28. COMMISSION DES NEBULEUSES EXTRAGALACTIQUES

PRÉSIDENT: W. Baade.

MEMBRES: MM. Aly, Baum, Bigay, Bondi, Carpenter, Dessy, de Vaucouleurs, D. S. Evans, Gold, Holmberg, Humason, Knox-Shaw, Kustaanheimo, Lemaître, Lindblad, Lundmark†, McCrea, McVittie, Madwar, N. U. Mayall, Omer, Oort, Page, Samaha, Sandage, Sciama, Mlle Scott, Seyfert, Shajn†, Shane, H. Shapley, Whitford, Whitrow, A. G. Wilson, Zwicky.

Report of Meetings. 16 and 19 August 1958

ACTING PRESIDENT: N. U. Mayall.

SECRETARY: G. C. McVittie.

At its first session, the Acting President and Chairman, N. U. Mayall, asked members of the Commission to submit to him in writing before the end of the Moscow meeting the names of suitable persons who might be made members of the Commission.

The Chairman then read the proposals by Sandage and by Zwicky for new catalogues of galaxies. Sandage suggested a small catalogue, an extension of the Index Catalogue, which would include about 100 or more galaxies such as Leo I, Leo II, the Sculptor and Fornax systems, etc. Zwicky proposed a far more ambitious project, a Catalogue of Special Galaxies. Zwicky is himself intending to publish a catalogue of galaxies down to the 15th magnitude. The Chairman then called on Holmberg to speak, who suggested postponing for some time the compilation of a general catalogue, say down to the 15th magnitude, because of the work involved. An extension of the Index Catalogue could, for the present, be used to identify the objects Sandage had in mind, and this work should be done at Mount Wilson and Palomar. H. Shapley pointed out that there are about 50,000 galaxies brighter than the 15th magnitude. He had considered extending the Shapley-Ames Catalogue, but had always been deterred by the difficulty of assigning a satisfactory limiting magnitude; a small special catalogue would be better for the present. Vorontsov-Velyaminov reported that he is compiling a catalogue of galaxies suitable for special studies of morphological features. It will include objects to the 16th magnitude over the sky covered by the Palomar Sky Atlas ($\delta > -24°$), with the co-ordinates measured to $\pm 1'$. A new detailed classification and description will be given, but without accurate magnitudes. He wished that the form of this catalogue could be discussed by the Commission and he hoped that there would be no overlap with other investigations. The catalogue should be finished by 1961. Arp and W. W. Morgan supported the Sandage proposal for a small catalogue because it could be quickly compiled. The Chairman then called for a show of hands on the question of appointing an *ad hoc* committee to consider the proposal for a small catalogue and also the suggestion for a large catalogue to some appropriate faint limit of magnitude. The setting up of such a committee was approved, and the appointment of its members was left to the Acting President. The latter subsequently named the following: Holmberg (Chairman), de Vaucouleurs, Vorontsov-Velyaminov, Zwicky.

The Commission considered next the Australian resolution for the formation of a Sub-Commission on the Magellanic Clouds. Bok read a memoir from Gascoigne, who had singled out the following tasks that could be performed by such a Sub-Commission: (1) preparation and circulation of observing charts and finding lists; (2) obtaining agreement on standard systems of magnitudes, radial velocities, spectral types, etc.; (3) arranging some degree of co-ordination of observing programs. Support for the proposal came from Gratton, B. Lindblad and Heckmann. It was resolved that the Sub-Commission should be formed and that the Acting-President should send forward a list of names to the Nominating Committee. Subsequently, Dr Mayall submitted the following list of Sub-

Commission members: Gascoigne (Chairman), Arp, Dessy, Kerr, Lindsay, Oosterhoff and Thackeray (Resolution no. 54).

The Chairman then called on Oort to address the meeting on 'Motions in the Nuclei of Galaxies'. Dr Oort spoke as follows:

Our chairman has asked me to give a brief account of some recent work on the nuclei of galaxies. I did not bring the data with me to Moscow and must therefore apologize for the fact that I can only quote numbers from a poor memory.

Let us first consider the Galactic System. The only observations of the nuclear region that we possess are observations at radio frequencies. These have shown that there is in the first place a concentrated mass of ionized hydrogen, presumably situated at the centre of the system. It has a radius (to half intensity) of about 35 pc, a density of roughly 100 protons/cm^3, and a total mass of about 10^5 solar masses. It is commonly referred to as the radio source Sagittarius A. It is super-imposed on a larger mass with gradually diminishing density, with half-density radius of $\simeq 150$ pc and density of $\simeq 10$ protons/cm^3 (cf. a recent investigation by Westerhout). In addition we observe near the centre a concentration of non-thermal radiation; the radius to half-intensity is about 150 pc in the galactic plane and perhaps half as much perpendicular to the plane (Mills). This is likely to represent a concentration of magnetic lines of force.

Very interesting phenomena are shown by the neutral hydrogen in the central region. The average density of this is about 0·4 protons/cm^3 for $R<3$ kpc. There is a fairly strong arm at a distance of roughly 3 kpc from the centre, which can be followed from about 305° to 331° in longitude. Near the longitude of the centre the arm has a motion of -53 km/sec with respect to the galactic standard of rest; it can, moreover, be observed in absorption against Sagittarius A. It follows that the arm passes between us and the centre and has in addition to its rotation around the centre a velocity component of 53 km/sec directed away from the centre. Recent investigations at Dwingeloo, mostly by Rougoor, have indicated that probably most, if not all, of the gas inside $R=3$ kpc shows considerable deviations from simple rotation. A careful study of the emission and absorption profiles in the direction of Sagittarius A has shown that absorption occurs for all negative velocities exceeding 30 km/sec in absolute value, while no absorption is found at the positive velocities above 30 km/sec. There is thus no higher-velocity matter streaming in towards the centre; all of it appears to be moving out. Opposite the expanding arm just mentioned there is another arm-like structure moving away from the centre at a velocity of around 130 km/sec. This latter structure is very much broken up into smaller bits moving at somewhat different velocities.

The expansional motions extend at least to 3 kpc. It may be that the outward motions diminish rapidly for larger distances. It is possible that the outer boundary of the expansion is connected in some manner with the steep maximum of ionized hydrogen between 3·0 and 4·5 kpc found by Westerhout.

We shall now briefly consider other systems. The most interesting new data in connexion with the nuclei are those obtained by Osterbrock. He studied the emission nuclei in elliptical galaxies. In a number of these he determined the gas densities. He has discovered that in many elliptical galaxies the λ 3727 [O II] lines show effects of rapid rotation (about 100 km/sec) at only a few seconds of arc from the centre. These velocities are approximately of the order of what we would expect for circular motions if the mass-luminosity ratio is assumed to be about 100. The masses of the gaseous parts of the nuclei were estimated to be of the order of 10^8 solar masses. The emission nucleus of M 87 (the Virgo A radio source), which has been observed by Minkowski, shows a more complicated line profile.

In this connexion reference should be made to the emission nuclei in some spirals, like that in NGC 1068, which show very wide lines that were studied long ago by Seyfert and others. The question arises whether in these cases the width of the order of 2000 km/sec can also be attributed to rotation or to random motions in the interstellar material. This problem certainly needs further elucidation and more observations.

The discussion of nuclei of spirals brings to mind the unsolved problem of the rotation curve in the central region of M 31, studied many years ago by H. W. Babcock. He found from the absorption lines that the rotation increased rapidly to a value near 100 km/sec in the first 4′, which confirmed earlier work by Slipher and Pease, but that thereafter it decreased again to a negligible value around 8′ or 10′, before beginning the general rise that continued to large distances. The latter has now been accurately determined from 21-cm observations, but a confirmation of the anomalous behaviour near the centre is very much needed.

In conclusion I wish to mention observations on the rotation of the E 7 or SO nebula NGC 3115 that were made by Minkowski during the past winter. He showed that the rotational velocity does not increase continually as indicated by earlier observations, but that after a sharp rise up to about 10″ from the centre there is a long stretch to about 30″ distance where it remains practically constant. Beyond 30″ it appears to rise again fairly steeply.

Minkowski remarked that there could be no doubt of the existence of the wide wings of the H-lines. But he did not favor their interpretation through the assumption of small, rapidly rotating central masses of the order of 10^{10} or 10^{11} Suns. He gave as a reason for this view the existence of galaxies having concentrated nuclei whose spectra show sharp emission lines. Fehrenbach then showed spectra of NGC 3627, 4631 and 5548, which had wide H-lines, and also of the Orion nebula. The spectra had been obtained by the photoelectronic technique of Lallemand-Duchesne.

At the second session of the Commission, the Chairman referred to the volume of photographs of extra-galactic nebulae that is being prepared at the Mount Wilson and Palomar Observatories by Sandage, as a memorial to Hubble. These photographs will illustrate Hubble's final conception of the classification of galaxies according to his system. The Chairman suggested that the Commission should endorse this project to indicate how important was the appearance of this volume. Ogorodnikov and Heckmann having strongly supported the Chairman's view, it was agreed that the consensus of the Commission was for prompt publication of the volume.

The Chairman next called on Dr Elizabeth Scott to present a proposal on the 'Co-ordination of Galaxy Counts', on which she spoke as follows:

In the statistical analyses of counts of galaxies to different depths of space over the same areas of the sky, carried out at Berkeley, we ran into the difficulty that we could not find any two surveys that would serve our purpose. To overcome this trouble, I propose that Commission 28 should recommend that any future survey of galaxies be co-ordinated with the existing surveys so as to provide important information on the distribution of galaxies in depth. Specifically, whenever new counts of images of galaxies (or of stars) are contemplated over an area covered by some earlier series of counts of galaxies, it is recommended that

(i) the size of the squares used in the new count should be either a multiple or a simple fraction of the size used in the earlier survey;

(ii) the squares of the new survey should have the same orientation as those of the earlier survey; and

(iii) some of the subdivision lines between the squares of the new survey should coincide, in the sky, with appropriate sub-division lines of the earlier survey.

With provisions (i), (ii) and (iii), a combination of the squares of one survey will create a single square of the other, so that the resulting data can be used for correlation studies of the distribution of galaxies in space. No additional labor would be required of the astronomer making the counts.

In explanation, it is emphasized that no recommendation is made that the new survey employ the *same* squares as the previous survey. All that is required is alignment and an appropriate adjustment of the size of the squares. For example, if one wants to co-ordinate his counts with the Lick census of Shane and Wirtanen, for which counts in 10′ × 10′ squares are available, it is not necessary to use 10′ × 10′ squares. With a larger telescope, smaller squares would be more convenient, and the recommended sizes are 5′ × 5′ or 2′ × 2′, etc., but not 3′ × 3′. If 5′ × 5′ squares are used and the new grid is aligned with the Lick grid, then the combination of four new squares will correspond exactly to one of the 10′ × 10′ squares. Correlation analyses of the two sets of counts will provide new observational material and a new possibility of verifying various theories on the distribution of galaxies in space. However, if the new squares are not co-ordinated with those of the previous survey, it is essentially impossible to unscramble the information on the details of the distribution of galaxies in depth, and it is lost.

J. Neyman pointed out that the same principles could be applied with advantage for counts of stars in our own Galaxy when studying the stellar distribution in depth. In reply to a question by Layzer, who had asked why counts to different limits of apparent magnitude on the same plates could not be made instead, he pointed out that counts had, in fact, already been made to different limiting magnitudes on certain sets of plates. The trouble arose when new counts were made on plates taken, for example, at a later date and with a larger telescope. The proposal was then voted upon as a resolution, which was carried unanimously (Resolution no. 55).

From these matters of business, the Commission turned to five scientific papers. The first speaker was Vorontsov-Velyaminov who spoke as follows:

I should like to discuss three topics, the first of which concerns the spiral arms of galaxies. Some years ago I came to the conclusion that the sense of rotation of the arms and their degree of tightening cannot be due to the rotation of the galaxy as a whole. Indeed, inside the spiral structure, a galaxy appears to rotate practically like a rigid body—an approximation suggested by Mayall's small-scale observations. The nature of the rotational motion changes when the boundary of the spiral structure is attained. I do not believe that, in our Galaxy, spiral arms exist as distinct formations in the vicinity of the Sun. Whether the arms trail or not is a matter independent of the rotation of a galaxy. Therefore one would expect to find galaxies with different directions of rotation relative to the direction in which the arms appear to be wound. I have presented many arguments for this point of view at the Dublin 1955 symposium and elsewhere. Some years ago Lindblad drew attention to a galaxy whose inner and outer arms appear to wind in opposite directions. On the Palomar Sky Atlas I have found several galaxies which possess arms having opposite curvatures. If some of these arms are trailing, the others are not.

My second topic is the catalogue to which I referred in our first session. I might add to the details I then gave that we shall supplement the excellent Palomar photographs by some of our own for those nebulae that are over-exposed. Recently de Vaucouleurs has given a refined classification of galaxies, but I fear that his system of classification is too complicated and yet does not include some very frequently occurring forms. In my own catalogue, a new classification will be made that will include the degree of tilt. Apart from the ellipticals, each galaxy is reproduced in three copies for a card catalogue and the photographs of 3000 spiral galaxies are already available.

My third topic is that of interacting galaxies. De Vaucouleurs' conclusion that the Large Magellanic Cloud may possess a tail directed away from our galaxy had puzzled me. It also did not seem to me that Zwicky's 'tidal phenomenon' in double galaxies conformed to our ideas of the nature of tidal interactions. We have already found 500 interacting galaxies on the Palomar Sky Atlas and expect to find as many more. The full statistics are not yet available, but we can already draw some important conclusions. The frequency of interacting galaxies, the relative velocities of the companions, etc., show that it is quite impossible that they originated by accidental collisions. The companions must have had a common origin, were formed in contact, one can suppose, and now are in process of separation. The splitting of the nucleus of a galaxy seems to me a less probable origin. We have also observed families or nests of galaxies embedded in a common stellar haze, and we have also found several chains of connected E galaxies.

A kind of repulsive force seems to predominate in these systems, for tails are observed more often than spanning filaments or bridges. As a rule, tails are much more luminous than the spanning filaments. The disruption of the spiral structure on the nearer sides of companions is a frequent form of interaction.

I have shown—and this was later confirmed by Zwicky—that the tails and spanning filaments consist of stars. I argue that these appendices have the same stellar population as the spiral arms, because I have found a number of cases similar to M 51, where a spiral arm is also a filament that links the two components.

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One may suppose that magnetic forces are at work in the formation of spiral arms, tails and filaments, all of which must have a common origin. But there is a difficulty, in that the appendices frequently do not show any emission lines, as Carpenter, Zwicky, Humason, and others have found—they consist mainly of stars. And such appendices also occur among elliptical galaxies in which there is little gas. Sometimes, also, two galaxies apparently close together show no signs of interaction, while a wide pair does. We may say that we have some evidence that, in the interaction of galaxies it is not only gravitational and magnetic forces that are at work, but some as yet unknown kind of interaction.

Hoyle asked, What is the frequency of occurrence of interacting galaxies in space, and was it because the frequency was too high that the collisional origin was rejected? In reply, Vorontsov-Velyaminov said that the space-frequency had not yet been determined. But interacting galaxies are mostly field galaxies, and they are not relatively more numerous in clusters where collisions might be expected to occur more often.

The Chairman then called on Page to describe his most recent work on the masses of double galaxies. He reported results supplementing those in his paper in *Ap. J.* **116**, 63, 1952. Spectra of twelve new double galaxies have been obtained and measured. Together with eighteen of the pairs previously reported, and thirty-five from the list of radial velocities published by M. L. Humason, N. U. Mayall and A. R. Sandage (*Astr. J.* **61**, 97, 1956), there are now sixty-five pairs of galaxies for which the angular separation, S, the differential radial velocity, ΔV, and the mean radial velocity, V, are known. In each case, the average mass of a single galaxy is:

$$M \geqslant [60/(2\pi^2 k(4{\cdot}74)^2)]\, SV(\Delta V)^2, \tag{1}$$

where k is Hubble's expansion parameter formerly determined as $5{\cdot}26 \times 10^{-4}$ km/sec/pc. Recent revisions of the extra-galactic distance scale, successively by Baade and by Sandage, have reduced k by factors ranging from 2 to 10, with 7 apparently the best, but still very uncertain, estimate (Sandage, *Ap. J.* **127**, 513, 1958).

For a random sample of pairs of all orbital-plane orientations, all orientations of the line of centers, and all space separations, the mean mass of a single galaxy is $3\pi/32$, or $0{\cdot}2945$ of the mean of eq. (1). The mean mass of a single galaxy for all sixty-five pairs is thus found to be about $3{\cdot}5 \times 10^{10}$ Suns, for $k = 0{\cdot}75 \times 10^{-4}$ km/sec/pc.

Of the sixty-five pairs, forty-five include E or So nebulae, and these types have average mass for a single galaxy of about 50×10^{10} Suns; the remaining twenty pairs, consisting of S and Irr galaxies only, have average mass for a single galaxy of about 3×10^{10} Suns. Thus, if these double galaxies are a fair sample, the average E or So nebula is seventeen times more massive than the average S or Irr nebula.

With magnitudes published by Sandage and by Holmberg, the average ratio of mass to luminosity in solar units was found to be about 30 for E and So, and 0·9 for S and Irr nebulae, which are values somewhat lower than those used in studies reported by Oort and by Schwarzschild. These numerical results will be modified slightly when proper weighting is introduced, and account is taken of selection effects. In certain individual cases eq. (1) yields high lower limits of the average mass per galaxy, for example,

NGC 5898/5903, $M \geqslant 14 \times 10^{10}$ Suns, $M/L = 20$,

NGC 7576/7585, $M \geqslant 136 \times 10^{10}$ Suns.

Sra. Pishmish de Recillas inquired whether the velocity dispersion in clusters had been determined, and Page answered that it had not. Mayall asked whether, in the case of double galaxies with bright 3727 lines, the line ran from one galaxy to the other in a way consistent with the differential velocity. Page replied that it did. The Hα line, however, does not connect up, but this was perhaps a photographic effect.

The Chairman then called on Baum to describe his work on the measurements of red-shifts greater than 0·2. Baum took as his theoretical models of the universe those in which the pressure and the cosmical constant are both zero. If z is the red-shift and R the scale-factor, then the relation between bolometric magnitude, m, and red-shift is

$$m = 5 \log (cz) + \left(1 + \frac{R\ddot{R}}{\dot{R}^2} + C\right)z + \ldots,$$

where C is a term dependent on evolutionary effects and obscuration between the galaxy and the observer. It is desired to find an estimate of the value of the term $R\ddot{R}/\dot{R}^2$ assuming some plausible values for C. For this purpose the spectrographic data used by Humason, Mayall and Sandage (*loc. cit.*) had two defects. First, photographic spectroscopy cannot apparently be profitably extended beyond $z=0.2$, and, secondly, the red-shifts are measured with a far higher degree of accuracy than can be achieved for the apparent photographic magnitudes of the galaxies in question. In Baum's photo-electric method, some of the accuracy in z is sacrificed in order to go beyond $z=0.2$, but, he believed, the red-shifts were determined to the same order of accuracy as the bolometric magnitudes. The method consists in finding the red-shift by first determining the spectral-energy curve for a galaxy. The energy received is measured at eight values of the wave-length λ, taken at equal intervals of $\log \lambda$. Absolute calibration is needed, and this is obtained by applying the procedure to those galaxies whose red-shifts have been measured photographically in the range $0 \leqslant z \leqslant 0.2$. Baum said that he had now measured energy-curves for galaxies in clusters up to $z=0.4$ by counting the photo-electron pulses during long integration times. It was a lengthy and laborious process, requiring six nights for one observation. He was attempting to construct a device that would measure in six colors simultaneously.

Baum believed that his measures of red-shift were correct to 10% in z for the large red-shifts and that his bolometric magnitudes were accurate to $0^m.2$. If all the data on clusters for $z=0$ to $z=0.4$ were taken at their face value, one found that

$$\frac{R\ddot{R}}{\dot{R}^2} = -1 \pm 0.5,$$

so that the expansion was proceeding with a retardation ($\ddot{R}<0$). The term C could, of course, affect this result, but C was unlikely to be appreciable compared with unity. The elliptical galaxies mostly used in the measurements are not population II objects, but those that have the same stellar populations as the disk of our Galaxy. Thus the evolutionary contributions to C should be small.

Following Baum's remarks, Bondi said that the disappearance of the Stebbins-Whitford effect was, from the standpoint of the steady-state theory, of more importance than the conclusion drawn by Baum from the data on large red-shifts. H. Shapley expressed surprise that the error in the magnitudes was as low as $0^m.2$. He feared that systematic errors might be present. Baum admitted that $0^m.2$ was perhaps a little optimistic, but he pointed out that, in his photo-electric method, the possibility of systematic error for clusters of increasing faintness was much smaller than if photography were employed.

The first of two theoretical papers was then given by A. L. Zelmanov, who began his remarks with a brief account of the Sixth Conference on Problems of Cosmogony held in Moscow in June 1957.

Turning to his own work,* he said he had been studying the relativistic theory of anisotropic non-homogeneous universes. Einstein's field equations and the usual general relativity interpretation of the energy-momentum tensor were accepted. It was assumed that there existed co-ordinate systems, co-moving with the matter, and only such systems were used. It is known, that in the general case, there exist no spatial sections, everywhere orthogonal to the time-lines of the co-moving system, and hence a privileged temporal co-ordinate does not exist. Therefore, first, the notion of a non-holonomic space,

* A. L. Zelmanov, *Dok. Akad. Nauk*, **61**, N 6, 1948; **107**, N 6, 1956; *Nauchnyje Doklady Vysshej Shkoly*, Serija fiziko-matematicheskaja, N 2, 1958; Trudy VI vsesojuznogo soveshchanija po voprosam kosmogonii (in press).

orthogonal in all world-points to the time-lines of the coordinate system, was used. Secondly, 'chronometrically invariant' quantities, that is, quantities invariant under transformations of the temporal co-ordinate, were introduced and, in particular, chronometrically invariant three-dimensional tensors. Chronometrically invariant differentiation operators with respect to the time and space co-ordinates were also defined. Generally speaking, these operators were not commutative, and so chronometrically invariant commutators were introduced. These commutators were quantities having a very simple physical significance, namely, they stand for the three-dimensional vector of gravitational force and the three-dimensional tensor of the angular velocity of absolute rotation (spin, or tensor of non-holonomity of space). Chronometrically invariant quantities, characterizing the velocity of deformation (strain-velocity tensor) of space, the curvature of space, and the properties of matter and energy were introduced as well.

The equations of general relativity were expressed in terms of the above-mentioned chronometrically invariant quantities and operators, and were used in several forms, convenient for considering the behavior of an arbitrary region of the spatially anisotropic and spatially non-homogeneous universe. The temporal behavior of the non-homogeneous universe as a whole was not considered, and the expansion of the universe in our surroundings was regarded as a local phenomenon.

A number of conclusions were drawn, of which the following may be mentioned. Deviations of the universe from spatial isotropy are reduced to six factors of anisotropy: anisotropy of the curvature of space, anisotropy of the deformation of space, absolute rotation (spin, non-holonomity of space), field of gravitational forces, viscosity, flow of energy (heat, radiation). On the one hand, these factors influence the temporal behavior of the volume of each element of the co-moving space. In this connexion, particularly, certain conditions were formulated, under which the singular states could be avoided (if it was possible to do so at all). On the other hand, as far as the anisotropy of deformation, absolute rotation, viscosity and flow of energy were concerned, it was shown under some simplifying assumptions that these factors of anisotropy tended to decrease rapidly during the expansion. Thus, even if it is established that there is at present an absence of an appreciable anisotropy, this would not warrant the absence of a very considerable anisotropy in the past. Hence, one could not be sure that the cosmogonic conclusions based on the theory of isotropic homogeneous universe were correct.

Approximate formulae for the red-shifts in the anisotropic universe were deduced and have been used by G. P. Pskovsky for interpretation of the observational data, published by Humason, Mayall and Sandage (*loc. cit.*).

Co-moving co-ordinates were also introduced in non-relativistic mechanics. They led to a new, so-called 'unitary', point of view on the problem of determining the motion of a continuous medium, different from the 'local' (Eulerian) and the 'substantional' (Lagrangian) points of view. The equations of motion of a continuous medium, corresponding to the 'unitary' point of view, were developed. These equations, conjointly with Poisson's equation (or its generalization with the cosmical constant), may be regarded in cosmology as an approximation to the relativistic chronometrically invariant equations in co-moving co-ordinates ('quasi-Newtonian approximation in co-moving co-ordinates').

The final speaker was Heckmann, who began by commenting that Zelmanov's paper appeared to contain one of the most important advances of the last ten years. He himself would briefly summarize a paper that would appear in the proceedings of the 1958 Solvay Conference. The question that he and his colleague Schücking had tried to answer was: 'Do model universes exist in which the material is simultaneously expanding, rotating and subject to a velocity-shear?' Homogeneous but anisotropic models have been found by using Bianchi's results of 1898 on Riemannian spaces invariant under three groups of motions. Even so it is still necessary to solve Einstein's equations for nine unknown functions. Schücking's main result is that there exist model universes in which the scale-factor R satisfies

$$\tfrac{1}{2}\dot{R}^2 = \frac{GM}{R} + h + \frac{\Lambda}{6} R^2 - \frac{\alpha^2}{R^2},$$

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in which h is a constant and the new term, due to the rotation of the material, is the one in α^2. Thus, if R is small enough, $\dot{R}$ is not real; hence the rotation effect introduces a lower limit to R, with a finite density at that moment, in place of the exploding point-source models of the usual homogeneous and isotropic theory. The theory also predicts that an observer would find density gradients in space of the material content of the universe.

The Acting President thanked the speakers for their contributions. He said that it had been made known to him that there was a considerable demand for a symposium on cosmological subjects. He suggested that all those interested should write to the new President of the Commission, who was to be appointed the following day, making known their ideas regarding a symposium to be held in conjunction with the eleventh General Assembly.

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