

INITIAL RESULTS FROM COMPTEL ONBOARD GRO

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ABSTRACT

COMPTEL is the first imaging telescope to explore the MeV gamma-ray range (0.7 to 30 MeV). At present, it is performing a complete sky survey. In later phases of the mission selected celestial objects will be studied in more detail. The data from the first year of the mission have demonstrated that COMPTEL performs very well. First sky maps of the inner part of the Galaxy clearly identify the plane as a bright MeV-source (probably due to discrete sources as well as diffuse radiation). The Crab and Vela pulsar lightcurves have been measured with unprecedented accuracy. The quasars 3C273 and 3C279 have been seen for the first time at MeV energies. Both quasars show a break in their energy spectra in the COMPTEL energy range. The 1.8 MeV line from radioactive ²⁶Al has been detected from the central region of the Galaxy and a first sky map of the inner part of the Galaxy has been obtained in the light of this line. Upper limits to gamma-ray line emission at 847 keV and 1.238 MeV from SN 1991T have been derived. Upper limits to the interstellar gamma-ray emissivity have been determined at MeV-energies. Several cosmic gamma-ray bursts within the field-of-view have been located with an accuracy of about 1°. On 1991 June 9, 11 and 15, COMPTEL observed gamma-ray emission (continuum and line) from three solar flares. Also neutrons were detected from the June 9 and June 15 flares.

1. INTRODUCTION

COMPTEL covers the middle energy range of the four GRO-instruments, namely 0.7 to 30 MeV. This is one of the most difficult spectral ranges to explore in astronomy. Prior to the launch of GRO only very few celestial objects were detected in this part of the electromagnetic spectrum. With COMPTEL the field of MeV gamma-ray astronomy can now be fully explored.

COMPTEL is the first imaging MeV gamma-ray telescope ever flown on a satellite. It has a large field-of-view of about 1 steradian. Different sources within this field can be resolved if they are separated by more than $\approx 3^\circ$ to 5° . With its energy resolution of 5 % to 10 % FWHM, COMPTEL is well suited to study continuum and line emission. COMPTEL has an unprecedented sensitivity: at 1 MeV, sources about 10-times weaker than the Crab can be detected in a 2-week observation period. In addition to gamma rays, solar neutrons above 15 MeV can also be measured. A comprehensive description of the capabilities and characteristics of COMPTEL is given in /1/, /2/.

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Together with EGRET, COMPTEL is at present performing a complete sky survey - the first in gamma-ray astronomy. Most of the pointings have lasted two weeks each. The analysis of the data from these observations is an arduous and difficult process. This is due to the fact that the arrival direction of each photon detected by COMPTEL is not defined unambiguously, but is only known to lie on a circle on the sky (see Fig. 1). Most of the scientific analysis is still preliminary. An overview of the most important results obtained from this analysis is given here.

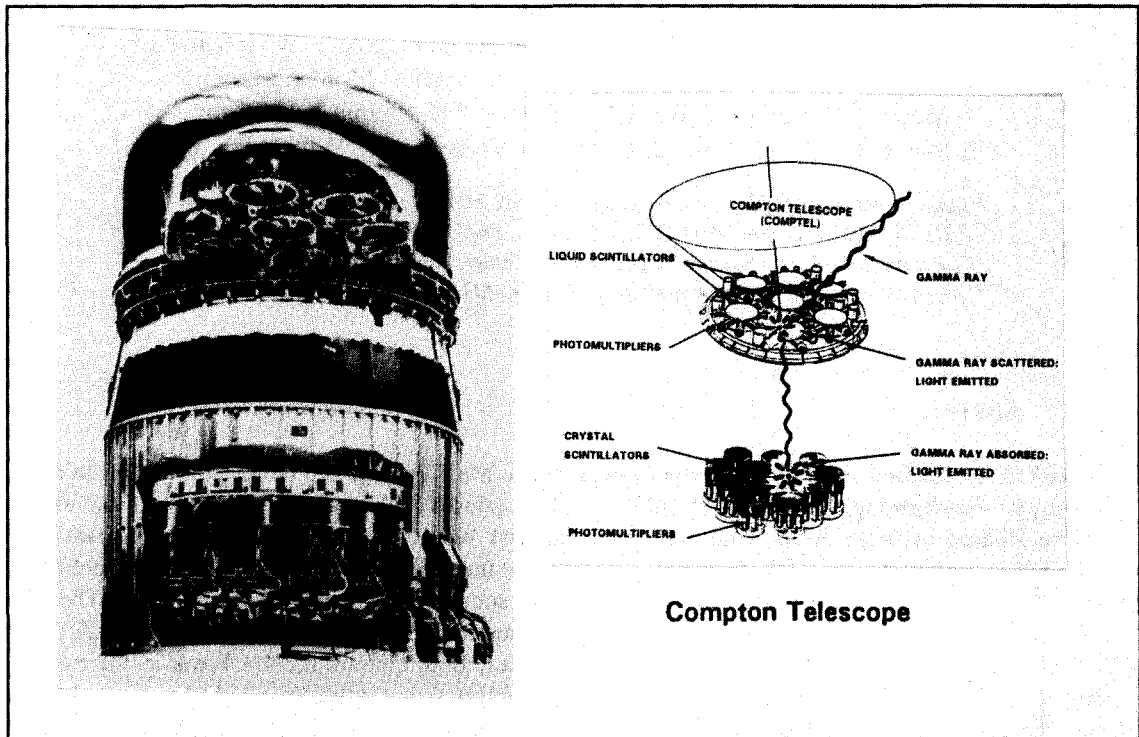


Fig. 1. Schematic view of COMPTEL. A gamma-ray is detected by a Compton collision in an upper detector, consisting of 7 modules of liquid scintillator NE 213 and a subsequent interaction in a lower detector, consisting of 14 modules of Na (Tl). The center of each event circle is defined by the direction of the scattered gamma ray, the radius of the circle by the energy losses in both interactions.

2. RESULTS

The preliminary results from COMPTEL can be grouped under the following headings:

1. Composite sky map of the inner part of the Galaxy
2. Observation of the anticentre of the Galaxy with the Crab nebula and its pulsar
3. Observation of the Vela pulsar
4. Search for gamma-ray emission from other pulsars
5. Study of the diffuse Galactic continuum emission
6. Study of the 1.8 MeV gamma-ray line from radioactive ^{26}Al
7. Search for other gamma-ray lines
8. Observations of the quasars 3C273 and 3C279, and the radio Galaxy Cen A
9. Localization of cosmic gamma-ray bursts and measurement of burst spectra and time profiles
10. Observation of gamma-ray and neutron emission from solar flares.

Each of these topics is briefly discussed.

2.1 Map of the Galactic Plane in the Central Region

A COMPTEL map of the entire Galactic plane in the light of continuum gamma radiation does not yet exist; first, the full sky survey is not yet completed and second, only a fraction of the observations along the galactic plane have been analyzed so far. Nonetheless, preliminary maps of the central part of the plane do exist already. They were derived by combining data from different GRO-observations. Examples were shown by Bloemen et al. (this conference) and will be published in /3/. The maps clearly show the emission to be concentrated towards the galactic plane. There seem to be localized sources as well as diffuse Galactic emission. The identification of the sources needs further study.

2.2 The Crab

The Crab is by far the strongest steady source in the sky so far seen by COMPTEL. The pulsar analysis of 4 weeks of data yields a light curve with strong emission between the two peaks, resembling very much that seen at hard x-ray energies /4/, /5/. The pulsed fraction of the total Crab emission is about 25 - 35 %. No significant differences in the shapes of the light curves for 4 observations of the Crab in 1991 have been found. The photon energy spectra of the total, the pulsed and unpulsed emission can all be fitted by single power-law spectra over the entire COMPTEL energy range /6/.

2.3 The Vela Pulsar

The Vela pulsar has been detected by COMPTEL between 3 and 30 MeV. The light curve in the 10 - 30 MeV range from 4 combined observations (0, 6, 8, and 14) clearly shows the two main peaks separated by 0.4 in phase. There is no statistically significant interpulse emission between the 2 peaks /5/.

The energy spectrum of the pulsar is shown in Fig. 2 (from /7/). The COMPTEL data points are compared with results from COS-B, OSSE, and ROSAT. There is a bending of the high-energy power law spectrum at MeV-energies.

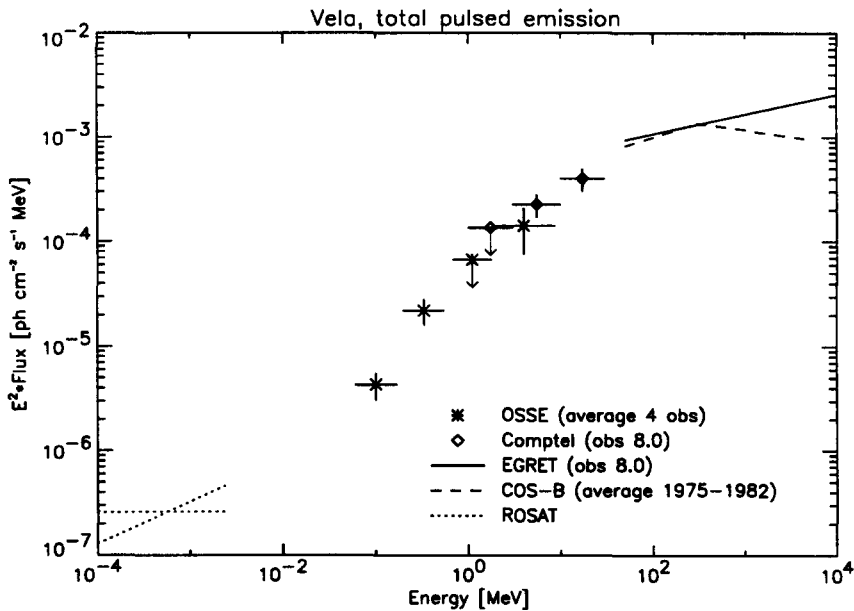


Fig. 2. Energy spectrum of the Vela pulsar between 0.2 keV and 1000 MeV. COMPTEL data points are compared with results from /25/, /26/, and /27/. For the ROSAT-flux two spectral shapes have been assumed: $\approx E^{-2}$ and $\approx E^{-1.6}$.

2.4 Other Pulsars

A search for pulsed emission from other radio pulsars has so far turned up negative results. In particular PSR 1706-44 and PSR 1509-58 are not seen by COMPTEL at this stage of the analysis. Furthermore, no signal (steady or pulsed) was observed from the Geminga pulsar. An upper limit to the total Geminga emission in the COMPTEL energy range is given in /6/.

2.5 Diffuse Galactic Continuum Emission

The continuum gamma-ray emission from interstellar space in the 1 - 30 MeV range is produced by interactions of cosmic-ray electrons, mainly via the bremsstrahlung process, and to a smaller amount by inverse Compton scattering. The contribution of the n° -decay component can be neglected in this spectral range. First attempts have been made to derive the gamma-ray emissivity (number of gamma rays produced per H-atom ster sec MeV) from COMPTEL observations towards the Galactic centre region. For this purpose the COMPTEL data were fitted to a sky model based on the total gas column density (from HI and CO data), and the diffuse cosmic gamma-ray background. The instrumental background was derived from high latitude observations. Fig. 3 shows the resulting emissivity spectrum (from /8/, in comparison with earlier COS-B data /28/. It has to be noted that the COMPTEL emissivities should strictly be regarded as upper limits, because point sources may contribute significantly to the observed emission. The COMPTEL results are in reasonable agreement with calculations of the bremsstrahlung emissivity, using a "leaky box" propagation model for the cosmic ray electrons (/8/, /9/).

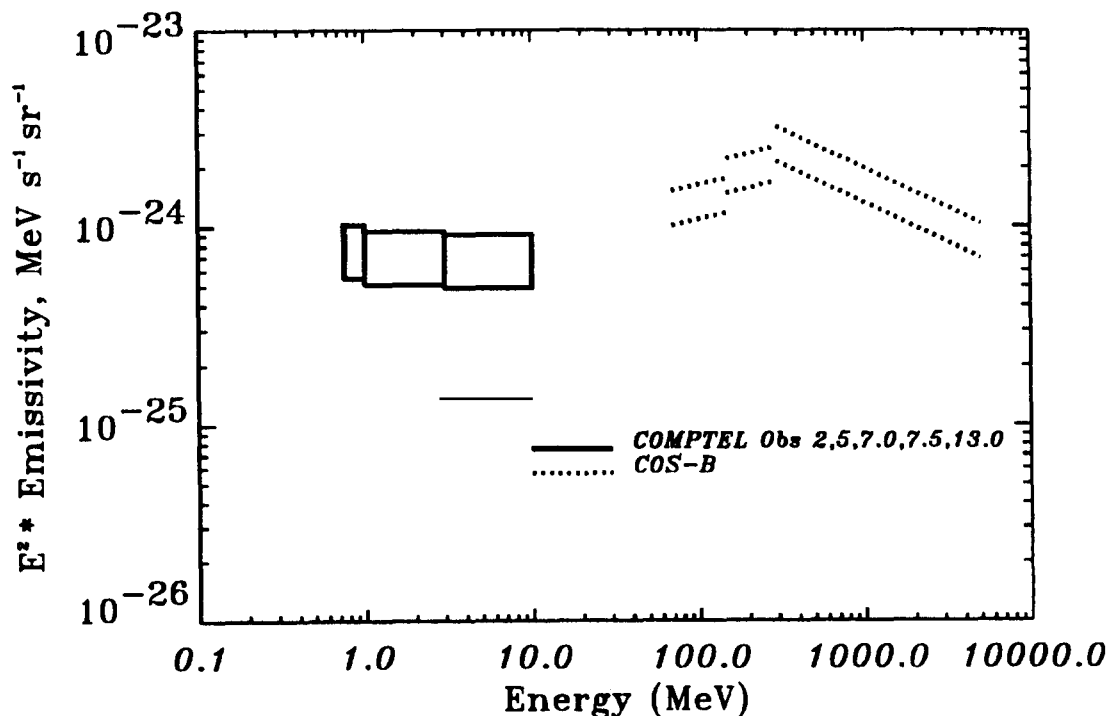


Fig. 3. Interstellar gamma-ray emissivity. The COMPTEL results are compared with the COS-B emissivity (from /8/).

2.6 Galactic 1.8 MeV ^{26}Al Gamma-Ray Line

The 1.8 MeV gamma-ray line from radioactive ^{26}Al was discovered more than 10 years ago by HEAO-C /10/. Little information was available from those measurements regarding the location of the line emission except that it originates from the general direction of the Galactic-centre region.

^{26}Al is an isotope with a radioactive decay time of $1.04 \cdot 10^6$ years. Therefore, one can expect to see the line from the accumulation of all ^{26}Al formation sites over the last million years. It has been suggested that supernovae, novae and peculiar massive stars (like Wolf-Rayet stars) might be the sites in which ^{26}Al is produced and then ejected into interstellar space. Obviously, a map of the entire galactic plane in the light of the line is of utmost importance to constrain the various models.

COMPTEL has detected the line /11/ and first images of the central part of the Galaxy ($-40^\circ < l < +30^\circ$) have been derived /12/. The Galactic plane is clearly visible in this part of the sky. The emission covers the entire longitude range investigated so far, although the emission is not uniform: instead, there are regions with indications of enhanced emission. Bootstrap analyses are at present being applied to assess the statistical significance of these excesses.

2.7 Search for Other Gamma-Ray Lines

A search for gamma-ray lines from SN 1991T has yielded a negative result. The type Ia supernova, which occurred on or shortly before April 10, 1991 in the spiral galaxy NGC 4527 at a distance of about 13.5 Mpc, was observed by COMPTEL in June and October, 1991. The preliminary 2σ upper limits to the ^{56}Co lines at 846 keV and 1.2383 MeV are $4.4 \cdot 10^{-5} \text{ cm}^{-2} \text{ s}^{-1}$ and $4.1 \cdot 10^{-5} \text{ cm}^{-2} \text{ s}^{-1}$ (June observation) and $3.9 \cdot 10^{-5} \text{ cm}^{-2} \text{ s}^{-1}$ and $3.4 \cdot 10^{-5} \text{ cm}^{-2} \text{ s}^{-1}$ (October observation), respectively. Though these limits are close to the predicted line fluxes, they do not yet constrain different theoretical models /13/.

Efforts are at present taken to improve the COMPTEL limits by making use of the full knowledge of the response function of the instrument. The limits may also be improved by combining OSSE and COMPTEL data on this supernova. A factor of two improvement in sensitivity would begin to provide constraints on some of the available models /14/.

2.8 Active Galactic Nuclei

Prior to the launch of GRO quasars and other nuclei of active galaxies were thought to be promising objects in the COMPTEL energy range. Many have hard x-ray spectra, from which one might conclude that at least some of them have their peak luminosity at MeV-energies. The two quasars 3C273 and 3C279 were the first AGN's detected by COMPTEL /15/. Though both objects were rather weak during the COMPTEL observation in June 1991 (about 10 % of the Crab flux between 3 and 10 MeV), their detection was statistically significant (7σ and 4σ , respectively). In the COMPTEL energy range (0.7 to 30 MeV) 3C273 has a significantly softer spectrum than 3C279. The spectral difference becomes more evident when combining COMPTEL, EGRET and OSSE results. The energy spectra of both quasars can be described by two power-law components, which show a break and steepening between 1 and 3 MeV (3C273) and near 10 MeV (3C279). Whereas the peak luminosity of 3C273 lies between 1 and 3 MeV, that of 3C279 ranges from 10 MeV to 5 GeV (/15/, /16/).

Since its discovery last year, the origin of the gamma-ray emission from 3C279 has been widely discussed in the literature. In most cases (/17/ /18/ /19/), it is proposed that the gamma-ray emission is not produced in the central nucleus, but in the jets. The beamed jet-emission (due to the relativistic Doppler-Lorentz factor) would require a 10^4 -times smaller luminosity than isotropic core-emission.

A search for other AGN's in the COMPTEL data is underway. So far, only one additional object, the radio galaxy Centaurus A, has been seen. The flux derived from COMPTEL at ≈ 1 MeV is consistent with a power law extrapolation of the OSSE-observations /16/.

2.9 Gamma-Ray Bursts

During the all-sky survey, a number of gamma-ray bursts and solar flares could be detected within the COMPTEL field-of-view. The positions of nine of the measured gamma-ray bursts have been derived from their maximum-entropy images and maximum-likelihood maps (see Table 1).

TABLE 1 Preliminary list of nine significant bursts located by COMPTEL in its field-of-view

Date	TJD	Time[sec]	Significance (Sigma)	Counts	Likelihood location Galactic Longitude / Latitude	
910425	8371	2268	4.7	120	228.1	-21.1
910503	8379	25455	13.0	285	172.6	5.2
910601	8408	69736	12.0	208	74.4	- 5.0
910609*	8416	2909	4.7	6		
910627	8438	16159	4.3	44	314.2	58.4
910709	8446	41604	5.5	37	ca. 140	34
910814	8482	69275	12.8	323	93.7	-25.9
911118	8578	68260	4.3	58	271.4	33.1
920502	8744	68705	4.5	41	300.5	-24.5
920622	8795	25506	14.7	249	163	58

* Burst too far from telescope axis to be located.

Energy spectra and time profiles of some of these bursts are described in /20/, /21/. The combination of the COMPTEL error boxes with the one-dimensional localisation by triangulation using Ulysses and GRO burst arrival times, leads to elongated error boxes of the burst positions, which are a few degrees wide in one dimension and a few arcminutes wide in the other dimension. Based on such an error box, a counterpart search for GRB 910503 has been performed (/22/) using ROSAT data. No positive identification is reported from this search. The counterpart search continues for other bursts, listed in Table 1.

2.10 Solar Flares

On June 9, 11, and 15, 1991 COMPTEL observed three x-class solar flares within its field-of-view. Preliminary results from these flares are described in /23/, /24/. In all three flares the gamma-ray spectra show continuum and line components. Lines are seen at 1.6 MeV (^{20}Ne), 2.2 MeV (neutron capture line), and weakly at 4.4 MeV (^{12}C). The June 15 flare still showed observable MeV-emission 90 minutes after the onset of the flare, suggesting a correspondingly long-lasting particle acceleration time. The detection of the 2.2 MeV neutron-capture line in all three flares indicates that neutrons were produced in these flares. In the case of the June 9 and June 15 flares, these neutrons have already been detected by COMPTEL in the energy range 15 - 80 MeV. The simultaneous measurements of the 2.2 MeV line and the neutron flux provide a powerful diagnostic tool to study the emission processes and geometries.

3. CONCLUSION

The first results from COMPTEL have demonstrated that a multitude of phenomena can be studied at MeV-energies. One of the biggest surprises of the sky-survey is that there is only one steady MeV-source as bright as the Crab. All other sources found by COMPTEL so far are at the (10 to 20) % Crab flux level at best.

4. LITERATURE

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