the heavens but had to be generated in the upper regions of the air.

Tycho erroneously connected the brightness of a star with its size, assuming that a first magnitude star is 105 times as large as the earth. From this it followed that the new star must have been tremendous to begin with, but must have decreased in size.

Tycho did not fail to express himself concerning the astrological effects of the new star, which could not be estimated in the usual manner because the star was a most unusual phenomenon. As late as 1632 this portion of his work was cited at length in two tracts in English which were trying to show that the nova of 1572 was currently having its effect. This was during the Thirty Years War and the year of the death of King Gustavus Adolphus of Sweden.

But even in these astrological treatises, the supra-lunar position of the star was stressed. Here again was posed the philosophical problem of disagreement with the long accepted Aristotelian notion of the immutability of the heavens.

The observations of the new star focused attention on the discrepancies in the older systems of cosmology and alerted the philosopher-scientists to the need for testing Copernicus's new theory. Consequently, when a spectacular comet appeared three years after the nova disappeared, more eyes were trained on the heavens and more hands were recording what could be seen there.

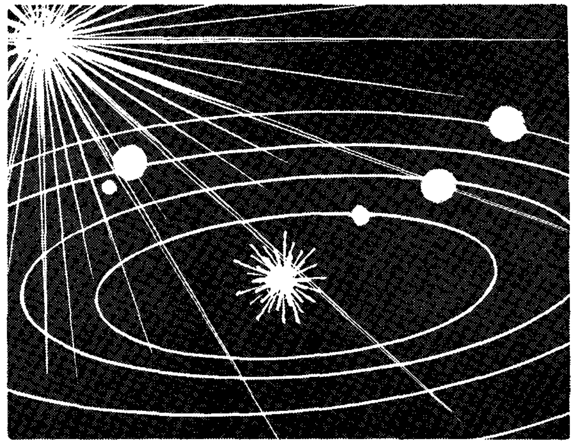
Tycho Brahe especially was convinced of the necessity of reforming astronomy. He realized that to do this he must accumulate a large body of observations of the motions of the sun, moon and planets—systematically and consecutively. In the years between the nova of 1572 and the comet of 1577 he had been granted the island Hveen off the coast of Denmark, and there had built an elaborate observatory equipped with astronomical instruments more accurate than any hitherto assembled. This was before the time of the telescope. The instruments were large to minimize errors, and their arcs were divided at small intervals to increase accuracy. Some even had dotted lines to facilitate calculation of the intervals between divisions. The unique quality of the observatory attracted a continuous stream of young students. Brahe taught them not only to be patient and careful but to compensate for errors introduced by the instruments themselves.

He wrote a tract on the comet of 1577, in German, the year after the comet appeared. In this paper, Tycho stressed the comet's supra-lunar position and what it meant to Aristotelian doctrine. The tract was not printed until the twentieth century, but the composition of it served a purpose in focusing Brahe's thought. By the time the words were set down, Tycho was already at work on his own system of the universe, which he hoped would do away with the inaccuracies of Ptolemy's system without introducing what he considered the absurdities of Copernicus's heliocentric theory.

It was in a Latin treatise on the comet of 1577, published in 1588, that the Tychonic system was announced. Tycho could not conceive of a moving earth because of disagreement with literal reading of Scripture and also because, confident of the accuracy of his observations, he could not account for his failure to detect a change in the apparent position of a fixed star—a change which would seem to occur as the position of an observer standing on earth actually would change if the earth moved. Tycho could not comprehend a universe so vast that the distance of the stars would be too great for the motion of earth to be noticeable by comparison. For this failing he, who had no telescope, certainly may be forgiven; actual observation of the displacement he was looking for occurred only after ever more powerful tele-

SCIENCE IN BOOKS

Exploding Stars and Evolution



—*Doug Anderson.*

LET us inquire what would happen if one of the stars nearest to the sun were to explode as a supernova. The optical effect of such an outburst would be very striking, although not of a catastrophic character. For several days there would blaze forth in our sky an object of stellar magnitude −15 or even −20. After some hundreds or thousands of years a shock wave would pass through the solar system—the gaseous envelope of the supernova. We may readily satisfy ourselves that during this event our solar system would experience no palpable physical or dynamical changes.

Far more important is the fact that in the course of a few thousand years the solar system would have found itself in a region where the density of cosmic rays was tens, possibly even hundreds, of times as great as it is now. This could have most serious genetic consequences for a wide variety of species. For some species, these consequences might well be catastrophic; but for others the irradiation might be of little effect, or even favorable.

Given the frequency with which supernovae appear in the galaxy and the mean number of relativistic particles formed in such an outburst, we may estimate the probability that the solar system will enter a region of excess cosmic-ray density. It turns out that every few hundred million years the sun must find itself, for some tens of thousands of years, in a region where the cosmic-ray density exceeds the present density by a factor of a score or two.

In other words, over the span of its evolution our solar system has repeatedly passed through radio nebulae, the remnants of supernova explosions.

Who knows whether this might not be the explanation for such paleontological phenomena as the wholesale extinction of the reptiles at the close of the Cretaceous Period, or the exceptionally luxuriant growth of vegetation in the Carboniferous Period!

Indeed, the rise of life itself on the earth may have been stimulated by a prolonged, powerful irradiation of primeval organic molecules, not yet living.

At any rate, paleontology today must take into account, along with other basic factors which have governed the evolution of life on the earth, such an extremely vital genetic factor as the general level of hard radiation. Radio astronomy can provide an estimate, although a crude one, of the magnitude of the variation in this factor over the geological history of the earth.

—I. S. Shklovsky
in *Cosmic Radio Waves*,
translated by Richard B. Rodman
and Carlos M. Varsavsky,
(Harvard U. Press, $12.50)

scopes had been developed for two and a quarter centuries.

Nevertheless, the comet of 1577 undoubtedly had traveled across the supposed crystalline spheres. And the Ptolemaic system of cosmology did not locate the planets where Brahe's observations were finding them to be. So Ptolemy had to be abandoned.

In the Tychonic system, a stationary earth was the center of revolution for the moon and for the sun. The sun, in turn, was the center of motion for the five then known planets and carried them along in its journey around the earth. The comet, too, traveled around the sun, but in an ovoid, not a circular path.

Although awkward, the system was mathematically as useful as the Copernican and later, like the Copernican, proved able to account for certain telescopic observations which Tycho could not have anticipated, such as those of the phases of Venus (due to the motion of Venus around the sun). So the Tychonic system offered a welcome alternative to the many persons who were dissatisfied with the systems of antiquity but could not accept a moving earth.

Tycho, on his island, carried on a correspondence with scholars scattered over Europe and acted like a clearing house for information on techniques of observing, on observational data, new books and new ideas. It can almost be said that he played the role now played by scientific societies through the publication of their journals. In the seventeenth century his instruments were copied in Islam and his system was made known there. He brought glory to his native land.

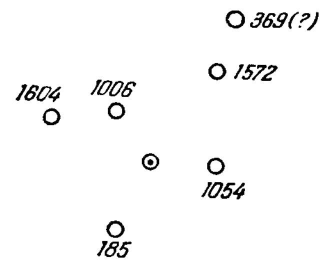
Brahe was haughty, however, and heedless of the welfare of his tenants on Hveen. After some twenty years of observing on his island, Tycho left Denmark in disagreement with his sovereign. For a short time he wandered in Europe, then settled in Prague in 1599 as imperial mathematician to the Hapsburg emperor, Rudolph II. Tycho subsequently moved to a castle near that capital. It was there, in 1601, about a year after the arrival of a young new assistant, Johannes Kepler, that the famed Danish observer died.

Tycho had envisioned himself not only as a completely accurate observer but also as a builder of a cosmology which would replace those of antiquity. This latter he was not. But his observations, which began in earnest with the new star of 1572, were sufficiently accurate so that when they fell into the hands of his new assistant, they formed the basis for computations which revolutionized astronomy and ultimately destroyed the doctrine of the immutability of the heavens with its sharp distinction between terrestrial and celestial phenomena.

Johannes Kepler, the great theoretician and mathematician, was born just one year before the 1572 nova appeared. When he was six years old, his mother took him to a hilltop to show him the comet of 1577. Four years after he joined Tycho Brahe in Prague, he witnessed the flaring and declining of another nova.

These events helped to shape Kepler's view that the heavens were subject to change as was the region beneath the moon. Since the Copernican theory was not only simpler but more straightforward than Tycho's theory, Kepler accepted Copernicus and, ironically, used Brahe's data to make the Copernican hypothesis acceptable to others.

Starting with the 2,000-year-old doctrine that all heavenly motion had to be circular, Kepler tried to fit Tycho's observations of the positions of the planet Mars into a circle. When Kepler thought he had succeeded, he came out with a discrepancy of eight minutes of arc. Finally, Kepler was forced to decide whether Tycho's observations had been inaccurate or whether the ancient doctrine of circularity was wrong. Faith in Tycho brought the conclusion that the orbit of Mars, rather than being circular, was an ellipse. After the earth's orbit also proved elliptical, the sun-



—*Cosmic Radio Waves.*

"NEW STAR OF 1572," once considered rare, has enough companions scattered around the sun (indicated above by circled period) to convince statisticians that supernovae probably appear at thirty-to-sixty year intervals.

Supernovae have advanced science by:

1) helping to determine existence of galaxies other than our own Milky Way;

2) providing comparative means for studying the sun's atmosphere;

3) providing means of studying faint atmosphere of the moon.

centered system of Copernicus worked with classical elegance.

As long as the crystalline spheres survived, they provided the mover that moved the planets. Once the spheres were discarded to explain novae and comets, it became necessary to find a cause for planetary motion. For Kepler this cause was a propelling force which rested in the sun and pushed the planets around. They moved so much the quicker the nearer they were to the sun. He had some realization of gravity but did not clearly apply its force as scientists do today; nonetheless, his suggestion marks the beginning of celestial dynamics.

Kepler's famous Italian contemporary, Galileo Galilei, devoted a long section of his *Dialogue on the Two Chief Systems of the World* to the supra-lunar position of the nova of 1572. By pointing a new Dutch invention, the telescope, at the sky, Galileo discovered four satellites of Jupiter, little bodies moving around a larger body, not the earth, in the manner in which Copernicus had assumed the planets traveled around the sun. Galileo also saw the phases of Venus and the mountains on the moon. Even more important in the context being considered here, he investigated the motion of projectiles and the laws of falling bodies—the laws of uniformly accelerated motion. Bodies in motion continue to move in the same direction and at the same speed unless acted upon by an outside force. He pointed to the need to find a force which kept the planets in their orbits.

Later in the seventeenth century, Sir Isaac Newton synthesized the work of Kepler, Galileo, and others, formulated the three laws of motion, demonstrated that gravity is the force governing motion of the planets, and, along with Leibnitz, introduced the calculus, a new mathematics capable of solving problems of varying velocity.

Scientific revolutions, unlike political ones, are not sudden upheavals. Tycho was a great man and his work had a tremendous impact, even if it did not encompass a reform of astronomy in the terms he had envisioned. What startled him and his contemporaries was the possibility of generation or change (and it would not have mattered which) in the supposedly immutable heavens. They were shaken by the subsequent breakdown of the traditional distinction between the terrestrial and celestial regions.

In the very earliest reports of the observations of the nova of 1572, many of them made while the star was still visible, its position beyond the supposed sphere of the moon had not only been stated but also appreciated in terms of the effect this had on the doctrine of the heavenly immutability. It is evident that even without Tycho the break with Aristotelian tradition would have been made, although it might have remained only a crack for a much longer time.

Tycho does not lose stature by this because the consistent excellence of his observations after 1572 formed the cornerstone for Kepler's dynamics. Had Tycho's observations been less accurate than they were, Kepler could not have discovered the planet laws. Had the observations been more accurate, Kepler would have been kept from discovering the laws by variations for which he would not have been able to account. The observations were of just the right degree of accuracy and they were made at just the right time.

The star of 1572 was a big explosion, not only physically but also intellectually. Modern astronomers call it "Tycho's star," and recognize it as a supernova—not a new star at all but an old one that reached a stage of its evolution where nuclear instabilities caused it to collapse and throw off practically all of its remaining energy in one enormous burst. Though invisible except to the strongest optical telescopes of today, whatever is left in the neighborhood once occupied by "Tycho's star" is still radiating at long wavelengths detectable by radio-telescopes. And just as the matter from this exploding star continues to spread out in space, so the ideas it set off in the minds of its sixteenth century observers have continued to expand for generations.

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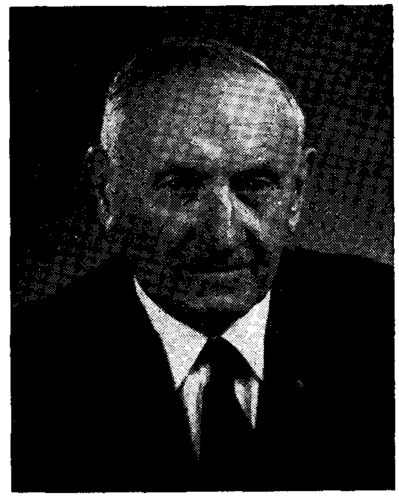
PERSONALITY PORTRAIT—XCVI

THE CHIEF WATCHMAN

Dr. Fritz Zwicky



—*Caltech.*

ON THE THEORY that it takes one to find one, Dr. Fritz Zwicky, Professor of Astrophysics at California Institute of Technology and a member of the staff of the astronomical observatories on Mount Wilson and Palomar Mountain, is splendidly qualified for his present post—planet earth's head watchman for supernovae.

For supernovae are highly explosive and controversial objects.

And few scientists are more explosive and controversial than Professor Zwicky.

"He goes off on tangents," some of his colleagues say, and "He's a most stubborn man."

Then there is the opposite opinion: "He sticks to his ideas. He's genuine."

And finally this third view: "I think Fritz Zwicky is a very normal man for an astronomer."

Whatever reaction Professor Zwicky's ideas provoke, no one who knows him doubts that the ideas are his own. He has been spinning them off in a steady stream since he came to the United States from his native Switzerland forty years ago. Trained as a physicist, with special interest in crystals and gases, he arrived in California as a research fellow of the International Education Board (Rockefeller Foundation) at a moment when physics was transforming astronomy.

Under the old tradition begun by Galileo Galilei in 1609, observers of the skies actually sat up nights looking through the lenses of telescopes. Old-timers were resisting the new trend, which called for cameras to be attached to the lenses in order to obtain a permanent record. The Rockefeller Foundation was financing a 200-inch reflecting telescope (best for concentrating light for pictures) on Palomar with the intention of completing the change from passive looking to scientific laboratory analysis of photographic plates.

"Although the Carnegie Institution had worked out a pilot plant on Mount Wilson, and the telescope on Palomar would have to be operated in connection with it, the Rockefeller Foundation gave the money for the big new telescope to Caltech," Professor Zwicky recalls. "So a few of us in the Caltech physics lab were moved over to apply physical principles to astronomy."

One of the first principles that came to Professor Zwicky's mind was the principle of mutual attraction. It governed both electrical and gravitational forces. From it he reasoned that "there must be in the universe many compact bodies."

In the spring of 1934, in a report he co-authored with the late Dr. Walter Baade, Professor Zwicky drew the first clear-cut professional distinction between common nova (stars which flare and dim repeatedly) and supernovae. Supernovae, the report said, blew off considerable mass and could leave a pure neutron core.

The neutron star concept has gained increasing acceptance as the years have passed (see pages 44-45). Wherever the Professor's iron-gray head appears, towering above his powerfully shouldered six-foot frame, ears begin to strain for sound of new pronouncements.

If he talks (as he has) of pushing the planets around and knocking pieces off them to serve as vacation spots for the harassed (as an Alpine climber his notions of safety are somewhat unconventional), listeners have learned to wait for less imaginative treatment of the situation. On jet propulsion, underwater as well as in and above the atmosphere, the patents he holds make anything he says worth hearing. On the search for supernovae, his word is final.

Professor Zwicky has studied 4,000 galaxies, found scores of explosion fragments. Since 1961, he has chaired a committee of the International Astronomical Union which coordinates a continuous patrol of the sky by telescopes in twelve observatories: four in Russia; one each in Italy, Switzerland, Mexico, Argentina, France, Belgium; Kitt Peak in Arizona, and Palomar. —WILL JONATHAN.