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New Light on Cosmic History

THE PRESENT ERA is one of new approaches to the universe. Astronomy has been revolutionized during the past decade. Perhaps the most remarkable change has come from the newly developed ability to receive radio signals from outer space. The mysterious "cosmic static" of a couple of decades ago has blossomed into the new science of radio astronomy, whose telescopes are measured in feet where the optical instrument is measured in inches. It is not an idle dream that the radio telescope will soon reach to greater distances than have been probed by the study of the light of stars and stellar systems.

Another new approach is of still more recent date: it is less than a year since the first man-made satellite was launched into space. But the satellite is not yet a fully astronomical tool. At present it is looking inward, not outward; it is primarily a means of studying geophysics. When satellite astronomy does look outward, the astronomical consequences can hardly be foreseen. But that day is still in the future.

The new approaches are not confined to techniques. The whole system of ideas concerning the universe is in a state of flux; the whole emphasis in our cosmic picture is changing.

It has been said that there have been three eras in modern astronomy. The first, which dates back less than two centuries, was concerned with the great stellar system in which we live — the Milky Way system. The stars were counted, and their positions were surveyed; their motions were measured, and many attempts were made to discern structure in the great system of stars. Gradually it dawned on astronomers that our Milky Way system has limits, and then it appeared that we are not unique — our own Milky Way is only one of many, separated by vast empty spaces. Only now are we beginning to realize how many Milky Way systems, or galaxies, there are — not hundreds or thousands, but thousands of millions, extending to the utmost limit that our telescopes have been able to reach.

The study of the Milky Way was essentially an era of map-making. The next great stage came when the stars were recognized as individuals with special, identifiable properties of their own. Some are hundreds of times the size of the sun, some are proportionately smaller; some have surface temperatures a hundred times the sun's, some are so cool that they barely shine. The star as an individual has dominated the first half of the present century, and we have learned to find out not only their superficial properties, but even to analyze their chemical composition. The results are surprising: most stars are of very nearly the same materials, and in nearly the same proportions. Hydrogen, the simplest of the atoms, dominates the composition of the universe: it has been said that stars "are made of hydrogen, with a smell of other elements."

Today we have taken a further step: not content with recognizing an amazing variety among the population of the heavens, we have begun to ask the question: What makes them differ? Have they always been as they are today? What was their past history, and what will be their future? These are the questions that dominate astronomy today. It might be thought that these questions can never lead to more than fruitless speculations, but remember that only a hundred and fifty years ago a famous philosopher stated that one thing we can be very sure of is that we shall never know what the stars are made of. Famous last words! I wish I could present you with the details of the quantitative analysis of the sun's atmosphere, and the beautiful, intricate evidence on which it is based.

Two roads have converged to give us our present knowledge of the development of stars. I prefer not to call it "evolution," because that word has come to have a special biological use, which is not transferable to cosmic processes. The first was the recognition of families of stars; the second, the understanding of what keeps the stars shining, a problem that had puzzled astronomers and physicists for three-quarters of a century.

Our own Milky Way system contains about a hundred thousand million stars — many of them, of course, too faint or too distant to be seen, but the number can be stated with some confidence. Those that can be studied reveal a surprising tendency to occur in groups. The majority of the stars have at least one companion, a physically associated body in orbital motion around it. Many of these groups are multiple, like the bright star Castor which has six components, and the famous "Trapezium" in the Orion nebula, which seems to have eight. The very nearest of the stars is a triple system. And we can feel sure that these multiple stars have always been associated together since their beginning; the stars, though numerous, are so far apart that a chance capture is out of the question.

Even more striking than the double and multiple stars are the star clusters. Everyone who knows the sky is familiar with the Pleiades — the "seven stars in the sky" that are visible to a keen eye. A telescope shows that this cluster contains far more than the seven bright stars, indeed it has hundreds of members. The Hyades, not far from the Pleiades in the sky, is another cluster well known to the stargazer; here again there are hundreds of members in addition to the small number visible to the unaided eye. There are thousands of such clusters, and many more, faint and distant, remain to be discovered. If a double star has no chance of being an accidental association, how much less likely is a star cluster to be one!

If star clusters and double stars are not chance groupings, but have been together from the first, we can draw an inescapable conclusion: they were born together of the same materials and at the same time, or very nearly so. This is the basic fact that underlies the modern study of stellar development.

The stars of the Pleiades cover a large range of brightness; some are much brighter than our sun, and they are found to range all the way to stars much fainter. When these various members of the Pleiades family are studied with care, their individual properties determined, and their sizes and temperatures measured, they are found to be arranged in a very orderly progression. The brightest are the largest and the hottest, and their sizes and temperatures are uniformly graded downward as we pass from brighter to fainter. The members of the cluster were born together and have developed in company. Why, then, are they so different? The answer to this question was provided by the second discovery that has ushered in the new era of astronomy — the discovery of the food of the stars.

Speculation has succeeded speculation on the question of what keeps the stars shining. Specifically, how has the sun maintained a virtually unchanged output of heat and light during geological time? Mere combustion would be hopelessly inadequate. The idea that the sun might be releasing gravitational energy in the form of heat, and contracting as it did so, while it improved matters over the combustion theory, was still insufficiently prolific. When radioactivity was discovered, and the release of energy from the nuclei of atoms was seen to be possible, speculation began to play with the idea that the stars might be subsisting on the energy of their own atoms. It was less than twenty years ago that these speculations gave way to convincing theories. At nearly the same time, Hans Bethe and C. F. von Weizsäcker showed how stars could release energy from their own hydrogen atoms under the very high pressures and temperatures in their interiors. The food of the sun was shown to be hydrogen, simplest and commonest of all the elements, and the supply of energy was seen to be adequate within our luminary for a long time to come. There is little doubt that the stars in the Pleiades are similarly fed.

If stars shine by consuming their own internal hydrogen, it is clear that their careers must be limited by the amount of hydrogen available. It was therefore a matter of great interest to determine how fast they are using up this essential material. There is a very simple way of finding this out: the amount of hydrogen used is proportional to the amount of light given out.

Stars give out light at very different rates, which is the reason why they differ so much in brightness. The brighter members of the Pleiades are giving out far more light than their fainter brothers. But are they all equally well supplied with food? Have the brighter ones, perhaps, more hydrogen within them than the fainter ones?

On this point the evidence, also, is very convincing. As stars are mainly made of hydrogen, the amounts of available food that they possess must be proportional to their masses. And, although the masses of the stars in the Pleiades cannot be measured, we are confident that they resemble the masses of many other stars that can be measured (because they belong to close double-star systems whose mutual gravitation can be determined). The study of such stars leads to the striking conclusion that a star's light output is not proportional to its mass, but goes up much faster — nearly as the *cube* of its mass. The light output of a star of a hundred times the sun's mass would be about a million times as great as the sun's. So the more massive star must use up a million times as much hydrogen in a given time. Since it has a hundred times as much hydrogen to start with, such a star is "living" at a rate 1,000,000/100, or 10,000 times that of the sun. We cannot escape the conclusion that it can last 1/10,000 times as long.

Now we take a close look at the physical properties of the stars in the Pleiades. When a star is beginning to come to the end of its hydrogen resources, we can predict what will happen to it: it will begin to draw on new sources of energy, and will grow in size and fall in temperature. Some of the very brightest stars in the Pleiades show unmistakable marks that this process has begun, whereas the fainter ones, like the sun, still have ample supplies. By knowing the characteristic mass of a star like those that begin to show signs of departing from the sunlike pattern, we can calculate how long they have been shining. And this enables us to assign an age to the Pleiades cluster — an age that is about ten million years.

Large as this time is, it is small compared to the probable age of the sun — perhaps five thousand million years. The Pleiades, however, is old compared to some other clusters that we know. The great double cluster in Perseus is little more than a million years old; and the group of stars that shine through the meshes of the Lagoon Nebula in Sagittarius is perhaps five hundred thousand years old, younger than the datable life upon our own planet!

There are clusters older than the Pleiades; the Hyades contains some stars that have departed very far from the sunlike pattern, and this cluster is perhaps ten times the age of the Pleiades. There are still older clusters, inconspicuous in the sky, but dear to astronomers, "NGC 752" and "Messier 67," for instance (known only by the numbers assigned to them in catalogues), the latter being perhaps 5,000-million years old, as old as the stellar system itself.

How, you may ask, do we know the age of our stellar system? We date it by the oldest objects in it, and corroborate the date from our studies of the energy sources of the sun itself (about 5,000-million years old) and the geological estimates of the age of the earth, which are not much smaller.

The oldest objects that we know in the stellar system are clusters, but clusters of a very different kind from the Pleiades. Whereas the clusters we have spoken of have hundreds of stars in them, these old clusters have populations of hundreds of thousands, if not millions, of stars. They are known as the "globular clusters" because they look like globes of stars, which they probably are.

Globular clusters show development patterns that confirm and supplement the patterns shown by the galactic clusters, though they are different in important and striking ways. These clusters can be dated in much the same way as the Pleiades-like clusters, and they all turn out to be nearly of the same great age, about 5,000-million years, perhaps rather more.

What makes them differ from the Pleiades-like clusters? Probably they are of different composition, and contain more hydrogen and less of the heavy elements. We ascribe the difference to their greater age: they were formed at a time when the star-generating clouds consisted mainly, perhaps entirely, of hydrogen.

How, then, did the Pleiades-like clusters come to be formed from materials of different chemical composition? We now believe that these clusters are a second generation in stellar development. As stars consume their hydrogen, they form other, heavier elements; first helium, later oxygen, neon, and finally the metals. Many of the heavy, luminous stars become unstable and explode, scattering these products of their digestive processes into space. The clouds of material thus formed are able to form again into stars and clusters of stars — very likely all stars are born in clusters, and some of them get lost as the cluster ages. Thus, the younger stars, the second-generation stars, are of different chemical composition from the primitive stars, and their course of development is somewhat different. The difference is reflected in the pattern of physical properties that is displayed by the members of a cluster like the Pleiades.

The new outlook in astronomy has led to a complete transformation of ideas. Today we look out at the stars and star clusters that make up the Milky Way system and recognize that they span a vast variety of ages: some infant groups are less than a million years old, the oldest that we know are five thousand million years of age. The static universe of yesterday has been transformed into a picture of perpetual change, development and rejuvenation. The stellar system known to astronomers — even the bright stars visible to the casual observer — has changed immensely since life first walked the earth. And yet this conclusion is a triumph of *ideas* — the idea that groups of stars are of the same age and origin, and the idea that stars sustain themselves by consuming their own substance. We have yet to observe, *directly,* any change in a single star that can be ascribed to development. The coming era of astronomy will look for such changes; and I have little doubt that the astronomers of tomorrow will find them.