Space Astronomy

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Ground-based astronomical observations are confined to the two spectral windows of the terrestrial atmosphere, the optical and the radio. The narrow spectral sensitivity of the human eye coincides with the optical window of the atmosphere. This very fortunate coincidence, or evolutionary adaptation of all living organisms, made possible the early development of naked-eye astronomy. The radio window was discovered by Karl Jansky in only 1932. Since then, radio-astronomical observations have produced many fascinating and often totally unexpected discoveries such as the pulsars, the quasars, and the 3°K cosmic radiation.

After a slow beginning with balloons and modest rocket flights in the 40's and the 50's, space astronomy was truly established in the 60's with the launching of special astronomical satellites. These flights have already produced an impressive harvest of scientific discoveries and the future appears most promising for all the fields (gamma-ray, x-ray, ultraviolet, infrared, and radio) of solar and galactic space astronomy.

Gamma-ray astronomy must cope with very low counting rates (less than one photon per hour), the intense cosmic ray background, and the gamma rays produced by the cosmic rays in the atmosphere. In spite of these difficulties, Clark, Garmire, and Kraushaar managed to detect last year, with the Orbiting Solar Observatory III (OSO) satellite, the galactic center and the galactic plane, in spite of the limited directivity of their gamma-ray detector. Spark chambers can provide much higher directivity but they are too heavy for present satellite missions. They have been tested successfully, however, in balloon flights setting upper limits for different suspected discrete gamma-ray sources. No such source has yet been clearly identified.

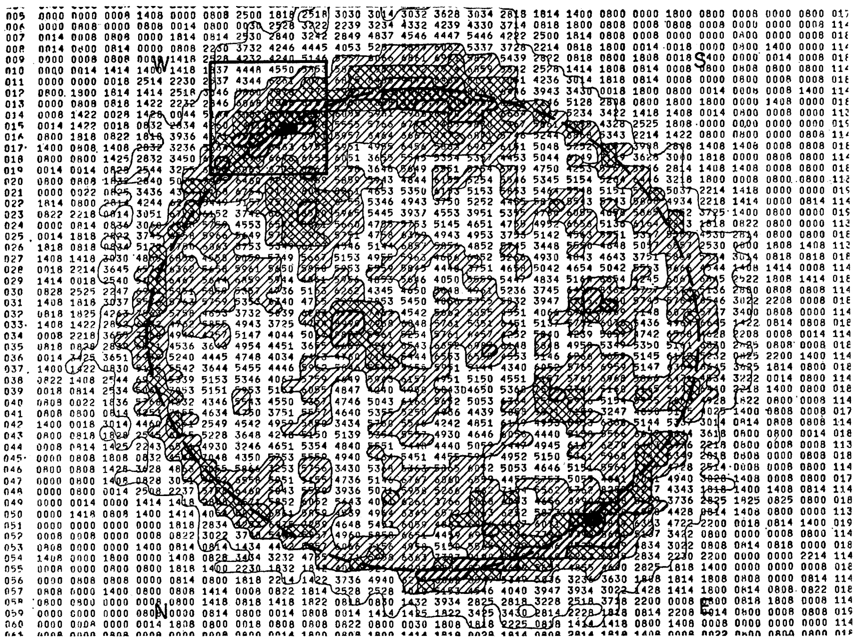
Solar x-ray astronomy is now providing a nearly continuous patrol for x-ray bursts from flare events. These bursts can cause shortwave fadeouts and other sudden disturbances on earth, and can be dangerous for astronauts in space. A spectacular x-ray picture of the sun (Fig. 1), with several active regions, was obtained by a group from American Science and Engineering, Inc., last year with a special rocket-borne x-ray telescope.

The discovery of the first discrete nonsolar, x-ray sources came as a totally unexpected bonus when Giacconi, Gursky, and Paolini tried to detect the x-ray albedo of the moon in 1962. More than 30 such sources have been discovered since then. One of them was identified with the famous Crab Nebula (a past supernova) by launching a rocket, during its brief occulation by the moon, in July of 1964. Now we have also detected x-ray pulses from the Crab Nebula pulsar (NP 0532). The only positively identified extragalactic source is the exploding galaxy M87 (Virgo A). The association of x-ray sources with cataclysmic events in stars and galaxies, and the diffuse x-ray background that has been detected in the range between 1 kev and 1 Mev, place x-ray astronomy in the frontier of the most puzzling cosmological problems.

Solar ultraviolet astronomy was pioneered by the Naval Research Laboratory group of Friedman and Tousey with early rocket flights. Today we have a detailed picture of the solar spectrum in the ultraviolet region; the Harvard group of Goldberg has been scanning continuously the solar disk. with a resolution of approximately 35 arc seconds, from the recent OSO satellites. These scans are made at the wavelengths of many different spectral lines in the 300- to 1400-Å range, and provide a detailed description of the chromospheric or coronal layer where the emission of the particular line prevails. A series of such spectroheliograms at different wavelengths has confirmed that the temperature gradient in the transition zone is extremely steep, rising from 40,000°K to 400,000°K in only a few hundred kilometers of this complex solar layer. Figure 2 is a monochromatic contour diagram of the sun in the line of Mg X (625 Å) from the OSO-VI satellite.

The first Orbiting Astronomical Ob-

Fig. 1. X-ray photograph of the sun taken by a rocket-borne x-ray telescope, 8 June 1968. Active regions are easily identified. [American Science and Engineering, Inc., Cambridge, Massachusetts]



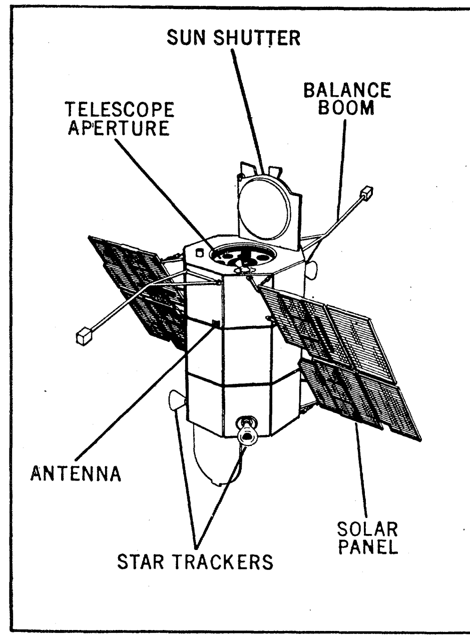


Fig. 2 (left). Intensity pattern of the sun in the 625-Å line of Mg X, drawn from the digital data obtained by Harvard with their OAO-VI ultraviolet spectroheliograph. The Mg X line originates in the corona, and one can readily see the enhancement over active regions, especially at the east and west limb. Fig. 3 (right). Configuration of the OAO-II which is now successfully conducting galactic and planetary observations in space.

servatory (OAO-I) had an early power failure and did not accomplish its mission in 1966. OAO-II, however (Fig. 3), is now carrying out successfully galactic and planetary observations in the ultraviolet with a battery of eleven 8- to 16-inch telescopes. Early results from the Smithsonian experiment, which is scanning the sky at four wavelengths in the ultraviolet, indicate that the young blue stars so far observed are about ten times hotter than expected. The Wisconsin experiment, which is doing a spectroscopic analysis of individual stars and galaxies, reports that the nucleus of the Andromeda Galaxy contains many more hot blue stars than it was suggested by extrapolations from the visible.

Infrared observations are still carried out to a considerable extent from balloons and aircraft which can fly above most of the atmospheric absorption in the 1- to 1000-micron range. Observations have revealed the existence of many bright infrared stars and nebulae, and have shown that a significant fraction of galaxies and quasars radiate more energy in the far infrared than in all other wavelengths combined. The infrared region contains several spectral lines of great importance such as those of water vapor and different organic molecules. Such observations have already been carried out by the Mariner missions to Mars and Venus. The rather crude infrared detectors of the past years are now improving rapidly and infrared astronomy, with its ability to penetrate through the interstellar dust clouds, will undoubtedly make invaluable contributions in the coming years.

Low-frequency radio astronomy can be performed only from space vehicles above the maximum of the ionosphere; radio waves longer than about 50 meters are reflected back at the top side of the ionosphere. Most of the past observations, in some of which I was directly involved, give only the integrated emission of the entire galaxy. The reason is that at these long wavelengths ($\lambda \sim 300$ meters), the relatively short dipole antennas ($L \sim 30$ meters) carried by spacecraft have a very limited directivity. These observations, which have shown that the low-frequency spectrum of the galaxy reaches a maximum near 2 megahertz, provide valuable information on the magnetic fields of the galaxy and the energy spectra of the cosmic rays. The first Radio Astronomy Explorer (RAE-I) satellite is now trying to make observations of higher resolution using two huge, symmetrically arranged, V-type antennas, nearly a quarter of a mile long. In the solar domain, space radio astronomy can make a valuable contribution in the study of the outer corona by extending the type II and type III solar radio bursts in the low-frequency region of the spectrum.

Optical astronomy should not be excluded from space astronomy. The beautiful pictures of the solar granulation, taken 80,000 feet above the ground with Princeton's balloon-borne telescopes, are a testimonial of what small telescopes can accomplish above the turbulent layers of the terrestrial atmosphere. A 12-inch telescope, for example, can attain in space the resolving power of the 200-inch Palomar telescope.

A panel of distinguished scientists, under the chairmanship of Goldberg, was convened recently by NASA to set the objectives and plan the future missions of space astronomy. It is expected that their report will be published by the end of October 1969 and therefore it will be available at the symposium on Space Astronomy that will take place in Boston, 29–30 December 1969, during the Annual Meeting of the AAAS. In this symposium many prominent scientists in the different fields of space astronomy, such as Goldberg, Code, Friedman, Low, and others, will review the many exciting discoveries of the recent years and will discuss the fascinating prospects for space astronomy in the years to come.

Michael D. Papagiannis
Boston University,
Boston, Massachusetts