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The W4 chimney/superbubble

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Abstract. A conical void in the Galactic HI within the Perseus arm has been proposed to be a chimney. However, Hα data suggest that the structure may be closed at higher latitudes and therefore is a superbubble rather than a chimney. Recent observations have extended our view of the HI and the radio continuum emission to higher latitudes, up to 8°. The new images show the HI structure to be open at the top and a small filament suggests recent breakout. The conical shape of the structure is not easily explained by superbubble models.

1. The original observations: morphology and energy source

The pilot project of the Canadian Galactic Plane Survey (CGPS) brought to light a conical void in the HI above the W4 HII region (Normandeau, Taylor, & Dewdney 1996; hereafter NTD96). This cone is perpendicular to the plane and opens up towards higher Galactic latitudes. At its apex is the OCl 352 cluster containing nine O-stars, two of which are of very early type. Given this, it is unlikely that there has been a supernova in the cluster.

Within the lower density region there are HI “streamers” and two elongated molecular clouds, all of which point away from OCl 352 (Heyer et al. 1996 and Taylor et al. 1998). These features combine to suggest that this is a Galactic chimney blown by the stellar winds of the O-stars, with gas streaming upward toward the halo.

2. Is it really a chimney?

2.1. Hα imaging

Narrow band Hα observations by Dennison, Topasna, & Simonetti (1997; hereafter DTS97) suggest the presence of a faint cap at b ~ 7°, corresponding to a height of approximately 200 pc above the star cluster. Their data, scaled by sin(b) to highlight the faint higher latitude emission, are shown in the left-hand panel of Figure 1.

2.2. Modelling

In NTD96, the structure’s approximate age was derived from the Weaver et al. (1977) formalism for a bubble expanding in a uniform medium. However, the evolution of the superbubble must be affected by the general decrease in density
Figure 1. The W4 superbubble/chimney in Hα and HI
In both images, a sin(b) scaling has been introduced to highlight the low level, upper latitude emission, greatly suppressing the dominant Galactic plane emission. **Left panel:** Narrow band, Hα image (DTS97). Note that the \(\sim 2^\circ\)-wide band of lower emission near the top of the image is an instrumental artefact. The curve is the best fit Kompaneets model derived by BJM99. **Right panel:** HI image for \(v_{\text{LSR}} = -41.8 \text{ km s}^{-1}\) to \(-45.0 \text{ km s}^{-1}\).

with increasing latitude. Basu, Johnstone, & Martin (1999; hereafter BJM99) modelled the wind blown bubble and the ionisation structure, using both the data from NTD96 and from DTS97. For the wind-blown bubble, they used the Kompaneets model (Kompaneets 1960) for a shock wave propagating in an exponential atmosphere.

The most surprising result from the dynamical modelling is the implication of a very small scale height \((H)\), namely 25 pc. This value was obtained by matching the aspect ratio of the superbubble as seen in Hα, assuming a distance of 2.35 kpc. The authors also point out that a small scale height is unavoidable in any model because the current maximum radius of the bubble must be significantly greater than \(H\) in order for the bubble to have become so elongated.
3. New HI data

Data from the CGPS pilot project (Normandeau, Taylor, & Dewdney 1997) were combined with observations of six new fields taken with the Dominion Radio Astrophysical Observatory’s Synthesis Telescope. The right-hand panel of Figure 1 shows the resulting mosaic for velocities near $-43.4 \, \text{km s}^{-1}$, again scaled by $\sin(b)$ to highlight the weaker high latitude emission.

3.1. Scale height

Using the data from complementary low resolution observations, which extend further up in latitude, almost to $+10^\circ$, and fitting an exponential to the decay in column density, a scale height of roughly 140 pc is found for the HI in the vicinity of the superbubble. Apart from the contradiction with the prediction by BJM99, this result is not particularly surprising: scale heights for the neutral medium are in the 100-200 pc range. It does suggest that the local medium into which the superbubble grew is quite different even from the relatively nearby gas.

3.2. Open or closed?

In the new data, there is no evidence of a cap at high latitudes in the HI. The eastern HI wall of the superbubble is clearly visible up to $5.5^\circ$, at which point it curves slightly inward and disappears. The western wall is only well defined up to $3.4^\circ$. An open geometry in HI images and a closed one in data showing ionised gas are not mutually exclusive as pointed out by BJM99. The superbubble’s shell could be sufficiently thin at high latitudes that while it closes the shell and prevents streaming of gas towards higher latitudes, it does not trap the ionizing radiation which then obliterates the HI at higher latitudes.

Extending approximately from $(134.2^\circ, +6.0^\circ)$ to $(134.2^\circ, +7.3^\circ)$, there is a small filament of HI pointing upward, away from the plane, which may be the signature of recent break out. This low level feature is present in four channels of the mosaic, from $-41.76 \, \text{km s}^{-1}$ to $-46.70 \, \text{km s}^{-1}$. It is suggestive that it is perpendicular to the tangent to and at the (high longitude) extremity of an equally faint arc of HI. This arc follows the natural line that flows from the low longitude wall to the high longitude one as seen in the HI and seems to mark the boundary beyond which the HI emission is less at these velocities. The faint arc is below the latitude of the cap claimed by DTS97 and therefore below the upper boundary of the best fit Kompaneets model by BJM99. The upper tip of the vertical filament is above the latitude claimed for the ionized cap suggested by the DTS97 data.

3.3. Shape

It is noticeable that the OCl 352 cluster is at the base of the HI cone, as was described in NTD96 whereas the Kompaneets model by BJM99, which was fit primarily to the H$\alpha$ image, shows a bubble extending to lower latitudes, to the base of the ionized gas loop which forms the lower half of W4.

This cone shape with an energy source at the apex is not unique, something similar is seen at the base of the Aquila supershell (Maciejewski et al. 1996),
but it is unclear how such a structure could form. The W4 cone extends approximately 200 pc upward from the OCl 352 cluster, based on the well-defined upper longitude wall. This is comparable to the cone at the base of the Aquila supershell which extends roughly 175 pc for an assumed distance of 3.3 kpc.

Tenorio-Tagle, Różycka, & Yorke (1985) present models of supernova remnants crossing large density discontinuities which result in shapes that are more conical than ellipsoidal. The opening angle of the structure above W4 is more regular however, it is more nearly a cone than are the models.

4. Conclusions and future endeavours

The classification of the structure above the W4 HII region, whether a super-bubble or a chimney, remains undecided at this time. It may be an object in transition between the two phases of evolution. However, it is clear that there is no impediment to ionizing radiation escaping towards higher latitudes and therefore the OCl 352 cluster can contribute to maintaining the Reynolds layer of ionized gas via this conduit.

Along with the HI data, the DRAO observations also yield images of the radio continuum at two frequencies, with full polarimetric information at 1420 MHz. It is hoped that the latter data set will help to confirm or infirm the marginal detection of a possible cap in the Hα emission.

The shape of the structure along with the scale height of the adjacent gas present challenges for modelling. The scale height inferred from the aspect ratio is surprisingly small and may reflect a local enhancement. The walls are very straight, making the structure conical rather than ellipsoidal as are the results of most models. The location of the presumed energy source at the apex of the cone rather than within it is also unusual.

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