THE DISK POPULATIONS IN THE [MG/H]-[FE/MG] PLANE

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Abstract. The disk populations' metal abundance degeneracy is shown to be considerably relaxed in a two-dimensional presentation of their chemical properties. As such, the metallicities of a sample of nearby F- and G-stars are given in terms of magnesium abundances along the abscissa and iron-to-magnesium abundance ratios perpendicular to that. In combination with stellar age estimates and kinematics the disk populations turn out to be fairly well separable in this *abundance plane*, which in turn allows to address a number of important issues on the Milky Way's history.

1. Introduction

The thick disk of the Milky Way Galaxy is and has always been an elusive member of its main constituents. The intermediate character of this population in view of kinematics and metallicity repeatly caused doubts as to whether this is indeed a distinct entity on the stage of Galactic evolution or merely part of the high and low endings of rather ill-understood distribution functions of halo and disk stars. As a particular example one may refer to the so-called metal-weak thick-disk stars, some of which reach down to at least [Fe/H]~ -1.6, i.e. considerably deep into the halo star regime. With respect to the formation and age of the thick-disk population a good deal of our understanding persists in the dark. It is however important to note that a number of observations lend support to a very old population, presumably not much different from that of the Galactic halo (e.g. Marquez & Schuster 1994), and there is now also growing evidence that the disk populations are separated in age by a gap in star formation (e.g. Gratton et al. 1996).

Many excellent reviews of the thick disk exist in the literature and many updates of the most recent results can be found in this volume, to which we refer here for convenience. Our own focus will be on the separability of thick- and thin-disk stars by means of chemistry, kinematics and age estimates of nearby F- and G-type stars.

2. Observations and analyses

The data presented here consist of spectroscopic observations obtained in 1995-1998 at the Calar Alto Observatory in Spain. The fiber optics Cassegrain échelle spectrograph FOCES (Pfeiffer et al. 1998) was employed with a spectral resolution up to $\lambda/\Delta\lambda \sim 60000$.

The basic stellar parameters of our F- and G-star sample are derived from the Balmer lines (T_{eff}), the iron ionization equilibrium and/or the wings of the Mg Ib lines (log g), and the profile analyses of iron and magnesium lines for the metallicity ([Fe/H]), microturbulence (ξ_t) and abundance ratio ([Fe/Mg]). Details are given in Fuhrmann (1998), where most of the derived stellar parameters are tabulated as well. Here we only briefly recall the basic features of our analysis, namely its differential character with respect to the Sun, the use of purely spectroscopic tracers for the basic stellar parameters, the full wavelength coverage and low level stray-light ($\sim 1\%$) provided by FOCES, the high spectral resolution that enables detailed line profile analyses, and, in particular, the reference to the accurate Hipparcos parallaxes that provides the robust framework for almost every aspect. The investigated F- and G-stars belong to the main-sequence and turnoff region, with only a small number of subgiants. The accuracy of the atmospheric parameters is characterized by $\Delta T_{eff} \sim 80$ K, $\Delta \log\ g \sim 0.1$ dex, Δ[Fe/H]~ 0.07 dex, and Δ[Fe/Mg]~ 0.05 dex. In combination with the kinematics, and with age estimates from evolutionary tracks, we now proceed with the separability of the thin- and thick-disk stars.

3. The disk populations in the [Mg/H]-[Fe/Mg] plane

One of the main characteristics of the thick-disk population is that its metallicity distribution function – which may peak at [Fe/H]~ -0.6 – shows considerable overlap with the halo and thin-disk stars. We have already mentioned the metal-weak thick-disk stars, but there is also a noticeable common region towards high metallicities, as thin-disk objects reach down to at least [Fe/H]~ -0.6.

In view of this abundance overlap along the [Fe/H] "coordinate" the introduction of an additional chemical component by means of e.g. an appropriate *abundance ratio* may rectify this degeneracy. Thus a 2-d presentation of the chemical properties of stars may establish a better definition of the individual stellar populations. We therefore arrange our program stars in Fig. 1 in a [Mg/H]-[Fe/Mg] plane, i.e. we refer to the α-element magnesium

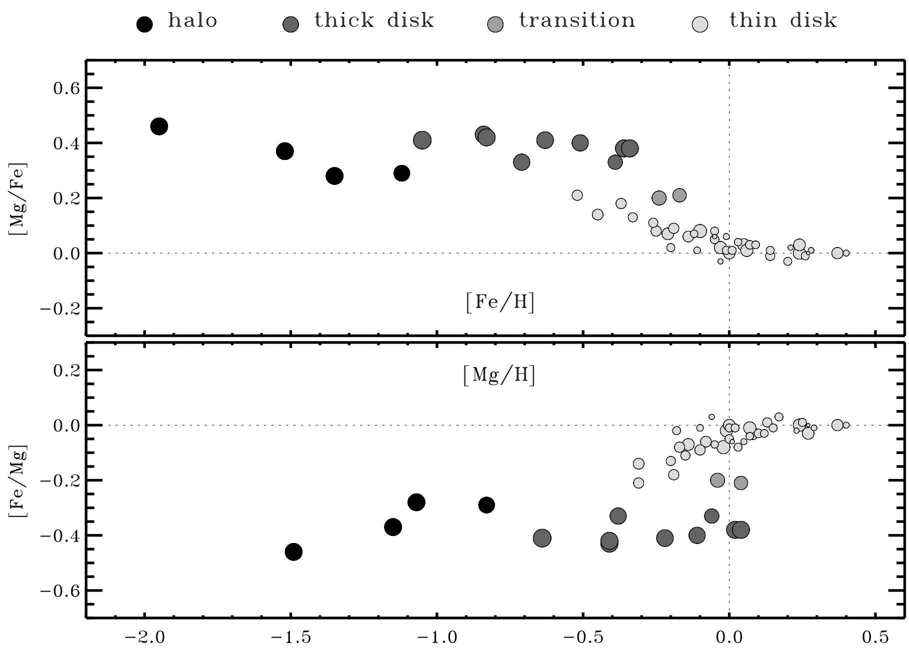

Figure 1. Abundance ratios of the α-element magnesium for the sample of nearby F- and G-stars. Circle diameters are in proportion to the stellar ages. Different *stellar populations* are given with various grayscale symbols as illustrated in the legend on top, and are based on chemistry, kinematics and age informations

as the primary abundance indicator and compare the relative enrichment of iron with respect to this element. The opposite perspective, [Mg/Fe] vs. [Fe/H], is the more common version in the literature, which we also include for comparison. Note that with respect to the stellar ages the data in Fig. 1 are depicted such that small circles correspond to young stars. The principal importance of the α-element abundance ratios is based on the well-known fact that α-chain nuclei are predominantly produced in massive stars and rapidly distributed via type II SNe, whereas the bulk of iron comes from SN Ia, i.e. on considerably longer timescales. Thus the observational fact that many metal-poor stars are overabundant by $\sim +0.4$ dex in the α-elements is a very useful constraint to our understanding of the evolution of the Galaxy.

Keeping in mind that the sample in Fig. 1 is yet rather small, the displayed data may be summarized as follows:

– the stars of the thin-disk population (light circles) are fairly well separable from thick-disk objects by means of their relative positions in the abundance plane, the mean rotational velocities with a differential lag of $\langle \Delta V_{rot} \rangle \sim -70$ km s^{-1} for the identified thick-disk members, and the finding that all thin-disk stars are younger than $\sim$9 Gyr

- the stars of the thick disk are throughout old objects, most of them exceed 12 Gyr. Hence, the thick disk is most evidently the precursor population of the thin disk. A merger scenario like that discussed in Quinn, Hernquist & Fullagar (1993) is thereby very unlikely
- from the latter item it is also clear that the thick disk's pre-enrichment in metallicity provides a simple answer to the well-known G-dwarf problem (cf. e.g. Gilmore & Wyse 1986)
- the data of Fig. 1 give no permission to distinguish between thick-disk stars and halo stars. For this purpose we made use of the data in the [Fe/H]-V_{rot} diagram of Schuster, Parrao & Contreras Martínez (1993)
- the abscissa in Fig. 1 is not a useful timescale: 72 Her and HD 221830, the two most metal-rich thick-disk stars, have an age close to $\sim$14 Gyr, whereas the most metal-poor thin-disk stars are at best half as old
- the metallicity distribution of thin-disk stars spans a range of at least $-0.6 \leq$[Fe/H]$\leq +0.4$. Thick-disk stars show a considerable abundance overlap and can even exceed the solar magnesium abundance
- there is at best a weak age-metallicity relation for the stars of the thin disk. In particular, old thin-disk stars, such as μ Her or 31 Aql, can be very metal-rich
- the metal-poor thin-disk stars at intermediate [Fe/Mg] values may be interpretable in terms of a delayed infall of processed thick-disk material. At the high side of the thin-disk metallicities the restriction to solar [Fe/Mg] ratios argues against a short-term starburst of, say, less than 10^8 years at the onset of the thin disk and provides valuable constraints on the relative occurrence and/or yields of SN II vs. SN Ia
- the relative distribution of the disk populations in Fig. 1 implies the existence of a star formation gap with considerable enrichment of iron, before the thin disk came into play. The two transition stars ρ CrB and HR 7569 at intermediate [Fe/Mg] values are also intermediate in their ages ($\sim$9.5-10 Gyr), and thus provide a firm upper limit for the age of the thin disk

References

Fuhrmann, K. (1998) A&A 338, 161
Gilmore, G., Wyse, R.F.G. (1986) Nature 322, 806
Gratton, R., et al. (1996) ASP Conf. Ser. 92, 307
Marquez, A., Schuster, W.J. (1994) A&AS 108, 341
Pfeiffer, M.J., et al. (1998) A&AS 130, 381
Quinn, P.J., Hernquist, L., Fullagar, D.P. (1993) ApJ 403, 74
Schuster, W.J., Parrao, L., Contreras Martínez, M.E. (1993) A&AS 97, 951