Post-AGB Stars in the Magellanic Clouds

Ideal tracers of AGB nucleosynthesis (*s*-process) and mixing

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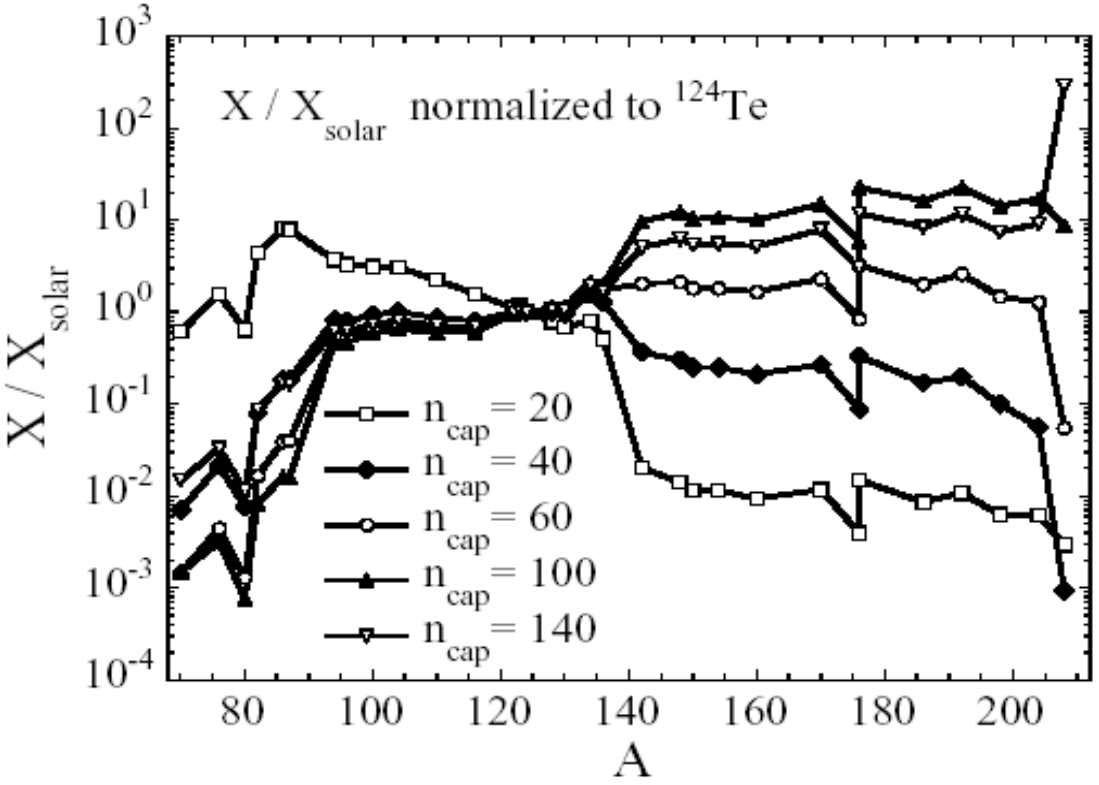
568 WE-Heraeus-Seminar on 'Nucleosynthesis in Asymptotic Giant Branch Stars' 15 July 2014 Physikzentrum Bad Honnef

AGB Model Uncertainties

- Third Dredge-up (TDU)
- The *s*-process
- Convection
- Opacities
- Mass loss
- …

s-process Uncertainities

Yields dependent on neutron captures



Goriely & Mowlavi 2000

Heavy element distribution traces the integrated neutron irradiation

Drawback: quite some elements should be traced to constrain the distribution

Abundance peaks
(neutron magic numbers)
ls = Sr, Y, Zr (n=50), hs = Ba,La,Ce,Pr,Nd (n=82), lead-peak: double magic (p=82, n=126)

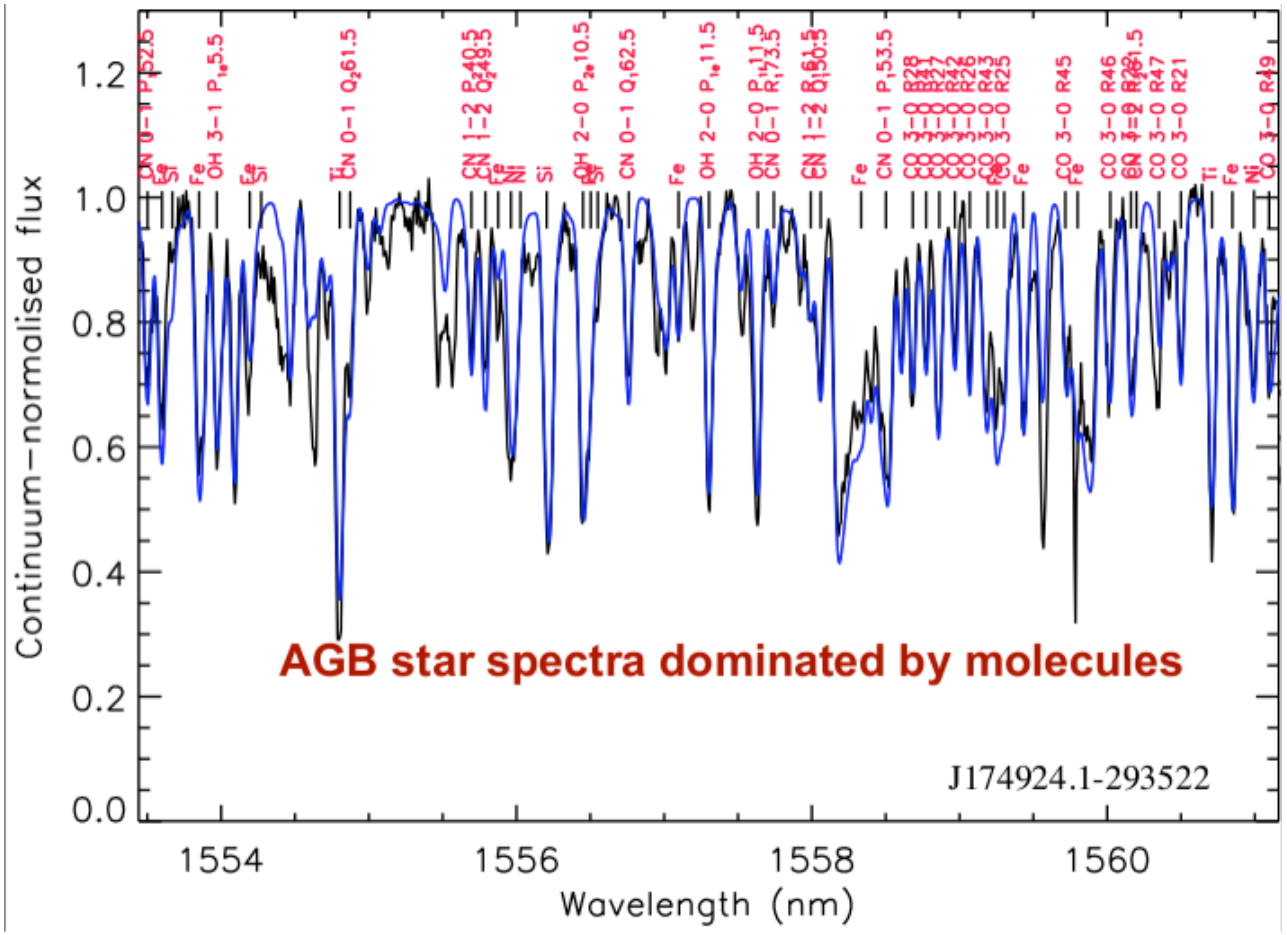
When Theory Meets Observations…

Observational constraints from:

AGB stars…

BUT

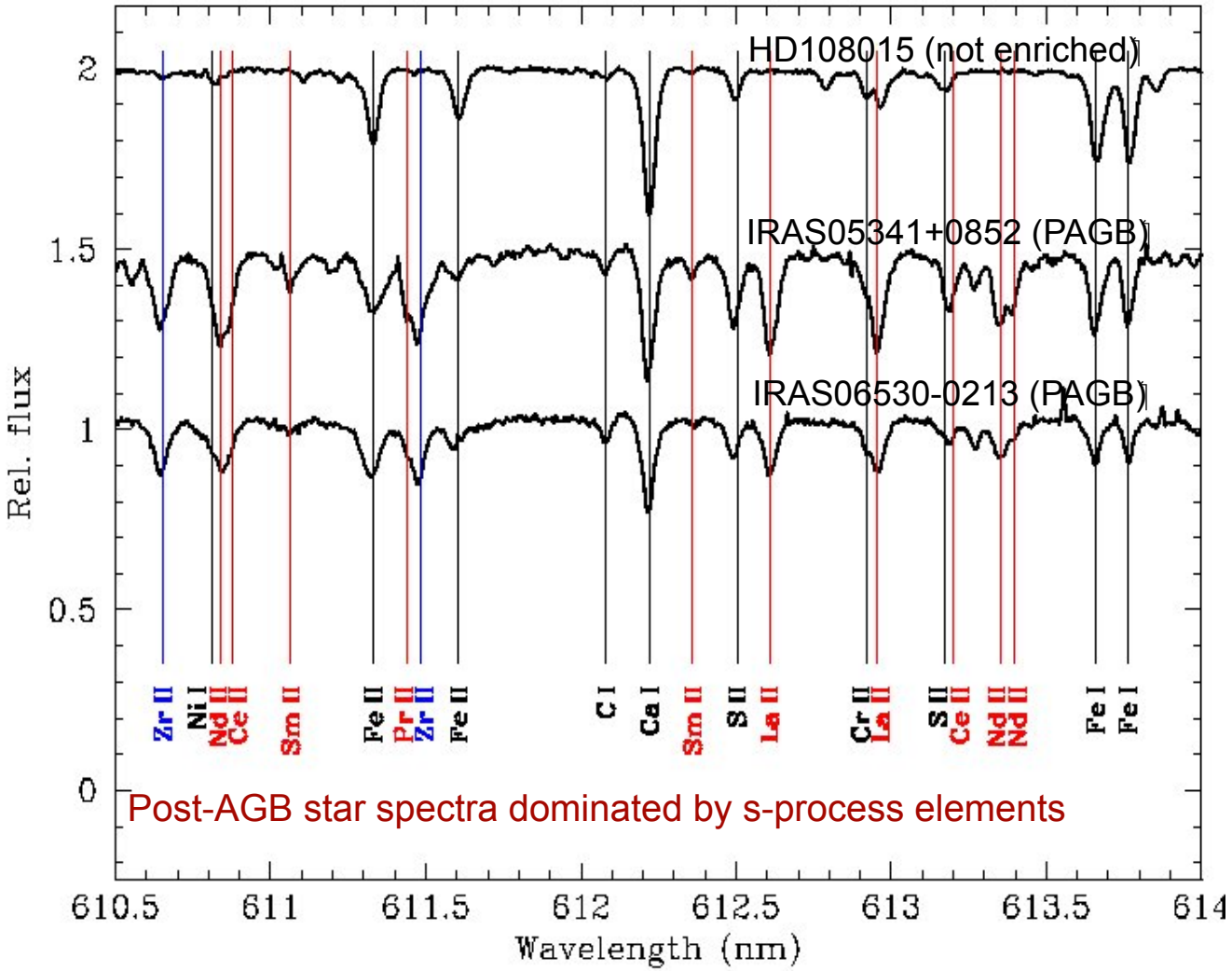
AGB star spectra dominated by molecules



Uttenthaler et al., 2011

Observational constraints from Post-AGB stars AND

these are EASY!



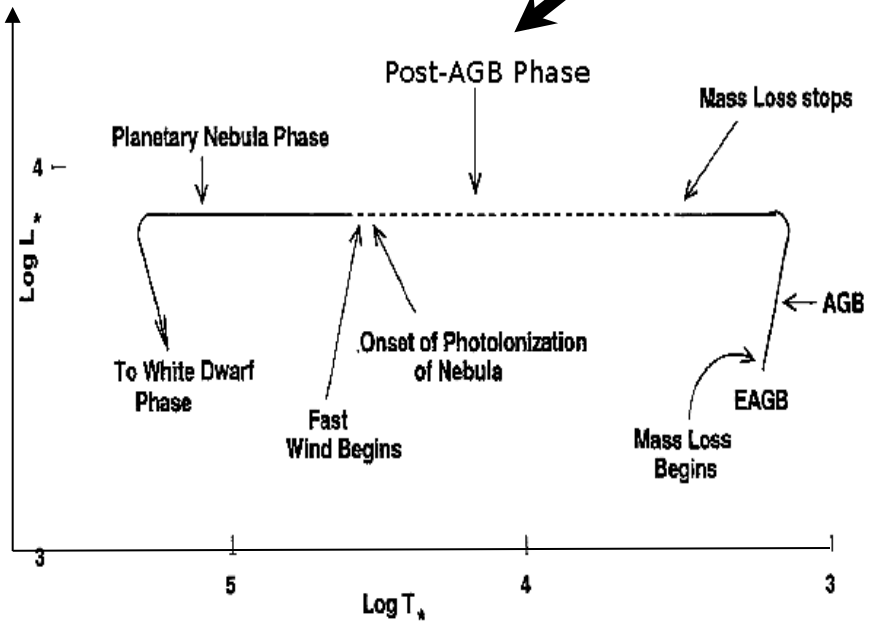
Reyniers et al., 2003, 2004, 2007 etc.

- Post-AGB star photospheres contain the cumulative nucleosynthetic pollution from AGB evolution

- Spectra are dominated by s-process atomic transitions (Up to Gd, Yb, Lu, W) + CNO + Li + Mg + Al +…

(Single) Post-AGB Stars

AGB ⟶ Post-AGB ⟶ PNe



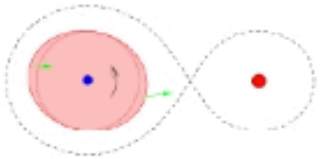
- Transient phase ~1000 - 10000 years
- A - K Spectral Types
- Masses: 0.6 - 0.8 M_{sun}
- R* ~ 1 AU on the AGB to R_{WD}
- Variable (Pop II Ceph. Instability strip)
- Obscure to naked..

Observationally: A Diverse Set of Objects....

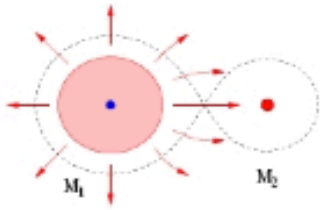
Great majority of PNe are not spherical: axi-symmetry; point-symmetry
jet-like structures are common

BINARY evolutionary Channels connect individual objects!

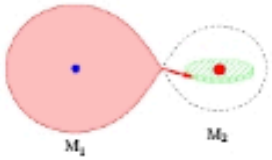
Binary Evolution : A likely alternative evolutionary channel



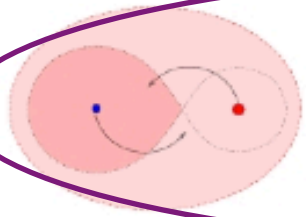
tidal interaction



wind accretion & tidally enhanced winds



Roche-lobe overflow

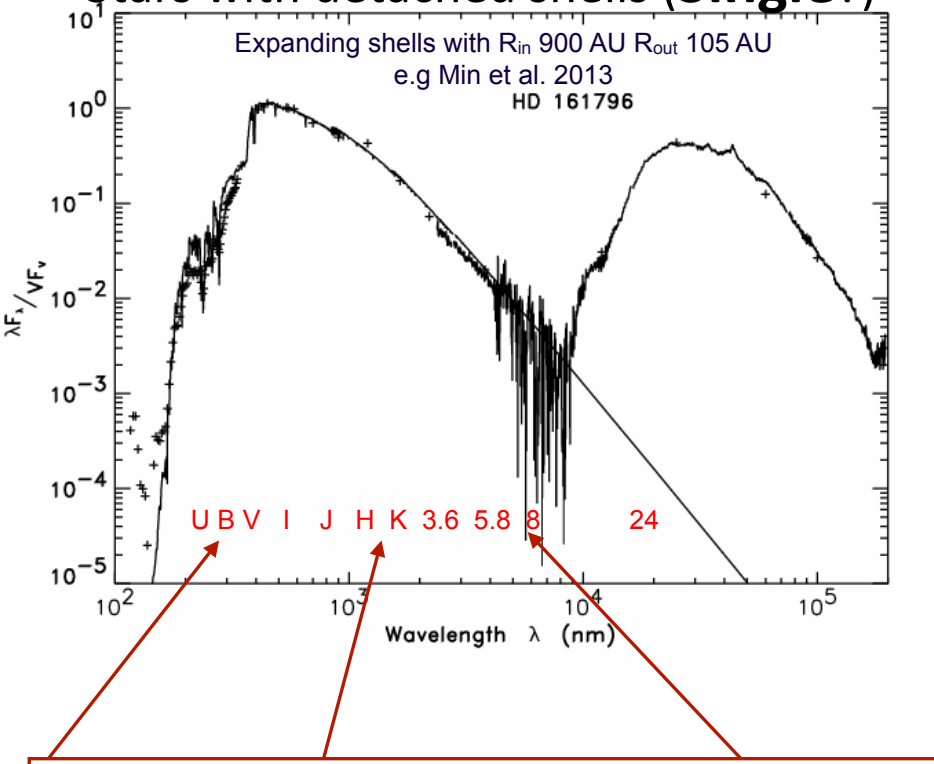


common envelope evolution

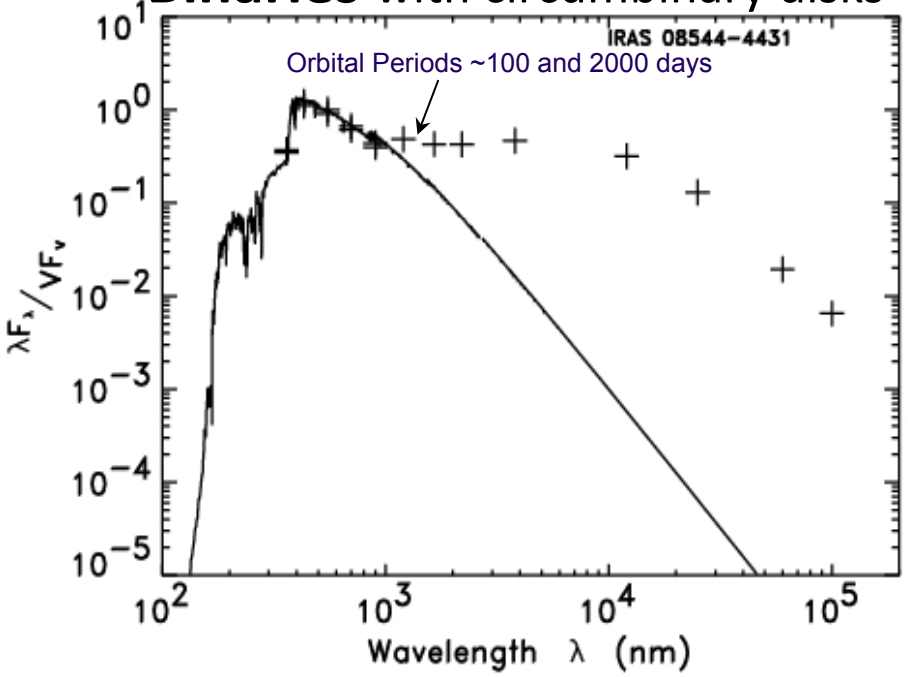
Resulting in circumbinary disc

Optically Visible Galactic Post-AGB Stars (Toruń Catalog - Szczerba et al. 2007)

Stars with detached shells (**Single**?)



Binaries with circumbinary disks

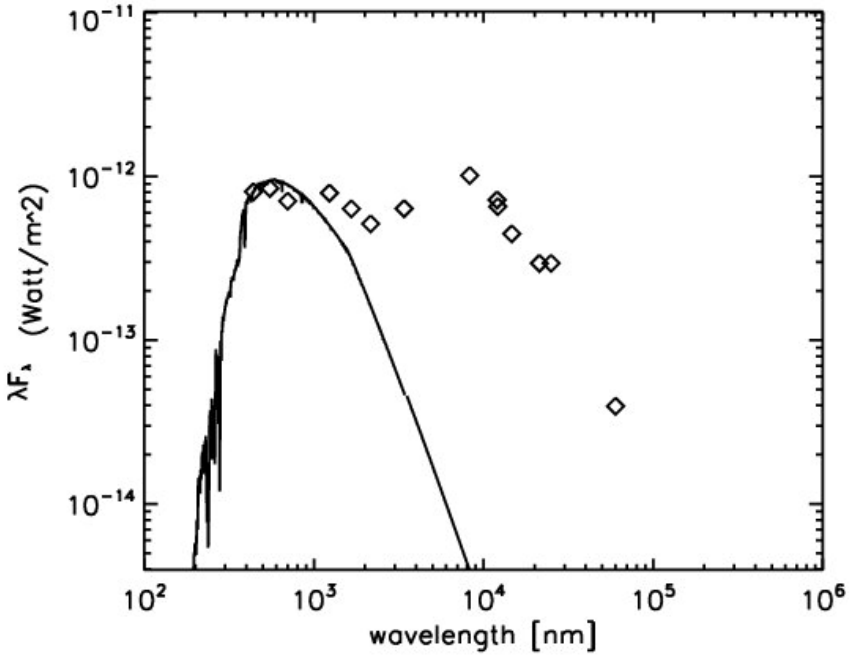


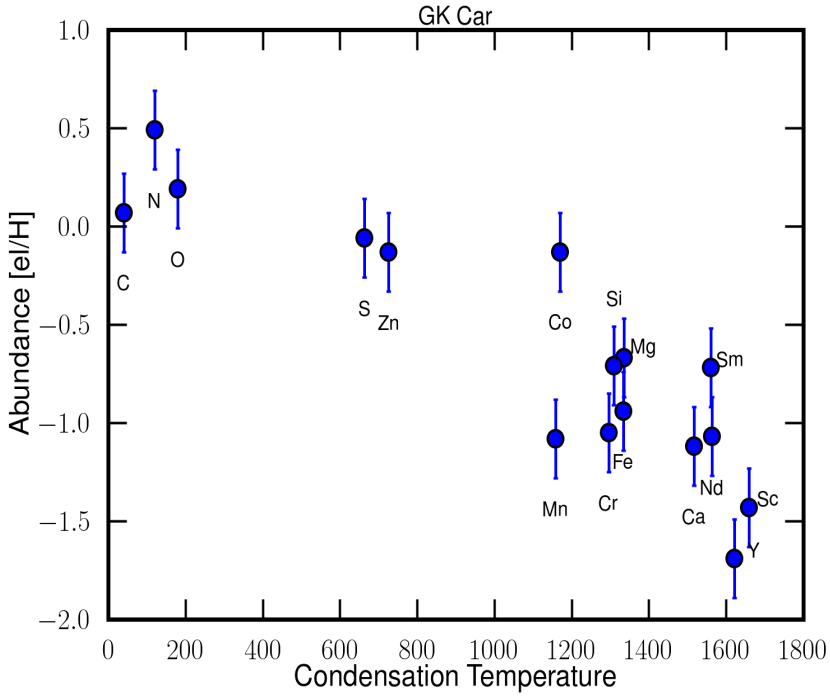
Optical + 2MASS + Spitzer bands allow us to distinguish between the two types - not always...

Characteristic Feature: Mid-IR excess

Studies by: Van Winckel 2003,2007, 2009; De Ruyter et al. 2006; Gielen et al. 2009; Dermine et al. 2012 ...

Chemical Diversity in the Galaxy
1. Depleted binary disc sources



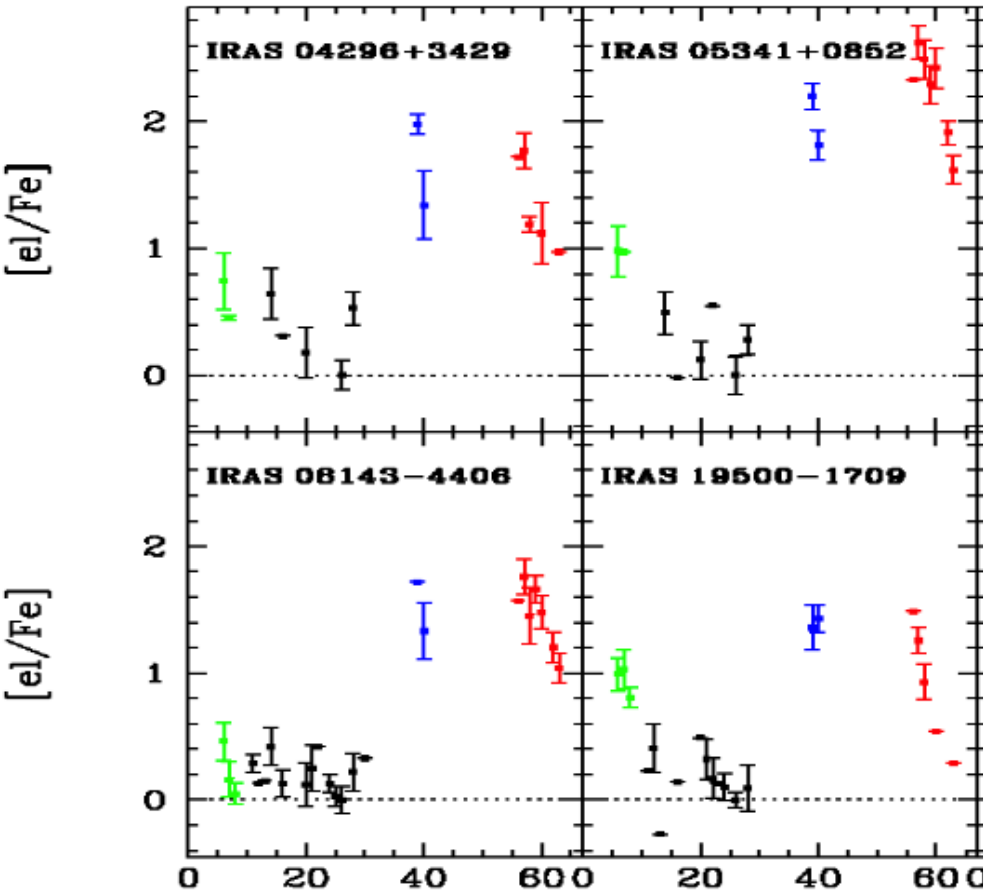


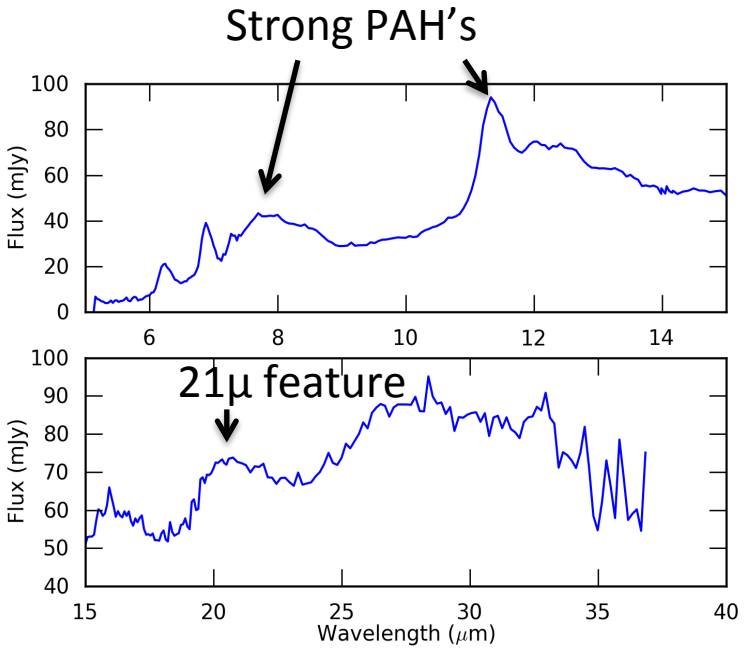
- Chemical fractionation due to dust formation in the CSE followed by decoupling of gas and dust
- Re-accretion of clean gas and all refractory elements are blown away

Waters et al., 1992; Van Winckel et al., 1992, 2003 ; Giridhar et al., 2005; Gielen et al., 2009 etc

Chemical Diversity in the Galaxy
2. 21 micron sources

Post-AGB (post- carbon) single shell sources
s-process rich with 21 micron spectral feature

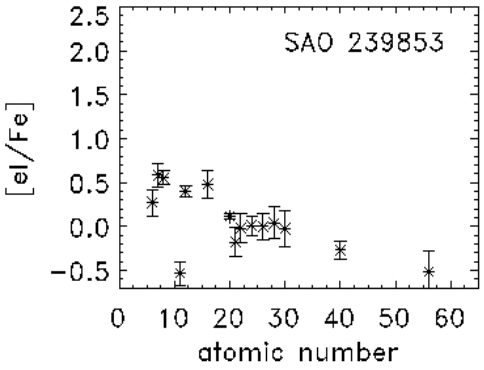


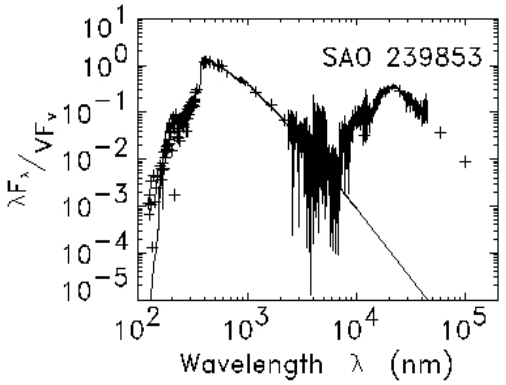


Van Winckel & Reyniers 2000

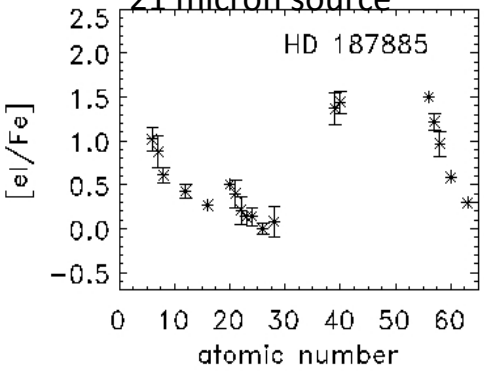
Volk et al. 2011

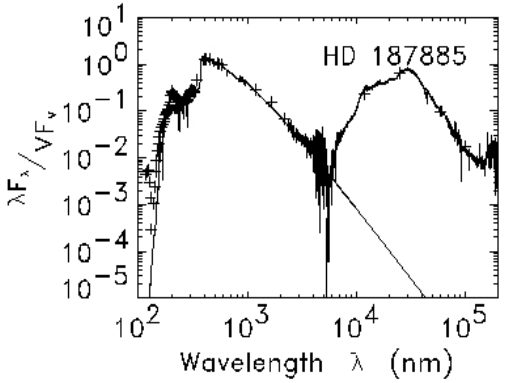
Chemical Diversity in the Galactic sample
3. Single post-AGB stars

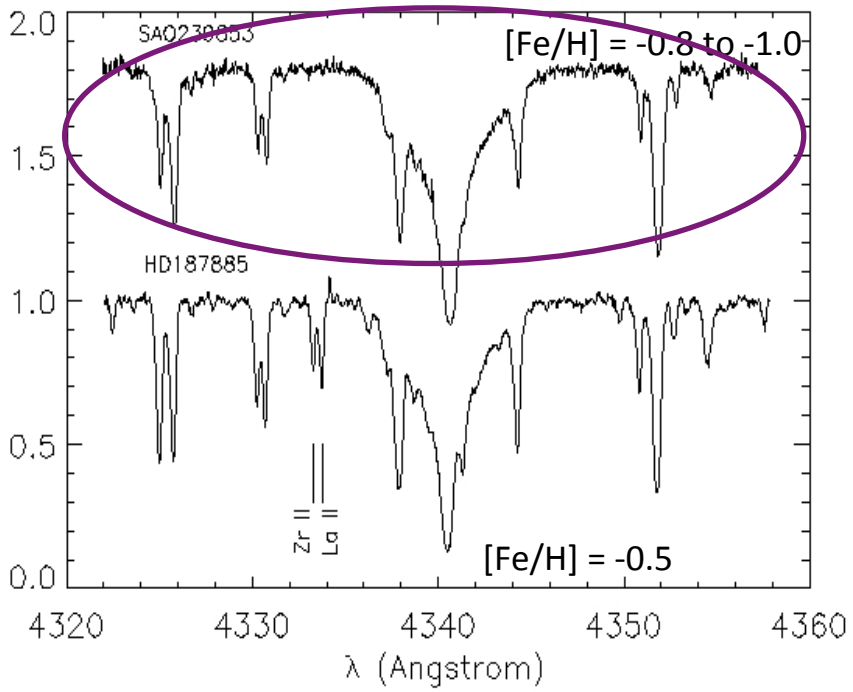




21 micron source







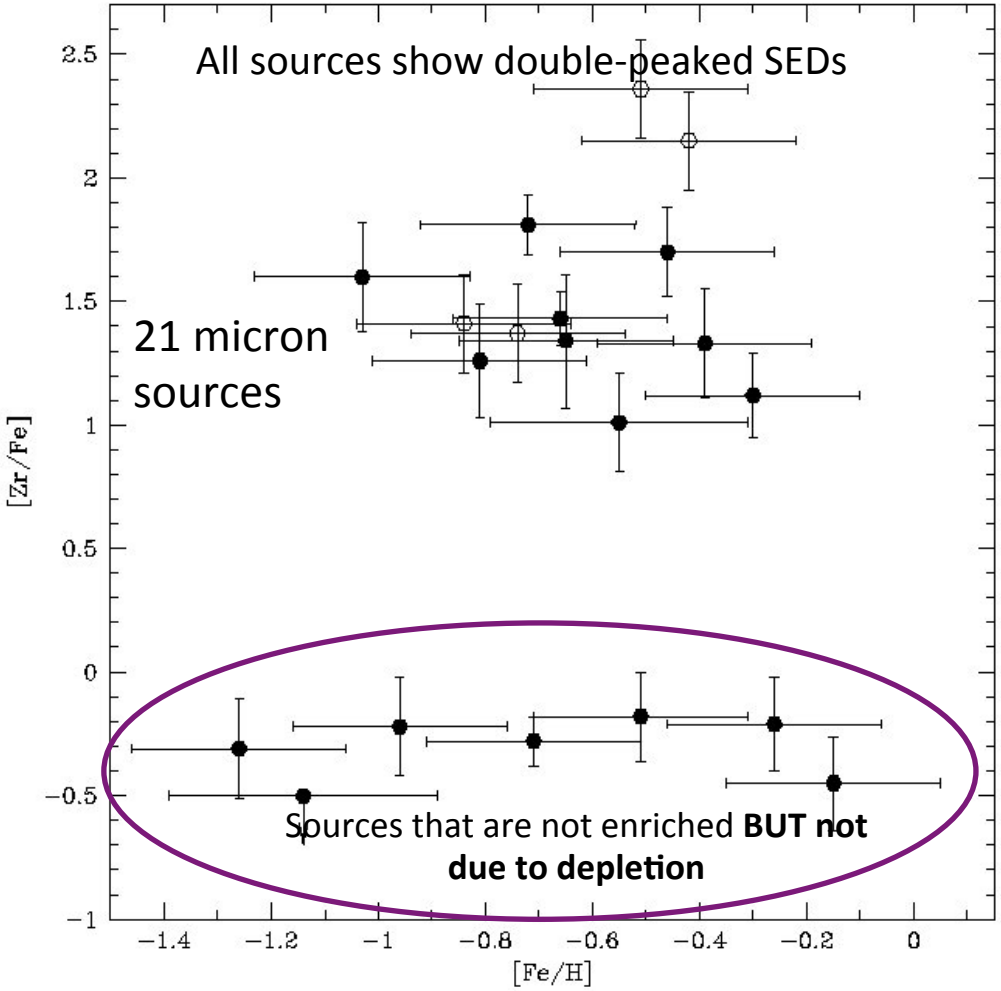
Similar Stellar Parameters BUT Diverse Chemical patterns…

WHY???

Van Winckel et al., 1996

Chemical Diversity in the Galactic sample21 micron source Vs post-AGB single stars

Dredge-up Vs Metallicity



Van Winckel 1991

IR-emission, kinematics, metallicity of all stars are similar

BUT

chemically they are diverse!

Crucial missing parameter: Absolute luminosities!

Optically visible Post-AGB stars in the Magellanic Clouds (where distances are known)

- Initial Photometric Classification – sample selected based on the presence of a mid-IR excess (using Spitzer data) + colour and luminosity criteria

  (LMC – Van Aarle et al., 2011; SMC – Kamath et al., 2014)

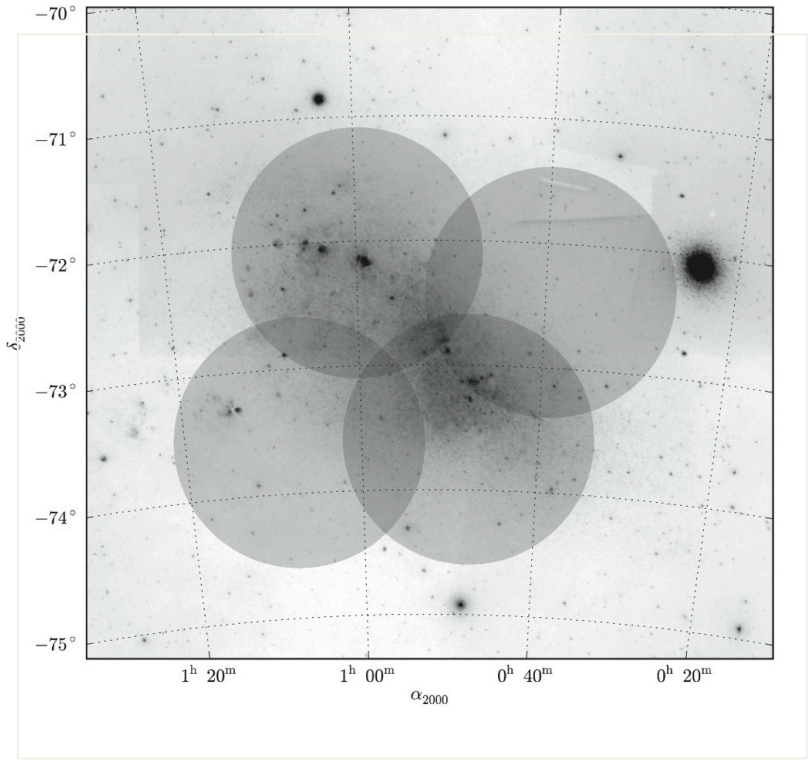
- Extensive Optical Low-res Spectral Survey + SED analysis + Variability analysis (with 1000 spectra of SMC objects and 2500 spectra of LMC objects)

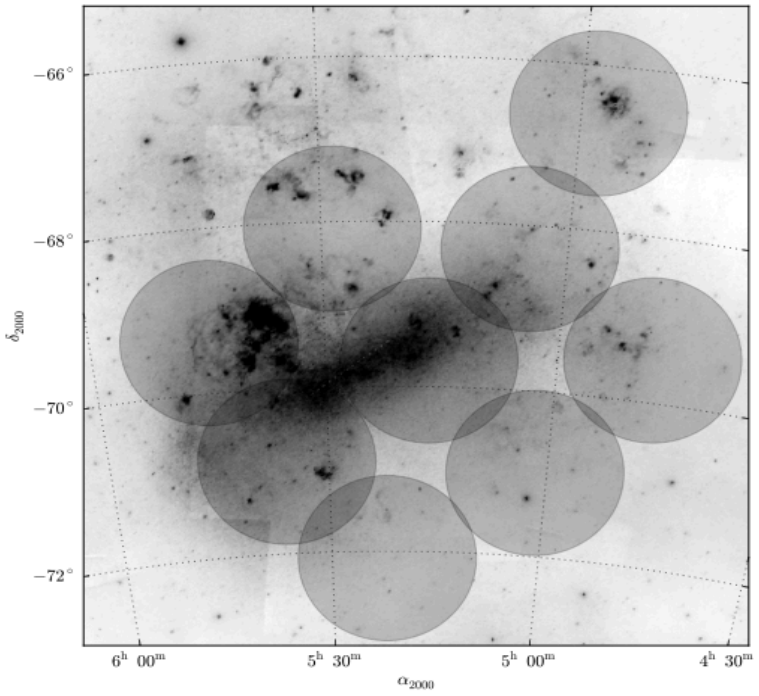
  (SMC – Kamath et al., 2014; LMC –Kamath et al., in prep)

Now Available:

Spectroscopically verified post-AGB candidates in the LMC/ SMC

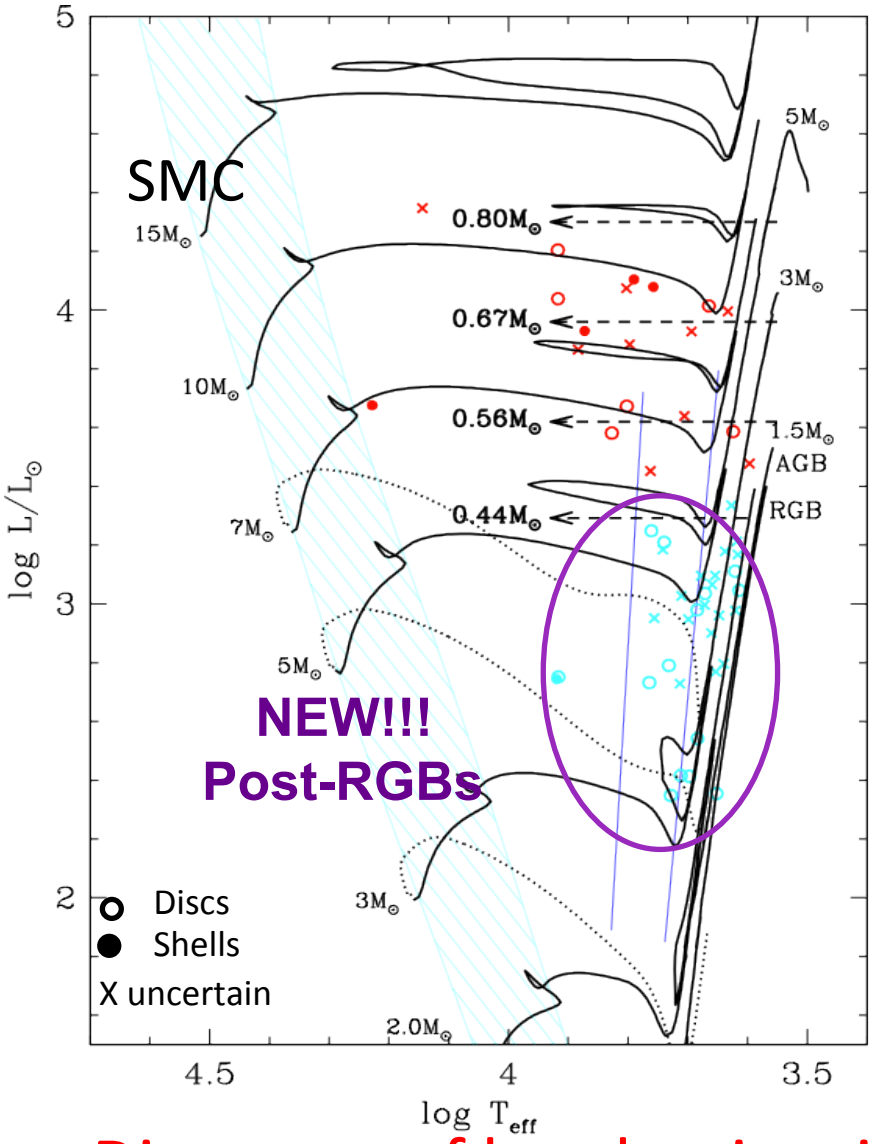
with stellar parameters: T_{eff}, Logg, [Fe/H], E(B-V) and Luminosity estimated from spectra (+SEDs)



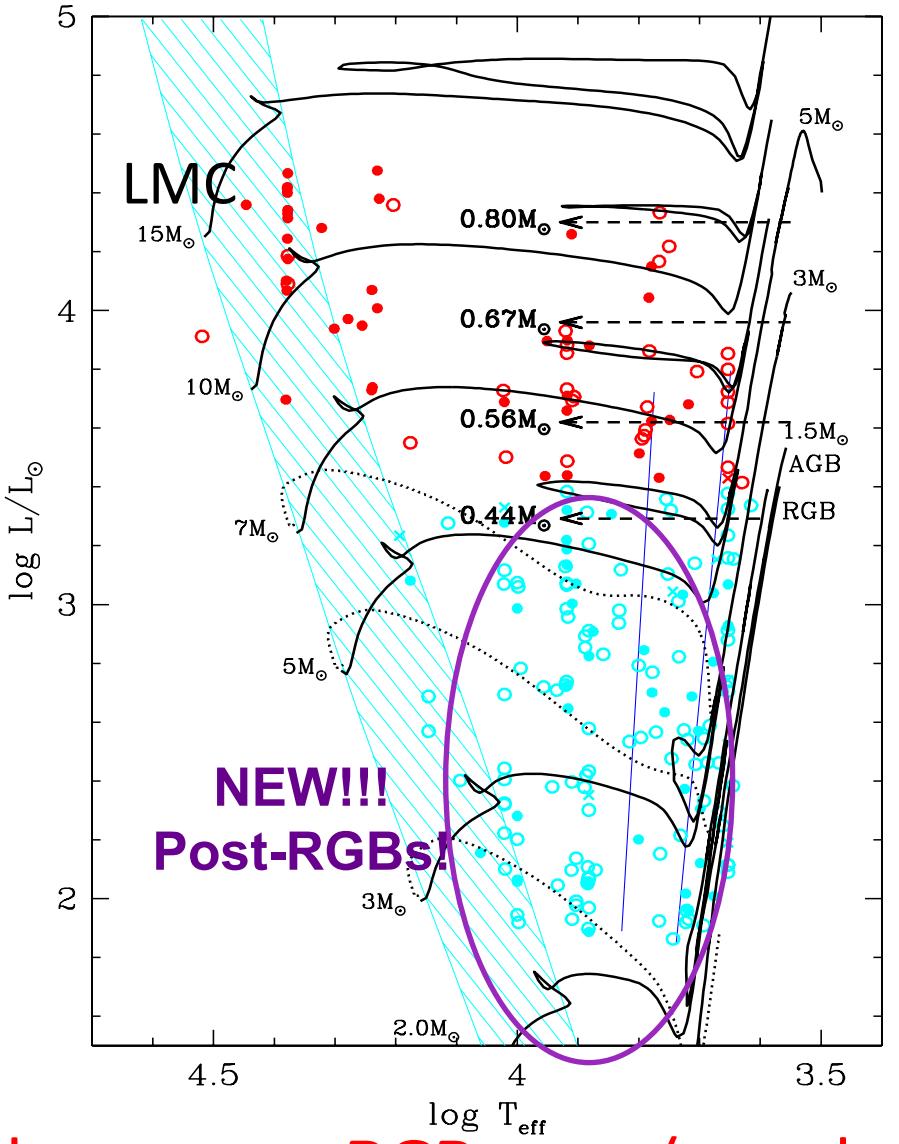


(LMC –Kamath et al., in prep; SMC – Kamath et al., 2014)

21 post-AGB stars 42 post-RGB stars



70 post-AGB stars 150 post-RGB stars

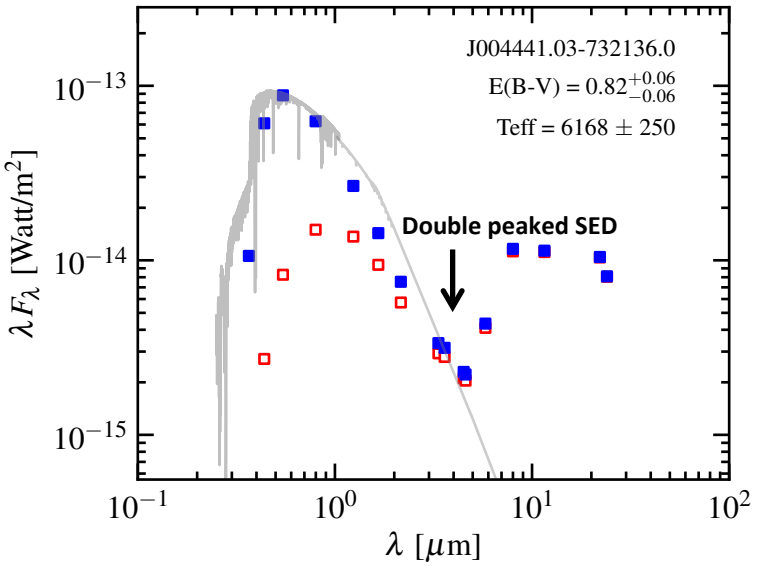


- Discovery of low-luminosity, dusty, **post-RGB stars** (mostly binaries)

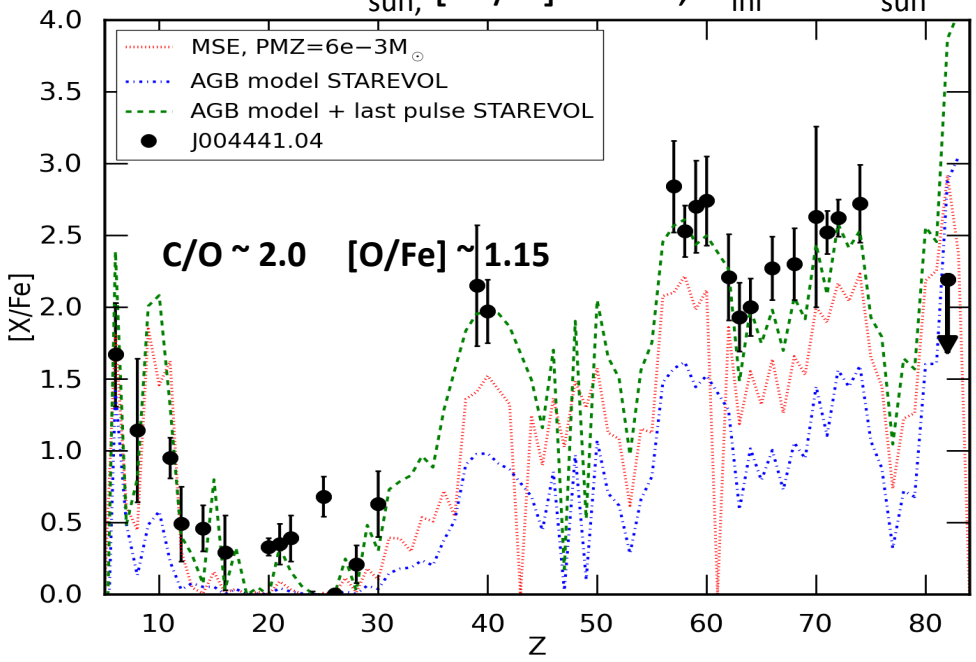
Chemical Diversity in the SMC
1. single star J004441.04-732136.0

One of the most s-process objects known…

Shell Source (single star)



L ~ 7500L$_{sun}$, [Fe/H]= - 1.3,M$_{ini}$ ~ 1 M$_{sun}$



De Smedt et al. 2014

***s*-process over abundance**

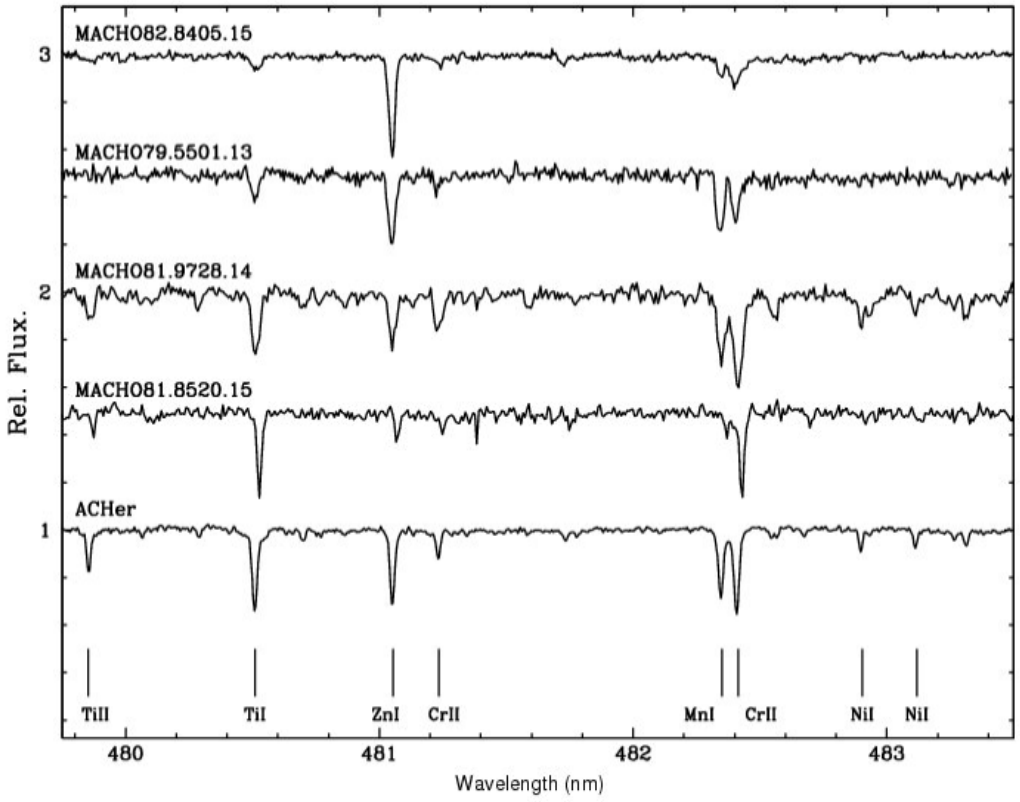
Estimated Lead (Pb) does not correlate with predicted overabundances…

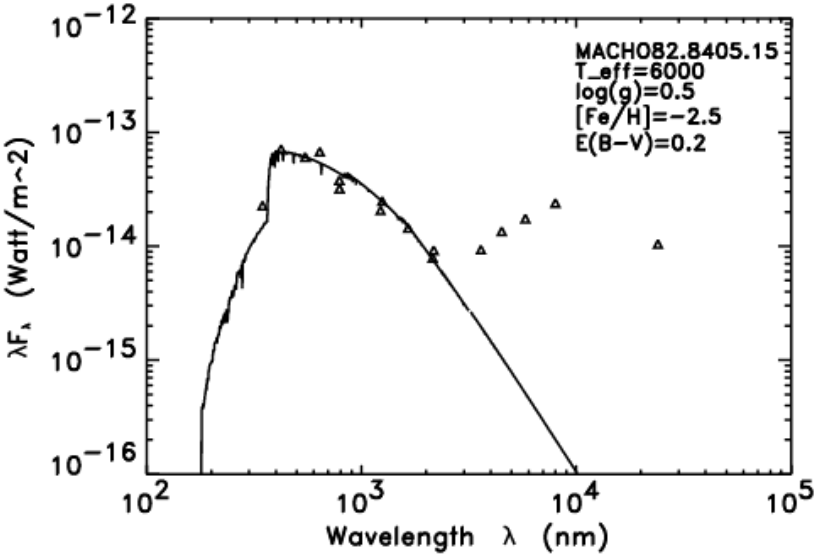
Talk by Kenneth De Smedt – Thursday!

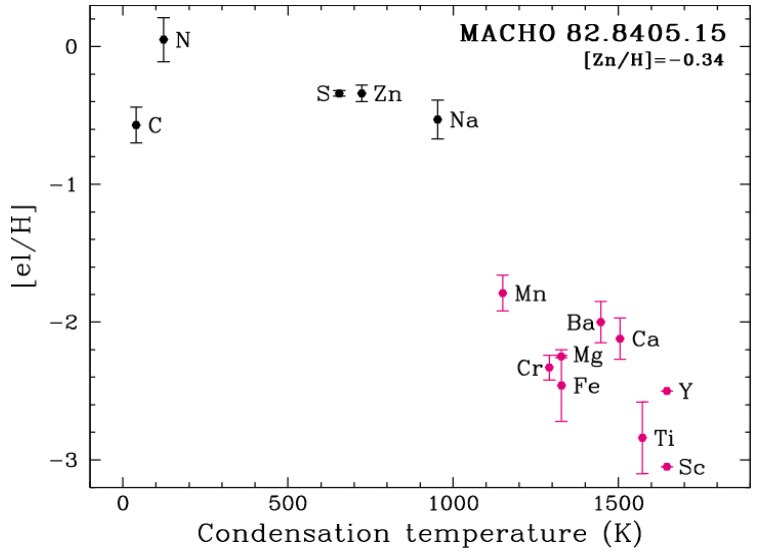
Chemical Diversity in the LMC
1. RV Tauri Stars – post-AGB binary disc sources

Macho 82.8405.15: [Fe/H] = -2.1, [Zn/Fe]=+2.2, [S/Ti]=+2

strongly depleted !





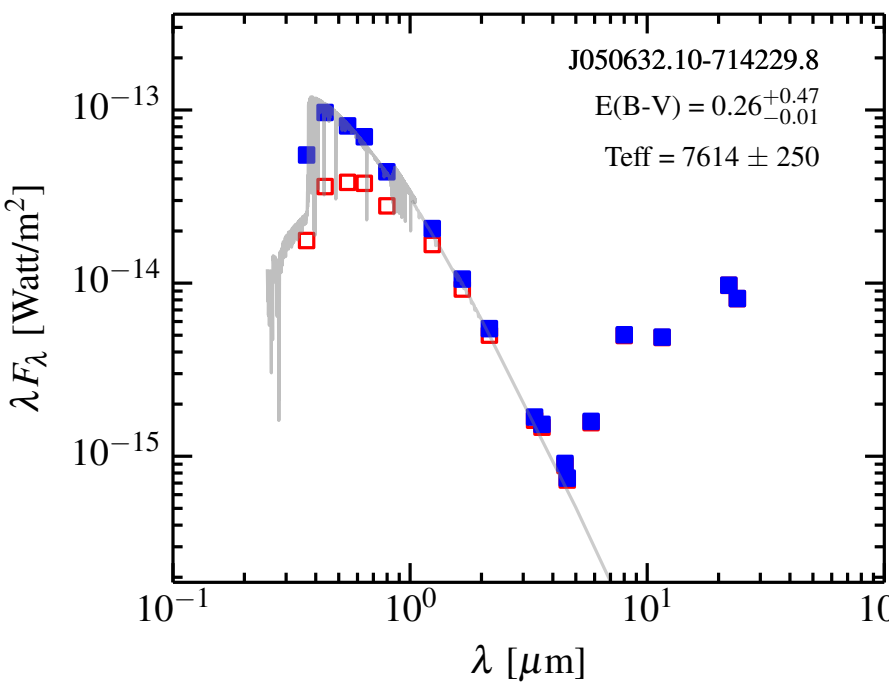


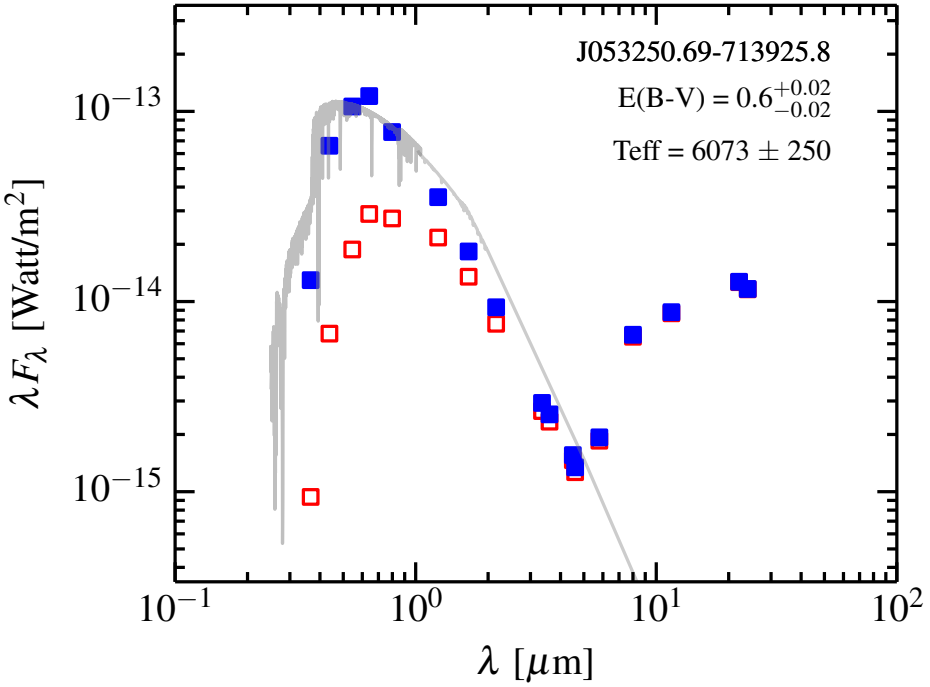
IR spectra are very rich and strongly crystalline !

(Reyniers et al., 2007; Gielen et al., 2009, 2011)

Chemical Diversity in the LMC
2. Likely single stars

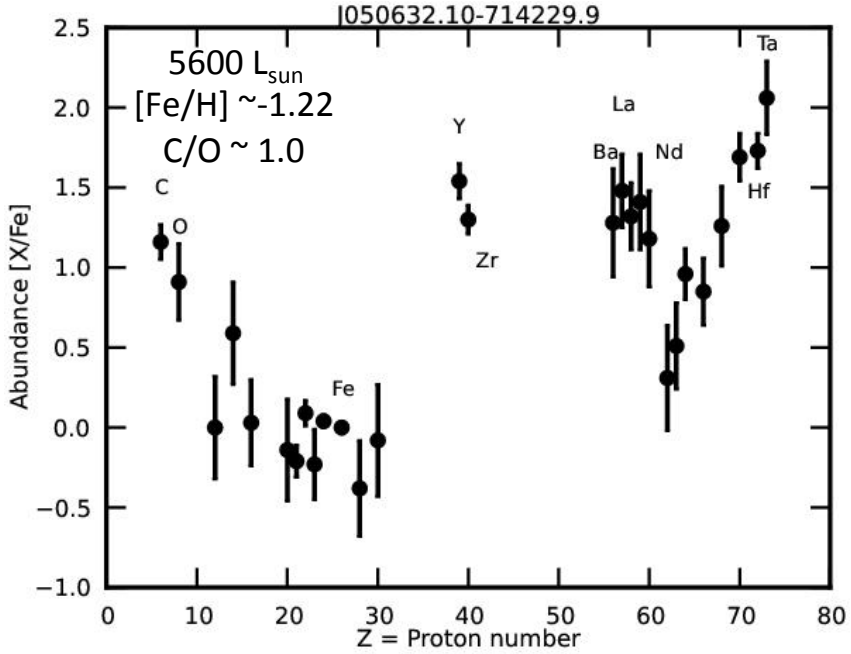
J050632.10-714229.8, J052043.86-692341.0, J053250.69-713925.8, J053253.51-695915.1

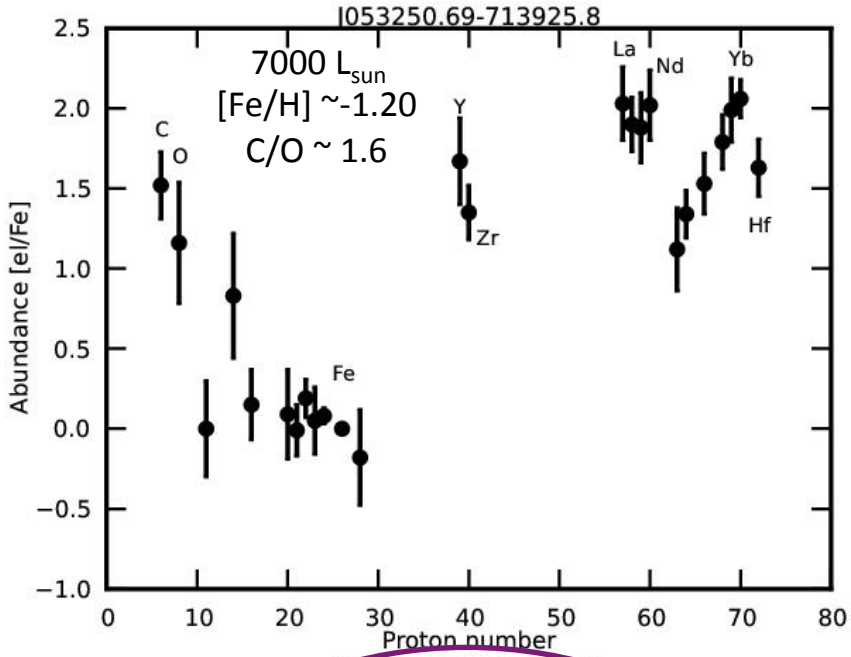


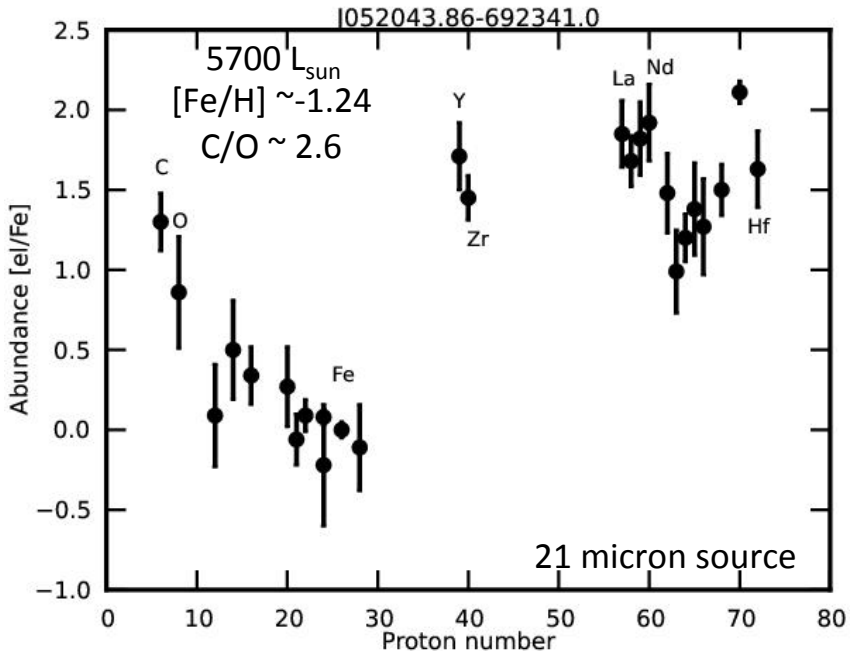


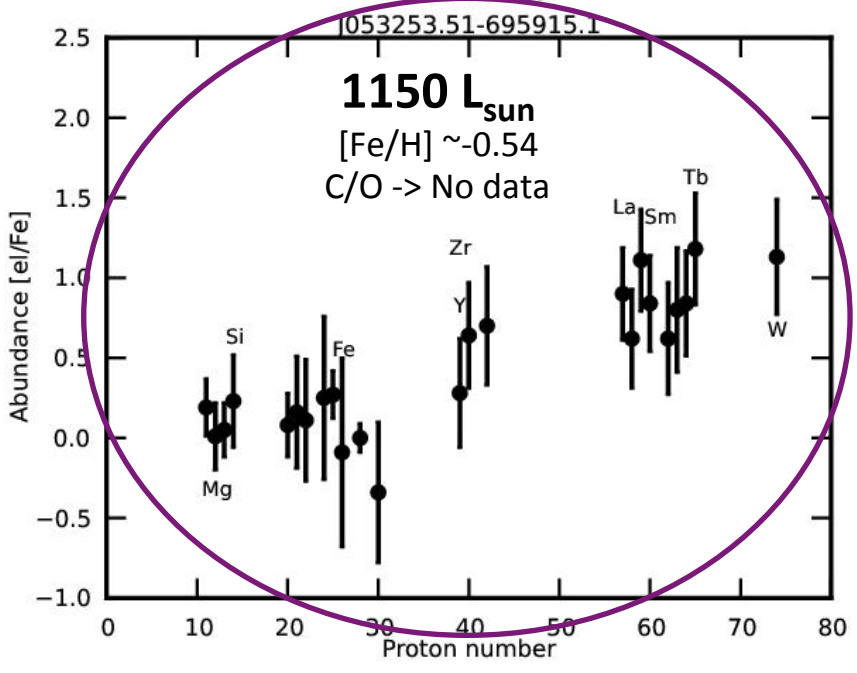
- All 4 SEDs: Shell Type -> likely single stars
- Expected Chemical Pattern : s-process enriched

Chemical Diversity in the LMC II (continued)



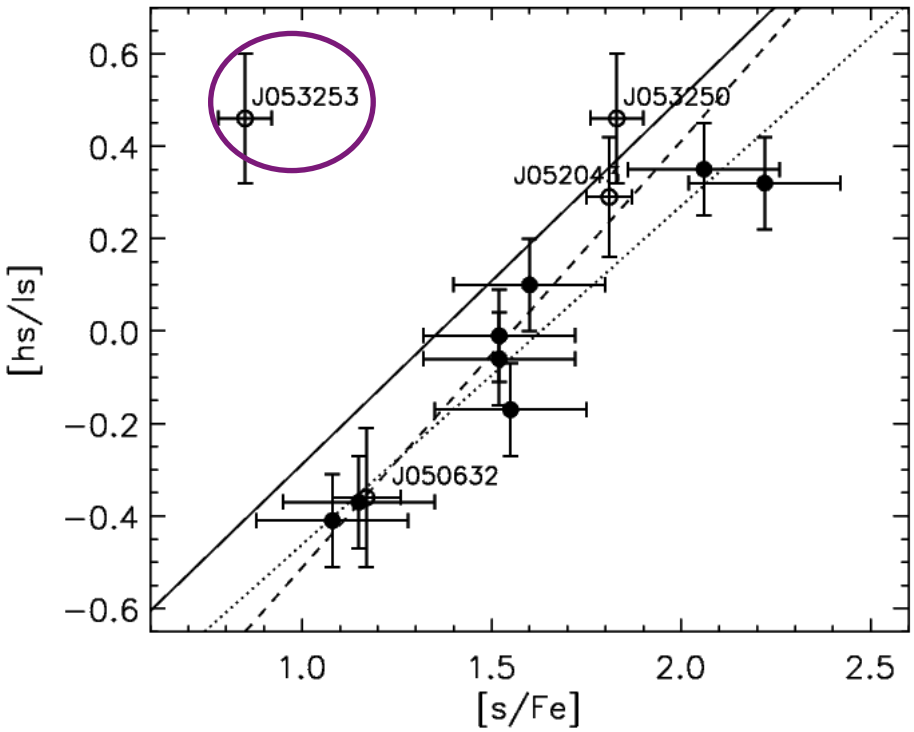






van Aarle et al., 2013

What's happening with the post-RGB star J053253??



- Is this the LMC initial chemical composition?
- Is this enrichment by binary mass transfer ?
  - UNLIKELY
    - The orbit is too compact for the original mass transfer

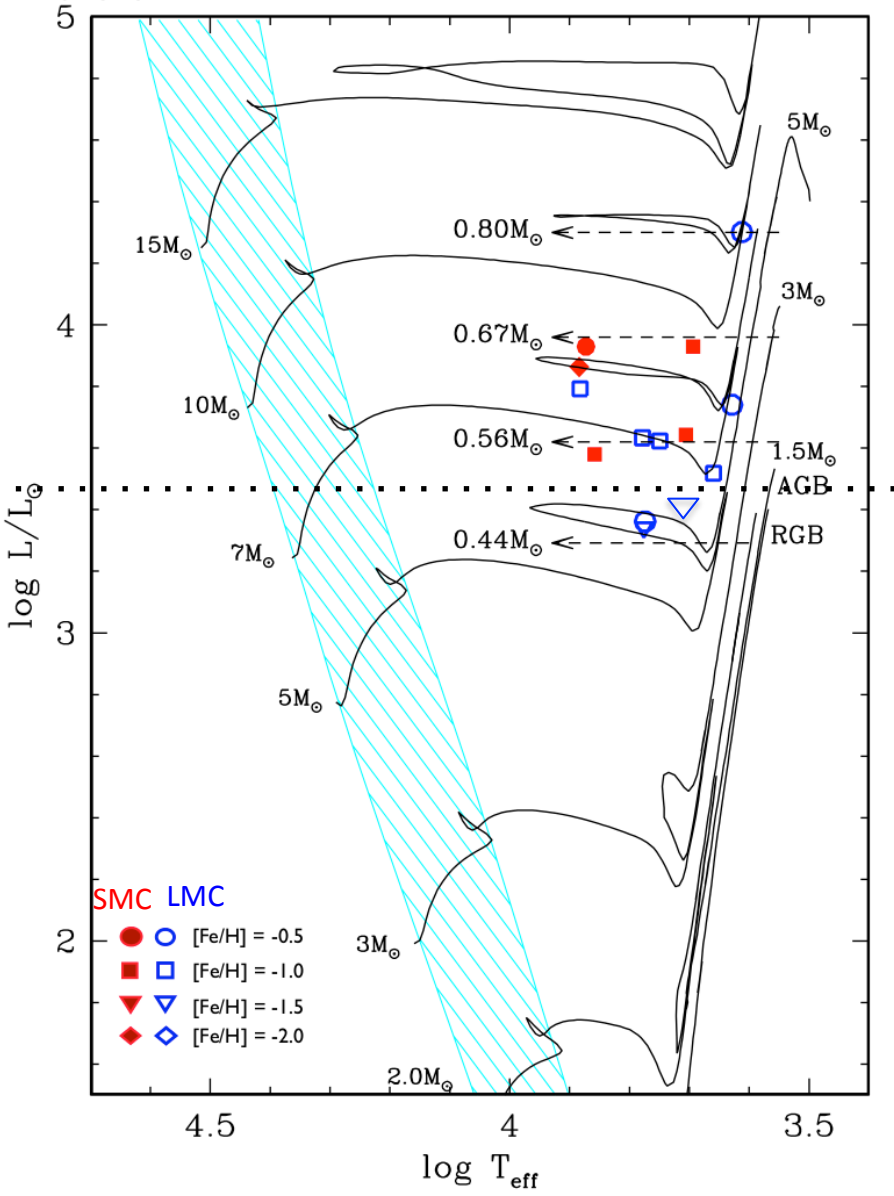
van Aarle et al., 2013

New UVES sample of LMC/SMC post-AGB/post-RGB shell sources

(10 Post-AGBs & 3 Post-RGBs) covering a wide range of luminosities and metallicites within the LMC and SMC

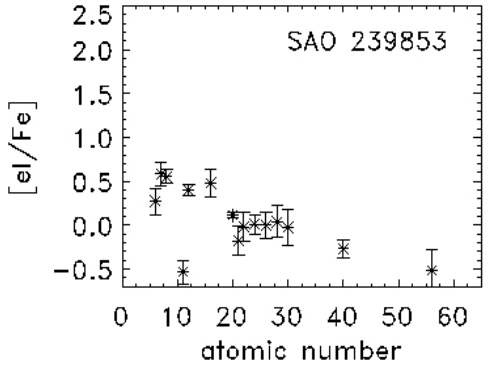
To understand the diversity between within the shell population

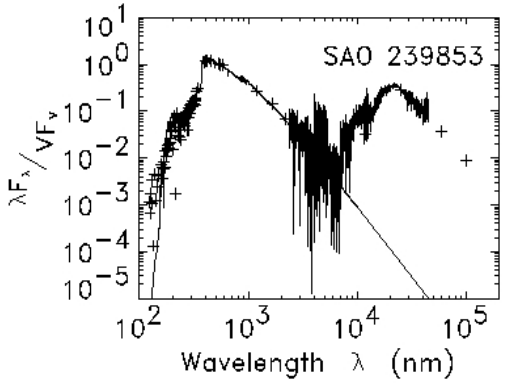
Future work:
Disc sources



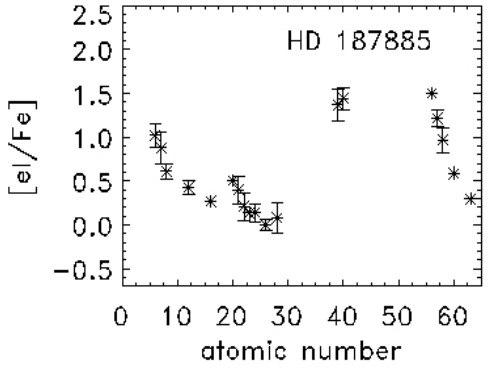
Chemical diversity in the Galaxy – DECODED?!?

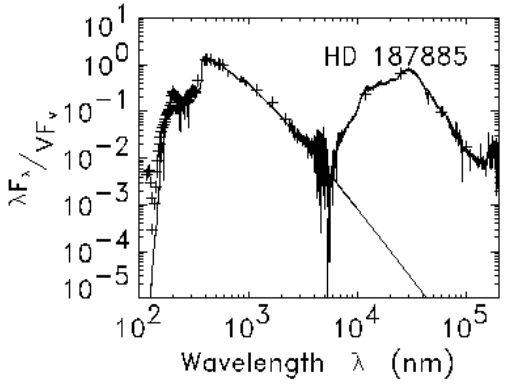
Very likely a Luminosity effect

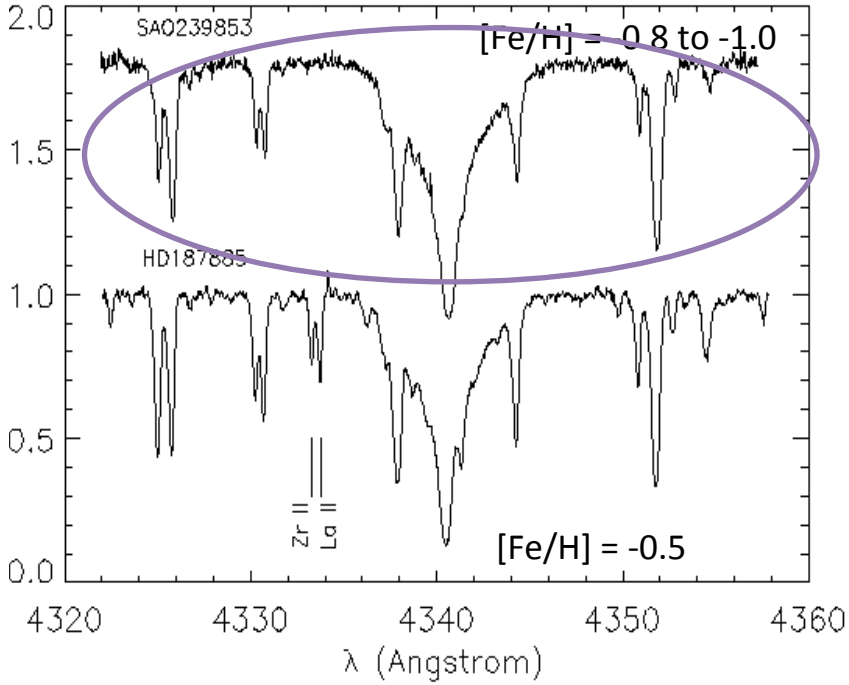




21 micron source





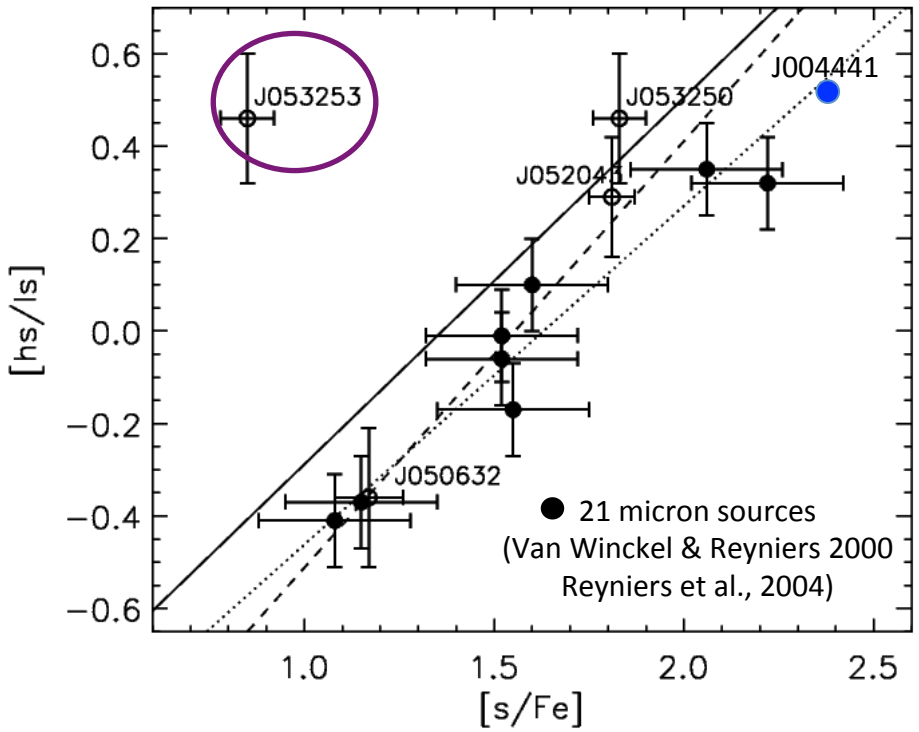


a post-RGB star or a low luminosity post-AGB

Van Winckel et al., 1996

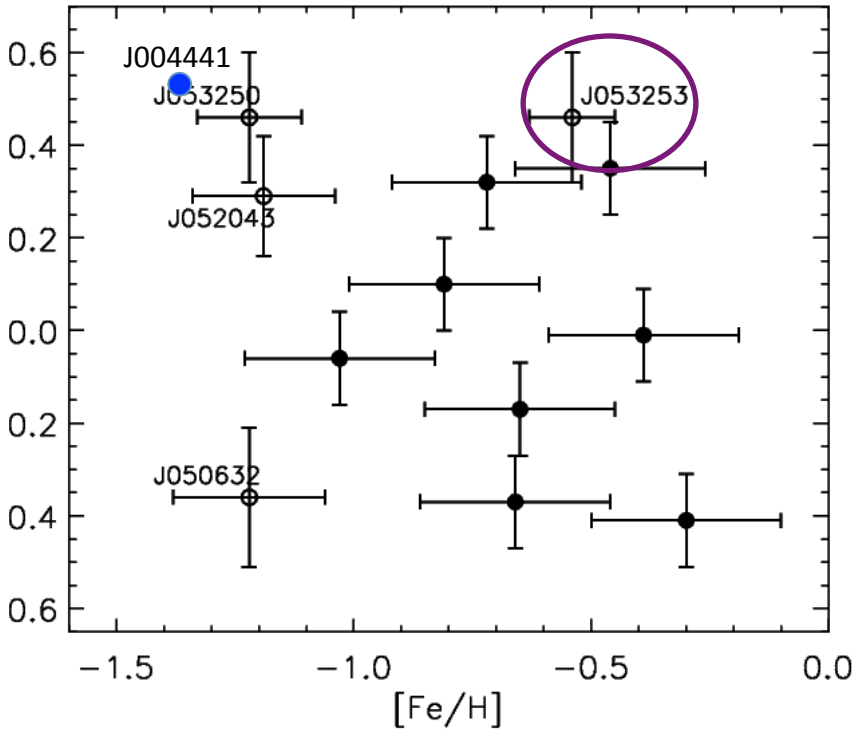
Chemical Diversity in the **LMC, SMC and Galaxy**

Correlation between strength of the neutron irradiation and efficiency of TDU



Overabundance and *s*-process efficiency is strongly correlated !

Correlation between metallicity and efficiency of TDU



No metallicity dependency of *s*-process efficiency

van Aarle et al., 2013

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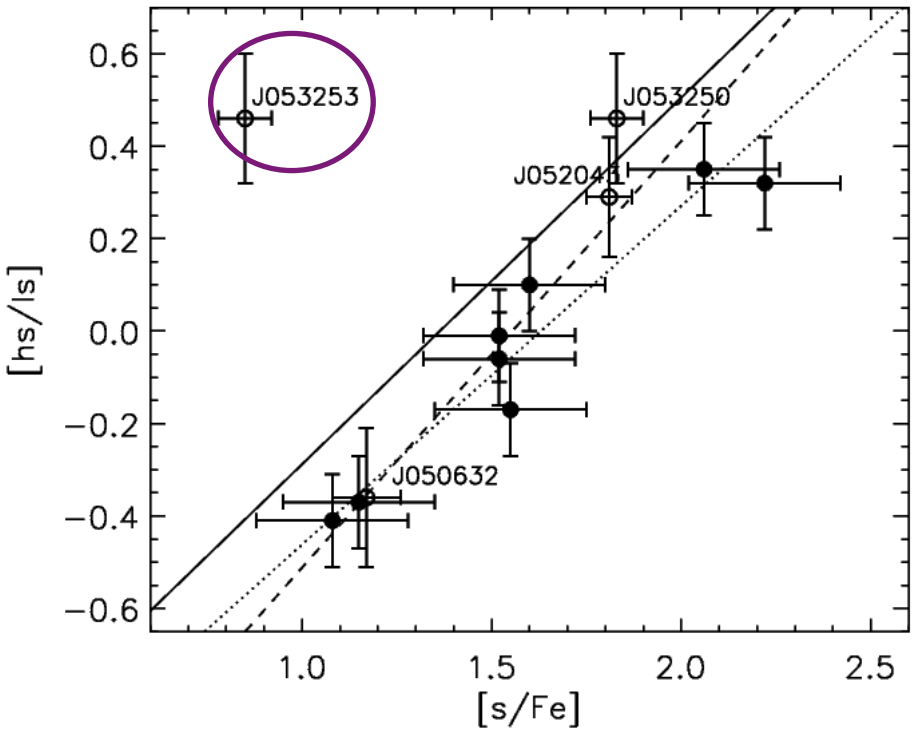

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van Aarle et al., 2013

When Theory Meets Observations…

Observational parameters from post-AGB/RGB stars

- Initial Luminosity (hence mass) + Stellar parameters (Teff, Log g, [Fe/H])
- Chemical Abundances of all CNO + *s*-process + elements upto Pb
- Isotopic ratios : $^{12}C/^{13}C$, $^{16}O/^{18}O$ [using ALMA]
- Wish list from you….???

When Theory Meets Observations…

Uncertainties that **CAN** be constrained

- The relevance of extra mixing schemes along the different evolutionary tracks
- Mixing regimes and their influence on the photospheric abundances
- Overshoot parameters related to the creation of the ^{13}C pocket
- The integrated mass-loss on the AGB
- Luminosity and metallicity dependence of efficiency TDU, neutron irradiation, etc.
- ?


The answers are out there...