The Monash Chemical Yields Project

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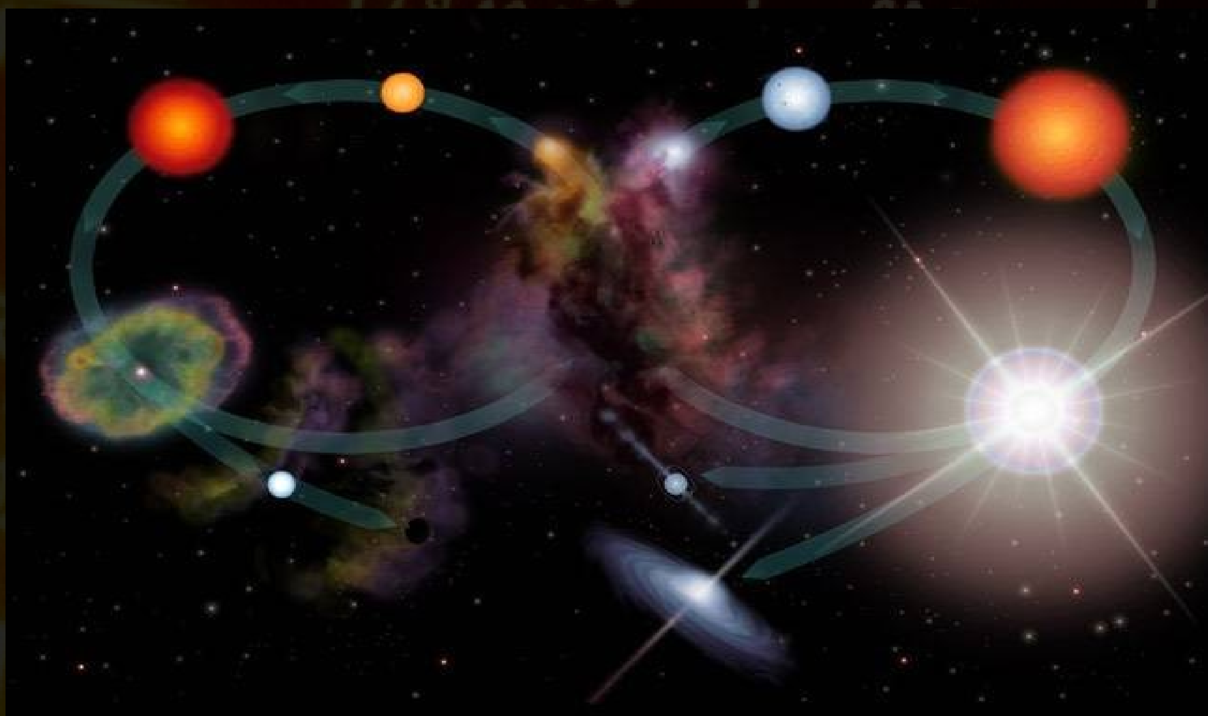

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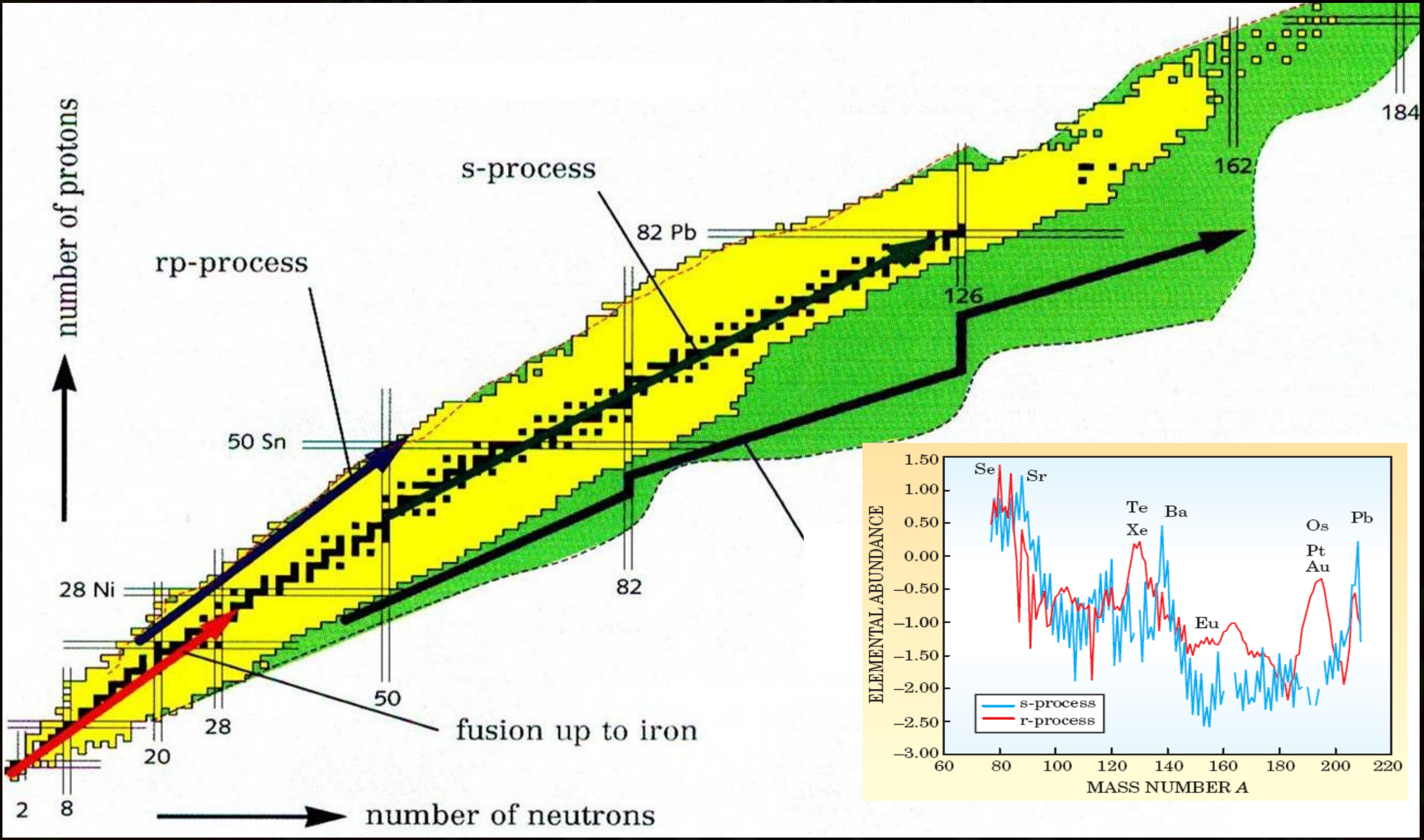
Element production

Low- and intermediate stars are important for galactic chemical evolution as they enrich the environment with C, N, F, and ~ ½ of all of the elements past Fe via the s-process



Goal: to produce a large and homogeneous set of (single star) nucleosynthetic yields for low and intermediate mass stars

Overview

* Low & intermediate mass star evolution (AGB stars)

* Computational programs

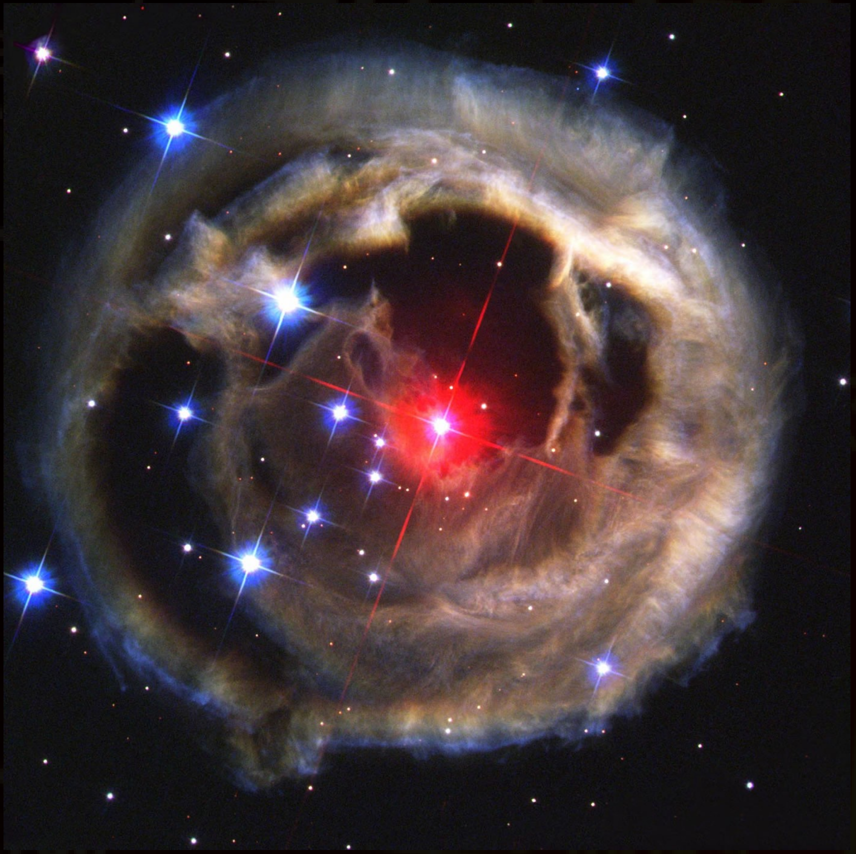
* Our computational grid

* Mass loss rates?

* Low metallicity models

* Proton ingestion episodes

* Summary & Conclusions



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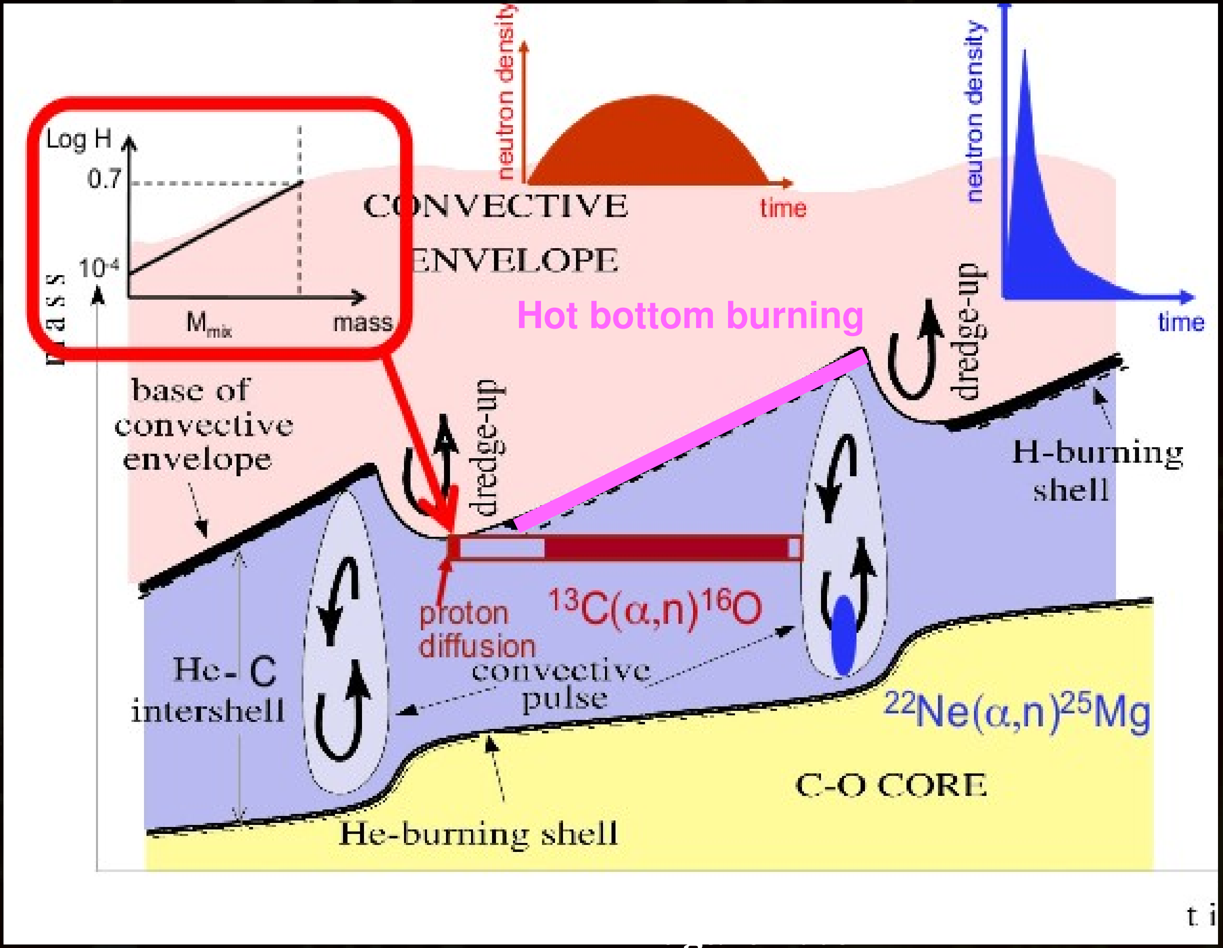
AGB Stars Recap

Stars in the mass range
~ 0.8 – 10 Msun

After core H & He (& C) burning they enter the thermally pulsing AGB phase which consists of alternating H & He shell burning phases

Strong mass loss erodes the envelope to leave a CO (or ONe) white dwarf



TP-AGB nucleosynthesis : Third dredge up events
Hot Bottom burning

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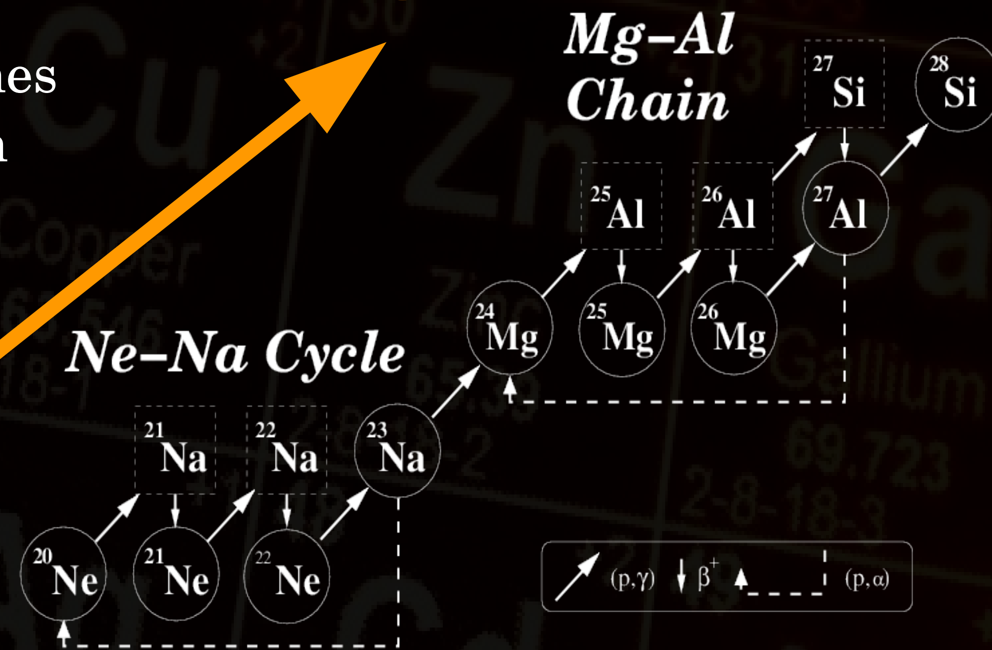
Hot Bottom burning (HBB)

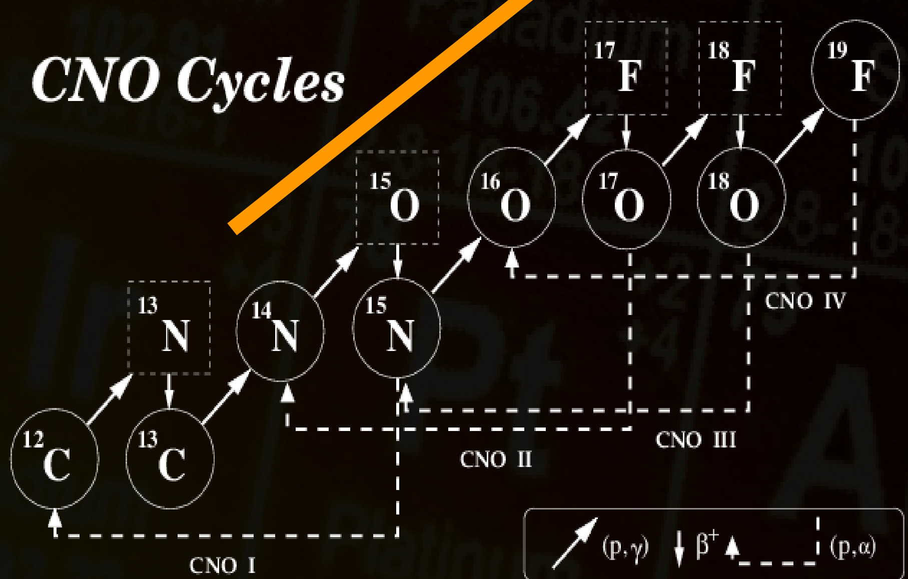
Base of the convective envelope reaches high enough temperatures for proton capture reactions

Increasing HBB temperature with increasing mass

~ 30-150 MK

Increasing HBB temperature





Minimum mass for HBB decreases with decreasing metallicity

~4-5 Msun solar

~2-3 Msun low Z

Activation of

* CNO cycles
* Ne-Na cycle
* Mg-Al-Si chain

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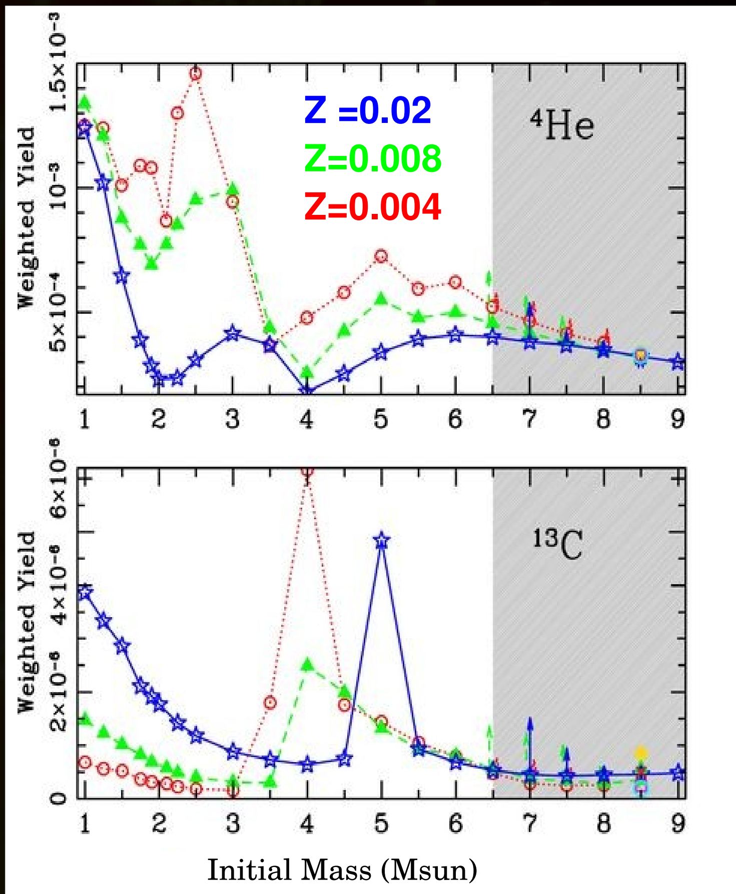
Mass & metallicity coverage

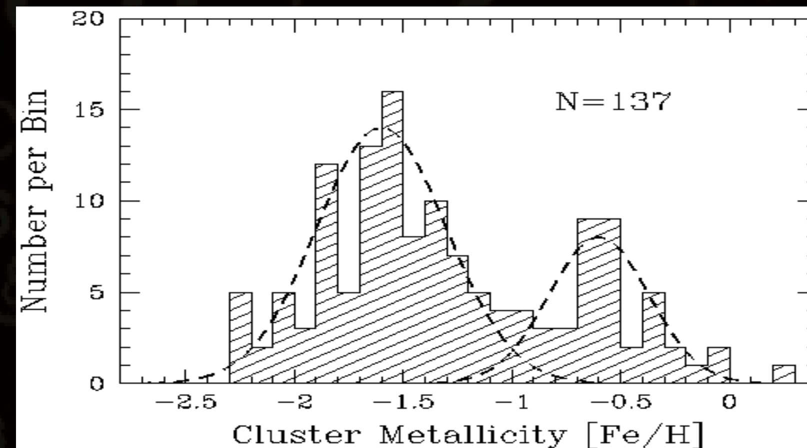
IMF Weighted yields



Doherty et al. 2014a (inc Karakas 2010)

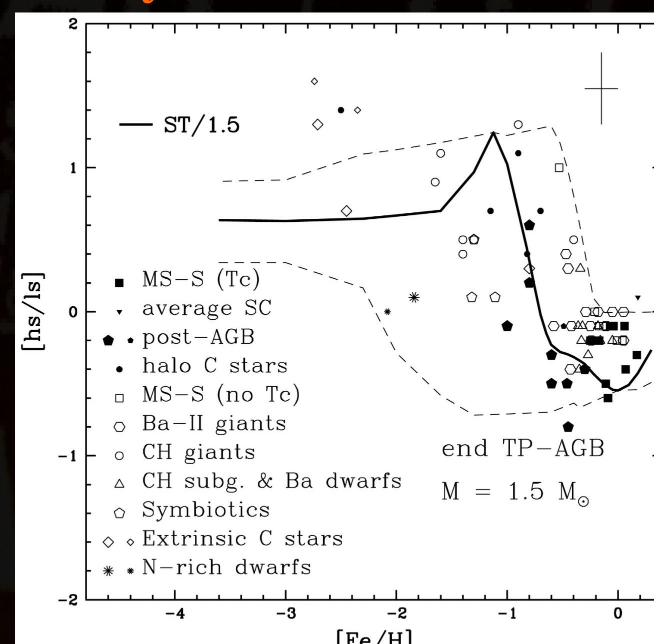
Some isotopes are only produced in narrow mass range – we want to capture these peaks

Galactic Globular cluster Z distribution



Harris 1996

Heavy element observations



Busso et al. 2001

* Globular clusters
* CEMP -s stars
* First Stars
* Super-solar

Programs used

2 step process : Evolution calculations then post processing nucleosynthesis

Evolution (MONSTAR)

Monash version of Mount Stromlo stellar program
(e.g. Campbell & Lattanzio 2008, Karakas 2010, Doherty et al. 2015)

1D hydrostatic code

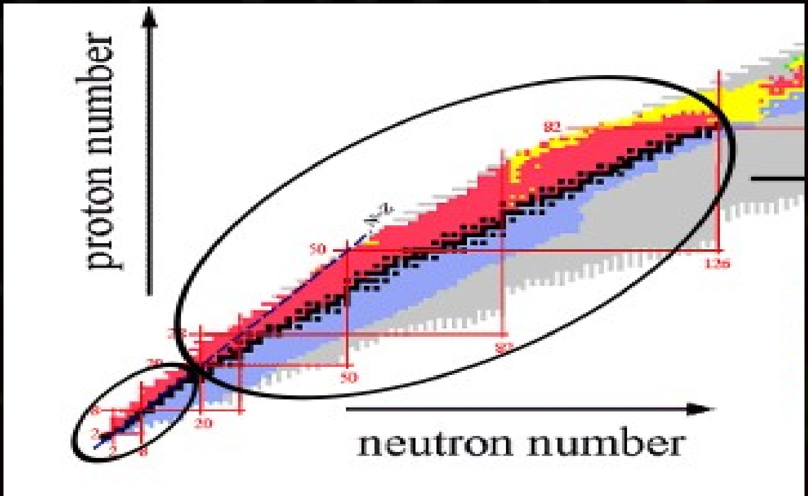
- No rotation
- No magnetic fields

* Low temperature variable composition opacities from ÆSOPUS (Marigo & Aringer 2009) & updated equation of state to OPAL & Helmholtz (see Constantino et al. 2014).

Nucleosynthesis (MONSOON)

Modified Monash nucleosynthesis code
(Church et al. 2009)

475 or 717 nucleosynthesis species
Enough to follow heavy element production in low/intermediate mass stars



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The Monash Chemical Yields Project

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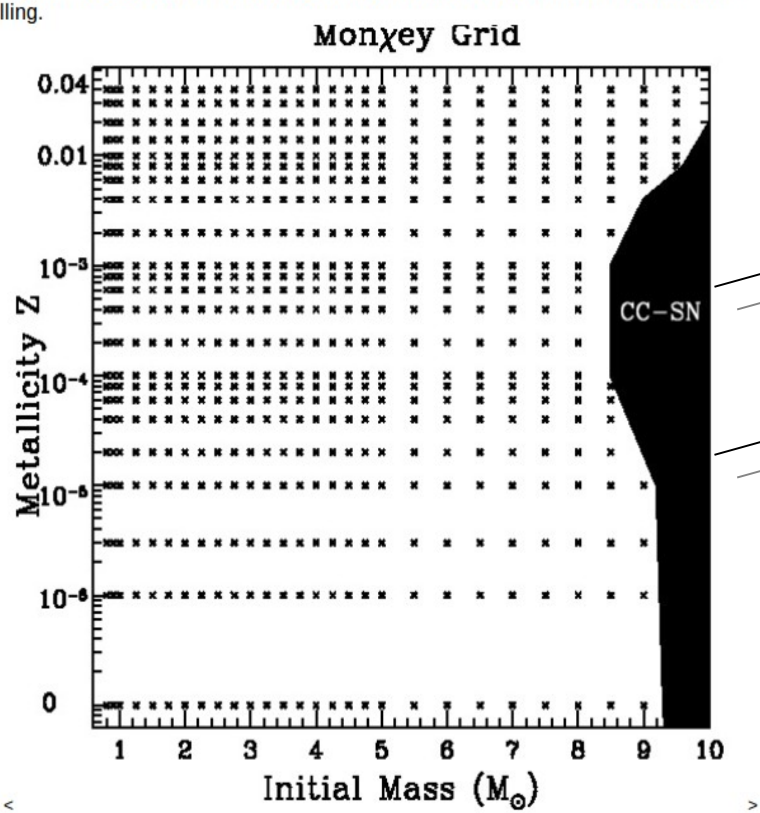
Goals:

Preliminary!!!

The Monχey project provides a large and homogeneous set of stellar yields for the low- and intermediate- mass stars and has applications particularly to galactic chemical evolution modelling.



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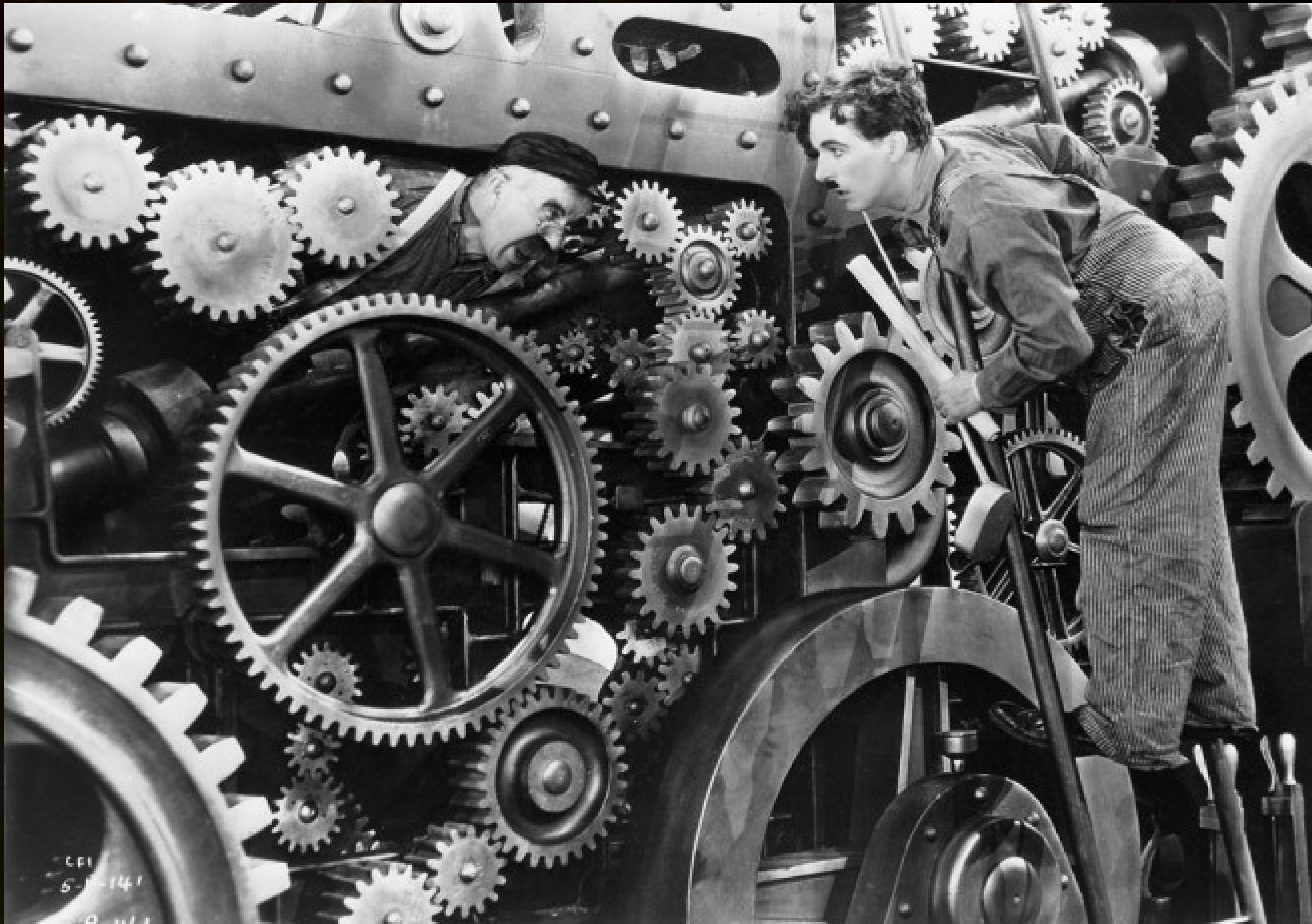

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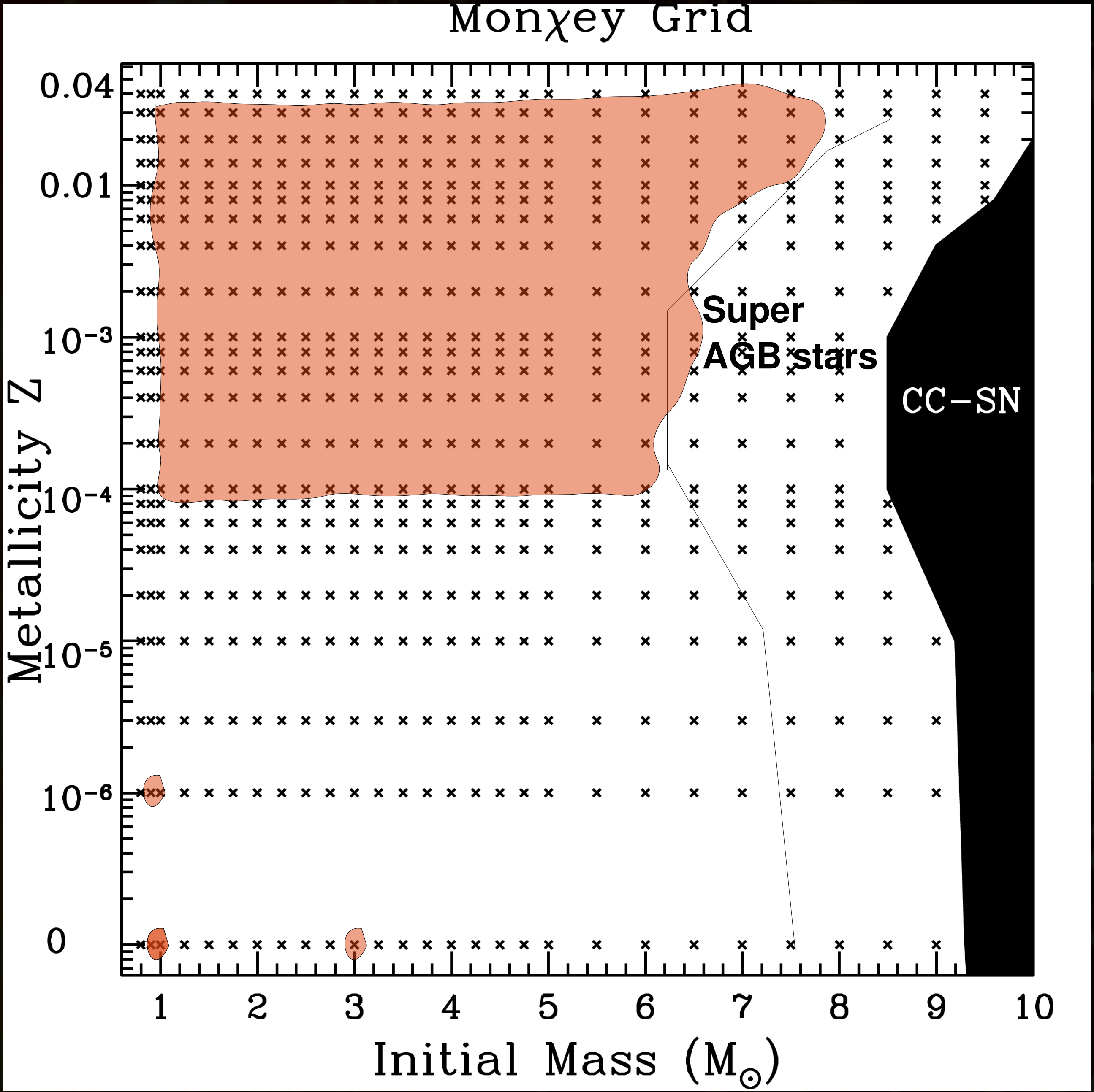

Heavy element works

Only listed groups with computed yields

Teramo Group
E.g Cristallo et al 2011, Straniero et al 2014

Monash Group
E.g. Lugaro et al 2012, Fishlock et al 2014, Karakas et al 2016,

NUGRID
Pignatari et al. 2016

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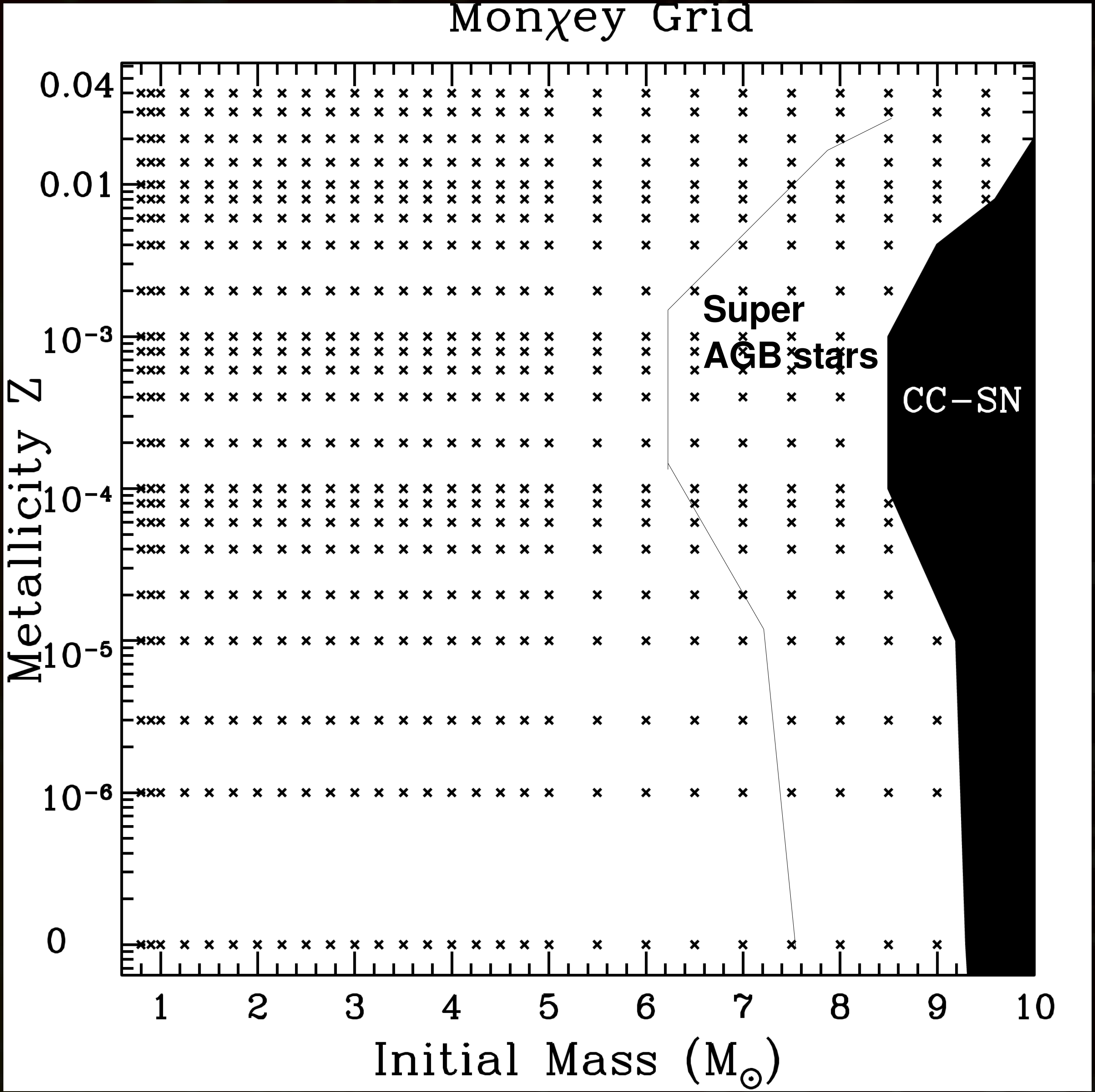
Mass loss rate?



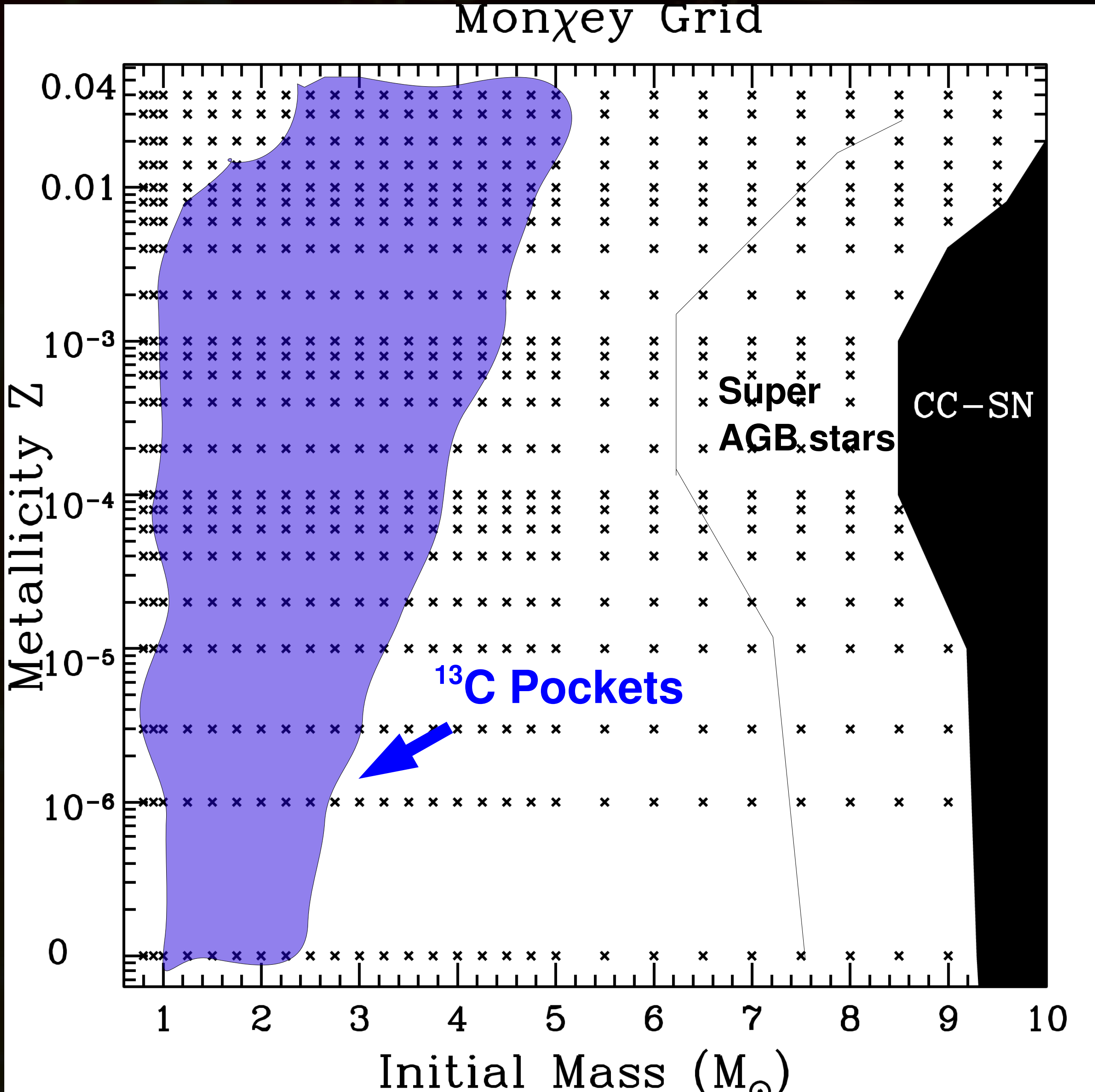
Currently we use

RGB phase:
Reimers eta 0.4

AGB phase:
Vassiliadis &Wood 1993

Low metallicity?

^{13}C pockets



Main s-process component in the solar system stars in mass range ~ 1-3 Msun

Not enough c13 within in the intershell to produce these heavy elements so we must artificially introduce a c13 pocket, which is added at deepest extent of 3DU

Shaded region mainly overlaps where stars will become C/O > 1

We insert a partially mixed zone (PMZ) for ^{13}C pocket

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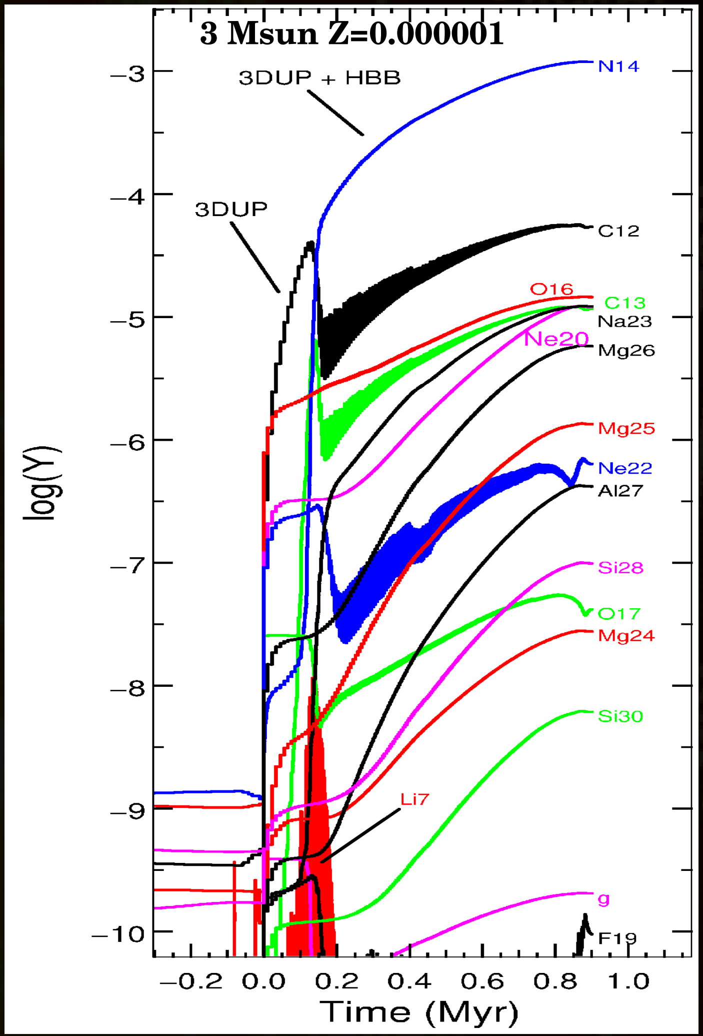
Low metallicity AGB stars

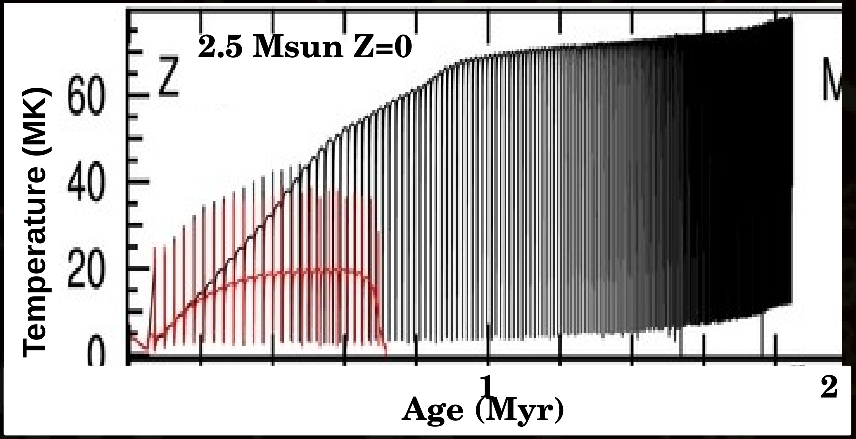
Update to the light element, low mass, low Z AGB star yields

OLD Model results



Campbell & Lattanzio 2008

Constantino et al. 2014 (+ works Marigo & collaborators)



NEW Model results

Currently handful of heavy element nucleosynthesis predictions for low Z

Goriely & Siess 2001, Campbell et al. 2010, Cruz et al. 2013

Inclusion of low temp. variable compositional molecular opacity shortens duration of the TP-AGB phase and reduces HBB temperatures

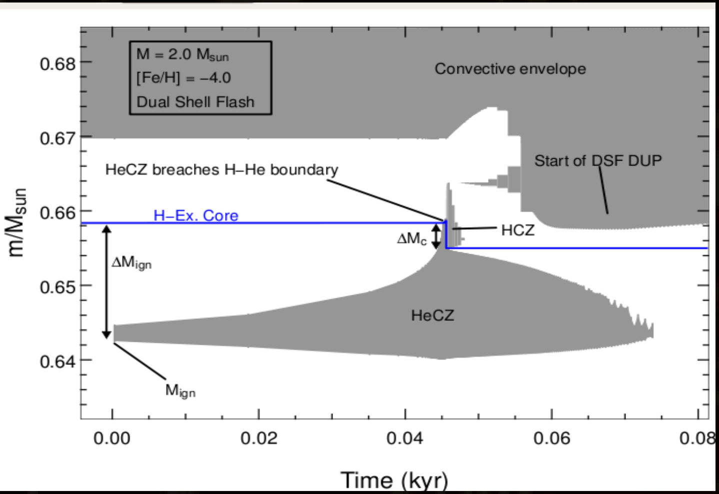
NEW models: Greatly reduced 3DU/HBB products and lower mass white dwarfs

Proton ingestion episodes (PIEs)

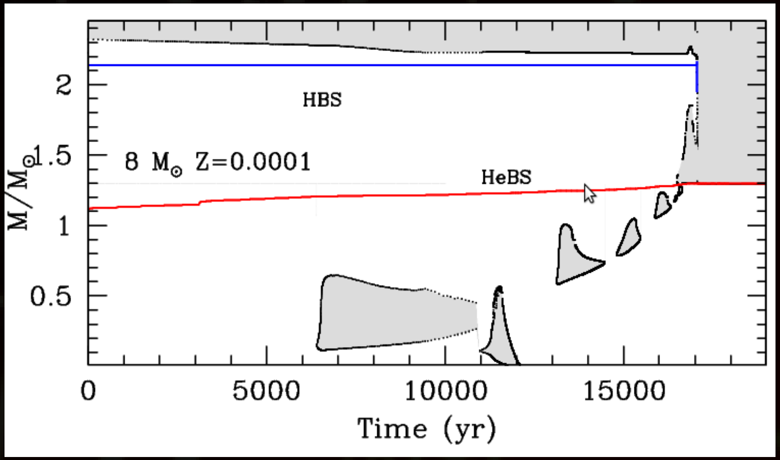
Low Z, low mass AGB stars Convective He burning region comes in contact with H rich region
Protons are ingested (PIE) where it has high temperature and density
Production of ^{13}C from ^{12}C and then activation of the $^{13}C(a,n)^{16}O$ neutron source
e.g. Fujimoto et al. 1990,Lau et al. 2009 Campbell et al. 2008/10, Herwig 2011, Bertolli et al 2013 etc

Dredge-out event in massive Super-AGB stars
Similar to above – but H comes from envelope

High neutron densities ($\sim 10^{15}$ n cm^{-3})



Campbell 2007



Doherty et al. 2015

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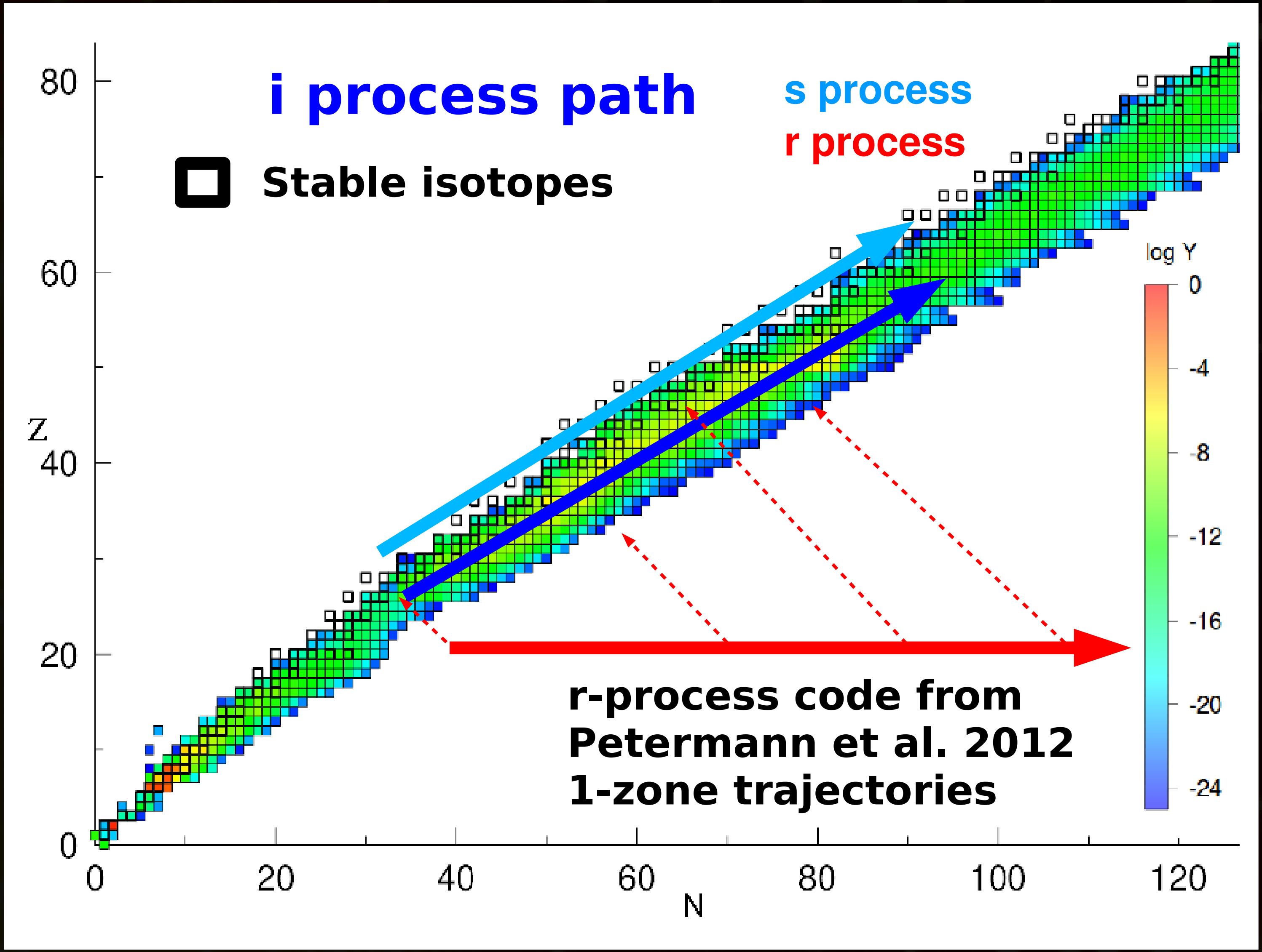
s/r or i process nucleosynthesis



With the high neutron densities the abundances can venture far from beta stability

i-process

(Cowen & Rose 1977)

s-process

Sr, Y, Zr, Ba, La and Pb

r-process

Eu, Pt

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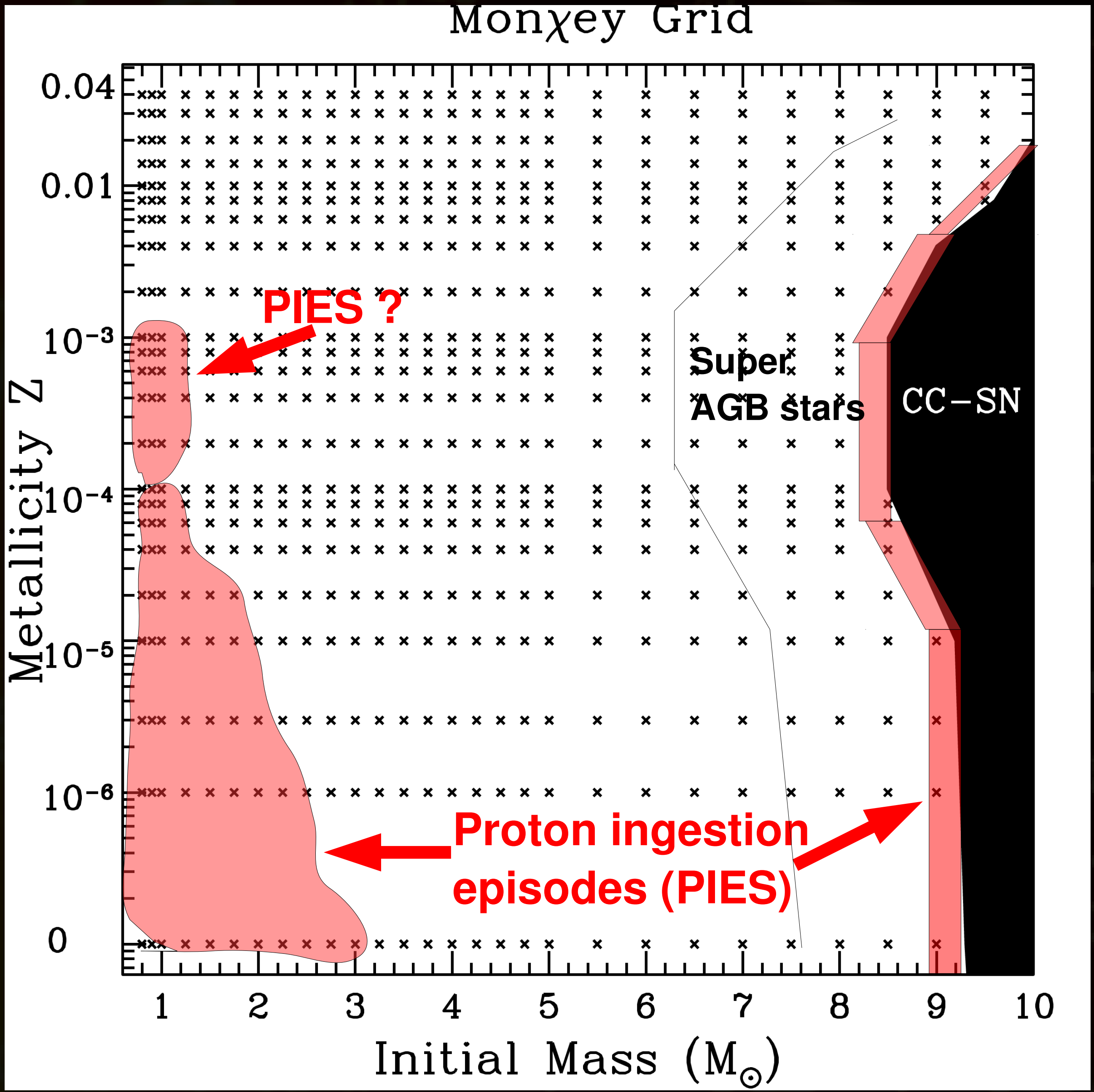

PIEs

What elements do these events produce?

Are they important?

These types of events may produce the correct abundance patterns of the CEMP s/r stars

Interestingly massive Super-AGB stars may explode as EC-SN

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Summary and Conclusions

- Low and intermediate mass star nucleosynthetic calculations and stellar yields have a large range of applications from Galactic Chemical evolution, presolar grain abundances comparisons, planetary nebula studies, CEMP-s (s/r) etc.

- Large range of uncertainties such as:
- * c13 pockets, size, shape (and cause)
- * convective boundary mixing (3DU efficiency)
- * nuclear reaction rates
- * interplay between mixing and burning etc etc.

- But arguably the most important is
- * Mass loss rates (especially at low metallicity!)

Computations for the Monχey project are underway
We expect a release of the first results later this year

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