THIN HI EXPANDING SHELLS. WHICH ARE THE BEST OBSERVATIONAL CONDITIONS TO DETECT THEM?

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RESUMEN. Se presentan los resultados de una simulación numérica de cáscaras delgadas de HI en expansión con diferentes ambientes circundantes. Se analiza cómo se verían a través de diferentes radiotelescopios. Se investigan las distorsiones introducidas durante los procesos de adquisición y reducción de los datos, en los parámetros derivados de las observaciones.

ABSTRACT. HI thin shells numerically reproduced as if they were placed into different galactic environments and were observed with different angular resolutions. Possible alterations introduced in the characteristic parameters of the shell during the observation and data reduction processes are analysed.

I. INTRODUCTION

Theoretical evolutive models of SNRs (Supernova remnants) (cf. Mansfield and Salpeter 1974, Chevalier 1974, Preite-Martinez 1981, etc.) predict the formation, in the later stages of evolution, of massive thin neutral shells behind a shock front. On the other hand, the dynamical interaction between the blast wave of a SN and the surrounding medium, either homogeneous interstellar gas or preexisting clouds, leads to the formation of compressed neutral gas, or swept-up gas and accelerated clouds. The swept-up gas is generally observed to outline a spherical shell (Mc Kee and Cowie 1975).

Since the observed optical filaments in older SNRs are believed to form at those positions where the expanding remnant encounters denser clouds of the interstellar medium, we expect to observe, from outside to inside: a) dense HI interstellar clouds adjacent to b) the optical filament and c) the thin expanding shell of neutral hydrogen formed by the cooling of the gas compresses behind the shock front, and sometimes X-ray emission. However, the currently available observational data do not show such a simplified scheme; on the contrary the features shown in the different spectral bands are rather complex. Sometimes, the only correlations observed among X-ray, optical and radio brightness distributions is the confinement to a common envelope (Levine *et al.* 1979, Gorenstein *et al.* 1979).

The 21 cm HI line observations in the direction to old SNRs provide a very useful tool to study both the interaction between SNRs and the interstellar medium and the hierarchy of structure in the surrounding medium, and to verify the validity of the theoretical models of

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evolution of SNRs. In Table I we have summarized the results obtained up to the present on those objects investigated in the 21 cm line, correlated, whenever possible, with observations carried out at other frequencies. In columns 1,2 and 3 the remnant distance, its linear radius and shell thickness are listed. In column 4 the total HI mass of the envelope is quoted. In columns 5, 6 and 7 the numerical density of the HI shell (n_{HI}), the ambient density (n_o) and the density of the adjacent interstellar clouds (n_c) are given. In column 8 the initial energy is listed. Column 9 includes the age of the remnant. In columns 10, 11 and 12 the envelope expansion velocity as derived from radio, optical and X-ray observations are summarized. In column 13, the ratio between both, the HI derived radius and radio continuum one is given. Finally, column 14 lists the references. It can be noticed that for a given object, IC443 for instance, apparent discrepancies exist between X-ray, optical and radio observations.

TABLE 1

	d (Kpc)	R (pc)	ΔR (pc)	M_{HI} ($M_\odot$)	n_{HI} (cm^{-3})	n_o (cm^{-3})	n_c (cm^{-3})	$E_0 \times 10^{50}$ (erg)	t (yrs)	v_{HI} (km/s)	v_{op} (km/s)	v_X (km/s)	R_{HI}/R_c	Ref.
G6.4-0.1 W28	3±0.5	41	17	6.9×10^4	12	9.8		84	5.8×10^5	20			0.96	1
G34.7-0.5 W44	3	40	30	5×10^3					$<10^7$				1.69	2
G189.1+2.9 IC443	1.5			$730d^2$		0.2-0.3	≈100 5-20	2		≈100	65	900-1200		3,4,5, 6,13
G74.0-8.6 Cygnus Loop	0.8					0.16	5.5				116-250	400-600		3,7,8 20
G116.9-0.2 CTB1	1.3	21									-33±2			9,10
G78.2+2.1	1.5	20	6	2.7×10^3		0.6			$1.4\pm0.6 \times10^4$	25		470±80		11,12
G89.0+4.7 HB21	1.1	26	≈19	$4\pm2 \times10^3$	2.5			3.2		25	22±8		1.37	14,15
G180.0-1.7 S147	1.5	40		750-2400				1	9×10^4	25±5	90		1.48	16,17
G261.9+5.5	2.2	50	≈30	$\approx10^4$		0.23		2.9	1.4×10^6	14			1.96	18
G330.0+15.0 Lupus Loop	0.5	32±4	15	3800	5	0.13		0.22	2×10^4	23±3			1.19	19

References to the Table 1: 1. Venger *et al.* 1982; 2. Knapp and Kerr 1974; 3. Giovanelli and Haynes 1979; 4. Lozinskaya 1969; 5. Winkler and Clark 1974; 6. Parkes *et al.* 1977; 7. Kirshner and Taylor 1976; 8. Minlowski 1958; 9. Landecker *et al.* 1982; 10. Lozinskaya and Pustovoit 1975; 11. Landecker *et al.* 1980; 12. Culhane 1977; 13. De Noyer 1977; 14. Assousa and Erkes 1973; 15. Lozinskaya 1972; 16. Assousa *et al.* 1974; 17. Silk and Wallerstein 1973; 18. Colomb and Dubner 1980; 19. Colomb and Dubner 1982; 20. Gorenstein *et al.* 1971.

If it were possible to pick up the post shock HI shell, that predicted by the evolutive models,out of preexisting HI clouds, some light could be shed upon the origin of the observed discrepancies and perhaps a better understanding of the phenomenon as a whole could be obtained. However, both the galactic environment where the SN explosion takes place and instrumental limitations, conspire against a good detection of very thin shells.

In regard to the galactic environment, the nearby HI interacting with the SN shock-front produces a number of effects that complicate the observation of post-shock HI shells. Moreover, pre-shock inhomogeneities of the gas are enhanced by the post-shock cooling processes, which may be accompanied by fragmentation processes (Duin and van der Laan 1975). Locally, it is reflected by producing anisotropy in the velocity field, spreading the HI shell emission contribution over a broad velocity range. However there are examples, as Lupus Loop, where the explosion has taken place within a region previously depleted and smoothed by the action of stellar wind, and the shell appears clearly defined and nearly complete (Colomb and Dubner 1982).

On the other hand, regarding instrumental limitations, the angular resolution could be not high enough to resolve a very thin shell. In this case, the HI shell should appear coincident with the optical shell. Generally, it would be impossible to separate the predicted HI shell from density inhomogeneities which have been overtaken by the SN shock. Hence the measured expansion velocity may be quite different from the true shock velocity.

The purpose of this work is to analyze the influence of both the galactic environment and the instrumental characteristics upon the chances of detection of an HI shell around old SNRs. In this progress report we present, mainly qualitatively, results of a numerical simulation of a cold HI shell placed into different galactic environments and observed with different angular resolutions. These simulated "observational data", were reduced and analysed in the usual way.

II. DESCRIPTION OF THE MODEL

The theoretical shell used has been extracted from Chevalier's (1974) model A. A supernova has exploded with initial energy $E_o = 3 \times 10^{50}$ erg, in an homogeneous medium with $n_o = 1\ cm^{-3}$ and $B_o = 3 \times 10^{-6}$ gauss. In this case, a spherical thin shell will develop behind the shock-front and at the age of 2.5×10^5 years, the characteristic parameters would be:

Radius = 30 pc

Thickness = 2.5 pc

Density = 10 cm^{-3}

Expansion velocity = 20 km/s

A uniform density distribution has been assumed within the shell.

Starting with this ideal shell, blank "noise" was added to simulate different galactic environments. The chosen noise levels roughly correspond to the following galactic height ranges:

Noise index "N"	z range (pc)
4	0 - 40
2	80 - 140
1	150 - 300
0	>> 300

The resulting density distribution was convolved with three different "slit" shaped beams, gaussian along the horizontal coordinate with 3', 10' and 30' arc min FWHM, and infinitely thin along the vertical coordinate. Although it is not a realistic beam, the consequences are smoothed in the data reduction.

In all the cases the filter bandwidth of the receiver was assumed to be 2 km/s.

III. RESULTS

Fig. 1 is intended to show the influence of the surrounding medium and the angular resolution on the quality of detection of a thin shell. There, it is shown a half of the resulting structure after scanning with different beams the theoretical thin shell placed into different environments.

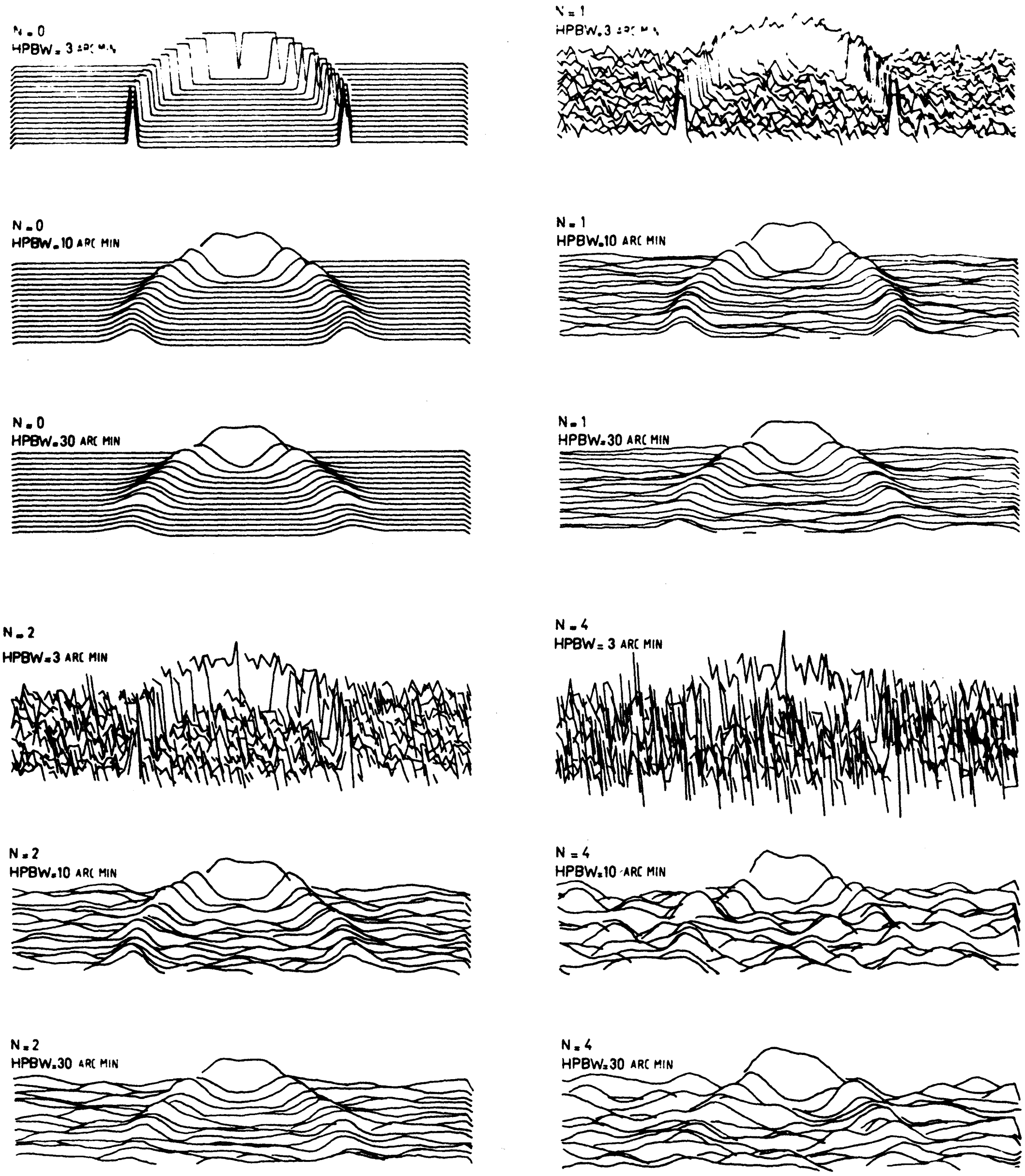

Fig. 1. Drift curves computed for a half of a shell using three different beams: 3,10 and 30 arc min, for the noise levels represented by N = 0, 1, 2 and 4 (See text).

In the first case, when the shell evolves within an ideal medium without any background noise, the effect of beam disolution can be observed.

With respect to the surrounding medium influence, notwithstanding the simplicity of the model, it is apparent that the detection would be difficult when high noise level is present (e.g.: case with N = 4), even having good angular resolution.

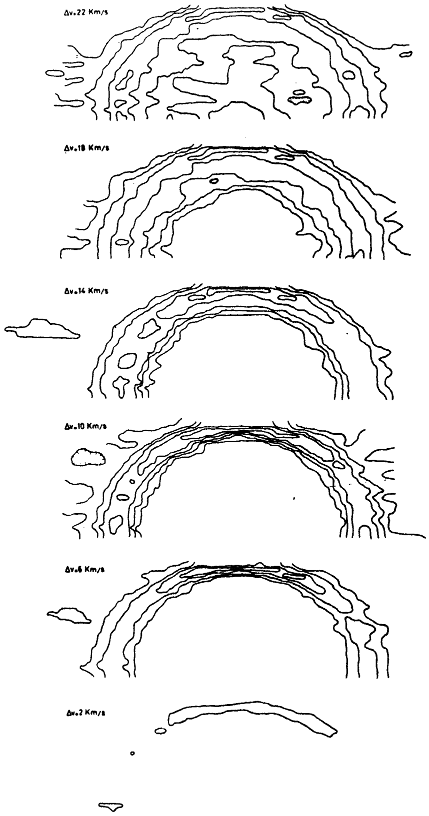

Fig. 2. HI column density distribution (represented in arbitrary units) as obtained integrating over different velocity ranges. The correspondent velocity intervals are included in each map.

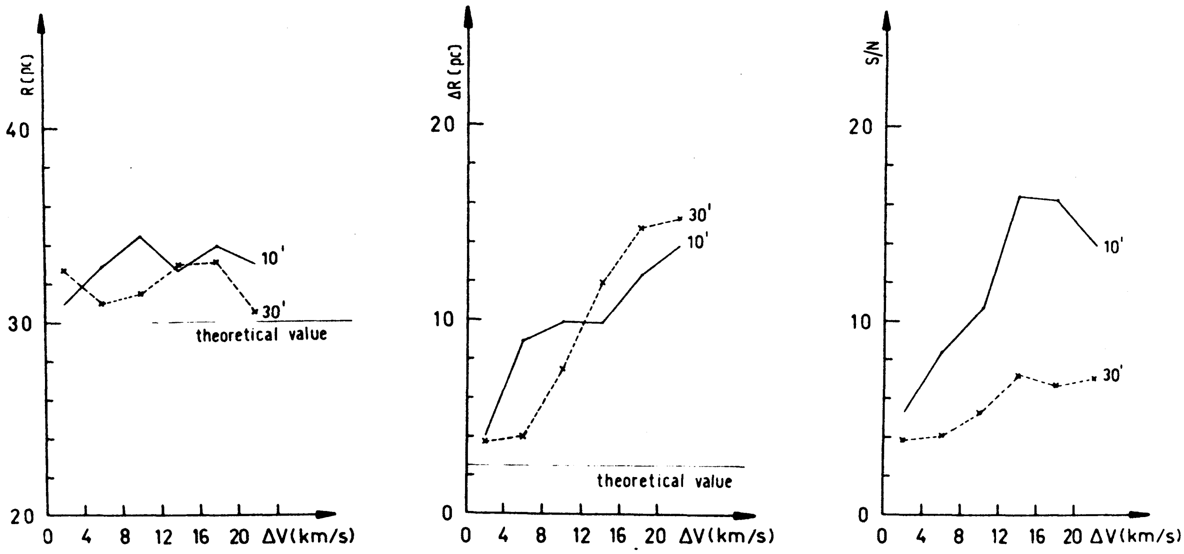

Fig. 3. Radius, thickness and S/N ratio versus integration velocity interval for the simulated shell with the noise index N = 2 and observed with 10 and 30 arc min beam.

Sometimes, in order to improve the signal/noise ratio, the usual procedure is to estimate the column density of HI by integrating over extended velocity ranges. In these cases, it is safe to investigate whether the technique alterates the characteristic parameters, such as thickness or radius, of the shell, since it could be important in the comparison between observations and theoretical predictions. To study the possible changes in thickness and radius, we have produced maps of "HI column density" integrated over increasing velocity ranges, from 2 km/s (one channel) to 20 km/s (the assumed maximum expansion velocity) (Fig. 2). Both parameters have been estimated as is usually done in a "standard" data handling procedure. In Fig. 3 we have represented, as an example, the variation of radius (R), thickness (ΔR) and signal to noise ratio (S/N) versus integration velocity interval, for the simulated shell with noise index N = 2 and observed with 10 and 30 arc min beams. Errors of 10% in the radius and around 25% in the thickness are typical.

It can be noticed that the radius estimate has no obvious trend neither upon the velocity range, nor upon the angular resolution. On the other hand, the thickness show a strong dependency with the integration velocity interval. The signal to noise ratio attains a maximum at those velocity ranges where the line of sight has a longer run through the shell. In the velocity ranges with the best S/N ratio, the thickness can be overestimated up to a factor of four.

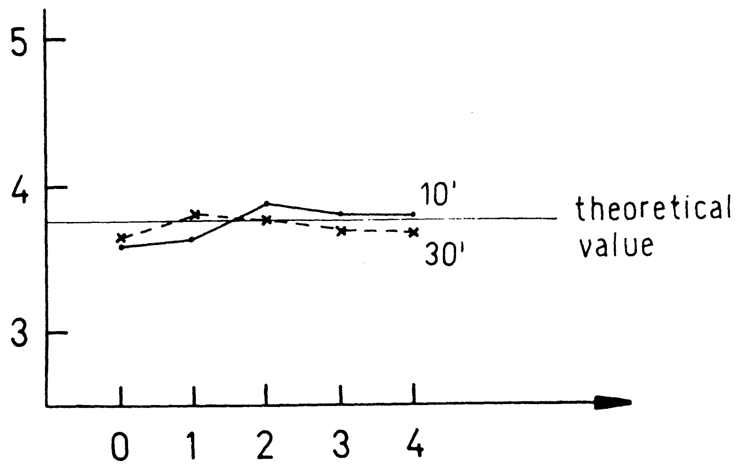

Fig. 4. Dependence of the total HI mass (in logarithmic scale) with the surrounding medium noise index.

In Fig. 4 it is shown the dependence of the logarithm of the total mass with the surrounding medium characteristic index. For 10' and 30' arc min HPBW, the behaviour is very regular, and the derived masses are, within the uncertainties, close to the theoretically expected value.

Finally we have considered the inclusion of external clouds. Fig. 5 represents a shell generated with noise index N = 2, HPBW = 10 arc min and perturbed by random adjacent clouds with densities variable between 5 and 10 cm^{-3} and sizes ranging from 4 to 10 pc. Though overall appearance is conserved, it looks wider and less defined that the shell obtained without external clouds.

Summing up, we think that this first set of results support the ability of our mathematical simulation to reproduce theoretical HI expanding shells, as they would be viewed under different observational conditions. This technique could be a useful link between theoretical predictions and observations carried out to confirm them.

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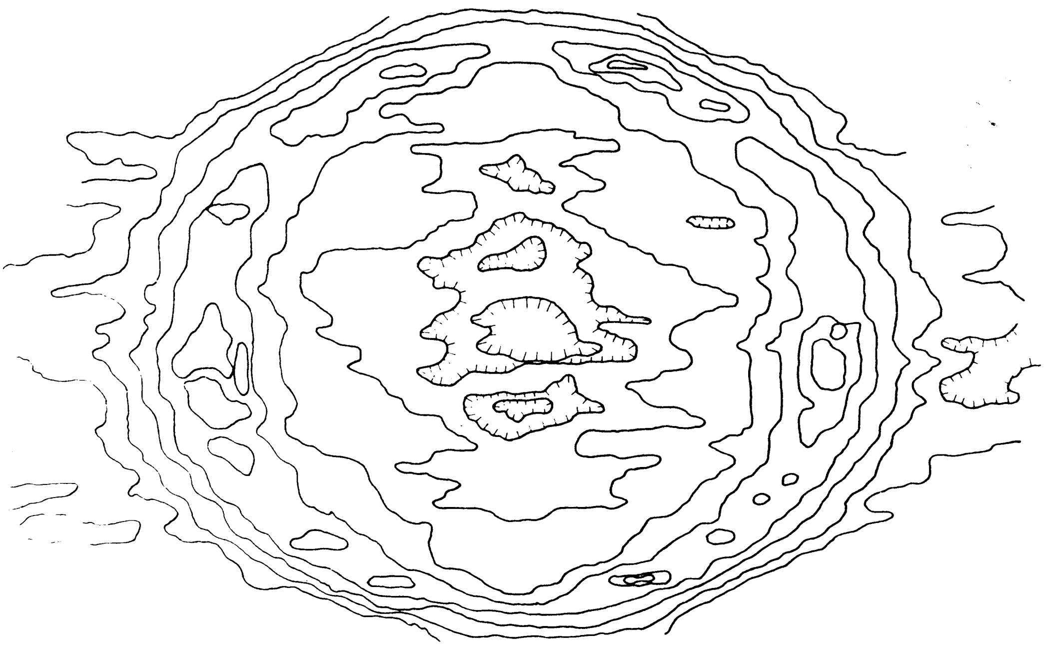

Fig. 5. Simulated neutral hydrogen shell with adjacent HI clouds, with different sizes and densities, randomly distributed. As in Fig. 2 the N_H levels are in arbitrary units.

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