PROCEEDINGS OF SCIENCE

High energy properties of PKS 1830-211

Shu Zhang[*] [a], **Yu-peng Chen**[a], **Werner Collmar**[b], **Luigi Foschini**[c], **Ti-Pei Li**[a,d], **Diego F. Torres**[e], **Jian-Min Wang**[a,f]

[a] *Key Laboratory for Particle Astrophysics, Institute of High Energy Physics, 19B YuQuan Road, Beijing 100049, China*
[b] *Max-Planck-Institut für Extraterrestrische Physik, P.O. Box 1603, 85740 Garching, Germany*
[c] *INAF/IASF-Bologna, via Gobetti 101, 40129, Bologna, Italy*
[d] *Center for Astrophysics,Tsinghua University, Beijing 100084, China*
[e] *ICREA & Institut de Ciències de l'Espai (IEEC-CSIC), Campus UAB, Facultat de Ciències, Torre C5-parell, 2a planta, 08193 Barcelona, Spain*
[f] *Theoretical Physics Center for Science Facilities (TPCSF), CAS*
E-mail: `szhang@ihep.ac.cn`

We report on an analysis of X- and γ-ray observations of PKS $1830-211$, a gravitational-lensed high-redshift quasar, based on the long-term campaigns carried out by *INTEGRAL* and COMPTEL. The *INTEGRAL* data currently available present a 33σ significance detection in the $20-100$ keV band, while the COMPTEL 6-years data provide a 5.2σ significance detection in the $1-3$ MeV energy band. At hard X-rays, *INTEGRAL* and supplementary *SWIFT* observations show flux variability on timescales of months. At γ-rays, the source shows persistent emission over years. The hard X-ray spectrum is well represented by a power-law model, with $\Gamma \sim 1.3$ in the $20-250$ keV band. This photon index is well consistent with the previous report of $\Gamma \sim 1.3$ obtained at $E > 3.5$ keV from the best fit of *XMM-Newton* data with a broken power law model. The joint *XMM-Newton*/*INTEGRAL* spectrum presented here is fitted with a broken power-law model and the parameters are refined compared to the previous. The results show that the photon index changes from ~ 1.0 to ~ 1.3 at a break energy of ~ 4 keV. At MeV energies, the spectrum softens to $\Gamma \sim 2.2$. These results, together with the EGRET measurement at $E \geq 100$ MeV, constitute a broad-band spectrum containing the peak of the power output at MeV energies, similar to most high-luminosity γ-ray blazars. The measured spectral characterstics are then discussed in the framework of the gravitational lens effects.

7th INTEGRAL Workshop
September 8-11 2008
Copenhagen, Denmark

---

[*] Speaker.

1. Introduction

Since the first gravitational lens candidate was detected in 1979, the total number of such system has grown. Among them is the high redshift blazar PKS $1830-211$ ($z = 2.507$), gravitationally lensed by an intervening galaxy at $z = 0.89$. The discovery of such gravitational system traces back to radio observations [1]. The radio map was composed of two compact components separated by $1''$, supposed to be the split images from the central region of the source and an extended structure which is most probably from the jet and regarded as an unusually strong Einstein ring [2]. Steppe et al. [3] have shown that PKS $1830-211$ is radio variable on timescales of months.

The previous X-ray observations (*Chandra* and *INTEGRAL*) revealed a quite hard spectrum, modeled with a power-law with a photon index 1.09 ± 0.05 over the energy band $0.5-80$ keV [4]. *XMM-Newton* observations gave the best fit of a broken power-law model, with the photon index changing from ~ 1.0 to ~ 1.3 at energies around 3.5 keV [5].

PKS $1830-211$ was included in the first *INTEGRAL* AGN catalogue by [6], with a photon index $1.96^{+0.27}_{-0.24}$ in the $20-100$ keV energy band and in the *INTEGRAL* extragalactic survey by [6], with a $20-100$ keV flux ~ 3 mCrab level averaged over the first 2.5 years of the *INTEGRAL* observations.

At MeV energies PKS $1830-211$ was firstly reported by [7]. The COMPTEL first 4-year observations (1991-1995) revealed a detection of 4.5σ in the $1-3$ MeV band. Contemporaneously, PKS $1830-211$ was detected by EGRET at ≥ 100 MeV with 7.8σ significance and a photon index of 2.59 ± 0.13 [8].

Since the amount of *INTEGRAL* public data has been significantly increased after the last report, we carried out a detailed analysis of PKS $1830-211$ with all available *INTEGRAL* data. We also reanalyzed the *XMM-Newton* data with a newer software version, which allows us to extend the analysis down to 0.2 keV. The data from COMPTEL and EGRET are also reanalyzed and added in order to obtain the best broad-band high-energy spectrum available to date.

2. Observations and data analysis

2.1 *INTEGRAL*

The available *INTEGRAL* observations comprise about 1095 science windows (scw), for a total exposure of 2500 ks. The analysis were performed by using the *INTEGRAL* OSA 7.0. All the sources within the FOV which are brighter or comparable to PKS $1830-211$ were taken into account in extracting the source spectrum and light curve. An additional 3% systematic error was added to the spectra because of calibration uncertainties. The spectra were fitted with `XSPEC v 12.3.1` and the model parameters were estimated at 90% confidence level.
The sum of all observations provide a detection with IBIS/ISGRI at $\sim 33\sigma$ level in the $20-100$ keV energy band (Fig.1). The average $20-100$ keV flux is 0.75 ± 0.03 counts/s, corresponding to ~ 3 mCrab. The spectrum of the entire ISGRI data set is well fitted ($\tilde{\chi}^2 = 0.59$ with 8 degrees of freedom) by a power-law model with $\Gamma = 1.29^{+0.16}_{-0.15}$ in the $20-250$ keV energy band.

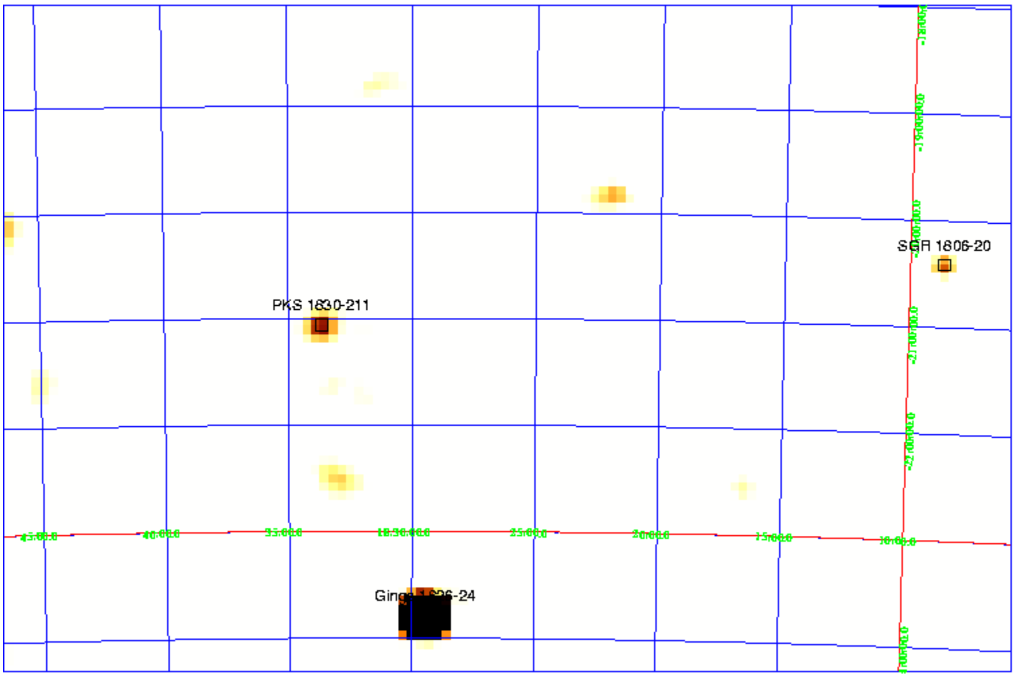

Figure 1: The ISGRI significance map of PKS 1830 – 211 region in the 20 – 100 keV band, obtained by combining the observations of 2003 – 2006.

2.2 *XMM-Newton*

The available three *XMM-Newton* observations (0204580201, 0204580301, 0204580401) are combined to obtain an average spectrum for the joint fit with ISGRI data. Although, the broken power-law and the log-parabola models can be fit with similar results in the χ^2 test, the broken power-law is slightly better and we consider this model as the best fit.

2.3 *SWIFT*

Swift/BAT has a very large FOV and makes it possible for a source to be daily monitored at the hard X-rays. The data products are therefore the source lightcurves and are publicly available[1]. The BAT lightcurve has a weighted-average flux value of $4.56 \pm 0.48 \times 10^{-3}$ counts cm^{-2} s^{-1}, corresponding to 2 mCrab at $\sim 9.5\sigma$ over a time period of roughly 2.5 years.

2.4 COMPTEL

Here we take the complete 6-years COMPTEL data, until the second reboost of the satellite in 1997, after which the background changed a lot making it difficult for further research, to investigate again the MeV emission. These data are subdivided into the so-called *CGRO* phases, with each period covering typically one year of observations. The source is again detected mainly in the $1-3$ MeV band, but the detection significance is improved to 5.2σ (Fig.2).

---

[1] See the *Swift*/BAT transient monitor results provided by the *SWIFT* Team at `http://swift.gsfc.nasa.gov/docs/swift/results/transients/`

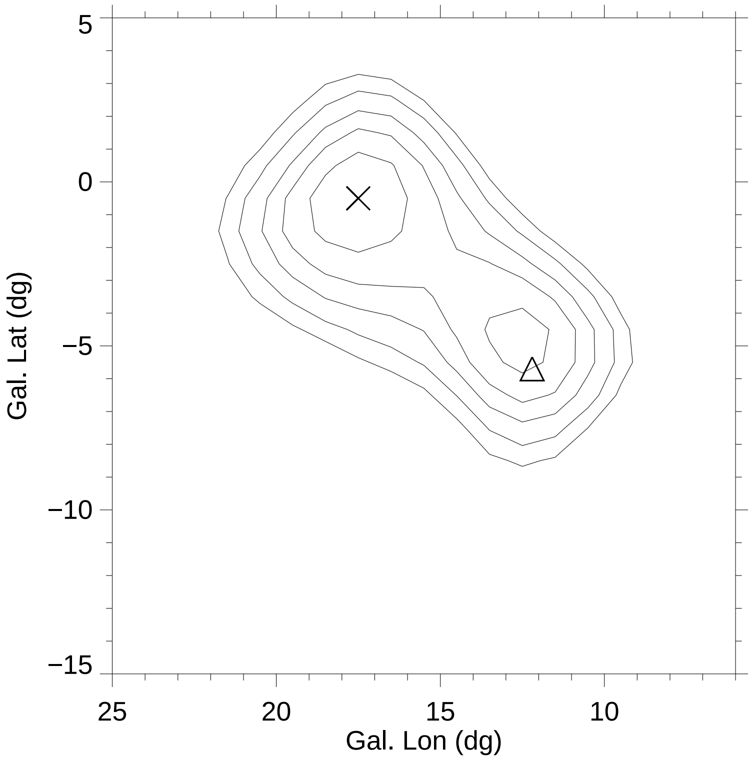

Figure 2: The $1-3$ MeV map from COMPTEL observations of phases $1-6$. The contours start at detection significance level of 3σ, with steps of 1σ. The triangle represents the location of PKS $1830-211$, and the cross the location of the so-called MeV source $l = 18$, namely GRO J1823-12.

3. Time variability

The ISGRI lightcurve shows that the flux tends to drop smoothly during the first 2.5 years since 2003 and then to raise in the following years. A search for the flux variability on shorter time scales (4 days bins) resulted in two interesting episodes (around MJD $\sim$ 53050 and 53600). *SWIFT*/BAT data are combined in 10-days bins and the resulted lightcurve shows several time periods with persistent flux excess. Accordingly, the observations are divided again into these 6 long term intervals. The resulted lightcurve suggests that PKS $1830-211$ is rather variable at the hard X-rays on the time scale of months. The lightcurves from COMPTEL ($1-3$ MeV, time period $1991-1997$) and EGRET (≥ 100 MeV, time period $1991-1995$), with each bin presenting the average of one *CGRO* satellite observing phase, indicate that PKS $1830-211$ is likely to have persistent emission over years at $\gamma-$rays. The details of the lightcurves refer to [9].

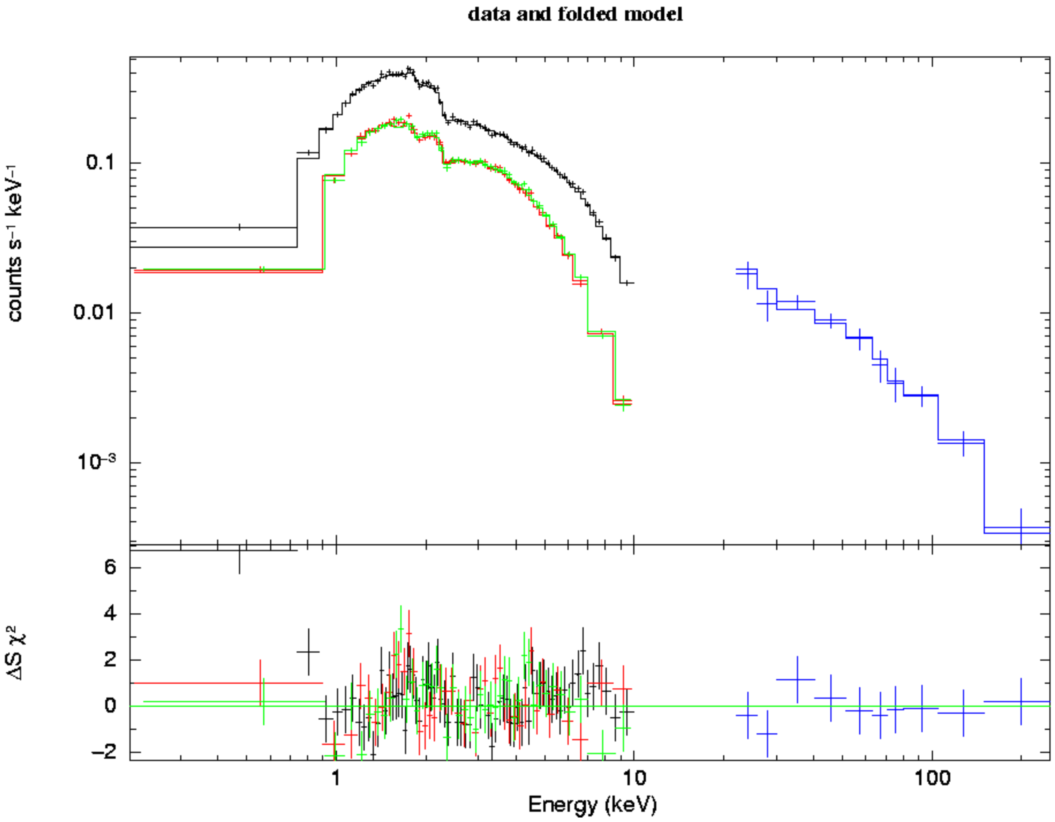

Figure 3: Spectral fit with a broken power law model for the combined *XMM-Newton* data (at energy below 10 keV, with the black for PN and the red/green for MOS), and the ISGRI data (at energy above 20 keV). For better visibility the *XMM-Newton* spectra have been rebinned in the plot.

4. Broad-band energy spectrum

We performed a joint fit of the *XMM-Newton*/*INTEGRAL* data. The source luminosity in the $0.2-250$ keV energy band is of 3.5×10^{48} erg s^{-1}. The broken power-law model results to be again the best fit model, with an improvement with respect to the single power-law model $> 99.99\%$ as calculated with the F-test. The results show the photon index changes from ~ 1.0 to ~ 1.3 at a break energy ~ 4 keV (Fig.3). We notice that, although the overall spectrum is well fitted with a reduced χ^2 derived as $\sim$1.04, there may exists an evidence for Iron line red-shifted from 6.4 keV to 1.8 keV (Z+1=3.5). At MeV energies the spectrum can be well represented ($\tilde{\chi}^2 = 0.4$ for 2 dof) by a single power-law model with $\Gamma = 2.23^{+0.36}_{-0.27}$ measured from COMPTEL data combined from *CGRO* phases 1-4. Fig.4 shows the high-energy broad-band spectrum for the results derived in this paper, including the data from *XMM-Newton* and *INTEGRAL* to cover the soft/hard X-rays ($0.2-250$ keV); from COMPTEL for the γ-rays ($0.75-30$ MeV); and from EGRET for the $\gamma-$rays in the ≥ 100 MeV energy band [8]. In such a broad-band view, the power output of PKS $1830-211$ shows a bump located at MeV energies, as expected in the common view of a high-luminosity blazar, where the high-energy part of the spectral energy distribution (SED) is due to inverse-Compton emission from the relativistic electrons in a jet scattering off seed photons coming from a source external to the jet.

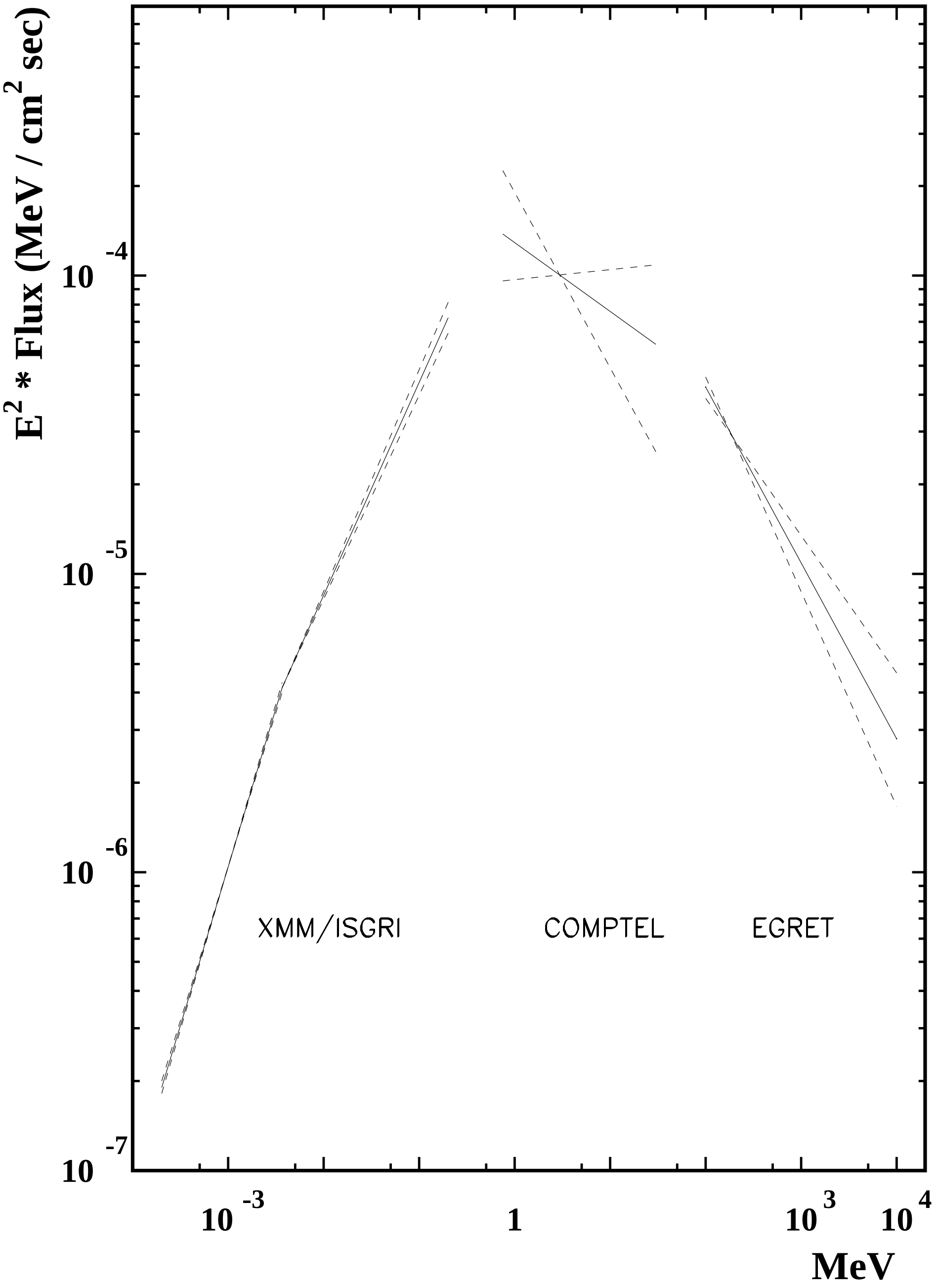

Figure 4: The broad energy spectrum of PKS 1830 – 211. The solid lines are the broken power law shape as obtained by *XMM-Newton*/*INTEGRAL* at X-rays, power law shapes by COMPTEL at MeV energies, and by EGRET at ≥ 100 MeV [8]. The dashed lines represent the 1σ error in spectral index.

5. Discussion and summary

The most interesting feature in the broad-band high-energy spectrum of PKS $1830-211$ is the spectral flattening below ~ 4 keV. Such a flattening has been observed also by [4] in the combined *Chandra*/*INTEGRAL* spectrum, but the best fit model proposed is a single power-law with $\Gamma = 1.09 \pm 0.05$ extending over the entire $0.5-80$ keV band absorbed by cold gas from the intervening galaxy at $z = 0.89$, with column density $N_{\rm H}^{z} \sim 2 \times 10^{22}$ cm^{-2}. Instead, in the present work, by analyzing a spectrum covering a wider energy range ($0.2-250$ keV), we have shown evidence of a photon deficit at low energies in addition to the absorption from the intervening galaxy, confirming and extending the results obtained with *XMM-Newton* only ($0.4-10$ keV) reported by [5]. This low-energy photon deficit can be best fit with a power-law harder ($\Gamma \sim 1.0$) than the one at energies greater than ~ 4 keV ($\Gamma \sim 1.3$).

However, in the case of PKS $1830-211$, the gravitational lensing should have an impact on the spectral and variability properties of the source, but it is not clear how to weight it at high-energy. These effects in the γ-ray band on distant blazars have been discussed by [10] and [11]. The observed hard X-rays and, probably the soft X-rays as well, are the combination of the contributions from SSC and EC, which in turn are generated from different places. Therefore, the lensing can act differently, resulting in changes in spectral shape.

In summary, we presented here the most up-to-date broad-band high-energy spectrum of PKS $1830-211$. The source presents a low-energy roll-off that can be explained efficiently in terms of a natural interplay between SSC and EC, as shown in other high-z Flat Spectrum Radio Quasars (FSRQ) [12]. However, it is not clear what is the weight of the amplification factor due to the gravitational lensing. Future observations at X-rays with higher spatial resolution should allow us to measure this factor. More details can be found in [9].

References

[1] Pramesh Rao A. & Subrahmanyan R., *1830-211 - A flat-spectrum radio source with double structure*, MNRAS **231** 229 (1988)

[2] Jauncey, D. L., Reynolds, J. E., Tzioumis, A. K., et al., *An unusually strong Einstein ring in the radio source PKS1830 - 211*, Nature **352** 132 (1991)

[3] Steppe, H., Paubert, G., & Sievers, A., *Millimeter continuum measurements of extragalactic radio sources - part three*, A&AS **102** 611 (1993)

[4] De Rosa, A., Piro, L., Tramacere, A., et al., *The broad-band X-ray spectrum of the blazar PKS B1830-211 by Chandra and INTEGRAL*, A&A **438** 121 (2005)

[5] Foschini, L., Ghisellini, G., Raiteri, C.M., et al., *XMM-Newton observations of a sample of gamma-ray loud active galactic nuclei*, A&A **453** 829 (2006)

[6] Beckmann, V., Gehrels, N., Shrader, C., R., et al., *The First INTEGRAL AGN catalog*, ApJ **638** 642 (2006)

[7] Collmar, W., *New blazar detections at MeV energies by COMPTEL*, ASPC **350** 120 (2006)

[8] Hartman, R. C., Bertsch, D. L., Bloom, S. D., et al., *The third EGRET catalog of high-energy gamma-ray sources*, ApJS **123** 79 (1999)

[9] Zhang, S., Chen Yu-Peng, Werner Collmar, et al., *High energy properties of PKS 1830-211*, ApJ **685** 400 (2008)

[10] Combi J.A. & Romero G. E. 1998, A&AS 128, 423 *Observations of the radio emission field around the gamma -ray source 2EG J1834-2138*, A&AS **128** 423 (1998)

[11] Torres, D. F., Romero, G. E. & Eiroa, E., *Gravitational lensing as a possible explanation for some unidentified gamma-ray sources at high latitudes*, ApJ **569** 600 (2002)

[12] Worsley, M.A., Fabian, A.C., Turner, A.K., et al., *XMM-Newton confirmation of a warm absorber in the z= 4.4 blazar PMN J0525-3343*, MNRAS **350** 207 (2004)