

Testing Stellar Theory with Joint Spectroscopic and Asteroseismic Catalogs

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AstroCoffee @ Pitt
October 20, 2025



The Life of Sun-like Stars

Main Sequence

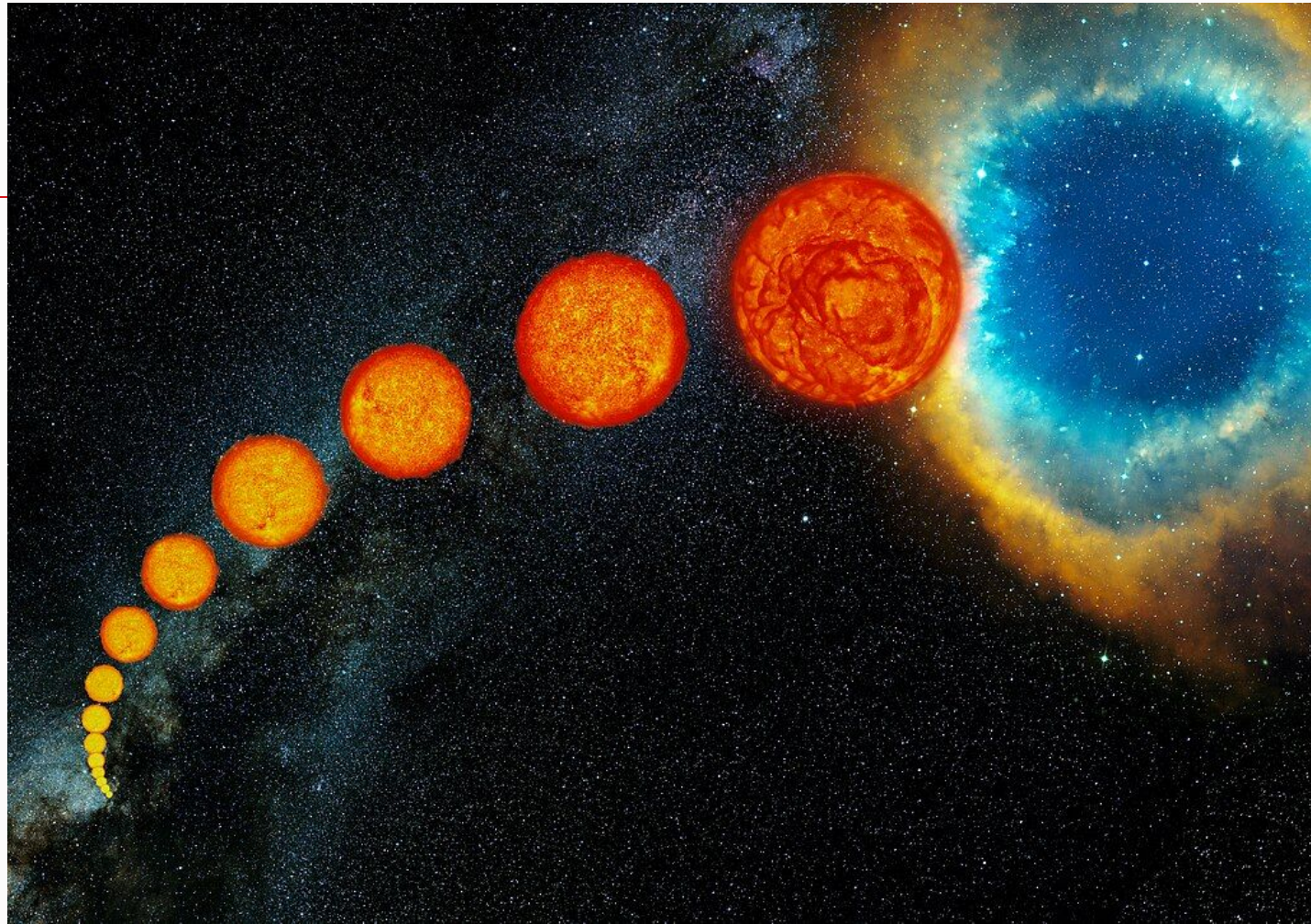


Red Giant Branch



Planetary Nebula
(+ White Dwarf)

Image Credit:
ESO/S. Steinhöfel



The Red Giant Branch (RGB)

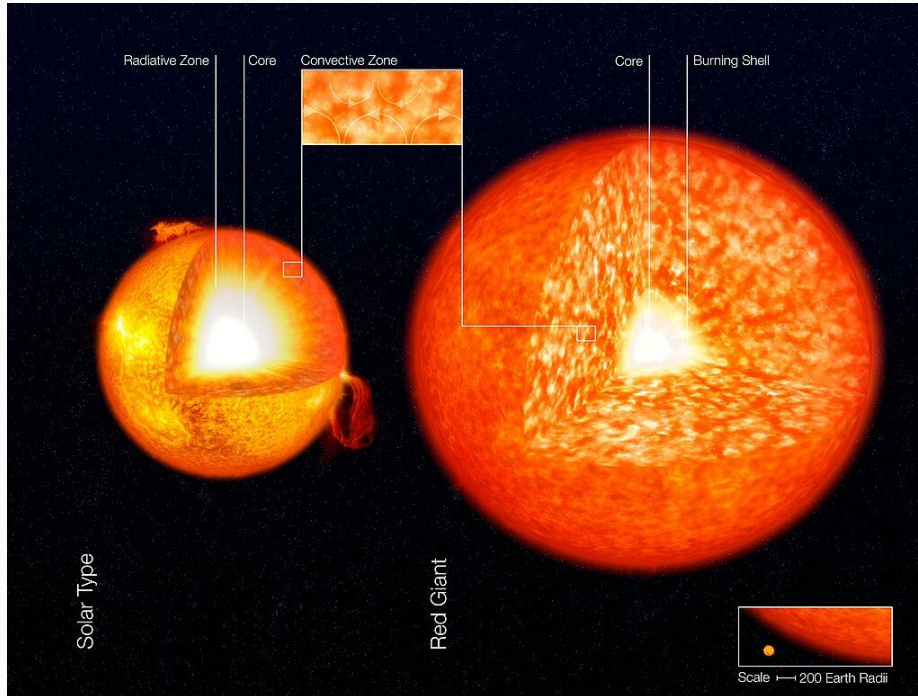
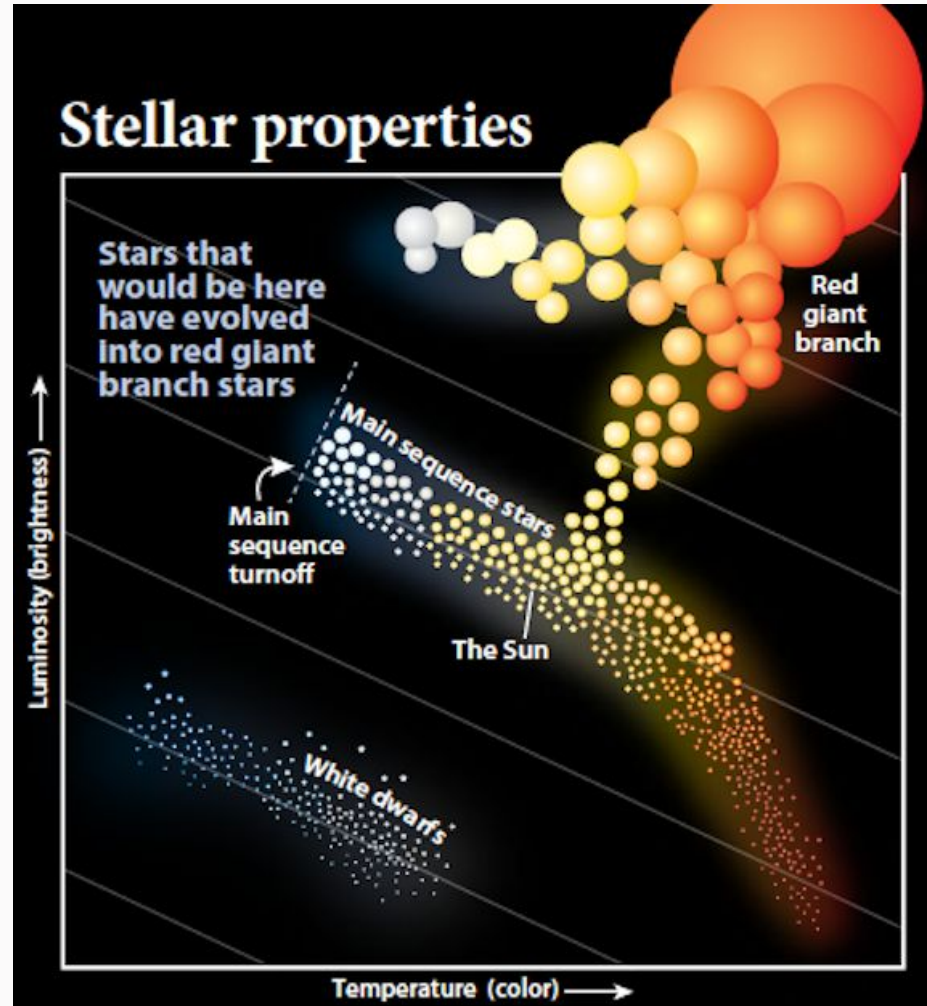


Image Credits: ESO (↑) / Roen Kelly (→)



How do we know that?

- Mass Conservation
- Hydrostatic Equilibrium
- Energy Generation
- Energy Transport
- Chemical Evolution

$$\frac{\partial r}{\partial m} = \frac{1}{4\pi r^2 \varrho} , \quad (10.1)$$

$$\frac{\partial P}{\partial m} = -\frac{Gm}{4\pi r^4} , \quad (10.2)$$

$$\frac{\partial l}{\partial m} = \varepsilon_n - \varepsilon_v - c_P \frac{\partial T}{\partial t} + \frac{\delta}{\varrho} \frac{\partial P}{\partial t} , \quad (10.3)$$

$$\frac{\partial T}{\partial m} = -\frac{GmT}{4\pi r^4 P} \nabla , \quad (10.4)$$

$$\frac{\partial X_i}{\partial t} = \frac{m_i}{\varrho} \left(\sum_j r_{ji} - \sum_k r_{ik} \right) , \quad i = 1, \dots, I . \quad (10.5)$$

[Kippenhahn et al. \(2013\)](#)

MESA

*How do we **test** that?*
→ APOKASC-3 Catalog!

[Pinsonneault et al. \(2025\)](#)

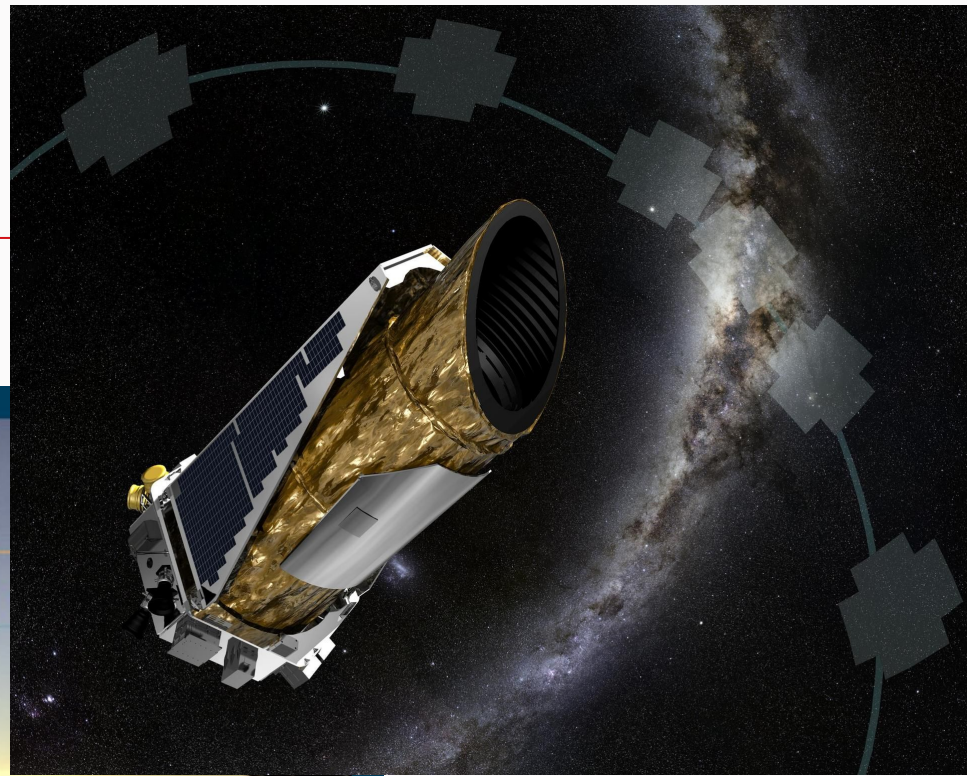
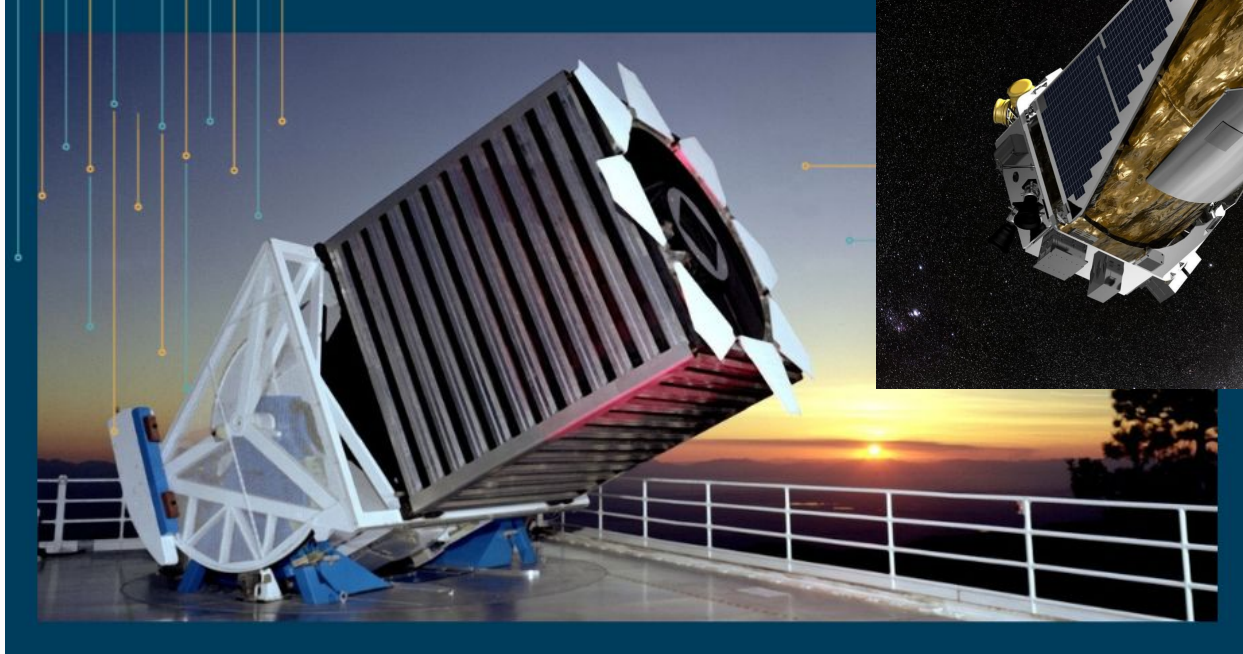
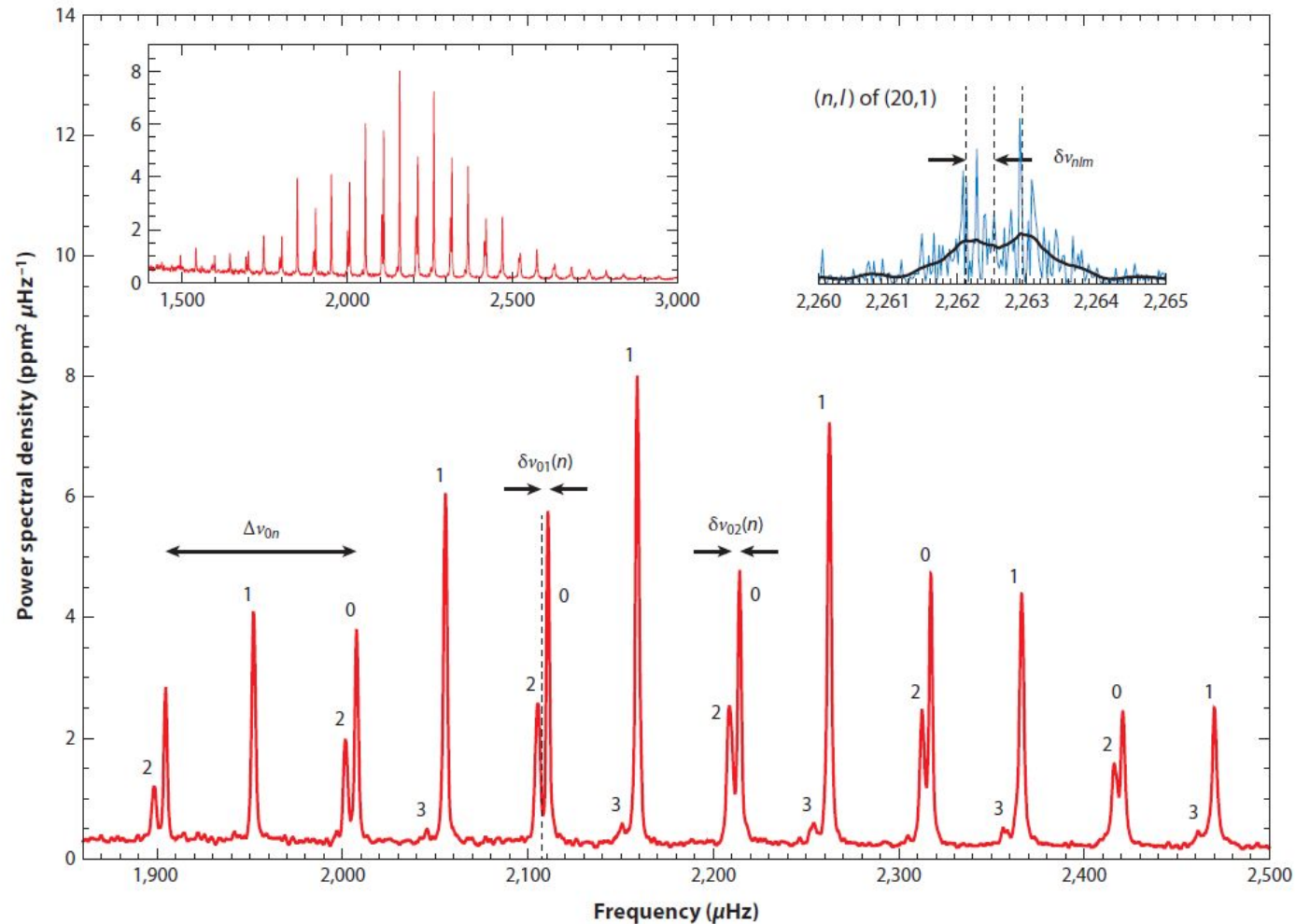


Image Credits: Sloan
Foundation (↵) / NASA,
ESA, CSA, and STScI (↑)

Astro- seismology

Two figures of merit:
Frequency of the maximum power – $\nu_{\max}$
Large-frequency spacing – $\Delta\nu$

[Chaplin & Miglio \(2013\)](#)



Spectroscopy

- (Effective) Temperature
- (Surface) Chemical Composition
- (Surface) Gravity
- Atmospheric Microturbulence

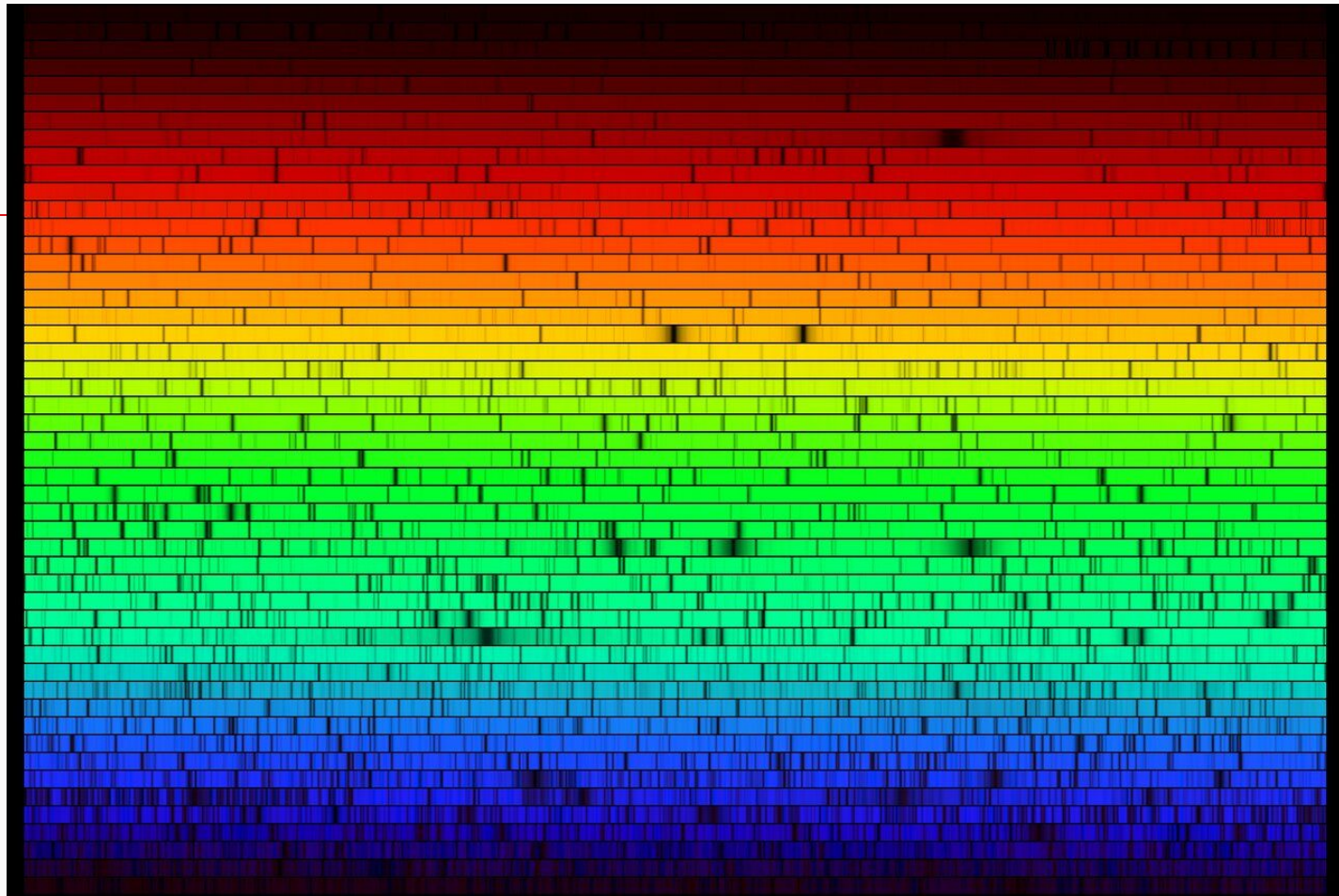


Image Credit: N.A. Sharp/KPNO/NOIRLab/NSO/NSF/AURA

Carbon–Nitrogen–Oxygen (CNO) Cycle

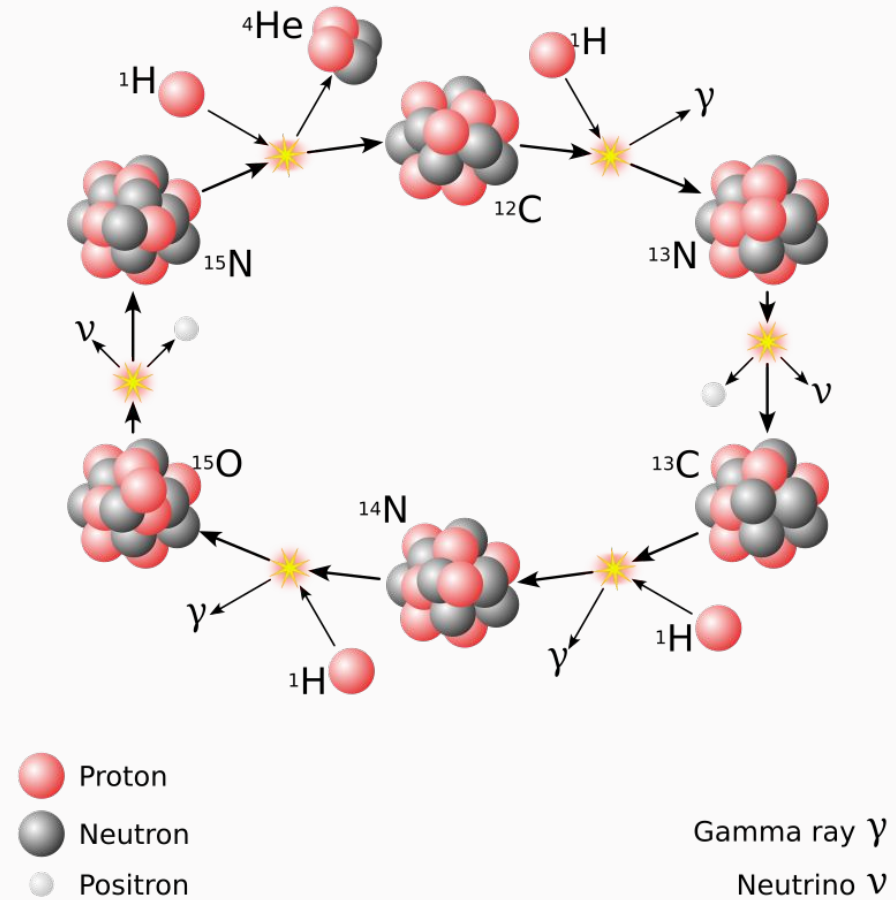
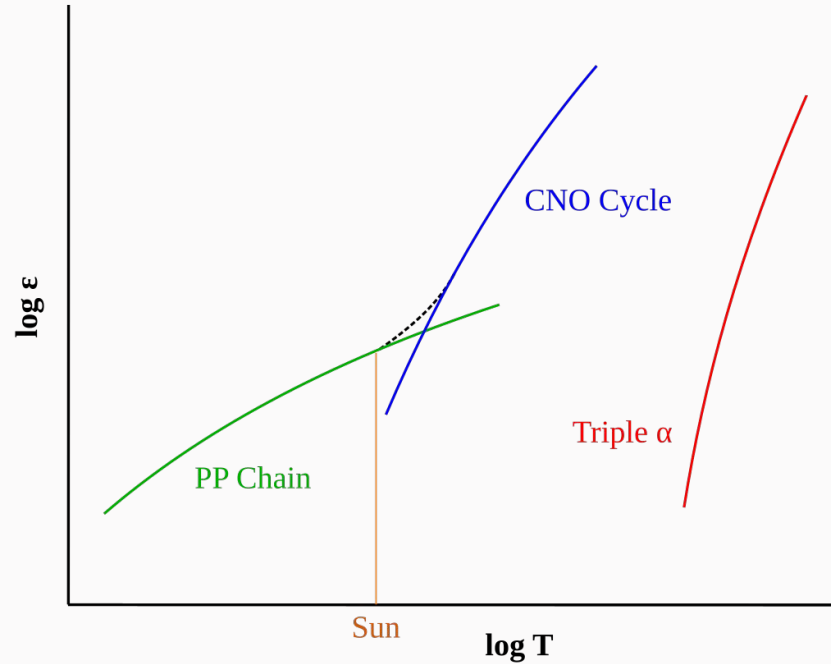


Image Credits: RJHall & Manlleus (Left) / Borb (Right)

The First Dredge-Up (FDU)

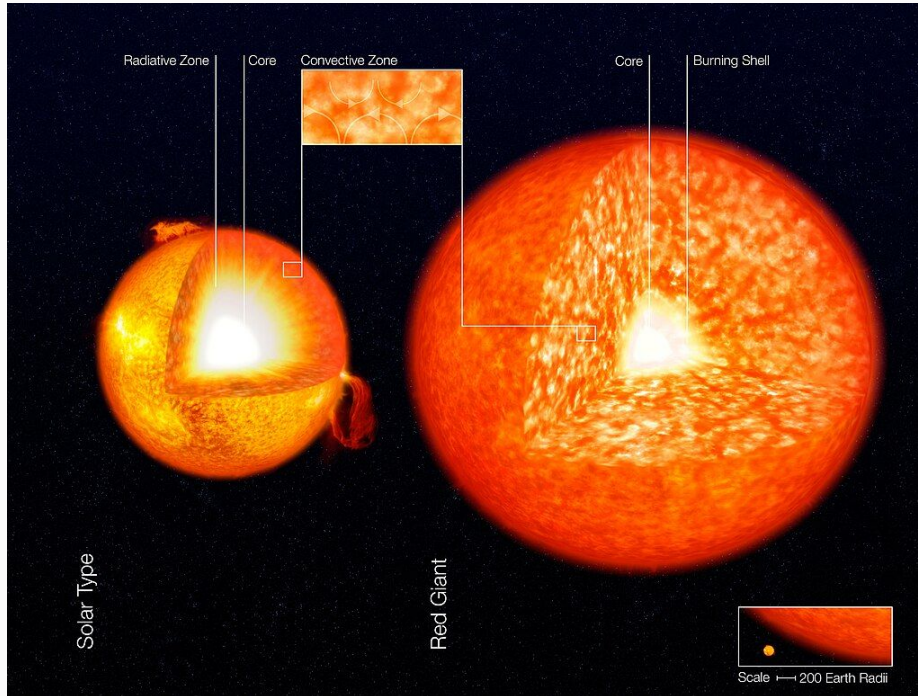
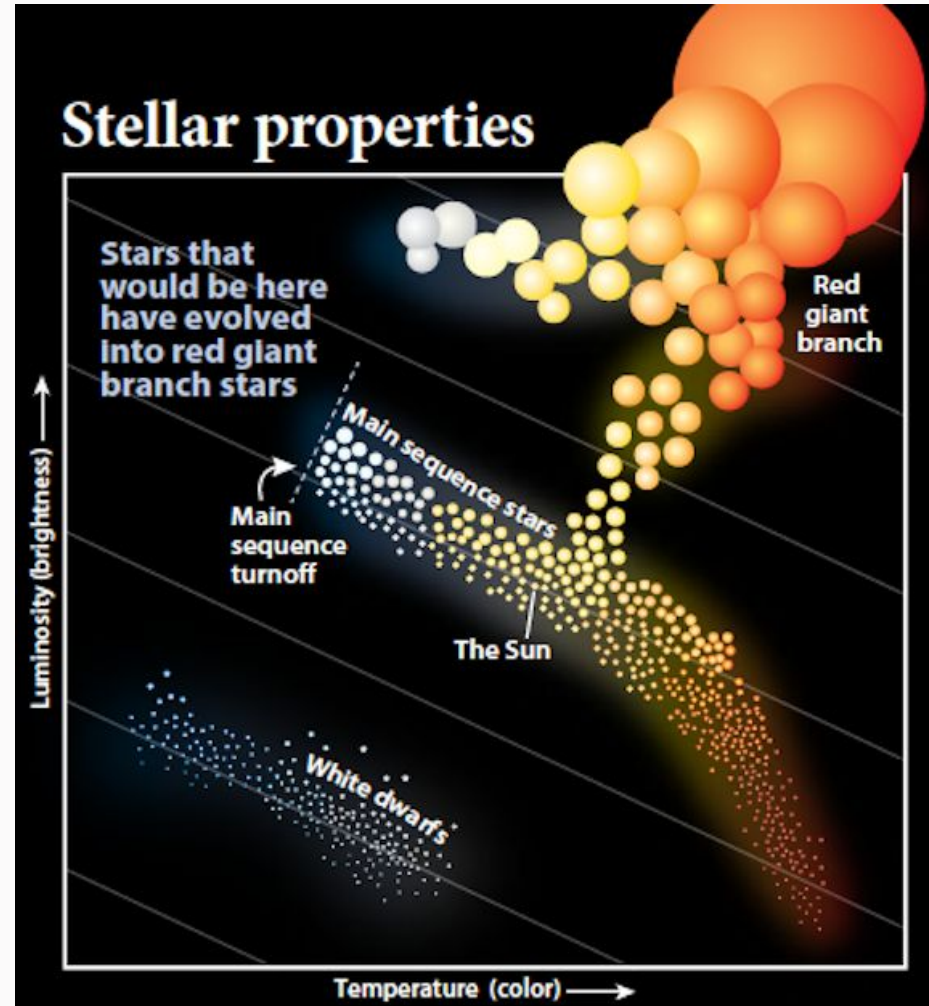


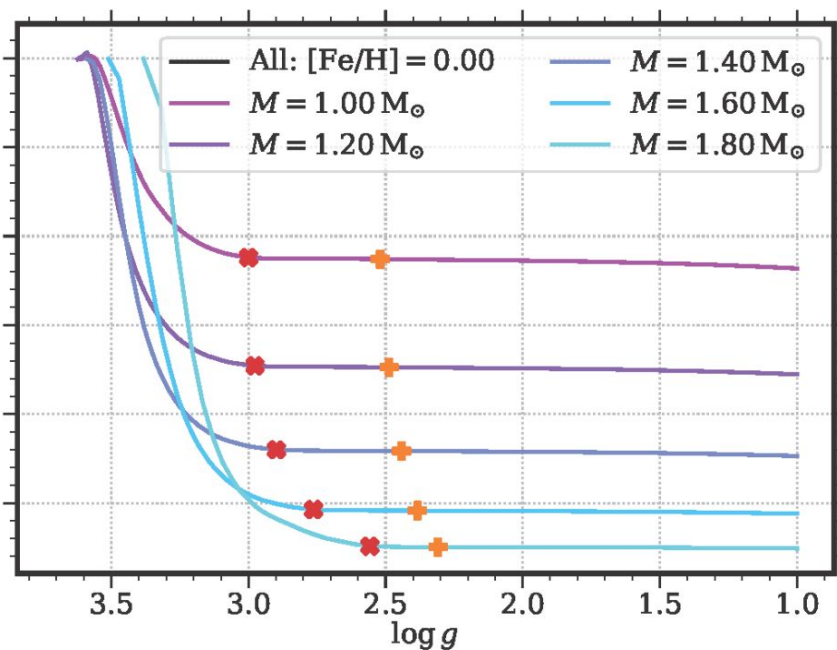
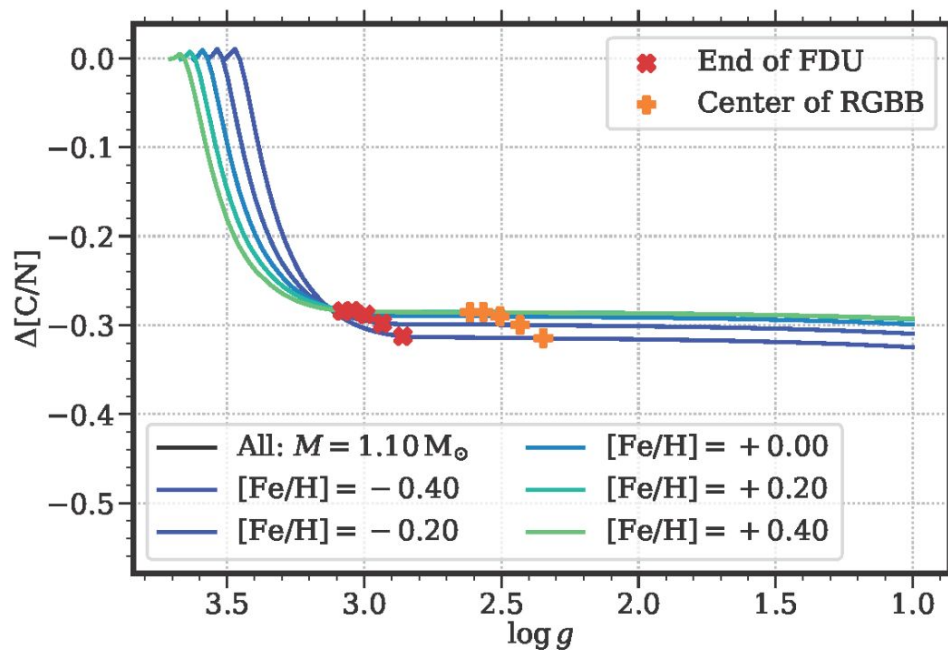
Image Credits: ESO (↑) / Roen Kelly (→)



FDU: Theoretical Predictions

Slight dependence on metallicity
Significant dependence on mass

[Cao & Pinsonneault \(2025a\)](#)



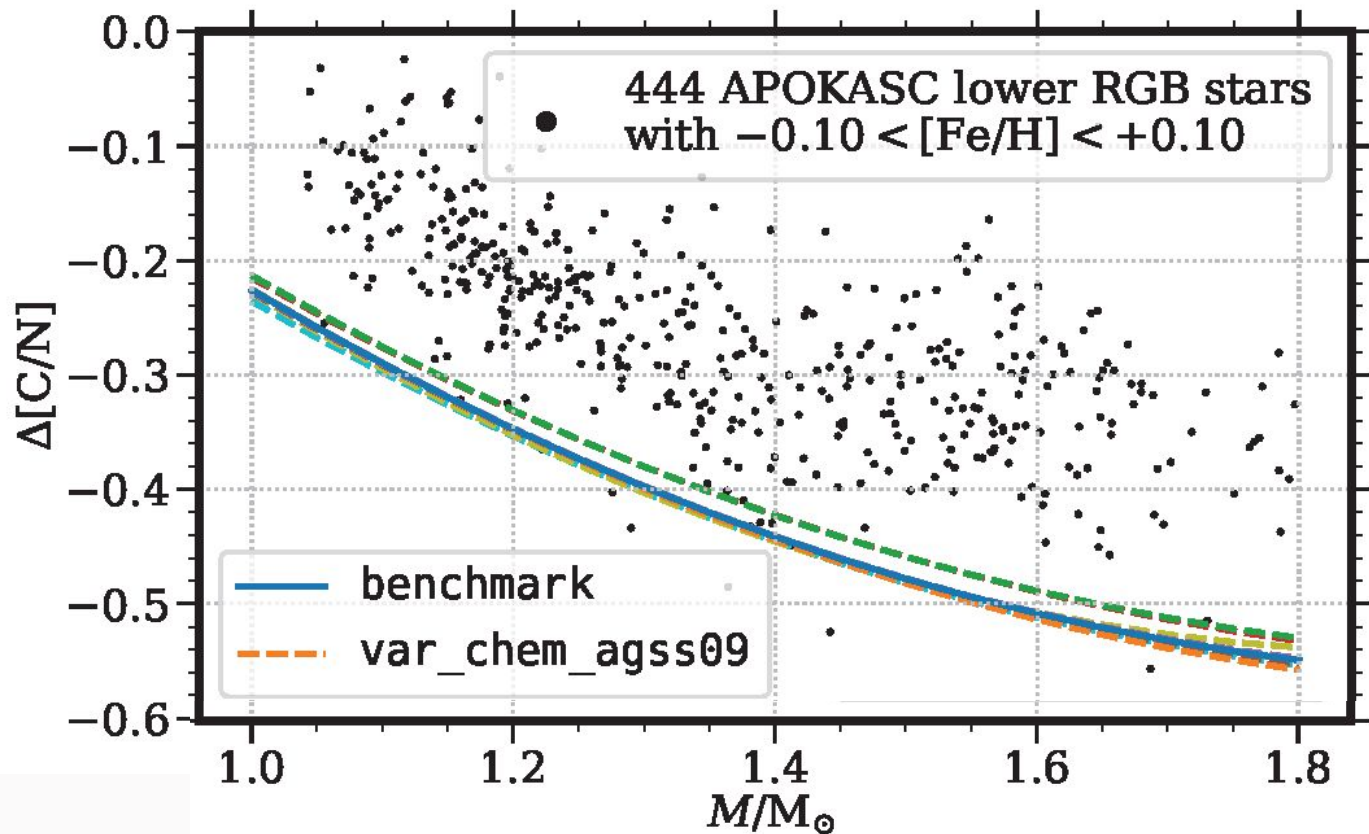
FDU: Comparison with Data

[Cao & Pinsonneault \(2025a\)](#)

Significant
zero-point
offset: ~ 0.16

Robust to
physics models

Observational
systematics?



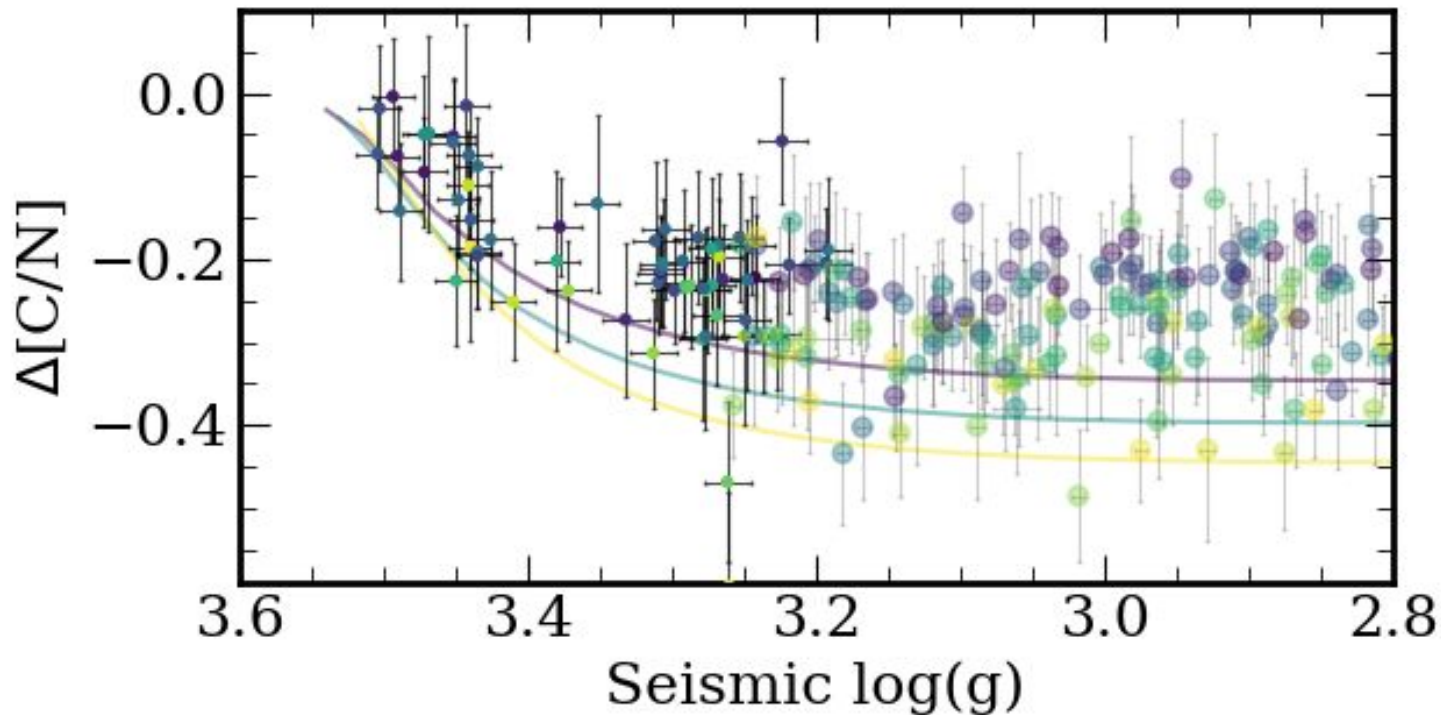
FDU: Super-Nyquist Sample

[Liagre et al. \(2025\)](#)

$\log g < \sim 3.2$:
APOKASC-3

$\log g > \sim 3.2$:
super-Nyquist
sample

Color-coding:
mass (1.2 to 1.4)



The Red Giant Branch Bump (RGBB)

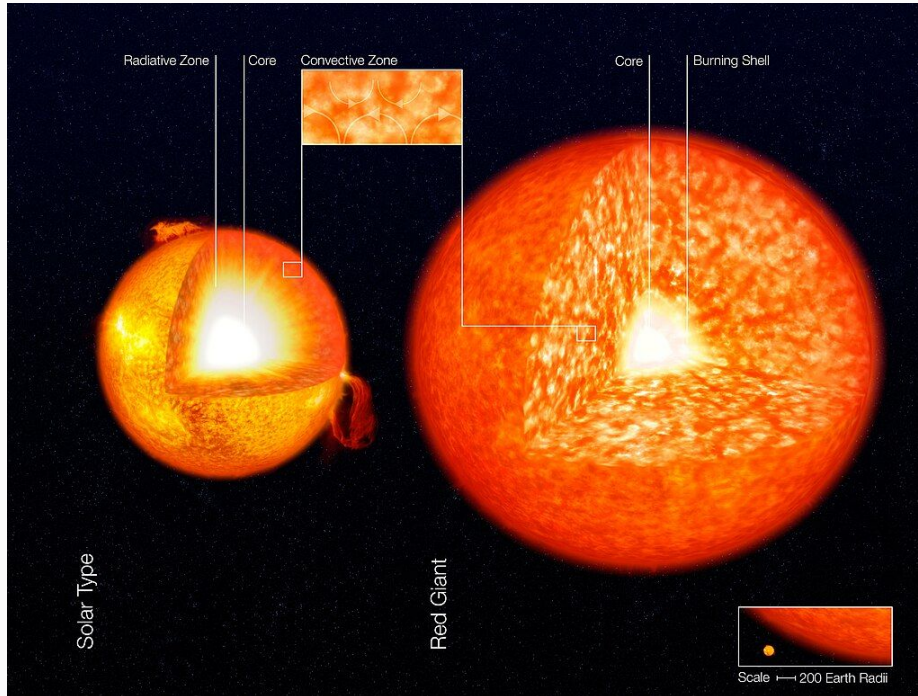
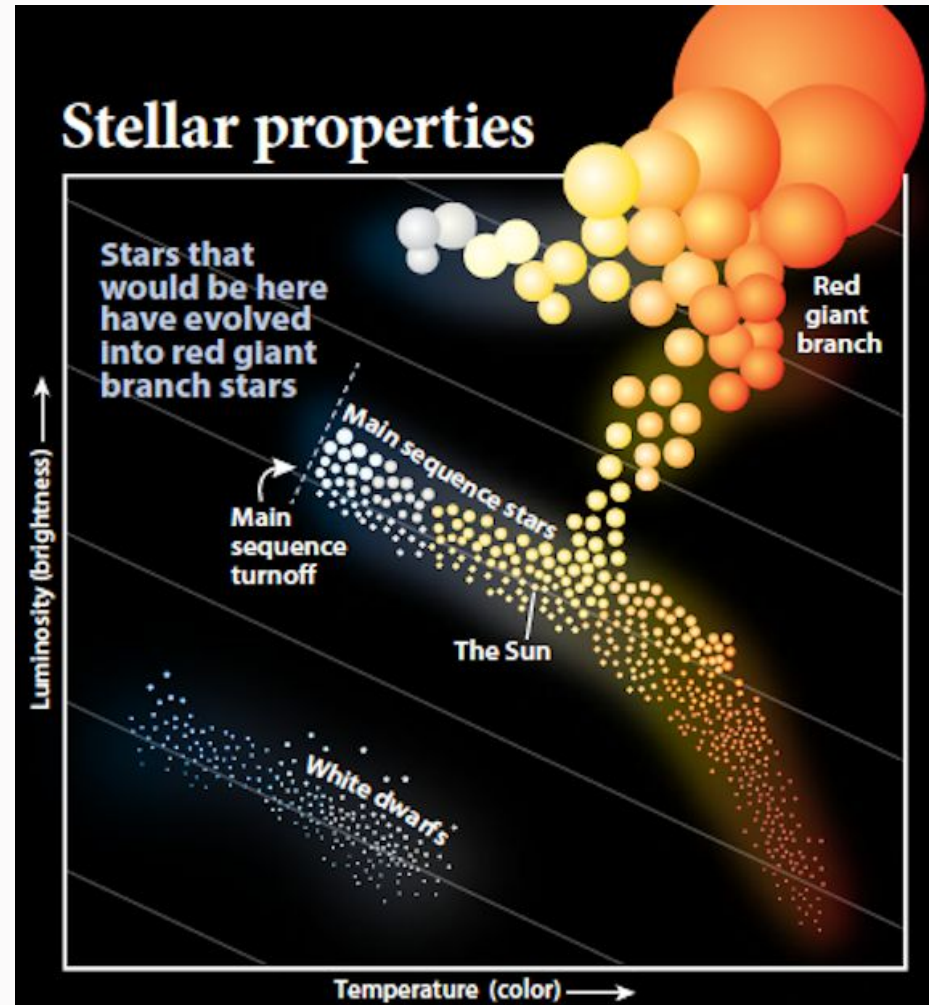
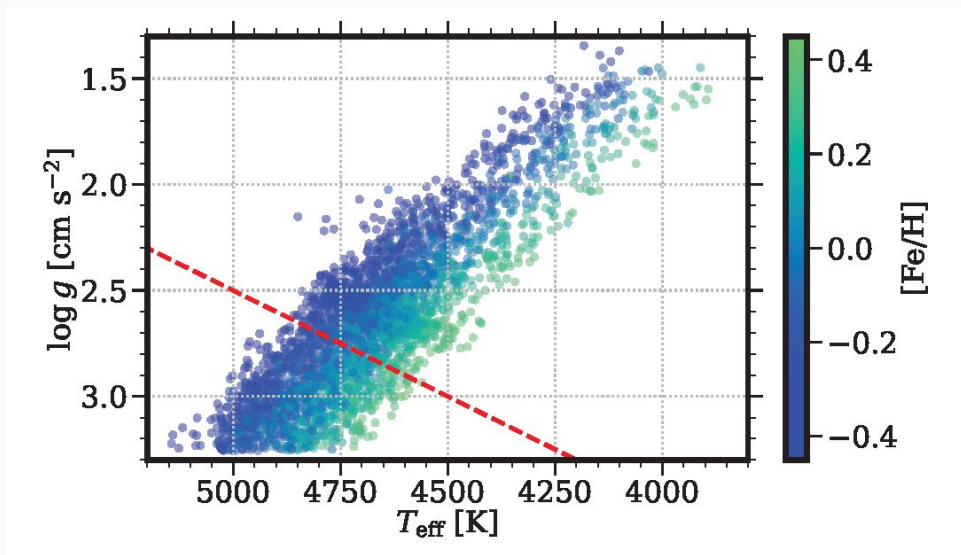


Image Credits: ESO (↑) / Roen Kelly (→)

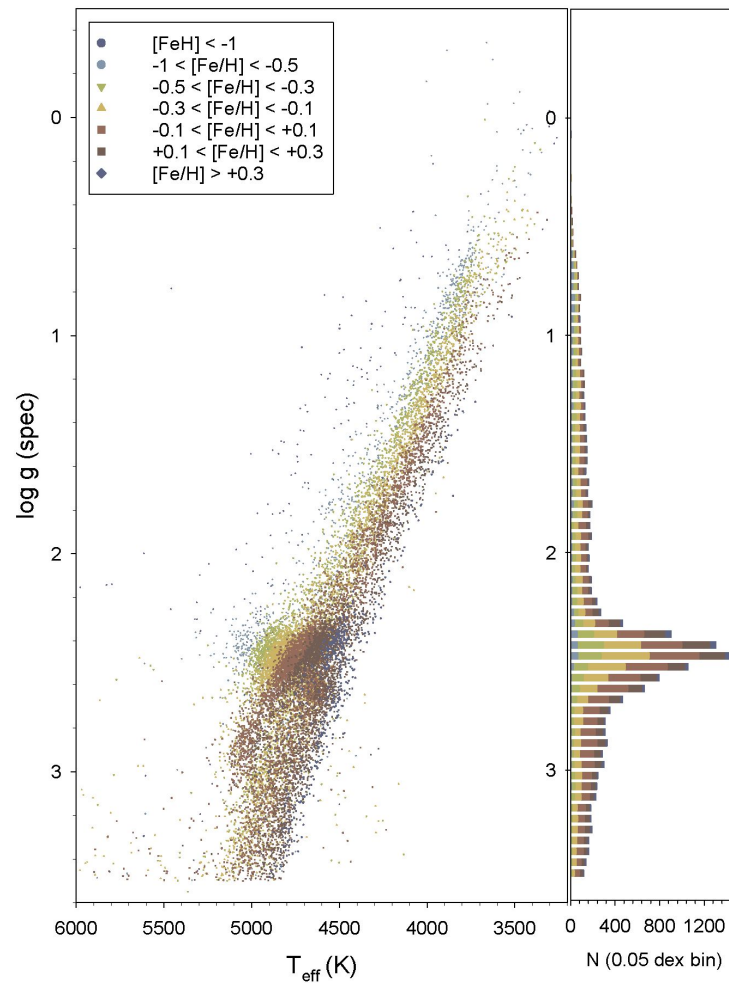


RGBB: Observational Data



↑: [Cao & Pinsonneault \(2025a\)](#)

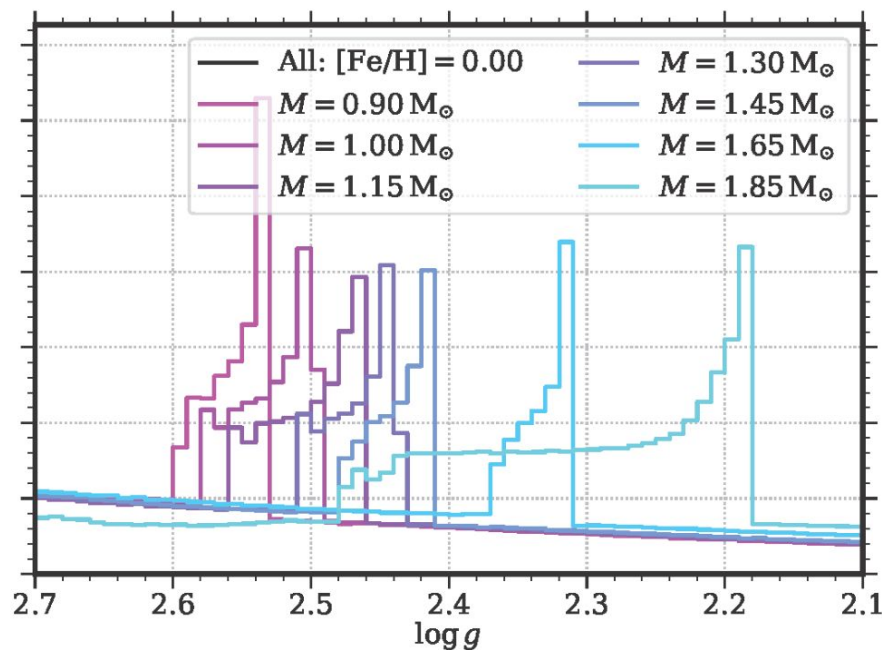
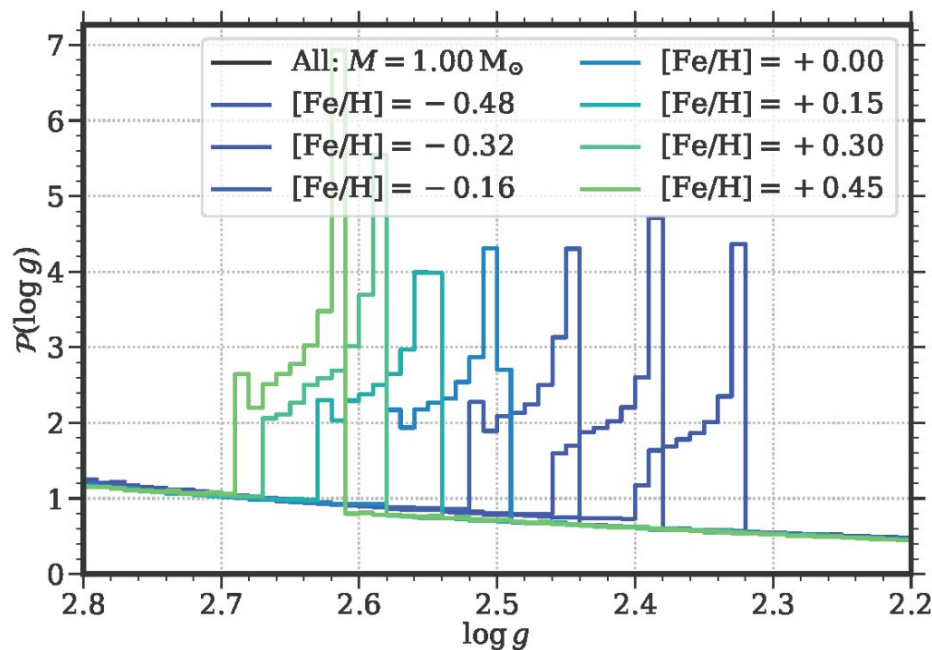
→: [Pinsonneault et al. \(2025\)](#)



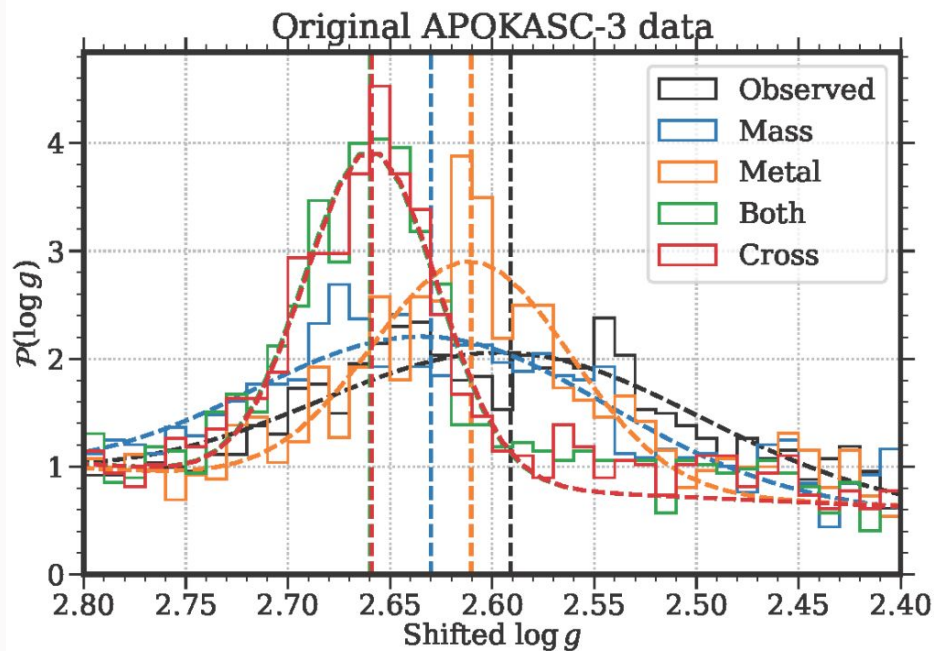
RGBB: Theoretical Predictions

Dependence on both mass
and metallicity

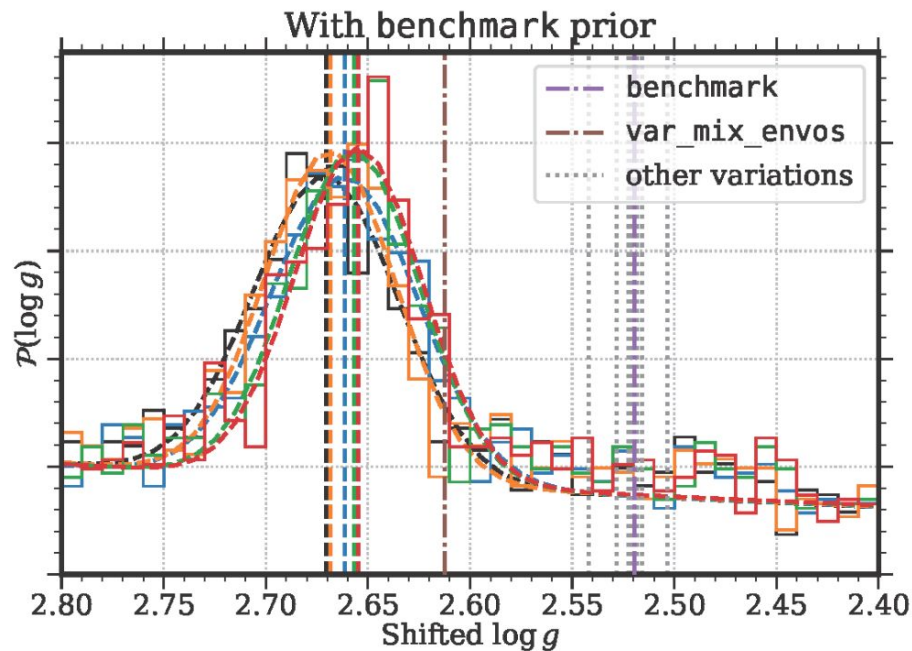
[Cao & Pinsonneault \(2025a\)](#)



RGBB: Stacking Analysis



Left: Detrending by fitting
Right: Detrending by theory
[Cao & Pinsonneault \(2025a\)](#)



Envelope Undershooting?

A type of
convective
overshooting.

→: Mirror Lake at
The Ohio State
University

October 23, 2023



Lithium Depletion

Data from APO-K2

Fractions of Li detections

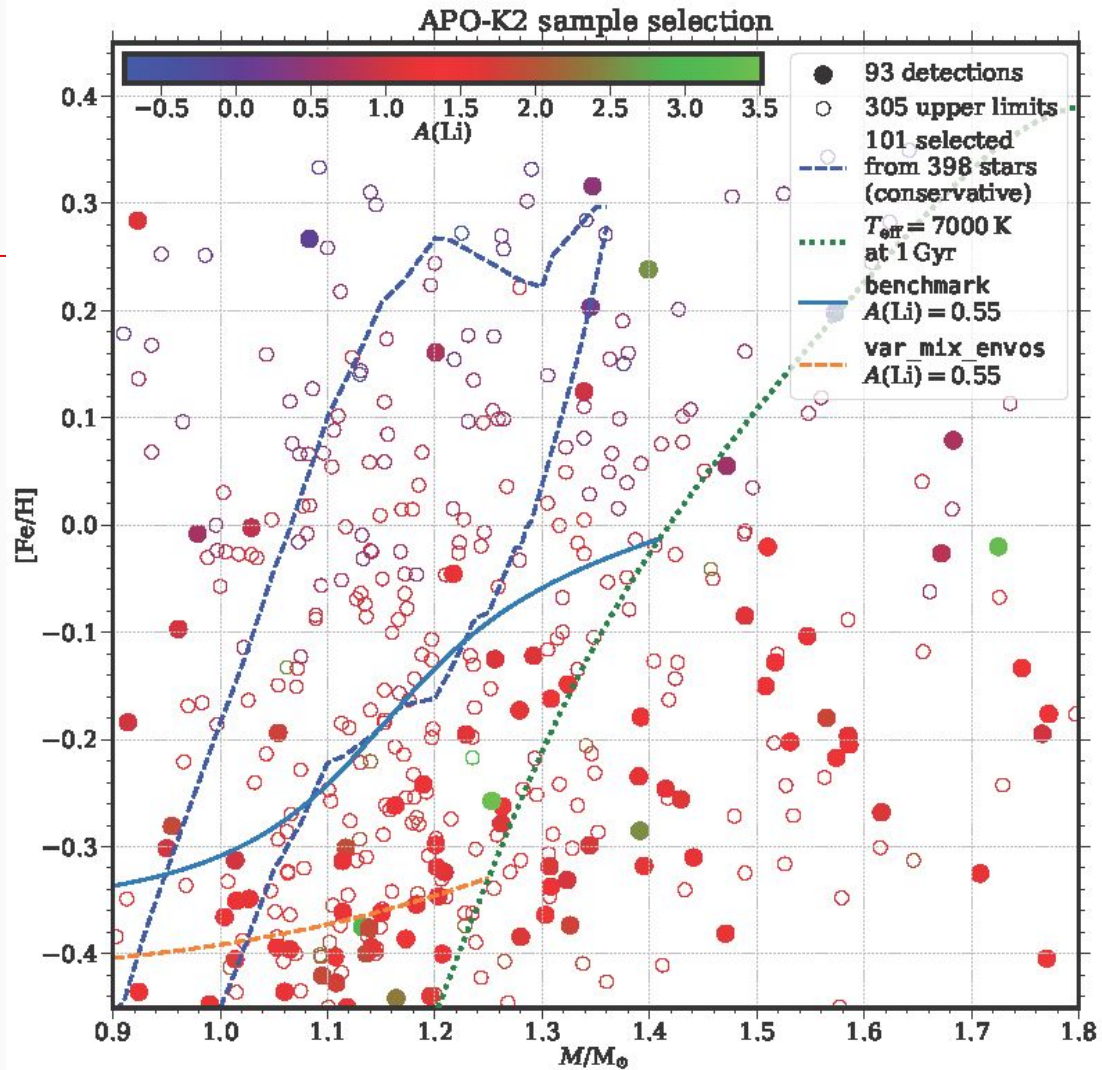
Upper left: $16/176 = 9.09\%$

Middle left: $21/87 = 24.14\%$

Lower left: $21/43 = 48.84\%$

Right: Other mechanisms?

[Cao & Pinsonneault \(2025a\)](#)



Luminous Giants (Upper RGB Stars)

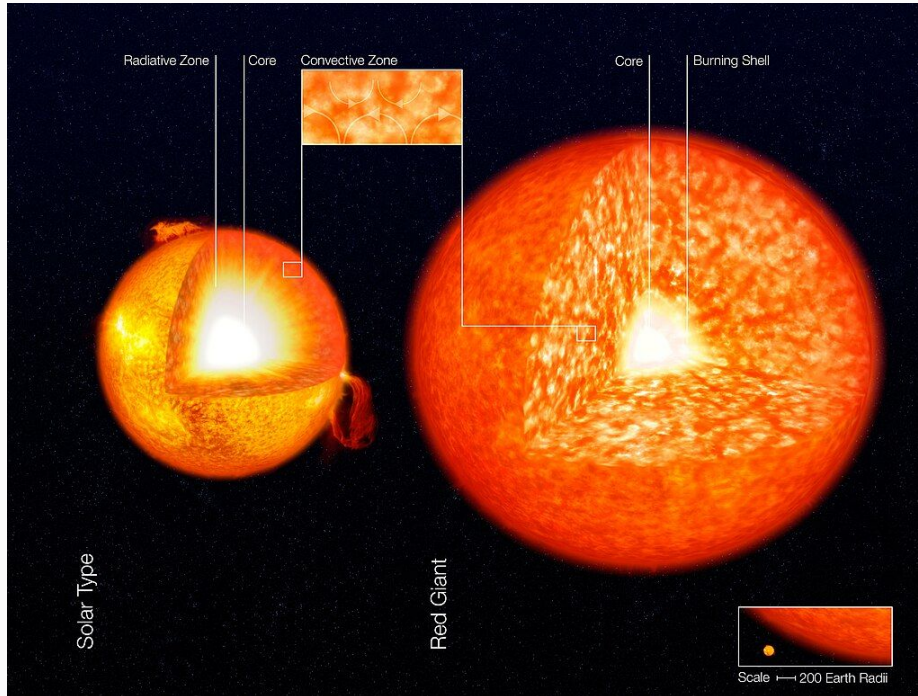
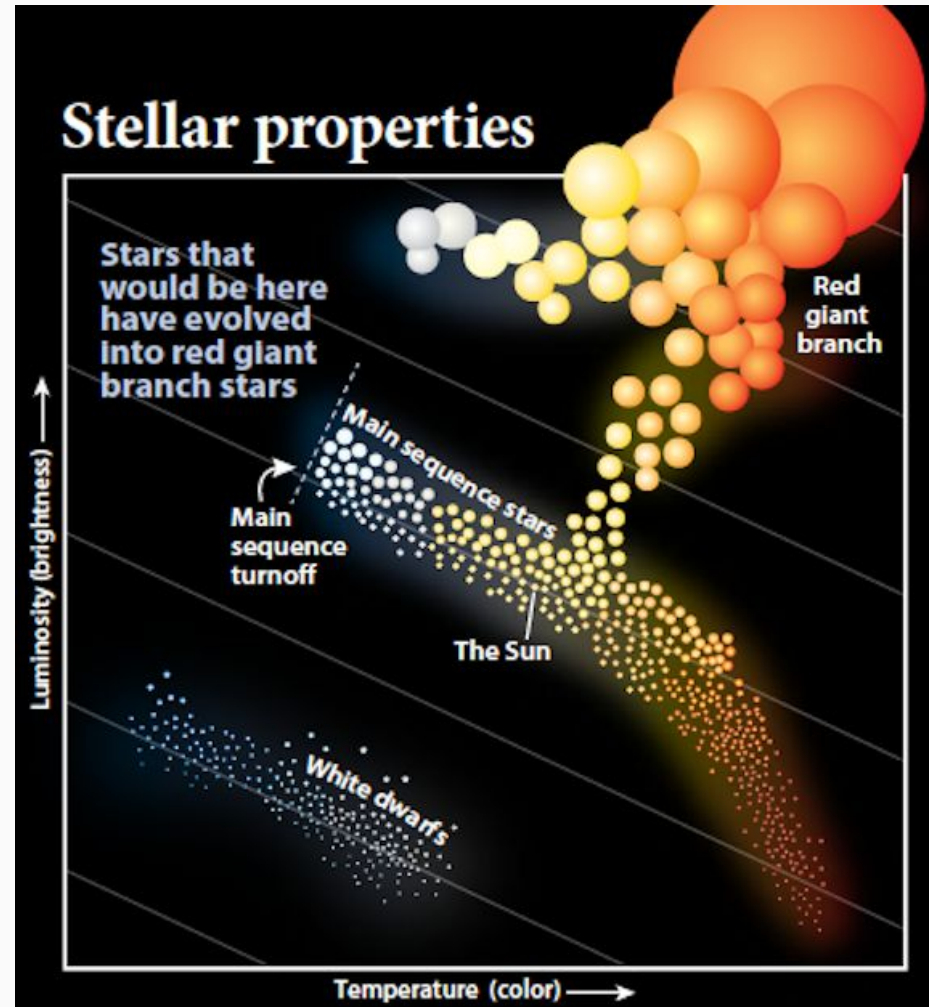


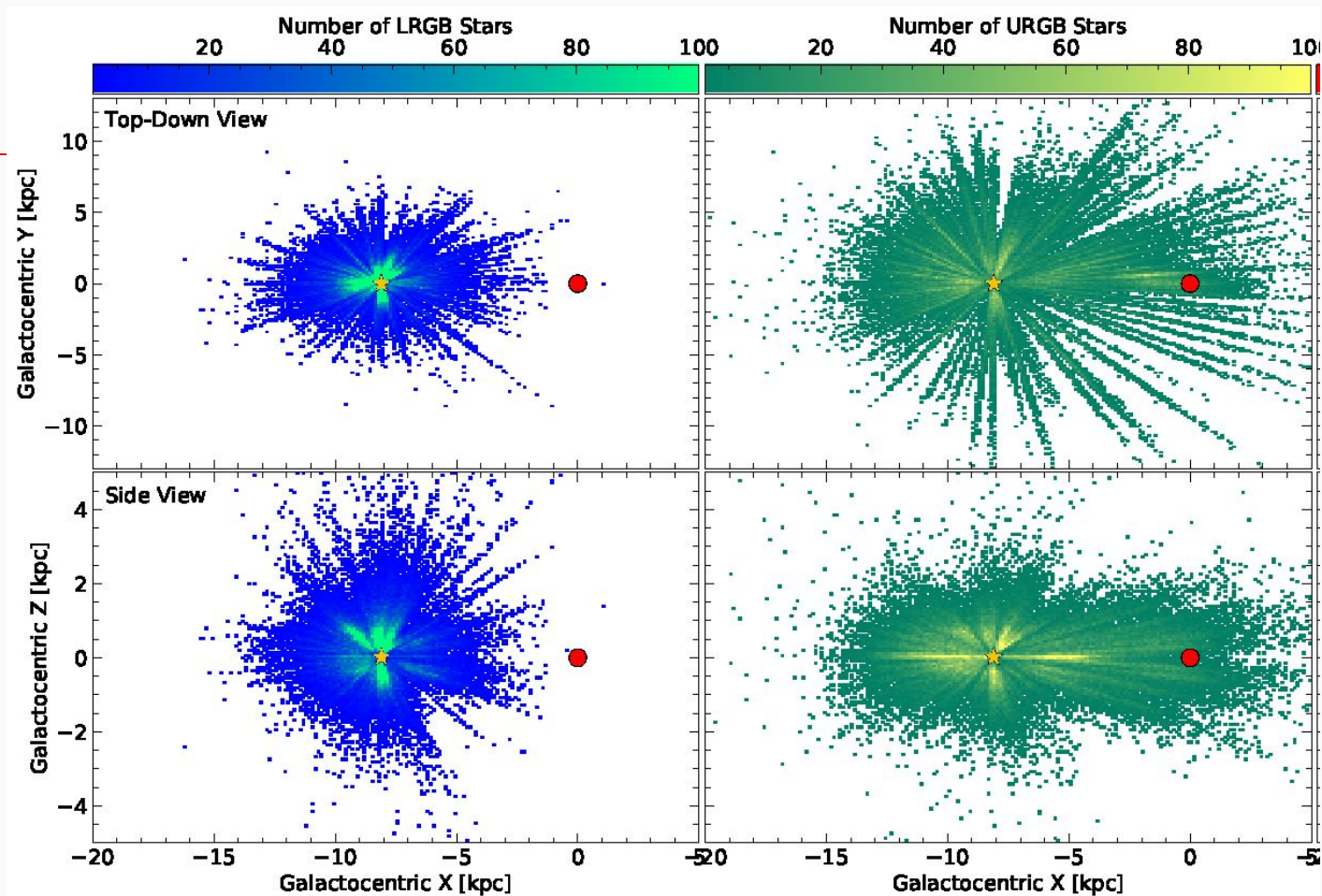
Image Credits: ESO (↑) / Roen Kelly (→)



Luminous Giants

... can be seen from great distances.

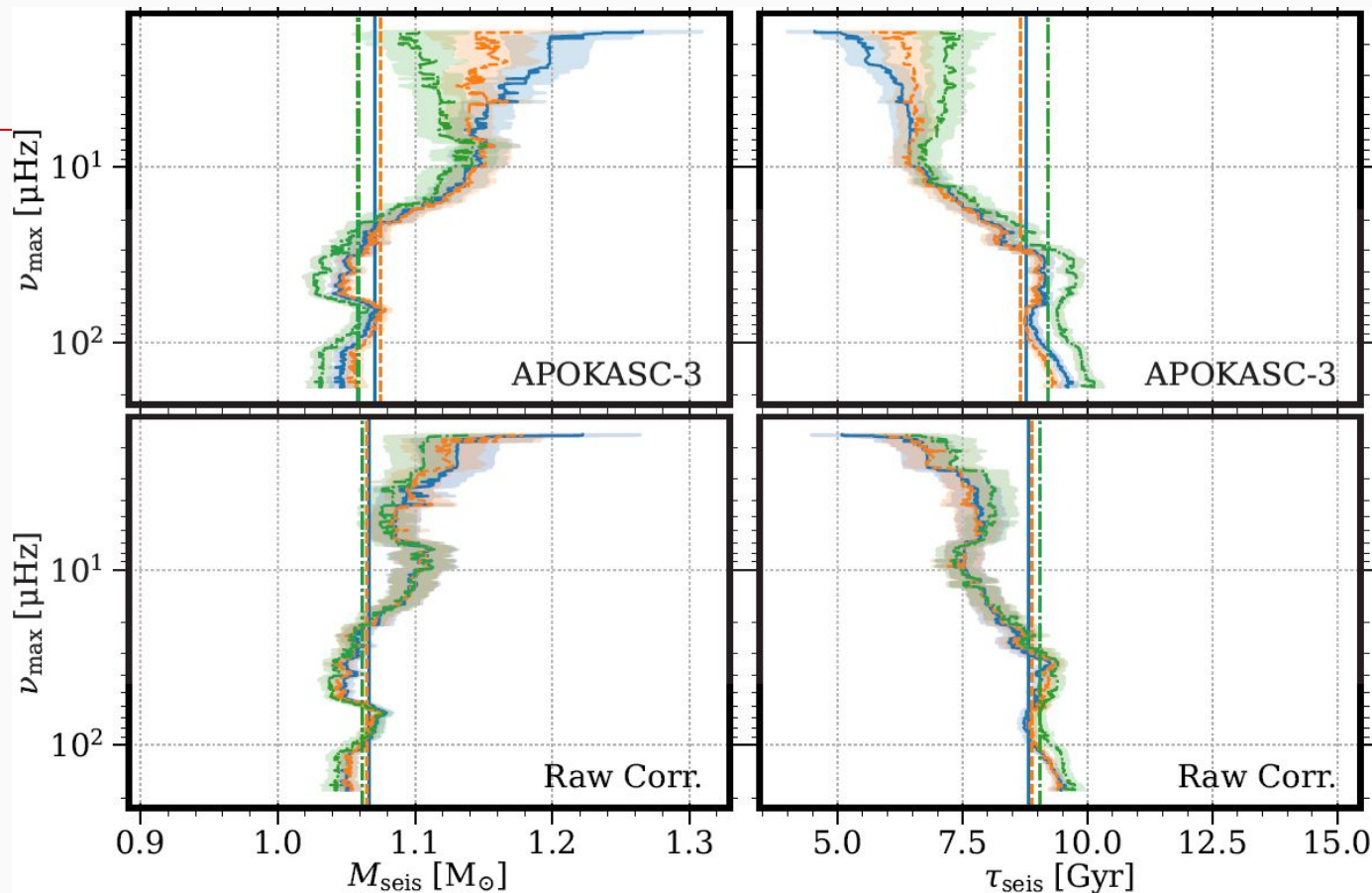
[Roberts et al. \(2025\)](#)



New Correction Scheme

Dual reduction in systematics:
Consistency
between methods
Agreement with
vertical lines
(medians)

[Cao & Pinsonneault \(2025b\)](#)



Future Prospects

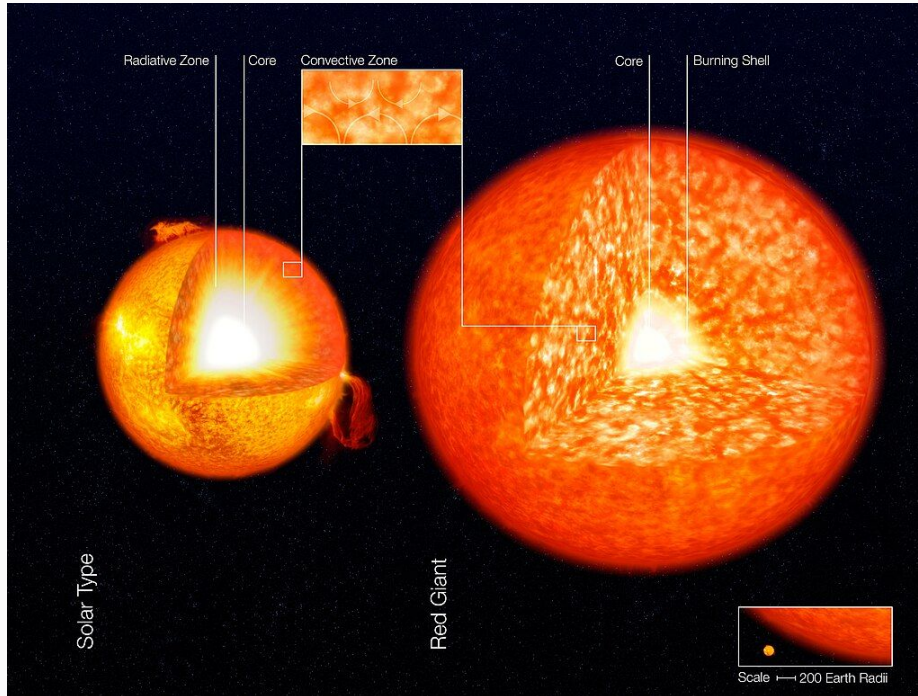
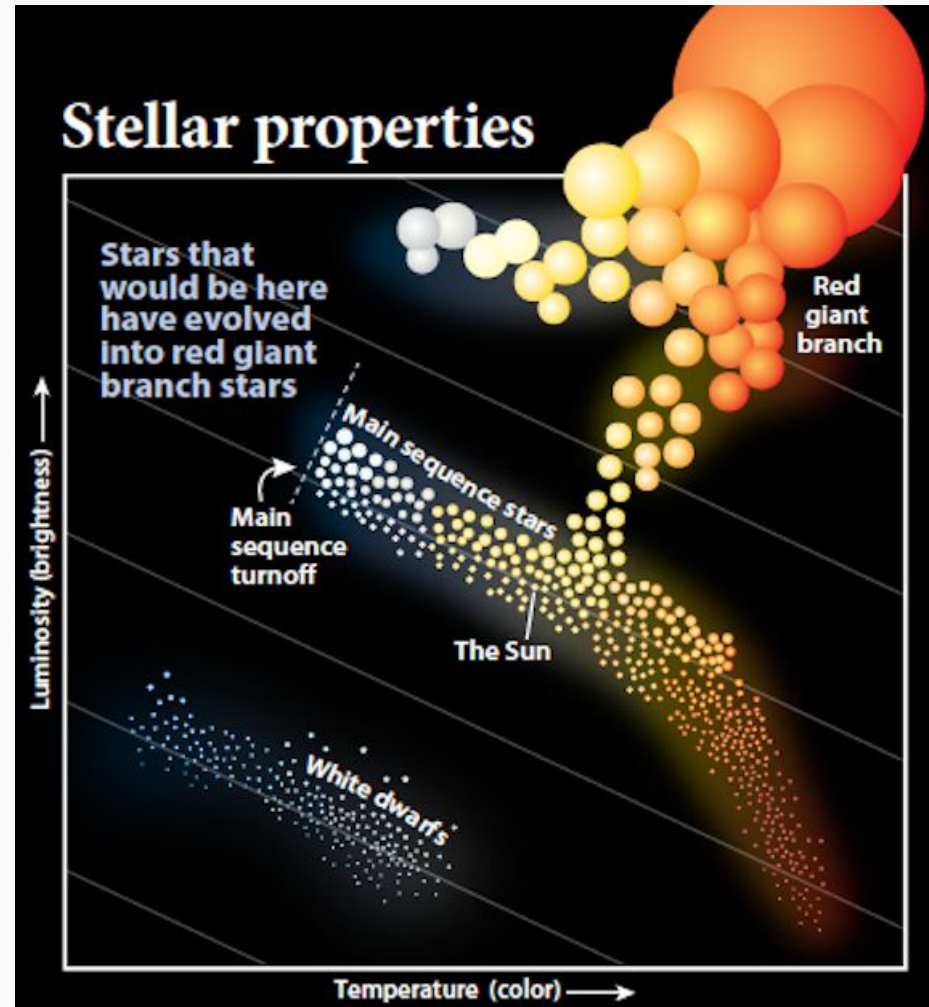


Image Credits: ESO (↑) / Roen Kelly (→)



The Yale Rotating Evolution Code

 yreclab / yrec

  |     

[Code](#) [Issues 1](#) [Pull requests](#) [Actions](#) [Projects](#) [Security](#) [Insights](#) [Settings](#)

 yrec Public

[Edit Pins](#) [Watch 0](#) [Fork 3](#) [Star 2](#)

[main](#)  



[Code](#)

 **rendinam** Merge pull request #11 from yreclab...  b182e6c · 4 days ago  97 Commits

 docs	Added build files for documentati...	6 months ago
 examples	Update test suite docs	3 weeks ago
 input	removed duplicate atmos tables	6 months ago
 src	Changed undocumented constant...	last week

About

a pseudo-2D stellar evolution code with rotation, modern microphysics, and starspots

-  [Readme](#)
-  [Activity](#)
-  [Custom properties](#)
-  2 stars

The Yale Rotating Evolution Code

yrec^{lab} v.4.31 | [docs](#) | [github](#) | [about](#)

NML1: control [Download](#)

```
$CONTROL  
  
DESCRIP(1) = "model4.31 run. diffusion pre-MS.  
Alexander06/OP95/Potekhin opacity"  
DESCRIP(2) = "Kurucz Atm; SCV/OPAL06 EOS"  
  
LCALS = .FALSE.  
TOLL = 5.0D-6  
TOLR = 5.0D-6  
  
LCALST = .FALSE.  
XLS = 8.945D0  
XLSTOL = 0.05D0  
LTEFF = .TRUE.  
STEFF = 6050.0D0  
  
LZRAMP = .FALSE.
```

Step

Run

Pause

Hertzprung-Russell Diagram



NML2: physics [Download](#)

```
These are not necessarily the defaults, they are what we agreed on  
to use as defaults among Marc, Franck and I.   LLP 07/03/2009  
  
$PHYSICS  
WEAKSCREENING = 30.0D0  
CLSUN = 3.8418D33  
CRSUN = 6.9598D10  
SSTANDARD = 0.98526,1.01165,1.03704,0.92414,1.3818,0.5,1.12766,  
1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0108,0.85597,1.0750  
LMONTE = .FALSE.  
IMBEG = 1  
IMEND = 1  
LTHOUL = .TRUE.  
LTHOULFIT = .FALSE.  
FGRZ = 1.0D0  
DT_GS = 0.1D0  
XMIN = 1.0D-3  
YMIN = 1.0D-3
```

THE NANCY GRACE ROMAN SPACE TELESCOPE



ROTAC Recommendations: Sky Map

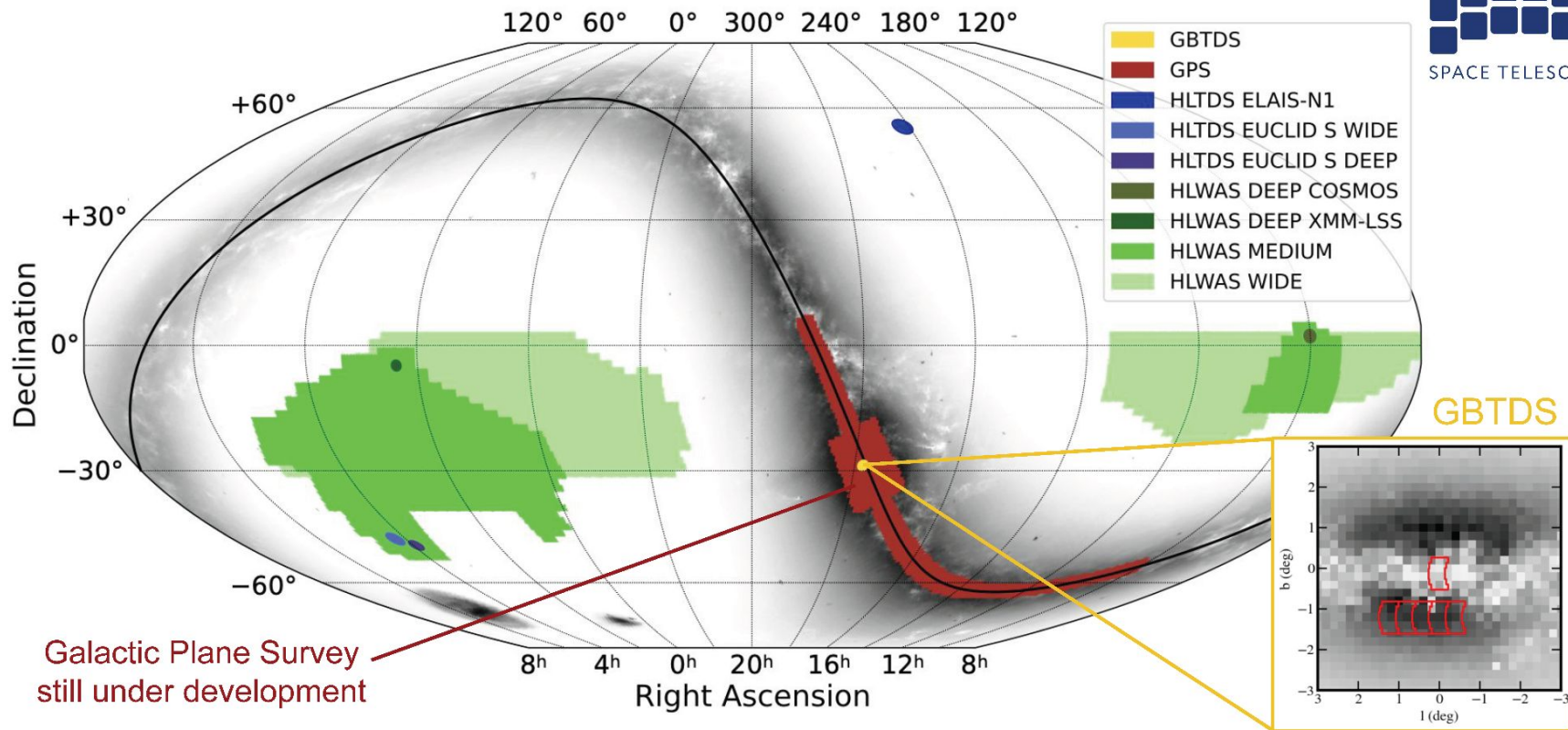
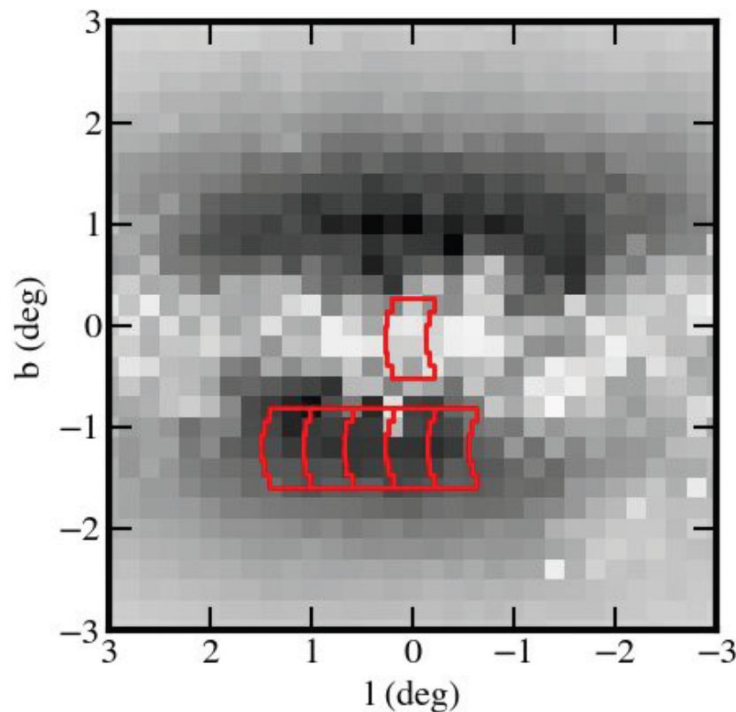


Figure credit: Javier Sanchez and Saurabh W. Jha, with assistance from Eli Rykoff and Alex Drlica-Wagner; data credit: ESA/Gaia/DPAC

Recommended GBTDS



4 Components

- 6 × 70.5 day **high-cadence seasons**
 - first & last 3 bulge seasons
 - 5 fields + Galactic Center
 - 12.1 min cadence
 - wide F146 filter, 67 sec exptime
 - F087 and F213 at 12 hr cadence
- 4 **low-cadence seasons**
 - 3 or 5 day cadence (tbd based on scheduling constraints)
- 30 **photometric snapshots** (5 filters)
- 30 **grism snapshots**

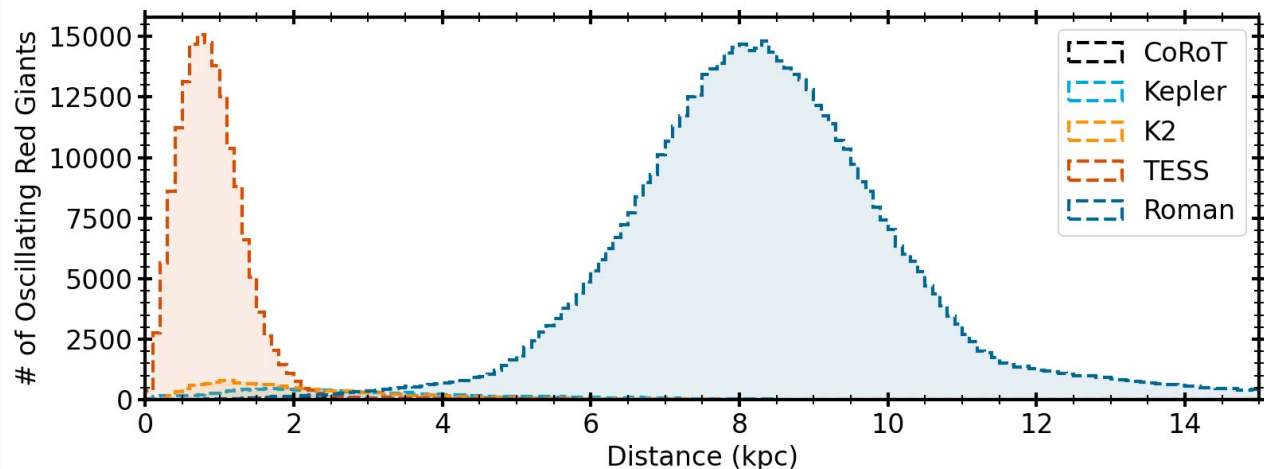
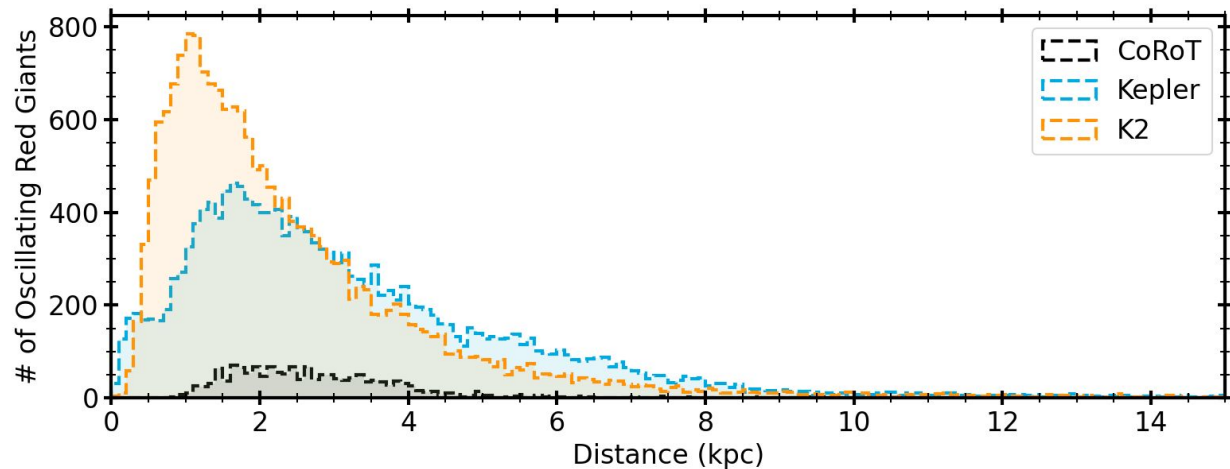
Roman Astero-seismology

Larger number of
oscillating red giants

In the Galactic Bulge
and Galactic Center
fields

[Huber et al. \(2023\)](#)

[Weiss et al. \(2025\)](#)



HLIS



roman-hlis-cosmology.caltech.edu



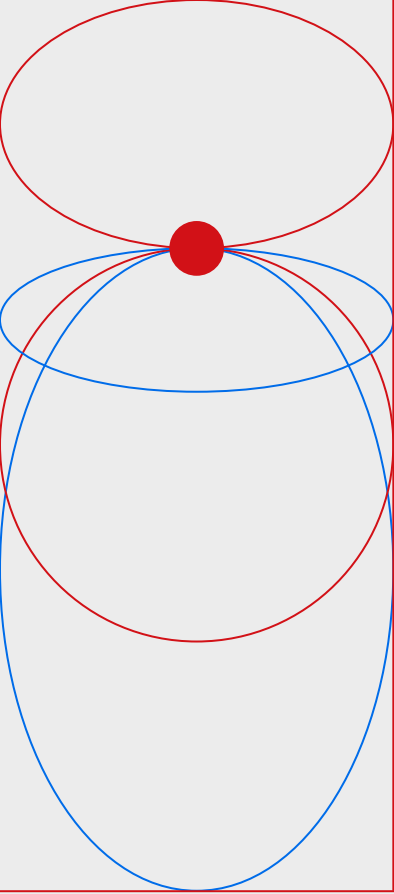
github.com/Roman-HLIS-Cosmology-PIT



Forecasts for Weak Lensing Cosmology with Nancy Grace Roman Space Telescope

Presenter: Kaili Cao (The Ohio State University)

28th International Conference on Particle Physics and Cosmology (COSMO-25), October 13, 2025



*Thank
you*