The X-ray Transient Population of M31

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For the past 6 years, we have been monitoring M31 to learn about the X-ray transient (XRT) population. The bright transient sources are of particular interest because a large fraction of Galactic low-mass X-ray binaries that exhibit transient outbursts have been shown to contain black holes [1]. M31 offers a large equidistant sample of such sources in a small field, providing XRT statistics for a large spiral galaxy. We have recently completed a homogeneous statistical study of the XRTs detected with Chandra and XMM from 1999-2002 (see Figures 1-6), and we continue to find new XRTs in our ongoing campaign. Through coordinated Chandra and HST observations of these sources, optical counterparts can be found and orbital period predictions can be made (see Figures 7-12).

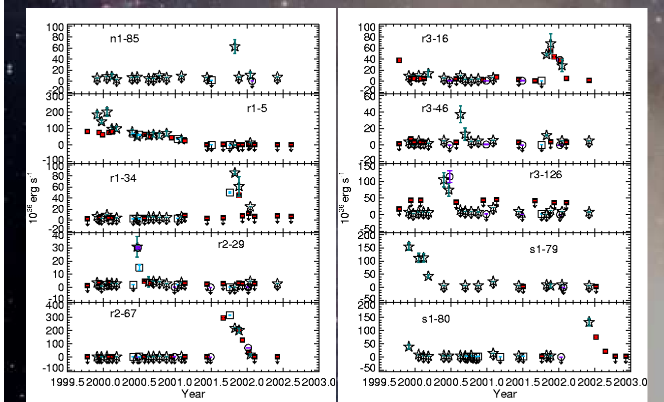

Figure 1: Light curves of 10 of the 45 cataloged M31 XRTs from 1999-2002 [2]. Different symbols mark observations from different instruments. Stars = Chandra HRC. Filled squares = Chandra ACIS-I. Open squares = Chandra ACIS-S. Circles = XMM.

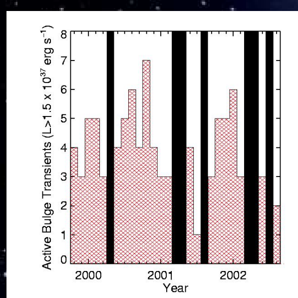

Figure 2: The number of active transients during the first few years of monitoring. 3 ± 2 transient sources are active in M31 at any given time. The program has detected ~10 new transients each year, higher than the Galactic rate of ~3 per year [2,3].

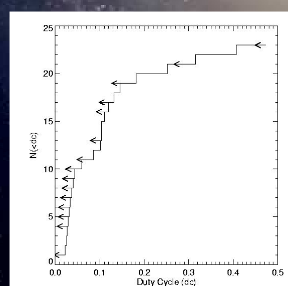

Figure 3: The cumulative distribution of the duty cycle estimates (mostly upper limits) from the best-sampled light curves. About half are constrained to <0.1, and nearly all are <0.2. About 1% of M31 sources with L_X> 2e36 erg/s are XRTs. If the XRTs are black holes (BH) and the persistent sources are neutron stars (NS), then NS/BH≈dc/0.01, where dc is the duty cycle.

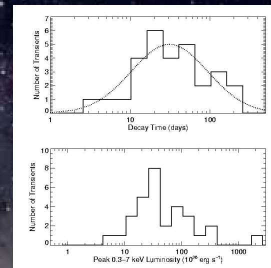

Figure 4: The distribution of decay time estimates for the 1999-2002 XRT sample (top). A Gaussian fit yields log (τ_d) = 1.5 +/- 0.5 (Galactic distribution is 1.2 +/- 0.4 [3]). The distribution of peak luminosities (bottom). Most sources 10^{37}<L_X<10^{38} (Galactic sample has mean of L_X=0.2 L_{Edd} [3]).

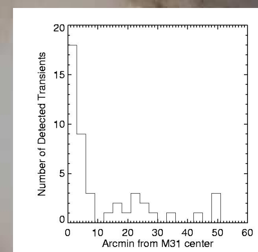

Figure 5: The distribution of XRTs as a function of angular distance from the M31 nucleus. About half of the XRTs lie in the bulge, within 7′ of the nucleus, and within the bulge, the number appears to decline with GCD.

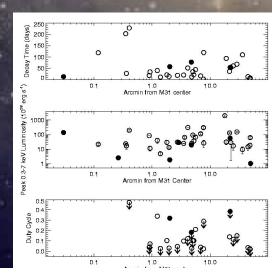

Figure 6: The distribution of decay times (top), peak luminosities (middle), and duty cycles (bottom) as a function of angular distance from the M31 nucleus. Filled circles are super-soft transient sources. No trends are observed.

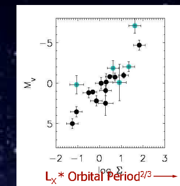

Figure 7: Orbital periods of Galactic LMXBs are correlated with optical and X-ray luminosity [4]. Blue points show recent transient outbursts. Larger disks may be associated with longer period binaries and hence glow brighter in the optical.

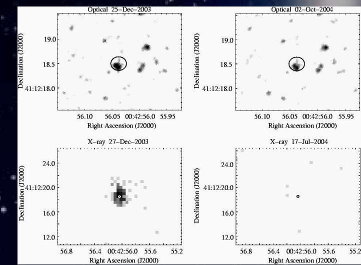

Figure 8: Coordinated HST (top) and Chandra (bottom) observations of an M31 XRT 4′ SE of the nucleus. Error circles are 0.2″ in all frames. If the variable star to the NE in the blend (top panels) is the optical counterpart, M_V ~ -1.2 and Lx ~ 6e37 erg/s, yielding a predicted period ~8 days [5].

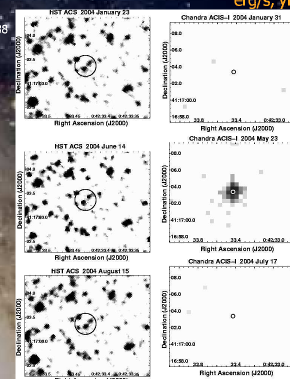

Figure 9: Coordinated HST (left) and Chandra (right) observations of an M31 XRT 2′ NW of the nucleus. No significant optical variability was detected in the 0.2″ error circles shown.

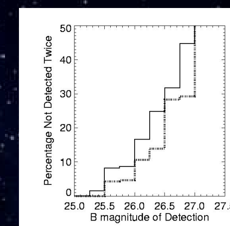

Figure 10: Histograms of the percentage of stars detected in one epoch of HST data and not another. These results show that the data were sensitive to variability to B=25.5. Together with the measured L_X of 4e37 erg/s, these observations suggest the orbital period is <1.6 days [6].

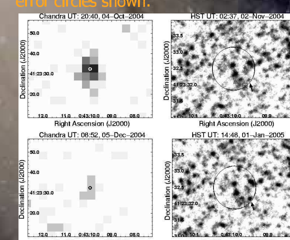

Figure 11: Coordinated Chandra (left) and HST (right) imaging of a recent XRT (L_X =1.1e37 erg/s). The arrow marks the optical counterpart candidate, which has M_V = 0.5. These measurements provide a period estimate of ~2 days [7].

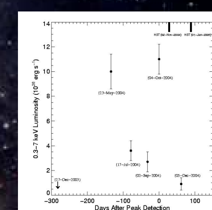

Figure 12: ACIS-I light curve for the XRT in Fig. 12. The complexity shown by the double peak may explain the uncorrelated optical variability (see Fig. 11). Such complex X-ray/optical variability has been observed in Galactic XRTs (e.g. XTE J1550-564 [8]).

Conclusions

The M31 XRT population appears similar to the Galaxy in luminosities, decay times, and orbital periods (L_X/L_{opt}). Most M31 XRTs lie close to the galaxy center, and the rate of outbursts is about one per month. Through coordinated Chandra and HST observations, we have found 5 optical counterpart candidates (Figs. 8 & 11 show recent examples) and meaningful upper-limits for 2 optical non-detections (Figs. 9 & 10 show a recent example).

References

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