SPECTRUM OF THE GAMMA-RAY DIFFUSE COMPONENT OBSERVED FROM HEAO-1

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ABSTRACT

The spectrum of the diffuse X- and gamma-ray background has been measured between 15 keV and 4 MeV with the scintillator detectors of the UCSD/MIT instrument aboard the *HEAO-1* satellite. The apertures of the detectors were modulated on time scales of hours and the difference in counting rates measured the diffuse component flux. The observed spectrum is presented and compared with other measurements. At least two components are indicated, one below ~100 keV and the other above. Possible origins are discussed.

1. Introduction. The question of the origin of the X-ray and gamma-ray diffuse component has been revitalized in recent years through more precise measurements of the spectral shape (Marshall *et al.* 1980) and isotropy (Shafer 1983) at energies below 100 keV, and also through statistical studies of X-ray emitting active galaxies (*e. g.* Piccinotti *et al.* 1982) and QSO's (*e. g.* Tananbaum *et al.* 1979). The current theoretical situation, as reviewed by Fabian (1985), is far from decided. Much of the more recent work, based on the *HEAO-1* and *EINSTEIN* surveys, has attempted to model the diffuse component as the unresolved emission from numerous distant point sources. Such modeling has generally found it necessary to invoke evolution in the number density, luminosity and/or spectral shape of the candidate population; that is, the population must be substantially different at early epochs than at present. A truly diffuse mechanism, such as the hot gas suggested by the thermal bremsstrahlung spectral shape of the *HEAO-1* measurements of Marshall *et al.* (1980), has its own difficulties with spatial density, spectral shape and evolution. While these efforts must be continued, it is also likely that further precise and reliable measurements of the spectrum, isotropy and fluctuations of the diffuse emission will guide the course of such work, or may even suggest an alternate origin. We present measurements of the diffuse component spectrum measured between 15 keV and 4 MeV. Below 100 keV these closely confirm the spectral shape of Marshall *et al.*,

above this energy a steep power-law extension is measured, and a flattening is indicated above 500 keV.

2. Instrumentation and Method. The UCSD/MIT Hard X-Ray and Low-Energy Gamma-Ray Experiment aboard *HEAO-1* consisted of seven actively-shielded phoswich scintillation detectors. The two Low Energy Detectors (LED's) were sensitive from 15 kev to 150 keV, the four Medium Energy Detectors (MED's) from 80 kev to 2 MeV, and the High Energy Detector from 140 keV to 10 MeV. A movable shutter, consisting of a 5 cm thick CsI scintillator detector, was placed periodically over the aperture of several of these detectors in order to permit measurement of the internal cosmic-ray-induced background (CRIB) counting rate. To first order, the diffuse component is measured simply by subtracting the CRIB from open-aperture observations of blank fields. Actually, a number of open and blocked accumulations are subtracted, each open/blocked pair corresponding to a given range of geomagnetic parameters, to compensate for the time variation of the CRIB. Further corrections must be applied to these differences to account for small changes of the CRIB by the shutter, and to correct some residual time-variability of the CRIB. The complete method is described in Kinzer *et al.* (1985). For each of the three detector types, the aperture flux was equal to or larger than the CRIB near the lower energy threshold, but in the upper portion of the energy range it was only a few percent of the CRIB. The most complete and systematic program of aperture modulation was performed for the MED detectors. Results for the other detectors are based on a few blockings only, and thus are more subject to systematic error.

3. Results. In Figure 1 are displayed the combined *HEAO-1* results, including those from the A-2 experiment (Marshall *et al.* 1980). The LED results extend from 15 to 100 keV; data at higher energies was eliminated because of poor signal-to-noise. The LED spectral shape is in exact agreement with the A-2 spectrum in the region of overlap, and a 20% difference in flux level is consistent with the 10-15% estimated 10-15% uncertainty in the calculation of the solid angle for each instrument. The LED spectrum is well-fit up to 100 keV by a thin thermal bremsstrahlung spectrum with temperature kT = 43±1 keV, assuming statistical errors only. The A-2 best-fit kT is 40±5 keV, where the quoted error is a generous allowance for systematic error. The MED results, extending from 50 to 800 keV, are inconsistent with an extension of this thermal spectral form; instead, they agree quite well with a power law shape of spectral index -1.81±0.08 in energy flux which is tangent to the curved (thermal) LED spectrum between 80 and 100 keV.

The HED results extend upwards from 140 keV, and agree with the MED results in the region of overlap (140 to 500 keV). The net significance above 1 MeV is only 2σ. Taken at face value, the HED points indicate yet another change of spectral shape: a flattening to an energy index of about -1. These highest-energy points are only 2% of the HED internal background and are comparable to the modulation of the internal background by the shutter. This modulation is known, through a combination of measurement and calculation, to an estimated error of 0.7% of the internal background. The sum of systematic uncertainties is of the order of the statistical error (1% of internal background), thus a positive detection above 1 MeV cannot be claimed. Still, these points are in remarkable agreement with previous measurements in this energy range from a scintillator (Trombka *et al.* 1977) and Compton telescopes (White *et al.* 1977; Schönfelder *et al.* 1980).

4. Discussion. The combined A-2 and A-4 LED *HEAO-1* data together show a 2-100 keV spectrum with precisely the *shape* of thin thermal bremsstrahlung at about 40 keV temperature. But compelling theoretical arguments need to be advanced before a thermal origin for this part of the diffuse component can become accepted. On the other hand, if this radiation is assumed to arise from active galaxies, there is the difficulty that active galaxies show no sign of having thermally cut-off spectra, although this problem can be avoided by resorting to spectral evolution. Explaining the power law extension above 100 keV poses its own difficulties, perhaps more so for a thermal model.

The spectrum just above 1 MeV has yet to be measured convincingly. The observations, by various experimenters, are in good agreement with each other, but all are at the limit of sensitivity of the instrumentation or the analytical method. There remains, therefore, a reasonable possibility that the true flux lies lower, as extension of the 100-400 keV spectrum would indicate. But extrapolation of two other observations indicates that the 1-10 MeV observations may be correct. The SAS-2 diffuse component spectrum at 30-100 MeV (Fichtel *et al.* 1978) is steep and inconsistent with an extrapolation of the 100-400 keV data, thus indicating a flattened region between 400 keV and 30 MeV. Also, a mean active galaxy spectrum from 2 to 150 keV has been measured by Rothschild *et al.* (1983). Converted to an equivalent diffuse flux (unevolved), this spectrum passes right through the 1-10 MeV data, if extrapolated. Thus active galaxies could give rise to the entire diffuse component above 1 MeV. Unfortunately, there exists yet no direct observational evidence that their spectra extend into this energy range.

5. Conclusions. The thin thermal bremsstrahlung shape of the diffuse component spectrum has been confirmed to high precision between 15 and 60 keV. This shape has been observed to extend to about 100 keV, above which energy it continues smoothly as a power law of spectral index -1.8. Measurements from 500 keV to 4 MeV have only weak significance, but are in agreement with other measurements on this interval. The coincidence with an extrapolation of a mean active galaxy spectrum suggests the possibility that the diffuse component near 1 MeV is largely due to this population.

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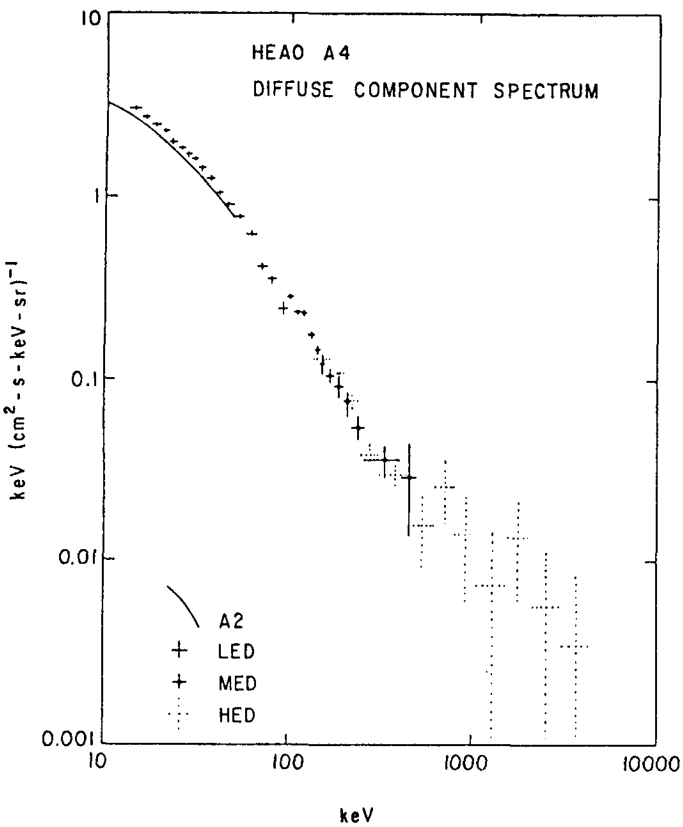

Figure 1. The spectrum of the diffuse X-ray background, as measured by instruments aboard HEAO-1. Excellent agreement between the different instruments is obtained, allowing for the ~10% calibration uncertainties. Below 100 keV the data fit a thin thermal bremsstrahlung spectrum with kT=40 keV. Above 100 keV a power law of index -1.8 describes the data. This may flatten above 500 keV.