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On the interaction of Neutron Stars with their surrounding medium: two extreme examples

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Summary

Neutron Stars, compact endpoints of the evolution of massive stars, hold the most peculiar physical conditions that may be observed in the present day universe. In this thesis we cover two of the many facets of pulsars: the relativistic outflow of young isolated pulsars and an old binary pulsar enshrouded by the matter lost by the companion.

Pulsar Wind Nebulae (PWNe) are extended formations that arise when the relativistic wind ejected from a rotation-powered pulsar is confined by the circumstellar matter, such as a supernova remnant or the interstellar gas. Aside from the complex internal structure, PWNe act like calorimeters that store and slowly release most of the rotational energy lost by the pulsars. Recently PWNe around young pulsars have emerged as the most numerous class of Galactic sources in very high energy γ-rays (photons with energy $E_\gamma > 100$ GeV). The γ-ray radiation of PWNe, produced by inverse Compton scattering of low energy ambient photons with the particles injected in the nebula by the pulsar, carries a luminosity around 10^{35} erg s^{-1} lasting for several ten thousands of years. Such new probe of the particle energy distribution within the nebula makes it possible to address the problem of the pulsar energy balance, far from understood 40 years after the discovery of the first radio pulsar.

We tried to correlate the spectral and morphological properties of PWNe observed by the *H.E.S.S.* experiment in very high energy γ-rays with those of their soft X-ray counterparts and with the parameters of their parent pulsars. We found that the offset between the pulsar position and the nebular emission centroid increases with the pulsar characteristic age and decreases with the pulsar kinetic energy loss rate inferred via the timing parameters. The same trends are found also for the γ- to X-ray flux ratio. These two relations, naturally interpreted in the framework of the standard PWNe leptonic model, strengthen the identification of candidate PWNe, support the existence of the so-called "relic" PWNe and provide a tool to pinpoint promising candidates.

We also investigated the poorly known hard-X-ray synchrotron tails of PWNe with the IBIS/ISGRI spectral imager on board the *INTEGRAL* satellite. In the IBIS/ISGRI public data archive we surveyed

the field of 34 previously known PWNe hosting a pulsar. This sample constitutes a substantial fraction of the 50 PWNe known so far, and includes all PWNe hosting a young isolated pulsar, expected to be potentially the brightest. The analysis of the IBIS/ISGRI data revealed 7 hard X-ray counterparts, 3 of which are detected for the first time. Timing and spectral analysis are needed to distinguish whether the radiation originates from the nebula, the pulsar, or the possible supernova remnant. For the composite remnant G21.5-0.9, the most significant of the new sources, the combined *XMM-Newton*/EPIC and *INTEGRAL*/ISGRI spectrum allowed to ascribe the hard X-ray radiation to the nebula.

When a rotation-powered pulsar ages, the generation of high-energy particles become less effective, the residual formation heat fades and the pulsar becomes undetectable unless fed by the infalling matter from a companion star. 4U 1954+319 is a Galactic source whose nature was unclear since its discovery 25 years ago. We investigated 4U 1954+319 through spectral and timing analysis of data collected by operating X-ray telescopes. The highly absorbed spectrum and the timing characteristics point to a binary system in which a neutron star accretes matter from the stellar wind of its companion, an M-type giant star. Therefore 4U 1954+319 is the second confirmed member of the emerging class dubbed "symbiotic low-mass X-ray binaries" to host a neutron star. With a spin period of about 5 hours, 4U 1954+319 is the slowest accretion-powered X-ray pulsar to date. Due to the age of the companion star, such a long period can be explained in the framework of the standard spin-down processes.