Models of the Solar Vicinity:
The Metal Rich Stage

By
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I present a review of chemical evolution models of the solar neighborhood. I give special attention to the necessary ingredients to reproduce the observed [Xi/Fe] ratios in nearby metal and super metal rich stars, and to the chemical properties of the solar vicinity focusing on [Fe/H] ≥ −0.1. I suggest that the observed abundance trends are due to material synthesized and ejected by intermediate mass stars with solar metallicity in the AGB stage, and also by massive stars with (super) solar metallicity in the stellar wind and supernovae stages. The required tool to build chemical evolution models that reach super-solar metallicities is the computation of stellar yields for stellar metallicities higher than the initial solar value. Based on these models it might be possible to estimate the importance of merger events in the recent history of the Galactic disk as well as the relevance of radial stellar migration from the inner to the outer regions of the Galaxy. I also present a short review of the photospheric solar abundances and their relation with the initial solar abundances.

1. Introduction
The solar neighborhood is an invaluable laboratory for the chemical evolution models because the number of free parameters is similar to the number of observational constraints.

A number of different assumptions are typically adopted by chemical evolution models of a galactic zone: i) the galactic zone formation mechanism and formation time, ii) when, how many, and what types of stars are formed, iii) when those stars die, and, iv) which are the chemical abundances of the material ejected during the life and death of the stars.

Once a chemical evolution model for the solar vicinity satisfies the observational constraints, it is also possible to test both the Galaxy formation process and the properties of the underlying stellar populations. Therefore, the accuracy of the stellar and HII regions abundances estimations define the strength of our tests.

For that reason, this review is in large extent based on new data for the solar neighborhood: i) HII regions obtained by Esteban, Peimbert and collaborators (see Bresolin in this volume) and ii) F and G dwarf stars obtained by Bensby and Feltzing (see both of them in this volume). Also I will compare these data to the abundances of other galactic components and other galaxies, in particular to Bulge stars and extragalactic HII regions, in order to analyze the origin of the abundance trends at high metallicity.

2. Observational Constraints
The definition of “solar vicinity” has several interpretations ranging from a zone including all low redshift galaxies until a region as small as the one including the stars within 1 pc of the Sun. In the chemical evolution context the solar vicinity corresponds to a cylinder centered around the Sun, at 8 kpc from the Galactic center, that includes objects belonging to the Galactic halo and disk. The dimensions of this cylinder depend on the locations of the objects used as observational constraints. Typical adopted dimen-
sions are 1 kpc in radius and \(\sim 3\) kpc in height, for a cylinder oriented orthogonally from the Galactic plane.

Since I am interested in (super) metal rich objects, I will focus on objects with metallicity near or higher than solar.

2.1. Solar Abundances

The photospheric solar abundances provide the reference pattern for general abundance determinations in the Universe (stars, ionized nebulae, galaxies) and, the inferred initial solar abundances correspond to the interstellar medium (ISM) of the solar neighborhood 4.5 Gyr ago. During the last \(\sim 20\) years the observational estimations of photospheric solar abundances regarding the most abundant heavy elements, like C, N, O, and Ne, have decreased their value.

In Table 1 I show the chemical abundance determinations for some common elements in the solar photosphere computed by Anders & Grevesse (1989, AG89), Grevesse & Sauval (1998, GS98), and Asplund, Grevesse & Sauval (2005, AGS05). These abundances are in \(12 + \log(X_i/H)\) by number. I have added the values of the mass fraction of He and metals, \(Y\) and \(Z\), respectively. I also present the decreasing factors in the abundance determinations between the Anders & Grevesse work and the Asplund et al. data and between the Grevesse & Sauval work and the Asplund et al. data.

Since Fe is one of the most common elements and the value of its solar photospheric determination has kept almost constant during the last years, I will compare the available stellar data based on [Fe/H]. For HII regions, I will consider the O/H value determined in those nebulae as the reference ratio, since Fe is strongly dust depleted in ionized nebulae.

In order to reproduce the helioseismology observations, Sun models require more metals than the solar \(Z\) value obtained by Asplund et al. (2005). Bahcall et al. (2006) considering the photospheric metallicity of the Sun determined by Asplund et al. (2005) found that the initial solar metallicity, \(Z_{\infty}\), is 0.01405, 15\% more metals than those observed in the solar photosphere. This difference is due to diffusive setting of the elements in the photosphere during the last 4.5 Gyr, the age of the Sun (for details, see Carigi & Peimbert 2007). This fact has implications for the chemical evolution models, because the solar abundances in the photosphere have been taken as representative of the abundances of ISM when the Sun was born, but those photospheric solar abundances should be corrected by solar diffusion. Moreover, the diffusive settling effect should be considered in the abundance determinations of other stars, taking into account that the amount of material settled depends on the stellar age.

During this review I assumed that \(Z_{\odot} = 0.012\), \(Z_{\infty} = 0.014\), and \(Z_{\text{can}} = 0.020\) as the photospheric, initial, and canonical solar metallicity, respectively.

2.2. Abundances from HII Regions

Abundance estimations in HII regions give us the preset-day abundances, for that reason they are very important chemical evolution models.

Esteban et al. (2005) based on C and O recombination lines derived the C/H and O/H values of 8 Galactic HII regions. They found higher C/H and O/H values than the photospheric solar ones for the Orion nebula and other 5 Galactic HII regions closer to the Galactic center (see Fig. 2). These values are in agreement with the C/H estimations derived by Slavin & Frish (2006, and references therein), who find C/H = 8.78 \(\pm 0.20\), a value higher than solar (photospheric and internal), along one line of sight of the Local Interstellar Cloud. HII regions gradients, particularly in the inner Galactic disk, might be useful to analyze the chemical enrichment at high metallicities.

Discussion on the abundances of galactic and extragalactic metal rich HII regions, and
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Table 1. Chemical Composition in the Solar Photosphere

| Element | AG89    | GS98    | AGS05   | \(\frac{\text{Xi}/\text{Fe}}{\text{AG89}}\) | \(\frac{\text{Xi}/\text{Fe}}{\text{GS98}}\) |
|---------|---------|---------|---------|-------------------------------------------------|-------------------------------------------------|
| C       | 8.56 ± 0.04 | 8.52 ± 0.06 | 8.39 ± 0.05 | 0.68                                             | 0.74                                             |
| N       | 8.05 ± 0.04 | 7.92 ± 0.06 | 7.78 ± 0.06 | 0.54                                             | 0.72                                             |
| O       | 8.93 ± 0.04 | 8.83 ± 0.06 | 8.66 ± 0.05 | 0.54                                             | 0.68                                             |
| Ne      | 8.09 ± 0.10 | 8.08 ± 0.06 | 7.84 ± 0.06 | 0.56                                             | 0.58                                             |
| Fe\(^a\) | 7.51 ± 0.03 | 7.50 ± 0.01 | 7.45 ± 0.05 | 0.87                                             | 0.89                                             |
| Y       | 0.2743     | 0.2480     | 0.2486     | 0.91                                             | 1.00                                             |
| Z       | 0.0189     | 0.0170     | 0.0122     | 0.65                                             | 0.72                                             |

\(^a\)Fe abundance in meteorites only for AG89.

also the different methods of abundances determinations have been presented by Bresolin (2007 and this volume). Since different methods to determine abundances provide different chemical abundances, a consensus in the abundances determinations for HII regions is required.

2.3. Age-[Fe/H] relation

One of the most fundamental cosmochemistry observational results is the age-[Fe/H] relation because it links the age of the different dwarf stars with their chemical properties. This relation presents a large scatter along all of the metallicity range and metal rich stars are no exception. According to Bensby et al. (2005) thin disk stars with [Fe/H] > +0.2 present ages between 3 and 9 Gyr, but stars with 0 < [Fe/H] < +0.2 have ages between 0 and 6 Gyr. According to Soubiran & Girard (2006) the mean age of the thin disk stars of [Fe/H] > +0.15 is 5 Gyr with a dispersion of 3.4 Gyr, while the mean age of stars of 0 < [Fe/H] < +0.2 is 3.8 with a dispersion of 2.1 Gyr.

The dispersion is partly caused by stars born at other galactocentric radii with different star formation histories (SFHs) that migrated to the solar vicinity. Since this stellar migration requires time, Rocha-Pinto et al. (2006) showed that the solar neighborhood has been polluted by old and metal poor stars from inner and outer radii (between 6 and 9.5 kpc). The age dispersion of the metal rich stars might be explained by a superposition of young stars that were born in the solar vicinity and by old stars that were born at inner radii with an early and efficient star formation rate (SFR) as chemical evolution models of the Galactic disk predict (e.g. Carigi et al. 2005).

An alternative explanation for the age dispersion presented in the age-[Fe/H] relation are mergers of one or several satellite galaxies with different SFHs.

2.4. \([\text{Xi}/\text{Fe}]\) vs \([\text{Fe}/\text{H}]\) relations

Other important observational constraints are provided by the [Xi/Fe] vs [Fe/H] relations derived by dwarf stars in the solar neighborhood. These relations give information to infer the past of the solar vicinity and the properties of its stellar populations.

- \(\alpha\) enhancement

Some studies have found \(\alpha\) enhancement in thick disk stars compared to the thin disk stars in the \(-0.7 < [\text{Fe}/\text{H}] < -0.1\) range (Feltzing in this volume and references therein). No chemical evolution model that assumes a simple formation for the disk can reproduce that behavior. But, in the literature there are some models with complex disk formation histories that can explain the \(\alpha\) enhancement:
i) Nykytyuk & Mishenina (2006) suggest a two-zone model with different gas infalls and SFHs for the thick and the thin disks. Their model can reproduce the $\alpha$ enhancement in the thick disk stars compared to the thin disk stars, but not the dispersion in the age-[Fe/H] relation. Chiappini (2001 and this meeting) has suggested a similar model assuming a double infall for the Galactic disk and the thin disk formed with material from the thick disk and from the intergalactic medium.

ii) Brook et al. (2005) suggest hierarchical mergers and fragmentation models. Specifically the thick disk formed by multiple gas rich mergers at early times (7.7 Gyr ago) at redshifts higher than $\sim 1$. Part of the gas of the thick disk was leftover by shock heating, then the thin disk formed from primordial infalling gas and the pre-enriched gas by the thick disk stars that falls later onto the thin disk. Their results are in good agreement with $\alpha$ enhancement but in partial agreement with the dispersion in age-[Fe/H] relation.

- **Metal Rich Disk Stars**

Bensby et al. (2005) have determined chemical abundances in F and G dwarfs and they found strong abundance trends, which are shown in Fig. 1. As can be noted from this figure the slope of $[\Xi/Fe]$ vs [Fe/H] relation for [Fe/H] $> -0.1$: i) change significantly for Na, Ni, and Zn, with $\Delta[\Xi/Fe]/\Delta[Fe/H] > 0$, and for Ba with $\Delta[\Xi/Fe]/\Delta[Fe/H] < 0$, i) change moderately for Mg, Al, Si, Ca, and Ti, being $\Delta[\Xi/Fe]/\Delta[Fe/H] \sim 0$, and iii) does not change for O, Cr, and Eu.

Similar trends have been observed in the red giants of the Galactic Bulge (Cunha & Smith 2006, Leceurer et al. 2006): i) the [Na/Fe] increase with [Fe/H], ii) the [Na/Mg] increase with [Fe/H] $> 0$ but not as much as in the thin disk, and iii) the [O/Mg] decrease with [Fe/H] $> 0$ like in the disk stars.

Recently Johnson et al. (2006) have determined abundances for a super metal rich G-dwarf of the Galactic bulge and they find that the [$\alpha$/Fe] ratios are subsolar, while the odd-Z elements are slightly supersolar, these values are in agreement with the trends seen in the more metal-rich stars of the Galactic disk (see Fig. 1).

3. Chemical Evolution Models of the solar vicinity

The goal of any chemical evolution model is to explain the observed chemical properties. In the literature there are successful models that match the abundance trends for [Fe/H] $\leq 0$, for example, see the excellent reviews by Gibson et al. (2003) and by Matteucci (2004). Those models are computed with different codes and assumptions. In Fig. 1 I present the [Xi/Fe] vs [Fe/H] evolution predicted by some well known models. If those theoretical trends are extrapolated to [Fe/H] $\sim +0.5$ no chemical evolution model is able reproduce the change in the [Xi/Fe] vs [Fe/H] relation for [Fe/H] $> -0.1$.

Therefore, I will study the dependence of [Xi/Fe] with the different ingredients of a chemical evolution model, in order to find an explanation of the [Xi/Fe] trends presented by metal rich stars of the Galactic thin disk.

It is well known that the [Xi/Fe] ratios depend on gas flows, star formation rates, initial mass function, and stellar yields, being the last two ones the most important factors.

3.1. Gas and star flows

Infalls and outflows change the [Xi/Fe] ratios depending on the abundances and the amount of gas of the flows. Rich outflows with SNII material reduce [Xi/Fe] as opposed to the increment required by most of the observed trends. Rich outflows with SNIa material increase [Xi/Fe] but they also decrease [Fe/H] preventing the formation of metal rich stars. A metal rich gas infall of overabundant elements present in metal rich stars, like
Figure 1. Evolution of [Xi/Fe] vs [Fe/H] predicted by different models: Al by Timmes et al. (1995), Ca by Portinari et al. (1998), Ti, Ni and Zn by Francois et al. (2004), O by Gavilán et al. (2005), Mg, Si and Cr by Prantzos (2005), Ba and Eu by Cescutti et al. (2006) and Na by Izzard et al. (2006). Filled circles: F and G dwarf disk stars by Bensby et al. (2005). Open squares: The most metal rich G dwarf Bulge star by Johnson et al. (2006). [Xi/H] corrections due to different photometric solar values assumed by the authors are not made.

Na, can reproduce the [Xi/Fe] raise, but how does the infalling gas get those [Xi/Fe] values?

Brook et al. (2005) explain the chemical properties of the thick and thin disk stars
with models that assume mergers and infalls mainly at redshifts lower than 1, but their results do not predict the abundance trends for $[\text{Fe/H}] > -0.1$.

Reddy (in this meeting) showed a secondary peak in that $[\text{Fe/H}]$ distribution for $[\text{Fe/H}] > 0$. An inclusion of a significant amount of stars (or gas that triggered the star formation) from a merger event could explain the secondary peak. If the thin disk metal rich stars formed in one or several galactic satellites that settled in the Galactic disk, how did the stars of those satellites reach supersolar $[\text{Fe/H}]$ with (super)solar $[\Xi/\text{Fe}]$?

Based on the merger scenario, the Bulge also formed by satellites that fell early in the Milky Way, therefore the origin of old and metal rich stars of the Bulge and Galactic disk is in small galaxies or metal rich stars form of the material comes from small structures, but again, how did those structures reach $[\Xi/\text{Fe}] > 0$?

Based on another scenario the Bulge could form by the stars that were born in the inner Galactic disk and were dynamically heating by the bar (Colín et al. 2006). Moreover, the same bar could be able to produce radial flows of stars from the inner to the outer part of the Galactic disk. Therefore the metal rich stars of the Bulge and the solar neighborhood formed in the inner disk, but how did the inner disk reach $[\Xi/\text{Fe}] > 0$?

Radial gradients can be powerful tools to decide if metal rich stars observed in the solar vicinity and the Bulge formed in situ or alternatively were formed in inner galactocentric radius or merged satellites. In the most complicated case (or the most realistic) a combination of these three ones should be the answer.

Therefore, stellar or gaseous infalls can explain the abundance trends observed for $[\text{Fe/H}] > -0.1$ but they pose the question of how could these infalls get those (super) solar $[\Xi/\text{Fe}]$ values?

### 3.2. Star formation rate

Important changes in the star formation rate, affect the $[\Xi/\text{Fe}]$ ratios mainly after a significant star formation burst (e.g. Carigi et al. 1999, 2002; Chiappini 2001). The spiral wave is the most important inner mechanism that triggers star formation and that recently could have formed stars from a metal-rich gas. Rocha-Pinto et al. (2000) and Hernández et al. (2000) inferred the star formation history from the color magnitude diagram for the solar vicinity. They found: i) a decreasing exponential general behavior of the SFH in the last $\sim 10$ Gyr, and ii) variations from the general behavior related directly to the spiral wave passages. Based on these results, it is found that there were no significant bursts of star formation in the last $\sim 6$ Gyrs, therefore it is unlikely that a burst could have modified the $[\Xi/\text{Fe}]$ slope.

An important fact is that metal rich stars with similar $[\Xi/\text{Fe}]$ values have been observed in the solar neighborhood and in the Bulge, galactic components with different SFHs. The solar vicinity had a moderate SFR during 12 Gyr, (e.g. Carigi et al. 2005) while the Bulge formed very quickly, in less than 0.5 Gyr, with a high SFR (Ballero et al. and Matteucci, both in this volume).

Therefore, I discard changes in the star formation rate as the explanation of the change in the $[\Xi/\text{Fe}]$ slopes for $[\text{Fe/H}] > -0.1$.

### 3.3. Initial Mass Function

The initial mass function, IMF, gives the mass distribution of the formed stars in a star formation burst. This function is parametrized by the slope for different mass ranges and by the lower and upper mass limits of the formed stars. Since $[\Xi/\text{Fe}]$ depends strongly on the IMF, a dependence of the IMF with metallicity, density or gas mass could explain the change of the $[\Xi/\text{Fe}]$ slope.

According to Kroupa (in this volume) there is no evidence that the IMF changes with
Z. Nevertheless, Bonnell suggested (in this meeting) that the IMF changes with \( Z \): for supersolar metallicities the slope for massive stars (MS) could be steeper and the upper limit could be lower than for subsolar metallicities, producing \([\text{Xi}/\text{Fe}]\) subsolar values, in contradiction with the observed values.

In a metal rich gas it is more difficult to create MS due to the Jeans mass dependence on \( Z^{-2/3} \) and metal rich stars truncate the star formation process by their stellar winds. This suggestion could explain the low ionization of the metal rich HII regions compared to that of HII regions with subsolar metallicity: in a metal rich gas the number of MS may be lower leading to a smaller number of ionizing photons, on the other hand, the lower stellar temperatures of the metal rich stars help to to reduce the number of ionizing photons, further work on this suggestion needs to be done.

The IMF dependence on the gas density should be less important, because the same abundance trends have been observed in Galactic components with different densities (Bulge, open clusters, isolated dwarfs), but with a same property: super solar metallicity.

According to Weidner & Kroupa (2005) the IMF depends on gas mass. They found that the slope and the upper mass limit change with gas mass available to form stars. In dwarf galaxies the upper mass limit is lower and the slope in the MS range is steeper producing lower \([\text{Xi}/\text{Fe}]\) values than those of normal galaxies for elements synthesized only by MS.

Moreover, Carigi & Hernández (2007) found important effects on the abundance ratios when the IMF is stochastically populated. The \([\text{O}/\text{Fe}]\) values varied within three orders of magnitude for a stellar population of 500 \( M_\odot \) that enrich a gas mass of \( 10^4 M_\odot \). This effect could explain the dispersion observed in the abundances ratios, but not the abundance trends.

Therefore, possible modifications in the initial mass function cannot explain the abundance trends observed for \([\text{Fe/H}] > -0.1\).

3.4. Stellar Yields

Since supersolar \([\text{Xi}/\text{Fe}]\) values seem to be a common property of stars with \([\text{Fe/H}] > 0\) in galactic components (thin disk, bulge, open clusters) with different formation histories, the abundance trends can be explained due to the stellar yields of (super)solar metallicity stars. The observed abundances will provide strong constraints on the physical processes taking place in the stellar cores.

The models shown in the Fig. 1 consider different \( Z \)-dependent yields for massive stars, for low-and-intermediate mass stars (LIMS), and for SNIa. These stellar yields were computed for \( Z \leq Z_{\text{can}} \) with the exception of the Portinari et al. (1998) yields, but these authors never used their yields for \( Z = 0.05 \) because they stopped their computations at \([\text{Fe/H}] = 0\). Cescutti et al. (2006) and François et al. (2004) modified the stellar yields obtained by stellar evolution models in order to reproduce the observed trends for \([\text{Fe/H}] < +0.1\).

Edmunds (in this meeting) suggested that stellar yields increasing with \( Z \) raise the \([\text{Xi}/\text{Fe}]\) values for \([\text{Fe/H}] > -0.1\). The \([\text{O}, \text{Mg}/\text{Fe}]\) values for Bulge and thin disk stars indicate a \( Z \) dependence in the ratio of the \( O \) to \( Mg \) yield.

Meynet et al. (in this volume) show that no-rotating MS with \( Z = Z_{\text{can}} \) and a high mass loss rate eject more C than O, and that these stars are an important source of He, C, Ne, and Al, but not so much of O. These facts could explain the \([\text{O}/\text{Fe}]\) decrease with increasing \([\text{Fe}/\text{H}]\) while the \([\text{Al}/\text{Fe}]\) values remain almost constant for \([\text{Fe}/\text{H}] \geq 0\).

The significant change in the \([\text{Na}/\text{Fe}]\) slope suggests an extra source of Na production. Assuming that SNII and AGB stars produce Na, Izzard et al. (2006) reproduce the \([\text{Na}/\text{Fe}]\) values for \([\text{Fe}/\text{H}] < -0.2\), but fail to reproduce the \([\text{Na}/\text{Fe}]\) increase for \([\text{Fe}/\text{H}] > \)
Figure 2. Model predictions by Carigi (2000) (dashed lines) and Carigi et al. (2005) (continuous lines) considering yields of metal-rich massive stars by Portinari et al. (1998) and Maeder (1992), respectively. Left Panels: [C/O,Fe] evolution with [O,Fe/H] in the solar vicinity. Right Panels: Present-day ISM abundances ratios as a function of galactocentric distance. Open circles: Galactic HII regions, gas plus dust, by Esteban et al. (2005) and Carigi et al. (2005). Star: Extragalactic HII region (H1013) in M101 by Bresolin (2007). Filled triangles: F and G dwarf disk stars by Bensby & Feltzing (2006). Filled squares: dwarf stars by Akerman et al. (2004). Photometric solar values by AGS05 are considered except for data by Bensby & Feltzing (2006) because they assumed their own solar abundances.

They suggest that the change in the [Na/Fe] slope may be explained by secondary Na produced by SNII. Nevertheless, according to Frohlich (in this meeting) the core collapse supernovae cannot explain the [Na/Fe] increase observed for [Fe/H] ≥ 0.

Another channel that contributes to the enrichment of a metal rich gas is provided by SNIa. According to Yoon (in this volume) there are different scenarios for SNIa with different time delays, but the amount of heavy elements ejected is similar for the different scenarios. The role of rotation might be important in the production of chemical elements, but this effect has not been studied yet.

Therefore, new stellar yields for massive stars and intermediate mass stars of solar and supersolar metallicity are required.
• **Importance of Stellar Winds in Metal Rich Stars**

One of the most important problems in the chemical evolution of Galaxies is the C production. Carigi et al. (2005, 2006) have studied the contribution of the C enrichment by MS and LIMS in different types of galaxies. We have found that the MS have contributed with 48% and 36% to the total C produced in the solar neighborhood and in the dIrr galaxy NGC 6822, respectively. The difference is due to the $Z$ effect on the stellar winds of MS. Massive stars of solar $Z$ eject more C than those of subsolar $Z$ through stellar winds (see Meynet et al. and Crowther, both in this volume).

Carigi et al. (2005) made a chemical evolution model of the Galaxy where they assumed that the metal rich stars behave like stars of $Z_{\text{can}}$. They are able to reproduce the C/O and O/H values of the solar vicinity as well as the O/H and C/O gradients observed by Esteban et al. (2005) but cannot reproduce the decrease in the [C/Fe] for [Fe/H] $> -0.1$ shown by Bensby & Feltzing (2006) and Allende-Prieto in this meeting (see Fig. 2).

Carigi (2000) made a model considering yields of MS by Portinari et al. (1998) for $Z = 2.5 Z_{\text{can}}$ and predicted a C/O gradient flatter than the observed one. The flattening of the gradient is due to the increase in the mass-loss rate with $Z$ ($\propto Z^{0.5}$) assumed by Portinari et al., consequently metal-rich MS are stripped before C is synthesized and their C yields are lower than those of stars with $Z = Z_{\text{can}}$.

Based on Meynet et al. (in this volume) the rotating stars of $Z = Z_{\text{can}}$ are more efficient ejecting C and O than the rotating stars of $Z = 2 Z_{\text{can}}$. This could explain the [C/Fe] decrease shown by metal rich stars of the thin disk, but the C contribution due to LIMS must be included also to have a complete picture of the evolution at high $Z$.

In order to reproduce the high C/O values for inner galactocentric radii the mass-loss rate for metal-rich stars has to be lower than that assumed by Portinari et al. (1998). On the other hand, to reproduce the low C/Fe values for [Fe/H] $> 0$ in the solar neighborhood the mass-loss rate has to be higher than that assumed by Portinari et al. Puls (in this meeting) gave limits for the mass-loss rate, that depends as $Z^{0.62 \pm 0.15}$.

Consequently, there is an inconsistency between theory and observations for the behavior of C/O and C/Fe for high metallicities and a more complex explanation is needed.

### 4. Conclusions

Chemical evolution models of the solar vicinity for metal rich stars are in the early stages of development, nevertheless based on this review I present the following conclusions:

- Models that assume hierarchical mergers and fragmentation explain most of the chemical and kinematic properties of thick and thin disks for [Fe/H] $\leq 0$.
- Models that assume different star formation histories and infalls for the thin and the thick disk explain only their chemical properties for [Fe/H] $\leq 0$.
- There is no published chemical evolution model of the solar vicinity that can reach the maximum [Fe/H] value observed in the thin disk, that is, [Fe/H] $\sim +0.4$.
- Simple extrapolations of chemical evolution models that assume [Fe/H] $\leq 0$ to the [Fe/H] $\sim +0.4$ regime, result in predictions that fail to match the chemical abundances found in (super) metal-rich stars.
- The similar abundance ratios trends observed for stars in the solar neighborhood and the high metallicity Bulge stars suggest that both were created by the pollution of supersolar massive stars and solar intermediate mass stars. The stellar yields of these stars are required to study the metal enrichment of the interstellar medium in the solar vicinity and the Bulge.
• No current chemical evolution model includes adequately the contribution of metal-rich massive stars, because their yields have not been computed completely yet.
• The intermediate mass stars in the AGB may produce an important amount of the chemical elements heavier than oxygen, but in the case of Na their contribution is not enough to explain the [Na/Fe] rise for [Fe/H] > −0.1.
• The large dispersion in age shown by metal rich stars in the solar vicinity could be indicating an external origin: like merger events or stellar migrations from the inner disk.

In my opinion, we are going into a new phase of Astronomy: from the past to the future of the Universe (before this meeting the emphasis was from the present to the past) the metal-rich past and present give us hints to the future.

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