PoS PROCEEDINGS OF SCIENCE

XMM Newton Observation of Low Energy Peaked BL Lac Object S5 0716+714

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This paper contains spectral and temporal information obtained from analyzing BL Lacertae object S5 0716+71. The broadband spectral energy distribution of this object is known to have two components, with the synchrotron emission peaking in the optical and the higher energy component taking over at X-ray energies, believed to be of inverse-Compton origin. Here we analyze XMM-Newton observations of S5 0716+71 obtained on April 4-5, 2004. During the observation, the object displayed significant variability, including a major flare in the last few hours. Light curves and spectra were created and analyzed to look for evidence of spectral variability. A previous analysis of this data set has been done by Ferrero et al. [1]; we discuss differences. The data shows that the X-ray emission for this object requires two components, likely due to the synchrotron and inverse-Compton processes. Interestingly, very little correlation was seen between the emission strength and the spectral slope, likely indicating that the synchrotron component varies but that the slope of the component does not change. This analysis of XMM-Newton data of S5 0716+71 is a work in process and there may be several aspects where conclusions may evolve slightly in the future.

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1. Introduction

S5 0716+71 is one of the brightest, most active, and most variable blazars in the sky. Because of its brightness in all bands (typically its 5 GHz radio flux is ~0.9 Jy, R magnitude ~14, and X-ray flux ~ 1×10^{-11} erg s^{-1} cm^{-2}) and frequent, large-amplitude variability, it has been historically well monitored by telescopes around the world and has been the target of many multi-wavelength campaigns. As part of this history, it has been observed many times by X-ray instruments, including HEAO-A, Einstein, ROSAT-PSPC, ASCA, RXTE, BeppoSAX, and XMM-Newton [1]. The longest (~60 ksec) uninterrupted, highest signal-to-noise ratio observation of S5 0716+71 by the XMM-Newton satellite was carried out on April 4-5, 2004. Presented here is an analysis of this observation of S5 0716+71. The observations provide the opportunity to disentangle the contributions of synchrotron and IC components within the X-ray band and to determine the variability of both with improved accuracy.

2. Data and Reduction

Spectral and temporal analyses were performed on the XMM-Newton data of S5 0716+71 described above. Data analyzed at the time of this writing includes Mos 1, Mos 2, and Optical Monitor (OM) data; PN and RGS data have not been analyzed as of yet. The data were reduced using the scientific reduction software package Science Analysis Software (*xmmsas* v. 7.1.0) available for download from the XMM Newton website (http://xmm.vilspa.esa.es/sas/) and using the procedures in the XMM-Newton ABC guide [2]. All spectral analysis was done in XSPEC v. 12.3.0.

The observation of S5 0716+71 was first analyzed over the entire time frame and with combined Mos 1 and Mos 2 instruments. There is a possible small background flare that occurs at the end of the exposure which was omitted by Ferrero et al. The flare was not omitted for this analysis but there are plans for further investigation of this event. Light curves were also analyzed separately in the soft (0.3-0.5 keV), medium (0.5-2.0 keV), and hard (2.0-8.0) energy bands, differing from previous research by Ferrero et al. [1], which divided light curves into five somewhat overlapping energy bands: 0.5-1.0 (soft), 1.0-10.0 (hard), 0.5-0.75, 0.75-1.2, 1.2-10.0. Thereafter, the light curves of S5 0716+71 were divided into 8 regions that looked visually interesting according to the rate (divisions shown in Figure 1), or counts per second, also slightly different than previous research which divides the light curve into only 5 sections [1]. It is believed that by further dividing several of the five original sections of Ferrero et al. into several smaller sections, one may get a more in-depth look at what is happening during times of steeply changing rates. For this reason, section 6 was created at the end if section 3 to study the spectrum during the sudden increase then decrease of the count rate at that time. Section 7 was created from the end of section 4 during a period of steeply increasing count rate. And Section 8 was taken from the beginning of section 5 where the count rate increases to a maximum and the starts to decrease (specifically at 54,000-57,500 seconds in Figure 1). These regions of rapidly changing count rates were considered periods of interest because investigation may lead to information on particle acceleration/injection timescales, cooling timescale, and geometry of the region.

Each of the eight sections was fitted to a power law, broken power law, double power law, power law plus black body, power law plus bremsstrahlung, and logarithmic parabola. An example spectrum is shown in Figure 2. All models were fit in conjunction with constant Galactic absorption 3.00×10^{20} cm^{-2} [3]. The three fits chosen for final comparison were the power law, broken power law, and log parabola. While the power law plus black body and power law plus bremsstrahlung models attain reasonable fits, blazars are probably not best physically explained by these models, the details of which are beyond the scope of this summary. Further analysis was performed on the power law fits for the spectra of each of the 8 sections. Each section was further broken into five different energy bands and then fit to the power law in XSPEC (following a procedure similar to that in Perlman et al. [7]). To track the evolution of any spectral curvature across the X–ray band, energy band ranges were as follows (in keV): 0.2-0.5, 0.5-1.0, 1.0-2.0, 2.0-4.0, and 4.0-8.0.

3. Results and Discussion

The power law model was analyzed first as it is the simplest model; it is, however, probably not the best model to use since previous work indicates that in this object the two components responsible for most of the broadband emission, due to the synchrotron and inverse Compton processes respectively, are believed to cross in the X-rays [1, 4]. Thus it is highly unlikely that a single power law component can represent the spectrum across the entire X-ray energy range seen by XMM-Newton. As can be seen in the example spectra shown in the left-hand side of Figure 2, all spectra with the power law fit show a strong upturn above 3 keV. This shows that a second component is needed to obtain a good fit in the upper energy range. The broken power law, double power law, and log parabolic models give acceptable fits to the X-ray spectrum and are a definite improvement over the power law model, especially in the higher energy range (see Figure 2, right-hand side, for broken power law sample). In these models the higher-energy component represents the inverse-Compton emission.

As mentioned earlier, the light curves were divided into 8 sections to analyze what is happening during flares. The very beginning of the exposure, section 1, records a period of decreasing flux which continues very slightly through ~25,000 seconds. After that is a period of increased flux during which several flares are seen at around 45,000 (section 6) and 53,000 seconds (section 7) respectively. These sections are particularly interesting as one looks for variations of spectral parameters between the different time and energy ranges.

After analysis, we observed very little correlation between emission strength and spectral slope which suggests that the synchrotron component varies but that the slope of the component does not change (Figure 3). This is rather unusual considering that the X-ray band in this object is roughly 2-3 decades in frequency above the peak of the synchrotron component in νF_ν (compare to the steepening observed in HBLs in Perlman et al. [7] and also the behaviour in Padovani, Giommi & Fiore [8] for large samples of BL Lacs). The hard x-ray spectral indices appear slightly softer and greater than two. However, an unusual aspect of this dataset is that no "looping" of the spectral index, and/or lagging of one band with respect to others, is seen. Counter-clockwise and clockwise looping are often seen in hardness ratio analysis of BL Lac objects [5, 6] and is interpreted as synchrotron radiation from short-lived particles accelerated *in situ*, where clockwise loops reflect acceleration timescales that are shorter than the cooling timescales, and the reverse is the case for counter-clockwise loops. One possible explanation of this set of observations is that the variability seen in the synchrotron emission represents an injection of particles into the region, where any aging is via escape rather than radiative cooling. It also suggests that the location of the break was moving through the hard x-ray band.

4. Future Work

Other low energy BL Lac objects are also being analyzed at this time in an effort to reanalyze all XMM-Newton data of low energy BL Lacs, similar to the efforts of Perlman et al. [7] for high energy BL Lacs.

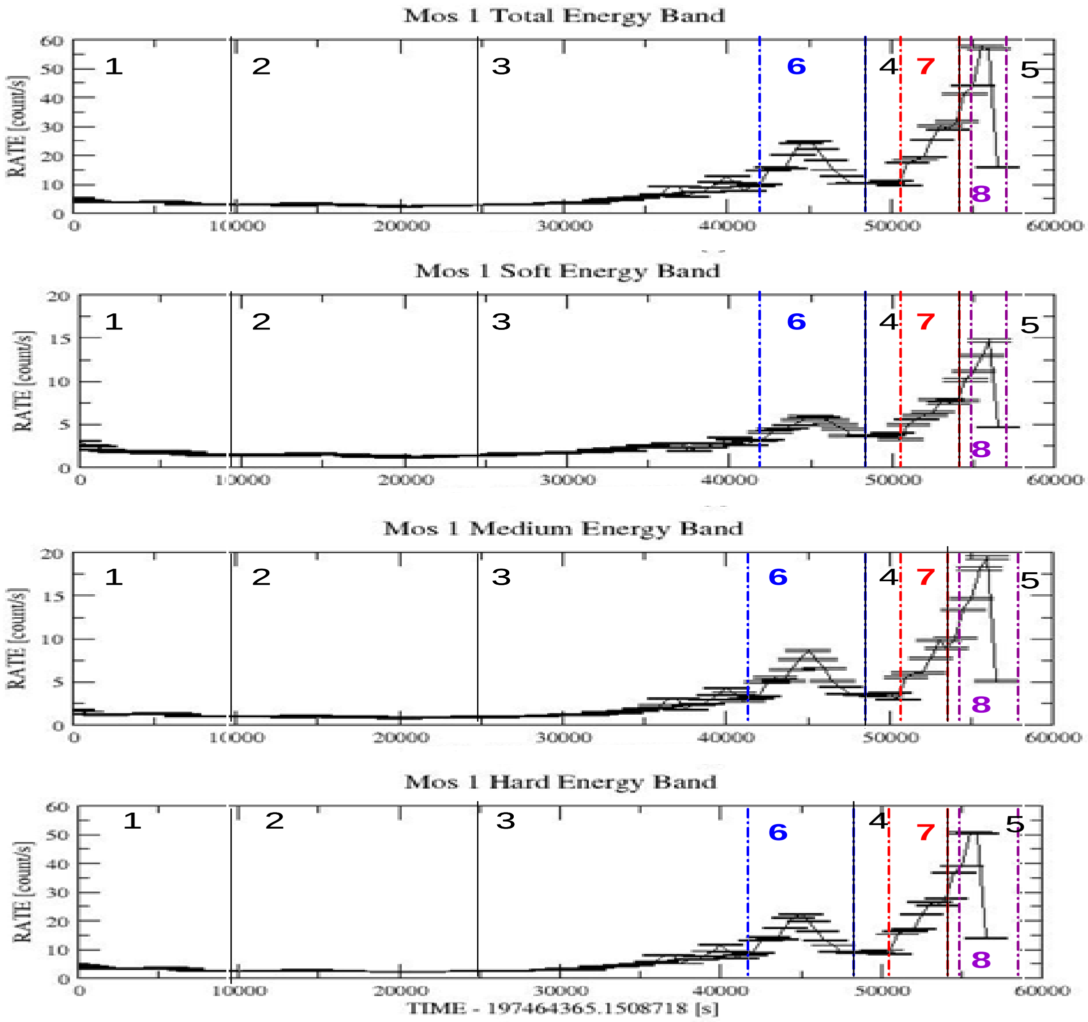

Figure 1. Example light curves (before background subtraction) from Mos 1 showing total, soft, medium, and hard energy ranges respectively. The bin size is 500 and time is counted from the beginning of the observation. The light curves were divided into intervals 1-8 as shown for time-resolved spectral analysis. Similar light curves were obtained with Mos 2 data and the same time intervals were used in spectral analysis.

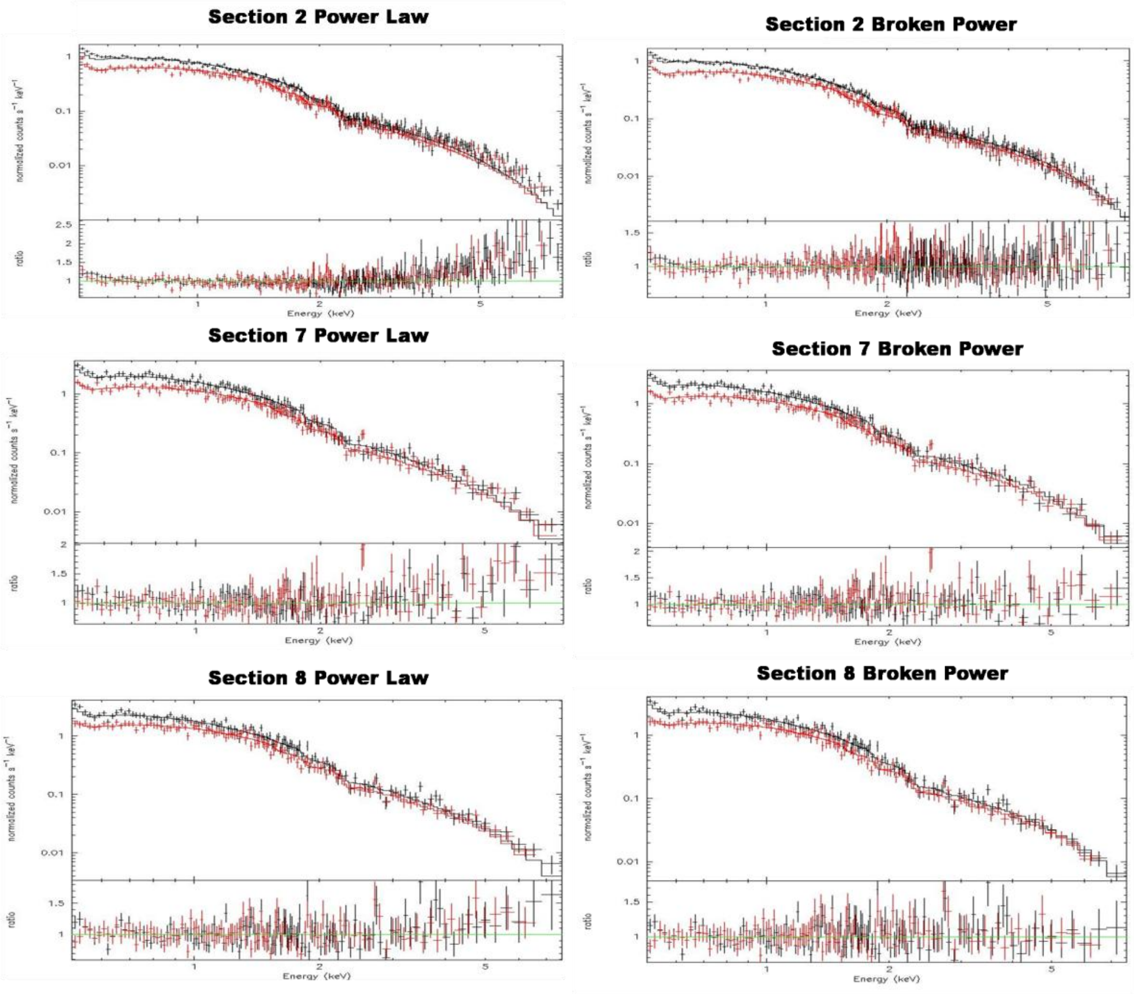

Figure 2. Fitted spectra of S5 0716+71 with data-to-model ratios (bottom panels). The section number corresponds to the section of the light curve that was fit (Figure 1). Sections 2, 7, & 8 from the light curves are shown for power (left side) and broken power laws (right side). Data from Mos 1 is shown in black and data from Mos 2 is shown in red. The power law is the worst fit with deviation from the curve in the higher energies. The broken power law yields a much better fit.

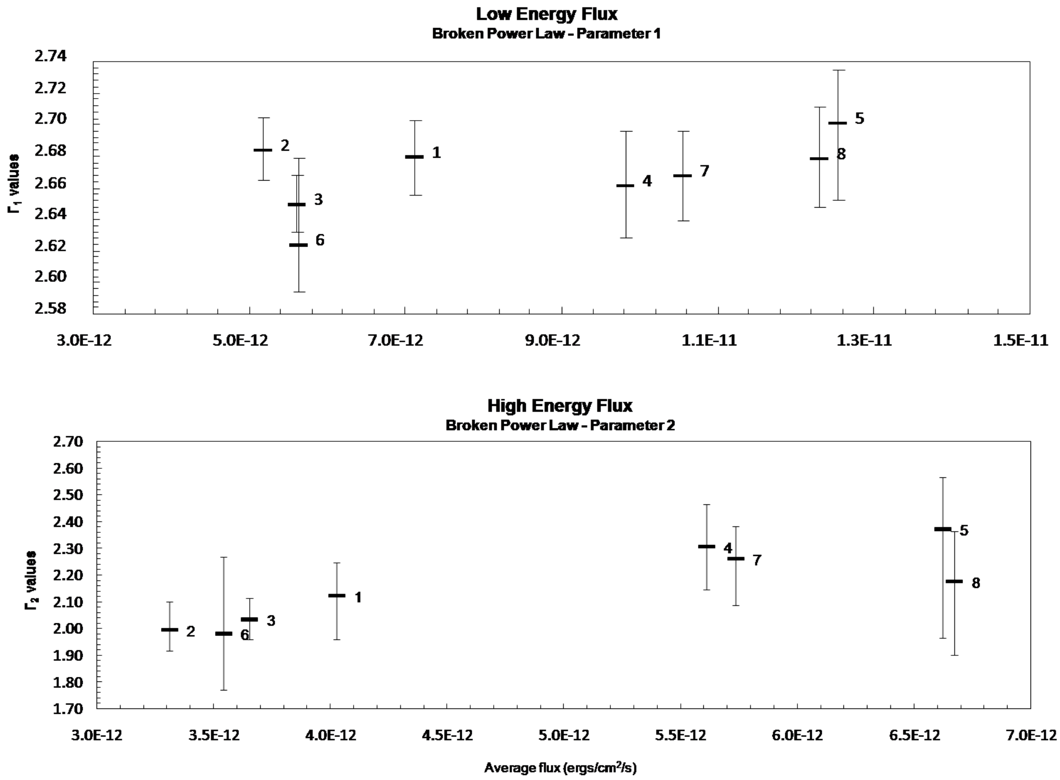

Figure 3. Plots of Γ vs. flux values from fitting Mos 1 and Mos 2 to a broken power law. Low energy flux is 0.5 to 2.0 KeV and high energy flux is 2.0-8.0 KeV. Parameters 1 & 2 are the gamma values obtained from spectral fitting in XSPEC. The number on each point corresponds to the section of the light curve that was fit (Figure 1). Error bars have a 90% confidence range.

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