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Planetary Nebulae as Astronomical Tools

SNe Ia and Novae: their roles in galactic chemical evolution

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- Supernovae Ia and chemical evolution
- Novae and chemical evolution

Type Ia SN progenitors

- Single degenerate scenario $\rightarrow$ classical scenario of Whelan and Iben (1973), namely C-deflagration in a C-O WD reaching M_{Ch} after accreting material from a companion (RG) $\rightarrow t_{SNIa_{min}}$=0.03 Gyr (Greggio and Renzini 1983)

- Double Degenerate scenario: the merging of two C-O WDs, due to gravitational wave radiation, which explode by C-deflagration when M_{Ch} is reached (Iben and Tutukov 1984; 1985) $\rightarrow$ $t_{SNIa_{min}} = 0.03 + \Delta t_{grav}$=0.03+ 0.15Gyr (Tornambè & Matteucci, 1986)

- More recent model by Hachisu et al. (1996; 1999) is based on the classical scenario of WI73 but with a metallicity effect $\rightarrow$ no type Ia systems can form for [Fe/H]$< -1.0 \rightarrow t_{SNIa_{min}} = 0.33$ Gyr plus metallicity delay

Nova progenitors

- Classical novae are binary systems, where one component is a white dwarf (either carbon-oxygen or neon-oxygen-magnesium), accreting hydrogen rich material from a less evolved companion
- When the pressure and temperature at the bottom of the accreted layer exceed critical values the nuclear reactions are ignited and novae exhibit a sudden and rapid increase of their brightness
- The thermonuclear runaways are responsible for the production of interesting chemical species, such as ^{13}C, ^{15}N, ^{17}O, ^{22}Na, ^{26}Al, ^{22}Ne and possibly ^{7}Li (see Jose' and Hernanz 1998, Gehrz et al. 1998, Della Valle et al. 2002)

Nova progenitors

- Although the matter processed through nova explosions is a small fraction (a few 10^{-3}) of the total mass of the interstellar gas and dust in the Milky Way, the concentrations of these rare isotopes in the nova ejecta can be enhanced, relative to solar abundances, by factors 10^{2-3} $\rightarrow$ novae non-negligible contributors to the galactic nucleosynthesis (Romano et al. 1999, 2001; Romano & Matteucci 2003)

Theoretical type Ia SN rates

- The SNeIa rate (single degenerate, Greggio & Renzini 1983; Matteucci & Recchi 2001):

$$R_{SNeIa} = A \int_{M_{B_m}}^{M_{B_M}} \phi(M_B) \int_{\mu_m}^{0.5} f(\mu)\psi(t - \tau_{M_2}) d\mu \, dM_B,$$

  where M_2 is the mass of the secondary, M_B is the total mass of the binary system, $\mu = M_2/M_B$, $\mu_m = max\left\{M_2(t)/M_B, (M_B - 0.5M_{B_M})/M_B\right\}$, $M_{B_m} = 3\ M_\odot$, $M_{B_M} = 16\ M_\odot$. $\phi(M_B)$ is the initial mass function for the total mass of the binary system

- $\psi(t)$ is the SFR, $\phi(m)$ is the IMF, $f(\mu)$ is the distribution function for the mass fraction of the secondary, $f(\mu) = 2^{1+\gamma}(1+\gamma)\mu^\gamma$, with $\gamma = 2$ $A = 0.05$ for MW, fixed by reproducing the observed SNe Ia rate at the present epoch

Theoretical nova rates

- Yungelson et al. (1997) computed nova rates with population synthesis models and various SF histories
- D'Antona and Matteucci (1991) and Matteucci et al. (2003) assumed that the nova rate is $\propto$ the rate of formation of WDs:

$$R_{novae}(t) = \alpha \int_{0.8}^{8.0} \psi(t - \tau_m - \Delta t)\phi(m)dm = \alpha R_{WDs}$$

- Δt is a delay time whose value has to be fixed to guarantee the cooling of the white dwarf (WD) to a level that ensures a strong enough nova outburst

Theoretical nova rates

- They assumed a distribution of Δt varying from 1 to 5 Gyr
- The rate of nova eruptions is therefore:

$$R_{outbursts}(t) = \alpha R_{WDs}(t) n,$$

and $n = 10^4$ is the average number of nova outbursts for a typical nova system (Ford, 1978; Bath and Shaviv 1978; Shara et al. 1986)

- The parameter $\alpha = 0.01$, is a constant in space and time and is fixed by reproducing the rate of nova outbursts at the present time in the Galaxy (25 novae yr^{-1})

Nucleosynthesis in Novae and Supernovae

- Low & intermediate mass stars ($0.8 \leq M/M_{\odot} \leq 8$) $\rightarrow$ ^{4}He, ^{12}C, ^{14}N, heavy s-process elements (Ba, Y, Sr)
- Type II SNe ($M > 8M_{\odot}$) $\rightarrow$ α-elements (O, Ne, Mg, Si, S, Ca), part of Fe and r-process elements
- Type Ia SNe produce mainly Fe-peak elements ($\sim 0.6 - 0.7 M_{\odot}$ of ^{56}Fe)
- Novae can possibly be important in producing ^{7}Li, ^{13}C, ^{15}N, ^{17}O
- Type Ia SNe (and novae) restore their products with a time delay relative to type II SNe $\rightarrow$ time-delay model. The delay for novae is even longer than for SNIa

Chemical Evolution Models

- Chemical evolution models predict the evolution of the abundances of the most common elements in the gas and stars in galaxies
- The assumed SFR and IMF determine the SF formation history for a given galaxy and this is a crucial ingredient
- Detailed nucleosynthesis prescriptions and SN (I, II) rates should be considered, stellar lifetimes should be taken into account
- Infall, inflow and outflow should also be taken into account
- Absolute abundances are very model dependent whereas abundance ratios depend only on the nucleosynthesis, IMF and stellar lifetimes

Basic Equations

If G_i is the mass fraction of gas in the form of an element i, we can write:

$$\dot{G}_i(t) = -\psi(t)X_i(t) + \int_{M_L}^{M_{Bm}} \psi(t-\tau_m)Q_{mi}(t-\tau_m)\phi(m)dm$$

$$+\alpha \int_{M_L}^{8.0} \psi(t-\tau_m-\Delta t)Q_{mi}(t-\tau_m-\Delta t)\phi(m)dm$$

$$+A \int_{M_{Bm}}^{M_{BM}} \phi(m) \cdot [\int_{\mu_{min}}^{0.5} f(\mu)\psi(t-\tau_{m2})Q_{mi}(t-\tau_{m2})d\mu]dm$$

$$+B \int_{M_{Bm}}^{M_{BM}} \psi(t-\tau_m)Q_{mi}(t-\tau_m)\phi(m)dm$$

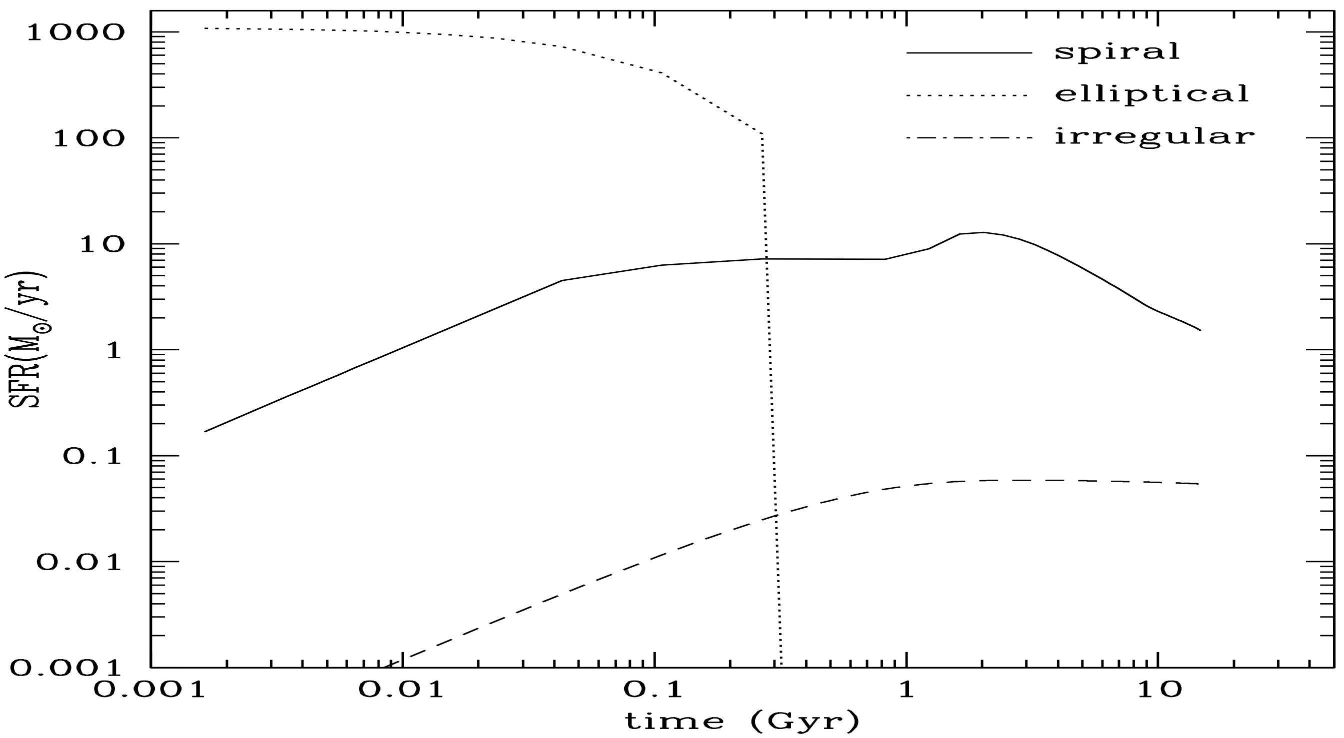
$$+ \int_{M_{BM}}^{M_U} \psi(t-\tau_m)Q_{mi}(t-\tau_m)\phi(m)dm$$

$$+X_{A_i}A(t)$$

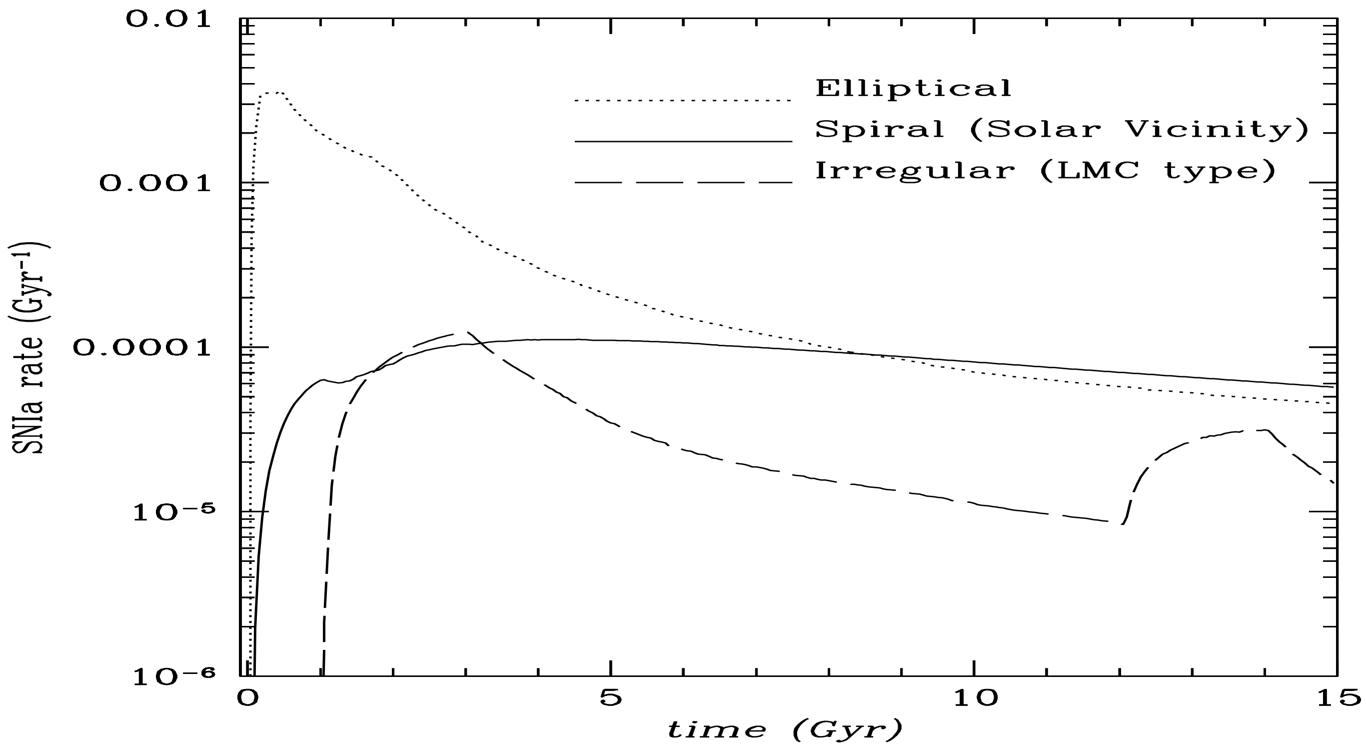
B=1-A, A=0.05-0.09, $\alpha = 0.01$, $M_L = 0.8M_\odot$, $M_U = 100M_\odot$

The star formation rate in galaxies

Different efficiency of SF in each galaxy type

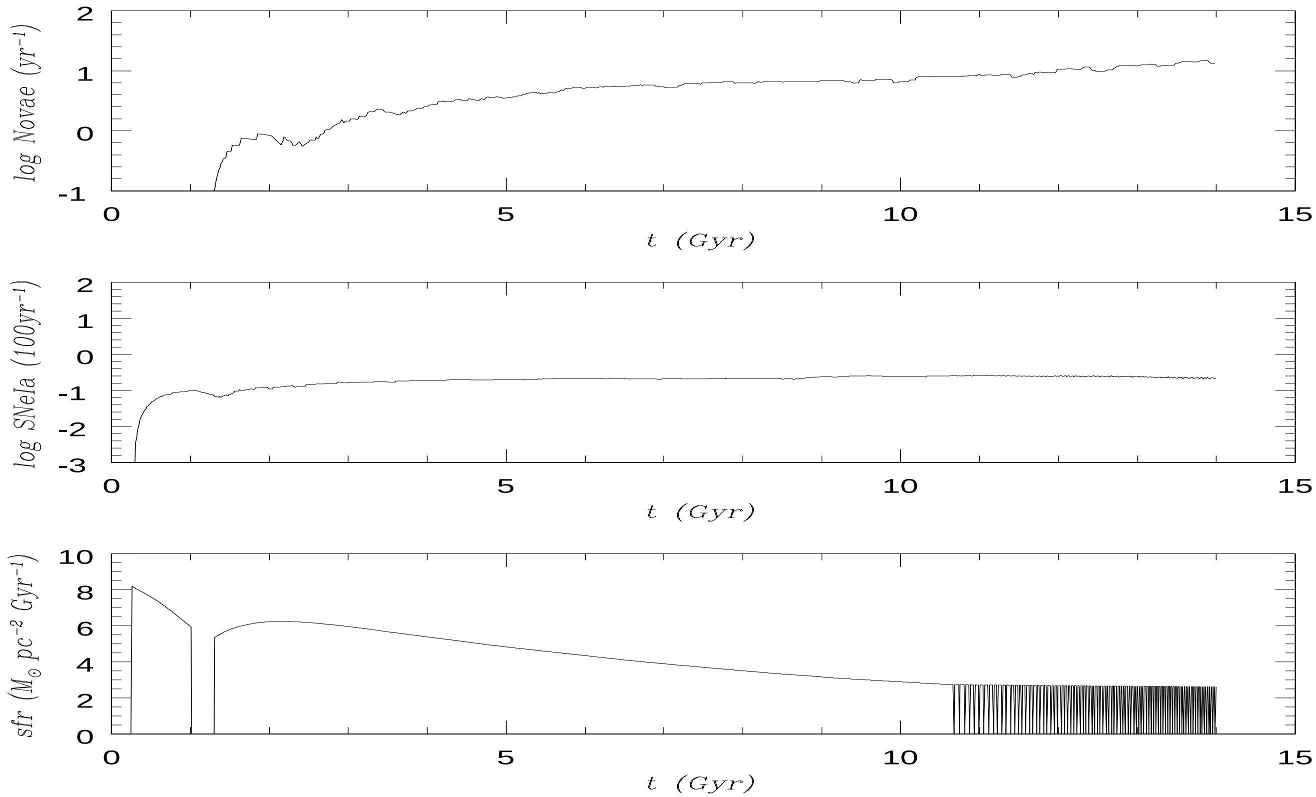


Type Ia SN RATES IN GALAXIES



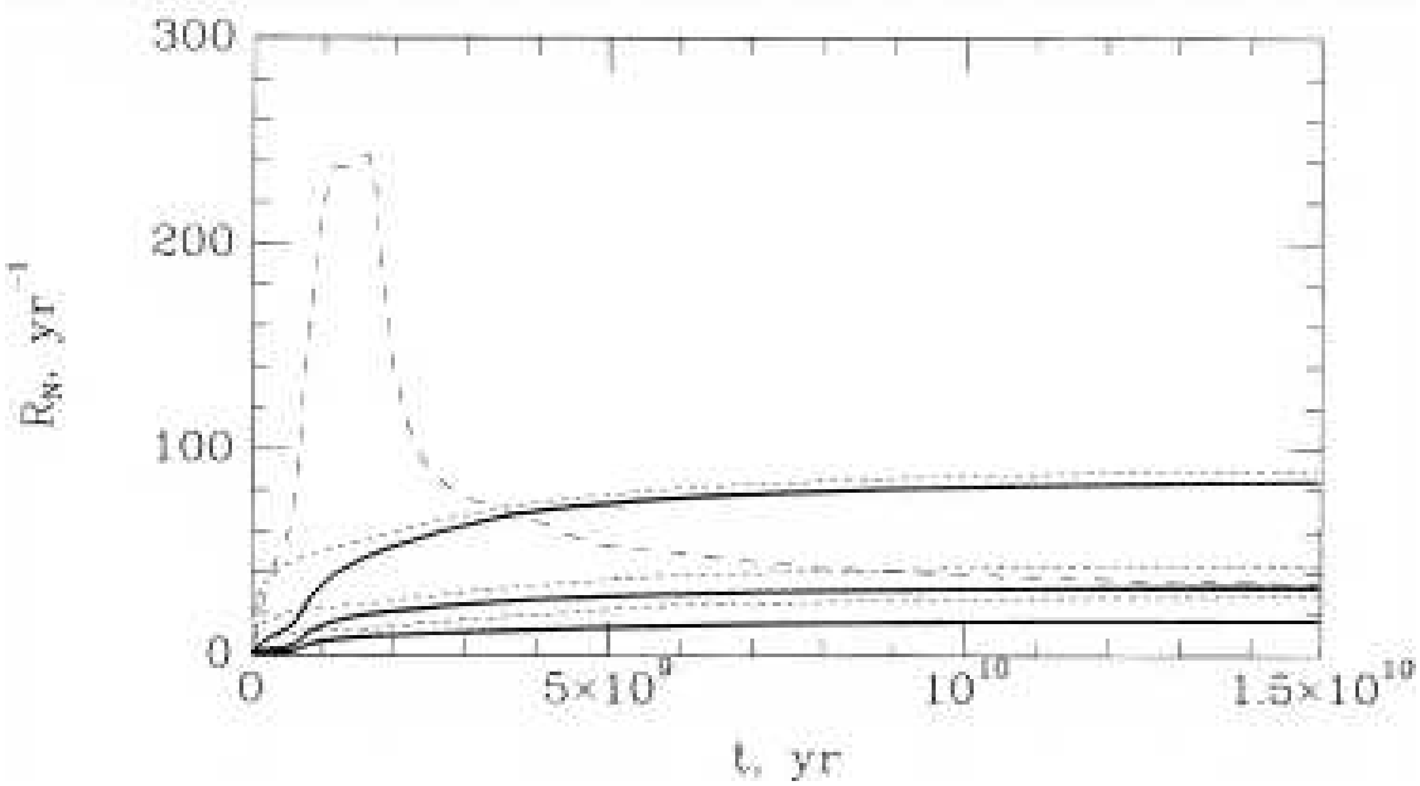
Novae and SNeIa in the MW

Matteucci et al. (2003)

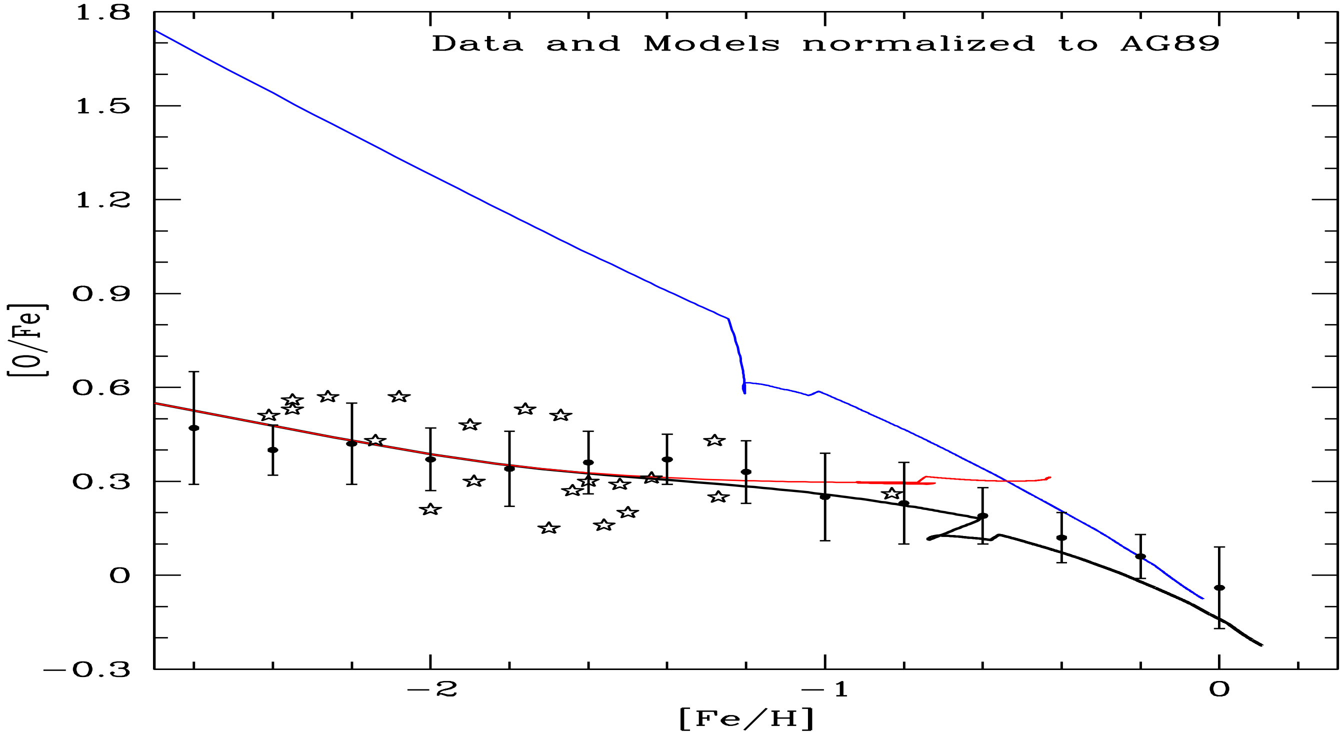


Nova Rates

Yungelson et al. (1997) → nova rates for different SFRs

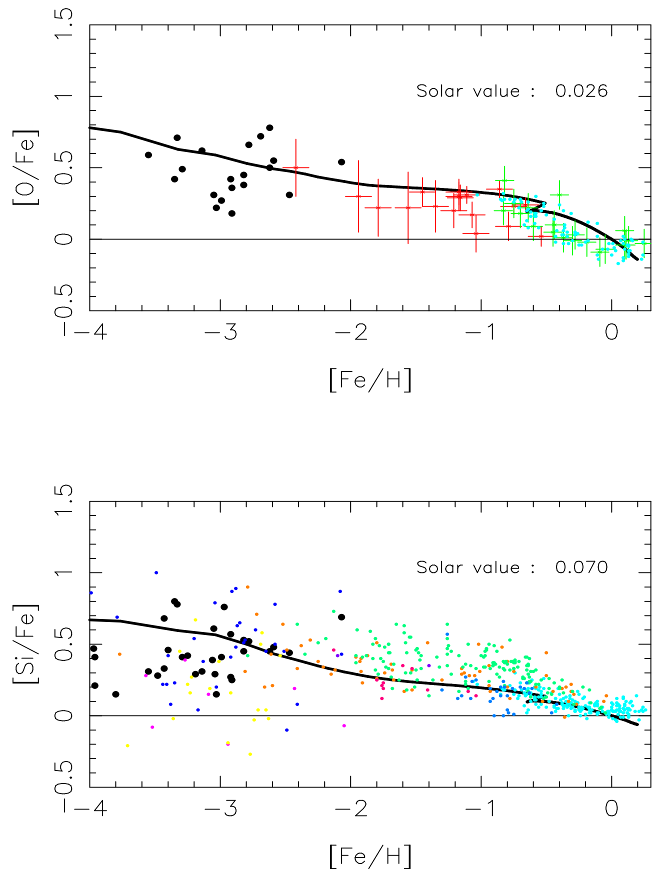


The time-delay model



MW: [X/Fe] vs. [Fe/H]

François et al. (2004)- Black dots → Cayrel et al. (2004)



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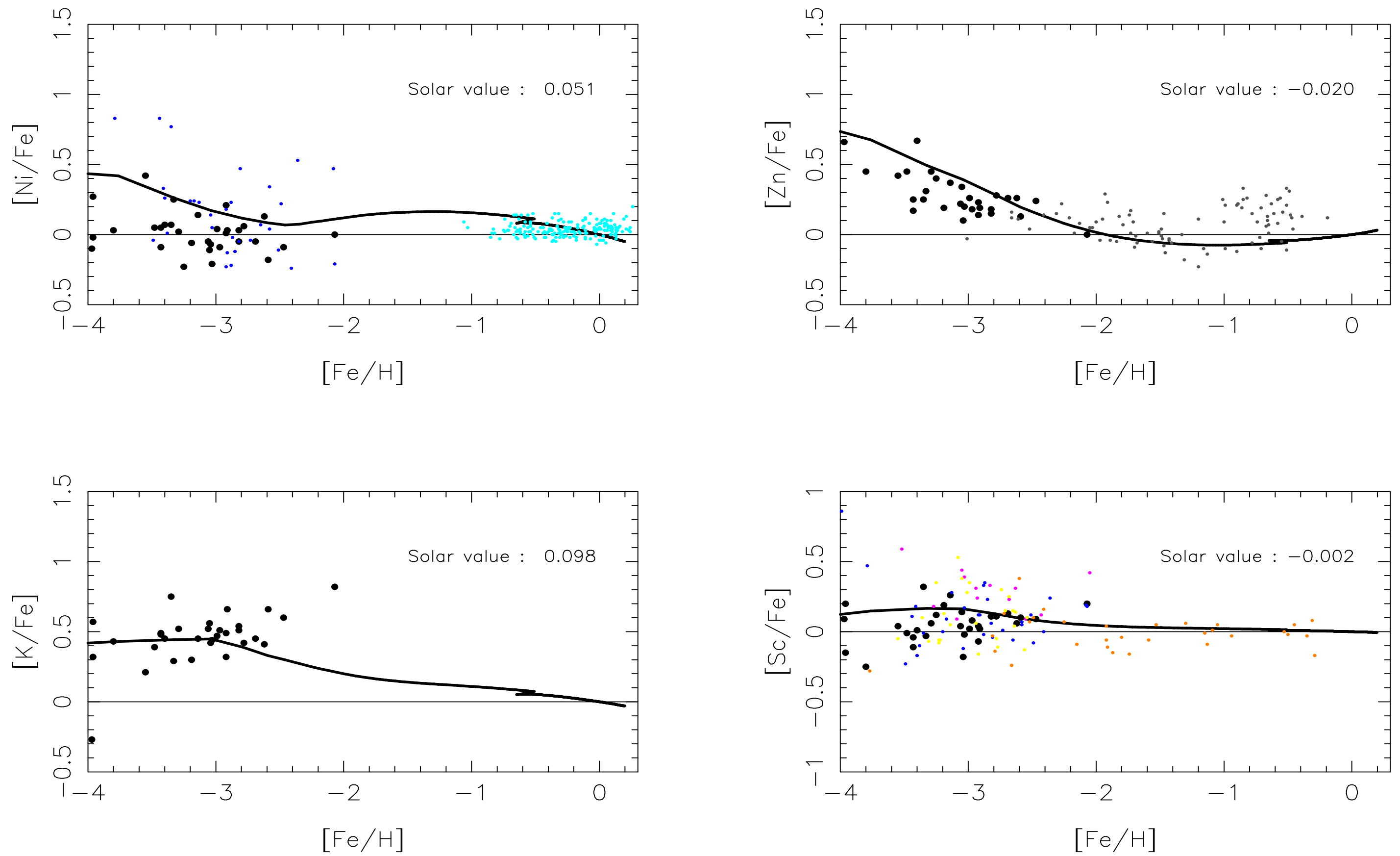

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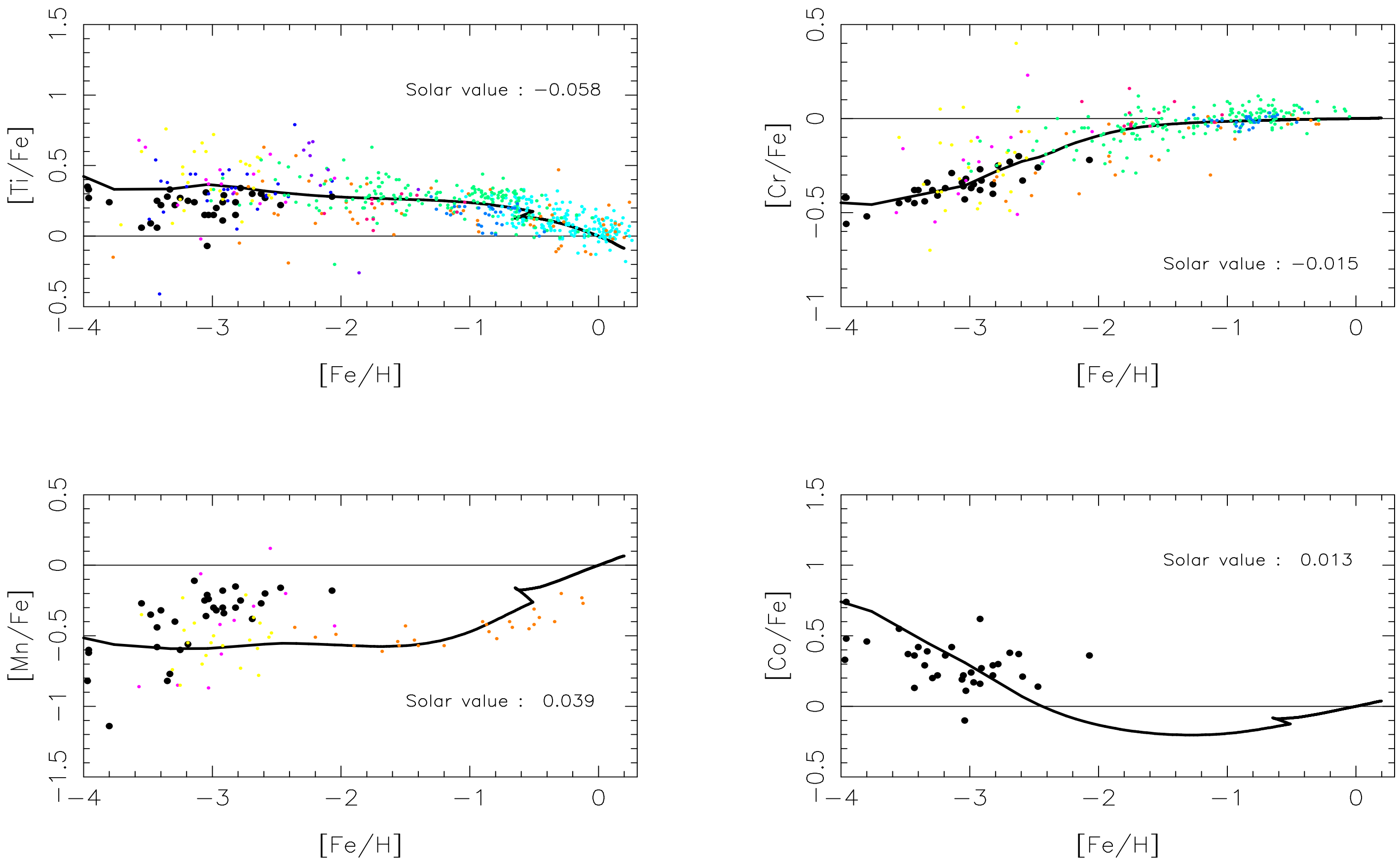
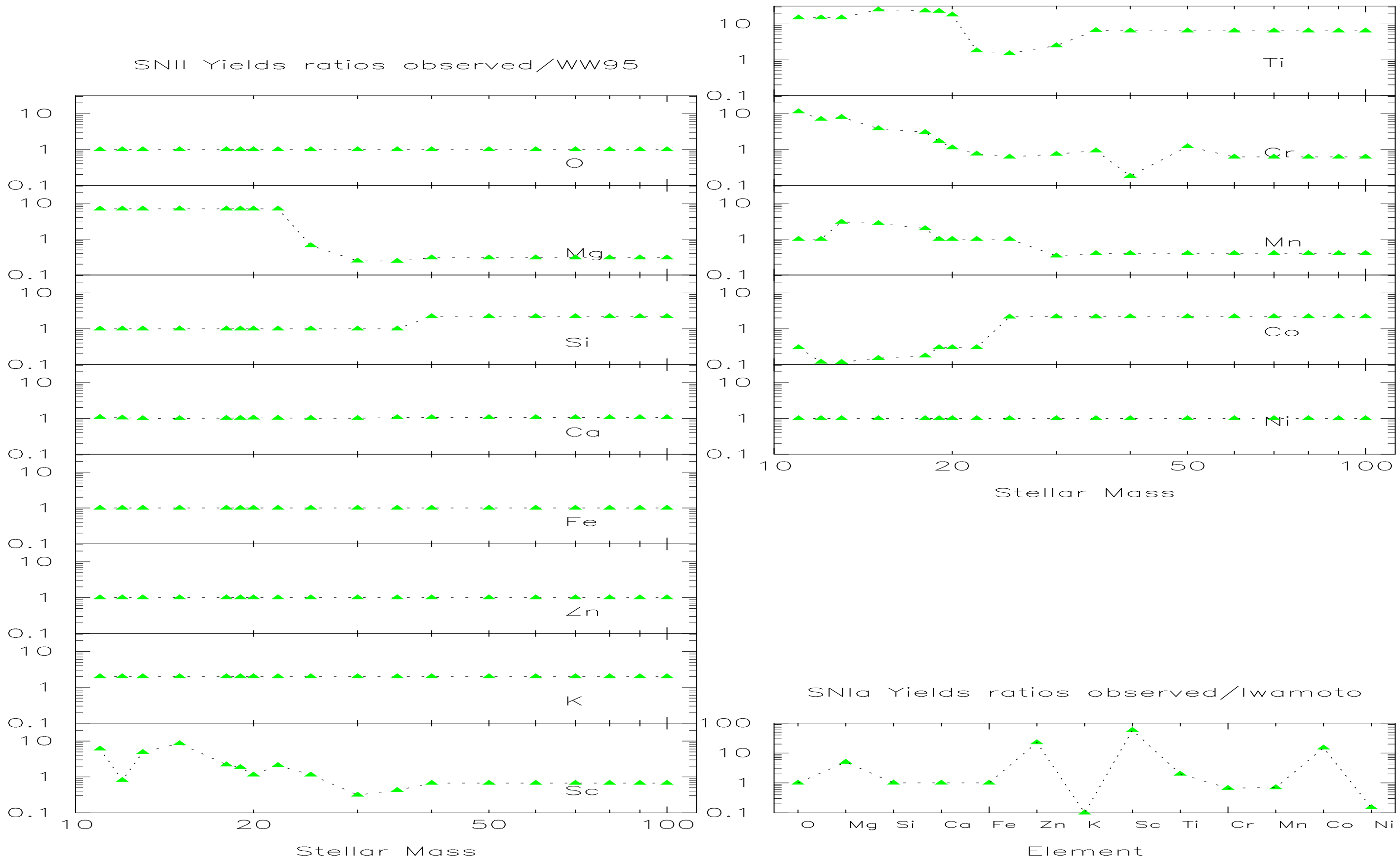
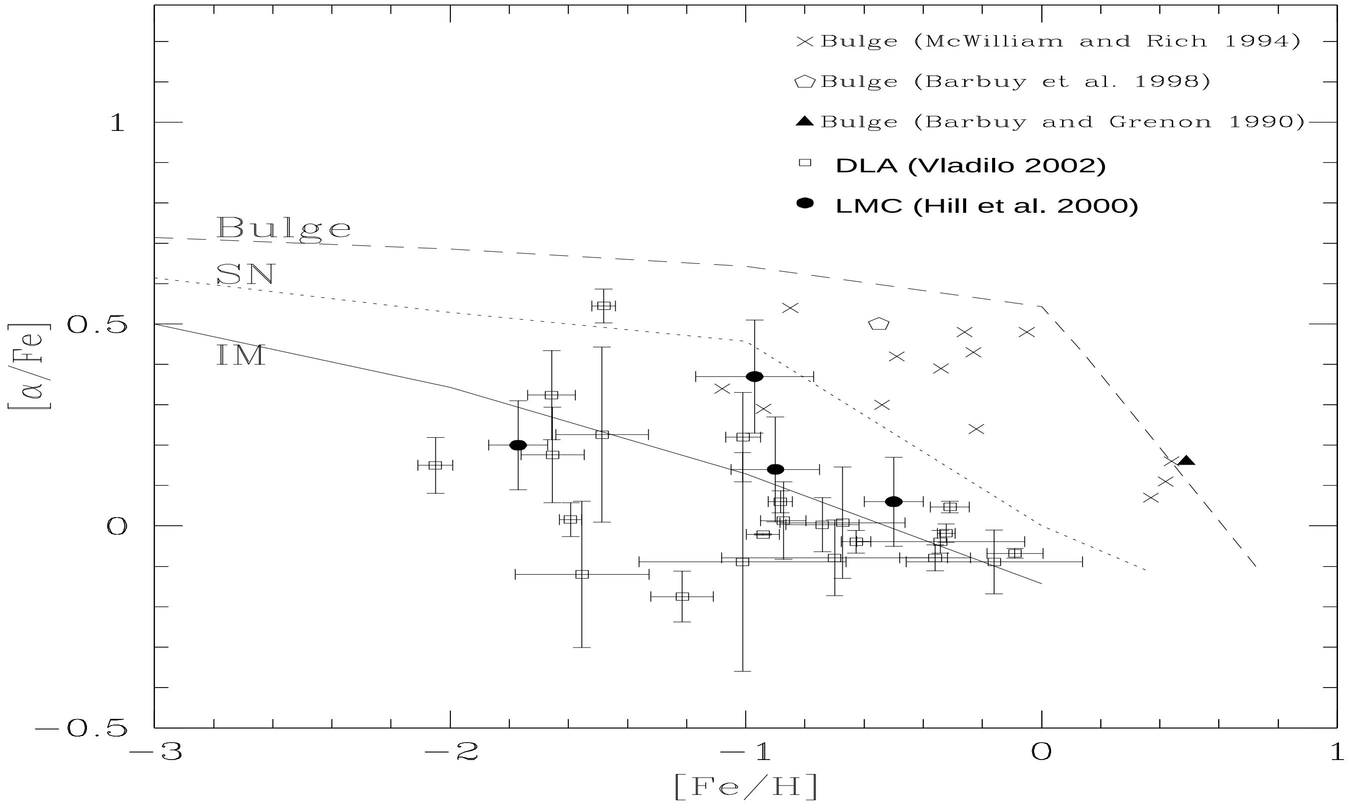


Best yields/WW95 yields



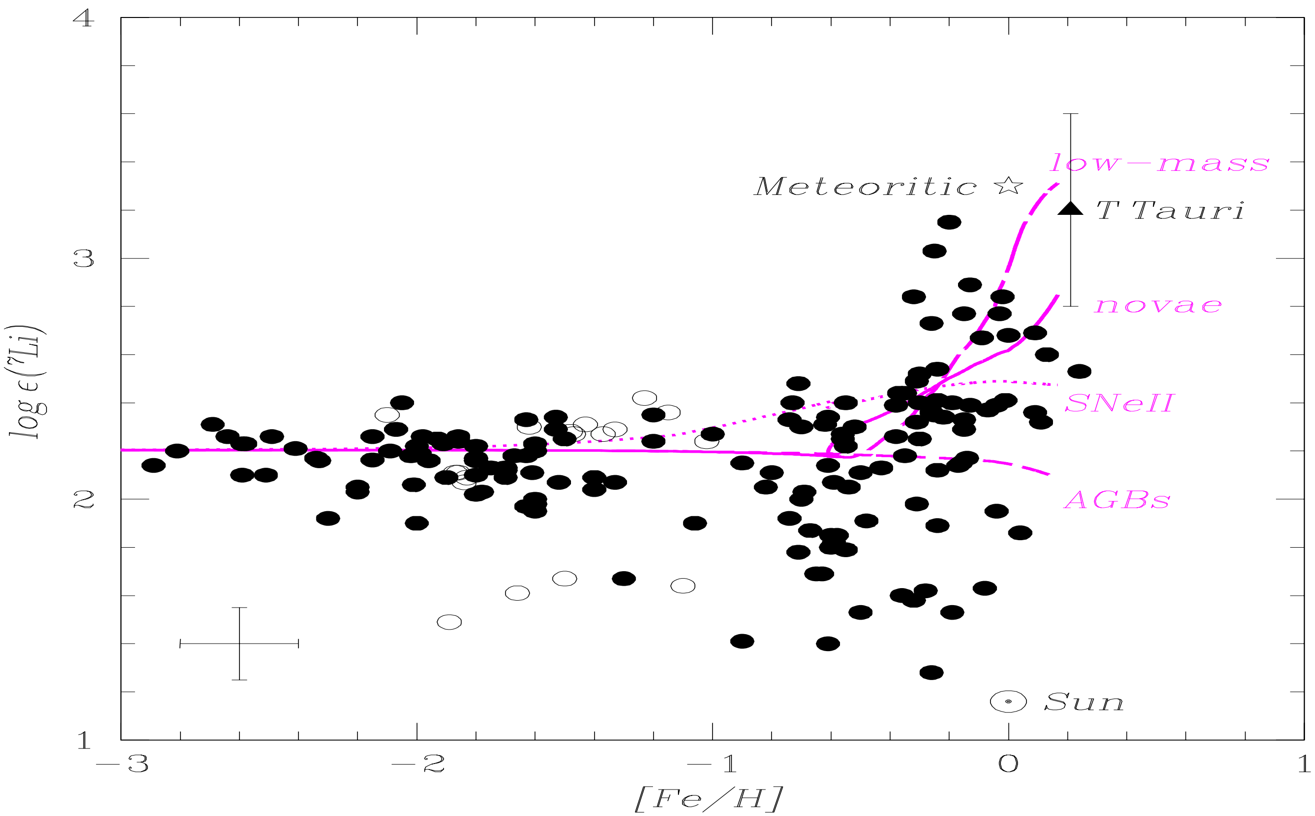
The time-delay model



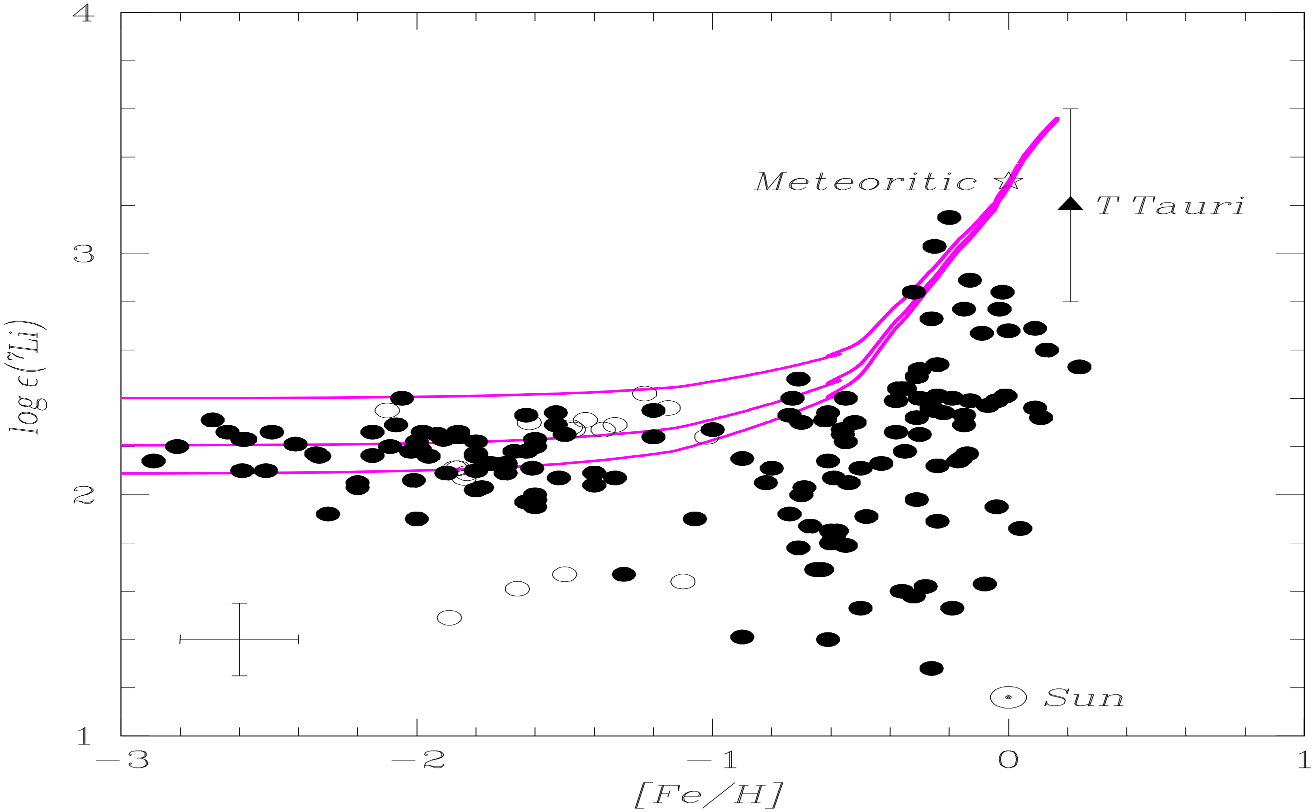
Novae and Li in the MW

- Romano et al. (2001,2003) assumed as stellar Li sources → SNII, AGB stars, RGB stars and novae
- They showed that the AGB stars produce a negligible contribution to the meteoritic ^{7} Li (0.5%), at variance with Travaglio et al. (2001), the SNII contribute 9%, the low mass giants 41% and the novae 18%
- They also showed that novae and RG stars are necessary to reproduce the steep rise off the Spite plateau. Cosmic rays can contribute the remaining 25% (Reeves 1993)
- There is a discrepancy between the primordial ^7Li from WMAP ($log\epsilon_{Li} = 2.6 \cdot 10^{-10}$) and the value of the Spite plateau (last derived value $2.34 \cdot 10^{-10}$, Melendez & Ramirez 2004)

Novae and Li in the MW

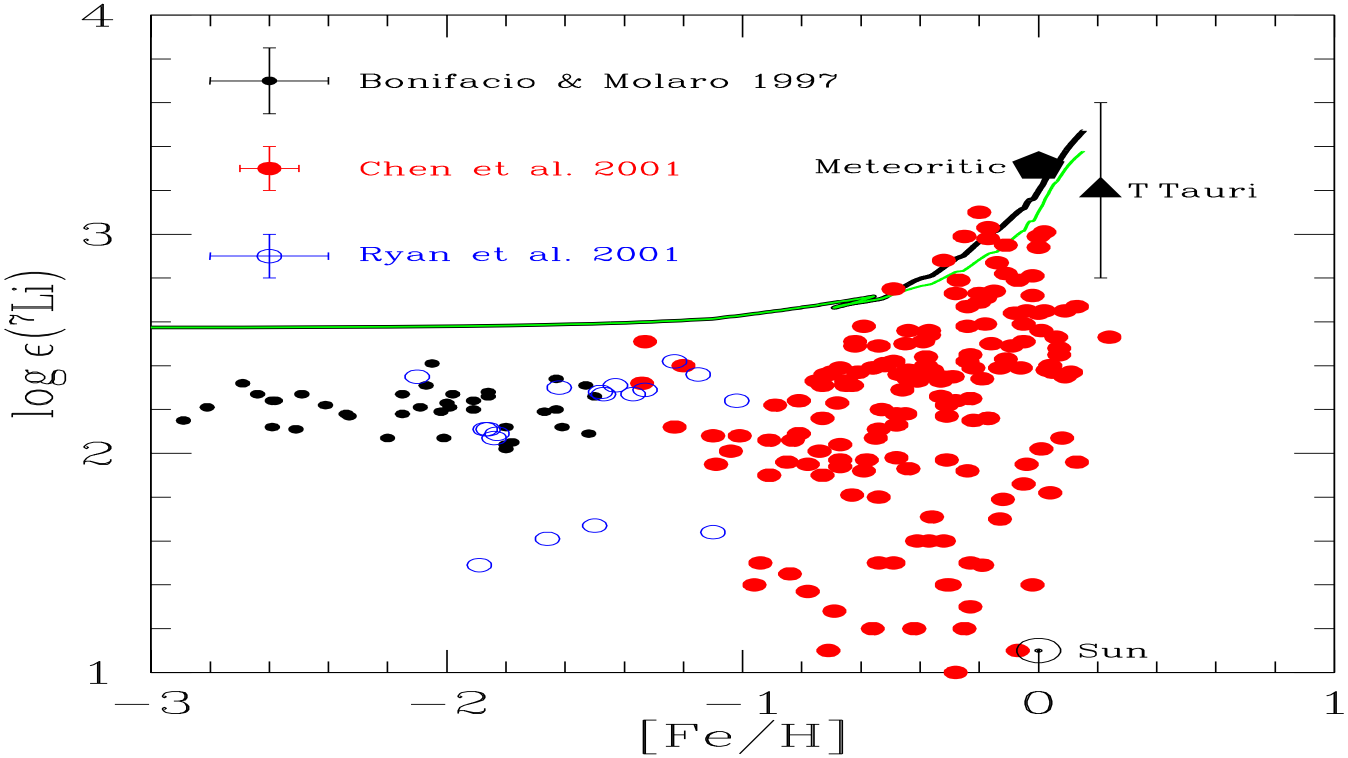


Novae and Li in the MW



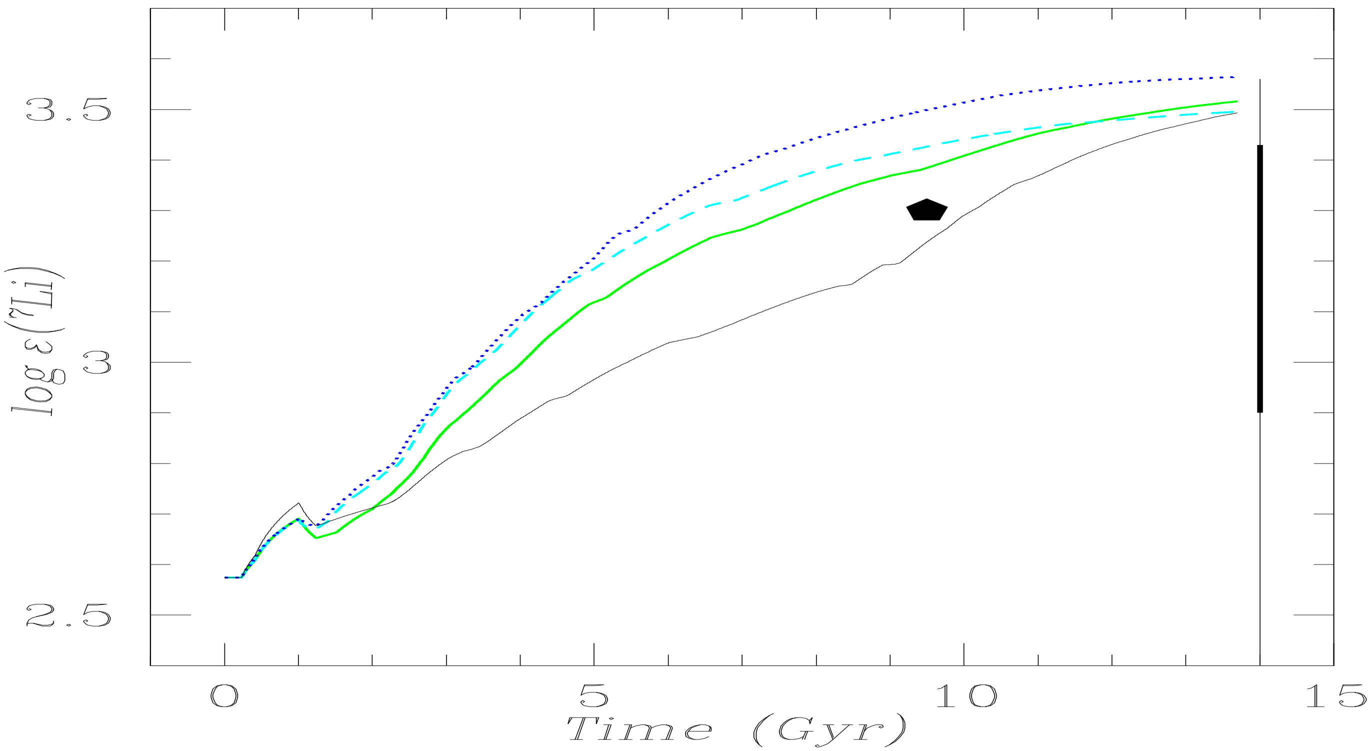
Novae and Li in the MW

Primordial Li from WMAP



Novae and Li in the MW

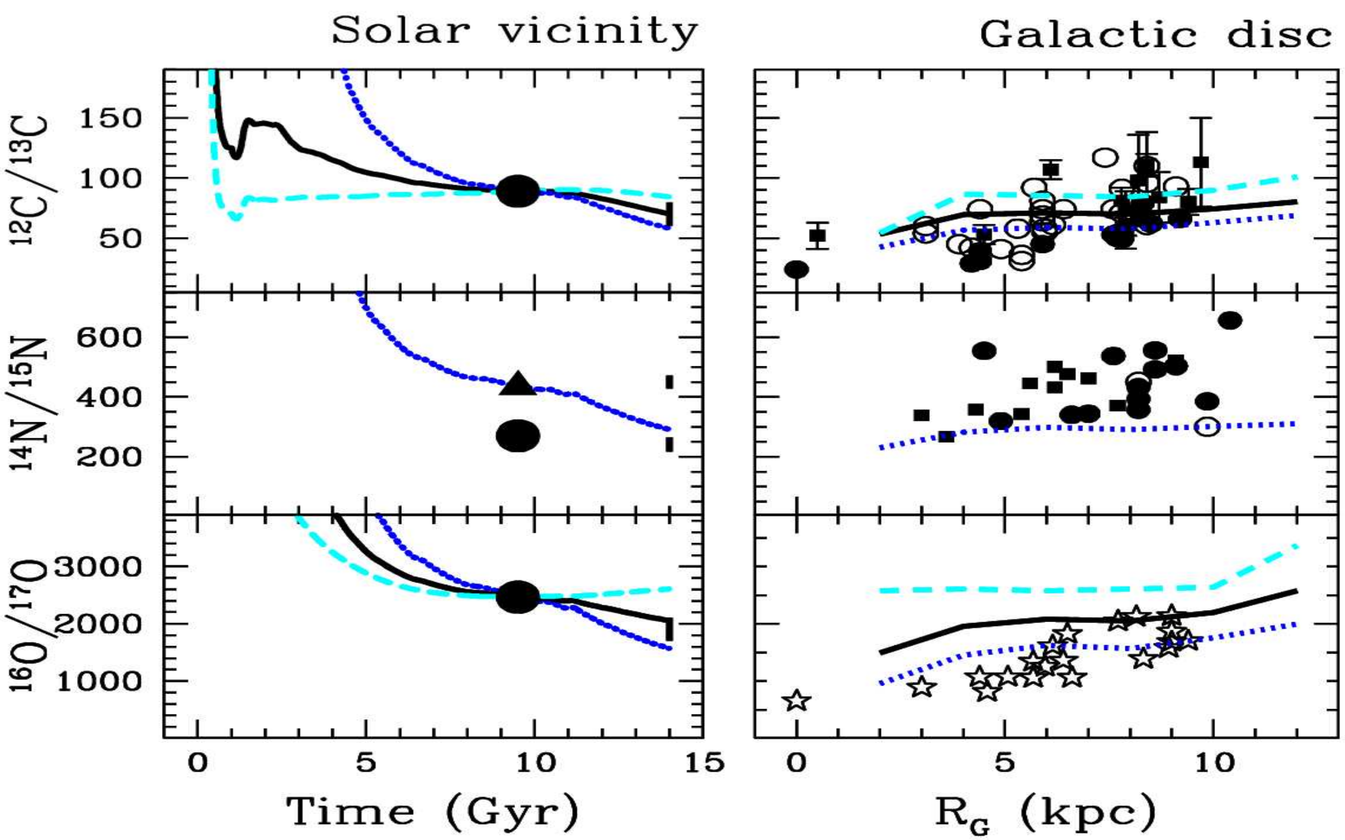
Different stellar lifetimes (Romano et al. 2005)



Novae and CNO in the MW

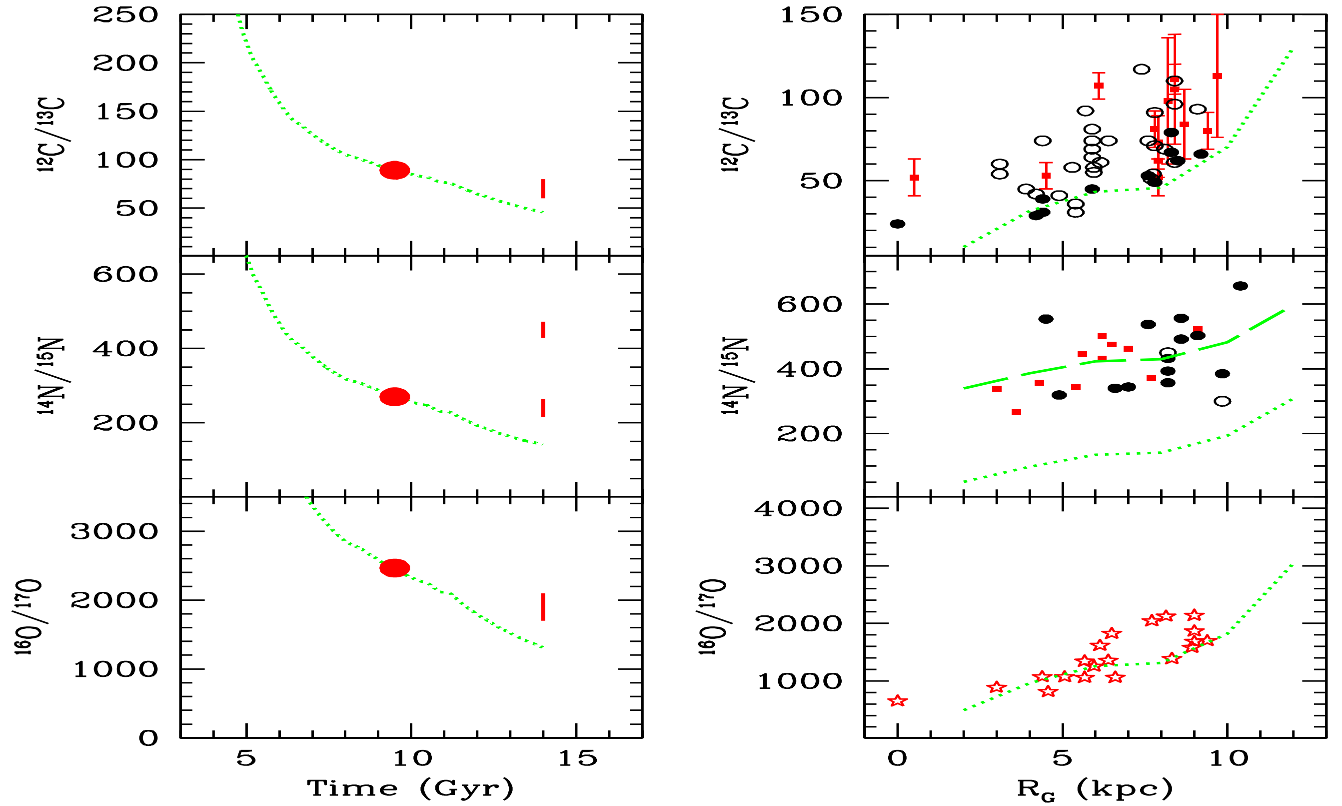
- Romano & Matteucci (2003) run several models for the evolution of CNO isotopes with and without novae
- Model 1 (dashed lines) → CNO isotopes originate only from single low and intermediate mass stars (van den Hoeck & Groenewegen 1997; Ventura et al. 2002)
- Model 2 (dotted lines) → CNO isotopes are produced only by novae (Jose' & Hernanz 1998)
- Model 3 (solid lines) → CNO isotopes are produced both by stars and novae
- Model 4 (green line) → CNO isotopes only from novae and behaving as secondary elements

Novae and CNO in the MW



Novae and CNO in the MW

CNO isotopes produced in novae as secondary elements



Conclusions

- Type Ia SNe are fundamental to explain the abundance of Fe and the behaviour of [X/Fe] vs. [Fe/H] in galaxies (time-delay model)
- Novae can produce CNO isotopes (^{13}C, ^{15}N,^{17}O) and $\rightarrow$ they could be the only producers of ^{15}N and help in reproducing the evolution of ^{13}C and ^{17}O
- Abundance gradients of isotope ratios are too flat if ^{13}C, ^{15}N and ^{17}O from novae are considered primary elements. A dependence of the yields on metallicity can improve some gradients
- Novae can produce a non negligible percentage of ^{7}Li during the galactic evolution ($\sim$ 18% of the meteoritic Li) and contribute, together with low mass red giants, to the steep rise off the Spite plateau at low metallicity