Observational constraints on nucleosynthesis from AGB and post-AGB stars in our Galaxy and its satellites

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Outline:

1. **Why to study AGB & post-AGB stars?**

2. **Chemical analysis and observational issues**

3. **Constraints on stellar nucleosynthesis & mixing**
   - **s-elements**
   - **Flourine**
4. **Summary & near future**

Why AGB & post-AGB stars?

- They represent the last phases of low and intermediate mass stars $1 < M/M_{\odot} < 8$:

- Tracers of intermediate age stellar populations in galaxies

- More than 50% of the material returned by all stars to the ISM come from them, critical for GCE studies: Li, CNO, F, ^{26}Al, ^{25,26}Mg and s-elements...

- Dust producers: sources of many pre-solar grain types

- Excellent laboratories for stellar studies: mixing processes + nucleosynthesis

Observations and analysis: pros (+) & cons (-)

✓ **AGB stars:**

- \- Cool (T_{eff} < 3500 K) : molecular & dust opacities
- \- Variable stars: shock waves, dynamical atmospheres
- \- Very crowded/blended spectra: high resolution spectroscopy needed
- \+ They are numerous and bright (extragalactic)

✓ **Post-AGB stars**

- \+ Warm atmospheres (T_{eff} > 4500 K): no molecules in the spectrum
- \- Short life-times: very few objects (difficult to identify...)

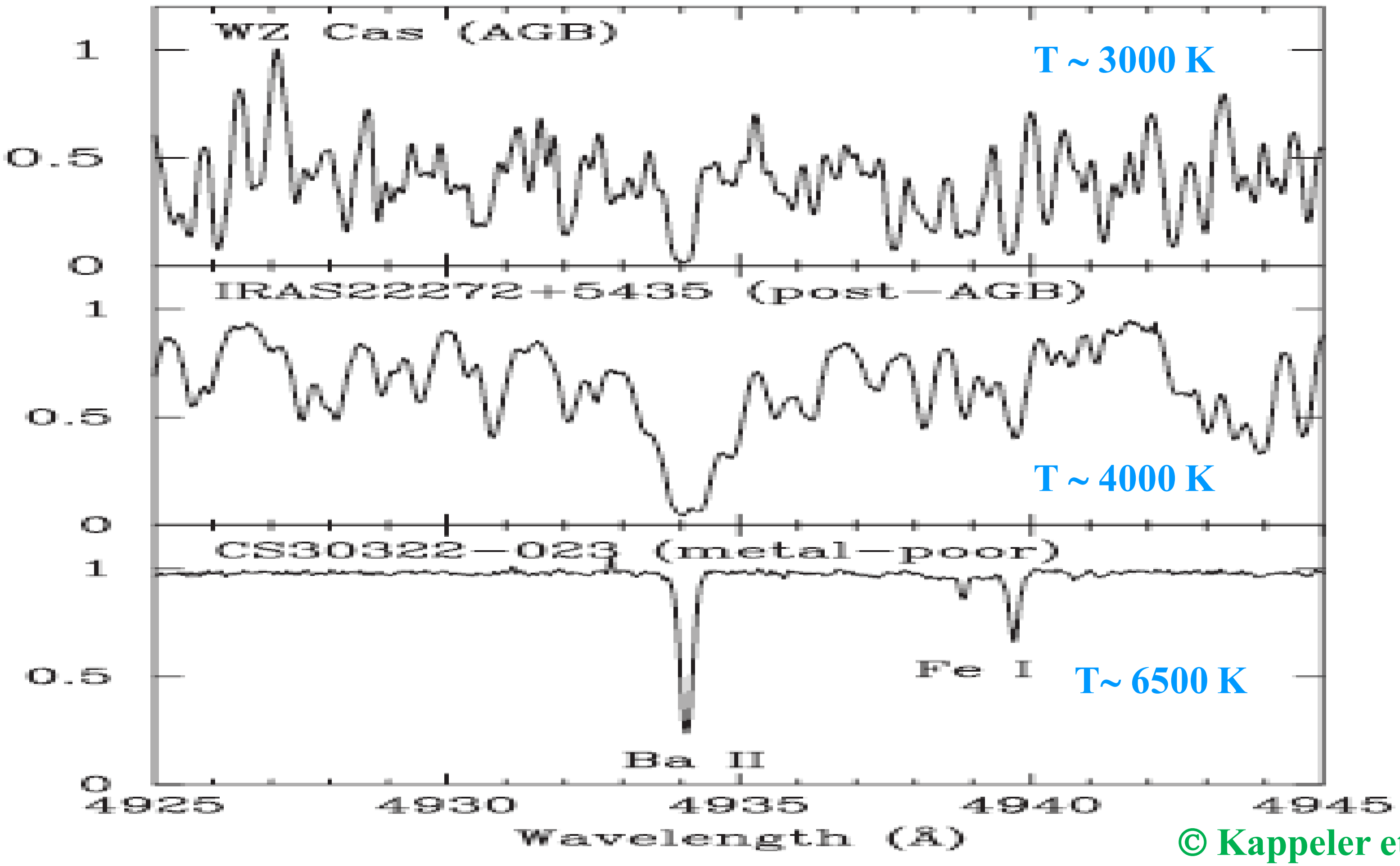
✓ **Local and/or extragalactic ?**

- * Galactic: unknown distances, most [Fe/H]≈ 0.0
- * Extragalactic: well known distances, in a range of [Fe/H]

Intrinsic stars: in-situ nucleosynthesis

Extrinsic stars: element enhancements acquired from a companion (binary) star

Samples of spectra



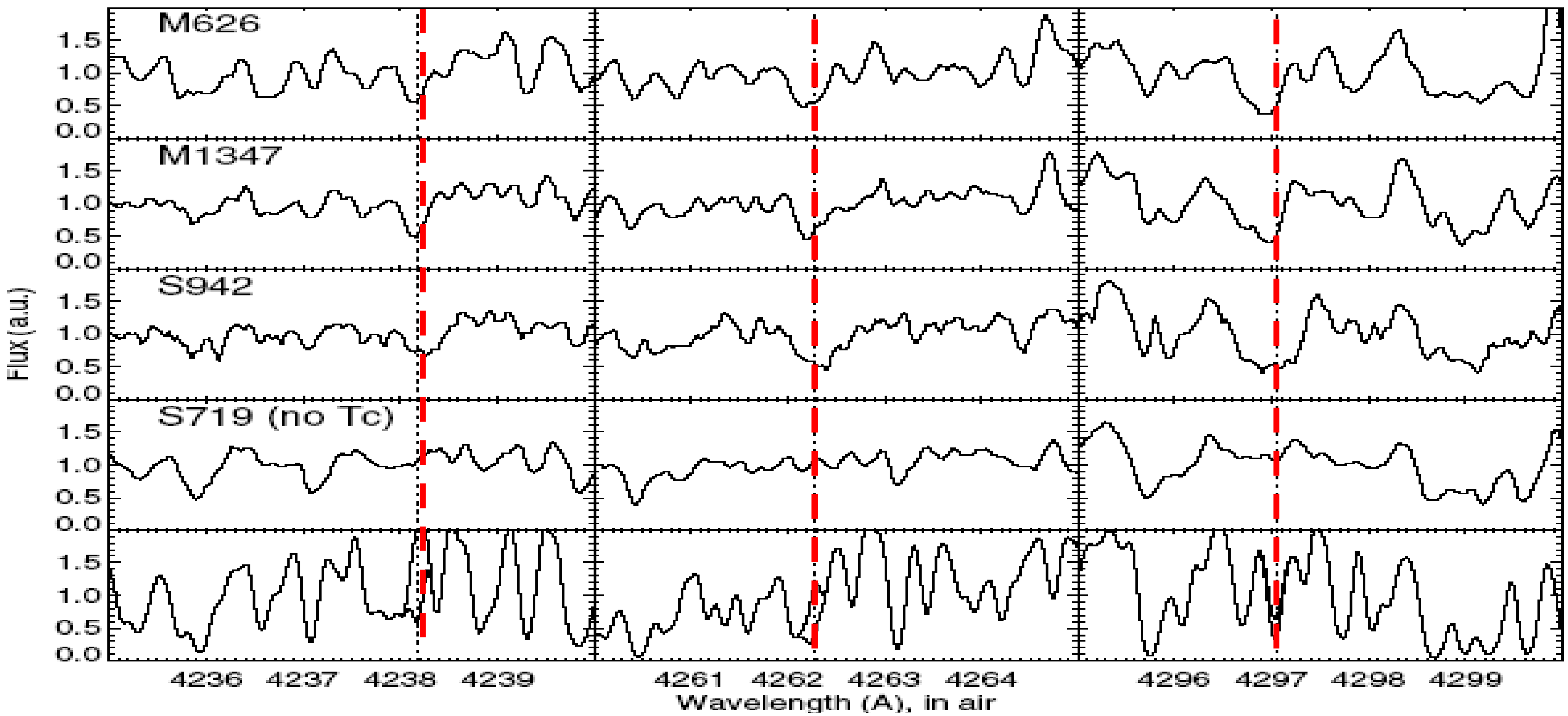
© Kappeler et al. (2011)

AGB stars: the site of the s-process (main component)

✓ **Responsible for ~ 50% of the elements beyond Fe-peak**

In-situ **production in stars:** ^{99}**Tc** ($\tau_{1/2}$~ 2 ·10^{5} yr)

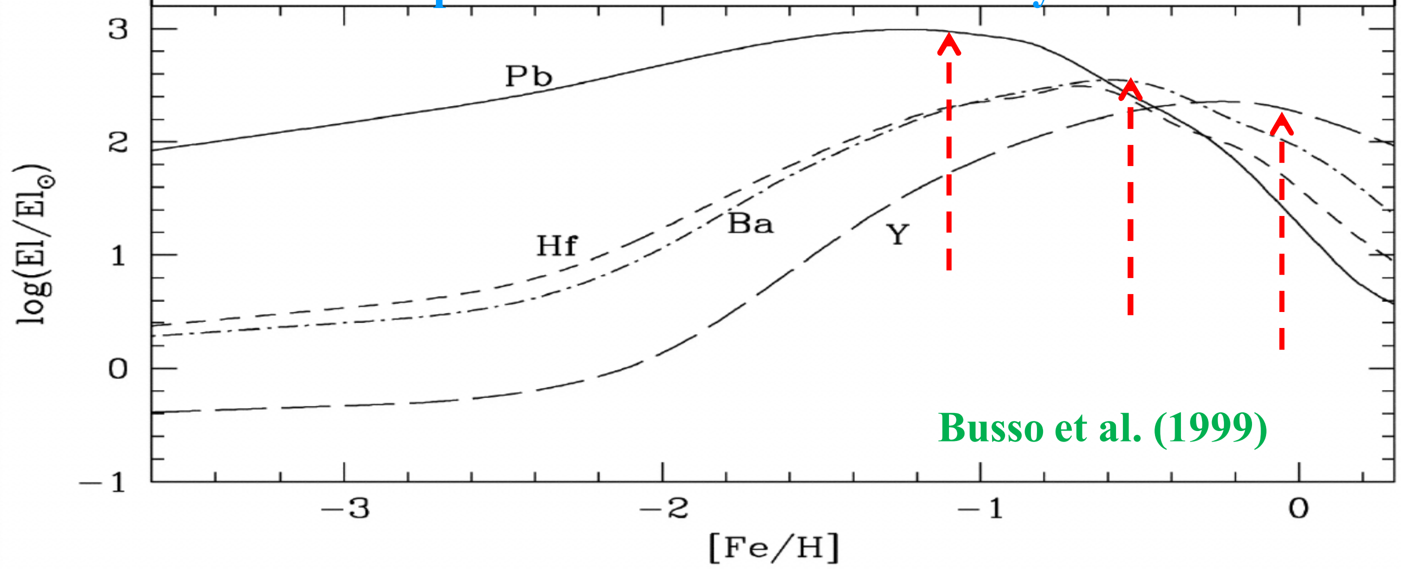
Merrill (1952)



AGBs: test to the s-process theory

- ✓ Abundance patterns: neutron source(s) $^{13}C(\alpha,n)$; $^{22}Ne(\alpha,n)$ → stellar mass
- ✓ s-element enhancements: efficiency of the 3rd dredge-up (TDU) and mixing
  [s/Fe] ↑ [Fe/H] ↓
- ✓ The neutron exposure [hs/ls]: dependence on the metallicity

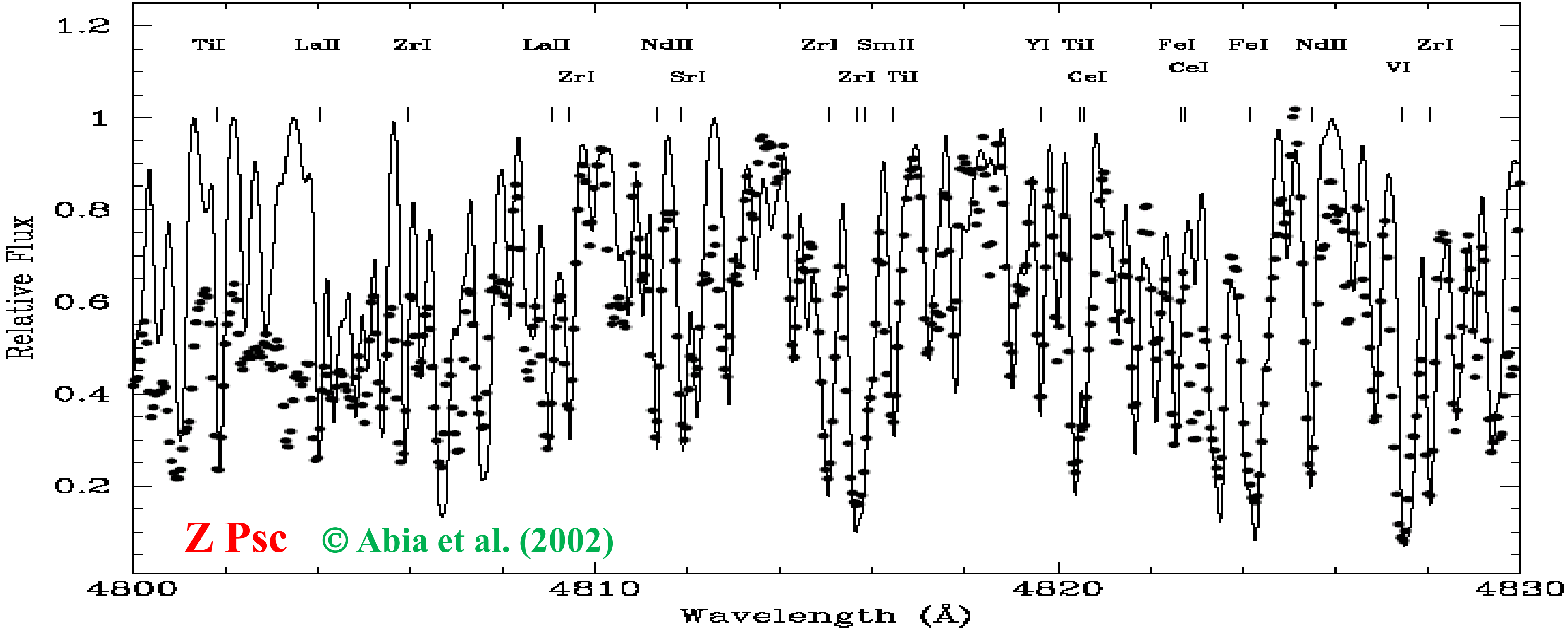
The abundance ratio between heavy-s (Ba,La,Ce…) and light-s (Sr,Y,Zr) elements [hs/ls], depends on the stellar metallicity



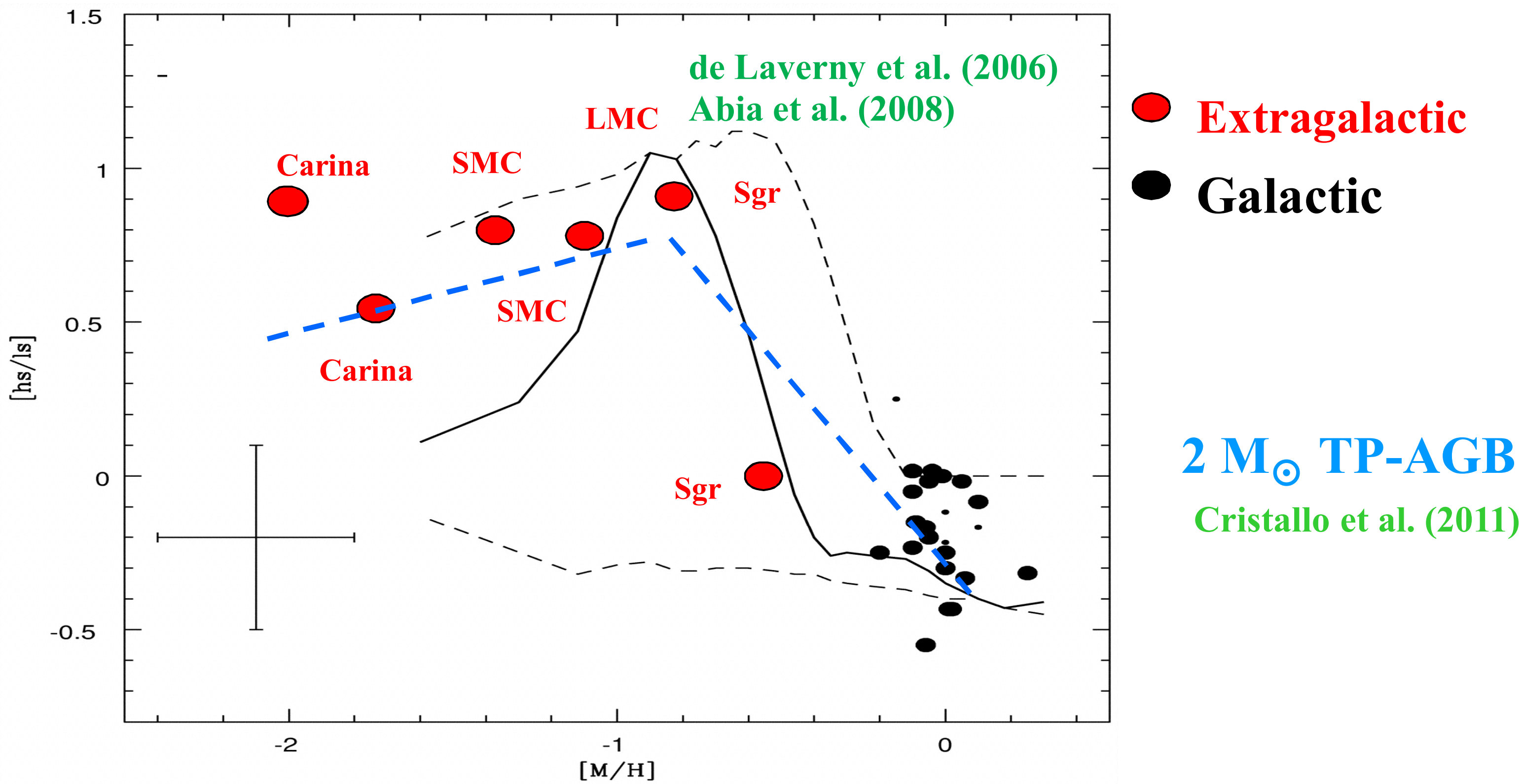
AGB stars: Utsumi (1985)

- Galactic O- & C-rich ([Fe/H]~0) AGBs show enhancements , [s/Fe] ~ 0.5
- Metal-poor AGBs in satellite galaxies show larger enhancements , [s/Fe] ~ 1-2

[s/Fe] ∝ 1/Z ok!!

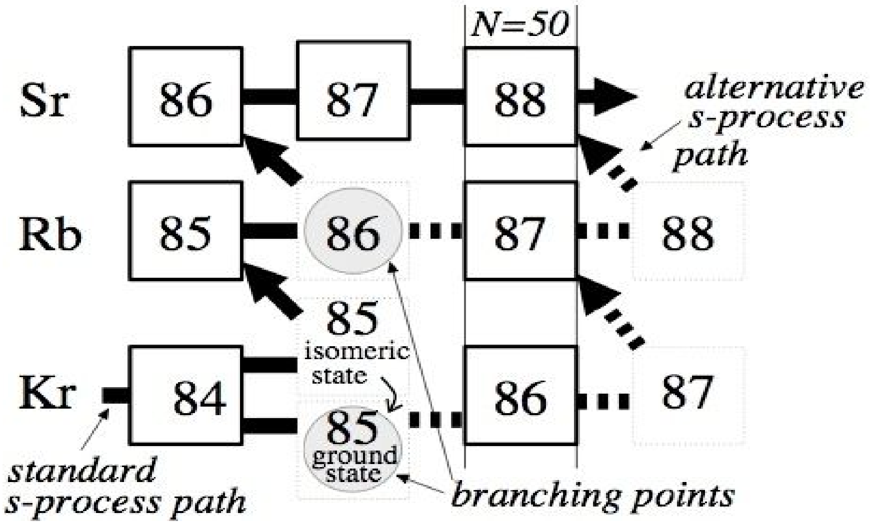


The neutron exposure: [hs/ls] vs. [Fe/H] in AGB C-stars



In O-rich AGB stars, similar agreement with theoretical models is found, however a large dispersion exists in all AGB stars at a given [Fe/H] → ^{13}C-pocket

Neutron source: ^{85}Kr-branching reveals the scenario



Lambert et al. (1995)
Abia et al. (2001)

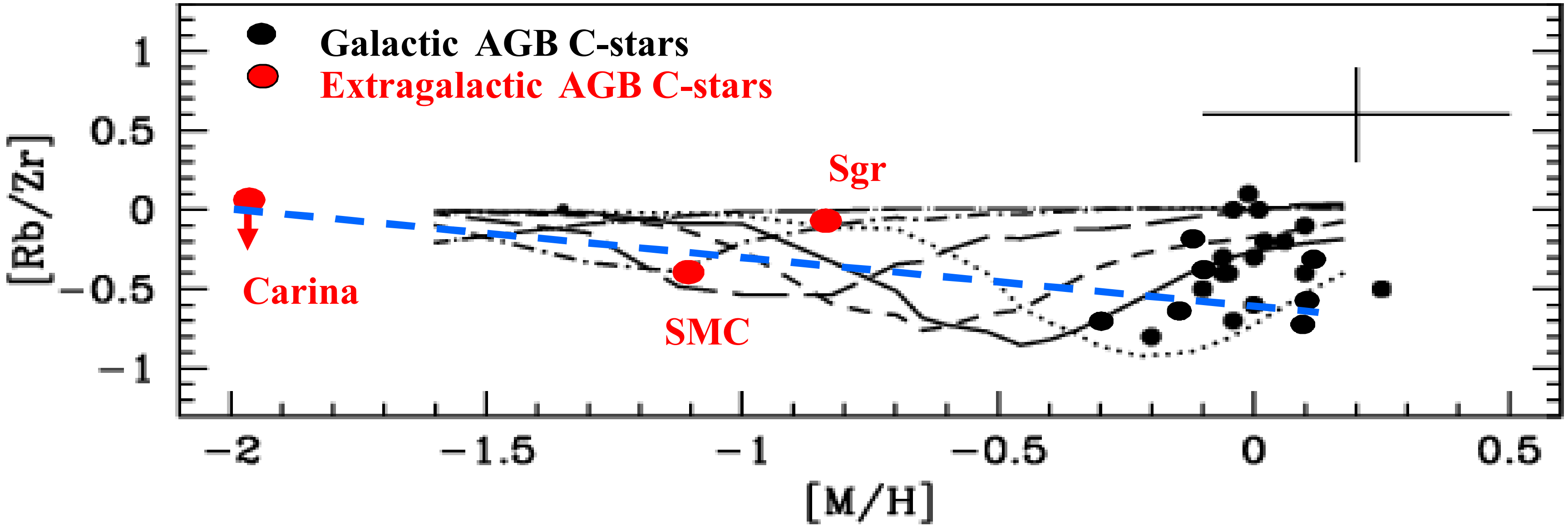
^{85}Rb, σ = 240 mb (30 keV)

^{87}Rb, σ = 15 mb (30 keV)

N_n ~10^8 cm^{-3}, radiative $^{13}C(\alpha,n)^{16}O$ → low [Rb/Sr,Y,Zr]

N_n ~10^{11} cm^{-3}, convective $^{22}Ne(\alpha,n)^{25}Mg$ → high [Rb/Sr,Y,Zr]

The low [Rb/Zr] ratios in AGB C-stars supports the $^{13}C(\alpha,n)^{16}O$ as the main neutron source in low mass stars, $M < 3\ M_\odot$



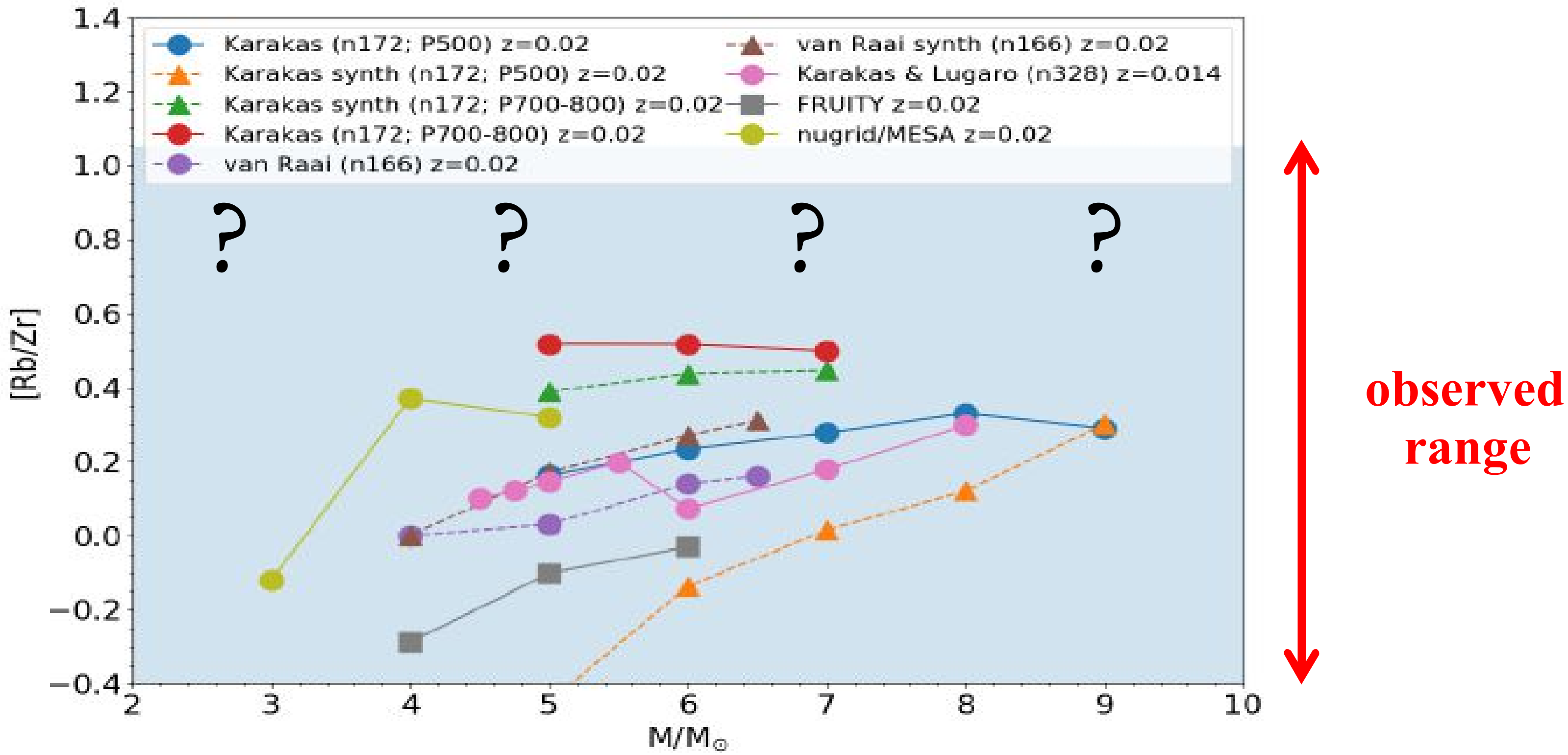
Black lines: Post-processing 1.5 $M_\odot$ model for different ^{13}C-pockets, Gallino et al. (1998)

Blue-dashed line: 2 $M_\odot$, after 10th TP, Cristallo et al. (2011)

Other calculations obtain very similar results (Monash, Brussels...)!!

instead... the high [Rb/Zr] found in massive (M > 4 $M_{\odot}$) AGB stars, favours the $^{22}Ne(\alpha,n)^{25}Mg$ reaction in these stars

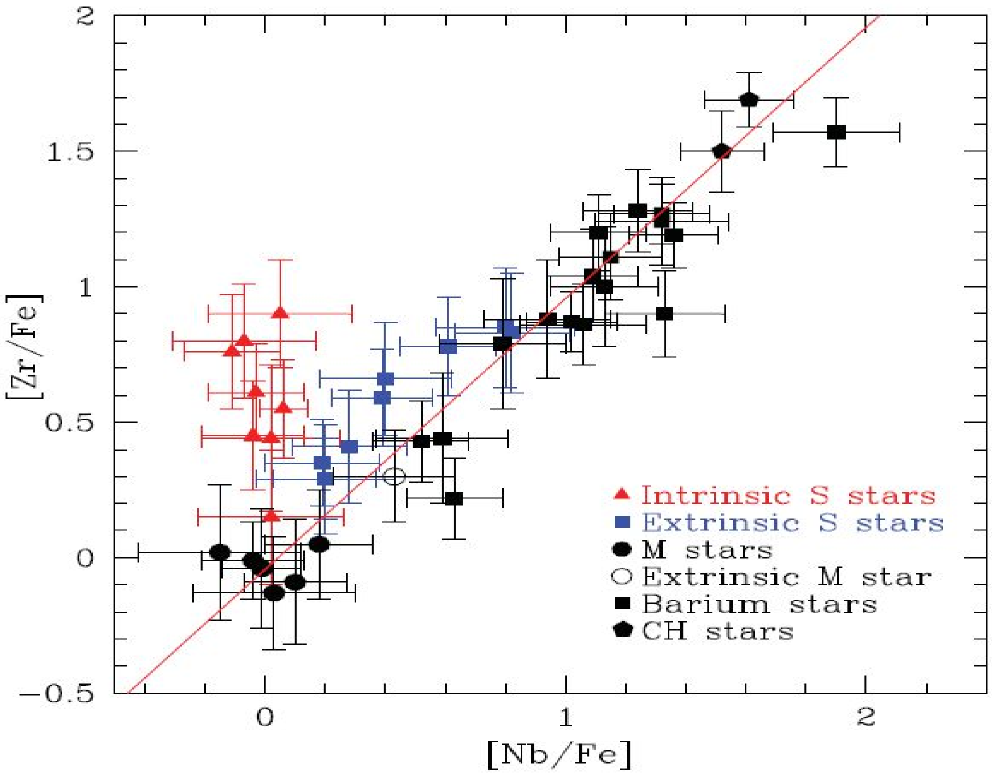
García-Hernández et al. (2007), Zamora et al. (2014), Perez-Mesa et al. (2017)



Intrinsic or extrinsic AGBs? The Zr/Nb alternative to Tc

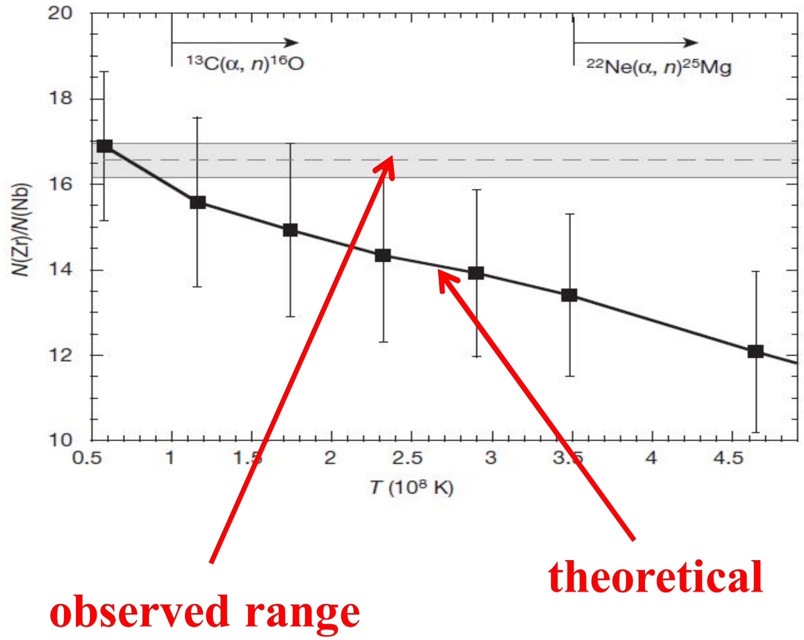
$^{93}Zr \longrightarrow ^{93}Nb$

$\tau_{1/2} \sim 1.53$ Myr



The Zr/Nb can be used a probe of the s-process temperature

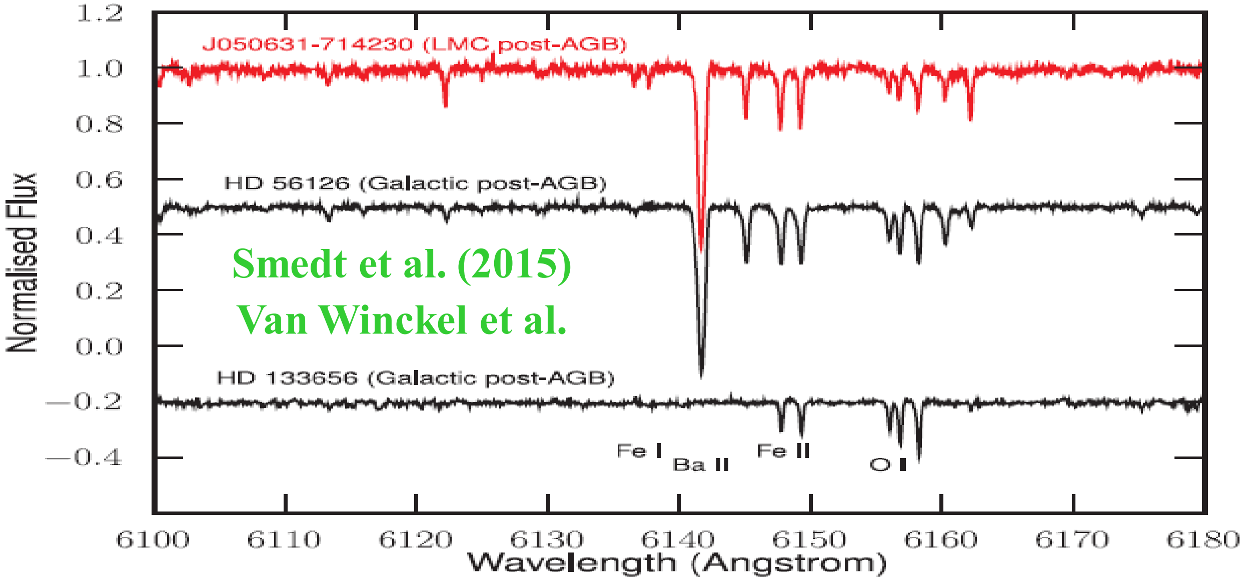
Neyskens et al. (2015)
Van Eck et al. (2017)



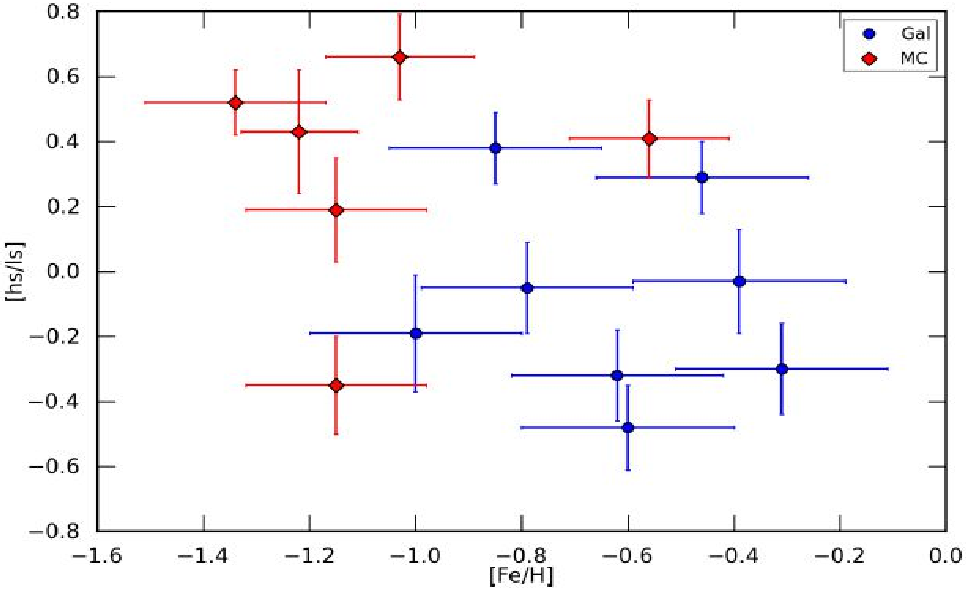
Post AGB-stars

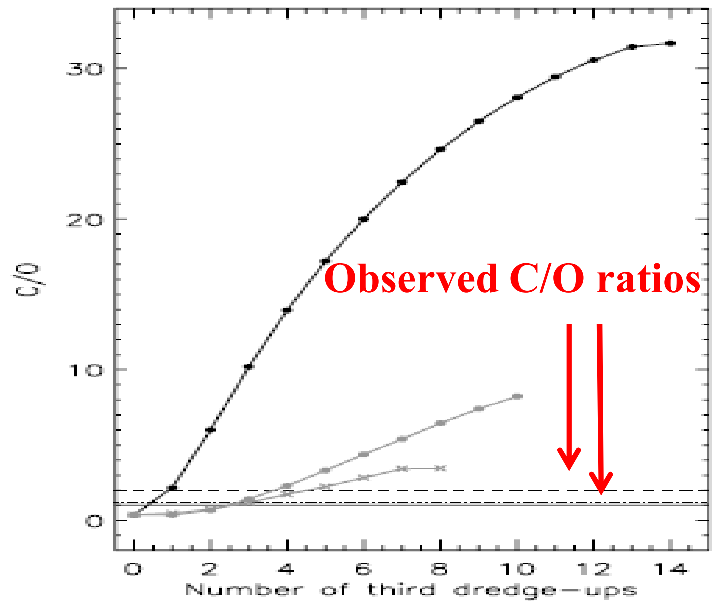
Tracers of the s-process at the end of the AGB phase...however

- **Large diversity in [s/Fe] in Galactic & MCs post-AGB at a given Z (mass)**
- **Some do not show s-element enhancements (M < limit for TDU)**

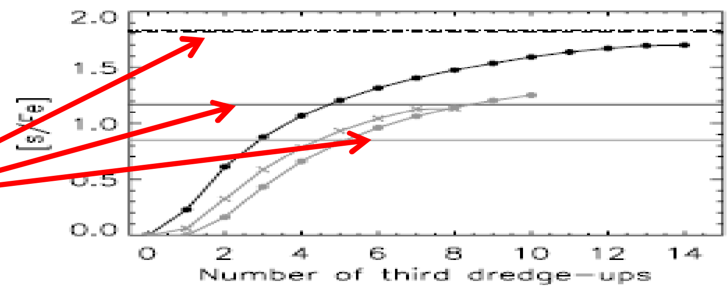


Post-AGB stars do not show the expected correlation [hs/ls] vs. [Fe/H] ...nor the [s/Fe] vs. C/O !!!





De Smedt et al. (2015)
Van Earle et al. (2013)

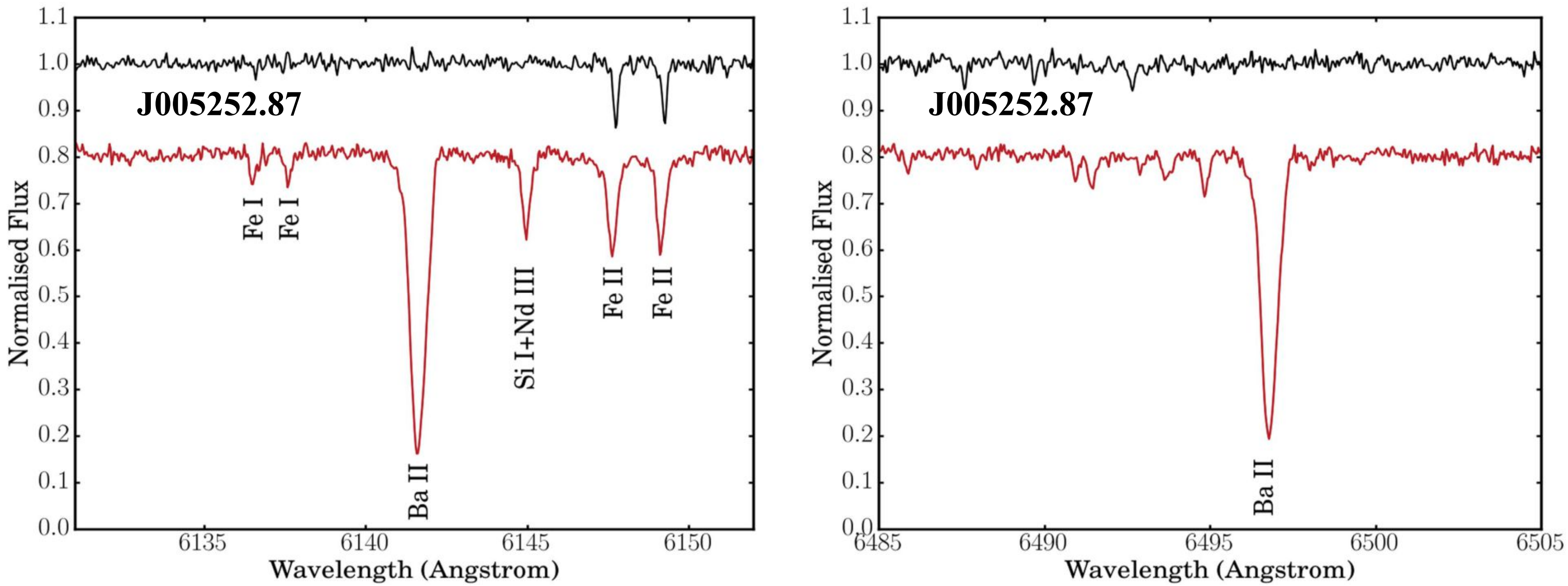


Observed s-element enhancements

J005252.87 a failed TDU post-AGB in the SMC?

Kamath et al. (2017)

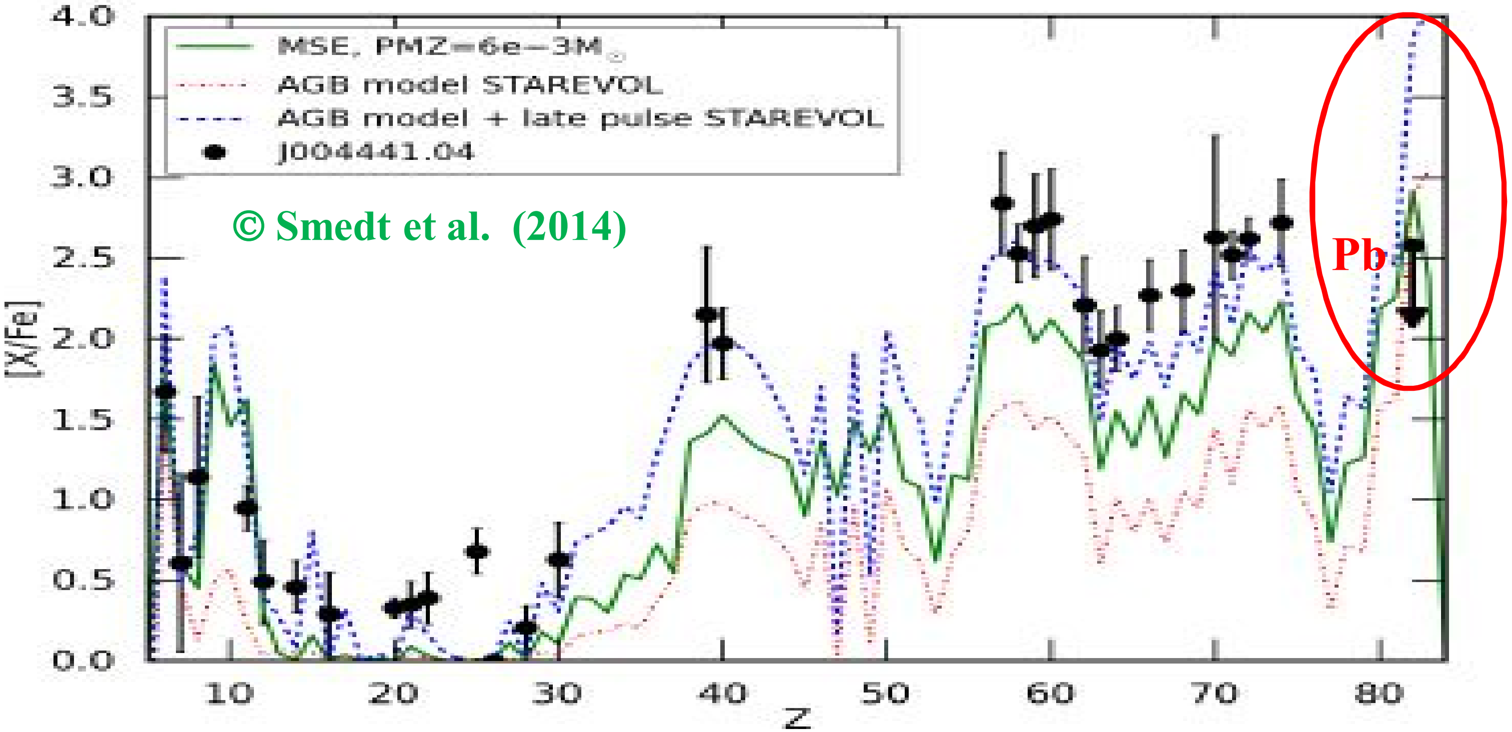
T_{eff} ~ 8250 K, [Fe/H]= -1.2, L ~ 8200 $L_{\odot}$ → M_{ini}~ 1.5-2.0 $M_{\odot}$



A new evolutionary channel in the AGB phase without TDU ??

The lead discrepancy in post-AGB

Several metal-poor post-AGB stars show much lower [Pb/Fe] ratios than predicted



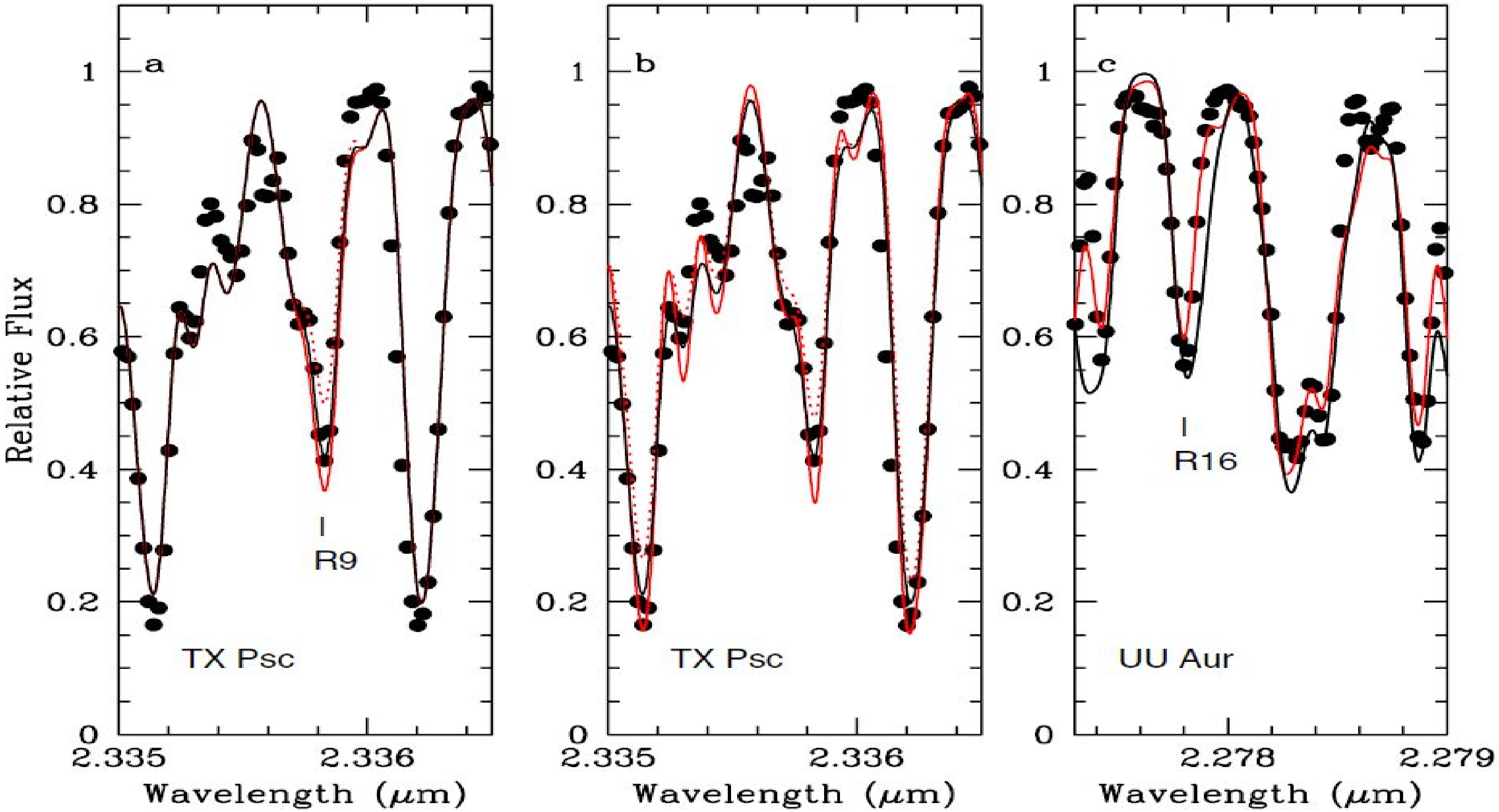
A neutron density in between the s and the r-process (i-process) may do the work but would be at odd with the [Rb/Zr] ratios

Lugaro et al. (2015)
Côte et al. (2018)

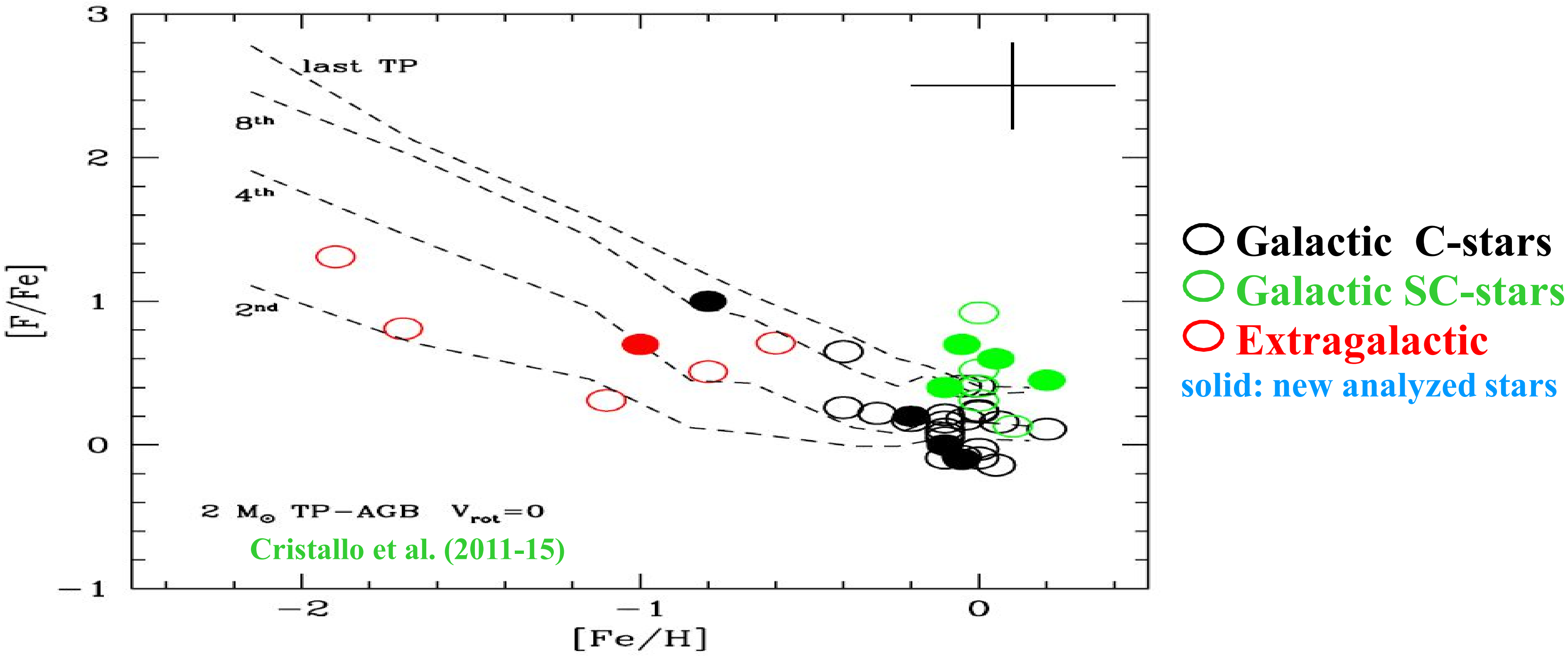
The ^{19}F puzzle in AGBs

✓ ^{19}F is produced by AGB stars... but is not the sole source

Jorissen etal. (1992)
Abia et al. (2015)
Jönsson et al. (2017)

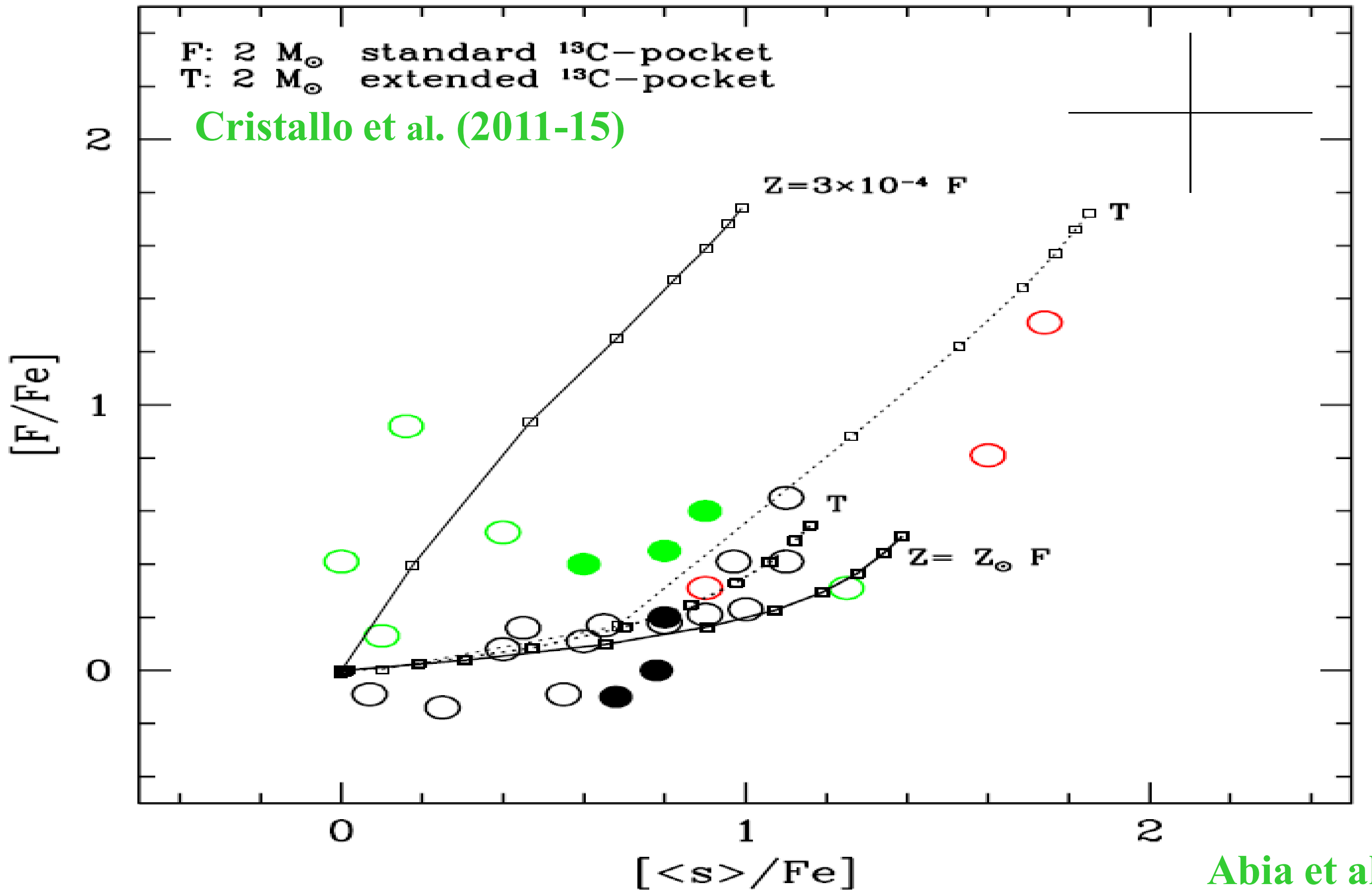


✓ ^{19}F has primary & secondary origin in AGBs (^{13}C): at low metallicity primary source dominates → large [F/Fe] are expected



Abia et al. (in prep)

✓ The expected correlation with the s-element enhancements is not so clear !



Galactic C-stars
Galactic SC-stars
Extragalactic

Abia et al. (in prep)

Summary & near future

- **Abundance determinations in AGB and post-AGB stars are useful tools to test current theories of nucleosynthesis in stars**
- **The bulk of observations in AGB and post-AGB stars can be explained from ^{13}C and ^{22}Ne being the main neutron sources in low and intermediate mass stars, respectively**
- **Discrepancies exist between observed and predicted abundances of F, Pb, and C/O ratios which require further theoretical and observational study**
- **GAIA parallaxes will allow the accurate determination of luminosities (masses) of many AGB and post-AGB for a better comparison with theoretical models**
- **JWST will identify thousands of AGBs and post-AGBs in the Local Group of galaxies....so be prepared !**