Using Carbon and *s*-process Enriched Low Mass Evolved stars as Tracers of s-process Nucleosynthesis

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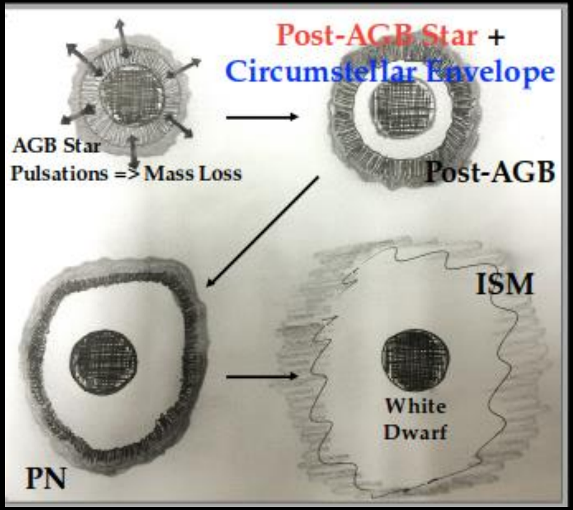
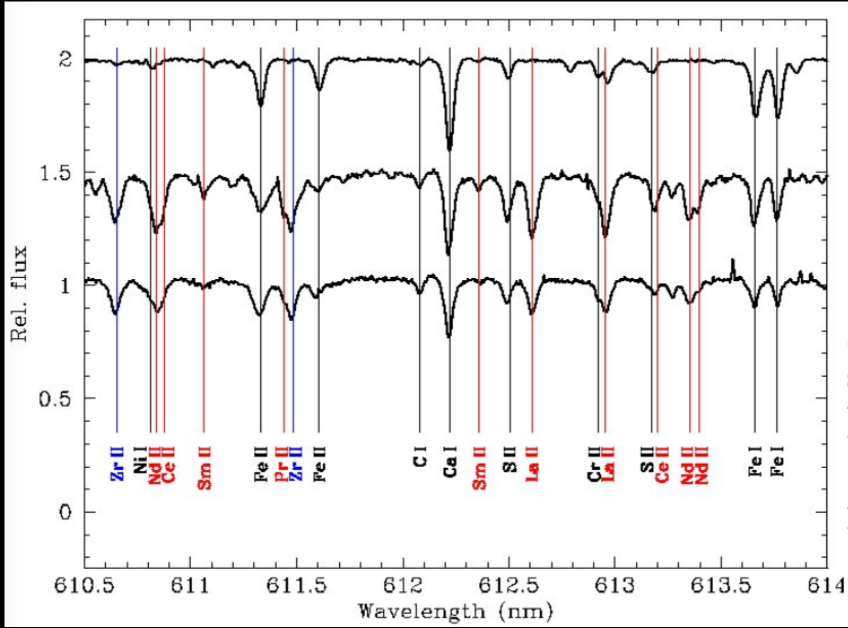
Post-AGB Stars as Tracers of *s*-process

Devika Kamath's Talk



Schematic of Post-AGB Evolution



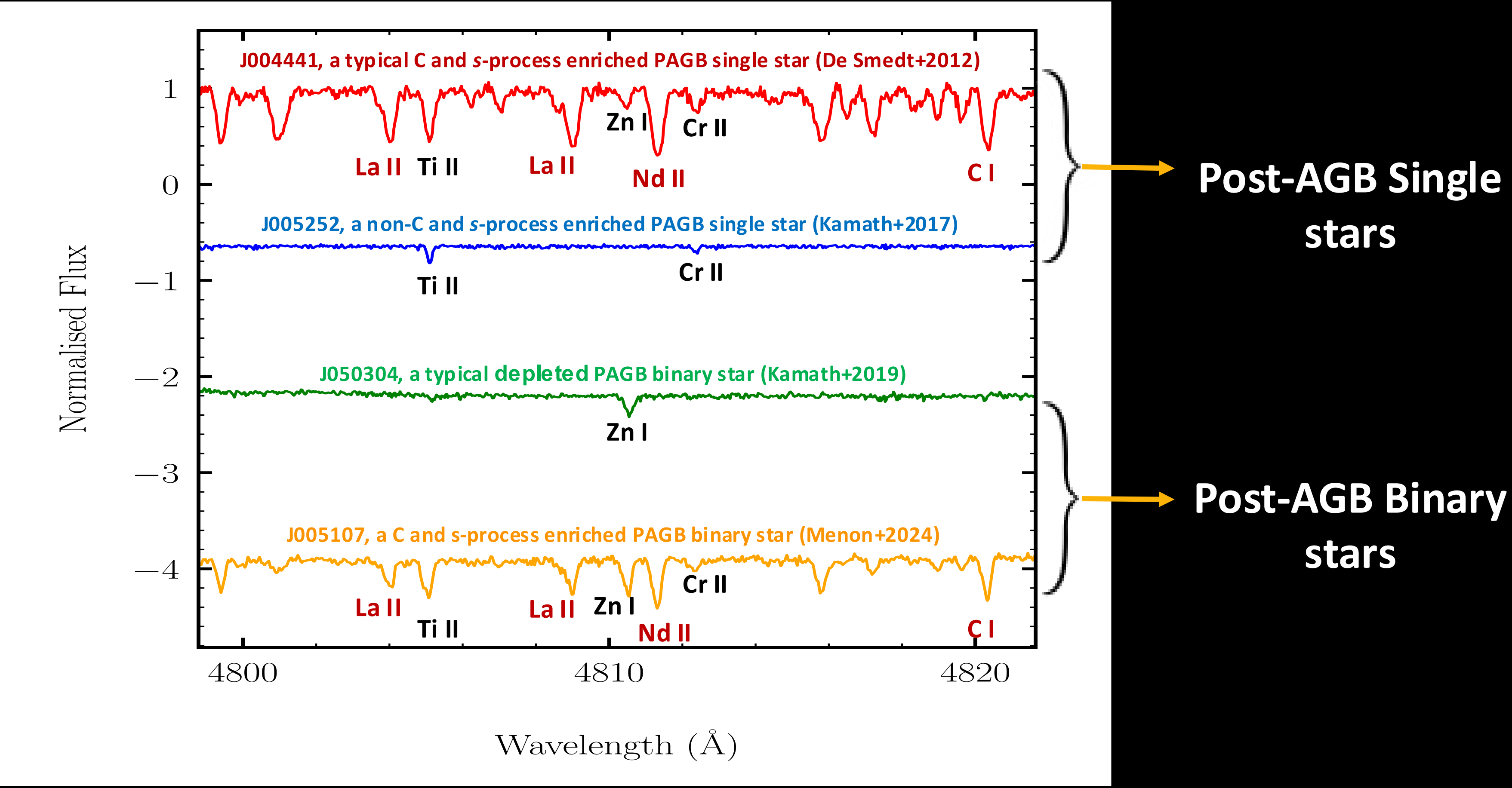
Spectra are dominated by s-process atomic transitions.
Up to Gd, Yb, Lu, W

Range of n-exposures

Van Winckel & Reyniers 2000; Van Arle+2011; De Smedt+2012,2015,2016; Kamath+2022

Post-AGB spectra are Ideal for accurate elemental abundance quantification

Chemical Diversity in Post-AGB Stars



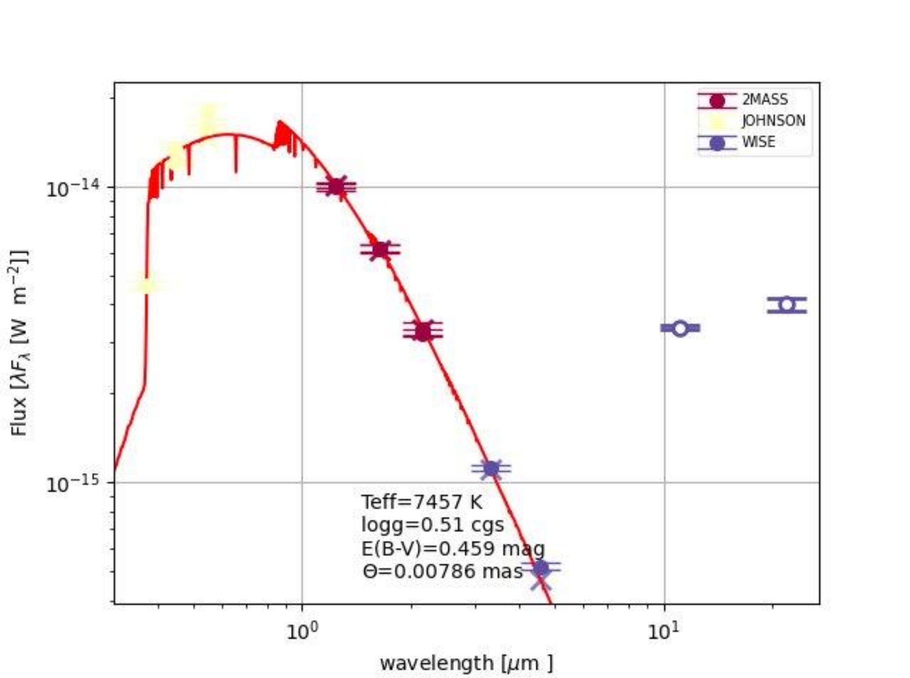
Primary Target of this study

J003643.94–723722.1

(hereafter J003643)

SMC Single Post-AGB star

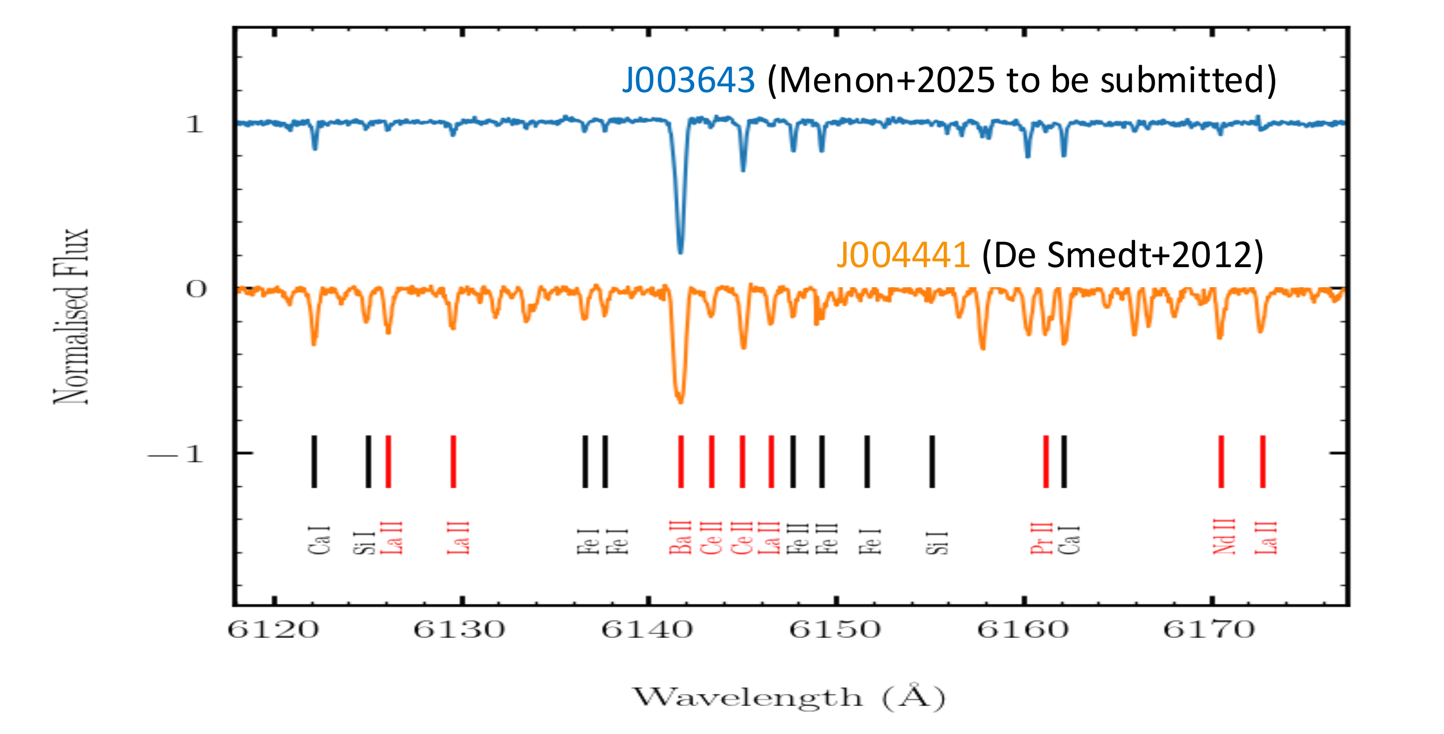
Luminosity 7623L⊙



Spectral Energy Distribution

Menon+2025 to be submitted

High Resolution Optical Spectra from VLT+UVES



E-iSpec: Evolved Stars Solution of iSpec

iSpec

Radiative transfer codes:

Turbospectrum, SPECTRUM, Moog, SME, Synthe/WIDTH9

Model atmospheres:

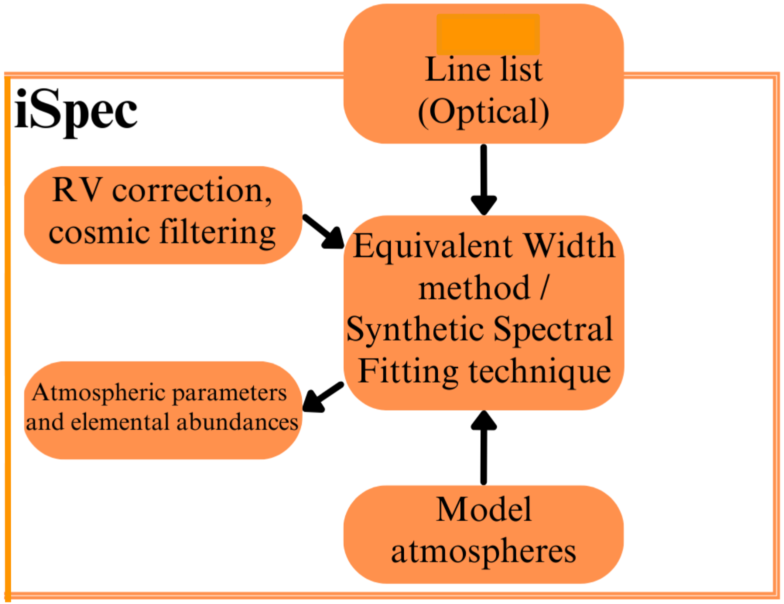
ATLAS9, MARCS

Solar abundances:

from Anders+1989 to Asplund+2021

Line lists:

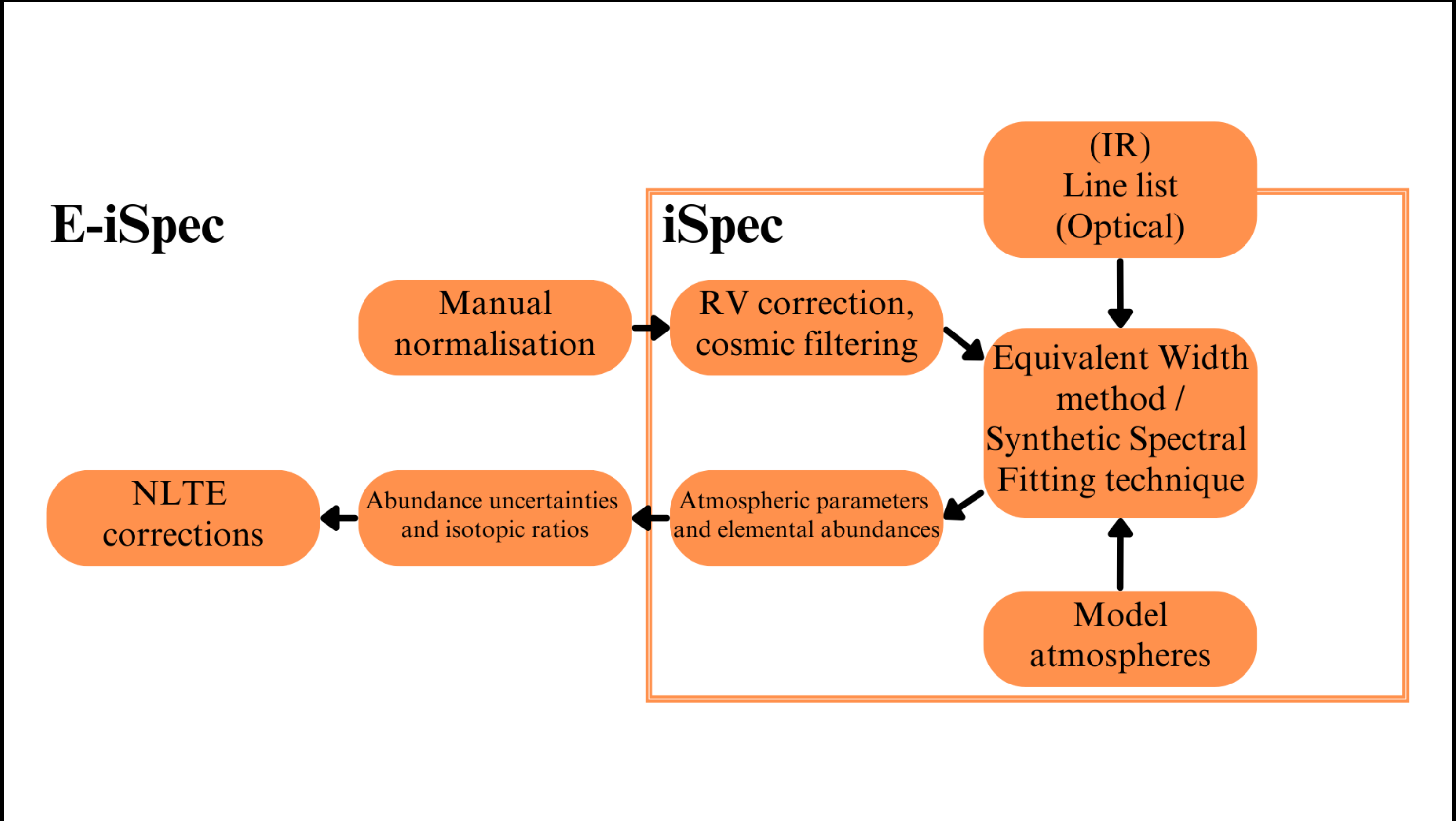
VALD3, Gaia-ESO, ATLAS9, SPECTRUM



E-iSpec GitHub

Mohorian+2024,2025; Menon+2024,2025 to be submitted

E-iSpec: Evolved Stars Solution of iSpec



E-iSpec GitHub

Mohorian+2024,2025; Menon+2024,2025 to be submitted

Atmospheric Parameters of J003643

Spectroscopic Analysis: E-iSpec (Mohorian et al., 2024)

Teff = 7552 ± 91 K

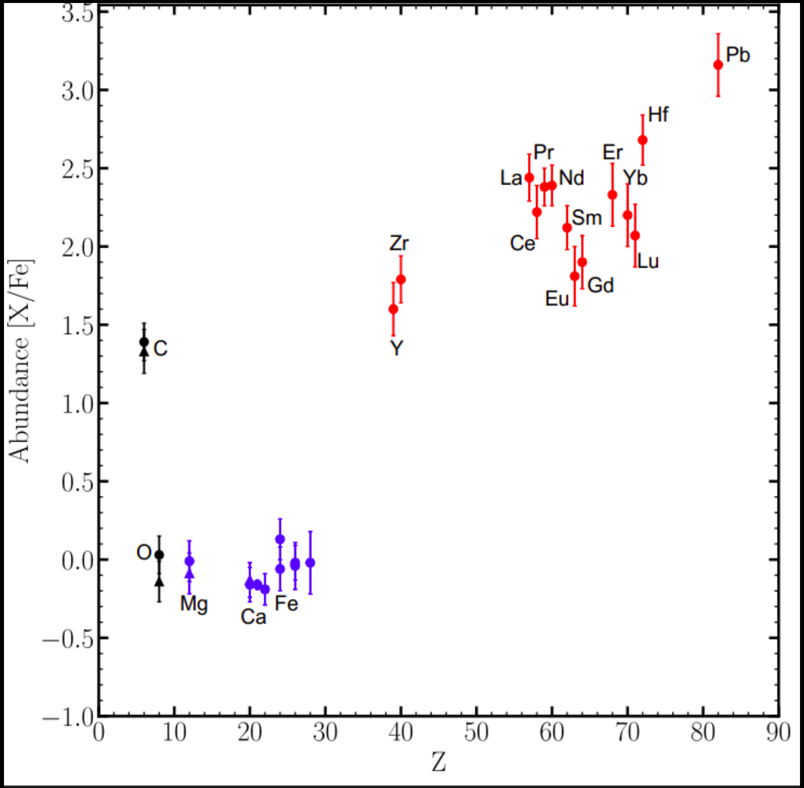
log g = 1.04 ± 0.16 dex

[Fe/H] = –0.92 ± 0.11 dex

ξt = 4.02 ± 0.13 km/s

Photospheric Chemistry of J003643

Spectroscopic Analysis: E-iSpec (Mohorian et al., 2024)
NLTE Analysis: Balder Code (Amarsi et al. 2018a)



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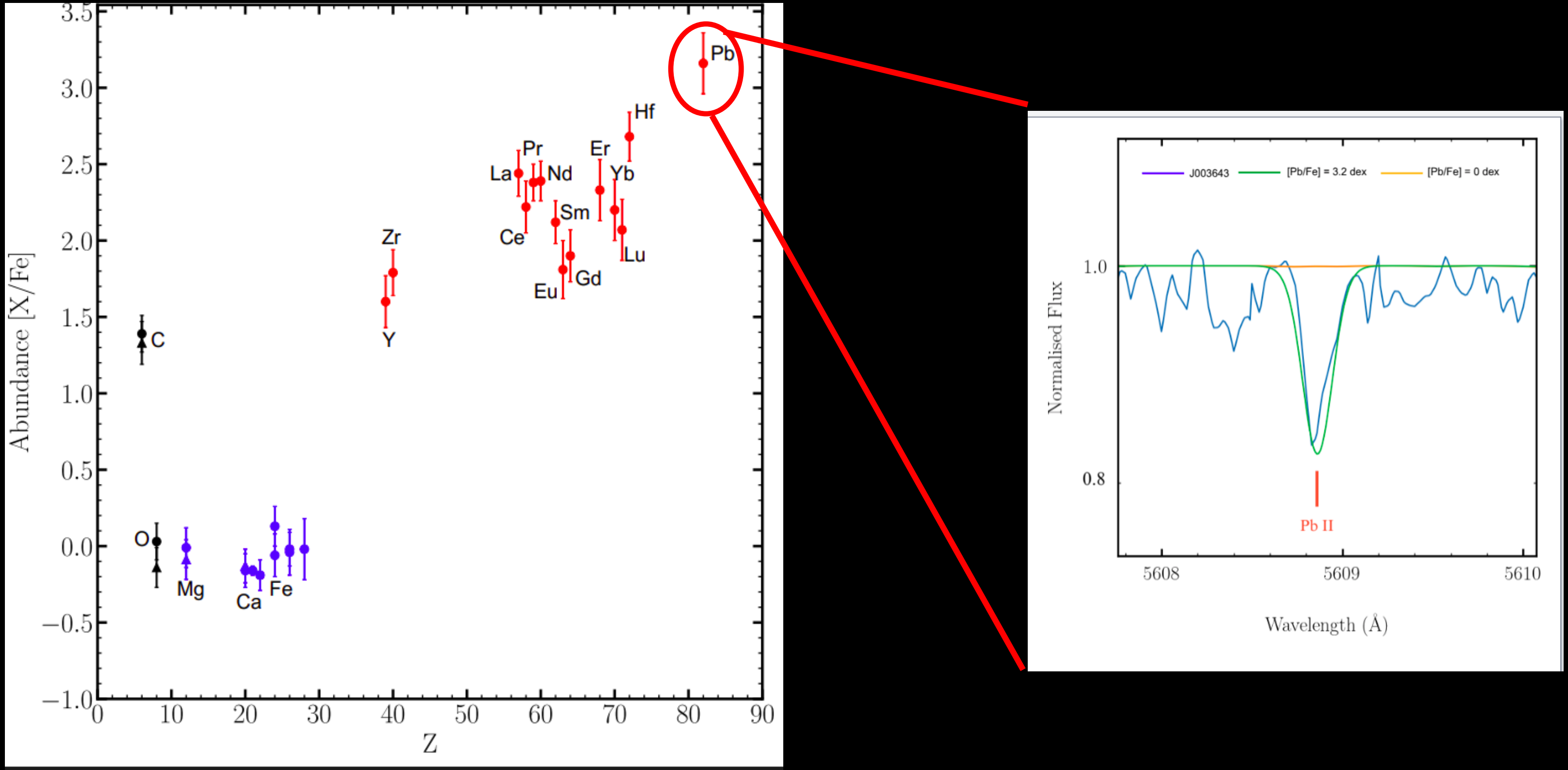

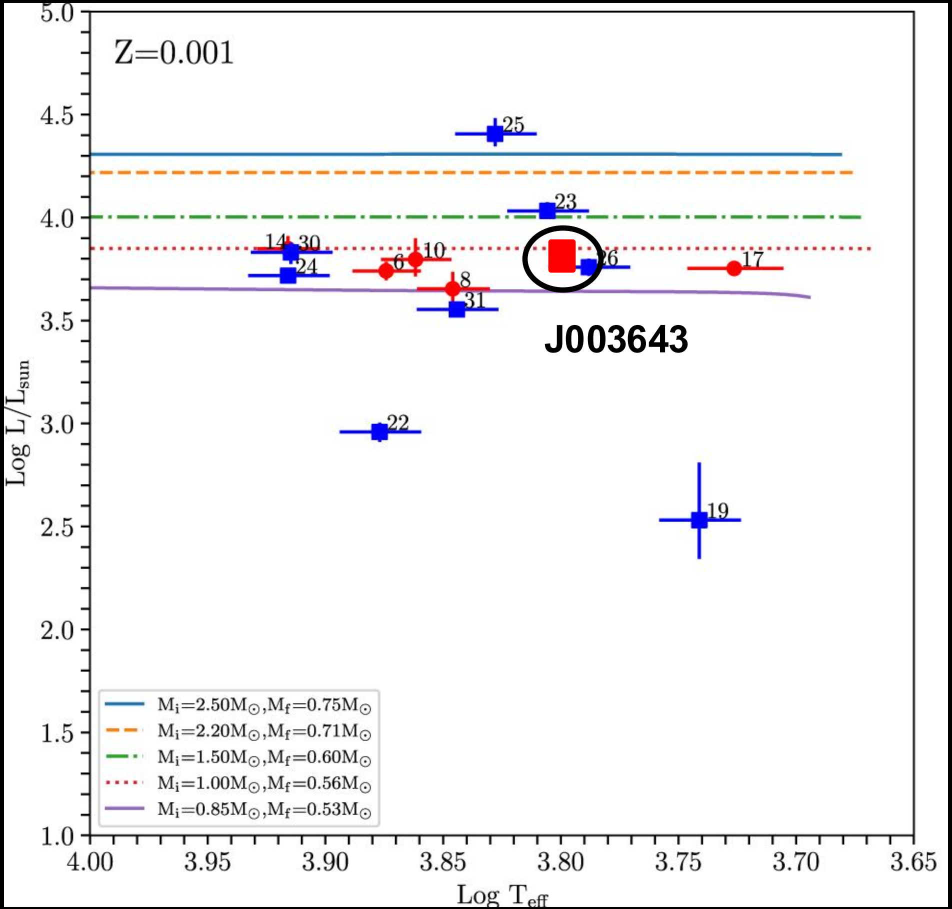

Z=0.001
25
23
14
30
10
6
24
26
17
8
31
J003643
22
19
$M_i=2.50M_\odot, M_f=0.75M_\odot$
$M_i=2.20M_\odot, M_f=0.71M_\odot$
$M_i=1.50M_\odot, M_f=0.60M_\odot$
$M_i=1.00M_\odot, M_f=0.56M_\odot$
$M_i=0.85M_\odot, M_f=0.53M_\odot$
Log L/L_{sun}
Log T_{eff}

Photospheric Chemistry of J003643

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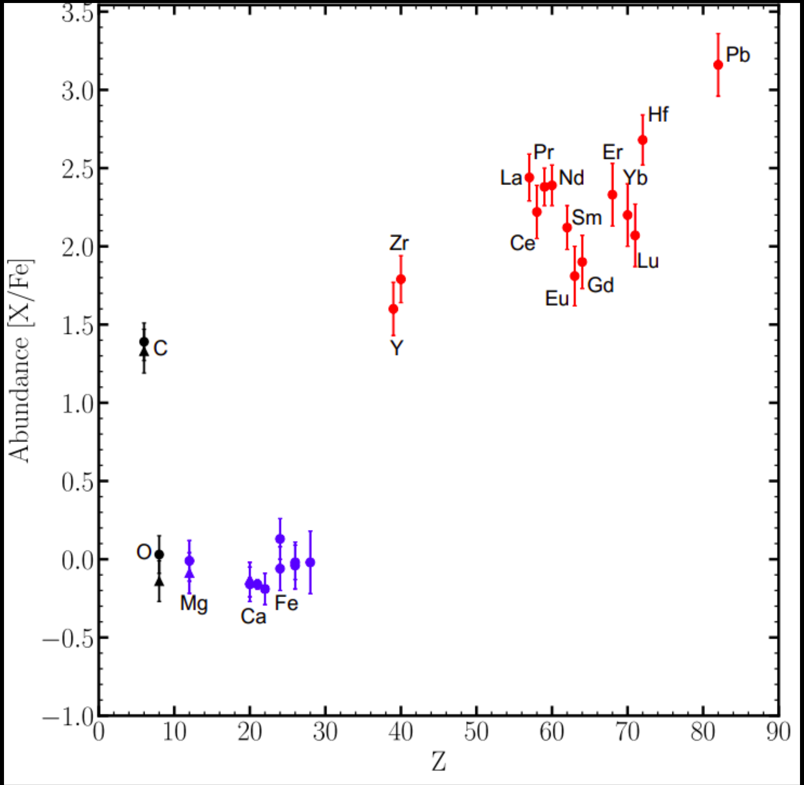
NLTE Analysis: Balder Code (Amarsi et al. 2018a)



[s/Fe] = 2.09 ± 0.20 dex

[hs/ls] = 0.48 ± 0.12 dex

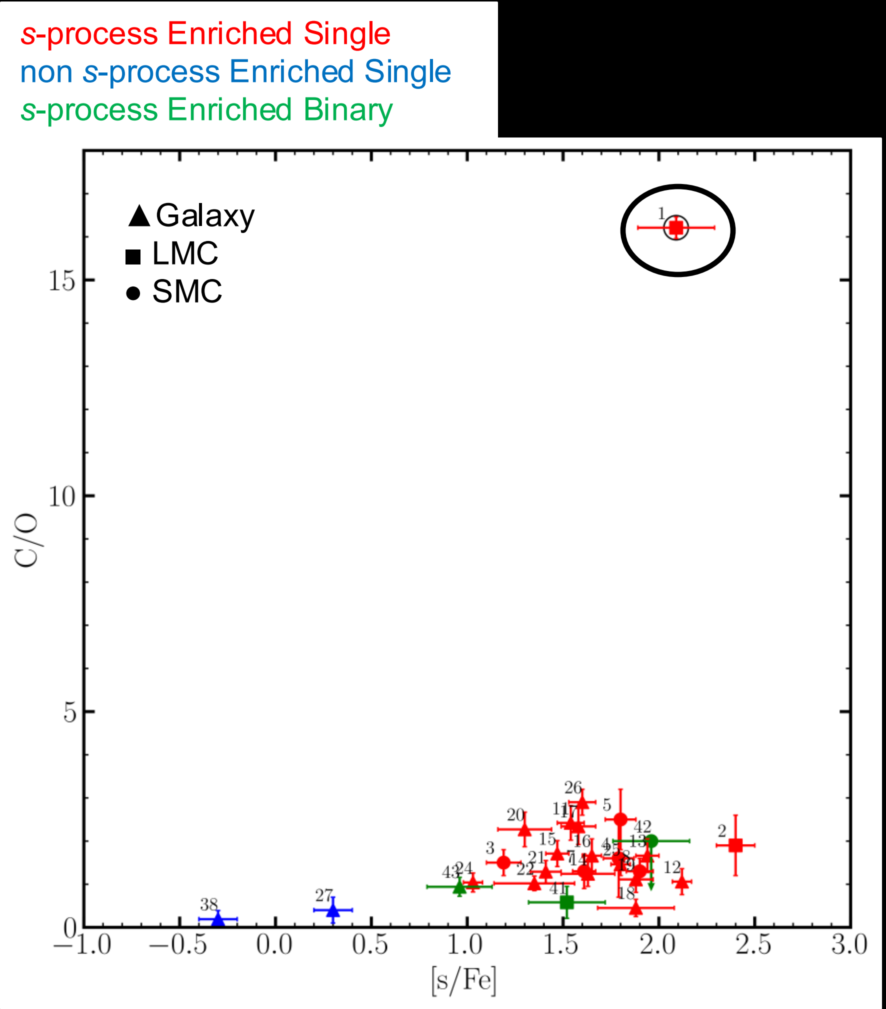
[Pb/Fe] = 3.16 ± 0.18 dex

[Pb/ls] = 1.39 ± 0.16 dex

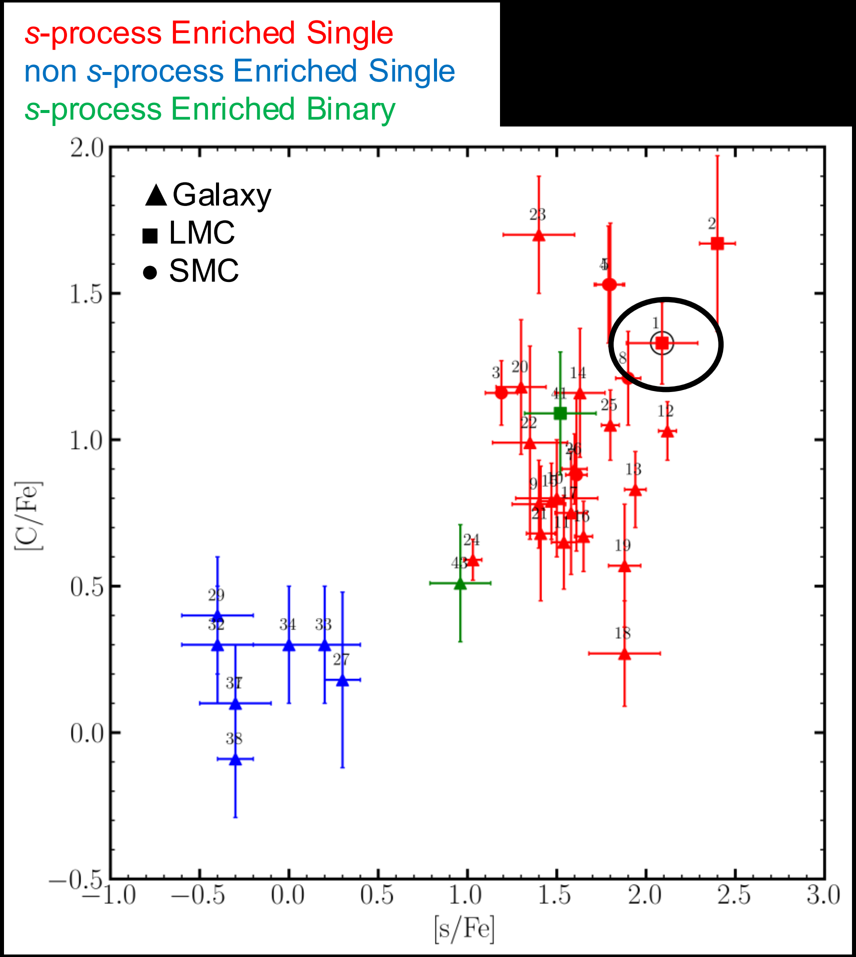
[Pb/hs] = 1.86 ± 0.15 dex

C/O = 16.2 ± 0.22

Comparision with Comprehensive Post-AGB Sample



Typical C/O ratio of PAGB stars: ~1 – 3
C/O ratio of J003643: ~ 16

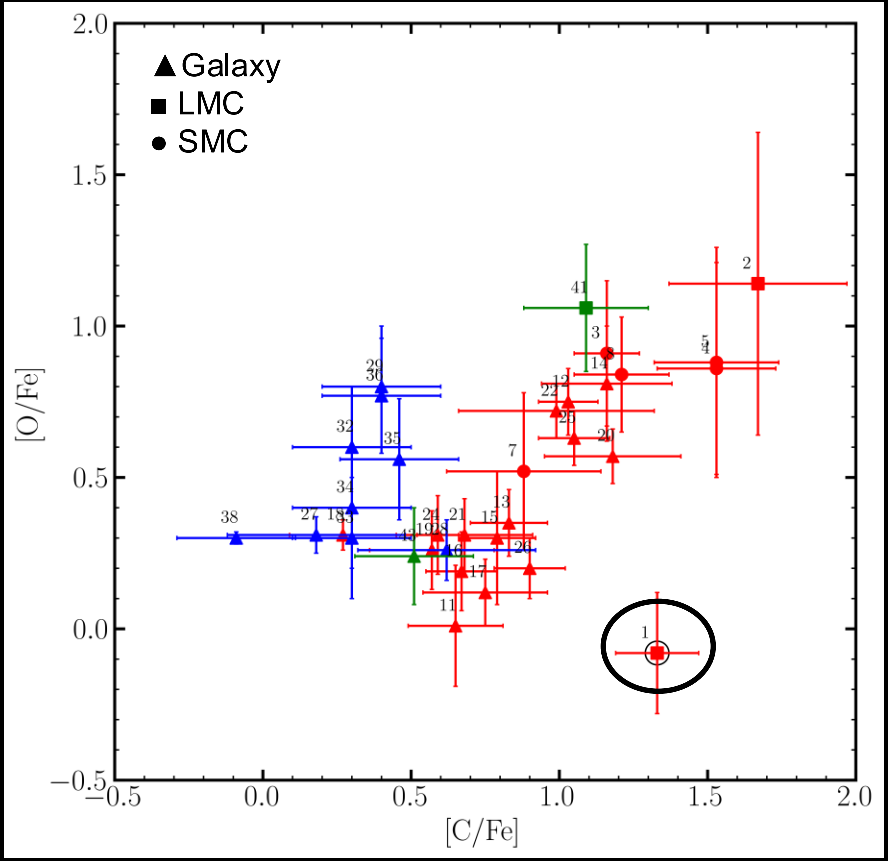


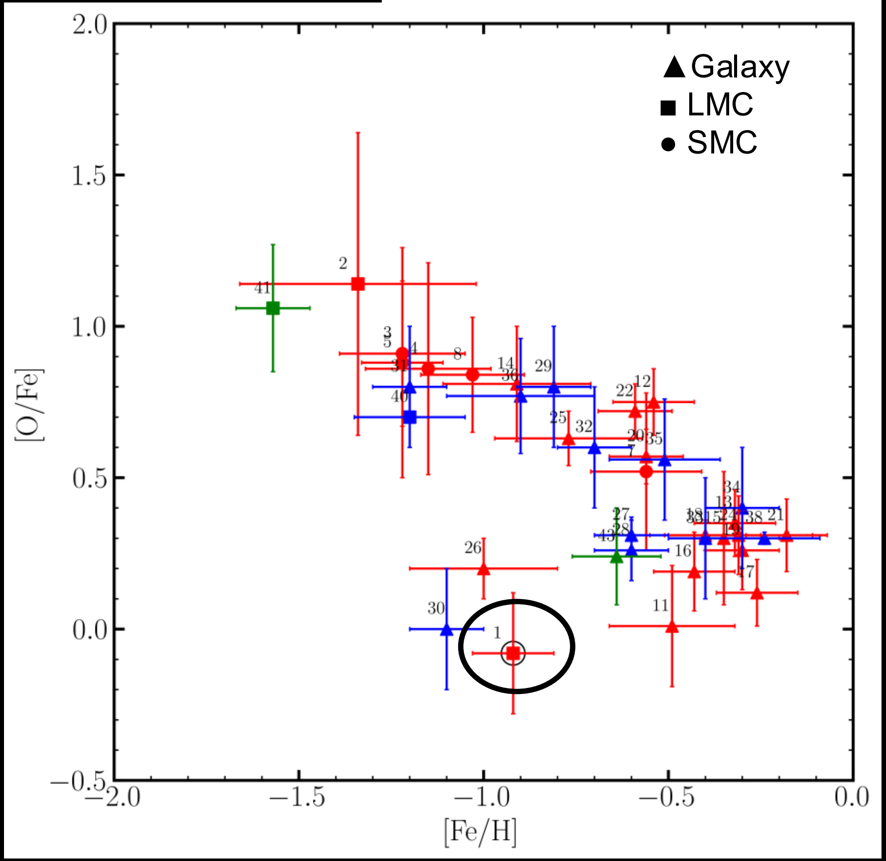
[C/Fe] of J003643 is consistent with other Post-AGB stars indicating its C enhancement scales with its *s*-process enrichment.

C/O is not high due to an unusually high C abundance

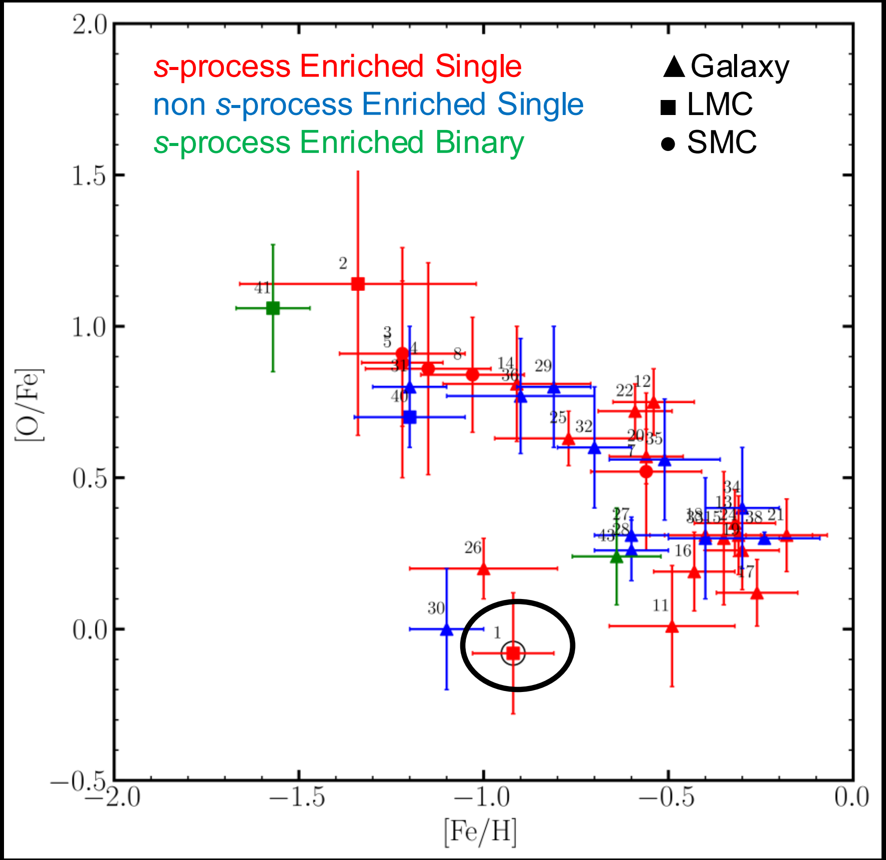
[O/Fe] of J003643 is relatively low compared to its counterparts

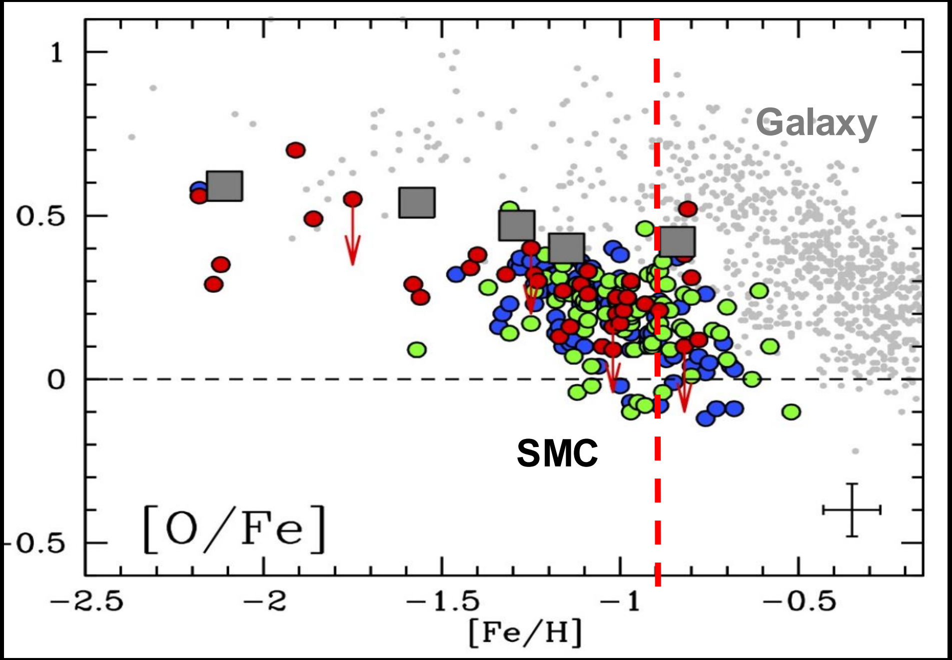
s-process Enriched Single
non *s*-process Enriched Single
s-process Enriched Binary





Oxygen Enrichment of Galaxy, LMC and SMC





Helmi+2018; Bensby+2005; Reddy+2006; Mucciarelli+2023; Pompéia+2008; Van der Swaelmen+2013

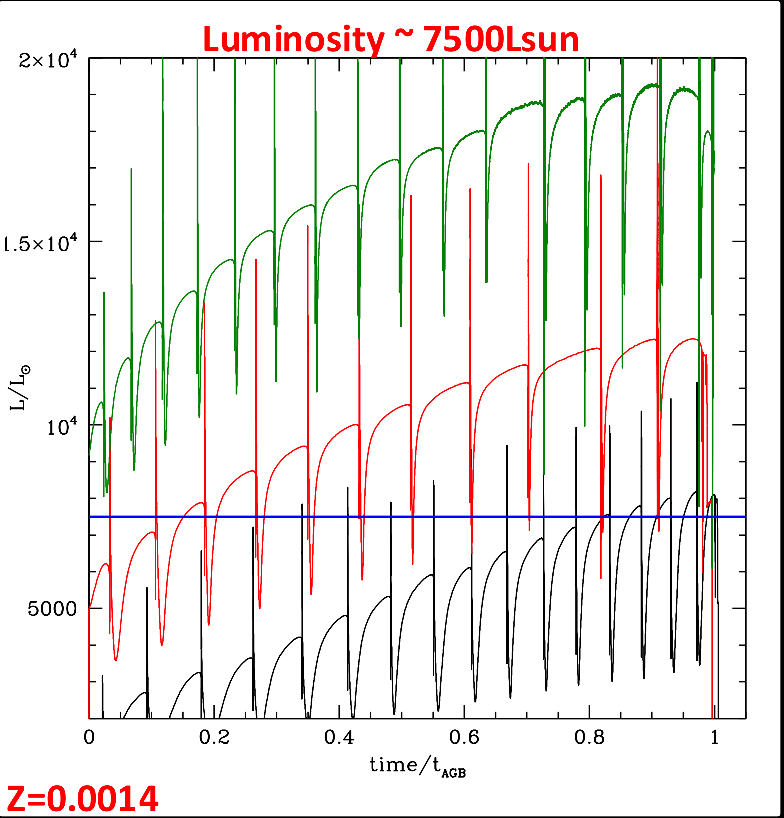
J003643: **[O/Fe]=–0.08±0.20 dex and [α/Fe]≈0 dex at [Fe/H]≈–1.0 dex**
is consistent with SMC's chemical Enrichment.
Its low [O/Fe] reflects formation from an O-poor ISM in the SMC.

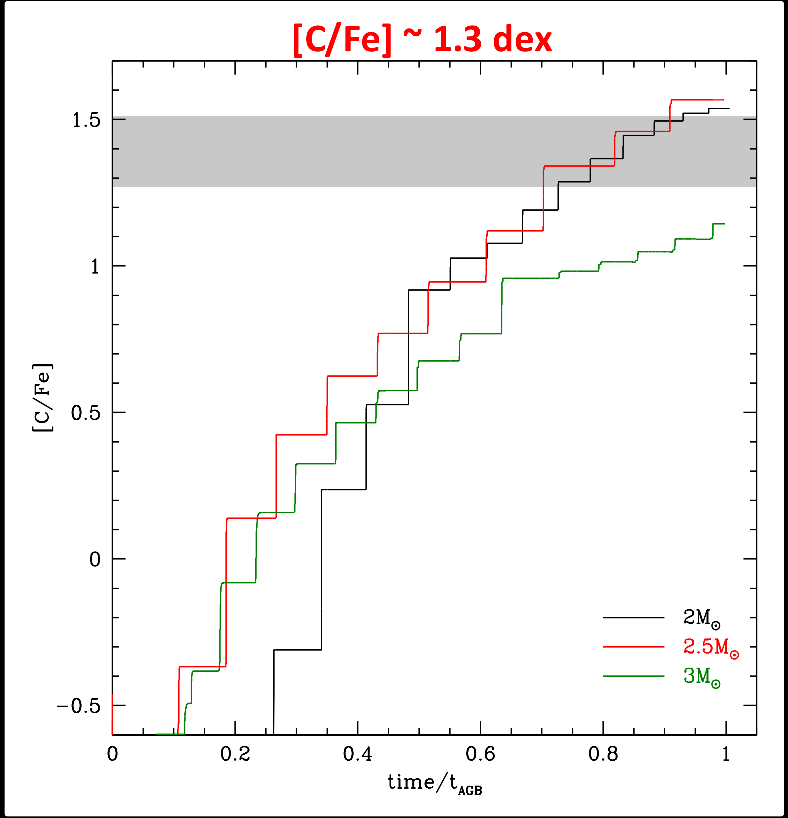
Therefore, the high C/O ratio of J003643 is driven by an intrinsic oxygen deficiency at birth, not by an unusually high C abundance

Comparision with Yields from Various Stellar Evolutionary Models

ATON

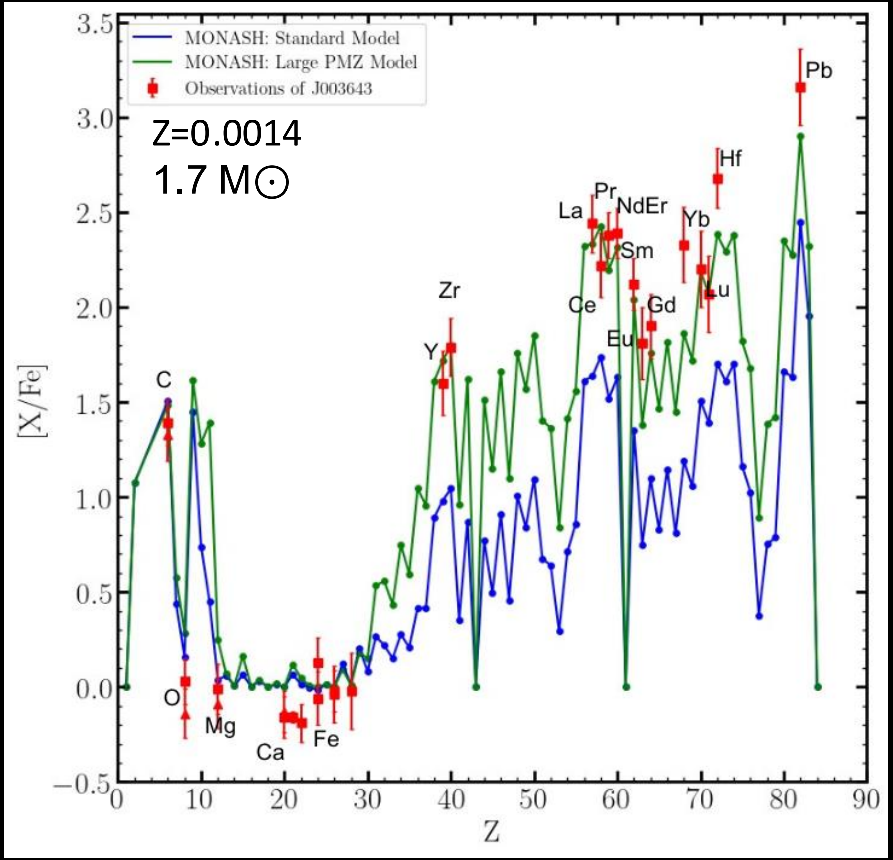
Initial mass ~ 2Msun





Ventura et al., 2018; Menon+2025 to be submitted

MONASH

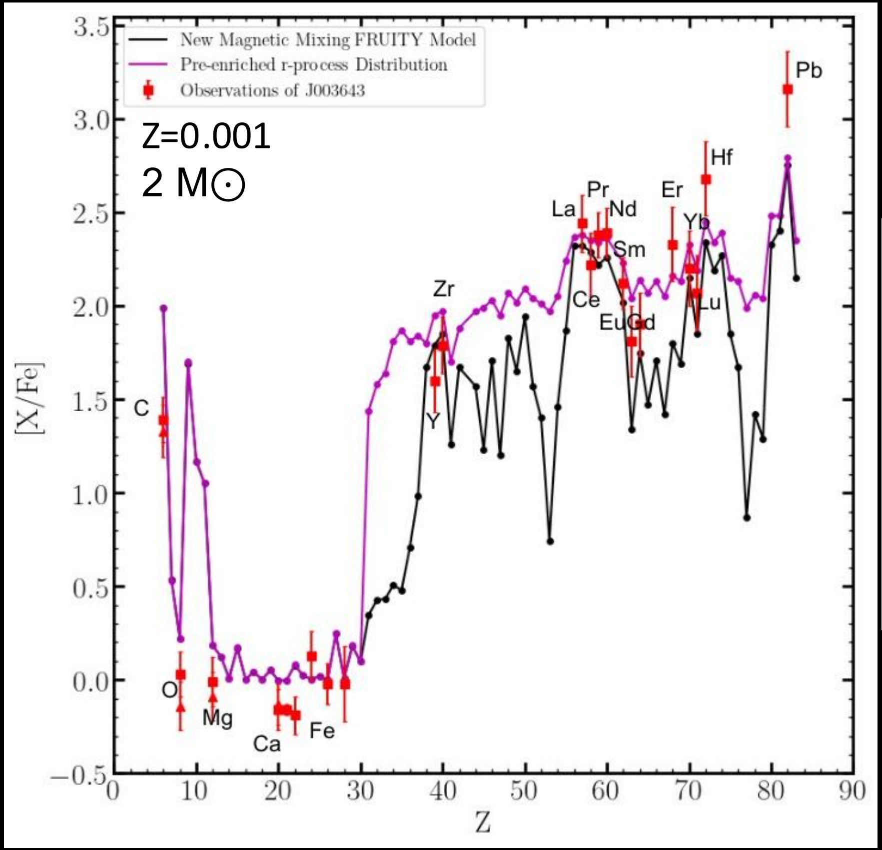


Standard MONASH Model

MONASH Model with PMZ of 0.006M☉

Karakas et al., 2018; Menon+2025 to be submitted

FRUITY

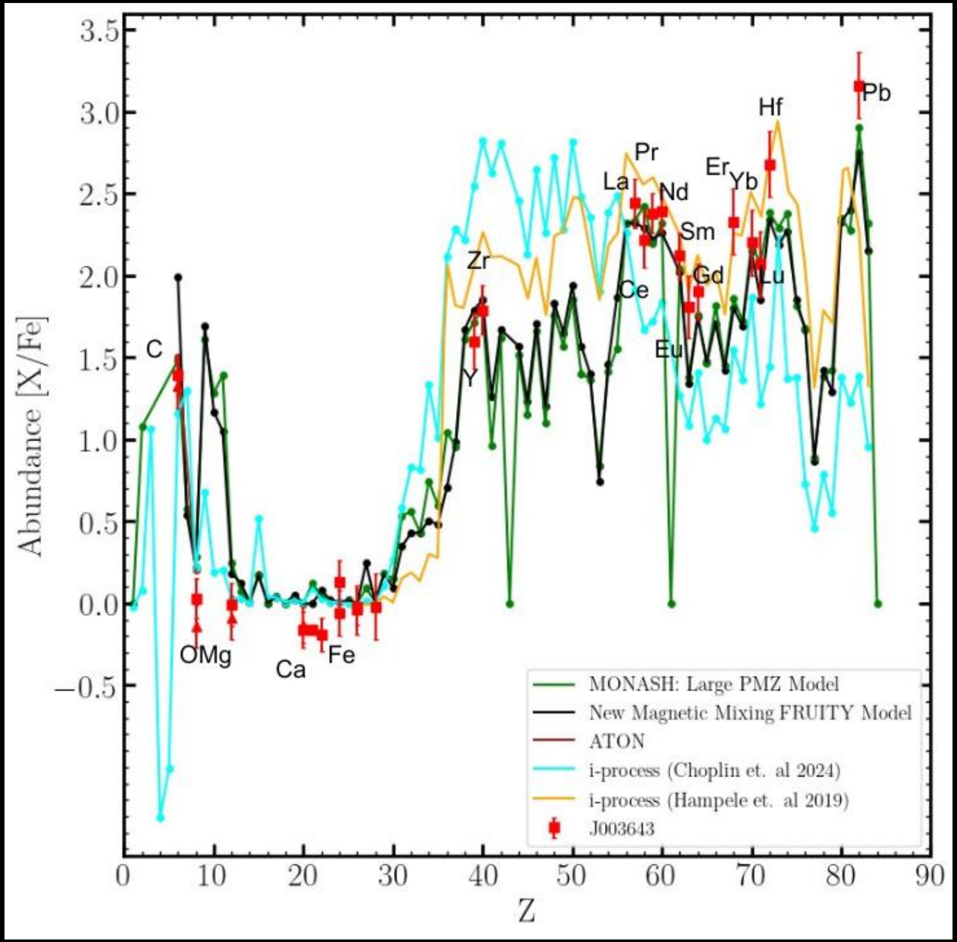


Magnetic Mixing FRUITY Model

Model with an initially r-process enhanced composition, adopting a solar r-process distribution scaled by +2 dex ([r/Fe] = +2)

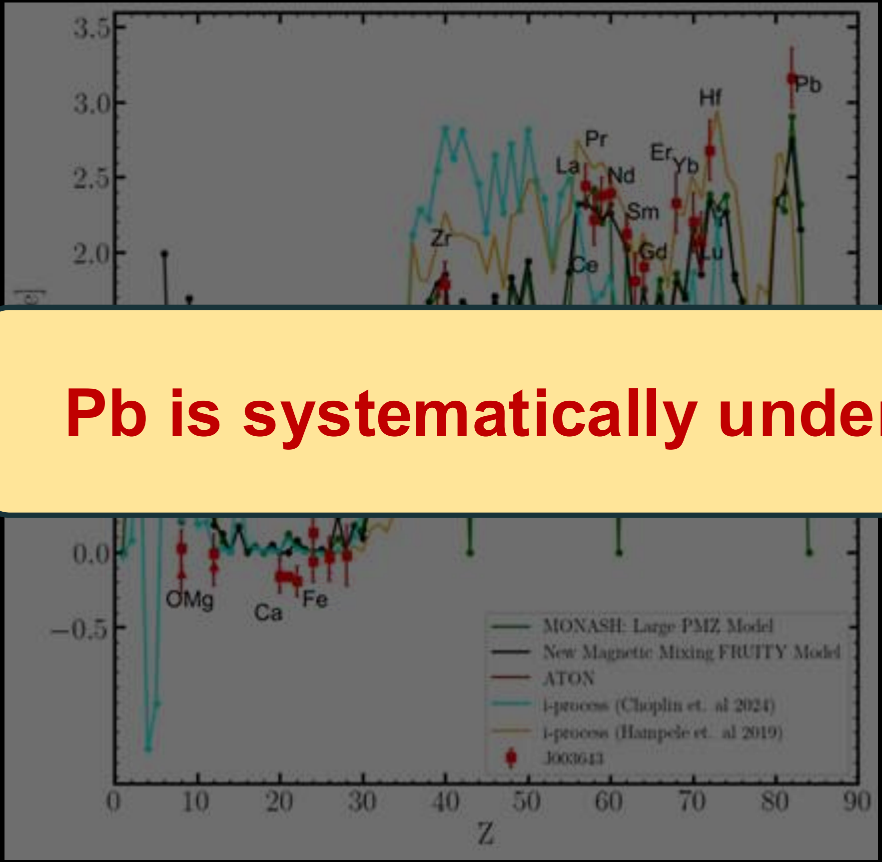
Cristallo+2016; Vescovi+2020; Prantzos+2020; Menon+2025 to be submitted

Comparing all the Models



i-process Models do not fit the abundance of J003643 well

Comparing all the Models



i-process Models do not fit the

Pb is systematically underestimated by all models

Key Takeaway Points

1. This study further expands the observed chemical diversity among post-AGB stars, highlighting that AGB nucleosynthesis is more complex than previously understood.

2. J003643 is the first post-AGB star with both a high C/O ratio and a precise Pb abundance derived, providing critical constraints on CNO and s-process nucleosynthesis in low mass stars.

3. J003643 is the second single, s-process enriched post-AGB star identified in the SMC. This highlights the need for more detailed observations across a wide range of stellar mass and metallicity to fully understand the diversity of nucleosynthetic outcomes.

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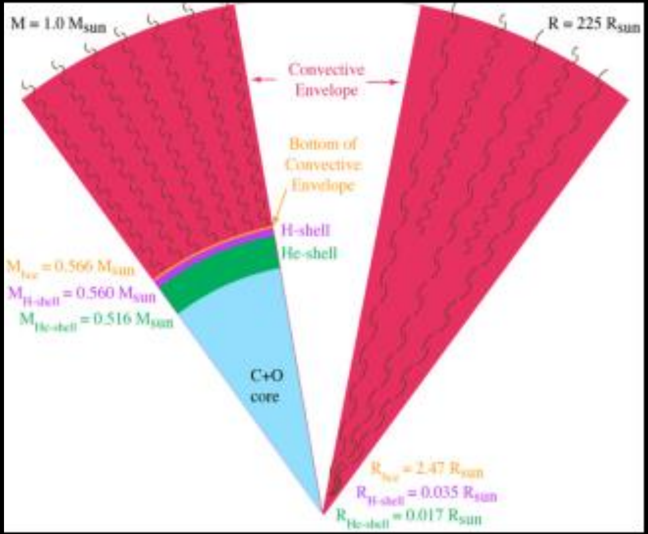
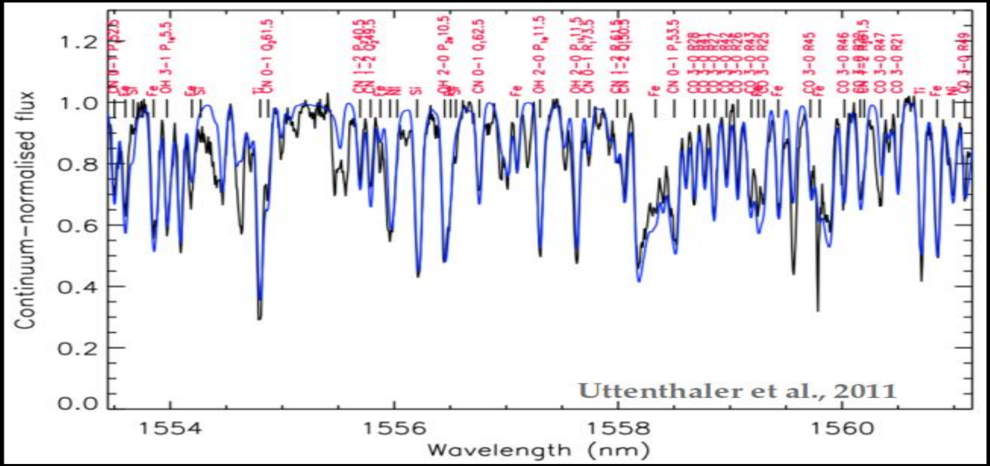
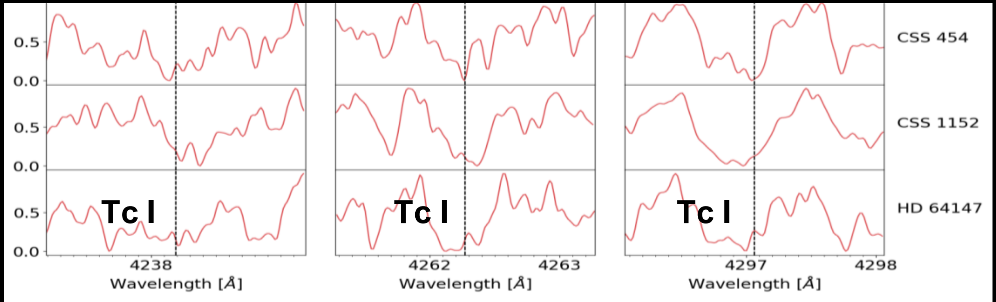
s-process and AGB Stars



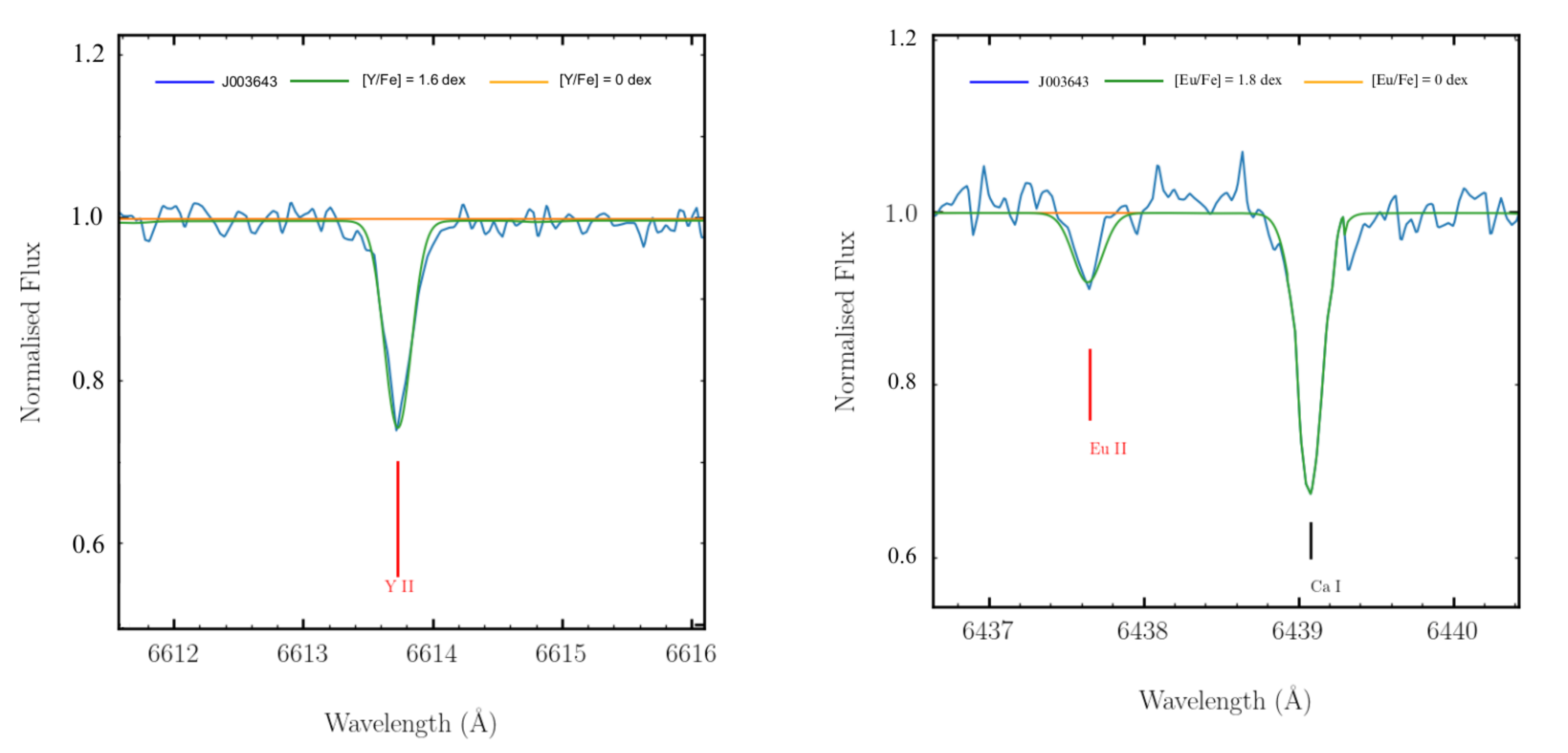
Schematic Structure of an AGB Star



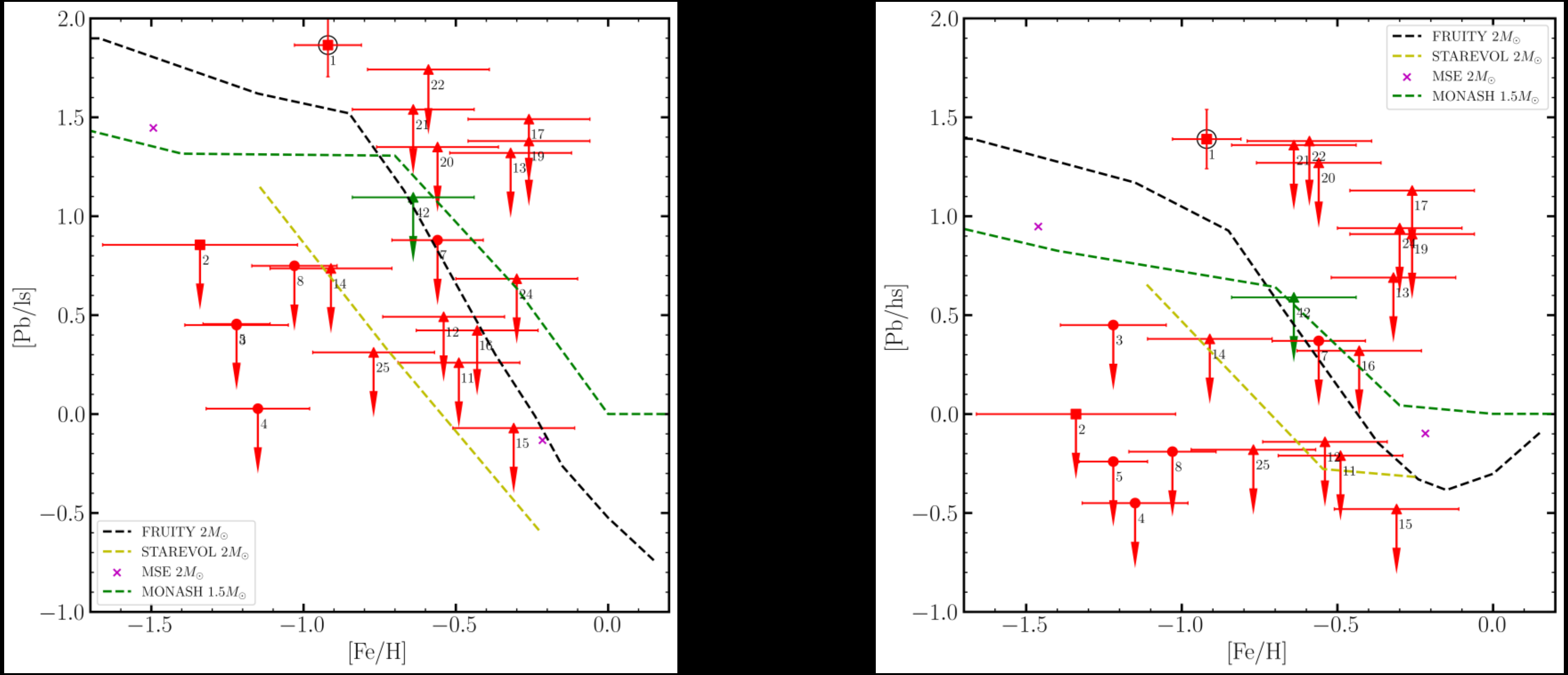


Shetye+2021

Molecular veiling makes elemental abundance quantification challenging



J003643
[Y/Fe] = 1.6 dex
[Y/Fe] = 0 dex
Y II
Normalised Flux
Wavelength (Å)
J003643
[Eu/Fe] = 1.8 dex
[Eu/Fe] = 0 dex
Eu II
Ca I
Normalised Flux
Wavelength (Å)



At low metallicities, the upper limits of lead are much lower than what is predicted.
At high metallicities, the upper limits of lead are more than what is predicted.

Kamath and Van Winckel 2021; De Smedt+2016; Menon+2025 to be submitted

NLTE Toy Model For Lead

Toy Model Atom for Pb I

- Energy levels & oscillator strengths from NIST ASD
- Hydrogenic photoionization to capture UV over-ionization
- Electron collisions (van Regemorter 1962; Allen 1973) and H collisions (Lambert 1993)

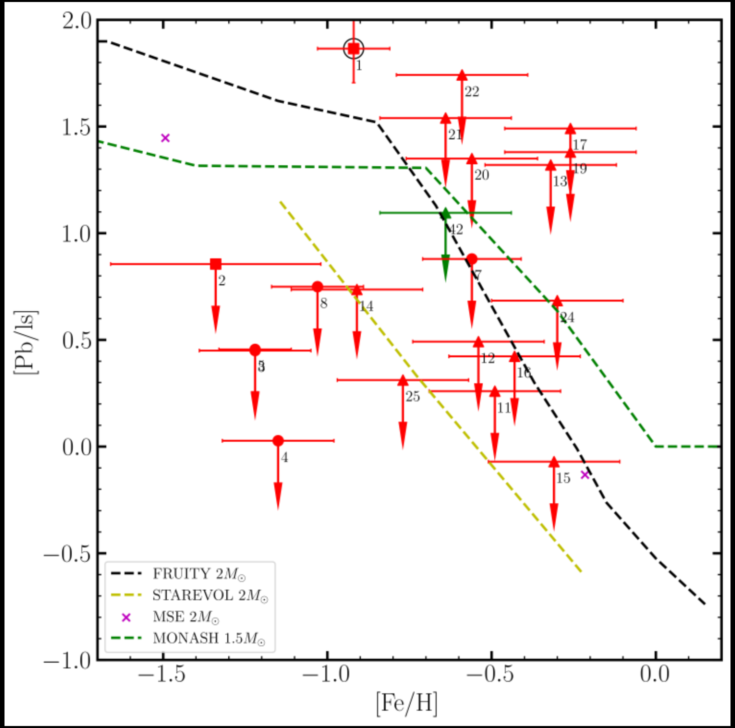
NLTE Radiative Transfer

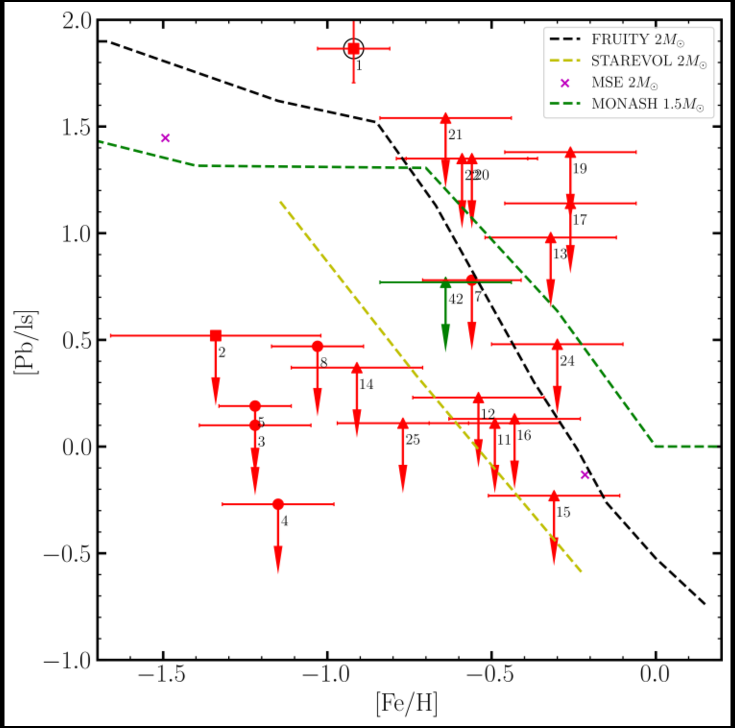
- Balder (Amarsi+2018; Leenaarts & Carlsson 2009) on MARCS atmospheres (Amarsi+2020)

⟶ NLTE level populations & opacities

Parameter Grid

- Teff, log g, [Fe/H], ξt
- [Pb/Fe] from –1.5 to +3.5 (interpolated for each star)

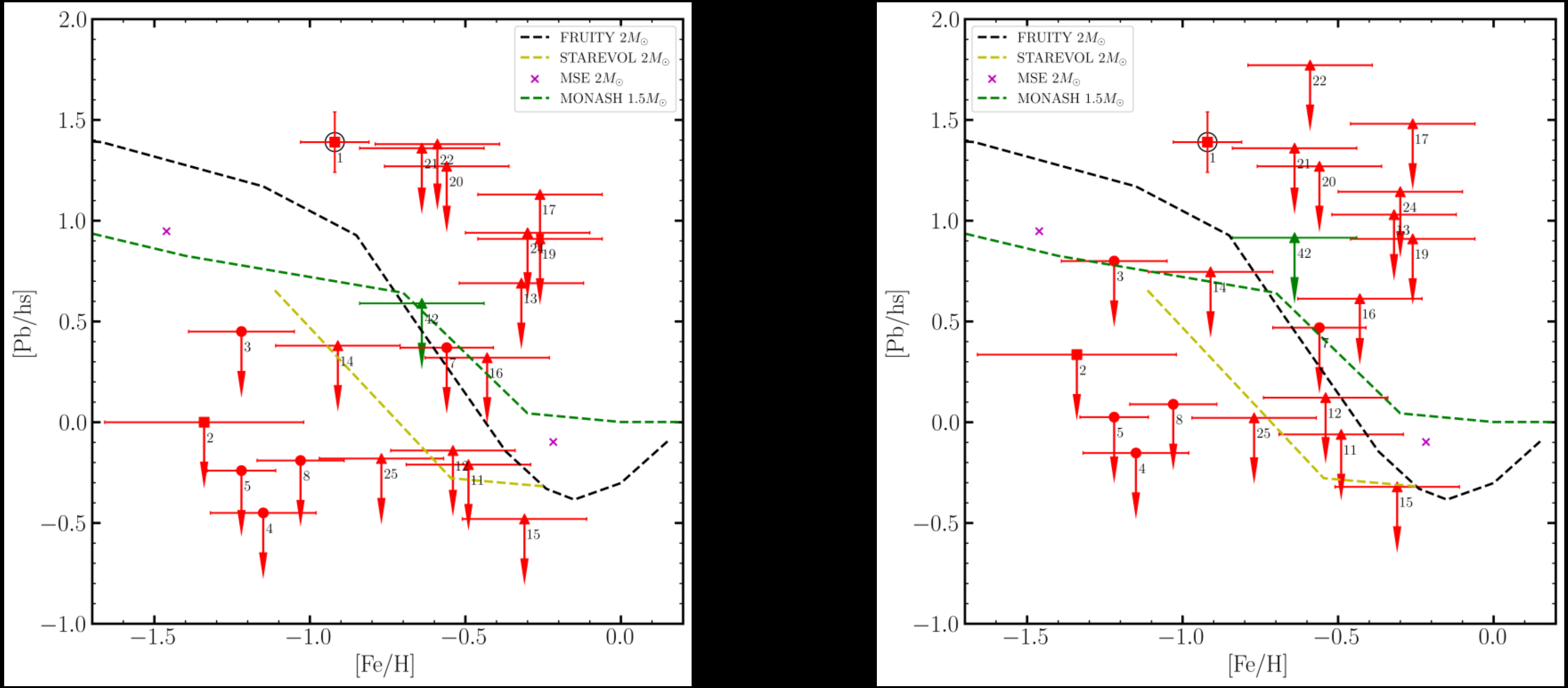




Models are clearly under predicting the derived lead abundance of J003643.

While NLTE corrections improve consistency in some cases, discrepancies remain at [Fe/H]<-0.5 dex

Kamath and Van Winckel 2021; De Smedt+2016; Menon+2025 to be submitted



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