Novel Astrophysical Constraint on Axion-Photon Coupling

Maurizio Giannotti,
Barry University

In collaboration with:
A. Friedland, *Los Alamos National Laboratory*
M.Wise, *Barry University*

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Summary

- Evolution of intermediate mass stars

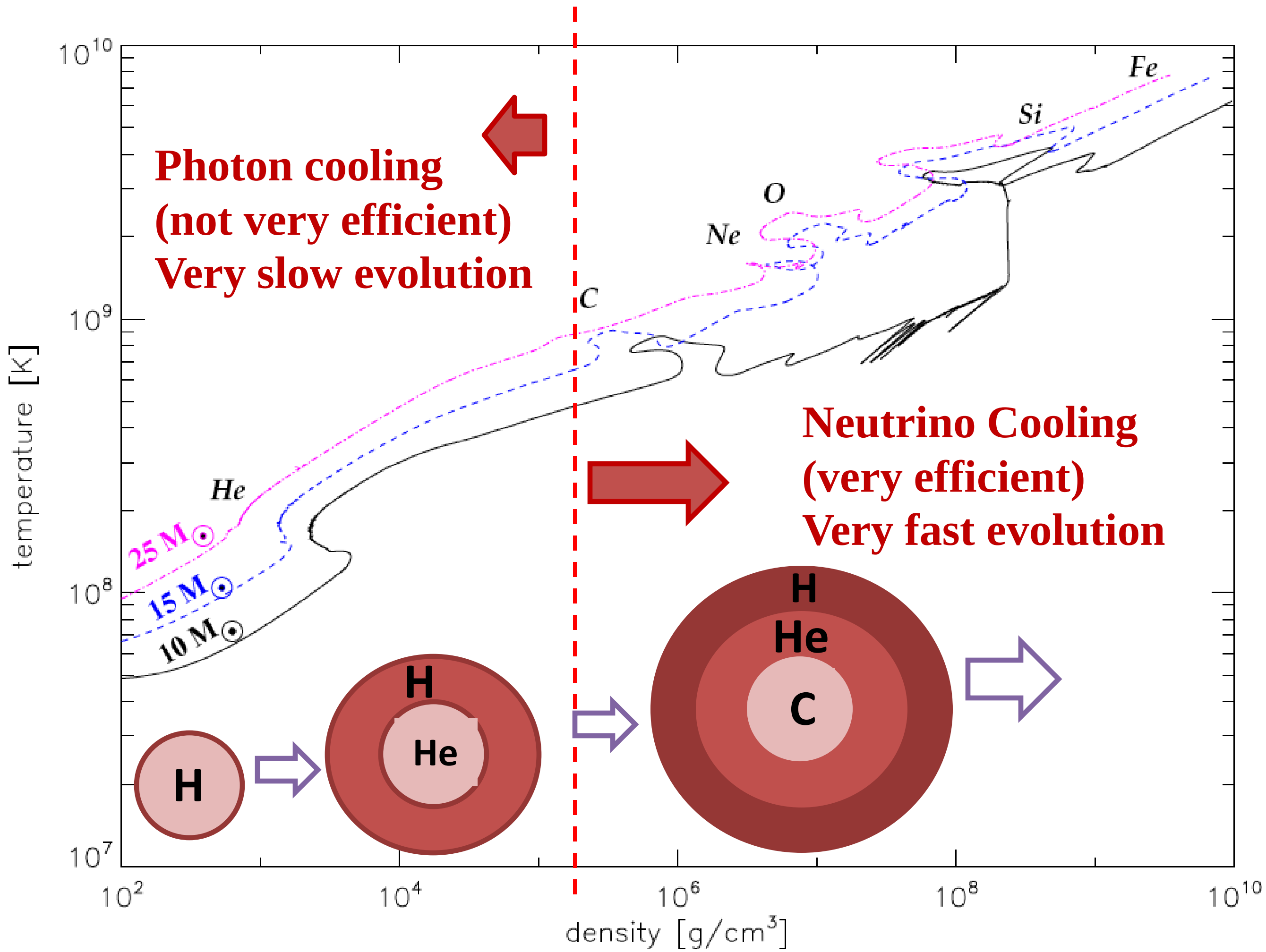
- Blue loop phase and the observable evolutionary sequences of intermediate mass stars

- Blue and red super giants

- The axion. Current bounds

- New constraints on axion-photon coupling from observations of blue and red super giants

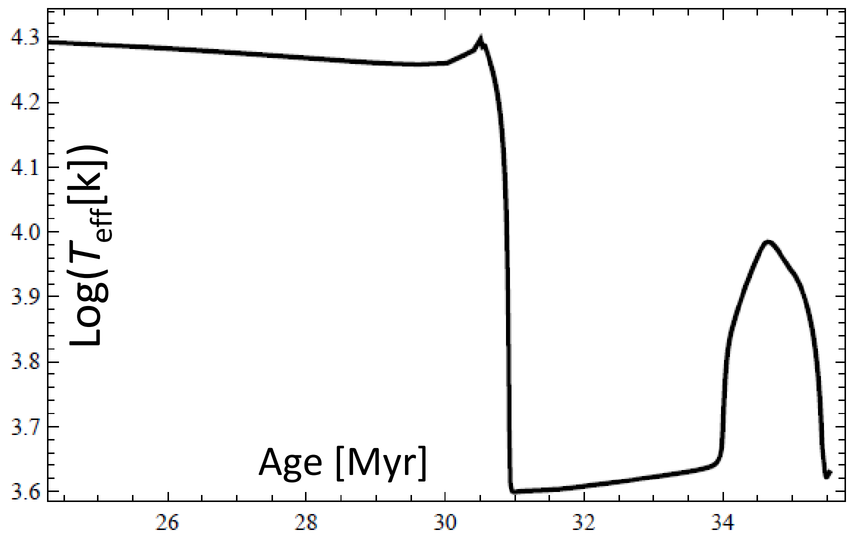
Core Evolution of Massive Stars

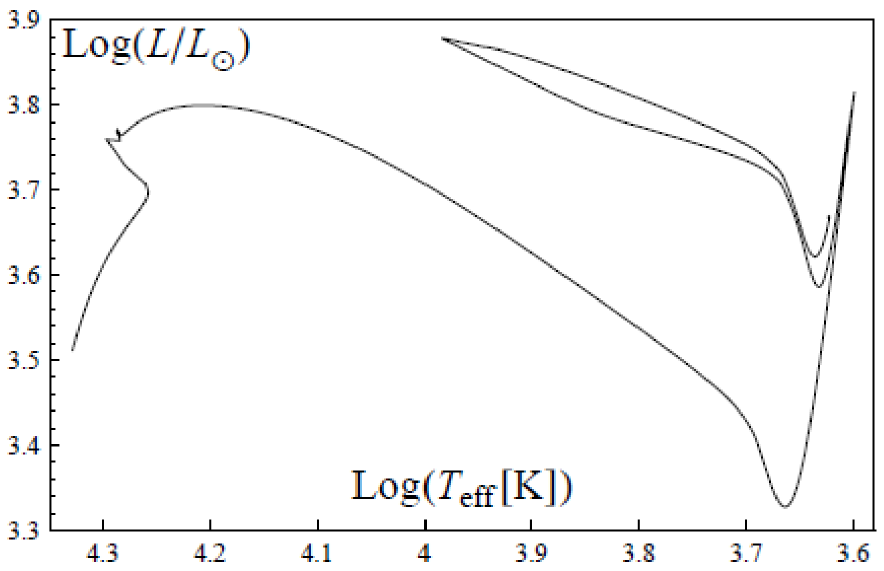


In collaboration with A.Heger, A.Friedland and V.Cirigliano,
using the Kepler code for stellar evolution APJ:696 (2009)

Observable evolutionary Phases: Central H- and He-burning

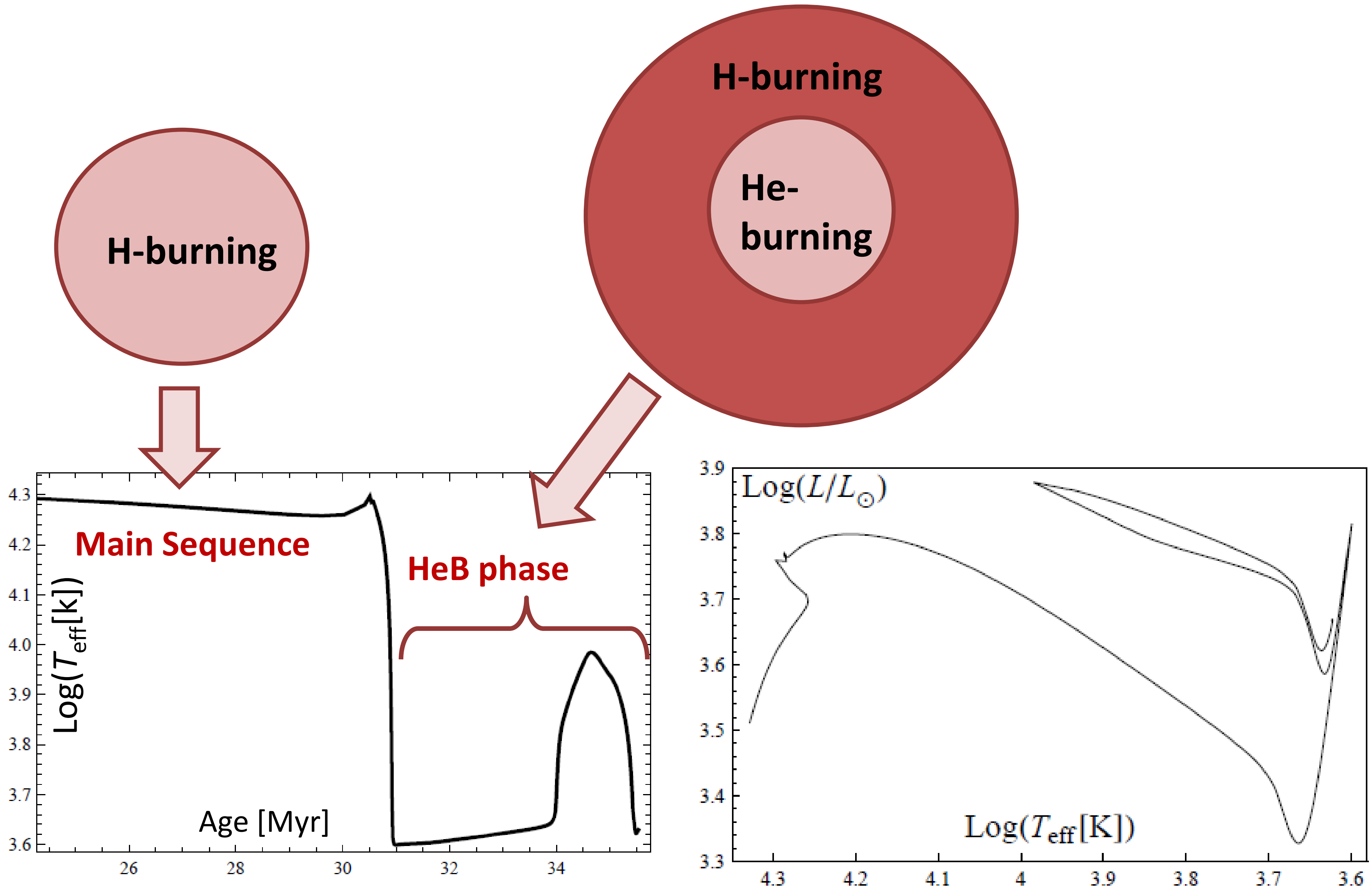
Massive stars spend 80% to 90% of their life burning hydrogen in their core (H-burning stage), and almost all the rest of their life burning helium in the core and hydrogen in a shell (He-burning stage). Consequently, these are the only stages that can be observed astronomically.





Simulations for a $8M_\odot$, solar metallicty, from main sequence to end of He-burning.

MESA (Modules for Experiments in Stellar Astrophysics), Paxton et al. *ApJ Suppl*. **192** 3 (2011) [arXiv:1009.1622]



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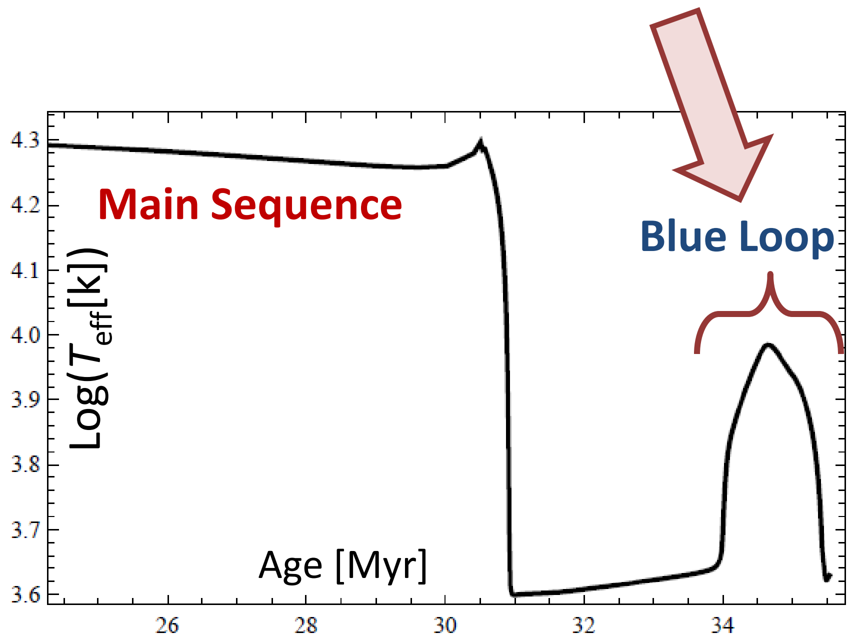
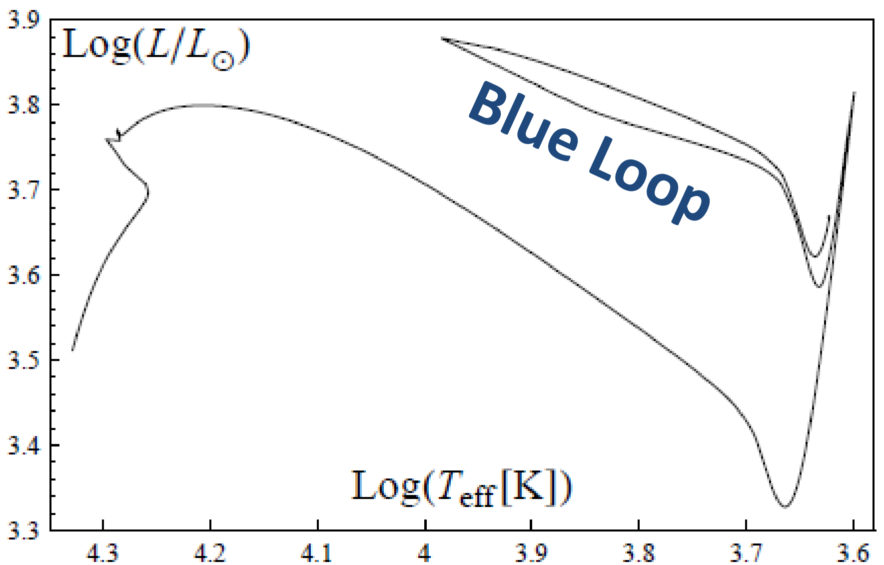
Observable evolutionary Phases: Central H- and He-burning

Blue Loop:

the <u>beginning</u> is set by the H-burning shell time scale the <u>end</u> is set by the He-burning core time scale [e.g., Kippenhahn and Weigert (1994)]





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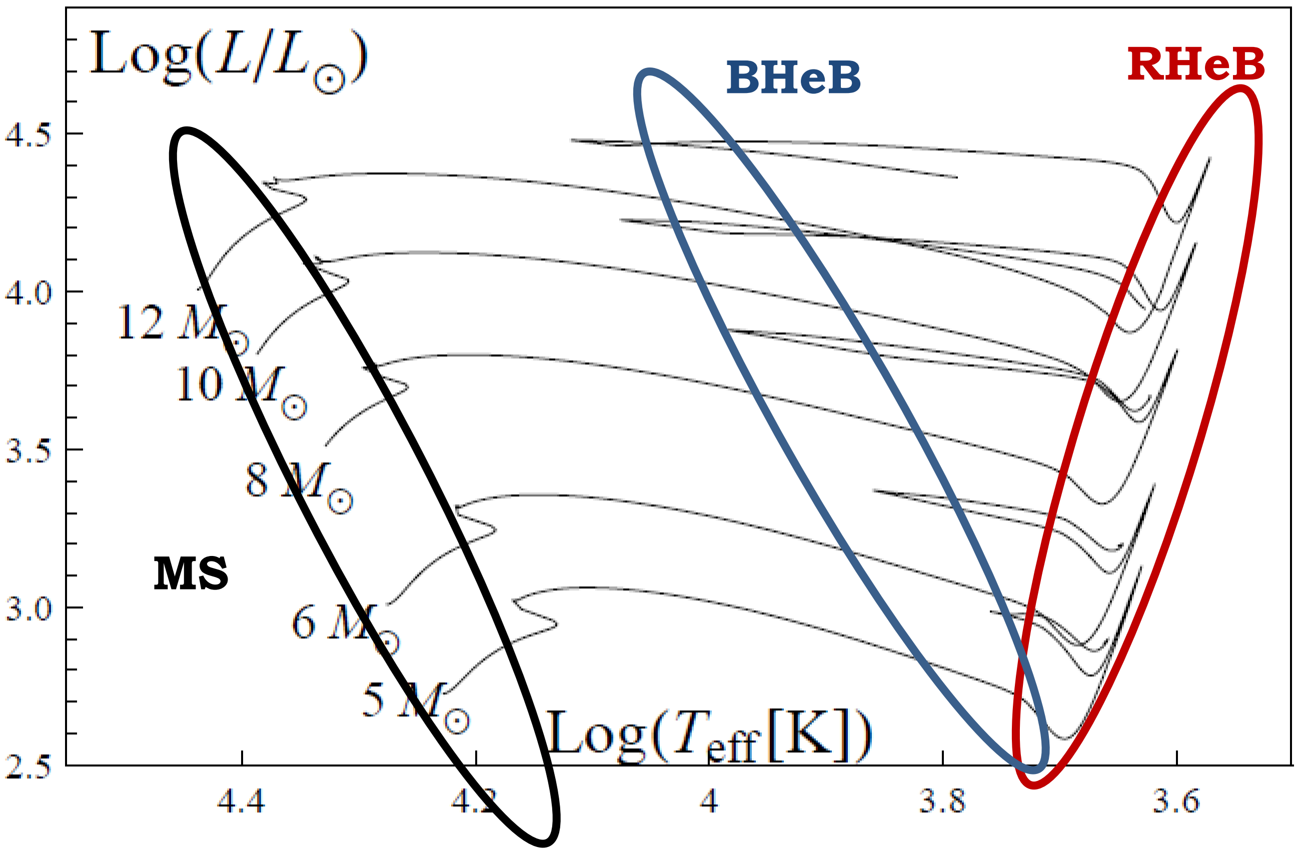
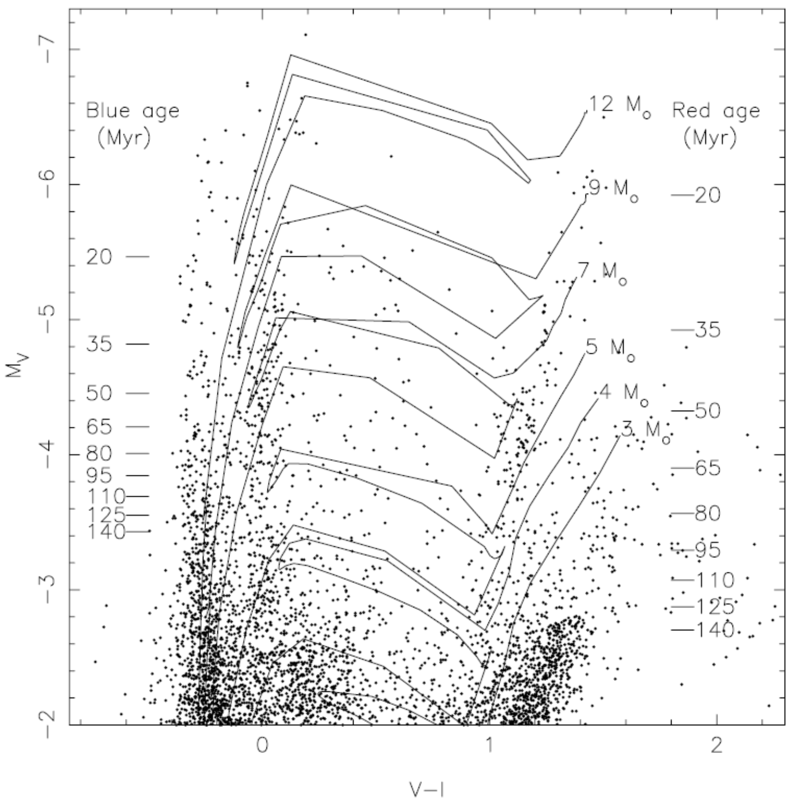


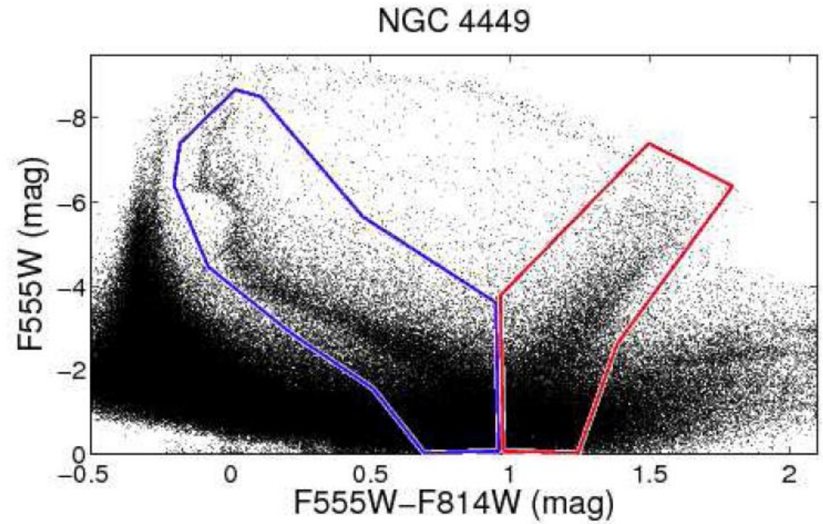
Most of the star life-time is spent in one of the three sequences: the **Main Sequence** (central H-burning), the **Red** central **He-Burning** sequence, and the **Blue** central **He-Burning** sequence

Simulations of evolution in H-R diagram of stars with solar metallicty, from main sequence to end of He-burning. **[MESA]**

Observable evolutionary Phases: Central H- and He-burning

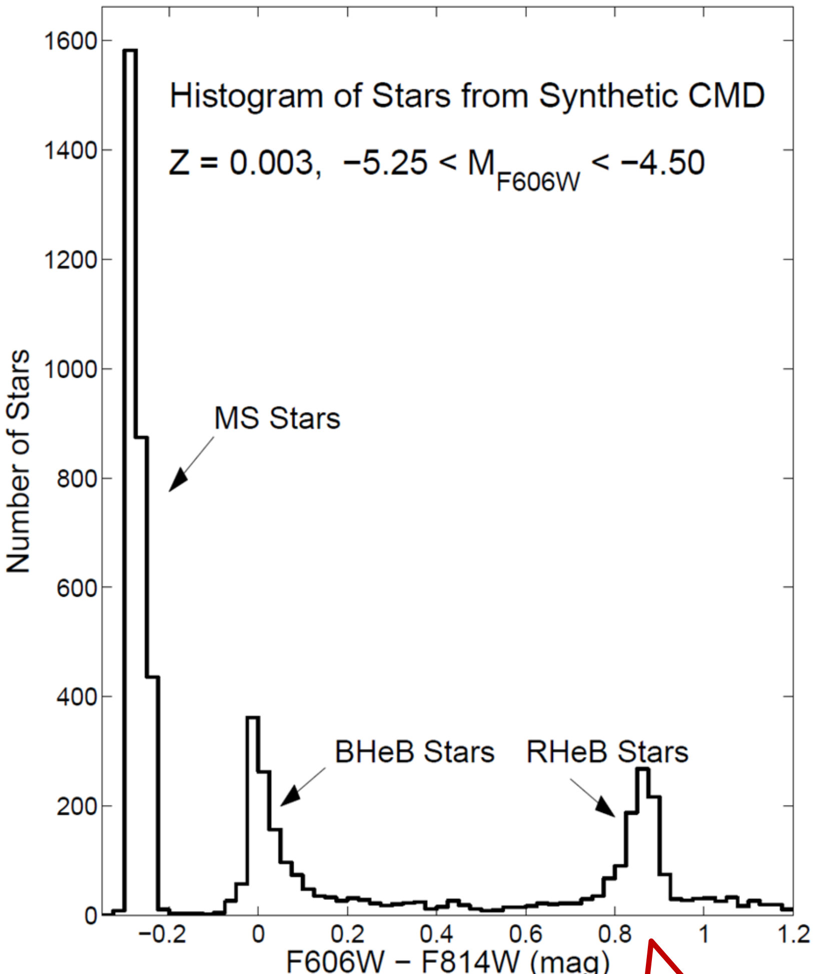


Color-magnitude diagram for Sextans A
Dohm-Palmer and E. D. Skillman, (2002)



from Kristen B. W. McQuinn et. al., Astrophys.J. 740 (2011)

Observable evolutionary Phases: Central H- and He-burning



Log T[k]=4

Log T[k]=3.7

The relative number and position in the color magnitude diagram of the red and blue He-burning stars has been subject to deep investigation in the last decade.

Currently there is a small discrepancy between predictions and observations: (at high luminosities) B/R is too high, and the blues stars are too blue.

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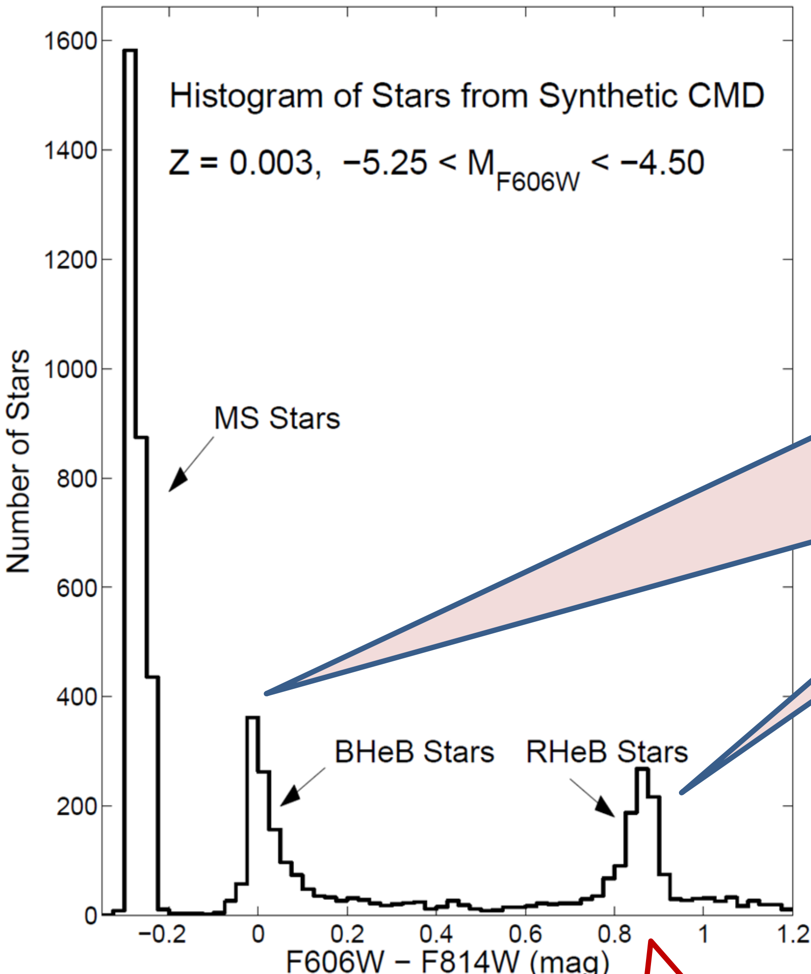
Observable evolutionary Phases: Central H- and He-burning



Any **new-physics** process that is more efficient in the He-burning core than in the H-burning shell during the He-burning stage would change the relative position and number of RHeB and BHeBa stars.

From Kristen B. W. McQuinn et. al., Astrophys.J. 740 (2011)

Log T[k]=4

Log T[k]=3.7

The Axion

Axions are hypothetical particles whose existence is a prediction of the Peccei-Quinn solution of the Strong CP problem.

Peccei and Quinn (1977)
Weinberg (1978), Wilczek (1978)

In addition, the axion is a prominent dark matter candidate

Preskill, Wise and Wilczek (1983)
Abbott and Sikivie (1983)
Dine and Fischler (1983)

Axions interact with matter and radiation:

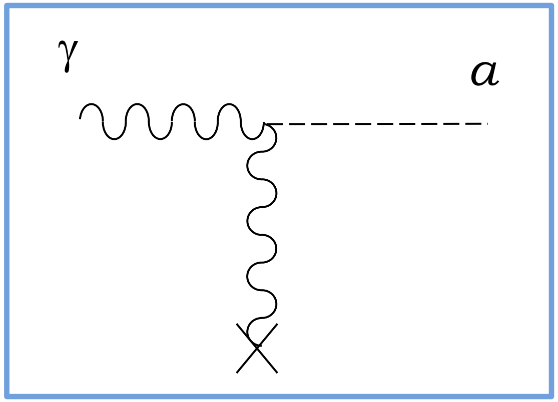
$$L_{a\gamma} = -\frac{1}{4}\, g_{a\gamma} a\, F_{\mu\nu} \tilde{F}^{\mu\nu}$$

Here we are interested on in the interactions with photons.
The current bound on the axion-photon coupling is $g_{a\gamma} \leq 10^{-10}\mathrm{GeV}^{-1}$

Today, the research in axion is experiencing a revival in terms of new experimental effort for its detection, and new theoretical ideas and models.

Experimental Axion Search

One of the major experiments searching for the axion is the Cern Axion Solar Telescope (**CAST**), based on the microwave cavity detection of axions proposed by P. Sikivie (1983).



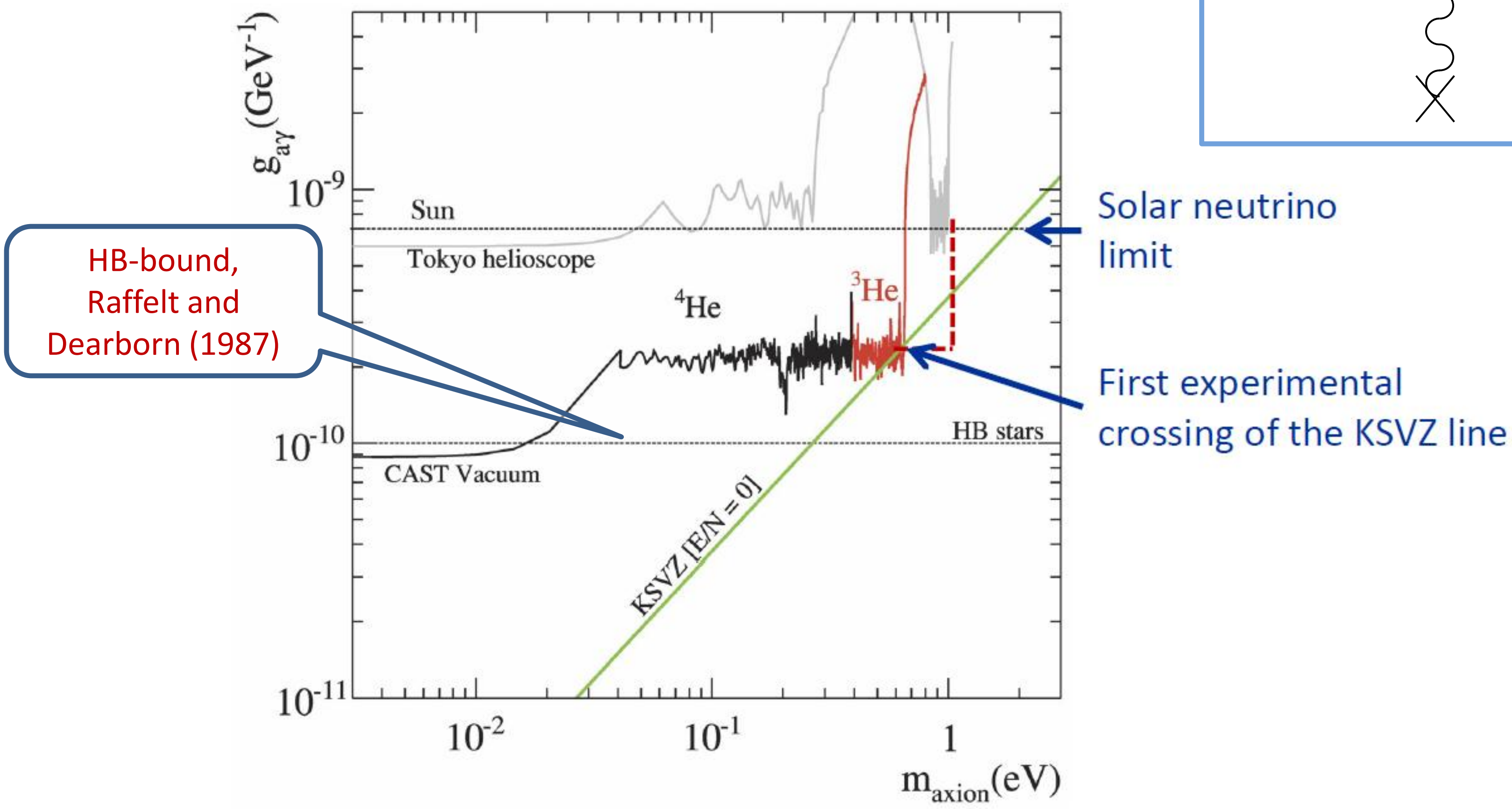
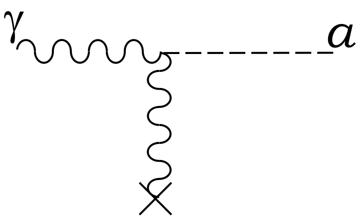


Figure from G.Raffelt, talk given at Vista in Axion Physics, INT, Seattle, April 2012

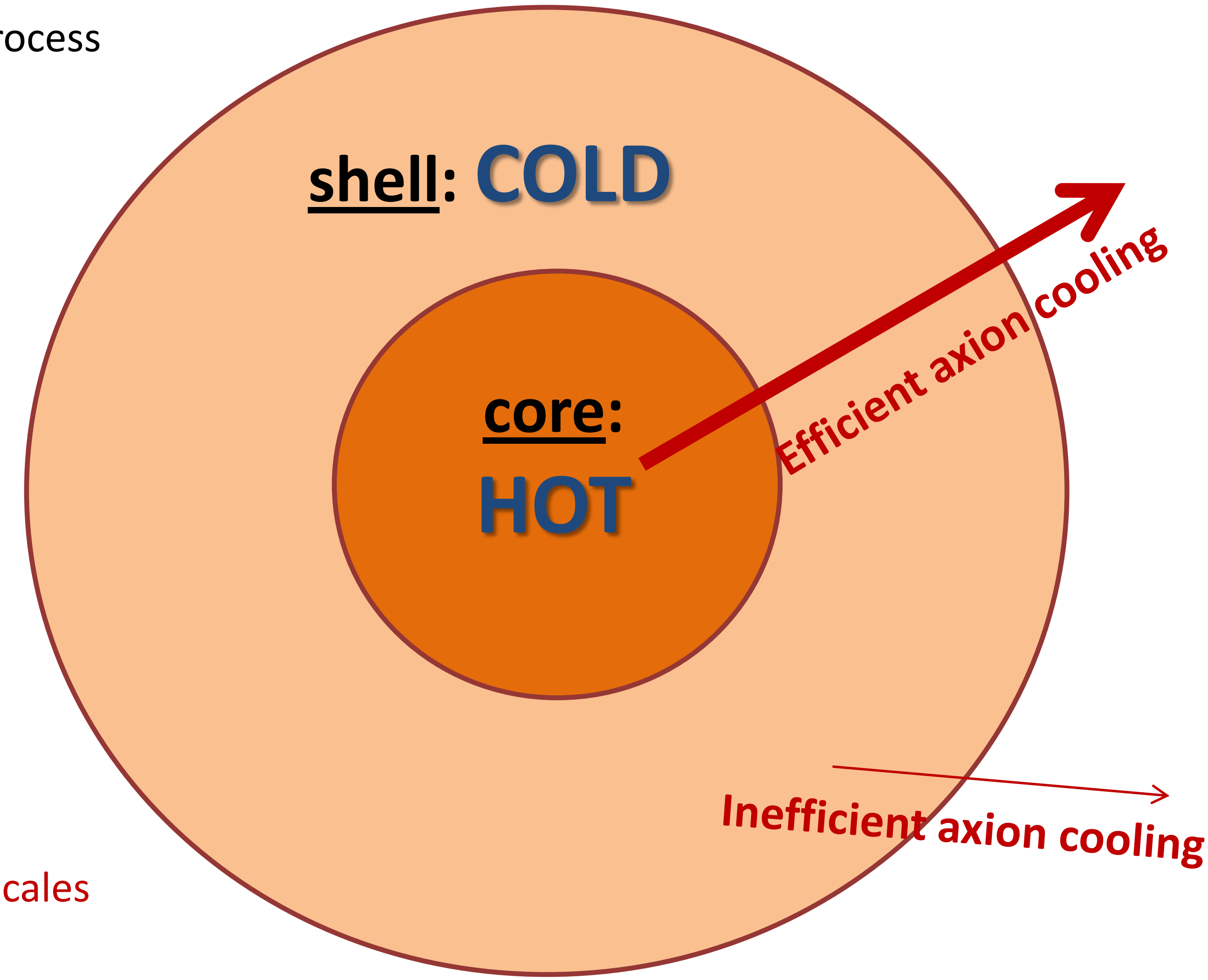
The Axion and the Blue Loop

Axions can be produced in stars through the Primakoff process



This process is very sensitive to the temperature of the plasma and so it is more efficient in the hot core than in the cold shell.

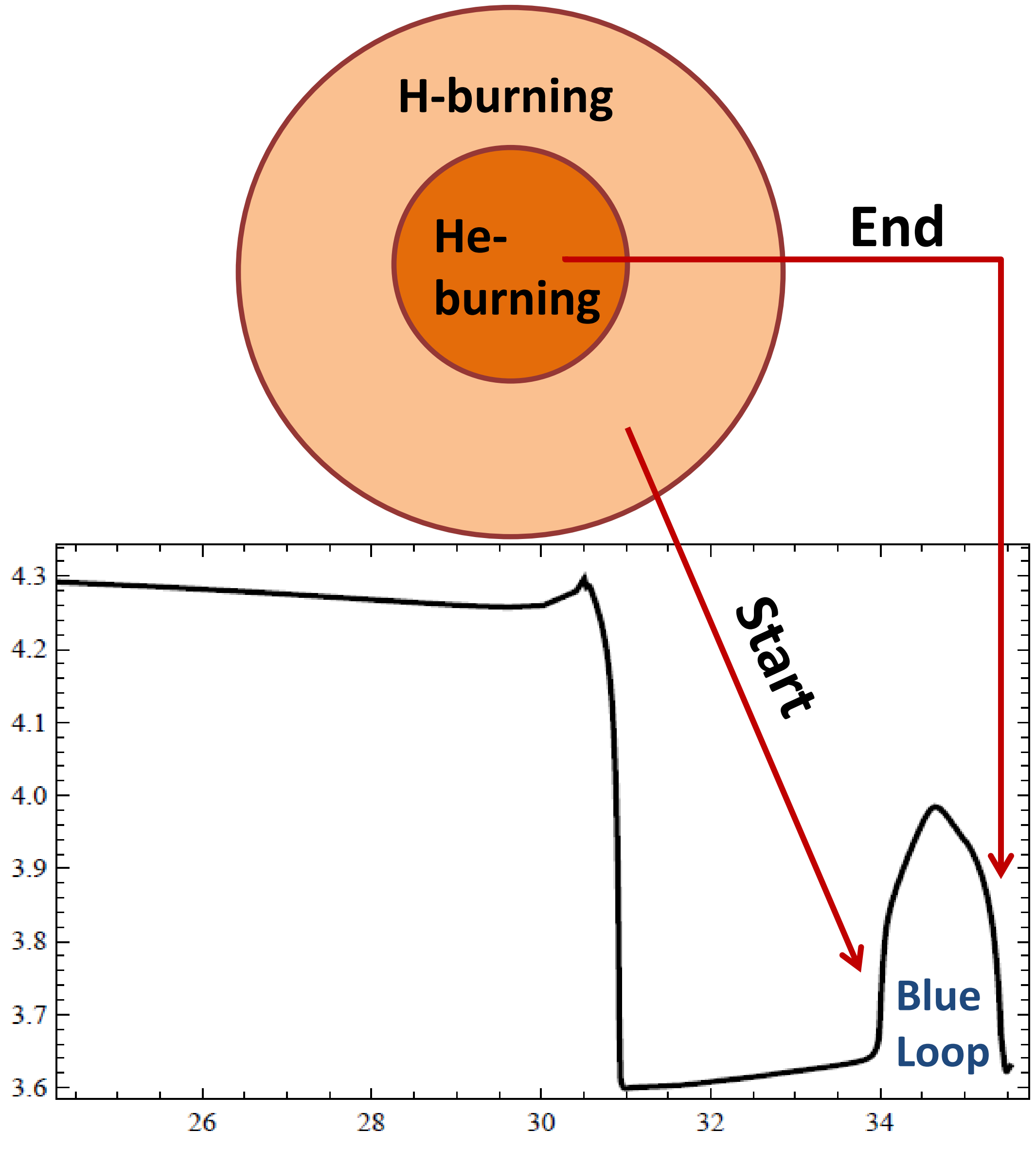
Axions would modify in different ways the time scales of the core and shell



The Axion and the Blue Loop

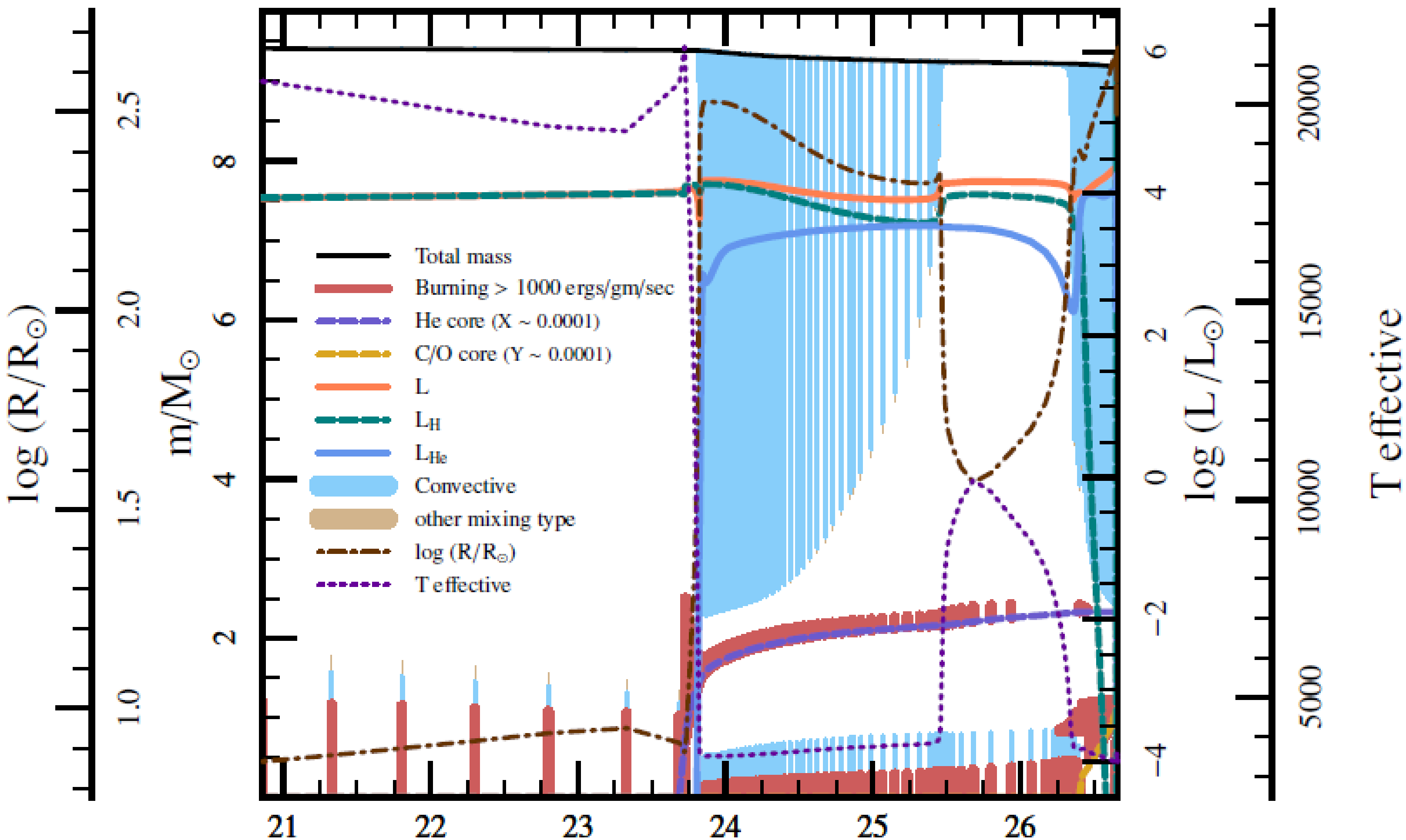
Blue Loop:

the <u>beginning</u> of the blue loop is set by the H-burning shell time scale whereas the <u>end</u> is set by the He-burning core time scale [e.g., Kippenhahn and Weigert (1994)]



Axions effects on the Blue Loop

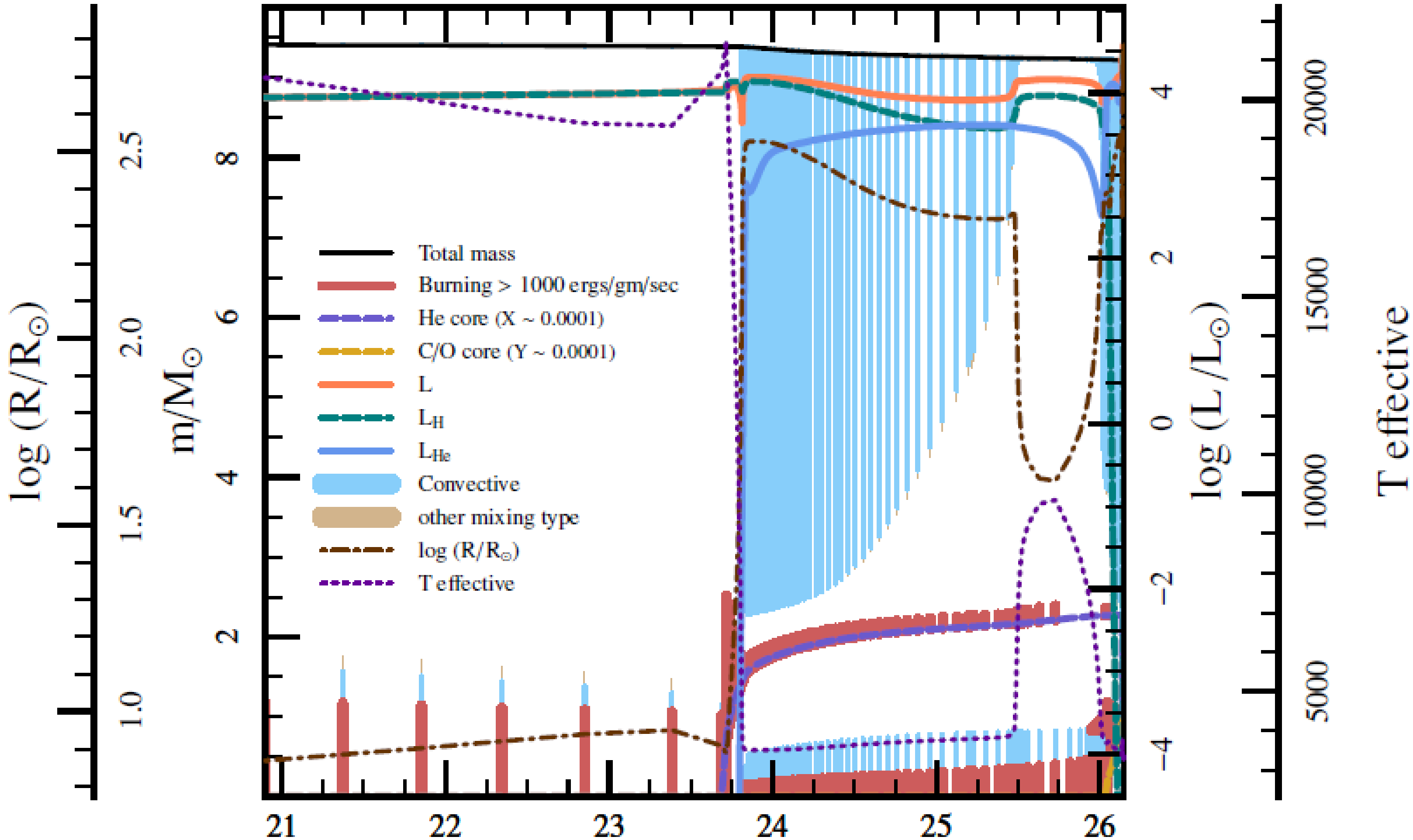
9.5 $M_\odot$ star, g_{10}=0 (No Axion)



MESA Simulation. Friedland, M.G., M. Wise, in preparation

Axions effects on the Blue Loop

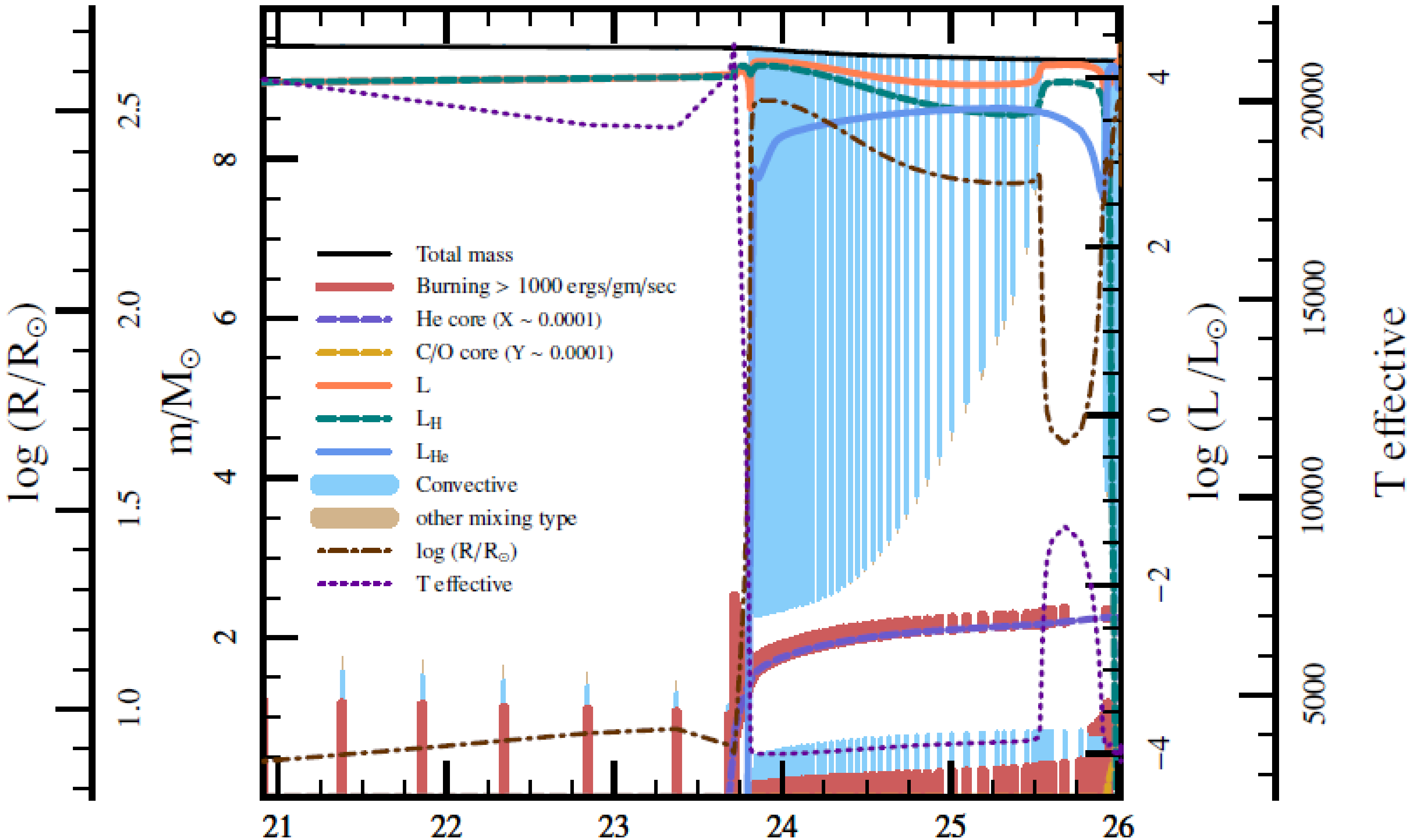
9.5 $M_\odot$ star, g_{10}=0.6



MESA Simulation. Friedland, M.G., M. Wise, in preparation

Axions effects on the Blue Loop

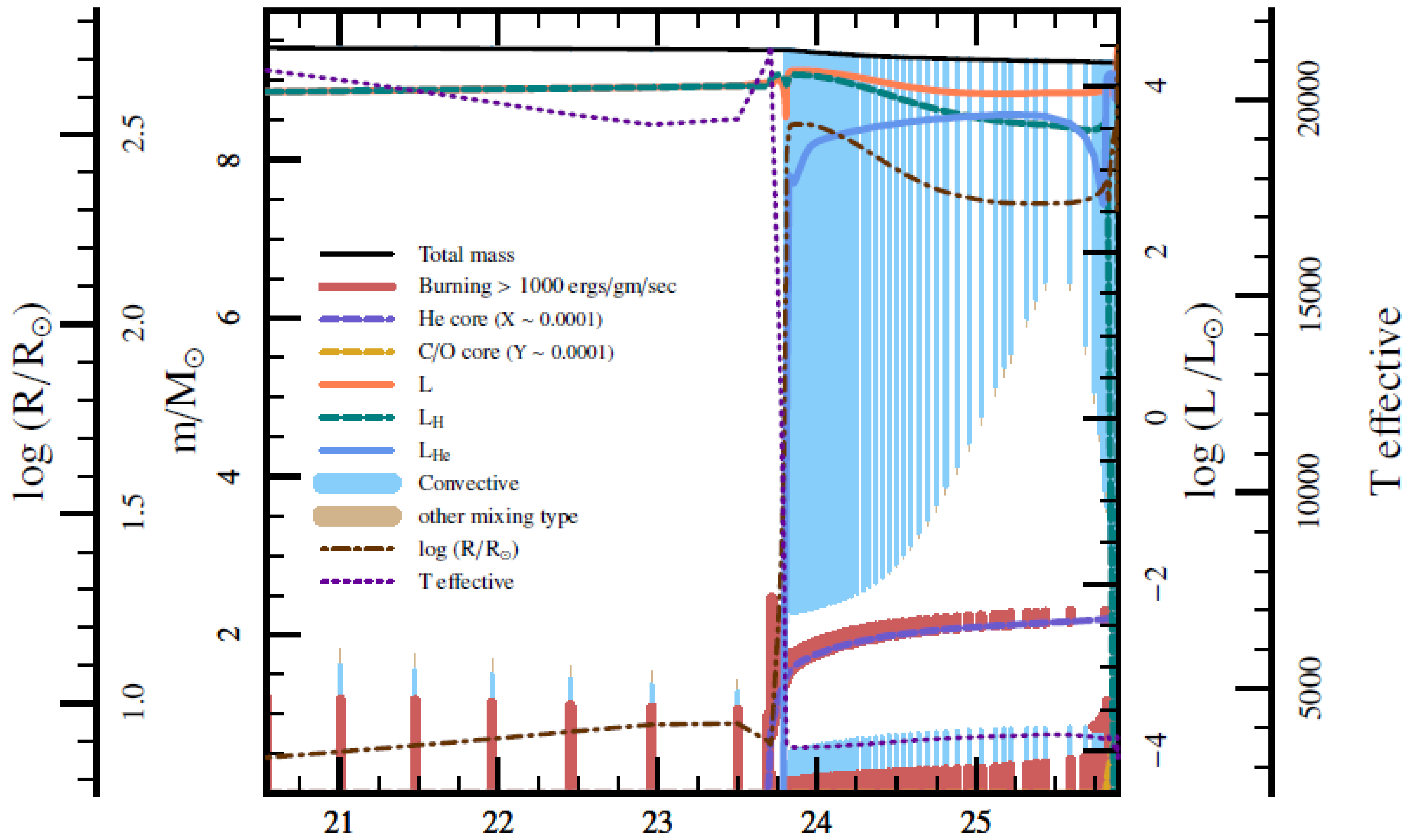
9.5 $M_\odot$ star, g_{10}=0.7



MESA Simulation. Friedland, M.G., M. Wise, in preparation

Axions effects on the Blue Loop

9.5 $M_\odot$ star, g_{10}=0.8 (No Axion)



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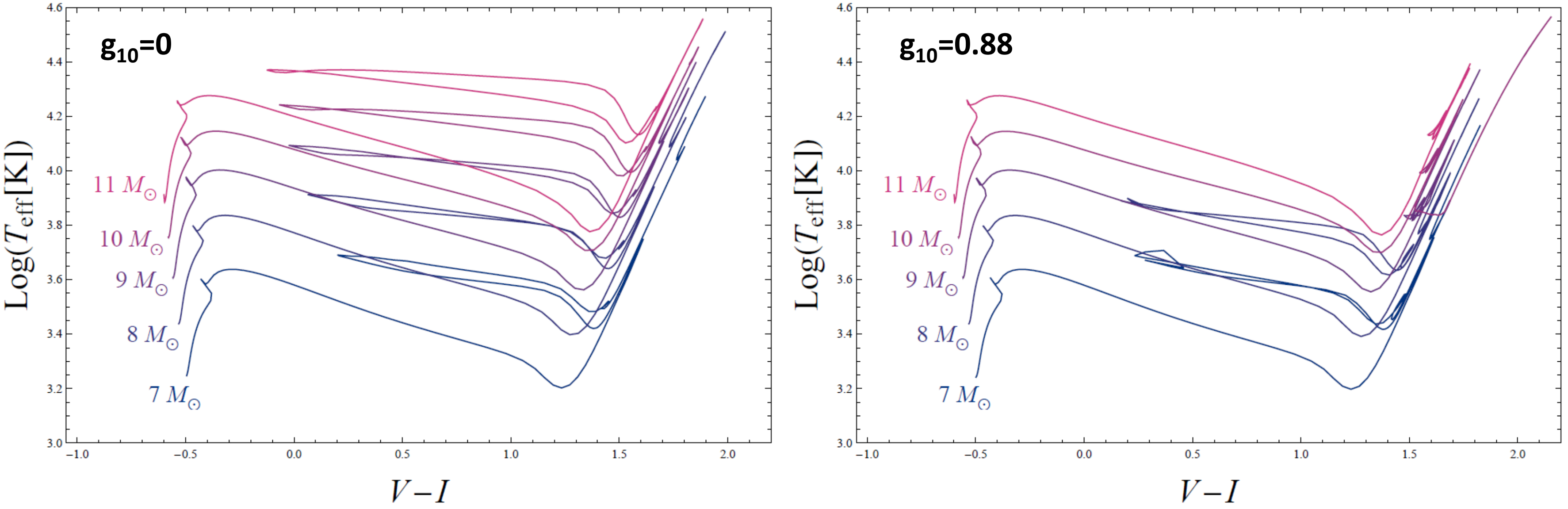
Axions effects on the Blue Loop

The value g_{10}=0.88 corresponds to the current CAST bound on the axion-photon coupling.



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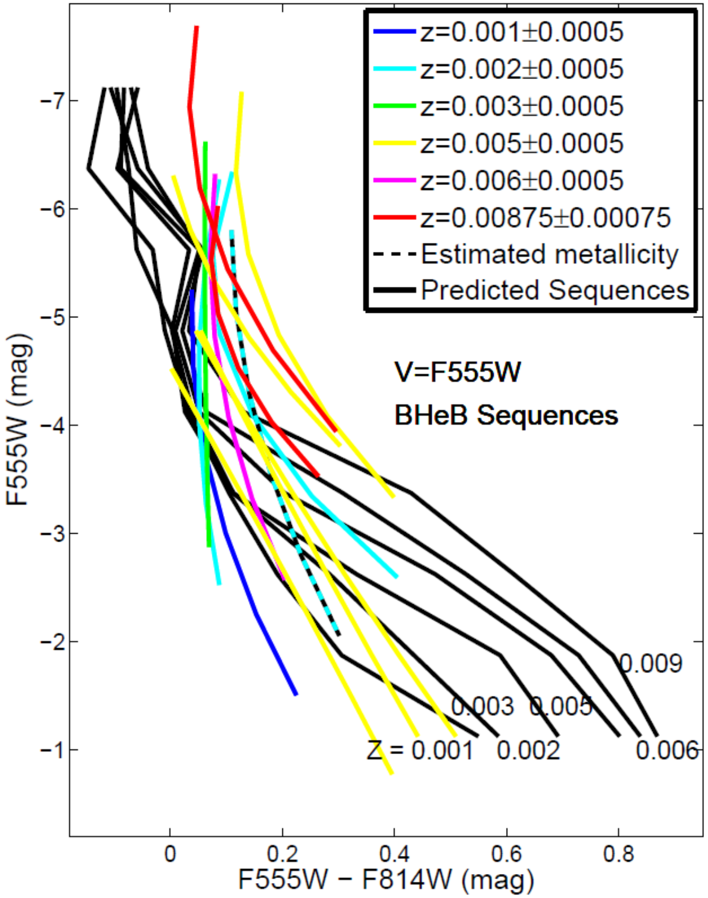
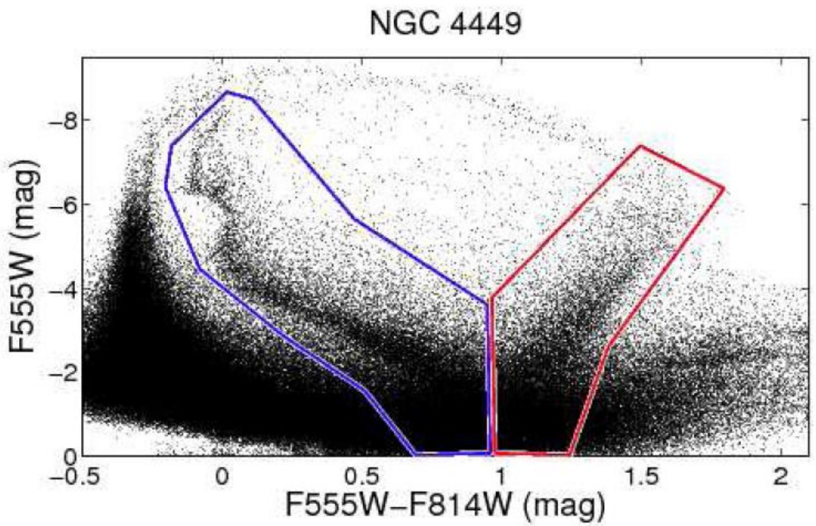
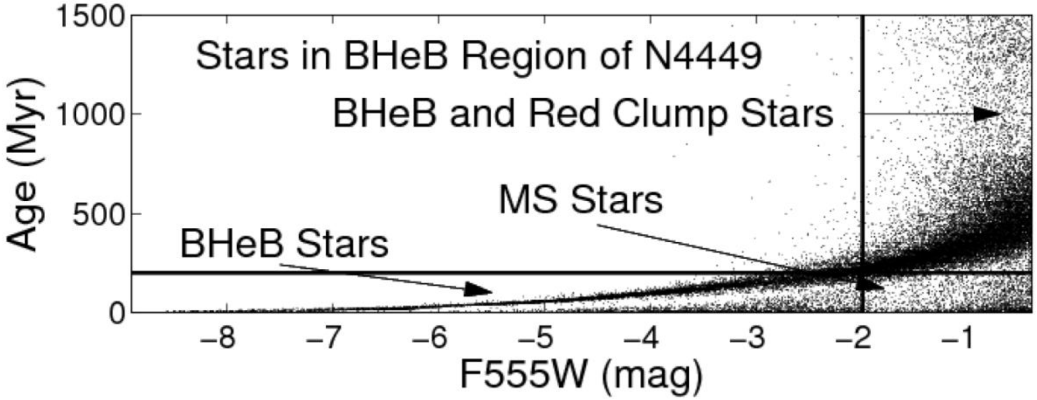
Experimental Evidence for Blue Sequences



V-I Color



High metallicity Galaxy



Figures from Kristen B. W. McQuinn et. al., Astrophys.J. 740 (2011)

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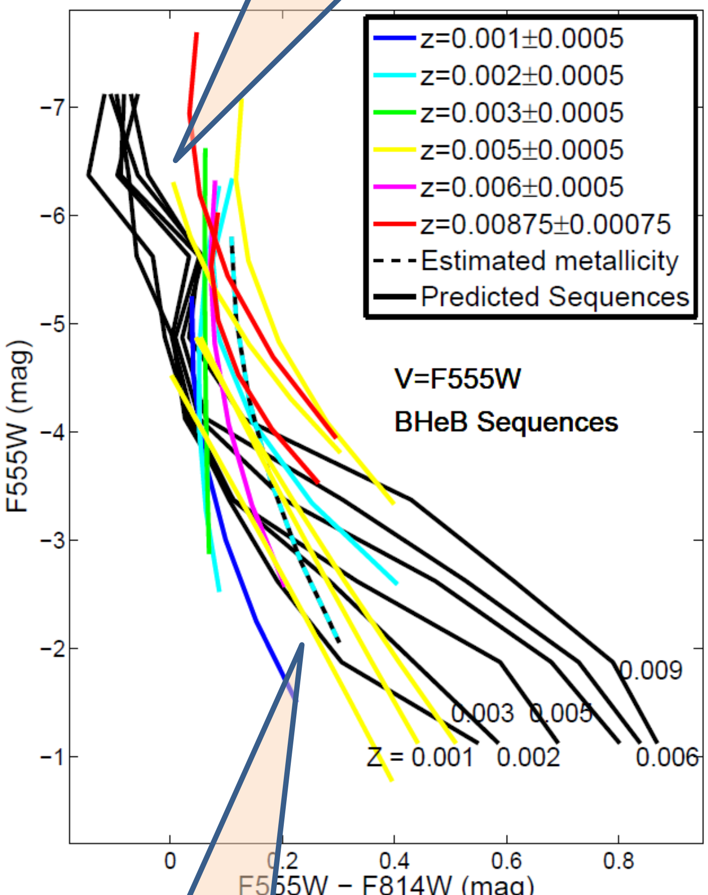

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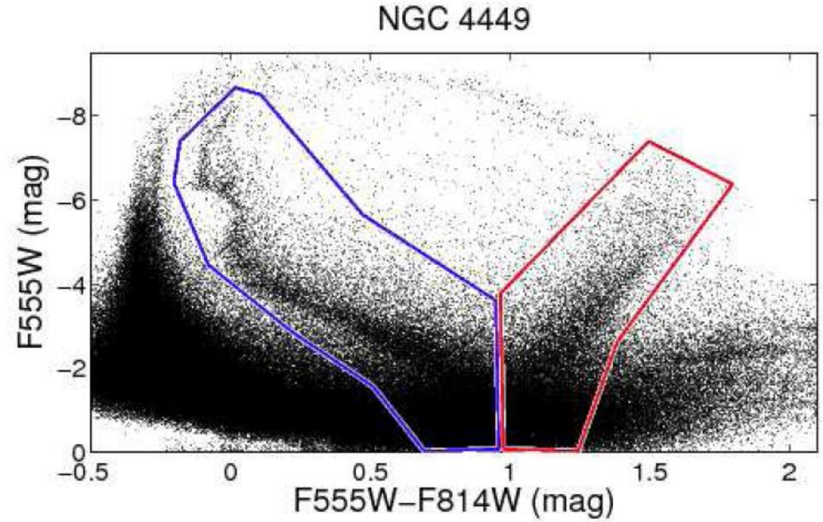

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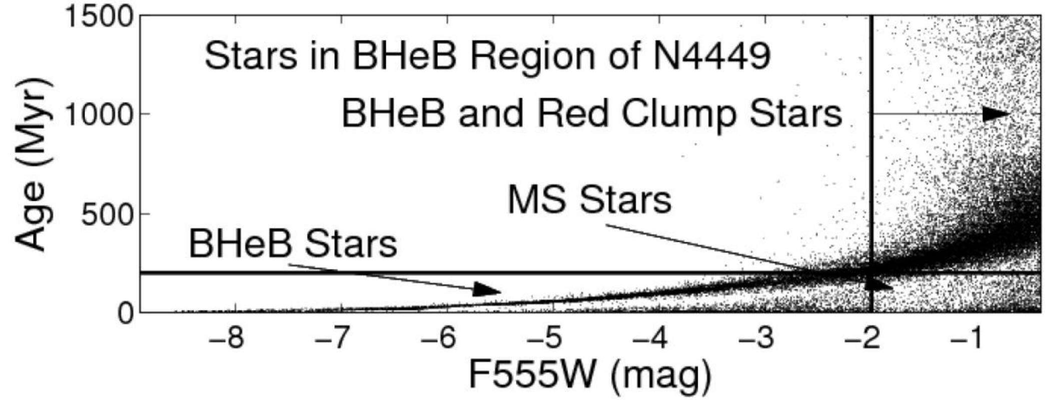

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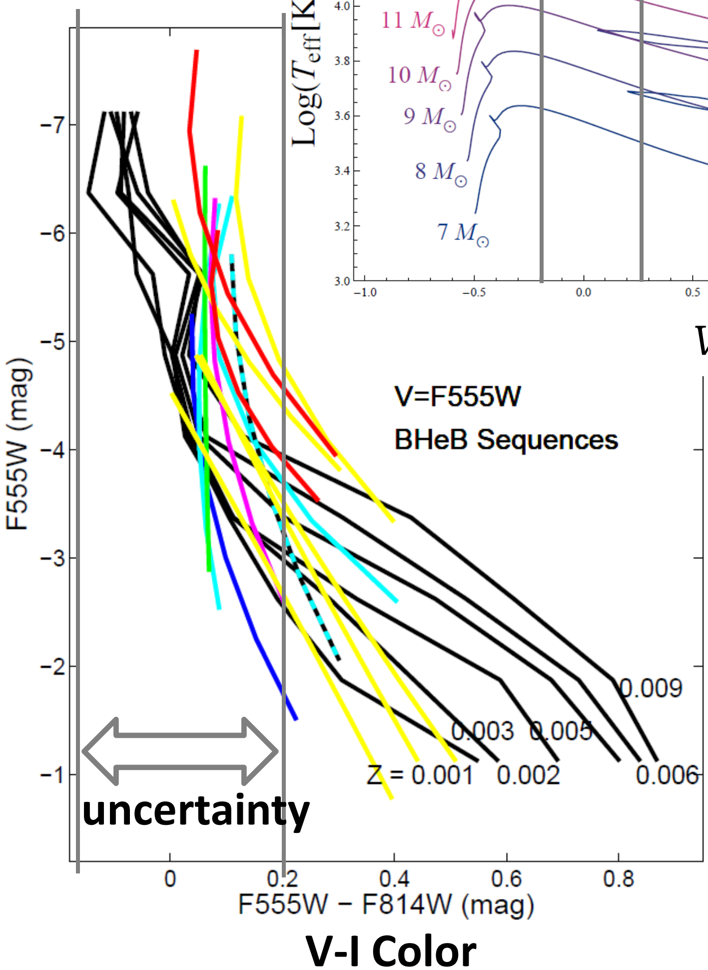
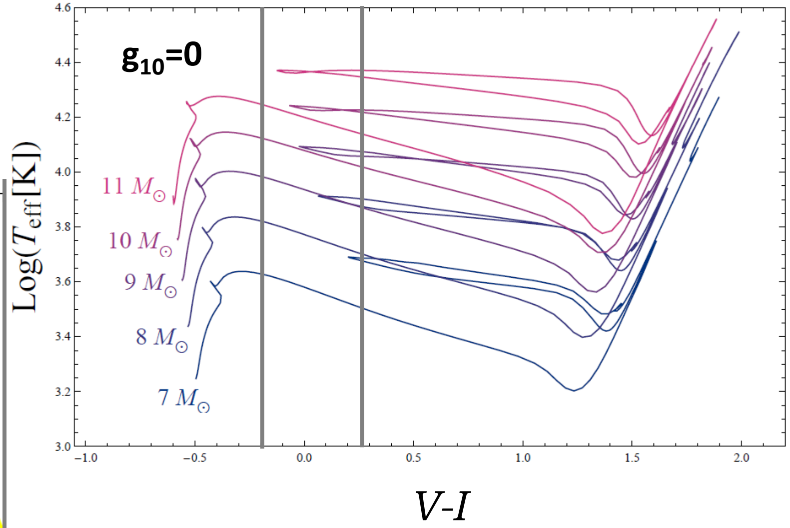
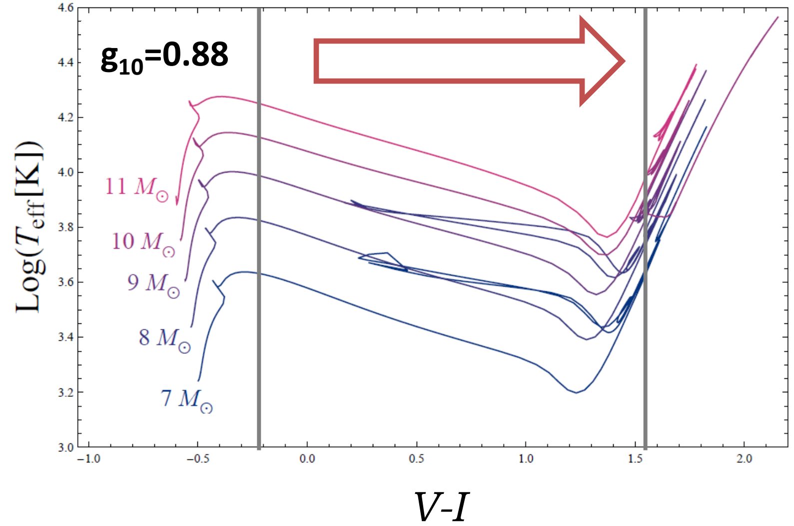
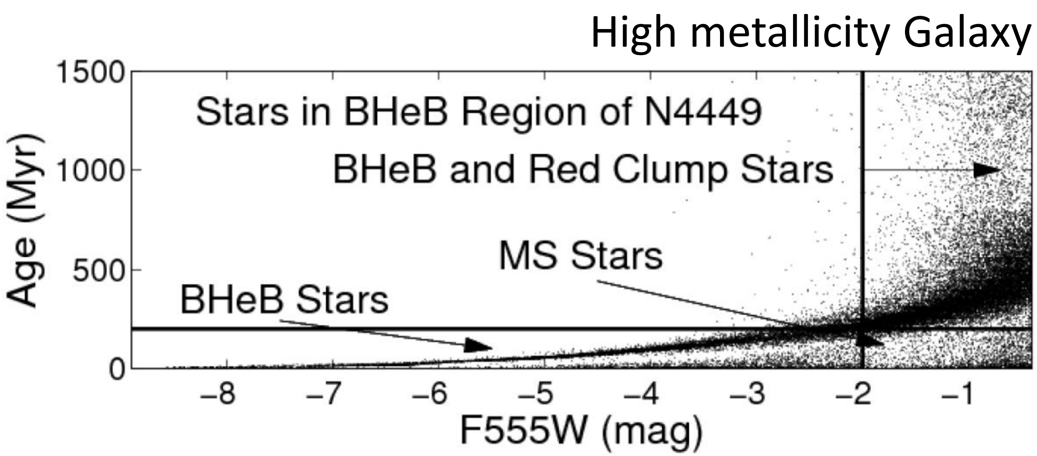


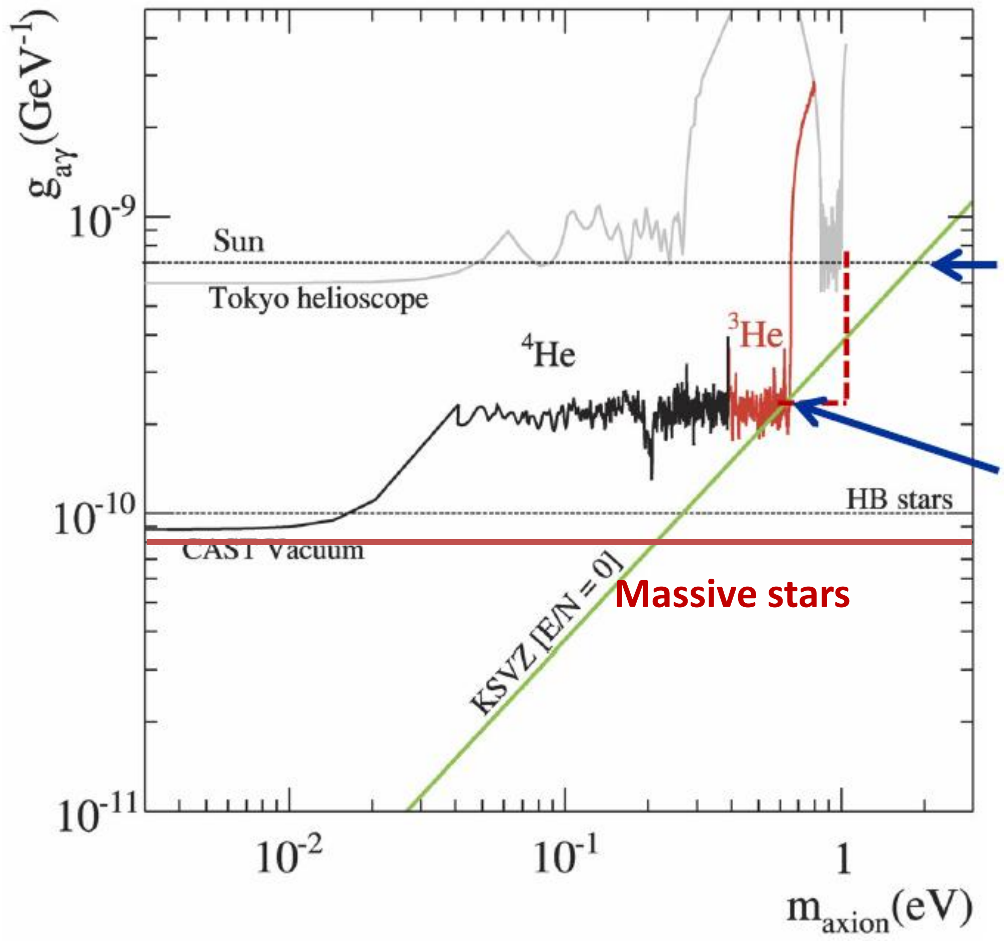






Figures from Kristen B. W. McQuinn et. al., Astrophys.J. 740 (2011)

Results



Result:

A value of g_{10} above 0.8 would be incompatible with the current observations of HeB sequences.

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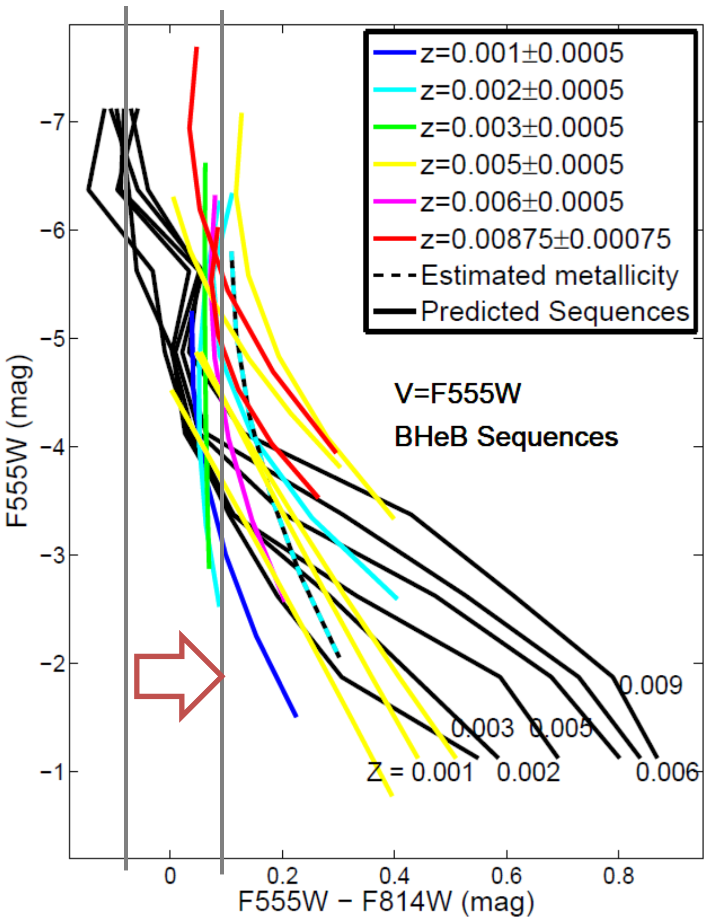

V-I Color

Kristen B. W. McQuinn et. al., Astrophys.J. 740 (2011)

Result:

A value of g_{10} above 0.8 would be incompatible with the current observations of HeB sequences.

Open questions:

- Can the axion explain the small red-shift of the bluest point of the blue loop in the high luminosity region of the CMD?

- Can the axion explain the discrepancy in the number of blue and red stars observed experimentally, namely the fact hat B/R is larger than expected?

Conclusions

➢ Axions affect considerably the evolution of intermediate mass stars. The axion cooling has the effect of shifting toward the red the bluest point of the blue loop and of lowering the vale of B/R. The effect is particularly strong for stars of initial mass ~ 9-11$M_\odot$

➢ Our analysis suggests also the possibility of axions being responsible for the observed anomaly in the BHeB and RHeB stars, namely, the fact that the blue stars appear to be less blue than expected and that B/R is overestimated in the standard numerical simulations. If this picture were to be supported by further analysis, it would provide an indication of the existence of the axion with a coupling to photons just below the current bound from CAST and testable in the next generation axion helioscope experiments. If not, the methodology would still indicate a new way to constrain the axion and a possible new direction of investigation of the impact of the physics beyond the standard model on astrophysics.

Thank

You