Revealing Galaxy Associations in Abell 119

V.G. Gurzadyan* and A. Mazure†

*University of Sussex, Brighton, UK and Department of Theoretical Physics, Yerevan Physics Institute, Armenia (permanent address)
†IGRAP, Laboratoire d’Astronomie Spatiale, Marseille

We report the results of an analysis of the hierarchical properties of the cluster of galaxies Abell 119. Observational data from the ESO Nearby Abell Cluster Survey (ENACS) are used, complemented by data from previous studies, while the analysis is performed with the S-tree method. The main physical system and its three subgroups with truncated Gaussian velocity distributions are identified; due to their remarkable physical features and possible cosmogonical mission we call these subgroups galaxy associations. The mass centre of the core of main system is shown to coincide with the X-ray centre of the cluster. An alignment of the mass centres of the 3 galaxy associations is also shown.

The cluster of galaxies Abell 119 has attracted much attention, particularly due to its remarkable X-ray properties, known since Ariel-V measurements\(^1\). Later observations by EXOSAT\(^2\) allowed more detailed analysis of the physical conditions within the cluster, and, combined with photometric and spectroscopic data for the member galaxies, study of the substructuring properties of the cluster\(^3\). The question of substructure of cluster of galaxies is critical to an understanding of the mechanisms of their formation, and numerous studies support the existence of subgroups in clusters (see, e.g., ref. 4). Below we reconsider the problem of the substructure of A119, based the ENACS data complemented with the data from ref. 3; this sample includes information on the redshifts, 2-D co-ordinates, and magnitudes of 142 galaxies. The ENACS dataset\(^5,6\) contains redshifts for over 5000 galaxies in 107 southern-sky clusters selected from the Abell-Corwin-Olowin catalogue. The reliability and accuracy of the ENACS velocity measurements have been extensively discussed in the presentation of the survey (e.g., Fig. 4 in ref. 6). Specifically for A119, comparison has been made between
ENACS results and data by Fabricant et al.$^3$, and no systematic errors have been found (see Table 2 in ref. 6).

Method. We have performed an analysis of the hierarchical structure of A119 by means of the S-tree method; for details of this geometrical technique we refer the reader to refs. 7–10. The method is based, essentially, on the concepts of theory of dynamical systems, and particularly on the property of structural stability, enabling the identification and study of robust properties of nonlinear systems from limited amounts of information. In the given problem, the method self-consistently takes into account the positional, redshift, and magnitude information for the galaxies. The basic concepts of the method are the degree of bound-ness between various members, and the corresponding S-tree diagrams, which represent the hierarchical substructure of the system. The problem is formulated such as to determine the correlation, which should exist between the co-ordinates and velocities of $N$ bodies if they are interacting gravitationally. It is performed by using the degree of deviation of the trajectories of the system in $6N$-dimensional phase space, by means calculating the two-dimensional curvature of that space$^7$:$^{10}$:

$$K^\mu_\nu = R^\mu_{\lambda\nu\rho} u^\lambda u^\rho.$$  

As described in the cited references, numerical experiments show that the results of the subgrouping typically are statistically significant (greater than 90 per cent confidence) when the total number of bodies is $N > 30$–$35$; the significance of the individually identified subgroups is the same, since the dynamics of the whole system is being considered. The method has been applied to the Local Group$^{10}$ and to the core the of Virgo cluster$^{11}$, as well as for a sample of ENACS clusters$^{12}$; their substructure was revealed, including the membership of each individual galaxy in the subgroups and, in some cases, morphological segregation between the subgroups have been noticed. Let us briefly mention how the results of S-tree method correspond to, say, those of wavelets$^4$. In collaboration with Eric Escalera, we have performed a thorough comparative study of Abell-cluster data by both S-tree and wavelet techniques (see ref. 12). The results are in fair agreement when defining the main system, but S-tree method is additionally able to reveal small-scale subgroups, where the significance of the wavelets is limited. This is not unexpected since, for wavelets, a giant galaxy
Table 1: Derived parameters for Abell 119: the co-ordinates of the mass centres of the core of main system (cMS) and of its subgroups; N denotes the number of galaxies; $m$ the median velocity; and $\sigma$ the standard deviation of redshift distribution.

|     | cMS | 1s    | 2s    | 3s    |
|-----|-----|-------|-------|-------|
| A119| 00 53 31.84 | 00 53 31.65 | 00 53 34.03 | 00 53 29.13 |
|     | -01 30 30.64 | -01 31 33.29 | -01 30 31.13 | -01 24 27.80 |
| N   | 97  | 53    | 18    | 13    |
| $m$ | 13173 | 13152 | 13702 | 12487 |
| $\sigma$ | 477 | 212   | 100   | 80    |

and its satellite have the same statistical weight while attracting the companions, while S-tree also uses information on the magnitudes, by assuming $M \propto L$; for details we again refer to refs. 7–9.

Substructure. The main results of the analysis are given in Table 1, which includes parameters for the core of main system (cMS) and the subgroups (1s, 2s, 3s). The redshift histograms are shown in Fig.1. The S-tree technique allows us to investigate further the mutual degree of interaction of various subsystems or individual galaxies. For example, our analysis does not attribute the group of galaxies at $cz < 12000$ to the main system; its probable foreground nature has also been suggested in ref. 3. On the other hand, the analysis indicates the existence of a system of 12 galaxies, with mean redshift around 14200 km s$^{-1}$, which probably has a physical connection with the cMS, in that the S-tree diagram supports a weak correlation (with respect to the variation of degree of boundness for cMS itself) between the cMS and subgroup. The standard deviation, $\sigma$, for both systems (109 galaxies) presumably situated in the same potential well, is $\sigma = 604$ km s$^{-1}$. If the cluster of galaxies is a more or less isolated system, then, depending on the total number of galaxies and other initial conditions, its velocity distribution can be close to Gaussian, as we have found for the case of A119-cMS. However, the subgroups – 'galaxy associations' – can have truncated Gaussian distributions, as it was shown in ref. 11, based on both observational data and theoretical considerations. It was predicted that galaxy associations, while moving through the host cluster, will inevitably lose their high-velocity members, i.e., the 'wings' of the Gaus-
sian, so that the timescale for the cut-off of the wings is smaller than that for their recovery. It seems that A119 presents a similar case. Quantitatively, this fact can be seen by estimating the 4th moment of the velocity distribution (the kurtosis); this yields $-1.0$, $-1.0$, and $-1.1$ for the 1s, 2s, and 3s subgroups, respectively, and 0.3 for the cMS.

Comparison with X-ray data. To probe the potential well, X-ray data for the cluster are of particular importance. In the simplest case a single parameter, $\beta = \sigma^2 \mu m_p/kT_x$, is often used to describe that correspondence. For A119 we have $\beta = 0.68$, if the Einstein IPC value for the X-ray temperature is used\textsuperscript{13}, $T_X = 5.9$ keV (see also ref. 14). As one can see from refs. 13 and 14, this value of $\beta$ is not exceptional for clusters with known X-ray temperatures, though one should recall that the content of this parameter cannot be the same for a cluster with and without substructure. The mass centre of the cMS (Table 1) lies within the centre of X-ray map of A119\textsuperscript{3}, thus supporting the hypothesis of a common potential well for the galaxies and the X-ray gas. X-ray observations with higher angular resolution can be of considerable importance in resolving more-detailed structure of the distribution of the X-ray gas, especially in view of the existence of the subgroups and the possible hierarchical distribution of the X-ray gas, and, therefore, of dark matter\textsuperscript{15}. In that case, obviously, the phenomenon should be described not by a single parameter $\beta$, but by a sequence of more informative parameters corresponding to the cMS, to each of subgroups, and so on.

Centres of galaxy associations. Once the centres of mass of the subgroups – galaxy associations – are obtained, their mutual location can be investigated; this can conveniently be done with respect to the equation of a line intersecting the three given points ($\alpha_i, \delta_i, i = 1, 2, 3$):

$$tg\delta_2 \sin(\alpha_3 - \alpha_2) + tg\delta_3 \sin(\alpha_2 - \alpha_1) + tg\delta_1 \sin(\alpha_1 - \alpha_3) = 0.$$ 

For the estimated co-ordinates of the 3 centres given in Table 1, the left-hand side of this equation yields $3.4 \times 10^{-6}$, thus implying good alignment of the projections of the centres.

Conclusion. We have performed an S-tree analysis of the substructure of A119. The centre of core of the main system of this cluster, extracted by the S-tree method from the total sample of galaxies, coincides with
the centre of its X-ray image, i.e., with the region of maximum X-ray emission. The substructure reveals 3 subgroups, the mass centres of which are well aligned in projection. In principle, chain-like structures might be expected from various formation mechanisms for clusters of galaxies; however, more informative descriptors should be involved for deeper study of this phenomenon (see e.g., refs. 16, 17). There is little value in comparing these 3 subgroups with the subsystems mentioned in3. Indeed, the 2-projection of galaxies up to 19m should, in the absence of information on their redshifts, typically show ‘subsystems’ having no actual connection to A119, but being fractions of various projected clusters. Thus no visible correlation was noted in ref. 3 between the subsystems and X-ray image of A119, while our study has revealed a correspondence with the X-ray data. In general, the existence of box subgroups, i.e. galaxy associations, with common parameters for host clusters with a rather wide range of parameters12, as we have found for A119, could be an interesting challenge for various theories, since obviously they should have primordial nature. Observational study of the galaxies of the galaxy associations, such as their morphology, star-forming properties, certain features of the disk and the bulge of spirals and so on, in comparison with other galaxies of the cluster, can be of particular importance. We thank A.Melkonian for assistance with calculations. V.G. was supported by Royal Society and French-Armenian PICS.

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Figure caption.

(a): The redshift histogram of the sample of Abell 119 galaxies (solid line), with the core of the main physical cluster, as extracted by means of S-tree technique, indicated (dashed line). (b): The redshift histogram of the core of main cluster (solid line), with the three identified box subgroups (dashed lines): 1s is in the centre, 2s on the right, and 3s on the left.