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RELEVANCE OF THE OBSERVATION OF UHE γ'S TO HARD X-RAY ASTRONOMY

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ABSTRACT

A number of consequences of the presence of sources of UHE γ-rays, exemplified by Cygnus X-3, are examined. It is shown that there should be a flux of hard X-rays at all Galactic latitudes; a significant flux of extra-galactic hard X-rays may also result. Relevance to theories of cosmic ray particle origin and propagation is discussed.

1. Introduction. The observation of ultra high energy γ-rays from Cygnus X-3 and other Galactic sources has a number of implications for cosmic ray Physics. Here we deal with the production of a halo of hard X-rays round the Galaxy due to the electron pairs produced in γ-γ collisions and extragalactic consequences.

2. Galactic halo X-rays. As is well known, the mean free path for collisions of UHE γ-rays with the microwave radiation photons is of the order of Galactic dimensions. Typically, the values are, respectively for T = 2.7K and 2.93K (the presently preferred temperature), 7 and 5.6 kpc for $E_\gamma = 10^{15}$eV and 17 and 15 kpc for $E_\gamma = 10^{16}$eV. The result is that γ-rays in this energy range will generate e^+e^- pairs in the halo and these will in turn generate hard X-rays by synchrotron radiation in the Galactic magnetic field.

We have examined the phenomenon in detail (Rana et al., 1984) and derived the predicted energy spectrum for b = 90° shown in Figure 1 for the case where there is just one UHE γ-ray source (of the 1978 strength of Cygnus X-3) in the Galaxy at any one time. Insofar as the frequency of Cygnus X-3-type sources is unknown the predictions are imprecise but they probably represent an order of magnitude estimate (we bear in mind that the much larger path length for source → electrons → earth compared with direct source → earth means that the source(s) responsible for the high latitude X-rays were probably not Cygnus X-3 itself).

Unambiguous observations of a high latitude hard X-ray flux are not yet available but some preliminary observations by Ubertini et al. (1983, and private communication), shown in Figure 1, are tantalising. Confirmation of hard X-ray fluxes in the region predicted would give added weight to the initial assumptions, viz. ubiquity of the '3K' radiation, frequency of Cygnus X-3 'outbursts' and the existence of γ-γ interactions.

In the context of the universality of the 3K radiation, the recent observation of UHE γ-rays from LMC X-4 (Protheroe and Clay, 1985,

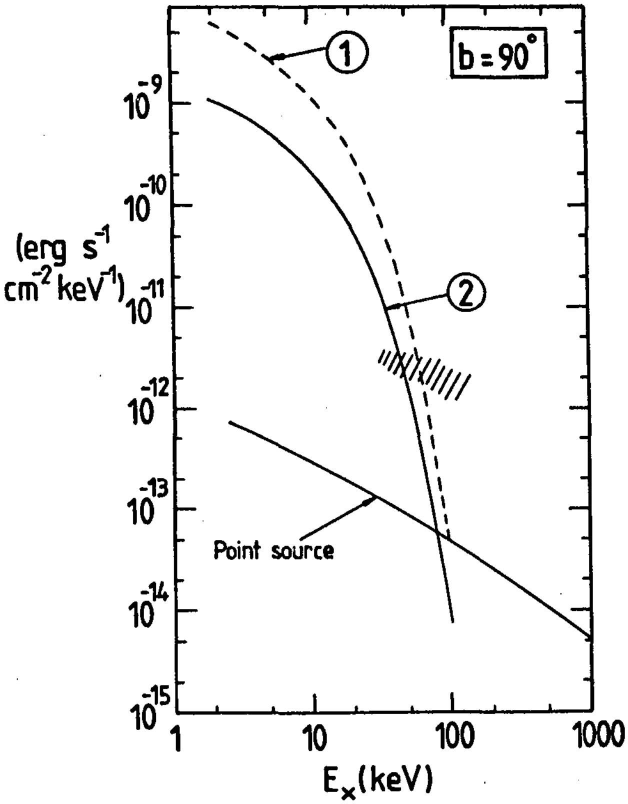

Fig. 1. The predicted X-ray intensities at b=90° for just one Cyg X-3 like source. the remaining line spectra refer to the measurements of Iwan et al. (1982). 1. The preferred spectrum from Iwan et al. themselves (kT=9keV). 2. Spectrum (1) displaced downwards in intensity to be consistent with our earlier estimate of the intensity in the range 2-10 keV (Sadzinska et al., 1983). None of the "observed" spectra can be trusted above 50 keV in that the highest energy band in the experiments was 6-60 keV. The shaded area represents a possible flux detected by Ubertini et al. (1984).

private communication) would, according to our calculations, suggest that this source must be emitting an order of magnitude higher in the integral flux in the 10^{15}-10^{16} eV range than in the 2-11 keV X-ray range. This implies the average slope of the unattenuated differential spectrum to be about 1.8, which is roughly the same as that of Cyg X-3, indicating that the origin of UHE γ-rays in such exotic binaries, irrespective of their immediate galactic environment, may have a common physical basis; if understood properly, the mystery of the origin of cosmic rays at ultra high energies might be elucidated.

3. Relevance to extragalactic observations. The comparatively large mean free path for γ-γ interactions, particularly the 10's of kpc for $E_\gamma \sim 3\times10^{14}$eV and few 10^{16}eV means that UHE γ's provide a way of transporting electrons considerable distances from a central source other than by diffusion with its attendant losses. There may be relevance to the situation in galaxy clusters here.

Turning to the observed isotropic flux of hard X-rays and γ-rays the products of UHE γ-rays might be a significant contributor for the following reason. The output of our Galaxy in γ-rays from cosmic ray interactions in the ISM is probably $\sim$ 4 x 10^{38} erg s^{-1} above 100 MeV (Worrall, 1977) and the output from Cygnus X-3 (in 1978, at least) was probably only about a factor 10 smaller. When we realise that there are probably other strong (as yet unresolved) sources in the Galaxy and that the sources seem to have flatter spectra (differential exponent $\sim$ 2) than the CR particle spectrum (exponent above 1 GeV tending to about 2.7) the Cygnus X-3 type sources probably dominate above 1 GeV. The net result is that extragalactic sources of UHE γ-rays probably give the biggest contribution to the extragalactic γ-ray flux in this energy region.

In fact, observations have not yet been made of an extragalactic diffuse flux above about 200 MeV but if the present arguments are correct the spectrum at higher energies will be observed to flatten significantly.

Even in the 100 MeV region, where as is well known (e.g. Strong and Worrall 1976) normal galaxies fall short of explaining the observed diffuse extragalactic flux by a factor of about 20, a significant enhancement may result from the cascading of UHE γ-rays in the 3K radiation field. If active galaxies have both an excess of low energy γ-rays and even more dramatic UHE γ-ray sources the diffuse extragalactic flux will be explained rather easily.

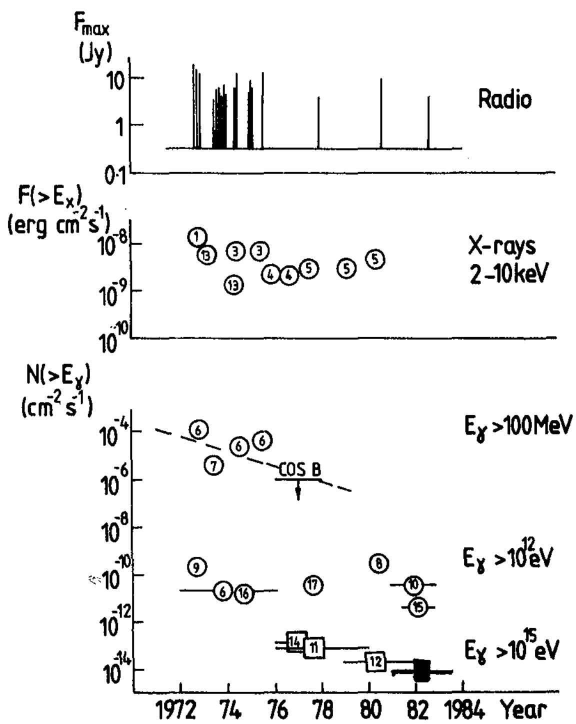

Fig. 2. Time variability of the Cyg X-3 flux in different energy ranges: radio, X-rays, and three energy ranges of γ-rays, after Rana et al. We have added, for 1982, the mean of the most recent measurements from Akeno, Baksan and Haverah Park.

4. Cosmic ray particle origin.

It has been pointed out by many authors that the energy involved in Cygnus X-3 γ-rays ($\sim 2 \times 10^{37}$ erg s^{-1} during 1978) is so high that if, as seems very likely, the γ-rays are produced by initial protons the protons will contribute considerably to the cosmic ray particle flux. Insofar as the proton energy input in the Galaxy as a whole required to produce the whole of the observed cosmic rays is probably a few times 10^{40} erg s^{-1} the energy going into protons needs to be about 10^3 times the 1978 γ-yield of Cygnus X-3.

There are a number of possibilities, of which two can be mentioned.

(i) Cygnus X-3 may be alone responsible, with a high proton output and low efficiency ($\gtrsim 10^{-3}$), for conversion p→γ, the long term average being the 1978 value.

(ii) Cygnus X-3 may be a variable source, the average output being lower than seen in 1978, and either the efficiency being higher than 10^{-3} or, if low, other as yet undetected Cygnus X-3-type sources being alive in the Galaxy at present. There is, in fact, some evidence favouring variability in the output of Cygnus X-3 at a variety of wavelengths (Figure 2).

The observation by Protheroe and Clay, already referred to, of UHE γ's from LMC X-4, in which the source appears to emit at about ten times the 1978 emission from Cygnus X-3, can be indicative of single isolated sources yielding singularly high γ-ray and thus proton yields. Perhaps Cygnus X-3 goes through such phases from time to time?

The possibility of a small number of sources being responsible for the energetic cosmic ray protons at any one time raise a number of interesting problems, apart from the manner in which the protons achieve their energy. One such is the magnitude of the observed anisotropy of arrival directions. There is much scope for future work.

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