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Summary of the Conference

EVEN if the Conference did not establish whether all systems of galaxies are stable, or whether at least some of them are expanding, it has raised a wide variety of questions. This summary is an attempt to sort out these questions and to connect the various ideas expressed at the Conference; it may gain a certain persepective on the proceedings, even though our impressions are undoubtedly subjective. In this process of abstracting and re-ordering, the problem of the stability of systems of galaxies may emerge in better clarity.

We begin by calling attention to the important new observations presented by the Burbidges and Minkowski.

The analysis of the evidence for and against stability, presented in an extensive review by Ambartsumian and several other authors, suggests a subdivision of the systems of galaxies into several classes, for which the question of stability may well have different answers. At least four different classes appear necessary. A tentative classification, with even more tentative conclusions, is as follows:

(i) Close pairs of galaxies: apart from optical systems, probably stable.

(ii) Small groups with trapezoidal configuration (Stephan's Quintet): prime suspects of expansion, particularly those containing peculiar objects, with jets, "projectiles," etc. In some cases, the suspected expansion is of an explosive character.

(iii) Loose irregular clusters (Virgo): some suspicion of instability, not violent.

(iv) Compact regular clusters (Coma): indications of stability, negative total energy.

We wish to emphasize the tentative character of the conclusions on stability, as representing our own impressions gained at the Conference. In addition, there are several difficulties with these conclusions, particularly (ii), (iii), and (iv), described below.

One of the main difficulties, mentioned by most of the speakers concerned with empirical evidence, is the assignment of particular galaxies to specified systems. Is NGC 7320 a physical member of Stephan's Quintet, or is it a foreground object? If the former, then, in the words of Mrs. Burbidge, it is "literally exploding away from the other members" and the explanation "falls outside conventional ideas on the dynamics of systems of galaxies." In a number of papers, efforts were made to reinforce confidence in the assignment of objects to membership in a particular group by probability calculations. The weakness of this argumentation was pointed out by Joseph Bertrand and Emile Borel long ago; as a result we find the intuitive feelings of experienced observers to be more persuasive than elaborate probability calculations. Moreover, the studies of forms and projected configurations of small groups may be said to show primarily our ignorance of the processes whereby galaxies are formed and set in motion. Without such an understanding, many participants felt, we cannot speak meaningfully of the low probability of the chance occurrence of a given configuration.

In addition to the classification of systems of galaxies, it appears desirable to classify also the kinds of instability that these systems may possess. Here we wish to distinguish three categories:

(a) Explosive expansion,
(b) Mild expansion, perhaps simply the general expansion of the universe, and
(c) Contraction.

To these should be added two distinct categories of stability:

(d) Ordinary, dynamical stability to which the virial theorem applies, and
(e) Stability of form, with exchange of galaxies between clusters and the field, to which the virial theorem does not apply.

Category (a), mentioned in the above quotation from Mrs. Burbidge, is the core of what is now known as the Ambartsumian hypothesis. Vorontsov-Velyaminov presented a point-by-point formulation of this hypothesis, involving violent phenomena within nuclei of the giant galaxies, occasionally radio emissions, and jets and projectiles visible on photographs. While many details remain obscure, Vorontsov-Velyaminov is inclined to believe that, in order to explain the many peculiarities observed by him for multiple galaxies, it is necessary to admit the existence of some unexplored forces in addition to gravitation.

Instability of category (b) suspected for loose clusters and clouds, if it exists at all, is visualized as a relatively slow process, not comparable to an explosion—perhaps a phase in the evolution of clusters.

The possibility of category (c), predicted by the dynamical study of van Albada, is also visualized as a relatively slow process in the evolution of a cluster under gravitational forces.

Category (e), investigated by Lemaître, implies that the members of a cluster had no common origin, that clusters are maintained by the motions of galaxies in the general field, and that their cause is to be found in the earlier history of the expanding universe.

The evidence adduced to substantiate the various opinions is essentially of the following five categories:

(1) Radial velocities of individual members of the systems studied,
(2) Configuration of the systems,
(3) Association between clusters and radio sources,
(4) Discrepancy between the masses of galaxies

estimated from internal rotations and also from double galaxies, and those obtained from the application of the virial theorem to clusters,

(5) Correlation between radial velocities and luminosities in groups and clusters of galaxies.

Category 1 may be exemplified by differences in radial velocities of the order of 6000 km/sec or more observed for apparent members of Stephan's Quintet by the Burbidges, and of the triple system IC 3481, Anon, and IC 3483 by Zwicky.

The configuration of the system (category 2) is very relevant for asserting stability of close pairs and compact clusters and for asserting instability of trapezoidal multiples. In the case of pairs the argument is that if a pair of objects is disintegrating it cannot remain a close pair for an appreciable length of time. Thus, unless most or all of the close pairs were of unusual form suggestive of very recent creation, objects of this class are most likely stable. On the other hand, the formation of pairs by capture seems unlikely for dynamical reasons, and Page's preliminary statistics, if confirmed, will probably be explained by another formation process.

These arguments do not apply so clearly to the small groups of trapezoidal configuration that are found frequently among galaxies and infrequently among stars. Such groups are expected to lose members through perturbations even if they were not formed by some kind of explosion. Formation by capture is somewhat more likely than in the case of pairs. Nevertheless, the question of their age remains a problem as indicated below.

Van den Bergh gives evidence that the extragalactic radio sources are associated with ellipticals in the rich clusters of galaxies (category 3). Tentative statistics show that the probability of a radio source occurring in a cluster is independent of the number of member galaxies, which argues against collisions of galaxies causing the radio sources. In fact, Minkowski now finds no evidence that radio sources are specifically associated with double galaxies as formerly thought. Interestingly enough, more and more of the radio sources are found by Kerr and other to be double themselves, and as the precision of locating them improves, it appears that the radio emission often originates from regions symmetrically on either side but quite far from the optical image of a galaxy. This adds weight to the evidence for intergalactic material and may later provide a clue to the process of formation of galaxies.

Category 4 is the most frequently mentioned evidence of instability of systems of galaxies: Masses estimated from the virial theorem exceed those estimated otherwise by a considerable factor. Both types of estimate have been subject to doubt, but van den Bergh's review of Page's masses of the double galaxies, and the summary of individual masses determined from rotations, tend to strengthen confidence in these estimates and to throw suspicion on those obtained by application of the virial theorem.

Several possible explanations of this mass discrepancy were discussed at the Conference and are covered in more detail below. The magnitude of the discrepancy is emphasized by van den Bergh, whereas Holmberg seeks to explain it away as a combination of observational errors, misidentifications and misapplication of the virial theorem. Nevertheless, many of those present consider that it may be real and due to invisible intergalactic material in the clusters, totaling 90 to 99% of their mass. If these possibilities are excluded, however, the discrepancy in mass indicates positive total energy and instability of the system involved.

Category 5 is based on the consideration that, if a system is stable, its particles must approach the center with any given velocity as frequently as they recede from it with that velocity. That is, the correlation between the radial velocities of galaxies and their distances from the observer would be zero for stability of this type, positive for expansion, and negative for contraction. In principle, apparent magnitude can be substituted for distance in this correlation, but if there is no intergalactic absorption the apparent magnitude is a very poor distance indicator. However if we observe a significant correlation between magnitude and radial velocity, this is indicative both of instability and of intergalactic absorption—the latter adding further evidence of intergalactic material. Several types of error may invalidate such a conclusion, as noted below.

Returning now to the question of the stability of the four different categories of systems of galaxies, the application of the five types of evidence just enumerated leads tentatively to the following conclusions:

(i) The stability of close pairs is generally accepted; Page's calculations confirm that only a small fraction of bright pairs can be optical, although this proportion rapidly increases with faintness.

(ii) Small groups of galaxies are the chief suspects of instability for the reasons of large dispersion in radial velocity, of unstable configuration, of the large masses computed from application of the virial theorem, and of positive correlation between apparent magnitude and radial velocity. This conclusion is based on the unavoidable assumption that objects assigned to the given systems are physical members. In a number of instances this assumption was vigorously questioned at the Conference, although it was not clear that dropping one or two "outliers" would always correct the situation.

(iii) Analysis of motions in the Virgo cluster gives excessive mass from an application of the virial theorem, and a mild indication that the magnitude-redshift correlation is positive. However, a strong counterargument is the evidence for subclustering suspected by Abell, de Vaucouleurs, and Holmberg. According to de Vaucouleurs, the Virgo cluster is in reality a superposition of at least two clusters, one composed of spirals.

and irregulars and the other of ellipticals and S0 galaxies. The two clusters have substantially different radial velocities, and the application of the virial theorem cannot give correct estimates of the mass. Also, this combination of systems creates a spurious luminosity-redshift correlation even if the separate systems are stable.

According to Holmberg, the large radial velocity dispersions within the Virgo cluster has nothing to do with expansion. He points out first that the Virgo cluster contains a large number of small subsystems, and that the motions within these subsystems should be counted separately. (Some of these subsystems are small groups strongly suspected by Markarian of explosive instability.) Second, Holmberg suspects the presence of a substantial number of foreground and background objects, possibly 12, not belonging to the cluster. Finally, the difference between radial velocities of the spirals and irregulars, on the one hand, and of the elliptical and S0 galaxies, on the other, is attributed by Holmberg to systematic errors in measuring radial velocities. After allowing for the subsystems, the 12 nonmember galaxies, and the presumed observational errors, Holmberg arrives at an M/L ratio derived from the application of the virial theorem which agrees with that estimated by other methods. His argument, in which no appeal is made to the hypothesis that the cluster contains a large amount of invisible matter, may also be applicable to other clusters of galaxies.

Two of Holmberg's points call for careful investigation: first is the suspected systematic error in measured radial velocities which would affect a number of other studies; the other is the elimination of suspected outliers. Four of these "outliers" are also suspected by de Vaucouleurs, who adds two others not suspected by Holmberg.

(iv) Our assessment that there is less reason to suspect instability of compact clusters such as the Coma cluster is based on several considerations: First, with reference to the configuration of the Coma cluster, even Ambartsumian felt that "it might be conjectured that perhaps in the Coma cluster a negative total energy can still occur . . . ." The symmetry of this cluster and the time necessary for this to be achieved were also mentioned frequently by other speakers.

It is true that applications of the virial theorem, such as van den Bergh's, yield excessive M/L ratios for the Coma cluster, but these findings should be considered in conjunction with Oort's similar calculations which led to lower values of M/L. Also, the theoretical study of van Albada indicated that the evolution of a stable cluster, subject to gravitational forces alone, is a complicated process during which the usual application of the virial theorem may lead to biased results. In one phase of the evolution, the theory predicts contraction, and the virial theorem would give estimates of the mass exaggerated by a factor as large as 3. Slight indications of a contraction of the Coma cluster were found empirically by Neyman and Scott.

Both Abell and de Vaucouleurs feel that superclustering is established beyond doubt, and that the dimensions of second-order clusters (clusters of clusters of galaxies) are 30 to 60 Mpc. This means that clusters cannot be treated as isolated systems embedded in an isotropic, homogeneous medium of field galaxies, and the virial theorem must be modified. An estimate of the magnitude of this effect in accounting for the apparent instability of clusters has not yet been made.

Another theoretical possibility of obtaining exaggerated masses through the application of the virial theorem to essentially stable clusters of galaxies was presented by Lemaître. According to him, clusters may be stable in form under a continuous exchange of galaxies, some evaporating from the cluster and some others entering it from the surrounding field. This model, which has yet to be shown rigorously to develop from reasonable conditions during a phase of instability in an evolutionary cosmology, was criticized because observed clusters appear to be constituted of a mix of galaxy types different from that of the field in which they are embedded. This difference is cited as evidence that the galaxies in a cluster had a common origin, though it must be admitted as slender evidence; morphological types are uncertain in many clusters, and the mix of field galaxies is indeterminate, in principle, without further knowledge of the luminosity function and its variation among morphological types. Ambartsumian's argument that clusters must have a common origin because stable clusters could not be built by capture, does not apply to Lemaître's model, where galaxies in a cluster are not captured.

The previous discussion was concerned with the dynamical aspects of particular systems of categories (i) to (iv); we now turn to how the hypothesis of widespread instability fits into the general picture provided by the rest of astrophysics.

Limber, in his discussion of the local system and the M81 group, which are better explored than other systems, found it extremely difficult to interpret available information either in terms of positive energy and disruption or in terms of stability. He concludes that the reconciliation of all the data will require "a significant revision of parameters that we had believed were reasonably well tied down," perhaps admitting a large mass of unseen intergalactic matter, or some unknown process communicating large kinetic energies to newly formed galaxies. One particular difficulty with the hypothesis of expansion is that it implies an age of order of 2×10^8 years for the M81 group; it is difficult to believe that M81 can be nearly this young.

The same time-scale argument against the hypothesis of widespread instability of clusters and groups was put forward by van den Bergh: The typical age of a supercompact cluster appears to be of the order of 10^8

years—considerably less than the typical age attributed to the apparently normal giant elliptical galaxies contained in such a cluster. Furthermore, if a large proportion of the clusters are rapidly disintegrating, then the relative number of field galaxies would be much greater than is observed. Also there would have been among the field galaxies many more ellipticals than observed, since ellipticals are predominant in clusters. Finally, the redshift dispersion of field galaxies, many of which would then represent high-speed escapees from clusters, would have been much higher than observed.

According to the Burbidges, if groups and clusters are predominantly unstable the major problem is that of the time scale. Can the members of expanding groups have evolutionary ages as small as the expansion ages of 10^8 to 10^9 years? Is the age of the universe, as currently estimated from the Hubble constant, sufficient for the development of the Coma-type clusters? Is it, indeed, sufficient for the oldest galactic star clusters? According to the Burbidges, no definite evidence exists against a positive answer to the first question. An indirect answer to the second and third questions was provided in Heckmann's paper.

In this paper Heckmann takes another look at the concept of the "big bang" and, with it, the whole question of the age of the universe. By the established routine of thought, the "big bang" appears to be an inescapable consequence of a well-founded theory. Contrary to this, Heckmann finds that it is only a special feature of models he considers oversimplified; by introducing a general rotation (of unobservably small magnitude at the present epoch) he finds that the discontinuity in density from which the "primeval atom" and "big bang" theories are observed would be smoothed out to a compression of only a few powers of 10. That is, condensations, which may easily originate during the period of contraction prior to the state of maximum density of the universe, might go unaffected through that phase of evolution. As a result, clusters of stars and of galaxies may exist that are older than the inverse Hubble constant. However, this may in itself raise a physical problem for any evolutionary cosmology in such a rotating universe: If there were no high compression of matter at a finite time in the past, what has limited the "ashes" of processes that are essentially irreversible? Why isn't *all* hydrogen used up in fusion reactions that have gone on for an infinite time? Why aren't *all* stars white dwarfs or older?

It is just possible that the time-scale arguments are particularly relevant with reference to the prime suspects of explosive expansion. Are the interacting galaxies all young? Could it be that the distant young galaxies, as argued by Shklovskii, are frequently misclassified as old ellipticals?

It must be admitted that more questions have been raised than settled. To the question of the stability of clusters and groups of galaxies, about which this Conference was organized, we have added the following, among others:

What is the evidence that members of a cluster had a common origin?

Can the age of a galaxy be as little as 10^8 years?

Are nongravitational forces necessary to understand the dynamics and configurations of small groups of galaxies?

In what way are the extragalactic radio sources associated with individual galaxies or with clusters?

What is the mechanism by which the galaxies were formed, and how does it account for clustering?

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