COMPTEL OLD AND NEW

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Abstract

This is a summary of some of the scientific highlights of the COMPTEL instrument aboard the Compton Gamma-Ray Observatory which ended its operational phase during the time of the workshop after more than 9 years in orbit. Results, which by the COMPTEL collaboration are considered to be important, include observations of solar flares, the detection of lines from radioactive elements, observations of pulsars and AGN, the all-sky maps and the measurement of diffuse radiation from the Galaxy and the cosmic background.

1 Introduction

When the Compton Gamma-Ray Observatory (CGRO) was launched on April 5, 1991 with Space Shuttle Altantis, it carried four scientific experiments into a low earth orbit which together covered the wide energy range from 50 keV to $\sim$ 30 GeV (Gehrels et al. 1993). The COMPTEL instrument was an imaging gamma-ray telescope measuring in the energy range 0.75 to 30 MeV with an angular resolution of a few degrees. It was the first time such an expeiment was operated on a satellite platform. The instrument and its characteristics are described in detail in Schönfelder et al. (1993).
When the CGRO mission ended on June 4, 2000 with a very controversal intentional "de-orbiting", all instruments had operated flawlessly over 9 years and a total of 359 observation periods (spacecraft pointings) had been achieved. Due to the wide field-of-view, the COMPTEL observations covered the entire sky and the average total

exposure time is about 75 effective days.
This paper presents a summary of some of the scientific highlights of the COMPTEL instrument covering a variety of astronomical objects ranging from near (Sun) to far (cosmic diffuse background). In cases where appropriate, also results from the other CGRO instruments (BATSE, EGRET, and OSSE) are included.

2 Highlights

2.1 Solar Flares

2.1.1 Extended gamma-ray emission from solar flares

An exciting discovery during solar cycle 22 was the existence of extended gamma-ray emission of solar flares. COMPTEL measured extended emission of the flares on 9, 11 and 15 June 1991 in the 2.223 MeV neutron capture line for several hours after the impulsive phase (Fig. 1, left). The emission originates mainly from accelerated protons with energies of 10 to 100 MeV. A similar time dependence was found in the 4 to 7 MeV range, and above 50 MeV (EGRET data). Therefore, the protons have to be continuously accelerated. If the particles would have been trapped, the trapping time should be energy dependent, which was not observed. (Rank et al. 1996)

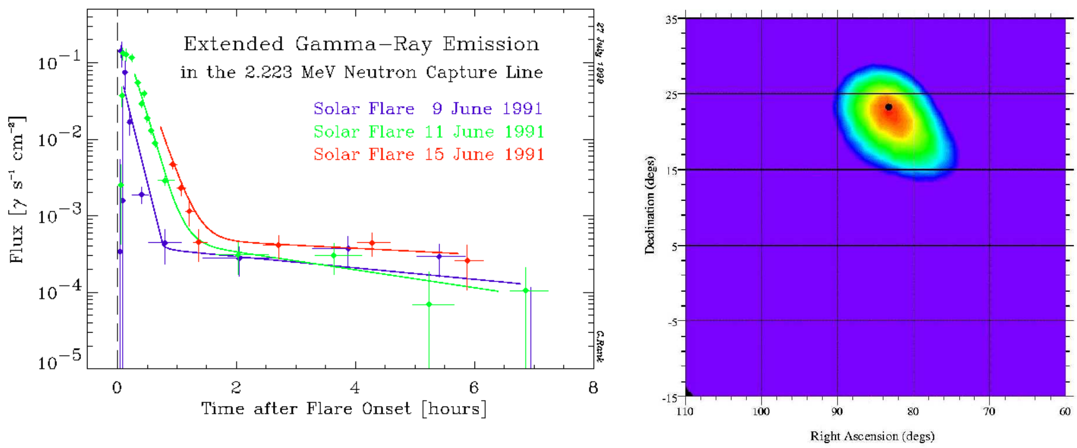

Figure 1: *Left: extended gamma-ray emission of a solar flare; right: neutron image of the Sun*

2.1.2 COMPTEL Neutron Image of the Sun

A major capability of the COMPTEL instrument is that it can measure the energy of individual neutrons arriving at the Earth after their production in solar flares, while measuring simultaneously the gamma radiation from the same event. The neutrons detected by COMPTEL (of energy 20 to 100 MeV) provide complementary information to the gamma-ray measurements, and ultimately relate to the spectrum of energetic protons at the site of the solar flare. Figure 1 (right) shows an "image" of the Sun obtained by mapping back to their origin the neutrons detected by COMPTEL following the solar flare of 15 June 1991. It represents one of the few images of an astrophysical source in particles other than photons. Analysis of the neutron data indicates that neutron emission extended for over an hour, implying that energetic protons continued to interact at the flare site long after the impulsive phase. (Ryan et al. 1993)

2.2 Radioactive Lines

2.2.1 ^{44}Ti Gamma-Ray Line Emission from Cas A

The first-ever detection of the radioactive ^{44}Ti gamma-ray line at 1.157 MeV from a supernova remnant has been achieved by COMPTEL. COMPTEL has detected this line from Cas A, the youngest known supernova remnant, with an age of $\sim$ 300 years at a distance of about 3 kpc. The measured line flux of $(4.8 \pm 0.9) \cdot 10^{-5}$ photons cm^{-2} sec^{-1} translates into a ^{44}Ti mass of $(1.62 \pm 0.31) \cdot 10^{-4} M_{\odot}$ ejected during the event for an assumed distance of 2.8 kpc, an age of 315 years and the decay time constant τ = 90 years. (Iyudin et al. 1994)

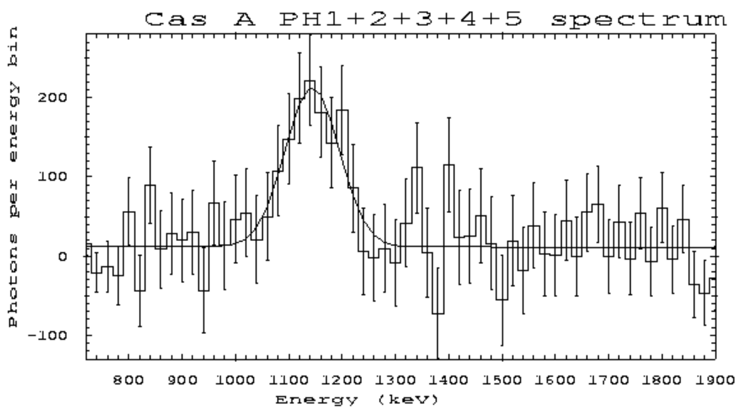

Figure 2: *Spectrum from Cas A around the 1.157 MeV ^{44}Ti line*

2.2.2 ^{44}Ti Gamma-Ray Line Emission from a Previously Unknown Galactic Supernova

The signature of the gamma-ray line at 1.157 MeV from radioactive ^{44}Ti was measured by COMPTEL also from a recently discovered X-ray supernova remnant RX 0852-4622. If the plausible assumption is valid that the X-radiation and gamma-ray line emission refer to the same object, an age of about 700 years and a distance of about 200 pc is obtained. The further search for ^{44}Ti line sources is a powerful method to discover young, previously unknown supernova remnants in the Galaxy. Figure 3 shows the ROSAT image of the Vela supernova remnant in X-rays above 1.3 keV. The ring-like structure at the bottom left of Vela is the previously unknown supernova remnant. The corresponding gamma-ray line map is shown as insert at the bottom right. (Iyudin et al. 1998)

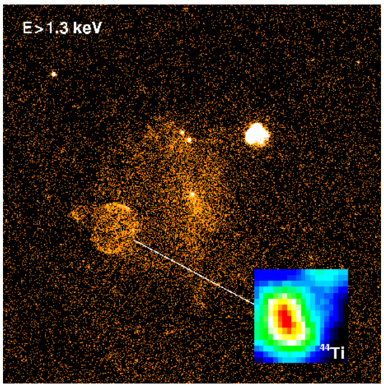

Figure 3: *ROSAT picture of the Vela supernova remnant with the new ^{44}Ti source*

2.2.3 COMPTEL 1.809 MeV All-Sky Map

COMPTEL has produced the first-ever all-sky map in the light of a radioactive gamma-ray line, namely the 1.809 MeV line from ^{26}Al. This isotope has a decay time of a million years, it is produced along with other elements at cosmic sites of nucleosynthesis. Therefore, the sky image in these gamma rays integrates nucleosynthesis events over million years and shows the spatial distribution of these events. From the image (Fig. 4) we learn that ^{26}Al-producing events are predominantly Galactic sources. Several localized regions appear prominent (Inner Galaxy, Cygnus, Vela), teaching us that massive stars (via their Wolf-Rayet winds and core-collapse supernovae) are the true sources. (Plüschke et al. 2000)

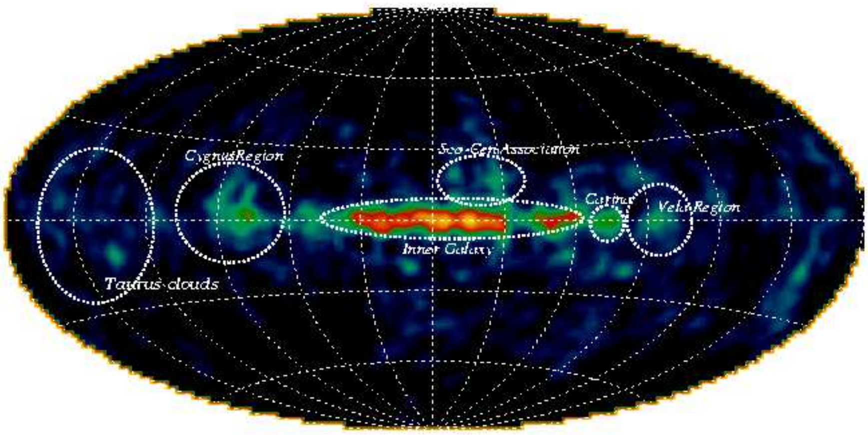

Figure 4: *COMPTEL 1.809 MeV All-Sky Map in galactic coordinates*

2.3 Pulsars

CGRO has detected gamma-ray emission from 7 young pulsars (isolated neutron stars): six were seen by EGRET at high energies (Crab, Vela, Geminga, PSR 1706-44, PSR 1055-52, PSR 1951+32), and three by COMPTEL in the 1 to 30 MeV range (Crab, Vela, PSR 1509-58). From the light curves of the seven pulsars (Fig. 5) it is visible that at least four (Crab, Vela, Geminga, and PSR 1951+32) show a double peak structure. (Kanbach 1998)

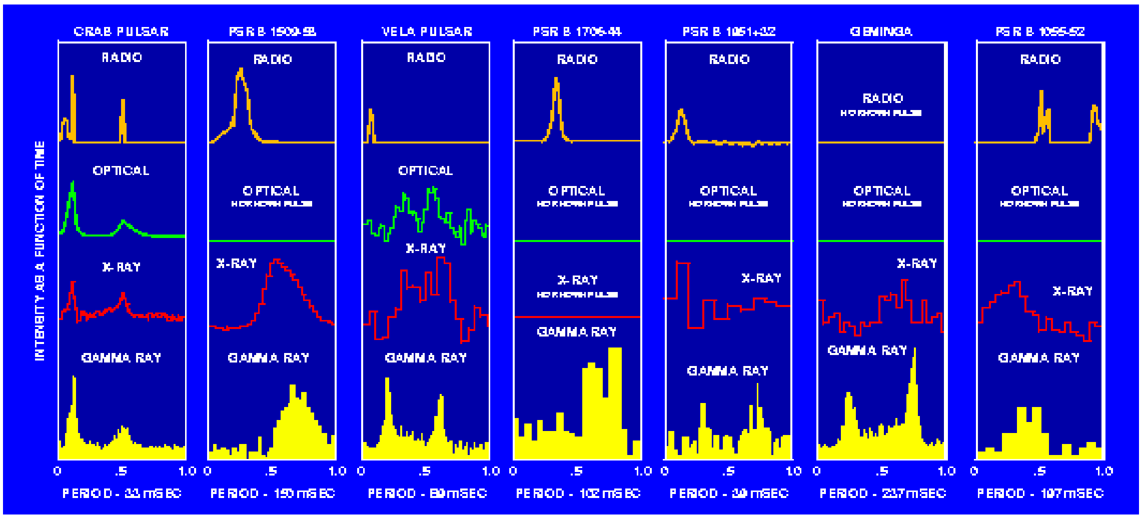

Figure 5: *Compilation of the seven pulsars detected with CGRO*

2.4 AGN: Centaurus A Multiwavelength Spectrum

CGRO has observed the nearest active galaxy Centaurus A (Cen A) many times and added high quality spectra above 50 keV to the many observations at other wavelengths. A coordinated world-wide campaign in 1995 to observe Cen A from radio to gamma-rays resulted in the first simultaneous multiwavelength spectrum (see Fig. 6) of this "misaligned" blazar (AGN). Cen A is the only AGN other than blazars which has been detected by COMPTEL, an interesting result by itself.
A Centaurus A dedicated web site was established at URL

http://www.mpe.mpg.de/Cen-A/

which contains all available information on this special AGN. (Steinle et al. 1999, Steinle 2000a)

2.5 COMPTEL 1 to 30 MeV All-Sky Map

This COMPTEL map in continuum gamma radiation (Fig. 7) represents the results of the first-ever survey of the sky at these energies. The concentration of the emission along the Galactic plane is the most striking aspect of the map. Superimposed on the Galactic emission are point-like sources (Crab, Vela, Cyg X-1), but many of the Galactic point sources remain unidentified at this time. A significant contribution of unresolved

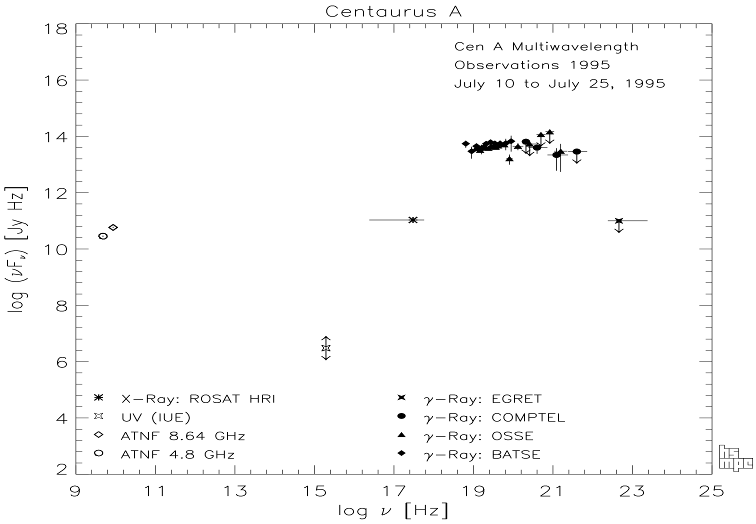

Figure 6: *Multiwavelength spectrum of Centaurus A (NGC 5128)*

point sources to the apparently diffuse Galactic emission cannot be excluded. At higher Galactic latitudes, a few of the gamma-ray blazars, discovered by EGRET, are visible (e.g. 3C 273, 3C 279, PKS 0528+134) as is the radio galaxy Cen A. Some of the objects detected by COMPTEL, are not visible because they flare-up only occasionally and thus are too weak to be visible in this time-averaged all-sky map. (Strong et al. 1997)

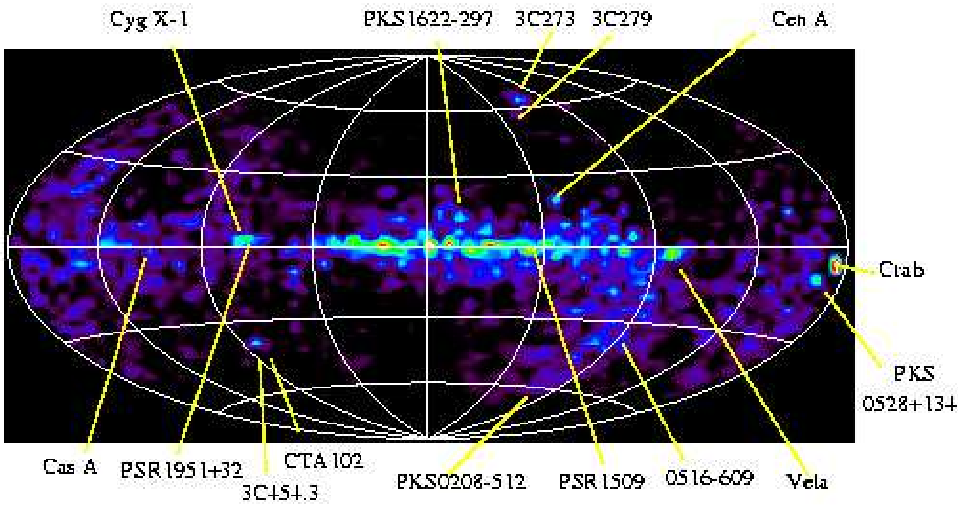

Figure 7: *COMPTEL 1 - 30 MeV all-sky map in galactic coordinates*

2.6 The COMPTEL Source Catalogue

Type of Source	No.	Comments
Spin-Down Pulsars	3	Crab, Vela, PSR B1509-58
Stellar Black Hole Candidates	2	Cyg X-1, Nova Persei
Supernova Remnants	1	Crab nebula
Active Galactic Nuclei	10	CTA 102, 3C 454.3 PKS 0528-135, 3C 279, PKS 0208-512, 3C 272, PKS 1222+216, GRO J0516-609, PKS 1622-297, Cen A,
Unidentified Sources:		
$\|b\| < 10^o$	4	GRO J1823-12, GRO J2228+61, GRO J0241+6119, Carina/Vela (x)
$\|b\| > 10^o$	5	GRO J1753+57 (x), GRO J1040+48, GRO J1214+06, HVC M + A (x), HVC C (x)
Gamma-Ray Line Sources:		
1.809 MeV (^{26}Al)	3	Cygnus (x), Vela (x), Carina (x)
1.157 MeV (^{44}Ti)	2	Cas A, RX J0852-4621
0.847 and 1.238 MeV (^{56}Co)	1	SN 1991T
1.223 MeV (n-capture)	1	GRO J0317-853

(x) indicates an extended source. (Schönfelder et al. 2000)

2.7 Diffuse Radiation

2.7.1 The Origin of the Diffuse Galactic Gamma-Ray Continuum Radiation

The energy spectrum of the diffuse Galactic continuum emission presents several puzzling features (compare Fig. 8). The main ones are:

- the excess above 1 GeV relative to the flux expected from interactions of cosmic-ray protons with the interstellar gas, which was expected to dominate in this range. One possibility is that the local measured proton spectrum is not typical of the large-scale Galactic environment; if the average spectrum is harder, then the gamma-rays could be explained. Alternative theories have been sought; most promising is inverse-Compton emission from a hard electron spectrum, the locally measured electron spectrum above 100 GeV (the relevant range for GeV inverse-Compton gamma rays) being strongly affected by energy losses and therefore very inhomogeneous so that local measurements are not necessarily typical. By postulating both a hard electron spectrum and slightly modified proton spectrum, it is possible to reproduce the observed spectrum above 30 MeV.

- below 30 MeV the observed emission is again more than expected using the best current estimates of the cosmic-ray electron spectrum including constraints from Galactic synchrotron radiation. The latter precludes the steep electron spectrum which would be required to explain the gamma-ray emission as bremsstrahlung or inverse Compton. For this reason it might be that this emission is actually dominated by unresolved point-sources, such as supernova remnants or black-hole binaries. Hard X-ray measurements by OSSE, GINGA and RXTE suggest that point-source populations produce the diffuse emission from the Galactic ridge below a few 100 keV, so that the switchover from sources to truly diffuse emission must occur at some energy in the few-MeV range. (Strong et al. 1997)

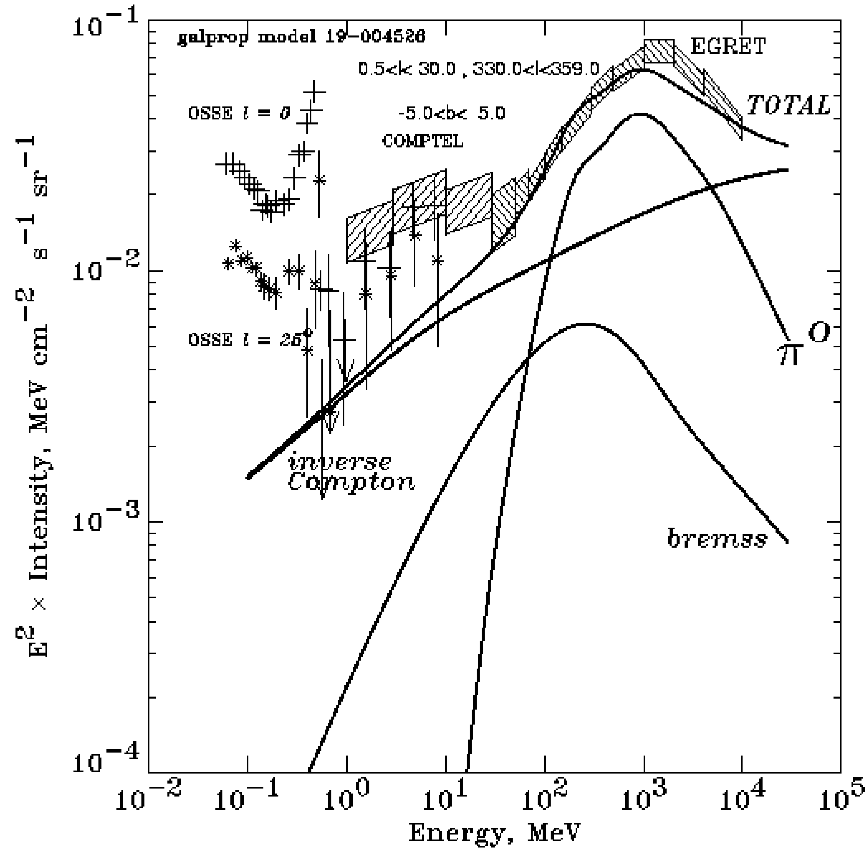

Figure 8: *Diffuse Galactic continuum emission*

2.7.2 The Cosmic Diffuse Gamma-Ray Background Measured with COMPTEL

One of the principal scientifics goals of COMPTEL was to study the cosmic diffuse gamma-ray background (CDG). COMPTEL measures gamma-rays from 0.8-30 MeV and is uniquely suited to study the CDG because of its wide field-of-view (~1 sr) and its long exposure time. The measured MeV CDG spectrum (Fig. 9) merges smootly with the spectra at higher and lower energies, marking the transition from a softer to a harder component. No evidence for the MeV-bump, an excess of emission at MeV energies detected by previous experiments, could be found. Upper limits on the relative deviations from isotropy of the CDG consistent with the data at the 95 % confidence limit range from about 24 % to 45 % on scales of a few steradian. (Weidenspointner et al. 1999)

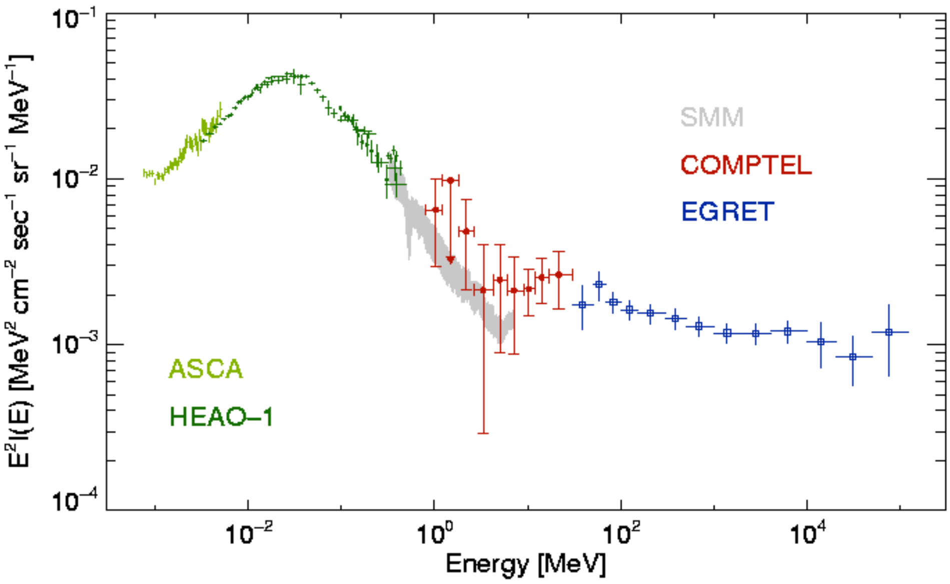

Figure 9: *Cosmic diffuse gamma-ray background*

3 The COMPTEL Bibliography

To make all the results of the COMPTEL instrument aboard CGRO available to the scientific community, all publications which contain

- descriptions of the instrument,
- descriptions of analysis techniques used to analyze COMPTEL data,
- COMPTEL observation data,
- COMPTEL data analysis results, and
- results derived using published COMPTEL data

have been compiled into the **COMPTEL Bibliography** which is available through the World Wide Web at the following URL:

http://www.gamma.mpe-garching.mpg.de/CBIB/

It consists of a set of 7 pages which offer a full and short bibliography, the latest entries, an input form (for internal use), a search facility, the possibility to request hardcopies, and a way to contact a COMPTEL person. All publications have been made available on-line whenever possible. In addition several links to related sites are provided as well as a version without frames.
The COMPTEL Bibliography is based at MPE, the site of the COMPTEL principal investigator. (Steinle 2000b)

4 References

Gehrels N., Fichtel C.E., Fishman G.J., Kurfess J.D., Schönfelder V., 1993, Scientific American **269**, No. 6, p. 68.

Iyudin A.F., Diehl R., Bloemen H., et al., 1994, Astron. Astrophys. Lett. **284**, p. L1.

Iyudin A.F., Schönfelder V., Bennett K., et al., 1998, Nature, **396**, p. 142.

Kanbach G. 1998, Adv. Space Res. Vol. **21**, No. 1/2, p. 227.

Plüschke S., Diehl R., Schönfelder V., et al., 2000, Proc. 5th Compton Symposium, Sept. 15 - 17, 1999, Portsmouth, NH, USA, AIP **510**, p. 35.

Rank, G. Debrunner H., Lockwood J., et al.: 1996, Proc. 25^{th} Int. Cosmic Ray Conf., Vol. **1**, p. 5.

Ryan, J. V., Bennett K., Debrunner H., et al.: 1993, Adv. Space Res. **12**, p. (9)255.

Schönfelder V., Aarts H., Bennett K., et al.: 1993, Astrophys. Journ. Suppl. **86**, p. 657.

Schönfelder V., Bennett K., Blom J.J., et al.: 2000, Astron. Astrophys. Suppl. Ser. **143**, p. 145.

Steinle H., Bonnell J., Kinzer R.L., et al.: 1999, Adv. Space Res. **23**, No. 5/6, p. 911.

Steinle H., 2000a, in: Proceedings of the 5th Compton Symposium, Sep 15 - 17, 1999, Portsmouth, NH, USA, eds. McConnell M.L., Ryan J.M., (New York: AIP), AIP Conf. Proc. ¡b¿510¡/b¿, 821.

Steinle H., 2000b, in: Proceedings of the 5th Compton Symposium, Sep 15 - 17, 1999, Portsmouth, NH, USA, eds. McConnell M.L., Ryan J.M., (New York: AIP), AIP Conf. Proc. ¡b¿510¡/b¿, 823.

Strong A., Schönfelder V., Bloemen H., et al., 1997, In: Proc. 2nd INTEGRAL Workshop, "The Transparent Universe", St. Malo, France, September 16-20, 1996, ESA **SP-382**, p. 533.

Strong A., Schönfelder V., Diehl R., et al. 1997, In: Proc. Fourth Compton Symposium", Eds. C.D. Dermer, M.S. Strickman & J.D. Kurfess (New York: AIP), AIP Conf. Proc., **410**, p. 1198.

Weidenspointner G., Varendoff M., Bennett K., et al., 1999, Proc. 3rd INTEGRAL Workshop, Taormina, Italy, Sept. 14-18, 1998, Eds. G. Palumbo, A. Bazzano, and C. Winkler Astrophys. Letters and Communications, **39**, p. 193/[661].