Observation of the supernova remnant RX J1713.7-3946 in hard X-rays with INTEGRAL

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Introduction

Supernova remnants (SNRs) are well-known accelerators of cosmic rays. RX J1713.7–3946 (hereafter RXJ1713), also known as G347.3–0.5, is one of the best studied young shell-type SNRs. It was detected in soft X-rays, radio and gamma-rays. We present the first detailed spatial and spectral study of RX J1713 with the *INTEGRAL/IBIS*, using the significantly increased exposure time on the source since the work by Krivonos et al. (2007). The shell-type morphology of the entire remnant is mapped in hard X-rays for the first time and significantly detected up to 50 keV. The *INTEGRAL* 17-120 keV spectrum of RX J1713.7-3946 is characterized by a power-law continuum with the photon index of Γ~3, that is significantly softer than Γ~2 determined by *XMM-Newton* in the 1-10 keV energy range, suggesting a progressive steepening of the spectrum with the energy.

1. Observations

This work is based on data acquired with the *IBIS* coded-mask telescope on board the *INTEGRAL* gamma-ray observatory from December 2002 to March 2017. In order to extend the image and spectral analysis of RX J1713 to the standard X-ray energy band of 1−10 keV, we use all available *XMM-Newton* archival observations from 2001 to 2017 with the total (effective) exposure of 711 ks (549 ks).

2. Hard X-ray morphology

The IBIS/ISGRI 17-60 keV image of RX J1713 is dominated by two extended hard X-ray excesses (A and B) with common significance of >18σ (see Fig. 1). The positions of A and B are spatially consistent with the brightest parts of the northwest and the southwest rim of the SNR in the 1-10 keV energy band (see Fig. 2).

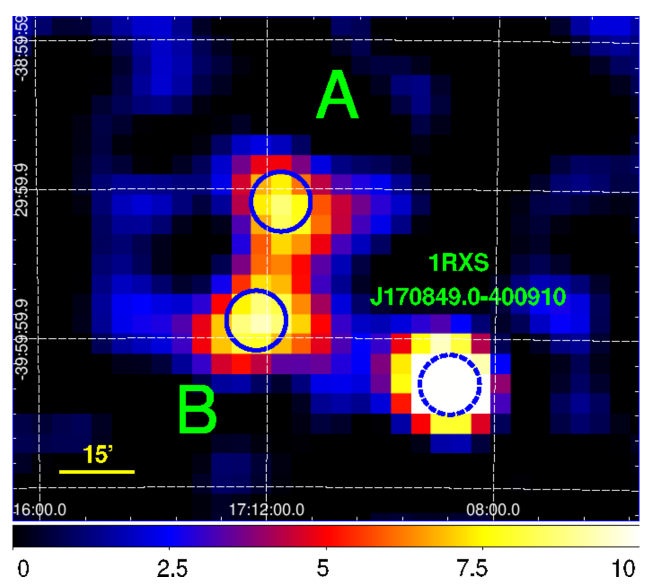

Fig. 1. *IBIS/ISGRI* 17-60 keV image of RX J1713 in terms of S/N convolved with instrumental PSF (Gaussian, σ = 5′). All circles are with 6′ radius. Blue dashed circle shows the position of the X-ray source 1RXS J170849.0–400910.

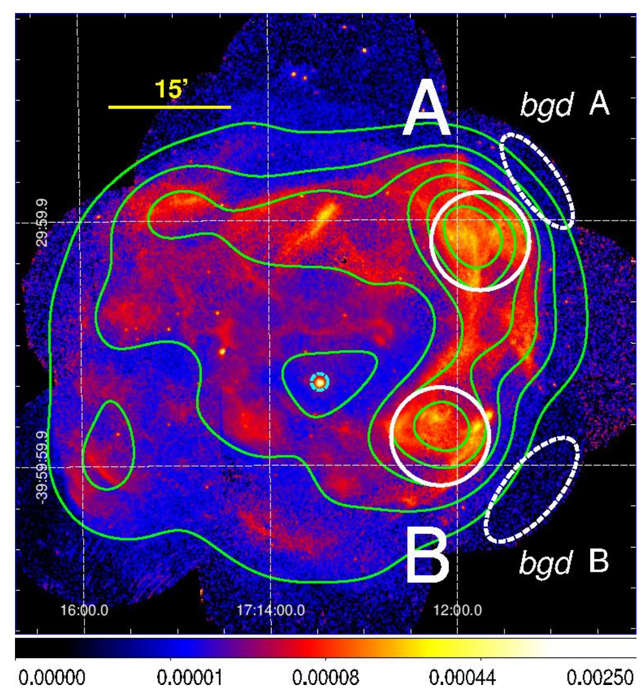

Fig. 2. The *XMM-Newton* (*MOS1+2*) 1-10 keV surface brightness maps of RX J1713 in units of counts $s^{-1}cm^{-2}arcmin^{-2}$. Dashed elliptical regions were used for the background spectra evaluation. Green contours denote isophotes of the same *XMM-Newton* image convolved with the IBIS instrumental PSF (after removal of the 1WGA J1713.4–3949, the small dashed circle).

To compare the RX J1713 morphology in soft and hard X-rays, we extracted radial profiles from two angular sectors containing A and B excesses from the *XMM-Newton* and *IBIS* images (see Fig. 3).

The obtained best-fit central positions of the Gaussian functions for *IBIS* radial profiles are consistent with the corresponding peaks of the *XMM-Newton* radial profiles. A double-shell structure along the western limb of the remnant is clearly seen in the soft X-ray image. In the *XMM-Newton* image convolving with *IBIS* PSF, we see the shell-like structure with two bright clumps, which are consistent with the *IBIS* A and B excesses (see contours in Fig. 2). This agreement indicates that a double-shell structure is likely to be remaining in hard X-rays.

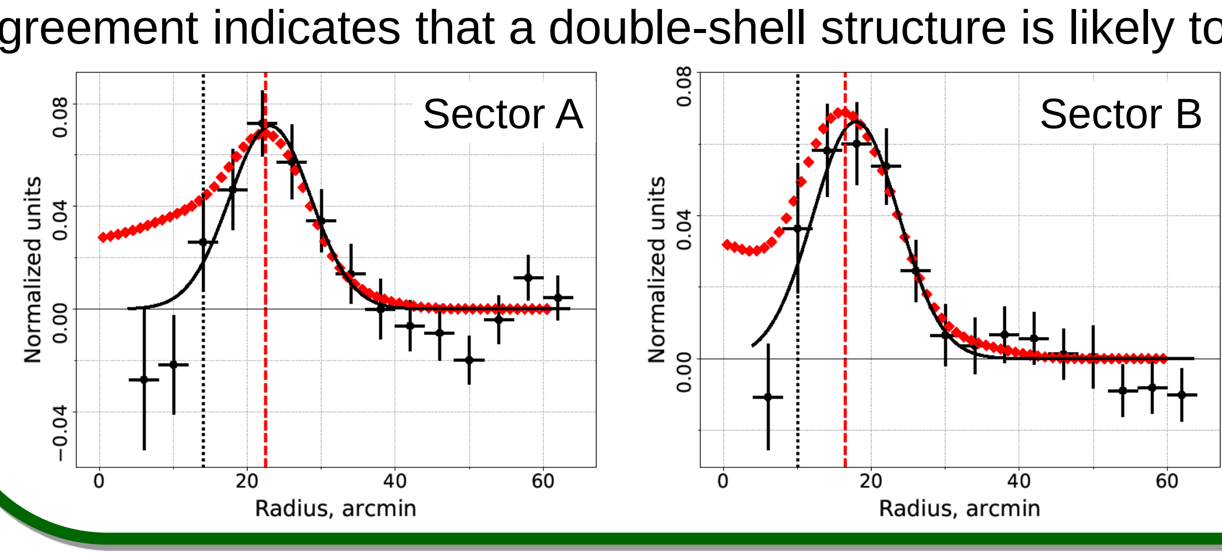

Fig. 3. *IBIS* (circles) and *XMM-Newton MOS1+2* (squares) radial profiles of sectors A and B. The solid lines represent the Gaussian model for the *IBIS* data. The positions of the *XMM-Newton* emission peaks are marked as vertical dashed lines.

3. Spectrum

The 17-120 keV *IBIS* spectrum of RX J1713 is well described by a power-law model with $\Gamma = 3.13^{+0.36}_{-0.33}$.
The 0.8-10 keV *XMM-Newton* spectra of regions A and B (R=6') were fitted with an absorbed power-law model with $N_H = 1.26 \pm 0.08 \cdot 10^{22} cm^{-2}, \Gamma = 2.32 \pm 0.05$
The broadband spectrum was approximated by the broken power-law model and the exponential cutoff model. We conclude that *IBIS* data favors the first model (Fig.4). The quality of the *IBIS* data do not allow us to constrain the cutoff or break energy. We, therefore, fixed this value to 17 keV, i.e., at the lower end of the *IBIS* energy range.

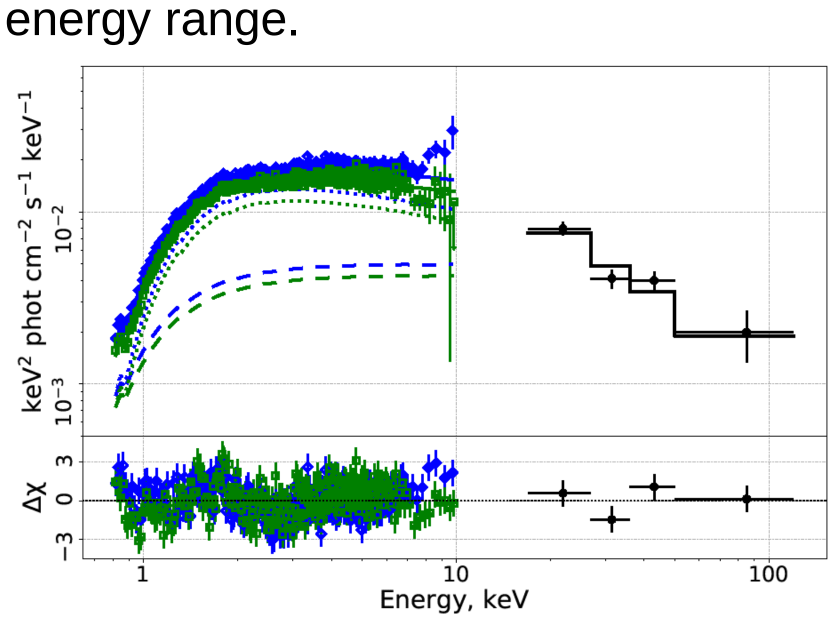

Fig. 4.The 0.8-10 keV *XMM-Newton MOS1+2* spectra of sources A (blue) and B (green) and the 17-120 keV *IBIS* spectrum of A+B (black). The source (*bknpower*) and background model components are shown by dotted and dashed lines. The total models are shown with solid lines.

4. Discussion

To avoid the normalization uncertainties of the RXJ1713 spectra obtained with different telescopes, we plot individual slopes as a function of energy. We use the analytical model of the synchrotron emission of electrons accelerated by a non-relativistic shock-wave in a shell-type SNR with the isotropic magnetic field (Zirakashvili & Aharonian, 2007, ZA07). The running photon index for the model is consistent with the available observational data (Fig. 5).

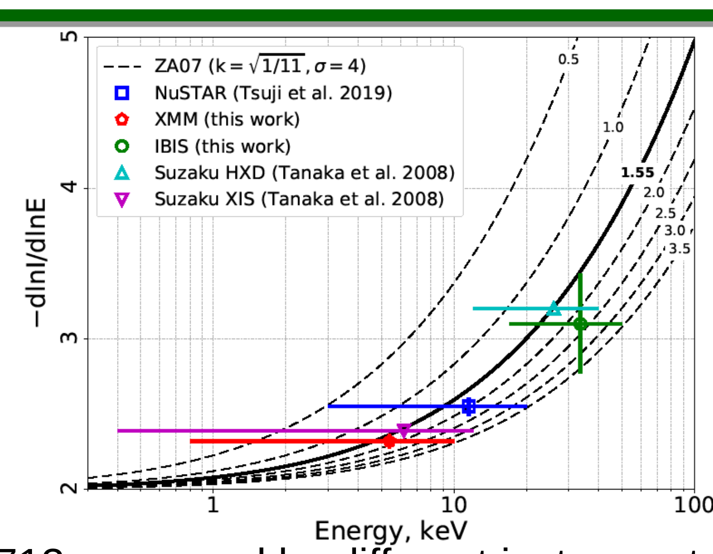

Fig. 5. Photon indexes of RX J1713 measured by different instruments. Dashed lines are logarithmic derivatives of ZA07 model as a functions of characteristic energy ε_0. Solid line shows the ZA07 model with ε_0 = 1.55 keV estimated for the Bohm limit regime (Tsuji et al. 2019).

5. Summary

The *IBIS* images of RX J1713 are in a good agreement with the 1-10 keV *XMM-Newton* map of RX J1713, which points to a single emission mechanism operating in the soft and hard X-ray bands. Two extended hard X-ray sources spatially coincident with the brightest parts of the SNR. Considering the shell structure of RX J1713, we find a good agreement between the position of the shocks in the hard and soft X-ray bands. The difference in photon indexes of the SNR spectrum in the soft and hard X-ray bands points toward a change in the slope of the power-law spectrum during the transition from the soft to the hard X-ray bands. We conclude that ZA07 model well describes the observational data with ε_0 energy ~1.5-2 keV, in agreement with expectations for the acceleration regime close to the Bohm limit. This work was submitted to MNRAS.