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Scientific Objectives and First Results from COMPTEL

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ABSTRACT

COMPTEL is the first imaging telescope in space to explore the MeV gamma-ray range. At present it is performing a complete sky survey. In later phases of the mission selected celestial objects will be studied in more detail. Targets of special interest in the COMPTEL energy range are radio pulsars, X-ray binaries, novae, supernova remnants, molecular clouds, and the interstellar medium within the Milky Way, as well as the nuclei of active galaxies, supernovae, and the diffuse cosmic background radiation in extragalactic space. The first four months of operation have demonstrated that COMPTEL basically performs as expected. The Crab is clearly seen at its proper position in the first images of the anticenter region of the Galaxy. The Crab pulsar lightcurve has been measured with unprecedented accuracy. The quasar 3C273 was seen for the first time at MeV-energies. Several cosmic bursts within the COMPTEL field-of-view could be located to an accuracy of about 1°. On June 9, 11, and 15, 1991 COMPTEL observed gamma-ray (continuum- and line-) emission from three solar flares. Neutrons were also detected from the June 9 flare. At the present state of analysis, COMPTEL achieves the prelaunch predictions of its sensitivtity within a factor of 2. Based on the present performance of COMPTEL, the team is confident that COMPTEL will fulfill its primary mission: to survey and explore the MeV-sky.

1. INTRODUCTION

COMPTEL covers the middle energy range of the four GRO-instruments - namely 1 to 30 MeV. This part of the electromagnetic spectrum belongs to the least explored ones in astronomy. So far only a few celestial objects have been observed in this energy band. With COMPTEL we have now the possibility to open this field. Since COMPTEL is an instrument with a wide field-of-view of about 1 steradian, about 8 % of the entire sky can be viewed in one single observation. Different sources within the field-of-view, which are separated by more than about 5° can be resolved - in this sense, COMPTEL is an imaging telescope. COMPTEL's sensitivity is about one order of magnitude better than that of any previous gamma-ray experiment at MeV energies. With its energy resolution of 5 % to 10 % FWHM COMPTEL is well suited to not only study continuum, but also line emission. The celestial targets which are of interest to COMPTEL are the following (not in order of importance, but with increasing distance from the Earth).

1) The Sun

The Sun is a bright gamma-ray source during major solar flares. COMPTEL is not only able to observe the gamma-ray emission (continuum and line-emission) during the flares, also solar neutrons can be measured by COMPTEL. During the one week in early June 1991, when GRO was pointed towards the Sun, three major flares (on June 9, 11, and 15) were observed by COMPTEL. Preliminary results from the June 9-flare are presented by Ryan et al. in these proceedings.

2) Galactic Gamma-Ray Sources

From COMPTEL we expect an answer to the question: "What kind of objects in the Galaxy do we see at MeV gamma-ray energies?" So far, only the Crab and Vela-pulsar and the Crab nebula have been observed as permanent gamma-ray sources in this energy range. Further, interesting objects are other radio pulsars, X-ray binaries containing neutron stars or black holes (especially Cyg X-1), the galactic center region, which contains a few variable hard X-ray sources (1E 1740-2942, GRS 1758-258, and GX 1+4), supernovae and their remnants, novae, the unidentified COS-B/SAS-2-sources (especially Geminga), and finally, dark clouds as extended sources.

3) Diffuse Galactic Gamma-Ray Emission

The interstellar medium is expected to be a strong source of continuum and line emission. From the continuum component we shall be able to derive conclusions about the flux, the spectral shape, and the spatial distribution of low energy cosmic ray electrons. From different gamma-ray line components we may be able to derive conclusions on nucleosynthesis sites. The mapping of the Galaxy in the light of the 1.8 MeV ^{26}Al-line will be one of the prime goals of COMPTEL.

4) Cosmic Gamma-Ray Bursts

The objects which are responsible for the cosmic gamma-ray bursts are not yet identified. According to the exciting BATSE results presented at this workshop, most of the sources have to be nearby if they are galactic, or very distant if they are extragalactic. COMPTEL is able to measure the energy spectra and time history of bursts in its single detector mode (0.1 to 10 MeV). It is also able to locate those bursts quite accurately (within 1° or less), that happen to occur in the field-of-view.

5) Extragalactic Objects

In the extragalactic sky the most interesting objects to be studied by COMPTEL are the nuclei of active galaxies (radio-galaxies, Seyfert-galaxies, and quasars). Some of them are expected to have their maximum of luminosity exactly in the COMPTEL energy range (see also later Fig. 8). Clusters of galaxies may be of interest as well, if they show non-thermal intra-cluster emission extending into the MeV-range.

6) The Cosmic Gamma-Ray Background

The question of the origin of the cosmic gamma-ray background radiation is of fundamental interest. COMPTEL will not only measure its absolute flux, its spectral shape and its spatial variations, it will also allow to estimate the contribution of active galactic nuclei to the background radiation.

This certainly is a very ambitious program, and it will take years until all questions raised above will find their proper answers. At the time of this workshop - four months after the start of the GRO sky survey - only first, still very preliminary results on a few selected topics can be presented.

2. COMPTEL IMAGE DECONVOLUTION

The COMPTEL team so far has concentrated on the scientific analysis of two sky regions: the anti-center region of the galaxy with the Crab as an expected strong source, and the galactic pole region with 3C273 as an expected weak source. The data from these observations are being used to optimize our data analysis tools, to study the instrumental background characteristics, and to exercise the image reconstruction.

In addition, we were lucky enough to observe a few transient events (solar flares and cosmic bursts) within the COMPTEL field-of-view in the early part of the mission. These events did not only contain interesting science, they also provided very powerful tools to study the inflight telescope performance under practically background-free conditions.

The image reconstruction from COMPTEL data requires the knowledge of the COMPTEL Point Spread Function. The telescope response to a gamma-ray point source can be described in the simplest way in a three-dimensional data space, defined by the scatter direction (χ, ψ) and the Compton scatter angle $\bar{\varphi}$. Each detected photon is represented by one point in this three-dimensional data space. In the idealised case, in which the scattered gamma ray is totally absorbed in the lower detector, the distribution of all data points resulting from a point source with coordinates (χ_o, ψ_o) lies on a cone in the (χ, ψ, $\bar{\varphi}$)-space, where the cone apex is at (χ_o, ψ_o), and the cone semi-angle is 45°. This idealised cone mantle is actually blurred due to measurement uncertainties and especially due to incomplete absorption in the lower detector.

At present, three different approaches are used by the COMPTEL team for the image reconstruction. The first one is the maximum entropy method, which searches for an input sky, which - after convolution with the response of the telescope - yields an acceptable match to the data and at the same time fulfills the entropy criterion. The second one is the likelihood method, in which the likelihood of a model-sky with and without a point source are compared. Again, the model-sky has to be convolved with the response in order to make the comparison between model and data.

The third approach - in contrast to the previous two methods - does not require the detailed knowledge of the three-dimensional response. It simply determines the one-dimensional ARM-distributions at different trial source positions. (The term "ARM-distribution" is explained in the paper of den Herder et al., in these proceedings. In terms of Figure 1 an ARM-distribution is the one-dimensional projection of all data points in the three-dimensional data space along the ideal cone mantle). If a trial source position coincides with a real one, the ARM distribution will have a maximum around $\bar{\varphi}$-φ_{geo} = zero.

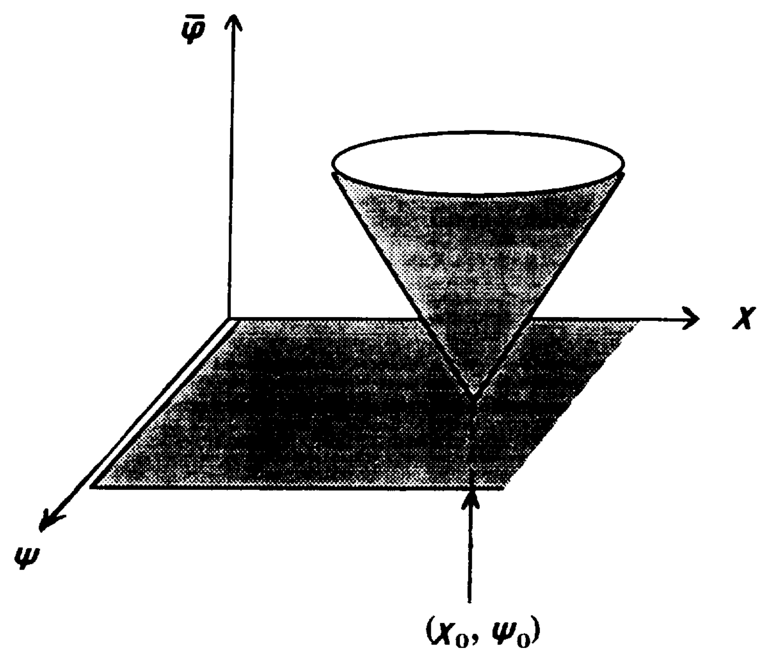

Fig. 1. Illustration of the COMPTEL response to a gamma-ray point source at $(\chi_0\ \psi_0)$.

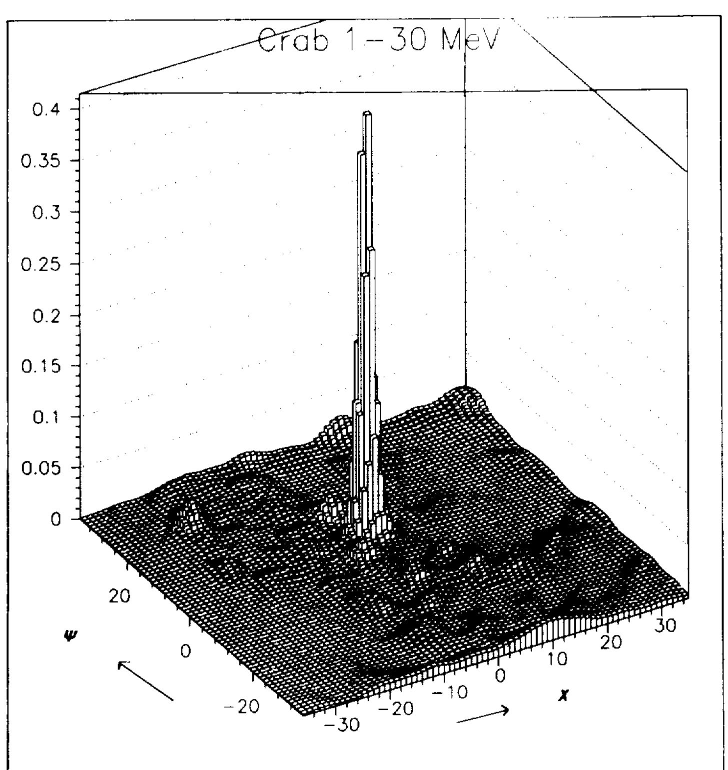

Fig. 2. Maximum Entropy image of the Anticenter region showing the Crab. Coordinates are in the telescope system. Crab is at $\chi = 0.1$, $\psi = 6.4$. The position of Geminga is at $\chi = 8.2$, $\psi = 5.6$.

3. FIRST RESULTS

3.1 The Anticenter region of the Galaxy. Figure 2 contains the maximum entropy image of the anticenter region of the galaxy as derived from 14 days of COMPTEL data in the 1 to 30 MeV range. Within the wide field-of-view of about 50° x 50°, the Crab stands out clearly as the only gamma-ray source. The derived position of the Crab agrees within 18 arcminutes with its known position. The structure around the Crab needs more investigations. At present, the instrumental background is not yet completely understood and, therefore, it is not possible to draw any conclusion about the structure around the Crab. On the other hand, it is already evident from this analysis that gamma-ray emission of Geminga in this energy region is significant smaller than that of the Crab.

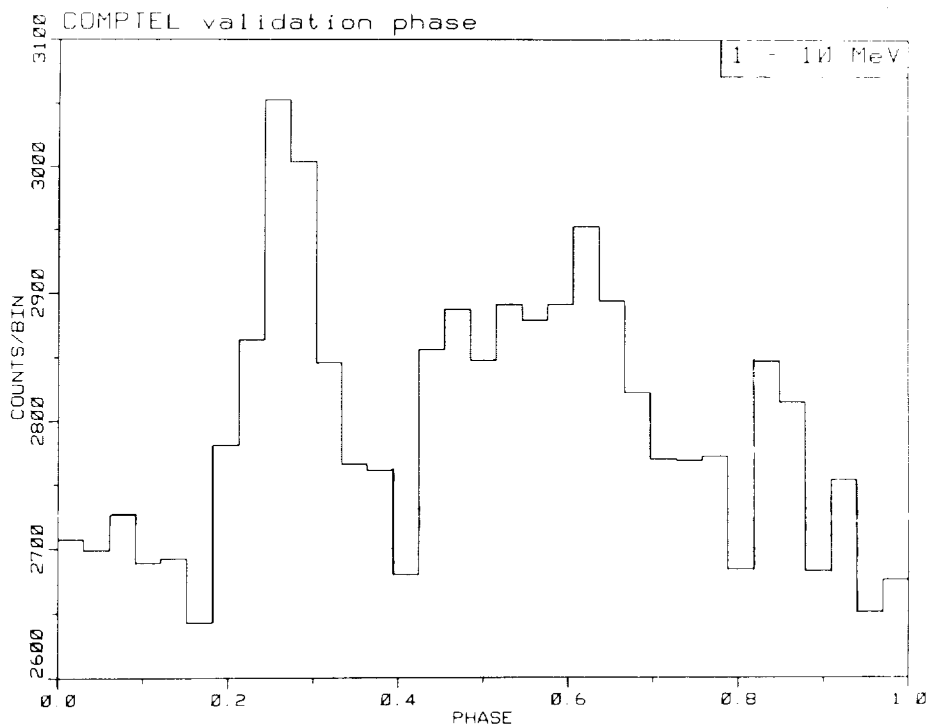

Fig. 3. Crab pulsar light curve from 10 days of data during the GRO verification phase.

The lightcurve from the Crab pulsar analysis of the first 10 days of observation is shown in Figure 3 for the energy interval 1 to 10 MeV. The two peaks of the light curve stand out at the 22 σ confidence level. There is a clear interpulse emission between the two main pulses similarly as in the several hundred keV-band (see Ulmer et al., these proceedings). The analysis of Crab pulsar data from 20 additional days of observation is in progress. There are hints for time variability of the shape of the pulsar light curve over this time interval. However, further analysis is needed before any firm conclusions can be derived.

3.2 Gamma-Ray Emission from 3C273. The quasar 3C273 was in the COMPTEL field-of-view when GRO pointed towards the target-of-opportunity SN 1991T from June 15 to June 28, 1991. 3C273 has always been a promising candidate source for COMPTEL, since its expected flux at MeV-energies - as estimated from an interpolation between X-ray and COS-B high energy gamma-ray measurements - was expected to be larger than the COMPTEL sensitivity limit (see also later Fig. 8).

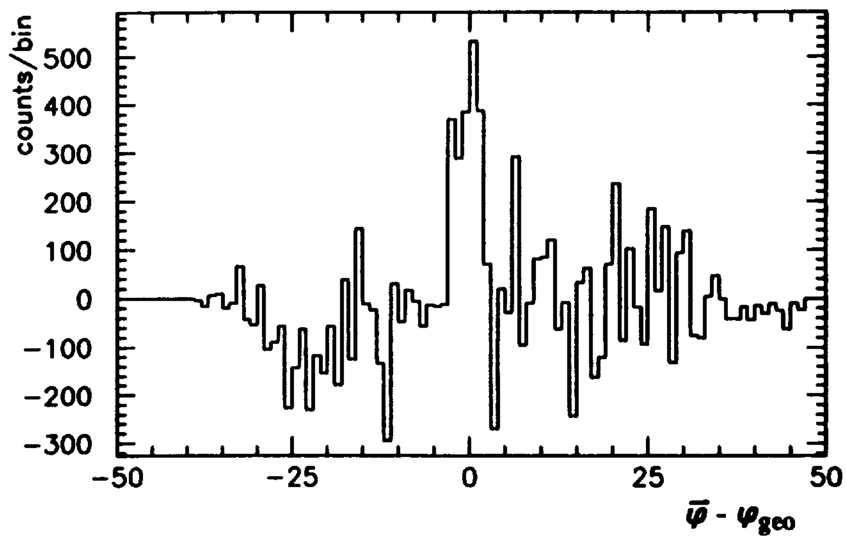

Fig. 4. The background-subtracted ARM-distribution at the position of 3C273 displays a detection of this quasar.

In Figure 4 the background subtracted ARM distribution centered at the position of 3C273 is plotted from 14 days of data in the energy range 0.7 to 20 MeV. There is a clear excess at $\bar{\varphi}$-φ_{geo} = zero, the width of this excess is consistent with that expected from a point source (4° to 5° FWHM). The statistical significance of the excess (using single count rate statistics) is about 6 σ. In principle a contribution to the excess from SN 1991T cannot be excluded (it is only 1.3° apart from 3C273). The strength of the source is about 15 % of that of the total Crab-emission.

It should be noted that no excess is found at the position of the quasar 3C279, which appeared in the EGRET observations at several 100 MeV, nearly as bright as the Crab (Fichtel et al., these proceedings). In the COMPTEL energy range its emission must be at least a factor of 2 below that of 3C273.

3.3. COMPTEL Observations of Cosmic Gamma-Ray Bursts. Apart from cosmic gamma-ray bursts, which were detected in the COMPTEL single detector mode, four bursts (on April 25, May 3, June 1, and August 14) were observed in the COMPTEL field-of-view. Here preliminary results from the May 3 and June 1 bursts are presented.

In Figure 5 the time profile of the May 3 bursts as measured in the telescope mode is plotted. The profile shows two main peaks of a few seconds duration each, separated by about 50 secs. Because on average no more than 20 events per second can be transmitted in the COMPTEL telescope mode, there are gaps in the time profile at the peaks due to dead-time effects, which, however, can be corrected for using internal scalar rates, transmitted during this interval. As the burst happened to occur in the field-of-view, it could be located on the sky.

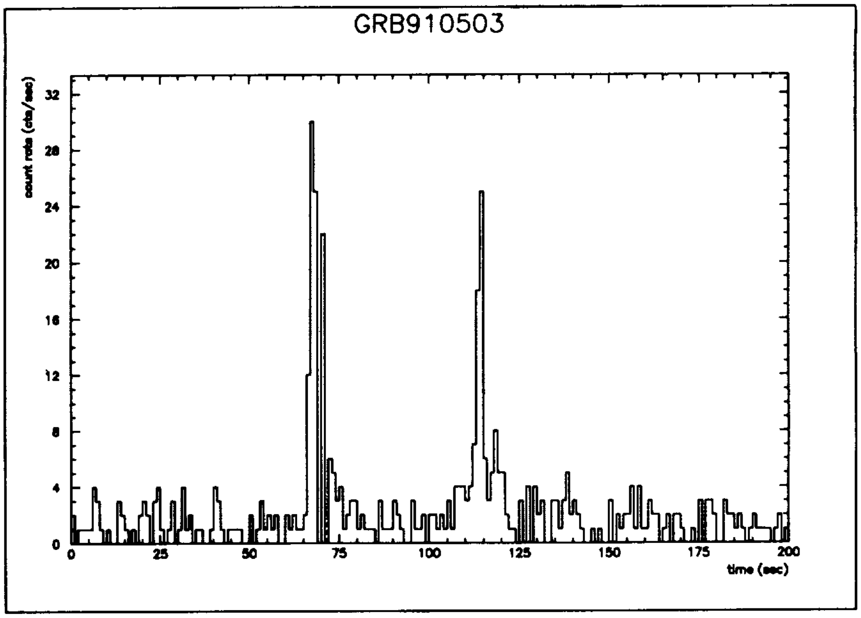

Fig. 5. Time Profile of GRB 910503 as measured in the COMPTEL telescope mode (1-20 MeV).

Figure 6 contains the maximum entropy image of that burst. The best position of the burst source is at l = 171°, b = 7°. The uncertainty of the position is about 1°. This position coincides with a one-dimensional location by triangulation using COMPTEL and Ulysses arrival times of this burst.

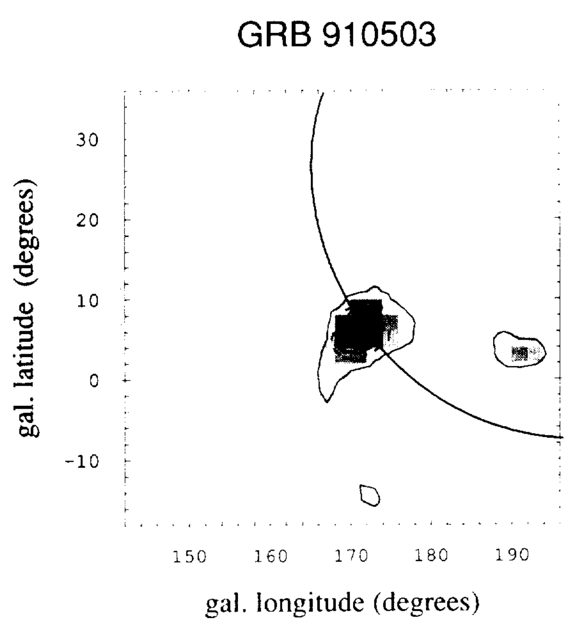

Fig. 6. (1 to 20 MeV) COMPTEL image of GRB 910503 in comparison with the triangulation circle from COMPTEL / Ulysses arrival times.

Similarly, the COMPTEL maximum entropy image of GRB 910601 and the COMPTEL / Ulysses triangulation circle of this burst are shown in Figure 7. Here the best position of the burst is l = 72.5°, b = -5°, again with an uncertainty of about 1 degree. This burst consisted of one spike of 2 sec duration, only.

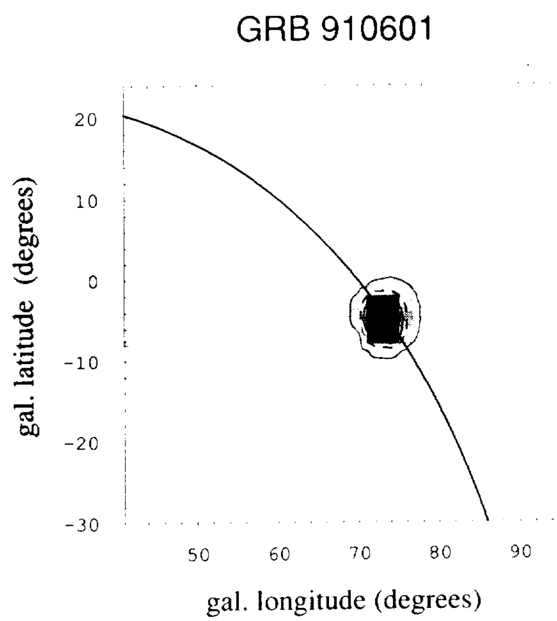

Fig. 7. (1 to 20 MeV) COMPTEL image of GRB 910601 in comparison with the triangulation circle from COMPTEL / Ulysses arrival times.

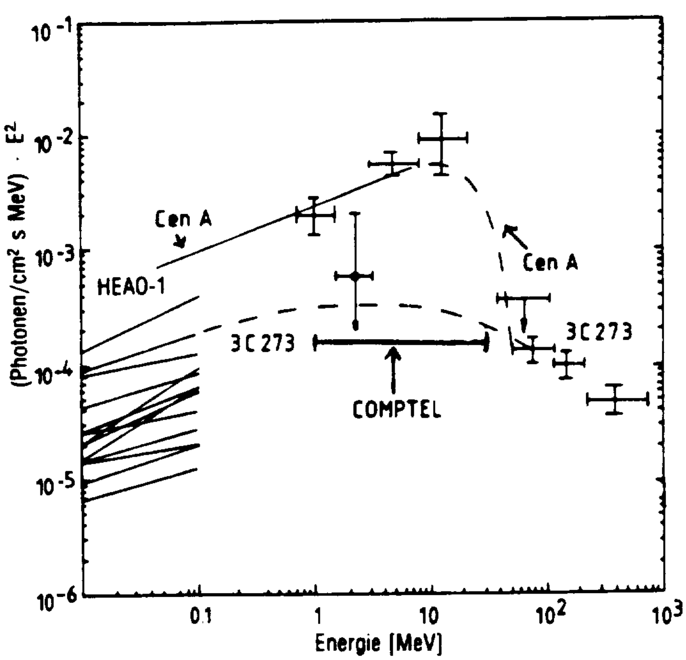

Fig. 8. 3 σ-COMPTEL point source continuum sensitivity for a 14 days observation period.

3.4 COMPTEL Point Source Sensitivity. Based on the first results from COMPTEL in the anti-center and north-galactic pole region of the Galaxy we are able to recalculate the COMPTEL point source sensitivity.

The sensitivity is mainly determined by the background count rate. This was one of the great unknown of COMPTEL, because all experience with Compton telescopes prior to the launch of GRO was based on balloon flights. Nobody really knew, how COMPTEL would perform in orbit.

The background count rate can be influenced in a very sensitive way by application of certain event selection criteria. A preliminary set of event selection criteria has been defined to optimise the signal-to-noise ratio. With this set the COMPTEL point source sensitivity to continuum-emission was recalculated.

The result of this calculation is shown in Figure 8 for an observation time of 2 weeks. The blockage of the field-of-view by the Earth during part of the time is taken into account. The 3 σ sensitivity is compared with the X-ray spectra of 12 active galactic nuclei below 100 keV. The presently achieved sensitivity approaches our predicted sensitivity within a factor of 2 and might be further improved after a more detailed study of the background and the instrument response.

4. CONCLUSION

COMPTEL performs to our full satisfaction. Based on the early results presented in this paper, we are confident that COMPTEL will fulfill its primary mission: to survey and explore the MeV-sky.

5. ACKNOWLEDGMENT

We are grateful to the Ulysses Team for providing us the Ulysses arrival times of GRB 910503 and GRB 910601.