Galaxies and the Universe: Properties of the universe are revealed by the rotation of galaxies and their distribution in space

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Galaxies and the Universe

Properties of the universe are revealed by the rotation of galaxies and their distribution in space.

J. H. Oort

It is rather generally accepted that the universe began by a gigantic explosion which took place roughly 10 milliard (10^{10}) years ago. It is not known what caused the explosion or what was before, but it is possible to tell a great deal about what happened *during* the so-called "big bang." For some time after, the mass of the universe consisted mostly of radiation, and there was strong interaction between radiation and matter. This period, which Wheeler has termed the "fireball" stage, ended when the radius, or the scale, of the universe had become approximately 1/1000 of the present scale. The universe was then about 300,000 years old, that is, 1/30,000 of its present age. Around that time matter and radiation were decoupled. The temperature had dropped to a few thousand degrees.

Observationally, the most striking consequence of the "big bang" is the universal expansion. Distant galaxies all move away from us, and from each other, at speeds proportional to their distance. This is what had to be expected for things which have all started at the same time from a small volume. But several other characteristics of the universe as we see it today must likewise be connected with the circumstances of the initial explosion.

In this article I shall discuss primarily the question of what information we can get about early stages of the universe from the properties we observe at present, and the question as to how this information can help us to understand these properties.

The most directly relevant phenomena are (i) general expansion, (ii) isotropic "blackbody" radiation, (iii) present large-scale distribution of matter in the universe, (iv) existence of galaxies, (v) rotation of galaxies, (vi) evolution effects in the population density of radio sources, and (vii) instability of the nuclei of galaxies.

Blackbody Radiation

In recent years radiation has been observed at centimeter- and millimeter-wavelengths with a spectrum and intensity which, so far as one can tell, corresponds with the radiation emitted by a blackbody with a temperature of about 3° Kelvin. This radiation, which was first discovered by Penzias and Wilson (*1*), just 5 years ago, comes apparently from the universe. It comes in equal intensity from all sides. In fact its isotropy is so complete that, with a relatively small improvement of the precision reached at present, one may expect to be able to measure the effects of the motion of the earth's sun and of our galactic system relative to this universal radiation field, a measurement which would give tremendously interesting information.

The universe appears to be filled with this low-temperature radiation. The existence of such a radiation is a necessary consequence of the big-bang theory of the expanding universe. In fact, it was already predicted 25 years ago by Gamow (*1a*). From his theory of the big bang he predicted a present temperature of 5°K, remarkably close to what has now been observed. This prediction had been entirely forgotten, and the actual discovery of the radiation came as a complete surprise.

At the time of the initial explosion the radiation was of course enormously more intense, and corresponded with a temperature of 10^{12} degrees or higher. It consisted then of hard gamma rays. This initial radiation has been degraded by the expansion of the universe to the 3°K radiation that we now observe. The measurement of the present temperature makes it possible to compute the temperature and radiation density in the entire past history of the universe, down to the actual "big bang."

Another intriguing aspect of the 3°K radiation is that, as Zeldovich and collaborators have pointed out, it may ultimately give an insight into the larger-scale deviations from homogeneity existing during the "fireball" stage. It is from these inhomogeneities that the present larger structural features in the universe must have come, and direct information on these early inhomogeneities is thus evidently of great importance for understanding the present structure.

Average Density in the Universe; Intergalactic Gas

The second category of phenomena I want to discuss refers just to this large-scale distribution of matter in the universe. The only way in which one can at present study this is by observing the galaxies.

The first problem to be considered is that of the average density. It is a question of prime importance. Unfortunately it is impossible to give an answer with anything like the precision that is wanted. One can give a rough

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lower limit by computing the overall mass density given by the galaxies. This gives 3×10^{-31} gram per cubic centimeter, if the Hubble constant is taken to be 75 kilometers per second per megaparsec. However, there is likely to be a considerably larger amount of matter which is *not* condensed in galaxies. From a tentative theory of the process by which galaxies were formed, to which I want to return later, I have estimated that at most about 1/15 of the gas in the universe would have been involved in the formation of galaxies. If this is so, the actual overall density would be at least 0.5×10^{-29} g/cm^{3}.

Up to the present there is only little direct evidence for the existence of this intergalactic gas. With the aid of 21-cm line observations, astronomers in Leiden and Groningen have, in recent years, discovered rather remarkable clouds of high velocity in high galactic latitudes, which are apparently moving toward the galactic layer. The most likely explanation of their motions, it seems to me, is that they are caused by intergalactic gas falling into the Galactic System (*2*). But even if this interpretation is correct the phenomena are much too local to allow an estimate of the general density of intergalactic gas in the universe.

The intergalactic gas must have a temperature of at least a hundred thousand degrees, otherwise it would have been observed in absorption in the spectra of distant quasi-stellar radio sources. But it cannot be hotter than about a million degrees, because, with a density such as that suggested above, it would then emit more radiation in the soft x-ray region than is compatible with observations. Actually, observations of soft x-rays have indicated the presence of isotropic radiation which may well be the radiation of the hot intergalactic medium, but the interpretation of the results is still somewhat uncertain. If the interpretation is correct it indicates a general density of just about the order of 10^{-29} estimated from the formation process of galaxies.

Perhaps the most convincing evidence for the existence of considerable intergalactic mass is furnished by the internal motions in some clusters or groups of galaxies, like the central part of the Virgo cluster, where the velocities are much too high for the galaxies to be kept, or even to be temporarily drawn, together by their own gravitation. The mass needed to accomplish this is about 25 times the estimated mass of all galaxies in the cluster. Still more direct and compelling evidence is furnished by a consideration of the local group of galaxies, where the two largest members, the Andromeda nebula and the Galaxy, which contain almost the entire visible mass in the group, approach each other with a velocity of 102 km/sec. This velocity of approach can only be understood if there is at least a two times greater mass than that contained in the two galaxies in the form of intergalactic matter.

There is a remarkable thing with the density of about 10^{-29} that I have mentioned. It is roughly equal to the so-called "critical" density at which the universe would just expand to an infinite scale, or radius, without any velocity left at infinity. In slightly different terms physicists express this by saying that the universe would just about be a *closed* universe, of finite mass, instead of an open, infinite universe. This seems a surprising coincidence. Is there a physical reason why the explosion velocity should have been so closely balanced with the total mass as to give the exploded matter just the velocity of escape and not a velocity of an entirely different order? Or should one reason that, if the explosion velocity had been very much lower, the universe would have collapsed before life could have developed; whereas if it had been very much higher, no condensation would have taken place and no galaxies and stars would have been formed?

Radio galaxies and quasi-stellar radio sources (quasars) can now be observed out to distances which, in a closed universe, would be about equal to its radius. The majority of these radio sources are *double*. At such large distances the angular separation of these doubles depends strongly on the geometry of the universe. There is good hope that, in a nearby future, measures of these angular separations combined

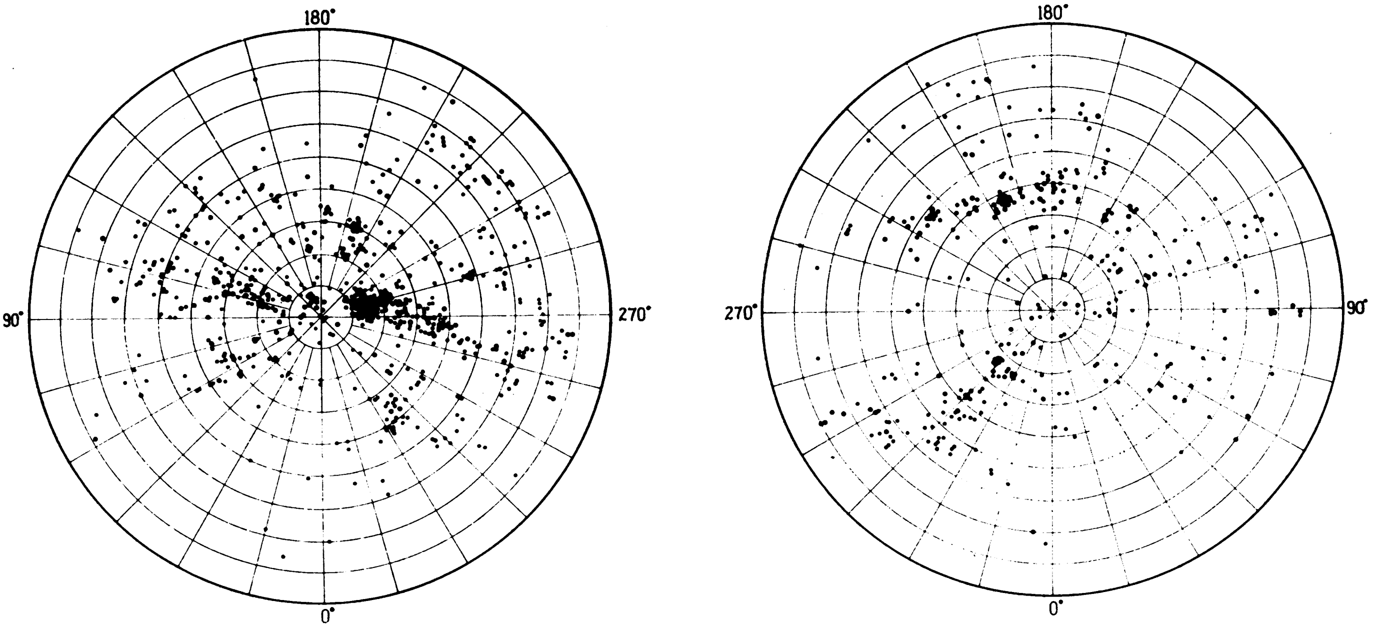

Fig. 1. Distribution of galaxies brighter than the 13th magnitude. The left- and right-hand diagrams show the North- and South-galactic hemispheres, respectively. The galactic poles are in the centers, the outer circles are the galactic equator [from Shapley and Ames (*3*)].

with a complete study of the intrinsic properties of radio galaxies may enable astronomers to measure the radius of curvature of the universe, and thereby also the average density, which is directly related to the radius.

Large-Scale Features

But let us return to the observations, and consider the deviations from homogeneity. Figure 1, taken from a classical survey by Shapley and Ames (*3*), shows the distribution over the sky in galactic coordinates of the galaxies brighter than the 13th magnitude. The distribution is strikingly uneven. Not only is there the dense conglomeration near the North-galactic pole (the Virgo cluster), where several hundred galaxies are concentrated on a surface of 10°, or 9 million light-years, diameter, but there is a striking unevenness over the entire sky, both on a larger as well as a smaller scale. In the zone below 20° galactic latitude the distribution is strongly influenced by absorption in our own galaxy; because of this absorption hardly any galaxies are observed below 10° latitude. But above 20° latitude the absorption effects are small, and all the features observed reflect real density concentrations of the galaxies in space.

The total volume surveyed has a radius of roughly 10^8 light-years. It looks as though the largest structural features in the universe have roughly this dimension. When one surveys larger regions, the average density shows less and less variation. Averaged over regions of the order of 10^9 light-years diameter, the universe appears to become practically homogeneous, with isotropic expansion.

Counts of radio sources, which extend to still larger distances than those of ordinary galaxies, seem to confirm the isotropy of the universe, though it has sometimes been suggested that quasi-stellar sources would show large deviations from an even distribution in the sky.

The unevenness on the scale of 10^8 light-years and less, which is so striking in the Shapley-Ames catalog (*3*), is most likely to have originated from large-scale density fluctuations following directly from the big bang. Mass concentrations of the order of 10^{14} to 10^{15} solar masses, such as we find in the Virgo cluster and in its appendages (see below), would have been able to survive the fireball stage of the universe. They can therefore be considered to have, in a sense, separated from the surrounding universe directly at the beginning and to have maintained themselves as separate units throughout the entire further evolution. These features therefore teach us very directly something about conditions in the earliest stage of the universe. What distinguished the features from their surroundings must have been either a slightly larger density or a slightly smaller expansion, or both. The contrasts with the surroundings were exceedingly small.

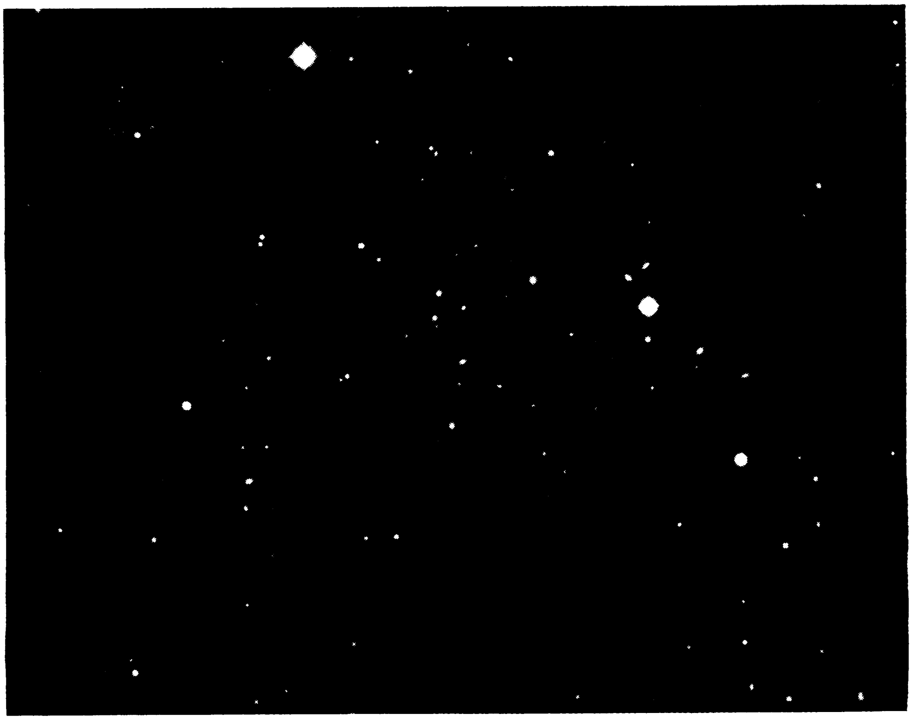

Fig. 2. Cluster of galaxies in Corona Borealis (200-inch Hale telescope on Mount Palomar). Photograph from the Hale Observatories. Round images with sharp borders are foreground stars in our own galaxy. The fuzzy, and often elongated, images are the distant galaxies in the cluster.

From the present situation we can estimate that, at the time of decoupling of matter and radiation, when conditions began to be somewhat as they are today, the contrast required to produce the larger-scale features was about two per mil. The *slight* retardation in the expansion caused by the corresponding excess density or expansion deficiency resulted in the density contrasts of the order of 100 to 1 that we observe today. Ultimately these structures must collapse entirely and may end up as regular, dense clusters of galaxies, such as that in Corona Borealis (Fig. 2). This sort of evolution of density fluctuations of initially extremely small amplitude will happen even if the average density in the universe would be as low as the lower limit estimated from the galaxies only.

A striking characteristic of the distribution of the galaxies is their tendency to form long arrays. An example is the appendages extending on opposite sides of the Virgo cluster over a total length of some 90°, or about 100 million light-years. Two other long chains may be seen in the South-galactic hemisphere. This is a tendency which has puzzled me ever since I studied this subject for an introductory lecture at a Solvay conference in 1958 (*4*). However, recent studies of the evolution of a spheroidal gaseous mass in an expanding universe have shown how such a mass will always collapse first along its smallest axes. The axial ratio will increase enormously during the evolution, so that, even if at the time of decoupling of matter and radiation the shape of the volume in which the density excess occurs deviates only a few percent from an exact sphere, it will always collapse first into a threadlike formation. The computations on the evolution of a nonspherical mass were made by Icke (*5*).

Because it seems exceedingly improbable that the original density fluctuations in the universe would have had precisely spherical shapes, the longish form may be considered as the natural shape which any initial density excess must assume during its evolving stage. Eventually these forms will also collapse along their *long* axes. Evidently this has not yet generally happened. Insofar as the general distribution of matter is concerned, the universe, as we observe it today, is still in a midway stage of evolution. Apparently, it is only in rather exceptional cases that the collapse of a large feature has been completed and that a stable cluster has been formed. This consideration leads one to speculate that most galaxy clusters may have been formed only recently, and that they would rapidly become rarer as we look back in time. We should seriously consider the possibility that there might be practically no clusters beyond, say, $z = 1$, when the age of the universe was about one third of its present age.

Evidently we cannot have large contrasts in the density distribution such as discussed above, without having correspondingly large deviations from the average expansion. A long feature like the two appendages of the Virgo cluster may be expected to be not far from its maximum extent, and the expansion along the chains must be considerably slower than the average expansion of the universe over the same distance. A discussion of the average radial velocity of various parts of the chain which Icke and I made indicates indeed that the expansion may be practically zero. For the determination of the Hubble constant—which purports to represent the average expansion in a homogeneous universe—it is desirable to take account of the local deviations that must accompany these large structural features.

In all of the foregoing reasoning it has been assumed that there is much intergalactic gas beside the galaxies, and that this gas has the same general distribution as the galaxies. The gas provides the ***stabilizing*** factor, because presumably it radiates away most of the kinetic energy gained in the collapse. The gas must likewise have been the main agency for stabilizing the large symmetrical clusters like those in Coma and in Corona Borealis.

Rotation and Origin of Galaxies

So far, we have taken the existence of galaxies for granted. It looks as though the process of their formation differs in essential respects from that of the formation of the large groups and clusters of galaxies that we have just considered.

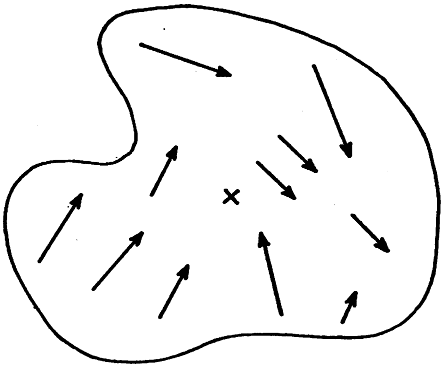

Fig. 3. Streaming which might lead to the formation of a rotating galaxy.

In the first place there is the problem of their sizes. Galaxies, with their relatively small masses, from 10^{11} to 10^{12} suns downward, may not have been able to survive through the fireball stage and may not, therefore, have been direct consequences of the big bang, like the groups and clusters of galaxies. In the second place, most galaxies must have reached their present shapes much earlier than the structures observed in the galaxy distribution. But the feature that is most important in connection with their origin is the rotation.

While the large galaxy clusters show little or no signs of rotation, the individual galaxies are mostly fast rotators. This holds in particular for the spirals and So galaxies. From measured rotation of our own galaxy and of some other nearby spirals we can obtain a fair estimate of their angular momenta and of their masses. Here something interesting turns up.

Until recently most cosmologists have assumed that galaxies originated from density fluctuations, of small amplitude but large-scale, existing at the time of decoupling of matter and radiation at the end of the fireball stage, much in the same way as described above for the formation of the large features in the distribution of galaxies. However, at that epoch the general density in the universe was so high that the radius of a volume containing a mass equal to that of a galaxy was far too small for the volume to contain an angular momentum comparable to what we find in spiral galaxies.

We must therefore conclude that, either the angular momentum was put into the "protogalaxy" in a later stage of its evolution by external forces, or that the protogalaxy separated itself from the surrounding universe only at a later epoch, when the average density had decreased so much that a cell containing a mass equal to that of a galaxy could contain the required angular momentum. At this time the scale of the universe was about 1/30 of the present scale, 30 times larger than at the time of decoupling. The first possibility, discussed by Hoyle (*6*) in 1951, has recently been proposed again by Peebles (*7*). However, somewhat more detailed considerations, based on a backward extrapolation of the present conditions in the universe, have shown that the possible external couples which may have been expected to act on a protogalaxy were at least an order of magnitude too small to have caused the rotations that we observe in the spiral galaxies [Oort (*8*)]. It therefore seems that we have to choose the second alternative.

This now teaches us something new, namely that, on the scale of galaxies, the universe must have been in a highly turbulent state. This turbulence at the time of the formation of the protogalaxies must presumably have been derived from a still higher degree of turbulence at earlier epochs, a turbulence which may have come down to us from the initial explosion. By what mechanism this could have been done is still far from clear. Ozernoy and Chernin (*9*) have made the interesting suggestion that photon whirls of galactic mass may have provided the turbulent elements required.

The considerations given above teach us also something about the general epoch in which most galaxies were actually born. The reasoning for this goes as follows: It is plausible to think that the same turbulence which caused the rotations made it possible to form galaxies in the rapidly expanding universe. If we imagine a whirl of galactic dimensions, the currents in such a whirl which give it the required angular momentum will be likely not to be exclusively in transverse directions, but equally in radial directions relative to the center of the volume considered. When measured relative to a frame of reference expanding with the average velocity of expansion of the universe we might have motions like those sketched in Fig. 3. In volumes where the radial currents flow in an outward direction the volume will expand faster than the universe. Such volumes will evidently disperse and will not form galaxies. But in volumes where the currents are systematically *inward* the general expansion of the universe will be locally retarded, and it will become possible for the volume to collapse eventually under its own gravitation.

As we can estimate from the observed rotations what the size of the transverse components must have been, we can also get some idea of the amount of decrease in expansion we may expect in the favorable cases. And this again makes it possible to get an estimate of the time it would take these volumes to recollapse. The radial currents will in general compensate only part of the universal expansion. As a consequence the volume (or the"protogalaxy") considered will first expand with the universe, though at a much slower rate, and only collapse at a much later date. It is at this epoch that, because of the collapse of the gas of which the protogalaxy consisted, *stars* are formed and a real galaxy will appear.

We must thus distinguish two different epochs in the birth of a galaxy.

1) The time when the mass of gas which is to form a galaxy first detaches itself from the surrounding universe and becomes an independent unit. This we might call the inception time of the protospiral. The age of the universe may then have been of the order of 1/100 of the present age, which I shall in the following denote by t_0.

2) The time of collapse of the protogalaxy. This is the actual birth time of the spiral galaxy. Only the roughest estimate can be made of this time. It may, for most galaxies, have been around the epoch when the universe had 1/4 to 1/5 of its present age. Undoubtedly there must have been a large spread in these ages, and it is easily conceivable that galaxies are still forming today, while others may date from a much earlier epoch.

An interesting consequence of this process of galaxy formation is that the *afterbirth* continues for a very long period, presumably extending long beyond the present time. Though the bulk of the mass of a galaxy would have collapsed around the time mentioned, it is to be expected that the inflow of gas from the surrounding universe is still going on, but on a reduced scale.

As I have already mentioned, phenomena indicating such an inflow into the Galactic System have indeed been found from 21-cm observations. This inflow is an important effect that must influence the dynamics of spiral galaxies, possibly also their nuclear regions, and, furthermore, the abundance of elements.

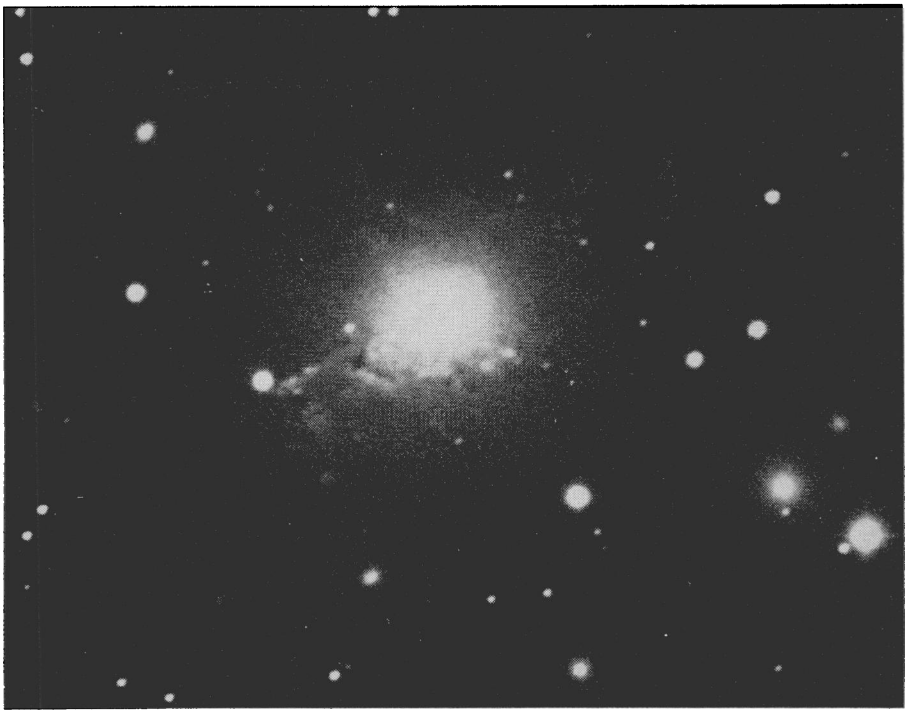

Fig. 4. The galaxy NGC 1275. About half of the ionized interstellar gas is moving at a velocity of 3000 km/sec relative to the galaxy; the other half has the same velocity as the galaxy. The galaxy, which lies at a distance of 2.2×10^8 light-years, is a strong radio source, Perseus A [Minkowski (*16*)]. Photographs from the Hale Observatories.

With the process of galaxy formation as envisaged, only a fraction of the gas in the universe will have condensed into galaxies. From general considerations it may be estimated that this fraction can hardly have comprised more than 1/15 of the total volume and is likely to have been less. If we combine this result with the estimate of the mass contained in the galaxies, we arrive at a minimum total density which is close to the critical value mentioned earlier. It is not at all implausible then that the universe may have a higher than critical density, and that it is finite and closed.

Evolution Effects

I must now turn to a description of phenomena that have greatly fascinated astronomers since they were first discovered by Ryle (*10*) and his co-workers many years ago. From a survey of what in those days were faint radio sources, Ryle found that these were considerably more numerous than was expected from the counts of brighter radio sources. What made this so exciting was that, in all likelihood, the anomalous increase should be ascribed to evolution. These evolution effects were later confirmed in an independent way by Schmidt from measures of velocities of quasars.

It appears that, at a time when the universe was about one third as old as it is now, the population density of radio sources was some hundred times larger than at present. This factor is over and above the geometrical factor due to the smaller scale (about two times smaller) of the universe at that time, and therefore represents a true evolution effect.

When one looks still further into the past the factor continues to increase until we reach $t \sim 0.20\ t_0$. At still earlier times the frequency of strong radio galaxies and quasars drops rapidly. Not a single radio source has been found at a distance larger than that corresponding to $t = 0.13\ t_0$.

At the time when the evolution effects were discovered, it seemed surprising that such enormous differences could exist at such relatively nearby epochs. Conditions were expected to have been radically different at the end of the fireball stage, when the universe had about 1/10,000 of its present age, but one would not have expected its general character to have been very different when it was only a factor of 5 younger than at present.

However, as I have mentioned, there is one thing that seems to have happened during a period which was just a factor of this order ago, namely the birth of the rotating galaxies.

It is true that our estimate applied only to spiral galaxies, but one could speculate that all galaxies may have evolved similarly, and that the absence of radio sources at earlier times is due to the fact that no galaxies had been formed before the epoch referred to. It is then also tempting to relate the occurrence of the very bright stage in radio sources with the moment of the formation of a galaxy, or soon thereafter, and to speculate that the enormous increase in the frequency of radio sources in the past is in some way connected with the strong increase in the birthrate of galaxies which, as we have just seen, may have occurred at approximately the same epoch.

Nuclei of Galaxies and Their Instability

The existence of radio galaxies and the fantastically intriguing phenomena which they exhibit brings me to the last peculiarity of the universe that I wish to describe: the tendency toward instability. It is a very remarkable property, the universal importance of which has only been realized since the advent of radio astronomy, although some optical evidence existed already earlier. It is now generally accepted that most, if not all, of the large-scale instability phenomena observed originated in the *nuclei* of galaxies and probably in nuclei which are exceedingly small compared to the general dimensions of galaxies.

There is no time to give even a cursory review of the many forms in which the instabilities show up. I must confine myself to a few examples. In the galaxy NGC 1275 (Fig. 4) there is an enormous mass of ionized gas, estimated as having perhaps a hundred million times the mass of our Sun, which moves away from that galaxy at a velocity of 3000 km/sec. It has most likely been set into motion by some mechanism residing in the nucleus. If so, the tremendous explosive event by which the gas has been pushed out must have started several million years ago; but the explosion is of a *continuing* sort, for it still goes on at the present time. The NGC 1275 galaxy, by the way, is a strong radio source, and has given rise to several other remarkable phenomena.

An eruptive phenomenon of a different kind is shown by M 87, a famous radio source near the center of the Virgo cluster. Optically M 87 is just an ordinary giant elliptical star system. It is beautifully regular and symmetrical, except for one most curious feature which does not fit in at all with the regularity of the stellar system: a luminous jet, apparently coming out of the center and extending to about 5000 light-years. The light of the jet is strongly polarized and must be due to the synchrotron mechanism, which is known to be responsible for the radio-frequency radiation of radio galaxies. As in the case of NGC 1275 the violent activity that has given rise to the jet and to the large halo of strong radio-frequency radiation enveloping the stellar system must have continued for a long time, because activity is still seen to go on in the nucleus.

The extreme of violent events occurs in the quasi-stellar objects, or quasars, the true nature of which was first recognized by Maarten Schmidt. These objects are the beacons by which the farthest observable parts of the universe can be investigated.

They emit an enormous amount of radiation of the synchrotron type. So enormous that one has had great difficulties in understanding what can have been the source of the energy. The energy contained in a quasar is equivalent to what one would get by complete annihilation of 10^7 to 10^8 solar masses.

Activity on such scale as shown by quasars is extremely rare. But activity of galactic nuclei on a somewhat smaller scale appears to be very common. Among the half-dozen nearest giant galaxies there are at least two (M 82 and NGC 5128) that show indisputable evidence of having recently been the source of violent activity. In this context one should also point to the so-called Seyfert galaxies. This is a fairly common class of spiral galaxies whose general structure is quite like that of ordinary spirals, except that they possess small, bright nuclei in which discrete clouds are seen to be moving at velocities which are probably higher than the velocity of escape. These clouds, which have masses of the order of 10^3 or 10^4 times the mass of our Sun, are apparently being expelled by a very small nucleus. Again, in these Seyfert nuclei, enormous energies are being poured out. We may well ask whether or not practically all larger galaxies might possess nuclei which have the potentiality of developing explosive activity at certain times.

It is of interest in this connection to draw attention to some phenomena in our own galaxy. In several respects we can more effectively study the central regions in the Galactic System than in the much more distant external galaxies.

We observe two sorts of phenomena that are directly relevant to the problem of instability. The first is that the Galaxy contains a small nucleus emitting synchrotron radiation at radio frequencies. It also emits radiation of a different sort in the far infrared which has the same unusual spectrum as found in Seyfert nuclei, but is intrinsically about 30,000 times less intense. In addition, there appears to be a very dense nucleus of stars, the central density of which is at least 10^8 times the star density near our Sun (compare the schematic Fig. 5a). For a more extensive survey of the phenomena in the nucleus and central region there is a recent review (*11*). The low intensity of the infrared radiation indicates that the present activity is slight. There are, however, indications that it may have been different in the past. In 1965 Shane found from 21-cm line observations in Dwingeloo that in the central region there are large quantities of gas outside the galactic disk which have presumably been expelled from the center less than 10 million years ago. Subsequent extensive observations by Van der Kruit (*12*) have substantiated this. The expulsion was probably in two roughly opposite directions, making a large angle with the galactic plane, and involved a mass of at least 10^6 solar masses. These "clouds" are schematically indicated in Fig. 5b, which shows a section through the central region of the galaxy perpendicular to the galactic plane. If the interpretation is correct it must mean that our nucleus must have been very active in the nearby past.

Expanding motions *in the disk*, comprising structures as massive as spiral arms, had been known for a long time: these had been especially investigated by Rougoor (*13*). In the case of these expanding arms in the plane of the disk, mechanisms other than eruption from the nucleus could possibly explain the large radial motions. But now that there is direct evidence that large masses have actually been thrown out of the nucleus, we might speculate that these arms also were set in motion by matter expelled from the nucleus. Computations concerning this possibility have been made by Van der Kruit. Very large masses would have had to be ejected, with a high velocity, to explain the motion of an object like the so-called 3-kiloparsec arm.

What is the ultimate origin of the remarkable phenomena coming from the galactic nuclei?

There are two central problems, namely, the origin of the energy, and the origin of the enormous quantities of matter that are ejected. It seems possible that the origin lies in a very large, superdense, fast-rotating mass that contains a strong magnetic field with an axis inclined to the axis of rotation. This suggestion, first made by Morrison (*14*), was inspired by the discovery of the pulsar in the Crab nebula, that supernova remnant which, during the last 15 or 20 years, has contributed more to our insight into the explosive aspect of the universe than perhaps all other celestial objects together. However, it is still entirely uncertain whether an explanation along such more or less conventional lines can really explain all the phenomena concerned. An opposite view has been favored by Ambartsumian, who in the past has shown such an intuition for discovering things that were never imagined by anybody else, and who had prophesied the fundamental significance of galactic nuclei long before most of the phenomena referred to were known (*15*). He has suggested repeatedly that the nuclei of the galaxies have existed from the very beginning, possibly as remaining fragments of the explosion from which the universe originated, and that they have properties from which all the phenomena we observe in galaxies may have been derived.

Though, at present, most astronomers will hesitate to accept such a rather extreme view concerning the origin of galaxies we must keep in mind that there is a whole category of instability phenomena for which no satisfactory explanation has been found. In the study of galactic nuclei we are only just reaching the borders of a largely unknown domain, and future observations may well reveal things which can give a quite unexpected turn to our present thinking.

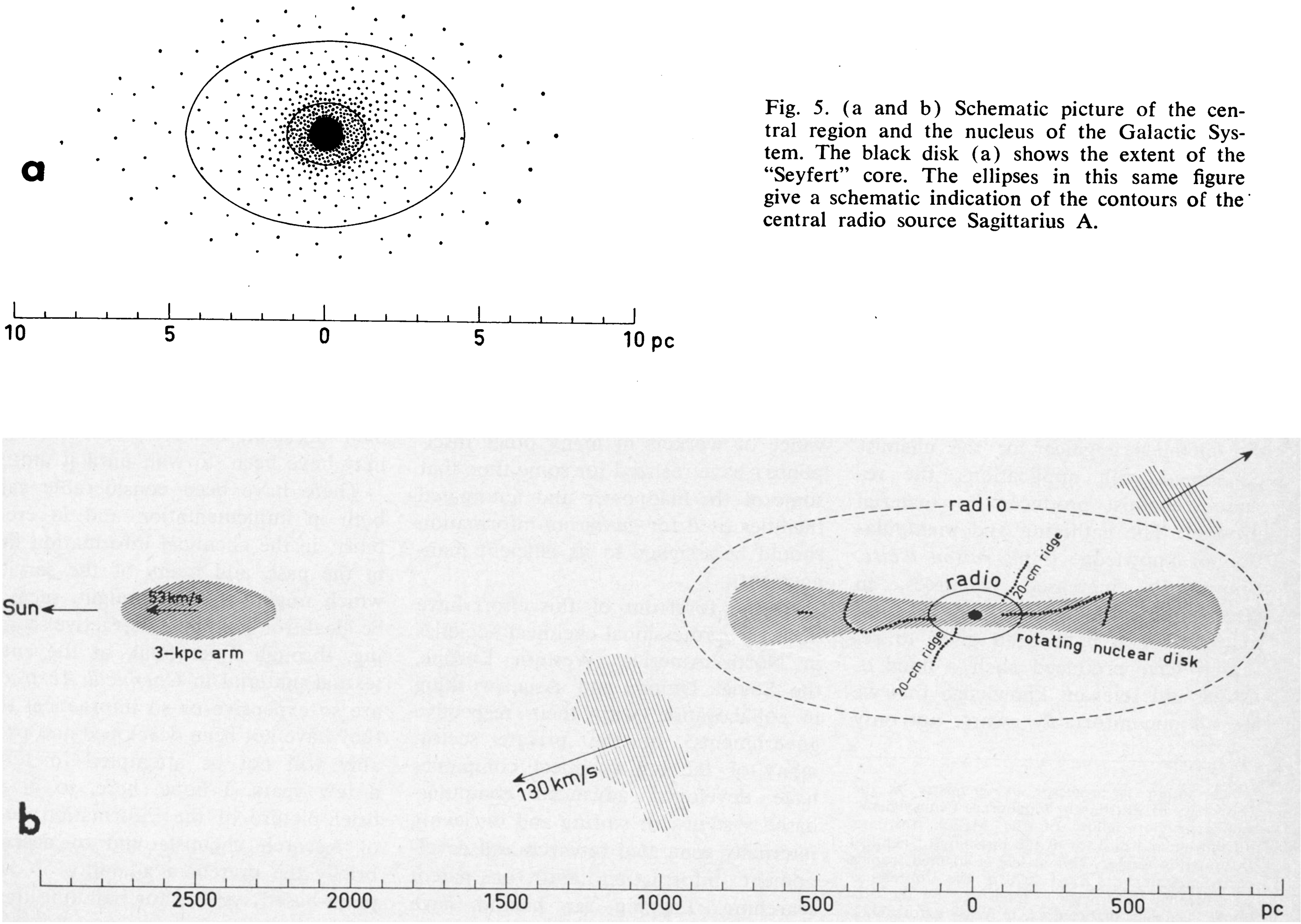

Fig. 5. (a and b) Schematic picture of the central region and the nucleus of the Galactic System. The black disk (a) shows the extent of the "Seyfert" core. The ellipses in this same figure give a schematic indication of the contours of the central radio source Sagittarius A.

Summary

A brief review is given of what the study of galaxies has taught us about properties of the universe. It is assumed that the universe started from a general "explosion," and that the general expansion observed today, as well as the 3°K blackbody radiation, are consequences of this explosion. The present average density in the universe is probably close to the critical value of 10^{-29} g/cm^3. Only about 3 percent of this is contained in galaxies; the rest consists probably of intergalactic gas at a temperature between 10^5 and 10^6°K. Observations in our own galaxy indicate that this intergalactic gas is still flowing into it.

The distribution of matter in the universe is highly irregular. Even apart from the clusters of galaxies density contrasts of the order of 100 : 1 are common. It is indicated that the strongly elongated shapes which seem to be characteristic for the more extended regions of high galaxy density are a natural consequence of the expansion of the universe. The largest structural

features have dimensions of the order of 10^8 light-years. These features appear to be in a midway stage of evolution. Concentrated clusters of galaxies may be very recent formations.

The high angular momentum per unit mass in spiral galaxies indicates that at the time of their detachment—long after the ending of the fireball stage—the universe must have been in a vehemently turbulent state. After their detachment the protogalaxies first expanded; they became stellar systems only upon their recollapse, which may have taken place when t/t_0 was approximately between 0.1 and 0.2 (t_0 being the present age of the universe). This period may coincide with that of the high frequency of powerful radio sources.

In the last section a very cursory review is given of the large instability phenomena displayed by some galaxies. These appear to come from the nuclei. There are indications that the nuclei of most large galaxies are from time to time susceptible to enormous violent activity.

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Computer-Based Chemical Information Services

Some new aids for the research scientist are described.

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It may come as a shock to many research chemists to realize that, from one point of view, all of their activities are concerned with chemical information—its acquisition, evaluation, storage, retrieval, and transmission. Unlike the chemical engineer or the chemist concerned with applications, the research chemist produces no material product. The gathering and manipulation of knowledge is his *raison d'être*. Enormously increased resources, in terms both of manpower and of automation, which have been given to research have produced such a flood of useful and relevant knowledge that we are all uncomfortably aware, not only of our intellectual and psychological limitations for assimilating this embarrassment of riches, but of the physical difficulties of sorting, storing, and retrieving the information that we might need to assimilate. Chemists (far in advance of workers in many other disciplines) have realized for some time that some of the manpower and automated facilities used for *gathering* information should be assigned to its efficient management.

In the forefront of this effort have been the professional chemical societies in North America, Western Europe, the Soviet Union, and Asia, working in collaboration with their respective governments. In the private sector, many of the big chemical companies have developed advanced computer-based systems for storing and retrieving internally generated research and development information and for patent searching. Lagging far behind have been the universities. One can identify at least three reasons for this gap.

1) University science libraries serve a broader spectrum of users, with more general goals, than do the libraries of mission-oriented government agencies or most industrial organizations, where the range of interest is, for the most part, clearly defined over a period of years. Furthermore, the libraries of agencies and industry are more accustomed to playing an active role in performing searches than university libraries are.

2) Academic chemists and teachers are primarily interested in the behavior of molecules and students, respectively, and are less interested than information scientists in manipulation of the symbols used to store material describing how molecules behave.

3) Up until the past 2 or 3 years, computer-based chemical information had relatively little to offer most academic chemists; they were correct in their decision, however unconscious it may have been, to wait until it did.

There have been considerable gaps, both in implementation and in credibility, in the chemical information field in the past, and many of the services which might, at first thought, seem to be ideal (for example, interactive searching, through a terminal, of the entire textual material in *Chemical Abstracts*) are so expensive or so impractical that they have not been developed and probably will not be attempted for quite a few years. I hope, here, to give a brief picture of the information needs of research chemists and to describe briefly the present availability of computer-based systems for handling them.

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