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The High Energy Source 3C 273

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Abstract

In this paper I review the properties of 3C 273 and attempt to find an answer to the question why 3C 273 is the only extragalactic source so far, which has been detected at energies $\geq$ 50 MeV.

Introduction

3C 273 ((α, δ)=1226-02, z = 0.158) is a very bright optical quasar with a one-sided, faint optical jet. Its apparent magnitude is m_v = 12.5 mag and its optical luminosity at 2500 Å is $L_{opt} = 2.3 \cdot 10^{31}$ erg/sec (Wilkes & Elvis, 1987).

In 1962 it was detected to be a very bright radio double source with an intensity at 20 cm of 46 Jy ($=46 \cdot 10^{-26} W/m^2 Hz$) (fig.1).

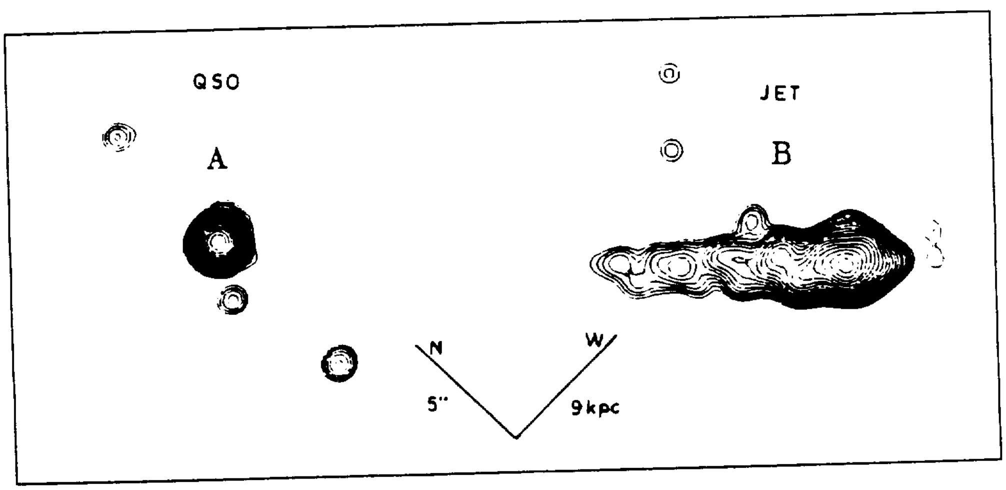

Figure 1: 408 MHz radio contour map of 3C 273 (adapted from Conway 1982).

Component A of the double source was identified with the optical quasar and has a very flat but complex radio spectrum with a spectral index between 2.7 GHz and 5 GHz of $\alpha_r = 0.01 \pm 0.07$ (Kühr *et al.*, 1981). Component B is associated with the optical jet and its radio spectral index is $\alpha_r \approx 0.7$.

3C 273 was detected in X-rays in 1970. Its luminosity in the 2 - 10 keV band is $\sim 10^{46}$ erg/sec and the X-ray spectral index lies in the range $0.35 \leq \alpha_X \leq 0.5$. Two positive detections of a high energy source in the Virgo region have been reported with the COS-B satellite in 1976 and 1978. This source has been identified with 3C 273 because of the positional coincidence (Swanenburg *et al.*, 1978) and has been confirmed by Bignami *et al.*, 1981. So far the radio-loud quasar 3C 273 is the only extragalactic source which has been detected at energies ≥ 50 MeV. Since it shows all the characteristics which are typical for high luminosity quasars: an optical and radio jet, superluminal motion and an UV excess, it seems to be the source which is best suited for detailed studies in order to learn more about the physical processes taking place in quasars.

Observations

Recent simultaneous multifrequency observations from radio to X-rays (Courvoisier *et al.*, 1987) have once again confirmed that 3C 273 is variable in all wavebands. The source was observed at several epochs between December '83 and March '86. The temporal behavior of 3C 273 in the far infrared (FIR) and near infrared (NIR) regions is shown in fig. 2a. The fluxes were normalized to the flux of the first observation. To avoid confusion the flux variations in the three NIR bands have been averaged after the normalization. This seemed to be appropriate, because the temporal behavior in these three bands was the same.

As fig. 2a clearly shows there is no direct correlation between the FIR and the NIR. After a sharp rise shortly after the beginning of the observations, the FIR decreased rather steadily while the NIR stayed nearly constant, except for a possible dip in May '85. From this behavior can be followed that there have to be two well separated components which do not overlap. This implies a sharp cut-off of the FIR component between 10 and 5 μm, the beginning of the NIR (Courvoisier *et al.*, 1987).

The latest theories attempt to explain the generation of X-rays by inverse Compton scattering on infrared synchrotron photons. Therefore the temporal

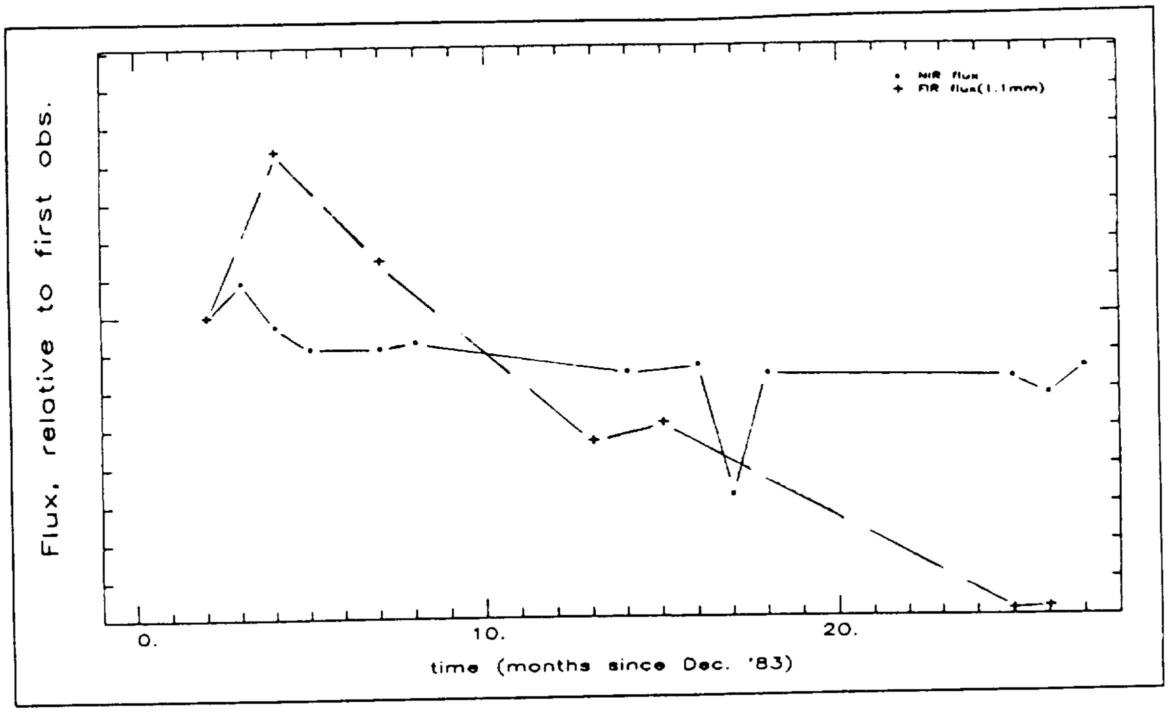

Figure 2a: Temporal behavior of 3C 273 in the FIR and NIR domain. Data from Courvoisier *et al.*, 1987)

behavior in these IR bands is of great interest to the X-ray observations (fig. 2b). After an irregular decrease of the soft and hard X-rays, the flux increased again slowly while the FIR flux decreases further and the NIR is nearly constant.

In the sub-mm band there was a totally different behaviour: During '84 the flux was constant and decreased in '85 and '86 (fig.2c).

From this behaviour and the absence of direct correlations it is concluded that the same electron population cannot be responsible for the FIR synchrotron emission and the self-Comptonization process generating the X-ray emission. Therefore, simple homogeneous SSC models can be excluded.

However, one has to be aware of the fact that the observations still did not have a complete temporal coverage and the span of $\sim$ 2.3 years was rather short. Very subtle correlations might therefore have been missed.

The overall energy distribution of 3C 273 at different observation periods is shown in fig.3. In all three spectra one can see that the FIR varied not only in flux but also in spectral slope whereas the NIR slope was almost constant. This

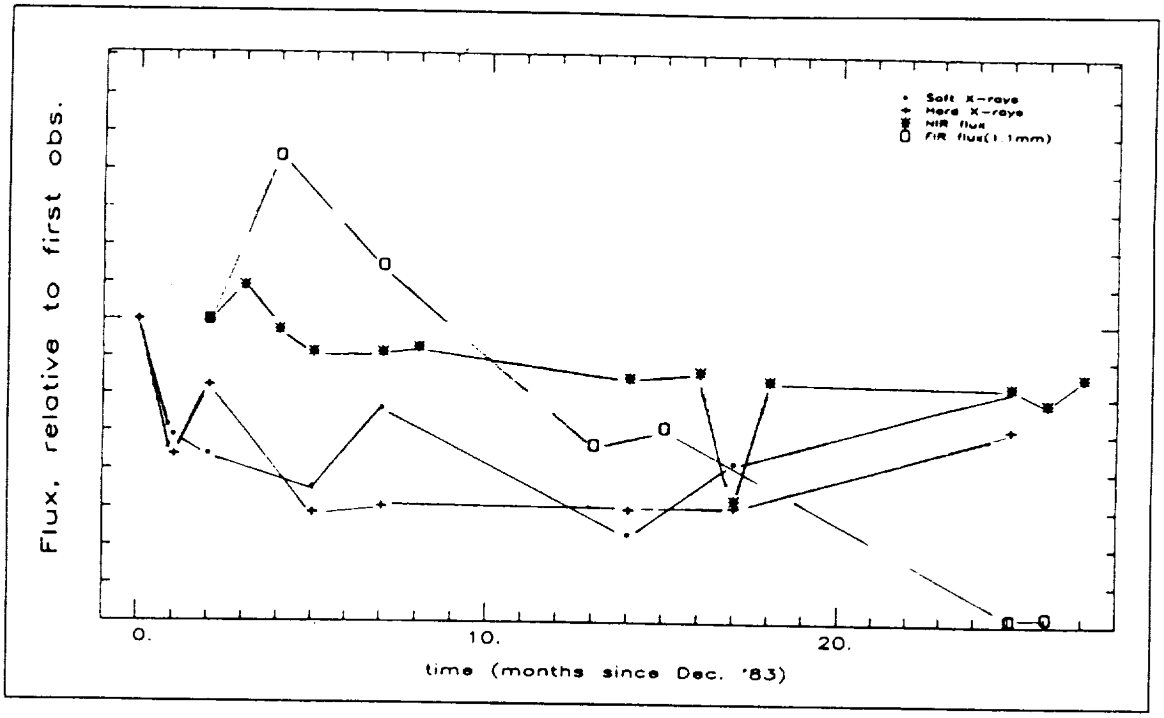

Figure 2b: Temporal behavior of 3C 273 in the FIR and NIR domain compared to the variations of the soft and hard X-ray fluxes. Data from Courvoisier *et al.*, 1987)

leads to the presence of a break at $\sim 10\mu$m which can be seen in all three spectra and is illustrated by the lines. A spectral fit by two powerlaws is not convincing from the spectral data alone but together with the different temporal behavior it is justified. From these arguments follows that the "cut-off" of the FIR is really a true feature.

The spectra of 3C 273 have therefore been fitted by three powerlaws and two blackbody distributions (Courvoisier *et al.*,1987). Fig.4 shows the spectral energy distribution from Feb. 84 to which the IUE data were added. Best fit values for the spectral slopes are $\alpha_{FIR} = 0.58$ for the far infrared region, $\alpha_{NIR} = 1.76$ for the near infrared and for the X-rays between 2 - 10 keV $\alpha_X = 0.45$. The optical and UV data have been fitted with two black body components with temperatures of $(16.2 \pm 0.3) \cdot 10^3 K$ and $(122 \pm 56) \cdot 10^3 K$. The fit in the UV domain (second black body distribution) is of course not very well constrained because of the lack of observational data.

Although 3C 273 is variable in all wavebands the shape of its spectrum does not change dramatically. The spectral slopes in the NIR band vary from 1.5 to

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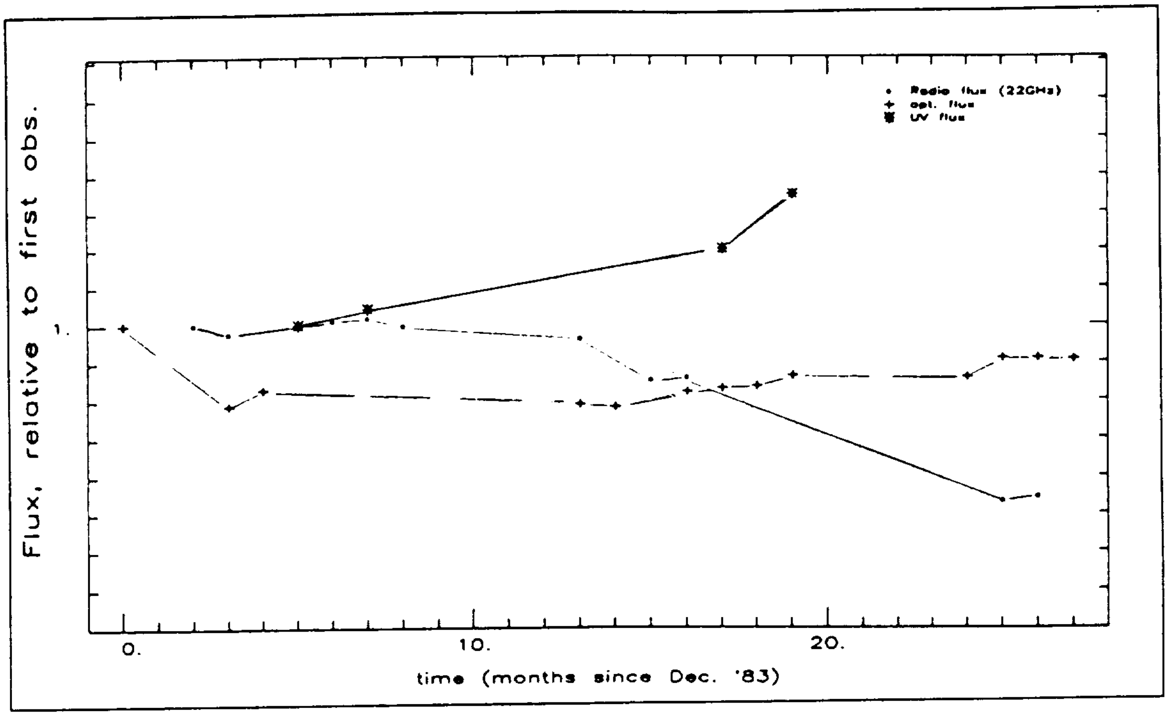

Figure 2c: Temporal behavior of 3C 273 in the Radio, optical and UV domain. Data from Courvoisier *et al.*, 1987)

1.75, in the FIR band from 0.6 - 0.9 and in the 2 - 10 keV X-ray range from 0.35 - 0.5. All in all it is a very usual spectrum.

Comparison with other QSR's and AGN's

Since the Einstein IPC database is now available many investigations of large samples of quasars and AGN's (here Seyfert I) have been done. One of those investigations was performed by Wilkes & Elvis, 1987. They found that radio-loud (RL) quasars have a flatter X-ray spectrum than radio-quiet (RQ) quasars (see fig. 5). 3C 273, a member of their sample, is encircled by a dashed line. This correlation between radio-loudness and steepness of the X-ray spectrum has been very well confirmed by Brunner *et al.*, 1989.

In the beginning of 1989 Canizares & White published investigations of high redshift quasars. They had a more detailed look into the properties of RL quasars. They found that if they divide them into two classes, one class with flat radio spectra (FRS; $\alpha_r \leq 0.35$) and one class with steep radio spectra (SRS; $\alpha_r \geq 0.35$), the average steepness of the X-ray spectra is different (fig. 6). Unfortunately,

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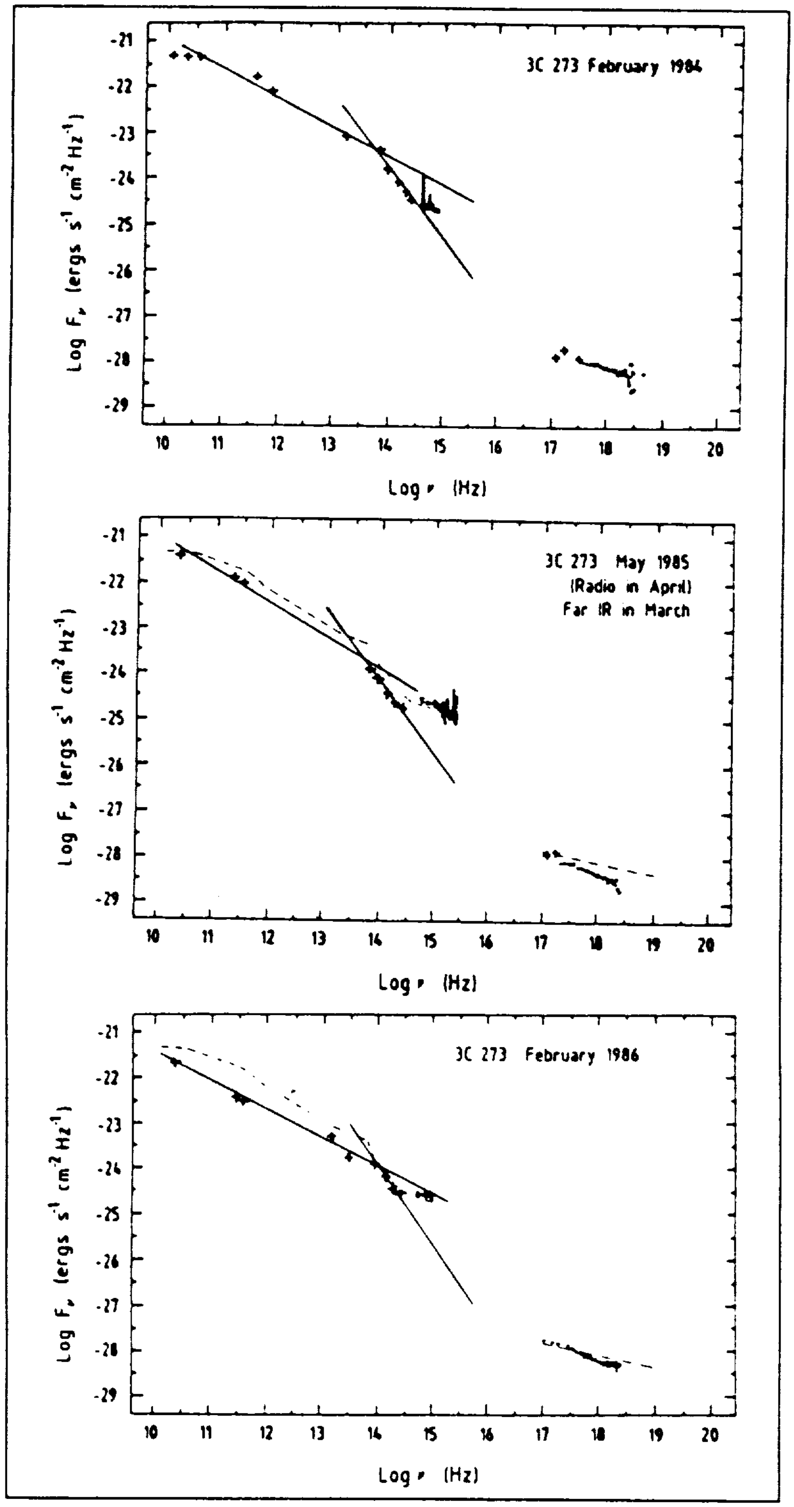

Figure 3: Overall energy distributions of 3C 273 from different observations where the spectral coverage was most complete (adapted from Courvoisier *et al.*, 1987).

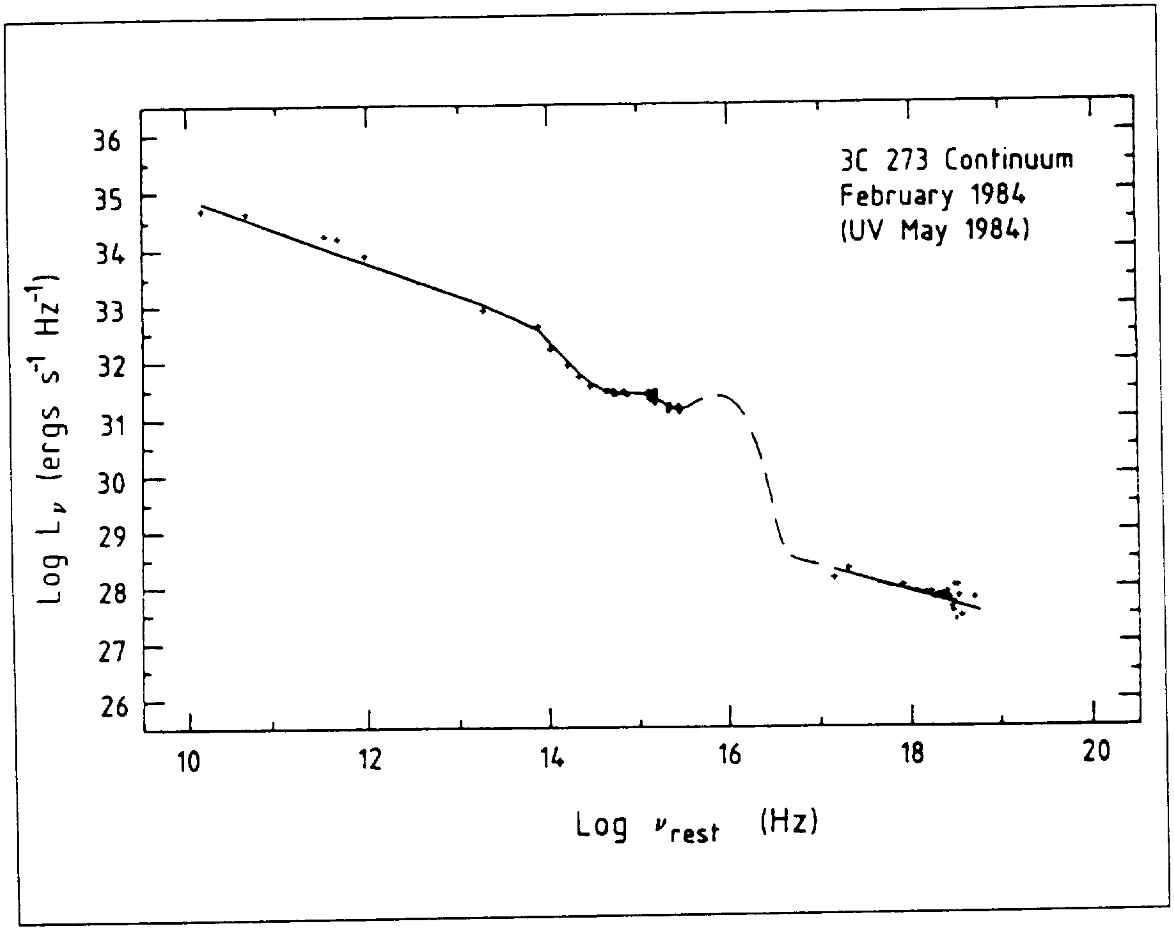

Figure 4: Fitted continuum spectrum of 3C 273. Data are shown as crosses and the best fit is given by the continous line (from Courvoisier *et al.*, 1987).

3C 273 was not a member of their sample. But it fits in very well if one localizes its position (asterisk) in figure 6.

Another investigation of a large sample of QSR's and AGN's has been published by Mushotzky & Wandel, 1989. They investigated the IR-UV continuum to X-ray ratio of about 120 objects. Since 3C 273 was also a member of their sample it could be identified in their results (fig. 7a-d).

In fig.7a the correlation of the X-ray luminosity and the "blue" luminosity at 4200 Å is illustrated. The position of 3C 273 is marked by the arrow. Fig.7b demonstrates the very good correlation between the X-ray luminosity and the "red" luminosity at 7500 Å for AGN's. This behavior of a large sample (see also: Malkan, 1984) is in contrast to the behavior of 3C 273 in the detailed

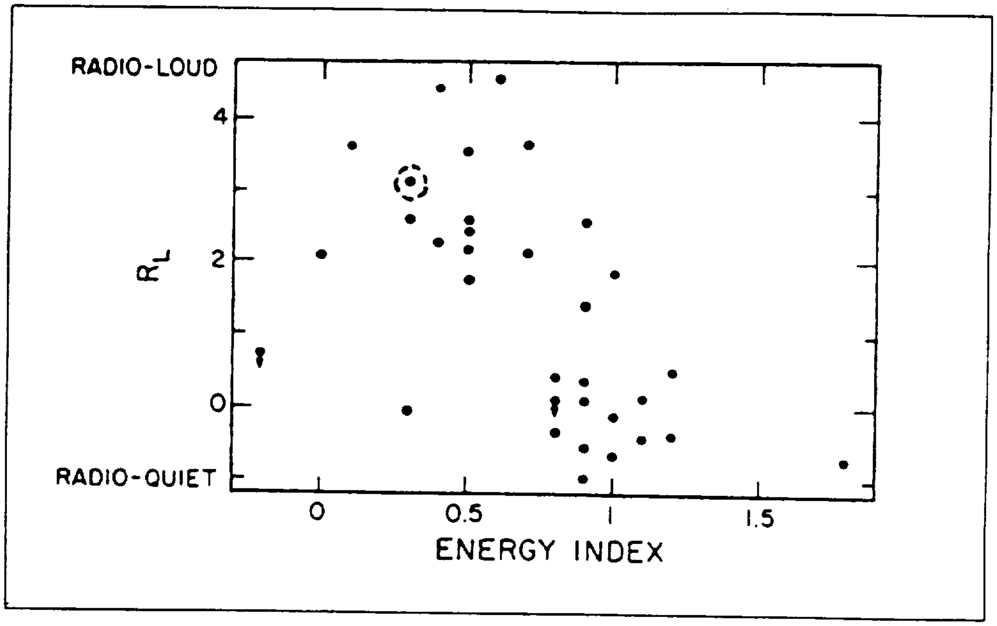

Figure 5: Radio loudness of quasars versus X-ray slope α_E (from Wilkes & Elvis, 1987).

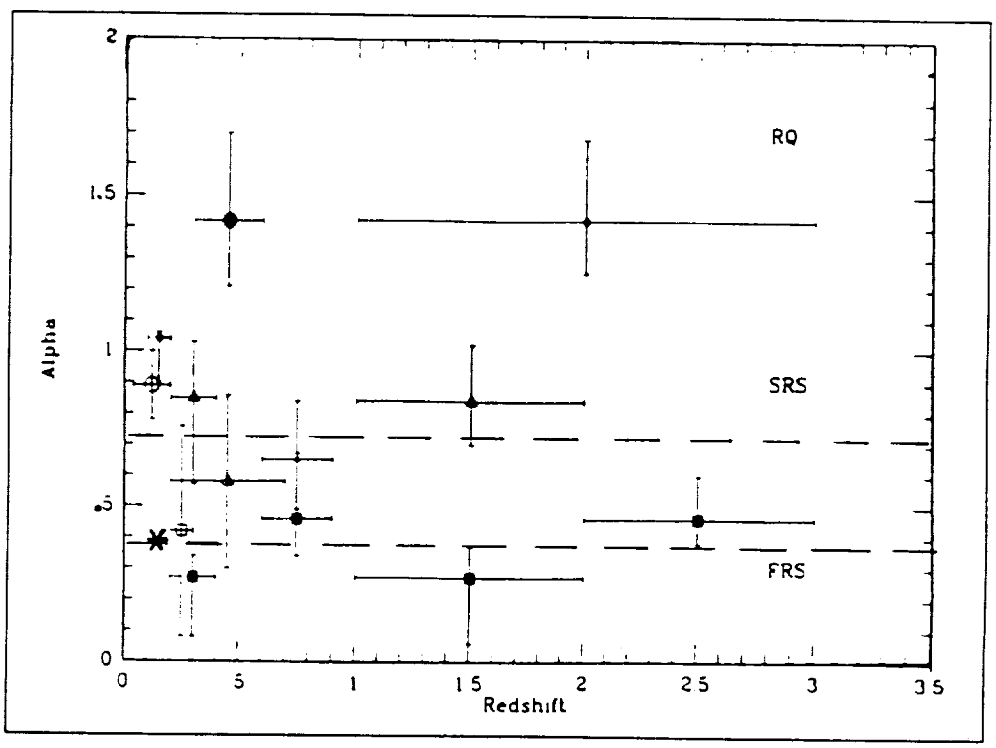

Figure 6: X-ray power-law index α versus redshift for FRS, SRS and radio quiet (RQ) quasars.

observations by Courvoisier *et al.* 1987, where a correlation between the infrared and X-ray emission could not be found. Therefore, there must exist some kind

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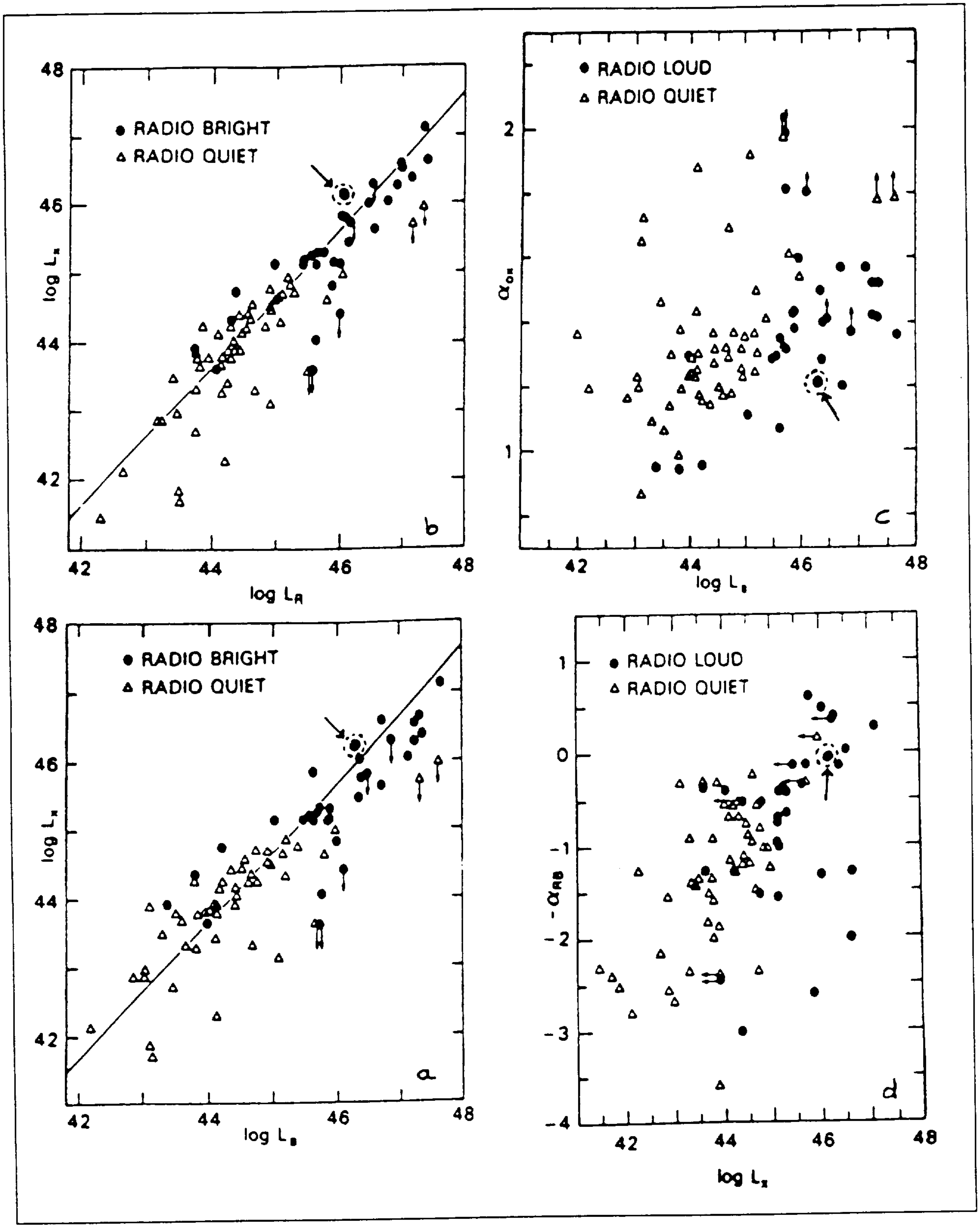

Fig.7a-d: relations between the "blue" and "red" luminosity and the X-ray luminosity and the spectral slopes α_{OX} and α_{rX}.

of time averaging mechanism which correlates the infrared to the X-ray emission. But this does not change the fact that even here 3C 273 behaves very normal.

Figures 7c and 7d show the relation between the "blue" luminosity of AGN's (quasars and Seyfert I's) and their spectral slopes between the optical and the X-ray region (α_{ox}) and between the "red" and the X-ray region (α_{rx}), respectively. Although there is no correlation between these parameters these figures demonstrate that 3C 273 fits in here, too.

The only difference which could be found is demonstrated in figure 8 where the 2 - 10 keV X-ray luminosities of the Mushotzky & Wandel sample are plotted versus redshift. Here, 3C 273 clearly stands out against the general trend which might be due to some kind of evolution effect.

Conclusion

3C 273 is not at all a particularly special source. This follows from the comparisons with other active galactic nuclei. It shows no extraordinary spectral features, neither in its radio to X-ray ratio nor in its IR-UV continuum to X-ray ratio. The only peculiarity is its extreme luminosity in all wavebands together with a relatively small distance ($z = 0.158$). It is therefore very probable that the γ-ray emission is not a special feature of 3C 273 but is common for all quasars and Seyfert I galaxies. Under this assumption and the requirement that the γ-ray luminosity is at least as high as the X-ray luminosity (as it is the case for 3C 273 and possibly for all radio loud quasars) EGRET should be able to detect some more AGN's in the γ-ray domain.

This prediction is illustrated by figure 9 which shows once again the 2-10 keV X-ray luminosity of quasars and AGN's versus redshift relation. Since 3C 273 was the only source detected by COS-B it is taken as reference point. The solid line then indicates the detection limit for sources to be detectable by COS-B.

A corresponding limit is shown for EGRET (broken line). Here a sensitivity for EGRET is assumed which is at least a factor of ten better than that of COS-B. As can be seen then from figure 9, EGRET should be able to detect new sources especially at low redshifts. Since the radio loud sources are expected to be more luminous in the γ-ray region than the radio quiet AGN's (Kazanas, 1989)

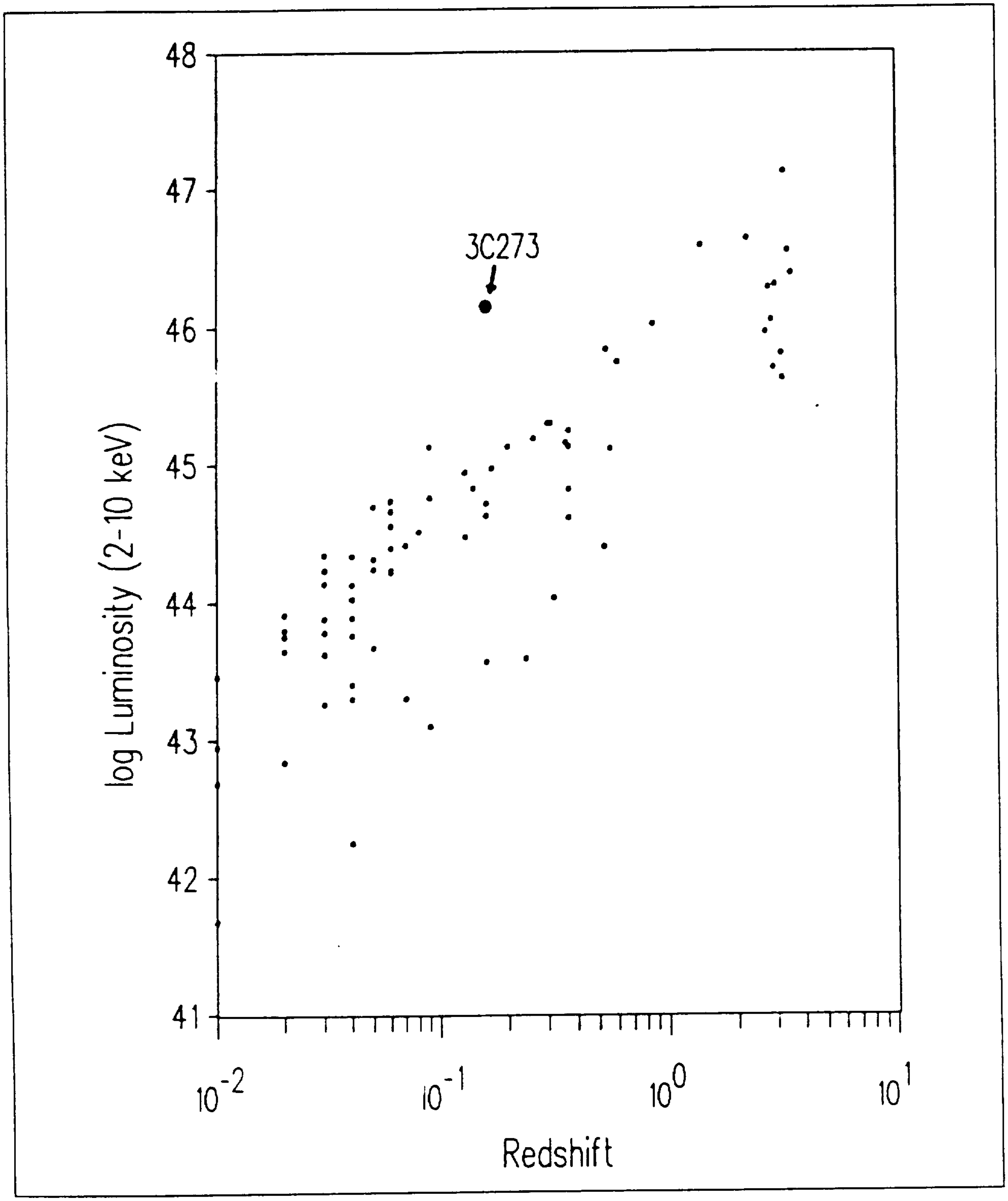

Fig.8: 2-10 keV X-ray luminosity of quasars and AGN's versus redshift (Data from Mushotzky & Wandel, 1989).

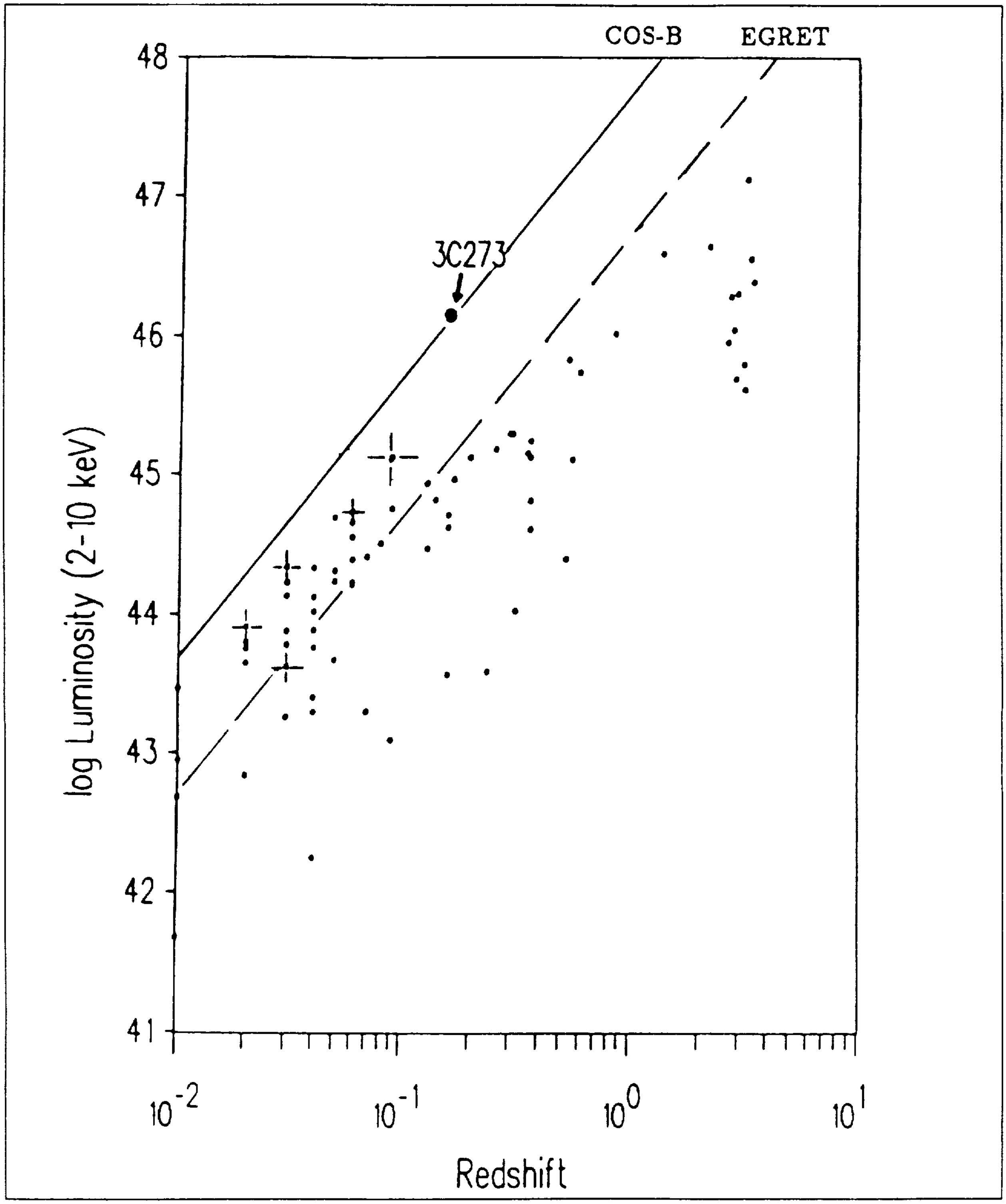

Fig.9: 2-10 keV X-ray luminosity of quasars and AGN's versus redshift. The solid line indicates the "detection limit" of COS-B, the broken line that of EGRET. The crosses mark the radio loud quasars and AGN's.

the probability of detecting RL quasars (marked by crosses) is of course higher. These radio loud objects are: MCG 8-11-11, 3C 120, 3C 390.3, III Zw 2 and Mkn 618. These sources should therefore be good candidates for an observation with EGRET.

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DISCUSSION

Richard Mushotzky:

The diagram shown is conservative in its prediction of the number of AGN that EGRET will detect because the x-ray data are not a complete sample over the relevant flux range. The ROSAT complete sample should provide several times the numbers of candidate objects as shown in the figure.

Corinna Von Montigny:

Yes, that's true.