Probing, weighing and dating stars with the PLATO mission

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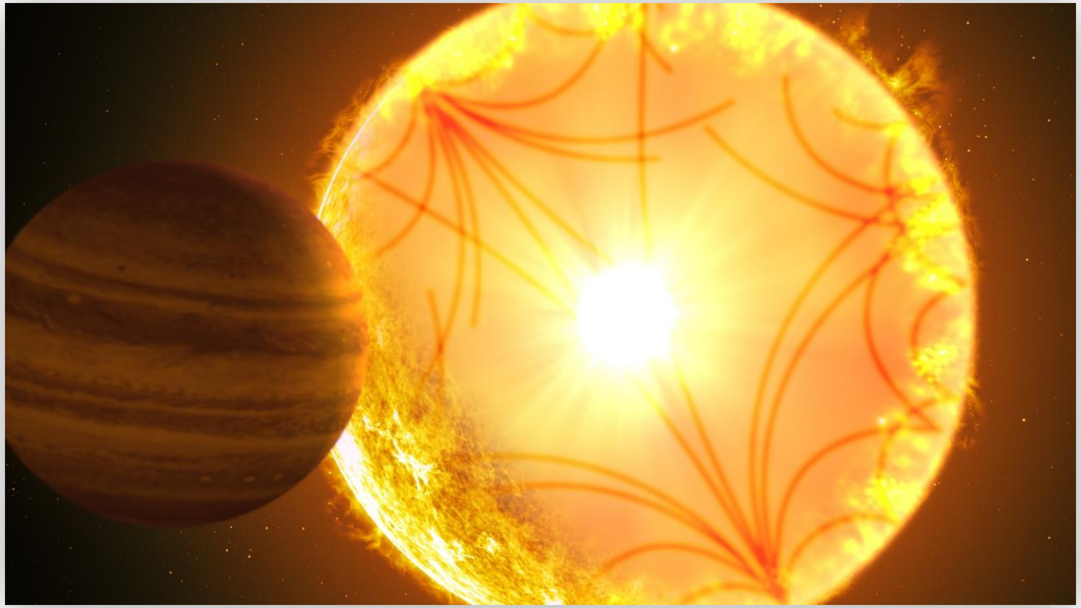
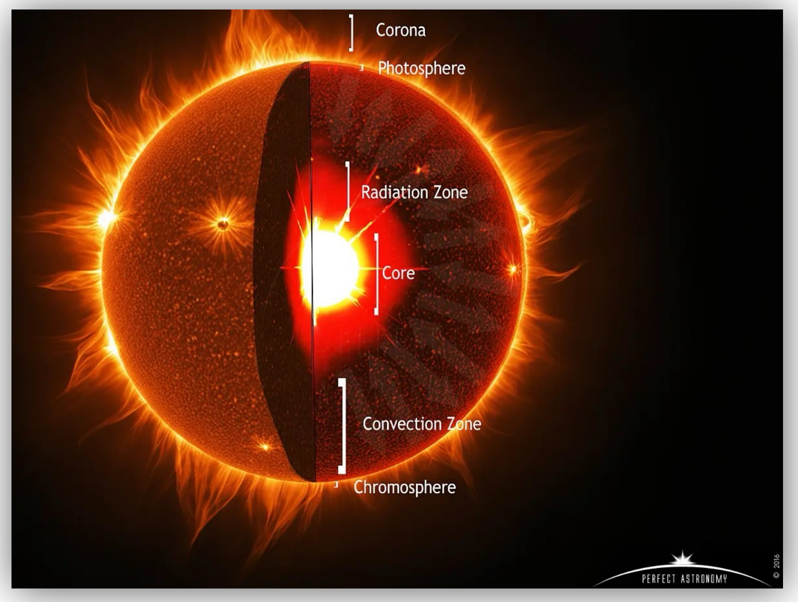
PLATO main objectives in stellar physics

Stellar characterisation

Precise and accurate determination of radius, mass and age of planet-hosting stars

For a Sun-like star at magnitude V = 10, we will obtain…
… ages better than 10% accuracy
… radii up better than 2% accuracy
… masses better than 15% accuracy



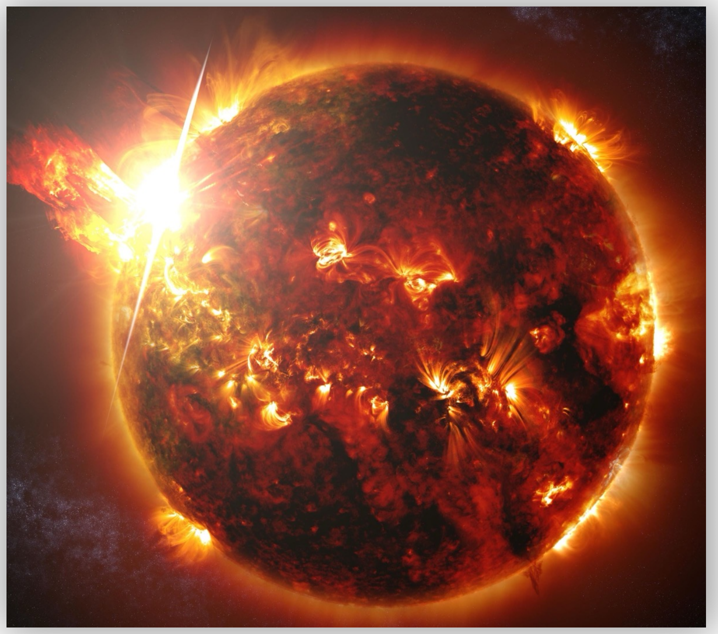


Internal structure and evolution of stars

Asteroseismology to constrain stellar evolution models and probe stellar interiors

Inferring stellar internal dynamics (in particular rotation and angular momentum redistribution)

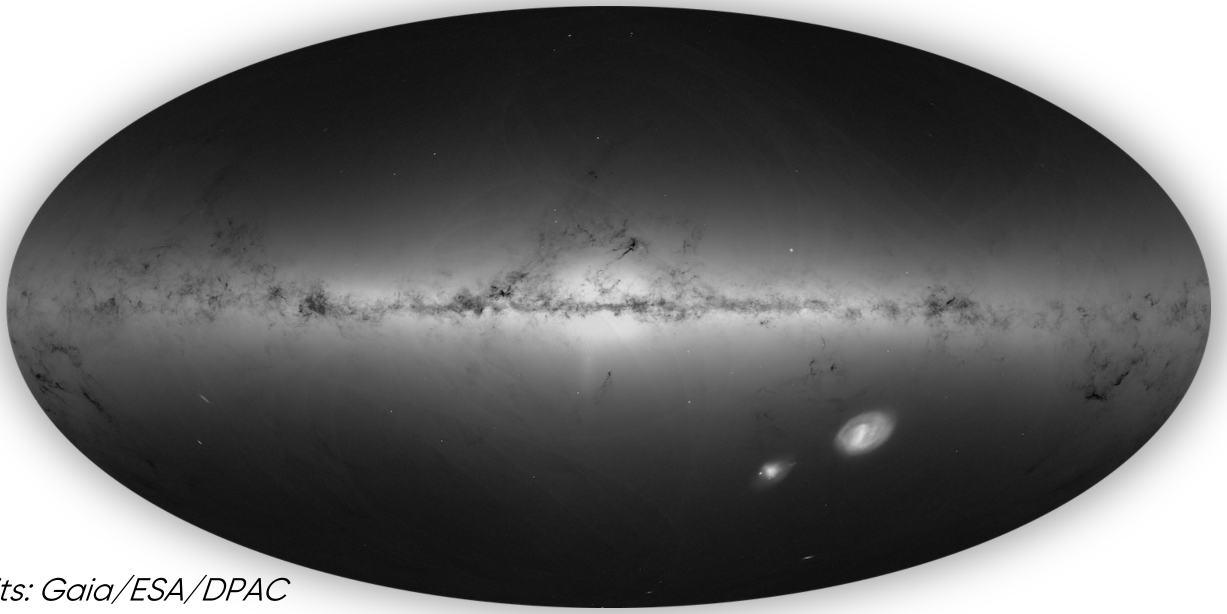
PLATO main objectives in stellar physics



Stellar activity and surface rotation

Measuring surface rotation and monitoring photometric activity for tens of thousands of stars

Investigating rotation – activity relations will help constrain theories on stellar dynamo



Credits: Gaia/ESA/DPAC

Complementary science program

Galactic populations

Massive stars seismology

Binary stars

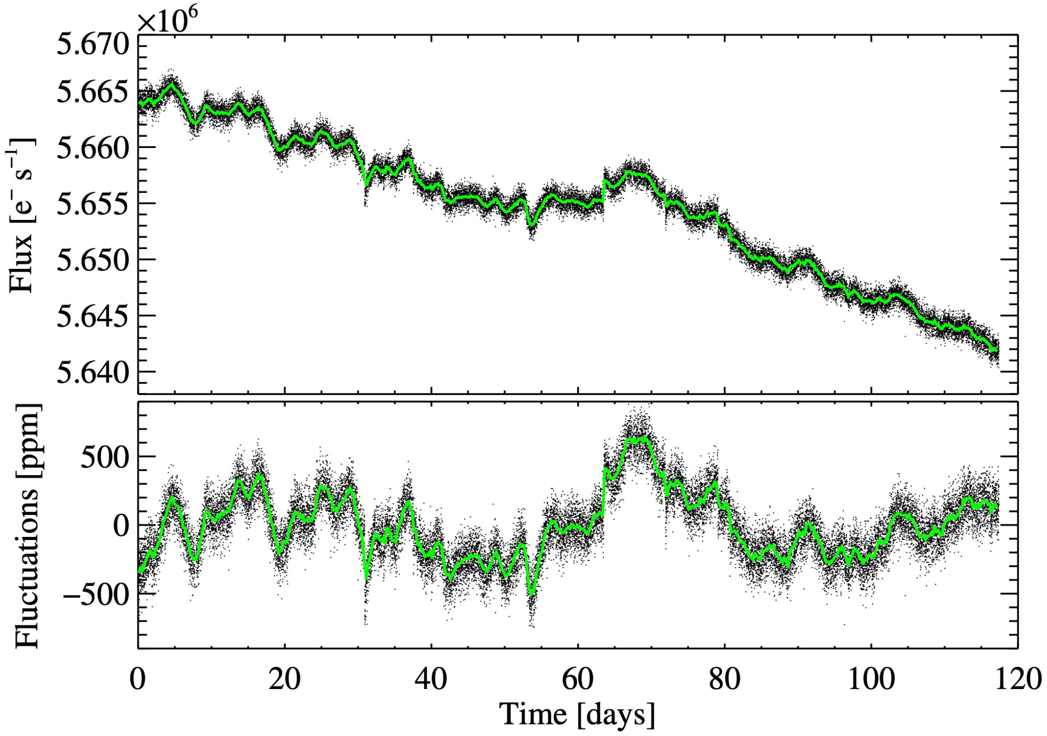
And more!

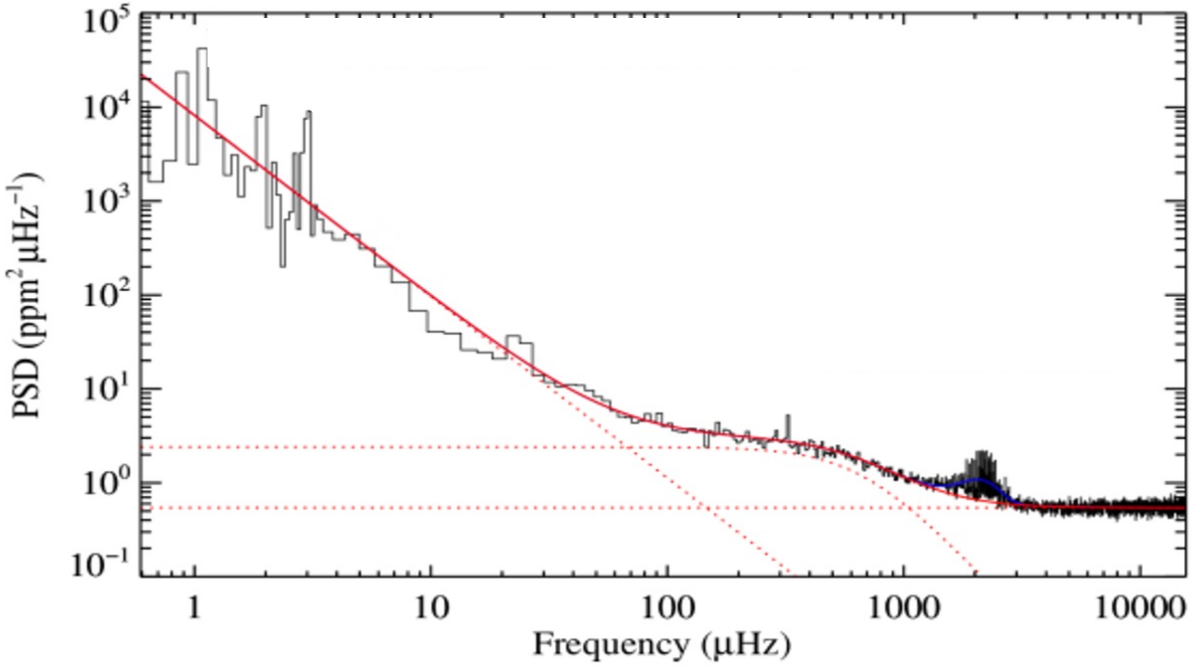
A wealth of information from lightcurves

Example

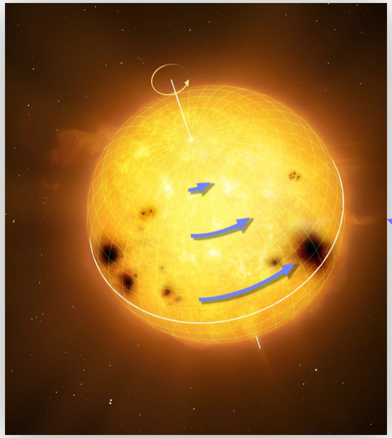
CoRoT target HD52265
Credits: Garcia and Ballot 2019

Fourier transform

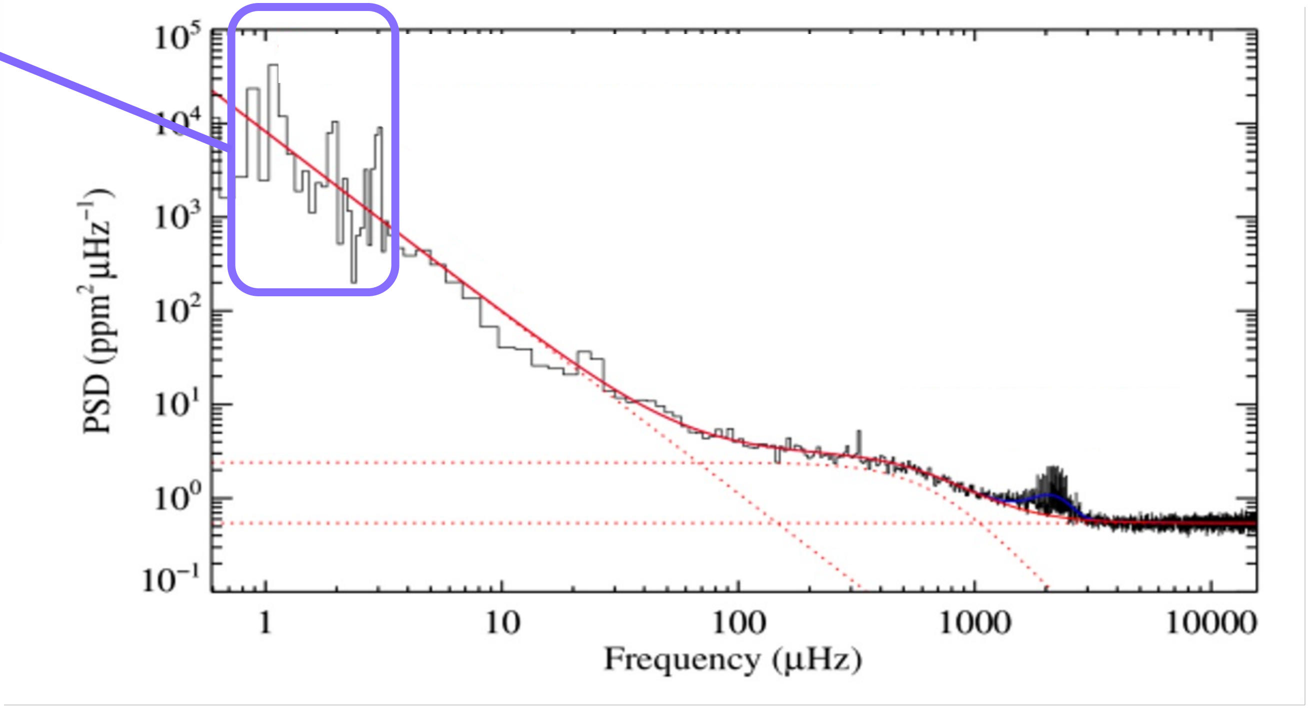




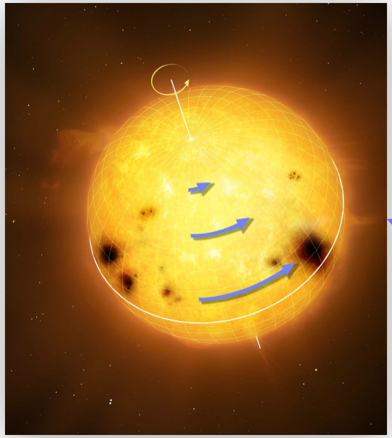
A wealth of information from lightcurves



Rotation

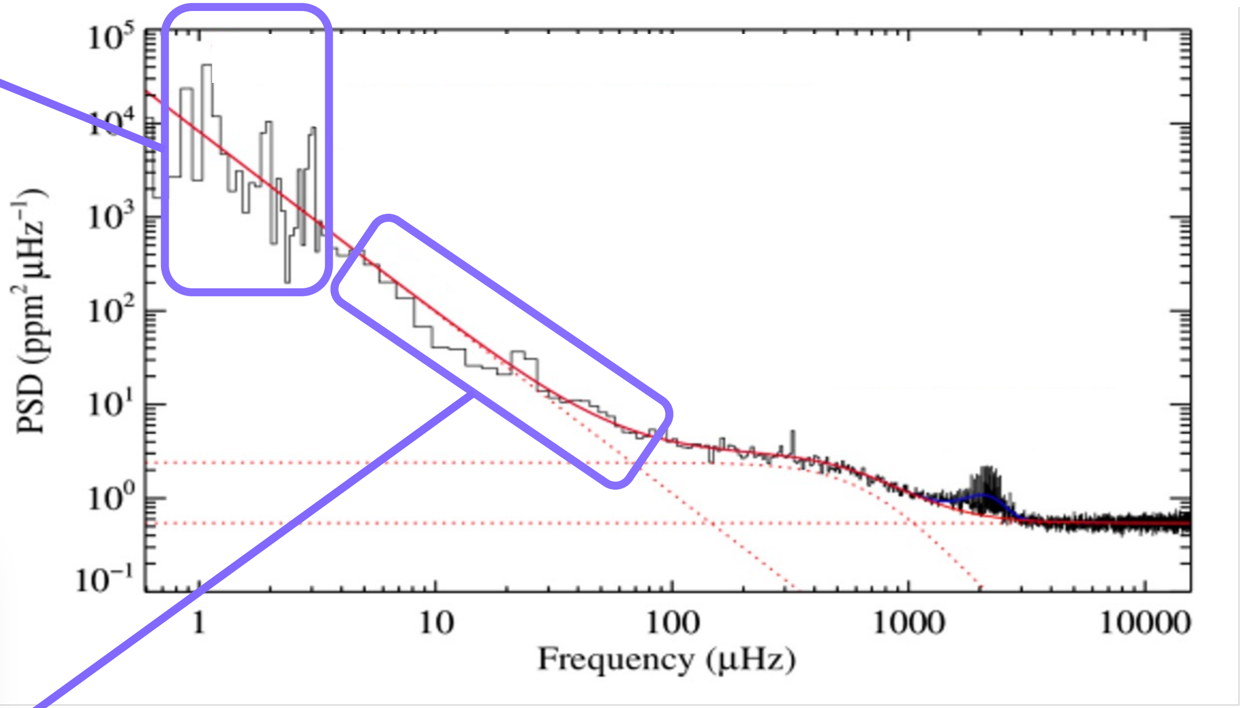


A wealth of information from lightcurves

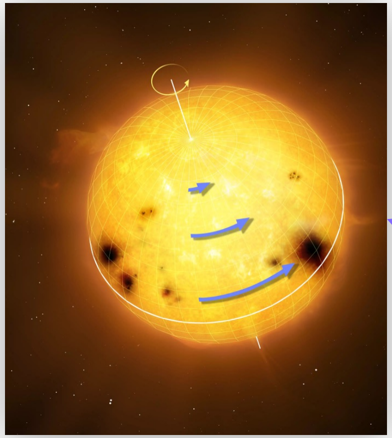


Surface Rotation

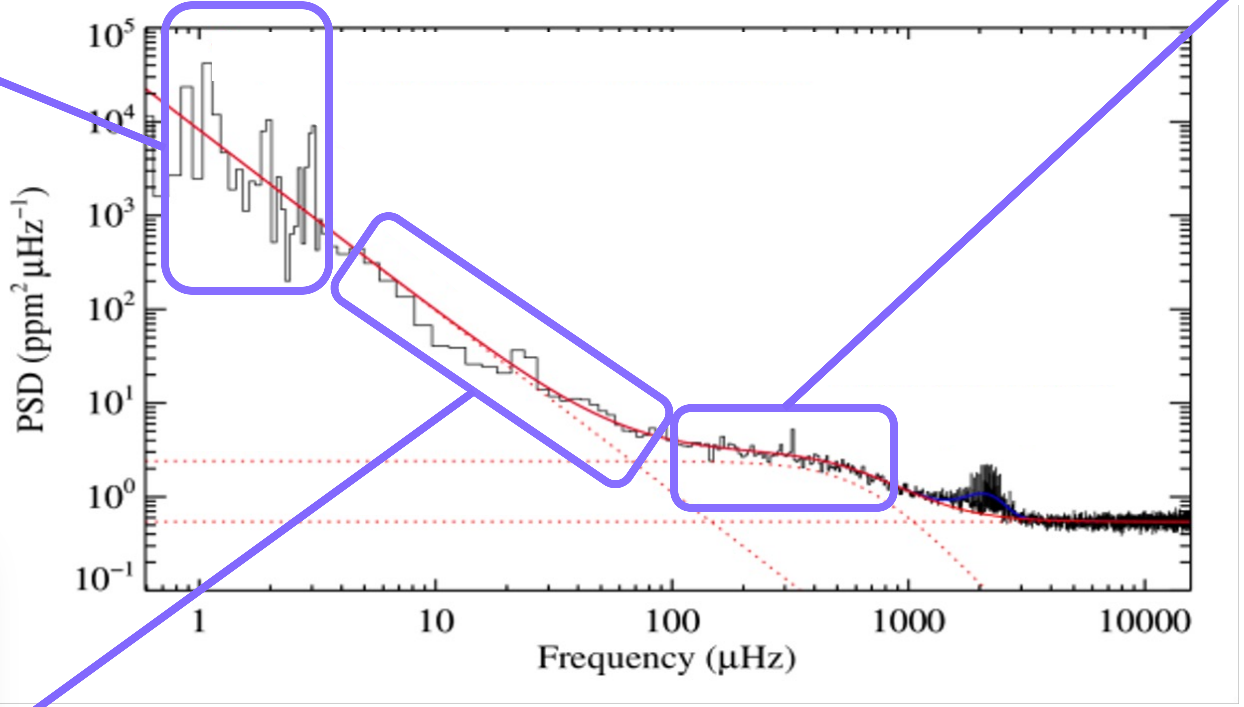
Activity

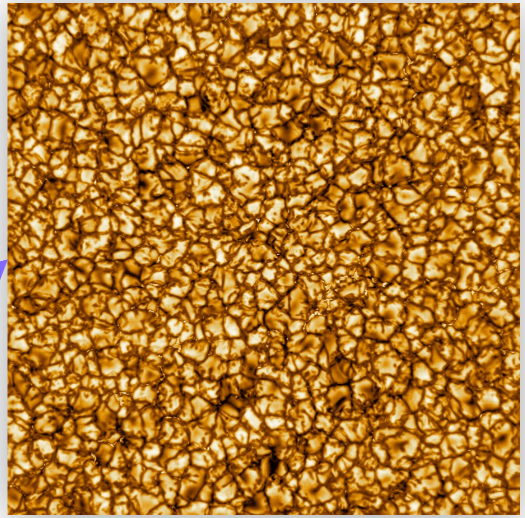


A wealth of information from lightcurves



Surface Rotation

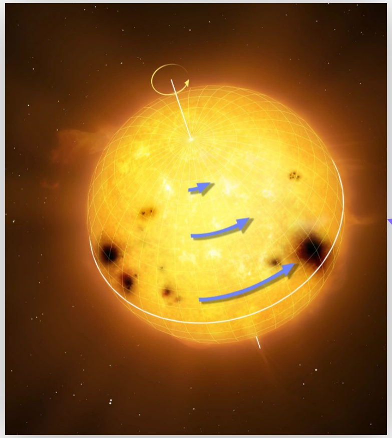




Granulation

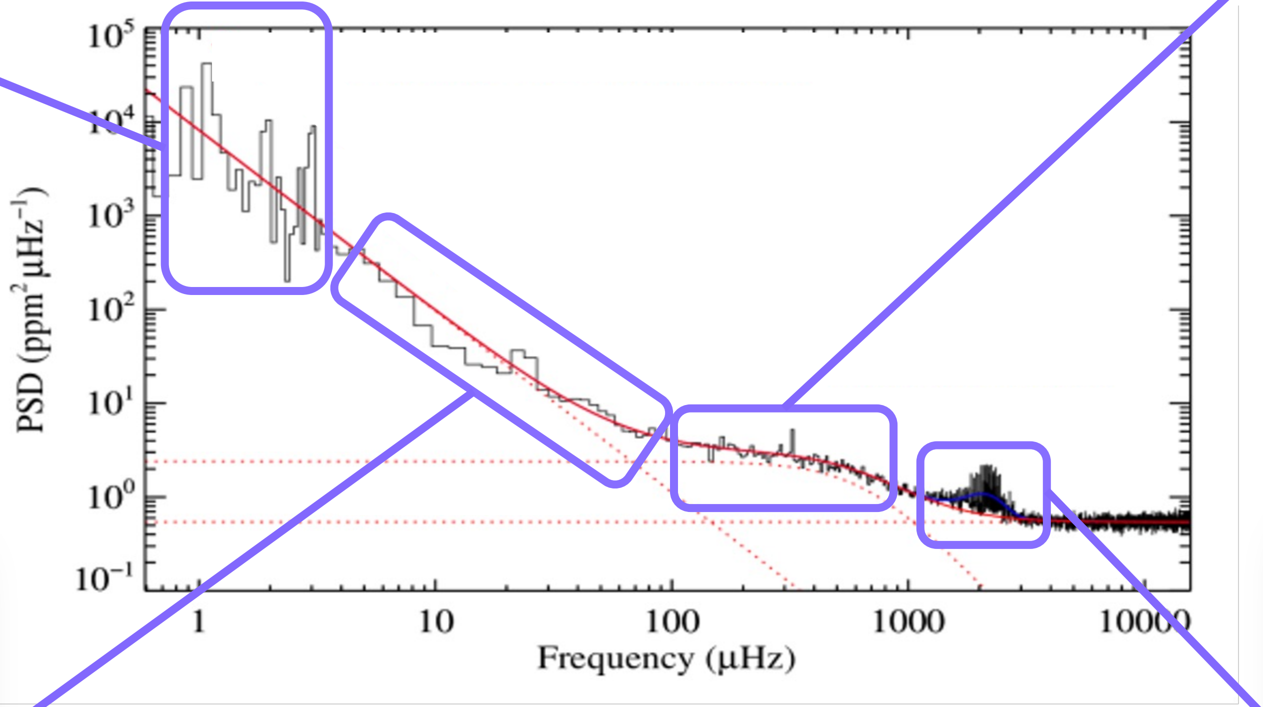
Activity

A wealth of information from lightcurves

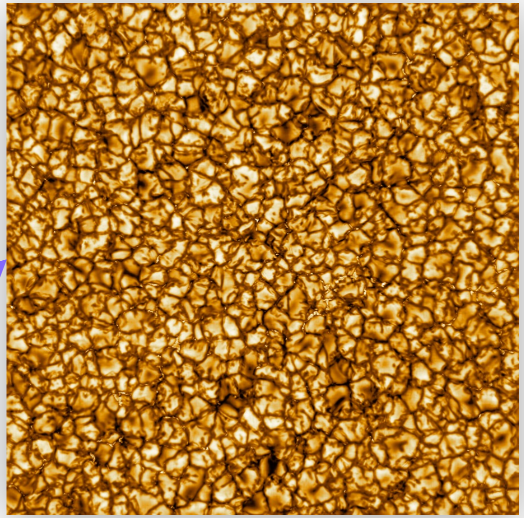


Surface Rotation

Activity

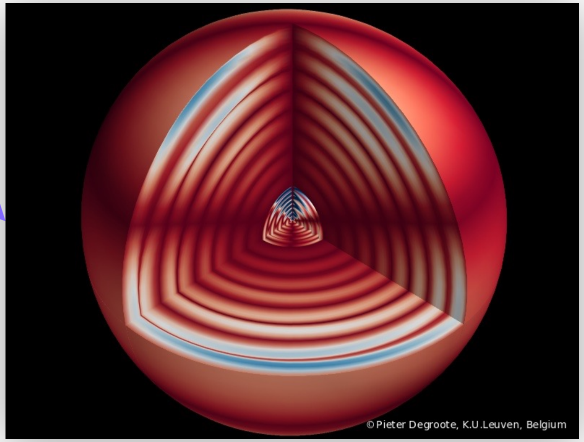


Credit: NSO/NSF/AURA



Granulation

Oscillations
→ asteroseismology



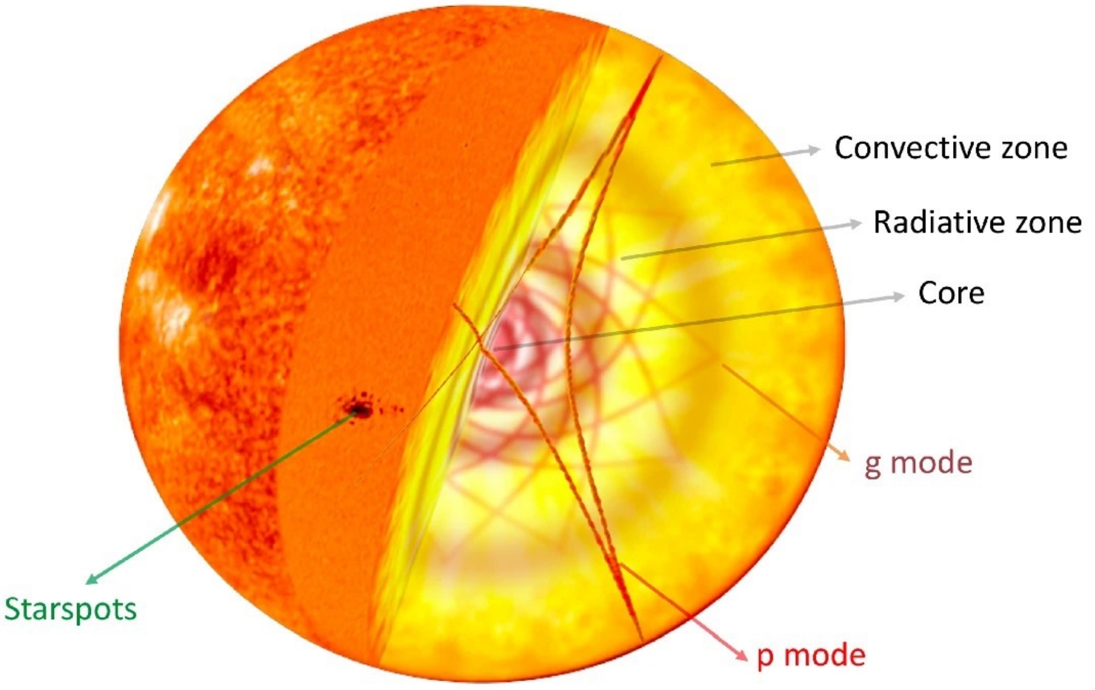
Asteroseismology in a nutshell

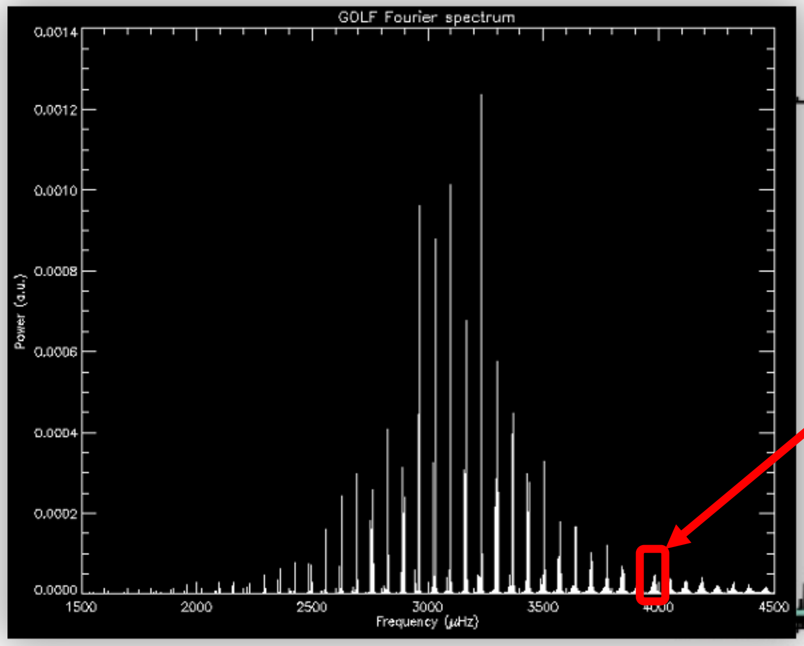
Solar-like oscillations...

Stars act as resonant cavities for acoustic waves → discrete spectrum

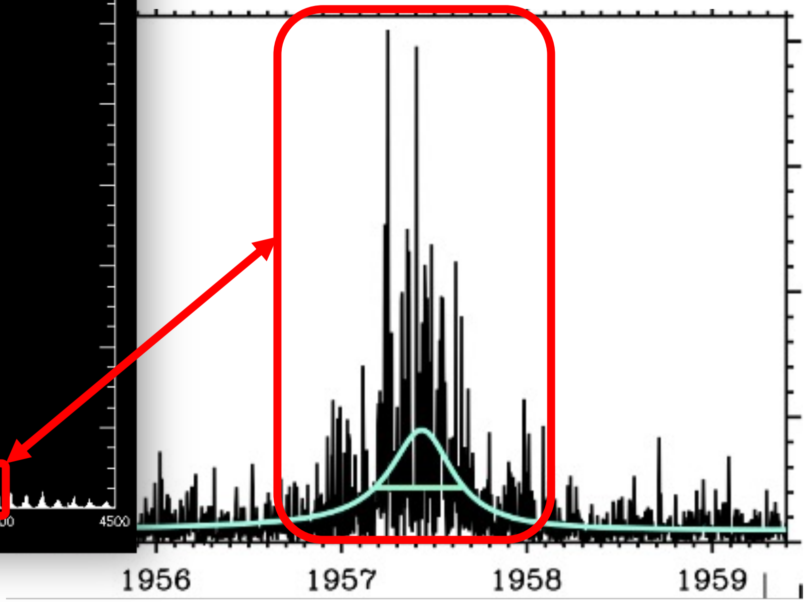
About 1 million modes detected in the Sun, around 20-30 for other targets

Garcia & Ballot 2019





Chaplin et al. 2005



... are hard to catch

Solar-like oscillations have small amplitudes (~ tens of cm/s, ~ ppm)

Stochastically excited and damped by turbulent convection → noisy profiles

Need long time series, need to go to space

Helioseismology: probing the Sun

Helioseismic observations

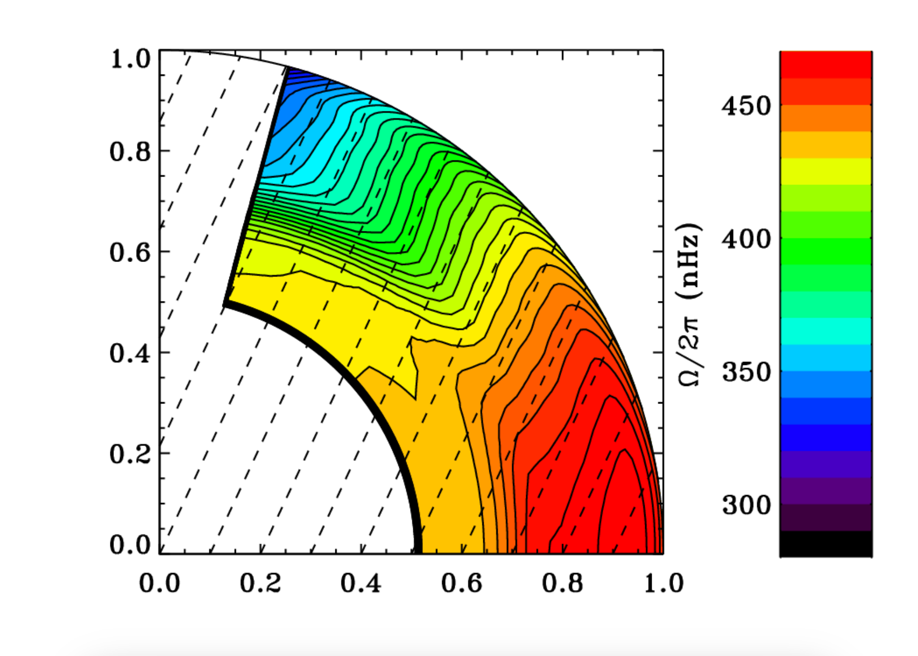
Observations from space (SoHO, SDO) and ground instruments (GONG, BiSON)

Now more than 20 years of continuous observations (both velocity and photometry)

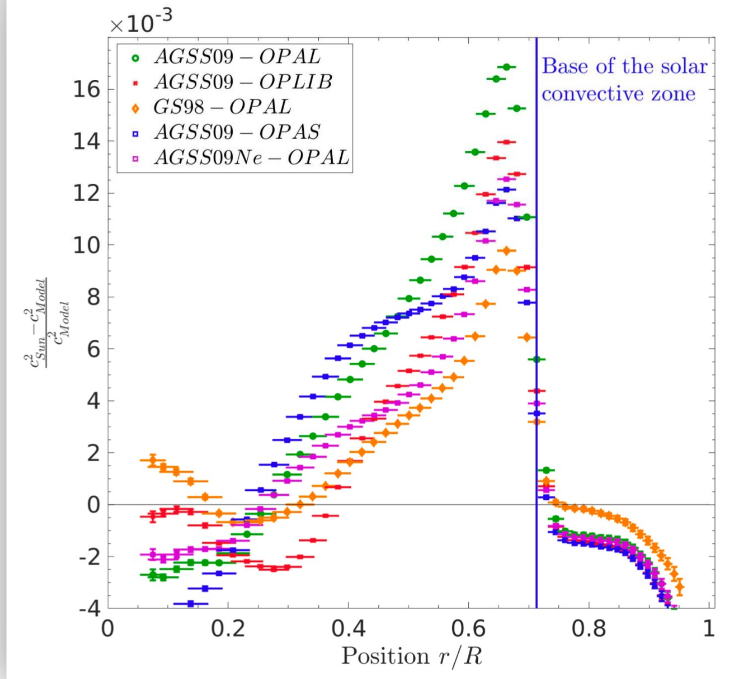
Mapping of subsurface flows using local travelling waves → local helioseismology

Using global resonant modes to probe the inner structure → global helioseismology

NSO/GONS, https://gong.nso.edu/



Buldgen et al. 2019



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Asteroseismology: beyond the Sun

1990
First detection of oscillations in star other than the Sun

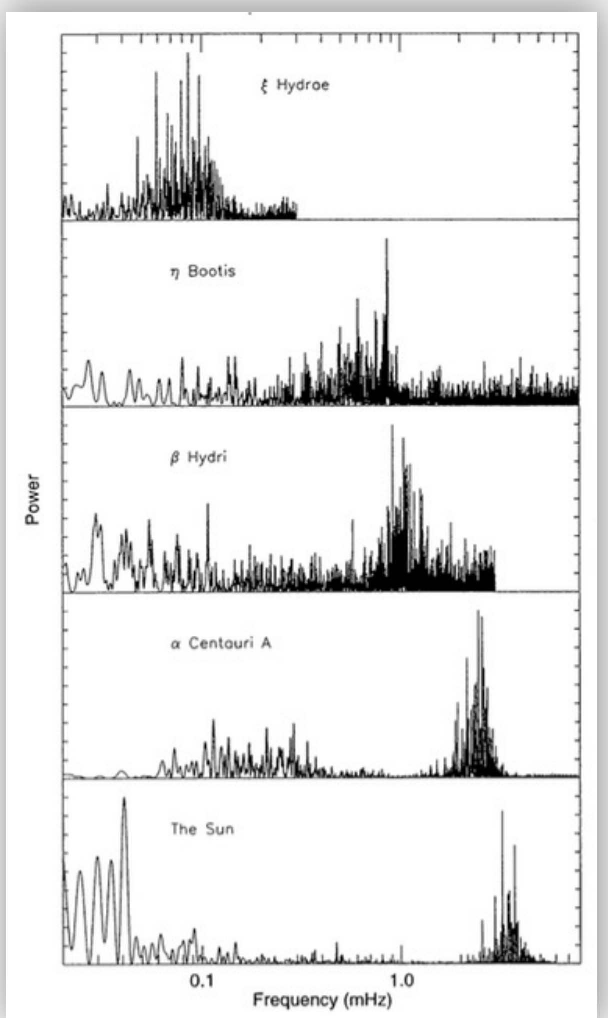
~2000
A dozen pulsating solar-like stars detected

Twenty years ago

Solar-like oscillations only detected in a handful of stars

Quality was not enough to properly detect individual modes
→ no seismic inferrence of stellar interiors

Bedding & Kjeldsen 2004



Age

Asteroseismology: beyond the Sun

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A dozen pulsating solar-like stars detected

December 2006
Launch of CoRoT

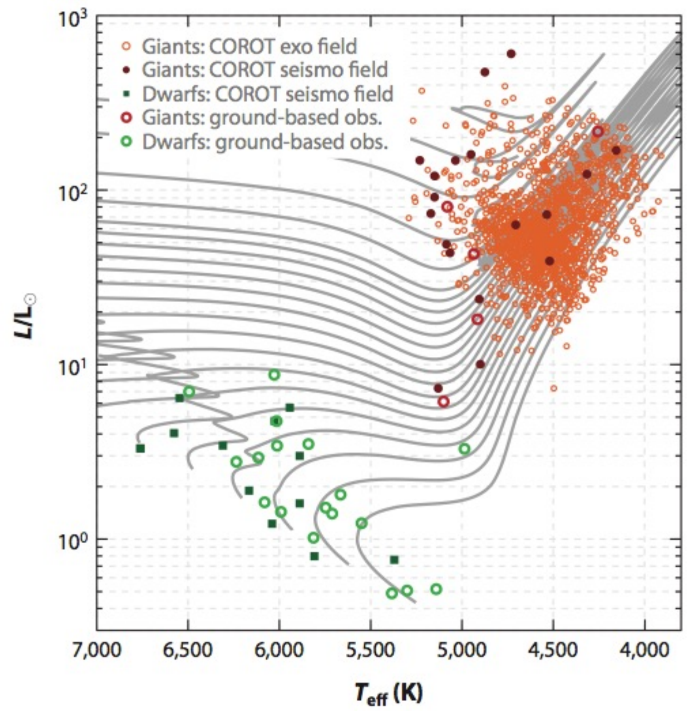
And then came CoRoT…

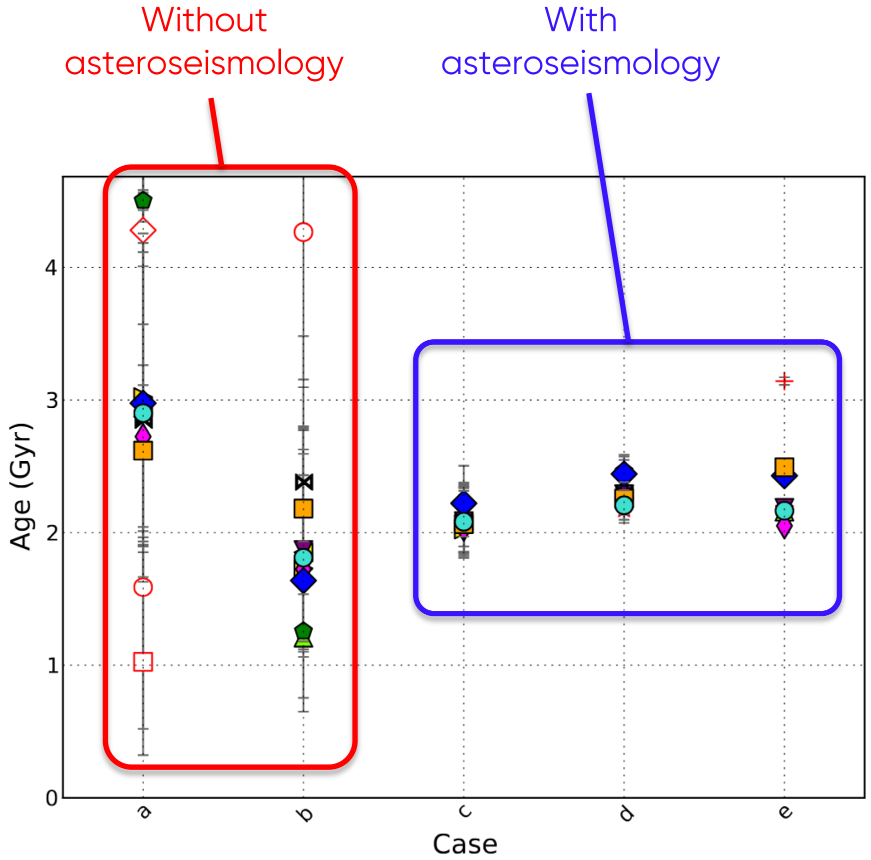
Pathfinder for asteroseismology

Oscillations detected in ~ 1000 red giant stars

Individual modes detected → much better stellar characterisation

Chaplin & Miglio 2013





CoRoT HD52265 (Lebreton & Goupil 2013)

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March 2009
Launch of *Kepler*

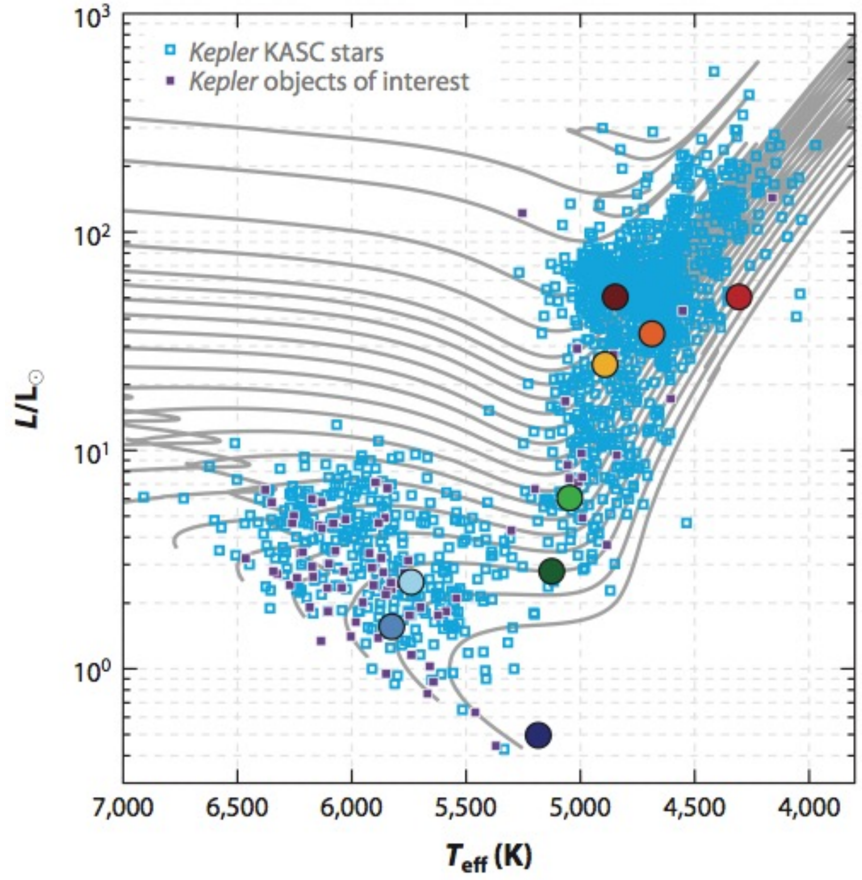
… and Kepler…

Extension of asteroseismology to hundreds of main sequence stars

Individual frequencies detected with high accuracy → seismic characterisation possible

Inferrence of internal structure only possible for ~ 10 stars from Legacy Sample

Chaplin & Miglio 2013



Asteroseismology: beyond the Sun

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A dozen pulsating solar-like stars detected

December 2006
Launch of CoRoT

March 2009
Launch of *Kepler*

April 2018
Launch of TESS

Hopefully 2026
Launch of PLATO

… and now, PLATO

Precise and accurate seismic inferrence for a huge sample of nearby stars (more than 15000 FGK dwarves)

« Golden » PLATO sample will be ~ 80 times bigger than Kepler Legacy Sample

Synergy with astrometry (Gaia) and spectroscopy (e.g. WEAVE)

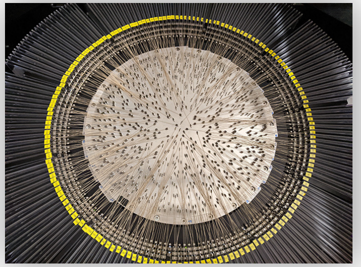
Asteroseismology

Global seismic indicators ($\Delta\nu$, ν_{max})
Individual seismic frequencies

Astrometry

Luminosity, …

Spectroscopy



WEAVE fibers © Gavin Dalton/U. Oxford/STFC-RAL Space

Effective temperature, metallicity, …

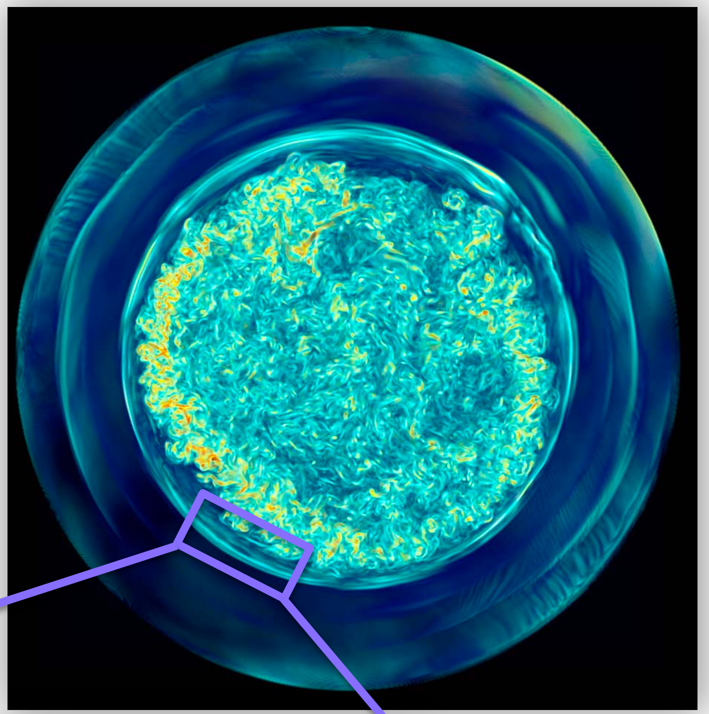
Best possible mass, radius, age

Stellar physics: the challenges PLATO will allow us to tackle

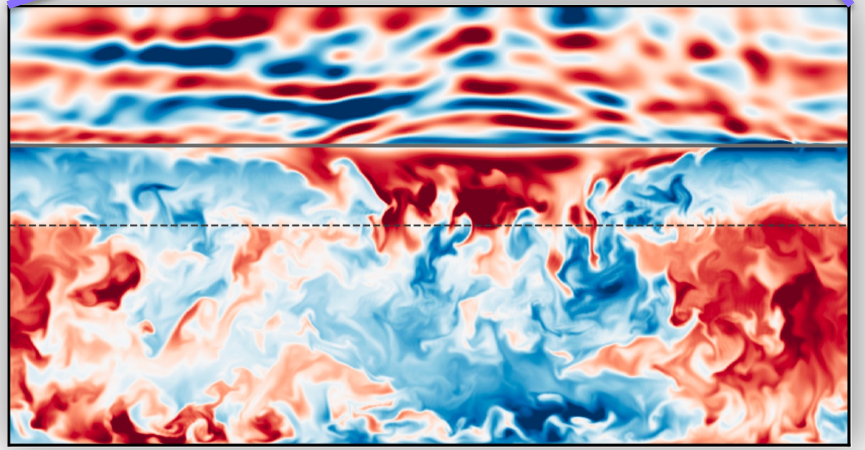
Convective/radiative interfaces

Immensly complex regions
- very turbulent → non-linear processes
- lots of different time and space scales

Mixing of…
- … energy
- … angular momentum
- … chemical species
- → impacts structure and evolution of the star



Mao et al. 2024

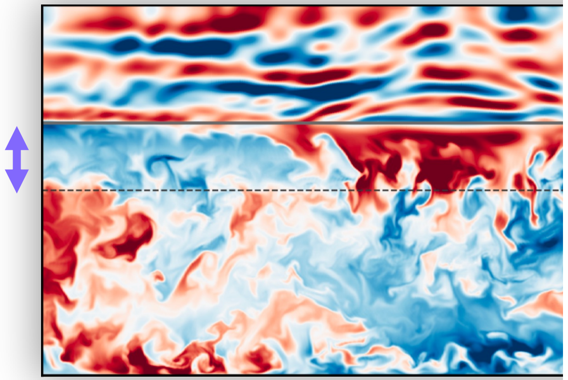


Anders et al. 2023

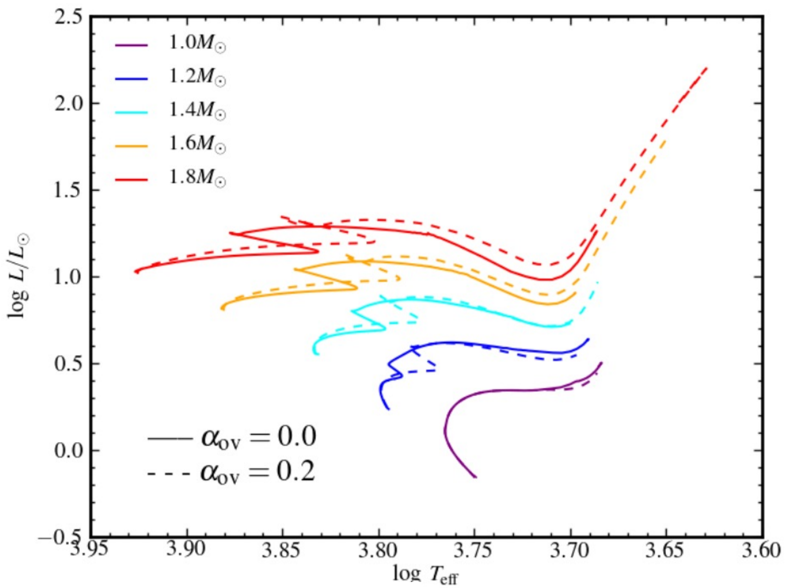
Stellar physics: the challenges PLATO will allow us to tackle

Convective/radiative interfaces

Interface characterised by convective penetration, or overshoot



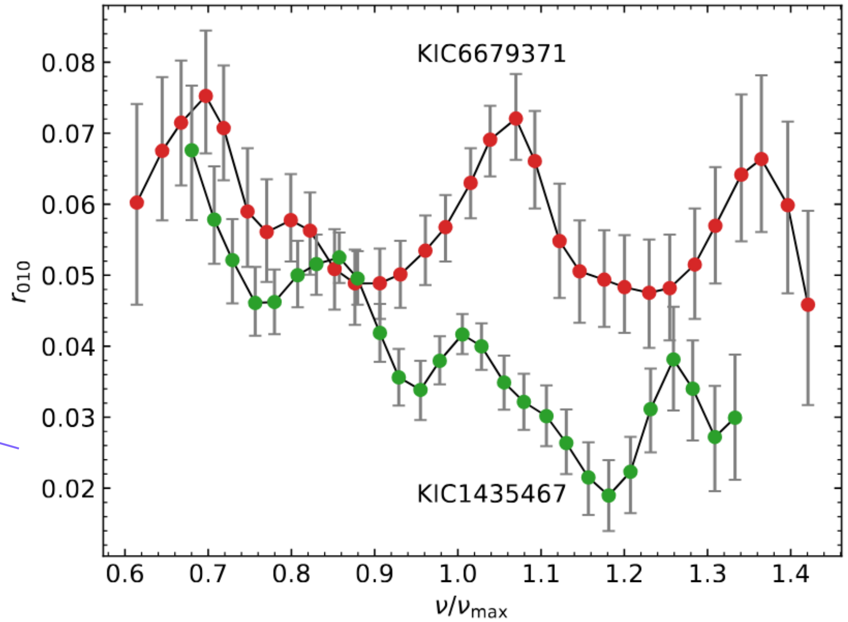
Included in stellar models through extra diffusion coefficient in transport equations → overshoot parameter



Lebreton et al. 2014

Model uncertainty on overshoot → bias in age determination (can reach 30% for M > 1.2 M☉)

Seismic glitch signature carries information on this interface



Deal et al. 2023

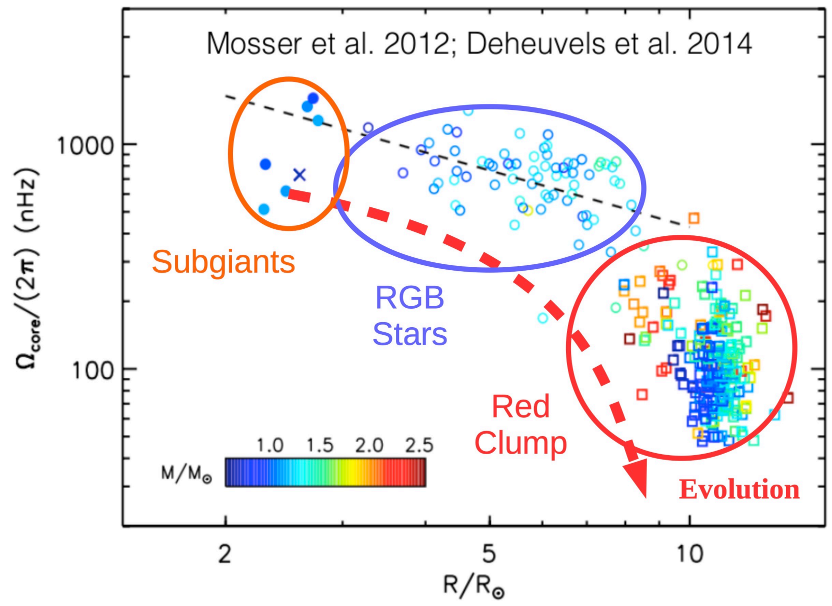
PLATO will allow us to constrain interface mixing and grasp the underlying physics

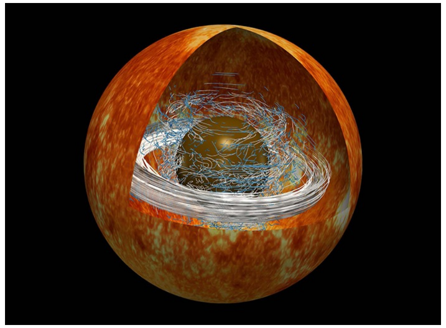
Stellar physics: the challenges PLATO will allow us to tackle

The « internal rotation crisis »

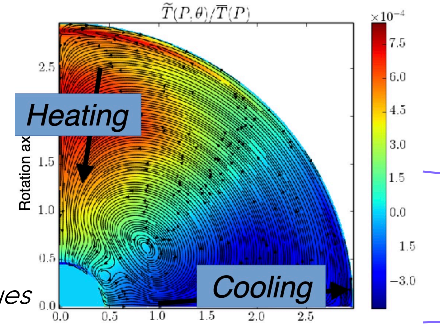
Evolved stars: core contracts, envelop expands, differential rotation should increase

Observations show the opposite
→ there is a physical ingredient missing in the stellar models, able to extract angular momentum from the core of the star





Petitdemange et al. (2023)



J. Marques

Rogers et al. (2006)

Possible candidates include…
… interaction with large scale flows (meridional recirculation, etc.)
… impact of internal magnetic field, through MHD instabilities
… angular momentum transport by waves

PLATO will allow us to identify the missing ingredient, and solve this crisis

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Stellar physics: the challenges PLATO will allow us to tackle

Activity-rotation relation

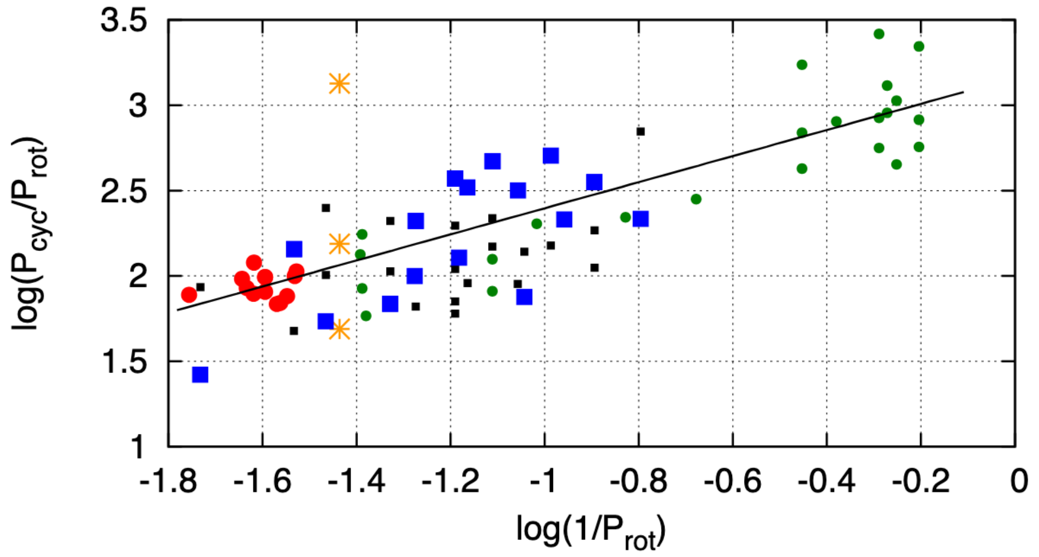
Observations show relation between rotation and…
… period of activity cycle
… amplitude of magnetic activity

These relations shed light into the underlying dynamo process

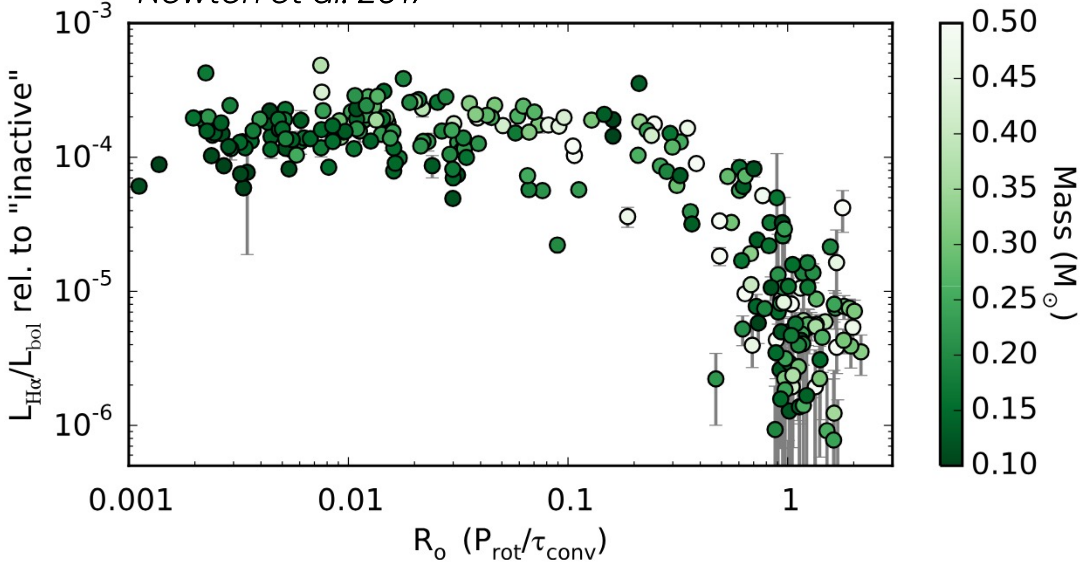
PLATO will consistently deliver rotation periods, cycle periods, and activity levels when available

PLATO will help us understand the link between rotation and activity, and constrain stellar dynamo models

Olah et al. 2016



Newton et al. 2017



Conclusions

Characterising stars better than ever before

After CoRoT and Kepler, PLATO will constitute a leap forward in characterisation of stellar masses, radii and ages, thanks to synergies with Gaia and ground-based spectroscopy

Number of stars with accurate and precise global parameters and internal structure will increase by two orders of magnitude

Towards a new generation of stellar models

Unprecedented insight into stellar interiors
- access to dynamical properties of stellar interiors
- constraints on convective/radiative interface mixing

Rotation and activity monitoring
- → insight into stellar magnetism and dynamo processes