# VIEWS OF THE UNIVERSE

**Man has been led to various views of the universe at various times in his history. Here's how he sees it today.**

by H. P. ROBERTSON

PERHAPS the greatest and the most universal of all the problems which have intrigued the mind of man are those which deal with his own place in the world in which he lives. But before he can even formulate these problems, before he can set himself out as something apart from the rest of the world and inquire about his relations to it, he must construct some picture or model or theory of the universe as a whole. He must, in the learned jargon which he has invented to help keep his thoughts in order, develop a *Cosmology*.

He may wish, however, at times to go beyond a mere description of his universe and speculate on its inner nature, or its purpose, or its origins; that is, again in the learned jargon, he may supplement his Cosmology with an *Ontology*, or a *Teleology*, or a *Cosmogony*.

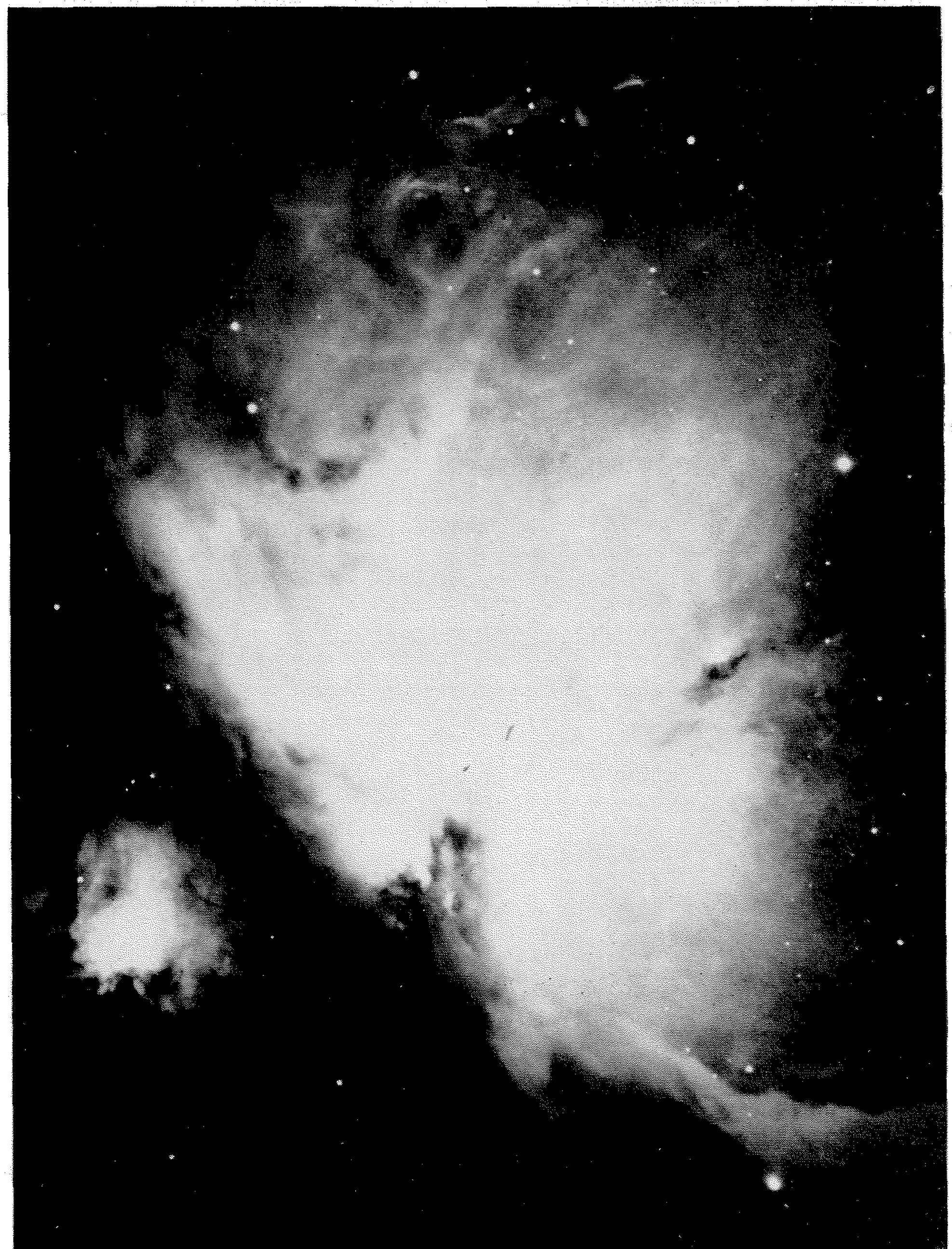
The views of the universe to which man has been led at various times in his history have invariably reflected the environment in which he belonged. Thus, one finds among the ancient peoples of India a primitive cosmology built out of objects and concepts common to their everyday experience; the Earth was pictured as a huge flat tea tray, supported on the backs of three elephants, who, in turn, stood on the shell of an enormous tortoise. Their cosmogony, on the other hand, seems not to have developed to the point of inquiring about the origin of the tortoise!

Again, the ancient Greeks, influenced by the Aristotelian dogma of the perfection of circles and spheres, considered the Earth as a solid sphere surrounded by the Moon, the Sun, and the planets, traveling in orbits built out of perfect circles. The whole system was contained inside a heavenly sphere, upon which the stars were fixed, and which rotated daily about its center within the Earth.

Our modern views of the universe are no less a product of the age in which we find ourselves, an age which has seen the development of science into a creed which permeates our every way of life. And because I intend to emphasize those aspects which fall within the sphere of science, my account will deal with those more philosophical aspects of inner nature or purpose or origins mentioned in my opening remarks.

I shall, in short, deal with those views of the universe to which we have attained by the scientific method of alternating observations and hypotheses—by peering into the heavens with the aid of those technological devices, such as the telescope and the spectroscope, which increasing understanding of the laws of nature has enabled

*"Views of the Universe" was originally presented as a radio talk in the Columbia University Bicentennial Series.*



*Visible to the naked eye as a dim, hazy spot in the sword of Orion, the Great Nebula Messier 42 is more than 1,000 light years away from us. It weighs 1,000 times as much as the sun, and consists of gas and dust illuminated by very hot stars.*

us to build, and by ordering what we there see in accordance with those laws which have proven successful in ordering our more limited earthly experience.

The objects with which I shall deal start with the Earth and its immediate companions in the Solar System. From them I go rapidly to the stars which make up our own Milky Way system, of which the Sun is but an undistinguished member among the hundreds of thousands of millions of stars in the galaxy. And finally, I want to take you—in the mind's eye only—out across the enormous reaches of space to those other island universes, the great nebulae, many of which are similar in size and structure to our own, separated from each other by distances so great that light, which takes only eight minutes to travel from the Sun to us, takes millions of years to pass from one nebula to another.

Throughout the most of human history the Earth, that seemingly solid platform to which we are as yet confined, was regarded as the center of the universe. The Copernican revolution in astronomical thought, barely four hundred years ago, first effectively replaced the Earth by the more stable Sun as the pivotal point about which all else moved. This change of view was in itself not nearly as significant as its consequences, for within the following century it led, through the observation and theories of Tycho Brahe, of Kepler and of Galileo, to the crowning achievement of the new dawn of science, the mechanics and the theory of gravitation of the incomparable Sir Isaac Newton. Here, for the first time, men saw in the uniformities of the heavenly motions the workings of the simple laws of nature, which governed the motions of the planets in their orbits as surely and as impartially as they did the fall of little green apples from the tree.

But with this extension of physical law from the terrestrial to the celestial realm, the Sun, as well as the

Earth, was destined to lose its claim to occupying the central position in the universe. Already in the seventeenth century there were those, like Thomas Digges and Giordano Bruno, who envisioned an infinite universe more or less uniformly populated by stars, stars which might even be accompanied by lesser bodies like the Earth and the other planets, which loomed so importantly in the earlier cosmologies.

## A limited system

But this too simple picture was, in turn, destined to give way before the advancing front of observation, made possible by the development of the telescope from the puny tubes of Galileo to the mighty reflectors now studded over the face of the Earth. What these revealed to us was that while the Sun was indeed but a member of that system of stars which made up the Milky Way, this system was itself a strictly limited one—although one consisting of hundreds of trillions of stars, and so vastly extended that light would take a hundred thousand years to cross from one edge of it to the other.

This myriad of stars was found to be arranged like a great lens, with the Sun near the central pane but about half-way from the center to one side. From our vantage point on the Earth the stars then seem to be spread out like a great veil wound around the sky. And as we study it, guided again by Newton's laws, we see in the galaxy a universe of stars rotating slowly about its center, but so vast in extension that the "Cosmic Year" required for one revolution of the system is a hundred million times that year in which the Earth revolves about the Sun.

Is this, then, the universe? If so, we can place its center at that point, some tens of thousands of light-years from us in the direction of the constellation Sagittarius, about which the galaxy rotates. (And here, in measuring the vast distances with which we are forced to deal, I have used the astronomers' most expressive unit of distance, the *light-year*—that is, the distance light travels in one of our terrestrial years.)

The most striking feature of this galaxy of ours is its myriad of stars, which modern observations allow us to infer is moving in a stately procession about its center. But the telescope reveals that among these stars are other types of objects—compact clusters of stars, bright patches of luminous matter, and dark patches of matter dimming or even obscuring the light from stars lying behind them.

Among these other objects are little fuzzy blobs of luminous matter called *nebulae*—or, more precisely, *extra-galactic nebulae*, for the improvement in our observing instruments and methods within the century has enabled us to identify these tiny dim patches as themselves great collections of stars and other luminous matter, comparable in every way with our own galaxy, but lying far without its borders. The most conspicuous, and one of the very nearest of these, is the Great Nebula in the constellation Andromeda, which we now place at a distance of well over a million light-years from us. This distance has, within the past two years, been upped from the previously held figure of seven hundred thousand light-years to nearly twice that, largely through the researches of Walter Baade of the Mount Wilson and Palomar Observatories.

I will refrain from going into the intricate processes by which the astronomer assigns these distances—the extension of our terrestrial distance scale to the Moon and Sun, thence to the nearer stars, and then by successive steps to Andromeda and the other nebulae. It is enough here to indicate that the first two steps are a quite straightforward application of geometry to celestial mechanics, and that the guiding principle of the later steps is that, given two objects known (or suspected) to be of the same intrinsic brightness, that one which is further away will appear to us less bright than the other by a factor which varies inversely with the square of its distance from us.

To return to the world of nebulae, it is estimated from the number which show up on plates taken with the great telescopes, that there are, within the range of the 200-inch Mount Palomar reflector, almost a million million nebulae, and that these nebulae are more or less uniformly distributed throughout a sphere whose radius is two billion light-years.

The typical nebula of this great collection contains as much luminous matter as ten thousand million of our Suns—and could harbor, in addition, as much or more dark matter in the form of gas, dust, or dead stars. The uniformity of their distribution in space is, however, at most a statistical one, as the nebulae are often found to aggregate in groups containing from a few to clusters of hundreds of members, loosely bound together by their mutual gravitational attraction.

This, then, is the astronomical universe as we now conceive it to be, a grand aggregation of billions of nebulae, separated from each other, on the average, by millions of light-years. And since these nebulae are scattered pretty much at random throughout the whole of the visible universe, man's search for a true center has come to naught—every part of this vast domain is much the same as any other, and so there is no privileged position on behalf of which such a claim could be made.

## Some observed facts

Let us therefore give up the search for such a center, and go on to describe certain of the gross properties of the universe of nebulae as now observed. We shall then try to "explain" these observed facts by ordering them in terms of physical laws extrapolated from our more limited terrestrial or galactic experience. And if, as appears likely to many competent men of science, this attempt proves too great a strain on the laws as heretofore formulated, we can inquire what modifications or new points of view can be called upon to bring order into our extended cosmos.

Perhaps the most striking feature of the extra-galactic nebulae, as we view them from our position within our own galaxy, is that they all (with minor exceptions) appear to be fleeing away from us, and that the further away they are, the faster they are going. I say "appear" to be fleeing, for we have already here a good instance of the process of extending our ways of thinking from the known to the novel.

We do know, from terrestrial experiments, that light from a bright source can be broken up by a spectroscope into component wavelets of certain characteristic frequencies or wave-lengths. When this same source is receding from us these characteristic wave-lengths are increased by a factor which depends sharply on the velocity of the source relative to us—that is, they are shifted to the red end of the spectrum. This is comparable to the Doppler effect of sound, where the pitch of the whistle on a receding locomotive is lowered by the motion.

Now, when light from a star or a nebula is observed through the spectroscope, bright lines appear which, because of their relative positions and intensities, are identified as characteristic of certain of the chemical elements whch can be isolated here on Earth, and which are therefore assumed to exist in the heavenly body under examination.

## An expanding universe

But in the case of the nebular light these bright lines are observed to be shifted toward the red end of the spectrum, and the inference is quite reasonably made that this shift is caused by the motion of the source away from us, as in the familiar Doppler effect just described. The extrapolation is the basis for the assertion that the nebulae are fleeing our galaxy, and that the further away they are—that is, the dimmer they appear—the greater is their velocity of recession. Roughly, the velocities thus inferred increase in proportion to the distance of the nebula from us.

Observations with the great reflectors by Hubble and Humason, to whom much of the work on the velocity-distance relationship is due, yield Doppler shifts which are interpreted as due to velocities up to almost one-fifth the velocity of light. At the top end of the scale, then, we find objects whose velocities are well over 30 thousand miles a second, at distances approaching 700 million light-years! But nebulae can still be seen when their light is too weak to be spread out effectively into its component wavelets in a spectroscope; could we measure the Doppler effect in nebulae at the limit of our present capabilities of observation, and if its rate of increase held up at these greater distances, we should expect to find nebulae receding from us at half the velocity of light—more than 90 thousand miles a second!

It is time now to turn from an inductive amassing of observations, and to set up a simplified model of the universe which will exhibit the same salient features as those observed in the actual universe. The primary purpose of this exercise is to replace the practically unsolvable problem of predicting the motions of the actual nebulae in the actual universe with a more tractable problem, the solution of which may indicate the kind of behavior to be expected in the actual universe.

In so doing we are guided by an assumption, called by some the Cosmological Principle, that the model is spatially uniform—that is, that the ideal nebulae are distributed uniformly throughout space in such a way that the world-view obtained by an observer on one of them will not depend either on his position in space or on the direction in which he is looking. The inferred motion of the nebulae away from us is reflected in the model by assigning to each ideal nebula that velocity which corresponds to its distance away from us, in accordance with the smoothed-out velocity-distance relationship described a short time ago.

## The future and the past

A little reflection—aided perhaps by pencil and paper—will convince you that this assignment of velocities in no way singles us out as a unique center of this Expanding Universe; an observer on any other nebula would find that all the nebulae, including ours, appear to be receding radially from him in accordance with exactly the same velocity-distance relationship as applies to our own observations. The Cosmological Principle is thus valid for observations of motions, as well as of the positions, of nebulae in this model Expanding Universe.

How, then, will this expanding model behave—what is its future, and what its past? If we ignore for the moment interactions between the nebulae, we would predict that each pair will continue to move apart at the same rate as at present, and that they have been so moving ever since the beginning of time. This would imply that about three and one-half billion years ago all of the nebulae must have been bunched together within a quite small region of space, and suggests that they are now flying apart with the velocities acquired in some great primeval explosion.

And here we run into our first hint of possible trouble with the model, for the geologists tell us that the Earth itself must be some three or four billion years old. This near coincidence is by no means fatal to the model, for it may well be that the Earth itself is some minor by-product of the initial cataclysm. Nevertheless, the time scale suggested by this first view is uncomfortably short, and alerts us to the danger of winding up with a model universe whose age is less than that of one of its minor inhabitants, the Earth!

The detailed investigation of the behavior of the model must be based on some theory of the interaction of matter in the large. The theory which is in best accord with our previous experience is Einstein's General Theory of Relativity, whose field equations are designed to account for the gravitational attraction between massive bodies. But these equations further imply that the geometrical properties of space depend upon its physical content—and I have so far tacitly assumed that the space in which the nebulae are imbedded is the flat, infinitely extended theatre of events with which we are all familiar from our early study of Euclidean geometry.

This opens up a new range of possibilities for our model, for although the uniformity of distribution of the ideal nebulae will induce a corresponding uniformity of the space, this space need by no means be the flat Euclidean one. It could indeed be a closed space, the three-dimensional analogue of an ordinary spherical *surface*, whose total volume is finite, and whose straight lines return into themselves as in the case of great circles on the surface of a sphere. In this case, we would truly have a finite, but unbounded universe, containing but a finite number of nebulae.

In contrast with the flat Euclidean space, such a space is said to have a *positive curvature*, which can be expressed in terms of a so-called *radius of curvature*, a significant distance analagous to the radius of the sphere in the two-dimensional example. Here the motion of the nebulae is reflected in the fact that the radius of curvature would vary in time in just the same ratio as the distance between any two of the nebulae—and a complete knowledge of the velocity-distance relationship would enable us to deduce the dependence of the radius on time. Still a third possibility is open to us—the universe could be an infinitely extended space of *negative* curvature, one which is harder to visualize, but which is again characterized by a radius of curvature whose change in time is proportional to the motion of the nebulae.

## Relativistic Cosmology

Relativistic Cosmology, the study of the behavior of our model universe under Einstein's gravitational field equations, traces the mutual relationships between density and motion of nebulae on the one hand, and the curvature of space on the other. Unfortunately, the observations presently available to us do not suffice to single out one of the possible solutions as uniquely representing our actual universe. Some possibilities can be thrown out as leading to too short a time since the initial explosion, but among those which remain are several which quite adequately reflect what we now know for certain concerning the nebulae.

We can confidently look forward to future observations yielding the data required to narrow down our choice—or perchance to show that none of the relativistic models is adequate to portray reality. It does appear, however, that according to this line of thought we may expect the universe to continue, and even to accelerate, its expansion. The distant nebulae will then eventually escape from our causal universe (i.e., that part of the universe that has any effect on us), and we shall be left with only a few nearby companions, with whom we are caught in our mutual gravitational attraction.

The ghosts of our erstwhile Universe of Nebulae may still be present in the form of a dim infra-red light, drained by the Doppler effect clear out of the visible spectrum, but quite probably undetectable by any who may remain to see. But long before this the Sun will have burned up its atomic fuel, and the Torch of Learning will perhaps have been passed to, or kindled anew by, life on another Earth revolving about another Sun.

Is there, then, no escape from these grim conclusions? We have been led to them by an insistence on extending our knowledge of the near and familiar to the distant and novel. And even here we have allowed an untested element to creep into the process. For among the terms contained in the relativistic field of equations is one which implies a force tending to drive the nebulae apart, a term introduced by Einstein in 1918 in his initial attack on the cosmological problem—a term which has no observable consequences for nearby objects, and which has since been repudiated by its author. We surely cannot, in good conscience, leave the subject without probing some of the various alternatives which have been proposed—even though, as in the case of the cosmological term, there is no more immediate evidence of their validity.

## Avenues of escape

The first avenue of escape which appears to one is that possibly the reddening of light from the nebulae is due to some unknown small influence on it during its tremendous journey to us, rather than to a Doppler effect caused by a motion of the source. Then, the nebulae may remain indefinitely where they are, and the degradation of the universe is one of frittering away of light rather than of loss of matter through escape. Such is indeed a possible out, but good scientific methodology demands that before we accept it some better picture—and preferably some more direct confirmation—of the process be advanced.

Yet another, and even more revolutionary, possibility is that somewhere in the universe matter is being created out of nothing to replace that lost in the vanishing nebulae. Such proposals have been made, by Hoyle and by Bondi and Gold in England, and by Jordan in Germany. They differ among themselves in method and in detail, but all would have the effect of creating new nebular matter—whether by the gradual accretion of newly created gaseous matter, or by the sudden and spectacular flaring up of super-novae, those fantastic "new stars" which are observed to occur every century or so in the nearer nebulae. Such proposals would compel us to give up one of our most tenaciously held general principles, that of the conservation of matter and energy.

These are but two of the more promising alternatives to the picture painted by Relativistic Cosmology. Which of these views of the universe, if any, will prevail is a question for the future to decide. Of this we can, however, be sure—the advancing front of science will always root out more questions than it can answer at the time, and the problem of the Universe of the Nebulae will be no exception to this fundamentally healthy state of affairs.