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# NUMERICAL MODELS FOR MULTI-SUPERNOVA REMNANTS IN THE DIFFERENT VELOCITY CHANNELS

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## RESUMEN

Se utilizan modelos numéricos hidrodinámicos en 3D para estudiar las manifestaciones de superburbujas en la línea de 21 cm del hidrógeno neutro (H I). De los modelos de las galaxias M31 y HoII se muestra que el centro de agujeros la distribución de H I se puede desplazar significativamente en los canales de velocidad adyacentes. Por lo tanto, ponemos en duda el criterio de un centro estático utilizado para identificar superburbujas en galaxias cercanas.

## ABSTRACT

Manifestations of superbubbles in the 21 cm H I line have been studied on the basis of 3D numerical hydrodynamic calculations. From models for the M31 and HoII galaxies, it is shown that the center of H I holes can be significantly shifted in different channels. Thus, the criterion of a static hole center used for identifying superbubbles in nearby galaxies is questioned.

*Key words:* **GALAXIES: GENERAL — ISM: BUBBLES — ISM: STRUCTURE — HYDRODYNAMICS**

## 1. INTRODUCTION

Four intuitively obvious criteria are usually used to uncover the holes in the H I distribution of the external nearby galaxies (see Brinks & Bajaja, 1986): 1) an H I hole must be clearly visible in at least three successive channels, 2) the hole must have a good contrast with respect to its surroundings in all relevant channel maps, 3) the shape of the hole must be clearly defined and adequately described by an ellipse, and 4) the center of the hole should not change its position in different velocity channels. Brinks & Bajaja (1986) applied these criteria to the M31 galaxy, Deul & den Hartog (1990) used the same rules when compiling the H I holes catalog in the M33 galaxy, and Puche et al. (1992) applied criteria 2 and 3 to the Holmberg II galaxy.

These criteria, however, are not strictly grounded, and are rather based on intuitive notion about what an expanding shell appearance should be. Here we report on the continuation of the analysis started by Palouš et al. (1990) and Silich et al. (1996), and discuss the appearance of H I holes in different velocity channels using the results from 3-dimensional numerical simulations. We use a numerical hydrodynamic scheme based on the thin layer approximation (see review by Bisnovatyi-Kogan & Silich, 1995) developed by Bisnovatyi-Kogan & Silich (1991) and Silich (1992), and extend the procedure for shell projection on the plane of sky developed by Mashchenko & Silich (1995) and Silich et al. (1996) to different velocity channels.

## 2. NUMERICAL SCHEME

In an optically thin layer of neutral hydrogen in thermodynamic equilibrium, the H I column density is directly proportional to the brightness temperature of the gas in 21 cm line (Spitzer 1978). In what follows we deal directly with the H I column density distribution which follows from the numerical model. The total H I column density in a unit velocity interval, measured along any line of sight through a Gaussian spectral filter with dispersion $\sigma_f$ can be written as:

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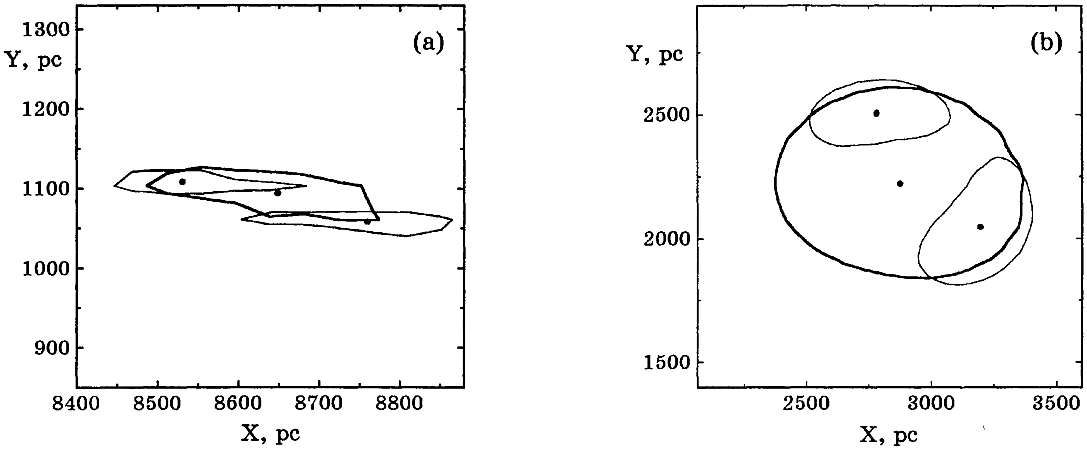

Fig. 1. Location of the hole center in different channels for a supershell: *(a)* in M31; *(b)* in HoII.

$$N_j = \frac{1}{\sigma_f\sqrt{2\pi}} \sum_l N_l \exp\left\{-\frac{1}{2}\left[\frac{V_l - V_j}{\sigma_f}\right]^2\right\} + \frac{1}{\sigma_*\sqrt{2\pi}} \int\limits_{-\infty}^{\infty} n(z) \exp\left\{-\frac{1}{2}\left[\frac{V(z) - V_j}{\sigma_*}\right]^2\right\} \mathrm{d}z, \tag{1}$$

where the first term is a contribution to the total column density from the supershell elements, and the second term takes into account the external gas contribution. When deducing the formula (1) the chaotic motions in the ISM were taken into account, with a velocity dispersion in the cold dense shell $\sigma_{sh}$ being significantly less than the filter half-width, $\sigma_{sh} \ll \sigma_f$. In expression (1) the index $j$ numbers the successive velocity channels, $V_j$ are the velocities corresponding to the centers of the relevant filters, index $l$ numbers the shell elements intersected by the line of sight, $N_l$ is the contribution of every such an element to the total column density under the spherical segment approximation (Silich et al. 1996), $V_l$ is the radial velocity of this element. The $z$-axis is directed along the line of sight, $V(z)$ and $n(z)$ are the radial velocity and number density of the emitting gas, respectively. $\sigma_* = \sqrt{\sigma_f^2 + \sigma_g^2}$, where $\sigma_g$ is the one-dimensional velocity dispersion of the H I chaotic motions, which takes into account the turbulent and thermal motions of the neutral hydrogen atoms. Here $\sigma_g$ is assumed constant along the line of sight. The H I column density distribution smoothing by the finite radio-telescope beam resolution over the region under consideration was also taken into account.

## 3. RESULTS AND DISCUSSION

We have considered bubble evolutions in two galaxies with extreme sets of morphologies: the grand design spiral M31 and the dwarf irregular Holmberg II (UGC 4305). The input energy rate, $L$, and galactocentric distance of the parental OB-association, $R$, have been chosen to be $L = 1 \times 10^{38}$ ergs s$^{-1}$, $R = 10$ kpc for the galaxy M31, and $L = 1 \times 10^{37}$ ergs s$^{-1}$, $R = 4$ kpc for the HoII galaxy. The energy source was switched off after 30 Myrs —the assumed lifetime of the OB-association. After 25 Myrs of evolution in the M31 galaxy, and 40 Myrs of evolution in the HoII galaxy, the supershells are projected onto the plane of sky. Following Brinks & Bajaja (1986) and Puche et al. (1992), the velocity interval between adjacent channels $\Delta V$, filters half-width $\sigma_f$ and beam smoothing parameter $\sigma_b$ are adopted to be $\Delta V = 4.1$ km s$^{-1}$, $\sigma_f = 4.1$ km s$^{-1}$, $\sigma_b = 42.3$ pc for M31 galaxy, and $\Delta V = 2.58$ km s$^{-1}$, $\sigma_f = 1.29$ km s$^{-1}$, $\sigma_b = 28$ pc for HoII galaxy. For the one-dimensional velocity dispersion of the gaseous chaotic motions, $\sigma_g$, we use the values $\sigma_g = 8.1$ km s$^{-1}$ for M31 (Unwin 1983) and $\sigma_g = 6.8$ km s$^{-1}$ for the HoII galaxy (Puche et al. 1992). The projections are performed for several values of the polar angle $\theta$, which is counted from the galactic line of nodes. $\theta = 0°$, $30°$, $60°$ and $90°$ for M31, and $\theta = 0°$, $45°$ and $90°$ for HoII.

Shells appear as holes in the H I column density distribution, in at least three successive velocity channels, in all the cases with the only exception of the $\theta = 90°$ for M31, where the simulated hole is prominent just in one channel. The depth and contrast of the holes depend on polar angle, and as a rule are bigger for smaller values of the angle $\theta$. The shape of holes is well described as elliptical. All these features are in good agreement with the three criteria mentioned above.

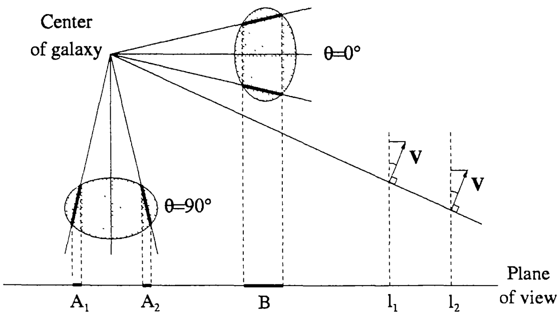

Fig. 2. Scheme illustration of the shifting of the hole center in different velocity channels (see text).

However, the fourth criterion in use —the requirement that the hole center is stationary in all relevant velocity channels— is in disagreement with the model predictions. The hole center is shifted from channel to channel in all models. The distance between hole centers in two extreme channels may be even compared with the hole diameter.

The shifting of the hole center for different channels is shown in Figure 1. Here the shell images in the central and two extreme channels, where the hole is still distinguishable, are superimposed. The thick line represents the hole half-depth contour in the central channel, the thin lines are the hole half-depth contours in extreme channels. The OB-association in M31 is assumed to be located at $R = 10$ kpc from the galactic center, with the polar angle $\theta = 30°$. In the HoII galaxy, the galactocentric distance is $R = 4$ kpc and $\theta = 45°$. From Figure 1, one can see that the holes in extreme channels separate so far that they no longer overlap.

The qualitative explanation of the effect is presented in the scheme in Figure 2. Let us assume that an observer is located in the galactic plane and observes the H I distribution through narrow spectral filters. The gas in the galaxy is distributed homogeneously and the rotation velocity does not depend on galactocentric distance: $n(x,y) \equiv const$, $V(x,y) \equiv const$. Then, the contribution to the current velocity channel is associated with the gas placed along the particular radius-vector (lines of sight $l_1$ and $l_2$ in Figure 2). A hole in the H I distribution falls into the spectral channels which correspond to the radius-vectors intersecting a free-of-gas cavity. If the H I deficit region is located around the polar angle $\theta = 0°$, then centers of the holes observed in the column density distribution coincide in all the relevant velocity channels (zone $B$ in the scheme). For the shells with polar angles $\theta \neq 0°$, the hole centers in different spectral channels are shifted systematically. For the uttermost case of $\theta = 90°$ (Figure 2) holes in extreme channels (zones $A_1$ and $A_2$) are separated and do not overlap. The scheme in Figure 2 illustrates an extreme case of galactic inclination angle $i = 90°$. It stands to reason that for $i \rightarrow 0°$ the value of the hole center shifting has to decrease. The effect of a hole center displacement comes from a galactic gas rotation and has to be taken into account when the H I column density distribution is discussed. It should be more pronounced for galaxies with fast rotation and large inclination angles $i$, and for shells located far from the galactic line of nodes. It should be noted that in the models here considered, the maximum shifting is observed in extreme channels where the hole contrast $\xi$ is relatively small: $\xi \simeq 10 - 20\%$, where $\xi = 2\,(N_{max} - N_{min})/(N_{max} + N_{min})$; $N_{min}$ and $N_{max}$ —minimum and maximum column densities within the hole.

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