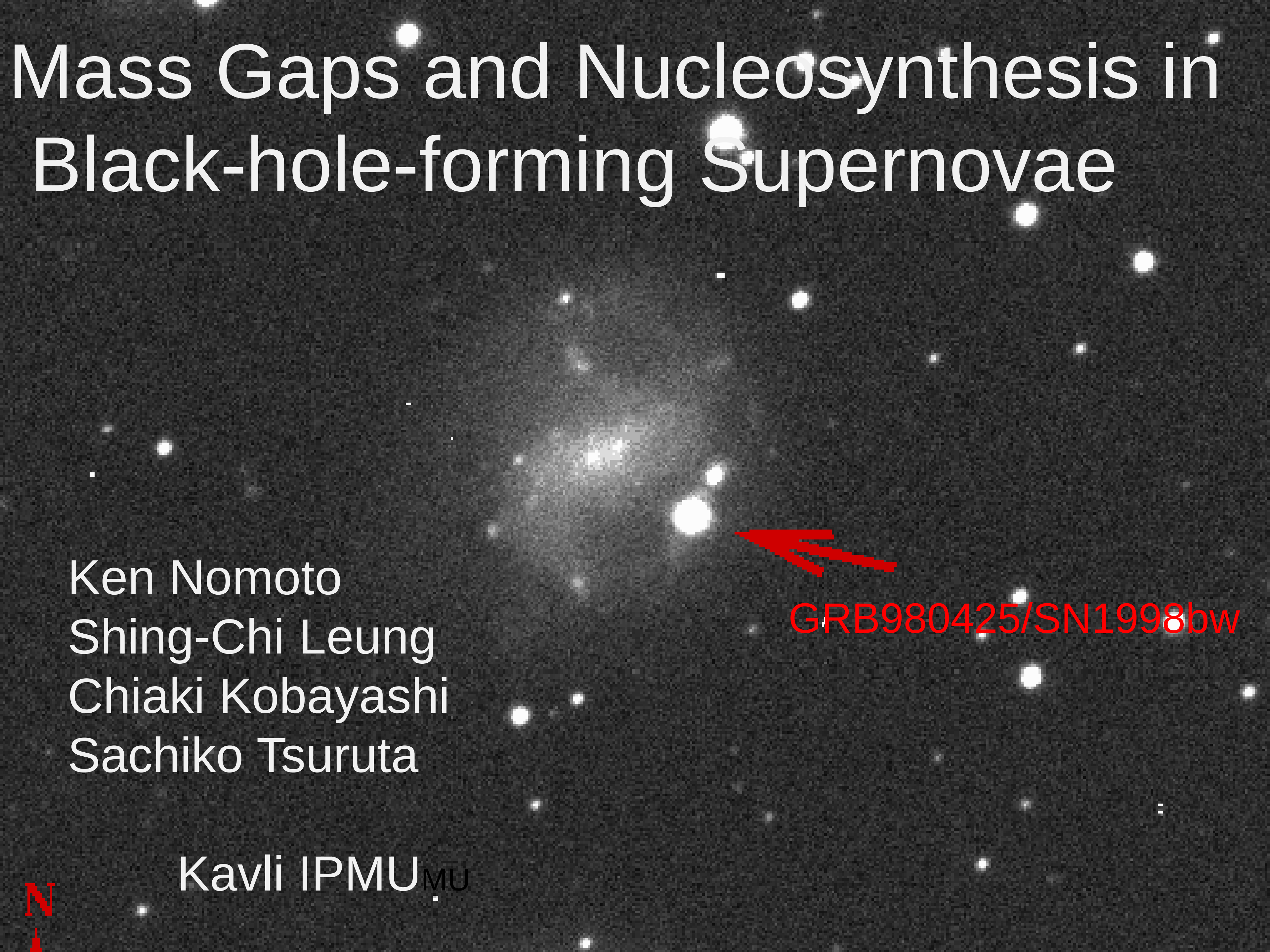
Mass Gaps and Nucleosynthesis in Black-hole-forming Supernovae



Ken Nomoto
Shing-Chi Leung
Chiaki Kobayashi
Sachiko Tsuruta

Kavli IPMU

Pop III Stars – Pop III GRBs – Pop III SNe ?

$M > 10^5 M_\odot$:SMS (Super Massive Stars)

→ GR instability → Collapse

$M \sim 300 - 10^5 M_\odot$:

→ Collapse (& Explosion) → IMBH → SMBH ?

→ **Pop III GRBs ?**

$M \sim 140 - 300 M_\odot$:

→ **Pair Instability SNe** → Complete Disruption

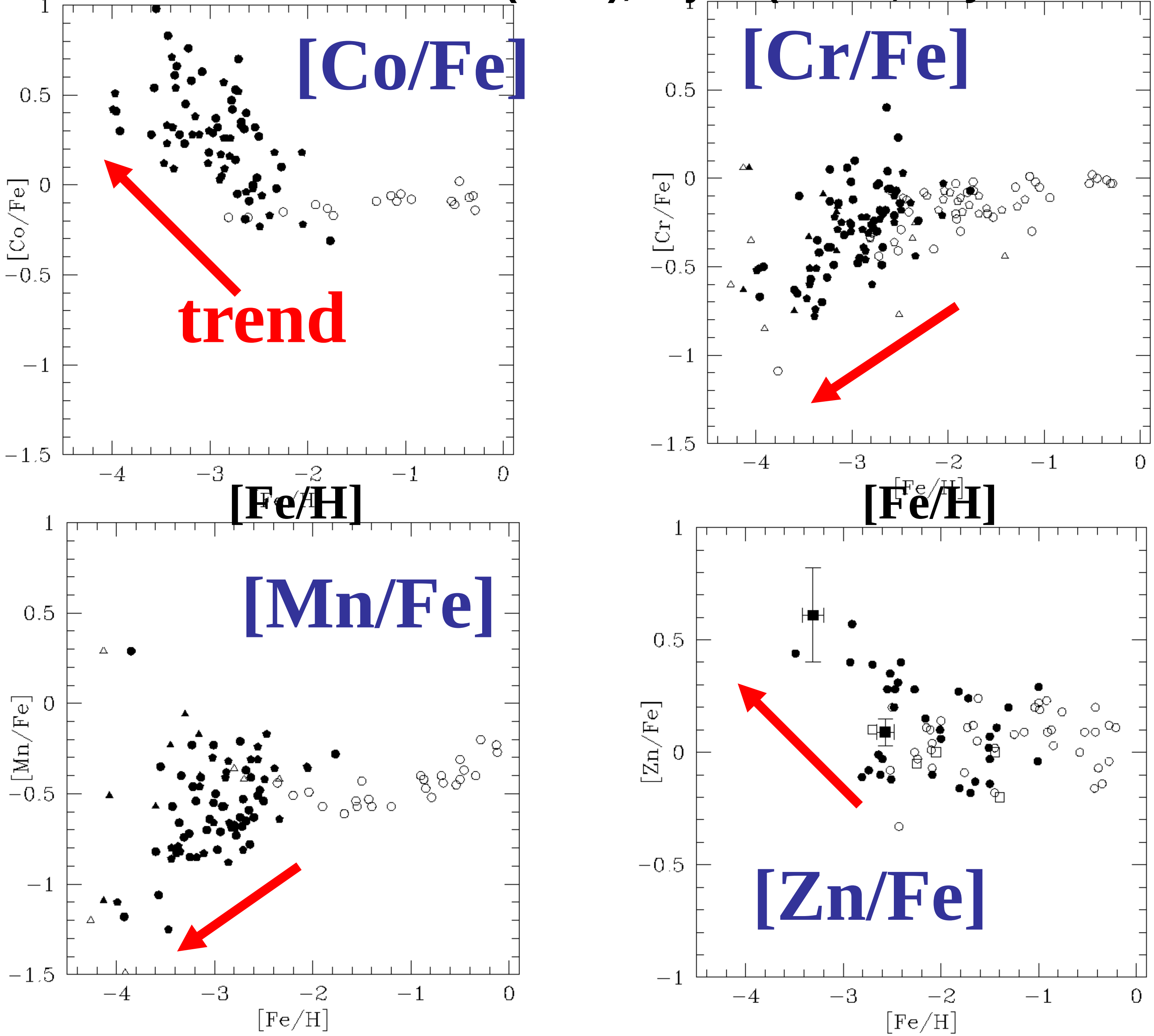
$M(^{56}Ni) < 40\ M_\odot$

$M \sim 8 - 140 M_\odot$: → **Pop III GRBs, Hypernovae**

→ **SNe II** **$M(^{56}Ni) < 10\ M_\odot$**

→ Core Collapse

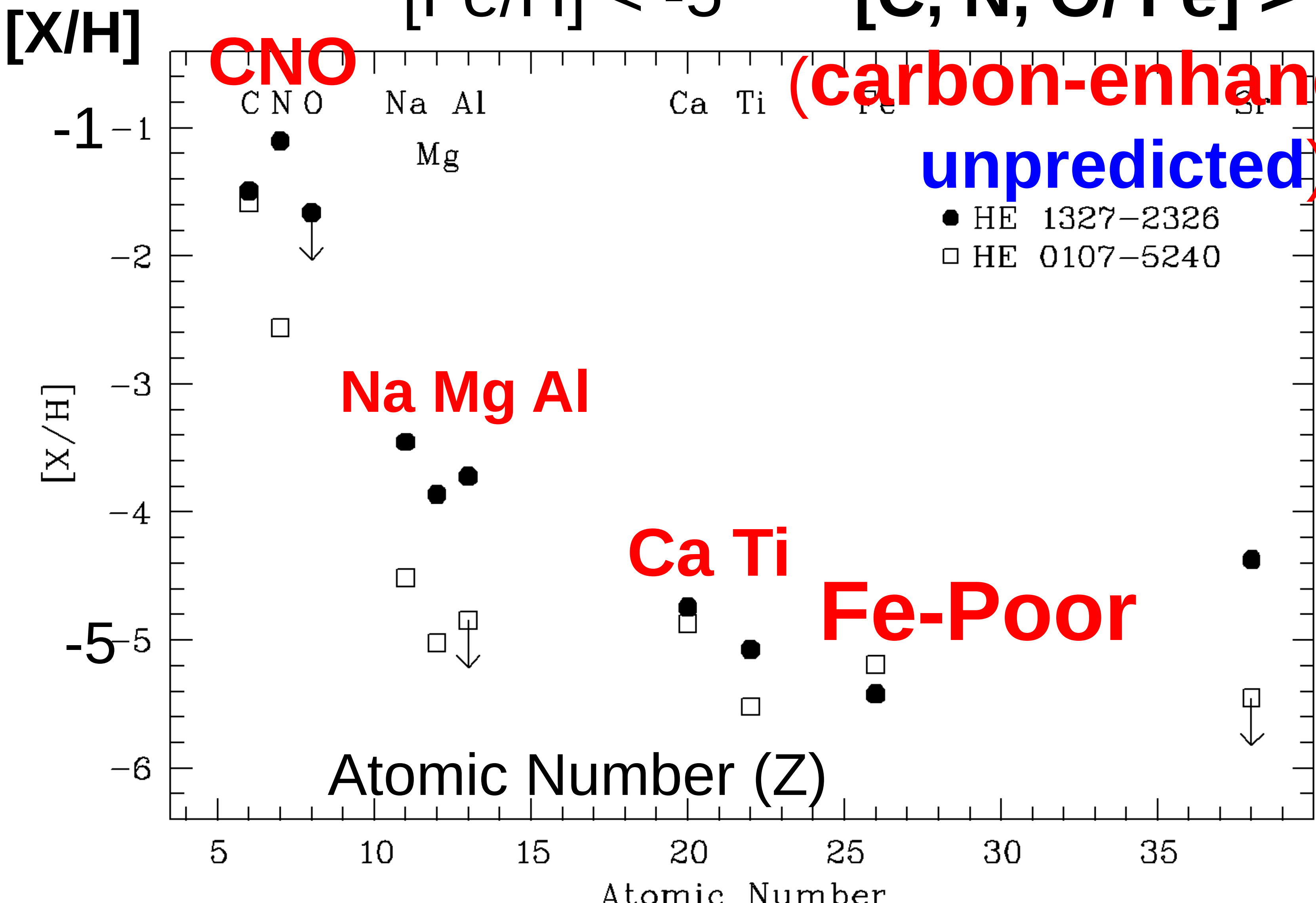
McWilliam (1995), Ryan (1996）, Cayrel +04



Hyper Metal-Poor (HMP) Stars

[Fe/H] < -5 **[C, N, O/ Fe] > 3**

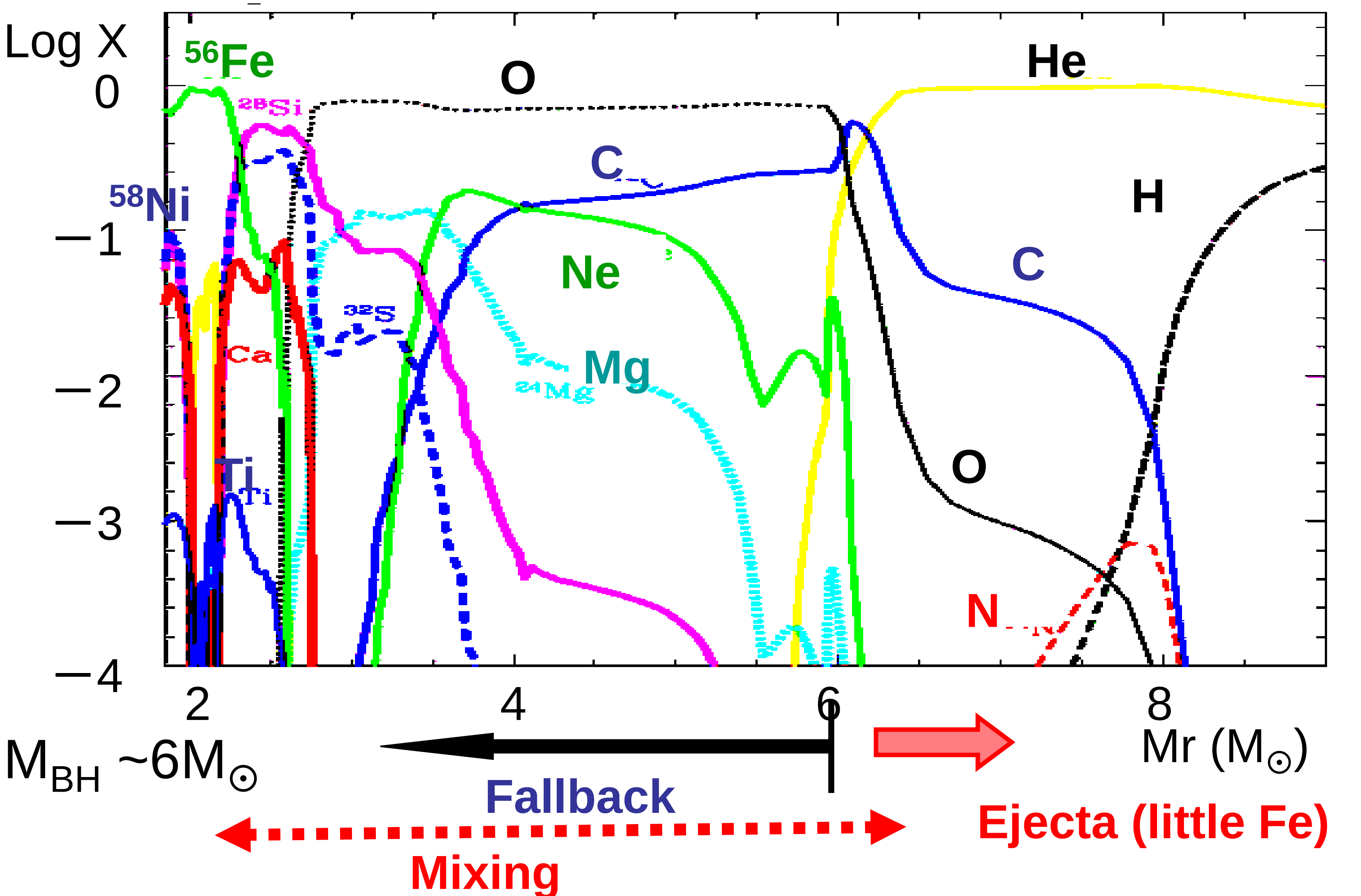
(carbon-enhanced! unpredicted)



Christlieb, Frebel, Aoki, et al.

Mixing and Fall-back Model

M=25M$_\odot$, [Fe/H]=−5.3

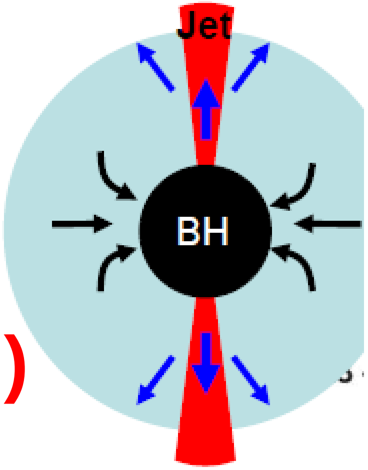


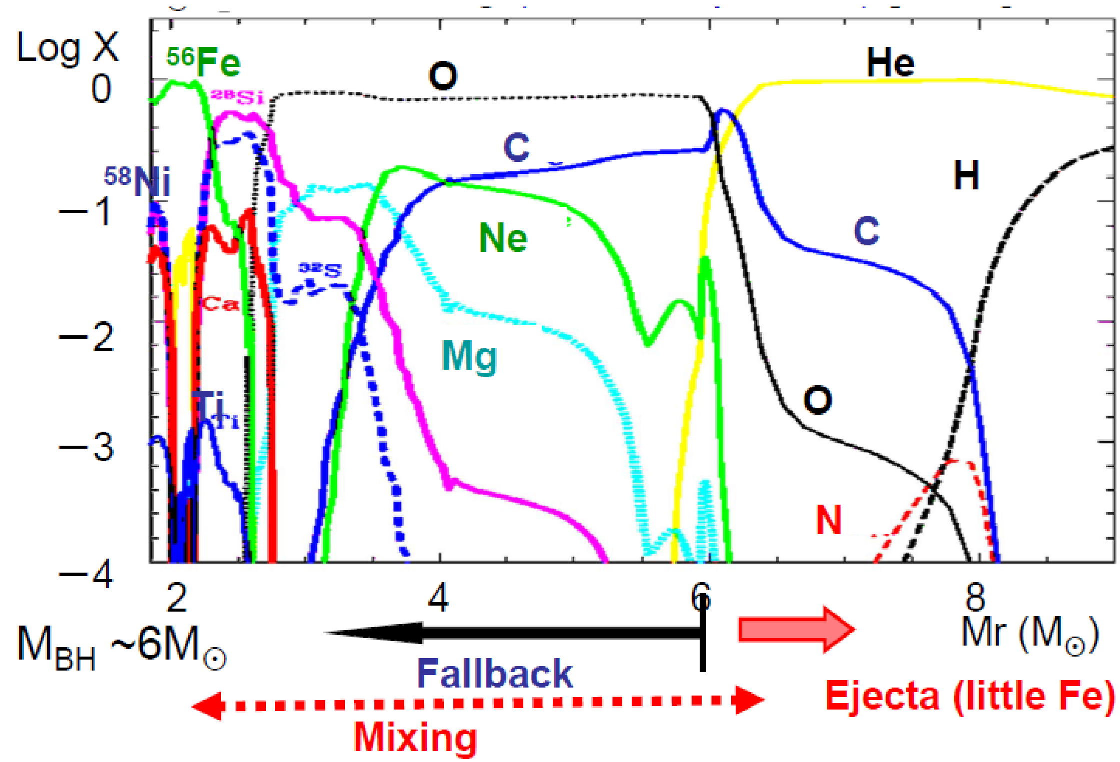
Umeda & Nomoto (2003)

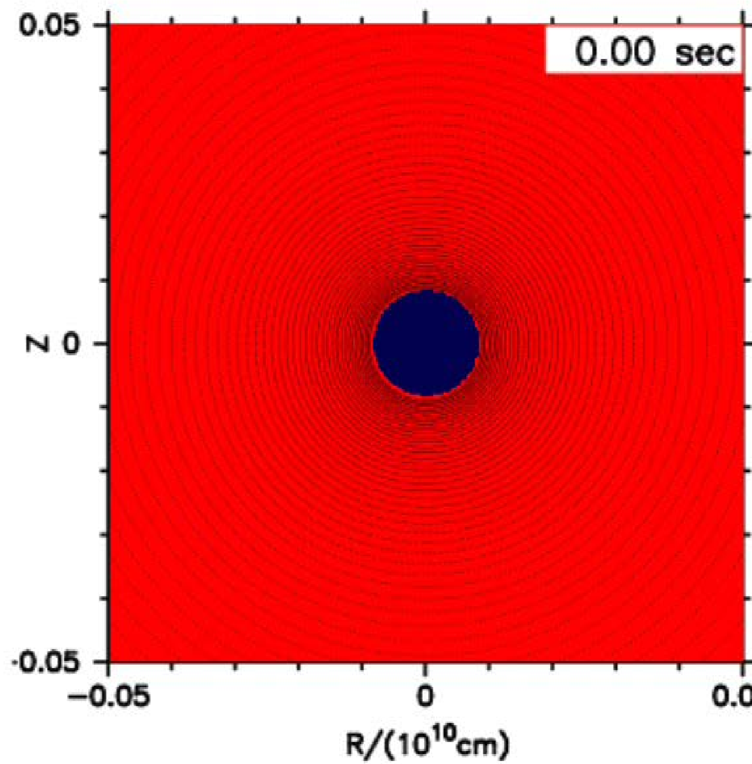
Mixing & Fallback Supernova

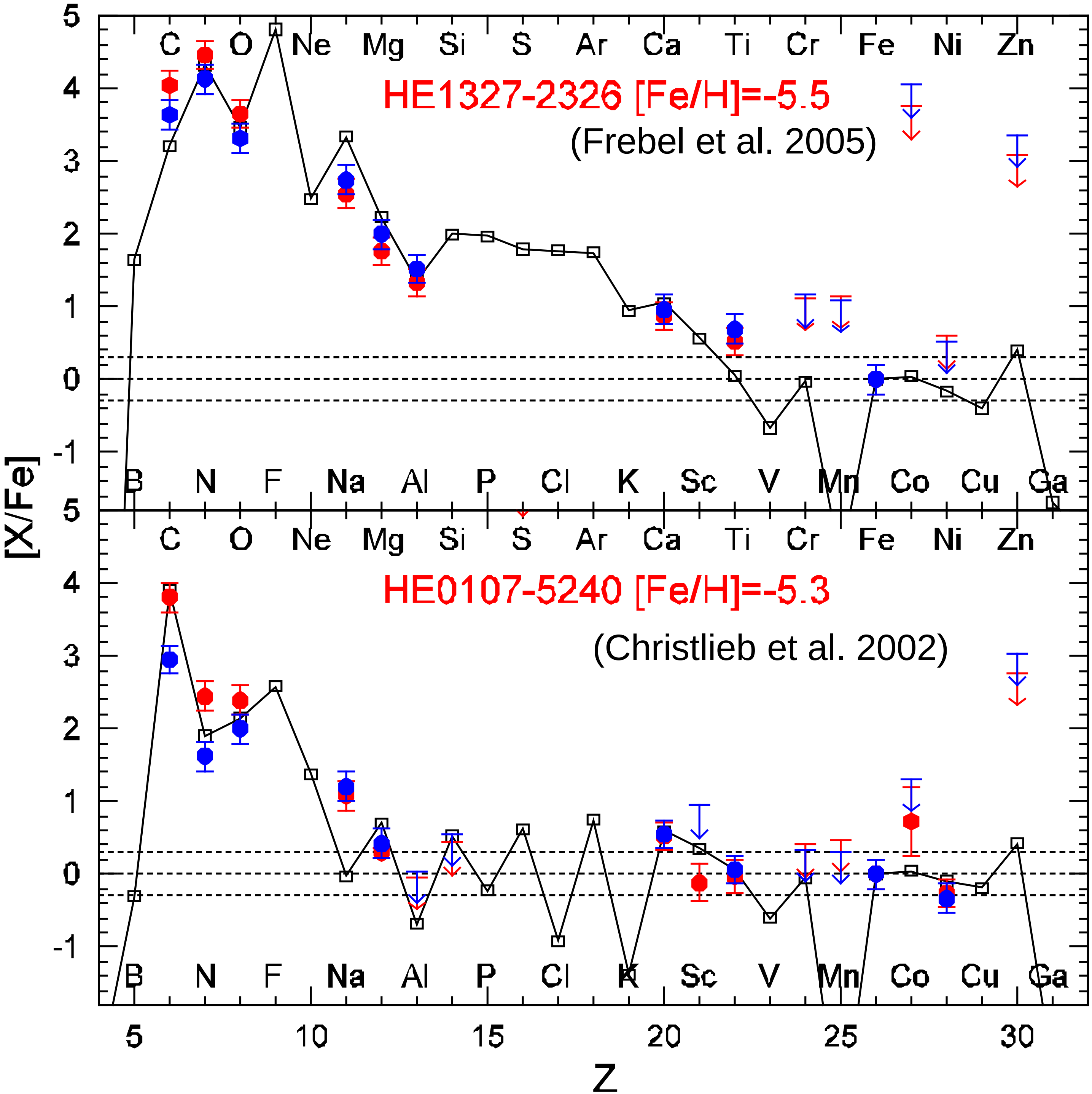
➔ Carbon Enhanced Metal Poor (CEMP-no) Stars

➔ **M(Fe) small ➔ Faint SN (Jet-induced)**









HMP Stars

Jet-induced SN models

High E ➔

High Co/Fe

➔

Fallback ➔

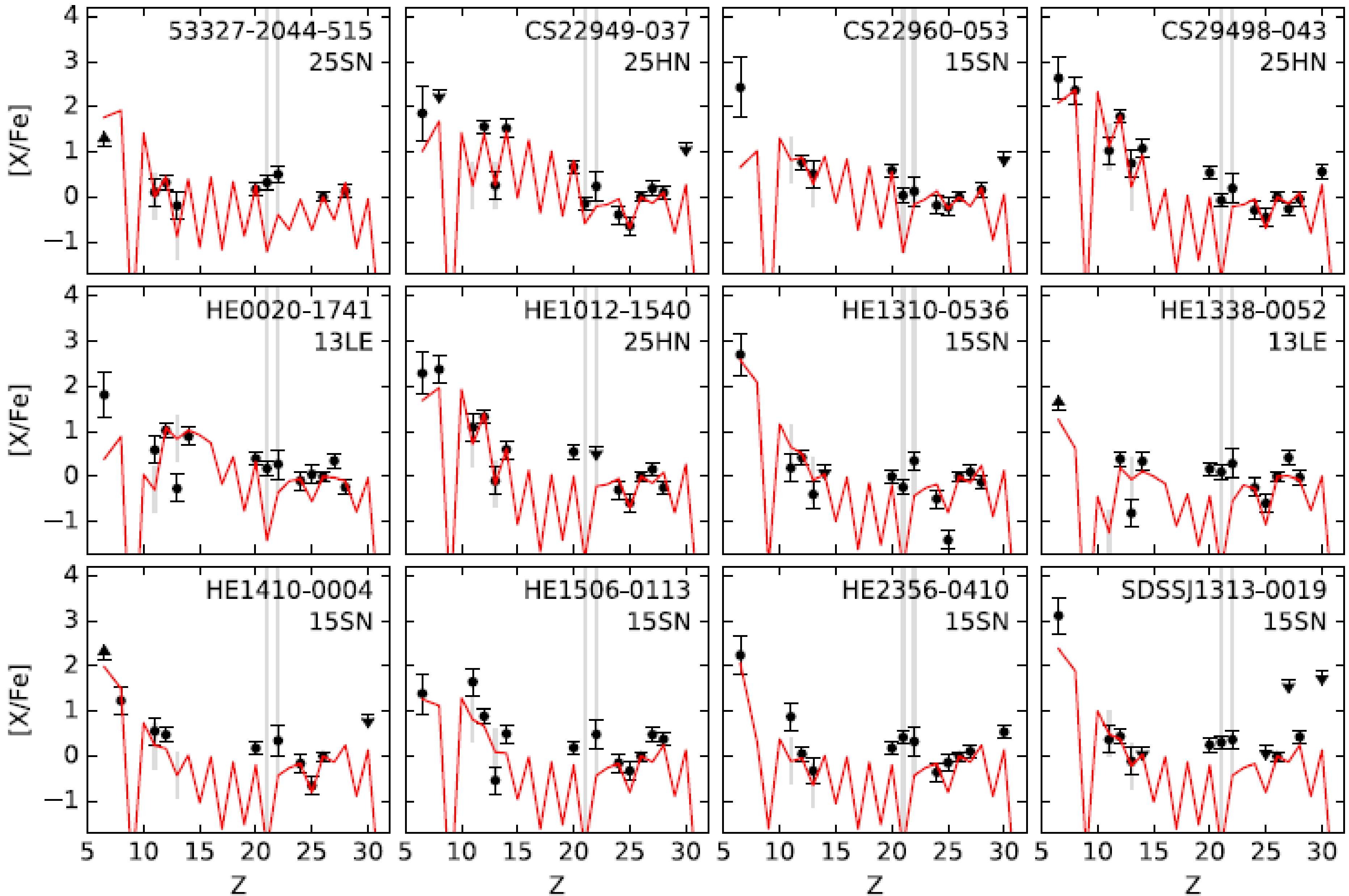
Small Fe

Dark Hypernova

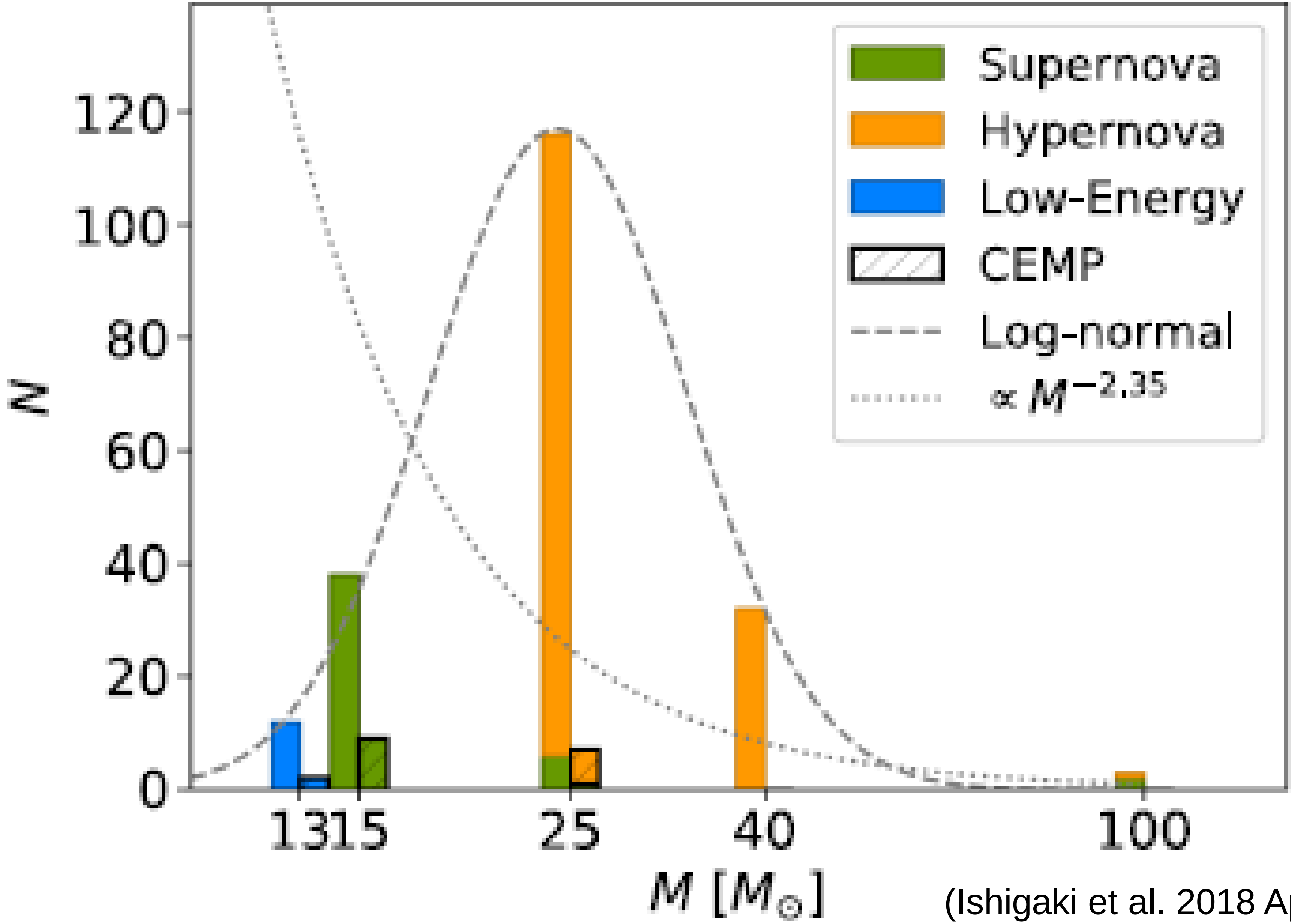
Tominaga et al. 2007

Best fit models

(Ishigaki et al. 2018 ApJ)



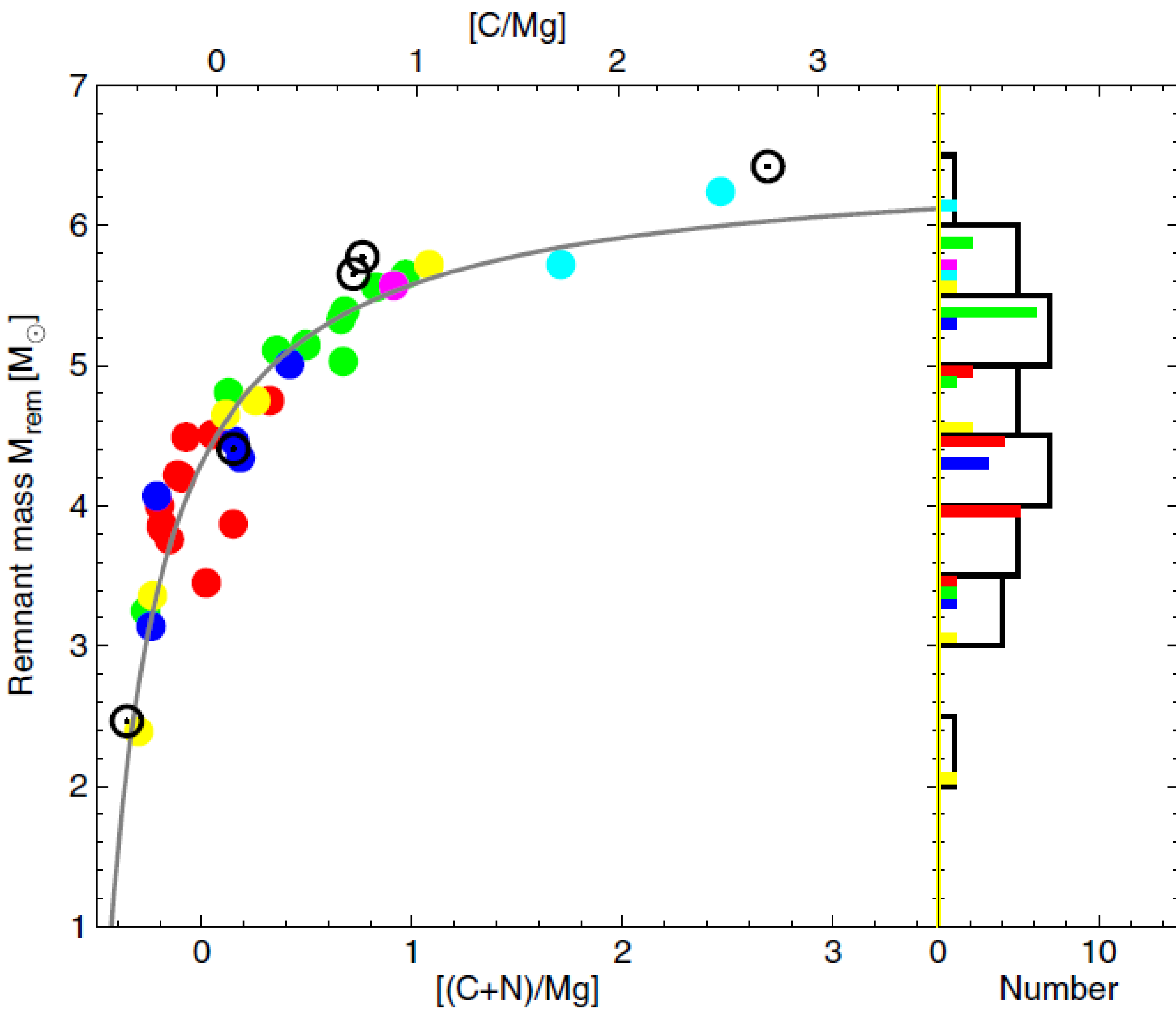
Mass distribution



(Ishigaki et al. 2018 ApJ)

Mixing-Fallback (Jet-induced) SNe
➔ EMP stars ➔ BH Mass (incl. mass gap)

(Spinning BH)



(Tominaga+14)

Pop III Stars – Pop III GRBs – Pop III SNe ?

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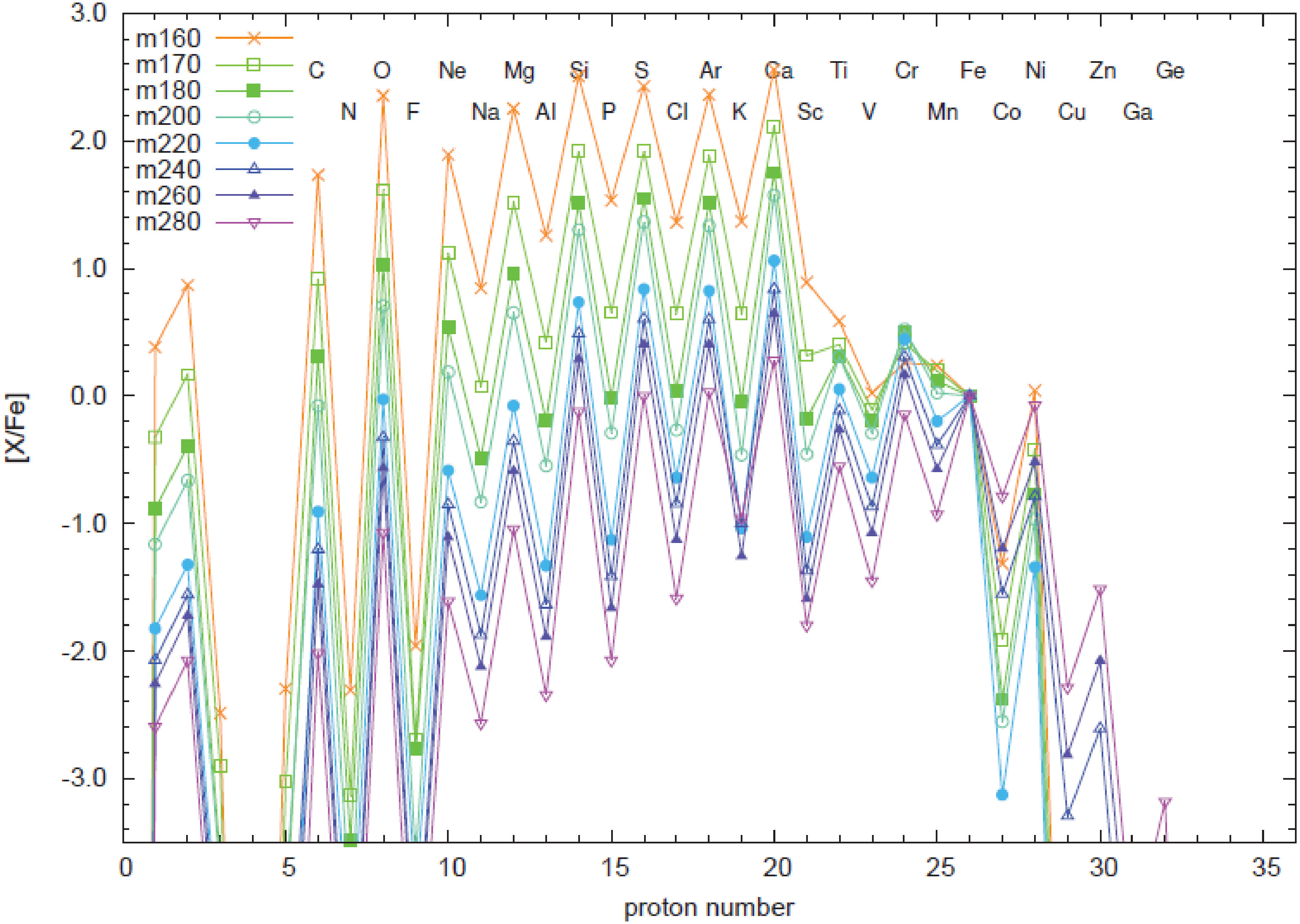
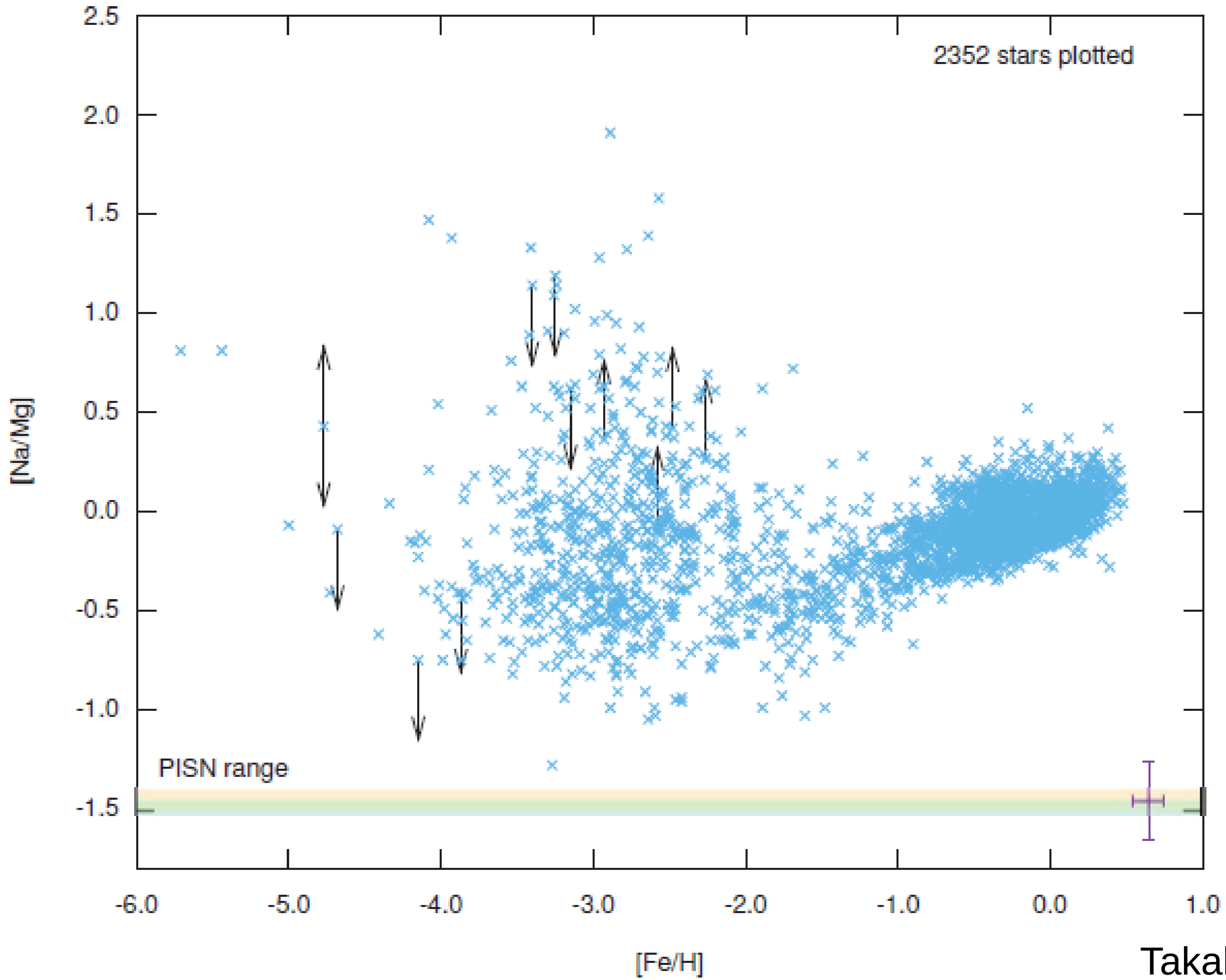
→ **SNe II** **$M(^{56}Ni) < 10\ M_\odot$**

Pair-Instability SN yields: large odd/even Z



Takahashi+18

PISN: [Na/Mg] too small



Takahashi+18

The Astrophysical Journal, 645:1352–1372, 2006 July 10

CORE-COLLAPSE VERY MASSIVE STARS: EVOLUTION, EXPLOSION, AND NUCLEOSYNTHESIS OF POPULATION III 500–1000 $M_{\odot}$ STARS

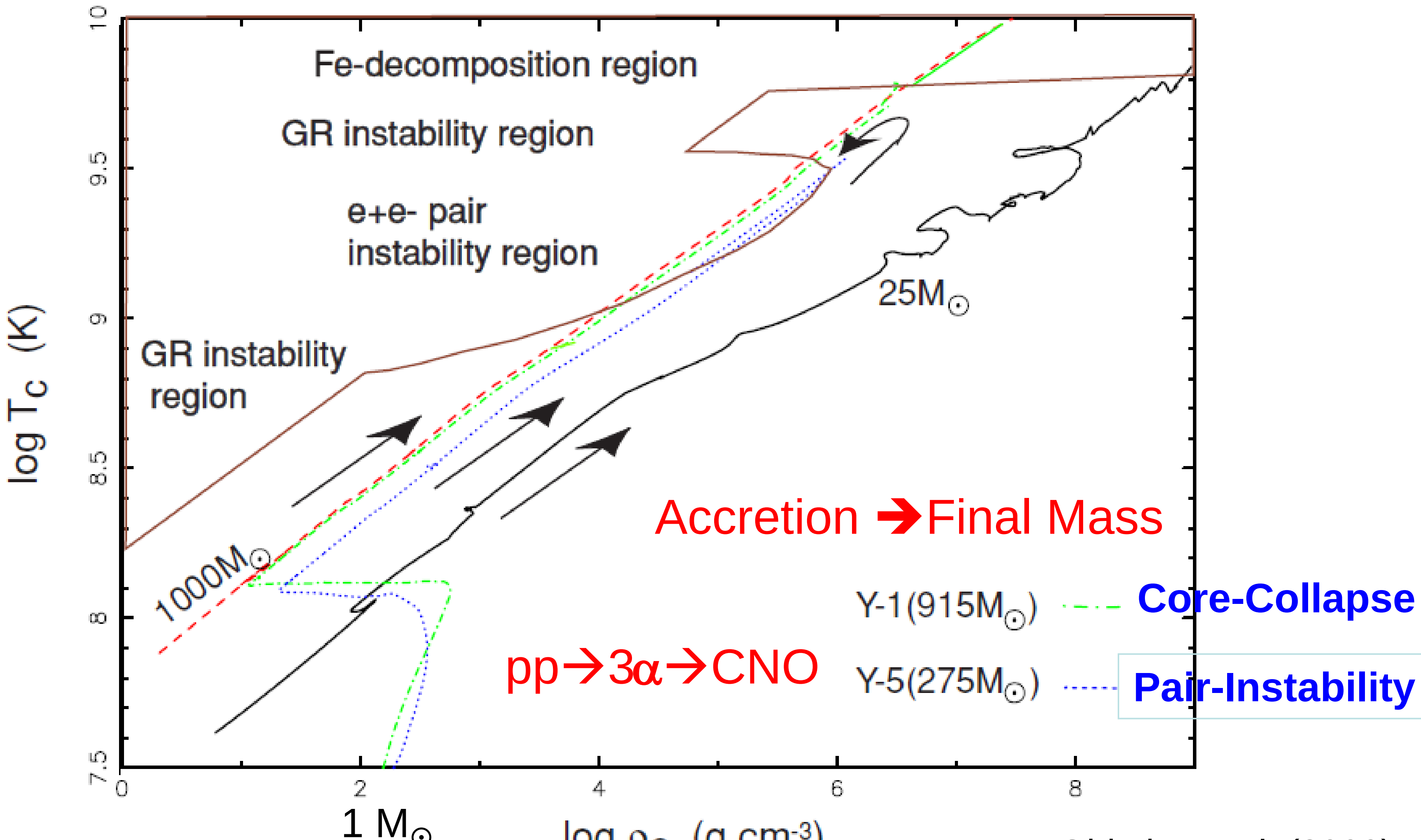
Takuya Ohkubo,[1] Hideyuki Umeda,[1] Keiichi Maeda,[2] Ken'ichi Nomoto,[1,3]
Tomoharu Suzuki,[1] Sachiko Tsuruta,[4] and Martin J. Rees[5]

The Astrophysical Journal, 706:1184–1193, 2009 December 1 doi:10.1088/0004-637X/706/2/1

EVOLUTION OF VERY MASSIVE POPULATION III STARS WITH MASS ACCRETION FROM PRE-MAIN SEQUENCE TO COLLAPSE

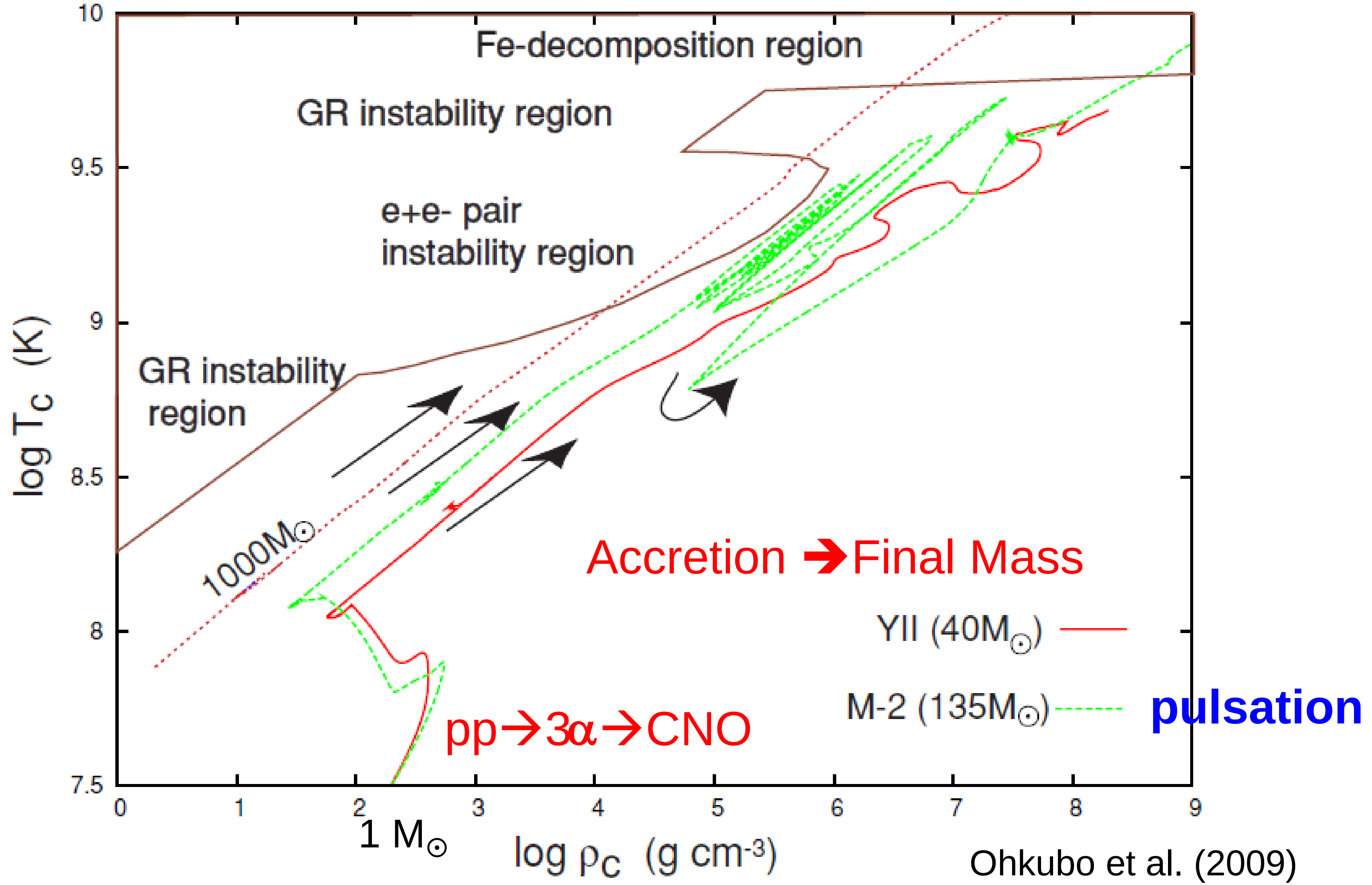
Takuya Ohkubo[1,2], Ken'ichi Nomoto[1,2], Hideyuki Umeda[1], Naoki Yoshida[2,3], and Sachiko Tsuruta[4]

Pop III Stars: Mass Accretion ➔ **Pair-Instability** (140-300 $M_\odot$) or **Core-Collapse**



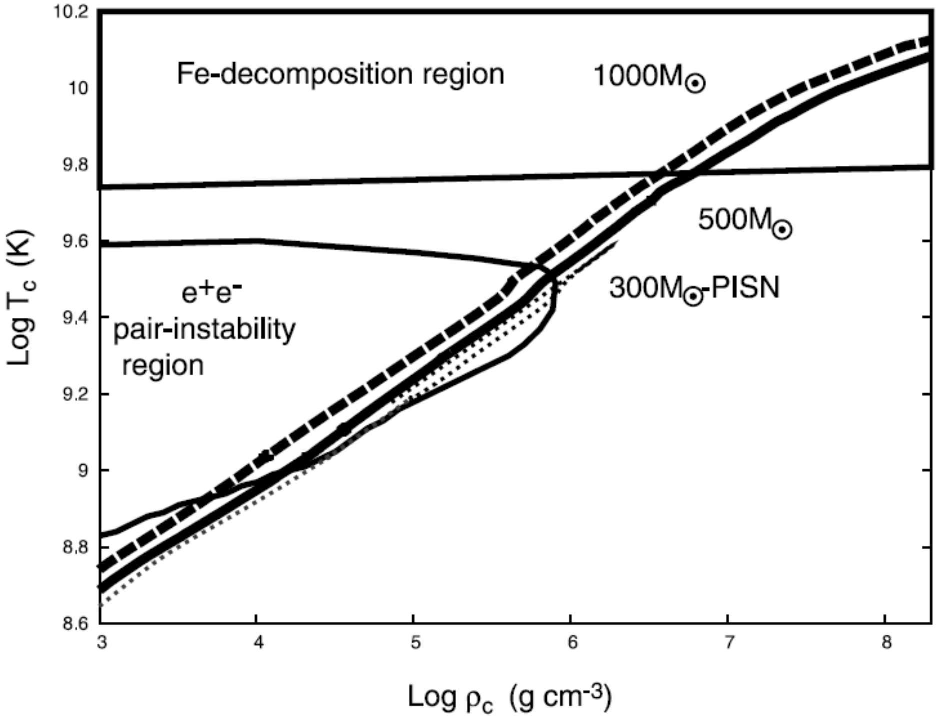
Ohkubo et al. (2009)

Pop III Stars: Mass Accretion ➔ Core Collapse (40-140 $M_\odot$) ➔ SLSN or GRB?

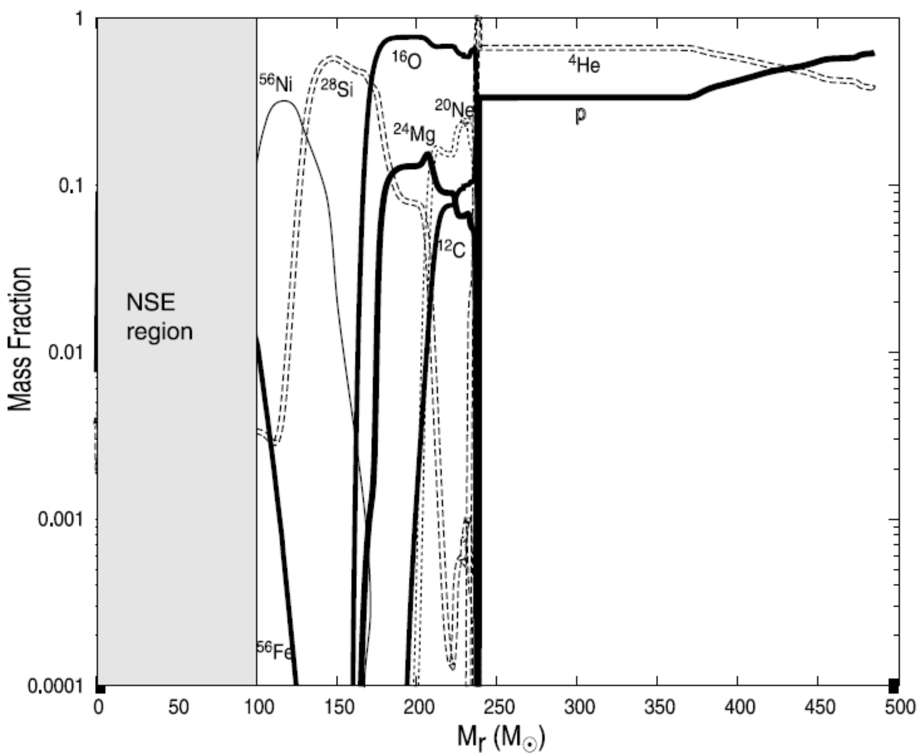


Ohkubo et al. (2009)

Collapse of 500 $M_\odot$ Star

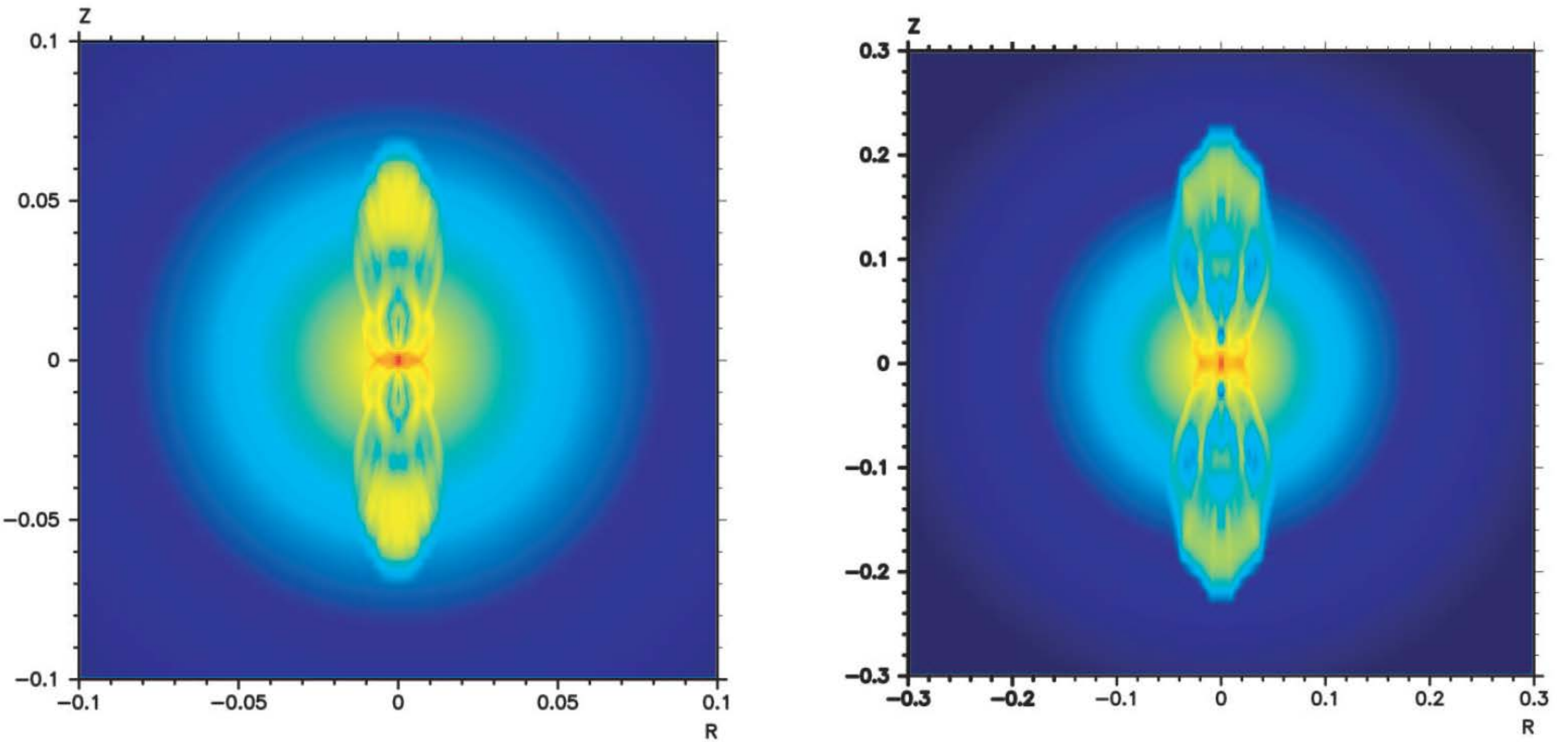


Pre-Collapse: 500 $M_\odot$

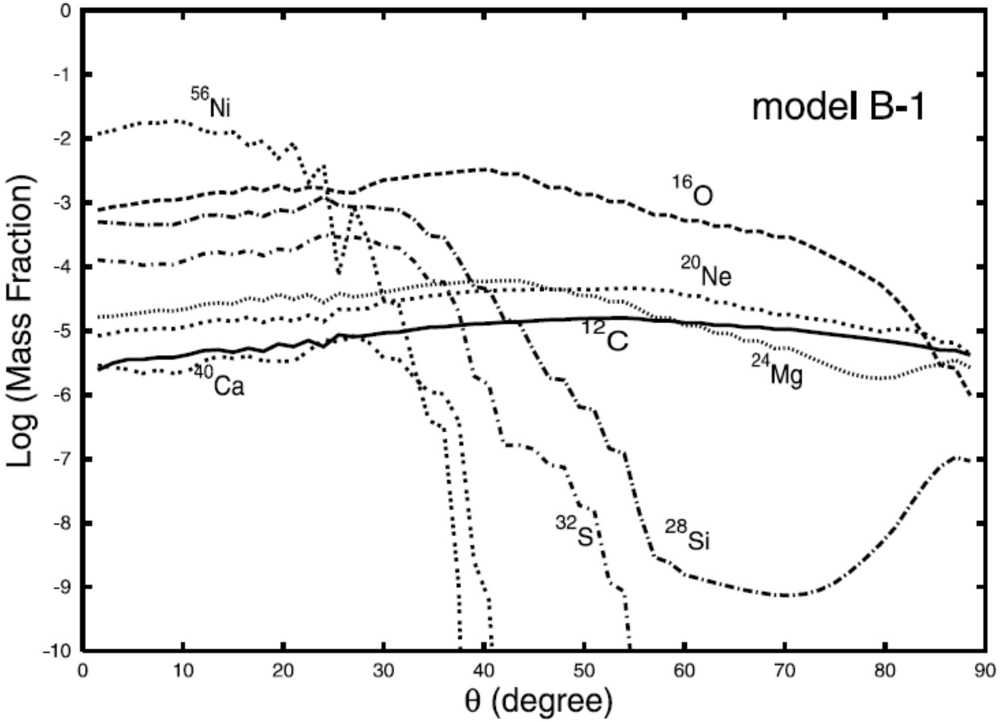


Ohkubo+ (2006)

Black Hole forming Supernovae of 500 – 1000 $M_\odot$ Stars

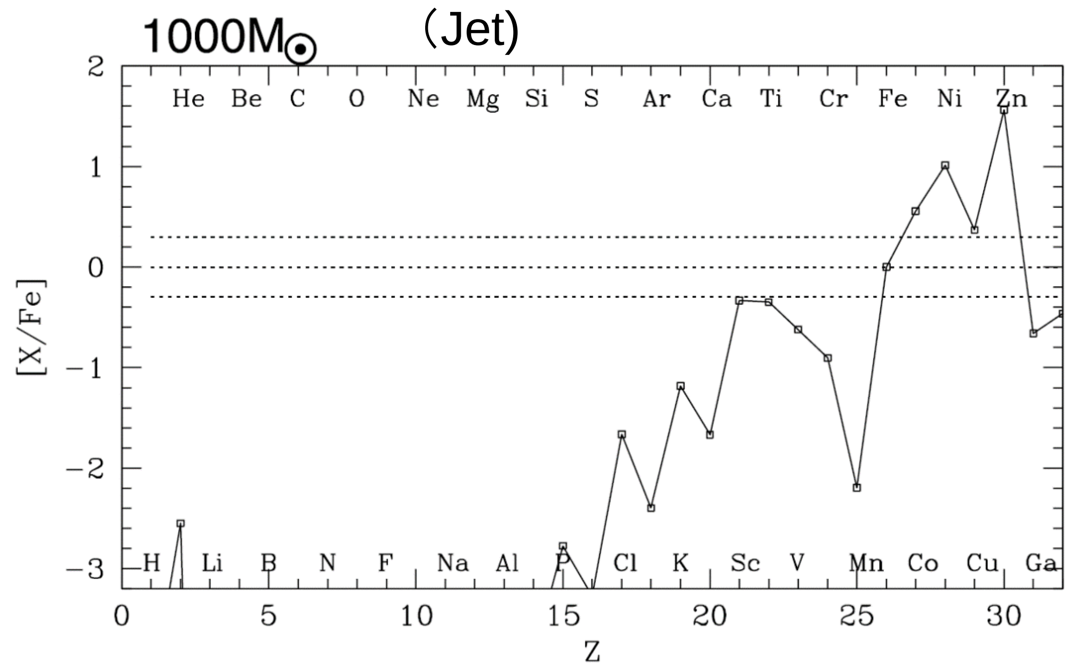


Ohkubo+ (2006)



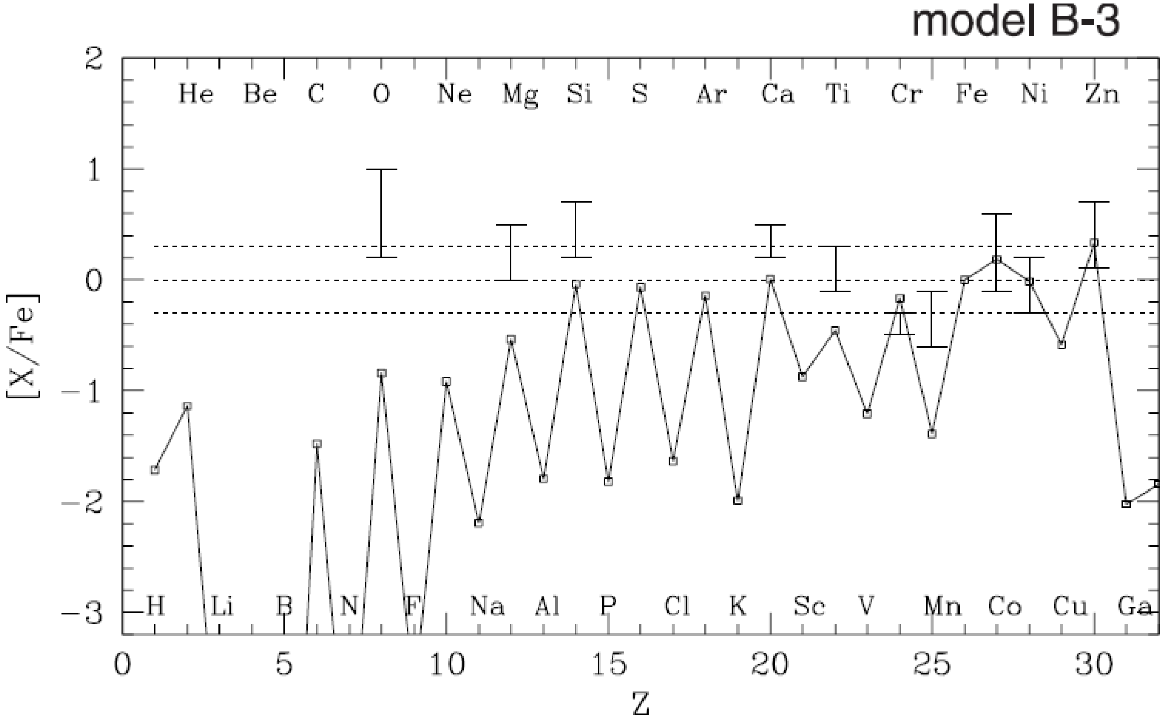
$M/M_\odot$	$M(^{56}Ni)$ $(M_\odot)$	$M(^{16}O)$ $(M_\odot)$	$M(^{28}Si)$ $(M_\odot)$
1000	10.1	23.1	6.2
500	9.3	10.3	4.8

Nucleosynthesis in 500 – 1000 $M_\odot$ Stars



Ohkubo+ (2006)

$M = 500\ M_\odot$

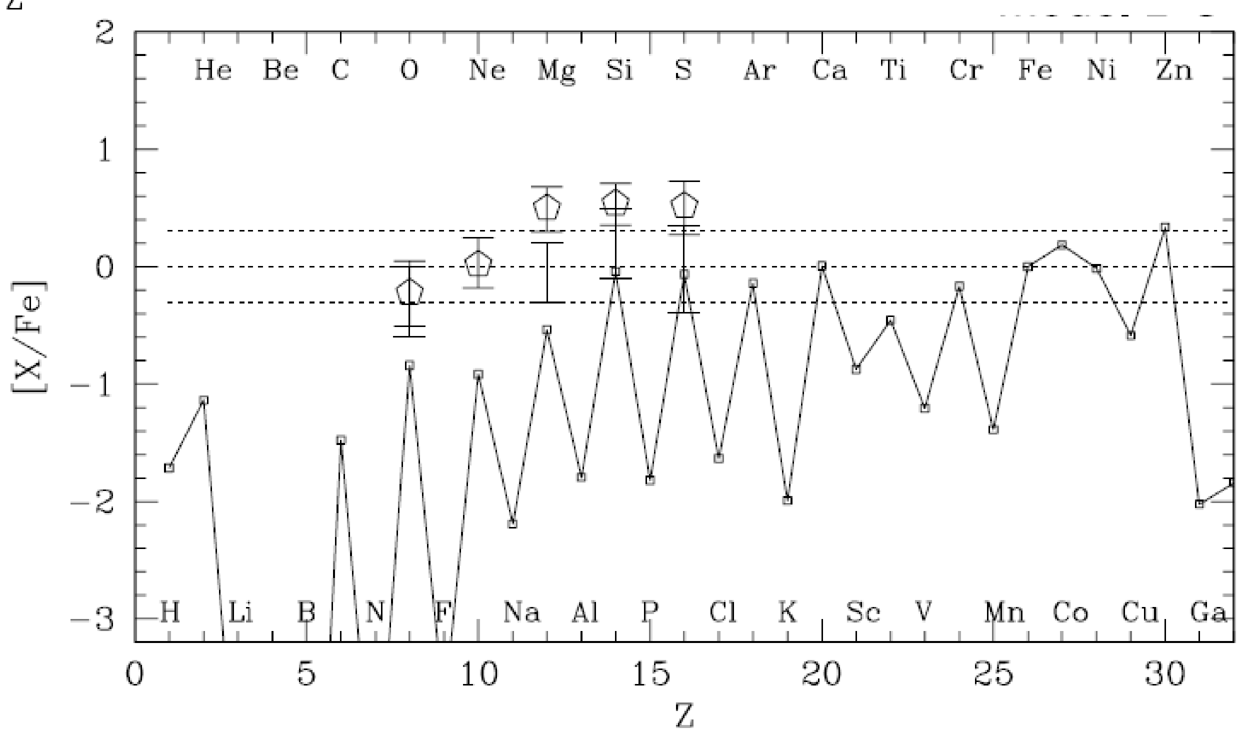


EMP Stars

[O/Fe] : too large

M82
ICM

[O/Fe]



Ohkubo+ (2006)

BH Mass of 300 – 1000 $M_\odot$ Stars

$M/M_\odot$	$M(He)/M_\odot$	$M(BH)/M_\odot$
1000	~500	480
500	~240	230
~320	~150	~140

M(BH) can be smaller (~100 $M_\odot$) if [O-Si/Fe] of associated objects (ICM, EMP stars, etc.) are significantly large.