Unveiling the Mystery of Technetium-Rich M Stars: Implications for AGB Evolution

Shreeya Shetye

In collaboration with: Sophie Van Eck, Alain Jorissen, Ana Escorza, Lionel Siess, Stephane Goriely, Hans Van Winckel, Stefan Uttenthaler

- Late-type giants with distinctive molecular bands:

  M stars : TiO

  S stars : TiO + ZrO

- M stars : C/O ~ 0.5

  S stars : $0.5 \leq C/O < 1$

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S stars can be classified based on the presence of Technetium (Tc):

Intrinsic S stars : TP - AGBs

Extrinsic S stars : Polluted binaries

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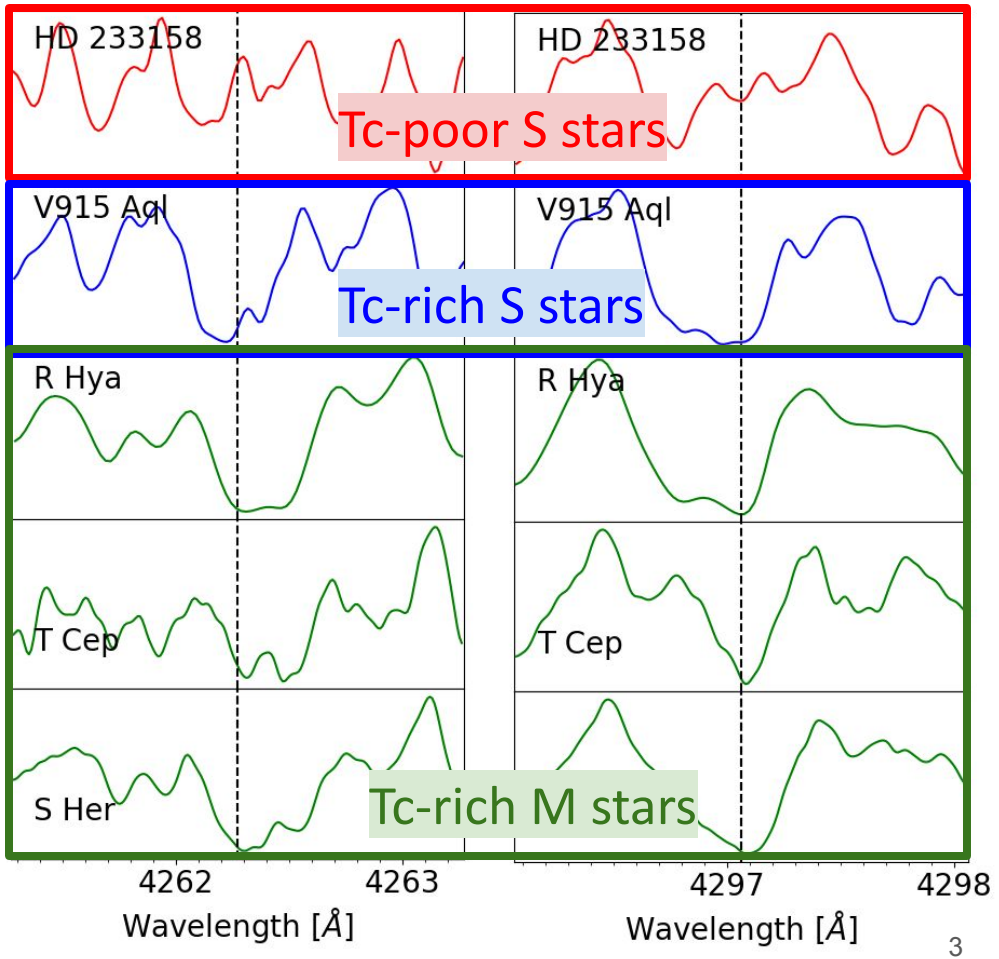


Laying the puzzle and some open questions:

- ➔ What are the key characteristics (like temperature, mass, and luminosity) of Tc-rich M stars?

- ➔ What is the evolutionary status of the Tc-rich M stars ?

- ➔ How is the s-process abundance profile of these M stars ? Are they different from the ones of S-type or Carbon stars?

- ➔ Besides technetium (Tc), do these stars have unusually high levels of any other elements?

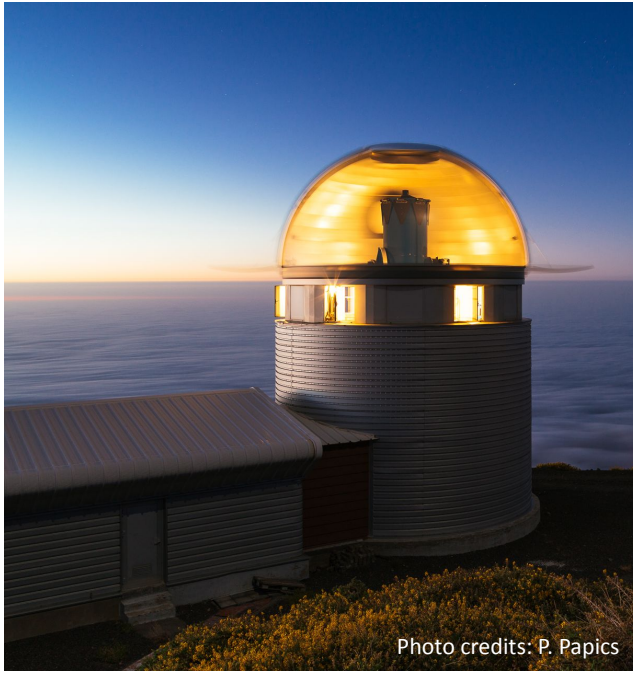
Spectroscopic study of a ‘large-sample’ Tc-rich M stars

Total no. of stars: 57

V-band: 4-11 mag

Gaia G-band: 3-10 mag

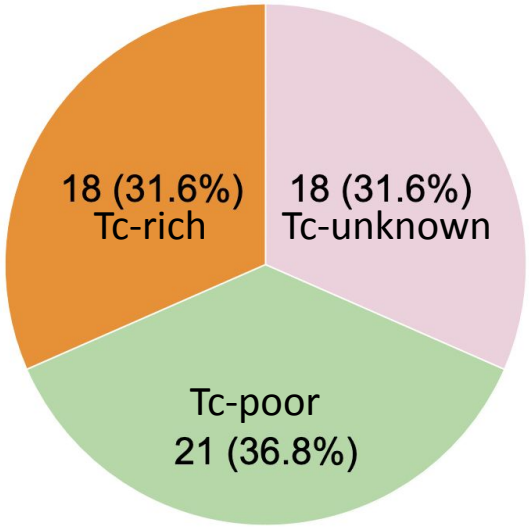
Hermes S/N: 40-50 in V-band



HERMES, Mercator telescope (La Palma)

<u>Goal:</u> Identify Tc-rich M stars ⟶ perform a spectroscopic and evolutionary study

Technetium signatures of sample stars



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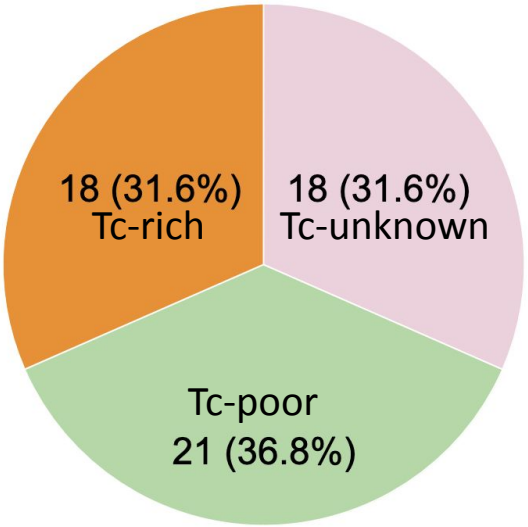

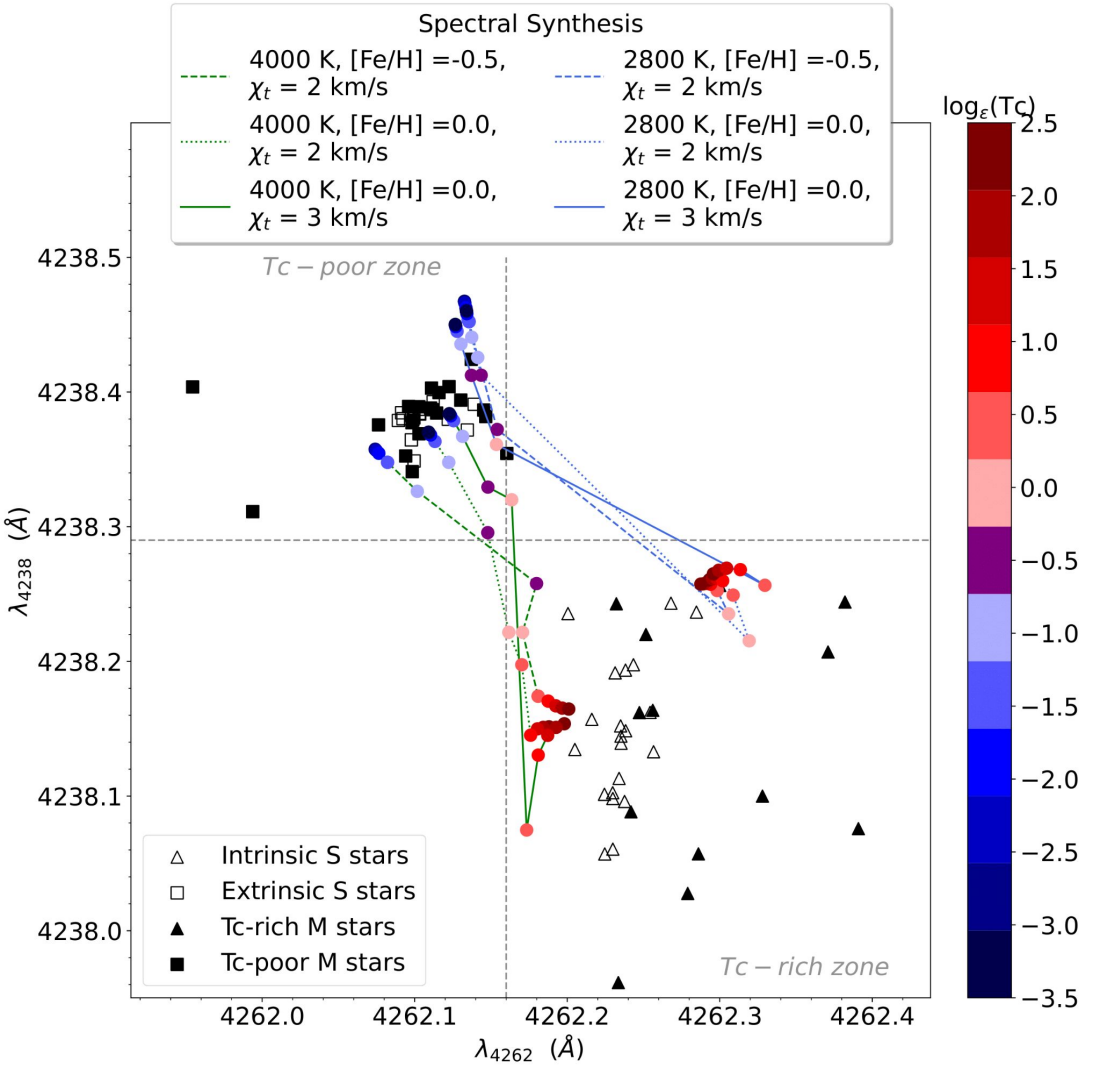

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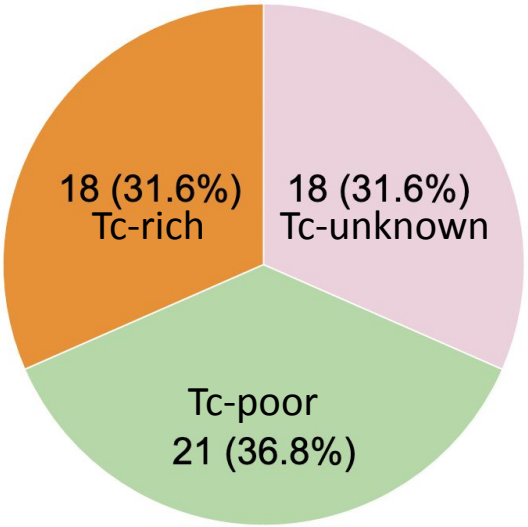
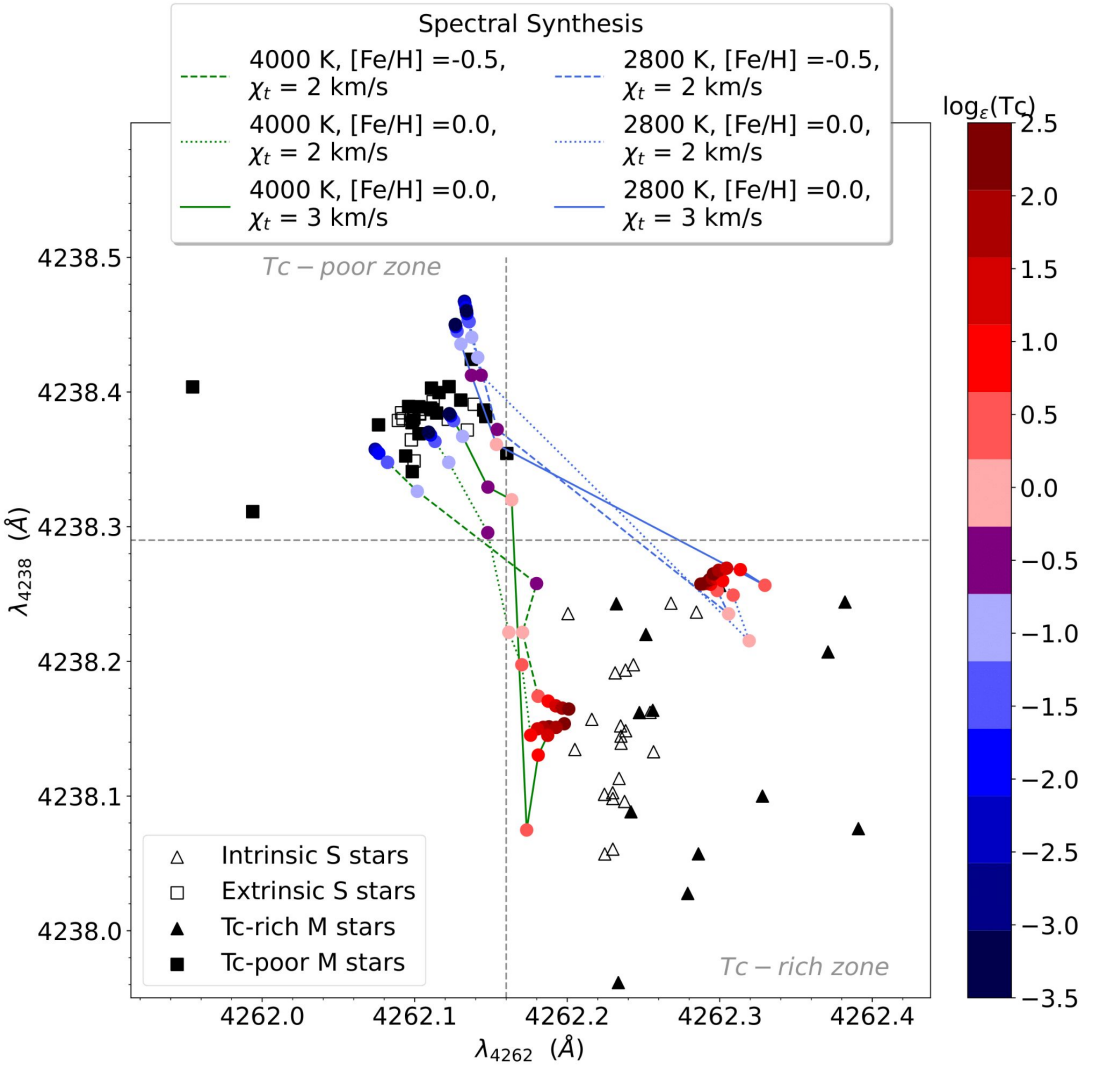
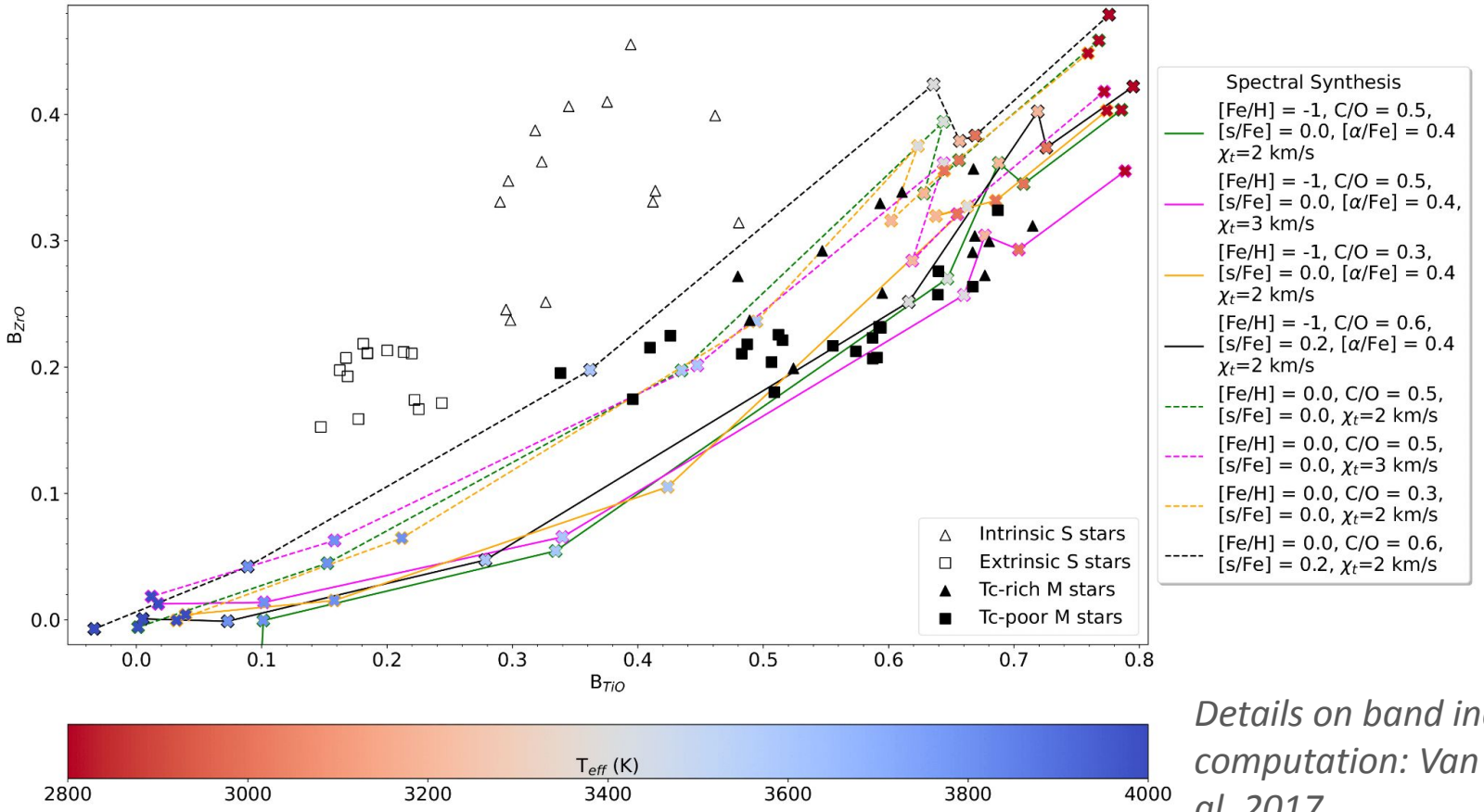


S and M stars exhibit similar Technetium signatures



TiO-ZrO band strength indices



Details on band indices computation: Van Eck et al. 2017

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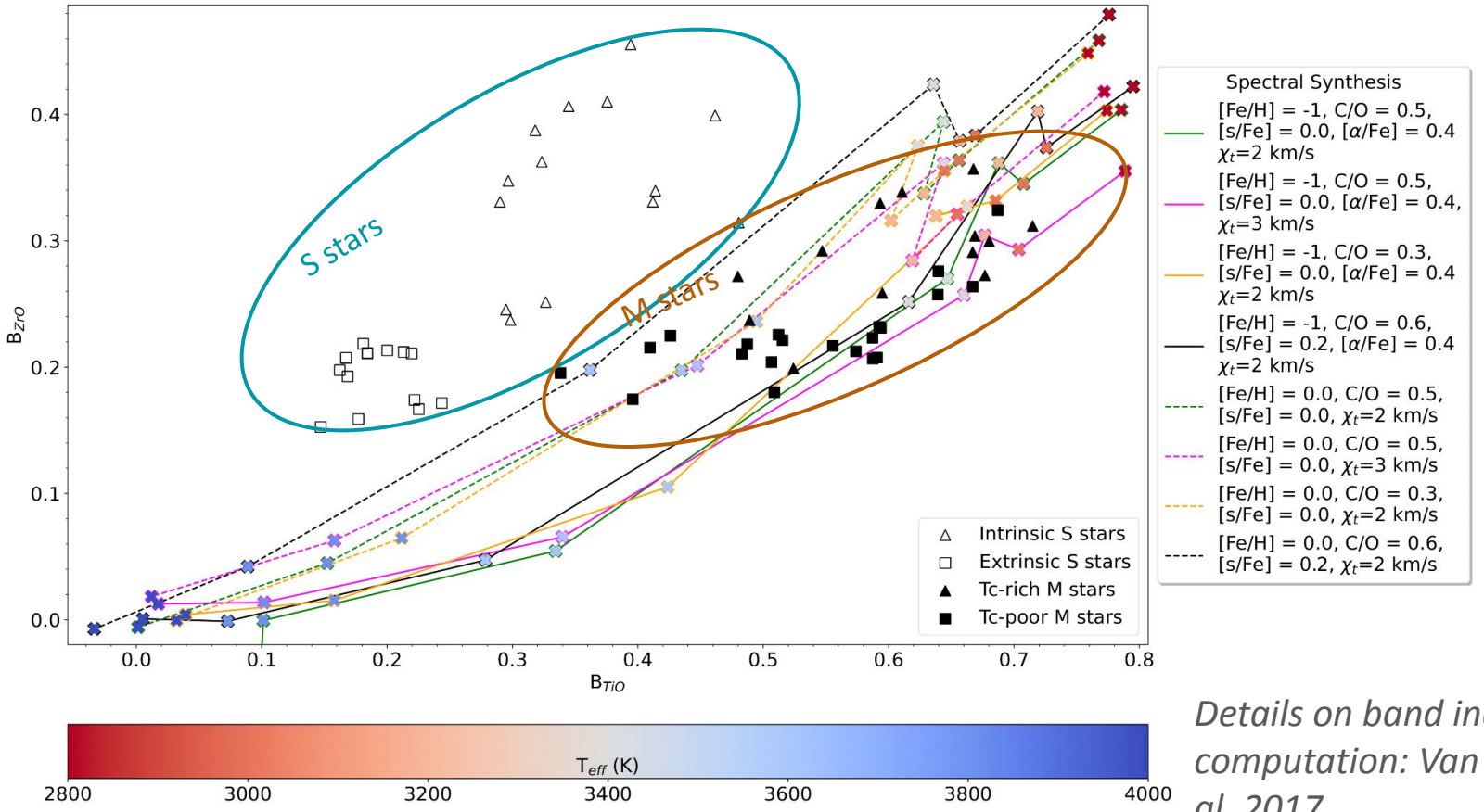

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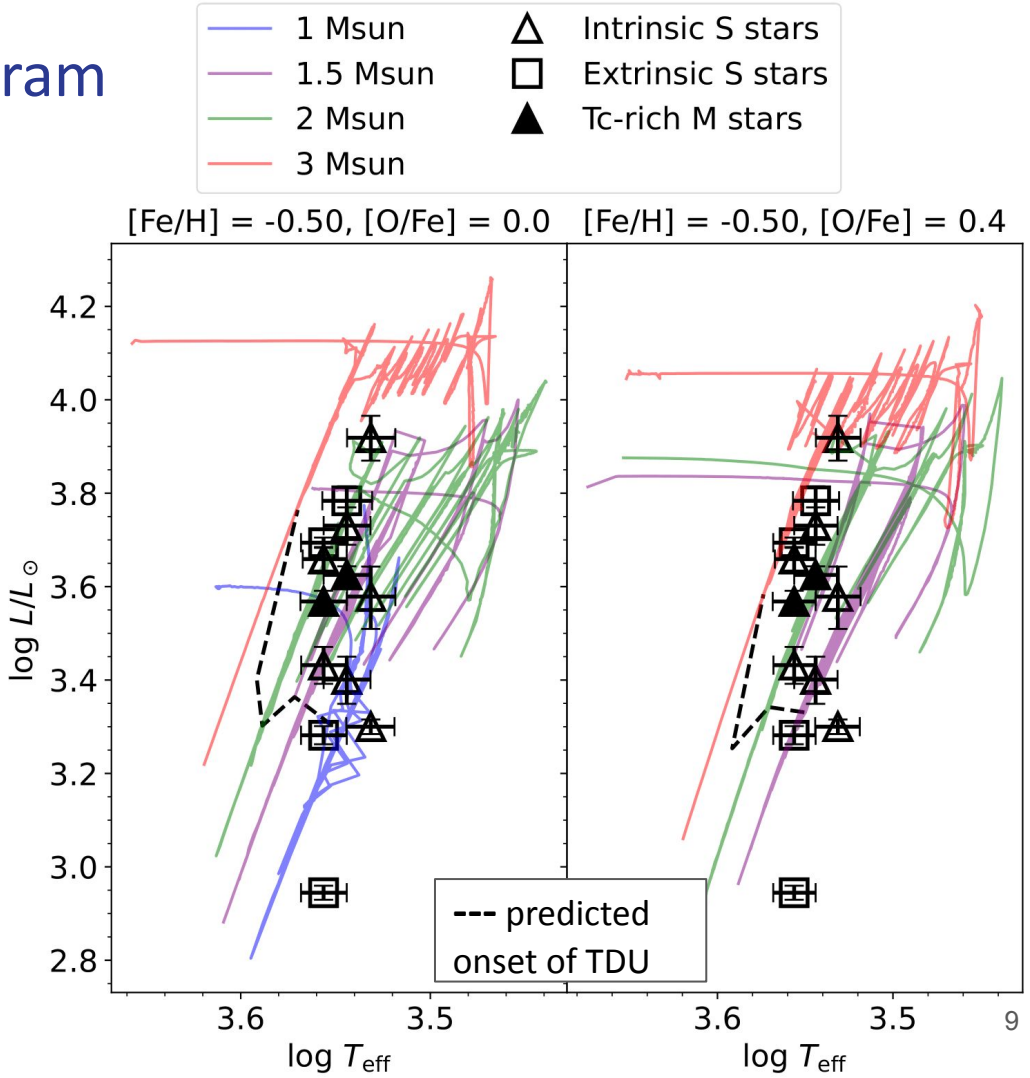
Tc-rich M stars in the HR diagram

- Tc-rich M stars lie beyond the predicted onset of third dredge-up.

- Stellar tracks remain largely unaffected by high oxygen.



STAREVOL AGB evolutionary tracks: Siess et al. 2000

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- Tc-rich M and S stars have similar luminosities.

M ⟶ MS ⟶ S ⟶ SC ⟶ C?

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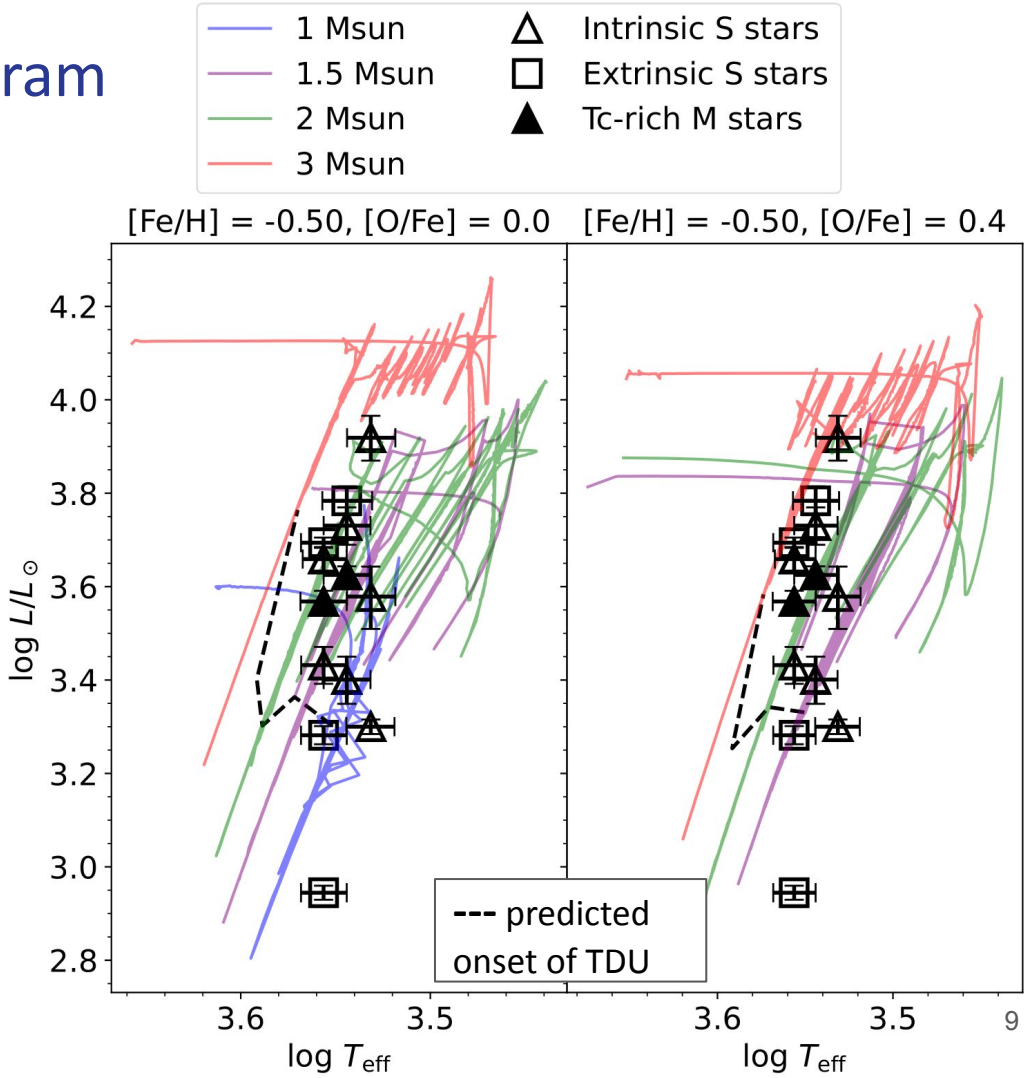
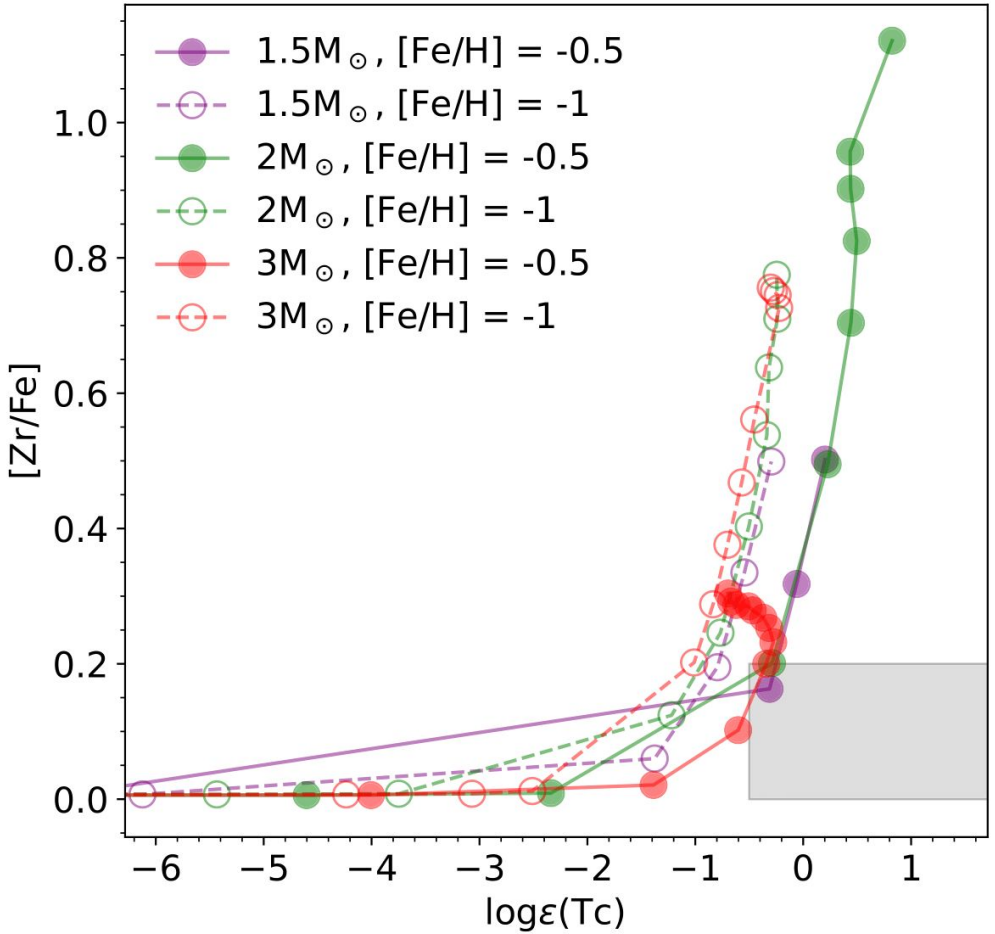


Predicting Tc-rich M stars with nucleosynthesis models

- Metallicity effect > Mass effect on when the star becomes Zr-enriched.



AGB nucleosynthesis models:
Siess et al. 2000, Goriely & Siess 2018

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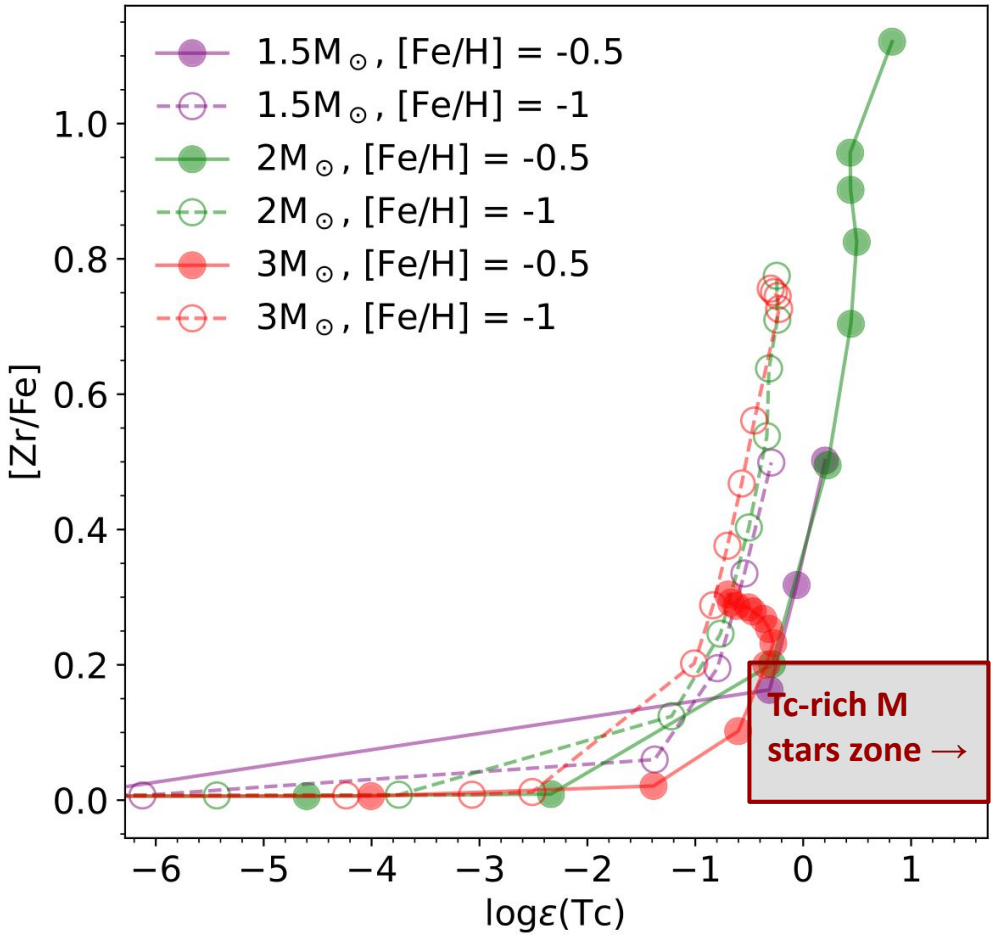
- M stars can exhibit clear Tc absorption features without significantly strong ZrO bands.



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Our findings about the Tc-rich M stars:

(Shetye et al. 2025 under review in A&A)

- Comparison of spectral features of S and M stars:
  - Technetium features of M stars are not different than S stars.
  - Tc-rich M stars follow a distinct sequence in the BTiO- BZrO plane.

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- From an evolutionary (HRD) point-of-view:
  - Tc-rich M stars lie beyond the predicted onset of TDU.
  - Tc-rich M and S stars have similar luminosities.

- Nucleosynthesis predictions suggest that some M stars can exhibit clear Tc absorption features without significantly strong ZrO bands.

- Spatial and kinematic properties: Tc-rich M stars may also be older than Tc-rich S stars

Torino workshop 2016 (Budapest)

Thermal pulses + Third dredge-up ⟶ AGB s-process production

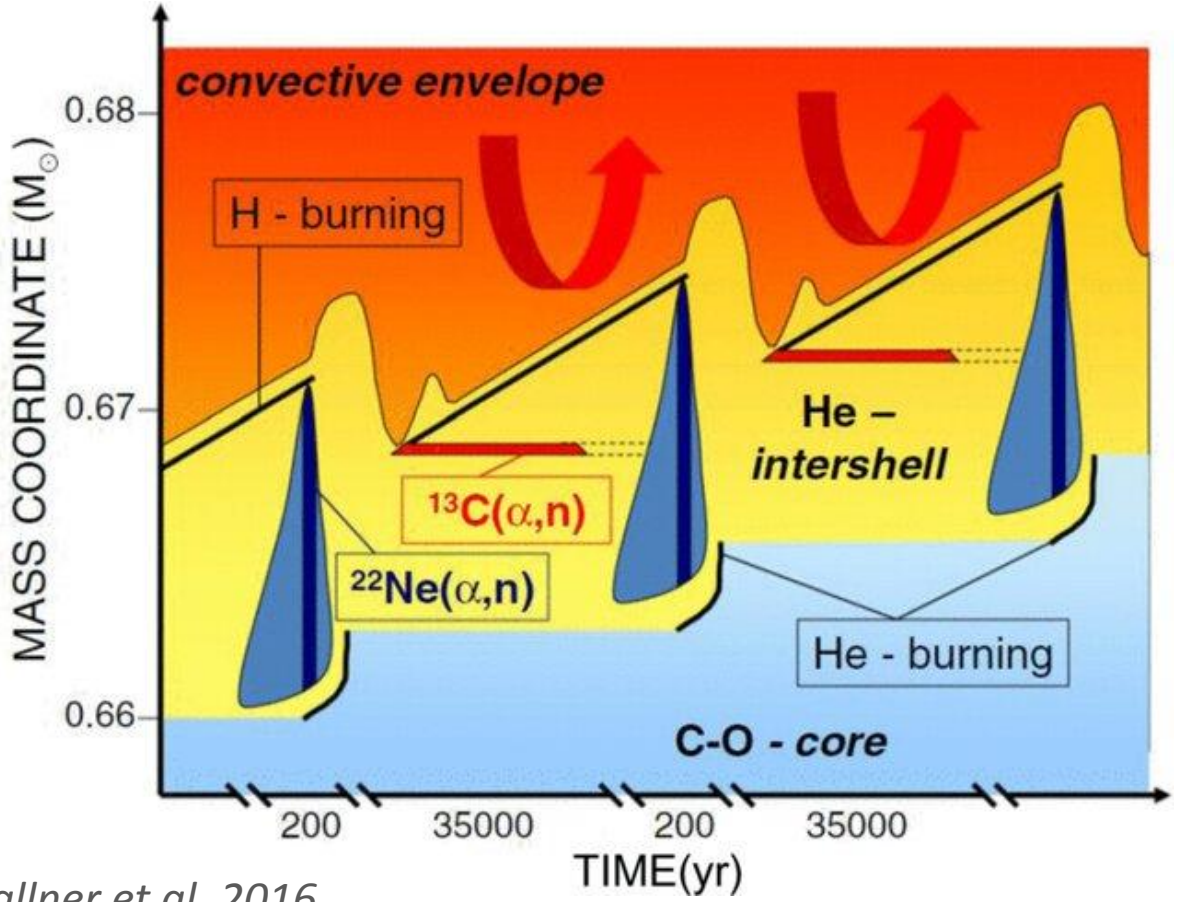

Image credits: Wallner et al. 2016

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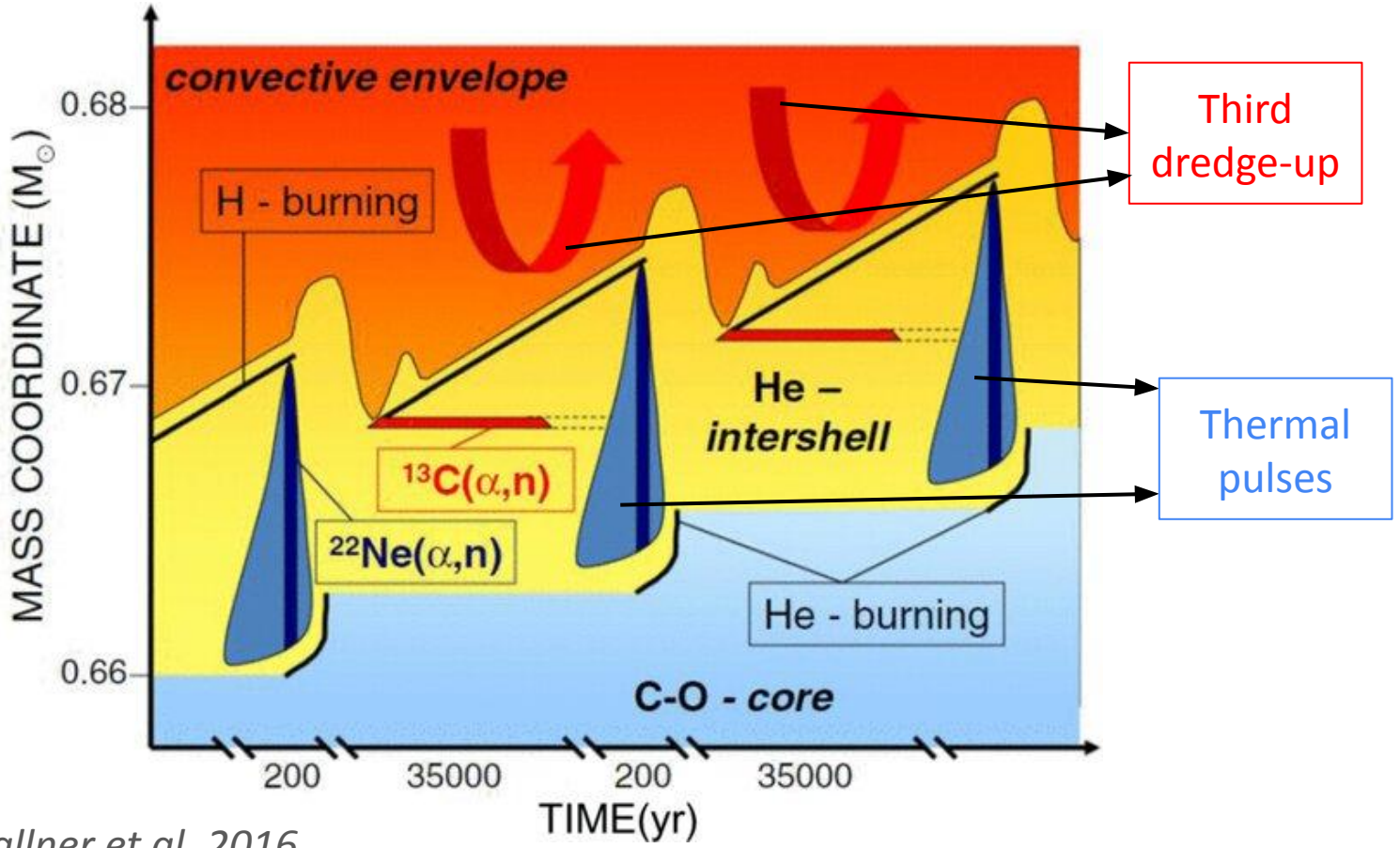

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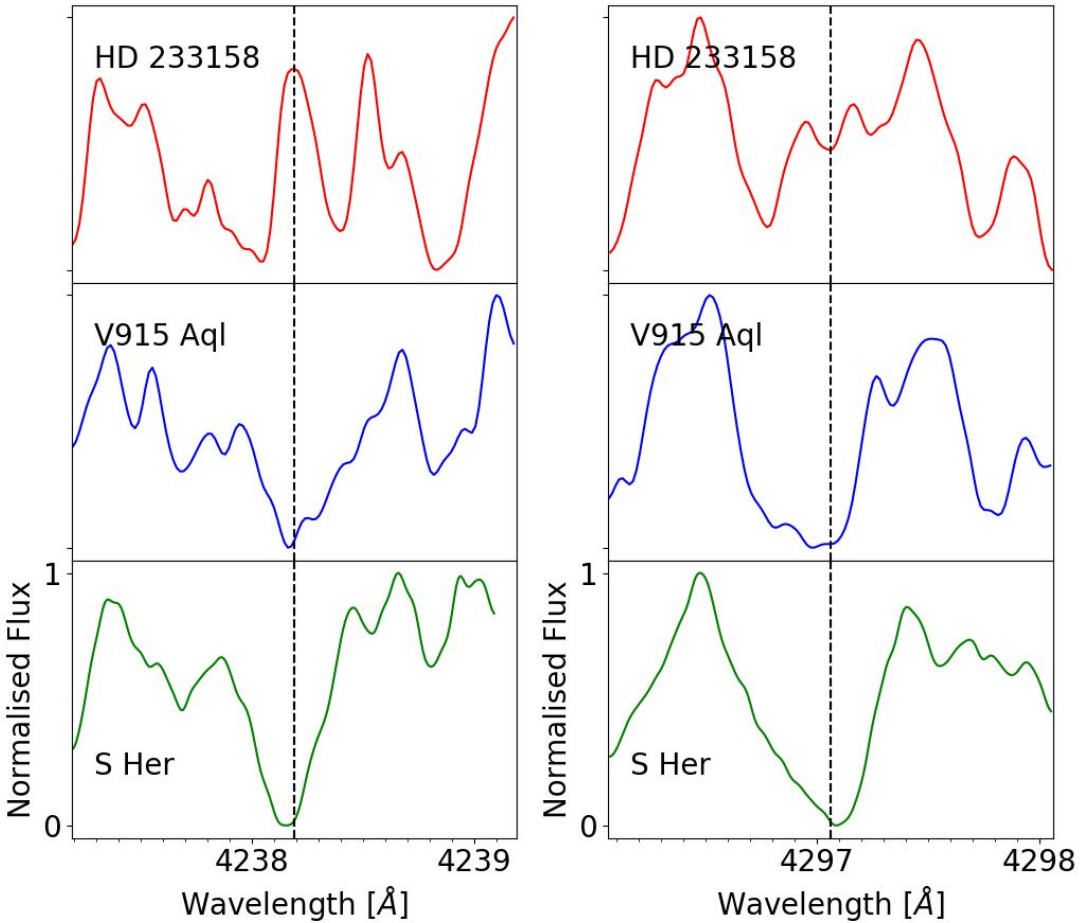
Testing the waters with a pilot study: the case of S Her



S Her

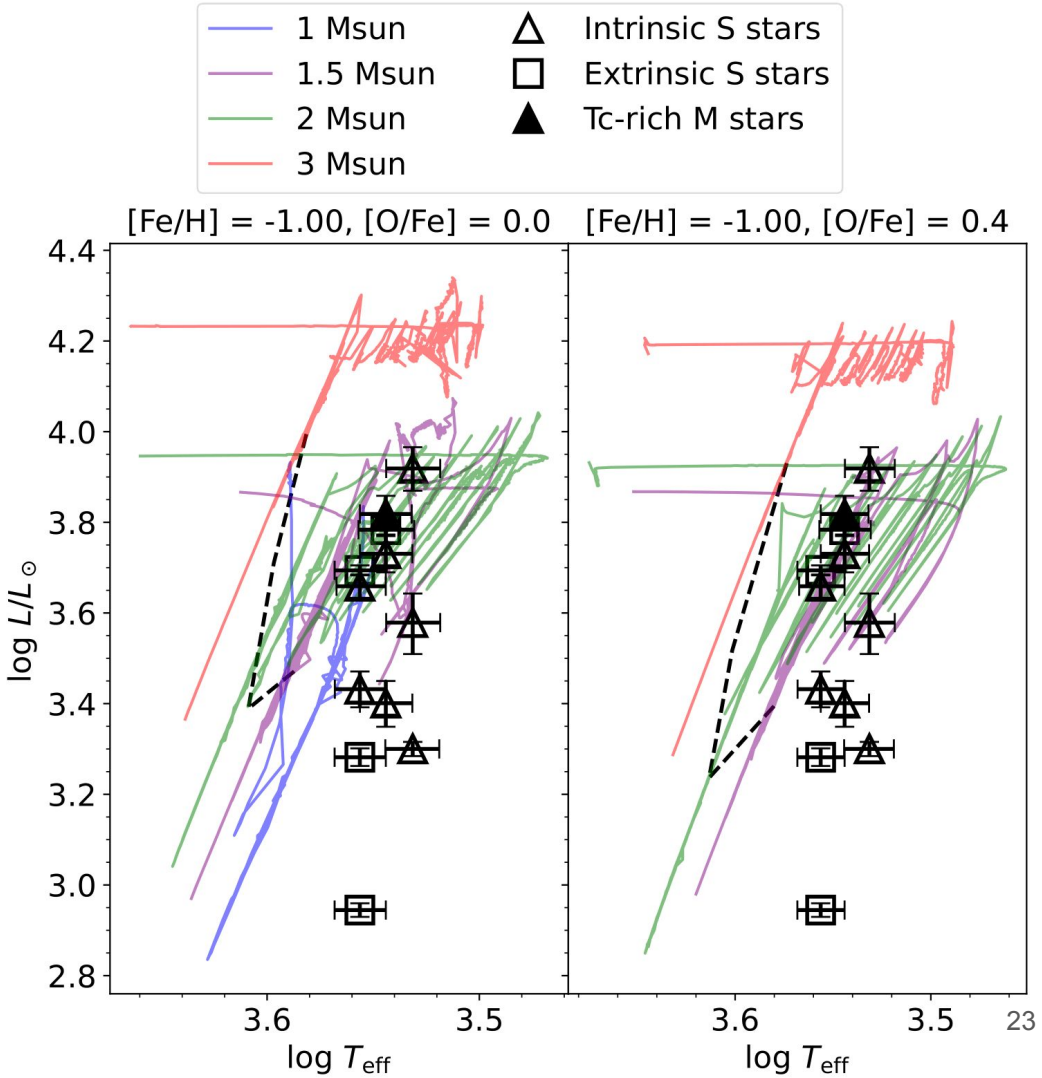
Spectral type : **M4-7.5**

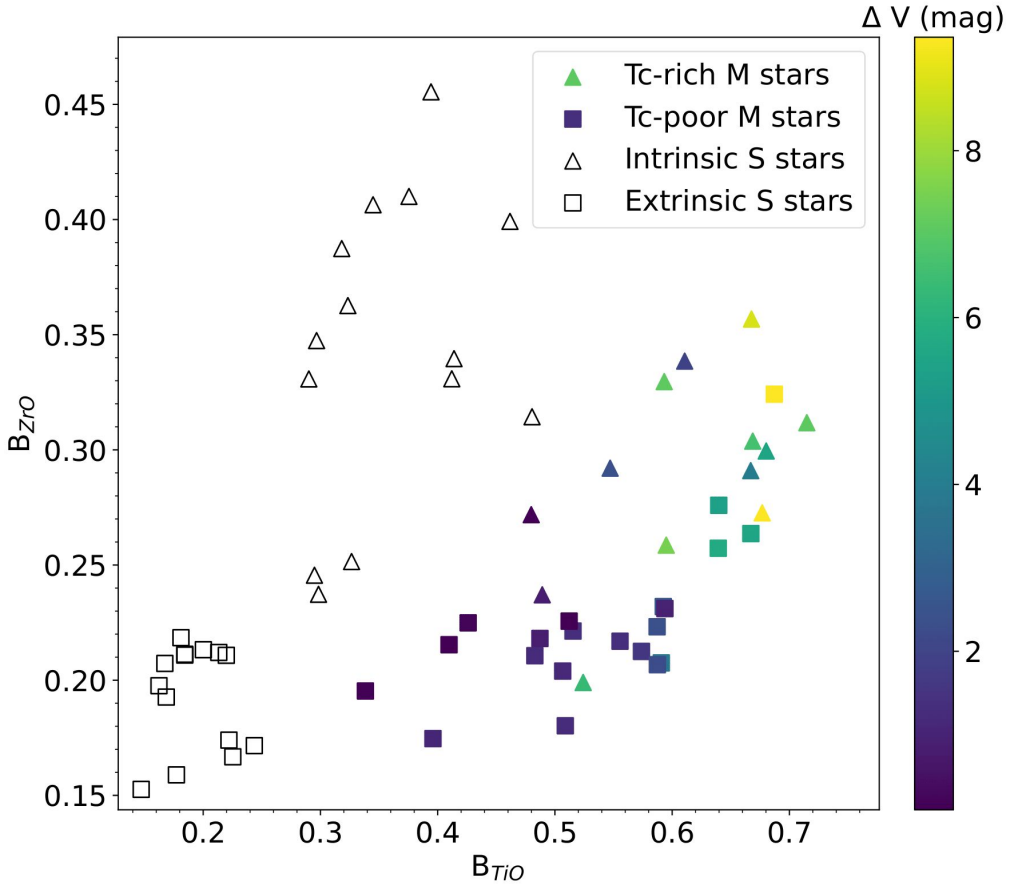
*V*mag : 6.4 *B*mag : 9.7

ΔV : 6mag

Pulsation and mass-loss studies: Uttenthaler et al. 2019, Vogt et al. 2016…

Backup slides



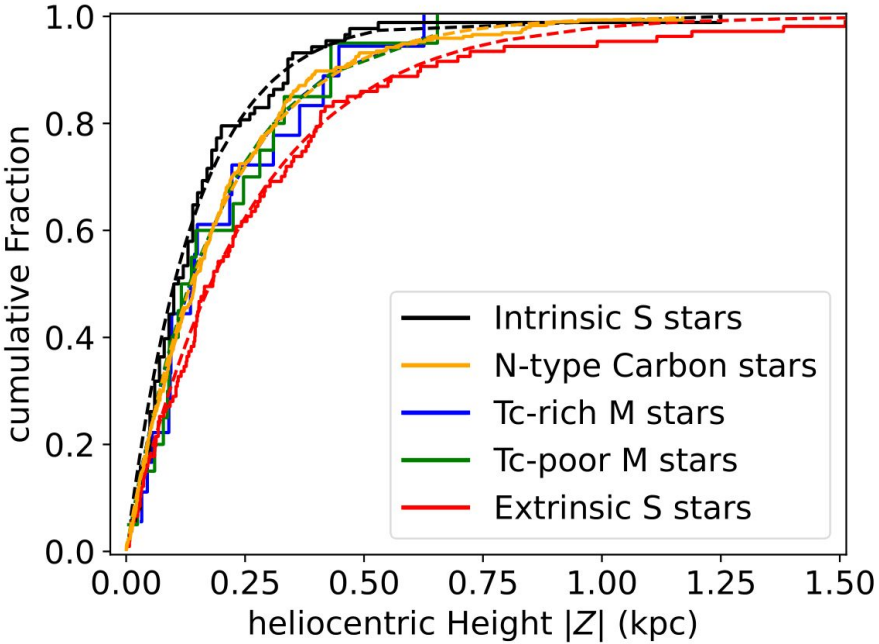

Δ V (mag)
Tc-rich M stars
Tc-poor M stars
Intrinsic S stars
Extrinsic S stars
0.45
0.40
0.35
0.30
0.25
0.20
0.15
B_{ZrO}
0.2
0.3
0.4
0.5
0.6
0.7
B_{TiO}
8
6
4
2

Abundance analysis of 3 Tc-rich M stars

Table 1. Stellar parameters and metallicity of some sample stars.

Star	T_{eff} (K)	L ($L_\odot$)	log g	[Fe/H] (dex)	$\sigma_{[Fe/H]}$ (dex)	C/O
AA Cam	3600	3700^{+200}_{-100}	1.0	-0.3 (13)	0.13	0.5
OP Her	3500	4200^{+200}_{-100}	0.0	-0.6 (8)	0.32	0.3
RX Lac	3500	6600^{+700}_{-600}	0.0	-0.9 (7)	0.16	0.4

Spatial properties



- Tc-rich and Tc-poor M stars belong to the same population

  ! Tc-poor M star ≠ Tc-poor S star

  (Extrinsic S star)

Spatial and kinematic properties of Intrinsic S, Extrinsic S and N-type Carbon stars : Abia et al. 2022

Kinematic properties

- Tc-rich M stars may have masses as low as 1.5–1.0 M⊙
- They appear older than S and C stars → possible shift in metallicity distribution?

		Tc-poor M	Tc-rich M
	σ_u *(km/s)*	38.8 ± 0.5	46.3 ± 0.7
	σ_v *(km/s)*	19.7 ± 0.2	29.4 ± 1.3
	σ_w *(km/s)*	18.6 ± 0.4	12.3 ± 0.3
Besançon Galactic Model	*Age*	5 - 7 Gyr	7 - 10 Gyr
	Mass	1.3 - 1.15 M⊙	1.15 - 1 M⊙

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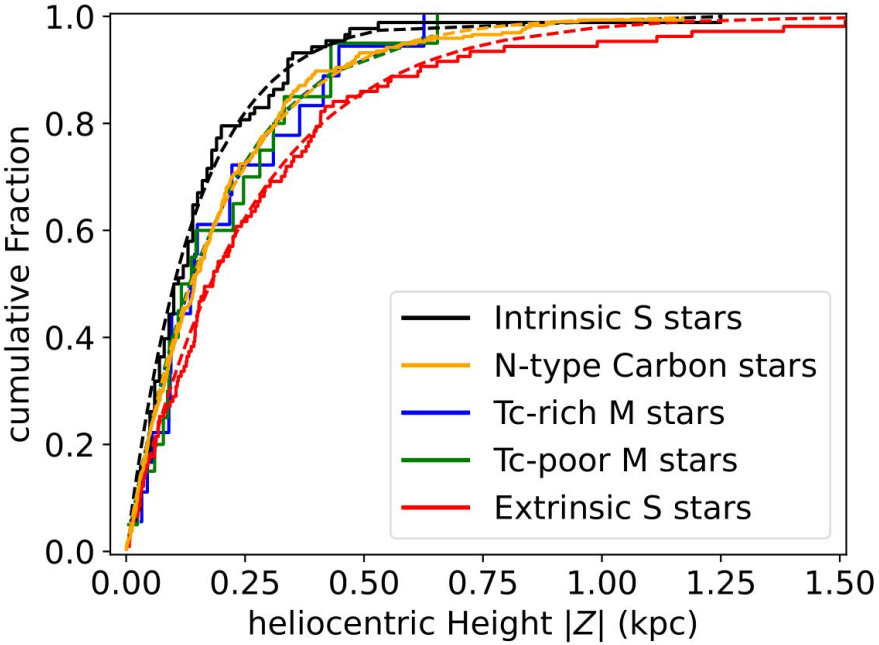

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Tc-rich M stars - have potentially masses as low as 1.5 - 1 M$\odot$
- are oldest when compared to S and C stars