INTEGRAL observations of galaxy clusters

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Abstract

• BeppoSAX and RXTE observations of several clusters of galaxies showed an excess in hard X-rays (HXR) (see e.g. Fusco-Femiano et al. 04, ApJ 602, L73). This result is interpreted as IC scattering of the relativistic (E~GeV) electrons that produce radio halos with the CMB.

• However, this result is controversial (Rossetti & Molendi 04, A&A 414, L41), and the HXR instruments on board BeppoSAX and RXTE are non-imaging, so contribution of point sources could not be excluded.

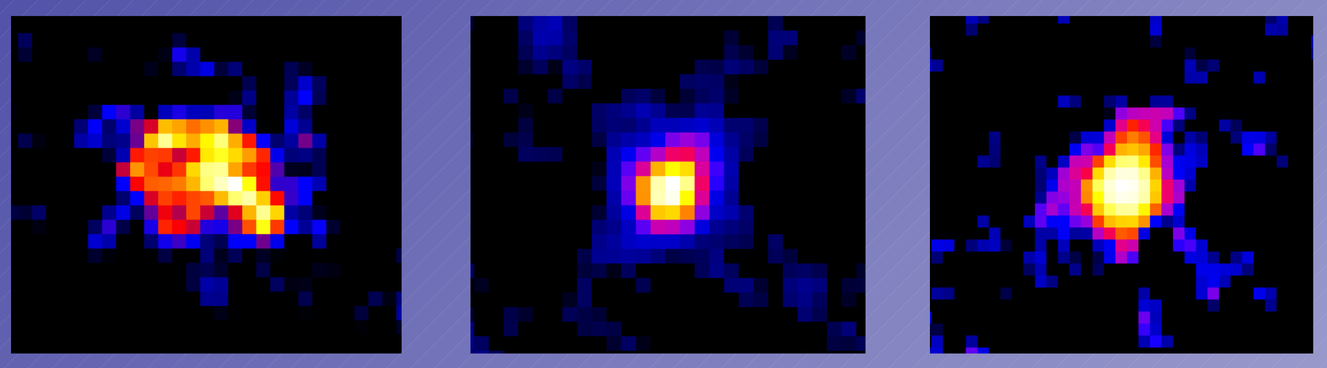
• Here we present the results of INTEGRAL observations of the Coma, Ophiuchus and Perseus clusters (Eckert et al. 07, A&A 470, 835, Eckert et al. 08, A&A 479, 27).

• In the Ophiuchus and Perseus clusters, we find a significant excess at hard X-rays compared to the extrapolation of the thermal emission. In the Coma cluster, we resolve the source spatially, and we find evidence for a hard X-ray emitter South-West of the cluster core.

INTEGRAL observations

• In the INTEGRAL IBIS/ISGRI hard X-ray (17-60 keV) all-sky survey, 6 galaxy clusters have presently been detected: Coma, Ophiuchus, Perseus, Virgo, Triangulum Australis and Abell 2256. However, only Coma, Ophiuchus and Perseus have been detected with a significance larger than 10σ.

• These three sources have also been detected by the JEM-X X-ray monitor in the 3-20 keV band. The angular resolution of JEM-X (3.5 arcmin FWHM) allows us to resolve all three sources. On the other hand, the angular resolution of ISGRI at hard X-rays (12 arcmin FWHM) is only sufficient to resolve the Coma cluster, while Ophiuchus and Perseus appear as point sources.



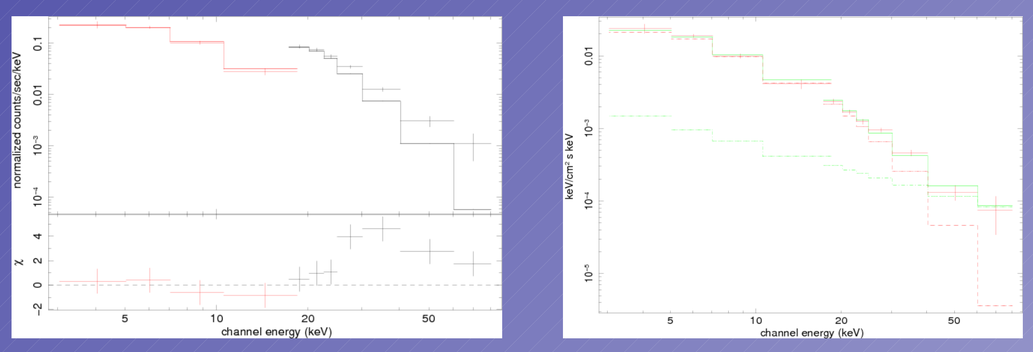
→ *INTEGRAL/JEM-X 3-20 keV images of the Coma (left), Ophiuchus (center) and Perseus clusters*

HXR excess in the Ophiuchus cluster

• The Ophiuchus cluster is the most massive nearby (z=0.028) cluster. Its temperature was found to be very high (e.g. ASCA, kT=11.7 keV). The INTEGRAL exposure time is very large (3 Ms), which leads to a very good detection of the cluster in the 3-80 keV band.

• Fitting the low-energy part of the spectrum (3-20 keV) with a thermal model, we find a temperature kT=8.5±0.3 keV. Extrapolating the thermal model to higher energies, we find a 6.4σ excess above 25 keV.

• The flux of the non-thermal component is 9×10^{-12} ergs/cm^2 s in the 20-60 keV band, with a spectral index Γ=1.6±0.4.

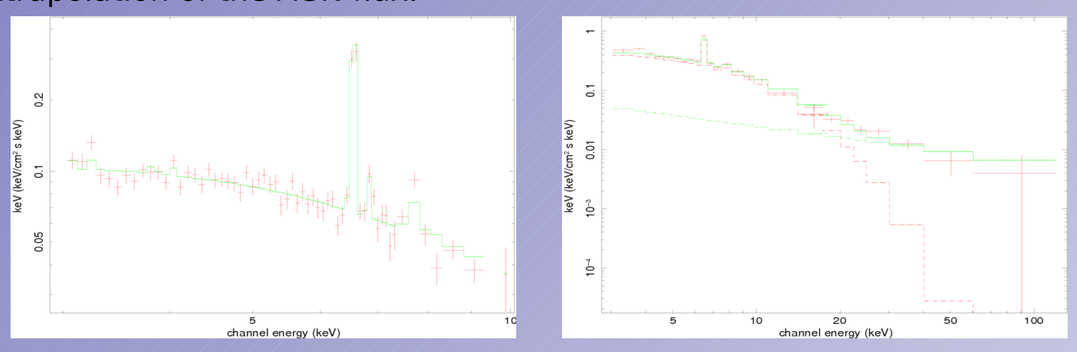


→ *Combined INTEGRAL ISGRI/JEM-X spectrum of the Ophiuchus cluster. The non-thermal component (dashed green line) is detected at the 6.4σ level*

HXR spectrum of the Perseus cluster

• Detection of non-thermal emission was claimed from *Chandra* data (Sanders et al. 05). Extrapolation of the flux in the 2-10 keV band (6.3×10^{-11} ergs/cm^2 s, Γ≃2.0) would be firmly detectable by ISGRI. The central AGN (NGC 1275) also adds a contribution to the hard X-ray flux, with a spectral index Γ=1.8.

• INTEGRAL detects the cluster in the 3-120 keV (exposure: 400 ksec). The temperature is well-constrained by the high-statistics JEM-X data, kT=3.9±0.1 keV. At high energies, a clear excess (10.5σ) is visible. The power-law index is quite steep, Γ=2.6±0.3. The HXR flux exceeds the extrapolation of the AGN flux.



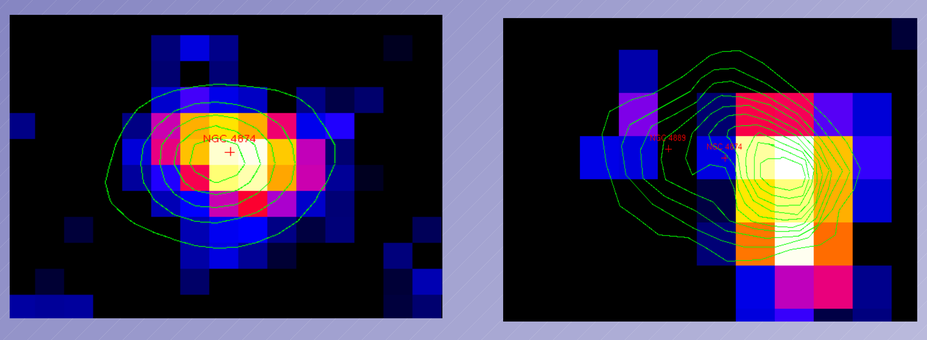
→ *INTEGRAL/JEM-X full-resolution spectrum in the 3-10 keV band (left), at kT=3.9 keV. Right: broad-band ISGRI/JEM-X spectrum. The dashed green line is a power-law with photon index Γ=2.6±0.3*

HXR morphology of the Coma cluster

• The Coma cluster was detected by ISGRI in the 17-60 keV band (exposure: 1.1 Ms). A significant excess compared to the 2-10 keV profile is found at the SW of the cluster center.

• We find that the excess region is extended and cannot be due to a point source at this position. It could be due to a hot (kT~12 keV) component thermal component or to non-thermal emission.

• The excess coincides spatially with the 1.4 GHz radio peak, which suggests that the emission is non-thermal. However, the signal at high energies is yet too weak to distinguish between the two scenarios.



→ *Left: INTEGRAL/ISGRI image of the Coma cluster in the 20-60 keV band, with 2-10 keV XMM contours. Right: INTEGRAL image subtracted from the XMM profile, with 1.4 GHz radio contours from Deiss et al. 97*

Discussion

• We have presented observations of the Coma, Ophiuchus and Perseus clusters in the hard X-ray band with INTEGRAL, in the aim of detecting inverse-Compton scattering from relativistic (E~GeV) electrons on the CMB. In all cases, we find signs of non-thermal activity.

• In the Ophiuchus cluster, we find a statistically significant (6.4σ) excess at high energies. This excess cannot be explained by the presence of very hot thermal gas or by a point source. Combining this result with existing radio data, we find a mean magnetic field B~0.1-0.2 μG.

• In the Perseus cluster, we find evidence for a second spectral component which cannot be explained by the central AGN. We confirm the result of Sanders et al. 05, MNRAS 360, 133. The steep spectral index compared to the soft X-ray band indicates the presence of a cut-off at E~20 keV in the non-thermal spectrum.

• In the Coma cluster, the source can be spatially resolved by ISGRI. We detect a region SW of the cluster core (in the direction of the falling group of NGC 4839) in excess compared to the 2-10 keV profile. The position of the excess coincides with the peak of the 1.4 GHz radio emission, which suggests that the emission is non-thermal. Additional observations with INTEGRAL are required to confirm this result.