Interstellar Abundances of Boron and Neutron-Capture Elements from *HST*/STIS Spectroscopy

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Abstract: The wealth of UV spectroscopic data contained in the *HST*/STIS archive has enabled detailed studies of the interstellar abundances of rare elements with poorly-understood nucleosynthetic origins. In particular, *HST* provides the only means of studying the abundance of the spallogenic element B and has also yielded information on the abundances of neutron-capture elements, such as Ga, Ge, As, Kr, Cd, Sn, and Pb. Our understanding of the various processes responsible for the synthesis of these elements (i.e., cosmic-ray and neutrino-induced spallation for B; slow and rapid neutron-capture processes for the others) remains incomplete. Here, we present the results of the most comprehensive *HST*/STIS survey to date of the interstellar abundances of B, Ga, As, Cd, Sn, and Pb. We derive depletion parameters for each element (following the methodology of Jenkins 2009) and discuss the implications of our results for Galactic nucleosynthesis.

Motivation

The study of elemental abundances in the interstellar medium (ISM) is traditionally hampered by uncertainties related to the amount of dust grain depletion that exists for a given element or for a given line of sight. Recently, a new approach to characterizing interstellar depletion was presented by Jenkins (2009) for the more abundant elements in the ISM. Here, we extend the Jenkins methodology to the rare elements B, Ga, As, Cd, Sn, and Pb in an effort to more fully understand the depletion process and to glean important information about aspects of Galactic nucleosynthesis that remain uncertain.

Archival *HST*/STIS Survey

Building on our recent comprehensive survey of interstellar B II λ1362 (Ritchey et al. 2011), which also included measurements for Ga II λ1414, we mined the STIS archive for new detections of As II λ1263, Sn II λ1400, Pb II λ1433, and Cd II λ2145. The final sample triples the number of sight lines with published abundances for these species. Our survey probes both low and high-density regions of the diffuse ISM out to a few kpc, mostly in the Galactic plane.

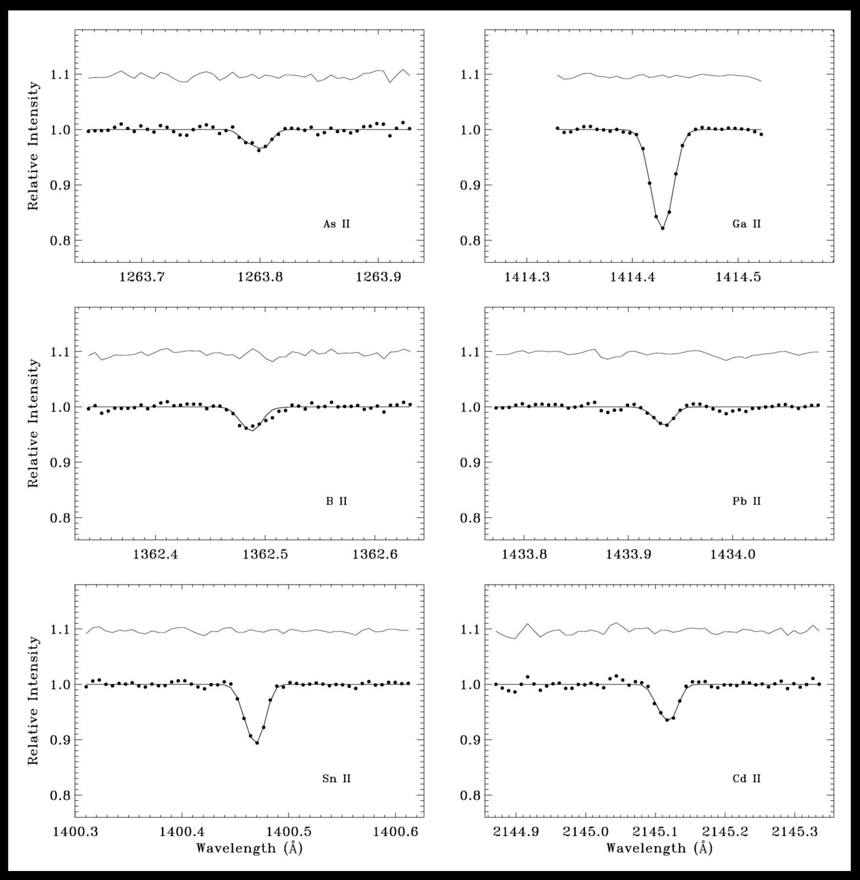

Figure 1: Profile synthesis fits to the interstellar lines toward X Persei (HD 24534). The spectra are from high-resolution ($R \approx 100{,}000$) STIS observations using the E140H and E230H gratings. The profiles were modeled with two dominant absorption components separated by about 2 km s^{-1}. Residuals are given above each fit.

Column Densities through Profile Synthesis

Multiple Voigt profiles were fit to the observed spectra using the program ISMOD (developed by Y. Sheffer) to derive the column densities, *b*-values, and velocities of the absorption components. The O I λ1355 absorption profile was used as a template for the component structure in each direction.

Determination of Depletion Parameters

Following Jenkins (2009), we performed a linear least-squares fit to the gas-phase abundance data for each element. The linear function is given by

$$[X/H]_{\rm fit} = B_X + A_X(F_* - z_X),$$

where F_* is a generalized parameter describing the overall amount of depletion in a given line of sight, A_X is the depletion slope for a given element, and B_X is the depletion in that element at $F_* = z_X$.

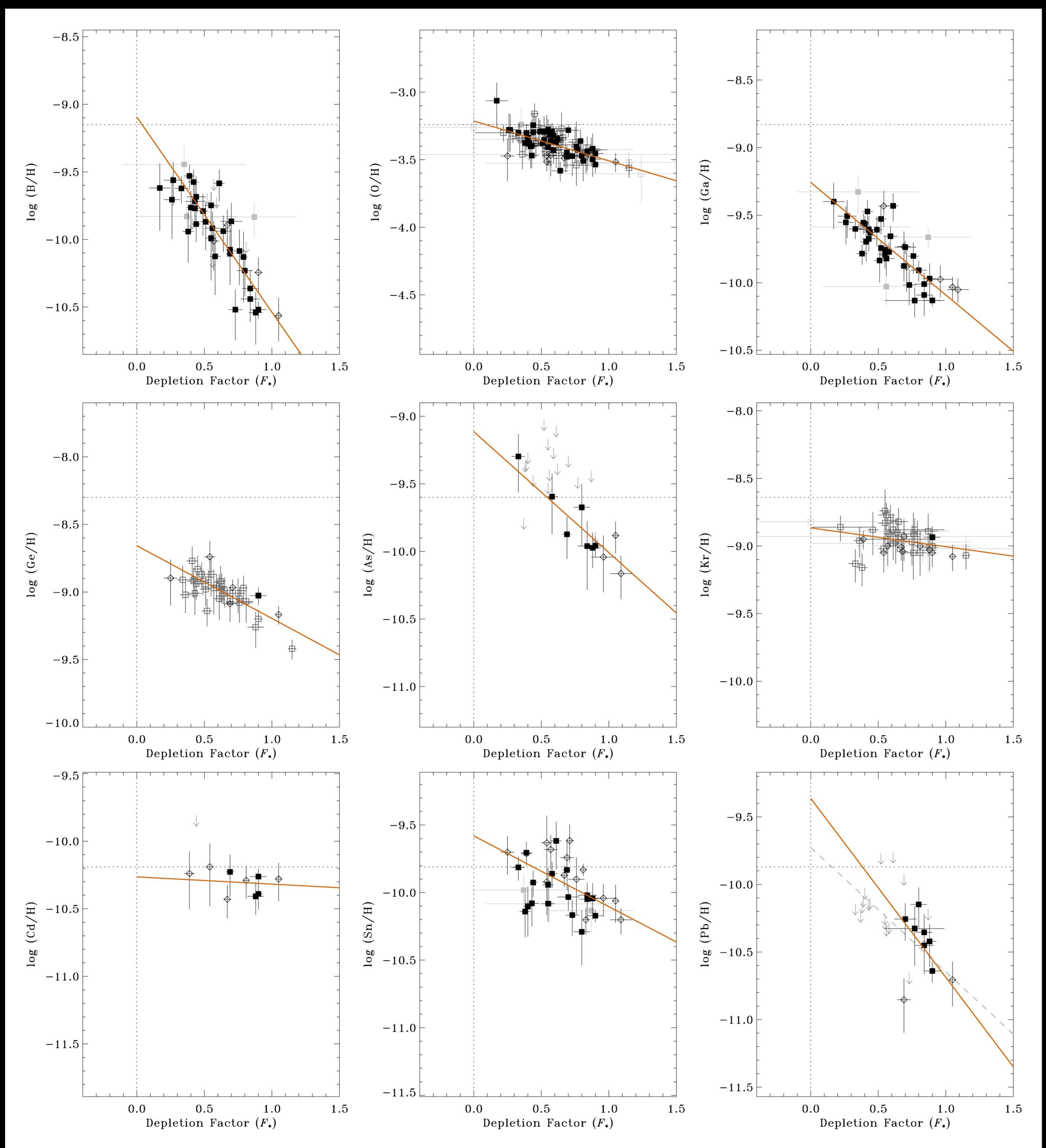

Figure 2: Linear least-squares fits to the gas-phase abundance data for B, O, Ga, Ge, As, Kr, Cd, Sn, and Pb. Values of F_* for each sight line were obtained from Jenkins (2009). Solid symbols (and upper limits) are our determinations; open symbols are data from the literature (squares: STIS; diamonds: GHRS). The horizontal dotted line in each panel gives the adopted solar system abundance from Lodders (2003). The fit results are listed in Table 1. Our results for O, Ge, and Kr are consistent with those of Jenkins (2009), who also examined these elements. Note that the slope for Pb is not particularly well defined because all of the measurements are clustered at high values of F_*. The dashed line in that panel gives the slope if the upper limits are included in the fit as if they were real detections. If this fit were adopted, the slope would be $A_X = -0.920 \pm 0.174$ and the depletion at $F_* = 0$ would be $[X/H]_0 = +0.143 \pm 0.136$.

Table 1: Element Depletion Parameters

Elem.	A_x	B_x	z_x	$[X/H]_0$	$[X/H]_1$	χ^2	ν	Prob. Worse Fit
B	−1.444 ± 0.113	−0.795 ± 0.047	0.590	+0.056 ± 0.081	−1.387 ± 0.066	43.5	36	0.181
O	−0.295 ± 0.044	−0.148 ± 0.051	0.595	+0.027 ± 0.057	−0.268 ± 0.054	68.1	88	0.942
Ga	−0.832 ± 0.069	−0.918 ± 0.062	0.589	−0.428 ± 0.074	−1.260 ± 0.068	55.6	40	0.051
Ge	−0.538 ± 0.072	−0.714 ± 0.052	0.662	−0.358 ± 0.071	−0.896 ± 0.058	30.5	36	0.725
As	−0.894 ± 0.216	−0.279 ± 0.069	0.855	+0.486 ± 0.197	−0.408 ± 0.075	6.3	8	0.609
Kr	−0.139 ± 0.063	−0.319 ± 0.081	0.670	−0.226 ± 0.092	−0.365 ± 0.084	30.2	44	0.944
Cd	−0.054 ± 0.218	−0.118 ± 0.050	0.829	−0.074 ± 0.187	−0.128 ± 0.063	4.8	7	0.686
Sn	−0.524 ± 0.075	−0.128 ± 0.044	0.683	+0.230 ± 0.067	−0.294 ± 0.050	81.3	33	<0.001
Pb	−1.324 ± 0.483	−0.622 ± 0.072	0.853	+0.507 ± 0.418	−0.817 ± 0.101	17.1	7	0.017

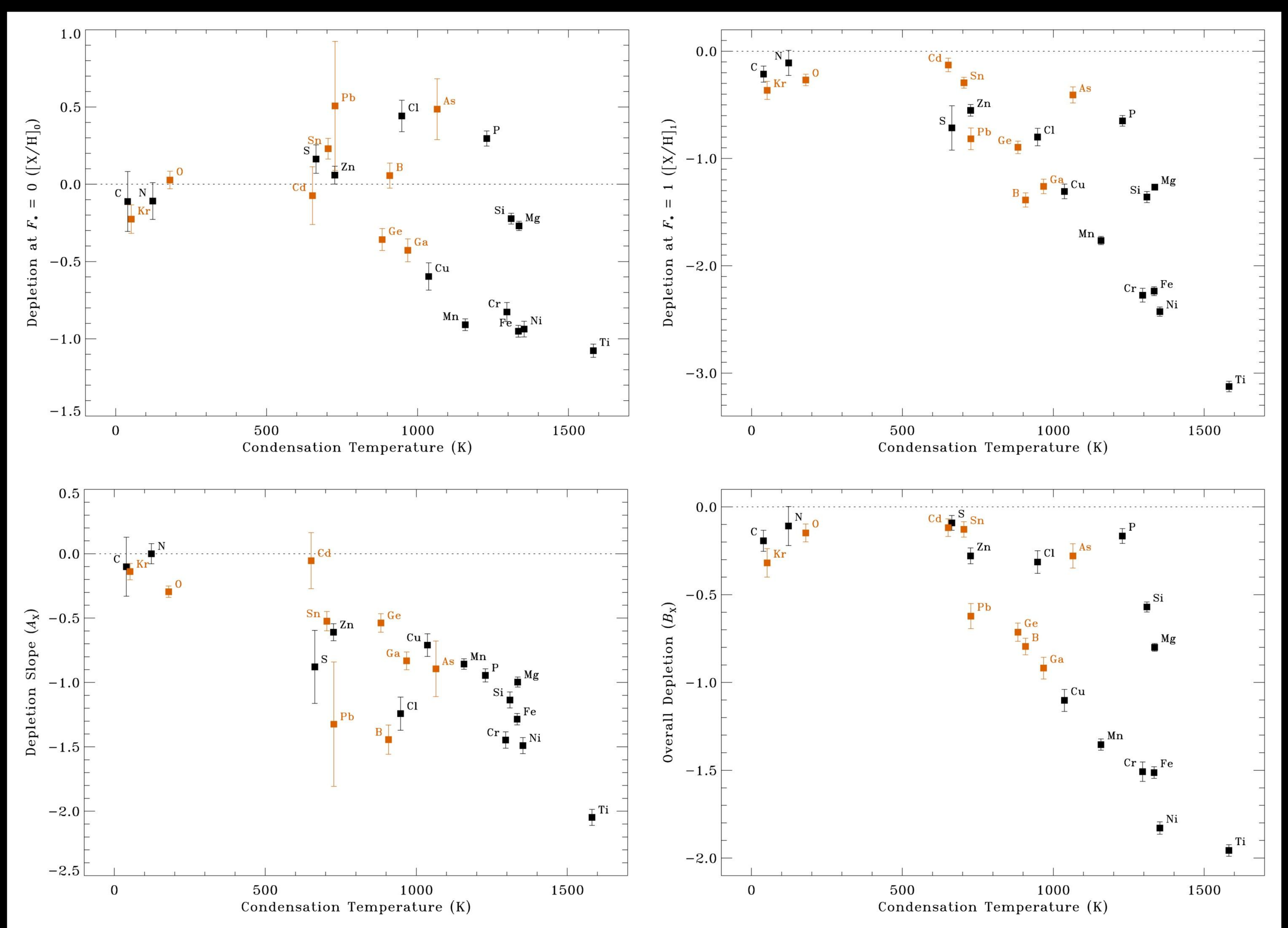

Figure 3: Trends versus condensation temperature ($T_{\rm cond}$). Orange symbols are new results; black are results from Jenkins (2009). Values of $T_{\rm cond}$ were adopted from Lodders (2003). **Upper Left:** Depletion at $F_* = 0$ versus $T_{\rm cond}$. **Upper Right:** Depletion at $F_* = 1$ versus $T_{\rm cond}$. **Lower Left:** Depletion slope versus $T_{\rm cond}$. **Lower Right:** Overall depletion versus $T_{\rm cond}$.

Results

- Ga, Ge, and (probably) Pb follow normal depletion patterns.
- Depletion levels for Cd and Sn are similar to those for S and Zn.
- Cd shows very little (if any) differential depletion.
- As appears overabundant, with initial depletion levels being supersolar.
- Kr appears underabundant (for a noble gas) and may show differential depletion.
- Overall depletion level for B is normal but the slope is much steeper than expected.

Conclusions

- As may be inhibited from being incorporated into grains that condense in the outer atmospheres of late-type stars because (like P) *it can form stable molecules with N.*
- The small amount of Kr depletion may be related to *the trapping of Kr atoms in water clathrates (cage compounds).*
- The large amount of scatter in the Sn data may be evidence for *real intrinsic scatter in the abundance of Sn due to s-process enrichment and incomplete mixing in the ISM.*

References

Jenkins, E. B. 2009, ApJ, 700, 1299
Lodders, K. 2003, ApJ, 591, 1220
Ritchey, A. M., et al. 2011, ApJ, 728, 70

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