ON THE ORIGIN OF THE SOFT X-RAY EMISSION IN FRII RADIO GALAXIES. THE CASE OF CYGNUS A AND 3C 33.

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ABSTRACT: the nature of the soft X-ray emission in FRII powerful radio galaxies is still unclear. One possible interpretation concerns a jet-related origin as in FRI. However recent studies of two radio galaxies, 3C 445 and 3C 234, indicate that the soft X-ray spectra could be not produced by non-thermal radiation but by photoionized circumnuclear gas. Their soft excesses are well fitted indeed by highly ionized lines over-imposed to a weak continuum, possibly produced in warm gas located well beyond the torus.

Here we report on other two radio sources that seem to present features of photoionized gas in the soft X-ray spectrum.

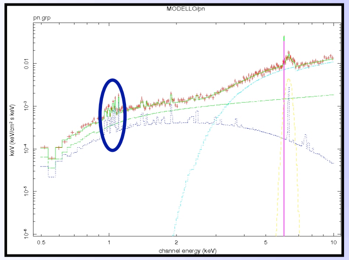
Cygnus A (3C 405) (z=0.0562)

Cygnus A has been observed twice by XMM-Newton. Here are reported the preliminary results of the longer observation (OBSID 0302800101) of ≈ 22 ksec.

HARD BAND (2-10 keV): the basic model we have used to fit this part of the spectrum is a **heavily absorbed power-law** plus the **fluorescence Fe Kα emission line** and a **thermal component (MEKAL)** that reproduces the emission of the cluster in which the source is embedded.

SOFT BAND (0.5-2 keV): a simple less absorbed power law that represents the nuclear radiation scattered by extragalactic gas is not satisfactory. The residuals show excesses around 1 keV that do not disappear adding another thermal component. These excesses could mimic emission lines produced by a photoionized gas that the PN can not resolve.

THE EPIC PN SPECTRUM

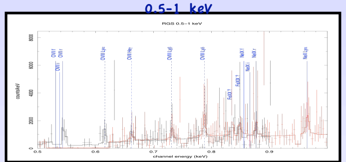


$$\Gamma = 1.63 \pm 0.11$$
$$kT = 2.73^{+0.88}_{-0.32}\ keV$$
$$N_H = 2.1^{+1.5}_{-1.6} \times 10^{23}\ cm^{-2}$$
$$FeK\alpha = 6.37^{+0.02}_{-0.03}\ keV$$
$$EW = 119^{+124}_{-81}\ eV$$

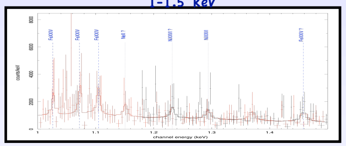
THE RGS SPECTRUM

We used the Reflection Grating Spectrometer (RGS) on board XMM to make a more accurate analysis of the soft spectrum in the 0.5-2 keV band. Its spectral resolution (E/ΔE=100-500) allowed us to resolve the excess @1 keV detected in the PN as a blending of emission lines. Altough most of the detected lines are produced by the thermal gas of the cluster, other lines corresponding to the energies of the OVII and Ne IX triplets, the Ne XLyα and the OVIII Lyα seem to have a different origin. Infact if they were produced by a collisional thermal gas, this gas would have temperature kT≲ 1.5 keV, never observed for Cygnus A.
Another possibility is that these lines are really the diagnostics of photoionized gas.

0.5-1 keV



1-1.5 keV



CONCLUSIONS: the analysis performed with XMM-Newton on the radio galaxy Cygnus A confirms that its nuclear emission is similar to that observed in other Narrow Line Radio Galaxies (NLRGs). According to the Unified Model the nuclei of NLRGs are observed through cold material (the torus) as happens in their radio-quiet counterparts, the Seyfert 2 galaxies.
Guainazzi e Bianchi 2006 showed that the soft X-ray emission in Sy2s is due to photoionized gas, while in radio galaxies this is a very new result. Until now only two radio sources, 3C 445 and 3C 234 have shown the diagnostics of photoionized gas.
For Cygnus A the gas emitting the soft excess has two possible origin: colder thermal gas @1.5 keV or photoionized gas.

3C 33 (z=0.0597)

3C 33 is the right target to investigate the nature of the soft excess. It is a genuine type II radio galaxy, the jet radiation is strongly dumped thanks to its spatial orientation and allows to reveal soft emission lines. Moreover it has the highest [OIII] luminosity among the NLRGs with z<0.3 of the 3CRR catalogue (L[OIII]≈ 1.09×10^{42} erg s^{-1}).

We analyzed all the *Chandra* (ACIS-S) and *XMM-Newton* (PN, MOS1, MOS2) observations available in the public archives and we collected evidence favouring the hypothesis that the soft X-ray emission is produced by a photoionized gas rather than a collisional hot gas.

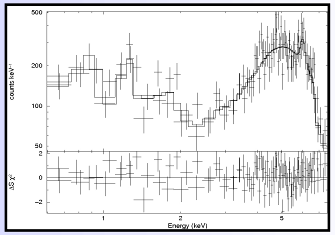
THE *CHANDRA* SPECTRUM

The spectrum has been extracted from a circular region of radius 1.5''.

HARD BAND (2-10 keV): we applied to the spectrum an absorbed power-law plus a Gaussian line profile and a reflection component.

SOFT BAND (0.5-2 keV): we extrapolated the hard model to the soft band. The soft excess is well reproduced by a scattered power-law plus emission lines.

ACIS-S



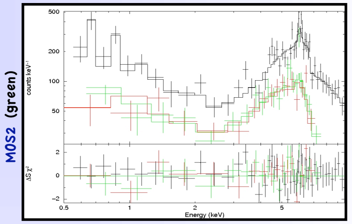
$E = 0.77^{+0.02}_{-0.12}$	$E = 0.93^{+0.04}_{-0.02}$	$E = 1.30^{+0.02}_{-0.03}$
OVII RRC	NeIX rif	MgXI Heα

THE *XMM-NEWTON* SPECTRUM

We checked the results obtained with *Chandra* against the *XMM-Newton* data.
The fit is good χ^2(dof)=25(34), and the residuals show excesses corresponding to the lines found in *Chandra*.

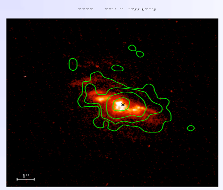
These soft emission-lines can be attributed to a gas located beyond the torus and photoionized by the central engine. We could not perform an accurate analysis with the RGS because the observation was too short and the statistics was insufficient.

PN (black) MOS1 (red) MOS2 (green)



IMAGING ANALYSIS

The *Chandra* contours (green) overlay the [OIII]λ5007 emission detected with the *Hubble Space Telescope*. This emission maps the Extended Narrow Line Region which is generally believed to be constituted of gas photoionized by the nuclear continuum.



CONCLUSIONS: the X-ray spectrum of 3C 33 is quite complex and is similar to that observed in Sy 2 galaxies. The *Chandra* and *XMM* data show a soft X-ray spectrum rich of emission lines, suggesting that the jet plays a marginal role in the overall emission. We are confident that the soft lines are emitted by a **photoionized gas**. The coincidence in morphology and dimensions of the extended X-ray emission and the [OIII] emission support this hypothesis. Also in both spectra we detected lines corresponding to several diagnostics of the photoionized gas. Optical spectroscopic studies on the extended kpc emission-line region (EELR) performed by Baum et al. 1989,1992 revealed that the circumnuclear gas is photoionized by the central engine. This strengthens our conclusions.