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Neutron star binaries in star clusters: a radio-optical synergy to test fundamental physics and general relativity

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Millisecond pulsars (MSPs) are fast-spinning neutron stars formed in binary systems through mass-accretion from a companion star. A large fraction are found in star clusters, such as globular clusters, whose high stellar densities create a collisional environment in which 2 and 3-body gravitational interactions are promoted. These interactions are responsible not only for the formation of a large population of neutron star binaries and MSPs, but also for the production of a wealth of exotic systems not predicted by standard evolutionary models. Among these, the long-sought MSP orbiting a black hole is considered one of the holy grails of pulsar astronomy. Indeed, its discovery would open the door to unprecedented tests of fundamental physics and general relativity, and would allow the investigation of the precursors of several gravitational wave events.

Here I will present the discovery of the first MSP orbiting a companion in the mass-gap between neutron stars and black-holes. By exploiting the synergy between high-precision radio timing observations with MeerKAT and high-resolution optical observations with the Hubble Space Telescope, we discovered in the inner regions of the cluster NGC1851 a binary system consisting of a neutron star orbiting a mass-gap object: either a low-mass black-hole or a high-mass neutron star. I will discuss the formation mechanisms of such an exotic binary, the implications for gravitational wave astrophysics, and follow-up tests of general relativity.

Finally, I will show how we are capitalising on the synergy between MeerKAT and dedicated James Webb and Hubble Space Telescope observations to characterise compact binaries that are likely to host a supermassive neutron star. The characterisation of these systems and the determination of the neutron star masses can be used to constrain the equation-of-state of ultra-dense matter, which is one of the still open and most debated questions in fundamental physics.

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