Chapter 6

Conclusion and summary

6.1 Summary

In the thesis neutron stars compact objects mainly neutron stars are taken up to investigate its features from X-ray detection of the sources from different observatories. The binary systems formed between neutron star and its companion are the typical sources of X-rays. The companion of the neutron star may be a normal star or a white dwarfs. The sources we have taken here are different from one another in terms of their mass accretion process and the types of their companion. The X-ray emitting from these sources are the valuable tools in understanding the objects at the extreme conditions namely, high temperature, high magnetic field, more than nuclear density which cannot be attained in the terrestrial laboratory. In the thesis we consider the following source SMC X-1, Swift J1756.9-2508 and 4U 1901+03, the observed data taken from the RXTE, NuSTAR, Swift and NICER were used for the analysis.

The source SMC X-1 was bursting frequently which is observed as flares that are detected in the light curves of the source. The average interval between the two bursts is almost 800 s and the average number of bursts per hour is 4-5. The bursts observed in the source is of Type II, when an instability in the accretion column is observed. The bursts were of short duration covering few tens of seconds however few of the burst were large having duration of more than a hundred of second. The flares covered 0.025 fraction of the total observational time of 225.5 ks. It is noted here that a total of 272 flares with mean FWHM of $\sim$21 s can be observed. The variability of the light curves are independent of flares. The shape of the pulse profiles for different observations are unchanged with almost similar feature indicating that the accretion geometry were unchanged during those observations. No correlation of hardness ratio and r.m.s. variability of the light curves with the flares are seen. The flare fraction however exhibits positive correlation with the peak-to-peak ratio of the primary and that of the secondary peaks of the pulse profiles. There was no indication of the hardening or softening of the spectrum being caused by flares but possibly can be due to the absorption of X-rays by interstellar medium as it is supported by the change in hydrogen column density (n_H). The luminosity of the source is found to increases with the increase in the flaring rate. Taking the viscous time scale equal to that of the mean recurrence time of the flares, the viscosity parameter α is estimated which is nearly equal to 0.16.

The accreting millisecond X-ray pulsar Swift J1756.92508 undergone through a outburst in 2018 for almost ten days. It was observed by different X-ray observatories like Swift, NICER, NuSTAR, ASTROSAT and XMM-Newton. The source is studied using the Swift and the NUSTAR observations. The simultaneous fitted spectra of the Swift in 0.3-10 keV and NUSTAR in 3-79 keV indicate that the source was in the hard state with a high cut-off energy 74.58 keV. The pulse profile of the AMXP and its relation with energy are investigated. We performed phase and time-resolved spectroscopy of the source using NUSTAR observations. From the pulse phase resolved spectroscopy it is observed that a significant variation exists in the spectral parameters with the pulse phase. The orbital phase and the time-resolved spectra were fitted by cut-off power-law model. From the orbital phase resolved spectral analysis it is found that the column density and photon index shows some anti-correlation with the flux. In the case of the time-resolved spectral analysis, we found that the spectral parameters show a bit positive correlation with one another and that with the flux also. We do not find presence of emission lines or Compton hump in the spectrum of the AMXP.

The X-ray source BeXB 4U 1901+03 went through a large outburst during 2019. Flares were observed in all the NuSTAR observations which were of tens to hundreds seconds in duration. Change in the pulse profiles are observed with time and the luminosity of the source. As the one moves from the soft to hard X-ray ranges the height of the peak of pulse is found to increase. The pulse fraction of the pulse profiles increases with the energy and that at the end of the outburst. The variation of the pulse profiles during different observations can be as a result of the change in the accretion regime. The absorption like feature at 10 keV were observed in the spectra of all the NuSTAR observations and show positive correlation with the luminosity. This feature is also pulse phase dependent. Another absorption like feature at 30 keV were observed in the last two NuSTAR observations. Fitting with the absorption models we found that the line energy of the feature were about 30.51 ± 0.42 and 30.41 ± 0.54 keV for that last two observations respectively. This feature is confirmed to be CRSF by Beri *et al.* (2021). The softening of the spectrum along with an increase in the pulse fraction is also observed near the end of the outburst. Also it is found that the pulsation of the source was absent after 58665.09 MJD which indicate that the source has entered into a propeller phase. This fact is also correlated with the abrupt change in the flux at the end of the outburst.

6.2 Future work

Study of burst storm from a magnetar SGR 1935+2154 - A magnetars is a neutron star having very high magnetic field - about an order of 10^{15} G. They frequently undergone through short bursts of duration $\sim$ 0.1-1 s and intermediate bursts of $\sim$

1-40 s. During a short burst the luminosity can reach about $\sim 10^{39}$-10^{41} erg s^{-1}, whereas during intermediate burst the peak luminosity lies between $\sim 10^{41}$-10^{43} erg s^{-1}. It is known that some the magnetars show giant burst where the luminosity can reach $\sim 10^{43}$-10^{47} erg s^{-1}. These bursts are powered by the magnetic energy (for review see Turolla *et al.* (2015)). SGR 1935+2154 was discovered during burst in the year 2014 (Stamatikos *et al.*, 2015) with Swift-BAT. The magnetic nature of the source was confirmed later with the help of X-ray observations along with its spin period of P = 3.25 s (Israel *et al.*, 2016). The spin-down rate is $\dot{P}$ = 1.43×10^{-11} s s^{-1} from which the magnetic field is estimated to be 2.2×10^{14} G (Israel *et al.*, 2016). The magnetar again went through a burst storm with the emission of tens of burst in between 27-28 April (Fletcher and Team, 2020). In future the analysis will be extended to study the burst.

Observations of X-ray pulsars using ASTROSAT - ASTROSAT is India's first multi-wavelength observatory. It consist of Large Area X-ray Proportional Counters (LAXPC), Soft X-ray telescope (SXT), Cadmium Zinc Telluride Imager (CZTI), Ultra-Violet Imaging Telescope (UVIT) and Scanning Sky Monitor (SSM). LAXPC operates in 3-80 keV and has an excellent timing resolution is good for the timing analysis of pulsars. SXT (0.3-8.0 keV) has good spectral resolution and helpful in understanding the phenomena which occurs in soft energy range. The SMC X-1 was observed once in high state using ASTROSAT, it is important to work in future with the source. It is also interesting to look for other X-ray pulsars like LMC X-4, Cen X-3, Vela X-1 using the ASTROSAT data.