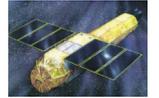


Testing the Spectral cross-calibration of the Swift BAT/XRT and the Suzaku HXD/XIS by the simultaneous observation of Cyg X-1



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Abstract

We report the spectral cross-calibration effort of the Swift BAT/XRT and the Suzaku HXD/XIS using simultaneous observations of Cyg X-1, which were taken on May 6, 2009 and provided ~1 ksec of completely overlapping data. Given the complementary energy band coverage of the Swift BAT (15-150 keV) and XRT (0.3-10 keV) with the Suzaku HXD (10-600 keV) and XIS (0.2-12 keV), along with the bright broad-band spectral properties of Cyg X-1, which spans the soft to hard X-ray range, the observation will help us understand and improve the cross-calibration between the instruments. We present the joint spectral fit results for all four instruments and discuss the remaining cross-calibration uncertainties.

1. Observation and Data reduction

Swift/Suzaku Cyg X-1 observation: 2009-05-06 19:15-19:31 UTC
(total overlapping exposure: 925 seconds)

Instruments

- Swift X-Ray Telescope (XRT):** X-ray CCD with a focusing optics
- Swift Burst Alert Telescope (BAT):** 32,768 CdZnTe detectors with a coded aperture mask
- Suzaku X-ray Imaging Spectrometer (XIS):** X-ray CCD with a focusing optics
 - XIS0 and XIS3: front-side illuminated CCD
 - XIS1: back-side illuminated CCD
- Suzaku Hard X-ray Detector (HXD):** HXD-PIN: Silicon PIN diodes
HXD-GSO: GSO well-type counter (BGO active shield)

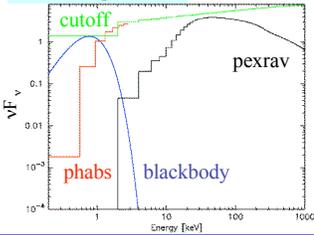
Data reduction/analysis

- WT mode grade 0-2 (Swift/XRT), Timing mode (Suzaku/XIS)
- XRT/XIS: excluding the piled-up region
- latest (preliminary) RMF/ARF for all instruments
- latest gain correction (Swift/BAT)

Spectral fitting range

- Swift/XRT: 0.7-10 keV
- Swift/BAT: 14-150 keV
- Suzaku/XIS: 0.7-10 keV
- Suzaku/HXD-PIN: 12-70 keV
- Suzaku/HXD-GSO: 70-330 keV

2. Fitting model



- Empirical (simple) model rather than a physical model
- Added a reflected power-law model (pexrav) for the hard X-ray data (e.g. Makishima et al.)
- The model is multiplied by an instrument specific constant factor, C

Model

- phabs(blackbody+cutoff+pexrav) [XRT-BAT; XIS-HXD; XRT-XIS-BAT-HXD]
- cutoff+pexrav [HXD;BAT-HXD]
- phabs(blackbody+power-law) [XRT; XIS; XRT-XIS]
- power-law [BAT]

* blackbody: BB, cutoff power-law: CPL, pexrav: RPL, power-law: PL

3. Joint XRT-XIS and BAT-HXD fit

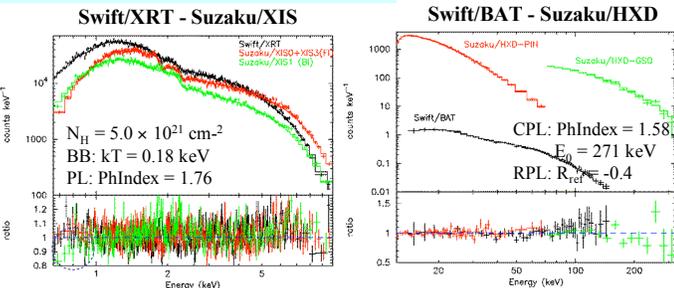


Fig. 3 [left] The joint XRT-XIS fit by phabs*(BB+PL) model. Although there is a small residual at low-energy bins from the best fit model in the Suzaku/XIS1 data, overall agreement between XRT and XIS is good. [right] The joint BAT-HXD fit by CPL+RPL model. The HXD constant factor of 1.22 (BAT constant factor is fixed to 1) is consistent with the constant factor difference between XIS and HXD (Suzaku Memo 2008-06). Good agreement between BAT and HXD.

Table: Best fit spectral fit parameters (90% error in parentheses)

| Instruments | N_H [10^{21} cm^{-2}] | BB: kT [keV] | BB: Norm 10^{-2} | PL/CPL: PhIndex | CPL: E_0 [keV] | PL/CPL Norm | R_{ref} | C(XRT) | C(XIS-FI) | C(XIS-BI) | C(BAT) | C(HXD) | χ^2/dof |
|-------------|--|-----------------|-----------------------|-----------------|---------------------|-------------|--------------|---------|-------------|-------------|-------------|-------------|---------------------|
| XRT | 5.5 (0.4) | 0.16 (0.01) | 8.4 (2.7) | 1.76 (0.03) | --- | 2.3 (0.1) | --- | --- | --- | --- | --- | --- | 761/659 (1.16) |
| XIS | 4.7 (0.3) | 0.21 (0.02) | 3.5 (0.9) | 1.75 (0.03) | --- | 2.4 (0.1) | --- | --- | 1 (fix) | 0.95 (0.01) | --- | --- | 2756/2691 (1.02) |
| BAT | --- | --- | --- | 1.79 (0.04) | --- | 3.1 (0.4) | --- | --- | --- | --- | --- | --- | 35/57 (0.62) |
| HXD | --- | --- | --- | 1.57 (0.09) | 257 (117) | 1.6 (0.3) | -0.4 (0.2) | --- | --- | --- | --- | --- | 196/166 (1.18) |
| XRT-XIS | 5.0 (0.3) | 0.18 (0.01) | 4.9 (0.1) | 1.76 (0.02) | --- | 2.28 (0.06) | --- | 1 (fix) | 1.08 (0.01) | 1.02 (0.01) | --- | --- | 3582/3354 (1.07) |
| BAT-HXD | --- | --- | --- | 1.58 (0.08) | 271 (120) | 1.4 (0.2) | -0.4 (0.2) | --- | --- | --- | 1 (fix) | 1.22 (0.03) | 240/224 (1.07) |
| XRT-BAT | 5.5 (0.4) | 0.158 (0.007) | 8.4 (2.3) | 1.78 (0.02) | >1000 | 2.35 (0.08) | -0.4 (fix) | 1 (fix) | --- | --- | 1.04 (0.06) | --- | 794/716 (1.11) |
| XIS-HXD | 4.8 (0.3) | 0.20 (0.01) | 3.5 (0.9) | 1.82 (0.01) | >1000 | 2.53 (0.05) | -1.12 (0.2) | --- | 1 (fix) | 0.95 (0.01) | --- | 1.03 (0.04) | 2957/2858 (1.03) |
| All | 5.0 (0.2) | 0.175 (0.006) | 4.7 (0.9) | 1.81 (0.01) | >1000 | 2.37 (0.04) | -0.98 (0.13) | 1 (fix) | 1.08 (0.01) | 1.02 (0.01) | 0.92 (0.04) | 1.09 (0.04) | 3831/3579 (1.07) |

4. Joint XRT-BAT and XIS-HXD fit

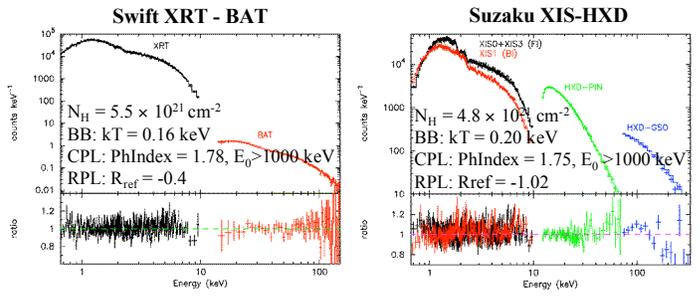


Fig. 4 [left] Joint Swift's XRT-BAT fit by phabs*(BB+CPL+RPL) model. The agreement between XRT and BAT are good with a constant factor difference less than 10%. [right] Joint Suzaku's XIS-HXD fit by phabs*(BB+CPL+RPL) model. Although there is a residual from the best fit model in the HXD data, this is very likely due to our empirical model rather than physical model (see Makishima et al. 2008). There is a good agreement between XIS and HXD.

5. Joint XRT-XIS-BAT-HXD fit

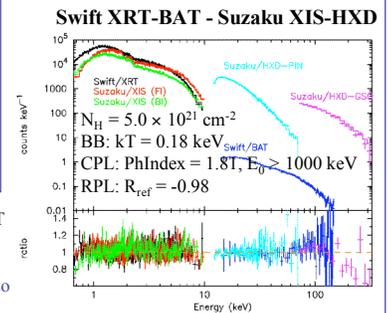


Fig 5 All instruments (Swift's XRT- BAT and Suzaku's XIS - HXD) joint fit by phabs*(BB+CPL+RPL) model. The constant factor agrees within 10% and also no significant residual from the best fit model for all instruments.

6. Summary

- XRT and XIS** : Good agreement
No significant residual from the best fit model. The constant factors agree within 10%.
- BAT and HXD** : Good agreement
HXD constant factor of 1.22 ± 0.03 relative to BAT is consistent with XIS-HXD cross normalization (Suzaku Memo 2008-06).
- XRT and BAT** : Good agreement
No significant residual from the best fit model. The constant factors agree within 10%.
- XIS and HXD** : Good agreement
The constant factors agree within 10%. The residual from the best fit model in the HXD data is very likely to be the artifact of using an empirical model rather than physical model (e.g. Makishima et al. 2008).
- All** : Good agreement
No significant residual from the best fit model. The constant factors agree within 10%.