WHAT DO WE KNOW ABOUT STARS?*

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WE know a great deal about the outsides of stars, the physical conditions existing in their gaseous atmospheres, but we know very little about the deep interiors of stars. We know a good deal about their numbers, their distribution in clusters and galaxies, their motions, and their course of evolution from infancy to age.

Let us ask and attempt to answer as briefly as possible some specific questions.

What are the stars? Each star is a vast, more or less spherical aggregation of matter, partly if not entirely in the state of incandescent gas. Some astronomers think that deep down beneath the gaseous outer layers the matter may be in liquid form, others think it is gaseous to the very centre. Certainly the outer layers are composed of gases, of this there is no doubt, for the light which comes out of the stars, when studied with a spectroscope, exhibits just those characteristics which are found in the light produced from various gases in the physicist's laboratory when these gases are raised to incandescence by the application of heat or by the excitation of an electric discharge. And this is one of the astounding secrets of the Universe, revealed by spectroscopy within the last century, that almost all the elements—iron, carbon, oxygen, hydrogen, silicon, calcium, and so on,—which go to make up the earth, are found to be the stuff of which the stars are made. There is no perfect, unchanging, unchangeable substance composing sun and stars, as the Greek philosophers maintained,—the whole universe is made up of similar aggregations of the two fundamental entities, the electrons and the protons which are the ultimate negative and positive electrical charges of which all the elements,—all matter,—all things animate and inanimate—are made.

How large and how heavy are the stars? A super-giant star,

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like Antares in the constellation of Scorpio or like Betelgeuse in Orion, is several hundred million miles in diameter. If its centre were coincident with the centre of the sun, half the Solar System would be inside the star. Thus the volume of one of these great stars is several million times that of the sun, and the sun's volume is one million times that of the earth. But the density of such a star is very low, much less than that of the air we breathe, and so its mass, or the amount of matter it contains, is only ten or twenty or perhaps thirty times that of the sun. Very few stars are known to be more massive than this. At the other extreme are the stars about one-tenth as massive as the sun, and so dense, so compacted into very small volume, that one cubic inch of such a star would weigh a ton on our terrestrial scales.

It is just because the stars, even the smallest of them, are so massive that they are able to retain their heat, and hence their ability to radiate light and heat for many millions of years, whereas relatively small aggregations of matter like the planets of the Solar System have cooled off and ceased to radiate.

How hot are the stars? The radiating surface of the coolest star is at just about the highest temperature producible in an electric arc. The light emitted by such stars, like Betelgeuse in Orion, contains a large proportion of red rays. Hotter stars, like our sun, whose surface temperature is about 10,000°F., shine with a yellow or golden light. Still hotter stars like Vega emit that harmonious blend of all the visible rays which we recognize as white light, while the hottest known stars like Rigel in Orion, shine with a steely blue light.

We cannot measure the central temperatures directly, but all theoretical calculations point towards internal temperatures of many millions of degrees. The interior of a star is pictured as a vast storehouse of energy where the material atoms are in some unknown manner being transformed into radiant energy, and this radiation rushes outward like a mighty wind. Four million tons of the sun's mass are being transformed every second into radiation to supply the stream of heat and light and invisible ultra-violet rays pouring out continuously into surrounding space.

How old are the stars? Suppose an observer with no knowledge of the past looked suddenly upon the world of humanity, he would see infants and children, youths with strength and vigour, men whose powers were fully developed, and yet others whose strength was on the wane. Seeing many at every stage from infancy to old age, he might, perhaps, hazard the guess that with the passage of time each individual passed through one stage to the next—an evolution of man from cradle to grave. So, too, the astronomer sees stars in their infancy with latent undeveloped potentialities, stars whose energy output is that of vigorous youth, stars at the peak of their vitality, stars on the wane, on the descending road towards inactivity and darkness. Can he avoid the hypothesis that there is a majestic evolution of the stars? The evolution of a man takes place to the ticking of the seconds hand, hour by hour for four score years, but the evolution of a star requires a different time-scale.

In a vast region of space, sparsely filled with nebulous matter, concentrations begin inevitably to take place and gravitation draws more and more matter towards each centre of concentration,—thus is born a cool, diffuse star. As it grows more massive and more compact its internal temperature of necessity grows greater and it begins to radiate more and more vigorously. It ceases to grow indefinitely more massive when the outward hurricane of radiation blows off the surface layers as fast as gravitational attraction augments them. The star is now of giant proportions, but as it continues to contract and radiate away its energy, it passes in due time into the dwarf stages of its career. Gradually its course of evolution brings it to a stage where its mass is greatly reduced, its energy largely expended, its ability to radiate almost, or perhaps entirely, gone. This evolution takes place to the beat of units of time measured not in seconds but in millions of years.

This is not a sad picture any more than should be the picture of the evolution of a human being from infancy to age, where faith stands firmly on the principle of conservation of spiritual values. The energy of the youthful, giant star is gradually transformed and dissipated and the star becomes old and cold and outwardly inactive—but its energy is not lost—the Law of the Conservation of Energy is a fundamental bulwark of physical science. We do not know what ultimately will become of this energy. Is it, perhaps, used up in the process of the expansion of space itself? Here is an unsolved problem. The universe of a far remote future may be very different from the universe of to-day. Nature has many secrets as yet hidden from us.

Is the sun a typical star? The answer is both yes and no. The sun is in itself quite an ordinary dwarf star—there must be thousands just like it, and there are many stars somewhat smaller and many that are larger. It is, however, a star with an exceptional history. Some 2,000 million years ago it befell that another star approached very closely to it, perhaps even collided with it, and as a result the sun lost a portion of itself. These disrupted gases gradually condensed to form the system of planets and satellites, comets and swarms of meteors which revolve in their respective orbits about their parent sun. These planets in order of proximity to the sun are Mercury, Venus, the Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto, the recently discovered outermost planet.

This disruption of a star is a catastrophe so improbable in the universe that it is almost certain that very very few stars have thus acquired an attendant retinue of planets. For though the stars are all moving in various ways through space, often with exceedingly high velocities, yet their relative separations are so tremendous that the chance of a collision is extremely small. Imagine four or five little minnows as the sole inhabitants of the Atlantic Ocean into which they have been thrown at various places, from north to south, from Europe to America. Here is a picture of the distribution of stars in our galaxy. The chances of a collision are obviously very small. Theoretical calculations alone are useful in a search for other solar systems, for so distant are even the nearest stars that no telescope could reveal such planets as those surrounding our sun even if these neighbouring stars were to possess such an entourage.

How many stars are there? With the naked eye one can rarely see more than about 2,000 stars at one time. Altogether there are some 6,000 visible without telescopes. But with powerful telescopes and long exposures, photographs have been obtained of many million stars. Astronomers calculate that around our sun in this great galaxy there are some ten thousand million stars.

Far out in space beyond our great galaxy there are yet other star galaxies, perhaps not quite as large as our own, but large enough to contain star material equivalent to a thousand million suns in each galaxy. Much of this material is as yet in the form of primeval nebulosity, while much of it has already condensed into stars. The vastness of the universe baffles our imaginations.

What is our debt to the stars? Our earth was once a portion of the surface material of the sun, and the sun, as we have seen, is just one star amongst the many millions of stars of a great galaxy. A chance fragment of a star is our planet, and man, as far as his physical framework is concerned, being "of the earth, earthy" is therefore of the stars, starry! Or, rewriting a famous line of the great poet, "We are such stuff as stars are made on."

When we seek the source of the energy which maintains the surface temperature of the earth at a reasonable degree of warmth, the energy which makes possible the existence of life upon the earth, we find that almost all this energy comes from without. It is brought to the earth in the sunlight and in the starlight, but since the term starlight in its strictest sense includes sunlight, we may simply say, and with absolute scientific accuracy,—Of star dust are we made and by starlight we live.

Perhaps you would remind me that man does not live by bread alone. To which the astronomer would make reply that if you are seeking food for the spirit of man, one of the unfailing sources is to be found in the contemplation of the beauty, the harmony, the majesty and the deep mystery of the Universe of Stars.