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The age of the Galactic thin disk from Th/Eu nucleocosmochronology: extended sample

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Abstract. We report the determination of the age of the Galactic thin disk by means of Th/Eu nucleocosmochronology. This method is only weakly dependent on stellar evolutions models, therefore allowing an important verification of the most used dating techniques, which are the fitting of isochrones to the oldest Galactic open clusters, and the calculation of white dwarf cooling sequences. This work builds upon our previous determination (del Peloso *et al.* 2005a, 2005b), by including 7 new objects to the sample which was originally composed of 19 disk dwarfs/subgiants of F5 to G8 spectral types – a 37% extension. The obtained result, (8.8 ± 1.7) Gyr, corroborates the most recent white dwarf ages determined via cooling sequence calculations, which indicate a low age ($\lesssim$10 Gyr) for the disk.

Keywords. Galaxy: disk, Galaxy: evolution, stars: late-type, stars: abundances

1. Introduction

Current Galactic disk age determinations are carried out by dating either the oldest open clusters with theoretical isochrones, or the oldest white dwarfs with cooling sequences. Nucleocosmochronology is the determination of time scales using abundances of radioactive nuclides. It can be used to date the Galactic disk with low dependence on stellar evolution calculations. The nuclides used by us to accomplish this are ^{232}Th, with a 14 Gyr half-life (i.e., of the order of magnitude of the age being assessed), and ^{151,153}Eu, the two stable isotopes of the comparison element (97% produced by the same nucleosynthesis process as all Th, the r-process). The sample is composed of 26 thin disk dwarfs/subgiants with F5–G8 spectral types, $5600 < T_{\rm eff}({\rm K}) < 6300$ and $-0.9 \leqslant [{\rm Fe/H}] \leqslant +0.3$. This represents a 37% increase in the number of objects, relative to the original work – del Peloso, da Silva & Arany-Prado (2005a) and del Peloso, da Silva & Porto de Mello (2005b).

2. Determination of Th and Eu Abundances

For our stars, only one adequately strong and uncontaminated line is available for Eu abundance determination, at 4129.72 Å. It has a significantly non-gaussian profile, due to its hyperfine splitting and isotope shift. Thus, spectral synthesis must be employed. High resolution, high S/N spectra were obtained for Eu with ESO's 1.52 m telescope and FEROS, and with ESO's CAT and CES. Th also has only one adequate line available, at 4019.13 Å. It is highly contaminated, also requiring spectral synthesis. High resolution, high S/N spectra were obtained for Th with ESO's CES fed by CAT and by the 3.60 m telescope. Atmospheric parameters were determined by photometric and spectroscopic differential analysis. Abundances of elements contaminating the Eu and Th spectral regions were determined using equivalent widths of lines measured in 10 orders of the same FEROS spectra used for Eu. Comparison with the literature – Morell, Källander & Butcher (1992), Woolf, Tomkin & Lambert (1995), and Koch & Edvardsson (2002) – shows that our results present the same behaviour, but with lower scatter.

3. Galactic Chemical Evolution (GCE) Model

We have developed a GCE model based on Pagel & Tautvaišienė (1995), with the inclusion of refuse, following an improved version of the formulation of Rocha-Pinto, Arany-Prado & Maciel (1994). Refuse is composed of stellar remnants (white dwarfs, neutron stars and black holes) and low-mass stellar formation residues (terrestrial planets, comets, etc.). Residues evaporate considerable amounts of H and He, retaining metals and diluting the interstellar medium. The effect of this dilution is equivalent to a second source of metal-poor infall, contributing to a better fit to observational constraints. We adopted the delayed production approximation of Pagel (1989), which considers the delay in production of elements synthesised mainly in stars of slow evolution, like Fe, which is predominantly generated in type Ia supernovae (with a typical timescale of 1 Gyr).

4. The Age of the Galactic Disk

We used two different methods to determine the age:

(*a*) Comparison of GCE model parameters with production ratio data from the literature: $T_G = 8.7 \pm 5.0$ Gyr. The high uncertainty reflects the difficulties of estimating theoretically the production ratio of r-process elements, whose production sites are not well known.

(*b*) Comparison of our stellar abundance data with [Th/Eu] vs. [Fe/H] curves obtained from the GCE models, calculated for four different Galactic disk ages – 6, 9, 12, and 15 Gyr: $T_G = 8.8 \pm 1.8$ Gyr. The uncertainty is relative only to the abundance ratio uncertainties, not considering the uncertainties intrinsic to the GCE model itself.

Taking the weighted mean of these results, using the reciprocal of the square of the uncertainties as weights, we arrive at the final result:

$$\text{Age of the Galactic thin disk} = 8.8 \pm 1.7\,\text{Gyr}$$

This represents a reduction of 0.1 Gyr (6%) in the uncertainty, relative to our previous determination. The obtained value agrees well with the latest white dwarf cooling estimations, which favour a low disk age ($\leqslant 10$ Gyr).

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