1. On the maximum ^{56}Ni production in SNe Ic: SN1999as & 2007bi (& 2006gy)

(ref.) H.U. & K.Nomoto (2008, ApJ , 673, 1014)

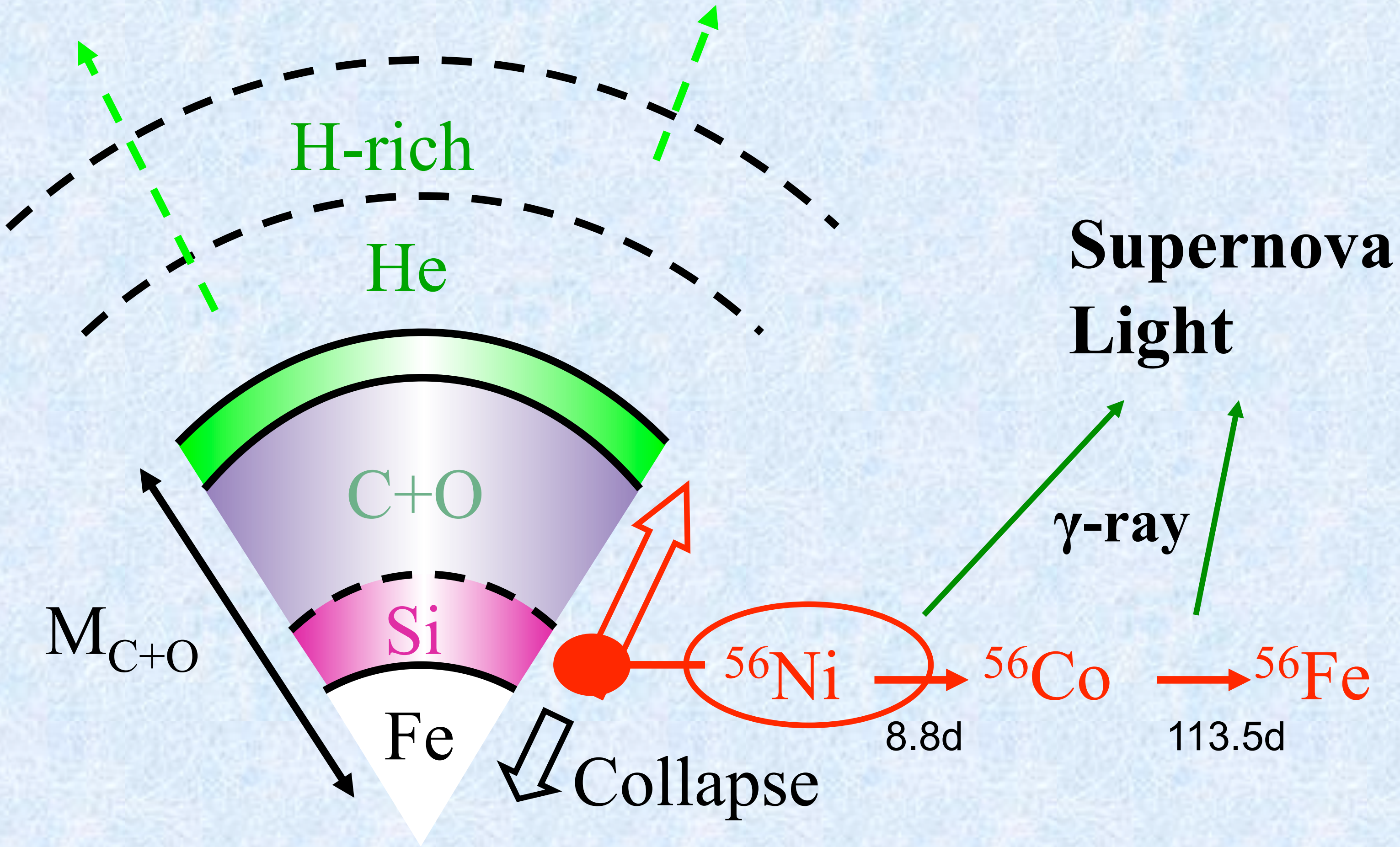
2. Nucleosynthesis of Weak r-process elements in Core-collapse SNe

N.Izutani, H.U., N. Tominaga (2009, ApJ , in press)

Hideyuki Umeda

(Univ. of Tokyo, Dept of Astronomy)

SNe Ib/c



Parameters

[M_{ej}, E, M(^{56}Ni)]

Explosion Parameters (SNe Ic)

$$M_{ej}, M(^{56}Ni), E$$

Ejecta mass

Explosion Energy

Light Curve

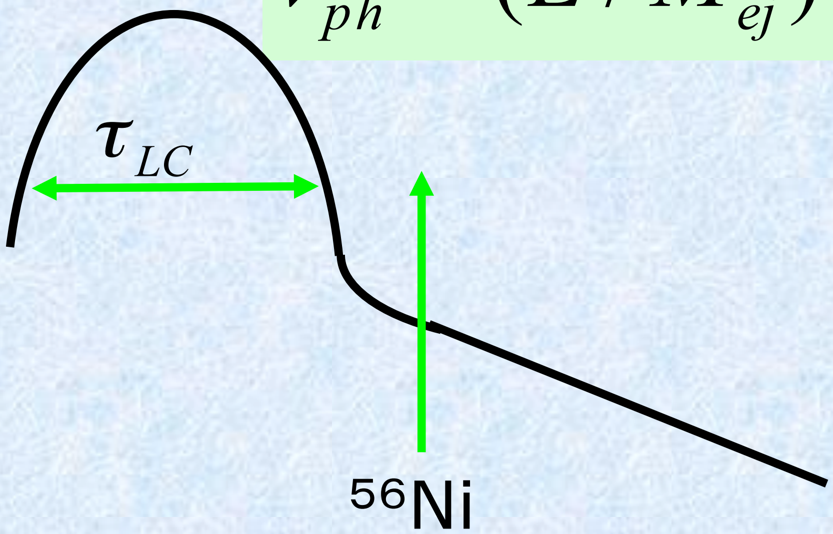
$$\tau_{LC} \sim (\tau_{dyn} \cdot \tau_{diff})^{1/2}$$

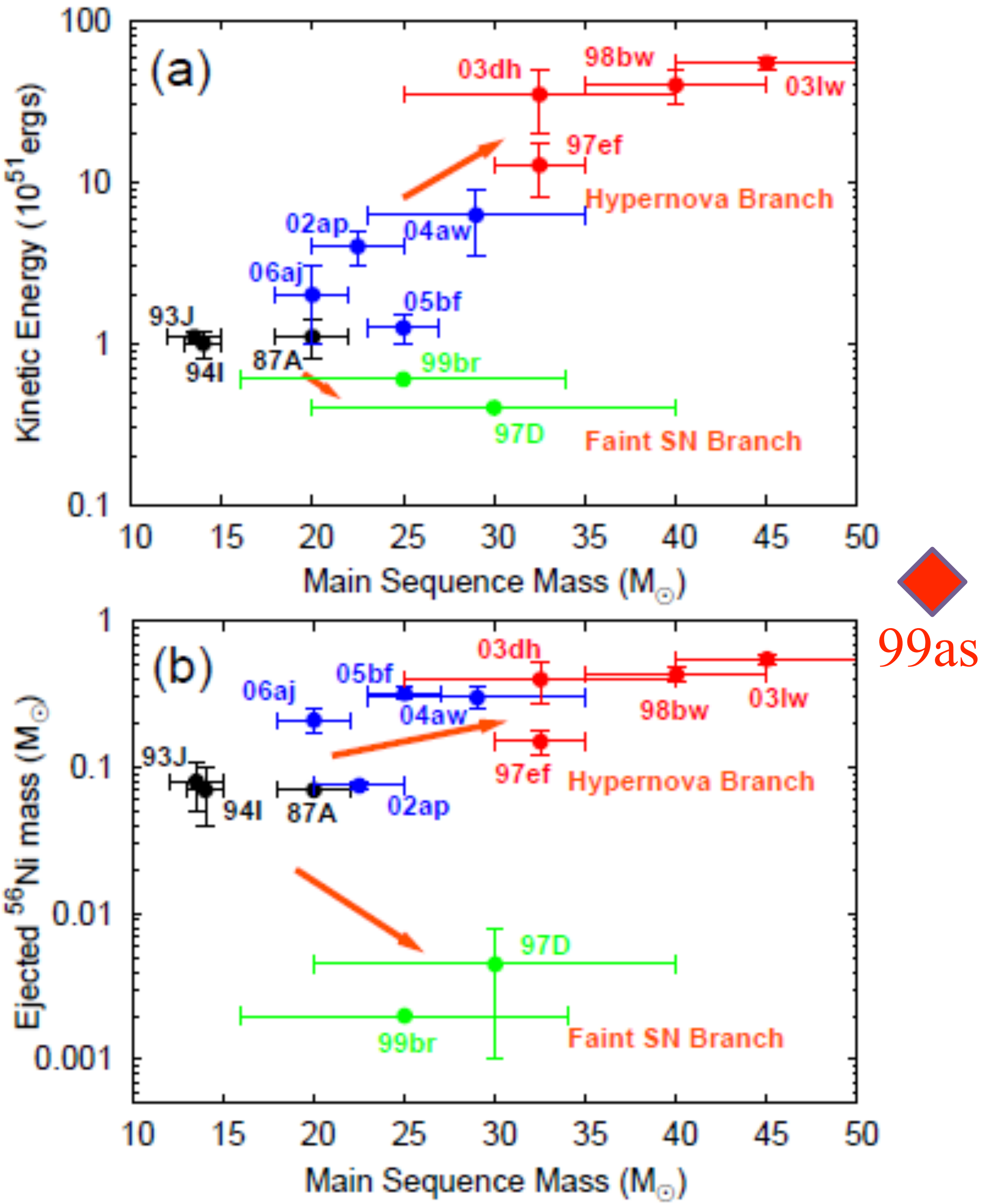
$$\sim \left[\frac{R}{V} \quad \frac{\kappa M_{ej}}{R c} \right]^{1/2}$$

$$\tau_{LC} \propto \frac{\kappa^{1/2} M_{ej}^{3/4}}{E^{1/4}}$$

Spectra

$$v_{ph} \propto (E / M_{ej})^{1/2}$$





Variations of core-collapse SNe

Normal SNe
(87A, 93J)
M(^{56}Ni) ~ 0.07M$_\odot$

Hypernova
(98bw, 03dh)
M(^{56}Ni)
~ 0.3-0.6 M$_\odot$

Peculiar – 99as
M(^{56}Ni) ~ 4M$_\odot$

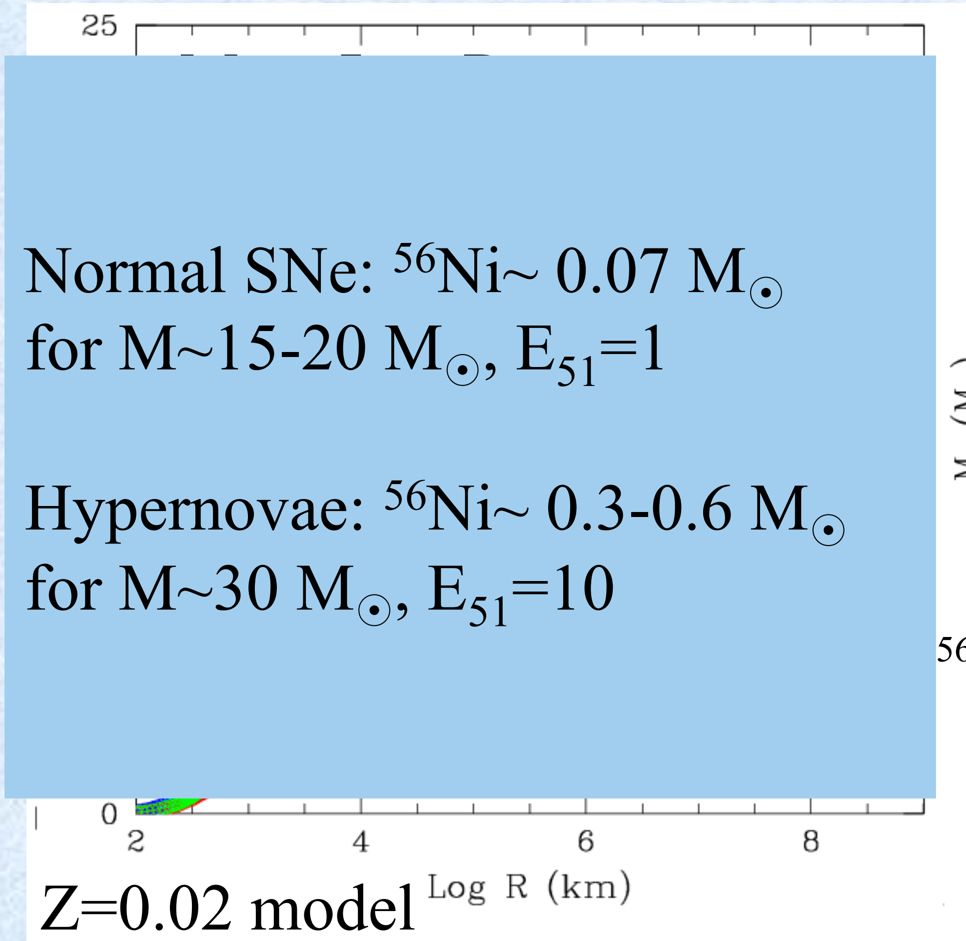
Progenitor's density structure and ^{56}Ni production

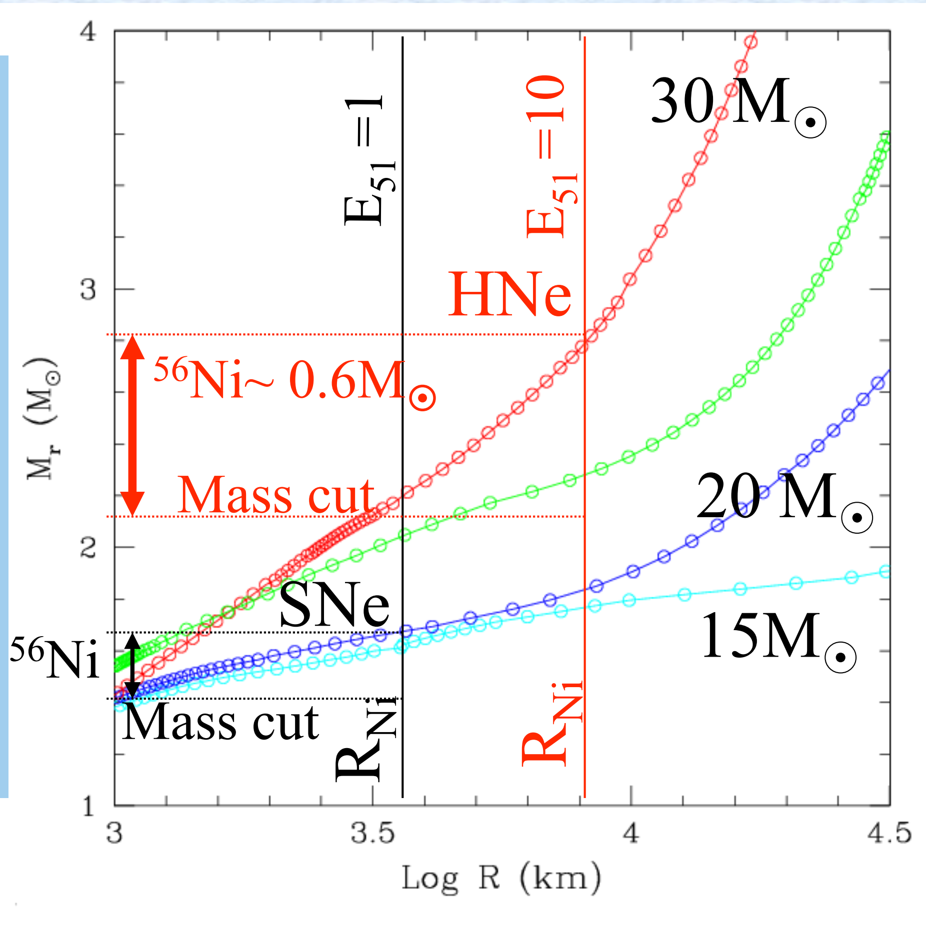
$E = 4\pi R^3 a T^4/3$ (Just after shock passage ---Radiation dominant)

(^{56}Ni for $T > 5 \cdot 10^9$K – complete Si-burning) $R_{Ni} \sim 3700 E_{51}^{1/3}$ (km)

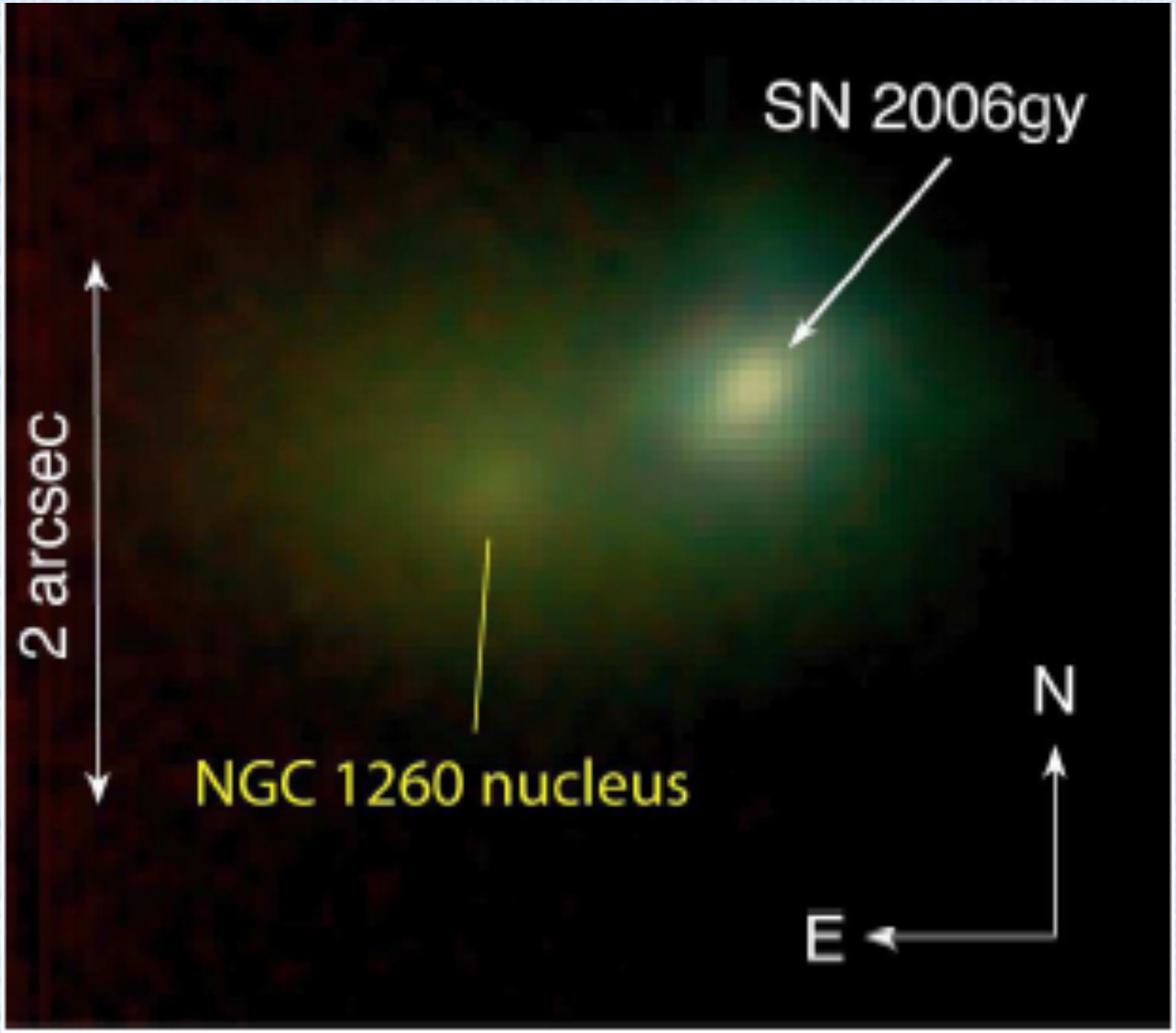
Normal SNe: ^{56}Ni~ 0.07 $M_\odot$
for M~15-20 $M_\odot$, E_{51}=1

Hypernovae: ^{56}Ni~ 0.3-0.6 $M_\odot$
for M~30 $M_\odot$, E_{51}=10





Brightest SN : SN 2006gy



(Z=0.019)

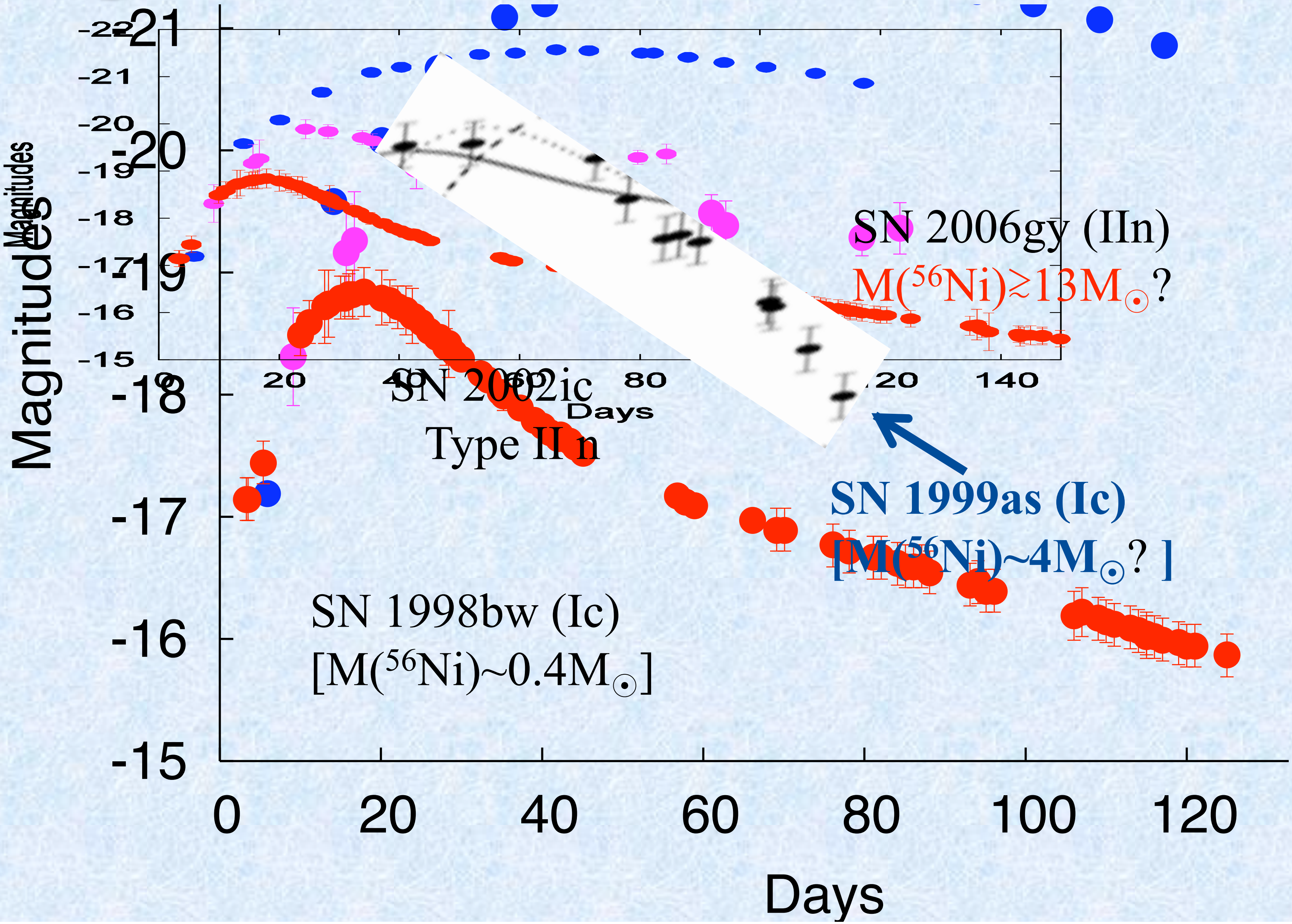
SN Ic ?

↓

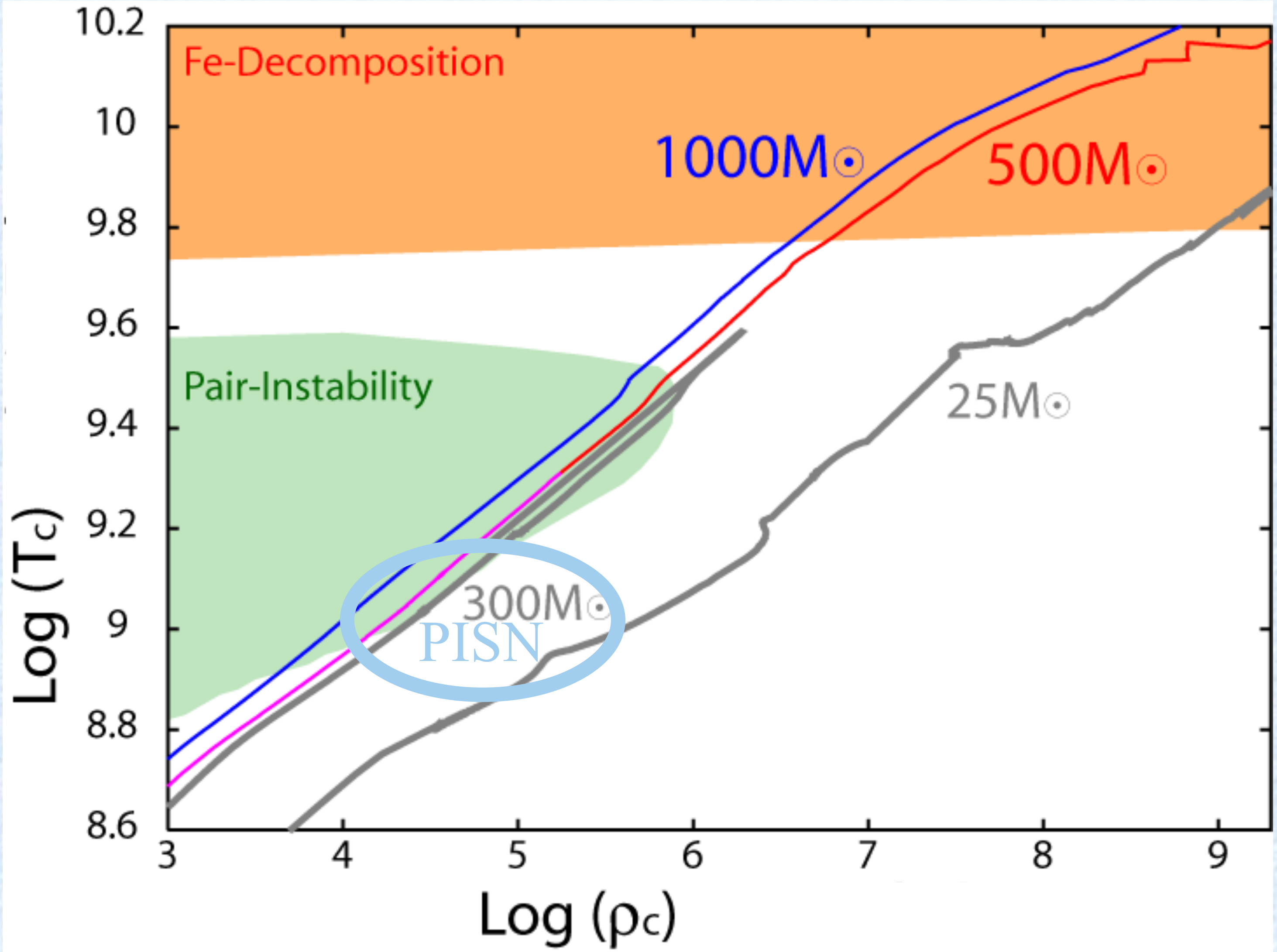
SN IIn

Smith et al. 2007
Ofek et al. 2007
Nomoto et al. 2007

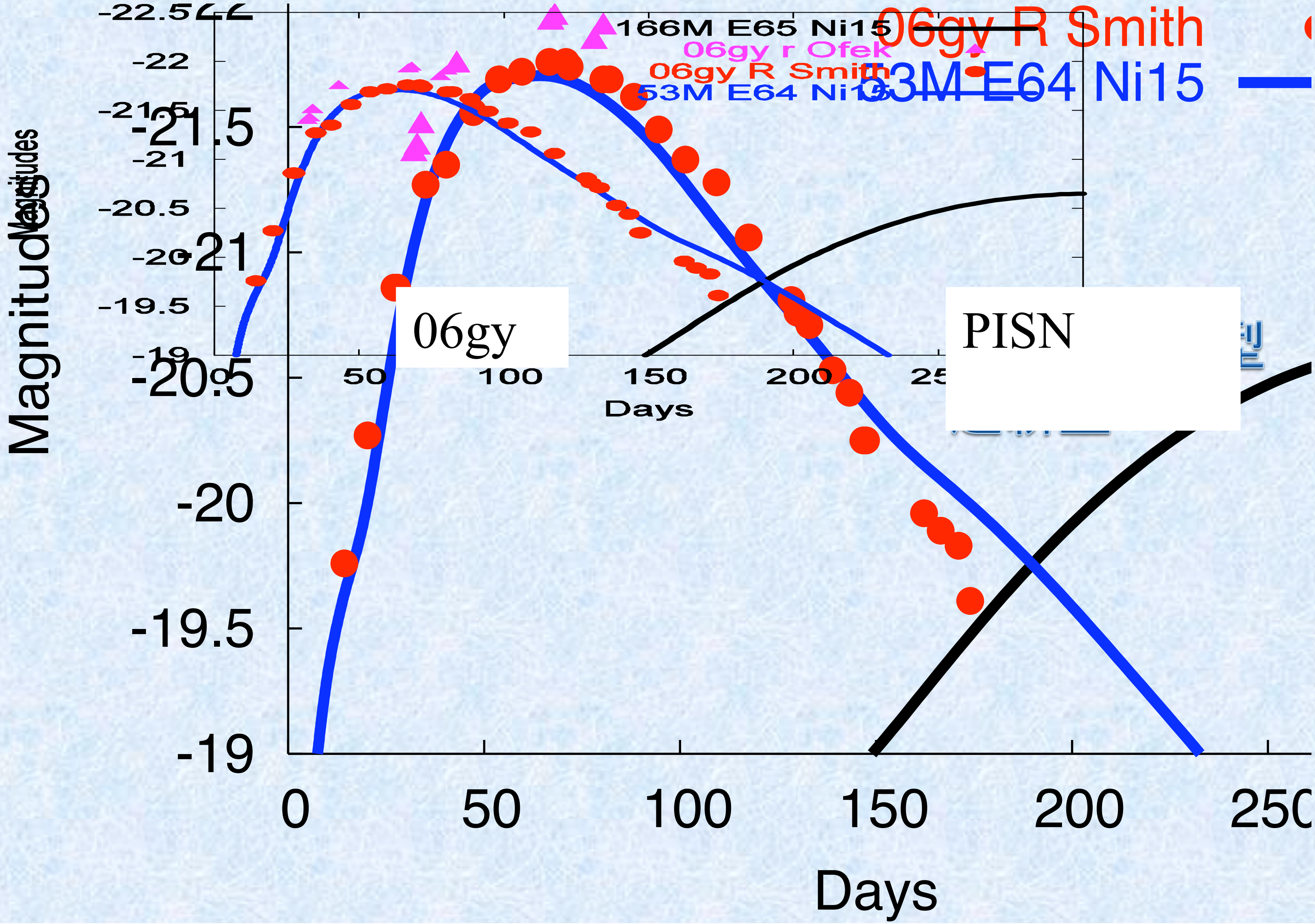
Light Curves



Pair-instabillity SNe?

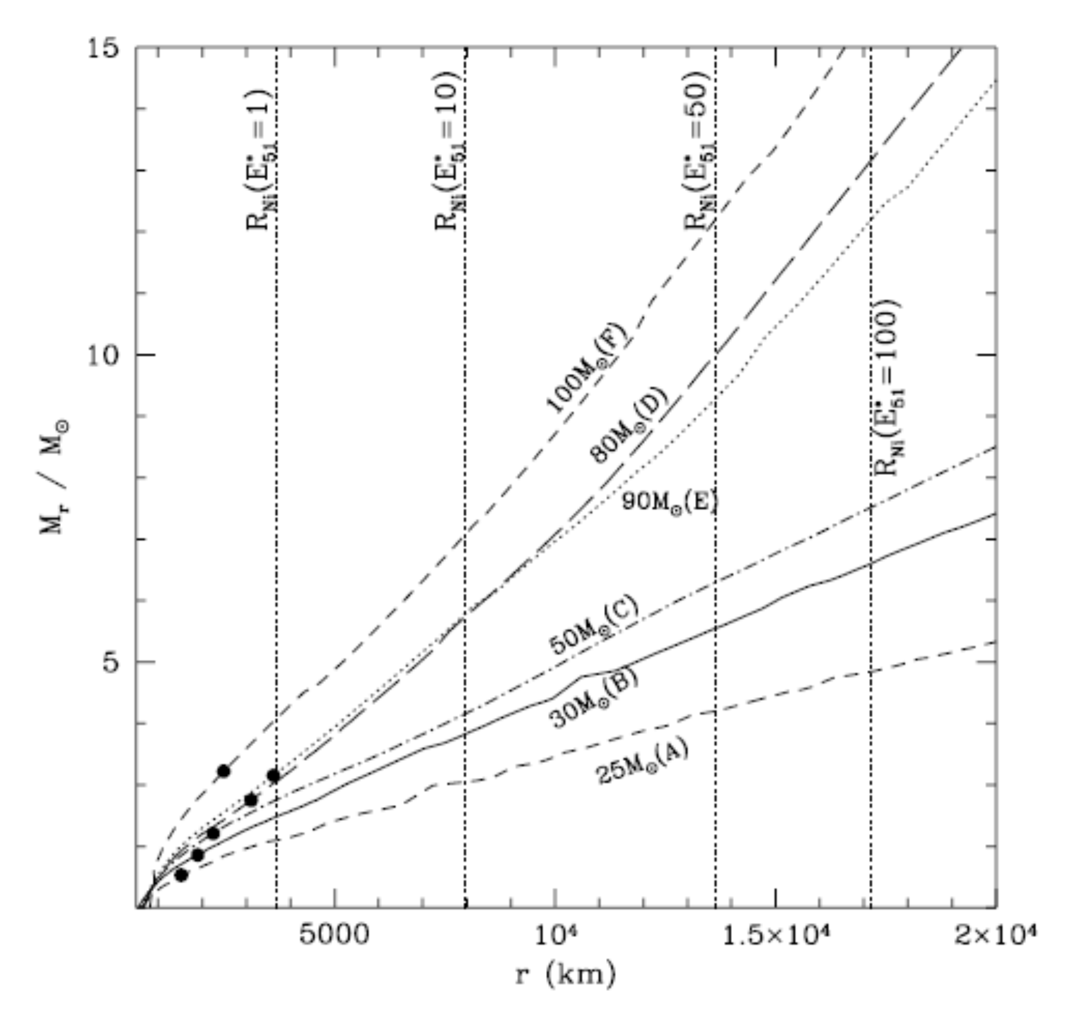


PISN (M~150-300$M_\odot$) (too broad) and Ni56 SNe (too much Ni?)



How much ^{56}Ni can be produced in CCSN?

- **Most Massive CO-core model for CCSN**
  - Umeda & Nomoto (2008, ApJ , 673, 1014)



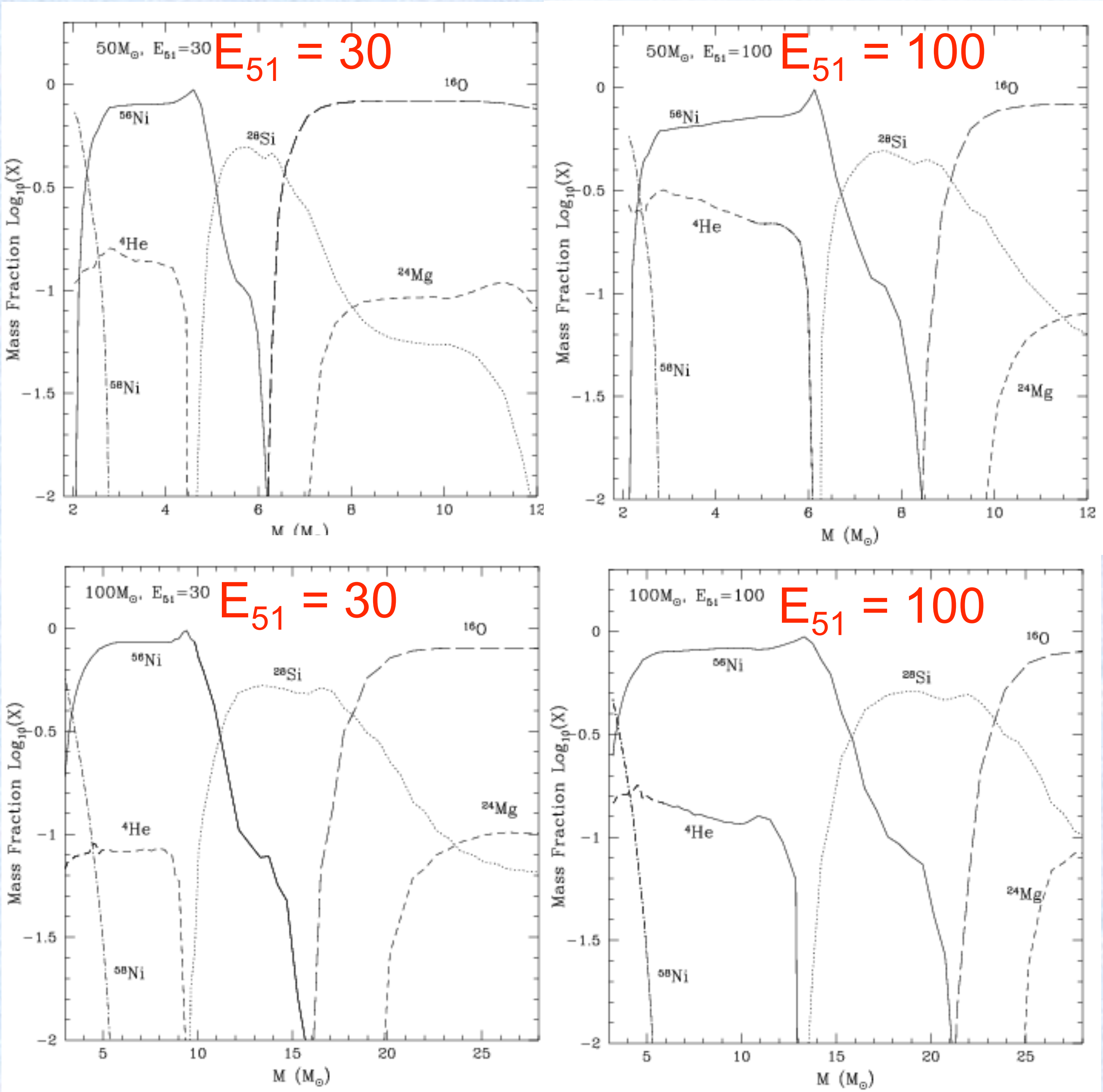
Metal Poor Model
(to avoid Heavy Mass Loss)

$M= 80M_\odot \Rightarrow M_{CO} = 34.0M_\odot$
$M=100M_\odot \Rightarrow M_{CO} = 42.6M_\odot$

For the Most massive models
^{56}Ni~ $4M_\odot$ is NOT impossible
for $E_{51} \sim 20$

The same results are applicable
to metal rich models as well
if M_{CO} is roughly the same.

Results



50M☉

100M☉

Results

Maximum 56Ni mass
(depend on Mass-cut)

TABLE 3

…E MASSES OF MG, O AND UPPER MASS LIMITS OF THE ^{56}NI IN THE EJECTA OF CORE-COLLAPSE SNE AS A FUNCTION OF PROGENITOR MASS AND EXPLOSION ENERGY.

C	50		1	2.46	0.79	12.52	1.90	1.65	0.83
			10	4.22	0.73	11.67	1.77	1.54	1.48
CO19.3			30	5.44	0.79	10.73	1.91	1.42	2.28
			50	6.26	0.80	9.96	1.94	1.32	2.74
			70	6.90	0.80	9.49	1.92	1.25	2.97
			100	7.62	0.78	8.91	1.87	1.18	3.19
			150	8.62	0.76	8.16	1.82	1.08	3.60
D	80	E_{51}	1	6.08	1.41	18.71	3.40	2.47	2.14
			10	8.00	1.35	17.45	3.25	2.30	3.36
			30	10.61	1.28	15.31	3.09	2.02	4.99 $M_\odot$
CO34.0			50	11.89	1.20	14.33	2.89	1.89	5.74
			60	12.24	1.17	14.07	2.82	1.86	6.06
			100	15.04	0.88	12.09	2.11	1.60	7.86
E	90		1	6.08	0.38	20.59	0.92	2.72	1.85
			10	7.82	0.36	19.69	0.86	2.60	2.69
			20	9.42	0.33	18.67	0.80	2.46	3.51
			30	10.75	0.31	17.84	0.74	2.36	4.19
			50	11.75	0.28	17.01	0.68	2.25	4.85
			70	13.07	0.26	16.00	0.62	2.11	5.78
			110	14.71	0.23	14.87	0.55	1.96	6.97
F	100		1	8.74	1.58	22.41	3.81	2.96	3.34
			30	14.22	1.34	19.27	3.34	2.54	6.64
CO42.6			70	17.62	1.38	16.67	3.33	2.20	8.78
			100	19.81	1.28	15.31	3.08	2.02	10.17
			210	24.43	0.83	12.50	2.00	1.65	13.49

Conclusion

- SN1999as ($M(^{56}Ni) \sim 4M_\odot$) possible for $M_{CO} \gtrsim 34.0M_\odot$ ($M \gtrsim 80M_\odot$), $E_{51} \gtrsim 20$
- SN2006gy ($M(^{56}Ni) \sim 13M_\odot$) requires E_{51}($\sim$ 210) even for ($M_{CO} = 42.6M_\odot$, $M = 100M_\odot$)

$M_{CO} \sim 35M_\odot$ is large but not too difficult compared with a PISN model ($M_{CO} \gtrsim 70\ M_\odot$ for $M \gtrsim 170M_\odot$, Umeda & Nomoto 2002)

Such stars may exist at z = 0.127

SN 2006gy: was it really extra-ordinary?

I. Agnoletto[1]

They say : not extra-ordinary if $M(^{56}Ni) \sim 3M_\odot$,
$M(ejecta) \sim 5\text{-}14\ M_\odot$ + $CSM \sim 6\text{-}10M_\odot$
then $E_{51} \lesssim 5$ is sufficient.

Our results suggest that if $M(ejecta) \sim 5\text{-}14\ M_\odot$
or $M(CO) \lesssim 20$ ($M \lesssim 50$),
then $E_{51} \lesssim 5$ is not sufficient to produce $M(^{56}Ni) \sim 3M_\odot$

My Conclusion : SN2006gy is extra-ordinary !

M. Della Valle[5,6]

European Southern Observatory, Karl-Schwarzschild-Strasse 2 D-85748 Garching bei München, Germany

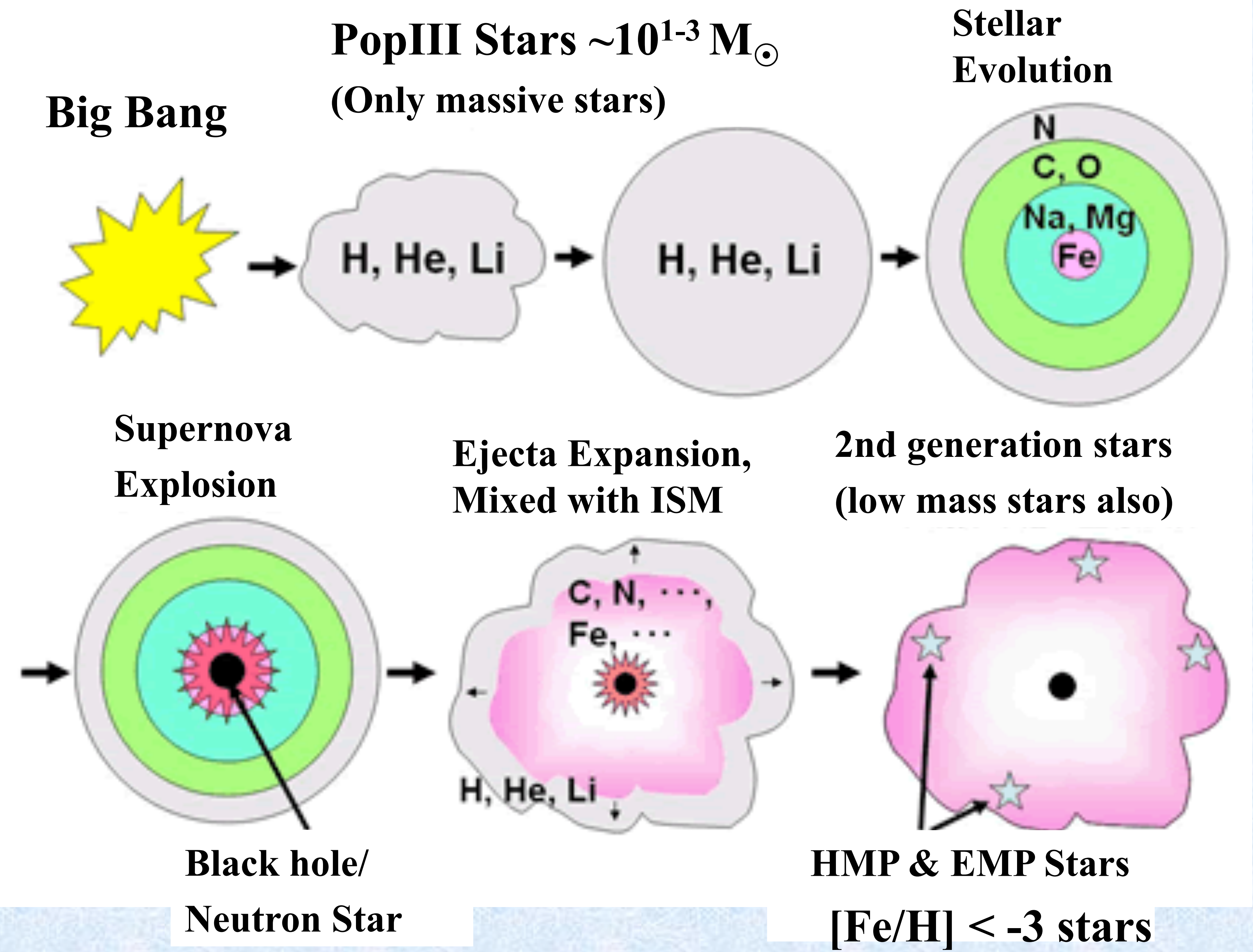
F. Bufano, A. Harutyunyan, H. Navasardyan

2. Nucleosynthesis of Weak r-process elements in Core-collapse SNe

N.Izutani, H.U., N. Tominaga

(2009, ApJ , in press)

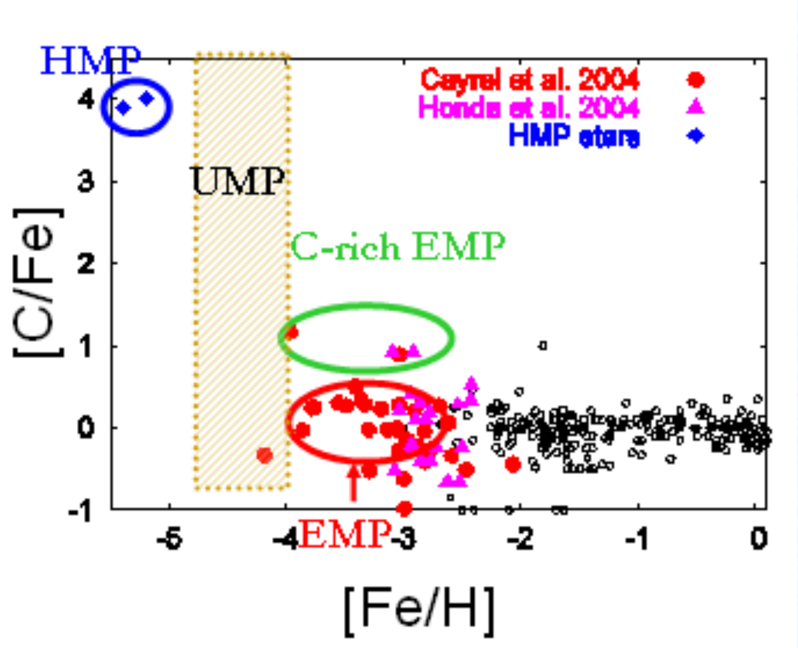
◎Origin of HMP & EMP Stars



Metal-Poor Stars

$[Fe/H] = \log_{10}(N(Fe)/N(H)) - \log_{10}(N(Fe)/N(H))_\odot$

- Hyper Metal-Poor (HMP): [Fe/H] < -5
- Ultra Metal-Poor (UMP): [Fe/H] < -4
- Extremely Metal-Poor (EMP) : [Fe/H] < -3
- Very Metal-Poor (VMP): [Fe/H] < -2
- Solar: [Fe/H] ~ 0



VMP: mixture of all SNe

EMP: Hypernova

C-EMP: Faint SN

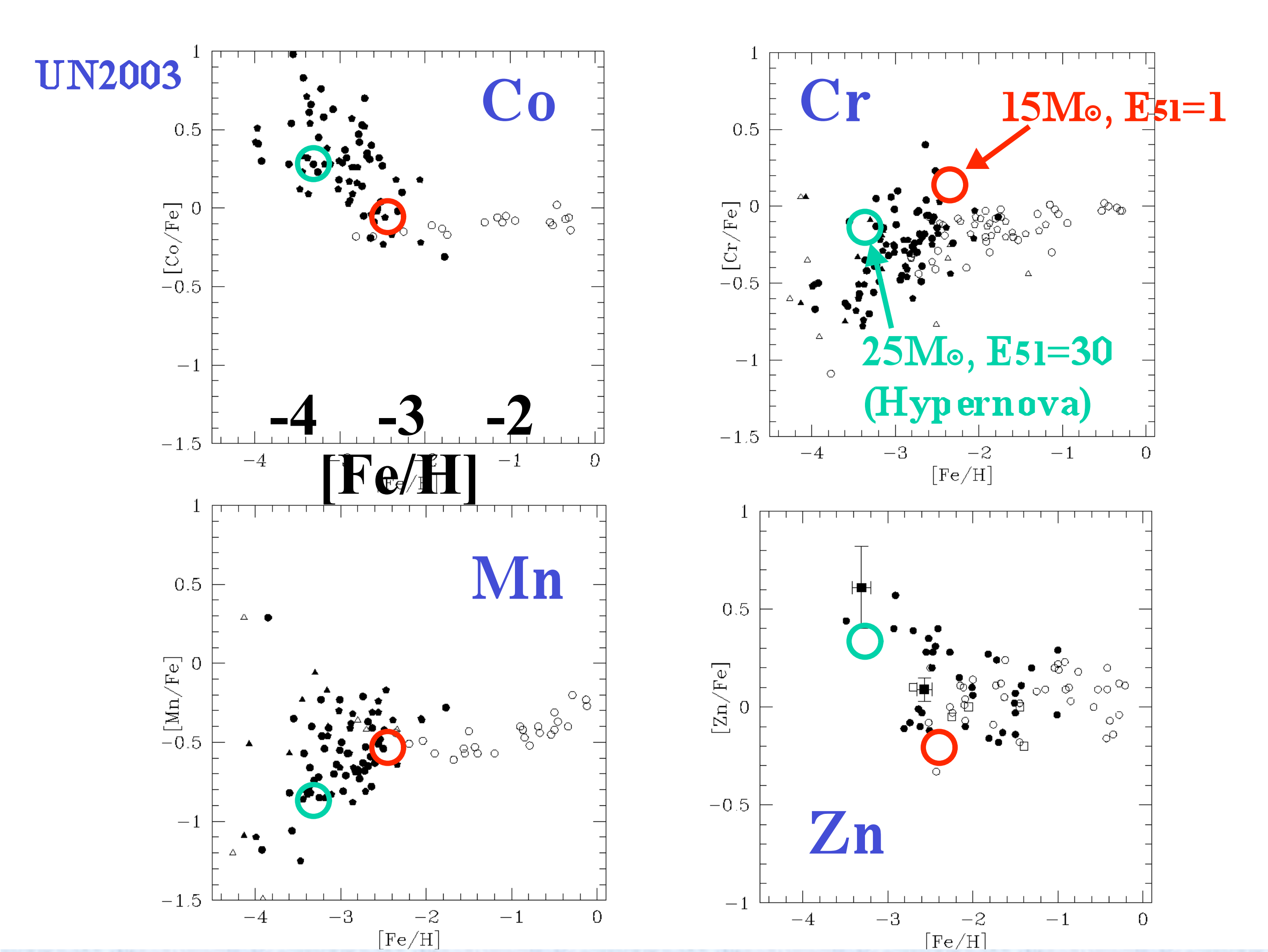
HMP: very Faint SN

(Umeda & Nomoto 2005 ApJ; Tominaga et al. 2007 ApJ)

Our previous models (e.g. Umeda & Nomoto 2002, 2005; Tominaga, H.U., Nomoto 2008) could roughly reproduce EMP stars' abundance up to Zn.

[Fe/H] < -3 trends in Fe-peak elements

Fe/H of EMP stars ~ (M(Fe) / M(H)) ∝ (M(Fe) / E)



Hypernovae:

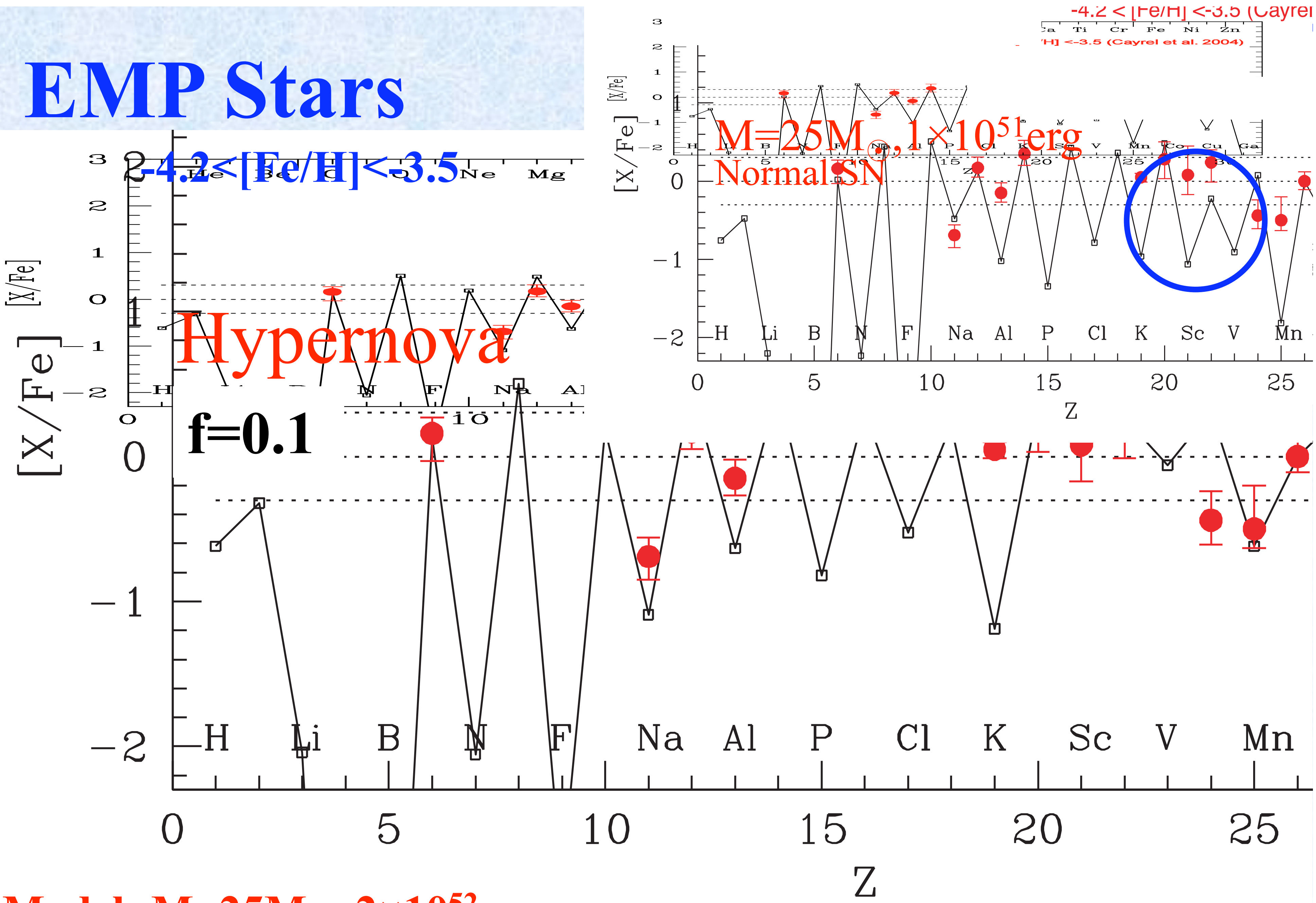
[Zn/Fe], [Co/Fe] ↑

[Mn/Fe], [Cr/Fe] ↓

Umeda & Nomoto (2002; 2003)

[X/Fe]=log(X/Fe) −log(X/Fe)⊙

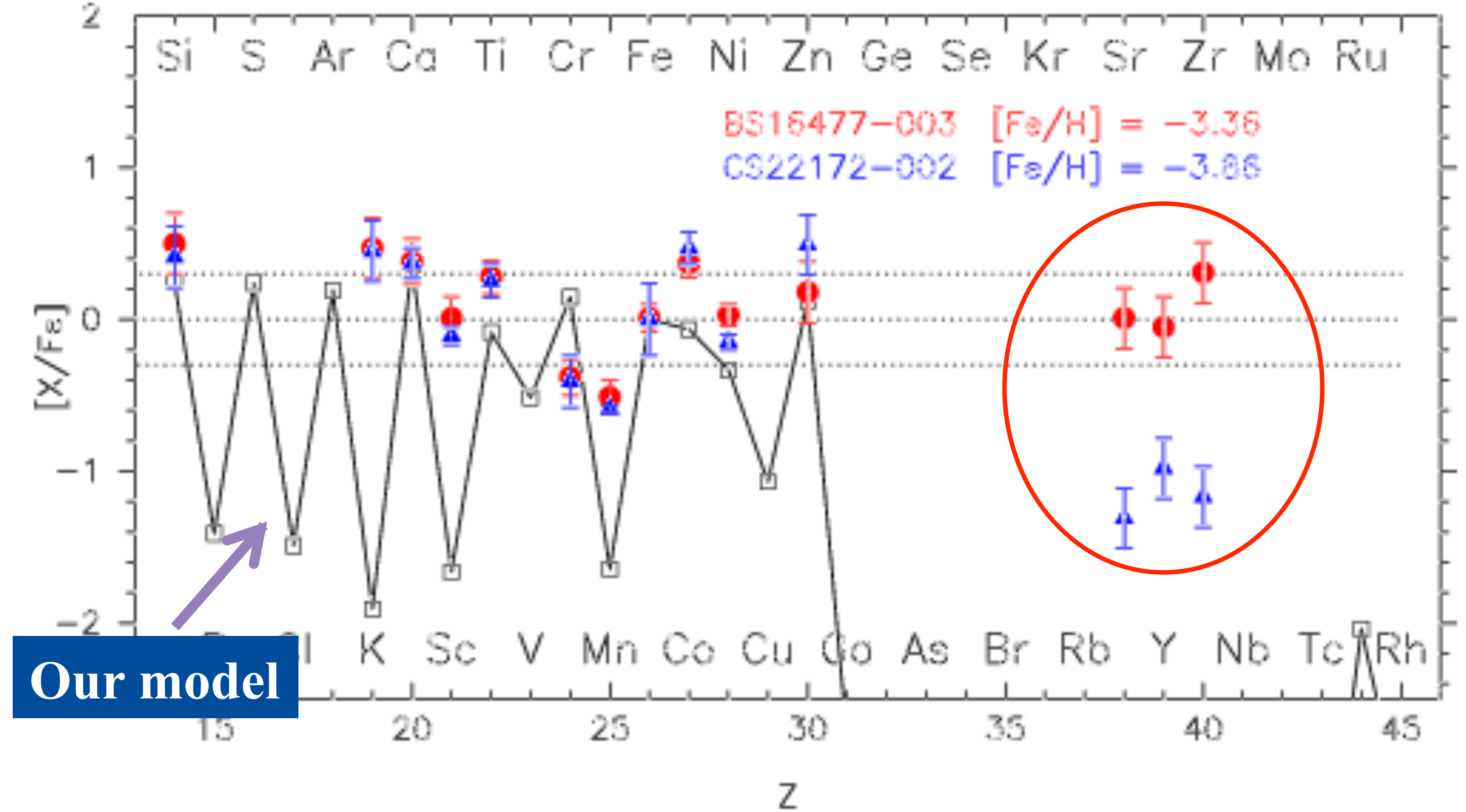
EMP Stars



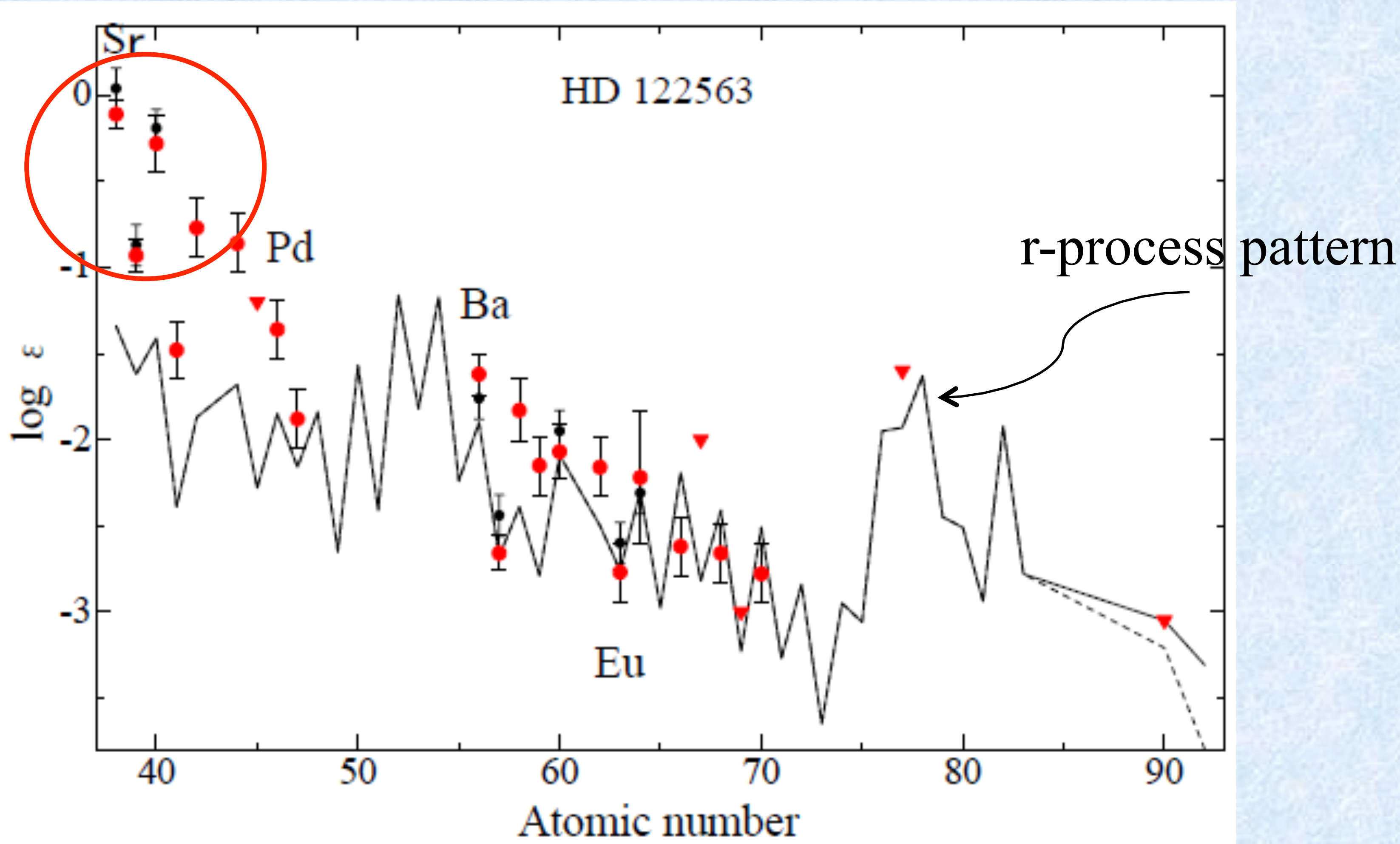
Model: M=25M$_\odot$, 2×10^{52}erg

Umeda & Nomoto 2005; Tominaga et al. 2005

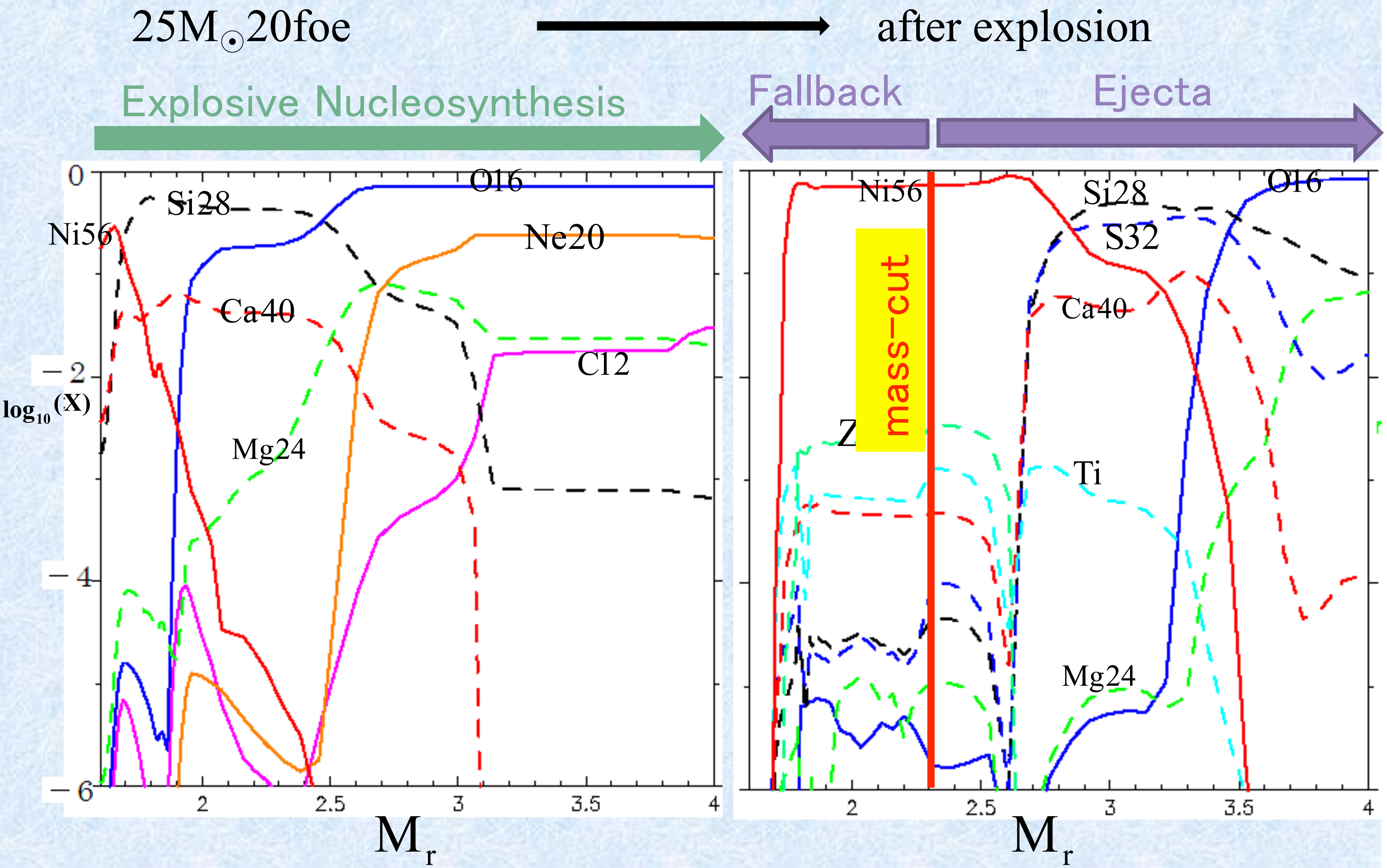
But, some EMP stars show High Sr, Y, Zr/Fe ratios !



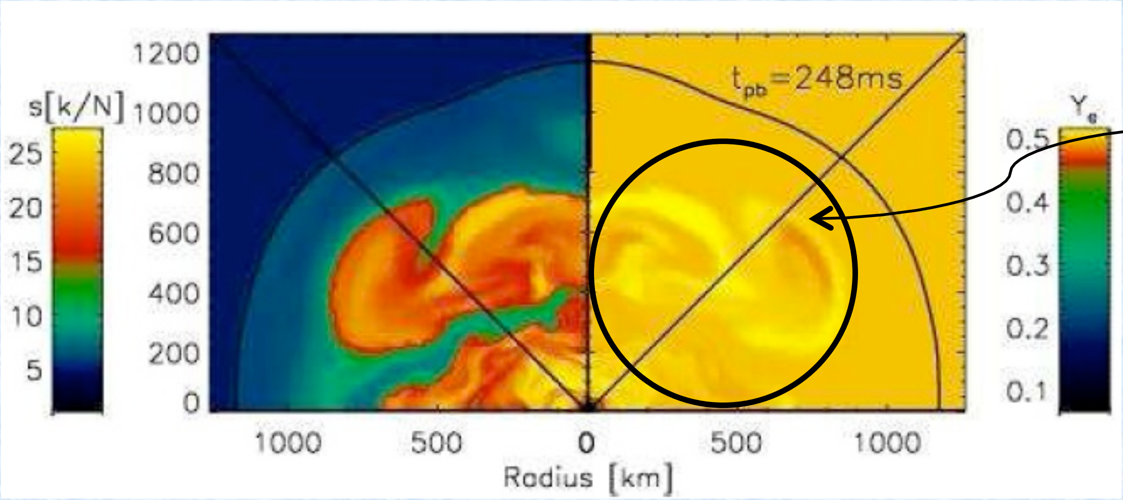
weak r-process EMP stars (high ratio of Sr,Y and Zr)



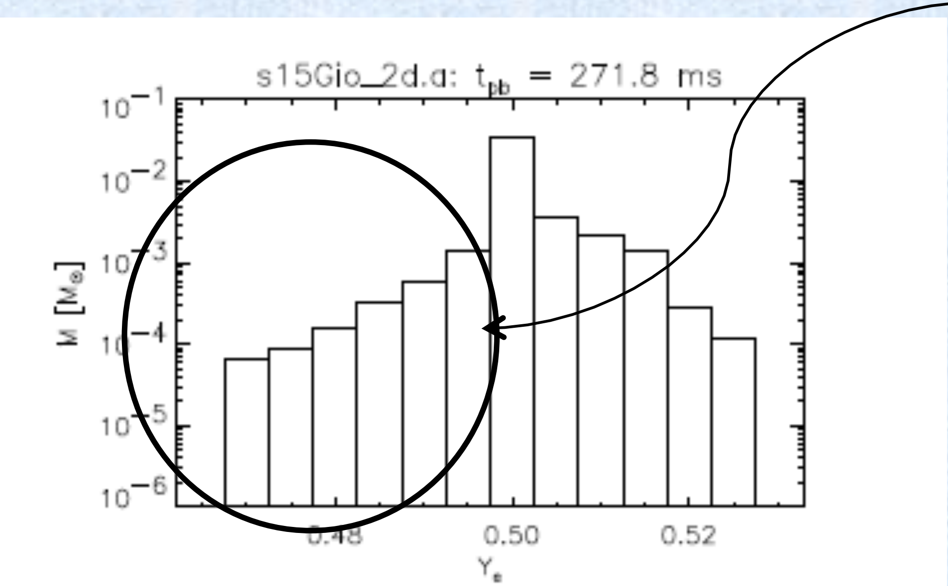
Our previous model: definite Mass-cut



2D Simulation (Janka et al. 03)



Convection,
Variety of Ye
(Ye :electron fraction)

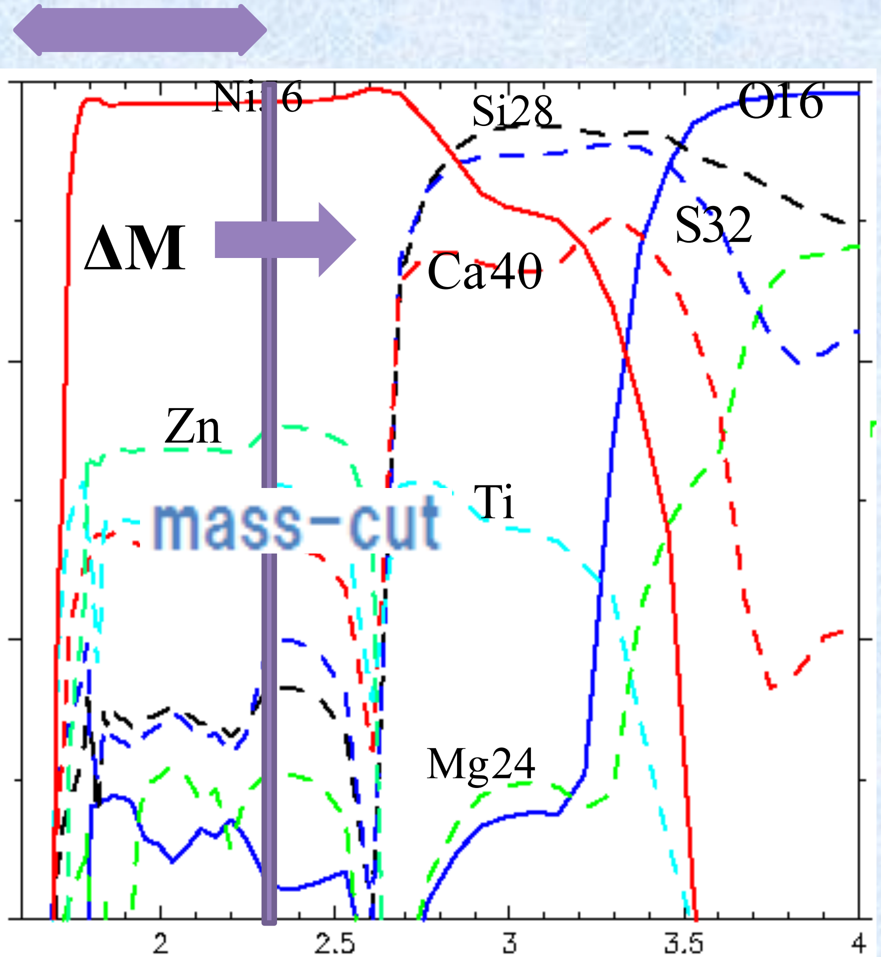


Low Ye (~ 0.46) matter
may be ejected

Origin of
weak r-process element ?

New model : Same as before except two things.

Ye=0.40-0.50



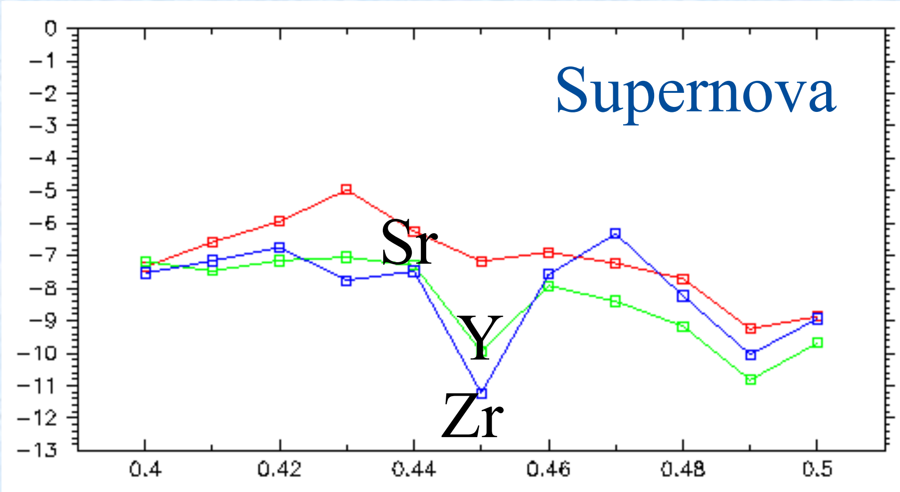
1) Set Ye = 0.40-0.50 for the regions below the "mass-cut"

2) Assume small mass ejection (ΔM) below the mass-cut

Mass ($M_\odot$)	Explosion energy ($\times 10^{51}$ erg)	Model name
13	1.5	1301
25	1	2501
25	20	2520

Results

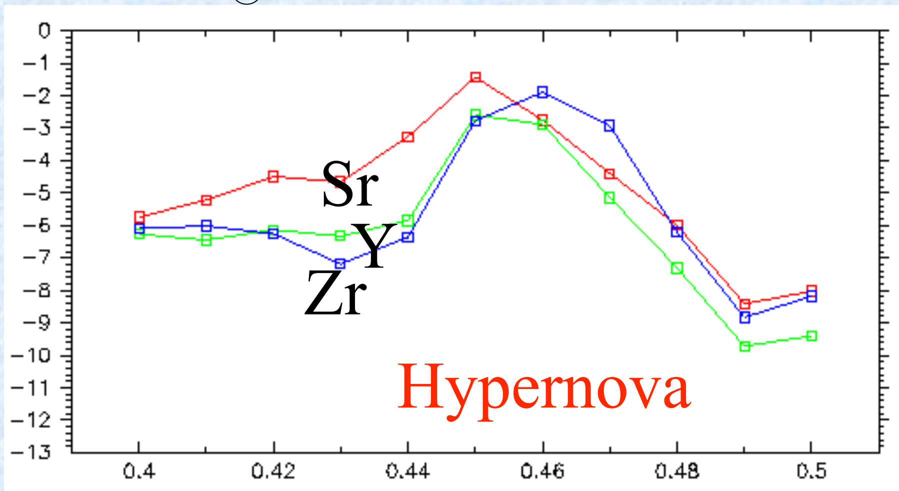
$13M_{\odot}$ E=1.5foe



log X

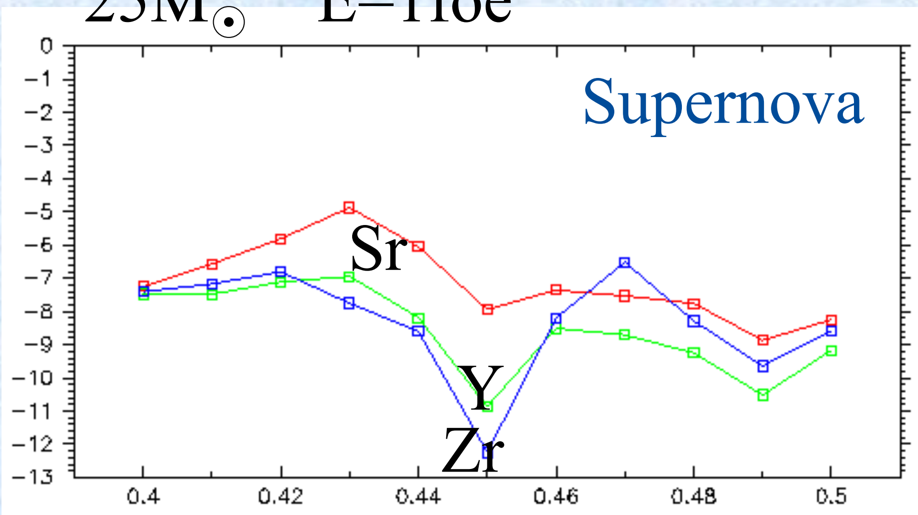
Ye

$25M_{\odot}$ E=20foe



Ye

$25M_{\odot}$ E=1foe



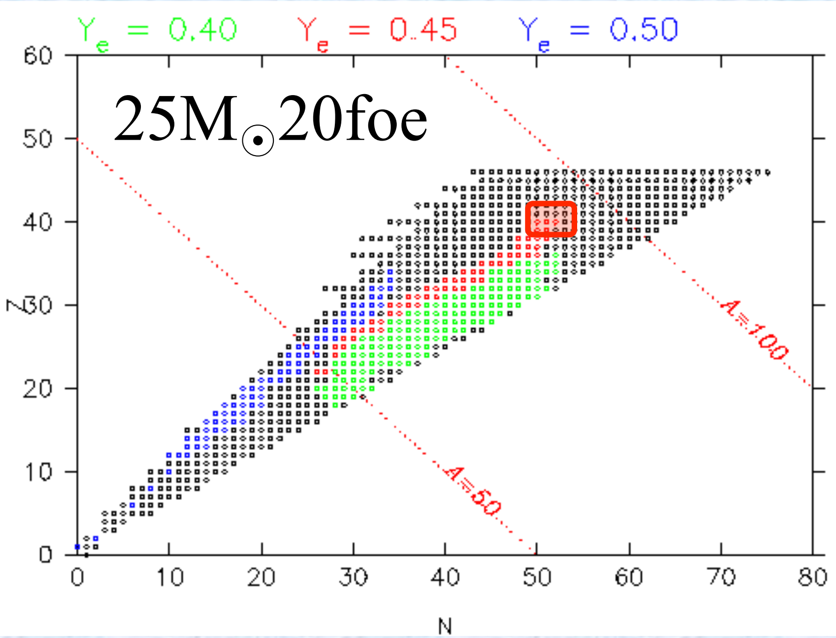
log X

Ye

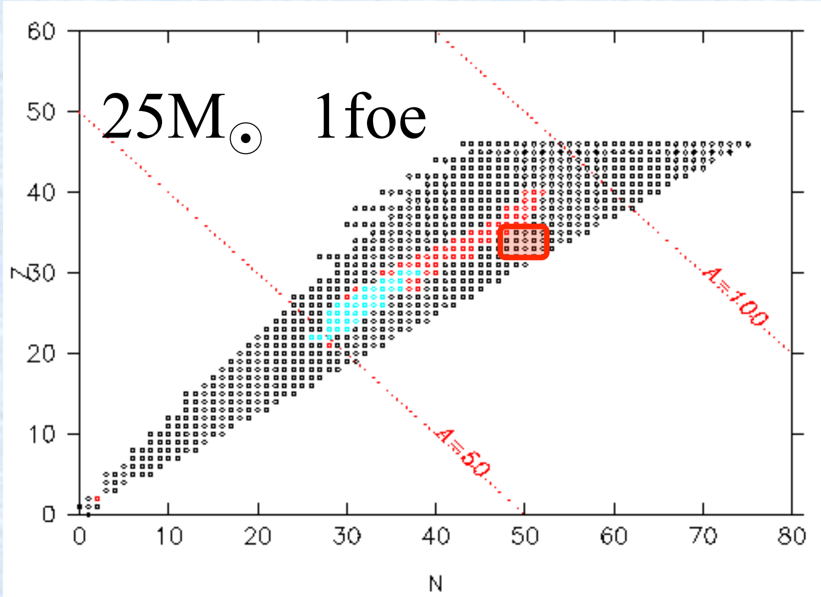
1foe = 10^{51} erg

X : mass fraction

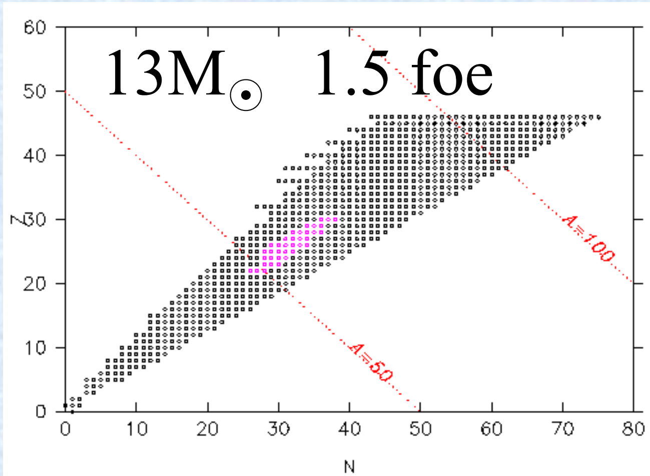
Results



Y_e = 0.40 Y_e = 0.45 Y_e = 0.50
25M$_\odot$ 20foe
A=100
A=50
Z
N



25M$_\odot$ 1foe
A=100
A=50
Z
N



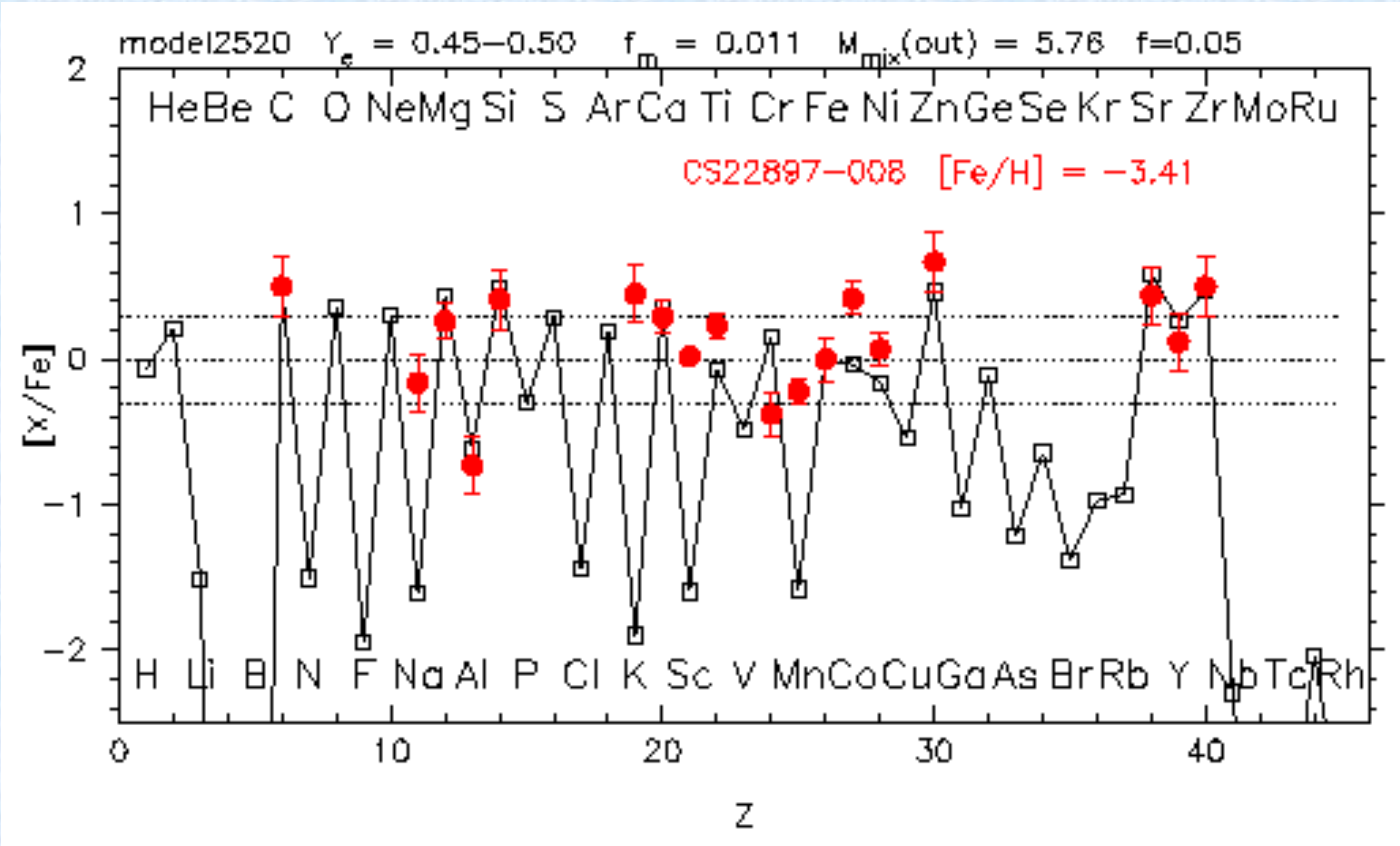
13M$_\odot$ 1.5 foe
A=100
A=50
Z
N

Results

Among model-1301,-2501,-2520
Only the high E model-2520 produce Sr,Y,Zr

model-2520, Ye=0.45-0.50, ΔM=1.2E-4$M_{\odot}$

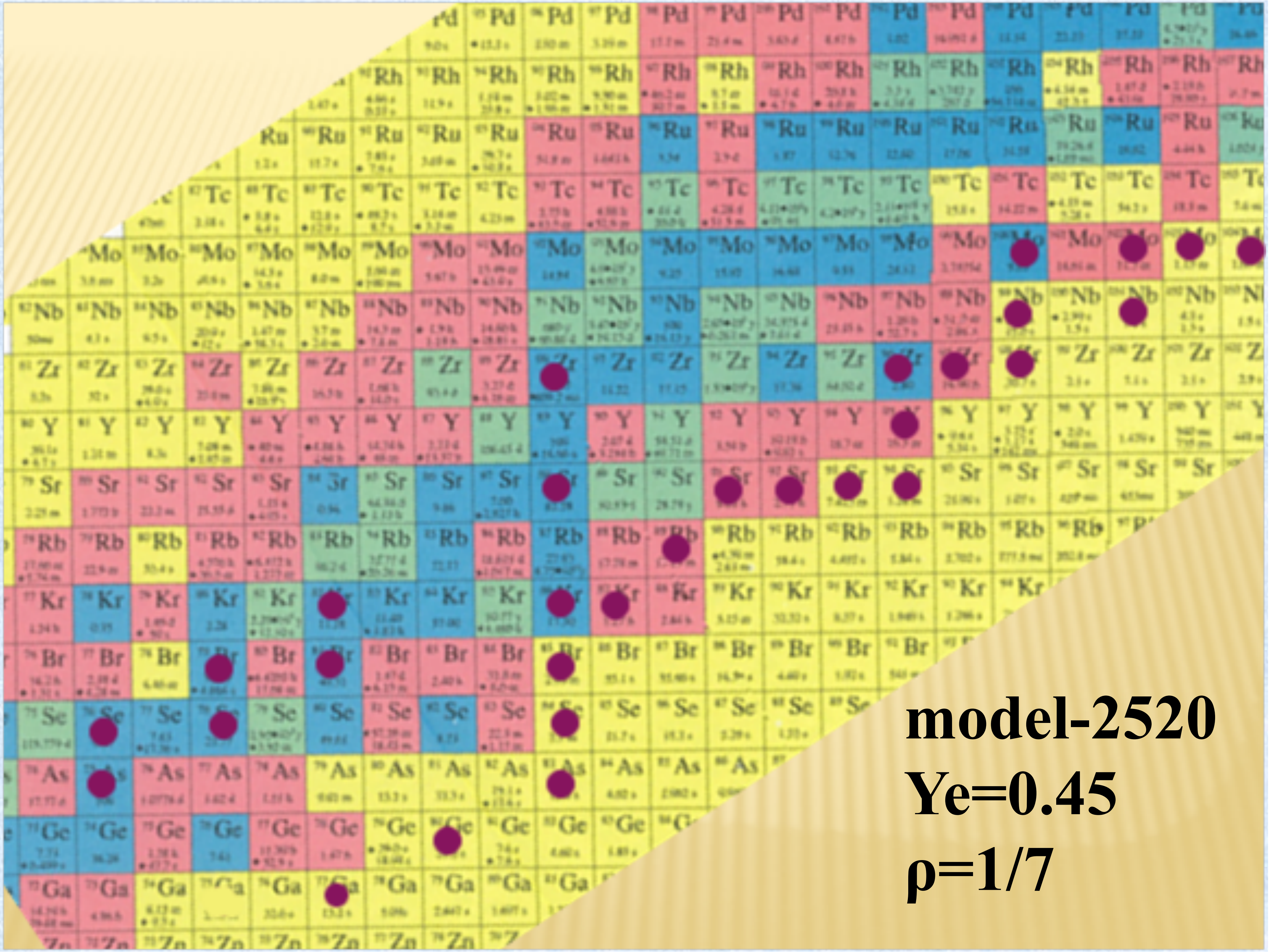
Could reproduce Sr, Y, Zr ratios ↓



Discussion

- The shock wave of hypernovae (with entropy per baryon s/k ∼15) can synthesize weak r-process elements (Sr, Y, Zr) if Ye is as small as ∼0.45.
- The shock wave of supernovae (with s/k ∼3) cannot p roduce weak r- elements even with low Ye.

- However, if high entropy matter (s/k ≳15) is ejected from the hot bubble region of normal SNe, Sr, Y, Zr may be ejected from normal SNe as well.
- Need to look at all elemental abundances to decide the main contributors of the weak r-process elements. (future work in progress)



model-2520
Ye=0.45
ρ=1/7