Shedding light on the first stars with CEMP-no stars

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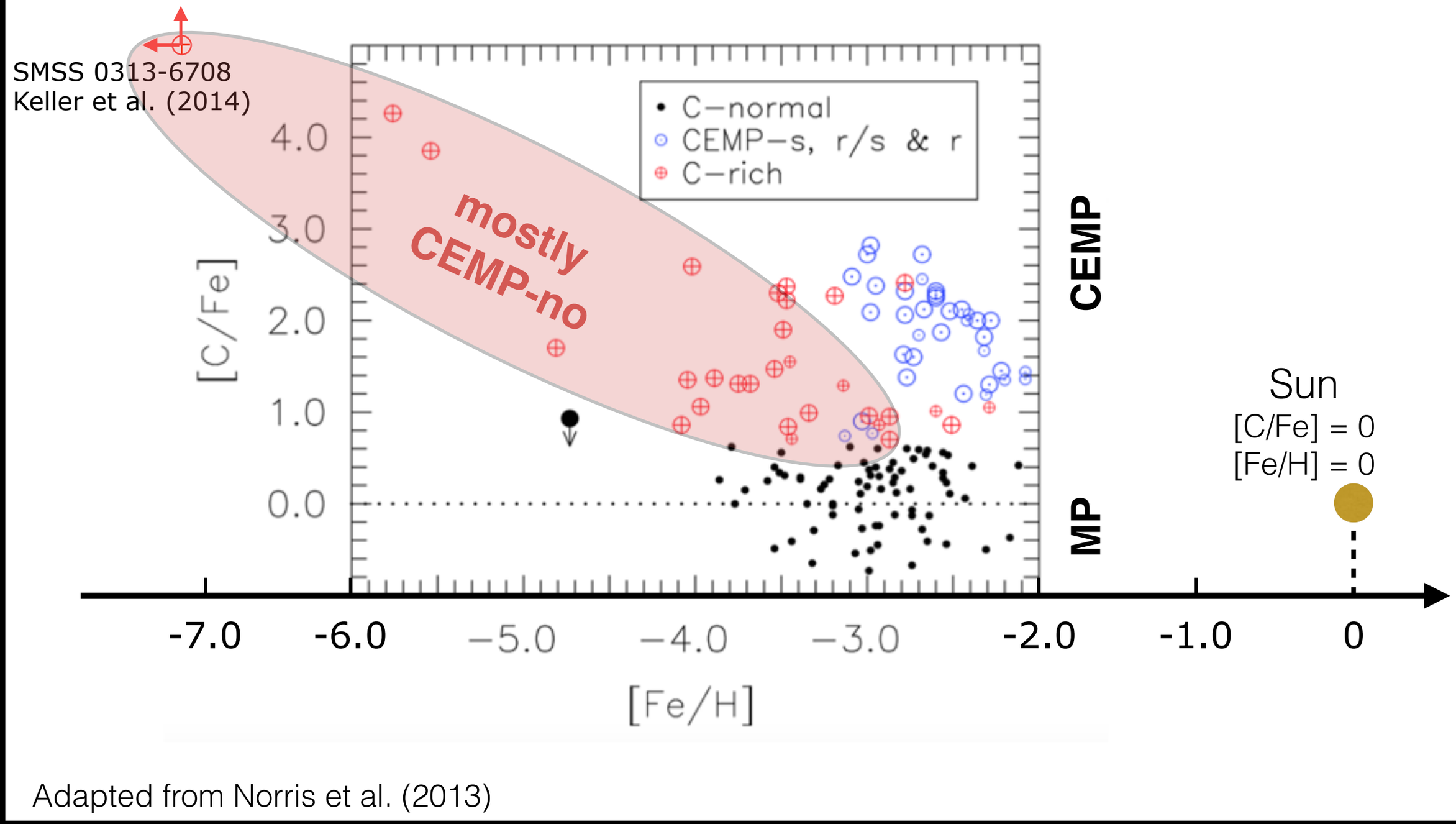
November 15th, 2017

The CEMP-no stars

[C/Fe] > 1, [Ba/Fe] < 0 *(Beers & Christlieb 2005)*



Adapted from Norris et al. (2013)

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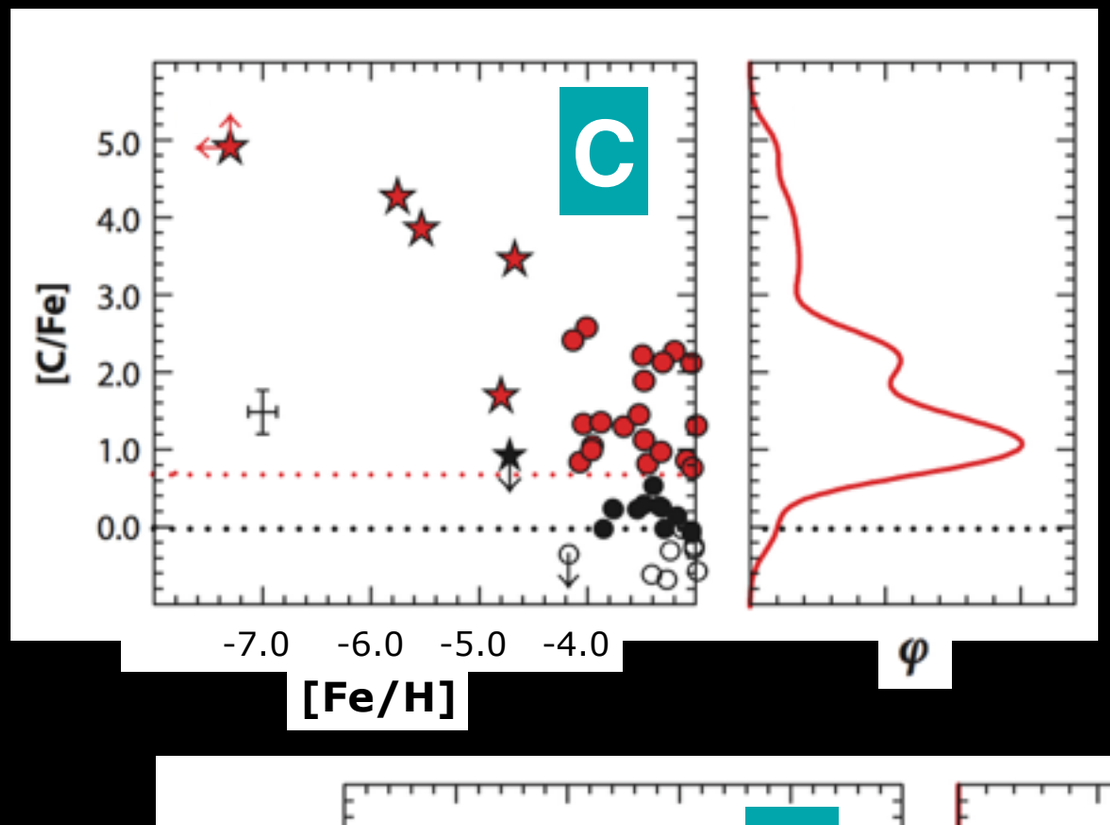

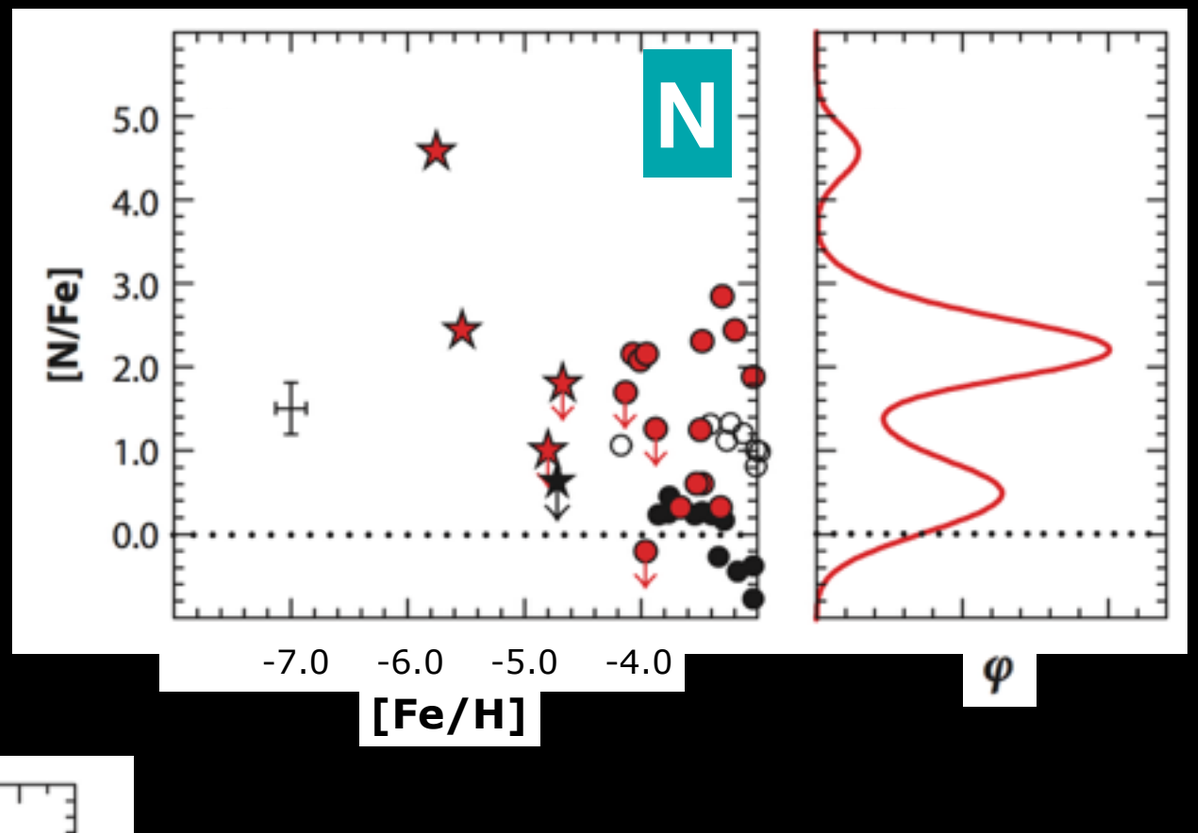

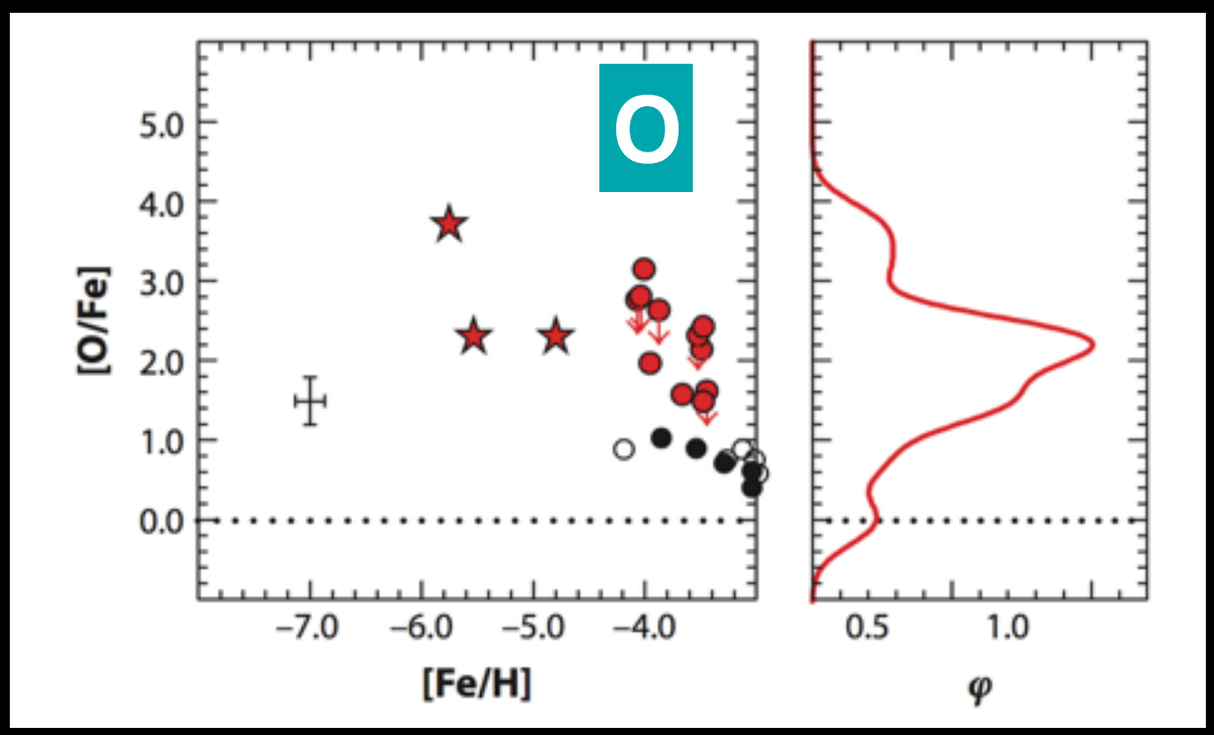

From Frebel+15,
data from Cayrel et al. (2004), Spite et al. (2005), Sivarani et al. (2006), Caffau et al. (2012), Cohen et al. (2013), Norris et al. (2013), Yong et al. (2013a), Hansen et al. (2014), and Keller et al. (2014)

CEMP-no :
often N- and O-rich

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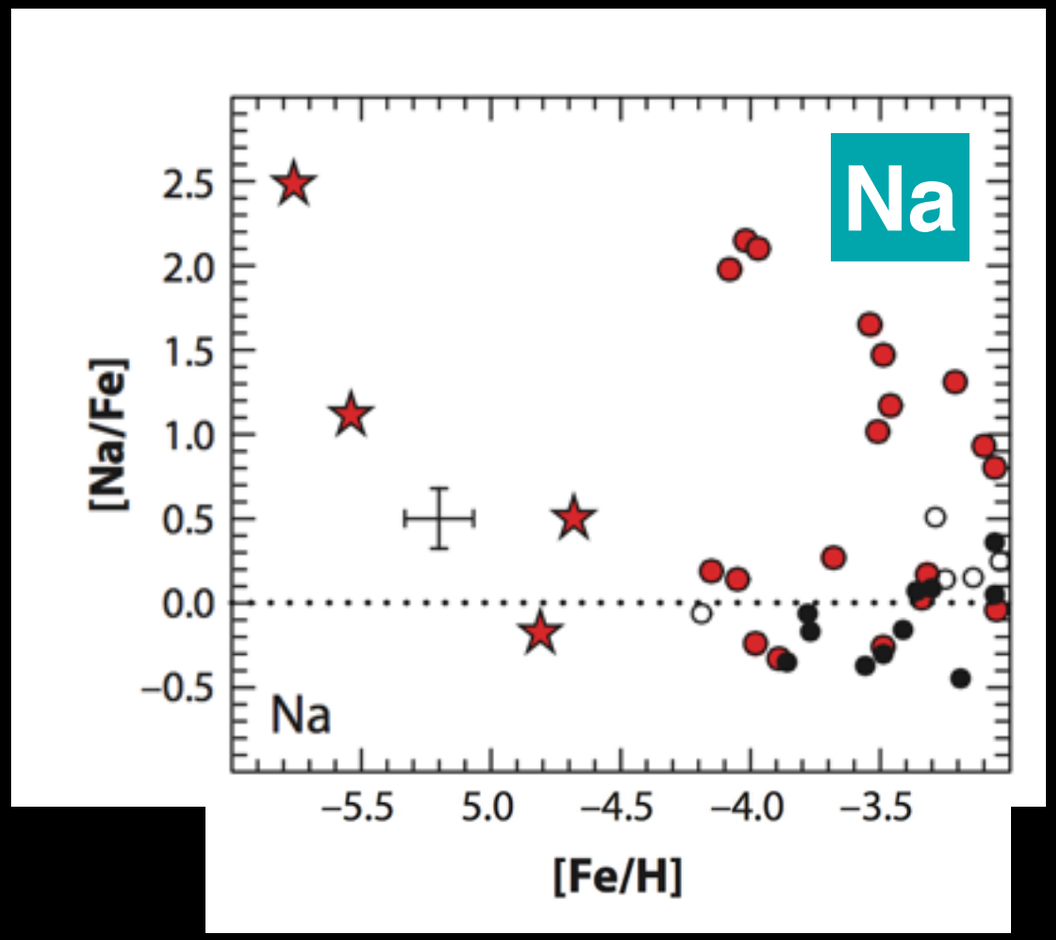

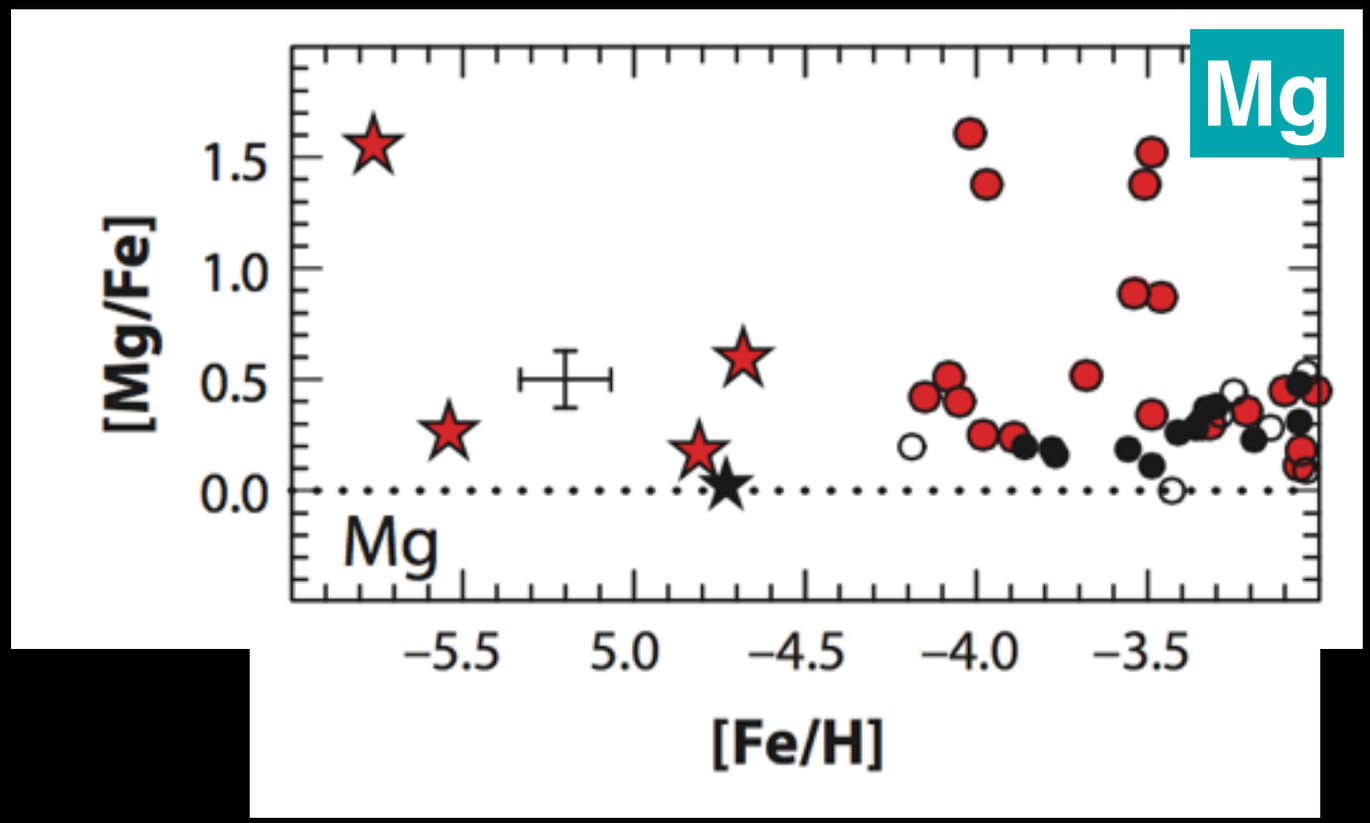

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CEMP-no : sometime Na- and Mg-rich

Scenarios to explain CEMP-no stars

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- **Mixing & Fallback + faint SN** — *Umeda & Nomoto 2003, 2005, Iwamoto+2005, Ito+2013, Tominaga+2007, 2014, Kobayashi+2014, Ishigaki+2014*
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- **Dust-gas around CEMP-no** — *Venn+2014*

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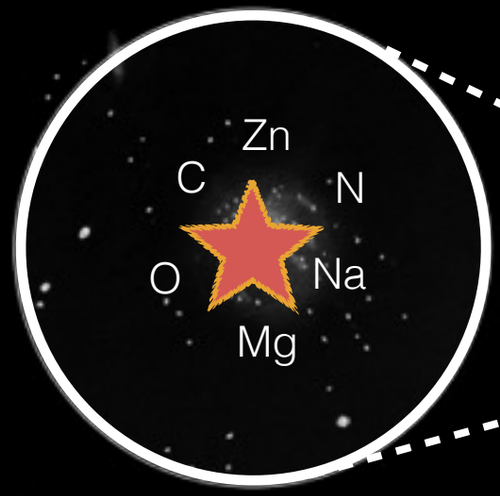
Mother star(s) (>10 $M_\odot$)
= 1st star ?

?

N
Na
O
C
Mg
Zn

Daughter star (~ 0.8 $M_\odot$)
= CEMP-no



Mother star birth
Mother star death
CEMP-no birth
Now
Time

Chemical composition of the mother star ejecta
= observed CEMP-no abundances?

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Event during the CEMP-no life

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Mixing & Fallback

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Rotation

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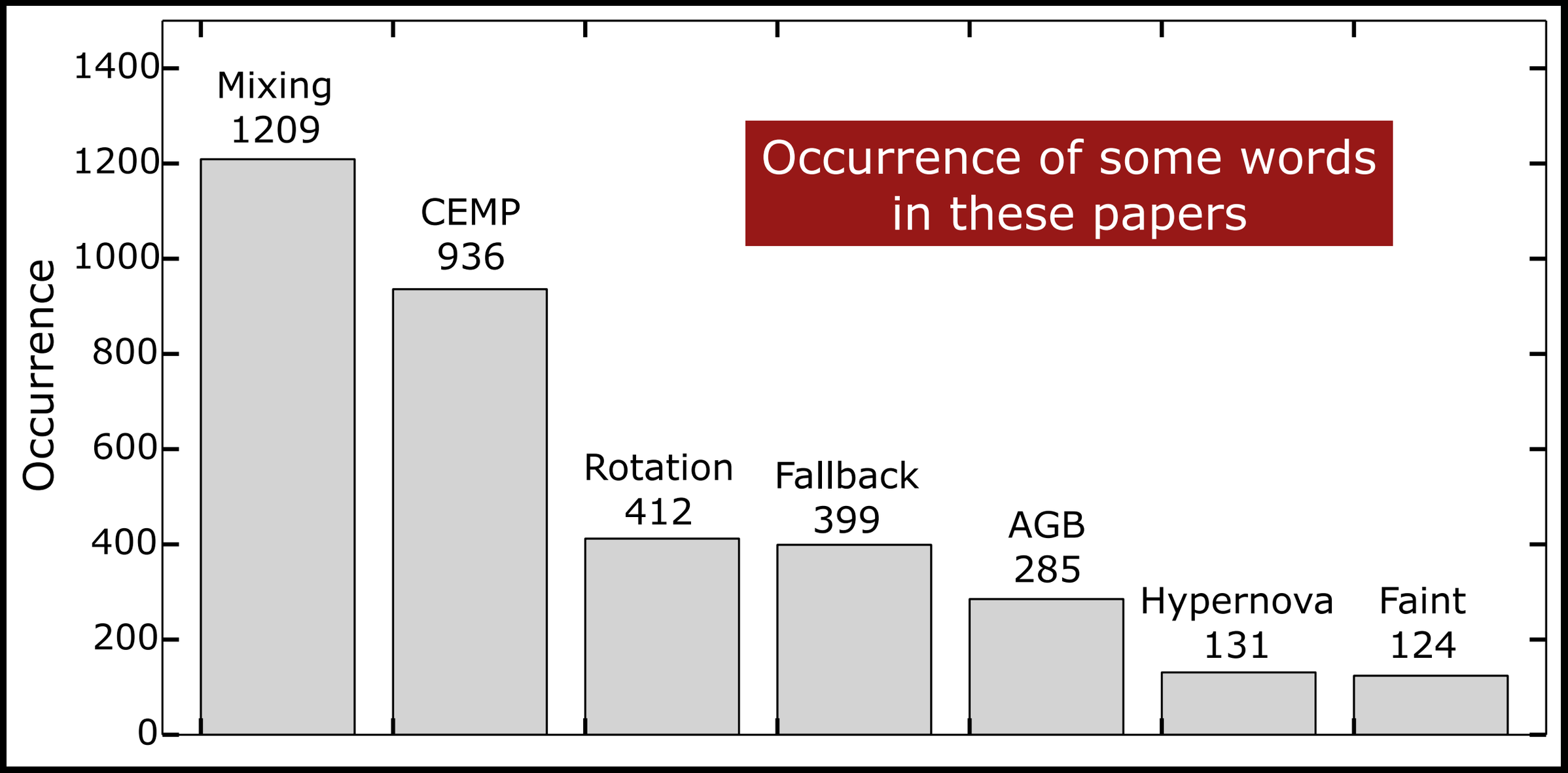
Occurrence of some words in these papers
Occurrence
1400
1200
1000
800
600
400
200
0
Mixing
1209
CEMP
936
Rotation
412
Fallback
399
AGB
285
Hypernova
131
Faint
124

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More than one scenario?

e.g. Yoon+16, Placco+16, Choplin+17, Chiaki+17

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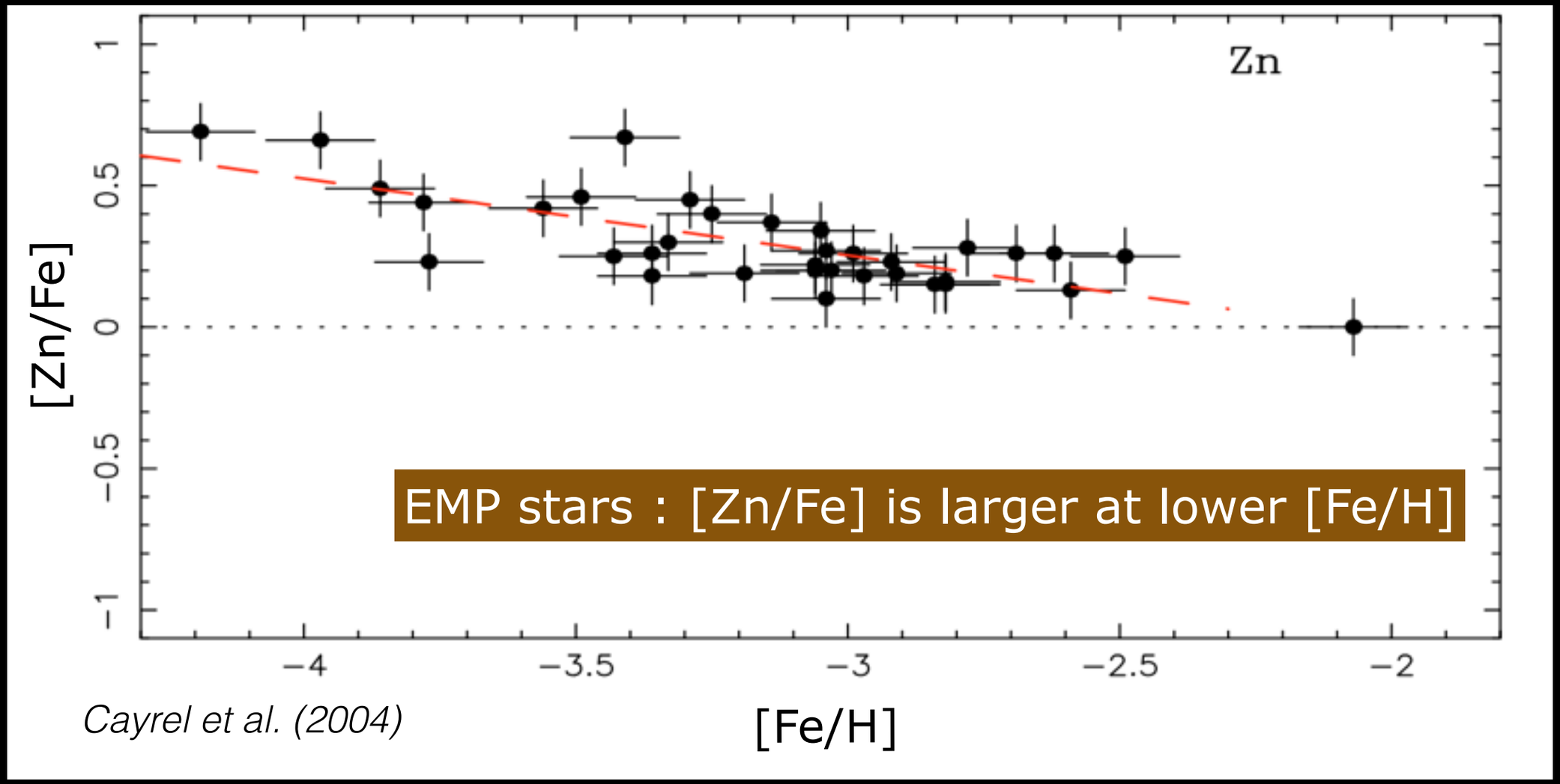
The Mixing & Fallback scenario

Umeda & Nomoto 2002



Cayrel et al. (2004)

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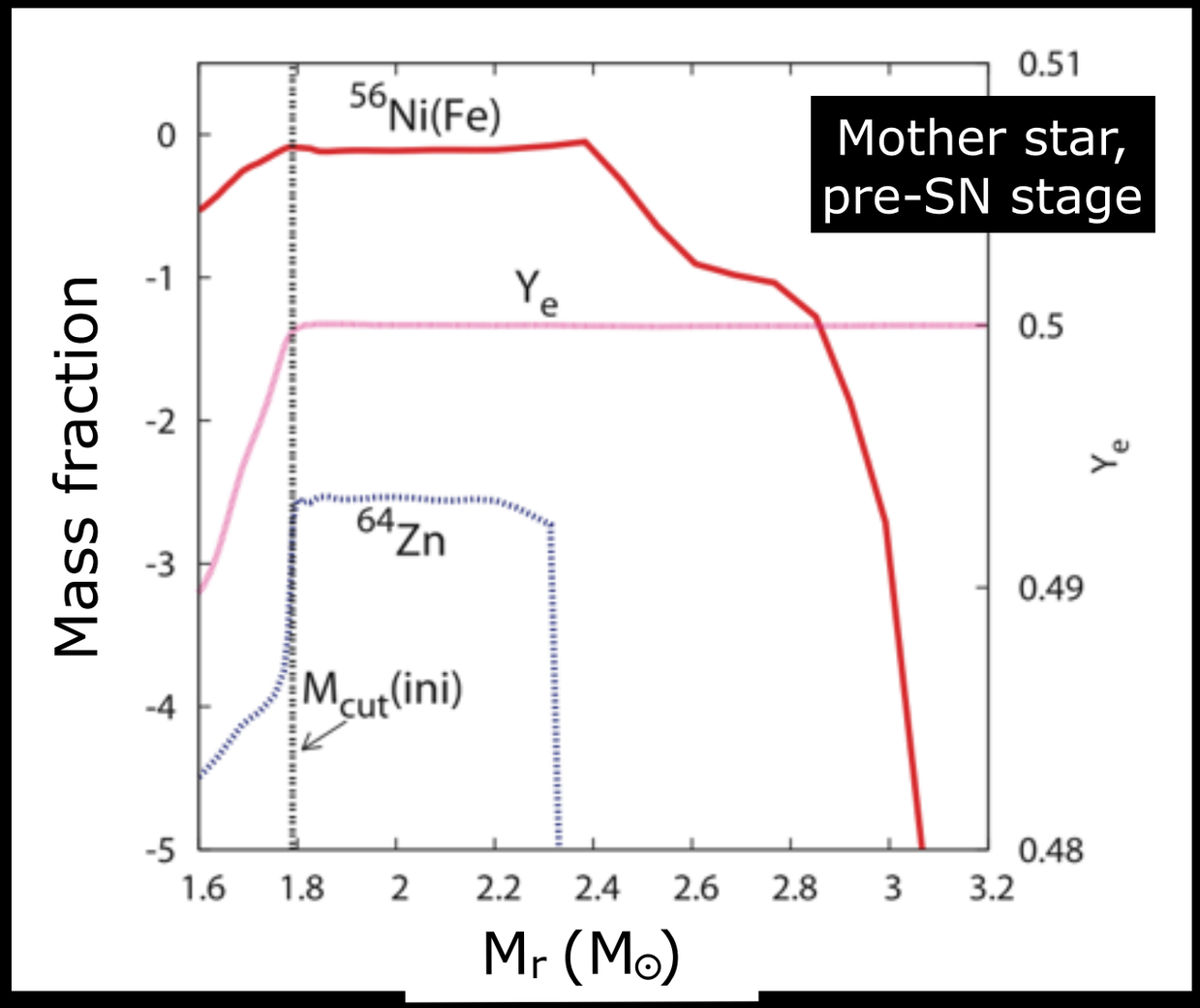

Tominaga et al. (2007)

To eject some Zn
=> deep mass cut
But then : too much Fe

The Mixing & Fallback scenario

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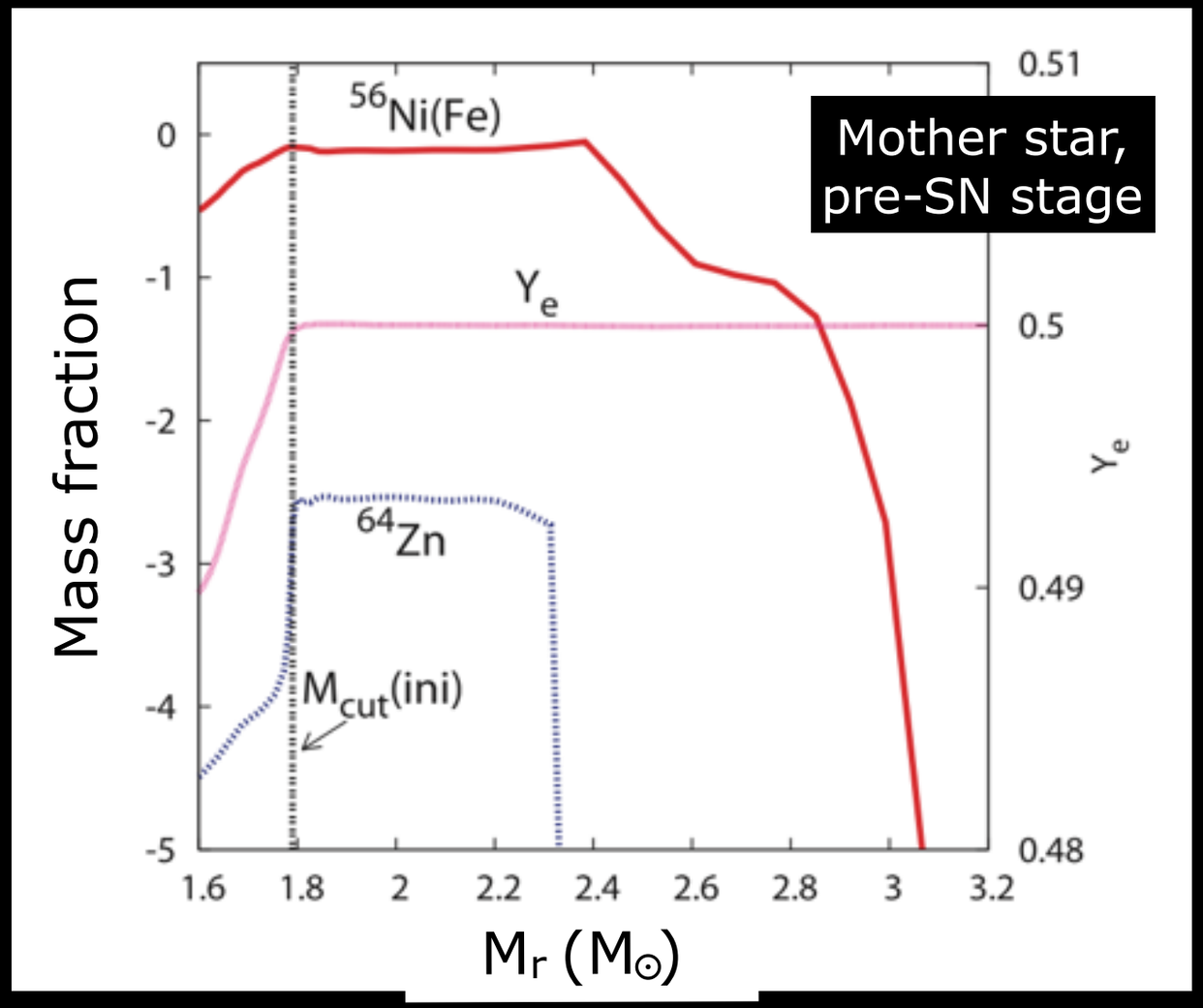

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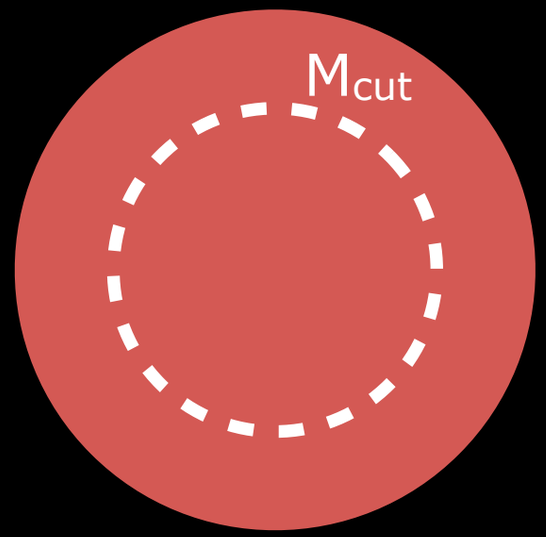

Mother star
(pre-supernova)

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=> deep mass cut
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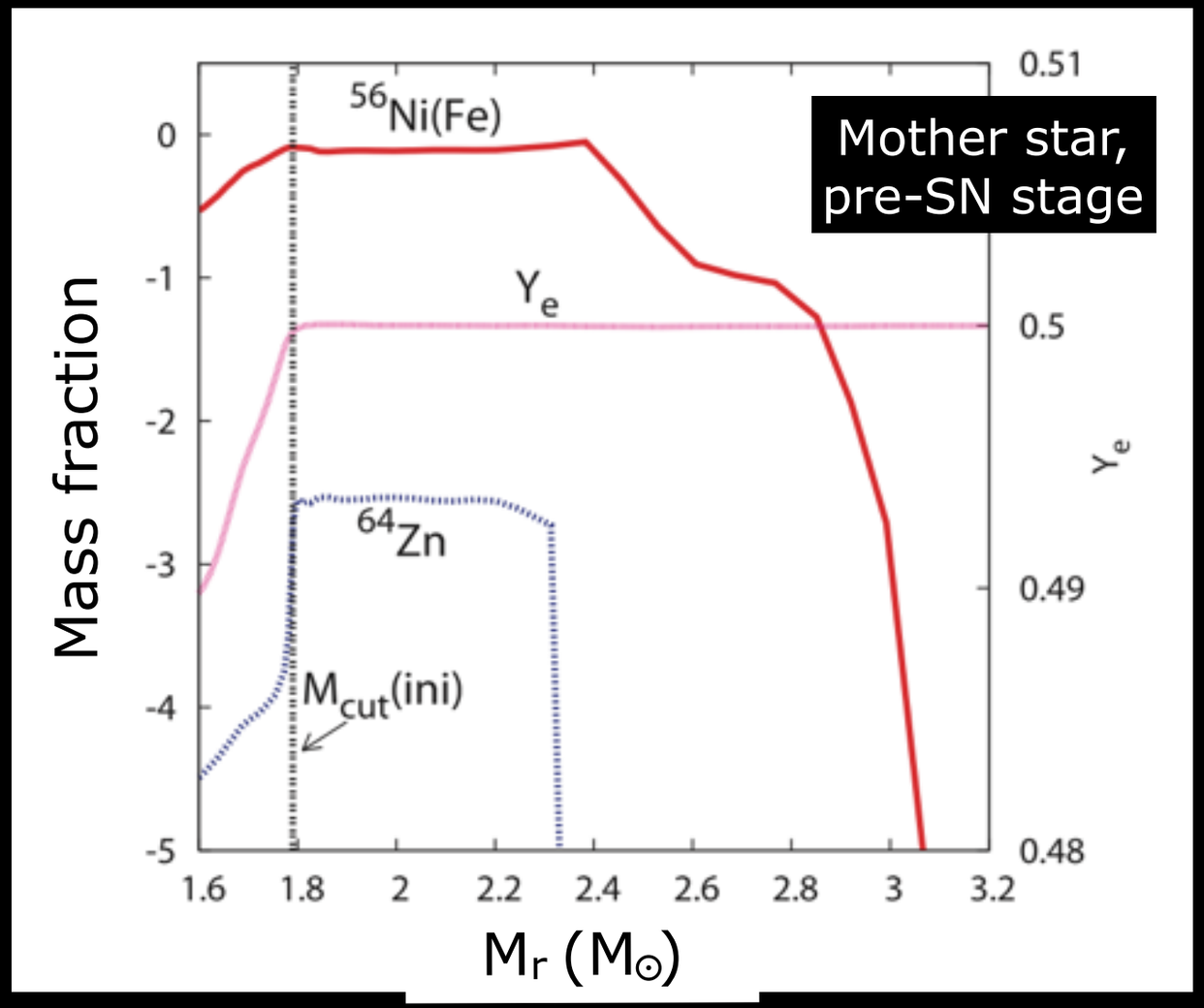

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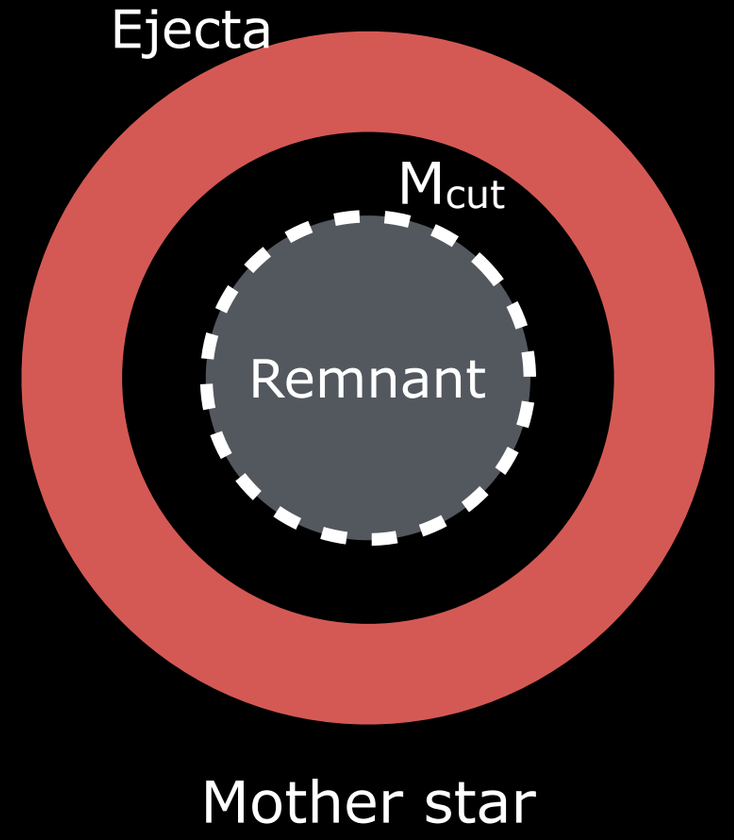

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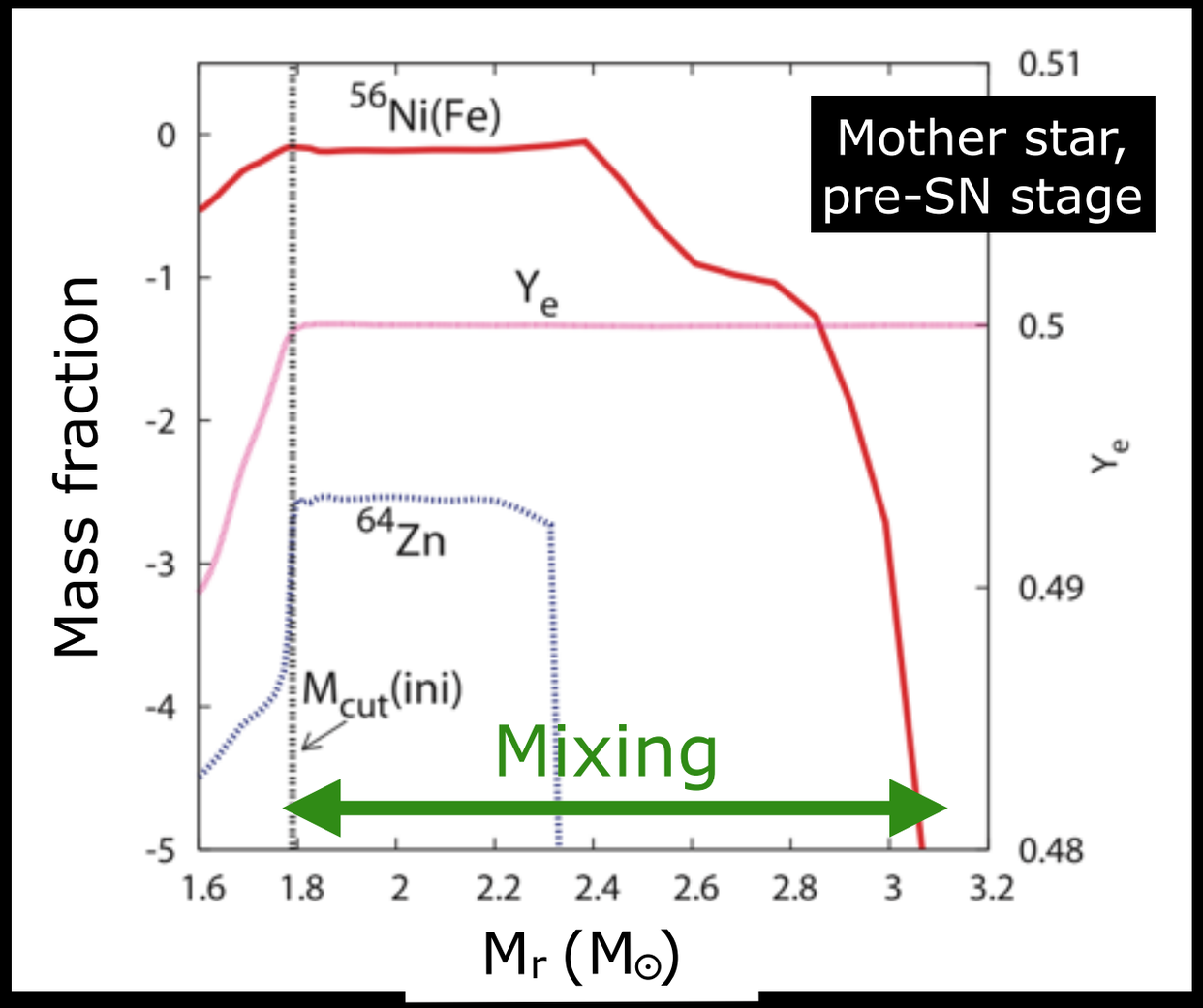

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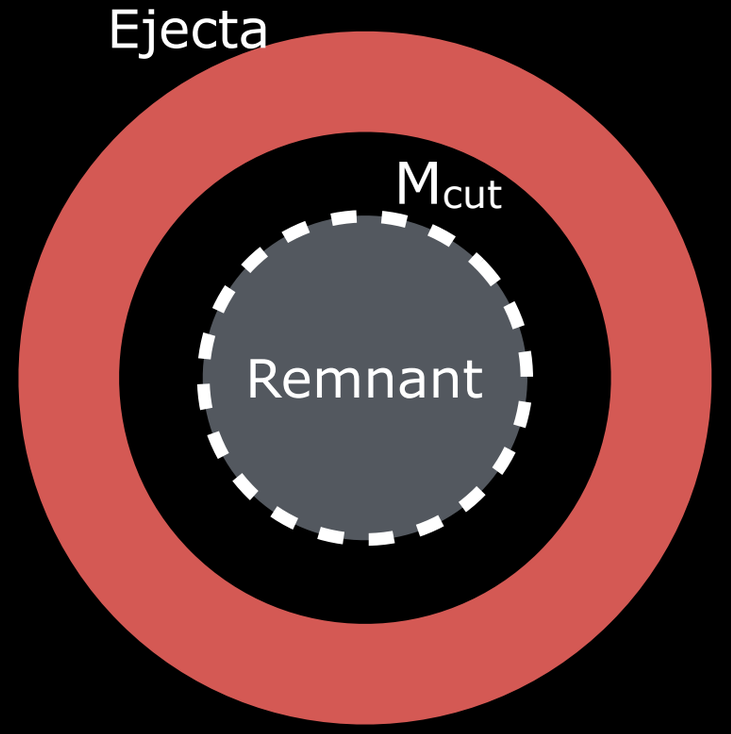

To eject some Zn
=> deep mass cut
But then : too much Fe

→

Mixing & fallback
+ SN (faint for a large C/Fe)

Stellar evolution with rotation

- Differential rotation **=>** turbulence **=>** calibration of 1D models

Stellar evolution with rotation

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to reproduce surface N/H of Galactic B-type at solar Z

Ekstrom+12

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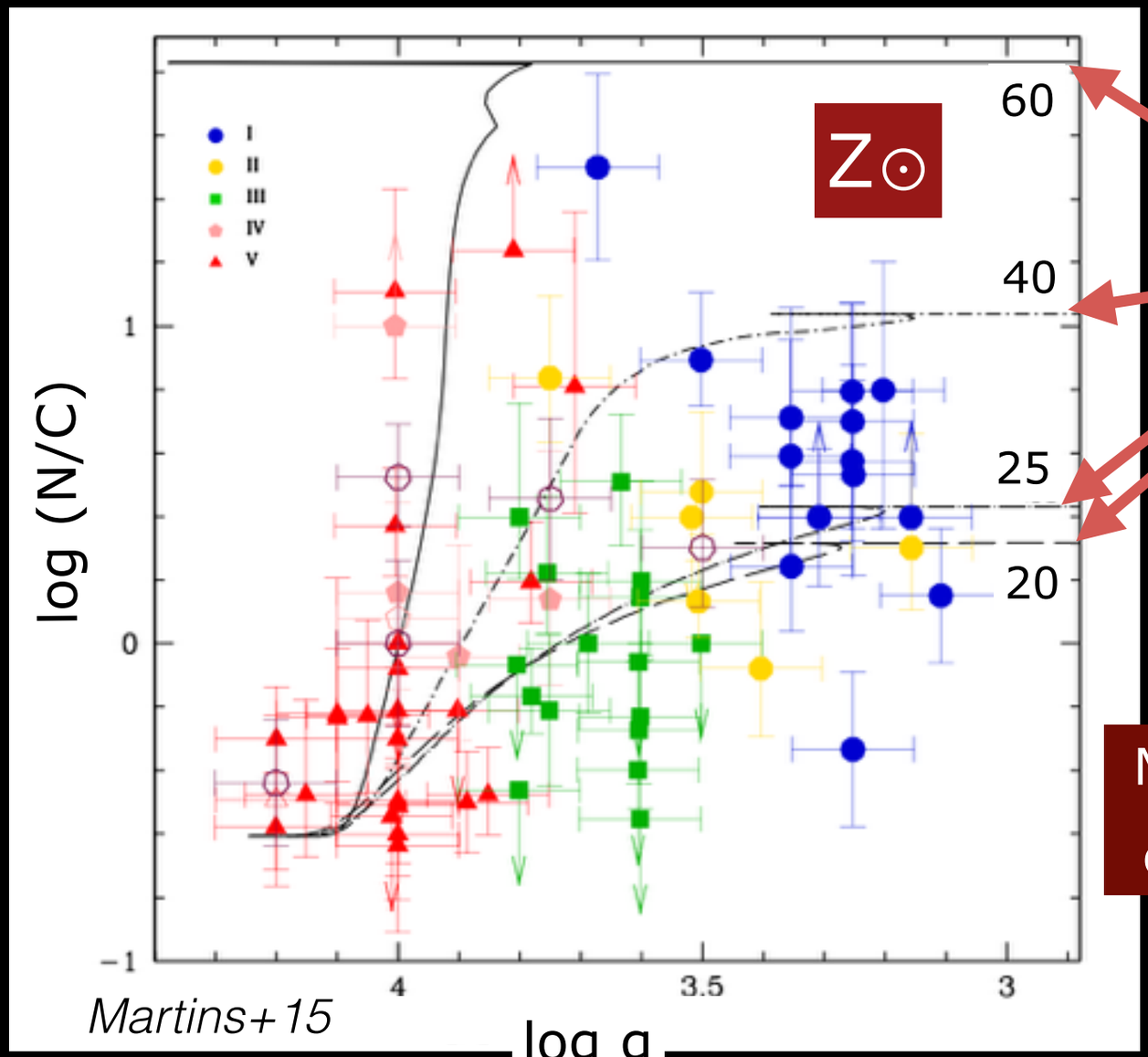

20 - 60 M⊙ Rotating models from *Ekstrom+12*

Models vs. Obs. of O-type stars

Stellar evolution with rotation at low Z

- Physics or rotation at low Z = physics of rotation at solar Z

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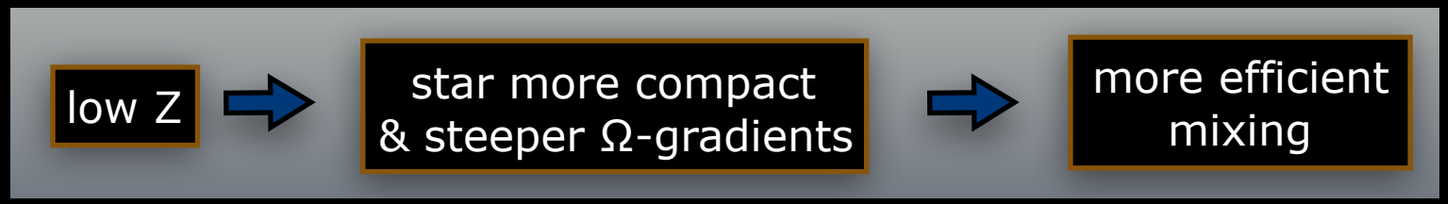

Stellar evolution with rotation at low Z

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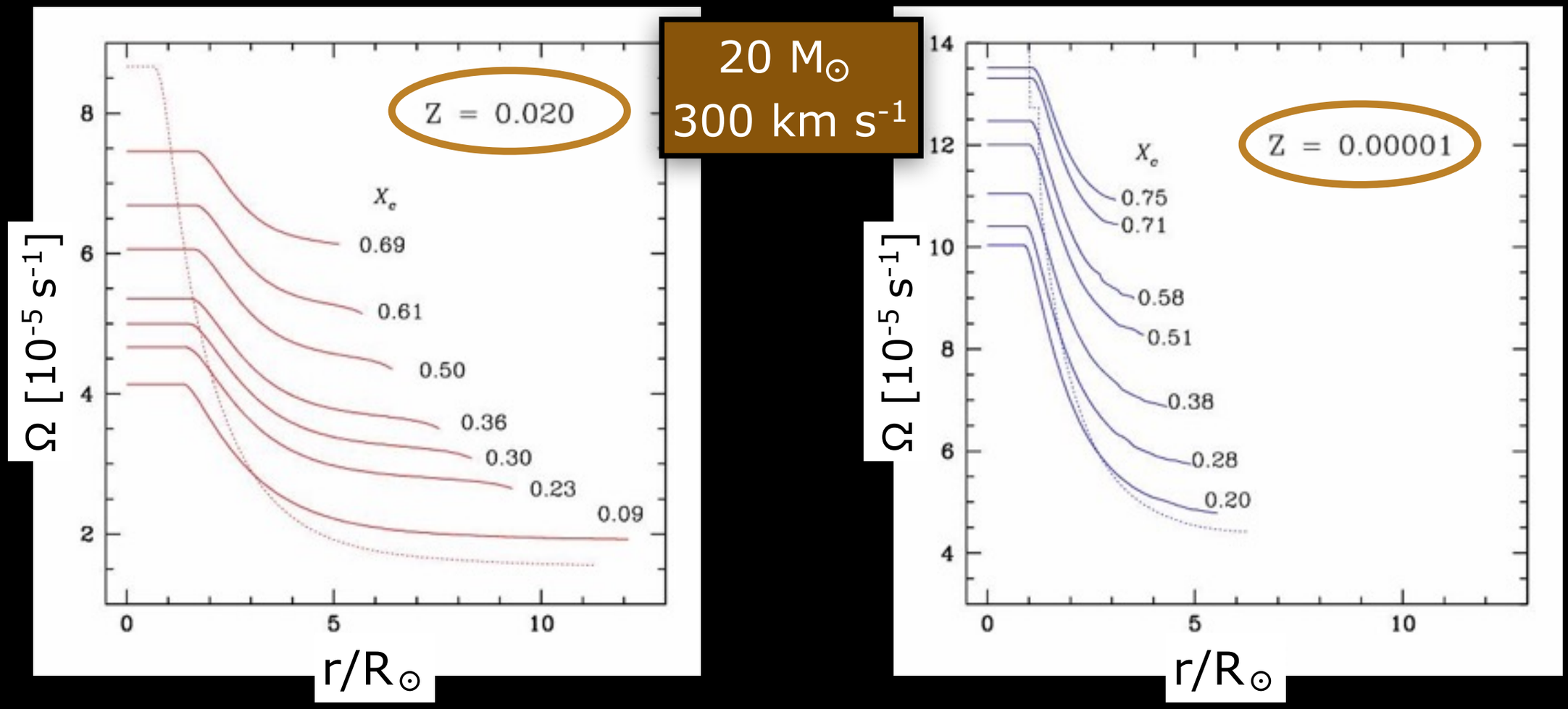
low Z → star more compact & steeper Ω-gradients → more efficient mixing



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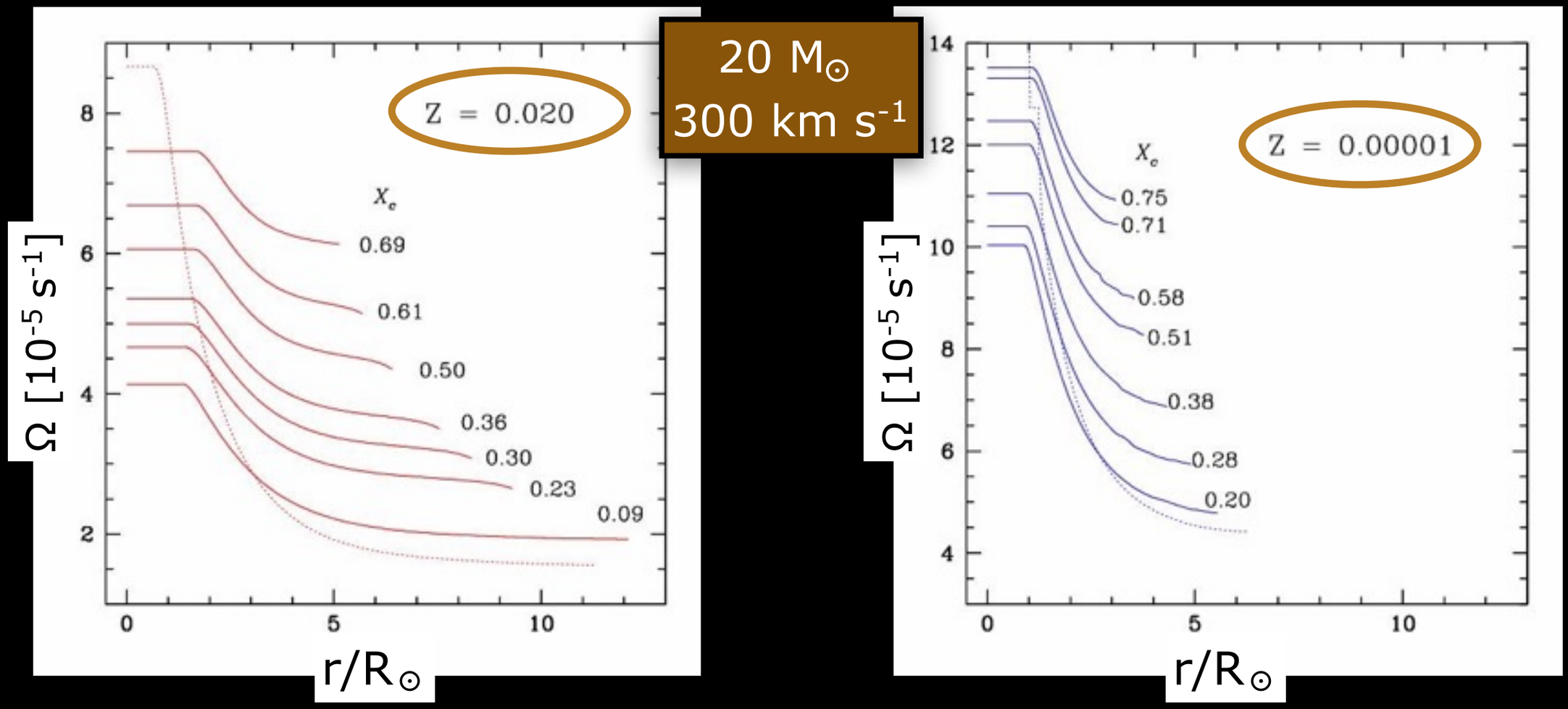

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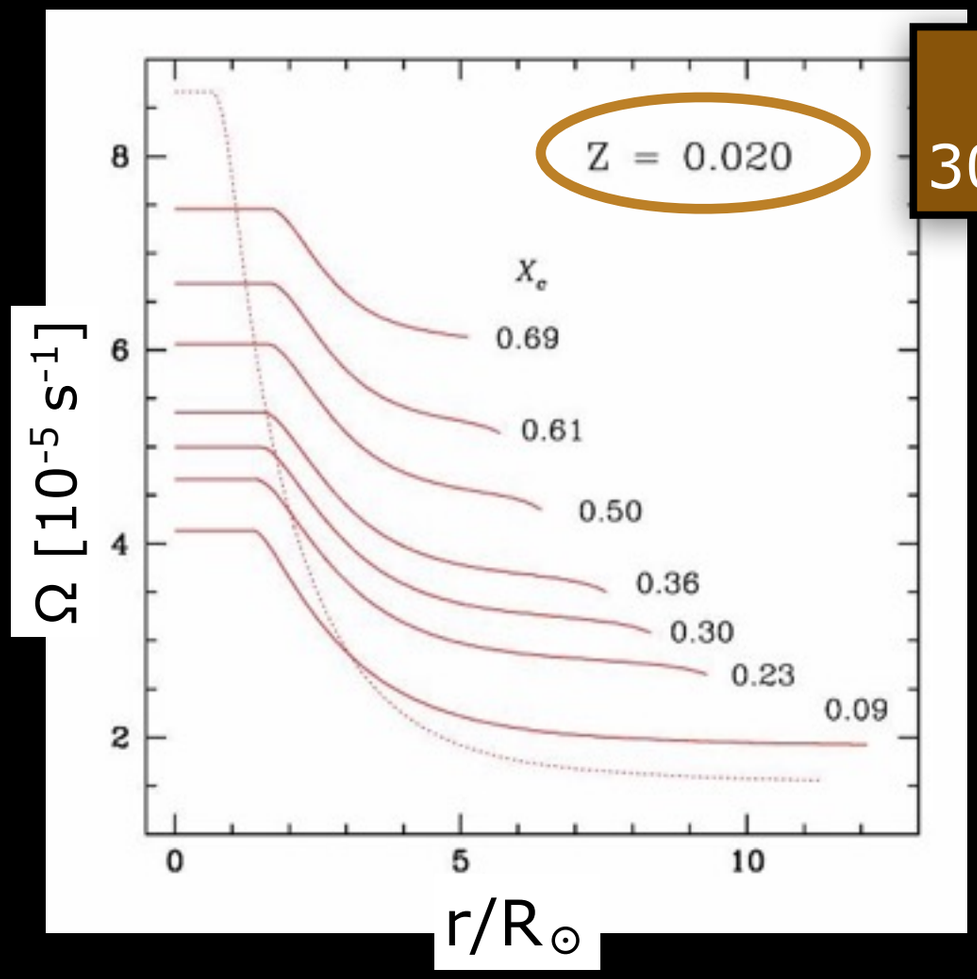
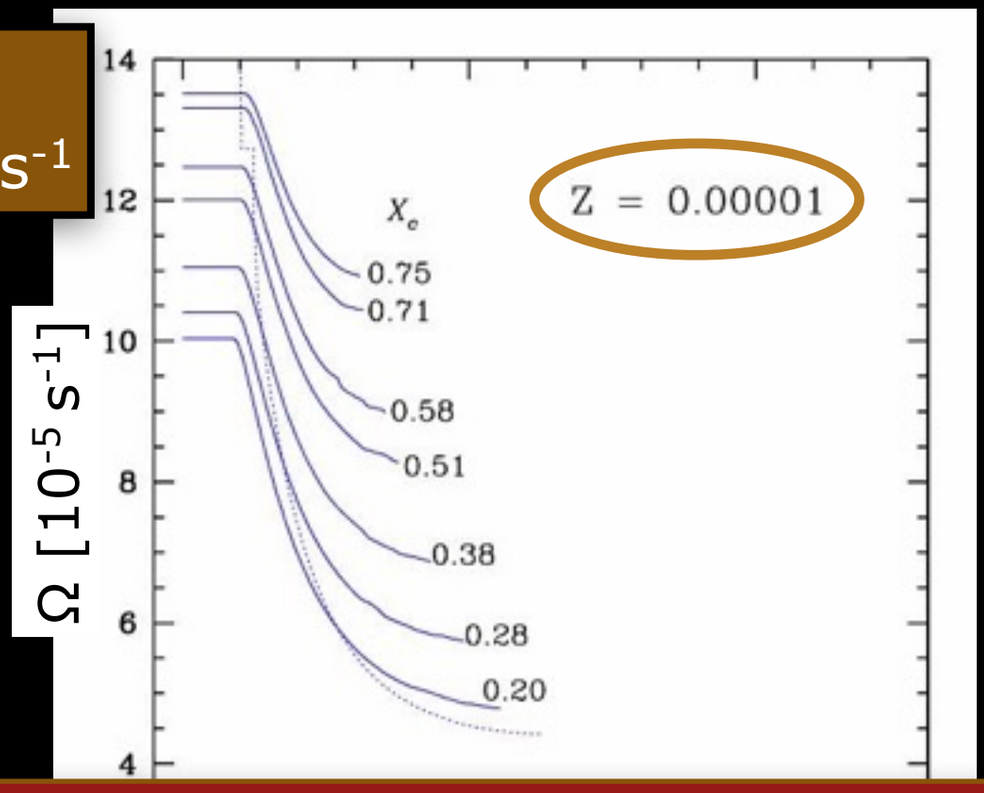


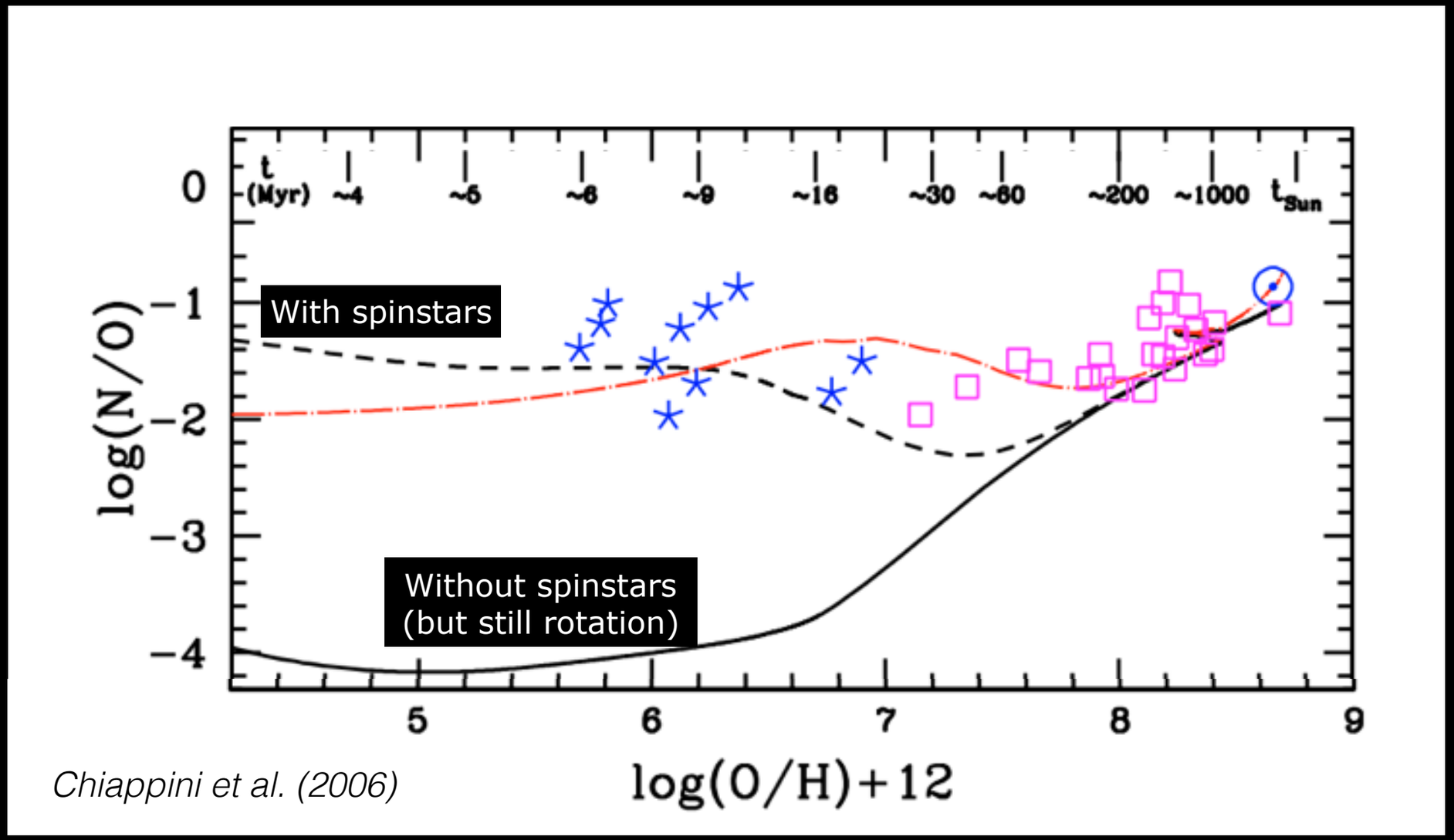


Spinstar : massive low metallicity star whose evolution is significantly affected by rotation

Hints of fast rotation at low metallicity

N/O in VMP normal stars (also C/O, $^{12}C/^{13}C$, Sr/Ba)

Chiappini et al. 2006, 2008, 2011; Fabbian et al. 2009; Cescutti et al. 2013



Data : normal VMP stars from Israelian et al. (2004) and Spite et al. (2005)

Anatomy of a rotating star

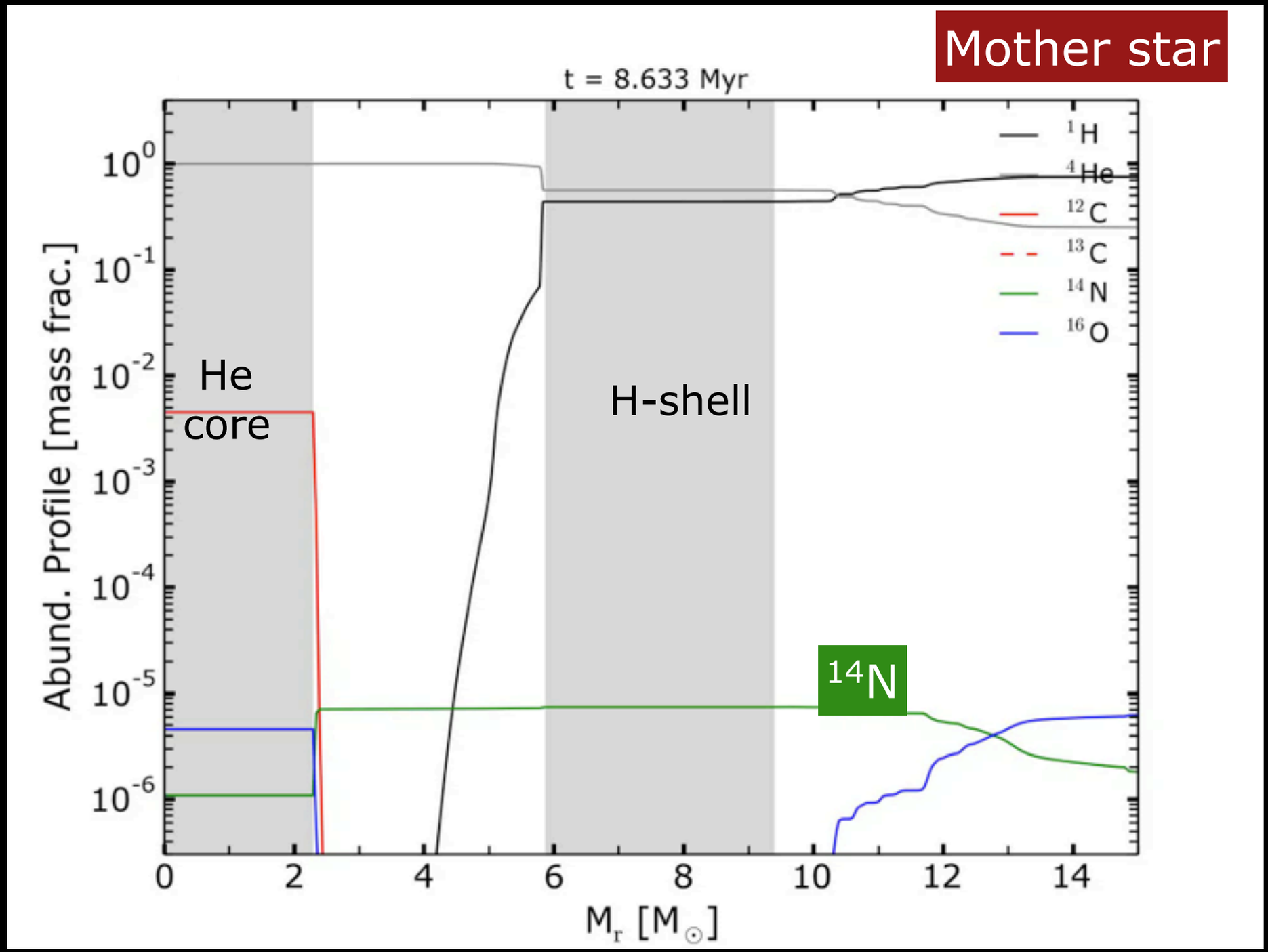
20 $M_\odot$

$Z=10^{-5}$

$\Omega_{ini}/\Omega_{crit}$ = 0.15

(v_{ini} = 90 km s^{-1})

- ^{14}N,^{13}C (CNO cycle)



Anatomy of a rotating star

20 $M_\odot$

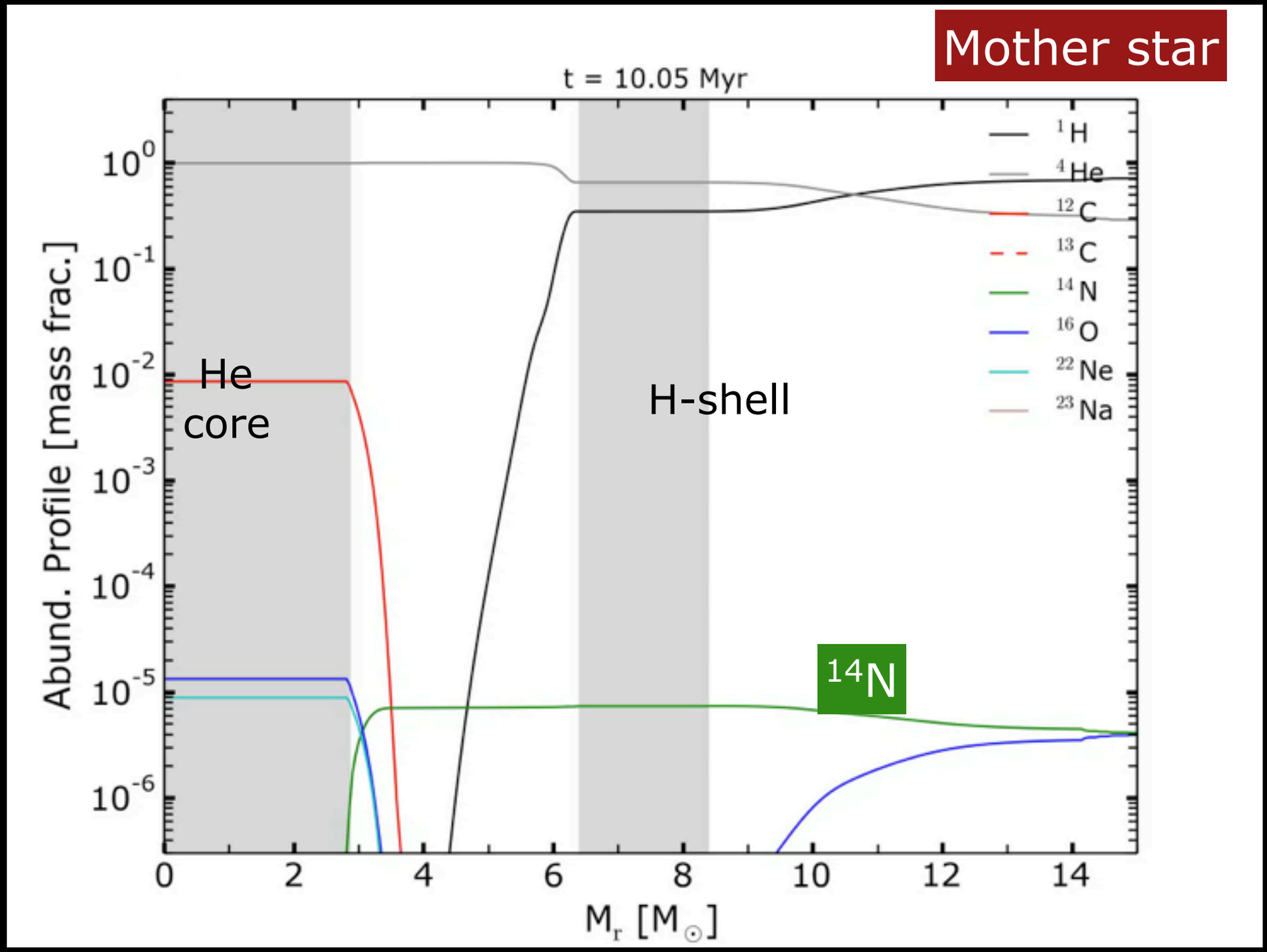
$Z=10^{-5}$

$\Omega_{ini}/\Omega_{crit}$ = 0.9

(v_{ini} = 640 km s^{-1})

- ^{14}N,^{13}C (CNO cycle)
- ^{22}Ne

$^{14}N + 2 \times {}^{4}He \rightarrow {}^{22}Ne$



Anatomy of a rotating star

20 $M_\odot$

$Z=10^{-5}$

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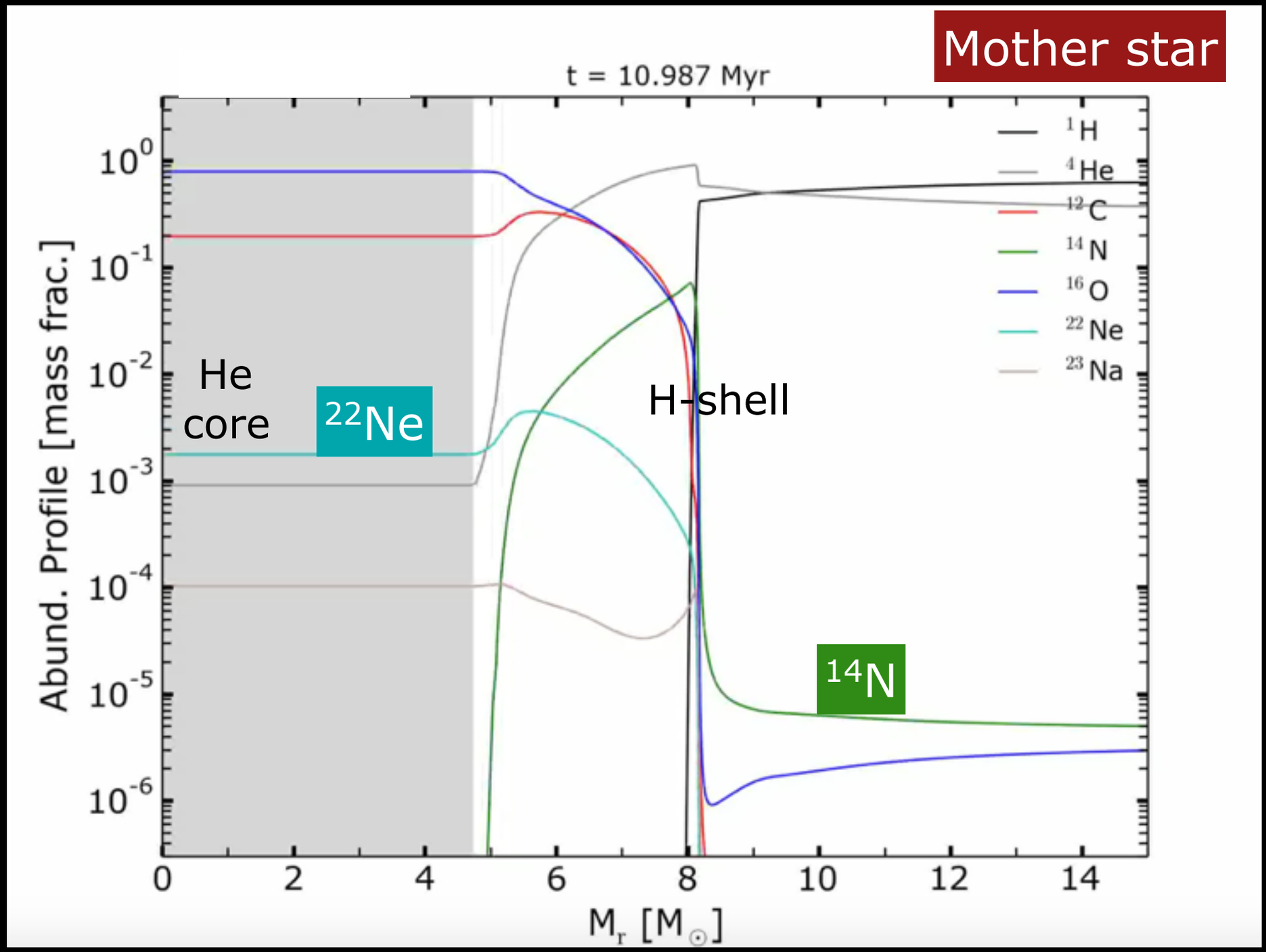

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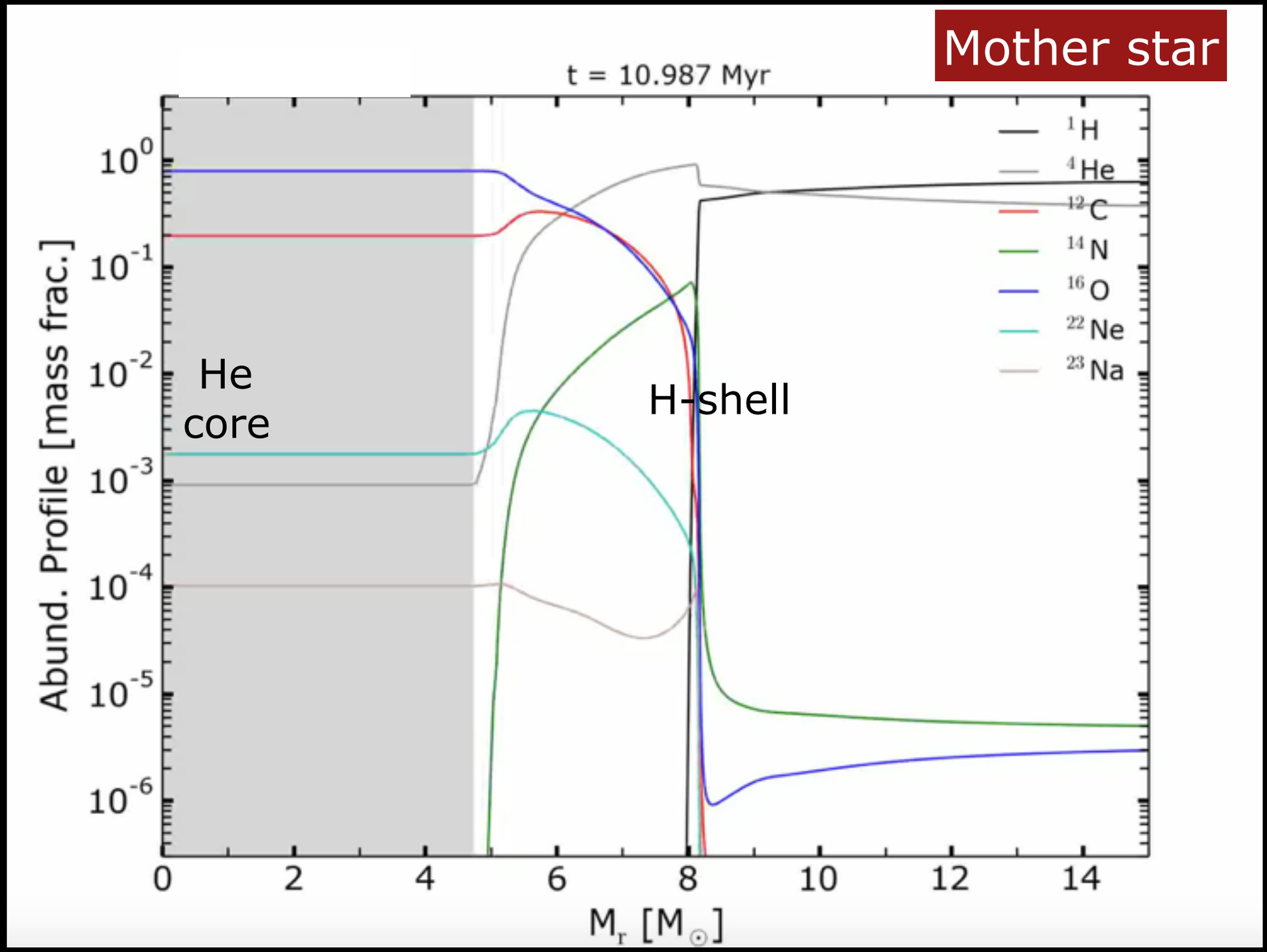
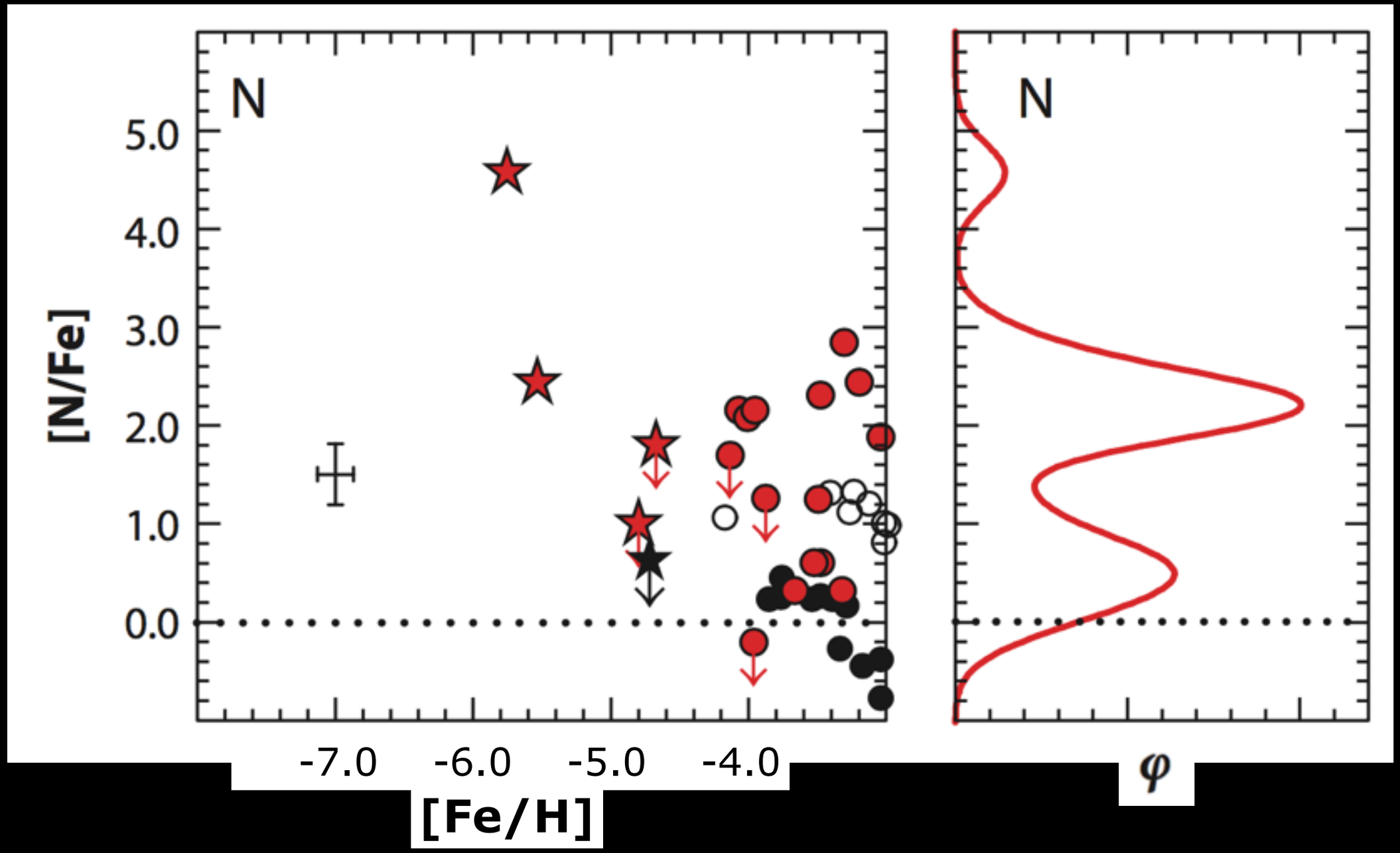
- s-process (if Fe)

—> e.g. Sr

(Frischknecht+12,16)

Spinstar : rich and varied nucleosynthesis





From Frebel+15

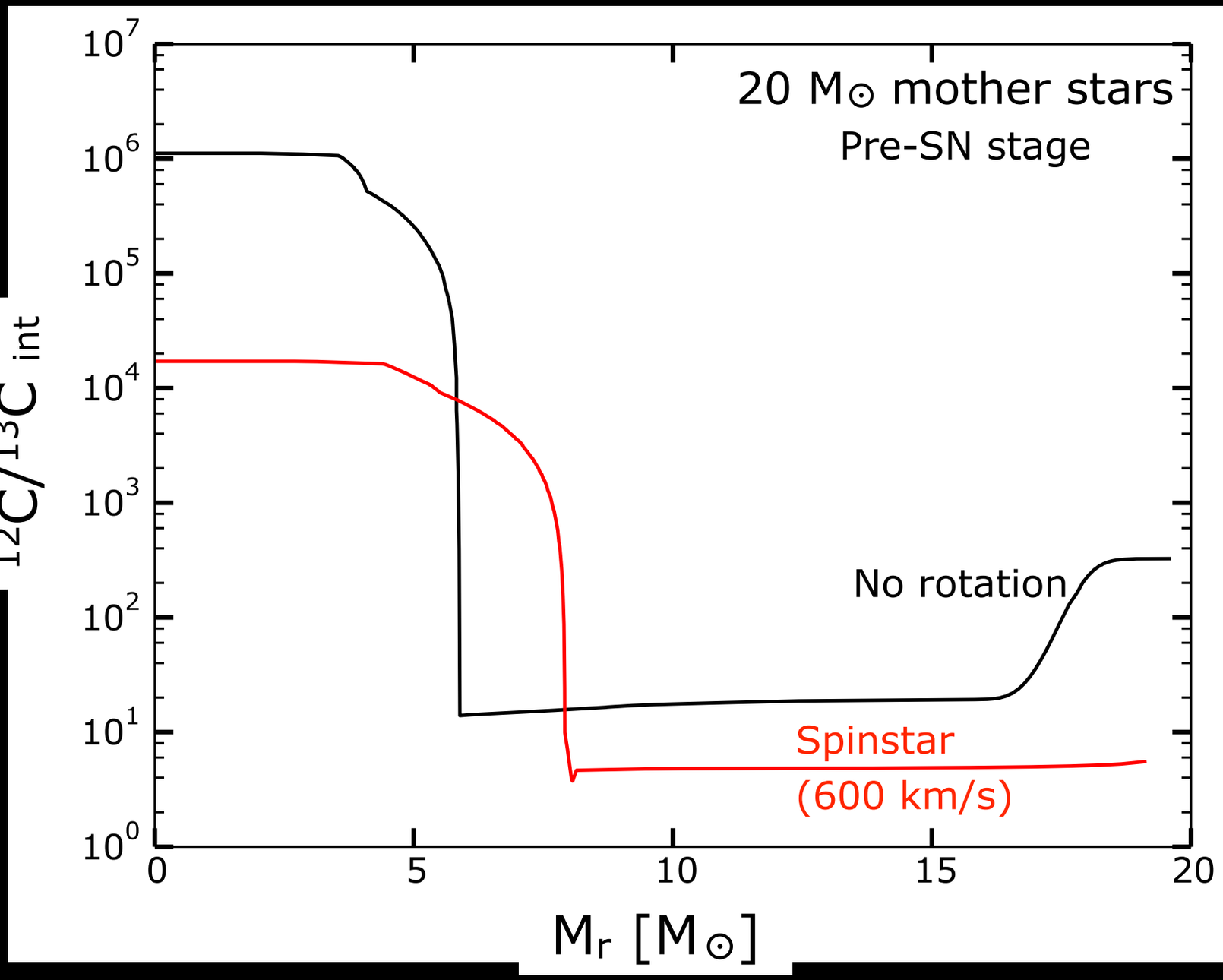
data from Cayrel et al. (2004), Spite et al. (2005), Sivarani et al. (2006), Caffau et al. (2012), Cohen et al. (2013), Norris et al. (2013), Yong et al. (2013a), Hansen et al. (2014), and Keller et al. (2014)

	Spinstar	**Mixing & fallback**
Mixing during the evolution of the mother star		
Mixing at the end of evolution of the mother star		

	Spinstar	**Mixing & fallback**
Mixing during the evolution of the mother star	✓	✗
Mixing at the end of evolution of the mother star	✗	✓

Do we need both kind of mixing ?

The $^{12}C/^{13}C$ ratio



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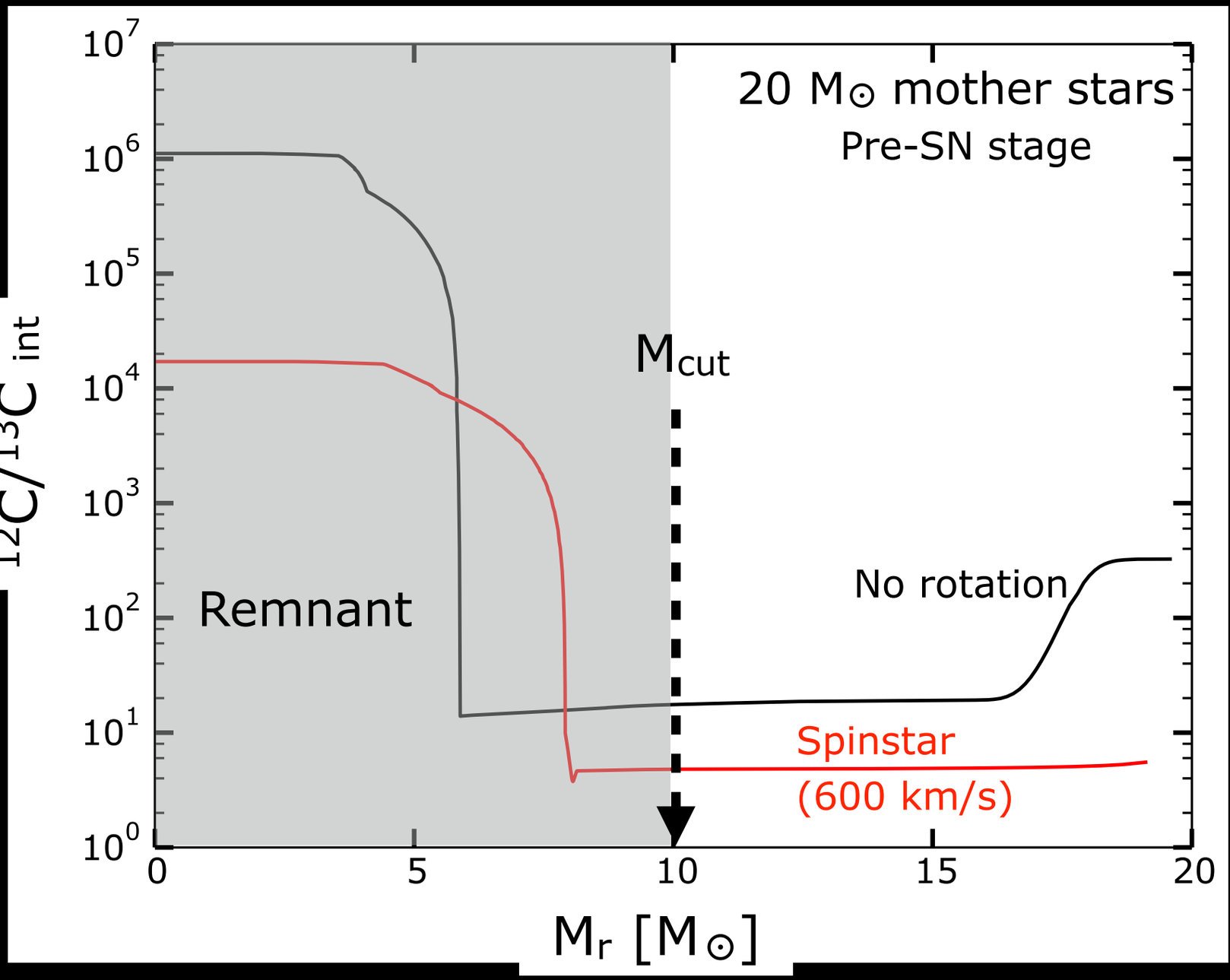

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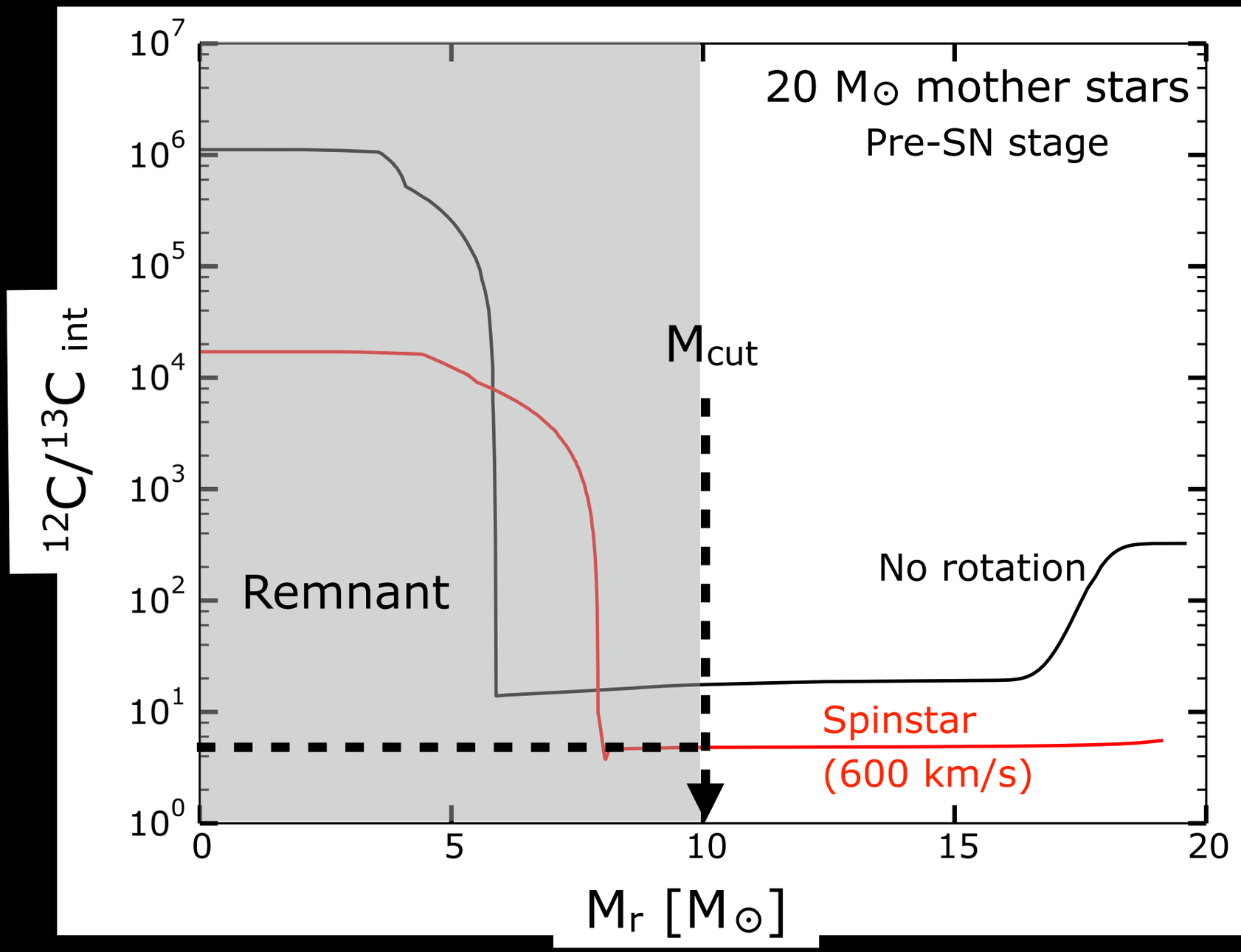

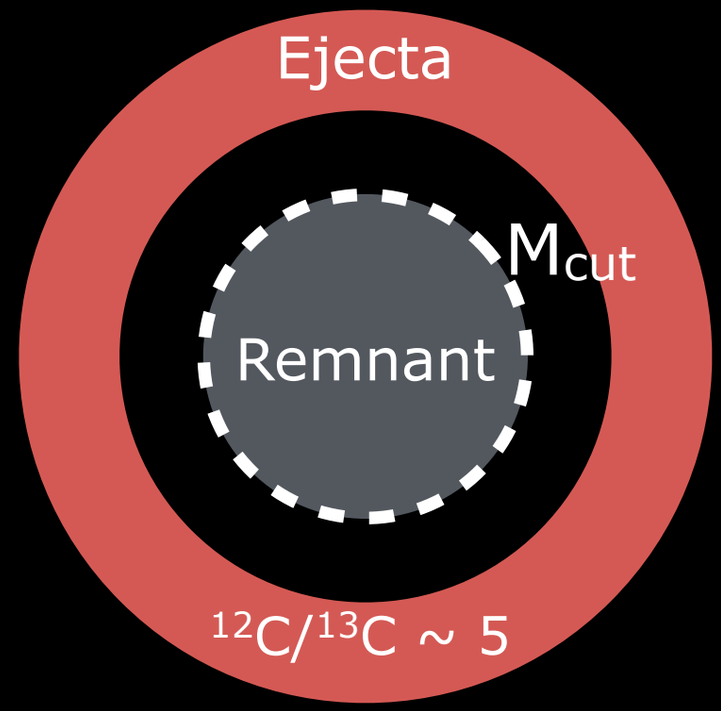

Spinstar

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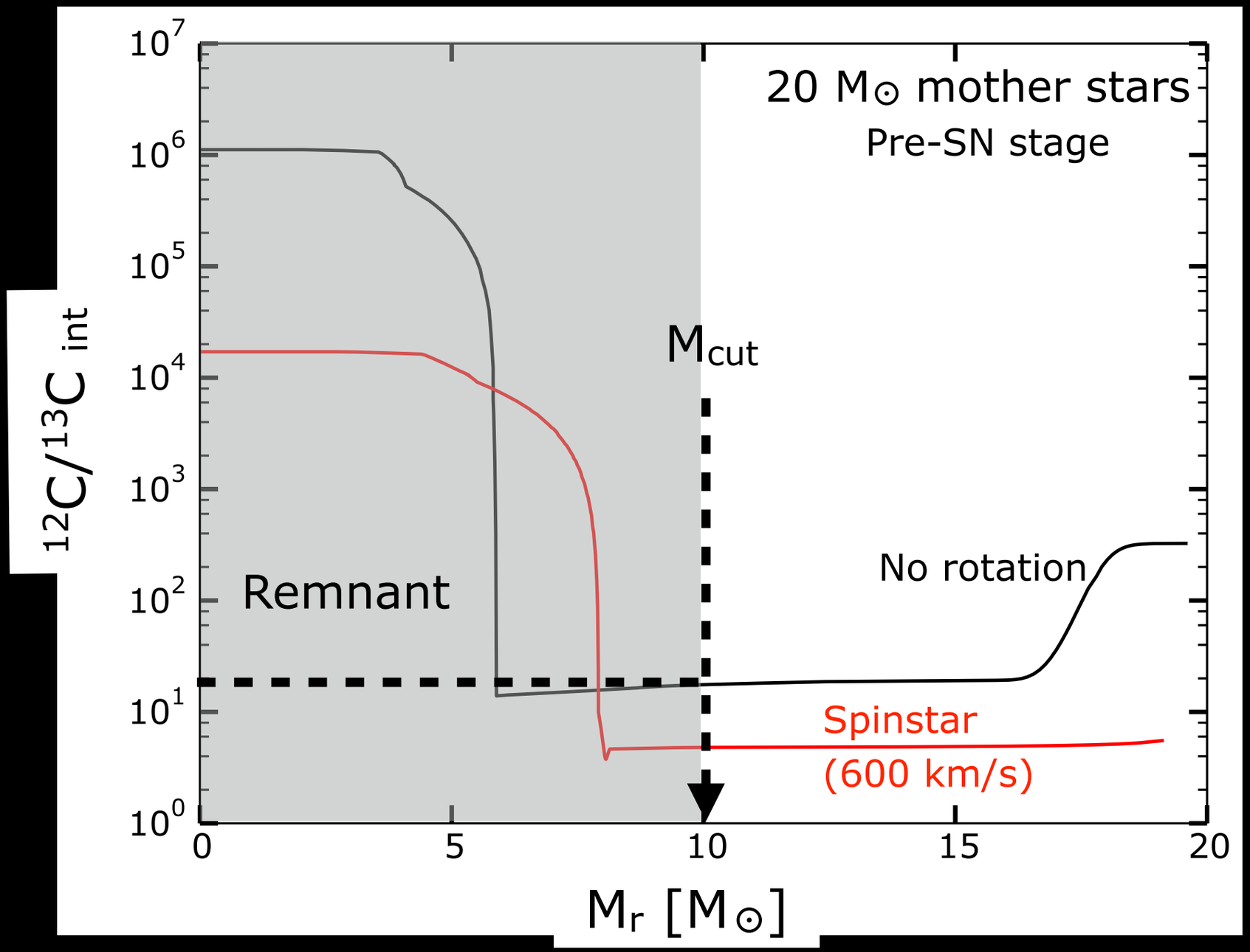

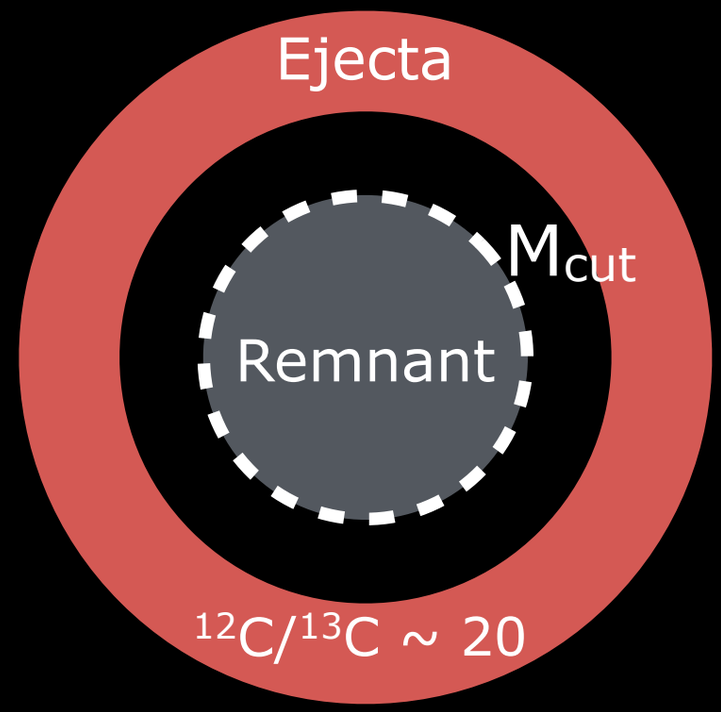

Non rotating
mother star

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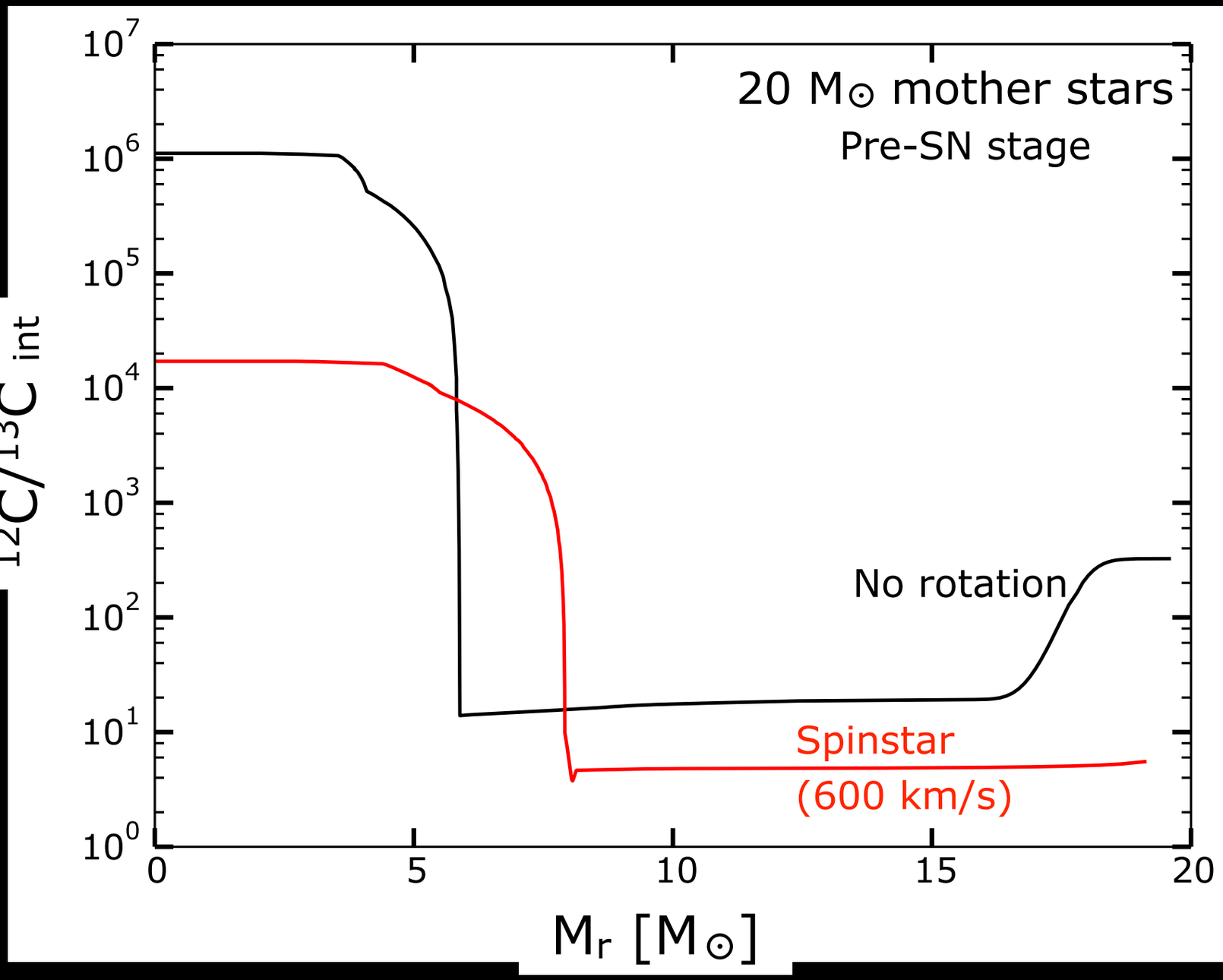

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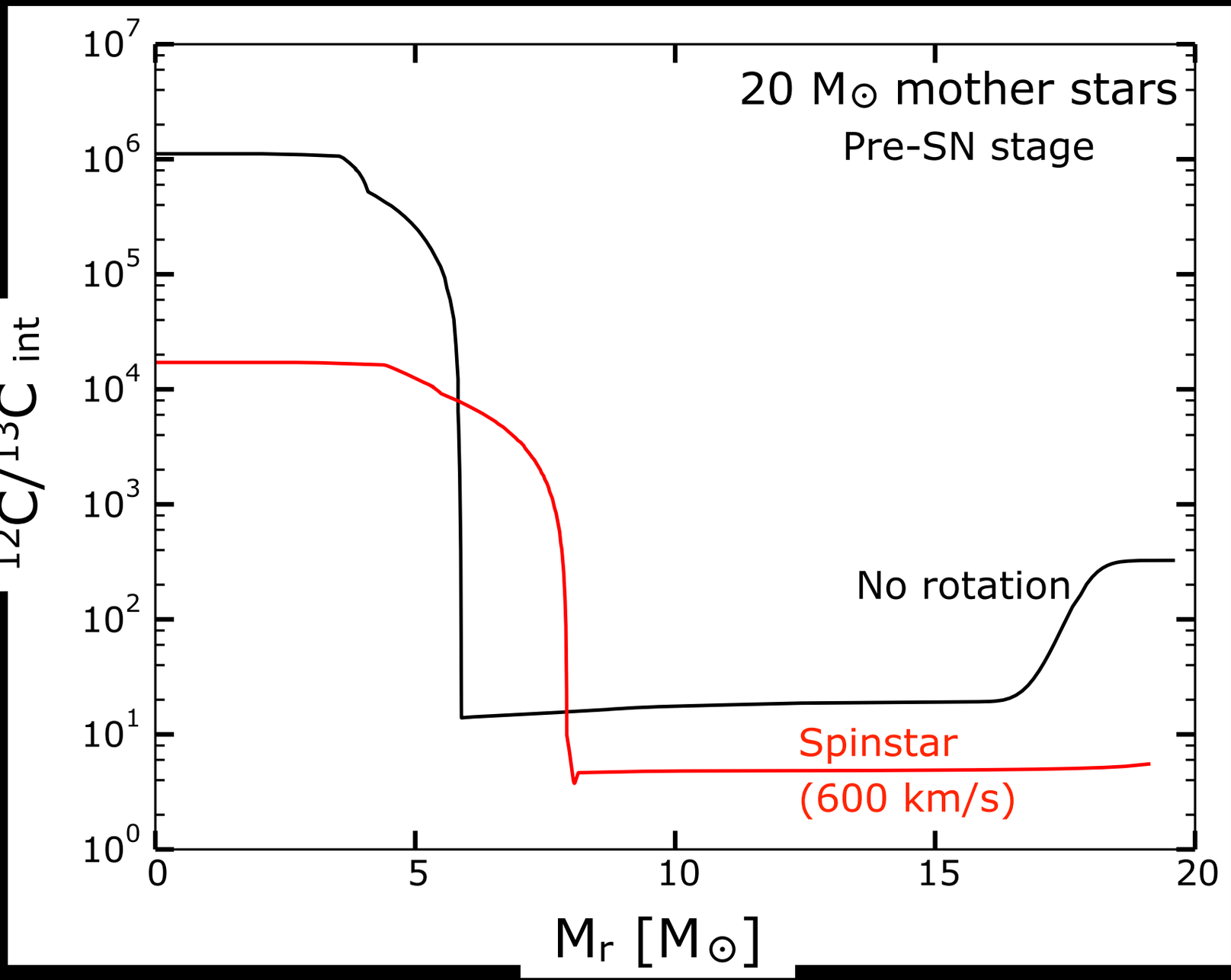

[Fe/H] < -3

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G77-61 **(MS)**
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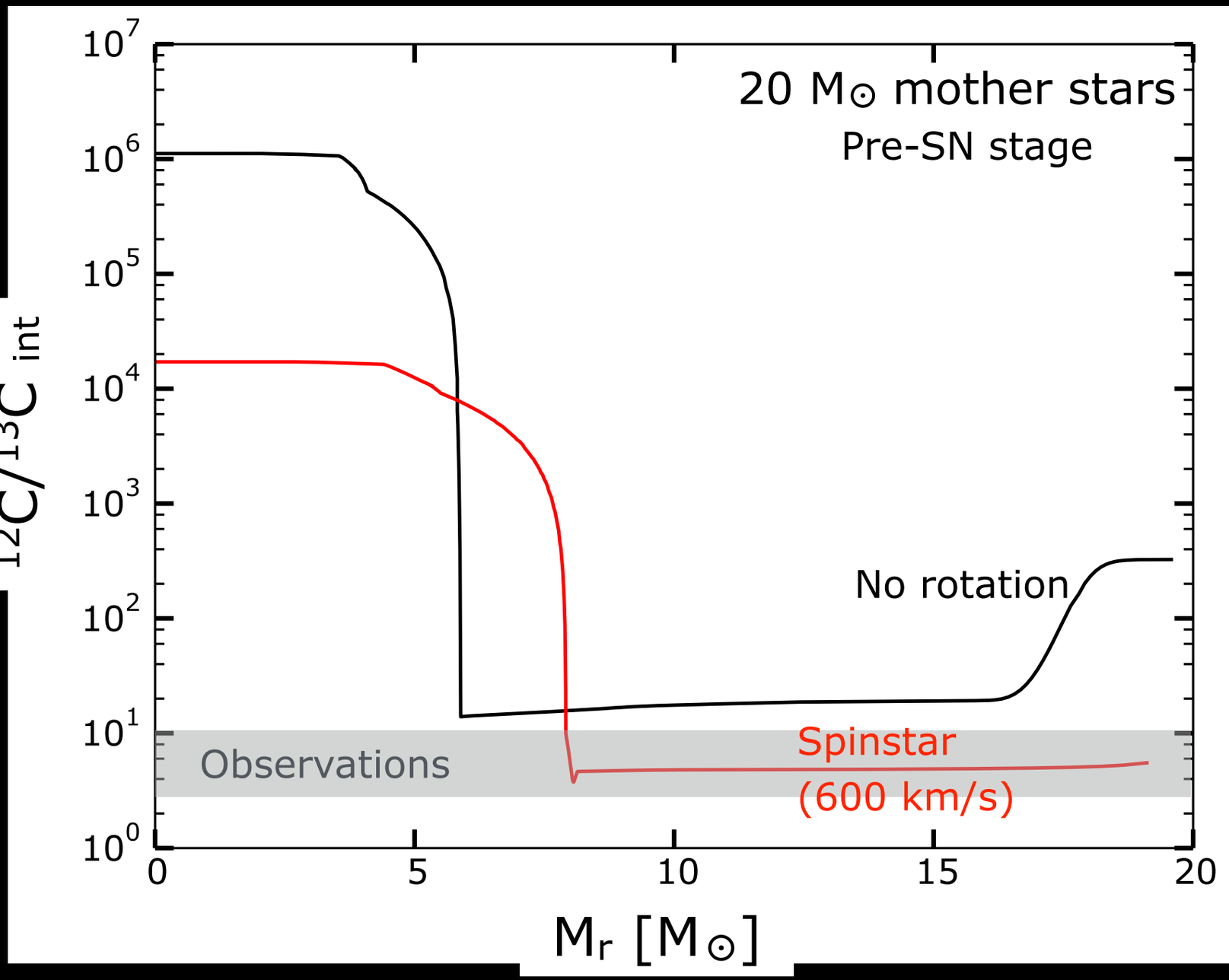

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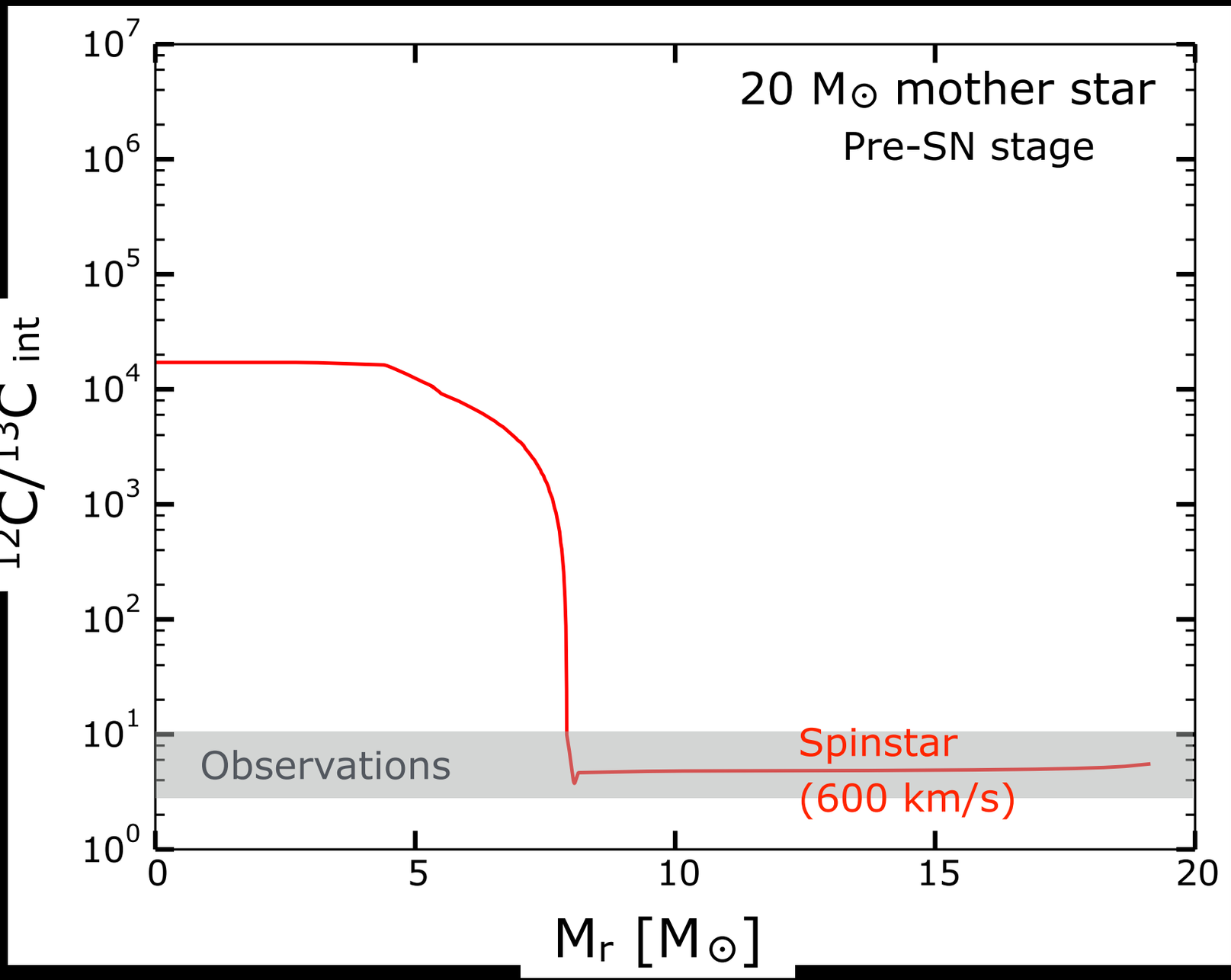

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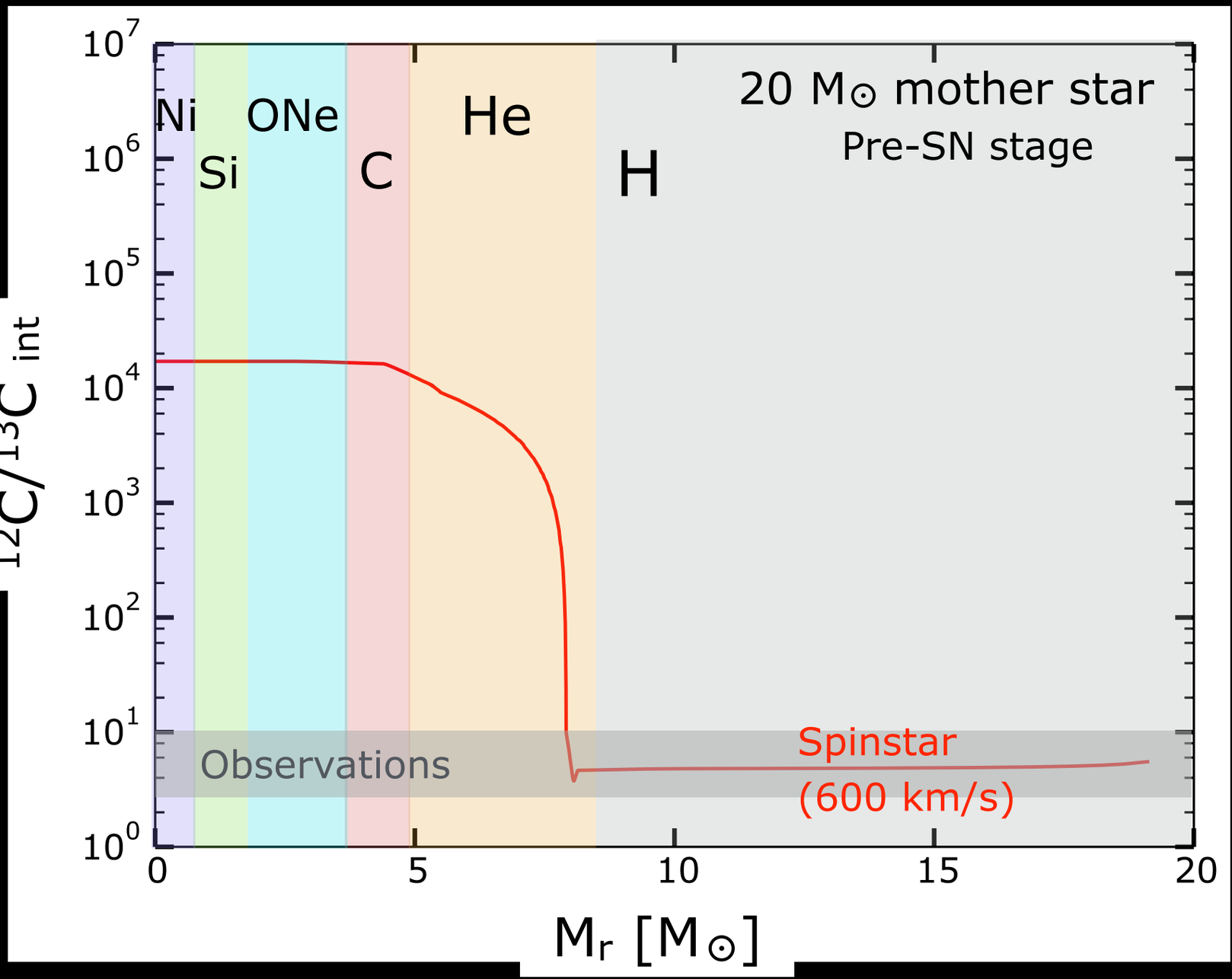

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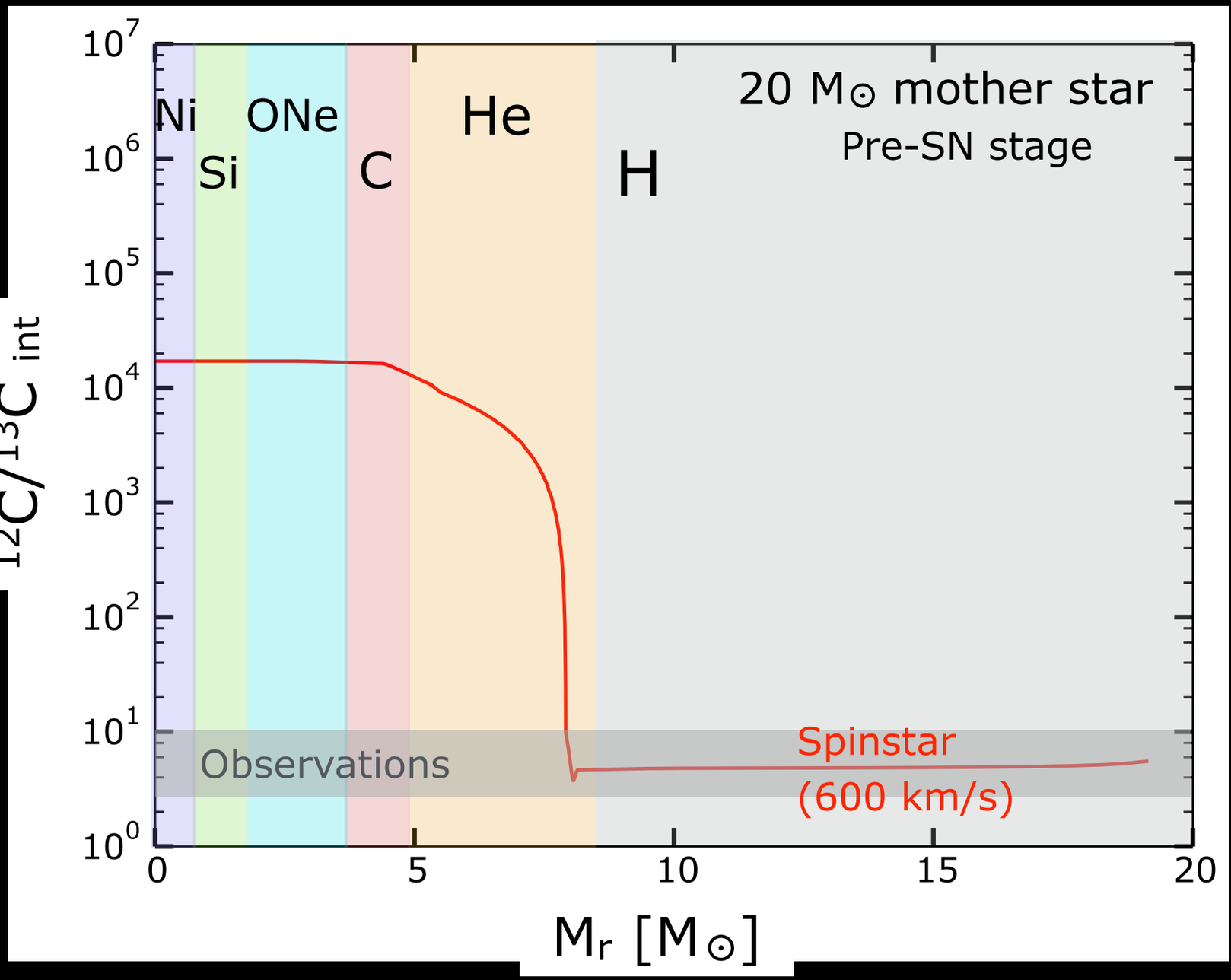

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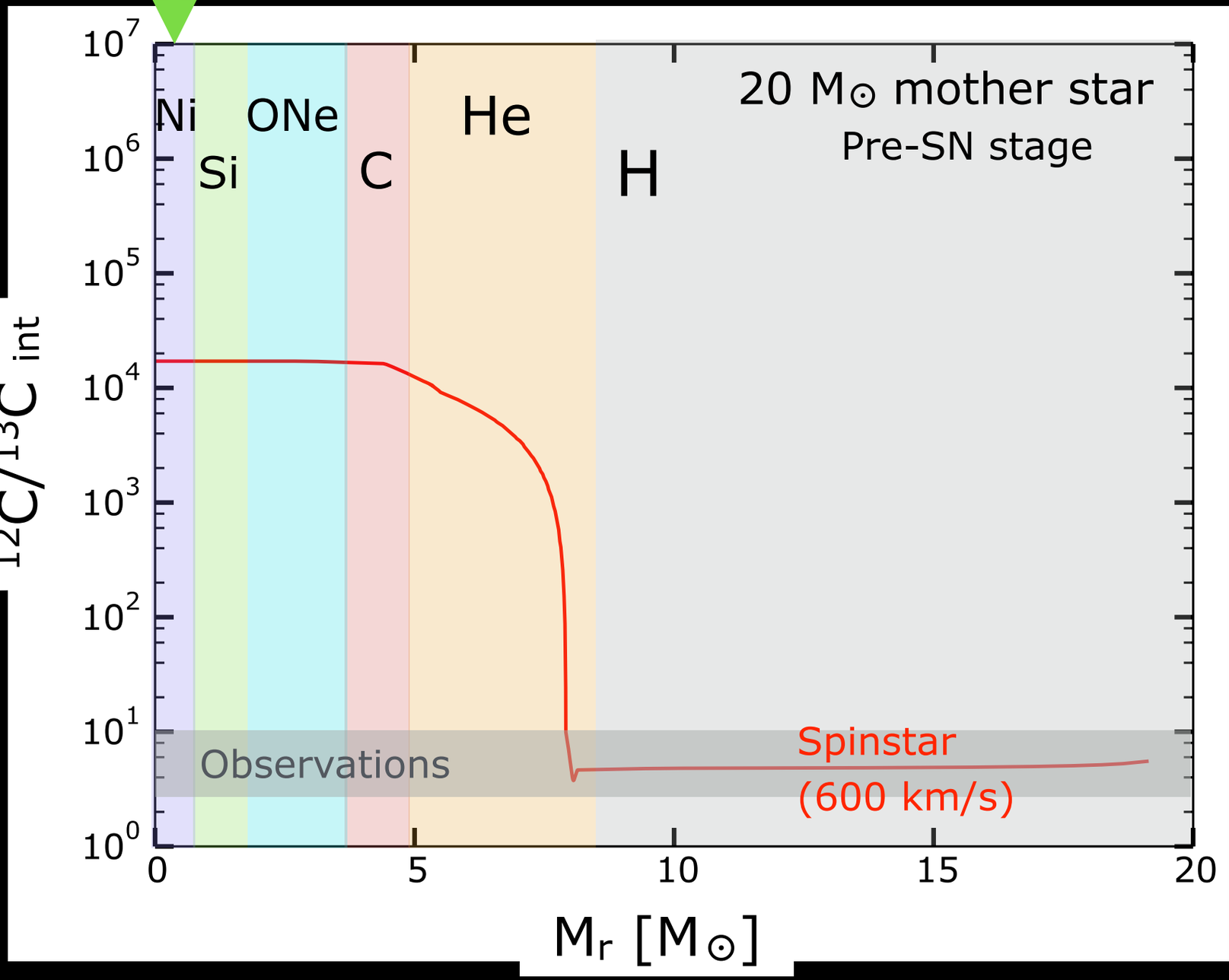
Zn



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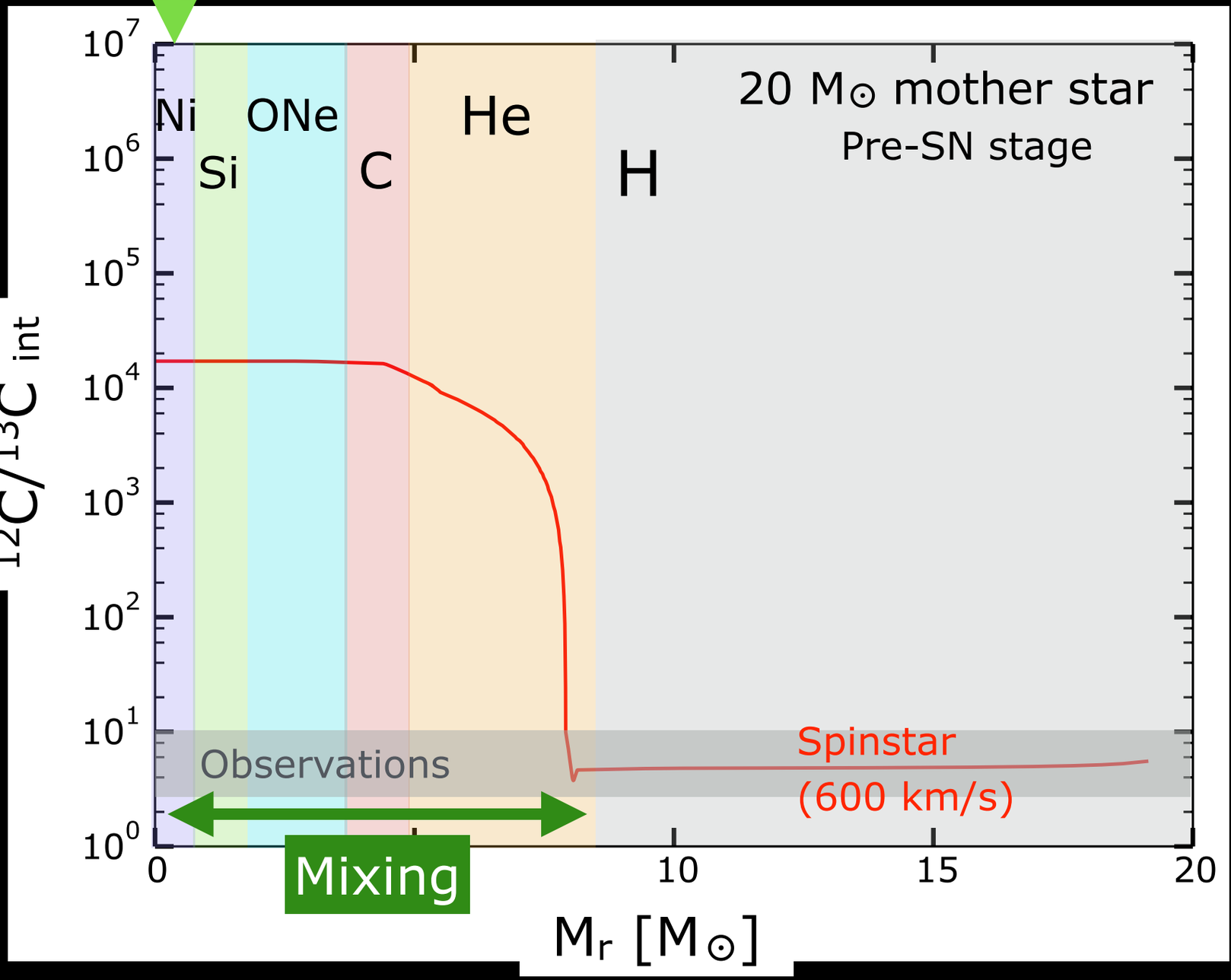

=> Mixing at the end of the mother star evolution

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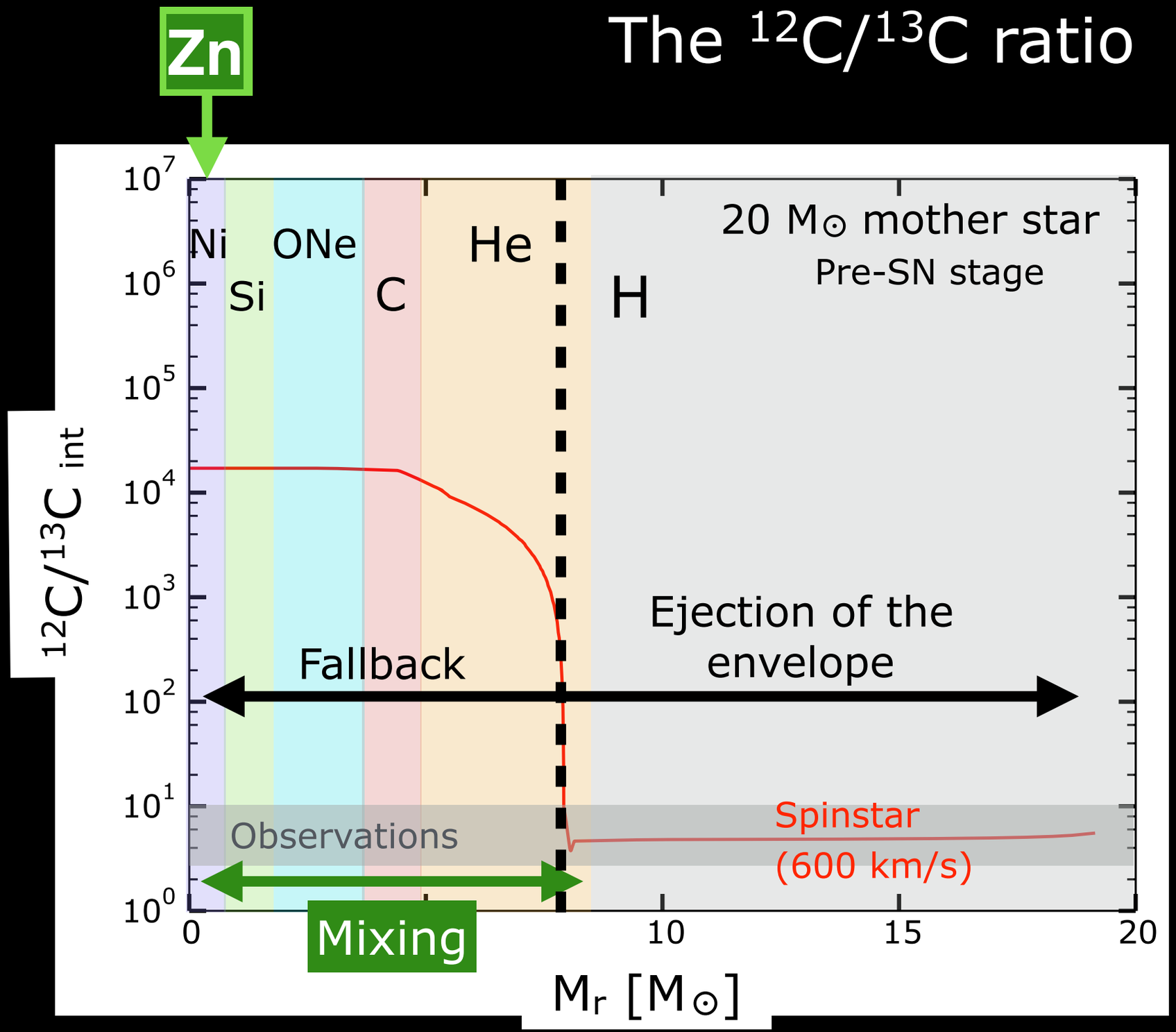

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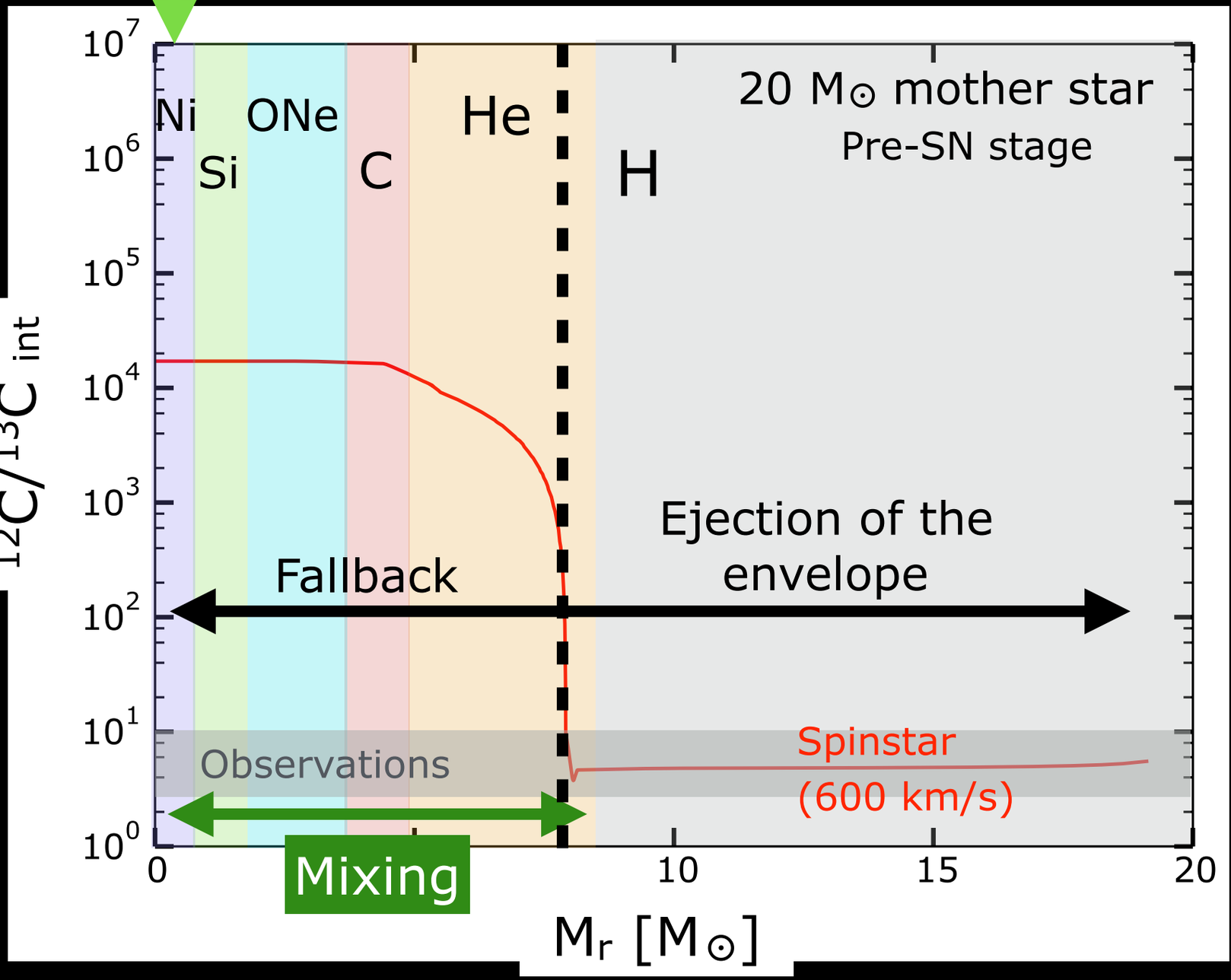

=> Mixing during and at the end of evolution

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18 / 22 CEMP-s in binary systems

Hansen+16

see O. Pols presentation !
see A. Karakas presentation ?

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- CEMP-s : AGB scenario but some CEMP-s appear to be single

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4 / 22 single

see O. Pols presentation !
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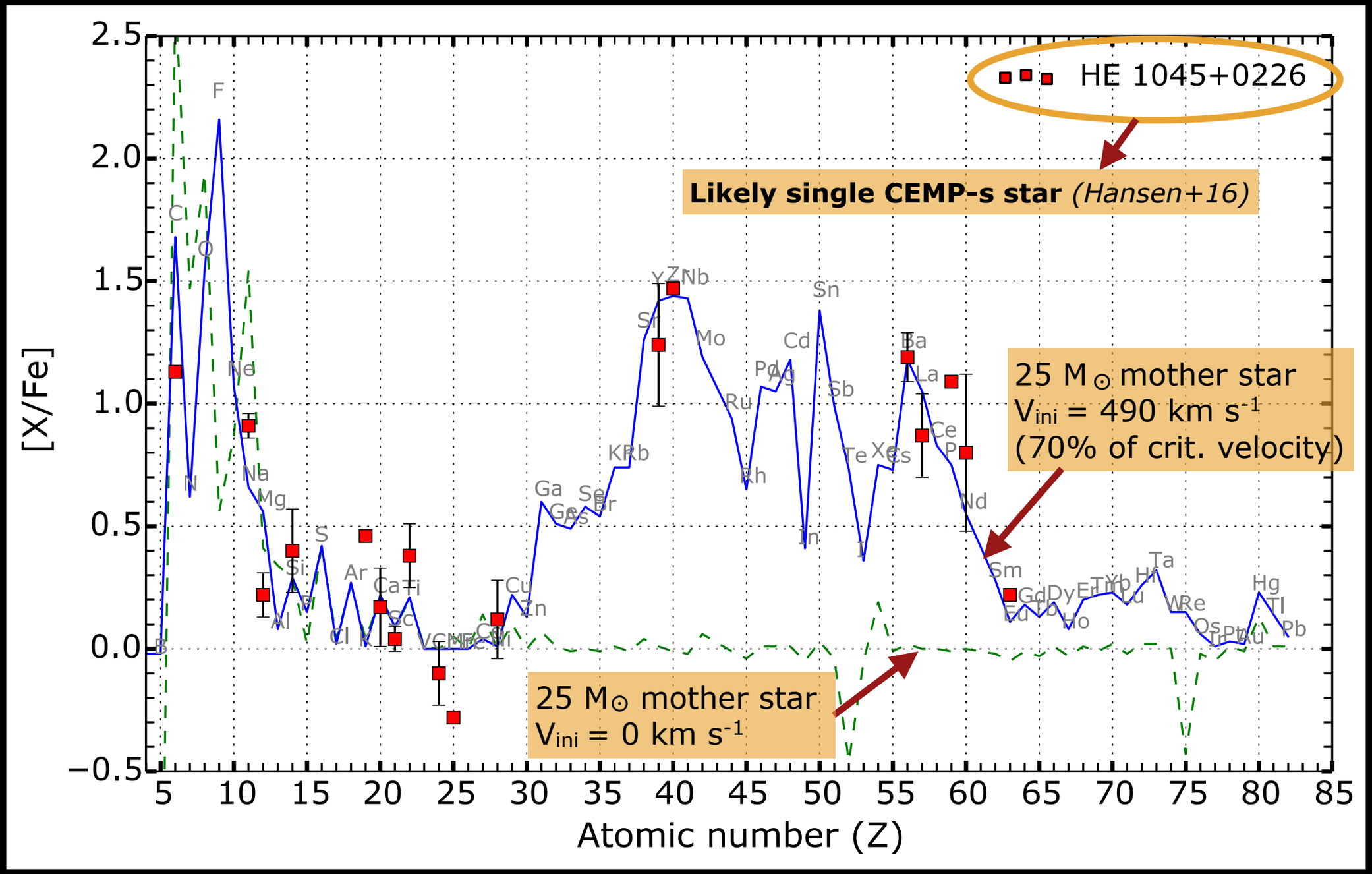
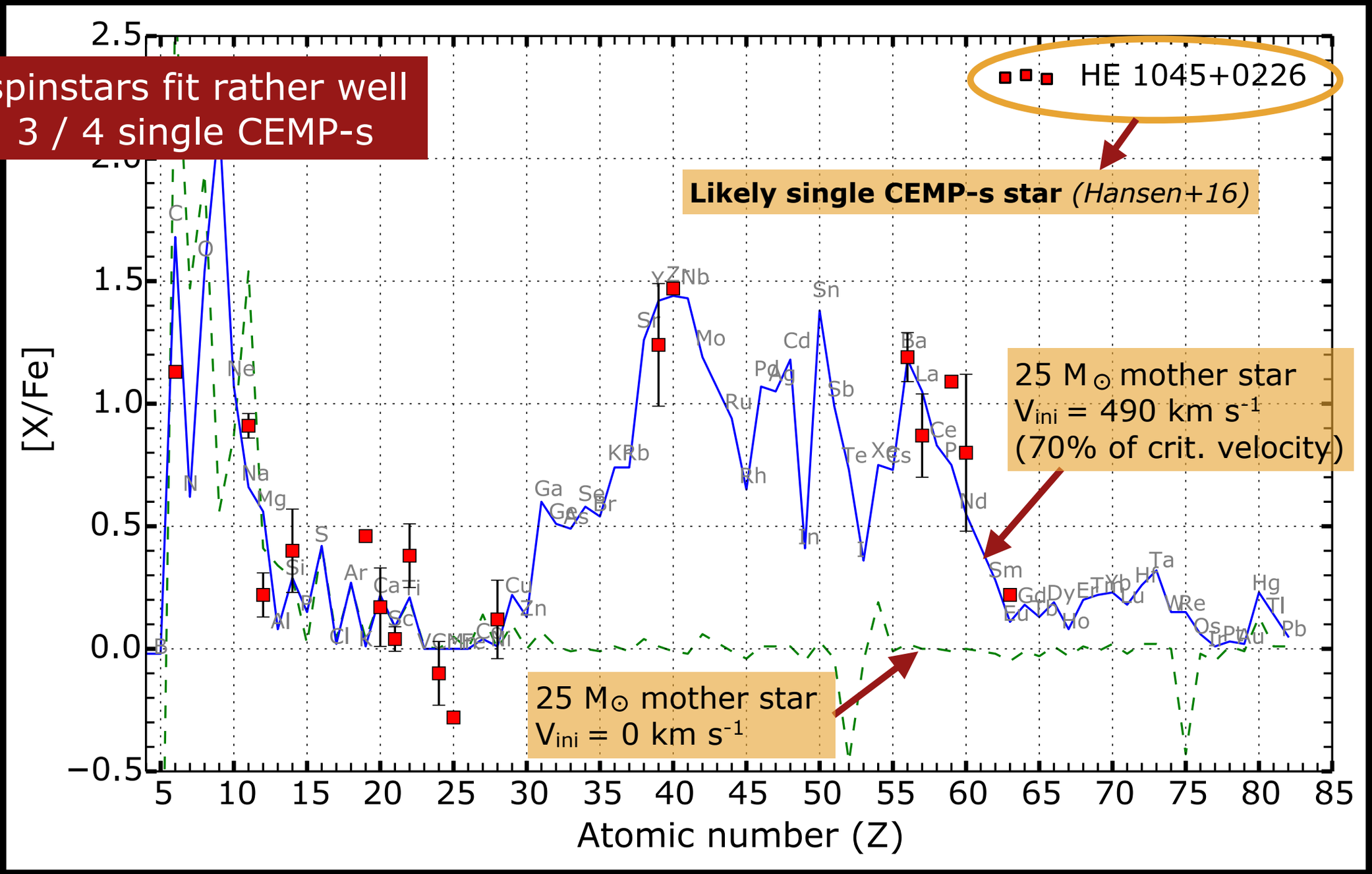
Spinstars and single CEMP-s stars



Adapted from *Choplin+17*, abundance data from *Cohen+13*

Spinstars and single CEMP-s stars



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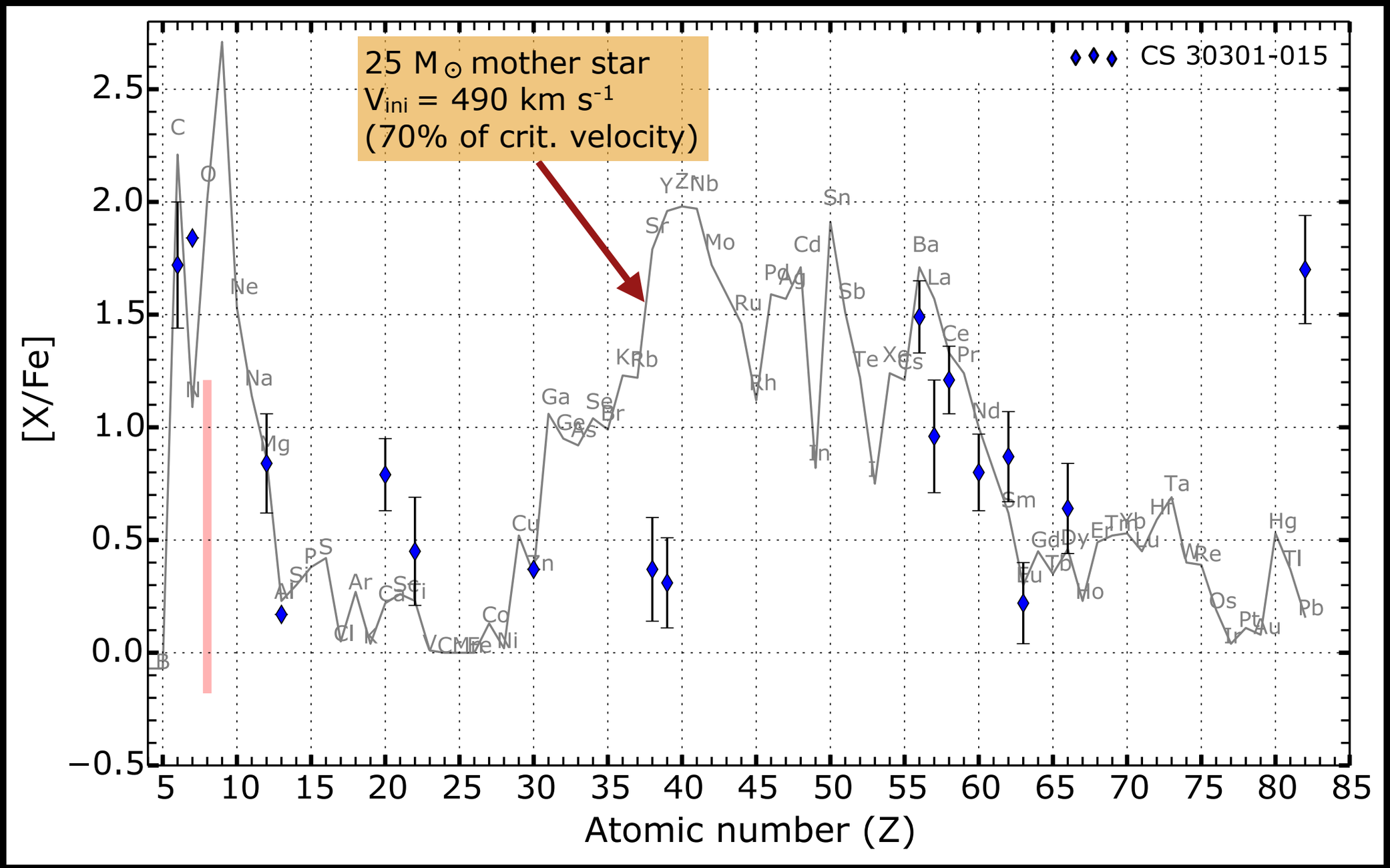
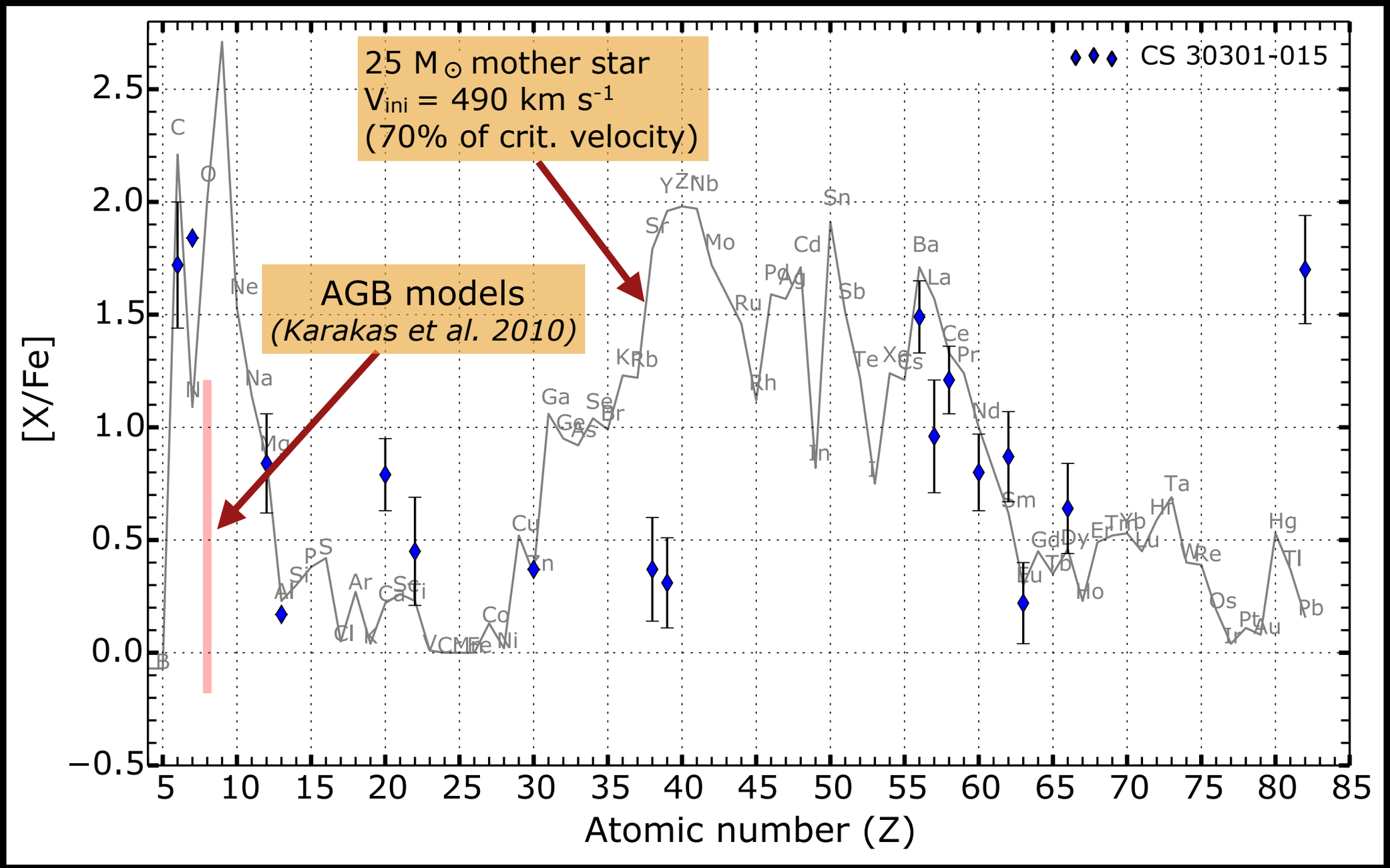


Adapted from *Choplin+17*, abundance data from *Aoki+02a,b*

Spinstars and single CEMP-s stars



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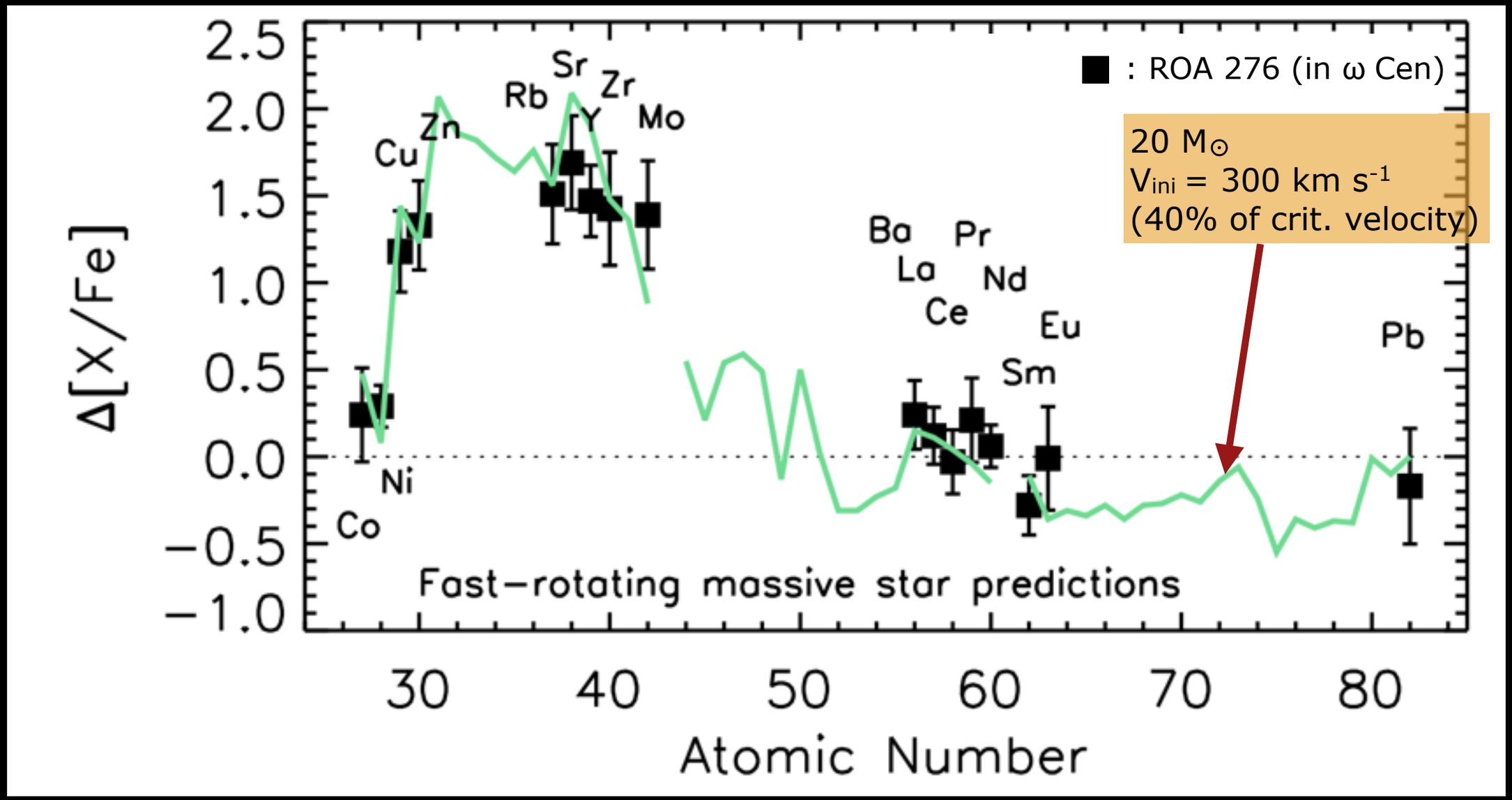
A spinstar in ω Centauri ?



Yong+17, model from *Frischknecht+12,16*

Conclusions

CEMP-s

Signature of spinstars in single CEMP-s ? —> [O/Fe] ?

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CEMP-s

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CEMP-no

in the CEMP-no star		in the mother star
• **High N, low $^{12}C/^{13}C$**	→	Mixing during the life of the mother star (rotation?)
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• **But some Zn ?** (e.g. CS 29498-043)	→	Mixing at the time of the SN

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but at which point rotation is compatible with a strong fallback?