Abell Clusters
Peter Katgert

From
Encyclopedia of Astronomy & Astrophysics
P. Murdin

© IOP Publishing Ltd 2006

ISBN: 0333750888
Abell clusters are the most conspicuous groupings of galaxies identified by George Abell on the plates of the first photographic survey made with the Schmidt Telescope at Mount Palomar in the 1950s. Sometimes, the term Abell clusters is used as a synonym of nearby, optically selected galaxy clusters.

George Abell constructed a catalogue containing 2712 of the richest such groupings in the northern sky, which was later extended to the southern sky. It is no exaggeration to say that the total sample of 4076 cluster candidates over the whole sky has revolutionized the study of the large-scale structure in the universe. The Abell catalogue has formed the basis for the first quantitative studies of the densest component of the large-scale structure in the local universe. In recent years, the definition of samples of candidate clusters from wide-field survey plates has been repeated with automatic plate-scanning machines. This showed objectively that the subjective factor in Abell’s visual selection is quite small, at least for the richer and more nearby clusters.

The reality of the cluster candidates in Abell’s catalogue has been the subject of some debate, until spectroscopic observations of large numbers of galaxies in the directions of the Abell clusters showed convincingly that only a small fraction of the rich clusters are the result of chance superpositions. That is, a very large fraction of the rich cluster candidates in the catalogue made by Abell (or, including the southern clusters, by Abell, Corwin and Olowin) represent compact, localized peaks in the spatial distribution of galaxies, mostly with redshifts less than 0.2, and held together by gravity.

Already in the 1930s, Fritz Zwicky had concluded that the luminous matter (i.e. the galaxies) in clusters represents only about 10% of the total cluster mass, most of which can therefore be detected only through its gravitational. This has led to estimates of the total mass (both visible and dark matter) by various means. The most common of has led to estimates of the total mass consisting of baryonic (i.e. ‘ordinary’ nucleonic) matter. An important recent development is the search for, and study of, galaxy clusters at very large distances (i.e. at high redshifts), which are the ‘forebears’ of the local rich clusters in the Abell catalogue. For those younger clusters at high redshifts, the Abell clusters serve as a local, present-day, reference population.

**Abell clusters as a subset of the total cluster population**

When searching for cluster candidates on the Palomar Sky Survey plates, Abell had no information about distances (or redshifts) of the galaxies. Therefore he used the distribution of the galaxies in apparent magnitude to select those peaks in the projected galaxy distribution that are most likely to correspond to a spatially compact structure. Taking the magnitude of the 10th brightest galaxy as an approximate ‘standard candle’, a redshift was estimated; this yields the angle subtended by a fixed linear size of \(1.5h^{-1}\) Mpc at the distance of the cluster (where \(h\) is the value of the present Hubble parameter, expressed in units of 100 km s\(^{-1}\) Mpc\(^{-1}\)). In a circular aperture with radius equal to that angle, the number of galaxies with a magnitude not more than two magnitudes fainter than the third-brightest galaxy was counted. Finally, the number of unrelated galaxies in the aperture (and down to the same magnitude limit) was estimated from the galaxy density in background fields without obvious cluster candidates.

The corrected number of galaxies (the richness count, i.e. the estimated number of members in the aperture above the magnitude limit) was found to have an uncertainty of about 17. Therefore, only clusters with a corrected galaxy count of at least 50 were considered by Abell to have been sampled in an unbiased fashion out to redshifts of 0.1–0.2. In Abell’s original (‘northern’) catalogue, 1682 of the 2712 cluster candidates have a count of at least 50. The lower limit in richness count must be applied if one uses the Abell catalogue for statistical purposes. Clearly, many less rich clusters exist but at larger distances–redshifts their contrast with respect to the field is too low to allow a robust definition of a statistically reliable sample.

In recent years, an extensive redshift survey (the ESO Nearby Abell Cluster Survey) has been made of close to 6000 galaxies in about 100 cluster candidates (mostly from the southern part of the Abell, Corwin and Olowin catalogue) with a richness count of at least 50 and estimated redshifts less than 0.1 (see Galaxy Redshift Surveys). The contamination in these redshift surveys by galaxies that do not belong to the main cluster is far from negligible, i.e. about 25%. However, the majority of the redshift surveys contains a spatially compact cluster to which at least 50% of the galaxies with measured redshifts...
belong. Only about 10% of the candidate clusters appear to be a superposition of two almost equally rich (but relatively poor) systems at different redshifts along the same line of sight.

For the spatially compact systems, the velocity dispersion shows a global correlation with richness count (clusters with higher richness counts on average have larger velocity dispersions), but the correlation is very broad (at least a factor of 2 in both quantities). The uncertainty in the visually estimated richness counts might be thought to be responsible for this, but the width of the relation does not decrease if one uses richness counts based on machine scanning instead of the original ones.

For a sample of about 150 Abell clusters with redshifts less than 0.15, cluster masses were calculated from the relative velocities and positions of the galaxies, assuming that the virial theorem holds in the central regions of the clusters. The cluster masses correlate fairly well with the velocity dispersions, but the mass distributions in the various intervals of richness counts appear to have considerable overlap. Therefore, application of a limit in richness count to a sample of Abell clusters (which is necessary for practical reasons) induces quite a diffuse limit in mass.

The clusters, or rather cluster candidates, in Abell’s catalogue with richness counts of at least 50 are therefore a subset of all clusters in the mass range from about \(4 \times 10^{15} \) to \(2 \times 10^{12} M_\odot\). However, for clusters with a velocity dispersion of at least 800 km s\(^{-1}\), essentially all richness counts are larger than 50. In other words, all clusters with a velocity dispersion of at least 800 km s\(^{-1}\) are contained in the sample with a limiting count of 50, and the estimate of their space density is unbiased. Clusters with apparent velocity dispersions greater than about 1200 km s\(^{-1}\) turn out either to be superpositions or to have lots of dynamical substructure.

With the advent of all-sky x-ray surveys like those from the Einstein (HEAO-2) and ROSAT missions, it has become possible to construct complete samples of clusters for which the x-ray flux from the hot gas in the potential well of the cluster is larger than a threshold value. This produces cluster catalogues that are fundamentally different from, and thus complementary to, the Abell catalogue, although there is quite some overlap. The mass of the x-ray gas is generally at least as large as the mass of the cluster galaxies, but the combined mass of these baryonic components is typically only 10–15% of the total mass. When the total mass of a cluster can be estimated both from the kinematics of the galaxies and from the x-ray temperature and brightness, the two estimates in general agree reasonably well.

Properties of the galaxy population in Abell clusters

In the past, several schemes have been proposed for the classification of Abell clusters. All of them summarize in one way or another the distribution of the cluster galaxies in position, magnitude or morphological type, or any combination of those. The projected distribution of the galaxies has many forms and ranges between the following extremes. There may be a central concentration of bright galaxies, generally of early type, i.e. ellipticals, and frequently one of them is a cD galaxy, i.e. a giant elliptical surrounded by an extended envelope (see elliptical galaxies). At the other extreme there are clusters that do not have a clear central concentration.

In some clusters, the galaxy distribution is quite smooth, and in general those clusters contain relatively few spiral galaxies. When the fraction of spiral galaxies is large, the galaxy distribution is in general less regular. The relative fractions of early- and late-type galaxies are correlated with richness count, and this is a manifestation of the morphology–density relation. The latter shows a clear correlation between the relative fractions of ellipticals, lenticulars (S0s) and spiral galaxies, and the (local) projected galaxy density (and therefore radial distance). The S0s may contribute up to 50% in the center, with ellipticals not far behind and spiral galaxies about 10%. In the outer parts, ellipticals are almost absent while spiral galaxies may represent up to 60%. Note that these are global values: individual clusters show a considerable spread around these.

Even though in a sizeable fraction of the Abell clusters the galaxy distribution is not very regular or circularly symmetric, one can always derive the azimuthally averaged projected number density profile \(\Sigma(R)\), in which \(R\) is the projected distance from the cluster center, i.e. the shortest distance between the line of sight through a galaxy and the cluster center. Several expressions have been proposed for the mathematical description of \(\Sigma(R)\), all of which have three parameters. Those are the central value of \(\Sigma(R)\), i.e. \(\Sigma(R = 0)\), a characteristic length \(R_c\) (the distance at which \(\Sigma(R)\) has decreased by a given factor, say 2) and a measure of the decrease of \(\Sigma(R)\) in the outer parts (generally the logarithmic slope \(\alpha\) of \(\Sigma(R)\)).

Recently, \(\Sigma(R)\) has been derived for galaxies of different morphological types in about 70 rich Abell clusters. In individual clusters, the number of galaxies of a particular type is generally not sufficient to allow an accurate estimate of the three parameters of \(\Sigma(R)\). By properly combining data for many clusters one can compare the representations of \(\Sigma(R)\) for ellipticals, S0s, spirals and galaxies with emission lines (mostly very ‘late’ spirals, such as Sc and Sd, with ionized gas in their interstellar medium). In other words, by sacrificing the detailed properties of individual clusters, one obtains a picture of an average rich Abell cluster.

There appears to be a clear correlation between galaxy type and \(\Sigma(R)\): the characteristic length \(R_c\) increases markedly from early to late galaxy type (from about 0.1 to 0.5 Mpc). This shows that ellipticals are indeed much more centrally concentrated than spirals, while the emission-line galaxies form the most extended population. These differences must be accompanied by differences in the kinematics of galaxies of the various types, because all
galaxy classes move in the same cluster potential, which is mostly determined by the dark matter.

Such kinematical differences are indeed observed: the ellipticals and S0s show the smallest dispersion of the line-of-sight component of their velocities, and this dispersion varies little with projected distance from the center. Spirals, and in particular emission-line galaxies, have a larger velocity dispersion (by as much as 20–30%) which decreases markedly towards larger projected distances. Actually, the kinematics of the emission-line galaxies indicates that they have not yet traversed the dense central cores, which is probably the reason why they have not yet lost their line-emitting gas in encounters with other galaxies.

Combining the projected galaxy distributions with the kinematics one may estimate the distribution of the total (visible plus dark) mass via the Jeans equation of stellar dynamics. By comparing the distribution of the dark matter with that of the luminosity of the galaxies, one can in principle study the variation of the so-called mass-to-light ratio with distance from the cluster center. This may give clues about details of the formation process, such as the effects of galaxy encounters, the role of the dark matter haloes of the galaxies, etc.

**Abell clusters as cosmological probes**

Several observational properties of Abell clusters have been used to constrain the theories of formation of large-scale structure in the universe and the parameters in those theories (see also **UNIVERSE: SIMULATIONS OF STRUCTURE AND GALAXY FORMATION**). These properties include the spatial distribution of Abell clusters, their shapes and their masses. In different ways, these all carry information on the way in which the largest well-developed structures in the universe have formed through the growth of the initial fluctuations in the matter density.

The spatial distribution of Abell clusters has been analyzed through the two-point correlation function $\xi(r)$, i.e. the fraction of cluster pairs with a certain separation, in excess of the expected number of pairs for a random distribution, which has been derived for clusters of various richness counts. In general, the correlation function is found to have a power-law form: $\xi(r) = (r/r_0)^{-\gamma}$; the exponent $\gamma$ (about 2) does not appear to depend on the limiting richness count, but the value of the correlation length $r_0$ does, and is larger for the richer clusters (with a characteristic value of about 20 Mpc).

In principle, these data allow one to derive the value of the cosmological density as well as the amplitude of the fluctuation spectrum.

Another aspect of the distribution of rich Abell clusters is that they are generally located in the vertices where the sheets and filaments in the general galaxy distribution come together. Therefore, the distribution of rich clusters has sometimes been compared with the distribution of the vertices in so-called Voronoi tessellations, which are geometric partitionings of space.

The shapes of Abell clusters have been derived from the projected distributions of galaxies. Using the galaxy positions irrespective of galaxy type, one can calculate the apparent ellipticity of a cluster. In general, the richer clusters are less elongated than the less rich ones. The apparent ellipticities for a cluster sample of about 100 northern Abell clusters suggest that the elongated clusters are prolate (cigar like) rather than oblate.

Comparison of these data with the results of numerical N-body calculations can constrain the theories of structure formation.

The full distribution of the masses of a volume-limited sample of Abell clusters (i.e. its shape and normalization) can also give information for cosmological structure formation theory. As the sample of Abell clusters with a limiting richness count of 50 has a rather badly defined completeness at smaller masses, one must restrict the comparison between observations and predictions to the most massive clusters for which the Abell catalog is complete.

It is far from trivial to derive independent information for the several parameters in the formation theories that influence the properties of the most massive structures. Yet, there seems to be general agreement that the latter are more naturally understood in a universe in which the matter density is considerably smaller than the critical density.

**Bibliography**

**Book:**


**Journal articles:**


**Reviews:**


Sarazin C L 1986 X-ray emission from clusters of galaxies *Rev. Mod. Phys.* 58 1

Peter Katgert