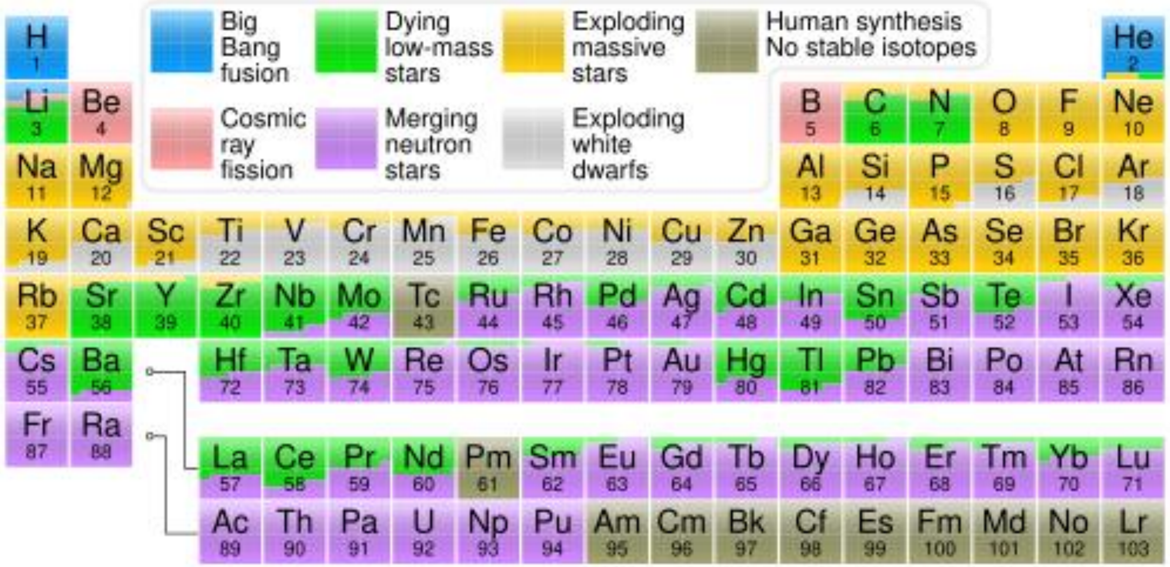
The evolution of elements in the Milky Way

2026.08.14 陈天奕

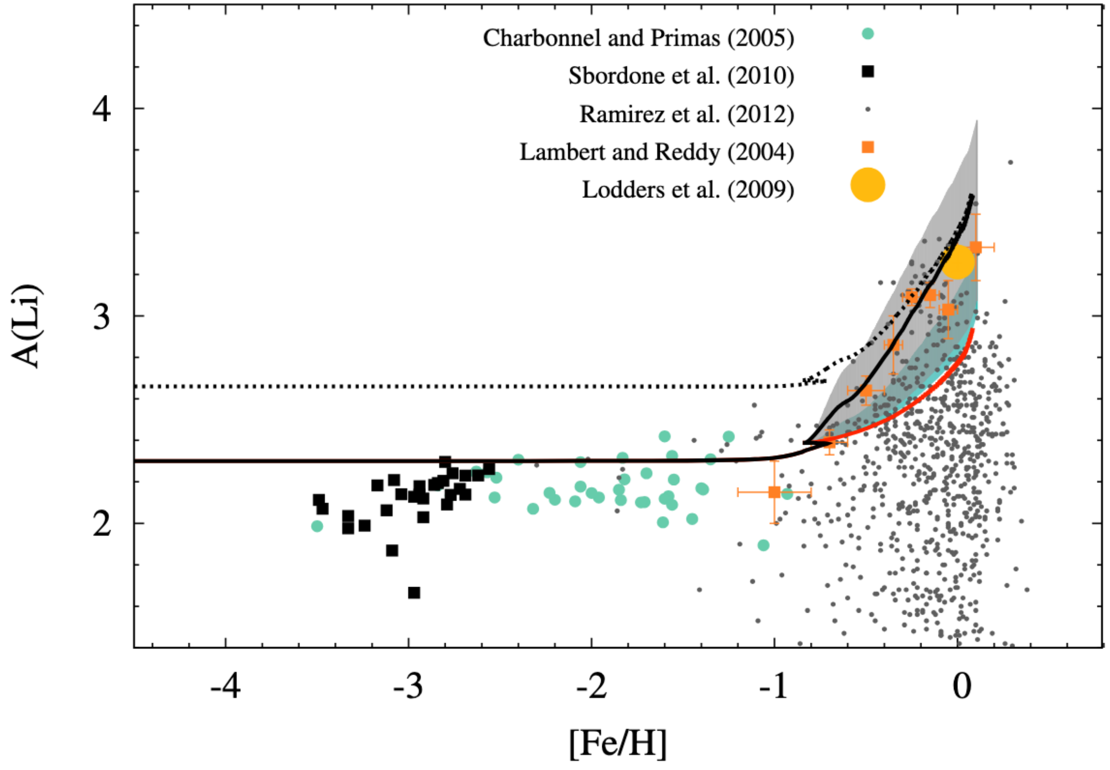
中国科学院大学

CONTENTS

- **light elements** (He, D, Li, Be and B)
- **heavy elements** (C, N, O, α-, Fe-peak, s-,r-)
- **halo and disks, bulge**



The chemical evolution of Li^7



production

Big Bang

CC-SNe
giant stars
AGB-stars
novae
cosmic rays

behaviour

- steep rise for [Fe/H]>-1.0: novae
- **Spite-plateau**

  -2.4 <[Fe/H]<-1.4

  A(Li) ~ **2.2 dex**

cosmological Li problem

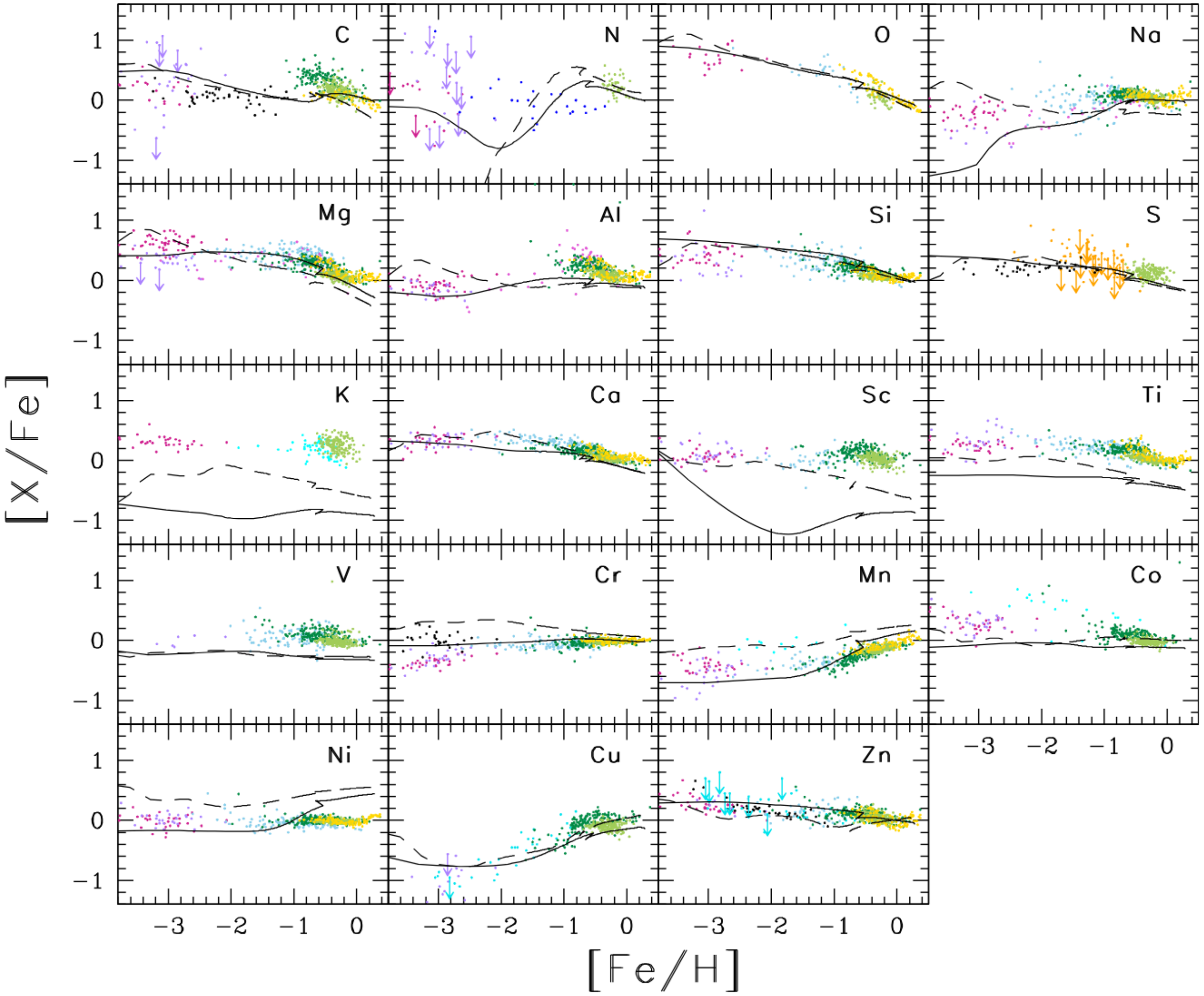
WMAP results: primordial **2.6 dex**

for [Fe/H]<-2.8, Li ↓

The evolution of heavy elements in halo and disks

- C, N, O, α-elements
- Fe-peak elements
- *n*-caputure elements: *s*- and *r*-process elements

Romano+2010



two-infall model

+

two different sets of stellar yields

solid curves (best)

massive stars (include hypernovae): Kobayashi+2006

but for **C, N, O**

mass loss and rotation from Geneva group better

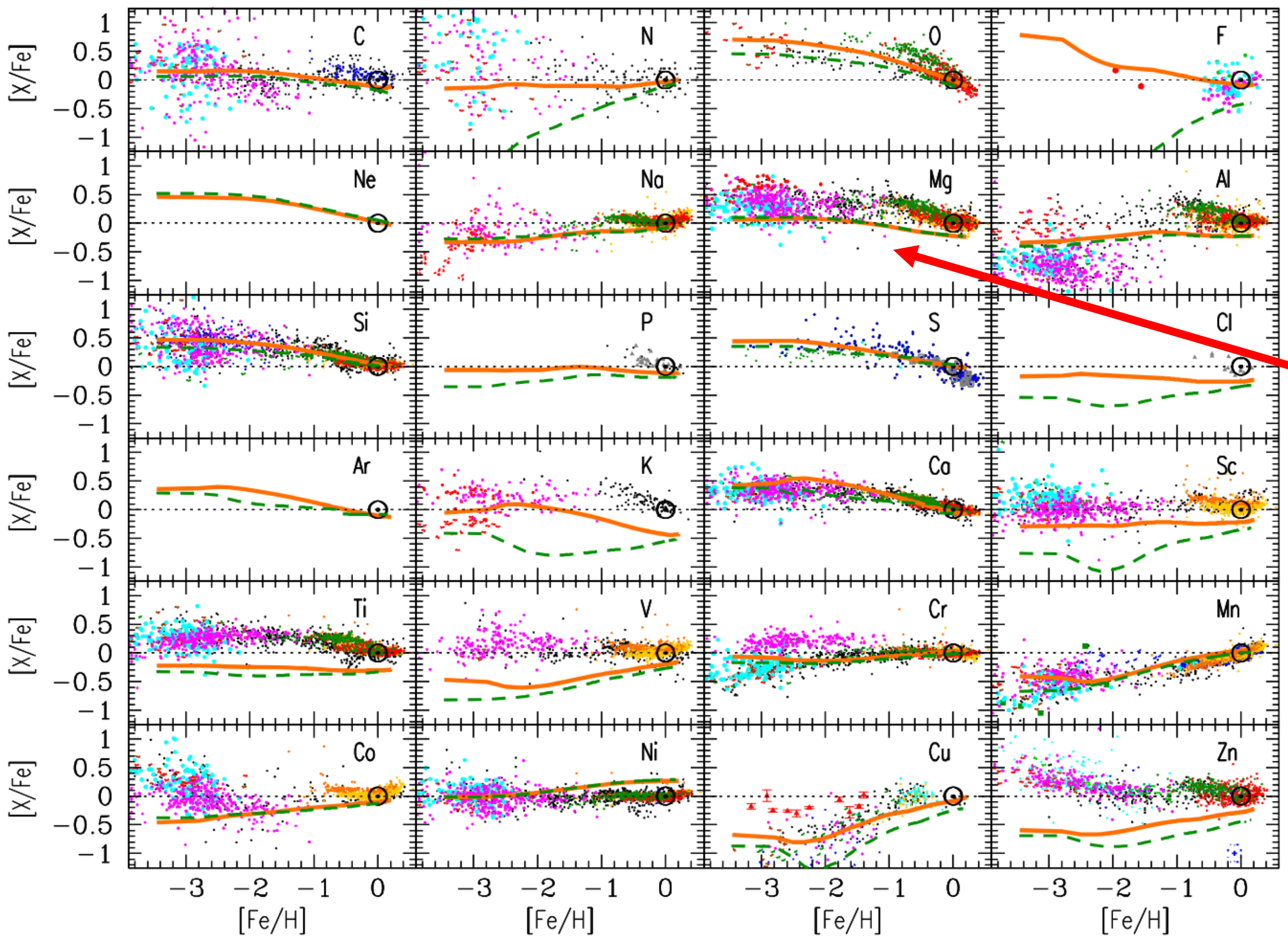
dashed lines

massive stars (no mass loss and rotation): Woosley+1995

intermediate mass stars: Hoek+1997

K, V, Ti, Sc both not reproduce well

Prantzos+2018



one-infall model

+ metallicity dependent

rotating and non-rotating massive stars

α-elements: most well

rotation not change the results

(a small increase of C and O at low metallicities)

Mg underproduce

not for Kobayashi+2006 and Nomoto+2013

K, V, Ti, Sc not reproduce well

rotation improves slightly K and Sc at low metallicities

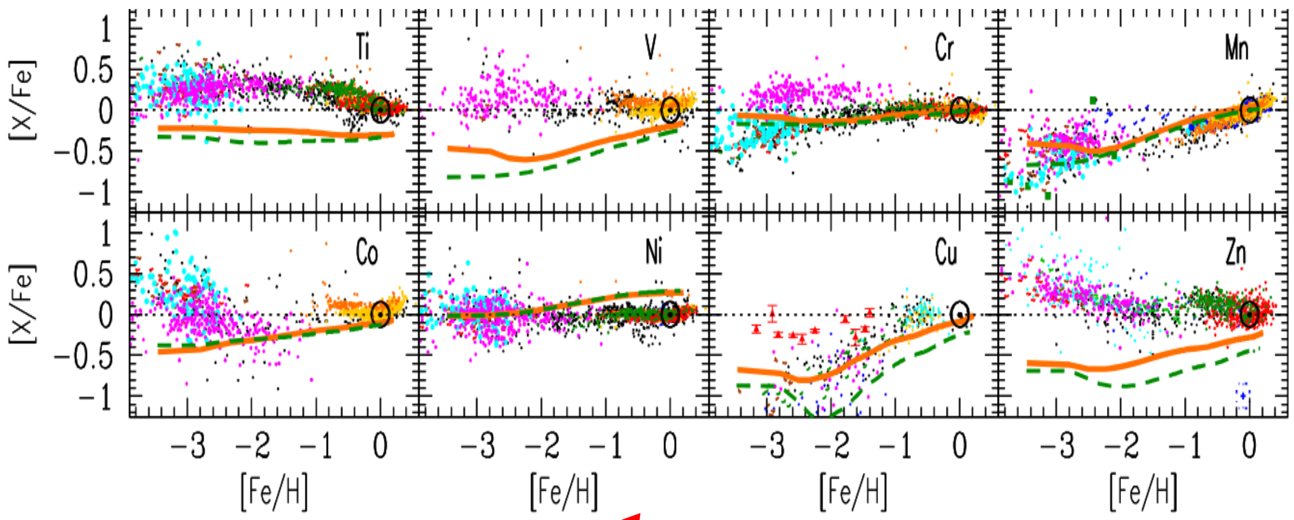
Zn fail in reproducing

Fe-peak elements

Cr, Mn, and Ni

Production: Type Ia SNe

Prantzos+2018



Mn

↑ : metallicity dependence yields in massive stars

Co

↑ for [Fe/H]<-2.0 dex:

no yields are able to reproduce

Co: hypernovae

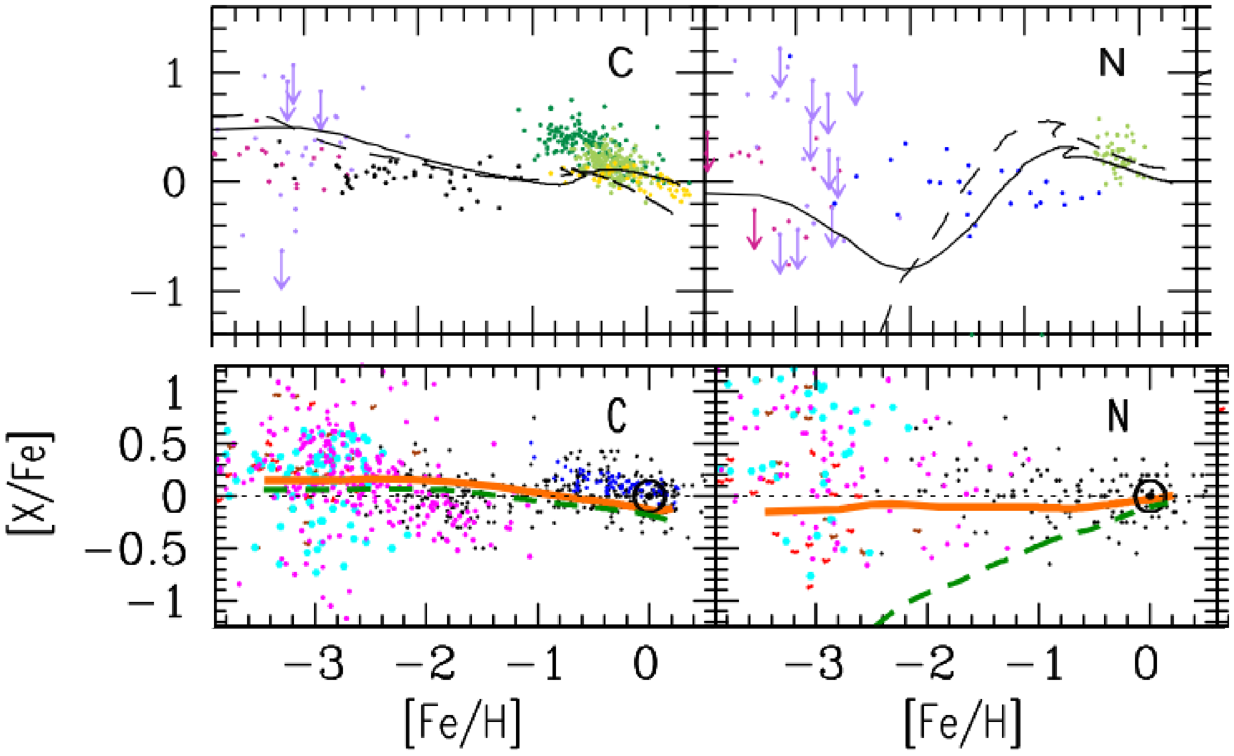
Ni

↑ overproduction in the typical nucleosynthesis model of Type Ia SNe

more recent nucleosynthesis studies (e.g.,Kobayashi+2020) do not overproduce Ni

Romano+2010

Prantzos+2018



^{12}C

was believed from **low and intermediate mass stars**

massive stars with mass loss and rotation
can be the dominant source of carbon

recent observational data, showing an overabundance of C relative to Fe, seem to confirm the massive star

^{14}N

a typical secondary element (should ↑ with Fe)
reveals a primary behavior at low metallicities
(constant [N/Fe])

N also produced as a primary element

- hot bottom burning phase of intermediate mass stars
- rotating massive stars

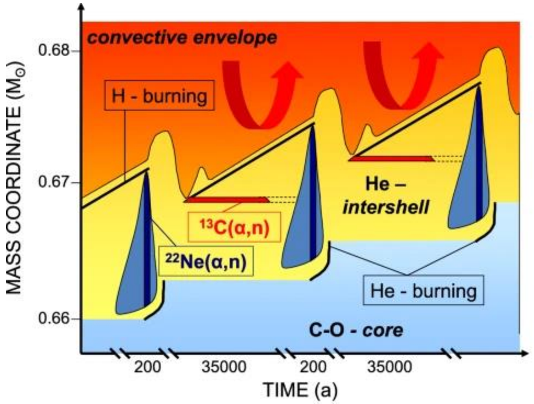
s-process elements

1st-peak: Sr, Y, Zr
2nd-peak: Ba, La, Ce, Nd, Sm
3rd-peak: Pb

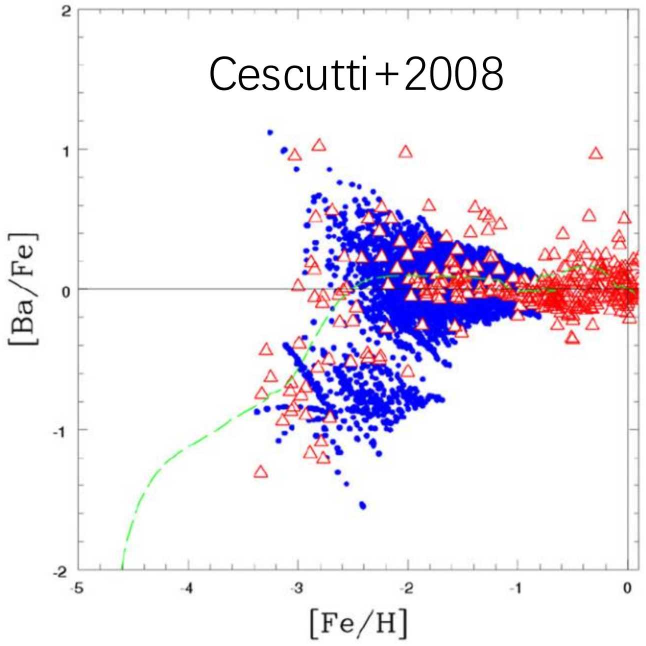
production

mainly in AGB stars

partly massive stars (>10$M_\odot$)



MRSN: r-process in the early Galaxy
spinstars: Sr, Ba, Y
electron-capture SNe: Sr, Y, Zr



typical behaviour

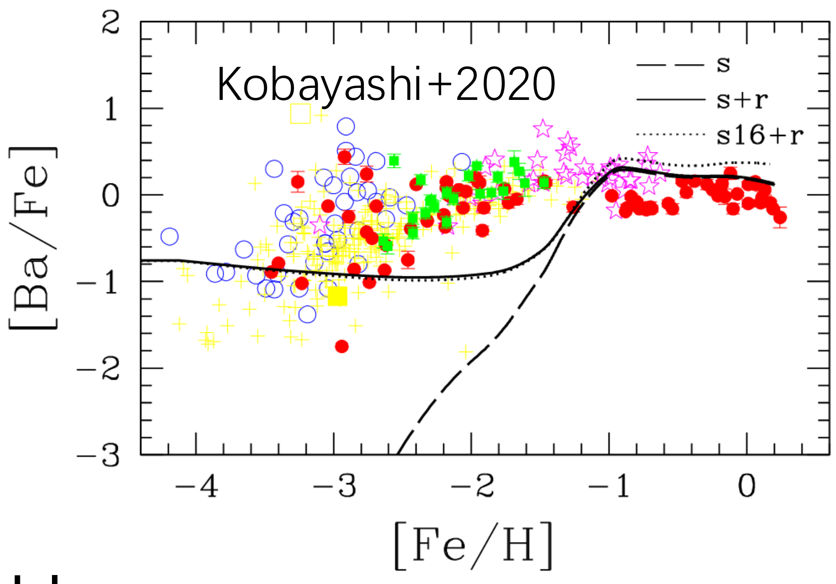
[Fe/H]>-2.0

- **constant**

[Fe/H]<-2.0

- **increase**
- **large spread**

inhomogeneous model



r-process elements

Eu, Gd, Dy, Er, Yb

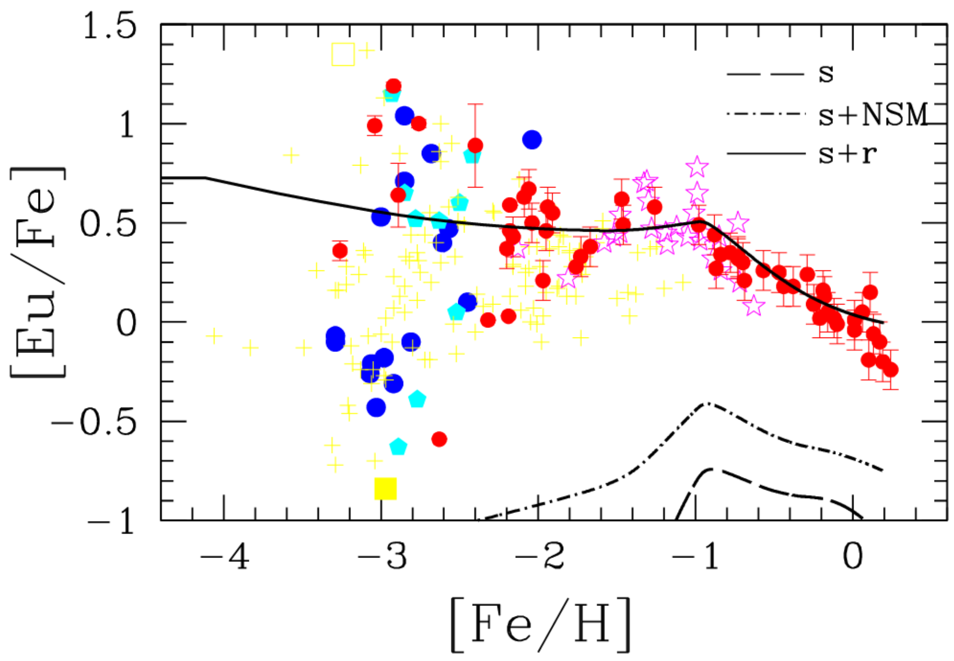
- easily observable in stellar atmospheres
- pure r-process

production

- **CCSNe** X too few neutrons
- **MRSN**
- **collapsars**
- **merging of compact objects** (neutron stars black holes)

√ GW170917

Haynes+2019



long delay time 10^8 yr

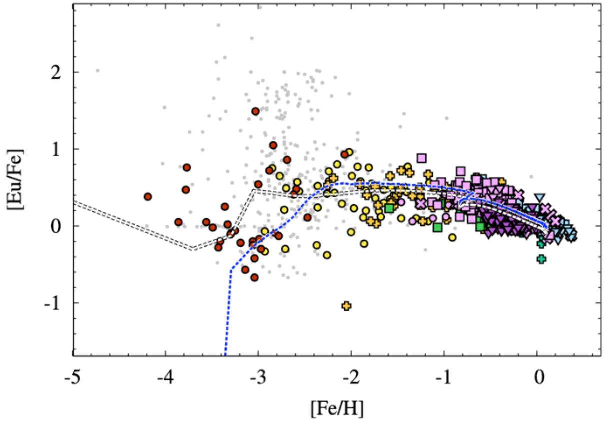
1. plus other quick resources
2. change the delay time of NSM

high r-abundance at **low** metallicity

behaviour

r-process elements

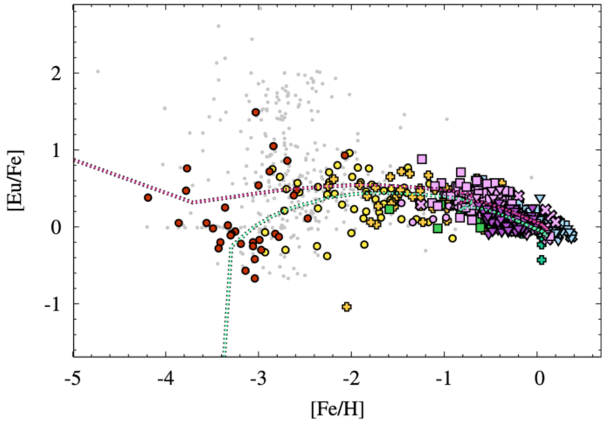
1. plus other fast resources
2. change the delay time of NSM: short/distribution



CCSNe+NSM

Progenitors: 9–30 $M_\odot$

- White: delay time 1 Myr
- Blue: delay time 10 Myr



only NSM

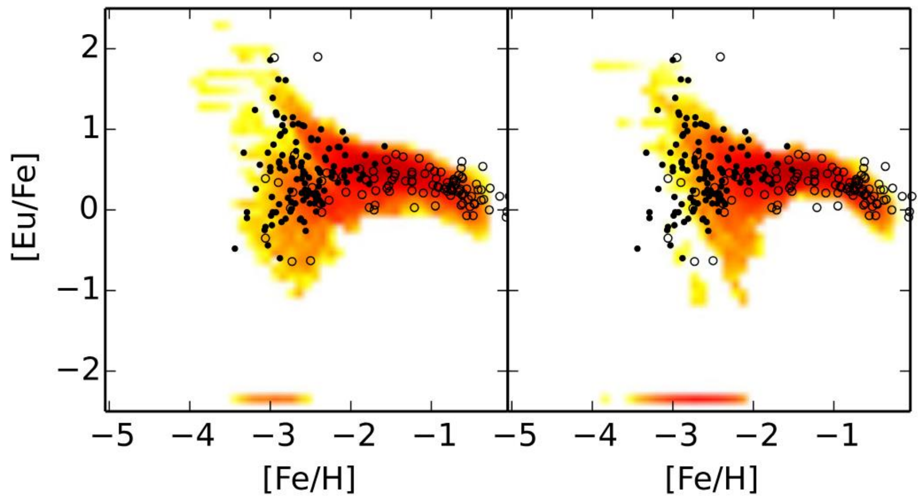
- green: progenitors 9–30 $M_\odot$
- purple: progenitors 9–50 $M_\odot$

delay time 1 Myr

Matteucci+2014

instantaneous mixing approximation
no spread

Cescutti+2015



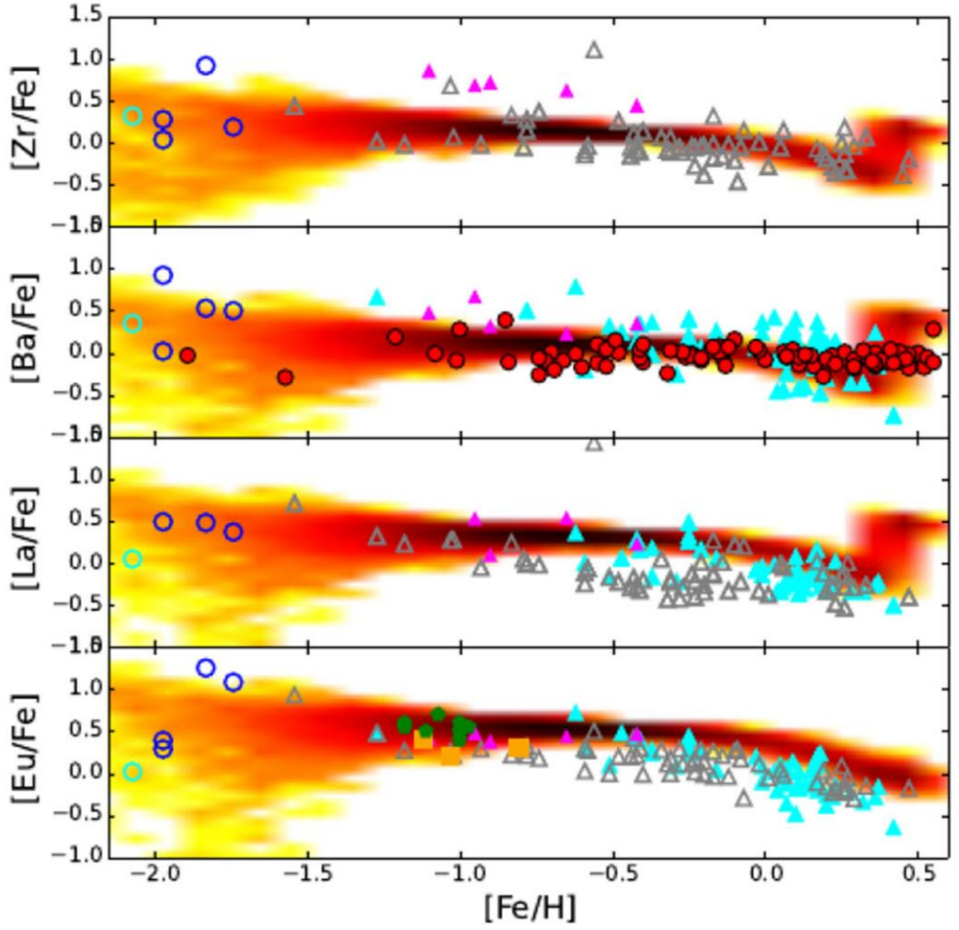
only MNS
delay time 1Myr

MNS+MRSN
delay time 100Myr

inhomogeneous model
large spread

Schönrich+2019
DTD (delay time distribution) for MSM
typical timescale of 150 Myr
2-phase interstellar medium

n-capture elements in the bulge

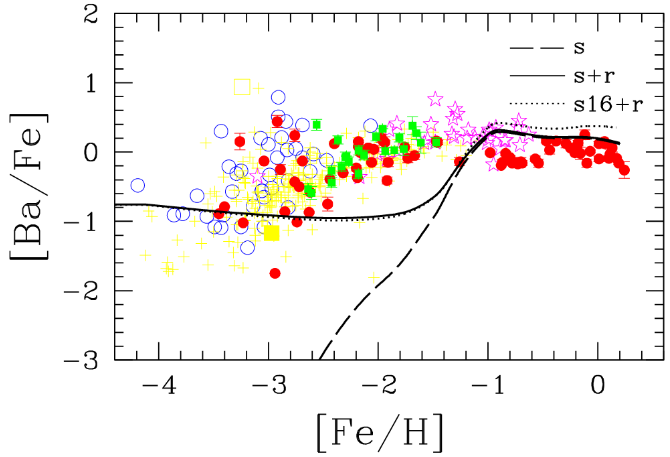


Barbuy et al. (2018)

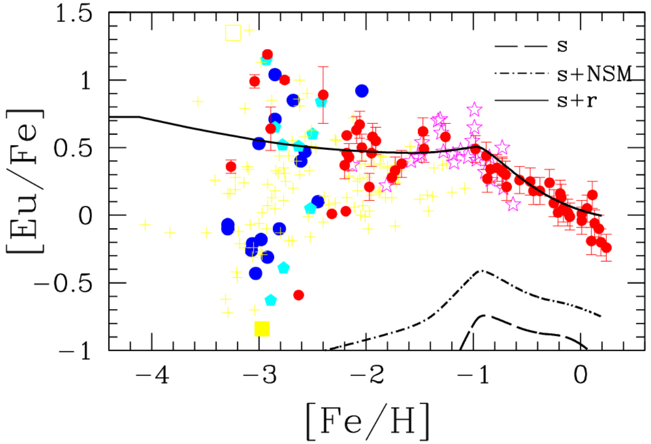
Zr, Ba, La:
↓ with [Fe/H] ↑

Eu: less spread

disk and halo
for comparison

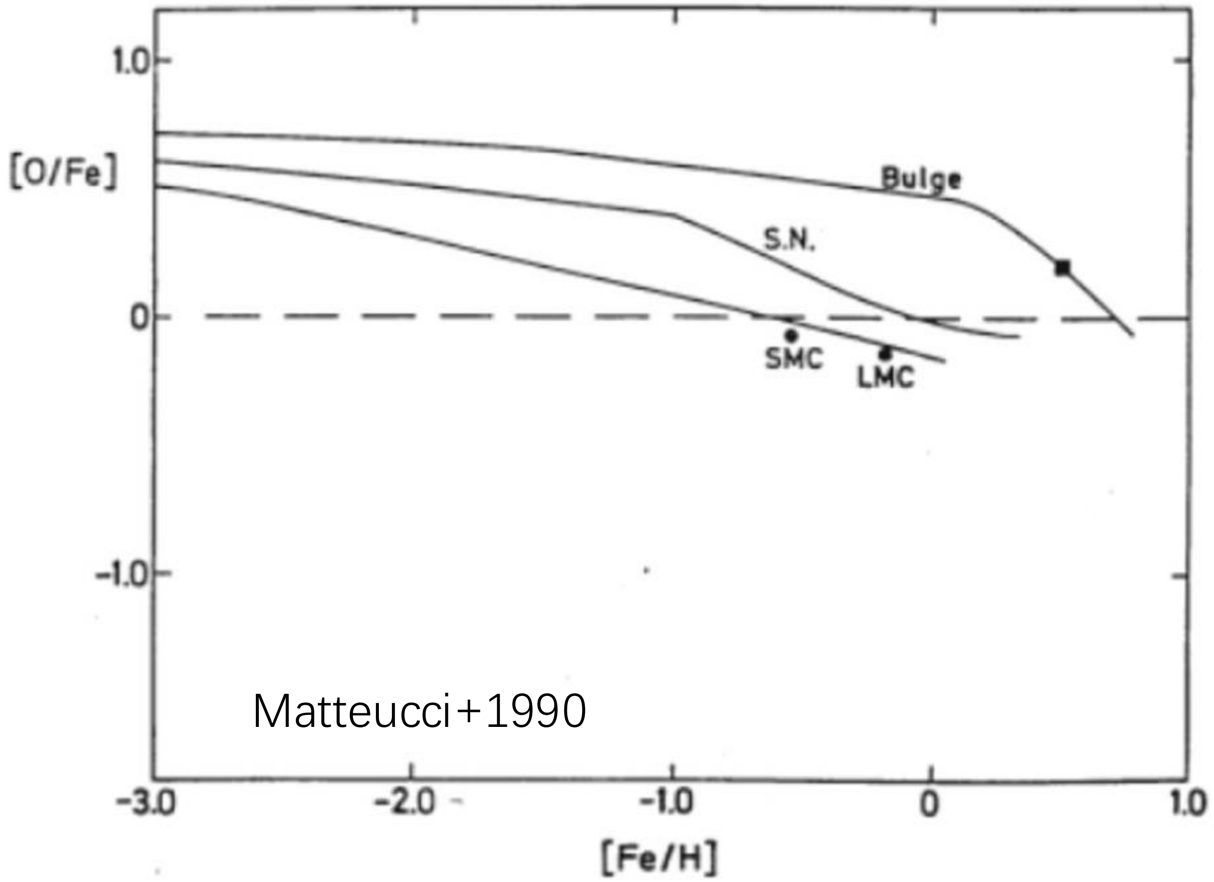


Kobayashi+2020



Haynes+2019

α-capture elements in the bulge



the solar vicinity

the Galactic bulge

The Magellanic Clouds (LMC and SMC)

bulge stars should have shown **a longer plateau**

the knee in the [Mg/Fe] ratio is **0.06 dex higher** than the knee in the **thick disk**

a **faster bulge formation**