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Abundance Ratios in the Milky Way: The Halo/Thick Disk and Thin Disk Discontinuity

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Abstract

We computed the evolution of different abundance ratios in the MW for two different sets of stellar yields. In one of them stellar rotation is taken into account and we investigate its effects on the chemical evolution model predictions. Moreover, we show that some abundance ratios offer an important tool to investigate the halo-disk discontinuity. For the first time it is shown that the effect of a halt in the star formation between the halo/thick disk and thin disk phases, already suggested from studies based both on Fe/O and Fe/Mg, should also be seen in a C/O versus O/H plot *if C is produced mainly by low- and intermediate-mass stars* (LIMS). The idea that C originates mainly from LIMS is suggested by the flat behavior of the [C/Fe] ratio as a function of metallicity, from [Fe/H]~ -2.2 to solar and by the fact that very recent C/O measurements for stars in the MW halo and disk seem to show a discontinuity around log(O/H)~ -3.6. Finally, a more gentle increase of N abundance with metallicity (or time) is predicted when adopting the stellar yields with rotation of Meynet & Maeder (2002 - which do not include hot-bottom burning) than when adopting the yields of van den Höek & Groenewegen (1997), for intermediate mass stars. This fact has some implications for the timescales for the N enrichment and thus for the interpretation of the nature of Damped Lyman Alpha systems (DLAs).

1.1 Main Results

In the past years new observations have suggested that the Milky Way (MW) was made in a less smooth dissipational collapse than suggested originally by Eggen, Lynden-Bell & Sandage (1962, ELS). Their model assumed continuous evolutionary transition in the formation of the thick disk and the think disk. Apart from dynamical arguments, the chemical properties of the MW disk are convincingly showing us that its formation was neither smooth nor continuous. As an example, Gratton et al. (1996, 2000) presented a compilation of stars for which both the kinematics and the [Fe/O] abundance ratios were known. They observed for the first time a discontinuity in the [Fe/O] vs. [O/H] plot which was interpreted as a halt in the formation of stars preceding the think-disk formation. In particular they observed that around [O/H]$=-0.2$dex (in solar scale) the oxygen abundance remained constant whereas the [Fe/O] ratio kept increasing. This is interpreted as a break in the star formation since in this case oxygen would not be produced whereas Fe would continue to originate from long-living systems giving rise to type Ia SNe. The same behavior was found by Fuhrmann (1998) for [Mg/Fe] vs. [Mg/H]. Chiappini et al. (1997) have shown that a two-infall model for the formation of the MW, where the halo (and part of the thick disk) formed on a short timescale whereas the thin-disk formed on a much longer one, can explain not only the above observations but also provides a good fit to the G-dwarf metallicity distribution in the solar vicinity (see also Kotoneva et al. 2002). In this work we argue that, if we believe that there was such a halt in the star formation rate and if the carbon enrichment of the interstellar medium is mainly due to low and intermediate mass stars (LIMS) and hence is produced on long timescales as iron, the same kind of discontinuity observed for Fe/O and Fe/Mg should be seen in a log(C/O) vs. log(O/H) diagram.

However, the origin of C (and N) we see today in the interstellar medium (Henry et al. 2000, Chiappini et al. 2003a, CRM2003) is still an open problem. In particular, while Henry et al. (2000) favor the hypothesis that most of the carbon we observe today in the ISM comes from massive stars, CRM2003 suggest that most of the carbon comes from LIMS. These conclusions are very dependent on the adopted stellar yields.

Many are the processes involved in the computation of the stellar yields of C and N and there are still many uncertainties present in these calculations (see Henry, this conference). Chemical evolution models can thus be used to test and constrain the stellar yields. In this work we discuss how the abundance ratios depend on the adopted stellar yields and also how they can be used to infer the star formation history of our Galaxy and the nature of Damped Lyman Alpha systems (DLAs). In particular we compare two different models a) models computed with van den Höek & Groenewegen (1997) for LIMS and WW (1995) for massive stars and b) models computed with the recent published stellar yields of Meynet & Maeder (2002), which take into account the effects of rotation on stellar evolution, for the whole range of stellar masses.

Our results are going to be published in Chiappini et al. (2003b). Here we just outline our main conclusions:

A. We suggest on the basis of the available data in the solar vicinity that C should come mainly from low- and intermediate-mass stars. This is at variance with the interpretation by several authors (e.g. Carigi 2000, Henry et al. 2000) that C should originate mainly in massive stars. This conclusion was based on the yields of Maeder (1992) predicting a strong metallicity dependence of the C produced in massive stars. However, this work is now superseded by the new models of Meynet & Maeder (2002) which take into account rotation effects. We show that with the new stellar yields of MM, massive stars are not anymore able to explain the solar C/O ratio and that, once the 3rd dredge will be included in their calculations, a rise in the C/O ratio will be obtained due to the contribution of LIMS. This is in fact seen once one adopts the stellar yields of vdHG which include the C dredge-up during the TP-AGB stellar phase. Moreover, the C yields from massive stars are underestimated in WW calculations (which do not include rotation) as already noticed by Henry et al. (2000) and CRM2003. This is in agreement with the new calculations of Meynet & Maeder (2002).

B. Given our previous conclusion, we would expect that the "gap" already observed in the [Fe/O] vs. [O/H] and [Fe/Mg] vs. [Mg/H] diagrams (Gratton et al. 2000; Fuhrmann 1998) is also seen in the log(C/O) vs. log(O/H) plot. The homogeneous sample of Nissen (2003) seems to show the predicted discontinuity but more data are needed in order to confirm this prediction. The existence of such a "gap" is due to the halt in the star formation between the end of the thick disk and beginning of the thin-disk phase.

C. The new yields of MM predict primary N in massive stars. We show that models computed with this new set of yields are still consistent with the abundance data for the MW. Moreover, a plateau in log(N/O) due to massive stars would be seen at log(N/O) ~ -4 in systems where the N enrichment was only due to massive stars (when adopting the yields of MM for stellar rotational velocities of the order of 300km/s). Thus it seems that the primary component produced in intermediate mass stars ($5 \leq M/M_{\odot} \leq 8$) is the dominant one (in agreement with the conclusions of CRM2003 and Henry et al. 2000) even in BCGs and DLAs. Moreover, when these yields are applied to the whole range of masses, a slower increase of N with respect to what is obtained with vdHG yields is obtained which has some important implications for the interpretation of the DLAs abundance data. However, we call attention to the fact that the primary N given by MM for the intermediate mass range should be seen as a lower limit as HBB can contribute to further increase this element.

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