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An Unprecedented View of a Galaxy's Dynamic X-ray Source Population

David Pooley

Astronomy Department, University of California at Berkeley, 601 Campbell Hall, Berkeley, CA 94720, USA
email: dave@astron.berkeley.edu

Abstract. In May/June 2005, *Chandra* observed M81 fifteen times, roughly once every three days, as part of our proposal to explore the days to weeks timescale of variability for extragalactic point sources. Each observation reached a sensitivity of 5×10^{36} erg/s. Because these observations probe the timescale on which X-ray binaries typically evolve, we can now compare extragalactic sources to Galactic X-ray binaries on a more equal level than has been possible in the past. In addition, we can measure and quantify any possible time variability of M81's X-ray luminosity function and investigate alternative methods to characterize a galaxy's dynamic X-ray source population. We present here preliminary results of the observations.

Keywords. galaxies: individual (M81), X-rays: binaries.

1. Motivation

X-ray luminosity functions (XLFs) are almost universally used as a tool to compare different galaxies or to investigate sub-populations within a single galaxy. In fact, in a recent review of X-ray sources in normal galaxies, Fabbiano & White discuss XLFs on 10 of the 11 pages in the section on the X-ray binary populations in spiral galaxies (Fabbiano & White 2003); there are eight figures in that section — three are *Chandra* images (M31, M83, and the Antennae) and the other five are XLFs. However, despite the ubiquity of XLFs in studying other galaxies, the variability of the XLF of a galaxy has never been properly addressed before (see Maccacaro *et al.* 1987 for the variability of the XLF of a set of random fields observed multiple times with *Einstein*). An analysis of five observations of NGC 3877 (Gonzales 2004) reveals a strongly variable XLF (see Fig. 1 which shows the XLF of two different observations as well as an XLF constructed by considering the maximum $L_{\rm X}$ achieved by each source). Above $\sim 3 \times 10^{38}$ erg s^{-1}, the XLF of Obs. 4 indicates only 1 source while the XLF of Obs. 5 indicates 7 sources, and the maximum-XLF shows 10 sources. This order of magnitude difference is very interesting, to say the least.

Clearly, the XLF of a single observation may not be a good representation of the galaxy, especially since we have almost no information about the full range of XLF variability. NGC 3877 is one of only a few galaxies that have been observed more than once or twice (note: the observations were performed to follow the evolution of supernova 1998S; Pooley *et al.* 2002). Our observations of M81 are intended to provide much needed information in this area. *Chandra* observations over the past five years have resulted in the discovery of an astounding number (many thousands) of X-ray sources in other galaxies. As mentioned above, XLF properties (such as slope, maximum $L_{\rm X}$, a break at a certain $L_{\rm X}$, etc.) have been almost universally used to investigate these sources and compare galaxy populations, yet our findings on NGC 3877 could cast doubt on their reliability as an accurate characterization of a galaxy. As long as such doubts remain, the power

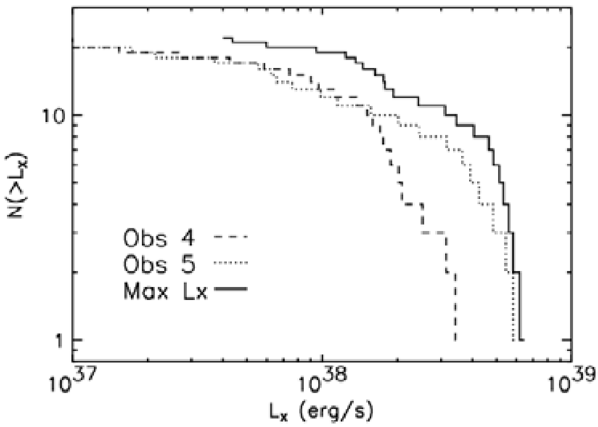

Figure 1. Three X-ray luminosity functions of the Sc galaxy NGC 3877 (Gonzales 2004). Two are of individual observations (notice the large difference) and one is based on the maximum observed luminosity of each source (SN 1998S was not included).

of these galaxy to galaxy comparisons is greatly weakened. To truly utilize the *Chandra* data, we must first understand and calibrate the XLF tool.

2. Observations

To explore XLF variability, we used *Chandra* ACIS-S in imaging mode to observe M81 fifteen times over the course of about a month and a half during the summer of 2005. Each observation lasted 12 ksec and reached a limiting luminosity (near the aimpoint) of 5×10^{36} erg/s at the distance of M81 (3.6 Mpc; Freedman *et al.* 2004). The observations log is listed in Table 1, and a composite image is shown in Figure 2.

3. Preliminary Results

We constructed XLFs of the inner $5' \times 5'$ region of M81, shown in Figure 3, and performed pairwise Kolmogorov-Smirnov tests to compute the probability that the observed XLFs came from the same parent distribution. The most discrepant pair of XLFs had only a 4% chance of being from the same parent distribution, but, considering the number of trials performed, this is not significant. Therefore, the bulge population of M81 shows no evidence for a varying XLF. We have not yet performed the same test on the spiral-arm population. It has been shown that the XLF of the M81 bulge X-ray sources is different than that of the disk X-ray sources (Tennant *et al.* 2001).

Individual sources showed a remarkable amount of variability, and we present prelimary results of the two most luminous. The ultraluminous source X-6 (Fabbiano 1988) has had

Table 1. Observation Log

Date	Good time	Date	Good time	Date	Good time
2005-05-26	11.0 ks	2005-06-09	12.0 ks	2005-06-24	11.6 ks
2005-05-28	11.4 ks	2005-06-11	11.8 ks	2005-06-26	12.0 ks
2005-06-01	12.0 ks	2005-06-15	11.9 ks	2005-06-29	10.7 ks
2005-06-03	11.8 ks	2005-06-18	12.0 ks	2005-06-03	12.0 ks
2005-06-06	11.8 ks	2005-06-21	11.8 ks	2005-07-06	12.0 ks

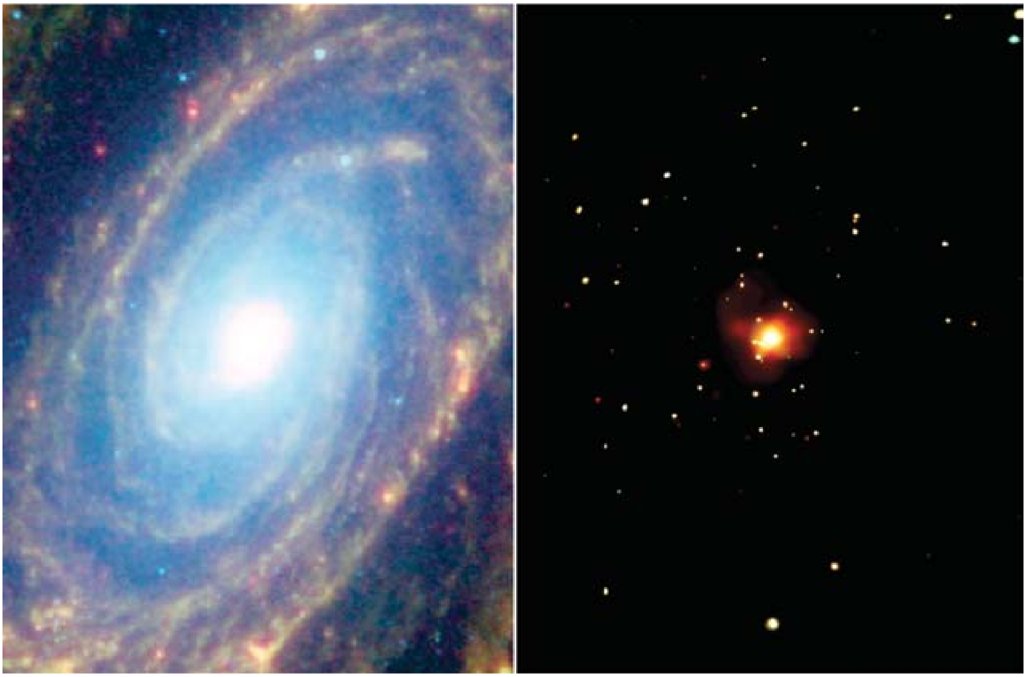

Figure 2. Images of the inner 6′ × 8′ of M81 taken with *Spitzer* (left) and *Chandra* (right). The *Spitzer* image is courtesy NASA/JPL-Caltech/K. Gordon (University of Arizona) & S. Willner (Harvard-Smithsonian Center for Astrophysics). The *Chandra* image is the composite of the observations listed in Table 1. In the *Spitzer* image, red represents 24 μm emission, green represents 1.2–2.5 μm, and blue represents 2.5–6 μm. In the *Chandra* image, red represents 0.5–1.2 keV, green represents 1.2–2.5 keV, and blue represents 2.5–6 keV.

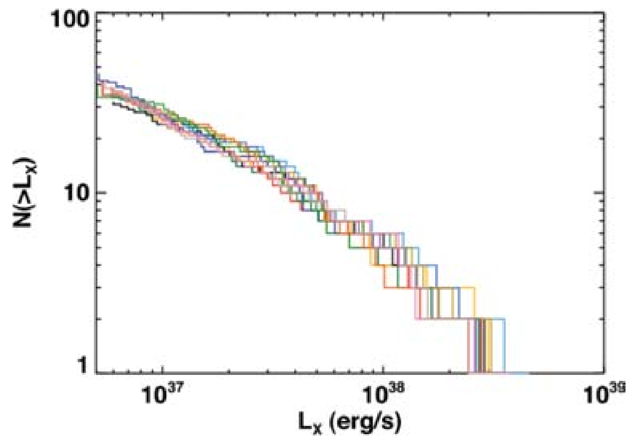

Figure 3. Individual X-ray luminosity functions of the inner 5′ of M81. There is no evidence for variation among them.

conflicting reports of its variability. Immler & Wang reported a factor of two variability over six days (Immler & Wang 2001), but Swartz *et al.* reanalyzed those data, as well as a previous *Chandra* observation, and found no evidence for variability on short or long times scales (Swartz *et al.* 2003). We find variations of ∼30% on a timescale of days (see Figure 4).

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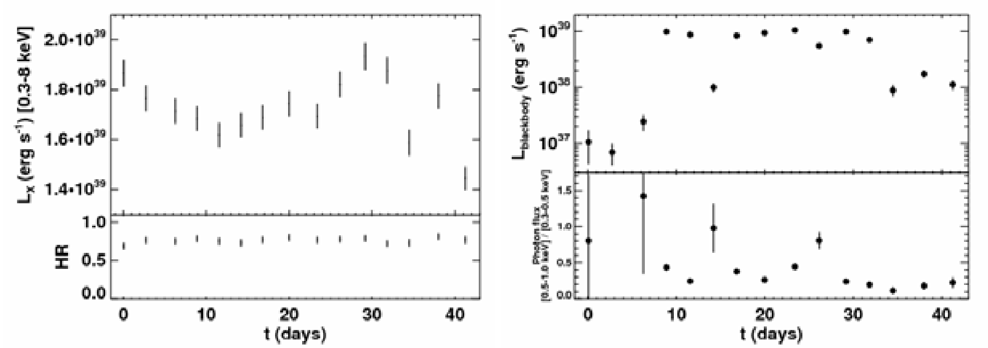

Figure 4. *Left:* X-ray luminosity and hardness ratio (HR) of the ultraluminous X-ray source X-6 in M81. The average absorbed 0.3–8 keV luminosity of each observation is plotted. HR is defined as the ratio of photon flux in the 2–8 keV band to that in the 0.5–2 keV band. *Right:* The bolometric luminosity of a very luminous soft source in M81. The source specrum is well described by a blackbody of $kT = 80$ eV. There is roughly a factor of two correction going from the detected in-band flux to the unabsorbed in-band flux, and another factor of two going from in-band to bolometric.

We also observe dramatic variability of a very soft source in M81, as shown in Figure 4. The source is very soft, with almost no emission detected above 1.5 keV and a spectrum well described by an absorbed blackbody of temperature $kT = 80$ eV. The source flux was observed to rise by two orders of magnitude over the course of a about a week. The very soft spectrum and extreme luminosity of this source have been interpreted in terms of an intermediate-mass black hole of $\sim$1200 $M_\odot$ (Swartz *et al.* 2002).

4. Conclusions

As *Chandra* and *XMM* will no doubt continue to probe nearby galaxies very deeply, it will be beneficial to split up the observations into series of closely-spaced short observations to probe this timescale of variability that is virtually unexplored outside the Milky Way.

Acknowledgements

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