2nd China-India Workshop on High Energy Astrophysics

Study of Thermonuclear Bursts in 4U 1728-34 Using AstroSat

Prepared By
Kewal Anand

Under the Supervision of
Prof. Pankaj Jain & Prof. J S Yadav
Department of Physics
Indian Institute of Technology Kanpur 208016, India

7th December 2021

Outline:

1. Introduction to NS-LMXB 4U 1728-34
2. Thermonuclear Bursts
3. Why the study of bursts is important?
4. About AstroSat/LAXPC
5. Previous Studies with AstroSat/LAXPC
6. Results
7. Conclusion

Introduction to Neutron Star LMXB:

4U 1728-34 NS-LMXB i.e. the source of our interest.

Discovered by Uhuru Satellite

RA = 17 hours and 28 minutes

Dec = -34 degrees

Distance of source = 5.2 kpc (Galloway et al. 2008)

$\boldsymbol{N_H = 2.6 \times 10^{22}\ cm^{-2}}$ **(Worpel et al. 2013)**

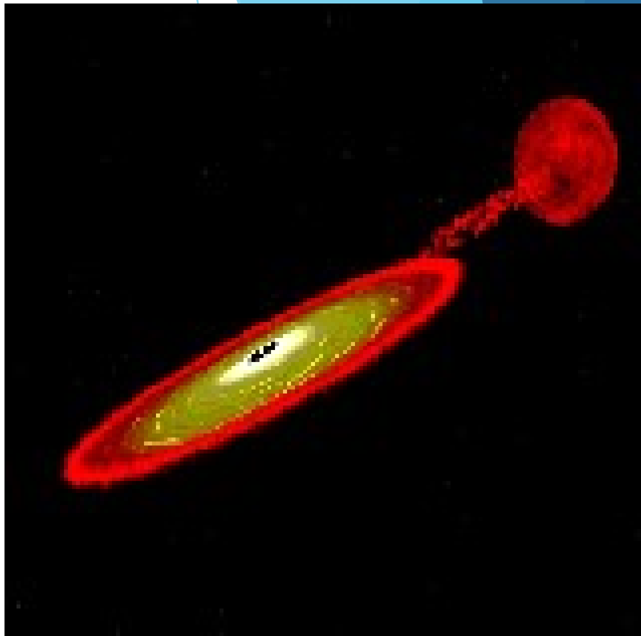

Image Source: *X-ray Binaries Research Group*, The University of Birmingham, School of Physics and Astronomy (U.K)

4U 1728-34 is an atoll source which has been continuously showing X-ray burst since it was first discovered.

Thermonuclear Bursts:

Thermonuclear burst

- It is caused by unstable nuclear burning of accreted hydrogen and helium from the low-mass stellar companion.
- Sharp rise and gradual decay.

Importance of Thermonuclear Burst

- Measurement of neutron star parameters from the spectral and timing analyses of bursts.
- The crust (nuclear) physics of these neutron stars crucially depends on bursts.
- To probe the strong gravity regime and many more.

During thermonuclear bursts the binary system radiates the energy of about 10^{39} erg just in few of seconds.

LAXPC onboard AstroSat:

- LAXPC consists of three identical proportional counters(LAXPC10, LAXPC20 & LAXPC30) with a total **effective area of $6000\ cm^2$.**
- Each LAXPC has **time resolution of 10 μs** and each works in the **energy range of 3-80 keV.**

Image Source: Department of Astronomy & Astrophysics, TIFR Mumbai

Previous Studies with AstroSat/LAXPC:

- Beri et al. 2019 showed the rare triplet of X-ray burst in NS-LMXB 4U 1636-536. They also detected QPO at around 5 Hz however kHz-QPO feature was not observed.

- Chauhan et al. 2017 revealed the presence of kHz-QPO in 4U 1728-34 which evolved with time from 815 Hz to 850 Hz. They also detected the burst oscillation at around 360 Hz.

- Pinaki Roy et al. 2021 observed burst oscillation in 4U 1636-536 at around 580 Hz.

Results: (*work in Progress)

LAXPC observed 4U 1728-34 covering 20 orbits during 7-8 March 2016. The four Type-I X-ray bursts have been detected in orbits 2398, 2407, 2415 & 2417.

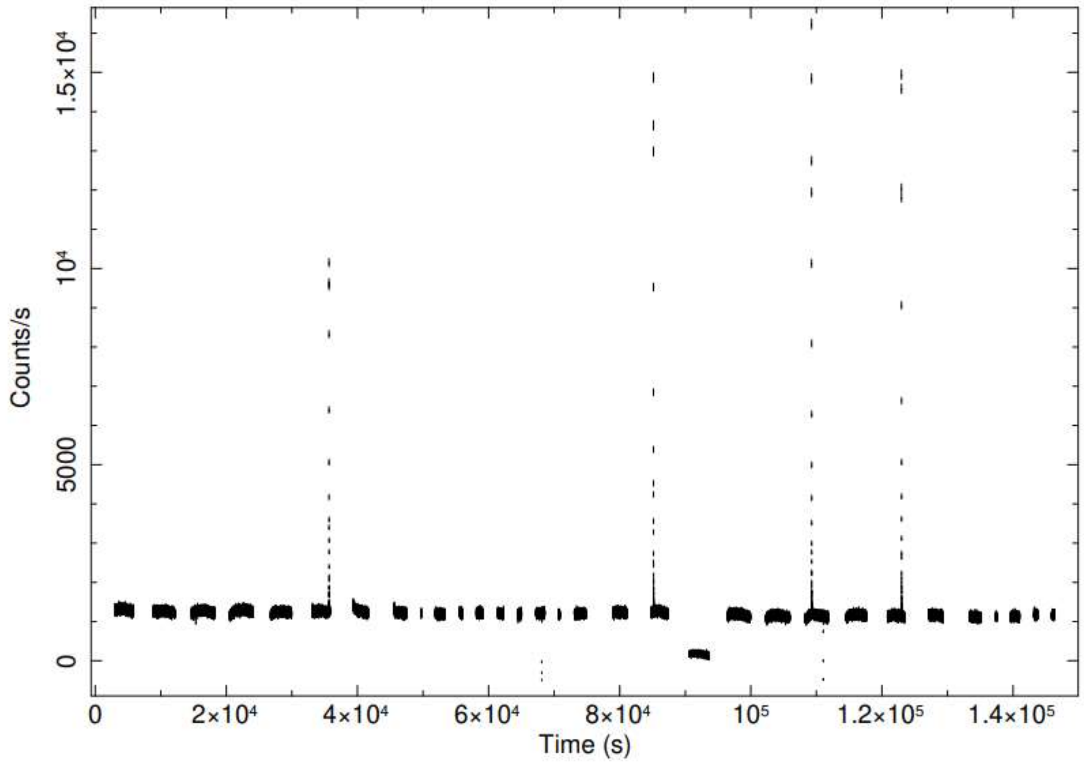

Figure-1 3-80 keV light curve with time bin of 1 s. Light curve shows 4 thermonuclear bursts in 20 satellite orbit data.

- The analyses have been carried out using **LAXPCsoftware** and **HeaSoft** of NASA's High Energy Astrophysics Science Archive Research Centre (HEASARC).

Results:

Thermonuclear Burst Profile-

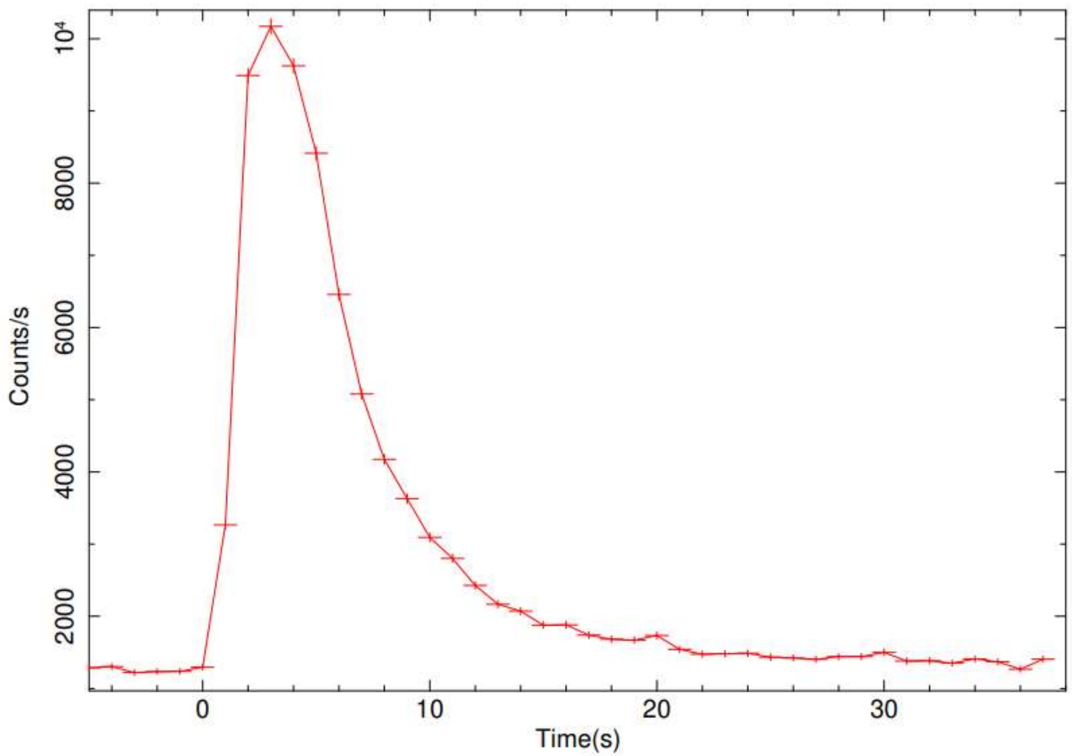

Figure-2 3-80 keV light curve with time bin of 1 s. This light curve shows the X-ray burst profile.

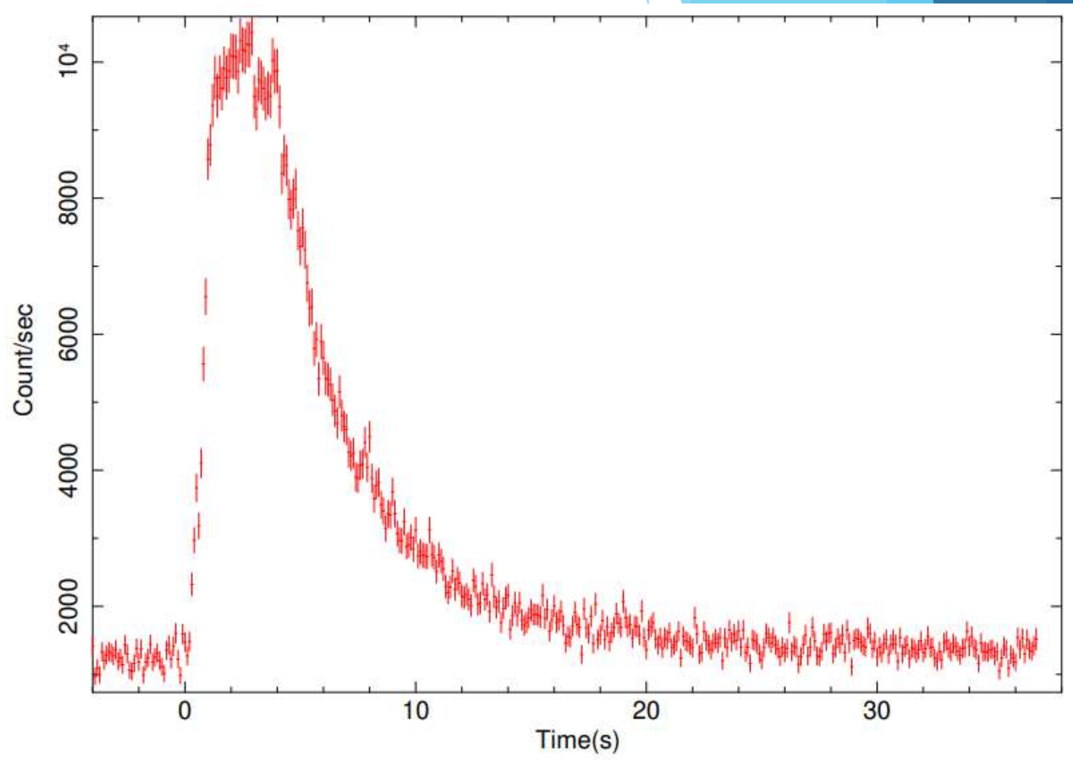

Figure-3 3-80 keV burst profile with 0.1 s time bin.

Results:

Hardness Ratio-

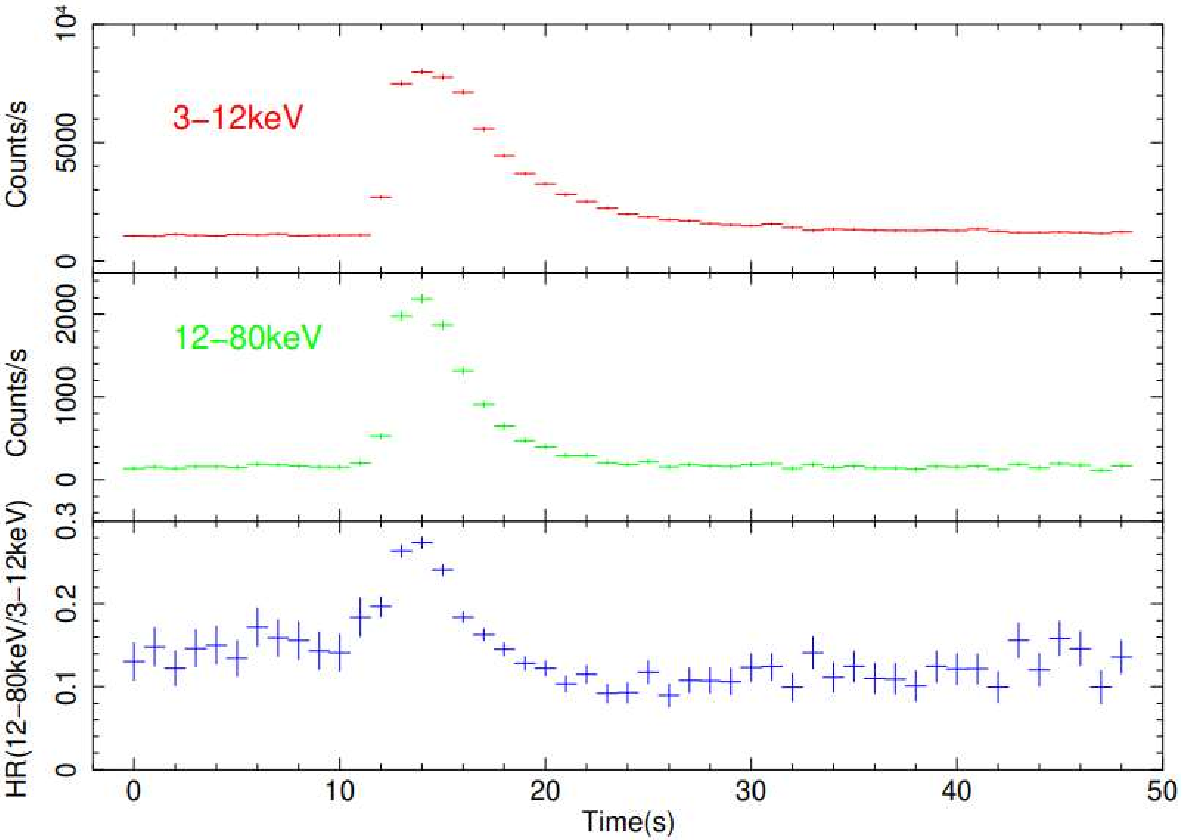

Figure-4 Hardness Ratio Plot. The time has been binned with bin size of bin 1 s.

- The average count rate ~ 1720 counts/s Maximum count rate during X-ray burst has been observed around 10630 counts/s.
- The X-ray burst the luminosity of the source has increased about 6 times its persistent emission

Increase in hard X-ray photons

Results:

Energy-Resolved Light Curve of X-ray Bursts-

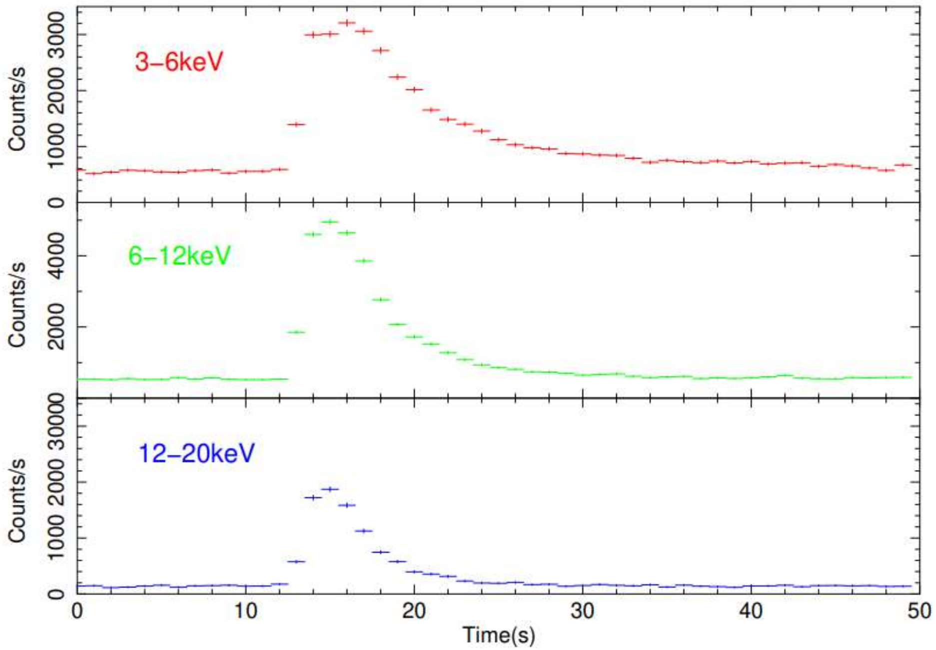

Figure-5 Shows the light curves for energy range 3-6 keV, 6-12 keV and 12-20 keV with 1 s time bin

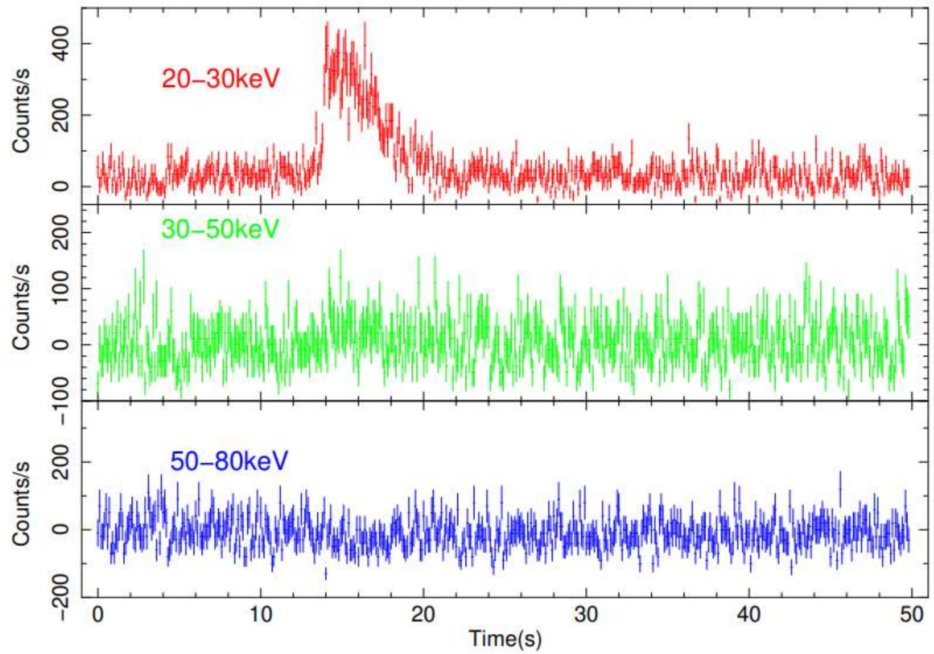

Figure-6 Shows the light curves for energy range 20-30 keV, 30-50 keV and 50-80 keV with 0.1 s time bin

A gradual decrease in the temperature due to cooling of burning ashes along the burst decay is the cause of observed energy dependence of burst duration.

Results:

kHz-Quasi-Periodic Oscillation-

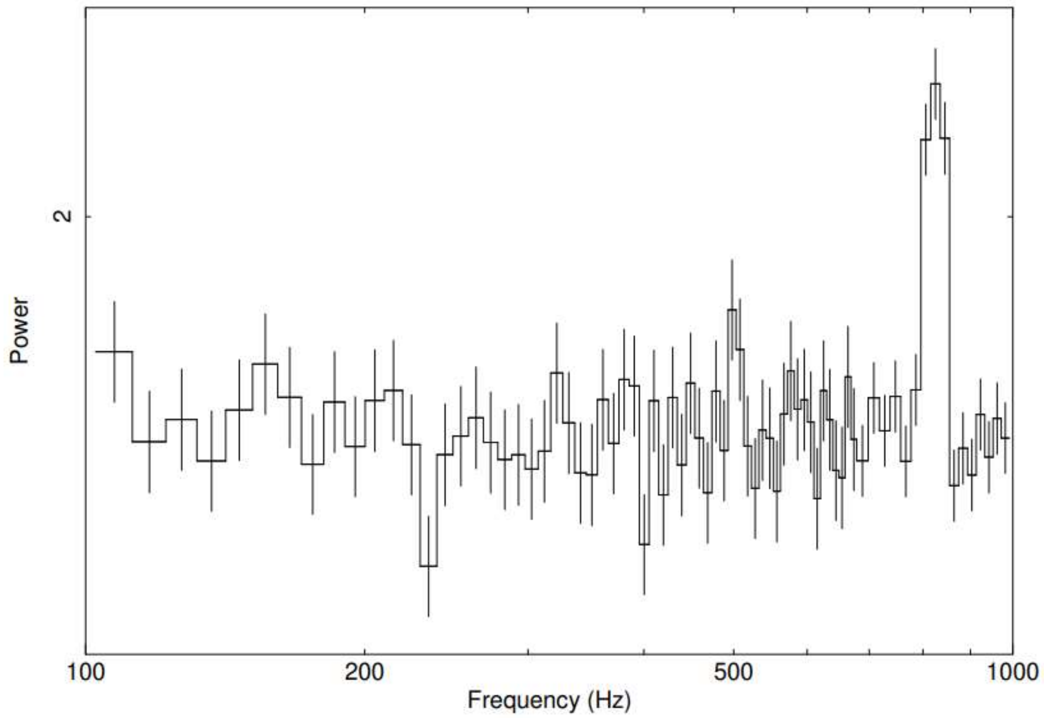

Figure-7 3-20 keV PDS of persistent emission for orbit 2398 excluding the X-ray burst.

- We have searched for the presence of high-frequency QPOs in the data of orbit 2398 excluding the X-ray burst
- Figure 7 shows the PDS of persistent emission 2500 seconds before and excluding the X-ray burst
- We have detected HF-QPO at ~ 800 Hz

Results:

Dynamics Power Density Spectrum of QPO-

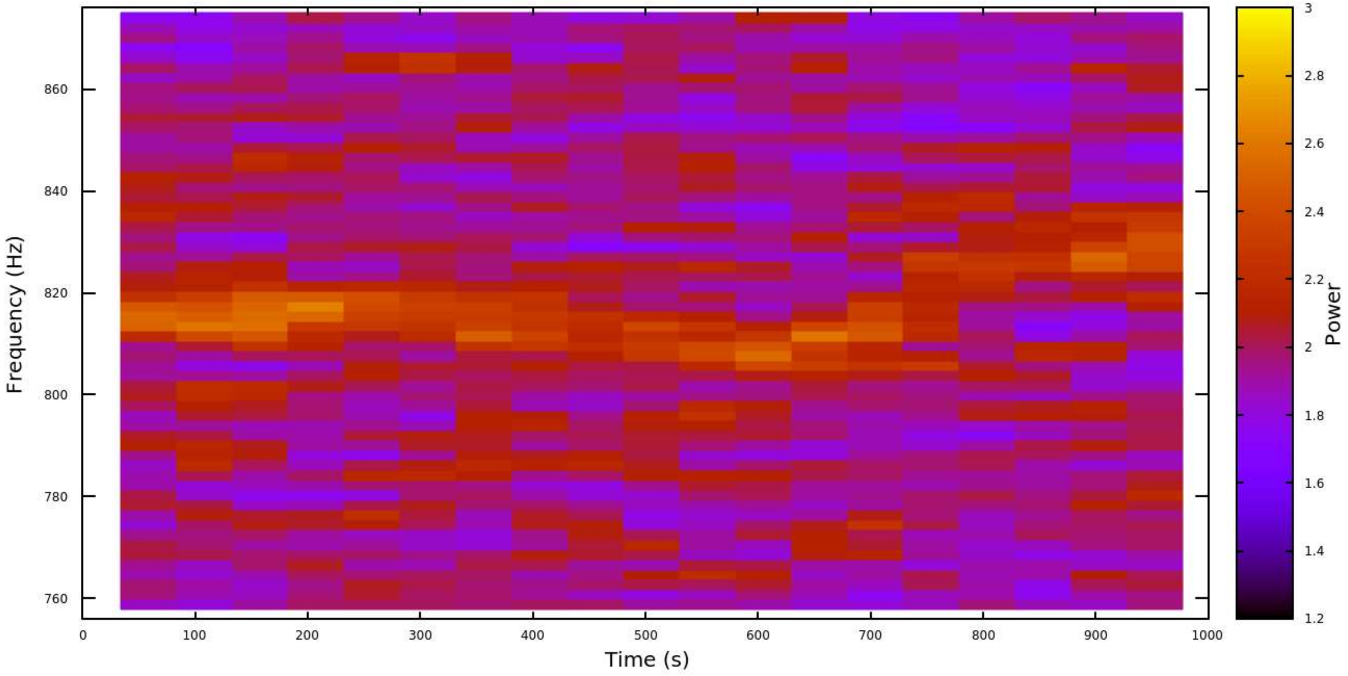

Figure-8 3-20 keV Dynamic PDS of persistent emission for orbit 2398 excluding the X-ray burst.

- It indicates the drifting QPO frequency with time.
- QPO frequency started increasing by the end of the observation gradually shifting from ~ 814 Hz in beginning to ~ 832 Hz at the end.

Results:

Burst Oscillation-

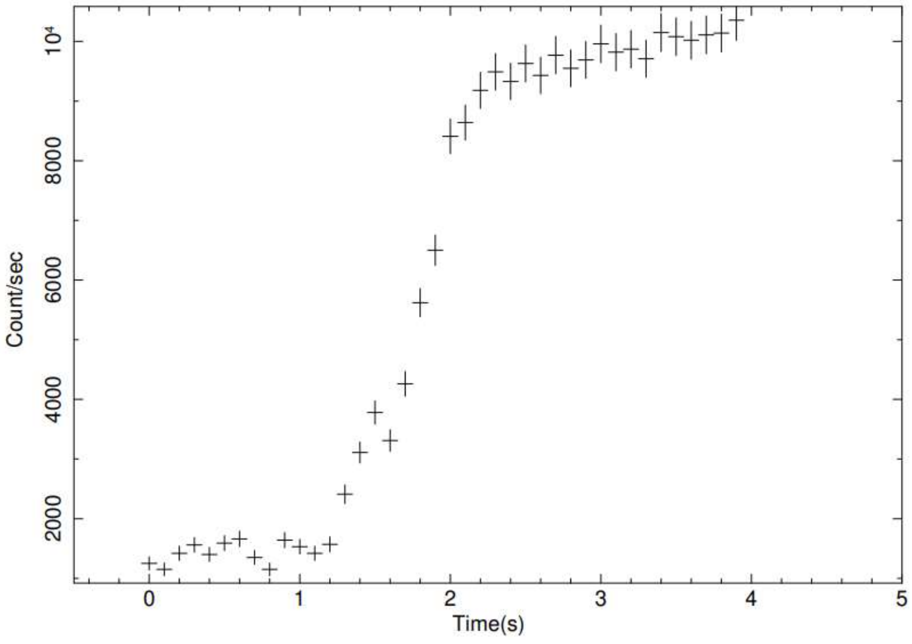

Figure-9 3-20 keV light curve of initial 4 s of X-ray burst with time bin 0.1s

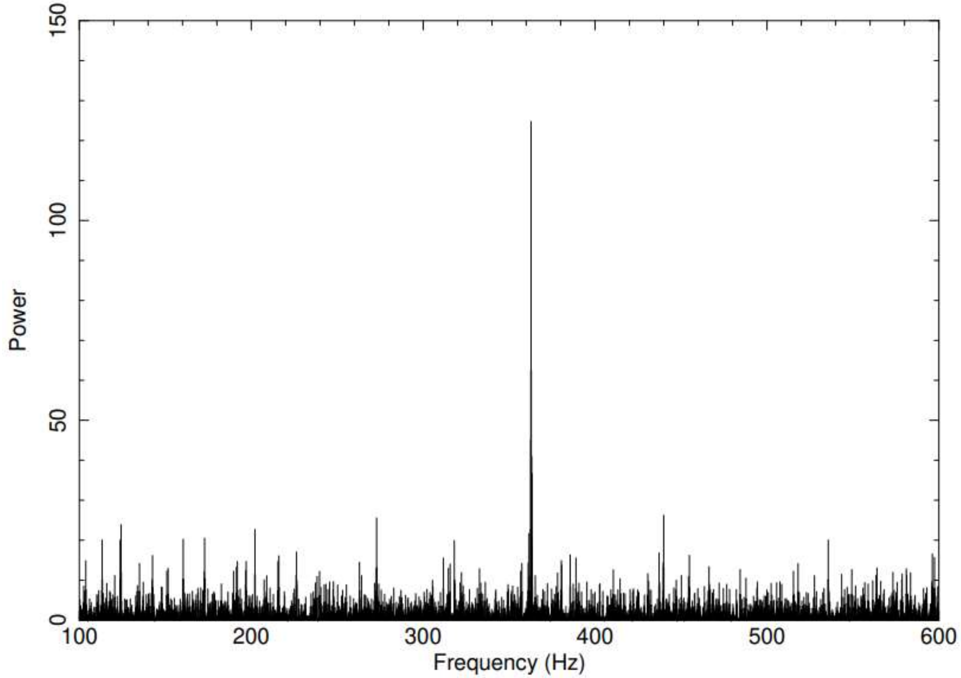

Figure-10 3-20 keV PDS of initial 4 seconds of X-ray burst in orbit 2398.

Burst oscillation at 362 ± 1.2 Hz

Results:

Energy Spectrum of X-ray Burst-

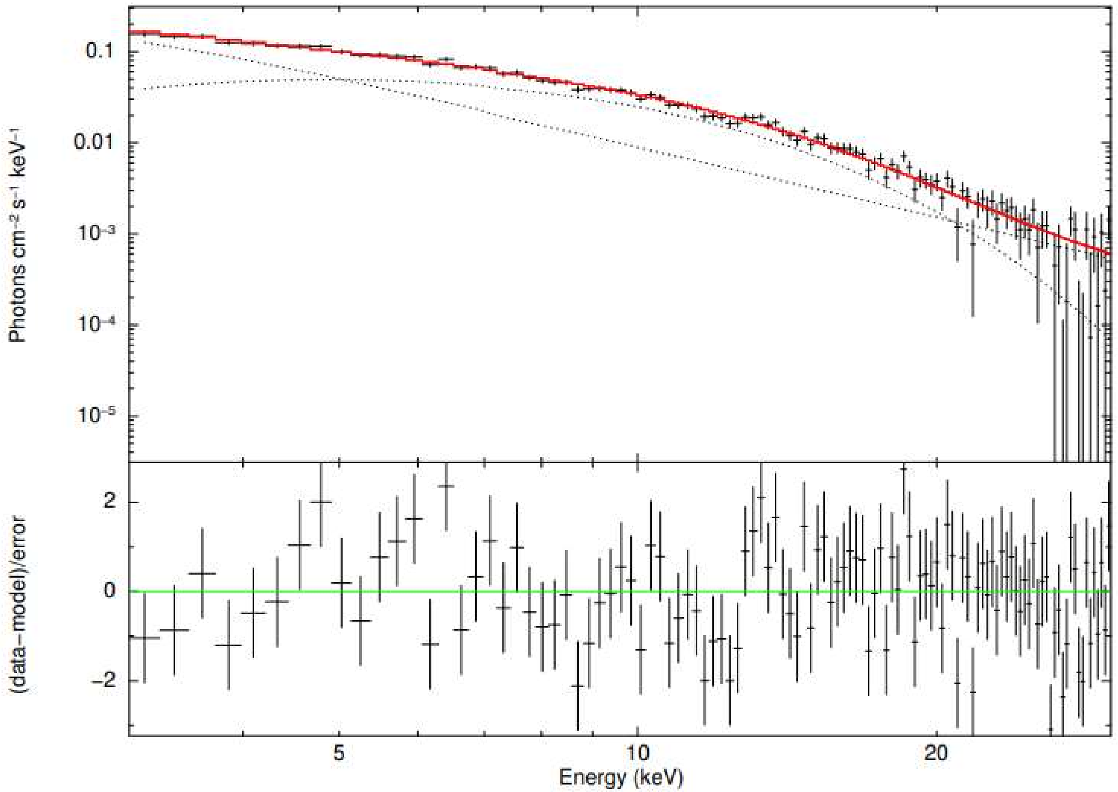

Figure-11 3-30 keV energy spectrum of the X-ray Burst fitted with model **tbabs*(bbodyrad+powerlaw)**.

- The burst spectrum using the data from all the layers of LAXPC10 has been fitted with model **tbabs*(bbodyrad+powerlaw).**
- Figure 11 shows the best-fitted spectrum of X-ray burst with $\chi^2_{red} = 1.12$ for 68 degrees of freedom.

Results:

Spectral Fit Parameters-

Table 1. Shows the detail of model used for fitting the X-ray burst spectrum along with best-fit spectral parameters.

Model	Parameter	Value
tbabs	nH (10^{22} cm^{-2})	2.6 (fixed)
bbodyrad	$k_B T_{BB}$ (keV)	$2.47^{+0.07}_{-0.08}$
	$K_{BB} = R^2_{km}/D^2_{10}$ (unitless)	$13.88^{+1.79}_{-1.53}$
Powerlaw	PhotonIndex (unitless)	$2.59^{+0.14}_{-0.12}$
	K_{PL}(Photons cm^{-2} s^{-1} keV^{-1})	$3.55^{+0.87}_{-0.67}$

$$A(E) = \frac{K_{BB} \times 1.0344 \times 10^{-3} \times E^2 dE}{\exp\left(\frac{E}{k_B T}\right) - 1}$$

$$A(E) = K_{PL} E^{-\Gamma} dE$$

Results

Temperature $= 2.47^{+0.07}_{-0.08}$ keV~ 28 MK

Photon Index $= 2.59^{+0.14}_{-0.12}$

Conclusion:

- The strong thermonuclear burst with rise time of 3 s and decay time of about 19 s, Count rate increases by the factor of 6.
- The Hardness Ratio shows there is increase in number of hard X-ray photons. No X-ray burst has been observed above 30 keV and with increase in energy there is decrease in burst duration.
- Power Density Spectrum **shows kHz-QPOs at ~ 800** Hz which changes with time.
- The spin frequency of NS in 4U 1728-34 has been found to be **362 ± 1.2 Hz**.
- The energy spectrum of X-ray burst **shows the presence of non-thermal component**. The temperature of burning is $2.47^{+0.07}_{-0.08}$ keV.

Future Plan:

- We will study evolution of temperature and radius of burning using time-resolved spectroscopy.

- We will also study kHz-QPO dynamical power spectra in all satellite orbits and will try to understand the time evolution in HF-QPO.

Acknowledgements:

This work has been done using the data of ISRO's satellite **AstroSat/LAXPC**. The data analyses have been carried out using **LAXPCsoftware** and **HeaSoft** of NASA's High Energy Astrophysics Science Archive Research Centre (HEASARC). I would like to express my sincere gratitude to my supervisors **Prof. J S Yadav** and **Prof. Pankaj Jain** for guiding me into this wonderful world of astrophysics. I am also immensely grateful to **Prof. Ranjeev Misra** from Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune for his constant support and collaboration.

References:

1. A. Beri, B. Paul, J. S. Yadav, H. M. Antia, P. C. Agrawal, R. K. Manchanda, D. Dedhia, J. V. Chauhan, M. Pahari, R. Misra, T. Katoch, P. Madhwani, P. Shah, Varun, and S. Mate, *Thermonuclear X-Ray Bursts in Rapid Succession in 4U 1636-536 with AstroSat-LAXPC*, Mon. Not. R. Astron. Soc. **482**, 4397 (2019).
2. J. S. Yadav, P. C. Agrawal, R. Misra, J. Roy, M. Pahari, and R. K. Manchanda, *LAXPC Instrument Onboard AstroSat: Five Exciting Years of New Scientific Results Specially on X-Ray Binaries*, High Energy Astrophys. Phenom. 1 (2021).
3. D. K. Galloway, M. P. Muno, J. M. Hartman, D. Psaltis, and D. Chakrabarty, *Thermonuclear (Type I) X-Ray Bursts Observed by the Rossi X-Ray Timing Explorer* , Astrophys. J. Suppl. Ser. **179**, 360 (2008).
4. L. Boirin, L. Keek, M. Méndez, A. Cumming, J. J. M. In't Zand, J. Cottam, F. Paerels, and W. H. G. Lewin, *Discovery of X-Ray Burst Triplets in EXO 0748-676*, Astron. Astrophys. **465**, 559 (2007).
5. J. J. E. Kajava, C. Sánchez-Fernández, E. Kuulkers, and J. Poutanen, *X-Ray Burst-Induced Spectral Variability in 4U 1728-34*, Astron. Astrophys. **599**, 1 (2017).
6. J. V. Chauhan, J. S. Yadav, R. Misra, P. C. Agrawal, H. M. Antia, M. Pahari, N. Sridhar, D. Dedhia, T. Katoch, P. Madhwani, R. K. Manchanda, B. Paul, and P. Shah, *AstroSat /LAXPC Detection of Millisecond Phenomena in 4U 1728-34* , Astrophys. J. **841**, 41 (2017).
7. P. Roy, A. Beri, and S. Bhattacharyya, *Thermonuclear X-Ray Bursts from 4U 1636 − 536 Observed with AstroSat* , Mon. Not. R. Astron. Soc. **508**, 2123 (2021).

Thank You…