Finding AGN in Deep X-ray Flux States with Swift

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We report on our ongoing project of finding Active Galactic Nuclei (AGN) that go into deep X-ray flux states detected by *Swift*. *Swift* is performing an extensive study on the flux and spectral variability of AGN using Guest Investigator and team fill-in programs followed by triggering *XMM-Newton* for deeper follow-up observations. So far this program has been very successful and has led to a number of *XMM-Newton* follow up observations, including Mkn 335, PG 0844+349, and RX J2340−5329. Recent analysis of new *Swift* AGN observations reveal several AGN went into a very low X-ray flux state, particularly Narrow-Line Seyfert 1 galaxies. One of these is RX J2317-4422, which dropped by a factor of about 60 when compared to the ROSAT All-Sky Survey.

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1. Introduction

The *Swift* mission [1] has revolutionized the ability to monitor and study Active Galactic Nuclei (AGN). With its flexible scheduling and multi-wavelength capacity, *Swift* has enabled observers to quickly react to changes discovered in the fluxes of AGN. AGN often exhibit rapid and dramatic flux and spectral changes in X-rays. These changes can be associated with absorption, reflection, or dramatic changes in the accretion rate. Some of the most dramatic X-ray flux and spectral changes have been observed in Narrow Line Seyfert 1 galaxies (NLS1s). This class of AGN is characterized by relatively small black hole masses and high accretion rates relative to the Eddington accretion rate. The most extreme of these AGN is the NLS1 WPVS 007 which was bright in the X-ray sky during the ROSAT All-Sky Survey (RASS) in 1990. However, when observed a few years later with ROSAT its X-ray flux had dropped by a factor of 400 [2]. During the RASS it WPVS 007 displayed the softest X-ray spectrum of all bright X-ray detected AGN. FUSE observation in 2003 revealed strong absorption troughs in the UV spectrum of WPVS 007, which are unseen in low-luminosity AGN. These deep absorption troughs are seen in Broad Absorption line Quasars (BAL QSOs) and are the results of strong outflows. WPVS 007 represents a link between BAL QSOs and NLS1s.

This research compares AGN X-ray fluxes found in the ROSAT All-Sky Survey with measurements from recent *Swift* observations. A decrease in the X-ray flux of an AGN can result from absorption by gas, reflection on the accretion disk, or a change in the accretion rate. Out of 80 AGN analyzed, six were found in a low X-ray flux state. A 1 ks *Swift* observation of each AGN confirmed our findings. One object, RX J2317−4422, was found to have decreased in X-ray flux by a factor of about 60 [3]. A follow up observation of RX J2317.8−4422 with *XMM-Newton* reveals an usually soft X-ray spectrum.

2. Sample Selection and Swift

The Active Galactic Nuclei are selected from the ROSAT All-Sky Survey (RASS) Bright Source Catalogue by [4]. The total sample size is 400 AGN, many of which have already been observed by *Swift* multiple times [5]. Between 2014 April and September *Swift* observed 80 of these AGN.

The Space Science Center at Morehead State University in Eastern Kentucky has an apprenticeship program that allows local senior high school students to participate in active research projects. In Fall 2014 four high school students from the Rowan County Senior High School participated in this program. Each student was given 20 AGN to check for significant X-ray flux variability.

3. Description of the Data Analysis

To compare the *Swift* XRT count rates with those obtained during the RASS, dividing the RASS count rate by 4 is an appropriate estimate of the expected count rate. Students compared the expected *Swift* XRT count rate with the measured *Swift* XRT count rate. The XRT count rates were obtained by using the *Swift* XRT analysis web-interface at the University of Leicester *Swift* website

Name	Expected *Swift* Count Rate	Actual *Swift* Count Rate	Factor Change
RX J2317.8–4422	0.1775	0.010	17.8
RX J2216.8–4451	0.3250	0.0325	10
PKS 2310–322	0.085	0.010	8.5
RX J1007.1+2203	0.155	0.025	6.2
RX J1117.1+6522	0.1375	0.025	5.5
MS 0117–28	0.135	0.025	5.4

Table 1: List of AGN which have been found to show a decrease in their X-ray flux obtained by *Swift* compared with the ROSAT All-Sky Survey (RASS). The first column lists the source names, the second the expected *Swift* XRT count rate estimated from the RASS count rate, the actually measured XRT count rate, and the last column lists the factors between the estimated and measured count rates.

[6, 7] (http://www.swift.ac.uk/user_objects/;). Students were task to find AGN which exhibited a change in their count rate by factors of 5 or greater. Out of the sample of 80 AGN, 6 displayed a count rate that was at least a factor of 5 below the expected value. The 6 AGN that exhibited shuch a large change in their count rate are listed in Table 1. To confirm the X-ray low states, short 1 ks Swift ToO observations were requested. Chelsea Pruett became the first high school student ever requesting and obtaining a ToO observation with *Swift*. All ToO observations confirmed the X-ray low state. One AGN turned out to be very interesting: RX J2317.8−4422, which displayed a decrease in its X-ray flux by a factor of 20.
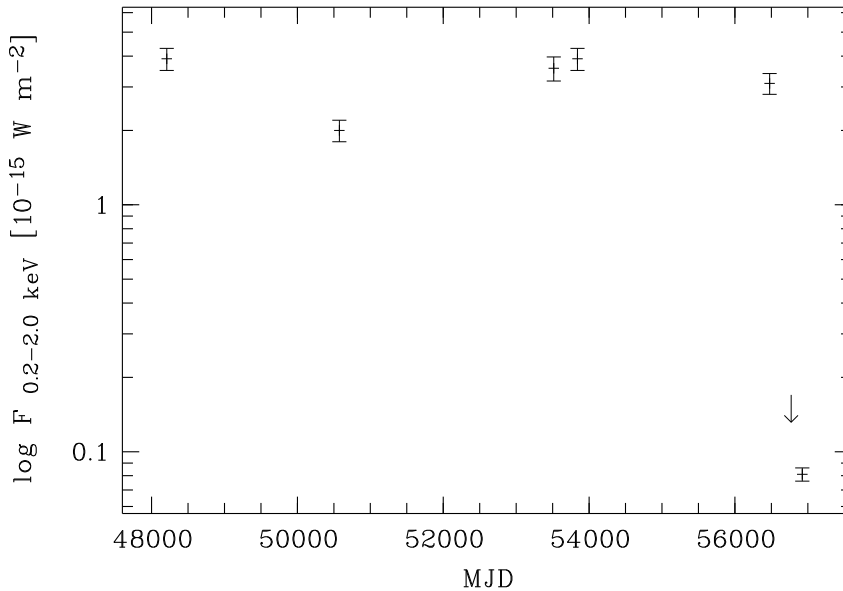

Figure 1: Long-term 0.2 - 2.0 keV light curve of RX J2317.8−4422. The first data point is the X-ray flux during the RASS and the second data point was derived from a ROSAT HRI observation (see [8]). All other data points were derived from *Swift* observations starting in 2007 [5].

4. The NLS1 RX J2317.8-4422

RX J2317.8−4422 (RA-2000: 23 17 49.9; Dec-2000: -44 22 28; z=0.132) is a Narrow-Line Seyfert 1 galaxy that has exhibited X-ray variability in the past with factors up to 7 [8, 5]. *Swift* observed this NLS1 in April 2014 and obtained a 3σ upper limit of 1.76×10^{-16} W m^{-2}, which means a drop by a factor of more than 20 compared with the previous observation in August 2013. Figure 1 displays the long-term 0.2-2.0 keV light curve of RX J2317.8−4422. We triggered a *Swift* ToO observation in September 2014 to confirm this X-ray flux low state and detected the AGN at a level of 8×10^{-17} W m^{-2}.
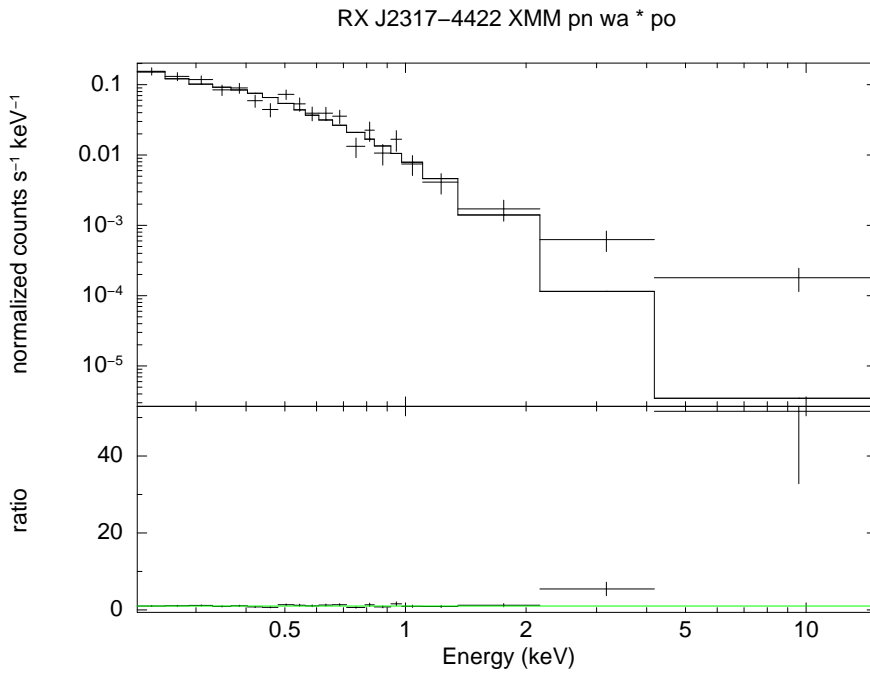

Figure 2: 0.2-12 keV X-ray spectrum of RX J2317.8−4422 obtained by the EPIC pn onboard *XMM-Newton* on 2014-October-29 fitted with a single power law model with α_x=2.81.

The extreme X-ray flux change of RX J2317.8−4422 made it a valid target for an *XMM-Newton* follow up program of AGN in deep minimum X-ray flux states. We obtained an observation with *XMM-Newton* for 13 ks on 2014-October 29. The X-ray spectrum obtained with the EPIC pn shown in Figure 2 shows a very soft spectrum that can be modeled by a single power law model with an X-ray spectral slope of α_x=2.81±0.21 with an absoption column density fixed to the Galactic value $N_\mathrm{H} = 1.07 \times 10^{20}$ cm^{-2} (1.07×10^{26} m^{-2}). There is a hard X-ray component in the spectrum. To better understand the cause of this X-ray spectrum a second *XMM-Newton* observation was performed. A 100ks observation was performed by *XMM-Newton* on 2014-November-17 simultaneously with *Swift* and NuStar. The second *XMM-Newton* observation showed that the X-ray flux of RX J2317.8−4422 had decayed even more and was found at a level of $(6.0\pm0.6) \times 10^{-17}$ W m^{-2}. Figure 3 compares the spectral energy distributions of RX J2317.8-4422 during the RASS (large squares) and the *XMM-Newton* observation on October 29.
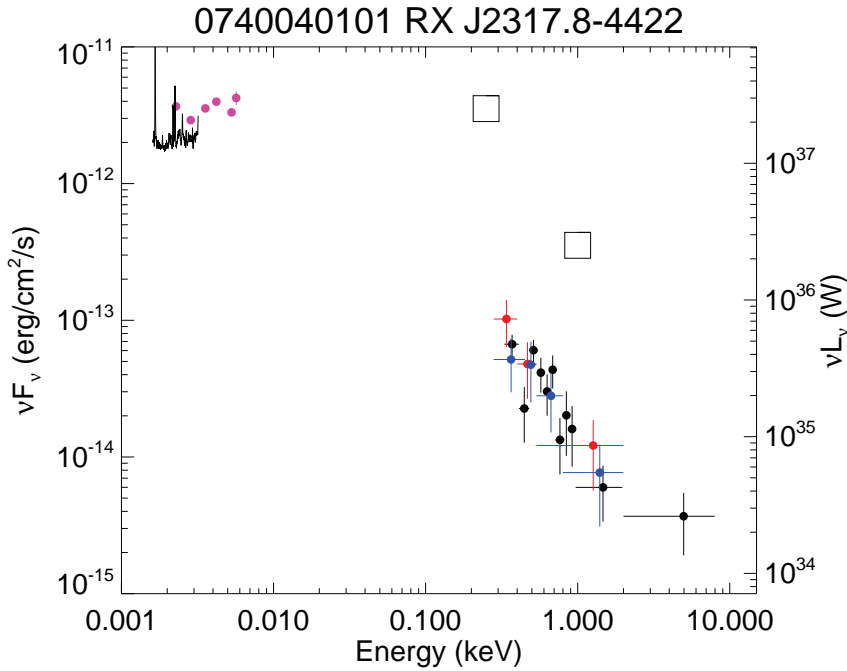
Figure 3: Spectral Energy Distribution of RX J2317−4422. The large squares display the X-ray data during the RASS. The optical/UV data points were derived from the *XMM-Newton* OM, and the X-ray data were obtained from the EPIC pn and MOS detectors. The optical spectrum was taken in 1995 with the ESO 1.52m telescope in La Silla/Chile [9, 10].

5. Conclusions

Results of finding AGN in deep minimum states have again shown that *Swift* has become a game changer in finding these unusual AGN. *Swift* is not only able to survey large samples of AGN very efficiently, it also allows fast follow up observations to verify the state of an AGN. Our *Swift* fill-in program of observing AGN is ongoing and is expected to find more AGN with high X-ray variability in the future. The goal of the fillin program is to understand the changes in the spectral energy distributions of AGN. We can conclude that these AGN in deep minimum states under extreme conditions. Our current understanding of the dramatic changes in the X-ray flux and spectra is that this can be caused by absorption or X-ray reflection [11, 12]. A preliminary analysis of the *XMM-Newton* observation of RX J2317.8−4422 from November 2014 displays very soft X-ray spectrum, similar to that of WPVS 007 during the RASS. Is RX J2317.8−4422 maybe the next link between NLS1s and BAL QSOs? We are currently working on the publication of the *Swift*, NuStar, and *XMM-Newton* observations of RX J2317.8−4422.

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