Neutron Star Astrophysics at the Crossroads: Magnetars and the Multimessenger Revolution
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Astrophysical entomology: dissecting the black widow population through multi-band light curve modelling

Daniel Mata Sánchez[1,2,3], **Mark R. Kennedy**[1,4], **Colin J. Clark**[1,5,6], **Rene P. Breton**[1] and **Vikhram S. Dhillon**[7]

[1]Jodrell Bank Centre for Astrophysics, Department of Physics and Astronomy, University of Manchester, Manchester M13 9PL, UK
email: matasanchez.astronomy@gmail.com

[2]Instituto de Astrofísica de Canarias, E-38205 La Laguna, Tenerife, Spain

[3]Departamento de astrofísica, Universidad de La Laguna, E-38206 La Laguna, Tenerife, Spain

[4] Department of Physics, University College Cork, Cork T12 ND89, Ireland

[5] Max Planck Institute for Gravitational Physics (Albert Einstein Institute), Hannover, Callinstraße 38, D-30167 Hannover, Germany

[6]Leibniz Universität Hannover, 30167 Hannover, Germany

[7]Department of Physics and Astronomy, University of Sheffield, Sheffield S3 7RH, UK

Abstract. The population of black widows, binary systems containing a millisecond pulsar and a very low-mass companion star exposed to the high-energy pulsar wind, has grown exponentially in the past few years. The number of black widow candidates is now over 30 systems, but only 14 have been confirmed so far. Their relevance in analysing the extremes of the neutron stars properties led to multiwavelength dedicated studies that revealed a rich phenomenology. In this work, we provide a glimpse into the black widow class through modelling of high-cadence multi-band light curves of 6 systems, accounting for almost half of the confirmed population. A better understanding of the black widow population, which hosts some of the most massive and fastest spinning neutron stars, will ultimately benefit future modelling of compact object mergers.

Keywords. (stars:) binaries: general,(stars:) pulsars: general, stars: low-mass.

1. Introduction

Millisecond pulsars are thought to be born within binary systems, where an epoch of mass transfer from their companions onto the pulsar is responsible for speeding them up to such short spin periods. Among the known population of millisecond pulsars binaries, "black widows" arguably represent the most extreme case, as proven by the discovery of some of the heaviest (van Kerkwijk et al.(2011; Linares et al. 2018) and fastest spinning (Bassa et al. 2017) pulsars. They possess a very low mass companion star orbiting close to the millisecond pulsar and being exposed to the high-energy pulsar wind, which irradiates the former. The irradiation of the companion star leads to its evaporation over time down to a mere $\sim 1\%$ of the Solar mass. This destructive behaviour has been compared with some arachnid species, where the heavier female consumes the lighter male upon mating, and earned them the nickname of "black widows". Such a violent phenomenon leaves an imprint over all wavelength scales, from radio eclipses to gamma-rays pulses. In the optical range, the companion star dominates and produces periodically variable light

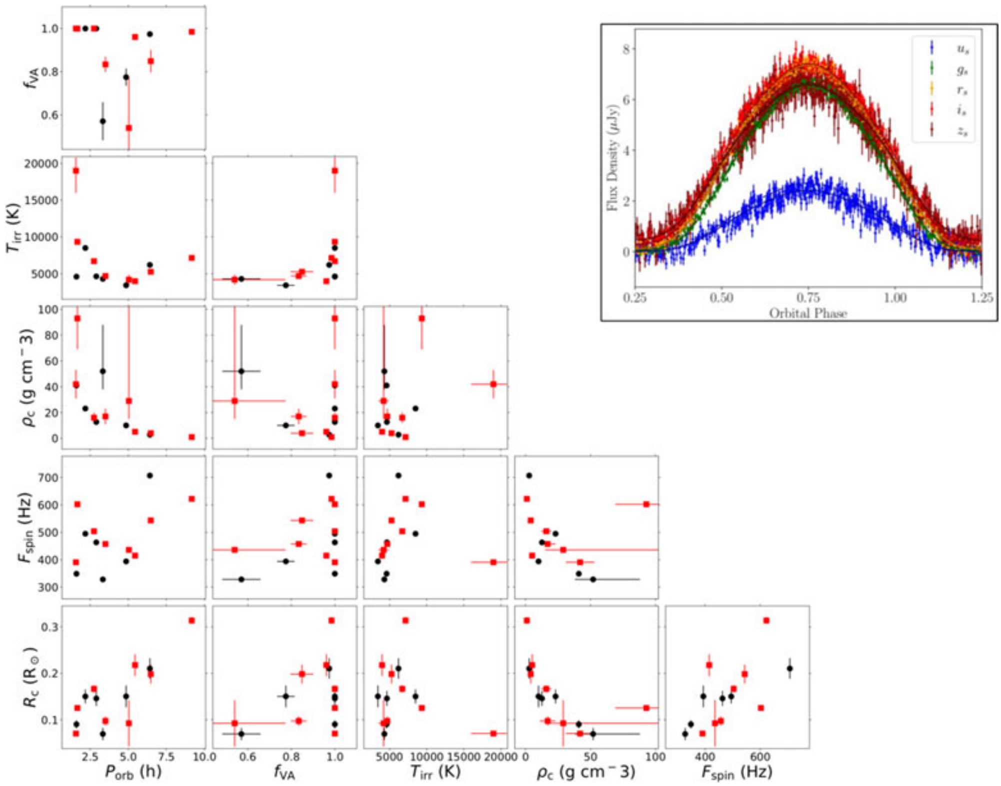

Figure 1. Corner plot comparison of the derived parameters from light curve modelling with ICARUS. We include the 6 black widows analysed in this work (circles) as well as the remaining members of the known population (squares). The top-right inset shows the multi-band light curve and best fit for one of the analysed systems.

curves. For black widows, the dominant effect is due to the side of the companion star facing the pulsar being highly irradiated, and heated to a much higher temperature and thus brighter than their opposite cold face.

2. Data analysis and discussion

We present simultaneous multi-band observations obtained with the HIPERCAM instrument at the 10.4-m GTC telescope for six of these systems. The combination of this five-band (ugriz) fast photometer with the world's largest optical telescope allows us to cover the fainter epochs of their light curves. The modelling of the characteristic shape of these light curves with the PYTHON-based code ICARUS (Breton et al. 2012) enables us to derive the parameters of the binary, including the companion star temperature profile, the elusive orbital inclination or the mass ratio. We show the first ever light curve for one of these systems, as well as attain a significant improvement on the data quality compared with previous publications for the remaining targets. We report on the results of the light curve modelling for all six of them and compare the parameters derived with the remaining known population of black widows for which optical modelling has been performed (Fig. 1). This limited but steadily growing population reveals a number of correlations between parameters that we discuss and interpret as either true, intrinsic parameters dependencies or observational biases. A systematic analysis of their physical properties enables us to investigate this population, which stands as an extreme of the more prolific family of millisecond pulsar binaries.

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