OG 2.5-12

FURTHER STUDIES OF X-RAY STRUCTURE OF THE PERSEUS CLUSTER

M.M. Lau and E.C.M. Young
Department of Physics
University of Hong Kong

ABSTRACT

The X-ray sources in the Perseus cluster have been studied by many authors. In the present study, we have examined and summarized available data on the spatial and spectral distributions. Based on these observations, a consistent model is proposed for the production of X-rays and γ-rays in the region around NGC 1275. It is shown that good agreement with observations is obtained by assuming the emission of soft X-rays from thermal bremsstrahlung and of hard X-rays and γ-rays from the inverse Compton process.

1. Introduction

The Perseus cluster has been extensively studied at X-ray energies below 400 KeV. It is well-known that NGC1275 is an active radio and X-ray source in the Perseus cluster and it contains a discrete component and an extended component (1-5). Recent observations also show a γ-ray excess at the position of the cluster and this is interpreted as emission from NGC1275 (6).

The nature of the emission of X-rays and γ-rays from the Perseus cluster has been an open question. The two models most frequently advanced are the inverse Compton scattering of relativistic electrons on the 2.7K background in the halo and the synchrotron self-Compton (SSC) process in the active nucleus of the Seyfert galaxy NGC1275. In the present study we shall examine these models and attempt to give a consistent explanation of the radio, through IR, X-ray and γ-ray data.

2. Observations

The experimental data of the Perseus cluster are shown in Figures 1 and 2, which include spectral bands in the radio, infrared, X-ray and γ-ray regions. The radio data (3,7,8) from NGC1275 give the nuclear emission as well as the nonnuclear emission. It is found that the radio source in the Perseus is extended. The infrared emission region is larger than the milli-aresec VLBI core (9,10).

The X-ray data are from the OSO-7 for energies above 7 KeV (11, 16), Uhuru in 2-10 KeV (3) and below 2 KeV (4,12), Copernicus in 0.5-3 KeV (5) and in 53-93 KeV (13), the Einstein HRI data in 0.5-3 KeV (14), the HEAO-1 above 10 KeV (15) and the CAL in 0.5-1.5 KeV (2).

The satellite results show that the X-ray structure of the Perseus cluster is centred on NGC1275 and is complex. It consists of a core which is associated with NGC1275 and an asymmetric extended region. Furthermore the high resolution image with the Einstein Observatory has revealed a point source coincident with the optical nucleus of NGC1275 (14), in addition to the very extended thermal cluster emission and a sharply peaked component at NGC1275 previously known. A structure is therefore assumed that the NGC1275 contains, in addition to the milli-arc sec VLBI core, a 30" component and a "halo" 7'-10' in extent.

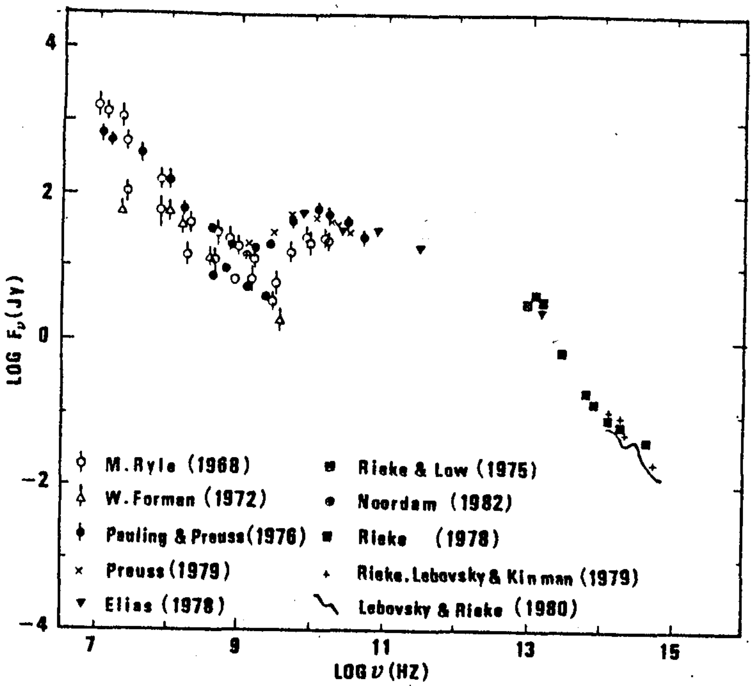

Fig.1 The radio spectra of Perseus cluster

3. Discussion It has been proposed (6,16) that the hard X-ray flux originates in the active nucleus of the NGC1275 through the various synchrotron self-Compton processes. It is shown that if an index of 0.5 is used for the nonthermal spectrum extended to 10^{15} Hz (16,17), reasonable agreement is obtained with observations. However, based on the data as summarized in Fig.1, the spectral indices are 1.27, 0.40 and 1.27 in the ranges 10 MHz - 9.5 GHz, 9.5 GHz - 10^4 GHz and 10^{13} - 10^{15} Hz respectively. We have calculated the X-ray flux from the SSC process with these indices, and the expected flux is found to be between 1 to 2 order of magnitude below the observed flux. It appears therefore that the SSC process alone would be unlikely to account for all the observed X-ray flux.

We now consider a possible explanation for the emission of the soft X-rays, hard X-rays and γ-rays: the soft X-rays are due to thermal bremsstrahlung and the hard X-rays and γ-rays due to the inverse Compton process.

Below $\sim$25 KeV the best-fit spectrum was obtained by adjusting the spectral parameters to minimize the χ^2 (1.3 per degree of freedom) with respect to all the satellite data. The best-fit temperature is KT = 8.10 ± 0.10 KeV and the spectrum is

$$\frac{dN}{dE} = 0.127\, E^{-1} G\,(E,KT)\, e^{-E/KT}\ \mathrm{ph.cm^{-2} s^{-1} KeV^{-1}}$$

with $G(E,KT) = 0.90\ (E/KT)^{-\alpha}$ and $\alpha = 0.37\left(\frac{30.0}{KT}\right)^{0.15}$

The high-energy excess have been fitted by a power law with photon index 2.23 ± 0.02. For the present purpose, it is sufficient to lump together all the nonnuclear emission as a power law with an index of 1.27 from

10 - 1415 MHz (8,10,18). A radio index $\alpha = 1.27$ would give an X-ray index of 2.27; this agrees well with the value for our best-fit power law index. With these values, the predicted inverse Compton flux for the hard X-rays and γ-rays is

$$F_{IC} = 1.6 \times 10^{-2} B_{-7}^{-2.27} E_{20}^{-2.27} \text{ ph. cm}^{-2}\text{s}^{-1}\text{KeV}^{-1}$$

where B_{-7} is the magnetic field of the radio source in units of 10^{-7} gauss and E_{20} is the photon energy in units of 20 KeV. The magnetic field B is related with the size of the source. If all the hard X-rays and γ-rays are due to the IC process, a value of $B \gtrsim 10^{-7}$ gauss in the radio source is required. If the "halo" is assumed to be 7' in extent, then B is $\sim 10^{-7}$ gauss. The predicted flux is shown in Fig.2 together with the X-ray and γ-ray data.

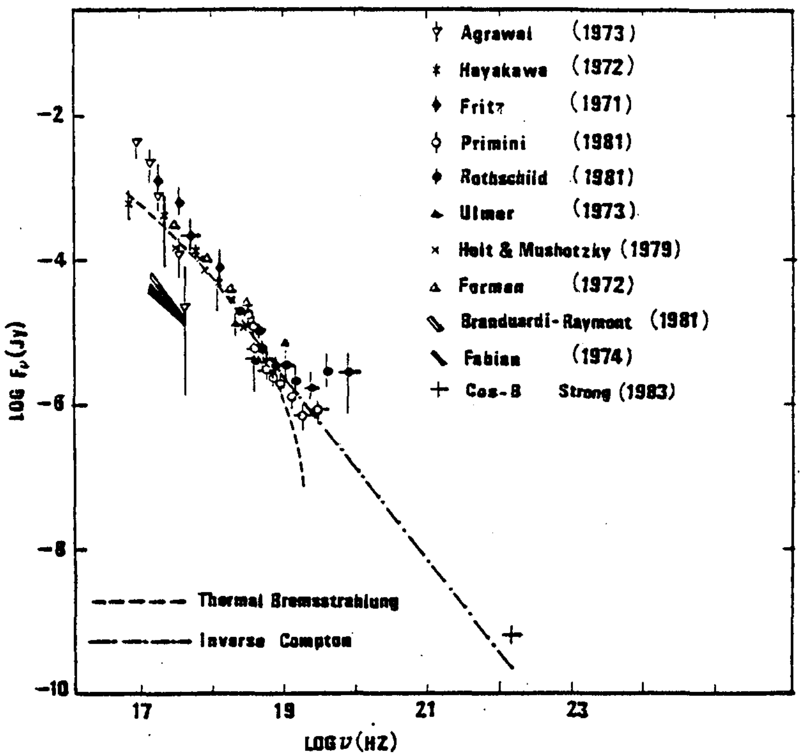

Fig.2 The X-ray spectra and γ-ray data of Perseus cluster. The dashed line and dot-dashed line represent the best-fit curves.

<u>4. Conclusion</u> It is shown that with the assumed structure of the NGC1275 in the Perseus cluster, reasonable agreement with experimental data from radio, IR, X-rays to γ-rays has been obtained by assuming the emission of soft X-rays from thermal bremsstrahlung and hard X-rays and γ-rays from the inverse Compton process.

<u>References</u>

1. H. Gursky et al (1971) Ap. J. <u>165</u>, L43.

2. R.S. Wolff et al (1976) Ap. J. <u>208</u>, 1.

3. W. Forman et al (1972) Ap. J. <u>178</u>, 309.

4. G. Fritz et al (1971) Ap. J. 164, L81.

5. A.C. Fabian et al (1974) Ap. J. 189, L59.

6. A.W. Strong et al (1983) Ap. J. 274, 549.

7. M. Birkinshow (1980) M.N.R.A.S. 190, 793; G.R. Gisler et al (1979) Astron. Astrop. 76, 109; G.K. Miley et al (1975) Astron. Astrop. 45, 223; J.E. Noordam et al (1982) Nature 299, 597; I.I.K. Pauliny-Toth et al (1976) Nature, 259, 17; E. Preuss et al (1979) Astron. Astrop. 79, 268.

8. M. Ryle et al (1968) M.N.R.A.S. 138, 1.

9. J.H. Elias et al (1978) Ap. J. 220, 25; D.J. Ennis et al (1982) Ap. J. 262 451; R.H. Hildebrand et al (1977), Ap. J. 216, 698; G.H. Rieke (1978) Ap. J. 226, 550.

10. G.H. Rieke et al (1975) Ap. J. 200, L67.

11. M.P. Ulmer et al (1975) Ap. J. 183, 15.

12. S. Hayakawa et al (1972) Ap. Spc. Sci. 17, 30; P.C. Agrawal (1974) Ap. Spc. Sci. 28, 185.

13. A. Bui-Van et al (1974) Ap. J. 188, 217.

14. G. Branduardi-Raymont et al (1981) Ap. J. 248, 55.

15. F.A. Primini et al (1981) Ap. J. 243, L13.

16. R.E. Rothschild et al (1981) Ap. J. 243, L9.

17. J.E. Gindlay (1977) Ap. J. 199, 49; R.F. Mushotzsky (1977) Nature 265, 225; T.W. Jones et al (1974) Ap. J. 188, 353.

18. W.C. Erickson et al (1978) Ap. J. 222, 761; M.R. Viner (1975) Astron. J. 80, 11, 931.