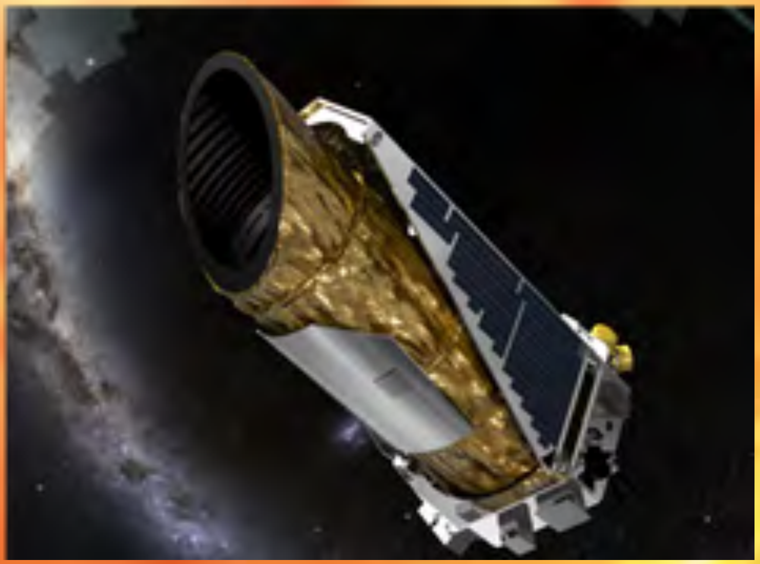
TESS Highlights in Asteroseismology & Stellar Astrophysics: Latest News from Last Week's TASC5/KASC12

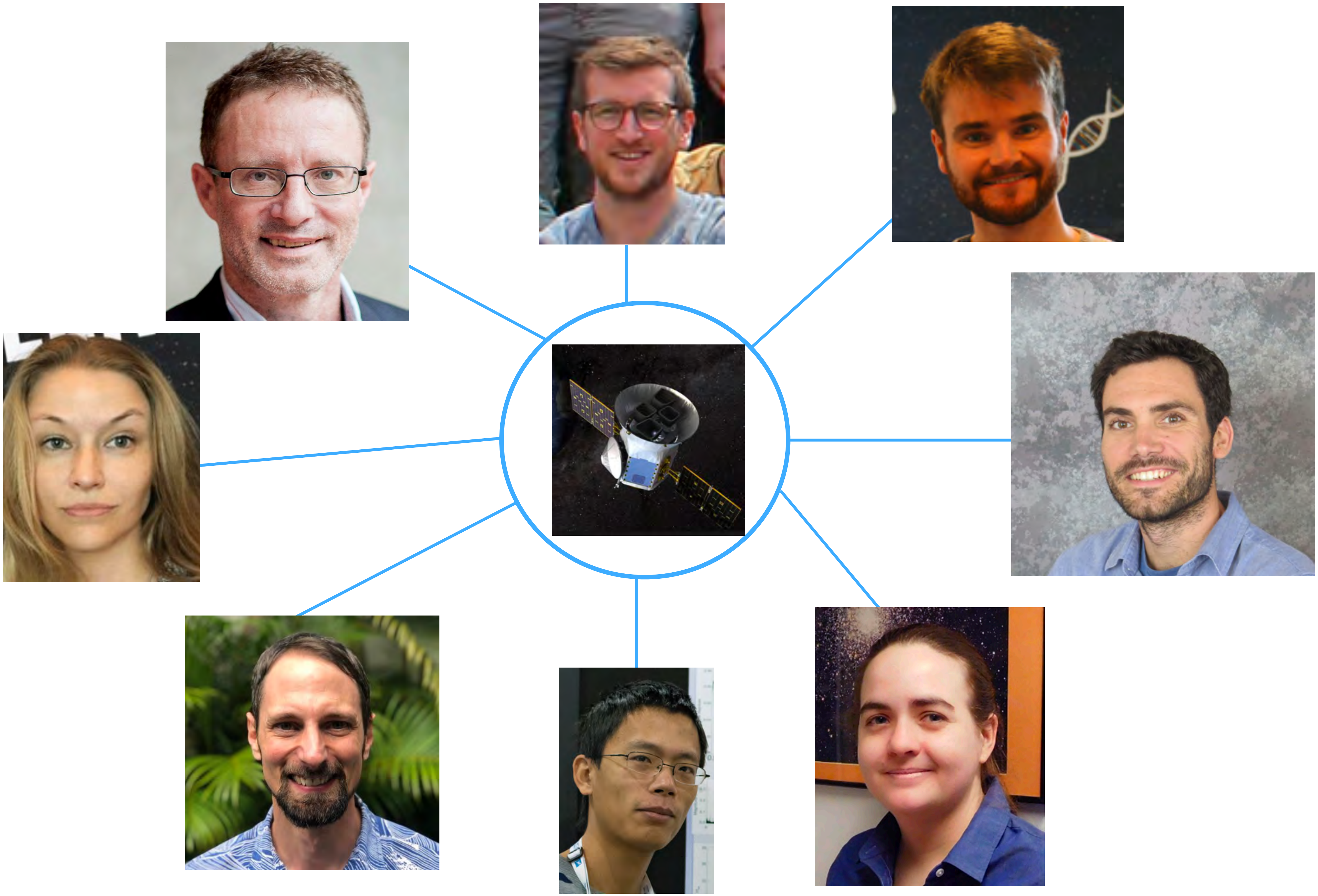
Image credit: NASA's Goddard Space Flight Center/S. Wiessinger



Conny Aerts, Leuven University, B

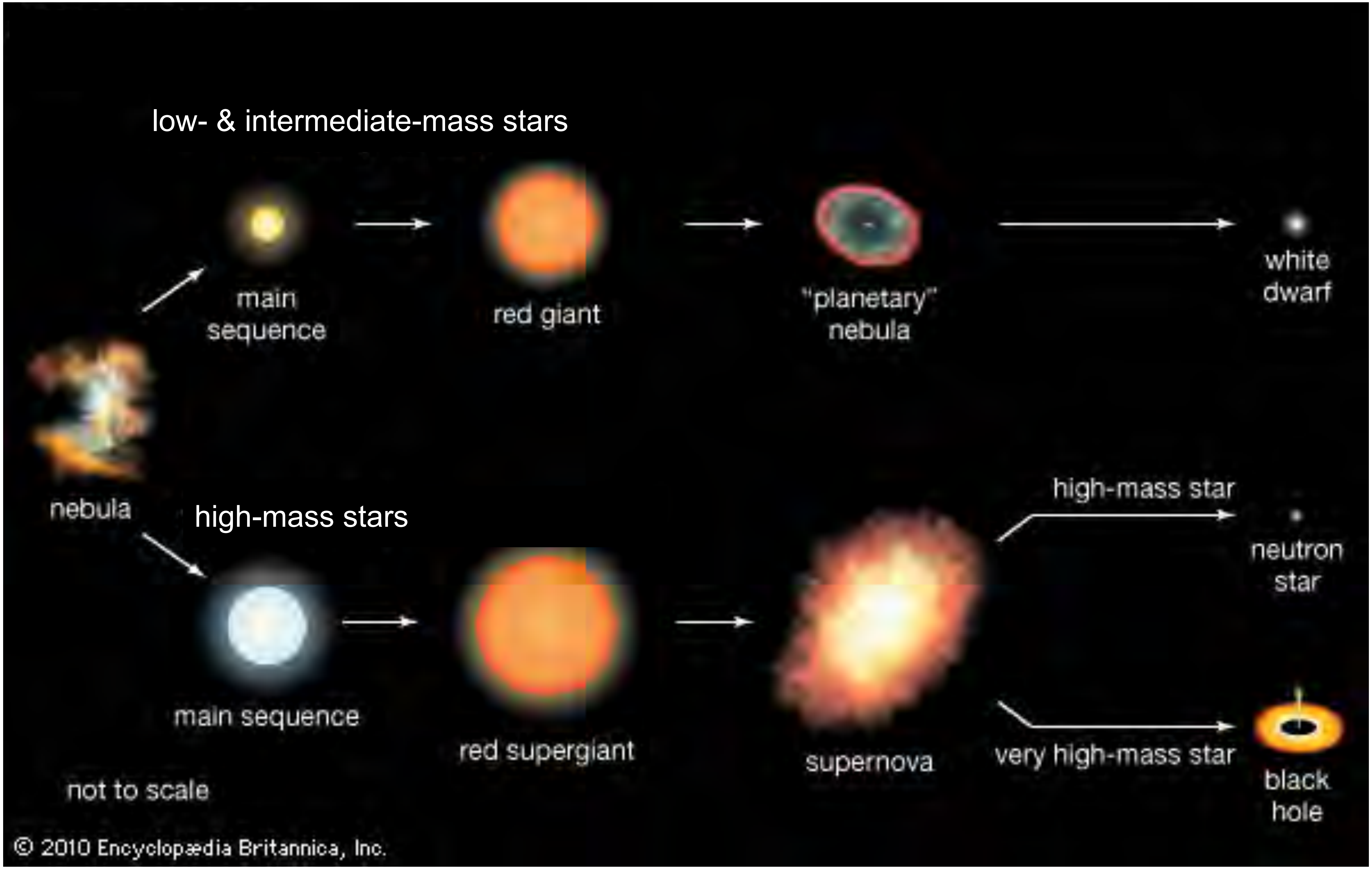
KU LEUVEN

With a little help from friends

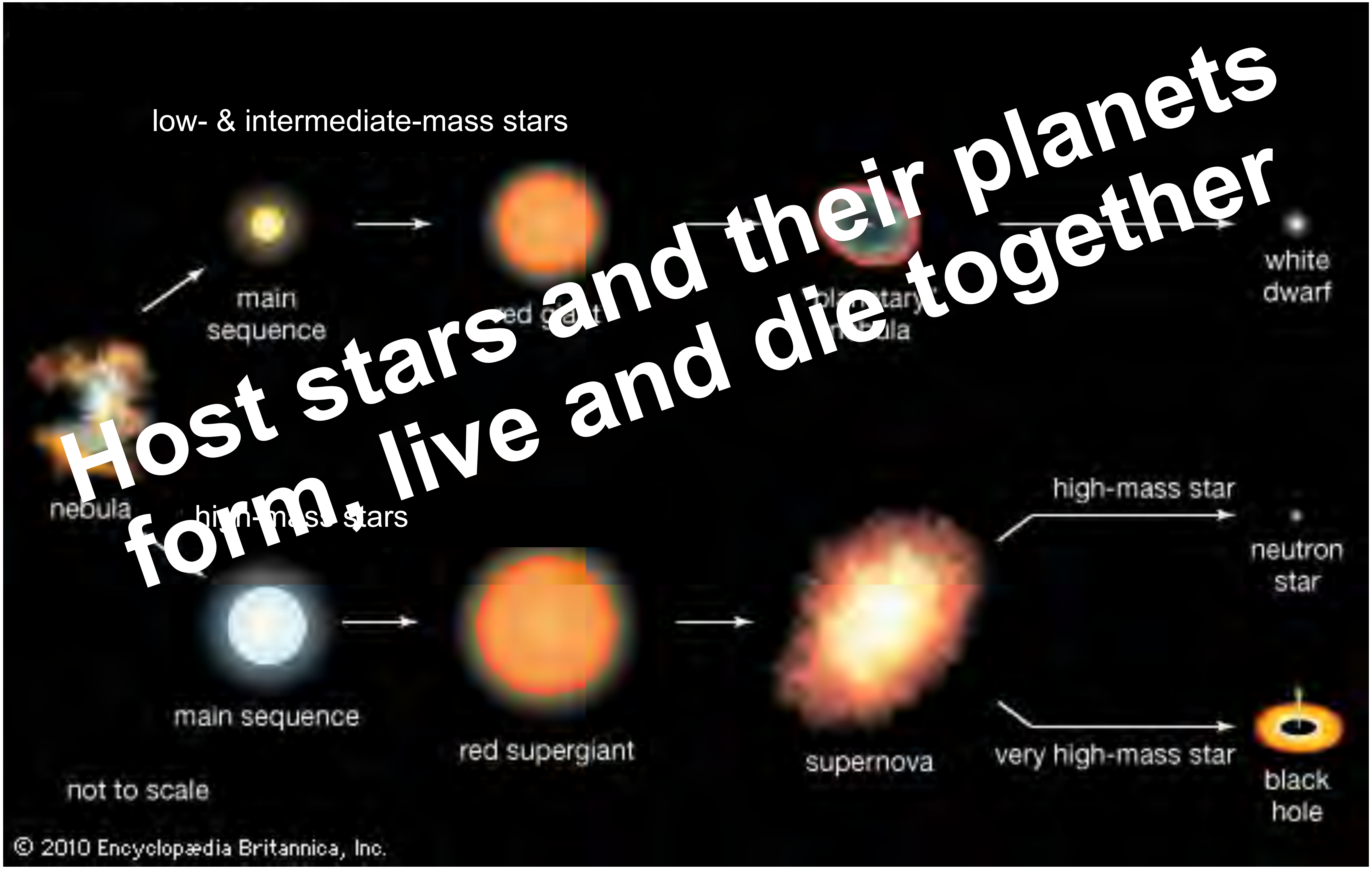


With a little help from friends

Why should you care about TASC?

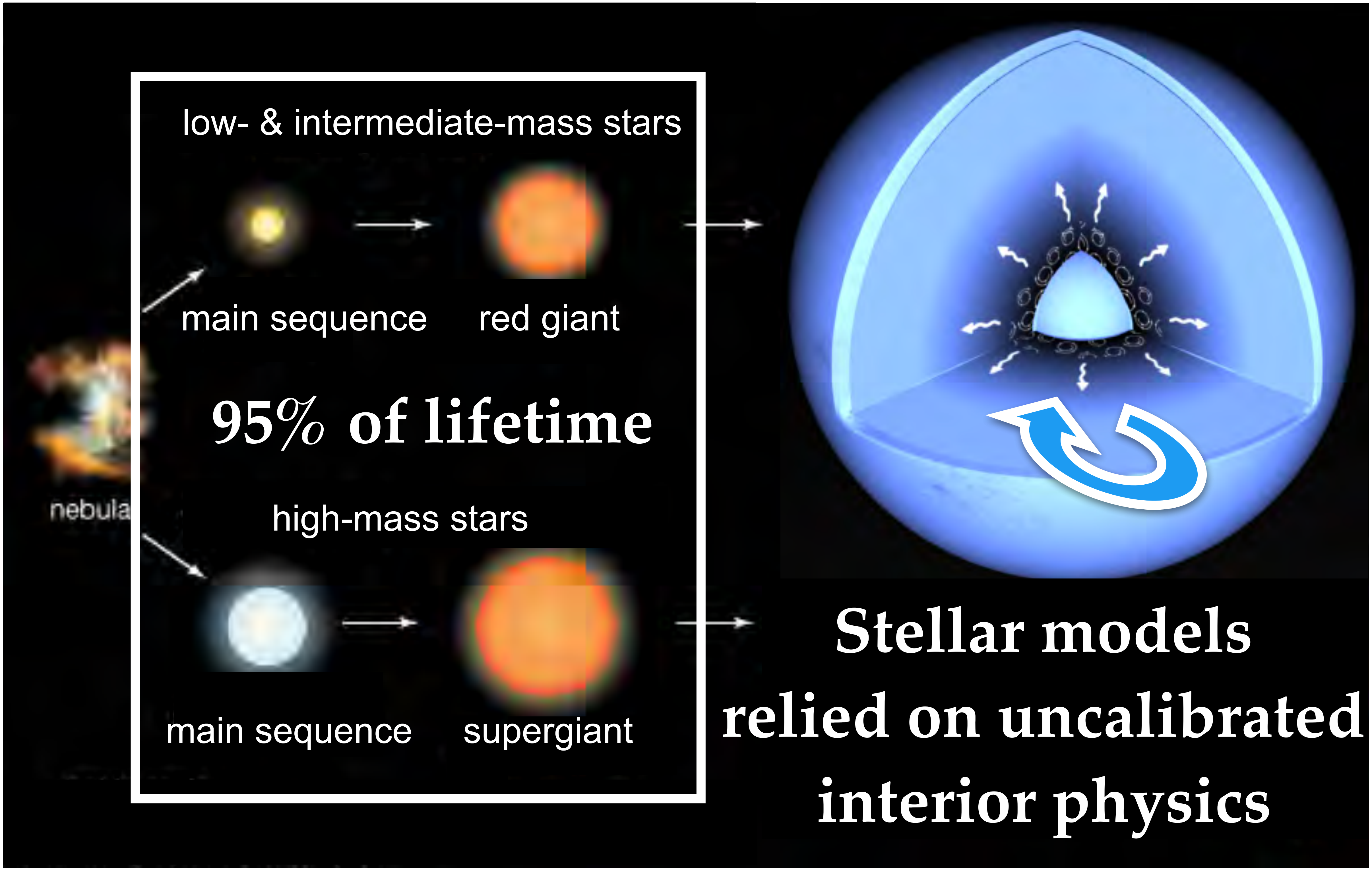


Why should you care about TASC?



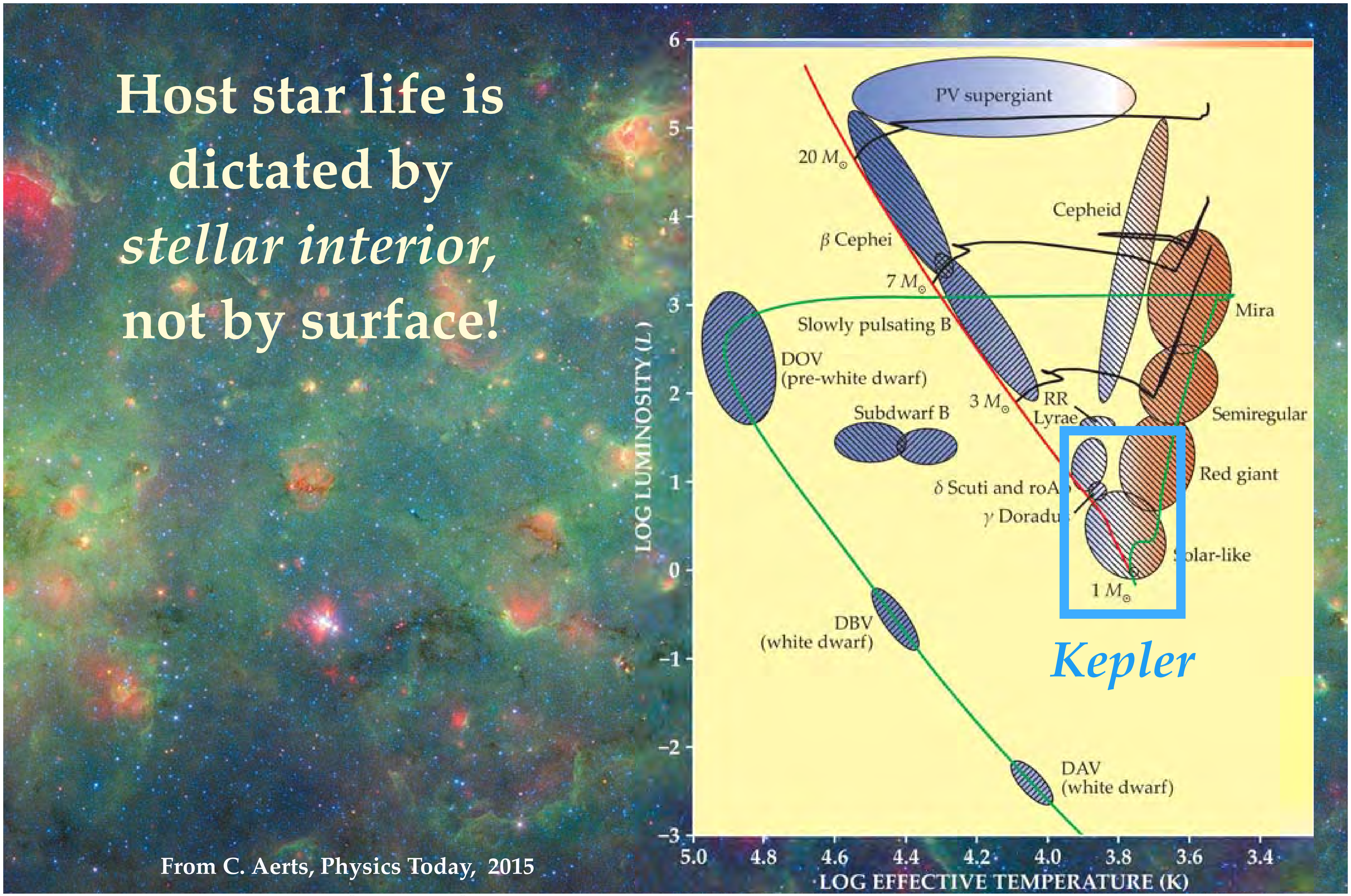
Host stars and their planets form, live and die together

Rotation? Convection? Mixing?



Asteroseismology to the rescue

Host star life is dictated by *stellar interior,* not by surface!



From C. Aerts, Physics Today, 2015

Asteroseismology to the rescue

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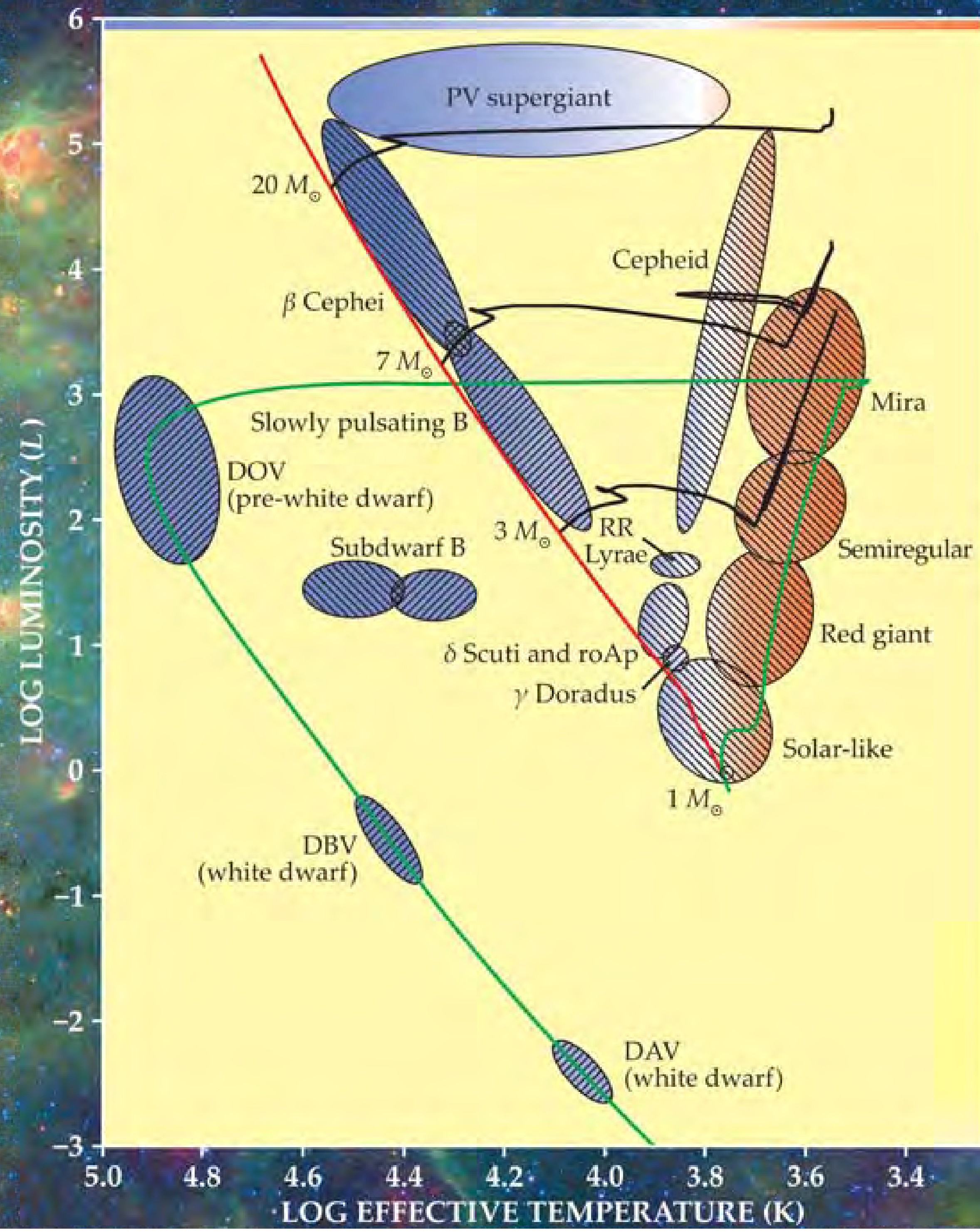
TESS covers HRD with *uninterrupted high-precision data*

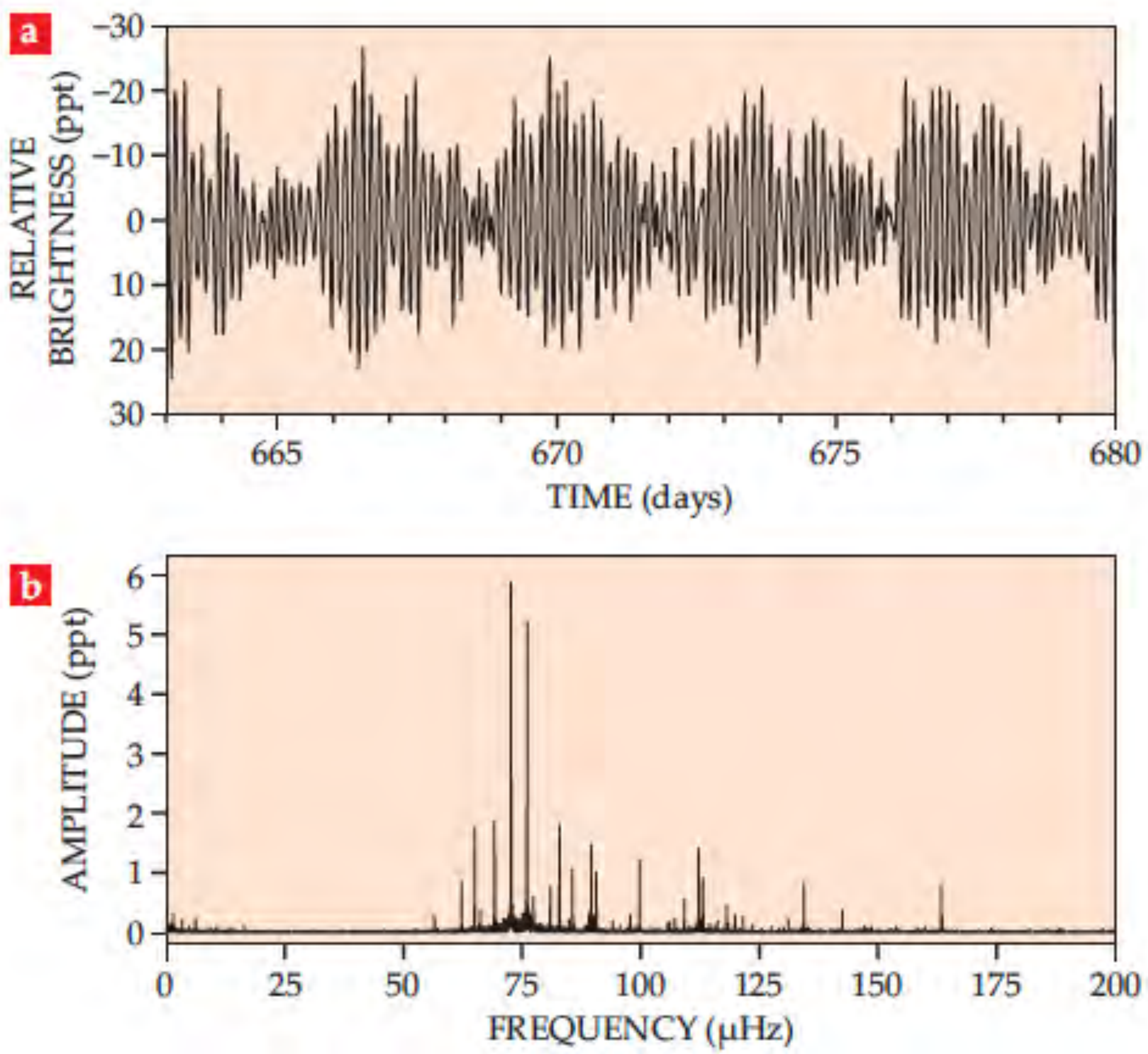
From C. Aerts, Physics Today, 2015

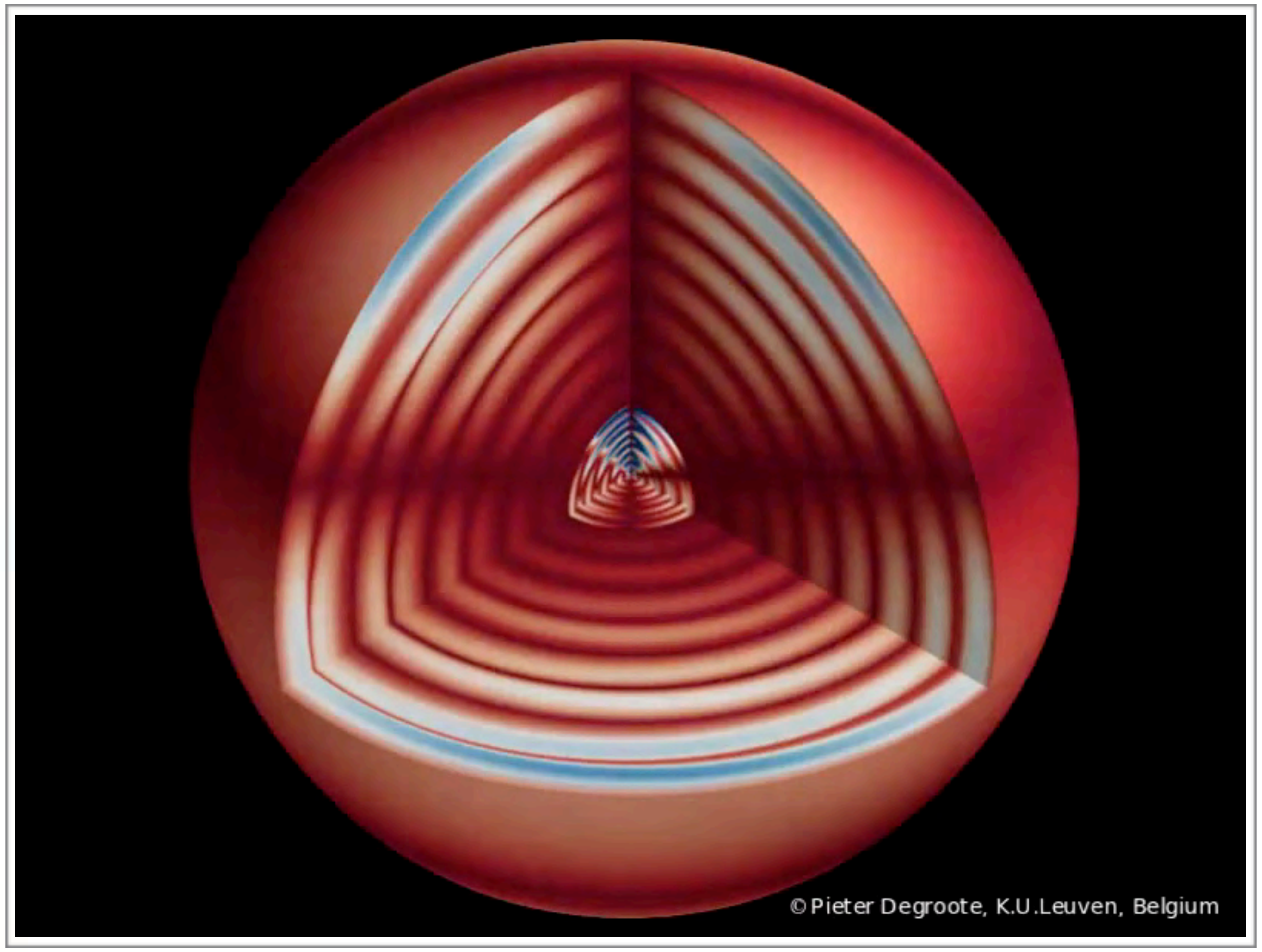


Starquakes Probe Stellar Interiors

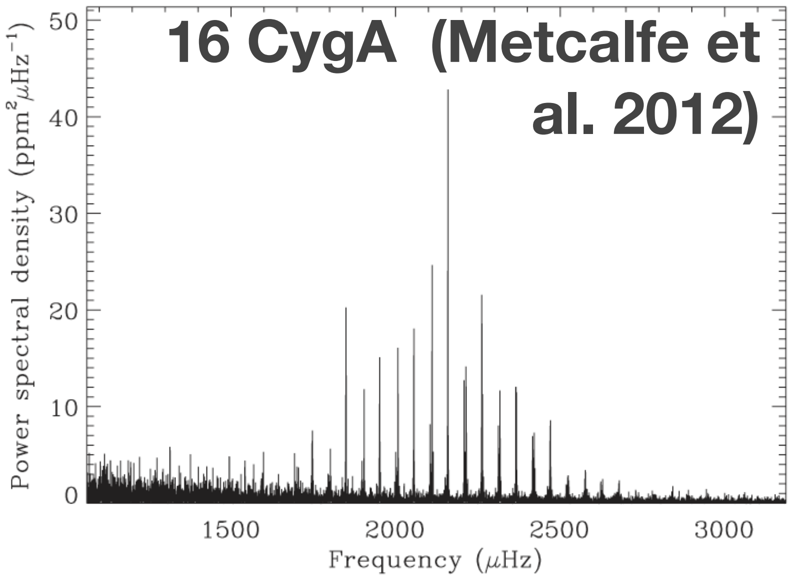
Astounding how much physics is hidden in an FT of an uninterrupted high-precision light curve

TASC-ers are artists in getting it out… 🤗🤗🤗

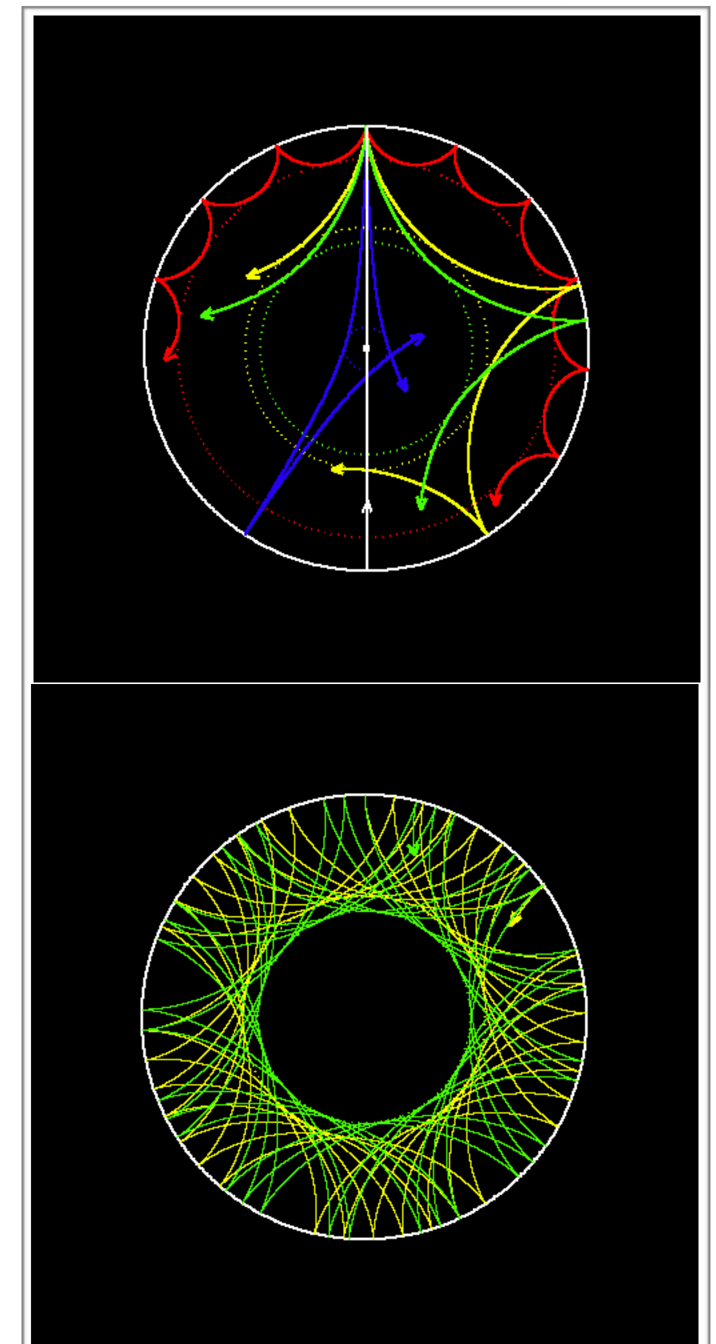




The Beauty of Asteroseismology



aster ⟶ star
seismos ⟶ waves
logos ⟶ discourse



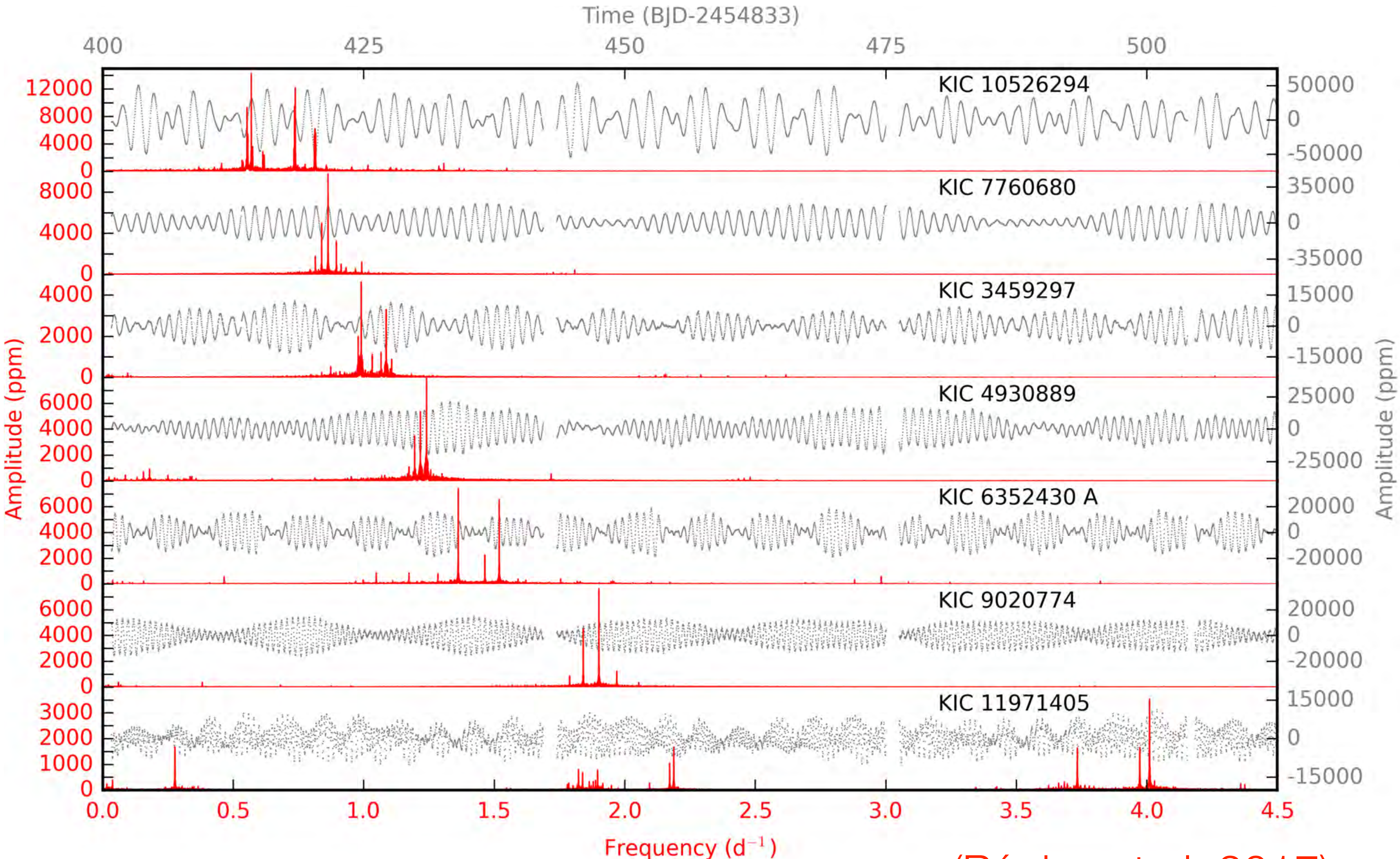
Different waves penetrate to different depths inside the star

$$\sqrt{4\pi}\Re\left\{\left[\tilde{\xi}_r(r)Y_l^m(\theta,\phi)\boldsymbol{a}_r + \tilde{\xi}_h(r)\left(\frac{\partial Y_l^m}{\partial\theta}\boldsymbol{a}_\theta + \frac{1}{\sin\theta}\frac{\partial Y_l^m}{\partial\phi}\boldsymbol{a}_\phi\right)\right]\exp(-i\omega t)\right\}$$

Mode Identification

Frequency Analysis

Don’t call this stellar noise!



(Pápics et al. 2017)

Data processing is crucial

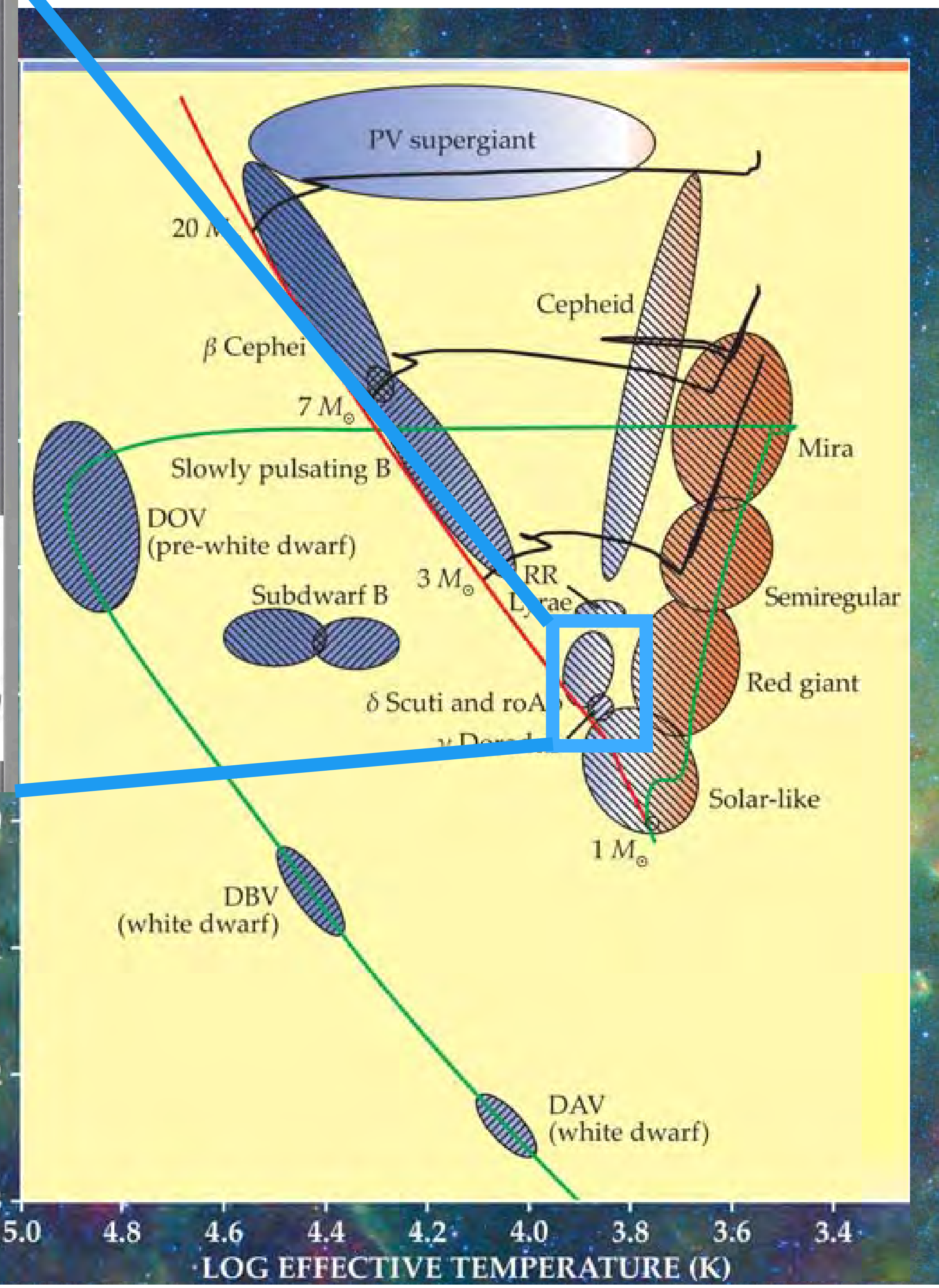
With immense appreciation for the *Kepler,* K2 & TESS GO & GI office members

Thank you, T'DA-ers!!

Numerous talks & software demo's

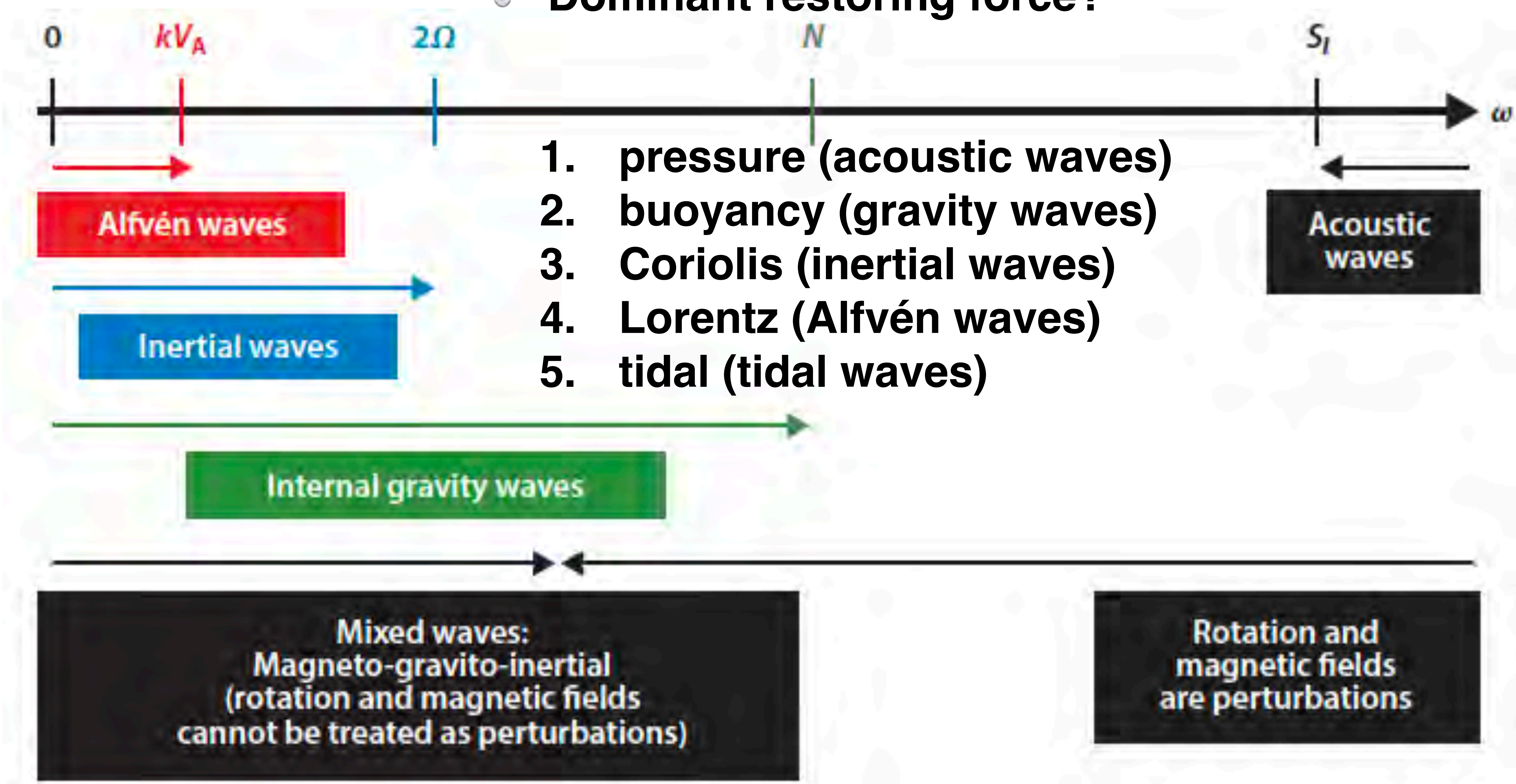
TESS: diversity is impressive

Slide: Vicky Antoci



Regimes of wave frequencies

- **Dominant restoring force?**



1. **pressure (acoustic waves)**
2. **buoyancy (gravity waves)**
3. **Coriolis (inertial waves)**
4. **Lorentz (Alfvén waves)**
5. **tidal (tidal waves)**

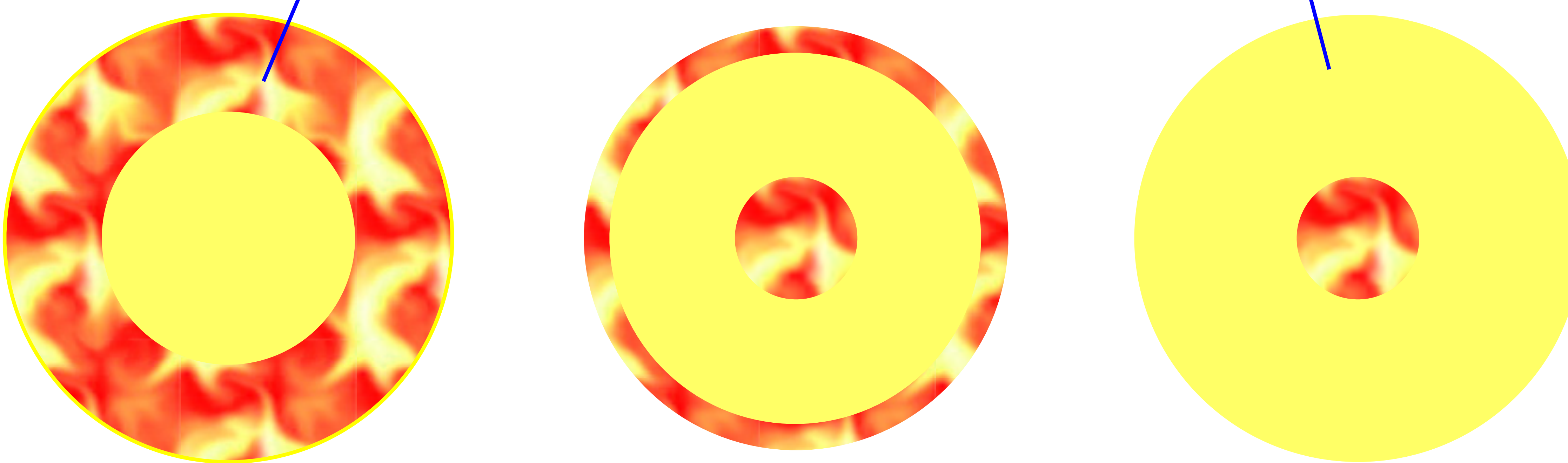
Aerts et al. (2019), ARAA, Vol. 57, in press
RiA via https://www.annualreviews.org/doi/pdf/10.1146/annurev-astro-091918-104359

Types of young exoplanet hosts

Scaling the Sun is OK for 4,8,20%-level R,M,age (bias?)

No "Sun" to scale… R, M, age from asteroseismic modelling

$\Delta\nu$, ν_{max}



ΔP

M < 1 $M_\odot$ | 1 $M_\odot$ < M < 2 $M_\odot$ | M > 2 $M_\odot$

Easy for large databases

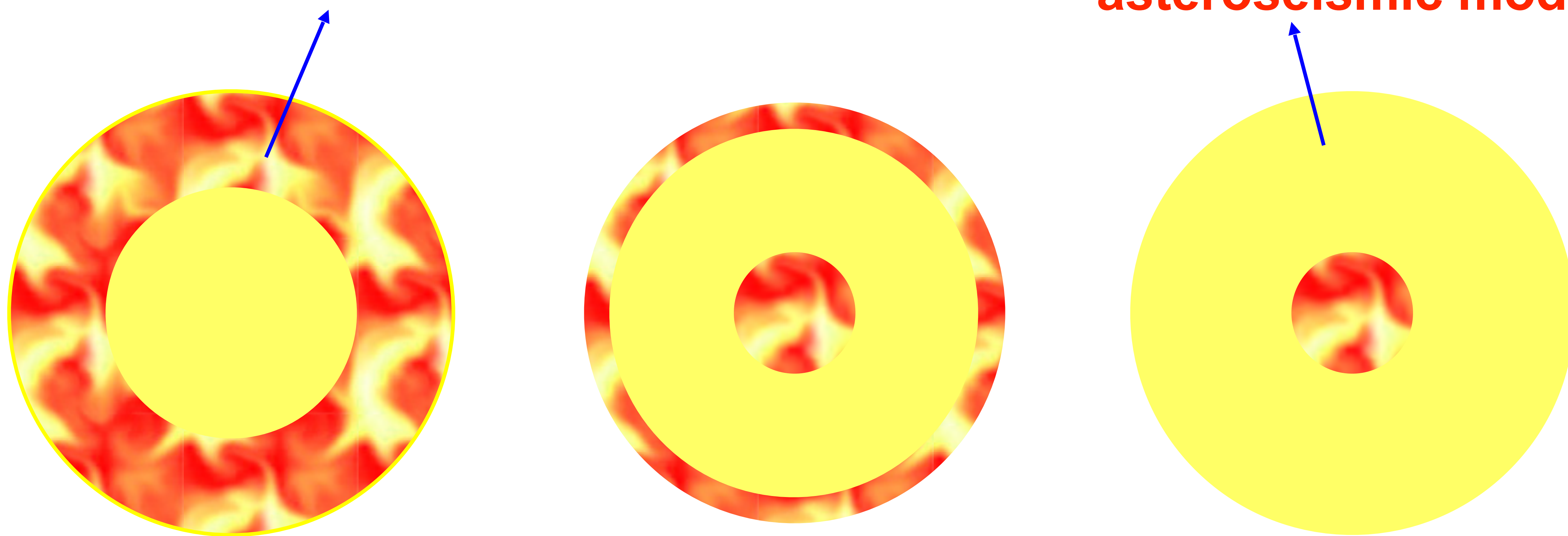
Unknowns for M above ~1.3 M_{sun}: M_{core} (r,t) & D_{mix} (r,t) & Ω_{rot} (r,t)

Various TASC WGs

Scaling the Sun is OK for 4,8,20%-level R,M,age (bias?)

No "Sun" to scale… R, M, age from asteroseismic modelling

$\Delta\nu$, ν_{max}

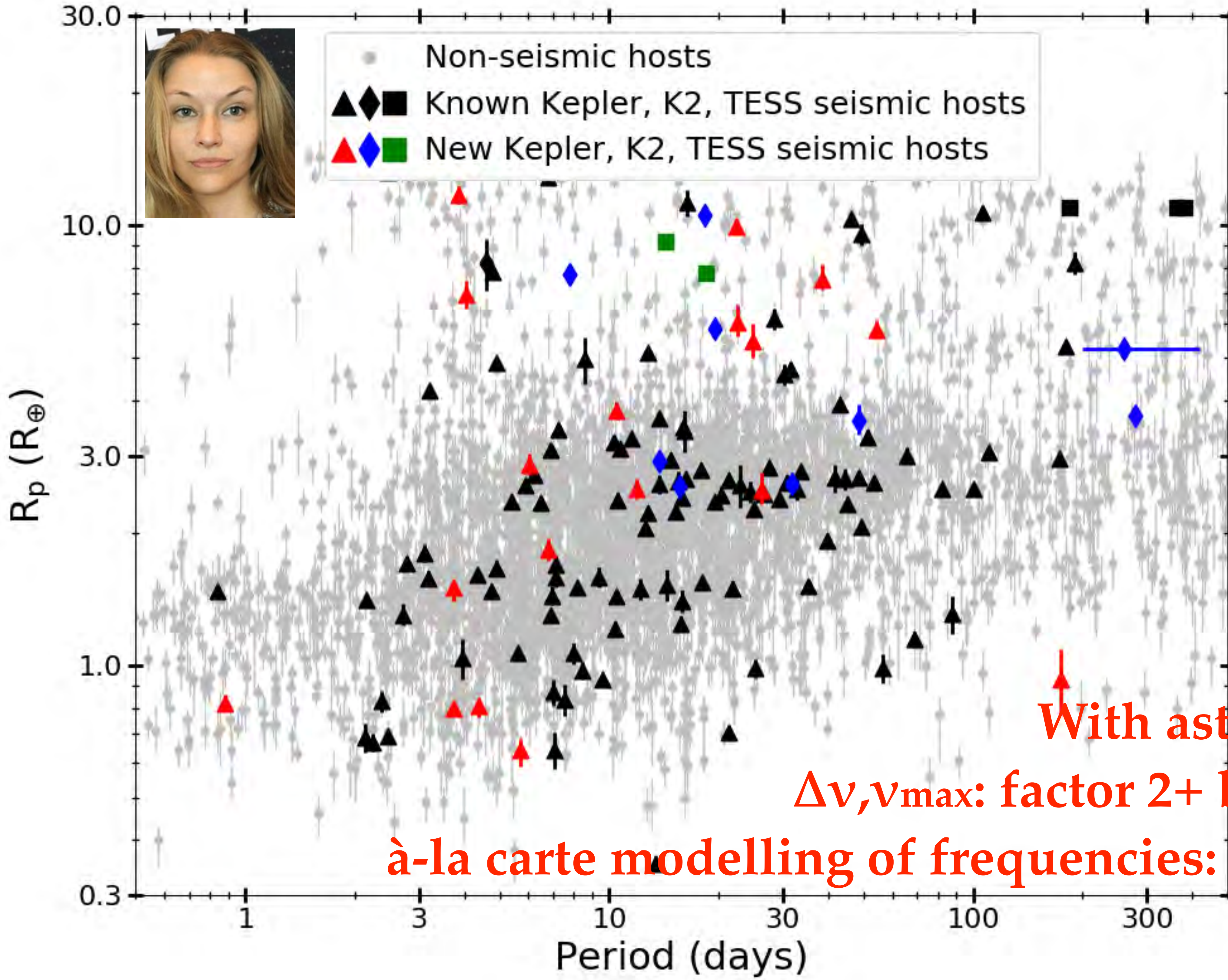


ΔP

$M < 1\ M_\odot$ | $1\ M_\odot < M < 2\ M_\odot$ | $M > 2\ M_\odot$

+ classical pulsators (RR Lyr, Cepheids) Kolenberg
+ compact pulsators (sdB/WD) Charpinet, Montgomery, Zong, Vanderbosch

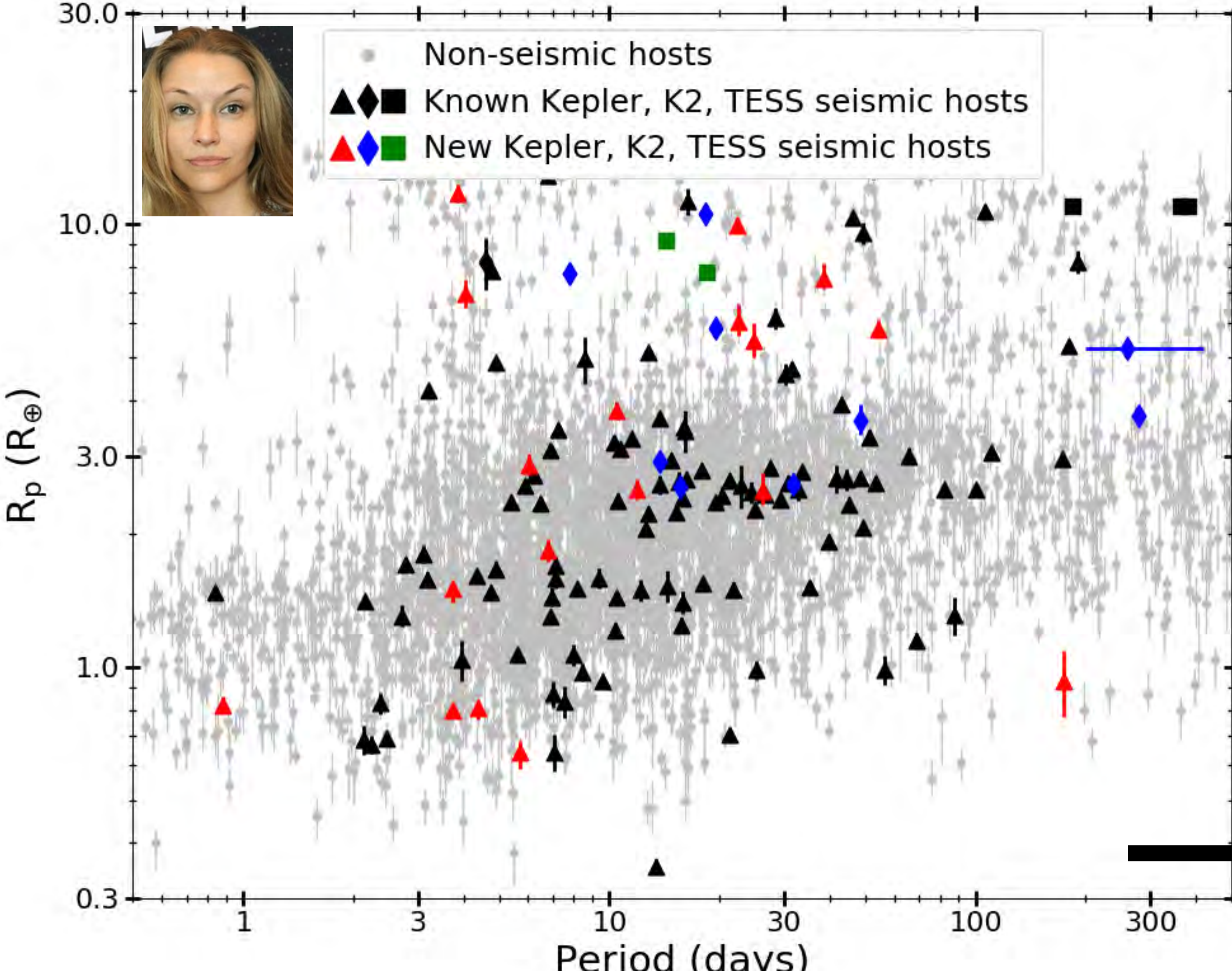
Exoplanets & Asteroseismology

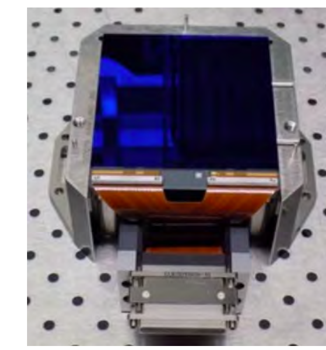


Van Eylen
Campante
Chontos
Nielsen
Seager
+
stellar
inclinations:
Gehan

With asteroseismology:
$\Delta\nu$,ν_{max}: factor 2+ better precision
à-la carte modelling of frequencies: factor 2+ better

TESS: short-P exoplanets





Planet Ages

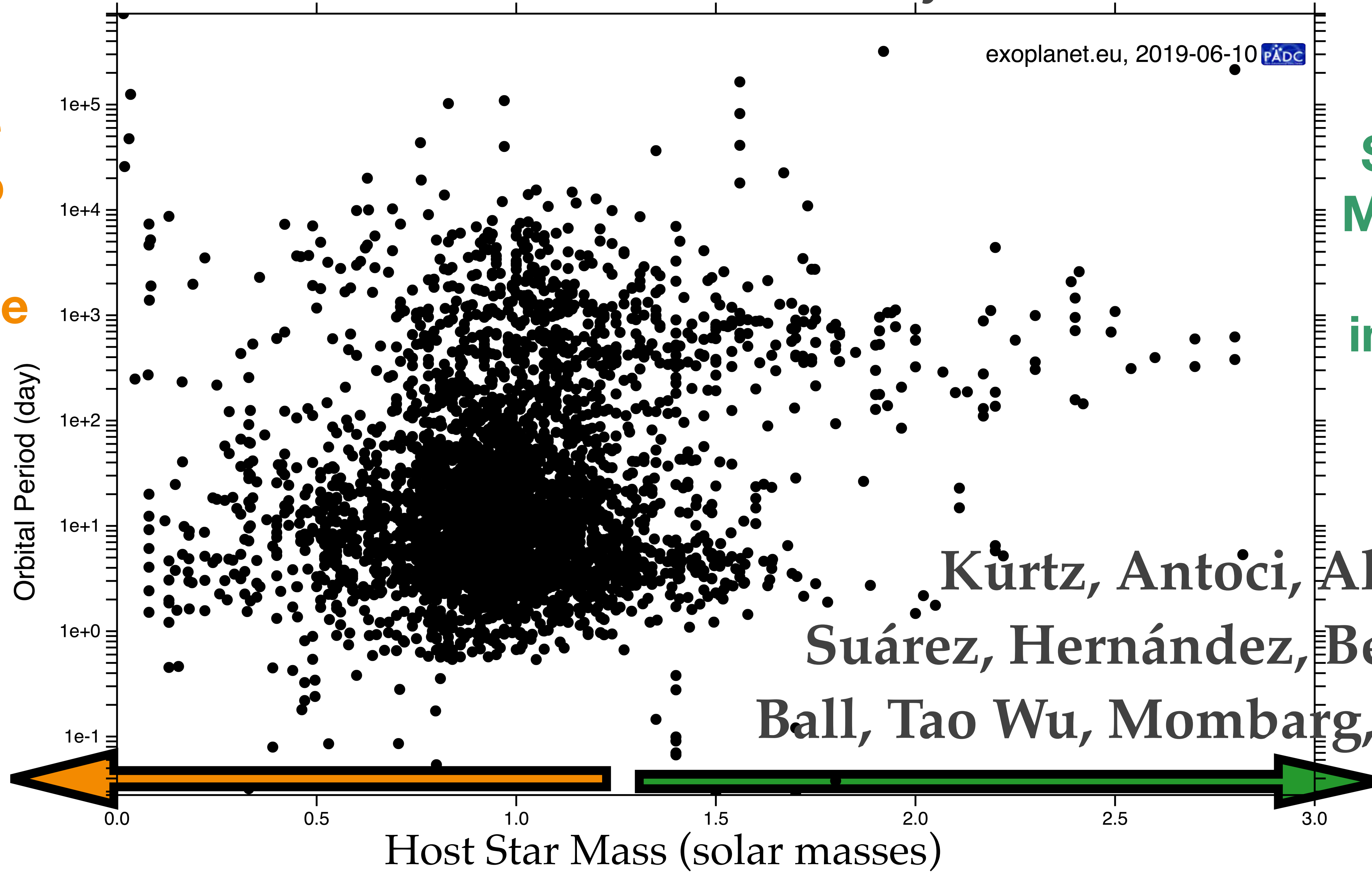
2026+

Host star oscillations & activity

Roettenbacher, Santos, Thomas, Mathur, Moya

Highly-Variable Dynamo Fields at Surface > 50%

GKM



Fossil Stable Surface Magnetic Fields in < 10%

OBAF

Kurtz, Antoci, Alicavus, Suárez, Hernández, Bedding, Ball, Tao Wu, Mombarg, Verma

Solar-like pressure modes excited by envelope convection

Pressure and gravity modes excited in radiative envelope

Asteroseismic Modelling

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THEORY

mass, metallicity, age +
convection? magnetism?
mixing? rotation?

↓

STELLAR MODEL
FOR SPECIFIED
INPUT PHYSICS

↓

Theoretical predictions
for oscillations

OBSERVATIONS

Space photometry,
high-res. spectroscopy,
Gaia astrometry

↓

Observed properties
of **identified** modes

Theoretical predictions for oscillations ↔ Observed properties of identified modes

Two Major Aims:

A) High-precision M, R, age, Z

**B) Improve Input Physics:
AM, Dmix(r)**

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Asteroseismic Modelling

THEORY

mass, metallicity, age +
convection? magnetism?
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STELLAR MODEL
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Space photometry,
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Observed properties
of identified modes

Two Major Aims:

A) High-precision M, R, age, Z

B) Improve Input Physics:
AM, Dmix(r)

A variety of methods: Bellinger, Themeßl, Mombarg, Verma

For binaries: Ong, Hey, McKeever, Sekaran, Johnston, Beck, Guo

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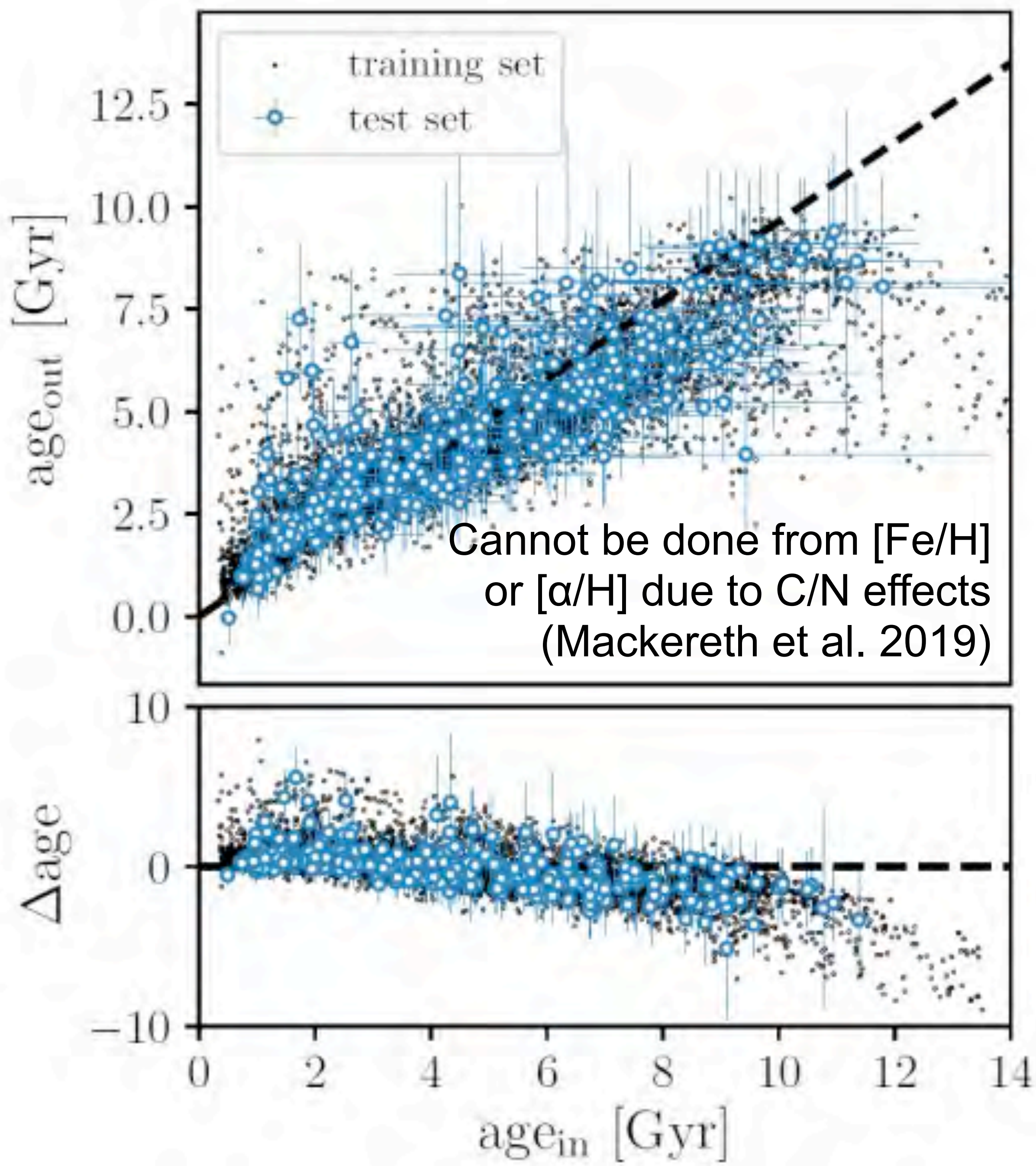
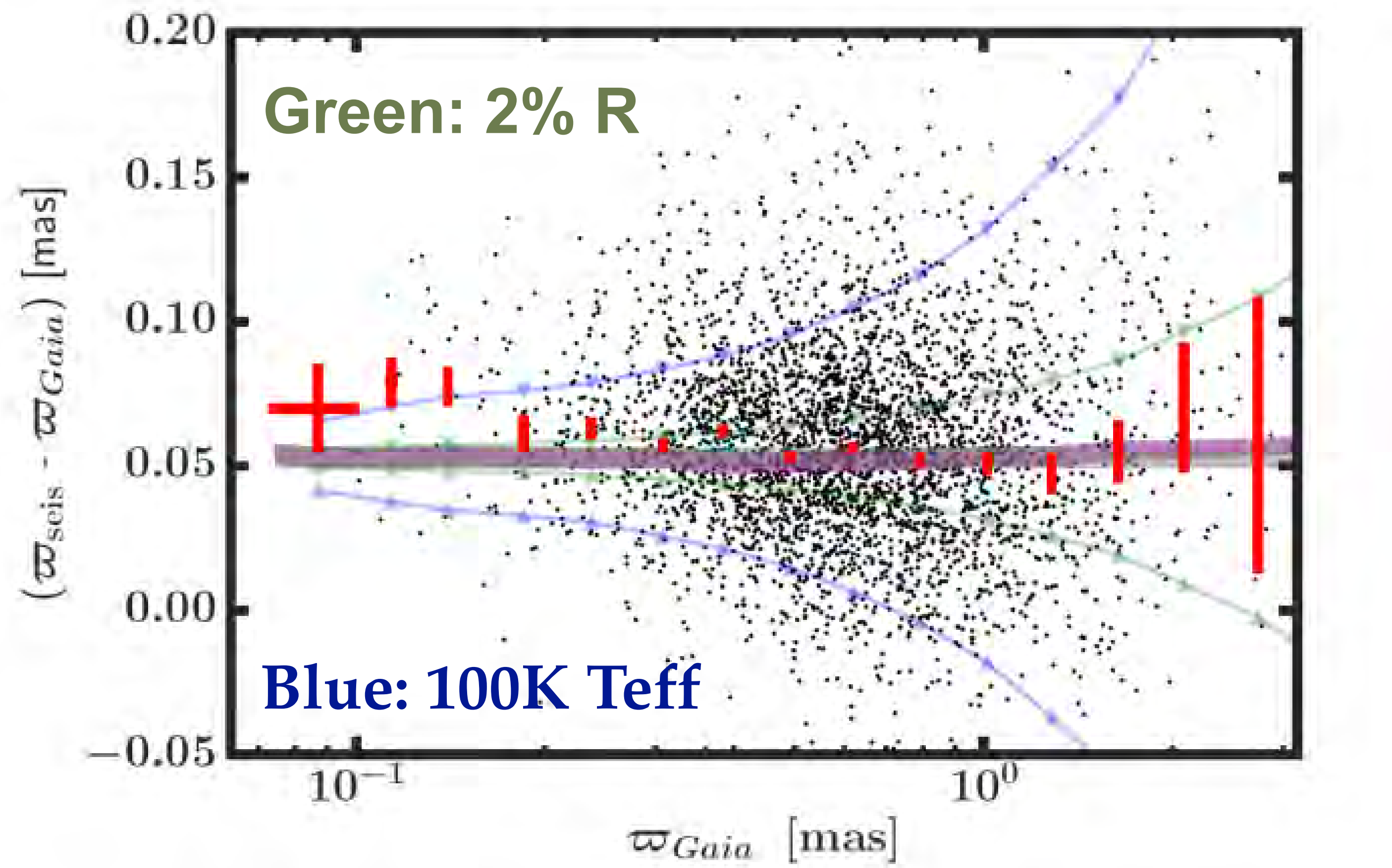
Scaling the Sun for galactic archeology

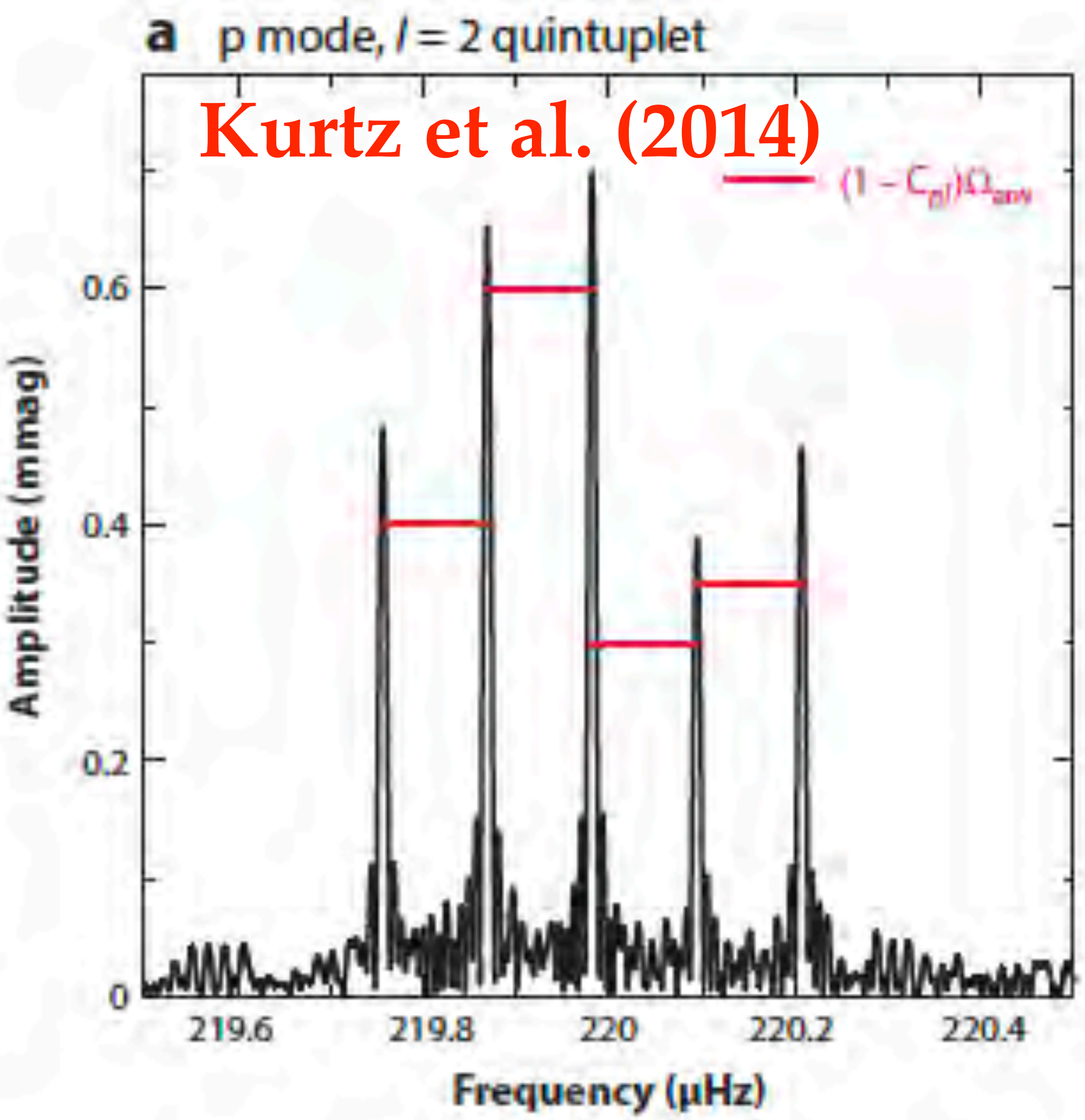


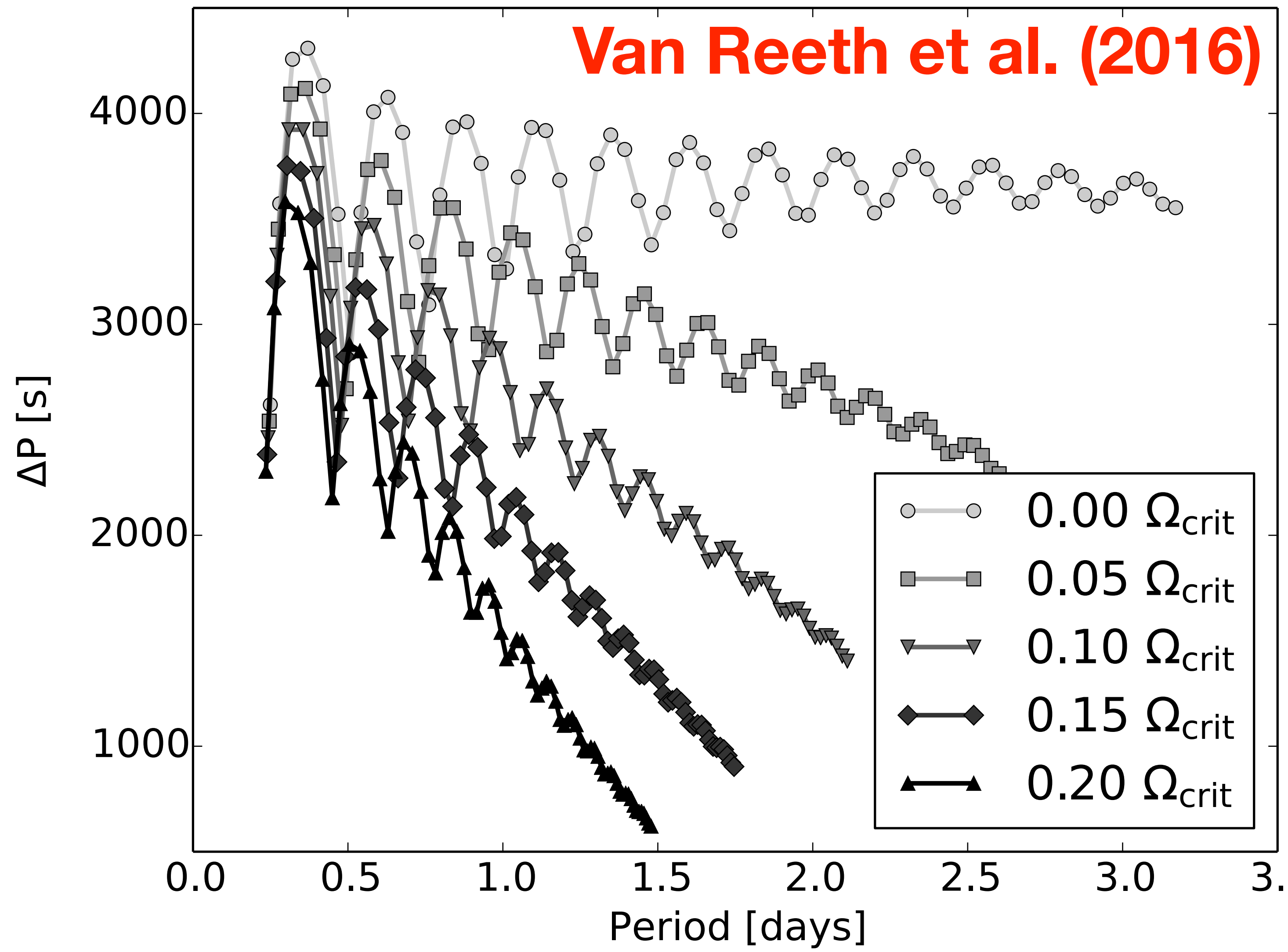


Space photometry
Gaia astrometry
SDSS/APOGEE spectroscopy:
Scaling relations work remarkably well

Slide courtesy: Marc Pinsonneault;
talks by Chiappini (20% age enough!), Stello, Slumstrup, Grunblatt

KU LEUVEN Interior Rotation of Stars





p-mode splitting gives envelope rotation

g-mode splitting gives near-core rotation

Talks on rotation: Tayar, Deheuvels, Gang Li, Van Reeth, Pedersen

A tribute to *Kepler* : Core Rotation

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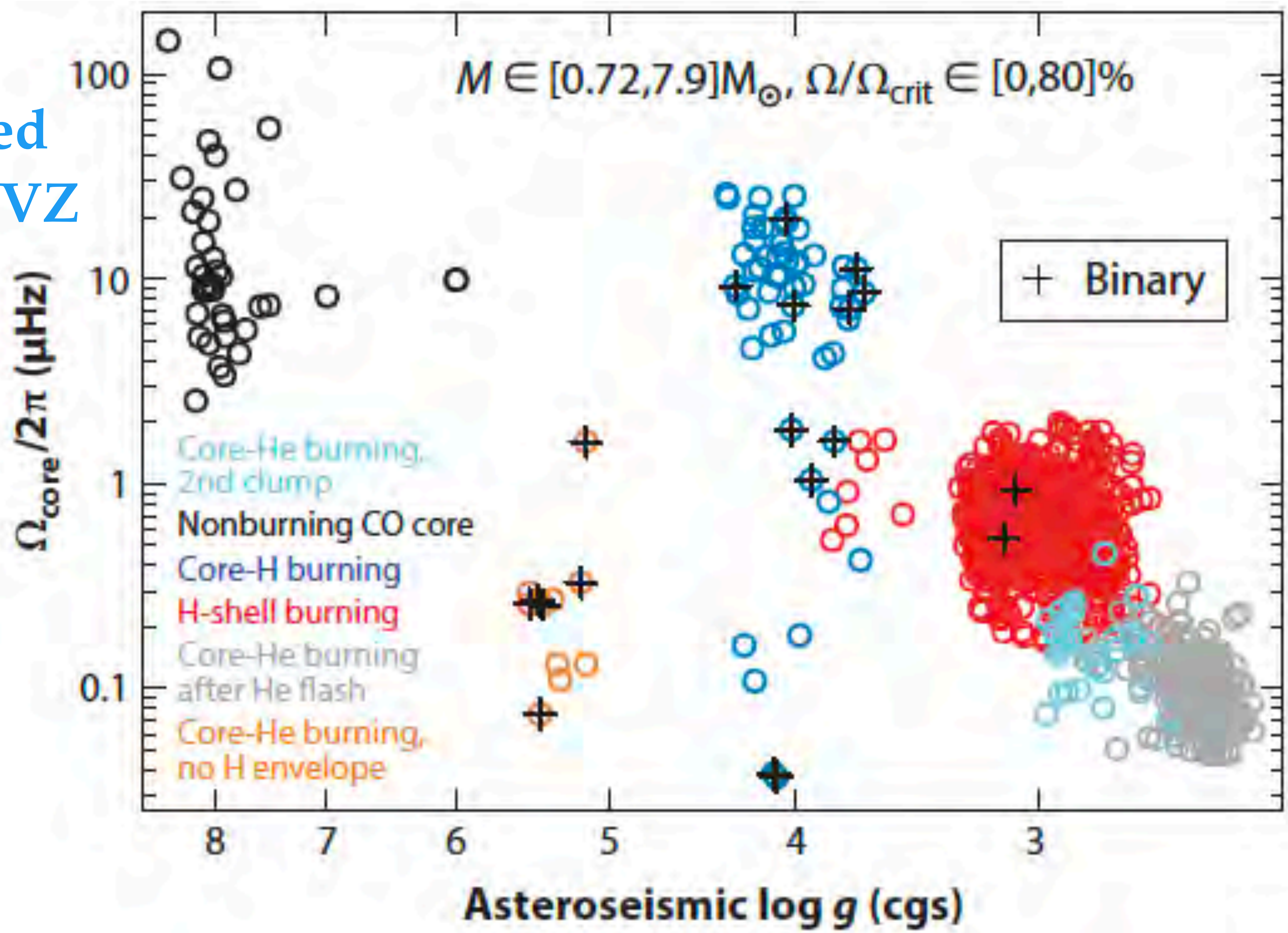
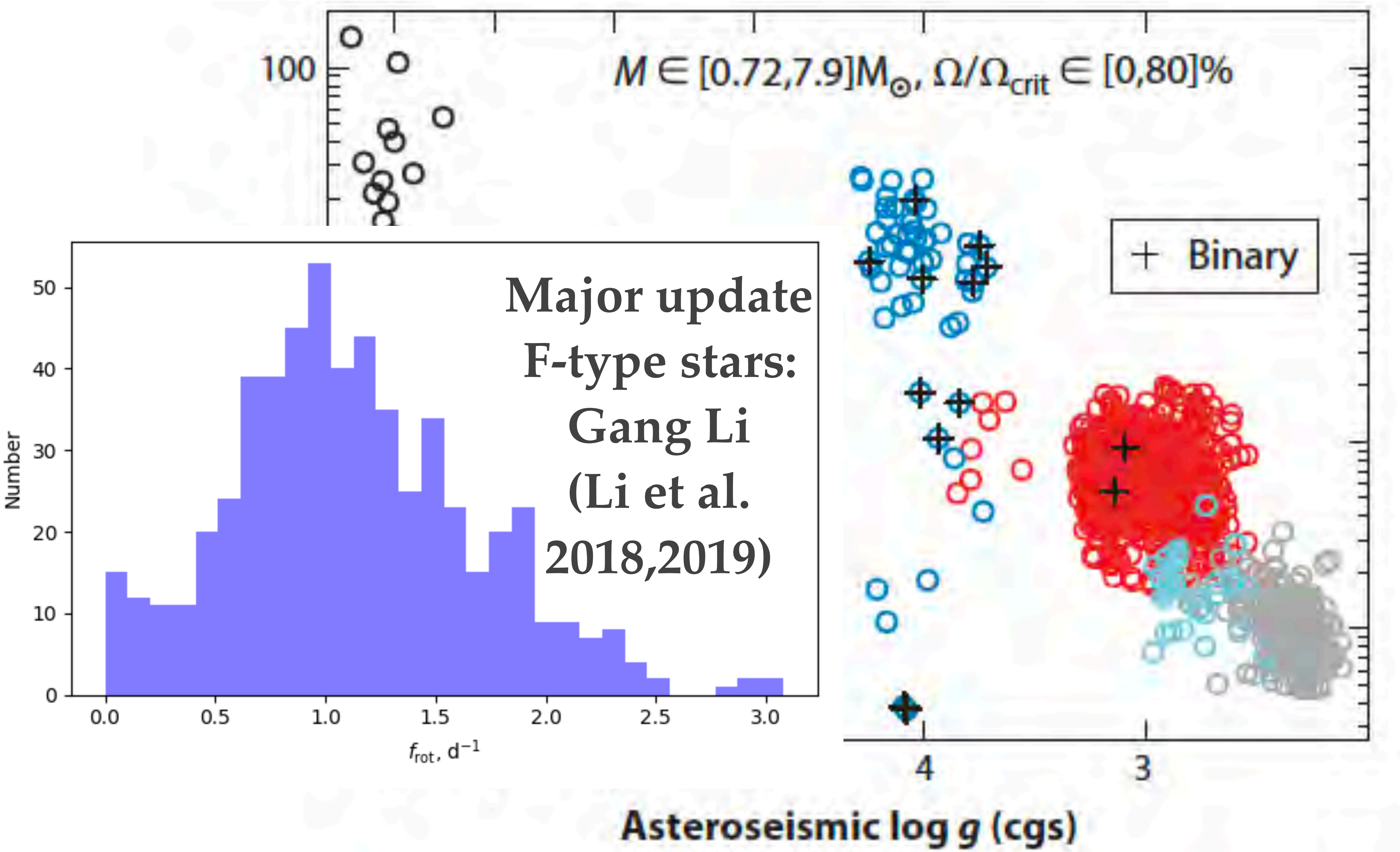
We need TESS-CVZ



Aerts et al. (2019), ARAA, Vol. 57, in press

RiA via https://www.annualreviews.org/doi/pdf/10.1146/annurev-astro-091918-104359

Addition of F stars with core rotation



Major update F-type stars: Gang Li (Li et al. 2018,2019)

Aerts et al. (2019), ARAA, Vol. 57, in press

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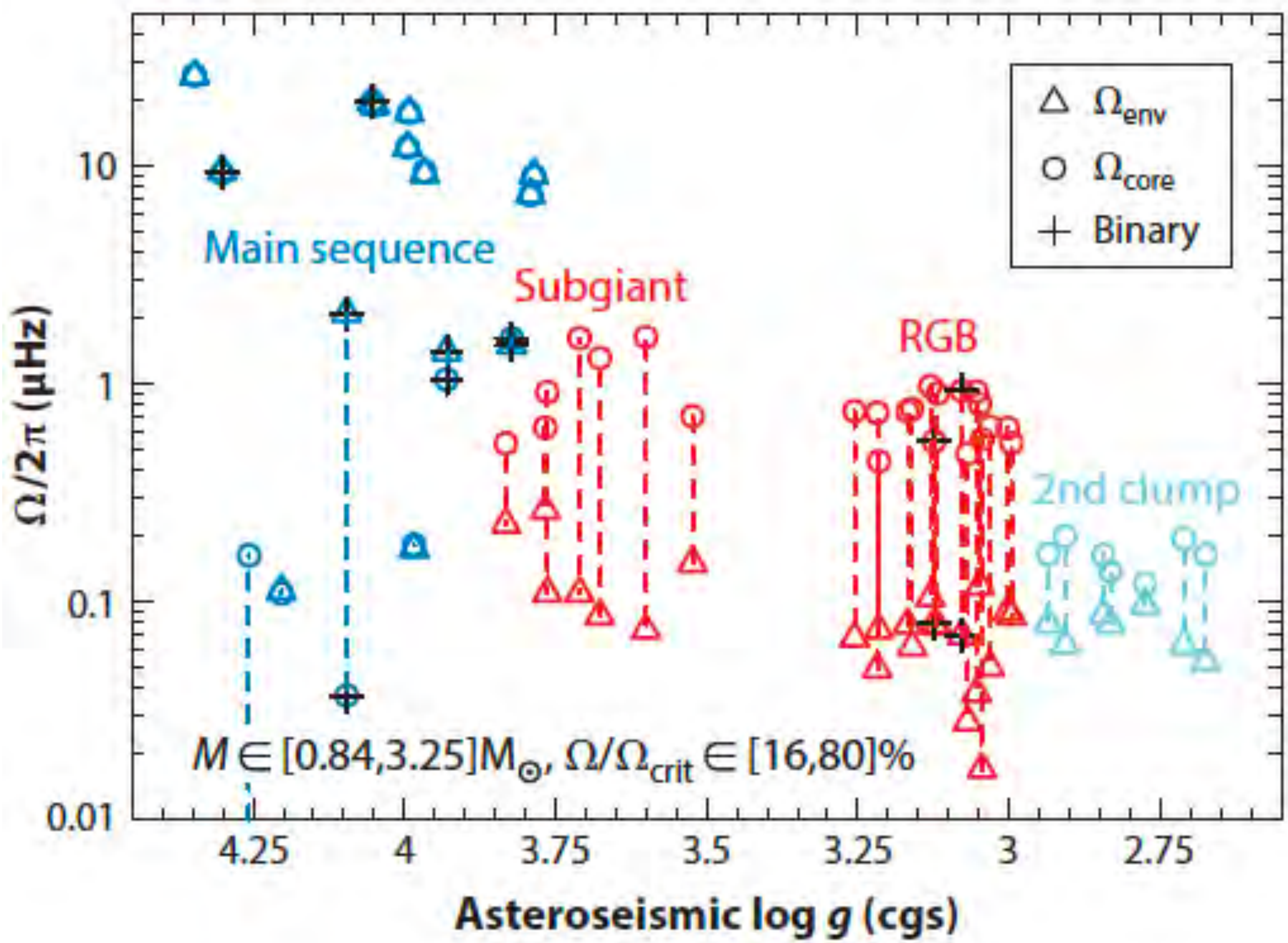
Core/Envelope Rotation



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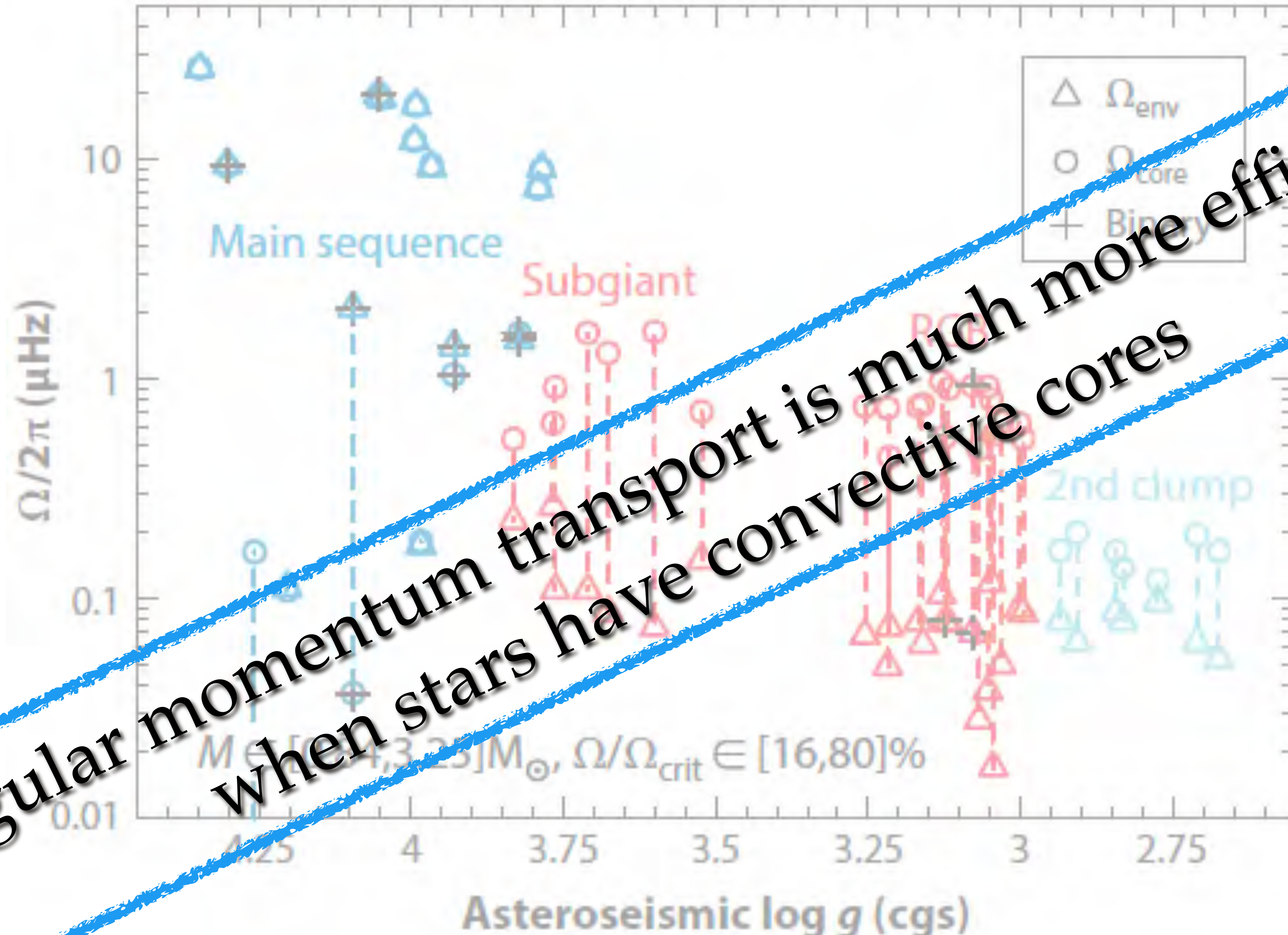
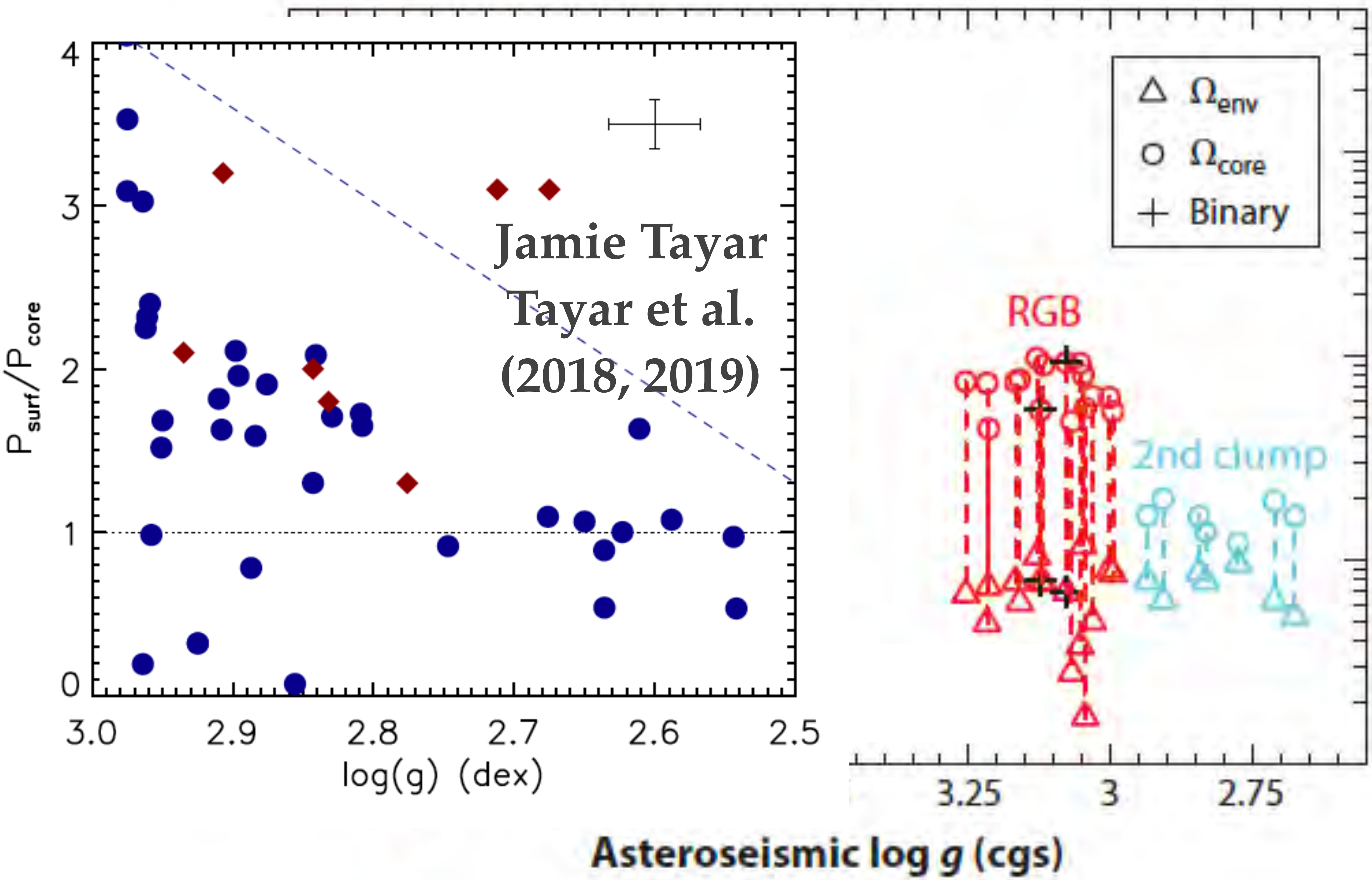
Core/Envelope Rotation



Angular momentum transport is much more efficient when stars have convective cores

Aerts et al. (2019), ARAA, Vol. 57, in press
RIA via https://www.annualreviews.org/doi/pdf/10.1146/annurev-astro-091918-104359

Critical assessment 2nd clump



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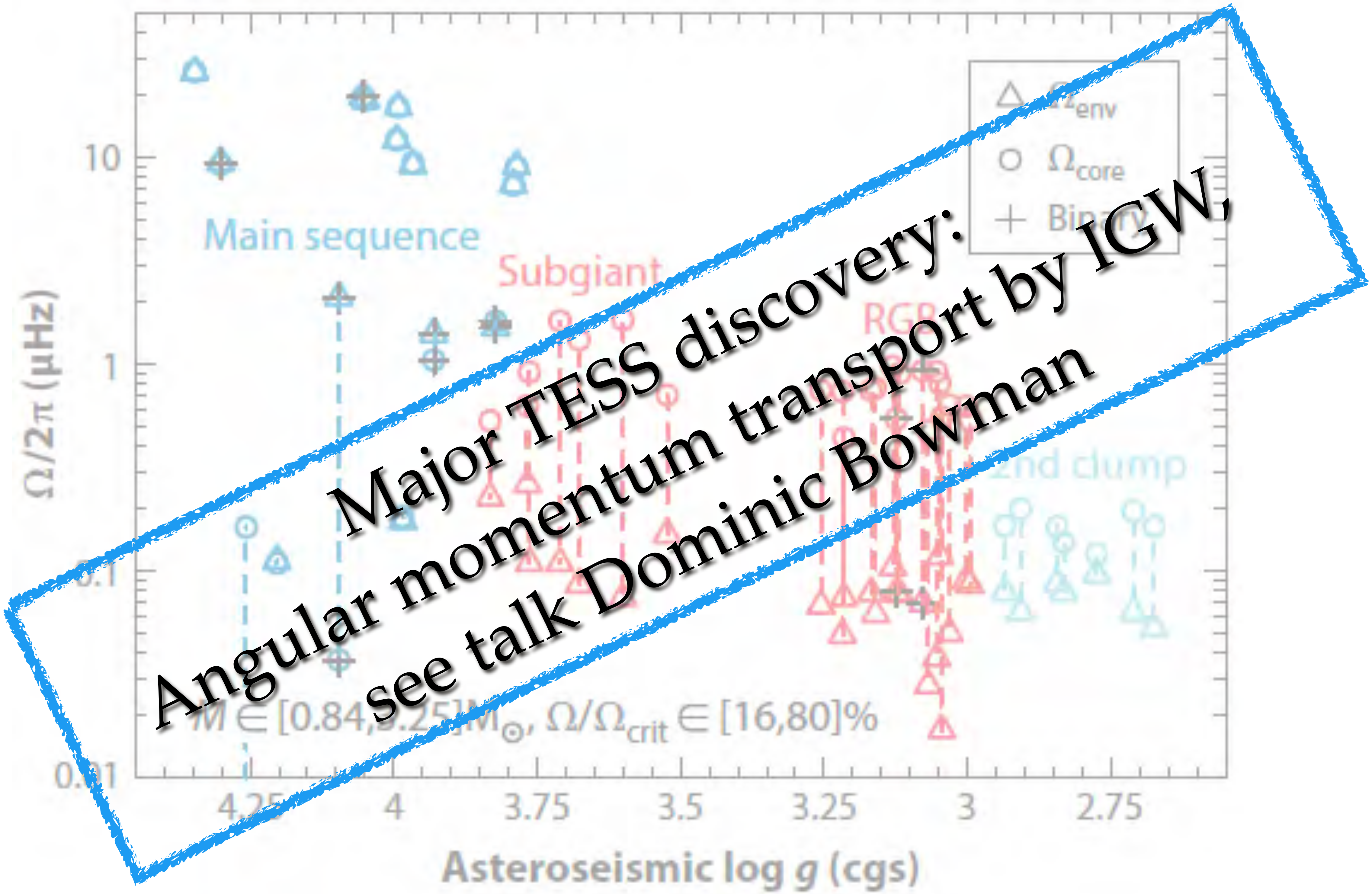
Core/Envelope Rotation



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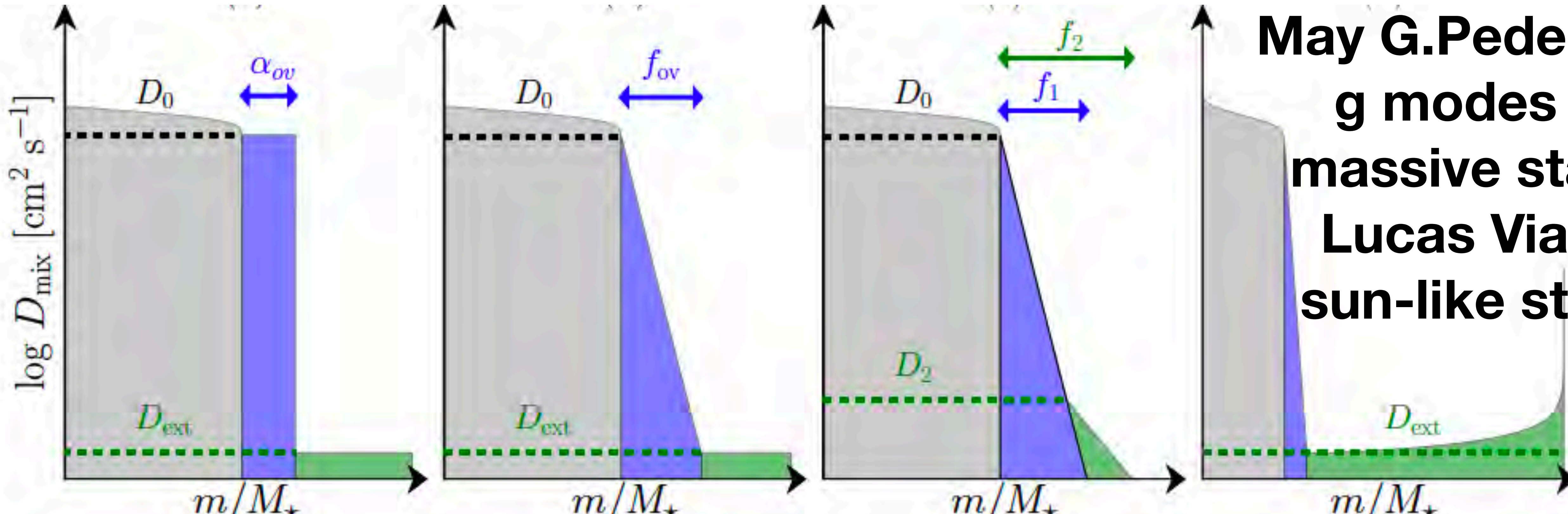
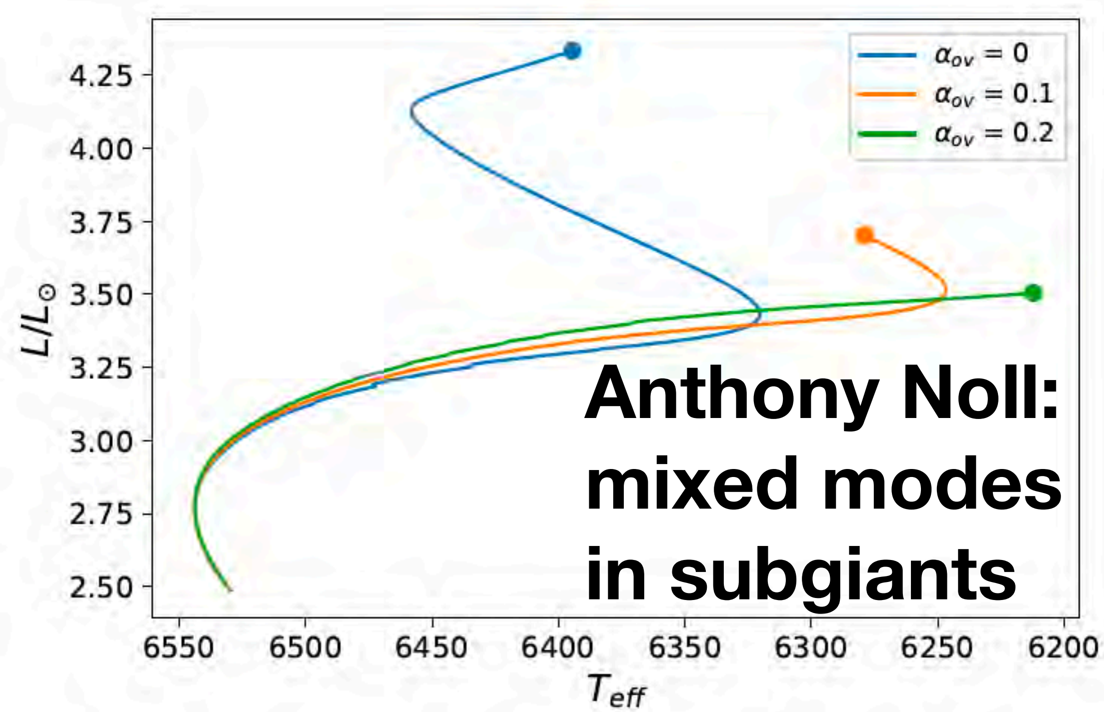
(Near-Core boundary) mixing

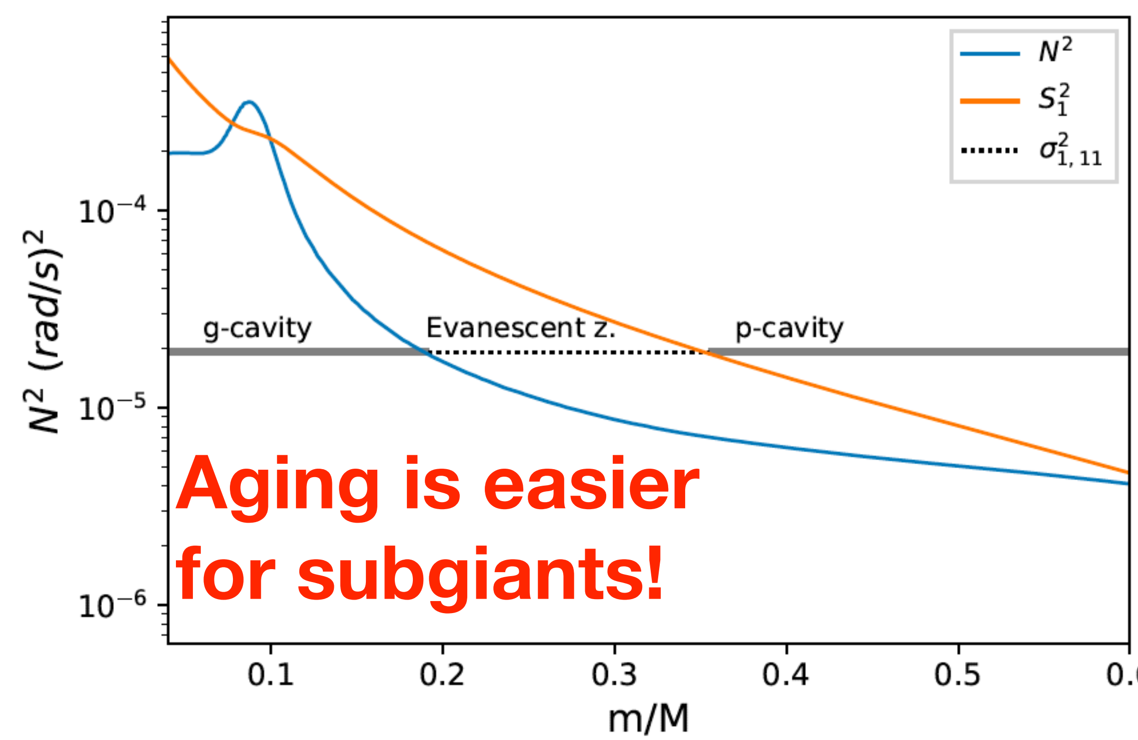


May G.Pedersen: g modes in massive stars; Lucas Viani: sun-like stars

Adding microscopic mixing from atomic diffusion? (Mombarg, Verma)



Anthony Noll: mixed modes in subgiants



Aging is easier for subgiants!

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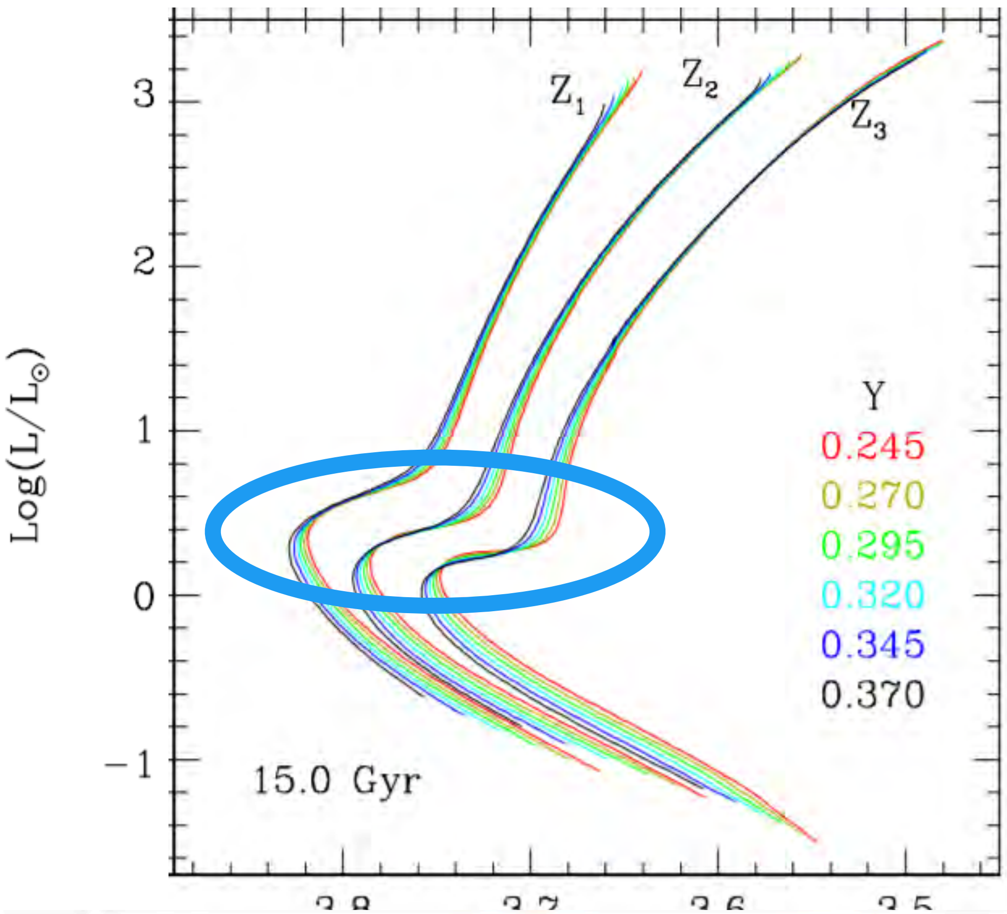
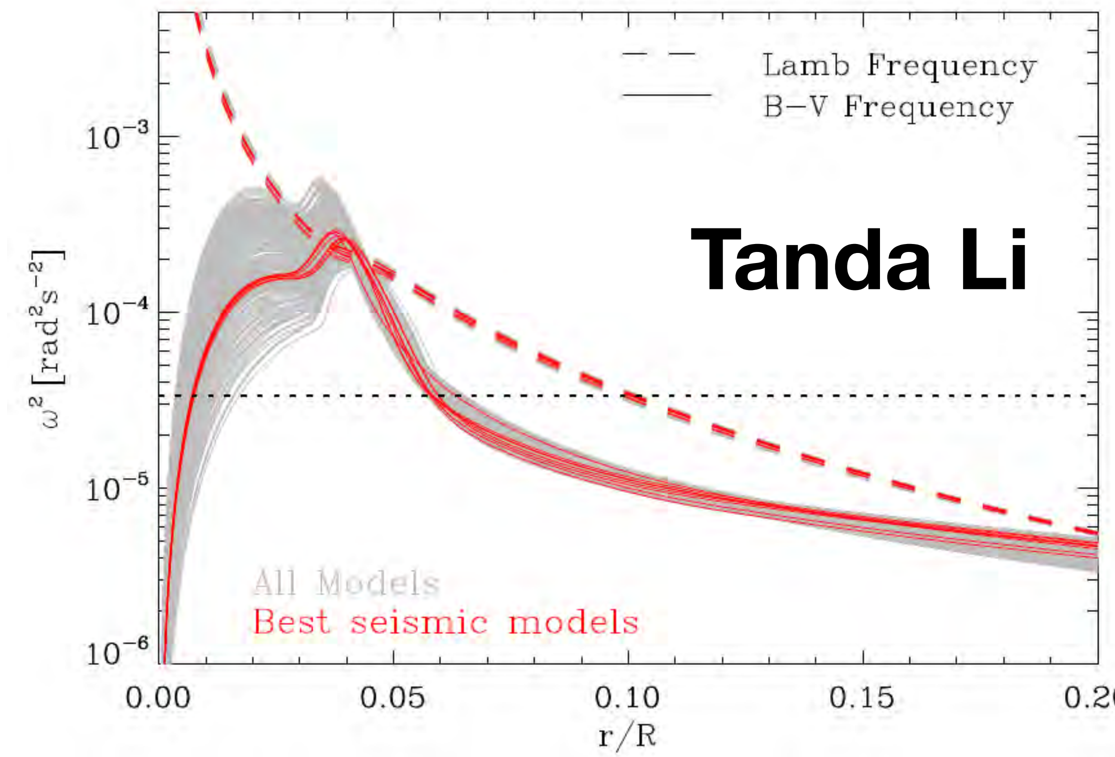
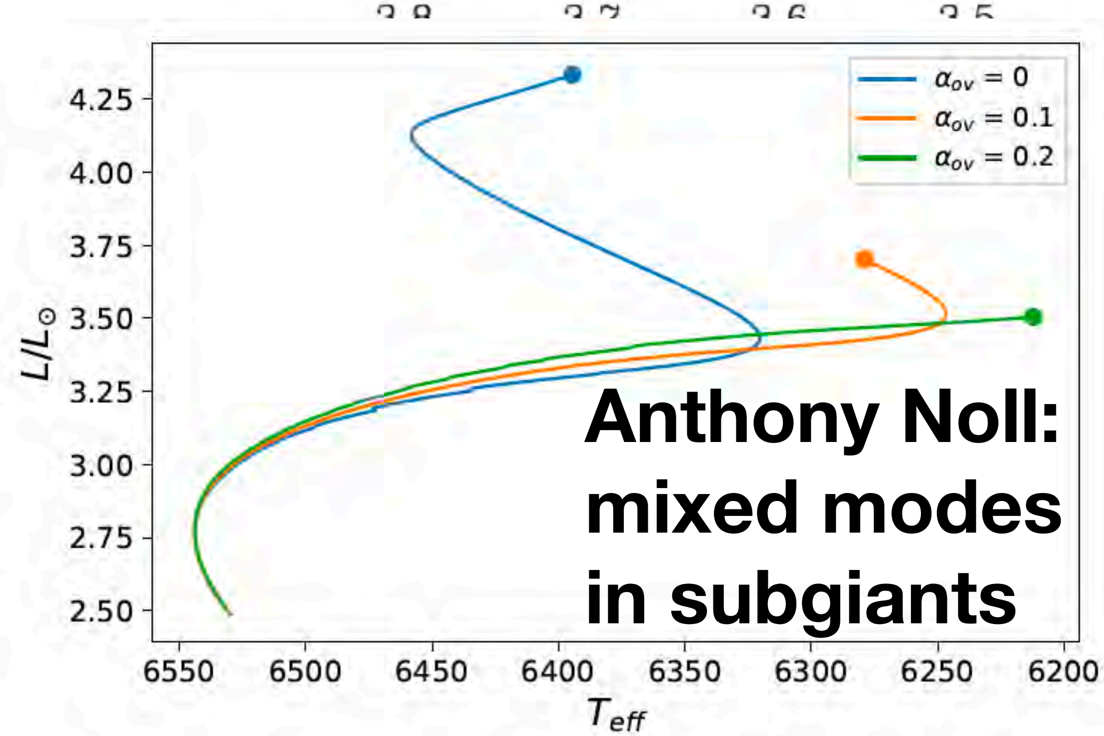
Subgiants with mixed modes: ages ~10%





Tanda Li



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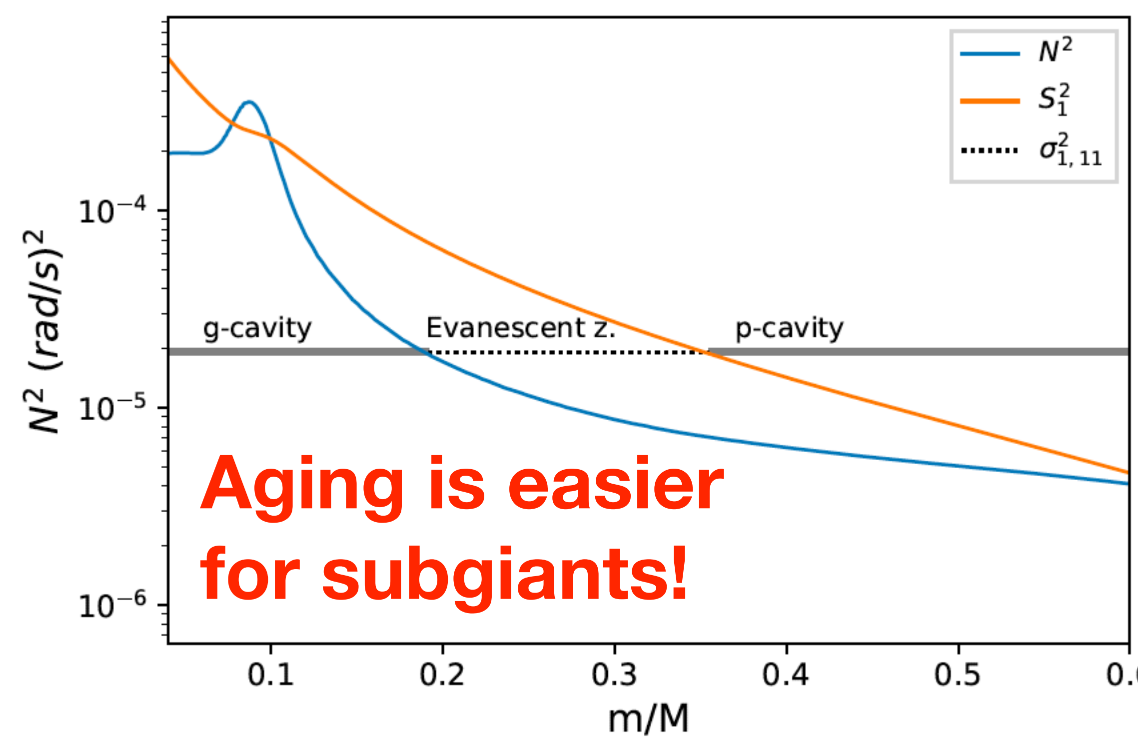


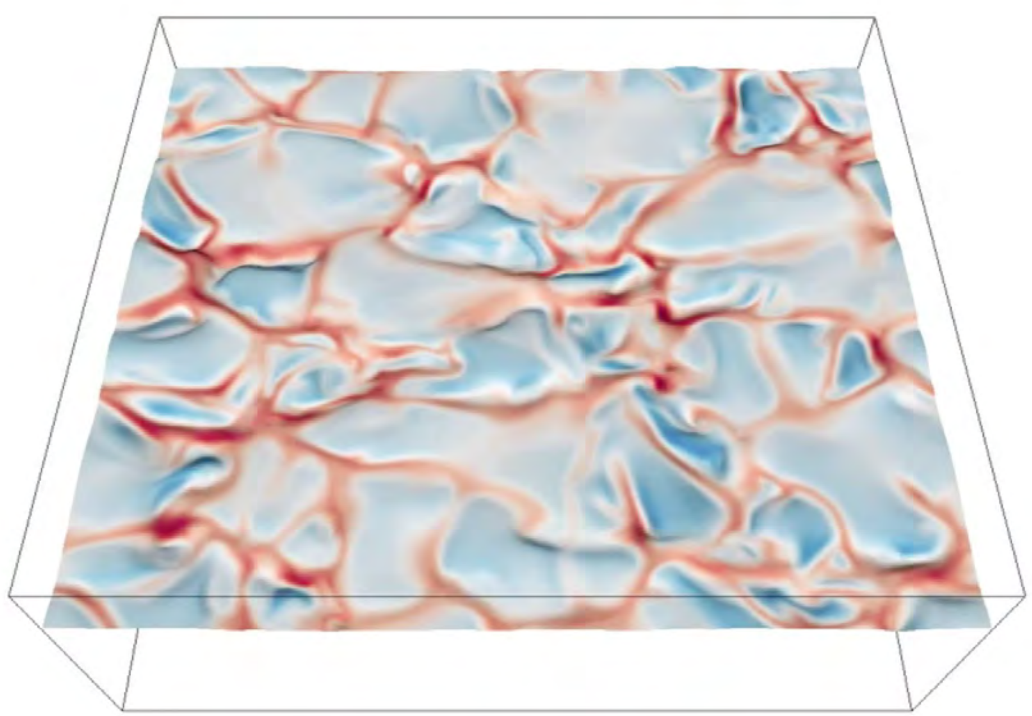
Aging is easier for subgiants!

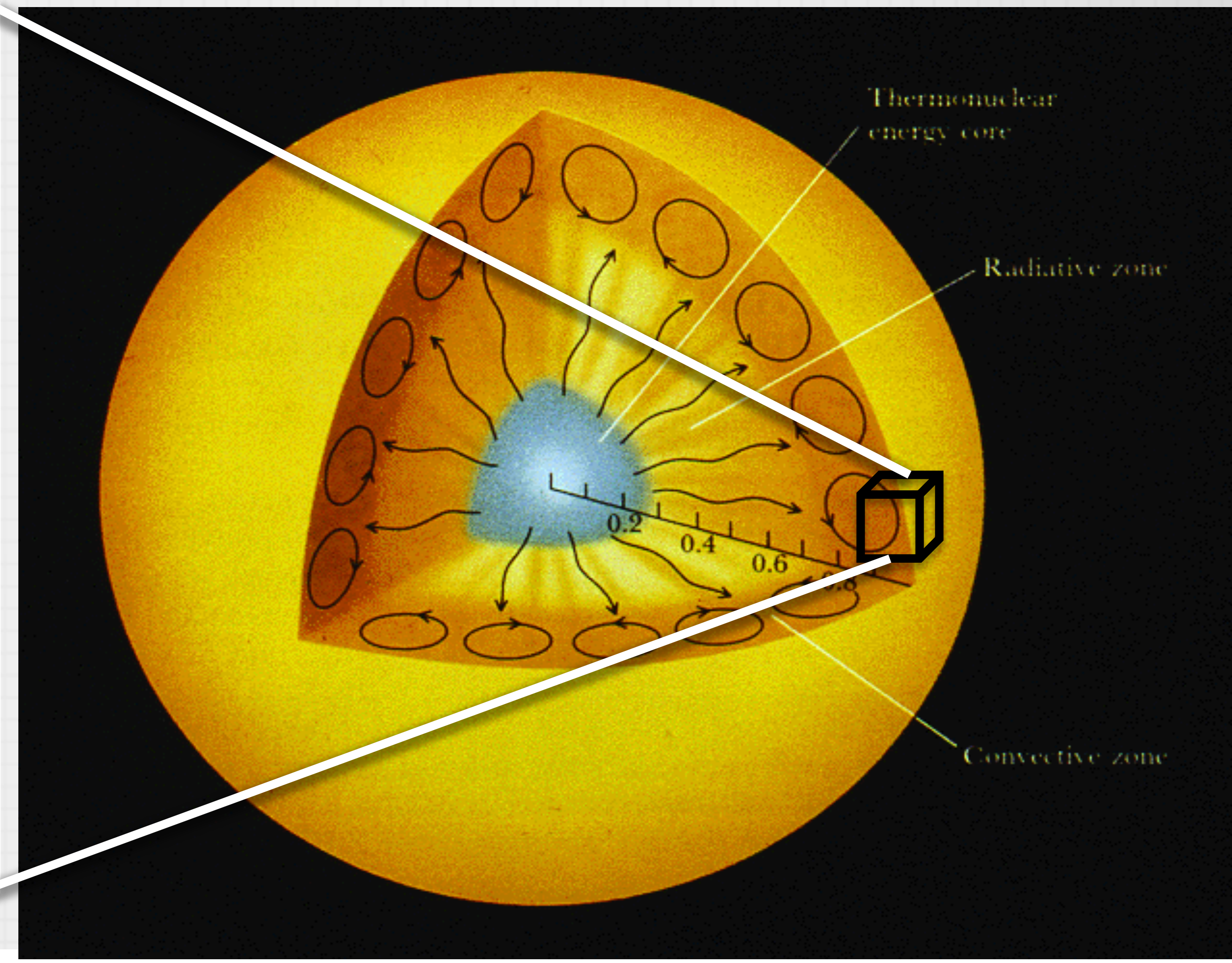
Coupling 3D hydro to 1D models

3D model atmosphere

Slide courtesy: Yixiao Zhou

Vertical velocity





Movie by Zazralt Magic

Asteroseismology of Solar-type Stars with 3D Stellar Modelling

Jørgensen, Zhou: better prediction of mode excitation, damping, v_{max} for velocities of radial modes; NRP? flux?

Nonlinear asteroseismology

Nonlinear oscillations

- The propagation of solar-like oscillations is typically described in terms of the linearized fluid equations

$$\text{Fluid forces} \sim c_1 \left(\frac{\delta r}{r}\right) + c_2 \left(\frac{\delta r}{r}\right)^2 + c_3 \left(\frac{\delta r}{r}\right)^3 + \cdots$$

linear nonlinear ===>

- In linear theory, waves propagate without interacting with each other.
- At order $(\delta r/r)^2$ have wave-wave interactions:

- Nonlinear effects can directly impact observables like mode surface amplitudes, linewidths, and frequencies.

Nonlinear wave interactions: so far ignored

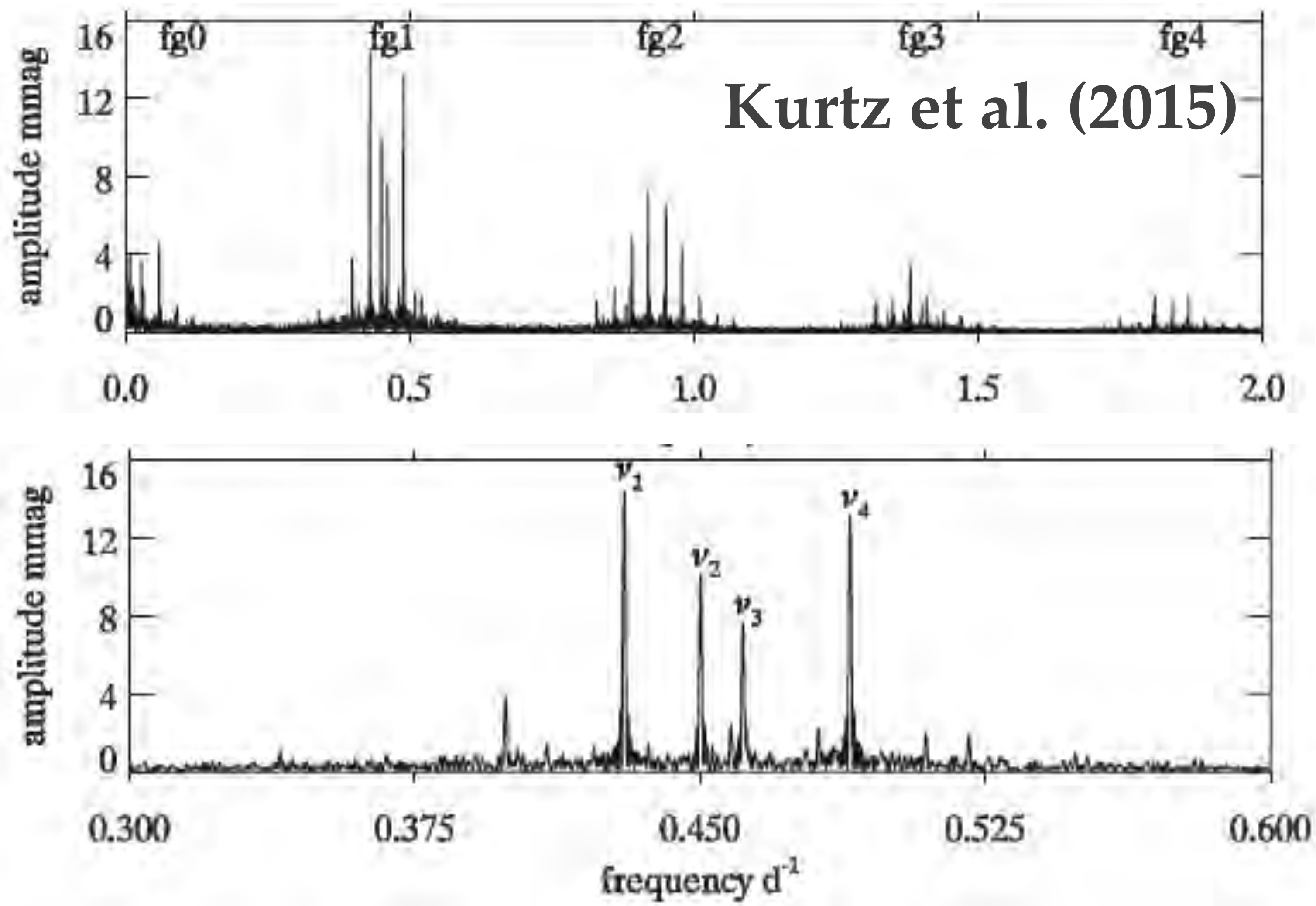
slide courtesy of Nevin Weinberg + talks by Guo, Zong, Vanderbosch

Nonlinear asteroseismology

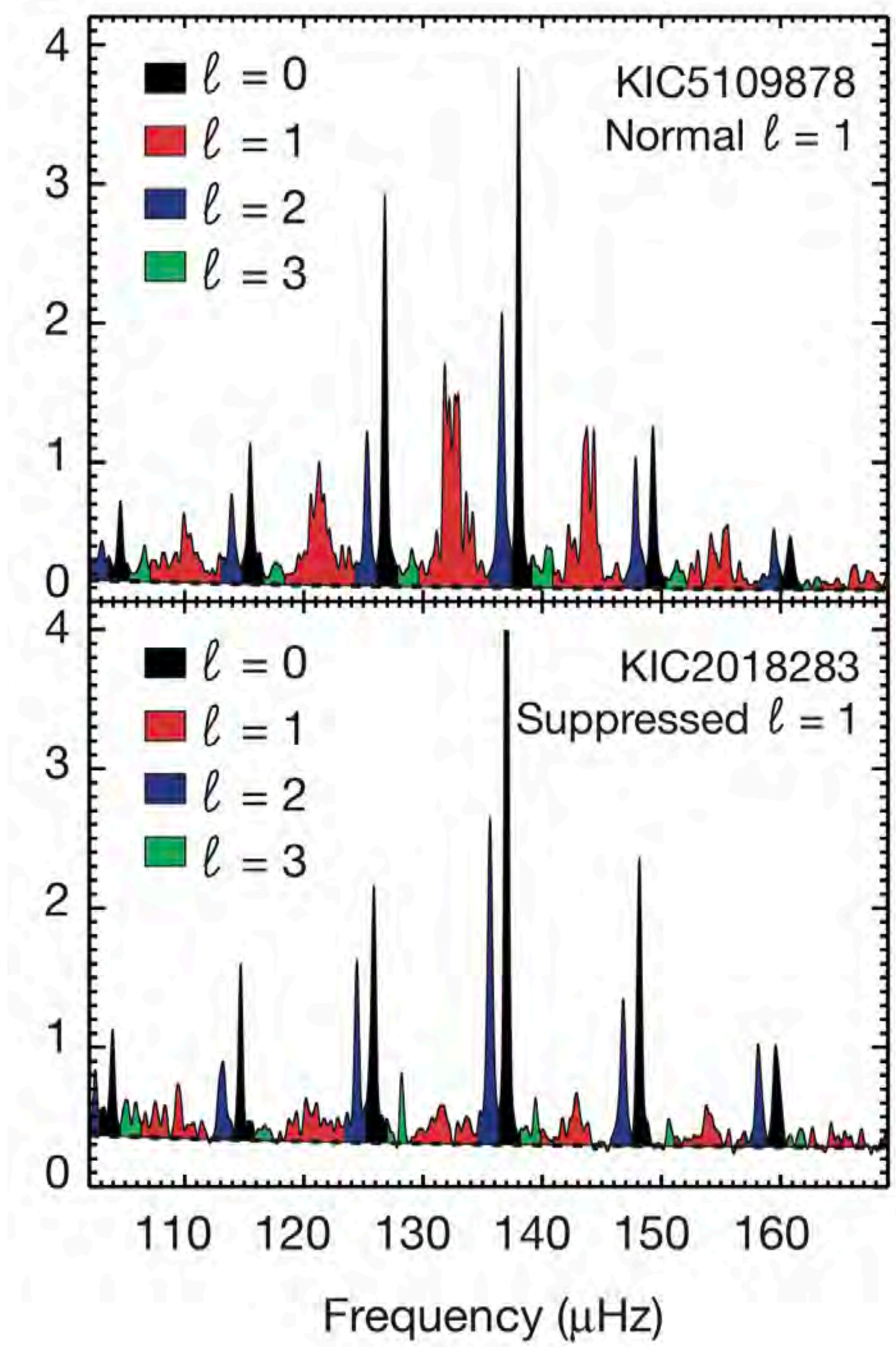
Potential applications:

- exploit observed amplitudes + frequencies
- nonlinear excitation of daughter modes
- nonlinear wave breaking & AM transport

and many more…

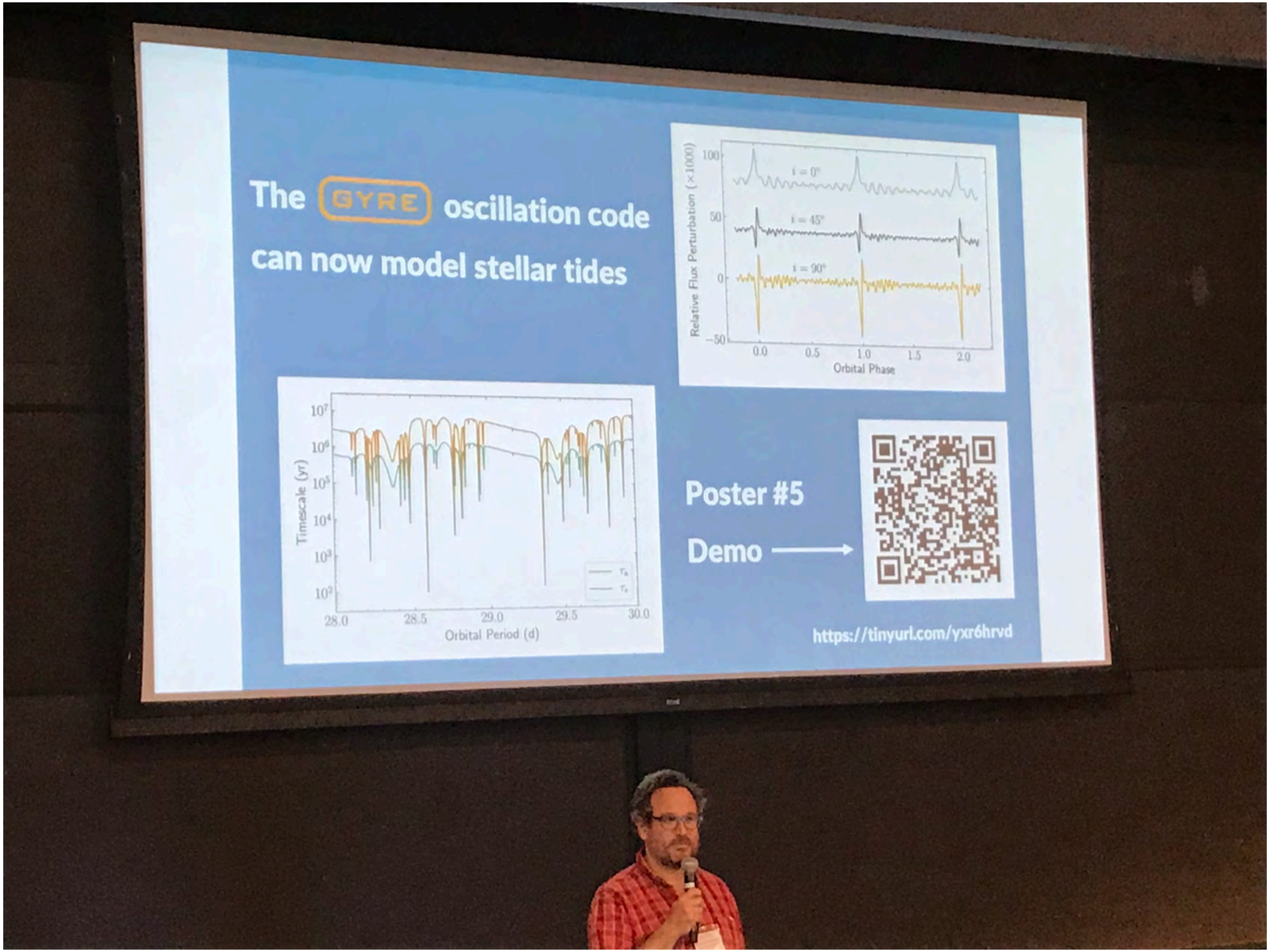


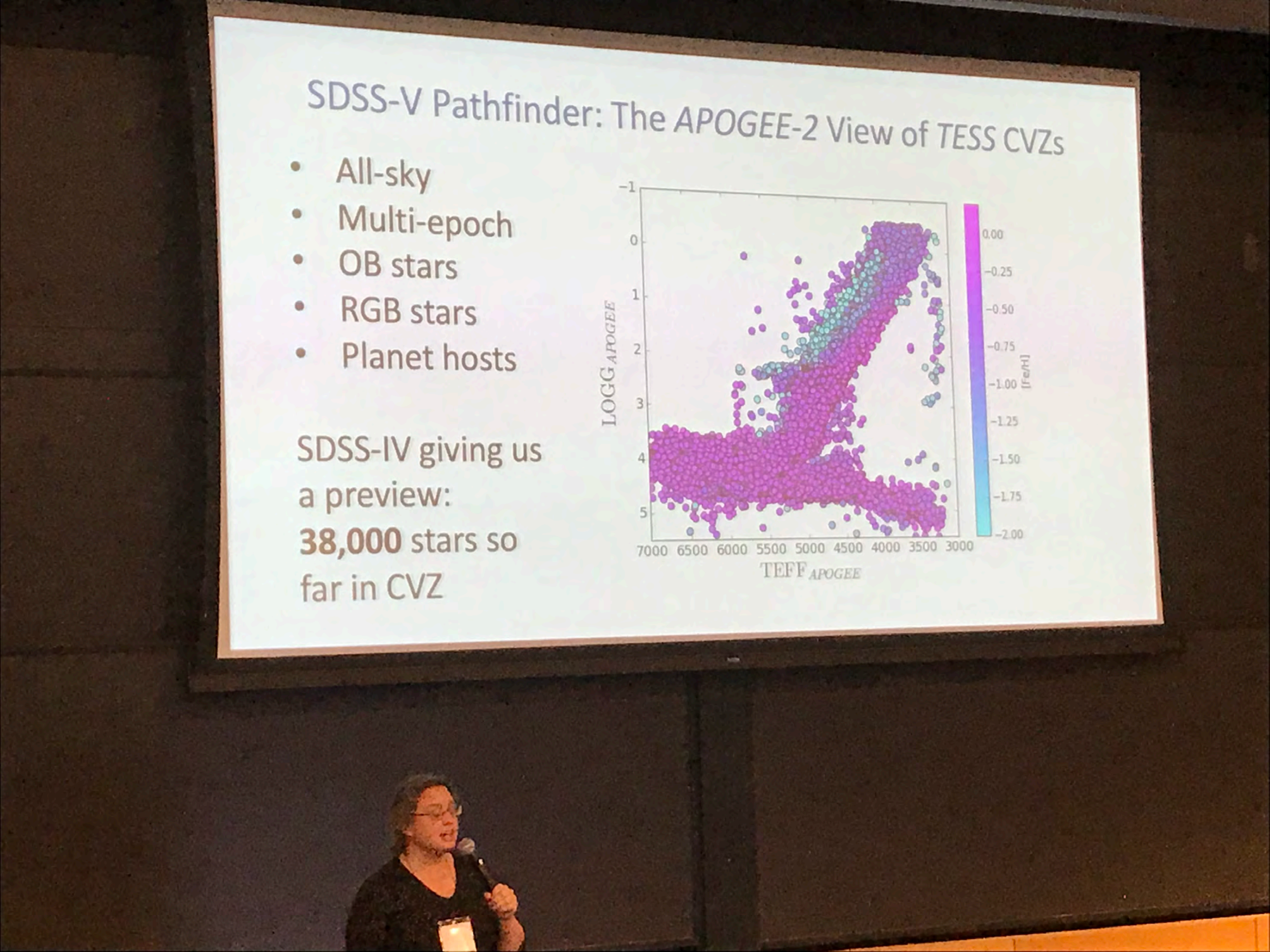
Kurtz et al. (2015)

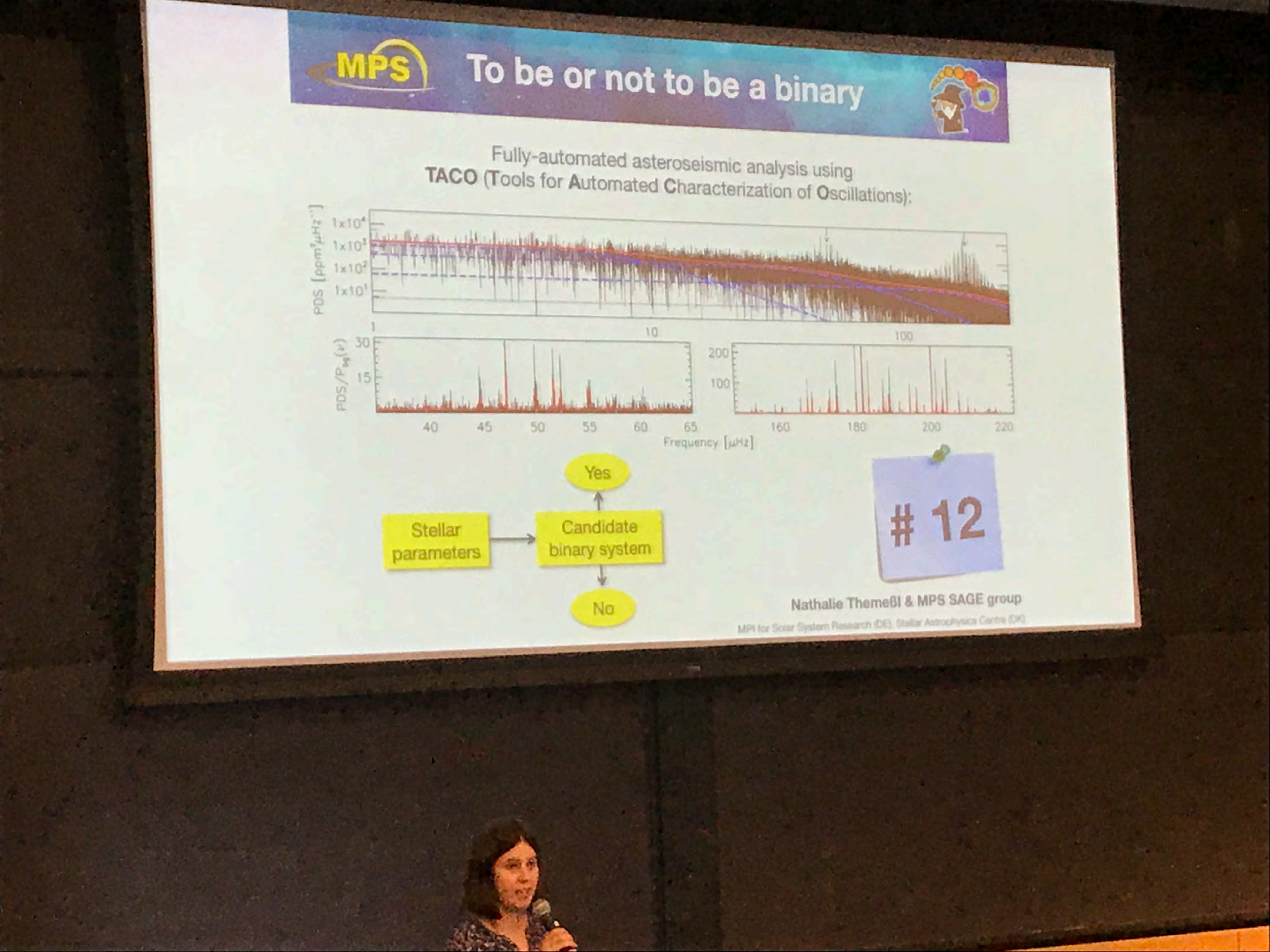


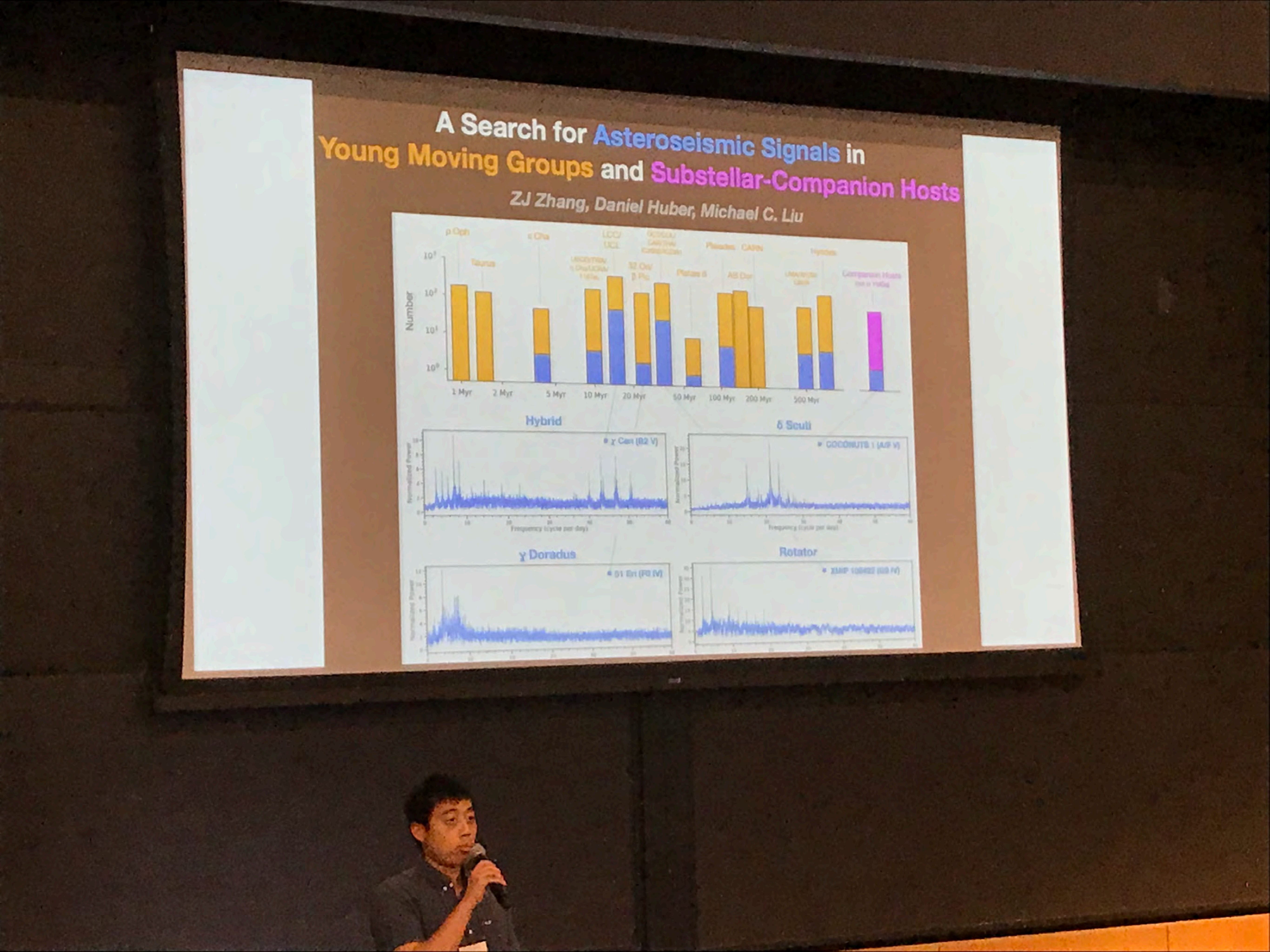
Stello et al. (2016)

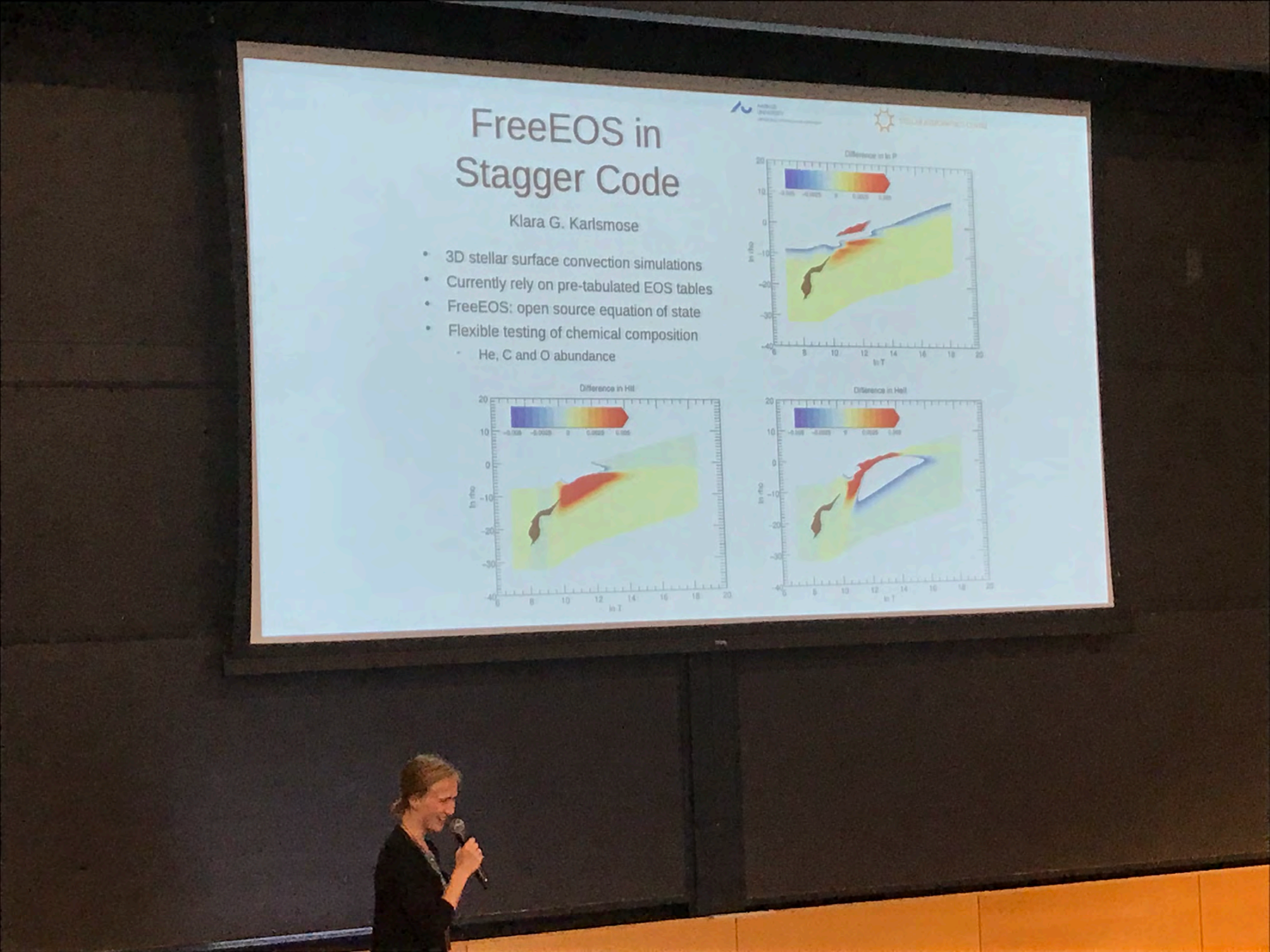
And lots of posters I could not discuss…




SDSS-V Pathfinder: The APOGEE-2 View of TESS CVZs
All-sky
Multi-epoch
OB stars
RGB stars
Planet hosts
SDSS-IV giving us a preview: 38,000 stars so far in CVZ
LOGG APOGEE
TEFF APOGEE
7000 6500 6000 5500 5000 4500 4000 3500 3000
−1 0 1 2 3 4 5
[Fe/H]
0.00 −0.25 −0.50 −0.75 −1.00 −1.25 −1.50 −1.75 −2.00


MPS
To be or not to be a binary
Fully-automated asteroseismic analysis using
TACO (Tools for Automated Characterization of Oscillations):
PDS [ppm²/μHz⁻¹]
1x10⁴
1x10³
1x10²
1x10¹
1
10
100
PDS/P_bg(ν)
30
15
40
45
50
55
60
65
200
100
160
180
200
220
Frequency [μHz]
Yes
Stellar parameters
Candidate binary system
No
12
Nathalie Themeßl & MPS SAGE group
MPI for Solar System Research (DE), Stellar Astrophysics Centre (DK)


A Search for Asteroseismic Signals in
Young Moving Groups and Substellar-Companion Hosts
ZJ Zhang, Daniel Huber, Michael C. Liu
Number
1 Myr
2 Myr
5 Myr
10 Myr
20 Myr
50 Myr
100 Myr
200 Myr
500 Myr
Taurus
LCC/
UCL
AB Dor
CARN
Hybrid
δ Scuti
γ Doradus
Rotator


FreeEOS in
Stagger Code
Klara G. Karlsmose
3D stellar surface convection simulations
Currently rely on pre-tabulated EOS tables
FreeEOS: open source equation of state
Flexible testing of chemical composition
He, C and O abundance

Handing over to my friends

13-17 July 2020
@Leuven, B