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A Differential Study of the Oxygen Abundances in the Galactic Thin and Thick Disks

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Abstract

First results from a study into the abundance trends of oxygen in the Galactic thin and thick disks are presented. Oxygen abundances for 63 nearby F and G dwarf stars, based on very high resolution spectra ($R \sim 215\,000$) and high signal-to-noise ($S/N > 400$) of the faint forbidden oxygen line at 6300 Å, have been determined. Our findings can be summarized as follows: **1)** at [Fe/H] < 0 the oxygen trends in the thin and thick disk are smooth and distinct, indicating their different origins, **2)** [O/Fe] for the thick disk stars show a turn-over at [Fe/H]~ -0.35, indicating the peak of the enrichment from SNe type Ia to the interstellar medium, **3)** the thin disk stars show a shallow decrease going from [Fe/H] ~ -0.7 to the highest metallicities with no apparent turn-over present indicating a more quiet star formation history, and **4)** [O/Fe] continues to decrease at [Fe/H] > 0 without showing the leveling out that previously has been seen.

1.1 Introduction

The Galactic thin and thick disks are two distinct stellar populations in terms of age distributions and kinematics. The chemical trends in the two systems are also most likely different although recent works give conflicting results, see e.g. Chen et al. (2000) and Fuhrmann (1998). We show that the abundance trends for oxygen are different for the thin and thick disks, when traced by kinematically selected F and G dwarf stars in the solar neighborhood. It is not only for oxygen we see distinct trends between the thin and thick disks. Also the abundance trends for Al, Na, Cr, Ni, Zn (Bensby et al. 2004a submitted), Mg, Si, Ca, Ti (Bensby et al. 2004a submitted, and Feltzing et al. 2003), Ba, Eu, and Y (Feltzing et al. these proceedings) are clearly different for the two disks.

1.2 Selection and Observation of the Stellar Sample

The selection of thin and thick disk stars was based on kinematics and is fully described in Bensby et al. (2004a, submitted). We calculated Gaussian probabilities for each star, in a larger sample of $\sim$14 000 stars, that it belongs to the thin and thick disk respectively, using the galactic velocity components $U_{\rm LSR}$, $V_{\rm LSR}$, and $W_{\rm LSR}$ of the stars. Stars with high probabilities of belonging to either the thin or the thick disk were then selected. The sample consists of 21 thick disk stars and 42 thin disk stars. In Fig. 1.1 we show the kinematical properties of our stellar sample.

Spectra were obtained with the CES spectrograph on the ESO 3.6m telescope with a

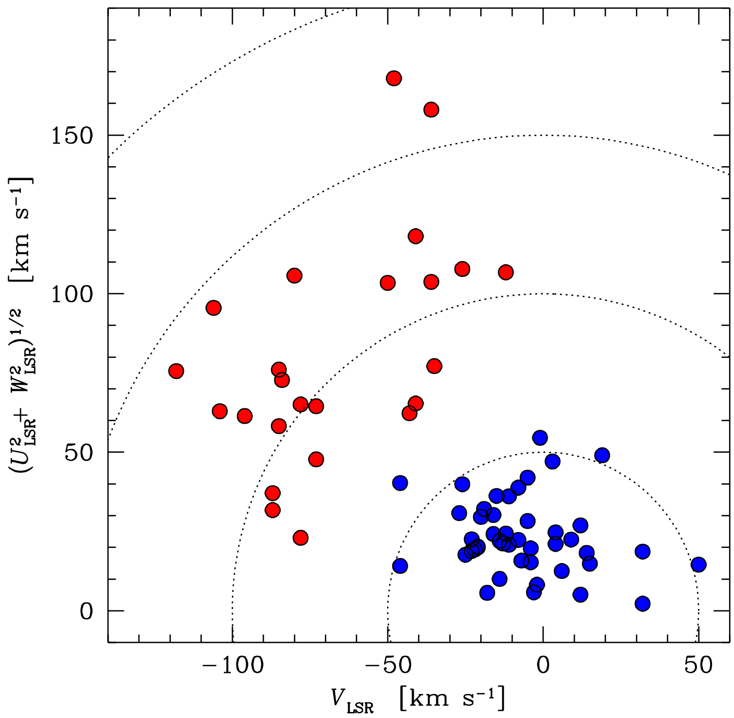

Fig. 1.1. Kinematical data for the selected stars. Dash–dotted lines indicate constant peculiar space velocities $v_{\rm pec} = (U^2+V^2+W^2)^{1/2}$ in steps of 50 km/s. Thick disk stars are marked as red, and thin disk stars as blue.

resolution of $R \sim 215\,000$ and a signal-to-noise $S/N > 400$. Telluric lines were divided out using spectra from fast rotating B stars. Further details are given in Bensby et al. (2004b, in prep).

1.3 Synthesis of the [O I] Line

The [OI] line have been synthesized taking the Ni I blend into account. From Fig. 1.2 it is clear that the Ni line is a main contributor to the observed line profile, and that O abundances will be severely overestimated in metal-rich stars if it is neglected. Atomic data for these two lines have been taken from Allende-Prieto et al. (2001). The stellar atmospheric parameters (effective temperature, surface gravity, and microturbulence) were derived from FEROS spectra, Bensby et al. (2004a submitted), using approximately 150 Fe I and 30 Fe II lines. Also the Ni abundances to the combined [O I]-Ni I line profile were taken from this work, where ~ 50 spectral lines were used in the Ni abundance determination.

1.4 The Oxygen Fossil Record

The four key findings for oxygen in the thin and thick disks, which can be seen in Fig. 1.3, are:

1: Below [Fe/H] = 0 the thin and thick disks show distinct and smooth abundance trends.

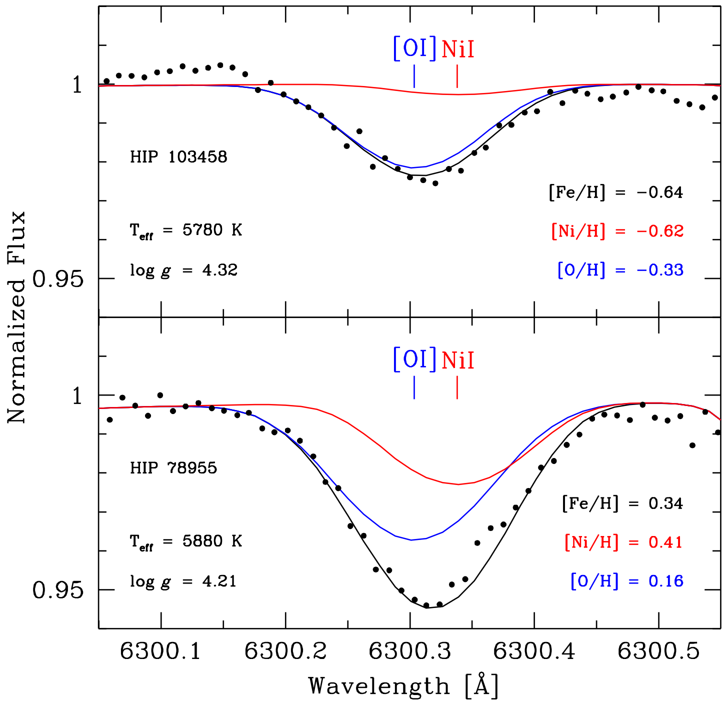

Fig. 1.2. Example of the observed and synthesized spectra for three stars at different metallicities. The observed spectra have been shifted in wavelength. The fitted oxygen line is marked in blue and the nickel line in red. Just to the left of the [OI] line for Hip 103458 there is a contribution from the sky emission of O_2.

This indicate that the thin and thick disks formed at epochs that are separated in time and in space, and from interstellar gas that were reasonably homogeneous.
2: The presence of SNe type Ia signatures in the thick disk. This shows up as a "knee" in the abundance trend at [Fe/H] ~ -0.4, and is interpreted as being due to the time delay between the SNe type II and the long-lived SNe type Ia in the elemental enrichment of the interstellar medium. Star formation must therefore have continued in the thick disk after SNe type Ia rate peaked, since we see thick disk stars with [Fe/H] > -0.4 that have been born out of interstellar gas with a lower [O/Fe]. This means that the SFR in the thick disk must have initially been fast to allow the build-up of oxygen from SNe type II at high metallicities before the enrichment from SNe type Ia, producing none or little oxygen, set in.
3: Quiet evolution in the thin disk. The abundance trend shows a decline when going from overabundances of [O/Fe] $\simeq 0.2$ at [Fe/H] $\simeq -0.7$ and reaching [O/Fe] $\simeq -0.2$ at [Fe/H] = 0.4. That the "knee" is not present in the thin disk implies that the star formation rate in the thin disk was quite low, with SNe type II and type Ia going off in an alternative manner.
4: At [Fe/H] > 0 the linear trend found at sub-solar metallicities continuous for the thin disk stars. In contrast Nissen and Edvardsson (1992) found the [O/Fe] to level out at these metallicities. However, they did not take the Ni I blend in the [O I] line into account, which

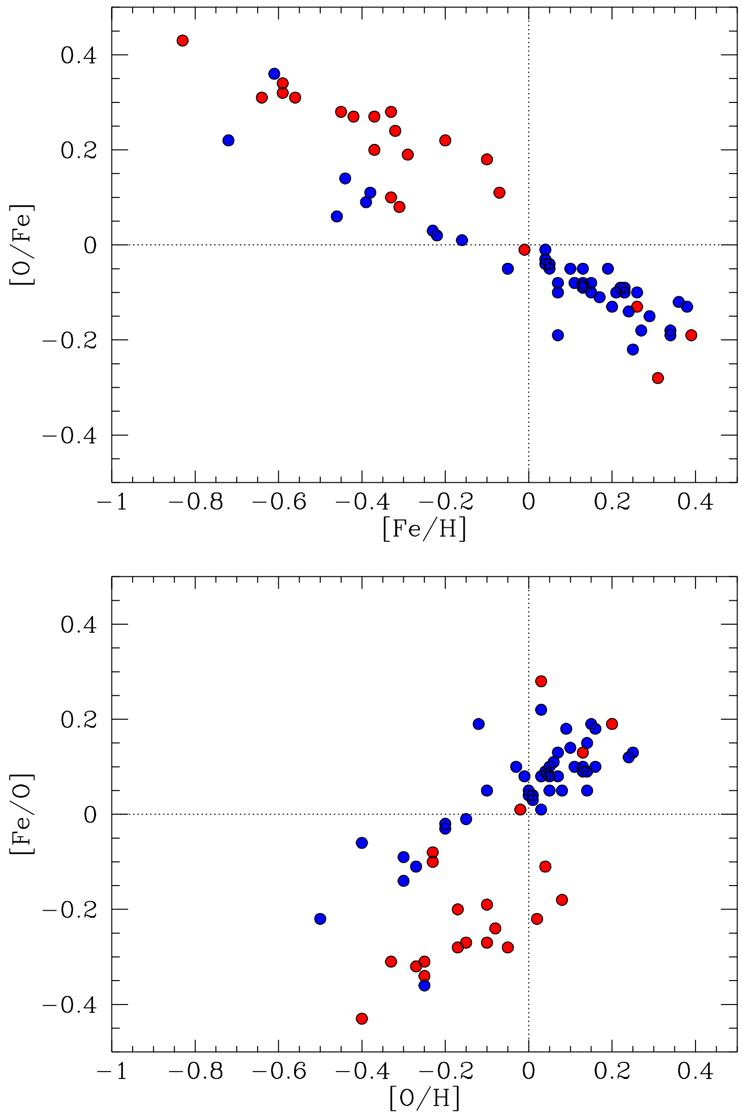

Fig. 1.3. Abundance trends for oxygen. Thick disk stars are marked as red, and thin disk stars as blue.

becomes severe at these metallicities, see Fig. 1.2. The Nissen et al. (2002) [O/Fe] trend also levels out at $[Fe/H] > 0$ even though they considered the Ni blend. They did however assume a solar ratio for [Ni/Fe] which according to our Ni results (Bensby et al. 2004a submitted) will lead to an underestimation of the Ni contribution. Our Ni trend show a prominent increase in [Ni/Fe] at $[Fe/H] > 0$.

The results we find for oxygen are fully consistent with the results we obtained for other

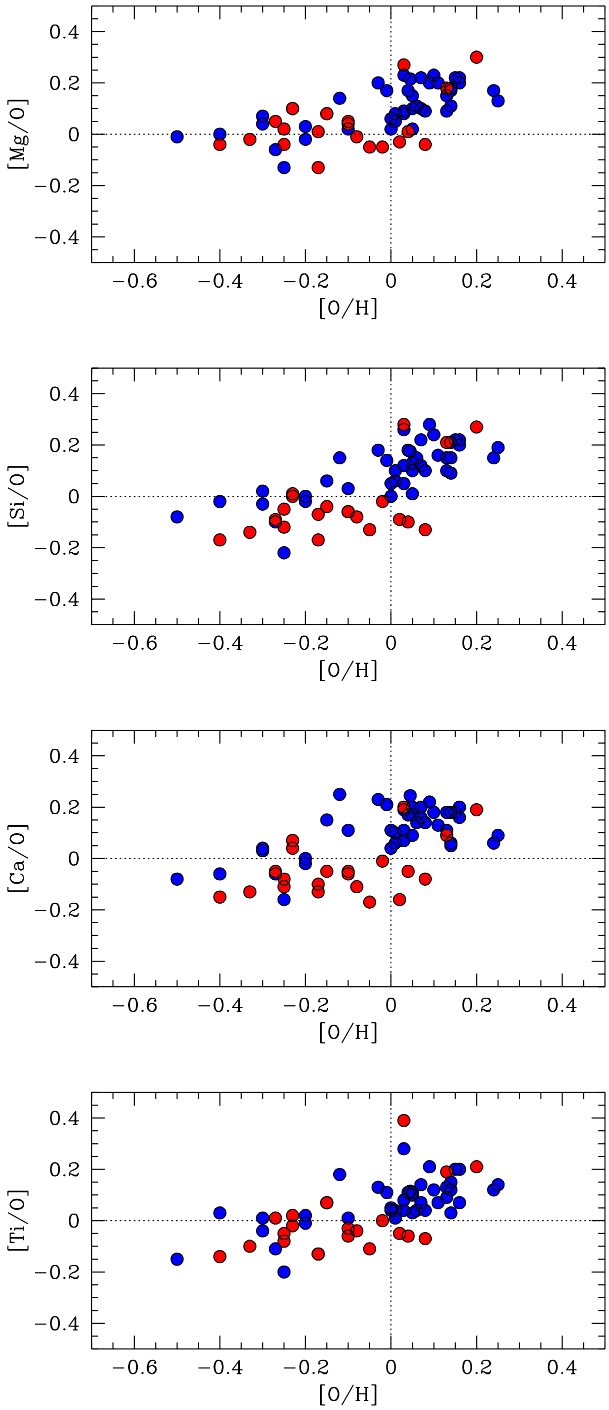

Fig. 1.4. Mg, Si, Ca, and Ti abundances compared to oxygen. Thick disk stars are marked as red, and thin disk stars as blue.

α-elements, Mg, Si, Ca, and Ti, for the same stars from FEROS spectra, Bensby et al. (2004a submitted) and Feltzing et al. (2003).

1.5 Implications for Nucleosynthesis

From our FEROS spectra we have derived, using equivalent width measurements, abundances for the other α-elements, Mg, Si, Ca, and Ti (Bensby et al. 2004a submitted). At $[\mathrm{O/H}] < 0$ the thick disk trends for these elements are mainly flat when compared to oxygen. This indicate the common origin of the α-elements, namely from massive stars that become SNe type II. For the thin disk the trends look different, showing an increasing $[\alpha/\mathrm{O}]$ ratio with increasing $[\mathrm{O/H}]$ and a flat trend at $[\mathrm{O/H}] > 0$. This could be due to that SNe type Ia play a role in the synthesizing of these elements. Also, the yields from later stellar generations might have become metallicity dependent?

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