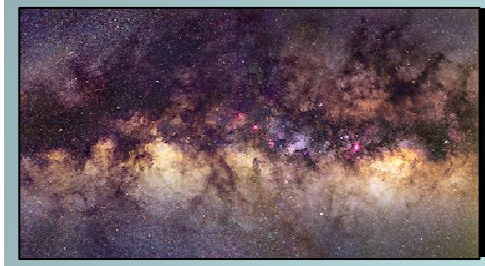
ABUNDANCES AND GALACTIC CHEMICAL EVOLUTION OF THE Fe-PEAK ELEMENTS

JENNIFER SOBECK
UNIVERSITY OF CHICAGO
OCTOBER 23, 2010

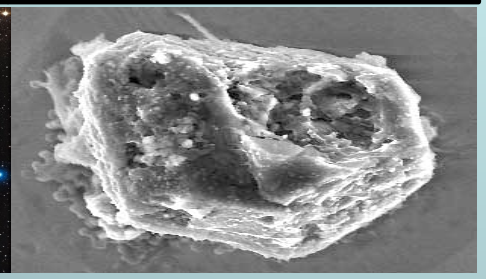
TELESCOPES: RELATIVE SIZES

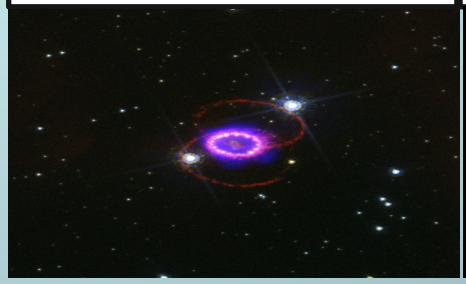
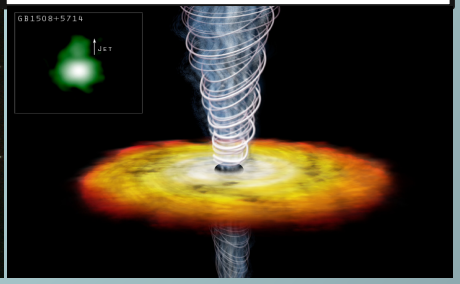
ELEMENT ABUNDANCES: OBSERVATION

Galactic Bulge	Galactic Halo	Galactic Disk
		

Globular Cluster	Open Cluster
	

Planetary Nebulae	HII Regions
	

Dwarf Galaxies	Pre Solar Grains
	

Supernovae	QSO
	

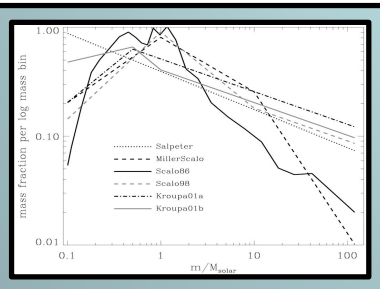
STELLAR ELEMENT ABUNDANCES: UTILITY

STELLAR ABUNDANCES

INITIAL MASS FUNCTION (IMF)

Distribution of masses at birth

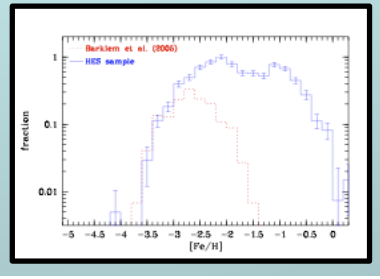
- In general, stellar masses range from ~0.1-100 M_{sun}
- Not all masses equally likely to be formed
- Detailed shape highly uncertain:
  lowest mass stars very dim
  highest mass stars bright but very rare
- General trends clear: most stars have low mass; massive stars are uncommon



METALLICITY DISTRIBUTION FUNCTION (MDF)

Number of Stars Per Metallicity (Bin)

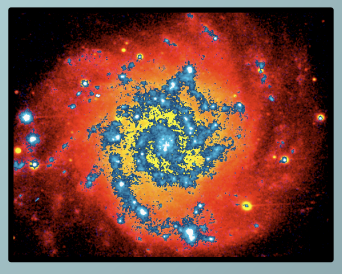
- Provides critical information on the enrichment history of a stellar population
- The lowest metallicity tail of the MDF sheds light on the earliest enrichment phases (minimum level of enrichment necessary to form low mass stars; critical metallicity)
- Age-Metallicity relation



STAR FORMATION RATE (SFR)

Production History of Stars

- High-Mass Stars- bright, blue, short-lived, rare
- Low-Mass Stars- dim, red, long-lived, common
- High-mass stars *trace* "instantaneous" SFR
- Low-mass stars *trace* integrated star formation history

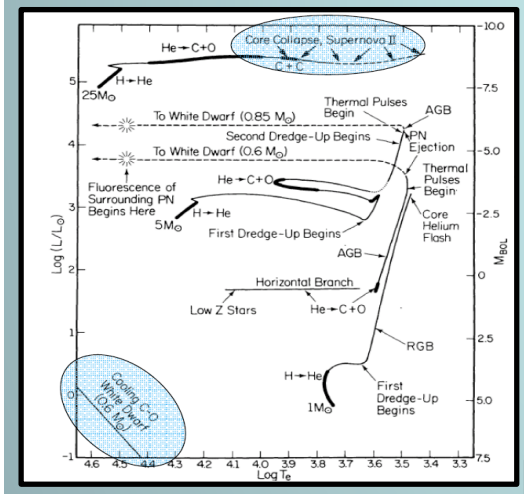


STELLAR ELEMENT ABUNDANCES: UTILITY

ELEMENT ABUNDANCES

STELLAR EVOLUTION

Life cycle of the star and associated stellar processes (e.g. thermal pulses)



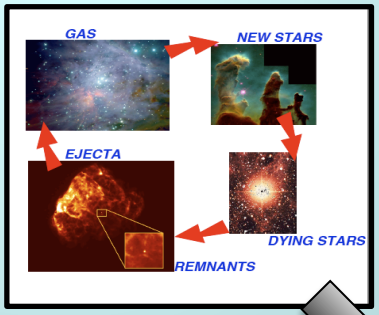
CHEMICAL EVOLUTION

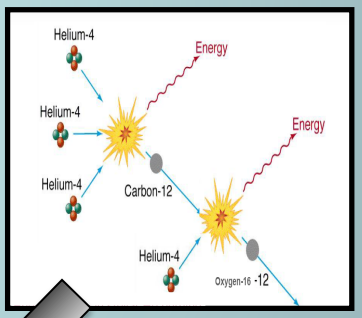
Processing of elements in the ISM and incorporation into new stars

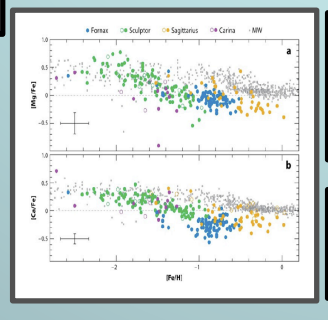
NUCLEOSYNTHESIS PROCESSES

Production of elements via coupled nuclear reactions in stars and other environments

rotation, mass loss, post-MS evolution, supernovae







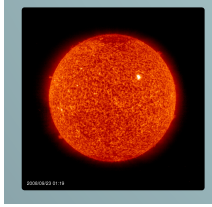
STELLAR POPULATIONS AND ABUNDANCE PATTERNS

Observed abundance trends in various stellar populations combine both nucleosynthesis and chemical evolution

STELLAR ELEMENT ABUNDANCES: ESSENTIALS

REFERENCE PHOTOSPHERIC VALUES

Element	Abundance (log ε)
Sc	3.05 ± 0.08
Ti	4.90 ± 0.06
V	4.00 ± 0.02
Cr	5.64 ± 0.10
Mn	5.39 ± 0.03
Fe	7.52 ± 0.05 **
Co	4.92 ± 0.08
Ni	6.23 ± 0.04
Cu	4.21 ± 0.04
Zn	4.60 ± 0.03



Asplund et al. 2005
(APSC, 336, 25)
One-dimensional, LTE solar abundance analysis

REFERENCE METEORITIC VALUES

Element	Abundance (log ε)
Sc	3.07 ± 0.04
Ti	4.93 ± 0.03
V	4.00 ± 0.03
Cr	5.65 ± 0.05
Mn	5.50 ± 0.03
Fe	7.47 ± 0.03
Co	4.91 ± 0.03
Ni	6.22 ± 0.03
Cu	4.26 ± 0.06
Zn	4.63 ± 0.04

Lodders 2003
(ApJ, 591, 1220)
Weighted survey of **several** CI meteorite samples

STANDARD ABUNDANCE NOTATION

$$\log \varepsilon(A) \equiv \log\left(\frac{N_A}{N_H}\right) + 12.0$$

$$\left[\frac{A}{B}\right] \equiv \log\left(\frac{N_A}{N_B}\right)_{STAR} - \log\left(\frac{N_A}{N_B}\right)_{SUN}$$

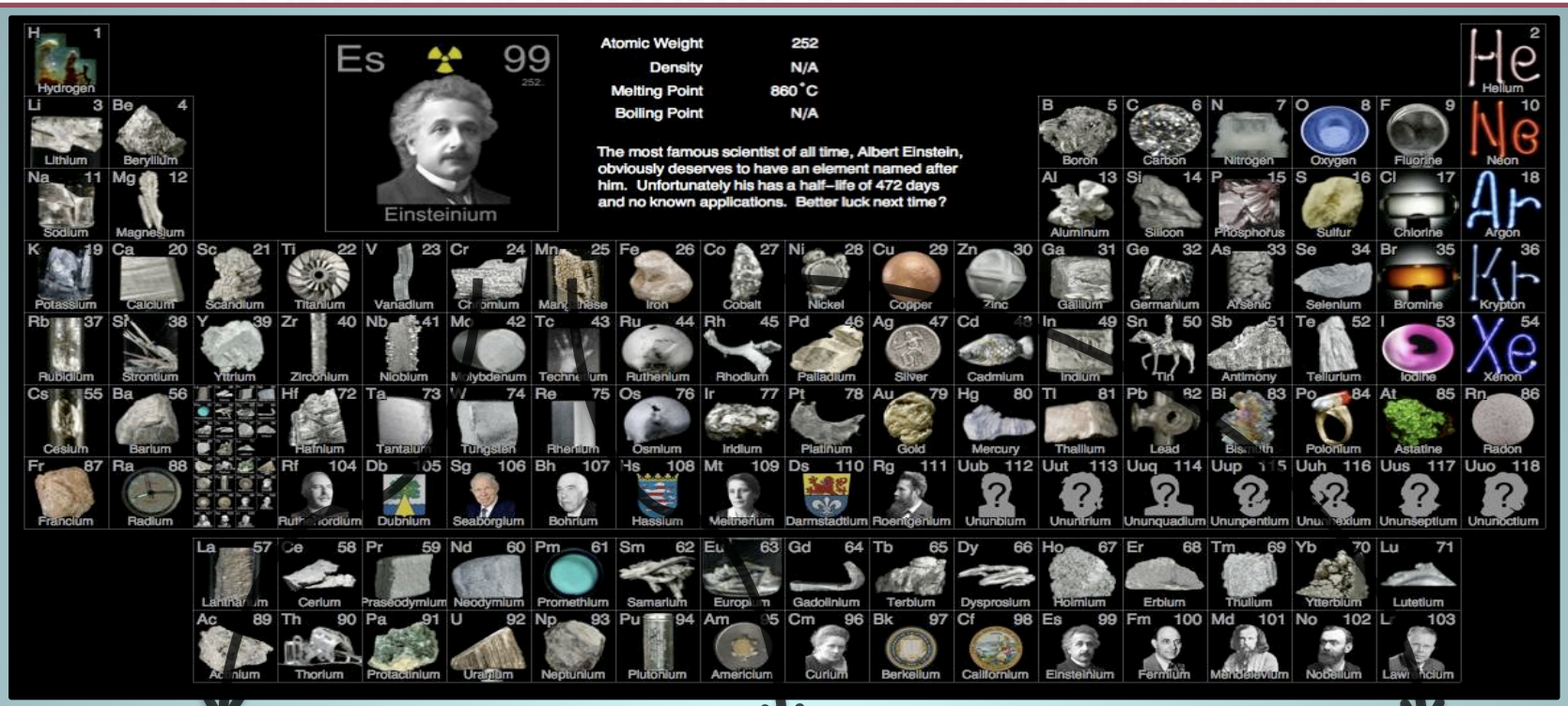
RELEVANT DEFINED QUANTITIES

$$\log \varepsilon(Fe)_{Sun} \equiv 7.52$$

$$\left[\frac{Fe}{H}\right]_{Sun} \equiv 0.00$$

* The [Fe/H] quantity for a star is its ***metallicity***

ELEMENT NUCLEOSYNTHESIS: Fe GROUP MEMBERS

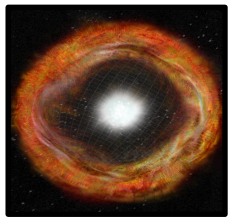


$^{50,52,53,54}_{24}Cr$

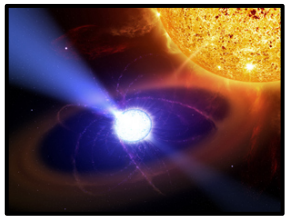
$^{55}_{25}Mn$

$^{59}_{27}Co$

EXPLOSIVE STELLAR NUCLEOSYNTHESIS



Type II



Type Ia

GALACTIC CHEMICAL EVOLUTION: CURRENT APPROACH

• The GCE investigation of Timmes et al. (1995) employed the massive star yield data of Woosley & Weaver (1995), made assumptions with regard to Type Ia and planetary nebulae/wind input, and used a Salpeter initial mass function (IMF; 1955). On the other hand, Kobayashi et al. (2006) employed their own massive stars yields, considered Type Ia yields from Iwamoto et al. (1999) as well as input from *hypernovae*, and used a Salpeter IMF (1995).

• As an *alternative* approach, the goal of the current study is to use the yield calculations of Chieffi & Limongi (2004) in conjunction with a Salpeter IMF to generate (first-order) relative abundance ratios for the elements of the iron peak (these elements originate primarily from explosive nucleosynthetic events). We do not weigh heavily the data for the metallicity region of [Fe/H] > -1.0 as we do not consider Type Ia (or other) contributions.

To determine the average yield of a particular element with regard to the Salpeter IMF, the formula below is utilized:

$$\langle Y_{Elem} \rangle = \frac{\int_{M_1}^{M_2} Y_{Elem}(m) m^{-2.35} dm}{\int_{M_1}^{M_2} m^{-2.35} dm}$$

To derive the relative abundance of a particular element at the six specified grid metallicities, the formula below is employed:

$$\left[\frac{Elem}{Fe}\right] = \log\left(\frac{N_{Elem,*}/N_{Fe,*}}{N_{Elem,Sun}/N_{Fe,Sun}}\right) = \log\left(\frac{\langle Y \rangle_{Elem,*}/\langle Y \rangle_{Fe,*}}{M_{Elem,Sun}/M_{Fe,Sun}}\right)$$

GALACTIC CHEMICAL EVOLUTION: CHIEFFI & LIMONGI YIELDS

Listed below are some of the relevant details of the process by which **Chieffi & Limongi** (2004 and references therein) generate element yields:

- Focus on **massive** star yields only

- Grid of *six masses* (13, 15, 20, 25, 30, and 35 M_{SUN}) and *six metallicities* ($Z = 0, 10^{-6}, 10^{-4}, 10^{-3}, 6\times10^{-3}$, and 2×10^{-2})

- Employment of a nuclear network which extends through ^{98}Mo

- Utilization of the reaction rate data from REACLIB (Raucsher & Thielemann 2000) and subsequent inclusion of approximately 3000 reaction rates

- FRANEC code (with hydrostatic and hydrodynamic components): propagation of shock front through mantle of star followed by solving hydrodynamical equations in spherical symmetry and in Lagrangian form

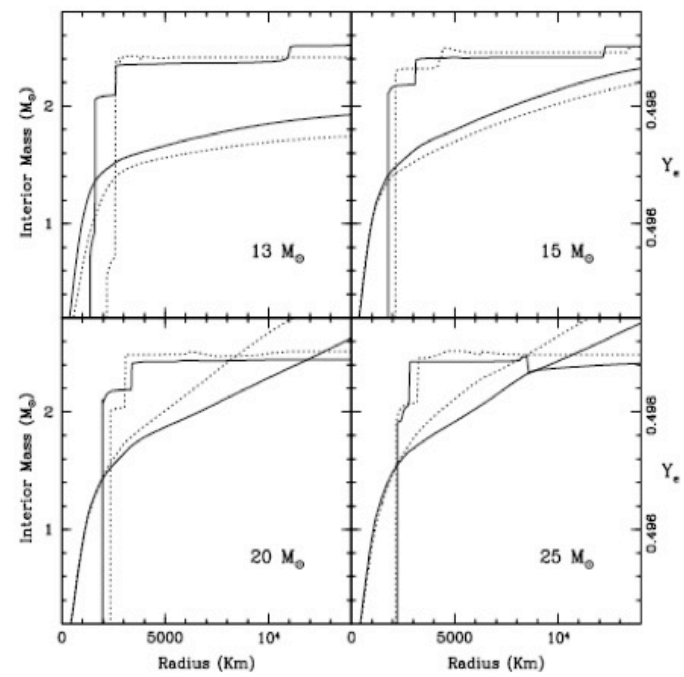


Figure: From Limongi & Chieffi (2003). Pre-supernova mass coordinate (*thick lines*) and electron mole number profiles (*Yel; thin lines*) as a function of radius for the four masses in common between Limongi & Chieffi (2003) and Limongi et al. 2000.

GALACTIC CHEMICAL EVOLUTION: CHIEFFI & LIMONGI YIELDS

Listed below are some of the relevant details of the process by which **Chieffi & Limongi** (2004 and and references therein) generate element yields:

- Avoidance of statistical equilibrium
- No consideration of mass loss or rotation
- Piston-induced explosion: explosion initiates via the transmittance an initial velocity (v_o) to a mass coordinate of approximately 1 M_{SUN}.

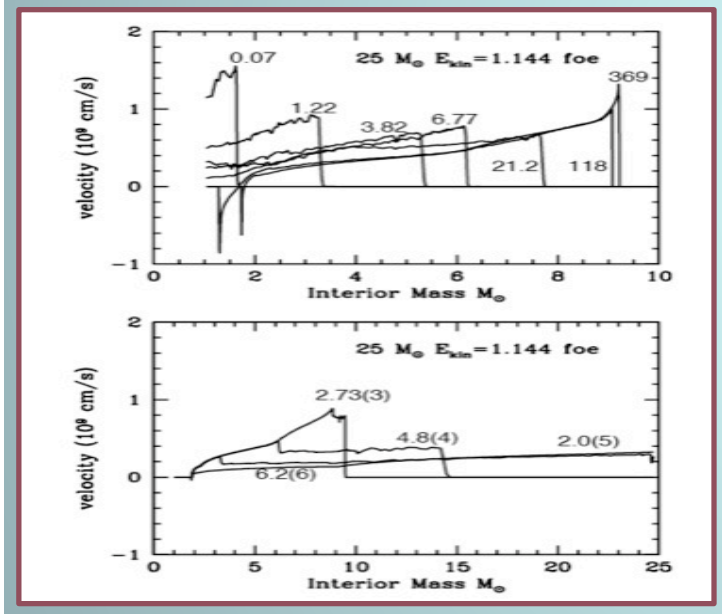


Figure: From Limongi & Chieffi (2003). Time history of the shock propagation in a 25 M_{SUN} model. Each curve is labeled by the time (in seconds) to which it refers.

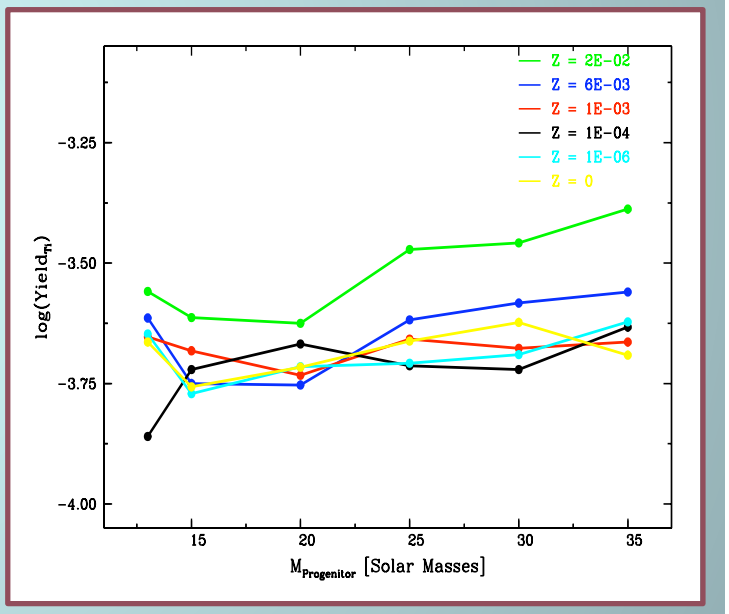


Figure: The yield of the element Ti as a function of progenitor mass (in M_{SUN}). The data are plotted for all six metallcities (denoted by color accordingly as described in the legend of the plot).

GALACTIC CHEMICAL EVOLUTION: Fe-PEAK ELEMENTS

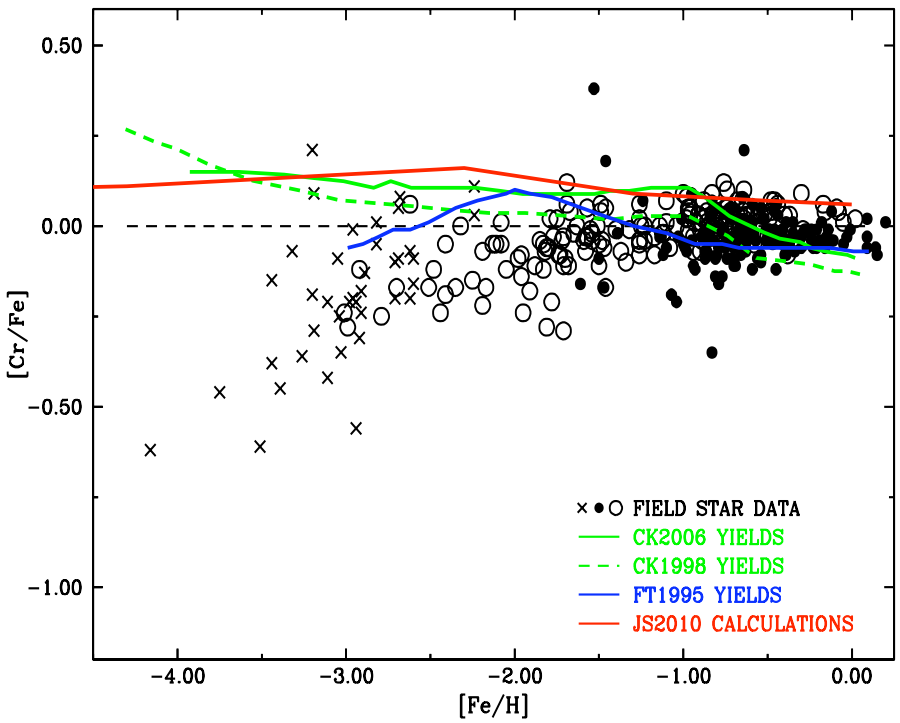
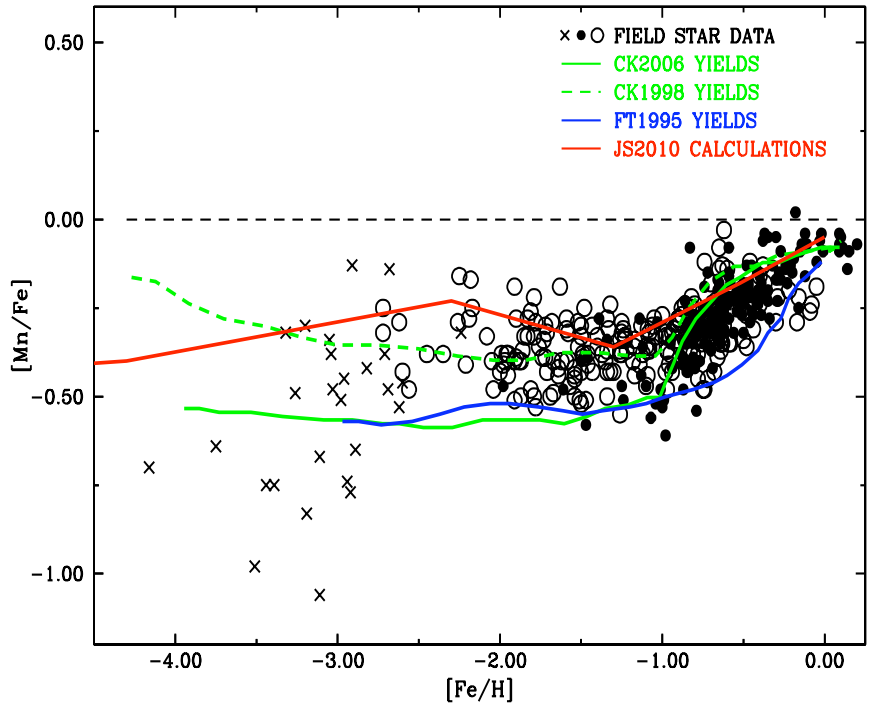


Figure: The evolution of **[Cr/Fe]** as a function of [Fe/H] for all studies considered. The red line indicates the calculations from the current study. The blue line signifies the data from Timmes et al. (1995). The green solid and dashed lines denote the yields from Kobayashi et al. (2006) and Kobayashi et al. (1998), respectively.

OBSERVATIONAL DATA SOURCES-

Cayrel et al. (2004)
Fulbright (2000)
Jonsell et al. (2005)
Lai et al. (2008)
Reddy et al. (2006)
Sobeck et al. (2006, 2008, 2010)

GALACTIC CHEMICAL EVOLUTION: Fe-PEAK ELEMENTS



OBSERVATIONAL DATA SOURCES-

Cayrel et al. (2004)
Fulbright (2000)
Jonsell et al. (2005)
Lai et al. (2008)
Reddy et al. (2006)
Sobeck et al. (2006, 2008, 2010)

Figure: The evolution of **[Mn/Fe]** as a function of [Fe/H] for all studies considered. The red line indicates the calculations from the current study. The blue line signifies the data from Timmes et al. (1995). The green solid and dashed lines denote the yields from Kobayashi et al. (2006) and Kobayashi et al. (1998), respectively.

GALACTIC CHEMICAL EVOLUTION: Fe-PEAK ELEMENTS

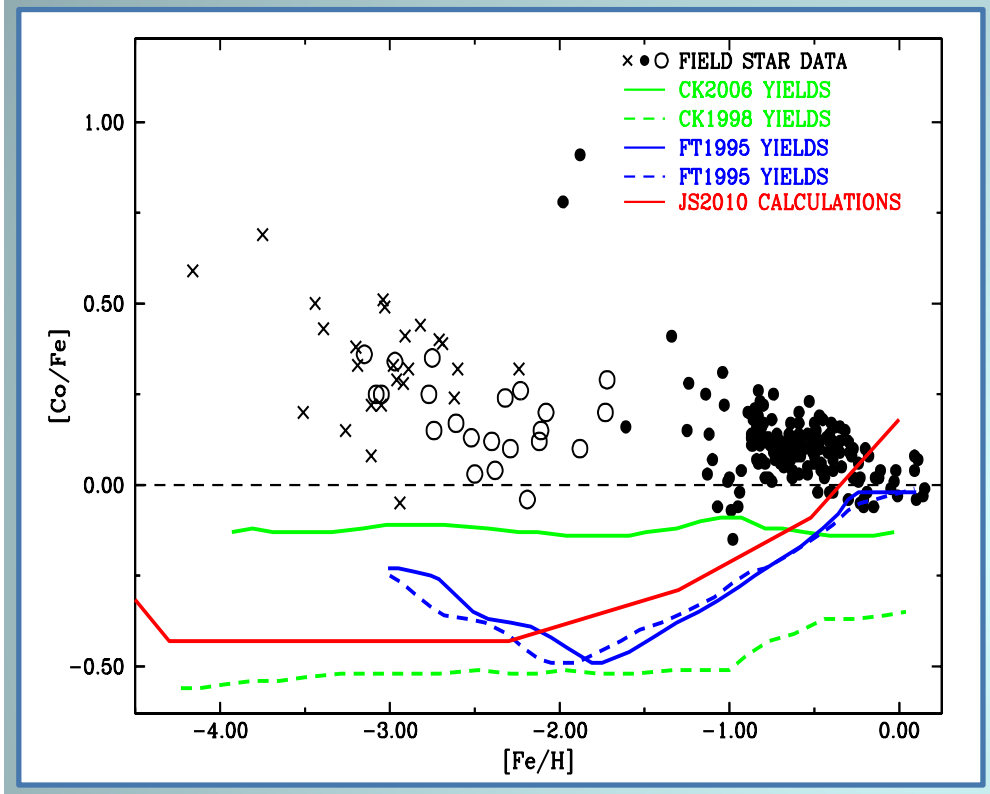


Figure: The evolution of **[Co/Fe]** as a function of [Fe/H] for all studies considered. The red line indicates the calculations from the current study. The blue line signifies the data from Timmes et al. (1995). The green solid and dashed lines denote the yields from Kobayashi et al. (2006) and Kobayashi et al. (1998), respectively.

OBSERVATIONAL DATA SOURCES-

Cayrel et al. (2004)
Fulbright (2000)
Jonsell et al. (2005)
Lai et al. (2008)
Reddy et al. (2006)
Sobeck et al. (2006, 2008, 2010)

GALACTIC CHEMICAL EVOLUTION: INITIAL FINDINGS

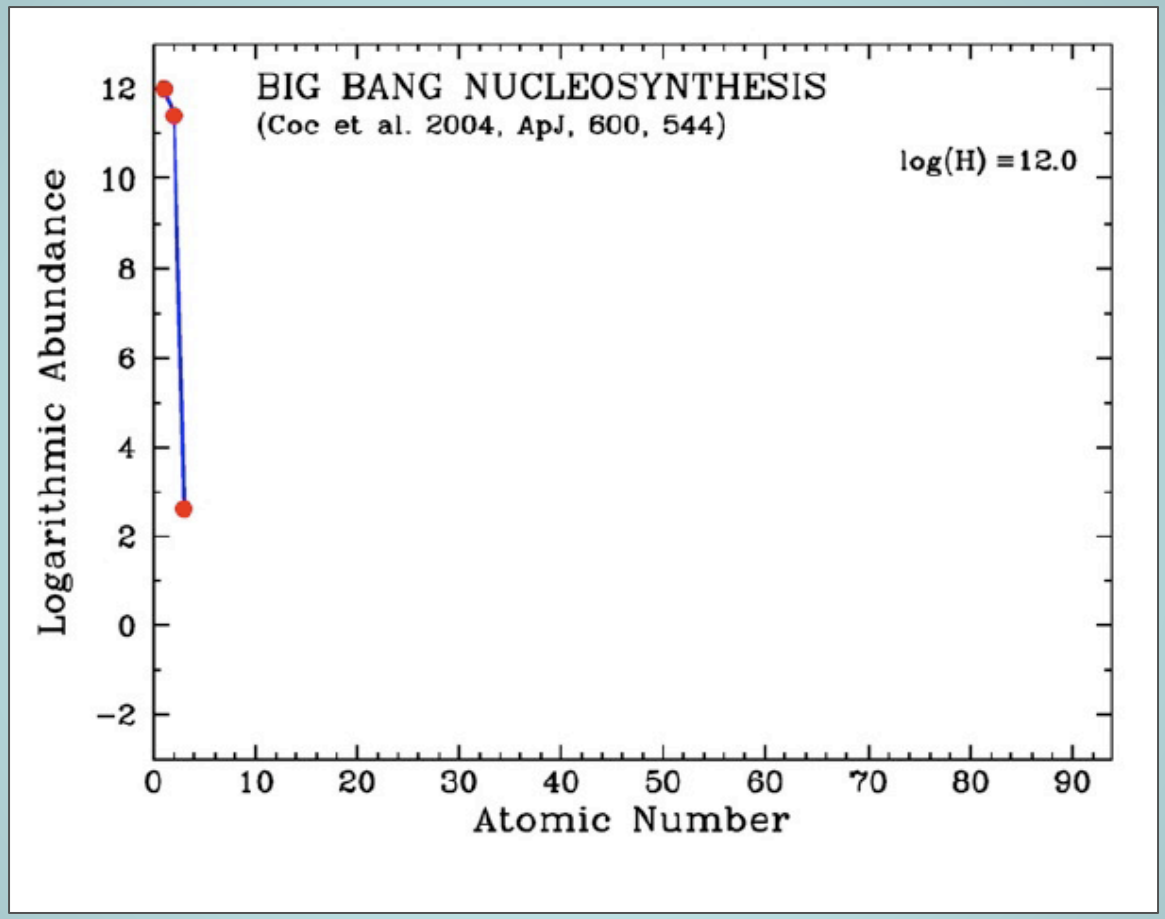
Z_{MODEL}	$[Fe/H]_{MODEL}$	[O/Fe]	[Sc/Fe]	[Ti/Fe]	[V/Fe]	[Cr/Fe]	[Mn/Fe]	[Co/Fe]	[Ni/Fe]
2.00E-02	0.0	0.26	0.11	-0.07	-0.09	0.06	-0.05	0.18	0.12
6.00E-03	-0.5	0.32	-0.37	-0.11	-0.27	0.07	-0.18	-0.09	-0.04
1.00E-03	-1.3	0.35	-1.20	-0.09	-0.52	0.09	-0.36	-0.29	-0.11
1.00E-04	-2.3	0.34	-1.50	-0.16	-0.36	0.16	-0.23	-0.43	-0.01
1.00E-06	-4.3	0.30	-1.59	-0.11	-0.55	0.11	-0.40	-0.43	-0.19
0	-INF	0.26	-0.82	-0.09	-0.52	0.09	-0.45	0.54	0.99

- For the elements Cr, Mn, and Ni, the fit quality between observational data points and IMF-weighted yields of the current study is good.
- The IMF-averaged yields from the current study for all Fe-peak elements compare favorably with those from Timmes et al. (1995) and Kobayashi et al. (2006).
- Fits of the current study yields to the observational abundances for Sc, Ti, and V are poor (the yields vastly under-produce these elements); the same is true for both Kobayashi et al. and Timmes et al.).
- Note that the trend for Mn is well-replicated across the entire metallicity regime *without* the input from Type Ia SNe.

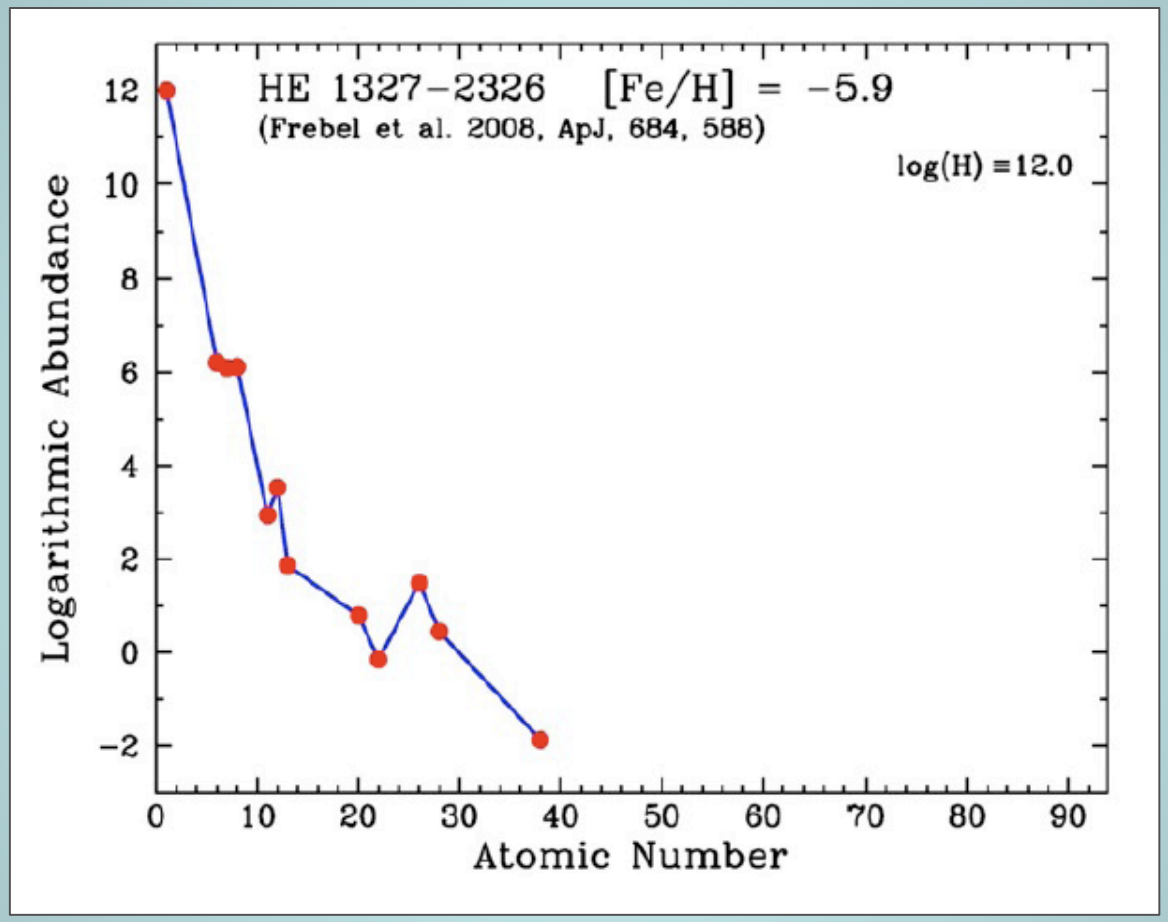
GALACTIC CHEMICAL EVOLUTION: FUTURE PLANS

- Employ additional numerical integration techniques and fine-tune average yield determination process
- Use alternate initial mass functions from Kroupa (2001, 2002) and Tumlinson (2006, 2007) and examine resultant yield values
- Extend the mass range employed with the inclusion of hypernova yield data from Tominaga et al. (2007; 40-50 M_{SUN}); focus on even higher mass contributions
- For completeness, compare yield as a function of progenitor mass results from other studies (for the Fe-peak elements) and attempt to pinpoint differences
- Examine (eventually) the more metal-rich end and nucleosynthetic input from Type Ia events (with data generated by JINA participant, D. Townsley)

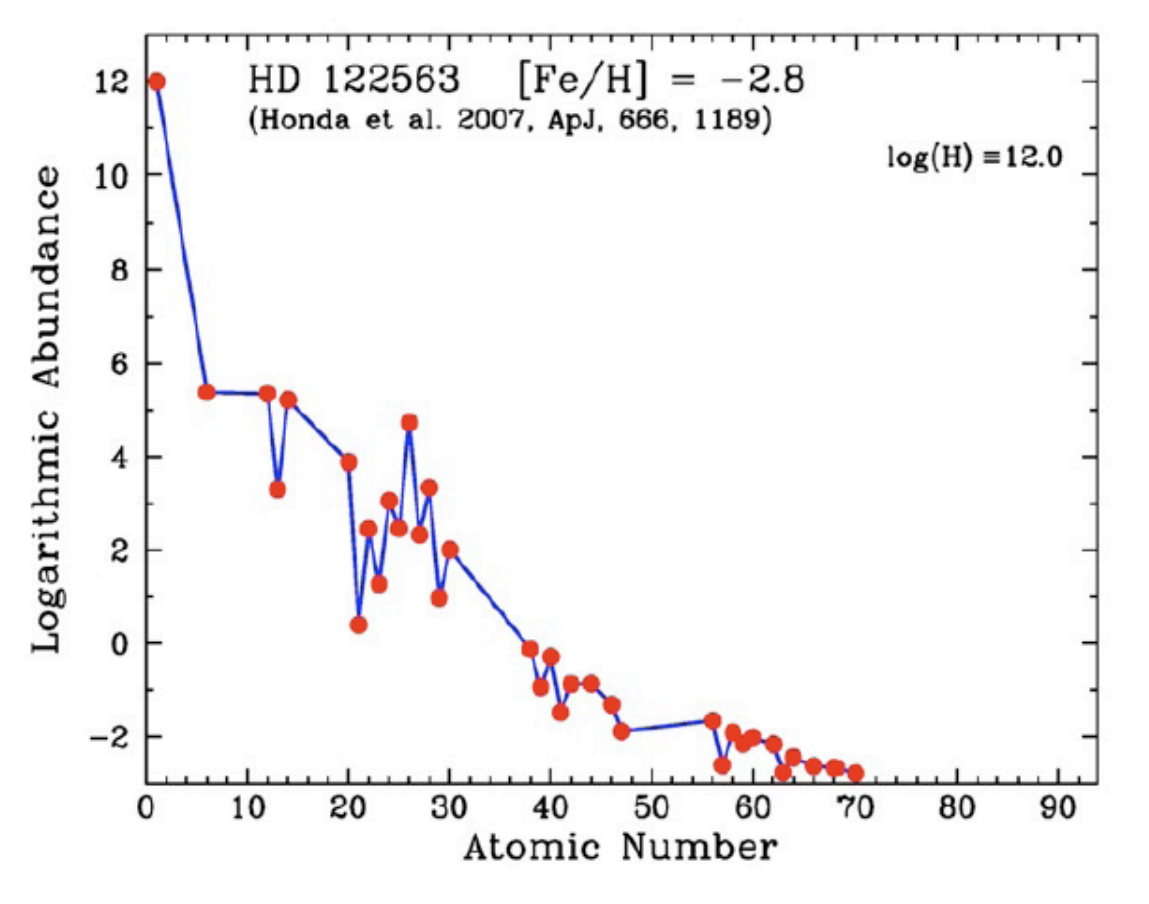
GALACTIC CHEMICAL EVOLUTION: BEHAVIOR WITH REGARD TO Z AND z



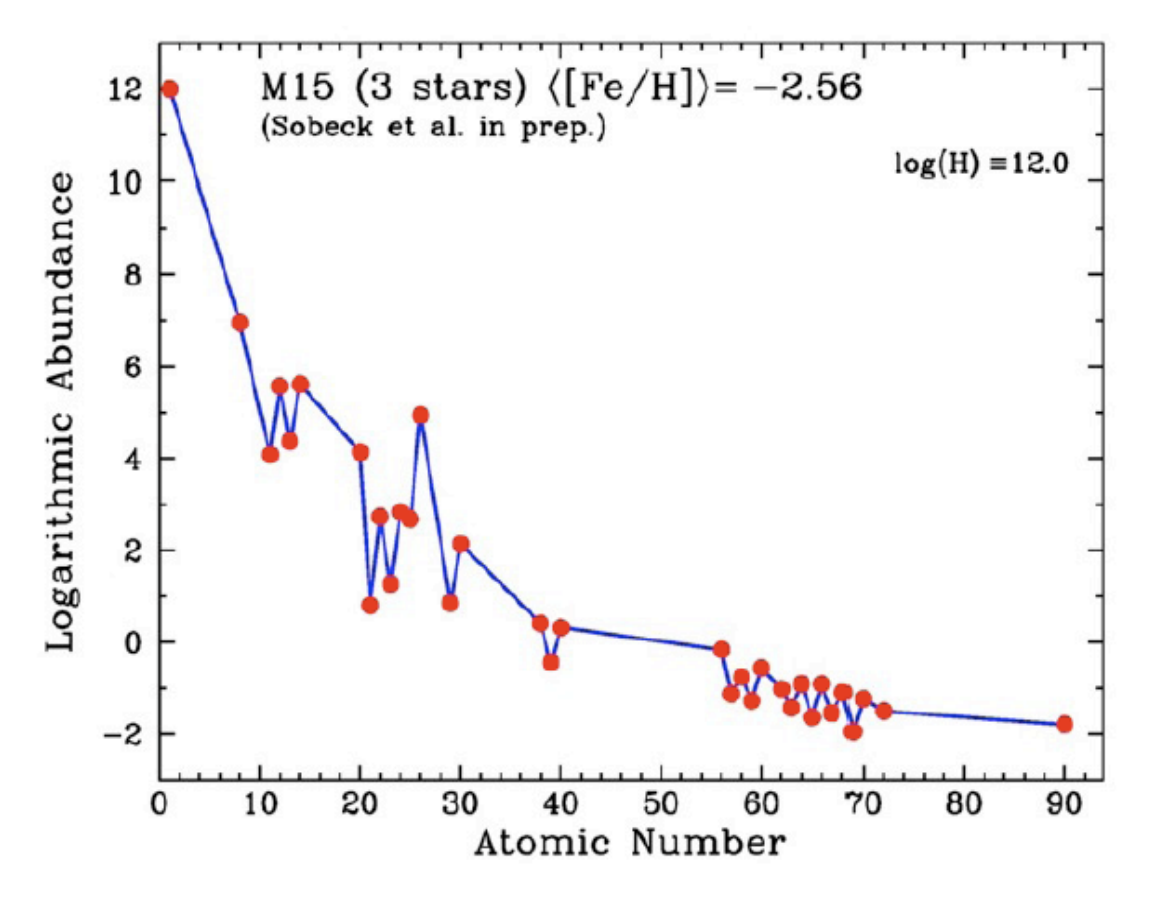
GALACTIC CHEMICAL EVOLUTION: BEHAVIOR WITH REGARD TO Z AND z



GALACTIC CHEMICAL EVOLUTION: BEHAVIOR WITH REGARD TO Z AND z



GALACTIC CHEMICAL EVOLUTION: BEHAVIOR WITH REGARD TO Z AND z



GALACTIC CHEMICAL EVOLUTION: BEHAVIOR WITH REGARD TO Z AND z