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Stellar yields from rotating stellar models: Their effect on chemical evolution model predictions

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Abstract. In this work we evaluate the impact of the new stellar yields recently computed by Meynet & Maeder (2002), where stellar rotation is taken into account, on important open questions related to the C, N and He enrichment in galaxies. Moreover, we show that some abundance ratios offer an important tool to investigate the halo-disk discontinuity. 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). Recent C/O measurements for stars in the MW halo and disk seem to confirm the above prediction. 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 Hoek & 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. Introduction

In addition to dynamical arguments (Wyse & Gilmore 1992), 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 star formation before the thin disk formation. In particular, they observed that around [O/H]$= -0.2$ dex (in solar scale) the oxygen abundance remains constant whereas the [Fe/O] ratio keeps 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. In this scenario no stars would have been formed during the gap and this implies that a gap should also be seen in an [α/Fe] vs. [α/H] diagram (see Fig.1). The same behavior

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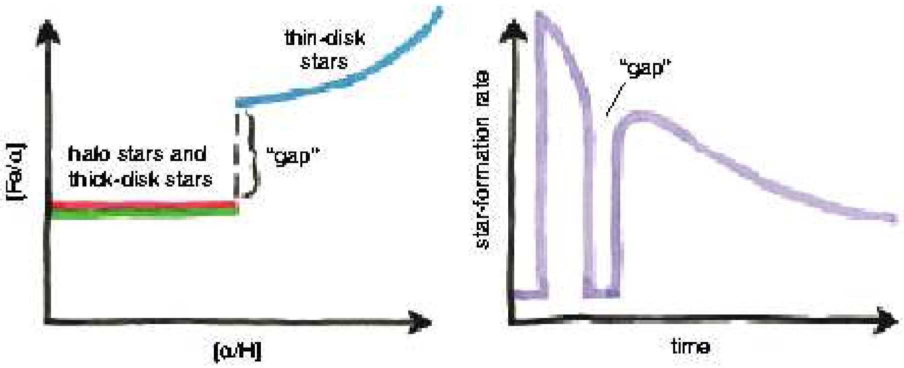

Fig. 1. The halt in the star formation before the formation of the thin-disk and its effect on the abundance ratios such as [Fe/α] as a function of [α/H] (from Chiappini, C. 2001, with kind permission of Tom Dunne, American Scientist).

was found by Fuhrmann (1998) for [Fe/Mg] vs. [Mg/H]. However, this should still be confirmed by larger data samples.

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 the present work we argue that, if we believe that there was such a halt in the star formation rate (SFR) and if the carbon enrichment of the interstellar medium (ISM) 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 (Chiappini et al. 2003a,b).

However, the origin of C (and N) we see today in the ISM 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, Chiappini et al. (2003a, hereinafter CRM) 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 Meynet & Maeder 2002, hereinafter MM). These authors have shown that stellar rotation can affect the predictions of the stellar yields especially for He, C, N and O. Chemical evolution models can thus be used to test and constrain the stellar yields.

2. Stellar yields

It should be noted that MM use a different approach from van den Hoek & Groenewegen (1997, hereinafter vdHG). While the latter authors computed their yields by means of synthetic AGB models, MM yields were obtained from self-consistent complete stellar models (without any fine tuning of parameters related to the so called Hot Bottom Burning - HBB). MM were able to show that rotation opens a new alternative for primary N production in intermediate mass stars, in addition to the classical HBB scenario. Moreover they also predict some primary N production in massive stars. However, for the intermediate mass star models MM calculations stop at the beginning of the thermal-pulse AGB phase (TP-AGB). The third dredge-up (and the HBB) would occur in more evolved stages and thus are not included in the MM results. Only, in the case of models with Z=10^{-5} they do obtain the third dredge-up in the sense that the stellar surface becomes enriched both in H and He-burning products. Forthcoming results (Meynet, private communication) will include the more evolved phases of stellar evolution thus predicting not only the 3rd dredge up contribution to ^{12}C but also obtaining the HBB effect as a natural consequence of the stellar evolution itself, without any parametrization. In fact, HBB may still appear and thus add its contribution to the synthesis of primary N.

In summary, one has to keep in mind that the stellar yields of MM offer a new alternative for the primary N production in intermediate mass stars and in massive stars. However, their results do not include the third dredge-up and hot-bottom burning and thus their yields of C and N for the intermediate mass range should be taken as lower limits. On the other hand, the vdHG yields, which include both HBB and 3rd dredge-up, depend strongly on the η_{AGB} and HBB efficiency parameters adopted in their synthetic models and are thus very uncertain.

3. Results

We computed chemical evolution models for the Milky Way, dwarf galaxies and damped lyman alpha systems (DLAs). In this work we show the results obtained with models computed with the following two choices for the stellar yields: a) a model computed with vdHG yields for LIMS and Woosley & Weaver (1995, hereinafter WW) yields for massive stars and b) a model computed with the recent published stellar yields of MM, which take into account the effects of rotation on stellar evolution, for the whole range of stellar masses. Below we summarize our main conclusions. Details and figures can be found in Chiappini et al. (2003b).

3.1. The ^{12}C, ^{14}N and ^{4}He enrichment

- 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 MM which take into account stellar 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. Once the 3rd dredge-up 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 if one adopts the stellar yields of vdHG which include the 3rd 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 CRM. This is in agreement with the new calculations of Meynet & Maeder (2002).
- 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 and in our model is naturally

produced by the assumed threshold gas density in the star formation process.

- The new yields of MM predict primary N production in massive stars. We show that models for the MW computed with this new set of yields show a plateau in log(N/O), due to massive stars with initial rotational velocities of 300 kmsec^{-1}, at log(N/O) ~ -4. This value is below the value of -2.2 dex observed in some DLAs and hence we suggest that in these systems both, massive and intermediate mass stars, are responsible for the N enrichment (in agreement with the conclusions of CRM and Henry et al. 2000). This is at variance with recent claims that massive stars were the only ones to enrich systems which show a log(N/O)~ -2.2.
- When the MM yields are applied to the whole range of masses, a slower increase of N with respect to what is obtained with vdHG yields is found and this has important implications for the interpretation of the DLAs abundance data. We suggest that DLAs are reproduced by "bursting models". Moreover, in this case the two groups of DLAs (if they really exist as separated groups) could be explained as systems which show differences in their star formation history rather than an age difference. In such a framework, we are able to obtain systems which show both a low log(N/O) and a [O/Fe]$\sim$0.2-0.3 dex during almost all their evolution. Outer regions of spirals can still explain the DLAs data but predict that DLAs with low log(N/O) are quite young systems (younger than $\sim$150 Myr) and this may happen as an odd coincidence. 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 possible HBB can contribute to further increase this element.
- The new yields of MM for helium lead to a better agreement between the solar abundance value predicted by the MW models and the observed one. Moreover, when the MM yields are adopted a larger $\Delta Y/\Delta Z$ is found. This shows that although the $\Delta Y/\Delta Z$ values obtained in chemical evolution models are independent of the primordial Y_p adopted (see Chiappini et al. 2002), they do depend strongly on the adopted stellar yields.

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