High Energy Astronomy: Observations of Gamma Radiation

Gamma ray astronomy is young, and there are many ambiguities in the few measurements obtained so far. Nevertheless, several point sources of high energy gamma rays have been recently observed, and one of them may be variable. Other data suggest that more gamma rays are emitted by the Milky Way than by other regions of the sky. Next year the second Small Astronomy Satellite, which will be launched by the National Aeronautics and Space Administration, and the Thor-Delta 1 (TD-1) satellite, which will be launched by the European Space Research Organization, should provide the first detailed map of the sky as obtained from gamma ray emission.

Two major problems occur in gamma ray astronomy which do not occur at the energies of visible light. The earth's atmosphere is impenetrable to gamma rays so that all experiments must be lifted above the atmosphere with balloons or satellites. Even above the atmosphere the intensity of celestial gamma rays is very low compared with the high background of cosmic rays.

Stellar radiation had previously been observed throughout the electromagnetic spectrum, except in the gamma ray region, which is defined roughly as radiation with energies of 50×10^6 electron volt (50 Mev) or higher. Gamma rays with the same energies are produced by large accelerators and have been routinely detected for years. Although the logistics of flying a gamma ray detector in a balloon or satellite can be quite complex, the essential designs of the instruments used in astronomy have been borrowed from those of high energy physics.

The way in which a gamma ray most often interacts with matter is fundamentally different from that of visible light. Whereas visible light is absorbed by transferring its energy to an electron already existing in matter, a gamma ray is absorbed in matter by decay into an electron-positron pair—that is, two new particles are formed. It is only through the detection of the electron-positron pair that the presence of a gamma ray can be inferred.

One basic instrument for detecting gamma rays is the optical spark chamber. It usually consists of a layered assembly of metal plates that can be quickly charged to a high voltage. The metal plates serve two functions. They provide material necessary to convert a gamma ray into an electron-positron pair, and they sustain a series of sparks that follow the paths of the pair. From a photograph of the spark paths, the energy and the original direction of the gamma ray can be determined. The data from these photographs can be correlated with the data from star sensors for the purpose of determining the origin of each gamma ray.

Because the conversion of a gamma ray into an electron-positron pair is relatively improbable, the efficiency of a spark chamber is usually only about 30 percent in detecting all the gamma rays that passed through it. An additional problem is that most gamma rays entering the spark chamber are not coming from outside the solar system, but from collisions of cosmic rays with the atmosphere. To minimize this problem most balloon experiments have been launched near the equator, where the earth's magnetic field is most effective in deflecting cosmic rays. In addition, a rather elaborate system of scintillation and Cerenkov detectors—also borrowed from high energy physics—is used to trigger the spark chamber only when desired gamma rays pass through.

Discrete sources of gamma rays, as well as a diffuse source of gamma radiation at the galactic center, have been observed. The concentrated sources have been identified by a group headed by G. M. Frye, Jr., of Case Western Reserve University in Cleveland and V. D. Hopper of the University of Melbourne in Australia. In a series of balloon flights launched from Australia they have reported four discrete gamma sources, two in the direction of the galactic center and one each in the directions of the constellations of Sagittarius and Libra.

The source identified in Libra is very interesting to the astronomers because it appears to be variable. It appeared clearly in one balloon flight but not in a different flight 9 months earlier.

In addition to discrete sources, there is evidence for a diffuse source of gamma radiation at the galactic center. The first certain measurements of celestial gamma rays, made by G. W. Clark of Massachusetts Institute of Technology, G. P. Garmire of California Institute of Technology, and W. L. Kraushaar of the University of Wisconsin, with the third Orbiting Solar Observatory (OSO), indicated that the flux of gamma rays along the galactic plane near the center is about four times greater than that in the rest of the sky. A group from Goddard Spaceflight Center in Greenbelt, Maryland, headed by C. E. Fichtel confirmed this result; but the Case-Melbourne scientists have not observed this effect. Present data are not precise enough to determine whether the excess flux is due to discrete sources or whether it has some other origin.

There are many theoretical models for the production of gamma rays; some of them have the π^0 meson as an intermediate stage. When cosmic ray protons collide with interstellar hydrogen, which is known to be abundant in the galactic center, these mesons are produced in copious numbers. Each π^0 can subsequently decay into two gamma rays. Such a model of radiation from the galactic center predicts a relatively large number of gamma rays with energies greater than 100 Mev. This prediction is consistent with both the OSO-III and Goddard experiments. Better measurements of the energies of gamma rays from the galactic center could give a decisive test of the validity of the galactic π^0 model.

Most models for the production of gamma rays do not allow for time variability. One model that predicts a variation with time has been proposed by a Russian astronomer, I. S. Shklovsky. In this model, gamma rays are produced by events that appear to resemble solar flares. Objects that emit radiation at abnormally fast rates, such as quasars and Seyfert galaxies, could produce powerful bursts of gamma rays with energies in the 1- to 1000-Mev range. This model would be consistent with the variability that appears to have been observed.

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