
QIAN AND WASSERBURG - 'THE EARLY DAYS' AND THE DANGERS OF OVER-SIMPLIFI-CATION
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JOE MARTIN

A bit of history –The "Prompt Inventory"

From "metal" abundances in low metallicity Halo stars–

There appears to be a "base line" of low atomic weight metals' at around [Fe/H]˜ –3.

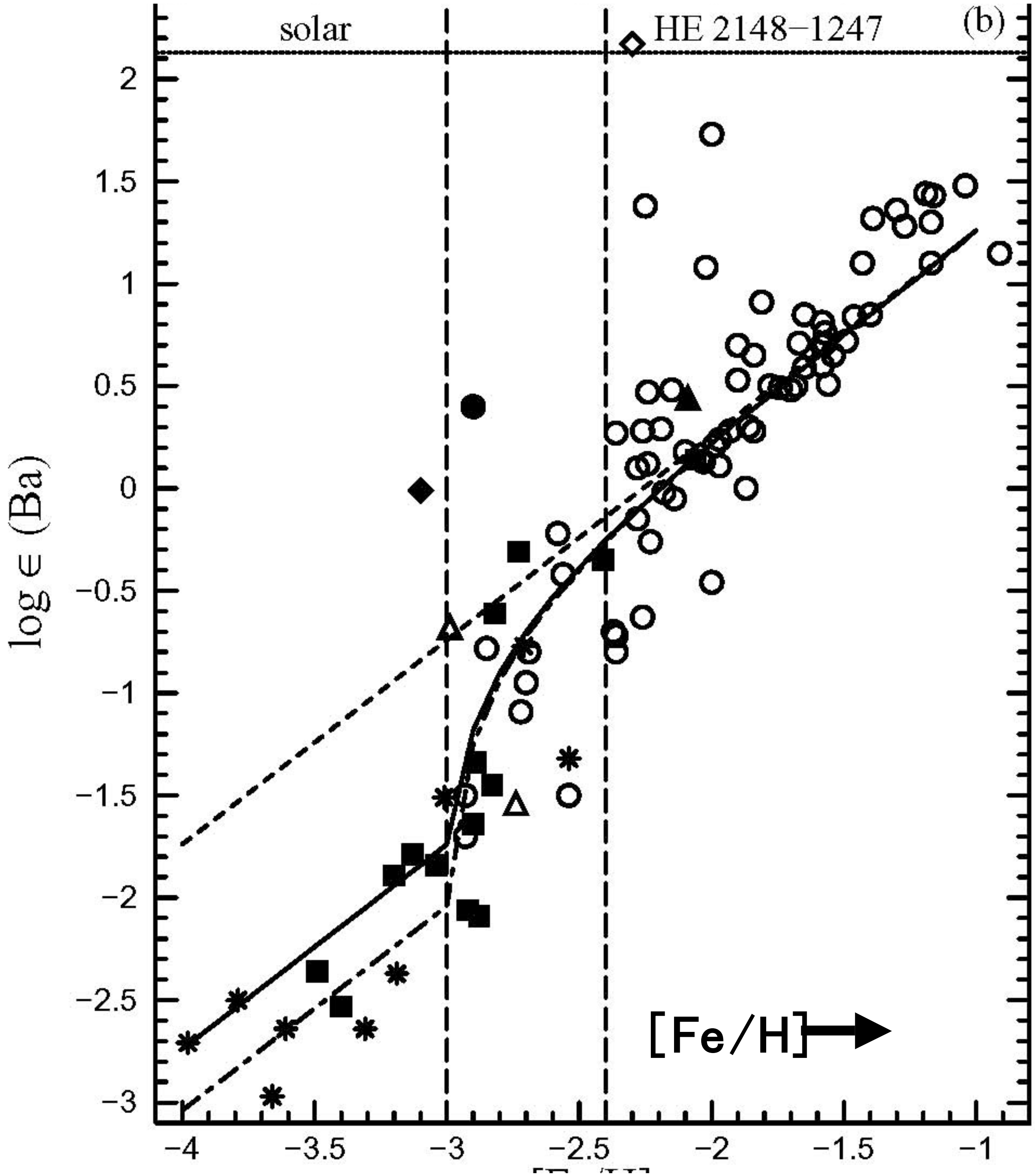
There is an "onset" of major heavy "r–process" injection into the ISM at [Fe/H]˜ –3.

A small amount of heavy "r" nuclei are present for [Fe/H]< –3.

The heavy "r–process" sources are unrelated to production of Fe and all lower mass elements.

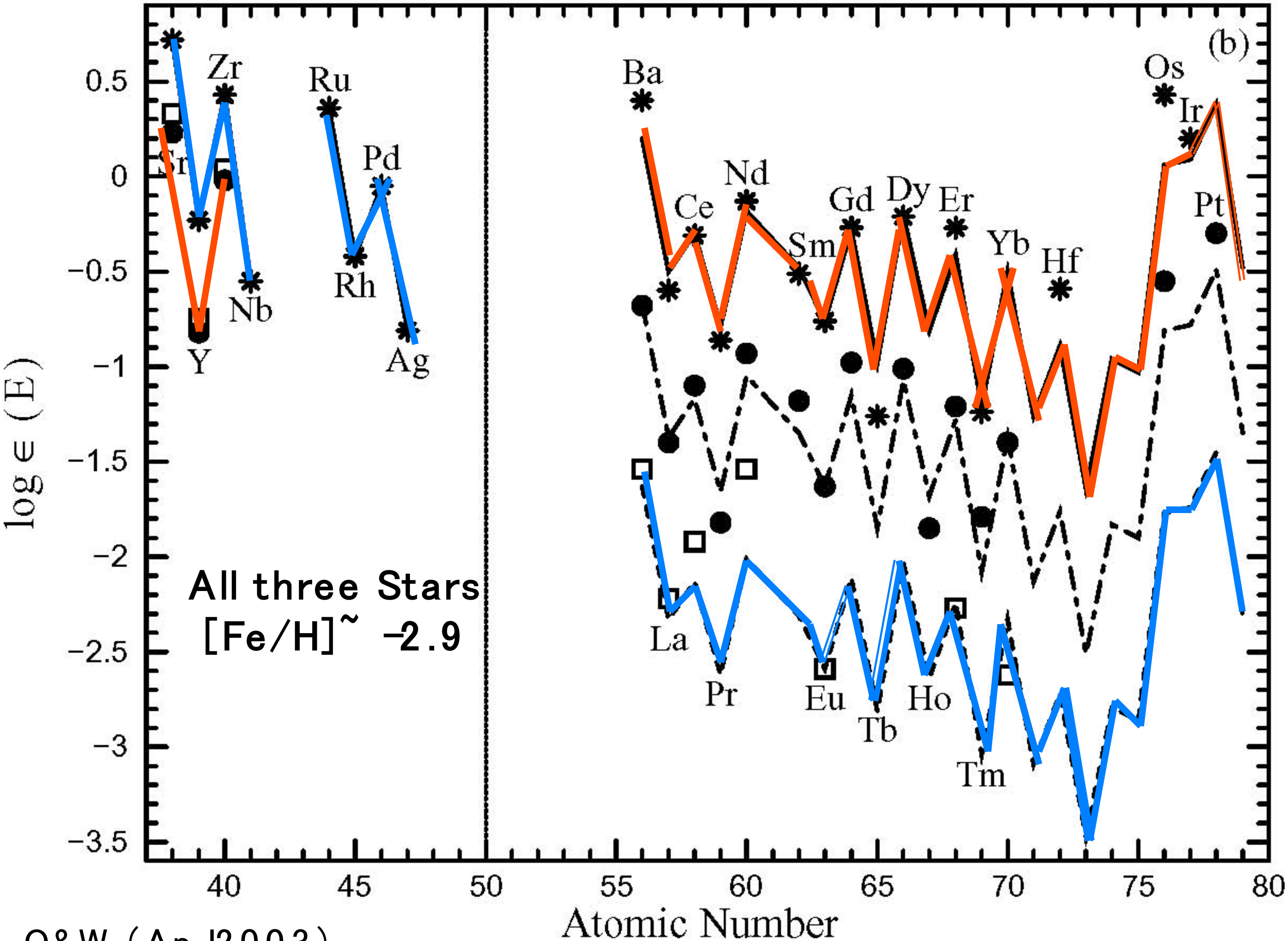
Stellar sources at low metallicities must be dominated by a different generation of stars ($M > 100 M_{SOL}$). (W&Q(2000),Q&W(2002))

Models of star formation at zero metallicity show that only very massive stars can form. (Bromm,Coppi & Larson(1999))

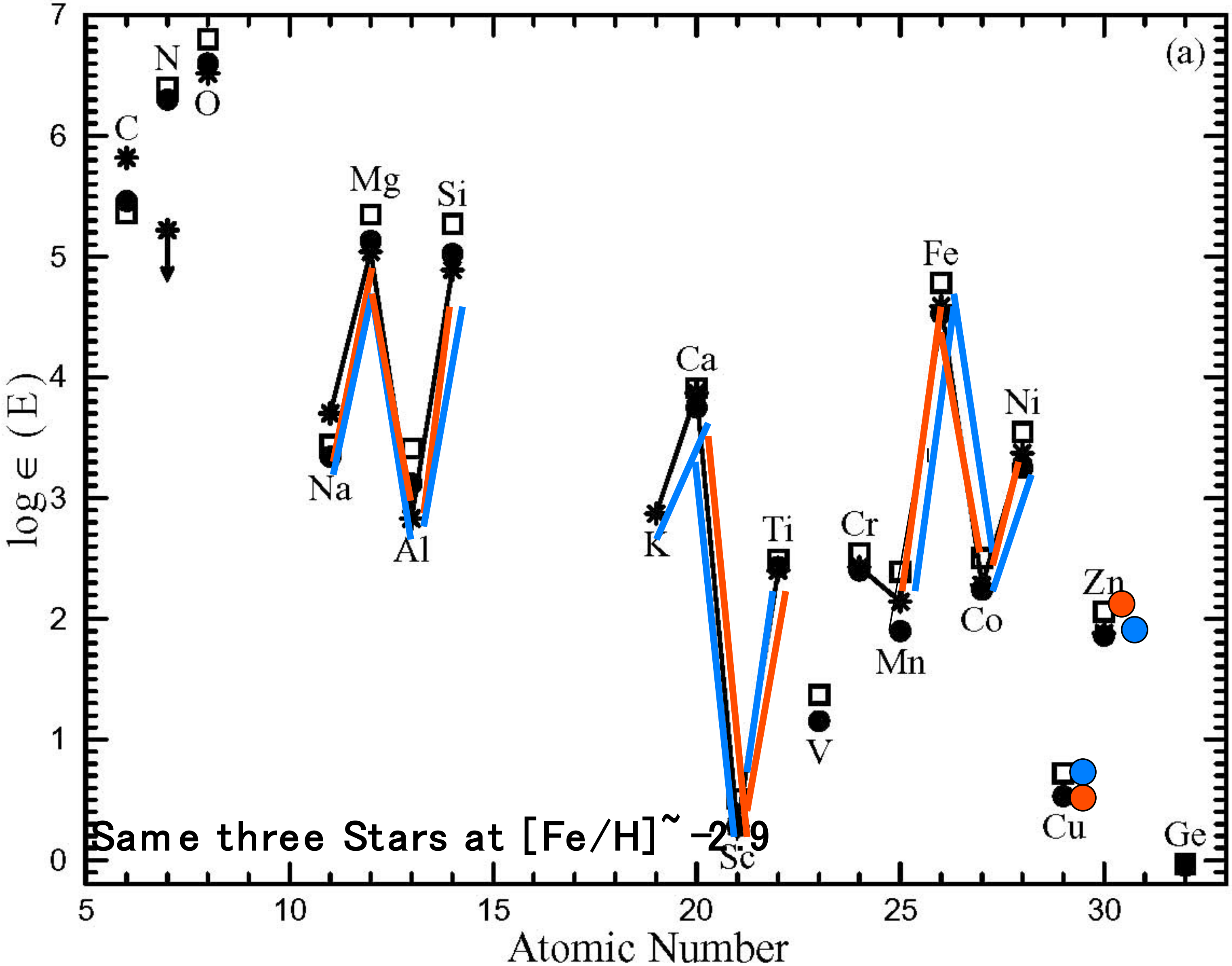


solar
HE 2148−1247
(b)
log ∈ (Ba)
2
1.5
1
0.5
0
−0.5
−1
−1.5
−2
−2.5
−3
−4
−3.5
−3
−2.5
−2
−1.5
−1
[Fe/H]

Data from Westin et al(ApJ 2000) & Hill et al(AA 2002)



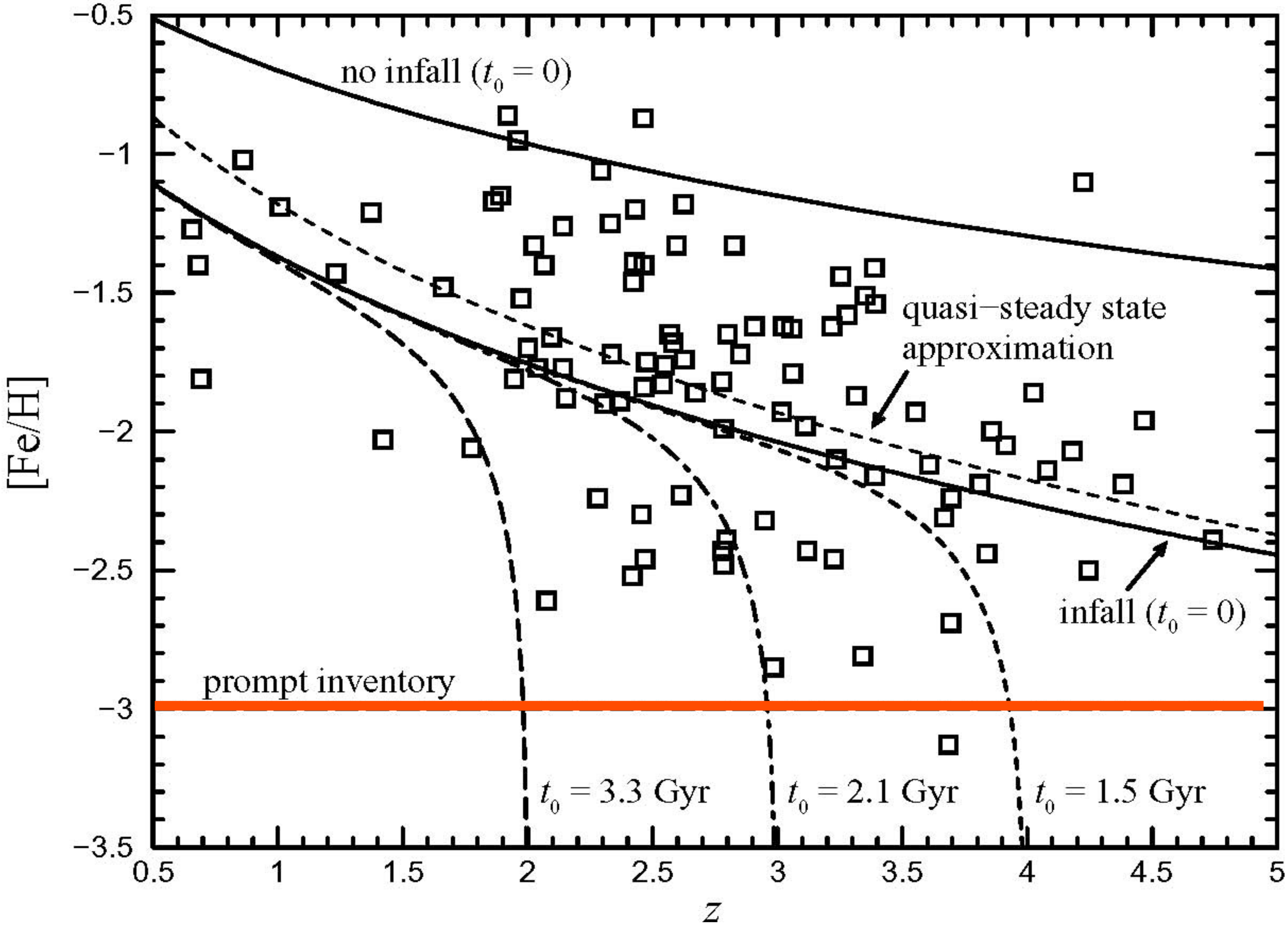
Q&W (ApJ2003)



(a)
log ∈ (E)
Atomic Number
C
N
O
Na
Mg
Al
Si
K
Ca
Sc
Ti
V
Cr
Mn
Fe
Co
Ni
Cu
Zn
Ge
Same three Stars at [Fe/H]~-2.9

Damped Lyman α abundances

Data from Prochaska et al (APJ 2003)



Evolution Curves Q&W (APJL 2003)

Yong-Zhong Qian & G.J. Wasserburg

Metal Enrichment of the IGM
&
Production of Massive Black Holes

Ap. J. (2005) in press

High Si/C in the IGM

Early Chemical Evolution ↔ Cosmology

High Si/C in the IGM requires VMS

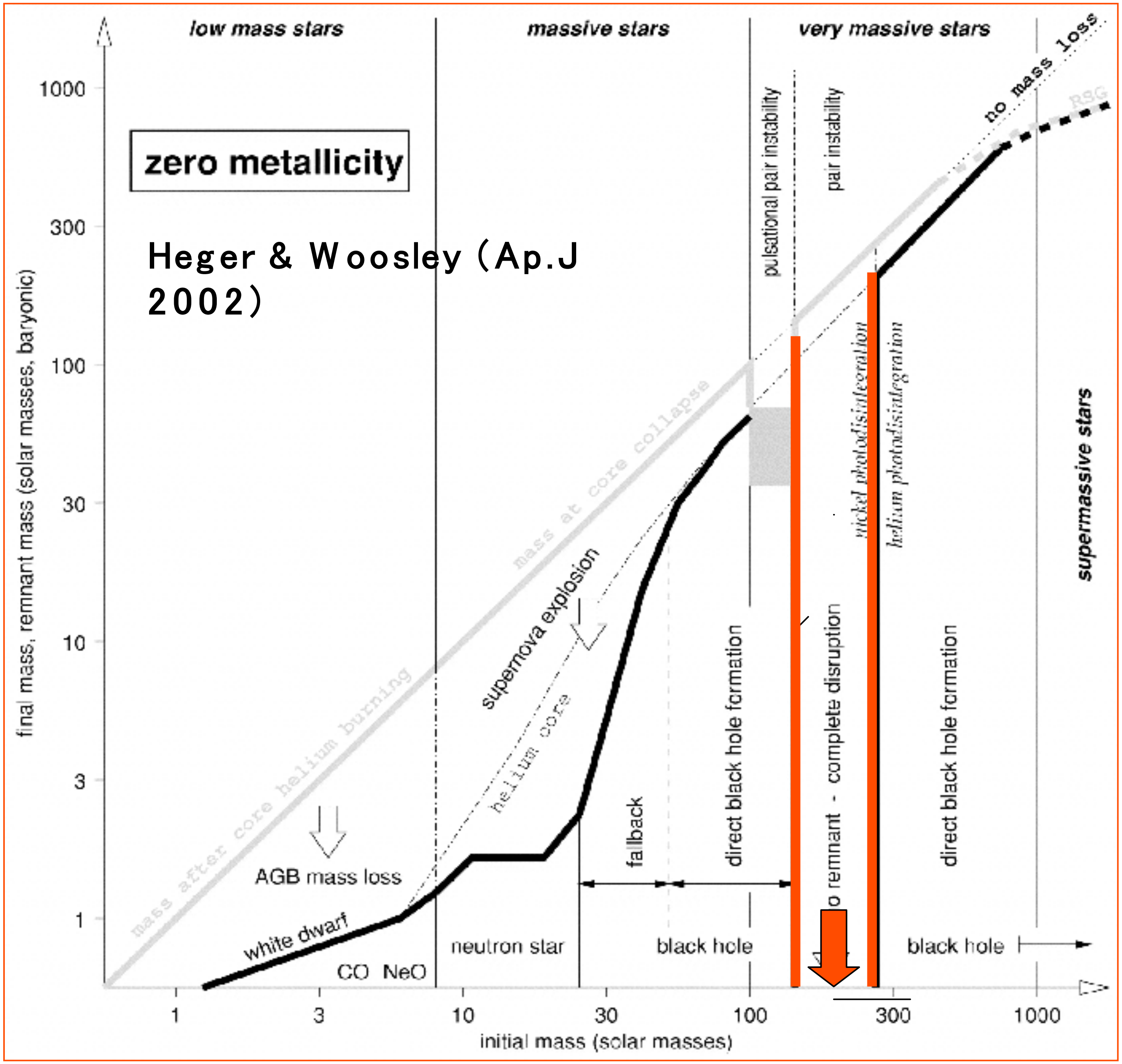
For VMS (PI-SNe)

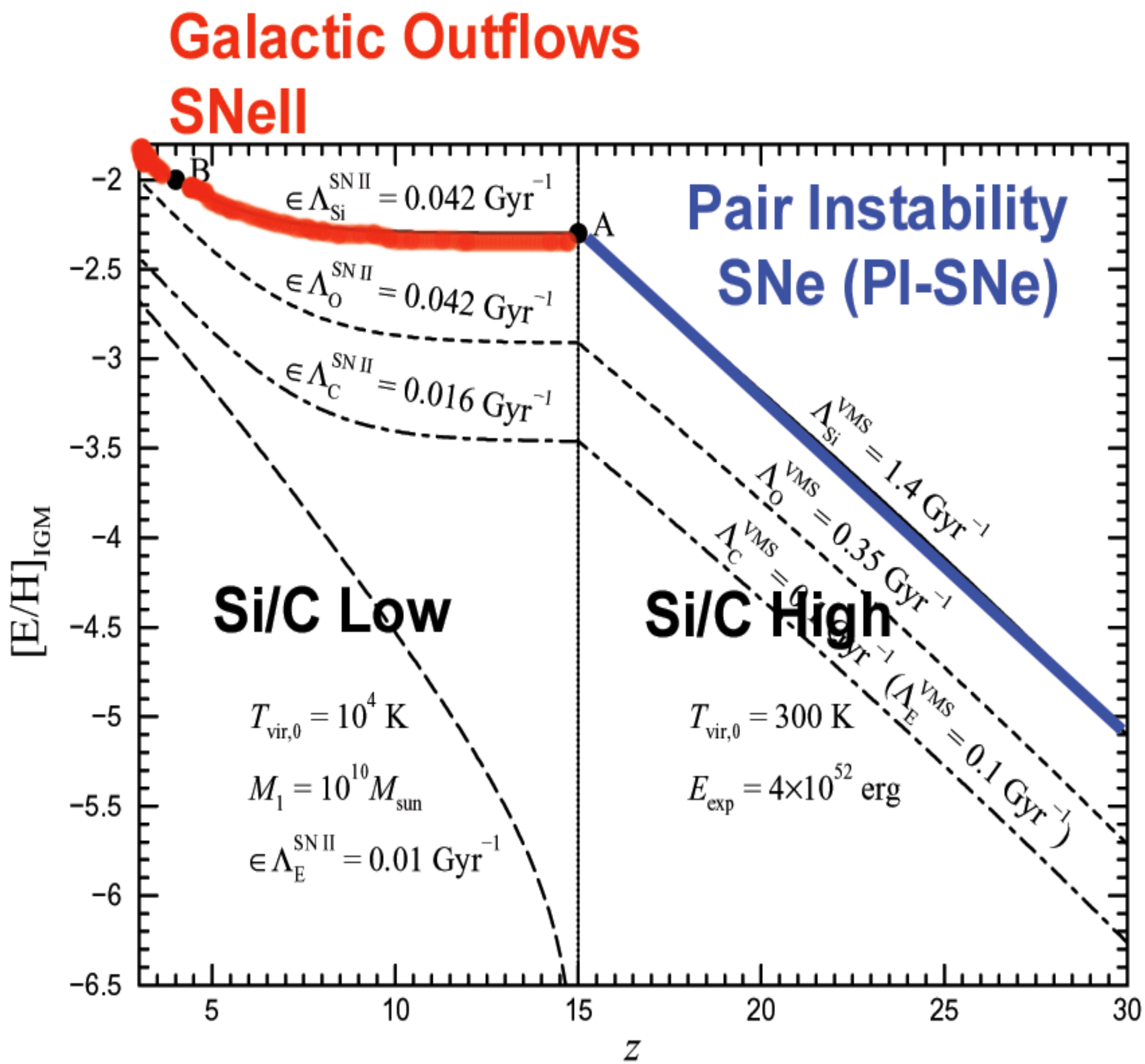
Si production ⇨ MBH production

$[Si/H]_{IGM} = -2.3$ ⇨ $f_{MBH} = 8.4X10^{-5}$ **Fraction of baryons in MBH**

The present value for the fraction of all baryonic matter in the universe is -

in SMBH $f_{SMBH} = 7.5x10^{-5}$


zero metallicity
Heger & Woosley (Ap.J 2002)
low mass stars
massive stars
very massive stars
no mass loss
RSG
pulsational pair instability
pair instability
nickel photodisintegration
helium photodisintegration
supermassive stars
mass after core helium burning
mass at core collapse
supernova explosion
helium core
AGB mass loss
white dwarf
CO
NeO
neutron star
fallback
direct black hole formation
black hole
no remnant - complete disruption
direct black hole formation
black hole
final mass, remnant mass (solar masses, baryonic)
initial mass (solar masses)
1000
300
100
30
10
3
1
1
3
10
30
100
300
1000



Galactic Outflows
SNeII
Pair Instability
SNe (PI-SNe)
∈ Λ_Si^SN II = 0.042 Gyr^-1
∈ Λ_O^SN II = 0.042 Gyr^-1
∈ Λ_C^SN II = 0.016 Gyr^-1
Λ_Si^VMS = 1.4 Gyr^-1
Λ_O^VMS = 0.35 Gyr^-1
(Λ_E^VMS = 0.1 Gyr^-1)
A
B
Si/C Low
Si/C High
T_vir,0 = 10^4 K
M_1 = 10^10 M_sun
∈ Λ_E^SN II = 0.01 Gyr^-1
T_vir,0 = 300 K
E_exp = 4×10^52 erg
[E/H]_IGM
z
-2
−2.5
−3
−3.5
−4
−4.5
−5
−5.5
−6
−6.5
5
10
15
20
25
30

Keys to the IGM

Lyman Forest Measurements of IGM

C IV,O VI, Si III,& Si IV *z*= 1.5 to 5.5

⇨ C/H, O/H,Si/H

Requires an Ultra Violet Background (UVB) model

Haardt & Madau(1996,2001)

Model Q-harder UVB QSO source only.

Si/C very high.

C,O,Si match no blend with SNe or VMS yields (Q&W2005).

Model QG-softer UVB QSO+Galaxies.

Si/C high.

C,O,Si match with a blend of SNe +VMS.

Other UVB give physically unreasonable results.

Major findings in the forest by:

Songaila (2001), Pettini et al (2003), Schaye et al (2003), Aguirre et al (2004),Simcoe et al (2004).

....

Rules of the day for z=1.5 to 5.5:

Strange log normal distribution of [Si,O,C/H].

No evidence of evolution over z range.

No apparent variation of Si/C or C/O for either UVB model.

Model Q gives $[Si/C]_{IGM}$ =1.45 (very high)

Model QG gives $[Si/C]_{IGM}$ =0.74 (high)

For both models the indications are for VMS sources.

We will take QG values.

$[Si/C]_{IGM}$=0.74

$[Si/H]_{IGM}$=-2.0

$[O/H]_{IGM}$ =-2.3

$[C/H]_{IGM}$ =-2.8

Using:
SNeII yields Weaver & Woosley(1995);
VMS yields Heger & Woosley(2002);
Salpeter IMF.
Calculate the fraction of Si in the IGM from VMS (Si is the diagnostic).

$(C/Si)_{IGM}=(C/Si)_{VMS}\, f_{Si}^{VMS} + (C/Si)_{SN\ II}(1-f_{Si}^{VMS})$

→ $f_{Si}^{VMS}=0.63$
$f_{C}^{VMS}=0.15$
$f_{O}^{VMS}=0.19$

- MOST of the Si is from VMS.
- MOST of the C is from SNeII.
- MOST of the O is from SNeII.

In VMS regime-- T_{VIR} **~300K**

Halos satisfying this

and $E_{bind,gas} < E_{explosion}$

$$d(E/H)_{IGM}/dt = Q_E/(H)_{IGM}$$

For element E

$$Q_E = \sum P_{E\,n\sigma} N_{n\sigma}$$

For a single $n\sigma$ **halo**

$$P_{n\sigma} = \langle y_E^{VMS} \rangle R_{n\sigma} = \Lambda^E_{(E/H)\odot} (H)_{n\sigma}$$

$$R_n \sim \Lambda_E \dot{X}_E f_b M_{n\sigma} / Y_E^{VMS}$$

In VMS regime-- T_{VIR} **~300K**

Halos satisfying this

and $E_{bind,gas}$ **<** $E_{explosion}$

For Element E

$$d(\mathrm{E}/\mathrm{H})_{\mathrm{IGM}}/dt = Q_{\mathrm{E}}/(\mathrm{H})_{\mathrm{IGM}}$$

$$Q_{\mathrm{E}} = \sum N_{n\sigma} P_{\mathrm{E},n\sigma}$$

For a single Halo

$$P_{\mathrm{E},n\sigma} = \langle y_{\mathrm{E}}^{\mathrm{VMS}} \rangle R_{n\sigma} = \Lambda_{\mathrm{E}}^{\mathrm{VMS}} (\mathrm{E}/\mathrm{H})_{\odot} (\mathrm{H})_{n\sigma}$$

$$R_{n\sigma} = \Lambda_{\mathrm{E}}^{\mathrm{VMS}} X_{\mathrm{E}}^{\odot} f_b M_{n\sigma} / \langle Y_{\mathrm{E}}^{\mathrm{VMS}} \rangle$$

$Z_E^{IGM} = (E/H)_{IGM} / (E/H)_\odot$; $[E/H] = \log(Z_E)$

During the VMS regime

$$Z_E^{IGM}(t) = \Lambda_E^{VMS} \int_0^{t(z)} F\,(M_0 < M < M_{bind} | z')\,dt'$$

After VMS shut off– go to the Galactic outflow regime

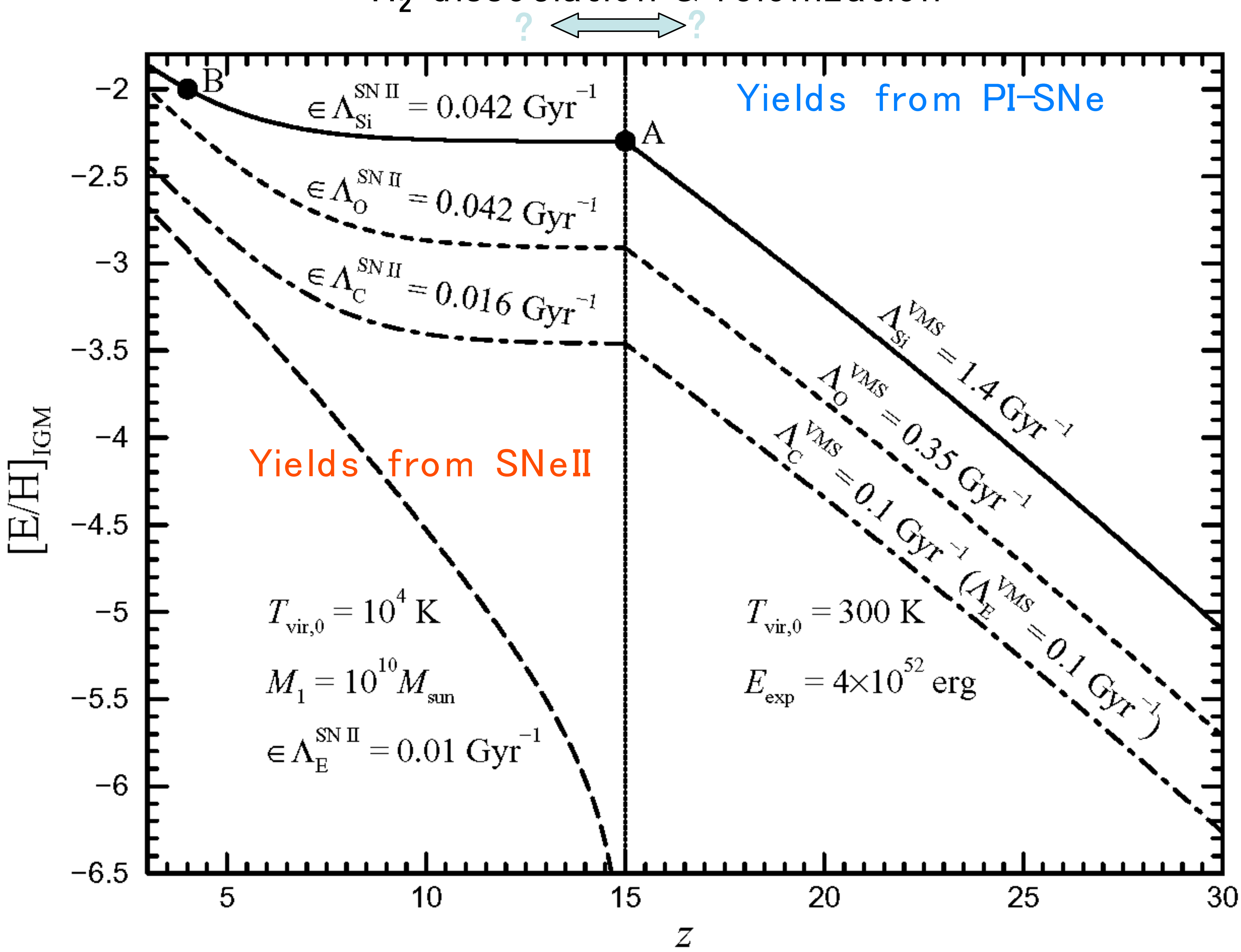
$$Z_E^{IGM}(t) - Z_E^{IGM}(t_{15}) =$$

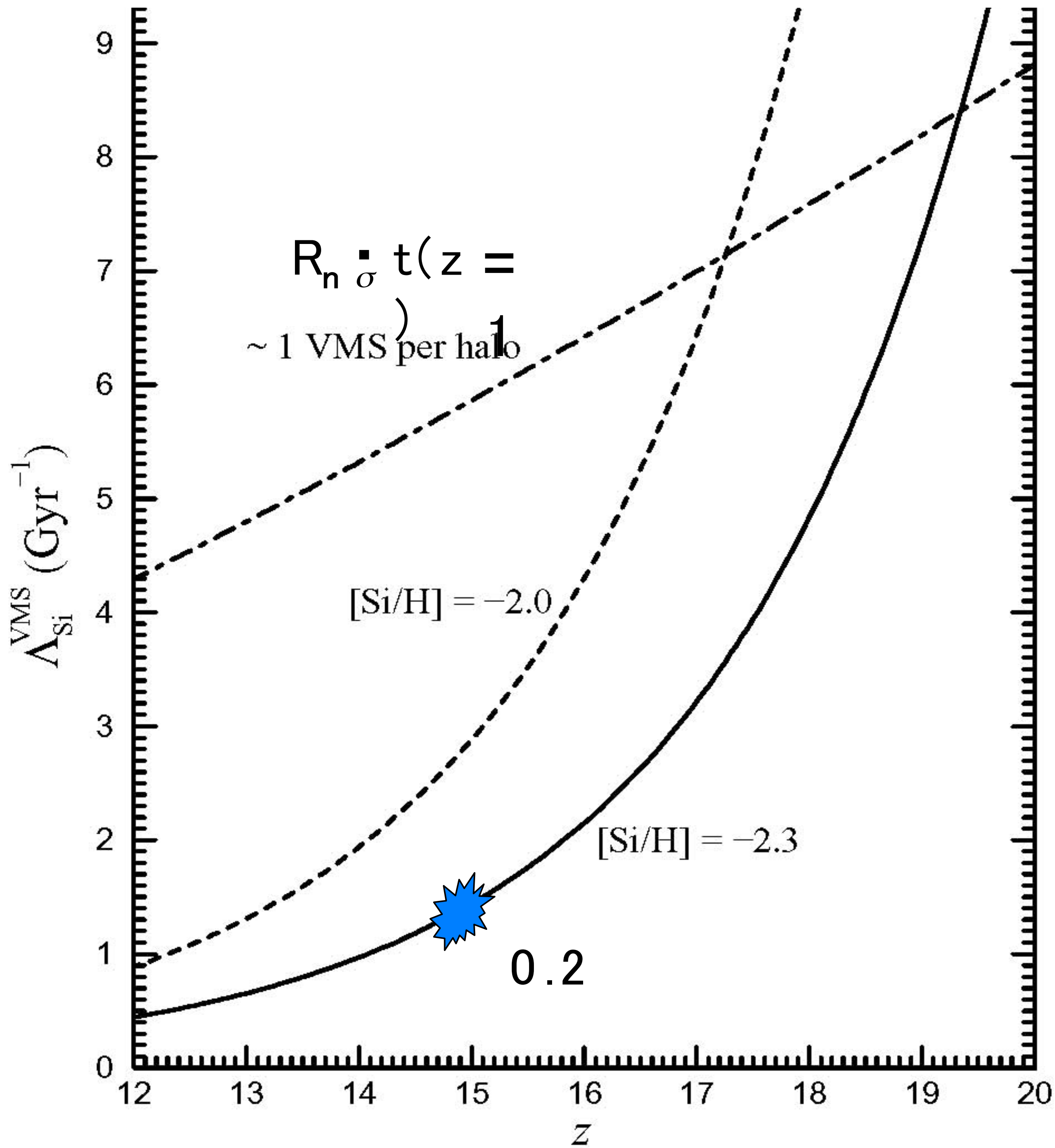
$$\varepsilon \Lambda_E^{SN} \int_{t(15)}^{t(z)} F(M_0 < M < {}_{bind} | z')\,dt'$$

ε = **fraction of SNeII ejecta into IGM**

{ [O/H]=−2.8 cf Bromm & Loeb(2003);[Si/H]=−2.3 cf Oh et al.(2001) }

H_2 dissociation & reionization





$R_n \cdot_\sigma t(z = 1)$
~ 1 VMS per halo
[Si/H] = −2.0
[Si/H] = −2.3
0.2
Λ_{Si}^{VMS} (Gyr^{-1})
z

If you make VMS → make MBH

To enrich IGM to Z_{Si} by PI−SNe VMS

$$N_{VMS} = Z^{IGM}_{Si} \; X^{\odot}_{Si} \; M_{IGM} \,/ \left\langle Y^{VMS}_{Si} \right\rangle$$

For a Salpeter IMF($m^{-2.3}$)

$$N_{MBH} = 0.72 \; N_{VMS}$$

$$M_{MBH} = 550^{\alpha} \; M_{\odot} \qquad \alpha = 0.5-1$$

$$f_{MBH} = N_{MBH} \; M_{MBH} \; / M_{IGM}$$

$$f_{MBH} = 8.4 \times 10^{-5} \alpha \left(Z_E^{IGM} / 5 \times 10^{-3} \right)$$

$$f_{SMBH} = (4.4 - 10.6) \times 10^{-5}$$

(see Marconi et al 2004, MNRAS)

These results are in remarkable accord!

Is this an accident, or is there quasi conservation of MBH mass?

What does this result mean?

If MBH are distributed uniformly
This would give $8 \times 10^6 M_\odot$ of black holes in a $10^{11} M_\odot$ galaxy.

★ If they all fell to galactic centers ➡ SMBH.

★ If they are in galactic halos
➡ MBH are very abundant.

★ Appears to be no major increase in BH inventory due to gas infall ?

Madau & Rees(ApJL, 2001) Showed that if all 3σ halos by z=20 produced MBH, then a mass of BHs would be made comparable with observed value of SMBH.

Islam, Taylor & Silk(2003,2004 MNRAS) studied the evolution of an initial distribution of σ seed MBH from 3 halos. They found that with reasonable probability that ~1000 seed MBH would fall into the center of the bulge. The remainder will be in the galactic halo. For SMBH>>$10^6 M_\odot$ this requires gas infall.

Maybe gas accretion is only important at high densities.
So MBH in halos do not grow much.

It is clear that the IGM inventory of Si requires VMS(PI-SNe) with concurrent MBH production at a connected rate.
The seed MBH for galaxies used in models
(Hopkins et al 2005 APJ) must have their
source in the mechanism given here.
The problem of H_2 destruction and universal re-ionization by VMS
(Peng Oh et al (2001 ApJ L)
In the transition region is not well

THERE IS AN INTIMATE CONNECTION BETWEEN THE DYNAMICS OF THE EARLY UNIVERSE AND CHEMICAL ABUNDANCES IN THE IGM.

The prompt inventory appears, in some manifestation, to be alive and well!