L. M. Ozernoĭ. Patterns in Systems of Galaxies and Their Relation to the Problem of "Latent" Mass. For several decades now, extragalactic astronomy has confronted a problem that has proven as difficult to solve as it was easy to formulate: are systems of galaxies stationary?

The dynamics of the systems is of enormous interest not only for astrophysics (where its importance is obvious from the bare fact that over 80% of all of the galaxies are observed in space not isolated but as parts of agglomerates containing any number of galaxies from pairs to superclusters), but also for natural science as a whole. In fact, proof of the nonstationarity of systems of galaxies (specifically, that they are expanding with velocities on the order of the velocity dispersion observed there) would mean an explosive origin of the systems, accompanied by the release of prodigious amounts of energy (up to $10^{64}$ erg) during a time that is in some cases shorter than $10^8$ years! The existence of sources of such power ($> 3 \times 10^{48}$ erg/sec) would not only contradict generally held cosmological conceptions, but could hardly be explained even within the framework of contemporary physics. On the other hand, if it were established that the galactic systems are stationary, the consequences would not be quite as dramatic for physics and cosmology, but they would also be important: this would shed light on the cosmogonic processes during which an expanding Universe, but one with a structureless past, acquired its present aspect by breaking up into galaxies and systems of galaxies.

The nontrivial nature of the dynamic problem is clearly detailed by the following fact: in their linear scales (or in the masses that they include), systems of galaxies occupy a position intermediate between the galaxies themselves (whose radii $R_1 \sim 10^{-2}$–$10^{-1}$ Mpc) and the radius $R_2 \sim 10^2$ Mpc of the region of the Metagalaxy in which the distribution of matter can still be regarded as homogeneous with good accuracy. While the inner limit $R_1$ of this scale does not by any means depend on time (galaxies do not expand or contract; they are stationary), the outer limit $R_2$ definitely participates in the over-all expansion of the Universe. Clearly, there is as yet no interpolation, no a priori principle from which we might draw an inference as to the dynamics of systems belonging to the intermediate range of scales $R_1 < R < R_2$. Solution of this problem requires a specific analysis of the galactic systems themselves.

It has long been known that the apparent mass of the galaxies in galactic systems ranging from pairs to rich clusters is in many cases much smaller than the mass necessary for stationarity of the systems (the so-called "virial" mass). It was precisely this discrepancy that presented the alternatives: either the systems are nonstationary or they contain invisible ("latent") mass, which provides the necessary stationarity. The lack of clear indications of either nonstationarity or the presence of "latent" masses in the necessary amount has stimulated the research for patterns in galactic systems interpretation of which might resolve the dilemma. Numerous empirical studies have been undertaken in this direction, especially in regard to the noncorrespondence between the virial and observed masses[1-4]. Although a number of interesting correlations have been brought out, no definite interpretation has as yet been found for them.

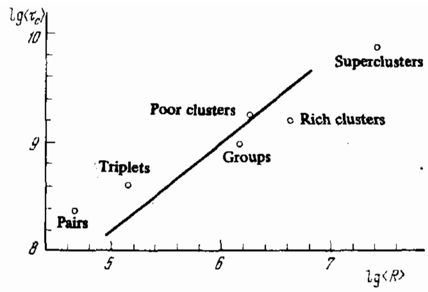
However, without resorting to calculation of the virial characteristics of the systems (this procedure introduces a number of additional uncertainties), and operating only with the basic observed quantities, it is possible to indicate a relationship that is the key for the choice between the stationary and nonstationary alternatives. We refer to the correlation between the dispersion V of the velocities of the galaxies in the system and its radius R, which is conveniently represented[5] in the form of a relation between the characteristic time required for a galaxy to travel the radius of the system ("crossing time") and the radius $\tau_c \equiv R/V$. The figure shows the correlation between $\tau_c$ and R as constructed from the averaged characteristics of 143 galactic systems ranging from pairs to rich clusters and superclusters, which were taken from[6]. Similar correlations are, of course, also observed for individual systems of galaxies of the same type (compact groups, rich clusters, etc.), where they can be studied in detail. For example, in the groups of[7], the values of $\tau_c$, in addition to their dependence on R, exhibit a correlation (though a weaker one) with the morphological type of the system. Thus, in groups consisting for the most part of elliptical galaxies, the values of $\tau_c$ are systematically lower than in groups in which spiral galaxies predominate[3-5].

The relation between the radius of the system and the dispersion of its internal velocities contains the key to solution of the problem of galactic-system dynamics.

It is found that the observed relation of $\tau_c$ to R can be explained in quantitative form as a consequence of the theory proposed earlier[8] for the formation of galactic systems. According to these notions, galaxies and galactic systems appear in the course of evolution of cosmological turbulence. Small inhomogeneities are generated at the time of recombination of the hot plasma (which occurs at a red shift $z \sim 10^3$) in scales containing a mass far in excess of the mass of the typical galaxy. They grow under the influence of gravitational instability. This growth of perturbations in the "dust" of protogalaxies ultimately results in their differentiation from the cosmological background (wherever the perturbations have time to grow to unity and differentiate). The final product of this process would be gravitationally bound systems of galaxies. Then, accurate to a numerical factor of the order of unity, $\tau_c$ would equal the age of the Universe at the time of differentiation of the particular system of galaxies, and $\tau_c$ and R would be related by

$$\tau_c \approx 10^9 \Omega^{-3/14} (R/1\ \mathrm{Mpc})^{6/7}\ \mathrm{yr}, \qquad (1)$$

which is that shown in the figure at $\Omega = 1$ ($\Omega$ is the ratio of the average density of the Metagalaxy to the critical density of Friedmann models). The absence of the only unknown parameter of the theory in (1) (the velocity of vortical motions in the maximum scale of the turbulence) is due to the fact that this parameter appears in the expression for the maximum mass of the galaxy, which was assumed equal to $10^{12} M_\odot$. Relation (1) is approximate basically because of two simplifications: 1) the end of the linear stage of density-perturbation growth was arbitrarily taken as the time of differentiation of the system in the form of the standard criterion $\delta\rho/\rho = 1$; 2) the change in the average density of the system during the time from its differentiation to its arrival in the stationary state was ignored. Despite these simplifications, the agreement between observations and the theory is found to be quite satisfactory. This also explains[5] a certain "stratification" of the values of $\tau_c$ as a function of the average mor-




phological composition of the galactic system that is superimposed on the growth of $\tau_c$ with increasing R.

If the rather good agreement between observations and the theory[8] on which the concept of stationary galactic systems is based is not accidental, then it can hardly be interpreted otherwise than as strong evidence in favor of the stationarity of most observed systems of galaxies. To make it conclusive, however, it is necessary to make certain that the relationships derived contradict conceptions in which the observed systems are nonstationary.

Up to now, nonstationarity of galactic systems has usually been identified with only one possibility: explosive formation of the galaxies themselves. Here $\tau_c$, the characteristic time of expansion of the system, should coincide essentially with the age of the galaxies of which it consists. However, as has been noted more than once, this idea is in sharp conflict with observational data because of the disagreement between the dynamic and evolutionary times: for many systems, the hypothetical expansion time is found to be 2–3 orders smaller than the actual age of the galaxies in the system.

Another, more subtle possibility has thus far received much less attention: the galactic systems are nonstationary as a result of continuous (or quasicontinuous) loss of mass. In this situation, $\tau_c$ no longer coincides with the dynamic age of the system (since the expansion rate is now dictated by the rate of mass loss). Therefore the contradiction between the dynamic time scale of the cluster as a whole and the evolutionary scale of the galaxies composing it vanishes in this version of nonstationarity.

The most probable causes of mass loss from galactic systems could prove to be ejection of gas as a result of one-time or repeated explosive activity of the galactic cores on the one hand and gravitational radiation on the other. Without going into the details of these mechanisms, one can obtain quite general consequences of the very fact of mass loss by the systems[9]. Comparison of these consequences with observational data indicates that interpretation of galactic systems as being in a state of decay owing to mass loss requires an anomalously large loss. Moreover, a qualitative disagreement with observations is observed in groups of galaxies for which the volume of the available data is sufficient for comparison of the expected consequences of the disintegration hypothesis separately for groups in which elliptical and spiral galaxies predominate. All of this forces us to the conclusion that the mass lost by the systems is immaterial and that the associated disintegration hypothesis is without basis.

The difficulties encountered by the notion of nonstationarity of the galactic systems (either in the explosive-expansion variant or in the case of slow disintegration) are so enormous that we must now acknowledge the stationarity idea as the only one possible. Thus there is good justification for the search for "latent" masses in the systems, which would ensure the necessary stationarity.

It is paradoxical, however, that all attempts to observe the sought "latent" mass in galactic systems have thus far been unsuccessful. According to detailed (though not exhaustive) calculations (see, for example[10]), the most realistic candidates—stars of low luminosity and hot gas—can make only a small contribution to the "latent" mass compared to that which is required. Also unresolved is the even more general question: where is the latent mass localized?[1)]

The discovery of broad faintly luminous coronas around numerous galaxies in recent years[11-13] revived the long-standing hope that the "latent" mass would be concentrated in the galaxies themselves. Dynamic arguments[14-17] are inclined to favor this idea, but a number of facts stand in the way of its final acceptance. Thus, the ratio of the virial mass to the observed mass continues to increase with increasing system radius even in systems whose dimensions are substantially larger than the average extent of the galactic coronas; this indicates the possibility that most of the "latent" mass is localized outside of the galaxies, in intergalactic space[18,19]. Further, the dynamic arguments lead to an isothermal ($\rho \sim r^{-2}$) distribution of the "latent" mass in the galaxies[20,21], while photometric data on the distribution of mass in the broad faintly luminous coronas[11] indicate an exponential distribution. The most likely implication of this is that the "latent" mass in the galaxies cannot be identified with their extensive faint coronas, but is of a different nature.

It appears that further progress in solution of the "latent"-mass problem will be possible only by comparative analysis of the virial characteristics of galactic systems in which galaxies of one morphological type or the other predominate. A preliminary analysis[22] brought out a difference in the virial velocities of groups composed primarily of elliptical and primarily of spiral galaxies. There need be no doubt that future efforts to observe "latent" mass will be rewarded by valuable results, with pertinence not only to the physics and cosmogony of galactic systems, but also to cosmology in general.

1)It is appropriate to emphasize that explanation of the galactic-system relationships discussed above did not require specification of either the nature of the "latent" mass or its localization.


1. I. D. Karachentsev, Astrofizika, 2, 81 (1966).
2. H. J. Rood, V. C. A. Rothman, and B. E. Turnrose, Astrophys. J. 162, 411 (1970).
3. G. B. Field and W. C. Saslaw, ibid., 170, 199 (1971).
4. H. J. Rood, ibid. 188, 451 (1974).
5. L. M. Ozernoĭ, FIAN Preprint No. 124, Moscow, 1974.
6. I. D. Karachentsev, Soobshch. Byurakan. Observ. 39, 76 (1968).
7. I. D. Karachentsev, Problemy Kosm. Fiz. 5, 201 (1970).
8. L. M. Ozernoĭ, Astron. Zh. 48, 1160 (1971) (Sov. Astron.—AJ 15, 923 (1972)].
9. L. M. Ozernoĭ, Pis'ma Astron. Zh. 1, (2) (1975).
10. J. Tarter and J. Silk, Quart. J. Roy. Astron. Soc. 15, 122 (1974).
11. G. de Vaucouleurs, Astrophys. Lett. 4, 17 (1969).
12. H. Arp and F. Bertola, ibid., p. 23.
13. J. Kormendy and J. N. Bahcall, Astron. J. 79, 671 (1974).
14. M. S. Roberts, in: Stars and Stellar System, v. 9, Ed. A. Sandage, M. Sandage, and J. Kristian, Chicago, Chicago Univ. Press, 1975.
15. J. Einasto, in: Proc. of 1st European Astronomical Conference, B., Springer-Verlag, 1974.
16. J. P. Ostriker and P. J. E. Peebles, Astrophys. J. 186, 467 (1973).
17. J. Einasto, A. Kaasik, and E. Saar, Nature 250, 309 (1974).
18. L. M. Ozernoĭ. Astron. Zh. 51, 1108 (1974) [Sov. Astron.-AJ 18, 654 (1975)].
19. L. M. Ozernoĭ, Astron. Tsirk. (Akad. Nauk SSSR), No. 844, 4 (1974).
20. J. P. Ostriker, P. J. E. Peebles, and A. Yahil, Preprint, 1974.
21. J. Einasto, E. Saar, A. Kaasik, and A. D. Chernin, Preprint No. 2, Tartu, 1974.
22. L. M. Ozernoĭ, Astron. Tsirk. (Akad. Nauk SSSR), No. 847, 1 (1974).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