



# A Study of the Extragalactic Gamma-ray Binary LMC P3 with XMM-Newton and NuSTAR

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## Introduction:

- Very few known gamma-ray binaries
  - Consist of compact object (neutron star or black hole) and a hot young star (Figure 1)
- LMC P3 originally discovered with the *Fermi* Large Area Telescope (GeV gamma-rays)
  - Period of 10.3 days, O5 III(f) star
  - First known extragalactic gamma-ray binary
  - Embedded in supernova remnant (SNR) DEM L241 in Large Magellanic Cloud (LMC) (Figure 2)
- Gamma-ray emission occurs through non-thermal processes
  - Shock between pulsar wind and the stellar wind (Dubus 2015)
  - Accretion-powered microquasar (Dubus 2015)
- This region of sky had been previously observed in X-rays (Bamba et al. 2006, hereafter B06, and Seward et al. 2012)
- Here we present results and conclusions from new XMM-Newton and NuSTAR observations of LMC P3 at three separate orbital phases
  - X-ray minimum, inferior conjunction, X-ray maximum



Figure 2: Optical image of supernova remnant DEM L241 with circle indicating O III(f) star (Seward et al. 2012)

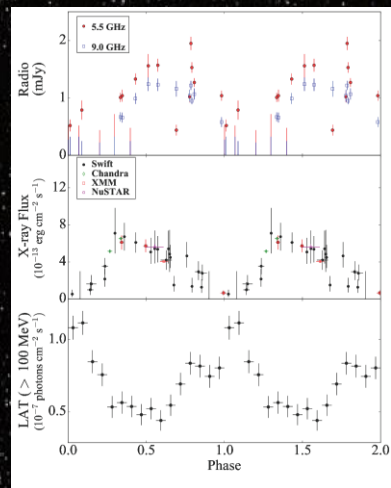


Figure 3: Light curves of radio (top), X-ray (middle), and gamma-ray (bottom) flux folded over the orbital period of LMC P3 (Modified from Corbet et al. 2016).

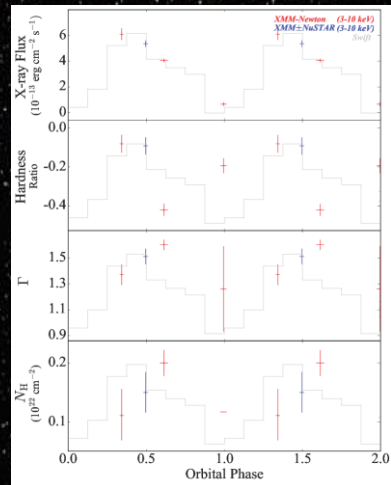


Figure 4: Plots of spectral parameters and hardness ratio vs. phase. In order of increasing orbital phase the observations are inferior conjunction, X-ray maximum, Bamba (B06), and X-ray minimum. Top: Unabsorbed X-ray flux (between 2-10 keV). Second: Hardness ratio, where  $HR = (H-S)/(H+S)$ , the soft band is 0.3-1.5 keV and the hard band is 2-10 keV. Third: Photon index. Bottom: Neutral Hydrogen column density. In gray is a histogram of the Swift X-ray flux.

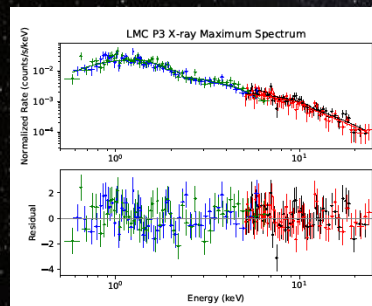


Figure 5: (Left) Spectrum of LMC P3 at X-ray maximum with data grouped to 20 counts, and using chi-squared statistics. Blue and green spectra are XMM-Newton MOS instruments. Black and red spectra are NuSTAR.

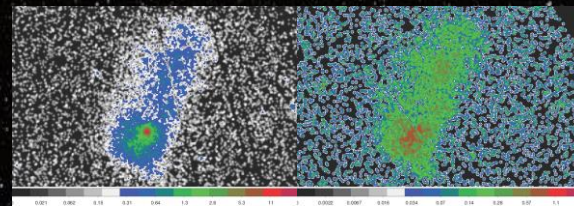


Figure 6: Log scale images of XMM-Newton observations of DEM L241. Left panel: B06 observation. Right panel: 2018 X-ray minimum observation.

## Summary:

- Flux of the SNR DEM L241 comparable to, if not more than, the flux of the binary itself at X-ray minimum (Figure 6)
  - Likely need to obtain more data to better constrain spectral parameters
- Unabsorbed X-ray flux anti-correlated with GeV flux
- Photon index anti-correlated with X-ray flux
- Neutral hydrogen column density remained roughly constant
- GeV flux and X-ray flux are out of phase by a value of 0.39
  - Possible eccentric orbit

## References

- Bamba, A., Ueno, A., Nakajima, H., Mori, K., & Koyama, K. 2006, *A&A*, 450, 585 (B06)
- Corbet, R.H.D., Chomiuk, L., Coe, M.J., et al. 2016, *ApJ*, 829, 105
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- Seward, F.D., Charles, P.A., Foster, D.L., et al. 2012, *ApJ*, 759, 123

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Figure 1: Schematic of gamma-ray binary LMC P3. Bluesphere represents the O type star. Pink sphere represents the compact object.

## Results:

- Light curve of LMC P3 shown in Figure 3
- Spectral parameters and hardness ratios shown in Figure 4
  - Parameters derived using the Xspec fitting software
  - Hardness ratio defined as  $(H-S)/(H+S)$
  - Soft X-ray band: 0.3-1.5 keV, Hard X-ray band: 2-10 keV
- Spectrum of LMC P3 at X-ray maximum is shown in Figure 5

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