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SUPERNOVA REMNANTS AND THEIR EFFECTS ON THE INTERSTELLAR MEDIUM

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RESUMEN

Los remanentes de supernovas (RSNs) son una de las principales fuentes de inyección de energía en las galaxias y grandes modificadores de la dinámica y la química del medio interestelar, constituyendo un laboratorio astrofísico muy valioso para estudiar numerosos procesos físicos involucrados en su evolución y en la interacción con el material circundante. En esta contribución resumo el estado actual del conocimiento de dos de los principales fenómenos asociados con estos objetos: si son aceleradores de rayos cósmicos galácticos y disparadores de la formación de nuevas estrellas.

ABSTRACT

Supernova remnants (SNRs) are one of the main sources of energy injection in galaxies and great modifiers of the dynamics and chemistry of the interstellar medium, constituting a very valuable astrophysical laboratory to study numerous physical processes involved in their evolution and the interaction with the surrounding material. In this contribution I summarize the current state of knowledge of two of the main phenomena associated with these objects: if they are sources of galactic cosmic rays and triggers of formation of new stars.

Key Words: cosmic rays — ISM: supernova remnants — stars: formation

1. INTRODUCTION

Supernova remnants (SNRs) are the astrophysical remains of a supernova (SN) explosion. This explosion is caused by either a gravitational core-collapse of a massive star ($M \geq 8\ M_\odot$ in the main sequence) that has exhausted its nuclear fuel (types Ib, Ic, and II SNe) or a white dwarf entering a thermonuclear disruption (detonation, degeneration, delayed detonation) accreting matter from a companion star (type Ia SN). In the first case, depending on the mass of the core of the star, it collapses leaving a neutron star or a black hole, while in the second case the explosion destroys the star completely.

In either case, about 10^{51} ergs of mechanic energy is deposited in the interstellar medium (ISM) and an outward propagating shock causes a large fraction of the stellar envelope to be ejected at velocities between 5000 and 10000 km s^{-1}. This ejecta mixes with the surrounding material, enriching the ISM with stellar fusion products. These products together with the swept up ambient gas and, eventually the compact stellar core left after the explosion, constitutes a SNR.

SNRs can radiate their energy across the whole electromagnetic spectrum, but they are mainly radio synchrotron sources. Out of the 294 catalogued SNRs at present in the Milky Way (Green 2014) about 95% are radio sources, in fact they were discovered and characterized in this spectrum band.

The strong SNR shock waves modify irreversibly the physical and chemical properties of the ISM. They can accelerate, compress, heat, ionize, dissociate molecules, and even create new species, as also destroy and form dust grains. Besides, it has been long proposed that the interaction between shocks in SNRs with molecular material should be capable of accelerating particles to galactic cosmic-ray (CR) energies through a hadronic mechanism, as well as initiate new cycles of stars. These issues will be discussed in the following sections.

2. SNRS AS SOURCES OF GALACTIC COSMIC RAYS ACCELERATION

SNRs have been considered the best candidates as sources of galactic cosmic rays (CRs) at least for energies up to 3×10^{15} eV (feature referred to as the knee in the CR spectrum). However, an unambiguously and conclusive proof showing that SNRs can accelerate nuclei, which make up 99% of the CRs observed on Earth, is still missing (e.g. Aharonian 2013, and references therein).

Gamma-ray astronomy has a key role in solving this problem since CRs produce gamma ray emission through hadronic interactions with dense clouds

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in the ISM, thereby creating among others, neutral pions that decay into two gamma ray photons. However, the problem is far from simple because although numerous SNRs interacting with molecular clouds show evidence of accelerating protons through a hadronic mechanism up to TeV energies (e.g. Slane et al. 2015), it is still necessary to disentangle the leptonic contribution (mostly inverse Compton scattering of electrons) that also explain the observed TeV gamma-ray emission.

There are two clear signatures in the gamma-ray spectrum to identify without ambiguity a hadronic origin for the gamma-ray emission. One of them is the so-called *pion-bump* feature at energies below 100 MeV. Recently, this feature has been identified in the SNRs W44 (Abdo et al. 2010a) and IC443 (Abdo et al. 2010b), using the Fermi satellite. However, these detections only prove that SNRs can accelerate protons at least up to the multi GeV domain. The other feature in the gamma-ray spectrum is a cutoff at above 100 TeV. In this range of energy, the leptonic contribution is strongly suppressed, being the hadronic process the only viable explanation. To date, this region of the electromagnetic spectrum is unexplored by the current Cherenkov instruments, so up to the present there is not a direct evidence that SNRs accelerate cosmic rays up to or beyond the knee. Observations with new Cherenkov instruments, such as HAWC and CTA, coming into operation in a near future, improving the sensitivity of gamma-ray detections above 100 TeV will help finding those sources accelerating protons up to PeV energies.

Other aspect pending a solution is that the chemical composition of CRs, consisting of a mixture of material of massive stars and normal interstellar medium (Murphy et al. 2016), support an alternative view in which galactic CRs are not accelerated by individual SNRs, but rather by collective effects of multiple SNRs and stellar wind shocks.

3. SNRS AS TRIGGERS OF STAR FORMATION

It has often been suggested that the interaction between SNR shock and molecular clouds can trigger the formation of new stars. Indeed, the remnants are often found in regions with active star formation and near young stellar objects (YSOs). This is reasonable because the SNRs produced by gravitational collapse of massive stars, due to their short lifetimes many of them explode while they are still inside, at the border, or very close to their parental molecular cloud. However, the observed physical association between star formation and SNRs does not necessarily imply a causal relationship. From a theoretical point of view, if favorable conditions are given (shock waves with velocities in the interval of 25-40 km s^{-1}), star formation triggered by SNRs is feasible (Vanhala & Cameron 1998; Melioli et al. 2006). From the observational point of view, several searches have been carried out and in all cases no indication was found that would lead to the conclusion that new stars were formed as a consequence of the interaction between the SNR shock front and a molecular cloud, even when the protostellar objects were immersed in shocked clouds. In all cases, the general conclusion is that the stellar formation started before the SN explosion (see Dubner & Giacani 2015). The same results have been found by Desai et al. (2010) who investigated the relationship between SNRs and star formation in a sample of 45 remnants in the Large Magellanic Cloud.

4. CONCLUSION

In this contribution I summarized the most recent results on the role SNRs play as factories of galactic CRs and initiators of new stars. We now know that at least two SNRs (W44 and IC443) accelerate CR protons up to multi-GeV energies. However, we still lack any direct observational evidence for the acceleration of PeV particles at SNR shock fronts. Moreover, we cannot say that SNRs are the only sources for the origin of CRs, alternative scenarios should be not discarded.

While it is true that SNRs are frequently seen near star formation regions, to date there is no observational evidence that proves that the remnants trigger the formation of new stars. What can be concluded is that SNRs located near or interacting with YSOs may change their physical and chemical properties.

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