Characterizing the NGC 1866 stellar populations

with new PARSEC tracks with rotation

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Introduction

Stellar rotation is a not negligible ingredient in stellar evolution!

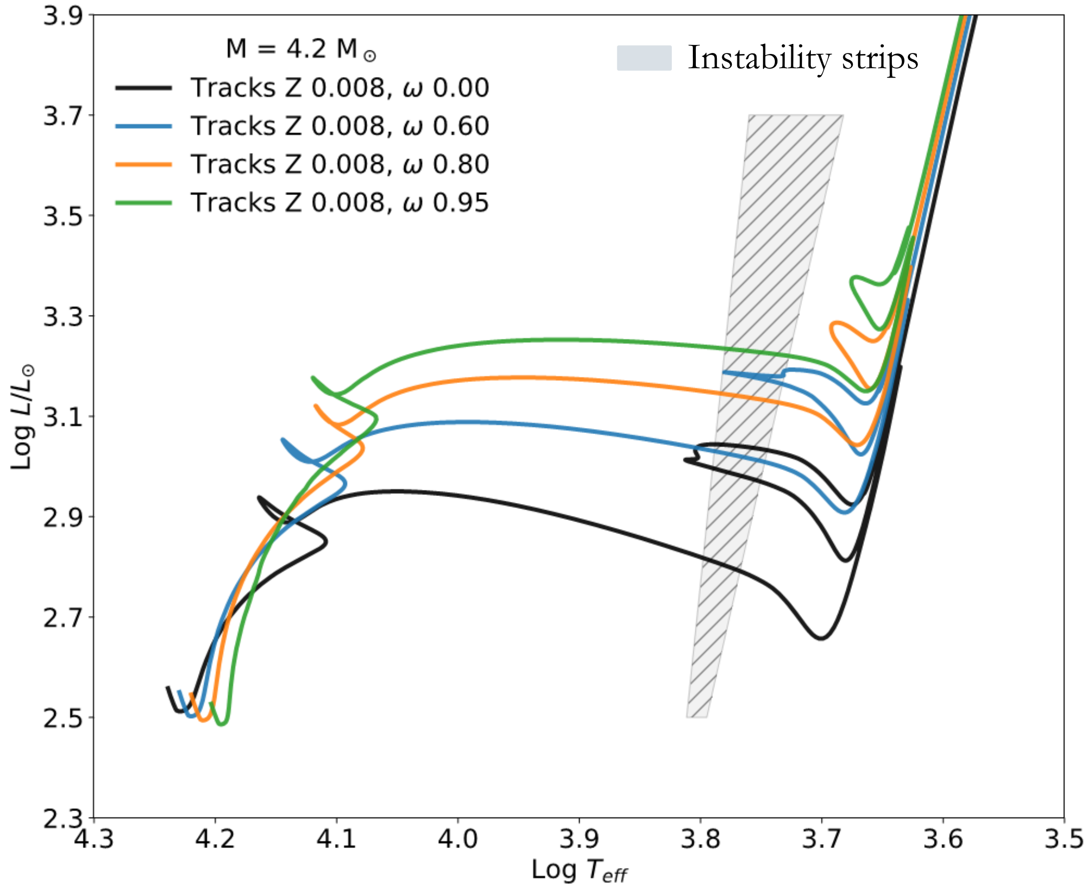
Rotation directly affect:

- The luminosity of the star and effective temperature (T_{eff})
- H and He lifetimes and the chemical profiles along the star
- Extension of blue loops

Initial rotation rate
$\omega = \Omega/\Omega_c = [0. - 1]$

Ω = surface angular velocity
Ω_c = sur. critical angular velocity

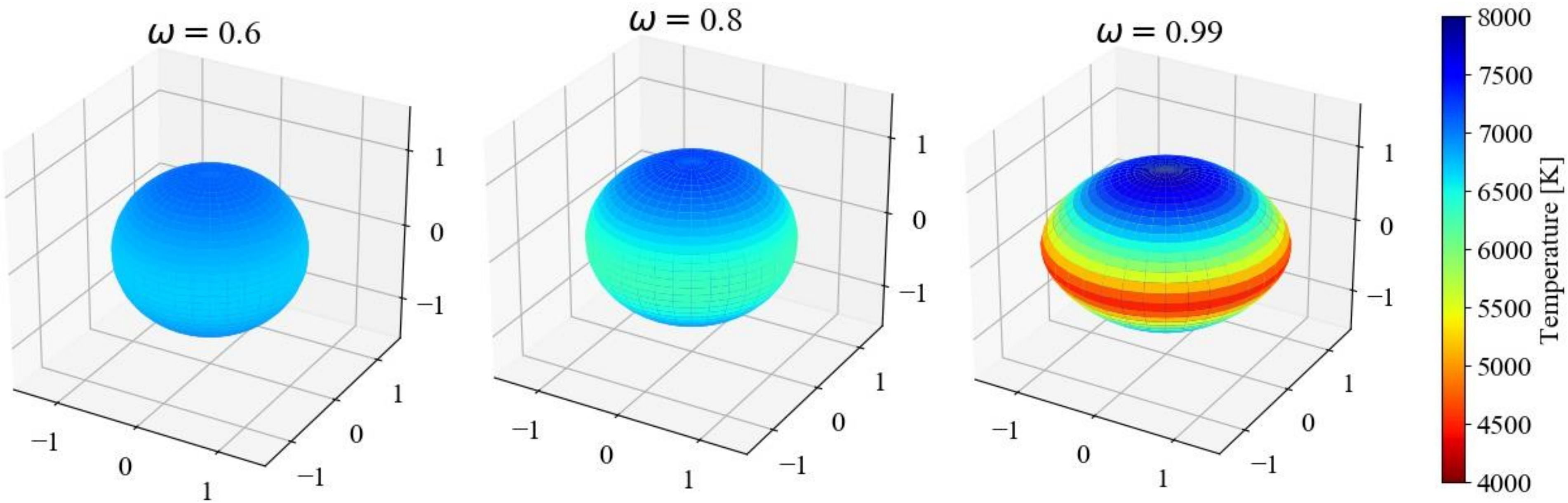
$\Omega_c \propto (M/R^3)^{1/2}$



Introduction

Departure from spherical shape of surface

Gravity darkening: $T_{eff} \propto g_{eff}$ (Von Zeipel 1924)



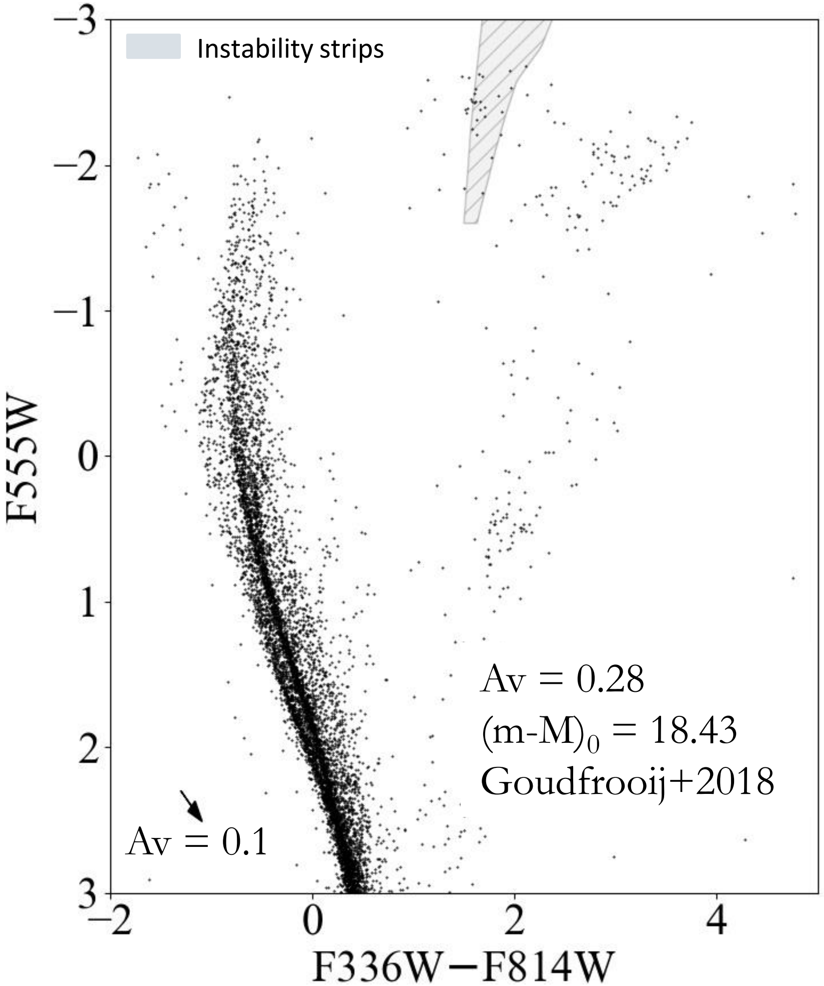
All the effects are taken into account in our models!!!

NGC 1866 star cluster

Main Features

Hubble Space Telescope (HST) Photometry

Colour Magnitude Diagram (CMD)



NGC 1866 star cluster

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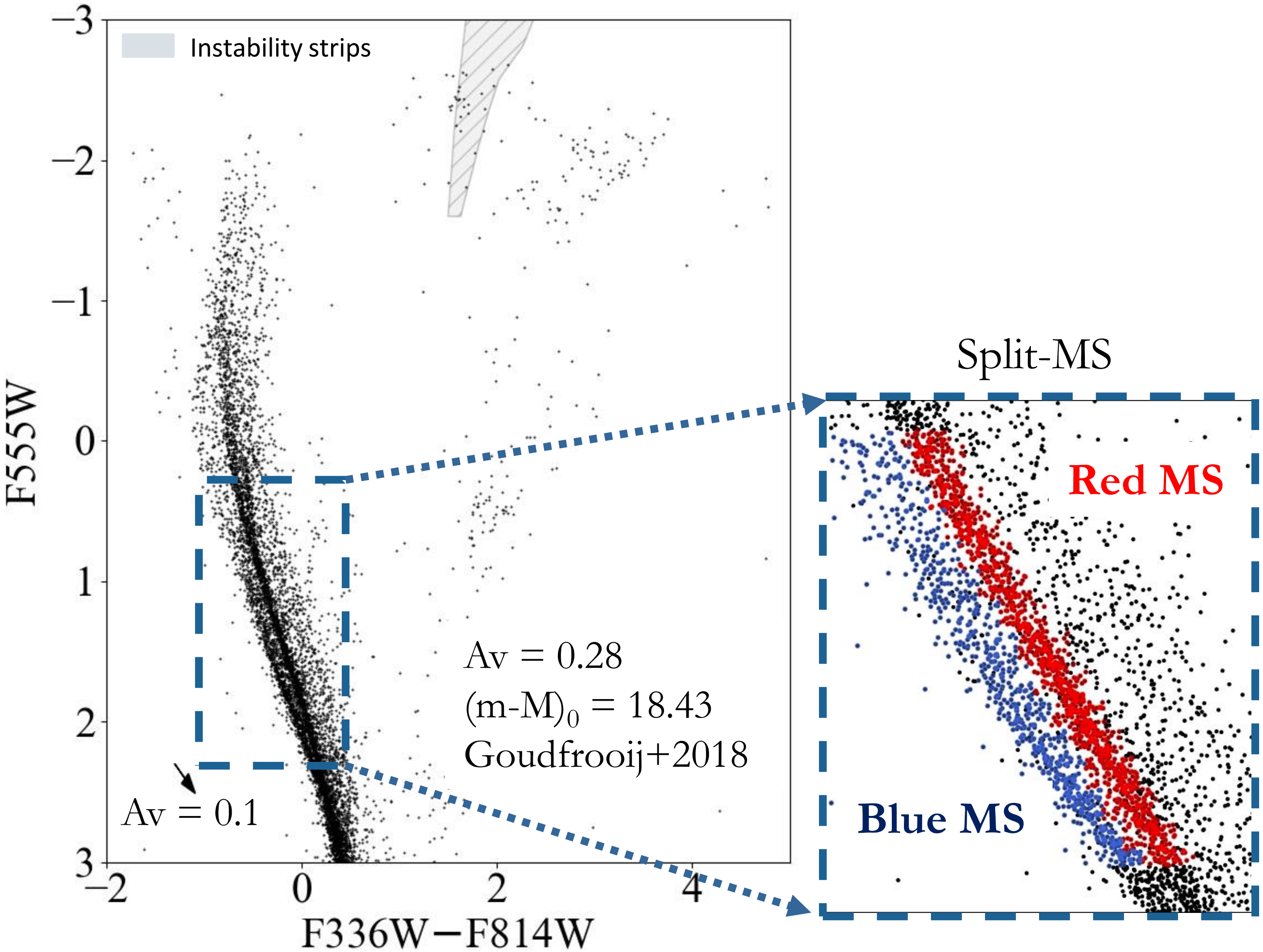

It is a **true** feature, confirmed by **photometric** studies (Milone+2017).

NGC 1866 star cluster

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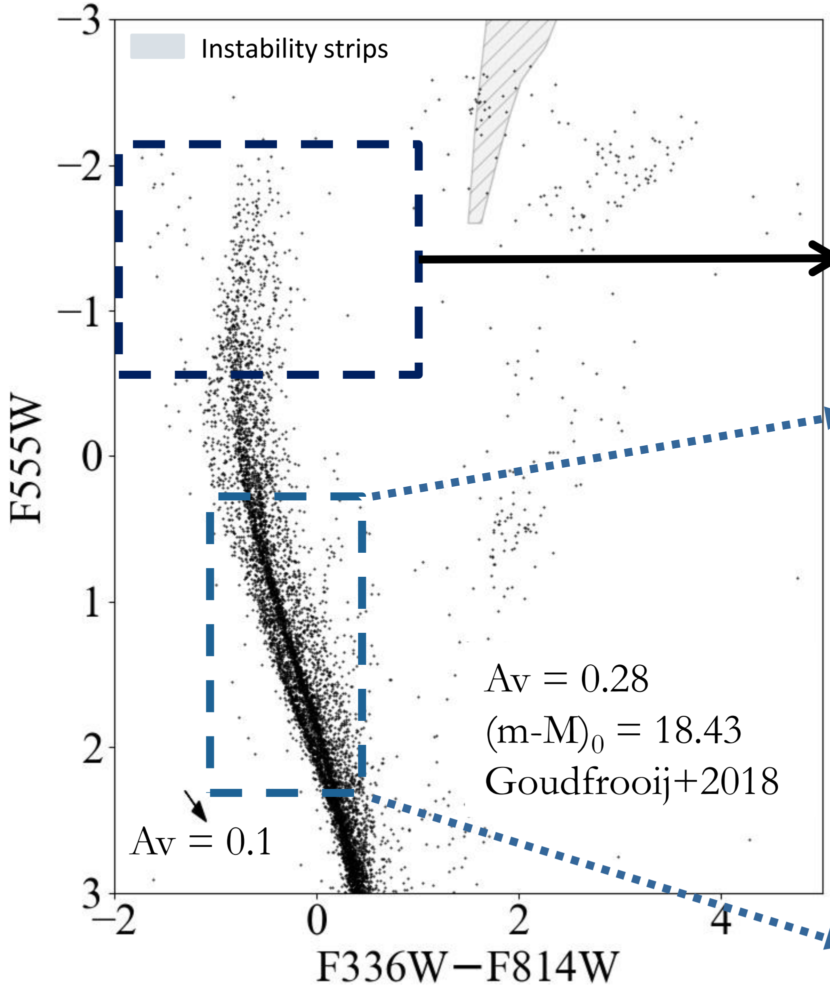
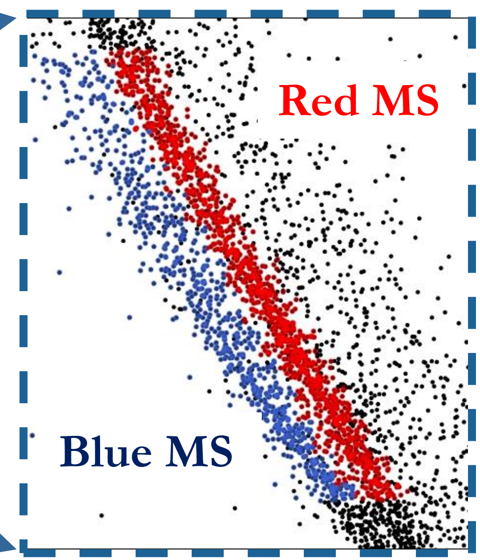


Extended Main Sequence Turn-off (eMSTO)
$\sim 4 - 5\ M_\odot$

Split-MS



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NGC 1866 star cluster

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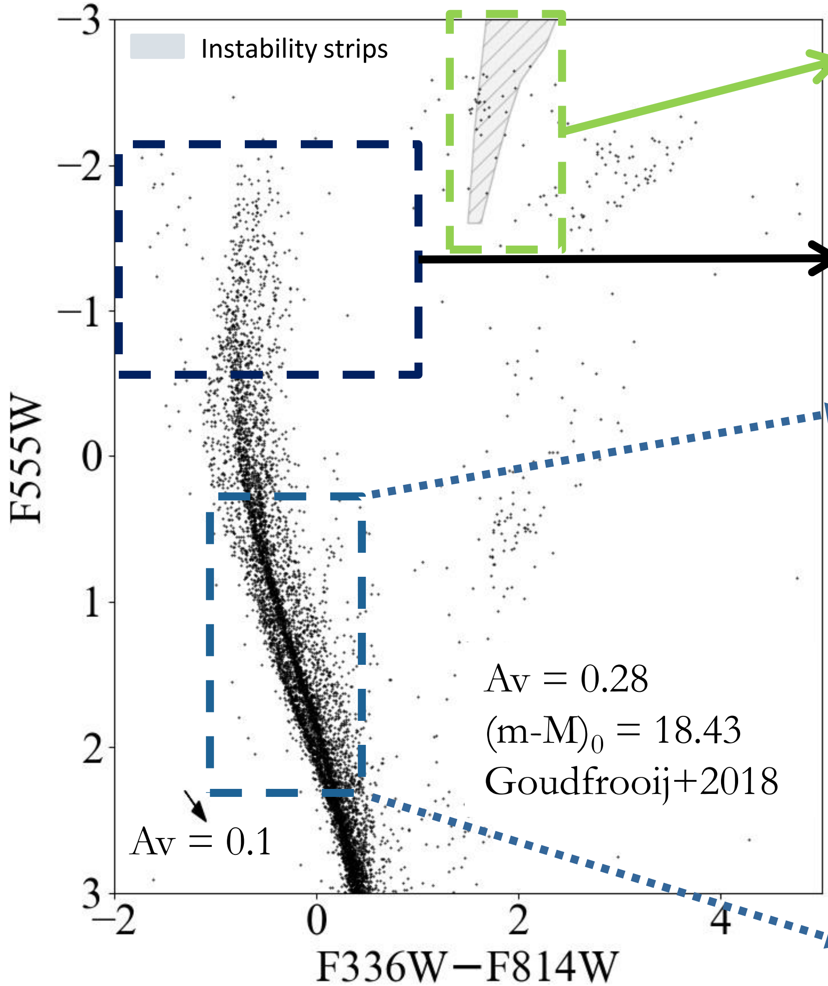
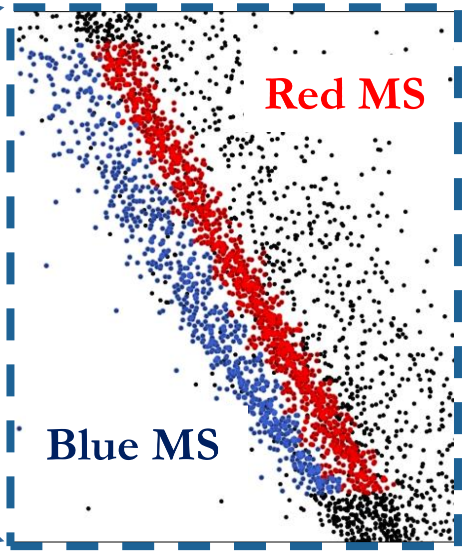


23 Cepheids

[Fe/H] = - 0.36 ± 0.03 dex (Lemasle+2017)

Extended Main Sequence Turn-off (eMSTO) ~ 4 – 5 $M_{\odot}$

Split-MS



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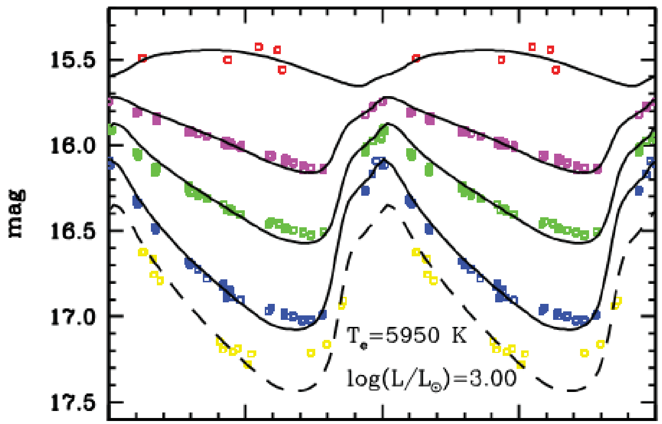
Cepheids data

Why Cepheids?

I - They are characterized by pulsational instabilities.

observed variability in light curve



U, B, V, I, K bands (Marconi+2013)

→ Pulsational Hydrodynamical Models

↓

Structural Parameters

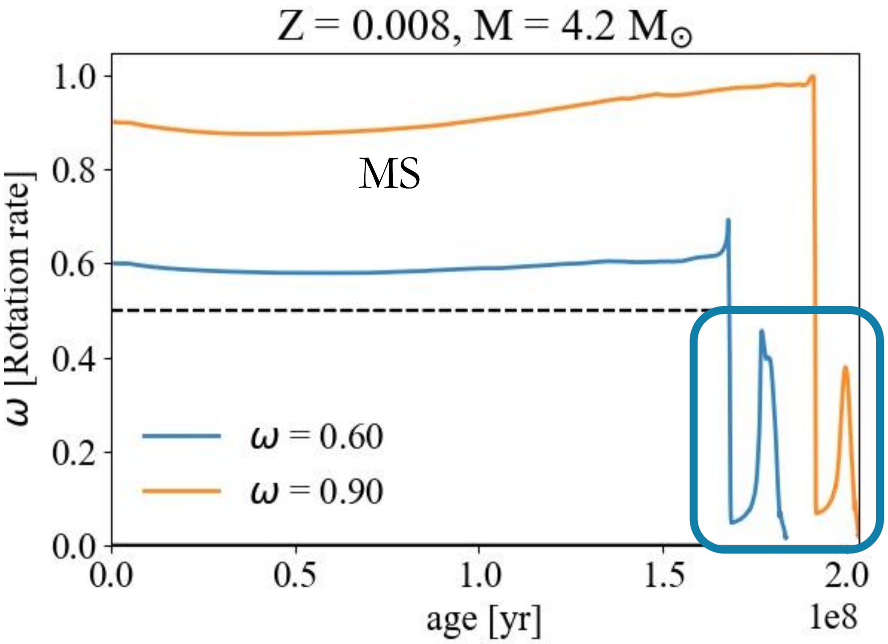
Name	Mass [$M_\odot$]	log L [$L_\odot$]	T_{eff} [K]
HV 12197	4.6 ± 0.2	3.045 ± 0.012	5950 ± 12
HV 12198	4.2 ± 0.1	3.10 ± 0.01	6050 ± 12
HV 12199	3.5 ± 0.1	2.91 ± 0.01	6125 ± 12
We 2	4.31 ± 0.15	3.00 ± 0.01	5925 ± 12
V6	4.0 ± 0.1	3.03 ± 0.01	6300 ± 12

Cepheids data

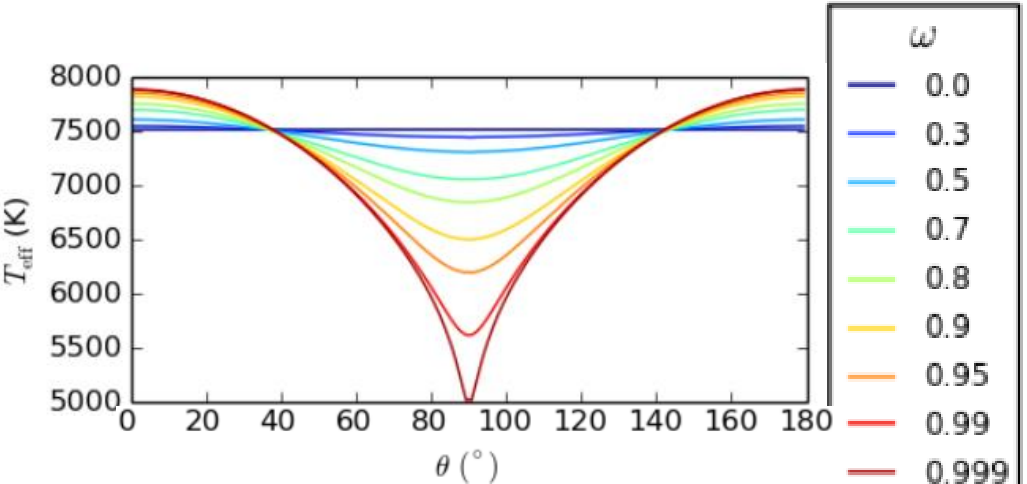
Why Cepheids?

II - They are evolved stars!

They have slow rotation velocities



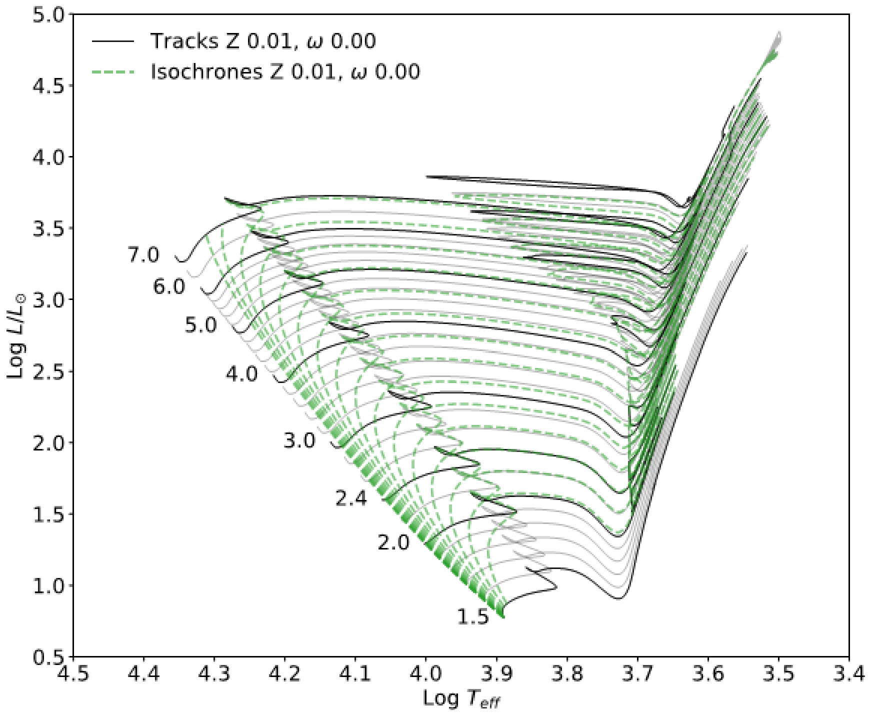
No gravity darkening effects. The analysis is independent on the inclination angle.

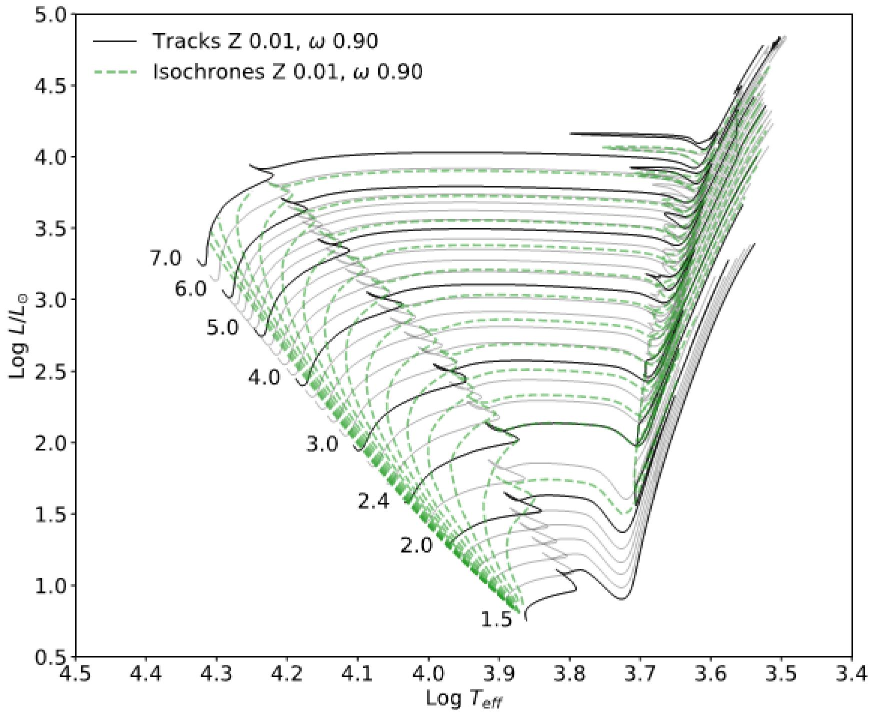


Girardi, GC et al. (submitted)

New Tracks & Isochrones

- Z = 0.004 to 0.01
- $\omega = \Omega/\Omega_c = 0.0$ and 0.95 (Ω = initial ang. vel. , Ω_c = critical ang. vel.)
- Masses = 1.5 to 7 $M_\odot$

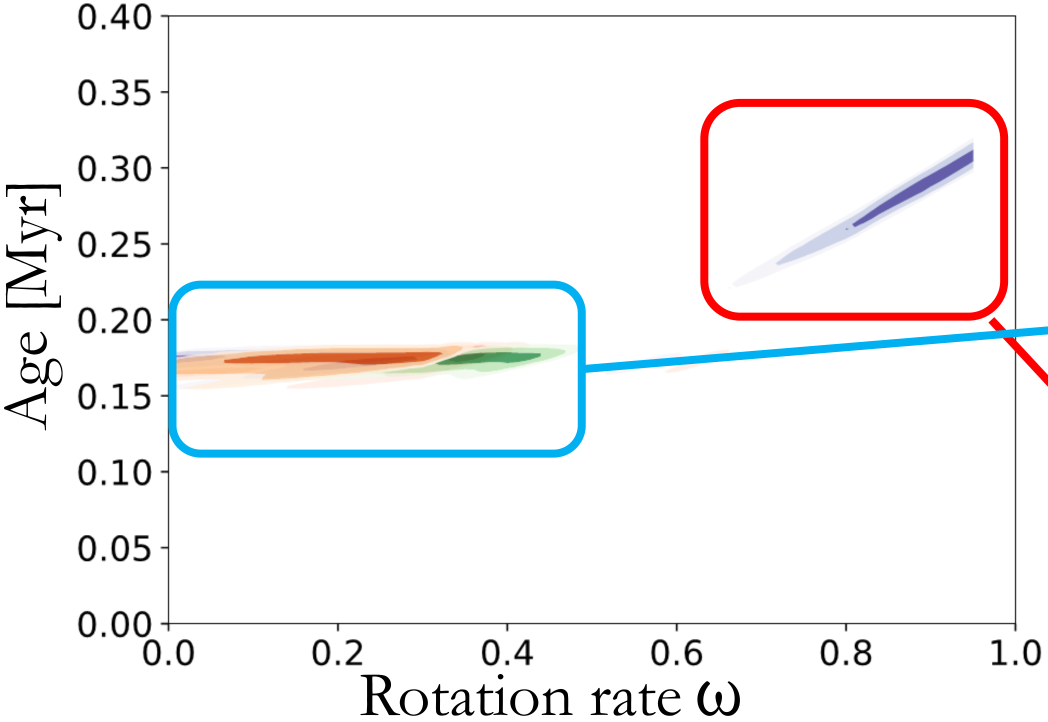




Bayesian Analysis Results

Cepheids data + New PARSEC tracks with rotation

PARAM code (Rodrigues+2017)



- 4 Young slowly rotating Cepheids (~160 Myr)

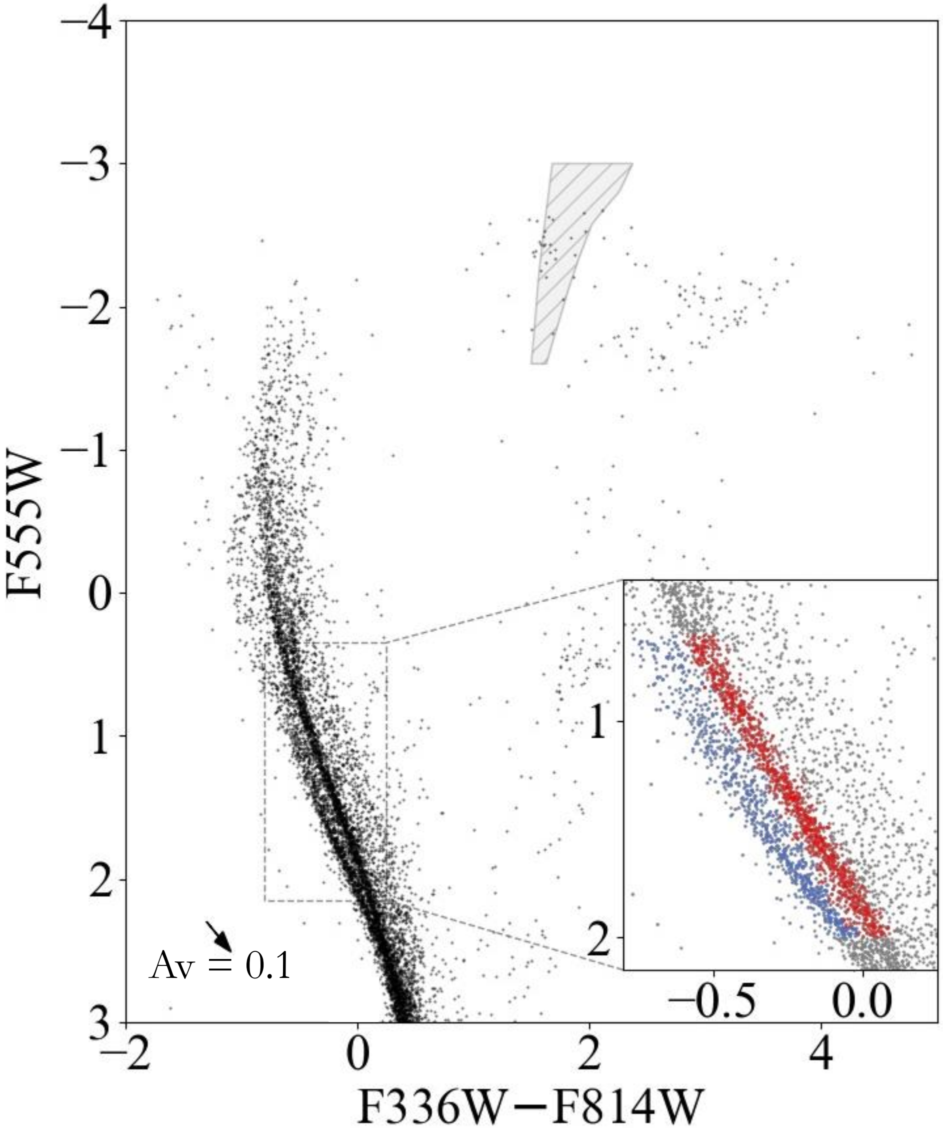
Cepheid Name	ω	Age [Gyr]	[Fe/H]
$HV12197_{corr}$	$0.31^{+0.05}_{-0.16}$	$0.176^{+0.004}_{-0.006}$	$-0.35^{+0.01}_{-0.02}$
$HV12198_{corr}$	$0.37^{+0.06}_{-0.05}$	$0.176^{+0.004}_{-0.006}$	$-0.35^{+0.01}_{-0.02}$
$We2_{corr}$	$0.20^{+0.09}_{-0.12}$	$0.176^{+0.004}_{-0.006}$	$-0.35^{+0.01}_{-0.02}$
$V6_{corr}$	$0.18^{+0.11}_{-0.08}$	$0.176^{+0.004}_{-0.006}$	$-0.35^{+0.01}_{-0.02}$
HV12199	$0.89^{+0.06}_{-0.06}$	$0.288^{+0.017}_{-0.023}$	$-0.36^{+0.02}_{-0.04}$

- 1 Old rapidly rotating Cepheid (~290 Myr)

ΔAge ~ 130 Myr

GC, Girardi, Bressan, et al. (in prep)

NGC 1866 CMD Fitting



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- 1 Old rapidly rotating Cepheid (~290 Myr)

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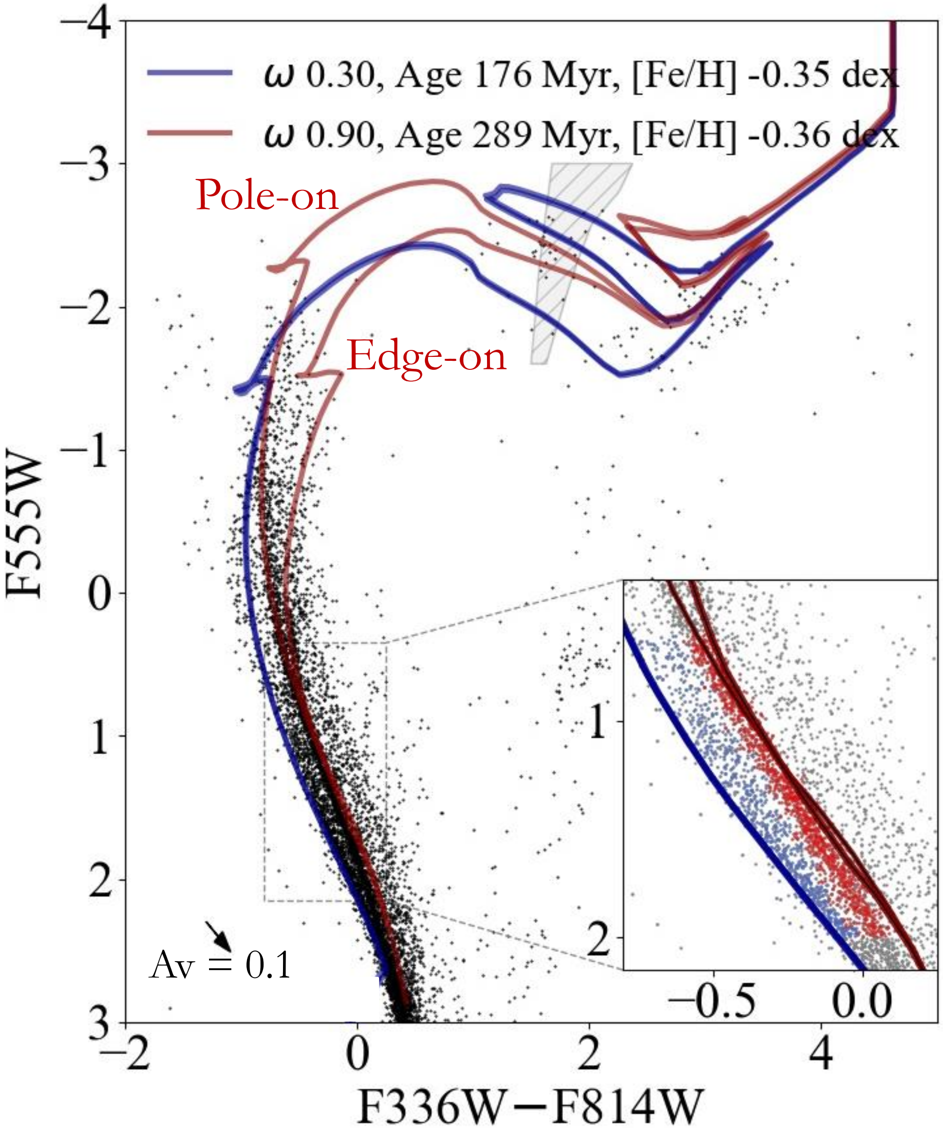

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Conclusions

- Rotation is a fundamental ingredient to study the still unknown processes that regulate the stellar cluster formation and evolution.
- The multiple populations are real features of clusters
- The biggest part of Cepheids belong to the slow rotating young population
- Our new tracks and isochrones, coupled with the adopted methods are a powerful diagnostic tool to disclose the clusters physics.

Submitted soon!!! (GC, Girardi, Bressan et al.)

FUTURE WORKS

- Star clusters simulations
- Use this methodology to study stellar clusters
- Publicly available sets of new PARSEC tracks and isochrones integrated with PARAM and TRIELGAL codes.

http://stev.oapd.inaf.it/cgi-bin/param (PARAM, Rodrigues et al. 2017)
http://stev.oapd.inaf.it/cgi-bin/cmd (TRIELGAL, Girardi, GC et al., submitted)
http://stev.oapd.inaf.it/YBC/ (Bolometric Corrections Tables, Chen et al., in prep)

Thank you

Bayesian Analysis

Bayesian estimation method with the code PARAM (Rodrigues et al. 2014, 2017).
The posterior probability:

$$p(\boldsymbol{x}|\boldsymbol{y}) = \frac{p(\boldsymbol{y}'|\boldsymbol{x})\, p(\boldsymbol{x})}{p(\boldsymbol{y})},$$

where $p(\boldsymbol{y})$ is a normalization factor, $p(\boldsymbol{x})$ represents the prior function.
The likelihood is:

$$p(\boldsymbol{y}'|\boldsymbol{x}) = \prod_i \frac{1}{\sqrt{2\pi}\sigma_{y'}} \times \left(-\frac{(y_i' - y_i)^2}{2\sigma_{y_i}^2}\right).$$

$\boldsymbol{y} = \{M, R, T_{eff}, [Fe/H]\}, \quad \boldsymbol{x} = \{t, \lambda_{ov}\}.$

Priors:

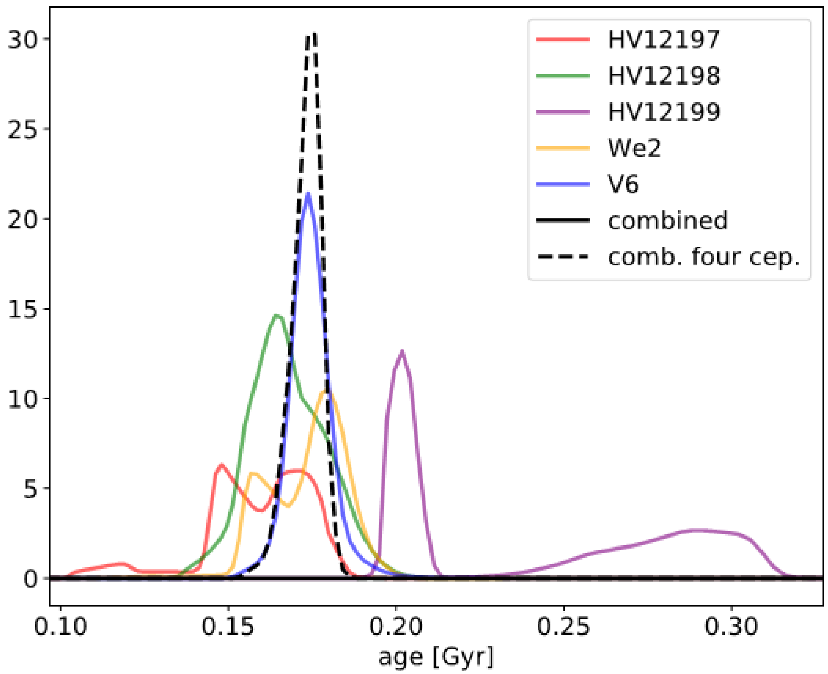
- Flat on ages t range $[5 \times 10^7 \, - 13 \times 10^9 \; yr]$.
- Flat on the overshooting parameter λ_{ov} range.
- A distribution given by the initial mass function (IMF) from (Kroupa)

The probabilities of the two stars of the binary are combined to constrain the λ_{ov} parameter for each binary.

Bayesian Analysis

Results

1D-Marg. PDF



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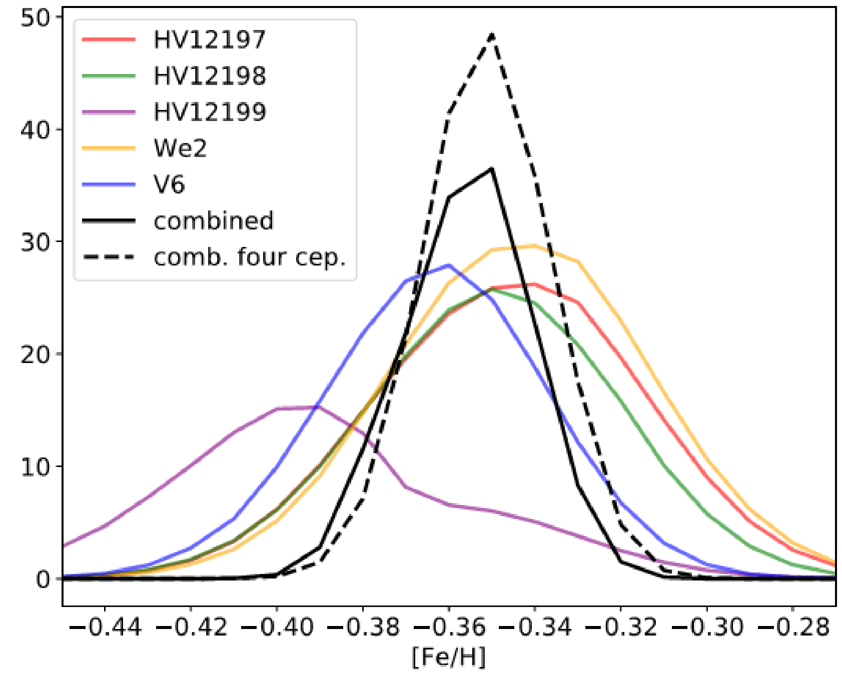

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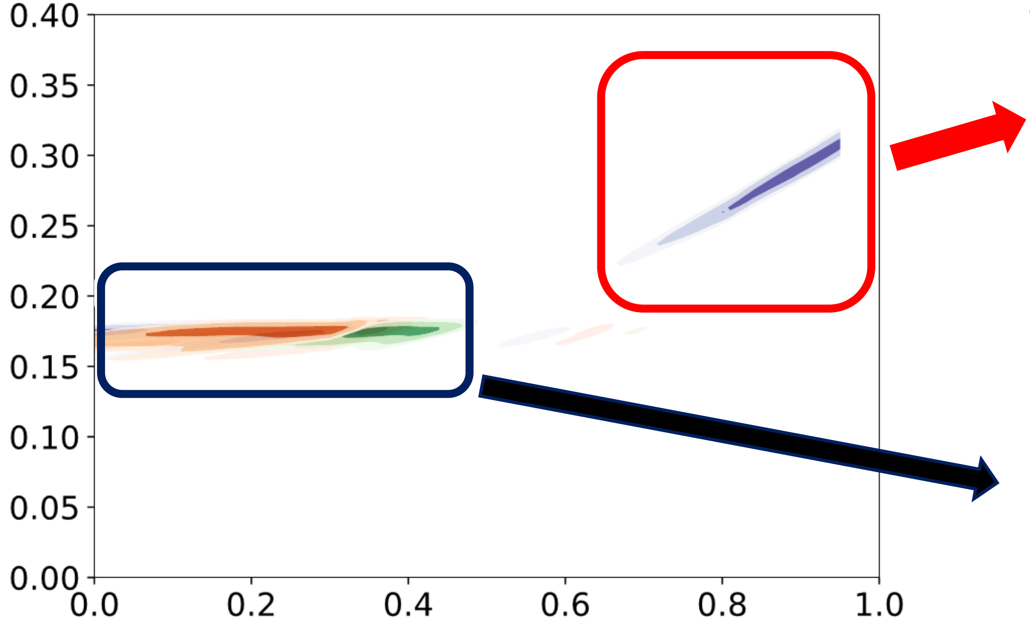

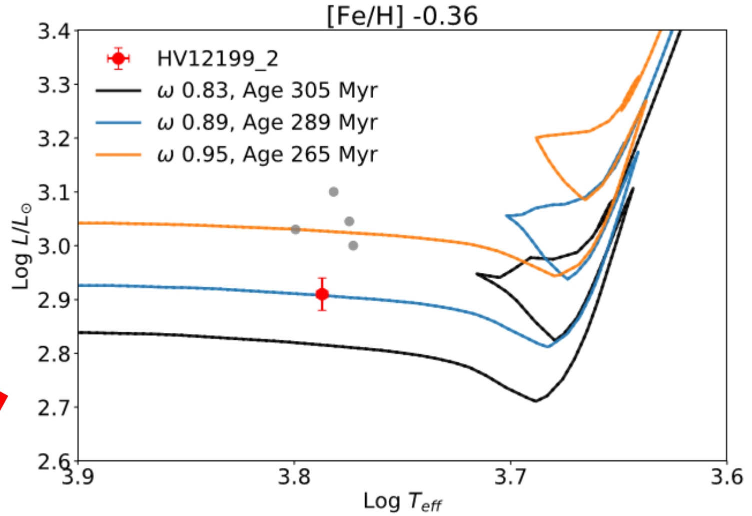

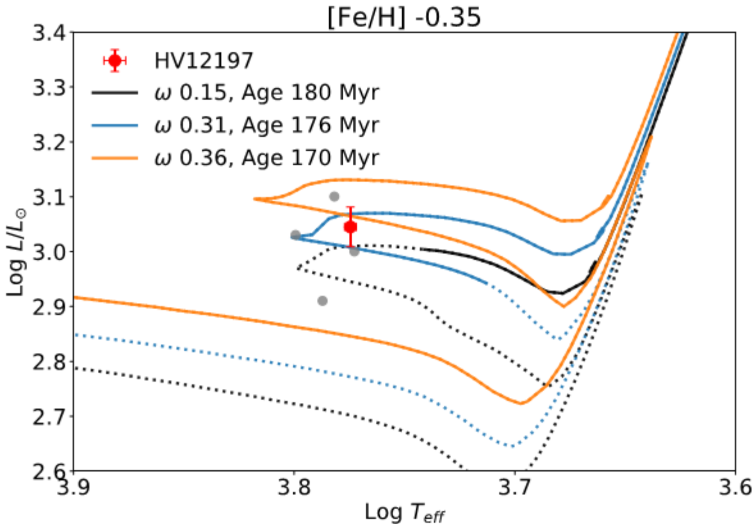

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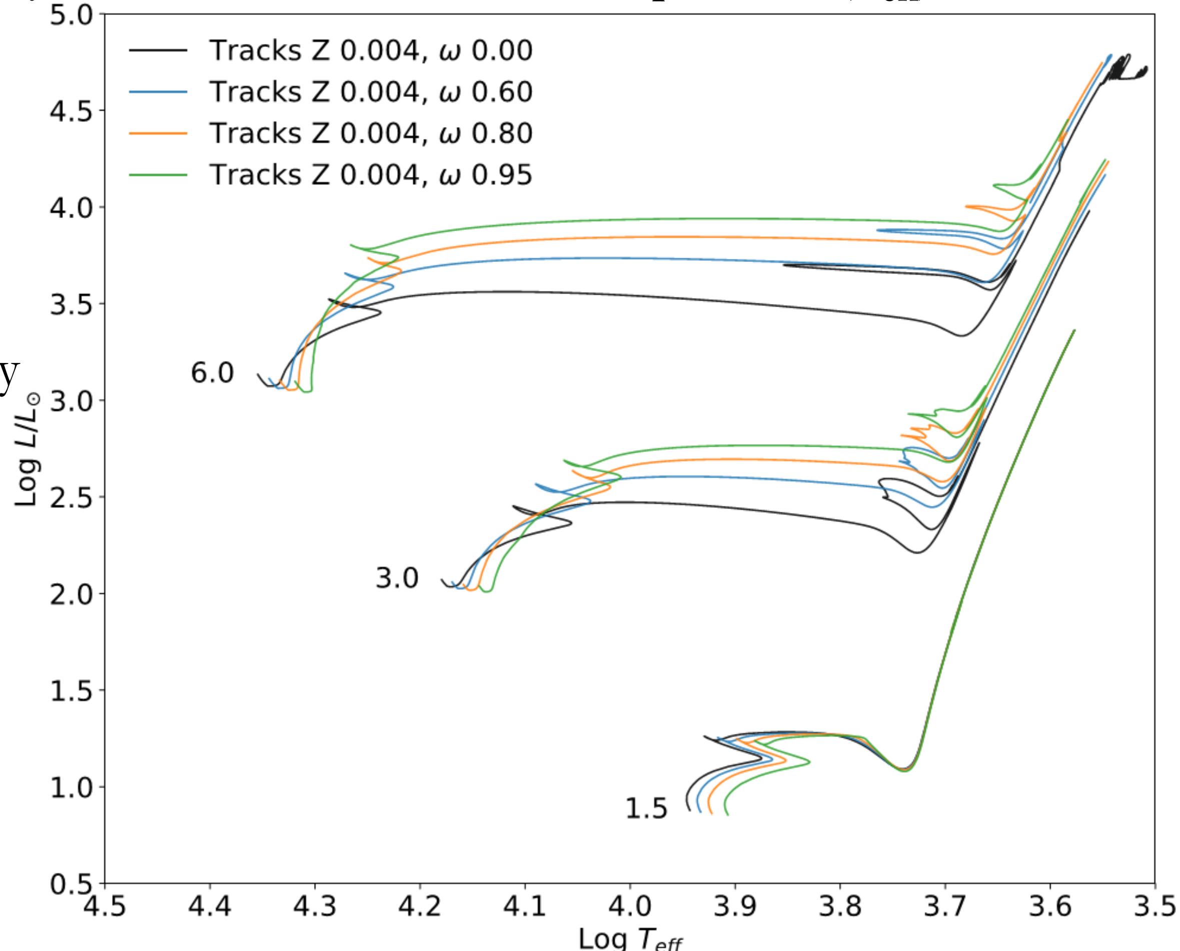

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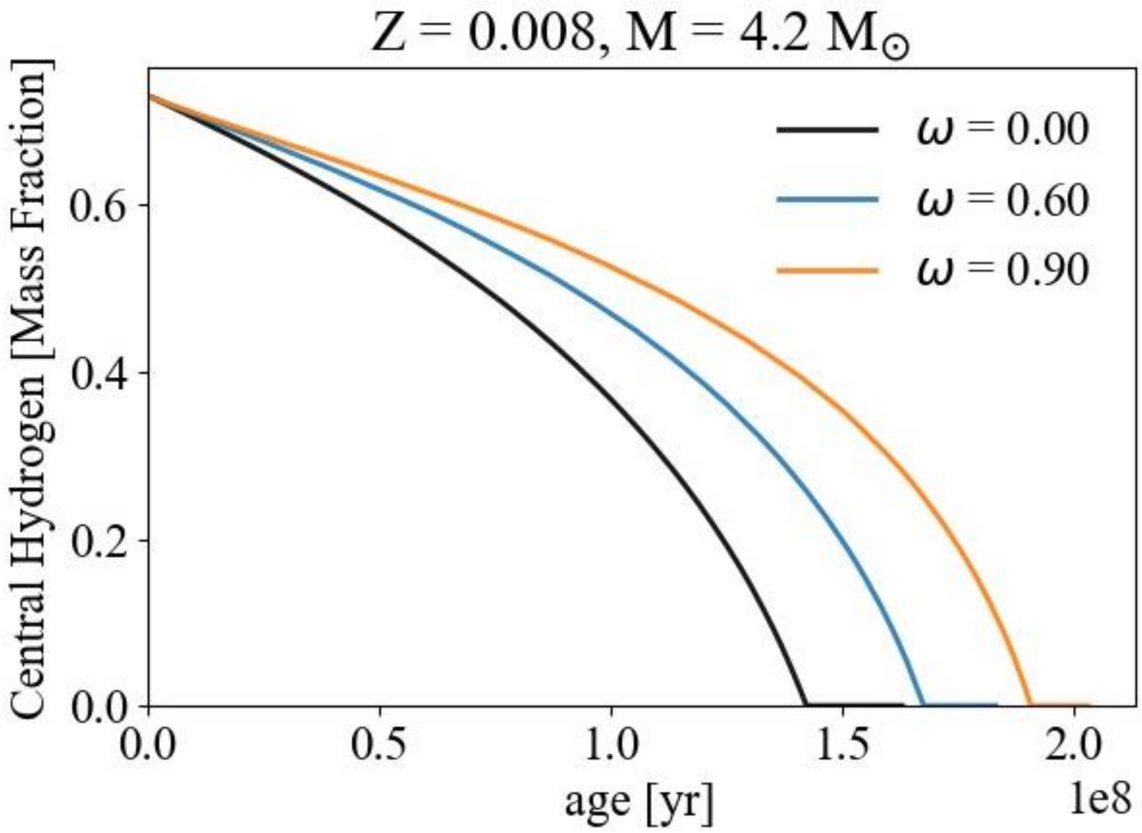
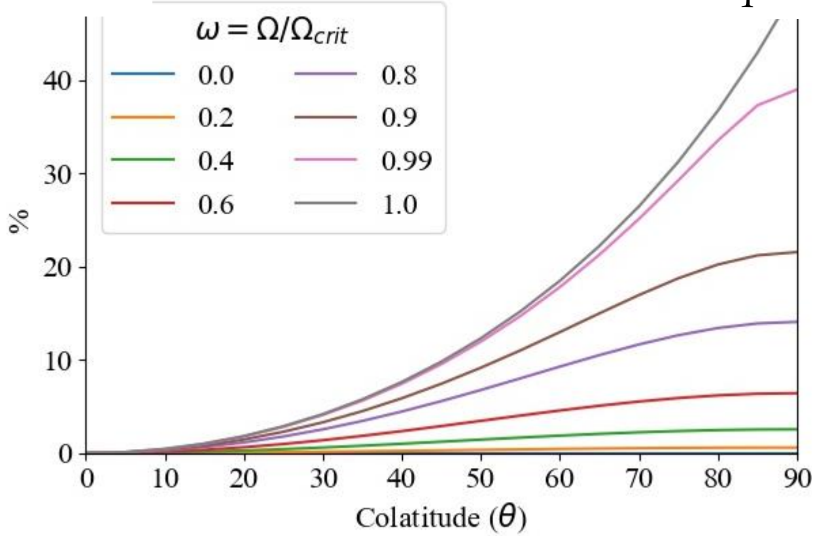


Introduction

Departure from spherical shape of surface

Pole ——— Radius ——— Equator



Gravity darkening (Von Zeipel 1924)

Pole ——— Temperature ——— Equator