6800 kms^{-1}. The group is composed of two elliptical and three spiral galaxies. The northern elliptical exhibits a rather regular morphology (North is up, east to the left). Note the filaments in the southern elliptical galaxy, which extend to the north and appear to be connected with the two spiral galaxies.*

early phase of galaxy formation certainly played an important role. Thereafter, the frequency of tidal interaction decayed, but still today there exists a large number of galaxy pairs, and the question arises whether they are in physical contact or just chance projections. A high fraction of the brightest cluster galaxies exhibits multiple nuclei and observations suggest that about half of these galaxy pairs are physical where both components are tidally interacting (Lauer, 1988). However, it is still unknown, whether galaxy collisions in the central parts of galaxy clusters lead to merging of galaxies. Small groups of galaxies, where the relative velocities of the galaxies are normally substantially lower than near cluster centres, are the preferred environment for merging.

Such an environment could be Arp 321 (Fig. 1), a group of five galaxies which all have similar redshifts. The morphology of the southern galaxies suggest that they are in physical contact. In the southern elliptical galaxy a tidal tail extends to the north and seems to be connected with the companion spiral galaxies.

The presence of tidal tails and major halo distortions indicates efficient tidal interaction. Normally, relatively low velocity differences and small impact parameters are required to lead to efficient, observable tidal effects. Many examples of interacting galaxy pairs can be found and the fundamental question arises whether these physical associations were formed together or whether they are recent chance encounters. Before an answer can be given, many details about tidal interaction have to be investigated. This is the purpose of the observations presented here.

Observations

We have undertaken a morphological investigation of 70 elliptical galaxy pairs mainly selected from the "Catalogue of isolated pairs of galaxies" (Karachentsev, 1972) and from the "Catalogue of southern peculiar galaxies" (Arp and Madore, 1985). For the galaxy pairs presented here, the CCD photometry was carried out with the Danish 1.54-m telescope (AM 2244-651) at ESO and the 1.23-m telescope at the German-Spanish Astronomical Centre on Calar Alto, Spain (NGC 4782/4783 and Arp 321). Typical exposure times were between 4 min in I and 20 min in V. Typical projected separations of both components of a galaxy pair are one or two half-light radii, or 20 . . . 50 arcsec, corresponding to 10 . . . 20 kpc.

According to their morphology, several obviously interacting galaxy pairs were selected for spectroscopy to determine their kinematics. All spectroscopic observations presented here were carried out with the ESO 3.6-m telescope. The B&C spectrograph was equipped with grating No. 26 which yields a spectral resolution of 0.9 Å/pixel and covered the wavelength range between 4600 and 5500 Å. In the slit direction we choose binning 4 to increase the S/N, resulting in a final spatial resolution of 2.3 arcsec. The slit width of the long slit was 1.5 arcsec and during all observations the seeing was better than 1.5 arcsec. During each night we observed several K0 III stars which were used as templates for the Fourier correlation quotient method (Bender, 1990). For each long-slit orientation we made two exposures of 90 min each. These long integration times are necessary to yield sufficient S/N. Two exposures are useful to eliminate all cosmic events after these long exposures with binning 4.

Morphology and Related Kinematics

The elliptical galaxies NGC 4782 and 4783 are the dominant members of a group of about 25 galaxies (De Souza and Quintana, 1990). Both are bright elliptical galaxies. The radial velocity difference between the two galaxies is 680 kms^{-1}. The galaxies NGC 4782 and 4783 (Fig. 2) exhibit an interesting morphology. The central parts of both galaxies are separated by 39 arcsec, corresponding to 16 kpc for H_O = 55 kms^{-1}Mpc^{-1}. Both galaxies have concentric isophotes in the innermost 7 arcsec. Further out the isophotes become nonconcentric, i.e. the central parts appear displaced with respect to the outer envelopes. Normally, the morphology in the outer parts is more strongly disturbed than near the centres. Therefore, it was quite surprising to find that the galaxy pair appears very regular at larger radii: the morphology of the envelopes of both galaxies does not exhibit any sign of perturbation. The regularity is further pronounced by the luminosity profiles, which show no deviations from the $r^{1/4}$-law for isophote radii

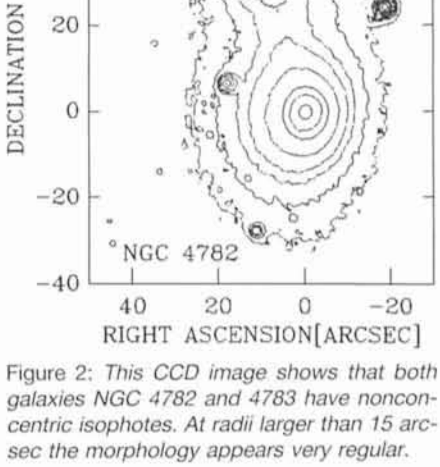

Figure 2: *This CCD image shows that both galaxies NGC 4782 and 4783 have nonconcentric isophotes. At radii larger than 15 arcsec the morphology appears very regular.*

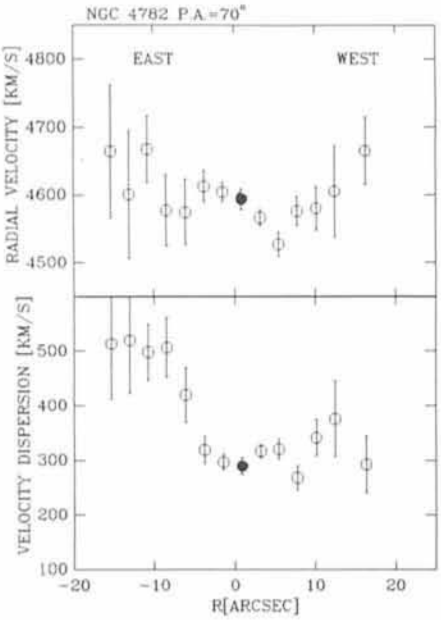

Figure 3: *The kinematical data for NGC 4782 for p.a. = 70°. In the upper part, the peculiar shape of the radial velocity is shown. A slightly U-shaped radial velocity curve is indicated in the innermost 5 arcsec. The velocity dispersion (lower part) increases from the centre of the galaxy towards the east by a large amount.*

larger than 15 arcsec (Madejsky et al., 1990). The regular morphology of the envelopes suggests that the encounter has taken place recently (2×10^7 yr ago): the stars forming the outer envolopes had not yet enough time to lead to changes of the luminosity profiles.

The kinematical data show no rotation in these galaxies (see Fig. 3). Further spectra have been obtained for other long-slit orientations, but no rotation is present at any slit orientation. However, all spectra show a drastic increase of the velocity dispersion with radius. The slight increase west of the centre can be explained by contamination from the neighbouring galaxy, while the drastic increase on the other side is real. Contamination from the neighbouring galaxy cannot account for this increase. If the observed radially increasing velocity dispersions in these galaxies are due to dynamical friction, the strength of tidal interaction can be estimated. Based on the assumption that in this high-velocity encounter the galaxy centres can be described in analogy to solid bodies while the envelopes behave like sticky bodies, we find that the galaxies lose $\approx$ 20% of their original orbital energies during the time of maximum interaction. The strong deceleration of the galaxies, however, is not sufficient to lead to merging of both galaxies since they have still a very high three-dimensional velocity difference. This scenario is based on the combined photometric and kinematical data. Further evidence for tidal interactions is given by the disturbed morphology of a radio jet which is centred on the southern galaxy NGC 4782 (3C 278). The eastern jet bends towards NGC 4783 (Baum et al., 1988).

Another example of interacting galaxies is AM 2244-651. The galaxies in AM 2244-651 are separated by 30 arcsec or 9 kpc in projection. From the east component a large tidal tail extends to the south (see Fig. 4); its entire length amounts to more than 20 kpc. Since the tidal tail is composed of stars, the length gives an estimate of the time elapsed since closest approach. A minimum time of $t = 2 \times 10^8$ yr is required to form the tail if the stars escape with a velocity of 100 kms^{-1}. A substantial part of the tail most probably is formed by escaping stars, i.e. they will be lost to the galaxy. In the west component, halo distortions are not easily detected. They are only seen at much fainter surface brightness levels and they appear much more diffuse.

The reason for the different morphologies presumably is the different kinematical behaviour of both galaxies (see Fig. 5). While the east component rotates rapidly, the west component rotates slowly. Stars in the rotating east component having accidentally a velocity vector parallel to the orbit of the other galaxy respond violently to the time-varying potential (the "perturbing" galaxy in this case is on a prograde orbit) and form the tidal tail. Stars with a velocity vector antiparallel to the perturbing galaxies' orbit (retrograde) experience only small tidal effects. The mean radial velocities of both galaxies are approximately the same, suggesting that we are viewing almost perpendicular onto the orbital plane of the galaxies.

Further kinematical data for the east component with slit orientation perpendicular to the line connecting both galaxy centres, are displayed in Figure 6. The galaxy shows no rotation along this axis. The velocity dispersion is obviously asymmetric. At one side, the velocity dispersion decreases to 100 kms^{-1}, at the other side the decrease levels off at a rather high value of 160 kms^{-1}. This high value is most likely due to the tidal interaction and exemplifies the strength of tidal effects even such a long time after the most efficient tidal interaction. Up to now we have only one spectrogram for the west component. Further kinematical data are required for various slit positions to model the velocity fields after the interaction. If the complete internal kinematics of both galaxies were known, their relative orbits could be determined approximately. Detailed kinematical data are necessary to probe the tides in interacting galaxies.

Conclusions

The two examples of interacting galaxy pairs presented here are in many respects complementary. The first pair NGC 4782 and 4783 is characterized by a very high velocity difference, recent closest approach (2×10^7 yr ago) and absence of internal rotation. The tidal interaction results in a disturbed but still rather regular morphology.

In contrast, the galaxies forming the second pair AM 2244-651 presumably have a low relative velocity and the time elapsed since closest approach is at least ten times as long as for the first pair. The east component of AM 2244-651 rotates rapidly, resulting in an asymmetric halo distortion. The central parts of both galaxies are rather regular, because they were not affected strongly by the tidal effects. Furthermore, since closest approach, i.e. since the moment of maximum perturbation, the central parts of both galaxies had enough time to return to equilibrium because the dynamical time scales there are shorter than the time elapsed since closest approach.

Similar relations between morphological and kinematical properties are also found for other galaxy pairs not presented here. Unfortunately, there are many parameters which are not known a priori for interacting galaxies and the different parameters may influence the ongoing interaction in a similar way, i.e. they often cannot be separated observationally. Important parameters are the relative velocities of the galaxies and the distance at closest approach. When these parameters provide the conditions for efficient interaction, the internal

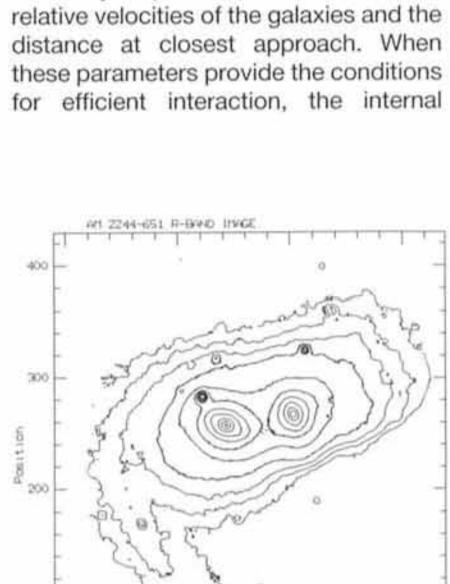

Figure 4: *While the morphology of both galaxies in AM 2244-651 is regular near the centres, the envelope of the eastern galaxy shows a large tidal tail (20 kpc in projection). The distance between both galaxy centres is 30 arcsec (9 kpc in projection).*

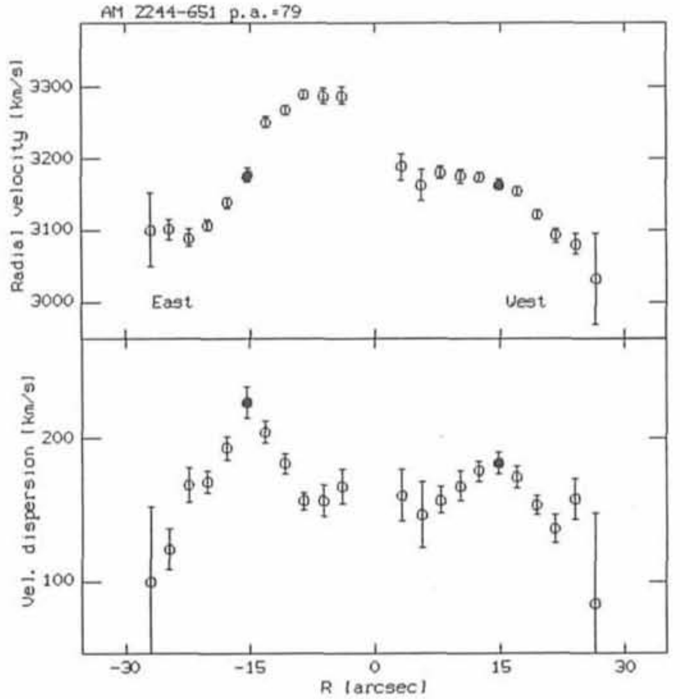

Figure 5: *The kinematical data along the line connecting both galaxy centres of AM 2244-651 show that the east component rotates rapidly. The generation of a large tidal tail as observed here requires such rapid rotation.*

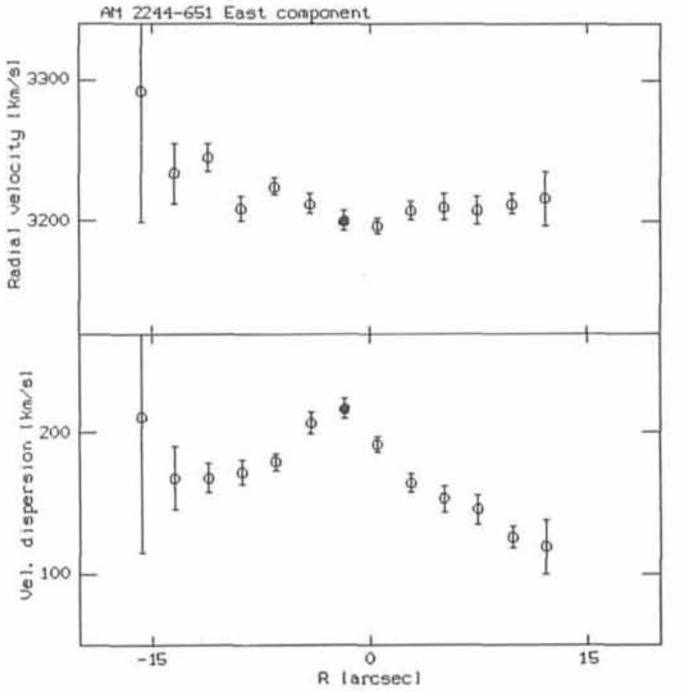

Figure 6: *The kinematical data for the eastern galaxy of AM 2244-651 perpendicular to the long-slit orientation of Figure 5. The galaxy shows no rotation along this orientation. The velocity dispersion decreases asymmetrically, probably a consequence of the tidal interaction.*

kinematics determine the strength of tidal interaction. When rotating galaxies are on prograde orbits, the interaction may lead directly to merging.

As shown, the morphology of interacting elliptical galaxies contains considerable information about the internal structure of galaxies. Only in a detailed morphological and kinematical investigation of interacting galaxies we can determine the different parameters in order to disentangle the various dynamical processes. Only then can we construct encounter scenarios and know how important are encounters in the evolution of galaxies.

Acknowledgements

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Galaxy Populations in Medium Distant and Distant Clusters

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1. Introduction

Observations of medium distant and distant clusters are of fundamental importance for the study of (a) the evolution of galaxies, (b) the evolution of clusters (c) the geometry of the universe.

Considerable efforts have been made in the past decade to understand the questions of galaxy and cluster evolution, galaxy and cluster formation but these questions are still open. Demonstrating the evolution of galaxies and clusters should be decisive for observational cosmology. Comparing galaxies and clusters of galaxies means to investigate their morphological, photometric and spectroscopic properties. The specific observations of distant clusters may also give information on the geometry of the universe. For example at $z \sim 0.7-0.9$, whether a cluster had time to form depends on the intensity of the corresponding peak in the initial density distribution, and also on H_o and q_o.

To detect evolution requires the comparison of similar clusters at various distance intervals. This means to define a local ($z \leq 0.05$), a medium distant ($z \sim 0.3-0.4$) and a distant ($z > 0.5$) sample of clusters and to investigate their photometric and spectroscopic properties.

We know that there is no detected evolution of the first ranked galaxies at $z \leq 0.4$. On the other hand, the Butcher-Oemler effect, i.e. the excess of blue galaxies in medium distant clusters in comparison with nearby clusters, is indicative of evolutionary phenomena within the last 5 Gy.

The dynamical time of galaxy clusters