Peculiar abundance patterns in Galactic bulge stars

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“Neutron star mergers: From gravitational waves to nucleosynthesis“, Hirschegg, Jan. 20, 2017

Galactic Components

M104 (HST) – unbarred spiral with ca. 40% x mass of MW

Disk(s)
Halo: stars, globular clusters, satellite galaxies, dark matter
Central bulge (bars)

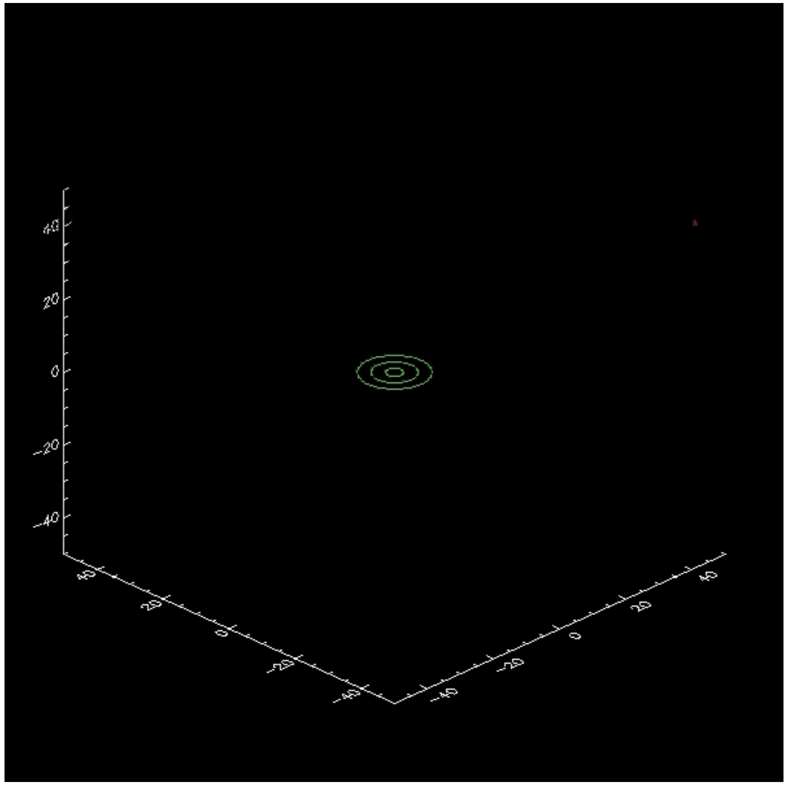
Halo formation

ΛCDM: hierarchical halo formation via accretion of dark matter dominated fragments.

Metal-poor halo stars were probably donated from satellite accretion.

Some stars in the dwarf satellites show chemical imprints from *individual* events (→ Pop III).
→ clues to the earliest enrichment phases.

What about the bulge?

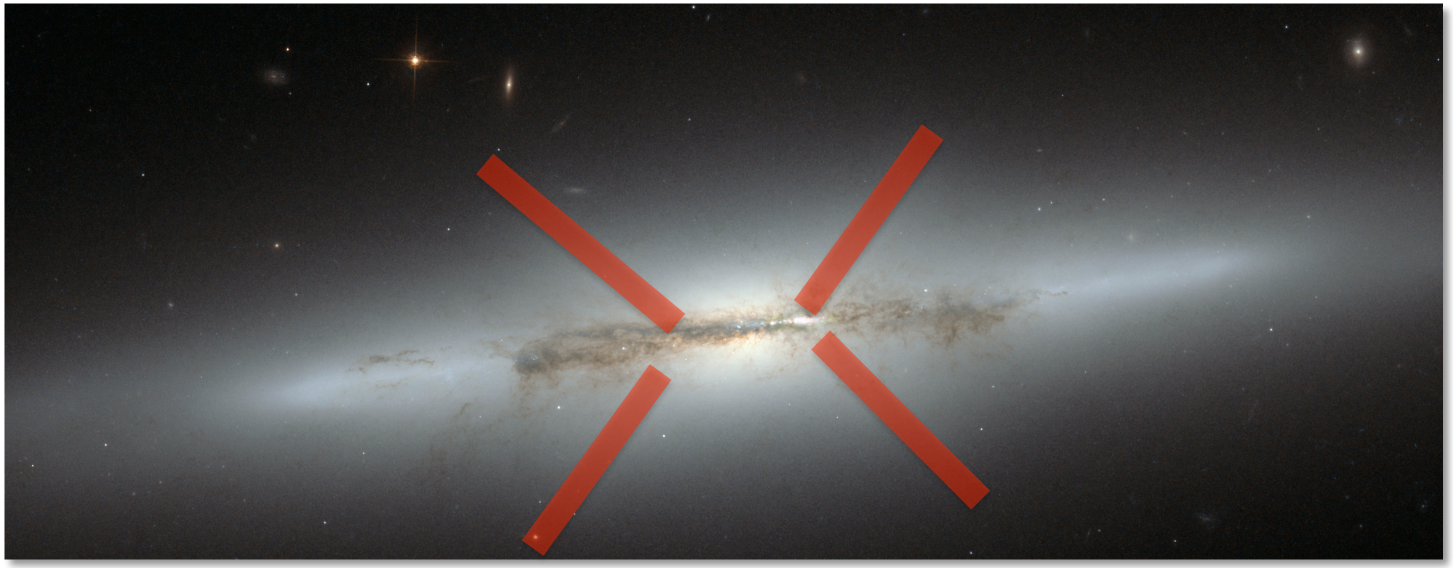


Bullock & Johnston (2005)

AK et al. 2008; Tolstoy et al. (2009); Simon et al. (2010); **AK** & Rich (2014)

Bulges

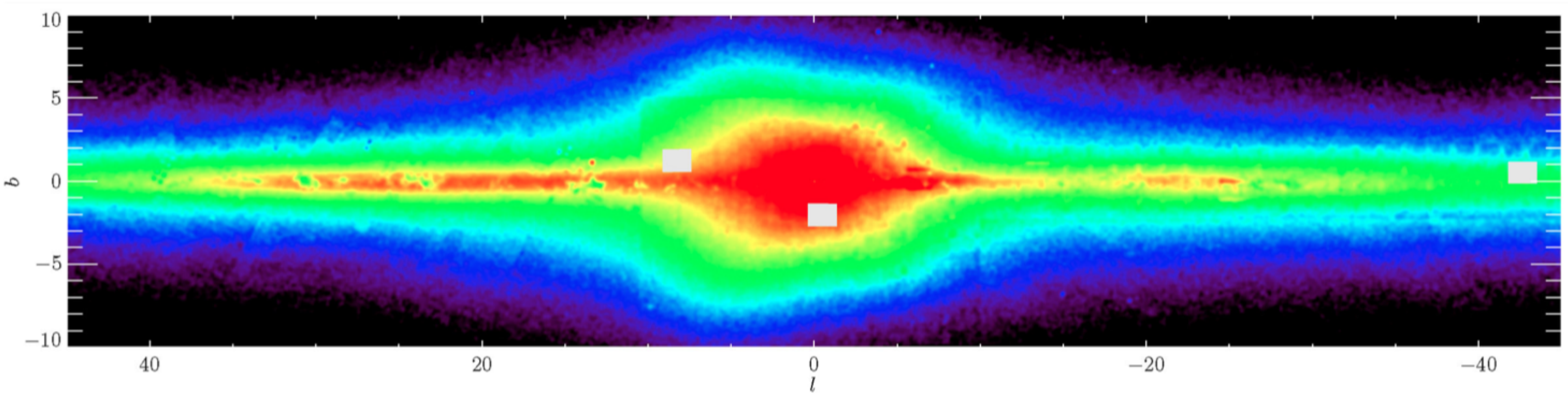
- 25% of the light in the local universe comes from bulges.
- Inhomogeneous class of objects with different formation channels:
    1) Spheroidal ("classical") bulges form rapidly via early mergers. Bulge forms before disk.
    2) Pseudo-bulges / bars evolve from a buckling instability over longer timescales (>1 Gyr).



NGC 4710 (HST); McWilliam & Zoccali (2010); Rich (2012)

(Galactic) bulge formation

- **The bulge is old and metal rich, yet very complex** (e.g., McWilliam & Rich 1994; Clarkson et al. 2008; Bensby et al. 2013).
- **Dynamical formation, where bulge == bar** (e.g., Shen et al. 2010; Wegg et al. 2015) **? Prominent X-shape** (McWilliam & Zoccali 2010)
- **No evidence for kinematic substructures (streams).** (e.g., Howard et al. 2008; Kunder, **AK**, et al. 2012; Kunder et al. 2014, 2015; C.J. Hansen, **AK**, et al. 2016).

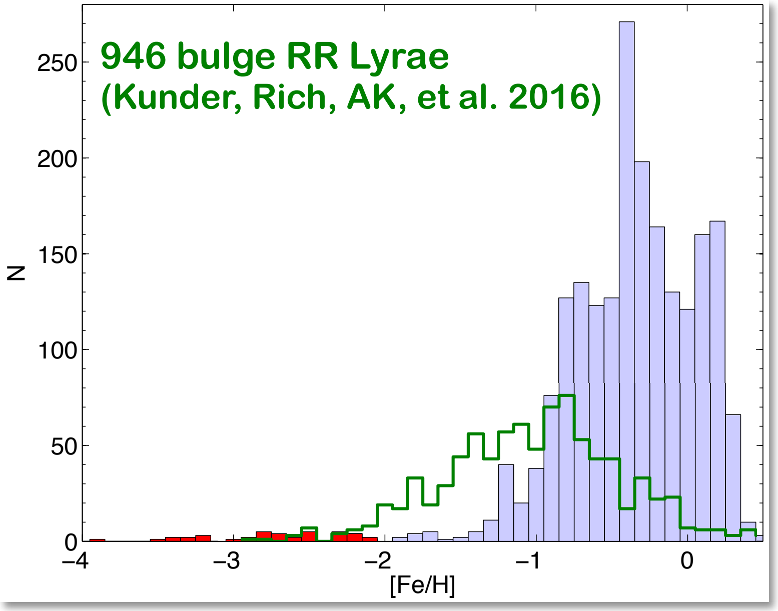


Wegg et al. (2015)

Bulge vs. halo formation

- Oldest stars with [Fe/H] < −3 (z > 6 - 10) are predicted on tight orbits in the *innermost* halo, due to inside-out nature of CDM: *"In the bulge, not of the bulge"* (Tumlinson 2010).

- E.g., ARGOS bulge survey: non-rotating, metal-poor tail; attributed to the inner halo (R_{GC} < 3.5 kpc; Ness et al. 2013).
See also BRAVA (Howard et al. 2008; Kunder, AK, et al. 2012).

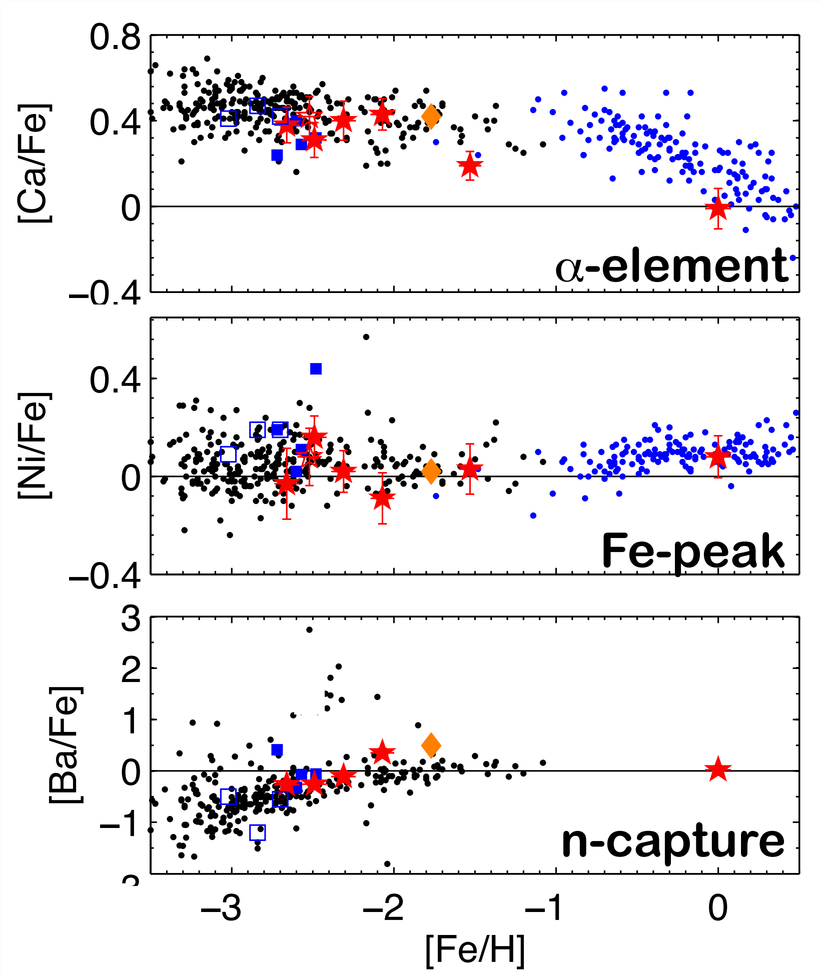


To date: 55 stars in high-res between -2 and -4 dex in surveys of several 10000s stars

(Ness et al. 2013; García Pérez et al. 2013; Howes et al. 2014, 2015; Casey & Schlaufman 2015, AK et al. 2016)

Abundance results

- High-resolution spectroscopy of seven bulge stars (AK et al. 2016)
- The majority of (23) species is compatible with the ***halo !***



Metal-poor Halo (Roederer et al. 2014)

Bulge (Johnson et al. 2012, 2014)

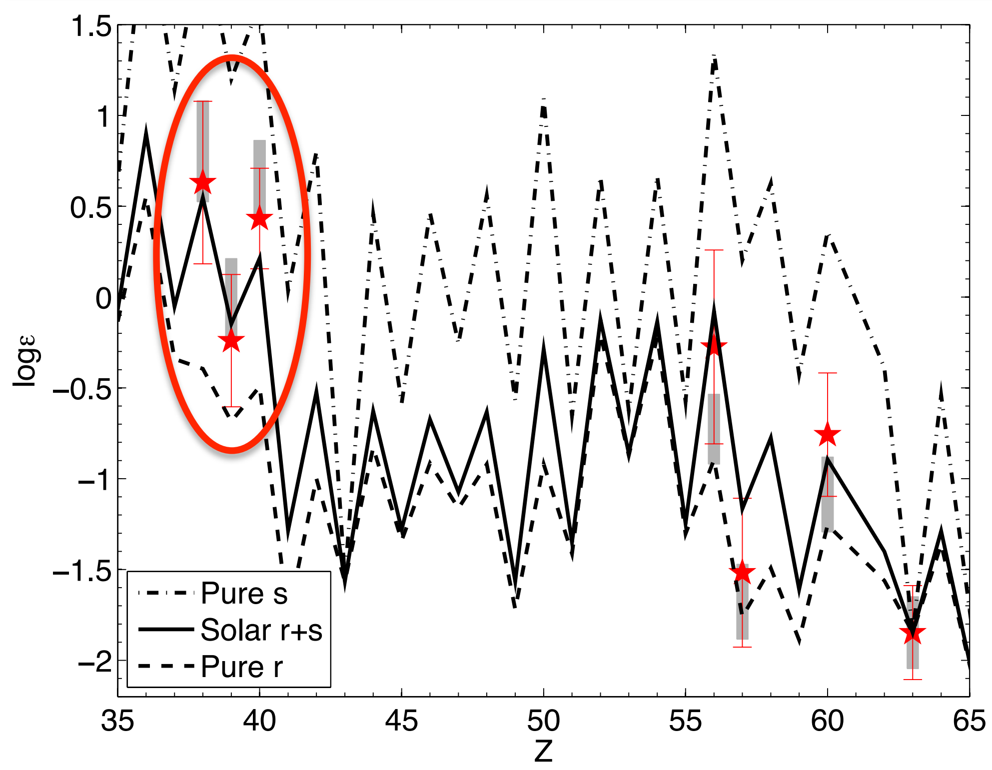
Metal-poor "bulge" (Casey & Schlaufman 2014; Howes et al. 2014)

This work (AK et al. 2016)

Bulge r-II star (Johnson et al. 2013) at [Fe/H] = -1.67
→ (SNe / NSM) r-process polluters are also active in the bulge!
r-process seems universal

Normal halo-(like) stars

- The majority of (23) species is compatible with the *halo* and points to standard enrichment processes !



Mean abundances of all stars compared to Solar r/s pattern (Simmerer 2004).

HD 122563, weak r-process star (Honda et al. 2004)

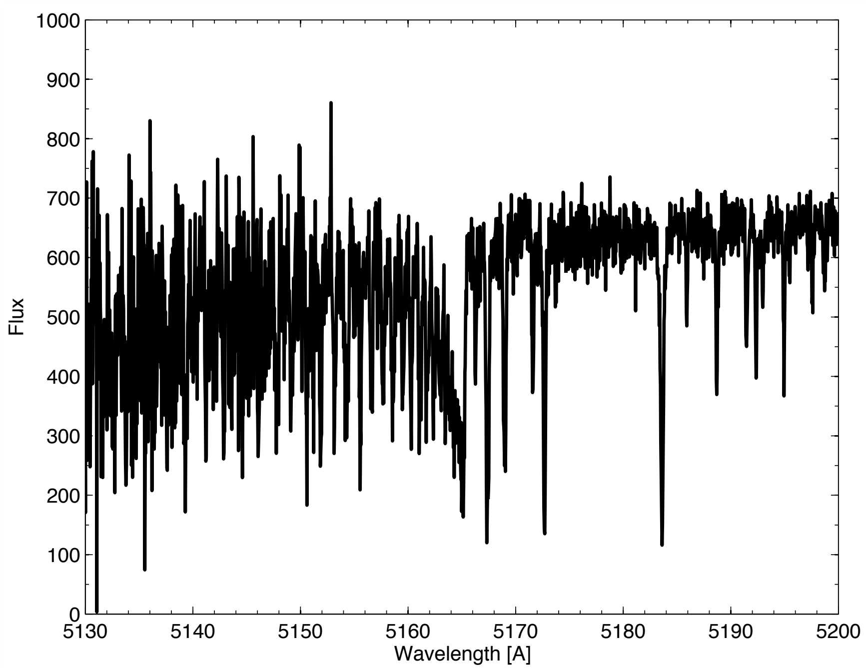
AK et al. 2016, A&A

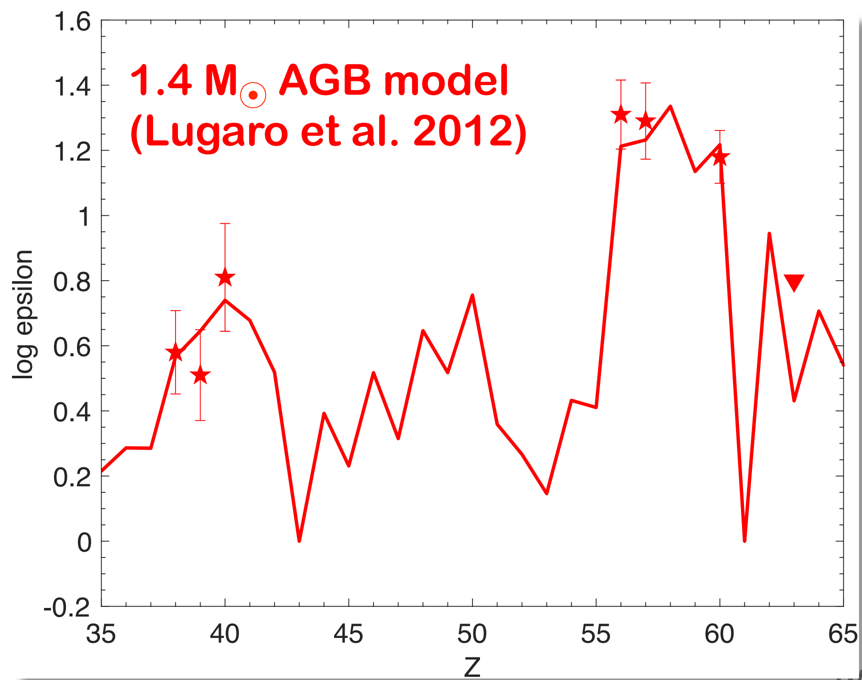
Some special guests

- one **CEMP-*s*** ([Fe/H] = -2.5, [C/Fe] = 1.4, [Ba/Fe] = 1.3)
- one **CH-**star ([Fe/H] = -1.5, [C/Fe] = 0.4, [Ba/Fe] = 1.3)

CEMP-s abundances indicate origin of C-enhancement from AGB transfer.

First contenders of this class towards the bulge.

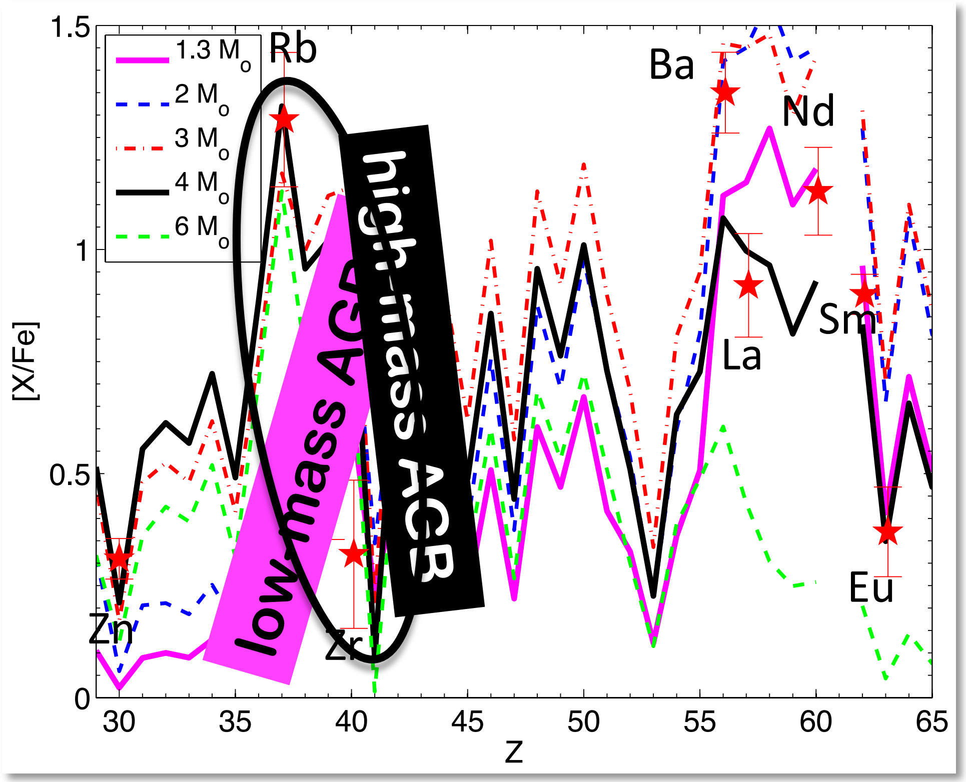




Special star #10464

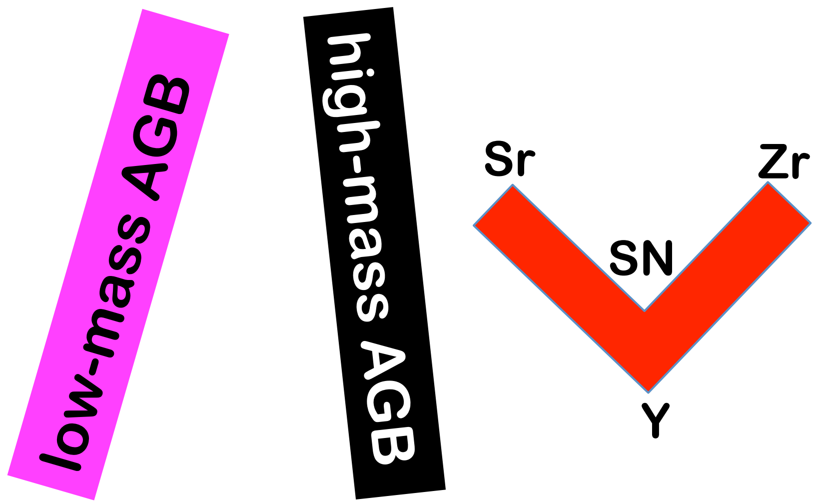
CH- / Ba-star ([Fe/H] = -1.5):

- **Low-metallicity AGB models yield a poor fit for any mass (e.g., ~1.3 $M_\odot$ vs. ~4 $M_\odot$ progenitor).**



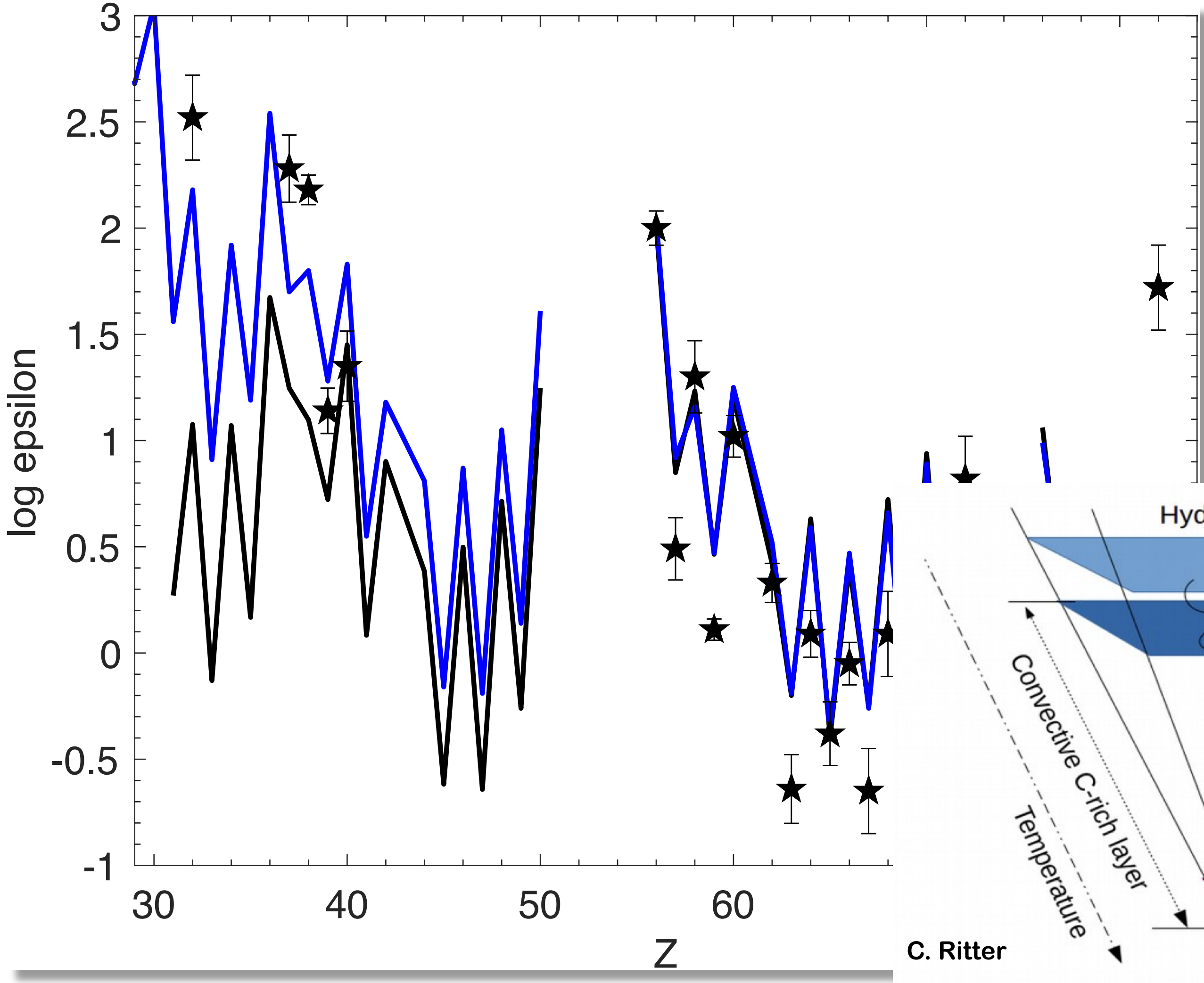
F.R.U.I.T.Y. (Cristallo et al. 2011)

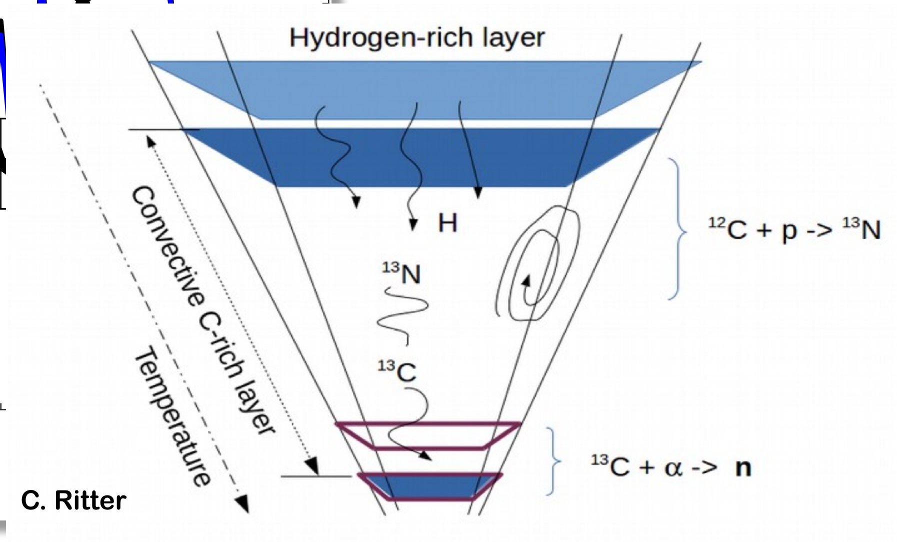
Each predicts various trends, at odds with the observations:



Many problems remain, mainly a very high [Rb/Fe] !

s-, i-, r- ?



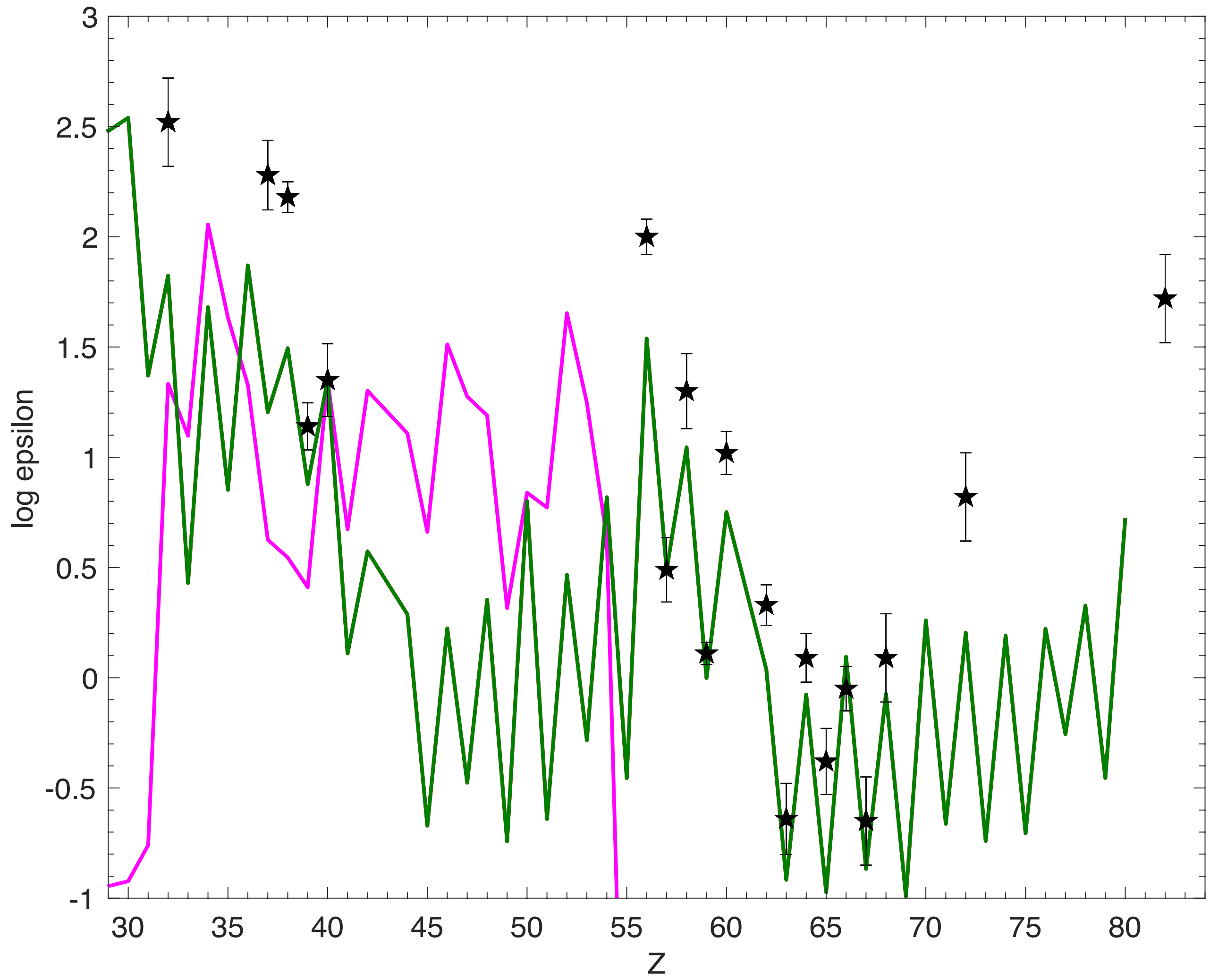


s-process from AGB ✗

i-process $N_n \sim 10^{12-15}$ cm^{-3} ✗

★ : **35 elements in the bulge star #10464** (AK et al. 2016; AK et al. 2017, subm.)

r-enrichment ?



AGB s-process

+ r-process

(Models by D. Martin, A. Arcones)

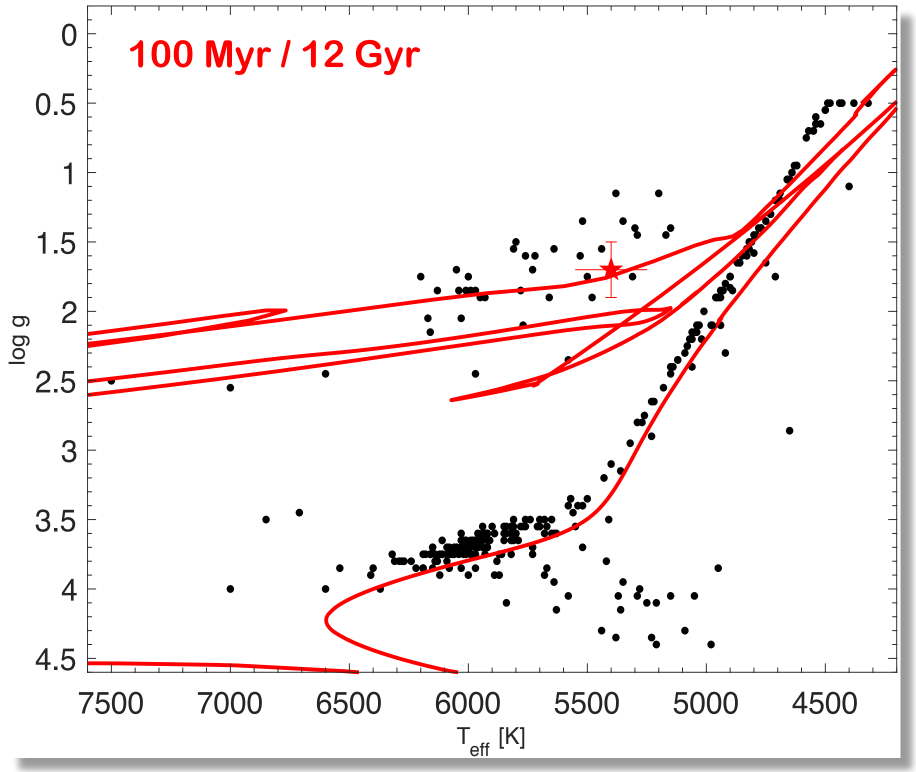
- **17% jet-like SN II (Y_e = 0.2)**
- **6% dynamical ejecta (Y_e = 0.1)**
- **0% ν-driven wind in NSM**

Decomposition ala C.J. Hansen, Montes, Arcones (2014):

$$Y_{tot} = c_{AGB} \times Y_{AGB} + c_{NSM} \times Y_{NSM}$$

Source(s) of #10464's patterns

- Neither standard s-process, nor i-process, nor SNe II or NSM r-process patterns can *fully* reproduce the pattern of this star – either 1st or 2nd peaks can fit, but not simultaneously.
- In particular, the high Rb (and Sr) remain problematic.
- Thinking aloud:
  ^{87}Rb could be produced, but hasn't decayed (to ^{87}Sr), yet
  → Sr is also high
  → requires that the star is young.
- Isochrone fits: < 200 Myr old. Contradiction to its position on the horizontal branch (→ ~12 Gyr).



Halo stars (Roederer et al. 2014)

The first bulge NEMP star

- Further challenge: [N/Fe] = 0.95 → [C/N] ~ -0.5
- NEMP star and heavily affected by internal mixing
  (Spite et al. 2005; C.J. Hansen et al. 2016)
- Presently observed photospheric abundances may not be representative of the actual nucleosynthetic processes.
- It is imperative to also look at light elements (CNO…) to ascertain that your stars are not self polluted!
- Most likely mixture of several events and nucleosynthetic sites. Internal processes unlikely to enhance (Rb…) to the observed levels.

Summary

- We detected "metal-poor" stars towards the bulge, down to -2.7 dex, but most of them are halo-like.
- First CEMP(-s) and NEMP-stars in that population.
- What enriched star #10464? Neither s-process alone, nor i-process, nor standard SNe II or NSM n-capture yields. 1st and 2nd peaks can never be simultaneously fit.
- It is likely that it was enriched by multiple events / sites.