A genuine new black hole candidate in the M31 globular cluster Bo 45

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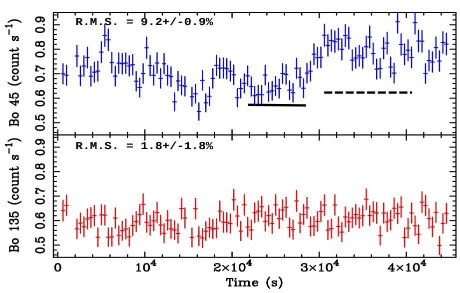
We analysed new XMM-Newton observations of the globular cluster X-ray source Bo 45, and found its variability and spectrum consistent with the low state for a LMXB, but at a luminosity too high for a neutron star accretor. Hence we identify it as a black hole LMXB.

1.) INTRODUCTION

XMMU 004143.1+413420 (hereafter referred to as Bo 45) is a bright X-ray source that is associated with the confirmed M31 globular cluster Bo 45. Prior to our 2006 December 26 XMM-Newton observation, it was not observed by XMM-Newton or Chandra. However, it was observed by Einstein in the 1979–1980 survey (Trinchieri & Fabbiano, 1991) and by ROSAT in 1991 and 1992 (Supper et al., 1997, 2001). The 0.2–4 keV flux of Bo 45 varied by a factor of ~2 between the Einstein and ROSAT observations, but did not vary significantly between ROSAT observations. We examined the X-ray variability and spectrum of Bo 45 from the XMM-Newton observation, to help determine the nature of the X-ray source.



4.) VARIABILITY OF BO 45

Here we compare the 0.3–10 keV background-subtracted light curve of Bo 45 with that of Bo 135, a similarly bright source in the same observation. The light curves are filtered for background flares and are binned to 400 s. Solid and dashed lines indicate intervals of low and high intensity respectively, used for measuring the spectral evolution of Bo 45. Bo 45 is clearly variable, while Bo 135 shows no significant variability. Bo 45 is likely to exhibit variability on time-scales shorter than 400 s, but the current observation is insufficiently sensitive. We do not see the characteristic PDS associated with the low state, and this may be due to the low count rates also.

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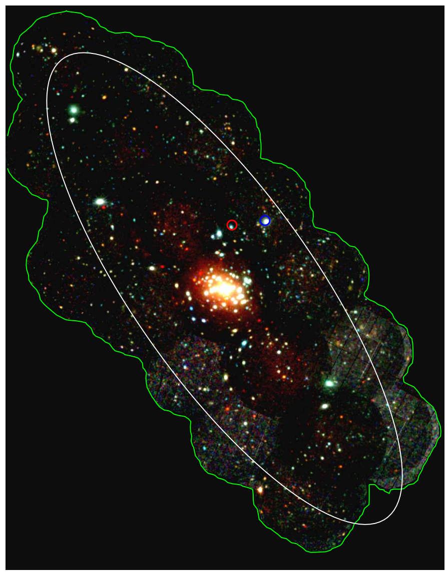
3.) OUR OBSERVATION OF BO 45

We present our three-colour mosaic of M31, (red = 0.2–1.0 keV, green = 1–2 keV and blue = 2–12 keV). Bo 45 was observed in the 2006 December 26 observation of the so-called NN1 region, which had a ~40 ks good time exposure after removing background flares. We highlight Bo 45 with a blue circle. We also highlight Bo 135 in red: this is a similarly bright globular cluster source in the same observation.



6.) DISCUSSION

The observed X-ray properties of Bo 45 are consistent with a BH/NS LMXB in the low state, but not a NS LMXB in the high state or a BH LMXB in the high or very high states.

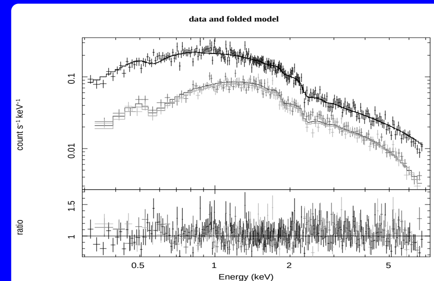
Van der Klis (1994) proposed that LMXBs switched from low to high accretion rate behaviour at some constant fraction of the Eddington limit. Barnard et al. (2003, 2004) realised that if this were true, then BH LMXBs would be capable of exhibiting low-state variability and spectra at higher luminosities than neutron star LMXBs, as the Eddington limit is proportional to the mass of the accretor. We would therefore expect a LMXB containing a ~10 $M_\odot$ BH to exhibit low-state characteristics at ~10 times the highest luminosity of low-states observed in 1.4 $M_\odot$ NS LMXBs.

There is empirical evidence for this in the behaviour of V404 Cygni and 4U 1705−44, two Galactic LMXBs with known primaries. V404 Cygni contains a BH primary with mass ~12 $M_\odot$ (Shabaz et al., 1994), and was observed in the low state at a 0.3–10 keV luminosity of 1.2±0.4×10^{38} erg s^{-1}. Meanwhile, the transition from low to high state for the NS LMXB 4U 1705−44 is likely to be 1.1–2.7×10^{37} erg s^{-1}, a factor of ~10 lower than the low-state observed in V404 Cygni, and ~6–15% Eddington for a 1.4 $M_\odot$ NS. **Bo 45 exhibits low state behaviour at an apparent luminosity of 2.4±0.2×10^{38} erg s^{-1}, or 130% of the Eddington limit for a 1.4 $M_\odot$ NS accretor. Hence, we identify it as a BH candidate.**

2.) CLASSIFIYING LMXBS BY X-RAY PROPERTIES

Galactic low mass X-ray binaries (LMXBs) are often classified by their X-ray properties, namely their power density spectrum (PDS), r.m.s. variability, and emission spectrum (see van der Klis 1994, 1995; McClintock & Remillard, 2006 and references within). The spectral and timing properties of each state are summarised as follows:

PDS	RMS	SPECTRUM	LMXB STATE
BROKEN PL	HIGH	POWER LAW Γ = 1.4–1.7	BH/NS LOW STATE
PL	LOW	DISC BLACKBODY 0.7–2 keV, ≥90% 0.4–10 keV FLUX	BH HIGH STATE
BROKEN PL	LOW	0.7–2 keV DISK BLACKBODY + POWER LAW (Γ >2.4)	BH STEEP POWER LAW/ VERY HIGH STATE
PL	LOW	POWER LAW + BLACKBODY (POWER LAW ≥50% FLUX)	NS HIGH STATE



5.) SPECTRAL ANALYSIS OF BO 45

Here we present the 0.3–7 keV pn, MOS1 and MOS2 spectra of Bo 45, with 16894, 7416 and 6953 net source counts respectively. We modelled these spectra simultaneously using an absorbed power law model, with normalising constants to account for the different instruments. A good fit was achieved with Γ = 1.45±0.04 and n_H = 1.41±0.11×10^{21} atom cm^{-2}; χ^2/dof = 517/487 (good fit probablilty, g.f.p., 0.17). Assuming a distance of 760 kpc (van den Bergh, 2000) yields an unabsorbed 0.3–10 keV luminosity of 2.4±0.2×10^{38} erg s^{-1}. Adding a second, blackbody component made no appreciable difference to the fit.

We also examined the spectral evolution between low and high intensity intervals. We simultaneously fitted pn spectra from the intervals indicated in the Bo 45 lightcurve, which yielded ~3000 and ~4500 net source counts for the low and high intensity intervals respectively. We were able to reject models where the evolution was due to change in the absorber (χ^2/dof = 193/129, g.f.p. 1.9×10^{-4}). However, a model with constant absorption and Γ but with varying intensity fitted well (χ^2/dof = 140/129, g.f.p. = 0.23). Hence the observed variability is clearly intrinsic to the source.

COMMENT ON PREVIOUS BH IDENTIFICATIONS

We note that the M31 BH candidates identified by Barnard et al. (2003, 2004) were contaminated by artifical variability that was introduced when combining non-synchronised lightcurves from the different instruments on board XMM-Newton (Barnard et al., 2007). However, the current work employs corrected techniques and represents the first genuine BH candidate to be identified using this method.