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National Aeronautics and
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Telescopes and Space Exploration

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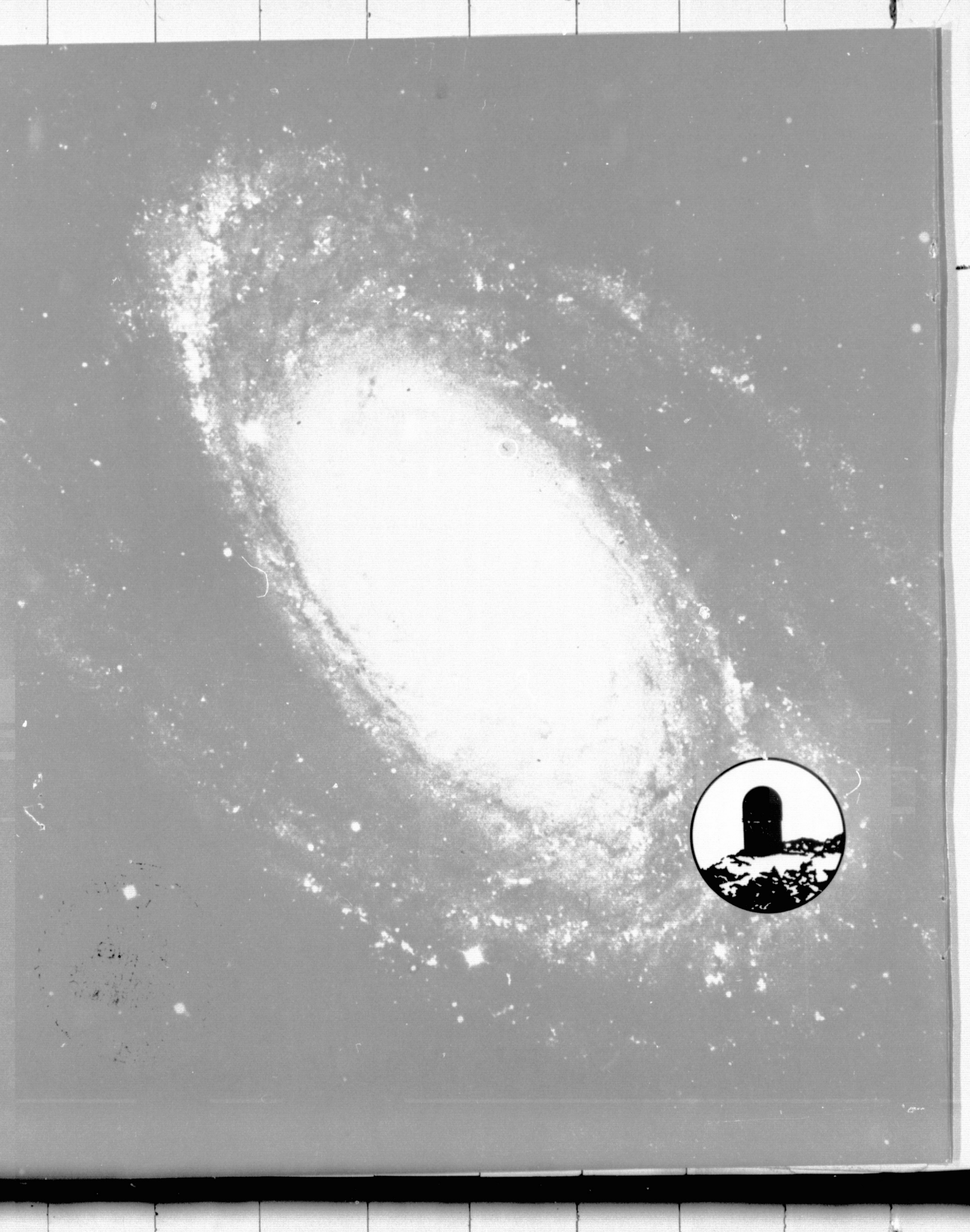
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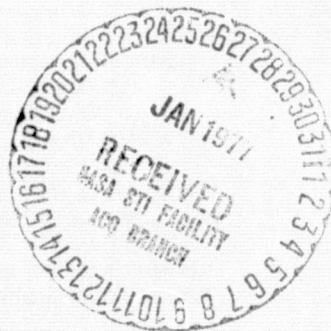
TELESCOPES AND SPACE EXPLORATION

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Astronomers are frequently asked to explain how telescopes are used to study the universe and, in particular, why many different kinds of telescopes are necessary for astronomical research. The purpose of this booklet is to show that progress in contemporary astronomy and astrophysics depends on complementary investigations with sensitive telescopes operating in several wavelength regions, some of which can be on the earth's surface and others of which must be in space.

**ORIGINAL CONTAINS
COLOR ILLUSTRATIONS**



Cover: An ejection of coronal material (above) at the time of a solar flare as photographed by the Skylab astronauts. The bright solar surface is blocked out by the central, dark disk that is supported by the post (below). (Courtesy of the High Altitude Observatory).

Astronomers continue a centuries-old intellectual tradition of exploring the universe at modern astronomical facilities on remote mountain peaks around the world (Figure 1). Their telescopes and associated instrumentation collect, focus, and record the light from stars, nebulae, galaxies, and other objects in space. Analyses of the recordings, whether made photographically or with electronic sensors, yield information about the physical properties of the celestial objects. Such information is helping us piece together the grand puzzle of the birth, evolution, and future of the universe.

Through the years it has become apparent that ground-based telescopes are limited in their capabilities and cannot provide adequate information about many aspects of the universe. This is due to the absorbing effect of our atmosphere which severely limits the radiation (and particles) that reach the surface of the earth. The light which penetrates the atmosphere and to which our eyes are sensitive constitutes a very small fraction of the radiation spectrum (Figure 2). Our atmosphere completely filters out such radiation as X rays, gamma rays, and most ultraviolet light. Much of the infrared radiation, and both low- and high-frequency radio waves that permeate space are also blocked by the atmosphere. All of this energy carries key diagnostic information from the objects in the universe.

A coherent investigation of the universe, therefore, requires not only ground-based telescopes, but also space-borne devices capable of observing from above the restrictive layers of the atmosphere. Balloons

and aircraft can carry instruments to high altitudes and sounding rockets can probe space above the atmosphere for brief periods of time. Long-term observations in space, however, require earth-orbiting observatories (Figure 3) or deep-space probes. In many cases, specialized telescopes and instrumentation are necessary to study particular kinds of radiation. X rays and gamma rays, for example, cannot be focussed by conventional telescopes using mirrors and lenses as in the case of our mountain-top observatories. These radiations require much more complex instrumentation to make detailed observations.

The ultraviolet and infrared radiation filtered out by our atmosphere require the use of telescopes in space which are similar to those employed on the earth, but there are still special problems. Telescopes in space used for observing the solar ultraviolet radiation need protection for their optical surfaces to avoid degradation during use. Parts of infrared telescopes must be kept extremely cold (below -320° F) so that the faint celestial radiation collected will not be swamped by infrared "heat waves" and electronic noise from the apparatus. Indeed, for the study of the little-known "far infrared" radiation with future space instruments such as those proposed for a possible Infrared Explorer satellite, the telescope and detector equipment would be housed in what is essentially a large thermos bottle lined with liquid helium at a temperature only a few degrees above absolute zero.

Figure 1. An aerial view of the Kitt Peak National Observatory, located west of Tucson, Arizona. (Courtesy of the Kitt Peak National Observatory, Copyright © 1975 by the Association of Universities for Research in Astronomy, Inc.)

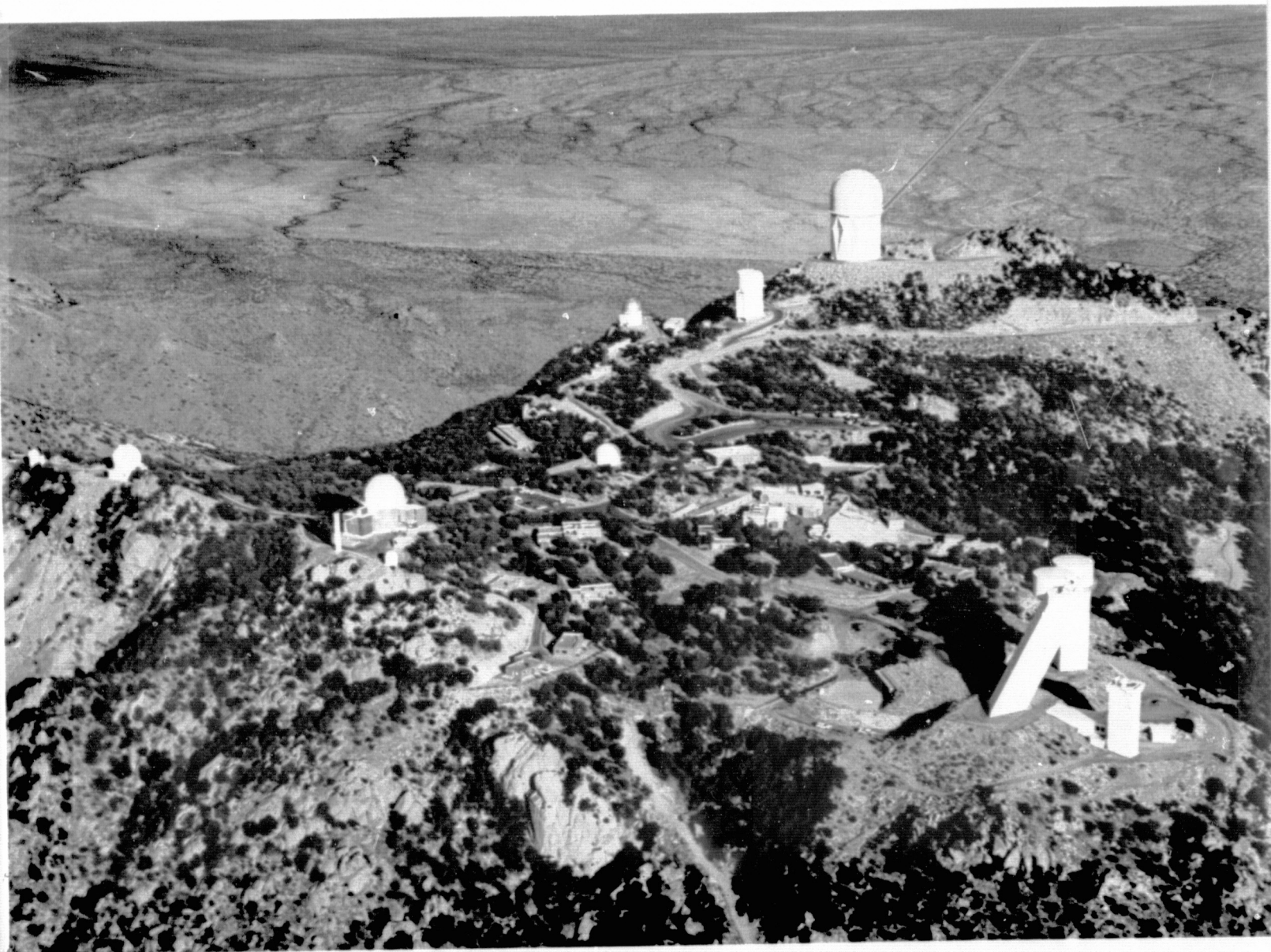


Figure 2. The radiation spectrum. The central part illustrates the visible light spectrum of the Sun with bands from the ultraviolet to the red. If we had a device that would record the spectrum of *all* radiation, not just visible light, there would be *many* bands of other "colors" above and below the familiar colors. This "extra" radiation constitutes the gamma rays, X rays, ultraviolet, infrared, and radio waves as indicated schematically. Visible light is actually a minute fraction of the total radiation spectrum.

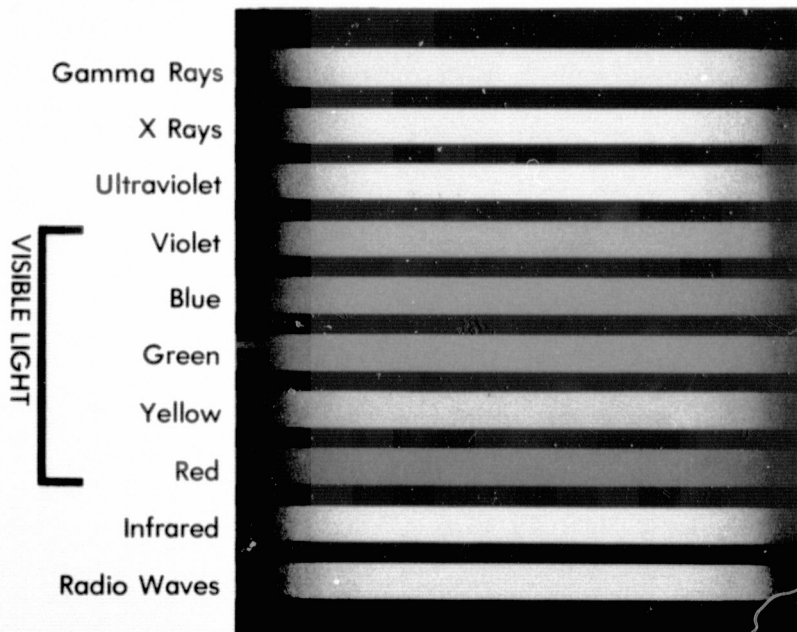


Figure 3. Artist's conception of the Orbiting Astronomical Observatory, *Copernicus*. (National Aeronautics and Space Administration.)

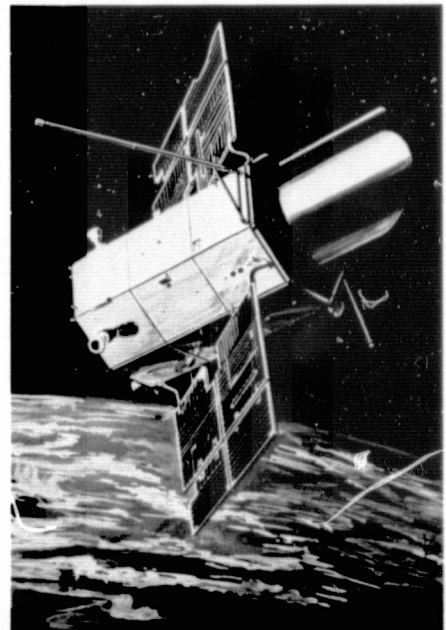


Figure 4. The Crab Nebula.
(Courtesy of the Hale Observatories,
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CASE HISTORIES

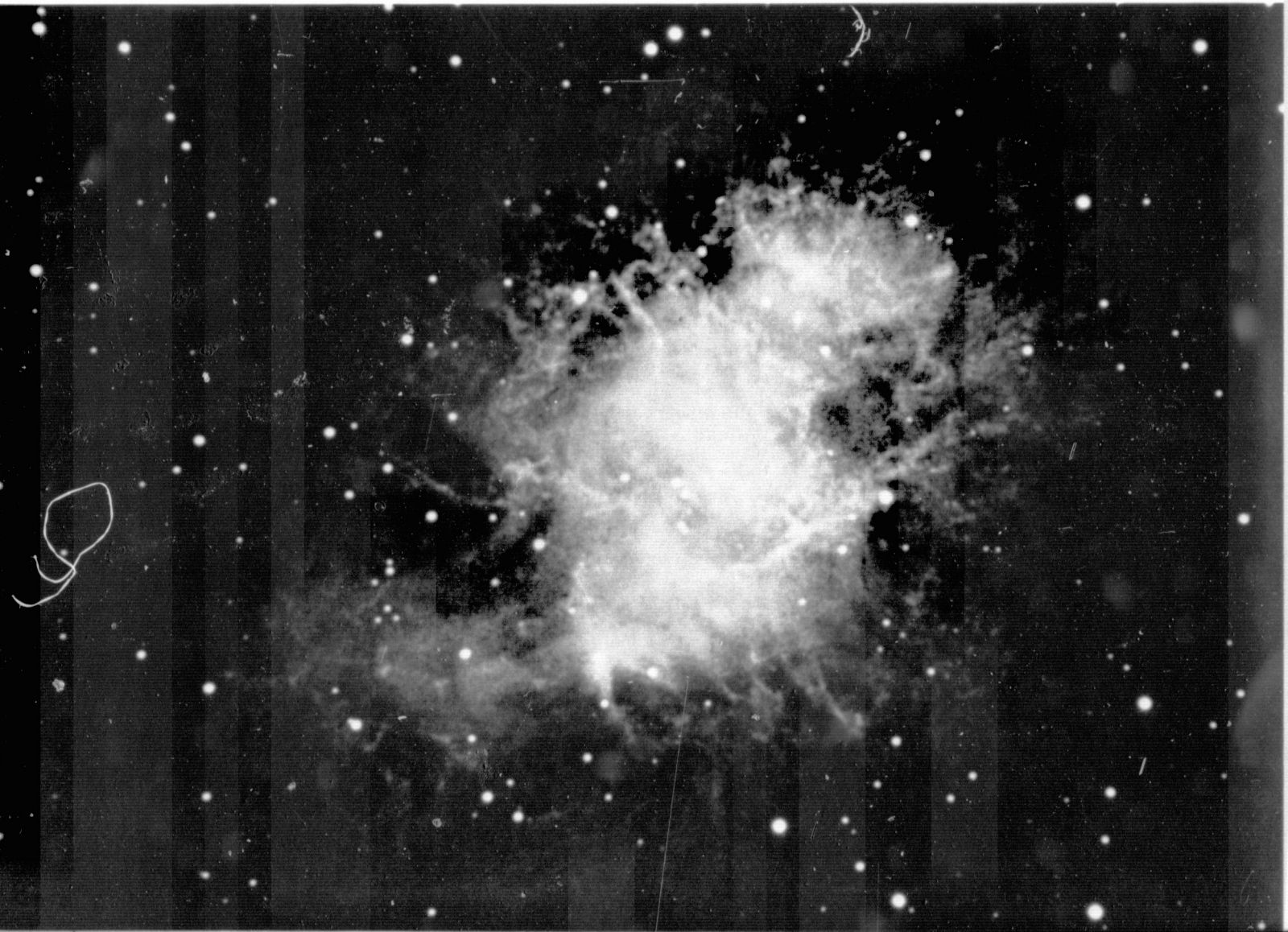
A few case histories of major findings in modern astronomy serve to illustrate the vital contributions made by telescopes operating in different wavelength regions. In each case, the results from any one telescope would not have solved the problem at hand. In some cases, the problems are still unsolved and are awaiting the availability of new investigative techniques.

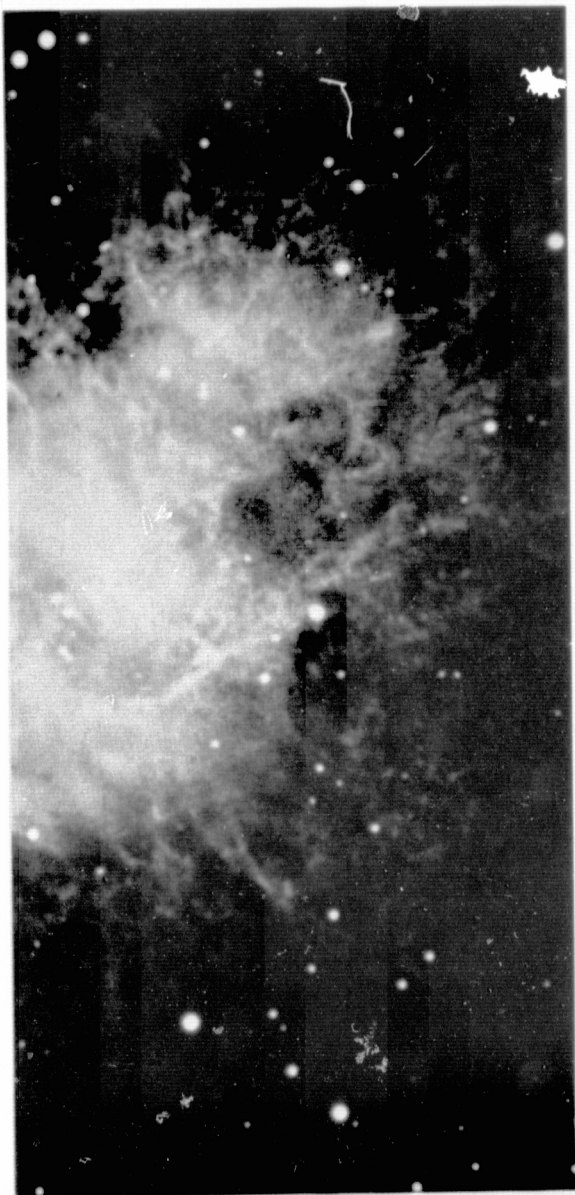
1. *The Crab Nebula*

In 1921, an astronomer at the Mt. Wilson Observatory noticed that photographs of the Crab Nebula (Figure 4) taken 11 1/2 years apart showed it to be expanding into space at a speed of almost 700 miles per second. By extrapolating the moving nebular filaments backwards along their trajectories, the observers found that they must have originated in a great explosion more than eight

centuries before. Indeed, just such an event, an extremely bright "new" star, had been seen at the same place in the sky by Chinese and Japanese astronomers in 1054 A.D. Thus, the Crab Nebula was explained (or so it seemed) as an expanding cosmic cloud, the remnant of the explosion of an old, dim star.

In 1948, an Australian radio telescope revealed that the Crab was one of the strongest sources of radio waves in space. A Soviet





astrophysicist explained this unanticipated radio emission, and also the visual light from the inner, smooth region of the Crab, as due to radiation from high-speed electrons, presumably produced in the original explosion, traveling through a magnetic field in the nebula. The situation thus appeared to resemble known phenomena in high-energy particle accelerators on earth, and the Soviet theory seemed verified when a basic prediction, namely that the light was polarized, was confirmed by other astronomers.

In the early 1960's, however, a series of U.S. rocket experiments discovered and measured X rays coming from the Crab. These measurements showed that the previous studies had barely fathomed the physical processes operating in the nebula. To begin with, the energy released from the Crab in the form of X rays was far greater than that represented by the visible-light and radio emissions. It was as though an engineer visiting the Hoover Dam had concluded that its hydroelectric output served only to run the elevators and lights directly associated with the facility and had overlooked the cables carrying immense electric current from the dam to power whole cities at distant locations. These X-ray studies established that the nebular emissions could not simply be energized by the explosion of 1054 A.D., for simple calculations showed that the electrons that generate the X rays have a lifetime of no more than a year or two. Thus, the true power source of the nebula remained to be found.

The final breakthrough came in

1968, when radio telescopes located a "beeping" source or "pulsar" in the Crab and visible-light observations then showed that the pulsar was a tiny star, in the heart of the nebula, that seems to blink on and off cyclically. In fact, the blink or pulse period corresponds to the rotation of the object, a dense neutron star. Beams of energy from this cosmic flywheel spin past the earth, creating the illusion of "pulses," and a gradual lengthening of the pulse period shows that the flywheel is decelerating, losing energy at just the right rate to produce the high-energy electrons that generate the nebular X rays and other forms of radiation. The compact neutron star, no larger than a typical city, was created and set spinning in the collapse and explosion of a star larger than our sun, as witnessed by oriental astronomers in the eleventh century, and as (apparently) recorded in rock drawings by American Indians in the southwestern United States. The story would be incomplete, and the nebula still an object of unrecognized significance, were it not for the complementary studies of X rays, radio waves, and visible light with space and ground-based telescopes.

Figure 5. The ejection of coronal material at the time of a solar flare as photographed from Skylab. (National Aeronautics and Space Administration and Naval Research Laboratory.)

2. Solar Flares

Solar flares are great eruptions on the sun, each one representing the release of enough energy to fill the United States' needs for many centuries. Their investigation is a particularly clear example of the need for correlated research with telescopes in the different wavelength ranges. The first solar flare was discovered in 1859 by an Englishman while he viewed a "white light" or visible-wavelength image of a large group of sunspots. Even from that initial observation, which was

accompanied by a magnetic disturbance on earth, it appeared possible that flares might have terrestrial effects. Today we know that they do indeed cause profound changes in the ionosphere and higher layers of the earth's atmosphere, thereby affecting broadcast communications. In addition, scientists are investigating the possible effects of flares and other transient solar phenomena on the weather.

As astronomers progressed in the study of flares, they found that the basic visible eruption (usually most

apparent in the red light of hydrogen) occurs in the chromosphere, a thin layer just above the visible surface of the Sun. From theoretical studies, it became clear that the only likely source of energy for flares is the solar magnetic field. However, very comprehensive measurements with ground-based telescopes have demonstrated that there is no consistent detectable change in the magnetic field at the solar surface ("photosphere") during a flare. On the other hand, profound changes in the structure of the corona (the hottest and outermost region of the

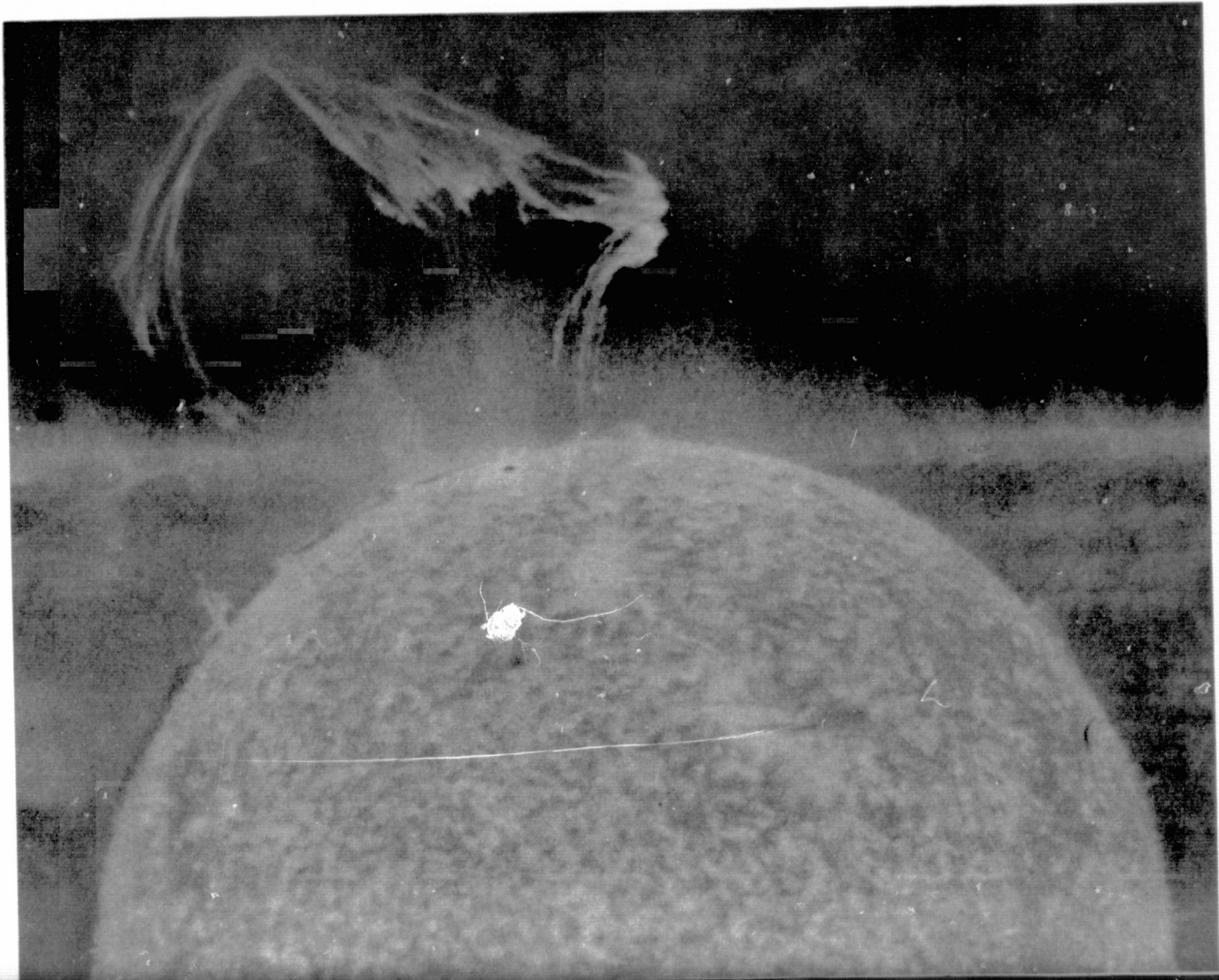
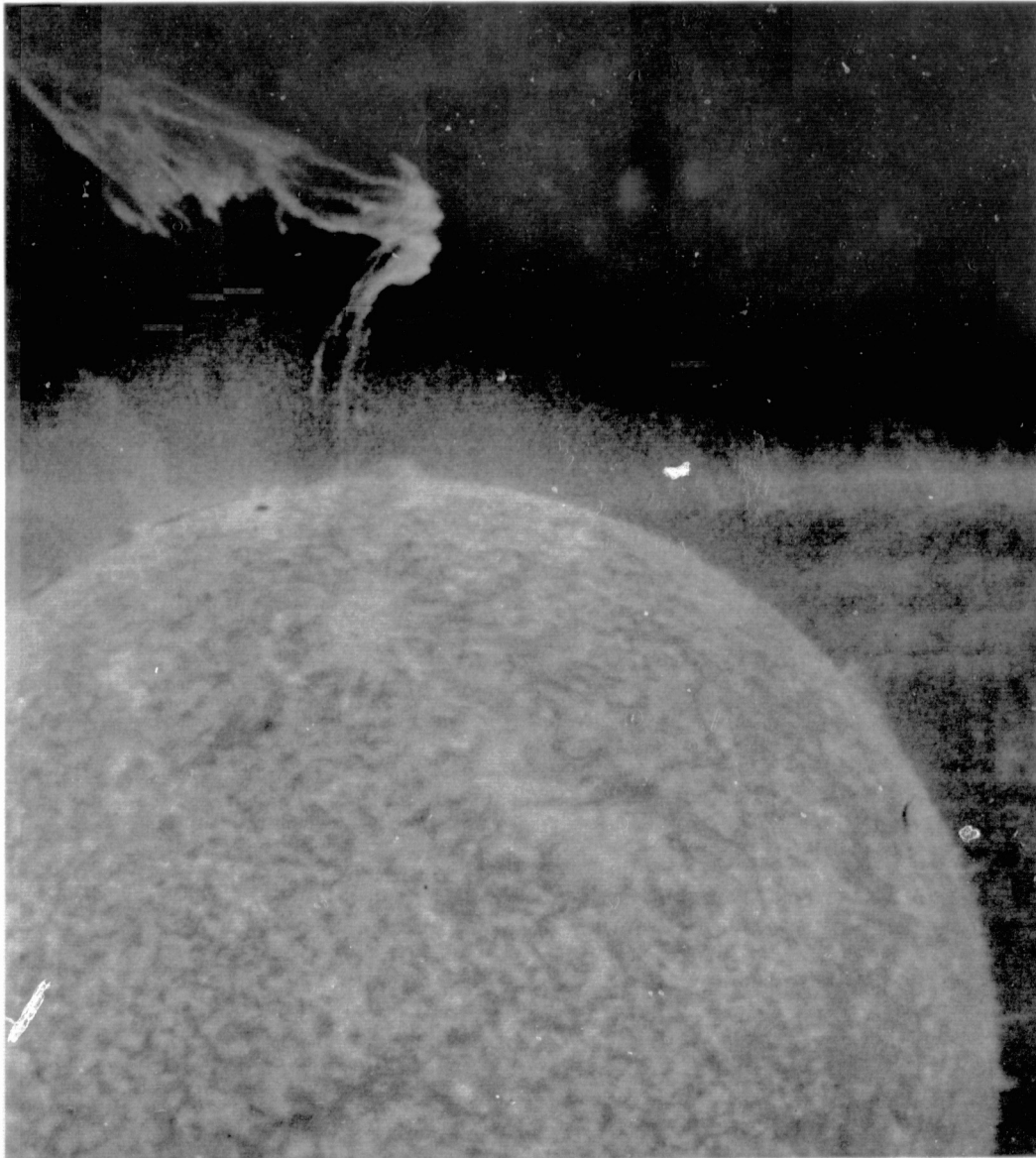
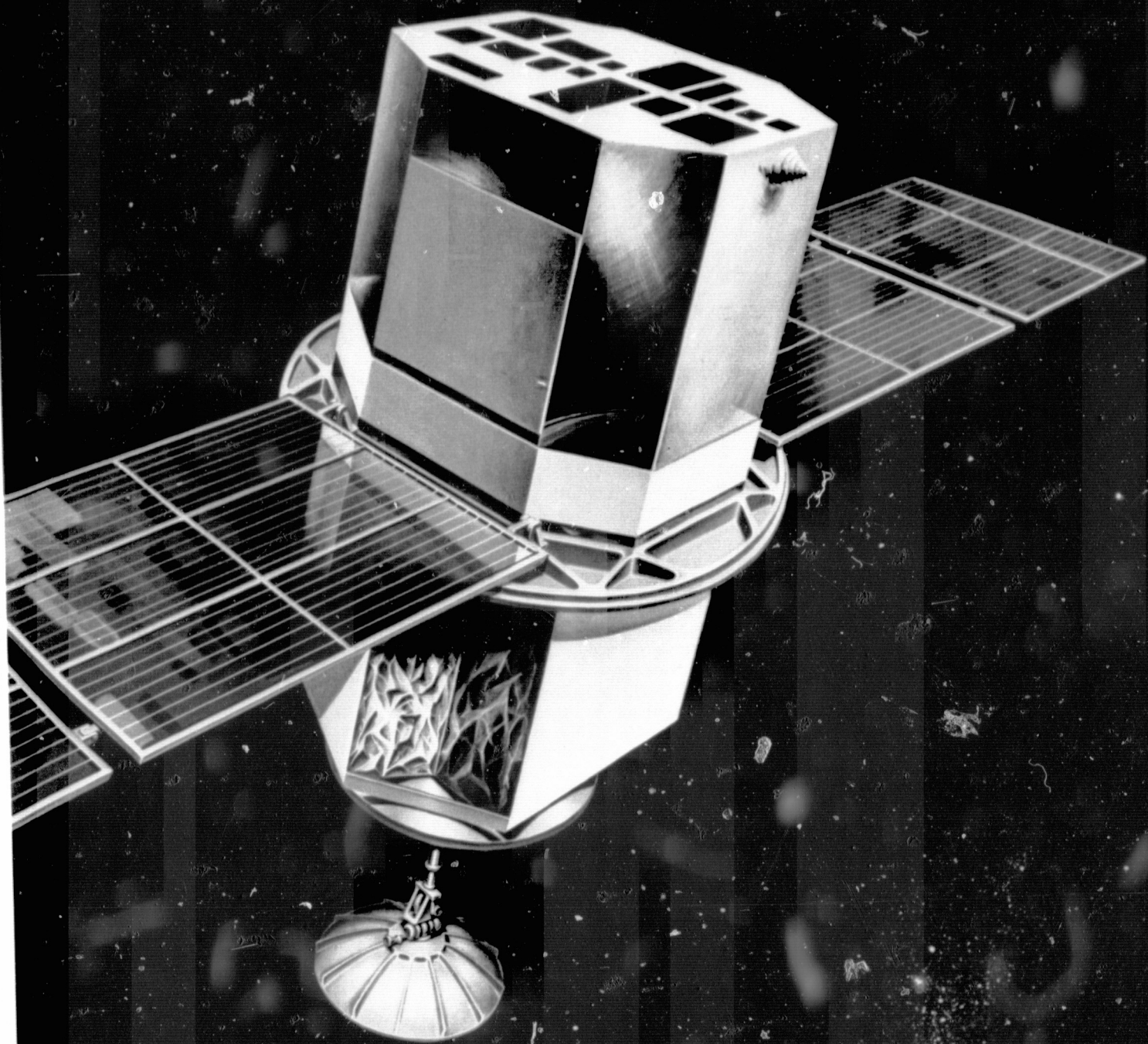


Figure 6. Artist's conception of the proposed Solar Maximum Mission. (National Aeronautics and Space Administration.)



solar atmosphere) have been observed during flares, thanks to telescopes carried on Skylab (see the cover and Figure 5) and on the seventh Orbiting Solar Observatory (OSO-7). Instruments on these spacecraft actually viewed the corona and its disturbance in white light at altitudes above the sun's surface that cannot be observed from the ground (except during brief moments of total eclipses) due to the interfering, much brighter light of the photosphere, which is scattered by dust and gas in our atmosphere. The changing coronal structures are thought to represent varying magnetic field configurations, thereby suggesting that the *in situ* source of solar flare energy may lie above the photosphere, in solar regions where the magnetic field has not yet been measured. Such measurements finally will be possible with a special ultraviolet telescope that is among the wide range of instruments to be carried on NASA's proposed Solar Maximum Mission (Figure 6).

Solar flares are of special interest because of their great energy, their effects on earth, and the remarkable plasma phenomena that occur in them, as revealed by X-ray, gamma-ray and radio telescopes. Examples are the nuclear reactions that occur in a large flare, as discovered with a gamma-ray telescope on OSO-7, and the propagation of large plasma disturbances from flares far out through interplanetary space to the earth's orbit and beyond, as recorded by radio telescopes carried on Explorer and Interplanetary Monitoring Platform satellites and by plasma detectors carried on many spacecraft.



3. *The Nature of Interstellar Gas*

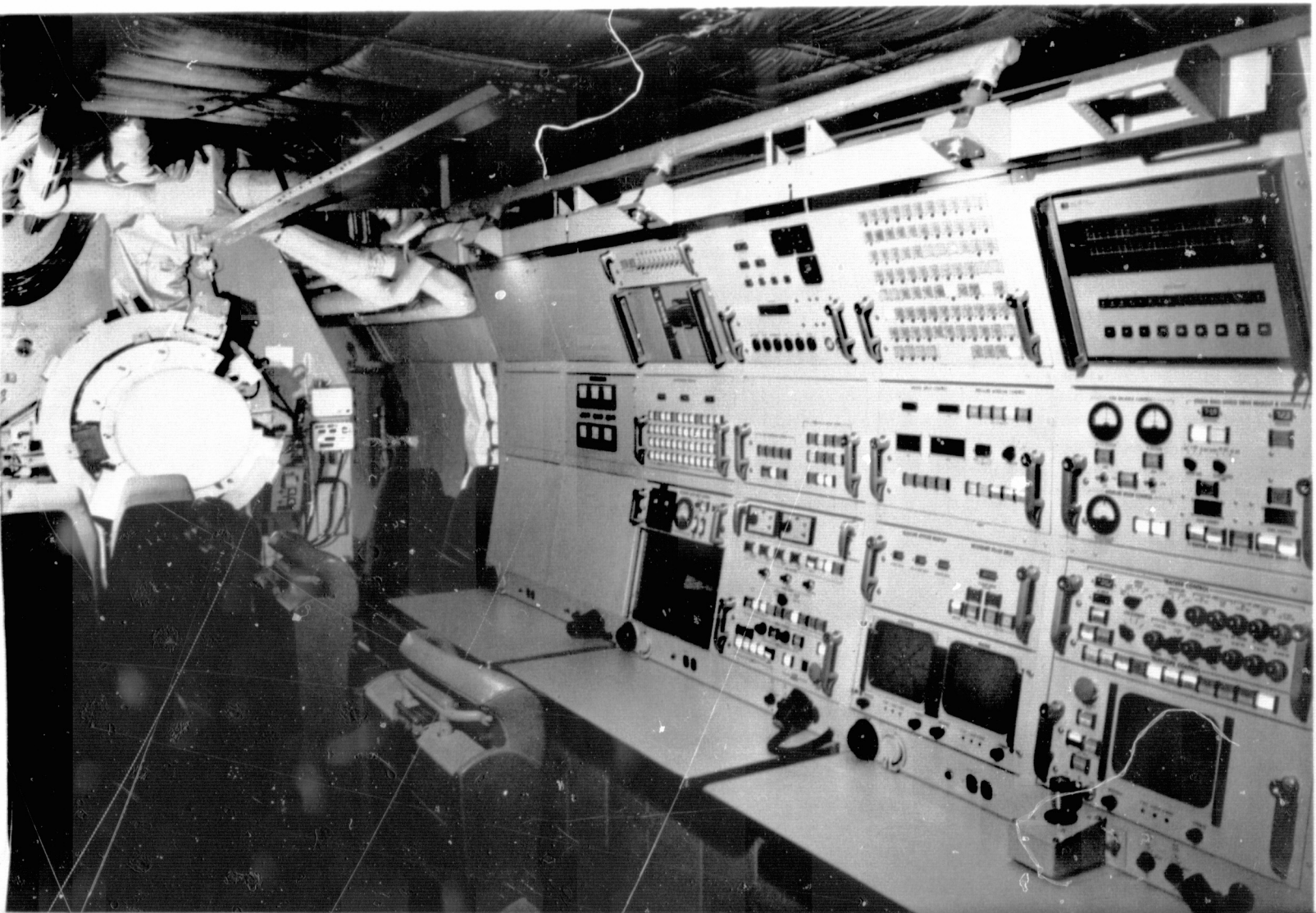
Since 1904, astronomers have known that a thin, gaseous medium pervades space in our Milky Way galaxy. In fact, it appears that stars are born from this gas when it clumps together and condenses in localized regions. Some stars explode at the ends of their lifetimes, returning much of their material to the interstellar gas. Others expel matter into space more slowly, as does our Sun through its "solar wind." With optical and radio telescopes, observers identified a few atomic constituents of the gas and several dozen molecules. However, these ground-based techniques were incapable of determining the abundances of the chemical elements in the interstellar gas, because the key diagnostic indicators of most of the important elements are produced in ultraviolet radiation. Recently, with NASA's Orbiting Astronomical Observatory, *Copernicus* (Figure 3), it became possible to study these diagnostic spectral "lines."

The remarkable result of these investigations is that many of the heavier elements are highly deficient in the interstellar gas, compared to their abundances in normal stars such as the Sun. This raises the question: if stars are born from the gas and return their matter to the gas, why don't the stars and gas have similar chemical composition? A preliminary conclusion is that the missing heavy elements have actually cooled and condensed from the gaseous to the solid state, so that they are present as tiny interstellar dust grains, which cannot be analyzed in detail with ultraviolet light. In fact, such grains often occur in dense

clouds that visible and ultraviolet light cannot penetrate. At the centers of such cold clouds, new stars may be forming, according to recent, limited results from infrared telescopes on aircraft (Figure 7), on balloons, and in high mountain observatories. The infrared rays *do* penetrate the clouds, and future studies of longer infrared waves, observable with spaceborne instruments, may enable us to pin down the physical nature of stellar creation. Thus, a discovery made possible by ultraviolet-telescope studies suggests follow-up investigations in infrared light that may be of even greater significance.



Figure 7. The Gerard P. Kuiper Airborne Infrared Observatory. A computer-controlled infrared telescope in a C-141 jet aircraft. External view (above) and internal view (below). (National Aeronautics and Space Administration.)



4. The Black Hole

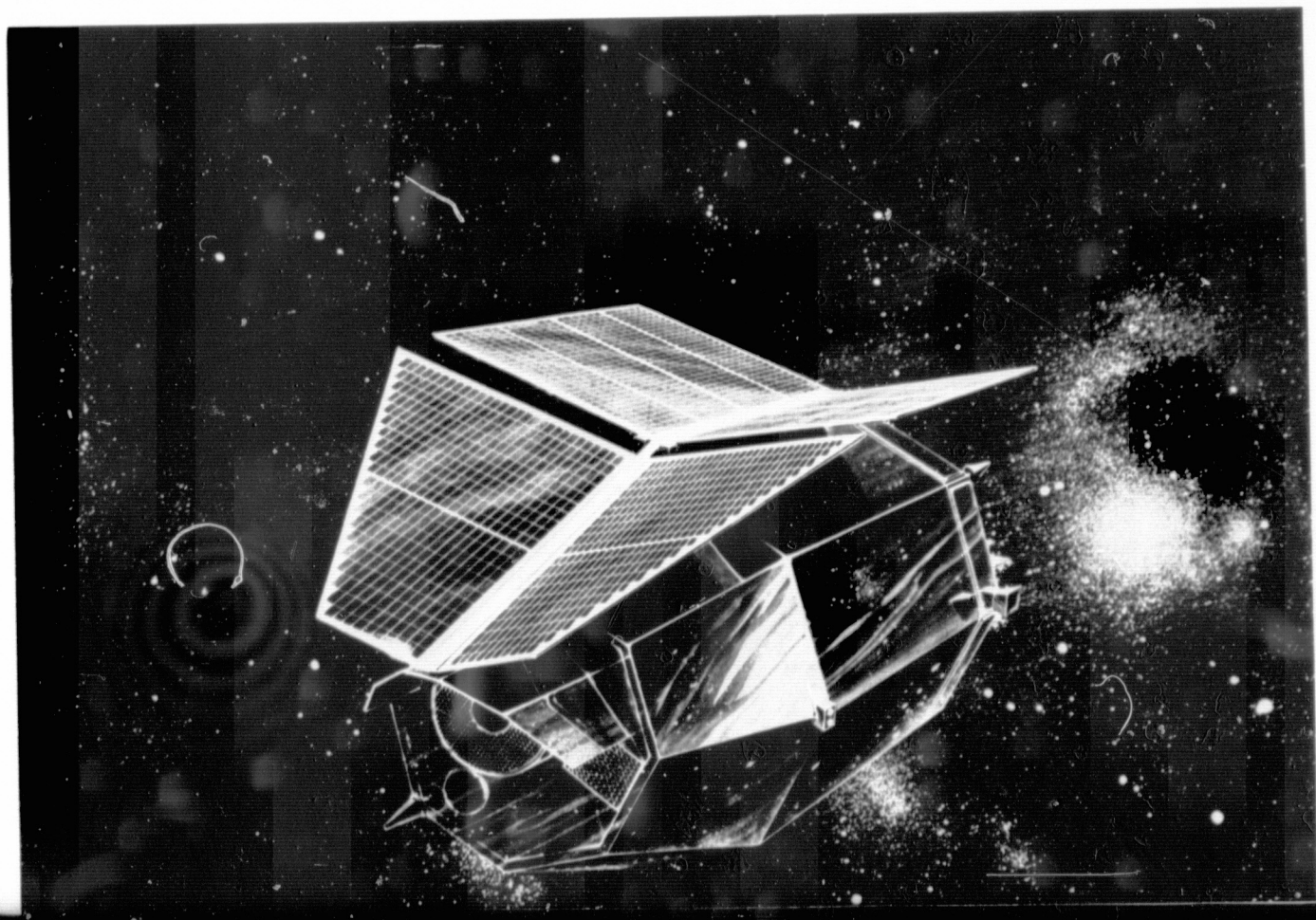
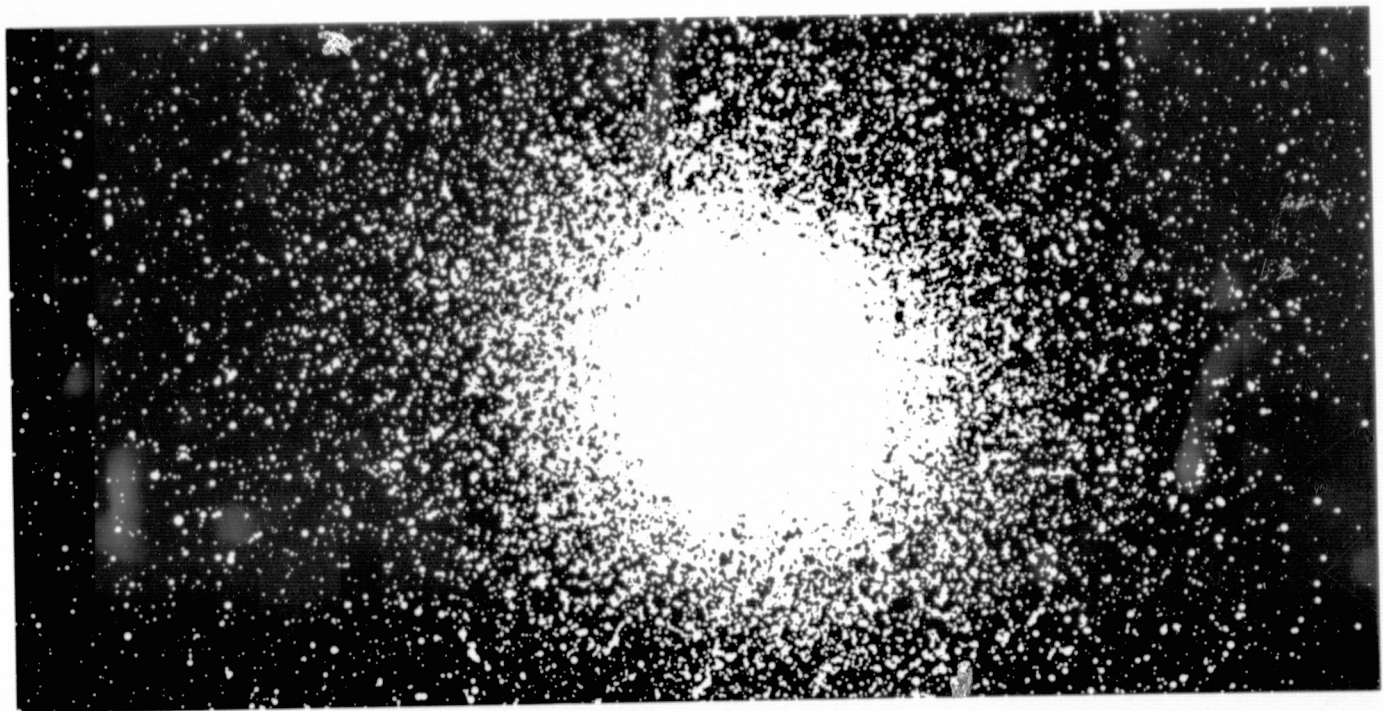
Since the 1930's, experts on gravitation and the general theory of relativity have speculated on the possible existence in space of the so-called "black holes." These hypothetical objects are stars that have been compressed so much that their interiors consist of matter in a denser state than is known anywhere else, and with gravitational fields so powerful that even a ray of light cannot escape. (Hence the name, "black hole.") Physicists wondered, however, if there were any way to detect such an object from earth and verify the abstruse theoretical predictions.

In the 1960's, a spaceborne instrument detected X rays originating in the constellation Cygnus. Further space experiments with the first Small Astronomy Satellite (SAS-1) showed that the X rays actually came from the direction of a faint blue star. Subsequently, it was found that the X-ray source must be the smaller member of a binary star system, and in fact, the orbiting companion of the blue star. From analysis of the blue star's motion, it was shown that the X-ray source is a star much more massive than our Sun. Yet, the light from any ordinary star as massive as this would be readily detectable with present visible-light instrumentation, and no such light was found. The X-ray source is probably not a neutron star because persuasive theoretical arguments indicate that its mass is too high. The only reasonable explanation appears to be that the unseen star is in fact the first likely case of a black hole.

Figure 8. The globular cluster 47 Tucanae. Several other globular clusters are X-ray sources which may result from the presence of black holes in the centers of the clusters. (Courtesy of the Cerro Tololo Inter-American Observatory.)

Further studies with X-ray telescopes aboard the NASA satellites OSO-7 and SAS-3 show that there also are X-ray sources located in several of the globular star clusters (Figure 8) of the Milky Way galaxy. According to one theory, these X rays are produced when stars near the very heart of such a cluster pass too close to a black hole and are literally torn apart in its immense gravitational field. Further research with the more powerful X-ray telescopes in NASA's future High Energy Astrophysical Observatories (Figure 9) may verify this hypothesis.

Figure 9. Artist's conception of a High Energy Astrophysical Observatory. (National Aeronautics and Space Administration.)



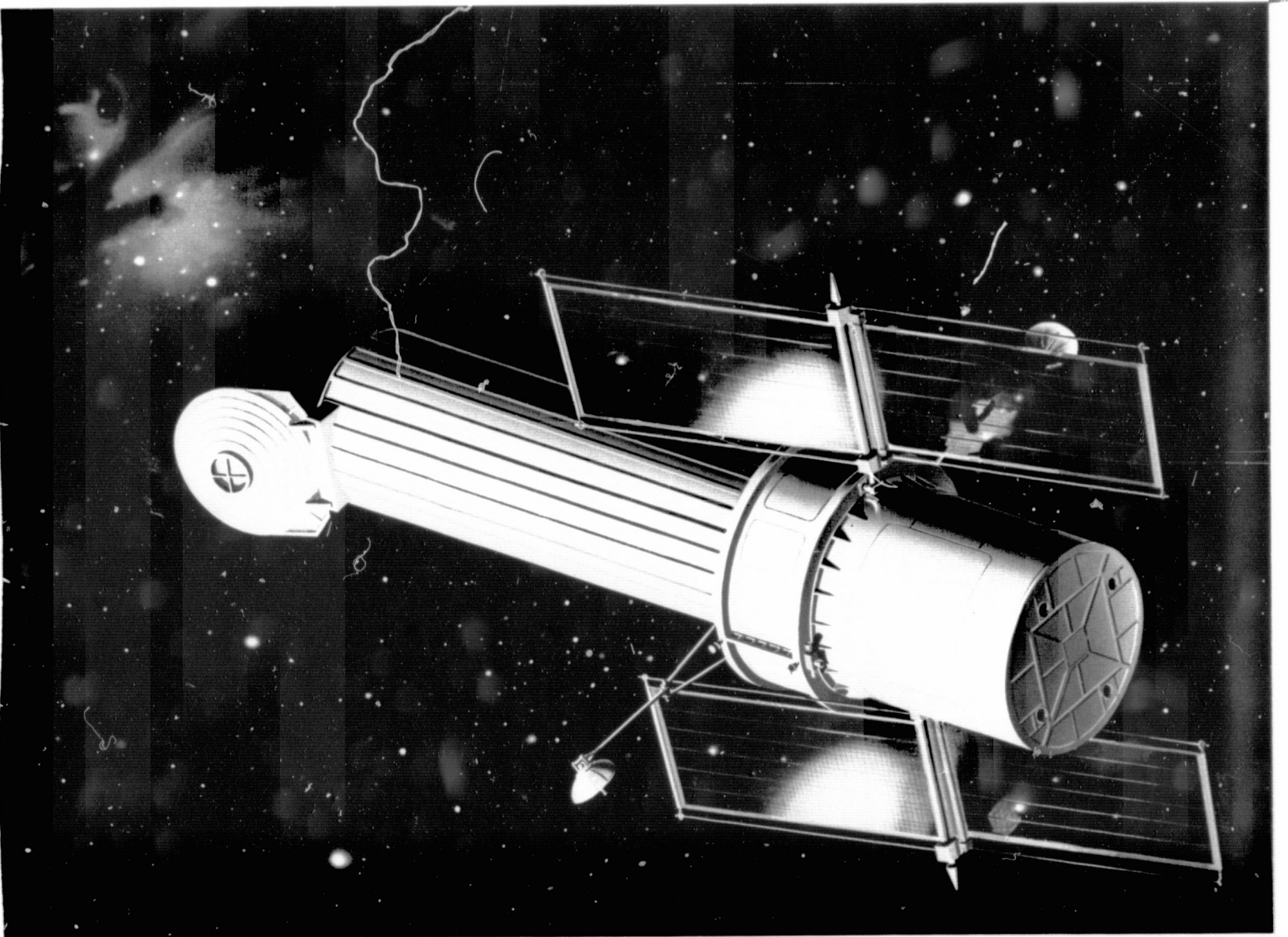
5. The Nature of the Universe

It should be noted that our atmosphere also exerts severe limitations on observations in visible light, as well as screening out ultraviolet, X rays and certain other radiations. Studies of the extremely faint light from distant objects near the edge of the observable universe are prevented by such atmospheric effects as the blurring of optical images and the dim, but seriously interfering light emissions of atmospheric molecules, plus light scattered by airborne dust particles. By study of the most distant galaxies and quasars with the proposed Space Telescope (Figure 10), located above the atmosphere, it should be possible to literally investigate the structure and history of the cosmos and to determine whether the universe was born in a giant explosion as proposed in the "Big Bang" theory of cosmology, or in some other manner. It will also be possible to determine whether the universe (now known to be expanding) will continue expanding forever, or if some day it will reverse and begin a collapse that will eventually merge and destroy all the galaxies and stars in space, only to expand again to form new galaxies, as proposed in the "Oscillating Universe" theory.

CONCLUSION

The solution of astrophysical problems in the exploration of space has been found to depend on complementary investigations with sensitive telescopes operating in several wavelength ranges. The preceding "case histories" illustrate how well this multidisciplinary approach has served us in our quest for understanding the astronomical universe.

Figure 10. Artist's conception of the proposed Space Telescope. (National Aeronautics and Space Administration.)



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