The Diffuse Interstellar Bands
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Probing the Local Bubble with Diffuse Interstellar Bands

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Abstract. The Sun is located inside an enormous local cavity filled with a million degree, ionized hydrogen gas and surrounded by a wall of dense and cold gas, this cavity is known as the Local Bubble (LB). Since the tempreture of Local Bubble is high, the typical singly-ionized atoms or molecules can not survive at this high tempreture. To overcome this problem we should probe the Local Bubble using species which survive under this condition so we have done a whole sky survey in north hemisphere by observing absorptions in the Diffuse Interstellar Bands (DIBs) for sight-lines with distance >300 pc. We have done 30 nights observation and have observed 473 bright stars. We found that the correlations between 5780 Å DIBs and Na I D doublets inside of the LB is much more than carriers outside of the LB.

Keywords. ISM: molecules, ISM: structure, ISM: lines and bands

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1. Introduction

The interstellar medium (ISM) is an extra-ordinarily dynamic place where cooling and heating processes are continuously at work to transform gas between different states, from hot ionized gas with $T \sim 10^6 K$ visible in X-rays to a cold neutral medium with $T \leqslant 100K$ visible in HI and far-infrared emission (Heiles & Troland 2005). The dynamics influence the formation of small-scale structure in the form of filaments and small clumps, which must be transient features as they are out of pressure equilibrium with their surroundings (Stanimirovis & Heiles 2005).

The Sun and many nearby stars are located inside a large hot ($\sim 10^6$ K) cavity with low gas density in the interstellar medium. The Sun lies nearly in the middle of this enormous local cavity which is known as the Local Bubble. The Local Bubble has a million degree, ionized hydrogen gas, surrounded by a wall of colder, denser neutral gas and extends for $\sim$ 100 pc in the plane of Galaxy and for hundreds of parsecs vertically presumably as far as the Galactic Halo (Welsh *et al.* 2010).

The low value of density in the Local Bubble first was detected by very low values of interstellar extinction measured for stars within a distance of $\sim$ 100 pc, as compared with the reddening of more distant regions of the galaxy (Fitzgerald 1968), another reason for this low gas density was found by the small H I column densities derived from Ly-α absorption measurements of nearby stars (Bohlin 1975) and the third reason is the lack of spectral hardening in the observed soft X-ray background signal (Bowyer *et al.* 1968). Then the first evidence for the existence of the Local Bubble was provided by observations of a diffuse soft X-ray background by the ROSAT satellite which was interpreted as indicating that the Sun was surrounded by a region of hot ($\sim 10^6$ K) gas.

According to Welsh *et al.* (2010) survey, in nearby stars to the distance of 300 pc, the distribution of neutral sodium absorptions reveal that the Local Bubble surrounding the Sun is about 100 pc in the galactic plane, this maps reveal two chimneys towards the halos and the cavity is tilted of about 20° towards the Galactic center, so the Local Bubble has a chimney shape in 3D.

The formation of such large cavity in the ISM, its age, the evolution and the composition of material inside the Local Bubble is not clear yet. The most plausible model in our view is that the Local Bubble has been created by a number of successive supernovae in the nearby (170 pc) Sco-Cen OB association that occurred about 2 Myr ago and this powerful winds of supernova explosions are responsible for the creation of this cavity.

The conditions in the ISM are typically probed via lines arising from neutral or singly-ionized atoms or molecules. Such atoms or molecules can not survive at the high temperature inside the Local Bubble so the understanding of the nature of the Local Bubble is complicated. To overcome this problem we should probe the Local Bubble using species which survive under this condition so we intend to use absorption in the Diffuse Interstellar Bands (DIBs). van Loon *et al.* (2009) shows that DIBs are seen in the relatively harsh environments such as the Disc-Halo interface and the high $\lambda5780/\lambda5797$ ratio indicates the existence of an interface between cool/warm and hot gas. So in this paper, we aim to use DIBs to probe the interaction region (the wall of LB) between hot gas in the bubble and its cooler neutral surroundings as well as looking for neutral structures located within the bubble itself. The neutral structures within the Local Bubble will be indicative of thermal instabilities leading to cold compact structures immersed within the hot gas.

The layout of this paper is as follows. First we describe the observations of our survey, then the results of data analysis will be explained.

2. Observations

Our targets have been taken from the 3D mapping of dense interstellar gas around the Local Bubble of Welsh *et al.* (2010). All of the selected objects have well-known distance from Hipparcos, spectral type earlier than A5 and most have accurate Na I D measurements. The targets are all bright, isolated stars so we need medium resolution spectroscopy.

We have done 30 nights observation in five times - October 2011, March 2012, September 2012, January 2013 and May 2013 - and as is shown in Fig. 1 our observations cover all northen hemisphere. In all these nights we have observed 473 target, all of them are within 300 pc. The selected targets are bright with V magnitude in the range 2–9 mag, so the spectroscopic measurements were not affected by moonlight.

A 2.5m-class telescope was sufficient for our purpose, so we use IDS spectrograph of INT Telescope with the 235mm camera. IDS is offered with a set of 16 gratings and has two CCDs, the blue-sensitive EEV10 CCD (4096×2048 pixels) and the new RED+2 detector (4096×2048 pixels). For our observations we use RED+2 detector with grating H1800V for effective resolution 0.31 Å/pix. The 235mm camera with the RED+2 CCD provides a spatial scale of 0.40 arcsec/pixel. H1800V is chosen as it provides a high spectral resolution well-matched to the typical width of DIBs and its wavelength coverage a range of 300 Å and includes the major $\lambda5780$, 5797, 5850, 6196 & 6203 DIBs. In this range we have two photosheric CaI and HeI absorptions as well as of the Na I doublet.

For detection of DIBs, we need a very high signal-to-noise ratio of at least 100 but for detection of very weak absorption like the one which was detected by Cordiner (2006) towards the nearby star μ^1 Cru with 5780 DIB equivalent width of 4 mÅ we need

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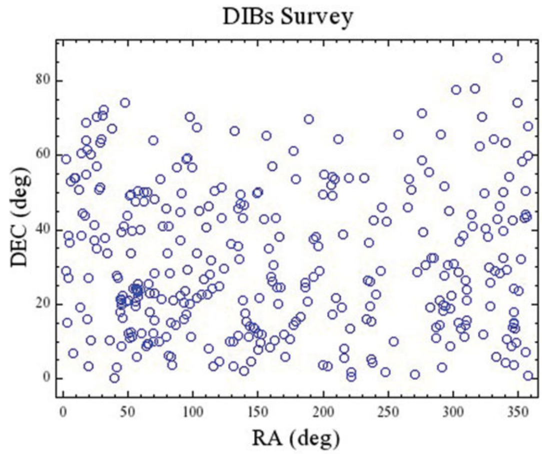

Figure 1. All observed targets in the northern hemisphere.

signal-to-noise ratio of at least 1000. A large number of targets are required to populate the volume of the Local Bubble sufficiently densely to allow derivation of the three-dimensional distribution and as mentioned our target list contains 473 stars. So this allow an average distribution of one star at every 30 pc (for comparison, Welsh *et al.* (2010) used 1800 stars to reach down to scales of 20 pc over both hemispheres).

2.1. *Diffuse Interstellar Bands (DIBs)*

The DIBs are a set of over 400 broad optical absorption features which are seen to be ubiquitous throughout the ISM. Heger (1922) first observed them, but the origin of DIBs is unknown and has been debated for many years, however today most researchers believe that organic matter in the form of large Polycyclic Aromatic Hydrocarbon (PAH) structures are responsible for the absorptions. Such molecules are resistant to UV radiation. Although the signal-to-noise required is high, Cordiner (2006) has shown DIB absorption towards stars within the Local Bubble with very unusual band ratios (e.g., $\lambda5780/\lambda5797$). We have seen very weak DIBs features because of very low reddening towards our stellar probes, but as shown by van Loon *et al.* (2009) DIBs are also seen in the relatively harsh environments such as the Disc-Halo interface and the high $\lambda5780/\lambda5797$ ratio indicates the existence of an interface between cool/warm and hot gas. This opens the possibility of probing the distribution and conditions within the Local Bubble via DIBs absorption, whilst constraints on the nature of carriers can be provided by the differences in distribution of the various DIBs carriers.

3. Results

Moutou (1999), in spectra of nearby stars, showed that there is a correlation between 6614 Å , 5780 and 5797 Å DIBs and van Loon *et al.* (2013) show that there is a correlation between 6614 Å and 4428 Å DIBs too, so the 4428, 5780, 5797 and 6614 Å DIBs are all correlated with one another. As is shown in Fig. 2 the correlation between 5780 Å and 5797 Å in whole distances is 0.5485 and the correlation for DIBs that lies inside of Local Bubble is 0.5524 and for DIBs outside of Local Bubble the correlation is 0.4982. With compare this correlations, all summarized in Table 1, we find that there are no large differences between DIBs inside and outside of the Local Bubble while the temperature inside of the LB is much higher than the temperature outside of LB.

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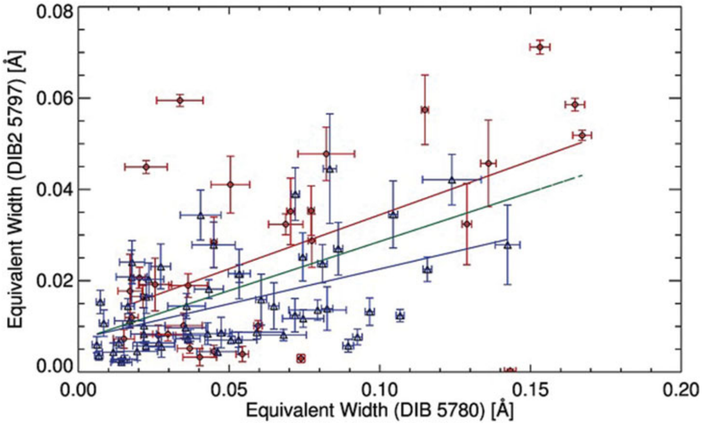

Figure 2. Correlation between 5780 Å and 5797 Å inside and outside of Local Bubble. The red line is a linear fit to targets inside of LB, blue is fit to targets outside of LB, and green is fit to all targets.

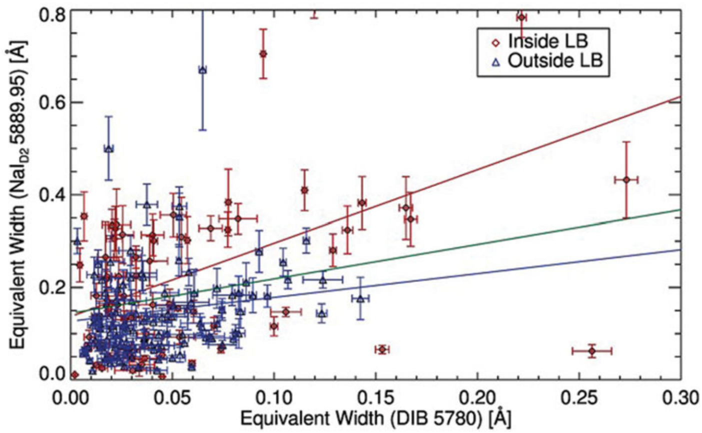

Figure 3. Correlation between 5780 Å and Na I D_2 5889.95 Å inside and outside of Local Bubble. The red line is a linear fit to targets inside of LB, blue is a fit to targets outside of LB and green is a fit to all targets.

For another correlation we check the correlations between 5780 Å DIBs and doublet of Sodium. As is shown in Fig. 3 the correlation between 5780 Å DIBs and Na I D_2 5889.95 Å for all distances is 0.4885, but if we just consider the absorption features inside of Local Bubble the correlation changes to 0.6764 and for carriers outside of Local Bubble the correlation is 0.4407, so the DIBs carriers inside of the Local Bubble are much more correlated with Na I D_2.

In the same way, according to Fig. 4 the correlation between 5780 Å DIBs and Na I D_1 5895.92 Å inside the Local Bubble is 0.6837 and for carriers outside of the Local Bubble $c = 0.3884$ while the correlation for all distances is 0.4488, so the DIBs carriers inside of LB are much more correlated with the sodium doublet compared to DIB carriers outside of the Local Bubble.

In our observed range we have two photospheric feature that arise from the photosphere of target stars and are not from the ISM, so according to Table 1 there is not any correlation between 5780 Å and Ca I 5857 Å and He I 5875.6 Å.

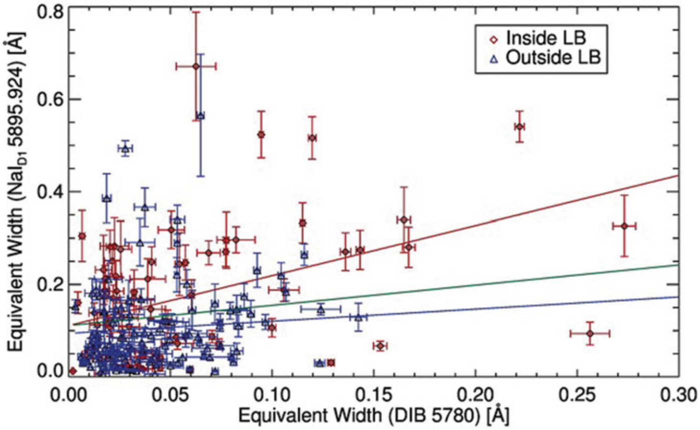

Figure 4. Correlation between 5780 Å and Na I D_1 5895.92 Å inside and outside of Local Bubble. The red line is linear fit to targets inside of LB, blue is a fit to targets outside of LB and green is a fit to all targets.

Table 1. The correlation between 5780 Å DIB and other absorption features in our observed range. The correlations between absorptions inside of the LB are much stronger than for features that lie outside of the LB.

	DIBs 5797Å	Ca I 5857Å	He I 5875.6Å	Na I D_2 5889.95Å	Na I D_1 5895.92Å
Inside LB	0.5524	0.0882	0.084	0.6764	0.6837
Outside LB	0.4982	0.0505	0.276	0.4407	0.3884
In whole	0.5485	0.0002	0.093	0.4885	0.4488

These results represent a preliminary analysis of results to be described in detail in a forthcoming publication.

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