THE COSMOLOGICAL DIFFUSE γ-RAY BACKGROUND: MYTH OR REALITY ?

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1. Introduction

This paper is by no means a critical review of what have been thought, calculated or written about the cosmological diffuse γ-ray background. More simply, it is intended to tell its story, in order to answer a may be more historical than astronomical question:

> "How ideas about the cosmological diffuse γ-ray background has evolved since the beginning of the space era ?"

As the γ-ray energy range is quite large, this story will be divided in two parts. The first one, which is given here, will address only the low energy part of the γ-ray domain, that is γ-rays whose energy is less than a few MeV. The high energy domain will be described by Prof. Bignami (this issue).

2. First observations of the "MeV bump"

So, let's return to the sixties, at the beginning of our story ... An "interstellar" γ-ray emission has been observed indeed for the first time by the experiments Ranger 3 and 5 in 1964 (Metzger *et al.*, 1964). These experiments consisted of a phoswitch system composed of a caesium iodide scintillation crystal and a plastic scintillator. Most of the instruments we will consider later on were built on the same principle. This is an important point to keep in mind as we will see below.

At that moment, it was only known that this emission did not come from the Solar System, so they called it "interstellar". The "diffuse γ-ray

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background" was not yet really born ... However, as we can see in Figure 1, the spectrum of this emission shows a excess over a single power law around one MeV, excess which will be very important further on in our story.

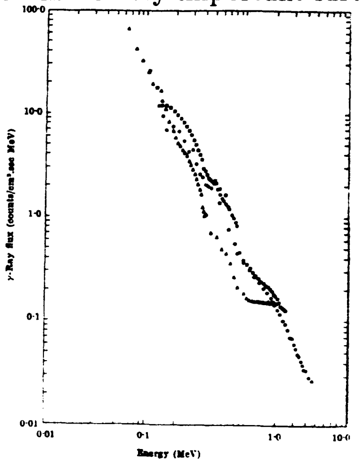

Figure 1. First spectrum obtained from space (Ranger 3 and 5, Metzger et al. 1964)

This excess, which will be called later on the "MeV bump", was detected afterwards by several experiments such as the omnidirectional NaI detector onboard the ERS 18 satellite (Vette *et al.*, 1970), or the 7 × 7 cm NaI detector placed on a boom 7.6 m away from the Apollo 16 spacecraft (Trombka *et al.*, 1973). The bump is clearly seen in the ERS 18 data , but is less prominent in the Apollo 15 spectrum (see Figure 2), a difference that we will explain in the next part.

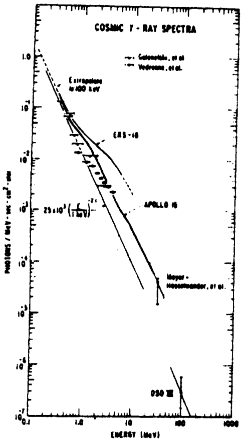

Figure 2. Appolo 15 spectrum (Trombka et al. 1973)

3. The MeV bump: myth or reality ?

In fact, an isotropical diffuse γ-ray background is intrinsically difficult to separate from a local background. As the emission is everywhere in the sky, there is no possibility of "on-off" (one observation on sources followed by one observation off sources in order to measure the background). One has to rely on other criteria, such as the study of the shape of the spectrum, in order to determine the origin of the detected emission.

If difficult to observe, the MeV sky is nevertheless interesting for astrophysicists, as it is the domain where nuclear reactions occurs. It is then the key range of energy for the nucleosynthesis studies. Unfortunately, it is also, of course, the energy range where nuclear reactions occurs *in* the detector itself and *in* its environment, reactions induced by the high energy protons crossing the whole experiment.

So, these reasons make the determination of the origin of the "MeV bump" difficult. A solution of these problems consisted to use a boom in order to remove the detector from the spacecraft, supposed to be the locally induced background source. This has been used for the Ranger 3/5 experiment but the boom was only 2 meters long. A longer one (7.60 m) has been used by the astronauts on Apollo 15/16, which has enabled them to obtain a better discrimination between the local and the cosmic background (see Figure 3). This explain the discrepancies between the results of Ranger 3/5, ERS 18 on one side and Apollo 15/16 on another side.

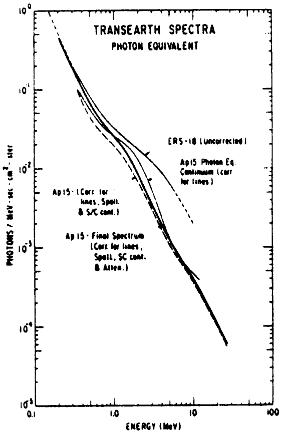

Figure 3. Appolo 15: spectra at different stages of data correction (Trombka et al. 1973)

This importance of the local background at MeV energies, has been pointed out as early as 1972 by Fishman et al., who have shown that they can reproduce the MeV bump seen by ERS 18, with Monte-Carlo simulation of the crossing of protons in the detector, and also by measures in particles accelerator (see Figure 4). As we have noticed earlier, as the detectors onboard Ranger 3/5, ERS 18 and Apollo 15/16 are of the same type, these calculation applied to all of them in the same way.

As it can be seen in Figure 2, taking into account the local background in the Apollo 15/16 case reduce seriously the MeV bump intensity, but there is still an excess over a single power law. This excess has been detected later on by numbers of satellites and balloon (Schönfelder, 1980), so even if the possibility of a local emission cannot be rejected, we can have some confidence in its existence. So, if we suppose that the cosmic MeV bump really exists, where does it come from ? This will be the leading question of our story from now ...

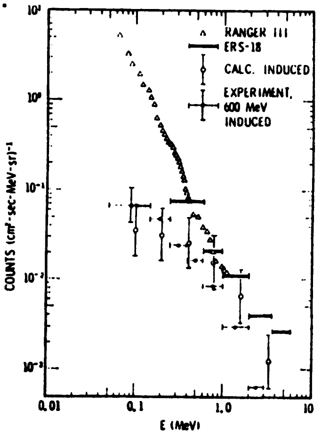

Figure 4. Ranger III and ERS 18 data points compared to simulations and experimental measures of the local background (Fishman 1972)

4. Is the MeV bump cosmological in origin ?

As soon as the discovery of the MeV bump was known, a lot of theoretical works have been done in order to explain it. Most of these theories was cosmological, as γ-ray coming from cosmological distances are practically not absorbed. So, "extragalactic γ-ray astronomy must be considered with cosmological questions" (Pinkau, 1979). It will be too long to describe all these models in details here, so we give below only a list of the most frequently used ones:

- Compton scattering of electrons leaking from radio-galaxies (Brecher *et al.*, 1969).
- Redshifted π^0 annihilation (Stecker *et al.*, 1971).
- Nuclear γ-ray in supernovae from distant galaxies (Clayton *et al.*, 1969).
- Intergalactic electron bremsstrahlung (Arons *et al.*, 1971).
- Radiation from exceptional galaxies (Bignami *et al.*, 1979).

One of the cosmological model the most used in the seventies explained the "MeV bump" in term of annihilation of cosmologically redshifted π^0 (Stecker 1971, see Figure 5). As π^0 annihilation gives rise to two 70 MeV photons, a redshift of 70, and thus a z of nearly 100 is needed to shift these photons down to one MeV. So, this annihilation must occur in the early phases of the universe. According to Stecker (1971), this emission arises from matter-antimatter transition zones, zones which should be created naturally in a baryon-symmetric big bang model (Omnes, 1969).

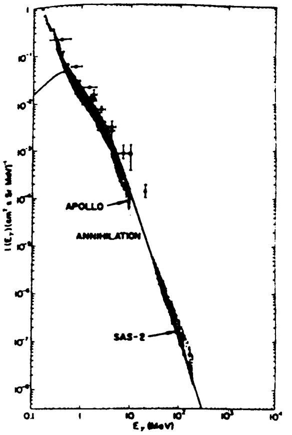

Figure 5. Redshifted π^0 annihilation model (Stecker et al. 1971)

5. Is the MeV bump extragalactic in origin ?

The situation changed completely at the beginning of the eighties, with the observation of a hard tail up to one MeV from the Seyfert galaxy NGC 4151 (see Figure 6), by the MISO experiment in 1979 and 1980 (Perotti *et al.*, 1981). Indeed, it appears that the MeV bump observed by Apollo and several other experiments could result from the sum of MeV emissions from several AGN. This was detailed in a subsequent paper by Bignami et al. (1979):

"With reasonable value of luminosities and present space density, Seyferts, BL Lacs objects and quasars may account for a major portion of the observed isotropic diffuse gamma-ray emission above 1 MeV ..." (Bignami *et al.*, 1979).

This "extragalactic" explanation took then for some years the precedence of the "cosmological" one, as it can be seen from the quotation below:

"In view of this discussion, it is perhaps not surprising that no single power law dependence is observed over the entire X and gamma-ray range, since different types of galaxies may contribute and dominate at different energies; the question of a really diffuse component like the one from

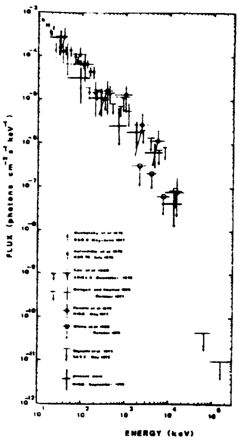

Figure 6. MISO spectrum of NGC 4151 (Perotti et al. 1980)

matter- antimatter annihilation in a baryon symmetric universe can only be answered if much more information on the X and gamma-ray emission of active galaxies and quasars is available. Only then will it be possible to derive that part of the background that cannot be explained by unresolved sources." (Schönfelder, 1985)

6. Back to cosmology ?

But, in 1984 and 1992 , the need for more information about the X and γ-ray emission of AGN became indeed more and more evident with the observation of a spectral break around 50 keV in the NGC 4151 spectrum, by the HEAO 1 (Baity *et al.*, 1984) and SIGMA (Jourdain *et al.*, 1992) experiments. This leads to the existence of at least two spectral states in Seyfert galaxies, a hard one as the one detected by MISO in 1979 and a soft one observed by HEAO and SIGMA (see Figure 7). So the knowledge of the origin of the MeV bump became more and more related to the knowledge of the occurrence of these spectral states. The spectral break around 50 keV was confirmed later on by the *GRO*/OSSE calculation of the Seyfert mean spectrum (see Figure 8), obtained between 1991 and 1993 (Kurfess *et al.*, 1994). The soft states seems then to occurs much more often than the hard one, which strengthen a cosmological origin of the "MeV bump".

7. What is the situation now ?

So, a definitive explanation of the origin of the MeV bump, if this bump really exists, is not yet available, and must await a good knowledge of the AGN spectral states. This will be precised by the future observations done by the *Compton* observatory, and by the *INTEGRAL* observations available at the beginning of the next millennium. Only then shall we know

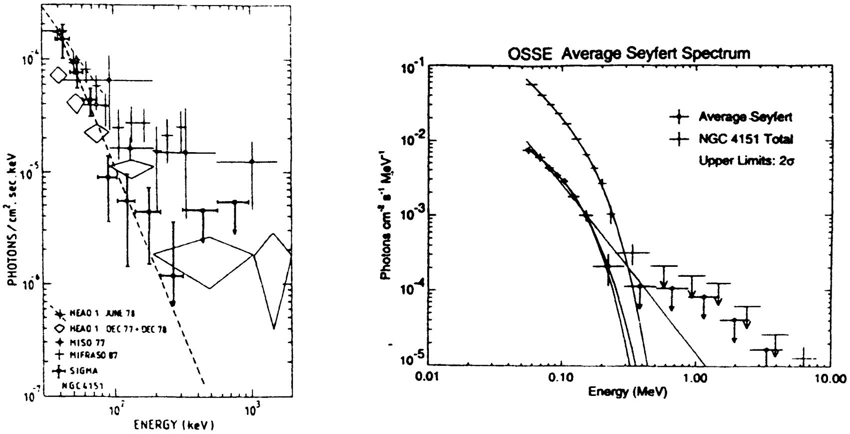

Figure 7. (a) SIGMA spectrum of NGC 4151 compared to the MISO and the HEAO 1 observations (Jourdain et al. 1992) (b) Seyfert mean spectrum (*GRO*/OSSE, Kurfess 1994)

if it originates from active galaxies or from regions of high cosmological redshift, or both.

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