JOURNAL OF THE KOREAN ASTRONOMICAL SOCIETY
29: S127 ~ S128, 1996

EVOLUTION OF THE GALACTIC DISK: FOCUS ON THE SOLAR NEIGHBOURHOOD

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ABSTRACT

The solar neighbourhood is the starting point for studies of the structure and evolution of the Galactic disk. Yet, our knowledge of the relative frequencies, distances, ages, chemical abundances, velocities, and birthplaces of the nearby stars is severely incomplete. We have determined complete, homogeneous, and precise such data for a kinematically unbiased sample of ~12,000 local F and G dwarf stars and describe a first, significant result from it.

Key Words : Galactic evolution, stellar kinematics

I. INTRODUCTION

F and G dwarfs are ideal probes of the evolution of the Galactic disk: Their lifetimes span the entire age of the disk; ages can be derived from direct comparison of $uvby\beta$ photometry with theoretical isochrones; their spectra are suitable for cross-correlation radial-velocity determinations and accurate differential spectroscopic analyses; and their convective envelopes ensure that their surfaces reflect their initial compositions. As a solid basis for studies of the evolution of the solar neighbourhood, we have determined abundances, ages, and galactic orbits for a kinematically unbiased sample of ~12,000 local F and G dwarfs. A first significant result is described here.

II. THE PROGRAM

The F and G dwarf were selected from the all-sky $uvby\beta$ catalogues by Olsen (1994 and refs. therein), and repeated radial velocities were determined with the CORAVEL scanners (Mayor 1985) in both hemispheres. The large majority also has proper motions of adequate quality. Using these, we have computed space motions (U, V, W) and, further, key Galactic orbital parameters of the individual stars by direct numerical integration. Finally, the majority of spectroscopic binaries have been identified (for details, see Nordström et al. 1996).

In parallel, the detailed chemistry of ~200 F dwarfs sampling the metallicity range of the disk about equally was studied with precise high-resolution spectroscopy by Edvardsson et al. (1993; E93). The complementarity between the large volume of statistically better-defined, but individually less precise data for the complete sample and the state-of-the- art spectroscopic results for the strongly metallicity-biased subsample of E93 is a key feature of the overall strategy.

Several of the key questions to be addressed from the sample will require careful and lengthy analysis of limiting distances, completeness factors, and scale height corrections. Other questions can be addressed immediately with the data at hand. The present contribution describes one of these.

III. THE NON-UNIQUE LOCAL AMR

The large scatter in the age-metallicity relation (AMR) for nearby stars has been known for decades, but usually been ascribed by theorists to observational scatter. The AMR derived from the accurate E93 data ended that discussion: The *cause* of the scatter is now debated. Four main possibilities are:

(1) Non-synchronised evolution of local regions,
(2) Tight AMRs at fixed galactocentric radius R_m, combined with a radial abundance gradient and diffusion of stellar orbits,
(3) Clumpy, episodic infall of metal-poor intergalactic gas, or
(4) Gradual accretion of dwarf galaxies.

Some accretion of gas and stars clearly does occur (e.g. the Sagittarius dwarf galaxy). However, abandoning the assumption of a well-defined AMR, at least for fixed R_m, would signal the demise of the present generation of one-dimensional Galactic evolution models. Examining option (2) above is therefore not without interest.

IV. STELLAR BIRTHPLACES: THEORY AND PRACTICE

Assuming that the present mean galactocentric distance of a star is our best estimate of its birthplace, Fig. 14 of E93 contradicts the suggestion by Francois & Matteucci (1993) that the scatter is due merely to admixture of stars from the inner (metal-rich) and outer (metal-poor) disk: The effect is weakly seen, but quite inadequate to explain the observed scatter.

However, Wielen et al. (1996) propose that, due to orbital diffusion, present orbits no longer remember initial conditions. Assuming a constant, linear radial abundance gradient and a unique, exponential AMR at each R_m, they derive the distance from the Galactic centre at which a star was born, R_i, entirely from its

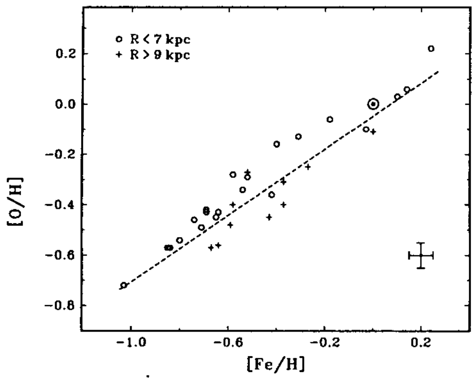

Fig. 1.— [O/H] vs. [Fe/H] from E93 for two subgroups in R_m. The line shows the relation for solar-circle stars.

position in the AMR. E.g., the Sun would then have been born at $R_i = 6.6$ kpc and subsequently migrated to its present distance (R_0). For stars born at a given R_i, the current value of $< R_m - R_0 >$ is predicted to be ~60% of the initial $< R_i - R_0 >$.

We have tested this prediction by computing individual values of R_i for ~4,500 of our local F and G dwarfs with the necessary data (binaries of all types removed). Subsamples were then defined with R_i within 1 kpc of the values 5.5, 8.5 (R_0), and 11.5 kpc in each of four age groups. $< R_m - R_0 >$ was computed within each of these 12 subsamples. Typical values of $< R_m - R_0 >$ are ~200-500 pc with standard errors below 100 pc, far less than the 2 kpc predicted. Two explanations offer themselves:

(1) Orbital diffusion is so strong that present orbits carry no memory whatever of the birthplace of stars older than 2-3 Gyr. One would thern expect to see more metal-rich stars from the dense inner regions of the disk than stars of solar abundance; the opposite is observed. The entire concept of a 'local sample' also becomes somewhat hazy.

(2) Orbital diffusion is in reality a minor perturbation of present stellar orbits, and the majority of stars now found near the Sun were in fact also born near the solar orbit.

The second explanation not only has the beauty of simplicity, but also some independent observational support: Fig. 1 shows [O/H] vs. [Fe/H] as observed by E93 with stars coded by R_m value. The separation of stars with present orbits in the inner and outer disk seems difficult to understand unless R_m is indeed correlated with birthplace.

V. CONCLUSIONS

From the evidence above, we conclude that:

(i): The scatter in the AMR *cannot* be explained by orbital diffusion acting on any known radial abundance gradient;

(ii): Metallicity is *not* a unique function of time and galactocentric radius;

(iii): Diffusion of stellar orbits in the disk is a relatively minor effect, and orbital parameters remain useful indicators of the Galactic pedigree of nearby stars; and

(iv): Galactic evolution models unable to account for these facts are missing a crucial piece of the real physics of galaxy formation.

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