Revealing the Nature of a very Luminous Globular Cluster X-Ray Source Bo375 in M31 Galaxy

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Abstract

We present results of observations of a very luminous M31 globular cluster (GC) X-ray source Bo375 with *Suzaku*, *Chandra*, *XMM-Newton* and *Swift*. Bo375 is one of the most luminous GC X-ray sources in M31 (Andromeda Galaxy), and has a luminosity consistently above 10^{38} ergs s^{-1}, which is much more luminous than typical GCs found in our own Milky Way galaxy (the brightest GC X-ray source in our Milky Way galaxy is in the order of 10^{37} ergs s^{-1}). There are several possible explanations for such a high luminosity: 1) the source might contain multiple components; 2) the source radiation might be beamed; 3) the source might be an accreting black hole, and 4) the source might be an accreting neutron star. To investigate why Bo375 has such a high luminosity, we study the light curves, X-ray spectra, and timing properties of the source from the data taken by *Suzaku*, *Chandra*, *XMM-Newton* and *Swift* in detail. Previous observations showed that Bo375 has short-term and long-term variability. The *Chandra* HRC-I data also shows that the source is consistent with a single point source. In this paper, we will further present the new results from *Suzaku*, *XMM-Newton* and *Swift*, which might reveal the nature of Bo375, and of other luminous GCs in nearby galaxies.

Key words: X-ray binaries, accreting black holes, accreting neutron stars

1. Introduction

Bo375 has been observed for 30 years since first discovered by *Einstein* in 1979. It has been visited by many X-ray satellites, such as *ROSAT*, *ASCA*, as well as *Suzaku*, *Chandra*, *XMM-Newton*, and *Swift*. In this paper, we present results taken from *Suzaku*, *Chandra*, *XMM-Newton*, and *Swift*, with a total of 30 observations spanning from 1999 to 2007. We constructed a multi-mission long-term lightcurve with all the observations (see Figure 1) and showed that the X-ray source in Bo375 is a variable, and its luminosity is persistently above 10^{38} ergs s^{-1}.

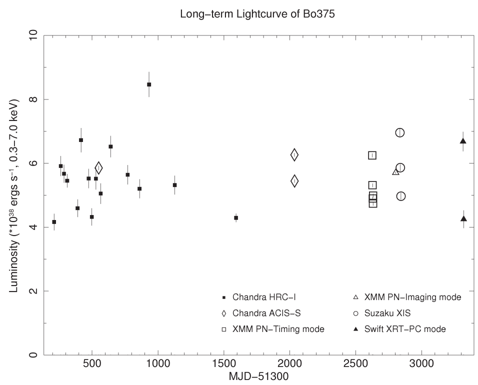

Fig. 1. This figure shows the multi-mission long-term lightcurve of Bo375 source. There is clearly variability on a time scale of days, but overall the source luminosity is persistent (always above 10^{38} ergs s^{-1}).

2. Discussion

2.1. Multi-Components?

The radial profile shows that the source is consistent with a single component, however, if we calculate the angular separation of two very close luminous X-ray sources in a Galactic globular cluster (taking M15 as an example), we would find that even with Chandra HRC, it is not possible to resolve the M15 sources at a distance of M31. Even with the multi-component scenario, it cannot fully explain such a high luminosity. There must be at least one source which dominates most of the emission output and is responsible for the high luminosity. Taking the brightest globular cluster X-ray source in our own galaxy for example ($\sim 10^{37}$ ergs s^{-1}), it would require at least ten of such sources to produce a luminosity comparable with Bo375; not to mention that all the sources would

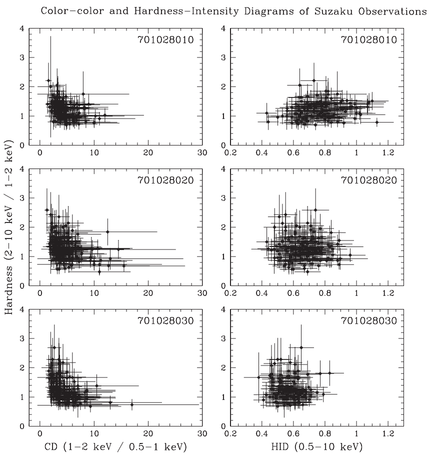

Fig. 2. Color-color diagram (left panel) and hardness-intensity diagram (right panel) of all three *Suzaku* observations.

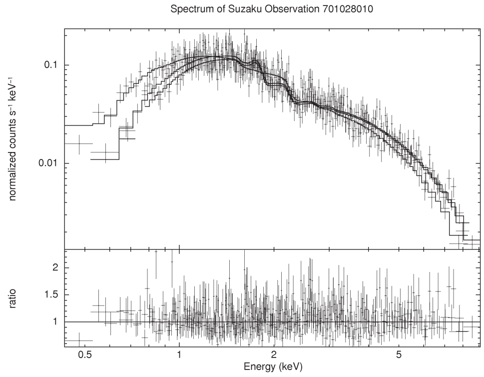

Fig. 3. Simultaneous spectral fit of *Suzaku* XIS0, XIS1 and XIS3 (0.3 to 10 keV) detectors of Bo375 from observation 701028010. The spectrum was best fitted with an absorbed power law plus blackbody model.

have to be squeezed within a 2 pc region (Chandra limit), which is unlikely to be the case.

2.2. Beaming Effect?

From the persistent brightness of the source (for a period over 30 years), and the spectra (not a typical pulsar spectrum), the relativistic beaming is unlikely to be responsible for such a high luminosity. However, considering a neutron star binary scenario, the high luminosity might be explained by anisotropic beaming due to the strong outflow and corona surrounding the neutron star.

2.3. Black Hole Binary? or Neutron Star Binary?

Since the source is associated with a GC, it is most likely a low-mass X-ray binary (LMXB). Because we did not find any pulsation nor radio emission from the observations, the source could either be a stellar-mass black hole binary in its high state, or a weak magnetic field slow-rotating neutron star binary with strong outflow and high mass accreting rate. The real difficulty and challenge is to distinguish these two systems, since they have many similarities in spectral behavior and intensity variability. We first examined the color-color diagram and hardness-intensity diagram (Figure 2.) of all observations and we did not see any obvious pattern like those seen in Galactic X-ray binaries. A similar accretion disk structure is commonly considered for either a stellar-mass black hole binary, or a neutron star binary. For the black hole case, the soft thermal emission is usually suggested as the multi-color black body emission from the accretion disk. For the neutron star case, it is thought to be from the neutron star surface, or the boundary layer between the neutron star and the accretion disk, or the combination of both. The difference between high-luminosity neutron star LMXBs and black hole LMXBs is that a neutron star has a surface, but the black hole does not. Many studies have shown that the high-luminosity neutron star LMXBs can be well fitted by a simple black body component plus a power-law model. This black body emission is interpreted as emission from the neutron star surface. However, a 3-4 solar-mass black hole might also show very similar properties. Two widely used properties to diagnose whether or not the central object in a binary system is a black hole are the ultra-soft spectra, and a power-law tail above 20 keV. In our *Suzaku* HXD observations, we did not see any tail above 20 keV, and the spectra are not soft (Figure 3. and Table 1). But this does not lead to the conclusion of a black hole scenario. In recent years, it has been discovered that there are more sources found not to follow the classical trend of the diagnoses. For an ambiguous case like Bo375, the task seems to be more difficult. Due to the limited quality of the current data, we are unable to determine the source nature at this current stage. Further observations are needed in order to draw a complete picture of the source. A properly sampled monitoring program will certainly provide us with more information to constrain the physical properties and nature of the source.

Table 1. Spectral fits of *Suzaku* Observations

ObsID	N_H [3]	Γ	T_{KT} or T_{in} [4]	χ^2/dof
701028010[1]	1.67 ± 0.28	1.87 ± 0.09	0.89 ± 0.05	0.96/449
701028010[2]	1.06 ± 0.53	1.72 ± 0.45	1.56 ± 0.18	0.96/449
701028020[1]	1.63 ± 0.29	1.89 ± 0.10	0.95 ± 0.06	0.91/464
701028020[2]	1.18 ± 0.66	1.99 ± 0.66	1.74 ± 0.19	0.92/464
701028030[1]	1.33 ± 0.33	1.63 ± 0.08	0.87 ± 0.14	0.82/331
701028030[2]	1.05 ± 0.46	1.50 ± 0.21	1.43 ± 0.35	0.82/331

[1]Power-law+blackbody. [2]Power-law+disk blackbody.
[3]In units of 10^{21}cm^{-2}. [4]In units of keV.