A Closer Look at Some Gas-Phase Depletions in the ISM: Trends for O, Ge and Kr vs. F_*, f(H_2) and Starlight Intensity

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ABSTRACT

An analysis of interstellar absorption features in UV stellar spectra in the HST and FUSE archives reveals column densities of O I, Ge II, Kr I, Mn II, Mg II, H I and H_2 in many different directions. Expanding on earlier studies by Jenkins (2009) and Ritchey et al (2018), this effort probes the partial correlations of the element abundances of atomic O, Ge, and Kr relative to atomic plus molecular hydrogen for three fundamental parameters:

(1) a generalized parameter F_* for the strength of depletions of elements by dust,
(2) the fraction of hydrogen in molecular form f(H_2), and
(3) a measure of the local intensity of starlight.

Abundances of Mg II and Mn II relative to atomic and molecular hydrogen establish values of a generalized depletion strength F_*. Previous claims that the chemically inert element Kr is sometimes depleted are substantiated in this study, but correlations with any of the three parameters are very weak, especially after one accounts for error covariances arising from uncertainties in the total hydrogen column densities. The ratio of gas-phase O to H in the ISM exhibits positive correlations with both f(H_2) and starlight intensity, and as expected, a negative correlation with F_*. Photodesorption of oxygen atoms from some solid constituents ($H_2$0 ice?) probably accounts for the positive relationship between concentrations of gas-phase O and starlight intensity, but the reason for the correspondence with f(H_2) is more difficult to explain and may arise from some indirect effect, such as changes in the compositions or sizes of dust grains that are more or less likely to create H_2 and sequester O atoms. Ge/H has a negative correlation with F_* and no significant dependence on the other two parameters. A marginally significant negative trend for Kr/H vs. starlight intensity may arise from differences in ionization [σ(Kr) ≈ 10σ(H) above 14eV].

1. Motivation

O abundances: Within regions that have large depletions (F_*), the amount of O withdrawn from the gas phase exceeds what can be expected from forming silicates and oxides. Concentrations of CO are not sufficient to explain the missing O. A possible presence of $H_2$0 ice within large grains that would not exhibit IR absorption features may explain the O deficiencies.

Ge abundances: A control neutron-capture element to indicate changes in the total abundances of Kr for different sight lines.

Kr abundances: Explore whether Kr/H is anticorrelated with f(H2), in addition to being reduced when F_* increases. Such an anticorrelation might indicate that the production of KrH^+ or KrH_3^+ is an important channel for depleting free Kr atoms.

2. Data

UV Spectra of 100 stars recorded by the STIS echelle spectrograph on HST reveal absorption features for the species of interest, as illustrated for Mg, Kr and Ge below:

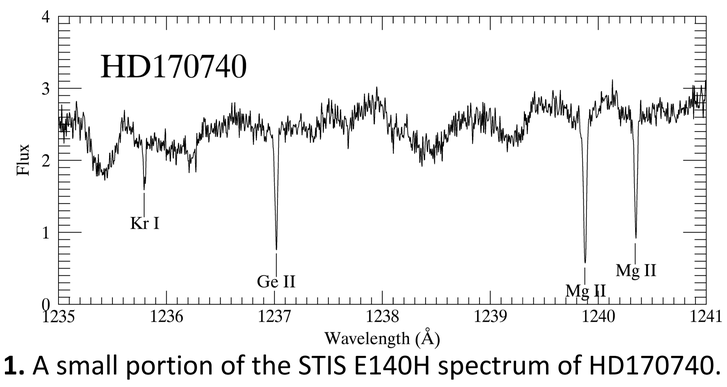

Figure 1. A small portion of the STIS E140H spectrum of HD170740.

Additional data: absorption by a semi-forbidden transition of O I at 1356 Å, the L**α** transition of H I, and the Lyman series absorptions by H_2 recorded by the FUSE spectrographs.

3. Results

We can express the logarithms of the gas-phase abundances $[X_{\rm gas}/{\rm H}]$ for element X in terms of a linear relationship with 3 slope coefficients A_3, a generalized offset B_3 from a reference (protosolar) abundance, and 3 offset parameters z_3 (to eliminate covariances in the errors for B_3 and A_3)

$$\begin{aligned}[X_{\rm gas}/{\rm H}] = B_3\{X\} &+ A_3\{X,F_*\}\left(F_* - z_3\{X,F_*\}\right) \\ &+ A_3\{X,\log f(H_2)\}\left(\log f(H_2) - z_3\{X,\log f(H_2)\}\right) \\ &+ A_3\{X,\log (I/I_0)\}\left(\log(I/I_0) - z_3\{X,\log(I/I_0)\}\right)\end{aligned}$$

where the molecular hydrogen fraction f(H_2) equals $2N(H_2)/[N({\rm H\ I}) + 2N(H_2)]$, and the starlight intensity is expressed in terms of the logarithm of I relative to an overall average value I_0 in our part of the Galaxy. Values of $\log(I/I_0)$ are computed from the observed ratios of neutral and ionized carbon atoms established by a balance between photoionizations and recombinations. Probabilities for different combinations of A_3 appear below:

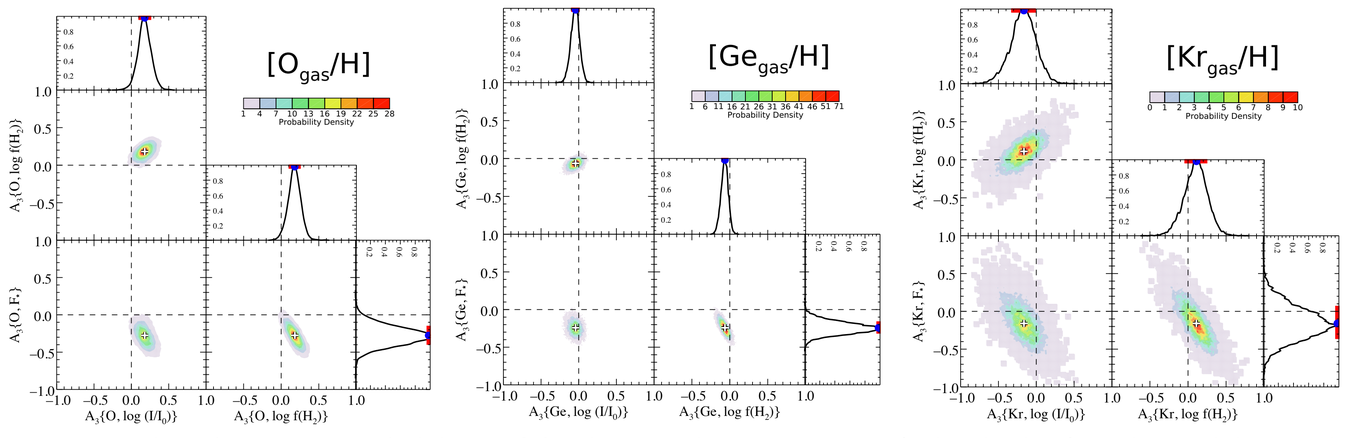

Figure 2. The relative joint probabilities of the three A_3 slope parameters (color displays). Each panel depicts the distribution of the probabilities for two coefficients as they would appear in projection over the distribution of the third, unspecified coefficient. The plots on the sides showing the curves show the probability distributions for a single coefficient marginalized over the distributions of the other two quantities. At the tops of the distribution plots, the preferred values and ranges inside ±1σ limits are shown with a blue dot and red bar, respectively.