Rotational Effect on The Surface Chemical Abundances along Stellar Evolution with PARSECv2.0 Database

IFPU FOCUS WEEK

Galactic Archaeology: reconstructing the history of galaxies

Chi Thanh NGUYEN

Trieste, 10/10/2023

Outlines

- The new release of **PARSEC V2.0**
  - Tracks of rotating stars
  - Variation of surface abundances
  - Isochrones of rotating stellar population
  - Applications
- Summary

Rotating stellar evolutionary group:

Astrophys Space Sci (2008) 316: 43–54
DOI 10.1007/s10509-007-9511-y

ORIGINAL ARTICLE

GENEC

The Geneva stellar evolution code

P. Eggenberger · G. Meynet · A. Maeder · R. Hirschi ·
C. Charbonnel · S. Talon · S. Ekström

A&A 631, A77 (2019)
https://doi.org/10.1051/0004-6361/201935160

Astronomy & Astrophysics

STAREVOL

First grids of low-mass stellar models and isochrones with self-consistent treatment of rotation

From 0.2 to 1.5 $M_\odot$ at seven metallicities from PMS to TAMS*

L. Amard[1,2,3], A. Palacios[2], C. Charbonnel[1,4], F. Gallet[5,1], C. Georgy[1], N. Lagarde[6], and L. Siess[7]

The Astrophysical Journal, 764:21 (36pp), 2013 February 10 doi:10.1088/0004-637X/764/1/21

FRANEC

PRE-SUPERNOVA EVOLUTION OF ROTATING SOLAR METALLICITY STARS IN THE MASS RANGE 13–120 $M_\odot$ AND THEIR EXPLOSIVE YIELDS

Alessandro Chieffi[1,2] and Marco Limongi[2,3,4]
[1] Istituto Nazionale di Astrofisica-Istituto di Astrofisica e Planetologia Spaziali, Via Fosso del Cavaliere 100, I-00133 Roma, Italy; alessandro.chieffi@inaf.it
[2] Centre for Stellar & Planetary Astrophysics, School of Mathematical Sciences, P.O. Box 28M, Monash University, Victoria 3800, Australia; marco.limongi@oa-roma.inaf.it
[3] Istituto Nazionale di Astrofisica-Osservatorio Astronomico di Roma, Via Frascati 33, I-00040 Monteporzio Catone, Italy
[4] Kavli Institute for the Physics and Mathematics of the Universe, Todai Institutes for Advanced Study, The University of Tokyo, Kashiwa 277-8583, Japan
Received 2012 September 18; accepted 2012 December 6; published 2013 January 21

PARSEC V2.0: Stellar tracks of low- and intermediate-mass stars with rotation

Input Physics

Basic input physics

- Includes the new calibration of overshooting
  λ_{ov} = 0.0 - 0.4 (Costa et al., 2019)
  Λ_e = 0.5 - 0.7 H_p (Fu et al., 2018)
- Includes the improvements of nuclear network and the treatment of chemical mixing scheme
- Includes mass loss during the evolution phases

Rotation

- rotation rate: $\omega = \Omega/\Omega_c$
  with $\Omega_c \propto (GM/R^3_{pol})^{½}$
- Considered initial rates: **ω_i = 0.00, 0.30, 0.60, 0.80, 0.90, 0.95, 0.99**
- Applied rotating model depends on the initial mass, up to a value $\omega_{i,max}$,
  $\omega_{i,max}(M) = 0.99(M - M_{O1})/(M_{O2} - M_{O1})$

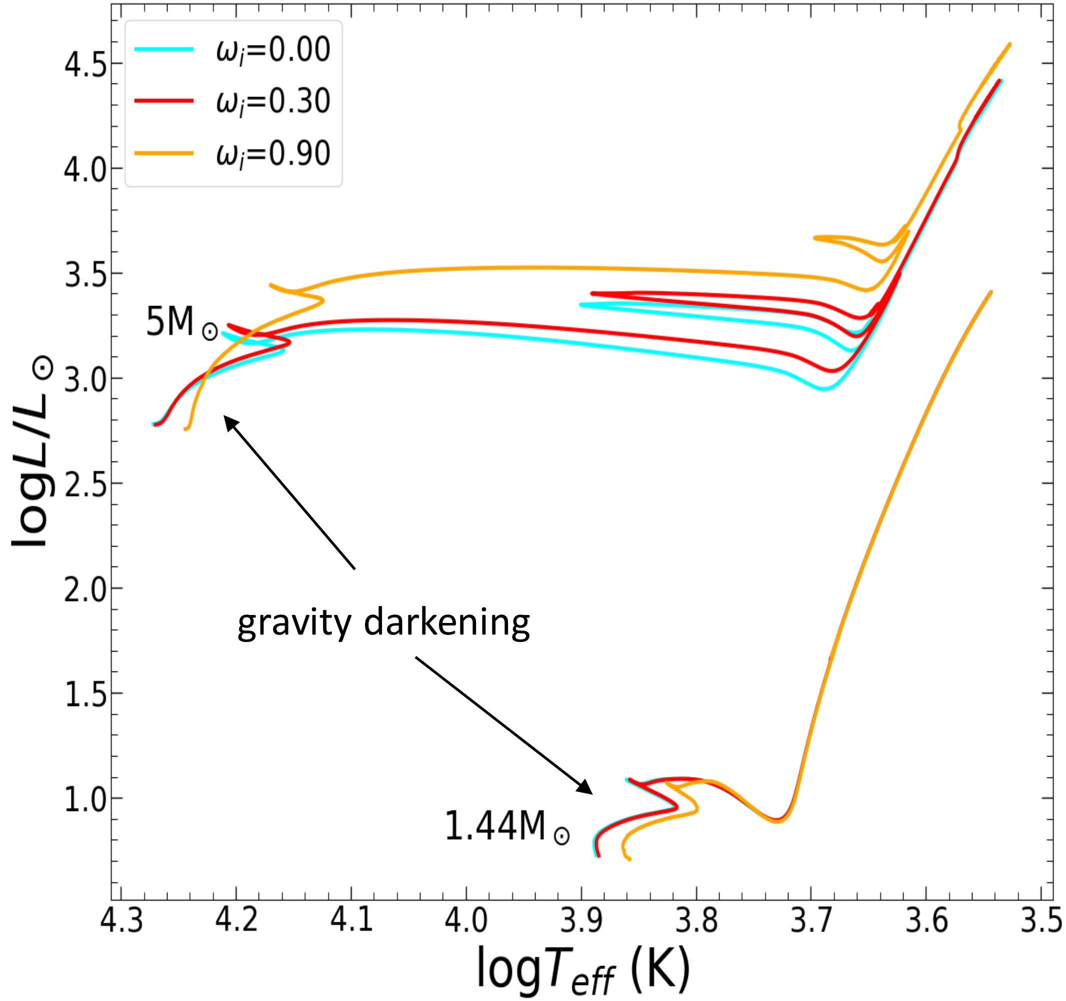
Metallicity & Mass range

- Z-range: 0.004 - 0.017
- Mass range: 0.09 - 14 $M_\odot$

Mass loss

- For rotating models:
  $\dot{M} = \dot{M}(\omega=0)\ (1 - v/v_{crit})^{-\xi}$
  with $v_{crit} = Gm(1 - \Gamma_e)/r$ and $\xi = 0.43$
- For non-rotating models:
  - Low-mass stars:
    Using Reimers' law
  - Intermediate-mass stars:
    Using de Jager et al. (1988) and Vink et al. (2001), corrected by a Z-dependence factor:
    $\dot{M} \propto (Z/Z_\odot)^{0.85}$

Effects on the HRD



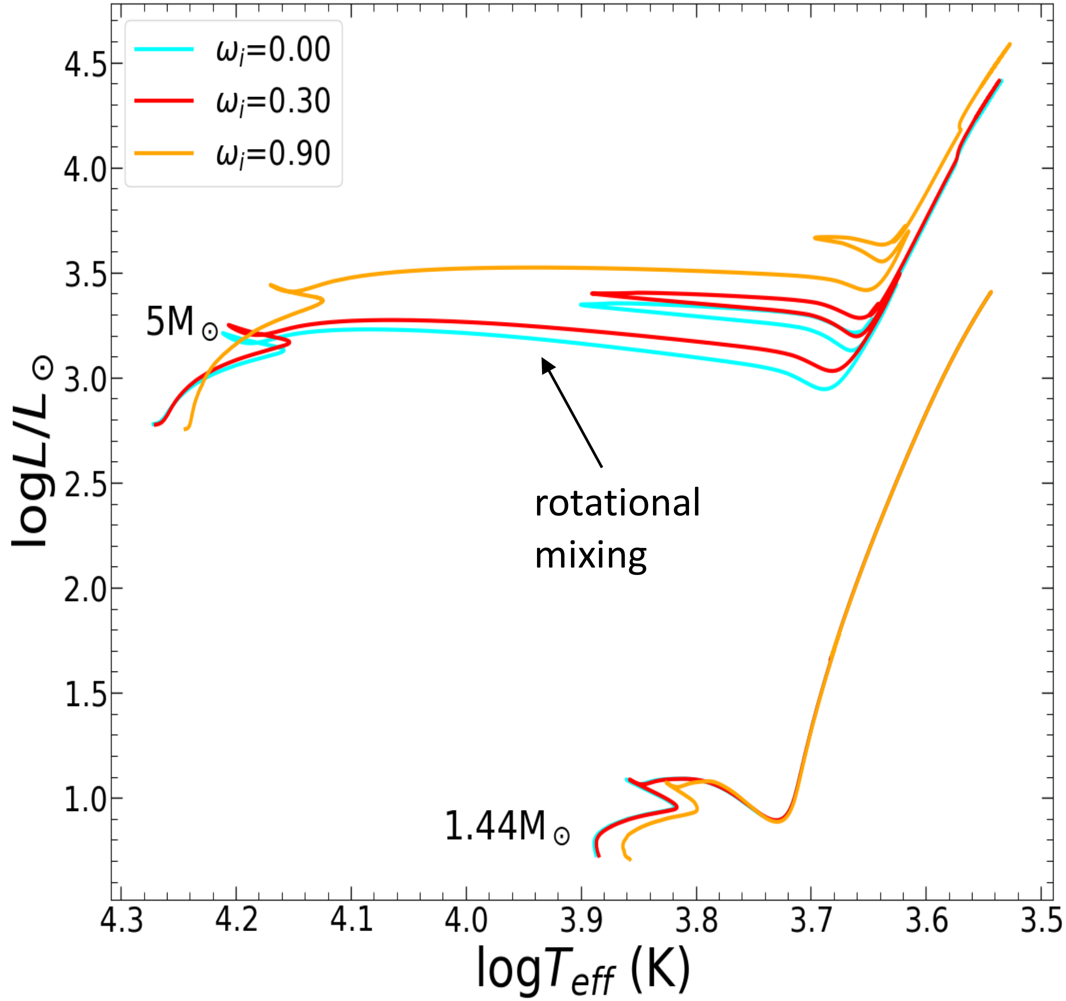
Low-mass stars:

- During the MS, higher rotation rate, cooler of the star

- In the post-MS, the drop down on rotation rate results in the evolution as a non-rotating star

PARSEC V2.0: Stellar tracks of low- and intermediate-mass stars with rotation

Effects on the HRD



Intermediate-mass stars:

- At the beginning, models that rotate faster are cooler

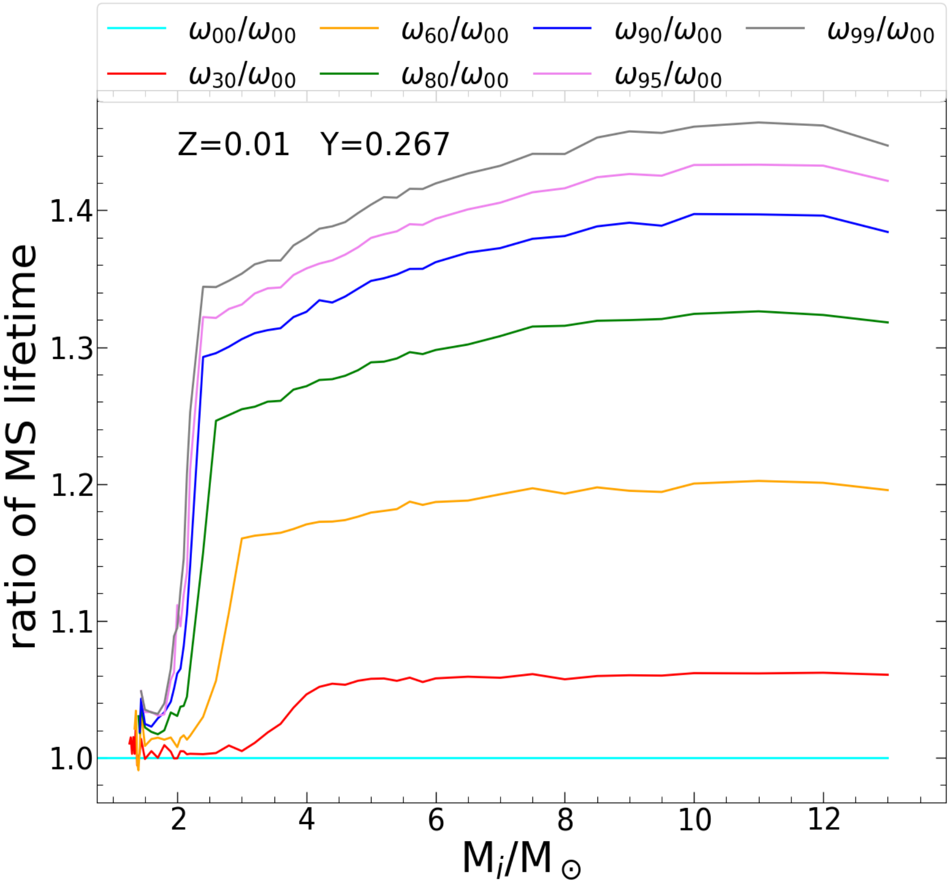
- At further phases, models that rotate faster to become more luminous

Low-mass stars:

- During the MS, higher rotation rate, cooler of the star

- In the post-MS, the drop down on rotation rate results in the evolution as a non-rotating star

MS-lifetime

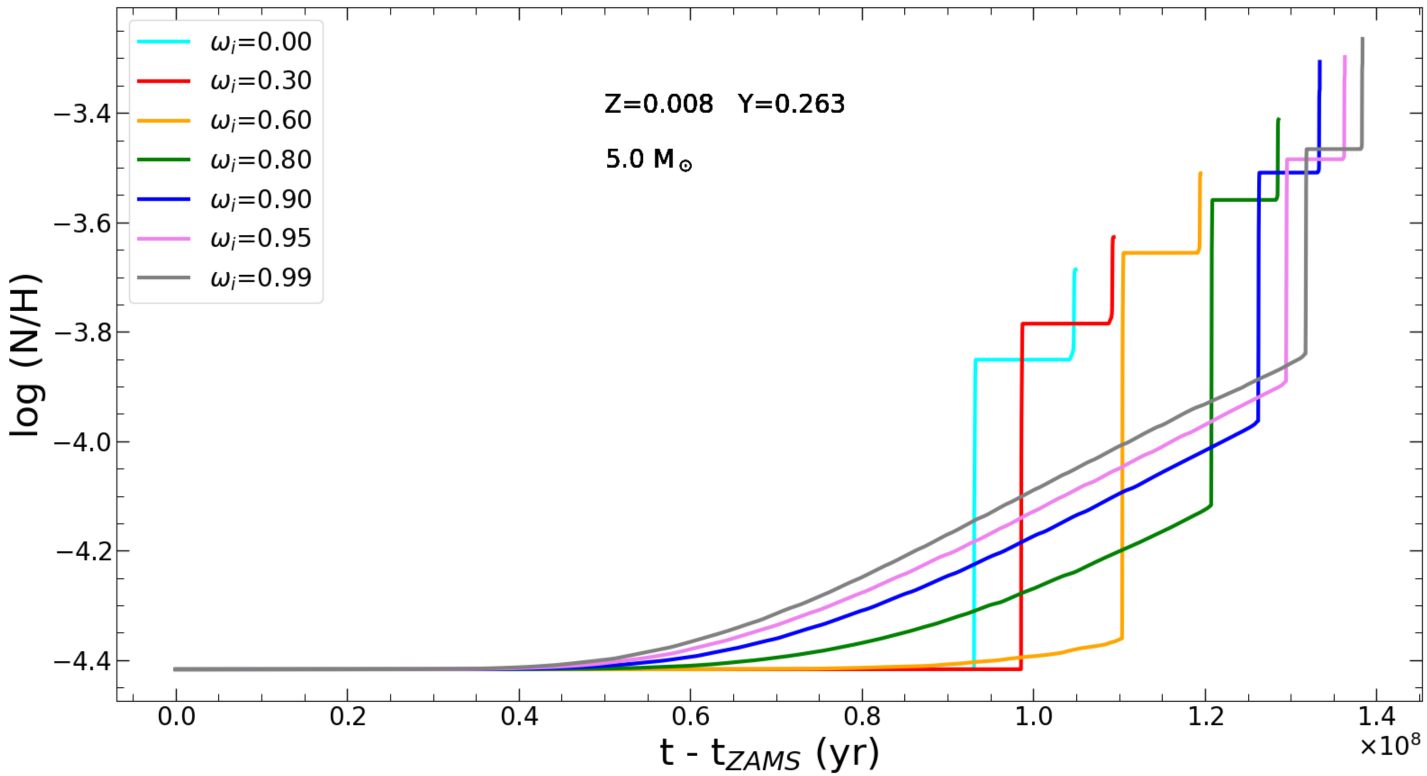


the faster the stars rotate, the longer they stay in the MS

- LMSs: the ratio remains modest because of the lower efficiency of rotational mixing

- IMSs: rotational mixing provides more fresh fuel to the central core due to the well developed radiative envelope

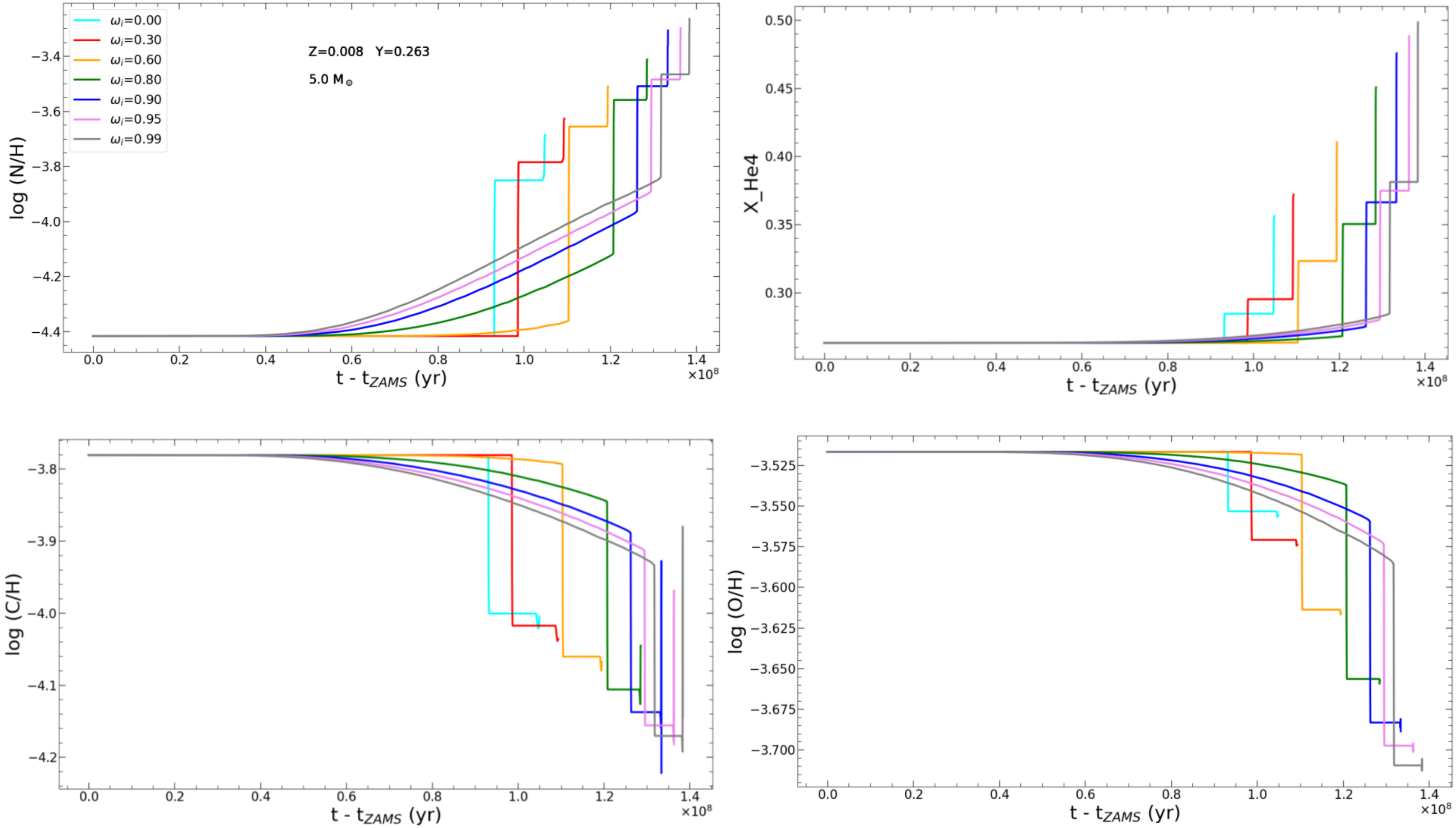
PARSEC V2.0: Transport of nuclear-burned products



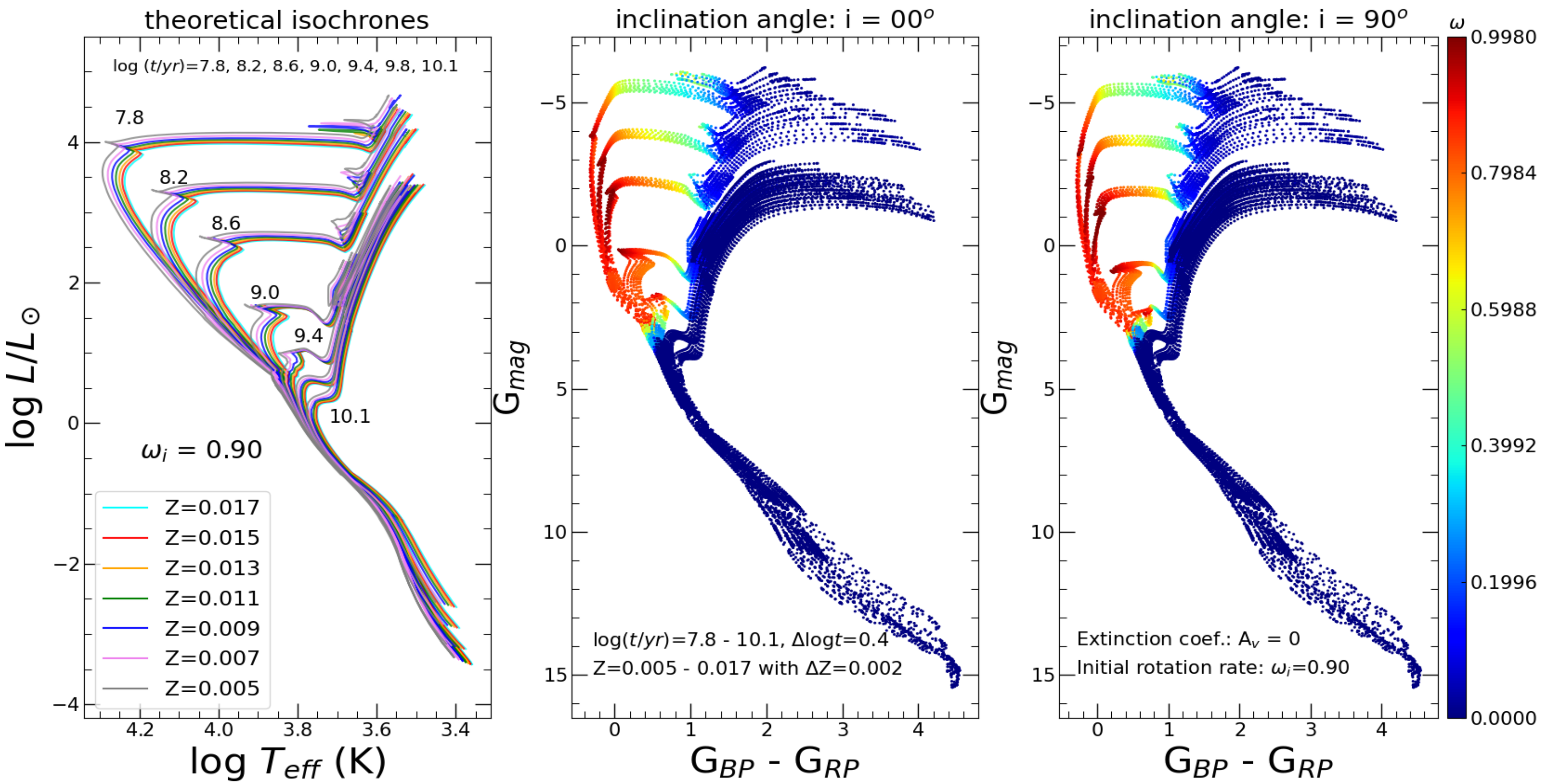
The transport of nuclear-burned products from the central region to the surface due to rotational mixing

- A significant mixing can occur at much earlier stages, proportional to the initial rate
- evident by the enhancement in the surface nitrogen and helium, or depletion of oxygen and carbon

Transport of nuclear-burned products



Isochrones

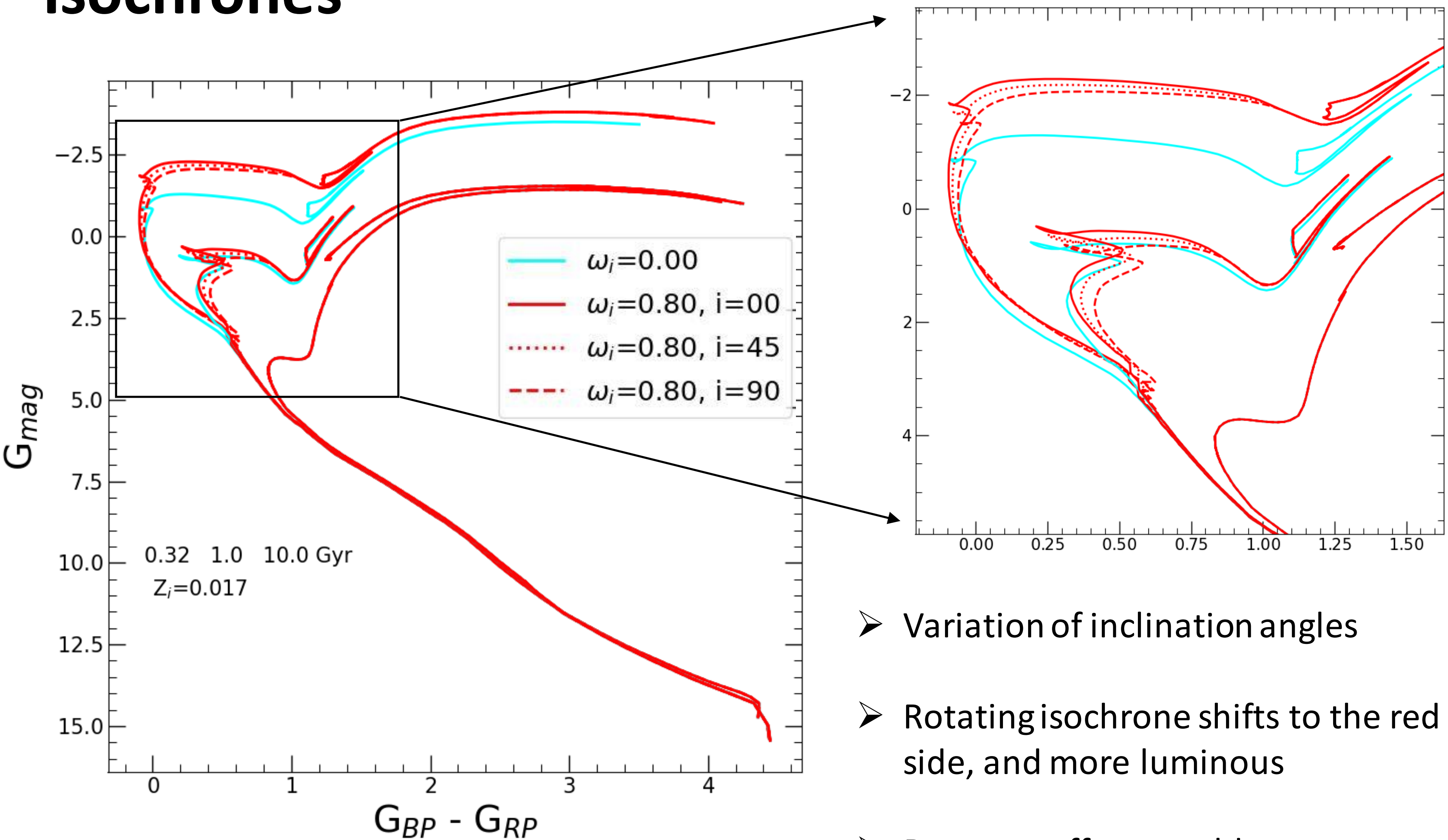


produced by TRILEGAL code

applied BC tables from YBC database

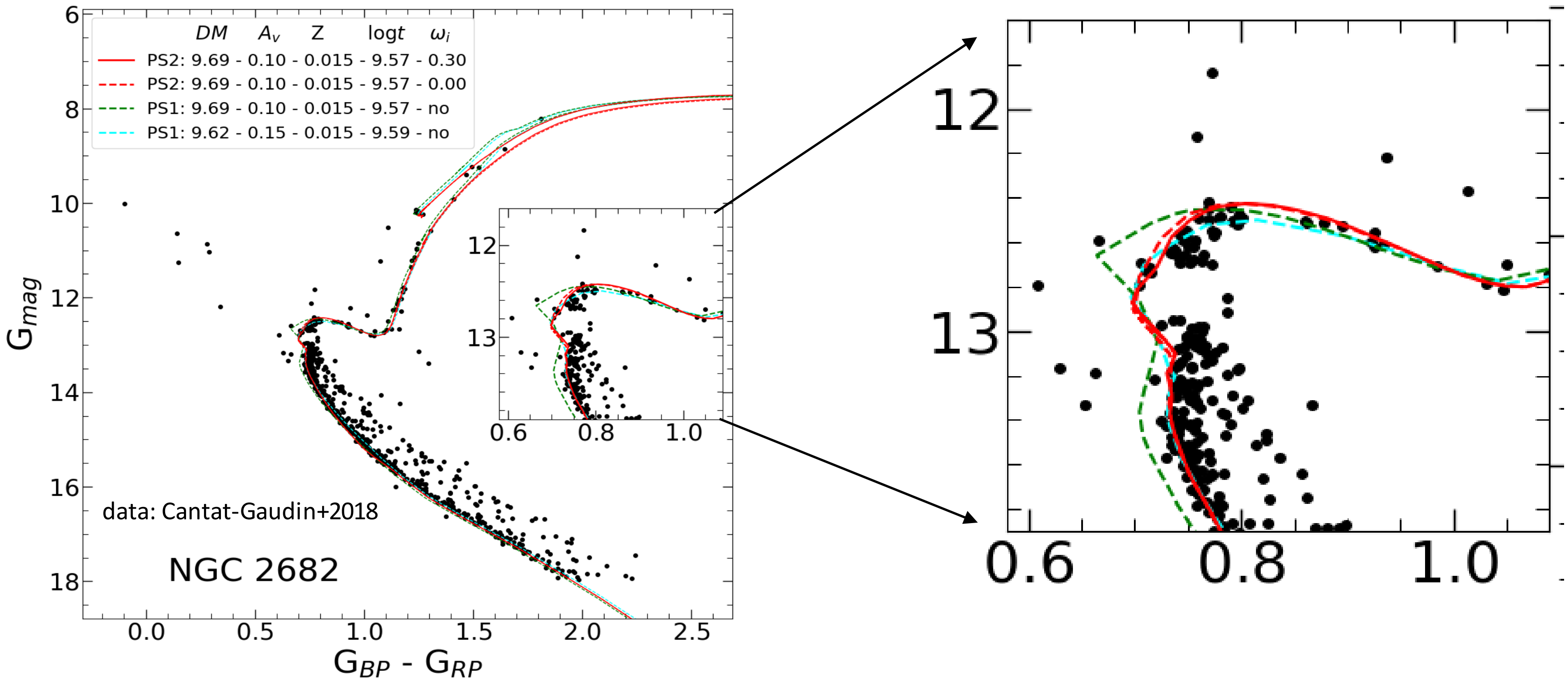
- evolution of rotation rate is clearly witnessed by the changes in color
- isochrones available at: http://stev.oapd.inaf.it/cgi-bin/cmd

Isochrones



- Variation of inclination angles
- Rotating isochrone shifts to the red side, and more luminous
- Does not effect on old age

CMD fit



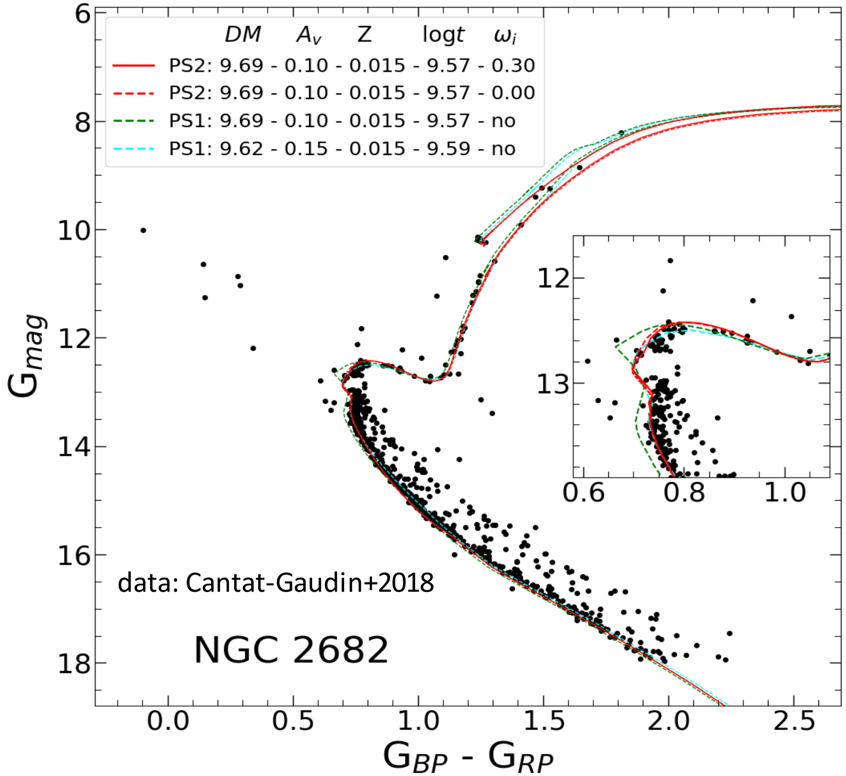
M67

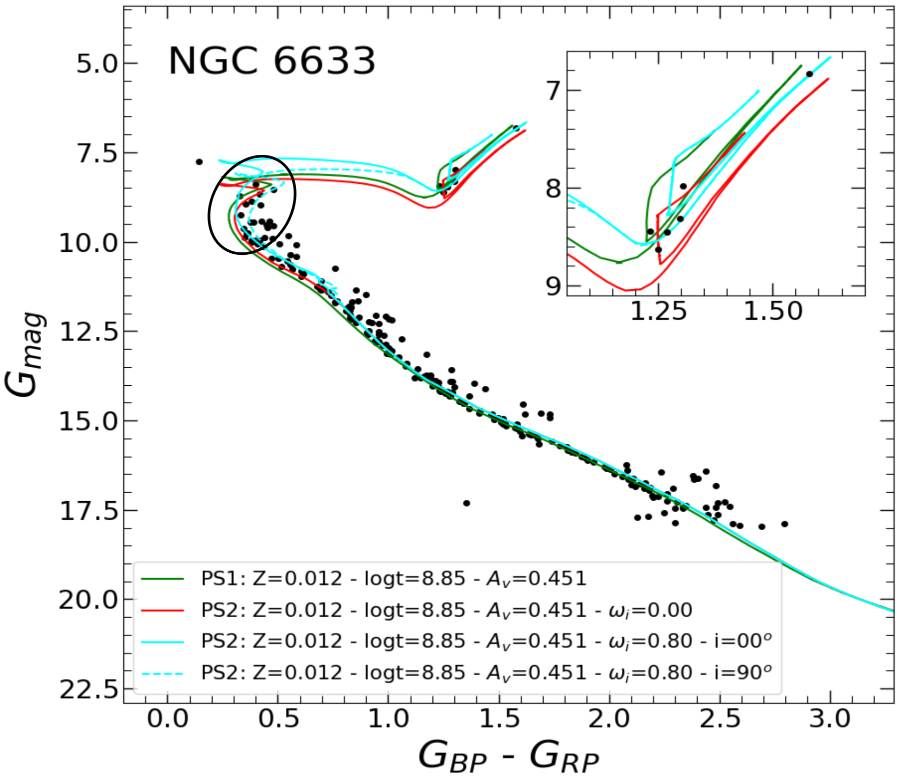
PS2: $(m-M)_0 = 9.69$, $A_V = 0.1$, [Fe/H] ≈ 0, t = 3.7 Gyr

PS1: $(m-M)_0 = 9.62$, Av = 0.15, [Fe/H] ≈ 0, t = 3.9 Gyr

New stellar tracks and isochrones: CMD fit

CMD fit





M67

PS2: $(m-M)_0$ = 9.69, A_V = 0.1,
[Fe/H] ≈ 0, t = 3.7 Gyr

PS1: $(m-M)_0$ = 9.62, Av = 0.15,
[Fe/H] ≈ 0, t = 3.9 Gyr

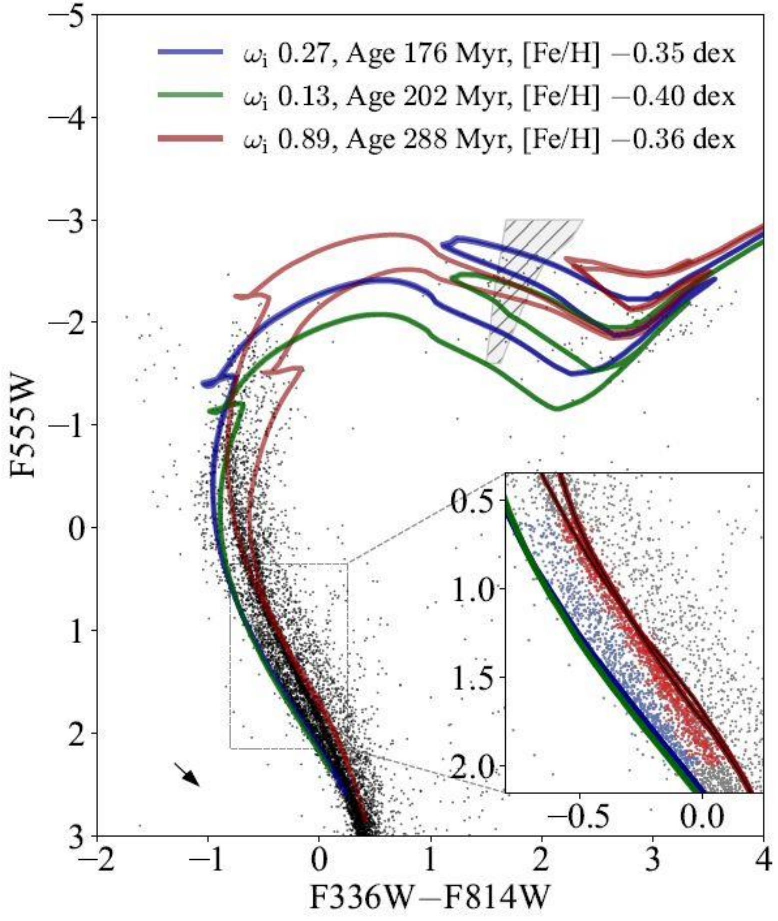
NGC 6633

$(m-M)_0$ = 7.841, A_V = 0.451,
Z = 0.012, t = 708 Myr

- hints for the presence of at least one population of non-rotating stars and another of fast rotators

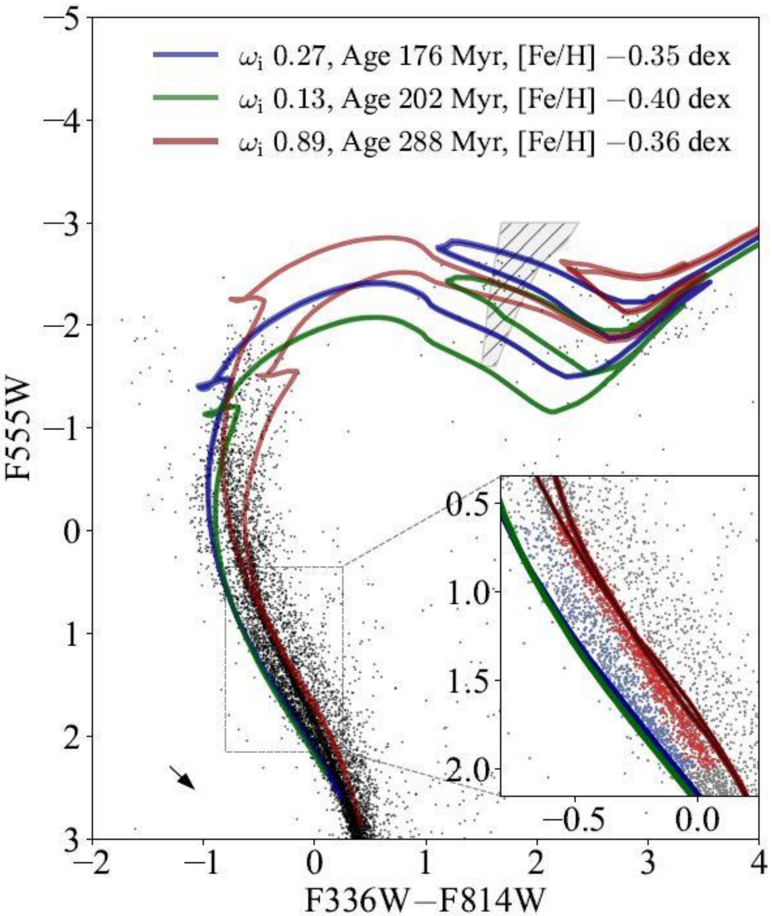
New stellar tracks and isochrones: CMD fit

CMD fit & M-R relation



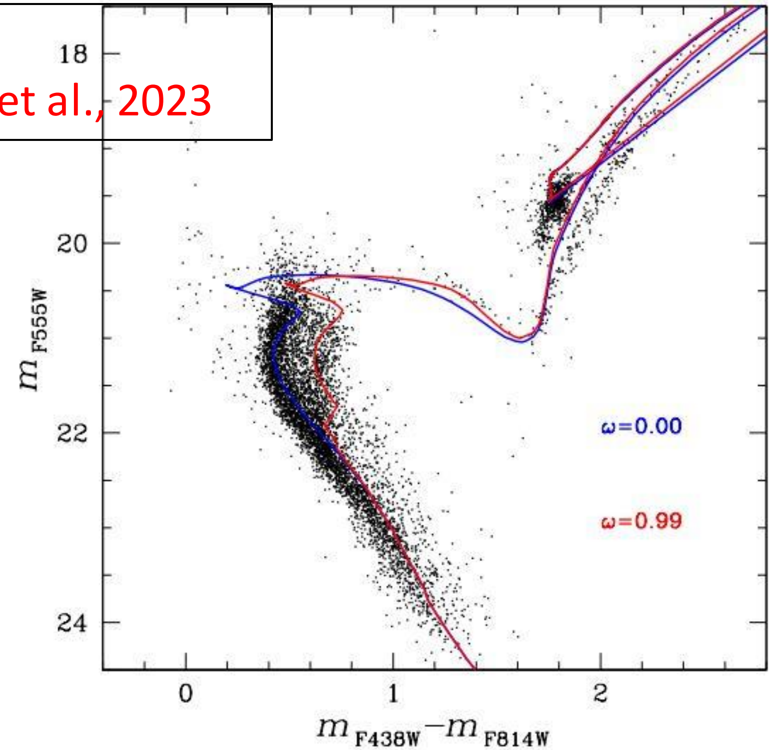
NGC 1866
Costa et al., 2019

CMD fit & M-R relation



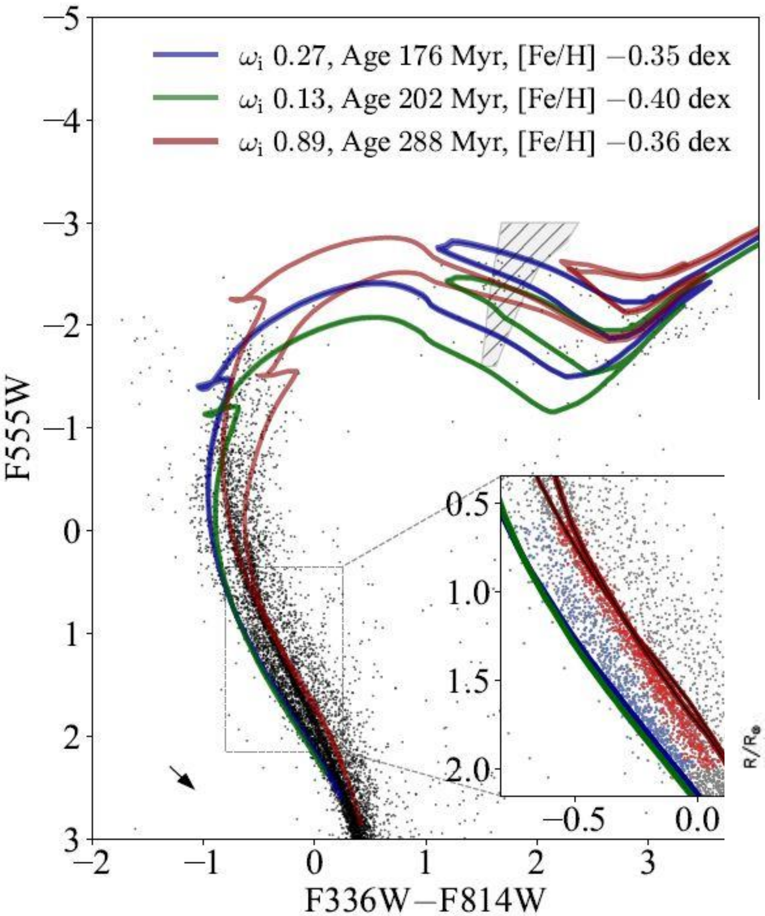
NGC 1866
Costa et al., 2019

NGC 419
Dresbach et al., 2023

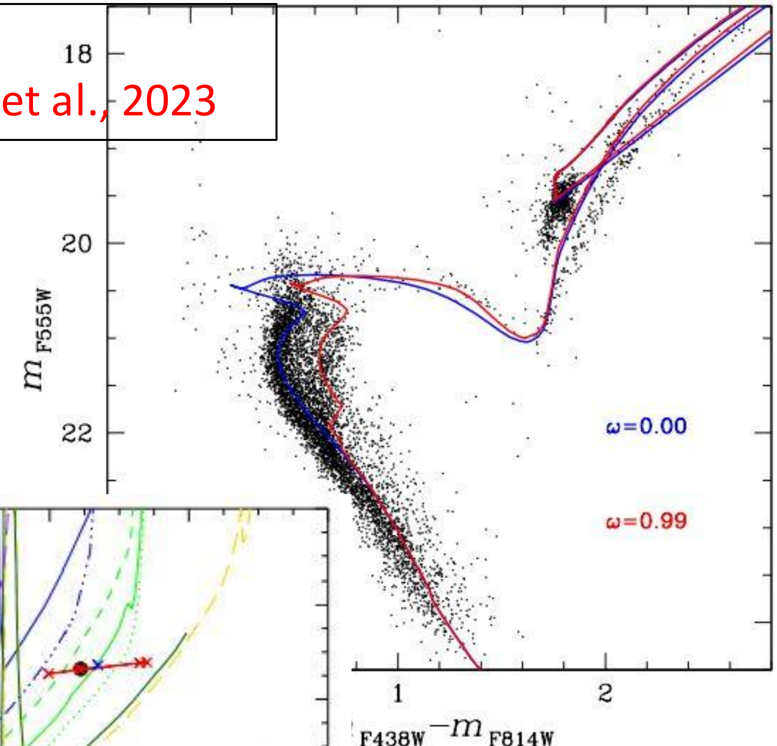


New stellar tracks and isochrones: CMD fit

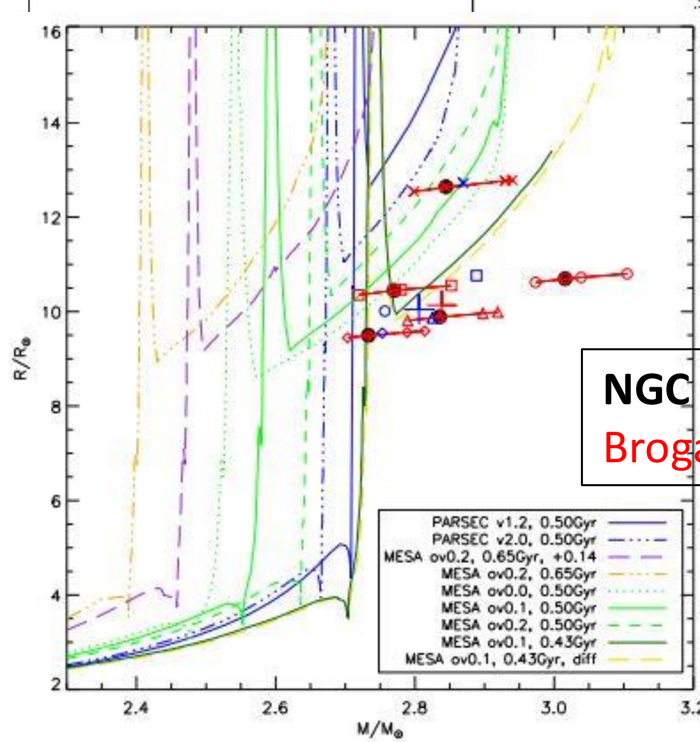
CMD fit & M-R relation



NGC 1866
Costa et al., 2019



NGC 419
Dresbach et al., 2023



NGC 6866
Brogaard et al., 2023

PARSEC V2.0: Database available online

Evolutionary tracks: http://stev.oapd.inaf.it/PARSEC/tracks_v2.html

Isochrones: http://stev.oapd.inaf.it/cgi-bin/cmd

PARSEC

PAdova **T**R**i**este **S**tellar **E**volutionary **C**ode

HOME | STELLAR TRACKS | TOOLS | PAPERS

STELLAR TRACKS DATABASE

This is the stellar tracks database of **PARSEC v2.0**.

Please cite the following papers if you use these tracks (**Costa et al. 2019a**, **Costa et al. 2019b**, **Nguyen et al. 2022**).

Detailed description of stellar tracks quantities are available **here**.

PARSEC V2.0 | PARSEC V1.2S

PARSEC V2.0

Metallicity	All	$\Omega/\Omega_{crit}=0.00$	$\Omega/\Omega_{crit}=0.30$	$\Omega/\Omega_{crit}=0.60$	$\Omega/\Omega_{crit}=0.80$	$\Omega/\Omega_{crit}=0.90$	$\Omega/\Omega_{crit}=0.95$	$\Omega/\Omega_{crit}=0.99$
0.004	GET	GET	GET	GET	GET	GET	GET	GET
0.006	GET	GET	GET	GET	GET	GET	GET	GET
0.008	GET	GET	GET	GET	GET	GET	GET	GET
0.01	GET	GET	GET	GET	GET	GET	GET	GET
0.014	GET	GET	GET	GET	GET	GET	GET	GET
0.017	GET	GET	GET	GET	GET	GET	GET	GET

CMD 3.7 input form

A web interface dealing with stellar isochrones and their derivatives

Latest news

- Bug corrected! (11nov22) Removed a small artefact at Mini=0.45 Msun, in the PARSEC v2.0 tracks.
- Bug corrected! (19oct22) When computing LFs, the first magnitude bin was overestimating the star counts. Accuracy was improved.
- NEW! (19jul22) First version of isochrones with rotation (PARSEC v2.0). We are still expanding their features.
- (23nov21) Added DP0 version of LSST filters.

Help FAQ

Submit Reset

Evolutionary tracks

PARSEC tracks (Bressan et al. (2012)) are computed for a scaled-solar composition and following the Y=0.2485+1.78Z relation. The present solar metal content is $Z_\odot$=0.0152. Tables of evolutionary tracks are also available. **COLIBRI** tracks (Marigo et al. (2013)) extend their evolution to the end of the TP-AGB phase, for several choices of mass loss and dredge up parameters.

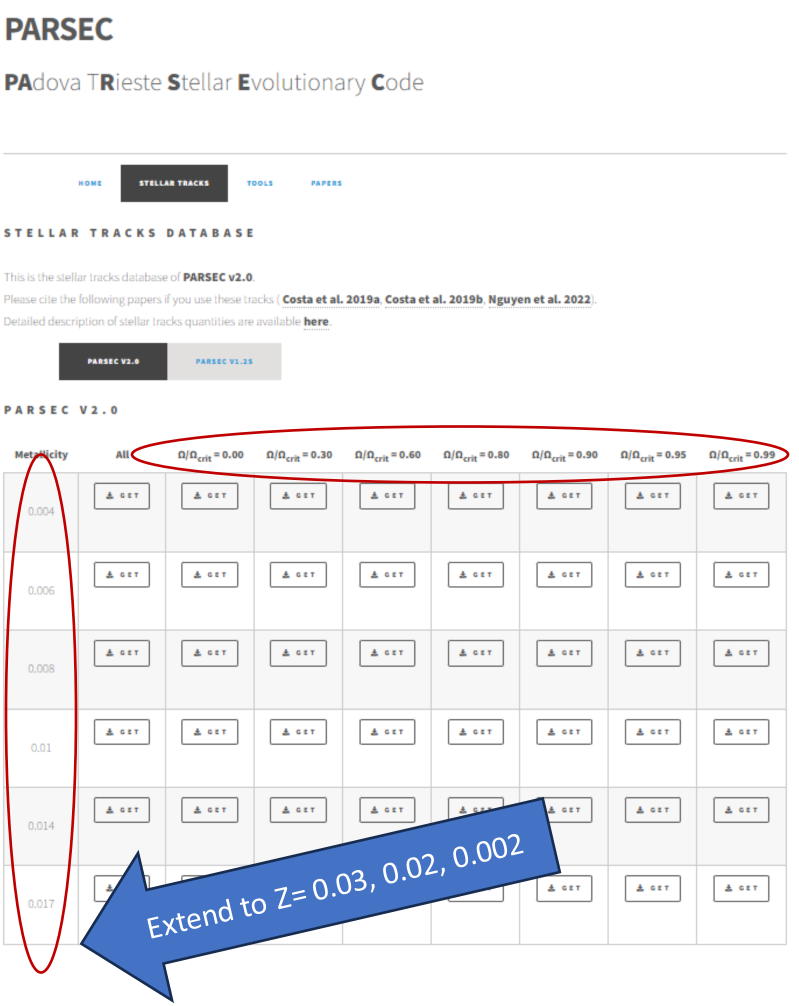
Available sets of tracks:

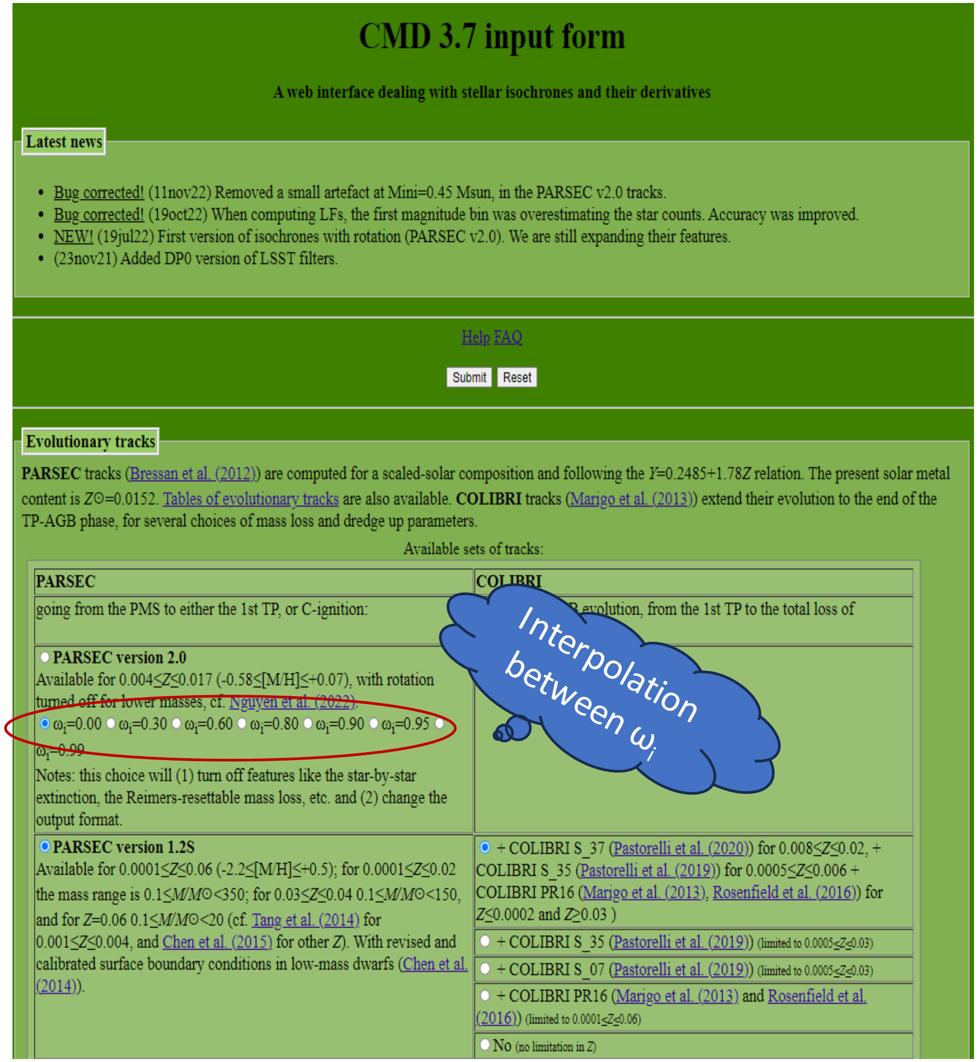
PARSEC	COLIBRI
going from the PMS to either the 1st TP, or C-ignition:	add the TP-AGB evolution, from the 1st TP to the total loss of envelope:
PARSEC version 2.0 Available for $0.004 \lesssim Z \lesssim 0.017$ ($-0.58 \lesssim$[M/H]$\lesssim +0.07$), with rotation turned off for lower masses, cf. Nguyen et al. (2022). ω_i=0.00 ω_i=0.30 ω_i=0.60 ω_i=0.80 ω_i=0.90 ω_i=0.95 ω_i=0.99 Notes: this choice will (1) turn off features like the star-by-star extinction, the Reimers-resettable mass loss, etc. and (2) change the output format.	
PARSEC version 1.2S Available for $0.0001 \lesssim Z \lesssim 0.06$ ($-2.2 \lesssim$[M/H]$\lesssim +0.5$); for $0.0001 \lesssim Z \lesssim 0.02$ the mass range is $0.1 \lesssim M/M_\odot < 350$; for $0.03 \lesssim Z \lesssim 0.04$ $0.1 \lesssim M/M_\odot < 150$, and for Z=0.06 $0.1 \lesssim M/M_\odot < 20$ (cf. Tang et al. (2014) for $0.001 \lesssim Z \lesssim 0.004$, and Chen et al. (2015) for other Z). With revised and calibrated surface boundary conditions in low-mass dwarfs (Chen et al. (2014)).	+ COLIBRI S_37 (Pastorelli et al. (2020)) for $0.008 \lesssim Z \lesssim 0.02$, + COLIBRI S_35 (Pastorelli et al. (2019)) for $0.0005 \lesssim Z \lesssim 0.006$ + COLIBRI PR16 (Marigo et al. (2013), Rosenfield et al. (2016)) for $Z \lesssim 0.0002$ and $Z \gtrsim 0.03$)
	+ COLIBRI S_35 (Pastorelli et al. (2019)) (limited to $0.0005 \lesssim Z \lesssim 0.03$)
	+ COLIBRI S_07 (Pastorelli et al. (2019)) (limited to $0.0005 \lesssim Z \lesssim 0.03$)
	+ COLIBRI PR16 (Marigo et al. (2013) and Rosenfield et al. (2016)) (limited to $0.0001 \lesssim Z \lesssim 0.06$)
	No (no limitation in Z)

PARSEC V2.0: Database available online

Evolutionary tracks: http://stev.oapd.inaf.it/PARSEC/tracks_v2.html

Isochrones: http://stev.oapd.inaf.it/cgi-bin/cmd





Summary

PARSEC V2.0: Tracks & isochrones of low- and intermediate-mass stars with rotation

1. initial metallicity: 0.004 - 0.017
2. initial masses: 0.09 - 14.0 $M_\odot$
3. initial rotation rate: 0.00 - 0.99
4. public use:
   - tracks: http://stev.oapd.inaf.it/PARSEC/tracks_v2.html
   - isochrones: http://stev.oapd.inaf.it/cgi-bin/cmd
   - reference: Nguyen et al., 2022

Soon to be updated:

1. Complement the 3 sets: Z=0.002, 0.02, 0.03 to the database

Thank You!!!