X-Shooter Spectral Library (XSL) & Stellar Population Models:

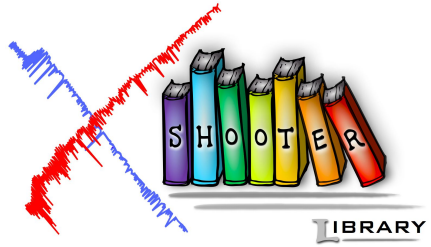
the role of AGB stars in stellar population models

Kristiina Verro (verro@astro.rug.nl)

and the XSL team

@ Torino workshop on AGB stars
21.06.2022

university of groningen / faculty of science and engineering / kapteyn astronomical institute



XSL team

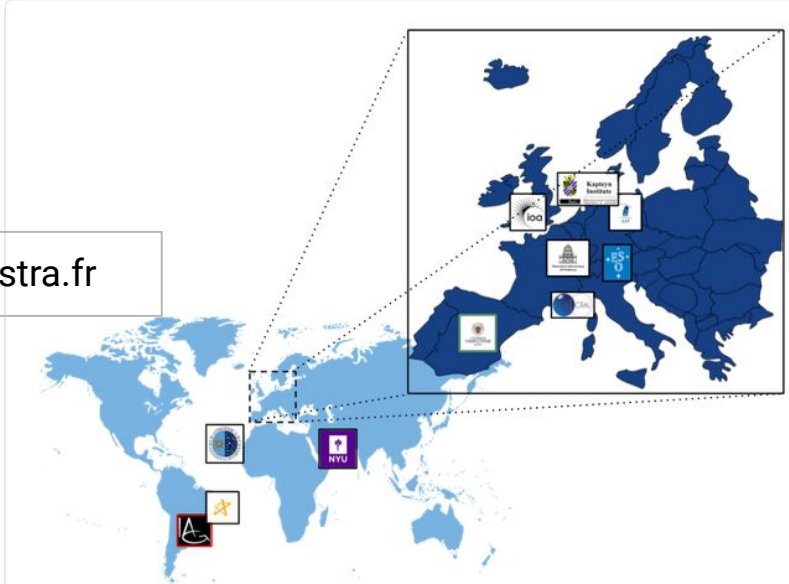
Current members

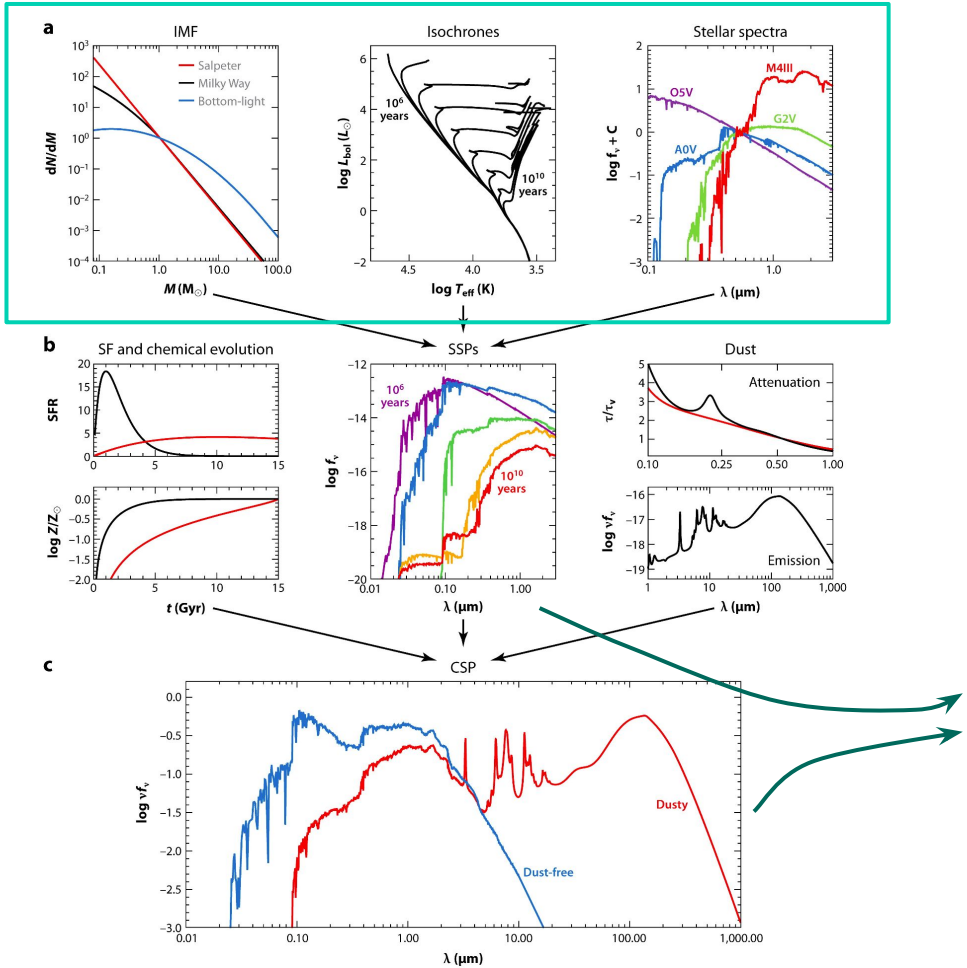
- Anke Arentsen
- Yanping Chen
- Paula Coelho
- Jesus Falcón-Barroso
- Anaïs Gonneau
- Ariane Lançon
- Mariya Lyubenova
- Lucimara Pires Martins
- Reynier Peletier
- Philippe Prugniel
- Patricia Sánchez-Blázquez
- Scott Trager
- Alejandro Vazdekis
- Kristiina Verro

ariane.lancon@astro.unistra.fr

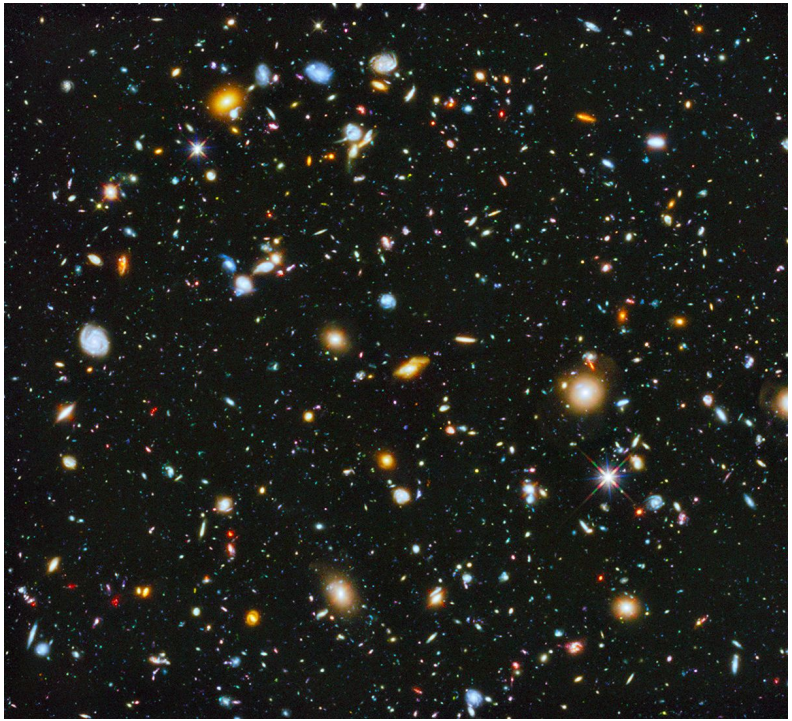
sctrager@astro.rug.nl

verro@astro.rug.nl

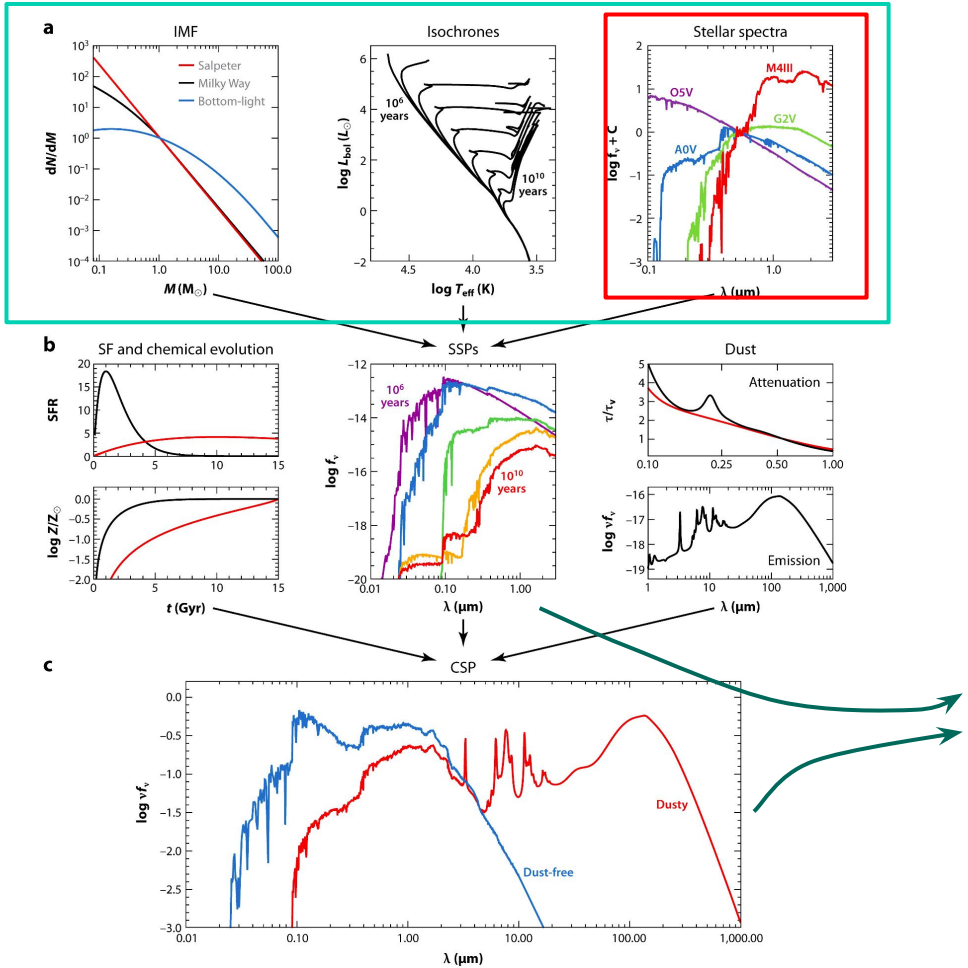




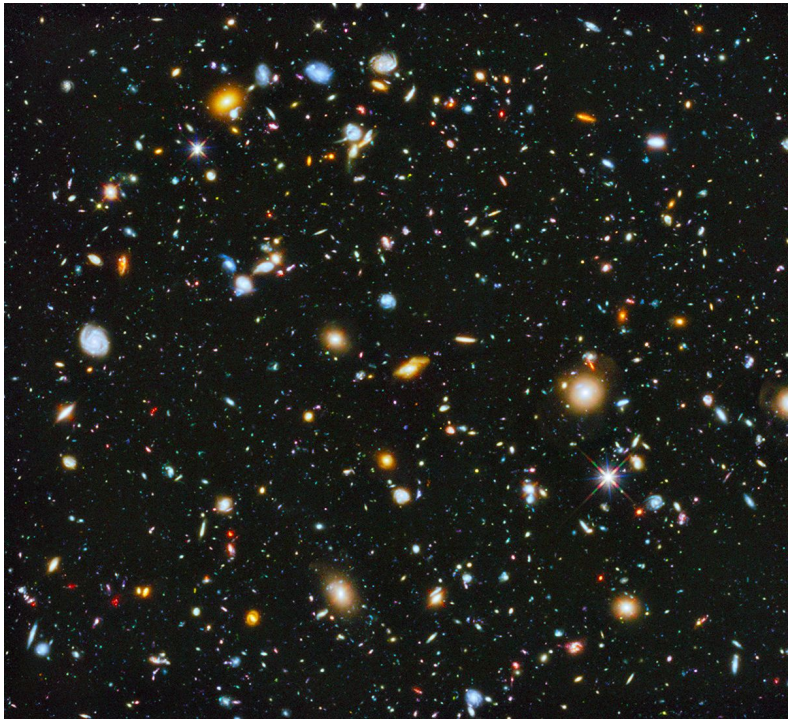
Conroy C. 2013.
Annu. Rev. Astron. Astrophys. 51:393–455



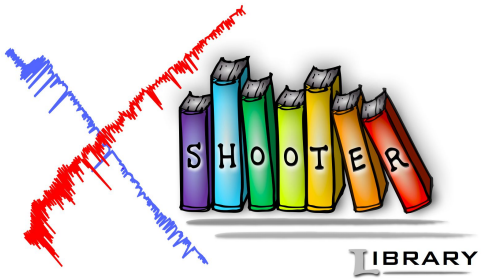
NASA, ESA, H. Teplitz and M. Rafelski (IPAC/Caltech), A. Koekemoer (STScI), R. Windhorst (Arizona State University), and Z. Levay (STScI)



Conroy C. 2013.
Annu. Rev. Astron. Astrophys. 51:393–455



NASA, ESA, H. Teplitz and M. Rafelski (IPAC/Caltech), A. Koekemoer (STScI), R. Windhorst (Arizona State University), and Z. Levay (STScI)



2009 ... 2014

Observations with the X-shooter spectrograph on ESO's VLT

2014

DR1

Chen, Y-P. et al.
A&A 565, A117

2016

2017

Carbon stars in the XSL

Gonneau, A. et al.
A&A 589, A36
A&A 601, A141

2019

Stellar parameters for 754 spectra

Arentsen, A. et al.
A&A 627, A138

2020

DR2

Gonneau, A. et al.
A&A 634, A133

2021

XSL vs PHOENIX models

Lançon, A. et al.
A&A 649, A97

2022

DR3

Verro, K. et al.
A&A 660, A34

2022

Interplay between the IMF and AGB stars in SSP models

Verro, K. et al.
to be submitted

2022

SSP models

Verro, K. et al.
A&A 661, A50

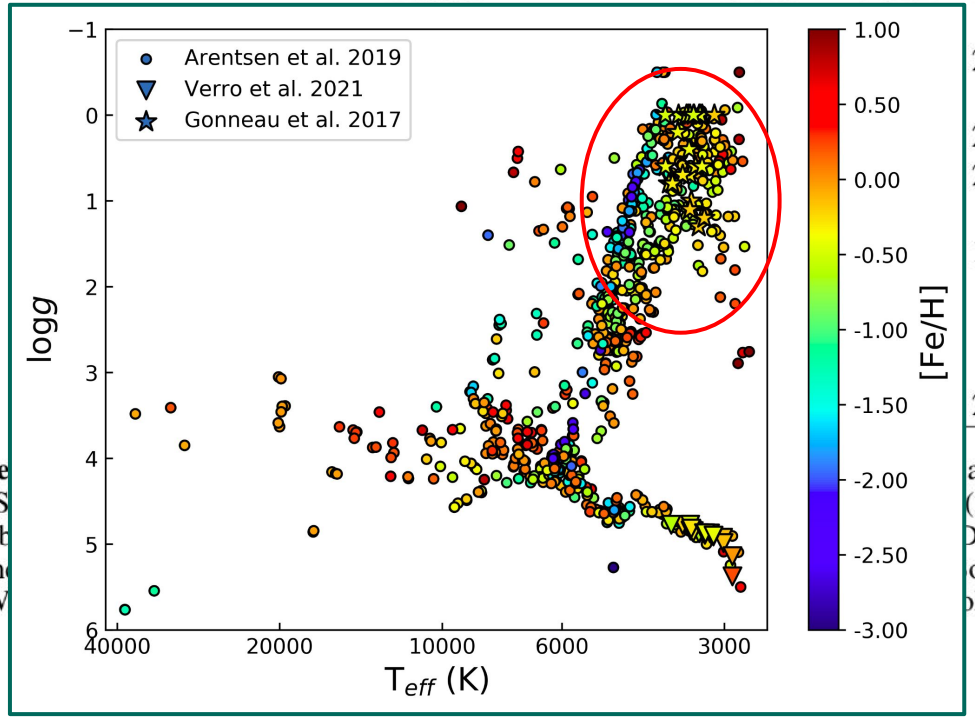
Table 1: Main characteristics of some recent empirical libraries.

Empirical libraries	# of spectra	λ start (nm)	λ end (nm)	$\sim R$ ($\lambda/\Delta\lambda$)
XSL[1,2,3]	**830**	**350**	**2 480**	**10 000**
MaStar[4]	8 646	362.2	1 035.4	1 800
LEMONY[5]	1 273	380	900	1 500
E-IRTF[6]	284	700	2 500	2 000
MILES[7,8]	985	352.5	750	2 100
IRTF[9]	210	800	2 500	2 000
CO-library[10]	220	2 110	2 370	2 500
ELODIE[11,12,13]	1 962	389.2	680	10 000
HST-NGSL[14]	374	167.5	1 025	1 000
INDO-US[15]	1 273	346	946.4	5 000
STELIB[16]	249	320	950	1 600
CaT[17]	706	834.8	902	6 000
L&W[18]	182/142/108	500	2 500	150/1 100

References. (1) Chen et al. (2014); (2) Gonneau et al. (2020); (3) this paper; (4)Yan et al. (2019); (5) Wang et al. (2018); (6) Villaume et al. (2017); (7) Sánchez-Blázquez et al. (2006); (8) Falcón-Barroso et al. (2011); (9) Rayner et al. (2009); (10) Mármol-Queraltó et al. (2008); (11) Prugniel & Soubiran (2001a); (12) Prugniel & Soubiran (2004); (13) Prugniel et al. (2007), ELODIE is also available at $R = 42\,000$, with the flux normalized to the pseudo-continuum; (14) Gregg et al. (2006); (15) Valdes et al. (2004); (16) Le Borgne et al. (2003); (17) Cenarro et al. (2001a); (18) Lançon & Wood (2000), λ coverage for optical/NIR/combined spectra, with lower optical resolution.

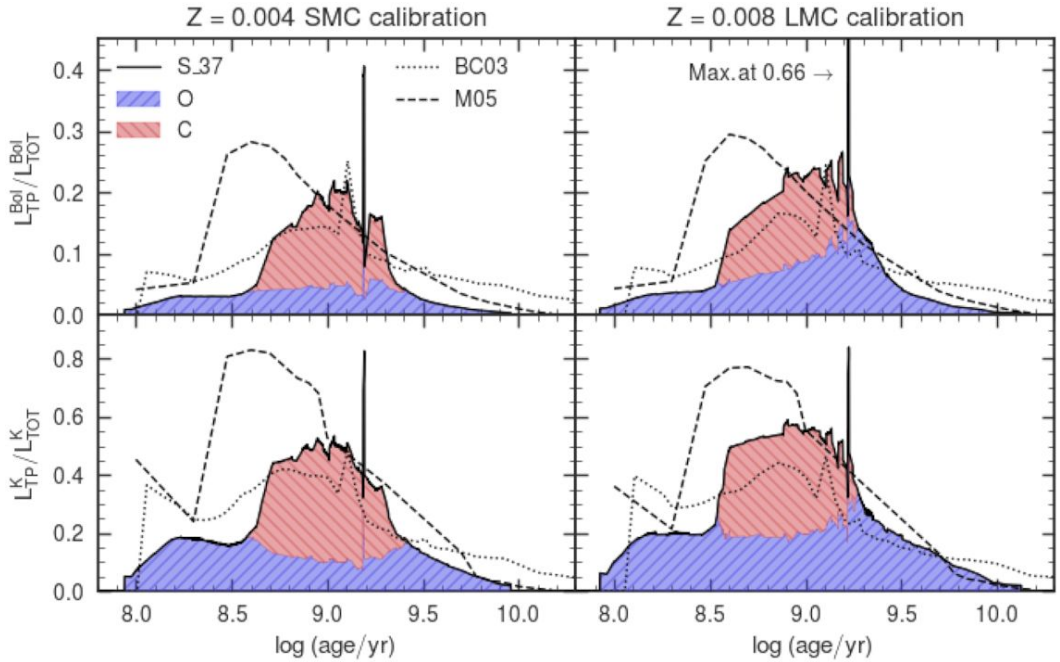
Table 1: Main characteristics of some recent empirical libraries.

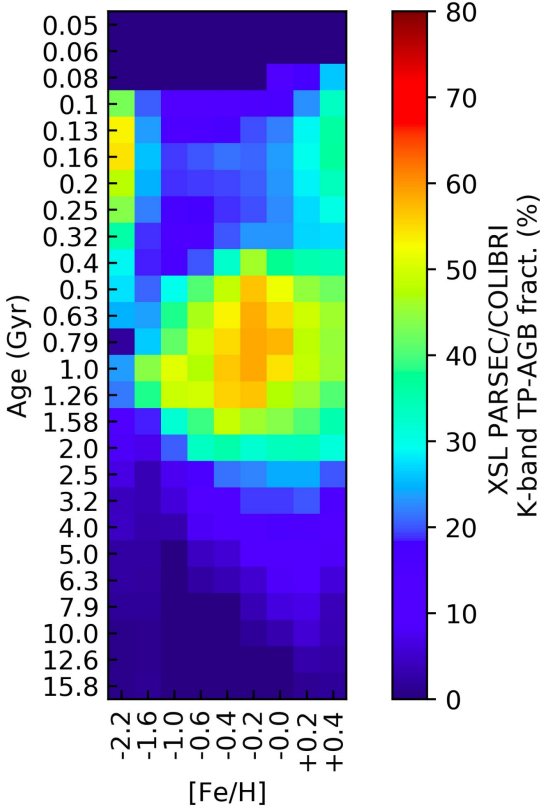
Empirical libraries	# of spectra	λ start (nm)	λ end (nm)	$\sim R$ ($\lambda/\Delta\lambda$)
XSL[1,2,3]	**830**	**350**	**2 480**	**10 000**
MaStar[4]	8 646	362.2	1 035.4	1 800
			900	1 500
			2 500	2 000
			750	2 100
			2 500	2 000
			2 370	2 500
			680	10 000
			1 025	1 000
			946.4	5 000
			950	1 600
			902	6 000
			2 500	150/1 100



Refe al. (2019); (5) Wang et al. (2018); (6) Villaume et al. (2017); (7) S (2009); (10) Mármol-Queraltó et al. (2008); (11) Prugniel & Soub DIE is also available at $R = 42\,000$, with the flux normalized to th orgne et al. (2003); (17) Cenarro et al. (2001a); (18) Lançon & W olution.

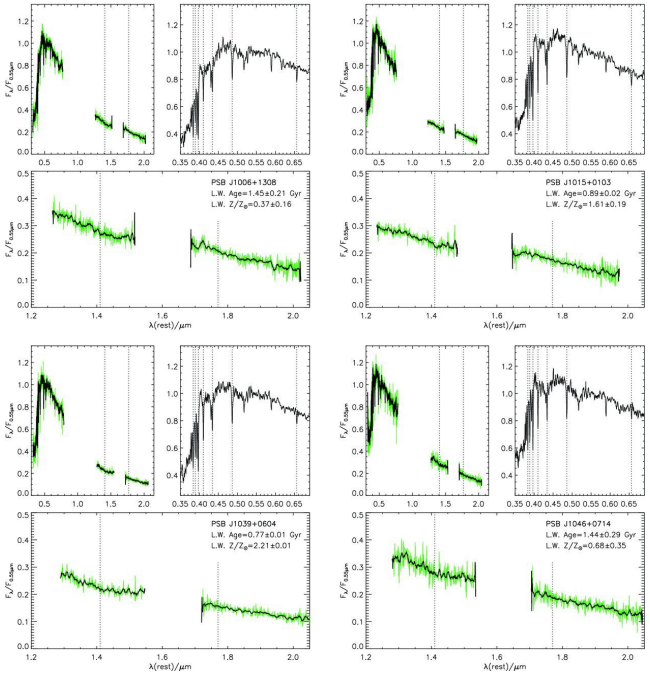
The role of AGB stars in stellar population models





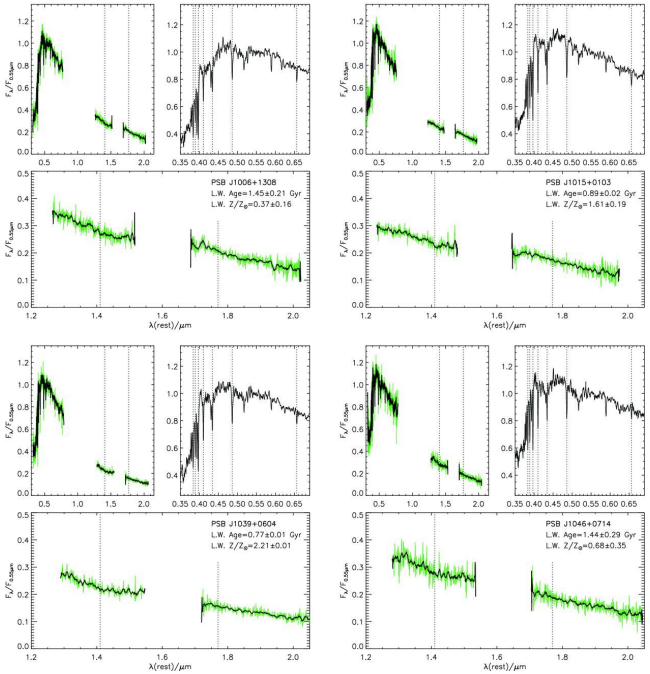
Predicted contribution of TP-AGB stars to the total bolometric luminosity (upper panel) and the K-band luminosity (lower panel), as a function of age. Comparison of COLIBRI model results with Maraston [2005, M05] and Bruzual and Charlot [2003, BC2003] Image credit: Pastorelli et al. [2020]

The poorly understood role of evolved cool stars in SSP models



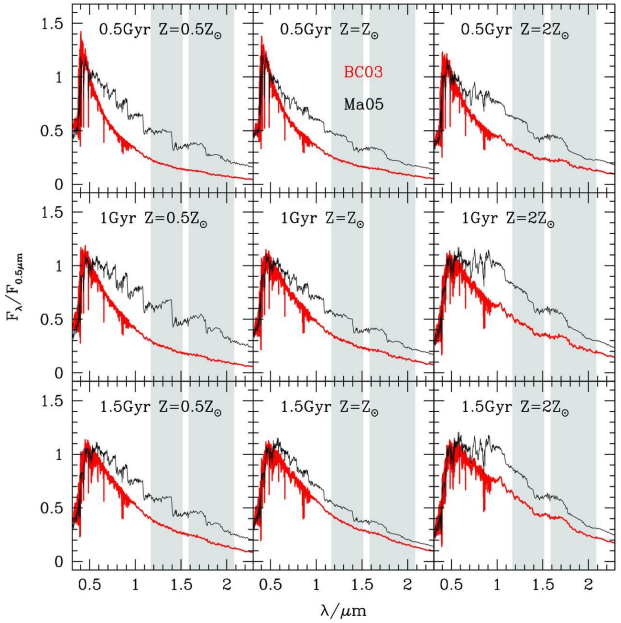
Zibetti 2013 post-starburst galaxies

The poorly understood role of evolved cool stars in SSP models



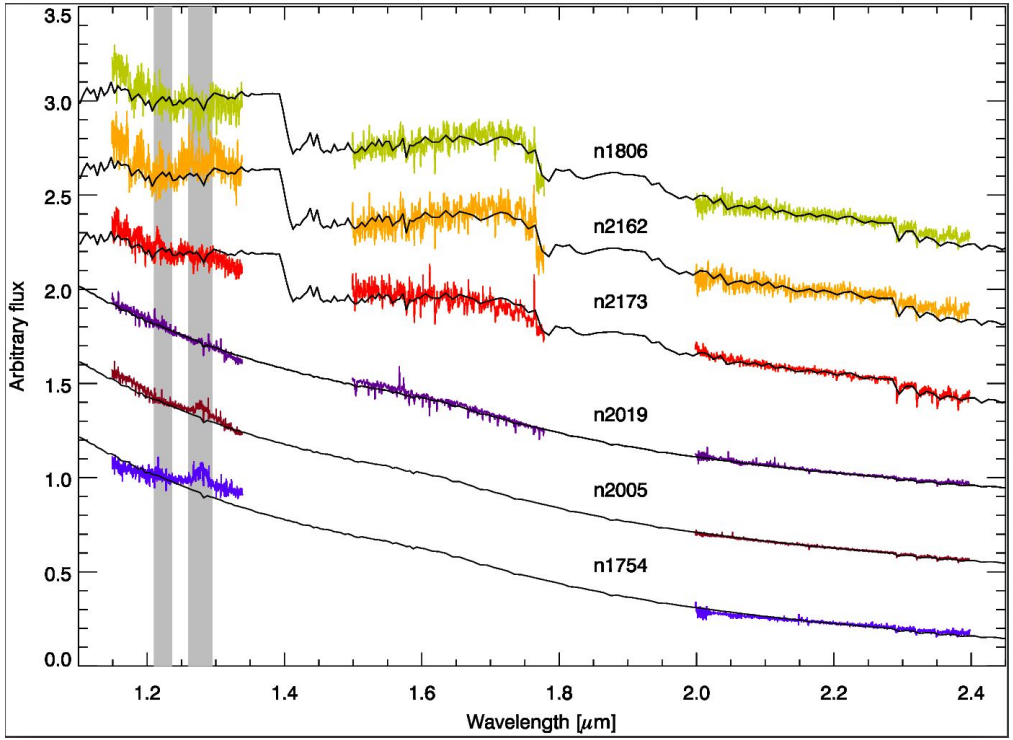
Zibetti 2013 post-starburst galaxies

?



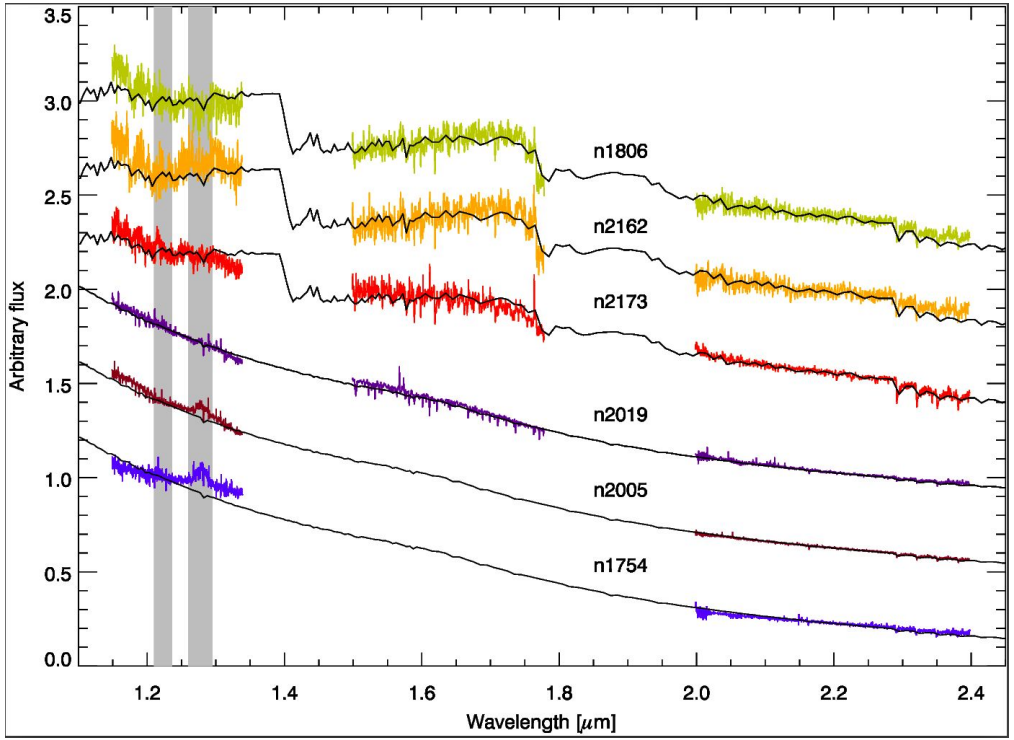
Zibetti 2013, Figure 1.Comparison between Maraston05 models (black lines) and BC03 (red lines).

The poorly understood role of evolved cool stars in SSP models

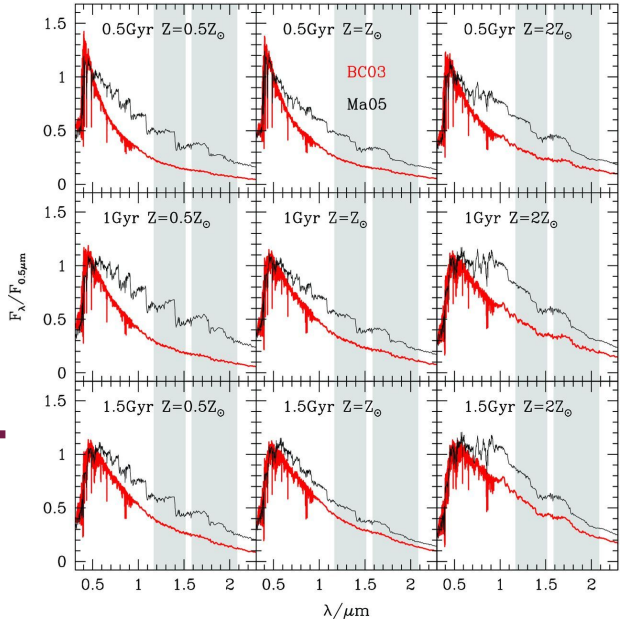


J, *H*, *K*-band spectral energy distributions of our sample of six LMC globular clusters. Lyubenova et al. 2012

The poorly understood role of evolved cool stars in SSP models

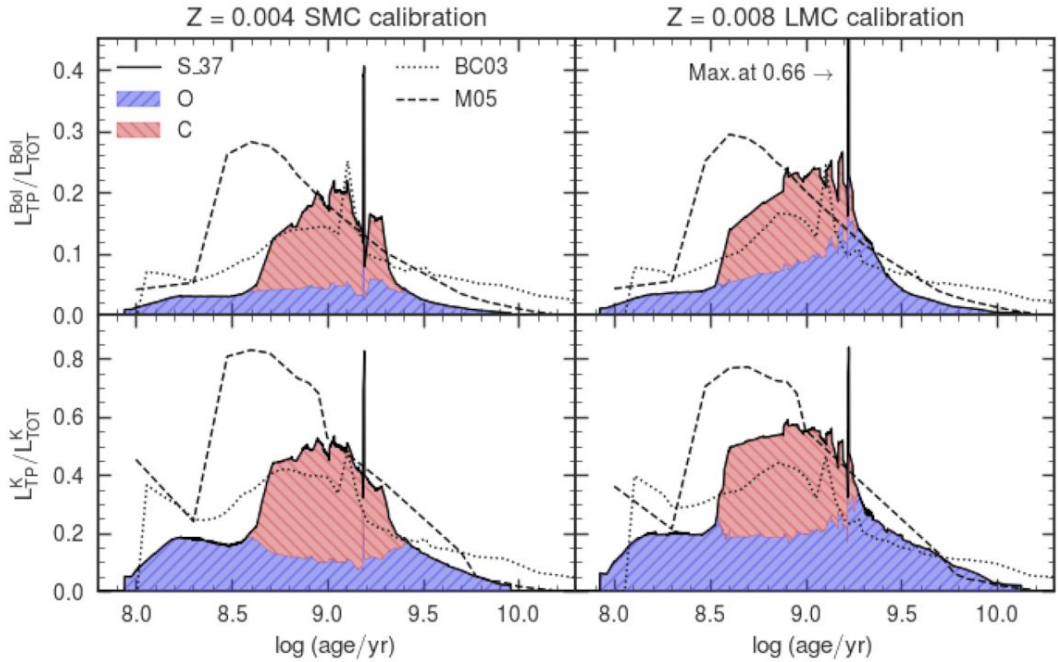


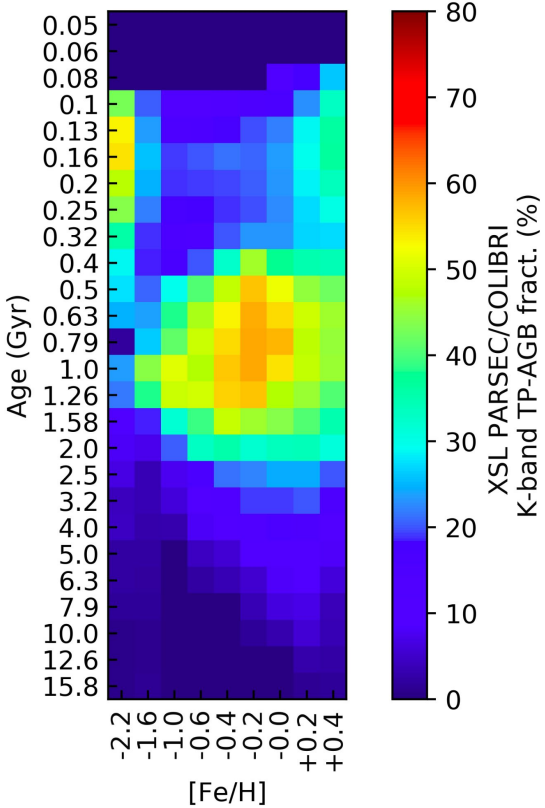
?



J, *H*, *K*-band spectral energy distributions of our sample of six LMC globular clusters. Lyubenova et al. 2012

The role of AGB stars in stellar population models

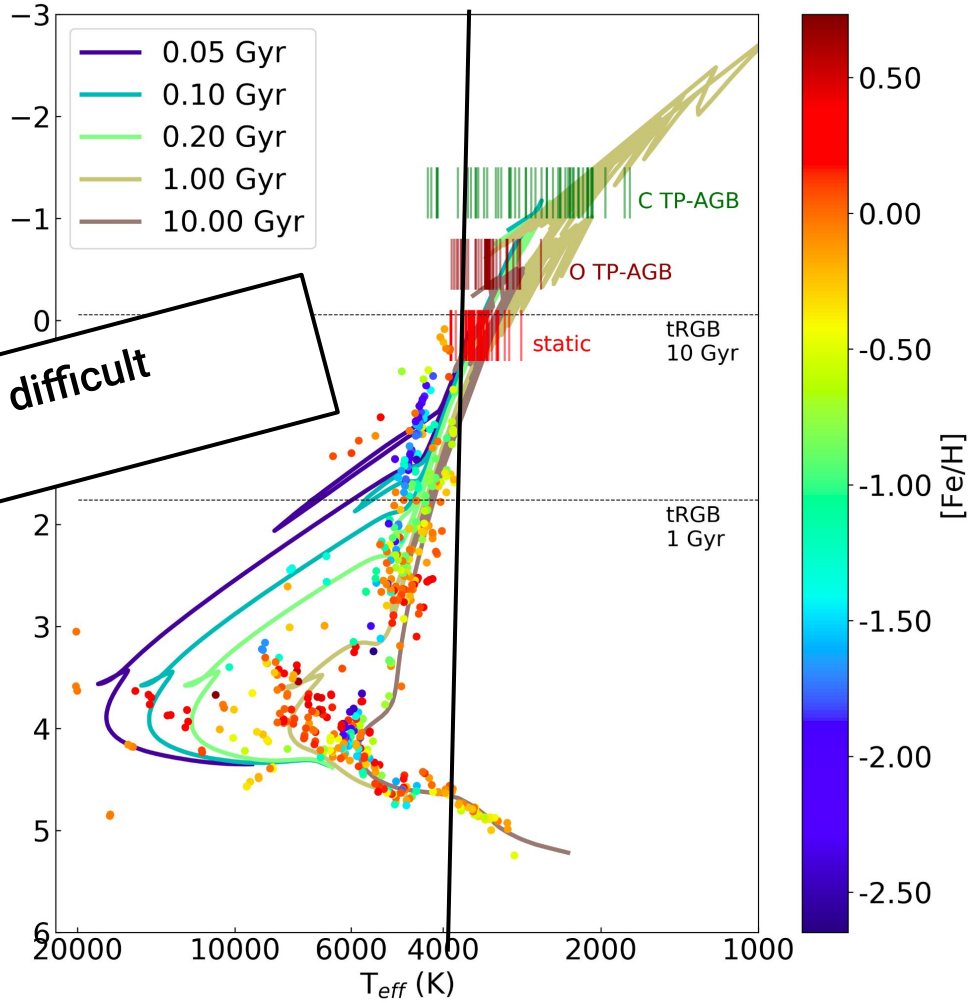




Predicted contribution of TP-AGB stars to the total bolometric luminosity (upper panel) and the K-band luminosity (lower panel), as a function of age. Comparison of COLIBRI model results with Maraston [2005, M05] and Bruzual and Charlot [2003, BC2003] Image credit: Pastorelli et al. [2020]

XSL giants:

I practice SSP modelling is difficult (specially in the NIR)!



XSL giants:

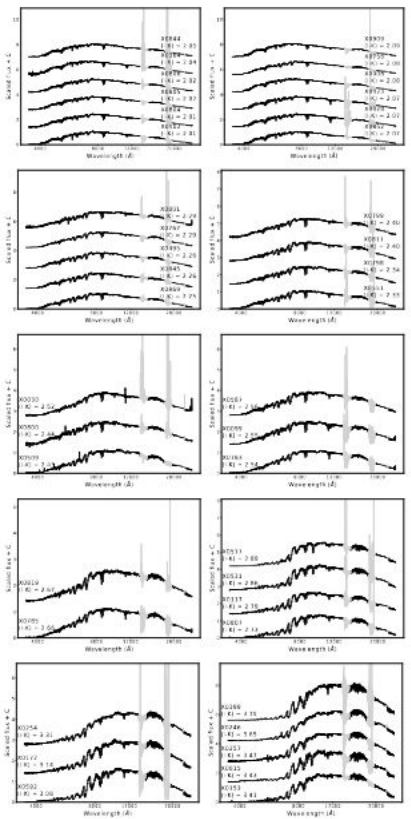


Fig. B.1. XSL spectra of O-rich, cool static giant stars from which the static sequence is constructed.

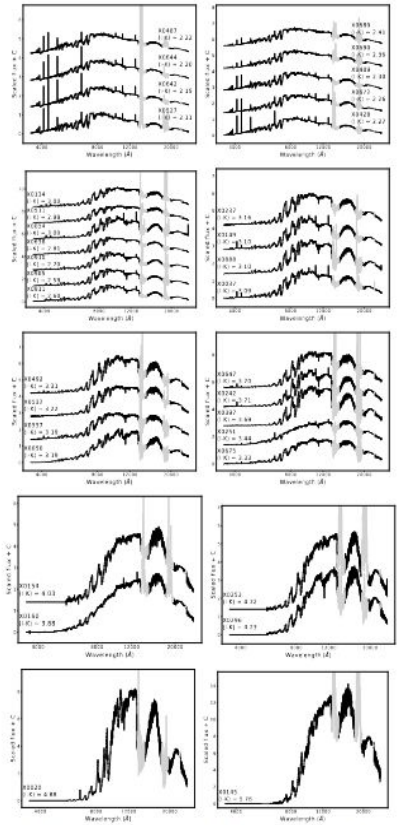


Fig. C.1. XSL spectra of O-rich TP-AGB stars from which the variable O-rich TP-AGB sequence is constructed.

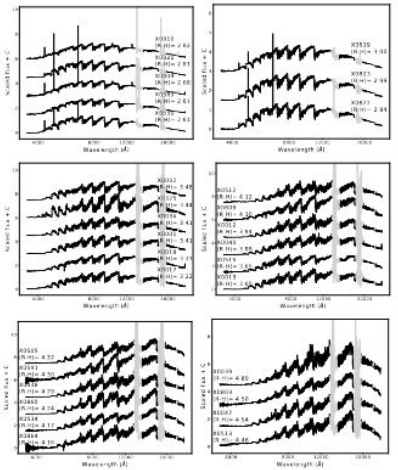


Fig. D.1. Spectra of XSL C-rich TP-AGB stars from which the C-rich TP-AGB sequence was constructed.

XSL giants:

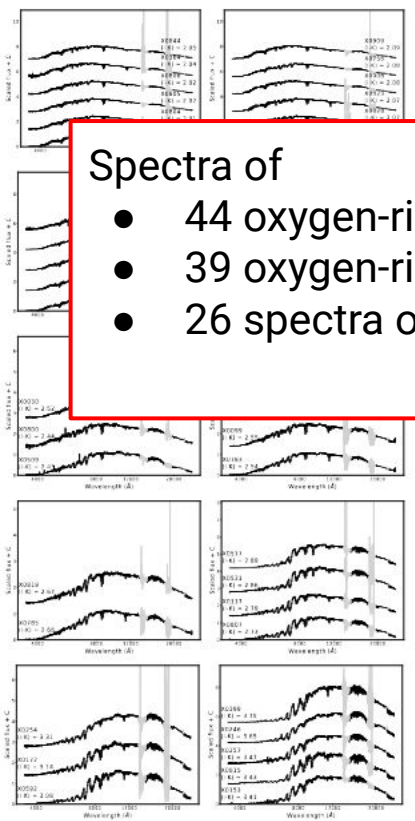


Fig. B.1. XSL spectra of O-rich, cool static giant stars from which the static sequence is constructed.

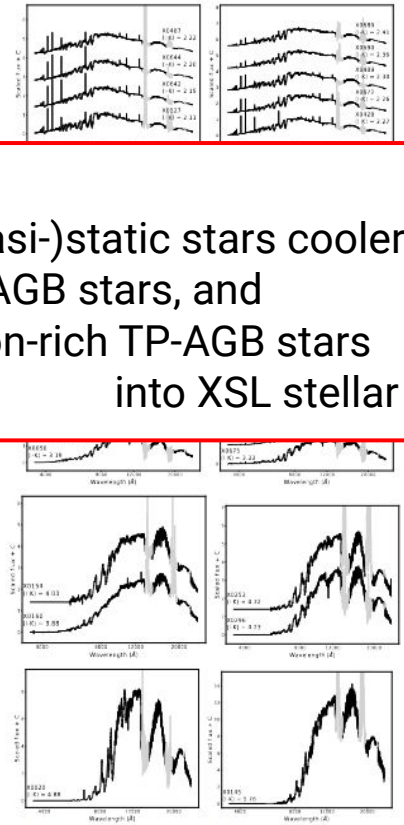


Fig. C.1. XSL spectra of O-rich TP-AGB stars from which the variable O-rich TP-AGB sequence is constructed.

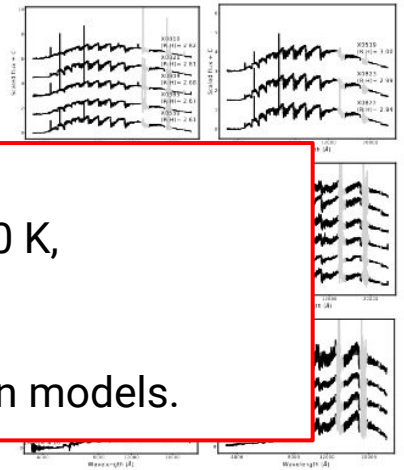


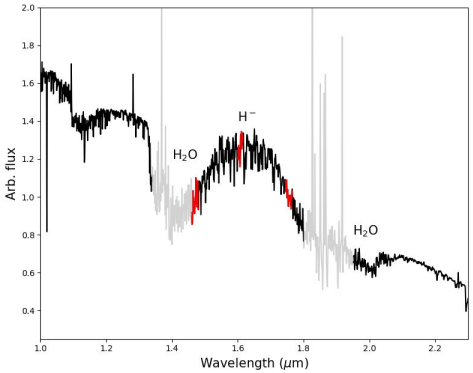
Fig. D.1. Spectra of XSL C-rich TP-AGB stars from which the C-rich TP-AGB sequence was constructed.

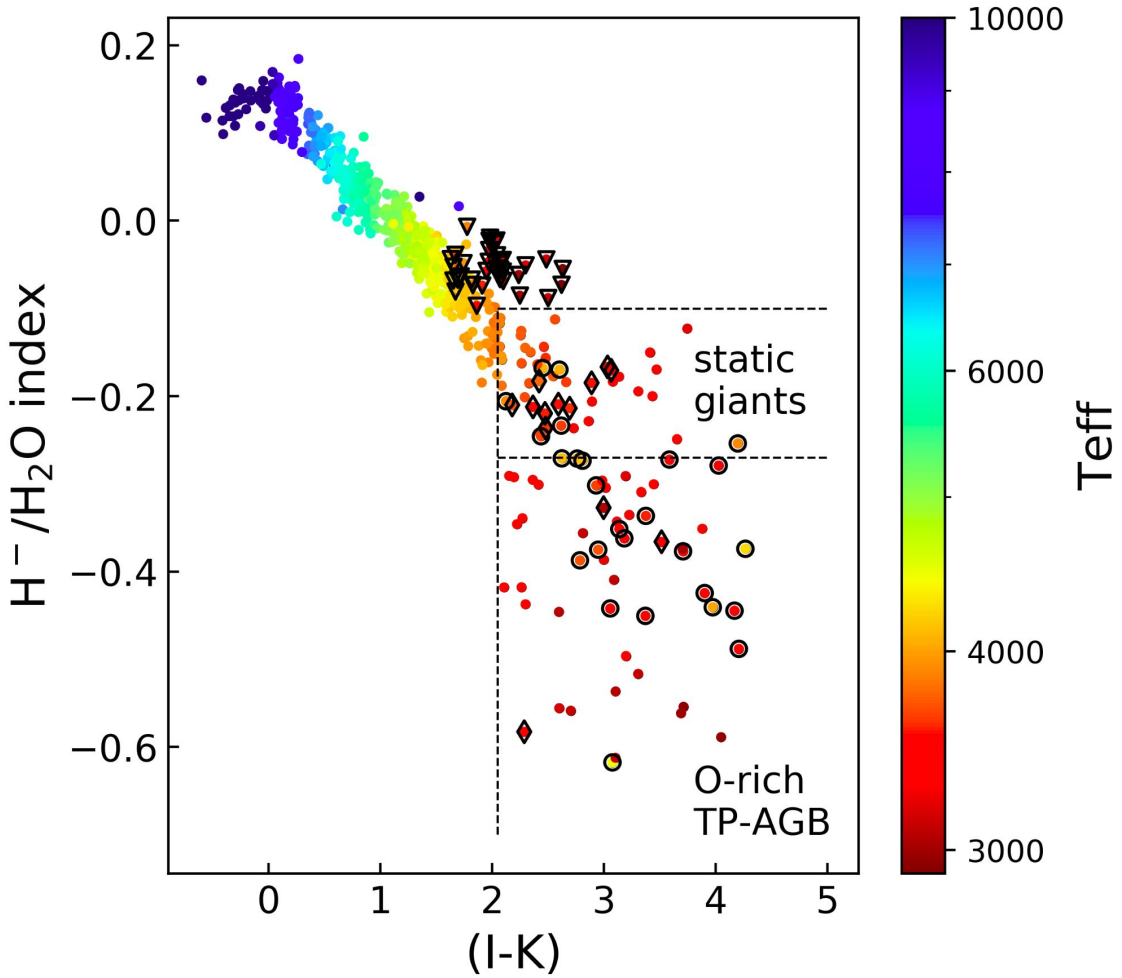
Spectra of

- 44 oxygen-rich (quasi-)static stars cooler than 4000 K,
- 39 oxygen-rich TP-AGB stars, and
- 26 spectra of carbon-rich TP-AGB stars

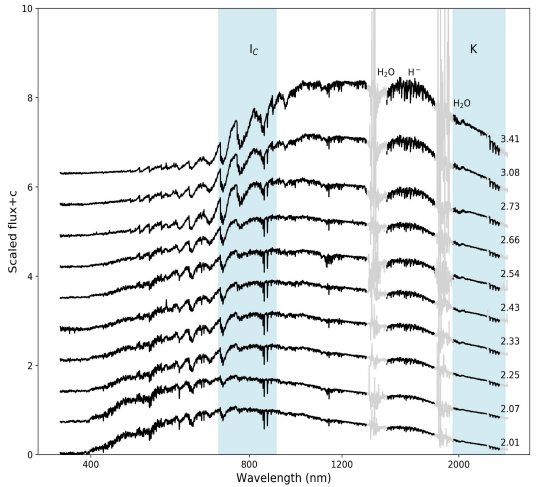
into XSL stellar population models.

XSL giants:

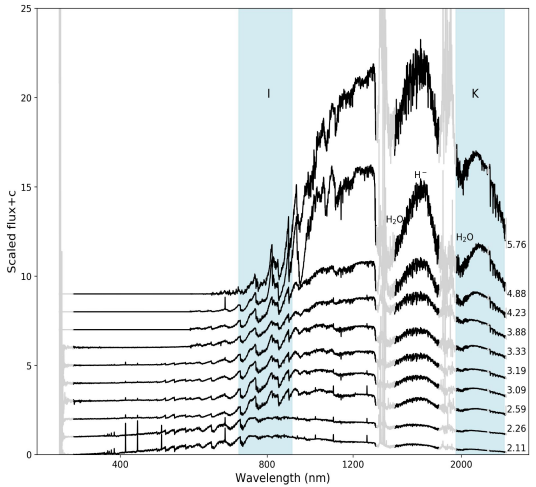

Arb. flux
Wavelength (μm)
H⁻
H₂O
H₂O


H⁻/H₂O index
(I-K)
static giants
O-rich TP-AGB
Teff
10000
6000
4000
3000

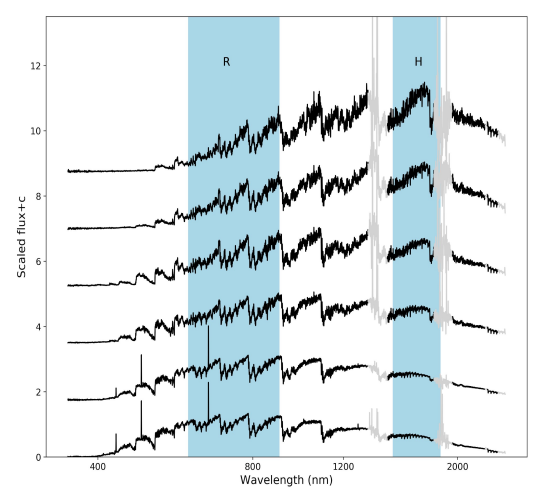
XSL giants:



Sequence of XSL O-rich static cool giants (RGB/E-AGB)

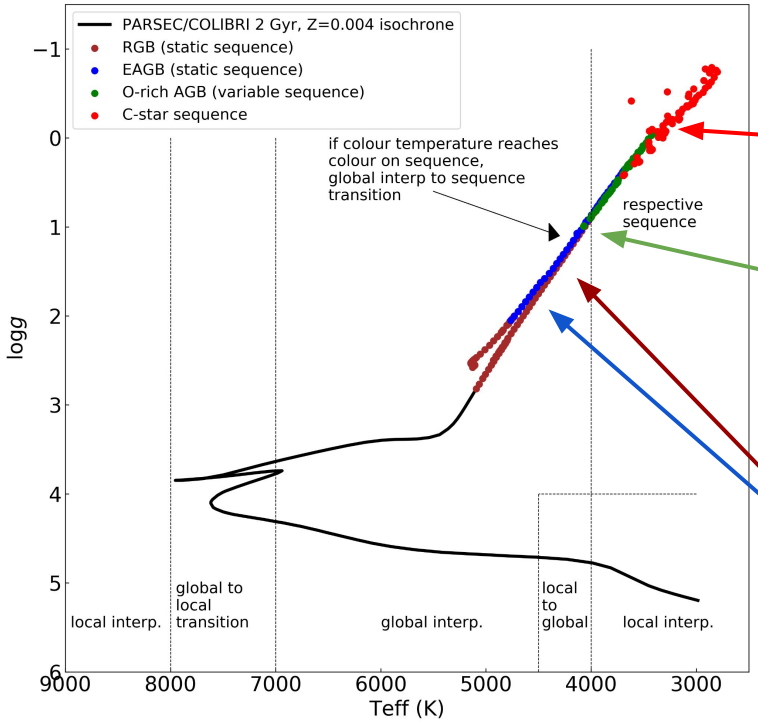


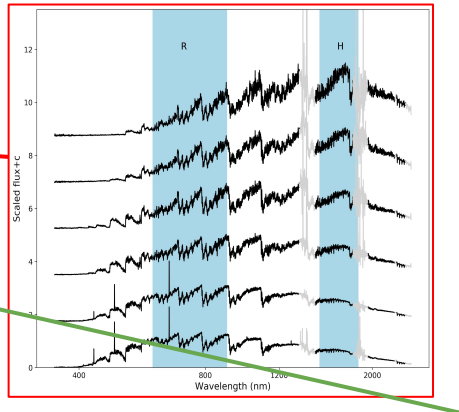
Sequence of XSL O-rich variable cool giants (TP-AGB).



Sequence of XSL C-rich AGB stars.

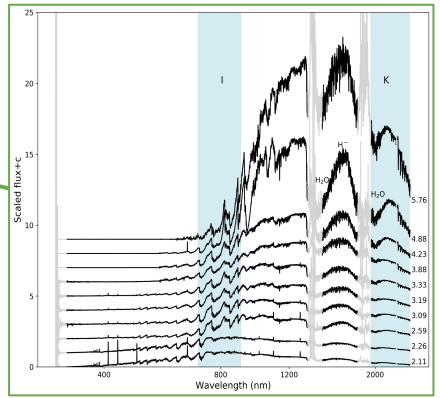
The role of evolved cool stars in SPOP models.





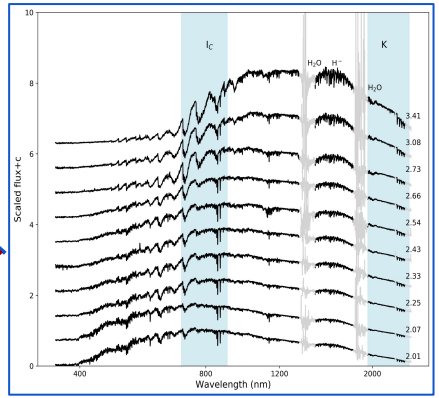
Carbon stars

O-rich TP-AGB

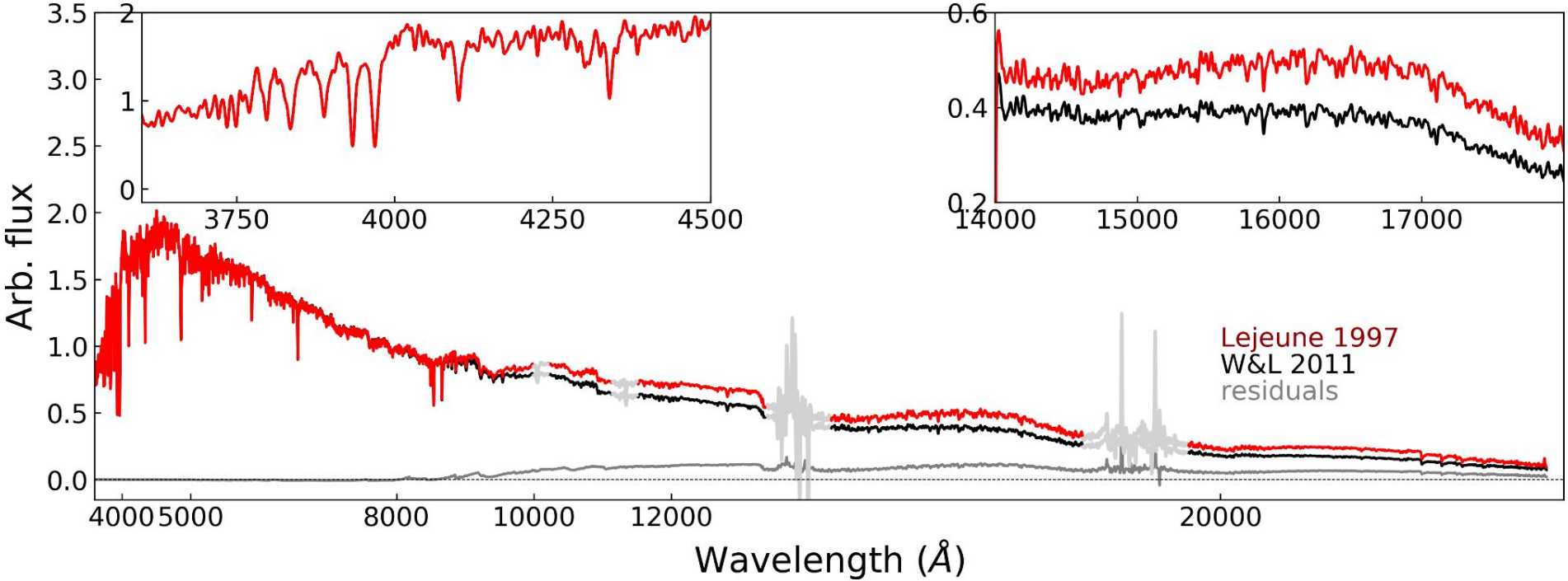


RGB

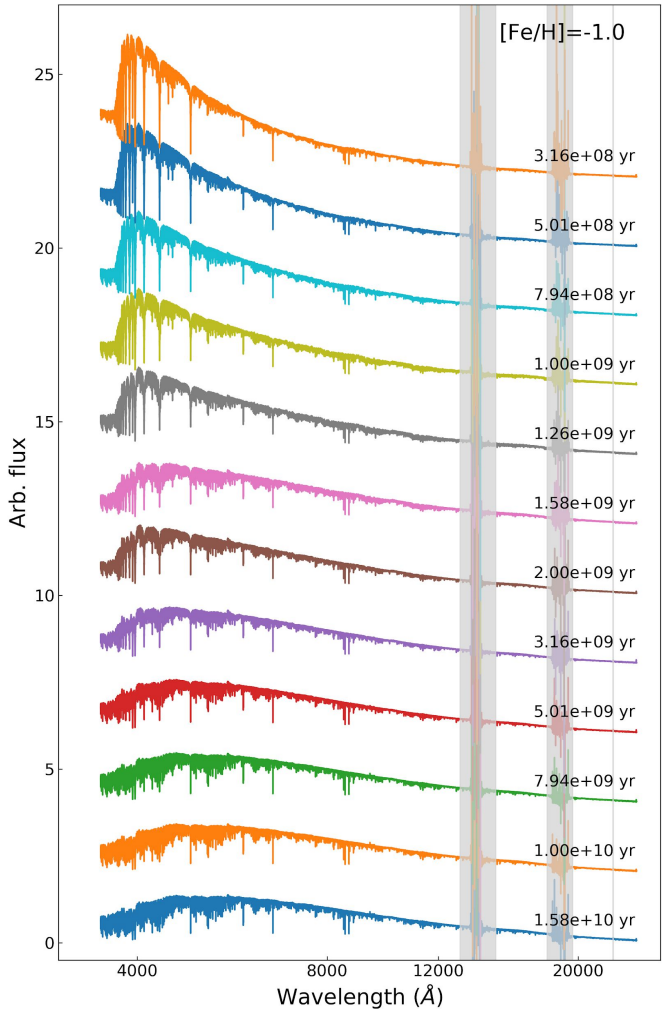
E-AGB



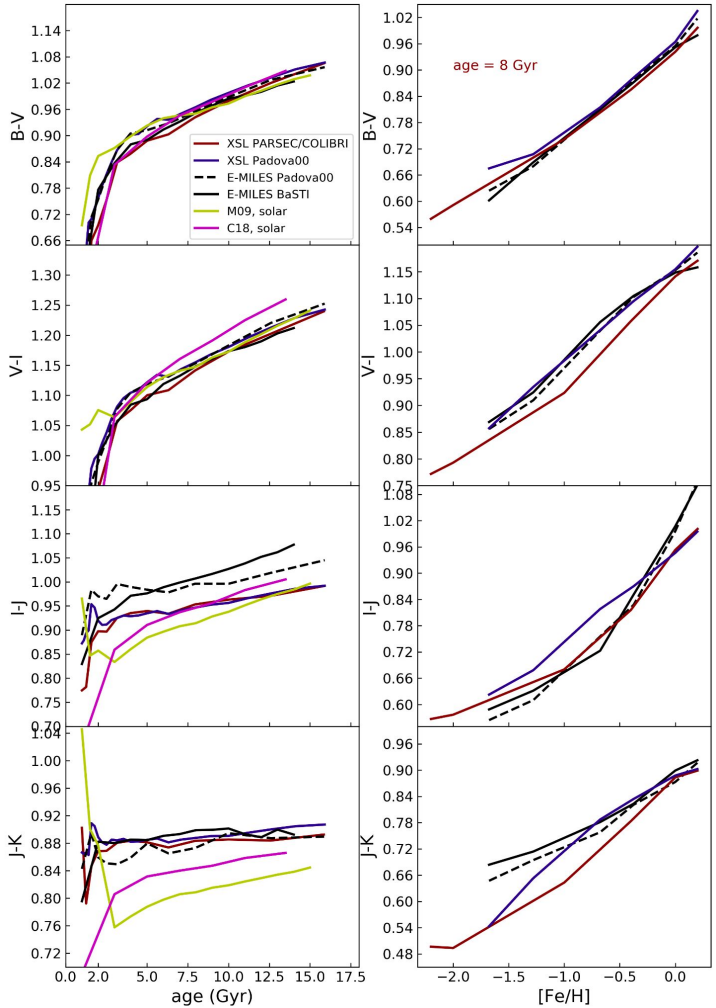
XSL SSP models:



XSL SSP models:



XSL SSP models:



Conclusions:

- **XSL giant stars with temperatures less than 4000 K need special attention in SSP modelling!**
- XSL was designed to contain a large number of such objects.

- Separating static from variable giant stars only based on NIR colour and one molecular feature is probably too rough.
- As is assigning a temperature to them with a general colour-temperature relation.

- It is difficult to separate the effects of temperature, gravity, metallicity, circumstellar extinction and variability in these stars.

- In the future, using distance-based luminosities, information on dust extinction and variability from the literature (star by star), is inevitable.

- We hope that future dynamical models of cool giants will help us relate spectral properties to those of the static and variable stars.

http://xsl.astro.unistra.fr/

The X-shooter Spectral Library

&

Simple Stellar Population Models

[03/2022] The DR3 merged spectra and the XSL single stellar population models are now available.

[03/2022] Prefer the following address next time : xsl.astro.unistra.fr

The X-shooter Spectral Library is a stellar spectral library covering the wavelength range 3000–25000 Å, at a resolution R ~ 10 000. The library was built using the medium-resolution spectrograph X-shooter (ESO, VLT).

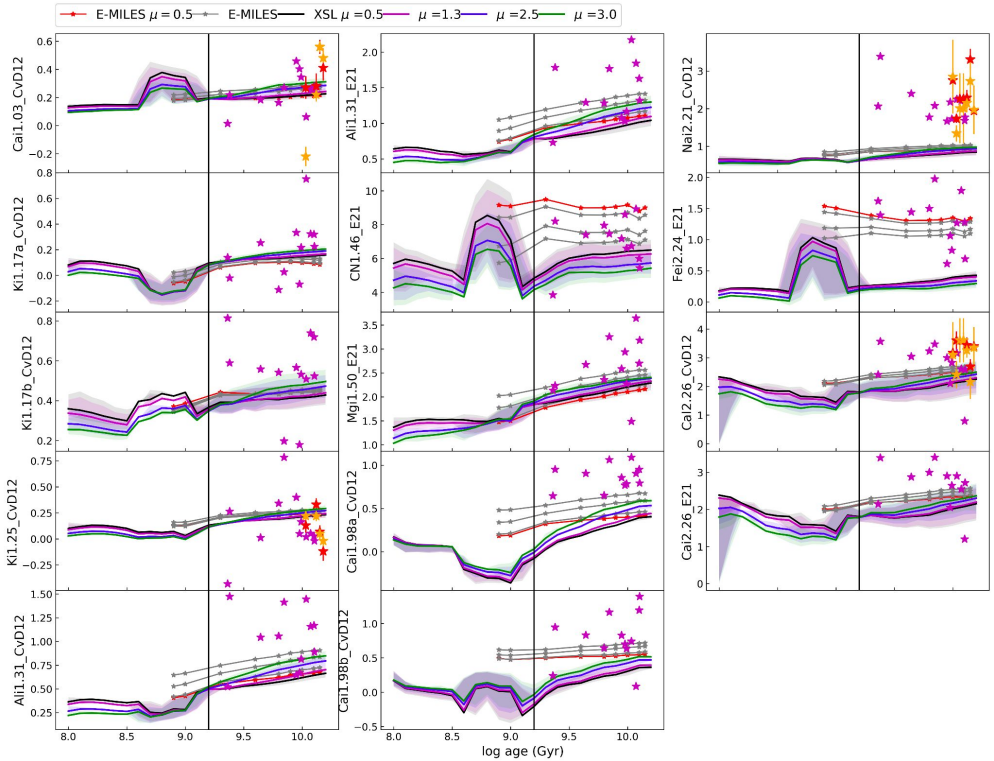
The third data release (DR3) contains 830 stellar spectra of 683 stars stars. The DR3 spectra are arm-combined to the full wavelength range of the X-shooter spectrograph, and both original and galactic dust exinction corrected spectra are available. It also covers most of the HR diagram with spectral types between O and M, as well as AGB stars.

Simple stellar population models based on the empirical X-shooter Spectral Library (XSL) from NUV to NIR wavelengths. The models span the metallicity range −2.2 < [Fe/H] < +0.2 and ages above 50 Myr.

The second data release (DR2) of XSL covers the full X-shooter range (UVB to NIR), but is arm-separated, and contains 813 observations of 666 stars. The first data release (DR1) contains UVB and VIS spectra for more than 200 stars.

830 stellar spectra of 683 stars, covering the full X-shooter wavelength range (3500–24800 Å). [Verro et al. (2022a)]
Quick access to DR3 data
Simple stellar populations in the NUV to NIR with the X-shooter Spectral Library. [Verro et al. (2022b)]
Quick access to SSP models

What about spectral line indices?



Bolometric corrections – not optimal

best fits to VIS (600-950nm)