PROGRESSION OF X-RAY ASTRONOMY AND ITS SIGNIFICANCE IN UNDERSTANDING NEUTRON STAR SOFT X-RAY TRANSIENT

Abstract

Soft X-ray transients are one of the many varieties of Low Mass X-ray Binaries (LMXB), which typically radiate in a latent state with very low luminosity but on rare occasions outgo sporadic outbursts with a 100-1000 times increase in its luminosity. Out of 166 LMXB, 30 have so far been classified as Neutron Star Soft X-ray Transients (NSSXT) with spatial distribution $|l| = \pm 10$ deg and $|b| < 20$ deg. In this paper, we attempt to summarise the role of High-resolution X-ray Spectroscopy(HRXS) and models conceived in evaluating various activities exhibited by NSSXTs during X-ray emission, particularly the process of X-ray emission during outburst and quiescence states and thereby how our understanding of the Physical and Chemical structure of NS comprising NSSXTs has evolved. The Choice of NSSXT is significant because in SXT X-ray emission during quiescence in principle is because of the mechanism without inflow of matter into the primary star.

Keywords: HRXS, NSSXT, Model, LMXB, Quiescent, Outburst

Authors

Rabindra Mahato
Faculty & Research Scholar
Department of Physics
Science College, Kokrajhar
Department of Physics
School of Fundamental and Applied Sciences
Assam Don Bosco University
Sonapur, Guwahati, Assam, India.
rabi_1777@yahoo.com

T D Peter Lianlunthang
Department of Physics
School of Fundamental and Applied Sciences
Assam Don Bosco University
Sonapur, Guwahati, Assam, India.

Monmoyuri Baruah
Department of Physics
School of Fundamental and Applied Sciences
Assam Don Bosco University
Sonapur, Guwahati, Assam India.

I. INTRODUCTION

It was always challenging to study the supranuclear degenerate matter surrounding the neutron star (Bhattacharya et al., 2010). Efforts were consistently put forth by various groups and individuals to study this matter because of the wide possibility of revealing many new insights about neutron stars, the core collapse of massive stars and also to gather information about the phenomenon of supernovas (Van Kerkwijk, 2004). It is next to impossible to obtain such matter in a laboratory which makes these studies highly significant and unparalleled. The X-ray radiation from neutron stars and nearby atmosphere contains information about the matter around the neutron star (NS) and these pieces of information can be derived from the timing and spectral analysis of these X-ray emission. The High-resolution X-ray Spectroscopy (HRXS) evolves as a powerful tool in this direction. X-ray Spectroscopy is also useful in probing larger column density because it is less affected by extinction and is thus very helpful for finding out the properties of the ISM across the galactic disk. High-resolution X-ray Spectroscopy (HRXS) has turned up as a sustainable diagnostic tool for evaluating the chemical and physical properties of the NS, the atmosphere near it and ISM. Different charge states of the elements and transition from K-shell and L-shell allow us to constrain multiphase, ISM its ionization state, and temperature distribution.

The journey of X-ray astronomy is not too old; it starts with the discovery of Scorpius X-1 (SCO X-1) by Giaconni et al. in the year 1962 and presently we have a sea of data because of the launching of a series of dedicated astronomical study satellite starting from the first X-ray satellite Vela launched in 1963. X-ray astronomy opened up a new dimension of understanding the universe, its dynamics, and various governing phenomena. New edge instrumentation and advanced technical tools of observation have paved the path to the detection of multiple numbers of X-ray sources. Since the Earth’s atmosphere prohibits X-rays from reaching the surface of the Earth. Thus observatories on Earth are unable to study a good chunk of the electromagnetic spectrum and are devoid of the information carried by X-rays originating at neutron stars and its nearby area. This problem was resolved by setting up X-ray observatories outside the Earth’s atmosphere. The launching of satellites equipped with X-ray detectors on-board started in the year 1963 with the launching of the satellite named Vela. Since then more than 50 (fifty) satellites have already been commissioned up to 2022. The major upcoming projects are XPoSat, XRISM, ASTROSAT2, ATHENA etc. The most popular among them are - XMM Newton of the European Space Agency (ESA); Rossi X-ray Timing Explorer (RXTE) of the National Aeronautics and Space Administration (NASA); Suzaku of the Japan Aerospace Exploration Agency (JAXA); NASA’s Chandra and ASTROSAT of Indian Space Research Organisation. Since X-ray emission is associated with different phenomena such as Thermonuclear bursts, and Kilohertz quasi-periodic oscillations (KQPO) apart from the continuum energy spectrum, therefore variety of instruments such as Proportional Counter Array or PCA, Reflection Grating Spectrometer or RGS etc. were designed and installed to acquire X-rays according to the demand. The large photon collecting area and time resolution of ~11s turned out the PCA (installed in RXTE) to be the ideal tool for studying fast-timing phenomena such as KQPO (Bhattacharya et al., 2010). However, its poor energy resolution limits its capacity to study the spectral lines. The XMM Newton satellite and Chandra resolved this problem to a great extent and turned out to be ideal for detecting and analysing closely spaced spectral lines (in the 0.1–12 keV range). The high-resolution “Reflection Grating Spectrometers (RGS)” on-board XMM-Newton and the “Low Energy Transmission Grating (LETG)” and “High Energy Transmission Grating

(HETG)" spectrometers in CHANDRA help us to do so. The XMM-Newton and Chandra play an appreciable role in the study of the quiescent emission of neutron star Low Mass X-ray binaries (LMXB). Likewise, the satellite Suzaku with the help of the "Hard X-ray Detector" (HXD) on board, facilitates the study of the broadband energy spectrum by detecting the broad relativistic iron emission lines (Bhattacharya et al., 2010). The "Large Area X-ray Proportional Counter (LAXPC)" installed in ASTROSAT (launched in the year 2015) is capable of measuring hard X-rays (~50keV) high-frequency timing features and accretion-powered pulsations.

To date, in the universe, thousands of X-ray emitting sources have been detected, We restricted ourselves to the LMXBs, particularly to the neutron star soft X-ray transients (NSSXT) in this review. Such LMXB sources are outstanding test beds for a wide range of astrophysical queries and analysis of fundamental physics. Observations of neutron star LMXBs can also help constrain the equation of state of matter at supranuclear densities. These sources also help in testing theories, such as "Einstein's theory of general relativity", in the strong field regime. The Soft X-ray transients are a special class of Low Mass X-ray Binary which radiates X-ray of varying luminosity ranging from 10^{36} -10^{38} erg s^{-1} (during outburst) (F.CotiZelati et al., 2018) to 10^{32}–10^{33} erg s^{-1} (during quiescence) (S. Campana et al.,1998) with soft thermal component below 2keV and hard component above 2 keV. The several orders of luminosity variation in transient binaries is a common practice. These variations reflect, at least partially, the change of the matter inflow rate towards the primary object and generate an opportunity to sample a variety of physical conditions and regimes that are inaccessible to persistent (bright) sources. SXRTs in the state of quiescent are most interesting because X-ray emission mechanisms during quiescence do not involve the inflow of mass onto the compact star (neutron star) surface (S.Campana& L. Stella, 2003). It may help us to understand what causes the accretion onto the primary object in SXTs to be intermittent, This may reveal the strength of magnetic intensity and rotation period of the compact star (neutron star) at low accretion rates. The field strength and period thus obtained may then be compared with the field strength and period of the recycled radio pulsars with low-mass white-dwarf companions. (Frank Verbunt, 1996)

So far around 30 NSSXTs have been detected since the first popular catalogue of LMXB was published by P.R.Amnuel et al. in the year, 1979. The most latest catalogue published in the year 2020 comprises 166 LMXBs, out of which 103 are transient. In this paper, we attempt to summarise the contribution of High-resolution X-ray Spectroscopy (HRXS) and models conceived in evaluating various activities exhibited (Particularly the process of X-ray emission during outburst and quiescence states) by NSSXTs during X-ray emission. Further, we attempt to summarise the outcomes of the physical and chemical structure of NS comprising NSSXTs. The choice of NSSXT is significant, because in SXT X-ray emission during quiescence in principle is in the absence of inflow of matter into the primary star.

II. SOURCES OF X-RAYS

It is now more than six decades since the Sun was identified as the first celestial object to give off X-rays from its outer atmosphere in 1949 detected using rocket-borne radiation counters. It is an essentially weak X-ray source. At present, we know various categories of X-ray radiating sources such as Seyfert galaxies, Quasars and Radio Galaxies.

The Clusters also emit the X-rays but these do not come from their member galaxies but rather from a pool of hot gas between them. However, the X-ray binary stars are among the prominent X-ray-emitting sources. They radiate 1,000 times as great as the Sun's radiation at all wavelengths and therefore in this review our focus is NSSXT, one of the types of Low Mass X-ray binary. The most latest catalogue published in the year 2020 speaks about 166 LMXBs detected in Milkyway, out of which 103 are transient (Q.Z. Liu et al., 2007).

The Catalogue published by Q.Z. Liu et al. in the year 2007 showed a consistent growth in the number of LMXB in Large Magellanic Cloud (LMC) because of the constant development and deployment of the sensitive telescopes, spectrometers and launching of new survey missions. The comparison of mass between the Galactic centre and LMC tells that the availability of LMXB in LMC appears to be comparable to that in the Milky Way. (S. Sazonov et al., 2020). However, to date, only a few LMXBs were confirmed like LMC X-2 (Grebenev et al., 2013), 3FGL J0427.9-6704 discovered by Fermi (Strader et al. 2016), LHG 83 and LHG 87 (M.W.Pakull et al., 1987). A.P. Cowley et al. in the year 1997 predicted that there would be ~ 1-2 dozen of LMXB in LMC. X-ray binaries were also detected in NGC 720 (Jeltema et al., 2003) and NGC 1399 (Angelini et al., 2001). Barnard et al., 2003, even discovered a Z-source Low-Mass X-ray Binary, RXJ0042.6+4115, in M31. Most of the ultra-luminous X-ray sources in elliptical galaxies (Liu & Mirabel, 2005) are believed to be LMXBs with a black hole. Till now 57 faint X-ray sources and 13 LMXB with neutron stars as compact stars are known in the Galactic globular cluster systems (Verbunt, 2001). Some of these were believed to be quiescent LMXBs (qLMXBs) containing neutron stars (Verbunt et al, 1984). Many such quiescent low-mass X-ray binaries were also detected by the Chandra and XMM-Newton observatories in several globular clusters (e.g. NGC 6440, Heinke et al., 2003). These LMXBs, however, have not been included in this catalogue. The stellar mass of the Small Magellanic Cloud (SMC) is just 1/10th of that of the LMC (Van der Marel et al., 2009) and maybe because of that, no LMXBs have been found in SMC.

1. **X-Ray Transients:** An X-ray binary system is broadly categorised into High Mass X-ray Binary (HMXB) and Low Mass X-ray Binary (LMXB). In HMXB the compact star is a strongly magnetized neutron star (NS) while in the case of LMXB, it is either a neutron star (NS) or a black hole (BH). Again, the secondary star in the case of HMXB is a very massive O or B-type star while in the case of LMXB, the secondary star may be a white dwarf, late-type sequence star, F-G type subgiant star, or A-type star. The LMXB is additionally divided into two groups Z-track LMXB and Atoll LMXB (Hasinger& Van der Klis, 1989). The majority of the LMXB is an Atoll source. According to Liu's 2007 catalogue, there are 150 LMXBs, of which 18 are Atoll sources, 63 X-ray burst sources, 11 Dipping LMXBs, 13 Globular cluster X-ray sources, 15 X-ray pulsars, 76 transient X-ray sources, and 7 Z-type sources, among others. A single LMXB may fall into two or three of the above categories.

   The transient X-ray sources are a special class of LMXB that remain dormant and undetected for the majority of the time and undergo sporadic outbursts. The sudden outbursts typically last for 10 to 100 days and then fade into invisibility. Their high luminosity (10^{37} to 10^{38} erg s^{-1}), (F.CotiZelati et al., 2018) time variability all through outbursts and optical counterparts are similar to the persistent bright X-ray sources. These are also similar to close binary systems powered by the accretion of mass onto a compact star. Transient systems are significant because they enable accretion onto compact stars to be studied for a considerably wider range of luminosities and consequently accretion rates than persistent sources. Further, the transient LMXBs are categorised into three groups- Hard X-ray transients (HXRTs/ HRTs) Soft X-ray transients (SXRTs/ SXTs) and Ultra Soft X-ray transients (USXT).

HXRTs are typically connected with persistent X-ray pulsars in HMXBs and typically comprise of a young, pulsating neutron star circling a Be star companion. SXRTs, on the other hand, are close binary systems in which a compact object is either a black hole or a neutron star that quickly and efficiently absorbs mass from a low-mass companion, a lower main sequence star, or a (sub) giant star (J.P.Lasota, 1996).

The transient X-ray source population has also been identified in Magellanic-type galaxies such as the Small and Large Magellanic Clouds (SMC and LMC) and NGC 55 (Kahabka&Pietsch, 1996; Coe et al., 2001; Jithesh& Wang, 2016, and references therein).

2. **Soft X-ray Transients (SXT/SXRTs):** As implied by its name, the "Soft X-ray Transient" emits the majority of its outburst energy in soft (a few keV) X-rays (J.P.Lasota, 2001). A Pronounced increase in the luminosity of their (faint) optical counterparts and the onset of type-1 bursts associate SXRTs with LMXBs containing an old neutron star. Typical SXTs are generally very faint or even remain latent in X-rays. This state is called the "quiescent" state (S.Campana et al., 1998). The SXTs have outbursts with a recurrence time of 60-350 days (Simon Vojtech, 2004). In a few months, the system resumes its state of quiescence. The probable mechanism of this dwindling between outbursts and quiescence state is explained in section 3.1.

During the outburst, the X-ray luminosity of an SXT can rise by a factor of 100-10^4. Whether you consider the peak intensity I_{max} of the individual outbursts or the outburst-to-outburst variations of I_{max} are highly variable (Simon Vojtech, 2004). Most SXTs exhibit a rapid ascent (~a few days) followed by a slower descent (about 30 days), with the X-ray light curve rebrightening about 20 days after the maximum, as illustrated in Fig. 1. It is also observed that during outburst the optical output of the secondary star also rises by about 4-7 magnitudes, depending on the size of the star. There is a special group of SXTs that has several years-long outbursts before they return to quiescence. These quasi-persistent SXTs act as an ideal testing ground because of their prolonged outbursts, which heat the neutron star crust to a temperature greater than the neutron star core, Contrary to that, the X-ray luminosity released during quiescent state provides data on the cooling properties of the neutron star (Brown, Bildsten& Rutledge, 1998; Colpi et al., 2001; Wijnands et al., 2001; Rutledge et al., 2002; Cackett et al., 2006a).

When a transient LMXB goes into an outburst, the system's accretion rate increases, and the accumulated in-falling matter is heated up and emits X-rays (e.g., Shakura&Sunyaev 1973). Not all of the in-falling material ends up on the central object, however, some fraction is expelled from the system. In some cases, a jet is formed. (N.V. Gusinskaia et al., 2017).Thus an SXRT always shows the following two characteristics:

- When the source goes back to quiescence, the accretion rate is reduced by several orders of magnitude and

- During outburst the spectra become soft. The graph proposed by King and Ritter-1998 shown in Fig. 1 represents an SXT schematically.

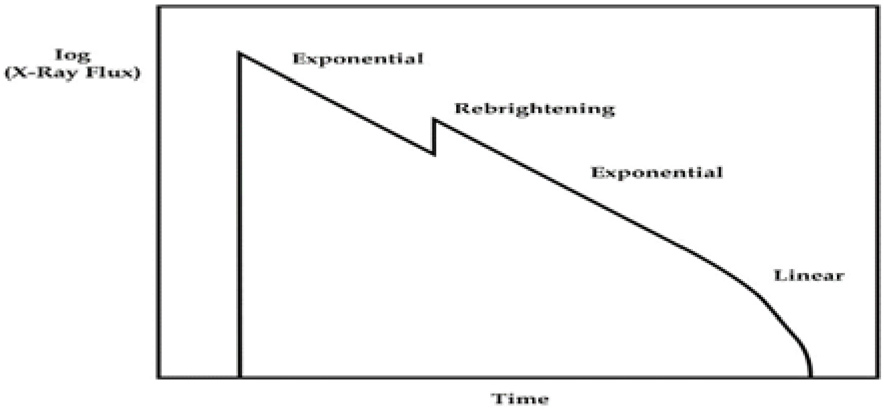

Figure 1: Schematic Representation of an SXT outburst according to King & Ritter-1998 model (This Figure is Taken from the Paper Published in MNRAS by A.R. King and H. Ritter, 1998)

Among the 30 NSSXTs identified and tabulated (Table 1), Aql X-1 is observed to be the most active NSSXT, more than 30 X-ray and/or optical outbursts have been so far detected. This paved the way to correlate the characteristics of various eruptions and to trace out possible (quasi) periodicities in the recurrence times. A cycle of ~ 125 d was quite evident in the 1969–1979 observations from the Ariel V and Vela 5B satellites while recent Ginga and Optical observations (1987-1992) on the contrary suggest a ~310 d periodicity. The analysis presented by Vojtech Simon of Czech Republic in the 5th Integral Science Workshop, 16-20 February 2004 shows that the cycle of outbursts is 60-350 days, which means up to 19 bursts have been witnessed in some of them (Vojtech Simon, 2004). It is also clear that the cycle of outburst for SXTs containing black holes is longer than in SXTs containing neutron stars.

Van Paradijs (1984) draws an analogy between SXT and dwarf novae. Dwarf novae super outbursts tend to have larger amplitudes and a longer duration than the normal ‘U Gem-type’ outbursts. Dwarf novae are similar to SXT in many respects (J.P.Lasota, 2001). The discs during an outburst in dwarf novae and SXTs are nearly alike except for the fact that the discs in the SXTs are heavily irradiated by the central X-ray source (Van Paradijs& McClintock, 1994; Shahbaz&Kuulkers, 1998). In a paper (King & Ritter, 1998), King and Ritter note that irradiation prolongs the entire cycle of the SXT outburst, causing the SXT light curve to have long tails (exponential or linear) since the outburst can be shut off only by the viscus decay of central accretion rather than through a cooling front (as is the case with dwarf novae).

The Catalogue accounts for 103 transient X-ray sources of which approximately 75% have BH as compact objects and 25% have NS as the compact object (Catalogue of Liu, 2001). Thus around 25-30 sources can be NSSXTs. It is also seen that the X-ray transients with NS are generally SXTs. The list of verified NSSXTs and their locations are included in Table 1. Table 1 is prepared using information from S. Campana et al.

(1998), Q.Z. Liu et al. (2001), and Y.X. WU et al. (2010) as well as additional sources listed in the reference column. Fig. 2 represents the spatial distribution of the NSSXTs summarised in Table 1. From Fig. 2 it is clear that these are concentrated mostly within latitude ± 20 deg, galactic plane region. While the following NS SXTs 1H 1905+000 (l, b = 35, 3.7), XTE J2123-058 (l, b = 58.1, - 9.0), XTE J 0929-314 (l, b = 260.1, 14.21), EXO 078-676 (l, b = 280, 19.3) & 4U 1456-32 (l, b = 332.2, 23.9) has exception and spread up to ± 30 deg. The previous missions support these observations (Gursky and Schreier, 1975; Skinner, 1993; Grebenev et al., 1996; Grimm et al., 2002). The concentration of HMXBs found in spiral arm tangents and LMXBs towards the Galactic Center is becoming increasingly apparent as the size of the INTEGRAL catalogue grows. (Dean et al., 2005; Bodaghee et al., 2007; Krivonos et al., 2015).

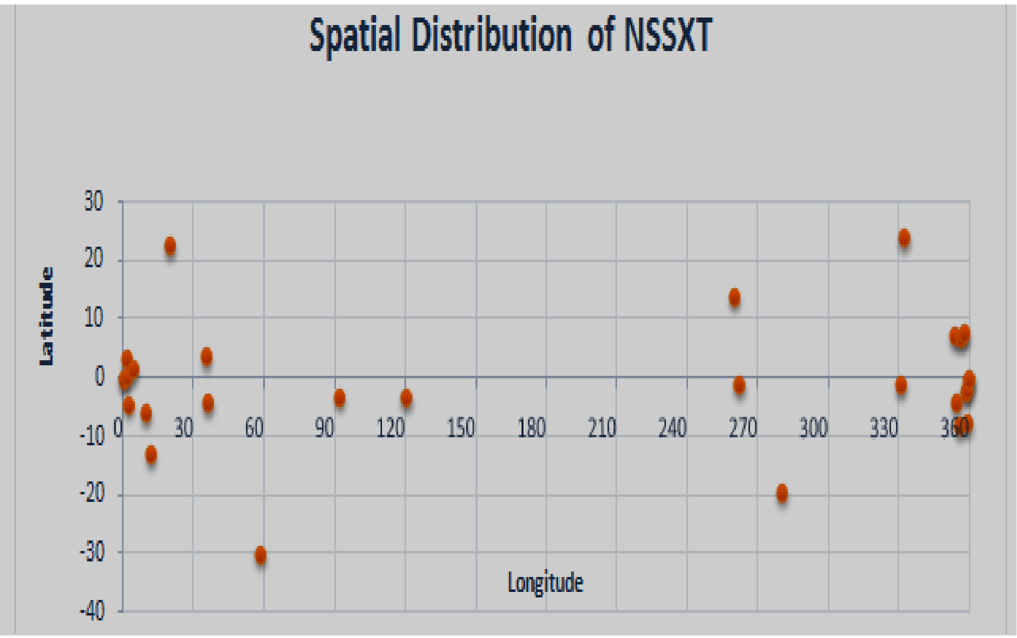

Figure 2: Spatial Distribution of NSSXTs

Table 1: Summary of all the NSSXTs so far reported in various catalogues and Papers

Sl. No.	Source	List of Soft X-ray Transients as per S Campana et al.-1998	Type of the source as per Liu et al.-2001	List of Transients type as per Wu et al .-2010	Based on Papers mentioned in the reference apart from S. Campana et al., Liu et al. and Wu et al.	Year of Outburst (Wu et al. 2010 & S. Campana 1998)	RA and Dec	Longitude and Latitude, Liu, 2001 Galactic Co-ordinate	Dist (Kpc) * Campana	Luminosity during outburst and quiescent (erg per Sec) (see Campana)	Porb (hr)	Referenece
1	2	3	4	5	6	7	8	9	10	11	12	13
1	4U 1456-32 (cen X-4)/ 1455-314 (Liu)	B-0	TB	NS(B)	X	1969, 1979	14 55 19.6, -31 28 09	332.2, +23.9	1.2	35.5-32.5	15.1 (C,W)	X
2	4U 1908+005 (Aql X-1)	B-O-Q	TBA	NS(B)	X	1978 Recurrent (C)	19 08 42.8 +00 30 05	35.7 -4.1	5 (W), 2.5	36-32.8	18.95 (W) 18.9 (C)	X
3	4U1608-52	B-O-Q	TBA	NS(B)	X	1976, Recurrent (C)	16 08 52.2, -52 17 43	330.9 -0.9	3.5	36-33.3	12.89 (W)	X
4	AXJ 1745.6-2901	X	TB	NS(B)	X	1996	17 45 36 -29 01 34	359.9 -0.035	> 8 kpc *	X	8.4 (W)	* (Ponti et al. 2017; Jin et al. 2017).
5	EXO 0748-676	B-O	TBD	NS(B)	X	1985 Recurrent (C)	07 48 25.8 -67 37 32	280.0 - 19.3	5.9-7.7 (W) 10	36-34	3.8	X
6	GRS 1747-312	X	GT	NS(B)	X	1990, 1996-1999	17 47 31.2 -31 16 45	358.6 -2.2	9.5 (W) 13	36.5	12.36 (W)	X
7	GS 1826-238	X	TB	NS(B)	X	1988 Recurrent	18 26 24 -23 49 31	9.3 -6.0	4-6	X	2.08 (W)	X
8	HETE J 1900.1-2455	X	X	NS(B)	X	2005	19 00 08.65 -24 55 13.7	11.30 -12.87	5 (W)	X	1.39(W)	X

Sl. NO.	Source	List of Soft X-ray Transients as per S Campana et al.-1998	Type of the source as per Liu et al.-2001	List of Transients type as per Wu et al .-2010	Based on Papers mentioned in the reference apart from S. Campana et al., Liu et al. and Wu et al.	Year of Outburst (Wu et al. 2010 & S. Campana 1998)	RA and Dec	Longitude and Latitude, Liu, 2001 Galactic Co-ordinate	Dist (Kpc) * Campana	Luminosity during outburst and quiescent (erg per Sec) (see Campana)	Porb (hr)	Referenece
1	2	3	4	5	6	7	8	9	10	11	12	13
9	1A1744-36	X	T	NS(B)	X	1976, 1989, 2003, 2004, 2005	17 44 50.9, -36 06 54	354.1, - 4.2	< 9 (W)	X	1.62 (W)	X
10	IGR J 00291+5934	X	X	NS(MP)	X	2004	00 29 03.06 +59 34 19.0	120.09 -03.17	2.6-3.6 (W)	X	2.46 (W)	X
11	MXB 1659-298	B-O	TBD	NS(MP)	X	1976, 1978, 1999	16 58 55.4 -29 52 28	353.8 +7.3	10 (W)	36	7.2 (C)	X
12	SAX J1808.4 -36.58	B	TPB	NS (MP,B)	X	1997,1998, 2000,2002, 2005, 2008	18 08 27.54 -36 58 44.3	355.4, -8.14	2.5/3-4-3.6 (W) ~4 (C)	36.3	2.014 (W)	X
13	XTEJ 0929-314	X	X	NS (MP,B)	X	2002	09 29 20.19 -31 23 03.2	260.10 +14.21	10 ± 5 (W)	x	0.73	X
14	XTEJ 2123-058	X	TBA	NS (MP,B)	X	1998	21 23 14.54 -0547 52.9	58.10 -29.9	8.5±2.5 (W)	X	5.96(W)	X
15	XTEJ 1710-281	X	TB	NS (MP,B)	X	1998	17 10 12.3 -28 07 54	356.4 +6.9	12-16	x	3.28 (W)	X
16	XTEJ 1751-305	X	X	NS (MP,B)	x	2002	17 51 13.49 -30 37 23.4	359.18 -01.91	~ 8.5/>7	X	0.71 (W)	X
17	XTEJ 1807-294	X	X	NS (MP,B)	X	2003	18 06 59.8 -29 24 30	1.93 -04.27	X	X	0.668 (W)	X
18	XTEJ 1814-338	X	X	NS (MP,B)	x	2003	18 13 39.03 -33 46 22.3	358.74 - 07.58	8±1.6	X	4.27(W)	X

Sl. NO.	Source	List of Soft X-ray Transients as per S Campana et al.-1998	Type of the source as per Liu et al.-2001	List of Transients type as per Wu et al .-2010	Based on Papers mentioned in the reference apart from S. Campana et al., Liu et al. and Wu et al.	Year of Outburst (Wu et al. 2010 & S. Campana 1998)	RA and Dec	Longitude and Latitude, Liu, 2001 Galactic Co-ordinate	Dist (Kpc) * Campana	Luminosity during outburst and quiescent (erg per Sec) (see Campana)	Porb (hr)	Referenece
1	2	3	4	5	6	7	8	9	10	11	12	13
19	4U 2129+47	B-O	BT	X	NS LMXB	up to 1981	21 29 36.2 +47 04 08	91.6 -3.0	6 (C)	36.8-32.8	5.2	Michael R. Garcia and Jonathan E. Grindlay, 1987
20	KS 1741-293	B	TB	X	NS LMXB	1971	17 41 38 -29 19 53	359.5 -0.07	10 (C)	~37	X	N. Degenaar and R. Wijnands, 2012
21	EXO 1747-214	B	TB	X	NS LMXB	1985	17 47 25.7 -21 24 33	19.8 +22.73	10 (C)	35.6	X	J Tomsick et al. 2005
22	1A 1743-288/ SAX J1747.0-2853	X	TB	X	NS LMXB	1971, 1976/ 1998, 1999, 2000 and 2001*	17 43.9 - 28 52 36	0.11 -0.11	10 (C)	37	X	L Natalucci, A Bazzano, M Cocchi, P Ubertini et al. 2000
23	KS 1731-260	X	BT	X	NSLMXB	1990	17 31 06.8 -26 03 10	1.1 +3.6	7*	X	X	R Wijnands, M Guainazzi, M van der Klis, 2002…
24	IGR J 17473-2721	X	X	X	NST	2005, 2008	17 47 18.06 -27 20 38.9	1.55 +0.51	X	X	X	NS, S. Zhang, Y.-P. Chen, J.-M. Wang, D. F. Torres, Chenevez, D Altamirano and DK Galloway, 2011
25	EXO 1745-248	X	X	X	TGB/ NS tran LMXB,	2000, 2010, 2011	17 45 51 -24 52 45	3.8 +1.5	X	X	X	N. Degenaar and R. Wijnands, 2012
26	1H 1905 +000	X	X	x	B/NSSXT	2006	19 05 53.4 +00 05 18	35.0 3.7	X	X	X	P. G. Jonker C. G. Bassa, G. Nelemans, A. M. Juett, E. F. Brown and D. Chakrabarty, 2006

Sl. NO.	Source	List of Soft X-ray Transients as per S Campana et al.-1998	Type of the source as per Liu et al.-2001	List of Transients type as per Wu et al .-2010	Based on Papers mentioned in the reference apart from S. Campana et al., Liu et al. and Wu et al.	Year of Outburst (Wu et al. 2010 & S. Campana 1998)	RA and Dec	Longitude and Latitude, Liu, 2001 Galactic Co-ordinate	Dist (Kpc) * Campana	Luminosity during outburst and quiescent (erg per Sec) (see Campana)	Porb (hr)	Referenece
1	2	3	4	5	6	7	8	9	10	11	12	13
27	RXS J170930.2-263927	X	X	X	NSSXT	2002	17 09 30.2 -26 39 27	357.5 +7.9	X	X	X	P. G. Jonker, M. M´endez, G. Nelemans, R. Wijnands and M. van der Klis, 2003
28	MX 0836-42	B	TB	X	NSSXT	1970, 1971, 1990, 1991	08 35 37 -42 42.6	261.9 -1.1	10 (C)	36.5-35	X	L Stella, S Campana, M Colpi, 2006
29	4U 1735-28	X	T	X	X	1971	17 35.4 - 28.45	359.6 +1.56	10 (C)	36.5	X	
30	MX 0656-07	X	T	X	X	1975	06 56 01 -07 11.7	220.2 -1.7	10 (C)	36	X	

Note: In table 1, (c) stands for Campana et al., 1998 and W stands for Wu et al., 2010.

The label B indicates SXTs in which the burst occurred, T indicates Transient, O indicates optically identified SXTs, Q indicates kHz QPO and A stands for Aroll.

III. MODELS THAT HAVE HELPED IN UNDERSTANDING SOFT X-RAY SPECTRA EMITTED BY NSSXTS

Radiations from SXTs during outburst and/or quiescence have now become an exciting and important area of study because the high accretion rate variability of SXTs allows for the study of a range of different regimes of the neutron stars in those systems, which are otherwise inaccessible to persistent LMXBs (Campana et al., 1998). So, far we know X-rays are created by the inner accretion disk and/ or the boundary layer due to the impact of the accretion flow with the compact star. (Dacheng Lin et al. 2007).

There are a whole lot of questions associated with the emission of radiation from SXTs. With time, many propositions have been made, tested and retested. Various physical conditions were measured but still, it is believed that there is a lot many which needs to be established. To understand and explain the range of radiations emitted from various regimes of the accretion disk and NS, several models have been proposed since the proposal made by N. I. Shakura and R. A. Sunyaev in the year 1973.

So far, several approaches have been developed to elucidate the X-ray spectral profiles of accreting NSs.. These can be broadly categorized as:

1 Spectral surveys of a vast number of sources, across a broad spectrum of luminosities (Church &Baluci´nska-Church 2001; Christian & Swank1997),
2 Detailed analysis of hundreds of observations generated from a single burst of NS X-ray transients (Gierli´nski& Done 2002b; Maccarone&Coppi 2003b; Maitra&Bailyn 2004),
3 Fourier frequency-resolved X-ray spectroscopy (Gilfanov et al. 2003; Olive et al. 2003), and
4 To figure out which characteristics might be caused by having or not having a solid surface, a comparison of spectral and timing properties is done with those of BH LMXBs. (Wijnands 2001; Barret 2001; Done &Gierli´nski 2003).

However, no consensus has been reached on the right X-ray spectral model for the various subtypes and states of accreting NSs (Barret et al. 2001). The different models give different interpretations of the structures and energy of NS accretion.

The most detailed theory of accretion disc was proposed by Shakura and Sunyaev in the year 1973, in which the compact object is considered to be a Blackhole. (Shakuraet al.1973). Till 1996 no model was there that could explain the formation of the accretion disc around the pulsar. (Lasota et al. 1996) Theoretical models were conceived and tested to enhance knowledge about the highly-dense NS. The models proposed has focus on the radiation process, radiation regime, phenomena involved, frequency released form of light curve etc. Thus an analysis of X-ray spectra fitting an appropriate model may lead to extract information about the physical and chemical composition and status of the source and its surroundings along with the content of line of sight (LOS).

The Spectrum of energy released by an SXT can be roughly categorised into two parts: Spectrum during outburst (Periods of high luminosity) and radiation released during the period of quiescence (Periods of low luminosity).

1. **Models for the Outburst Emission:** Until 1996, there was a lack of consensus as to the underlying cause of SXT episodes. It is because of instability in the disc or is it because the companion is transferring more mass or a combination of both? (Lasota 1996). One group of models relies on accretion disk instabilities (Cannizzo 1993 and references therein; Huang & Wheeler 1989; Mineshige& Wheeler 1989; Cannizzo, Chen &Livio 1995) and the other on instabilities in the mass transfer from the companion star (Osaki 1985; Hameury, King &Lasota 1986).

According to Cannizzo(1993) the accretion disk can become locally thermally and viscously unstable due to strong opacity variations caused by the partial ionisation of hydrogen (Cannizzo 1993) which is the basis of the disk instability model (DIM). The mechanism of mass transfer instability (MTIM) on the other hand is based on the gradual expansion of the super adiabatic convective layers of the companion star that is irradiated by hard ($E > 10$ keV) X-rays, which are supposed to be produced by low-level accretion onto the surface of the compact star (NS) (Hameury, King &Lasota 1986). After the commencement of accretion at a high rate, the high energy radiation is blocked by the growing accretion disk and the companion contracts again within a few weeks, leaving a disk fed at a low rate.

In a critical review, Lasota (1996) came out with the major shortcoming of these two classes of models: First, the DIMs cannot reproduce the observed recurrence times whereas the MTIM requires a quiescent hard X-ray luminosity at a level of 10^{34}–10^{35} erg s^{-1} and a subgiant or stripped giant companion to produce outburst recurrences in the observed range.

Contemporary to that King and Ritter-1998 (KR) have demonstrated that the timing analysis of SXTs can be described by a modified disk instability model considering irradiation by the central X-ray source during the outburst. Even a very low level of irradiation has a significant effect on the duration, shape and recurrence time of the outburst (G. Dubus et al., 2001). According to KR, irradiation hinders the disc from returning to the cool state until the central accretion rate is sharply reduced. There could be two possibilities-

- If irradiation is capable of ionizing the disc all the way to the edge, the X-ray light curve will be roughly exponential, and the time to recur to the next explosion will be very long as the disc has to be regenerated by mass transfer from its companion star.
- Instead if the X-rays are too weak to ionize the whole disc, the light curve should have an approximately linear decline, returning to quiescence after a timescale. In a linear decay, the outer disc remains cool and is unaffected by the outburst. Since it is likely to contain a significant portion of the disc's mass, viscous evolution can restore the critical density somewhere within the disc relatively quickly, allowing for another explosion.Thus after a series of such linear outbursts, the disc may well enter a much longer quiescent state in which the disc is rebuilt.

KR gives expressions for the critical central accretion rates (L_{crit}) essential to ionize the disc up to to a given radius R_h depending on whether the central source is point-like or disc-like.

$$L_{crit}\text{ (point-like)} = 3.7 \times 10^{36} R^2 \text{ ergs s}^{-1} \quad (1)$$

L_{crit} (disc-like) = $1.7 \times 10^{37} R^2$ ergs s^{-1} (2) Here Ris the ionized disc radius R_h in units of 10^{11} cm.

The same has been shown by T. Shahbaz, P.A. Charles and A.R. King in the year 1998 in the case of sources Aql X–1 (=4U1908+005), Cen X–4 (=4U1456–32), 4U1543–47 and GROJ1744-28 etc.

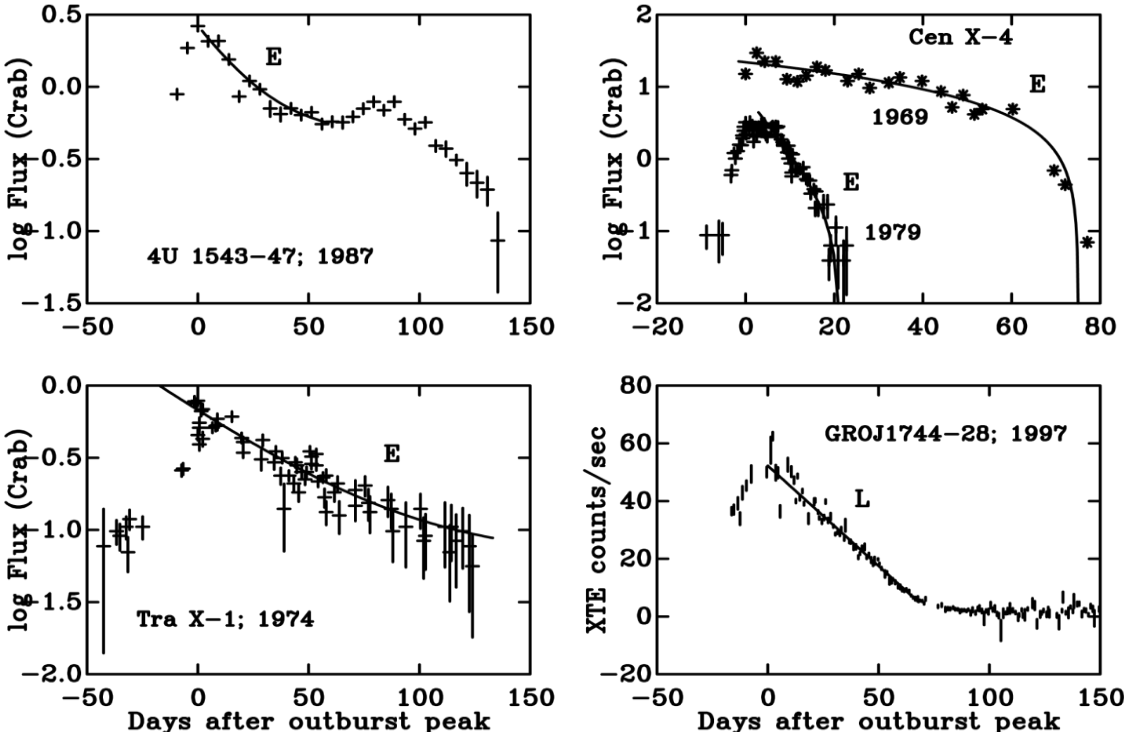

Figure 3: X-ray light curves of SXTs. Top left: 1971 (Vela 5) X-ray outburst of 4U1543–47; top right: 1969 (Ariel 5/ASM) and 1979 (Vela 5) X-ray outbursts of Cen X–4; bottom left: 1974 (Ariel 5/ASM) X-ray outburst of 4U1524–62; bottom right: 1997 *RXTE* X-ray outburst of GS1354–64. E and L denote exponential and linear fits respectively. The data were taken from CSL (This figure is taken from the paper published in MNRAS by T. Sahbaz et al., 1998)

To elucidate the temporal behaviour of X-ray binary discs, the current model of disc instability has edge over that of models of Lasota et al. (2001), F CottiZelati (2018), and others. This model proposes that the disc oscillates in a state of cold neutrality (quiescence), and a state of hot ionisation (outburst). During quiescence, matter accumulates in the disc, and during an outburst, it is transported to the compact object.

2. **Models for the Quiescent Emission:** Quiescent emission is the state in which a source remains for months to years (Bhattacharya, 2010). During this state, X-ray emission is devoid of maas accretion and primarily believed to be from a neutron star's atmosphere. During the quiescent state, the emitted X-ray component may have both thermal and non-thermal components (Rutledge et al, 2002). During quiescent emission, episodic higher accretion is also inferred (Kuulkers et al., 2009), these factors make it challenging to design a model which may fit the emission from an NSSXT in the quiescent state.

S. Campana in the year 1998 proposed that the emission from an SXT during its quiescent state could result from:

- Accretion on the surface of the neutron star;
- Accretion down to the radius of the magnetosphere (when the “centrifugal barrier” is closed);
- Non-thermal processes powered by the rotational energy loss of a rapidly spinning neutron star (Tavani&Arons, 1997);
- Thermal emission from the cooling neutron star (S. Campana, 1998).

Years later different models based on accretion of matter came up. Menou et al. (1999); and Menou& McClintock(2001) put forward that accretion of matter onto the Neutron Star may be in several flavours such as advection-dominated accretion flow (ADAF), convection-dominated accretion flow and with outflows etc. While Fender et al., (2003) proposed a model based on the accretion of matter onto Jets. Similarly, it was also proposed accretion of matter on (i) to neutron star cooling after long-term (104 yr) heating during outbursts (Brown et al. 1998) and (ii) to emission regimes connected to the existence of a magnetic field (Campana et al. 1998b, Campana& Stella 2000). The neutron star cooling after deep crustal heating proposed by Brown et al., (1998) is the most popular model in explaining the soft component released during the quiescent state of SXTs.

The X-ray spectra thus obtained are usually divided into two spectral components:

- A soft component modelled as a black body or, more physically, by cooling emission from the entire surface of the neutron star;
- A hard component modelled as power-law energy tail. The ADAF model is most suitable for hard components.

The bulk of the flux (50−100%) comprises soft components. The power-law tail is present only in a fraction of sources and contributes up to 50% in the (0.5–10) keV energy band (S. Campana, 2001).

Observationally, quiescent X-ray spectra typically include a soft thermal component of less than 2 keV and a hard component of more than 2 keV in low mass X-ray transients (LMXs) that host an NS. (Campana et al., 1998; Rutledge et al., 1999; Campana, 2004). In soft state, spectra are typically described by a soft and hard component, or by a thermal and a Comptonized component. Accordingly depending on the selection of the thermal and Comptonized components two classic models were proposed: the Eastern model (see Mitsuda et al., 1989) and the Western model (see White et al., 1988). In the hard state, a hard or a Comptonized component dominates the spectra, but a soft or a thermal component is usually still required (Christian& Swank, 1997; Barret et al., 2000; Church &Baluci´nska-Church 2001; Gierli’nski&Done 2002b).

The soft part is described in detail by pure hydrogen atmospheric models, and it's usually seen as thermal emissions from the surface of the NS in the cooling stage after an explosion. According to Brown, Bildsten, Rutledge, and Colpi's deep crust heating model (Colpi et al., 2001), the matter that accumulates after the explosion pushes the innermost parts of the crust down, which triggers nuclear reactions and heats up the core. Then, the heat is radiated out in the next phase, which is called quiescence. (Zampieri, 1995).

The hard component has a good representation in the form of a power law tail. However, the physical nature of this component is still under discussion. Accretion onto the magnetospheric boundary seems to be an intriguing possibility. Although the physics of disc magnetosphere interactions at low rates of accretion (e.g. in a propeller regime) is not fully understood, it is widely accepted that the disk is truncated close to the compact object where the magnetic fields are stronger (F.CotiZelati, 2018).

The light curves of SXTs are much more complex than the expected simple exponential or slow decay. This suggests that there is still more missing physics to consider. In light of the above facts, it becomes an uphill task to propose a robust model for X-rays that are emitted during the quiescence phase and a single model may not be suitable for every situation.

IV. CONCLUSION

Soft X-ray transients are a special class of Low Mass X-ray Binary which radiates X-ray of varying luminosity ranging from 10^{36} -10^{38} erg s^{-1} (during Outburst) (F.CotiZelati et al., 2018) to 10^{32} -10^{33} erg s^{-1} (during quiescence) (Campana et al.,1998) with soft thermal component below 2 keV and hard component above 2 keV.

This class of LMXB may contain NS or BH as Compact objects. In this review, we restricted ourselves to NSSXTs only. With the constant development and commissioning of powerful telescopes, spectrometer etc. in space observatories like Integral, Chandra, XMM-Newton, Swift, etc. we could defy the hindrance caused by Earth's atmosphere and become possible to study various types of X-ray binaries. This also made it possible to evaluate the physical and chemical structure of NS and the ideal tool for evaluating metal abundances in ISM via absorption spectra. So far around 30 NS SXTs have been identified and listed (Table 1) since the first popular catalogue of LMXB was published by P.R. Amnuel et al. in the year 1978. The most latest catalogue published in the year 2020 comprises 166 LMXBs, out of which 103 are transient.

The HRXS paved the path of understanding the accretion mechanisms, and various phenomena exhibited by LMXBs e.g. Bursting, Dipping, Eclipsing, QPO, Transient, etc. In turn, it helps us to constrain the content of NS and ISM. The development of a model and our understanding of the nature of the X-ray sources, the phenomenon involved, chemical and physical composition of the source go hand in hand. The availability of X-ray data because of the variety of highly sophisticated instruments onboard the X-ray observatories further facilitates exploration. It started with the disk instability model proposed by N.I. Shakura& R.A. Sunyaev in the year 1973, which was later modified by Ghosh and Lamb as the Magnetically Threaded Disk Model in the Year 1979 but till 2001 spectral modelling of Neutron Stars has been controversial (Barret et al., 2001). The spectral analysis of the radiation emitted can be broadly divided into two parts Spectrum during Outburst and Spectrum during the quiescence period. Thermal-Viscous disk instability model explains the transition between outburst and quiescence (J.P.Lasota 2001). The spectrum emitted during quiescent is further divided into soft and hard state, The two classical models that were proposed to explain the soft state are models proposed by Mitsuda et al. in the year 1989 namely the Eastern model and by White et al., 1988 namely the Western model. Later, the soft component is well described by pure hydrogen atmosphere models (Zavlin, Pavlov &Shibanov 1996; Heinke et al. 2006) and the deep crustal heating model (Brown, Bildsten& Rutledge 1998; Colpi et al. 2001), the hard component is well represented by a power-law tail model.

Still, ample scope is there and constant work is going on to address issues like the detection of new SXTs, finalizing the structure of accretion disk, evaluating the origin of X-rays from various regimes, the composition of NS, or evaluating the composition of ISM.

V. ACKNOWLEDGEMENT

We are thankful to the anonymous referee for the useful and detailed comments and suggestions. We highly appreciate and are thankful to Monthly Notices of the Royal Astronomical Society (MNRAS) for their policy to relief the authors from obtaining permission to reuse figures published in the journal for academic, educational or non-commercial research.

REFERENCES

[1] Amnuel, P. R., &Guseinov, O. H. (1979). X-ray transient sources. *Astrophysics and Space Science*, *63*, 131-154.

[2] Angelini, L., Loewenstein, M., &Mushotzky, R. F. (2001). The X-ray globular cluster population in NGC 1399. *The Astrophysical Journal*, *557*(1), L35.

[3] Balucińska-Church, M., Barnard, R., Church, M. J., &Smale, A. P. (2001). Neutron star blackbody contraction during flaring in X 1624-490. *Astronomy & Astrophysics*, *378*(3), 847-860.

[4] Barnard, R., Kolb, U., & Osborne, J. P. (2003). Tracing a Z-track in the M 31 X-ray binary RX J0042. 6+ 4115. *Astronomy & Astrophysics*, *411*(3), 553-557.

[5] Barret, D. (2001). The broad band x-ray/hard x-ray spectra of accreting neutron stars. *Advances in Space Research*, *28*(2-3), 307-321.

[6] Bhattacharyya, S. (2010). Measurement of neutron star parameters: A review of methods for low-mass X-ray binaries. *Advances in Space Research*, *45*(8), 949-978.

[7] Bodaghee, A., Courvoisier, T. L., Rodriguez, J., Beckmann, V., Produit, N., Hannikainen, D., ...& Wendt, G. (2007). A description of sources detected by INTEGRAL during the first 4 years of observations. *Astronomy & Astrophysics*, *467*(2), 585-596.

[8] Brown, E. F., Bildsten, L., & Rutledge, R. E. (1998). Crustal heating and quiescent emission from transiently accreting neutron stars. *The Astrophysical Journal*, *504*(2), L95.

[9] Cackett, E. M., Wijnands, R., Linares, M., Miller, J. M., Homan, J., &Lewin, W. H. (2006). Cooling of the quasi-persistent neutron star X-ray transients KS 1731− 260 and MXB 1659− 29. *Monthly Notices of the Royal Astronomical Society*, *372*(1), 479-488.

[10] Campana, S. (2004, April). Emission processes in quiescent neutron star transients. In *AIP Conference Proceedings* (Vol. 703, No. 1, pp. 260-265). American Institute of Physics.

[11] Campana, S. 2001, in “X–ray astronomy : stellar endpoints, AGN, and the diffuse X–ray background”, eds. N.E. White, G. Malaguti, G.G.C. Palumbo, AIP 599 63

[12] Campana, S., & Stella, L. (2000). On the bolometric quiescent luminosity and luminosity swing of black hole candidate and neutron star low-mass X-ray transients. *The Astrophysical Journal*, *541*(2), 849.

[13] Campana, S., & Stella, L. (2003). The Evolution of the High-Energy Tail in the Quiescent Spectrum of the Soft X-Ray Transient Aquila X-1. *The Astrophysical Journal*, *597*(1), 474.

[14] Campana, S., Colpi, M., Mereghetti, S., Stella, L., &Tavani, M. (1998). The neutron stars of Soft X-ray Transients. *Arxiv preprint astro-ph/9805079*.

[15] Campana, S., Stella, L., Mereghetti, S., Colpi, M., Tavani, M., Ricci, D., ...&Belloni, T. (1998). Aquila X-1 from outburst to quiescence: the onset of the propeller effect and signs of a turned-on rotation-powered pulsar. *The Astrophysical Journal*, *499*(1), L65.
[16] Cannizzo, J. K. (1993). The accretion disk limit cycle model: toward an understanding of the long-term behavior of SS Cygni. *The Astrophysical Journal*, *419*, 318.
[17] Cannizzo, J. K., Chen, W., &Livio, M. (1995). *The accretion disk limit cycle instability in black hole X-ray binaries* (No. X-RAY-95-22). SCAN-9512042.
[18] Chen, Y. P., Zhang, S., Torres, D. F., Zhang, S. N., Li, J., Kretschmar, P., & Wang, J. M. (2011). The 2008 outburst of IGR J17473–2721: evidence for a disk corona?. *Astronomy & Astrophysics*, *534*, A101.
[19] Christian, D. J., & Swank, J. H. (1997). The survey of low-mass X-ray binaries with the Einstein observatory solid-state spectrometer and monitor proportional counter. *The Astrophysical Journal Supplement Series*, *109*(1), 177.
[20] Colpi, M., Geppert, U., Page, D., &Possenti, A. (2001). Charting the temperature of the hot neutron star in a soft X-ray transient. *The Astrophysical Journal*, *548*(2), L175.
[21] CotiZelati, F., Campana, S., D'Avanzo, P., &Melandri, A. (2014). A year in the life of the low-mass X-ray transient Aql X-1. *Monthly Notices of the Royal Astronomical Society*, *438*(3), 2634-2641.1
[22] Cowley, A. P., Schmidtke, P. C., McGrath, T. K., Ponder, A. L., Fertig, M. R., Hutchings, J. B., &Crampton, D. (1997). Magellanic Cloud X-ray sources observed with ROSAT. *Publications of the Astronomical Society of the Pacific*, *109*(731), 21.
[23] Dean, A. J., Bazzano, A., Hill, A. B., Stephen, J. B., Bassani, L., Barlow, E. J., ... & Willis, D. R. (2005). Global characteristics of the first IBIS/ISGRI catalogue sources: unveiling a murky episode of binary star evolution. *Astronomy & Astrophysics*, *443*(2), 485-494.
[24] Degenaar, N., &Wijnands, R. (2012). Strong X-ray variability in the quiescent state of the neutron star low-mass X-ray binary EXO 1745− 248. *Monthly Notices of the Royal Astronomical Society*, *422*(1), 581-589.
[25] Degenaar, N., &Wijnands, R. (2012). The transient neutron star X-ray binary KS 1741–293 in outburst and quiescence. *Proceedings of the International Astronomical Union*, *8*(S290), 113-116.
[26] Done, C., &Gierliński, M. (2003). Observing the effects of the event horizon in black holes. *Monthly Notices of the Royal Astronomical Society*, *342*(4), 1041-1055.
[27] Dubus, G., Hameury, J. M., &Lasota, J. P. (2001). The disc instability model for X-ray transients: Evidence for truncation and irradiation. *Astronomy & Astrophysics*, *373*(1), 251-271.
[28] Fender, R. 2006, in Compact Stellar X-ray Sources (eds. W. Lewin& M. van der Klis, Cambridge University Press), 381–419
[29] Fender, R. P., Gallo, E., &Jonker, P. G. (2003). Jet-dominated states: an alternative to advection across black hole event horizons in 'quiescent'X-ray binaries. *Monthly Notices of the Royal Astronomical Society*, *343*(4), L99-L103.
[30] Garcia, M. R., &Grindlay, J. E. (1987). Discovery of an X-ray burst from 4U 2129+ 47. *Astrophysical Journal, Part 2-Letters to the Editor (ISSN 0004-637X), vol. 313, Feb. 15, 1987, p. L59-L64.*, *313*, L59-L64.
[31] Gierliński, M., & Done, C. (2002). The X-ray spectrum of the atoll source 4U 1608—52. *Monthly Notices of the Royal Astronomical Society*, *337*(4), 1373-1380.
[32] Grebenev, S. A., Lutovinov, A. A., Tsygankov, S. S., &Mereminskiy, I. A. (2013). Deep hard X-ray survey of the Large Magellanic Cloud. *Monthly Notices of the Royal Astronomical Society*, *428*(1), 50-57.
[33] Grebenev, S. A., Pavlinsky, M. N., &Sunyaev, R. A. (1996, February). Population of X-ray sources near the Galactic center according to ART-P/GRANAT. In *Röntgenstrahlung from the Universe* (pp. 141-142).
[34] Grimm, H. J., Gilfanov, M., &Sunyaev, R. (2002). The Milky Way in X-rays for an outside observer-Log (N)-Log (S) and luminosity function of X-ray binaries from RXTE/ASM data. *Astronomy & Astrophysics*, *391*(3), 923-944.
[35] Gursky, H., &Schreier, E. (1975). The binary X-ray stars–the observational picture. In *Symposium-International Astronomical Union* (Vol. 67, pp. 411-464). Cambridge University Press.
[36] Gusinskaia, N. V., Deller, A. T., Hessels, J. W. T., Degenaar, N., Miller-Jones, J. C. A., Wijnands, R., ... &Altamirano, D. (2017). Jet quenching in the neutron star low-mass X-ray binary 1RXS J180408. 9−342058. *Monthly Notices of the Royal Astronomical Society*, *470*(2), 1871-1880.
[37] Hameury, J. M., King, A. R., &Lasota, J. P. (1986). A model for soft X-ray transients. *Astronomy and Astrophysics (ISSN 0004-6361), vol. 162, no. 1-2, July 1986, p. 71-79.*, *162*, 71-79.

[38] Hasinger, G., & Van der Klis, M. (1989). Two patterns of correlated X-ray timing and spectral behaviour in low-mass X-ray binaries. *Astronomy and Astrophysics (ISSN 0004-6361), vol. 225, no. 1, Nov. 1989, p. 79-96.*, *225*, 79-96.

[39] Heinke, C. O., Grindlay, J. E., Lugger, P. M., Cohn, H. N., Edmonds, P. D., Lloyd, D. A., & Cool, A. M. (2003). Analysis of the quiescent low-mass x-ray binary population in galactic globular clusters. *The Astrophysical Journal*, *598*(1), 501.

[40] Heinke, C. O., Rybicki, G. B., Narayan, R., &Grindlay, J. E. (2006). A hydrogen atmosphere spectral model applied to the neutron star X7 in the globular cluster 47 Tucanae. *The Astrophysical Journal*, *644*(2), 1090.

[41] Huang, M., & Wheeler, J. C. (1989). Thermal instability accretion disk model for the X-ray transient A0620-00. *The Astrophysical Journal*, *343*, 229-240.

[42] Jeltema, T. E., Canizares, C. R., Buote, D. A., &Garmire, G. P. (2003). X-ray source population in the elliptical galaxy NGC 720 with Chandra. *The Astrophysical Journal*, *585*(2), 756.

[43] Jithesh, V., & Wang, Z. (2016). Transient X-Ray Source Population in the Magellanic-type Galaxy NGC 55. *The Astrophysical Journal*, *821*(1), 24.

[44] Jonker, P. G., Bassa, C. G., Nelemans, G., Juett, A. M., Brown, E. F., &Chakrabarty, D. (2006). The neutron star soft X-ray transient 1H 1905+ 000 in quiescence. *Monthly Notices of the Royal Astronomical Society*, *368*(4), 1803-1810.

[45] Jonker, P. G., Méndez, M., Nelemans, G., Wijnands, R., & Van Der Klis, M. (2003). Chandra observations of the neutron star soft X-ray transient RX J170930. 2− 263927 returning to quiescence. *Monthly Notices of the Royal Astronomical Society*, *341*(3), 823-831.

[46] Kahabka, P., &Trümper, J. (1996). Supersoft ROSAT sources in the galaxies. In *Symposium-International Astronomical Union* (Vol. 165, pp. 425-438). Cambridge University Press.

[47] King, A. R., & Ritter, H. (1998). The light curves of soft X-ray transients. *Monthly Notices of the Royal Astronomical Society*, *293*(1), L42-L48.

[48] Krivonos, R., Tsygankov, S., Lutovinov, A., Revnivtsev, M., Churazov, E., &Sunyaev, R. (2015). INTEGRAL 11-year hard X-ray survey above 100 keV. *Monthly Notices of the Royal Astronomical Society*, *448*(4), 3766-3774.

[49] Lasota, J. P. (1996). Mechanisms for dwarf nova outbursts and soft X-ray transients: A Critical review. In *Symposium-International Astronomical Union* (Vol. 165, pp. 43-55). Cambridge University Press.

[50] Lasota, J. P. (2001). The disc instability model of dwarf novae and low-mass X-ray binary transients. *New Astronomy Reviews*, *45*(7), 449-508.

[51] Lin, D., Remillard, R. A., & Homan, J. (2007). Evaluating spectral models and the X-ray states of neutron star X-ray transients. *The Astrophysical Journal*, *667*(2), 1073.

[52] Liu, Q. Z., Van Paradijs, J., & Van Den Heuvel, E. P. J. (2007). A catalogue of low-mass X-ray binaries in the Galaxy, LMC, and SMC. *Astronomy & Astrophysics*, *469*(2), 807-810.

[53] Maccarone, T. J., &Coppi, P. S. (2003). Spectral fits to the 1999 Aql X-1 outburst data. *Astronomy & Astrophysics*, *399*(3), 1151-1157.

[54] Maitra, D., &Bailyn, C. D. (2004). Evolution of spectral states of aquila X-1 during the 2000 outburst. *The Astrophysical Journal*, *608*(1), 444.

[55] Menou, K., & McClintock, J. E. (2001). The quiescent emission spectrum of centaurus X-4 and other X-ray transients containing neutron stars. *The Astrophysical Journal*, *557*(1), 304.

[56] Menou, K., Esin, A. A., Narayan, R., Garcia, M. R., Lasota, J. P., & McClintock, J. E. (1999). Black hole and neutron star transients in quiescence. *The Astrophysical Journal*, *520*(1), 276.

[57] Mineshige, S., & Wheeler, J. C. (1989). Disk-instability model for soft-X-ray transients containing black holes. *Astrophysical Journal, Part 1 (ISSN 0004-637X), vol. 343, Aug. 1, 1989, p. 241-253. Research supported by NSF.*, *343*, 241-253.

[58] Mitsuda, K., Inoue, H., Nakamura, N., & Tanaka, Y. (1989). Luminosity-related changes of the energy spectrum of X1608-522. *Astronomical Society of Japan, Publications (ISSN 0004-6264), vol. 41, no. 1, 1989, p. 97-111.*, *41*, 97-111.

[59] Natalucci, L., Bazzano, A., Cocchi, M., Ubertini, P., Heise, J., &Kuulkers, E. (2000). Broadband Observations of the New X-Ray Burster SAX J1747. 0–2853 during the 1998 March Outburst. *The Astrophysical Journal*, *543*(1), L73.

[60] Osaki, Y. (1985). Irradiation-induced mass-overflow instability as a possible cause of superoutbursts in SU UMa stars. *Astronomy and Astrophysics (ISSN 0004-6361), vol. 144, no. 2, March 1985, p. 369-380.*, *144*, 369-380.

[61] Pakull, M. W., Beuermann, K., Van der Klis, M., & Van Paradijs, J. (1988). LHG 87, a new low-mass eclipsing X-ray binary in the LMC. *Astronomy and Astrophysics (ISSN 0004-6361), vol. 203, no. 2, Sept. 1988, p. L27-L30.*, *203*, L27-L30.
[62] Rutledge, R. E., Bildsten, L., Brown, E. F., Pavlov, G. G., &Zavlin, V. E. (1999). The thermal X-Ray spectra of Centaurus X-4, Aquila X-1, and 4U 1608-522 in quiescence. *The Astrophysical Journal*, *514*(2), 945.
[63] Rutledge, R. E., Bildsten, L., Brown, E. F., Pavlov, G. G., Zavlin, V. E., &Ushomirsky, G. (2002). Crustal emission and the quiescent spectrum of the neutron star in KS 1731–260. *The Astrophysical Journal*, *580*(1), 413.
[64] Sazonov, S., Paizis, A. D. A. M. A. N. T. I. A., Bazzano, A. N. G. E. L. A., Chelovekov, I., Khabibullin, I., Postnov, K., ... &Wilms, J. (2020). The galactic LMXB population and the galactic centre region. *New Astronomy Reviews*, *88*, 101536.
[65] Shahbaz, T., &Kuulkers, E. (1998). On the outburst amplitude of the soft X-ray transients. *Monthly Notices of the Royal Astronomical Society*, *295*(1), L1-L5.
[66] Shahbaz, T., Charles, P. A., & King, A. R. (1998). Soft X-ray transient light curves as standard candles: exponential versus linear decays. *Monthly Notices of the Royal Astronomical Society*, *301*(2), 382-388.
[67] Shakura, N. I., &Sunyaev, R. A. (1973). Black holes in binary systems. Observational appearance. *Astronomy and Astrophysics, Vol. 24, p. 337-355*, *24*, 337-355.
[68] Šimon, V.. (2004). Long-Term Activity of the Neutron Star Soft X-Ray Transients. European Space Agency, (Special Publication) ESA SP. 552. 399.
[69] Skinner, G. K. (1993). X-and gamma-rays from the Galactic centre. *Astronomy and Astrophysics Supplement Series (ISSN 0365-0138), vol. 97, no. 1, p. 149-153.*, *97*, 149-153.
[70] Stella, L., Campana, S., Colpi, M., Mereghetti, S., &Tavani, M. (1994). Soft X-ray transients and millisecond radio pulsars. *MemoriedellaSocietàAstronomiaItaliana, Vol. 65, p. 311*, *65*, 311.
[71] Strader, J., Li, K. L., Chomiuk, L., Heinke, C. O., Udalski, A., Peacock, M., ... &Tremou, E. (2016). A new γ-ray loud, eclipsing low-mass X-ray binary. *The Astrophysical Journal*, *831*(1), 89.
[72] Tavani, M., &Arons, J. (1997). Theory of High-Energy Emission from the Pulsar/Be Star System PSR 1259–63. I. Radiation Mechanisms and Interaction Geometry. *The Astrophysical Journal*, *477*(1), 439.
[73] Tomsick, J. A., Gelino, D. M., &Kaaret, P. (2005). The Low Quiescent X-Ray Luminosity of the Transient X-Ray Burster EXO 1747–214. *The Astrophysical Journal*, *635*(2), 1233.
[74] Van der Marel, R. P., Kallivayalil, N., Besla, G., Van Loon, J. T., & Oliveira, J. M. (2009). Proc. IAU Symp. 256, TheMagellanic System: Stars, Gas, and Galaxies.
[75] vanKerkwijk, M.H. Properties of neutron stars, in: Hong, D.K., Lee, C.-H., Lee, H.K., Min, D.-P., Park, T.-S., Rho, M. (Eds.), Compact Stars: The Quest for New States of Dense Matter, vol. 116. World Scientific, Singapore, 2004.
[76] Van Paradijs J., Verbunt, F., 1984, in "High Energy Transients in Astrophysics", ed. S.E. Woosley, AIP Conference Proceedings No. 115, p49
[77] Van Paradijs, J., & McClintock, J. E. (1994). Absolute visual magnitudes of low-mass X-ray binaries. *Astronomy and Astrophysics, Vol. 290, p. 133-136 (1994)*, *290*, 133-136.
[78] Verbunt, F. (1984). Mass transfer and the period gap of cataclysmic variables. *Monthly Notices of the Royal Astronomical Society*, *209*(2), 227-240.
[79] Verbunt, F. (1996). ROSAT Observations of Soft X-ray Transients in Quiescence. In *Symposium-International Astronomical Union* (Vol. 165, pp. 333-339). Cambridge University Press.
[80] Verbunt, F. (2001). A census with ROSAT of low-luminosity X-ray sources in globular clusters. *Astronomy & Astrophysics*, *368*(1), 137-159.
[81] White, N. E., Stella, L., &Parmar, A. (1988). The X-ray spectral properties of accretion discs in X-ray binaries. *Astrophysical Journal, Part 1 (ISSN 0004-637X), vol. 324, Jan. 1, 1988, p. 363-378.*, *324*, 363-378.
[82] Wijnands, R. (2001). Recurrent very long type I X-ray bursts in the low-mass X-ray binary 4U 1636–53. *The Astrophysical Journal*, *554*(1), L59.
[83] Wijnands, R., Guainazzi, M., van der Klis, M., & Méndez, M. (2002). XMM-Newton observations of the neutron star X-ray transient KS 1731–260 in quiescence. *The Astrophysical Journal*, *573*(1), L45.
[84] Wijnands, R., Miller, J. M., Markwardt, C., Lewin, W. H., & van der Klis, M. (2001). A Chandra observation of the long-duration X-ray transient KS 1731–260 in quiescence: too cold a neutron star? *The Astrophysical Journal*, *560*(2), L159.
[85] Wu, Y. X., Yu, W., Li, T. P., Maccarone, T. J., & Li, X. D. (2010). Orbital period and outburst luminosity of transient low mass X-ray binaries. *The Astrophysical Journal*, *718*(2), 620.

[86] Zampieri, L., Turolla, R., Zane, S., & Treves, A. (1994). X--Ray Spectra from Neutron Stars Accreting at Low Rates. *arXiv preprint astro-ph/9407067*.
[87] Zavlin, V. E., Pavlov, G. G., &Shibanov, Y. A. (1996). Model neutron star atmospheres with low magnetic fields. 1. Atmospheres in radiative equilibrium. *arXiv preprint astro-ph/9604072*.