Host Star Properties: Possibilities, Hopes, and Uncertainties

Jamie Tayar

Know Thy Star, Know Thy Planet 2
February 3, 2025

jtayar.github.io

From Stellar Folks You Need:

- Stellar Temperature
- Stellar Luminosity
- Stellar Radius
- Stellar Composition
- Stellar Mass
- Stellar Age

Expected Uncertainties

- Luminosity uncertainty: 2.4% ± 0.6%: Photometric Zero Points, Offsets between surveys, Atmosphere Models, Reddening Maps, Spots
- Temperature uncertainty: 2.0% ± 0.5%: L, angular diameters
- Radius uncertainty: 4.2% ± 0.9%: L, T
- Metallicity- systematics between methods 0.15 dex

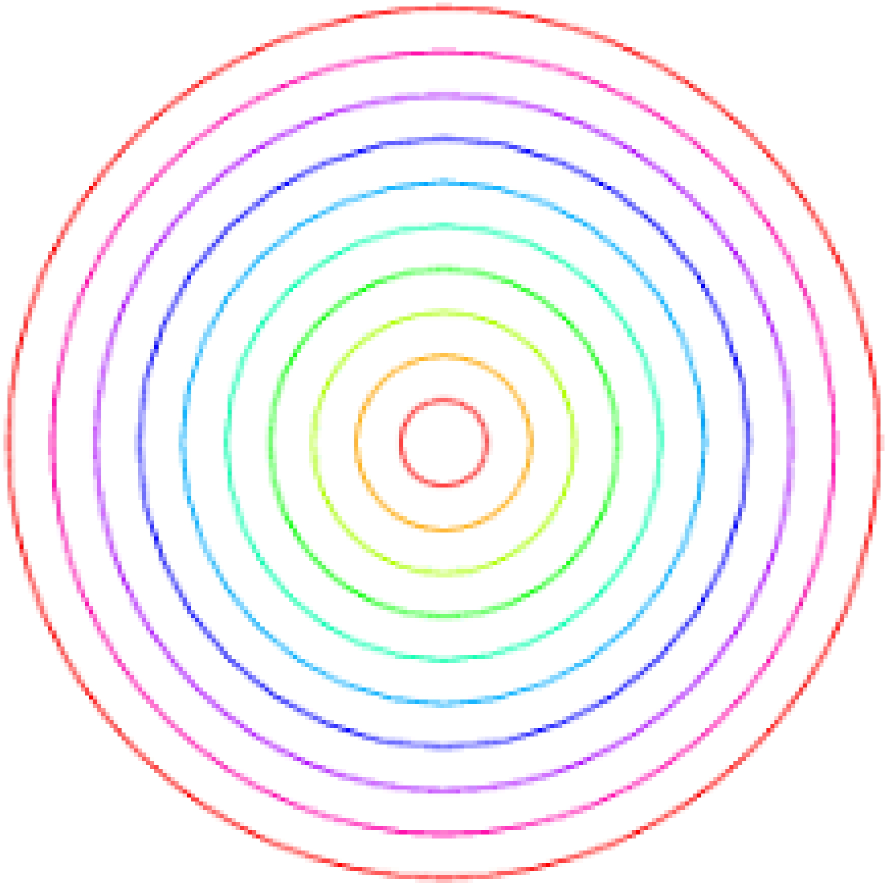
Tayar+ 2022; Mészáros+ (inc. **Tayar**) submitted; see Dan Huber's talk

How to estimate stellar mass and age

- Take known stellar parameters (e.g. Teff, L, [Fe/H])
- Look up answer in a grid of stellar models

Modeling a Star

- ~ spherical
- Conservation of Mass
- Conservation of Energy
- Hydrostatic equilibrium (pressure balances gravity)
- Nuclear fusion
- Energy transport



How Models Work

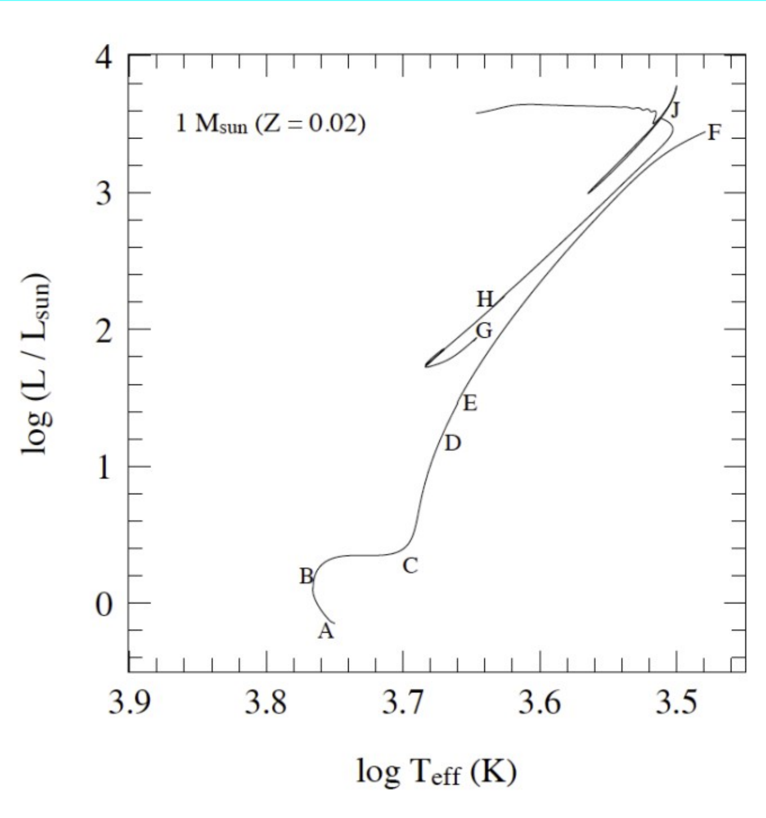
Inputs:

- Mass
- Composition
- Initial Rotation

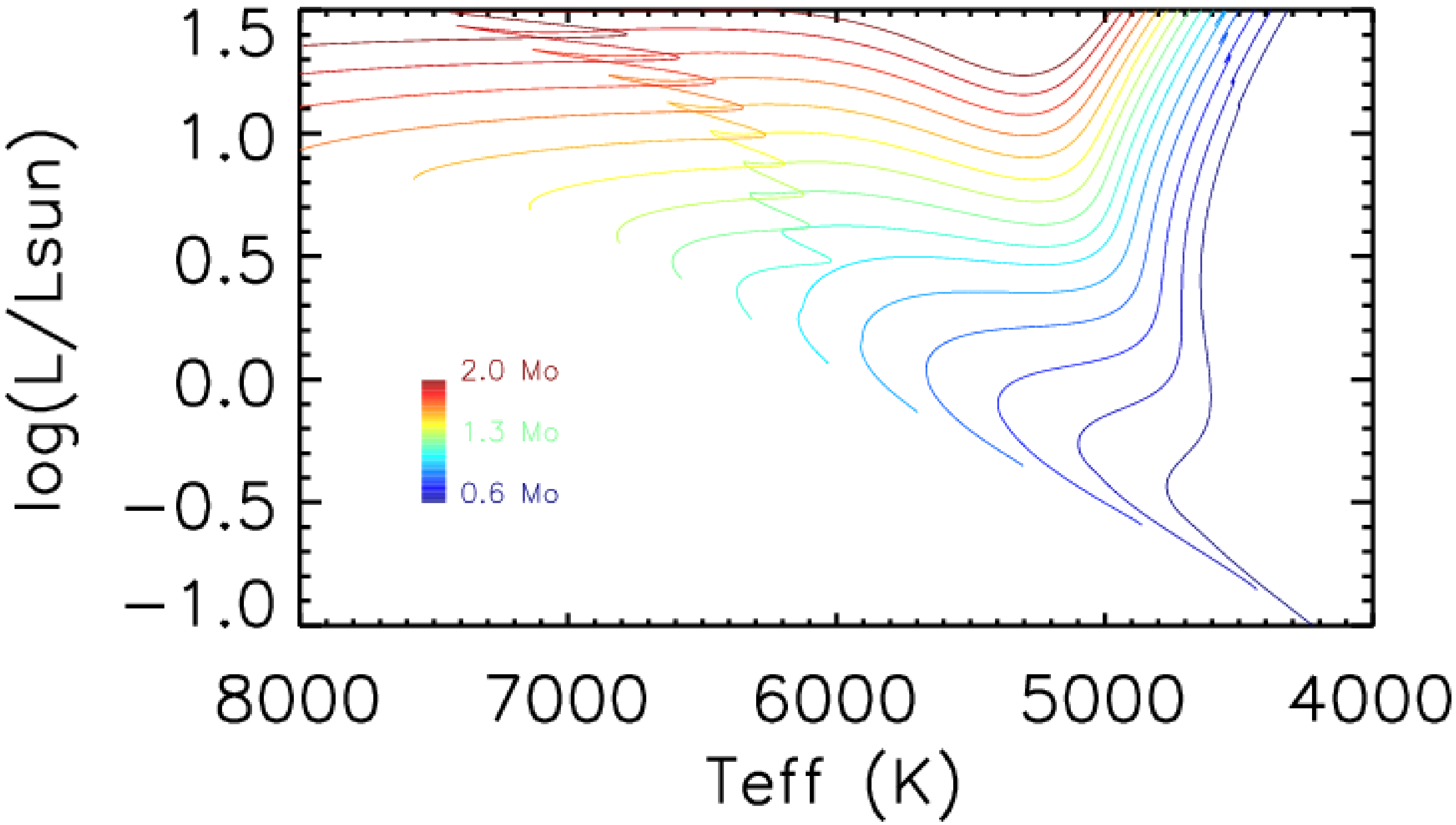
Modeling Code:

has physics assumptions
solve coupled
differential equations

Stellar Model:

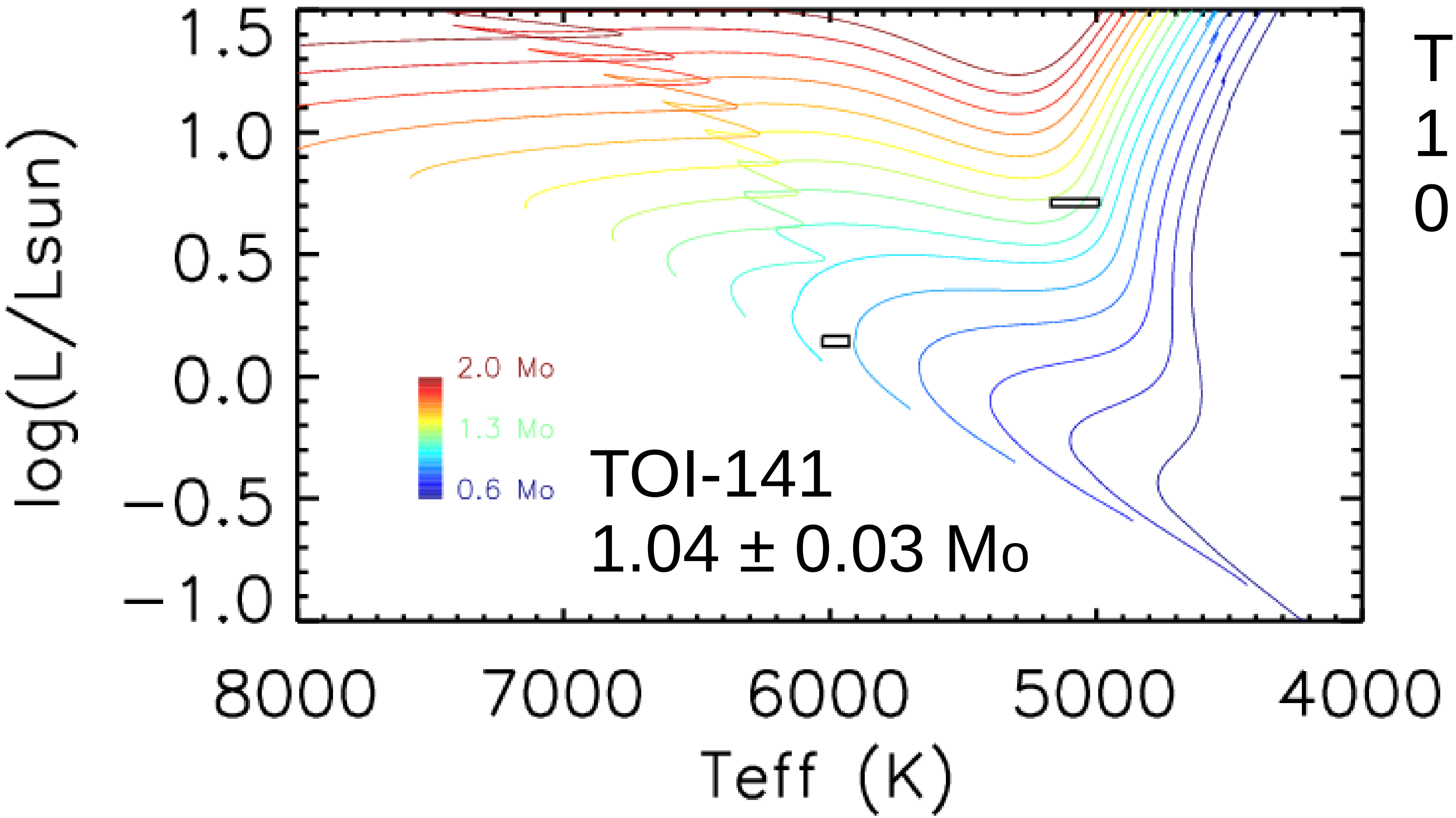


Model Grid



log(L/Lsun)
1.5
1.0
0.5
0.0
−0.5
−1.0
8000
7000
6000
5000
4000
Teff (K)
2.0 Mo
1.3 Mo
0.6 Mo

Model Grid



TOI-197
1.30 ±
0.09 Mo

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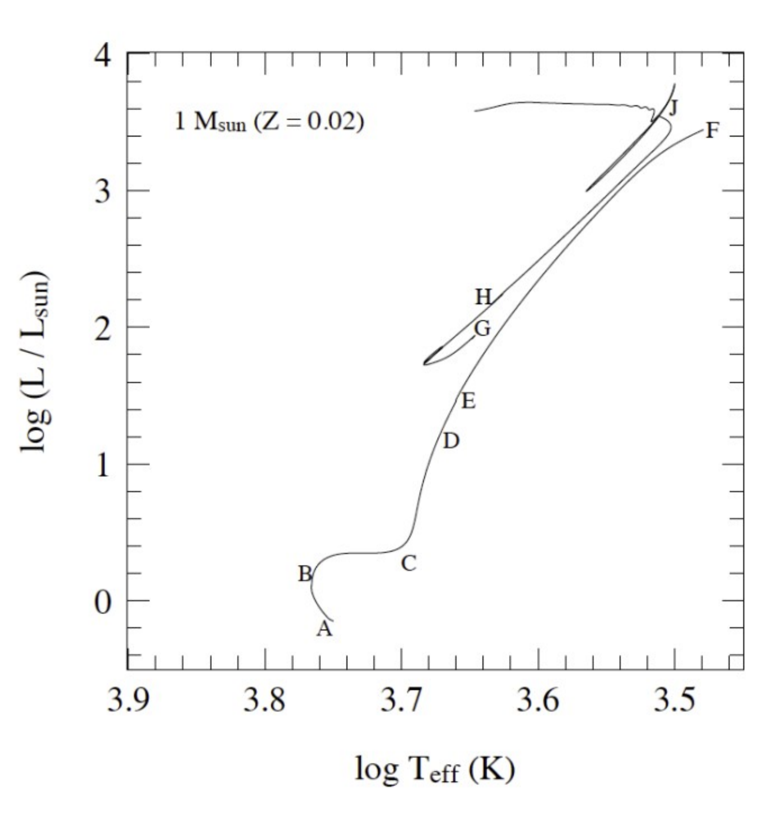
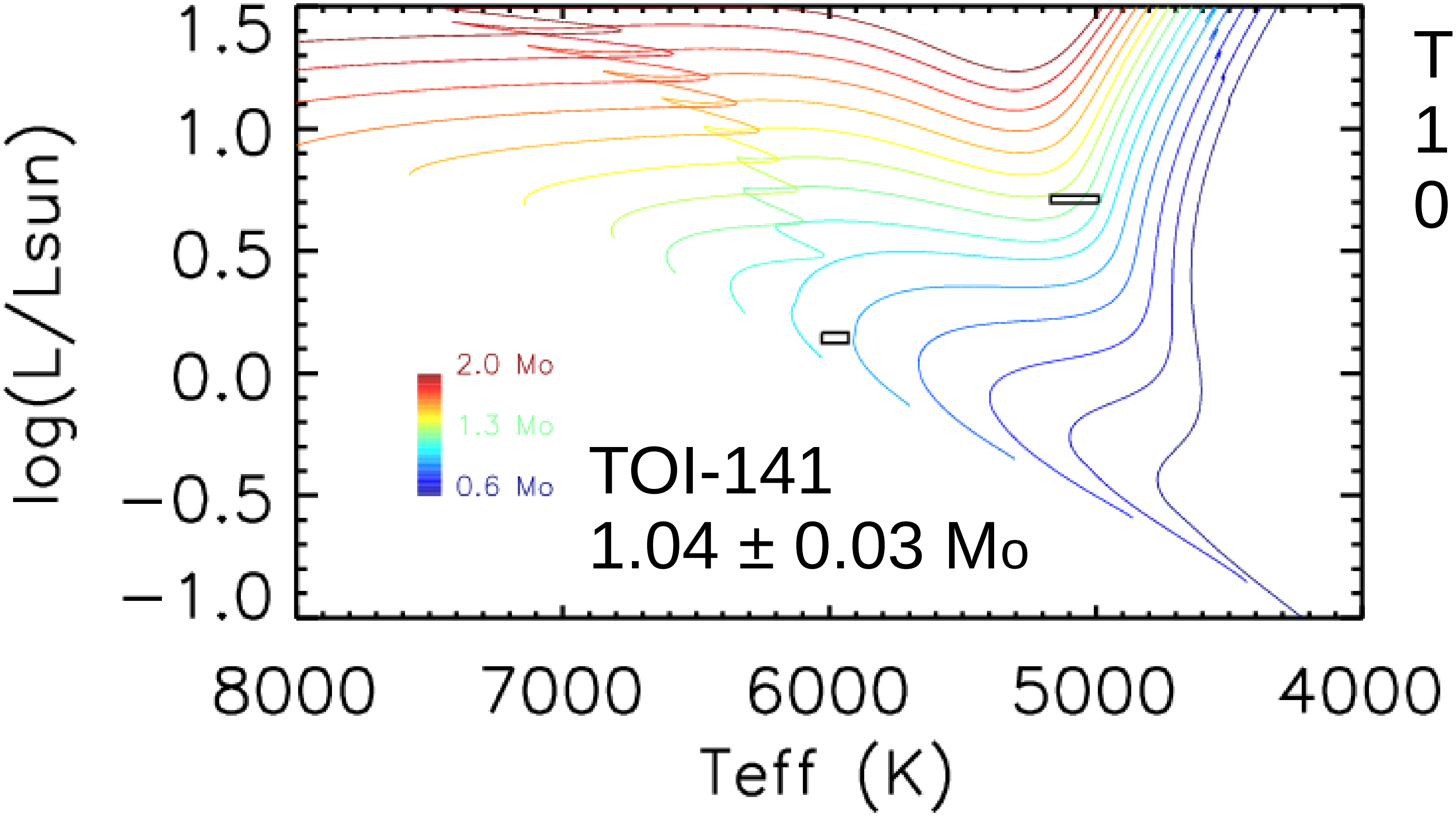


“has physics assumptions”

- Nuclear reaction rates & opacities
- Radiative processes and the atmospheric structure
- Fluid dynamics and convection parameterization (in 1 dimension…)
- Rotation and mixing
- etc

Model Grid



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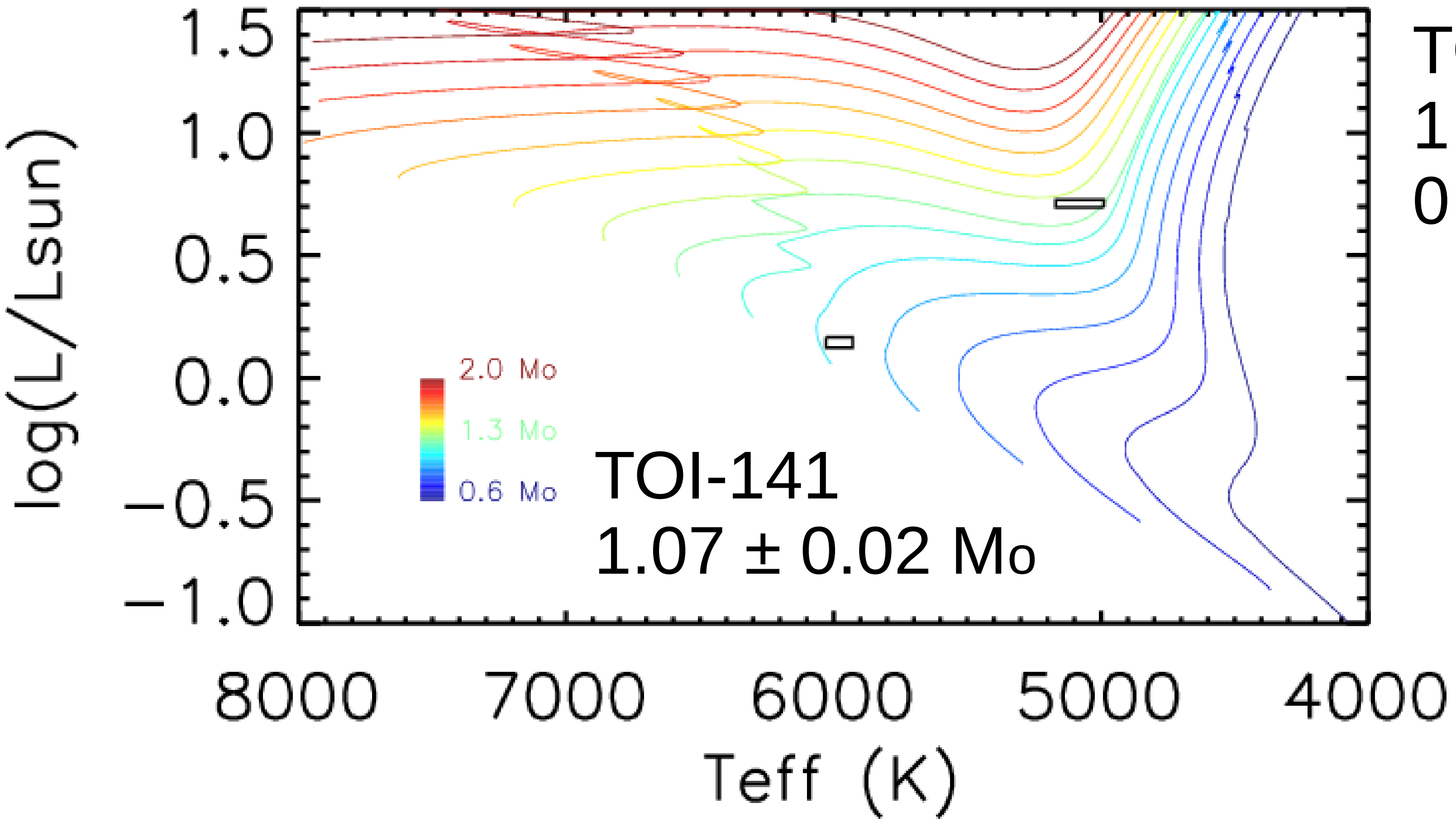
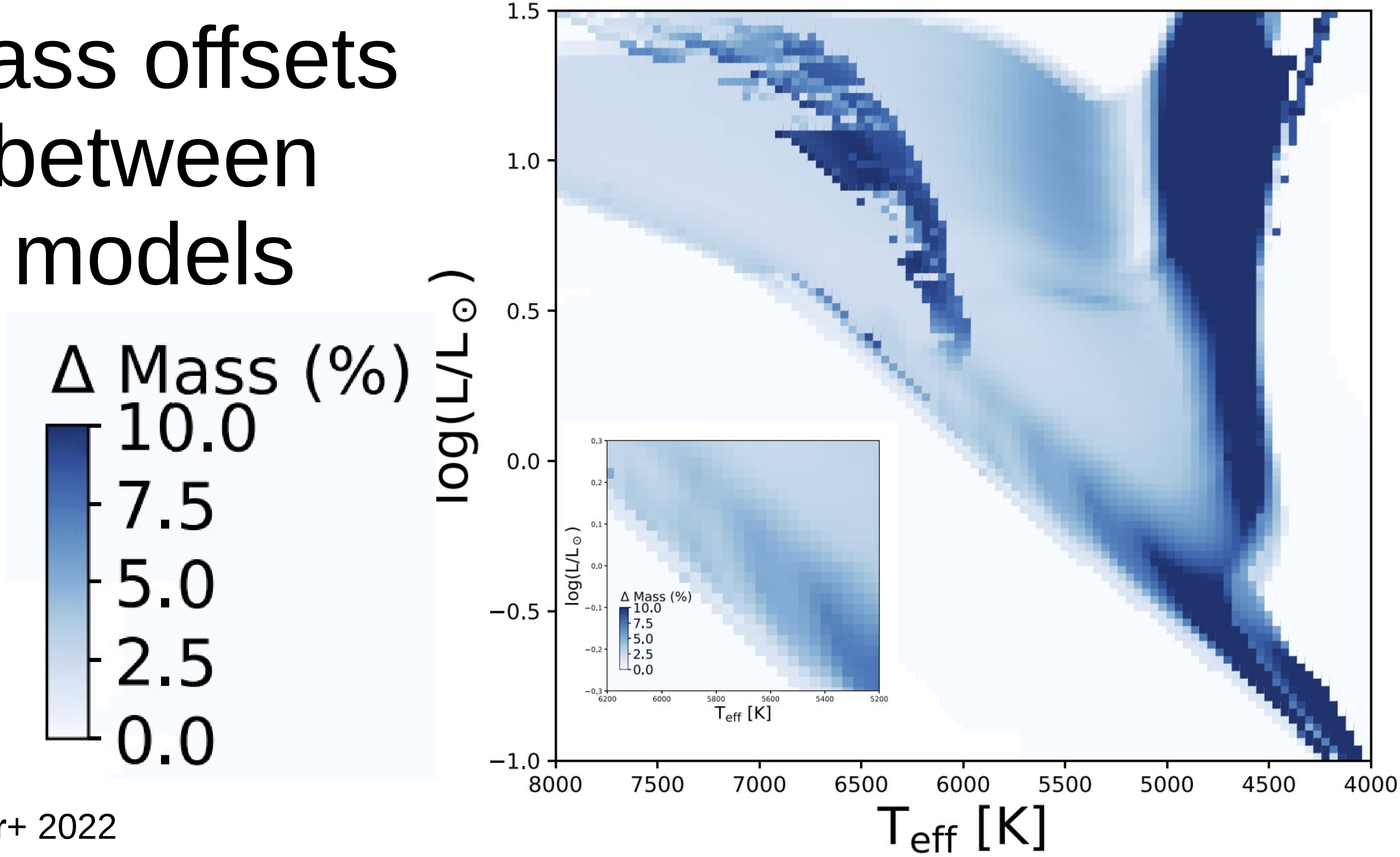
Different Model Grid



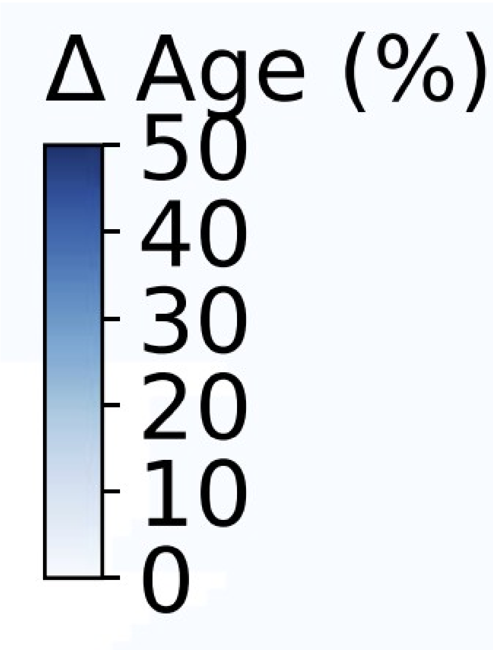
TOI-197
1.33 ±
0.07 Mo

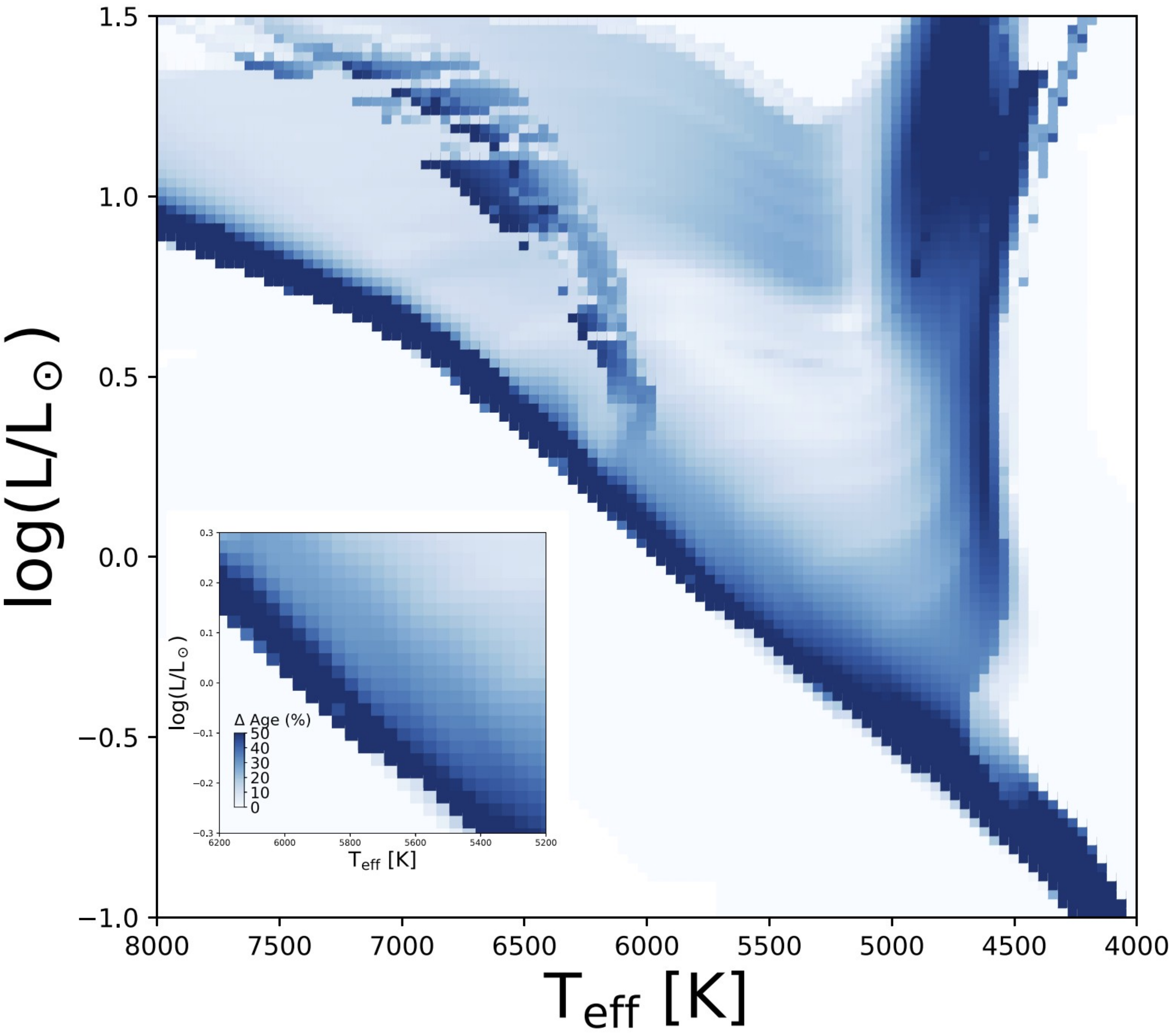
Mass offsets between models



Tayar+ 2022

Age offsets between models

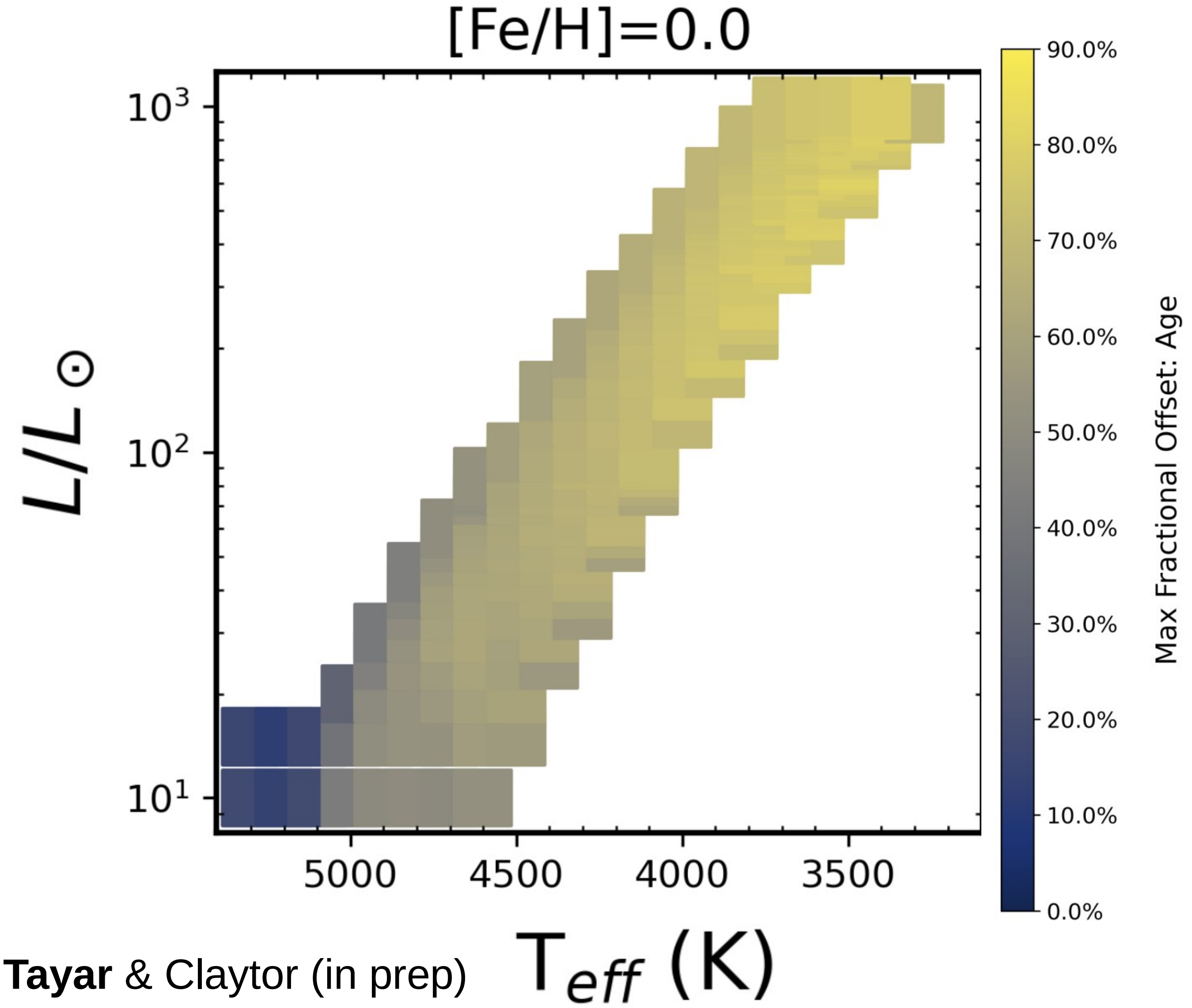




Tayar+ 2022

Worse for Giants

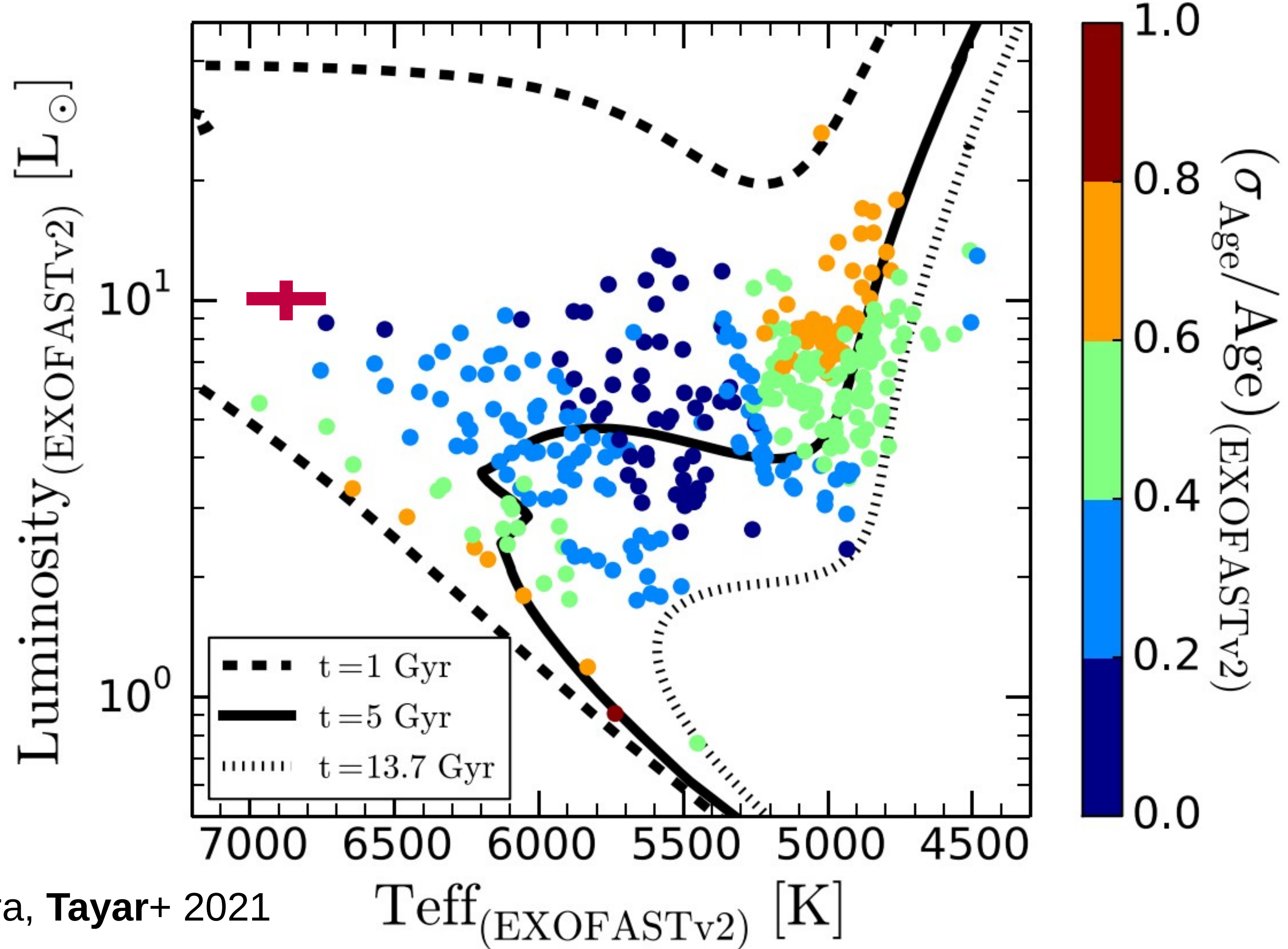
Leslie Morales



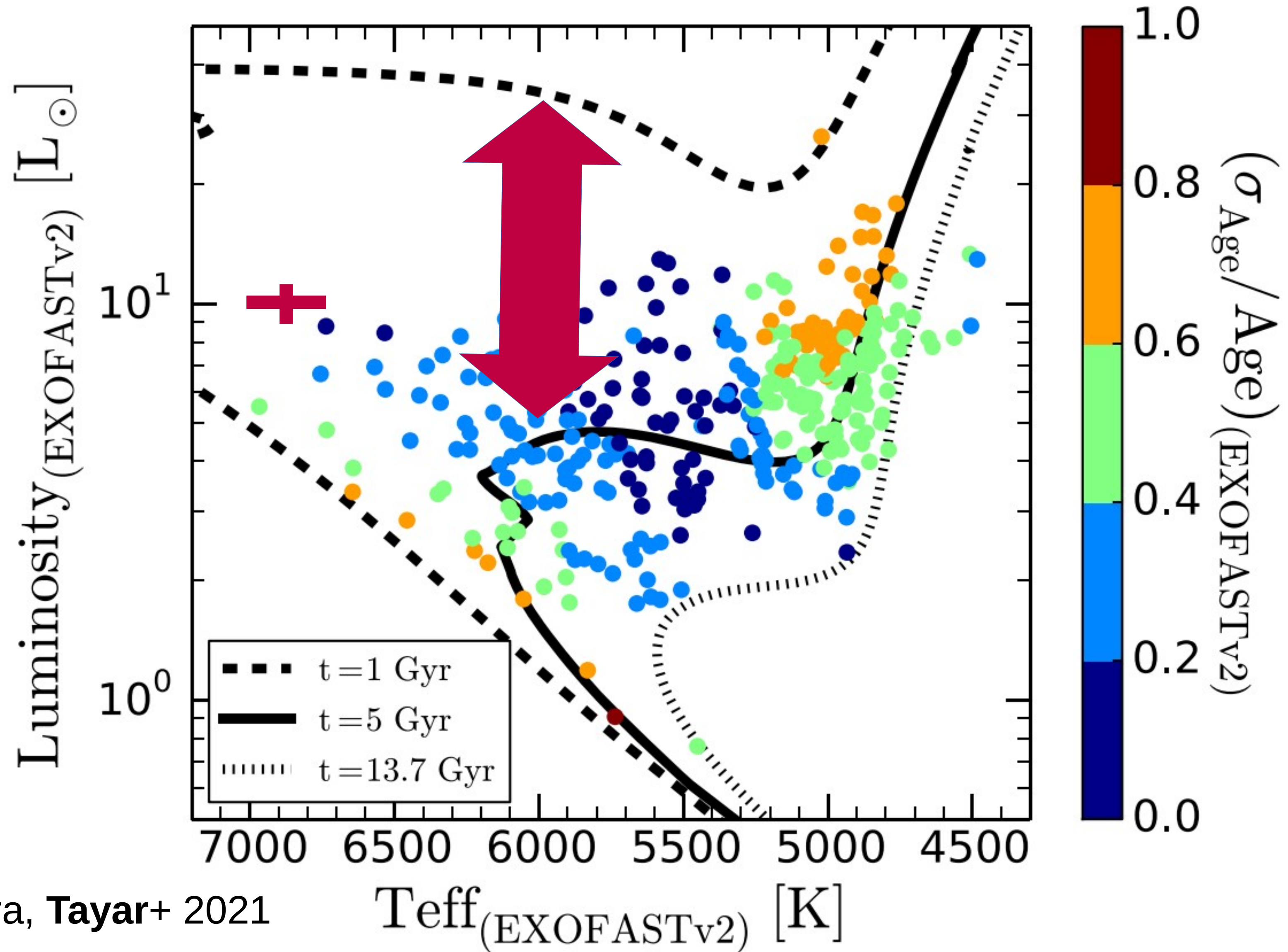
Morales, **Tayar** & Claytor (in prep)

Mass and Age Uncertainties

- Two components:
  - Model to Model Systematics
  - Properly Propagated Empirical Uncertainties



Godoy-Rivera, **Tayar**+ 2021



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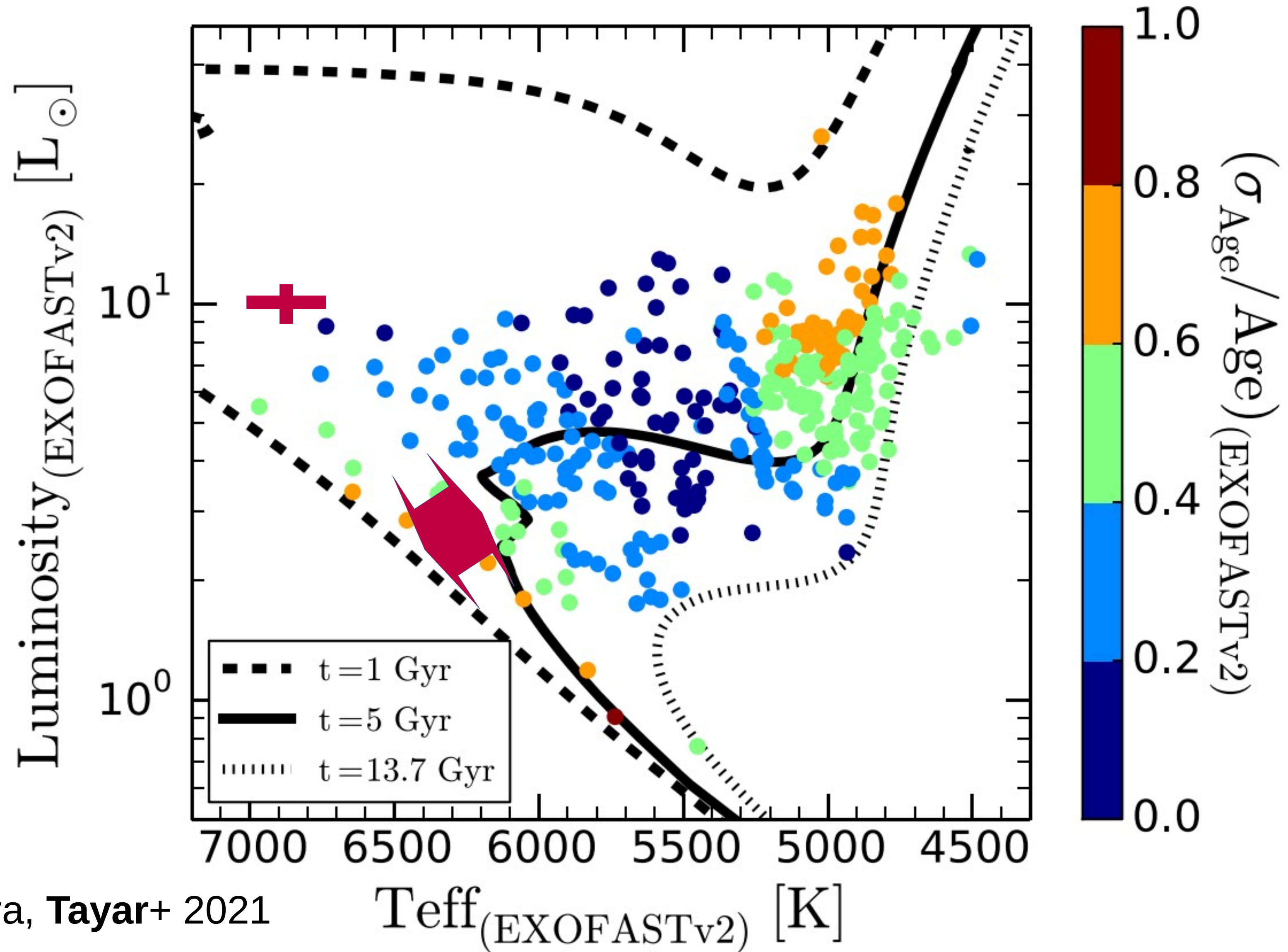

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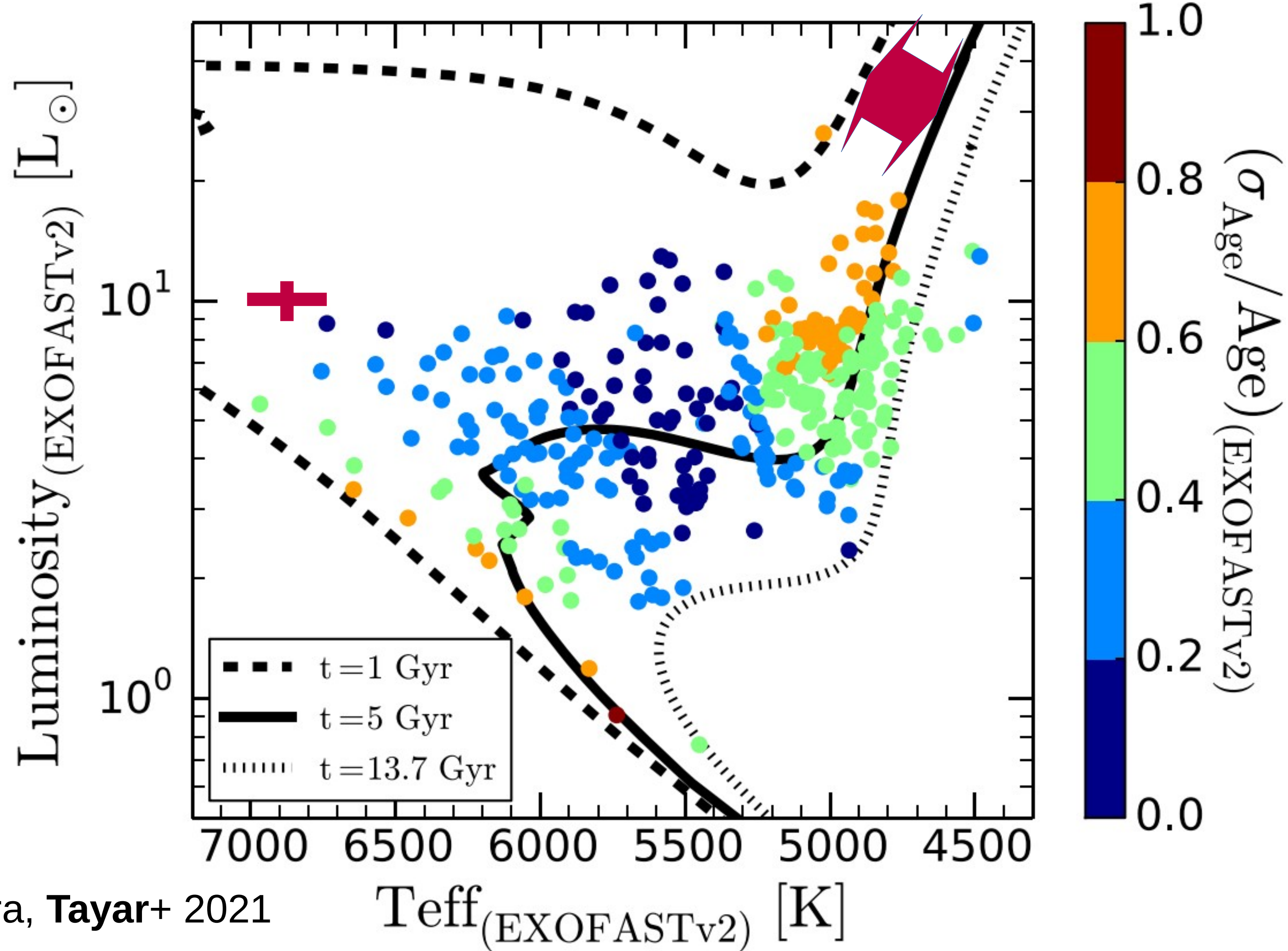
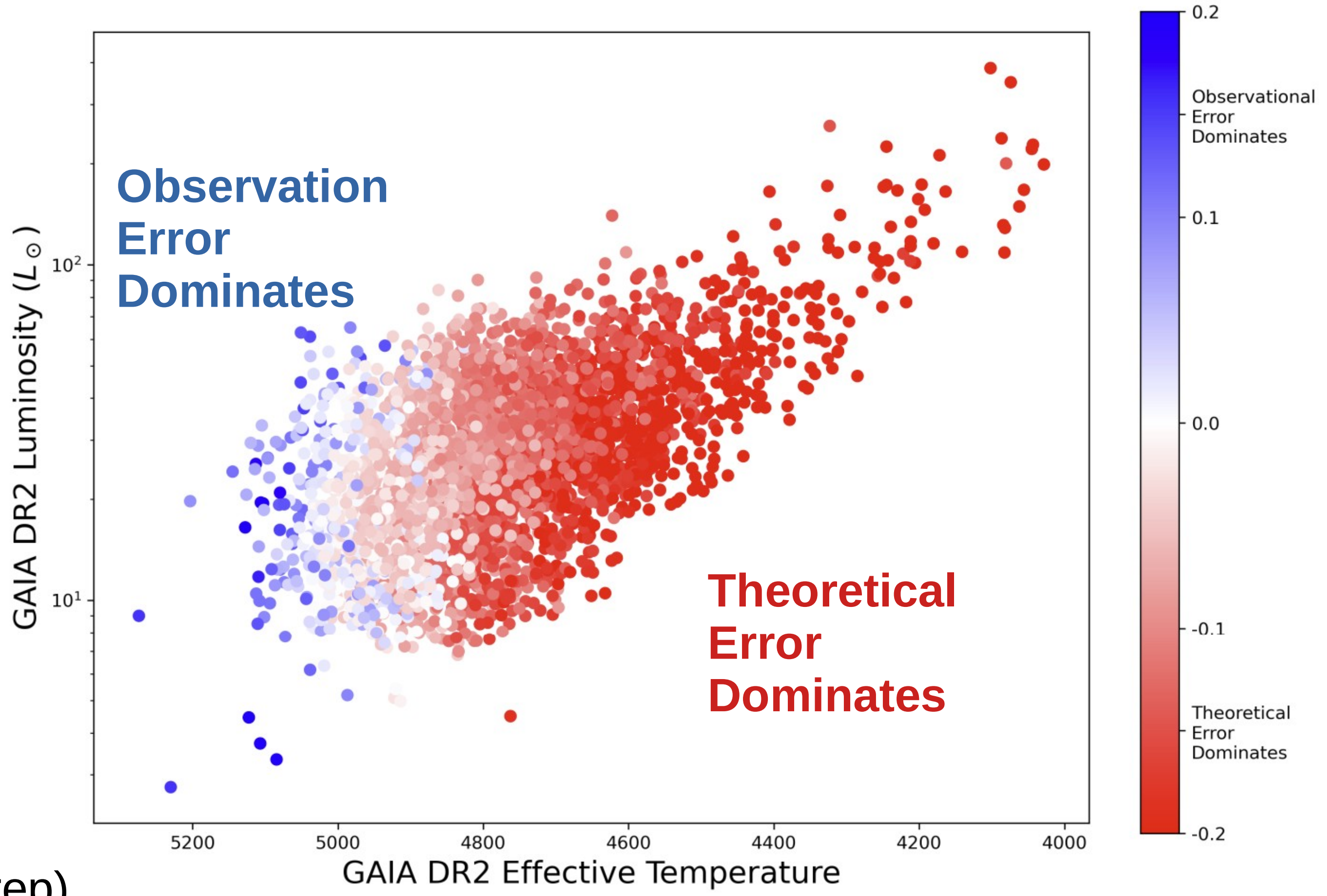


Godoy-Rivera, **Tayar**+ 2021

Compare Observation and Theory Errors

Leslie Morales



Morales, **Tayar** & Claytor (in prep)

Mass & Age Uncertainties

- Model to Model Systematics:
  - ~ 5% in mass
  - ~ 20% in age
- Empirical Uncertainties:
  - ~ 5 % in mass
  - ~ 20% in age

Get Better Masses & Ages

- Where observational uncertainties dominate, can we get better observations?
- Where theoretical error dominates, instead of assuming that all models are equally good, can we find the one that’s correct and use that?
- What about other methods for doing this?

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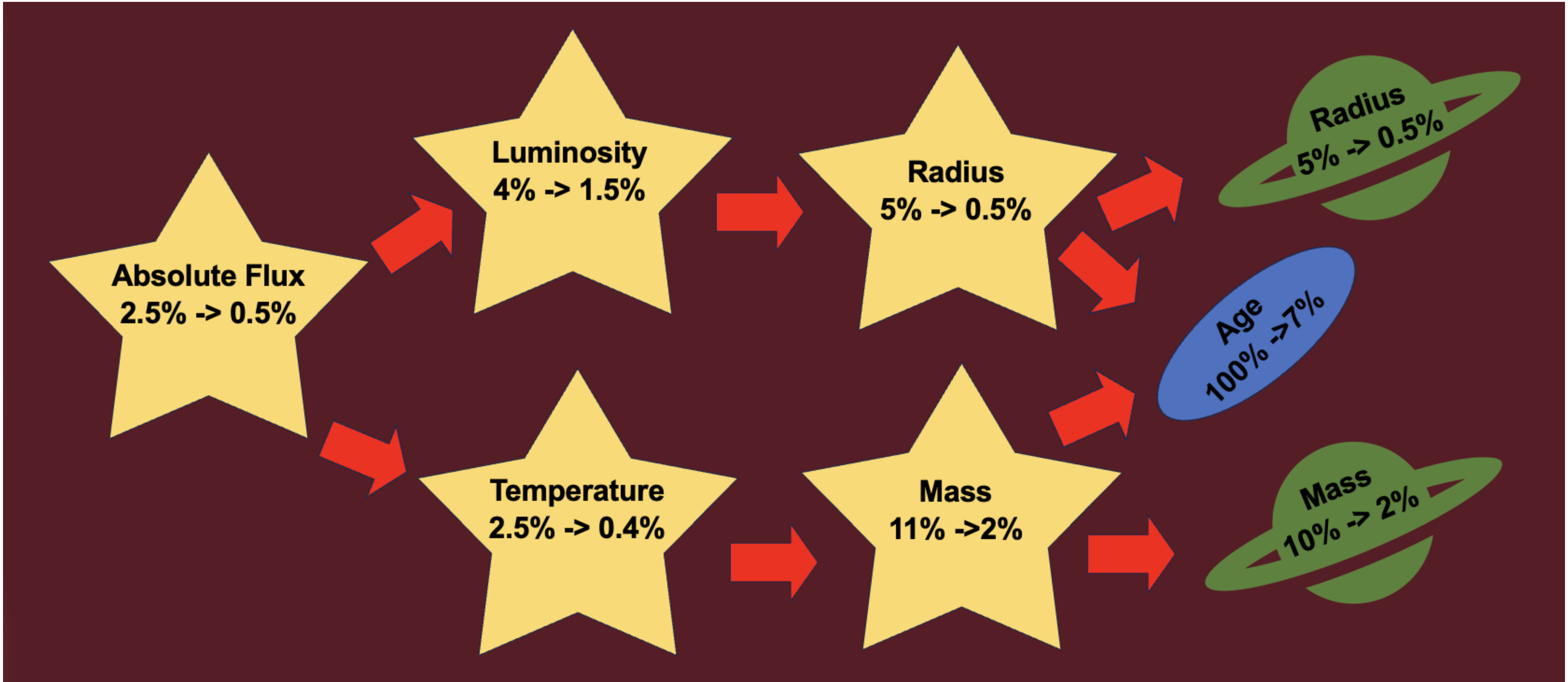
Landolt

- Provide absolute flux calibration
- Improve temperature and luminosity estimates
- Provide more stars of known parameters to anchor the scale and the models

Tanner

Landolt Improvements



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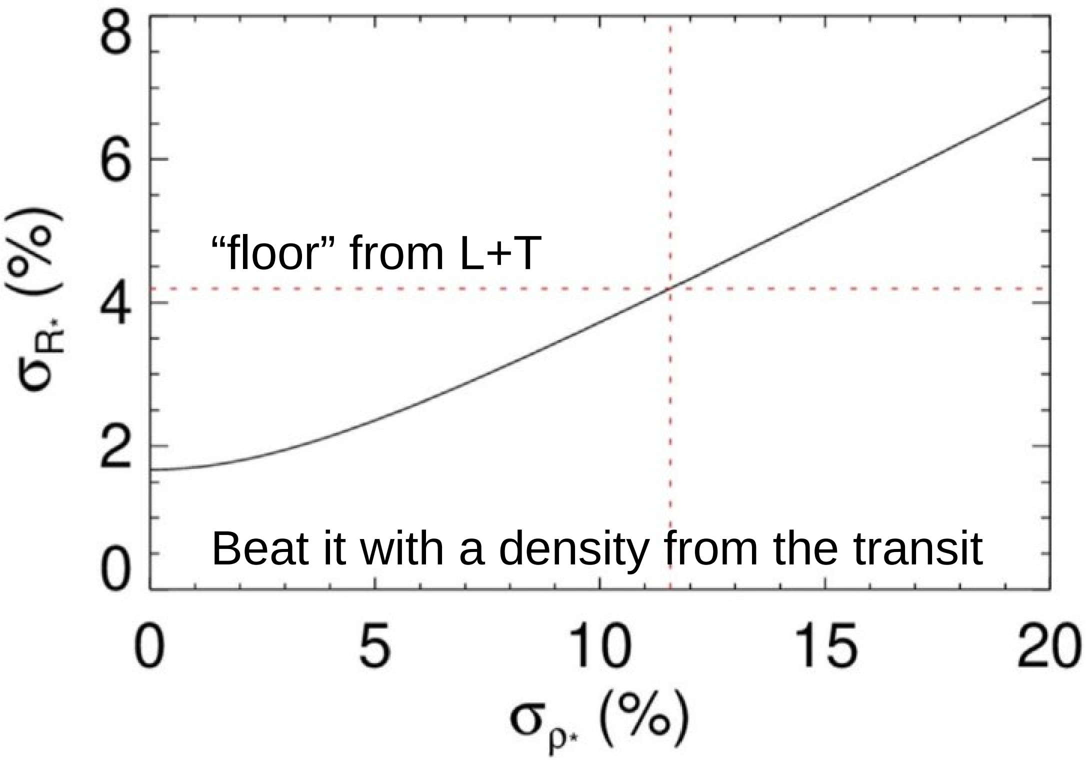
Using the stellar density

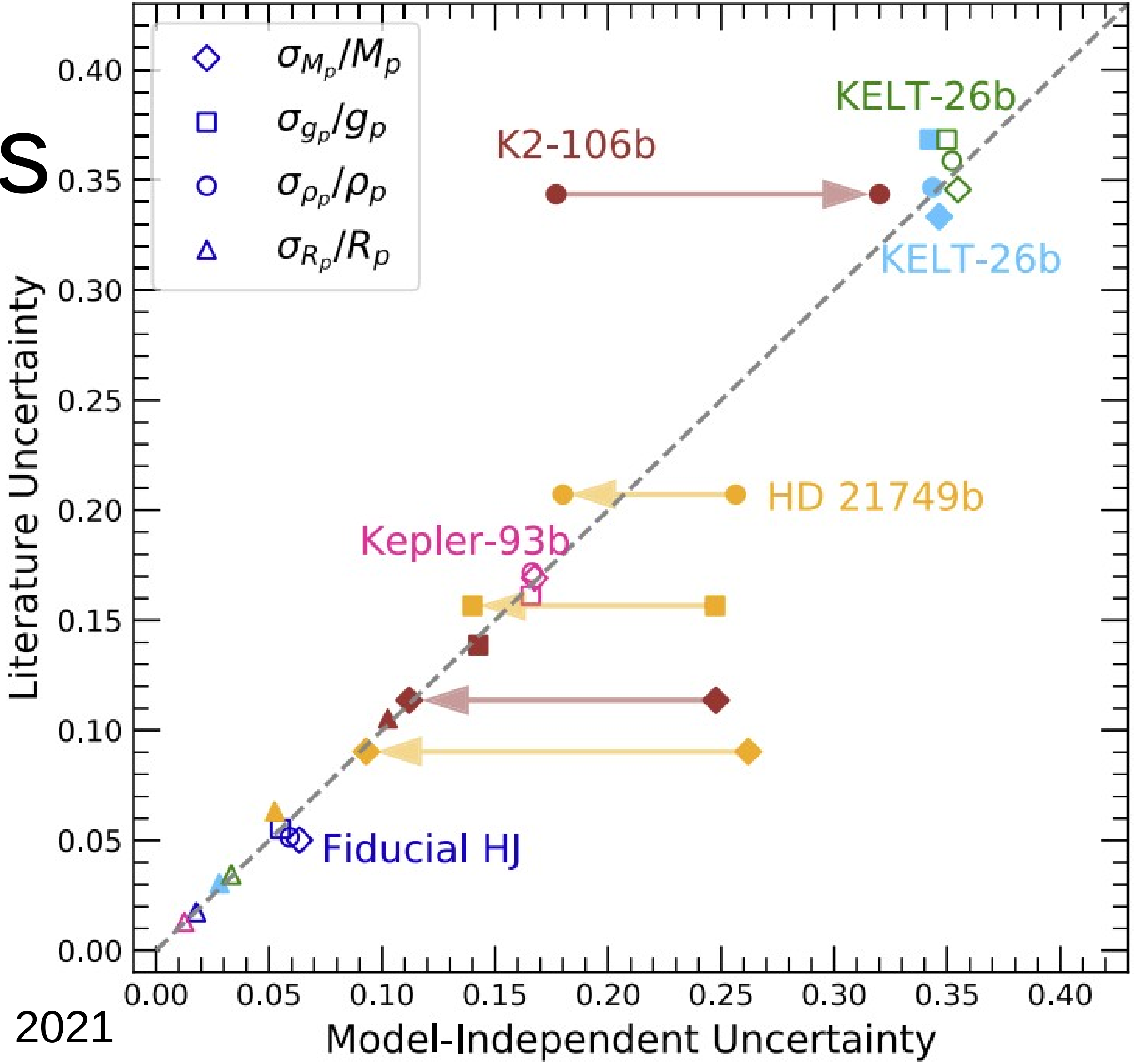
- Density from transit+ M from models = R (1.7% error)
- R+ good L = Great T (0.9% error)
- Similarly, logg (0.008 dex uncertainty R, rho)



Eastman, Diamond-Lowe, **Tayar** (2023)

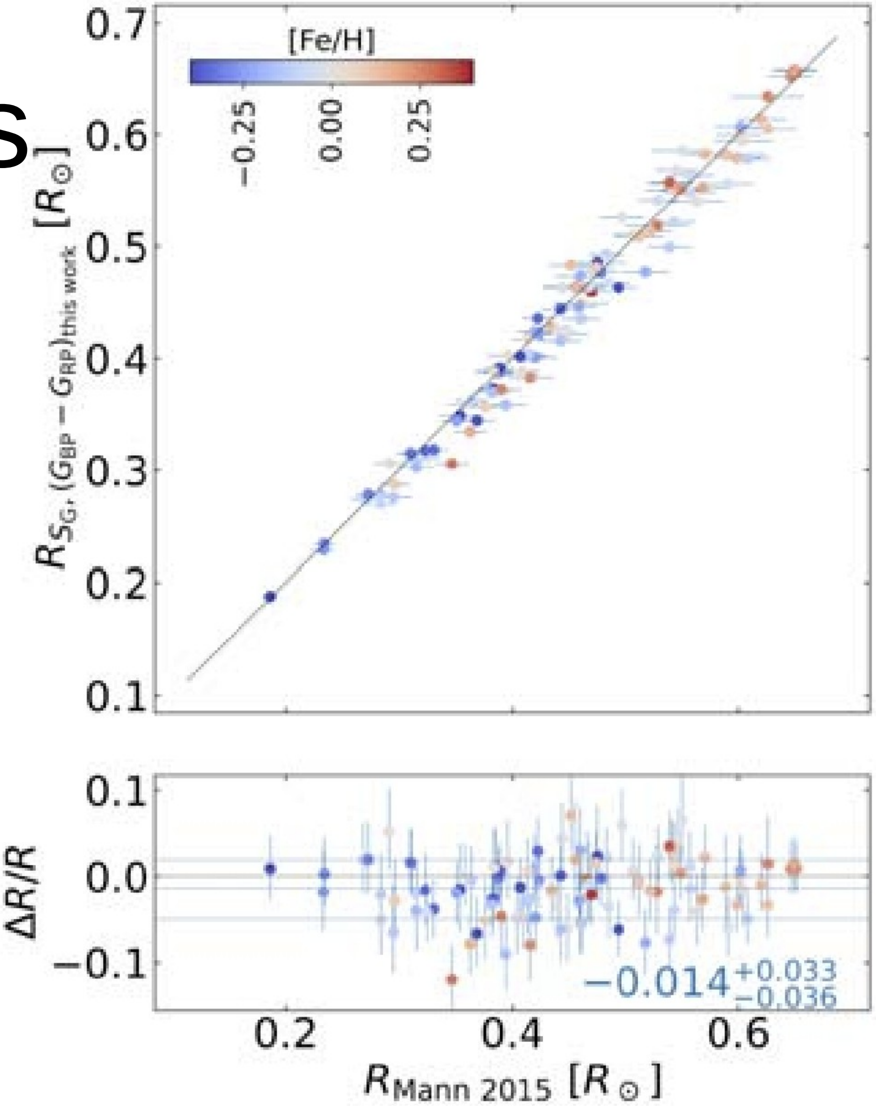
Empirical Constraints

- Planet period, transit depth, RV semi-amplitude, transit duration, and ingress/egress duration are related to the mass and radius



Rodríguez Martínez+ 2021

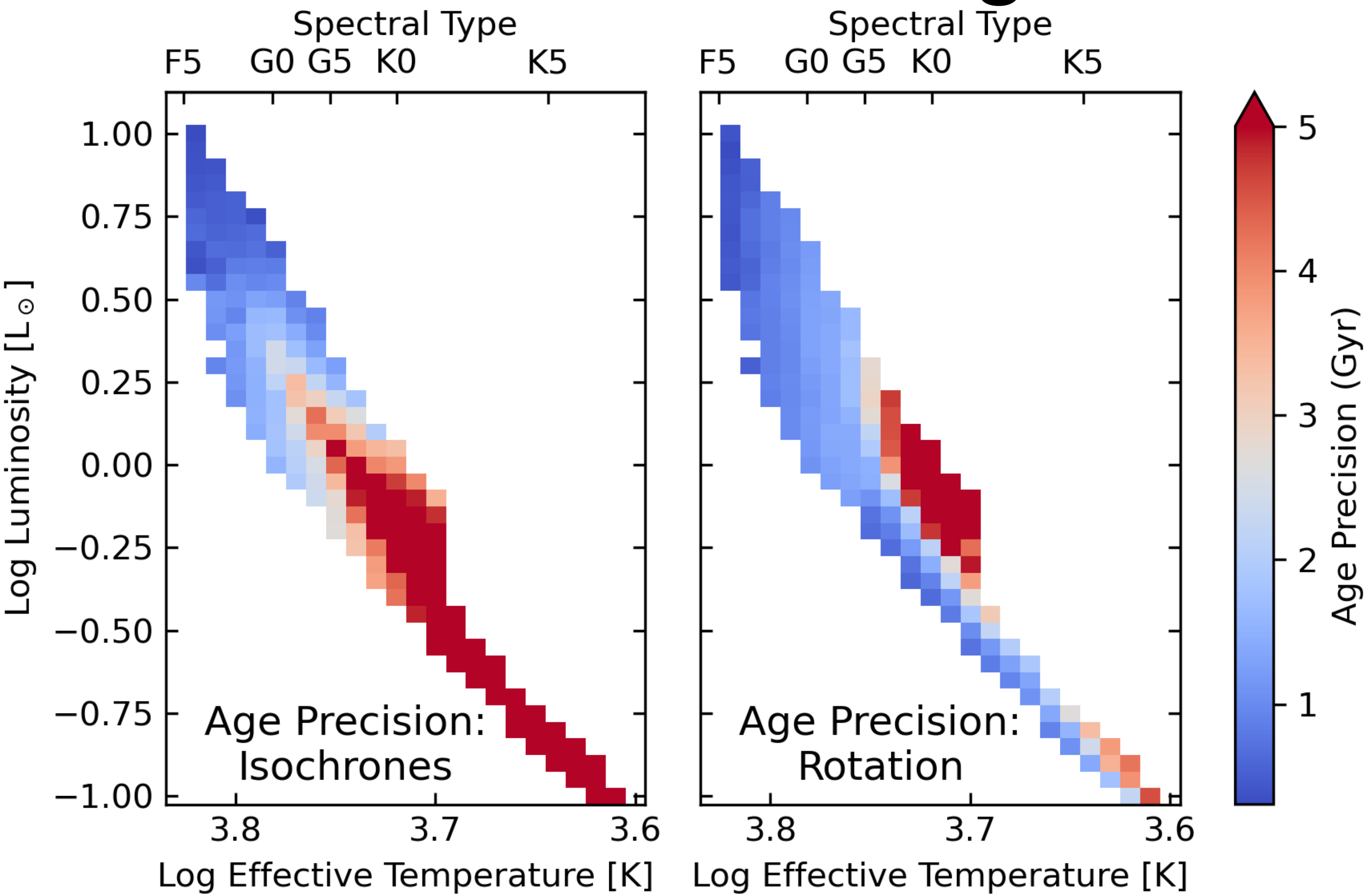
Empirical Relationships



- Similar to Mann et al. 2015 for M dwarfs
- Can calibrate surface brightness- Gaia colors relations
- Estimate radius to 4%

Kiman+ 2024

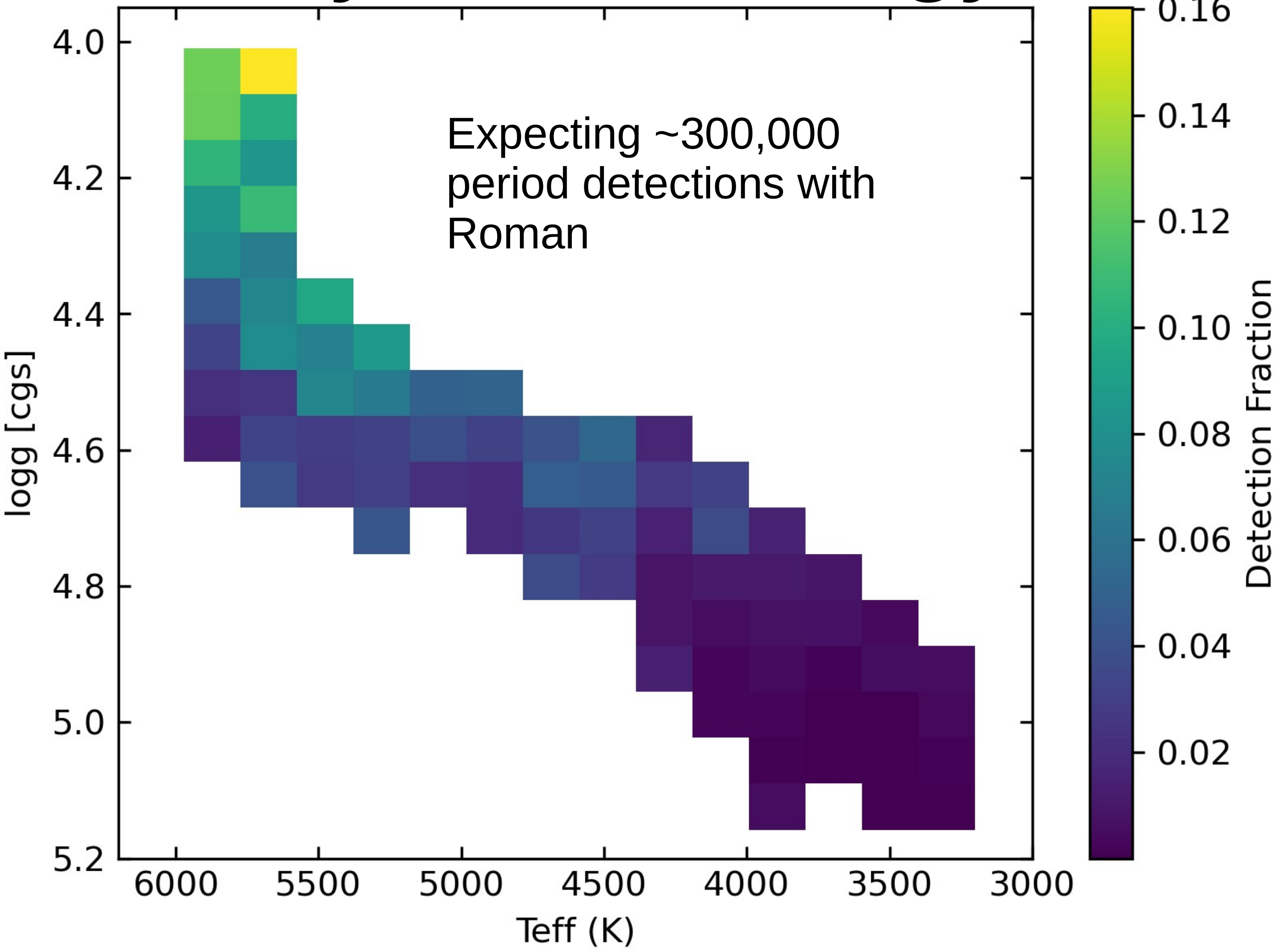
Rotation-Based Ages



- Rotation slows as stars age

Z. Claytor & **Tayar**
(Roman Proposal)

Gyrochronology



- Rotation periods from ground, Kepler, K2, TESS, and soon Roman

Z. Claytor

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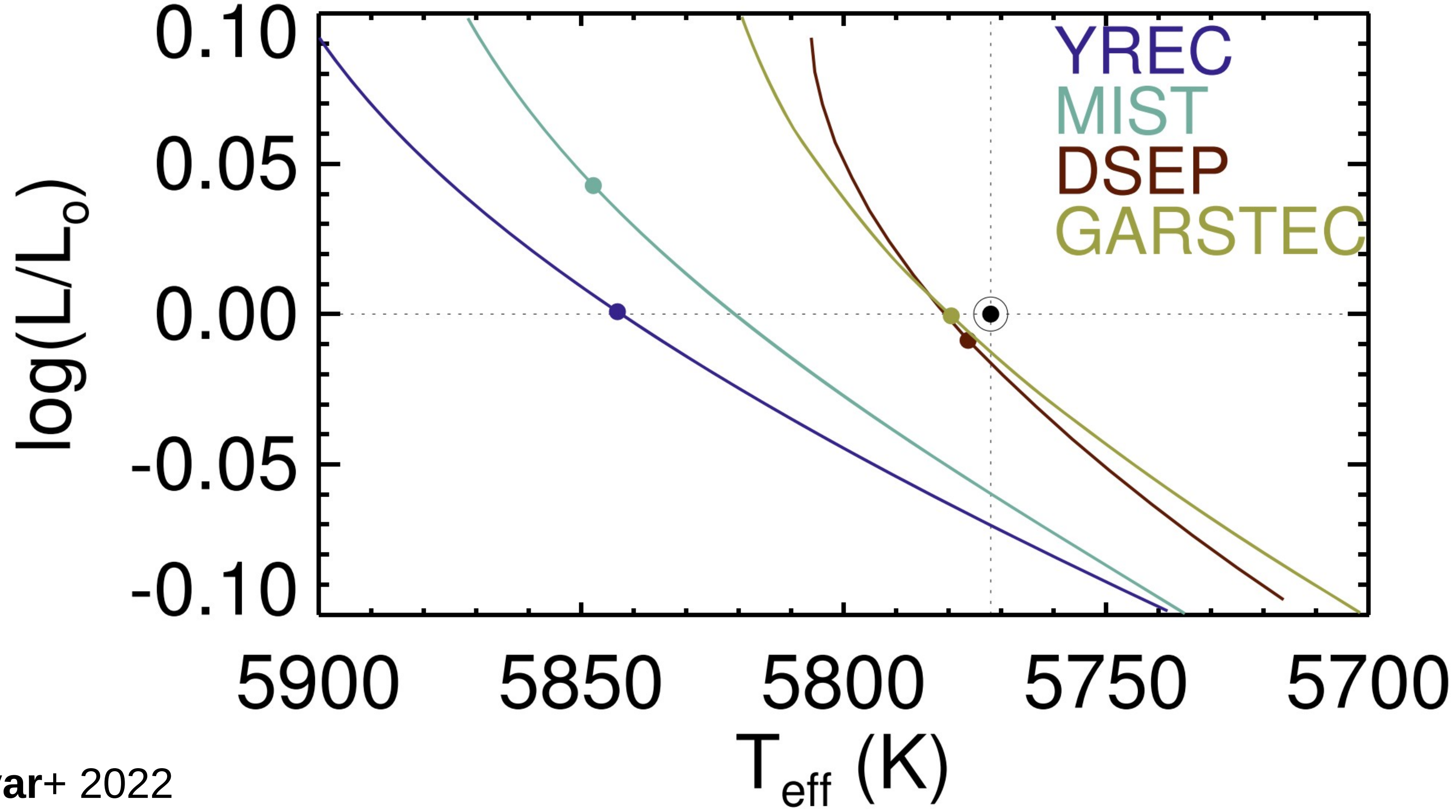
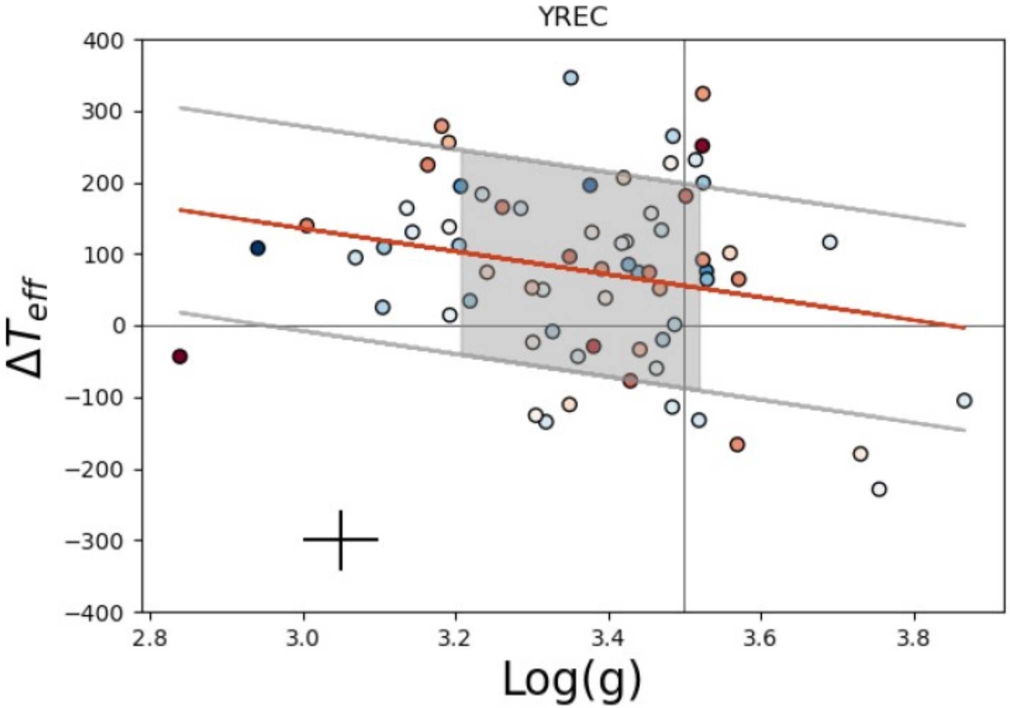
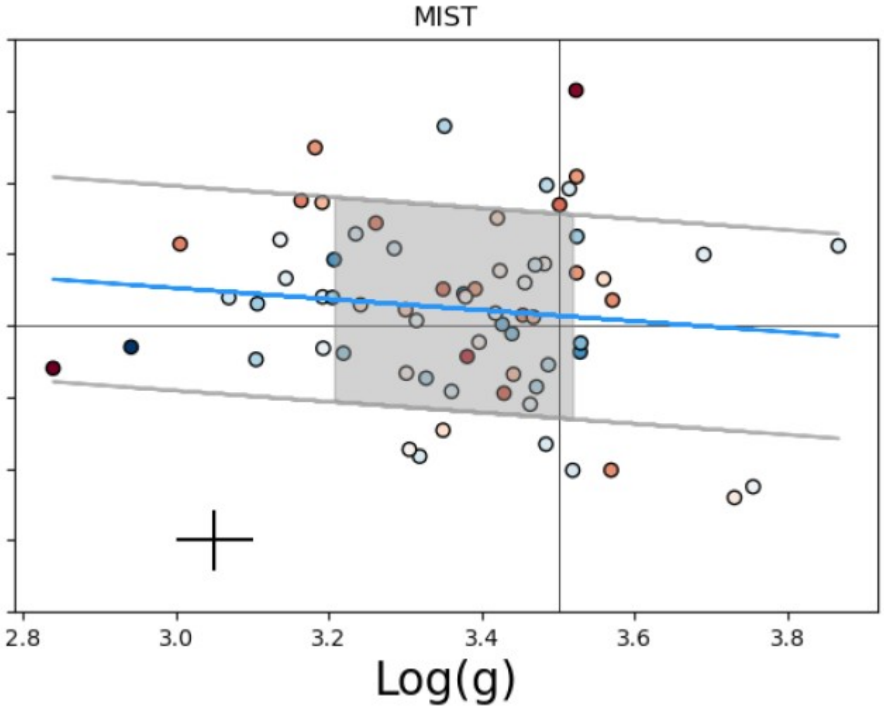
Solar Models



Tayar+ 2022

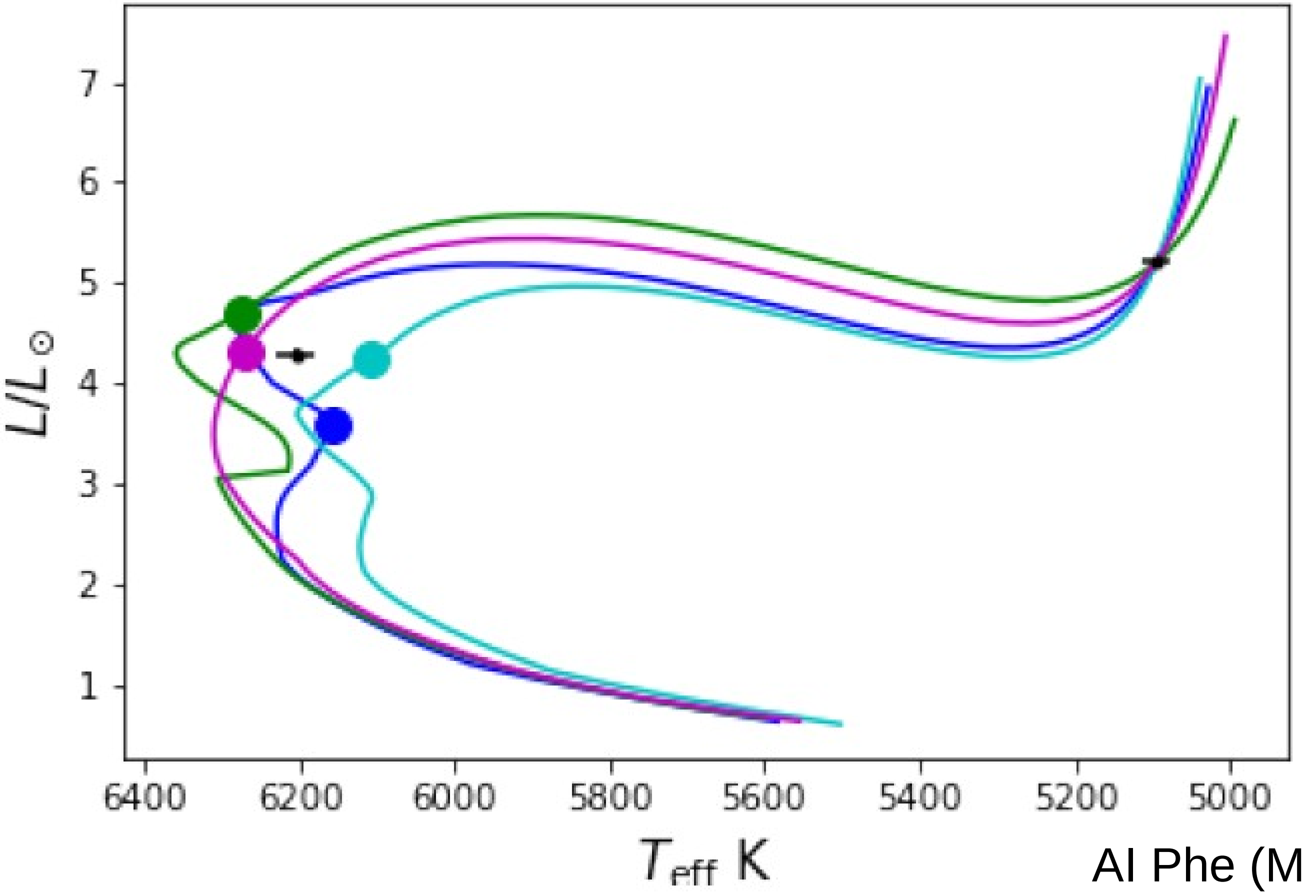
What about seismology?





Grusnis, **Tayar**, & Godoy-Rivera (submitted)

Eclipsing Binaries

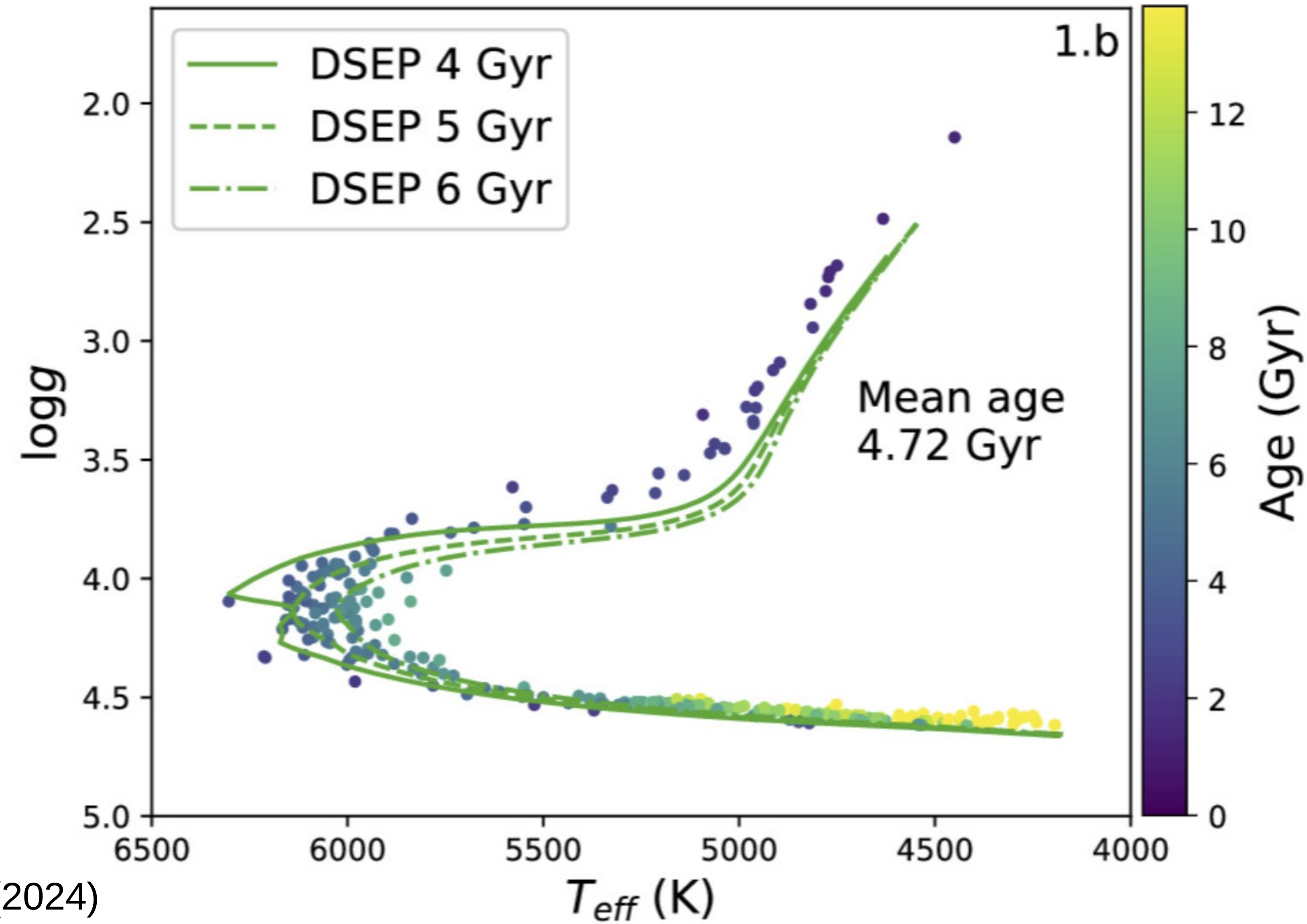


Again, no models match?

- E.g. in well characterized eclipsing binaries often the models cannot match both stars at the same time

AI Phe (Miller+ 2020, see also Valle+ 2023)

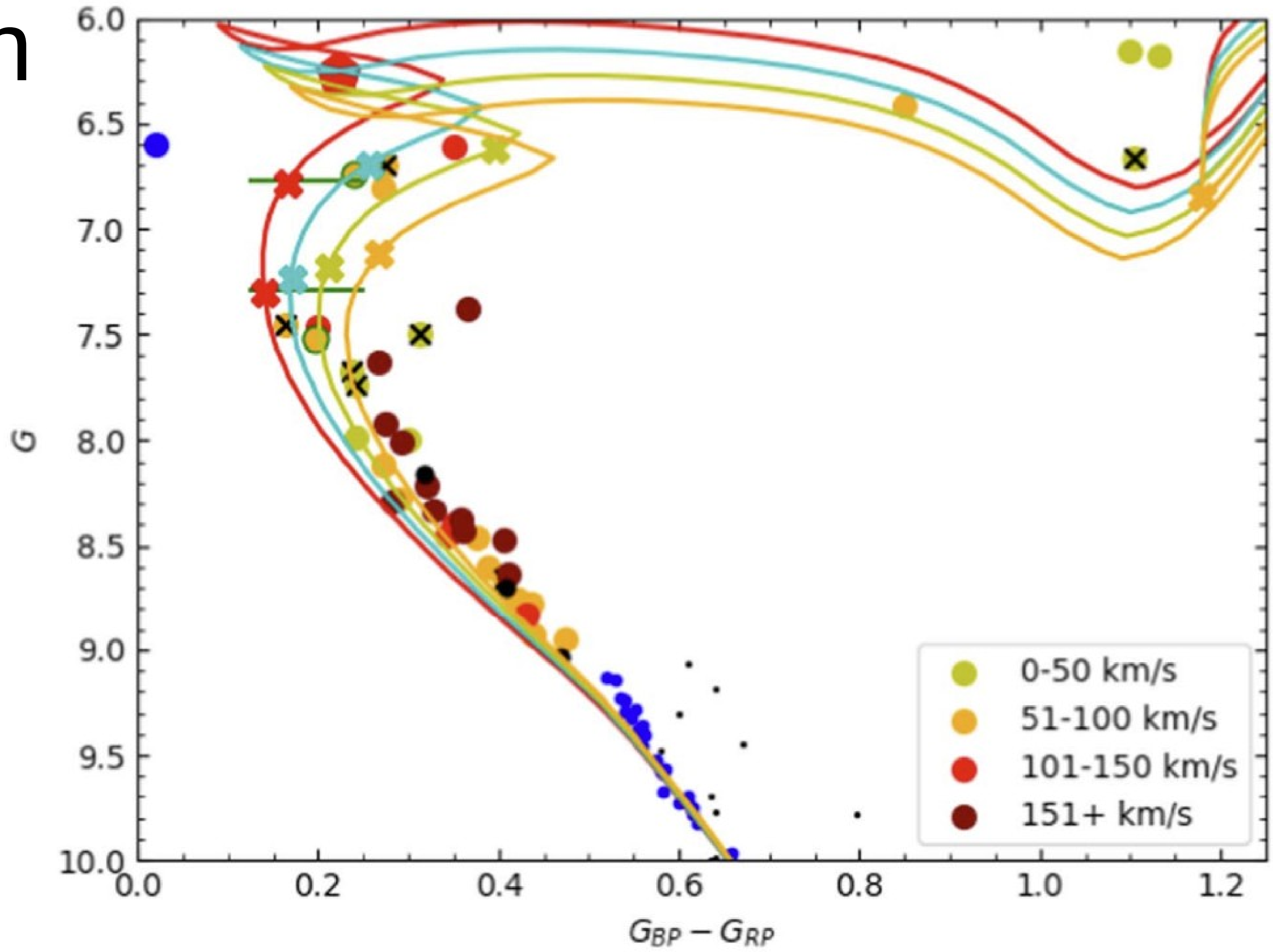
M67 Ages



Byrom & **Tayar** (2024)

Binaries in Clusters

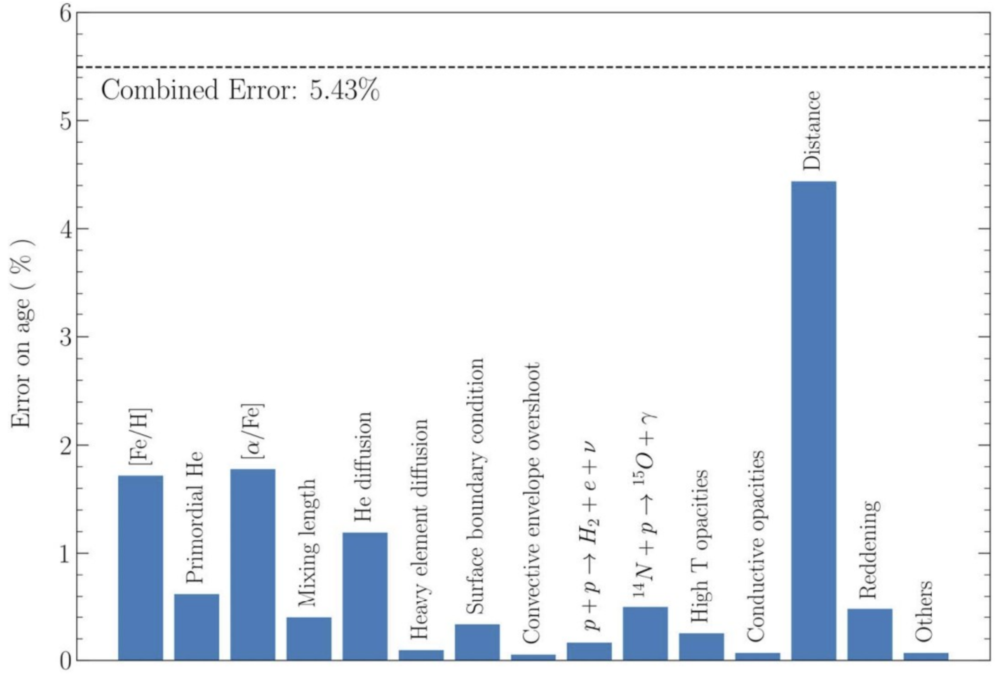
Leslie Morales

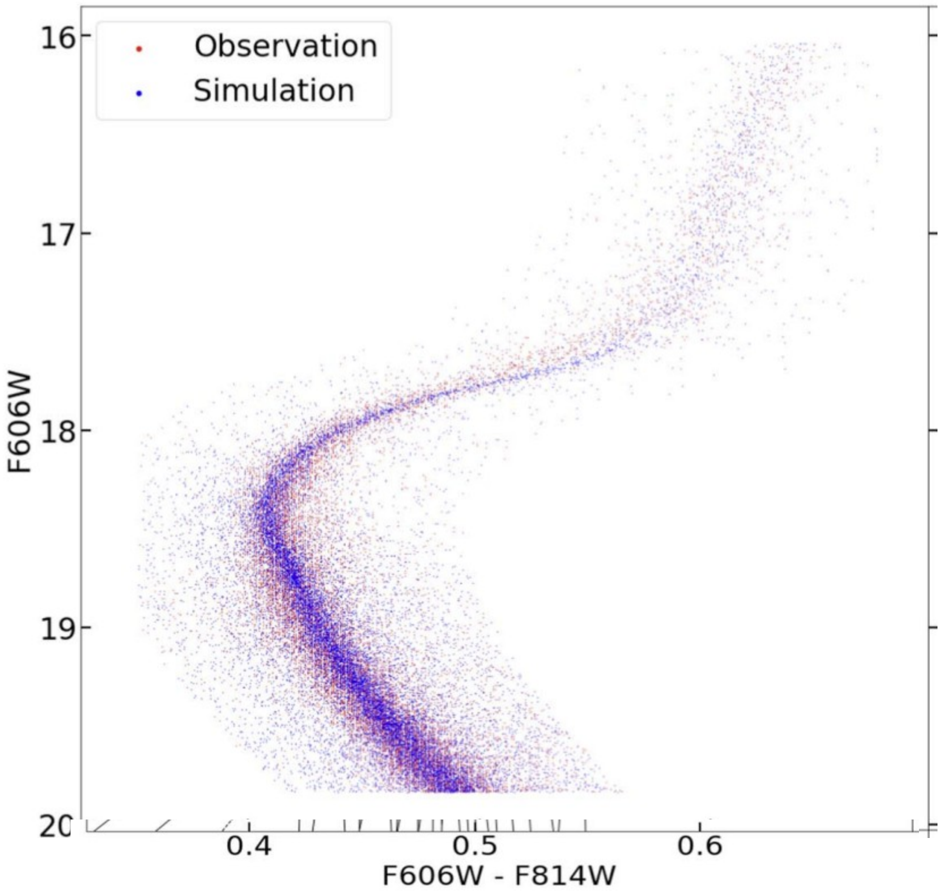


Morales et al. 2022

Clusters Constrain Models

- Ying et al. 2023 M92

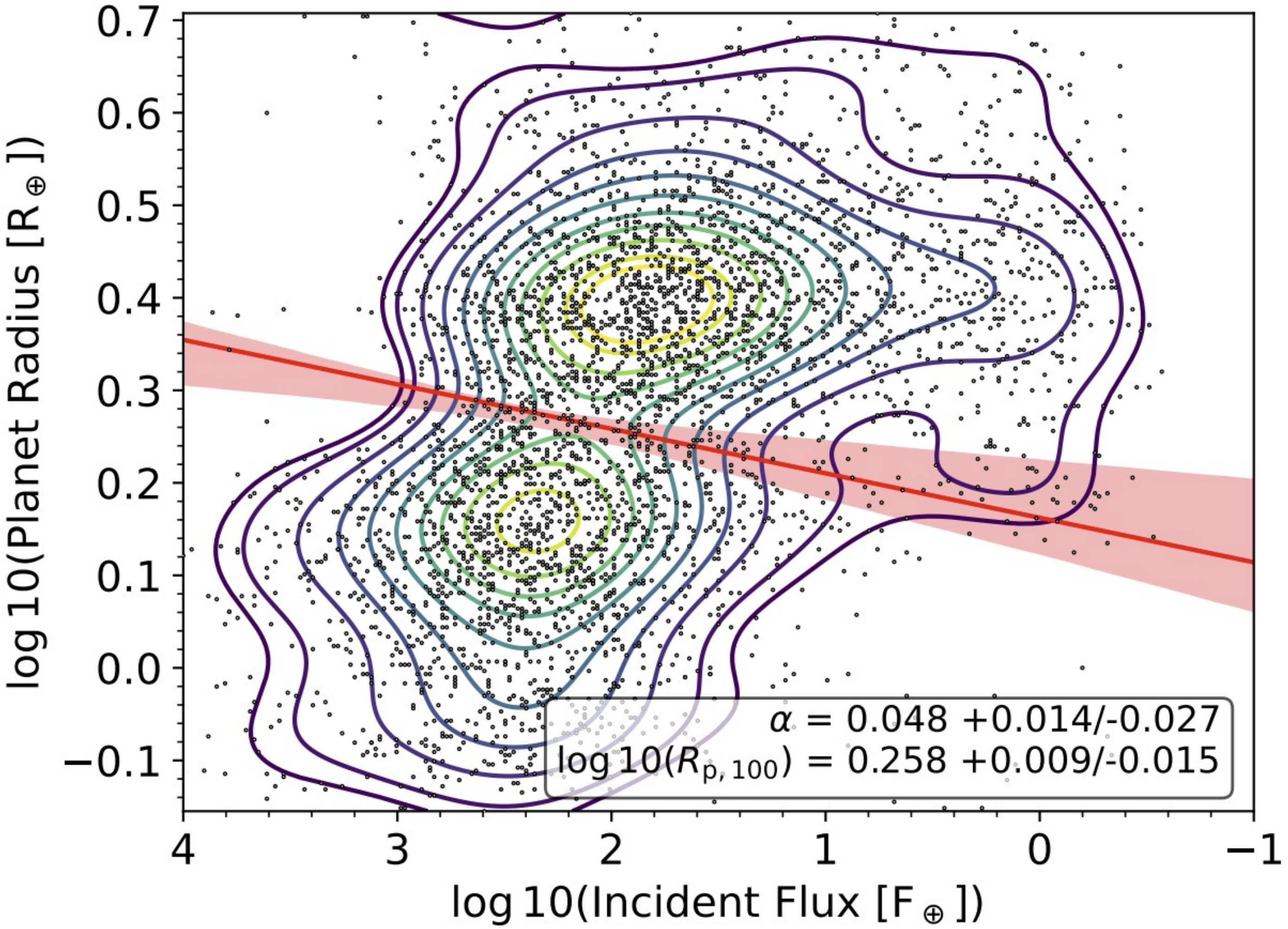




Ongoing & Future Work

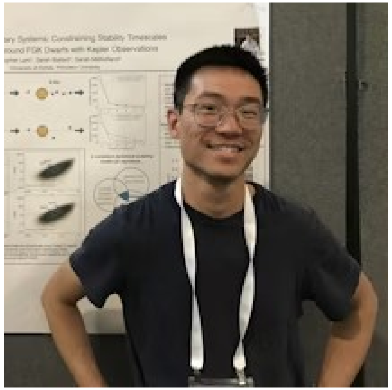
- Get more calibration systems- clusters, binaries, stars with well measured properties
- Explore how the physical uncertainties in the models map to changes on the HR diagram position
- Combine them to produce a grid of empirically calibrated models for general use?

Is Core-Powered Mass Loss a better fit to the radius valley?

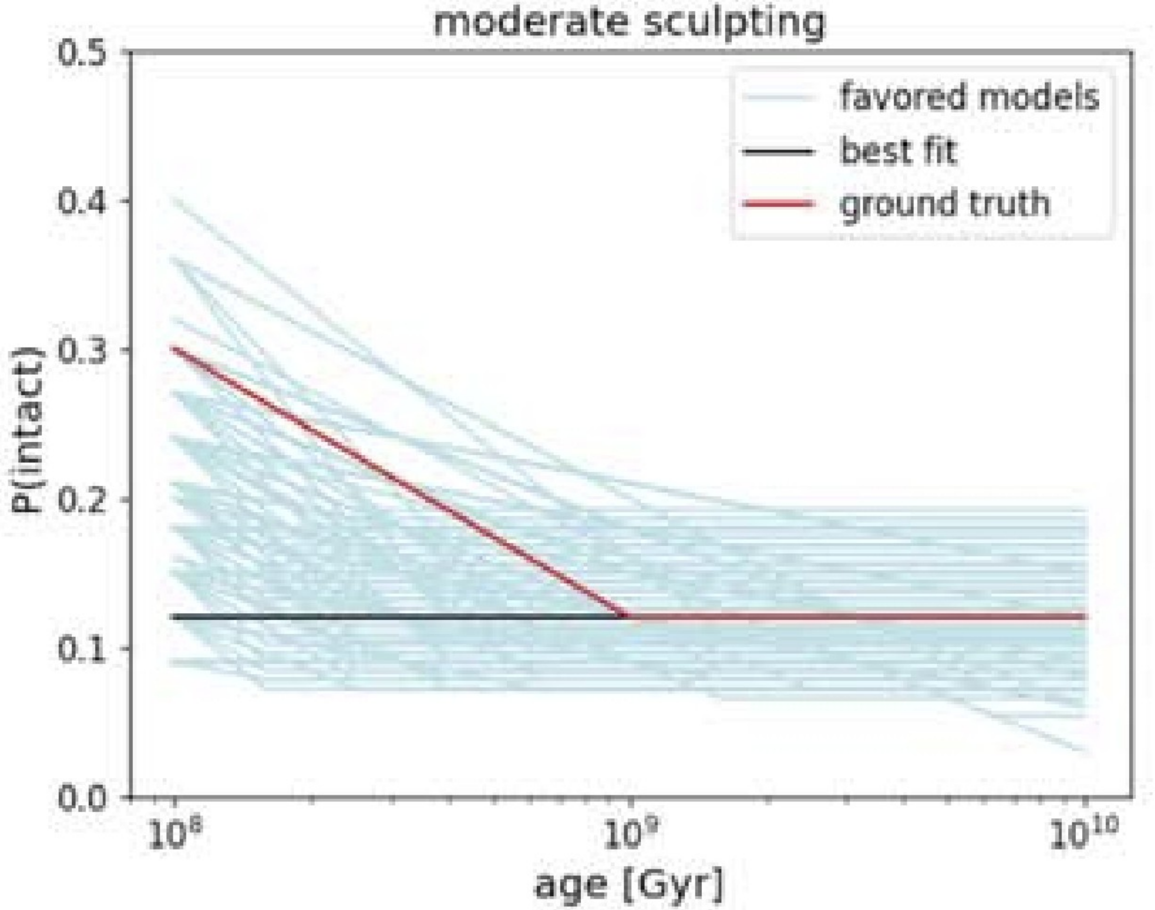


Berger+2023

Dynamical Sculpting

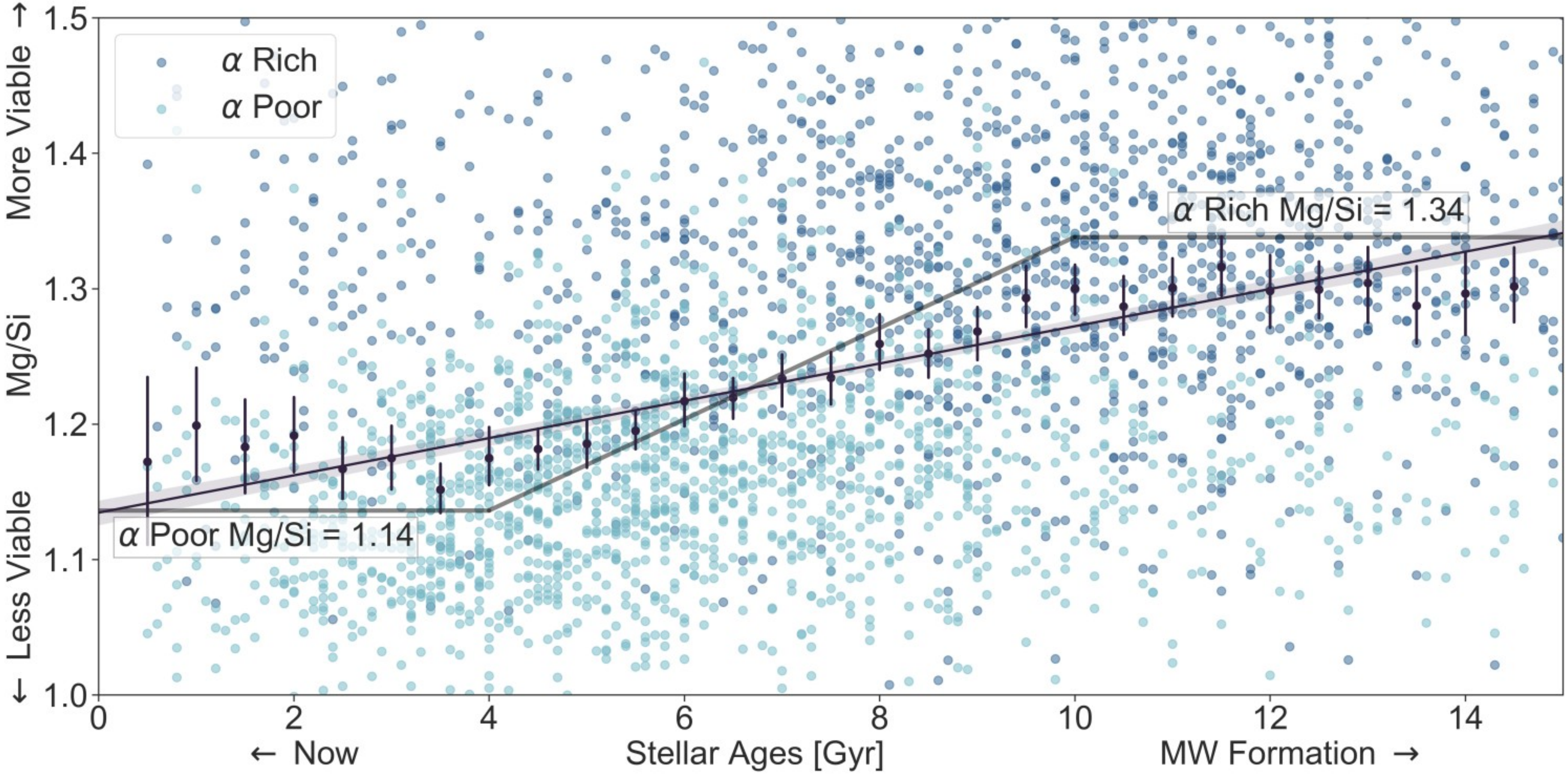


- Without a significant number of planets at a range of ages, with well constrained ages, it's hard to know what single vs multi-transit systems say about dynamical processes



Lam & Ballard (2024)

Has the likelihood of plate tectonics changed over time?

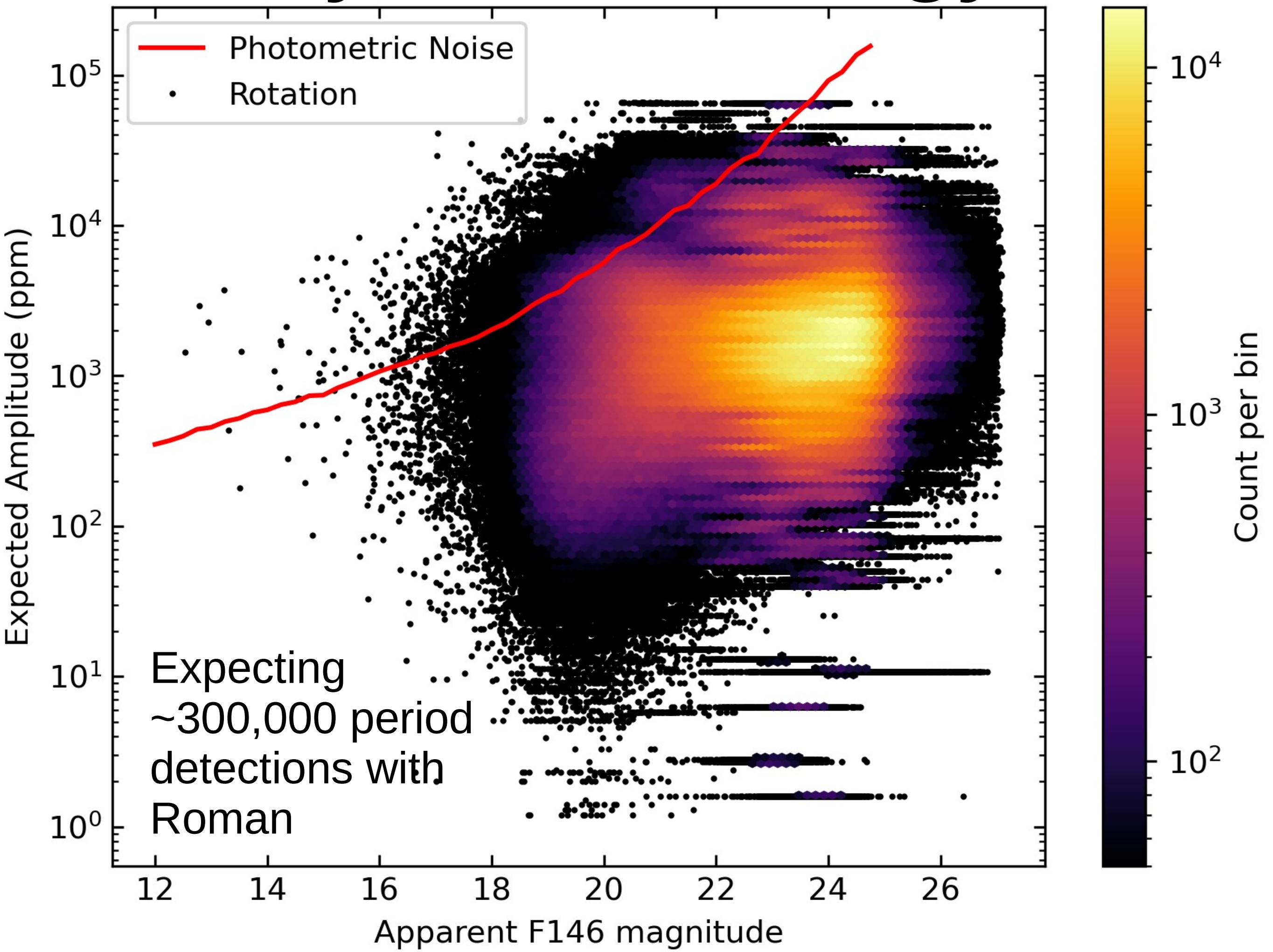


Schonhut-Stasik, **Tayar,** Stassun (in prep)

Conclusions

- There are still significant uncertainties (observational and theoretical) on host star properties
- Work is ongoing to reduce both the observational and theoretical uncertainties
- Additional information or other methods can have smaller uncertainties, but be careful about propagating your errors

Gyrochronology



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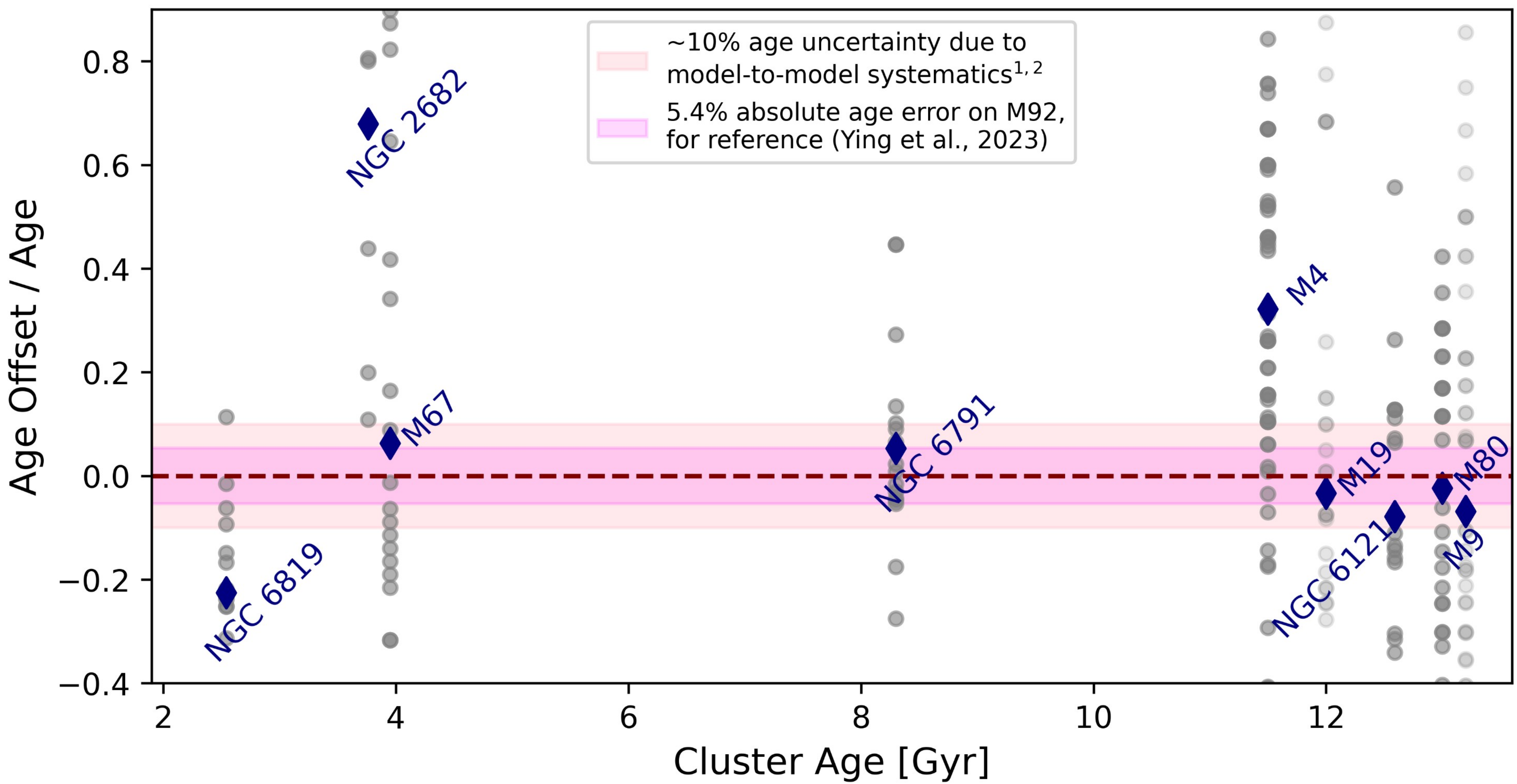
Z. Claytor

Tayar & Joyce (in prep)



STAR SCOUT

Pioneers Proposal for April 2025

PI: A. Gonzalez
Deputy PI/Science PI: J. Tayar

SFL

ASTRAEUS SPACE INSTITUTE

SATLANTIS

STAR SCOUT Summary

- Global Asteroseismology for giants in clusters to calibrate the age scale to 10%
- 8 clusters, Age: <1 Gyr-13 Gyr, Metallicity: -2.4 to +0.15
- ~30 day observing sectors, 2 years of observations = 70 days/cluster, 15-120 giants per cluster, 10% age per cluster
- Custom models for consistent cluster and asteroseismic age scales
- Calibrate the correction factor f_{age} to put 100,000+ field giants from TESS, Kepler, K2, Roman, and Plato on the cluster age scale and answer questions about the Milky Way's Evolution

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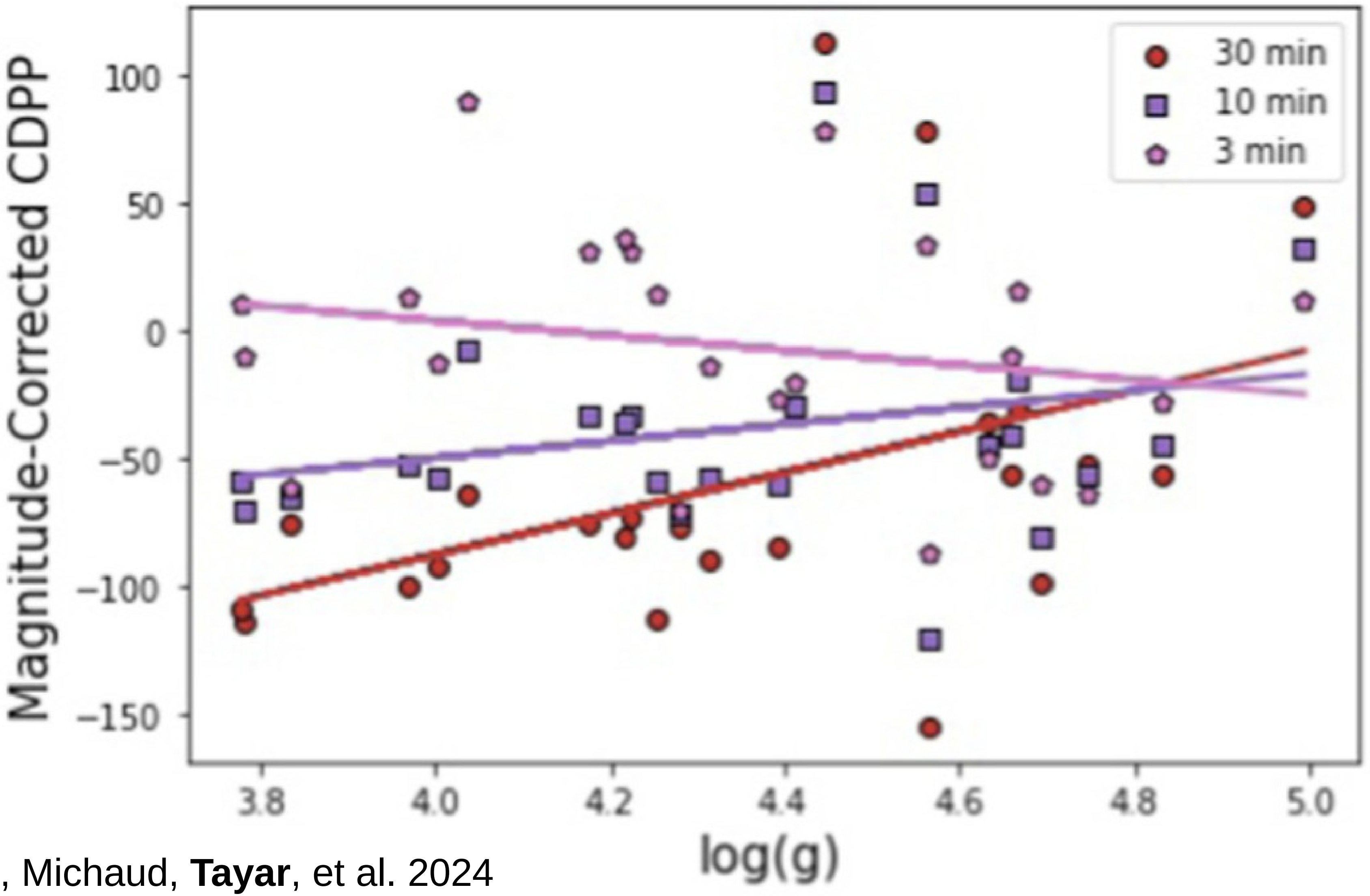
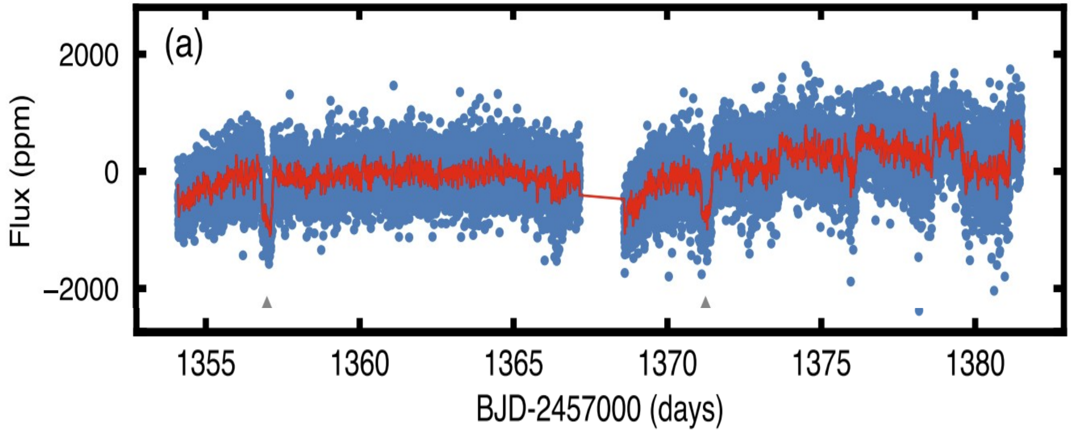
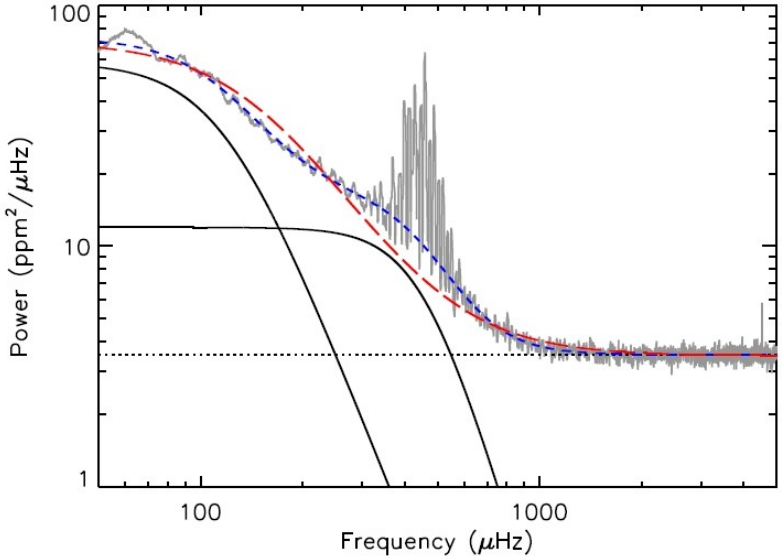
- Temperature uncertainty 2.0% ± 0.5%: L, angular diameters
- Metallicity- systematics between methods 0.15 dex
- Using additional information (e.g. stellar density from a transit) can potentially reduce uncertainties

Tayar+ 2022; Eastman, Diamond-Lowe & **Tayar** 2023, Mészáros+ (inc. **Tayar**) submitted

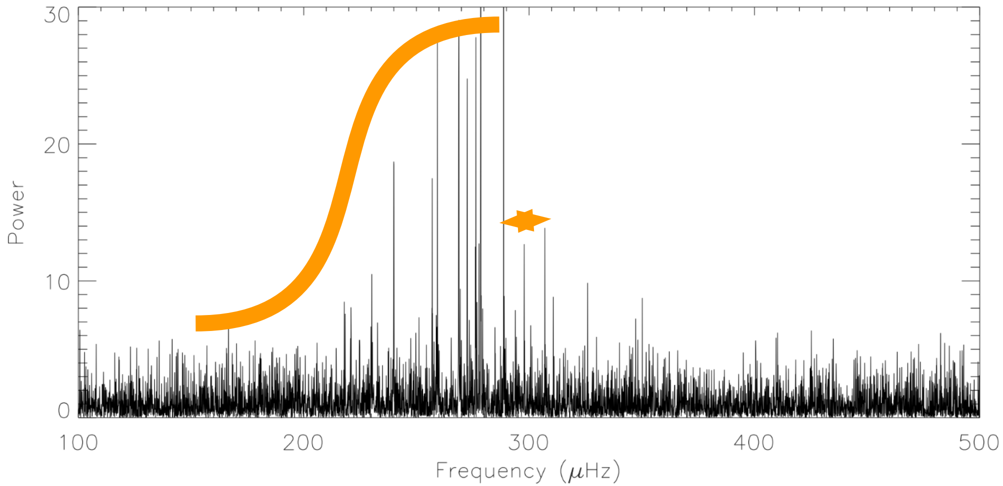


DeVane-Prugh, Michaud, **Tayar**, et al. 2024



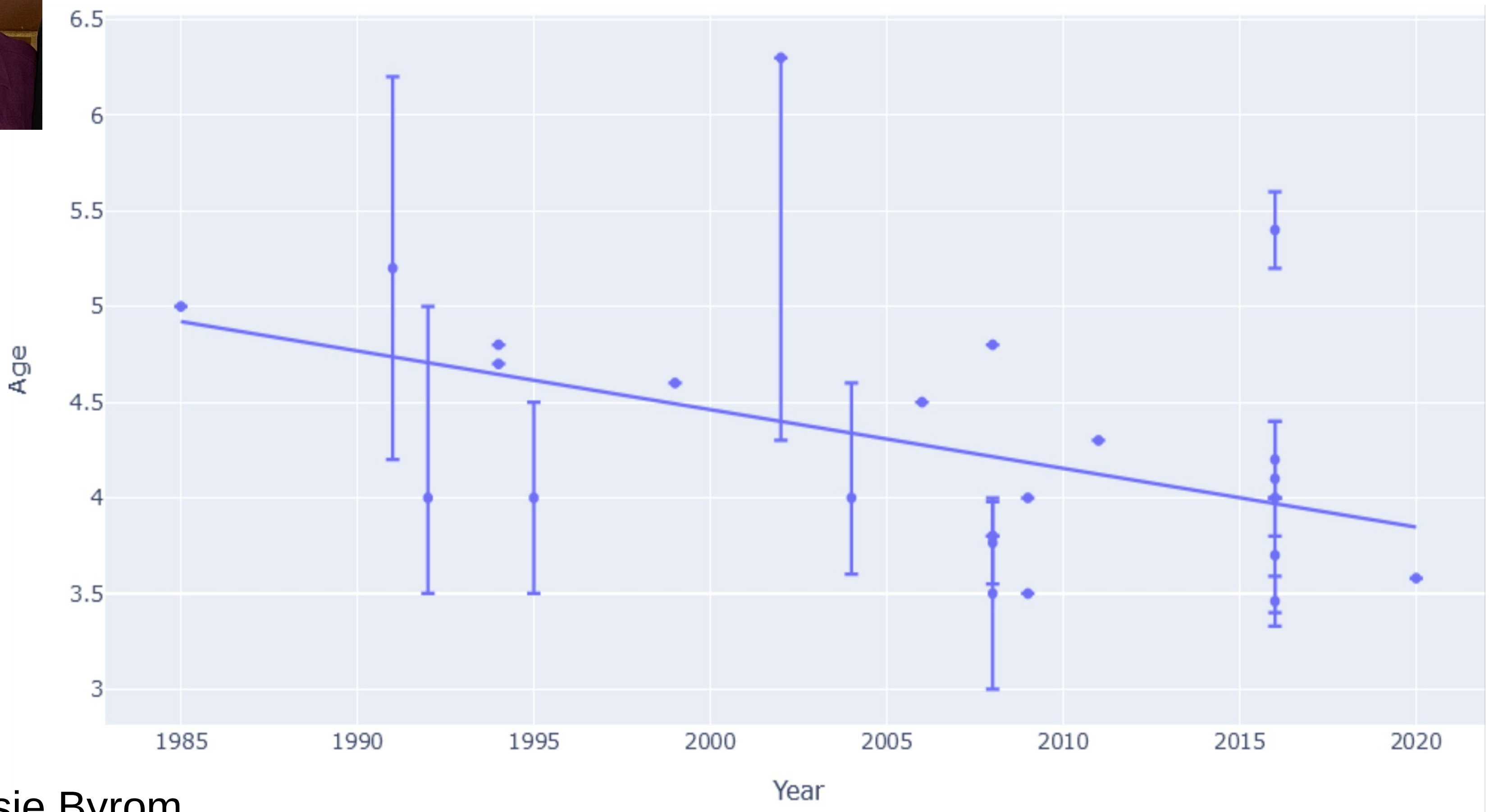


$$\frac{\Delta\nu}{\Delta\nu_\odot} = \sqrt{\frac{M/M_\odot}{(R/R_\odot)^3}}$$



$$\frac{\nu_{\max}}{\nu_{\max,\odot}} = \frac{M/M_\odot}{(R/R_\odot)^2\sqrt{(T_{\mathrm{eff}}/T_{\mathrm{eff},\odot})}}$$

M67 Age



Plot By Susie Byrom

M67 Age

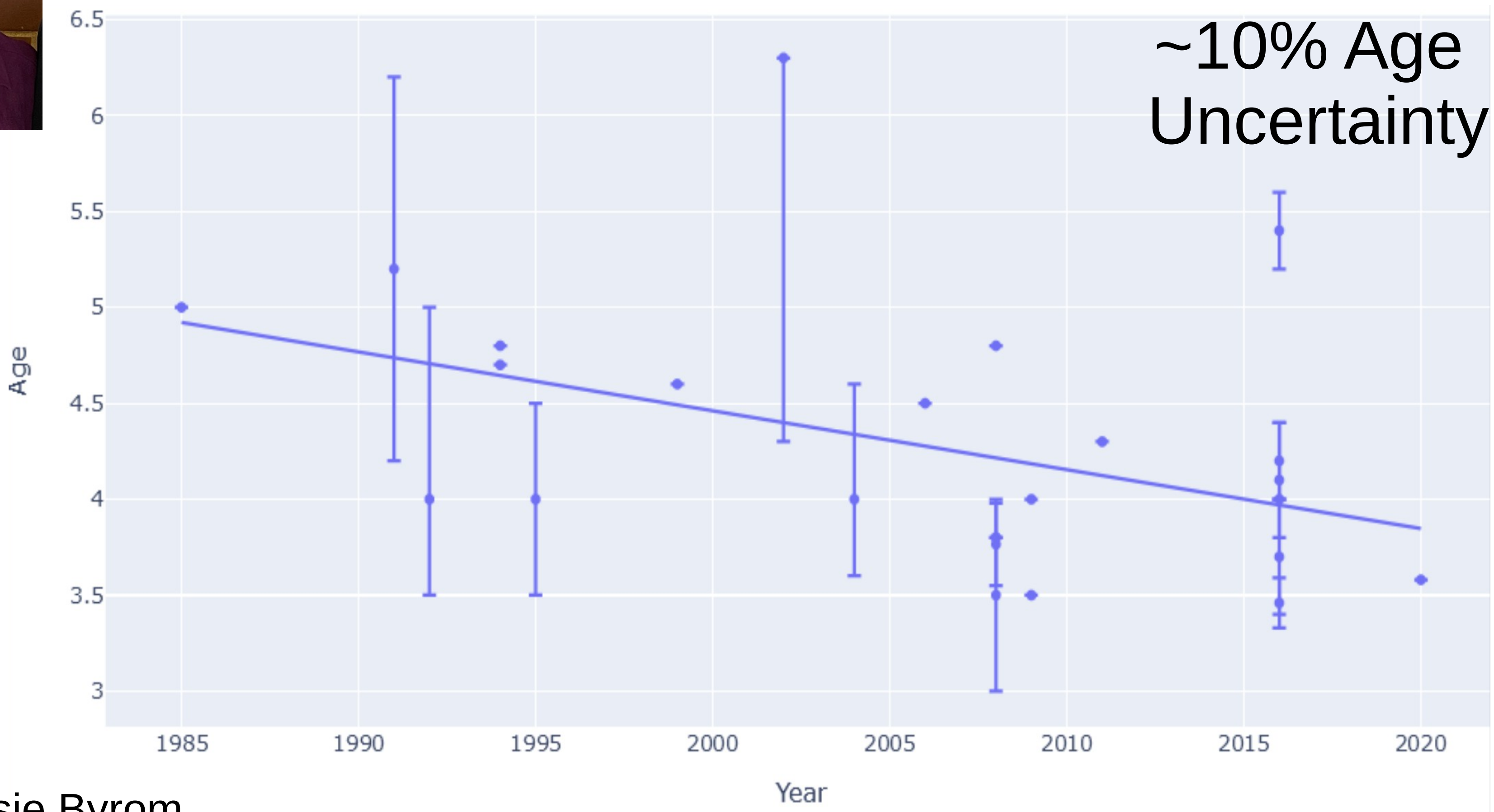


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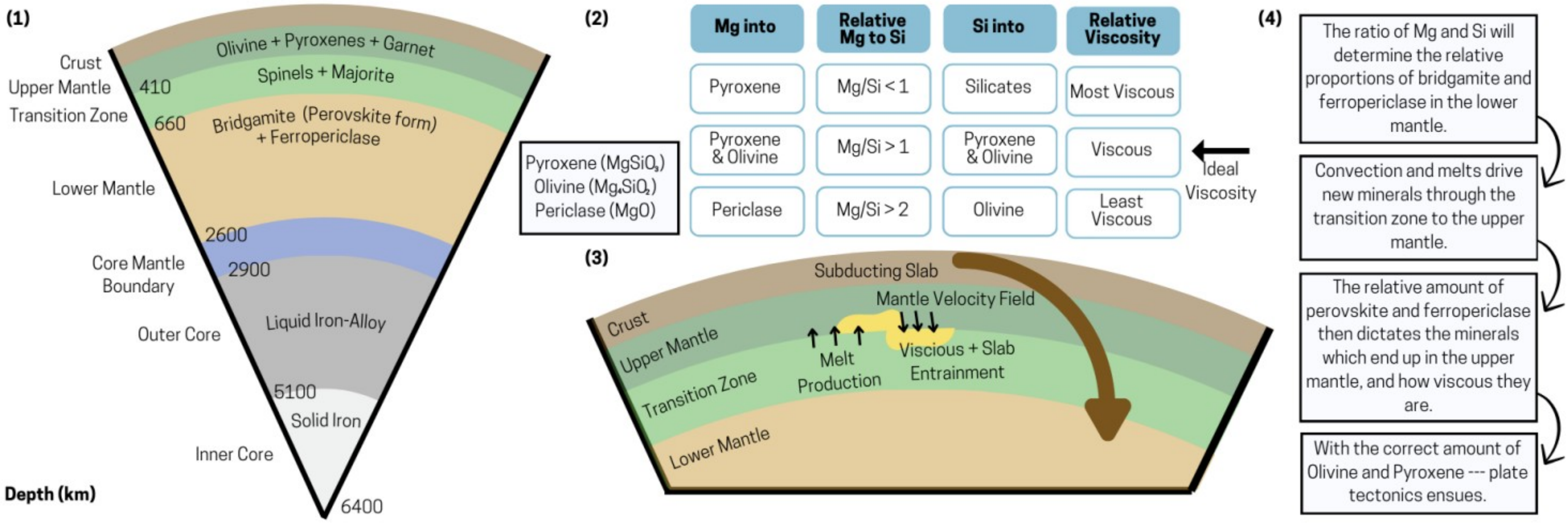
Plate Tectonics



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Eastman, Diamond-Lowe, Tayar

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