RXTE Observations of PKS 2155-304 during the November 1997 Gamma-Ray Outburst

W. Thomas Vestrand and P. Sreekumar

\textsuperscript{a}Space Science Center, University of New Hampshire, Durham, NH 03824
\textsuperscript{b}Laboratory for High Energy Astrophysics, NASA/GSFC, Greenbelt, MD 20771

Abstract

We present x-ray observations of the nearby BL Lac PKS 2155-304 taken when it was undergoing a GeV/TeV gamma-ray outburst. During the outburst we measured x-ray fluxes in the 2-10 keV band that are the largest ever observed for PKS 2155-304. Comparison of these November 1997 measurements and other x-ray observations made contemporaneously with GeV or TeV gamma-ray observations indicate that x-ray and gamma-ray emissions are correlated. Measurements with x-ray all-sky monitors such as the ASM/RXTE and MOXE can therefore signal the presence of outbursts at gamma-ray energies from PKS 2155-304.

Key words: x-rays; gamma rays; BL Lacertae objects; PKS 2155-304

1 Introduction

PKS 2155-304 is the archetypical X-ray-selected BL Lac object (XBL). It is one of the brightest BL Lacs at x-ray through optical wavelengths where it has a relatively featureless continuum and displays rapid, large amplitude variability. This continuum is thought to be direct synchrotron emission from a distribution of ultra-relativistic electrons which extends to unusually high energies (1).

The gamma-ray emission from PKS 2155-304 constitutes a second, separate, spectral component. Observations with the EGRET telescope aboard the Compton Gamma Ray Observatory (CGRO) show that the spectral energy distribution of this gamma-ray component must peak at energies above 10 GeV (2). This, plus the realization that the extension of the synchrotron component into the x-ray band meant that ambient photons would be scattered to TeV energies, led to predictions (2,3) that PKS 2155-304 would be a detectable TeV gamma ray source.
The University of Durham group has recently reported the discovery of TeV gamma ray emission from PKS 2155-304 (1, 2). The TeV emission was detected in 1996 September and 1997 October/November, with the largest fluxes being measured in 1997 November. During 1997 November, we detected a record high GeV gamma-ray flux from PKS 2155-304 with CGRO/EGRET (3) and subsequently very high x-ray fluxes were measured with BeppoSAX (4). Here we report, for the first time, on the record x-ray fluxes measured with the Rossi X-Ray Timing Explorer (RXTE) during the GeV/TeV outburst.

2 X-Ray Observations

In November 1997, after our detection of an extremely high GeV gamma-ray flux from PKS 2155-304, we began a short series of target of opportunity observations with RXTE to determine the x-ray properties of the source during the gamma-ray flare. Specifically, we made Proportional Counter Array (PCA) and High Energy X-ray Timing Experiment (HEXTE) observations of nominal 2.5 ksec duration on 20, 21, and 22 November 1997. Our analysis of those data indicate that the x-ray flux on 20 and 21 November 1997 was $F(2-10 \text{ keV}) = 2.3 \times 10^{-10} \text{ erg cm}^{-2} \text{s}^{-1}$. By 17:00 UT on 22 November, when BeppoSAX measured its highest flux value (5), the flux had slightly dropped to $1.6 \times 10^{-10} \text{ erg cm}^{-2} \text{s}^{-1}$. The 20-21 November x-ray fluxes measured by RXTE are the highest ever observed in the 2-10 keV band for PKS 2155-304.

The x-ray spectral shapes we measured during the 1997 November flare show downward curvature consistent with the idea that the synchrotron component is rolling off at keV energies. If we fix the column depth at the galactic value $n_H = 1.36 \times 10^{20} \text{ cm}^{-2}$ (5), then the 2.5-30.0 keV spectrum measured by the PCA on 20 November 1997 at 22:44-23:39 UT cannot be fit with a single power law. However, a good fit is obtained if we use a broken power law with a low energy photon index $\alpha_L = 2.51(\pm 0.08)$, a high-energy photon index $\alpha_H = 3.04(\pm 0.03)$, and a break energy $E_b = 4.01(\pm 0.22)$ keV. The 21 November measurements taken at 15:16-15:41 UT show a similar spectrum with $\alpha_L = 2.72(\pm 0.08)$, $\alpha_H = 3.06(\pm 0.04)$, and $E_b = 4.33(\pm 0.40)$ keV. While yielding a slightly lower flux, the 22 November measurements taken at 17:00-17:33 UT are also well fit by a broken power law but with parameters: $\alpha_H = 2.98(\pm 0.03)$, $\alpha_L = 2.20(+0.30/-1.41)$ and a break energy $E_b = 3.50(\pm 0.45)$ keV.

To act as control observations, we examined PCA measurements of PKS 2155-304 made when either the TeV or GeV gamma-ray fluxes were known to be low. During 30 December 1997-13 January 1998 we made follow-up EGRET observations of the GeV emission from PKS 2155-304 and marginally detected GeV flux at a level approximately a factor of four smaller than the November
1997 peak flux. Our simultaneous PCA observations on 9-11 January 1998 measured 2-10 keV fluxes that had decreased by a factor of seven from those observed on 20-21 November 1997. Unlike the November 1997 spectra, the 2.5-15.0 keV spectrum measured on 9 January 1998 at 2:59-3:40 UT can be acceptably fit ($\chi^2_\nu = 0.95$ for 32 d.o.f.) using the galactic column depth and a single power law having photon index $\alpha = 2.83(\pm0.04)$. Chadwick et al. [4, 5] report detection of significant TeV flux from PKS 2155-304 in September 1996, however the TeV flux apparently decreased and they were unable to detect it in October or November 1996. While we do not have simultaneous TeV and x-ray observations, the contemporaneous PCA observations made on 14 November 1996 show an x-ray flux which is a factor of five smaller than those observed during the November 1997 TeV gamma-ray flare. Our observations are therefore consistent with the pattern of correlated x-ray and gamma-ray flux outbursts observed in the two well-studied TeV emitting XBLs, Mrk 421 and Mrk 501 [11].

Measurements taken with the All-Sky Monitor (ASM) aboard the RXTE satellite also suggest a correlation between elevated x-ray and gamma-ray emission. While substantially less sensitive than the PCA, the broad field of view of the ASM provides much better temporal coverage and is sensitive enough to detect major flaring activity from PKS 2155-304. Comparison of monthly ASM counting rates derived by averaging over days when TeV observations were made with 5 months of TeV gamma-ray monthly counting rates indicates a
positive correlation \cite{4}. Our GeV gamma-ray measurements with EGRET suggest that the correlation between gamma-ray and x-ray flux exists on even shorter timescales (see Figure 2). Subdivision of the November 1997 EGRET observations indicates that the bulk of the >100 MeV emission was detected during 11-14 November. While the statistics are poor, measurements by the ASM hint at a strong x-ray flare on 12-13 November simultaneous with the GeV flare and perhaps a second smaller flare on 19-20 November. Since the TeV gamma-ray and pointed x-ray observations did not begin until the 19th and 20th respectively, we suspect that they missed an even larger outburst on 12-13 November.

3 Concluding Remarks

The available PKS 2155-304 data show a correlation between the 2-10 keV x-ray outbursts and GeV/TeV gamma-ray outbursts. The ASM on RXTE has demonstrated the importance of all-sky x-ray monitoring as a trigger for gamma-ray studies of XBLs and other blazars. The utility of this technique is currently limited by the sensitivity and duty cycle of the ASM. We expect
that the launching of MOXE — an all-sky x-ray monitor which is a factor of four more sensitive than the ASM and has a duty cycle of nearly unity (9) — and GLAST, the next generation GeV gamma-ray telescope, in conjunction with the construction of the ground-based VERITAS array will initiate an exciting new era of blazar study.

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