Toward a Comprehensive Grid of Cepheid Models with MESA

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- **Non-evolutionary effects on Period change in Magellanic Cepheids I: New binary systems revealed from Light Travel Time Effect [A&A]**
  R. S. Rathour, G. Hajdu, R. Smolec, P. Karczmarek, V. Hocdé, O. Ziółkowska, I. Soszyński, A. Udalski

- **Non-evolutionary effects on Period change in Magellanic Cepheids II: Empirical constraints on non-linear period changes [A&A]**
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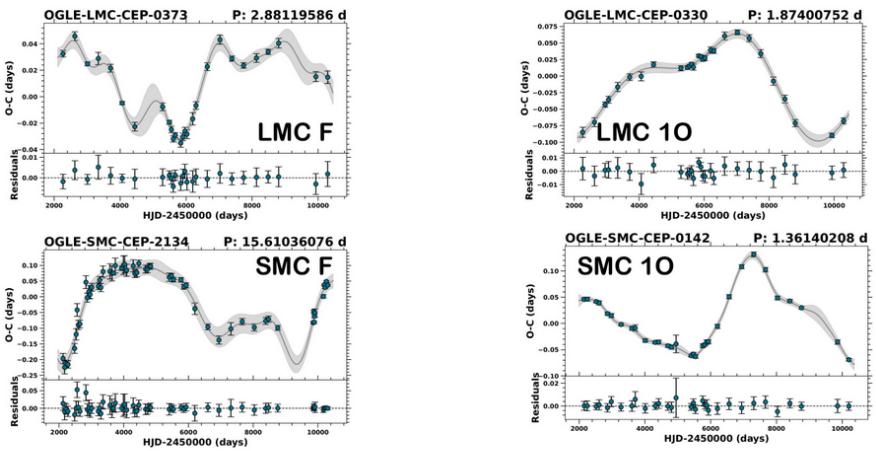
Irregular period change candidates



Key Results

- Candidates: ~1585 Cepheids;LMC: 695; SMC: 890
  Take away: Non-linear period changes are significant fraction (~33%)
- Pulsation mode dependence on non-linear period changes:
  1O mode more susceptible than F mode in Cepheids across the Magellanic Cloud.
- Amplitude of the random period fluctuations grows with pulsation period:
  At a given pulsation period, larger in 1O mode Cepheids.

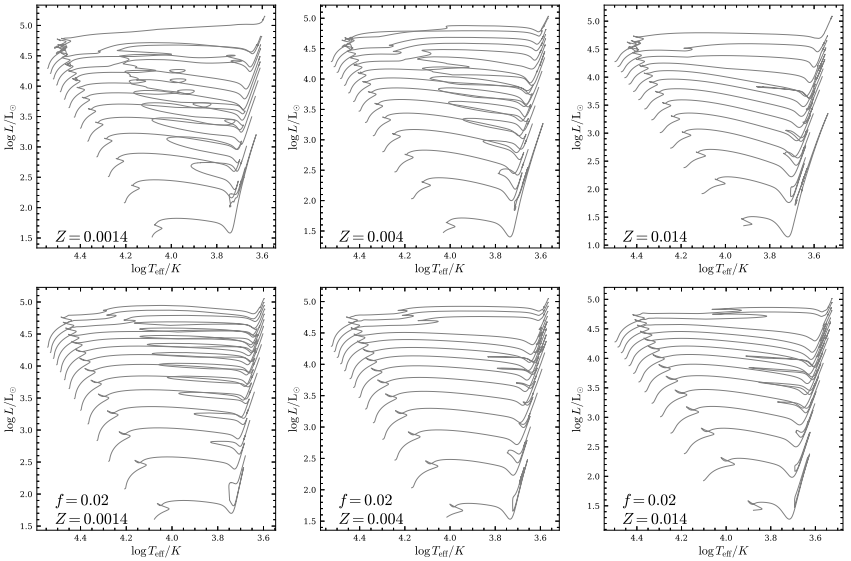
Classical Cepheids

Main goal: Construct a huge grid of self-consistent evolutionary and pulsation models for classical Cepheids.

- ⋆ There are a lot of **secondary** components to the evolutionary models with different prescriptions.
- ⋆ The choice of particular option depends on author's preference - no generally recognized physically motivated choices.
- ⋆ The goal of our first paper was to estimate uncertainties rising from this freedom.

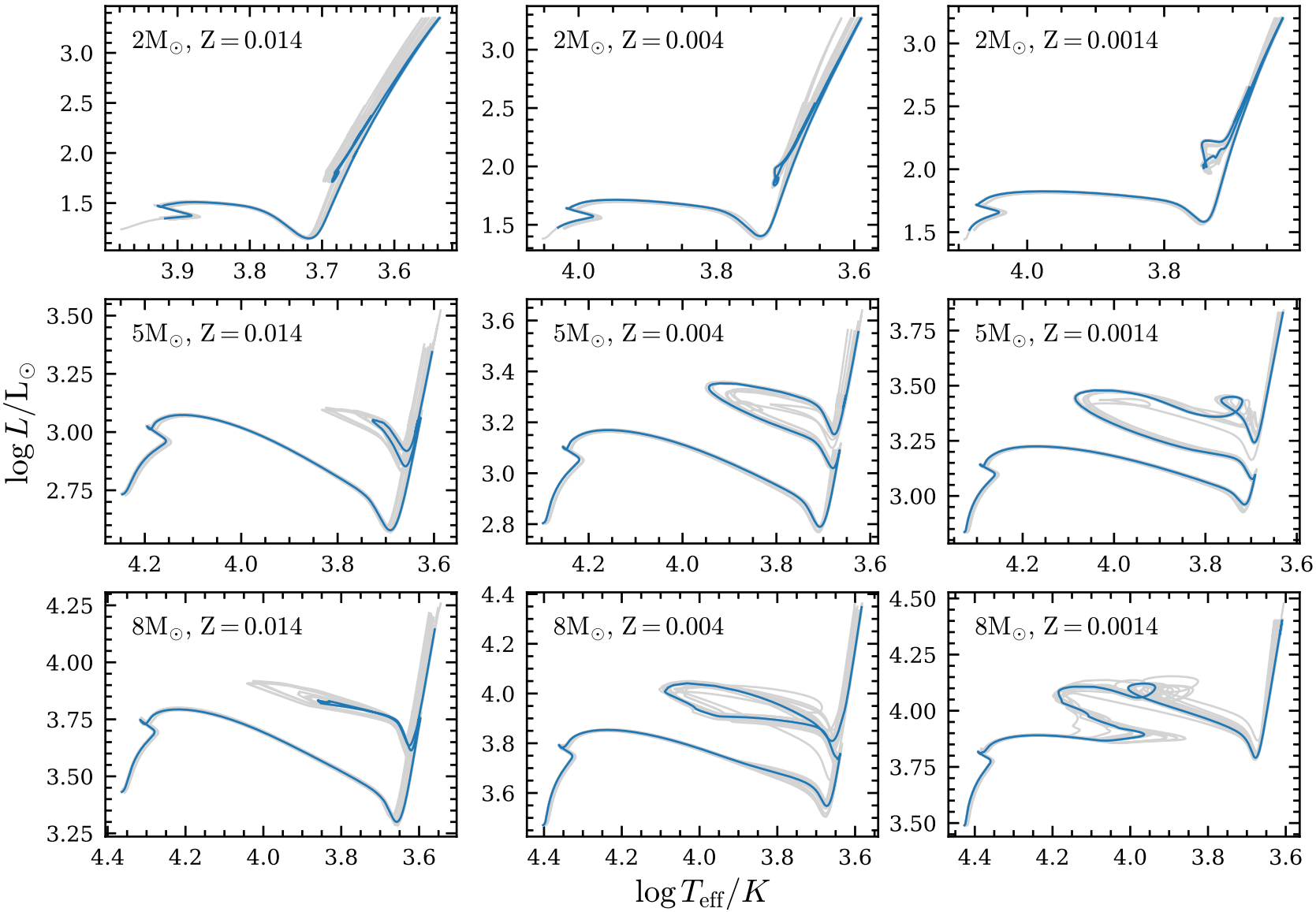
MESA

- ⋆ (M/Z) = 2-15 $M_\odot$ / 0.0014, 0.004, 0.014
- ⋆ overshooting and canonical models



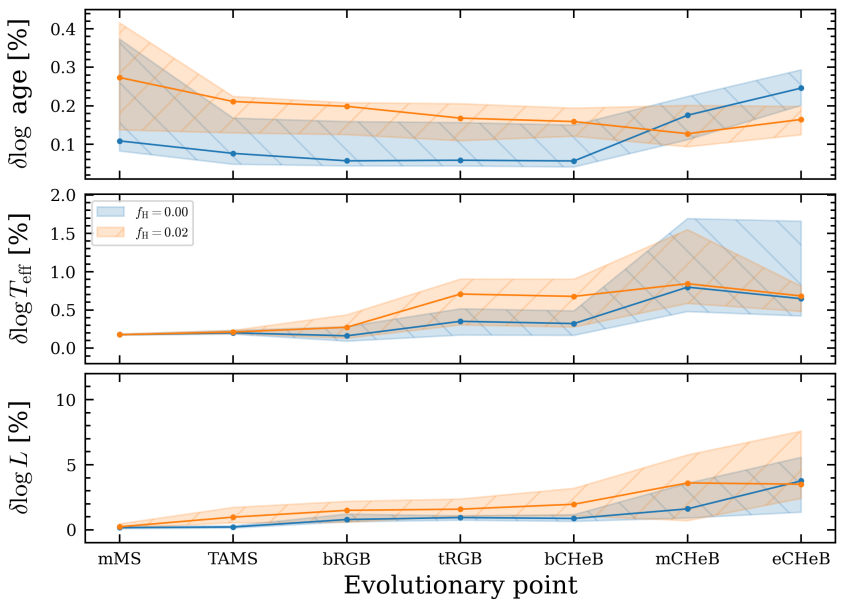
Reference tracks and 22 varied tracks.

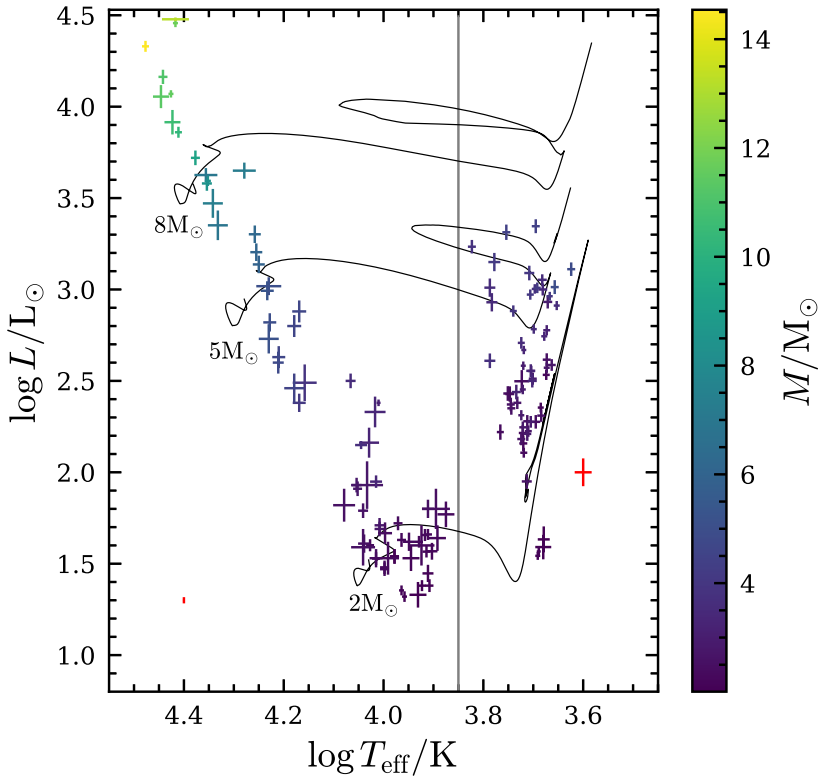
Next to the reference model (blue), we construct 22 modified models (grey) with modified atmospheres, MLT, nuclear reactions, etc.



The spread at evolutionary benchmark points gives us systematic uncertainties; They can be averaged over M, Z.

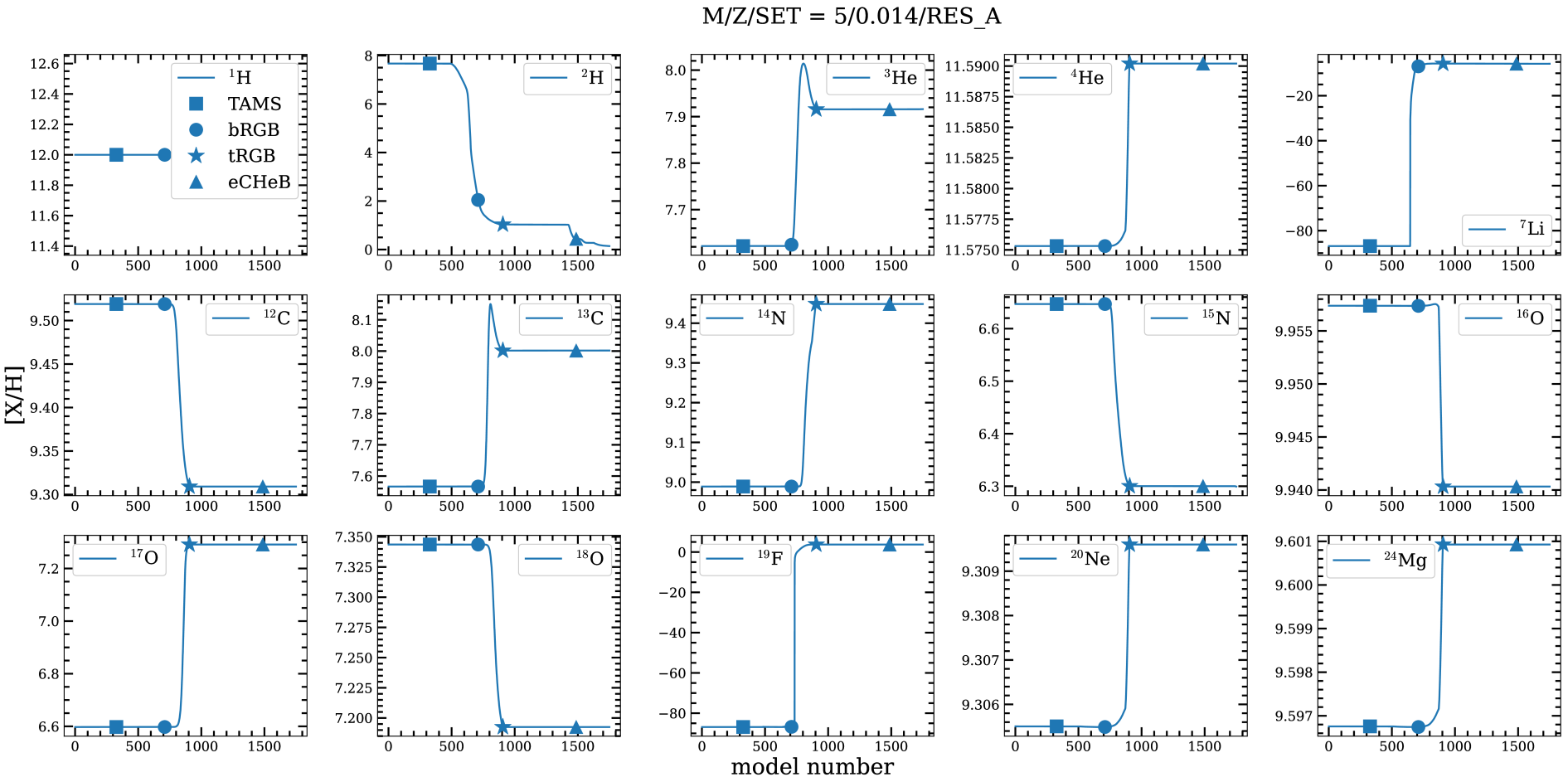
- ⋆ Systematic MESA uncertainties are significant for He-burning stars;
- ⋆ Slightly higher for higher (solar) Z;
- ⋆ Higher-mass stars (>9$M_\odot$) are tricky to model
- ⋆ Convection, metal mixture, nuclear reactions affect the Blue Loop most.



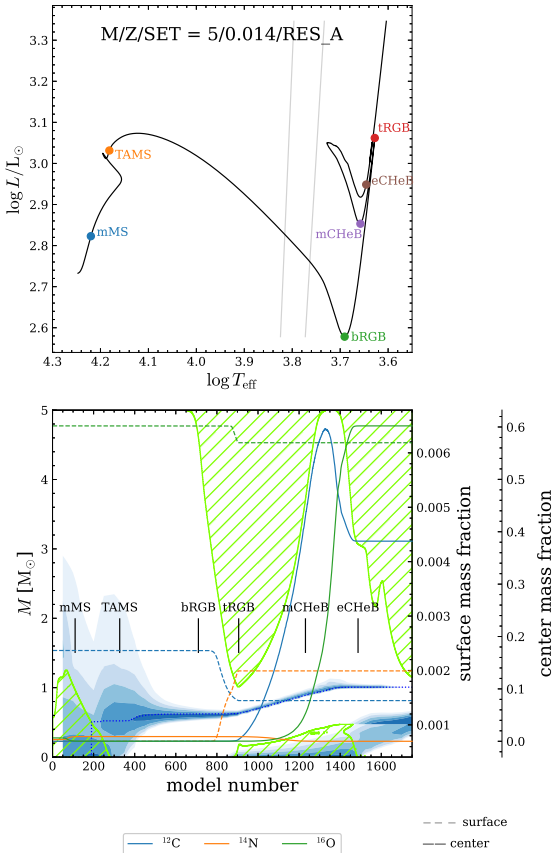


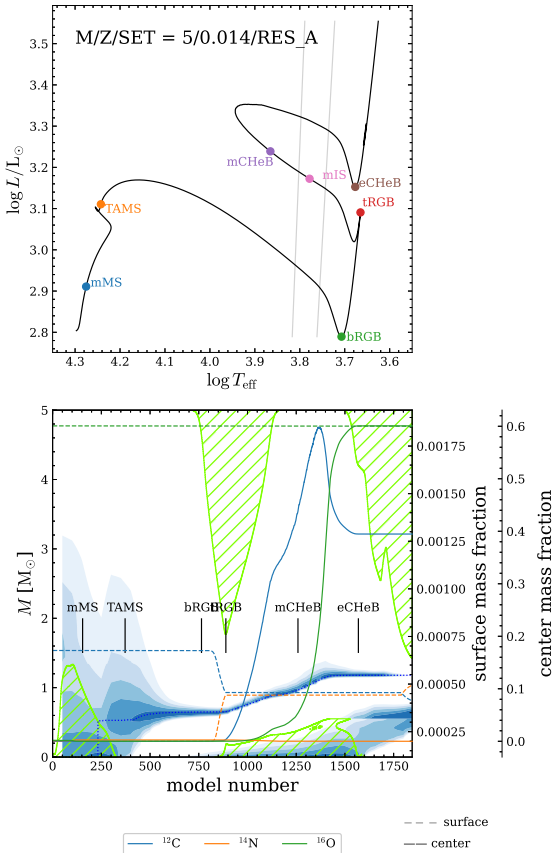
Part II: Abundances

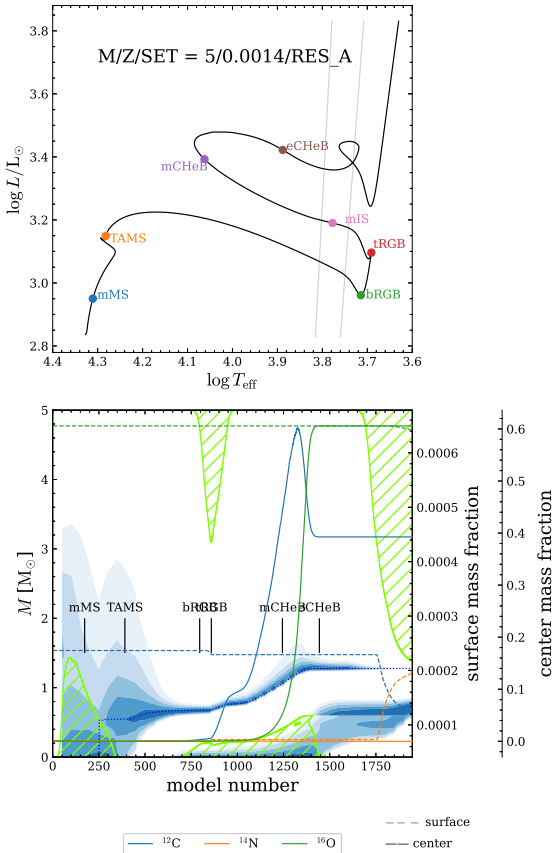
The same grid, similar procedure;
Significant difference - 0.01 dex.



The depth of the convection zone affects surface abundances.

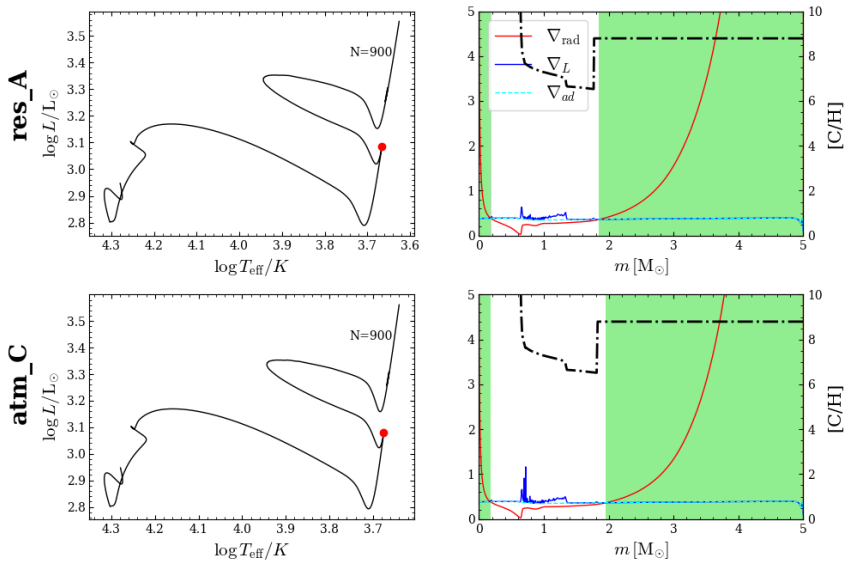


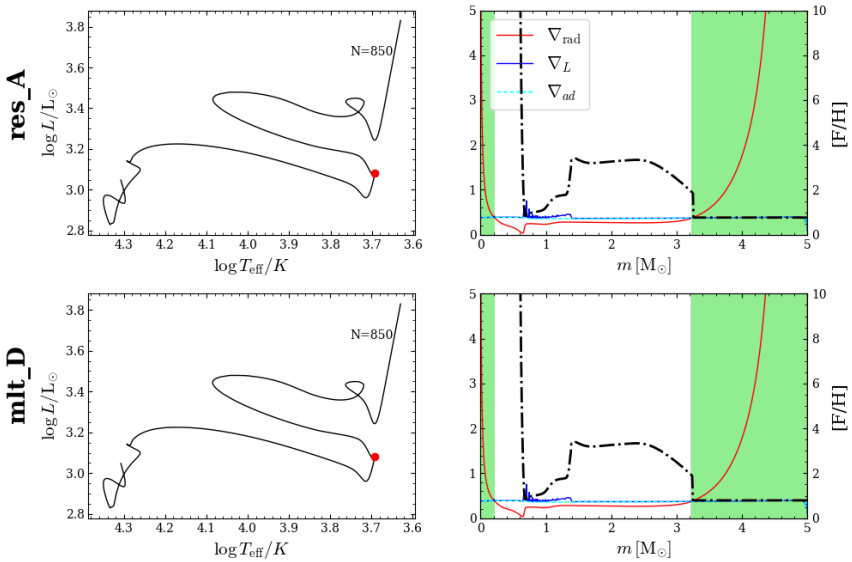




Abundances

Isotopes of steep profiles are affected more, e.g. ^{12}C and ^{19}F



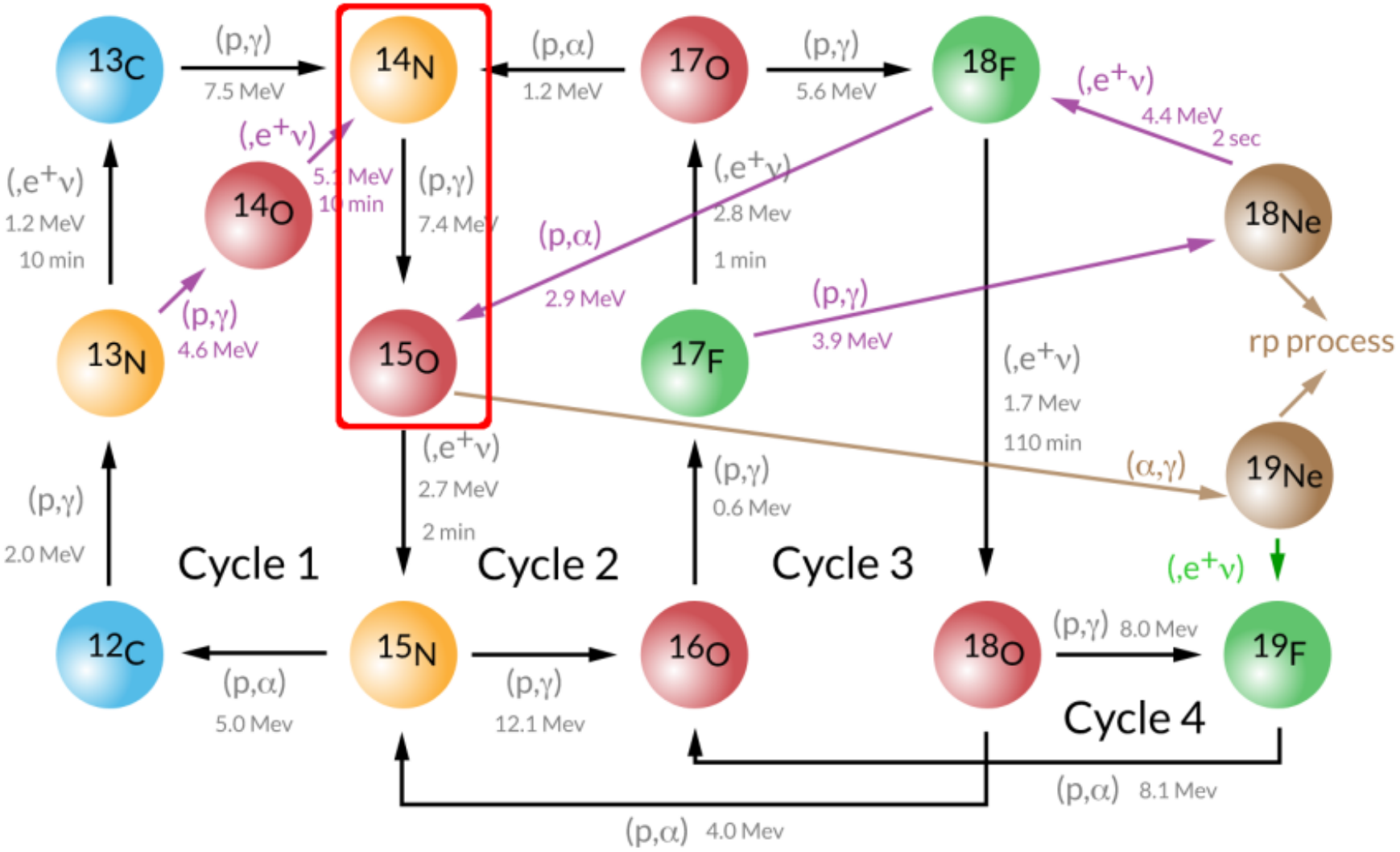


Scientific activities & outreach

- ⋆ 8th TESS/15th Kepler Asteroseismic Science Consortium Workshop, Porto
- ⋆ Porto Summer School on Asteroseismology, From Pixels to Stellar Ages
- ⋆ RR Lyrae and Cepheid meeting 2024, Marrakesh

Extra slides

CNO cycle, credit to Frank Timmes

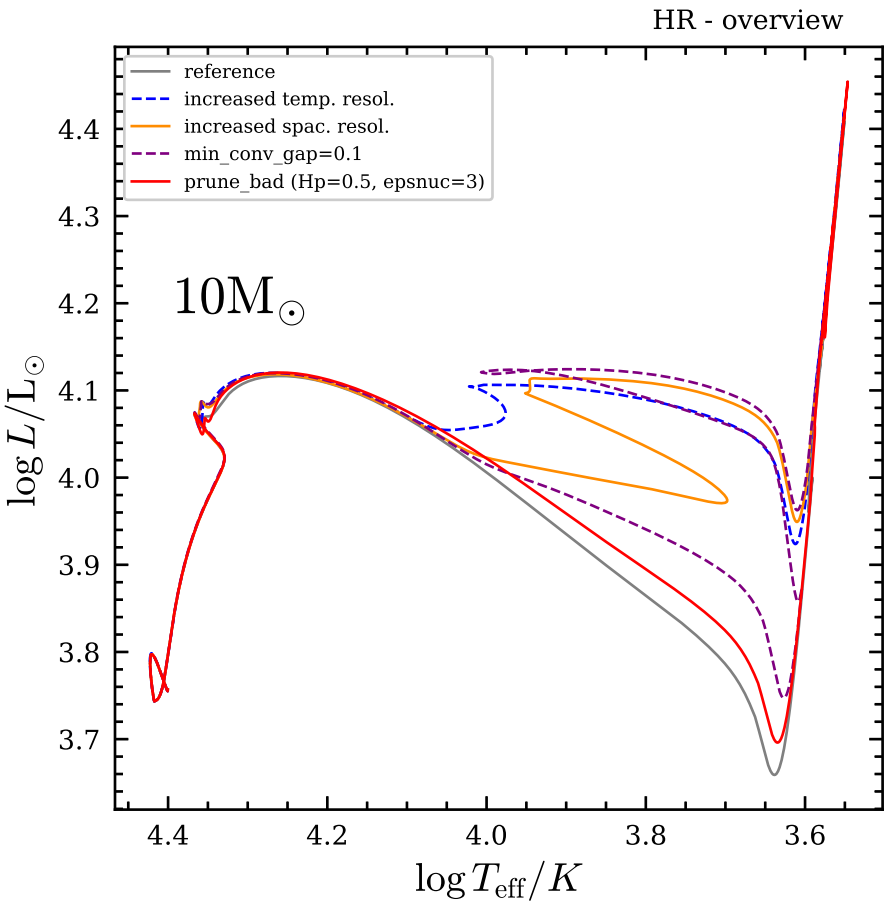


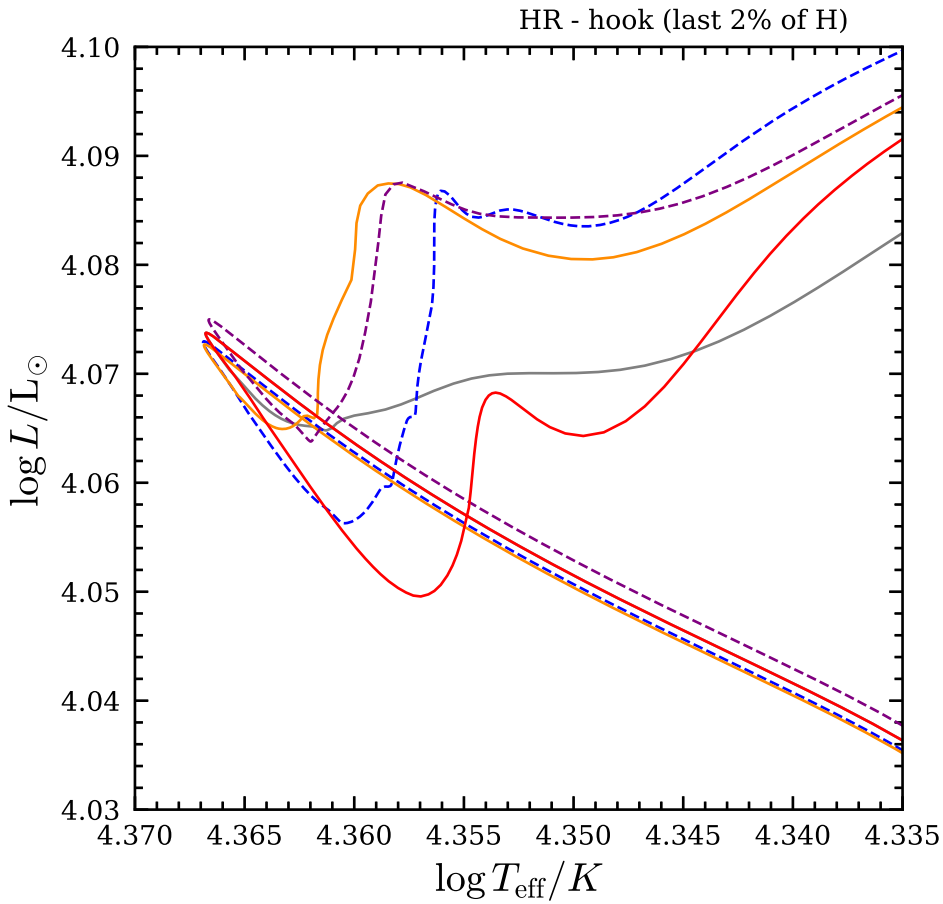
CNO: $T_9 < 0.2$ Hot CNO: $0.2 < T_9 < 0.5$ rp process: $T_9 > 0.5$

The problem with more massive models

For $M \geqslant 9M_\odot$ the tracks are qualitatively different.

- ⋆ No convergence (increasing numerical resolution changes shape of the track);
- ⋆ Erratic post-MS evolution;
- ⋆ Reason - thin, short-lived convective shells after MS that affect further evolution.





Thin convective shells in a massive model on a Kippenhahn diagram