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HUNTING FOR THE IMPRINTS OF THE FIRST STARS

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RESUMEN

¿Cómo hizo la primera red cósmica de materia para organizarse en las primeras estrellas y galaxias? Esta pregunta está íntimamente conectada con la pregunta sobre si el medio ambiente primigenio, distinto al actual, produjo efectos apreciables sobre las propiedades de las así llamadas *Primeras Estrellas*. Es en el alo de la Vía Láctea donde se encuentran las estrellas más viejas y más pobres en metales del Universo, nacidas en un tiempo ó con un corrimiento al rojo equivalente, aún fuera del alcance de los sondeos más profundos de galaxias primigenias. Estas estrellas contienen la memoria de la única nucleosíntesis en las primeras pstrellas y pueden ser utilizadas como registros fósiles. En este trabajo mostramos algunas observaciones recientes con las cuales se cree que se develarán algunas propiedades interesantes de las primeras estrellas.

ABSTRACT

How did thefirst cosmic web of matter organize into the first stars and galaxies? This question is intimately connected to the question of whether the different primordial environment produced noticeable effects concerning the properties of the so-called *First Stars*. It is in the Milky Way halo that the oldest and most metal-poor stars in the Universe are found, born at times or equivalent redshifts still out of reach for the deepest surveys of primordial galaxies. These stars contain a memory of the unique nucleosynthesis in the First Stars and can thus be used as fossil records. In this work we show some recent observations that are believed to unveil some interesting properties of the First Stars.

Key Words: Galaxy: evolution — stars: rotation — stars: abundances

1. SETTING THE SCENE

The very metal-poor stars observed in the recent years (stars with less than 1/300 down to 1/10000 the solar abundance) are low-mass stars with lifetimes comparable to the age of the Universe. These stars retain in their atmospheres the elemental abundances of the gas at the time of their birth and hence contain a memory of the unique nucleosynthesis contribution of the first stellar generations to the enrichment of the ISM. The latter massive stars are long dead and the current way to constrain their properties is to search for their imprints on the oldest extremely metal-poor stars (EMPs) in our galactic halo (Beers & Christlieb 2005).

Spite et al. (2005, hereafter S05) reported high N/O ratios in a sample of EMP stars, suggesting high levels of production of primary nitrogen in massive stars (see below). As discussed in Chiappini et al. (2005), the data of S05 happen to be in a very interesting metallicity range: at such low metallicities, their observed stars are probably made of only massive star ejecta diluted by the primordial ISM. Indeed, according to recent observations (Meléndez & Cohen 2007) of ^{25,26}Mg/^{24}Mg ratios in halo dwarfs, AGB stars would have played a minor role to the ISM enrichment below [Fe/H] ~ -2.0. If AGB stars[4] indeed had not had enough time to contribute to the ISM enrichment at such low metallicities and massive stars are not producers of primary nitrogen (as predicted by standard stellar models, e.g., Woosley et al. 2002), one would expect to observe a decline in the N/O or N/Fe ratios towards low Z, contrary to what has been found by S05. Hence, the high levels of N/O observed in halo stars have to be a result of the nucleosynthesis taking place in the metal-poor massive stars, suggesting a revision of standard models for the nucleosynthesis of these objects.

2. FAST ROTATORS: SOURCES OF N

The effects of stellar axial rotation are numerous and at low metallicity may lead to a drastic revision of current wisdom. The stellar models of the Geneva group, including rotation (Maeder & Meynet 2000, 2001), have proved to be successful in explaining some observations that could not be explained by

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[4]Classically the best candidates for the production of primary N through hot-bottom burning during the asymptotic giant branch (AGB) phase (Siess 2007).

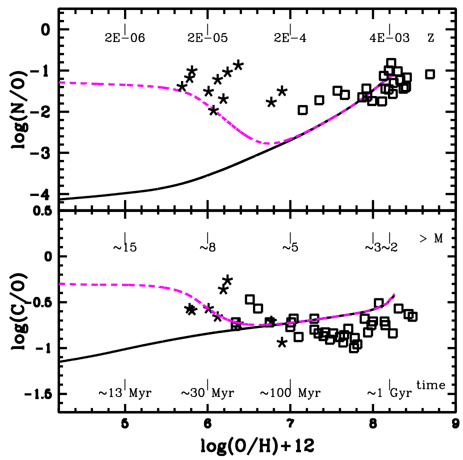

Fig. 1. See a detailed description of this figure in Chiappini et al. (2006b).

non-rotating models, namely, the observed number ratio of Wolf Rayet stars to O-type stars for different metallicities, the observed ratio of WN to WC for metallicities lower than solar, and the observed ratio of type Ib/Ic to type II supernovae at different metallicities. One of the consequences of rotation is that carbon and oxygen, produced in the He-burning core, are transported by rotational mixing into the H-burning shell, where they are transformed into primary ^{13}C and ^{14}C. Interestingly, the efficiency of this process increases when the initial mass and rotational velocity increase (see Maeder & Meynet 2000; Meynet & Maeder 2002), producing more N for fast rotators. Another fundamental prediction from models including rotation is that the rotational mixing also increases with decreasing metallicity.

3. FIRST STARS IMPRINTS?

Upon the inclusion of the new stellar calculations of Hirschi (2007) for $Z = 10^{-8}$ in a chemical evolution model for the galactic halo with infall and outflow, both high N/O and C/O ratios are obtained in the very-metal poor metallicity range in agreement with observations (see details in Chiappini et al. 2006a,b). This model is shown in panel (a) of Figure 1 (dashed magenta curve). In the same figure, a model computed without fast rotators (solid black curve) is also shown. Fast rotation enhances the nitrogen production by ∼3 orders of magnitude!

In addition, stellar models of fast rotators have a great impact on the evolution of the ^{12}C/^{13}C ratio at very low metallicities (Chiappini et al. 2008). In this case, we predict that, if fast rotating massive stars were common phenomena in the early Universe, the primordial interstellar medium of galaxies with a star

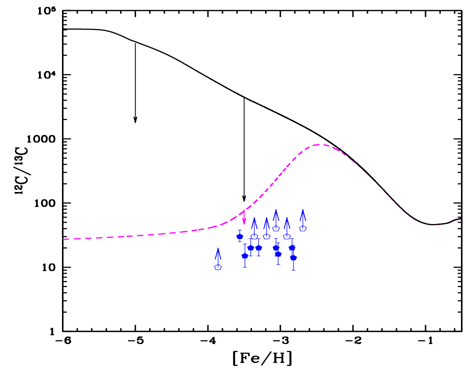

Fig. 2. See a detailed description of this figure in Chiappini et al. (2008).

formation history similar to the one inferred for our galactic halo should have ^{12}C/^{13}C ratios between 30–300. Without fast rotators, the predicted ^{12}C/^{13}C ratios would be ~ 4500 at [Fe/H] $= -3.5$, increasing to ~ 31000 at around [Fe/H] $= -5.0$ (see Figure 2).

Current data on EMP giant normal stars in the galactic halo (Spite et al. 2006) agree better with chemical evolution models including fast rotators. The expected difference in the ^{12}C/^{13}C ratios, after accounting for the effects of the first dredge-up (indicated by the arrows in Figure 2), between our predictions with/without fast rotators is of the order of a factor of 2–3. However, larger differences (a factor of $\sim 60-90$) are expected for giants at [Fe/H] $= -5$ or turnoff stars already at [Fe/H] $= -3.5$. To test our predictions, challenging measurements of the ^{12}C/^{13}C in more extremely metal-poor giants and turnoff stars are required.

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