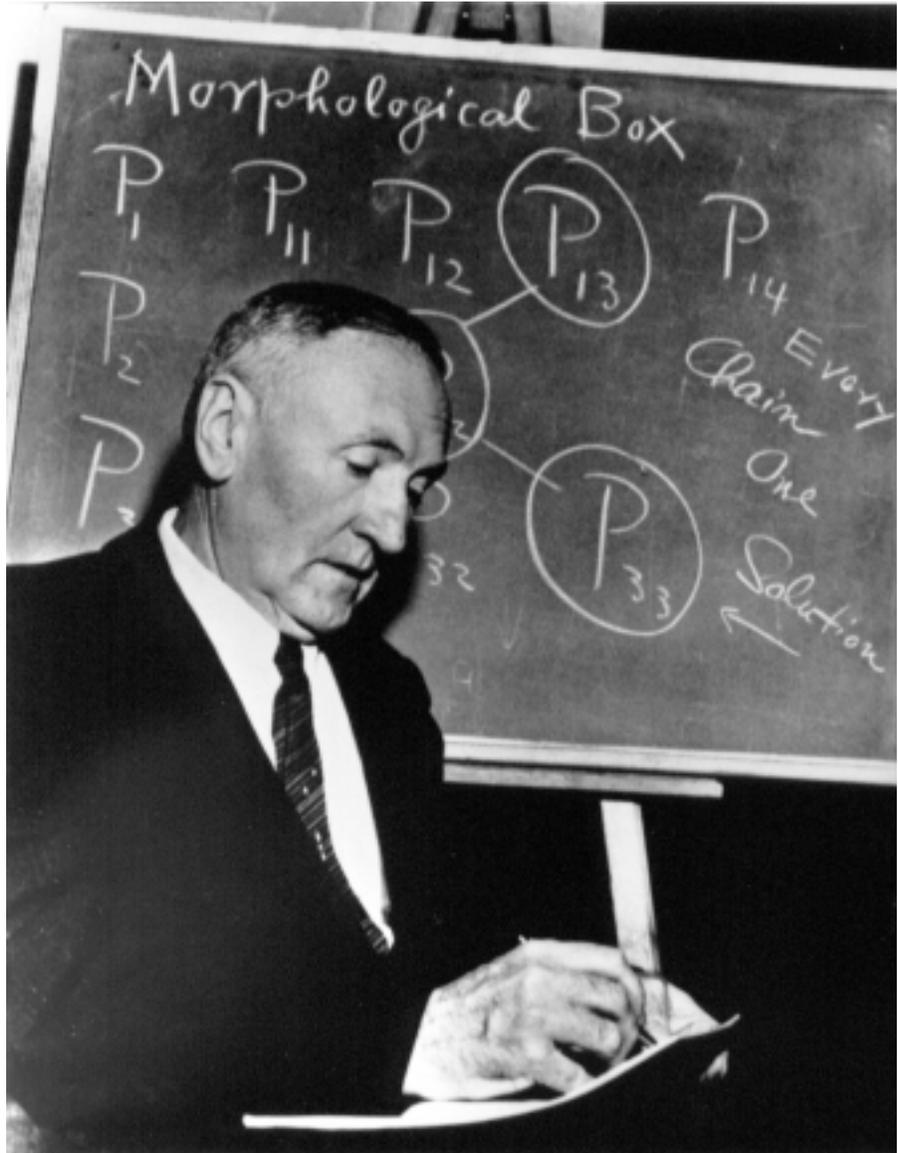


by STEPHEN M. MAURER

IDEAMAN

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Astronomical Society of the Pacific

WHEN FRITZ ZWICKY DIED IN 1974, he was remembered as a gifted observational astronomer who had discovered more supernovae than everyone else in human history combined. Today, Zwicky's reputation is bigger than ever, except that now astronomers think of him as a theorist. When researchers talk about neutron stars, dark matter, and gravitational lenses, they all start the same way: Zwicky noticed this problem in the 1930s. Back then, nobody listened . . .”

Fritz Zwicky was born in Bulgaria in 1898 but went to live with his grandparents in Switzerland at age six. In 1916, he enrolled in Zurich's Swiss Federal Institute of Technology to study mathematics, engineering, and physics. With World War I raging, Switzerland provided a haven for many of Europe's greatest minds. Zwicky met Albert Einstein, Wolfgang Pauli, and Vladimir Lenin. After graduation, Zwicky stayed on to pursue a degree in theoretical physics. His thesis applied the new science of quantum mechanics to crystals. He received his doctorate in 1922.

In 1925, the Rockefeller Foundation eager to bring quantum mechanics to the United States—gave Zwicky a fellowship. A lifelong skier and mountain climber, Zwicky asked the Foundation to send him where there are mountains. "Trying to comply, the Foundation sent him to the California Institute of Technology. Zwicky grumbled that Pasadena only had foothills." Nevertheless, Caltech was a happy choice. At nearby Mt. Wilson, Edwin Hubble was working on his famous redshift relation. Zwicky began thinking about astronomy. When his fellowship ended, Caltech hired Zwicky as a professor.

ZWICKY BEGAN collaborating with a fellow German-speaker named Walter Baade in 1931. Astronomers knew that certain stars flared abruptly from time to time. Although most of these "novae" were close to the Earth, Baade noticed that a few old records described novae inside galaxies. During the 1920s, astronomers at Mt. Wilson had shown that galaxies

were immensely distant. In order to be seen at all, Baade and Zwicky realized that these "super-novae" had to be enormously bright (100 million times brighter than the Sun). They announced their discovery at an American Physical Society meeting in late 1933.

Not content with this empirical result, Baade and Zwicky added two key theoretical insights. First, they connected supernovae to the mysterious high altitude particles known as cosmic rays. Unfortunately, their evidence which was limited to the "surprisingly good agreement" in energy between the two phenomena—remained circumstantial. Although Zwicky spent much of the 1930s trying to explain how particles heated inside an exploding supernova could escape into space, he admitted that his results fell well short of what was needed. The correct answer was found in 1949, when Enrico Fermi realized that shock waves hitting interstellar gas could produce cosmic rays outside the supernova itself.

Second, Baade and Zwicky tried to explain how such titanic explosions could occur at all. Then as now, any reasonable theory had to involve gravitational collapse. However, a simple calculation showed that the collapsing progenitor star had to free-fall over enormous distances in order to liberate enough energy. Unless the supernova remnant was unbelievably small (and dense) the process would stop too soon. By the early 1930s, quantum calculations had shown that the required densities could not be met by any form of matter that contained electrons.

The breakthrough came when English physicist James Chadwick

Previous page: Fritz Zwicky invented a technique called morphology in order to think more efficiently. He is pictured here in the 1950s doing just that.

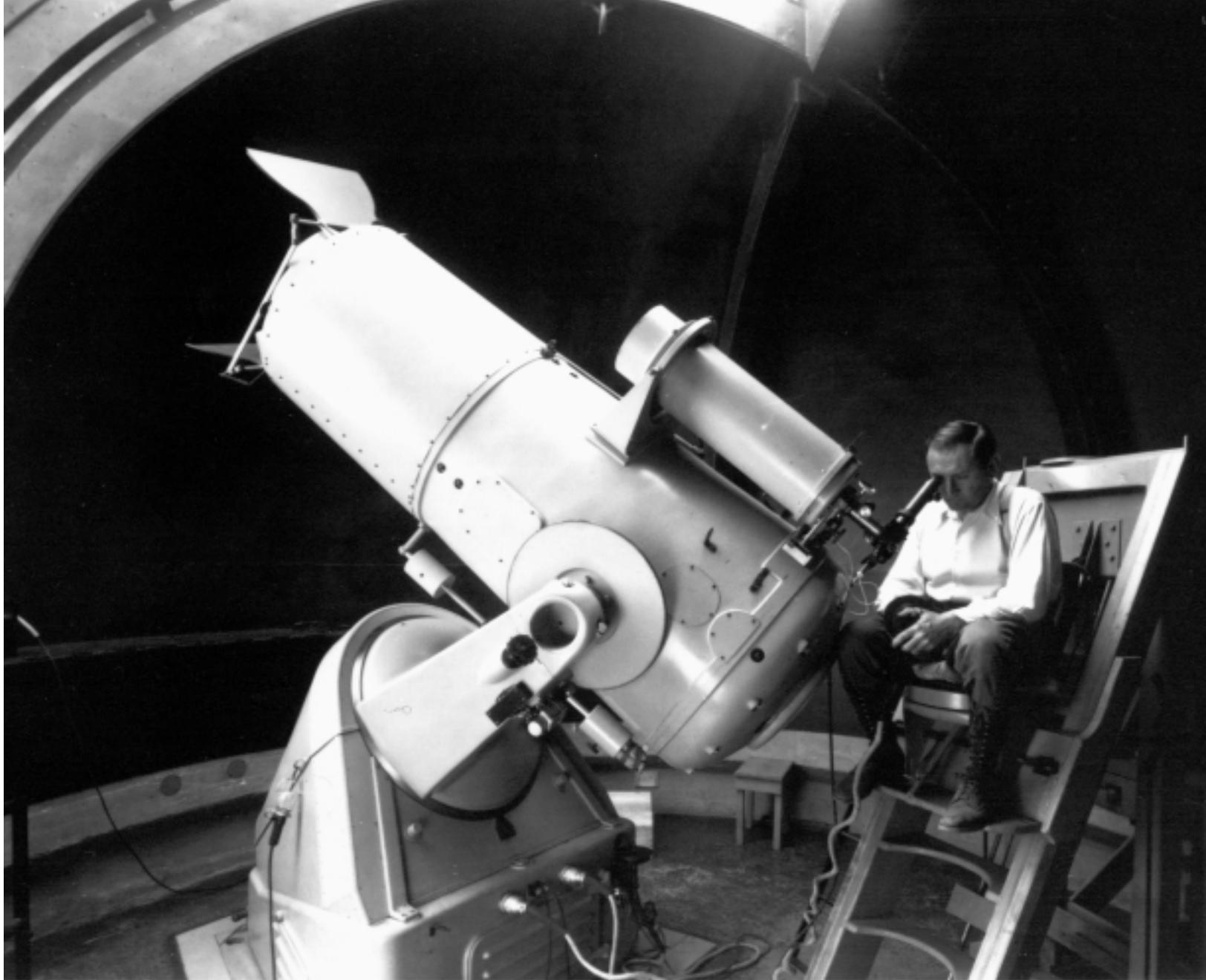
Opposite: Fritz Zwicky at the Mt. Wilson 24-in. telescope in approximately the late 1930s. (Courtesy of the Archives, California Institute of Technology)

discovered the neutron in 1932. Suppose that the star's electrons and protons could be turned into neutrons? "With all reserve," Baade and Zwicky wrote in March 1934,

"...we advance the view that a super-nova represents the transition of an ordinary star into a neutron star, consisting mainly of neutrons. Such a star may possess a very small radius and an extremely high density. As neutrons can be packed much more closely than ordinary nuclei and electrons, the gravitational packing energy in a cold neutron star may become very large, and, under certain circumstances, may far exceed the ordinary nuclear packing fractions. A neutron star would therefore represent the most stable configuration of matter as such."

Zwicky spent the next forty years pointing out that this comment had checked out in all essential aspects." However, it was largely ignored until Robert Oppenheimer and George Volkoff worked out the detailed physics of stellar collapse in 1939 without mentioning Zwicky's research. Even then, final confirmation had to wait until radio astronomers discovered the extraordinarily dense objects called "pulsars" in 1967.

IN ORDER TO LEARN more, Baade and Zwicky had to discover new supernovae. However, the chance of finding a supernova in any given galaxy was small, and conventional telescopes could only examine a few galaxies at a time. Fortunately, Baade had heard of a special telescope that could capture huge numbers of galaxies in a single, wide-angle photograph. Zwicky persuaded



Caltech to build an 18-inch Schmidt camera” in 1936. Zwicky used this instrument for the rest of his life, finding 129 supernovae in all. Beyond their intrinsic interest, Zwicky believed that supernovae would eventually allow us to survey the universe to distances of billions of light years. “That dream is only now coming true. (See ‘The Fate of the Universe’ by Gerson Goldhaber and Judith Goldhaber in the Fall 1997 *Beam Line*, Vol. 27, No. 3.)

Zwicky’s supernova search had an unexpected spinoff. Conventional telescopes had shown that a few

nearly galaxies were part of larger clusters. Now, Zwicky used the Schmidt to find new and more distant examples. These observations proved that clusters were the rule and not the exception.

ASTRONOMERS HAD already measured velocities for most of the galaxies inside Zwicky’s clusters. In 1937, Zwicky used astronomy’s “virial theorem” to infer the clusters’ masses from these data. (The virial theorem says that the total mass of a group of orbiting bodies can be

estimated from the velocity of its components. This is because, all else being equal, bodies in more massive systems must travel faster in order to resist the increased pull of gravity.) This led to a paradox. Based on data from the Milky Way, Zwicky should have been able to guess each cluster’s mass from its observed brightness. This estimate turned out to be 500 times too small. Had Nature hidden the extra mass in a second, unseen component? Zwicky dubbed the substance “dark matter.”

Most astronomers ignored Zwicky’s result, much as Zwicky himself had

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ignored an earlier paper by Johannes Kapetyn and Sir James Jeans on the ground that stellar motions inside the Milky Way were too complicated to interpret. Undaunted, Zwicky spent most of the next two decades conducting searches for previously overlooked gas and dust. In 1950, this dim object search uncovered starry bridges between galaxies, which Zwicky correctly attributed to near-collisions. Later searches found pygmy stars within the Milky Way and faint blue stars that were actually distant galaxies. Today we know that the latter objects are closely related to quasars.

Beginning in 1974, cosmologists began to rediscover the arguments for dark matter. Today, it is one of astronomy's hottest research topics.

THE IDEA that massive bodies can act as lenses goes back to the eighteenth century and received its most famous formulation in Albert Einstein's 1916 General Theory of Relativity. In 1935, a Czechoslovakian engineer named R. W. Mandl wrote to Einstein suggesting that nearby stars could act as gravitational lenses by bending light from more distant objects. (The physicist Oliver Lodge had made a similar suggestion in 1919.) Initially intrigued, Einstein soon became discouraged after calculating that the lensed image would almost certainly be overwhelmed by glare from the foreground star.

Meanwhile, word of Mandl's ideas had reached Zwicky. Zwicky realized that foreground glare could be overcome if searchers used galaxies instead of stars. In 1937, Zwicky published three articles predicting

that lensed galaxies would not only be amplified, but also bent into a distinctive ring. For the rest of his life, Zwicky begged astronomers to search for lensed galaxies. Finding even one lens, he insisted, could test general relativity; deliver light from unprecedented distances; and give astronomers a new way to detect dark matter. These are the same reasons that astronomers give for studying lensed galaxies today.

Zwicky was so confident of his prediction that he sometimes wondered why lensing hadn't been noticed already. In fact, the first gravitational lens was found five years after Zwicky's death.

ZWICKY WAS NEVER shy about describing himself as a romantic figure out of the Renaissance or lone wolf genius. In fact, he invented a technique (morphology) which supposedly allowed practically anyone to think one hundred times more efficiently. Zwicky credited the technique for most of his insights.

Naturally to hear Zwicky tell it genius was persecuted. Friends say that Zwicky could explain his ideas patiently and was given to boisterous laughter. This did not stop him from railing against astronomy's self-interested cliques and high priests. One of his favorite jokes was to call enemies spherical bastards (spherical, he explained, because they still looked like bastards from every possible angle). Zwicky even convinced himself that Baade had stolen his ideas. The famously gentle Baade was afraid that Zwicky might try to kill him.

DURING WORLD WAR II, the U.S. Army needed rockets to get heavily-loaded bombers airborne. Caltech aerodynamicist Theodore von Karman founded a corporation called Aerojet and won the contract. In 1943, Aerojet asked Zwicky to run its research department. At War's end, Zwicky toured secret weapons programs in Germany and Japan. Later, he helped Aerojet develop many of the high-energy fuels used in today's solid rocket boosters.

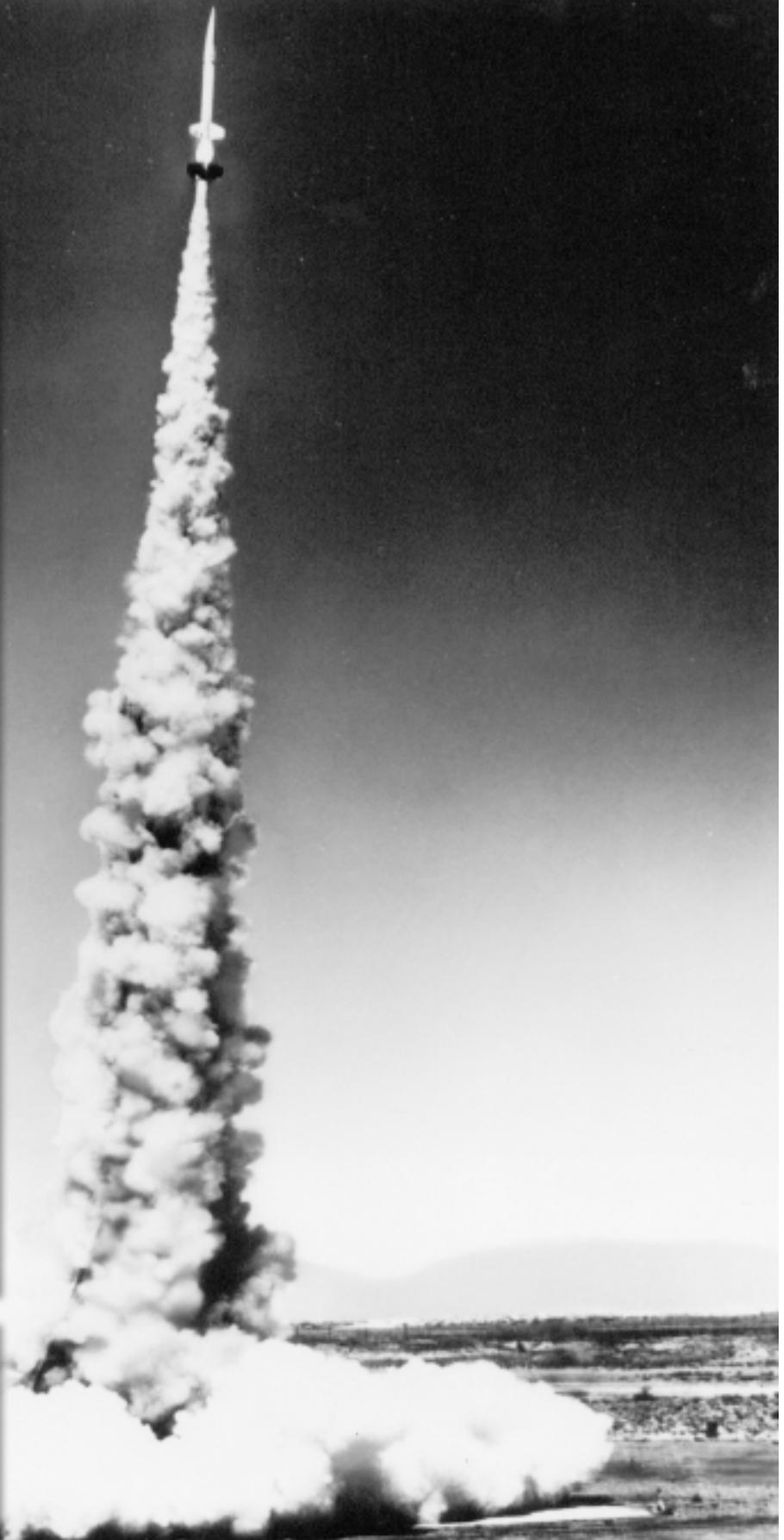
Corporate life did not improve Zwicky's people skills. Once, Zwicky met a visiting delegation (including two admirals) at the plant gate and ordered them to leave. To hear Zwicky tell it, they were a bunch of unqualified civilians who had somehow wangled commissions. Aerojet old-timers also claim that Zwicky liked to win arguments with his fists. But he was a small guy, they usually add, so it wasn't hard to pull him off.

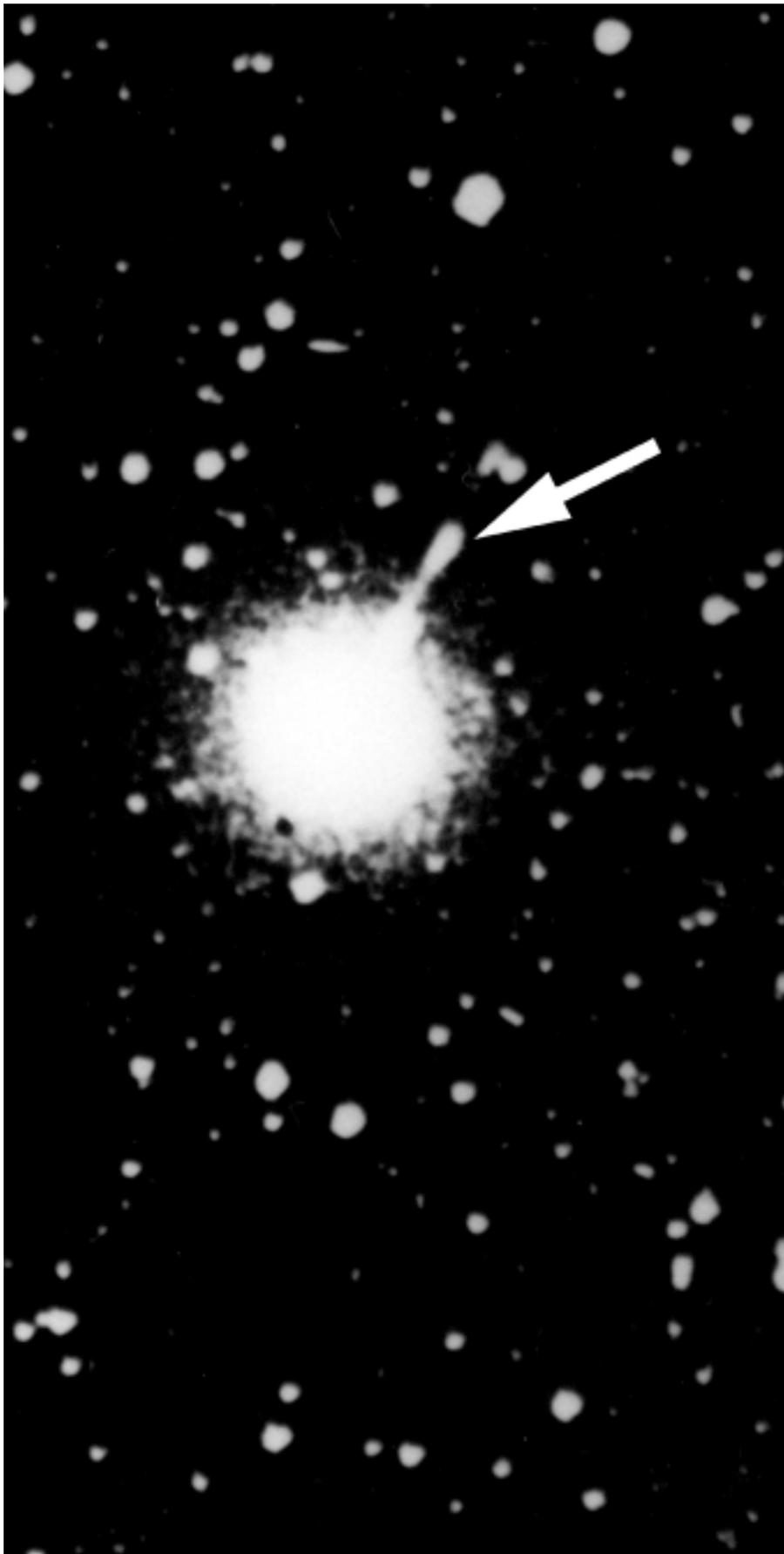
During the Second World War, the government gave Zwicky a security

clearance even though he had never taken out American citizenship. In 1955, the exception was revoked. Zwicky, who was intensely proud of being Swiss, decided to leave Aerojet rather than change his nationality. Besides, he told people, the U.S. Constitution does not allow naturalized Americans to become president. Why accept "second-class citizenship?"

SHORTLY AFTER THE War, Zwicky used his Aerojet connections to place an experiment aboard a captured V-2 rocket. Zwicky wanted to use shaped charges similar to the explosives used in Army bazookas to generate jets of liquid metal traveling at up to seven miles per second. Earthbound observatories could then photograph these "artificial meteors" to learn about natural meteors, atmospheric structure, and orbital reentry physics. Later experiments would have been more ambitious. Zwicky wanted to study flash and dust on the Moon and even return samples to Earth. Data from artificial meteor experiments also would have helped the U.S. to track shock waves from airplanes flying over Siberia. In 1999, the U.S. revived Zwicky's idea by crashing its Clementine satellite into the Moon. Earthbound observatories searched for water vapor, but saw none.

The Aerobee was America's first rocket to probe outer space. Here, a launch in the mid-1950s is shown, similar to the one that detonated Fritz Zwicky's explosives above the New Mexican desert. (Courtesy Aerojet, Sacramento, California)





In 1957, Fritz Zwicky used high explosives atop an Aerobee rocket to blast jets of metal into space. Tracking cameras proved that at least one jet escaped Earth (arrow) and became the first man-made object to achieve its own independent orbit around the Sun. (Courtesy AP/Wide World Photos)

Zwicky's V-2 flew on December 18, 1946. The *New York Times* called the experiment "a symbolic milestone in man's exploration of the universe" which might "open the secrets of travel between the planets." But while the rocket behaved flawlessly, observatories and amateur astronomers saw nothing. Zwicky believed that the charges had ~~fizzed~~ and asked for a second chance.

The Army said "no" and went on saying "no" until Sputnik was launched in 1957. Twelve days later, an Aerojet Aerobee rocket detonated three shaped charges 54 miles above the New Mexican desert. (This time, Zwicky installed the explosives himself.) Three jets were observed as far away as Mt. Palomar. Tracking cameras confirmed that at least one centimeter-sized projectile had become the first man-made object to escape the Earth and enter a separate orbit around the Sun.

ZWICKY HAD criticized President Harry Truman for dropping the atomic bomb on Japan. Now he brooded that scientists' inventions have gotten completely out of hand. "I myself," Zwicky said, "can think of a dozen ways to annihilate all living persons within one hour." Zwicky even claimed (mistakenly) that future weapons or misguided fusion experiments could reduce the Earth to a miniature neutron star.

Zwicky's dreams were usually less gloomy. During the war, Zwicky had patented an air-breathing pulse jet "similar to Germany's V-1 buzz bomb. Why stop there? By the late 1940s, Aerojet was testing a

hydropulse"engine that burned" water (using sodium fuel) to make steam. And if water could burn, why not rock? Zwicky dreamed of the day when terrajets"would burn minerals (using fluorine) in order to spit out jets of lava and gas. Zwicky claimed that the technology could dig tunnels and colonize the planets. Military versions could attack straight through the earth.

Terrajets were only the start. Eventually, atomic power could hollow out the moon, give it an atmosphere, or even move it elsewhere. And if mankind needed living space—for example, to separate its warring ideologies—the giant planets could be shattered into convenient, earth-sized pieces. Finally, future engineers could fire particle beams at the Sun to create a fusion-powered hot spot. This would generate enough thrust to move the whole solar system to Alpha Centauri in just 2,500 years.

FRITZ ZWICKY HATED the idea that galaxies were rushing apart because it implied a starting point, that is, that the Universe was young. He therefore called Hubble's redshifts "indicative" or "symbolic."* But if the Universe was not expanding, why was distant

light redshifted? Zwicky offered three answers. First, Einstein's laws implied that photons passing a star would first gain and then lose energy. Zwicky argued that the first effect was slightly larger, producing gravitational drag. "Second, small overlooked terms in Maxwell's equations and quantum mechanics might allow light to become "fired" after billions of years. Finally, the physical laws themselves might have changed: Why shouldn't light emitted billions of years ago be redder than it is today?

Strangely, the man who had shown that most galaxies reside in clusters refused to admit that "super clusters" (clusters of clusters) existed. This led to a series of acrimonious debates with astronomer George Abell during the 1950s. Zwicky even claimed that the absence of superclusters showed that gravity stopped working beyond 60 million light years or so thereby invalidating General Relativity and the Big Bang. According to Zwicky, a graviton "weighing 10^{-64} grams explained" the effect quite nicely.

Finally, Zwicky concocted a wild theory in which chunks of neutron matter (goblins) orbited deep inside massive stars. Goblins were ordinarily invulnerable, since a 10-meter (10^{29} ton) object would cut through the star like tissue paper. Occasionally, however, a close encounter between two goblins would boost one of them to a higher orbit. No longer stabilized by the star's high pressure core, the unlucky goblin would explode producing flare stars and gamma-ray bursts.

BELIEVING that educated people owe a debt to society, Zwicky organized a program after World War II that collected and shipped 15 tons of scientific journals to war-damaged libraries around the world. He also directed an organization that supported orphanages.

Charity reinforced Zwicky's contempt for the "inhuman and idiotic treatment" of native peoples under colonialism. "We are not likely to succeed in unifying the world," he warned, "as long as the Americans and the British, or for that matter any other people, feel and act as if they are better and superior to all others."

ZWICKY BECAME professor emeritus in 1968. Thereafter, he traveled extensively and opened a second home near Berne, Switzerland. Friends thought that he wanted to become a member of the Swiss Parliament. He died six days before his seventy-sixth birthday, on February 8, 1974. He was buried in Switzerland.

Zwicky often joked that he wanted to live to be 102, since hardly anyone gets to live in three centuries. He would have enjoyed his current reputation. In the final analysis, though, Zwicky probably didn't care whether people believed his ideas or not. Zwicky knew. That was enough.



**In 1939, Zwicky "proved" that the Universe had to be much older than Hubble's law implied. Many clusters, he argued, were beautifully spherical. But the laws of physics said that an initially chaotic group of galaxies could only become symmetrical through a series of close encounters among three or more galaxies. Since such encounters were fantastically rare, the Universe had to be at least 10^{18} years old.*