Production of Mn in stars, and comparison with stellar observations at different metallicities

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Odessa, September 2011

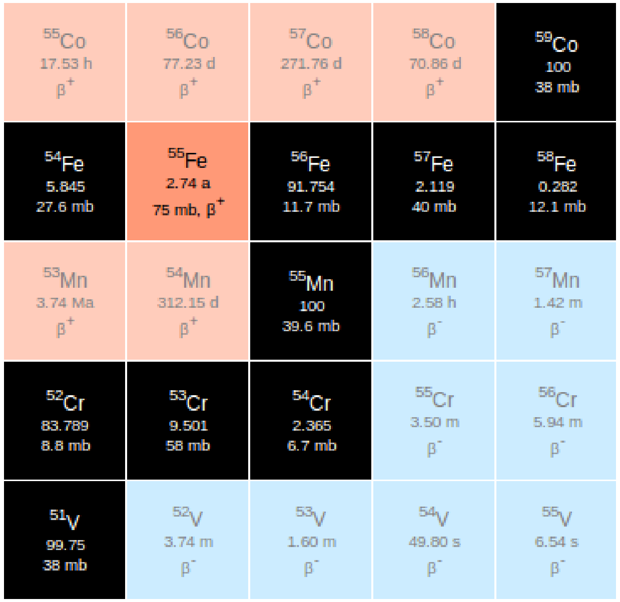
Mn (Z=25)

- Iron group element

- One stable isotope, ^{55}Mn

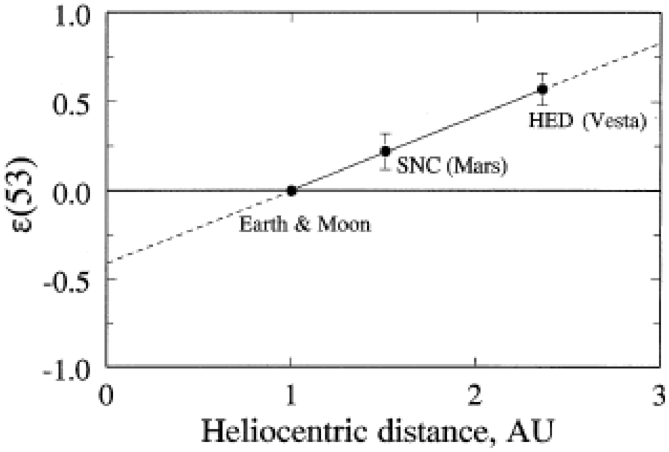
- Abundance measured in meteorites, observed at different metallicities and location in the Galaxy (Disk, Halo and Bulge), in Globular Clusters, Omega Cen, Dwarf Spheroidal Galaxies, etc.
(e.g., Prochaska & McWilliam 2000, McWilliam et al. 2003, Alves-Brito et al. 2006,Sobeck et al. 2006, Cunha et al. 2010, Pancino et al. 2011)

^{53}Mn decay ($\tau_{½}$ ~ 3.7 Myrs) detected as ^{53}Cr excess in different meteorites, possibly due to pollution of proto-solar cloud from a nearby star.
Chronological studies of the early solar system.
(e.g., Lugmair & Shukolyukov 1998)



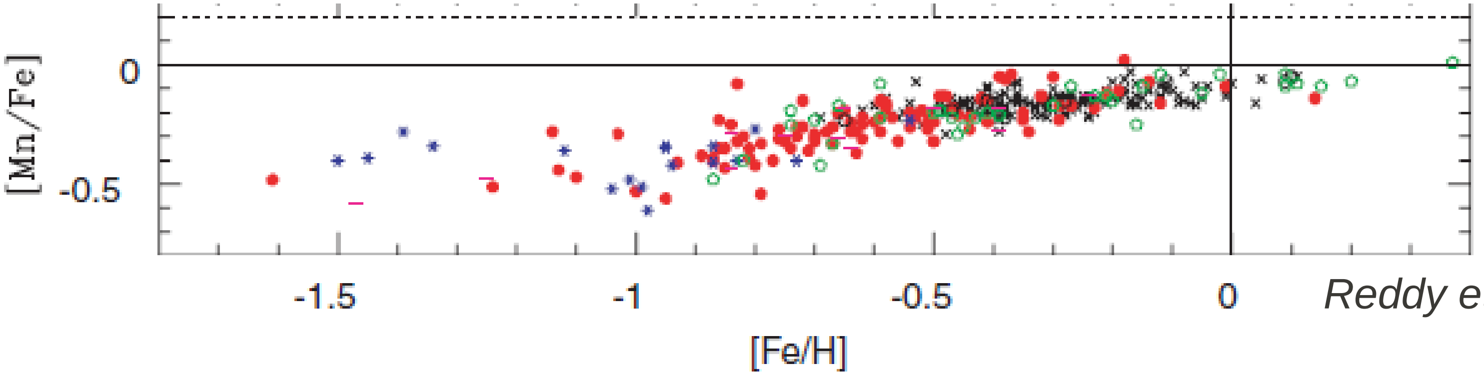
^{55}Co 17.53 h β^+	^{56}Co 77.23 d β^+	^{57}Co 271.76 d β^+	^{58}Co 70.86 d β^+	^{59}Co 100 38 mb
^{54}Fe 5.845 27.6 mb	^{55}Fe 2.74 a 75 mb, β^+	^{56}Fe 91.754 11.7 mb	^{57}Fe 2.119 40 mb	^{58}Fe 0.282 12.1 mb
^{53}Mn 3.74 Ma β^+	^{54}Mn 312.15 d β^+	^{55}Mn 100 39.6 mb	^{56}Mn 2.58 h β^-	^{57}Mn 1.42 m β^-
^{52}Cr 83.789 8.8 mb	^{53}Cr 9.501 58 mb	^{54}Cr 2.365 6.7 mb	^{55}Cr 3.50 m β^-	^{56}Cr 5.94 m β^-
^{51}V 99.75 38 mb	^{52}V 3.74 m β^-	^{53}V 1.60 m β^-	^{54}V 49.80 s β^-	^{55}V 6.54 s β^-

http://www.kadonis.org/

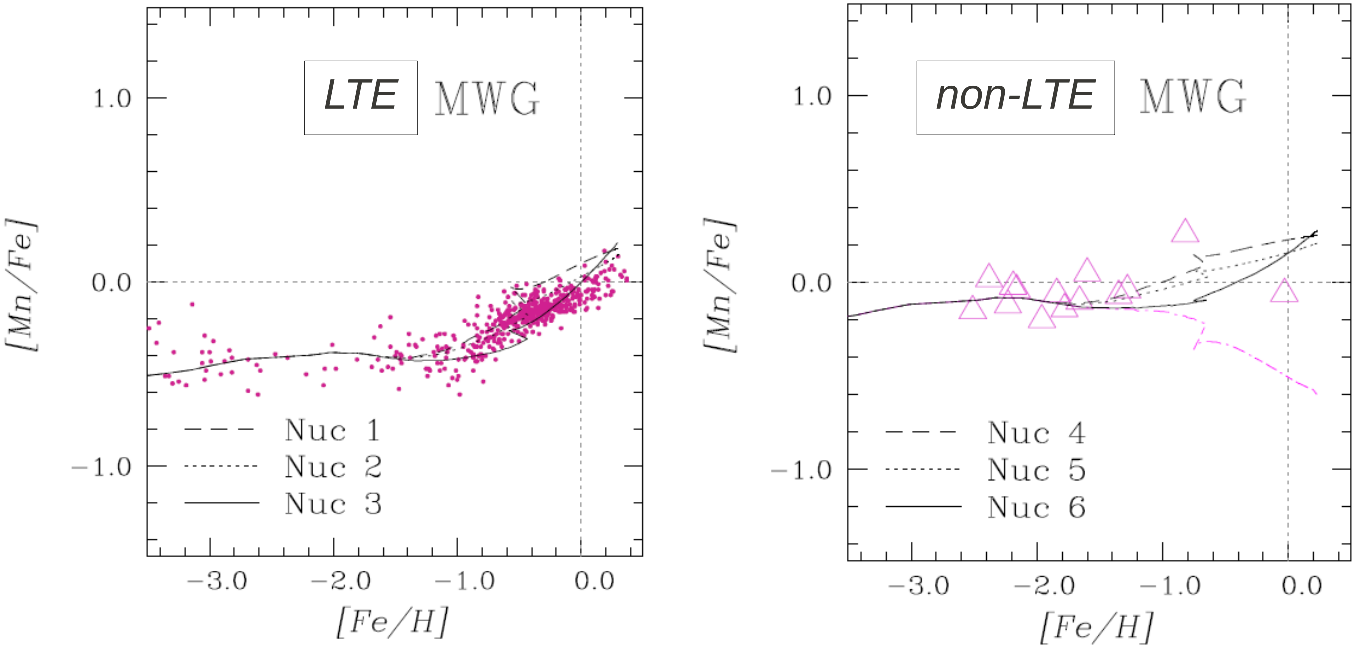


Lugmair & Shukolyukov 1998

Spectroscopic observation of Mn in the Galaxy.



Reddy et al. 2003

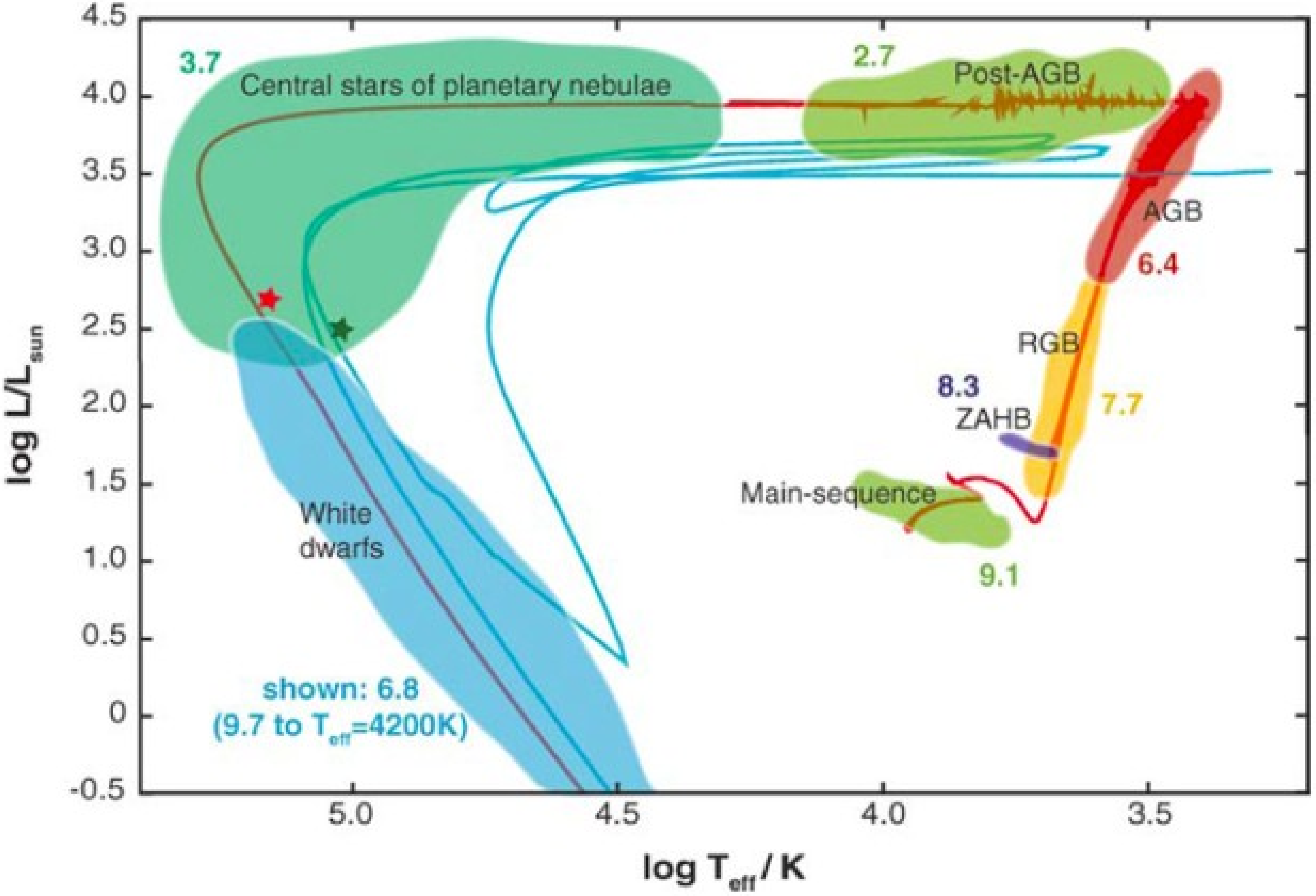


See also
Bergemann & Gehren 2008

Romano et al. 2011 and references there

Production of Mn in low mass stars

Low mass stars – HR diagram



Werner & Herwig 2006, PASP

AGB stars and s-process nucleosynthesis
no Mn production

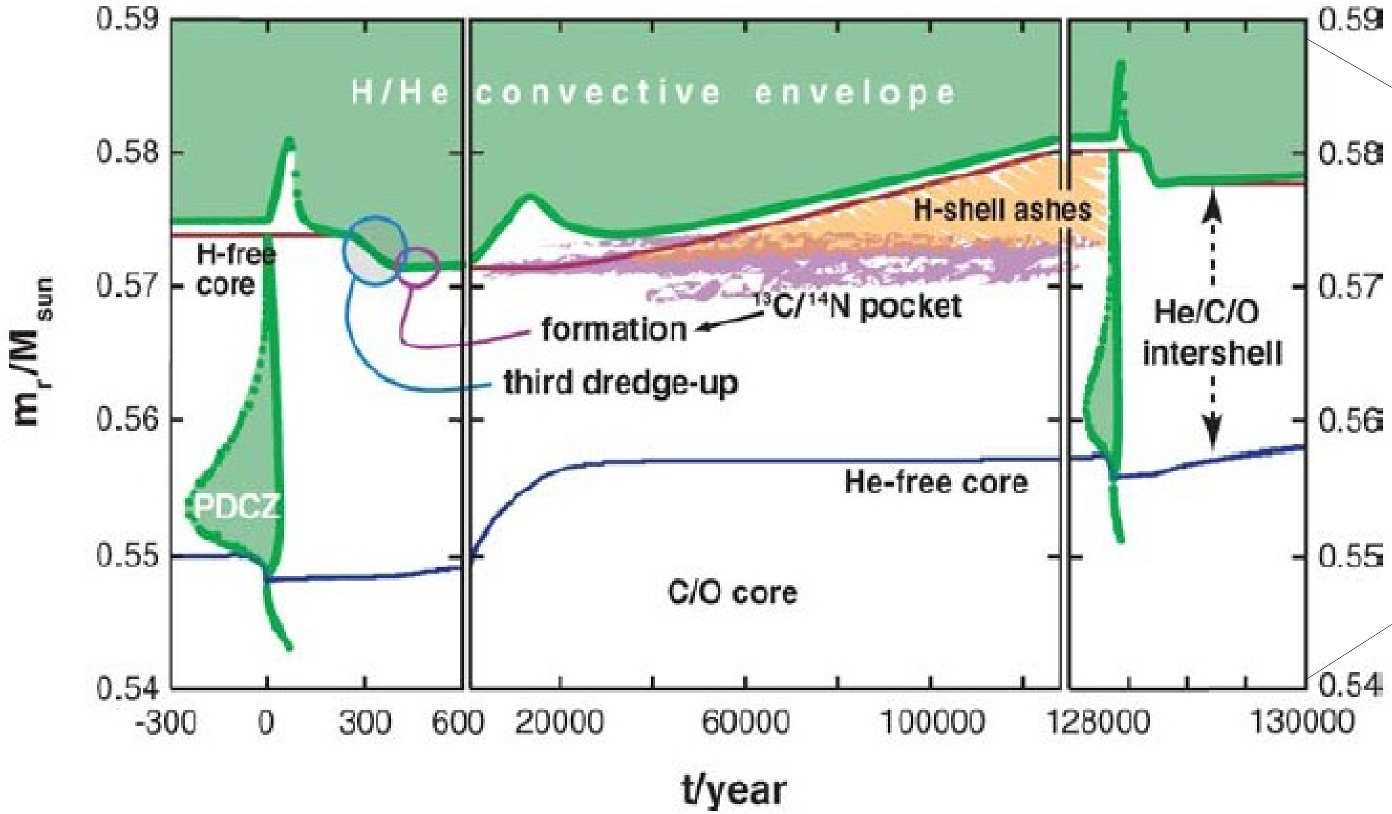
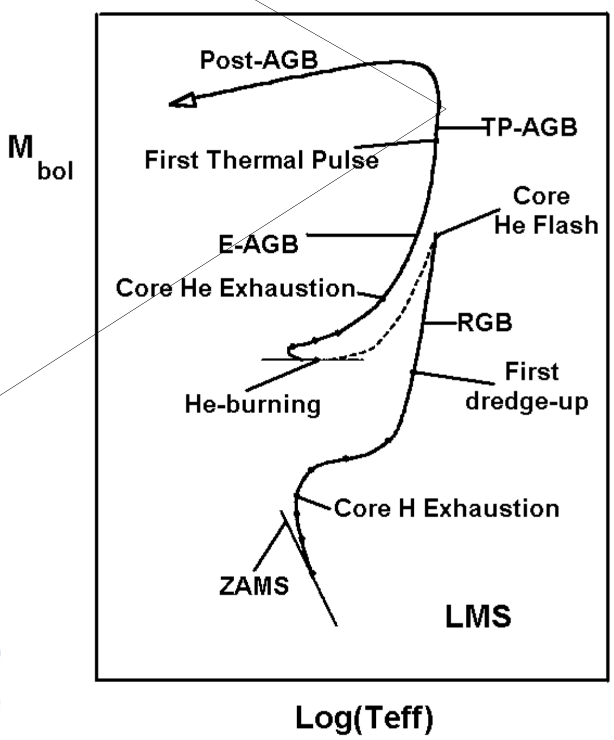


Figure 3 Thermal pulse 14, the subsequent interpulse phase and thermal pulse 15 of 2 $M_\odot$, $Z = 0.01$ sequence ET2 of Herwig & Austin (2004). The timescale is different in each panel.

Herwig 2005, ARAA 43

Busso et al. 1999



Major Neutron source:
$^{12}C(p,\gamma)^{13}N(\beta^{+})^{13}C(\alpha,n)^{16}O$.

Type: primary

When: interpulse $T_8 \sim 0.9$

Where: He-intershell zone

Neutron Density: 10^7 n/cm^3

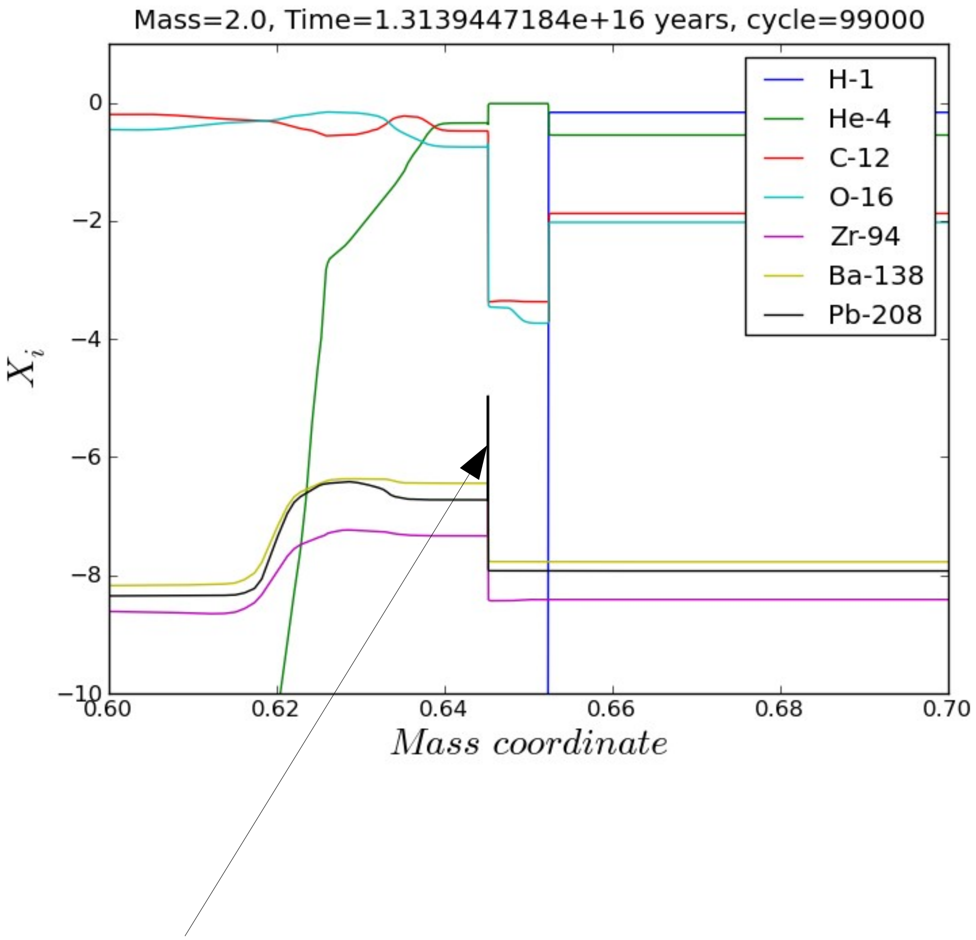
Minor neutron source

$^{22}Ne(\alpha,n)^{25}Mg$

When: Thermal pulse $T_8 \sim 3$

Neutron Burst: max 10^{10} n/cm^3

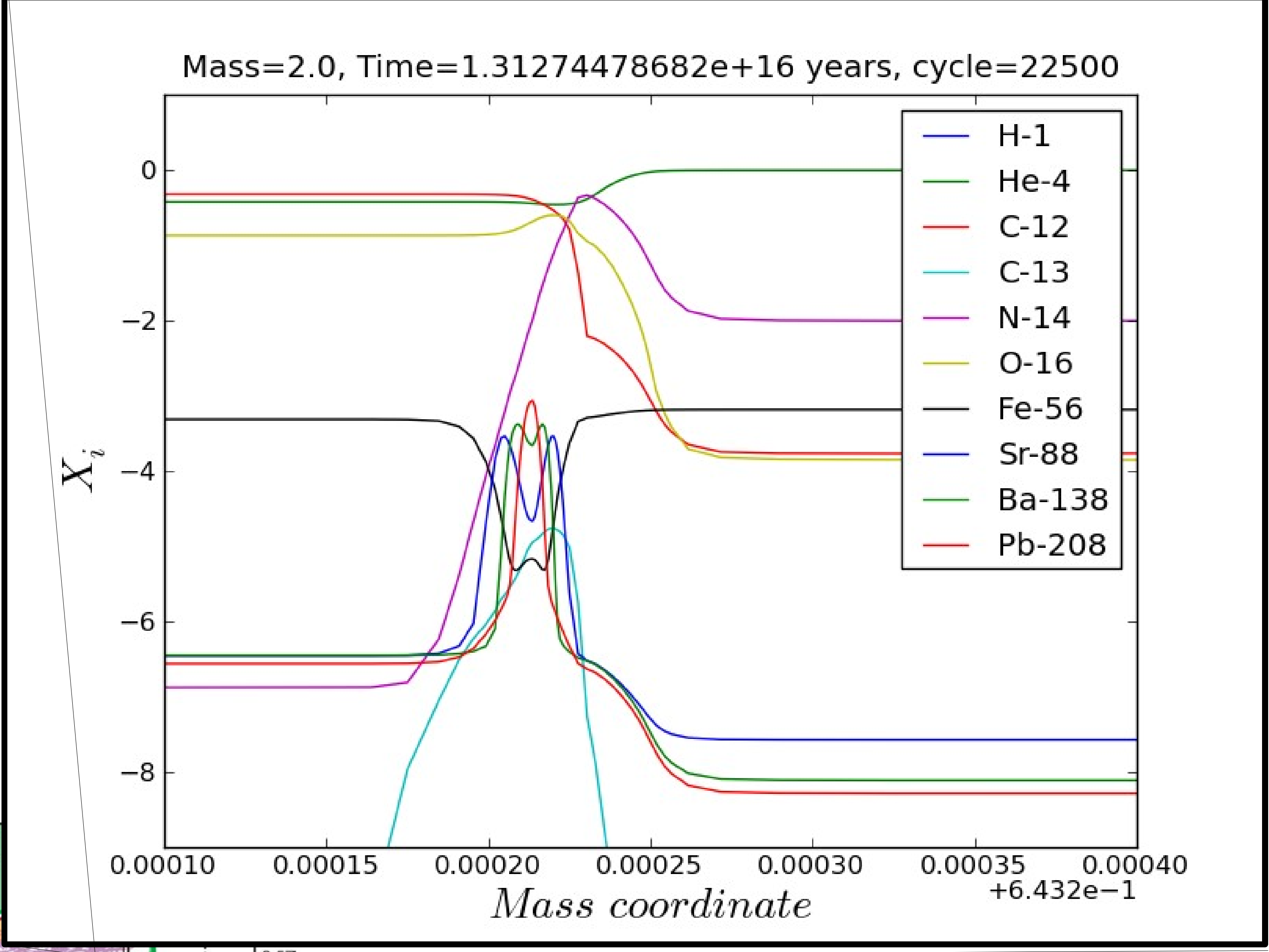
MESA models, Paxton et al. 2010
Pignatari et al. 2011, in prep.
NuGRID project



C13-pocket - size ~ $10^{-5} – 10^{-4}$ Msun

Radiative C13-pocket:

Straniero et al. 1995, Herwig et al. 1997, Gallino et. al. 1998, Goriely & Molawi 2000, Denissennkov & Tout 2003, Cristallo et al. 2007,2009, Karakas et al. 2010, Bisterzo et al. 2010 .....



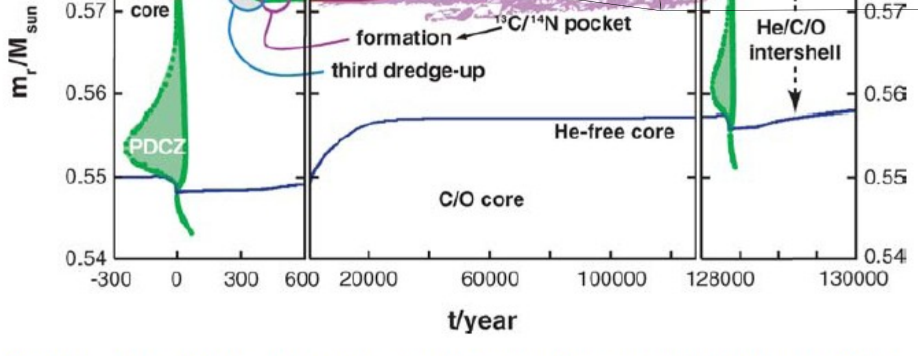
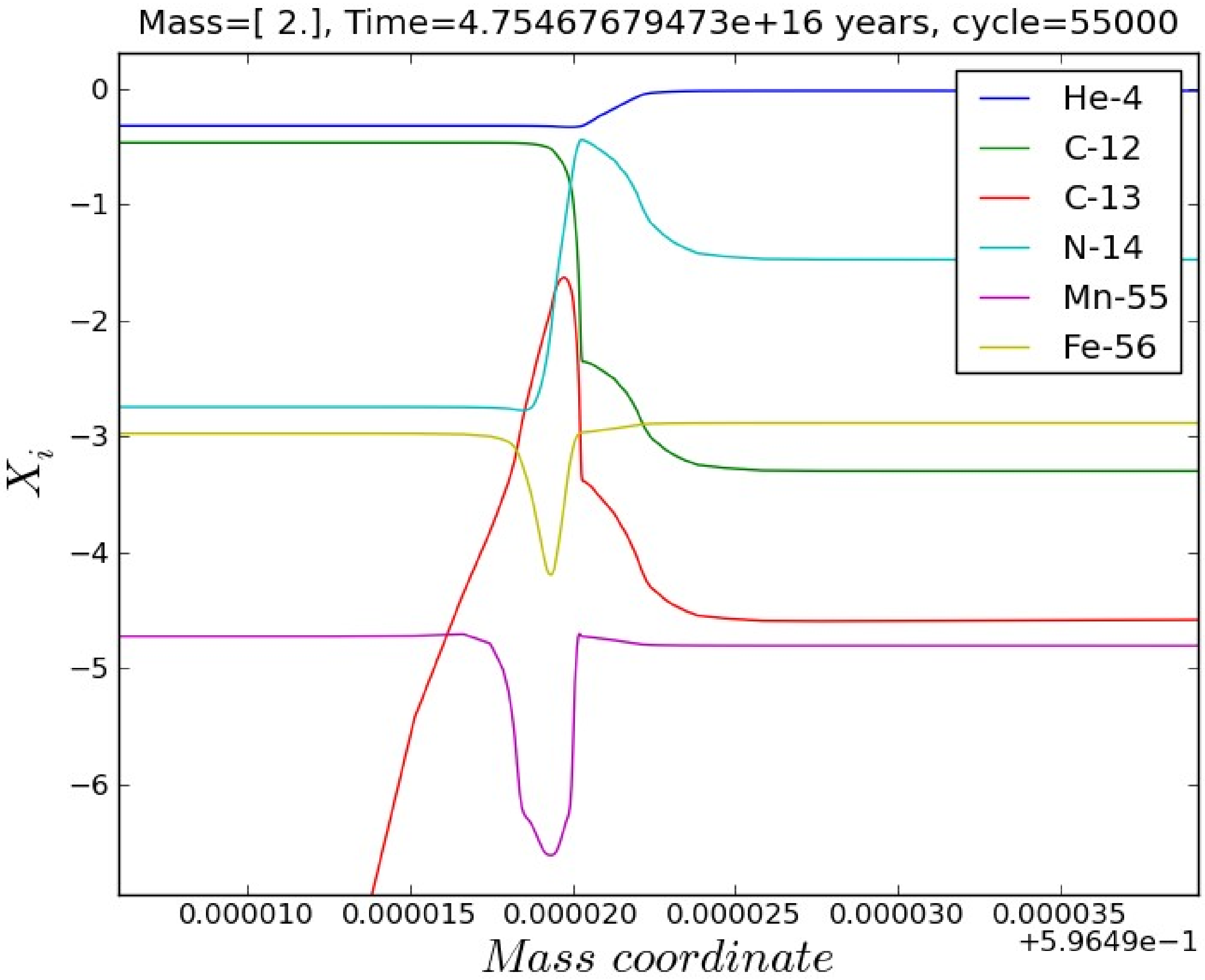


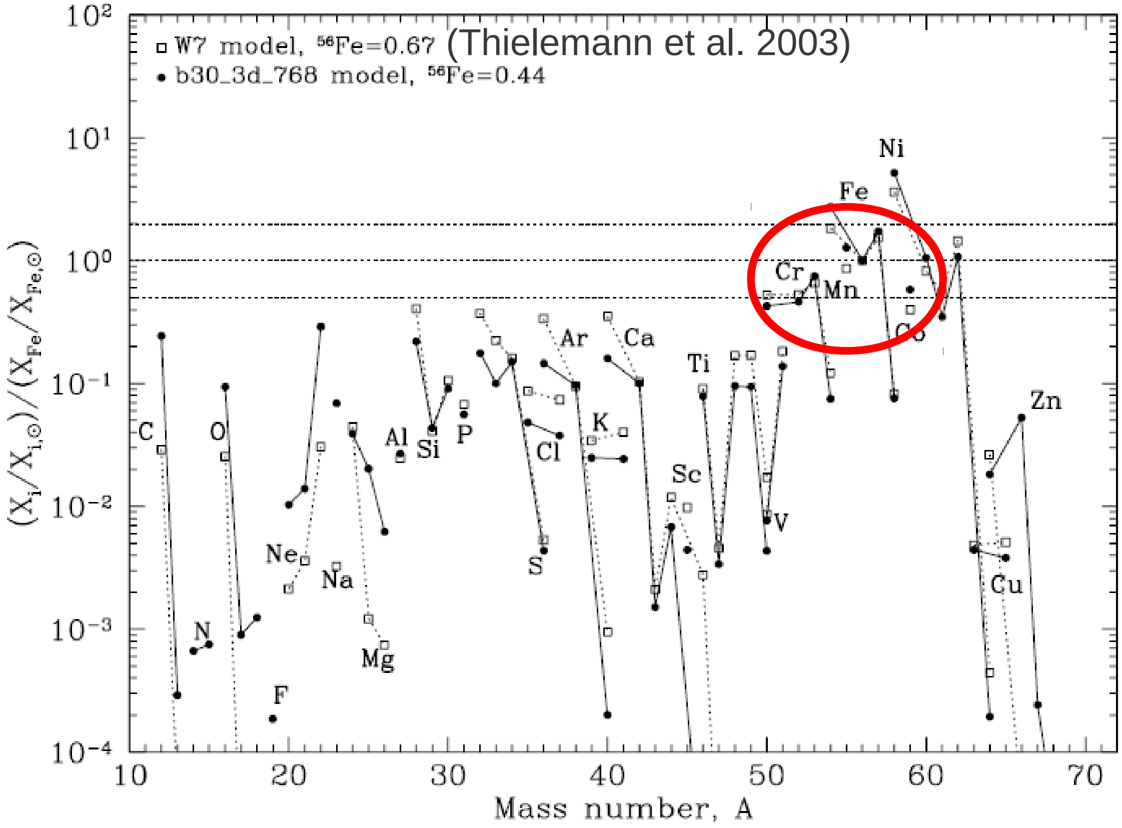
Figure 3 Thermal pulse 14, the subsequent interpulse phase and thermal pulse 15 of 2 $M_\odot$, $Z = 0.01$ sequence ET2 of Herwig & Austin (2004). The timescale is different in each panel.

C13 is finished, forming an s-process rich mass zone

Mn is depleted by neutron capture during the s-process in the AGB phase.



SNIa is one of the main sources of the Mn observed in the solar system.

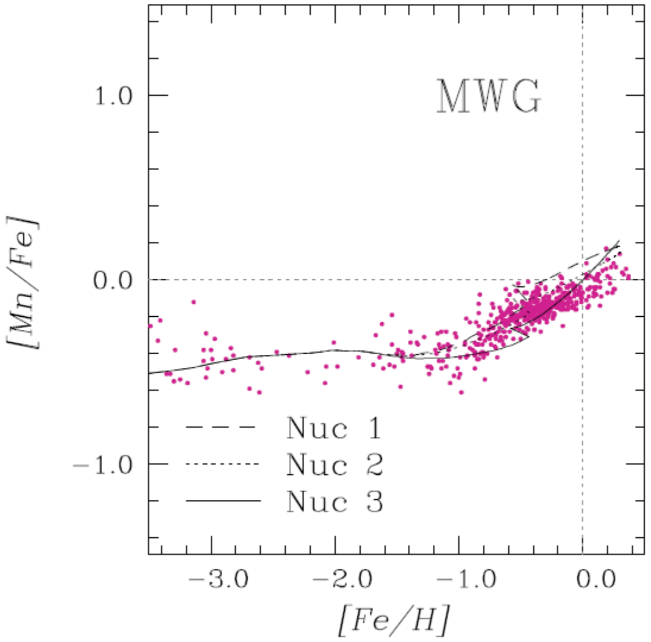


Travaglio et al. 2004

	W7	*Tr04*
Fe56	*= 1.0*	*1.0*
Mn55	*= 1.0*	*2.0*

=

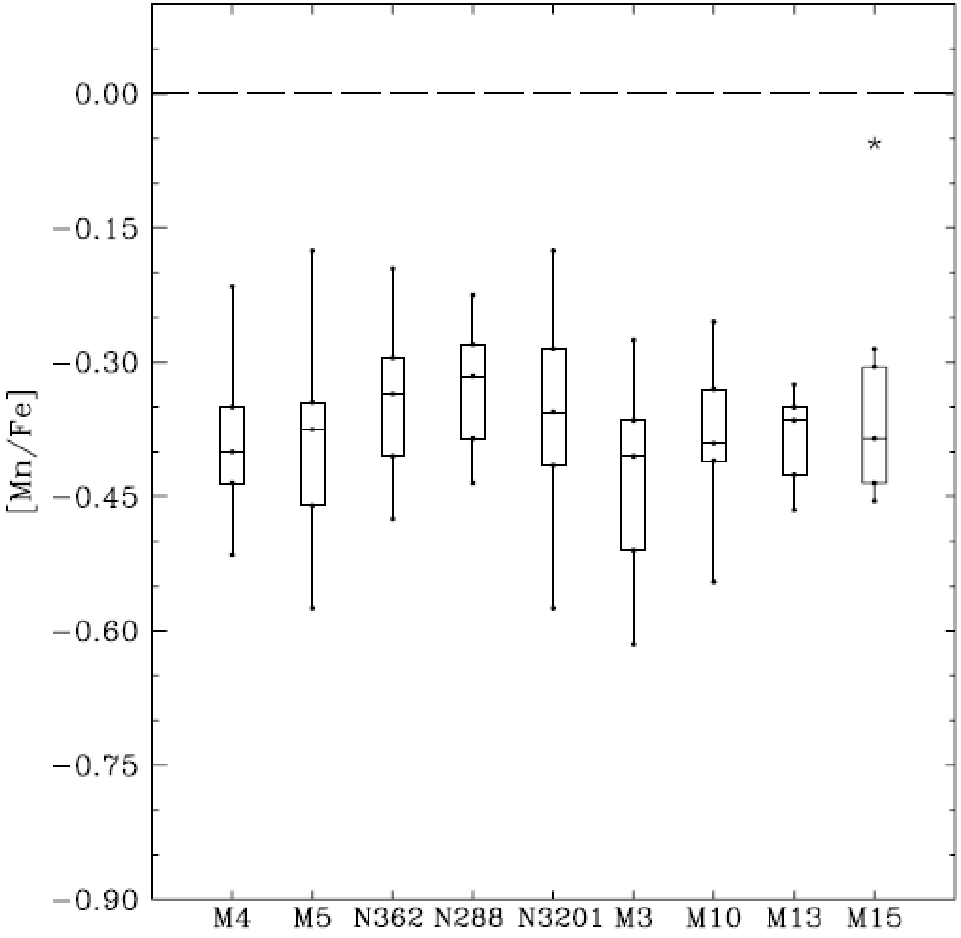
0.5-1. of solar Mn

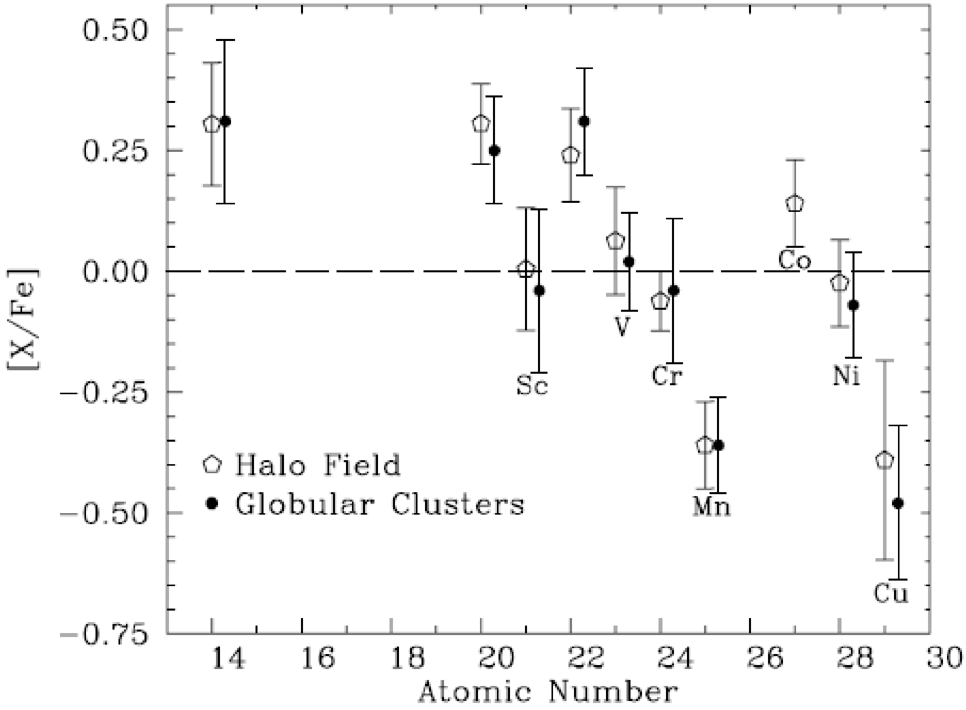


Metallicity dependence of Mn yields of SNIa ?
(e.g., Cescutti et al. 2008, Romano et al. 2011)

Production of Mn in massive stars

A good observational indication of Mn production in massive stars is given by halo stars at low metallicity and globular clusters (no significant contribution from SNIa).

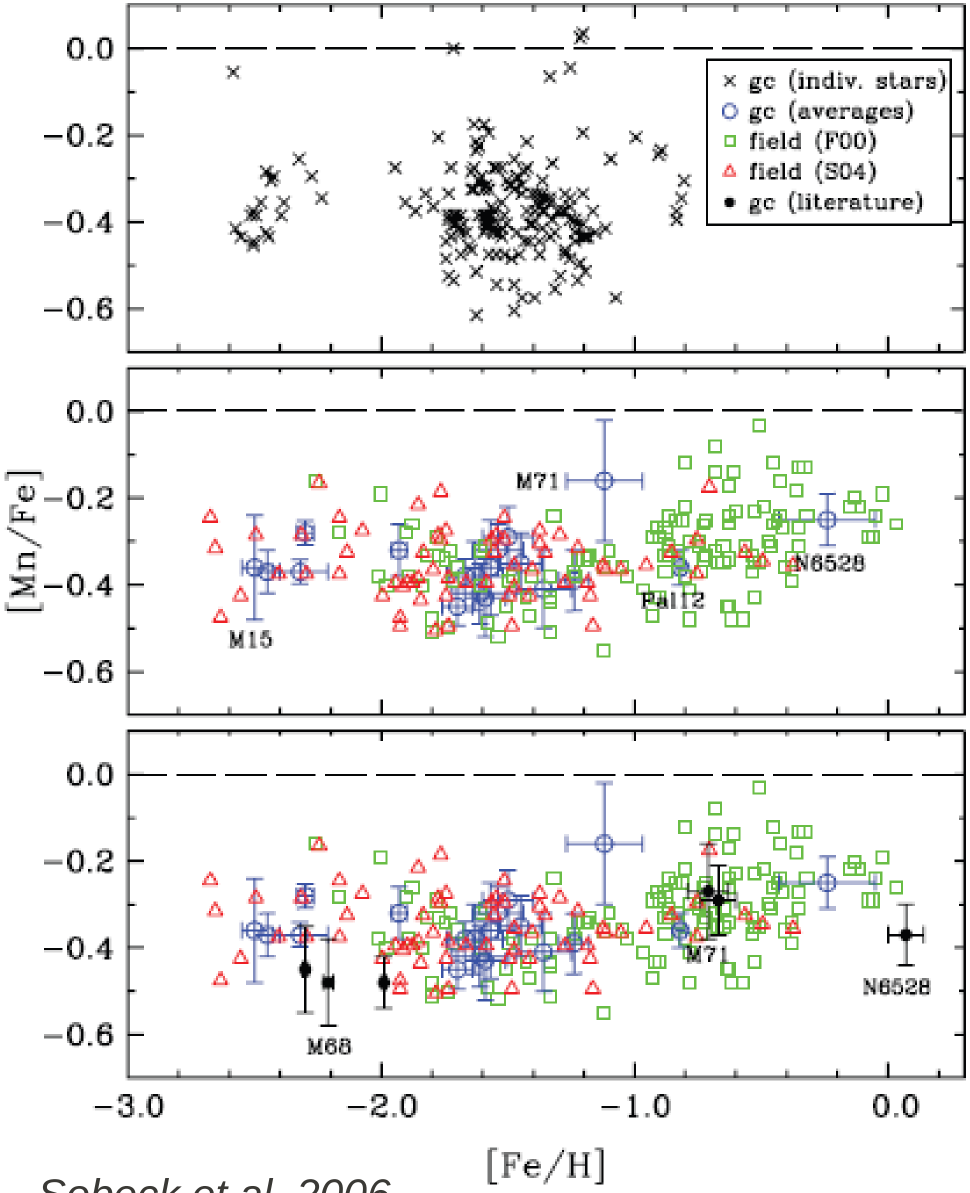




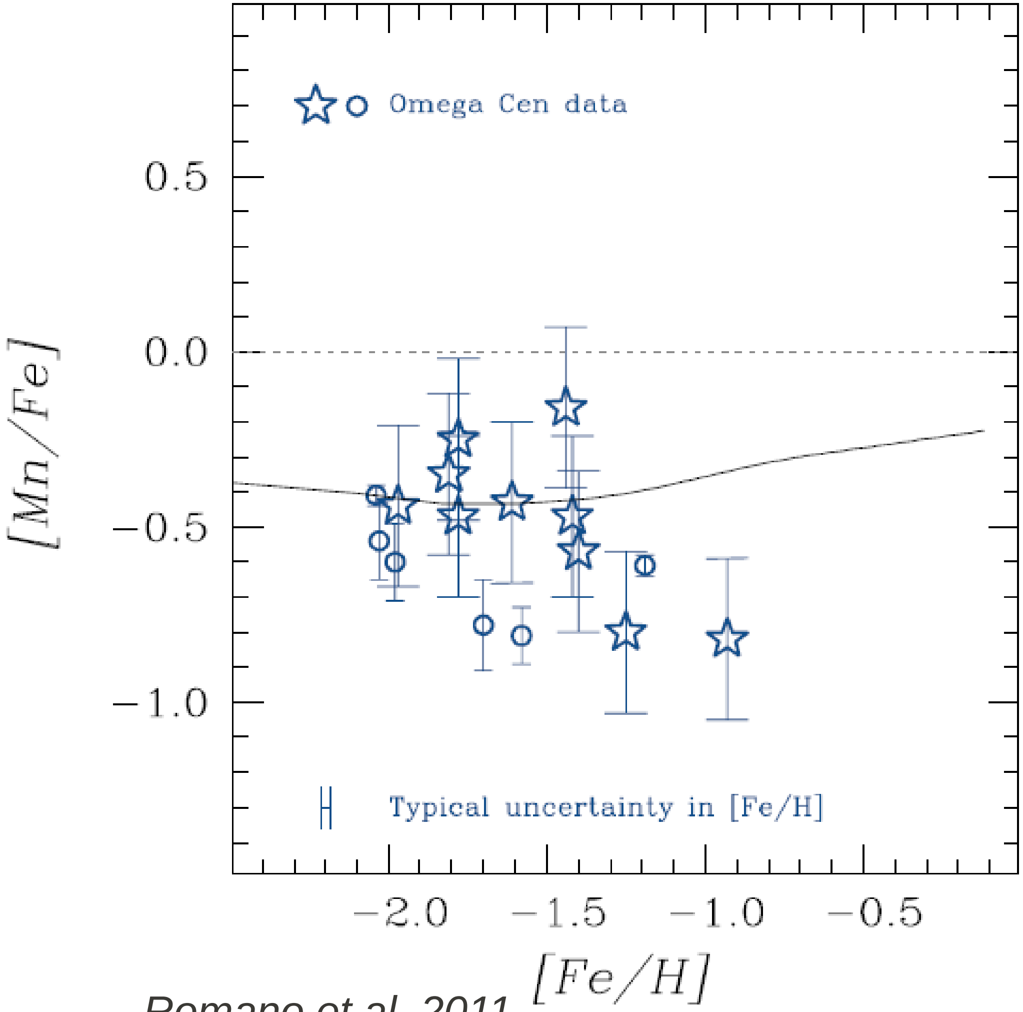
Sobeck et al. 2006:
agreement between halo stars and GCs

[Mn/Fe] = -0.5   10-16 % of solar Mn
-0.2   19-31 % of solar Mn

However, looking at star by star observations, there is a large variation in the observed [Mn/Fe].

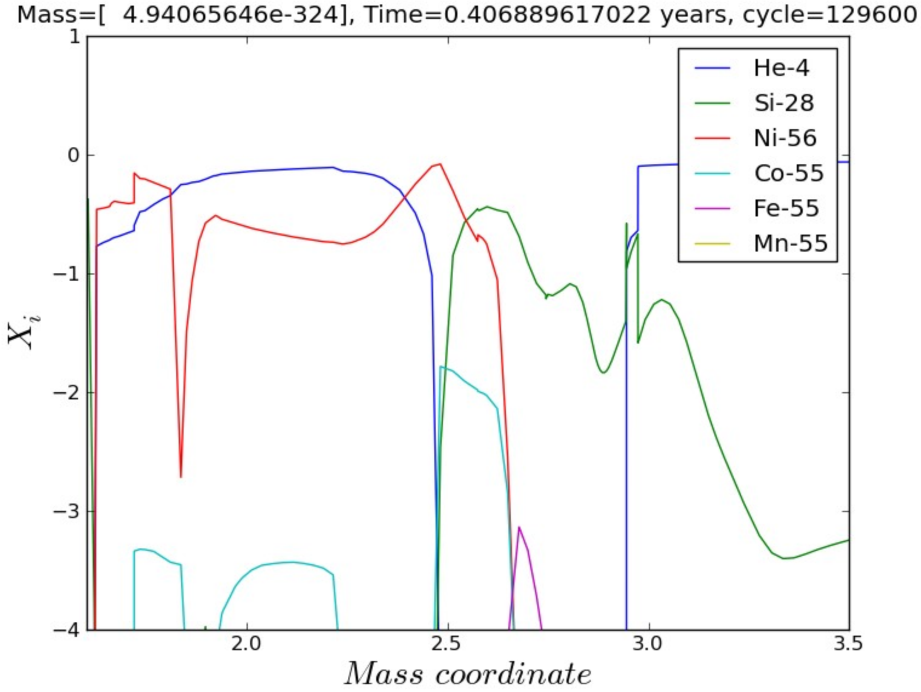


Sobeck et al. 2006

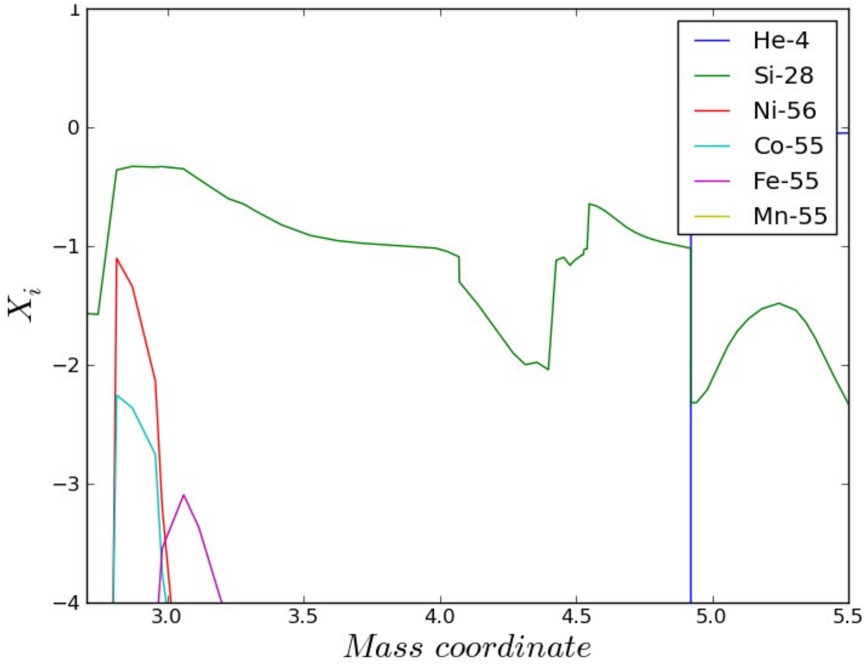


Romano et al. 2011
Data from:
Cunha et al. 2010
Pancino et al. 2011

Initial mass = 15 Msun
Metallicity = solar
Stellar code = GENEC
Remnant Mass = 1.6 Msun
(explosion/fallback prescription, Fryer 2009)
High energy, Ni56-rich ejecta
Final low Mn/Fe

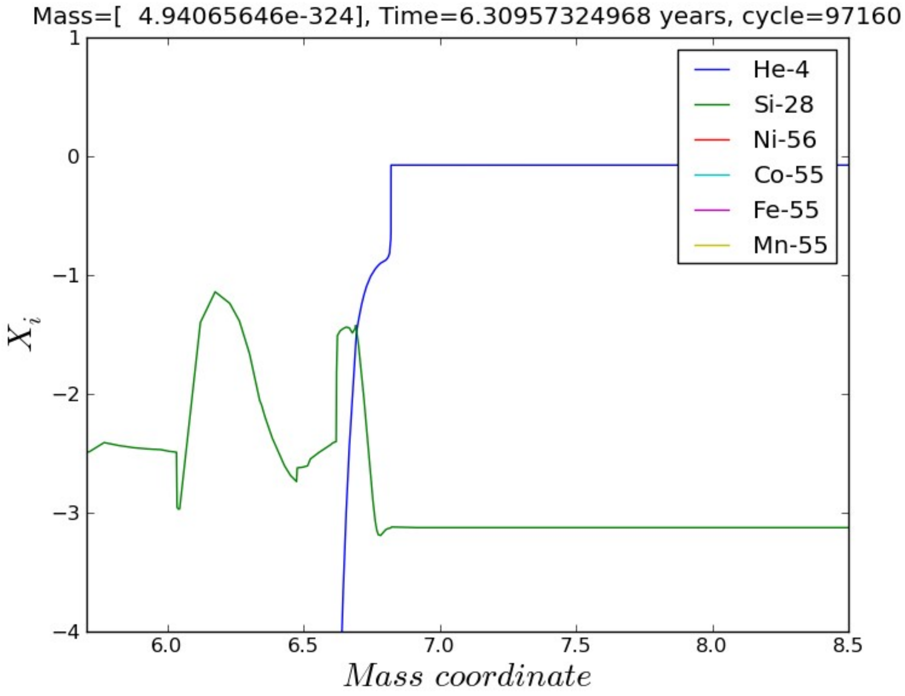


Pignatari et al. 2011, in prep.



Initial mass = 20 Msun
Metallicity = solar
Stellar code = GENEC
Remnant Mass = 2.73 Msun
(explosion/fallback prescription, Fryer 2009)
High energy, Ni56-poor ejecta
Final high Mn/Fe

Initial mass = 25 Msun
Metallicity = solar
Stellar code = GENEC
Remnant Mass = 5.7 Msun
(explosion/fallback prescription, Fryer 2009)
High energy, no Ni56 ejected
No Mn, Fe



Observables:

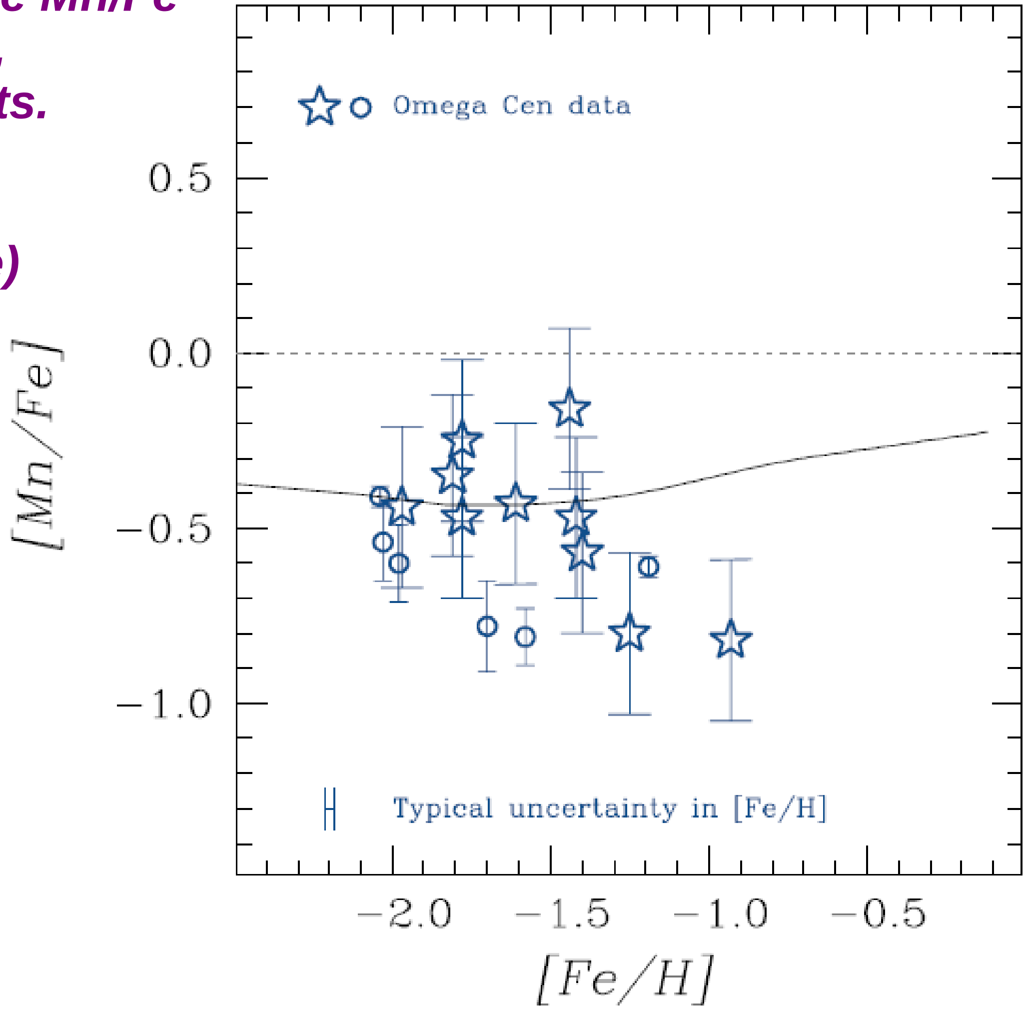
- SN light curve, constraining the amount of Ni56 ejected
From ~ 0.07 Msun, SN1987A to 0.0026-0.015 Msun, SN1994W.
See e.g., Sollerman et al. 1998

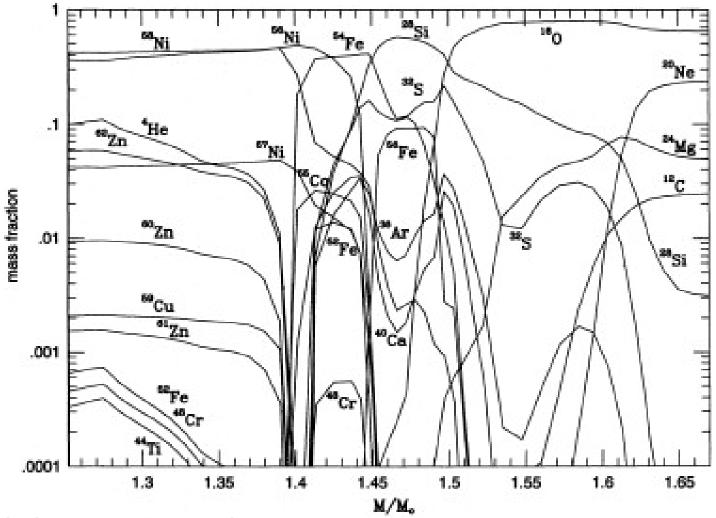
- Observation of TiC and Fe-Ni metal inclusions in presolar graphite grains from SNII (Lodders 2006). Required alpha-rich freeze-out condition, to obtain Fe-Ni-Ti-rich and Si-S-poor ejecta. Failure of standard models with mixing prescription from different zones (e.g., Meyer et al. 2005, Travaglio et al. 1999). High energy-alpha-rich freeze-out component from jet-driven asymmetric explosions (e.g., magneto-rotationally induced, Khokhlov et al. 1999, Nagataki 2000, work done in Basel, Kappeli et al. Nishimura et al. 2006)

Standard massive stars explosive yields with 'tuned' Ni56 ejecta can explain average Mn/Fe measured in halo stars, or GC/Omega Cen, but cannot explain the extreme components.

High Mn/Fe
(fallback component – higher mass regime)

Low Mn/Fe
(high energy component - lower mass regime)





Thielemann et al. 1996

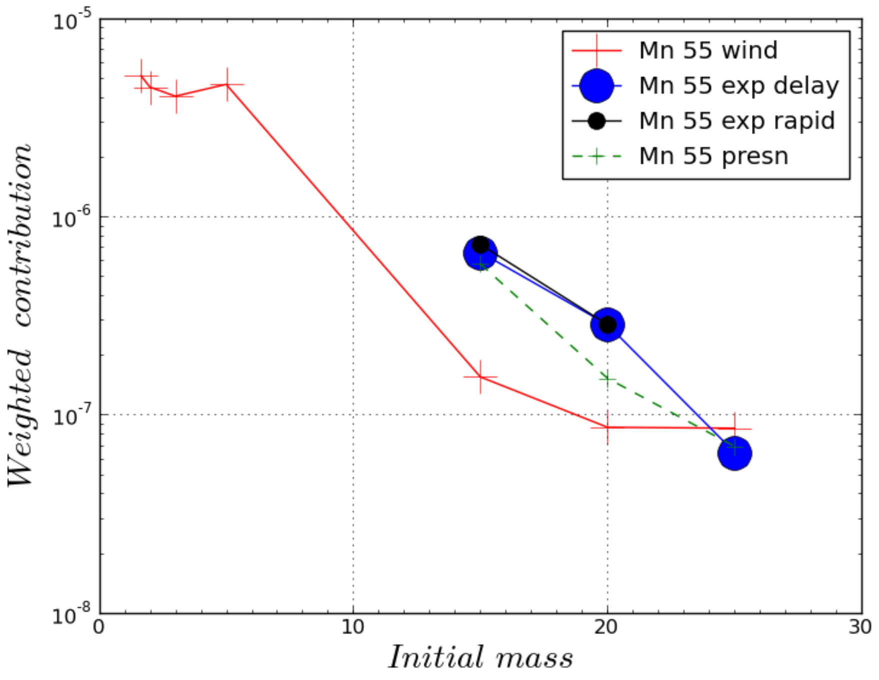
From Th96:

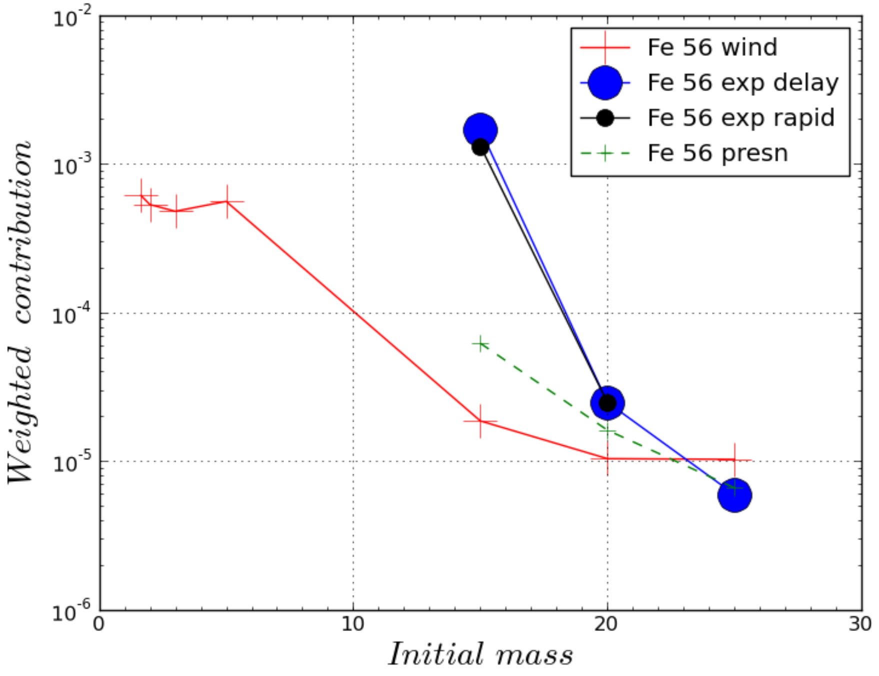
	Fe	Mn	[Mn/Fe]
15 Msun	0.13	2.4e-4	-0.58
20 Msun	7.4e-2	3.2e-4	-0.37
25 Msun	5.2e-2	4.8e-4	-0.04

Romano et al. 2011
Data from:
Cunha et al. 2010
Pancino et al. 2011

Mass ejected, weighted on Salpeter initial mass function.

	Mn/Ni
15 Msun	8e-6/2e-3 ~ 4e-4
20 Msun	3e-7/3 e-5 ~ 1e-2
25 Msun	-





Summary

Mn abundance observed today in the Solar System is made in part by explosive nucleosynthesis in core collapse SN (10-30% of solar Mn), in part by explosive nucleosynthesis in SNIa (50-100% of solar Mn).

In massive stars, Mn (mostly produced as Co55 and Fe55) is produced in conditions where also Ni56 is produced, but Ni56 is also produced deeper in the SN material, where no Mn55 is produced.

Impact of fallback when considered increases the Mn/Fe yields with increasing the initial mass. 'Fallback component' = high Mn/Fe component.

High energy ejecta should show a low Mn/Fe. High energy ejecta are in agreement with strong requirements of presolar grains measurements.
High energy component = low Mn/Fe component.

Check for correlation between Mn/Fe and r-process/alpha-elements (not iron), to test r-process scenario in high energy jets.