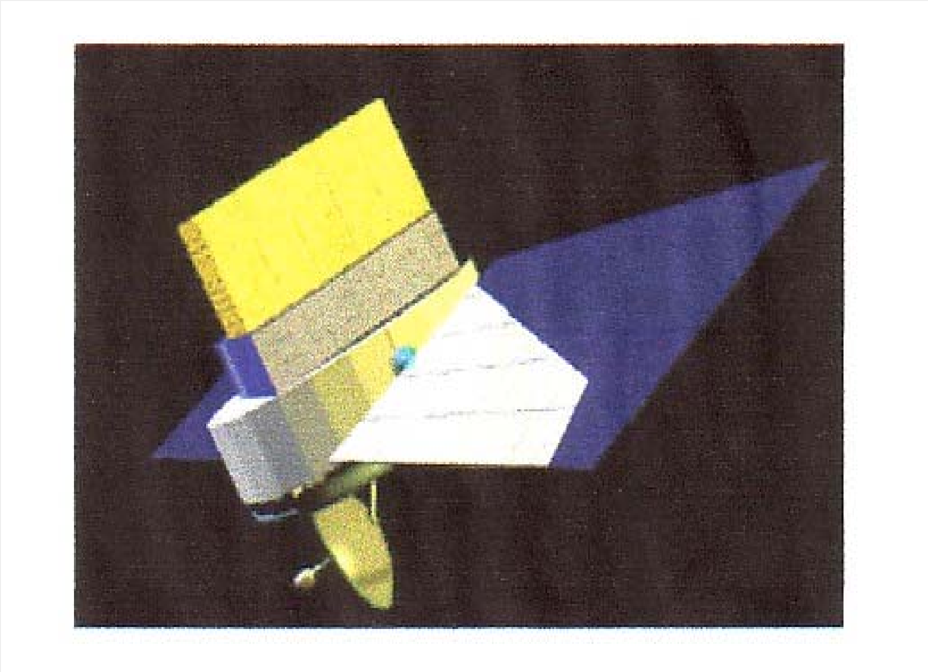
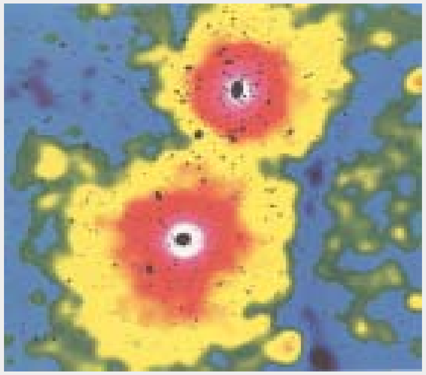
Non-thermal Emission from Clusters of Galaxies

GLAST Meeting in Roma
Roma, September 15-17, 2003



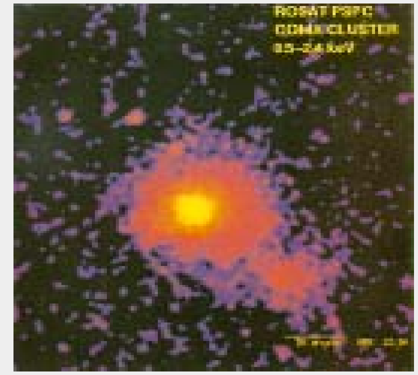
R.Fusco-Femiano - IASF/CNR, Roma, Italy

A3528

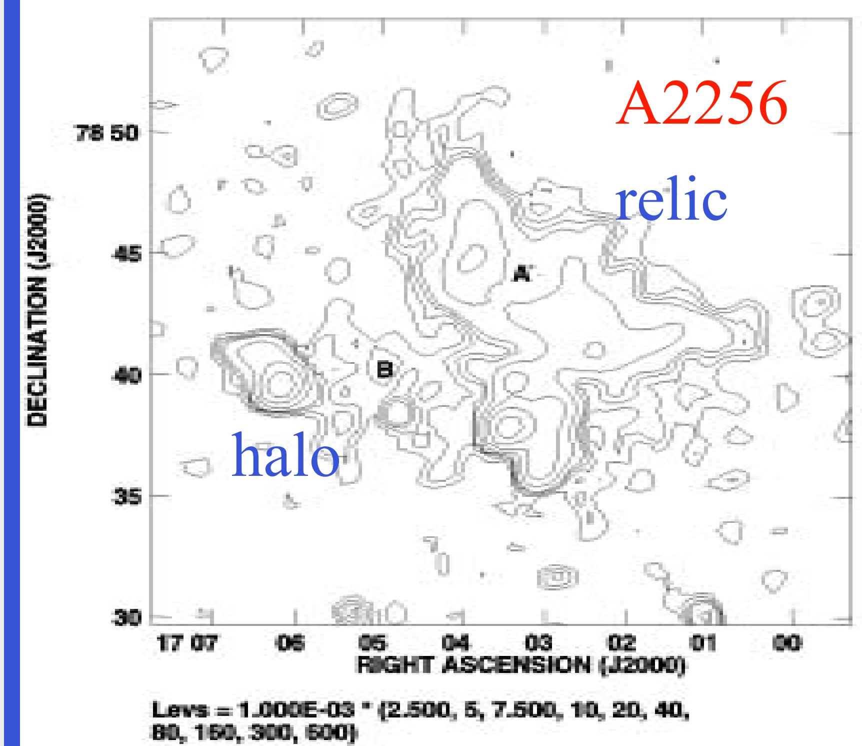


merger events

Coma



Hot Intracluster Gas
&
Non-thermal elements : Magnetic fields and Relativistic Electrons



New spectral components :

Cluster Soft Excess

(EUVE, *Lieu et al 1966*)

HXR Excess

(BeppoSAX, *FF et al 1999*)

(RXTE, *Rephaeli, Gruber & Blanco 1999*)

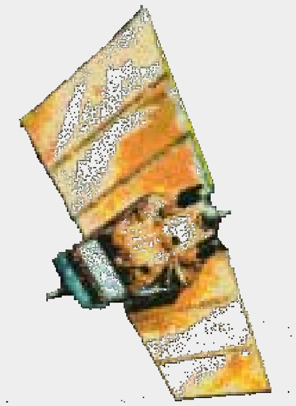
Non-thermal (NT) HXR emission was predicted at the end of the seventies in clusters of galaxies showing extended radio emission

(see *Rephaeli 1979*)

Radio electrons ⇔ CMB photons ⇒ IC NT X-ray radiation

Previous Experiments :

Balloon experiments	*Bazzano et al 1984;1990*
HEAO-1	*Rephaeli, Gruber & Rothschild 1987* *Rephaeli & Gruber 1988*
OSSE exp. (Compton-GRO)	*Rephaeli, Ulmer & Gruber 1994*
RXTE & ASCA	*Delzer & Henriksen 1998*



BeppoSAX

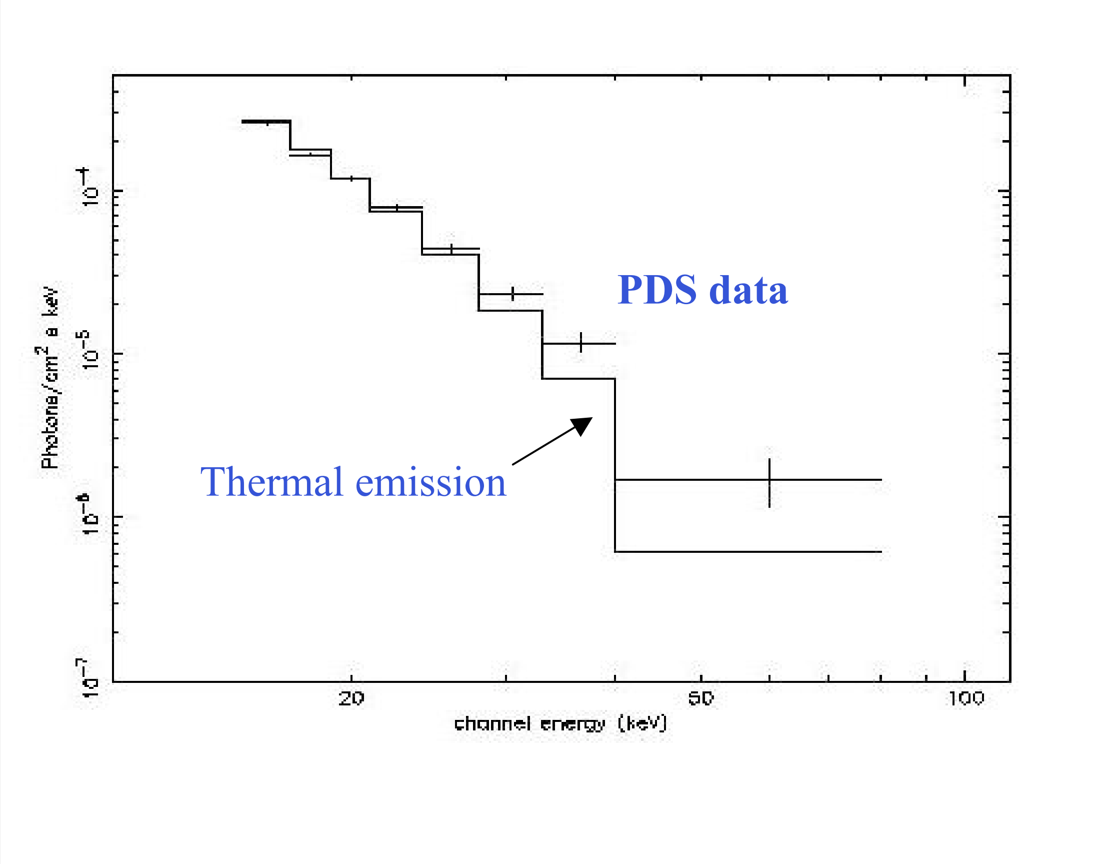
Phoswich Detector System (PDS)
(15-200 keV)

- overall sensitivity : ~ 10^{-6} cm^{-2} s^{-1} keV^{-1}
- background level : ~ 2 x 10^{-4} cts s^{-1} keV^{-1}
- FWHM : ~ 1.3°

Observed Clusters of Galaxies :

Coma, A2199, A2256, A1367, A3667, A119, A754

Coma



kT ~ 8.11±0.07 keV (90%, Ginga, *David et al 1993*)

σ ~ 4.5

$f_X^{NT} \sim (1.4 \pm 0.5) \times 10^{-11}$ erg cm^{-2} s^{-1} (20-80 keV)

$\Gamma_X = 2$

Coma

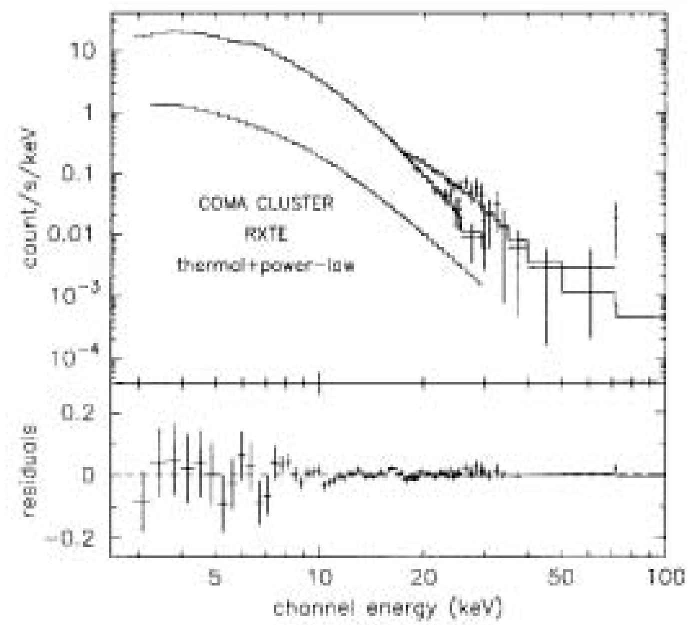
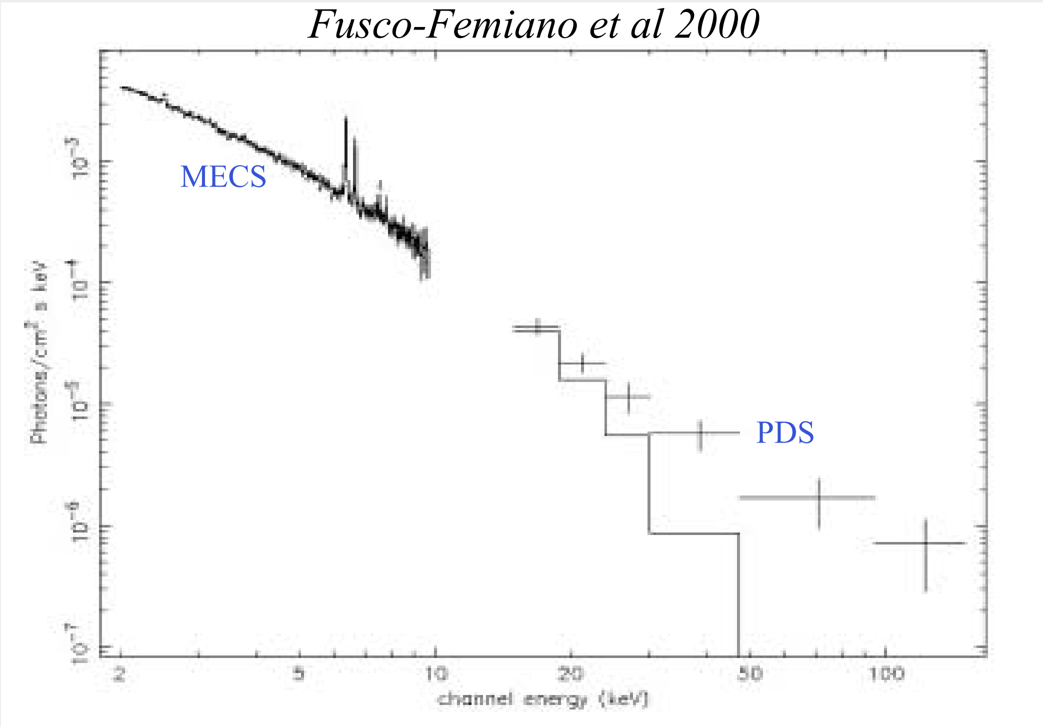


Figure 1. RXTE spectrum of the Coma cluster. Data and folded Raymond-Smith ($kT \simeq 7.51$ keV), and power-law (index = 2.34) models are shown in the upper frame; the latter component is also shown separately in the lower line. Residuals of the fit are shown in the lower frame.

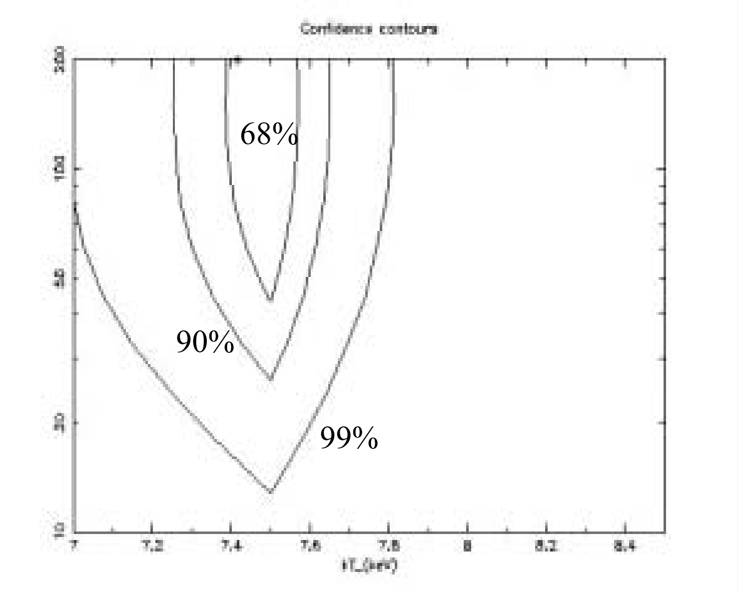
Rephaeli, Gruber & Blanco 1999

RXTE

A2256



Confidence contours



kT = 7.40±0.23 keV

σ ~ 4.6

f_X^{NT} ~ 1.2x10^{-11} erg cm^{-2} s^{-1} (20-80 keV)

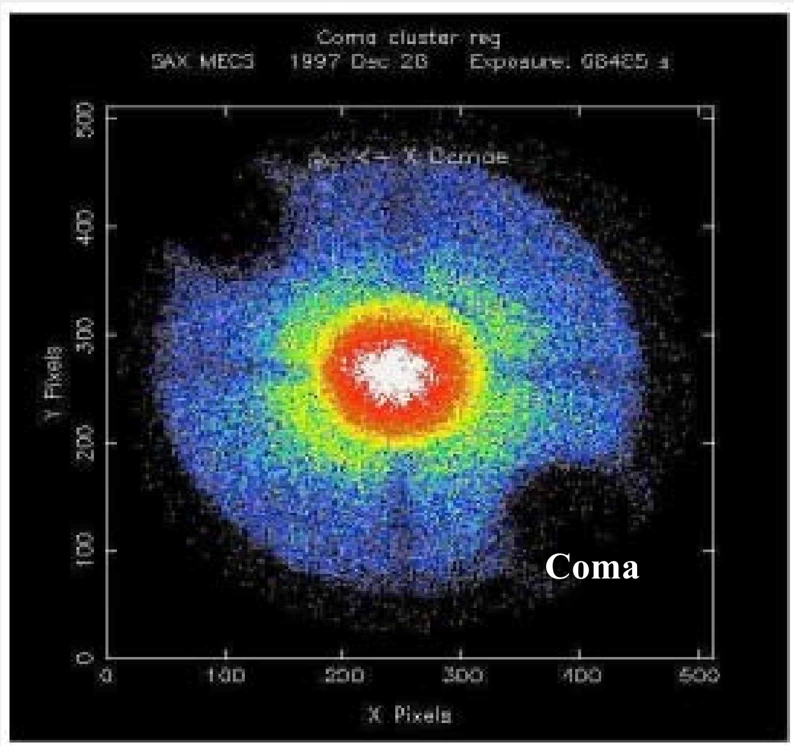
α_X ~ 0.3-1.7 (90%)

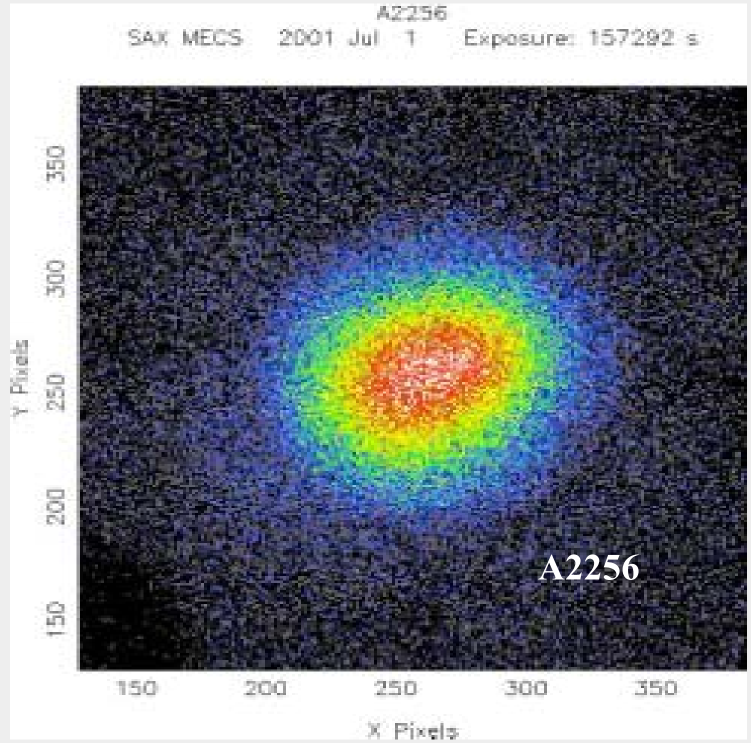
Non-thermal HXR Excesses : possible interpretations

Coma & A2256

- Emission by a point source in the field of view of the PDS
- IC model : primary or secondary electrons
- Non-thermal bremsstrahlung

Emission by a Point Source





X-Comae

Upper limit : ~ 4×10^{-12} erg cm^{2} s^{-1} (2-10 keV)

a factor 7 lower than the flux required

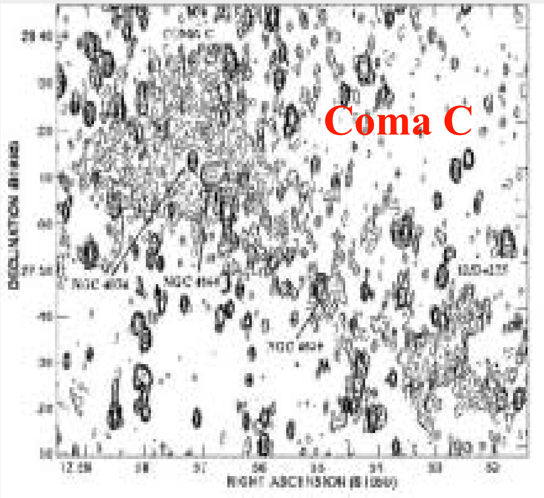
tentative identification of 3 quasars with XMM-Newton (*Briel et al 2000*)

QSO 4C+79.16

cts~0.041 c/s ⇒ (1.2 c/s)

Obscured sources (like Circinus)

IC Interpretation



Radio halo electrons ⇔ CMB photons

⇓

IC nonthermal X-ray radiation

Relating the synchrotron radio flux to the IC X-ray flux

$$f_X = C(\alpha)\, F_r\, B_X^{-(1+\alpha)}\, \nu_r^{\alpha}\, \varepsilon_X^{-(1+\alpha)}$$

$\alpha \sim$ 1-1.3 radio spectral index

- B_X = volume-averaged intracluster magnetic field ~ 0.15 μG

Assuming a radio halo size of R = 1 Mpc at the distance of Coma

$\Rightarrow \rho_e \sim 7 \times 10^{-14}$ erg cm^{-3}

Non-thermal Bremsstrahlung Model

NTB from suprathermal electrons formed through the current acceleration of the thermal gas (*Ensslin, Lieu & Biermann 1999; Dogiel 2000; Sarazin & Kempner 2000; Blasi 2000; Liang, Dogiel & Birkinshaw 2002*)

Low efficiency of the acceleration processes & bremsstrahlung
⇒ high energy input (*Petrosian 2001;2002*)
10^5 more energy than observed into the ICM which will ~ double its T every $3\text{x}10^7$ yr

HXR excesses ⇒ IC model
NT phenomena (radio, HXR)
⇒Primary or Secondary electrons ?

Primary Electrons

Acceleration by shocks ⇒ merger shocks

(*Takizawa & Naito 2000;Miniati et al 2001;Fujita & Sarazin 2001; Miniati 2003*)

~1-2 Mpc of radio halos & short lifetime of the electrons

- **Mach number > 5**

- **Synchrotron radiation highly polarized (relics but not halos)**

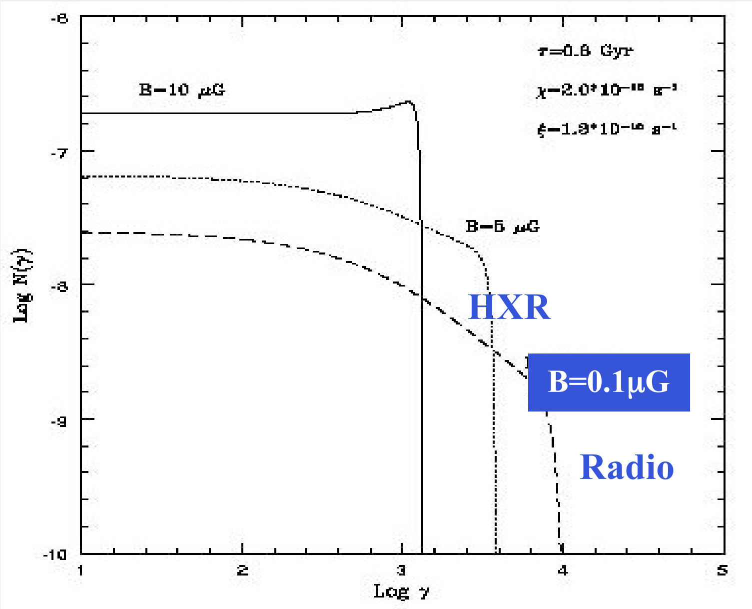
Primary Electrons

Re-accelerated electrons : *two-phase* model *(Brunetti et al 2001)*

first phase **:electrons injected by some sources (AGNs,starbursts)**

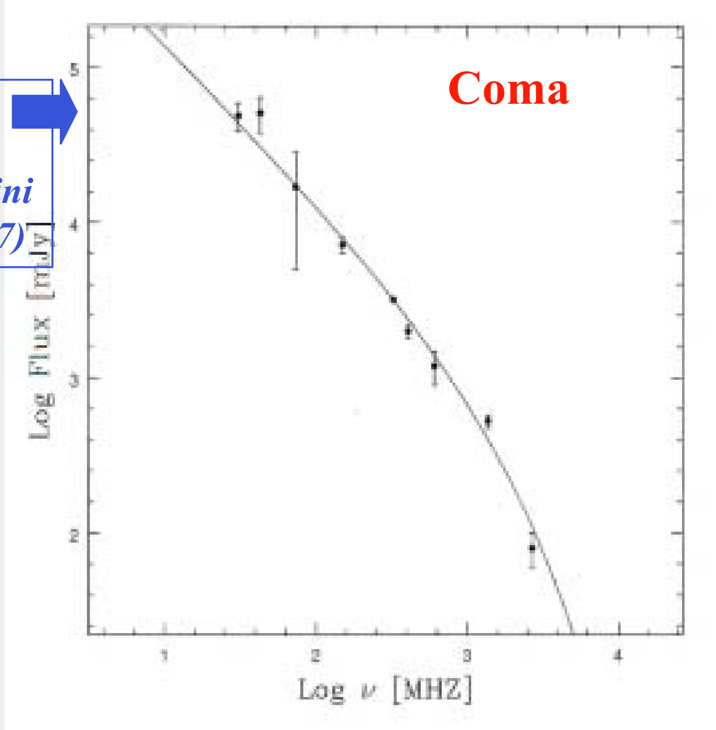
second phase **: electrons re-accelerated for ~ 1 Gyr (turbulence)**

***two-phase* model ⇒ spectral cutoff & radial spectral steepening & HXR excess**



Spectral cutoff

(Kim et al 1990; Giovannini et al 1993; Deiss et al 1997)



Spectral cutoff ⇒ cutoff in the spectrum of the emitting electrons.

Secondary Electrons

⇒ ~Mpc size of radio halos & short t_e (~$3x10^8$ yr)

⇒ $R_{Halo} >> V_D \times t_e$ (V_D~V_A~100 km s^{-1})

Dennison (1980) ⇒ continuous production of secondary electrons

⇒ decay of charged pions generated by p-p collisions in the ICM

• *Blasi & Colafrancesco (1999)* ⇒ γ-ray flux > EGRET u.l.
HXR & radio halo ⇒ different populations of electrons

• *Dolag & Ensslin (2000)* ⇒ radial profile of B taken from numerical simulations

• *Ensslin (1999)* ⇒ relativistic protons are released by ghosts

• *Miniati et al (2001)* ⇒ numerical simulations of cluster formation & injection of primary relativistic protons by strong shocks

Primary or Secondary Electrons ? Observational Constraints

• Profile of the radio emission broader than that of X-ray emission (*Govoni et al 2001; Feretti et al 2001*)

Secondary models ⇒ narrower radio profiles ⇒ $t_{pp} \propto n_{th}^{-1}$

⇓

secondary electrons are expected to be injected in the denser regions ⇒ radio emission stronger in the cluster core

(*Brunetti 2002*)

To skip the problem :

an *ad hoc* increase of ρ_p^{rel} with radius ⇒ an energetics of relativistic protons higher than that of the thermal pool

• Spectral cutoff observed in Coma

Spectral cutoff ⇒ cutoff in the spectrum of the emitting electrons

re-accelerated electrons naturally account for the electron spectrum cutoff (*Brunetti et al 2001*)

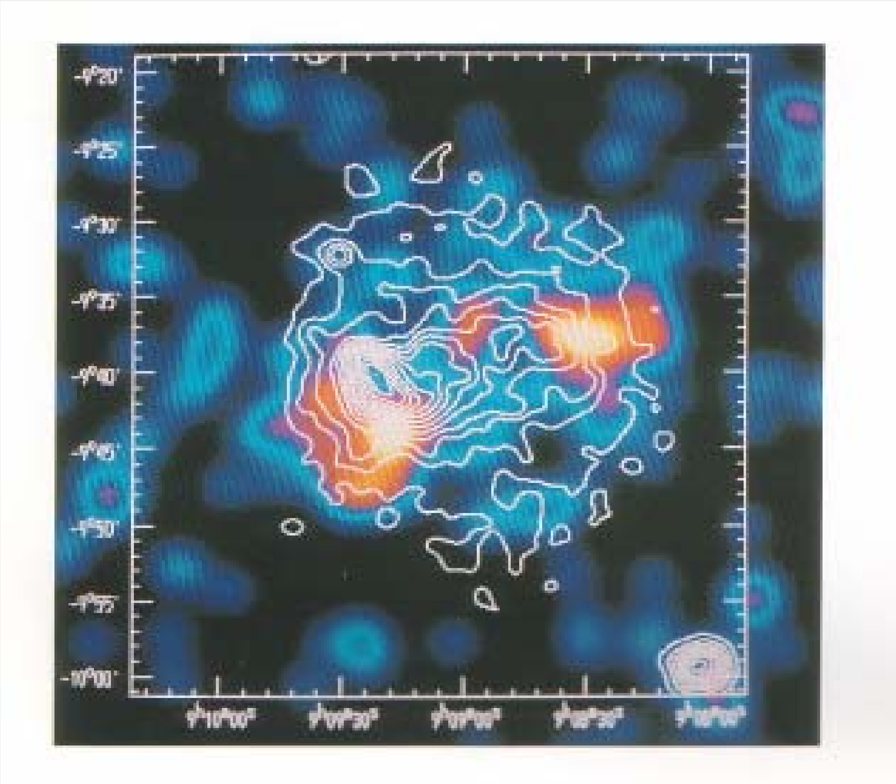
this cutoff is not naturally explained by a continuous production of secondary electrons unless we assume a cutoff in the energy distribution of the primary relativistic protons ⇒ Ep < 50 GeV ⇒ cutoff of the radio spectrum from the secondary electrons at ~GHz frequencies (*Brunetti 2002*)

≠ spectrum of galactic cosmic rays & theoretical expectations

-radio spectral properties ≠ secondary electrons

Are the synchrotron spectral properties of Coma common among radio halos ?

A confirmation of the scenario described by the re-acceleration models seems to be given by the radio & HXR observations of A754

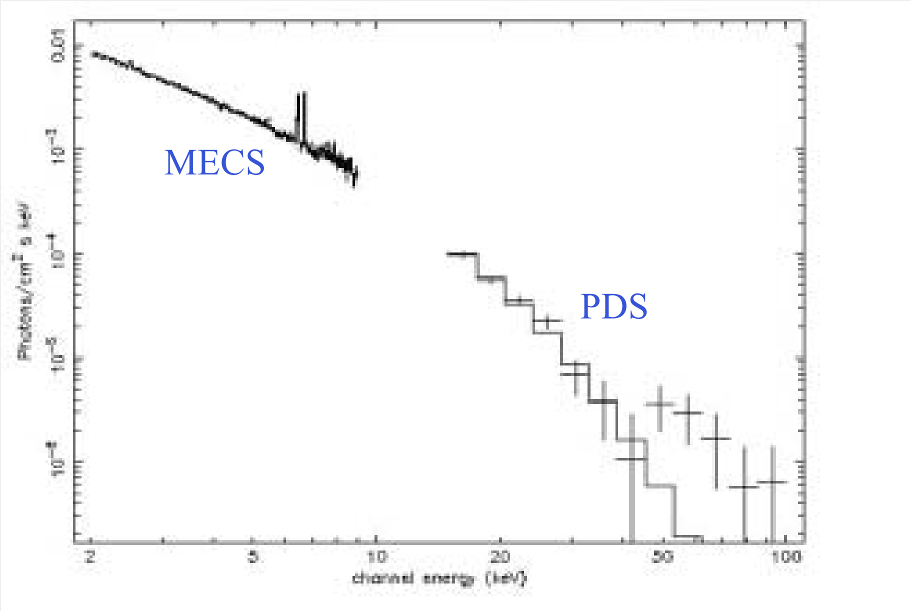


A754 is considered the prototype of a merging cluster. X-ray observations report a violent merger event (*Henry & Briel 1995; Henriksen & Markevitch 1996; De Grandi & Molendi 2001*),

very recent merger ⇒ hydro/N-body model (*Roettiger, Stone & Mushotzky 1998*)

A754

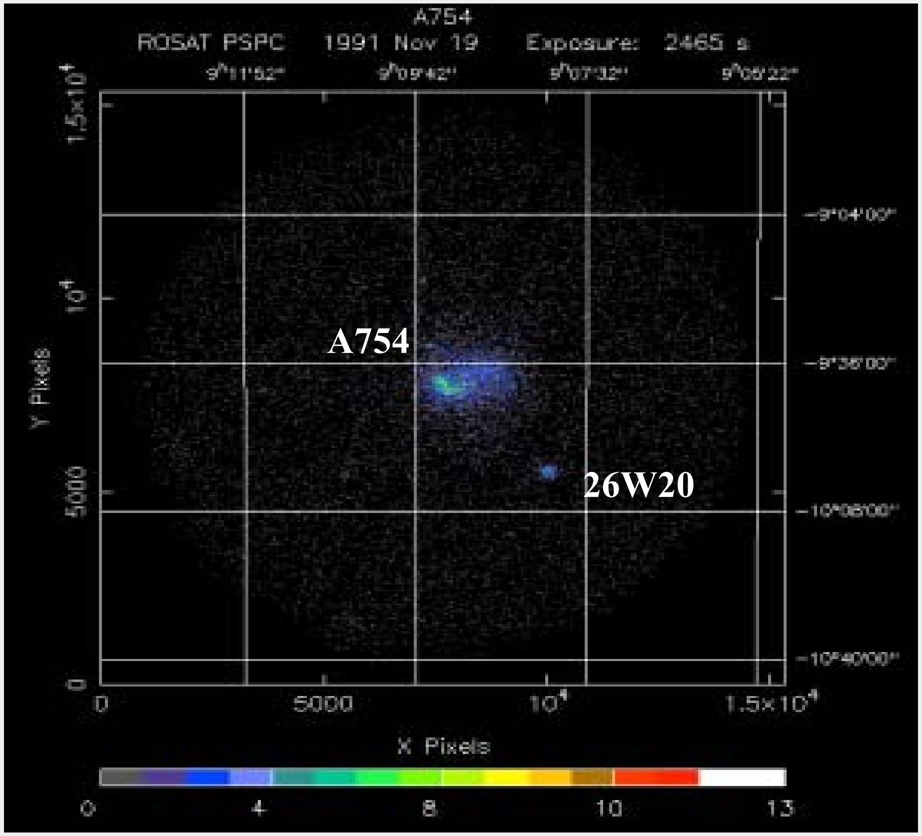
kT ~ 9.4 keV
σ ~ 3.2

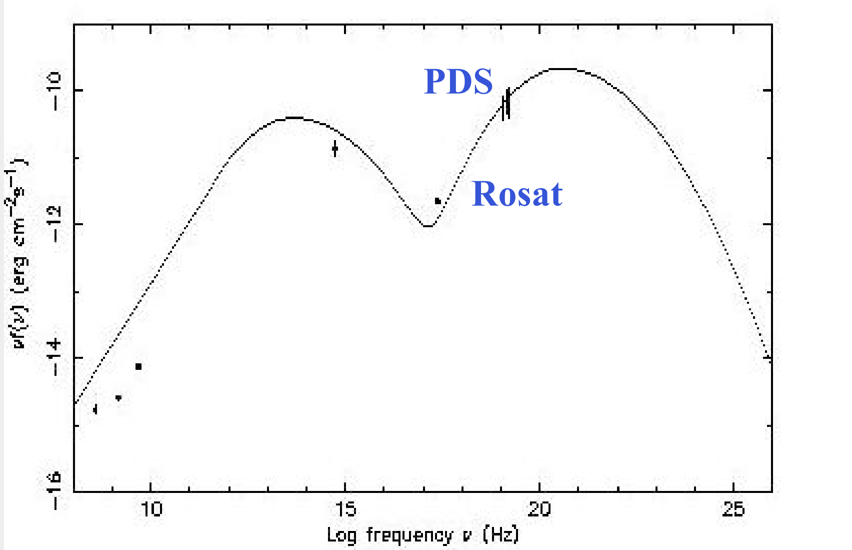


Fusco-Femiano et al 2003

f_X^{NT} ~ 1x10^{-11} erg cm^{-2} s^{-1} (40-100 keV)

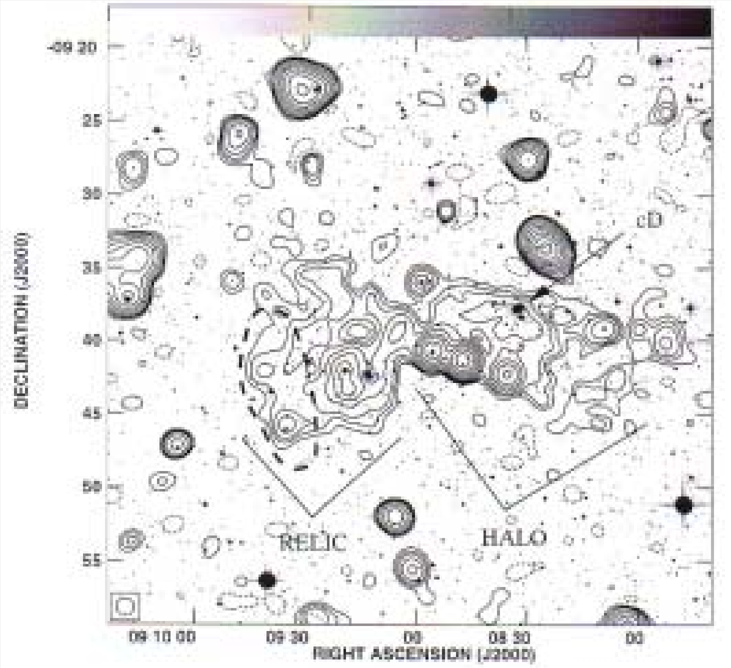
upper limit f_X^{NT} ~ 1.6x10^{-12} erg cm^{-2} s^{-1} (10-40 keV) - RXTE (*Valinia et al 1999*)





Fusco-Femiano et al 2003

The source 26W20 (*Harris et al 1980*) shows a X-ray bright core similar to that of a BL Lac object but weak emission lines. The fit with a SSC model to the SED is consistent with the SED of a BL Lac object (*Perry 2000*; *Padovani et al 2002*; *Giommi et al 2002*) but requires a flat energy index of ~ 0.3 to extrapolate the Rosat flux in the PDS energy range



IC Model

F_R(1.4 GHz) = 86±2 mJy ⇔
F_X^{NT}(40-100 keV) ~ 1x10^{-11} erg cm^{-2} s^{-1}

⇒ B_X ~ 0.1 μG ⇒ γ ~ 10^4 ⇒
IC losses determine a cutoff in the electron spectrum

spectral cutoff ⇒ VLA obs. at 1.4 GHz & obs. at 74 and 330 MHZ
(*Fusco-Femiano et al 2003; Kassim et al 2001*)
α_R (74-330 MHz) = 1.1
α_R (330-1400 MHz) = 1.5
cutoff in the radio emitting electrons ≠ secondary electrons

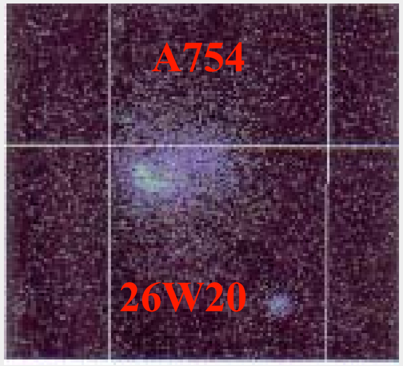
HXR excess & radio data ⇒ primary electrons

Conclusions

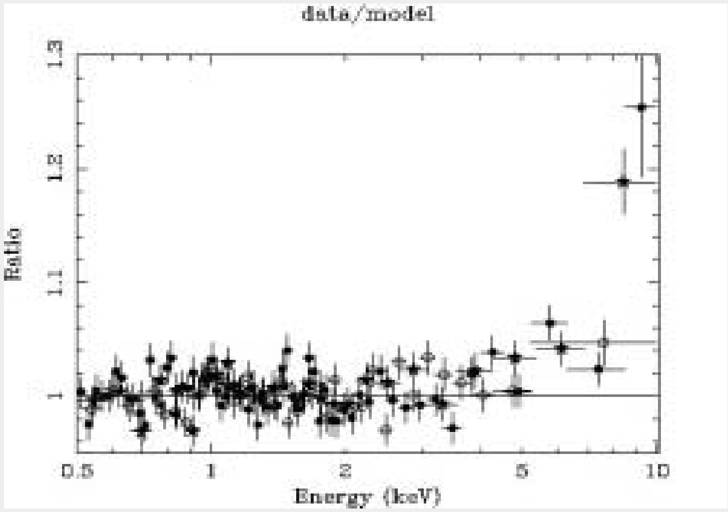
- BeppoSAX observed NT emission in Coma & A2256 that both show extended radio regions
- At a lower confidence level NT radiation has been observed in A754
  - ⇒ primary re-accelerated electrons are responsible for NT phenomena in the ICM
  - ⇒ link between Mpc-scale radio emission & very recent or current merger processes

Missions able to search for NT radiation:

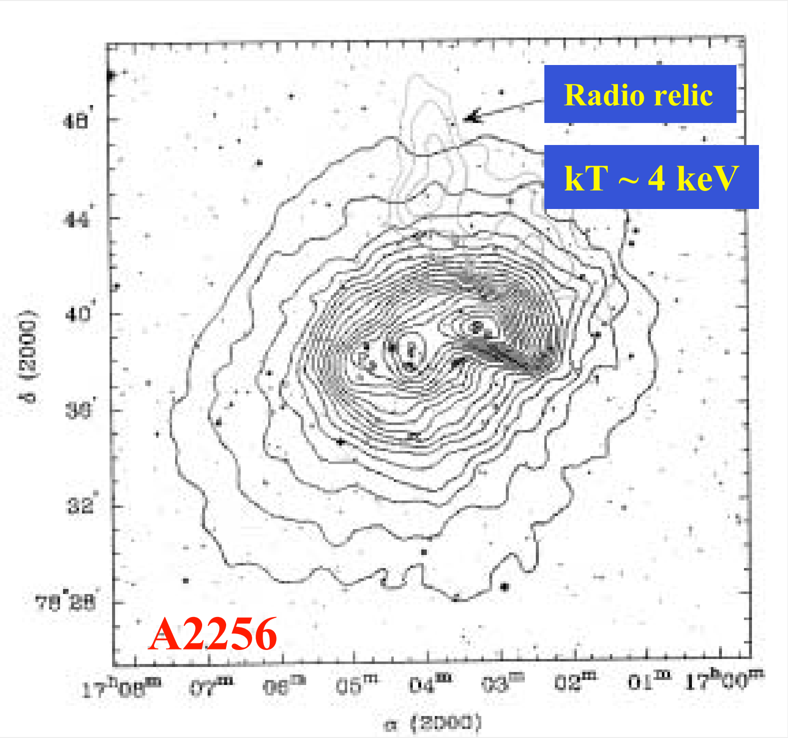
- INTEGRAL (IBIS, 12’) ⇒



• **XMM-Newton**



Chandra



Sun et al 2001

X-ray & radio structures
⇒ profiles of B and of relativistic electrons

Future missions: Astro-E, Con X, NEXT