INITIAL RESULTS FROM COMPTEL - AN OVERVIEW

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ABSTRACT

COMPTEL is presently completing the first full sky survey in MeV gamma-ray astronomy (0.7 to 30 MeV). An overview of initial results from the survey is given: among these are the observations of the Crab and Vela pulsars with unprecedented accuracy, the observation of the black hole candidates Cyg X-1 and Nova Persei 1992, an analysis of the diffuse Galactic continuum emission from the Galactic centre region, the broad scale distribution of the 1.8 MeV line from radioactive ^{26}Al, upper limits on gamma-ray line emission from SN 1991T, observations of the three quasars 3C273, 3C279 and PKS 0528+134 and the radio galaxy Cen A, measurements of energy spectra, time histories and locations of a number of cosmic gamma-ray bursts, and gamma-ray and neutron emission from solar flares.

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 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 ≈ 3° 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/ and /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.

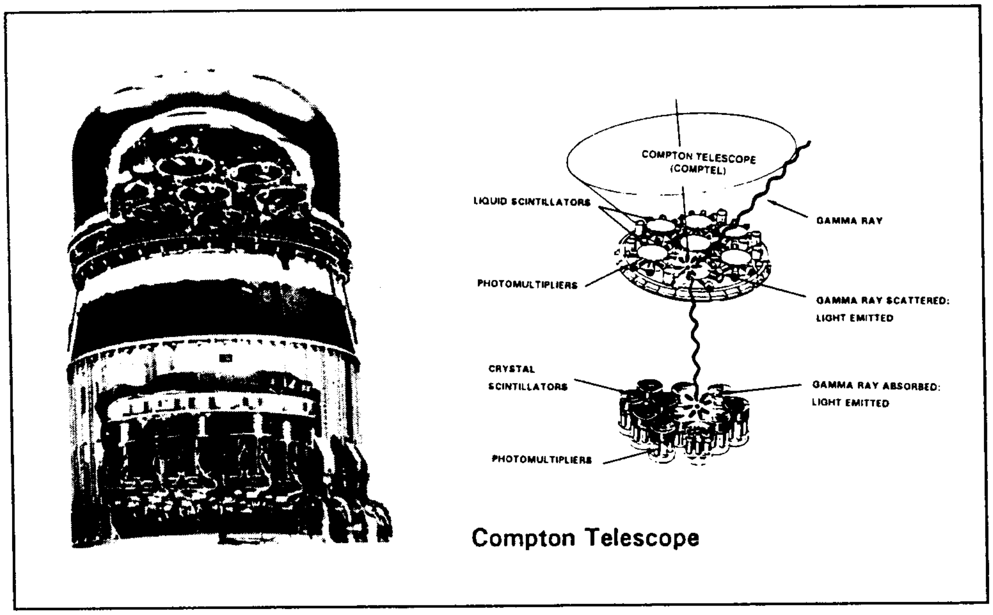

Fig. 1. Schematic view of COMPTEL. A gamma-ray is detected by a Compton collision in an upper detector consisting of 7 modules of liquid scintillator NE 213 and a subsequent interaction in a lower detector consisting of 14 modules of Na (Tl). The center of each event circle is defined by the direction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

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. Observation of the black hole candidates Cyg X-1 and Nova Persei 1992
6. Study of the diffuse Galactic continuum emission
7. Study of the 1.8 MeV gamma-ray line from radioactive ^{26}Al
8. Search for other gamma-ray lines
9. Observations of the quasars 3C273, 3C279 and PKS 0528+134, and the radio galaxy Cen A
10. Localization of cosmic gamma-ray bursts and measurements of burst spectra and time profiles
11. 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 has 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 are shown 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/ and /5/. The pulsed fraction of the total Crab emission is about 25 % to 35 %. No significant differences in the shape of the light curves in the 4 observations of the Crab in 1991 have been found /6/. 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 /7/.

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 as seen at higher energies. There is no statistically significant interpulse emission between the 2 peaks /5/. The energy spectrum of the pulsar shows a bending of the high-energy power law spectrum at MeV-energies /8/.

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 analysis /9/. 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 /7/.

2.5 Black-Hole Candidates

One characteristic signature of black hole candidates in x-ray binary systems may be the existence of temporary strong soft gamma-ray emission possibly extending into the MeV-range.

With COMPTEL we have been able to observe MeV-emission from two such black hole candidates. One is Cyg X-1, which has clearly been seen between 0.75 and 3 MeV in observation 7 (August 1992), and also in observation 2 (June 1992), see /10/. The MeV-flux measured by COMPTEL is more than a factor of 10 lower than the MeV-bump, measured by HEAO-C /11/. This is interesting in that Cyg X-1 was in a very low hard x-ray state during the time of observation 7. Therefore, a low hard x-ray flux seems not to be significant condition for MeV-emission to exist, as has been suggested /11/.

The other COMPTEL observation of a black-hole candidate is that of Nova Persei 1992 (GRO J0422+32). This low mass x-ray binary transient was discovered by BATSE on August 5, 1992. Its energy spectrum has been measured by OSSE up to about 600 keV with high accuracy (see these proceedings). The composite COMPTEL maximum likelihood map of Fig. 2 contains that transient in the 1 to 2 MeV range. During observation 36 (August 1992) the nova was seen up to 2 MeV, in observation 39 (September 1992) up to 1 MeV.

2.6 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 π°-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) and the differential gamma-ray flux per radian from COMPTEL observations towards the Galactic centre region (see /12/). The gamma-ray fluxes derived by COMPTEL in the inner Galaxy are consistent with previous measurements but more in agreement with the lowest end of the range of published values. In this context 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 extrapolations of the COS-B measurements /13/ and with calculations of the bremsstrahlung emissivity, using a "leaky box" propagation model for the cosmic ray electrons /12/, /14/.

2.7 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 /15/. 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 /16/ and first images of the central part of the Galaxy ($-40° < l < +30°$) have been derived /17/. 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. During this conference (/18/) evidence for line-emission even outside this longitude range is provided. Especially the direction of Vela is a source of the ^{26}Al-line, as well. Bootstrap analyses are at present being applied to assess the statistical significance of the excesses.

2.8 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. Preliminary 2σ upper limits to the ^{56}Co lines at 846 keV and 1.238 MeV derived by Lichti et al. /19/, are close to predicted line fluxes, however, they do not yet constrain different theoretical models /20/.

Efforts have now been taken to improve the COMPTEL limits by making use of the full knowledge of the response function of the instrument. The new limits are roughly two-times lower than the previous limits. Now, a few of the proposed theoretical models can be ruled out /21/.

2.9 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 /22/. 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).

During a second observation in October 1991 3C273 was roughly two-times weaker than in June /23/. 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 or 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 /22/.

Since its discovery last year, the origin of the gamma-ray emission from 3C279 has been widely discussed in the literature. In most cases (e.g. /24/, /25/ and /26/) 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 in a 10^4-times smaller luminosity than isotropic core-emission.

A search for COMPTEL-detections of other EGRET-AGN's resulted in the discovery of gamma-ray emission from PKS 0528+134. This object has one of the steepest energy spectra of all EGRET-AGN's (differential energy spectrum $\approx E^{-2.4}$). In so far, it was indeed one of the most promising candidates to be seen by COMPTEL. The fact that the source is seen by COMPTEL only between 3 - 30 MeV, but not below 3 MeV, suggest that also this AGN-object has a gamma-ray spectrum, which bends at MeV-energies like those of 3C273 and 3C279 /23/.

The only other AGN-object, seen by COMPTEL so far is the radio galaxy Centaurus A. The flux derived from COMPTEL at $\approx$ 1 MeV is consistent with a power law extrapolation of the OSSE-observations (see /23/ and /27/).

2.10 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. To this date, the positions of nine of the measured gamma-ray bursts have been derived from their maximum-likelihood maps /28/.

Energy spectra and time profiles of some of these bursts are described in /28/ and /29/. 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 by using ROSAT data /30/. No positive identification is reported from this search. The counterpart search continues for the other bursts contained in the COMPTEL field-of-view.

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 /31/. 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 cases of the June 9 and June 15 flare, 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.

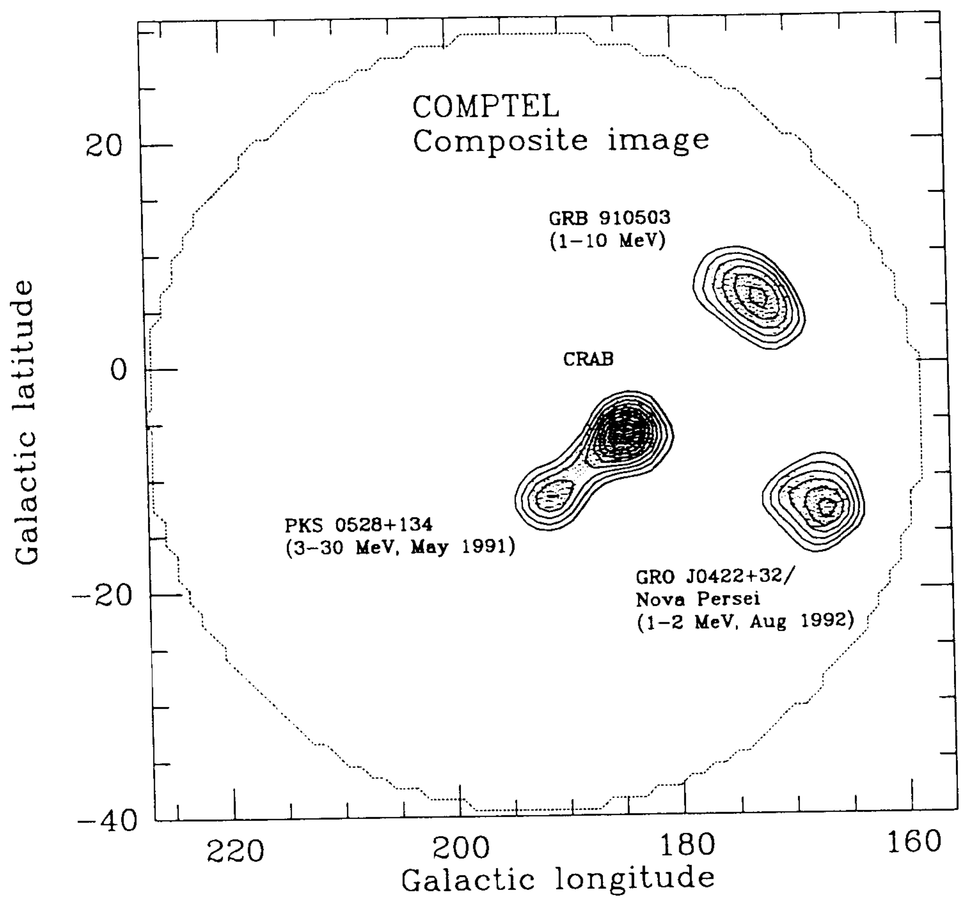

Fig. 2. Composite COMPTEL image of the anticentre region of the galaxy.

CONCLUSION

COMPTEL is the first imaging MeV gamma-ray telescope ever flown on a satellite. Its imaging capabilities are of great use in exploring the nearly unknown field of MeV-astronomy. The quality of images obtained by COMPTEL is illustrated in Fig. 2, which shows a composition of images obtained from different observations of the anticentre region of the galaxy. The Crab, the AGN PKS 0528+134, the transient GRO J 0422+32, and the gamma-ray burst GRB 910503 are all within a sphere of roughly 25 degrees in diameter.

The first results from COMPTEL have demonstrated that a multitude of phenomena can be studied at MeV-energies.

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