ASTRONOMY AND ESCHATOLOGY

By ALBERT G. WILSON

What the astronomer finds when he studies the cosmic disasters which could end the existence of mankind

After passing several centuries in a state of neglect, the ancient art of prophesying is again becoming quite fashionable. This is easily verified by going into any book store and looking over the drove of books currently appearing on such subjects as human destiny, the next million years, the end of the world, etc., etc. The men behind these books, the modern Jeremiahs and Daniels, do not get their source material from handwriting on walls, but from the data science has accumulated concerning the evolutionary processes of stars, rocks, and living organisms. And unlike their ancient predecessors, modern prophets generally avoid forecasting the time and place at which a specific event will occur; they prefer to confine their prophesying to the delineation of rough bounds within which future events must lie.

But in spite of this dilution, prophecy is still as popular as ever. For example, an informal sampling of the thousands who every year visit Palomar to view the world's largest telescope reveals that most of these people look on Palomar as a sort of 20th century Delphi, and are primarily interested in those phases of astronomy which are relevant to the old questions of the purpose, significance, and destiny of man in the universe.

Traditionally such questions as these have been the monopoly of theologians, who have gone into these matters in great detail, even giving a name to the subject—eschatology, the study of the ultimate destiny of man and the world. But with the great progress which science has made during the past few decades in disentangling evolutionary processes, it was inevitable that scientists should invade this field.

Though science has accumulated enough facts to enable certain types of long-range predictions to be made, the picture is still extremely fragmentary and fraught with uncertainties. The largest uncertainties in the predictions do not arise from the incompleteness of science's picture of nature and its evolutionary processes, but from the fact that intelligent life, through its increasing control over nature, can alter the course of future development to conform with its own purposes. If man's control of his environment were complete, and if his goals were well established and intelligently pursued, then a prophet could simply say that the future is circumscribed by these goals and he would be close to being right.

But this is not the case. The present situation is somewhat between that of the past, in which the laws of organic and inorganic evolution alone determined the course of events, and the case described above in which an intelligent organism possessing complete control of itself and its environment determines the future.

This uncertainty factor imposed upon evolutionary development by the impact of intelligence is negligible in those areas of the natural order which lie beyond the control of men. In such areas science may predict the future from natural laws with confidence.

The extraterrestrial universe stands as a region wherein man's influence will in all likelihood forever remain of minute importance. When the limited extent of man's domain is compared to the background of the vast distances of space, it is quite evident that the cosmic stage is almost completely unaffected by what man does on this planet. Even if he should choose to blow the earth to bits, the effects would be of no cosmic consequence. The cosmic order remains indifferent to the aspirations and efforts of man. And though man may eventually completely subdue nature on this planet, his ultimate destiny on earth is circumscribed by the earth's destiny in the cosmic order. And the earth's destiny, in turn, is circumscribed by the evolutionary processes of the universe.

The role of astronomy

It is then the role of astronomy, in science's prophecy of the future for man, to ascertain the earth's probable future as determined by the action of cosmic forces. Specifically, astronomy must seek to discover what the prospects are for the earth's continuing as a suitable abode for life, and study those events which could end the existence of mankind.

It is difficult to imagine life being obliterated by purely terrestrial forces. Cataclysmic earthquakes or meteorological changes which would terminate all human life could occur only as a result of a change in our cosmic environment.

What, then, are the cosmic events whose occurrence would either directly by their own action, or indirectly through the triggering of terrestrial forces, effect a termination of the delicate conditions necessary for life? Two types of such cosmic disasters are conceivable: first, a collision or a close encounter between the earth and another celestial body which could disrupt the earth, or cause gigantic earthquakes, tides, and/or loss of the earth's atmosphere, or perhaps even cause the earth to assume a new orbit which would alter its mean temperature; second, a change in the intensity or nature of radiation received by the earth from the sun, as for example would occur if the sun's luminosity or temperature were to change.

This array of "Sunday Supplement" material has been carefully considered by astronomers and it is now possible to make some evaluations and predictions.

First, the likelihood of collisions and encounters: Every day the earth's mass is increased by several thousand tons through its collisions with meteoritic material. For the most part, this accreted material consists of fine dust or of small grains which, striking the earth's atmosphere with velocities of the order of 30 miles per second, are immediately consumed by friction. Larger particles, weighing up to about 200 pounds, may strike the earth with frequencies of perhaps five or six each day. But this material poses no threat to human life, although a meteorite about the size of a fist struck a garage in Illinois a few years ago and, passing through the top of a car, came to rest in the car seat.

But larger masses frequently strike the earth. Twice during the present century two large meteorite falls have occurred, both fortunately in relatively uninhabited regions. In 1908 a group of large meteorites, estimated as having a mass of a few hundred tons, struck in the Tunguska River region in Siberia. The resulting hot air blast devasted an area of some 3000 square miles. And again in 1947 a fall of comparable size occurred in eastern Siberia. It has been estimated that meteorite falls of this size occur once every 50 to 100 years.

But what is the chance of the earth's colliding with a really large body? Within the past few years about a dozen new asteroids have been found whose orbits cross that of the earth. In October of 1937 one of these objects passed at a distance only three times that of the moon, a near miss on the celestial scale. If the number of these asteroids whose orbits bring them close to the earth is no greater than the number observed up to the present time, E. J. Opik (of the Armagh Observatory in North Ireland) then estimates that a direct hit would occur about once every 30 million years. If, as is more likely, there exist several hundred such asteroids, the estimate is every two million years.

But even a collision with one of these asteroids whose mass is comparable to that of a mountain would not be a total disaster. One recently discovered at Palomar is the smallest yet observed, having an estimated diameter of only a quarter of a mile. A collision with such a body would create a crater perhaps 25 miles across and devastate an area about the size of Texas. This is about the worst that could happen. The orbits of all objects significantly larger are known, and none come near the earth.

Strangers from outer space

This survey takes care of visitors from within the solar system, but what of strangers from interstellar space?

A subject very popular with writers of science fiction is the destruction of the solar system by an encounter with a passing star. This idea used to be popular with astronomers too, not for the destruction of the solar system, but for its creation. A once highly regarded theory would have the planets formed from pieces of the sun torn out by the tidal action of a passing star. But when the probability of such encounters was computed it was found that even among the hundreds of billions of stars in the galaxy, only one or two encounters would have occurred in the 3,000,000,000 years believed to be the galaxy's age.

A remaining possibility in this field of Sunday Supplement disasters is the disintegration of the moon, resulting

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in huge pieces raining down from the sky, leaving the earth dead and pock-marked like its late satellite. Actually this event could happen. Sir George Darwin and Harold Jeffreys have worked out the effects of tidal friction on the stability of the earth-moon system. If the loss of energy through tidal friction continues at the present rate, the month and the mean lunar distance will increase. The maximum will occur when the earth's sidereal day and the month are equal to 47 of our present days. After this time the effect of tidal friction will be to shorten the month and bring the moon closer. When the moon comes within a distance of about 2.4 times the earth's radius it will be torn apart by gravitational attraction, parts falling to the earth and parts going into the formation of rings like Saturn's. If this theory is correct, the date at which the disaster will occur is January first, 100,000,000,000 A. D.

The second type of cosmic event which could affect the existence of life on earth is a change in the sun's integral properties, such as its size, luminosity, or temperature. It is estimated that the atomic furnaces in the sun's interior have been operating for roughly three billion years, helping to maintain the earth's surface at a nearly constant temperature. How much longer the sun's thermo-nuclear reactions will continue to operate and what will happen when the fuel supply is exhausted are problems studied by a branch of theoretical astronomy called "stellar interiors."

The present theories of the structure of the sun do not pretend to be definitive and revisions are constantly being made. However, some zero order ideas concerning the sun's future can be derived from these present models.

One idea is to represent the sun by a model consisting of two zones: a core, whose temperature is sufficiently high to enable thermo-nuclear energy generation processes, such as the carbon cycle, to be operative; and a cooler surrounding envelope in which no energy generation occurs. Initially, a star is composed almost entirely of hydrogen. Within the core the hydrogen is being converted into helium, accompanied by convective currents which keep the substances thoroughly mixed. The envelope, cooler and less disturbed, remains hydrogen rich. As long as there exists an adequate supply of hydrogen in the convective core, there is little change in the star's integral properties. Eventually, however, the hydrogen in the convective core becomes exhausted and within the core there no longer exists nuclear energy production. The central core becomes an extremely hot isothermal core, and at the interface between the core and the hydrogen rich envelope, nuclear energy generation occurs in a thin shell. The isothermal core grows in mass and radius as the thermo-nuclear shell eats its way out through the hydrogen envelope. Chandrasekhar and Schönberg have shown that this process cannot continue until the shell traverses the entire envelope, but must terminate when the isothermal core acquires a mass about 12 percent that of the entire star. During the time of growth of the isothermal core, the star increases somewhat in luminosity, but remains constant in temperature. Schwarzschild and Sandage have developed an evolutionary sequence which comes into operation after the 12 percent limit has been reached. According to their theory, after the isothermal core reaches the critical mass it begins to contract, and through contraction gravitational energy is released. During this phase the total luminosity of the star remains nearly constant, but the envelope becomes greatly extended. Later, when the contracting helium core reaches a much higher temperature a thermo-nuclear reaction in which helium nuclei form carbon becomes operative. Then the star becomes more luminous. After this stage, the star may collapse and become what is known as a white dwarf star. These are stars whose matter is in a degenerative form. The nuclei of the atoms, devoid of their electronic shells, are pressed together, giving densities of the order of tons per cubic inch.

Theories and observational data

These are theories. But some very remarkable agreements have obtained between the consequences of these theories and the observational data. The rate at which a star consumes its hydrogen depends on its mass. The most massive stars burn their fuel at the highest rates and are therefore the most luminous. It follows that massive stars reach the Chandrasekhar-Schönberg limit earlier than less massive ones and start out earlier on an evolutionary track such as that proposed by Schwarzschild and Sandage. In a large aggregate of stars, such as a globular cluster, containing stars of all masses, there should be some which are still consuming the hydrogen in their cores and some which have reached the post-12 percent evolutionary stages. Sandage, at Mount Wilson and Palomar, has studied the luminosities and temperatures of several hundred stars in the globular cluster M3, and finds that all the stars heavier than 1.2 solar masses have taken off on an evolutionary track resembling that predicted by the theory.

If the universe is in the neighborhood of 3,000,000,000 years old, as is derived from several independent observations, and stars down to 1.2 solar masses have consumed the hydrogen available to them, how much time remains before stars of mass 1.0 reach this critical evolutionary stage? Assuming that our sun is of the same age as the stars in M3 and is subject to the same interior processes, then it should continue to radiate more or less as in the past for another four or five billion years.

We may now relax. Based on what has been observed of the cosmic order, it appears that man will not be exterminated by nature before he can perfect the means of doing the job for himself.

Our prophecy may well end here, but it is usual for the prophet to tell first what the future will be, and then tell how this future can be avoided by following his advice. In the present discussion, the future described can be avoided by simply constructing a different sort of stellar model.

Further, according to the best traditions of prophecy, the predictions must be supplemented by exhortations and admonitions. Whereas the predictions themselves are usually well received, the sermons which prophets insist on giving with their forecasts have always made them unpopular. (First-rate prophets have never measured their success by the success of their predictions, but by how unpopular they can become.) Therefore, both in order not to disappoint anyone and to help crystallize reader opinion, I shall conclude with some brief admonitions and exhortations.

A difficult problem of choice

Mankind today is in the position of the child who has spent his life thus far under rigid parental guidance, but now coming of age, suddenly acquires freedom and means. The laws of evolution which developed intelligence on this planet are now at the disposal of that intelligence. The knowledge of the processes of nature and the ability to utilize these processes for his own ends have come to man at the same time. But like the child with newly acquired freedom and means, man is faced with a difficult problem of choice: What shall he do with his control of nature? What ends shall he seek? What destiny should he wish?

Perhaps no better advice can be given than that the child should continue to pursue those ideals and principles laid down by its parents, at least until it acquires sufficient maturity to evaluate all the courses open to it. Man can set no better goal for himself than to emulate the goal of nature: To develop a species with the maximum possible survival potential. In the past, survival potential has depended on adaptability to environment; in the future it will also depend on control of environment. So man must use the understanding and control which his science affords him to increase further his control and to establish those conditions which enhance the long-range survival of his own or derivative species.

The astronomer can only assure man that cosmic forces give him a green light for whatever he plans. To others he gives the task which is the most important of all—to derive from the above general goals and principles the specific rules and patterns for action.