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

S. J. Sturner[1], C. R. Shrader[2], & G. Weidenspointner[3]

[1]CRESST/UMBC/GSFC, [2]CRESST/USRA/GSFC, [3]MPE, Germany

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 20-40 keV count rate is >140 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 no evidence for a powerlaw tail. 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.

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). Sco X-1 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).

Over the years, 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 results of our investigation into the nature of the hard X-ray emission from Sco X-1 using a INTEGRAL dataset that is much larger than the one used by Di Salvo et al. (2006).

Correlation of Spectral State with Color-Intensity

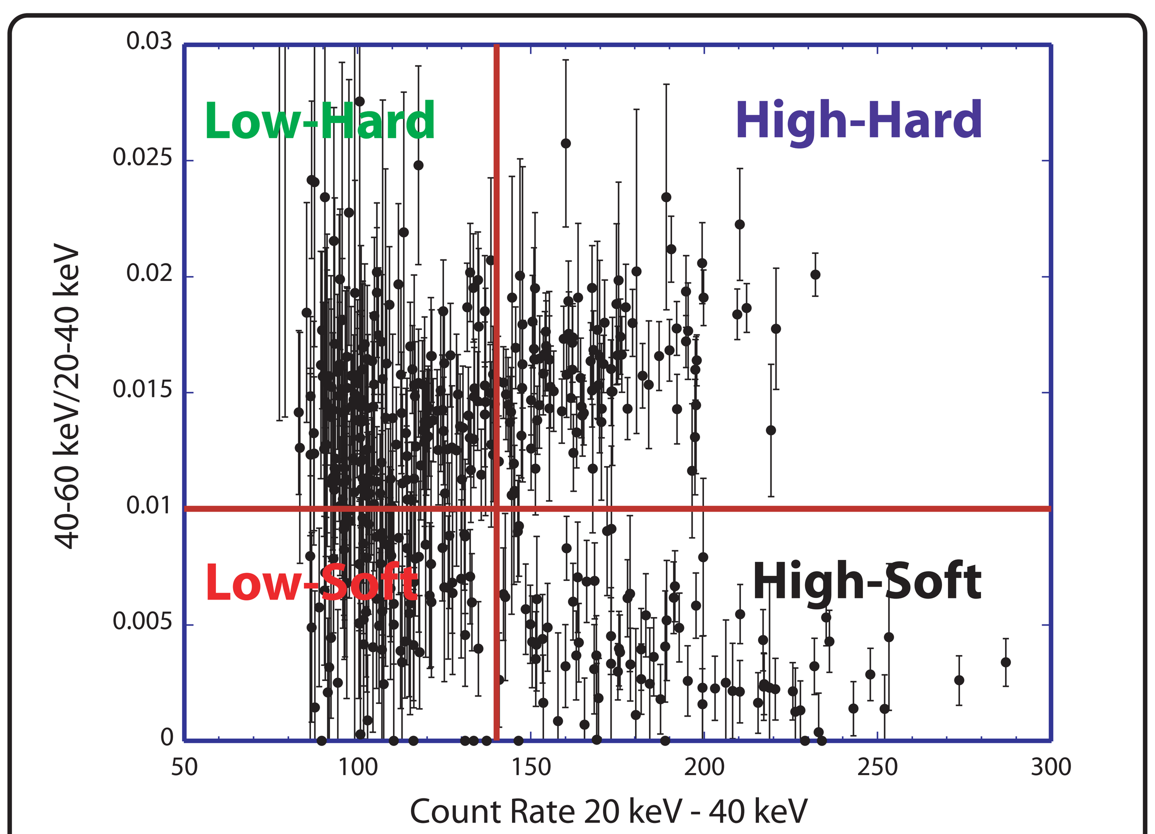

Figure 1: Color-Intensity diagram for Sco X-1 from IBIS/ISGRI data. Each data point represents 2 hours of data. The diagram shows distinct hard and soft spectral states.

- We produced ISGRI lightcurves for the 20-40 keV and 40-60 keV energy bands with 1800 second binning.
- We rebinned the data into 7200 second time bins (in order to reduce the statistical noise) and constructed the Color-Intensity diagram shown in **Figure 1**.
- **The diagram shows distinct hard and soft spectral states when the 20-40 keV count rate is >140 cts/s.**

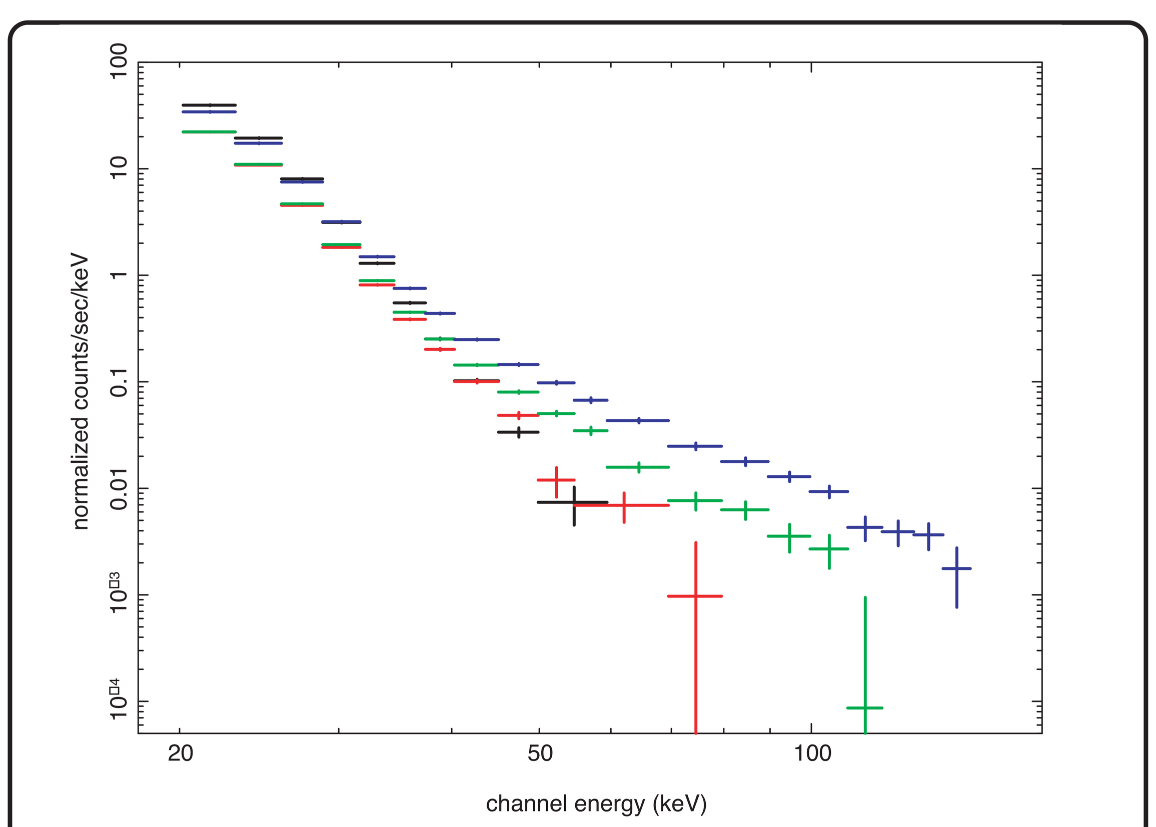

Figure 2: Count spectra for the 4 states illustrated in **Figure 1**. **High-Hard = Blue**, **High-Soft = Black**, **Low-Hard = Green**, and **Low-Soft = Red**.

- We identified the time periods for which Sco X-1 was in each of the 4 states labeled in Figure 1.
- We then constructed average spectra for each of those time periods. Those spectra are shown in **Figure 2**.
- **The spectrum for the high-soft state (black) is well fit by by the thermal Compton-ization model COMPTT. No power-law component is required.**
- **On the otherhand, the spectra associated with the high-hard (blue) and low-hard (green) states show significant nonthermal high-energy emission requiring an additional powerlaw component with Γ~2.9 for the high-hard state and Γ~3.9 for the low-hard state.**

Observations & Data Analysis

INTEGRAL was launched into a 3-day elliptical orbit on October 17, 2002. Here we present results from the IBIS imager. IBIS is a coded mask instrument with a 9° x 9° fully coded field of view and a 12' (FWHM) point spread function. It is sensitive over the energy range 15 keV to 10 MeV. There are two detector layers: ISGRI, an upper CdTe layer with peak sensitivity between 15 and 200 keV, and PICsIT, a bottom CsI layer, with a peak sensitivity above 200 keV. Here we have used only ISGRI data.

We have analyzed 1.77 Msec INTEGRAL/IBIS/ISGRI data for this work. We chose only those Science Windows (SCWs) with pointing directions within 10° of Sco X-1. The data consisted of 960 SCWs ranging from March 28, 2003 to August 25, 2006. INTEGRAL data reduction was performed using the standard OSA 6 analysis software package available from the INTEGRAL Science Data Centre. Spectral analysis was performed using the XSPEC data analysis package. Timing analysis was performed using the XRONOS data analysis package.

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.

Correlation of Spectral State with Color-Color Position

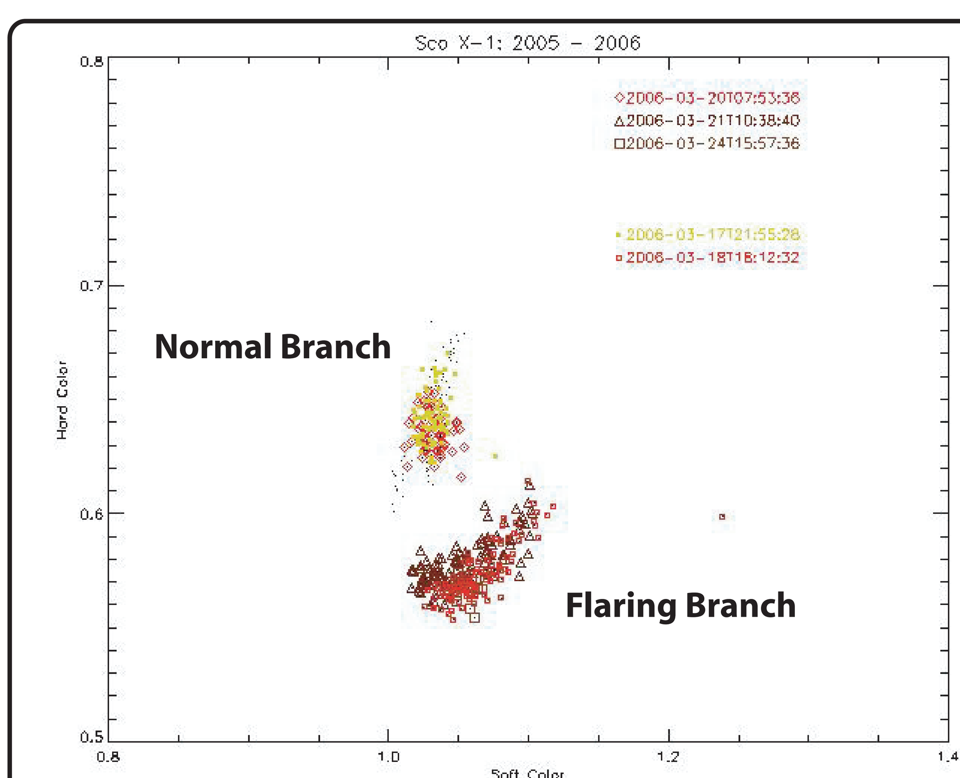

Figure 3: A Sco X-1 X-ray color-color diagram derrived from RXTE/PCA data. The data were chosen to due to there temporal overlaps with the INTEGRAL observations.

- 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.

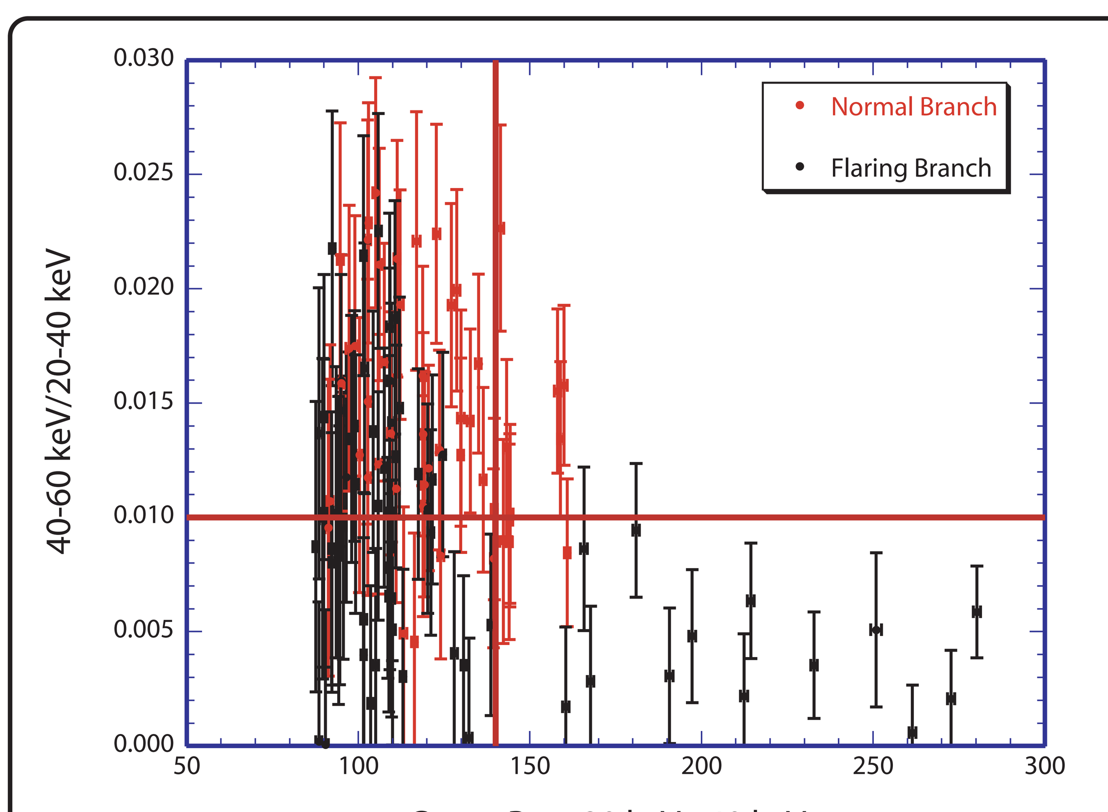

Figure 4: Color-Intensity diagram (1800 second time bins) for Sco X-1 using the subset of the data in **Figure 1** which fell within +/- 6 hours of a RXTE/PCA observation used to produce color-color diagram in **Figure 3**.

- 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 20-40 keV count rate exceeds ~140 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 no additional nonthermal.**
- **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.**

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