# The Hard X-Ray Emission From Scorpius X-1 As Seen By INTEGRAL

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## Abstract

We present the results of our hard X-ray and gamma-ray study of the LMXB Sco X-1 utilizing INTEGRAL data as well as contemporaneous RXTE PCA data. We have investigated the hard X-ray spectral properties of Sco X-1 including the nature of the high-energy, nonthermal component and its possible correlations with the location of the source on the soft X-ray color-color diagram. We find that Sco X-1 follows two distinct spectral tracks when the 20-60 keV count rate is >130 counts/second. One state is a hard state which exhibits a significant high-energy, powerlaw tail to the lower energy thermal spectrum. The other state shows a much less significant high-energy component. We found suggestive evidence for a correlation of these hard and soft high-energy states with the position of Sco X-1 on the low-energy X-ray color-color diagram. We have searched for similar behavior in 2 other Z sources: GX 17+2 and GX 5-1 with negative results.


## Introduction

Scorpius X-1 is the prototype low-mass X-ray binary (LMXB), consisting of a low magnetic field neutron star and an evolved ~0.42 solar mass sub-giant companion (Steeghs & Casares 2002). It is a high-luminosity Z source, so named because of the pattern traced out on its X-ray color-color diagram (see e.g. van der Klis 2004).

There have been multiple reports of both detections and non-detections of a hard nonthermal component to the X-ray spectrum of Sco X-1. Recently, it has been shown that this hard component is variable but efforts to associate it with particular states corresponding to certain positions on the X-ray color-color diagram have been mixed. Strickman & Barret (2000) found evidence using CGRO/OSSE and RXTE/PCA that the hard component was most prevalent when Sco X-1 was positioned near the junction of the normal (NB) and flaring branches (FB) on the color-color diagram. D'Amico et al. (2001) found using both HEXTE and PCA on RXTE that there was no correlation between the presence of the hard tail and the position on the color-color diagram but that hardest power-law indices where found when the source was on the FB. In contrast, Di Salvo et al. (2006) found using INTEGRAL/ISGRI and RXTE/PCA that the flux in the power-law component decreased as the source moved in the color-color diagram in the sense of increasing mass acretion rate, i.e. Horizontal Branch (HB) --> NB --> FB.

**Here we present the results of our investigation into the nature of the hard X-ray emission from Sco X-1 using an INTEGRAL dataset that is much larger than the one used by Di Salvo et al. (2006). We have also investigated whether the Z sources GX 17+2 and GX 5-1 exhibit similar behaviour similar to that found in Sco X-1.**

## Observations & Data Analysis

INTEGRAL data reduction was performed using the standard OSA 7 analysis software package. Spectral analysis was performed using the XSPEC data analysis package. Timing analysis was performed using the XRONOS data analysis package.

We have analyzed 1.77 Msec INTEGRAL/IBIS/ISGRI data for our work on Sco X-1. We chose only those Science Windows (SCWs) with pointing directions within $10^{o}$ of Sco X-1. The data consisted of 960 SCWs ranging from March 28, 2003 to August 25, 2006. The data used for GX 17+2 and GX 5-1 analyses consisted of 1732 SCWs resulting in an exposure of 2.62 Msec.

We searched the RXTE/PCA public data archive at the HEASARC for observations that were concurrent with the INTEGRAL observations. We analyzed the PCA data from these observations using FTOOLS suite of software available from the HEASARC.

## Sco X-1: Correlation of Spectral State with Color-Intensity

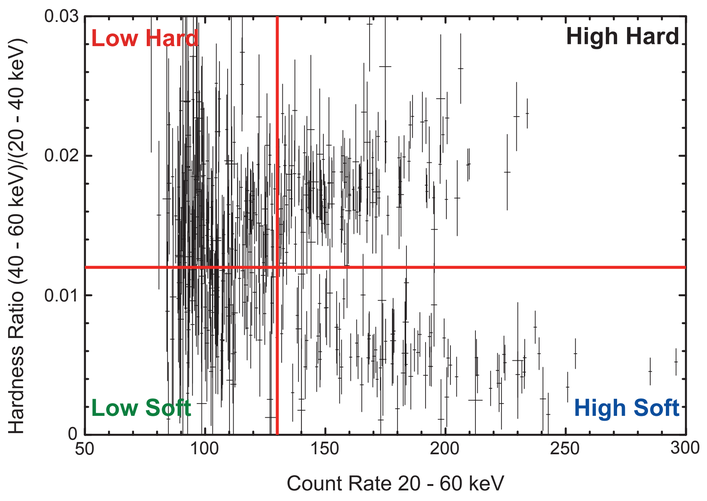


**Figure 1:** Color-Intensity diagram for Sco X-1 from IBIS/ISGRI data. Each data point represents 2 hours of data. The diagram shows distinct hard and soft spectral states.

- We produced ISGRI lightcurves for the 20-40 keV and 40-60 keV energy using OSA 7 for Sco X-1.
- The data were binned into 7200 second time bins. These data were used to construct the Color-Intensity diagram shown in Figure 1.
- **The diagram shows distinct hard and soft spectral states when the 20-60 keV count rate is >130 cts/s.**

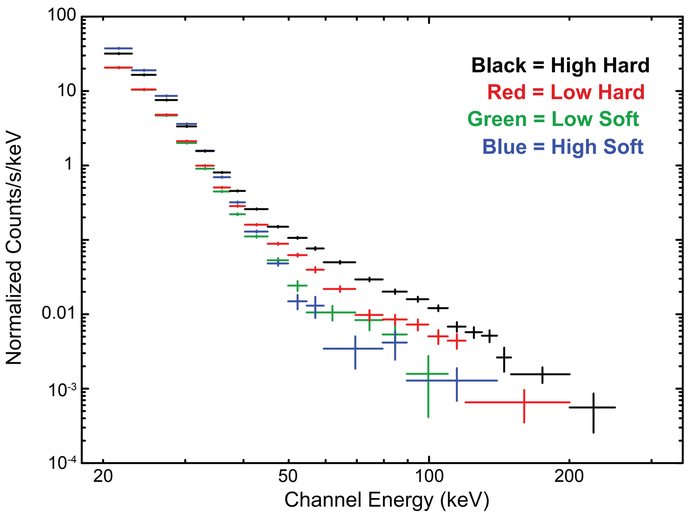


**Figure 2:** Count spectra for the 4 states illustrated in **Figure 1**.

- We identified the time periods for which Sco X-1 was in each of the 4 states labeled in **Figure 1**, and constructed average spectra for each of those time periods. Those spectra are shown in **Figure 2**.
- **The spectrum for the high-soft state (blue) is well fit by by the thermal Compton-ization model COMPTT with only a small contribution from an additional hard component.**
- **On the otherhand, the spectra associated with the high-hard (black) and low-hard (red) states show significant nonthermal high-energy emission requiring an additional powerlaw component with $\Gamma$~2.5 for the high-hard state and $\Gamma$~2.9 for the low-hard state.**

## Sco X-1: Correlation of Spectral State with Color-Color Position

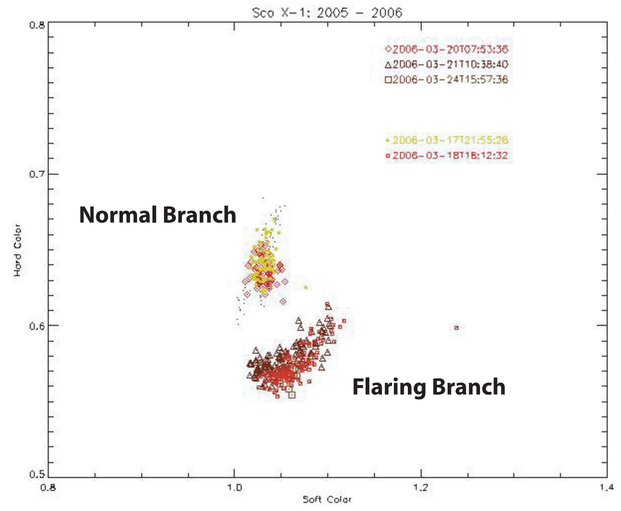


**Figure 3:** A Sco X-1 X-ray color-color diagram derrived from RXTE/PCA data. The data were chosen to due to there temporal overlaps with the INTEGRAL observations.

- We selected public RXTE/PCA from 5 separate observations from March 17-24, 2006 which were concurrent with our INTGREAL/IBIS data.
- The data were in Standard-2 format and we used only data from PCU 2 to avoid cross-calibration issues.
- We extracted background-subtracted RXTE/PCA light curves using channels corresponding to 4 energy bands, 2.0-3.5 keV, 3.5-6.0 keV, 6.0-9.7 keV, and 9.7-16.0 keV using FTOOLS.
- These lightcurves were used to construct the Color-Color diagram shown in **Figure 3**.
- The data fall onto both the Normal Branch and the Flaring Branch of the Color-Color diagram.

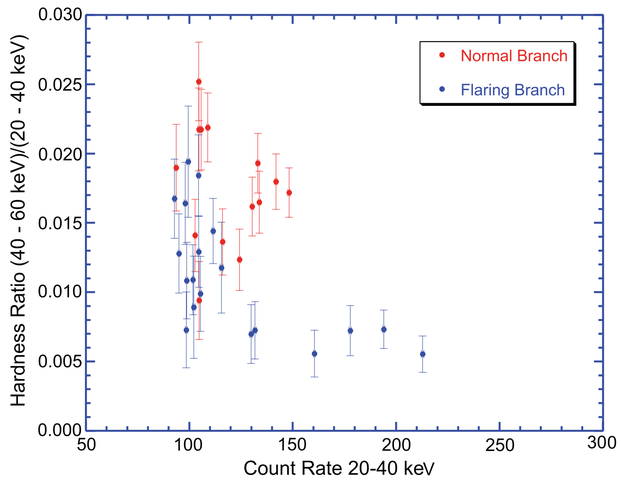


**Figure 4:** Color-Intensity diagram for Sco X-1 using the subset of the data in **Figure 1** which fell within +/- 6 hours of a RXTE/PCA observation shown in **Figure 3**.

- We selected time bins from our ISGRI lightcurves that were within +/- 6 hours of the start time for each of the RXTE/PCA observations.
- We then created a Color-Intensity diagram using only this time coincident data. The result is shown in **Figure 4**.
- **This Color-Intensity diagram shows that when Sco X-1 was on the Normal Branch of the Color-Color diagram, the hard X-ray emission was preferentially in the hard state.**
- **When on the Flaring Branch, Sco X-1 was preferentially in the soft state.**

## Conclusions

- **The Color-Intensity diagram shown in Figure 1 shows distinct hard and soft spectral states when the 20-60 keV count rate exceeds ~130 cts/s.**
- **The average spectrum when in the hard spectral state show significant nonthermal high-energy emission.**
- **The average spectrum when in the high-soft spectral state can be adequately fit by a COMPTT model spectrum with only a small contribution from an additional nonthermal component.**
- **The hard state preferentially occurs when Sco X-1 is located on the Normal Branch of the Color-Color diagram while the soft state occurs preferenctially while on the Flaring Branch.**
- **Possible explanations for this behavior include jet formation or changes to the accretion geometry.**
- **The Z sources GX 17+2 and GX 5-1 do not exhibit the distinct hard and soft states seen in Figure 1 for Sco X-1.**

## GX 17+2 & GX 5-1: Color-Intensity Diagrams

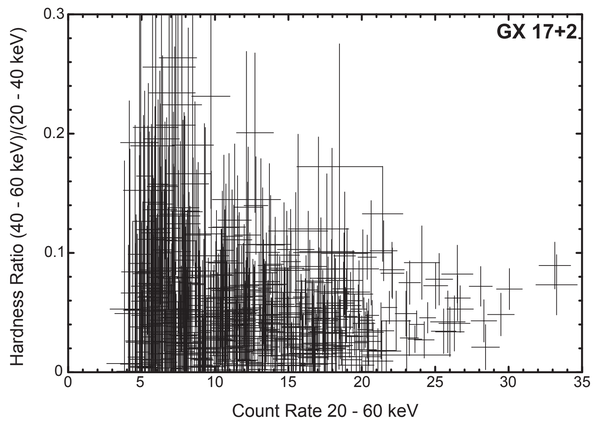


**Figure 5:** Color-Intensity diagram for GX 17+2 from IBIS/ISGRI data. Each data point represents 2 hours of data.

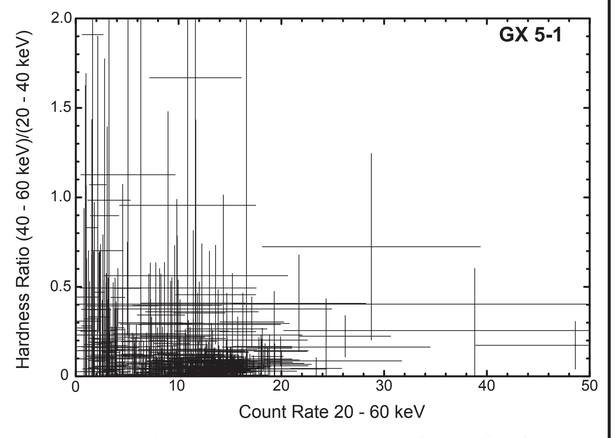


**Figure 6:** Color-Intensity diagram for GX 5-1 from IBIS/ISGRI data. Each data point represents 2 hours of data.

- We analyzed IBIS/ISGRI data for the Z sources GX 17+2 and GX 5-1 to search for behavior similar to that seen in Figure 1.
- **The Color-Intensity diagrams for the Z sources GX 17+2 and GX 5-1 show no distinct hard and soft states as seen in the Color-Intensity diagram for Sco X-1 (Figure 1).**
- **We will continue to search for such states using other energy and time binning.**

## References


van der Klis, M. 2004, astro-ph/0410551
D'Amico, F., Heindl, W.A., Rothschild, R. E., Gruber, D.E. 2001, ApJ, 547, L147
Di Salvo, T. et al. 2006, ApJ, 649, L91
Steeghs, D., & Casares, J. 2002, ApJ, 568, 273
Strickman, M., & Barret, D. 2000, in The Fifth Compton Symposium, ed. M. L. McConnell, & J. M. Ryan (Melville: AIP), 222