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Particle escape from evolved pulsar wind nebulae

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Pulsars and their associated pulsar wind nebulae are known to be efficient particle accelerators and antimatter factories in our Galaxy; the Crab nebula is the only leptonic accelerator firmly identified to date.

Observations at high and very high energies have shown in recent years that pulsar wind nebulae efficiently inject particles into the ambient medium, especially in their evolved phases.

In X-rays, we have detected a number of elongated, thin, almost monochromatic features apparently emanating from the heads of bow shock nebulae produced by fast-moving pulsars, injecting newly accelerated particles into the medium and tracking the ambient magnetic field.

Largely thanks to LHAASO, we now also know that the number of extended sources emitting in the TeVs (and up to PeVs) is much larger than originally predicted, and many of these sources have a possible pulsar nature. Two of the best-studied TeV halos are actually associated with evolved pulsars (Geminga and Monogem).

Understanding how particles can escape from the pulsar/pulsar wind nebula region of influence and how they then interact with the environment is a key point in unraveling the nature of these structures. Here I will discuss what we have learned in recent years.

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