A Compilation of Interstellar Lines

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Abstract

We have collated absorption line data toward 3014 stars (Fig. 1) in order to create a unified database of interstellar column densities. These data have been taken from a number of different published sources and include many different species and ionizations. The preliminary results from our analysis show a tight relation between N(H) and E(B–V) i.e. [N(H)/E(B–V) = 6.12x10^{21}]. Similar plots have been obtained with many different species, and their correlations along with the correlation coefficients are presented.

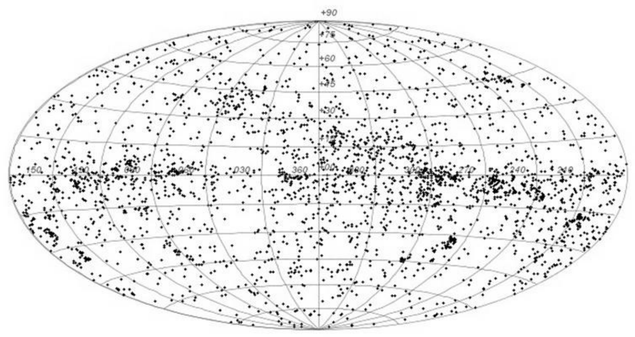

Figure 1. Distribution of observed stars plotted in an Aitoff plot with the Galactic center at the origin

Introduction

The interstellar medium is of prime importance as it governs the dynamics and energetic of the Galaxy and also affects our perception of stars and extragalactic objects. The purpose of this work is to understand the structure and dynamics of the interstellar medium through the absorption line observations of stars in our Galaxy, which is the only place where we have the spatial resolution to separate the different components and develop models for other galaxies.

The objectives of this work are :

1. To create a database of interstellar absorption line data
2. To resolve inconsistencies in the database, which is comprised of many different observations and atomic and molecular species
3. To derive a three dimensional map of the gas in the Galaxy
4. To derive the kinematics and dynamics of the interstellar gas
5. To create a template through which observations of other galaxies may be interpreted

Data & Analysis

We have tabulated the absorption line data towards the 3014 targets in Table 1. It includes the coordinates, spectral type and distance of each star and the column density of each species observed along that line of sight. Many sight lines had multiple observations and we consistently selected the last published and listed those in Table 2, which is a subset of Table 1. The complete reference list is tabulated in Table 3. All three tables will be published online and a sample table for each is given here.

We find a tight relation between E(B–V) and N(H) with a slope of (6.1±0.2)x10^{21} atoms cm^{-2} mag^{-1} (Fig. 2). This slope is close to the slope of 5.8x10^{21} atoms cm^{-2} mag^{-1} found in the classic work of Bohlin et al. (1978) but with almost five times as many lines of sight. Four stars in our sample fall far away from this mean relationship (filled circles in Fig. 2). These four stars (AzV 18, AzV 26, AzV 80 and AzV 476) are in the Small Magellanic Cloud (SMC), which has a low metallicity and hence a high gas-to-dust ratio (Lequeux et al. 1984; Cartledge et al. 2005).

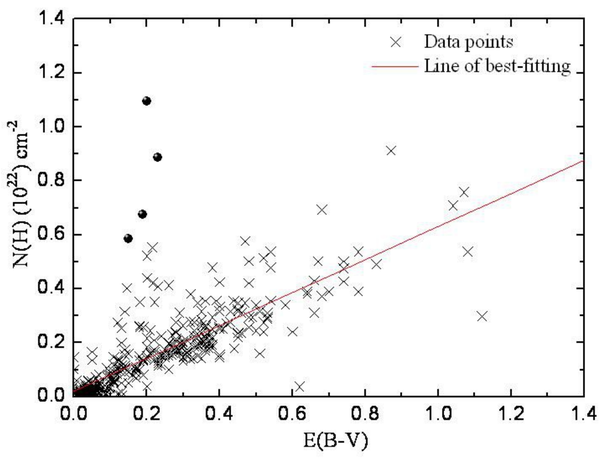

Figure 2. N(H) as function of E(B–V). The best-fit line has a slope of (6.1±0.2)x10^{21} atoms cm^{-2} mag^{-1}.

We have observations of many other species of different ionization states and their column density correlations with E(B–V) and N(H I) along with their correlation coefficients are tabulated in Table 4 and 5, respectively.

For instance, we find a fairly good correlation between singly ionised magnesium and neutral hydrogen with a slope of N(Mg II)/N(H I) being (7.6±0.3)x10^{-6} (Fig. 3). On the other hand, neutral magnesium is found to be correlated very poorly with H I. The ionisation energy of magnesium is low enough (7.5 eV) that most of the interstellar magnesium is in its ionised state and this is reflected in their respective abundances.

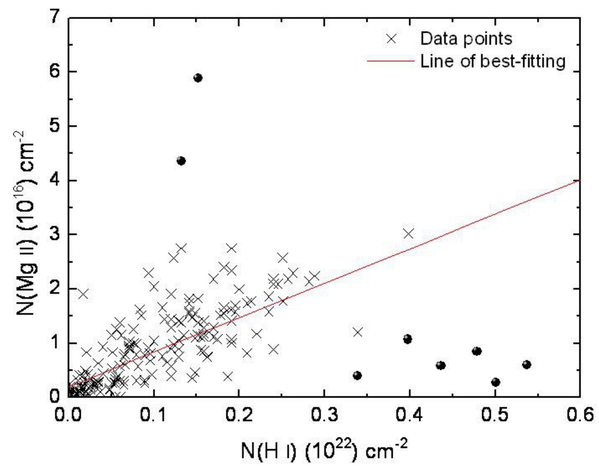

Figure 3. N(Mg II) as function of N(H I). The slope of line of best-fitting is (7.6±0.3)x10^{-6} atoms cm^{-2} mag^{-1}.

The stars HD 175360, HD 149038 and HD 209975 deviate from the correlation. The deviation for HD 175360 is probably due to contamination of the interstellar features by stellar lines (Cartledge et al. 2004) and the two sight lines (HD 149038 and HD 209975) have potential saturation problems (Jenkins, Savage & Spitzer 1986). Noted outliers also include HD 37021 and HD 37061 which are in Orion, HD 147933 from the Scorpius-Ophiuchus region, HD 63005 and HD 36841.

Similarly, the column density of neutral oxygen shows a good correlation with N(H I), whereas O VI, which arises in a much hotter phase of the interstellar medium, shows more scatter with N(H I). Regions that contain collisionally ionized gas at temperatures above 10^5 K, and thus show O VI, are unrelated to the cooler neutral gas that holds the H I. The fact that the two show some correlation is probably due entirely to the fact that with stars at larger distances, both species independently have their column densities increase.

Appendix

All data were taken directly from the published work except for the sky coordinates, spectral type, B, V, and K which were taken from the Simbad database, if not referenced in the original work. Stellar distances were taken from Hipparcos (Van Leeuwene 2007) for those stars closer than 300 pc, otherwise from the published works. Both tables have been sorted by HD number, primarily, but with other subgroups when not available (variable stars are listed as a subgroup towards the end only in Table 2).

S.No (1)	Star name (2)	E(B-V) (9)	Ref. (10)	N(Ca II) cm^{-2} (61)	Ref. (64)	N(H I) cm^{-2} (129)	Ref. (132)
1	AzV 018	0.200	34	1.0965E+13	34	9.0100E+21	31
2	AzV 018	0.174	31	8.5114E+12	34, 649	1.0965E+22	34
3	AzV 026	0.150	34	6.7608E+12	34	5.0119E+21	34
4	AzV 026	-999	-999	-999	-999	-999	-999
5	AzV 047	0.130	34	5.0119E+12	34	1.9953E+21	34
6	AzV 047	-999	-999	-999	-999	-999	-999
7	AzV 070	-999	-999	-999	-999	-999	-999
8	AzV 080	0.190	34	6.6069E+12	34	6.4565E+21	34
9	AzV 095	0.140	34	5.1286E+12	34	3.0903E+21	34
10	AzV 095	-999	-999	-999	-999	-999	-999

Table 1. Observed stellar parameters. The columns (1), (2), (9), (10), (61), (64), (129) and (132) represent the columns in the full table. '-999' indicate values that are not available.

S.No (1)	Star name (2)	E(B-V) (9)	Ref. (10)	N(Ca II) cm^{-2} (61)	Ref. (64)	N(H I) cm^{-2} (129)	Ref. (132)
1	AzV 018	0.200	34	1.0965E+13	34	1.0965E+22	34
2	AzV 026	0.150	34	6.7608E+12	34	5.0119E+21	34
3	AzV 047	0.130	34	5.0119E+12	34	1.9953E+21	34
4	AzV 070	-999	-999	-999	-999	-999	-999
5	AzV 080	0.190	34	6.6069E+12	34	6.4565E+21	34
6	AzV 095	0.140	34	5.1286E+12	34	3.0903E+21	34
7	AzV 120	0.090	34	4.8978E+12	34	-999	-999
8	AzV 207	0.120	34	5.8884E+12	34	2.6915E+21	34
9	AzV 214	-999	-999	7.2444E+12	649	2.5119E+21	647
10	AzV 321	0.120	34	2.8840E+12	34	-999	-999

Table 2. Observed stellar parameters. The columns (1), (2), (9), (10), (61), (64), (129) and (132) represent the columns in the full table. '-999' indicate values that are not available.

No.	Reference
1	Welsh & Lallement (2008)
2	Bowen et al. (2008)
3	Dixon & Sankrit (2008)
4	Dixon, Sankrit & Otte (2006)
5	Otte & Dixon (2006)
6	Savage & Lehner (2006)
7	Welsh & Lallement (2005)
8	Welsh, Sallmen & Jelinsky (2005)
9	Larson & Whittet (2005)
10	Oegerle et al. (2005)

Table 3. References for data

No. of sight lines	Correlations (atoms cm^{-2})	Error in slope	Correlation coefficient, R
55	N(Kr I) = 3.46x10^{10} + 7.67x10^{12} *E(B–V)*	0.66x10^{12}	0.85
207	N(CH) = -8.19x10^{12} + 6.67x10^{13} *E(B–V)*	0.29x10^{13}	0.85
374	N(H) = 1.87x10^{20} + 6.12x10^{21} *E(B–V)*	0.20x10^{21}	0.84
82	N(Cl I) = - 4.04x10^{12} + 2.50x10^{14} *E(B–V)*	0.19x10^{14}	0.83
139	N(O I) = 2.29x10^{16} + 2.45x10^{18} *E(B–V)*	0.15x10^{18}	0.81
396	N(H_2) = - 9.08x10^{19} + 1.19x10^{21} *E(B–V)*	0.04x10^{21}	0.81
66	N(Ge II) = 5.94x10^{11} + 4.47x10^{12} *E(B–V)*	0.46x10^{12}	0.77
42	N(Cu II) = 6.23x10^{11} + 6.95x10^{12} *E(B–V)*	0.93x10^{12}	0.76
94	N(N I) = - 1.97x10^{16} + 4.33x10^{17} *E(B–V)*	0.41x10^{17}	0.74
186	N(K I) = 2.65x10^{11} + 1.60x10^{12} *E(B–V)*	0.11x10^{12}	0.73
72	N(C_2) = 4.15x10^{12} + 5.63x10^{13} *E(B–V)*	0.65x10^{13}	0.72
326	N(Mn II) = 7.22x10^{12} + 8.31x10^{13} *E(B–V)*	0.48x10^{13}	0.69
173	N(CH+) = 1.33x10^{12} + 3.16x10^{13} *E(B–V)*	0.26x10^{13}	0.68
40	N(HD) = -1.99x10^{15} + 1.02x10^{16} *E(B–V)*	0.20x10^{16}	0.64
125	N(P II) = 2.48x10^{13} + 4.85x10^{14} *E(B–V)*	0.54x10^{14}	0.63
444	N(Ca II) = 6.88x10^{11} + 8.04x10^{12} *E(B–V)*	0.49x10^{12}	0.62
48	N(Mg I) = 8.02x10^{11} + 1.07x10^{14} *E(B–V)*	0.21x10^{14}	0.60
130	N(CN) = -3.93x10^{12} + 1.95x10^{13} *E(B–V)*	0.23x10^{13}	0.60

Table 4. The summary of the correlations obtained with E(B–V)

No. of sight lines	Correlations (atoms cm^{-2})	Error in slope	Correlation coefficient, R
56	N(C II) = -3.13x10^{15} + 2.69x10^{-4} N(H I)	0.06x10^{-4}	0.99
61	N(D I) = 1.67x10^{14} + 8.84x10^{-6} N(H I)	0.24x10^{-6}	0.98
221	N(Mg II) = 1.15x10^{15} + 7.58x10^{-6} N(H I)	0.34x10^{-6}	0.83
36	N(Cu II) = 9.61x10^{11} + 1.03x10^{-9} N(H I)	0.12x10^{-9}	0.83
159	N(O I) = 1.14x10^{17} + 4.48x10^{-4} N(H I)	0.24x10^{-4}	0.83
52	N(Kr I) = 6.43x10^{11} + 1.06x10^{-9} N(H I)	0.10x10^{-9}	0.82
123	N(P II) = 6.77x10^{12} + 1.34x10^{-7}N(H I)	0.09x10^{-7}	0.79
104	N(N I) = -3.75x10^{14} + 9.34x10^{-5} N(H I)	0.73x10^{-5}	0.78
58	N(Ge II) = 7.66x10^{11} + 7.59x10^{-10} N(H I)	0.93x10^{-10}	0.74
77	N(Cl I) = -1.68x10^{12} + 4.86x10^{-8} N(H I)	0.54x10^{-8}	0.72
417	N(Ca II) = 7.06x10^{11} + 1.28x10^{-9} N(H I)	0.07x10^{-9}	0.67
329	N(Ti II) = 4.65x10^{11} + 8.88x10^{-10} N(H I)	0.54x10^{-10}	0.67
319	N(Mn II) = 6.56x10^{12} + 1.65x10^{-8} N(H I)	0.11x10^{-8}	0.66
129	N(CH+) = 7.80x10^{11} + 7.10x10^{-9} N(H I)	0.79x10^{-9}	0.62
84	N(Cl II) = 1.25x10^{13} + 7.37x10^{-8} N(H I)	1.10x10^{-8}	0.60

Table 5. The summary of the correlations obtained with N(H I)

Conclusion

We have collated absorption lines from a number of different published sources in order to create a unified database of interstellar column densities. These data are interesting in their own right and we plan to use them to explore the three-dimensional morphology of the interstellar medium, but will also be invaluable in correcting for the effects of interstellar absorption in other observations. We plan to continue updating the data as well as building a tool for ready access to the data and to column density predictions in different directions. We are also working on developing and testing models of the interstellar medium using these and other data.

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***** This work has been submitted to ApJS (Astrophysical Journal Supplement Series) and is currently under review.***

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