On the Putative Class of B[e] X-ray Binaries

Journal Article

Stars with the B[e] Phenomenon
ASP Conference Series, Vol. 355, 2006
Michaela Kraus and Anatoly S. Miroshnichenko

On the Putative Class of B[e] X-ray Binaries

J. S. Clark

Dept. Physics & Astronomy, CEPSAR, The Open University, Walton Hall, Milton Keynes, United Kingdom

Abstract. We discuss the putative class of B[e] X-ray binaries, with reference to currently identified candidate systems, focusing on CI Cam and the newly identified class of highly obscured hard X-ray sources detected by *INTEGRAL*. We suggest that such a class will likely consist of two types of object in which the B[e] phenomenon is (i) intrinsic to the mass donor or (ii) a result of binarity. Finally, we discuss the difficulties inherent in observing B[e] X-ray binaries and the physical motivations for their study, which include the origin of the Galactic hard X-ray emission and the propagation of jets in dense media.

1. Introduction

High Mass X-ray binaries (HMXB) are systems composed of a massive OB star and a relativistic compact companion (cc), with accretion from the former onto the latter resulting in X-ray emission. Traditionally, HMXB have been classified via the nature of their mass donor, which for the majority of systems is either a classical Be star (BeXB), or OB supergiant (SgXB). Given that the X-ray behaviour of HMXB is dictated by the physical mechanism governing mass transfer, which differs between the two classes of object, such a classification has proved instructive.

Mass transfer in BeXBs occurs via the complex interaction between the quasi-Keplerian decretion disc of the classical Be star and the accretor, possibly mediated by a (transient) accretion disc (Okazaki & Negueruela 2001). This results in hugely diverse X-ray lightcurves that are typically characterised by transient X-ray flares, with luminosities which may on occasion approach the Eddington limit for a neutron star (10^{38}ergs^{-1}), interspersed with long periods of quiescence (see Negueruela 2004, for a comprehensive review). In contrast, the compact objects in SgXBs are thought to accrete material directly from the stellar wind of the mass donor. Since such systems typically have short orbital periods and low orbital eccentricities, they are found to be persistent X-ray sources with $L_x \sim 10^{36}$ergs^{-1}.

However, recent observations have revealed that such a blunt classification scheme is insufficient to understand the full range of accretion phenomena in HMXB. For instance a number of recurrent X-ray transients demonstrating rapid flaring have been identified with supergiant rather than Be star mass donors; the so called Supergiant Fast X-ray Transients (SFXTs; Negueruela et al. 2005). Moreover, a handful of systems appear to transfer matter via Roche Lobe Overflow (RLOF; Cen X–3, SMC X–1, LMC X–4 and almost certainly SS 433, see Sect. 3).

Given their dense circumstellar environment, one might expect supergiant B[e] (sgB[e]) stars to form a subset of mass donors within HMXB. However, *a priori* it is not obvious what the X-ray properties of putative sgB[e] X-ray binaries (sgB[e]XBs) should be. Under the assumption that sgB[e] stars lose matter via an aspherical 2 component outflow, comprising a high velocity polar wind and a slowly expanding (quasi-Keplerian?) equatorial disc (Zickgraf 2003), would mass transfer follow the paradigm of SgXBs or BeXBs? Indeed, can such a question be posed without knowledge of the orbital parameters of the putative binary, which are in turn dependent on the currently unknown evolutionary channels that yield sgB[e] stars?

Moreover, identification of such systems is further complicated because to date no comprehensive survey of the X-ray properties of sgB[e] stars (nor the possibly related Luminous Blue Variables; LBVs) exists to provide a baseline for the intrinsic emission from such objects. Since X-ray emission may also arise in shocks, either embedded within the winds of single OB and Wolf Rayet (WR) stars or in the wind interaction regions of Colliding Wind Binaries (CWBs), upon the discovery of X-ray emission we may not *a priori* conclude that it is generated via accretion onto a compact companion.

Consequently, in the remainder of this review we present a summary of the properties of candidate B[e]XBs, with the aim of trying to identify commonalities between the systems. In doing so we concentrate on CI Cam, the system for which the largest body of observations exist and also pay particular attention to the class of intrinsically absorbed hard X-ray sources discovered by the *Inte*rnational *G*amma-*Ra*y *L*aboratory (*INTEGRAL*), which appear to provide the best targets for a systematic search to identify further B[e]XBs (Kuulkers 2005). We then briefly discuss the circumstellar environment of the galactic microquasar SS 433 in the context of the B[e] phenomenon, recognising that any putative class of B[e]XB must incorporate a division between those binaries for which the B[e] phenomenon is an intrinsic property of the mass donor - which are likely to be sgB[e] stars - and those for which the B[e] phenomenon results from the effects of binarity. Finally, we briefly discuss the physical motivations behind the search for, and investigation of, such an elusive class of object.

2. Candidate B[e] X-ray Binaries

2.1. CI Cam

To date the most compelling candidate for a sgB[e]XB remains CI Cam. The presence of a compact companion was signalled by the detection of the X-ray transient XTE J0421+560 by Smith et al. (1998); it's association with CI Cam confirmed via radio observations. The X-ray outburst was unusual in both its rapidity and also its spectral characteristics (e.g. Boirin et al. 2002, and refs. therein), and was accompanied by dramatic flaring at all other wavelengths surveyed (optical → radio; Clark et al. 2000). Within 2 weeks X-ray emission had subsided to an assumed quiescent level, with the spectrum - discussed further in Sect. 2.2 - suggesting substantial intrinsic absorption. Significant variability has been evident in the quiescent X-ray lightcurve (Parmar et al. 2000), although to date no activity on the level of the 1998 March 31 flare has been observed.

Subsequent monitoring of CI Cam at optical to radio wavelengths has revealed long term changes in its physical properties, with Hynes et al. (2002) reporting that the optical spectrum had yet to return to the pre-outburst state some 3 years after the outburst. Likewise, the spectral energy distribution of the system showed a long term secular brightening between 1-5μm consistent with either the heating or production of additional circumstellar dust (Clark et al. 2000, Clark & Larionov, in prep.). Finally, radio observations revealed the presence of an expanding oval shaped remnant (Fig. 1; Mioduszewski & Rupen 2004); quite dissimilar to the highly collimated jets normally associated with radio emitting XRB, a point we return to in Sect. 4.

Despite the extensive literature available, the nature of the underlying binary components and the physical processes leading to the 1998 outburst remain the subject of considerable debate. While the rich emission line spectrum of CI Cam confirms the 'classical' 2 component outflow characteristic of the B[e] phenomenon, it also veils (m)any photospheric features that might serve to indicate the intrinsic stellar luminosity. Moreover, those features that are accessible appear self contradictory; the possible presence of broad absorption profiles in the higher Balmer lines are suggestive of an early B Main Sequence or Giant star (Barsukova et al. 2005), while the strong P Cygni profiles observed in the Si IV 1394, 1402Å and C IV 1549,51Å doublets indicate an early B*Supergiant* classification (Hynes et al. 2002); consequently, resultant distance estimates have ranged from ∼1-2kpc to >4kpc, respectively[1].

The uncertainty in the nature of, and distance to, CI Cam inevitably propagates through to the nature of the outburst and the accreting object. The lack of X-ray pulsations or orbital modulations and a spectrum dissimilar to those normally observed in X-ray transients have led to white dwarf, neutron star and black hole accretors all being suggested, with the outburst variously being attributed to a thermonuclear flash on the surface of a white dwarf, an accretion disc instability or a brief episode of (super Eddington?) accretion due to the interaction of the accretor - presumably in a highly eccentric long period orbit - with the dense circumstellar environment of the B[e] star mass donor.

We note that at a distance of ≥5kpc, the total energy emitted by both X-ray *and* optical flares exceeds the Eddington limit for accretion onto a $1M_\odot$ relativistic object by >an order of magnitude (Hynes et al. 2002). Such an energy budget should not, however, be used to disfavour such a distance, given that the energy released by e.g. the LMC HMXB A 0538-66 in outburst has also been observed to exceed 10^{39}ergs^{-1}. Clearly, a more accurate distance determination would greatly help to constrain both the binary properties and outburst mechanism, as indeed would a determination of the orbital parameters.

It is therefore of great interest that Barsukova et al. (2005) have recently claimed the detection of a ∼19.4 day period in optical photometry of CI Cam and *also* in the RV curve of the He II emission line; strong support for the former claim is provided by the identification of this period in a second, independent photometric dataset (Clark & Larionov, in prep.). Given that some massive

[1]We note that the latter value appears marginally favoured upon consideration of the Na D line absorption components and galactic structure in the line of sight to CI Cam (Hynes et al. 2002).

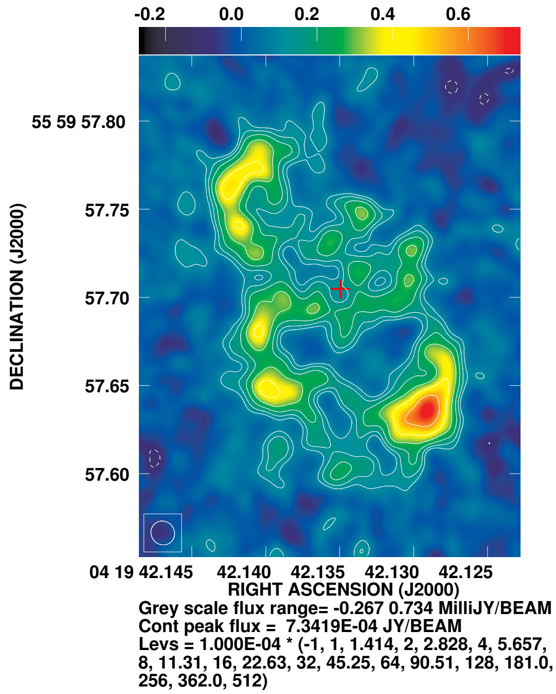

Figure 1. 1.7GHz radio map of the ejecta surrounding CI Cam on 1998 September 10, 163 days after the 1998 March 31 flare (from Mioduszewski & Rupen 2004). The position of CI Cam is indicated by the red cross, the peak flux density is 0.734 mJy beam^{-1} and beam size is 14.49 mas $\times$13.29 mas at 45.4°.

stars - the 'α Cygni' variables - also show photometric modulations of similar magnitude and periodicity, the verification of the spectroscopic period - to confirm an orbital rather than pulsational origin for the photometric modulation - is a matter of considerable urgency.

2.2. The *INTEGRAL* Sources

The ability of *INTEGRAL* to sample hard X-rays ($\geq$20keV) has revealed a new population of Galactic X-ray sources that were previously undetectable due to their high extinction ($N_H \geq 10^{23}$ergs^{-1}; Kuulkers 2005). Such values - significantly in excess of that expected from the ISM - suggest that there is a component of absorption intrinsic to the sources themselves, an hypothesis supported by the observation that for a subset of sources N_H is variable. Similar behaviour has been observed in HMXBs such as GX 301-2, Vela X-1 and tellingly CI Cam, implying that the hard X-ray *INTEGRAL* sources may also be HMXB, with the intrinsic absorption attributed to the circumstellar envelope of the system (Kuulkers 2005, and references therein).

Subsequent observations support this hypothesis, with four HMXB classified spectroscopically and the X-ray properties of a further six suggestive of such a classification. Of interest in the current context is the suggestion that 2 sources have potential counterparts with near-IR excesses. Of these, IGR J16320–4751

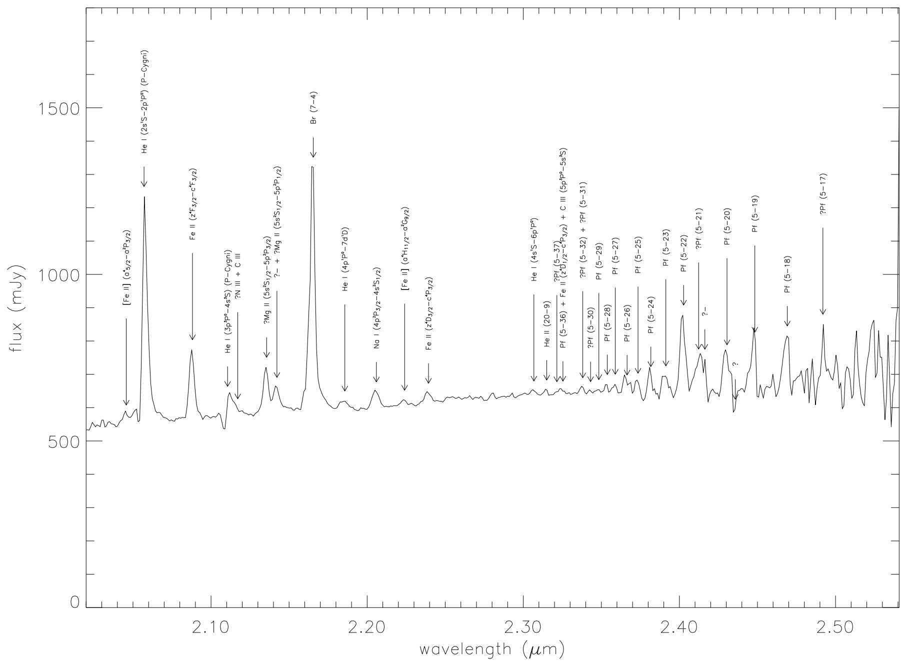

Figure 2. K band spectrum of the optical counterpart to IGR J16318–4848 from Filliatre & Chaty (2004), showing emission from both high (e.g. He II) and low (e.g. Na I) excitation species.

has yet to be observed spectroscopically, while IGR J16465–4507 appears to be a normal early B supergiant. However the 1-3μm spectrum of a third source, IGR J16318–4848 (Fig. 2; Filliatre & Chaty 2004), bears a remarkable similarity to that of CI Cam (Clark et al. 1999), being characterised by strong H I & He I emission and numerous permitted and forbidden low excitation metallic lines. Unfortunately no photospheric lines are visible, inevitably rendering a determination of temperature and luminosity difficult; hence no unique determination of distance, reddening or X-ray luminosity is possible[2]. However, inferring the presence of an early OB star from the emission lines present in the spectrum yields $\log(L/L_\odot) \geq 4.0$ (for a distance of $\geq$1kpc - consistent with the high value of A_v resulting for such a spectral classification), highly suggestive of a sgB[e] classification (Filliatre & Chaty 2004).

The strong similarity to CI Cam extends to the X-ray behaviour of both systems. Neither system shows any periodic modulation that might be attributed to orbital modulation or the pulse period of a neutron star. Both systems appear to show brief periods of activity separated by long periods of quiescence; CI Cam has only been observed to undergo a single outburst, while the non detection of IGR J16318–4848 by *Beppo-SAX* between 1996-2002 implies that it was at

[2]This uncertainty also precludes a determination of the spectral energy distribution - hence it is not possible to ascertain whether an IR excess due to dust emission exists. Nevertheless, the presence of Na I emission in the spectrum argues for dense, neutral regions within the circumstellar environment, which may permit the existence of hot dust.

least an order of magnitude fainter than observed during its 'active phases' in 1994 and 2003 (Walter et al. 2004). Moreover, both show rapid flaring activity on timescales of ∼hours, although we do not *a priori* claim identical flaring mechanisms given that the ratio of peak to quiescent flux for the 1998 outburst of CI Cam (Robinson et al. 2002) is greatly in excess of that observed for IGR J16318–4848 (Walter et al. 2004). Finally, strong emission lines are present in both spectra, which likely arise in the 'cool' dense circumstellar material responsible for the large intrinsic absorption inferred for both sources (e.g., Kuulkers 2005).

Table 1. Summary of the properties of the highly absorbed *INTEGRAL* sources; table adapted and expanded from that given by Kuulkers (2005). The presence of a question mark in the optical/IR counterpart column indicates that more than one potential candidate is found in the errorcircle. Sources for which the spectral type of the mass donor have been determined spectroscopically are given in bold type. References: [1] Sidoli et al. (2005), [2] Beckmann et al. (2005), [3] Filliatre & Chaty (2004), [4] Corbet et al. (2005b), [5] Rodriguez et al. (2006), [6] Patel et al. (2004), [7] Bodaghee et al. (2006), [8] Walter et al. (2004), [9] Negueruela et al. (2005), [10] Markwardt et al. (2005), [11] Corbet et al. (2005a), [12] Zurita Heras et al. (2006), [13] Hill et al. (2005), [14] Rodriguez et al. (2005), and [15] Negueruela, priv. comm.

IGR source	N_H [10^{23} cm^{-2}]	Opt/IR Cpt.	Remarks	Reference
16195–4945	≃1	?	**O9V/B1-2 Ia**?	[1]
16238–4838	≃0.4-1.7	?	candidate HMXB	[2]
16318–4848	≃20	Y	**sgB[e]**	[3]
16320–4751	≃2	Y	candidate SgXB	[4,5]
16358–4726	≃4	N	candidate LMXB	[6]
16393–4643	≃1	Y	candidate SgXB	[7]
16418–4532	≥1	N	-	[8]
16465–4507	≃7	Y	**B0-1 I**/SFXT	[9]
16479–4514	≃1	N	candidate SFXT	[9]
16493–4348	≃1	N	-	[10]
17252–3616	≃1-10	Y	candidate SgXB	[11,12]
18027–2016	≃0.7	N	candidate SgXB	[13]
19140+0951	≃0.3-1	Y	**O9 I**	[14,15]

2.3. Wd1 #9

Unlike CI Cam, the identification of Wd1 #9 with a massive ($\geq 35\,M_\odot$) progenitor is secured by its membership of the galactic super star cluster Westerlund 1 (Clark et al. 2005). First proposed as a sgB[e] star by Westerlund (1987), subsequent spectroscopic observations confirmed this classification but failed to reveal any photospheric features (Clark et al. 2005). Clark et al. (1998) confirmed the presence of a significant mid-IR excess, as expected for a sgB[e] star; however, *ISO-SWS* observations revealed the presence of [O IV] emission - requiring excitation temperatures of ≥80kK, greatly in excess of those expected for a B supergiant. Radio observations revealed the presence of spatially resolved emission with a ∼flat spectral index in addition to a strong thermal point source, suggestive of a compact, optically thin ejection nebula and a central star with a powerful stellar wind (Dougherty, in prep.). Recent *Chandra* observations by Muno et al. (in prep.) reveal Wd1 #9 to be coincident with an X-ray source with $L_x \sim 10^{33}$ergs^{-1}; no variability was observed during the period of observation (18ks+42ks, separated by a ∼month; Muno et al. in prep.). While the X-ray flux is consistent with an origin in either a CWB or HMXB, the value of N_H derived from modeling the spectrum requires no additional sources of absorption local to the system, in contrast to CI Cam and IGR J16318–4848, in turn suggesting an origin external to the complex circumstellar environment inferred from the optical, mid-IR and radio observations.

2.4. The Galactic Centre Sources

In a recent survey of the inner 25pc of the Galactic Centre, Muno et al. (2006) identified two new X-ray bright ($L_x \sim 10^{33}$ergs^{-1}) emission line stars, the low resolution 2μm spectra of which suggesting a classification of either sgB[e] or LBV (e.g. Morris et al. 1996; Clark et al. 2003), with the former slightly disfavoured on the basis of their near-IR colours. Both stars are spatially coincident with strong mid-IR sources; however, given the low spatial resolution of the observations, the nature of the emission (e.g. individual or blend of emitters) cannot be determined at present. Finally, both stars are detected at radio wavelengths, with the emission associated with X 174516.1 and H 2 (notation following Muno et al.) most likely originating in a stellar wind and ejection nebula respectively. Consequently, both sources are found to share common physical properties with Wd1 #9, a similarity compounded by their X-ray spectra, which as with #9, are best fit with a model consisting of a thermal plasma with a column density, N_H, consistent with no additional absorption local to the source.

3. SS433 - Accretion Driven Outflows & the B[e] Phenomenon

Finally, we turn to the relativistic jet HMXB - or 'microquasar' - SS 433, for which, despite over 25 years of intensive study, the natures of both binary components are still unknown. Nevertheless, a scenario under which the system is undergoing a brief phase of extreme mass transfer and accretion is commonly invoked to explain its observed properties. The resultant formation of a massive accretion disc around the compact object serves to obscure the central X-ray source, leading to the unexpectedly weak X-ray emission (0.1% of the kinetic energy (10^{39}ergs^{-1}) of the relativistic jets) observed. Moreover, it is supposed that the Super Eddington accretion rates also power a radiation driven outflow that is (in part) responsible for the rich emission line spectrum that veils with the underlying stellar spectrum of the mass donor (e.g., Barnes et al. 2006).

Both radio (Blundell et al. 2001) and optical (Clark et al. in prep.) observations strongly support such a scenario and help constrain the outflow geometry. In particular, the existence of a 'ruff' of radio emission perpendicular to the jet axis (Fig. 3) is identified with an equatorially concentrated outflow of material, although its kinematics and relationship to the accretion disc and/or an hypothetical *circumbinary* disc is currently unclear. However recent ∼8-9000Å spectra (Fig. 3) indicate that at least two kinematically distinct outflows must

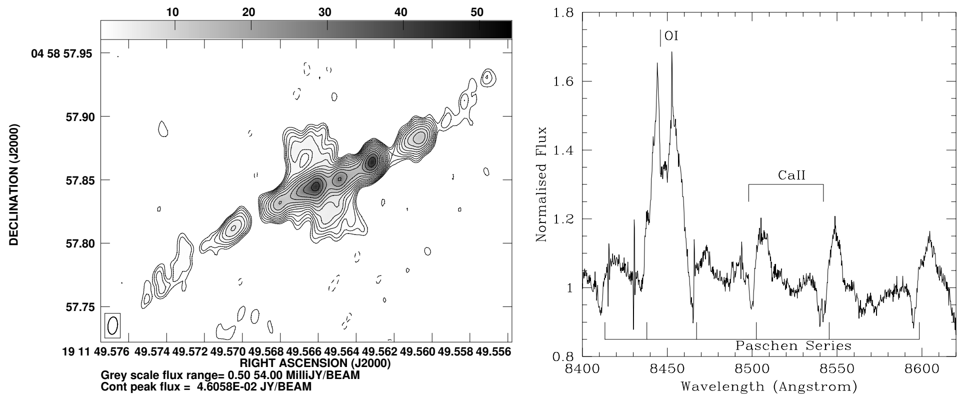

Figure 3. Left panel: 1.6GHz map of SS 433 from Blundell et al. (2001). Note the ruff of emission perpendicular to the well known relativistic jets. Right panel: Representative I Band spectrum of SS 433 from Clark, Barnes & Charles (in prep.). Note the pronounced P Cygni profiles of the H I Paschen series and the double peaked profile of O I 8446Å, possibly indicative of a wind+disc circumstellar geometry?

be present within the system, one dominated by radial motion and traced by the P Cygni profiles in the H I lines and a second, possibly rotationally dominated and traced by the low excitation O I emission.

Given the current debate as to the nature of the mass donor in SS 433, we state explicitly that we are *not* claiming that it is a sgB[e] star; moreover, given the apparent lack of forbidden line emission from this system we *do not* claim that it demonstrates the B[e] phenomenon as defined by Lamers et al. (1998)[3]. We merely note that in addition to the relativistic jets, the energy released via supercritical accretion in SS 433 appears to power two additional kinematically distinct outflows, of which one is confined to the equatorial/orbital plane of the system in a manner reminiscent of the B[e] phenomenon.

4. Discussion & Concluding Remarks

Defining the physical properties of a putative class of B[e]XRBs and the identification of possible members is currently hampered by a number of observational constraints. The difficulty in determining the intrinsic luminosity of, and distance to, stars demonstrating the B[e] phenomenon clearly afflicts the potential mass donors in B[e]XB and also leads to uncertainties in absolute X-ray fluxes. Moreover, the rich emission line spectra complicate the spectral determination of the radial velocity curves that would unambiguously determine the binary status and orbital parameters of B[e]XBs.

Other observational considerations - and possible defining physical characteristics - may be inferred from the properties of the candidate B[e]XBs. The

[3]Although in this context the suggestion by Fuchs et al. (2006) that a contribution from cool (∼150K) dust is required to adequately model the spectral energy distribution of SS 433 is of interest.

current lack of observational constraints regarding the intrinsic X-ray emission of both isolated sgB[e] stars and CWBs containing sgB[e] stars prevents an assessment of the nature of the comparatively weak X-ray sources Wd1 #9, X 174516.1 and H 2. While their X-ray luminosities appear consistent with the quiescent fluxes of SFXTs (Negueruela et al. 2005) - and X 174516.1 appears variable - none appear to show the significant intrinsic absorption that characterises the *INTEGRAL* candidates (although this might be due to a large orbital separation). Nevertheless, their similar X-ray properties, high bolometric luminosities and the possible presence of detached circumstellar ejecta is suggestive of a homogenous group of objects and by analogy to the LBV η Carinae, we *tentatively* suggest they are CWBs, containing either an LBV or sgB[e] star.

In contrast, the X-ray luminosities and hard X-ray spectra of CI Cam and the *INTEGRAL* sources strongly suggest an HMXB identification. However, while the presence of significant intrinsic absorption is likely to be a defining characteristic of B[e]XRBs, it is also likely to mitigate against their detection by missions sensitive to lower energies. For example, a combination of high intrinsic absorption and large distances (with resultant source confusion) may well explain the lack of detection of a putative cc for any of the sgB[e] stars within the Magellanic Clouds by RXTE ASM, without appealing to the additional possibilities of intrinsically low emission and/or a long duty cycle.

Unfortunately, without accurate distances, the evolutionary histories of CI Cam and IGR J16318–4848 are poorly constrained. The complimentary uncertainties in their orbital parameters (period, separation and eccentricity) also preclude a determination of the mode(s) of accretion occuring within them, and the nature of the interaction between the accretor and circumstellar environment of the mass donor. Observationally, both CI Cam and IGR J16318–4848 demonstrate long quiescent periods with low X-ray fluxes, occasionally punctuated with short lived flares. By analogy with the SFXTs such behaviour could be due to instabilities in a putative accretion disc or changes in the density of the circumstellar envelope as seen by the accretor, either due to a highly eccentric orbit or a highly structured environment (either small scale stochastic clumping or large scale density perturbations/kinematically distinct outflows). It is to be hoped that if orbital parameters for these systems are secured, analysis of time resolved multiwavelength datasets may be utilised to probe the kinematics and structure of the circumstellar environments of their mass donors in a manner analogous to BeXBs.

While it might be supposed that the probable short lifetime (10^4-10^5yr) of sgB[e] stars might make sgB[e]XBs extremely rare, we note that if rapid rotation plays a key role in the onset of the B[e] phenomenon (c.f. classical Be stars), mass transfer in the binary progenitors prior to SN may act to spin up the current mass donor and hence increase the proportion of HMXB that may become sgB[e]XBs. In any event, one might anticipate their existence from WR+cc binaries such as Cyg X–3 and IC 10 X–1. These evolve from long period OB+cc binaries as the mass donor leaves the main sequence, leading to RLOF, common envelope evolution & spiral in of the cc; if the 2 components avoid a merger the dissipation of orbital energy will lead to the ejection of the H rich mantle of the OB star, leaving a short period WR+cc binary. For stars $<40M_\odot$ this would occur during a Red Supergiant phase, but it is not thought that $>40M_\odot$ stars become RSGs, therefore spiral-in must instead occur during an LBV or sgB[e] phase, likely resulting in significant accretion rates. In this context SS 433 is clearly of relevance, given the apparent obscuration of the central engine of the system due to an extreme accretion rate. However, it is probable that the complex, kinematically discrete outflows found within the SS 433 system are driven by energy liberated by accretion, rather than being intrinsic to the mass donor, suggesting two potential causes for the B[e] phenomenon in accreting binaries.

Finally, what is the physical motivation for the identification and study of B[e]XBs given the attendant observational difficulties? In addition to providing insights into the different causes of the B[e] phenomenon, and the geometry and kinematics of the circumstellar environment it arises within, we identify three topics for which it is of direct relevance. Firstly, Lebrun et al. (2004) demonstrate that the hard X-/soft γ-ray background of the Galaxy is due to a population of hitherto unresolved point sources, of which a number are likely to be highly obscured HMXB, including sgB[e]XBs such as IGR J16318–4848. Hence an understanding of the physical properties of these sources and the evolutionary pathways leading to their formation is required to explain the high energy properties of both our own and external galaxies - in particular starbursts, for which the vigorous ongoing star formation may yield an XRB population dominated by HMXBs.

Secondly, King (2002) proposes that a significant population of the so called Ultraluminous X-ray sources - off nuclear point sources in external galaxies with $L_x \geq 10^{39}$ergs^{-1} - are likely to be anisotropically emitting X-ray binaries containing stellar ($\sim$5-15M$_\odot$) rather than intermediate mass ($\sim 10^2 - 10^3$M$_\odot$) black holes. If a subset of ULXs are indeed such 'normal' HMXB undergoing thermal-time-scale mass transfer, by analogy to the galactic 'prototype' SS 433 we might expect optical counterparts to possess many of the characteristics of B[e] stars; hence an understanding of such galactic objects will benefit studies of extragalactic examples, particularly informing searches for possible orbital modulation in order to obtain direct kinematic mass determinations for the accreting black holes.

Finally, we again highlight the finding of Mioduszewski & Rupen (2004) that the radio emission resulting from the 1998 flare in CI Cam does not arise in the highly collimated jets that appear ubiquitous to radio bright XRBs, but instead originates in a clumpy, edge brightened shell. They attribute this to the early 'smothering' of such relativistic jets by the dense circumstellar medium, with the radio emission produced by the resultant shock propagating outwards. As such CI Cam, and systems like it, may provide a unique laboratory to investigate the failed jet model for supernovae explosion in collapsars at kpc rather than Mpc distances.

Acknowledgments. JSC is supported by an RCUK fellowship, and wishes to thank Ignacio Negueruela, Katherine Blundell, Sean Dougherty, Amy Mioduszewski, Mike Muno, Phillipe Filliatre, Sylvain Chaty, Phil Charles and Andy Barnes for many informative discussions and/or their kind permission to present either unpublished results or reproduce the figures within the text.

References

Barnes, A. D., Caseres, J., Charles, P. A., Clark, J. S., Cornelisse, R., Knigge, C., & Steeghs, D. 2006, MNRAS, 365, 296

Barsukova, E. A., Borisov, N. V., Burenkov, A. N., Klochkova, V. G., Goranskij, V. P., & Metlova, N. V. 2005, ATel, 416, 1

Beckmann, V., Kennea, J. A., Markwardt, C., et al. 2005, ApJ, 631, 506

Blundell, K. M., Miodusewski, A. J., Muxlow, T. W. B., Podsiadlowski, P., & Rupen, M. P. 2001, ApJ, 562, L79

Bodaghee, A., et al. 2006, A&A, 447, 1027

Boirin, L., Parmar, A. N., Oosterbroek, T., Lumb, D., Orlandini, M., & Schartel, N. 2002, A&A, 394, 205

Clark, J. S., Fender, R. P., Waters, L. B. F. M., Dougherty, S. M., Koornneef, J., Steele, I. A., & van Blokland, A. 1998, MNRAS, 229, L43

Clark, J. S., Steele, I. A., Fender, R. P., & Coe, M. J. 1999, A&A, 348, 888

Clark, J. S., Miroshnichenko, A. S., Larionov, V. M., et al. 2000, A&A, 356, 50

Clark, J. S., Egan, M. P., Crowther, P. A., Mizuno, D. R., Larionov, V. M., & Arkharov, A. 2003, A&A, 412, 185

Clark, J. S., Negueruela, I., Crowther, P. A., & Goodwin, S. P. 2005, A&A, 427, 839

Corbet, R., Markwardt, C. B., & Swank, J. H. 2005a, ApJ, 633, 377

Corbet, R., et al. 2005b, ATel, 649

Filliatre, P., & Chaty, S. 2004, ApJ, 616, 469

Fuchs, Y., Koch Miramond, L., & Abraham, P. 2006, in ASP Conf. Ser., Massive Stars in Interacting Binaries, ed. N. St-Louis & A. Moffat (San Francisco: ASP), in press

Hill, A. B., et al. 2005, A&A, 439, 255

Hynes, R. I., Clark, J. S., & Barsukova, E. 2002, A&A, 392, 991

King, A. R. 2002, MNRAS, 335, L13

Kuulkers, E. 2005, in AIP Conf. Proc. Vol. 797, Interacting Binaries: Accretion, Evolution and Outcomes, ed. L. Burderi et. al. (Melville, AIP), 402

Lamers, H. J. G. L. M., Zickgraf, F.-J., de Winter, D., Houziaux, L., & Zorec, J. 1998, A&A, 340, 117

Lebrun, F., et al. 2004, Nature, 428, 293

Markwardt, C, B., Swank, & J. H., Smith, E. 2005, ATel, 465

Mioduszewski, A. J., & Rupen, M. P. 2004, ApJ, 615, 432

Morris, P. W., Eenens, P. R. J., Hanson, M. M., Conti, P. S., & Blum, R. D. 1996, ApJ, 470, 597

Muno, M. P., Bower, G. C., Burgasser, A. J., Baganoff, F. K., Morris, M. R., & Brandt, W. N. 2006, ApJ, 638, 183

Negueruela, I. 2004, in JENAM 2004 Astrophysics Reviews, The Many Scales of the Universe, ed. J. C. del Toro Iniesta et al. (Dordrecht: Kluwer), in press, [astro-ph/0411759]

Negueruela, I., Smith, D. M., Reig, P., Chaty, S., & Torrejon, J. M., 2005, in The X-ray Universe 2005, ESA-SP 604, [astro-ph/0511088]

Okazaki, A. T., & Negueruela, I. 2001, A&A, 377, 161

Parmar, A. N., Belloni, T., Orlandini M., Dal Fiume D., Orr, A., & Masetti, N. 2000, A&A, 360, L31

Patel, S. K., et al. 2004, ApJ, 602, L45

Robinson, E. L., Ivans, I. I., & Welsh, W. F. 2002, ApJ, 565, 1169

Rodriguez, J., et al. 2005, A&A, 432, 235

Rodriguez, J., et al. 2006, MNRAS, 366, 274

Sidoli, L, Vercellone, S., Mereghetti, S., & Tavani, M. 2005, A&A, 429, L47

Smith, D., Remillard, R., Swank, J., Takeshima, T., & Smith, E. 1998, IAU Circ. 6855

Walter, R., et al. 2003, A&A, 411, L427

Walter, R., et al. 2004, in The Integral Universe, ESA SP-552, 471

Westerlund, B. E. 1987, A&AS, 70, 311

Zickgraf, F.-J. 2003, A&A, 408, 257

Zurita Heras, J. A., et al. 2006, A&A, 448, 261