ASTROSAT MULTIWAVELENGTH OBSERVATIONS OF THE X-RAY BINARY HERCULES X-1

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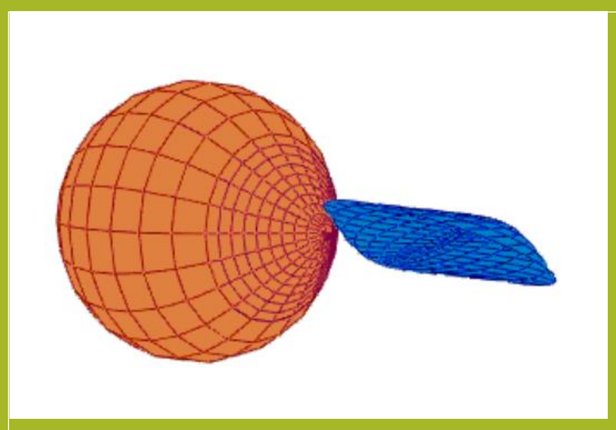


SUMMARY

ASTROSAT is a multi-wavelength observatory with 4 main instruments: UVIT, an ultraviolet and visible wavelength telescope; SXT, a soft X-ray imaging telescope; LAXPC, a broad-band large-area X-ray timing instrument; and CZT, a hard X-ray coded-mask imaging telescope. These four instruments operate simultaneously and are co-pointed, yielding a very wide band view of X-ray and UV emitting systems.

ASTROSAT carried out an observing campaign on the X-ray binary Hercules X-1 during 2016-2018. Here we report on the results of these observations, including FUV observations of Her X-1 with UVIT.

Sources of X-ray emission in Her X-1/HZ Her.

The X-ray emission regions consist of the following components

1. Direct X-ray beams (pencil and/or fan beam) originating in the accretion column of the accreting pulsar Her X-1 (Leahy 2004).

2. Weak isotropic emission high above the accretion column resulting from Thomson scattering of the direct X-rays (Scott et al. 2000).

3. Soft emission below 1 keV , modelled by a black-body of temperature kT = 0:1 keV , resulting from reprocessing of the hard X-rays in the outer neutron star magnetosphere and/or the inner edge of the accretion disc (McCray et al. 1982).

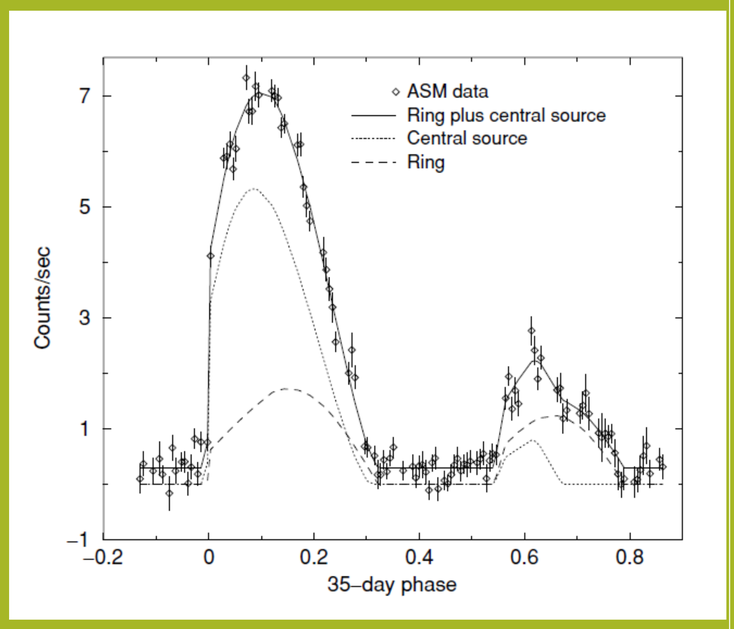
4. Reflection of the X-ray emission by the illuminated inner edge of the disc (Leahy 2002), and the irradiated face of the companion star(Leahy 1999).

5. Very weak (at 1% of the direct flux) unpulsed scattered emission by an extended accretion disc corona which is present throughout the 35-day cycle (Leahy 2015).

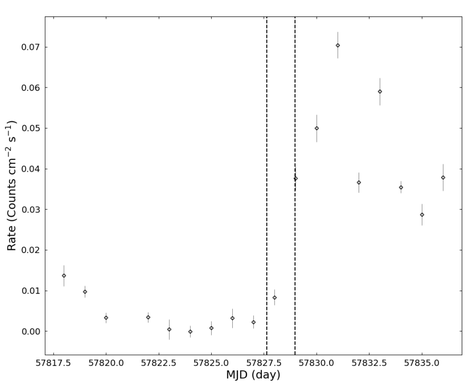
ASTROSAT Observations of Her X-1/HZ Her.

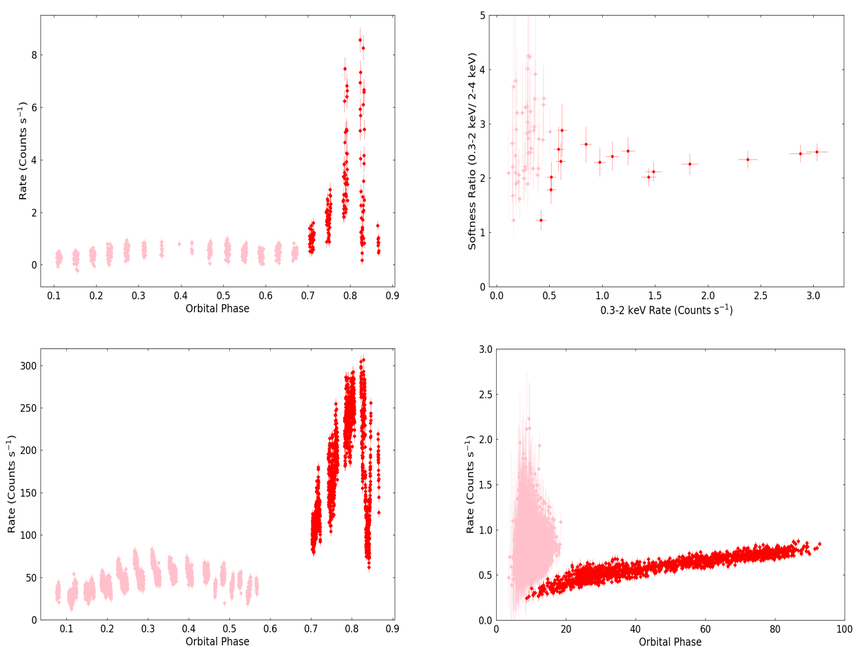
The 2016 observation was carried out in A02 during MJD57827.6 to MJD57829.0 and the 2017 observation in A03 during MJD57933.5 to MJD57934.3, the 2018 observation …

The orbital phase was found using the ephemeris of Staubert et al. 2009. The 35-day phase was found using the SWIFT-BAT light-curve of Her X-1.The 2016 observation was during late low state and turn-on to Main High state (see A02 below), the 2017 observations during early Main High state (see A03 below), and the 2018 observation ….



RXTE ASM 35-day folded light-curve of Her X-1 and the emission model (Leahy, 2002)

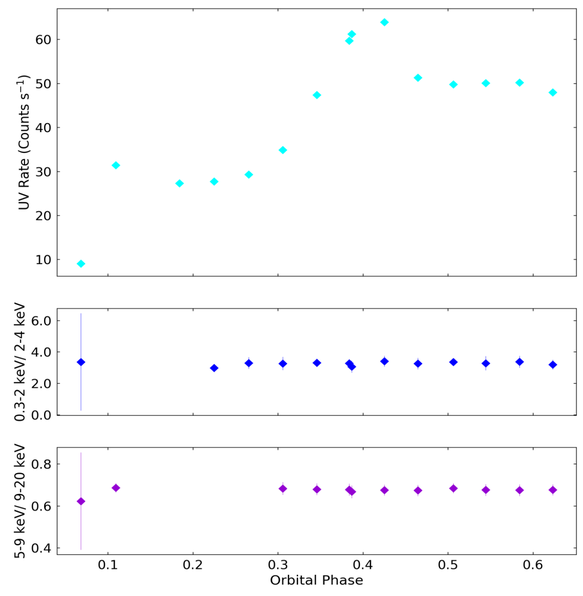




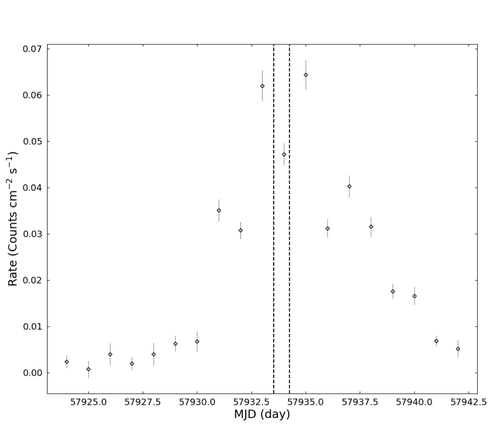
Above: Swift/BAT light curve of Her X-1 around the time of the ASTROSAT observation in 2016 (marked by the vertical dashed lines), showing Her X-1 is in turn-on to Main High State.
Top-Right: ASTROSAT SXT full band (0.3-10 keV) light curve and softness-ratio diagram. Low state is before orbital phase 0.72 and turn-on is after orbital phase 0.72

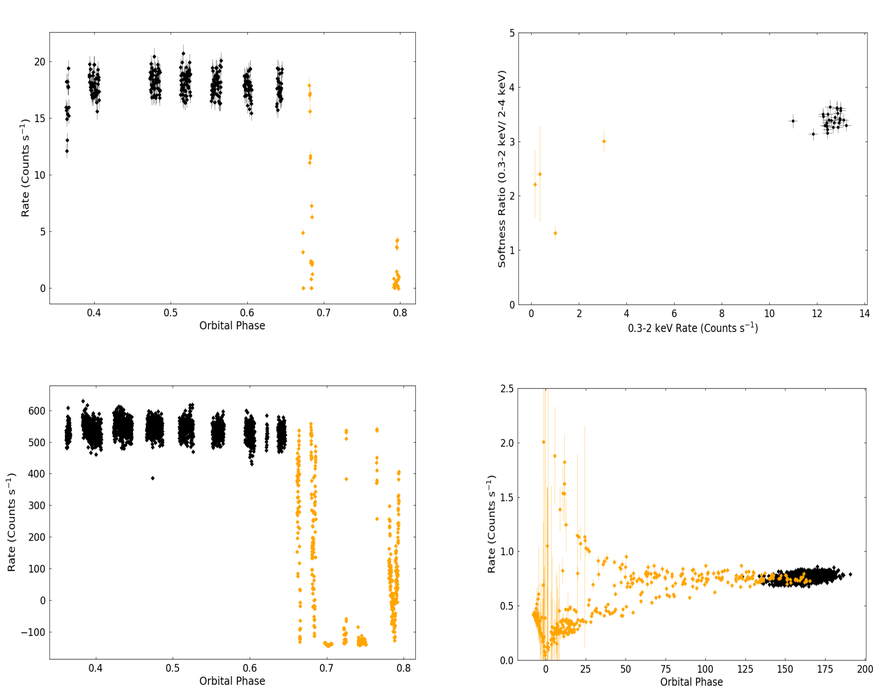
Bottom-Right: ASTROSAT LAXPC full band (3-80 keV) light curve and softness-ratio diagram.

Right: simultaneous ASTROSAT UVIT count rate (top). The SXT softness ratio (middle) and LAXPC softness ratio (bottom) for the same timebins as the UVIT data. Only the 2018 Her X-1 observation had UVIT data. The first point for all three data sets is during eclipse.



ASTROSAT SXT softness ratio 1 (0.2-2 keV/2-4 keV) vs. 2-4 keV count rate. Low state data is on the left with the turn-on to Main High giving the points at higher count rate





Above: Swift/BAT light curve of Her X-1 around the time of the ASTROSAT observation in 2017 (marked by the vertical dashed lines), showing Her X-1 is in middle of Main High State.
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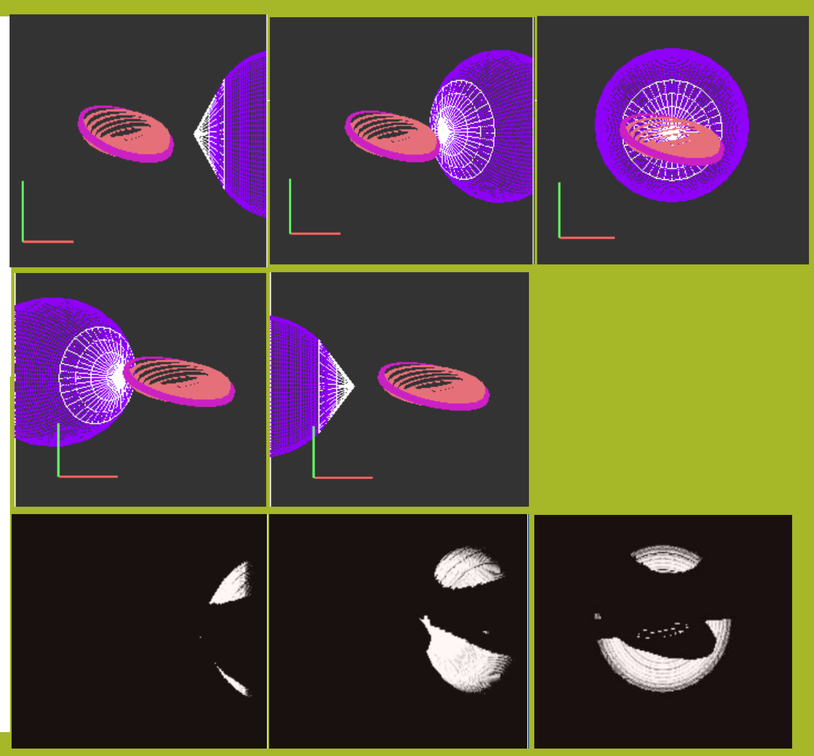
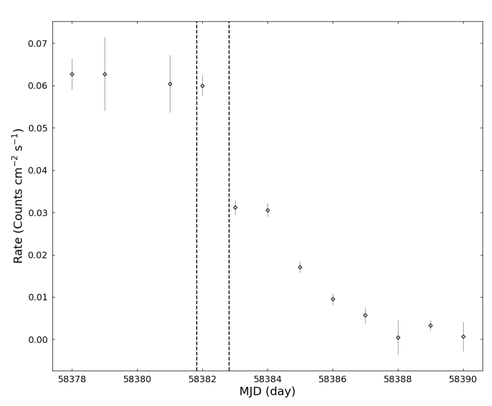
Top-Right: ASTROSAT SXT full band (0.3-10 keV) light curve and softness-ratio diagram. The orange points mark dips during Main High.

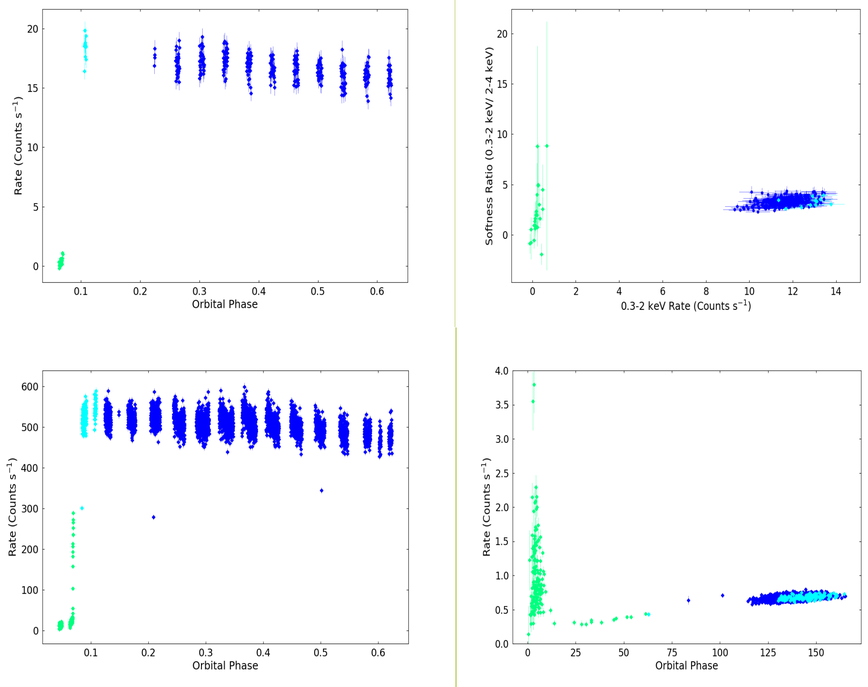
Bottom-Right: ASTROSAT LAXPC full band (3-80 keV) light curve and softness-ratio diagram.



Left: SHAPE software simultaneous of the Her X-1 binary. Roche-lobe filling HZ Her is in purple and white; the twisted-tilted accretion disk is shown in pink. The observer's view is at 5 degrees above the orbital plane. The 5 panels are for orbital phases of 0.25, 0.375, 0.5, 0.625 and 0.75 The orbit is counter-clockwise.

Left: SHAPE radiative transfer model for the emission from the unshadowed and heated part of HZ Her. The shadow caused by the accretion disk on HZ Her and the accretion disk blockages of HZ Her are shown in black. 5 panels are for orbital phases of 0.25, 0.375, 0.5, 0.625 and 0.75.





Above: Swift/BAT light curve of Her X-1 around the time of the ASTROSAT observation in 2017 (marked by the vertical dashed lines), showing Her X-1 is in late Main High State.
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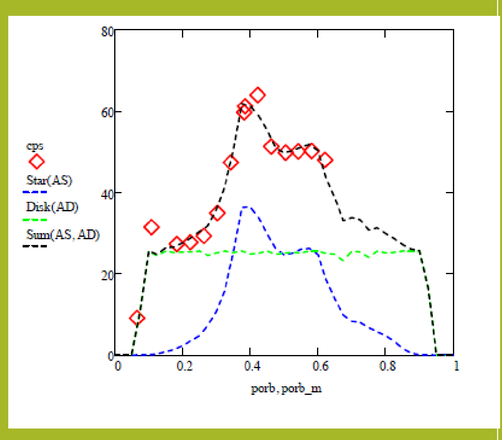
Top-Right: ASTROSAT SXT full band (0.3-10 keV) light curve and softness-ratio diagram. The green points mark when Her X-1 is in eclipse, cyan is just after eclipse egress.

Bottom-Right: ASTROSAT LAXPC full band (3-80 keV) light curve and softness-ratio diagram.

Right: UVIT FUV data (red points) compared to the SHAPE model. The emission from the heated face of HZ Her is the blue dashed line. The heated disk emission is the cyan dashed line, and the sum is the black dashed line. The twist and tilt parameters of the disk were adjusted to get a good fit to the data. The resulting twist and tilt are consistent with those of Leahy, 2002 but are better constrained.



Summary of ASTROSAT observations of Her X-1/HZ Her.

We have obtained observations during low-state and main high turn-on (in 2016), mid main high state with dips (in 2017) and late main high state (in 2018). The UVIT data from 2018 shows strong orbital phase variability. Unlike the EUV emission, which is from reflection of HZ Her (Leahy, Marshall, Scott 2000 ApJ 542, 446), the FUV emission is thermal emission from the heated face of HZ Her and from the surface of the accretion disk (Leahy & Chen, in prep). The FUV light curve is sensitive to the shape of the disk shadow and provides new strong constraints on shape of the tilted and twisted disk.

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