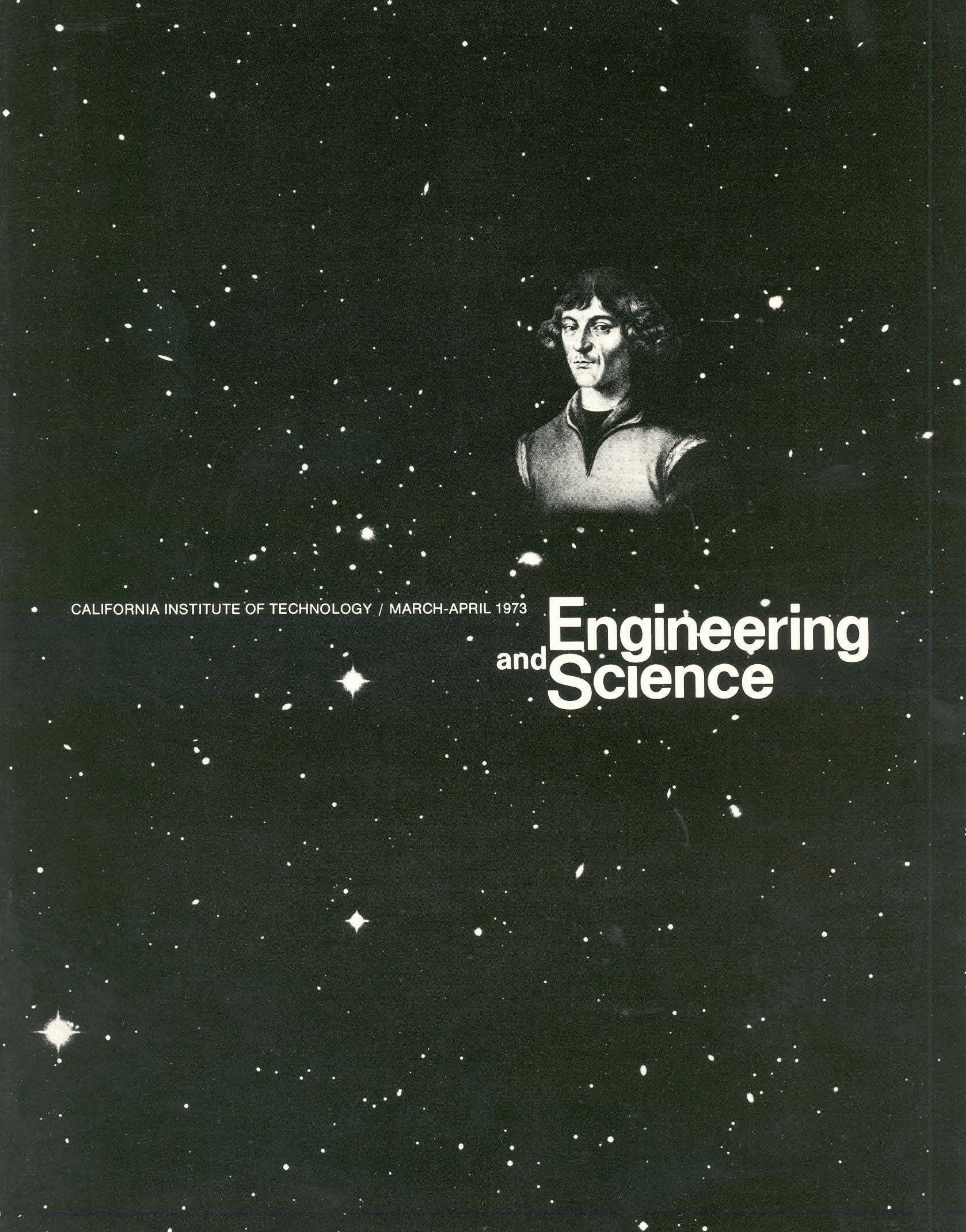
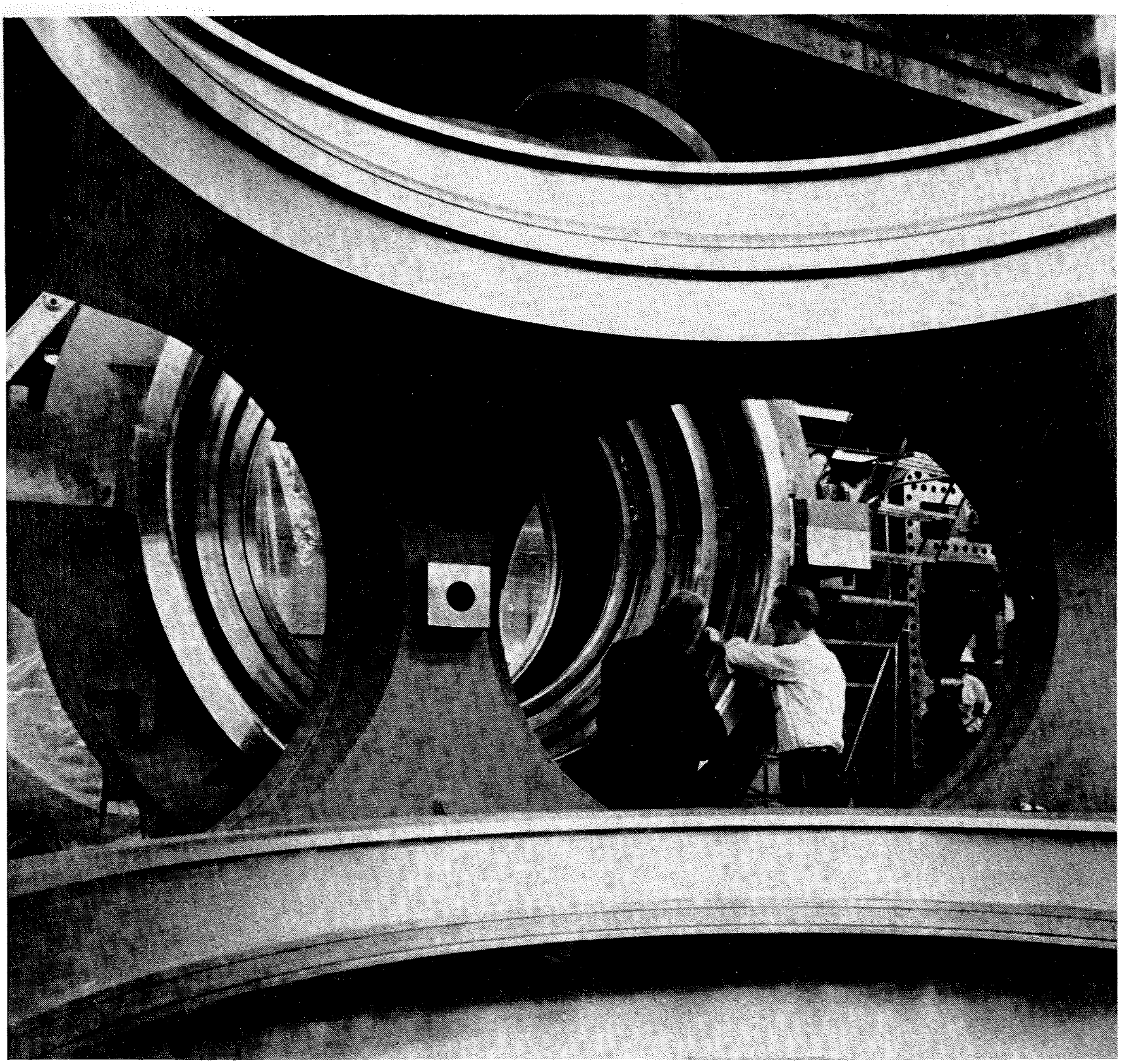


CALIFORNIA INSTITUTE OF TECHNOLOGY / MARCH-APRIL 1973

Engineering and Science



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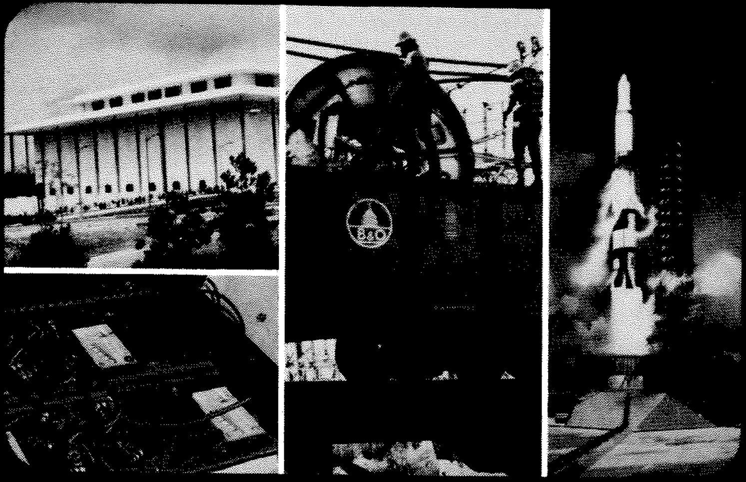

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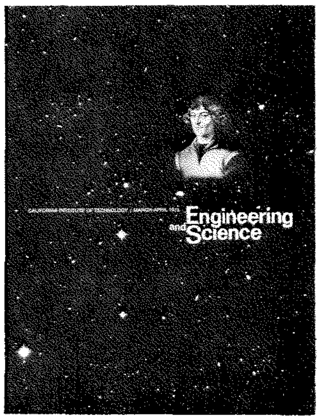

Pioneering Astronomy

On the cover—Nicolaus Copernicus and the Coma Berenices Cluster of galaxies make a particularly appropriate combination. Copernicus, the founder of modern science, changed man's understanding of the broad geography of the universe—and gave him a more realistic picture of his own place in it. This pioneering contribution to knowledge was so vast and so revolutionary that the word "Copernican" has been used to describe the astronomical scheme of things ever since.

But pioneering isn't over. In the last 50 years, astronomers—with the late Edwin Hubble of the Hale Observatories leading the way—have taken another giant leap in their grasp of the nature of the cosmos. In "Opening the Last Frontier" (page 4), Allan Sandage, staff member of the Hale Observatories, traces the unfolding of Hubble's discovery that galaxies exist, that they map the structure of the cosmos, and that they trace its history backward nearly to the creation event. And he points out that more recent developments in astronomy open up the questions of creation, origin, and evolution to the exploration of science.

Allan Sandage is a Caltech alumnus (PhD'53) and has been a member of the observatories' staff since 1952. His own trailblazing in astronomy, noted in the citation for the National Medal of Science that he was awarded in 1971, was "for bringing the very limits of the universe within reach of man's awareness and unraveling the evolution of stars and galaxies—their origins and ages, distances and destinies."

Dinner Address

Herman Wouk came to Caltech on March 6 to speak at the annual dinner of The Associates of the California Institute of Technology. Mr. Wouk has been a member of The Associates himself since 1971, and "Science —at the Leading Edge of Hope" (page 11) is adapted from his talk to his fellow members. His interest in science, and in Caltech, has been fostered by his brother Victor, who is also an Associate and a Caltech alumnus (MS'40, PhD'42).

Born in New York City in 1915, Wouk graduated from Columbia University in 1934. He began his writing career as a scriptwriter for Fred Allen and based his first novel, *Aurora Dawn*, on this experience.

In June 1941 Wouk went to Washington as a dollar-a-year man writing radio scripts for Treasury bond sales. After December 7, he joined the Navy and spent three years as a line officer on destroyer-minesweepers in the Pacific theater. He used this background in *The Caine Mutiny*, which won the Pulitzer Prize in 1952, stayed on the best-seller list for a year, and went on to become a successful play and movie as well.

Wouk's latest book, *The Winds of War*, is a panoramic historical novel about World War II that took him seven years to write. It even involved moving to Washington, D.C., from his home in St. Thomas in the Virgin Islands to be closer to research sources. The book has been a great success, and Wouk is now writing a sequel.

Step Two

After the crew of Apollo 17 completed man's on-the-spot exploration of the moon in December, many a puzzled layman needed a recapitulation of what each, and all, of those missions had contributed to scientific understanding—of the moon, of the earth, and of the solar system. In a Watson Lecture at Beckman Auditorium on February 12, Leon Silver, professor of geology, went a long way toward putting it all together. "The End of Exploration—and the Beginning of Science" (page 14) is adapted from that talk.

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OPENING THE LAST FRONTIER

Discovery of galaxies, the expansion of the universe, and the edge of the world

by Allan Sandage

After 60 centuries of speculation, man discovered the nature of the universe on its largest scale between 1923 and 1934. Proof that galaxies exist, that they may map the structure of the cosmos and trace its history from the present moment backward nearly to the creation event came from observations made with the large telescopes on Mount Wilson in the first third of the century. The work was concerned with the most ancient of inquiries about the universe as a whole. It opened the way for scientists to enter and explore the previously audacious questions of first origins and evolution.

What made this possible was Edwin Hubble's remarkable discovery that space itself is moving in a pattern of uniform expansion, carrying the galaxies with it. The regularity of the motion is what permits the past to be read. Astronomers, using the methods of science, were able to enter the domain held previously by metaphysics and even less substantially by speculation, and this revolutionary accomplishment changed all thought that followed. It had the same audacity and clarity as the revolution of Copernicus—and later of Kepler, Newton, and Einstein—in changing long-held views about the universe itself.

The development began with Hubble's final proof in 1923 that galaxies exist. It continued through his remarkable discovery of the systematic motion of all galaxies away from each other in 1929, and most importantly through his proof of the homogeneity of the galaxy distribution in 1934. These three fundamental ideas, combined with more recent proofs that stars in our Galaxy are of different ages and can be dated, that other galaxies are no older, that there is an oldest age, and that this age is almost the same as that inferred from the expansion motion, have put astronomy into its present period of extraordinary ferment. The root questions of *creation*, *origin*, and *evolution* are the central theme.

The Discovery of Galaxies

The time was early 1917. The place, the 60-inch reflector, then the largest in the world, at the isolated Mount Wilson Observatory in California. George Ritchey, chief optician at the observatory, was the man responsible for bringing the 60- and 100-inch telescope mirrors to the extraordinarily precise curves needed for the telescopes to work. He was also a fine observer and photographer.

After 1909, Ritchey and other members of the observatory staff regularly photographed white nebulous objects with spiral forms whose nature was then totally unknown. These faint nebulous regions of light, cataloged extensively by the Herschels between 1786 and 1864 (though they were known even before that), were curious objects because they avoided the central plane of the Milky Way. However, they appeared in large numbers near the galactic poles. Were they isolated "island universes" as discussed by such visionaries as Emmanuel Swedenborg, Immanuel Kant, and Thomas Wright, or were they connected with the local system of stars in our very immediate neighborhood?

On July 19, 1917, Ritchey took a photograph of the nebula NGC 6946 using the 60-inch reflector with an exposure of 4 hours 25 minutes. Comparing his plate with an earlier one, Ritchey discovered a new starlike image on the later exposure that was absent on the first. The situation and its consequence were not unlike the discovery and its implication for Tycho Brahe of the new star of 1572, which showed that the heavens themselves were subject to change.

Ritchey verified that the image was real, and the result suggested to him that a new star—a nova—had appeared in a white nebula. (Novae and supernovae are stars that have exploded, either in a minor fashion in a nova with a remnant left for further activity, or exploded "completely" in a supernova where the remnant changes fundamentally,

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This year marks the 500th anniversary of the birth of Copernicus and the 50th anniversary of Hubble's discovery of galaxies. This article is a condensation of an essay written for this year's Copernicus celebration.

either into a neutron star—pulsar—or perhaps a "black hole." In either case, the "new star" soon disappears from photographs.) Was it actually a nova, and if so, did it say something about the distance? Yes, and the discovery began the chain of events that finally proved the existence of galaxies in 1923.

Aware of the importance of his discovery, Ritchey searched the plate files of Mount Wilson and found that two new starlike images had appeared and had faded in the Great Nebula in Andromeda (NGC 224) in 1909, which showed that such objects occurred regularly in nebulae.

Heber D. Curtis, a perspicacious man trained as a classical scholar and destined to be a principal player in the drama of finding the universe, then searched old plates at the Lick Observatory taken with the Crossley 36-inch reflector. He discovered another nova in the nebula NGC 4227 and added two more in NGC 4321. From the six new objects known in 1917, Curtis was able to discuss the island universe hypothesis for the white nebulae, as contrasted to Harlow Shapley's belief that a *single* stellar system contained all visible astronomical objects. Curtis cautiously stated that the presence of novae favored the extragalactic nature of the white nebulae.

Shapley disagreed. Both men presented various arguments, which reveal about as much of the state of stellar astronomy in 1920 as they do about the disagreement itself. None of the arguments constituted a direct proof, and the disagreement settled into a peaceful stalemate in the absence of decisive new observations.

As late as 1922 there was still no agreement among astronomers as to whether galaxies existed. Shapley, indeed, had shown earlier that the galactic system was probably finite and that its center was in Sagittarius some 30,000 light years distant, but he did not make the necessary generalization outward to the galaxies.

Hubble did. He heeded the signs, made new observations, and discovered the universe.

Cataloging the Galaxies

Galaxies are always referred to by M or NGC numbers. These designations came from two catalogs: one prepared by the comet-seeking French astronomer Charles Messier and published in three installments between 1774 and 1784 by the Paris Academy; the other was compiled by J. L. E. Dryer in 1888, published by the Royal Astronomical Society, and called the *New General Catalogue.*

The brightest galaxies have Messier (M) numbers, but there are only about 100 objects set out in his three lists. Messier compiled this useful tabulation only as an aid for his principal activity of comet hunting, and, since nebulae resemble comets in the eyepiece of a telescope, Messier could keep track of the unwanted stationary nebulae during these searches.

The much more extensive NGC catalog grew out of the major search for diverse astronomical objects conducted from both hemispheres by the Herschels, father and son. The first major survey was that of Sir William Herschel (1738-1822) who systematically observed the northern sky from England with telescopes of his own design and manufacture beginning in the 1780's, long before the invention of photography.

Herschel, a professional musician in his early years and later the first president of the Royal Astronomical Society and the private astronomer to King George III, was a most industrious observer and one of the great figures in the history of astronomy. Herschel presented a copy of the preliminary catalog of 1,000 nebulae and clusters to the Royal Society in 1786; this was followed in 1789 by a second edition containing 1,000 additional entries, and in 1802 by a third list of 500 nebulae, all found by visual methods.

John Herschel continued the work by taking his father's telescopes to Capetown, South Africa, where he finished *The General Catalogue of Nebulae* in 1864. The list contains 5,079 objects, of which 4,630 were discovered by the two Herschels and 449 by others. This catalog is of enormous historical interest and forms the base upon which the *New General Catalogue*, used today, was published by Dreyer in 1888. All bright galaxies are known by their NGC numbers.

Hubble's discovery had the same audacity and clarity as the revolution of Copernicus in changing long-held views about the universe

John C. Duncan, professor of astronomy at Wellesley College in Massachusetts from 1916 to 1950, came west nearly every summer to help with the observing at Mount Wilson. He soon became an expert in astrophotography and was regularly assigned summer time on the Mount Wilson reflectors. In the summer of 1920 Duncan took a series of plates of M33 with the newly completed Hooker 100-inch telescope. By comparing the plates, he found three variable stars, presumably related to the nebula itself.


Edwin Hubble

At the same time, Hubble, following up Ritchey's continuing discoveries of novae, had been keeping M31 under surveillance. An object marked by him as a nova on a 100-inch plate taken on October 5, 1923, was, within weeks, found to be a periodic variable star—the first recognized Cepheid type in a white nebula. Further, one of Duncan's three variables later proved to be a Cepheid. Within a very few months, Hubble had located many similar periodic variables in the large nebulae NGC 6822, M33, and M31. On January 1, 1925, in a paper read in his absence to the American Association for the Advancement of Science in Washington, D.C., he publicly announced that Cepheid variables were present in white nebulae. And, because Hubble had found the characteristic relation between the period of the light variation and the luminosity of these special variables, it was clear that the distances to the parent nebulae were large, that they were clearly outside our own Milky Way, and that they were systems of stars similar in every way to our own Galaxy.

Important as this discovery was, the true Copernican aspect of the work came only later when Hubble showed in 1931 and 1934 that galaxies were the principal constituents of the large-scale structure of the universe itself. The demonstration was made by counting galaxies to successive limits of distance and showing that they are distributed in depth in a generally homogeneous and isotropic manner to the limit of the largest telescopes, providing that sufficiently large volumes are surveyed. The concept has not been seriously challenged since that time. Hubble's conclusions were strongly verified by independent work by Nicholas Mayall at Lick Observatory in 1934, and later by others. There are no indications that galaxies and their clusterings are themselves only subunits of a still higher ordering. Galaxies and their clusters appear to represent the markers in space that define the large-scale features of the cosmos.

Hubble, by this demonstration, breached the last frontier and found the universe itself. The change of thought brought about by these revelations was of the same kind as the Copernican message of 1543. A previously deeply held view of the nature and content of astronomical space was shown to be incorrect, and a large segment of truth was revealed by the new work.

The Expansion of the Universe

Remarkable as these researches were, they were but a prelude to further revelations in an area new to science—an area that had been the province of speculators, philosophers, and mystics for 6,000 years—*creation* and *eschatology*. The story did not begin in a classical astronomical environment, but rather was first foretold as a curious theoretical possibility shortly after the appearance of Einstein's gravitational theory in 1916. The details are too complex to describe completely, but the circumstances can be understood without them.

The general theory of relativity is a description of gravitational forces by the effect of mass on the shape of space and time. The presence of mass distorts the flatness of space-time, and this, in turn, controls the motion of particles placed near the mass.

In 1916 static or nonchanging solutions were sought for the Einstein equations that connect space, time, and energy because it was then believed that no large-scale systematic motions existed among astronomical objects. Three static solutions were in fact found. Two of them described ordinary geometry where the space and the time coordinates of an event agreed more or less with intuition. But the third, discovered by the Dutch astronomer Willem de Sitter, was scandalous. The measure of time depended on the position in space, meaning that time intervals were longer the further a clock was from an observer (us). Distant objects such as galaxies might be expected to exhibit an apparent redshift in the color of their light because all of their atoms, which are clocks, would have appeared to slow down. De Sitter predicted that distant galaxies should have large redshifts.

The de Sitter effect does *not* represent a true expansion of space where the distance between galaxies actually changes with time, but before the discovery of the true expansion effect in the Einstein equations in 1922 by Alexander Friedmann, and by George Lemaitre in 1927, many astronomers looked for the de Sitter effect in the astronomical data.

In 1925 no observer knew, or at least understood, the dynamical solutions of Friedmann and Lemaitre in which space itself is in a state of uniform motion compatible with Einstein's equations—a motion that enlarges all distances to galaxies at a velocity proportional to their distance from any given observer.

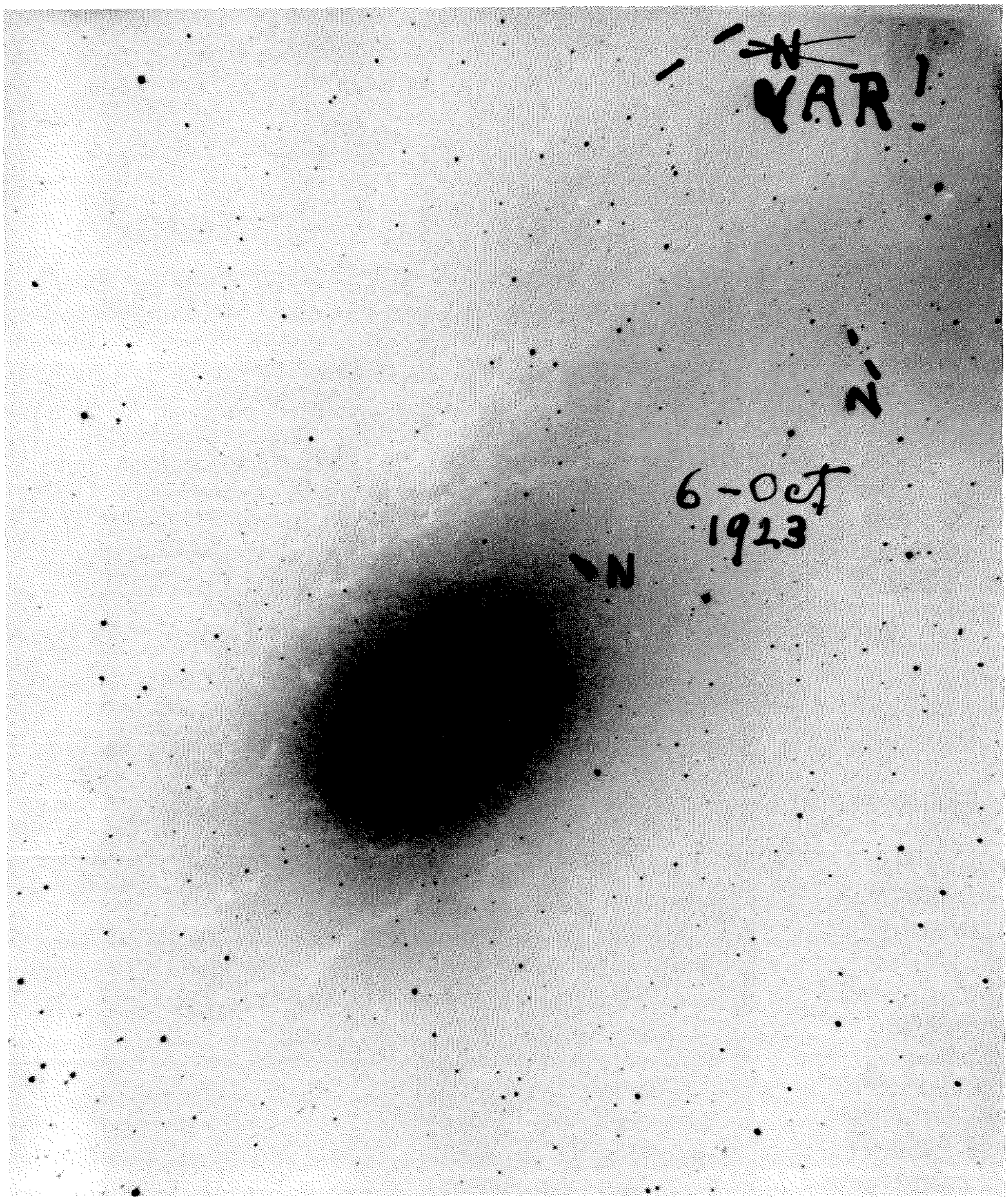
Hubble's remarkable discovery in 1929 that the universe

Allan Sandage

The redshift-distance effect is the vehicle by which we can travel backward into history

expands came only after inconclusive discussions in 1925 and 1926. It was based on new redshift observations of Milton Humason at Mount Wilson that could be added to the older material of Vesto Slipher of the Lowell Observatory in Arizona. But most importantly, Hubble's solution used his own improved data on the distances to galaxies. A linear relation between velocity and distance was announced by Hubble in 1929, with a tentative conclusion that the effect might be that predicted by de Sitter.

Events then proceeded very rapidly, both in and out of the Mount Wilson Observatory in the early months of 1930. Sir Arthur Eddington and George McVittie had rediscovered the literature papers of Friedmann and Lemaitre that gave genuine nonstatic solutions of a real expansion; de Sitter had acknowledged that these, rather than his curious static solution, apparently represented the true physical situation; and Hubble and Humason had quickly made new observations of velocities of very



Edwin Hubble's final proof that galaxies exist appears on a historic photograph taken with the 100-inch telescope on Mount Wilson. On October 6, 1923, Hubble marked with an N what he thought was a nova in the Great Nebula in Andromeda. He crossed the mark out a few weeks later when the object proved to be a periodic variable star —the first Cepheid type to be found in a white nebula. Using this star, then several other Cepheids, as measuring rods. Hubble found that the nebula was nearly a million light years away, far outside our own Milky Way, and was a system of stars similar in every way to our own Galaxy.

distant galaxies, with results that showed again the linear velocity-distance effect. From observations made at Palomar as late as 1972, Hubble's law is known to apply at redshifts that correspond to at least 1/3 the speed of light.

The Journey Backward Toward Creation

The incredible significance of the discovery is simply this: Interpreted in terms of the Friedmann-Lemaitre solutions of the Einstein equations, the data require that the universe is an *evolving* thing. It changes with time in a highly regular way. The observed linear velocity-distance relation is the only form of the motion in which the universe can remain similar to itself always, while changing its scale. It is also the only pattern that admits a creation event in the datable past. The fact that the observed form of the law has these properties leads us naturally to suppose that there was a time when the universe was totally different than it is now—that it was, in some sense, created.

The theory in its simplest form requires mutual distances between galaxies to increase with time. The distances were smaller in the past, and were exceedingly small at a particular instant (called the Friedmann singula time) when all space was together. Were the distances, in fact, ever so small as to lead one to believe that all energy, and hence all matter, came out of the Friedmann singularity to begin the expansion?

Some astronomers believe the evidence for change and aging in the universe that leads to this conclusion is overwhelming. Others are not yet convinced. Despite the debate, what *is* clear is that the existence of the redshift-distance effect among galaxies is one of the most profound facts in natural science.

The effect is general for all galaxies. It is the same in all directions. It is the vehicle by which we can travel backward into history. The regular motion, once mapped and calibrated, gives the time when the cosmos began as light, and hence turned into everything we now observe.

The expansion of the universe, through its possible connection with the earliest events in the world, has naturally dominated thinking about universal evolution during the past 25 years. It enormously stimulated the search for other evidence of systematic change and evolution of astronomical bodies.

A new development began along these lines in the 1940's with the realization that stars themselves have a finite life; the oldest of them live and die on time scales that are about the same as the expansion age. The discovery in the mid-1950's that there is an oldest age to stars in our Galaxy, and that this age is closely the same as the Friedmann time itself, was not only crucial to the case for an evolving universe (the big bang), but it opened the way to find the clues as to how our Galaxy formed at its own birthday.

The *oldest* stars were found to move in highly elliptical orbits about the center of our Galaxy rather than in nearly circular orbits like the younger stars such as the sun. The in-and-out plunging motion of these first-formed galactic stars betrays the early motions of matter in the Milky Way at the time of *its* formation, and shows that our stellar system perhaps formed by collapse of interstellar gas toward the galactic center about a Friedmann time (13 billion years) ago.

The important generalization of these results is the revolutionary change in thought and attitude forced by the discoveries. The universe has not always been the way it looks today; and the lights are either going out all over the world as the expansion proceeds or, if the expansion should stop and contraction start, a new cycle could begin.

The Edge of the World

What Hubble did in 1925, in 1929, and again in 1934 was to open the last frontier by his discovery of galaxies, of their generally homogeneous distribution, and the expansion of the universe. The boundary of this frontier clearly can never be reached, either because the universe is infinite, or—if finite—is unbounded, like the surface of a sphere.

However, in a real sense there must be an observational boundary due to the finite speed of light. We look back in time as we look out in space. If the universe has indeed evolved from an earlier time when galaxies did not exist, and if we could look back to that time by looking far enough away, the galaxies beyond a certain distance would not appear on photographic plates. They did not exist before the time of first-galaxy formation. If this edge of the world, given by the time horizon, could be found, it would be a unique proof for a big-bang universe.

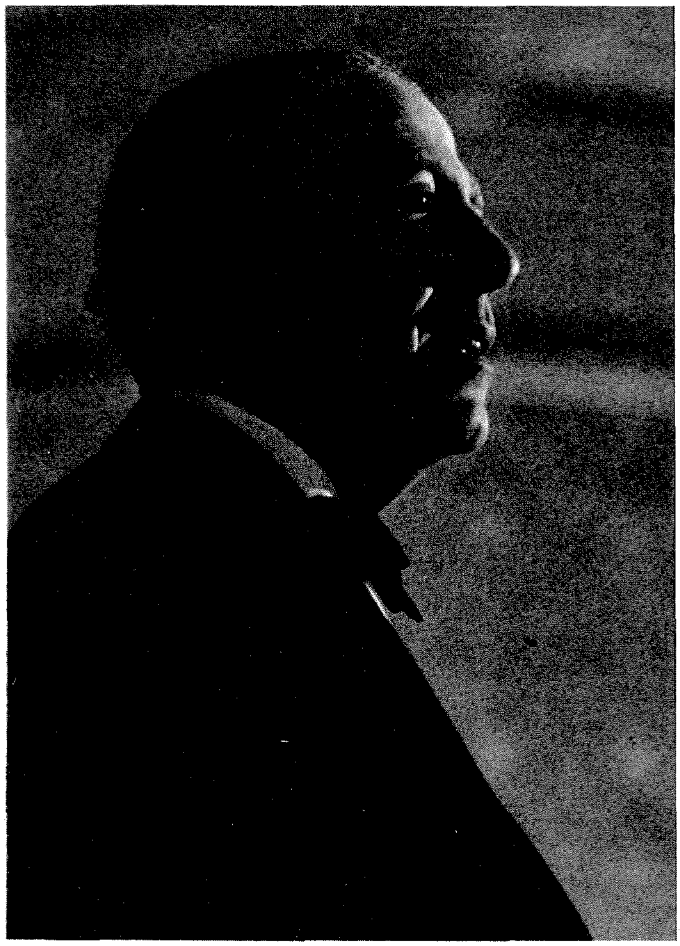
Can we see this far? Yes. Have astronomers already done so? Perhaps. Quasars are the nuclei of some galaxies that, for unknown reasons, generate enormous amounts of energy by some semi-explosive process. They are luminous enough to be seen at distances so large that light left them when the universe was only 10 percent of its present age. Said differently, with quasars we see the conditions in the cosmos as they were close to creation.

Now the curiosity of this almost unbelievable situation is even more startling. Quasars have been found with all redshifts up to a certain critical *limiting* value. None are known with larger velocities, although they should have been observed if they existed. The upper redshift limit corresponds to a look-back-time of about 12 billion years—only about a billion years short of the Friedmann creation event.

Does the absence of larger redshifts mean that the time horizon has been breached, and that we look back further than the time of first-galaxy formation? If so, we are now observing not only a matter-horizon in space, but the edge of the universe of galaxies in *time* as well. That we can, in principle, see the edge of the world is amazing. That we may have done so already would be unique. Observations planned for Palomar during the next few years are expected to illuminate this possibility.

Science—at the Leading Edge of Hope

by Herman Wouk



"Science—at the Leading Edge of Hope" has been adapted from an extemporaneous talk given by Herman Wouk, author of **The Caine Mutiny** and **The Winds of War**, at the annual dinner of The Associates of the California Institute of Technology on March 6.

When I was invited to address the Caltech Associates, a strange and rare feeling came over me—modesty. I think very well of my novels, but I had some trouble with high school physics; and except as a subscriber to the *Scientific American*, my scientific knowledge since then has not expanded a great deal. When, therefore, I was invited to address this august group, C. P. Snow's famous essay on the two cultures came to my mind. Well, I thought, here is a prime example of that gulf that has opened between two modes of thinking and looking at the world. I went back and read it—read it quite carefully.

It's a classic description, of course, of the truth that people in the humanities—where I count myself—in literature and the arts, in political and economic thought, have moved off into one direction of looking at the world; while the technicians, the theoretical physicists, the engineers, and the applied research people, have moved so far in another direction that there has almost grown up a difference of language between the two communities. C. P. Snow was, I believe, rightly concerned about the deleterious effect on the future of the human race, which—under the pressure of the Industrial Revolution—needs much working together of these very different groups.

I then groped around for some profound additional insights on this question of the different languages these two different groups of humanity spoke, but all I could think of was the story of the mouse who got into a cupboard—a female mouse with her three babies. They found a marvelous cheddar cheese and were feasting royally off it when into the open door of the cupboard there sprang the house cat—humped, bristling, and glaring. There was no way out of the cupboard past that cat. Step by step the cat advanced toward the mice. Suddenly the mother mouse reared back and went, "Woof! Woof! Woof!" The cat turned and sprang out of the cupboard. The mother turned to the baby mice and said, "Now, children, you see the advantage of having a second language."

Somehow or other I've been thinking a lot about my old, wonderful boss, Fred Allen. He brought me here to California on my first visit in 1937 as part of his staff. Few of us New York-based lads and girls had ever been to the West Coast before, and we expressed great excitement. And Fred, in an answer that has since become quite well known, said, "California is a great place—if you're an orange." This sounds like a prejudiced remark, but it really is not. Toward places west of the Hudson, Fred had no prejudices. He hated them all equally. I remember one evening just before the performance he looked around at a studio that was filling up with an audience of somewhat unsophisticated characters, and he said, "God! It looks as though there's a slow leak in Idaho."

I have been working now for almost a decade on an immense panoramic romance comprised of two novels—

each one almost a thousand pages long. The first has been published. It's *The Winds of War*, and I'm working on the second one now. If there is any point of contact between myself and the Caltech community, I make bold—abandoning my brief pose of modesty—to say that this panoramic work is an effort to come to grips with something of the first importance in human experience; to understand it, and if possible to make that understanding available for the use of my fellow men. It's a vauntingly ambitious task, and one can ask oneself, "Why do it?" I might have written more, shorter books with much less challenge for research and the kind of labor that has gone into *The Winds of War* and will go into the sequel. It's because the Second World War was a cataclysm in human experience which we have not fathomed—in the shadow of which we still live—and the real outcome of which none of us can yet wholly foresee. You can look at it from many viewpoints, but in essence it was an intersection of old ways of doing things and a new technology which these old ways could not master. The result was an explosion that all but wrecked the future of the human race. It was a very near thing.

My novel, however, is not—as those of you who have read it know—a work of despair. Most of the novels of the Second World War—and indeed most recent fiction—are what one would call anti-hero literature. In one way or another they say that man is trapped in an absurd universe and is surrounded by a technology that has run away from him. He has no fixed stars by which to steer because all traditional values have broken down and all human structures are toppling.

This is not a new cry. It emerged in the 19th century as the opposite side of the coin, the dark romantic face of the strident optimisim of the socialists. It emerges in Nietzsche and in Schopenhauer, and it bursts into fiction with those great masters of modernism, Dostoevski (especially in the *Notes from Underground*), Proust, Kafka, and Joyce—all of them one way or another offering the anti-hero as the central figure. In the case of Proust, a nervous, sick man at least recording each detail of this phosphorescently glowing civilization as it sinks in decay. Kafka, hauntingly and everlastingly the man trapped in the world that has grown too big and too dark for him—in a social structure that is beyond penetration and fathoming, but which is slowly killing him. Joyce, in the figure of Leopold Bloom, the trivial man who is every man, struggling to keep his nose above water when religion has gone and nothing works and all the world is a ruin of cultures that are dying and disintegrating.

That, I say, is the modern note. But my book is centered on a prosaic American who most strikingly is a man of action—a senior naval officer, who gets around, gets things done. He is a doer, not a D'Artagnan nor a Don Quixote, but the kind of guy we know well—a first-class guy who is outside of the war all during my book (because it ends at Pearl Harbor) but who is very active. And with this active, moving, strong figure, one sweeps through the panorama of the years before Pearl Harbor.

Question. Why, if you are serious—and I am deadly serious—move with this figure rather than with the almost obligatory anti-hero despairing of war, as most typically in the amusing figure of Yossarian in *Catch 22*? The reason is, above all, because I have a different view of the Second World War, which has come out of my experience of it and my study of it.

In the manner of Caltech, let's strike at the fundamentals. First of all, we won. We won the war. And when I say we won, I mean it quite literally, *pace* the revisionist historians. Men of good will, by the skin of their teeth, turned back a mortal challenge to the future of the human race. Had they failed to turn it back, our world would have sunk into a night of barbarism, in a fall unmatched even by the fall of Rome. I see—in this—hope.

It is true that every means of technology was used for murder, but that is nothing new. Yesterday, I had the immense privilege of talking to half a dozen members of the distinguished Caltech faculty who took part in the great Los Alamos effort. I did this as research for the sequel that I am writing. What emerged was what I had gathered from my reading: As quickly as this hellish stuff was boiled out of the substances that would not blow up—as soon as this horrible dynamite was isolated—it was rushed out to the Pacific to be used. As one man after another said, "We did not think then about not using it. It was war and we used it—or it was used." I'm sure that the first hominid who picked up a rock, and found that he could hold it, used it to smash the skull of his nearest neighbor and took the food from his hands and ate it—if, indeed, he did not eat the spattered brains. It is not by accident that the Bible begins with one brother slaying another.

Yet each time we have gone through a cycle of history there has been painful progress, and I see in this bleak picture around us, painful progress. We have shrugged off slavery. We have shrugged off human sacrifice. We have shrugged off feudalism, and it is my glimmering faith—but my faith—that we will shrug off war. Because we must.

I think I have some grounds for that faith—not only in my study of the Second World War, or in the fact that no one marches to these small or spin-off wars singing any more—but in the things that happen at Caltech. I'm not a scientist, but I'm the brother of one; and he has reported to me the things that are happening in science, and I have tried to follow them in the popular writings.

There has been a tremendous outpouring of discovery in the last 50 years, but you need only go back as far as Tycho Brahe and Kepler to see the beginnings of this whole avalanche of discovery. In this relatively short time there has been an uncovering of dazzling, orderly wonders in the universe, the structure of matter, the motions of the heavens, the workings of light. These are stunning in their beauty and their design. Where the classic theological argument from design was knocked out of court long ago in technical philosophy, it seems to overwhelm you again—in the words of the Psalmist, "the heavens declare the glory of God"—from the discoveries of science. Order in the heavens, order in the world about us, however mysterious and ill-defined, at least suggests mind and order that may care about human fate.

If there I lose you, being a religious man, surely you will agree that there is another wonder, perhaps greater than all these, and that is the wonder of the human mind—which is measuring this vast and complex universe, seeing it, understanding it. From Jesse Greenstein at the 200-inch telescope, peering as far into the business of God and the distant reaches of the universe as any human being ever has, to Dick Feynman, battering at the subnuclear world, mankind is showing a dignity, a power, and a stature in which one can find hope.

The distinguished author Saul Bellow recently gave a speech at the Smithsonian in Washington on "The Artist in the Age of Technology." He was gloomy about the future of the arts in a technological society. It was a wonderful speech. At one point he said, "This is not a time for the singing of the nightingale." He was expressing his fear that the arts and the life of thought would be crushed by the onrush of technology, and he was pleading against this.

It's not easy to wave off the fear of technology—and indeed the risk is a real one—but I'm not sure that Snow's useful separation of the two cultures may be quite the thing. He says, himself, in a later discussion, that it's always a mistake to divide anything into two and say, "Either this or that."

Going back to my Fred Allen days, you remember Nelson Eddy, the saccharine hero of every third musical. Groucho Marx once said: "There are only two kinds of people in the world, those who hate Nelson Eddy and those who despise him." This kind of oversimplification, I need not tell you scientists, haunts every attempt to schematize and diagram things.

I think, nevertheless, that there are at least two more groups that should be added to the humanities people and the scientists. And the interaction among these four, I suggest, is vital to all our futures. There are the people of power—the men of government that I have come to know in Washington, and for whom I've acquired considerable respect. They live in the tactical and in the contingent, but it is they who take the discoveries of the men of science and somehow or other lead people in the use of them. And there are the men of industry—the producers for whom I have also acquired much-increased respect in my study of the Second World War.

I had something confirmed yesterday in my chats with the distinguished men who served at Los Alamos. They concurred in saying that the picture of the atomic bomb as the work of a few great scientists getting together, discovering something, and loosing it on the world is distorted; that, in fact, there was also a stupendous industrial effort, most characteristic of this country. It would perhaps have been better for the human race without that effort, although I doubt it. Eventually the idea would have surfaced—the idea and the dreadful fact.

Some of you in industry are here tonight. Speaking to you as an artist, I profoundly feel that these people of Caltech and the scientific community are at the leading edge of hope for the world. Because so much remains to be done. This thin film of water and air on a dead ball, this biosphere wherein we live, is threatened; and the answers to the threats must come mainly from the scientists. It will then be up to the thinkers and the artists to make, if you will, the people at large aware of what our dilemmas are and where we must have leadership. And when that awareness is widespread, the masters of the contingent and the tactical can lead people in the directions in which they must go.

I think that's why I am an Associate. I was recruited by my brother. My arm survived the twisting because I am keenly aware that, in the first instance, the future lies with those things that these men who mark paper and blackboard can teach us in the way of mastering and saving our precious little earth.

The clangor of technology is terrifying; the smoke and the murk are dense and gloomy. But these things, I believe in my deepest heart, can—with the pursuit of knowledge and excellence, with leadership, with the penetration of thought into new ways and new habits of man's governing himself, and with the support that science must have—lead us to a better day.

The contribution that I have given to Caltech in money, modest though it is, is the largest I've given to any one institution except the divinity school which is headed by my Rabbi and teacher. If I put divinity ahead of science, it is because—in back of all this—the heart of my hope is a sense that the Redeemer, masked, mysterious, and loving, is there. For me His still small voice is the voice of the nightingale. By His grace, if not we, then our grandchildren and their children may yet hear the voice of the nightingale, thanks to technology, in a peaceful garden.

A geologist's-eye-view, in layman's language, of the results of the Apollo missions and what comes next—an adaptation of a Watson Lecture.

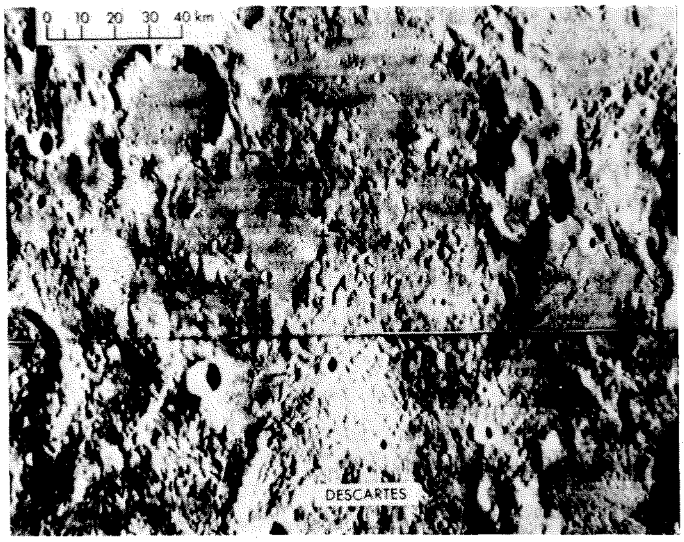
THE END OF EXPLORATION—

AND THE BEGINNING OF SCIENCE

by Leon T. Silver

Manned exploration of the moon, thrilling as it has been, represents only the opening phase of the scientific exploration of that planetary body. Scientists are now ready to begin making definitive studies of the Apollo crews' observations, photographs, lunar samples, and instrumental data. Their preliminary work indicates that important scientific yields will be the harvest of the immense effort we have put into the Apollo program.

From the beginning of the program, it was necessary for science to accommodate and adapt to the necessity of developing a technological capability to explore the moon. Although it wasn't as obvious, scientists were just as hard pressed as the builders of rockets and life-support systems to come up with adequate techniques and means to plan lunar-surface explorations, plot orbiting reconnaissance, and handle the samples. Thus, manned exploration of the moon involved some of the best and most hectic efforts of men in science, in engineering, and on the moon. But I want to emphasize that what remains to be done, now that the exploration phase of the Apollo program is over, is the main thrust of lunar science. That work—in its detail, its precision, and its depth—will go on for years.



From the earth, the moon seems to vary only between darker and lighter areas. Closer up, its variations also turn out to reflect the amount of cratering and differences in elevation. The Apollo 15 site (left) on a mare surface, though split by the sinuous Hadley Rille, is smooth by comparison with the rugged highlands near the crater Descartes (above), which was home base for Apollo 16.

Why did we want to go to the moon? As far as we could tell, it was so barren that there was nothing there to interest a man, unless he could look at it as a fascinating source of information about the universe of which it is a part. Perhaps if we came to understand how it was formed, we would be able to understand all the other planets better.

The moon is a striking example of a planet that apparently was frozen in the early stages of its development. In contrast to the variety and complexity of forces that continue to alter the face of the earth, the forces that have acted on the moon—at least for the last 3.2 billion years—have been relatively simple. This makes it possible for us to read its early record far more clearly than we can that of the earth.

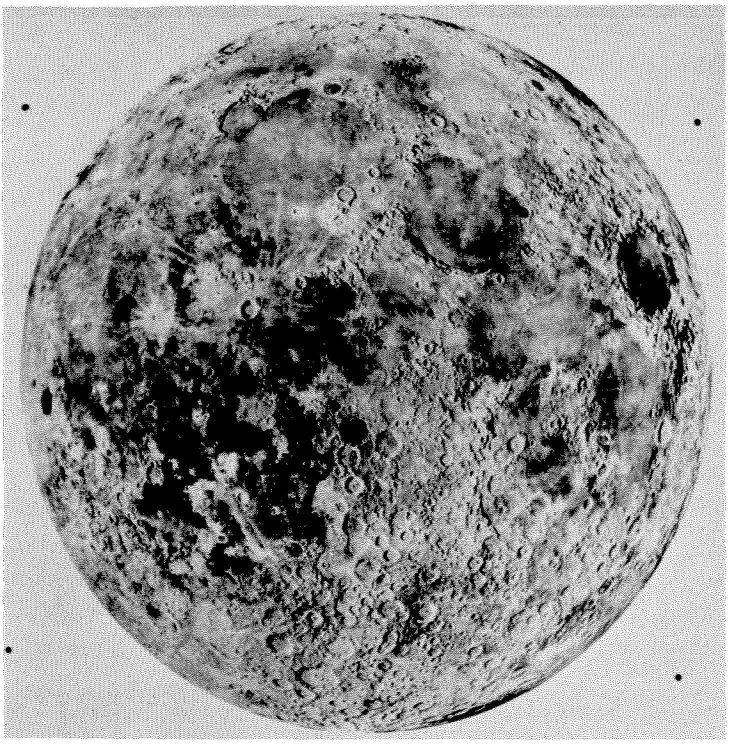
When ancient astronomers studied the moon with their primitive telescopes, they called the light-colored areas "terrae" or "highlands" and the darker ones "maria," the Latin word for "seas." We know now, of course, that there are no bodies of water on the moon, and that the highlands and the maria are quite different kinds of lands. They do have one feature in common, however: cratering. There are giant craters all over the moon's surface, and between them are somewhat smaller craters—with still smaller craters between *them*. Even the rocks are pitted with microscopic craters. We are not sure of the origin of all of these craters, but we think most of them are due to an external source of debris impacting upon the surface of the moon. And the debris ranged in size from giant asteroid-like masses of stone and iron down to very tiny charged particles, which smashed into the moon at velocities up to more than 15 miles per second. When they struck, their energy was immediately converted to surface explosions with production of intense heat, which caused the local melting that is a common phenomenon on the lunar surface.

In the last century geologists, including especially our own Gene Shoemaker, have worked out a tentative sequence for the development of the major features on the moon. Most recently—i.e., for about the last 3 billion years—the lunar surface appears to have been modified only by a sequence of cratering events, and the largest features that were formed had diameters no greater than 100-150 km. Before that, in one of the major intervals in its history, the moon went through a stage when great areas of the surface were flooded with lava, and there was even more intense cratering. Prior to this, the moon underwent its most extreme cratering. This was the formative period—at least 4.6 billion years ago—when objects that represented the initial accumulation of planetary bodies in the solar system were impacting on the lunar surface.

In order to understand the evolution of the moon, we need to know how far back in time each of these events occurred, what kinds of materials were produced, and what happened to the preexisting materials that were subjected to such enormous temperatures and pressures. In the early development of the moon, pressures exceeded anything we can reproduce in the laboratory.

When we started planning the exploration of the moon, we didn't know whether or not its whole surface was covered with a uniformly mixed layer of debris produced by billions of years of impacts. It seemed unlikely because there were obvious color differences between the maria and the terrae, but we couldn't be sure. What we have found is that each of the Apollo landing sites not only had rocky debris apparently indigenous to it but also some exotic materials whose sources we couldn't immediately identify. One of my colleagues, Gerald Wasserburg, decided after the first Apollo mission to emphasize these mysterious materials by calling them the "magic component." This turned out to be no trivial attribution; it focused our attention on something we are just now beginning to understand.

One clue to the sources of the magic component lies in the light streaks that radiate in all directions from some of the more recent huge craters. Some of these streaks can be followed all the way around the visible side of the moon. It's quite clear that the energy of the impact that created those craters was in part transferred to the impacted material—and debris was thrown clear around the moon. It has also become clear that the exotic materials may come from great distances away from any given spot.

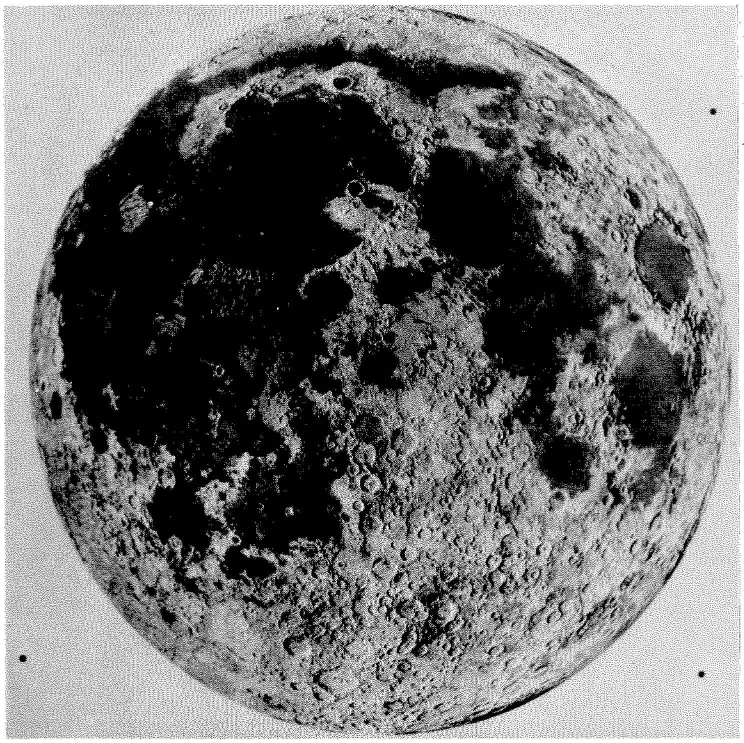


This mosaic of telescopic photographs of the moon as it looks today shows the familiar contrast between the dark maria and the lighter highlands. Slightly above the center and to the left, the giant crater Copernicus sits in the midst of rays of impact debris that radiate in all directions for hundreds of kilometers.

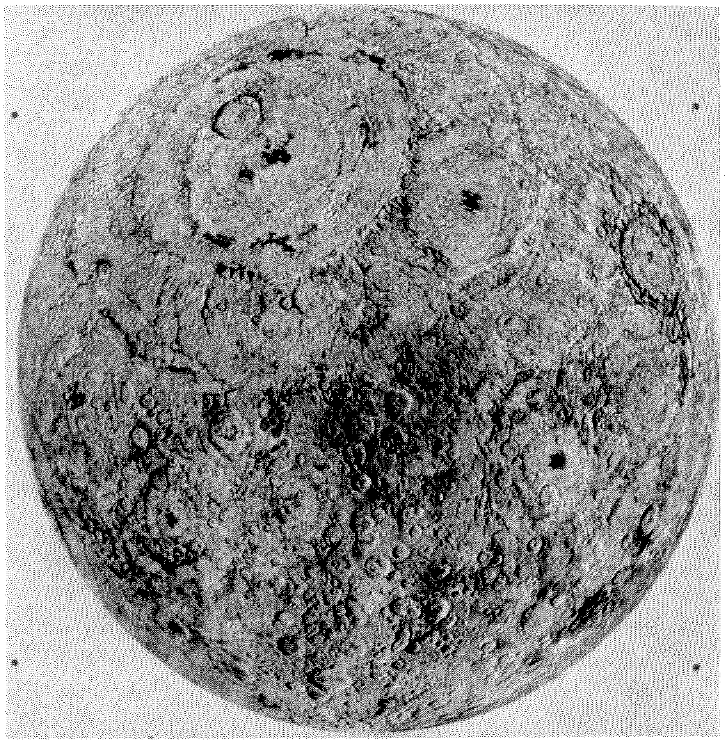
Men have now landed on the moon six times. They have explored the sites for increasing periods of time and at increasing distances from the landing modules. They have placed instruments on the moon, some of which have yielded immediate data and some of which will continue to collect and report information to earth for many years. They have given verbal accounts of their observations, and they have backed these up with photographs of everything from dust to panoramas. And they have collected and brought back to earth about 850 pounds of samples from the moon for earthbound scientists to analyze and build hypotheses from. The amount of material from any one of the missions is staggering; from all of them it is mountainous and will take years to understand.

Each of the Apollo missions answered some questions and created many more. It was only three and a half years ago that Apollo 11 landed at Mare Tranquilitatis. Astronauts Neil Armstrong and Buzz Aldrin found there a debris-strewn surface—a mixture of rocks, pebbles, sand grains, and dust. Pieces of ancient lava shocked us when we studied them, because they turned out to be at least 3.7 billion years old. No rock we knew of in the crust of the earth was that old. So, we immediately had to apply a different time perspective to the moon than we did to the earth.

The constituent minerals in one of these rocks are similar to minerals that we have on earth, but the ranges in composition are greater, and the rock has ten times as much titanium as comparable terrestrial rocks. This told



This is an artist's reconstruction of the lunar surface as it appeared about 3.3 billion years ago. Most of the mare material has been accumulated, but the "young" craters like Copernicus have not yet appeared. The maria look darker than they do today because such craters excavated the underlying light-colored material.

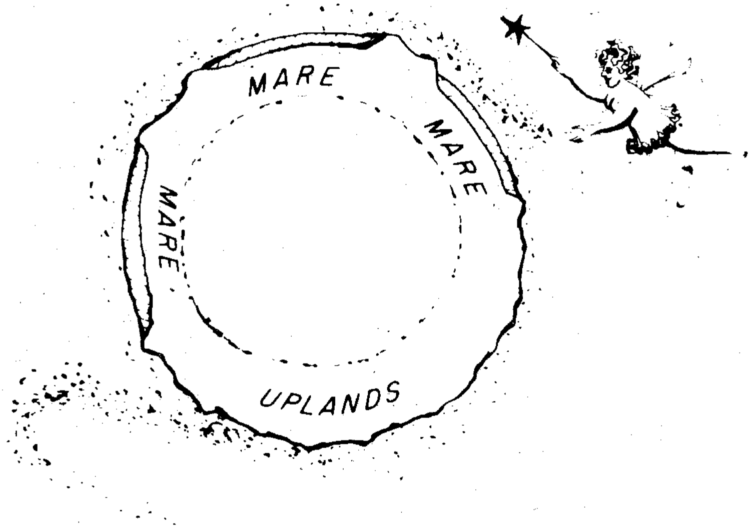


Around 4 billion years ago, the moon probably looked about like this. The great multiringed mare basins were formed—chief among them, at the top left, the giant Imbrium basin. Iridum, the sharply outlined crater perched on one of Imbrium's rings, was partly buried by later lava flooding and deposits of debris, but is still visible today.

us that the rocks had grown, cooled, and crystallized in a way that was very different from anything we know on earth. These rocks could not have formed in the presence of any significant amount of water; the mineral assemblage would not have been stable. On earth this kind of rock is tremendously unstable, but on the moon it's as fresh as it was 3.7 billion years ago. So we learned something about conditions on the surface of the moon at the time of the crystallization of these lavas: Things were very dry and inhospitable.

The lunar lavas and rocks from the Apollo 11 mission were very much like similar rocks on the earth in terms of their oxygen isotope composition. Oxygen is extremely important in the solar system; it's probably the most abundant element in the planets. And its isotopic properties are considered to be a good indication of the original uniformity or non-uniformity of the materials of which the planets were made. In these rocks we find evidence of similarities between the earth and the moon. But our analysis of the oxygen isotope composition of these lunar lavas also revealed that while they resemble one class of meteorites, the chondrites, they are not like other classes of meteorites that have similar volcanic characteristics. No known meteorites appear to have the right bulk chemistry and oxygen isotopic composition to suggest that they have been derived from the moon. These findings are very important fingerprints in our developing model of the moon.

The Apollo 12 mission was designated to another mare surface region—the Ocean of Storms—which was known to be on one of the bright rays coming from the crater



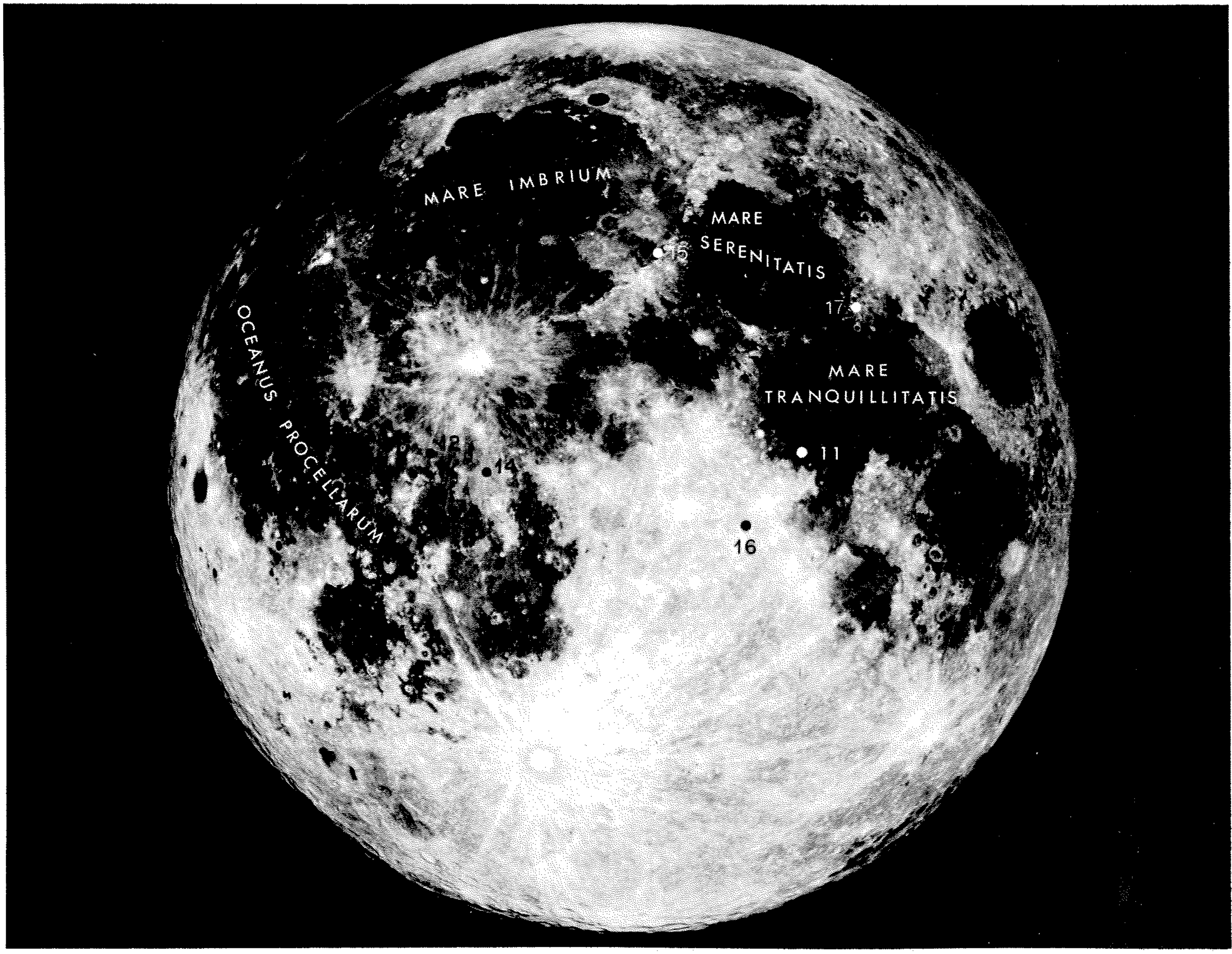
Whether this is the way it really happened or not, there is—in the words of Gerald Wasserburg, professor of geology and geophysics—a "magic component" in the mystifying mix of debris on the lunar surface.

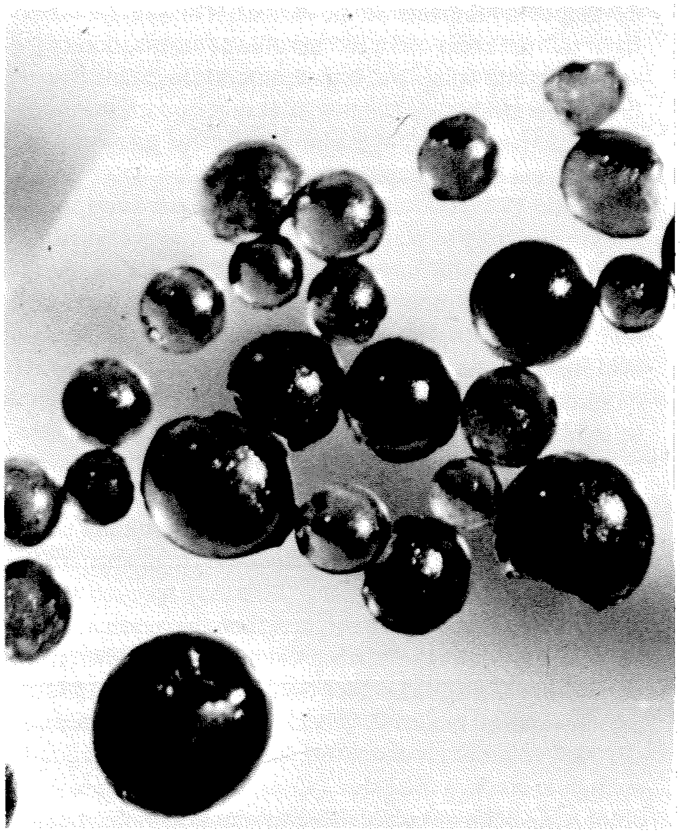
Copernicus. One of the reasons for choosing this site was to revisit Surveyor III, and astronauts Pete Conrad and Alan Bean did a superb job of piloting the landing module to a site just a few hundred meters away. One of their jobs was to dismantle a few key parts of Surveyor and bring them home. In the interval between the landing of Surveyor III in April 1967 and that of Apollo 12 late in 1969, there had been a series of strong solar flares, and we wanted to know how the materials of which Surveyor was constructed had stood up. The moon, unlike the earth, is not shielded from the sun, so it takes all the sun's output directly. When we analyzed the Surveyor materials later, we learned more about the spectrum of energy and the kinds of particles that are thrown out of the sun than we had gained in any other single experiment.

Apollo 12 also ran into some unusual things, among them a very special little rock about as long as a finger and twice as wide, which was given the number 12013. That little rock is now famous in lunar science because it shook us up so completely. It is a very complex, highly evolved rock with a chemistry closely approaching that of terrestrial granite. It represents a degree of chemical evolution beyond what we had thought existed on the moon—a change about as extreme as any of the chemical changes or differentiations that have occurred on earth.

Professor Wasserburg's group did detailed chemical analyses of the isotopic properties of 12013 and found that it was at least 4 billion years old. That showed us that very early in its history the moon had begun to develop the same kinds of materials in its crust that we find in the earth's continental crusts, which contain concentrations of elements of great use to man. But this rock turned out

Six Apollo missions reached the moon and took samples of the material at each of the landing sites, shown here by mission number. Rays fan out around several of the craters, particularly dramatically from Tycho (the large bright spot near the lower edge). Some of these rays can be followed across the whole lunar surface. The crater Autolycus or Aristillus (one above the other in Mare Imbrium north of the Apollo 15 site) may have been the source of the shocked rock round at that site.





In natural color, these microscopic glass spheres would be green. The rock sample in which they were found came from the Apollo 15 site in Mare Imbrium, though it was probably thrown there by an impact about a thousand kilometers away. Small amounts of identical material have also been found in samples from other landing sites.

to be much more radioactive than normal continental granite. In fact the whole Apollo 12 site was covered with a layer of this highly radioactive material that was deeper than we could penetrate in our sampling. We think it is foreign to this site. Apparently it is debris ejected from the crater Copernicus 300 km away. This kind of force is capable of introducing Wasserburg's magic component, and it demonstrates the tremendous impacts that could throw debris all over the surface of the moon.

Apollo 14 astronauts Al Shepard and Ed Mitchell brought back the first samples of big boulders that we had seen on the lunar surface. The landing site north of the crater Fra Mauro was chosen because it looked as if it would be underlain by material thrown out of the huge crater that we know as Imbrium. We thought we would be able to sample material thrown from more than 500 km away from the site and from very deep down in the moon. One sample of a boulder turned out to be a mixture of all kinds of broken particles. It's a kind of lunar concrete welded together by heat derived from the impact that pounded the lunar surface. It is radioactive and contains fragments similar to granite—just as material from Apollo 12 did. And it is about as old—on the order of 3.9 billion years. But it is very complex, containing billions of particles, each with a separate history. It will take a long time to understand it.

Apollo 15 landed in Mare Imbrium at the base of Mt. Hadley, one of the highest mountains on the moon, and beside a remarkable fracture called a rille. Having learned about the moon's traveling debris, we thought the site might have a little material from the craters Aristillus and Autolycus as well as that of local origin. We found—as we expected—some of the youngest lavas yet discovered on the moon (3.3 to 3.4 billion years old). On the other hand we found something we did not expect, and it turned out to make up most of the surface of the mare at the landing site. This was a blanket of shocked rock—a material in which shock pressures have produced such high temperatures that the rock had begun to melt. Many of us feel that this particular material was probably shocked when it was thrown south 150-250 km from Aristillus or Autolycus to this site, and we also think this happened quite recently—a billion years ago or less.

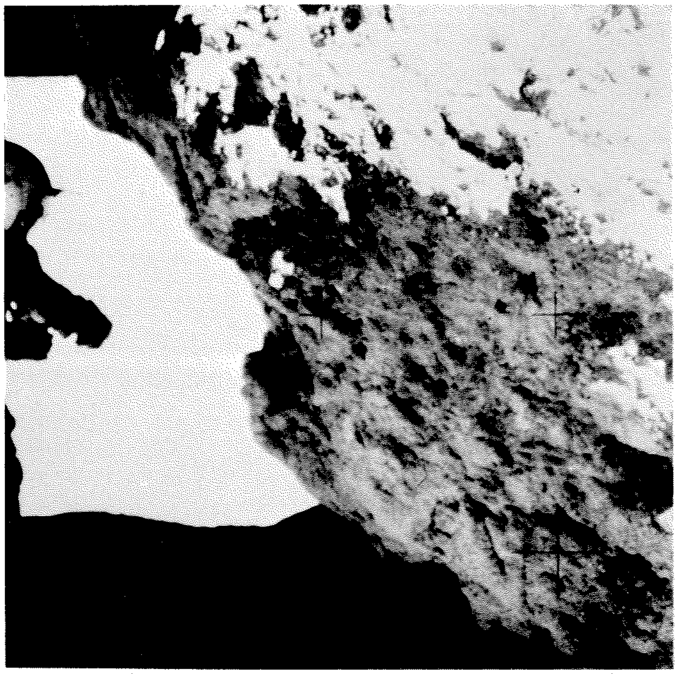
From the flank of the mountains, the crew brought back one of the most primitive materials we have found on the moon and one that we had speculated might be a constituent of the highlands. The Apollo 15 crew did a magnificent job of finding it for us. The rock is made up primarily of plagioclase feldspar. It is highly metamorphosed; i.e., it no longer has the original structure and crystals that formed it. It has been cooked up and recrystallized. We think the age of its metamorphism, which is about 4 billion years, is a minimum age for it, because it shows primitive abundance of strontium isotopes which contain almost no products of radioactive decay.

The Apollo 15 crew brought us back another surprise. The crews of the first missions reported seeing nothing but shades of black, white, and gray. But Dave Scott and Jim Irwin thought they saw green. They didn't believe their eyes, but when they brought a sample back, we found that it was indeed green. In fact, it turned out to be filled with tiny little spheres of green glass completely free of imperfections. It has clearly been raised to extraordinary temperatures. Its composition is very different from most of the materials at the Apollo 15 site, and its age is about 3.9 billion years. No natural glass anywhere near this old has survived on earth, but this lunar glass is perfectly preserved.

Once we had identified this glass and its unusual composition, we went back to samples from previous missions and checked them for the same thing. And here and there a few of them contained one or two spheres of an identical glass. We began to see the effect of material moving around on the moon—and this material has moved as far as 1,000 kilometers.

With the Apollo 16 mission, we made the first straightforward attempt to land in the center of the highlands—at the north end of the crater Descartes. This particular region has fresh-looking hills that we thought might be recently constructed lava mountains. It was chosen in the hope of finding relatively young material. We were wrong. We did not find any volcanic rocks, and the ages of the rocks that we did find are the oldest we have yet studied. But we are convinced that while the site is ancient—perhaps 4.1 to 4.2 billion years old—it is relatively young compared to the rest of the lunar uplands.

One very interesting sample brought back by the Apollo 16 crew, John Young and Charley Duke, was from a permanently shadowed area beneath the wide overhang of a boulder. In the lunar environment a permanent shadow is a cold place in which thermally excited gases that are generated in the lunar-vacuum environment are trapped. These gases may have escaped from the interior of the moon or they may have been boiled out by the temperatures developed by impacts on the surface. The sample taken from this area showed a remarkable concentration of lead, which is quite volatile at high temperatures. This confirmed our early suspicions that another contribution to the magic component in the lunar soils was gases produced by the great impact explosions.



Astronaut Charley Duke prepares to select an important sample—this boulder in the highlands near the crater Descartes which casts a permanent shadow on the moon, creating a kind of lunar refrigerator that traps thermally excited gases produced by the great impact explosions.

Apollo 17 landed on one of the great mare regions, chosen carefully by scientists to give maximum scientific yield. In trying for the greatest possible diversity, we chose a spot where we thought we could get samples of both highlands and maria material. There were giant blocks of lava from a crater, and a rock slide from a 7,000-foot mountain. The samples have only recently been distributed so there are few results yet announced. But photographs of the surfaces of great boulders that have rolled down the mountains show rock melted by impact to a point where it bubbled and frothed, though within it are unmelted fragments. And those unmelted fragments are very rich in the mineral plagioclase. This may turn out to be some of the most primitive material on the moon.

You may remember their great excitement when astronauts Gene Cernan and Jack Schmitt said they had found orange-colored material. (There was great excitement in the back room at Houston too, but our TV wasn't good enough to confirm the color.) Compared against a standard color scale back on earth, this material does indeed turn out to be orange. Now orange soil or rock on earth, especially in volcanic materials, is attributed to the action of hot water or steam gases modifying iron-rich rocks—literally rusting them. And we have not known of water or high-oxidizing materials on the moon. We don't know a great deal about this material yet, though we know it is of glass and of a unique composition. And, strangely enough, when we reexamine the fine debris from the Apollo 11 and 12 samples, we find a few grains with this same chemistry and composition.

It has turned out that the moon is not covered with a uniform well-mixed layer of debris. On the maria we find indigenous basalts and lavas—and also other materials. In the highlands we find materials that are characteristic of highlands, but we also find pieces of what look like mare basalt. So, it looks as if the moon has regional provincial characteristics, but all over its surface there may be bits and pieces of any other part of the moon. What this means is that unraveling the story is going to be a much more complicated job than we thought when we got our first samples back from Apollo 11. One of our main tasks right now is to sort out the extraordinary variety of material that is present in every sample.

We have been able to sample the moon directly only to a depth of about 3 meters, and indirectly—by use of craters—perhaps as much as a few kilometers. But we've been thumping it with explosive charges, listening to it for internal earthquakes, measuring the velocity with which sounds travel through it, measuring its temperatures, and developing a series of inferences about what kinds of materials the lavas could have been generated from. All of this gives us a preliminary picture.

We think that the interior of the moon may be quite warm—maybe 1000° Centigrade. We don't have any direct data for that, but we do know that at a depth of about 850 km we're getting moonquakes. And that means that some dynamic effect down there is sending signals. When those signals emerge, we measure their velocity, and this tells us something about the moon's density, which in turn makes it possible for us to draw some conclusions about its chemistry. What we are now deducing is that the moon's chemistry is very different from the models we had just three years ago for either the earth or the moon.

Being forced to change our interpretation of the moon has shaken up our prejudices about what the inside of the earth is like. We don't really know very much about that either. We've gotten samples from only 100 to 150 miles down. So, we work on inferences about the chemistry of the earth too. It may be that what we learn about the moon is going to make us revise many of our planetary models.

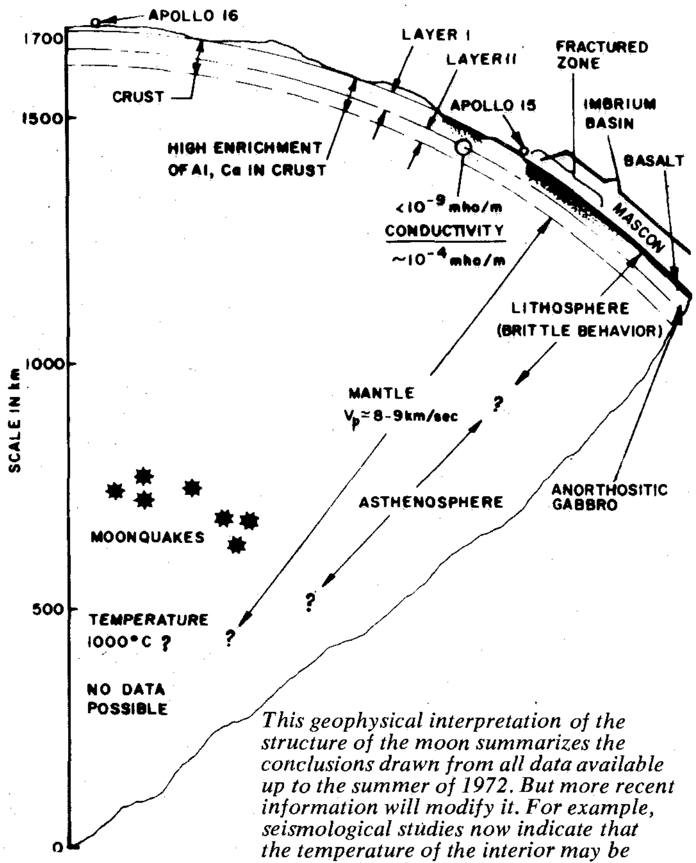
The moon has neither an atmosphere nor a strong magnetic field, both of which shield the earth. The massive atmosphere protects the earth's surface from much of the sun's radiation, and the strong magnetic field tends to divert the great variety of particles thrown at us by the sun in the form of solar wind. The moon is the place to go to find out what the sun is throwing out now and what its behavior has been like over the past 4 billion years.

In the last 15 years geologists have discovered that at intervals the earth's magnetic field drops to zero while it is reversing polarity. It has happened in the past, and it will happen again. When it does, for a time we will have only one shield instead of two. Perhaps some of the major changes in the history of the life cycle of the earth have been related to what happens in that case. It's important for us to know whether the intermittent exposure to the unshielded sun produces those changes.

One of the interesting things about the lava from the moon is that it shows evidence of once having had a distinct magnetic field. That's important because, if our models for our own magnetic field are correct, it is possible that the lunar magnetic field was produced by a hot, moving core in the moon. On the other hand, the moon may yet indicate how planetary magnetic fields may be created without a core dynamo.

The moon has not only been subjected to solar radiation but also to cosmic radiation, which comes from elsewhere in our galaxy—or maybe from outside our galaxy. The energies of cosmic rays are so great that they can penetrate any surface to great depths.

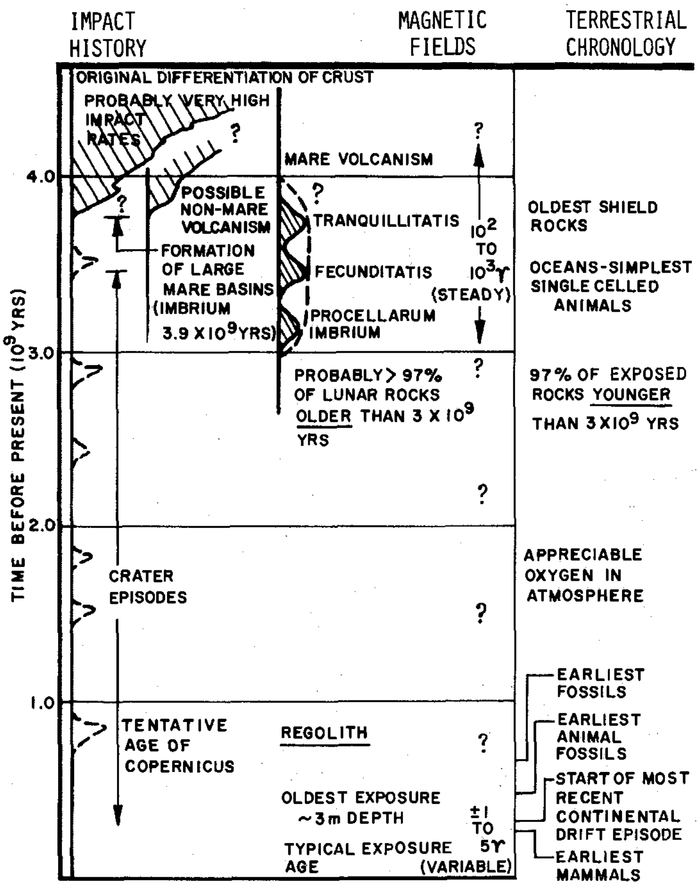
All of this particle bombardment on the unshielded surface of the moon produces effects, some of which are understandable as a measure of exposure. To some extent anything on the surface of the moon gets tanned, but the tanning is in a different form from what people get on a beach on earth. We measure the degree of solar exposure by measuring various isotopic effects. One of the experiments that has been carried out on each of the Apollo missions is called the Solar Wind Composition Experiment.



This geophysical interpretation of the structure of the moon summarizes the conclusions drawn from all data available up to the summer of 1972. But more recent information will modify it. For example, seismological studies now indicate that the temperature of the interior may be nearer 1500° than 1000°.

The only equipment required was a window shade of aluminum foil that was set up on the surface of the moon. In the short periods of exposure on each mission the foil captured evidence of the solar wind. Later analysis showed certain isotopes of rare gases and told us a great deal about the behavior of the sun.

Another experiment made it possible for Caltech professors Sam Epstein and Hugh Taylor to measure the ratio of two isotopes of hydrogen. They found material on the moon very depleted in the heavy hydrogen atom, deuterium. This depletion reflects the fact that the sun uses deuterium at a very great rate. And when it throws out its unburned debris in ash, it throws out a great deal of depleted hydrogen. At the same time it throws out a great deal of helium-3, which is a product of the solar furnace. The helium-3 enrichment in the lunar soil is a remarkable effect. With enough time we may be able to define this effect for many different samples and get a much more comprehensive look at what the sun is doing to the moon, what that means in the history of the sun, and what it may mean for the history of the earth.



In this summary, our present understanding of the history of the moon is compared with what was happening on the earth in the same billion-year periods. The most dynamic eras in the life of the moon occurred before 3 billion years ago, and there has been relatively little internal activity since. The early record of the earth has been obscured because of its subsequent very dynamic and complex behavior.

Professor Don Burnett was responsible for the lunar neutron probe experiment carried by Apollo 17. It was designed to measure the rates at which neutrons created by the impact of cosmic rays on the moon react with lunar material, and how depth causes these rates to vary. The data from this experiment should be helpful in our understanding the history of lunar samples more accurately. ["Probing for Neutrons on the Moon" — *E&S*, February].

We used to think we knew precisely when the moon formed, but we've become a bit more modest in our claims after half a dozen missions. We know that it's over 4 billion years old, and we know that early in its history it began to differentiate. When it differentiated, it produced rocks that are much like the beginning raw materials of our own continents. We know that enormous impacts were going on in its early history, producing tremendous ring structures. Starting perhaps 4 billion years ago and continuing until about 3.2 billion years ago, there were great outpourings of lava that filled the mare basins. Were there enormous impacts and similar outpourings of lava on earth? We are not sure, for the early history of the earth is obscure.

Postscript

Since writing this article, I had an opportunity to attend the Fourth Lunar Science Conference in Houston, Texas, in March. In the brief four days of these meetings, a number of basic premises of previous models for the evolution of the moon have been modified or overthrown. To begin with, materials from the Apollo 16 and 17 missions, including the orange soil, show evidence that there are regions in the moon where the volatile metals and other volatile elements are enriched to a much greater degree than observed before. The orange soil has been shown to be old (about 3.7 billion years), possibly volcanic material, recently exposed (20-30 million years ago) at the site where it was found. The orange soil is enriched in the isotope Pb-204 relative to the refractory element uranium. This enrichment approaches the levels that we know on the earth, and provides evidence that there may be regions on or within the moon that are not as different geochemically from the earth as we had thought.

At these meetings it was also reported that recent seismological studies of moonquakes and meteoroid impacts on the far side of the moon indicate that the lower 500-600 kms of the interior do not transmit shear waves as do the outer portions. This suggests that the deep interior of the moon may indeed be partially molten, which would imply temperatures perhaps as high as 1500° Centigrade or more and leads us to new estimates of the chemical nature of the interior of the moon. These new developments are characteristic of the possibilities for new discovery that lie in the tremendous quantities of materials brought back from the Apollo missions which still remain to be explored.

Research Notes

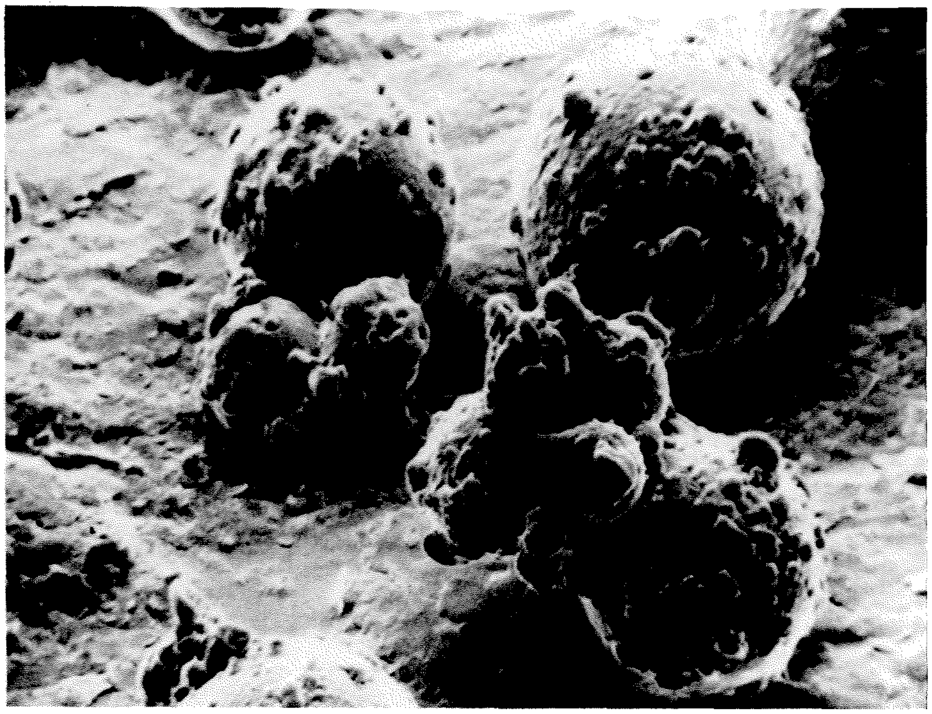
Capsulated Cops

Ever since the 1967 *Torrey Canyon* tanker disaster, when 700,000 barrels of oil poured onto English beaches, large-scale pollution from oil spills has increased sharply. With the newer and larger tankers now in use, it has been estimated that five to ten million tons of petroleum contaminate the oceans every year.

Beyond the difficulty and high costs of cleaning up the damage from such spills, there has been the additional problem of where to assign blame—often an almost impossible task. Many of the techniques proposed for identifying the sources of spills have been slow, expensive, and inaccurate. Now, Fredrick Shair, associate professor of chemical engineering, has developed a method that appears to have none of these drawbacks.

Working with graduate students Berill Mitchell and Peter Drivas, in collaboration with Peter Simonds, a former Jet Propulsion Laboratory scientist who has now returned to England, Shair has developed a quick, simple test that can be made at the site of a spill. The test reveals the identifying "license plate" with which a particular tanker's cargo of oil could be tagged at the time of loading. The system, for which a patent is being sought, has been successfully tested in the laboratory and in small-scale field tests. It is now ready for large-scale field tests.

The basic components of the tagging system are plastic microcapsules, similar to those used for timed-release medications. Measuring less than 1/800th of an inch in diameter, they are filled with combinations of 20 volatile liquids like, for example, Freon. About a million combinations of these liquids are possible, each a distinctive "license plate." Each vessel could be assigned its own particular combination. The cost of the system is less than 3/100ths of a cent for each barrel of oil, and as little as a pound of the microcapsules could tag the cargo of the world's largest tanker; tracer material from just one microcapsule is enough to make a positive identification of its source.



Each sphere in this oil-spill specimen is a plastic microcapsule about one-thousandth of an inch in diameter. When the capsules are heated to a temperature slightly above that of boiling water, they collapse and release a harmless gas that acts as a molecular fingerprint to reveal the source of the pollutant.

The microcapsules, which have no adverse effect on the oil in the tanker or on the environment in case of a spill, can be added to oil in a tanker by methods commonly used for mixing additives with petroleum products. They are tough and will last in ocean water for about three months, roughly the duration of the evidence of an oil spill. When a spill occurs, a sample of it would be taken by means of a small syringe fitted with a filter to trap the microcapsules. The next step is to remove the filter and heat it to slightly above the temperature of boiling water. This causes the microcapsules to break down and release their contents in vapor form. These vaporous gases are then trapped in an electron-capture gas chromatograph, which can provide rapid and accurate analysis of the tracer. Sampling and analysis takes less than an hour.

Embryo Stars

W3, a cloud of gas and dust about 10,000 light years away in our Milky Way Galaxy, is so dense that astronomers have been able to tell only from indirect evidence that it contains several fairly young stars. Now, by using sensitive infrared detectors attached to the Hale Observatories' 100- and 200-inch telescopes, three Caltech astronomers have discovered what may be a group of even newer objects—embryo stars in the process of condensing out of the cloud of interstellar gas.

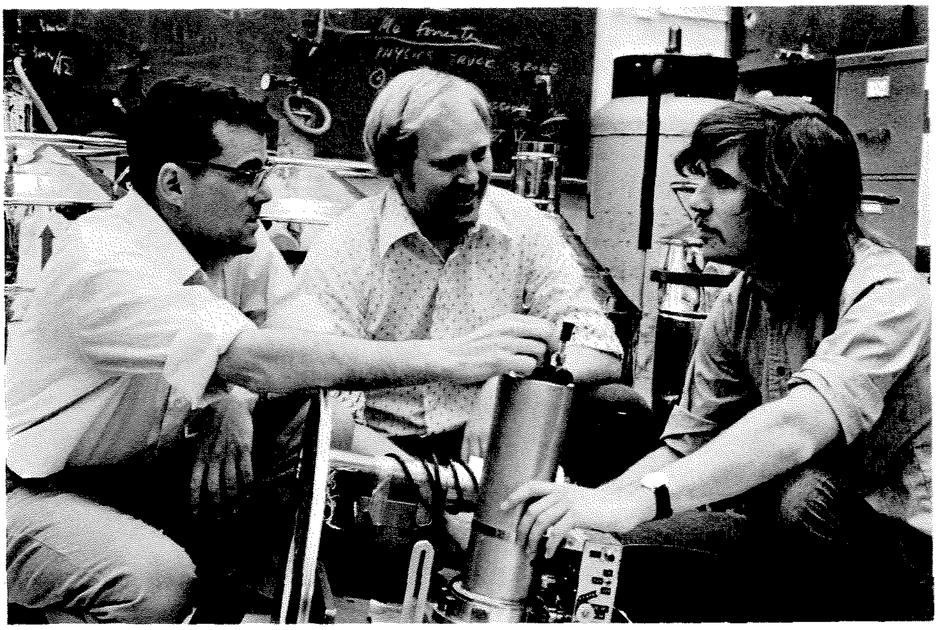
These new observations were made by Gareth Wynn-Williams, research fellow in astrophysics; Eric Becklin, senior research fellow in physics; and Gerry Neugebauer, professor of physics. Becklin and Neugebauer are also on the staff of the Hale Observatories.

Stars are believed to form from gas clouds that condense and shrink until their interiors get hot enough to cause nuclear reactions. Part of the energy of these reactions is then released as light. One of the newly discovered objects, called IRS-5 (for Infrared Source number 5), emits 30,000 times more energy than the sun and is larger than the whole solar system. Its temperature, however, is only 170 degrees Fahrenheit—which is extremely low when compared to the 5,000 degrees of a normal star.

IRS-5 is believed to be in the process of collapsing under its own gravitational pull to become—over the years—a much hotter and more compact star. This "protostar" is of great interest to radio astronomers because it is also an astrophysical "maser" that emits intense radiation at the precise wavelength of the H_2O molecule. Only one other such protostar—in the Orion Nebula—is known to astronomers, but IRS-5 is of even greater interest than that, because it is much more energetic and may eventually become an exceptionally bright star.

IRS-5 is only a few light years away from several very young, hot stars that were probably born within the last 10,000 years—a short time by astronomical standards. It is likely, then, that star formation is still taking place in cloud W3, especially since that region contains vast quantities of hydrogen gas—the raw material out of which stars are formed.

Unfortunately for astronomers, this hydrogen gas carries with it minute dust particles that make the inner part of W3 invisible to optical astronomers. Thus, in order to penetrate the cloud, it has been necessary to observe it at wavelengths in the infrared region, which are longer than those of visible light. The researchers speculate that eventually the radiation in the cloud will cause the dust to disperse and allow the new stars to be seen from the earth.

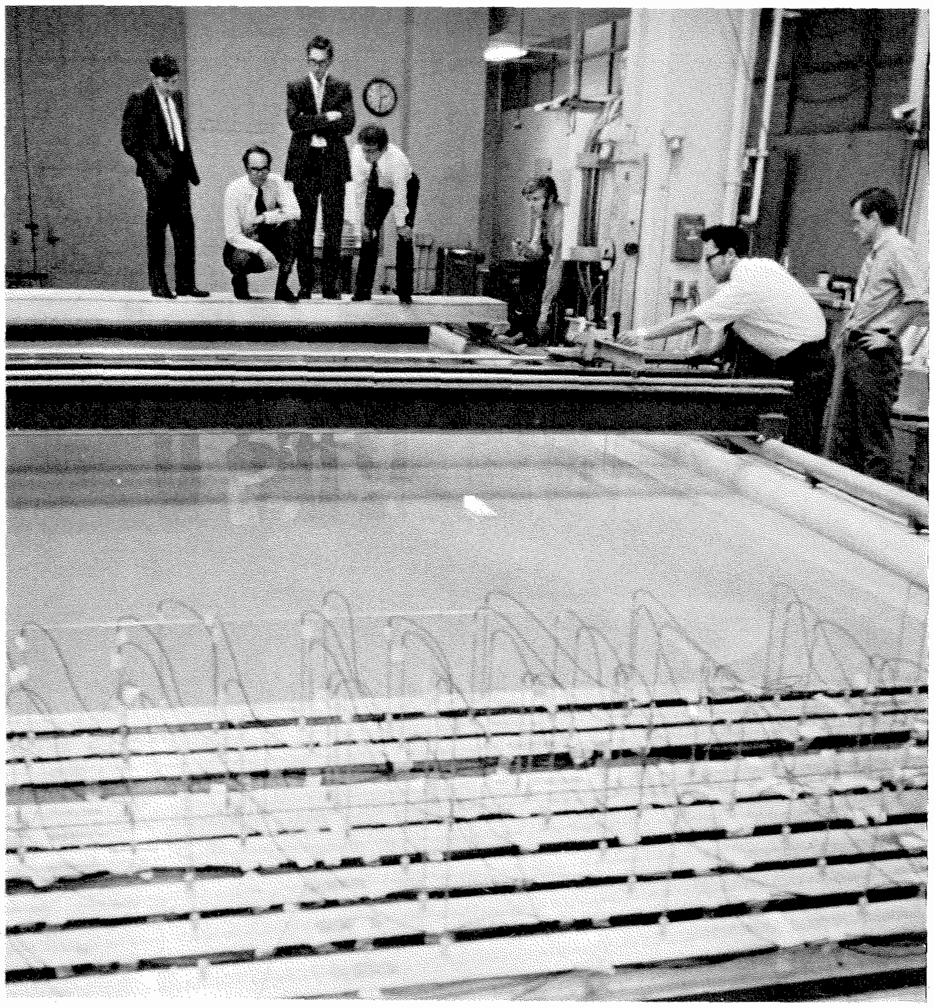


Gerry Neugebauer, Eric Becklin, and Gareth Wynn-Williams use an infrared detector to search for embryo stars. Attached to the 100-inch or the 200-inch telescope, the device uses a material cooled to within two degrees of absolute zero to detect small amounts of heat energy. This is often the only clue to the location of embryo stars.

Cooling It

How can water that is removing the heat from power plants be safely returned to the ocean without adversely affecting the marine environment? To answer this question, Norman Brooks, professor of environmental science and civil engineering, and John List, associate professor of environmental engineering science, have built a large water basin in Keck Hydraulics Laboratory. It is 36 feet long, 20 feet wide, and 16 inches deep, and it simulates 15 square miles of ocean off the California coast at San Onofre where the Southern California Edison Company and San Diego Gas and Electric jointly own a nuclear generating plant.

In this indoor ocean Brooks and List are exploring various techniques for diluting the warm water discharged by power plants so it can meet the new state standards that specify that this water must not increase the temperature of the ocean water more than 4 degrees once it has passed beyond the 1,000-foot mixing zone.


John List (under the clock), Norman Brooks (under the light), and Robert Koh and Eric Wolanski (far right) demonstrate the operation of their indoor ocean to officials of Southern California Edison. The tank is used to develop techniques for diluting warm water discharged into the ocean by coastal power plants.

When ocean water is used for cooling in steam-electric power plants, its temperature is increased by about 20 degrees Fahrenheit. When it is pumped back into the ocean through large outfall pipes, it must be diluted immediately to reduce the temperature increase in the ocean to the allowable limits. To get the information they need, Brooks and List have reproduced, to scale, the ocean floor, the coastal currents, and the outfall systems. Time is also scaled down; a day's tidal currents in the ocean take only 22 minutes in the laboratory basin.

The engineers monitor water temperatures at more than 100 locations in the basin to make sure there are no areas where the temperatures exceed the 4-degree legal limit. The temperature measurements are made by tiny thermistors that feed electrical impulses into a data-acquisition system. A computer uses data from this system to make maps showing contour lines that represent the surface water temperature. Brooks and his co-workers are also using colored water and overhead photography to observe and record the flow patterns of the returning water as it mixes in the basin.

List and Brooks are assisted by Robert Koh, research associate in environmental engineering science, who is in charge of the laboratory work; Eric Wolanski, research fellow in environmental engineering science; two engineers from the Jet Propulsion Laboratory, Wayne Marko and Don Kurtz; three graduate students, Nikos Kotsovinos, Philip Roberts, and Max Irvine; and undergraduate Bruce Bennett.

The work is being done under contract with Southern California Edison, and eventually the researchers will be able to make recommendations that will assist the company in preparing a detailed design of its cooling system outfalls. The study may also yield more general information on how water disperses in the ocean, which should be useful in doing similar studies on other coastal power plants.

Ira S. Bowen
1898-1973

A Tribute by Horace W. Babcock

With the passing of Ira Bowen on February 6, the scientific community has lost a great astrophysicist. Through many years of distinguished and diversified contributions, his work was marked by innovation, rigor, and a thorough respect for fundamentals. His career spanned a half-century, from the beginning of serious work in physics at Caltech to guidance of the Mount Wilson and Palomar Observatories during a period of remarkable growth.

Ira Bowen ("Ike" to his friends) was born at Seneca Falls, New York, and attended Oberlin College, graduating in 1919. For the next two years he was a graduate student at the University of Chicago, where he was strongly influenced by A. A. Michelson. This association, as well as that with R. A. Millikan, was important in developing Bowen's unusual physical insight and providing him with an exceptionally solid foundation in classical physics.

Millikan arrived in Pasadena in 1921 to head the California Institute of Technology, frankly stating that it was his main objective to "build an outstanding department of physics." And it was no coincidence that he brought Ira Bowen with him from Chicago. For the next several years, Bowen was extremely active and productive in laboratory spectroscopy, especially vacuum spectroscopy of the ultraviolet. His work, partly in collaboration with Millikan, provided basic data on energy levels of ionized atoms of a variety of elements. Bowen also contributed to the high-altitude measurement of cosmic rays, and found time at the urging of his associates to complete a PhD thesis on heat losses and evaporation from water surfaces. He became an assistant professor in 1926, associate professor in 1928, and professor in 1931.

Bowen took much satisfaction in teaching, and for years gave outstanding courses in spectroscopy and optics. It is illustrative of his deep commitment to research that on holidays he was often to be found in his laboratory on the south side of Bridge; according to his own account, on New Year's Day he would sometimes take an hour off to watch from his window the conclusion of the annual Rose Parade as it turned into Tournament Park.

Familiarity with atomic structure and knowledge of atomic energy levels led to a striking discovery that brought Bowen international renown among physicists and astronomers. Many lines in the spectra of gaseous (planetary) nebulae in the Galaxy, including the two brightest lines, had for many years defied explanation, and could not be reproduced in the laboratory. They had been tentatively attributed to a hypothetical element, "nebulium." Bowen showed conclusively that these lines were due to "forbidden" transitions between energy levels of ionized atoms of ordinary elements such as oxygen; although not permitted according to the ordinary selection rules, the lines were strong and accurately predictable under the extraordinarily low density prevailing in gaseous nebulae.

In the 1930's, Bowen's interests turned increasingly toward astronomy and astrophysics. The 200-inch telescope was being designed, and he took a major part in decisions as to its optical parameters. Later, he was chiefly responsible for the optical design of the equally successful 48-inch schmidt telescope that was also located at Palomar Mountain. He was a Morrison Research Associate at the Lick Observatory in 1938, where he collaborated with A. B. Wyse in a thorough study and interpretation of the spectra of planetary nebulae.

During World War II, on the Caltech ordnance rocket project, Bowen organized, equipped, and directed a group concerned with improved trajectory determination through metric photography. High-speed cameras designed by him were widely applied. He also found time to engage in wartime research on some aspects of oceanography.

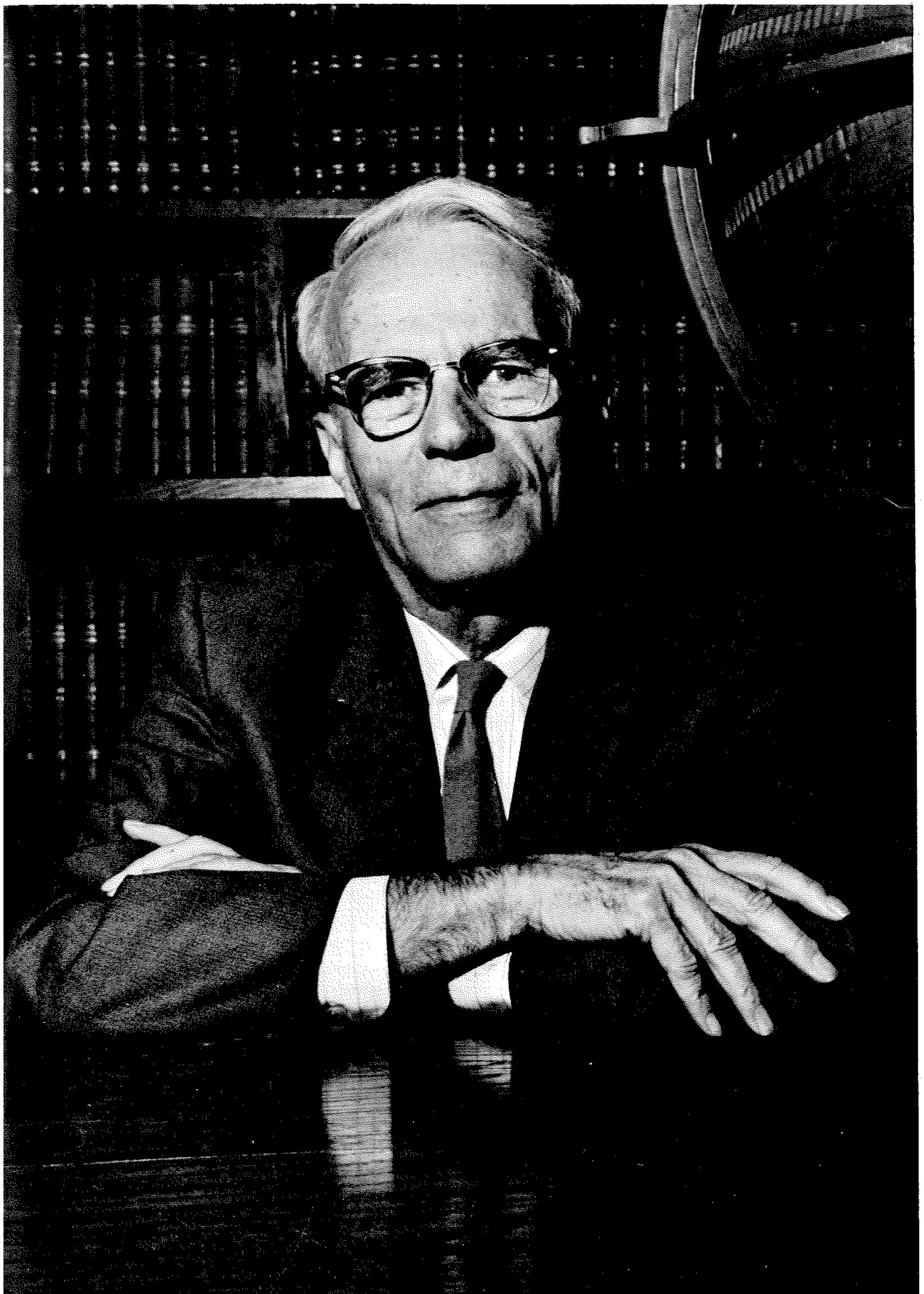
The year 1946 marked the beginning of a new phase of Bowen's career. He assumed the directorship of the Mount Wilson Observatory, and two years later presided over the establishment of the combined Mount Wilson and Palomar Observatories (now the Hale Observatories).

The optical figure of the 200-inch mirror was purposely left with a slightly "turned up edge" when it was transported from the optical shop to Palomar Mountain in 1948. Bowen personally assumed the task of testing the mirror on stars and of guiding the final steps of perfecting its figure by local polishing—accomplished in the dome by the optician, D. O. Hendrix. He took a quiet but firm pride in the performance of the 200-inch Hale Telescope, and sometimes commented on the thoroughness of the planning and engineering that made it such an excellent instrument: 75 man-years of effort by the Observatory Council and the engineering staff were devoted to the design.

In the early years of the Mount Wilson and Palomar Observatories, Ira Bowen took the lead in swinging the interests of many of the group away from investigations emphasizing the precise measurement of spectral wavelengths to those that depended on spectrophotometry—the measurement of the intensity rather than of the position of features in the spectra of celestial objects. This change of emphasis was informally guided by him at a series of gatherings at the Bowen residence on the brink of Eaton Canyon. His gracious wife, Mary, who survives him, contributed memorably to these warmly hospitable occasions. No less important was the support that Bowen gave to extragalactic research at the Observatories by speeding the application of the most modern photoelectric devices for photometry and by personally devising new and ingenious optical systems for the improvement of spectrographs. His effective planning and support were indispensable in the successful completion of the Palomar Sky Survey.

Bowen devised many new instruments and techniques for the advancement of observational astronomy. A partial list would include the baking of photographic plates to reduce reciprocity failure; the image slicer and the employment of composite gratings for improving high-dispersion spectrographs; fast optical cameras and ingenious optical designs for low-dispersion spectrographs; and perhaps of greatest recent import, the improvement of the optical design of telescopes to provide exceptionally large fields of excellent definition.

Although he retired from his administrative post in 1964, Ira Bowen continued



with characteristic energy as the first Distinguished Service Member of the Carnegie Institution. Not only did he remain active in the field of optics, but he found his advice sought more and more by astronomers and telescope designers the world over. He freely gave of his time and vast experience to other telescope and observatory projects, notably to the design of the 120-inch telescope of the Lick Observatory, to the planning of the Kitt Peak National Observatory, and to the design of its major instruments. He was consulted on the planning of the 98-inch Isaac Newton Telescope, the 156-inch Anglo-Australian Telescope, and the 6-meter telescope now approaching completion in the U.S.S.R. Bowen was responsible for the optical design of the new 60-inch telescope at Palomar Mountain. Finally, a most recent major optical design achievement—completed in collaboration with Arthur H. Vaughan—is that of the 100-inch telescope now under construction by the Carnegie Institution for the Las Campanas Observatory in Chile.

Except to a very few of his closest associates, Ira Bowen's peripheral interests were virtually unknown. As a young man, however, he was a devotee of the mountains of California. The trails and lakes of the High Sierra and the ridges and canyons of the San Gabriels were familiar to him. Later, he became a collector of early and rare books on physics and astronomy. He read much history; it was this, apparently, that led to an active interest in numismatics. Bowen left an impressive collection of ancient, medieval, and recent coins of many countries.

Numerous honors came to Ira Bowen during his lifetime: the Gold Medal of the Royal Astronomical Society (of which he was an Associate), the Potts Medal of the Franklin Institute, the Count Rumford Medal of the American Academy of Arts and Sciences, the Bruce Medal of the Astronomical Society of the Pacific, and the Ives Medal of the Optical Society of America. He was a member of the National Academy of Sciences, the American Philosophical Society, and the American Academy of Arts and Sciences, and he was the holder of a number of honorary degrees.

The Month at Caltech

One More Time

Every six years Caltech applies for reaccreditation by the Western Association of Schools and Colleges. This year the process took a new twist when the Institute was offered an alternative to the usual filling out of a bundle of forms. It chose, instead, to provide an introspective assessment of itself for the association to use as a basis for making an evaluation.

The vehicle for the self-scrutiny is an Ad Hoc Committee on the Undergraduate Program, headed by James Knowles, professor and academic officer for applied mechanics; he is assisted by 14 other faculty members and two undergraduate students. Their first step was to set up a series of four open meetings for people to voice their opinions and concerns.

Faculty, administrators, graduates, and undergraduates responded, and a half dozen speakers—invited and volunteer—spoke at each meeting for five to ten minutes. Equal time was allotted for questions from the committee members and the audience.

The discussions were held in the Millikan board room, which at times had wall-to-wall spectators. The subjects, new and old, included the role of the humanities division in the undergraduate program, option flexibility, Institute curriculum requirements being too strict, Institute curriculum requirements being too lax, criticism of life in the student houses, desirability of industrial experience during the undergraduate years, and the need for a larger diversity of interests in the undergraduate student body.

The students who attended the meetings were particularly interested (and in the case of *The California Tech,* particularly vocal) in the discussions of the recent reduction in foreign language staff at Caltech and in the lack of credits approved by the Division of the Humanities and Social Sciences for some of the courses it offers.

From now on the committee will concentrate on specific studies of the undergraduate program. A report is due at the end of the school year.

"The open meetings generated a lot of interest," Knowles says, "and that will help the committee in its search for recommendations to be made to the faculty. I hope we can come up with suggestions that will be implemented."

The hope is not without a slightly ironic note. Knowles reports that one of the committee members, David Goodstein, brought a faculty committee report from 1931 to the last open meeting. Many of the same questions were being raised then. "The report was dated two days after I was born," says Knowles.

Finkelstein Gift

Mr. and Mrs. Lester M. Finkelstein have made an unrestricted gift to the Institute of securities and real estate valued at $2,900,000. Finkelstein is a Los Angeles area industrialist, civic leader, and philanthropist, who is particularly interested in the fields of health and education.

Finkelstein, a steel manufacturer, is past president of Mt. Sinai Hospital and of the Brandeis Institute. He has also been on the board of directors of Hope for Hearing at UCLA, and a sponsor of the Concern Foundation for cancer research. The Finkelsteins were founders of the Los Angeles County Museum of Art and associate founders of the Music Center.

In recognition of the unrestricted gift, President Harold Brown has announced that a number of future teaching assistants will be designated as Finkelstein Teaching Assistants.

Fairchild Scholars

If exchange of ideas is the lifeblood of an educational enterprise, Caltech's opportunity for massive transfusions over the next ten years is extraordinary. Thanks to the Fairchild Foundation, the Institute now has $7.5 million to bring some of the world's intellectual leaders to the campus. "This means that Caltech is going to have the most distinguished group of visitors of any university in the world," says President Harold Brown. "They will be sharing their wisdom with our faculty and student body, influencing our research and teaching—and of course, in return, being influenced by us."

The grant will fund the Sherman Fairchild Distinguished Scholars Program, named in honor of the founder of the Fairchild Camera and Instrument Corporation and of Fairchild Industries. Mr. Fairchild, who died in 1971, was a pioneer—and an indefatigable inventor—in the fields of photography, aviation, and sound engineering.

There will be two general bases for selection of the Fairchild Scholars: persons of great distinction, and individuals —generally younger people—of outstanding promise and ability. Eventually, 20 to 25 of them will be in residence at any one time, and though they will not necessarily all be scientists or engineers, they will all be people who have shown an interest in science and technology and in applying knowledge from these fields to meeting human needs. Invitations have already gone out to 18 or 20 such people, most of whom have accepted.

The first Fairchild Scholar will be—appropriately enough—Harrison H. Schmitt, the first scientist (and geologist) on the moon. Schmitt, a Caltech alumnus (BS '57), received his PhD in geology from Harvard, and he has been an astronaut since 1965. He will arrive on campus this spring and then be here intermittently during the 1973-74 academic year. Howard K. Emmons, who is Gordon McKay Professor of Mechanical Engineering at Harvard University and an authority on the aerodynamics of combustion, supersonic aerodynamics, and the fundamentals of dynamics, will be on campus for six months starting in September.

In January 1974, Yuval Ne'eman, professor of theoretical physics at Tel Aviv University, will arrive for three months. Ne'eman has been at Caltech before, as a research fellow, visiting professor, and visiting associate. At about the same time, Norbert Bischoff, an authority on animal behavior, psychology, and ethology, will arrive from the Max Planck Institute for Behavioral Physiology in Seewiesen, Germany.

Executive Office

Roy W. Gould has been named the first executive officer for applied physics, an interdivisional program for both undergraduate and graduate study initiated in 1970. It is designed for students who like to work with problems in physics which originate or result in applications. With this appointment, the number of executive officers in the Institute's academic divisions totals ten.

Gould, professor of electrical engineering and physics, returned to campus this year from two years leave as assistant director for controlled thermonuclear research of the Atomic Energy Commission. He headed a $30-million research effort looking for ways to control nuclear fusion to produce clean, unlimited power.

Task Force

Robert D. Gray, director of the Industrial Relations Center and professor of economics and industrial relations, has been appointed by Governor Reagan to a seven-man task force investigating problems of workmen's compensation. Gray will represent the public on the board, which includes members of labor, management, and state government.

Hello Out There

In November 1961, several hundred scientists attended a conference on "Intelligent Extraterrestrial Life." A few months later each of them received a strange, indecipherable message from the organizer of the meeting—Frank Drake, professor of astronomy at Cornell University.

Drake's message was the kind that might possibly come from beings on another planet—and it was so skillfully constructed that only one of the recipients was able to decode it. He was Bernard Oliver, whose interest in the search for intelligent life in space goes back almost to his student days.

Oliver spent his first three college years at Caltech, got a BS in 1934 from Stanford University in radio engineering, then came back to Caltech for his MS in 1936 and his PhD in 1940, both in electrical engineering. Now vice president in charge of research and development for the Hewlett-Packard Corporation, Barney Oliver spent two weeks at Caltech in February as part of a continuing program started by Francis Clauser, chairman of the division of engineering and applied science, to bring spokesmen for industry to the campus. Oliver spent most of his time here talking about "Project Cyclops," a sophisticated and ambitious attempt to use radio telescopes to search for possible messages from space.

Cyclops grew out of a study group that Oliver co-directed at Stanford University in the summer of 1971, and he believes it could serve as the beginning of a serious, multinational effort to search the skies for messages from extraterrestrial races. The Cyclops system would use an array of one thousand 325-foot-diameter radio telescope dish antennas to send and receive interstellar communications. Initially, the searchers would look for radio signals from the nearest 1,000 stars. If that search produced no results, messages would be sent to those solar systems for a year or so before the probe went deeper into space. At regular intervals during later investigations, the stars that were first scanned would be reexamined for responses to our signals.

"So far, Cyclops is only a paper project," says Oliver. "But the hardware and know-how are available. It's a question of whether or not we are interested enough as a society to do it. The cost would run into billions of dollars, and it would be decades before any results could be obtained. And there would be no guarantee of success. But if we were successful, the ability to share knowledge with another species of intelligent life in the universe would be of tremendous importance to the human race."

During his Caltech visit, Oliver gave several lectures on the theory and hardware involved in such a search, consulted with scientists and engineers on the newest developments in electronics, and held seminars on the many projects in which his company is involved.

This unique mixture of interests—ranging from the esoterica of extraterrestrial biology to the practical applications of modern technology in industry—has characterized Barney Oliver's career ever since he left Caltech 33 years ago. For the first 12 of those years he was a member of the technical staff at Bell Laboratories, where he was involved in the early development of television, radar, and computer technology. He left Bell to become director of research and development at Hewlett-Packard in 1952. The job change coincided with a growing interest in extraterrestrial life.

In 1959, several serious scientific papers were published analyzing the mathematical probabilities of intelligent life—other than human—occurring in the universe. The writers concluded it was possible, and Oliver did some calculations on his own and decided they were right.

This conviction led to his interest in Frank Drake's "Project Ozma"—an attempt in 1959 to analyze two nearby stars for possible intelligent signals, using radio telescopes at the National Radio Astronomy Observatory at Green Bank, Virginia. Since then Oliver has participated in many of the conferences devoted to exobiology and attempts to locate intelligent life in space.

"If we are successful in establishing interstellar communication, it is certain that we will not have been the first civilization to have done so," he says. "The extraterrestrial races that have solved their ecological and sociological problems, and are therefore very long-lived, may already be in mutual contact, sharing an inconceivably vast pool of knowledge. Access to this 'galactic heritage' would certainly be worth many times the cost of a project such as Cyclops."

Books

A VICTORIAN GENTLEWOMAN IN THE FAR WEST
The Reminiscences of Mary Hallock Foote
Edited by Rodman W. Paul
The Huntington Library $8.50

Reviewed by Ray Allen Billington

Thanks to Rodman W. Paul, Mary Hallock Foote may be more remembered by future generations for the revealing memoirs published for the first time in this handsome volume than for the short stories, novels, and illustrations that gained her modest fame at the turn of the century. Prepared late in her life for the eyes of her family and written in flowing prose marred only by a tendency toward Victorian effusiveness, they tell a fascinating, if tragic, tale of a talented woman forced to leave her beloved East to brave the discomforts of life in mining camps, to bear her three children amid primitive conditions, and to provide much of the income needed to sustain a husband congenitally incapable of translating dreams into a livelihood or catering to the whims of his employers.

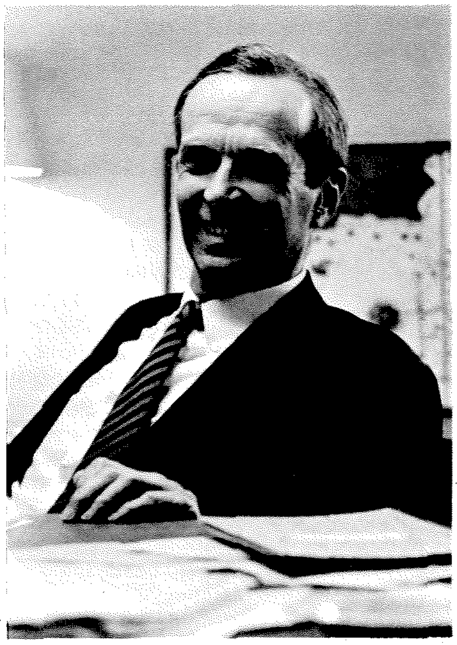
Born in 1847 on a worn-out farm near Milton, New York, Mary Hallock studied art in New York, where she established lasting associations with the literary world before she married Arthur De Wint Foote, an ambitious young mining engineer who had largely trained himself for a glamorous new profession that promised a lucrative career in the West.

They settled first at New Almaden in California, one of the largest producers of quicksilver in the world, and there Mary produced her first child and her first stories—stories of "Mexican Camp" and of a company store where "the policy was frank extortion" and of anxious hours when her husband would vanish for days at a time into the deep tunnels.

What seemed a promising career ended when Arthur Foote suddenly resigned—there were, his wife wrote, many people "he couldn't work for"—moved his family to Santa Cruz, and began a fruitless attempt to develop a new type of hydraulic cement for use in mine shafts. Only the paternalistic aid of his brother-in-law, James D. Hague, a successful mining engineer, rescued the family from that venture; Hague sent young Foote off to Deadwood to investigate Black Hills mining properties for eastern investors while Mary fled eastward to her family.

That was the first of a series of moves: to Leadville in Colorado (where logs for their cabin cost a dollar each "and they were not very long logs either"), to Mexico where he worked in mines near Morelia, to Idaho to manage properties near Boise. In Idaho, Foote succumbed again to his visionary dreams, abandoning his profession to spend years on an irrigation project that collapsed when British capitalists tired of pouring money into a scheme that was a generation in advance of its time. Only Mary's "potboiling," as she called it, kept her little family together during those trying times.

Not until James Hague again came to their rescue with a chance for his brother-in-law to manage his North Star mine in California's Grass Valley did their fortunes turn. This time Arthur Foote stayed on, using his considerable mechanical skills to turn the North Star into a profitable operation. For the next 30 years the Footes lived in Grass Valley, fairly comfortable despite his inability to resist expensive and unworkable ventures; most of his savings were squandered on an attempt to build a road into the High Sierra.



Rodman Paul

This is the story told by Mrs. Foote in her reminiscences, and a compelling story it is. She never really liked the West ("I love my West when I am in the East," she once wrote), yet she was so fond of the soft, dry air, the riotous scenery, the vastness of the landscape, that neither was she happy when visiting the literary circles of New York for which she constantly longed. Nor did she merge into western society; the Foote's friends were almost exclusively well-educated mining engineers of their own cultural level. With the ordinary folk they had nothing to do. Her memoirs, hence, shed little light on the frontier social order. They more than compensate for this lack with their magnificent descriptions of the countryside, their accounts of mining operations at New Almaden and Leadville, their word pictures of the lot of a cultured woman in Idaho's Boise River Valley.

Rodman Paul has performed well beyond the call of duty in placing Mrs. Foote's remembrances in a useful setting. His historical introduction is a model of compact writing, essential to understanding the story that follows. His editing, particularly in the identification of the many literary allusions, is unbelievably thorough; what labors went into locating the line "as the legs without a man" in William Cowper's *The Task* (1785), or "joy in its mighty heart" in Kipling's "The Conundrum of the Workshops"; what research was needed to explain such dated phrases as a "ha-ha fence," "wearing the willow," and "the softness of Baloo." The Huntington Library has provided these efforts with a worthy setting by publishing a superbly designed volume, lavishly illustrated with family portraits and Mrs. Foote's drawings, at a price that is today a remarkable bargain.

Ray Billington is a research associate on the staff of the Huntington Library, a distinguished historian, and author of the recently published book Frederick Jackson Turner.

Noted—Other Books of Interest to Caltech Readers

SEASONS OF REBELLION
Protest and Radicalism in Recent America
by Joseph Boskin and Robert A. Rosenstone
Holt, Rinehart & Winston .... *Clothbound $6.00*
Paperbound 3.00

Robert Rosenstone, associate professor of history at Caltech, and Joseph Boskin, professor of history at Boston University, are "historians concerned with social movements and interested in dissent." In 1968 they set out to try to report on the whole protest movement of the sixties, but there was just too much going on. The result was an anthology of articles, by specialists, on the entire range of contemporary protest—racial, political, educational, and social (youth, hippies, women's lib).

The material, which originally appeared as a volume of *The Annals of the American Academy of Political and Social Science* in 1969, has been updated and rewritten, and new articles have been added to make up *Seasons of Rebellion.*

THE LEGACY OF GEORGE ELLERY HALE
Edited by Helen Wright, Joan N. Warnow, and Charles Weiner
MIT Press *$17.50*

George Ellery Hale was a mover and shaker. One of America's greatest astronomers, he helped found the Yerkes Observatory, the Mt. Wilson Observatory, the Palomar Observatory, the California Institute of Technology, and the modern National Academy of Sciences.

Helen Wright wrote a lively biography of Hale (*Explorer of the Universe*) in 1966. Now, with two co-editors, she has produced a jumbo book that fills out the Hale biography with photographs, letters, documents, and newspaper clippings, a selection of Hale's papers, and a brace of essays on Hale's influence on astronomy research and instrumentation—including "Research on Solar Magnetic Fields from Hale to the Present," by Robert Howard, staff member of the Hale Observatories; and "Hale and the Role of a Central Scientific Institution in the United States," by Daniel J. Kevles, associate professor of history.

Research opportunities in highway engineering

The Asphalt Institute suggests projects in five vital areas

Phenomenal advances in roadbuilding techniques during the past decade have made it clear that continued highway research is essential.

Here are five important areas of highway design and construction that America's roadbuilders need to know more about:

1. Rational pavement thickness design and materials evaluation. Research is needed in areas of Asphalt rheology, behavior mechanisms of individual and combined layers of pavement structure, stage construction and pavement strengthening by Asphalt overlays.

Traffic evaluation, essential for thickness design, requires improved procedures for predicting future amounts and loads.

Evaluation of climatic effects on the performance of the pavement structure also is an important area for research.

2. Materials specifications and construction quality-control. Needed are more scientific methods of writing specifications, particularly acceptance and rejection criteria. Additionally, faster methods for quality-control tests at construction sites are needed.

3. Drainage of pavement structures. More should be known about the need for sub-surface drainage of Asphalt pavement structures. Limited information indicates that untreated granular bases often accumulate moisture rather than facilitate drainage. Also, indications are that Full-Depth Asphalt bases resting directly on impermeable subgrades may not require sub-surface drainage.

4. Compaction and thickness measurements of pavements. The recent use of much thicker lifts in Asphalt pavement construction suggests the need for new studies to develop and refine rapid techniques for measuring compaction and layer thickness.

5. Conservation and beneficiation of aggregates. More study is needed on beneficiation of lower-quality base-course aggregates by mixing them with Asphalt.

For background information on Asphalt construction and technology, send in the coupon.

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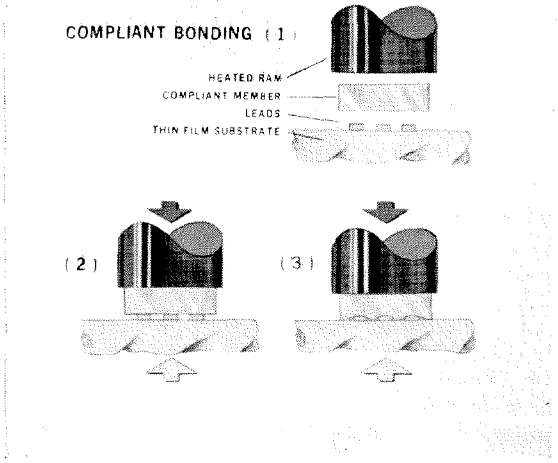
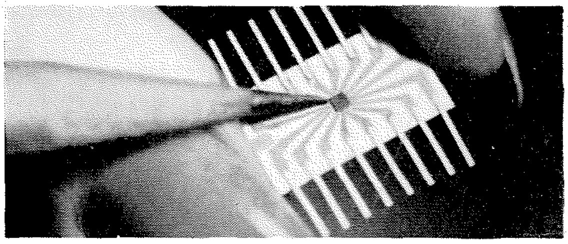
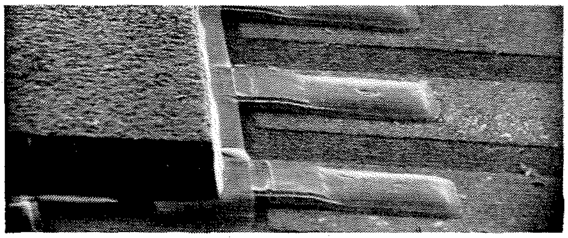
WESTERN ELECTRIC REPORTS



When heat and pressure are applied to the compliant medium, it begins to deform around the gold-plated leads. Deformation of leads is controlled by the flow stress properties of the medium. When the medium bottoms out, it stops the ram and the delicate metal parts are instantaneously and permanently bonded without damage.



Slightly magnified, the pencil points to a beam-leaded circuit chip which has been bonded to 16 gold conductors that converge on it. Within the silicon chip are dozens of microscopic transistors, diodes, resistors.



Greatly magnified, we can see gold beam leads projecting from a chip bonded to thin gold conductors on a thin ceramic substrate.

A new and better way to bond integrated circuits.

Engineers at Western Electric's Engineering Research Center (ERC) and Allentown Works have come up with a revolutionary but simple solution to some very complex circuit bonding problems. It's called compliant bonding.

As in other solid state bonding methods, heat and pressure are used to bond tiny integrated circuits to other components. (Some circuits have fifty or more delicate leads.)

However, our process differs in a very important way. ERC researchers added a compliant or yielding medium between the energy source and leads being joined. On contact, the medium compresses and transmits an equal amount of controlled, predictable bonding pressure to each lead.

There are many advantages to this new technique.

First, it is more reliable. Under heat and pressure, the compliant medium spreads the bonding pressure to all the leads uniformly. It automatically compensates for surface and lead irregularities. Strong, reliable electrical connections are assured for every lead.

It is also more versatile. We can now bond more than one circuit at a time, even with leads of different thicknesses or area widths. The compliant medium perfectly controls lead deformation in even the most complicated multiple bonding. It's no longer necessary to design and test complex bonding tools for each bonding job.

Engineers at Allentown are working to apply the process to large-scale manufacturing. They have developed the first production machines using the process. These machines are now in growing use at Allentown and many other Western Electric plants.

Conclusion: Compliant bonding is technically and economically superior to other solid state bonding techniques. Combined with automated production, compliant bonding promises reliable, high-speed production of circuit packages.

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Conversation Pieces

Technically intriguing items from TRW, guaranteed to add luster to your conversation and amaze your friends.

Storm on the Sun In Einsteins's famous equivalence of mass and energy, E = m C^2, the C^2 turns out to be a very large number (186,000 mi/sec × 186,000 mi/sec). This means that the destruction of a very small amount of matter yields a very large amount of energy. The immensely destructive forces released by a small hydrogen bomb are dramatic evidence of this fact.

We can begin to appreciate the staggering amount of energy put forth by our sun when we realize that every second the sun converts 5 million tons of mass into energy and radiates it out into space. Light, heat, X-rays—in fact, the entire electromagnetic spectrum—stream forth from this hydrogen-fueled holocaust. In addition, subatomic particles such as protons and electrons are hurled into space carrying with them magnetic fields. This plasma, called the solar wind, blows through the solar system forming a kind of interplanetary weather.

Our own spacecraft earth courses through the solar wind much like a ship plowing through the sea. At its prow, the belts of radiation trapped by earth's magnetic field (the Van Allen belts) are buffeted then flattened by the solar wind and a bow shock wave is formed. Behind, an electromagnetic wake trails out for thousands of earth radii (see Figure 1).

Ordinarily the speed of the solar wind is relatively steady. Sometimes, however, a storm erupts on the sun, and the wind is whipped to hurricane proportions. When this occurs, the earth experiences the assault of a full-blown magnetic storm.

On August 2, 1972, an enormous storm, the largest ever measured in space, suddenly erupted on the sun. Flares leaped hundreds of thousands of miles above the solar surface, and huge discharges of plasma hurtled into space. As the storm slashed out through the solar system, NASA's Pioneer 9 satellite was in orbit between the earth and the sun; Pioneer 10, on its way to Jupiter, was travelling through the asteroid belt. The alignment of the two spacecraft had been anticipated by Pioneer engineers and scientists as an important opportunity to evaluate the normal flow of solar radiation. The giant storm was an unexpected bonus.

Pioneer 9 clocked the gust of solar wind at 2¼ million miles per hour. By the time it struck Pioneer 10, 76 hours later, the wind had slowed to around 1 million miles per hour. Interestingly, its temperature had shot up to nearly 2 million degrees, and the interplanetary magnetic field was 100 times its normal strength. The effects are suggestive of the magnetic "pinch" that scientists seek to control fusion reactions.

After settling down, the sun erupted again on August 7. During this storm NASA's Pioneer 6 satellite counted the greatest number of high energy particles ever seen, over 4,000 times more than normal. In a one hour period, the storm produced energy equal to the U.S. electrical power consumption for 100 million years. As an aside in parting, it warped the earth's magnetic field so severely that power and communication blackouts occurred in Canada, the northern U.S., Sweden and Alaska.

The data collected by these TRW-built satellites during the solar storms of early August are now being evaluated to determine their effect on current theories of the space environment, the earth's atmosphere, and other aspects of space physics. The information is expected to increase our understanding not only of our own star, the sun, but of other stars in the universe as well.

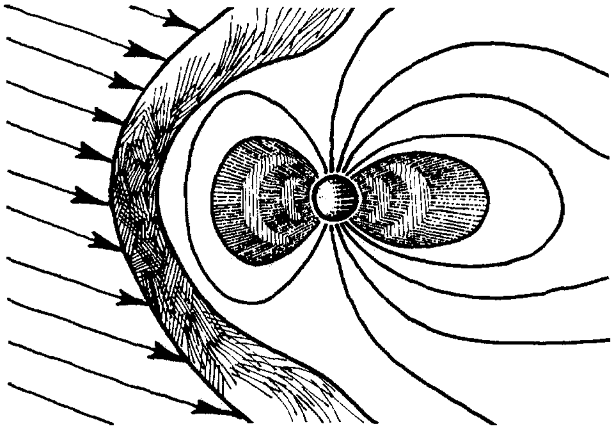

FIGURE 1. THE EARTH IN THE SUN'S ATMOSPHERE

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General Electric researchers and engineers first figured out how to refine germanium to such a pure level. (Less than one atom of impurity in a trillion.)

That was a major technical achievement. But that's not the reason it's important.

Ultra-pure germanium is very sensitive to certain radioisotopes. So it's making possible a revolutionary new sensing device for studying the brain. Conceived at the NYU Medical Center's Institute of Rehabilitation Medicine, this system is intended to give doctors their first 3-dimensional look at the entire brain.

A patient, wearing a helmet containing germanium sensors, will be given a radioisotope. As the isotope flows through the brain, the sensors will feed signals to a computer, resulting in a complete mathematical picture of the brain's blood-flow rates.

That information could be invaluable in treating hundreds of thousands of people with brain damage resulting from strokes or accidents.

For example, take an auto-accident victim with critical head injuries. Without fast treatment he could easily be a dead man.

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It's a pretty clear example of how a technological innovation can help solve a human problem.

That's why, at General Electric, we judge innovations more by the impact they'll have on people's lives than by their sheer technical wizardry.

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