Intensive monitoring of the strongly variable BL Lac S5 0716+714

K. Otterbein\textsuperscript{a}, M. J. Hardcastle\textsuperscript{b}, S. J. Wagner\textsuperscript{a} and D. M. Worrall\textsuperscript{b,c}

\textsuperscript{a}Landessternwarte Heidelberg-Königstuhl, D-69117 Heidelberg, Germany
\textsuperscript{b}Department of Physics, University of Bristol, Tyndall Avenue, Bristol BS8 1TL, UK
\textsuperscript{c}Harvard-Smithsonian Center for Astrophysics, Cambridge, MA 02138

The BL Lac object S5 0716+714 was monitored during a multifrequency campaign in 1996. Preliminary analysis of the optical, ROSAT and RXTE data are presented. Strong variability on short time scales was observed. The data suggest an interpretation within a multi-component model.

1. Introduction

Variability studies of AGN, in particular of the extreme blazar class, have proven to be powerful tools for the investigation of the nature of these objects. Shortly after the discovery of quasars the observation of variability of their radio fluxes on time scales of a few months \cite{10,4} led to the inference of relativistic bulk motion \cite{9,13} and consequently fuelled the development of the relativistic jet model \cite{2}. Short term variability on time scales of a day (intraday variability, IDV see review \cite{11}) provides even stronger constraints on the source size and the physical conditions. Correlations between IDV flares seen in different bands, particularly in the optical, UV, X-rays \cite{7,12}, provide the most conclusive implications for physical models.

Despite the success of the relativistic jet model, the emission processes which produce the overall spectral energy distribution in blazars are still unknown. The smooth radio to UV continuum is generally agreed to be synchrotron emission from the relativistic jet. However the origin of the X-ray and γ-ray emission is far from clear. The majority of present-day models explain the high-energy emission by soft seed photons which get up-scattered by the relativistic electrons of the jet plasma. Thus the main question is where do the soft seed photons originate? Since most of the total power emitted in blazars is in X-rays and γ-rays, solving this problem is crucial for our understanding of blazars.

In order to understand the emission processes in blazars, multifrequency monitoring of the fluxes is necessary to trace the evolution of variability patterns throughout the spectrum and to determine reliable time lags. The lags serve as diagnostics of the emission processes and allow one to infer the structure of the relativistic jet.

2. The case of S5 0716+714

The source S5 0716+714\textsuperscript{1} shows a featureless optical spectrum and its optical continuum flux is significantly polarized \cite{4}. Due to the featureless spectrum the redshift of the object is unknown. A lower limit of z ≥ 0.25 is inferred from the absence of a host galaxy brighter than M\textsubscript{R} = −21.0 in deep optical images \cite{12}.

The source belongs to a well studied subsample of the S5 catalogue \cite{8} which is selected by its high radio flux (S\textsubscript{5 GHz} ≥ 1 Jy), by its flat radio spectrum (α ≥ −0.5, S\textsubscript{ν} ∼ ν\textsuperscript{α}) and by its high declination (δ ≥ 70°) \cite{6}. 0716+714 displays a one sided VLBI jet which strongly bends towards the position angle of the arcsecond-scale structure \cite{6}. It is one of the first sources with reported intra-day variability (IDV). 0716+714 is also detected by ROSAT, SAX, and EGRET and has shown X-ray and γ-ray variability \cite{3}.

Flux variability of 0716+714 has been seen in almost all observations carried out to date regardless of wavelength. The variability time scales

\textsuperscript{1}We will drop the designation S5 for the rest of the paper
observed range from several hours to days. Correlated variability between the radio and optical regimes was found in February 1990 ([12] and references therein). Despite a sparse sampling of the data, simultaneous optical and X-ray measurements during a 21 ksec ROSAT PSPC observation in March 1991 suggest a close correspondence between these spectral bands. A ROSAT X-ray spectral index of $\alpha_x = -1.9 \pm 0.2$ and a two-point optical to X-ray spectral index of $\alpha_{ox} = -1.7$ imply that the X-ray emission at 1 keV may still be synchrotron emission. A more detailed review of the results of previous multifrequency campaigns is given in [12].

3. Multifrequency campaign in 1996

In spring 1996 a multifrequency campaign ranging from the mm-regime to the EGRET $\gamma$-ray regime was organized. In this contribution we present preliminary results of the optical and X-ray data analysis. We focus on the results obtained with the ROSAT and RXTE satellites, noting that because of the low count rate measured with the RXTE, these results are particularly sensitive to the RXTE background modelling which continues to be refined.

3.1. Data

Figure 1 shows the light curves of 0716+714 in three different energy bands. The top panel shows the data obtained with the RXTE-satellite, which pointed at 0716+714 for 34 individual observations during April 6$^{th}$ until April 22$^{nd}$. An average count rate over the 2 – 10 keV band of 0.95 cts/sec was measured. The pointings lasted 2.8 ksec on average.

ROSAT pointed at the source 28 times during the period from March 24$^{th}$ until April 22$^{nd}$. A nearly daily sampling was achieved. The average pointing lasted 2.8 ksec and the average count rate was 0.1 cts/sec. Several of these daily pointings had large gaps and stretched over as long as half a day.

The optical light curve is derived from measurements made with the 70 cm telescope at the Heidelberg site and kindly provided by H. Bock. The complete optical data set including observations performed at many other sites will be discussed elsewhere.

4. Results

0716+714 showed strong and rapid X-ray and optical variations during the campaign (Figure 1). Indications of variations on time scales of several hours were found in all bands. Due to under-sampling in the X-ray bands, especially in the ROSAT band, this kind of variability is most obvious in the optical. Surprisingly, the variations seen in the three bands are not correlated. The apparent discrepancy between the behaviour in adjacent RXTE and ROSAT bands is unexpected.

In order to investigate the discrepancy between RXTE and ROSAT, the total RXTE band was split into two distinct bands: a soft band
Figure 2. Light curve of 0716+714 in the soft RXTE band (2−4 keV, open triangles) compared to the ROSAT HRI (0.1−2.4 keV, filled circles) count rate variations. The RXTE data is shifted by 0.1 cts/s to the top.

Figure 3. Light curve of 0716+714 in the hard RXTE band (4−10 keV, open triangles) compared to the ROSAT HRI (0.1−2.4 keV, filled circles) count rate variations. The RXTE count rate is divided by 2 and shifted by 0.15 cts/s to the top.

(2 − 4 keV) and a hard band (4 − 10 keV). Figure 2 shows the soft RXTE data (open triangles) compared to the ROSAT HRI data (filled circles). The figure suggests a better overall agreement with the ROSAT data than for the broad-band RXTE data. Figure 3 shows that the hard RXTE data (open triangles) do not follow the variability characteristics of the ROSAT data, and here the gradually rising baseline is particularly suggestive of the trend seen in the optical data. Thus we conclude that the X-ray data suggest two components with different variability characteristics; one component is dominant in soft X-rays and the other at energies greater than about 4 keV.

5. Discussion

It is evident from Figure 2 that the trends in the ROSAT band and in the optical band are not correlated. Regarding the correspondence of the soft X-ray band and the optical band suggested by the previous ROSAT observation in 1991 the source seems to have changed its variability behaviour. Despite an apparent mismatch of the optical and the soft X-ray light curves the sampling of the optical data is at present insufficient for a more detailed investigation. Especially the most prominent features seen in the ROSAT band are not sampled in the optical data presented.

The distinct variability properties of the soft and the hard RXTE band might indicate two source regions. The spectral characteristics of the source as observed with RXTE also suggest the presence of more than one spectral component. The slope of a power law model fitted to the total RXTE band is \(\alpha_{\text{tot}} = -2.1 \pm 0.1\) whilst the spectral index of the hard band for a simple power law model is \(\alpha_{4-10\text{keV}} = -1.5 \pm 0.15\). The flattening of the spectrum in the hard RXTE band suggests the presence of at least two components in the total band. The contribution of the hard RXTE component to the ROSAT flux, however, seems to be negligible.

The detection of independent variability in the optical and the ROSAT regime favours multi-component models in order to explain the emission properties from the BL Lac 0716+714. Single component models (e.g. simple SSC) are not capable of explaining the observed variability behaviour. The probable division of the RXTE...
band into two independently varying bands supports this interpretation. From the data presented it is not clear how many components contribute to the overall source flux; similar variability trends (Figure 3) in the optical and in the harder X-ray may help to limit the number required.

6. Summary

The preliminary analysis of the optical, ROSAT, and RXTE data obtained within a multifrequency campaign in March/April 1997 suggests complicated variability properties of the BL Lac object 0716+714. The optical and the soft X-ray bands (ROSAT, soft RXTE) vary independently. In addition the hard RXTE band seems to vary independently from the soft X-ray band. Moreover, the hard RXTE band shows a flatter spectrum than the total RXTE band and reveals variability trends present in the optical data. These results provide evidence for a multi-component model of the source.

Acknowledgment: The work of K. O. and S. J. W. is supported by grants from DARA/DLR and DFG (SFB 328). The RXTE analysis was supported by NASA grant NAG5-3355, and M. J. H. acknowledges support from the PPARC. We thank the RXTE GOF members and Keith Jahoda for helpful advice. We also like to thank Holger Bock for kindly providing the optical data and Arno Witzel for useful discussions.

REFERENCES

1. Biermann P., Duerbeck H., Eckart A. et al., 1981, ApJL, 247, L53.
2. Blandford R. D., Rees M. J. in: Pittsburgh conference on BL Lac Objects, ed. A. N. Wolfe, Pittsburgh, University of Pittsburgh Press, p. 328, 1978.
3. Chiappetti L., 8th National Cosmic Physics (GIFCO) conference, 8 Apr 1997. http://www.ifctr.mi.cnr.it/~lucio/WWW/Personal/sax.html
4. Dent W. A., 1965, Science, 148, 1458.
5. Eckart A., Witzel A., Biermann P. et al., 1986, A&A 168, 17.
6. Eckart A., Witzel A., Biermann P. et al., 1987, A&AS, 67, 121.
7. Edelson R., Krolik J., Madejski G. et al., 1995, ApJ, 438, 120.
8. Kühr H., Pauliny-Toth I. I. K., Witzel A., Schmidt J., 1981, AJ 86, 854.
9. Rees M., 1966, MNRAS, 135, 345.
10. Sholomitskii G. B., 1965, Sov. Astron., 9, 516.
11. Wagner S. J., Witzel A., 1995, ARA&A, 33, 163.
12. Wagner S. J., Witzel A., Heidt J. et al., 1996, AJ, 111, 2187.
13. Woltjer L., 1966, ApJ, 146, 597.