Unveiling new quiescent black holes with IPHAS

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Abstract Soft X-ray transients (SXTs) provide the best evidence for the existence of stellar-mass black holes (BHs) with almost 20 confirmed systems based on dynamical studies. However, there is an estimated population of a few thousand dormant BH binaries, which slowly reveal themselves through secular X-ray outbursts. Therefore, new strategies aimed at unveiling this dormant population are clearly needed. We propose to use the IPHAS catalogue, together with several diagnostic diagrams, as a shortcut to unveil the brightest members of the Galactic population of BH binaries. Here we present some of the diagrams we are using to distinguish between SXTs and other types of object found by the IPHAS survey.

1 Introduction: X-ray binaries and black holes.

X-ray binaries are composed by a compact object, either a black hole (BH) or a neutron star (NS), and a companion star which transfers material to the compact object through an accretion disc. According to the mass of the companion star, they have been classified in Low-Mass (LMXBs), Intermediate-Mass (IMXBs) and High-Mass X-ray Binaries (HMXBs) [1]. Soft X-ray transients (SXTs), a subclass of LMXBs, provide the best hunting ground for stellar-mass black holes. Dynamical studies have revealed that $\sim$ 75% of SXTs harbour an accreting BH, which makes a total of 17 confirmed cases.

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The study of SXTs have implications in our understanding of a wide range of astrophysical subjects such as the late evolution of massive stars, supernovae models, relativistic outflows, or chemical enrichment of the Galaxy [2]. However, the most compelling evidence for the existence of stellar-mass BHs still relies on dynamical arguments [3]. All of these 17 Galactic BHs have been discovered through outburst episodes and most of them are located in the Galactic plane (Fig. 1). There are other 27 candidates based on X-ray timing and spectral properties, since the down of X-ray astronomy [10]. Nevertheless, these are only the tip of the iceberg, as an estimated population of a few thousand BHs binaries are awaiting discovery [2].

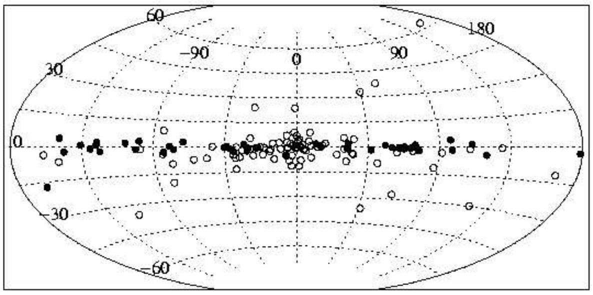

Fig. 1 Distribution of XRBs in the Galaxy. Solid dots represent HMXBs, open circles LMXBs. HMXBs are located around the Galactic plane, while LMXBs are mainly found in the bulge. Most LMXBs lie between $-10^{\circ} < b < +10^{\circ}$, the rest of them are associated to globular clusters or have a NS as accreting object [8].

The observed distribution of BH masses range between $4 - 14\ M_{\odot}$, with typical errorbars of 30% [1]. Models of supernova explosions in binary systems predict a continuum spectrum between neutron stars and BH masses with a maximum cut-off which depends on the details of the common-envelope stage and mass loss during the Wolf-Rayet phase [6]. Unfortunately, the observed BH mass distribution suffers from low-number statistics and cannot set useful constraints to the theory of BH formation.

2 The IPHAS survey

New strategies aimed at unveiling the dormant population are urgently needed. Since SXTs cluster at the Galactic plane [9] we have embarked in a project which uses the *INT Photometric Hα Survey of the Northern Galactic plane* (IPHAS) catalogue[1].

[1] www.iphas.org

IPHAS maps the Galactic plane between $-5^\circ < b < +5^\circ$ in the Hα, r', and i' bands using the Wide Field Camera (WFC) mounted on the 2.5m Isaac Newton Telescope (INT) at the Observatorio del Roque de los Muchachos on La Palma. The r'-magnitude range is between 13 and 20 (10σ) [5]. The first data release contains 200 million objects and currently more than 90% of the planned 1800 deg^2 have been observed. IPHAS is expected to conclude during this year [7].

There are other surveys in progress to extend IPHAS, for instance:

- **UVEX**: *The Northern Galactic Plane UV-excess Survey* will complete IPHAS in the blue range using U, g', r' and HeI 5870 (Groot, P. et al. 2008, draft).
- **VPHAS+**: *VST/OMEGACAM Photometric Hα and broad-band Survey of the Southern Galactic Plane*, will complete IPHAS and UVEX but in the Southern Hemisphere using the VST telescope.

3 Diagnostic diagrams

We use the IPHAS catalogue together with several diagnostic diagrams as a shortcut to unveil the brightest members of the Galactic population of BH binaries. Quiescent BHs reveal themselves by their strong Hα emission in a (r'-Hα) vs. (r'-i') colour-colour diagram, but so do other types of object such as Be-stars or cataclysmic variables (CVs). Fig. 2 shows the location in the colour-colour diagram of a sample of 11 CVs candidates discovered by IPHAS [11], together with other CVs already known in the Galactic plane, Be-stars, symbiotics, planetary nebulae and 9 SXTs from our own database. The figure shows a concentration of SXTs in a region that is not occupied by CVs. BHs tend to be redder ($(r'-i') > 0.8$) because of their lower mass accretion rates and larger reddening. Only A0620-00, the nearest SXT known at only 1 kpc, has a bluer ($(r'-i')$) colour, consistent with most CVs. The red solid line in Fig. 2 represents the unreddened main-sequence track, so objects above this line (as SXTs) have an Hα excess. In fact, these binary systems display strong Hα emission produced in the accretion disc.

According to Fig. 2, Be-stars are the main interlopers: half of them are located in the same region as SXTs, so to distinguish between these two populations may require data from radio/IR/X-ray catalogues. Therefore, we have created an IR diagram (Fig. 3) using 2MASS. In this case, we have represented in a $(H-K_{\rm s})$ vs. $(J-H)$ diagram the same objects as in the optical one. In addition, we have included IR information of T-Tauris, from which we do not have optical colours yet. By crossing these two diagrams we are able to discard most types of object. We tentatively define the SXT region by the limits $(r'-i') = 0.8-1.5$, $(r'-H_\alpha) = 0.5-1.5$, $(H-K_s) = 0.1-0.7$ and $(J-H) = 0.5-1.1$. Planetary nebulae are completely out of the SXTs in the optical, while they share the same region in the IR. On the other hand, Be-stars overlap with SXTs in the optical but not in the IR. In Table 1 we

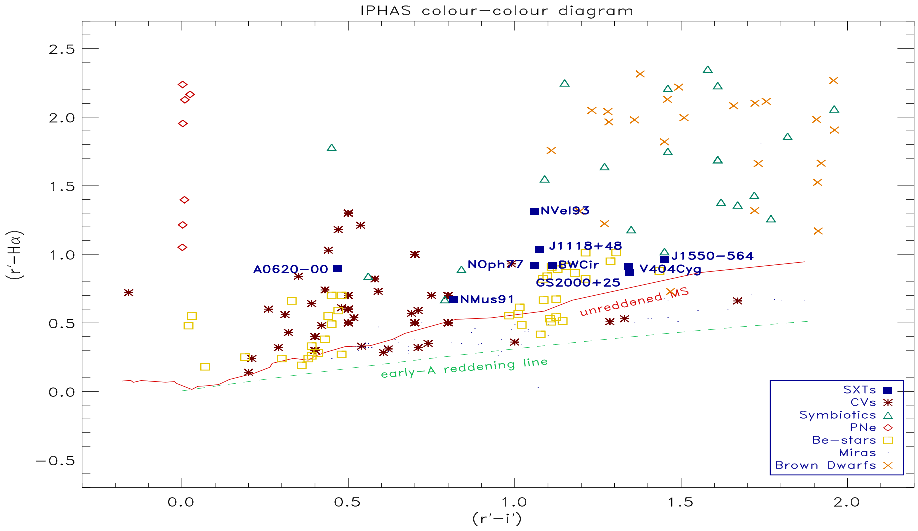

Fig. 2 (r'-i') vs. (r'-Hα) diagram. The red solid line represents de unreddened main-sequence track and the dashed green line is the early-A reddening line. In this diagram we represent almost every type of object we can find in the Galactic plane which can be confused with SXTs. CVs (brown $*$) ([11],[12]), planetary nebulae (blue $\diamond$) , symbiotic binaries (green $\triangle$), Miras ($\cdot$), and Be-stars (yellow $\square$) ([4]). These are probably the objects whose colours are more similar to SXTs.

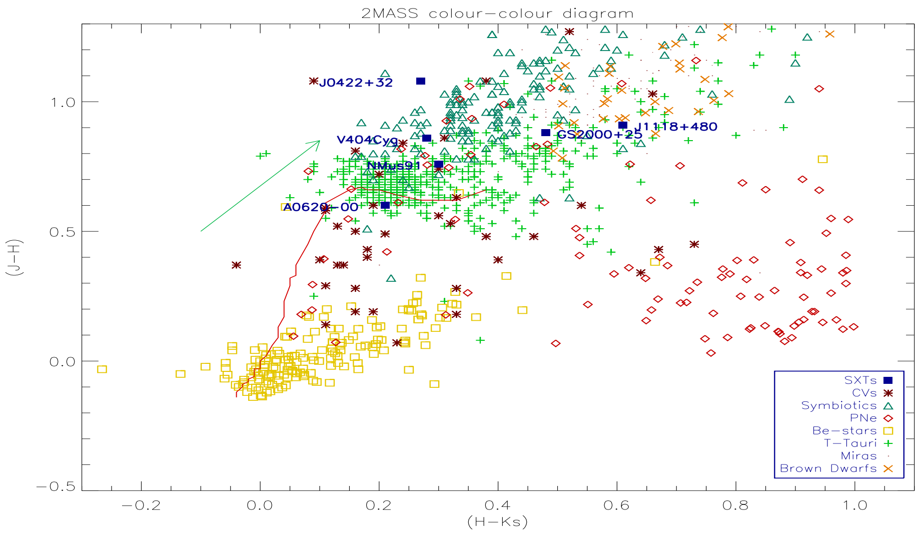

Fig. 3 $(H-K_s)$ vs. $(J-H)$ diagram. As in Fig. 2 the solid red line represents the unreddened main-sequence track and the arrow the reddening vector for normal stars. The same types of object are represented here. In this case, we have added T-Tauris (light green +) which are now the main overlaps with SXTs.

list the fraction of objects excluded from the SXTs region by each diagram. In the IR diagram more CVs and symbiotics appear in the SXTs area because they show greater dispersion than in the optical diagram. There are less SXTs in the IR than in optical because of their magnitudes in the infrared range.

This is clearly not enough to create a sample of BHs candidates from the IPHAS+2MASS catalogues. It is therefore essential to add extra information from other wavelength ranges before starting follow-up spectroscopic campaigns of selected candidates. Thus, we are now collecting of the different populations of Hα emitters in radio, X-rays and blue colours.

The aim of the spectroscopy project is to unveil new objects but also to measure radial velocities and mass functions of the compact objects, $f(M_1)$, for the XRBs candidates. With the mass function we will be able to confirm the type of compact object: if $f(M_1) > 3$ M$_\odot$, then the compact object must be a black hole.

Table 1 Percentage of objects discarted by each diagram after selecting an area around SXTs.

Objects	Optical	IR
Be-stars	50%	99%
Planetary nebulae	100%	89%
CVs	91%	69%
Symbiotics	89%	55%
Brown Dwarfs	91%	75%

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