

## The High Resolution Camera

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It has been another quiet, but successful year for HRC operations. The instrument performs well with no significant anomalies or instrumental issues. The HRC continues to be used for a wide variety of astrophysical investigations. In this chapter, we briefly describe two such science studies. First, a collaboration led by Dr. Wolfgang Pietsch of MPE used the HRC to study the X-ray state of the nova population in M31 in conjunction with *XMM-Newton* and optical studies. They found that there is a strong correlation between the optical and X-ray properties of these novae. Second, Guenther et al. (2012) used the HRC-I to measure the X-ray flux from the nearby star  $\beta$  Pic. Combining the sensitivity of the HRC-I below 0.5 keV with an *XMM-Newton* detection, they demonstrated that the emission originates in the stellar corona, not the dusty disk, and that the temperature of the gas is  $\sim 1.2$  MK, making it the hottest low-mass stellar coronal source known.

The *Chandra* HRC detector was used in a joint program with the *XMM-Newton* observatory to study the supersoft X-ray state of optical novae in our neighbor galaxy M31. X-ray studies of novae are vital to gain a direct access to the physics of the underlying white dwarf that hosts the nova event. In six dedicated monitoring seasons from June 2006 to June 2012 (41 total HRC observations with integrated exposure of 750 ks), we discovered the supersoft X-ray counterparts of 38 novae and thereby doubled the number of such sources known in M31. The *Chandra* HRC with its excellent spatial resolution, large field of view and response at X-ray energies below 0.5 keV was crucial for detecting nova counterparts in the crowded central region of M31, where other X-ray observatories suffer from source confusion. A statistical analysis of the overall sample of 79 X-ray-detected novae in M31 revealed strong correlations between the optical and X-ray parameters of novae, showing essentially that novae that decline rapidly in the optical are hot in X-rays, with short X-ray phases (Henze et al. 2010, 2011, 2013, see Fig. 1). In addition to the statistical analysis of the nova sample, several individual novae could be investigated in detail (e.g. novae in globular clusters and novae showing time variability).

To create a source catalog of the M31 center and search for time variability of the sources, we included 23 observations from November 1999 to February 2005 (adding about 250 ks exposure time). We detected 318 X-ray sources and created long term light curves for all of them. We classified sources as highly variable or outbursting (with subclasses short vs. long outbursts and activity periods). 129 sources could be classified as X-ray binaries due to their position in globular clusters or their strong time variability (see Fig. 2). We detected seven supernova remnants, one of which is a new candidate, and also resolved the first X-rays from a known radio supernova remnant (see Hofmann et al. 2013).

In a second study, Guenther et al. used the HRC to determine the origin of the X-ray emission from  $\beta$  Pic, a nearby star with a dusty disk. On the main sequence, there are two different mechanisms that generate stellar X-ray emission. Massive O and B stars have radiatively driven winds, and because these winds are unstable, X-ray emitting shocks form. On the other end to the main sequence are the cool stars that produce X-ray emission in a magnetically heated corona like our sun. Stars of spectral type A lie between these regimes and should be X-ray dark. Yet, some of them have been detected in X-ray observations. One of the most peculiar of those objects is  $\beta$  Pic, an A5 star at only 19.5 pc. A previous 70 ks *XMM-Newton* observation (Hempel et al. 2005) barely detected  $\beta$  Pic in a very narrow energy band just around the O VII band.  $\beta$  Pic also has a strong IR excess due to a massive debris disk surrounding the star, made up from dust and cometary bodies. There are at least three scenarios for the origin of this X-ray emission: (i) a stellar corona, (ii) a boundary layer where mass is accreted from the disk or (iii) charge-exchange between the stellar wind and the comas of many comets.

A grating spectrum would easily select between these models, but alas,  $\beta$  Pic is much too faint. So, how do we get any spectral information for a star that is detected with just a dozen photons in more than 70 ks of *XMM-Newton*? The answer is to go to a different band; scenario (ii) and (iii) should yield significant soft X-ray emission in the HRC bandpass, unique to *Chandra*. So, we observed  $\beta$  Pic for 20 ks with the HRC-I. In scenarios (ii) and (iii) there should have been hundreds of counts in the HRC-I, but we only saw 17 (see Fig. 3). From the ratio of count rates in the *XMM-Newton* observation and our new *Chandra*/HRC data, we conclude that  $\beta$  Pic has a 1.2 MK corona, and this X-ray emission

is unrelated to its dust disk. Instead, this makes  $\beta$  Pic the hottest cool star, i.e. the hottest known star with magnetic activity.

## References

- Guenther et al. 2012, ApJ, 750, 78
- Hempel et al. 2005, A&A, 420, 707
- Henze et al. 2010, A&A 523, A89
- Henze et al. 2011, A&A 533, A52
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- Hofmann et al. 2013, A&A 555, A65

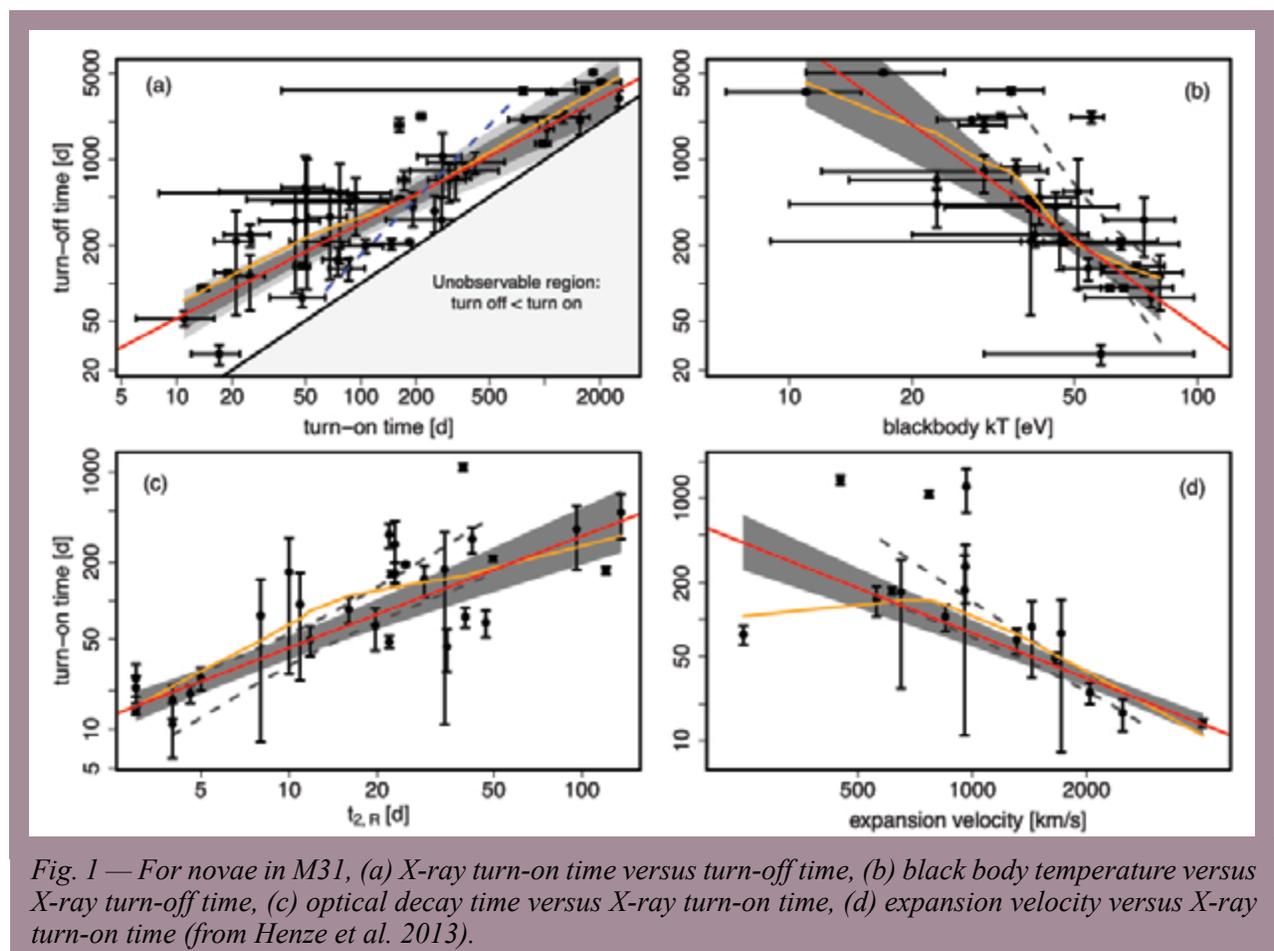


Fig. 1 — For novae in M31, (a) X-ray turn-on time versus turn-off time, (b) black body temperature versus X-ray turn-off time, (c) optical decay time versus X-ray turn-on time, (d) expansion velocity versus X-ray turn-on time (from Henze et al. 2013).

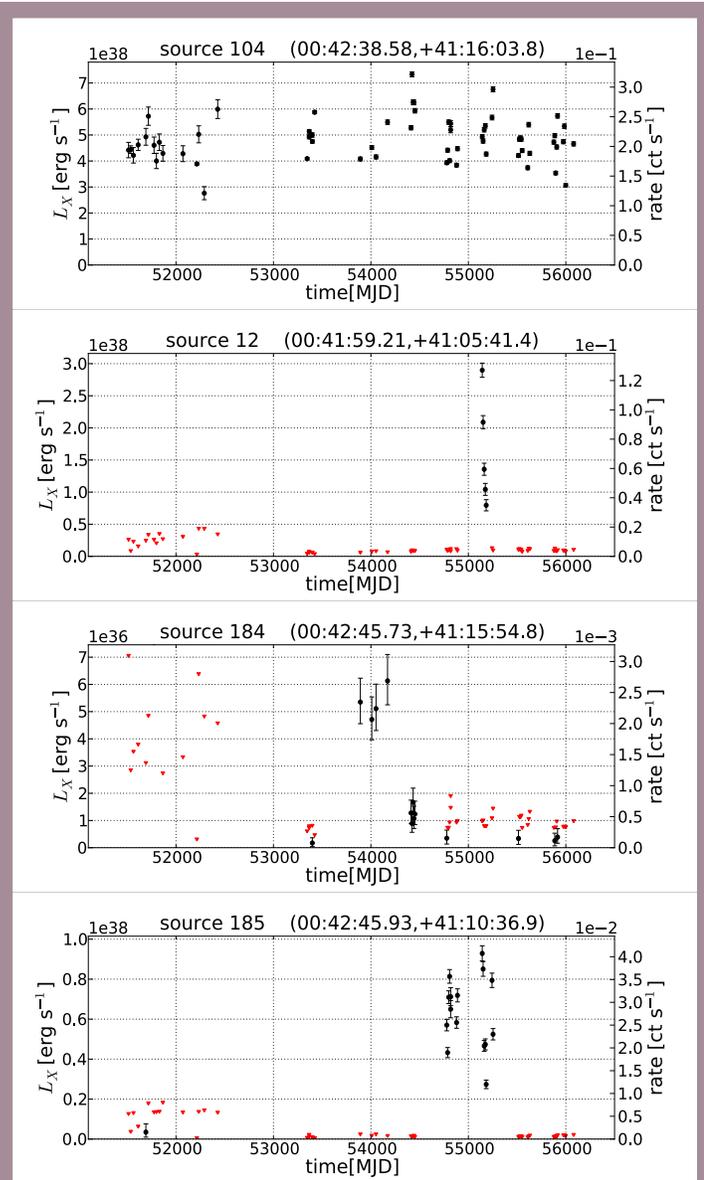


Fig. 2 — X-ray luminosity and photon count rate over modified Julian date: highly variable (source 104), short outburst (12), long outburst(184), activity period during outburst (185) (from Hofmann et al. 2013).

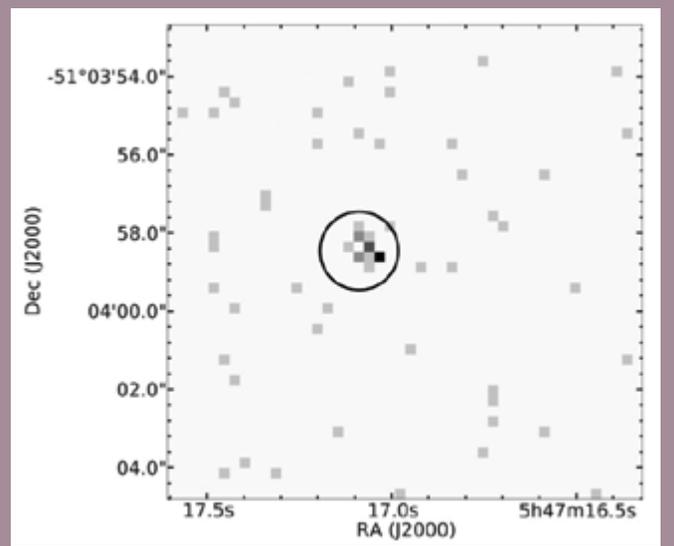


Fig. 3 — HRC-I image of  $\beta$  Pic, spatially binned by a factor of two. The shade indicates the number of counts per bin from light gray (1 count) to black (4 counts). The circle marks the extraction region centered on the optical position of  $\beta$  Pic (Guenther et al. 2012).

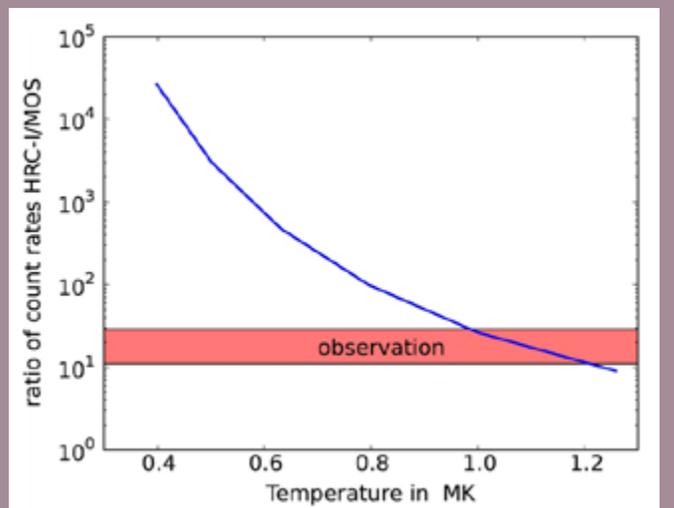


Fig. 4 — Ratio of HRC-I counts (full band) and MOS counts (OVII) as a function of plasma temperature for an optically thin, collisionally excited thermal plasma with solar abundances (Guenther et al. 2012).