The Initial-Final Mass Relation (IFMR) from AGB C-stars in open clusters

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XIV Torino Workshop on AGB stars, June 2024, OAR, Monte Porzio

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MINISTERIO DE CIENCIA E INNOVACIÓN

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FQM292-UGR
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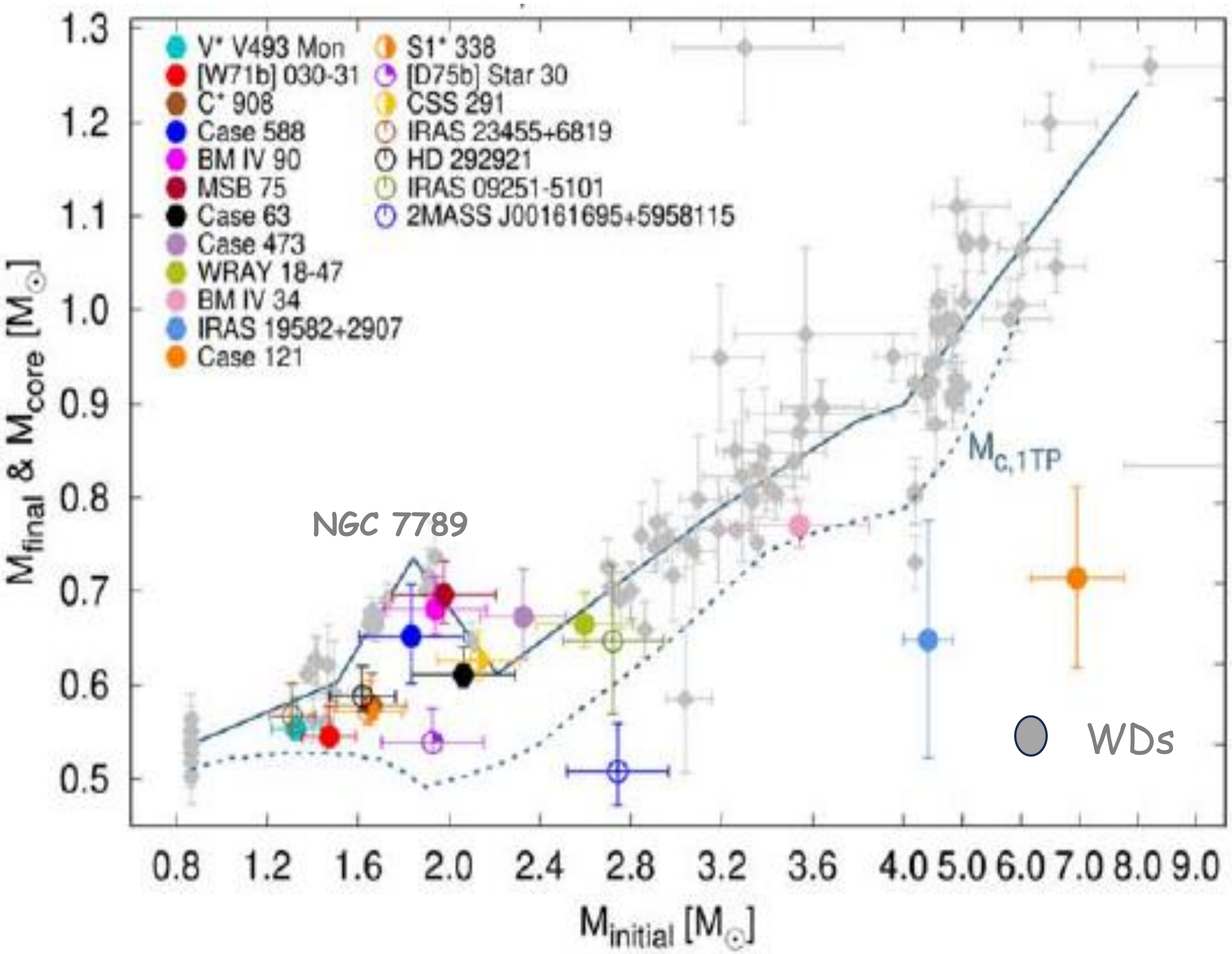
- Our knowledge of AGB stars is improving due to the accurate astrometric measurements by the *Gaia* satellite (DR3).

  The determination of the M_{bol} and Mass of AGB stars belonging to Open Clusters are useful for:

  - Mas range for the formation of C-stars (C/O>1 in the envelope) as a function of Z
  - Clues about the mass limit for the Hot Bottom Burning to work
  - Efficiency of the TDU and extra-mixing (?) as function of the mass & Z
  - Constraints to AGB nucleosynthesis models
  - ….
  - **Probe the semi-empirical Initial Final Mass Relation (IFMR)**

Marigo et al. (2022): WD & AGB stars in OCs of young-intermediate age may indicate the existence of a discontinuity in the IFMR between ~1.6-2.1 M_{ini}



Theoretical explanation
(previous F. Addari's talk)

- ✓ Weak TDUs
- ✓ Small mass-loss rate, < 10^{-7} $M_\odot yr^{-1}$

- ✓ C/O ≈ 1
- ✓ M_{core} grows above expected values

➢ Are these AGB stars chemically peculiar?

Observed sample: stars belonging to OCs with ages corresponding to turn-off masses close to the range 1.6-2.1 $M_\odot$, or candidates to HBB stars (M > 4-5 $M_\odot$)

Sample quality:

- ✓ Astrometric *Gaia* DR3 solutions: fidelity ~ 1, RUWE < 1.4 (no binariety)
- ✓ *Gaia* DR3 parallax uncertainty < 10%
- ✓ Available J and K_s 2MASS photometry with uncertainty ≤ 0.10 mag

Star	Cluster	log Age	p %
V493 Mon	Trumpler 5	9.63	0.68
C* 908	Ruprecht 37	9.37	0.99
MSB 75	NGC 7789	9.20	0.99
Case 63	Berkeley 9	9.14	0.99
Case 473	Berkeley 53	8.99	0.68
IR19582+2907	FSR 0172	8.20	0.99
Case 121	Berkeley 72	7.73	0.99
Case 588	Dias 2	9.24	0.99
DH Mon	Ruprecht 37	9.37	0.68

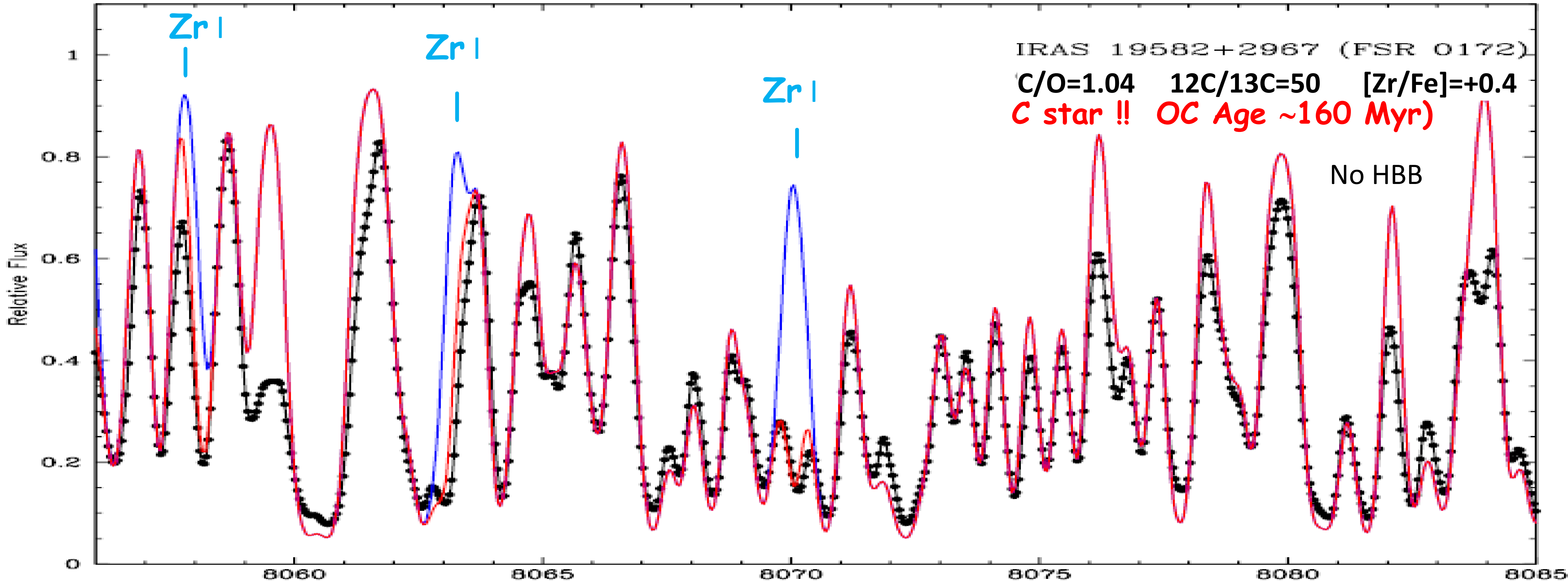
Ages: Cavallo et al. (2024) based on Gaia DR3 astrometry
p (cluster member probability): Marigo et al. 2022

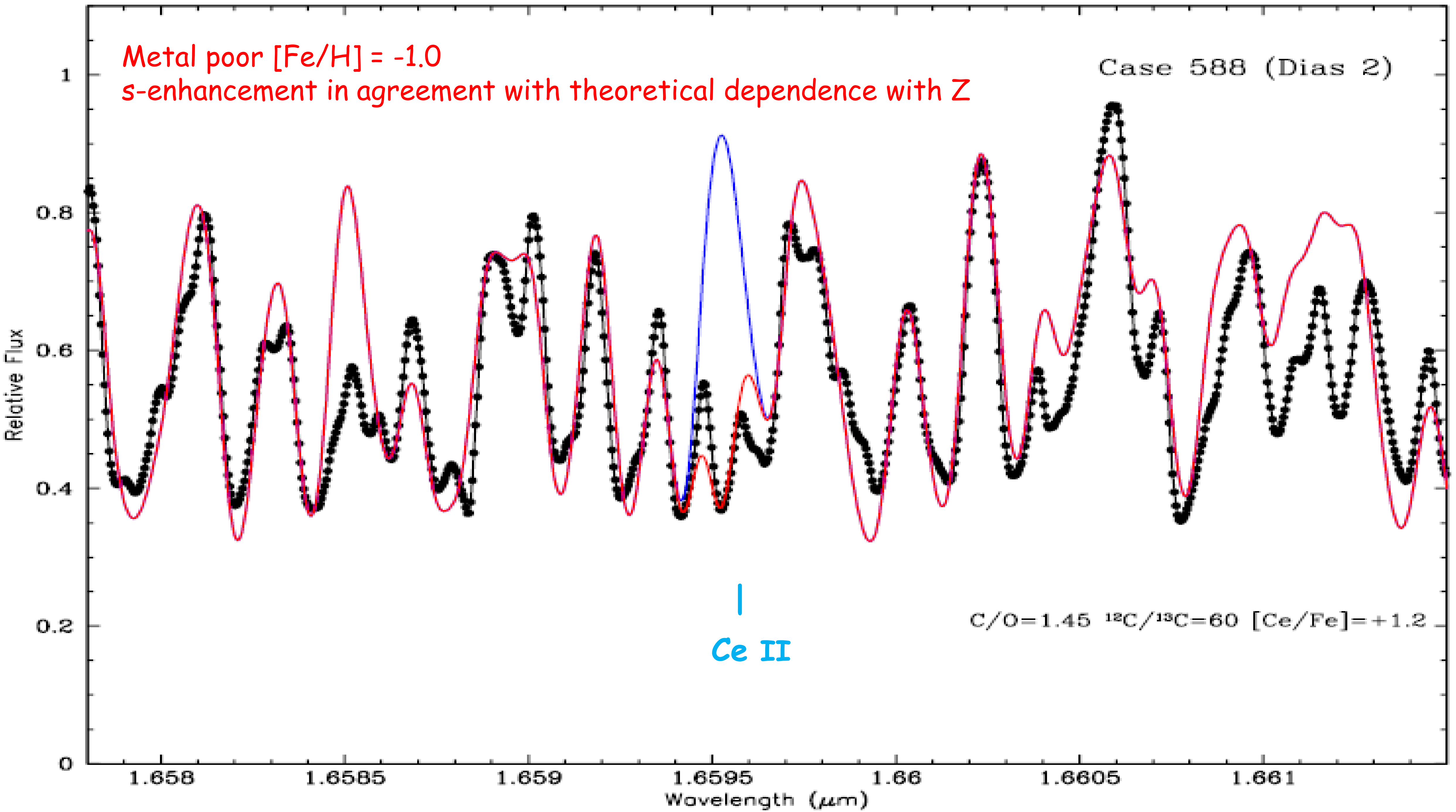
Observations and chemical analysis

- 3 m CAHA + CARMENES: 0.50 -1.70 μm; R~ 80000-100000
- 3.6 m TNG + HARPS-N + GIANO-B: 0.38-0.69 μm R~110000; 0.90-2.50 μm R~ 50000
- Stellar parameters from an iterative analysis using all spectra ranges

  TURBOSPECTRUM v.20 in LTE and MARCS atmosphere models for C- and/or O-rich AGB stars

Goal: [Fe/H], C/O, $^{12}C/^{13}C$, $^{14}N/^{15}N$, $^{16}O/^{17}O/^{18}O$, Li, F & s-process elements (Zr, Y, Ba, La, Ce)




Metal poor [Fe/H] = -1.0
s-enhancement in agreement with theoretical dependence with Z
Case 588 (Dias 2)
C/O=1.45 12C/13C=60 [Ce/Fe]=+1.2
Ce II
Relative Flux
Wavelength (μm)
0
0.2
0.4
0.6
0.8
1
1.658
1.6585
1.659
1.6595
1.66
1.6605
1.661

Star	[Fe/H]	C/O	$^{12}C/^{13}C$	$^{14}N/^{15}N$	$^{16}O/^{17}O$	A(Li)	[F/Fe]	[<s>/Fe]	
V493 Mon	-0.40	< 1.5	< 25						
C* 908	-0.30	1.07	50	1000		-0.50		0.25	
MSB 75	-0.25	1.05	35	>700	650	-0.60	-0.10	0.40	
Case63	-0.10	1.05	52	1250	580	-2.0	0.15	0.32	
Case 473	0.0	1.07	58		670	-1.0	0.30	<0.50	
IRAS 19582+2907	0.0	1.04	50			-0.50		0.60	
Case 121	-0.20	1.07	55	>1000	1000	-1.0	-0.10	0.20	
Case 588	-1.0	1.41	70	800		-0.60		1.00	Metal poor
DH Mon	-0.3	1.06	10	200-500		+0.60		No	J-type
	±0.25	±0.05	±10	±250	±250	±0.1	±0.2	±0.2	

- ✓ All the chemical features are NORMAL for C-stars of similar metallicity (no HBB). DH Mon probably is a J-type carbon star.

- ✓ C/O are slightly larger than 1 in agreement with Marigo/Addari models…but this is observed in the overwhelming majority of solar metallicity C-stars

For the IFMR, we need M_{final} → Luminosity (distance, extinction and BC/SED)
Comparison between models (all distances based on Gaia DR3)

We used two approaches to derive the luminosities:

Case 1

- ✓ Individual geometric DR3 distances from Bailer-Jones et al. (2023)
- ✓ A_V from the Galactic model by Lallement et al. (2023)
- ✓ BC_K from Kerschbaum et al. (2010)

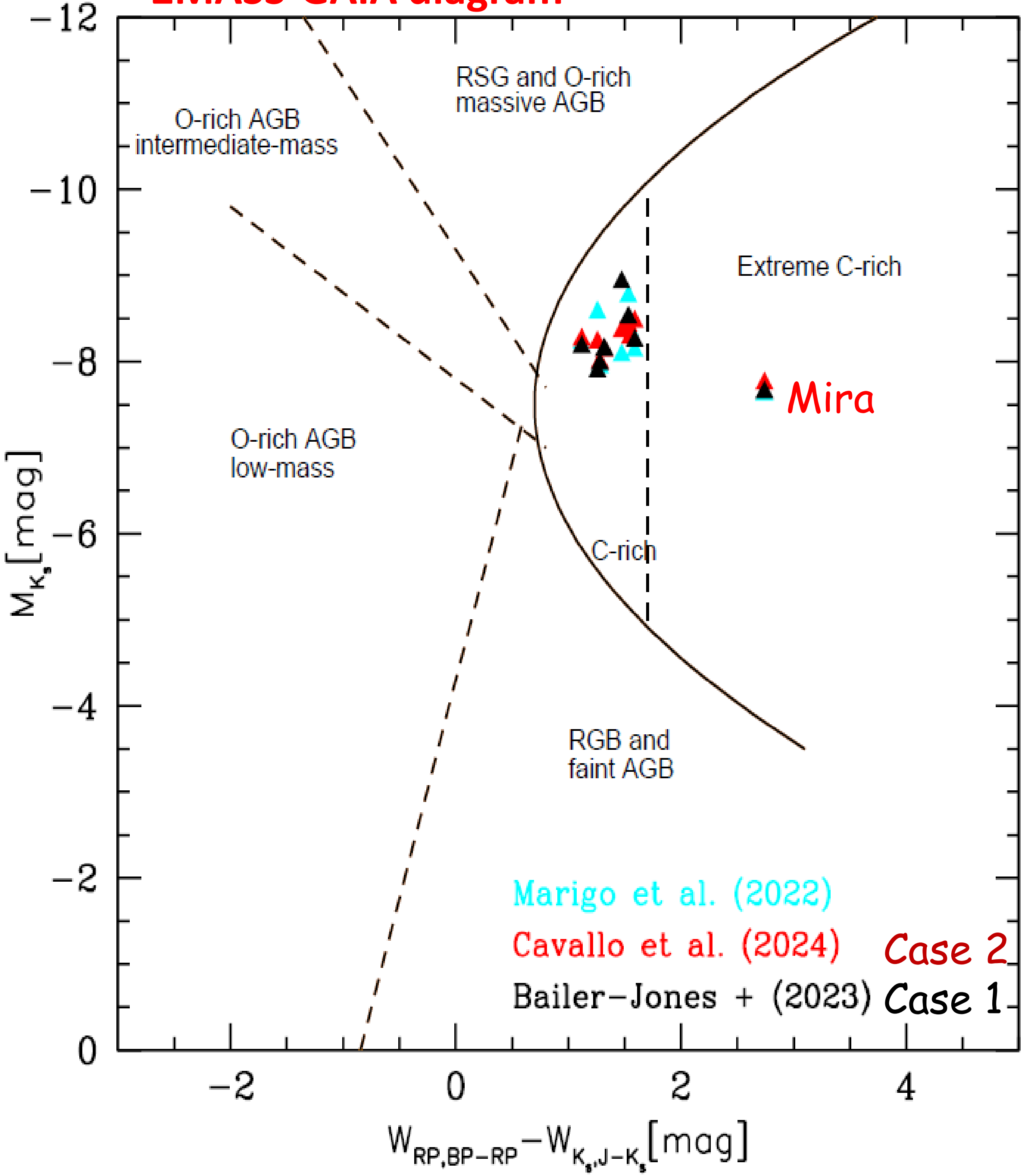
Case 2

- ✓ Distances & A_V (DR3) for each OC from Artificial Neural Network Cavallo et al.(2024)
- ✓ BC_K from Kerschbaum et al. (2010)

To be compared with Marigo et al (2022)

- ✓ Distances: purely parallax-based Gaia DR3
- ✓ A_V from Cantat-Gaudin et al. (2020) and/or Dias et al. (2021) from Gaia DR2
- ✓ Fits to photometric SEDs

2MASS-GAIA diagram



Case 2 → smaller dispersion in luminosity

$\langle M_K \rangle = -8.17 \pm 0.30$ → MCs C-stars

$\langle M_{bol} \rangle = -5.06 \pm 0.30$ → Abia et al. (2022) in the MW

- Differences in individual stellar luminosities are MAINLY due to differences in the distance !!

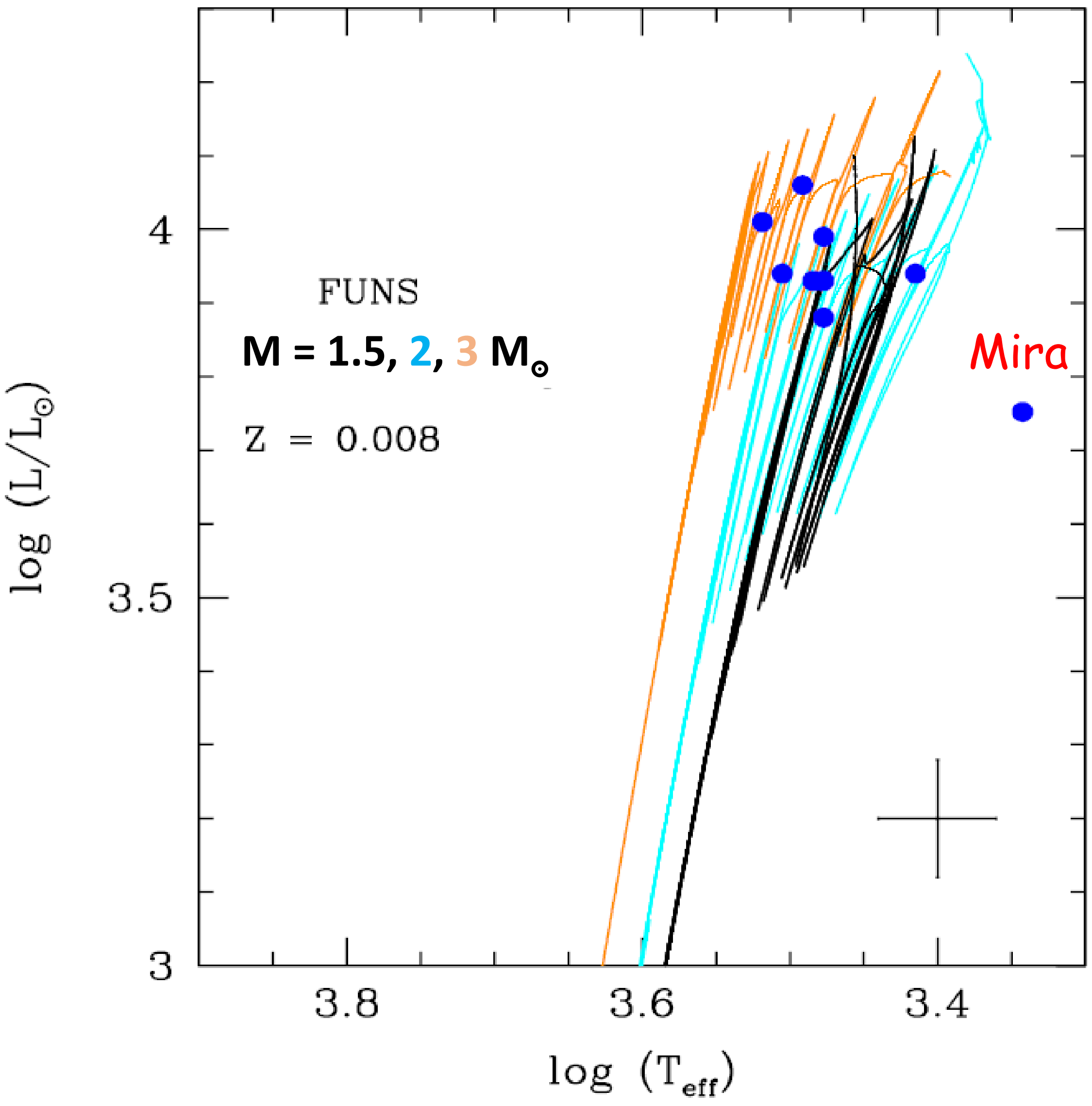
Distances mean difference

Marigo – Case 2= 120 ± 633 pc
Marigo – Case 1= 685 ± 1014 pc
Case2 - Case 1= 500 ± 1120 pc

Marigo's method results in larger distances → higher luminosities → higher core masses

Comparison with theoretical models

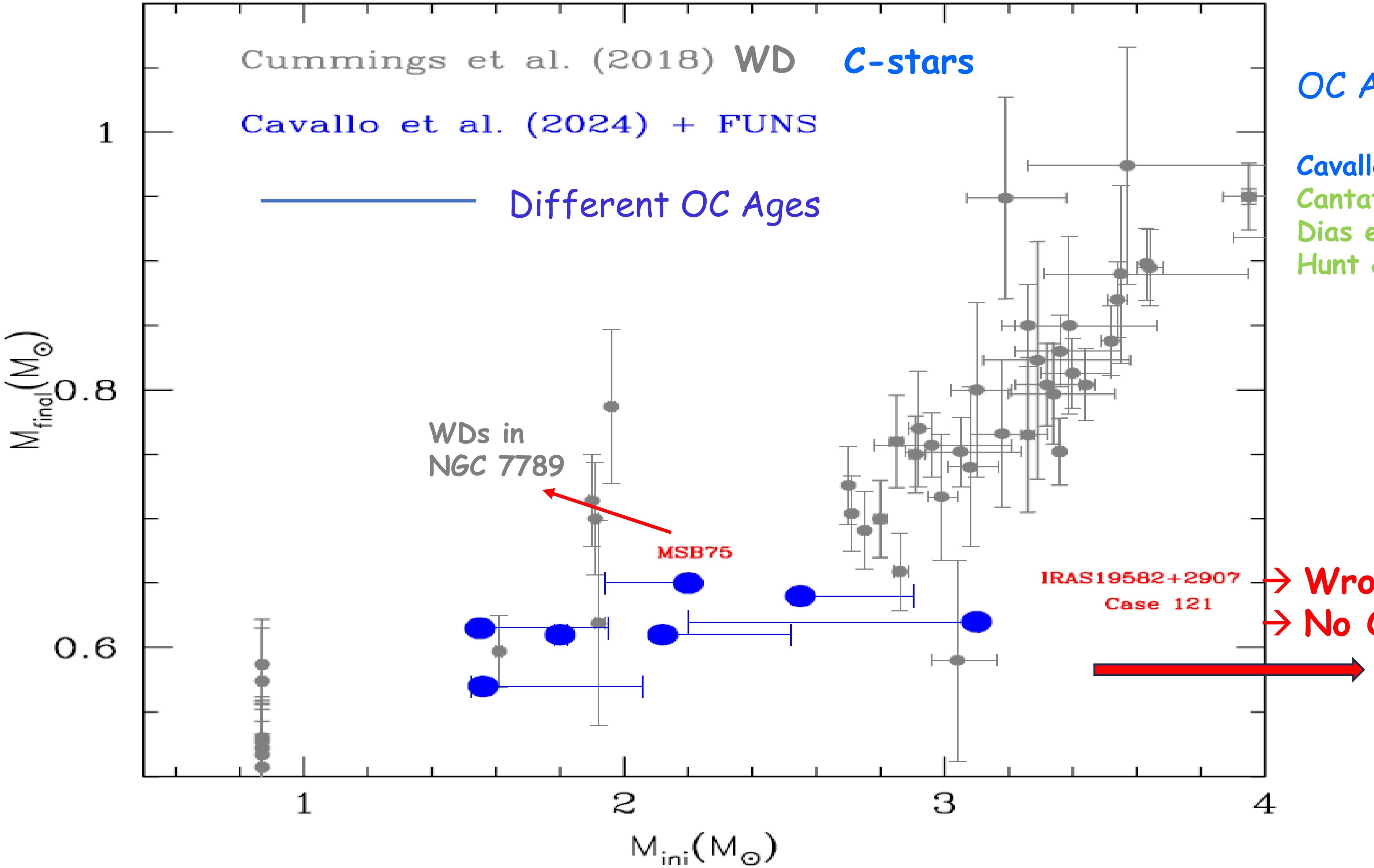
For the derived M_{bol} (Cases 1 & 2) + FUNS code



- All the chemical features can be fitted with 1.5 - 2.0 $M_\odot$ models with the corresponding Z value, except (as usual) the C/O and $^{12}C/^{13}C$ ratios
- The 2.5 $M_\odot$ fits some of the chemical features; no fit is found with the 3.0 $M_\odot$ model
- Marigo et al. (2022) M_{bol} + PARSEC/COLIBRI code fit the C/O and $^{12}C/^{13}C$ ratios with 1.5-2.0 $M_\odot$ models but not the N and O isotopic ratios (other abundances not derived)

IFMR: - M_{core} from FUNS models based on Luminosities (Case 2)

- M_{ini} from OC Ages Cavallo et al. (2024)



OC Ages from:

Cavallo et al. 2024

Cantat-Gaudin et al. 2020

Dias et al. 2021

Hunt & Sabine, 2023

→ Wrong OC ages ?

→ No OC members ?

Summary

- A detailed chemical analysis of AGB C-stars belonging to OC with ages corresponding to initial masses 1.6-2.1 $M_\odot$ that populate the possible kick (discontinuity) in the semiempirical IFMR, shows chemical features identical to other field AGB C-stars of similar metallicities.

- Most show C/O ratios slightly larger than unity → compatible with Marigo et al. (note that this is observed in the majority of solar metallicity C-stars)

- The luminosity of these stars → the expected M_{final}, depends critically on the existing alternatives to derive their distance (within Gaia DR3 astrometry). Extinction plays a secondary role.

More accurate distances and stellar statistic is needed to elucidate whether the discontinuity in the IFMR exists.

Work in progress !! GRAZIE MILLE !! → cabia@ugr.es