Argelander-Institut für Astronomie

Alexander von Humboldt Stiftung/Foundation

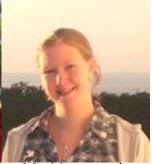
# Carbon-Enhanced Metal-Poor stars

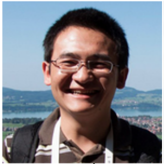
## Fingerprints of binary evolution and AGB nucleosynthesis

Carlo Abate

in collaboration with


R. Stancliffe

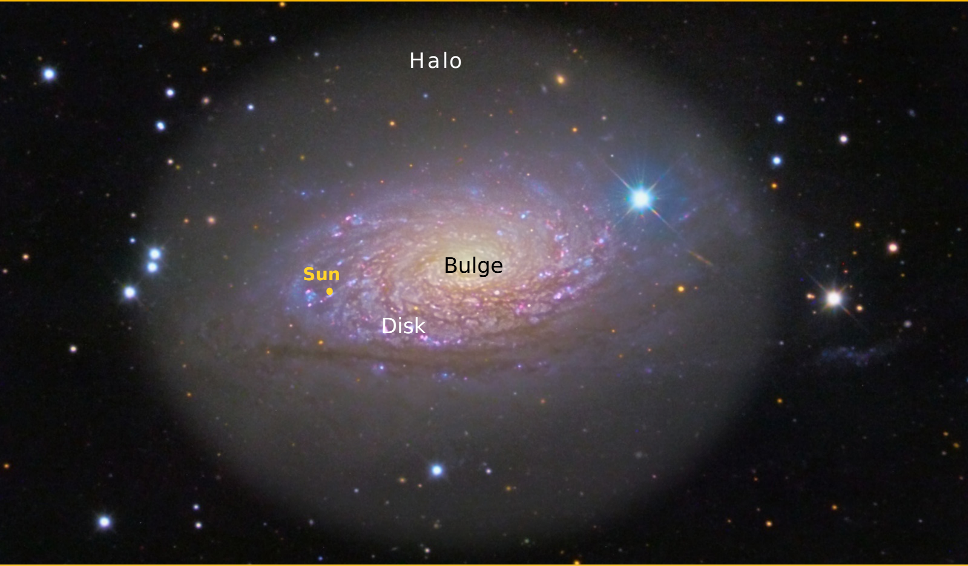

M. Hampel


Z. Liu


E. Matrozis


N. Langer

# Very metal-poor stars



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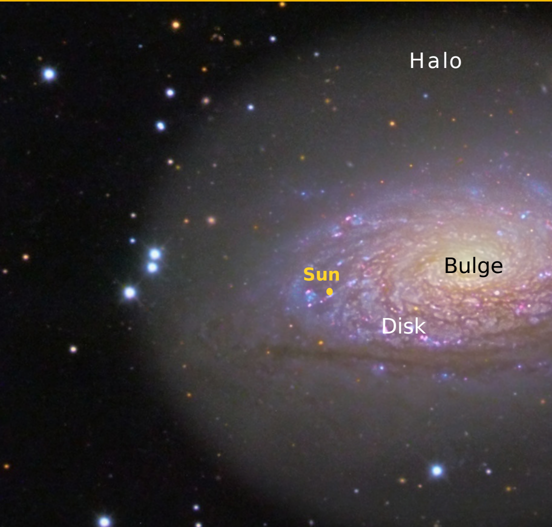
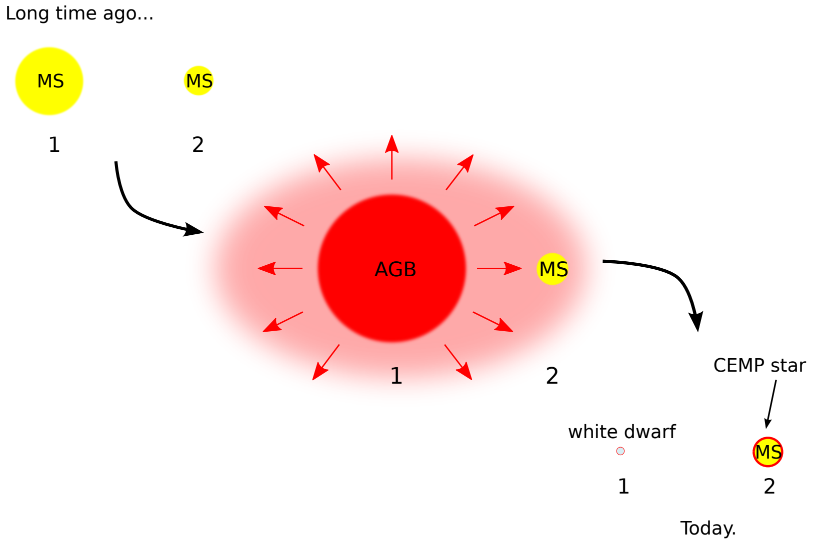



**Halo stars:**

- Old ($\gtrsim$ 10 billion years)
- [Fe/H] $< -2$ (very metal-poor)
- CEMP ($5-25\%$):
  $\rightarrow$ [C/Fe] $> 1$
  CEMP-$s$ $\rightarrow$ [Ba/Fe] $> 1$
  [Ba/Eu] $> 0$
  CEMP-$r/s$ $\rightarrow$ [Eu/Fe] $> 1$
- Mostly binaries

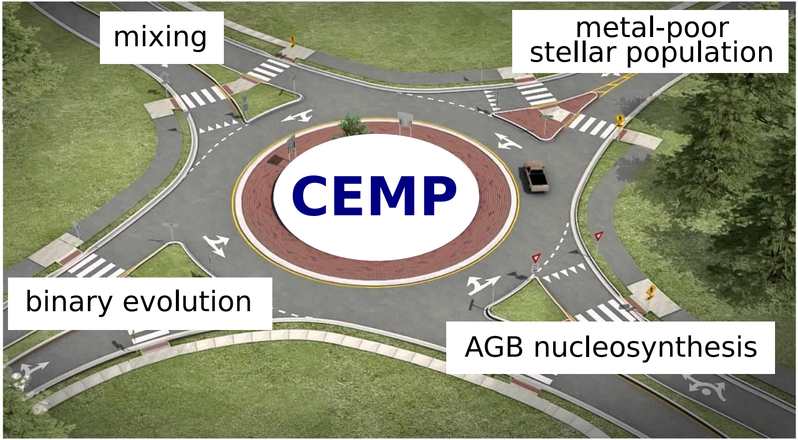
$$[\mathrm{X/Y}] = \log(N_{\mathrm{X}}/N_{\mathrm{Y}})_{*} - \log(N_{\mathrm{X}}/N_{\mathrm{Y}})_{\odot}$$

# Binary evolution

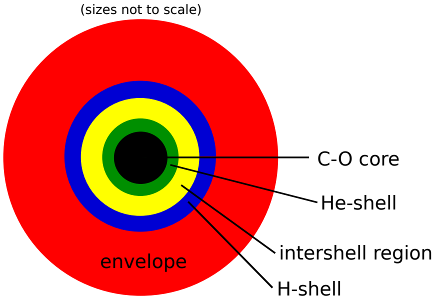



Asymptotic Giant Branch (AGB) → last nuclear-burning phase of stars with $M < 8\,M_\odot$

# CEMP intersection



# AGB nucleosynthesis: *s*-process




**Neutron sources:**

$$^{13}\mathrm{C}(\alpha,\, n)\,^{16}\mathrm{O}$$

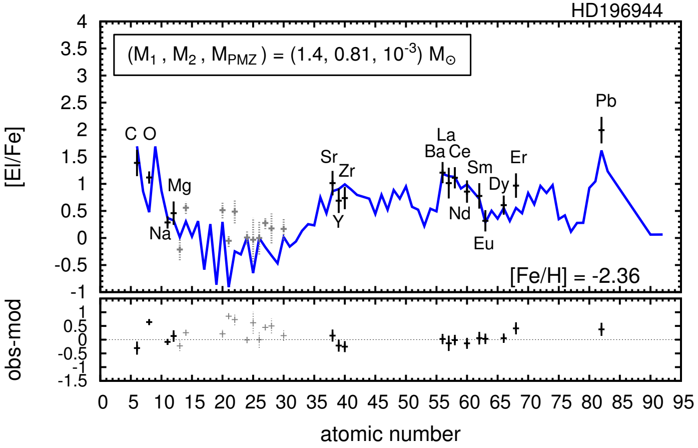
$$^{22}\mathrm{Ne}(\alpha,\, n)\,^{25}\mathrm{Mg}$$

$$\Downarrow$$

$$N_n \approx 10^6 - 10^{10}\ \mathrm{cm}^{-3}$$

*s*-process nucleosynthesis

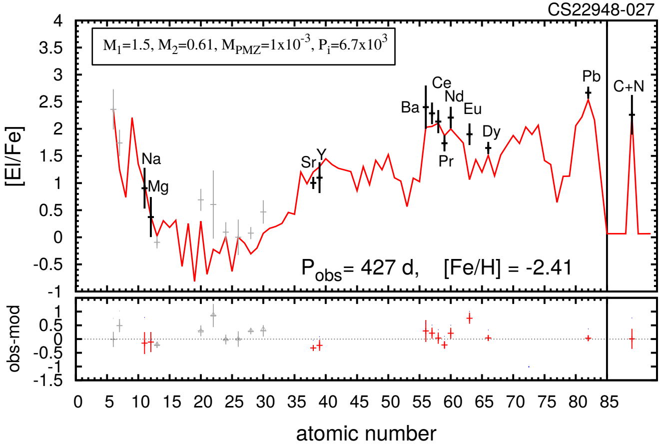
# Fit to observed abundances: CEMP-*s* star




Abate+2015a,b

[Ba/Fe] > 1, [Ba/Eu] > 0

# Fit to observed abundances: CEMP-$r/s$ star

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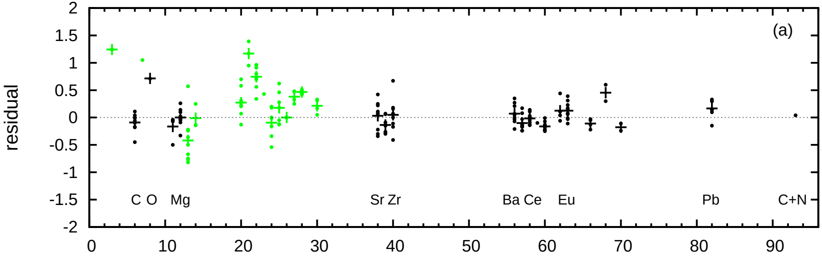
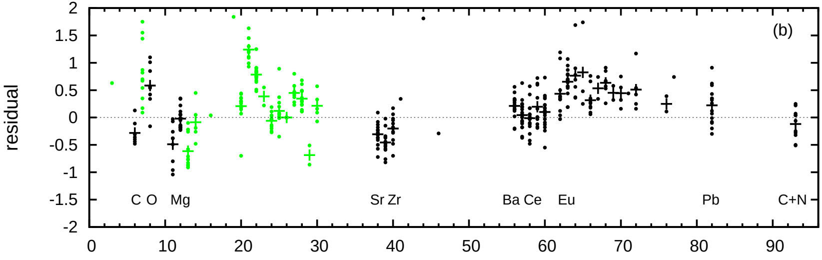
[Ba/Fe] > 1, [Ba/Eu] > 0, [Eu/Fe] > 1

# Best-fit residuals: CEMP-*s* stars



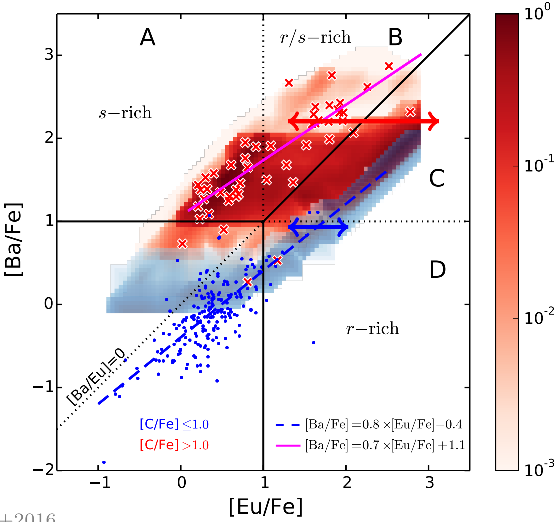

Abate+2015b

# Best-fit residuals: CEMP-$r/s$ stars




Abate+2015b

# Independent $r-$ and $s-$enrichments




$[\mathrm{Eu/Fe}]_{\mathrm{CEMP}} > [\mathrm{Eu/Fe}]_{\mathrm{C-nor}}$

Abate+2016

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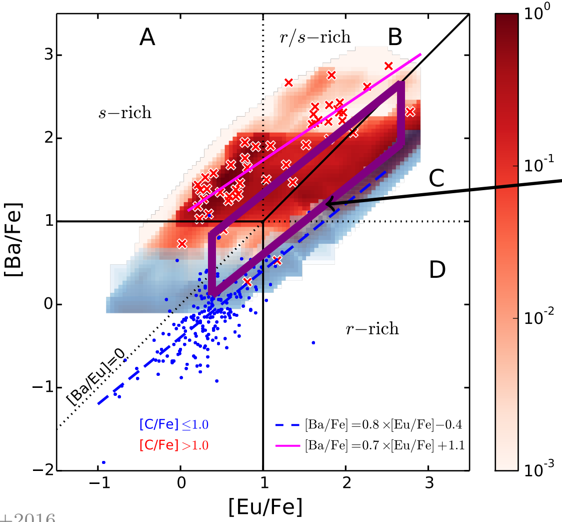


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Dearth of observed stars

Abate+2016

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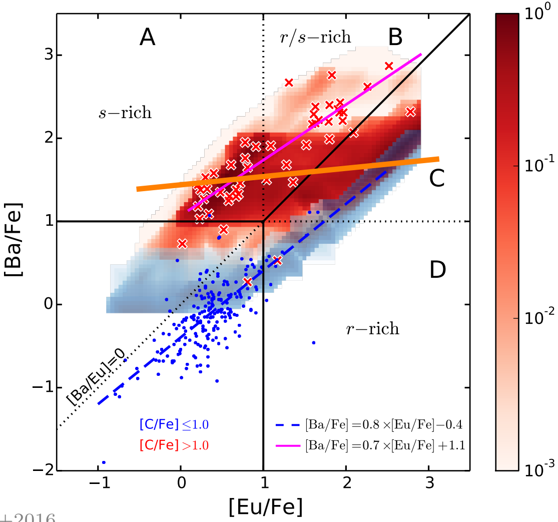


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Dearth of observed stars

Different Ba-Eu relation

Abate+2016

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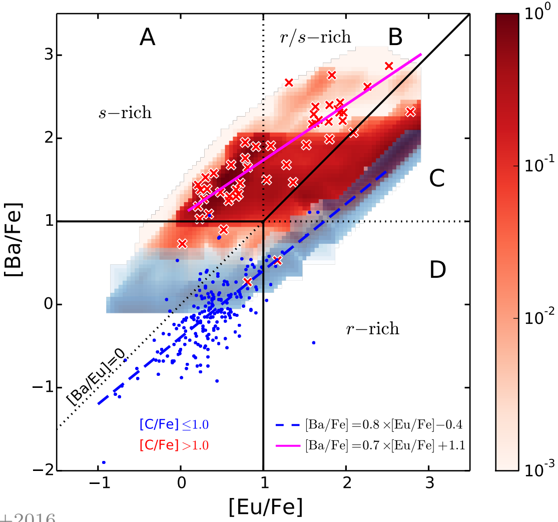


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Different Ba-Eu relation

$\frac{\mathrm{CEMP}-r/s}{\mathrm{CEMP}-s}$ obs: 26–51%, mod: 22%

Abate+2016

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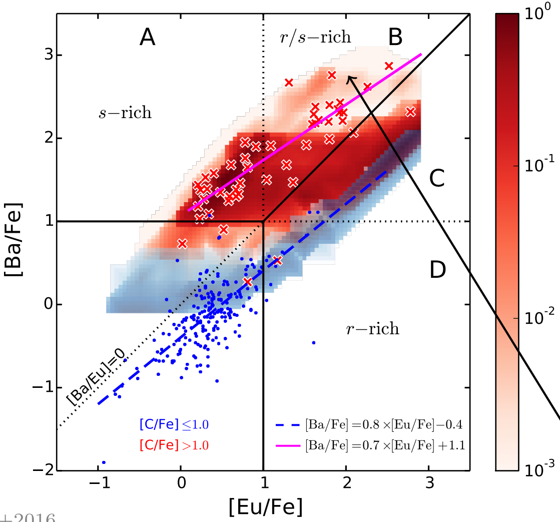


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Dearth of observed stars

Different Ba-Eu relation

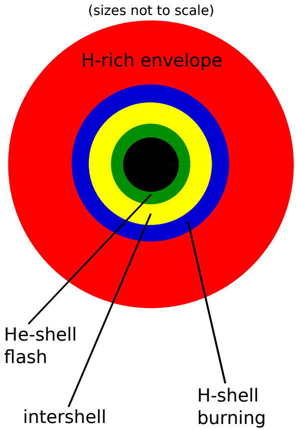
$\frac{\mathrm{CEMP}-r/s}{\mathrm{CEMP}-s}$ obs: 26–51%, mod: 22%

$\frac{\mathrm{CEMP}-r/s,[\mathrm{Ba/Fe}]>2}{\mathrm{CEMP}-r/s}$ 73%, 4%

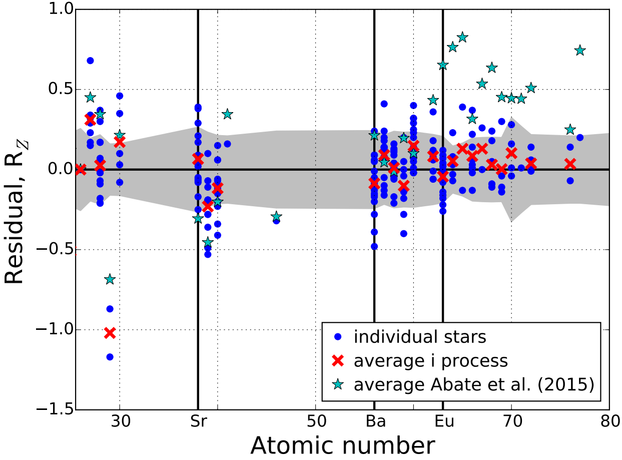
Abate+2016

# $i$-process in AGB stars?

- $i$–process $\Rightarrow N_n \approx 10^{12} - 10^{15}\mathrm{cm}^{-3}$
  (Cowan+Rose 1977)
- proton-ingestion episodes
  $\Rightarrow$ $^1$H penetrate in He-flash regions
- hydrodynamical symulations find "something"
  (Campbell+2008, Stancliffe+2011, Herwig+2014)
- promising: 1-zone model $\rightarrow$ intershell composition + $N_n \lesssim 10^{15}\mathrm{cm}^{-3}$
  (Hampel+2016)



# Call them CEMP-$i$ stars!




Hampel+2016, in press (arXiv:1608.08634)

# Take-home message