Asteroseismology from Line-profile variations

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ERASMUS +

Per aspera ad astra simul

A strategic partnership between Intituto de Astrofisica de Canarias (IAC) and various Czech and Slovak institutes

Opportunities:

- Students/postdocs spend ~6 months at the IAC/GTC
- Short-term stays at IAC for more senior staff
- Schools on modern astronomical instrumentation/observations
- *Host researchers from the IAC*

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IAC CALP, La Palma

IAC headquarters, La Laguna, Tenerife

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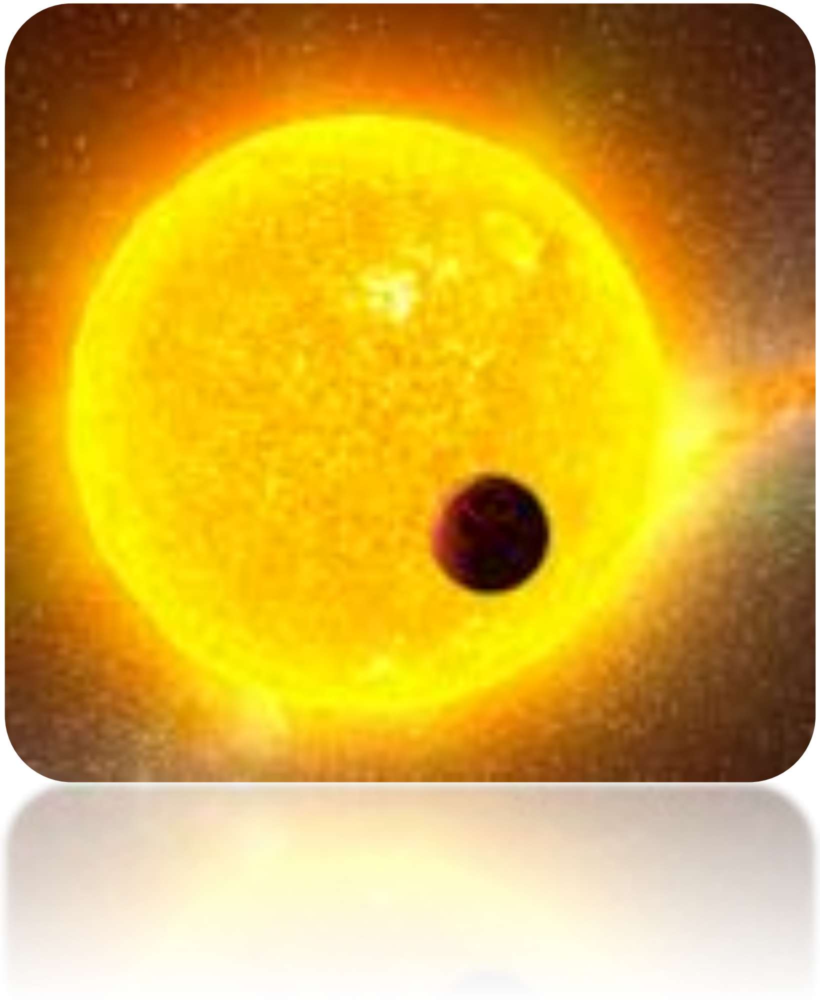
Roque de los Muchachos Obs., La Palma

Teide Observatory, Tenerife

Sales pitch: *"Stellar Noise"*

Asteroseismology is a unique tool to accurately characterize a planet-host star



Know thy star – know thy planet

98% of all exoplanet detections constrain the planetary properties relative to the star

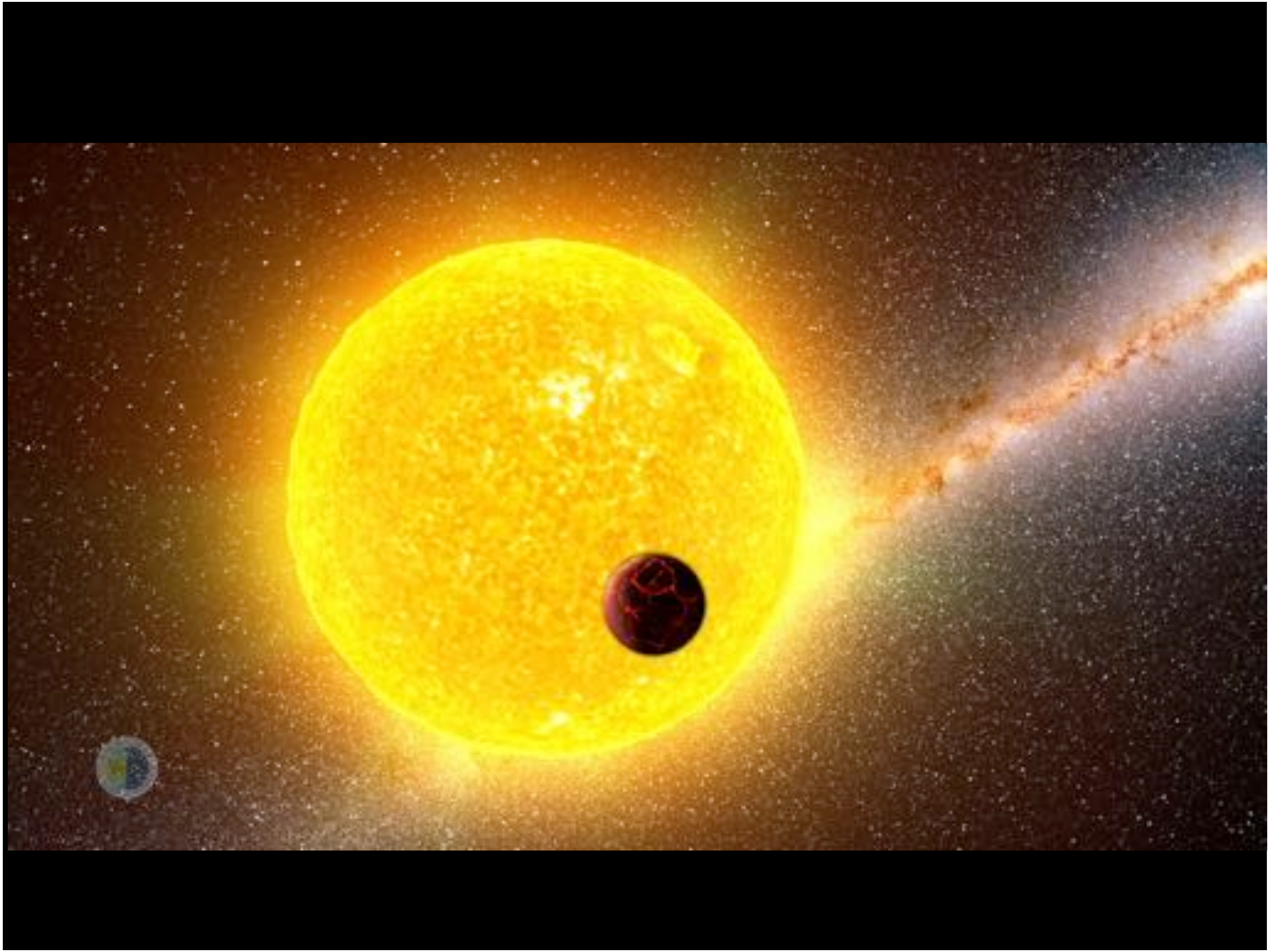
→ mass, radius, log*g* <5%, age <10%

Uncertainty:

stellar parameters <> planetary density
<> planetary structure

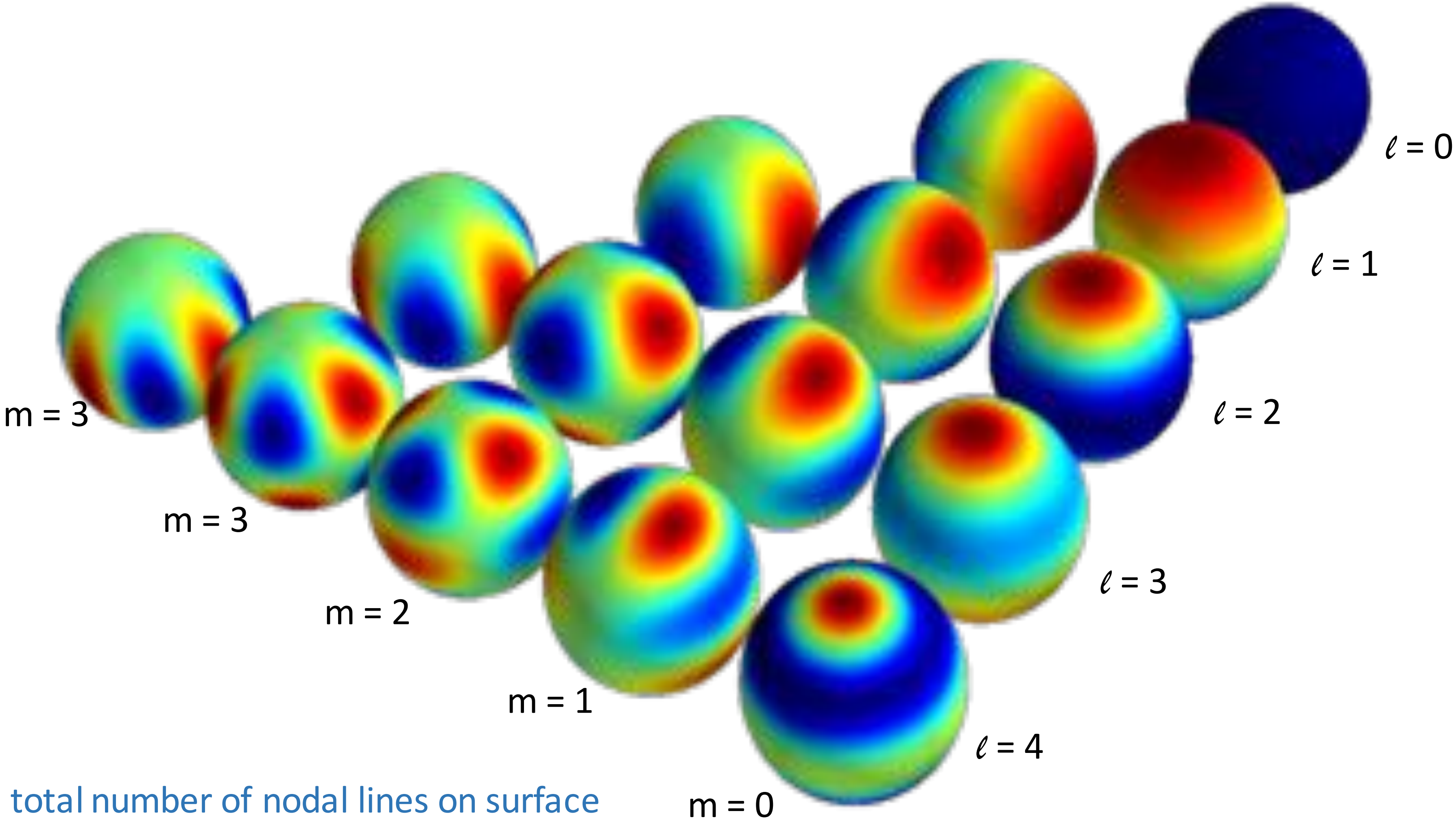
Summary of Talk

- Basics of observational Asteroseismology
- Line-profile variations and mode ID
- Examples of campaigns
  using spectroscopy for seismology



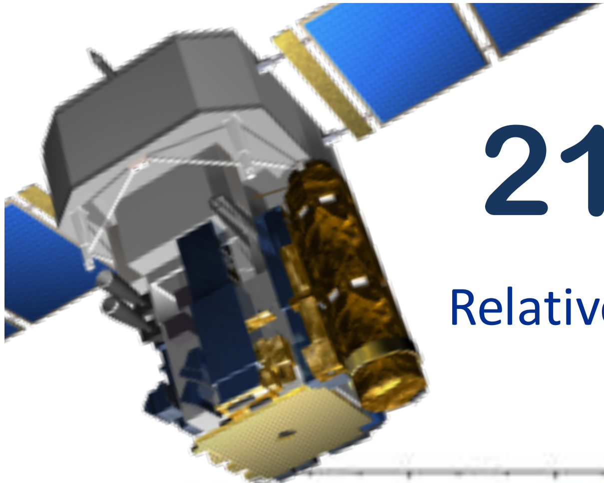
Temperature and Velocity Variations

Sensitivity to the internal structure depends on the oscillation mode



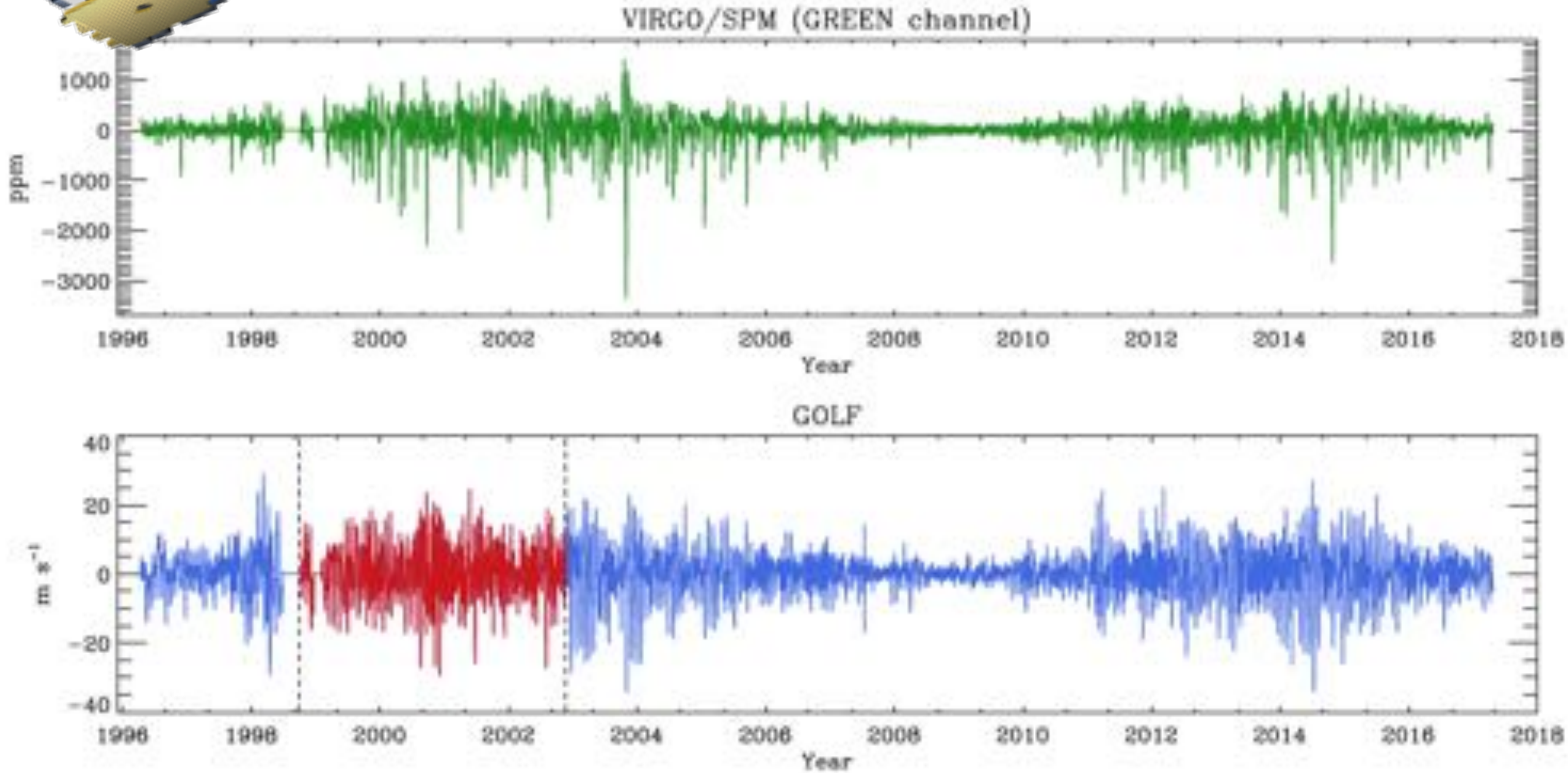
ℓ = total number of nodal lines on surface

m = nodal lines, perpendicular to equator (m ≤ ℓ)



21yr Time-series domain

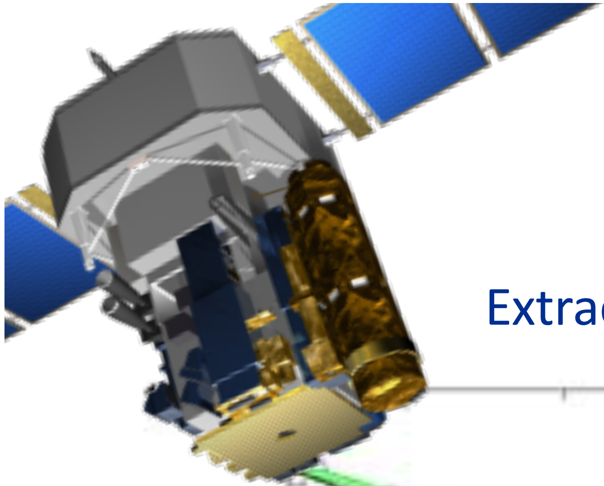
Relative variation of observable quantity with respect to the mean

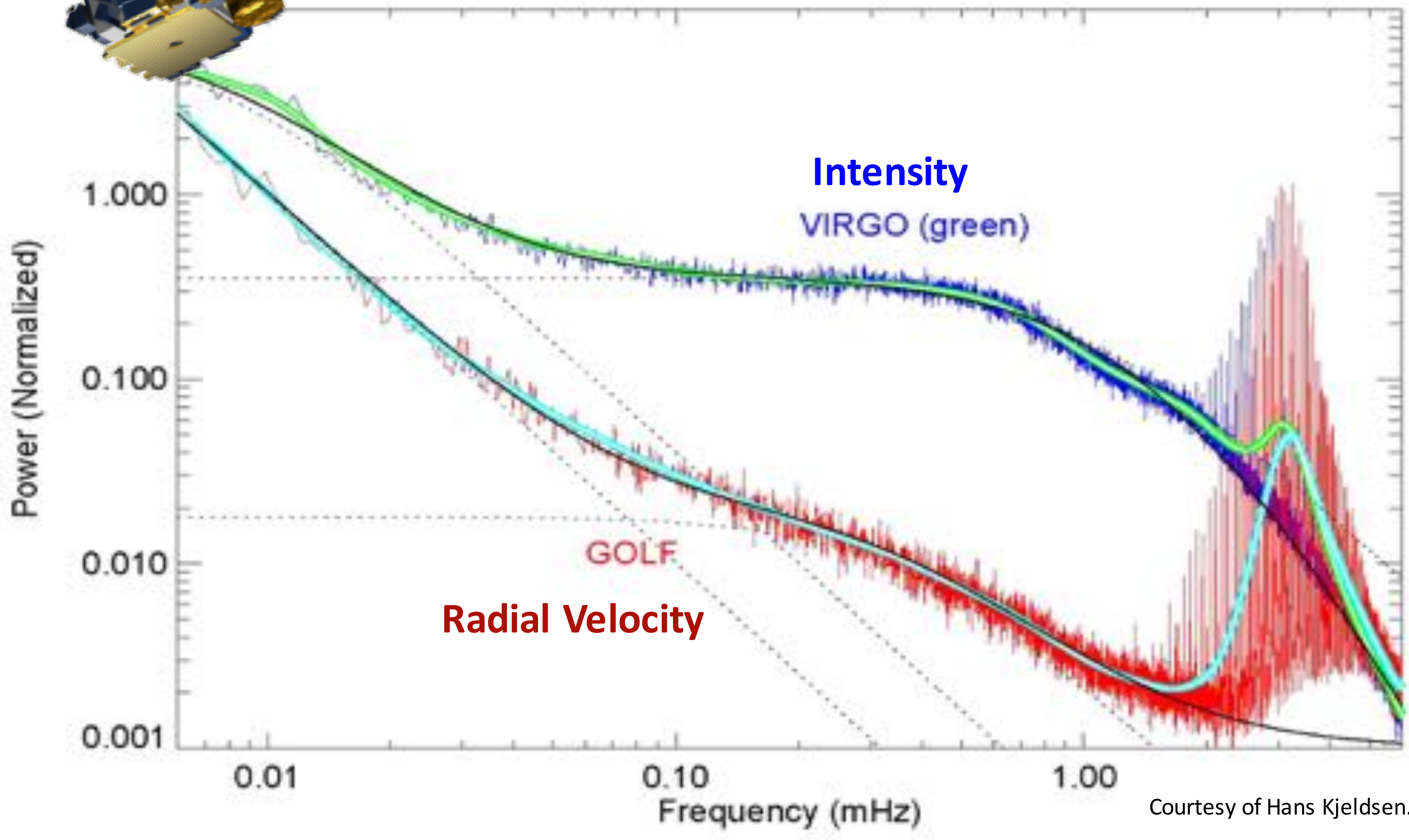


Latest data/plot by Salabert et al. (2017, ArXiv: 1709.05110)

Fourier Analysis

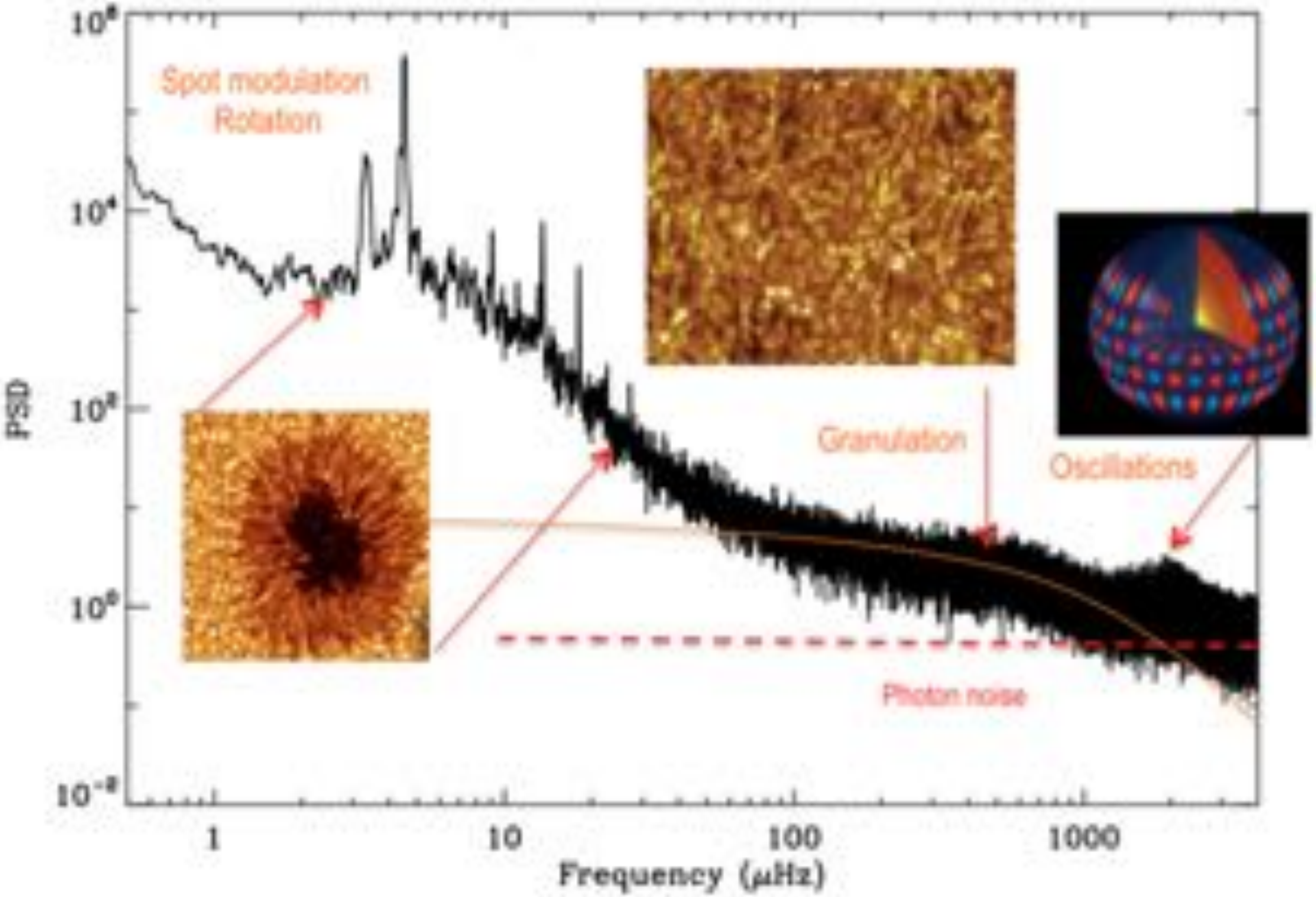
Extraction of oscillation mode parameters & Mode identification





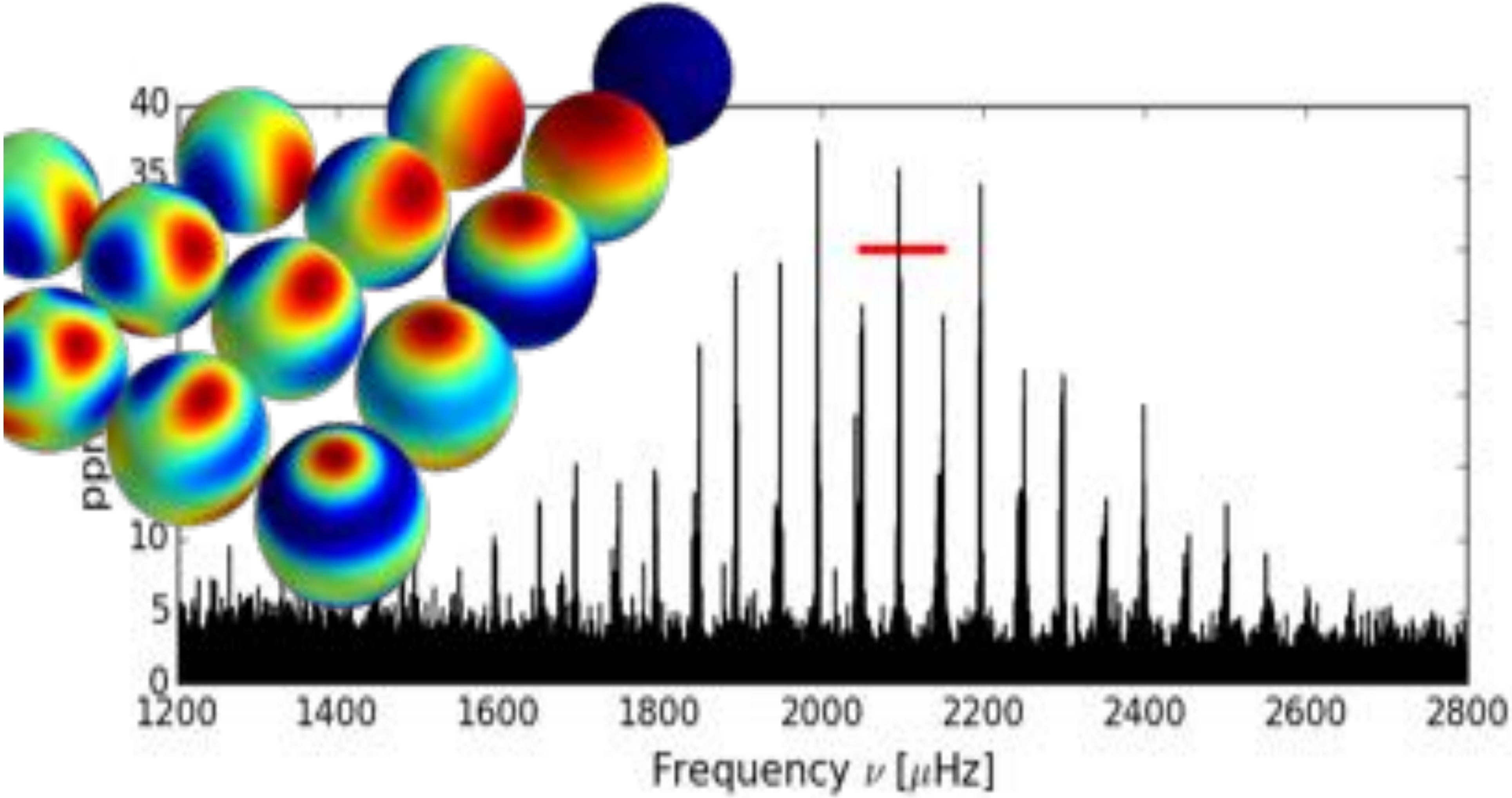
Courtesy of Hans Kjeldsen.

Contributions to the PSD



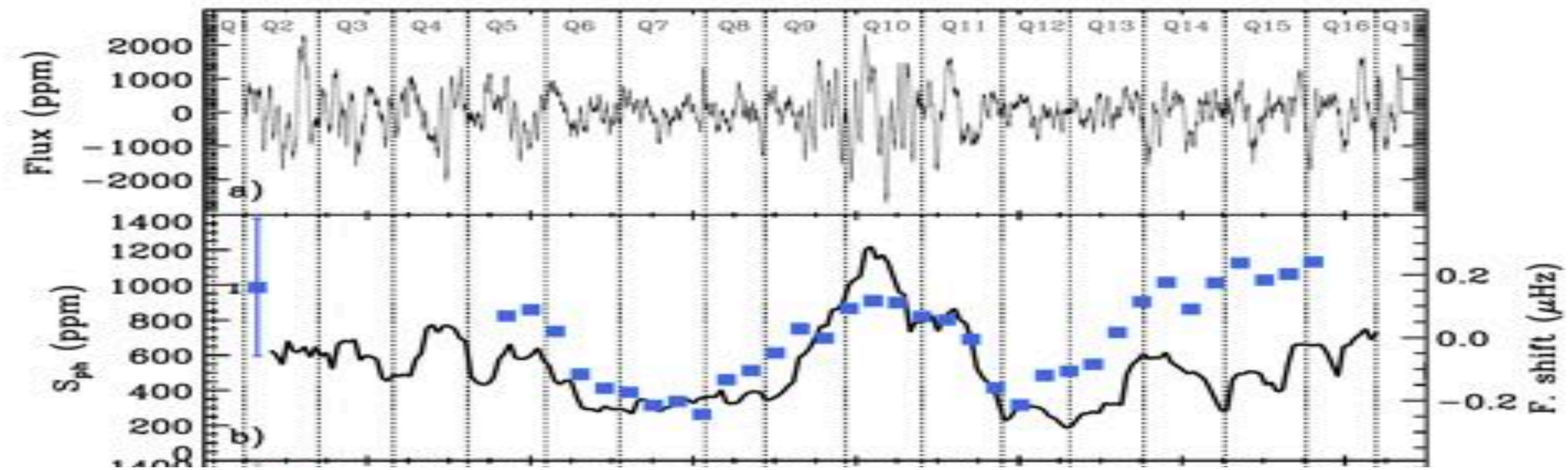
Solar-Like oscillators

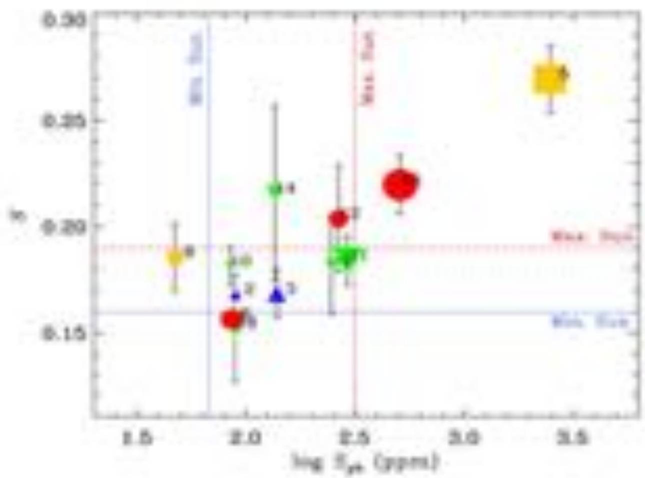
Each mode is an individual probe to the interior to the star

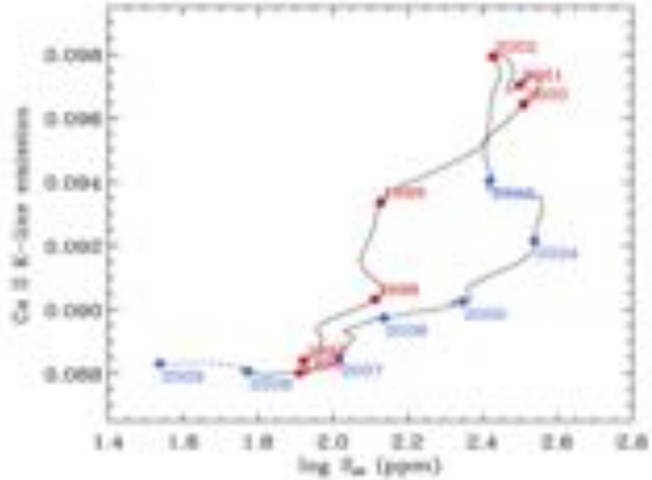


Stellar Rotation & Activity

A&A 589, A118 (2016)

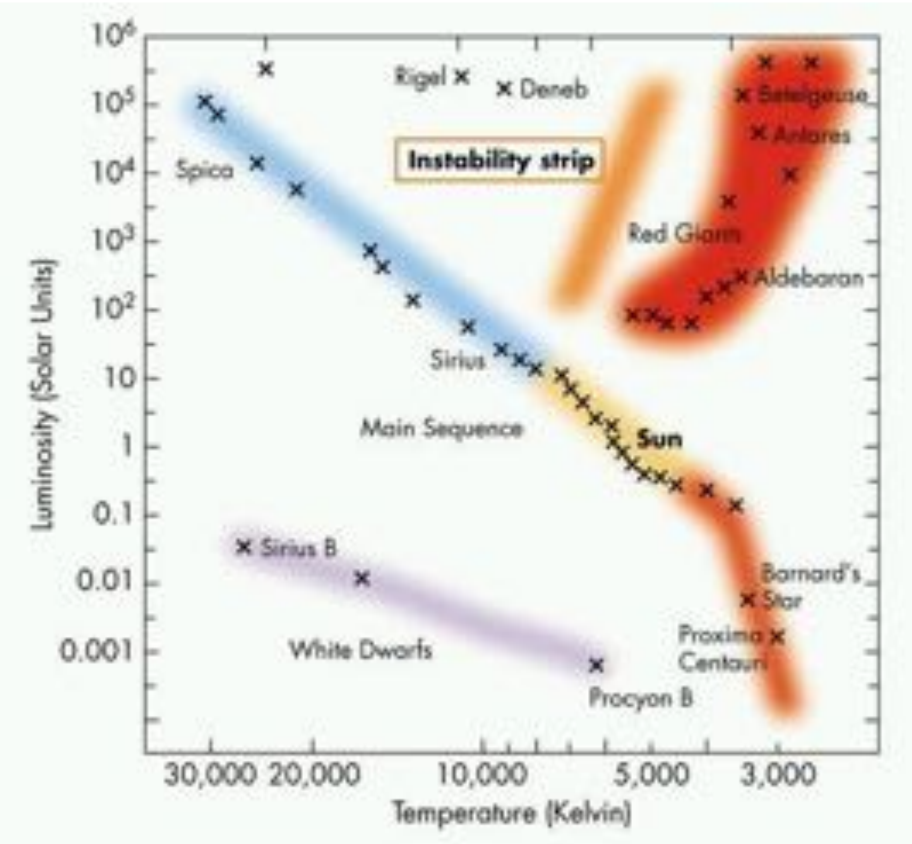






Oscillations Types & Characterisics

The position in the Hertzsprung-Russell diagram allows a first good idea of the properties



Excitation Mechanisms

- Opacity-variations
- Convective motion

Further,

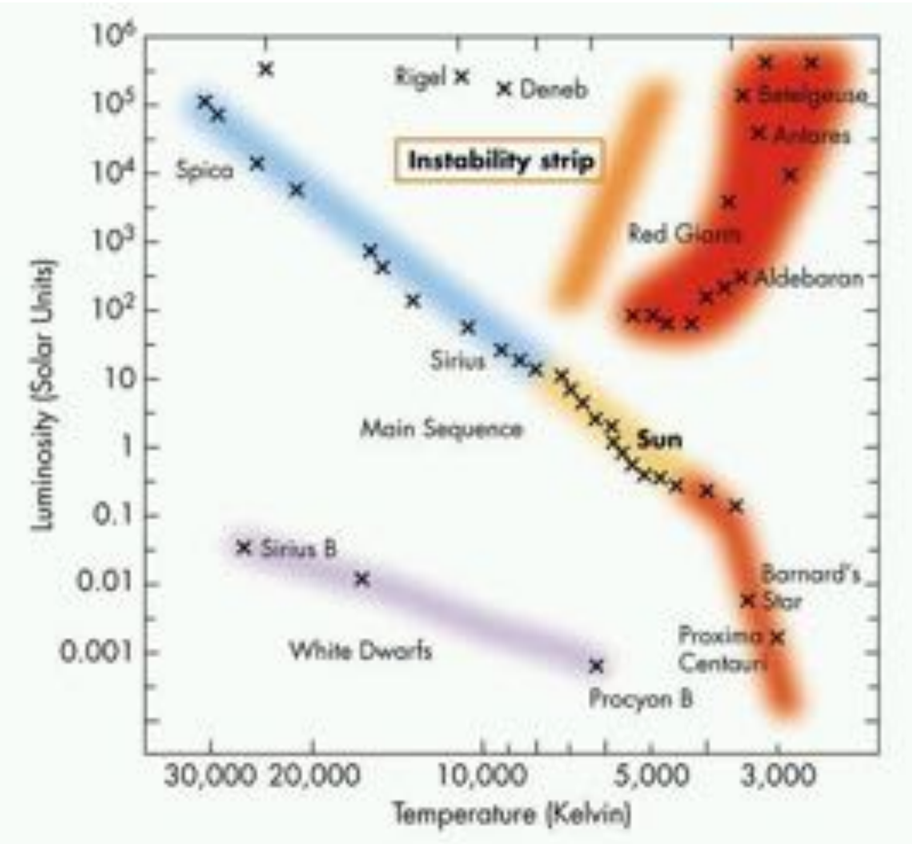
- Variations in energy production
- Rotational excitation
- Tidal excitation in close binaries

Each type is associated with a characteristic frequency range

→ Helps to plan the observing run

Oscillations Types & Characterisics

The position in the Hertzsprung-Russell diagram allows a first good idea of the properties



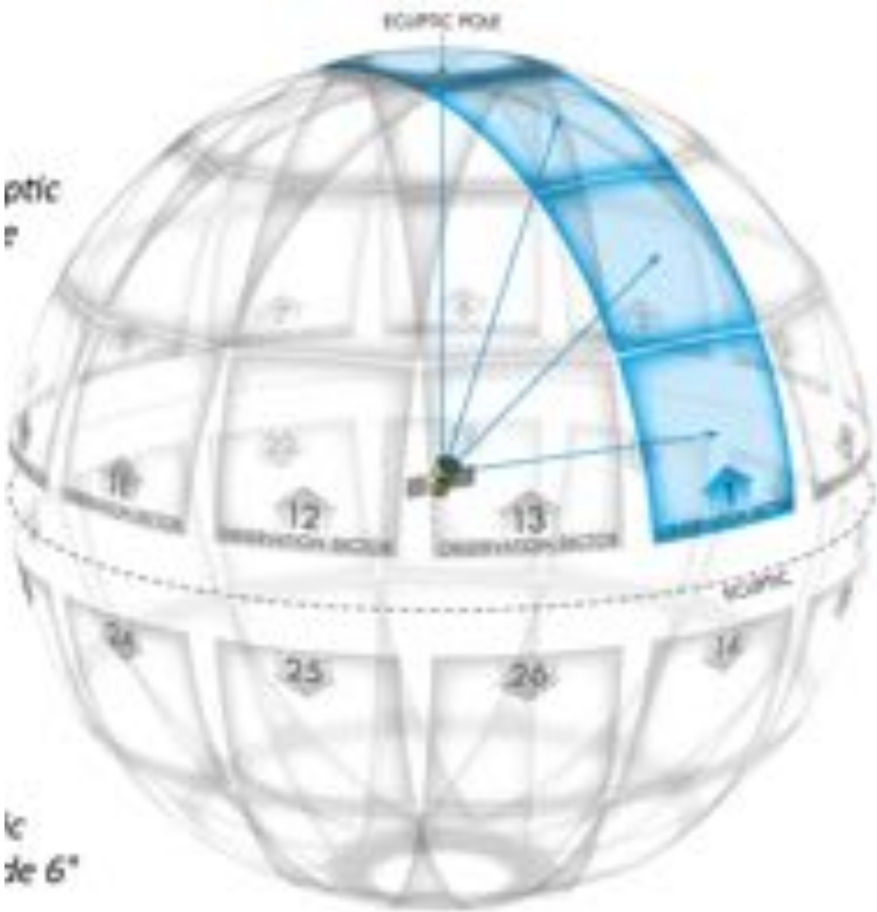
'Classical' heat-driven pulsators:

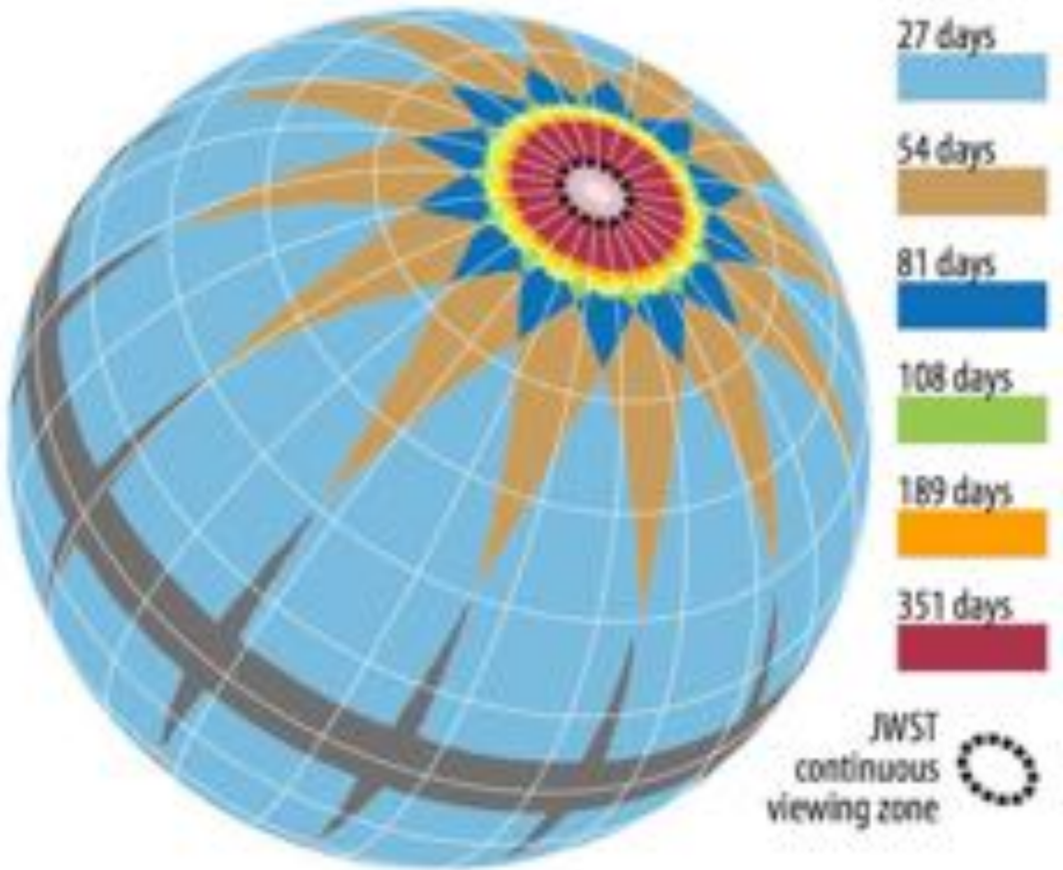
- large amplitudes (km/s)
- Fast rotators > lines resolved
- sinusoidal signal (coherent)

'solar-like' stochastic oscillators:

- small amplitudes (m/s-cm/s)
- slow rotators > unresolved lines
- Stochastic mode excitation (freq-resolution, mode line-width)

NASA TESS

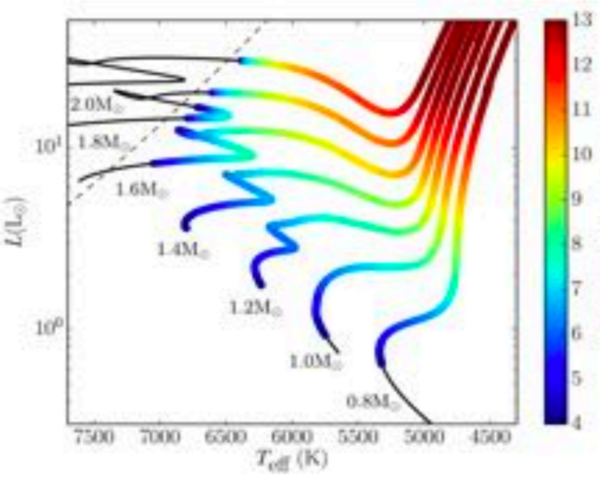



27 days
54 days
81 days
108 days
189 days
351 days
JWST continuous viewing zone

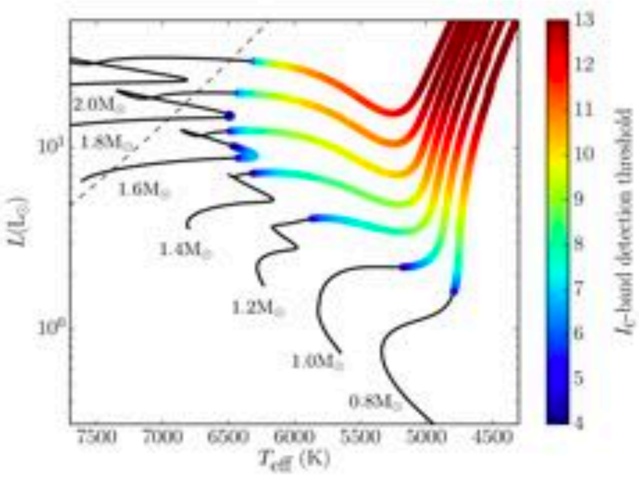
Photometric and Velocity Variations

Where solar-like oscillations can be detected

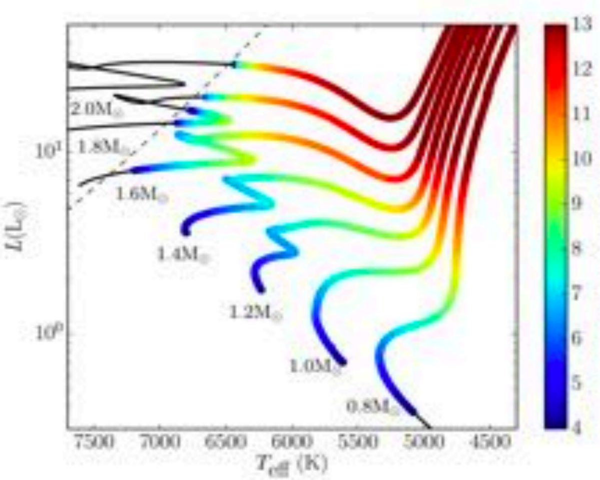
Campante et al. 2016, ApJ 830, 138



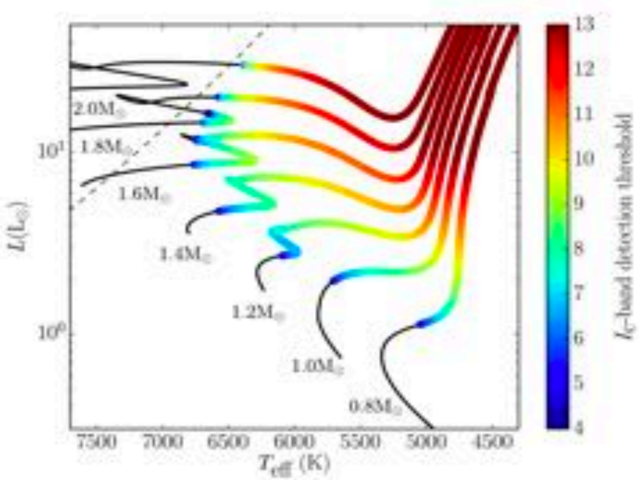
(a) $T = 27$ d, $\sigma_{sys} = 0$ ppm hr$^{1/2}$.



(b) $T = 27$ d, $\sigma_{sys} = 60$ ppm hr$^{1/2}$.



(c) $T = 351$ d, $\sigma_{sys} = 0$ ppm hr$^{1/2}$.

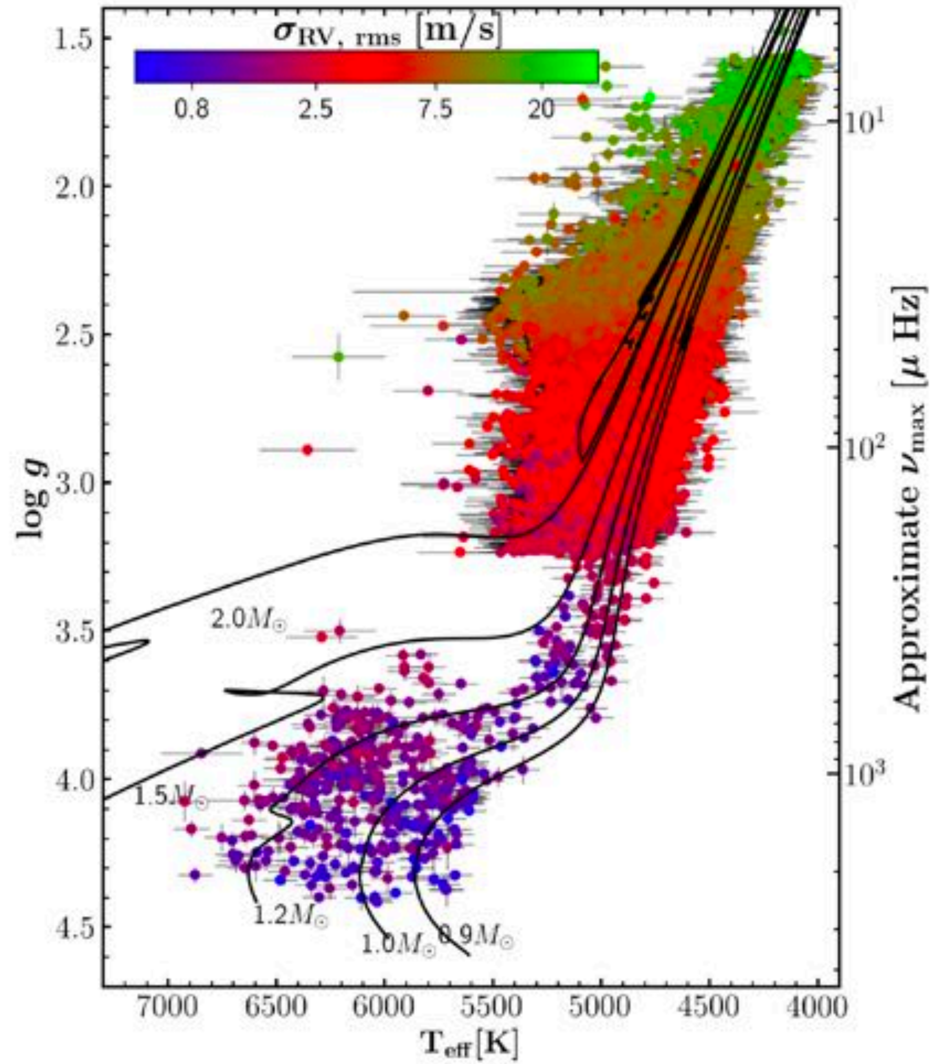


(d) $T = 351$ d, $\sigma_{sys} = 60$ ppm hr$^{1/2}$.

Photometric and Velocity Variations

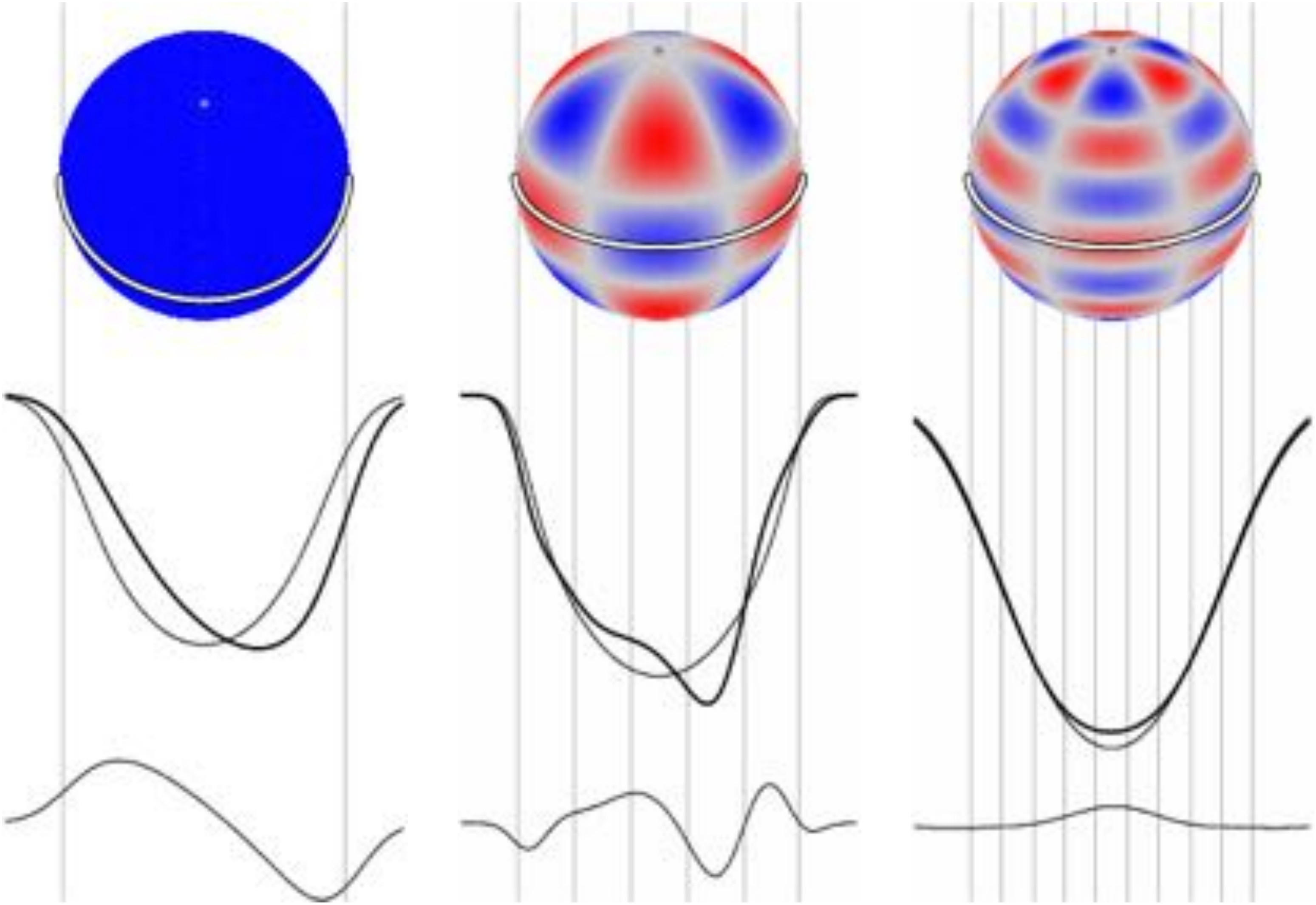
Where solar-like oscillations can be detected

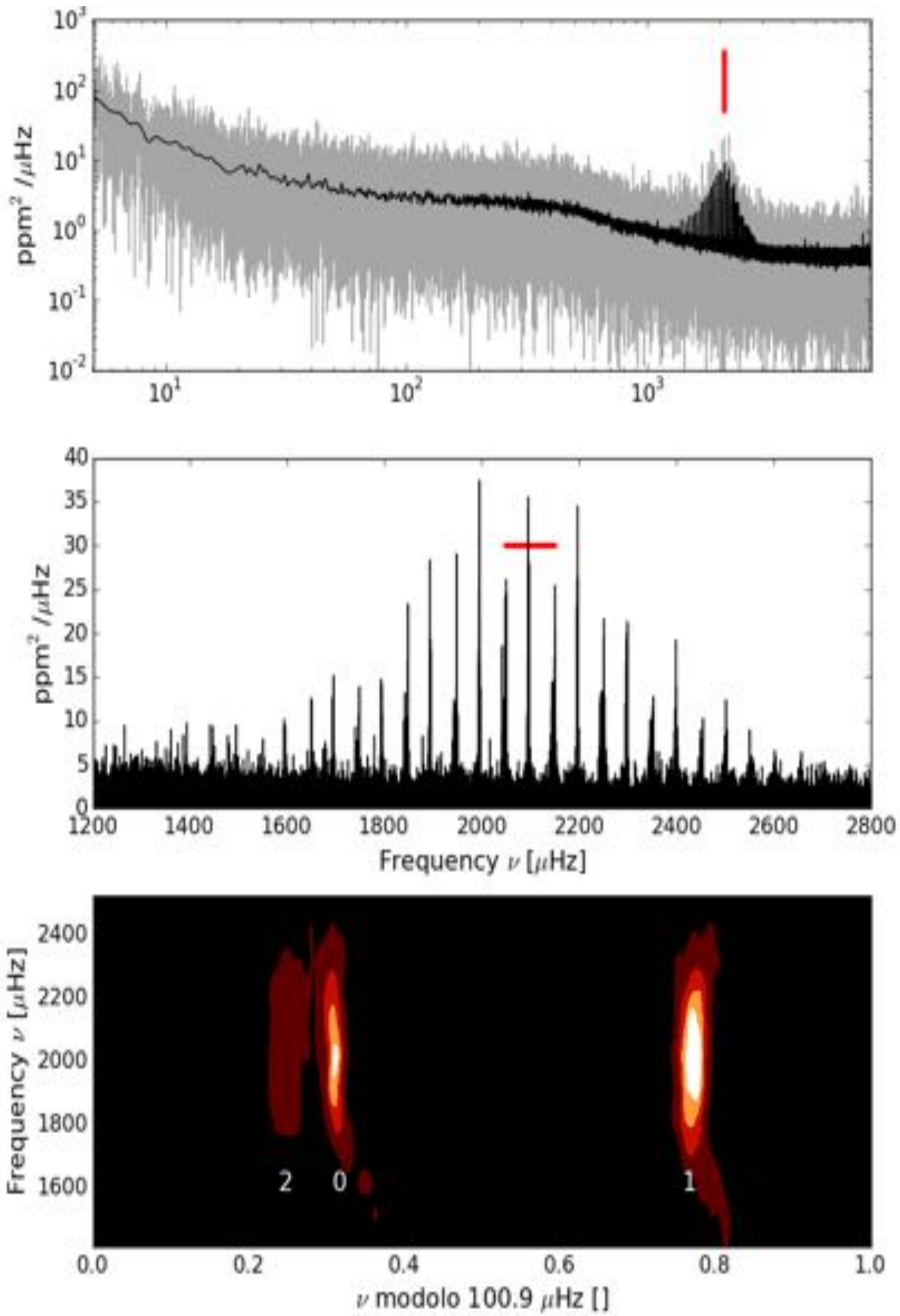
Yu, et al. 2018, MNRAS Letters, 480, L48



Forms of Line Profile Variations

Rotation resolves the mode in azimuth & lifts the mode degeneracy





Mode ID

For solar-like oscillators

Parameters (l, ±m) for a given oscillation mode are key for successful asteroseismology

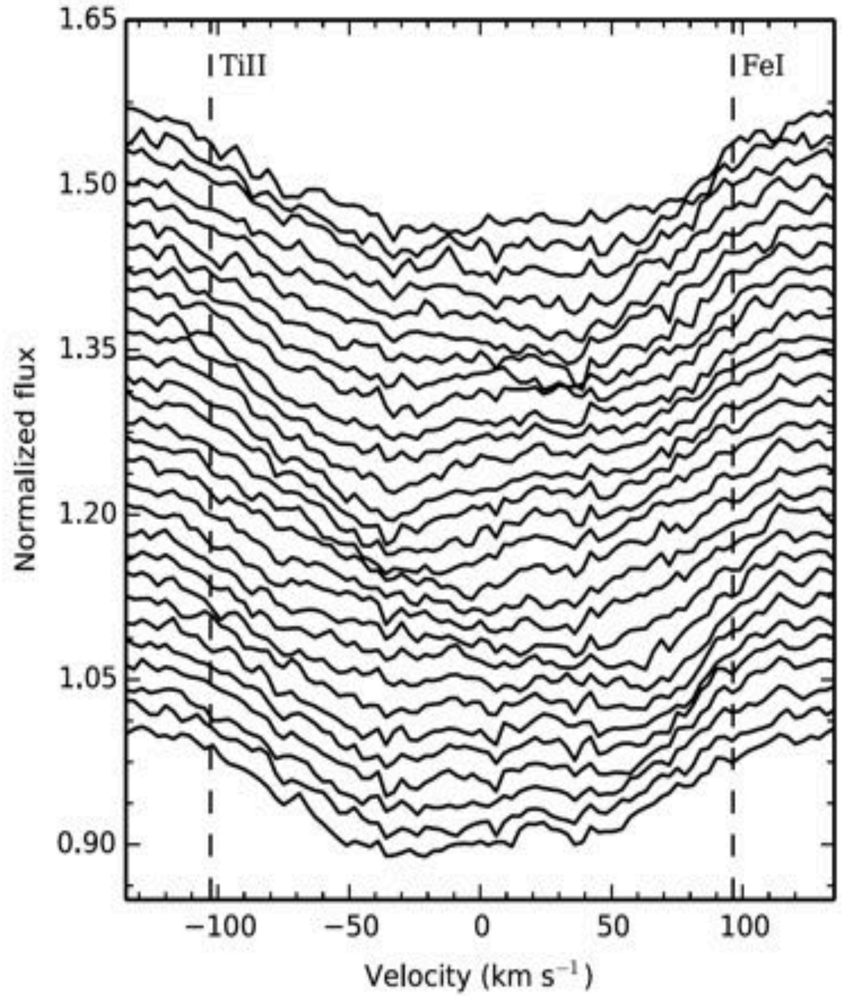
- **Echelle diagram**
- Requires a calculated frequency spectrum from a time series
- Searching regular spacing of frequencies, comb-like structure

Requires high-quality data (m/s !, high S/N, long time series)

→ PlatoSpec

Oscillation mode identification

For stars with well resolved lines



LPV in the Fe II at 4508Å over one night on 82” CasEchelle, McDonald observatory

Schmid, Themessl, Breger, et al. (2014, A&A, 570, A33)

Parameters (l, ±m) for a given oscillation mode are key for successful asteroseismology

- **Moment Method**
- Time series data
- Parameterization of shape of line
- Frequency ratios

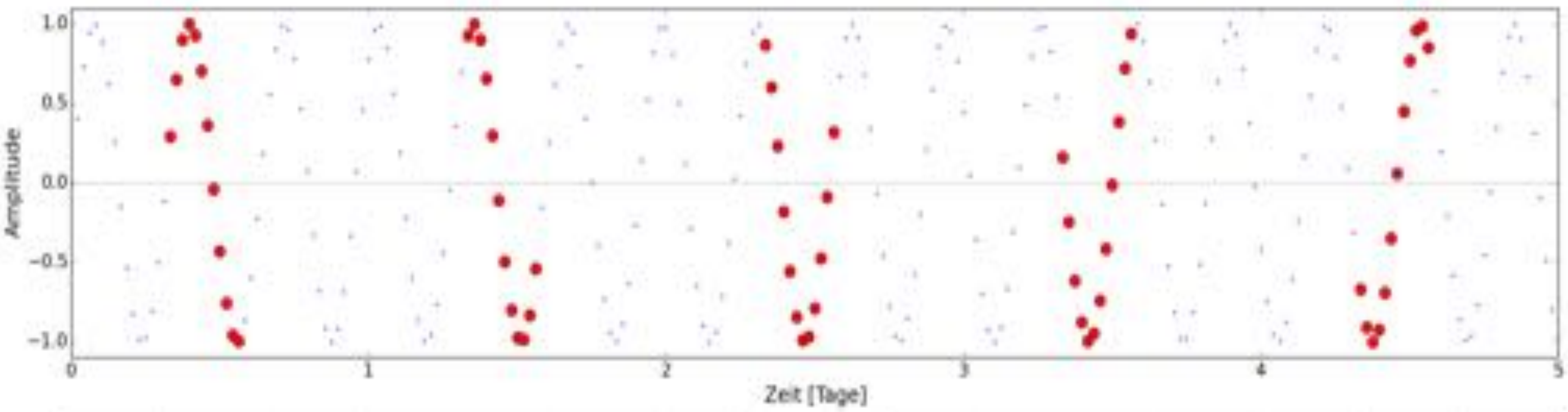
- **Fourier Parameter Fit**
- 2D Fourier analysis
- Extracts fourier paramter for each mode

Both techniques require high-quality data (high S/N, long time series)

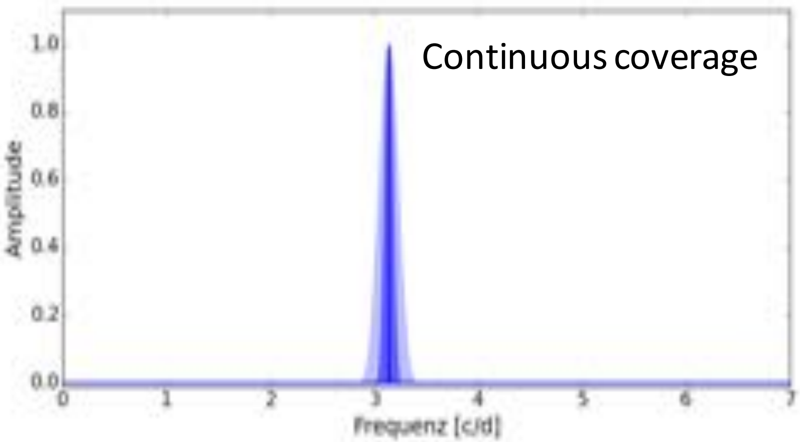
→ PlatoSpec

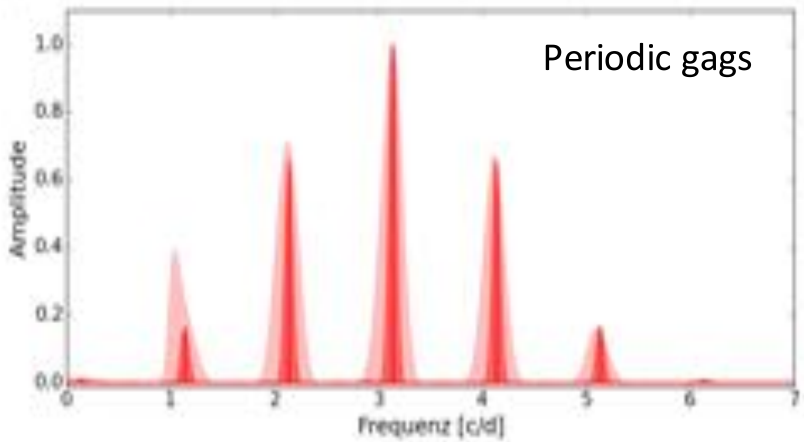
Frequency Aliasing

Let’s assume a monoperiodic star, i.e. 1 oscillation frequency with 3 cycles/day



The periodogram will look like for for this star in case of :

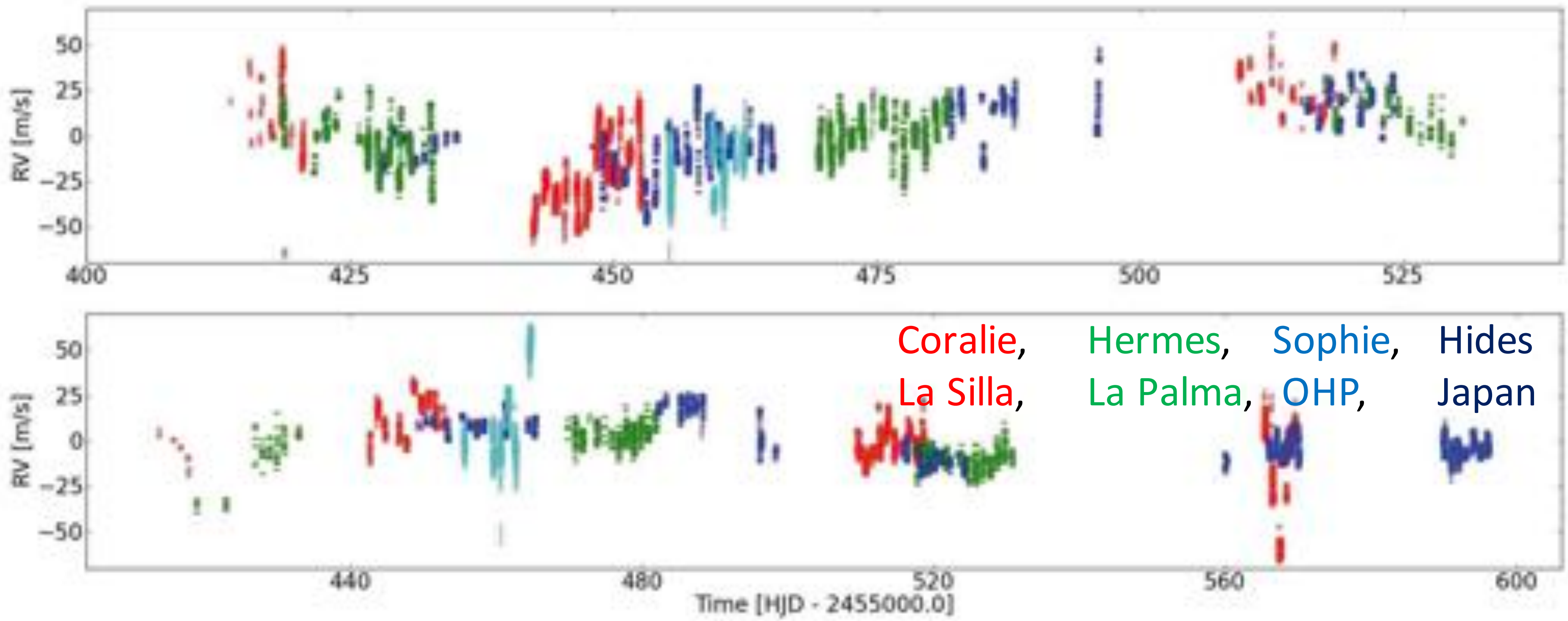


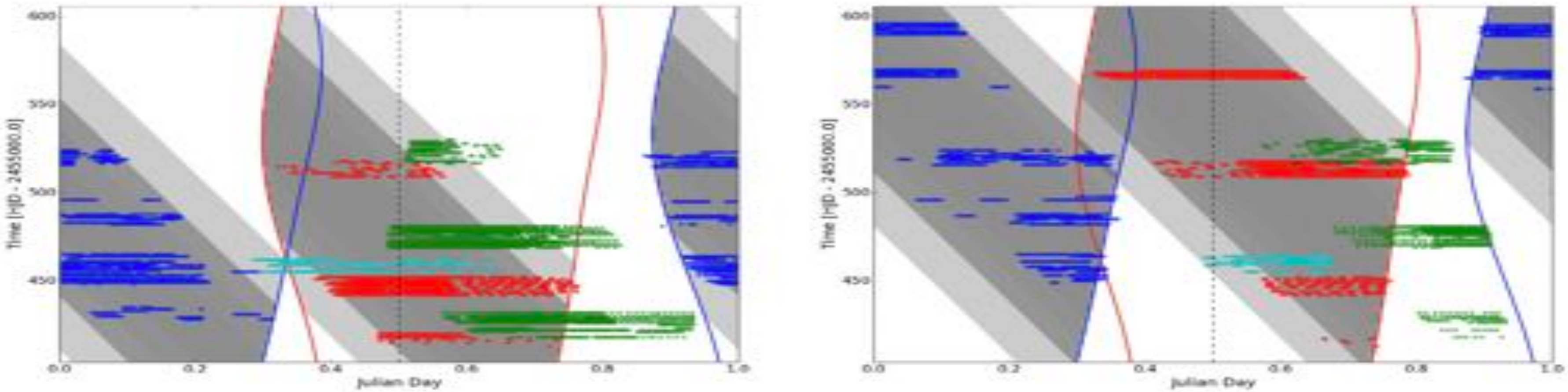


Multi-Site Campaign

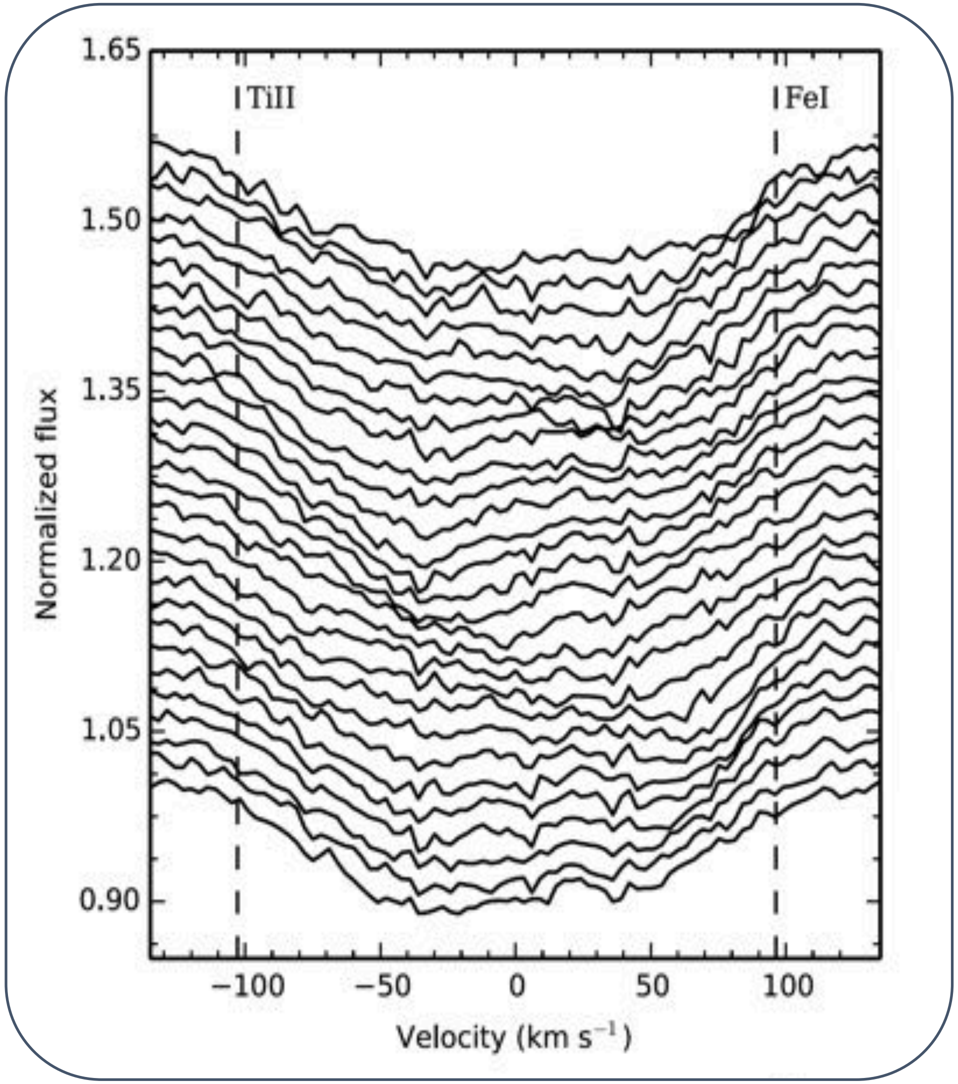
Examples for Line-Profile Variations

Beck et al, A&A 573, A138 (2015)





Examples for Line-Profile Variations



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Schmid, Themessl, Breger, et al. (2014, A&A, 570, A33)

A Typical delta Scuti: 4CVn (F3V)

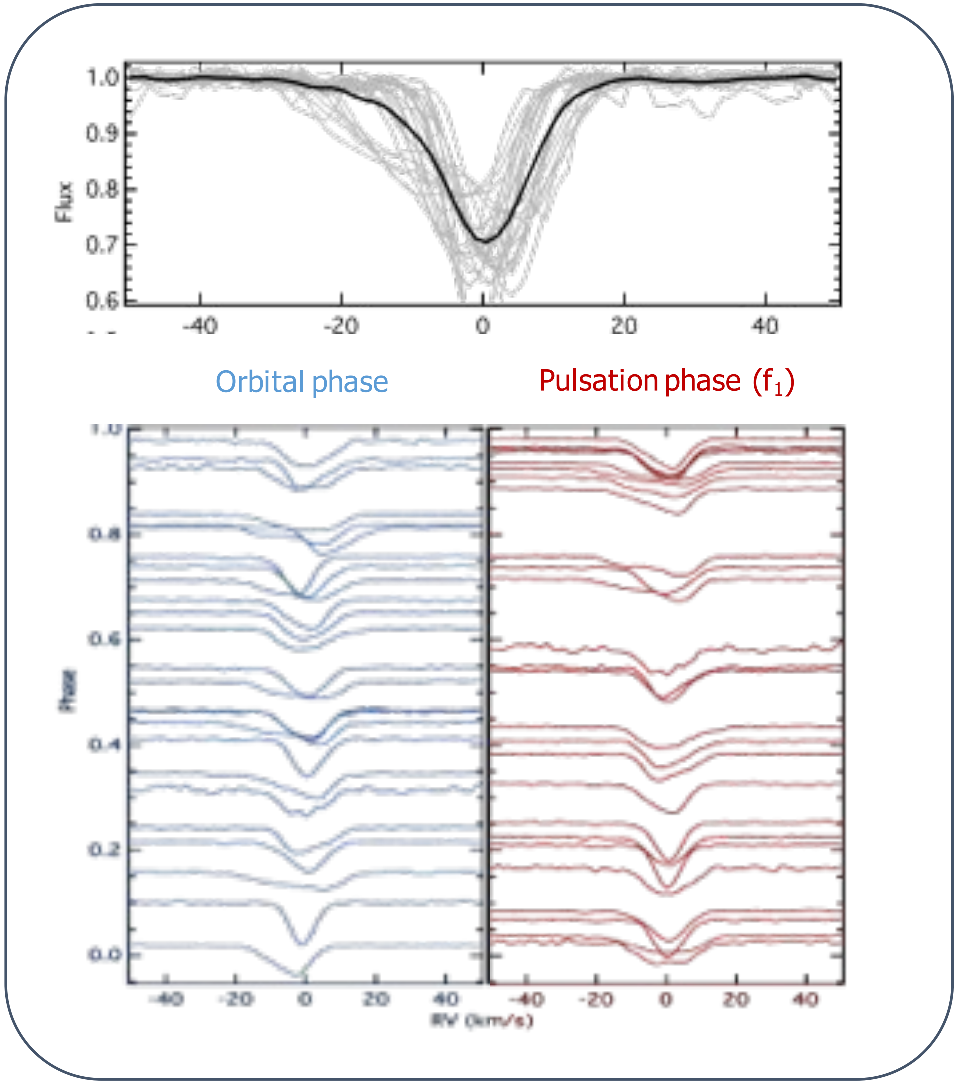
- Oscillation modes: 18
- Rotation: V sin I = ~105 km/s
  ~33% of break-up velocity

Photometry:
19 oscillation modes

Schmid et al. (2014)
From 4 years of data

- **Spectroscopy**
  20 oscillation modes
  9 unseen in photometry

Examples for Line-Profile Variations



LPV (Fe II 423.3nm) from HERMES spectra in HD 201433
from HERMES spectra

Kallinger, Weiss, Beck et al. (2017, A&A 603, A13)

Slowly pulsating B (SPB): HD201433 (B9V)

- Oscillation modes: ~20
  → solid body rotation
  → rapid spinning surface

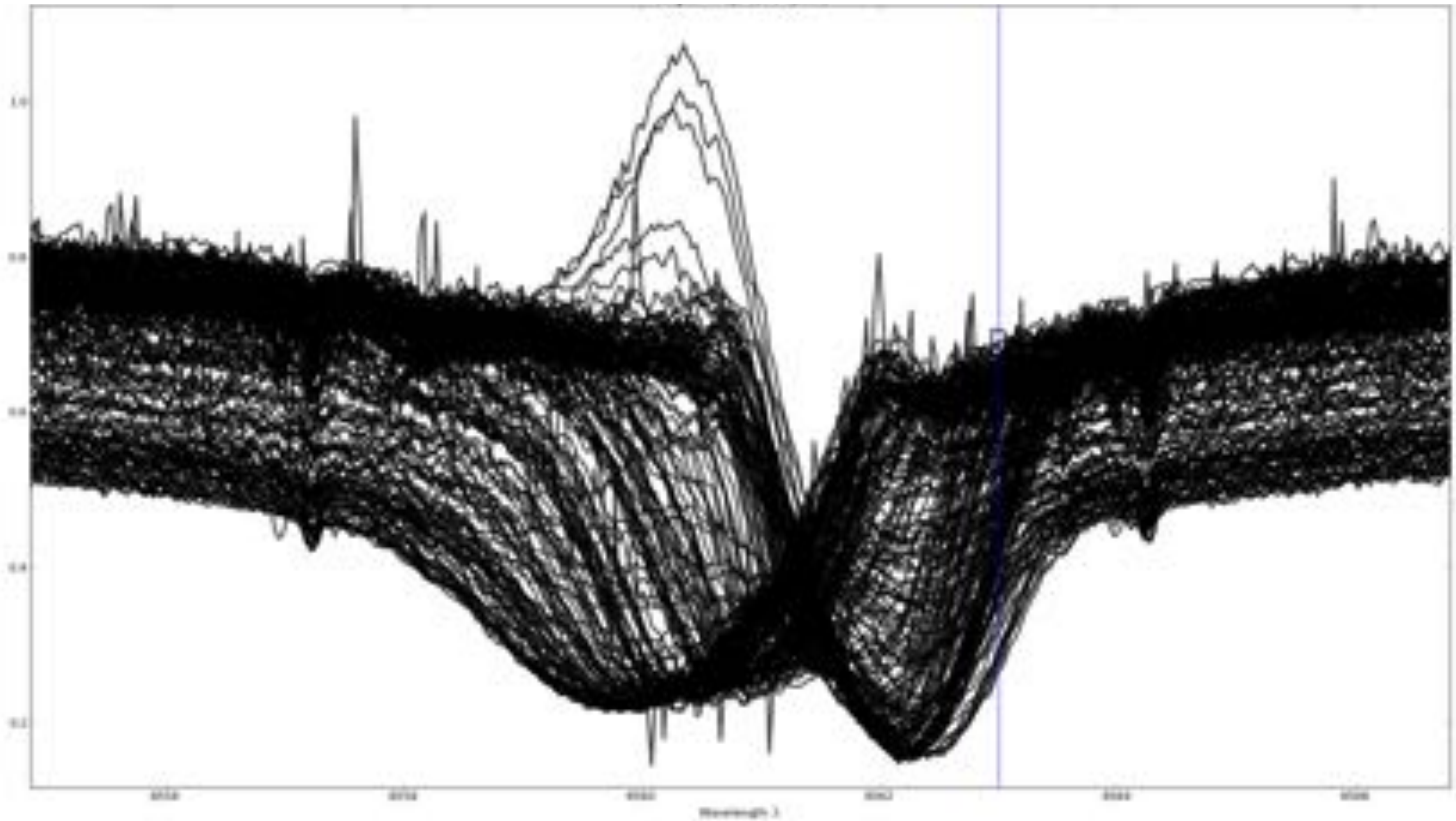
- Triple system

Kallinger et al. (2017)

- **LPV from multipl. Or oscillation**

- **Spectroscopy**
  1 additional unseen mode

LPV in RR Lyr



Stellar Oscillation Network Group

SONG project

- 1m Telescope, robotic
- 8 nodes planned
- 60.000 < R < 110.000
- Simultaneous Wavelength ref (ThAr, I2)
- 440nm – 690nm
- no Ca HK by default
- Readout: 2, 5 or 60 seconds
- V < 9 mag (hardware limited)

Optimized & dedicated to Asteroseismology

- long-term, time-demanding programs (e.g. delta scuti: 14 days, 120hrs)
- Daytime solar observations / helioseismology
- Study and discovery of exoplanets

UNIVERSITY OF COPENHAGEN

Seismology with *PlatoSpec*

- Is capable of detecting
  - classical oscillations
  - solar-like oscillations

  but is a time demanding project
- Mode identification is possible with current requirements / mission goals

- Single-Site is not optimal but do-able if planned well.
  → multi-site campaign
  → could serve as auxiliary node
- Parallel observations with PLATO to obtain simultaneous RV, parallel to photometry
- Ca H&K is important to distinguish stellar rotation/activity from planets

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