Deriving the mass of neutron stars in spider binaries using timing analysis of H.E.S.S. data

Lívia Silva Rocha, Jelena Celic, Tina Wach

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Neutron Stars (NS) are one of the most fascinating objects known in the universe. The maximum mass (M_{max}) they can achieve before collapsing into a Black Hole is closely related to the properties of the equation of state of matter above nuclear saturation density (Özel et al., 2016). Predicted from calculations of Tolman, Oppenheimer and Volkoff for the hydrostatic equilibrium under the theory of General Relativity (GR), this maximum mass can also provide us important insights into NS formation processes, supernovae physics, gravitational wave detection and many other fields.

Spider binaries are strongly interacting relativistic systems harboring one pulsar and a semi-degenerate companion star, with orbital periods shorter than a day. These systems are of particular interest since most of the largest masses up to now have been inferred from them, a characteristic that emerges from the long-lasting accretion history (Linares, 2020; Horvath et al., 2020). Classified in two groups, Black-Widow (BW) pulsars have companions with masses $m_c \leq 0.05\ M_\odot$, while for Redbacks $0.1 \leq m_c \leq 0.5\ M_\odot$. The companion's outer envelope is believed to be ablated by the intense pulsar wind, filling the system with intra-binary material that causes the radio pulsation to be scattered and absorbed (Kansabanik et al., 2021). As a consequence, their optical light curves are sensitive not only to the orbital inclination, but also to heating models of the companion's surface, difficult to determine. Large systematic errors on the inclination angle estimate can result in a large bias on the mass estimate of pulsars, given that $M_{PSR} \propto 1/\sin^3 i$.

A recent work claimed that, contrary to other wavelenghts, it is unlikely that γ-rays are absorbed by the diffuse intra-binary material. Consequently, eclipses observed at this energy could be associated only with the occultation of pulses by the companion, providing a robust determination of the inclination angle. By using this technique, they found the mass of PSR B1957+20 to be $1.81 \pm 0.07\ M_\odot$ (Clark et al., 2023), while previous results from spectrophotometric observations indicated a much higher mass, namely $2.4 \pm 0.1\ M_\odot$ (Van Kerkwijk et al., 2011).

Generally, pulsars in these systems are expected to be energetic, with a spin-down power exceeding 10^{34} erg/s, and their Hillas criterion and synchrotron radiation reaction indicate the existence of high energy electrons, capable of producing multi-TeV energy photons Wadiasingh et al. (2022). Additionally, a high-density environment is provided due to the proximity between the pulsar and the companion. This provides abundant target material for IC-emission and makes a population study of these systems in TeV interesting to prove the expected underlying physical properties.

Because of the absence of the high density environment, observations in the TeV energy range might reveal additional information, complementing the observations from Fermi-LAT and allowing a further constraint on the neutron star mass.

Therefore we propose to use timing analysis of archival H.E.S.S. data on known spider binaries. The results from this study could help to identify the underlying conditions and evolution stages of the system. Additionally, this data analysis can validate the resulting limits on the neutron star masses derived from Fermi-LAT data or add further constraints.

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