

GAMMA RAY SKY SURVEYS

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1. Introduction

Prior to the current Compton Gamma Ray Observatory (*Compton*) mission, no comprehensive all-sky gamma-ray surveys had been performed. There were, however, some surveys performed over limited energy bands and/or over portions of the sky. These include the HEAO-A4 hard X-ray survey and the COS-B and SAS-2 high-energy gamma-ray surveys. The early work forms a basis for understanding and appreciating the *Compton* results, and so is reviewed in Section 2.

The Compton Observatory was launched in April 1991 and spent the first 18 months performing an all-sky survey in the 1 MeV–30 GeV band. The results of this survey are given in Section 3. Plans for survey missions beyond *Compton* are presented in Section 4.

2. Pre-Compton Surveys

The pre-*Compton* surveys naturally divide into hard X-rays, high-energy gamma rays and gamma-ray bursts. There were no surveys in the medium energy range (0.1–30 MeV) prior to *Compton*.

2.1. HARD X-RAYS

The HEAO-A4 instrument performed an all-sky survey in 1977–79 (Levine *et al.* 1984). It was complete to a flux threshold at $\sim 8 \times 10^{-3}$ ph cm⁻² s⁻¹ (~ 15 mCrab) in the 13–80 keV band. The total number of sources detected was 70 of which $\sim 10\%$ were extragalactic. The galactic sources were almost all identified with known X-ray binaries or pulsars. The extragalactic sources were largely active galactic nuclei (AGNs) plus clusters.

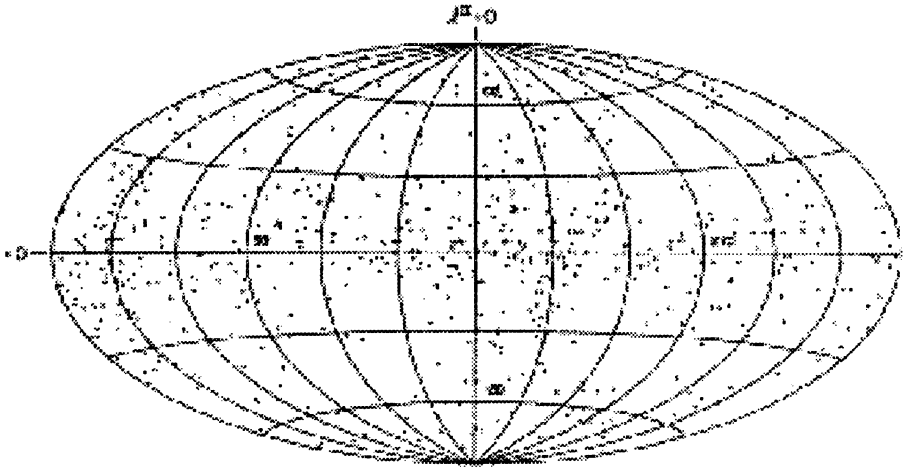


Figure 1. Distribution in galactic coordinates of individual gamma rays at > 50 MeV observed by OSO-3. From Kraushaar *et al.* (1972).

A diffuse galactic continuum radiation was detected in the hard X-ray range by OSO-7, HEAO-1 and balloon instruments (see Gehrels and Tueller 1993 and references therein). Known as the “galactic ridge,” it is centered on the galactic plane and has a width of approximately 5° in latitude and $\pm 40^\circ$ in longitude.

A diffuse extragalactic radiation had also been observed at hard X-rays in the 1960’s and 70’s by Ranger 3, Apollo 16/17, HEAO-1, and balloons (see Gruber 1992 and references therein).

2.2. HIGH ENERGY GAMMA RAYS

The first high energy (> 50 MeV) gamma-ray observation was in fact an all-sky survey. It was performed by OSO-3 in 1967–68 (Kraushaar *et al.* 1972) and detected only 621 celestial gamma rays. The distribution on the sky of these individual photons is shown in Figure 1. This early “map” already shows evidence for two main features now known to be characteristic of the high energy sky, namely a concentration along the galactic plane of a diffuse galactic radiation and an isotropic cosmic diffuse radiation.

The COS-B and SAS-2 missions followed on OSO-3 and early balloon instruments to perform the first good survey of the high energy sky. The coverage of the sky was not complete for either mission, but did include all of the galactic plane.

The COS-B map of the galactic plane is shown in Figure 2 (Mayer-Hasselwander *et al.* 1982). Strong emission is seen concentrated along the plane that was modeled as gamma rays produced by cosmic ray electrons

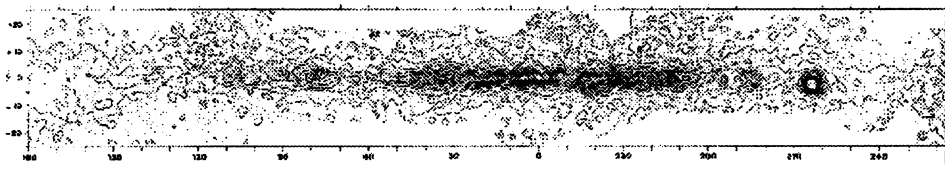


Figure 2. Contour map of the galactic plane emission at > 70 MeV observed by COS-B. From Mayer-Hasselwander *et al.* 1982.

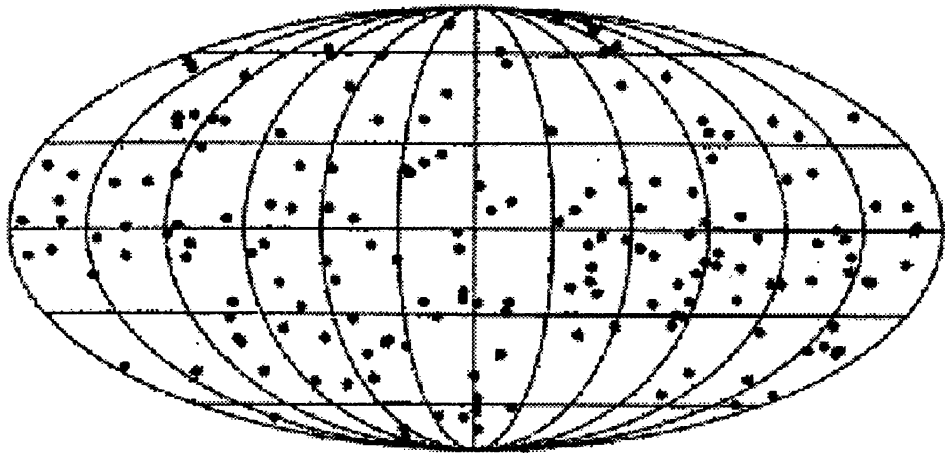


Figure 3. Map of 180 pre-Compton gamma-ray bursts in galactic coordinates. From Hurley (1992).

and protons interacting with the ISM. Also detected along the plane were ~ 25 flux concentrations consistent with point sources of emission (Swanenberg *et al.* 1981). Two of these in the > 100 MeV sky. Some of the other sources were thought to be ISM clouds or gas concentrations. Many of the sources were unidentified. The one extragalactic object seen by COS-B was 3C273.

2.3. GAMMA-RAY BURSTS

There were many different gamma-ray burst detectors flown prior to *Compton*. The missions included Vela, Konus, HEAO-A4, Sigma, Apex, Lilas, PVO, ISEE-3 and Ginga. Several hundred bursts were detected between 1968 and 1991. However, few of the instruments gave good positional information for the bursts and none provided positions for a large number of bursts. A map of 180 pre-Compton bursts from several missions was

compiled by Hurley (1992) and is shown in Figure 3. The map is consistent with an isotropic distribution of burst sources on the sky.

3. Compton Observatory Sky Surveys

Compton has four instruments on board with parameters summarized in Table 1. It was launched into a 28° inclination, 450 km altitude orbit on 1991 April 5. One of the prime scientific objectives of the mission was to carry out an all-sky survey in the 1 MeV to 30 GeV range with the COMPTEL and EGRET wide-field instruments. This was accomplished between 1991 May and 1992 November. Since that time, *Compton* has been observing selected fields. Because of the wide-field nature of COMPTEL and EGRET, this additional time has tremendously deepened the exposure in many regions of the sky. The maximum exposures are in the 10⁹ cm² s range.

Throughout the *Compton* mission, BATSE has been detecting gamma-ray bursts from the whole sky. In addition, the instrument monitors the sky for bright steady sources using the Earth occultation method.

Results from the *Compton* sky surveys are presented in the sections below. For more information about the observatory, see Shrader and Gehrels (1995) and the Web site

<http://coss.c.gsfc.nasa.gov/coss/coss.html>.

TABLE 1. Compton Observatory Instrument Parameters

Name	Key Capabilities	Energy Range	Field-of-view
BATSE ¹	gamma-ray bursts, all-sky monitor	15 keV–1.2 MeV	all sky (not occulted by Earth)
OSSE ²	narrow-field spectrometer	0.1–10 MeV	4° × 11°
COMPTEL ³	wide-field imager and spectrometer	1–30 MeV	64° (1 sr)
EGRET ⁴	wide-field imager and spectrometer	20 MeV–30 GeV	45° (0.6 sr)

¹BATSE = Burst and Transient Source Experiment (PI: G.J. Fishman)

²OSSE = Oriented Scintillation Spectrometer Experiment (PI: J.D. Kurfess)

³COMPTEL = Compton Imaging Telescope (PI: V. Schönfelder)

⁴EGRET = Energetic Gamma-Ray Experiment Telescope (co-PIs: C.E. Fichtel, K. Pinkau)

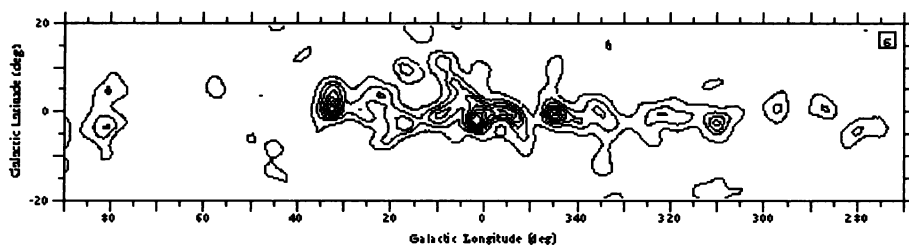


Figure 4. Map from COMPTEL observations of the 1.8 MeV line of ^{26}Al during 1991–93. From Diehl *et al.* 1995a.

3.1. EGRET SURVEY

A contour map of the >100 MeV sky as measured by EGRET is shown in Plate 1. As with the COS-B map, bright emission is seen along the galactic plane, but now the sensitivity and angular resolution are much improved. The emission is well fitted by models of cosmic rays interacting with the ISM (Hunter *et al.* 1996). The dominant component below 150 MeV is bremsstrahlung of cosmic ray electrons and above 150 MeV is nucleon-nucleon interaction of cosmic ray protons with interstellar gas.

Along the plane EGRET sees more than 50 point sources. Six of these are pulsars: Crab, Vela, Geminga, PSR 1706-44, PSR 1055-52, PSR 1951+32 and possibly PSR 0656+14 (Thompson *et al.* 1994; Nolan *et al.* 1996; Ramanamurthy *et al.* 1996). The remaining plane sources are largely unidentified. This is a remaining and increasing mystery of the gamma-ray sky since COS-B.

Off the galactic plane, EGRET detects more than 40 AGN compared to the one (3C273) seen by COS-B. All of them are in the blazar class consisting of BL Lacs and flat spectrum radio quasars (*e.g.*, Montigny *et al.* 1994; Dermer and Gehrels 1995). They are typically variable and have photon spectral indices of approximately -2 . The emission is thought to be due to photons Compton upscattered by relativistic jets of electrons and positions emanating from the central engine.

3.2. COMPTEL SURVEY

The COMPTEL instrument has performed the first medium energy (1–30 MeV) sky survey. The results in the upper portion of this band are qualitatively similar to the EGRET map. At lower energies, COMPTEL has made important observations of nuclear line emission.

Figure 4 shows the COMPTEL map along the galactic plane of the 1.809 MeV line from ^{26}Al (Diehl *et al.* 1995a). This radioisotope is spread into

the ISM by supernovae, novae and winds of massive stars. It has a half life of 7×10^5 years and is therefore a tracer of the sites of nucleosynthesis in the Galaxy over the last million years. The clumpiness of the emission is not well understood. A hot spot at $l = 265^\circ$ seems to be associated with the Vela supernova remnant (Diehl *et al.* 1995b). Other concentrations coincide with positions of the tangents to the arms of the Galaxy (Prantzos 1991; Chen *et al.* 1995) and therefore may be the sum of many supernova remnants and massive stars. COMPTEL also detects gamma-ray line emission from ^{44}Ti in Cas A (Iyudin *et al.* 1994) and nuclear excitation from cosmic ray interactions in the Orion region (Bloemen *et al.* 1994).

3.3. BATSE AND OSSE SURVEYS

Although there are no all-sky maps to show yet from BATSE and OSSE (excluding gamma-ray bursts which are discussed below), both instruments are contributing significantly to our understanding of the hard X-ray and gamma-ray sky. The BATSE team is developing software to generate all-sky maps using Earth occultation imaging. The maps will be complete to about 10 mCrab every month. OSSE has been doing some scanning surveys over limited portions of the sky. An all-sky survey is probably not feasible, but a galactic plane scan may be done.

A few characteristics of the hard X-ray/low-energy gamma ray sky as determined by BATSE, OSSE and previous satellite and balloon instruments are as follows.

- 1) There is a diffuse emission along the galactic plane (Section 2.1).
- 2) Some 100 steady or variable point sources are known in the plane. Most are X-ray binaries or pulsars.
- 3) Bright transient sources appear along the galactic plane every few weeks, with typical "on" times of days to weeks. They include X-ray novae, superluminal sources (GRS 1915+105 and GRO J1655-40) and Be binary pulsars.
- 4) There is a bright ($\sim 10^{-3}$ ph cm $^{-2}$ s $^{-1}$) gamma-ray line emission at 511 keV from positron annihilation that forms a diffuse glow of $\sim 10^\circ$ extent around the galactic center (possibly with imbedded hot spots or point sources).
- 5) Approximately 30 AGNs are seen, most of which are Seyferts.

3.4. GAMMA-RAY BURSTS OBSERVED BY BATSE

The primary scientific objective of BATSE is to observe gamma-ray bursts. BATSE is the first large gamma-ray burst instrument ever flown and has the capability to position each burst to few degree accuracy. Thus, BATSE has provided the first uniform and deep sky survey for bursts.

The BATSE burst map accumulated from 1991 April through 1995 November is shown in Figure 5. The burst distribution is statistically consistent with being isotropic. No physically meaningful sub-sample of the bursts has been found to deviate from isotropy.

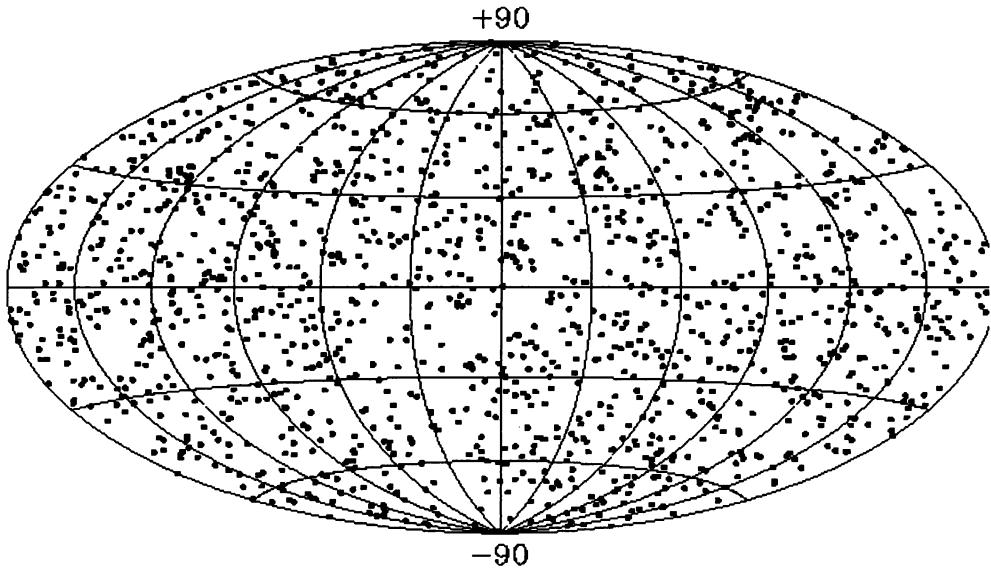


Figure 5. BATSE gamma-ray burst map from 4.5 years of observations. Courtesy of the BATSE team.

TABLE 2. Future Gamma Ray Survey Missions

Mission	Energy (MeV)	WWW URL (preceded by http://)
*INTEGRAL	0.02–10	astro.estec.esa.nl/SA-general/Projects/Integral/integral.html
GLAST	10–300,000	www-glast.stanford.edu
EXIST	0.005–0.6	hea-www.harvard.edu/EXIST/EXIST.html
*HETE	0.006–1	nis-www.lanl.gov/nis-projects/hete/
BASIS	0.01–0.15	lheawww.gsfc.nasa.gov/docs/gamcosray/legr/BASIS/basis.html
ETA	0.05–0.5	
BLAST	0.01–0.15	osse-www.nrl.navy.mil/blast.htm

*mission under development

4. Future Missions

Several future missions are currently being developed or planned that will perform excellent new surveys of the gamma-ray sky. Web sites and energy ranges for many of these missions are listed in Table 2. INTEGRAL is an approved ESA mission that will perform pointed gamma-ray observations, including a survey of the galactic plane, starting in 2001. EXIST is a proposed hard X-ray all-sky survey mission. GLAST is a proposed follow-on mission to EGRET. HETE is a gamma-ray burst mission that will be launched in late 1996. BASIS, ETA and BLAST are proposed gamma-ray burst missions.

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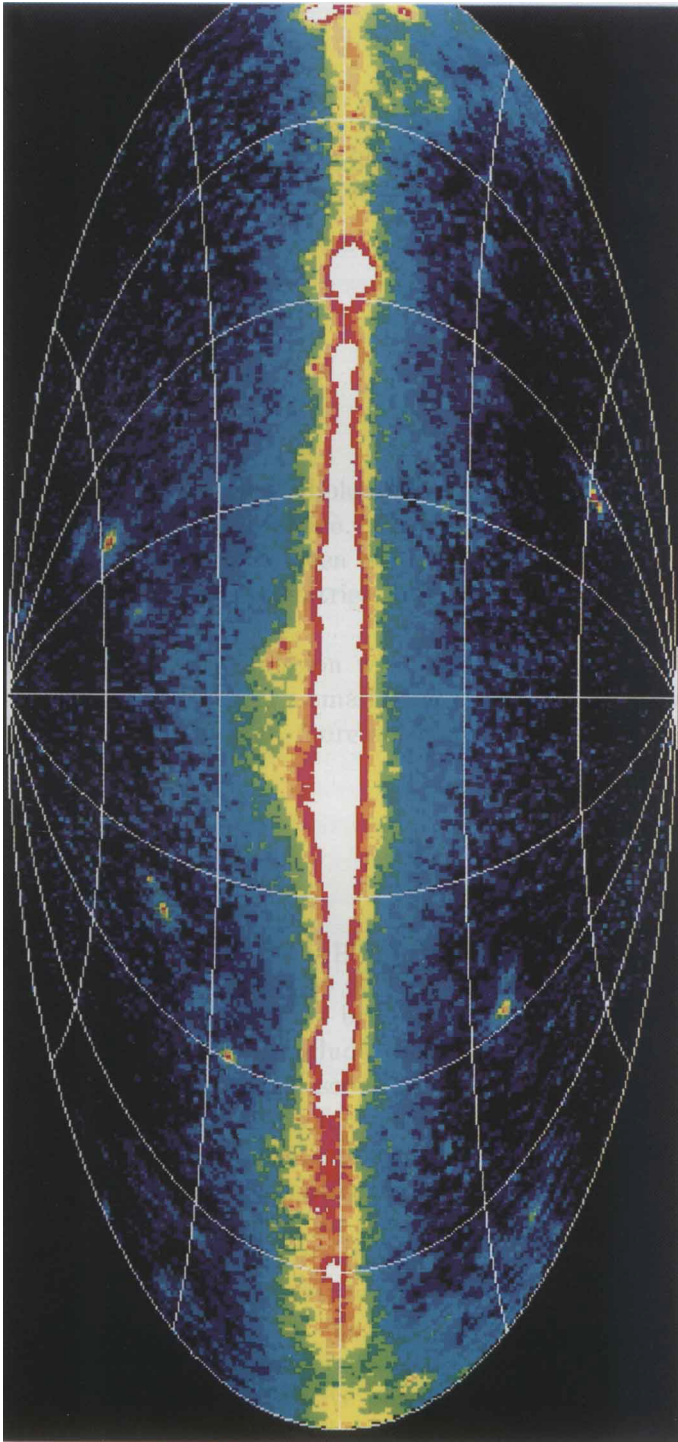


Figure 6. All-sky EGRET map at > 100 MeV energies observed from 1991 to 1995. Courtesy EGRET Team.