Part XI

Workshop

The Local Bubble is a breath-taking subject ...

... as a spontaneously organized workshop on Friday afternoon demonstrated.

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Workshop for Continued Discussion of the Local Bubble

Wilton T. Sanders[1] and Priscilla C. Frisch[2]

[1] Department of Physics, University of Wisconsin–Madison, 1150 University Avenue, Madison, WI 53706, USA
[2] Department of Astronomy and Astrophysics, University of Chicago, 5640 South Ellis Avenue, Chicago, IL 60637, USA

Abstract. At the end of the regularly scheduled conference, the organizers made available a large sunny conference room for the remaining participants to continue discussion. The main topics were the structure of the Local Bubble and the properties of the Galactic X-ray halo. Here we try to summarize the main points of those discussions.

1 Introduction

The above topics, and others that participants brought to the workshop, generated three more hours of creative and lively discussion. Remarkably, the discussion was able to stay focused on one particular topic for quite a long time, although excursions into related areas were common. The broad-ranging fast-paced nature of the discussions and the at-times-dizzying shifts in topic make it impossible to give a detailed summary of what was said or who said it. Over half of the conference attendees participated in the workshop, and we apologize for mentioning only a few names here.

2 The Structure of the Local Bubble

By far the most time was spent trying to find agreement on what might naively appear to be easy at a conference on the Local Bubble: what is the gross structure of the Local Bubble? and how did it get that way? It was apparent that each person had a slightly different picture in mind. Two competing pictures came out in the presentations by Egger and by Frisch and their contributions to this volume should be read for more details. An important part of each of these pictures is the relationship between the Local Bubble and disturbances in the interstellar medium caused by the hot stars of the nearby Scorpius-Centaurus OB association.

In the Egger picture, the interaction of the Local Bubble shell with the Loop I superbubble shell generated by stellar winds or supernovae from the Sco-Cen stars results in a circular ring of neutral hydrogen at the location of the interaction of these two shells. Inside this ring is a sheet of neutral hydrogen, a relatively dense "interaction wall," separating the two bubbles with the distance from the Sun to the wall set at 40 ± 25 pc by optical absorption lines. In this picture, the Local Bubble shell and the soft X-ray background were formed by a separate supernova explosion near the Sun.

The arguments in support of this view come from the ROSAT XRT/PSPC observations of the soft X-ray sky within $\sim$ 70 degrees of the center of the Sco-Cen association. These show large portions of a ring in absorption against the soft X-ray brightening from the interior of the Sco-Cen bubble. There are neutral hydrogen ridges or filaments coincident with this ring of increased X-ray absorption, and optical absorption measurements put their distance at roughly 70 pc. Earlier, these filaments were viewed as lying on the stellar wind bubble created by the Sco-Cen stars (Weaver 1979).

The Frisch picture begins with the view that there is not a separate supernova remnant surrounding the Sun, but that the Sun is located in an interarm region of our Galaxy where superbubble expansion would have taken place in an inhomogeneous medium. Frisch argues that superbubble shells formed by earlier star formation episodes in Sco-Cen will have swept past the Sun into the low density interarm region, and that the Sun is now embedded in a shell of a $\sim$ 4 Myr old superbubble or supernova from Sco-Cen. In this picture, the evolution of stars in Sco-Cen drives the observed outflow of interstellar gas, and the Local Bubble cavity is an artifact of the interaction of the initial Sco-Cen superbubble with the interarm region. Frisch claims that the general flow of interstellar matter from the Sco-Cen region, in which virtually all interstellar absorption lines seen in stars within 50 pc of the Sun have velocities between 0 and -20 km s^{-1} in the local standard of rest, is difficult to interpret if the Sun were immersed in a supernova remnant distributed symmetrically about the Sun, but is naturally explained in her picture.

In the Frisch picture the first and second of the Sco-Cen shells have passed the solar neighborhood and are responsible for the local hot plasma that we call the Local Bubble, but the third shell is only now reaching the Sun. A variation on this picture was suggested in which the third shell has not yet reached the Sun and is responsible for the hydrogen feature that Egger calls the wall, and possibly the ring also. The clouds seen in optical absorption lines and moving through the solar neighborhood from the direction of Sco-Cen at $\sim$ 15 km s^{-1} could be stragglers from the passing of the second shell, or they could be early arrivals associated with the third shell.

Heiles indicated that the 21 cm data show neutral material flowing towards the Sun from the general direction of Sco-Cen, but the direction of origin of the flow is not centered on Egger's ring, nor is it particularly associated with any of the Sco-Cen sub-associations.

Egger and Snowden argued that the lack of a general soft X-ray enhancement at energies less than 0.28 keV towards Sco-Cen required an $N_{\rm H}$ "wall" of at least 10^{20} cm^{-2} between the Sun and Sco-Cen. Frisch countered that a uniformly distributed neutral wall separating the Local Bubble and the

Sco-Cen superbubble does not exist because there are stars well beyond the distance of the "wall" that have an $N_{\rm H}$ of 1 - 3 $\times 10^{19}$ cm^{-2} (λ Sco and β Cen), so if there is a wall, it must be patchy or partially ionized.

Other data were considered to see if they could help decide between these two pictures. ROSAT WFC observations of white dwarfs and late-type stars are consistent with the Sun being in a Local Bubble with a wall towards the Galactic Center direction, but at a distance of 30 pc. The pressure of the Local Bubble was discussed, but did not appear to favor either picture. The velocities of the walls of the Local Bubble in various directions could be used to check for consistency with either picture, but there was not enough data in the hands of the workshop participants to come to a conclusion. If the wall velocities were more nearly in radial expansion in all directions, it would favor the Egger picture, while if there were an asymmetric flow in the wall velocities aligned with an axis away from Sco-Cen, it would favor the Frisch picture. Further analysis of the X-ray spectrum of the soft X-ray background (see presentation by Sanders), or additional measurements to look for spectral differences in different directions, may be able to distinguish among different plasma emission mechanisms and therefore models for the origin of the hot plasma.

A problem that was brought out in the workshop about the Frisch hypothesis is that it relies on a simple model of superbubble formation and neglects the radiative cooling of the bubble interior that occurs between star formation epochs.

At some point in the discussion, we mostly agreed that there was a ring of neutral hydrogen between the Sun and the Sco-Cen bubble and that its distance was of order 70 pc, but the cause of the ring was still being debated. The existence of a dense "wall" interior to the ring was accepted by the adherents to the Egger picture, but denied by the Frisch camp. And that's how we left it.

3 The Properties of the Galactic X-ray Halo

Two quite different pictures of the Galactic X-ray halo were presented by Snowden and by Wang, and their contributions to this volume should also be read for more details. The X-ray halo described by Snowden is very patchy and has a temperature, T $\lesssim 10^6$ K, while the corona described by Wang varies smoothly over the sky and covers a range of temperatures, from T $< 0.5\times10^6$ K in the outer Galaxy to T $> 5\times10^6$ K towards the center of the Galaxy. The easiest way to reconcile these two pictures is for the Snowden halo and the Wang corona to have different origins and to be located at different heights above the plane of the Galaxy.

Wang assumed that the corona is quasi-hydrostatic in the gravitational potential of the Galaxy, using the potential described by Wolfire et al. (1995), and assumed a polytropic equation of state for the gas with index 5/3. The

Wang corona extends more than 10 kpc above the galactic plane and more than 15 kpc radially from the galactic center, and could be interpreted as a hot outflow from the center of the Galaxy. The Snowden halo needs only to be above the neutral hydrogen gas layer of the galaxy, less than 1 kpc from the plane, and to have characteristic scale sizes of hundreds of pc.

The origin of the Snowden halo is not clear. Galactic fountains and winds, the Breitschwerdt and Schmutzler model, and supernovae in the halo were among the many mechanisms touched upon in the discussion. Again, understanding the spectra of the soft X-ray background was mentioned as a way to distinguish among the possible mechanisms for the Snowden halo, and as a check on the Wang corona.

A tangent to this discussion led to high latitude clouds and it was noted that there was still much information about the halo contained in observations of high latitude clouds that was not yet fully exploited. Of particular interest were the velocity distributions of neutral clouds and the wings of lines from low ionization state ions. But the difficulty of separating clouds from the intercloud gas was also noted as part of the reason for the lack of progress.

4 Conclusions

The origin of the soft X-ray background, both the halo component and the Local Bubble component, will not be understood until the spectrum is adequately modeled.

The resolution of the issue of whether or not the Local Bubble is the result of a separate supernova remnant will rest on both the correct interpretation of the soft X-ray data and an understanding of the sequence of propagating star formation in Sco-Cen which has evidently taken place, and how this star formation relates to the bright X-ray emission associated with Sco-Cen.

In the 3/4 keV band, Galactic center emission must be separated from the Sco-Cen contribution to make sense of either emission component.

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