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SUPERNOVA REMNANTS AND THE INTERSTELLAR MEDIUM

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RESUMEN

Se realiza una puesta al día de varios aspectos del estudio de los remanentes de supernovas y su interacción con el medio interestelar circundante, tanto desde el punto de vista observacional como teórico. Se señalan algunos de los principales problemas aun no resueltos.

ABSTRACT

The present review is an update of several aspects of the study of supernova remnants and their interaction with the surrounding interstellar medium, both from the observational and theoretical point of view. Some of the main unsolved problems are described.

Key words: **ISM – SUPERNOVA REMNANTS**

1. INTRODUCTION

The catastrophic end of a star as a supernova forces the sudden injection of chemically enriched material and enormous amounts of energy into the interstellar medium. These 'residuals' of a supernova explosion last for thousands of years interacting with their environs.

Supernova remnants (SNRs) are the only astronomical objects that can join the two extremes of the life cycle of stars through their interaction with the interstellar gas. They also constitute a dynamical connection between stars and gas, for they energize the interstellar material through radiative and magneto-hydrodynamic processes. In addition, observing SNRs is perhaps the only way in the whole lifetime of the star to inspect stellar interiors and to provide important clues to understand stellar evolution and the nature of supernovae (SN) explosions.

Since the early recognition of the SN phenomenon in 1934 (Baade & Zwicky 1934) and the identification of the associated remnants in our Galaxy (e.g., Baade 1938; Zwicky 1940), sixty years of observational and theoretical efforts have resulted in a considerable advance in the understanding of the remnants of SN and the impact of the explosions on the surrounding medium.

Supernova remnants can emit in most of the electromagnetic spectrum, from long radio wavelengths to the energetic X-rays, or even γ-rays. Based on their non-thermal radio emission, 194 SNRs have been identified in the Milky Way (Green 1995). In addition, approximately 90 galactic SNR candidates have recently been identified on basis of their X-ray emission (Aschenbach 1994). The number of identified extragalactic SNRs have dramatically increased in the last years with the use of new generation telescopes operating in different spectral ranges. At least 38 SNRs in the LMC and 12 in the SMC have been identified based either on radio, optical and x-ray searches (Mathewson et al. 1985; Rosado et al. 1992; Kahabka & Pietsch 1992; Dickel & Milne 1994; Chu et al. 1995, etc.). In M31, 15 SNRs have been positively identified among 178 good candidates (Magnier et al. 1995), while in M33, 53 SNRs have been recently reported (Gordon 1994).

The present review summarizes some of the more recent contributions to the study of SNRs and their interaction with the interstellar medium, aiming to outline some of the yet unsolved problems in the field.

2. RADIO SUPERNOVA REMNANTS

Radio observations constitute the best tool to investigate SNRs, since **all** SNRs are radio sources. The emission is non-thermal of synchrotron nature. The spectra of SNRs fit a power law of the form $S_\nu \propto \nu^{-\alpha}$, with

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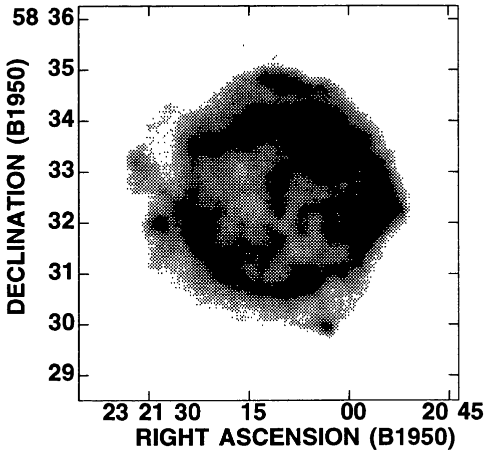

Fig. 1. Example of shell-type SNR: Cassiopea A (Courtesy of NRAO).

$0 \leq \alpha \leq 0.8$. In most of the radio remnants, the linear polarization amounts to 3–5%, with exceptions of up to 20–25%.

Based on their morphology, they can be empirically classified into three major groups (See Weiler & Sramek 1988 for a complete review): **1) classical shells** with radio brightness increasing from the center to the periphery, a spectral index $0.3 \leq \alpha \leq 0.8$ and low linear polarization (Examples: Tycho's SNR, Cygnus Loop, Cas A (Figure 1); **2) filled-center, plerionic or Crab-like SNRs**, with the radio brightness centrally concentrated, flat spectrum ($0 \leq \alpha \leq 0.3$) and strongly polarized (20 to 30%), (Examples: Crab nebula, 3C58, MSH15–57); and **3) composite remnants** which display, sometimes at different wavelengths, both characteristics: filled-centered and shell-like emission (Examples: G5.4–1.2, W44 (Figure 2), 3C400.2)

Actually, the main question that has to be answered in order to classify the remnants is **what is the origin of the radiation**. It is generally accepted that a shell-like appearance must be the consequence of an expanding shock wave interacting with the surrounding circumstellar (CSM) or interstellar medium (ISM). Departures from sphericity are usually explained as caused by the presence of inhomogeneities, both in the ejecta or in the ISM. If, on the other side, a young energetic pulsar is powering the radiation from the interior of the remnant, the source will look centrally concentrated, as a pure plerion. Concerning the composite class, the present knowledge is very poor, and no satisfactory explanation for the coexistence of shell and centrally concentrated emission, is in general provided for the cases where an associated pulsar is not detected. Lozinskaya (1980) suggested that composite remnants may represent an intermediate evolutive stage between pure plerions and shells.

Good descriptions of the dominant physical processes in the non-thermal emission of SNRs can be found for example in Reynolds (1988), Lozinskaya (1992), Baring et al. (1994).

In the last years, high angular resolution and high sensitivity images of SNRs obtained with synthesis radiotelescopes, have shown the radio emission in great detail, allowing the discovery of previously unnoticed morphological characteristics (Pineault et al. 1987; Dubner et al. 1993 and 1996, etc.). This fact leads to the necessity to revise the theoretical models developed to interpret the observations.

3. MULTIWAVELENGTH OBSERVATIONS

The study of the emission at different spectral ranges is useful to trace material with different physical conditions. Briefly, **optical filaments** normally indicate the distribution of cooling, recombining gas, heated by secondary shocks propagating into moderately dense clouds. **X-ray** emission is most likely of thermal origin, and its distribution traces the presence of hot, tenuous plasma, although a non-thermal origin, powered by a pulsar, is possible (Canizares 1990). **Infrared** emission marks the location of shock-heated dust (Dwek & Arendt 1992 and references therein).

Among the 194 listed galactic SNRs, roughly 70 have been also detected in X-rays (Aschenbach 1994), and only 40 have been optically identified (Magnier et al. 1995).

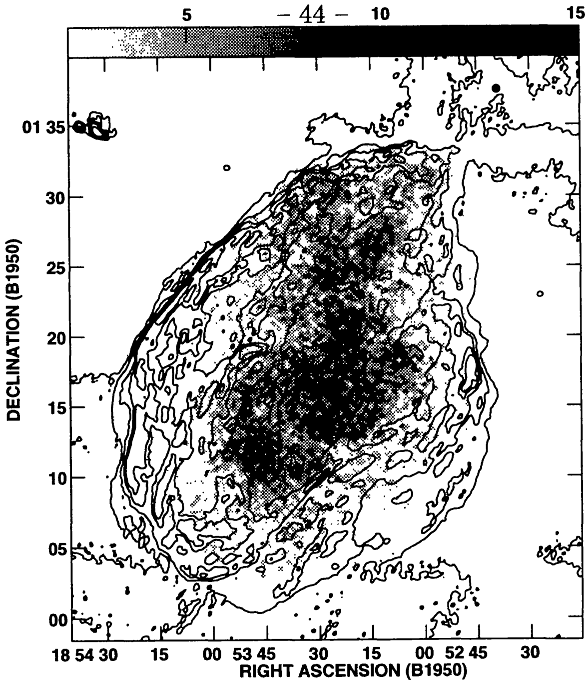

Fig. 2. Example of composite-type SNR: W44. The contours display the shell- shaped radio-continuum emission and in grey-scale the centrally concentrated X-ray emission (from Giacani et al. 1996).

From the joint study of different wavelengths emission, global properties of the remnants can be inferred and good plasma diagnostics then derived. The size, distance, plasma temperature and pressure, grain temperature, mass of radiating gas, ion population, ionization temperature and time, etc. can be derived. After the application of appropriate dynamical models for SNR evolution, parameters such as the age and initial energy, can be estimated.

The body of multispectral observations is not only useful to understand properties of the SNRs and their precursors, but also to explore the interstellar gas, since the remnants act as a probe of the density, composition and distribution of the ambient ISM.

4. PULSAR-SNR ASSOCIATION

Among about 560 catalogued galactic pulsars (Taylor et al. 1993), the Crab and Vela pulsars remained for many years as the only clear cases of PSR-SNR association, in spite of the fact that the presence of a neutron star is expected in the interior of **all** the remnants left by a type II SN. Several reasons have been classically invoked to explain such a poor agreement, like 'beaming effect', i.e., only pulsars with a beam pointing to the Earth would be detected, very high pulsar velocities (v$\sim$ 500 km/s, Lyne & Lorimer 1994), which rapidly would place the pulsar far from the parent SN, mean lifetime of a SNR much lower than the pulsar timescale, etc.

In the last five or six years, searches of PSR-SNR associations mainly focused to young sources, increased the number of potential associations to as many as 17. Fifteen of the 18 galactic pulsars younger than 60000 yrs show some sort of associated remnant. This progress was possible due to advances in high frequency pulsar surveys and low frequency radio imaging efforts. Important contributions in these new discoveries are those of Kassim & Weiler (1990), Srinivasan (1990), Frail & Kulkarni (1991), Kaspi et al. (1992), Kulkarni et al. (1993), Frail et al. (1993 and 1994a), Manchester 1994), etc.

The search for more PSR-SNR associations is an open field with potentially very important results in a number of key questions about origin and evolution of neutron stars and type II SNe. Also, it offers a unique database to investigate the interaction between the energetic pulsar wind and its coupling with the surrounding plasma. It can also provide independent estimates for the age and distance of the SNRs (See Frail et al. 1994a and references therein).

5. TEMPORAL EVOLUTION OF SUPERNOVA REMNANTS

The physical configuration of a remnant changes several times throughout the evolution. Woltjer (1972) proposed a simplified scheme separating the evolution into three major stages before it merges with the interstellar clouds; namely: **1)** free expansion (constant velocity), **2)** adiabatic phase (energy conserving) , and **3)** radiative phase (momentum conserving). This simple scheme has only limited relation to reality, and the duration of the phases is largely affected by the characteristics of the surrounding gas. In fact, not one of the three canonical phases has ever been unambiguously identified, and there are indications that two different phases can locally coexist (Braun 1985).

The evolution has been modeled analytically (Sedov 1959; Chevalier 1982), and numerically (e.g., Gull 1975; Falle 1975; Jones et al. 1981; Dickel & Jones 1985; Tenorio-Tagle et al. 1990 and 1991; Slavin & Cox 1992; 1993; Brighenti & D'Ercole 1994, etc.).

An important constraint in the study of SNRs evolution is the fact that the adiabatic (also known as Sedov-phase) is the only phase for which analytical models have been developed (e.g., Sedov 1959; Chevalier 1982), providing direct formulae to apply to the observed quantities in order to derive physical parameters (such as initial energy, age, etc.). Hence, lacking a better tool, they are sometimes indiscriminately applied, regardless of the actual evolutionary stage of the remnant under study. The development of analytical models for different phases and for remnants expanding in different environs, is desirable.

6. INTERACTION BETWEEN SNRS AND THE INTERSTELLAR MEDIUM

The mutual interaction between the expanding blast wave and the interstellar medium has a great impact both on the expanding remnant and on the surrounding gas.

On the remnant: the inhomogeneous distribution of the surrounding gas, can determine the appearance of the remnant in the different spectral regimes (Pineault et al. 1987; Dubner et al. 1991; Reynoso et al. 1995), regulate the temporal evolution defining the onset of the evolutive phases and can locally modify the spectrum (e.g., Braun 1988; Anderson & Rudnick 1993).

On the surrounding medium: the expansion of the SNR shock wave, can evaporate embedded cloudlets, adding mass to the hot ISM, and can accelerate, compress, and heat extended clouds (McKee & Hollenbach 1980; Draine & McKee 1993). The passage of a SN shock constitutes also the dominant destruction mechanism for interstellar dust grains and may have a major effect on elements depletion (Dwek & Arendt 1992; Draine & McKee 1993). Shock waves in molecular clouds can have important chemical consequences (see the review by Hartquist et al. 1990). Fast shocks can destroy H_2, but slower shocks favours the formation of certain species like OH, H_2O, CH^+, etc. (Draine & McKee 1993). Frail et al. (1994b , 1996) reported successful detection of OH masers associated with several galactic SNRs. Also the interaction between SNR shocks and large clouds, can compress them and possibly initiate star formation (Junkes et al. 1992 and references therein).

As pointed out by Graham et al. (1995), the theoretical models developed to describe the interaction of a SNR blast wave with the ISM consider the problem from two broad point of views. Either the interactions are with small clouds, that are engulfed and evaporated (e.g. McKee & Cowie 1975; White & Long 1991), or, on the other hand, the surrounding clouds are large compared to the physically important scales for gas dynamic and radiative processes behind the shock. In this last case, the models characterize the boundary of the SNR as a large-scale coherent shock, sharply dividing the interior from the exterior of the remnant (e.g., Hester et al. 1983, 1994, etc.).

One of the basic tools required in order to understand and correctly model the interaction of expanding supernova remnants with their surroundings is the observation of the atomic and molecular components of the interstellar medium in large fields around galactic SNRs situated in different environs.

7. CONCLUSIONS

At present many questions about SNRs, their formation and evolution, and the consequences of their interaction with the surrounding gas remain unanswered. However, enormous advances of the last years in the observational tools in the whole electromagnetic spectrum may well lend to solutions. The confrontation of theoretical research with this high-quality database is highly desirable in order to advance the understanding of one of the most powerful events in the sky.

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