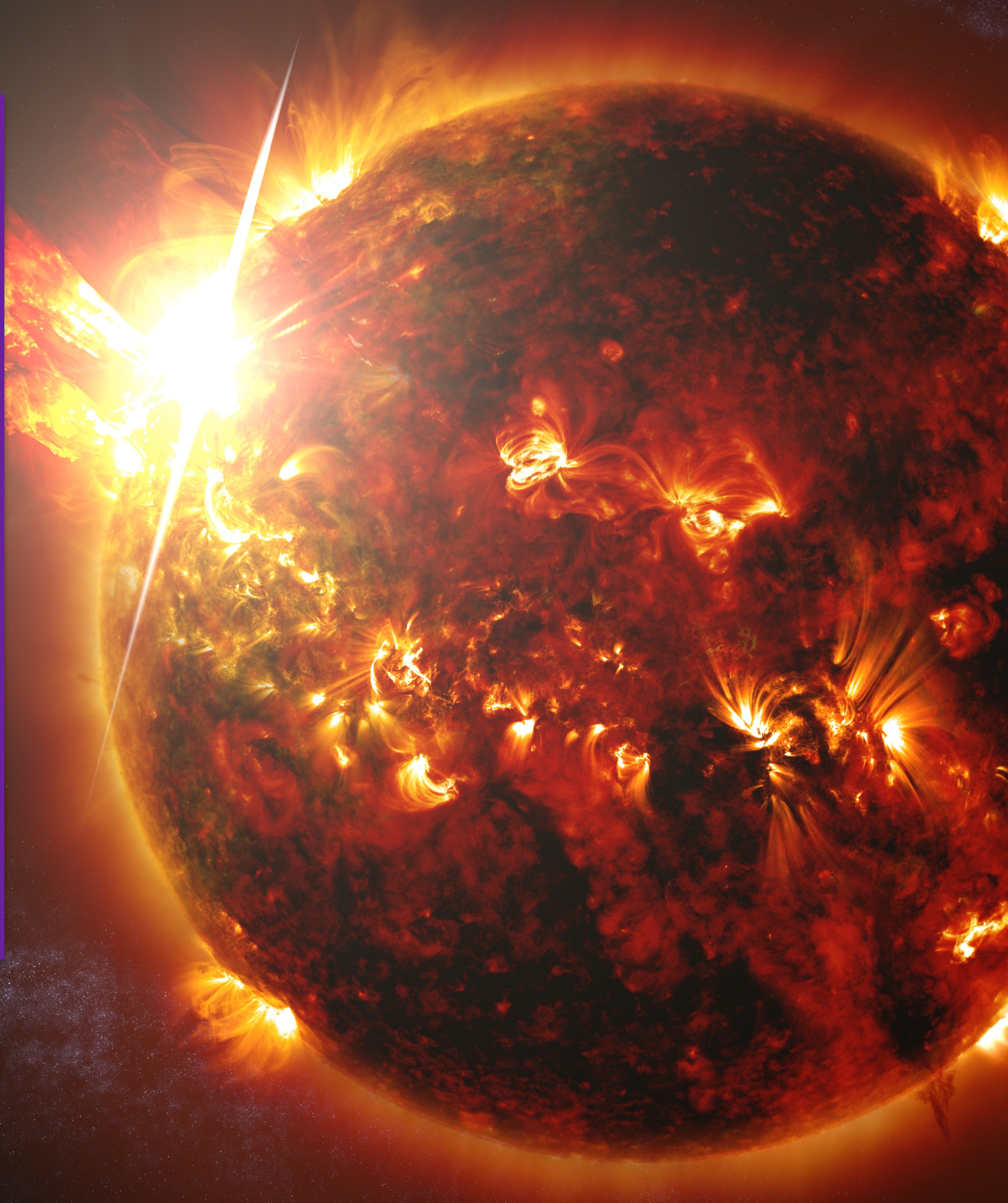
CENTER FOR SPACE SCIENCE NYUAD

جامعة نيويورك أبوظبي

NYU | ABU DHABI

Spin-orbit of exoplanets constrained with asteroseismology



Othman Benomar, Research associate

Asteroseismology

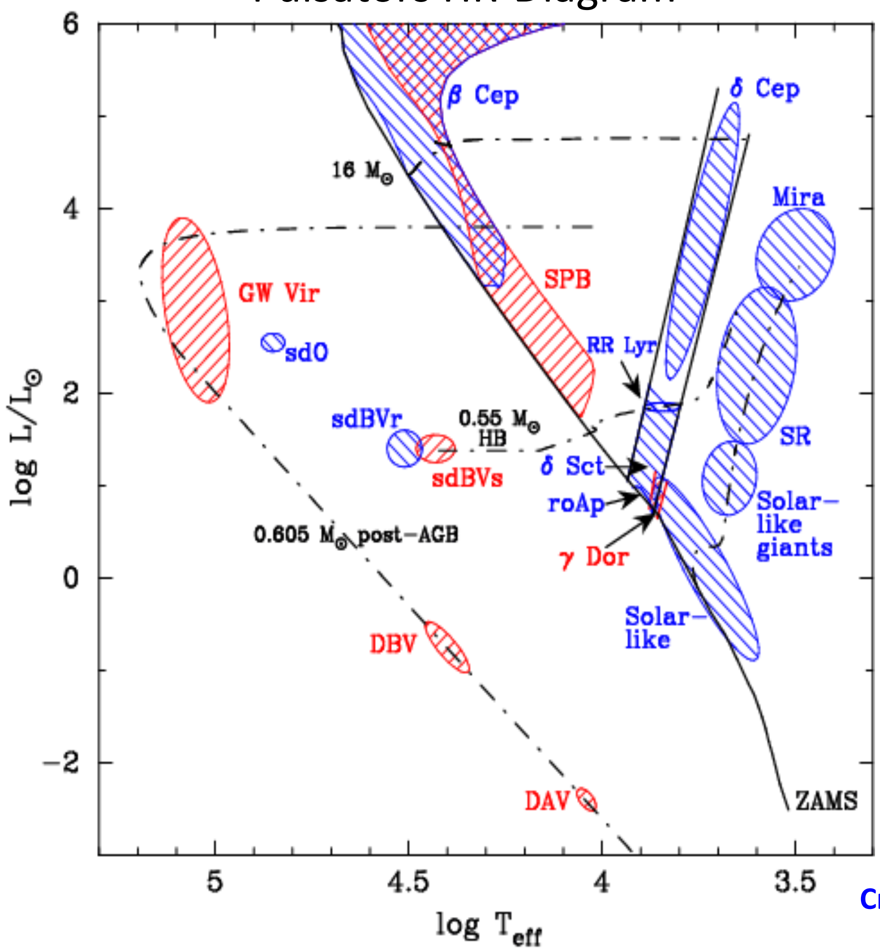
Asteroseismology: *Determines the physics of stars by observing their pulsations*

All stars pulsate: *M, K, G,F,A, B, O … Detecting and interpreting them is the main issue*

Origin of pulsations: *Tidal forces, opacity induced, convection,…*

Various kind of waves: *Alfven waves, gravity waves, acoustic waves, …*

Pulsators HR-Diagram

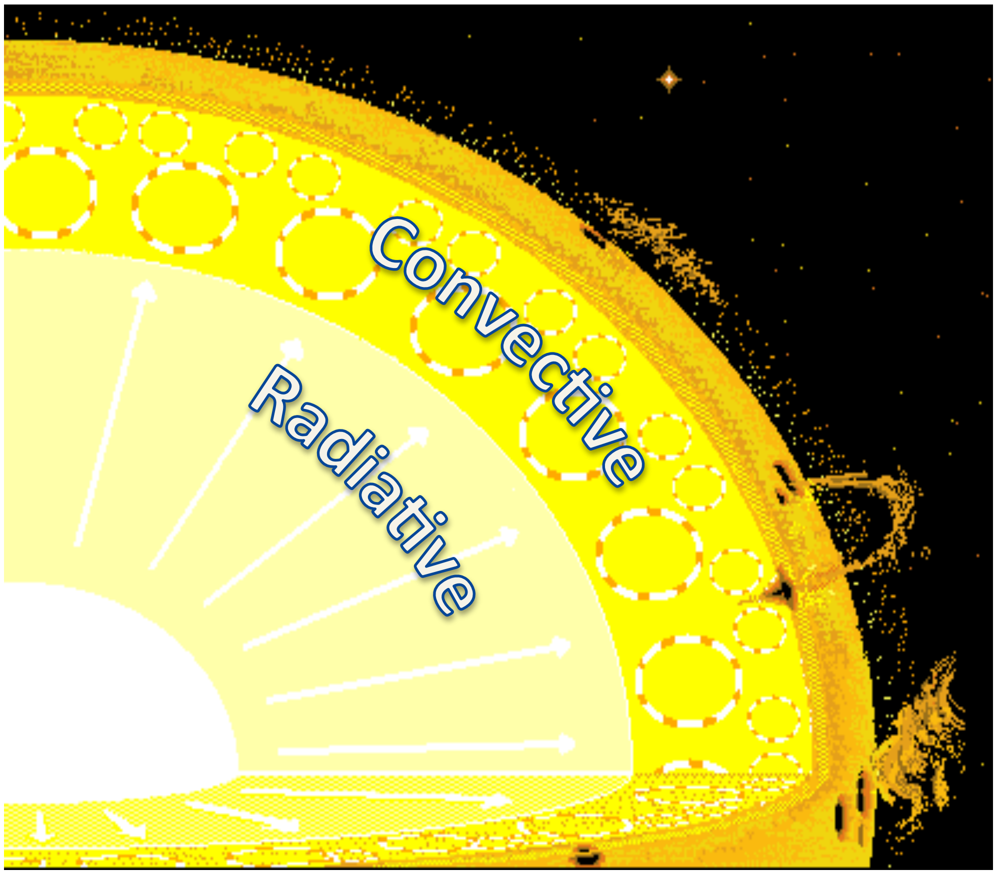


Credit: J.Christensen-Dalsgard

Asteroseismology of solar-like stars

Mass of solar-like stars with detectable pulsations: $0.8M_{sun}<M<2.5M_{sun}$

Sun/Solar-like origin of pulsations (p modes)



Global Seismology

- Convection: Source of local oscillations over a broad frequency range

- Oscillations: propagated waves

- Interference to form global standing waves for frequencies that match resonance frequencies of the cavity (eigenmodes)

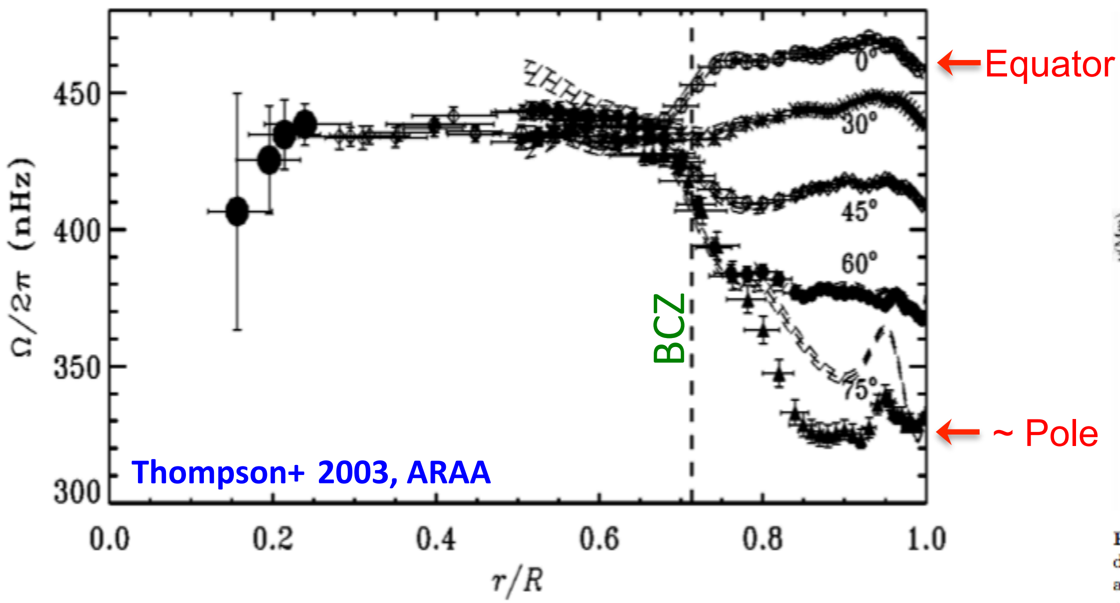
Eigenmode properties strongly depend on the cavity characteristics: shape, size, density, chemical composition …

Asteroseismology/Helioseismology

__Asteroseismology:__ Determines the physics of stars by observing their pulsations
__Sun (Helioseismology):__

- Constraints on the internal structure: Help to solve the Neutrino deficit problem (~1990)
- Determination of the solar rotation profile: Evidence of near-solid body rotation (~2000)
- Constraints on convective process: e.g. Sun spots emergence (local helioseismology, 2000-Now)

Sun Internal rotation profile



Emerging Sunspot 300km under the surface

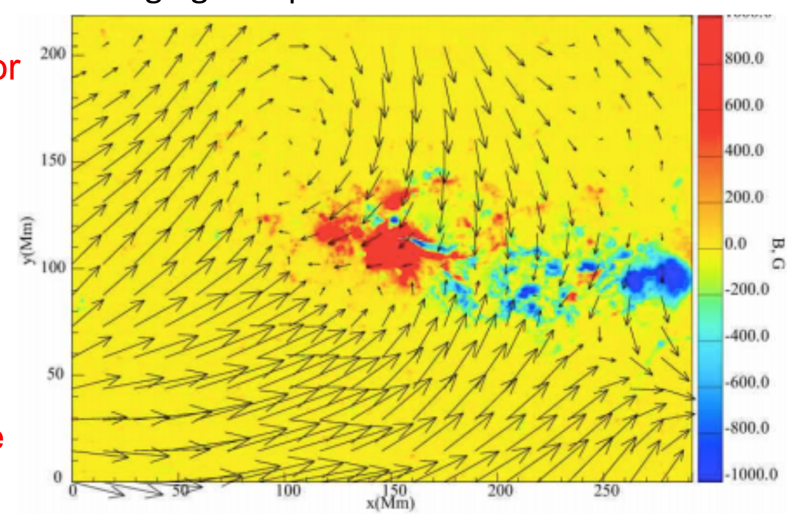


Fig. 6 Arrows show the horizontal flow map around the active region NOAA 11726 at the depth of 0.3 Mm on April 23, 2013, 03:00 UT (when the active region is fully developed) after averaging the high-resolution flow map on a grid with a 15-degree sampling. The color background image shows the surface magnetic field. The typical flow speed is about 50 m/s.

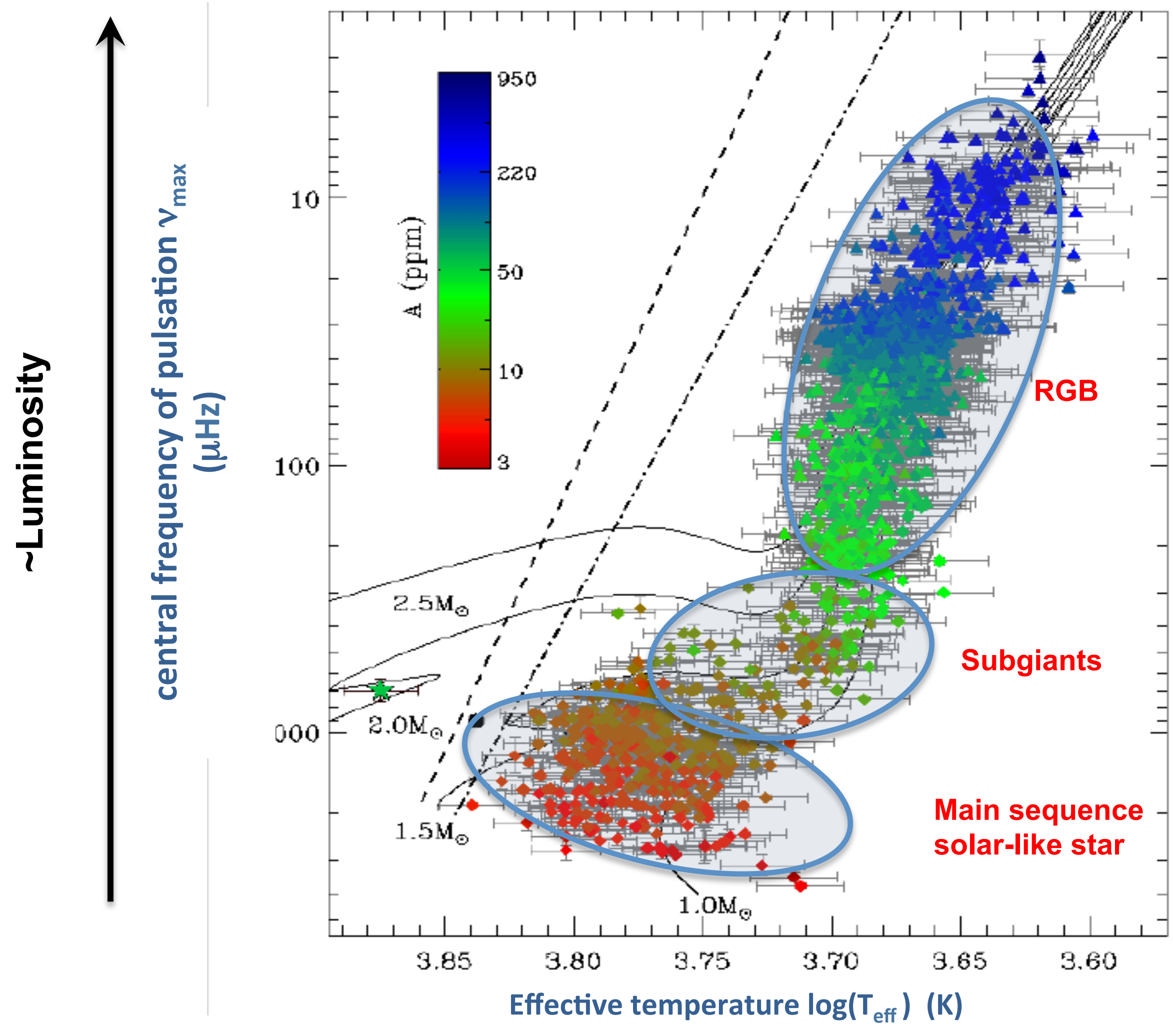
Kosovichev+ 2016

Asteroseismology of solar-like stars

<u>*Asteroseismology:*</u> *Determines the physics of stars by observing their pulsations*

<u>*Solar-like stars:*</u> *First detection from ground by Kjeldsen+1993… but low quality data*

Solar-like pulsators detected by Kepler (Initial phase)



>13 000 pulsators

Credit: Daniel Huber

Asteroseismology of solar-like stars

Improve understanding of stellar physics, e.g.

- Stellar rotation
- Internal stellar structure
- Stellar evolution
- Identification of missing physics

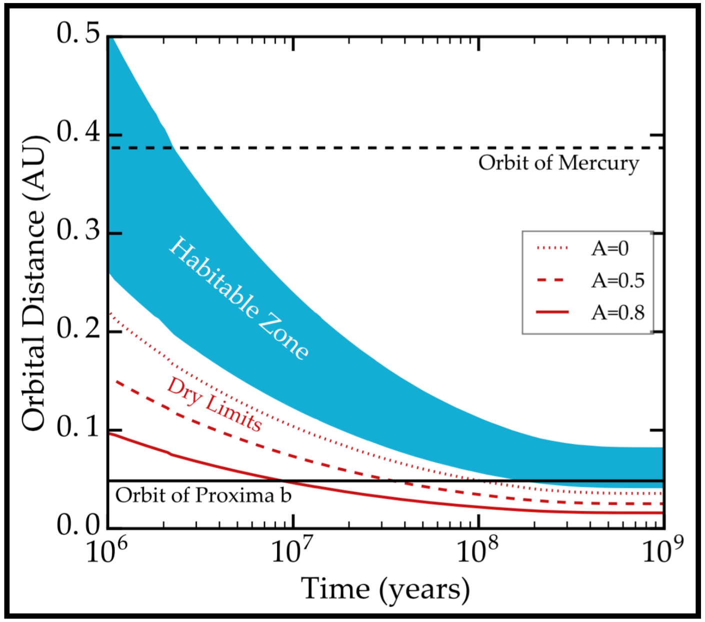
Support galactic evolution studies, e.g.

- Stellar population distribution study
- Formation and evolution of the milky way

Support exoplanet science, e.g.

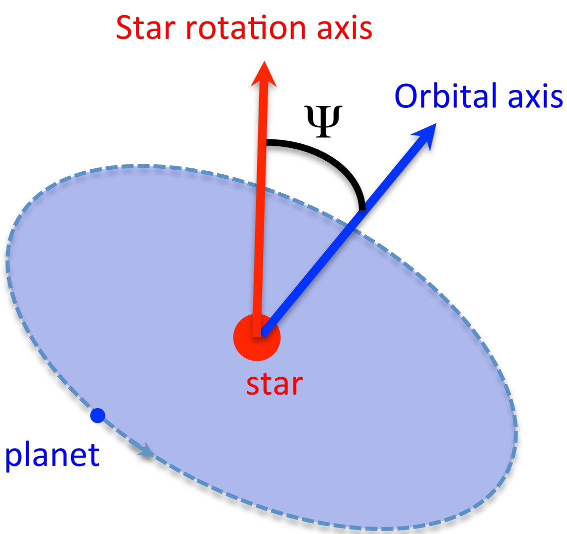
- Planet mass and radius
- Characterize habitable zone
- **Constraints on spin-orbit angle**

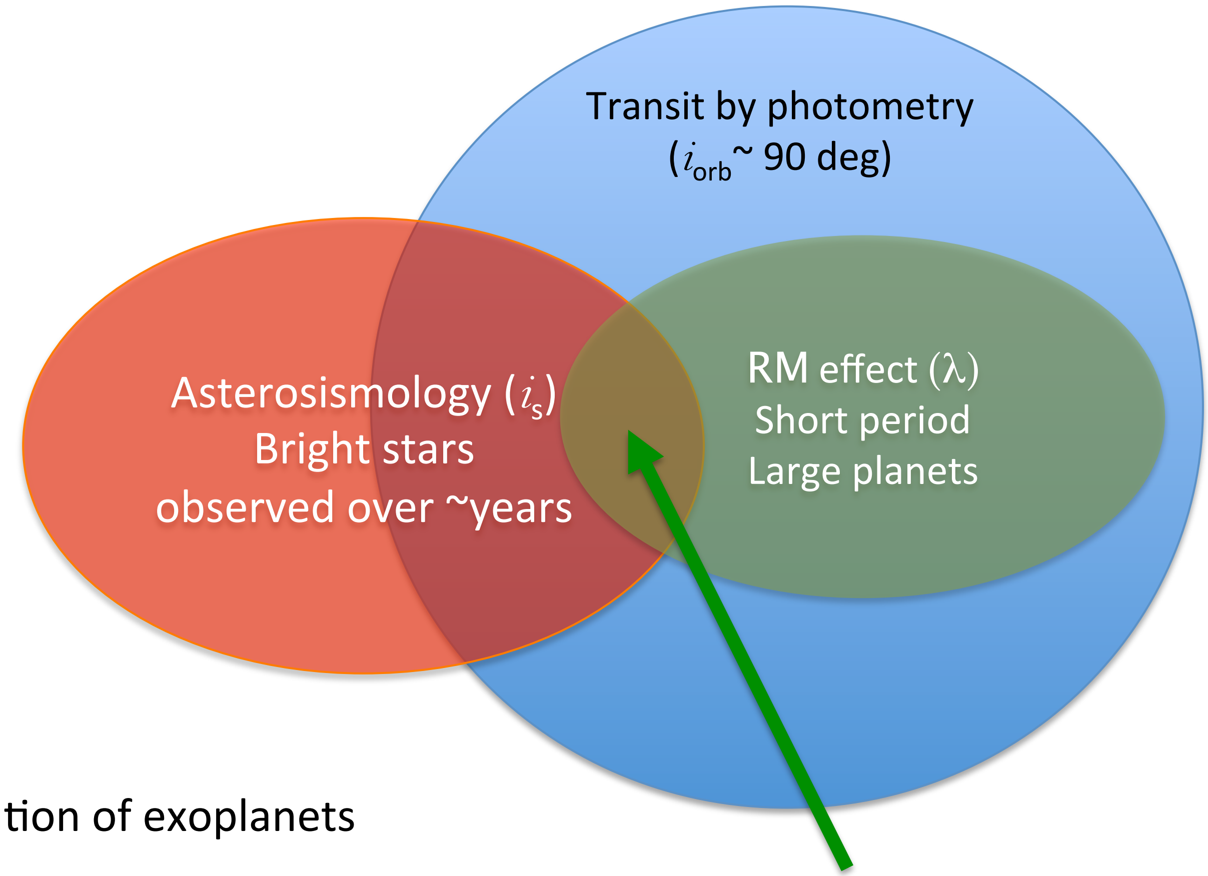
Barnes+ 2016



- **Precision achieved for stellar parameters with seismo:**
  - Few % for Radius
  - 5-10% for Mass
  - ~10-20% in Age

Importance of the spin-orbit angle





$\Psi(\lambda, i_{orb}, i_s)$: spin-orbit angle

Indicator of formation and evolution of exoplanets

Ψ_{SUN} = 7 deg.

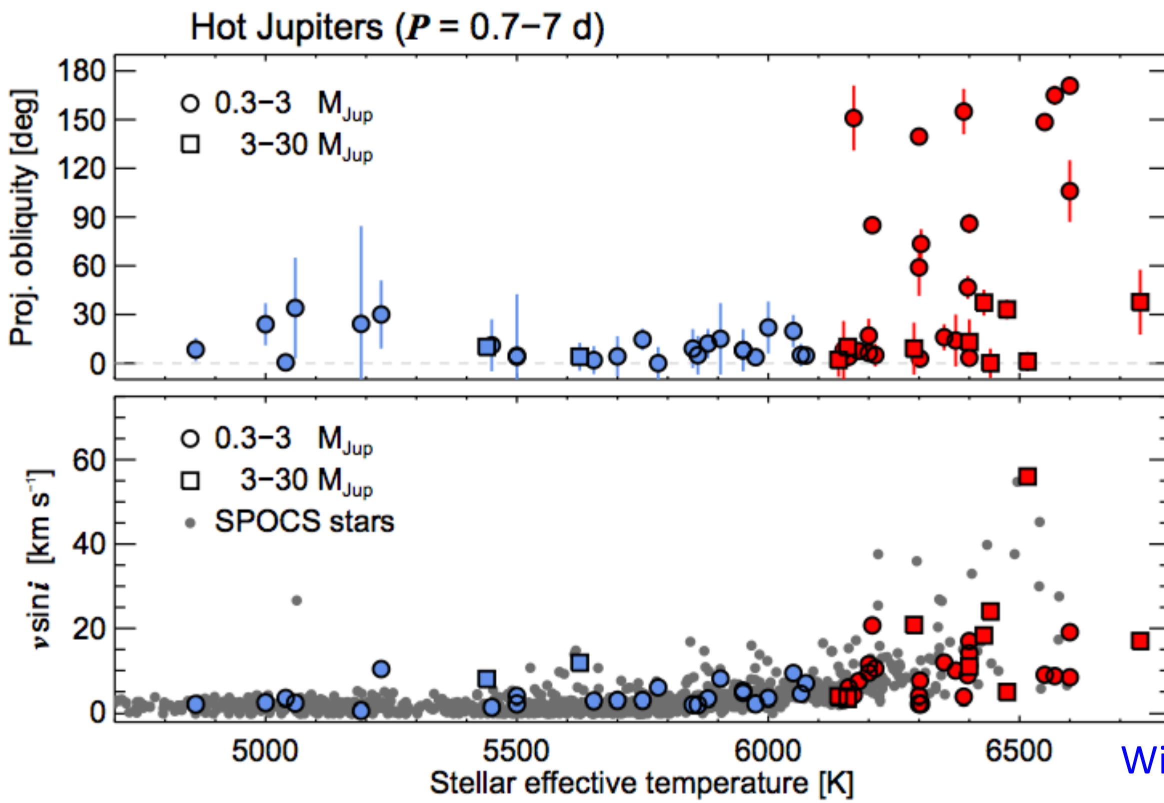
2 stars in the Kepler field: HAT-P-7, Kepler 25

TESS (2018) + PLATO (2026)
➔ ~100 stars (?)

- 3D spin-orbit angle is difficult to measure
- Use instead other indicators

Kepler-25: Likely aligned
HAT-P-7: Confirmed misalignement

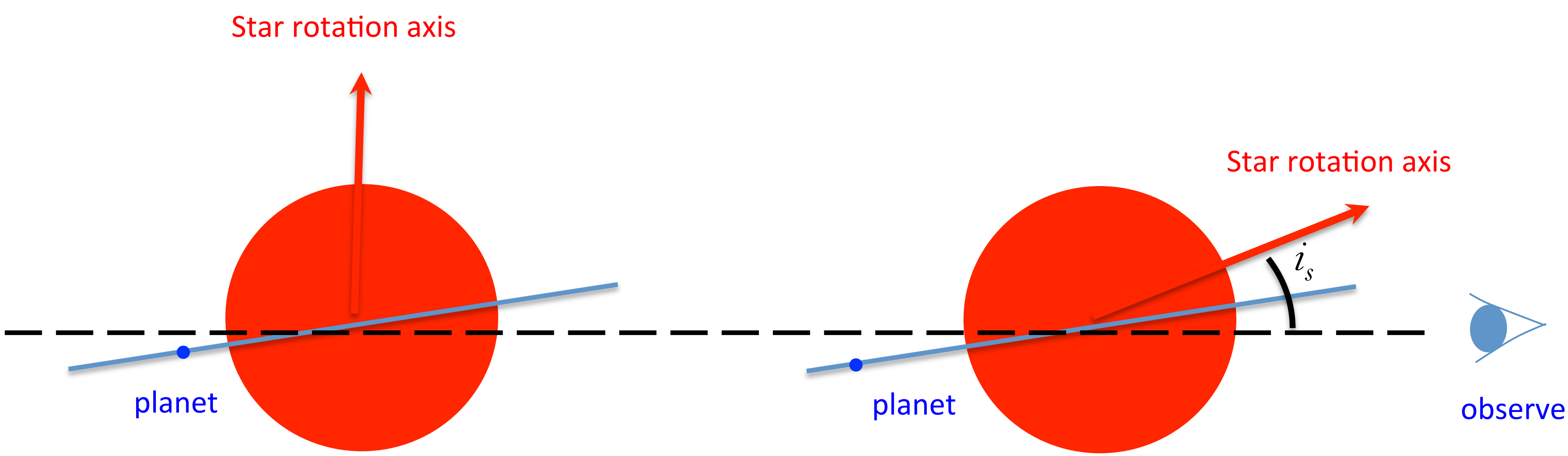
Importance of the spin-orbit angle



Winn 2015

- Use instead other indicators:
  - λ Projected spin-orbit into the plane of the sky from RM
  - $V sin(i)$ combined with transit (i_{orb})

Importance of the spin-orbit angle



i_s = 90 deg.
star seen from equator

i_s << 90 deg.
➔ Misalignment

Seismology brings independent way to constrain the spin-orbit by:

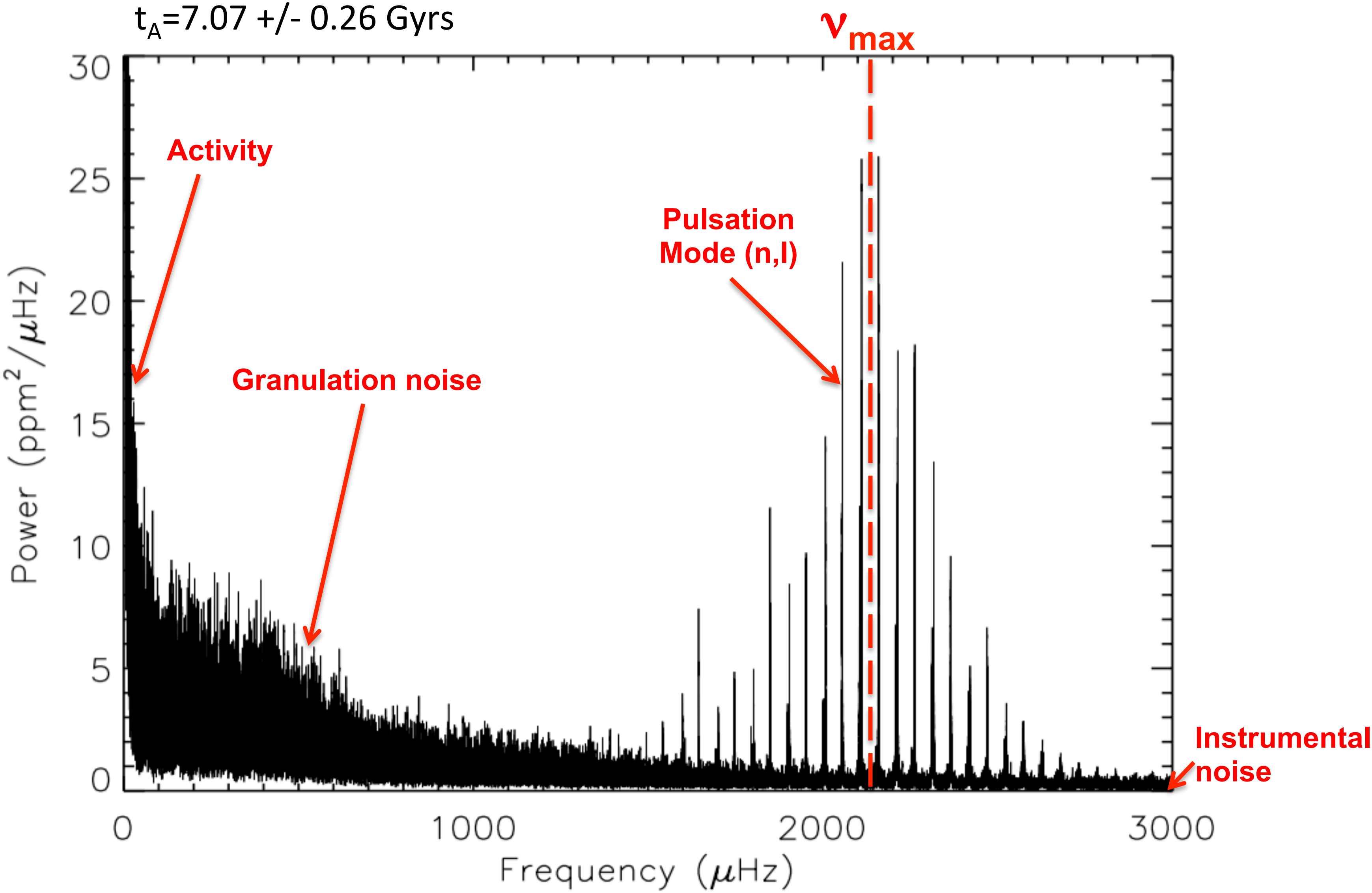
- stellar inclination + transit + RM: True spin-orbit: Benomar+ 2014, Lund+ 2014, Campante+ 2016

- stellar inclination + transit: detection of mis-alignement: Huber+ 2013

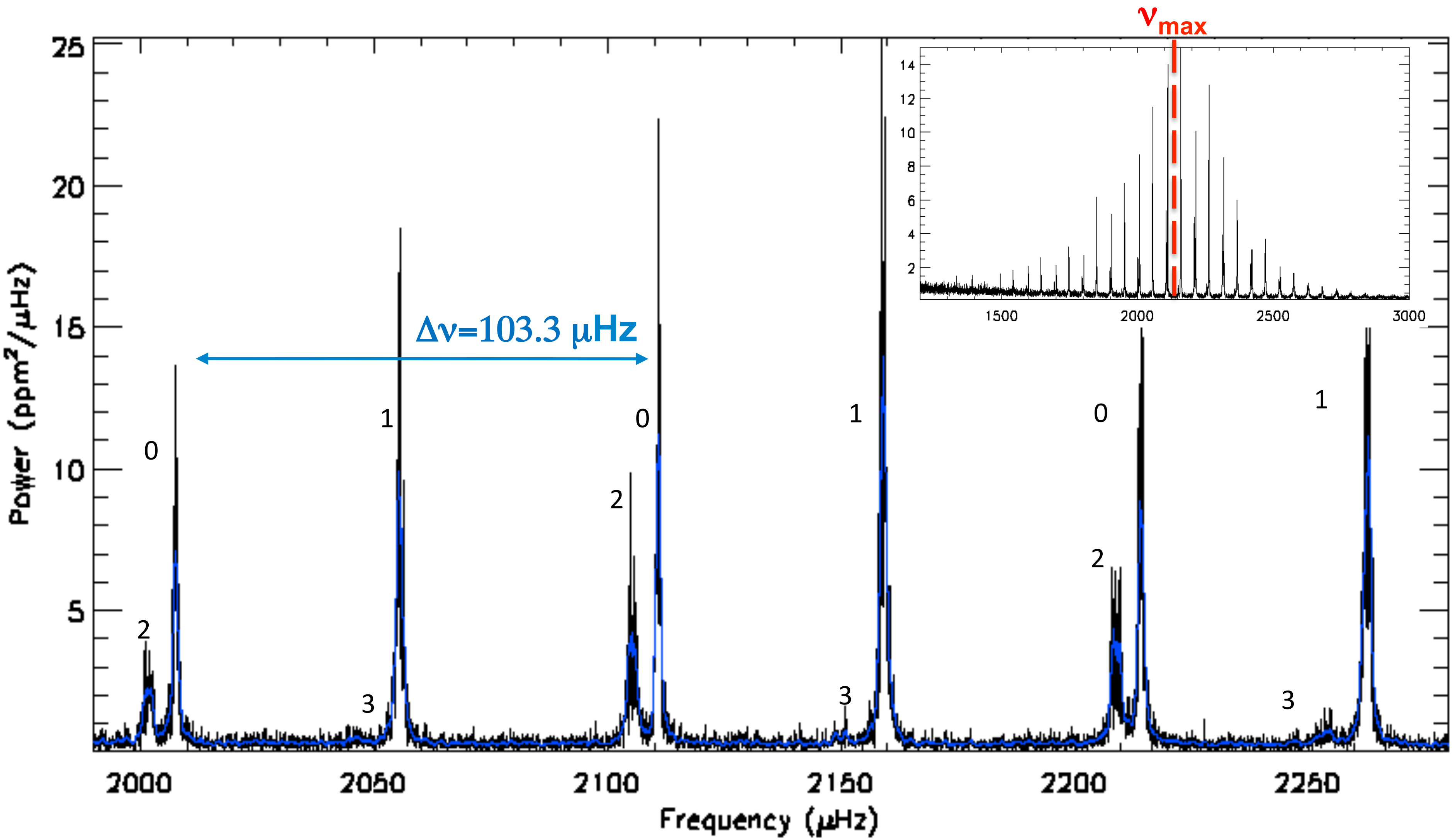
Useful for small planets

16 Cyg A : The brightest star of the Kepler Field

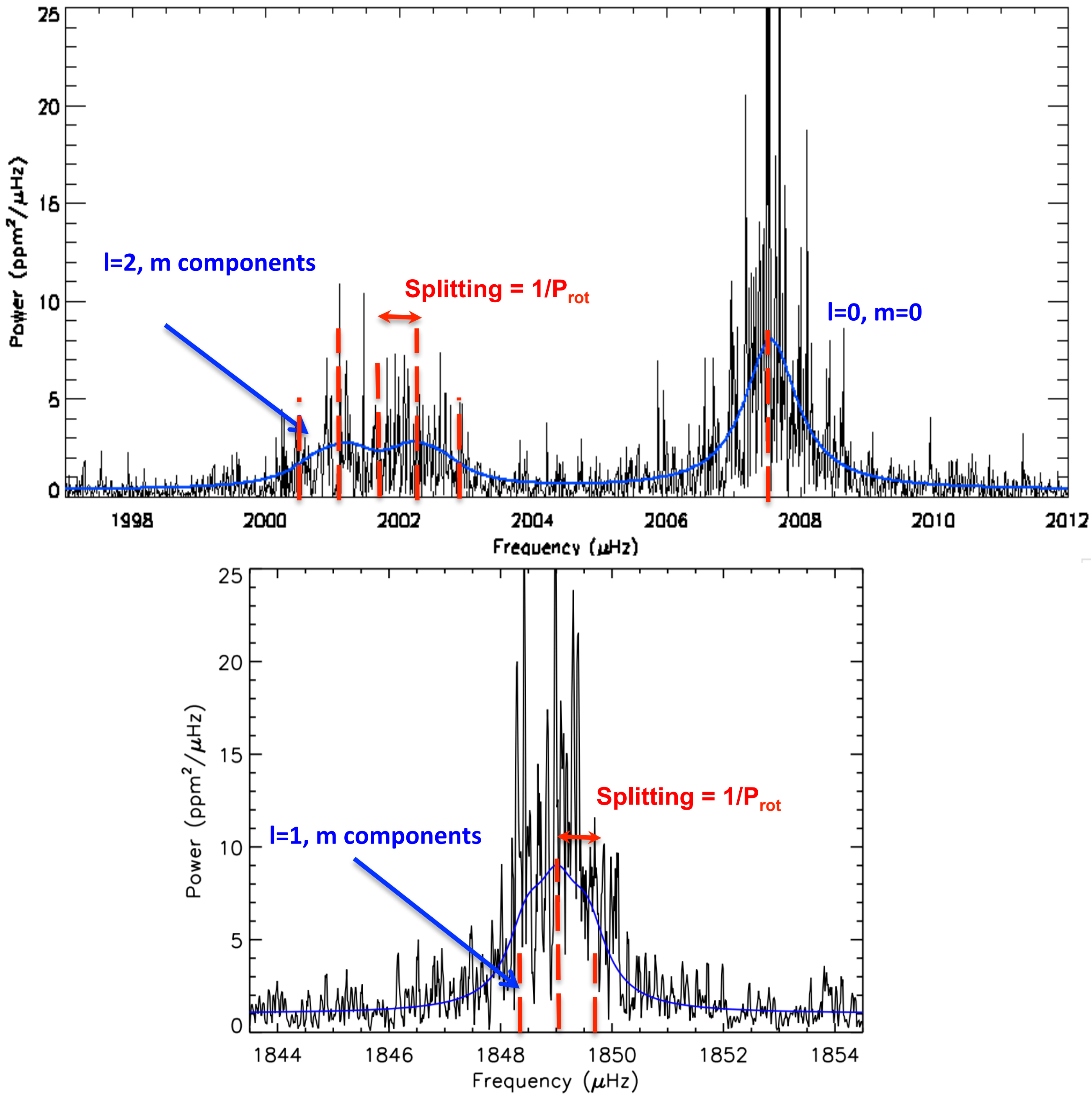
M_A=1.08 +/- 0.02 M_{sun}
R_A= 1.229 +/- 0.008 R_{sun}
t_A=7.07 +/- 0.26 Gyrs



16 Cyg A : The brightest star of the Kepler Field

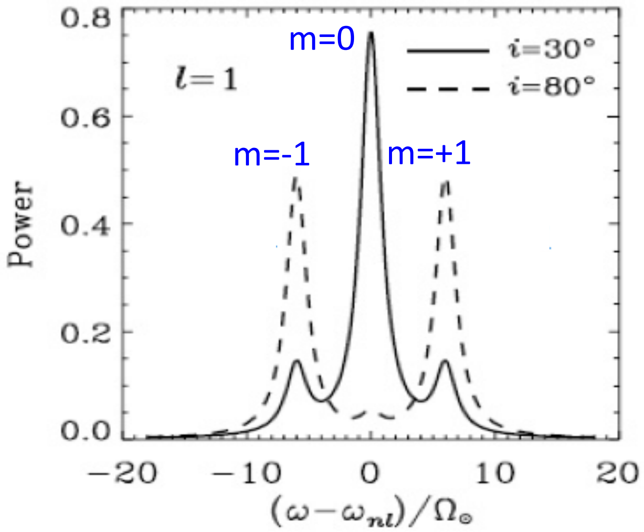


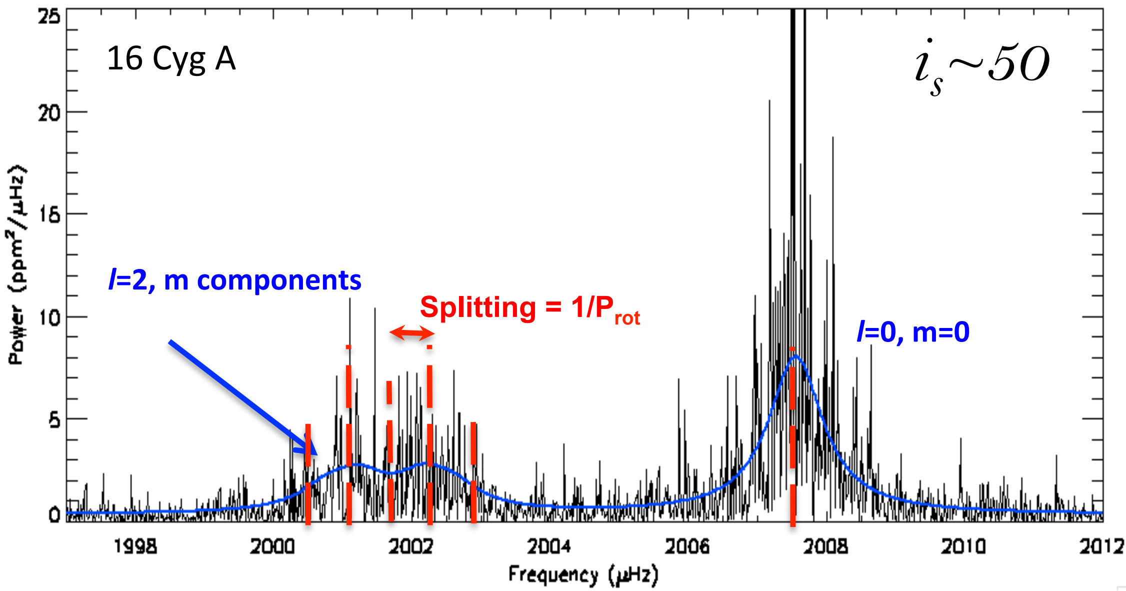
16 Cyg A : The brightest star of the Kepler Field

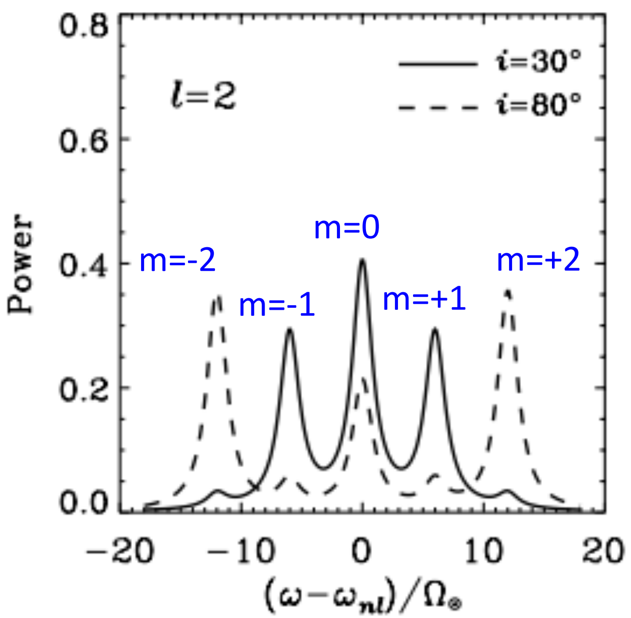


16 Cyg A : The brightest star of the Kepler Field

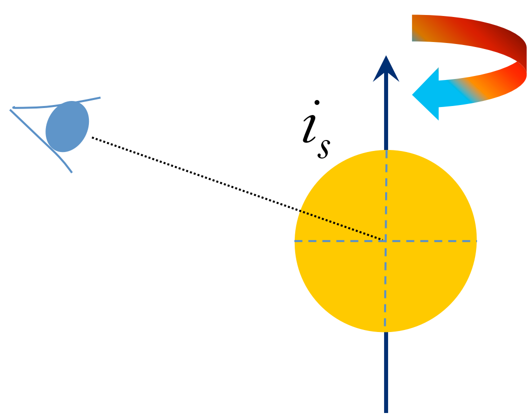
Toutain & Goutebroze, 1993
Gizon & Solanki, 2003





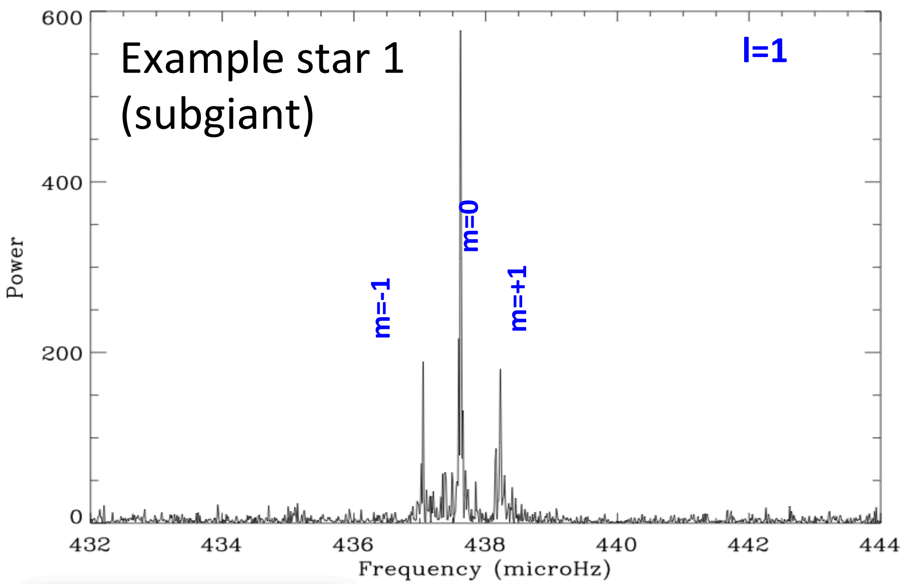


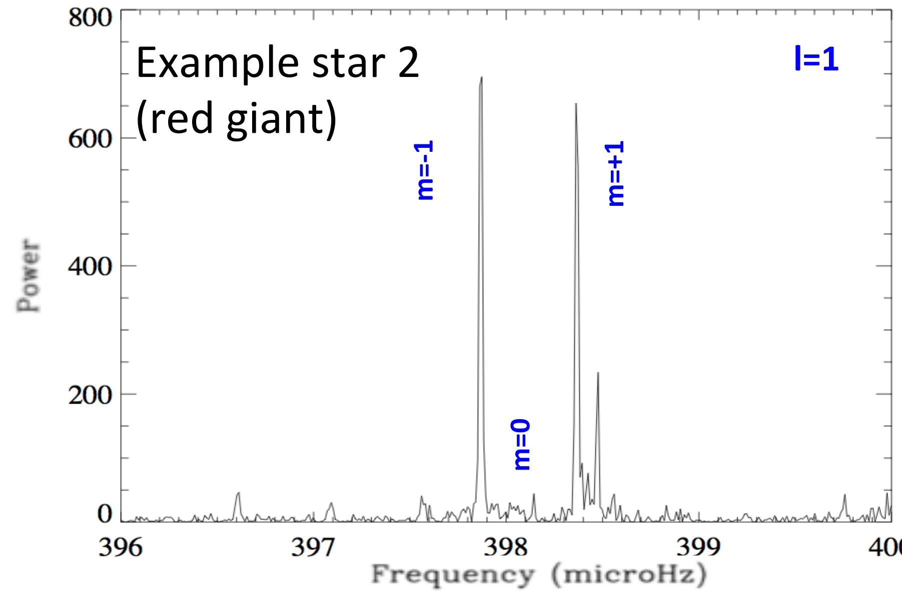
- For l>0, m component height is modulated by the stellar inclination



Evolved stars: example of remarkable accuracy

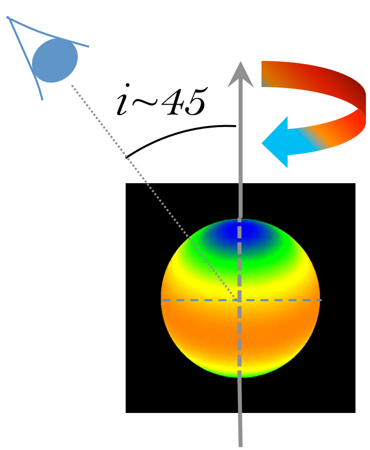
$$\nu_{n,l,m} = \nu_{n,l,0} + m\delta\nu_{n,l}$$

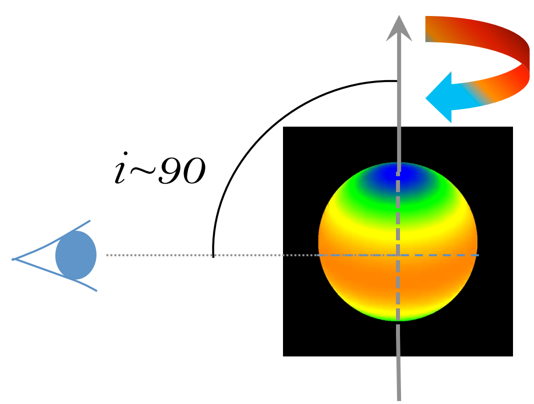




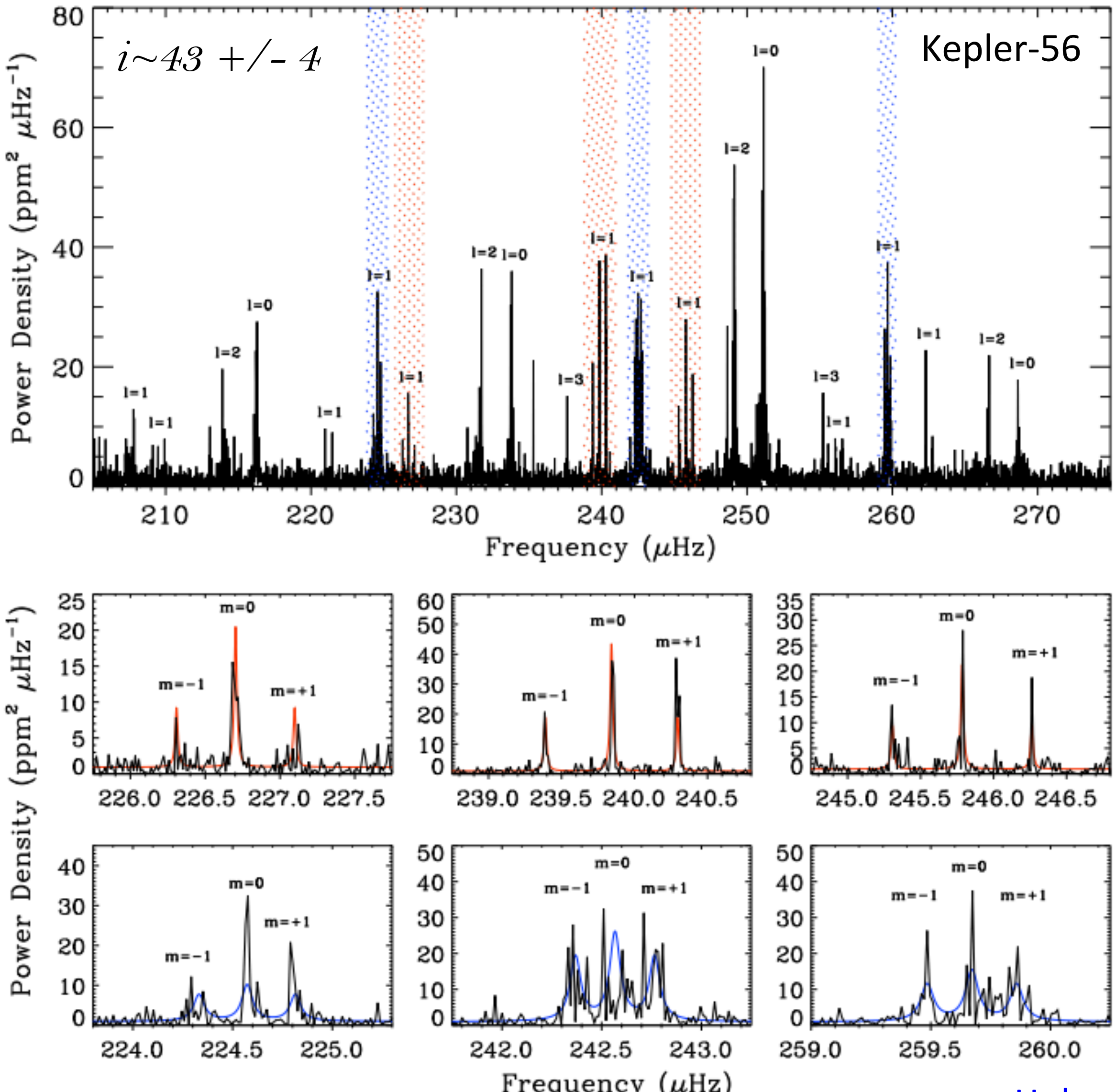
Why different amplitudes for the m-components of these l=1?

The star seen from different point of views





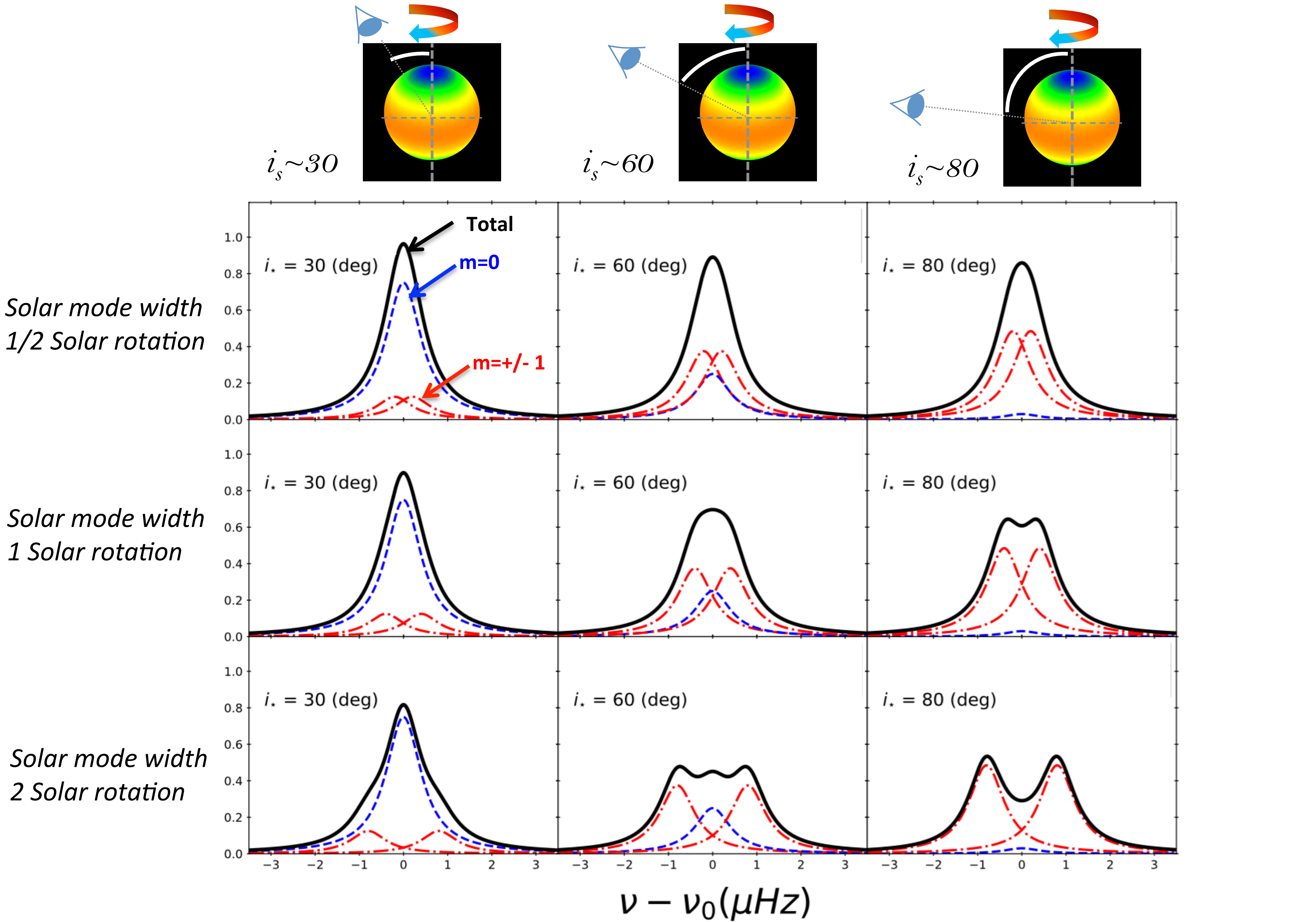
Evolved stars: example of remarkable accuracy



Huber+ 2013

Combining Transit (i_{orb}) and stellar seismology (i_{star}) has the potential to detect misaligned systems

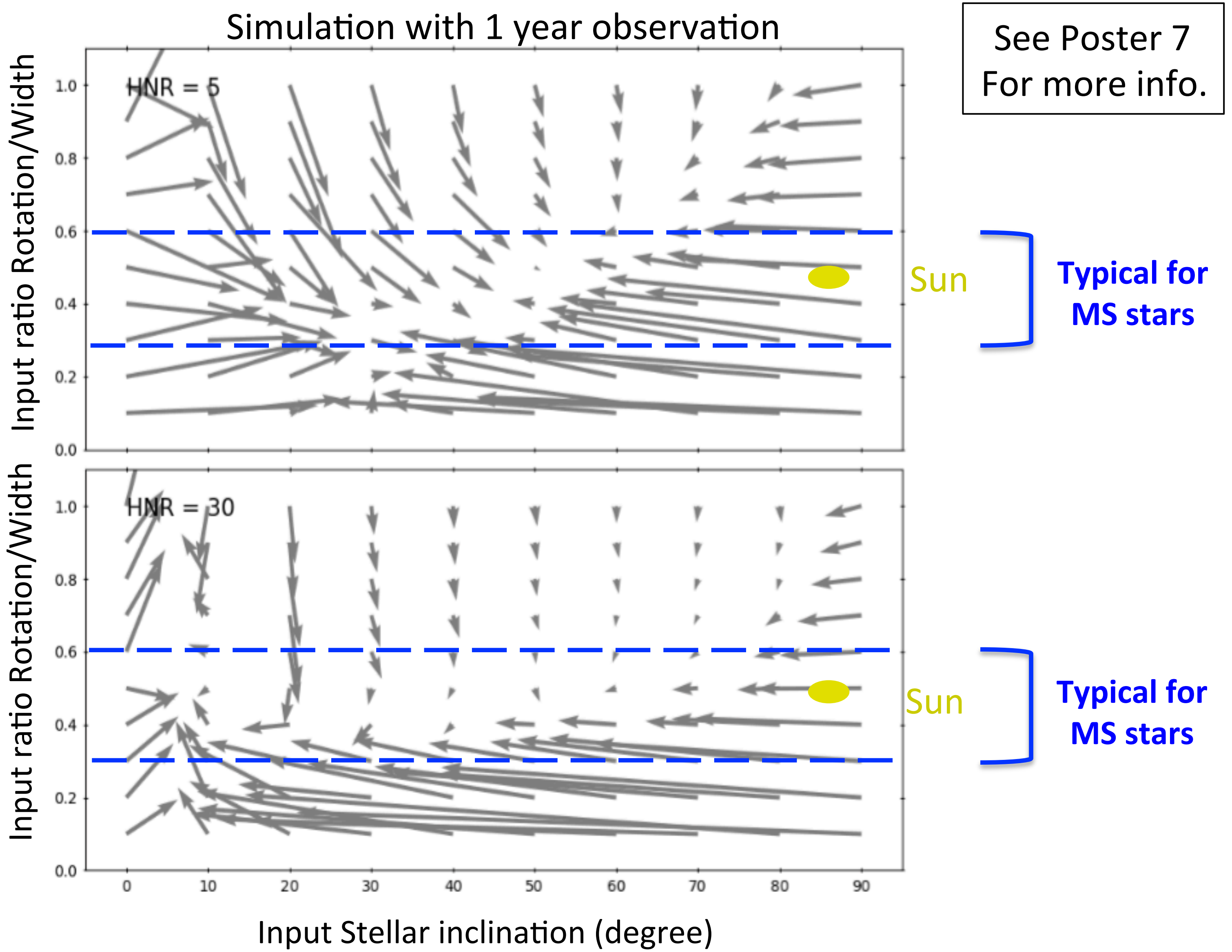
Main sequence stars: Larger uncertainty…



Main sequence stars: Larger uncertainty... lower accuracy

HNR=5
(Typical Kepler observations)

HNR=30
(Best Kepler observations)



See Poster 7
For more info.

Large systematics prevent us to accurately measure stellar inclination in the vast majority of Main sequence stars

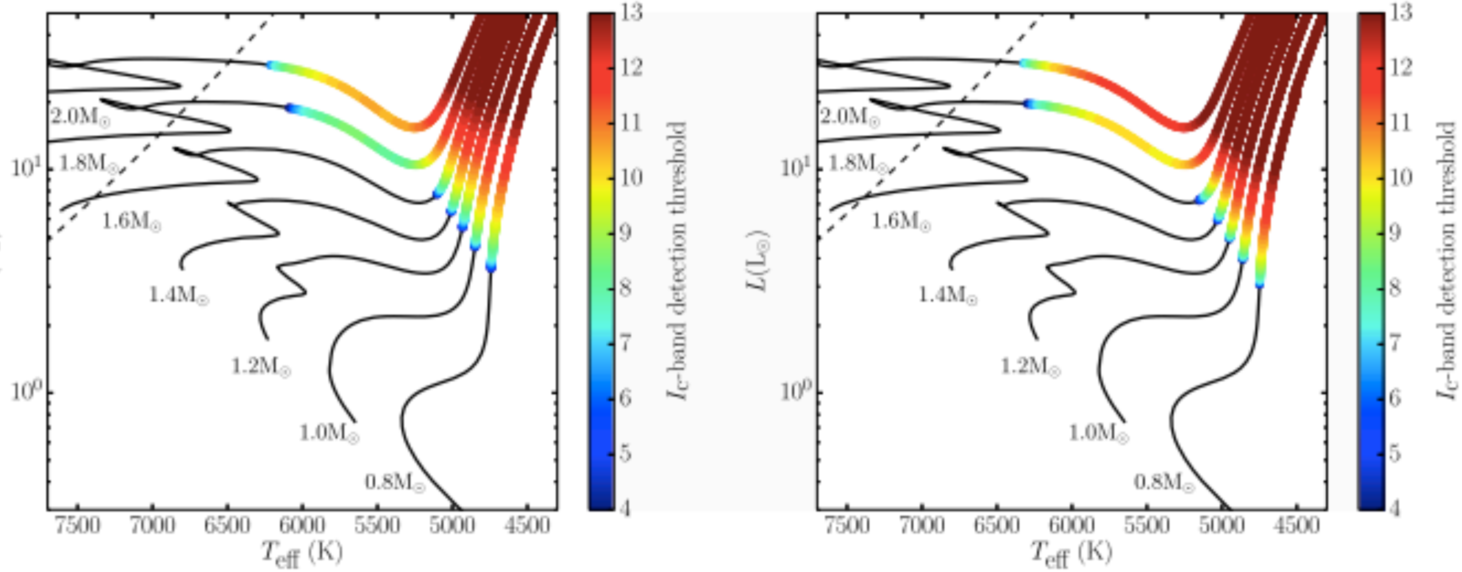
Conclusions/Remarks

Seismology can provide valuable insight on the interior of stars: Mass, Radius, Age, Rotation, Stellar inclination …

- Well established theory for solar-like stars ➔ Could provide stellar constraint for exoplanets
- But systematics are not well characterized because computationally intensive
- For the stellar inclination: Systematics are negligible for evolved stars
- Need an evaluation of the systematics when Tobs > 1 year for proper interpretation of results from Campante+ 2016 (First study of obliquities for sub-neptune sized planets)
    - 15-30% of systems with single planets are found to be misaligned
    - Alignment for multiple systems
- TESS:
    - Study of spin-orbit for evolved stars(SG, RGB) should be feasible and accurate
      ➔ What happens to planets when the star transition from MS to RGB?
    - Challenging to measure stellar inclination in MS stars
        - Lower SNR than Kepler
        - Less than 1 year observation

TESS: Detectability of pulsations across the HR-diagram

30min cadence

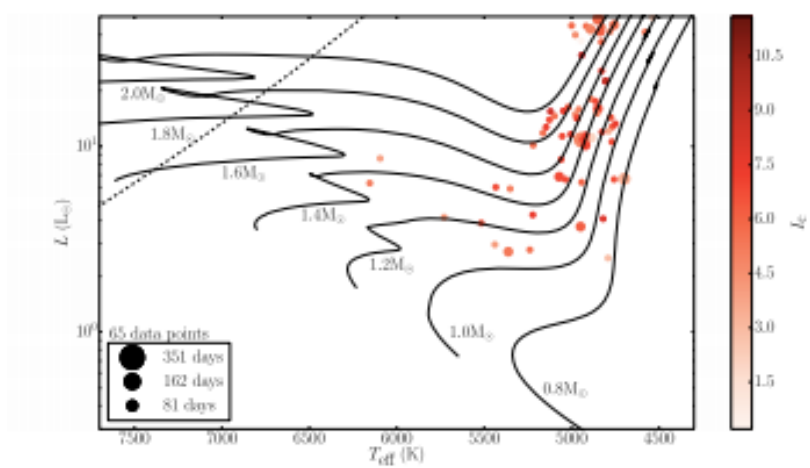


(a) $T = 27\,\mathrm{d},\ \sigma_{\rm sys} = 60\ \mathrm{ppm\,hr}^{1/2}$. (b) $T = 351\,\mathrm{d},\ \sigma_{\rm sys} = 60\ \mathrm{ppm\,hr}^{1/2}$.

Figure 6. Detectability of solar-like oscillations with *TESS* across the H-R diagram for a cadence of Δt = 30 minute. Solar-calibrated evolutionary tracks spanning the mass range 0.8–2.0 $M_\odot$ (in steps of 0.2 $M_\odot$) are displayed. I_C-band detection thresholds are color-coded (no detection is possible along those portions of the tracks shown as a thin black line). Modeled stars were assumed to be isolated (i.e., D = 1). The slanted dashed line represents the red edge of the δ Scuti instability strip. The two panels consider different lengths of the observations (T) and a systematic noise level of $\sigma_{\rm sys}$ = 60 ppm hr$^{1/2}$, as indicated.

Campante+ 2016

2min cadence



(b) $\sigma_{\rm sys} = 60\ \mathrm{ppm\,hr}^{1/2}$.

Main sequence stars: Larger uncertainty… lower accuracy

Spectroscopy

$$f_{surf} = \frac{V \sin i}{2\pi R \sin i}$$

asteroseismology

Vsini: average velocity field on the seen hemisphere. Sensitive to the micro/macroturbulence

Spots: rotation of the star (or lifetime of spots?) at the unknown latitude of the spots + multiple spots?