Broad-band mHz QPOs and spectral study of LMC X-4 with *AstroSat*

LMC X-4 is a highly luminous and eclipsing high-mass X-ray binary pulsar which is known to exhibit variations in X-ray flux over a wide range of time scales. The Large Area X-ray Proportional Counter (LAXPC) and Soft X-ray Telescope (SXT) instruments onboard the AstroSat observed the source in August 2016. The source was found to emit an X-ray luminosity of $\sim 2 \times 10^{38}$ erg/s in the energy range of 0.5–25 keV. A complete X-ray eclipse was detected with the LAXPC. The power density spectrum showed the presence of coherent pulsations at 13.5 s along with a ~26 mHz quasi-periodic oscillation feature. From the joint analysis of the SXT and LAXPC spectral data, the 0.5–25 keV spectra were found to be comprised of an absorbed high-energy cut-off power law with a photon index of $\Gamma \sim 0.8$ and cutoff at ~16 keV, a soft thermal component with kT ~0.14 keV and Gaussian components corresponding to Fe Kα, Ne IX and Ne X emission lines.

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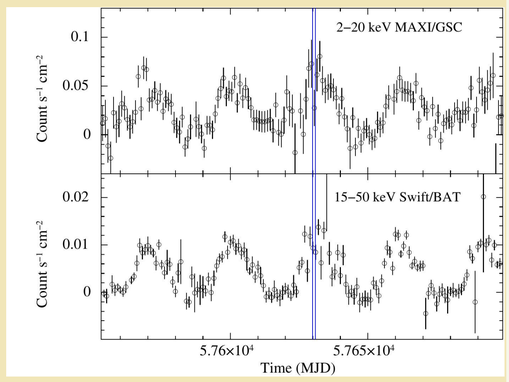
INTRODUCTION

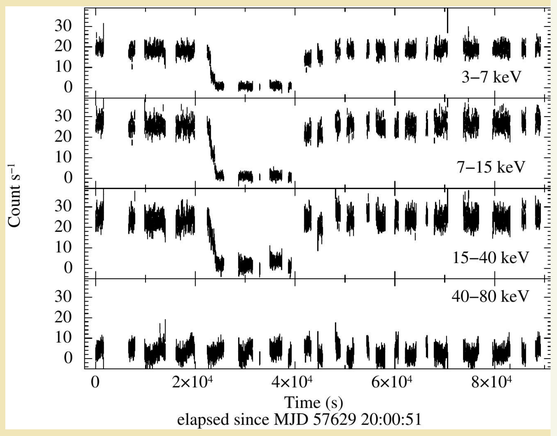
- LMC X-4 is a highly luminous, eclipsing high-mass X-ray binary (HMXB) located in the Large Magellanic Cloud.
- 13.5 s pulsar in 1.4 d orbit (Li et al. 1978).
- 30.5 d Variations in X-ray flux - Superorbital variations- precessing tilted Accretion disc (Paul & Kitamoto 2002).
- Large X-ray flares - Quasi-period variability at ~0.65-1.35 and 2-20 mHz (Moon & Eikenberry 2001).
- ~27 mHz Quasi-periodic Oscillation (QPO) with XMM-Newton (Rikame et al. 2022).

OBSERVATIONS

AstroSat (Agrawal 2006) is India's first dedicated multi-wavelength Astronomy mission, launched in 2015. LMC X-4 was observed in August 2016 for 90 ks during the high Superorbital phase.

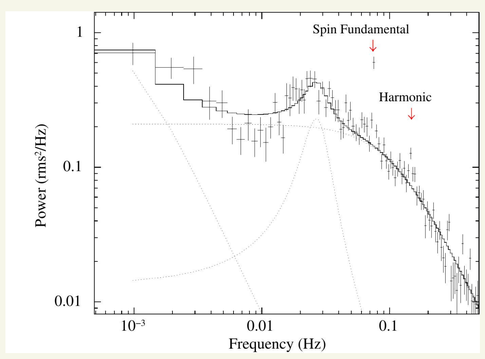


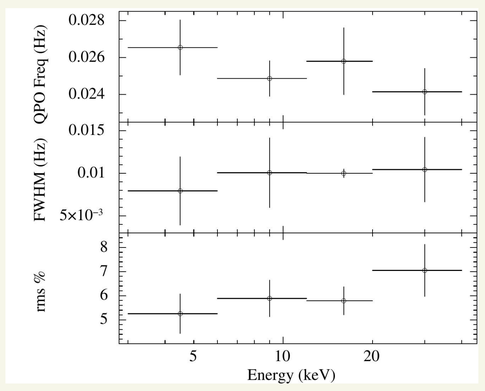
LIGHT CURVE

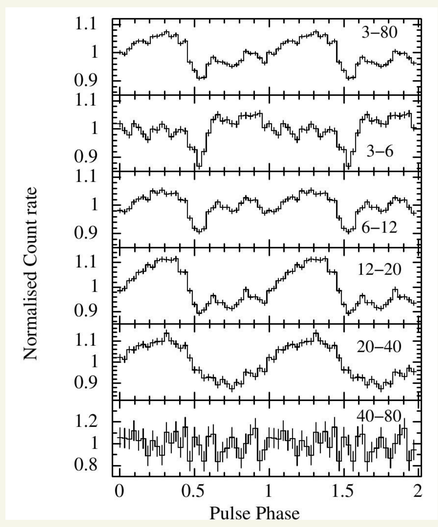


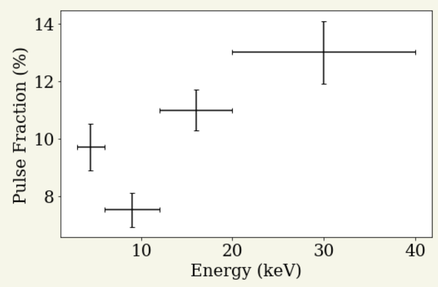
TIMING ANALYSIS

- Spin period = 13.501606 (16) sec.
- Energy dependence of Pulse profile and pulse fraction: complex dip-like features in soft X-ray energies, possibly due to absorption from the accretion stream (Beri & Paul, 2017).
- An X-ray eclipse of ~5 h.
- Above 40 keV, SNR was low.
- A 26 mHz QPO in the 3-40 keV energy range.
- QPO was detected with a Quality factor (QPO frequency/FWHM) of ~2 and rms of 6.8%.
- rms amplitude of QPO appears to be energy-dependent but not statistically significant.



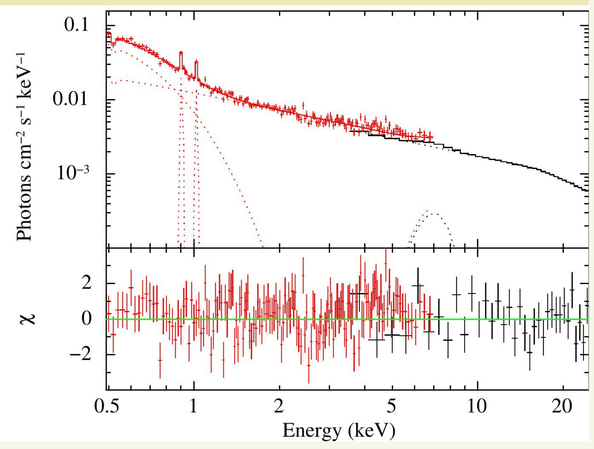






SPECTRAL ANALYSIS

- SXT+LAXPC spectra
- Soft excess - Thermal component of 0.14 keV,
- Power law ($\Gamma \sim 0.8$) with high energy cutoff at 16 keV,
- Broad iron emission lines,
- H- and He-like Ne line ,
- 0.5-25 keV X-ray Luminosity of ~2 x 10^{38} erg/s.



CONCLUSION

- The mHz QPOs suggests that instabilities or oscillations are occurring in the accretion disk.
- QPO can also be used to understand accretion disk dynamics and magnetospheric Interactions.
- This QPO feature can be explained by the magnetospheric beat-frequency model (MBFM). QPOs occur at the beat frequency between the orbital frequency of matter in the accretion disc at the Alfvén radius and the stellar spin frequency.
- Using the Keplerian frequency of the inner accretion disc as per MBFM (~74+26 mHz), the radius of the inner accretion disc can be estimated to be ~7800 km (Rikame et al. 2022).
- This QPO is transient. No QPO was detected in BeppoSAX and RXTE observations, A QPO at ~31 mHz with rms of 4.5% was detected only in one *Suzaku* observation.

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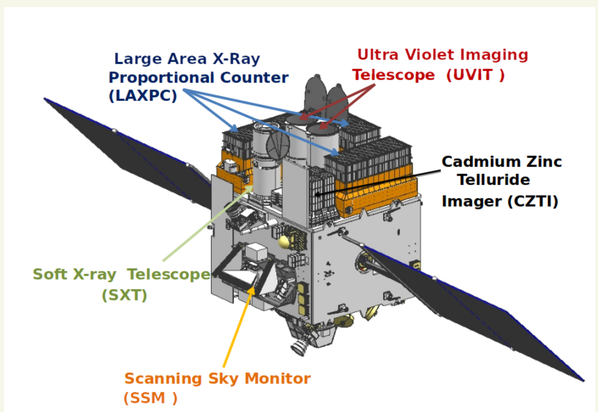

AstroSat consists of five scientific instruments – Scanning Sky Monitor (SSM), Soft X-ray Telescope (SXT), Large Area X-ray Proportional Counters (LAXPC), Cadmium Zinc Telluride Imager (CZTI) and Ultra-Violet Imaging Telescope (UVIT). Credit: ISRO