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THE EGRET HIGH ENERGY GAMMA RAY TELESCOPE

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ABSTRACT

The Energetic Gamma Ray Experiment Telescope (EGRET) on the Compton Gamma Ray Observatory is sensitive in the energy range from about 20 MeV to about 30,000 MeV. Electron-positron pair production by incident gamma ray photons is utilized as the detection mechanism. The pair production occurs in tantalum foils interleaved with the layers of a digital spark chamber system; the spark chamber records the tracks of the electron and positron, allowing the reconstruction of the arrival direction of the gamma ray. If there is no signal from the charged-particle anticoincidence detector which surrounds the upper part of the detector, the spark chamber array is triggered by two hodoscopes of plastic scintillators; a time-of-flight requirement is included to reject events moving backward through the telescope. The energy of the gamma ray is primarily determined by absorption of the energies of the electron and positron in a 20 cm deep NaI(Tl) scintillator. The Compton Observatory was placed in orbit on April 6, 1991; EGRET completed activation and on-orbit testing and calibration on May 16, 1991, at which time it began a 15-month full sky survey.

1. Introduction

Although the SAS-2 and COS-B gamma ray telescopes (Derdeyn et al., 1972; Fichtel et al., 1975; Bignami et al., 1975; Scarsi et al., 1977) provided the first maps of the high energy (~100 MeV) gamma ray sky, those observations covered only about 70% of the celestial sphere. Furthermore, the small size of the instruments limited the statistical weight of many of the observations, leaving a wide variety of important astrophysical questions only partially explored. The EGRET telescope on the Compton Gamma Ray Observatory was designed to provide at least an order of magnitude improvement in sensitivity over the earlier instruments, as well as better angular and energy resolution and a very broad energy range. EGRET was developed by a collaboration of 4

institutions: NASA/Goddard Space Flight Center (Co-PI, Dr. C. Fichtel), Max-Planck Institut für Extraterrestrische Physik (Co-PI, Prof. K. Pinkau), Stanford University (Co-PI, Prof. R. Hofstadter, deceased), and the Grumman Aerospace Corporation.

2. The EGRET Instrument

Since the EGRET instrument has been described in detail previously (Kanbach et al. 1988, 1989), only an outline of EGRET operation is provided here. Photons in the energy range covered by EGRET (20 MeV to about 30 GeV), interact almost exclusively via electron-positron pair production; thus that process is the basis for gamma ray detection in EGRET. As illustrated in Figure 1, the gamma ray photons enter through a dome of plastic scintillator. Having no electric charge, the gamma rays produce no signal in the scintillator. Charged cosmic ray particles, which outnumber the gamma rays by a factor of 10^3 to 10^4 , do produce signals in the dome. These signals are used to veto the triggering of the instrument by the charged particles, and therefore prevent them from saturating the instrument telemetry. The conversion of the gamma rays to electron-positron pairs takes place within a series of 27 tantalum foils which are interleaved with digital spark chambers. If the pair particles satisfy the proper coincidence criteria in two layers of plastic scintillation counters, including a correct time-of-flight between the scintillator layers, the spark chambers are triggered to produce an image of the tracks of the electron and positron. In addition to providing a unique means of identify gamma ray events, this image also defines the direction from which the gamma ray arrived. Except at the lowest energies, the energy of the gamma ray is determined primarily from the energy deposited by the electron and positron in a large array of NaI(Tl) scintillator blocks (designated the Total Absorption Shower Counter, or TASC) below the triggering scintillator array. At energies below about 100 MeV, scattering measurements in the spark chamber and corrections for energy losses in the tantalum foils are of increasing importance in the energy determination. Since the efficiency of the spark chamber image formation degrades slowly with time (believed to be due to the action of sparks on the ethane quench gas in the neon/argon mixture), EGRET carries a gas supply sufficient for 5 refills.

In addition to providing energy information on events which trigger the spark chamber, the TASC subsystem has independent modes of operation in which it records spectra of all events which deposit energy between 1 and about 190 MeV in the NaI. Under quiescent conditions, these spectra are recorded over 32.768 second time intervals; this mode is appropriate for recording spectra of gamma rays from solar flares, and is therefore designated the Solar Mode. When the TASC subsystem receives a signal from the Burst and Transient Source Experiment (BATSE) indicating that a gamma ray burst (GRB) has been detected, the TASC electronics switches to a Burst Mode in which spectra are recorded during 4 previously commanded time intervals. The commandable range for each of the 4 intervals is 0.125 second to 15.875 seconds; normally the intervals are set to 1.0, 2.0, 4.0 and 15.875 seconds. Because the threshold of the TASC spectral measurements (~ 1 MeV) is considerably higher than that of the BATSE instrument (~ 20 keV), EGRET obtains spectral information on only 2-3% of the events for which BATSE sends a burst trigger signal. In the Solar and Burst Modes, the TASC has essentially omnidirectional response. However, because of intervening material in the spacecraft, the spectra recorded can be strongly influenced by the direction from which the flare or burst gamma rays arrive. A relatively detailed Mass Model of the CGRO spacecraft will

soon be available which can be used in generating instrument response functions for specific burst or solar arrival directions.

3. EGRET On-Orbit Operations

Since completion of activation, EGRET operation has been essentially nominal. A period of several weeks following initial activation was spent in optimizing the operating conditions with regard to triggering requirements, anticoincidence threshold, Earth occultation and South Atlantic Anomaly (SAA) response. Since that time, the instrument operation has been essentially stable. The two significant exceptions are a slow gain drift in the TASC, for which software corrections are being routinely made based on weekly on-orbit calibrations, and the expected slow degradation of the spark chamber gas noted above. The primary effect of the latter is that the number of events for which manual graphic analysis is required has increased by about 25%. Smaller corrections will probably be required to the instrument sensitivity due to loss of gamma ray event recognition efficiency; this correction will be made on the basis of repeated observations on regions of diffuse flux, which do not change with time.

The EGRET coincidence system has an option to require a signal from the TASC above a specified threshold (1, 2.5, 6 or 13 MeV) in order to trigger the spark chamber. During the initial on-orbit testing of EGRET, it was confirmed that requiring the TASC 2.5 MeV signal in the coincidence reduced the overall triggering rate of the spark chamber; since this is expected to result in a correspondingly increased gas lifetime, and therefore the instrument time available to Guest Investigators, the TASC-in-coincidence mode is the normal mode of operation. As shown below, the TASC-in-coincidence requirement slightly raises the instrument energy threshold and slightly reduces its sensitivity, especially to wide-angle events.

Based on the experience from the first six months of operation, the expected lifetime of a single gas fill is expected to be at least 7-8 months, and the total lifetime of the spark chamber subsystem is therefore expected to be at least 3.5-4 years, roughly twice the 2-year design lifetime. Thus EGRET is expected to be fully operational well into the period during which a major share of its time is available to Guest Investigators. An option which will be considered for the latter part of the EGRET lifetime (e.g., after the last gas refill has been made) is the possible disabling of the spark chamber trigger except during observations of high priority targets, or for important time variation measurements.

4. EGRET Performance Characteristics

Table I (from Appendix G of the NASA Research Announcement for Phase 2 of the GRO Guest Investigator Program, NRA 91-OSSA-22) shows the scientific capabilities of the principal (spark chamber triggered) mode of EGRET operation, based on prelaunch calibrations as well as preliminary analysis of on-orbit testing and calibration. The values for effective area are still considered preliminary. Note that for parameters which are significantly affected by the TASC-in-coincidence requirement, values are shown both with and without that requirement. The parameter values without the TASC requirement are generally quite close to those presented in earlier instrument descriptions (Kanbach et al. 1988, 1989).

Table II (also from Appendix G of NRA 91-OSSA-22) shows the preliminary angular accuracy of EGRET for various energies. For data analysis by Guest Investigators, point spread functions will be provided for a set of standard energy intervals.

Since the GRO spacecraft is not repointed during Earth occultations, and additionally because the photomultiplier tubes are turned off during SAA passage, the fraction of time usable for spark chamber triggered operation is typically 40-45%. With the roughly 85% livetime fraction typically observed, the effective livetime during a viewing period is found to be 35-40% of real time.

5. Preliminary Scientific Results from the Initial Observations

A normal GRO observing period is 2 weeks in length. With the ~ 0.5 sr EGRET field of view, this allows completion of a full-sky survey in the first 16 months of operation (GRO Phase 1). The first few observation periods were devoted to regions of high scientific interest which could also provide various types of on-orbit calibration.

By combining the "tune-up" period with a normal 2-week observation and a solar target-of-opportunity during which the sun was in the galactic anticenter, EGRET obtained very early in the mission about a month of exposure to that region. Two bright sources, the Crab pulsar and the enigmatic source known as Geminga, are seen in that region, for which contour plots in two energy ranges are shown in Figure 2. An obvious difference in spectrum is apparent in that figure; in the lower energy plot, the Crab pulsar is considerably brighter than Geminga, while at the higher energies the situation is reversed. Clearly, the Geminga spectrum is significantly harder than that of the Crab.

Figure 3 shows the phase histogram of the Crab pulsar; for comparison, that of the Vela pulsar is shown in Figure 4. These two pulsars show much more similarity in gamma rays than they do in the radio, optical or X-ray bands. Nevertheless, some differences are apparent. While the first (main) pulse of each is quite sharp, the secondary pulse of the Crab is much broader than that of Vela. Furthermore, the Vela pulsar shows significant emission in the interpulse region, while the Crab pulsar shows little or none.

The most surprising observation by EGRET during the early portion of the GRO mission is the discovery of strong gamma ray emission by the quasar 3C279. During the latter half of June 1991, 3C279 was nearly as bright as Geminga; it was not detected in the SAS-2 observations in the early 1970's (Fichtel et al. 1978), and at the times of the COS-B observations (Mayer-Hasselwander et al. 1985) was at least a factor of 10 less intense than during the EGRET observations (Hartman et al. 1991). Over the energy range 70 MeV to 10,000 MeV the photon spectrum of 3C279 fits well to a power law with index -2.0. If the object radiates gamma rays isotropically, its luminosity at the time of the EGRET observation was about 10^{48} ergs/second. Furthermore, EGRET saw statistically significant evidence for time variations on time scales of a few days.

In contrast with the increased emission from 3C279 since the 1970's, quasar 3C273 was found by EGRET to be roughly a factor of 4 less intense than at the time of the COS-B observations.

EGRET has observed gamma radiation to at least 100 MeV from both solar flares and cosmic gamma ray bursts. In addition to detection in the independent TASC mode, 6

gamma rays were observed in its spark chamber mode from the GRB on 3 May, 1991. The burst direction obtained from a centroid of the directions of the 6 individual gamma rays is $l = 171.9 \pm 1.3$ degrees, $b = 5.3 \pm 1.1$ degrees.

EGRET has made observations of several regions of the galactic plane. Although structure is seen in the galactic ridge, the separation of diffuse emission from that of point sources will require detailed comparison of the gamma ray observations with models of the gas and cosmic ray content of the galaxy.

6. Summary

The EGRET high energy gamma ray telescope on the Compton Gamma Ray Observatory is successfully carrying out significant observations on a wide variety of astronomical phenomena, including solar flares, gamma ray bursts, pulsars, galactic structure and active galactic nuclei. Within 17 months after launch, it is expected to complete a survey of the full sky, 30% of which has never been observed in high energy gamma rays previously.

We wish to acknowledge the essential contributions to the EGRET program over many years by Drs. Robert Hofstadter and E. Barrie Hughes until their deaths shortly before the GRO launch.

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FIGURE CAPTIONS

Figure 1 - Schematic diagram of the EGRET telescope.

Figure 2 - Contour plot of gamma ray intensity in the general direction of the galactic anticenter, for two different energy intervals.

Figure 3 - Phase histogram for the Crab pulsar, 89 bins per period (1 ms/bin), for the energy range 100-150 MeV.

Figure 4 - Phase histogram for the Vela pulsar, 99 bins per period (0.3 ms/bin), for the energy range 100-150 MeV.

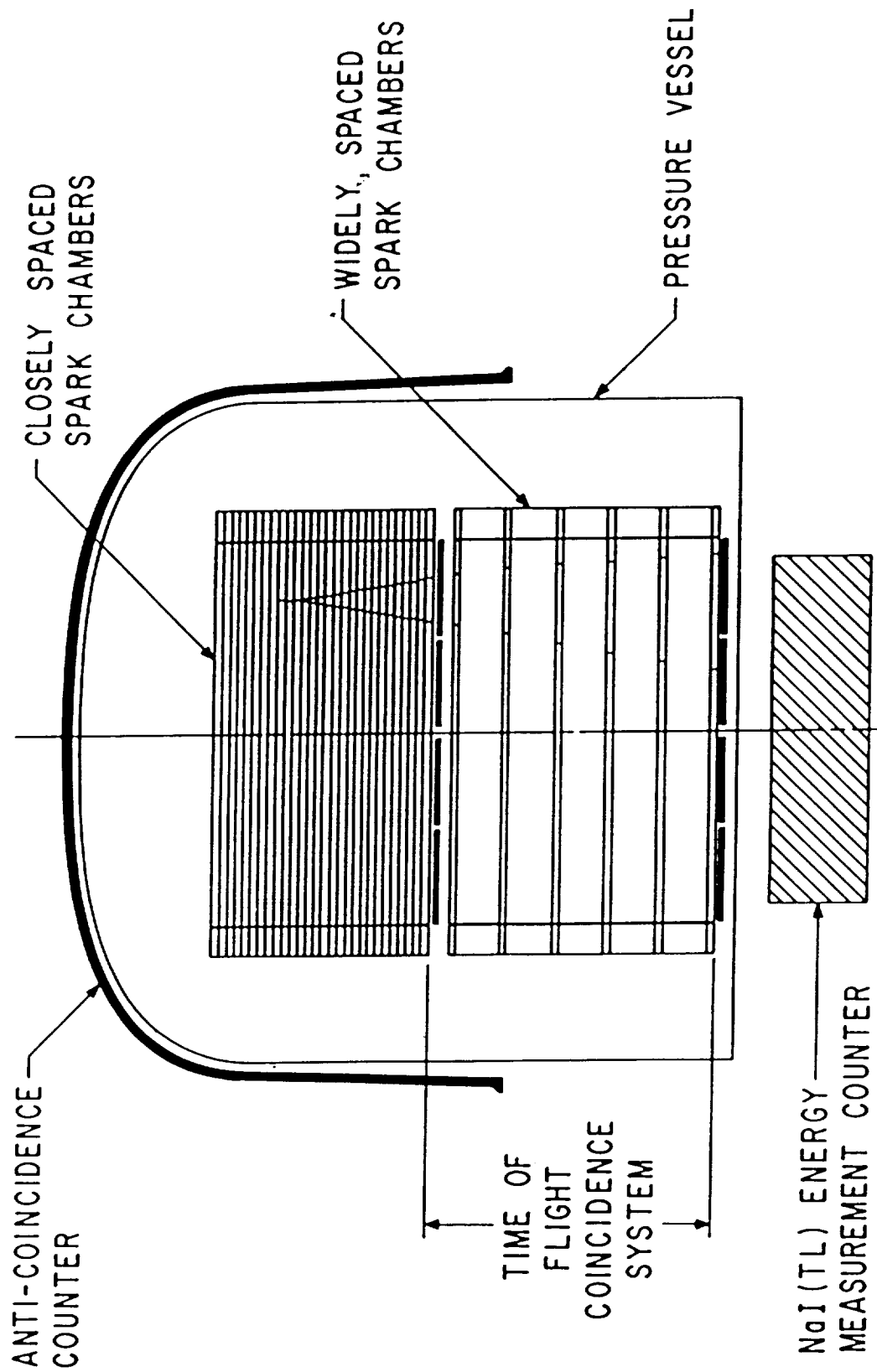
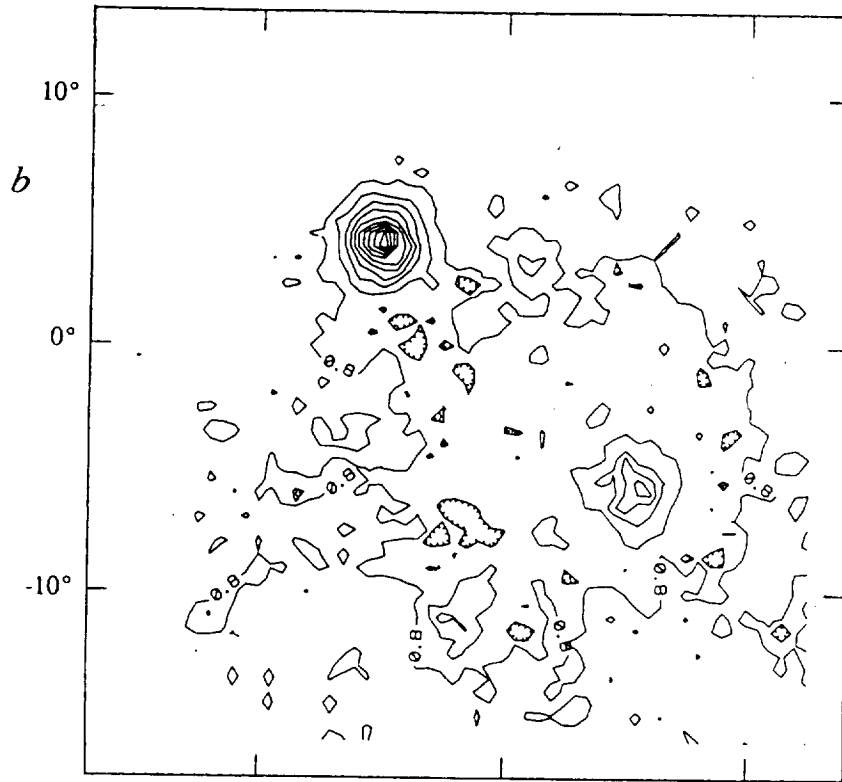
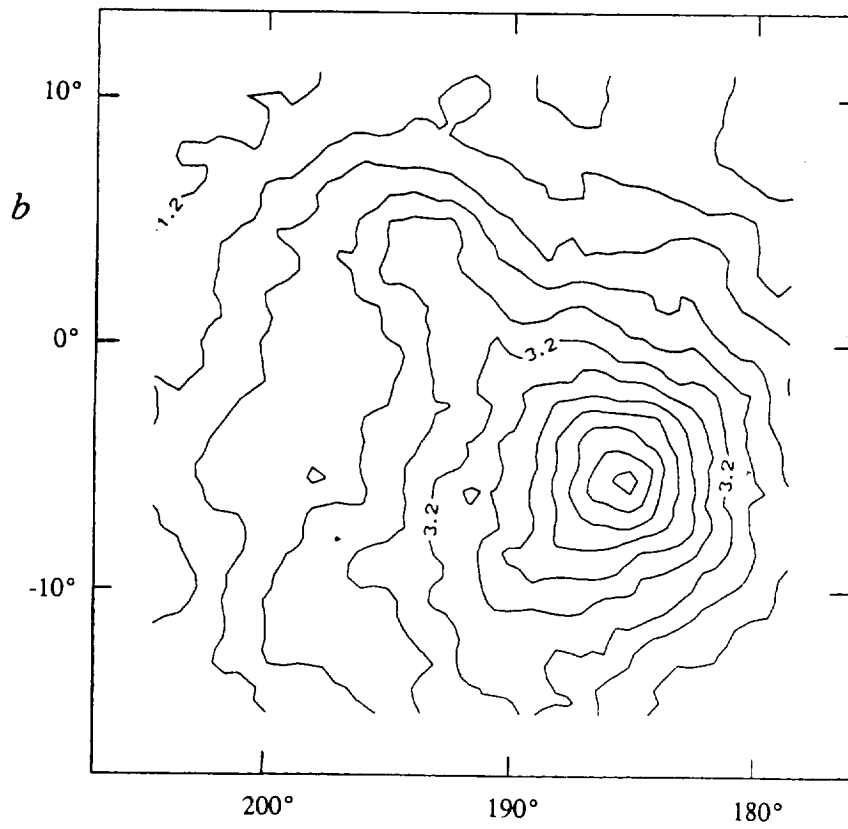


Figure 1



500 - 1000 MeV

Geminga



50 - 100 MeV

Crab

Figure 2

