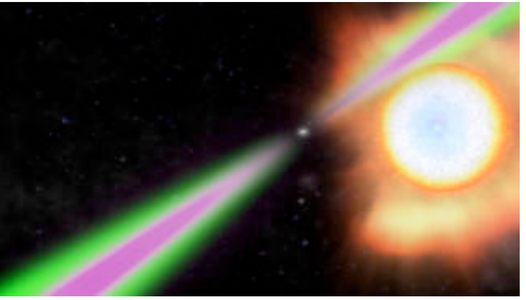


Gamma-ray Eclipses and Orbital Modulation Transitions in the Candidate Redback 4FGL J1702.7-5655

Robin H.D. Corbet, L. Chomiuk, J.B. Coley, G. Dubus, P.G. Edwards, N. Islam, V.A. McBride, J. Stevens, J. Strader, S.J. Swihart, L.J. Townsend

Abstract

Observations with the Fermi Large Area Telescope (LAT) of the gamma-ray source 4FGL J1702.7−5655, previously classified as a candidate millisecond pulsar, show highly-significant modulation at a period of about 6 hours. The folded light curve shows the presence of narrow eclipses and this is thus likely to be orbital modulation in a redback binary system.

An examination of the long-term properties of the modulation over 13 years of LAT observations indicates that the orbital modulation of the gamma-rays changed from a simple eclipse before early 2013, to a broader quasi-sinusoidal modulation. In addition, the time of the eclipse shifts to ~0.05 later in phase. This change in the orbital modulation properties is, however, not accompanied by a significant overall change in gamma-ray flux or spectrum.

The quasi-sinusoidal component peaks ~0.5 out of phase with the eclipse, which would indicate inferior conjunction of the compact object in the system.

Swift X-ray Telescope and Chandra observations reveal an X-ray counterpart that may be modulated on the orbital period. However, radio observations obtained with the Australia Telescope Compact Array do not detect a source in the region.

4FGLJ1702.7−5655 appears to have changed its state, perhaps related to changes in the intrabinary shock in the system. We discuss how the properties of 4FGLJ1702.7−5655 compare to other binary millisecond pulsars that have exhibited orbital modulation in gamma rays.

“Spider” Binary ms Pulsars

Millisecond pulsars (MSPs) have short pulse periods but their spin-down rates show they are old. They are likely descended from LMXBs. Some MSPs are in “spider” binaries where a low-mass companion is being ablated by the pulsar wind.

“Spiders” are divided into black widows, with very low-mass companions, and redbacks where the companion is a ~main-sequence star.

An intrabinary shock (IBS) may exist between the winds from the pulsar and its companion, which can produce X-ray and radio emission.

Candidate MSP: 4FGL J1702.7

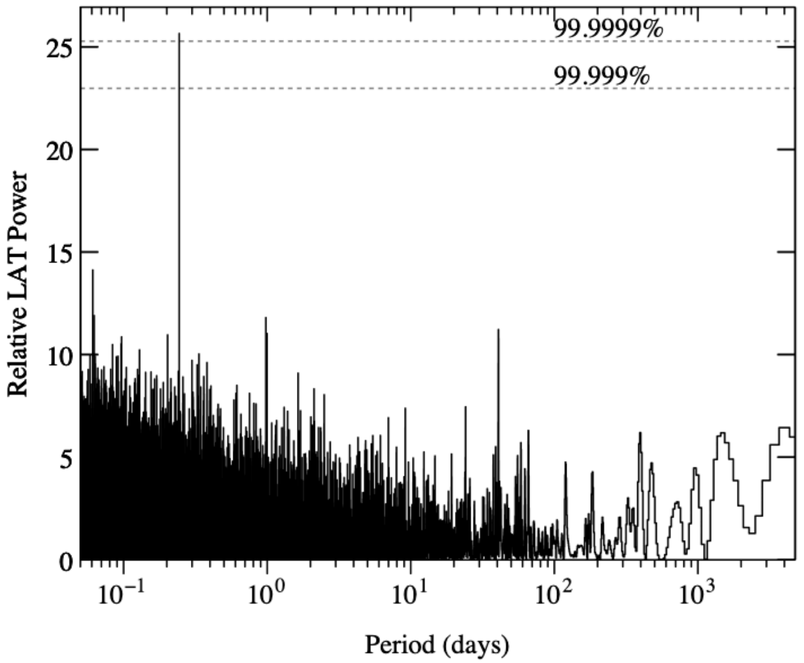
J1702.7 has been present in all LAT catalogs. It was classified as a potential MSP by Saz Parkinson+ (2016). However, searches for pulsations in gamma-rays (Clark+ 2017, Wu+ 2018) and radio (Camilo+ 2015) did not detect any.

4FGL Period Searches

For several years we have been conducting a hunt for gamma-ray binaries by searching for periodic modulation in LAT light curves. This enabled us to discover several high-mass systems.

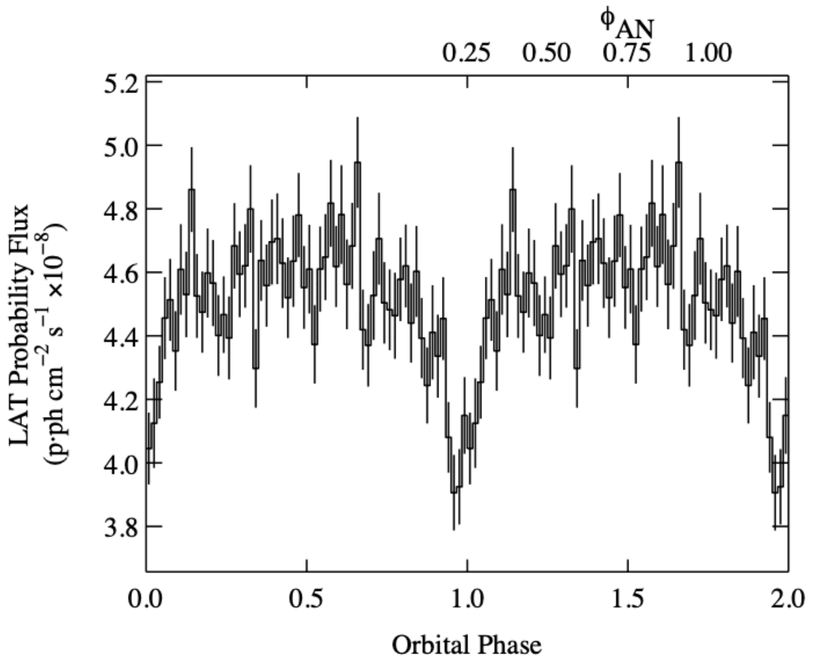
Although we expected to find more high-mass systems, we detected modulation from the MSP candidate J1702.7.

J1702.7’s 0.24 day Period



The LAT power spectrum shows modulation at ~0.24 days, typical for binary MSPs

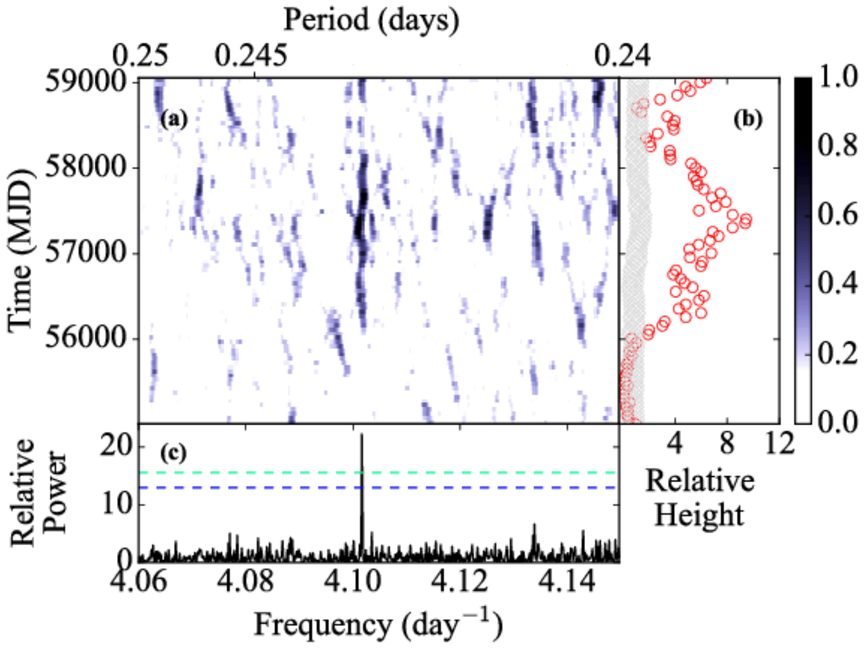
Folded LAT Light Curve



The folded LAT light curve shows a sharp dip, suggesting an eclipse and a high inclination angle.

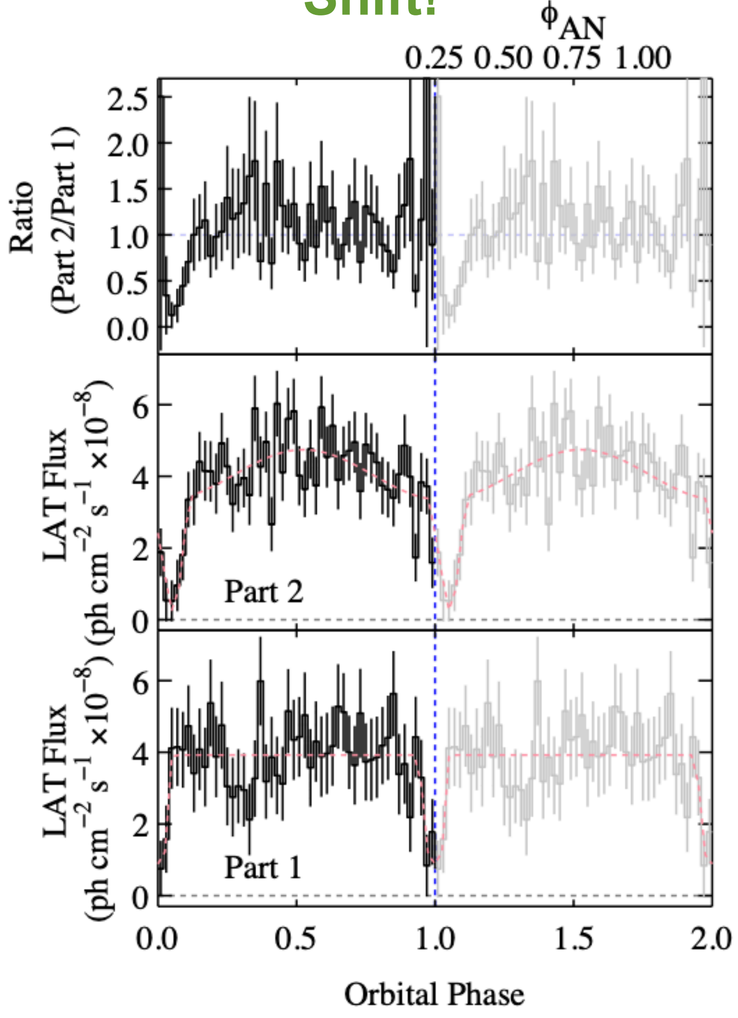
The bottom X-axis defines eclipse center as phase zero. The upper labels show orbital phases with expected time of ascending node as zero.

Sinusoidal Modulation Appears



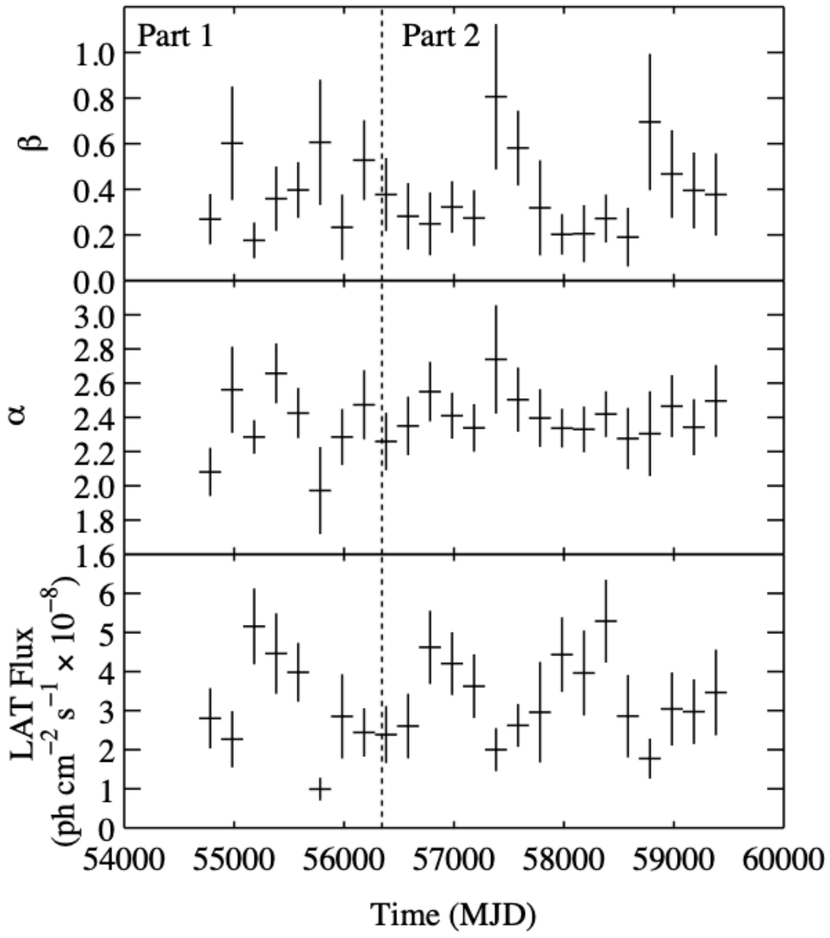
The dynamic power spectrum shows that modulation is only detected after ~early 2013 (~MJD 56,300).

+ an Eclipse Phase Shift!



The earlier part of the light curve (Part 1) shows a clear gamma-ray eclipse. In later observations (Part 2) the sinusoidal component appears, and the eclipse shifts to a later phase.

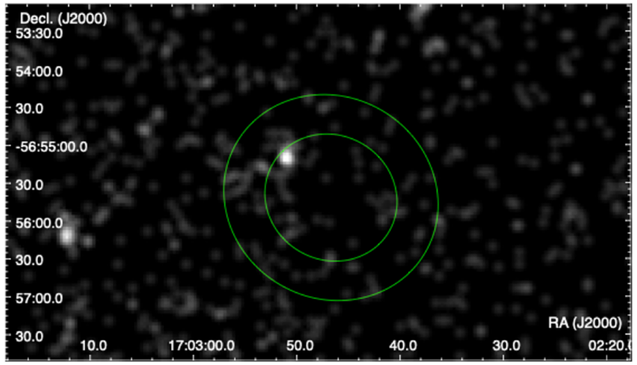
Long-term γ-ray Light Curve: No obvious change at transition



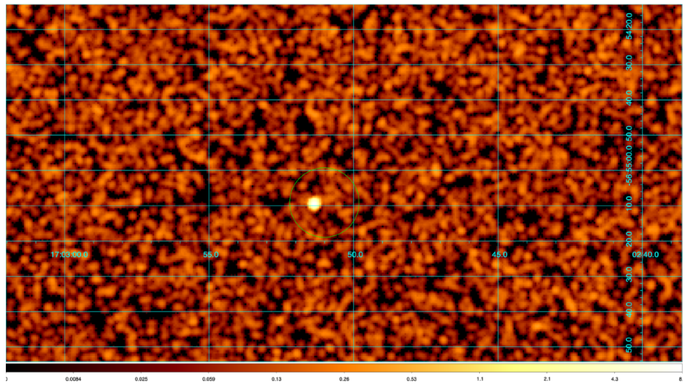
Despite the change in the orbital modulation, there is no large change in the gamma-ray flux or spectrum.

X-ray Counterpart

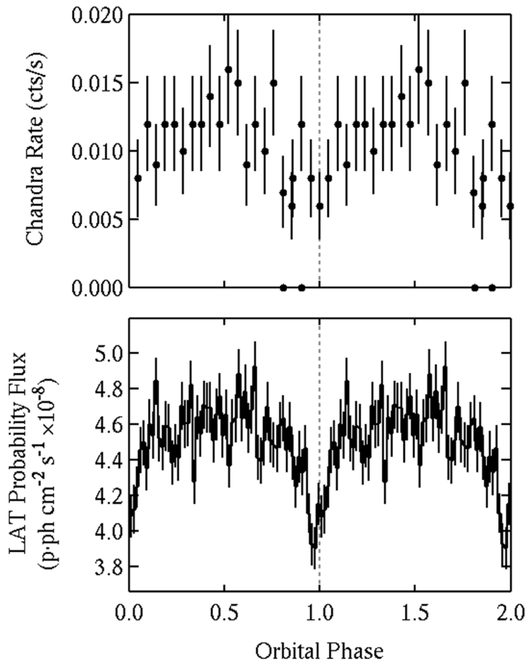
Candidate X-ray Counterpart from Swift XRT



Confirmed with Chandra

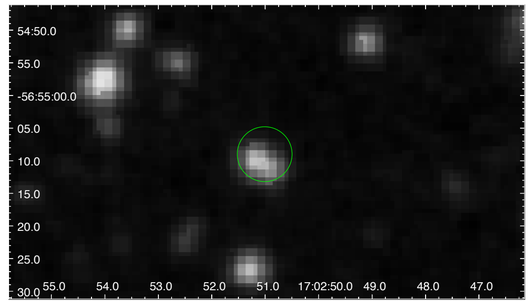


Hint of Orbital Modulation with Chandra



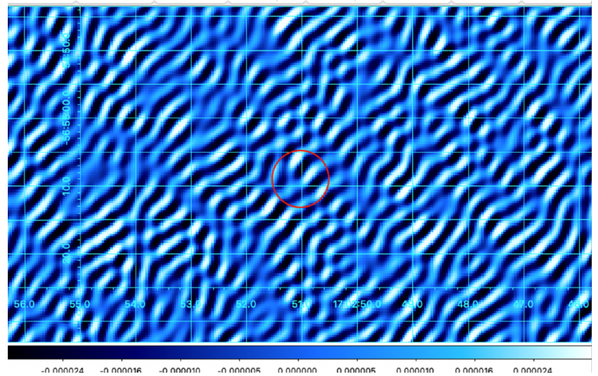
Chandra X-ray light curve shows hint of modulation with a peak at pulsar inferior conjunction. But no total X-ray eclipse is detected. Deeper X-ray observations will be obtained with XMM

Optical Candidate



The DSS2 red image shows two potential counterparts within the XRT error circle. Optical spectroscopy is in progress (Swihart+).

No radio detection (yet)



ATCA radio observations at 2.1, 5.5 and 9.5 GHz give upper limits of ~70 μJy. Radio quiet MSPs have flux densities < 60μJy, so a faint radio pulsar might be present. J1702.7 is included in the MeerKAT TRAPUM survey.

Comparison with Other Sources

Gamma-ray eclipses in MSP binaries are less common than X-ray or radio eclipses, although 4FGL J0427.8−6704 does exhibit likely eclipses (Kennedy+ 2020), and Clark+ (2021) reported "subtle" gamma-ray eclipses in four systems.

A few binary MSPs have been reported to show sinusoidal gamma-ray modulation, but typically maximum occurs at superior conjunction, not inferior conjunction as apparently occurs in J1702.7

Summary

The gamma-ray modulation found in 4FGL J1702.7−5655 is exceptional with its combination of both an eclipse and a quasi-sinusoidal component.

The sinusoidal component has a maximum near inferior conjunction which is unusual. The change in the orbital profile is also unprecedented. Surprisingly it is not accompanied by a large change in the gamma-ray flux or spectrum.

The change in the orbital modulation may be related to changes in an intra-binary shock. The eclipse has the potential to act as a probe on the origin of different emission components.

References

Camilo+ (2015) ApJ, 810, 85
Clark+ (2017) ApJ, 834, 106
Clark+ (2021) 9th Fermi Symposium
Kennedy+ (2020) MNRAS, 494, 3912
Papitto & **de Martino** (2020) arXiv:2010.09060
Saz Parkinson+ (2016) ApJ, 820, 8
Wu+ (2018) ApJ, 854, 99

For more details see: Corbet+ 2022, ApJ, 935, 2. doi:10.3847/1538-4357/ac6fe2