PROCEEDINGS OF SCIENCE

X-Ray Binary Systems - A Cauldron of Physical Processes (An updated review)

Franco Giovannelli∗†
INAF - Istituto di Astrofisica e Planetologia Spaziali, Via del Fosso del Cavaliere, 100, 00133 Roma, Italy
E-mail: franco.giovannelli@iaps.inaf.it

This paper is based on few updated sections of the book published in 2004 by the Kluwer Academic Publishers, reprinted from the review paper by Giovannelli & Sabau-Graziati (2004). Because of the impossibility of realizing a complete picture of the behaviour and physics governing the X-ray binary systems, I was obliged to make a selection of the arguments to be discussed and how to present them.
I have emphasized the important role played by the magnetic field in these systems, of course with limitations due both to a reasonable length of this paper and my knowledge.

4th Annual Conference on High Energy Astrophysics in Southern Africa
25-27 August, 2016
Cape Town, South Africa

∗Speaker.
†A footnote may follow.

PoS(HEASA 2016)031

1. Introduction

Important observations started early in the past century with the discovery of inexplicable effects - the supernovae. They had been observed in ancient times but it was only with the establishing of the stellar and galactic distance scales that their true enormity was realized, namely the release of $\geq 10^{50}$ erg within a matter of days.

The beginning of the Space Astrophysics Era is commonly located around the end of the fifties of the last century with the first space experiments, in the energy range 0.2–0.5 MeV, on board balloons. They were devoted to the detection of γ-rays generated in solar activity (Peterson & Winckler, 1958). But actually γ-ray astronomy was born in the last year of the XIXth century with the discoveries of penetrating gamma radiation (Villard, 1900), and the atmospheric ionization (Wilson, 1900). Wilson suggested that the extraterrestrial gamma radiation could be responsible for the atmospheric ionization. With balloon flights Hess (1912) demonstrated the extraterrestrial and extra-solar origin of the ionizing radiation, which was called *Cosmic Rays*.

Until 1927 it was thought that cosmic rays consisted of γ-rays. Thanks to the discovery of the dependence of the cosmic ray flux on the geomagnetic latitude during a trip from Java to Genoa made by Clay (1927), it was recognized that the composition of cosmic rays included charged particles. Later Hayakawa (1952) determined the contribution of γ-rays to the composition of cosmic rays as less than 1%. The experiments outside the atmosphere started in 1946, soon after the end of the second world war, when the Naval Research Laboratory (NRL) launched a V2 rocket with a payload which observed the Sun's UV spectrum.

Since that time many space experiments were prepared and several fundamental results were reached. In our opinion the actual beginning of the Space Era for studying the Universe is the year 1962. An X-ray experiment – prepared by Giacconi, Gursky, Paolini & Rossi – launched on board an Aerobee rocket discovered a strong X-ray emission from an extra-solar object, namely Sco X-1 (Giacconi et al., 1962). After this first historical experiment many others were launched on board rockets and later balloons and satellites. These experiments lead to our knowledge of an X-ray sky hitherto unknown which started to give experimental proofs of the first theories of Baade & Zwicky (1934) about the possible existence of neutron stars.

Indeed, Baade & Zwicky (1934) first suggested that the supernova was the result of the transition from a normal star to a neutron star. The essential point (Zwicky, 1939) being that the energy releases in such a process is comparable to the change in gravitational potential energy of a star, which collapses from its "normal" size of $\sim 10^6$ Km down to the size of a neutron star of ~ 10 Km.

In the 1950's, Burbidge et al. (1957) with their works on stellar nucleosynthesis suggested realistic models of stars prior to supernova explosion. The supernova process was seen as the result of catastrophic change of state occurring in the core of a highly evolved star, e.g. the transformation of an iron core into a helium core.

Contrary, Cameron (1958) suggested that this degenerate iron core would collapse to a neutron core through inverse beta decay.

The discovery (by chance) of the first X-ray source (Sco X-1) (Giacconi et al., 1962)[1] accelerated the studies on neutron stars, until that Zel'dovich & Guseinov (1965) suggested the presence of an unseen massive companion in a binary system.

[1]This was the first measurement that originated the Nobel Price of Riccardo Giacconi.

PoS(HEASA 2016)031

Space orbiting observatories with larger and more sophisticated experiments – from Uhuru launched in 1970 (Giacconi et al., 1971) up to HEAO-1 launched in 1977 (Wood et al., 1984) – discovered the most luminous galactic and extragalactic X-ray sources, such as pulsars, X-ray binaries, supernova remnants (SNRs), bursters, and active galactic nuclei (AGNs). But the qualitative jump in the observational capabilities was obtained with the HEAO-2 satellite (Einstein) (Giacconi et al., 1979) in which the X-ray focussing optics of the instruments enhanced the sensitivity in the soft X-ray range by a factor of about 1000 with respect to the old generation of detectors. Also the angular resolution was improved up to ~ 2 arcsec.

This allowed a re-definition of the positions of the already known X-ray sources and the discovery of a large number of weaker ones, such as the normal galaxies and normal stars spread on the entire HR diagram (Vaiana et al., 1981). The detected X-ray fluxes from these stars are definitively larger than those expected from theories of formation and heating of stellar coronae.

This led to a revolution in the comprehension of the role of the star rotation and of the magnetic field in the turbulent transport of energy from the nucleus to the external parts of a star.

Figure 1 shows the evolution of the discovery of X-ray sources starting from UHURU catalog to HEAO A-1 catalog (left upper and lower panels) and γ-ray sources, starting from COS B catalog to 3rd EGRET catalog (right upper and lower panels).

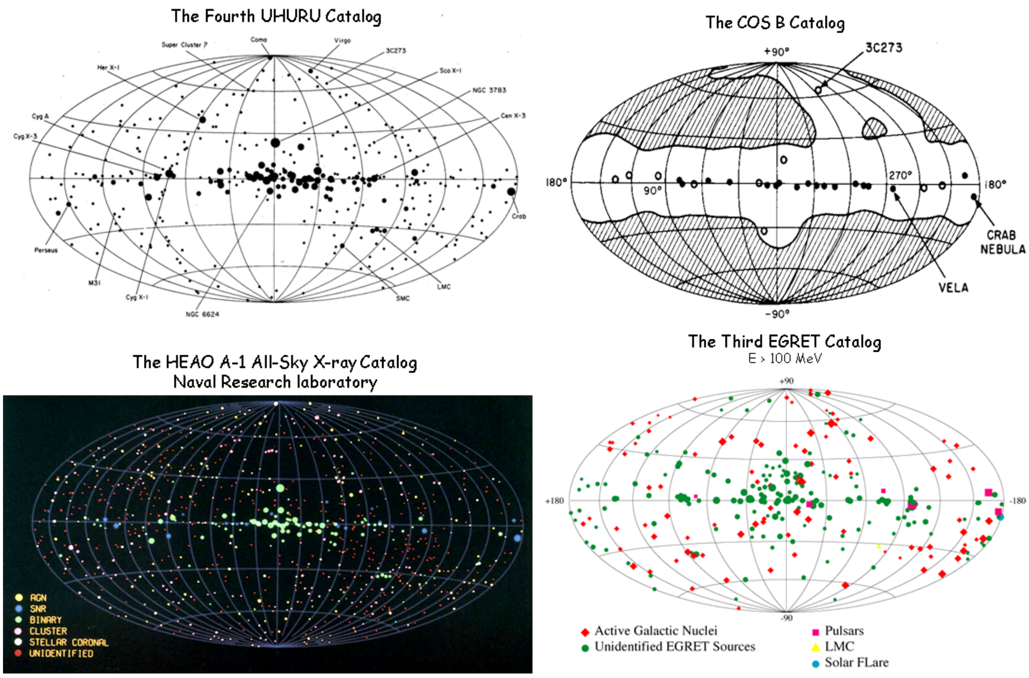


Figure 1: Clockwise from upper left panel: UHURU catalog (Forman et al., 1978), COS B catalog (Swanenburg, et al., 1981), 3rd EGRET catalog (Hartman et al., 1999), HEAO A-1 catalog (Wood et al., 1984).

After those experiments that opened the high-energy (HE) windows to the universe, many other satellites were successfully launched both in X-ray and γ-ray ranges, as well as ground-based experiments for the highest energies.

In the 1980-ies the VHE sky was empty and started to be populated only in the subsequent

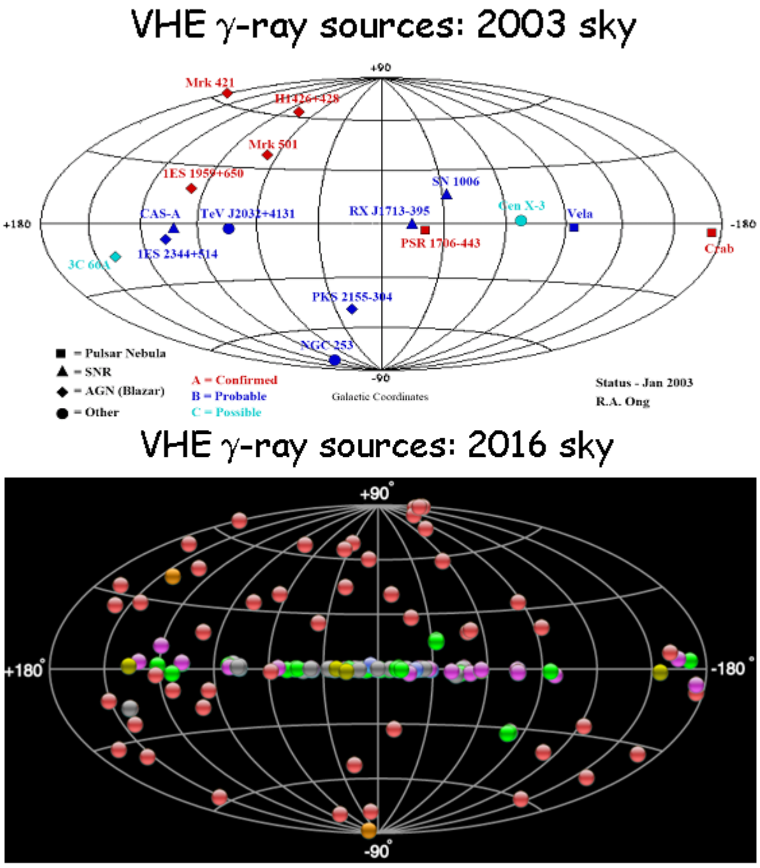


Figure 2: Upper panel: VHE sky as known in 2003 (Rene A. Ong, 2003); lower panel: VHE sky updated to 2016 (Current Catalog Version: 3.400) (Scott Wakely & Deirdre Horan, 2016)

decade. Indeed, in the 1990-ies, high-energy γ-rays have come to play an important role especially in the study of AGNs. Before the launch of the CGRO in 1991, the only known extragalactic source of high-energy γ-rays was 3C 273, which had been detected with the COS B satellite (Swanenburg et al. 1978). The EGRET detector on the CGRO has identified more than 65 AGNs which emit γ-rays at energies above 100 MeV (Hartman et al. 1999), and a substantial fraction of those sources which remain unidentified in the EGRET catalog are likely to be AGNs as well. In addition, the Whipple Observatory γ-ray telescope discovered three AGNs which emit at energies above 300 GeV (Mk 421: Punch et al., 1992; BL Lac object Mrk 501: Quinn et al., 1996; BL Lac object 1ES 2344+514: Catanese et al., 1998), and the detections of some other AGNs with Cerenkov telescopes (Blazar 3C 66A: Neshpor et al. 1998; 1ES 0323+022, PKS 0829+046, 1ES 1101-232, Cen A, PKS 1514-24, RX J10578-275, and 1ES 2316-423: Chadwick et al. 1999). During flaring episodes, the γ-ray emission can greatly exceed the energy output of the AGNs at all other wavelengths. Thus, any attempt to understand the physics of these objects must include consideration of the γ-ray emission.

Figure 2 shows the VHE sky as it was illustrated by Ong (2003) (upper panel) and how it is now (Wakely & Horan, 2016) (lower panel).

Following the review by Rieger, de Oña-Wilhelmi & Aharonian (2013), the discovery of more than 100 extraterrestrial sources of Very High Energy (VHE, $\geq$ 100 GeV) or TeV γ-radiation belongs to the most remarkable achievements of the last decade in astrophysics. The strong impact of these discoveries on several topical areas of modern astrophysics and cosmology are recognized and highly appreciated by different astronomical communities. The implications of the results obtained with ground-based TeV γ-ray detectors are vast; they extend from the origin of cosmic rays to the origin of Dark Matter, from processes of acceleration of particles by strong shock waves to the magnetohydrodynamics of relativistic outflows, from distribution of atomic and molecular gas in the Interstellar Medium to the intergalactic radiation and magnetic fields. TeV γ-rays are copiously produced in environments where effective acceleration of particles (electrons, protons, and nuclei) is accompanied by their intensive interactions with the surrounding gas and radiation fields. These interactions contribute significantly to the bolometric luminosity of young Supernova Remnants (SNRs), Star Forming Regions (SFRs), Giant Molecular Clouds (GMCs), Pulsar Wind Nebulae (PWNe), compact Binary Systems, AGNs, and Radio Galaxies (RGs).

Figure 3 shows the increasing number of X-ray and γ-ray sources, as seen by different experiments, since 1962, when the firs extra-solar X-ray source was detected.

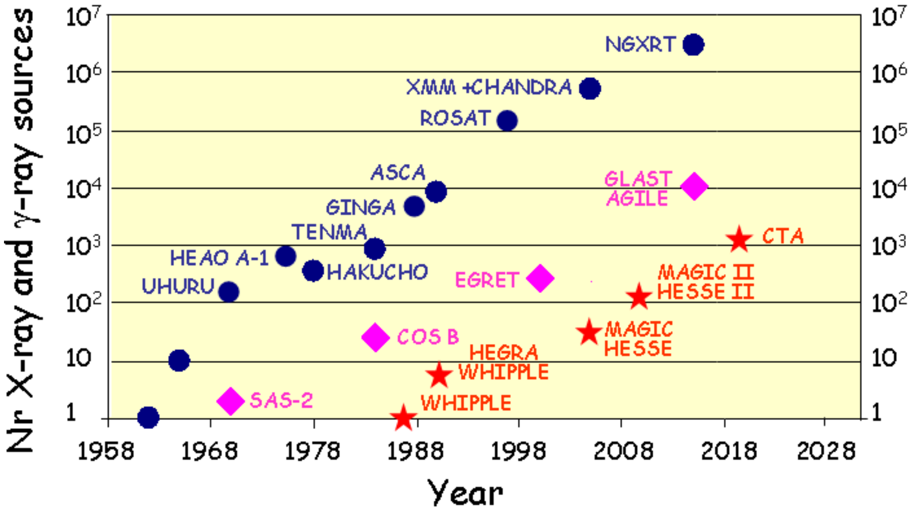


Figure 3: History of the number of X-ray and γ-ray sources detected (after Andrea Santangelo, 2006). Blue points: X-rays; fuchsia diamonds: HE γ-rays; red stars: VHE γ-rays.

2. X-ray binary systems

The trivial definition of X-ray binaries (XRBs) is that they are binary systems emitting X-rays. However it has been largely demonstrated that X-ray binary systems emit energy in IR, Optical, UV, X-ray, Gamma-ray and sometimes they show also valuable radio emission. They can be divided in different sub-classes

- High Mass X-ray Binaries (HMXB) in which the optical companion is an early type giant or supergiant star and the collapsed object is a neutron star or a black hole. They are concentrated around the galactic plane. The mass transfer is usually occurring via stellar wind; they show hard pulsed X-ray emission (from 0.069 to 1413 s) with KT $\geq$ 9 keV; typical X-ray luminosity is ranging from 10^{34} to 10^{39} erg s^{-1}, and the ratio of X-ray to optical luminosity is $\sim 10^{-3}$–10. The HMXBs can be divided in two sub-classes

- Hard Transient X-ray Sources (HXTS) in which the neutron star is eccentrically (e $\sim$ 0.2–0.5) orbiting around a V-III luminosity-class Be star ($P_{orb} > 10$ days); they show strong variable pulsed hard X-ray emission ($L_{Xmax}/L_{Xmin} > 100$) with KT $\geq$ 17 keV, and P_{spin} ranging from 0.069 to 1413 s; $L_X = 10^{34} - 10^{39}$ erg s^{-1}.
- Permanent X-ray Sources in which the neutron star or black hole is circularly orbiting (e $\sim$ 0) around a giant or supergiant OB star ($P_{orb} < 10$ days); they show an almost steady permanent pulsed hard X-ray emission ($L_{Xmax}/L_{Xmin} \ll 100$), and P_{spin} ranging from 0.069 to 1413 s; $L_X \sim 10^{37}$ erg s^{-1}.
  - Obscured Sources, which display huge amount of low energy absorption produced by the dense wind of the supergiant companion, surrounded by a weakly magnetized neutron star.
  - Supergiant Fast X-ray transients (SFXT), a new subclass of transients in which the formation of transient accretion discs could be partly responsible for the flaring activity in systems with narrow orbits. They show $L_{Xpeak} \approx 10^{36}$ erg s^{-1}, and $L_{Xquiecence} \approx 10^{32}$ erg s^{-1}.
- Anomalous X-ray Pulsars (AXPs) in which the optical counterparts probably are not OB and Be stars. They show a soft-hard X-ray emission with KT $\sim$ 0.4–4 KeV, $L_{Xmax}/L_{Xmin} \approx 10$, and $L_X/L_{opt} \sim 0.001$–10, being $L_X = 10^{34} - 10^{36}$ erg s^{-1}. On the contrary to the former two classes the rotational period of the pulsar is limited in a very narrow range: $P_{spin} \sim$ 6–12 s.

- Low Mass X-ray Binaries (LMXB) in which the optical companion is a low-mass-late-type star and the collapsed object is a neutron star or a black hole (P_{orb} from 41 min to 11.2 days). They are concentrated around the galactic plane and especially in the galactic center. The mass transfer in these systems is usually occurring via Roche lobe overflow. Their emission in soft X-ray range is usually not pulsed with KT $\leq$ 9 keV. Their X-ray luminosity is ranging from 10^{36} to 10^{39} erg s^{-1} and $L_X/L_{opt} \sim 10^2$–10^4; many LMXBs show Quasi Periodic Oscillations (QPOs) between 0.02 and 1000 seconds and few of them also pulsed X-ray emission, such as Her X1, 4U 1626-27 and GX 1+4. Unlike HMXBs, LMXBs rarely harbour an X-ray pulsar. This is because the magnetic fields of the neutron stars in LMXBs are $10^{-1} - 10^{-4}$ times those in HMXBs, and so the accreted material is not funneled onto the polar caps.

- Cataclysmic Variables (CVs) in which the optical companion is a low-mass-late-type star and the compact object is a white dwarf. The detected CVs are spread roughly around the solar system at distance of 200-300 pc. Orbital periods are ranging from tens of minutes to about ten hours. The mass transfer is occurring either via Roche lobe overflow or via accretion columns or in an intermediate way depending on the value of the magnetic field. Typical

X-ray luminosity is ranging from 10^{32} to 10^{34} erg s^{-1}. Updated reviews about CVs are those by Giovannelli (2008) and Giovannelli & Sabau-Graziati (2015a);

- RS Canum Venaticorum (RS CVn) type systems, in which no compact objects are present and the two components are a F or G hotter star and a K star. Typical X-ray luminosity is ranging from 10^{30} to 10^{31} erg s^{-1}. Usually in the current literature they are excluded from the class of X-ray binaries since historically they were discovered as X-ray emitters only with the second generation of X-ray experiments.

Relatively few binaries have been discovered at GeV and TeV energies (e.g. Rappoldi et al., 2016; Maier, 2015; Blanch Bigas et al., 2015). These objects are important test beds of our understanding of particle acceleration in astrophysical objects. The periodic occurrence of the same environmental conditions for the accelerator makes these objects one of the closest things a γ-ray astronomer can get to a physical "experiment" and can help to distinguish between external properties and the properties of the accelerator itself.

Thousand papers about these cosmic sources are available in the literature. We mention the last available exhaustive review by Postnov & Yungelson (2014) about "*The Evolution of Compact Binary Stars Systems*" in which they review the formation and evolution of compact binary stars consisting of WDs, NSs, and BHs. Merging of compact-star binaries are expected to be the most important sources for forthcoming gravitational-wave (GW) astronomy. Indeed, the Advanced LIGO observatory recently reported the first direct detection of gravitational waves (Abbott et al. 2016) as a merger of two black holes with the mass of 36^{+5}_{-4} $M_\odot$ and 29 ± 4 $M_\odot$, and the final black hole mass is 62^{+4}_{-4} $M_\odot$ with $3.0^{+0.5}_{-0.5}$ $M_\odot c^2$ radiated in gravitational waves.

Several review papers have been published for discussing the different classes of galactic compact sources: i) Cataclysmic Variables (CVs) and related objects (e.g. Giovannelli, 2008; Giovannelli & Sabau-Graziati, 2012a; 2015a); ii) High Mass X-ray Binaries (HMXBs) (e.g. Giovannelli & Sabau-Graziati, 2001, 2004, 2014a, and van den Heuvel, 2009 and references therein; iii) Obscured Sources and Supergiant Fast X-Ray Transients (e.g. Chaty, 2011); iv) Ultra–Compact Double–Degenerated Binaries (e.g. Wu, Ramsay & Willes, 2008; Wu, 2009); Magnetars (Kitamoto et al., 2014: White Paper for ASTRO-H Space X-ray observatory).

XRBs are the best laboratory for the study of accreting processes thanks to their relative high luminosity in a large part of the electromagnetic spectrum. For this reason, multifrequency observations are fundamental in understanding their morphology and the physics governing their behaviour.

Because of the strong interactions between the optical companion and collapsed object, low and high energy processes are strictly related.

Often, it is easier to perform observations of low energy processes (e.g. in radio, near-infrared (NIR) and optical bands) since the experiments are typically ground-based, on the contrary to observations of high energy processes, for which experiments are typically space-based.

The X-ray/Be binaries are the most abundant group of massive X-ray binaries in the galaxy, with a total inferred number of between 10^3 and 10^4. The ones which do occasionally flare-up as transient X-ray/Be systems are only the "tip" of this vast "iceberg" of systems (van den Heuvel and Rappaport, 1987). The mass loss processes are due to the rapid rotation of the Be star, the stellar wind and, sporadically, to the expulsion of casual quantity of matter essentially triggered by gravitational effects close to the periastron passage of the neutron star. The long orbital period (> 10 days) and a large eccentricity of the orbit (> 0.2) together with transient hard X-ray behavior are the main characteristics of these systems. Among the whole sample of galactic systems containing 114 X-ray pulsars (Liu, van Paradijs & van den Heuvel, 2006), only few of them have been extensively studied. Among these, the system A 0535+26/HDE 245770 – HDE 245770 was nicknamed Flavia star by Giovannelli & Sabau-Graziati, 1992) – is the best known thanks to concomitant favorable causes, which rendered possible forty one years of coordinated multifrequency observations, most of them discussed in the past by e.g. Giovannelli & Sabau-Graziati (1992), Burger et al. (1996), Piccioni et al. (1999), and recently by Giovannelli & Sabau-Graziati (2011) and Giovannelli et al. (2015d,e). Accretion powered X-ray pulsars usually capture material from the optical companion via stellar wind, since this primary star generally does not fill its Roche lobe. However, in some specific conditions (e.g. the passage at the periastron of the neutron star) and in particular systems (e.g. A 0535+26/HDE 245770), it is possible the formation of a temporary accretion disk around the neutron star behind the shock front of the stellar wind. This enhances the efficiency of the process of mass transfer from the primary star onto the secondary collapsed star, as discussed by Giovannelli & Ziolkowski (1990) and by Giovannelli et al. (2007) in the case of A 0535+26.

Optical emission of HMXBs is dominated by that of the optical primary component, which is not, in general, strongly influenced by the presence of the X-ray source. The behavior of the primary stars can be understood in the classical (or almost) frame-work of the astrophysics of these objects, i.e. by the study of their spectra which will provide indications on mass, radius, and luminosity. Both groups of HMXBs (transient and permanent) differ because of the different origin of the mass loss process: in the first, the mass loss process occurs via a strong stellar wind and/or because of an incipient Roche lobe over-flow; in the second group, the mass transfer is probably partially due to the rapid rotation of the primary star and partially to stellar wind and sporadically to expulsions of a casual quantity of matter, essentially triggered by gravitational effects because of periastron passage where the effect of the secondary collapsed star is more marked. A relationship between orbital period of HMXBs and the spin period of the X-ray pulsars is shown in Fig. 4 (updated from Giovannelli & Sabau-Graziati, 2001 and from Corbet, 1984, 1986). It allows to recognize three kinds of systems, namely disk-fed, wind-fed [$P_{pulse} \propto (P_{orb})^{4/7}$], and X-ray/Be systems [$P_{pulse} \propto (P_{orb})^2$].

Most of the systems having a Be primary star are hard X-ray (KT > 10 KeV) transient sources (HXTS). They are concentrated on the galactic plane within a band of $\sim 3.9^\circ$. The orbits are quite elliptic and the orbital periods large (i.e. A 0538-66: e = 0.7, P_{orb} = 16.6 days (Skinner et al., 1982); A 0535+26: e = 0.47 (Finger, Wilson & Hagedon, 1994), P_{orb} = 111.0 days (Priedhorsky & Terrell, 1983). The X-ray flux during outburst phases is of order 10-1000 times greater than during quiescent phases. For this reason, on the contrary, the stars belonging to the class of permanent X-ray sources, which do not present such strong variations in X-ray emission, can be also named "standard" high mass X-ray binaries. In X-ray/Be systems, the primary Be star is relatively not evolved and is contained within its Roche lobe. The strong outbursts occur almost periodically in time scales of the order of weeks-months. Their duration is shorter than the quiescent phases. During X-ray outbursts, spin-up phenomena in several systems have been observed (i.e. A 0535+26 and 4U 1118-61 (Rappaport & Joss, 1981). The observed spin-up rates during the outbursts are

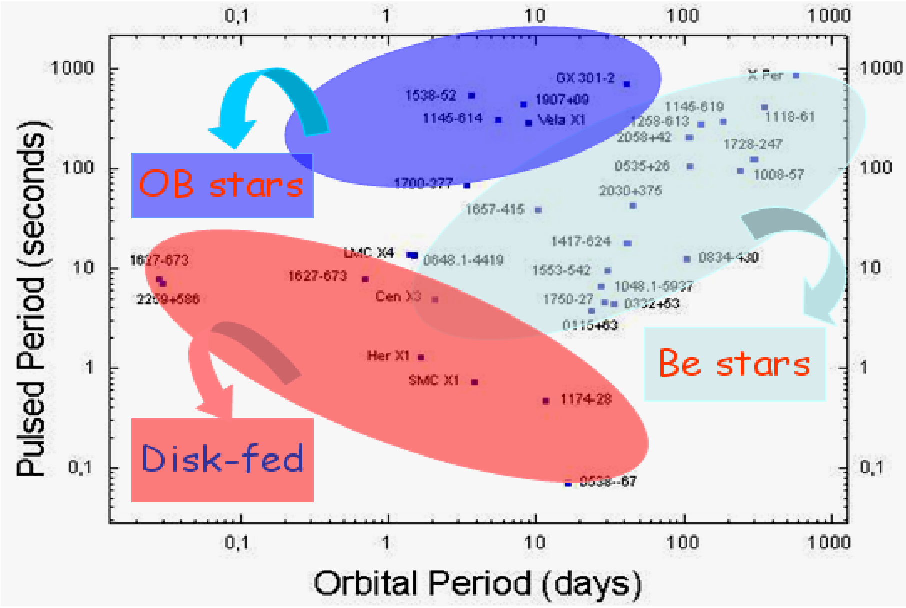


Figure 4: Spin period vs orbital period for X-ray pulsars. Disk–fed systems are clearly separated by systems having as optical counterparts either OB stars or Be stars (adopted from Giovannelli & Sabau-Graziati, 2001, after Corbet, 1984, 1986).

consistent with torsional accretion due to an accretion disk (e.g. Ghosh, 1994). So, the formation of a temporary accretion disk around the collapsed object should be possible during outburst phases (e.g. Giovannelli & Ziolkowski, 1990).

The number of X-ray pulsars slowly increases with time thanks to new detections performed with different new generation observatories. They were 95 in 2000 (Giovannelli & Sabau-Graziati, 2000) and the orbital periods were known only for about three dozens of them. They contain the group of the permanent HMXBs and that of transient HMXBs (X-ray/Be systems), whose components are an X-ray pulsing neutron star - the secondary - and a giant or supergiant OB or a Be star, respectively - the primary . Moreover, some low-mass X-ray Binaries (LMXBs) containing an X-ray pulsar and some pulsars belonging to Magellanic Clouds were contained too in the sample of 95 systems. In 2006 the known X-ray pulsars were 114 (Liu, van Paradijs & van den Heuvel, 2006). Coe et al. (2010) report $\sim$ 60 X-ray pulsars in the SMC. Later, Rajoelimanana & Charles (2012) listed 49 optical counterparts of SMC X-ray pulsars detected by MACHO and OGLE. Systems with known P_{spin} are 20 while the systems with known P_{orb} are 23, being 6 of them uncertain.

Another class of XRBSs is formed by the CVs, although usually the are not mentioned in literature as XRBSs, but as an apart class. The number of CVs is increasing very rapidly thanks to the many surveys, and in particular with the MASTER-Net Transient Detections program which detected 530 new CVs (Buckley, 2015). For reviews about CVs see the fundamental papers by Robinson (1976), Patterson (1984, 1994), Hack & la Dous (1993), and the books of Warner (1995) and Hellier (2001). The long review *The Impact of Space Experiments on our Knowledge of the Physics of the Universe* by Giovannelli & Sabau-Graziati (2004) contains also a part devoted to CVs. More recent reviews are those by Connon Smith (2007), Giovannelli (2008), and Giovannelli

& Sabau-Graziati (2015a), de Martino (2016).

After the first historical Frascati 1984 Workshop about "*Multifrequency Behaviour of Galactic Accreting Sources*" (Giovannelli, 1985), it is important to remind the long biennial series of the Frascati Workshops about "*Multifrequency Behaviour of High Energy Cosmic Sources*" started in 1995, whose refereed proceedings can be found in Giovannelli & Sabau-Graziati (1996, 1999, 2002a, 2002b, 2003, 2006, 2008, 2010, 2012b, 2014b, 2015b).

3. A general model for compact accreting stars: The Scenario Machine

Starting from the trivial definition of XRBs: they are binary systems emitting X-rays, a natural question arises. Are these systems governed by few physical parameters independent of their nature? The answer is positive. Indeed, HMXRBs, LMXRBs, AXPs, and CVs can be considered as gravimagnetic rotators: a body with mass M, having a magnetic moment $\vec{\mu}$, rotating with rotational velocity $\vec{\omega}$, being the two axis not necessarily coincident, as sketched in Fig. 5. Introducing a physical parameter, $y = \dot{M}/\mu^2$, named *gravimagnetic parameter*, all the gravimagnetic rotators are contained in a plane Log P_{spin} vs Log y (Lipunov, 1987; Lipunov & Postnov, 1988).

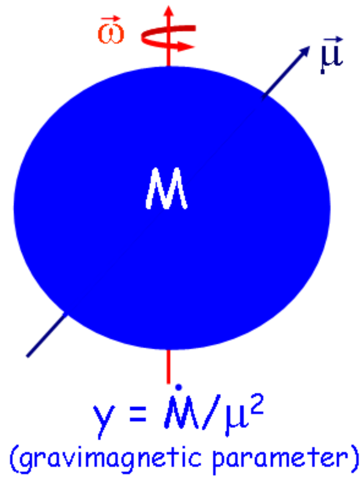


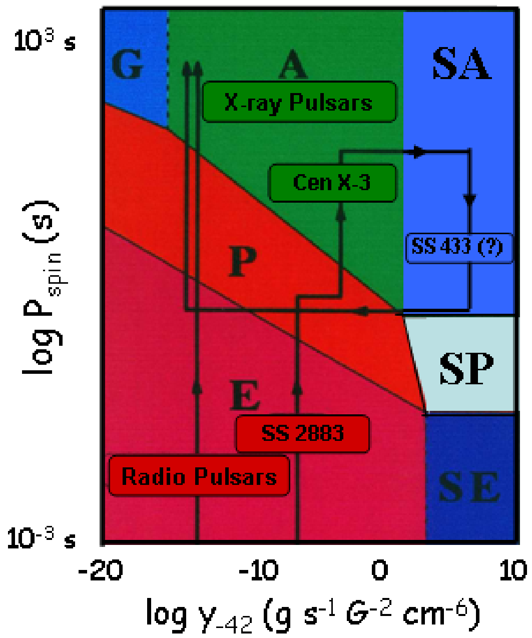
Figure 5: Gravimagnetic rotator: a body with mass M, having a magnetic moment $\vec{\mu}$, rotating with rotational velocity $\vec{\omega}$. The parameter $y = \dot{M}/\mu^2$ is called *gravimagnetic parameter* (Lipunov, 1987; Lipunov & Postnov, 1988).

The *Scenario Machine* (Monte Carlo simulations of binary evolution) permits to build up the complete picture of all possible evolutionary stages of binaries in the Galaxy. The basic evolution equation (3.1) used for 500,000 systems containing magnetized stars provided the results contained in the plane Log P_{spin}–Log y, reported in the upper panel of Fig. 6. P_{spin} is expressed in seconds and the gravimagnetic parameter is expressed in unit of 10^{-42} g s^{-1} G^{-2} cm^{-6}. The symbols used for the different types of binaries are explained in the lower panel of Fig. 6. The definition of the characteristic radii can be found in the paper by Lipunov (1987). Observational examples of various types of rotators are reported in Fig. 7 (Lipunov, 1987).

$$\frac{\mathrm{d}I\omega}{\mathrm{dt}} = \dot{\mathrm{M}}K_{\mathrm{su}} - \frac{\kappa_{\mathrm{t}}\mu^2}{\mathrm{R_t^3}} \tag{3.1}$$

where:

$\mathrm{K_{su}}$ = specific angular momentum applied by the accretion matter to the rotator;
$\mathrm{K_{su}} = \sqrt{\mathrm{GM_xR_d}}$ for Keplerian disk accretion;
$\mathrm{K_{su}} = \eta_{\mathrm{t}}\Omega R_{\mathrm{g}}^2$ for wind accretion in a binary;
$\mathrm{K_{su}} \sim 0$ for a single magnetic rotator;
$\mathrm{R_d}$ = radius of the inner disk edge;
Ω = rotational frequency of the binary system;
η_{t} = 1/4 (Illarionov & Sunyaev, 1975);
κ_{t} = dimensionless factor;
$\mathrm{R_t}$ = characteristic radius;
$\dot{\mathrm{M}}$ = accretion rate in different regimes.



The rotator classification

Designation	Name	Physical sense	
E	Ejector	$R_{st} > \max\{R_G, R_l\}$	
P	Propeller	$R_c < R_{st} \le \max\{R_G, R_l\}$	
A	Accretor	$R_{st} \le R_G$ and $R_{st} \le R_c$	$\dot{M}_c \le \dot{M}_{cr}$
G	Georotator	$R_G < R_{st} \le R_c$	
M	Magnetor	$R_{st} > a$ and $R_c > a$	
SE	Superejector	$R_{st} > R_l$	
SP	Superpropeller	$R_c < R_{st} \le R_l$	$\dot{M}_c > \dot{M}_{cr}$
SA	Superaccretor	$R_{st} \le R_c$ and $R_{st} \le R_G$	

Figure 6: Upper panel: distribution of magnetic rotators in the plane "Spin Period" – "Gavimagnetic Parameter" (adapted from Lipunov, 1995); lower panel: classification of rotators (Lipunov, 1987).

Type of rotator	Designation	The clearly confirmed observational example	Model assumptions
Ejector	E	Radiopulsars	LSI + 61°303, Cyg X-3, BL Lac objects,
Propeller	P	–	Transient X-ray sources, γ-bursts, some cataclysmic variables (dwarf novae), magnetic Ap-stars
Accretor	A	X-ray pulsars, X-ray bursters, cataclysmic variables with white dwarfs, novae, intermediate polars	–
Superejector	SE	–	SS 433, AGN, QSO
Superpropeller	SP	–	–
Superaccretor	SA	–	SS 433
Georotator	G	–	–
Magnetor	M	Polars	–

Figure 7: Observational examples of rotators (Lipunov, 1987).

Using the "Scenario Machine" Raguzova & Lipunov (1999) obtained an evolutionary track that can lead to the formation of Be/BH systems. The modern evolutionary scenario predicts the existence of binary black holes on eccentric orbits around Be stars and such systems may be discovered in the near future... Like happened!

Indeed, Raguzova & Lipunov (1999) calculations show that binary black holes with Be stars must have 0.2 < e < 0.8. It is particularly difficult to detect such systems as most of their spectroscopic variations occur in a relatively small portion of the orbit, and could easily be missed if the systems are observed at widely separated epochs.

The critical initial mass of the supernova star that collapses to a BH is accepted to be equal to $55 < M_{cr} < 75\ M_\odot$, and the fraction of the presupernova mass ($M_\star$) collapsing to the BH, $k_{BH} = M_{BH}/M_\star = 0.5$. The kick velocity v_m = 0–200 km s^{-1}. The age of the system, according to their evolutionary scenario is 4×10^6 yr.

The expected number of Be/BH binaries – with orbital period 10 d < P_{orb} < 1000 d, and eccentricity 0.2 < e < 0.8 – is 1 Be/BH for 20-30 Be/NS.

Belczynski and Ziółkowski (2009) used binary population synthesis models to show that the expected ratio of Be/XRBs with neutron stars to black holes in the Galaxy is relatively high ($\sim 30-50$), and so broadly in line with observations. Thus we can expect 1 Be/BH for 30–50 Be/NS.

Therefore, we can expect 1 Be/X-ray BH system for 20–50 Be/X-ray NS systems (Raguzova & Lipunov, 1999; Belczynski & Ziółkowski, 2009). We know 60 Be/X-ray NS systems (after INTEGRAL). Thus we expect 1–3 Be/X-ray BH systems. One of this systems has been detected: MWC 656 (Casares et al., 2014).

New simulations – using the StarTrack binary population synthesis models have been conducted to understand the formation channel of MWC 656 – constrain the population of Be/BH systems and study the fate of MWC 656 as a possible NS–BH merger, and then possible gravitational wave emitter. In particular, it has been assumed that all donors beyond main sequence are allowed to survive the common envelope (CE) phase. Ten Gyr of evolution of the Galactic disk originates $\sim$ 8700 B/BH systems, and 1/3 of them would be Be/BH systems: namely $\sim$ 2900).

However, only 13 of them had periods, eccentricities and masses similar to MWC 656 (Grudzinska et al., 2015).

There are so many black holes in the Universe that it is impossible to count them.

Stellar-mass black holes (SBHs) form from the most massive stars when their lives end in supernova explosions. The Milky Way galaxy contains some 10^{11} stars. Roughly one out of every thousand stars that form is massive enough to become a black hole. Therefore, our galaxy must harbor some 10^8 stellar-mass black holes. Most of these are invisible to us, and only nineteen have been identified (Wiktorowicz, Belczynski & Maccarone, 2014) with masses up to ~ 16 $M_\odot$. Theoretically the mass of a SBH depends on the initial mass of the progenitor, how much mass is lost during the progenitor's evolution and on the supernova explosion mechanism (Belczynski et al., 2010; Fryer et al., 2012). Mass is lost through stellar winds, the amount of mass lost strongly depends on the metallicity of the star. For a low metallicity star (~ 0.01 of the solar metallicity) it is possible to leave a black hole of ≤ 100 $M_\odot$ (Belczynski et al., 2010). In the region of the Universe visible from Earth, there are perhaps 10^{11} galaxies. Each one has about 10^8 stellar-mass black holes. And somewhere out there, a new stellar-mass black hole is born in a supernova every second.

However, some attempts of evaluation of the number of SBHs in the Galaxy have been done. For instance, taking into account the γ-ray emissivity of the Galaxy (1.3×10^{43} s^{-1} for $E > 100$ MeV) measured by the SAS II satellite (Strong, Wolfendale & Worral, 1976) and the processes of disk-fed accretion onto black holes, Giovannelli, Karakuła & Tkaczyk (1981, 1982) found a possible upper limit to the number of black holes ($M \sim 10$ $M_\odot$ and $\dot{M} \approx 10^{-8}$ $M_\odot$ yr^{-1}) of 10^{-5} or 10^{-4} of the total star population of the Galaxy, for Mach's number 1 and 2, respectively. (*)

There is a class of intermediate-mass black holes (IMBHs), with masses > 100 $M_\odot$ up to $\approx 10^5$ $M_\odot$. It contains a dozen systems, as listed in Johnstone (2004). However, black holes with masses of several hundred to a few thousand solar masses remain elusive, as reported in a recent review by Casares & Jonker (2014) where a deeply discussion about the mass measurements of SBHs and IMBHs is contained.

Supermassive black holes (SMBHs) are 10^6–10^9 times more massive than our Sun and are found in the centers of galaxies (see the exhaustive review by Kormendy & Ho, 2013). Most galaxies, and maybe all of them, harbor such a black hole. So in our region of the Universe, there are some 10^{11} SMBHs. The nearest one resides in the center of our Milky Way galaxy. The most distant one we know of resides in a quasar galaxy billions of lightyears away. SMBHs grow in size as they gorge on surrounding matter.

Figure 8 show the relative masses of super-dense cosmic objects versus the mass of the bulge (Kormendy & Ho, 2013).

A list of BH candidates, compiled by Wm. Robert Johnston (2004), provides the input for constructing the map of sky locations of BH candidates, as shown in Fig. 9. Stellar-mass black

(*) The Mach number is given by the ratio of the velocity of the gas to the local sound speed. In order to evaluate the temperature, concentration and velocity of the plasma near the black hole it is necessary to solve the system of equations describing the plasma motion (Michel, 1972) taking into account the distance from the black hole in units of gravitational radius and the u = R-component of four velocity. Mach's number 1 and 2 correspond to different values of u_0^2 (1.0266 and 2.1213, respectively) at a distance r_0 from the black hole (Giovannelli, Karakuła & Tkaczyk, 1981, 1982).

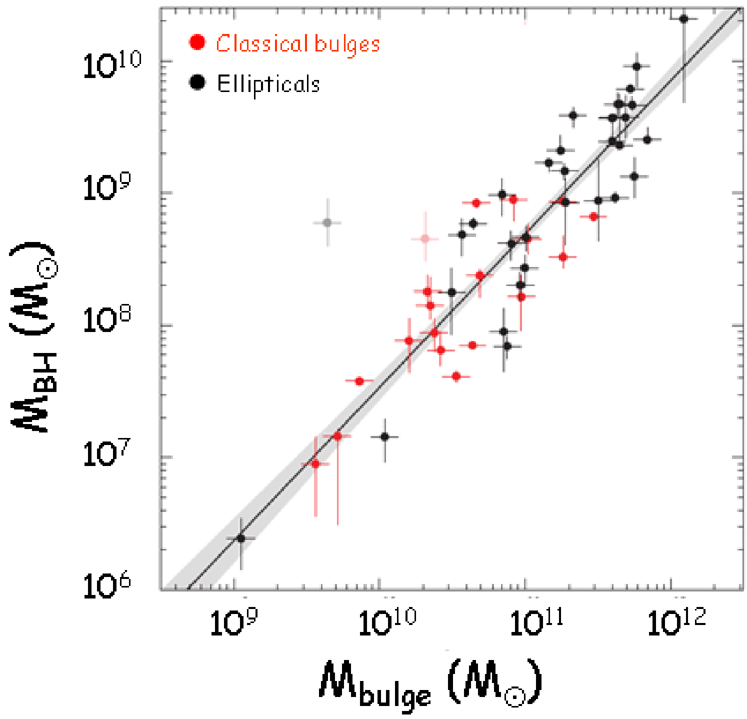


Figure 8: The correlation of the black hole mass (M_{BH}) versus the bulge mass (M_{bulge}) (adopted from Kormendy & Ho, 2013).

holes in red, intermediate-mass black holes in purple, supermassive black holes in blue. The base image is from Tycho sky map from JPL's Solar System Simulator.

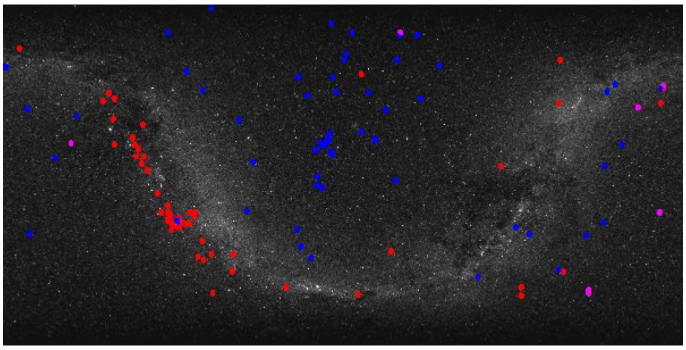


Figure 9: The map of sky locations of BH candidates. Red (stellar mass BHs), Purple (IMBHs), Blue (SMBHs). The base image is from Tycho sky map from JPL's Solar System Simulator (Johnstone, 2004).

In the case of galactic compact sources, by using the softness and hardness ratios, coming for the measurements of the many X-ray satellites, it is possible to construct a diagram in which BHs in high state are separated by those in low state, and by other kind of objects, such as X-ray pulsars and other systems, as shown in Fig. 10 (after Tanaka, 2001).

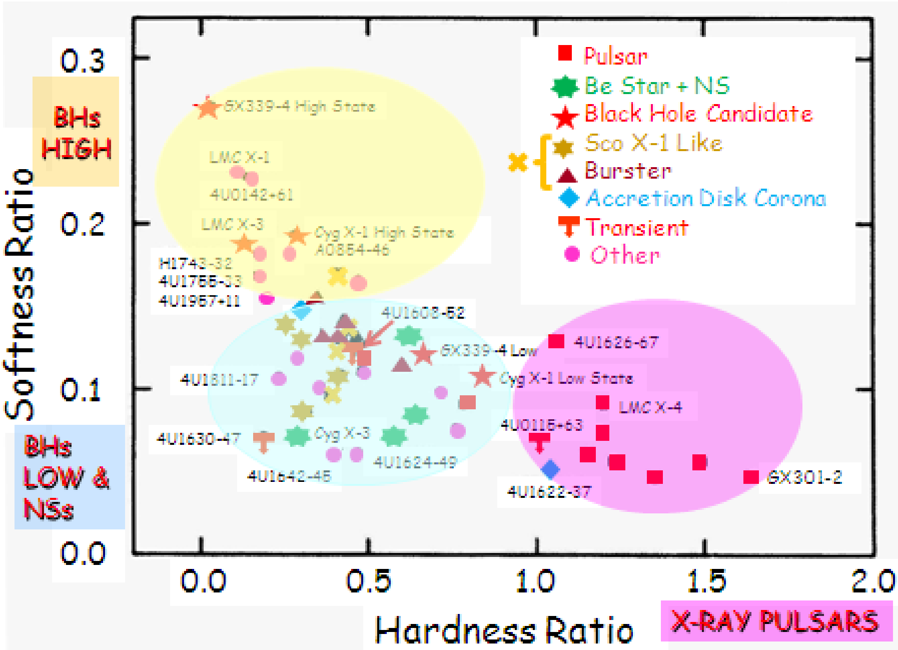


Figure 10: Softness ratio versus hardness ratio for galactic compact systems. Light yellow ellipse marks the zone where BHs in high state lie, light turquoise ellipse marks the zone of the BHs in low state and NSs, and light fuchsia ellipse marks the zone of the X-ray pulsars (after Yasuo Tanaka, 2001).

4. Magnetic field intensity in gravimagnetic rotators

Magnetic fields are observed in main sequence stars and their white dwarf and neutron star progeny. The fields in these three groups of stars are likely to be linked via stellar evolution. Super-strong magnetic fields are observed in both white dwarfs and neutron stars. Therefore, the formation of strong magnetic fields in gravimagnetic rotators is a question of crucial importance (see e.g. Ferrario & Wickramasinghe, 2007). While there is strong evidence that the magnetic fields in late type stars are dynamo generated, it is likely that the magnetic fields of stars on the upper main sequence are of fossil origin, perhaps dating back to the time of star formation.

Table 1: Approximate correspondence of magnetic fields in stars of upper main sequence and compact objects. HFMWDs = High Field Magnetic White Dwarfs; NSs = Neutron Stars (adapted from Ferrario & Wickramasinghe, 2007).

	B (Gauss)			B (Gauss)
Spectral type stars B-F	300-3,000	$\Longrightarrow$	HFMWDs	10^6-10^9
Spectral type stars O-B	???-30,000	$\Longrightarrow$	NSs	10^{11}-10^{15}

In the fossil scenario, the field strength B scales with the radius of the star ($R_\star$) as $B \propto R_\star^{-2}$. Therefore, if a star with initial magnetic field strength $B_i \sim 100$ G and typical radius $R_i \sim 10^6$ km collapses as a neutron star with a final radius $R_f \sim 10$ km, the final magnetic field strength will be

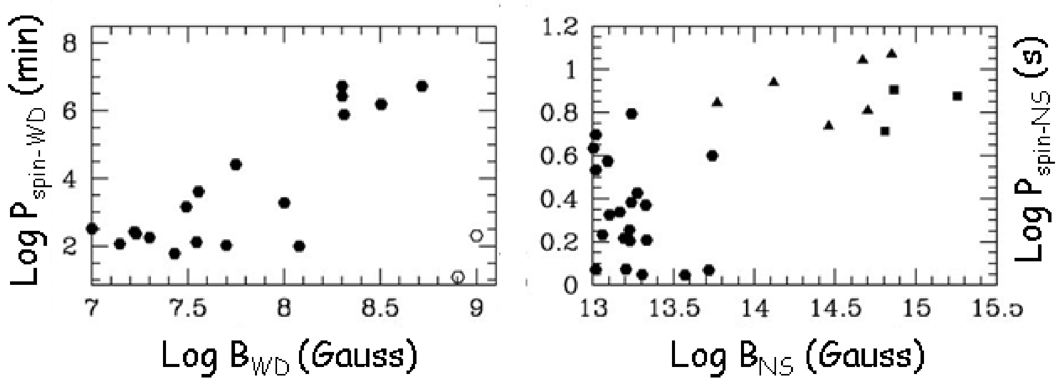


Figure 11: Relationships between spin period and magnetic field intensity for white dwarfs (left panel) and neutron stars (right panel) (adapted from Ferrario & Wickramasinghe, 2005).

$B_f \sim 10^{12}$ G, being valid the relationship $B_f = B_i \times (R_i/R_f)^2$.

The relationship between the spin period of a neutron star and a white dwarf is $P_{spin}^{NS} \approx P_{spin}^{WD} \times (R_{NS}/R_{WD})^2$. Therefore to a typical spin period of 1 ms of a NS corresponds a spin period of a WD of 1000 s.

The validity of the former relationships is clearly shown if Fig. 11 in which Log P_{spin} versus Log B are reported for WDs (left panel) and NSs (right panel) (Ferrario & Wickramasinghe, 2005) .

Following the interesting review by Ferrario, de Martino & Gänsicke (2015), magnetic fields of isolated MWDs are observed to lie in the range $10^3 - 10^9$ G. While the upper limit cutoff near 10^9 G appears to be real, the lower limit is more difficult to investigate. The incidence of magnetism below a few 10^3 G still needs to be established by sensitive spectropolarimetric surveys conducted on 8 m class telescopes. Highly magnetic WDs (HMWDs) tend to exhibit a complex and non-dipolar field structure with some objects showing the presence of higher order multipoles. There is no evidence that fields of HMWDs decay over time, which is consistent with the estimated Ohmic decay times scales of $\sim 10^{11}$ yrs. The slow rotation periods ($\sim$ 100 yrs) inferred for a large number of isolated MWDs in comparison to those of non-magnetic WDs (a few days) suggest that strong magnetic fields augment the braking of the stellar core. MWDs, as a class, also appear to be more massive (0.784 ± 0.047 $M_\odot$) than their weakly or non-magnetic counterparts (0.663 ± 0.136 $M_\odot$).

MWDs are also found in binary systems where they accrete matter from a low-mass donor star. These binaries, called magnetic Cataclysmic Variables (MCVs), comprise about 20–25 % of all known CVs. Zeeman and cyclotron spectroscopy of MCVs have revealed the presence of fields in the range $\sim$ 7–230 MG. Complex field geometries have been inferred in the high field MCVs (the polars) whilst magnetic field strength and structure in the lower field group (intermediate polars, IPs) are much harder to establish.

To date there are about $\sim$ 250 MWDs with well determined fields (as reported in the Table 1 of the review paper by Ferrario, de Martino & Gänsicke, 2015) and over $\sim$ 600 if we also count objects with no or uncertain field determination (see Kepler et al. 2013, 2015). The number of identified IPs has now increased to $\sim$ 60 systems (see Table 3 of the review paper by Ferrario, de Martino & Gänsicke, 2015 and updated results in Bernardini et al. (2015). The other $\sim$ 600 candidates still awaiting confirmation through X-ray follow-ups with sensitive facilities such as XMM-Newton and NuSTAR (see http://asd.gsfc.nasa.gov/Koji.Mukai/iphome/iphome.html).

Enormous progress has been made on observing stellar magnetism in stars from the main sequence through to compact objects. Recent data has brought stricter information on the origin of stellar magnetic fields. However, this theme is still one of the crucial points to be solved in astrophysics.

Ferrario, Melatos & Zrake (2015) review recent work in this area of research. In particular, they look at the fossil field hypothesis which links magnetism in compact stars to magnetism in main sequence and pre-main sequence stars and they consider why its feasibility has now been questioned particularly in the context of highly magnetic white dwarfs. They also review the fossil versus dynamo debate in the context of neutron stars and the roles played by key physical processes such as buoyancy, helicity, and superfluid turbulence, in the generation and stability of neutron star fields. Independent information on the internal magnetic field of neutron stars will come from future gravitational wave detections. the Laser Interferometer Gravitational Wave Observatory (LIGO) have already constrained the Crab pulsar gravitational wave luminosity to be $\lesssim 2\%$ of the observed spin-down luminosity, thus placing a limit of $\lesssim 10^{16}$ G on the internal field. Therefore we are witnessing the dawn of a new era of exciting discoveries in compact star magnetism driven by the opening of a new, non-electromagnetic observational window.

Beskin et al. (2016a) review about the role that strong magnetic fields play in the universe.

4.1 Magnetic field intensity measures

It is convenient to remind how the magnetic field intensity can be measured. A detailed discussion about the field determination in isolated magnetic WDs and in WDs in binary systems is reported in the review paper by Ferrario, de Martino & Gänsicke (2015). Direct measurements of the WD magnetic field strength in the high field magnetic CVs, the polars, can be obtained either (i) through Zeeman splitting of the photospheric hydrogen absorptions lines when these systems enter low accretion states or (ii) through the modeling of cyclotron emission features that characterizes the optical to IR spectra during intermediate and high accretion states (see Wickramasinghe & Ferrario, 2000) or (iii) via the study of Zeeman features arising from the halo of matter surrounding the accretion shock.

Figure 12 shows the distribution of B for MCVs and MWDs (adopted from Ferrario, de Martino & Gänsicke, 2015).

In MCVs there is an interesting relationship between the magnetic field strength and orbital period of the systems, as reported in Fig. 13 where the polars and IPs are separated by the blue line that marks the synchronization between orbital and spin periods of the cataclysmic systems.

Taking into account the average values of magnetic field intensity and orbital periods for polars and IPs, and the minimum and maximum value for both parameters (B and P_{orb}), it is possible to construct a very interesting plot (Fig. 14) that shows the evident continuity between the two classes of MCVs. Such a continuity has been noted by Schmidtobreick & Tappert (2014, 2015): CVs evolution is driven by angular momentum loss; as consequence P_{orb} decreases. All long P_{orb} CVs cross SW Sex regime before entering in the "Period Gap". Therefore SW Sex phenomenon is an evolutionary stage in the life of CVs (e.g. Rodriguez-Gil, 2003).

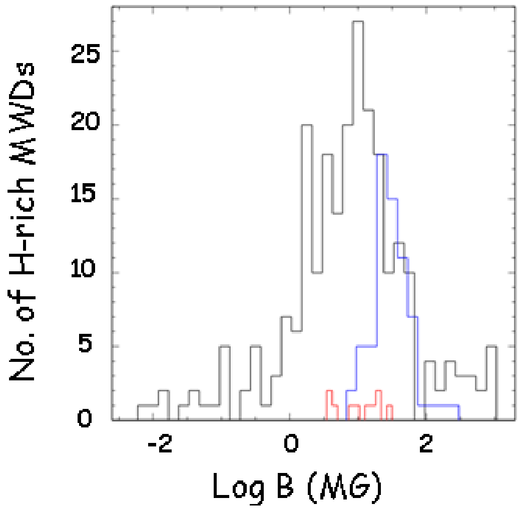


Figure 12: Distribution of magnetic field strength in polars (blue line), and IPs (red line) compared to that of single magnetic WDs (black line) (adapted from Ferrario, de Martino & Gänsicke, 2015).

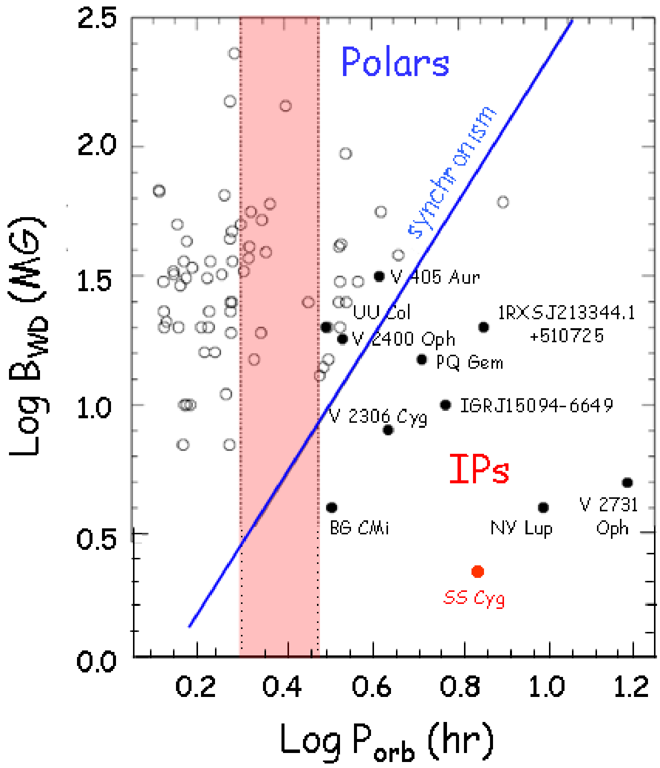


Figure 13: Magnetic field strength versus orbital period in MCVs. Polars and IPs are separated by the blue line that marks the border between systems with orbital period synchronized with the spin period (polars) and those without synchronization (IPs). Light red rectangle marks the so-called "period gap" (after Ferrario, de Martino & Gänsicke, 2015).

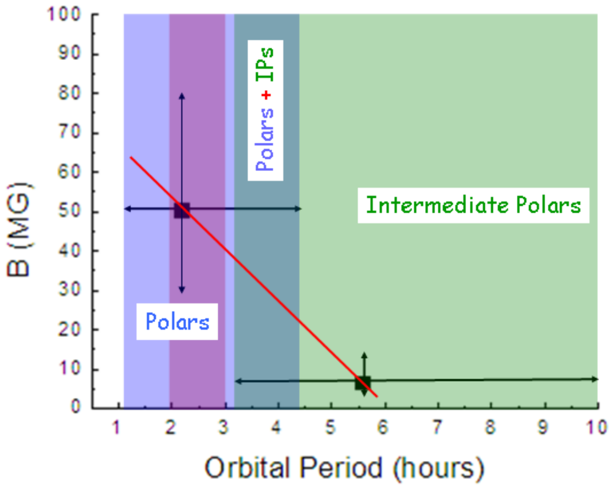


Figure 14: Magnetic field intensity versus orbital period for MCVs. Polars and IPs are contained in the light blue and light green rectangles, respectively. Violet rectangle indicates the so-called "period gap". Cyan-50 rectangle represents the intersection between the Polars and IPs.

An interesting indirect method for evaluating the magnetic field intensity in MCVs has been discussed by Giovannelli & Sabau-Graziati (2012a) in the case of SS Cyg whose nature (non magnetic or IP) is largely disputed. From the fluxes of UV emission lines of SS Cyg, placed at distance d = 166 ± 7 pc (Harrison et al., 1999), Giovannelli & Sabau-Graziati (2012a) – by using the IUE measurements obtained by Gaudenzi et al. (1986) – derived the luminosity of C II and C IV: $L_{CII} \simeq 7.8 \times 10^{30}$ erg s^{-1} and $L_{CIV} \simeq 6.2 \times 10^{31}$ erg s^{-1}. Using these values of luminosity and the extrapolation of the line best fitting the emission line luminosity of C II and C IV versus B (Howell et al., 1999), the magnetic field intensity of SS Cyg is $B_{CII} = 2.0^{+0.5}_{-0.4}$ MG, and $B_{CIV} = 1.1^{+0.3}_{-0.6}$ MG, as shown in Fig. 15, left and right panels, respectively.

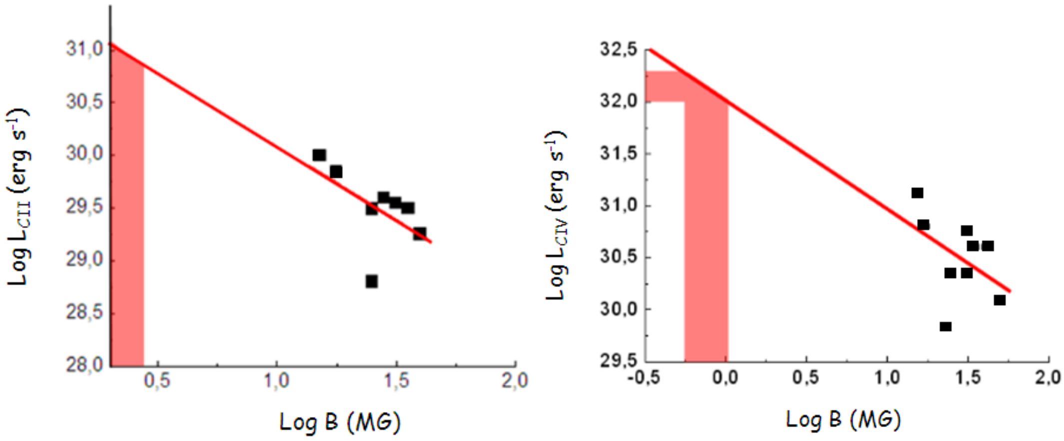


Figure 15: Observed emission fluxes converted to luminosity for magnetic CVs (after Howell et al., 1999) are indicated with black square. Left panel: C II luminosity versus B; right panel: C IV luminosity versus B. SS Cyg positions are indicated with red areas (Adopted from Giovannelli & Sabau-Graziati, 2012a).

Then a reasonable value of the white dwarf magnetic field in SS Cyg is $B = 1.6 \pm 0.7$ MG This value is in complete agreement with the evaluation made by Fabbiano et al. (1981) ($B \leq 1.9$ MG) by using simultaneous X-ray, UV, and optical data.

Many other circumstantial proofs in favor of the IP nature of SS Cyg have been discussed by Giovannelli & Sabau-Graziati (2012a). One of the most important proof is coming from the paper by Körding et al. (2008). They detected a radio jet from SS Cyg. The hardness intensity diagram shows an analogy between the XRBs (the BH GX 339-4, and the NS Aql X-1) and SS Cyg. Moreover there is a radio flare simultaneous with the optical outburst of SS Cyg. During the 1.1-mJy "flare" they found upper limits for the linear polarization and circular polarization of $3.2 \pm 2.7\%$ and $-3.2 \pm 2.7\%$, respectively.

It is hard to explain these results without invoking the presence of a magnetic field ($B \approx 2$ MG) in the white dwarf of SS Cyg system.

INTEGRAL/IBIS and SWIFT/XRT observations have shown that a conspicuous number of CVs have a strong hard X-ray emission (Landi et al., 2009; Scaringi et al., 2010). In their published sample of 23 CVs, 22 are classified as magnetic IPs and only one (SS Cyg) as NMCV, meanwhile all its characteristics are practically equal to those of the other 22 objects. This is a strong circumstantial proof in favor of the magnetic nature of SS Cyg. The experimental evidence that SS Cyg emits in the hard X-ray energy range is, in my opinion, the conclusive evidence about its magnetic nature.

Indeed, a simple question arises: "why all the CVs detected by the INTEGRAL observatory are magnetic (IPs) and SS Cyg non-magnetic? If so, why the same INTEGRAL observatory did not detect any other DN?".

The hard X-ray emission detected in those CVs is possible only if a sufficiently high magnetic field is present in those systems. Only accretion onto magnetic poles justify the hard X-ray emission in quiescence.

Probably, the "mistake" about the nature of SS Cyg born after the publication of a paper in Nature by Bath & van Paradijs (1983) where SS Cyg was classified as DN on the basis of optical behaviour, typical of DNe. This paper originated a bandwagon effect in the literature (see Michael Friedjung's comment in the first historical Frascati Workshop 1984: Giovannelli, 1985) that "obliged" almost all the subsequent authors to start the papers saying that SS Cyg is a DN (NMCVs), without paying attention to other possibilities well documented in the so-called second class literature.

Therefore, my suggestion is to reconsider the problem about the nature of SS Cyg without any a priori bias.

In the case of X-ray pulsars, B is expected to be of $\geq 10^{12}$ G. A method for measuring B was experimentally found with the first historical detection of a cyclotron line from Her X-1 at ~ 58 keV (Trümper et al., 1978). This detection opened the road for searching such a lines in X-ray binary systems. The relationship between the cyclotron line energy (E_c) and the magnetic field intensity B is:

$$E_c = 11.6 \times B/(10^{12}\ G) \times (1+z)^{-1}\ keV \qquad (4.1)$$

The value of B in Her X-1 is then $\sim 5 \times 10^{12}$ Gauss. Coburn et al. (2002) published a list of cyclotron lines and relative B for 10 X-ray pulsars. An updated list of 27 X-ray pulsars with cyclotron lines detected is reported in the paper by Walter et al. (2015). Some of these pulsars show also absorption-like features, like for instance 4U 0115+63 in which the four measured features are close to the harmonic relation expected from cyclotron resonant scattering in a strong magnetic field when relativistic effects are taken into account. These results provided the first evidence for four harmonically spaced lines in the spectrum of an accreting X-ray pulsar, yielding the clearest confirmation of their magnetic origin (Santangelo et al., 1999). Table 2 shows the list of the 27 X-ray pulsars with the detected energy of the cyclotron lines and the correspondent magnetic field intensity. The table reports only the energy of the first harmonic of the cyclotron lines.

5. Accretion driven X-ray sources

In binary systems there are essentially two ways for accreting matter from one star to the other: via accretion disk or via stellar wind (Giovannelli & Sabau-Graziati, 2001, adapted from Blumenthal & Tucker, 1974) (left panel of Fig 16). But in some cases there is a third way which is a mixture between the two, as for instance in eccentric binary systems close to the periastron passage where a temporary accretion disk can be formed around the neutron star (e.g. Giovannelli & Ziółkowski (1990), like shown in the right panel of Fig. 16 (Giovannelli & Sabau-Graziati, 2001, after Nagase, 1989).

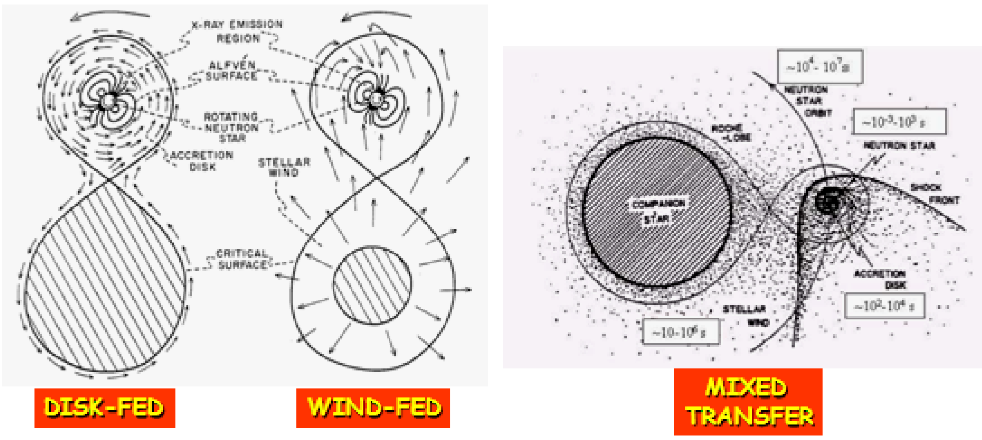


Figure 16: Left panel: accretion in X-ray binary systems disk-fed and wind-fed (Giovannelli & Sabau-Graziati, 2001, adapted from Blumenthal & Tucker, 1974). Right panel: mixed transfer (Giovannelli & Sabau-Graziati, 2001, after Nagase, 1989).

However, the accretion processes regulate the growth and evolution of all objects in the Universe, as sketched in Fig. 17 (after Scaringi's talk, 2015).

5.1 Some rightful remarks

It is very useful to remind some historical remarks in order to paint the developments of the theories that allowed to understand most of the accretion phenomena in cosmic sources. When the first theories about accretion disks around compact stars started to be developed around the 1960-ies, the class of the so-called CVs started to have a leading position in astrophysics. They constituted the perfect laboratories for testing those theories. When the UV window to the universe was opened at the end of 1970-ies with the advent of the historical IUE (International Ultraviolet Explorer), CVs became really one of the most interesting class of objects of the whole astrophysics. Previously, essentially two schools of thought born in Cambridge (UK) and in Warsaw (Poland) in order to tackle with the difficult subject of the mass exchange in close binary systems (e.g. Smak,

Table 2: The list of the 27 X-ray pulsars with the detected energy of the cyclotron lines and the correspondent magnetic field intensity (after Walter et al., 2015).

Source Name	Cyclotron Energy (keV)	B (10^{12}) (Gauss)
4U 0115+63	11.6	1
V 0332+53	28	2.4
4U 0352+309 (X Per)	29	2.5
RX J0440.9+4431	32	2.76
RX J0520.5-6932	31.5	2.7
A 0535+26	50	4.3
MXB 0656-072	36	3.1
Vela X-1	27	2.3
GRO J1008-57	88	7.59
1A 1118-61	55	4.7
Cen X-3	28	2.4
GX 301-2	37	3.2
GX 304-1	50.8	4.4
4U 1538-52	20	1.7
Swift J1626.6-5156	10	0.87
4U 1626-67	37	3.2
Her X-1	42	3.6
OAO 1657-415	36	3.1
GRO J1744-28	4.7	0.4
IGR J18179-1621	21	1.8
GS 1843+00	20	1.7
4U 1907+09	19	1.6
4U 1909+07	44	3.8
XTE J1946+274	36	3.1
KS 1947+300	12.5	1.1
EXO 2030+375	11	0.95
Cep X-4	30	2.6

PoS(HEASA 2016)031

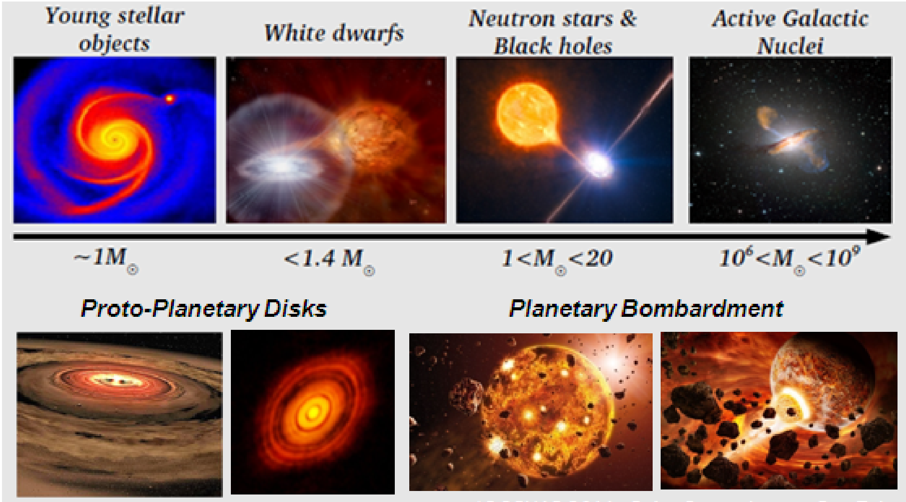


Figure 17: Accretion processes onto young stellar objects, white dwarfs, neutron stars, black holes, active galactic nuclei, proto-planetary disks, and planetary bombardment (this work, after Scaringi, 2015).

1962, 1972, 1981; Paczynski, 1965, 1977; Bath, 1969, 1975, 1976, 1978, 1980, 1984 and the references therein; Bath et al., 1974; Mantle & Bath, 1983). However, two fundamental papers about accretion disks appeared at the beginning of 1970-ies (Shakura, 1972, Shakura & Sunyaev, 1973). These papers marked substantially the development of theories about accretion disks around compact objects in binary systems, until present times. Pringle (1981) reviewed accretion disks in astrophysics. In my opinion, the paper by Shakura (1972) (*Disk model of gas accretion on a relativistic star in a close binary system*) posed the fundamental pillars of the theory of accretion disk, by introducing the α parametrization of the turbulent viscosity. In the following (section 6) I will show a few examples of the importance of the α-viscosity in accretion disks of several accreting sources for explaining their experimental behaviour correlated with the time delay between flares occurring at different frequencies.

Among the many papers and books devoted to accretion processes is timely to remind those by Lewin & van den Heuvel (1983): *Accretion-Driven Stellar X-ray Sources*, by Frank, King & Raine (1985): *Accretion Power in Astrophysics*, and a very interesting tutorial paper by Israel (1996): *Accretion Driven X-ray Sources* where it is possible to find in a clear way the basics of accretion.

Historically, CVs – close binary systems consisting of a hot WD and red main sequence star of spectral type M or K, which fills the volume of its inner Roche lobe and transfers matter to the vicinity of the WD – classification was based on the optical outburst properties, by which one may distinguish four groups: (i) classical novae; (ii) recurrent novae; (iii) dwarf novae; (iv) nova-like objects.

This classification, however, is neither self-consistent nor adequate and it is much better to consider primarily the observed accretion behaviour (Smak, 1985). The accretion behaviour are dependent on the WD magnetic field intensity.

According to strength of WD magnetic field this matter is creating an accretion disk (B $\approx 10^5$ G) or follows magnetic field lines and falls to surface of the WD (B $\approx 10^6 - 10^8$ G). If B $\approx 10^7 - 10^8$

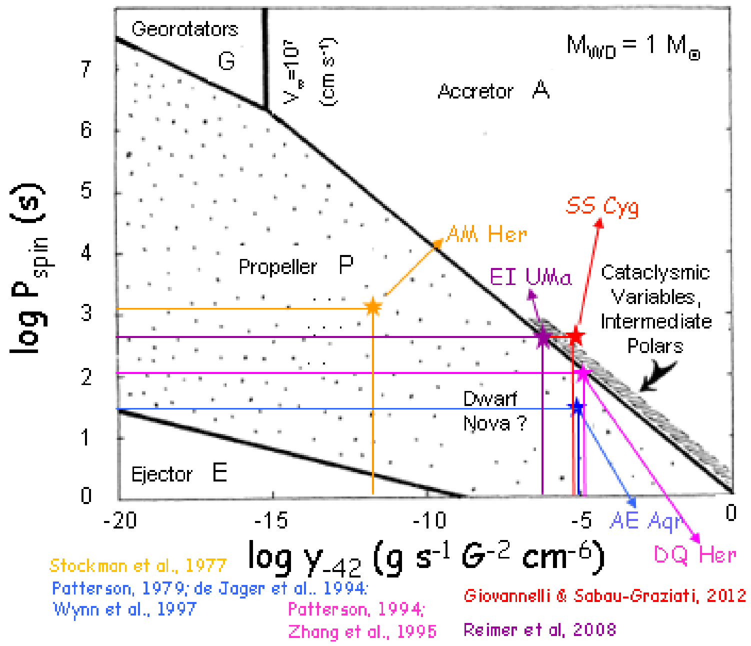


Figure 18: The position of several polars and IPs in Lipunov's diagram.

G, an accretion flow is directly channeled down towards the magnetic poles of the WD along the magnetic field lines (polars). If B $\approx 10^6 - 10^7$ G, the accretion disk is not entirely disrupted, but simply truncated in its inner part, and the accretion flow is also channeled onto the WD surface along the magnetic field lines (Intermediate polars).

Therefore, the role of magnetic field intensity plays a fundamental role in the process of accretion of matter onto the compact star. Therefore Lipunov's diagram (log P_{spin} vs log y) appears as the best way for localizing the position of MWDs, both polars and IPs, as shown in Fig. 18.

It is evident that a fundamental parameter characterizing the whole sample of CVs is the orbital period, which is strictly connected with the evolution of the systems. Fig. 19 shows the number of CVs versus the orbital period (after Gänsicke, 2005). Below and above the so-called "Period Gap" $\sim$ 39% and 50% of CVs lie, respectively; about 11% of CVs lie within the "Period Gap" which is partially filled by the zone where the SW Sextantis systems lie (e.g. Rodriguez-Gil, 2003). Howell, Nelson & Rappaport (2001) discussed critically the basic paradigm for the origin of the 2-3 hr "Period Gap" in CVs.

Accreting binaries with white dwarf primaries and main sequence secondaries have binary orbital periods greater than 80 mins. For shorter period systems the secondary must be degenerate or semi-degenerate: e.g. white dwarf - white dwarf binaries.

The shorter period AM Canum Venaticorun (AM CVn) systems lie well below the "Period Gap". The prototype HZ 29 = AM CVn, with $P_{orb} \sim 17.5$ min, was discovered by Smak (1967) and was recognized as a CV by Patterson (1992). Nelemans (2005) published a short review about "*AM Cvn Stars*" and later a review about "*AM CVn Stars: Status and Challenges*" was published by Solheim (2010). The importance of such systems is remarked in the study of interacting double

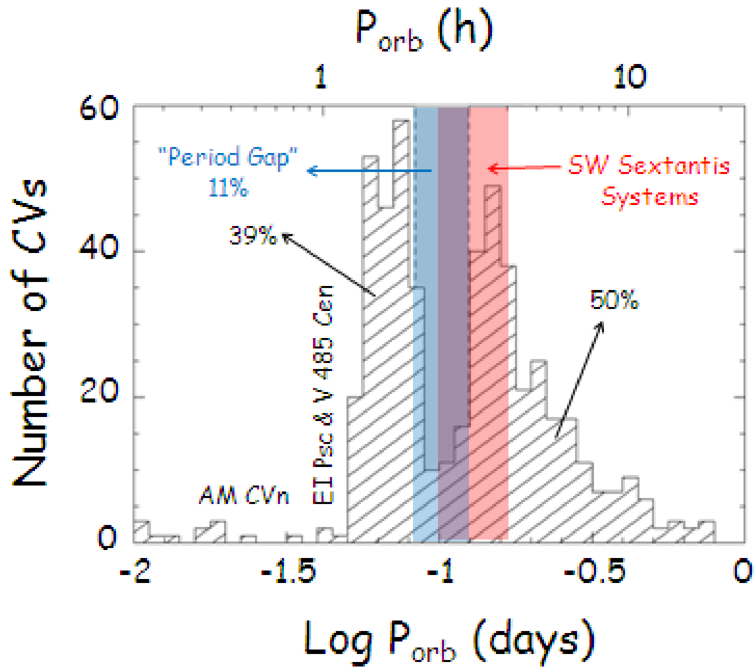


Figure 19: Number of CVs versus orbital period. Light blue rectangle shows the so-called "Period Gap"; light red rectangle shows the range of periods where SW Sextantis systems lie. Cyan-50 rectangle represents the intersection between the "Period Gap" and SW Sex periods (after Gänsicke, 2005 and Rodriguez-Gil, 2003).

white dwarf binaries that can give rise to a wide variety of astrophysical outcomes ranging from faint thermonuclear and Type Ia supernovae (Ia SNe) to the formation of neutron stars and stably accreting AM CVn systems. One key factor affecting the final outcome is whether mass transfer remains dynamically stable or instead diverges, leading to the tidal disruption of the donor and the merger of the binary. It is typically thought that for low ratios of the donor mass to the accretor mass, mass transfer remains stable, especially if accretion occurs via a disk. Shen (2015) examines low mass ratio double WD binaries and find that the initial phase of hydrogen-rich mass transfer leads to a classical nova-like outburst on the accretor. Dynamical friction within the expanding nova shell shrinks the orbit and causes the mass transfer rate to increase dramatically above the accretor's Eddington limit, possibly resulting in a binary merger. If the binary survives the first hydrogen-rich nova outbursts, dynamical friction within the subsequent helium-powered nova shells pushes the system even more strongly toward merger.

And the merging process of two compact stars has recently become extremely important for the gravitational wave (GW) astronomy. It is necessary to explore with particular attention each signal coming from GW detectors, possibly with multifrequency observations, in all the possible ranges, triggered by the GW detection.

Kalomeni et al. (2016) present a binary evolution study of CVs and related systems with white dwarf accretors, including for example, AM CVn systems, classical novae, supersoft X-ray sources, and systems with giant donor stars. They indicate where in the relationship P_{orb}–M_{donor} the accretion disks will tend to be stable against the thermal-viscous instability, and where gravitational radiation signatures may be found with LISA.

Cannizzo & Nelemans (2015) use the observed range of outbursting behavior for AM CVn systems as a function of orbital period to place a constraint on mass transfer rate versus orbital period. They infer a rate $\sim 5 \times 10^{-9}$ M$_\odot$ yr^{-1} $\times$ (P$_{\rm orb}$/1000 s)$^{-5.2}$. This functional form obtained is consistent with the recurrence time – orbital period relation found by Levitan et al. (2015) using a simple theory for the recurrence time.

5.2 Some rightful highlights on X-ray binary systems

The popular view of BHs is that they are ubiquitous in the Universe. Indeed, they are present both in microquasars (BH binaries) and in AGNs (Blazars, Radio-galaxies, Seyfert Galaxies) (e.g. Chaty, 1998). With the advent of a new generation of space- and ground-based telescopes in the last years, a new family of gamma-ray emitting systems has arisen: the gamma-ray binaries. Most of the known systems belong to the HMXB class. The detection of HMXBs at GeV and/or TeV energies has been the focus of extensive studies in the past few decades, but only a few systems have been confirmed as gamma-ray emitters. In order to explain the broadband emission of these systems, two main paradigms have appeared along the years (Maraschi & Treves, 1981, Bosch-Ramon & Khangulyan, 2009, Dubus, 2013): the microquasar and the binary-pulsar scenarios. In the first one, the compact object is accreting material from the companion star through Roche-lobe overflow via an accretion disk. Whilst this accretion takes place, two jets are formed perpendicular to the accretion disk. These jets carry on relativistic particles that would be behind the detected non-thermal emission. In the binary-pulsar scenario the non-thermal emission arises from the interaction of the relativistic wind of a young non-accreting pulsar with the wind of the massive companion star (Paredes & Munar-Adrover, 2014).

Cyg X-1 is the most popular microquasar harboring a black hole and a supergiant B star. Protons from the jet interact with ions in a cloud of clumpy wind from the companion star, producing inelastic pp-collisions and pion decay, which produces a flare in TeV gamma rays (e.g. Araudo, Bosch-Ramon & Romero, 2010).

Also Cyg X-3 is harbouring a black hole and a Wolf-Rayet star. The accretion launches two jets and the GeV emission would be produced when relativistic electrons in the jet up-scatter photons from the companion (e.g. Dubus, Cerutti & Henri, 2010).

A new member of the microquasar family is the first Be/BH system detected: MWC 656 (Casares et al. 2014). Munar-Adrover et al. (2014) established MWC 656 as a HMXB through X-ray observations with XMM-Newton.

Loh et al. (2016) with Fermi/LAT observations of V404 Cygni during its outburst in June-July 2015 detected a possible excess of γ-ray emission on 26 June 2015, with a very soft spectrum above 100 MeV, at a position consistent with the direction of V404 Cyg.

It is interesting to note that there is a universal correlation between Radio and X-ray (1-10 keV) luminosities for Galactic accreting binary BHs in the hard and quiescence states (Corbel et al., 2013). Later such a correlation has been verified also by Gallo et al. (2014), and by Munar-Adrover et al. (2014), as shown in Fig. 20.

Several books about BHs have been recently published:

PoS(HEASA 2016)031

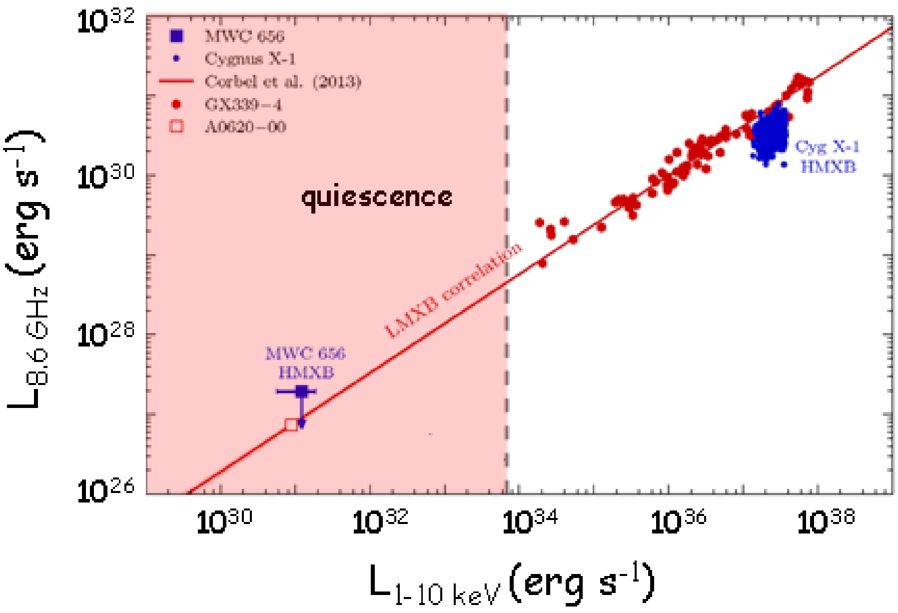


Figure 20: Radio versus X-ray luminosity diagram including the position of MWC 656 (blue square). The small blue dots indicate the region where Cygnus X-1 has been detected (Gallo, Miller & Fender, 2012). Red solid line shows the radio/X-ray correlation for BH LMXBs (Corbel et al., 2013); the BH LMXBs GX 339-4 (red hexagons) and A0620-00 (empty red square). The light-red rectangle shows the quiescent state region, which is separated from the other states, according to the threshold set by Plotkin, Gallo & Jonker (2013). The position of MWC 656 is very close to the one of the LMXB A0620-00 in quiescence, indicating that the radio/X-ray correlation might also be valid for BH HMXBs down to very low luminosities (adapted from Munar-Adrover et al., 2014).

- *The Physics of Accretion onto Black Holes* by Falanga et al. (2014). It provides a comprehensive summary on the physical models and current theory of black hole accretion, growth and mergers, in both the supermassive and stellar-mass cases.
- *Astrophysics of Black Holes* by Bambi (2016).
- *The Strongest Magnetic Fields in the Universe* by Beskin et al. (2016b)
- *The Formation and Disruption of Black Holes Jets* by Contopoulos, Gabuzda, & Kylafis (2015).

Black holes in X-ray binaries are often assumed to be rotating perpendicular to the plane of the accretion disk and parallel to the orbital plane of the binary. While the Bardeen-Petterson effect forces the inner part of the accretion disk to be aligned with the equatorial plane of a spinning BH, the disk may be warped such that the inclination angle of the outer part is different from that of the inner part. Cheng et al. (2016) identify a possible observational signature of a warped accretion disk in the spectrum of the polarization degree of the continuum. Such a signature would provide direct evidence for the presence of a warped disk and, potentially, even a measure of the warp radius, which, in turn, could be used to infer the viscosity parameter of the disk. This is very important since the knowledge of the viscosity in accretion disks is a critical point, as discussed for instance by Giovannelli, Bisnovatyi-Kogan & Klepnev (2013), and Bisnovatyi-Kogan & Giovannelli (2016).

Over the last couple of decades we have witnessed the discovery of a multitude of highly ionized absorbers in high-resolution X-ray spectra from both BH and NS XRBs. The first detections were obtained thanks to ASCA on the BH binaries GROJ1655-40 and GRS 1915+105. Narrow absorption lines in the spectra of these systems identified as Fe XXV and Fe XXVI indicated the first of many discoveries of photo-ionized plasmas in LMXBs (Chandra, XMM-Newton and Suzaku). Black hole hot accretion flows occur in the regime of relatively low accretion rates and are operating in the nuclei of most of the galaxies in the universe. One of the most important progress in recent years in this field is about the wind or outflow. This progress is mainly attributed to the rapid development of numerical simulations of accretion flows, combined with observations on, e.g., Sgr A*, the SMBH in the Galactic center. The mass loss from a BH via wind is related to the mass accretion rate onto the BH as (Yuan, 2016):

$$\dot{M}_{\rm wind}(r) = \dot{M}_{\rm BH} \times (r/20r_s)^s \qquad \text{with} \quad s \approx 1 \qquad (5.1)$$

At this point it is useful to make a sort of summary about the number of XRBSs, including CVs. Liu, van Paradijs & van den Heuvel (2006, 2007) and Ziółkowski (2013) report 315 galactic XRBs: 197 LMXBs (63%) and 118 HMXBs (37%), 72 of which are Be/X-ray systems; moreover there are 62 BH candidates. Coleiro & Chaty (2013) report that in the Milky way there are $\geq$ 200 HMXBs. Ritter & Kolb (2003) catalogue, in the 7.20 (Dec. 2013) version, reports 1166 CVs. Buckley (2015) reports about the discoveries of 530 new CVs from MASTER-Network and 855 CVs from Catalina Real Time Susrvey (CRTS) (http://nesssi.cacr.caltech.edu/DataRelease/). Ferrario, de Martino & Gänsicke (2015) report the number of MCVs as $\approx$ 250, and $\sim$ 60 of which IPs, and considering those systems for which the magnetic field intensity has not yet been determined, their number is of $\approx$ 600. Table 3 shows the content of XRBSs, including CVs, in the Galaxy, and in the LMC and SMC (Ziółkowski, 2013; Ferrario, de Martino & Gänsicke, 2015; Buckley, 2015). The mass are expressed in unit of SMC.

Grimm (2003) published: (i) a list of the 17 most luminous LMXBs contributing $\approx$ 90% to the integrated luminosity of LMXBs in the 2-10 keV band in the whole Galaxy, averaged over 1996-2000. The 12 most luminous sources (Cir X-1, GRS 1915+105, Sco X-1, Cyg X-2, GX 349+2, GX 17+2, GX 5-1, GX 340+0, GX 9+1, NGC 6624, Ser X-1, GX 13+1) contribute $\approx$ 80% of the integrated luminosity of the Galaxy; (ii) a list of the 10 most luminous HMXBs (Cyg X-3, Cen X-3, Cyg X-1, X 1657-415, V 4641 Sgr, GX 301-2, XTE J1855-024, X 1538-522, GS 1843+009, X 1908+075- that contribute $\approx$ 40% to the integrated luminosity of HMXBs in the 2-10 keV band in the whole Galaxy, averaged over 1996-2000.

Sion (http://astronomy.villanova.edu/faculty/sion/CV/index.html) states that in the Galaxy we could expect $\approx 10^6$ CVs. One of the big questions that arises is: "can all of the observed CVs and the phenomena associated with them be understood in terms of a single unified picture?" Other questions relate to the relative probabilities that CVs will be observed at particular stages in their evolution, and how the observations of CVs at the current epoch can be used to determine their ultimate fate. To address these questions Nelson (2012) and Goliasch & Nelson (2015) have undertaken a massive computational effort to theoretically simulate the evolution of most of the possible

Table 3: Comparison of numbers of different classes of X-ray Binary Systems in the Milky Way and in the Magellanic Clouds (Ziółkowski, 2013; Ferrario, de Martino & Gänsicke, 2015; Buckley, 2015).

Name of the Class	Milky Way	LMC	SMC
Total mass of the galaxy (in M_{SMC} units)	100	10	1
High Mass X-ray Binaries	118	26	83
in this Be/X-ray	72	19	79
Low Mass X-ray Binaries	197	2	-
Black Hole Candidates	62	2	-
Cataclysmic Variables	$\approx$ 2000	-	-
in this MCVs	$\approx$ 250	-	-
IPs	$\sim$ 60	-	-
B not yet determined	$\approx$ 600	-	-

CVs that could be produced by nature. The temporal evolution of 56,000 nascent CVs was followed over an age of 10 billion years using the MESA stellar evolution code. According to Nelson, "*This is the most ambitious analysis of the properties of an entire CV population that has ever been undertaken. The whole project required several core-years of CPU time*."

While many of the results confirmed what had already been inferred about the properties of CVs, there were a number of surprises including the identification of a number of previously unexplored evolutionary pathways. But, as expected, a sharp bifurcation was found between nascent CVs that evolved to produce double white-dwarf binaries (including ones containing helium and hybrid white dwarfs), and ones that continuously transferred mass over the lifetime of the universe. In addition, the predictions of the theoretical simulations were in good general agreement with the observations of CVs with reasonably well-measured properties.

What was surprising was the large number of short-period "ultracompact" binaries (AM CVn stars) that were produced and, especially, the enormous depletion of carbon relative to nitrogen and oxygen that is predicted at certain epochs for evolved systems. As Nelson points out, "*It seems that nature has provided us with a unique way to identify CVs that descended from a highly evolved state based on their carbon abundances. There is already some observational evidence to suggest that there is a significant depletion of carbon in certain CVs. This could be a really critical test that will allow us to infer the lineage of some CVs and predict what their fate will be*".

Szkody & Gänsicke (2012) provided a list of unanswered problems and questions and references for seeking additional information. Indeed, while the general evolutionary picture and the characteristics of the types of CVs are known at some level, there are major unsolved questions which remain. These include:

1. What is the actual number density and distribution of CVs in the Galaxy?

2. What happens to CVs once they reach the period minimum?

3. What are the detailed physics occurring in the common envelope?
4. What is the correct physics to describe viscosity in accretion disks?
5. What is the correct angular momentum prescription below the gap (besides gravitational radiation) that can account for the observed period minimum spike and the exact period distribution?
6. What causes the period gap?
7. How do Polars form and why are no magnetic white dwarfs in wide binaries observed? Are LARPS (Low Accretion Rate Polars) the progenitors of polars? Is there a difference in the emergence of systems containing magnetic white dwarfs versus non-magnetic?
8. What causes Polars, as well as the novalike disk systems with orbital periods between 3 and 4 hours, to cease mass transfer and enter low states? Are the associated mass transfer variations of the companion stars a general phenomenon among all CVs?
9. Can the white dwarfs in CVs grow in mass?
10. Do CVs contain exoplanets?

In order to answer to these not yet solved problems, a series of biennial Palermo Workshops about "*The Golden Age of Cataclysmic Variables and Related Objects*" has been organized since 2011. The refereed proceedings can be found in Giovannelli & Sabau-Graziati (2012c, 2015c, 2017).

6. Low energy indicators of high energy processes in cosmic accreting sources

X-ray binaries are cauldrons of fundamental physical processes which appear along practically the whole electromagnetic spectrum. The sub-class of X-ray transient sources show multifrequency behaviour which deserve particular attention in order to understand the causing physics. These binary systems consist of a compact star and an optical star, therefore there is a mutual influence between these two stars that drive the low energy (LE) (i.e. radio, IR, optical) and high energy (HE) processes. The LE processes are produced mostly on the optical star and the HE processes mostly on the compact star, typically a neutron star. Thus it appears evident that through the study of LE processes it is possible to understand also the HE processes and vice versa.

Giovannelli, Bisnovatyi-Kogan & Klepnev, 2013 (here after GBK13) – starting from the experimental evidence of a delay between LE and HE processes detected for the first time in the X-ray/Be system A0535+26/HDE245770 (e.g. Giovannelli & Sabau-Graziati, 2011) – developed a model for explaining such a delay. Briefly, the model is the following: in the vicinity of periastron the mass flux $\dot{M}$ increases (depending on the activity of the Be star) between $\approx 10^{-8}$ and $\approx 10^{-7}$ $M_\odot$ yr^{-1}. The outer part of the accretion disk – geometrically thin and optically thick without advection (Shakura & Sunyaev, 1973; Bisnovatyi-Kogan, 2002) – becomes hotter, therefore the optical luminosity (L_{opt}) increases. Due to large turbulent viscosity, the wave of the large mass flux is propagating toward the neutron star, thus the X-ray luminosity (L_x) increases due to the appearance of a hot accretion disk region and due the accretion flow channeled by the magnetic field lines onto magnetic poles of the neutron star. The time–delay τ is the time between the optical and X-ray flashes appearance. Figure 21 shows a sketch of this model.

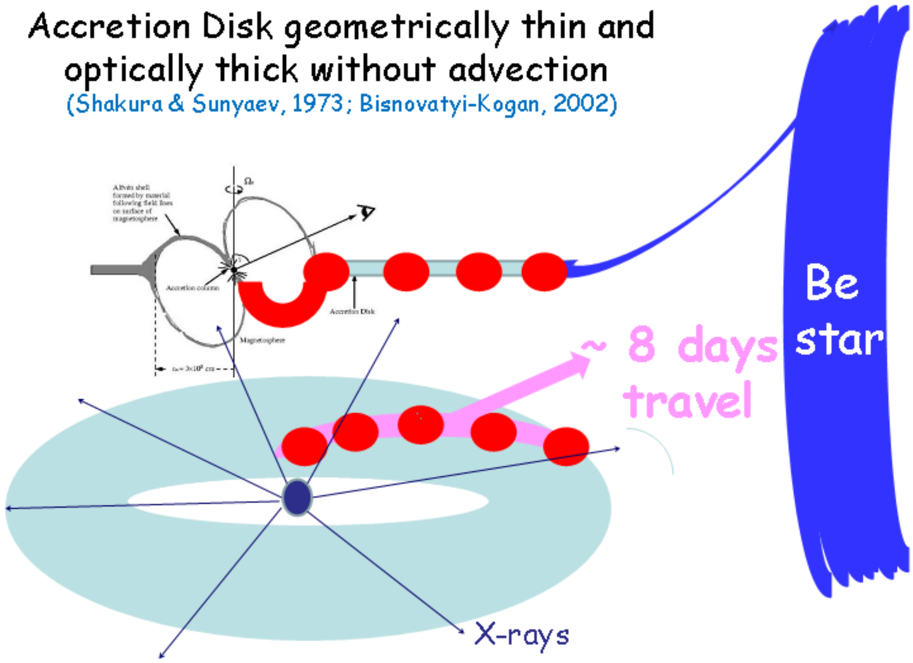


Figure 21: Sketch of the viscous accretion disk model for explaining the time-delay between X-ray and optical flashes (adopted from Giovannelli et al., 2015b).

By using the ephemerides given by GBK13, namely:

$$JD_{opt-outb} = JD_0(2{,}444{,}944) \pm n(111.0 \pm 0.4) \text{ days}$$

that fixed the reference point on 5th December 1981 (named 811205-E; E means Event) – when from HDE 245770 an optical flare in U,B, and V was detected and an X-ray flare from A0535+26 occurred just 8 days later – it was possible to explain the behaviour of the system during the year 2014 (Giovannelli et al., 2015a). It was possible not only to predict the arrival time of the X-ray outbursts following the optical flashes, but also the intensity I_x of the X-ray flares, thanks to the relationship I_x versus ΔV_{mag}, where ΔV_{mag} is the relative variations of the V magnitude of the Be star around the periastron passage with respect to the level before and after such a passage. Moreover they detected a jump in the H_α-EW and H_β-EW in correspondence with the rise of X-ray intensity, being the jump of H_β-EW delayed of $\approx$ 5 days with respect to that of H_α-EW. This important result deserves further investigations. However, the jumps of H_α-EW and H_β-EW could originate because of a contribution to the total emission in those lines coming from the temporary accretion disk around the neutron star (Giovannelli et al., 2015a, and the references therein). And if so, the delay between H_β-EW and H_α-EW jumps should be explicable within the framework of GBK13's model.

Giovannelli et al. (2015b) discussed many other events where the delay between X-ray and optical flares was detected, even going back in time until the first detection of the pulsar X occurred on April 1975. They clearly demonstrated the validity of GBK13's model.

It is right to remind that the mechanism proposed by GBK13 for explaining the X-ray-optical delay in A 0535+26/HDE 245770 is based on an enhanced mass flux propagation through the viscous accretion disk. This mechanism, known as UV-optical delay (the delay of the EUV flash with respect to the optical flash) was observed and modeled for cataclysmic variables (e.g. Smak, 1984; Lasota, 2001). Time delays have been detected also in several other X-ray transient binaries. This is the reason that urged Bisnovatyi-Kogan & Giovannelli (2016) to generalize the aforementioned model, developed for the particular case of A 0535+26/HDE 245770 (Flavia' star). This general model provides the formula (6.1) of the time delay in transient cosmic accreting sources:

$$\tau = 6.9 \frac{m^{2/3} \dot{m}^{1/15}}{\alpha^{4/5} (T_4)^{28/15}} \tag{6.1}$$

where:

$m = M/M_\odot$; $\dot{m} = \dot{M}/(10^{-8}\ M_\odot/yr)$; $T_4 = T_0/10^4$ K ; α = viscosity , and T_0 = maximum temperature in optics.

By using this formula it is possible to obtain an excellent agreement between the experimental and theoretical delays found in:

- X-ray/Be system A0535+26/HDE245770: $\tau_{exp} \simeq 8$ days (GBK13); $\tau_{th} \simeq 8$ days;
- Cataclysmic variable SS Cygni; τ_{exp} = 0.9–1.4 days (Wheatley, Mauche & Mattei, 2003); $\tau_{th} \simeq 1.35$ days;
- Low-mass X-ray binary Aql X-1/V1333 Aql: $\tau_{exp} \sim 3$ days (Shahbaz et al., 1998); $\tau_{th} \simeq$ 3.2days
- Black hole X-ray transient GRO J1655-40: $\tau_{exp} \sim 6$ days (Orosz et al., 1997); $\tau_{th} \simeq 6.5$ days.

In this general formula the α-viscosity parameter plays an important role, and usually it is hard to be determined. However, if the other parameters are known, because experimentally determined, the formula (6.1) can be used for determining α, taking into account the experimental delay measured in a certain source.

In the same paper, Bisnovatyi-Kogan & Giovannelli (2016) developed also a general model for explaining the X-ray/optical delay in Active Galactic Nuclei (AGN), such as Mrk 509, NGC 7469, 3C 120, NGC 3516, and NGC 4051. Briefly, the flashes in AGN occur when a disruption of a star on evolution phase of a giant enters the radius of strong tidal forces. The matter with low angular momentum, released from the star, falls into Super-Massive Black Hole (SMBH) in the form of a quasi-spherical flow with a speed close to free fall velocity. X-ray flash happens when the falling matter reaches the hot inner regions. The time lag observed in these sources is identified with the time necessary to the matter for falling from the tidal radius to the central region.

7. Conclusions

In this rather long review, not exhaustive, I hope to have given several important information about the updated knowledge of XRBSs. For a reader who have had the patience to arrive at the end of this review, I suggest to make use of the numerous references cited in this paper that can paint in a more general way the intriguing behaviour and physics governing such systems.

Acknowledgments I would like to thank the SOC and LOC of HEASA 2016 workshop for the invitation and for the support. This research has made use of NASA's Astrophysics Data System.

References

[1] Abbott, B.P. et al. (LIGO Scientific Collaboration and Virgo Collaboration): 2016, PRL 116, 061102

[2] Araudo, A.T., Bosch-Ramon, V., Romero, G.E.: 2010, in *High Energy Phenomena in Massive Stars*, J. Martí, P.L. Luque-Escamilla & J.A. Combi (Eds.), ASP Conf. Ser. Vol. 422, 32

[3] Baade, W., Zwicky, F.: 1934, Phys. Rev. 45, 138

[4] Bambi, C. (Ed.): 2016, *Astrophysics of Black Holes*, ApSSLibrary 440, Springer, pp. 214

[5] Bath, G.T.: 1969, ApJ 158, 571

[6] Bath, G.T.: 1975, MNRAS 171, 311

[7] Bath, G.T.: 1976, in *Structure and Evolution of Close Binary Systems*, P. Eggleton, S. Mitton & J. Whelan (Eds.), IAU Symp. No. 73, p. 173

[8] Bath, G.T.: 1978, QJRAS 19, 442

[9] Bath, G.T.: 1980, in *Close binary stars: Observations and interpretation*, IAU Symp. No. 88, p. 155

[10] Bath, G.T.: 1984, Ap&SS 99, 127

[11] Bath, G.T., Evans, W.D., Papaloizou, J., Pringle, J.E.: 1974, MNRAS 169, 447

[12] Bath, G.T., van Paradijs, J.: 1983, Nature 305, 33

[13] Belczynski, K., Ziółkowski, J.: 2009, ApJ 707, 870

[14] Belczynski, K., Dominik, M., Bulik, T., O'Shaughnessy, R., Fryer, C., Holz, D.E.: 2010, ApJL 715, L138

[15] Bender, R.: 2005, in *Growing Black Holes: Accretion in a Cosmological Context*, A. Merloni, S. Nayakshin & R.A. Sunyaev (Eds.), ESO Astrophysics Symposia, Springer-Verlag Berlin Heidelberg, p. 147-153

[16] Bernardini, F., de Martino, D., Mukai, K., Israel, G., Falanga, M. et al.: 2015, MNRAS 453, 3100

[17] Beskin, V.S., Balogh, A., Falanga, M., Treumann, R.A.: 2016a, in *The Strongest Magnetic Fields in the Universe*, Beskin, V.S., Balogh, A., Falanga, M., Lyutikov, M., Mereghetti, S. et al. (Eds.), Space Science Series of ISSI, Vol 54, 3

[18] Beskin, V.S., Balogh, A., Falanga, M., Lyutikov, M., Mereghetti, S. et al. (Eds.): 2016b, *The Strongest Magnetic Fields in the Universe*, Space Science Series of ISSI, Vol 54, Springer, pp. 579

PoS(HEASA 2016)031

[19] Bisnovatyi-Kogan, G.S.: 2002, in *Black Hole Astrophysics*, Proc. of the Sixth APCTP Winter School, Hyun Kyu Lee & Myeong-Gu Park (Eds.), World Scientific Publishing Co. Pte. Ltd., ISBN 9789812776761, pp. 187-206

[20] Bisnovatyi-Kogan, G.S., Giovannelli, F.: 2016, arXiv:1605.07013; A&A (in press, DOI: 10.1051/0004-6361/201628810)

[21] Blanch Bigas, O., Lopez, R., Carmona, E., MAGIC Collaboration, Pérez-Torres, M.A.: 2015, arXiv:1501.06405

[22] Blumenthal, G.R., Tucker, W.H.: 1974, Ann. Rev. A&A 12, 23-46

[23] Bosch-Ramon, V., Khangulyan, D.: 2009, Int. J. Mod. Phys. D, Vol. 18, Issue 03, 347-387

[24] Buckley, D., 2015, talk at the Palermo Workshop on "*The Golden Age of Cataclysmic Variables and Related Objects - III*"

[25] Burbidge, E.M., Burbidge, G.R., Fowler, W.A., Hoyle, F.: 1957, Rev. Mod. Phys. Vol. 29, Issue 4, 547-650

[26] Burger, M., van Dessel, E.L., Giovannelli, F., Sabau-Graziati, L., Bartolini, C. et al.: 1996, in *Multifrequency Behaviour of High Energy Cosmic Sources*, F. Giovannelli & L. Sabau-Graziati (eds.), Mem. SAIt. 67, 365

[27] Cameron, A.G.W.: 1988, Ann. Rev. A&A 26, 441

[28] Cannizzo, J.K., Nelemans, G.: 2015, ApJ 803, 19

[29] Casares, J., Jonker, P.G.: 2014, SSRv 183, 223-252

[30] Casares, J., Negueruela, I., Ribó, M., Ribas, I., Paredes, J.M. et al.: 2014, Nature 505,378

[31] Catanese, M., Akerlof, C.W., Badran, H.M., Biller, S.D., Bond, I.H. et al.: 1998, ApJ 501, 616

[32] Chadwick, P.M., Lyons, K., McComb, T.J.L., Orford, K.J., Osborne, J.L. et al.: 1999, ApJ 521, 547

[33] Chaty, S., 1998, Ph.D. thesis, University Paris XI

[34] Chaty, S.: 2011, in *Evolution of Compact Binaries*, L. Schmidtobreick, M. Schreiber & C. Tappert (Eds.), ASP Conf. Ser., 447, 29-43

[35] Cheng, Y., Liu, D., Nampalliwar, S., Bambi, C.: 2016, Class. Quantum Grav. 33, 125015 (12pp)

[36] Clay, J.: 1927, Proc. Nederlandsche Akad. v. Wet. 30, 1115

[37] Coburn, W., Heindl, W.A., Rothschild, R.E., Gruber, D.E., Kreykenbohm, I. et al.: 2002, ApJ 580, 394

[38] Coe, M., Corbet, R.H.D., McGowan, K.E., McBride, V.A.: 2010, in *High Energy Phenomena in Massive Stars*, J. Martí, P.L. Luque-Escamilla & J.A. Combi (Eds.), ASP Conf. Ser. Vol. 422, 224

[39] Coleiro, A., Chaty, S.: 2013, ApJ 764, 185

[40] Contopoulos, I., Gabuzda, D. & Kylafis, N. (Eds.): 2015, *The Formation and Disruption of Black Holes Jets*, ASSL 414, Springer

[41] Corbel, S., Coriat, M., Brocksopp, C., Tzioumis, A.K., Fender, R.P. et al.: 2013, MNRAS 428, 2500

[42] Corbet, R.H.D.: 1984, A&A 141, 91

[43] Corbet, R.H.D.: 1986, MNRAS 220, 1047

[44] Dubus, G.: 2013, A&A Rev 21, article id.64, pp. 71

[45] Dubus, G., Cerutti, B., Henri, G.: 2010, MNRAS 404, L55

[46] Fabbiano, G., Hartmann, L., Raymond, J., Steiner, J., Branduardi-Raymont, G., Matilsky, T.: 1981, ApJ 243, 911

[47] Falanga, M., Belloni, T., Casella, P., Gilfanov, M., Jonker, P., King, A. (Eds.): 2014, *The Physics of Accretion onto Black Holes*, Kluwer

[48] Ferrario, L., Wickramasinghe, D.T.: 2005, in *14th European Workshop on White Dwarfs*, D. Koester & S. Moehler (Eds.), ASP Conf. Ser., Vol. 334, 281

[49] Ferrario, L., Wickramasinghe, D.T.: 2007, in *15th European Workshop on White Dwarfs*, R. Napiwotzki & M.R. Burleigh (Eds.), ASP Conf. Ser., Vol. 372, 163

[50] Ferrario, L., de Martino, D., Gänsicke, B.T.: 2015, SSRv 191, 111-169

[51] Ferrario, L., Melatos, A., Zrake, J.: 2015, SSRv 191, 77-109

[52] Finger, M.H., Wilson, R.B., Harmon, B.A.: 1996, ApJ 459, 288

[53] Forman, W., Jones, C., Cominsky, L., Julien, P., Murray, S. et al.: 1978, ApJ Suppl. 38, 357

[54] Frank, J., King, A.R., Raine, D.J.: 1985, *Accretion power in astrophysics*, Cambridge and New York, Cambridge University Press, pp. 283

[55] Fryer, C.L., Belczynski, K., Wiktorowicz, G., Dominik, M., Kalogera, V., Holz, D.E.: 2012, ApJ 749, 91

[56] Gallo, E., Miller, B.P., Fender, R.: 2012, MNRAS 423, 590

[57] Gallo, E., Miller-Jones, J.C.A., Russell, D.M., Jonker, P.G., Homan, J. et al.: 2014, MNRAS 445, 290

[58] Gänsicke, B.T.: 2005, in *The Astrophysics of Cataclysmic Variables and Related Objects*, J.-M. Hameury & J.-P. Lasota (Eds.), ASP Conf. Ser. Vol. 330, 3

[59] Gaudenzi S., Giovannelli F., Lombardi R., Claudi R.: 1986, in *New Insights in Astrophysics. Eight Years of UV Astronomy with IUE*, ESA-SP 263, 455.

[60] Ghosh, P.: 1994, in *The Evolution of X-Ray Binaries*, S.S. Holt & C.S. Day (Eds.), AIP Conf. Proc. 308, 439

[61] Giacconi, R., Gursky, H., Paolini, F.R., Rossi, B.B.: 1962, PhRvL 9, 439

[62] Giacconi, R., Gursky, H., Kellog, E., Schreier, E., Tananbaum, H.: 1971, ApJL 167, L67

[63] Giacconi, R., Branduardi, G., Briel, U., Epstein, A., Fabricant, D. et al.: 1979, ApJ 230, 540

[64] Giovannelli, F. (Ed.): 1985 *Multifrequency Behaviour of Accreting Galactic Sources*, SIDEREA, Roma, pp. 371

[65] Giovannelli, F.: 2008, Ch. J. A&A Suppl. 8, 237-258

[66] Giovannelli, F., Karakuła, S., Tkaczyk, W.: 1981, in *Origin of Cosmic Rays*, Setti, G., Spada, G. & Wolfendale, A.W. (Eds.), IAU Symp. 94, p. 335

[67] Giovannelli, F., Karakuła, S., Tkaczyk, W.: 1982, Acta Astron. 32, 121

[68] Giovannelli, F., Ziółkowski, J.: 1990, Acta Astron. 40, 95

[69] Giovannelli, F., Sabau-Graziati, L.: 1992, SSRv 59, 1-81

[70] Giovannelli, F., Sabau-Graziati, L. (Eds.): 1996, *Multifrequency Behaviour of High Energy Cosmic Sources - I*, Mem. SAIt. 67, N. 1-2, pp. 634

[71] Giovannelli, F., Sabau-Graziati, L. (Eds.): 1999, *Multifrequency Behaviour of High Energy Cosmic Sources - II*, Mem. SAIt. Vol. 70, N. 3 - 4, pp. 755

[72] Giovannelli, F., Sabau-Graziati, L.: 2001, Ap&SS, 276, 67

[73] Giovannelli, F., Sabau-Graziati, L. (Eds.): 2002a, *Multifrequency Behaviour of High Energy Cosmic Sources - III*, Mem. SAIt. Vol. 73, N. 1, pp. 449

[74] Giovannelli, F., Sabau-Graziati, L. (Eds.): 2002b, *Multifrequency Behaviour of High Energy Cosmic Sources - IV*, Mem. SAIt. Vol. 73, N. 4, pp. 479

[75] Giovannelli, F., Sabau-Graziati, L. (Eds.): 2003, *Multifrequency Behaviour of High Energy Cosmic Sources - V*, Ch. J. A&A, Vol. 3, Supplement, pp. 562

[76] Giovannelli, F., Sabau-Graziati, L.: 2004, SSRv 112, 1-443

[77] Giovannelli, F., Sabau-Graziati, L. (Eds.): 2006, *Multifrequency Behaviour of High Energy Cosmic Sources - VI*, Ch. J. A&A, Supplement, Volume 6, Issue S1, pp. 408

[78] Giovannelli, F., Bernabei, S., Rossi, C., Sabau-Graziati, L.: 2007, A&A, 475, 651

[79] Giovannelli, F., Sabau-Graziati, L. (Eds.): 2008, *Multifrequency Behaviour of High Energy Cosmic Sources - VII*, Ch. J. A&A, Supplement, Vol. 8, pp. 426

[80] Giovannelli, F., Sabau-Graziati, L. (Eds.): 2010, *Multifrequency Behaviour of High Energy Cosmic Sources - VIII*, Mem. SAIt. Vol. 81, pp. 513

[81] Giovannelli, F., Sabau-Graziati, L.: 2011, Acta Polytechnica, Vol. 51, No. 2., p. 21

[82] Giovannelli, F., Sabau-Graziati, L.: 2012a, in *The Golden Age of Cataclysmic Variables and Related Objects - I*, F. Giocannelli & L. Sabau-Graziati (Eds.), Mem. SAIt 83, 446-465

[83] Giovannelli, F., Sabau-Graziati, L. (Eds.): 2012b, *Multifrequency Behaviour of High Energy Cosmic Sources - IX*, Mem. SAIt. Vol. 83, pp. 414

[84] Giovannelli, F., Sabau-Graziati, L. (Eds.): 2012c, *The Golden Age of Cataclysmic Variables and Related Objects - I*, Mem. SAIt. 83, pp. 433

[85] Giovannelli F, Bisnovatyi-Kogan, G.S., Klepnev, A.S.: 2013, A&A 560, A1 (GBK13)

[86] Giovannelli, F., Sabau-Graziati, L.: 2014a, in *Multifrequency Behaviour of High Energy Cosmic Sources - X*, F. Giovannelli & L. Sabau-Graziati (Eds.), Acta Polytechnica, CTU Proc. ISSN 978-80-01-05668-4 e-ISSN 2336-5382, Vol. 1 No. 1, 1-12

[87] Giovannelli, F., Sabau-Graziati, L. (Eds.): 2014b, *Multifrequency Behaviour of High Energy Cosmic Sources - X*, Acta Polytechnica, CTU Proc. ISSN 978-80-01-05668-4 e-ISSN 2336-5382, Vol. 1 No. 1, pp. 331

[88] Giovannelli, F., Bisnovatyi-Kogan, G.S., Bruni, I., Corfini, G., Martinelli, F., Rossi, C.: 2015a, Acta Astron. 65, 107

[89] Giovannelli, F., Rossi, C., Bisnovatyi-Kogan, G., Bruni, I., Fasano, A., Salas Procas, J.: 2015b, in *Multifrequency Behaviour of High Energy Cosmic Sources - XI*, PoS-SISSA - http://pos.sissa.it/cgi-bin/reader/conf.cgi?confid=246, id.39

[90] Giovannelli, F., Sabau-Graziati, L.: 2015a, in *The Golden Age of Cataclysmic Variables and Related Objects - II*, F. Giovannelli & L. Sabau-Graziati (Eds.), Acta Polytechnica, CTU Proc. ISSN 2336-5382, Vol. 2 No. 1, 3-20

[91] Giovannelli, F., Sabau-Graziati, L. (Eds.): 2015b, *Multifrequency Behaviour of High Energy Cosmic Sources - XI*, PoS-SISSA - http://pos.sissa.it/cgi-bin/reader/conf.cgi?confid=246

[92] Giovannelli, F., Sabau-Graziati, L. (Eds.): 2015c, *The Golden Age of Cataclysmic Variables and Related Objects - II*, Acta Polytechnica, CTU Proc. ISSN 2336-5382, Vol. 2 No. 1, pp. 333

[93] Giovannelli, F., Sabau-Graziati, L. (Eds.): 2017, *The Golden Age of Cataclysmic Variables and Related Objects - III*, PoS-SISSA (in press)

[94] Goliasch, J., Nelson, L.: 2015, ApJ 809, 80

[95] Grimm, H.-J.: 2003, PhD Thesis, Ludwig-Maximilians-Universitat, München, Germany

[96] Grudzinska , M. et al.: 2015, MNRAS, 452, 2773

[97] Hack, M., la Dous, C. (Eds.): 1993, *Cataclysmic Variables and Related Objects*, NASA SP-507, 1-860

[98] Harrison, T.E., McNamara, B.J., Szkody, P., McArthur, B.E., Benedict, G.F. et al.: 1999, ApJL 515, L93

[99] Hartman, R.C., Bertsch. D.L., Bloom, S.D., Chen, A.W., Deines-Jones, P. et al.: 1999, ApJ. Suppl. 123, 79

[100] Hayakawa, S.: 1952, Prog. Theor. Phys. 8, 571

[101] Hellier, C.: 2001, *Cataclysmic Variable Stars*, Springer, pp. 210

[102] Hess, V.F.: 1912, Physik Zh. 13, 1084

[103] van den Heuvel, E.P.J.: 2009, Ap&SS Library, 359, 125

[104] van den Heuvel, E.P.J., Rappaport, S.: 1987, in *Physics of Be Stars*, A. Slettebak & T.P. Snow (eds.), Cambridge and New York, Cambridge University Press, Proc. of the IAU Coll. N. 92, p. 291

[105] Howell, S.B., Cash, J., Mason, K.O., Herzog, A.E.: 1999, AJ 117, 1014

[106] Howell, S,B., Nelson, L.A., Rappaport, S.: 2001, ApJ 550, 897

[107] Illarionov, A.F., Sunyaev, R.A.: 1975, A&A 39, 185

[108] Israel, G.: 1996, Ph.D. thesis, Scuola Int. Superiore Stud. Avanzati (SISSA), Trieste, http://www.mporzio.astro.it/gianluca/phdthesis.html

[109] Johnstone, Wm. R.: 2004, http://www.johnstonsarchive.net/relativity/bhctable.html

[110] Kalomeni, B., Nelson, L., Rappaport, S., Molnar, M., Quintin, J., Yakut, K.: 2016, ApJ 833, 83

[111] Kepler, S.O., Pelisoli, I., Jordan, S., Kleinman, S.J., Koester, D. et al.:: 2013, MNRAS 429, 2934

[112] Kepler, S.O., Pelisoli, I., Koester, D., Ourique, G., Kleinman, S.J. et al.: 2015, MNRAS 446, 4078

[113] Kitamoto, S. et al.: 2014, arXiv:1412.1165v1 [astro-ph.HE] 3 Dec 2014

[114] Körding, E., Rupen, M., Knigge, C., Fender, R., Dhawan, V. et al.: 2008, Science 320, 1318

[115] Kormendy, J., Ho, L.C.: 2013, Ann. Rev. A&A 51, 511-653

[116] Landi, R., Bassani, L., Dean, A.J., Bird, A.J., Fiocchi, M. et al.: 2009, MNRAS 392, 630

[117] Lasota, J.-P.: 2001, New Astron. Rev. 45, 449

[118] Levitan, D., Groot, P.J., Prince, Th.A., Kulkarni, S.R., Laher, R. et al.: 2015, MNRAS 446, 391

[119] Lewin, W.H.G., van den Heuvel, E.P.J. (Eds.): 1983, *Accretion-Driven Stellar X-ray Sources*, Cambridge University Press, 450 p.

[120] Lipunov, V.M.: 1987, Ap&SS 132, 1

[121] Lipunov, V.M.: 1995, in *Frontier Objects in Astrophysics and Particle Physics*, F. Giovannelli & G. Mannocchi (Eds.), SIF, Bologna, Italy, 47, 61

[122] Lipunov, V.M., Postnov, K.A.: 1988, Ap&SS 145, 1

[123] Liu, Q.Z., van Paradijs, J., van den Heuvel, E.P.J.: 2006, A&A 455, 1165

[124] Liu, Q.Z., van Paradijs, J., van den Heuvel, E.P.J.: 2007, A&A 469, 807

[125] Loh, A., Corbel, S., Dubus, G., Rodriguez, J., Grenier, I. et al.: 2016, MNRAS 462, L111

[126] Maier, G. (for the VERITAS Collaboration): 2015, arXiv150805489

[127] Mantle, V.J., Bath, G.T.: 1983, MNRAS 202, 151

[128] Maraschi, L., Treves, A.: 1981, MNRAS 194, 1P

[129] de Martino, D.: 2016, in *The Universe of Digital Sky Surveys*, N.R. Napolitano et al. (Eds.), Springer International Publishing Switzerland, Ap&SS Proc. 42, 40

[130] Michel, F.C.: 1972, Ap&SS 15, 153

[131] Munar-Adrover, P., Paredes, J.M., Ribó, M., Iwasawa, K., Zabalza, V., Casares, J.: 2014, ApJL 786, Issue 2, article id. L11

[132] Nagase, F., Hayakawa, S., Kunieda, H., Makino, F., Masai, K., et al.: 1982, ApJ 263, 814

[133] Nelemans, G.: 2005, in *The Astrophysics of Cataclysmic Variables and Related Objects*, J.-M. Hameury & J.-P. Lasota (Eds.), ASP Conf. Ser., Vol. 330, 27

[134] Nelson, L.: 2012, J. Phys.: Conf. Ser. Volume 341, Issue 1, id. 012008

[135] Neshpor, Yu.I., Stepanyan, A.A., Kalekin, O.P., Fomin, V.P., Chalenko, N.N., Shitov, V.G.: 1998, AstL 24, 134

[136] Ong, R.A.: 2003, arXiv:astro-ph/0304336v3

[137] Orosz, J.A., Remillard, R.A., Bailyn, C.D., McClintock, J.E.: 1997, ApJL 478, L83

[138] Paczyński, B.: 1965, Acta Astron. 15, 89

[139] Paczyński, B.: 1977, ApJ 216, 822

[140] Paredes, J.M., Munar-Adrover, P.: 2014, in *Frontier Research in Astrophysics*, http://pos.sissa.it/cgi-bin/reader/conf.cgi?confid=237, id.17

[141] Patterson, J.: 1984, ApJ Suppl. 54, 443-493

[142] Patterson, J.: 1992, ApJ 384, 234

[143] Patterson, J.: 1994, PASP 106, 209-238

[144] Peterson, L.E., Winckler, J.B.: 1958, Phys. Rev. Lett. 1, 205

[145] Piccioni, A., Bartolini, C., Bernabei, S., Guarnieri, A., Tarozzi, F., Valentini, G.: 1999, in *Frontier Objects in Astrophysics and Particle Physics*, F. Giovannelli & G. Mannocchi (Eds.), SIF, Bologna, Italy, 65, 195

[146] Plotkin, R.M., Gallo, E., Jonker, P.G.: 2013, ApJ 773, 59

[147] Postnov, K.A., Yungelson, L.R.: 2014, Living Rev. Relativity, 17, 3-166

[148] Priedhorsky, W.C., Terrell, J.: 1983, Nature 303, 681

[149] Pringle, J.E.: 1981, Ann. Rev. A&A 19, 137-162

[150] Punch, M., Akerlof, C.W., Cawley, M.F., Chantell, M., Fegan, D.J. et al.: 1992, Nature 358, 477

[151] Quinn, J., Akerlof, C.W., Biller, S., Buckley, J., Carter-Lewis, D.A. et al.: 1996, ApJL 456, L83

[152] Raguzova, N.V., Lipunov, V.M.: 1999, A&A 349, 505

[153] Rajoelimanana, A.F., Charles, P.A.: 2012, African Skies 16, 126

[154] Rappaport, S., Joss, P.C.: 1981, in *X-Ray Astronomy with the Einstein Satellite*, R. Giacconi (ed.), D. Reidel Publ. Co., Dordrecht, Holland, p. 123.

[155] Rappoldi, A., Lucarelli, F., Pittori, C., Longo, F., Cattaneo, P.W. et al.: 2016, A&A, 587, A93

[156] Rieger, F.M., de Oña-Wilhelmi, E., Aharonian, F.A.: 2013, Fr. Phys. 8, 714-747

[157] Ritter, H., Kolb, U.: 2003, A&A 404, 301

[158] Robinson, E.L.: 1976, Ann. Rev. A&A 14, 119-142

[159] Rodriguez-Gil, P.: 2003, Ph.D. Thesis, La Laguna University, Spain

[160] Santangelo, A.: 2006, talk at the Vulcano Workshop on "*Frontier Objects in Astrophysics and Particle Physics*"

[161] Santangelo, A., Segreto, A., Giarrusso, S., Dal Fiume, D., Orlandini, M. et al.: 1999, ApJL 523, L85

[162] Scaringi, S.: 2015, talk at the Palermo Workshop on "*The Golden Age of CVs and Related Objects Ű III*"

[163] Scaringi, S., Bird, A.J., Norton, A.J., Knigge, C., Hill, A.B. et al.: 2010, MNRAS 401, 2207

[164] Schmidtobreick, L., Tappert, C.: 2014, in *Stella Novae: Past and Future Decades*, P.A. Woudt & V.A.R.M. Ribeiro (Eds.). ASP Conf. Ser. Vol. 490, 29

[165] Schmidtobreick, L., Tappert, C.: 2015, Acta Polytechnica CTU Proc. Vol. 2, 188

[166] Shahbaz, T., Bandyopadhyay, R.M., Charles, P.A., Wagner, R.M., Muhli, P., et al.: 1998, MNRAS 300, 1035

[167] Shakura, N.I.: 1972, Astron. Zh. 49, 921

[168] Shakura, N.I., Sunyaev, R.A.: 1973, A&A 24, 337

[169] Shen, K.J.: 2015, ApJL 805, L6

[170] Skinner, G.K., Bedford, D. K., Elsner, R.F., Leahy, D., Weisskopf, M.C., Grindlay, J.: 1982, Nature 297, 568

[171] Smak. J.: 1962, Acta Astron. 12, 28

[172] Smak, J.: 1967, Acta Astron. 17, 255

[173] Smak. J.: 1972, Acta Astron. 22, 1

[174] Smak. J.: 1981, Acta Astron. 31, 395

[175] Smak, J.: 1984, PASP 96, 5

[176] Smak, J.: 1985, in *Galactic Accreting Sources*, F. Giovannelli (ed.), SIDEREA, Roma, Italy, p. 3

[177] Solheim, J.-E.: 2010, PASP, 122, 1133-1163

[178] Strong, A.W., Wolfendale, A.W., Worral, D.M.: 1976, MNRAS 175, 23.

[179] Swanenburg, B.N., Bennet, K., Bignami, G.F., Buccheri, R., Caraveo, P. et al.: 1981, ApJL 243, L69

[180] Szkody, P., Gänsicke, B.T.: 2012, JAAVSO 40, 563

[181] Tanaka, Y.: 2001, in *The Century of Space Science*, J.A. Bleeker, J. Geiss & M. Huber (Eds.), Kluwer Academic Publishers, pp. 839-856

[182] Trümper, J., Pietsch, W., Reppin, C., Voges, W., Staubert, R., Kendziorra, E.: 1978, ApJL 219, L105

[183] Vaiana, G.S., Cassinelli, J.P., Fabbiano, G., Giacconi, R., Golub, R. et al.: 1981, ApJ 245, 163

[184] Verrecchia, F., Pittori, C., Chen, A., Bulgarelli, A., Tavani, M. et al.: 2013, A&A, 558, 137

[185] Villard, P.: 1900, Compt. Rend. Acad. Sci. Paris 130, 1010

[186] Wakely, S., Horan, D.: 2016, http://tevcat.uchicago.edu/

[187] Walter, R., Lutovinov, A.A., Bozzo, E., Tsygankov, S.S.: 2015, A&A Rev 23, pp. 99

[188] Warner, B.: 1995, *Cataclysmic Variable Stars*, Cambridge Astrophysics Series Vol. 28, Cambridge University Press

[189] Wheatley, P.J., Mauche, C.W., Mattei, J.A.: 2003, MNRAS 345, 49

[190] Wickramasinghe, D.T., Ferrario, L.: 2000, PASP 112, Issue 773, 873-924

[191] Wiktorowicz,G., Belczynski, K, Maccarone, T.J.: 2014, in *Binary Systems, their Evolution and Environments*, arXiv:1312.5924v2

[192] Wilson, C.T.R.: 1900, Proc. Cambridge Phil. Soc. 11, 32

[193] Wood, K.S., Meekins, J.F., Yentis, D.J., Smathers, H.W., Menutt, D.P. et al.: 1984, ApJ Suppl. 56, 507

[194] Wu, K.: 2009, Res. Astron. Astrophys., 9 (Issue 7), 725-744

[195] Wu, K., Ramsay, G. & Willes, A.: 2008, Ch. J. A&A. Vol. 8, Suppl., 169-174

[196] Yuan, F.: 2016, in *Astrophysics of Black Holes*, C. Bambi (Ed.), ApSSLibrary 440, 152-168

[197] Zel'dovich, Ya, B. & Guseinov, O.Kh.: 1965, Soviet Physics Doklady, Vol. 10, p.524

[198] Ziółkowski, J.: 2013, Acta Polytechnica Vol 53, Suppl., 665

[199] Zwicky, F.: 1939, Phys. Rev. 55, 726