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Stellar yields and Galactic chemical evolution

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Abstract. The chemical composition of stars belonging to the halo and the disk of our Galaxy as well as a few nearby galaxies are the primary sources of our understanding of the Galactic Chemical Evolution (GCE). The abundance trends implied by the abundance ratios of the chemical elements as a function of time and metallicity trace the chemical history of our Galaxy which could be understood in the framework of a Galactic Chemical Evolution Model (GCEM). Among the basic ingredients of a GCEM 'stellar yields' play an important role as they implicitly contain a physical scenario of stellar nucleosynthesis and evolution. Improved input along with a realistic model of chemical evolution are expected to result better simulation of the observed abundances.

Keywords : stars: stellar yields – stars: abundances – stars: chemical evolution

1. Introduction

The chemical evolution of the Galaxy leading to the observed elemental abundances still remains one of the poorly understood aspects in contemporary astrophysics. The enrichment and spatial distribution of the chemical elements depend on a variety of galactic and stellar processes. The relative role of these processes such as the star formation rate (SFR), infall, outflow, mixing processes in ISM etc cannot be directly derived quantitatively from observations. As such, a model describing all these processes, stands out as an important tool to address this complex problem. The input parameters in a GCEM play a crucial role in determining the degree of success of the model as they represent implicit physical scenarios. One such parameter is the initial 'stellar yields' where the term 'yield' represents the ejected mass of a particular element as computed from models of a stars leading to their 'deaths' (or supernovae).

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This yield not only depends on the mass of metals ejected by stars but also on the relative frequency of different mass stars born in a stellar generation which is often referred to as the initial mass function (IMF). Different grids of yields based on stellar models with an increasingly improved treatment of relevant physical processes are now available in literature. The main difference among the various sets of yields in massive star models lies in the treatment of mass loss and inclusion of rotation.

2. Current issues

The yields reported in literature do not always correspond to the same quantity as they are not necessarily derived from the same physical considerations. While the yields for intermediate mass stars of Renzini & Voli (1981) correspond to the mass of isotopes newly created by a star, the yields $Y_i(M)$ of massive stars found in Woosley & Weaver (1995) represent the mass ejected by a star (of mass M) in the form of isotope i. A GCEM can generate quite different simulations based on the use of different grids of stellar yields even if the input parameters, such as the SFR, IMF, infall and outflow prescription etc. are similar. A spectrum of models has been used in the past to compute isotopic yields so as to reproduce the observed abundances (Timmes et al. 1995; Aubert et al. 1996; Samland et al. 1997; Nakamura et al. 1999; Chiappini et al. 1999; Goswami & Prantzos 2000). However, success of these models is limited in several aspects. A few problems of particular significance are the case of a few Fe-peak elements, the observed primary nature of ^{14}N, evolution of beryllium and s-process elements produced by neutron-captures on seed Fe nuclei. The lack of observational signature of the secondary elements, production mechanism(s) of primary beryllium including the building of the Galactic halo in the framework of hierarchical galaxy formation as evidenced from its metallicity distribution are other important issues.

3. Observations and GCE model simulations

A GCEM can lead to widely different results depending upon the physics and the formulation of processes like isotopic evolution, SFR, initial mass function and stellar yields. An example of a comparison of theoretical predictions from a GCEM with observations is shown in Fig. 1 (adopted from Goswami & Prantzos 2000, Fig 7). Romano et al. (2010) have made detailed comparisons of the stellar yields available in literature including the most recent ones and examined their effect on predictions of a GCEM. The pioneering works on stellar models for low and intermediate-mass stars are by Iben & Truran (1978), Renzini & Voli (1981), and for massive stars by Arnett (1978). It was first shown by Maeder (1992) that mass loss driven by stellar winds mostly affects massive star models with solar or supersolar metallicities in which stars lose large fractions of newly produced helium and carbon. Subsequently, many others published yields for massive stars using lower mass loss rate than that previously used by Maeder (1992) and including stellar rotation (Meynet &

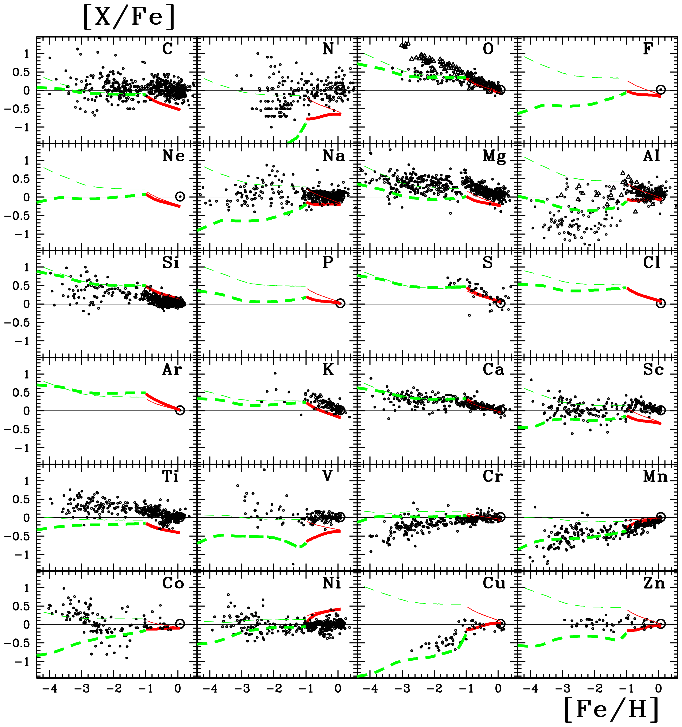

Figure 1. Abundance ratios [X/Fe] of stars in the halo and the local disk, as a function of [Fe/H]. Theoretical results are obtained with models that properly treat the halo (*dashed curve* assuming *outflow*) and the disk (*solid curve* assuming *slow infall*). Two sets of massive star yields are used both from Woosely & Weaver (1995, hereafter WW1995): at constant (=solar) metallicity (*thin curves*, Case A, only for illustration purposes) and at variable metallicity (*thick curves*, the reference case B). Yields of W7 and W70 models of Iwamoto et al. (1999) for SN Ia are used in both cases (properly interpolated as a function of metallicity); intermediate mass stars are not considered. It should be noted that WW1995 yields of Fe have been divided by 2, in order to obtain the observed α/Fe ratio in halo stars. Model trends below [Fe/H] = −3 are due to the finite lifetime of stars ([Fe/H]=-4 is attained at 10 Myr, corresponding to the lifetime of stars of $> 20M_{\odot}$, while [Fe/H]=−3 is attained at 20 Myr, corresponding to the lifetime of stars $\sim 10M_{\odot}$). In view of the yield uncertainties in individual stars and of the uncertainties in the timescales at those early times of the halo evolution, those trends *should not be considered as significant*. The observed data points in the figure are taken from sources as indicated in the Table 1 (of Goswami & Prantzos 2000). Observed abundance ratios of [O/Fe] from Israelian et al. (1998) and Boesgaard et al. (1999) are shown by *open triangles*; they suggest a trend quite different from all other α-elements. The *open triangles* in the [Al/Fe] panel correspond to observed data with NLTE corrections (Baumüller & Gehren 1997).

Maeder 2002; Hirschi 2007). Massive star models with rotationally induced mixing produce primary N by H-burning of C and O that are produced inside the star. It is suggested that N is produced due to mixing of protons in He-rich zones, where ^{12}C originates from the triple-α reaction and is subsequently ejected to the ISM by stellar winds. Low-metallicity massive stars rotating at ~ 800 km s^{-1}, thus leads to a large production of primary N that is in agreement with observations (Prantzos 2010, and references therein). While this is expected to throw some light on the evolution of 'primary' beryllium (Be and B are generally thought to be produced as secondaries, by spallation of CNO nuclei of the ISM during the propagation of protons and alpha particles of Galactic Cosmic Rays), the observed primary behaviour of light s-process elements Sr, Y and Zr at low-metallicity still remains unexplained at present.

4. Concluding remarks

Existing nucleosynthesis theories and stellar models seem to be able to explain most of the observational evidence derived from chemical composition studies of stars belonging to different Galactic components. However, there remain a few unexplained cases of Fe-peak elements and light s-process elements. Increasing efforts to improve and enhance the current existing grids of stellar yields are expected to aid in addressing these issues.

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