X-RAY SUPERBUBBLES

Webster Cash
Laboratory for Atmospheric and Space Physics
University of Colorado
Boulder, CO 80309

ABSTRACT

Four regions of the galaxy, the Cygnus Superbubble, the η Carina complex, the Orion/Eridanus complex, and the Gum Nebula, are discussed as examples of collective effects in the interstellar medium. All four regions share certain features, indicating a common structure. We discuss the selection effects which determine the observable x-ray properties of the superbubbles and demonstrate that only a very few more in our galaxy can be detected in x-rays. X-ray observation of extragalactic superbubbles is shown to be possible but requires the capabilities of a large, high quality, AXAF class observatory.

GALACTIC X-RAY SUPERBUBBLES

It has now been well established that the interstellar matter in our galaxy is not smoothly distributed, and, in fact, has coherent structures with diameters of hundreds and even thousands of parsecs (Heiles, 1979). What is not well established is the cause and driving force behind these huge structures. With the discovery of x-rays from the Cygnus Superbubble (Cash et al., 1980) it became clear that, at least in some cases, the large scale structures are carved from the interstellar medium by an expanding bubble of gas at coronal temperatures. The further link of the Cygnus Superbubble to the powerful Cyg OB2 association supplied a natural explanation for the power source--supernovae and stellar winds from the association.

A single object, however, is inadequate for studying the role that superbubbles play in the dynamics of the interstellar gas. We are lucky to have a second clear example of the same phenomenon. Although smaller than the Cygnus Superbubble, the Orion/Eridanus complex shows most of the same features. Reynolds and Ogden (1979) brought together the interstellar activity in Orion (Cowie et al., 1979) with the soft x-ray enhancement known as the "Eridanus Hot Spot"

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(Naranan et al., 1976) to describe a structure similar to the one in Cygnus.

Two other features near us in the galaxy have many of the same characteristics and are clearly candidates for being superbubbles. The first of these is the region surrounding η Carina. Cowie et al. (1981) have detected high velocity gas over a region more than 200pc in diameter. This is backed by the discovery of diffuse x-ray emission from the region (Seward et al. 1979; Seward and Chlebowski, 1982). The other candidate is the Gum Nebula. While it has never been detected in x-rays, it has so many of the characteristics of the other three that it naturally should be included in the discussion.

Table I is a summary of the physical characteristics of the four active regions. It demonstrates that while these superbubbles typically contain more thermal energy than the average supernova remnant it is really their immense volumes that set them apart from individual explosions.

TABLE I

X-RAY SUPERBUBBLES

	Distance (pc)	Diameter (pc)	L_x (erg s^{-1})	T (K)	n_e (cm^{-3})	N_x (cm^{-2})	E (ergs)
CYGNUS	2000	450	10^{37}	$2x10^6$	.02	$2x10^{22}$	10^{52}
ORI/ERI	400	200	$4x10^{35}$	$3x10^6$	.006	$2x10^{20}$	$2x10^{50}$
CARINA	2500	250	$4x10^{35}$	$8x10^6$	0.1	$2x10^{21}$	$3x10^{50}$
GUM	400	400	?	?	?	10^{20}	?

COMMON STRUCTURE

All four superbubbles share the same basic features. A schematic of a canonical superbubble is shown in Figure 1. In all cases we have an active OB association physically within the superbubble. The OB association is next to, and presumably formed from, a dense molecular cloud. Extending in one direction away from the association is a large, roughly spherical volume filled with a uniformly emitting x-ray gas. (In no case is there any evidence of the shell enhancement so common in supernova remnants.) Finally, surrounding and outlining the superbubble are elongated filaments of gas which are glowing brightly

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in Hα. The Hα is probably caused by photoionization from the Lyman continuua of the OB stars.

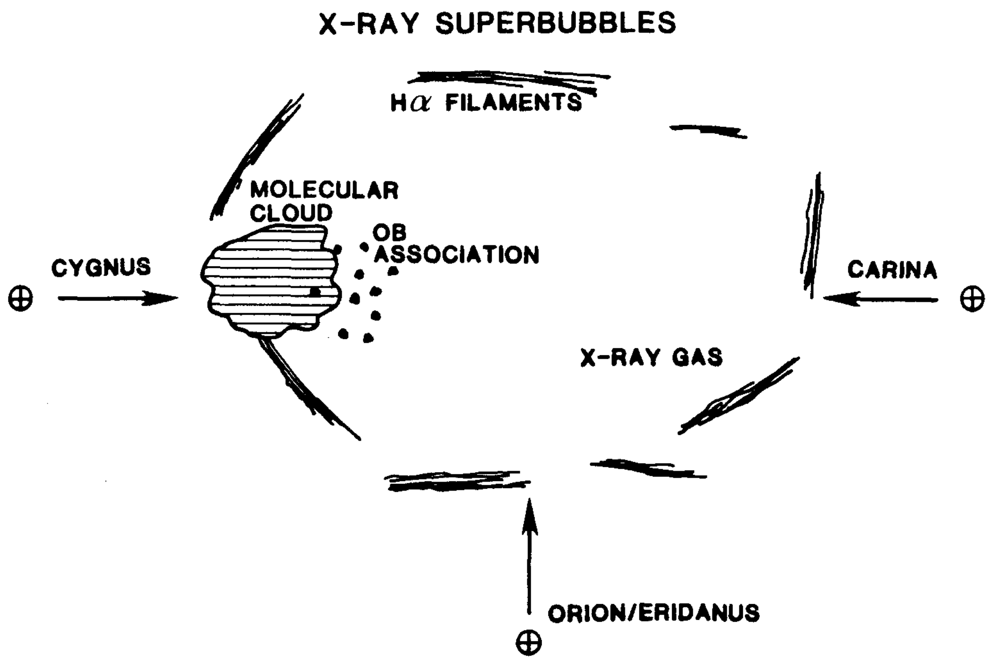

Figure 1. Schematic of a canonical superbubble. The common features of all superbubbles seem to be 1) an OB association by a molecular cloud, offset from the center of the bubble; 2) a giant bubble of x-ray emitting plasma; 3) filamentary Hα nebulae lighted by the UV emission of the association. The arrows represent the directions from which we are viewing this phenomenon in the cases of three known superbubbles.

In the four superbubbles we are viewing the phenomenon from three different directions. The great rift of Cygnus lies between us and the Cyg OB2 association, allowing the x-ray emission to be detected only in a horseshoe shape around the dark cloud. The direction we are viewing the Cygnus superbubble is shown in Figure 1. In the case of Orion/Eridanus we are viewing the bubble from the side. The molecular cloud and OB association are in Orion while the x-rays and Hα filaments are spread over a large area of sky to lower Right Ascensions. In the cases of Carina and Gum the situation is a little less clear, but it appears we are looking through the x-ray emission to the active region.

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SELECTION EFFECTS

As there are over twenty OB associations closer than η Carina, one must question why it is that these particular four objects are the ones which have been detected and studied. A recent survey by Abbott (1982) provides us with a clue. In his paper he compiles a list of the 21 OB associations within 3 kpc of the sun. He also estimates the power emitted in stellar winds from each of the associations, thereby providing a quantitative criterion for the size and activity of the associations. It is interesting to note that Cyg OB2 and η Carina are number one and two in the list when it is ranked by stellar wind power. On the other hand, the Gum Nebula and Ori OB1 are ranked seventh and seventeenth respectively.

The significance of detecting the interstellar effects of these two relatively insignificant associations becomes clear when one reorders Abbott's list by distance instead of power. Then Gum and Ori OB1 fall in first and second place. In short, if we are to detect a superbubble, it must be very close or very powerful. Since, with only one exception, all the other associations are at least three times as distant as Gum and Ori OB1, it is tempting to speculate that all OB associations are accompanied by superbubbles--we have not detected the others only because their structure is lost in the general clutter of the Milky Way.

It is not very difficult to obscure the x-ray emission from a superbubble. It should be noted that had any one of the three superbubbles which were detected in x-rays been five times fainter it would not have been detectable against the general x-ray background. In short, superbubbles are only somewhat brighter in x-rays than the average volume of the galactic plane. Also, because the bubbles have temperatures of only a few million degrees, their x-ray emission is very soft and can easily be shielded by modest amounts of interstellar absorption. Were the Eridanus Hot Spot three times as distant, no x-rays would be detectable.

This phenomenon can also explain the curious lack of x-ray emission from the Gum Nebula. If the gas inside is closer to one million degrees than the others, then the N_H of 10^{20} along the path (Savage et al., 1977) would be enough to absorb the emission.

An explanation for the situation in Carina is harder to find. Here, despite the detection of high velocity gas over a 5° circle, the x-rays are detected over only one degree (Seward and Chlebowski, 1982). Why have we not detected x-rays from the outer portions of the bubble?

A possible explanation is to be found in the principle of pressure equilibrium. A large, old object like a superbubble should be in pressure equilibrium in its interior, and is probably not very far from equilibrium with the surrounding interstellar gas. Now, the

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luminosity of an x-ray plasma is proportional to $n^2\Lambda$ where n is the electron density and Λ the emissivity of a thin, cosmic abundance plasma. If pressure is a constant then n will be inversely proportional to T; in the soft x-rays Λ is approximately proportional to the inverse of T. The result is that luminosity will be proportional to T^{-3}. This means that a mere factor of two increase in temperature can lead to an order of magnitude decrease in luminosity.

Perhaps the Carina bubble is filled with gas at temperatures substantially above 2×10^6 K. The detected gas, which has $T \approx 8\times10^6$ K could be in the conductive interface between the bulk of the x-ray gas (which would have $T \approx 30\times10^6$ K) and the cold gas of the molecular cloud. If the Carina bubble were filled with such a hot plasma then it should be a weak x-ray source detectable in the Uhuru band. A search of the literature reveals that there is a weak x-ray source of 1 UFU intensity at the position of η Carina (Becker et al., 1976). The source, however, is too weak to be established as a point source or otherwise. A further x-ray study of this region is clearly indicated.

EXTRAGALACTIC X-RAY SUPERBUBBLES

The previous section raised more questions about superbubbles than it answered. Because our view of superbubbles in the Milky Way is obscured by the interstellar gas, if we are to substantially increase the number of detected superbubbles we must look outside our galaxy. There can be little doubt that the superbubble phenomenon is a pervasive one and that many have already been detected through optical observations of nearby galaxies (see for example, Meaburn, 1983).

P. Charles of Oxford University and I have already made one attempt at x-ray wavelengths to detect extragalactic superbubbles. We obtained 3×10^4 seconds of guest time on the Einstein Observatory to observe the nearby giant spiral M74 with the HRI. We detected no clear examples of superbubbles, placing an effective limit of about 10^{38} erg s^{-1} on the maximum x-ray luminosity of a superbubble. Can we hope to detect extragalactic superbubbles given the failure to date? To do so we need a high resolution telescope. An object 400pc in diameter subtends only 20 arcseconds at a distance of 4Mpc. Thus, to distinguish a superbubble from an ordinary supernova remnant will require a telescope with at very worst 5 arcsecond resolution. A long observation will also be required; to obtain 100 photons from a 10^{37} erg s^{-1} source at 4Mpc one needs 7×10^6 cm^2s of data. This implies a need for about 100 cm^2 of effective collecting area in the telescope.

The ROSAT mission could come close to accomplishing this on a single galaxy if the observation is given sufficient time. It is worth noting that a typical galaxy should have dozens of superbubbles of the Cygnus class, thus a single deep observation could provide

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basic new data on the dynamics of interstellar gas. The data logjam will truly be broken, however, only after the launch of AXAF; with large collecting area, high resolution, long exposure times and spectral resolution, the images from AXAF will reveal the details of hundreds, even thousands of superbubbles.

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