LARGE-SCALE BUBBLE STRUCTURE OF THE INTERSTELLER MEDIUM (ISM) AND PROPERTIES OF THE LOCAL SPIRAL ARM (LSA)

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ABSTRACT

Bubbles are very common structure units in the Galaxy and galaxies. Collection of radio, optical, infrared and x-ray observations of the Cyg superbubble (CSB) region of the sky show that the CSB is not a single bubble object. Between 50 to 75 percent of its x-ray emission can be ascribed to discrete sources. The other 25 to 50% x-ray emission, probably originates from bubbles around 8 OB associations of the region. All bubbles located within the spiral structure of Galaxy, M31 and M33 have diameter $\lesssim$ 300pc.

The large distance of stellar association from the galactic plane (GP) combined with picture of the gas distribution within the LSA shows that a Reyleigh-Taylor instability in the LSA can develop and give use to the formation of compact steller clusters, such as the Cyg OB2 association. Development stages of the Reyleigh-Taylor instability, some peculiarities of the dust distribution and departures of the local structure from the galactic grand design suggest the absence of a spiral shockwave in the LSA.

I. Giant and Supergiant Ring Structure in the Intersteller Medium

Numerous HII shells about 100-200pc in size and several HII shells up to about 1 kpc in size have been found in the Magellanic Clouds (Goudis and Meaburn, 1978; Meaburn 1980). Some spiral galaxies have been found to contain HII bubble regions inside of the spiral structure up to about 300pc in diameter (see summary of Sharov's Data [1982] on M31 and M33).

In Galaxy large-scale shells are usually distinguished not from optical but from other ranges of radiation. Heiles (1979, 1984) found about 100 HI supershells in the Galaxy, while Georgelin et al. (1979) observed there 13 giant HII shells. Also described were two large bubbles showing soft x-ray radiation, one in the Orion and Eridanus, associated with the star formation complex in Orion (Reynolds and Ogden, 1980; Goudis, 1982) and others associated with Seo-Cen association and the North Polar Spur (Weaver, 1979, 1984). Nevertheless the very large (75°) Gum nebulae is not apparently a single object, because it does show x-ray radiation (e.g., Reynolds, 1976).

II. Cygnus Superbubble (CSB)

In connection with the data of section I, special attention was put to a giant (13°x18°) horseshoe shaped source emitting soft x-rays. This is the Cyg Superbubble discovered by Cash et al (1980). They suggested that the CSB corresponded to a ring of optical filaments (15°x13°) noted by Ikhsanov (1960), Dickel et al. (1969) and Brand and Zealey (1975) and to the Cyg OB2 association, located on the distance 2 kpc from the sun. In this case, sizes of the CSB equal 450 x 600pc, that is it could be the largest shell inside the spiral structure of our Galaxy.

Bochkarev and Sitnik (1983, 1984) showed that the CSB is a projection on the sky of many sources, located at different distances from the sun within

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the LSA, along which we are looking in the Cygnus direction. The main arguments against the singular nature of the CSB are: (1) Greater elongation of the CSB along the GP (18°) than across it (13°). For a quasipoint source of energy, as suggested by Cash et al. (1980), Higdon (1981), Abbott et al. (1981), Blinnikov et al. (1982), and a bubble size that exceeds the thickness of the gas disk (200-300pc), the CSB must show greater elongation across the GP, as found for the Ori-Eri region. (2) Comparison of the surface brightness of the ring of filaments in optical and radio radiation showed that the ring is not a single structure (Kapp-herr and Wendker, 1972). (3) Multicompnent radio source Cyg X which covers ~ 1/4 the CSB region is also a projection on the sky of objects located over 1-4 kpc from the sun (Dickel et al. 1969, Dickel and Wendker, 1978). (4) CSB radioradiation does not show any large-scale envelopes of thermal or nonthermal originations. (5) Comparison of the x-ray spectrum of the CSB (according to Cash et al., 1980) and individual parts of it, Cyg X-6 and Cyg X-7 (Davidsen et al., 1977) and also SS Cyg (Cordova, 1981) show that in spite of the statement by Cash et al., the CSB spectrum is, apparently, inhomogenious (Bochkarev and Sitnik, 1984). (6) According to Bochkarev and Sitnik (1983, 1984) 50-75% of the x-ray emission of the CSB originates from ~ 20 faint x-ray sources included mainly to Amnuel et al. (1982) catalogue. In particular, Higgs et al. (1982) discovered that in spite of Cash et al's. (1980) opinion the brightest part the CSB Cyg X-7 is the SNR DR4, as was suggested by Davidsen et al. (1977). The region of interest includes many other active objects capable of radiating x-rays: among them 8 OB-associations, 110 stars of superhigh luminosity (Hamphreys, 1978), about 15% galactic Of stars from Losinskaya's (1982) list and about 15% of the galactic WR stars from the list of Hucht et al. (1981).

Bochkarev and Sitnik (1983, 1984) concluded that 25-50% of the CSB x-ray emission which is not radiated by known x-ray sources is emitted by giant envelopes blown by the 8 steller association of the CSB region. Good correspondence of position on the sky with maximum of x-ray emission and the associations and gas and dust ring structures recognized by Brand and Zealey (1975) around the associations suggest this conclusion. Strong interstellar absorption and the low temperature of sources contribution to x-radiation of the CSB result in the similarity of the spectra of all components of the CSB (Bochkarev, 1984, Bochkarev and Sitnik, 1984).

III. On the Nature of the Giant Envelope around Stellar Associations

The quantative analysis by Bochkarev and Sitnik (1984) shows that for producing of caverns with observed radiation each amoung 8 OB association in the CSB region must have blown $3 \cdot 10^4 - 3 \cdot 10^5\ M_\odot$ of ISM. It is a typical mass for giant molecular clouds from which associations can be formed. A similar result was found by Dopita et al. (1981) for shell N70 (diameter ≈ 120pc) in the LMC.

Stellar winds of average total power $\langle L_W \rangle \gtrsim (3-5) \cdot 10^{35}$ erg/s are necessary for the formation of such gas caverns. But such L_W is very great for a typical OB association averaged over $(2-10) \cdot 10^6$ years, because only during short supergiant evolutionary stages of massive stars have $L_W \sim 10^{35}$ erg/s. Important contributions to $\langle L_W \rangle$ can come from WR and Of stars which produce strong winds of ~ 10^{37} erg/s (Abbott, 1982; Bochkarev and Sitnik, 1984).

Large contributions to cavern formation can be produced by SN explosions in stellar associations (Bruhwailer et al., 1980). Total contribution of SNR to support of peculiar movements of the ISM is ≈ 90% (Salpeter, 1979). But inside of OB associations the contribution must be lower as a result of (1) absence of SNI in the associations; (2) presence of a large quantity of high luminosity stars with strong stellar winds. Therefore within bubbles surrounding young OB associations appoximately equal contibution can be expected from L_W and impulse from SN explosions, WR stars and other stars.

To estimate exactly the corresponding contributions to cavern energy is not possible in view of indeterminate and, probably, nonuniversality of the initial mass function (Freeman, 1977; Zasov and Demin, 1979) and also the small number of stars in individual association and consequently large statistical deviations from an average value. Frequency of SN explosions in association and kinetic energy ejected by the most massive stars are also very uncertain (see Bochkarev and Sitnik, 1984).

Thus, the diffuse component of the CSB x-ray emission is, probably, traceable to ≈ 8 caverns surrounding associations located on 0.5 -2 kpc from the sun in the LSA. It may be that 30-40% of the CSB is occupied by a cavern around unusual Cyg OB2 association (Bochkarev and Sitnik, 1984).

According to the calculations of Castor et al. (1975) and Weaver et al. (1977), the gas caverns must be surrounded by cold gas envelopes. For parameters typical for the caverns ($R \sim 50$pc, $t=(2-10)\cdot 10^6$ yrs) the cold envelope must have column density ~ $10^{21}cm^{-2}$ and, therefore show important interstellar extinction (~ $0.^m5$). That means that around OB associations dust envelopes can be present. Such envelopes were discovered by Brandt and Zealey (1975).

IV. A Rayleigh-Taylor(RT) Instability and a Structure of the Local Spiral Arm

Stellar associations in the western part of the CSB located near tops of sinous-like system of gas filaments (Bochkarev and Sitnik, 1983) correspond to Pikel'ner's (1970) scenario of association formation by RT instability. Some of the association in the CSB region are distant from the GP. These assiciations have distances < 2 kpc from the sun, where curvature of the GP is not important. Therefore large distances from the galactic equator correspond to locations of the association out of the GP. Two other caverns found in the LSA (Ori-Eri region and cavern connected with Sco-Cen association discussed by Weaver, 1979, 1984) are also formed by associations on large distances (≈100 pc) from the GP.

Formation of associations at large distances from the GP are a difficult point for any mechanisms except the RT instability. However inside of spiral structures of S-galaxies, star formations by slow developing RT instability must be prevented by spiral shockwaves, which stimulate star formation inside the inner parts of spiral arms on shorter time scales than the RT instability. As a result, the RT instability can split the matter in gas-dust complexes, which are converted into a star formation region by spiral shocks before then RT instability forms massive stellar clusters. Thus, the presence of spiral shockwaves prevents the formation of objects similar to young globular clusters of Magellanic Clouds, as was suggested, e.g., by Efremov (1979).

But very compact (0.1 degree on the sky or 17 x 28pc) and massive ($(3-6)\cdot 10^4\ M_\odot$) stellar association Cyg OB2, which was studies in detail by Reddish et al. (1966), is very similar to young glubular clusters of the Magellanic Clouds. This fact can be very easily understood assuming that the LSA has no spiral shockwave. Such an assumption agrees with reconstructions of the galactic grand design by Georgelin and Georgelin (1976), Mishurov et al. (1979) and others, which shows that the sun is located almost exactly in the middle between spiral arms.

Distribution of the ISM extiction across the LSA also shows peculiarity of the LSA. Uranova (1984) discovered that the distribution has a cut off near the outer side of the LSA and smoothly decreasing to the inner side. Such distribution is difficult to understand in terms of blast wave theory.

The probable reason for the absence of a spiral shockwave in the LSA is close its position to galactic corotation radius. As a result the gas enters into the LSA with undersound speed and does not form a spiral shock-wave.

Thus, it is possible to think that in the LSA absence of the spiral shockwave results in the full development of a RT instability with subsequent formation of stellar associations far from the GP and also very dense ones, such as Cyg OB2. They have formed hot gas caverns, which we can see from the ~ 2 kpc distance because of the caverns located above the obscuring matter.

Typical sized of the caverns are probably ≈ 100-150pc. Such sizes are also typical for other spiral galaxies (Sharov, 1982). These are few examples of supergiant shells with diameters up to 3 kpc in spiral galaxies as given by Heiles (1979b, 1984) in the Galaxy and by Zasov and Kyasumov(1981) in NGC 157. Supergiant rings with diameters of 0.5-3 kpc can originate by Elmegreen and Lada (1977) mechanism where synchronizing action of spiral shockwaves is absent namely in irregular galaxies and outer parts of spiral galaxies.

V. Conclusions

1. Ring structures with diameters 100-300pc are typical kind of large-scale structures of the ISM of spiral and irregular galaxies. Inside of the spiral structure sizes of the rings are probably < 300pc (giant shells) and in IR galaxies and outer parts of S-galaxies together with giant shells are present supergiant shells with diameter >0.5kpc.

2. Observed picture of the x-ray Cygnus Superbubble is a result of projection on the sky of a large quantity of discrete sources and giant envelopes around 8 OB associations in the SCB region. These sources are located at different distances (mainly 0.5-2.5kpc) in the LSA, along which sight lines go to 4 kpc in the Cygnus direction.

3. Giant shells (as emissional as dust) can be produced by winds of stars of stellar association. Approximately equal contributions to shell formation apparently provided by SN explosions, WR stellar winds, and stellar winds of other stars in associations.

4. Positions of a number of stellar association of the LSA far from the GP and presence of the extremely compact and massive Cyg OB2 association suggests good conditions for a full developed RT instability in the LSA.

5. Galactic grand design, distribution of absorption matter in the LSA and evidences of full developing RT instability in the LSA suggests probably the absence of a spiral shockwave in the LSA.

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