ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

Advanced stellar evolution and asteroseismology

Andrea Miglio

Dipartimento di Fisica e Astronomia

“The internal constitution of stars” (Eddington, 1926)

“At first sight it would seem that the deep interior of the Sun and stars is less accessible to scientific investigation than any other region of the universe. Our telescopes may probe farther and farther into the depths of space; but how can we ever obtain certain knowledge of that which is hidden behind substantial barriers? What appliance can pierce through the outer layers of a star and test the conditions within ?”

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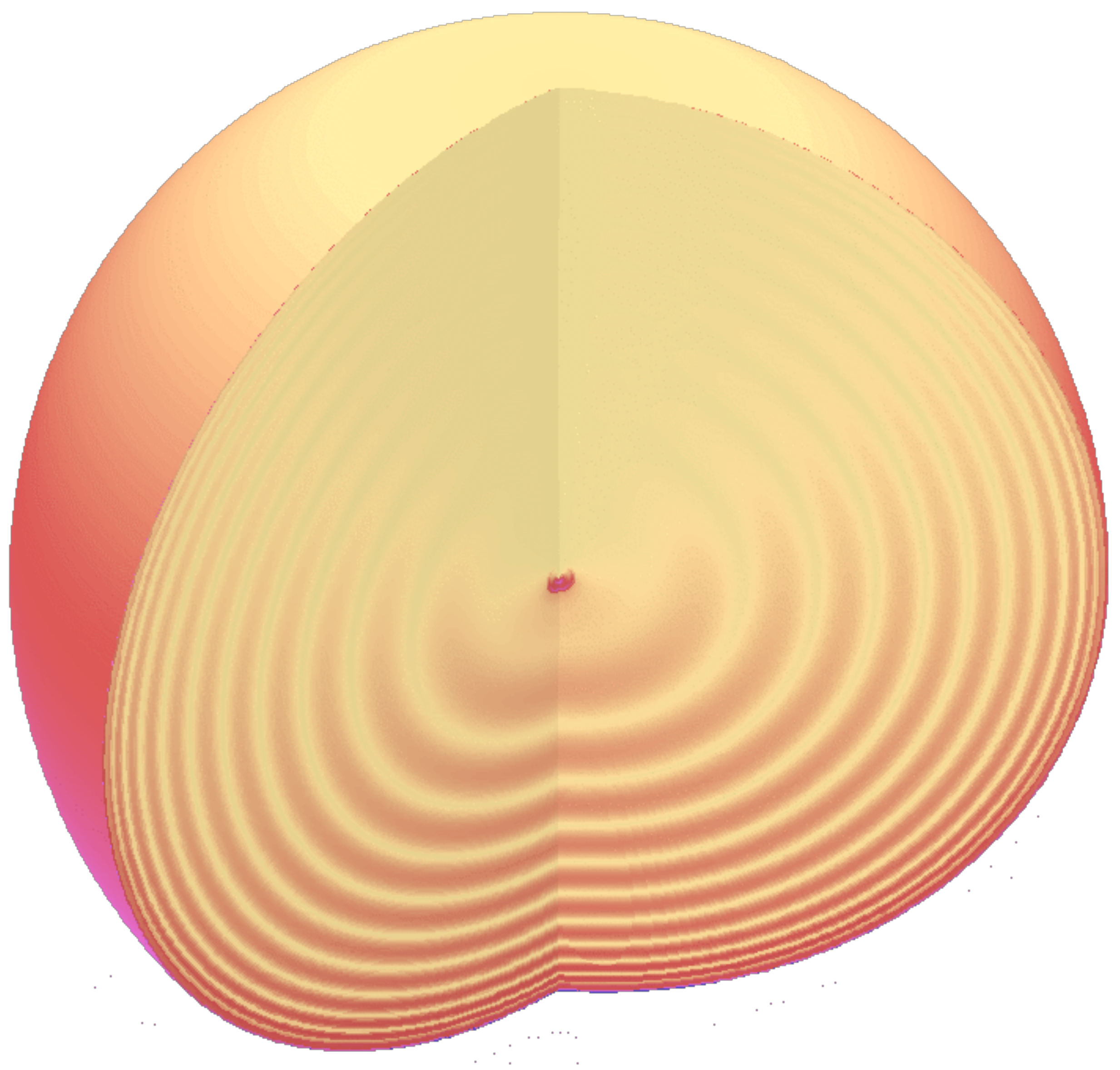

Asteroseismology and the "space photometry revolution"

field revolutionised by the advent of space-based telescopes

past/current: *CoRoT, Kepler /K2, TESS*

future: *PLATO*

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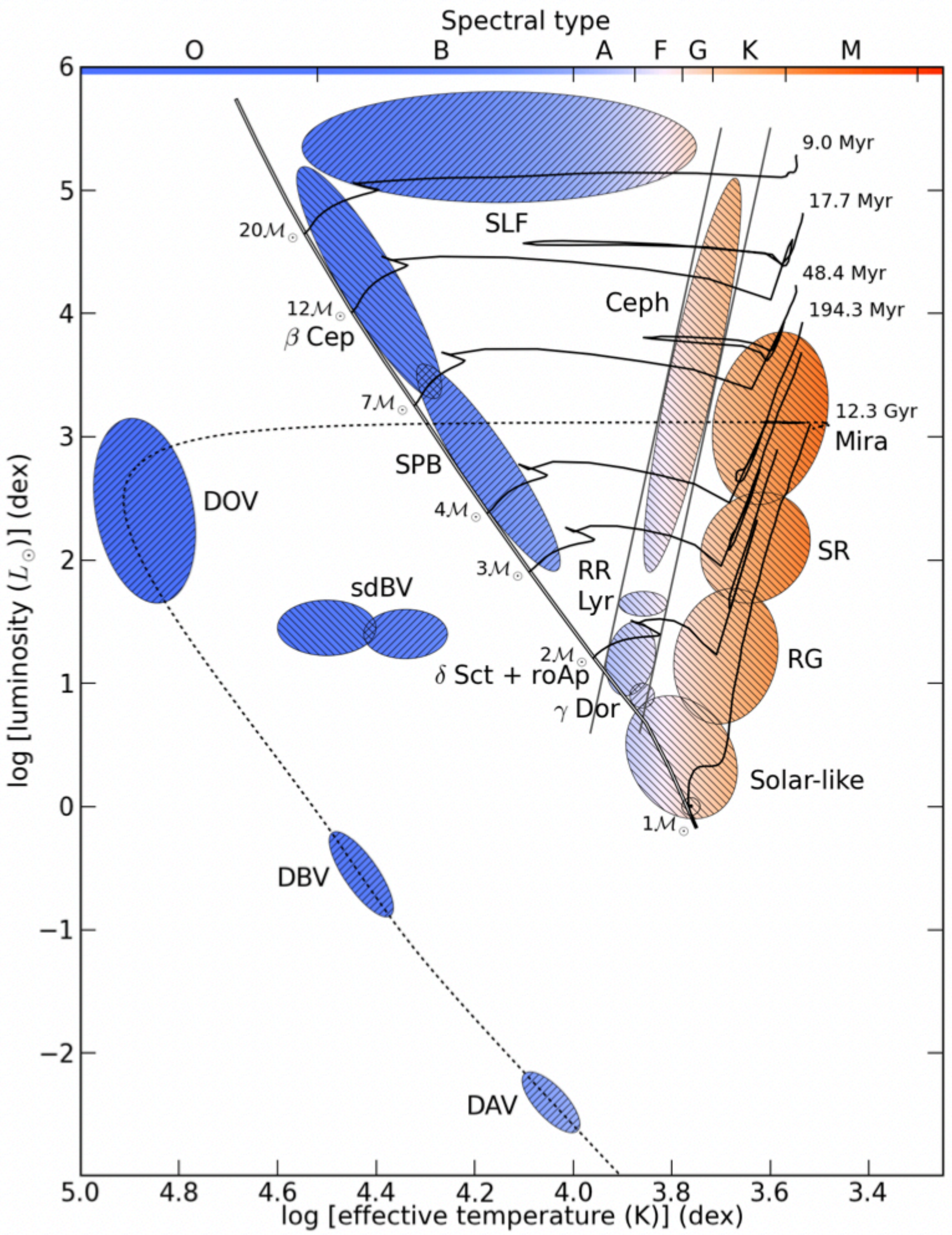
- photometric precision ⇨ micro-mag level changes
- frequency resolution ⇨ resolve subtle patterns in the frequencies e.g. rotational splittings, gravity modes
- number of stars with detected pulsation modes ⇨ ensemble asteroseismology

The zoo of pulsating stars

- variety of physical structures
  - mass
  - evolutionary state
  - physical processes at play

- variety of pulsation modes
  - pressure modes
  - gravity modes
  - mixed modes



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Theoretical underpinnings

- brief recall of the equations describing stellar structure
- method of small perturbations and equations of non-radial adiabatic stellar oscillations
- propagation diagrams and nature of normal modes in stars: acoustic, gravity and mixed modes
- asymptotic approximation of pressure and gravity modes
- analytical description of mixed modes
- variational principle of non-radial adiabatic stellar oscillations, analogies with simple physical systems
- effect of rotation on the oscillation frequencies
- mode excitation and damping
- case study: evolution of the surface properties, internal structure, and seismic properties of a 1-solar-mass star, from the main sequence to the white-dwarf stage

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analytical approximations to interpret numerical calculations and relate properties of pulsation spectra to features in the stellar interiors

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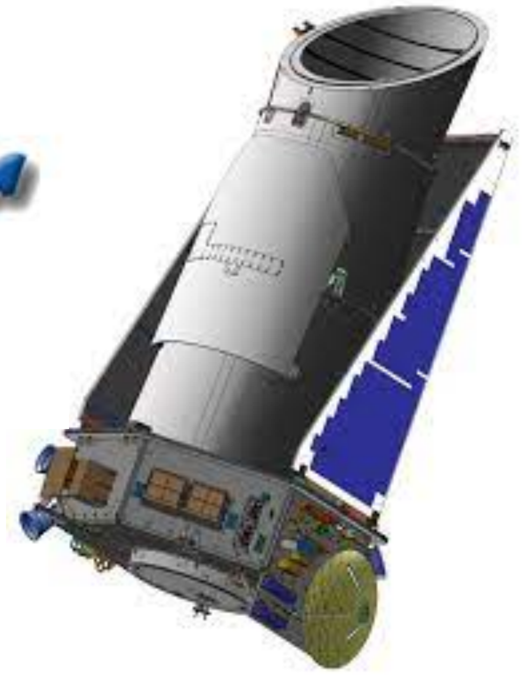
Analysis of asteroseismic data

- elements of time-series analysis
- heat-driven versus stochastically excited modes
- global properties of the oscillation spectrum
- measuring individual-mode frequencies



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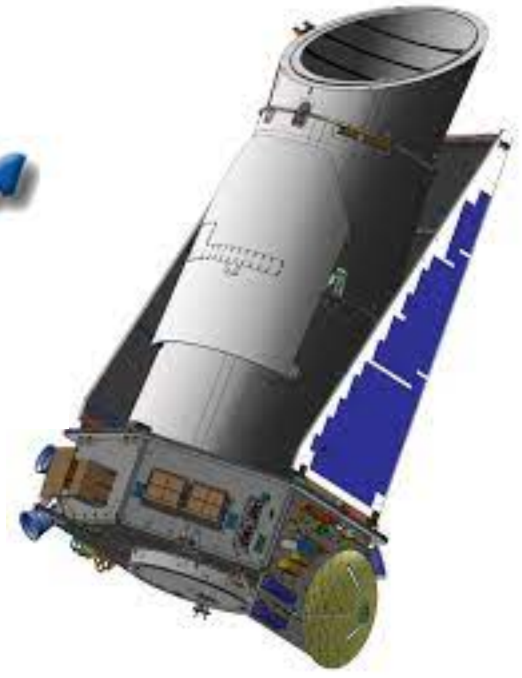
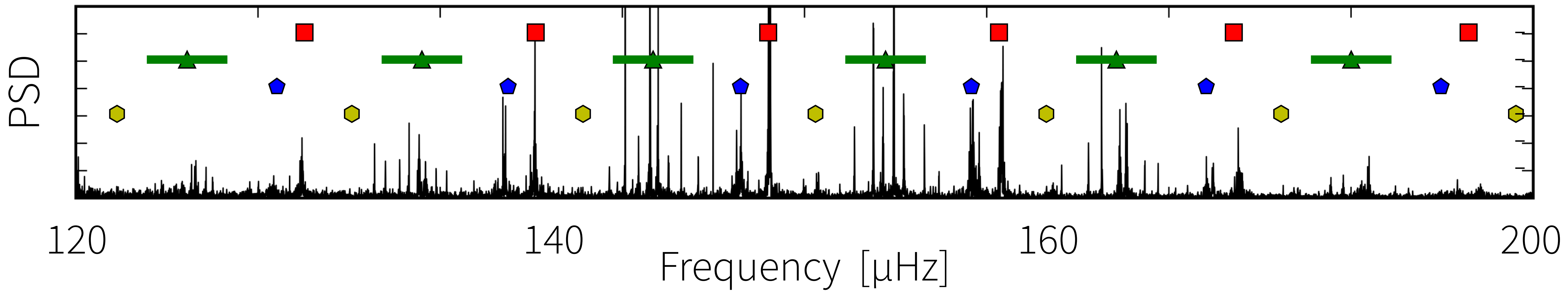
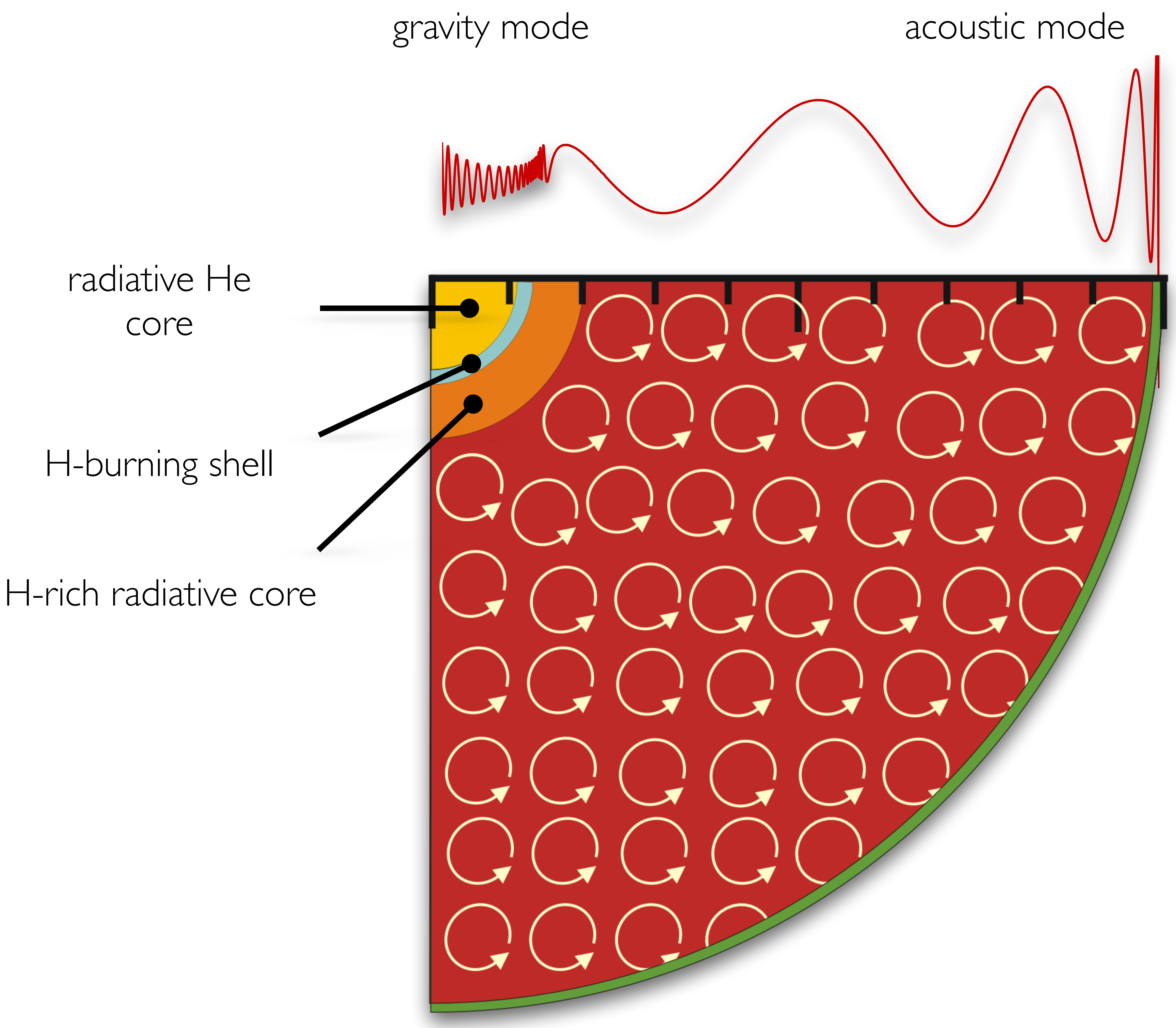




Asteroseismic inference



frequencies of global, resonant pulsation modes

Asteroseismic inference

A. testing stellar physics

examples:

- transport of angular momentum during the evolution
- convective boundary mixing, diffusion
- magnetic fields in the deep stellar interiors
- microphysics e.g. radiative opacity, EoS, nuclear reaction rates

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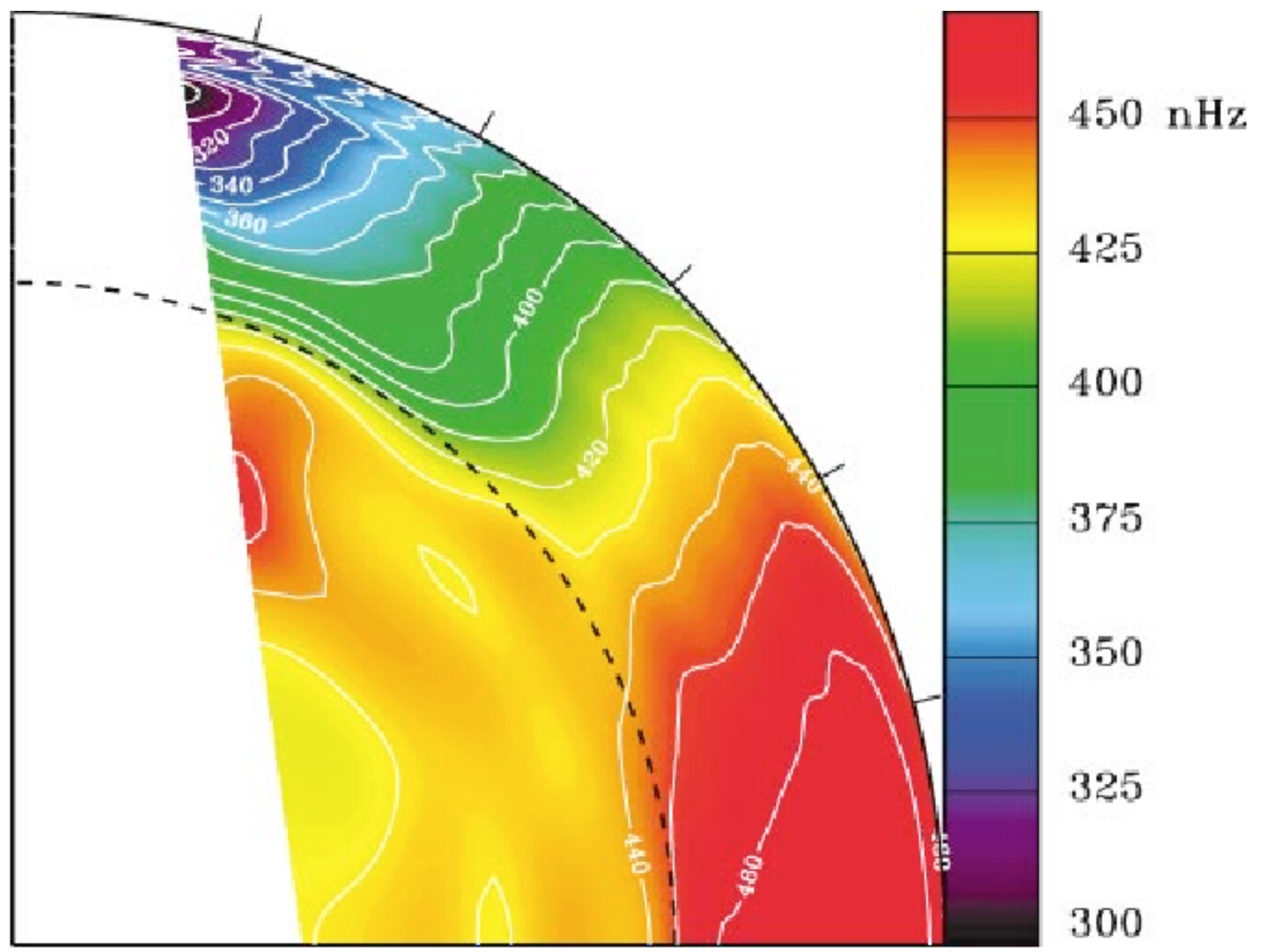


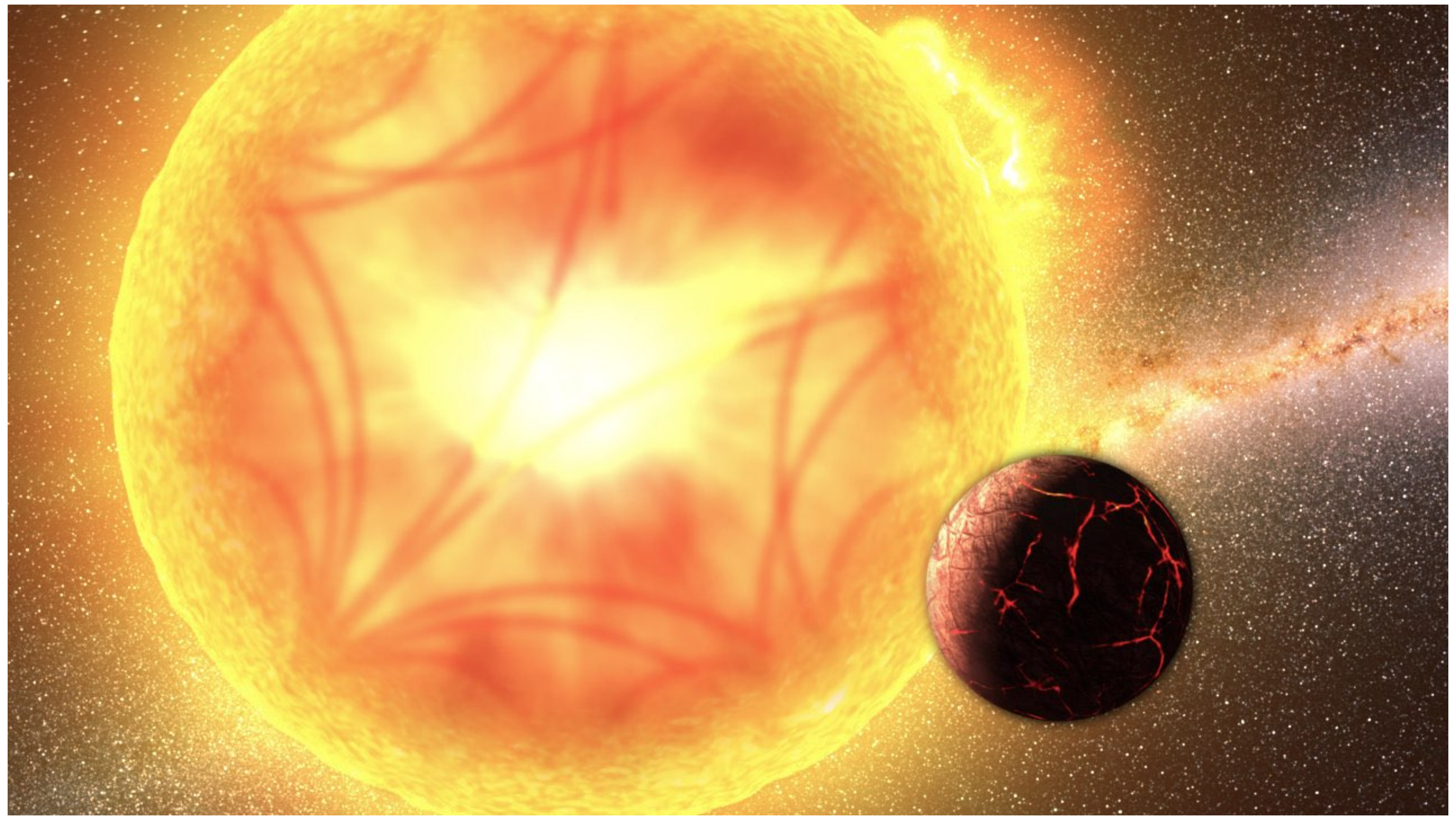
Thompson et al. 1998

Asteroseismic inference

B. precise, accurate stellar properties

(e.g. radius, mass, age, inclination angles)

characterise exoplanetary systems



plato

M3 mission of ESA's
Cosmic Vision

Asteroseismic inference

C. precise, accurate stellar properties

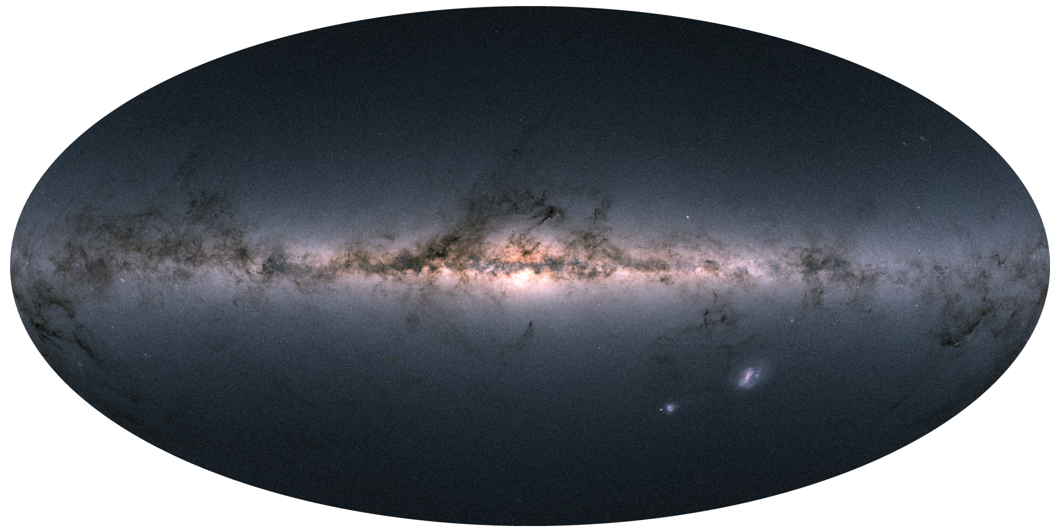
(e.g. radius, mass, age)

use stars as fossils to reconstruct the assembly and chemo-dynamical history of the Galaxy

Gaia astrometry

spectroscopy

asteroseimology



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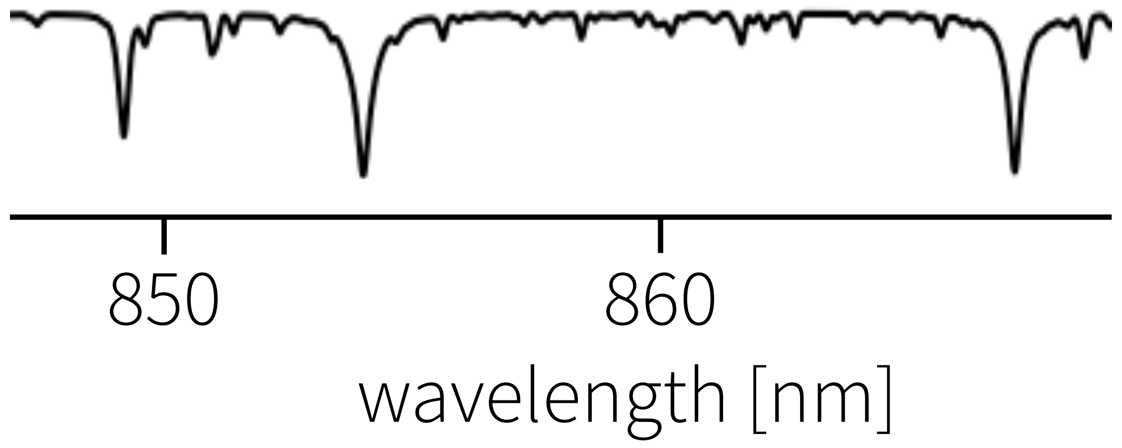

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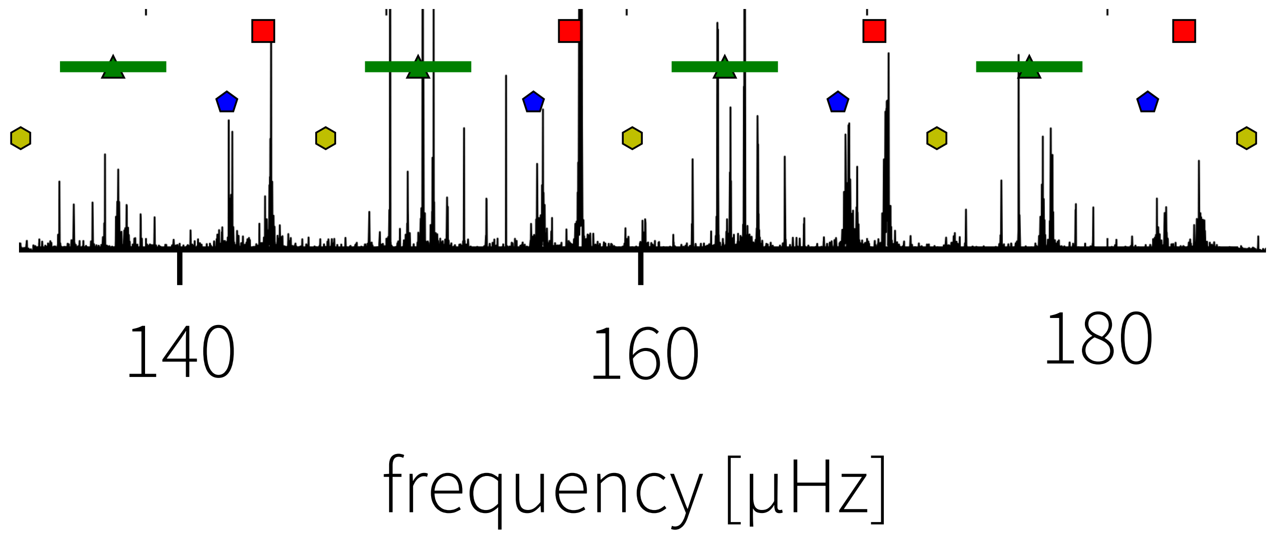

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How the module is delivered:

- Lectures, using a combination of slides and derivations on the board

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- 1 hour/week student-centred learning activities:
  "hands on" exercises and computer-based examples

  see e.g. GitHub https://github.com/amiglio/asteroseismology-unibo

  - compute and interpret evolution of stellar structures and pulsation spectra
  - data analysis and exploration of *Kepler* and TESS data

  review and discuss (recent) papers

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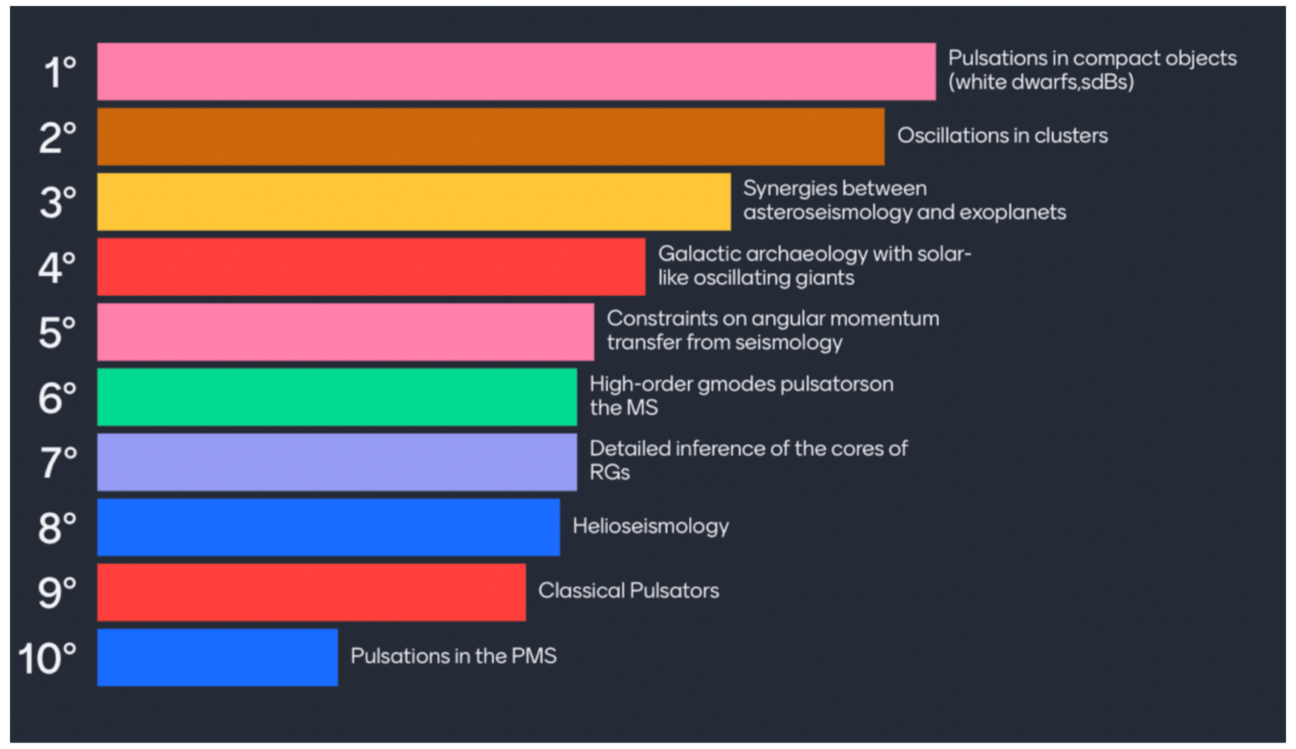
- last month: investigate in more depth topics of specific interest for students (within reason)



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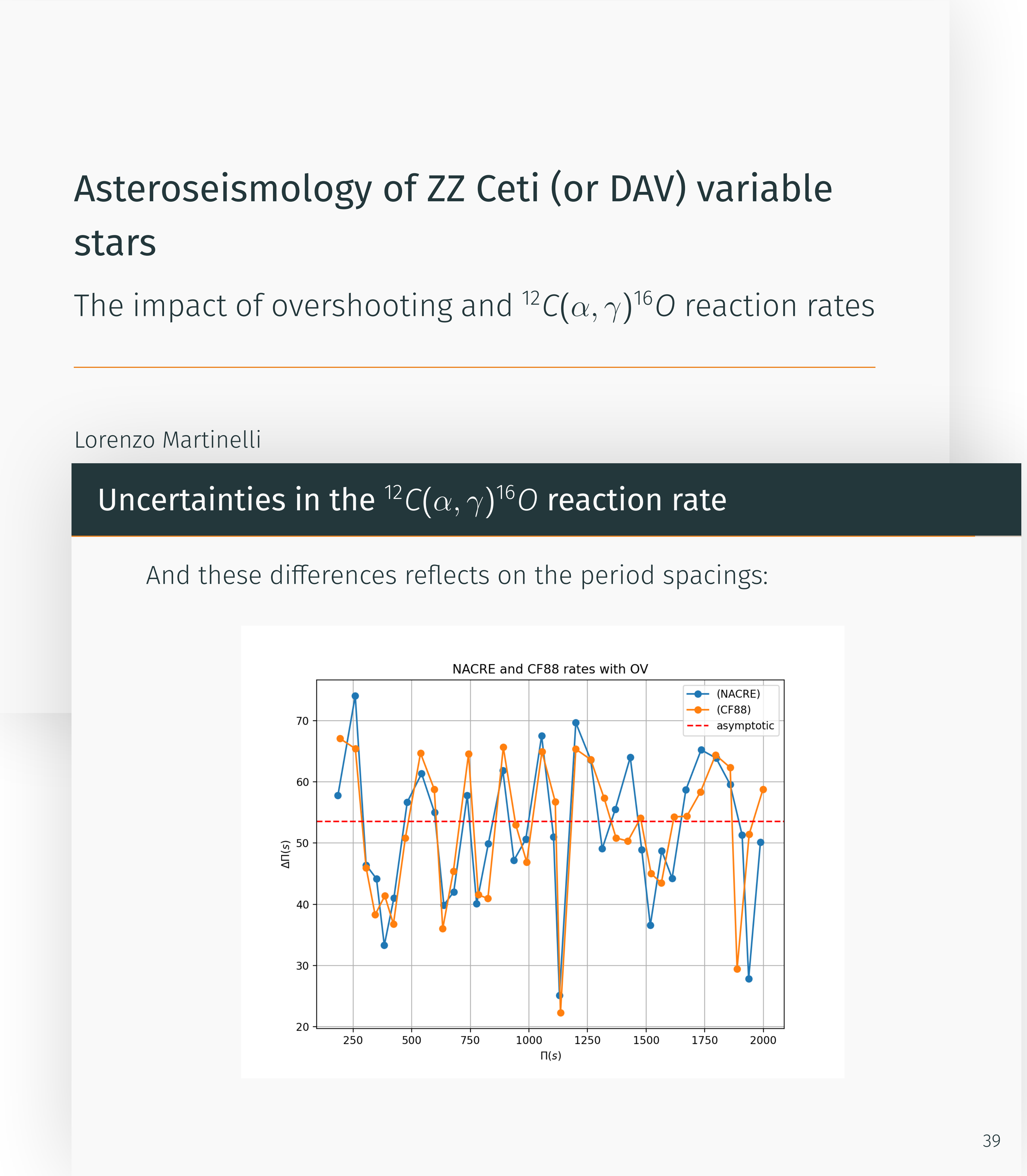

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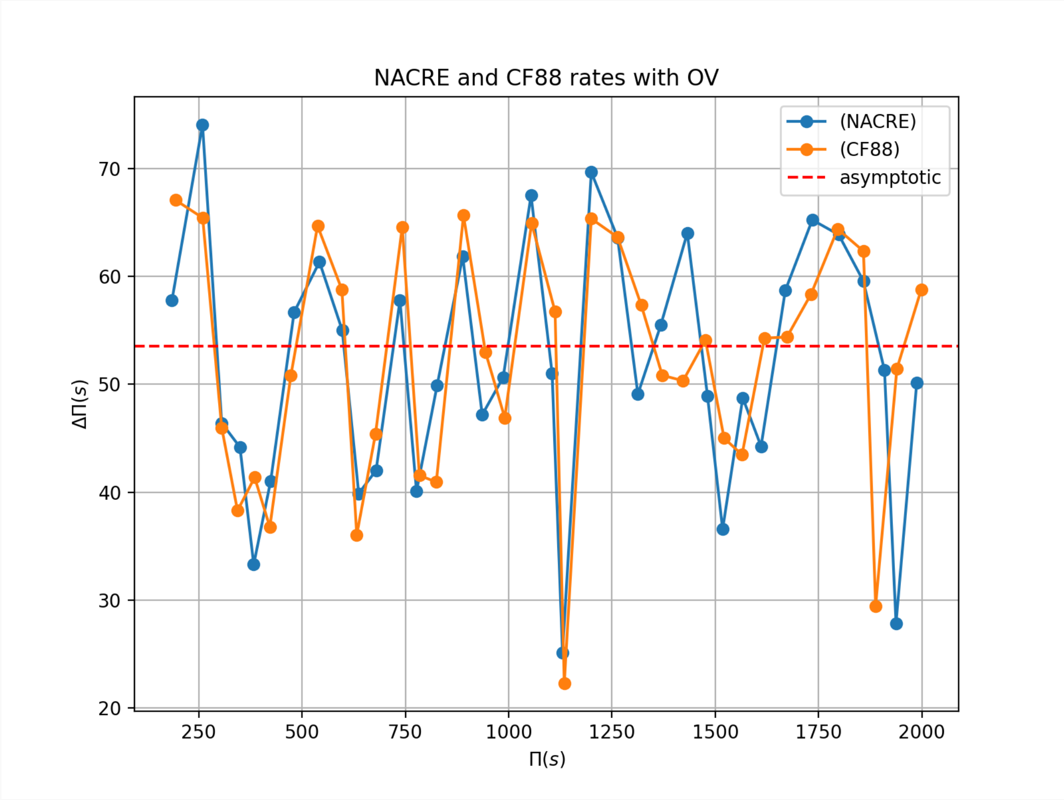
Asteroseismology of ZZ Ceti (or DAV) variable stars

The impact of overshooting and $^{12}C(\alpha,\gamma)^{16}O$ reaction rates

Lorenzo Martinelli

Uncertainties in the $^{12}C(\alpha,\gamma)^{16}O$ reaction rate

And these differences reflects on the period spacings:



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SYNERGIES BETWEEN ASTEROSEISMOLOGY AND EXOPLANETS APPLIED ON MS STARS

Course of: ADVANCED STELLAR PHYSICS AND ASTEROSEISMOLOGY

Speaker: Jenny Frediani

PLANET EQUILIBRIUM TEMPERATURE

$$T_{EQ} = T_{EFF}\left(\frac{(1-\alpha)R_*^2}{4\beta a^2}\right)^{1/4}$$

star effective temperature

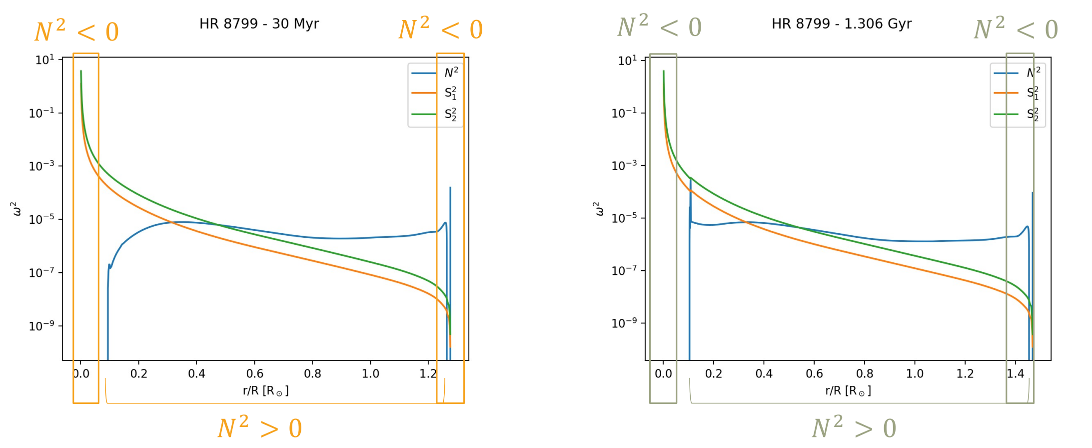
planet Bond albedo

radius of the star

planet semimajor axis

fraction of the surface of the planet that reradiates the absorbed flux

20



EIGENFREQUENCIES

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