Black Holes from Stars to Galaxies – Across the Range of Masses
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Optical, ultraviolet and X-ray analysis of the black hole candidate BG Geminorum

P. Elebert,[1] P. J. Callanan,[1] L. Russell[1] and S. E. Shaw[2]

[1]Department of Physics, University College Cork, Ireland

[2]School of Physics and Astronomy, University of Southampton, Southampton, SO17 1BJ, UK

email: p.elebert@ucc.ie

Abstract. We present the first high resolution optical spectrum of the black hole candidate BG Geminorum, as well as UV spectroscopy from the Hubble Space Telescope, and X-ray data from INTEGRAL. The UV spectra suggest the presence of material in BG Gem with velocities possibly as high as ∼1000 km s^{-1}, suggesting an origin at a distance of ∼0.7 R$_\odot$ from a 3.5 M$_\odot$ object; if real, this would be strong evidence that the primary in BG Gem is indeed a black hole. In contrast, the upper limit provided by the INTEGRAL data gives a maximum X-ray luminosity of only ∼0.1% of the Eddington luminosity.

Keywords. X-rays: binaries, accretion discs, stars: individual (BG Geminorum).

1. Introduction

In 1992, Benson *et al.* (2000) discovered an eclipsing and ellipsoidal variation in BG Gem with a period of 91.645 days. Combined with a sinusoidal secondary radial velocity curve, this suggested a binary system, with a K0 secondary feeding material into an accretion disc around the unseen primary. Kenyon *et al.* (2002) calculated the mass function to be (3.5 ± 0.5) M$_\odot$, greater than the theoretical minimum mass for a black hole, ~ 3M$_\odot$ (Rhoades & Ruffini 1974). However, because the primary cannot be observed directly (the inclination of the system is close to 90°) it could also be a B star (Kenyon *et al.* 2002). If confirmed to be a black hole, BG Gem would be the the longest period black hole binary system, by an factor of ∼3, as well as being the only known eclipsing black hole binary system in the Galaxy.

One method to investigate the nature of the primary is to acquire higher quality optical spectra, to determine the maximum rotational velocity of the accretion disc surrounding the primary. Large velocities would favour a black hole primary, as ∼700 km s^{-1} is the maximum velocity for a disc surrounding a B type star (Kenyon *et al.* 2002). If the primary is an un-obscured B star, then UV spectra should show a strong continuum and absorption lines from ionised Si. Detection of broad high ionisation emission lines would favour a black hole. Here, we present the first high resolution optical spectrum of this system, as well as the first UV spectra, and X-ray data from INTEGRAL.

2. Data

We acquired an optical spectrum with the ALFOSC instrument on the Nordic Optical Telescope (NOT) in La Palma on 2006 April 11. Kenyon (2001) acquired UV spectra with the Space Telescope Imaging Spectrograph on the Hubble Space Telescope (HST), on 4 nights between 2001 November and 2002 December. We have also examined archival X-ray data from the International Gamma-Ray Astrophysics Laboratory (INTEGRAL),

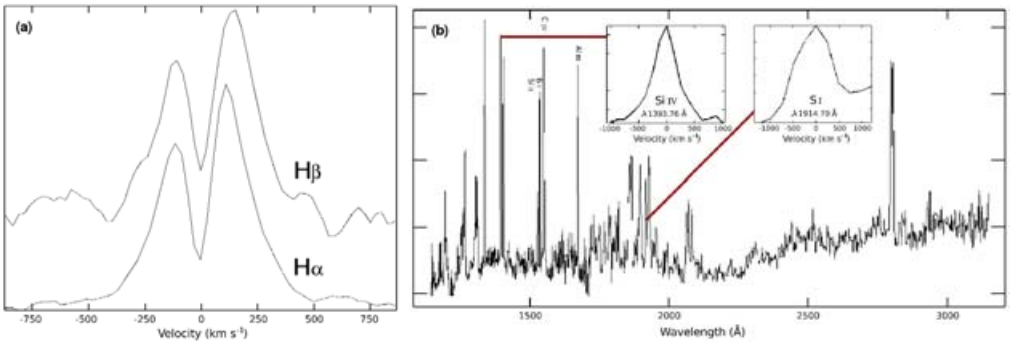

Figure 1. (a) Hα and Hβ emission lines normalised to the local continuum, and offset for clarity. (b) Combined HST UV spectrum from 2001 December 30.

consisting of 20–40 keV mosaics from the INTEGRAL Soft Gamma Ray Imager (ISGRI). The maximum exposure is ∼250 ksec, obtained between 2003 February and 2004 October.

3. Results and Discussion

Figure 1(a) shows double-peaked Hα and Hβ emission lines. The Balmer line emission in the wings is from material with velocities of $\lesssim$500 km s^{-1}, low enough that the central object could be a main sequence B star. The UV spectra, such as that in Figure 1(b), show strong emission lines from Si, Al and Mg ions, with a very weak continuum – indicative of a black hole primary rather than a B star. The maximum velocity in the wings of S I λ1914.70 Å is possibly as much as 1000 km s^{-1} – if confirmed with higher resolution spectra this would be strong evidence that the primary is a black hole. However, the INTEGRAL observations yield an upper limit of $\lesssim 10^{33}$ erg s^{-1} in the 20–40 keV band. If BG Gem were intrinsically luminous in the X-rays, but obscured by its accretion disc because of the high orbital inclination, we might still expect some fraction (∼1%) of its intrinsic flux scattered into our line-of-sight by an accretion disc corona (White *et al.* 1981). In this scenario our upper limit would then correspond to a limit on the intrinsic X-ray flux of $\lesssim 10^{35}$ erg s^{-1}. This suggests that, if the primary is indeed a black hole, the system must be in quiescence.

Acknowledgements

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