THE GAMMA RAY EXPERIMENT FOR THE SMALL ASTRONOMY SATELLITE B (SAS-B)

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Abstract

A magnetic core digitized spark chamber gamma ray telescope has been developed for satellite use and will be flown on SAS-B in less than one year. The SAS-B detector will have the following characteristics: Effective area = 500 cm^2, solid angle = ¼ SR; Efficiency (high energy) = 0.29; and time resolution of better than two milliseconds. A detailed picture of the galactic plane in gamma rays should be obtained with this experiment, and a study of point sources, including short bursts of gamma rays from supernovae explosions, will also be possible.

1. Introduction

The SAS-B gamma ray telescope represents the first satellite version of a planned evolution of a gamma ray digitized spark chamber telescope which began with the development of a balloon borne instrument. The telescope is aimed at the study of gamma rays whose energy exceeds about 20 MeV.

In the early 1960's, it was realized that the celestial gamma ray intensity was very low compared to the high background of cosmic ray particles and earth albedo. For this reason, a picture type detector seemed to be needed to identify unambiguously the electron pair produced by the gamma ray and to study its properties - particularly to obtain a measure of the energy and arrival direction of the gamma ray. In addition, the secondary gamma ray flux produced by cosmic rays in the atmosphere, even at the altitudes of the present large balloons, severely limits the gamma ray astronomy which can be accomplished with balloons and dictates that gamma ray astronomy must ultimately be accomplished with detector systems on satellites. The combination of the need to develop a satellite instrument together with the requirement of handling a large amount of data led us in 1963 to begin development of a rugged magnetic core digitized spark chamber which could also be used for many other experiments.

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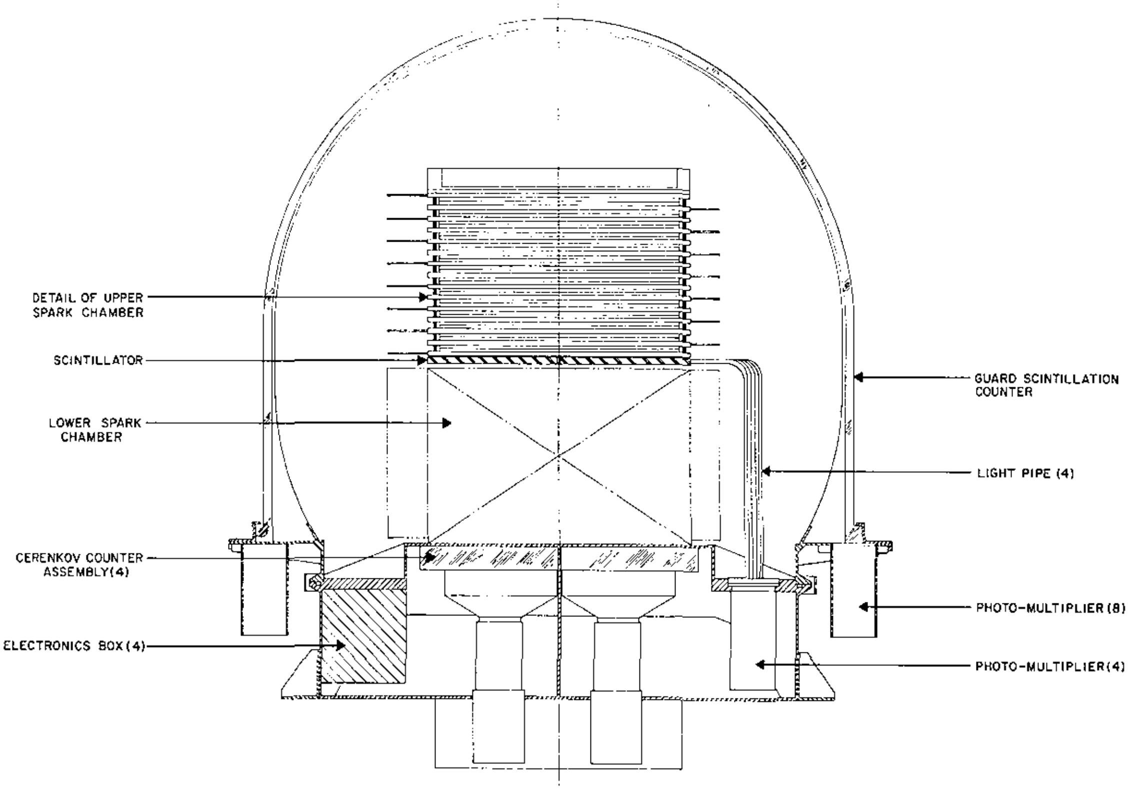
D. L. Bertsch will present the paper at the meeting.

2. General description of the Instrument

A schematic diagram of the gamma ray telescope to be flown on the SAS-B satellite is shown in Fig. 1.



SAS-B GAMMA RAY EXPERIMENT
FIG. I

The spark chamber assembly consists of 16 spark chamber modules above a set of four central plastic scintillators and another 16 modules below these scintillators. Thin tungsten plates, averaging 0.010 cm thick -- corresponding to 0.03 radiation lengths -- are interleaved between the spark chamber modules. In the upper-half of the spark chamber assembly these plates serve a dual purpose, first to provide material for the gamma ray to be converted into an electron pair and secondly to provide a means of determining the energy of the electrons in the pair. An estimate of the energy of each electron is obtained by measuring the average Coulomb scattering as they pass through the plates in the upper and lower spark chamber assemblies. The plates in the lower half of the spark chamber assembly are there primarily for this latter purpose.

The spark chamber assembly is triggered if a charged particle passes through one of the four equal plastic scintillator tiles and the corresponding directional lucite Cerenkov counter immediately below, and, at the same time, there is no pulse in the surrounding plastic scintillator anticoincidence dome. Each of the four scintillator Cerenkov counter telescopes acts independently of the others and has a full-width-half-maximum opening angle of about 30^{o}. The anticoincidence dome prevents the spark chamber system from being triggered by charged particles, and the directional feature of the Cerenkov counter prevents the telescope from being triggered by upcoming neutral events or charged particles which might stop above the central scintillator before reaching the anticoincidence dome. Absolute time of each gamma ray event will be known to about 1 millisecond; thereby, permitting a careful analysis of pulsars and other time varying objects.

Another spark chamber trigger mode is the hodescope trigger, which is included to detect bursts of gamma rays predicted to be associated with supernovae explosions. In this mode, the anticoincidence dome is not used since some of the gamma rays in the postulated short ($<$ 1 microsecond) pulse would probably convert in the dome giving rise to a pulse which would be detected by the phototubes viewing the anticoincidence dome. Instead all four scintillator counters and all four Cerenkov counters are required to have a coincidence within 0.4 microseconds, so that an electron shower produced in the telescope by several gamma rays interacting in the thin plates between the spark chambers will trigger the system. Some complex cosmic ray induced events may also trigger this mode, but they can be rejected by an analysis of the spark chamber data for the particular event.

Turning to the spark chambers, each module consists of two parallel planes of 200 wires with a gap between the planes of 0.4 cm. The wires in each plane are parallel and orthogonal to the wires of the opposite plane. Each of the grid wires threads a magnetic core which is activated when current flows along the wires intercepted by the spark. Thus reading out and recording the location of the set cores provides two orthogonal coordinates for the intersection of the charged particle trajectory with each modular or z-level.

The data obtained in orbit are stored at a one kilobit per second rate on magnetic tape. Once per orbit, the tape recorder will be commanded into a playback mode to telemeter the information accumulated for that orbit to a ground receiving station. The spark chamber information will be analyzed using advanced versions of automatic computer techniques developed over the last several years to analyze balloon experiment data (Fichtel et al., 1971). The computer programs will examine all spark chamber telescope events. Events which cannot be analyzed automatically will be transferred to a Graphics Display Unit where a data analyst will examine the event and make necessary decisions to allow the automatic analysis to proceed. The display will also be used to analyze a selected number of "good" events to check the performance of the automatic procedure.

The effective area, which is limited by the size of the Cerenkov scintillators, is 540 cm^2. The opening angle for detection of gamma rays is approximately ¼ Sr. The efficiency for detection of gamma rays of very high energy is 0.29, and for detection of 100 MeV gamma rays is about 0.21.

The efficiency and solid angle will be determined precisely as a function of energy before launch by calibration at the synchrotron facility of the National Bureau of Standards.

By combining the energy and directional information for each electron in accordance with procedures described previously (Fichtel, Kniffen and Ogelman, 1969), the direction and energy of the primary gamma ray can be obtained. The uncertainty in the arrival direction for a gamma ray is about 1 ½° at 100 MeV and varies with energy approximately as $E^{-2/3}$. The threshold is not sharp, but is about 20 to 25 MeV. The energy of the γ-ray can be measured up to about 200 MeV, with an accuracy of about 30 to 40%.

It is planned that SAS-B will be launched from San Marco off the coast of Kenya into an approximately circular equatorial orbit with a 3° inclination and a 550 kilometer apogee. The satellite is capable of being pointed in any direction, but the time to change the direction of pointing is relatively long so that normally for the period of one orbit the satellite will point in essentially the same direction. Hence, for approximately 0.38 of the orbit the detector will point at the earth, and for another approximately 0.08 of the orbit the earth albedo gamma ray flux will be quite high leaving about 0.54 of the orbit for collection of celestial gamma ray data. Combined with an expected percentage live time (the period when cores are not being read out and the gamma ray telescope is ready to accept another event) of about 90%, the portion of an orbit during which celestial data is collected is estimated to be just under 0.5. The net exposure for a one week viewing period directed at some point on the celestial sphere will be about 3.3×10^7 cm^2 sec for 100 MeV gamma rays from a point source and about 10^7 cm^2 sr sec for diffuse radiation.

3. Possible Scientific Studies

SAS-B should be able to explore the galaxy with fine spatial and energy resolution. The latter will separate gamma rays of π^o origin from other processes, and the former will permit a better understanding of the dynamic processes occurring in our galaxy, as well as a search for point sources. Our galactic disk is believed to be in a state of dynamic equilibrium. The expansive pressures of the hot cosmic ray gas, the magnetic fields, and the kinetic motion of matter in the galactic disk are counter-balanced by the gravitational attraction of galactic matter (Parker, 1966). Of the three expansive pressures mentioned, that due to the cosmic rays is the only one which seems likely to have the capability of changing markedly over short periods (less than 10^4 years in this context), if some of the more accepted current concepts of the origin of cosmic rays are correct. Therefore, a study of the cosmic ray distribution in the galaxy will permit an analysis of the expansive pressures of cosmic rays after their release and also aid in locating the origin of recent cosmic ray sources, as suggested by Pinkau (1970). The cosmic ray distribution can be determined with the aid of high energy gamma ray astronomy, since cosmic rays reveal their presence through interactions with interstellar matter which lead to π^o mesons which in turn decay into high energy gamma rays with a characteristic energy spectrum.

SAS-B may also be able to speak even more directly to the origin of cosmic rays. To associate the cosmic ray particles directly with a source experimentally, a neutral and long-lived component must be used, since the charged cosmic ray particles themselves suffer an unknown number of deflections and spirals in the complicated magnetic fields of the intervening space. With this in mind, Colgate (1968) predicted that a very short, highly energetic photon pulse should occur if the hydromagnetic supernova cosmic ray origin theory is correct. Following the calculations of Fichtel and Ogelman (1968), several such pulses should be seen by SAS-B in a year if the theory is correct.

Finally, the search for point sources can be pursued unencumbered by atmospheric background to the sensitivity levels indicated in the previous section. Pulsars can be examined to see if the source mechanism is such that radiation extends into the gamma ray region. Of particular interest will be the Crab pulsar. If the present estimates of the Crab x-ray pulsar flux are extended to the gamma ray region, 10^3 gamma rays could be seen in a week's observation. Thus, quite significant information will be obtained about the origin of the Crab pulsed radiation - even if there should be a null result. A positive result with an energy spectrum would, of course, provide very exciting information on the highest energy region of the source mechanism.

4. References

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