Radio/X-ray Monitoring of Gamma-ray Binaries: 1FGL J1018.6−5856 and LMC P3

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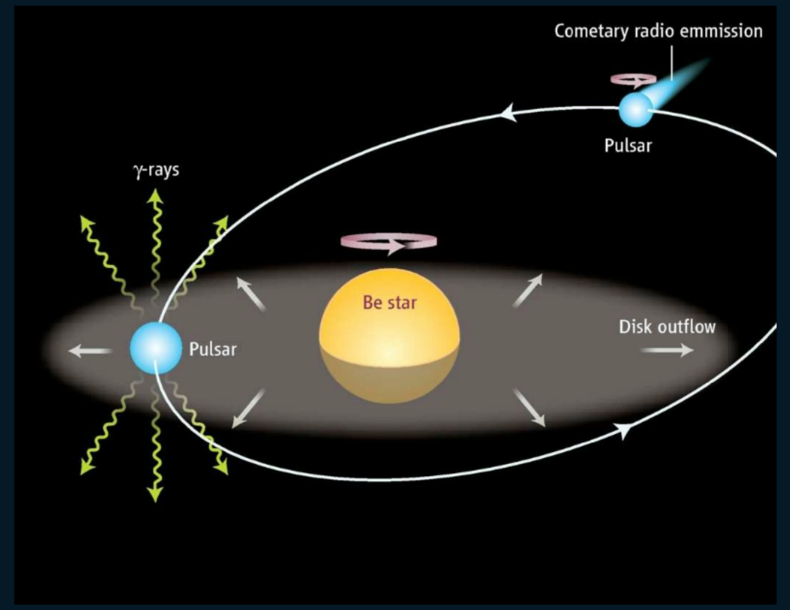
BACKGROUND *Gamma-ray Binaries*

A **gamma-ray binary** is a compact object — neutron star (NS) or black hole — in orbit around a massive O/B-type companion star, producing broadband non-thermal emission that **peaks above 1 MeV**. This high-energy emission criterion sets them apart from all other subclasses of high-mass binaries.

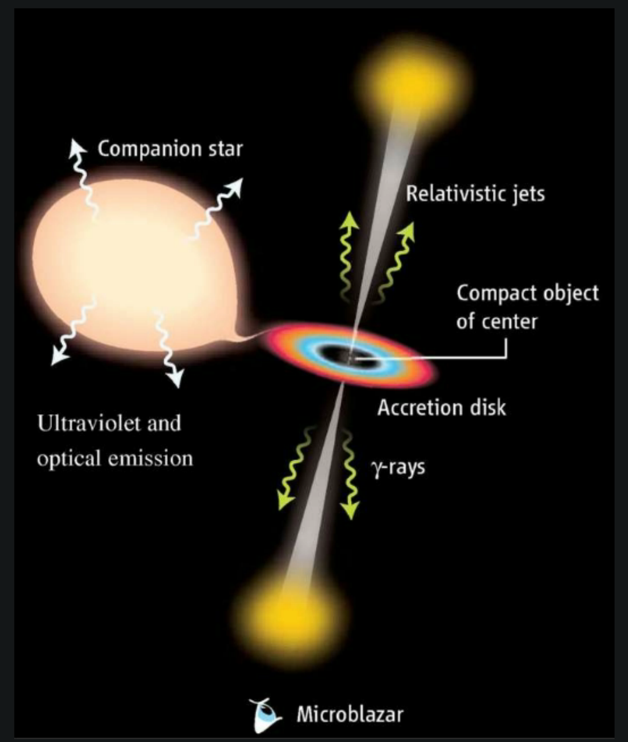
With only nine confirmed systems, they are among the rarest high-energy astrophysical objects. Moreover, the compact object remains **unidentified** in most of the systems leading to gaps in the understanding of their physical and emission mechanisms.

Competing Emission Models



Pulsar-wind Model

Pulsar wind collides with stellar wind at the stand-off shock → synchrotron (radio, X-ray) + inverse-Compton (GeV–TeV) radiation



Microquasar Model

Relativistic jet from an accreting NS or black hole → synchrotron emission along the jet

Mirabel (2012). The compact object is confirmed as a NS in only 3 systems: PSR B1259−63, PSR J2032+4127, and LSI +61°303. Both this study's targets have NS companions proposed from radial-velocity

THE STUDY *Targets & Data*

Scientific Goals

Constrain the **particle populations** responsible for non-thermal emission in **1FGL J1018.6−5856** and **LMC P3** by:

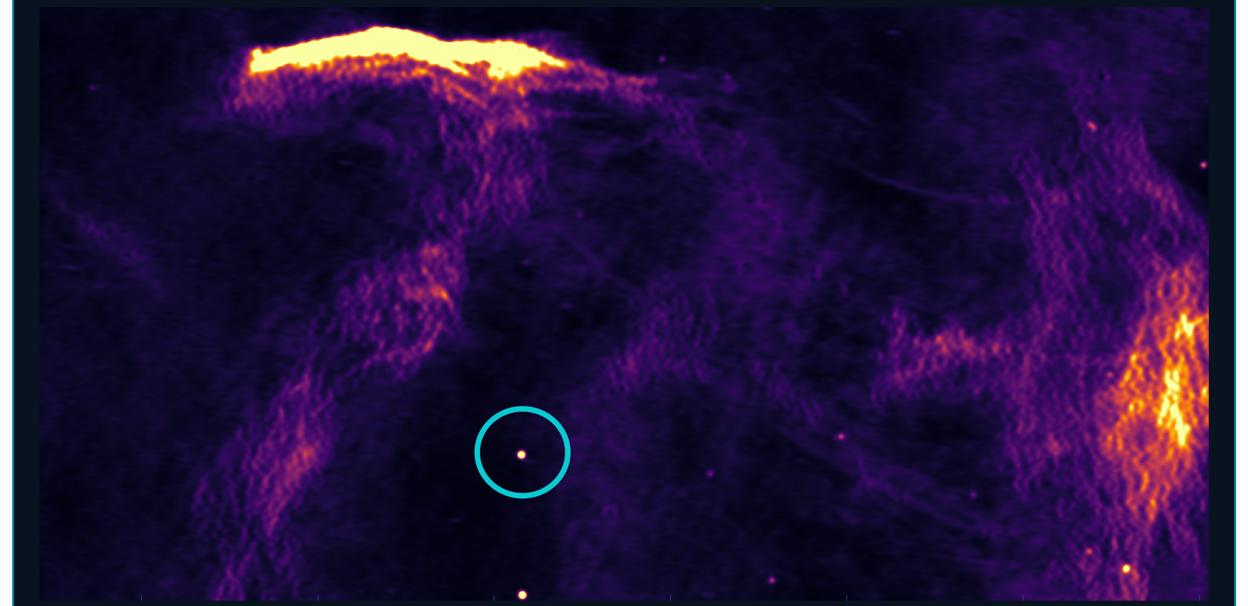
1. Reducing and analysing phase-resolved **MeerKAT L-band** observations (2019 campaign).
2. Performing a **Radio/X-ray cross-correlation** analysis to probe inter-band variability and constrain the dominant emission mechanism.

Contemporaneous campaign: **MeerKAT** 1.28 GHz and **Swift XRT** 0.3–10 keV
15 Aug – 18 Sep 2019 · cadence ≈2 d
Full orbital coverage of both targets

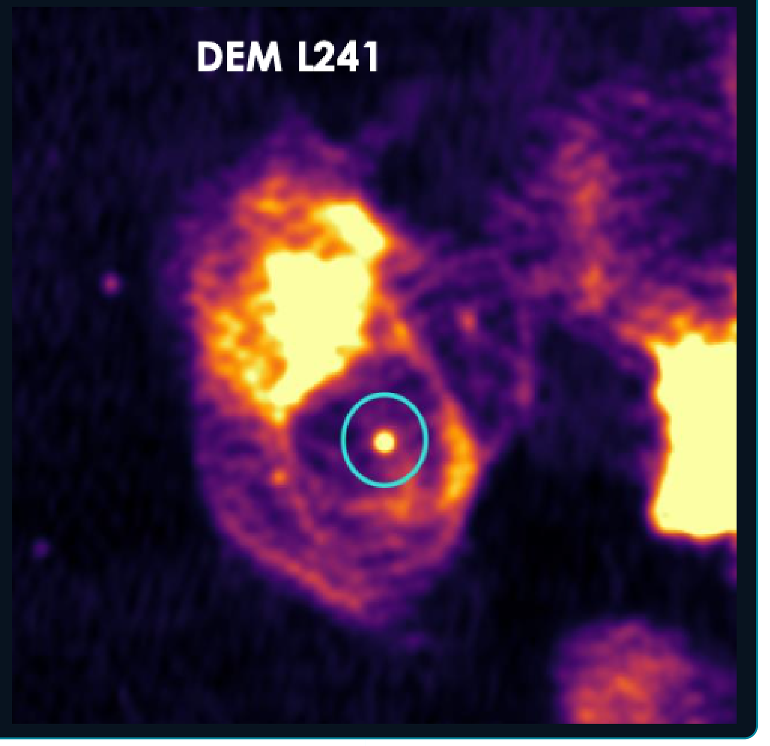
Study Targets

	LMC P3	1FGL J1018.6-5856
Star	O5 III(f)	O6 V(f)
P_{orb}	10.30 d	16.55 d
e	0.40	0.53

The compact object is **unconfirmed** in both systems; radial-velocity studies favour a neutron star in each case. Both systems are spatially coincident with candidate **supernova remnants** in MeerKAT radio maps — a rare environmental context potentially providing constraints on system age and natal kick velocity.



SNR G284.6−1.8 with **1FGL J1018.6−5856**



DEM L241
LMC P3

RESULTS *Radio/X-ray Analysis of Both Systems*

Radio Flux & Spectral Index

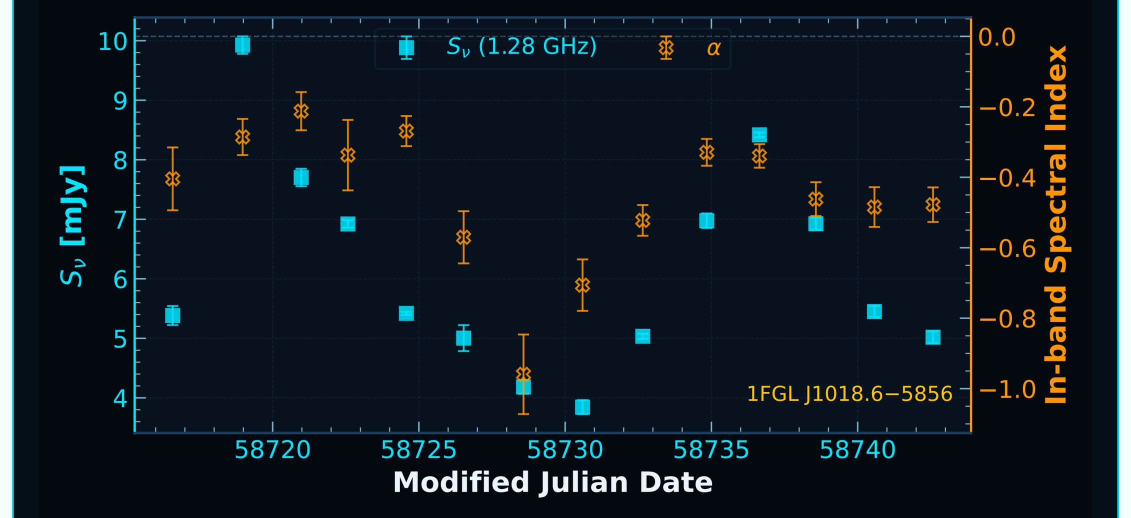


Fig. 1: MeerKAT flux density and spectral index vs time for **1FGL J1018.6−5856**.

- Both targets appear as **compact, unresolved** point sources in MeerKAT L-band continuum images.
- Flux densities are **sinusoidally modulated** on their respective orbital periods ($P_{orb} = 16.55$ **d** and $P_{orb} = 10.30$ **d**) — a hallmark of all γ-ray binaries.
- The in-band spectral index α mirrors the flux modulation in **both** systems (Fig. 1 shows 1FGL J1018.6−5856; LMC P3 shows a consistent but less pronounced trend).
- Spectral index ranges: $-1.0 \lesssim \alpha \lesssim -0.2$ for 1FGL J1018.6−5856 and $-0.9 \lesssim \alpha \lesssim 0.0$ for LMC P3, confirming a **non-thermal synchrotron** emission origin in both systems.
- A clear **"flatter-when-brighter"** trend is present: α flattens at flux maxima and steepens at minima, interpreted as **phase-dependent absorption** by the surrounding stellar wind material.

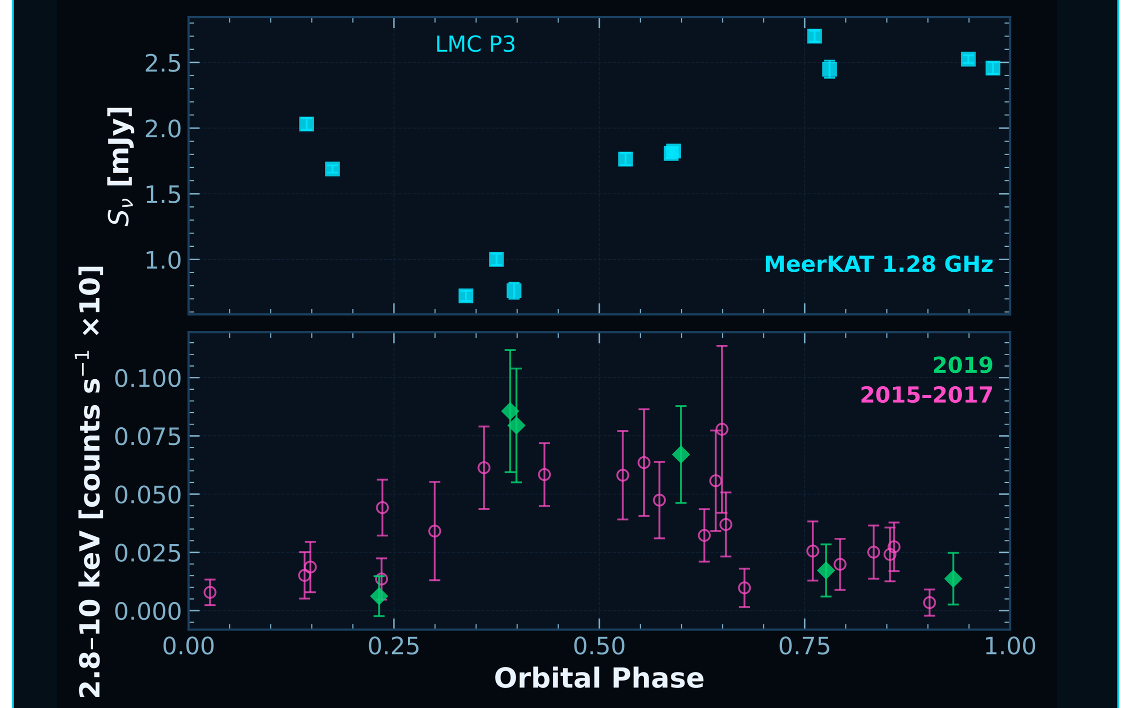


Fig. 2 : MeerKAT 1.28 GHz radio (top) and 2.8–10 keV Swift XRT (bottom) light curves for LMC P3, folded on $P_{orb} = 10.301$ d.

X-ray Light Curves

- X-ray emission in both systems is **orbitally modulated** on $P_{orb} = 16.5507$ **d** and $P_{orb} = 10.301$ **d**.
- In 1FGL J1018.6−5856, a **flaring episode** at early orbital phases is present in the long-term (2011–2014) archival data but was not captured during the 2019 campaign.
- Long-baseline Swift XRT data confirm **long-term orbital stability** in both targets.

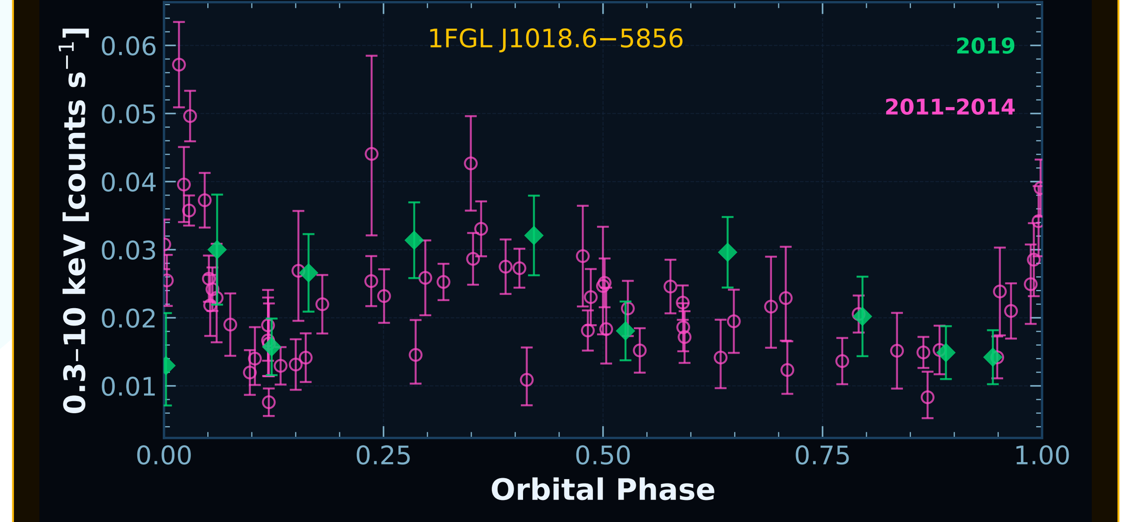


Fig. 3 : Folded 0.3–10 keV Swift XRT light curve for 1FGL J1018.6−5856 (one orbital cycle). Green: 2019; magenta: 2011–2014.

Radio/X-ray Cross-Correlation (DCCF)

- The Discrete Correlation Function (DCF; Edelson & Krolik 1988) is applied to 2019 MeerKAT radio and multi-epoch Swift XRT light curves.
- **Significant radio/X-ray coherence** is detected in **both** systems.
- **X-ray emission leads radio** across all X-ray epochs tested:

System	X-ray lead
1FGL J1018.6−5856	≈1 day
LMC P3	≈4 days

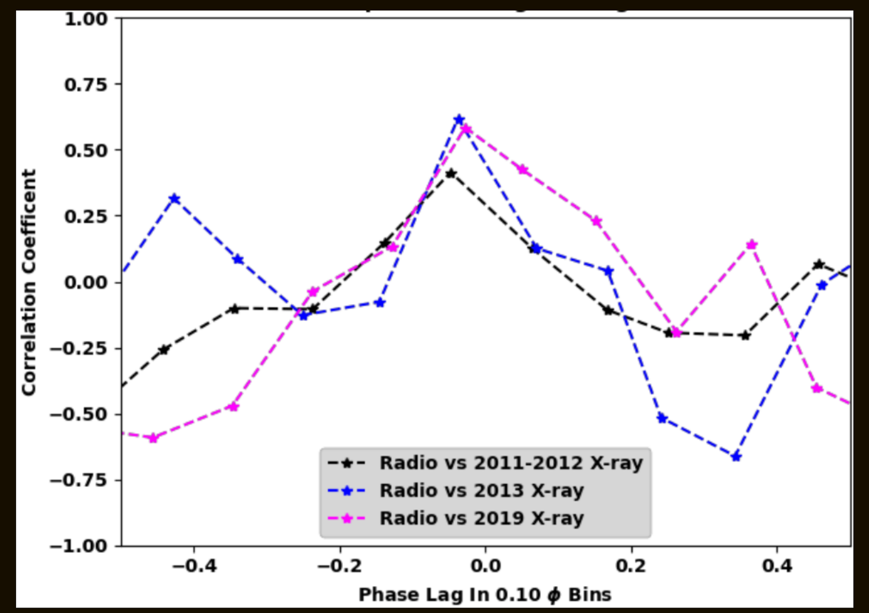


Fig. 4 : DCF between MeerKAT radio and three independent Swift XRT epochs for 1FGL J1018.6−5856.

Physical interpretation: high-energy electrons accelerated at the wind-collision shock first emit X-rays, then cool and radiate at radio frequencies further downstream – naturally producing the observed ***correlation and negative lag****.*

CONCLUSIONS & FUTURE WORK

Summary

1. **Compact, unresolved** radio sources with sinusoidal orbital flux modulation are confirmed in *both* systems with MeerKAT.
2. **Non-thermal synchrotron** emission is established from in-band spectral indices in both targets.
3. A **"flatter-when-brighter"** spectral index trend is present in *both* systems, attributed to phase-dependent absorption by stellar wind material at specific orbital phases.
4. Significant **radio/X-ray coherence** with **X-ray leading radio** is detected in both systems, consistent with **synchrotron cooling** at the wind-collision shock.
5. These results collectively favour the **colliding-wind binary pulsar scenario**, providing **indirect evidence for neutron star companions** in both **1FGL J1018.6−5856** and **LMC P3**.

Key Result

The timing, spectral, and cross-correlation properties of *both* systems are consistent with the **binary pulsar model**: particles are accelerated at the wind-collision interface and cool via synchrotron radiation, producing the observed multi-wavelength variability and inter-band time lags.

Future Work

- Include **Fermi-LAT** GeV γ-ray data in the cross-correlation analysis to complete the radio–X-ray–γ-ray picture and further constrain emission-zone geometry.
- Expand the sample to **6–7 gamma-ray binaries** for a systematic population study (ongoing PhD programme at UCT).
- Use deep MeerKAT imaging to confirm or exclude **SNR associations** and search for extended (jet or commentary tail) emission around each system.
- Investigate differences in emission properties between systems hosting **O-type** and **Be-type** stellar companions.

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