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Constraints on the 3-30 MeV emission of Seyfert galaxies

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Abstract. Seyfert galaxies have not been detected by COMPTEL on the Compton Gamma Ray Observatory (CGRO) in the energy range 0.75-3 MeV, placing upper limits on their emission which are more than an order of magnitude below previously reported detections. Here, we extend our previous work to the energy range 3-30 MeV. Again, we find no evidence for emission from a cumulative sample of X-ray bright Seyfert galaxies. We use the recent results on the extragalactic background at MeV energies to constrain the possible emission of these sources and their contribution to the cosmic extragalactic background (CXB). The lack of γ-rays from Seyfert galaxies strongly argues against hadronic cascades as the underlying radiation mechanism and, consequently, against recent claims that Seyferts might produce a high-energy neutrino background with an energy flux similar to that of the CXB.

Key words: Galaxies: active ; Gamma rays: observations

1. Introduction

The extragalactic sky at MeV energies, observed by CGRO COMPTEL and EGRET, has been found to be dominated by the radio loud class of blazars, not radio quiet objects such as Seyfert galaxies, as had been expected before the launch of CGRO (e.g. v. Montigny et al. 1995). In a study of the X-ray brightest Seyferts at energies 0.75-3 MeV, Maisack et al. (1995, hereafter Paper I) found no evidence for emission from Seyfert galaxies, deriving upper limits more than an order of magnitude below previously reported fluxes from balloon experiments (Perotti et al. 1981a, 1981b). No Seyfert galaxy has been detected by EGRET, either (Lin et al. 1993).

At the same time, OSSE observations ranging up to several 100 keV detected spectra significantly steeper than those found in the standard X-ray bands (Johnson et al. 1994), suggesting a thermal nature of the high-energy emission. Zdziarski et al. (1995, hereafter Z95) combined (non-simultaneous) Ginga and OSSE data of 9 Seyfert galaxies to derive a mean spectrum which is characterised by a continuum which falls off exponentially with an e-folding energy of several 100 keV, plus a Compton reflected component which contributes mainly between 10 and 50 keV.

Therefore, it is plausible that the primary hard X-rays are thermal X-rays from a hot corona (Haardt & Maraschi 1993) or other active regions above an accretion disk (Stern et al. 1995) which acts as the cold reflector. A Compton reflected component has been observed in many Seyfert galaxies (e.g., Nandra and Pounds 1994). However, a nonthermal origin of the *primary* emission is still not ruled out, since the nonthermal spectrum could turn over at ~100 keV as well or, if it extends to γ-ray energies, it could be anisotropic. Therefore, this radiation could go unobserved in most sources, and be mainly visible as reprocessed radiation. A likely candidate for such anisotropic emission are primary X-rays from a misdirected X-ray jet. Klein-Nishina driven nonthermal emission could also be highly anisotropic irradiating the disk (Ghisellini et al. 1991). Analogously, photo-pair or photo-pion driven hadronic cascades arising in a turbulent, low Mach number jet also produce much more flux in the direction of the disk than toward the observer (Mannheim 1995a). The cascade spectrum reaches up to a few MeV, and a diffuse high-energy neutrino background with an energy flux comparable to the CXB is expected from such hadronic models (Stecker et al. 1991). We probe the presence of a radiation component peaking at high energies by direct COMPTEL measurements employing the method of Paper I to the 3-30 MeV high energy range.

The remainder of the paper is organised as follows: in sections 2 and 3, we describe the instrument and data analysis, and give the results. We then discuss the upper limits in connection to the recent COMPTEL results of the CXB.

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Table 1. Individual 2σ upper limits for Seyfert galaxies observed by COMPTEL in Phase I

Source Name	l	b	Viewing Periods	UL 0.75-1 MeV^a	UL 1-3 MeV^a	UL 3-10 MeV^a	UL 10-30 MeV^a
NGC 7314	26.44	-59.17	42	108.8	11.7	0.85	0.14
NGC 6814	29.15	-16.01	7.5, 13, 43	49.0	4.7	0.79	0.08
NGC 5548	31.94	70.49	24	140.0	15.0	0.99	0.11
MRK 509	35.97	-29.85	7.5, 13, 19, 43	40.4	5.5	0.47	0.07
3C 445	61.87	-46.71	19	50.0	5.0	1.09	0.07
MCG -2-58-22	64.08	-58.76	19	37.5	7.5	1.13	0.08
NGC 7469	83.09	-45.46	19, 28, 37	32.4	7.2	1.05	0.10
III ZW 2	106.97	-50.63	28, 37	57.6	8.0	0.32	0.05
MRK 335	108.76	-41.42	28, 37	106.8	12.4	0.55	0.03
NGC 4051	150.12	69.71	4	39.6	4.8	0.59	0.06
NGC 4151	155.05	75.06	4	15.8	4.8	1.10	0.13
3C 111	161.67	-8.81	15, 31, 36, 39	22.8	3.0	0.31	0.07
MCG +8-11-11	165.72	10.40	30, 36, 39	58.2	8.8	0.38	0.05
NGC 1068	172.10	-51.93	21	51.0	7.0	0.69	0.08
3C 120	190.37	-27.39	1, 2.5	27.3	3.8	0.83	0.15
MCG +5-23-16	200.82	46.46	40	42.1	5.5	0.81	0.06
ARK 120	201.69	-21.12	1, 2.5	50.9	6.6	1.11	0.11
NGC 3227	217.01	55.44	40	40.6	9.4	1.27	0.07
NGC 3783	287.45	22.94	12, 14, 32	22.2	3.3	0.49	0.07
FAIRALL 9	295.07	-57.82	10	45.2	5.9	0.59	0.06
NGC 4593	297.47	57.40	3, 11	71.4	3.3	0.89	0.07
IC 4329 A	317.49	30.92	12	50.5	6.1	0.64	0.08
ESO 141-55	338.18	-26.71	35, 38	83.2	16.0	1.49	0.11
MCG -6-30-15	338.46	44.53	12	85.5	10.6	0.74	0.09
NGC 5506	339.14	53.80	3, 11, 24, 25	30.5	5.2	0.43	0.07
NGC 7582	348.07	-65.69	9, 42	122.2	9.9	1.71	0.12

^{a} in 10^{-8} photons cm^{-2} s^{-1} keV^{-1}

2. Instrument and Data Analysis Methods

The Compton telescope *COMPTEL* (Schönfelder et al. 1993), as part of CGRO, covers the energy range 0.75-30 MeV. An all-sky survey in this energy range was conducted during the first 15 months of the GRO mission. We have overlaid 50 observations of 26 individual X-ray prominent Seyfert galaxies obtained during this survey to improve the sensitivity over that of a standard two week observation. Relevant details about the instrument, data acquisition and the data analysis methods applied for this work have been described in detail in Paper I.

3. Observations and Results

We have used the same set of observations as in the analysis of the 0.75-3 MeV range reported in Paper I to be able to directly compare the results at 3-30 MeV to those in the lower energy bands.

Again, we detect no individual Seyfert galaxy, and no significant flux in the cumulative data which correspond to a net observation time of $\approx$ 70 days. The 2σ upper limits for the individual sources are listed in Table 1, together with those for the two low energy bands already presented in Paper I. The limits on the complete sample are 1.05 $\times$ 10^{-9} photons cm^{-2} s^{-1} keV^{-1} for the 3-10 MeV band and 1.32 $\times$ 10^{-10} photons cm^{-2} s^{-1} keV^{-1} in the 10-30 MeV band, and about the same in νF_ν as the limit in the 1-3 MeV band (9.7 $\times$ 10^{-9} photons cm^{-2} s^{-1} keV^{-1}), see Paper I). The 2σ upper limits are shown in Fig.1, together with the extension of the average spectrum of Seyfert galaxies at several 100 keV derived from OSSE observations (Johnson et al. 1994, Z95).

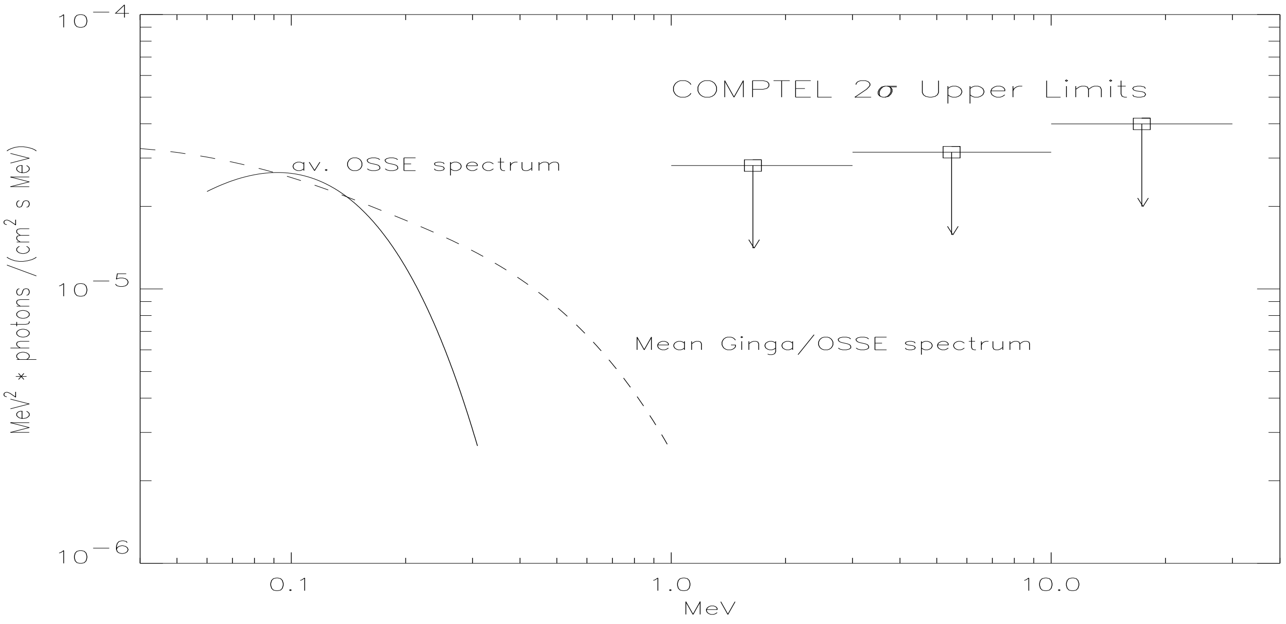

Fig. 1. COMPTEL 2σ Upper Limits Compared to X-Ray Samples of Johnson et al. (1994) and Z95

This result is not surprising when compared to the analysis of Z95 who analysed (non-simultaneous) Ginga and OSSE data of 9 Seyfert galaxies and found that the average spectra can be described by an exponentially truncated power law with photon indices around the canonical X-ray values of 1.8-2.0 and an e-folding energies of several 100 keV. The OSSE data alone indicate even steeper spectra with e-folding energies of $\approx$ 40-50 keV (Johnson et al. 1994). Simultaneous broad-band observations with XTE and OSSE could better constrain this parameter in the future. The best fit spectrum for the complete sample of Seyferts from Z95 is shown in Fig.1 for comparison. It is obvious that the upper limits we derive are still substantially above the level of emission expected from the work of Z95.

It has been suggested that the thermal appearance of the Seyfert X-ray spectra could be due to a highly anisotropic nonthermal source emitting most photons toward the disk, so that the observed spectrum is mostly due to reflection and Comptonization by the disk (Mannheim 1995a). A natural anisotropy of this kind develops for pair cascades produced by ultrarelativistic protons (Lorentz factor $\gamma_{\rm p}$) accelerated in a magnetized disk wind ('hadronic jet') as they cool by photo-production of secondary particles in the radiation field of the disk. Pions are produced by head-on collisions with UV photons (energy ϵ) from the inner disk. In the rest frame of the proton, the UV photons appear with energies $\epsilon' = 2\gamma_{\rm p}\epsilon$ which leads to catastrophic energy losses when $\epsilon' \gtrsim m_\pi c^2$, thereby stopping further proton acceleration. The pions subsequently decay giving rise to an anisotropic cascade irradiating the disk hemisphere. Infrared photons originating in the heated dust torus surrounding the central object appear with energies $\epsilon' \gtrsim 2m_{\rm e}c^2$ in the proton rest frame giving rise to Bethe-Heitler $e^{\pm}$ pairs. Owing to the solid angle $\sim 2\pi$ subtended by the infrared photons, the Bethe-Heitler pair distribution is nearly isotropic. The pairs produce synchrotron γ-rays in the 3-10 MeV energy range. The expected energy flux in the $3-10$ MeV range is maximally of the same order as the Compton reflected component, but does not contradict the already derived flux limits at ~MeV due to the rather flat spectrum (Fig.2). From our observation alone, no constraints on this extra component can be derived, as the upper limits are of about the same magnitude in νF_ν as the fluxes of the OSSE observations at several tens of keV (Z95).

Tighter constraints on the MeV emission of Seyferts than those obtained from the individual and cumulative observations can be derived from the recent results on the extragalactic background derived by Kappadath et al. (1996), who found that the MeV bump in the background (e.g. Gruber 1992) was an artifact owing to the detector background caused by charged particles being dependent on the geomagnetic rigidity at which individual measurements were conducted. Kappadath et al. (1996) conclude that there is no MeV bump, and that the spectrum of the CXB can be described by a power law from 100 keV to hundreds of MeV, as originally found by Mazets et al. (1975). The photon index of the power law connecting hard X-ray and MeV γ-rays lies in the range 2.5-3, significantly flattening toward EGRET energies where $s = 2.07 \pm 0.03$ (Kniffen et al. 1996).

Recent modeling of the CXB (Comastri et al. 1995, Z95) has shown that the CXB at several tens of keV can be described by the superposition of Seyfert galaxies (more generally radio quiet AGN) at various levels of obscuration. Assuming similar spectra for all Seyferts from hard X-rays to MeV energies, the steep spectrum of the CXB places stronger constraints on the γ-ray flux from Seyferts than the actual observations reported in this paper.

This can be seen from Fig.2, which shows the 2σ upper limits derived from the COMPTEL data together with the average X-ray spectrum of Seyferts from Z95, plus the spectrum of the CXB (following Mazets 1975, Kappadath 1996 and Kniffen 1996) scaled to the Z95 spectrum. Even neglecting the possible contribution of other AGN and Supernovae type Ia to the CXB, the persistent emission from Seyferts must lie a factor of ≈ 10 below the COMPTEL upper limits to be consistent with the CXB. Accordingly, these constraints imply that the anisotropic nonthermal cascades either have extremely large disk/observer flux ratios obtaining values $\gtrsim 10$ or, more likely, that they do not contribute substantially to the reflected component. This is in agreement with the non-detection of $>$ TeV neutrinos with the Fréjus proton-decay experiment (Mannheim 1995b). A diffuse neutrino background with an energy flux comparable to the CXB as proposed by Stecker et al. (1991) therefore cannot be expected from radio-quiet AGN.

The main contribution to the primary X-ray emission from radio-quiet AGN responsible for the reflection hump seems to come from coronal plasma near the inner accretion disk (e.g., Haardt and Maraschi 1993) or from a nonthermal (non-cascade) source with an intrinsic turnover at ~ 100 keV.

4. Future observations

The next generation γ-ray mission INTEGRAL (e.g. Winkler et al. 1994) is supposed to provide a sensitivity at several 100 keV to 1 MeV which will be a factor of 10 below that of COMPTEL. Given the tight limits which the CXB measurements put on the average emission of Seyferts, this may be marginally sufficient to probe deep enough to detect Seyfert galaxies at this energy.

5. Summary

Extending our work on Seyferts in the 0.75-3 MeV range, we find that Seyferts are not bright in the 3-30 MeV range, either. An emission component in this high energy range could have been expected from the ~ 5 MeV bump in the diffuse γ-ray background as it was obtained from Apollo data by Trombka et al. (1977) and from nonthermal models. The null-result is in accord with the absence of a bump in the diffuse background spectrum as it has recently been obtained from COMPTEL data by Kappadath et al. (1996). The diffuse γ-ray background implies that the average emission from Seyfert galaxies still lies a factor of ~ 10 below the current upper limits for selected X-ray bright Seyferts. In particular, since we do not find evidence for nonthermal X-ray and γ-ray emission from Seyfert galaxies, predictions of high-energy neutrinos from Seyferts (Stecker et al. 1991) are invalidated.

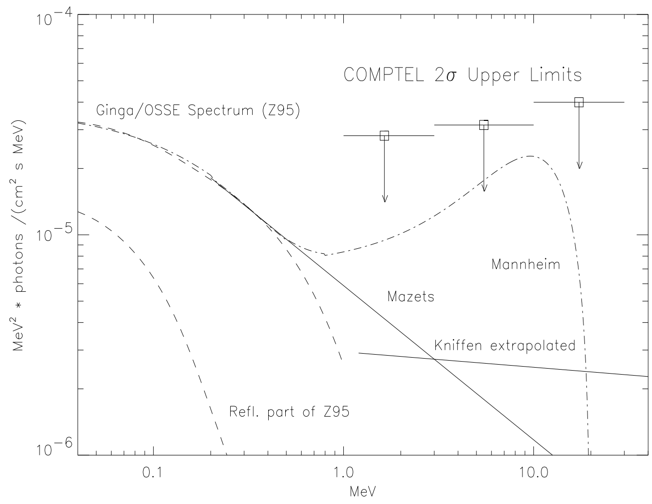

Fig. 2. Comparison of COMPTEL 2σ Upper Limits to those derived from the CXB (solid lines) which is scaled to the keV emission (dashed lines) derived by Z95. The dashed-dotted line represents the maximal flux expected from a Bethe-Heitler pair component in the hadronic jet model of Mannheim (1995a)

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