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Oxygen in Unevolved Stars

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Abstract. We have made observations of 24 *unevolved* stars of the OH lines in the ultraviolet spectral region at high spectral resolution and high signal-to-noise, typically 60 – 110 with Keck + HIRES. The O abundances have been computed by spectrum synthesis. For these cool, unevolved stars there is a linear relation between [O/H] and [Fe/H] over three orders of magnitude with very little scatter and a slope of +0.66 ±0.02. The relation between [O/Fe] and [Fe/H] is robustly linear with [O/Fe] = −0.35 (±0.03) [Fe/H]. There is no sign of a break at metallicities between −1.0 and −2.0.

1. Introduction

It is important to determine the abundances of O in stars because that helps us to understand a wide range of astrophysical issues concerning stellar and galactic evolution. Because O is the result of α-processing in the interiors of massive stars, the trends of [O/H] and [O/Fe] with [Fe/H] can reveal the chemical history of the Galaxy. Over a wide range of metallicity, O is more abundant than Fe relative to the solar ratio.

It is not easy to determine O abundances with precision, however. There are three spectral features of oxygen that have been used typically: the λ6300 line of [O I], the three high-excitation lines of O I near 7774 Å, and the UV lines of the OH molecule. Each method has its merits, difficulties and drawbacks.

Forbidden O I = [O I]: Only one line is used (the λ6363 line is weaker). The line at 6300 Å is very weak at low values of [Fe/H], which seem to be the most interesting stars. The spectral region has many telluric lines so spectra of rapidly rotating B stars must be obtained to remove the lines from our atmosphere; this process degrades the spectral quality somewhat. The abundances are very dependant on $\log g$ and on how well that is determined. The line is present in giants and subgiants, weak in dwarfs/subdwarfs. The effects of interior nuclear processing and mixing of those products to the photosphere is not well understood in the giant stars. The model atmospheres of giants are less certain as they are more extended and cannot be anchored to the Sun and the solar model as can those for dwarf stars. Examples of O abundances from [O I] can be found in Barbuy (1988), Nissen & Edvardsson (1992), Sneden et al. (1991, 1992), Kraft et al. (1993, 1997).

O I triplet: Although there are three lines to use in the analysis, for some stars and at some lower spectral resolutions, two of those lines may be blended with each other. The lines have very high excitation potentials, near 9 eV. There are strong effects of non-LTE at high temperature and there is disagreement on how to make the corrections for this. Uncertainties remain in the collisional rates/cross sections for collision with neutral H. Examples of O abundances from the O I triplet can be found in Sneden, Lambert & Whitaker (1979), Abia & Rebolo (1989), Tomkin et al. (1992), Boesgaard & King (1993), Edvardsson et al. (1993), Carvallo, Pilachowski & Rebolo (1997).

Ultraviolet OH lines: Although there are several useful lines of OH, they occur in a region of the spectrum that is difficult to observe, near 3140 Å. This region is near the atmospheric cutoff and there is low atmospheric transparency at these wavelengths. There is usually low spectrscopic efficiency in this spectral region and there may be low detector sensitivity. This region is crowded with spectral features of atoms and molecules, although this is less of a problem for the metal-poor stars, [Fe/H] <-2.0. Examples of O abundances from the UV OH lines can be found in Bessell, Sutherland & Ruan (1991), Nissen et al. (1994), Israelian, García López & Rebolo (1998), Boesgaard et al. (1999).

2. UV OH Observations and Analysis

We obtained very high-quality spectra with Keck I + HIRES (Vogt et al. 1994) of 24 unevolved stars in the ultraviolet region of 3100 – 3400 Å (Boesgaard et al. 1999). These are high resolution spectra, R ~45,000 or 0.022 Å pix^{-1}. They have high signal-to-noise ratios of 60 –140 per pixel, averaging 95. This is the highest quality data set yet assembled to address the O abundance issue.

We took special care in determining the stellar parameters. We used two plausible temperature scales: one that is widely used, essentially that of Carney (1983) and one that is based on Balmer lines and photometry, essentailly that of King (1993). The mean errors are typically 40 K in effective temperature, 0.22 dex in $\log g$, and 0.14 dex in [Fe/H]. We obtained two self-consistent sets of parameters.

The OH lines that were used are the (0,0) and (1,1) band of the A $^2\Sigma$-X $^2\Pi$ system in the spectral region of 3139-3147 Å. Typically 5-9 lines could be used to determine the O abundance by spectrum synthesis. The best fitting abundance was determined for each line and the mean for all lines for a particular star was found. The errors in the abundances were found from the uncertainties in the temperature, $\log g$, and the random errors in the mean O/H from the 3-9 OH features. The errors range from 0.06 to 0.30 dex. For nine of the ten stars we have in common with Israelian et al. (1998) the mean difference is 0.00 ±0.06 dex in our values for [O/H] (once the differences in temperature and $\log g$ have been taken into account).

All of our stars have published equivalent widths from the O I triplet, so we could use these to determine the O abundance with our stellar parameters. As shown by King & Boesgaard (1995) there is agreement between the O abundance as determined from the O I triplet and the [O I] line as long as the stellar temperature is less than ~6200 K, i.e. the effects of non-LTE are small. Again we determined the errors from the uncertainties in the parameters and in the agreement in the O abundance from the three lines; the errors range from 0.06 to 0.18 dex.

We concluded that the two methods were both valid and we could combine the resultant O abundances for each star. Interestingly, the two methods have opposite sensitivities to temperature and $\log g$. An increase of 100 K in temperature increases the O from OH by +0.16, but decreases the O from O I by −0.07 dex and an increase of +0.3 in $\log g$ leads to a decrease in O from OH by −0.08 and an increase in O from O I by +0.09. We took the mean abundance from the two methods and thereby reduced the sensitivity to the stellar parameters. The final abundance plot is shown in Figure 1 with the disk star O results from Edvardsson et al. (1993).

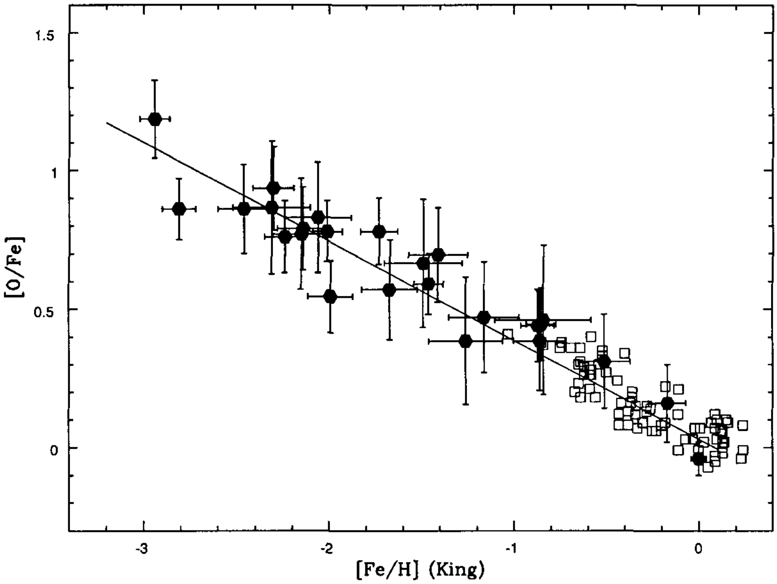

Figure 1. [O/Fe] (with O as the mean of OH and O I determinations) plotted against [Fe/H] with individual error bars, on the King temperature scale. The line is the linear fit that takes into account the errors in both coordinates. The slope of this relationship is −0.35. The open squares are disk stars from Edvardsson et al. (1993).

3. Results and Conclusions

We have found that the slope between [O/H] and [Fe/H] is 0.66 ±0.02 with no change in slope at low metallicity. For the disk stars of Edvardsson et al. (1993) the slope is also 0.66.

The relationship between [O/Fe] and [Fe/H] is also a straight line with a slope of −0.35. So at [Fe/H] = −3.0, [O/Fe] is >1.0. There is no sign of a break in that slope. This is true over the three orders of magnitude in [Fe/H]. The disk stars match this trend very well also.

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