Friedrich-Alexander-Universität
Erlangen-Nürnberg

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Deriving Pulsar Properties from Pulsar Wind Nebulae Using Gamma-Ray And Radio Data

S.T. Spencer[1,2] and A.M.W. Mitchell[1]

[1] Erlangen Centre for Astroparticle Physics (ECAP), Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany
[2]Department of Physics, Clarendon Laboratory, Parks Road, Oxford, OX1 3PU, United Kingdom

Abstract

A significant fraction of the highest energy gamma-ray astrophysical sources observed are associated with Pulsar Wind Nebulae (PWNe). Given recent observations, the postulated, but unverified, hadronic component from PWNe requires renewed attention. We estimate possible ranges for the average pulsar pair production multiplicity on 26 sources in the Australia Telescope National Facility (ATNF) catalogue. We then use the latest gamma-ray data from H.E.S.S. and LHAASO in combination with radio data available in the literature to further constrain associated pulsar properties for a set of well-known PWNe. These include lower limits for the pulsar birth period and average pair production multiplicity. Based on these, for all but one source, we cannot exclude the presence of hadrons in the PWN.

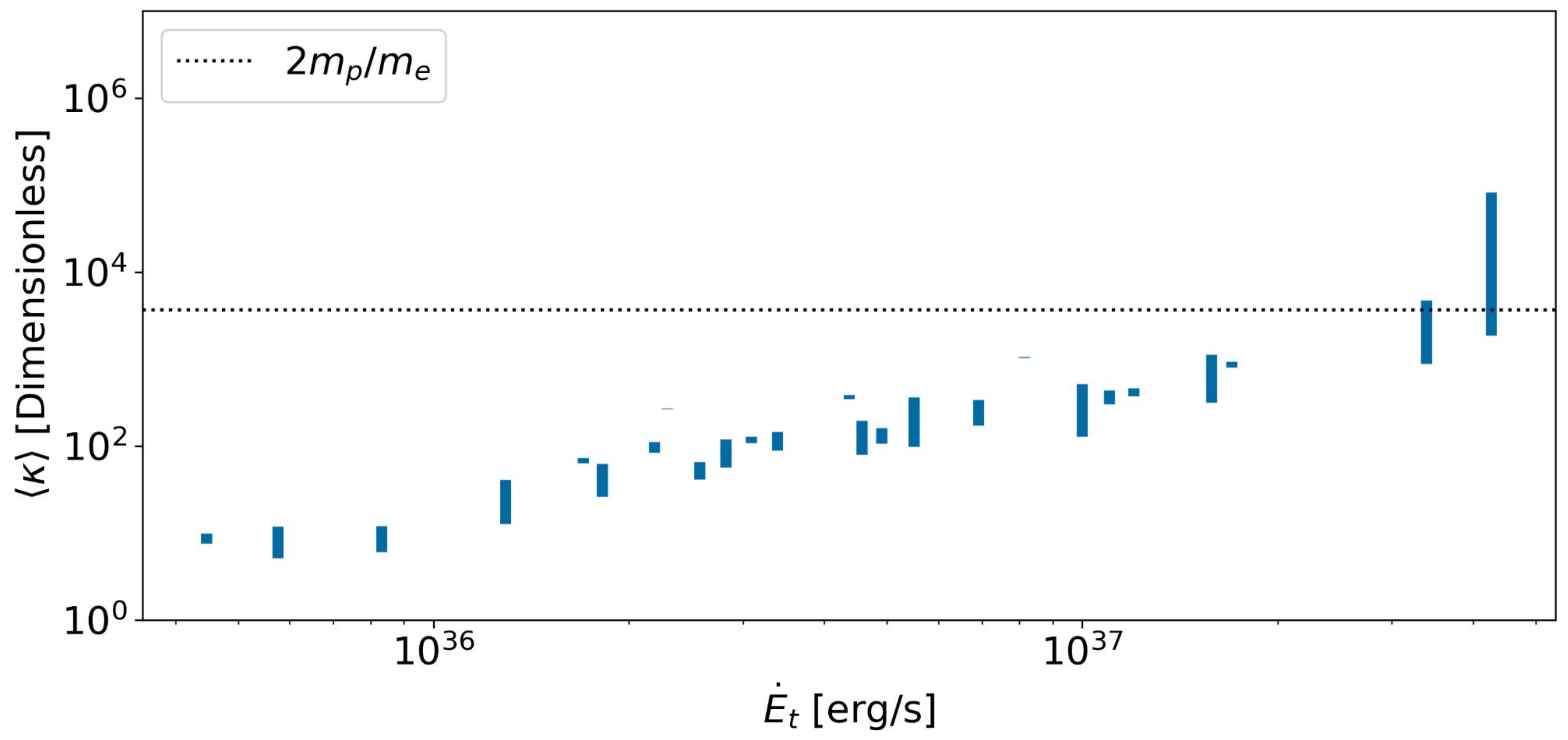

Fig. 1: Ranges on the lower bounds of multiplicities for ATNF pulsars with associated H.E.S.S. PWNe.

Introduction and Methods

- A key metric governing whether hadrons can escape the pulsar surface to enter the PWN is the average pair production multiplicity $\langle\kappa\rangle$.
- This describes the number of e+/e- pairs that escape the pulsar light cylinder per electron that escapes from the pulsar's surface (as a result of cascades produced by gamma-ray Bremsstrahlung).
- As $\langle\kappa\rangle$ goes as

$$\langle\kappa\rangle = \frac{N_{el}}{2N_{GJ}}$$

, where N_{el} is the number of electrons in the PWN and the Goldreich Julian density is

$$N_{GJ} = \int_{t=0}^{t=-\tau(P_0)} \frac{[6c\dot{E}(t)]^{1/2}}{e}(-dt)$$

and $\dot{E}(t)$ is the spin down power, one can construct curves of multiplicity as a function of birth period P_0 (given the dependence on pulsar age τ).

- Can estimate bounds on lower limits for $\langle\kappa\rangle$ for 26 pulsars associated with H.E.S.S. sources, using previous modelling in the literature for N_{el} (Giacinti et al. 2020) (see Fig. 1).
- Following van der Swaluw & Wu (2001), the pulsar birth period can be estimated using measurements in the radio of the PWN radius R_{PWN} and supernova radius R_{SNR}

$$P_0 = 2\pi\left[\frac{2E_0}{\eta_1 I}\left(\frac{R_{PWN}}{\eta_3 R_{SNR}}\right)^3 + \left(\frac{2\pi}{P_t}\right)^2\right]^{-1/2}$$

where η_1 and η_3 are constants, E_0 is the supernova energy, I the moment of inertia of the neutron star and P_t its period today.

- Where radio measurements are available, we can find the intersection between this line and the multiplicity curve, constraining $\langle\kappa\rangle$ and P_0 (see Fig. 2).

Contact: samuel.spencer@fau.de

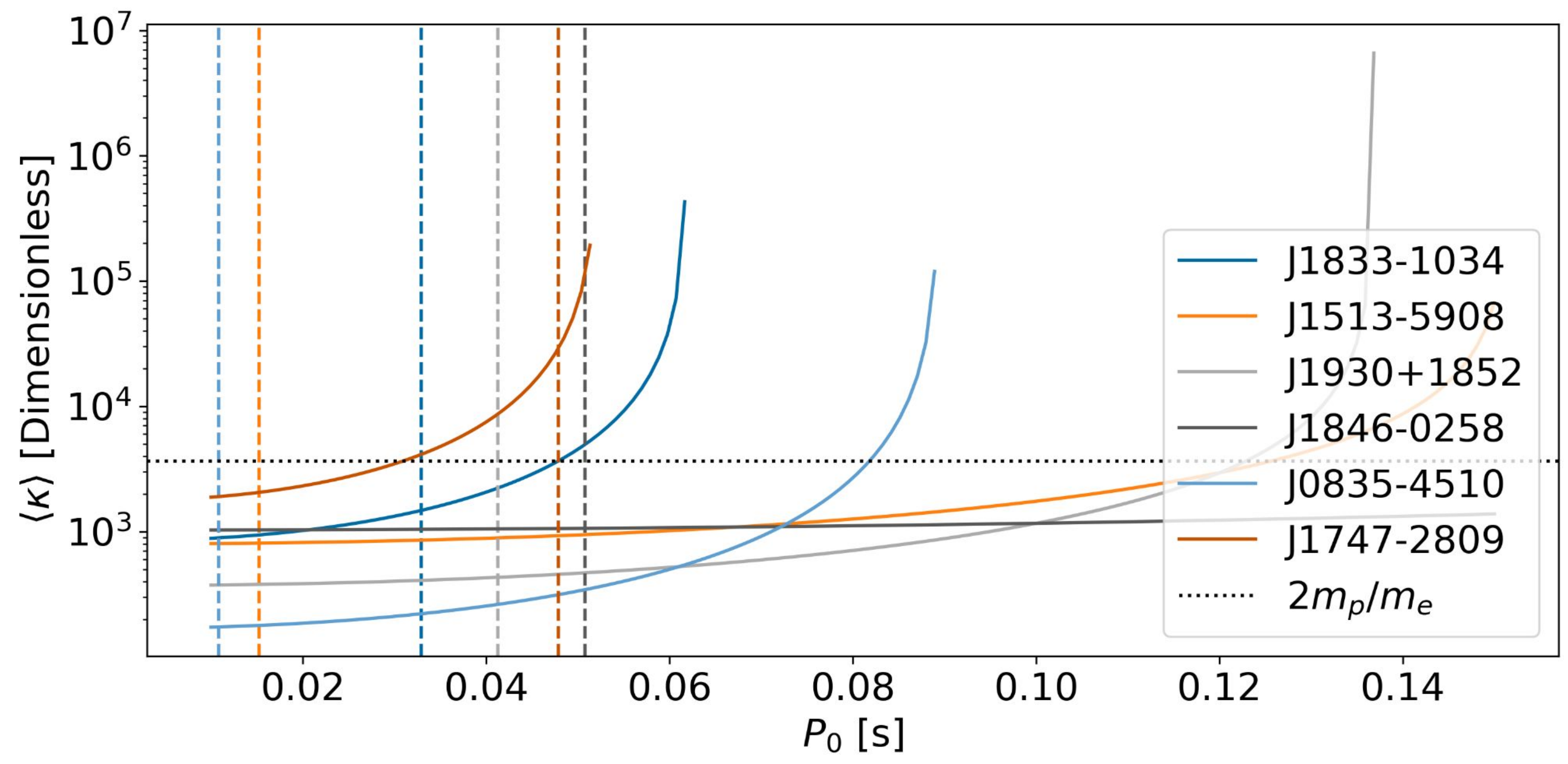

Fig. 2: Multiplicity curves for H.E.S.S. associated pulsars where the birth period can be estimated.

Results and Conclusions

- Results for multiplicities and birth periods derived consistent with theory (Timokhin & Harding 2019).
- Cannot exclude escape of hadrons into the pulsar wind for 5 out of 6 H.E.S.S. sources, assuming iron being stripped from a young pulsar (Kotera et al. 2015).
- Can also estimate multiplicity curves for 4 LHAASO sources using literature N_{el} values, see Fig. 3.

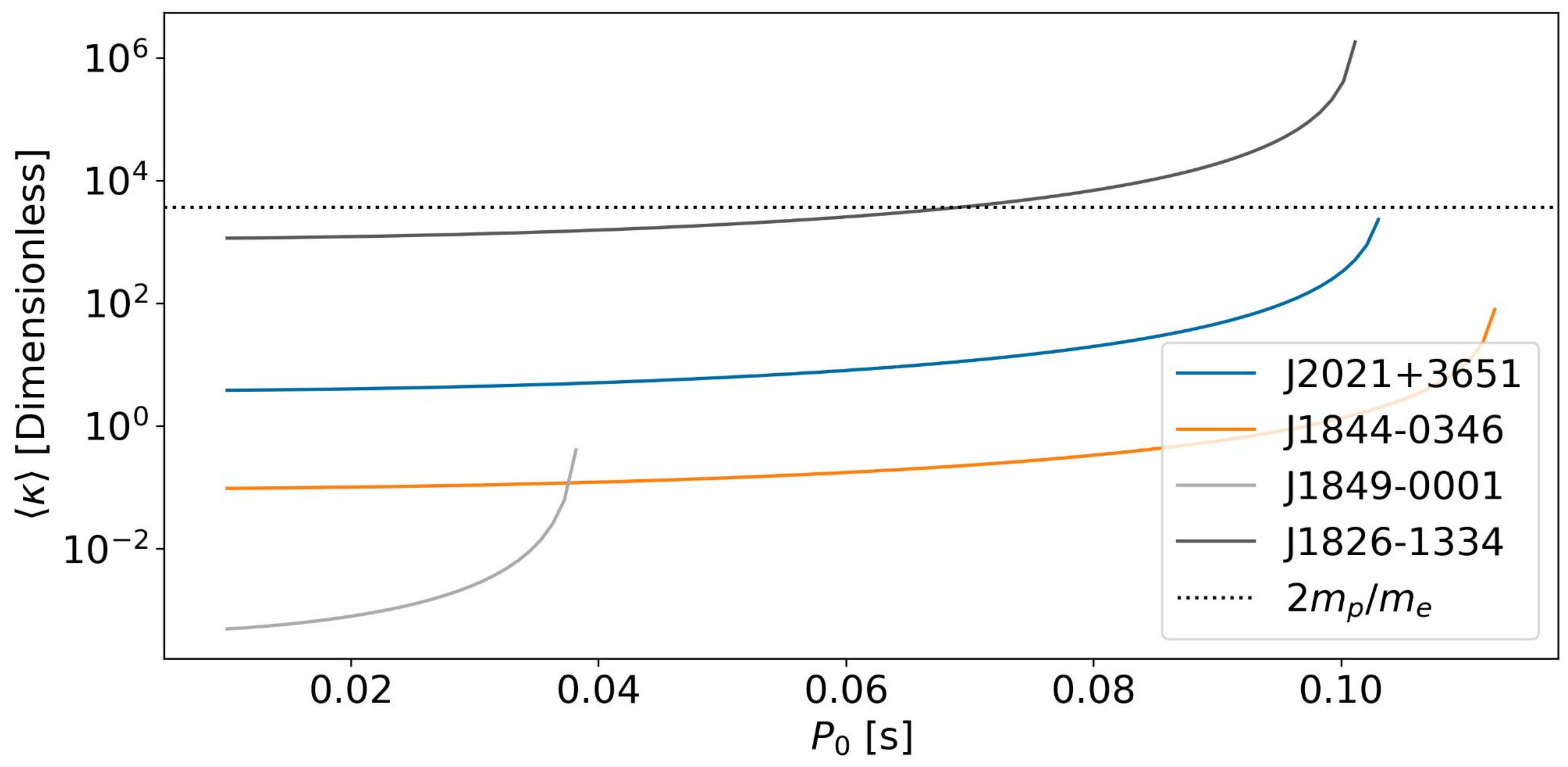

Fig. 3: Multiplicity curves for four pulsars associated with LHAASO sources.

References

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