DISCOVERY OF FOUR NEW SPIDER PULSAR CANDIDATES IN PREVIOUSLY UNASSOCIATED FERMI-LAT SOURCES

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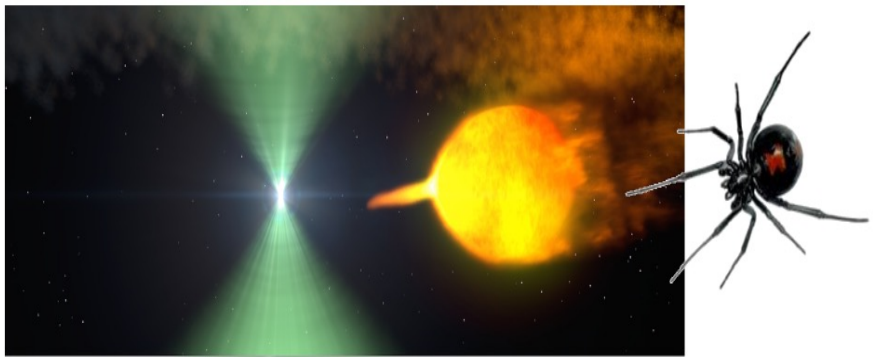
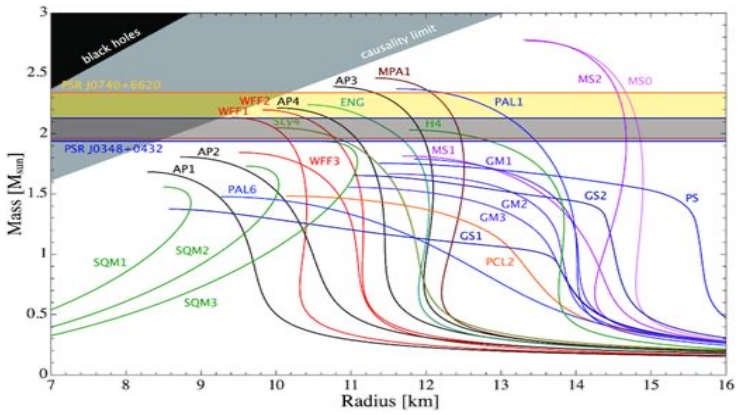
SPIDERS:

- Radio MSPs in **compact binary systems** (P_{orb}<1 d) descendants of LMXB systems [Bhattacharya & van den Heuvel 1991].
- **The pulsar wind can strongly irradiate and consume their "mate"**.
- Two sub-types of *spiders*:
  - ★ *REDBACKS* (RBs):
    $M_2 \sim 0.3-0.7\ M_\odot$,
    $T_2 = 4000-6000$ K
  - ★ *BLACK WIDOWS* (BWs):
    $M_2 \sim 0.01-0.05\ M_\odot$,
    $T_2 = 1000-3000$ K [Turchetta et al. 2023]





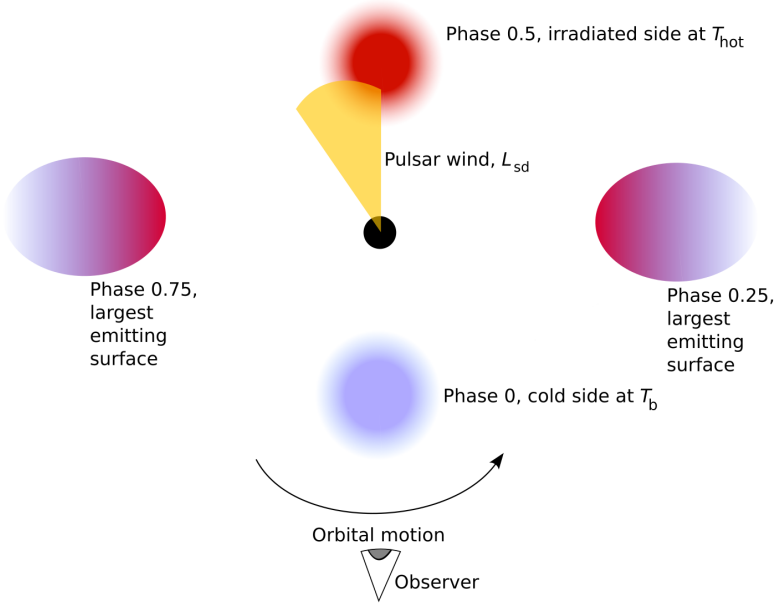
[Hu et al. 2020]

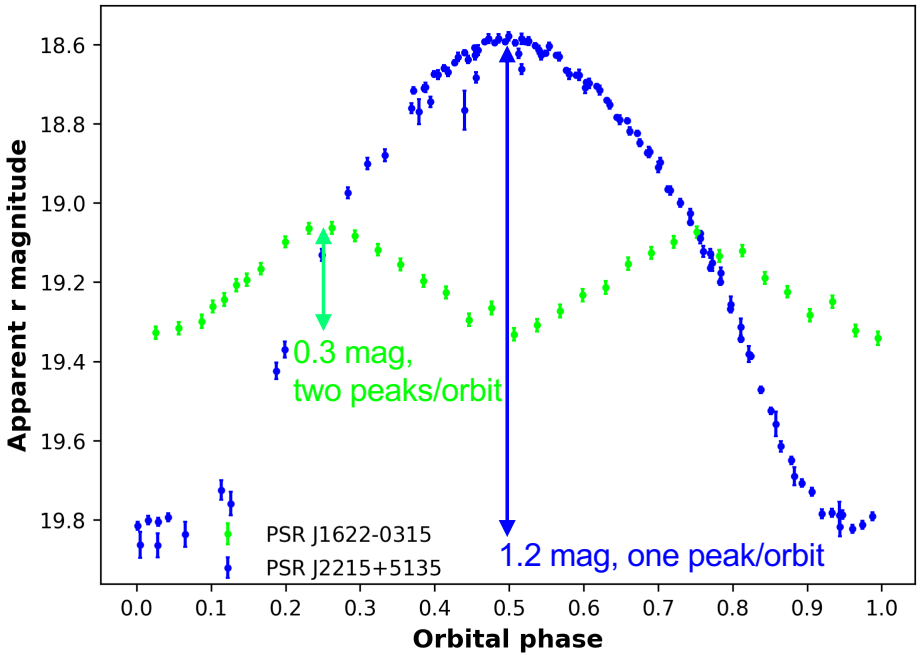
Important sites for:

- **supermassive neutron stars** [Linares 2020].
- pulsar/companion winds **intrabinary shock** (**non-thermal X-ray emission**) [Gentile et al. 2014].

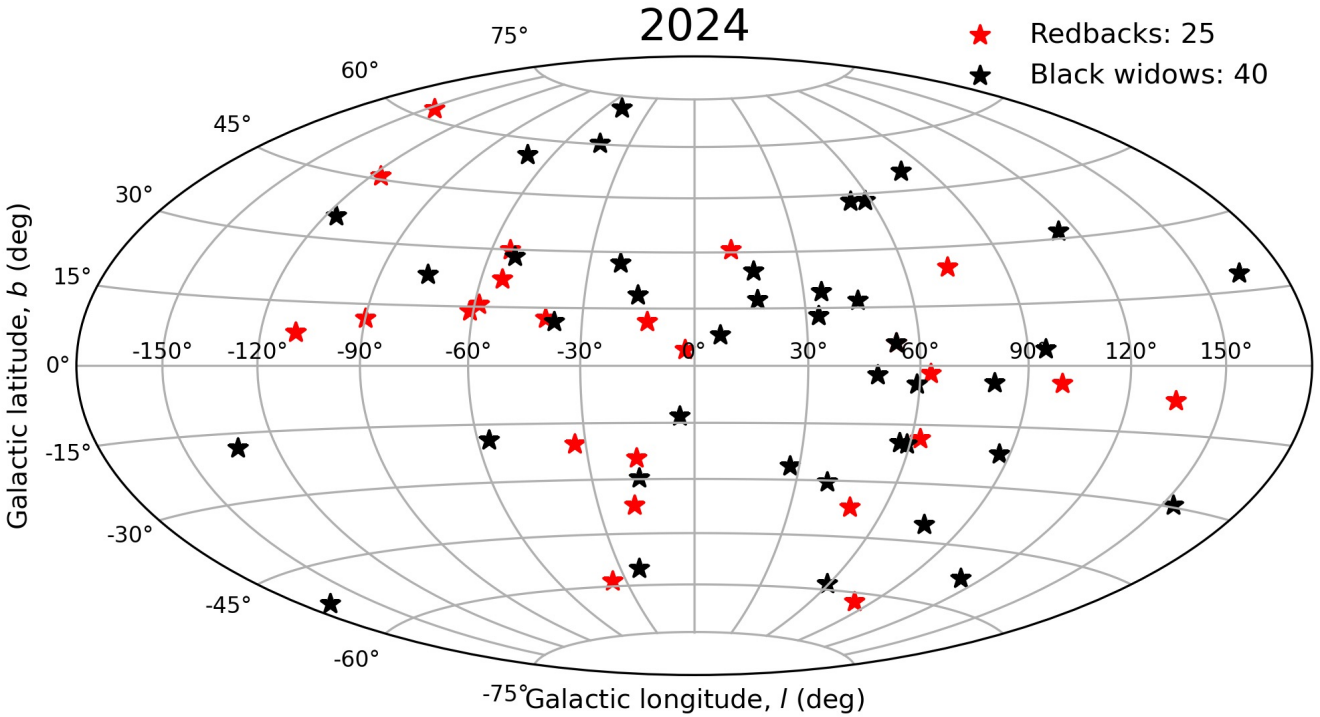
THE VARIABLE OPTICAL EMISSION FROM THE COMPANION

- **Spiders can be identified through their optical variability** due to the ellipsoidal shape of the distorted companion star and/or its irradiation by the pulsar wind [Breton et al. 2013, Linares et al. 2017].
- Depending on T_2, $P_{\rm orb}$, and $L_{\rm sd}$ their companion can be either irradiated or not [Turchetta et al. 2023].



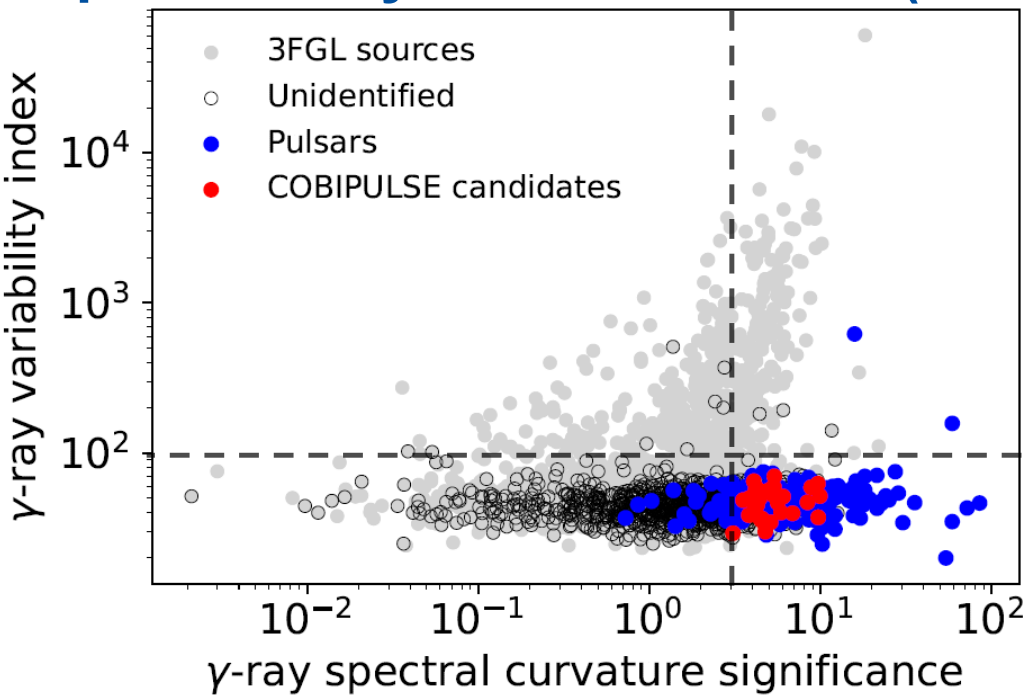


FERMI-LAT: THE SPIDERS HUNTER



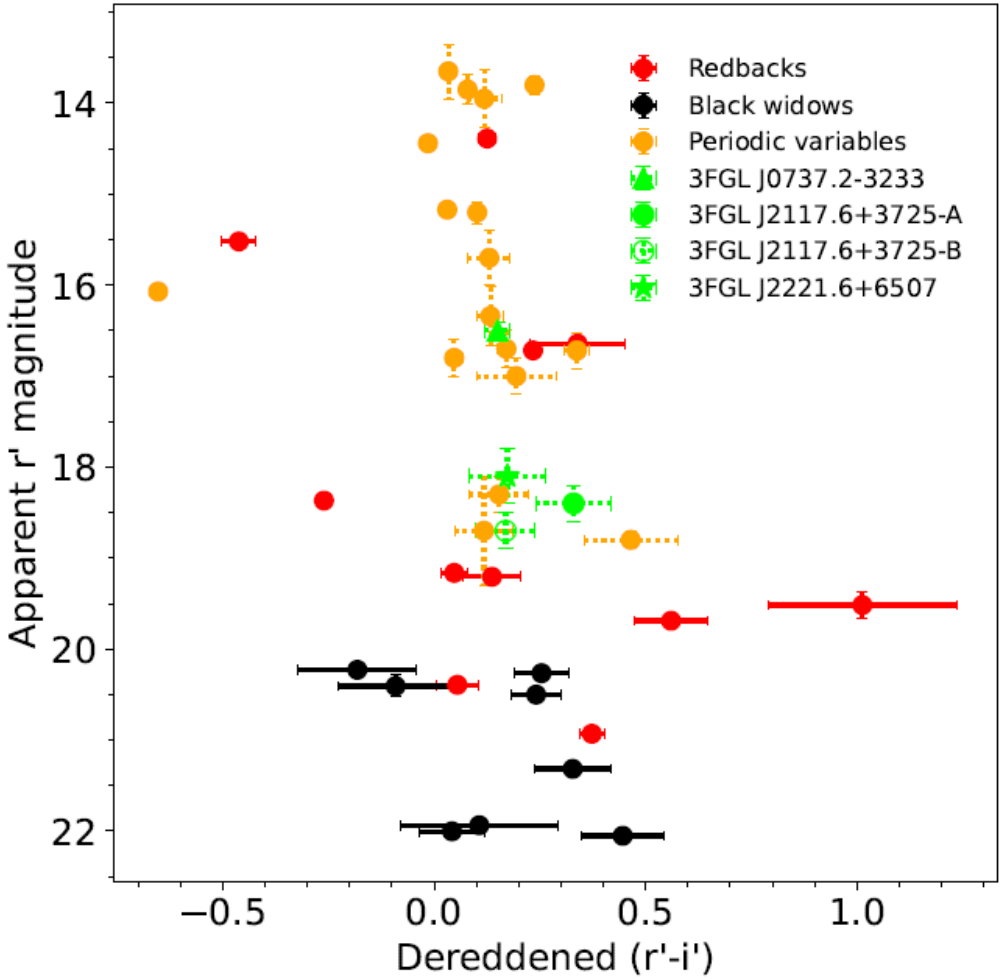
- Since 2008, Fermi-LAT has boosted the discovery of spiders MSPs, both in γ-ray and radio bands.
- **$\sim$ 20% of Fermi pulsars are spiders and 2153 4FGL-DR4 γ-ray sources still remain unassociated** [Ballet et al. 2023].
- **Identifying their variable optical emission can locate radio-obscured spiders at $\sim$ arcsec scale.**

COmpact BInary PULsar SEarch (COBIPULSE):



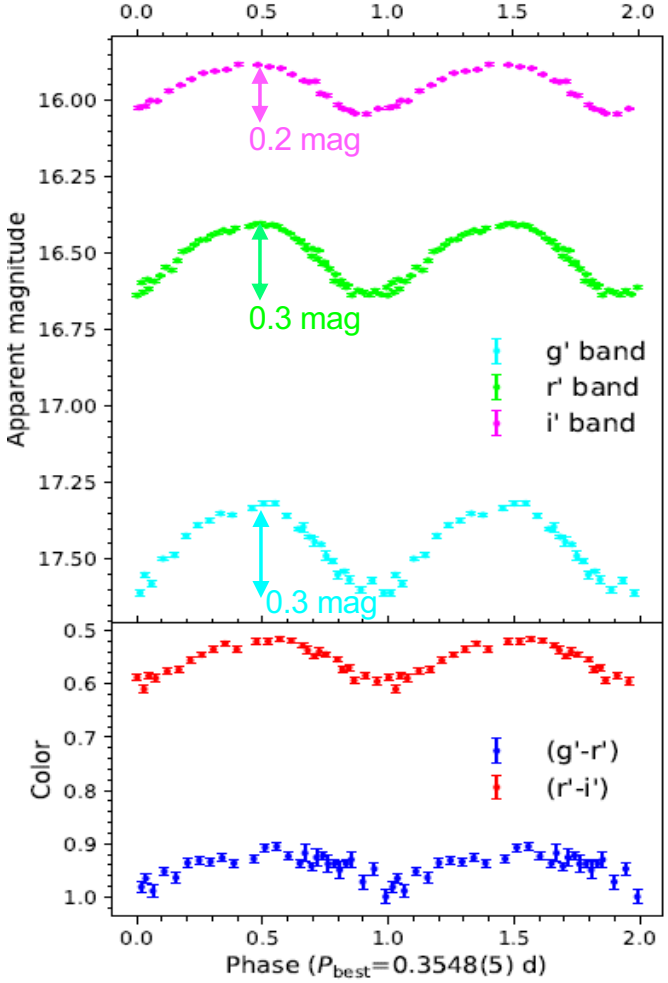
- **Multi-band optical photometric survey searching for new spiders in 33 Fermi-3FGL pulsar candidates**.
- Fully robotic 1.2-m STELLA/WiFSIP, 2.5-m INT/WFC, 1-m LCO/Sinistro, and 0.4-m LCO/SBIG telescopes.
- **We applied systematic variability and periodicity search**.
- *Periodic variables*: optical variables showing periodic flux modulation.
- ***Spider candidates***: periodic variables inside the Fermi 95% region **and** showing sinusoid-like light curves.

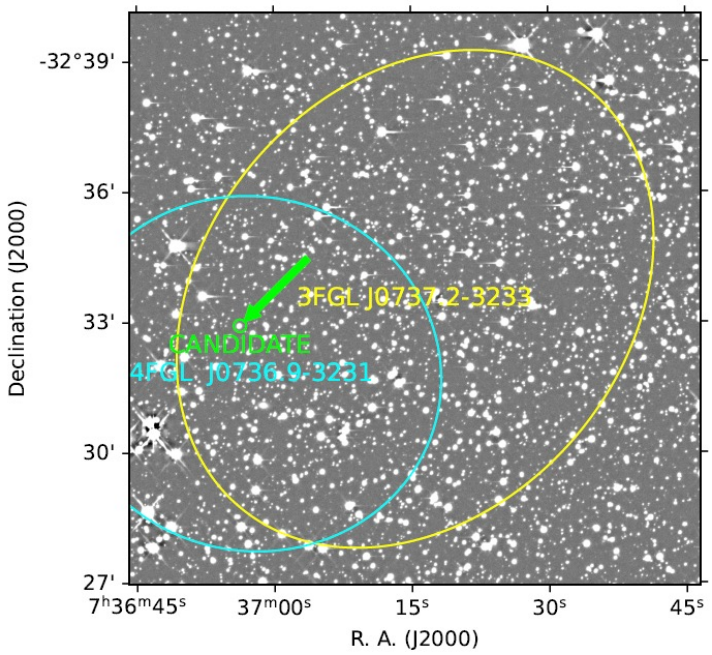
RESULTS: DISCOVERY OF FOUR NEW SPIDER CANDIDATES



- COBIPULSE is sensitive down to $r' \simeq 19$ mag, best suited to discover RBs rather than BWs.
- **Our candidates are all located in the RB region of the magnitude-color diagram**, and compatible with companion mean temperatures of **5000−6000 K.**
- **Inferred orbital periods are in the range 0.17−0.44 d**, consistent with spiders.

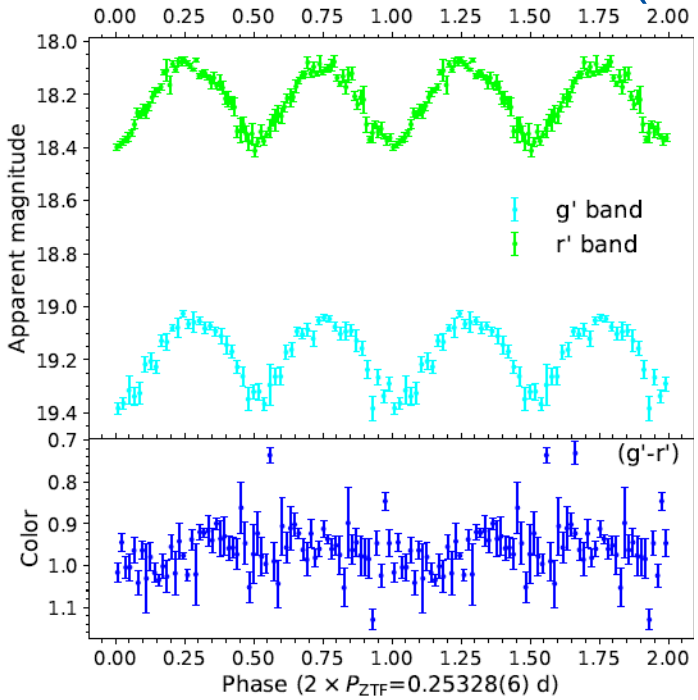
3FGL J0737.2−3233 (J0737): THE CLOSEST SPIDER

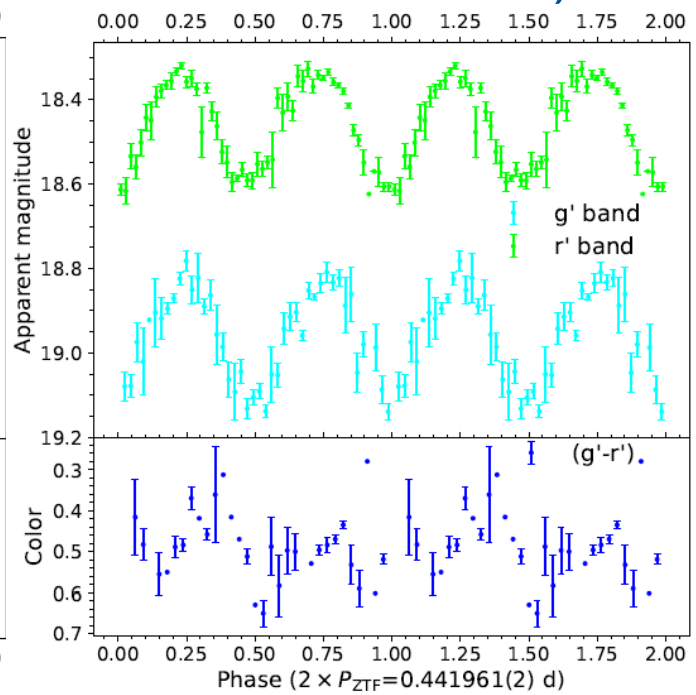


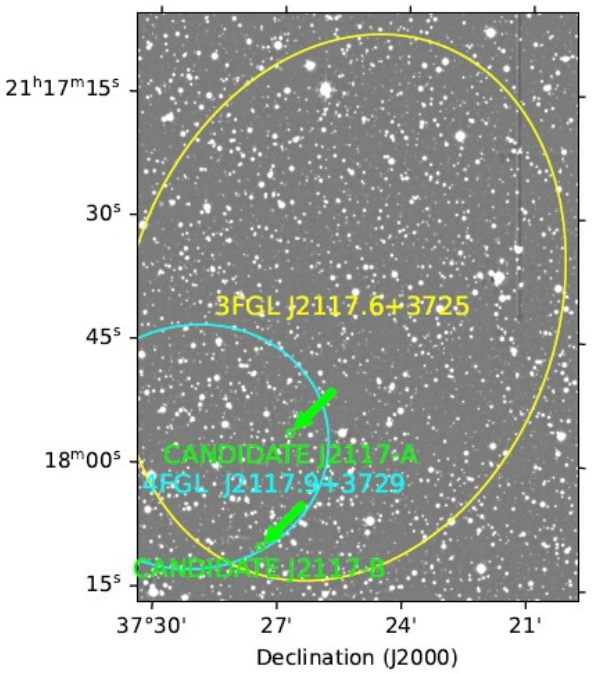


- Clearly periodic, colors peaking at the same phase of max. flux indicate an **irradiated RB system with P_{orb}=0.3548(5) d**.
- Yet small amplitudes suggest a low orbital inclination for J0737.
- Gaia parallax measurement, corresponding to $D=659^{+16}_{-20}$ **pc**, **it would be the closest known spider** (considering only parallax).
- $L_X<5.4\times10^{30}$ **erg/s** (Swift/XRT), **the least luminous RB in X-rays**.
- $L_\gamma=5.3\times10^{32}$ **erg/s** (4FGL), agrees with other γ-ray MSPs [3PC].

3FGL J2117.6+3725 (J2117-A and J2117-B): THE TWIN CANDIDATES

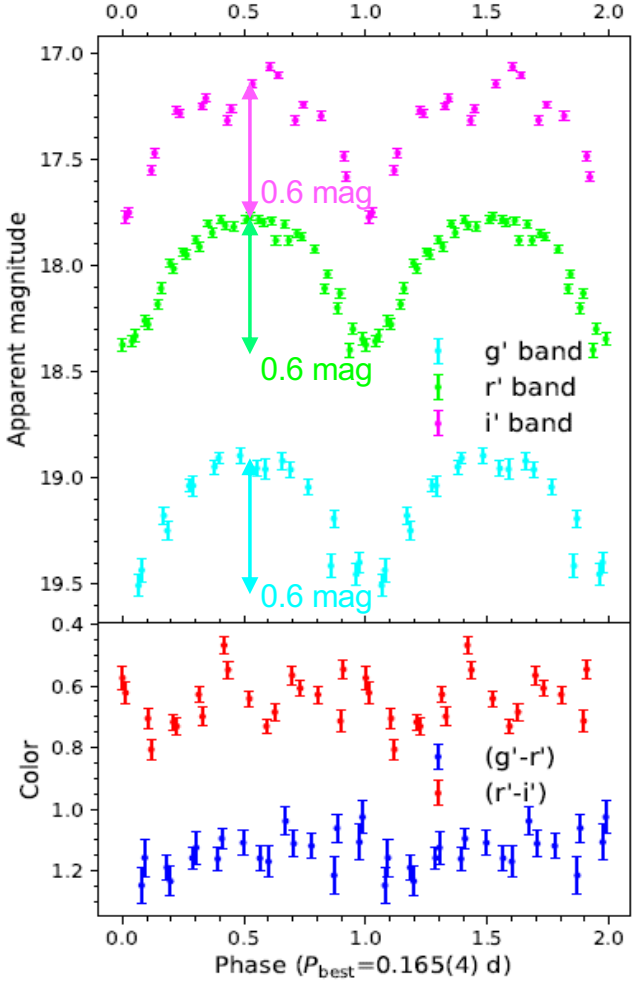


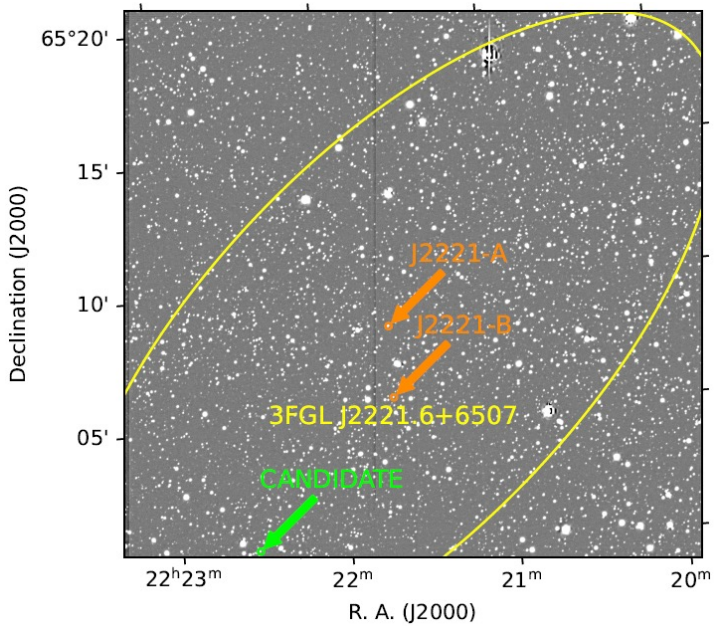




- Amplitudes of 0.3−0.4 mag and constant colors indicate the **absence of irradiation**, with $P_{\mathrm{orb,A}}$**=0.25328(6) d** and $P_{\mathrm{orb,B}}$**=0.441961(2) d**.
- They both match with two Gaia variable sources, parallax distances $D_{\mathrm{A}}=2.2^{+0.6}_{-0.4}$ kpc and $D_{\mathrm{B}}=4.5^{+1.5}_{-1.2}$ kpc.
- **X-rays and γ-rays**: $L_{\mathrm{X,A}}<1.6\times10^{32}$ erg/s, $L_{\mathrm{X,B}}<4.3\times10^{32}$ erg/s and $L_{\gamma,\mathrm{A}}=2.5\times10^{33}$ erg/s, $L_{\gamma,\mathrm{B}}=1.0\times10^{34}$ erg/s, **compatible with RBs luminosities**.

3FGL J2221.6+6507 (J2221): A GAMMA-RAY QUIET SPIDER?





- Amplitudes suggest a **mildly-irradiated companion**, P_{orb}**=0.165(4) d**.
- **No 4FGL association**, low latitude source (b=6.7°) likely contaminated in 3FGL. γ**-ray quiet spider?** (e.g PSR J1723−2837 or PSR J1720−0533, Koljonen et al. 2024)

SUMMARY AND NEXT STEPS

- **COBIPULSE led to the discovery of four new RB candidates**, providing their precise sky locations for targeted radio and γ-ray follow-up.

- **3FGL J0737.2−3233/4FGL J0736.9−3231 (J0737) would be the closest known spider to Earth**.

- **Phase-resolved optical spectroscopy will determine the neutron star masses of these systems**.

- **This work has just been submitted to ApJ**, and in 2022 we carried out optical observations of 41 more Fermi pulsar candidates selected from the 4FGL-DR3 catalog. Stay tuned!