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PLATO 2.0 Complementary & Legacy Science

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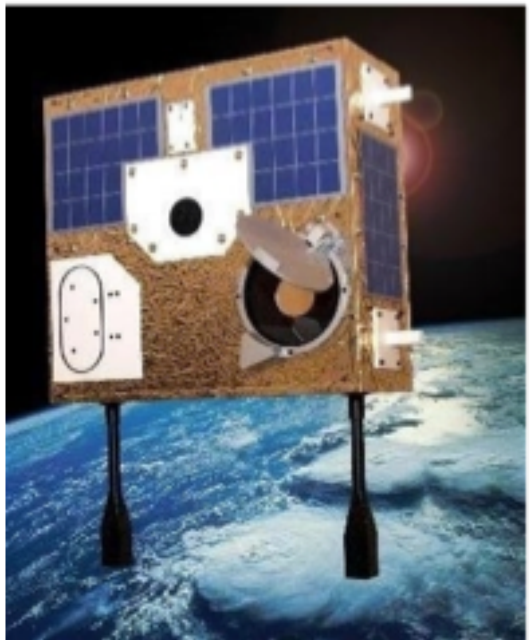
Potential of Legacy Science: Lessons learned from MOST

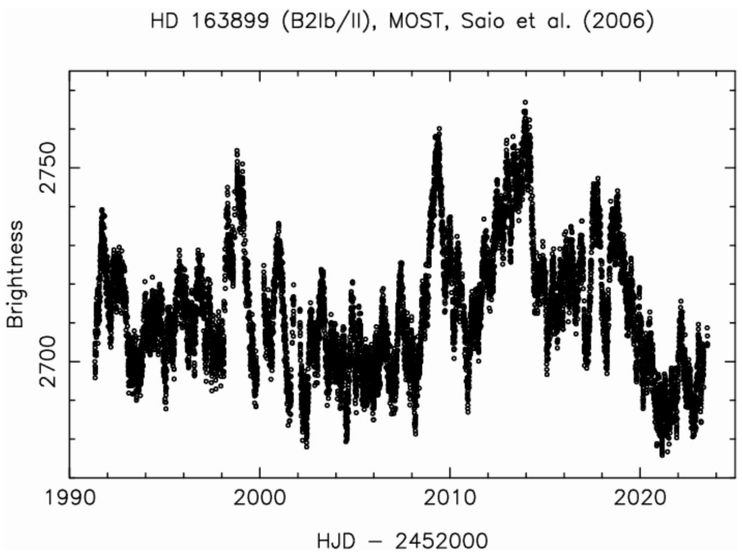
- **Major Science Goals**
  - Sun-like stars
  - Metal-poor subdwarfs
  - pulsating magnetic stars (roAp)
  - Wolf Rayet stars
  - giant exoplanets orbiting other stars

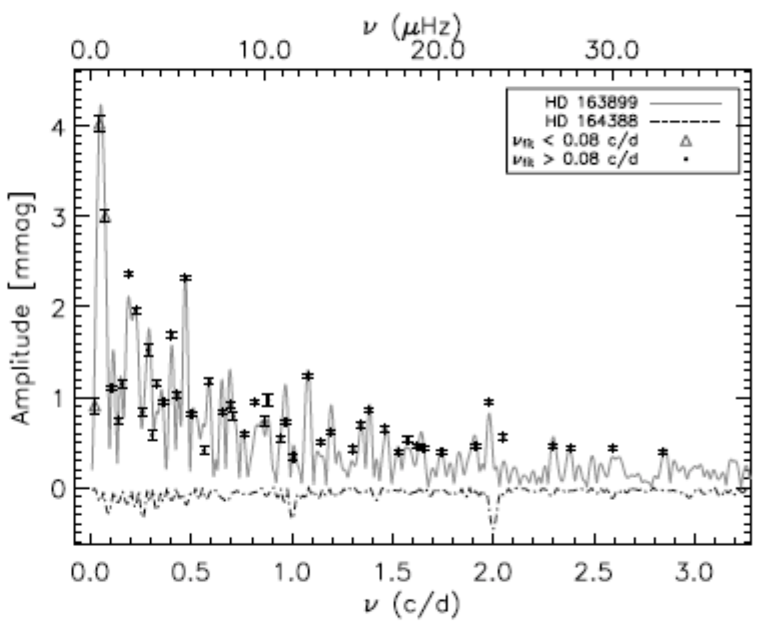


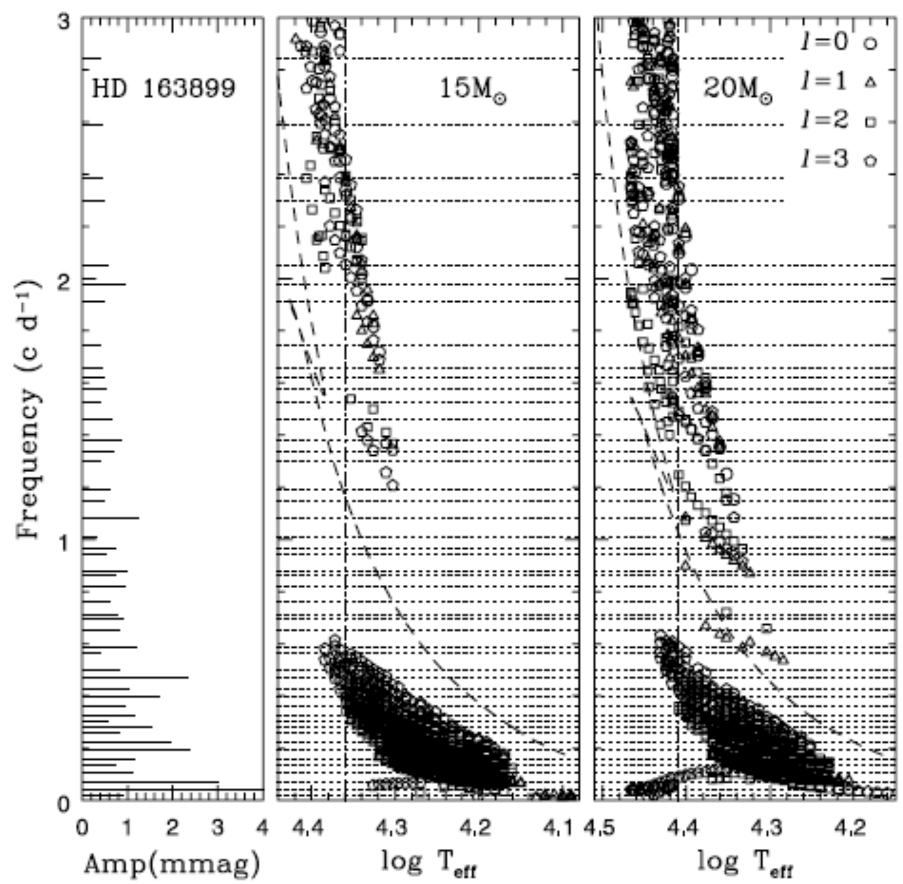
- **Additional Science Topics**
  - clusters, classical pulsators (δ Scuti, γ Dor, β Cephei, SPB, RR Lyrae stars, Cepheids etc.), binaries, T Tauris, Herbig Ae stars, pre-main sequence pulsators, red giant pulsators, ...

MOST Additional Science: Blue Supergiants with p- and g-modes

- **HD 163899**: B2Ib/II (Saio et al. 2006), V=8.3, MOST Guide star during a WR campaign... so no plan for simultaneous spectroscopy
- 48 frequencies ≲ 2.8 c/d with few millimagnitudes
- compatible with theory
- but no identification of modes possible
- previously unknown group: **slowly pulsating B super-giants (SPBsg)**







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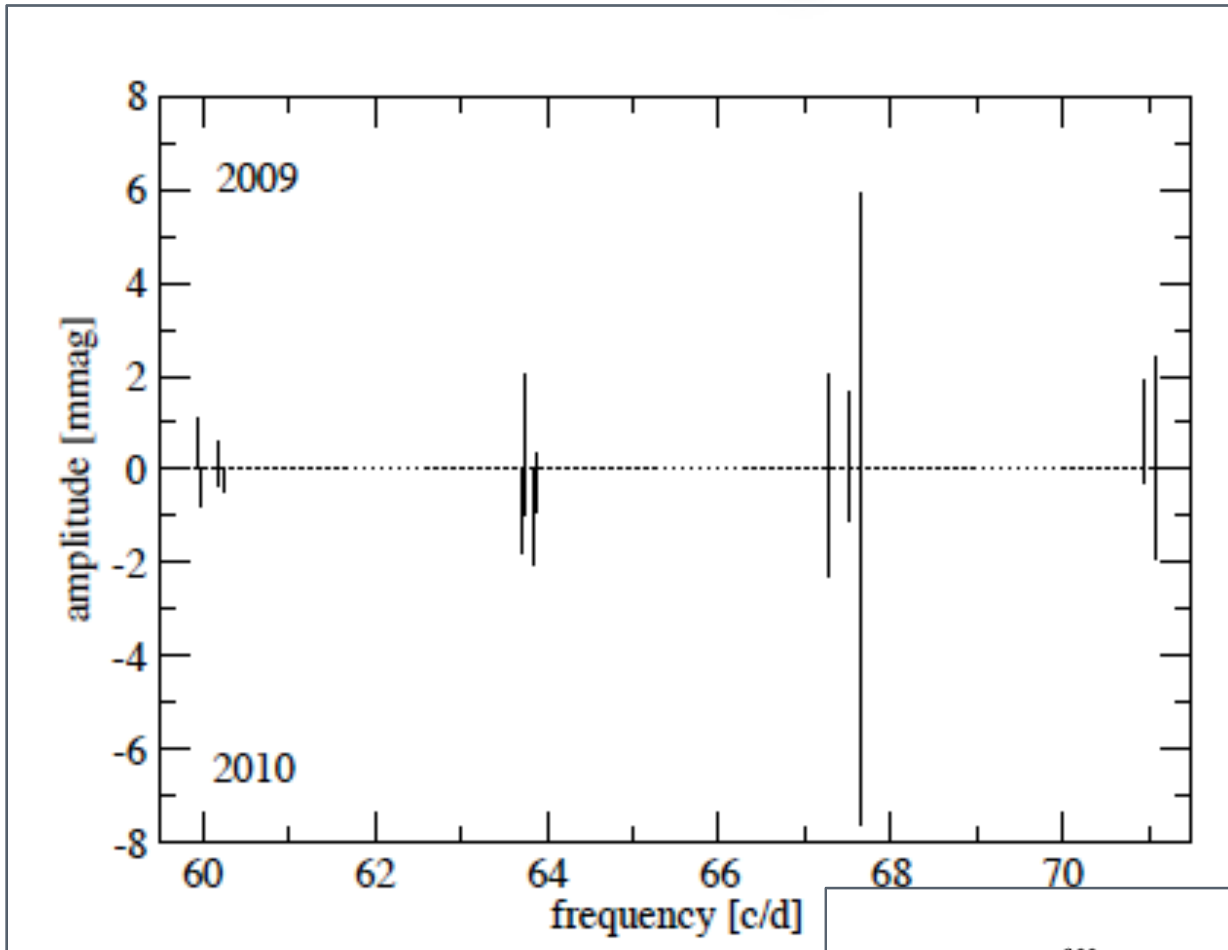
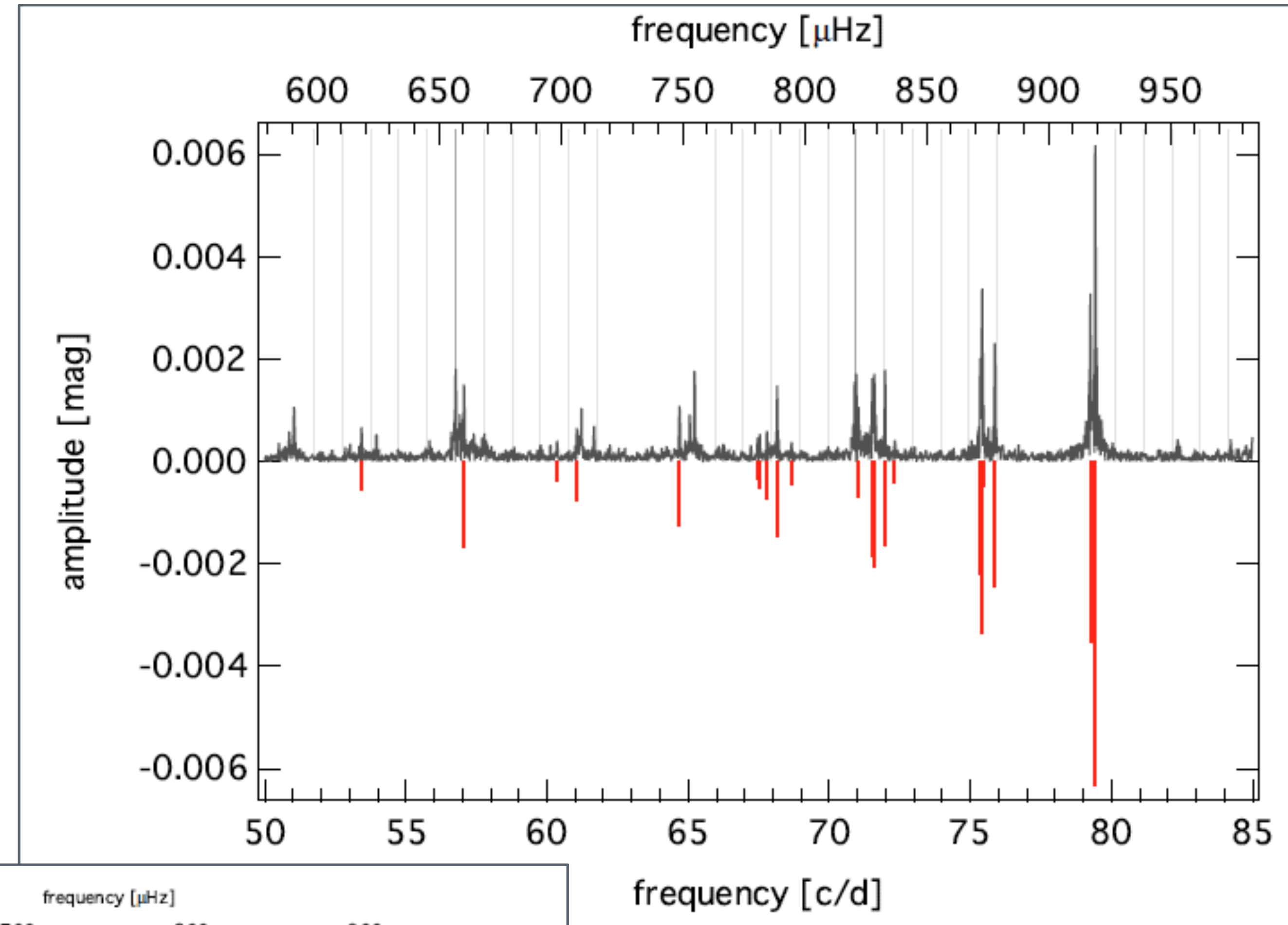
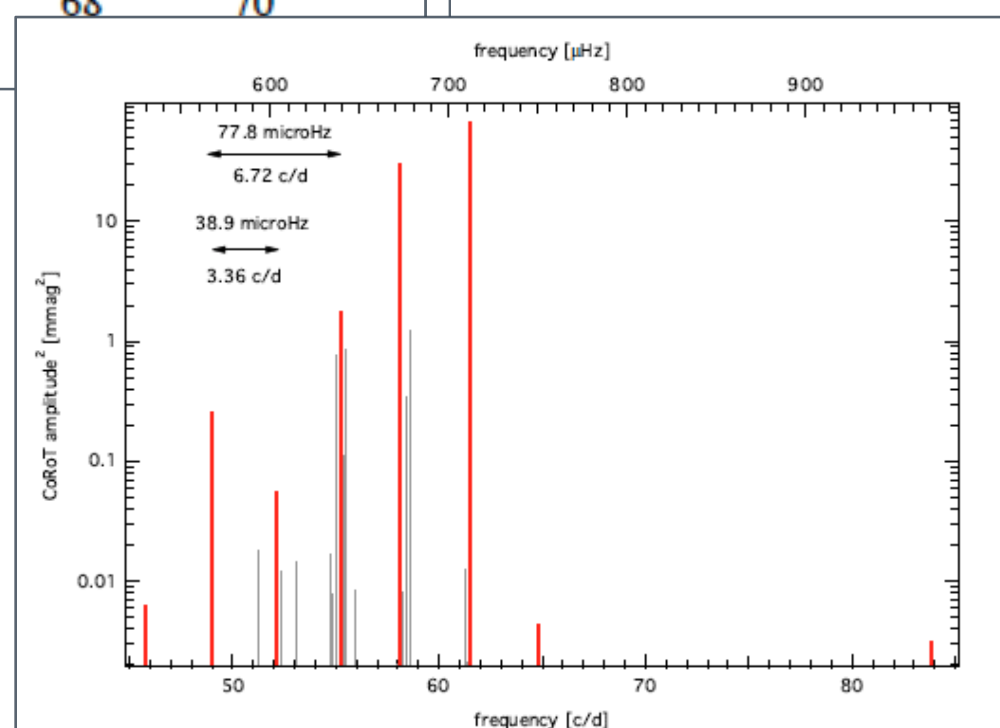
MOST Additional Science: Regular frequency patterns in δ Scuti stars







HD 144277

Zwintz et al. (2011)

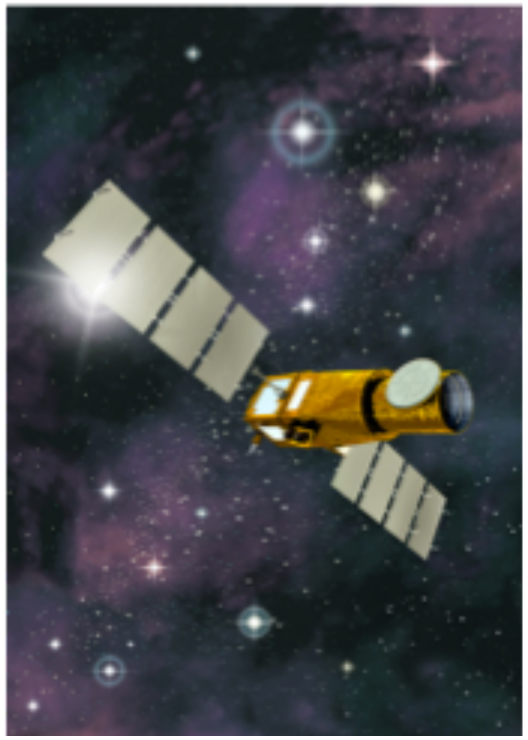
HD 34282

Casey et al. (2012)

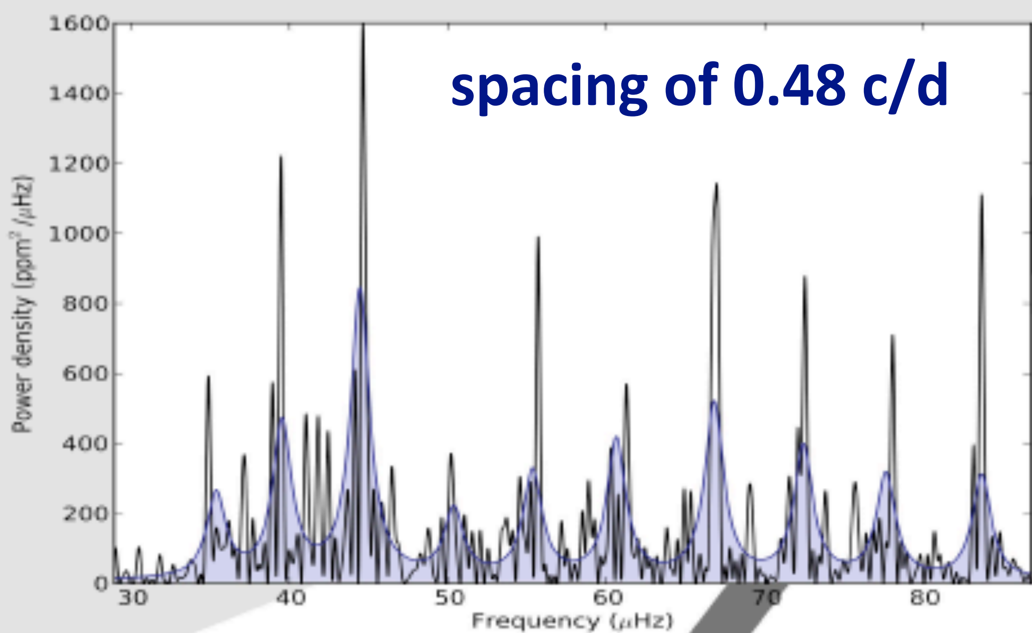
HD261711:
MOST & CoRoT
(Zwintz et al. 2013)

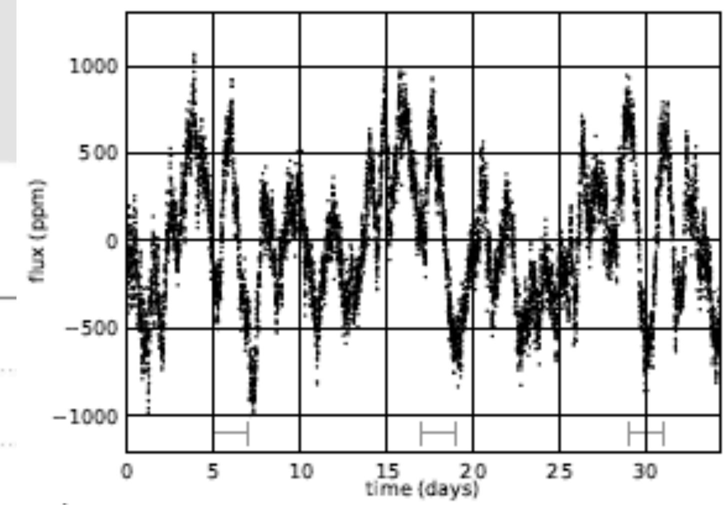
Potential of Legacy Science: Lessons learned from CoRoT

- **Major Science Goals**
  - Asteroseismology & Detection of Exoplanets
- **Additonal Program Working Group (PI: W. W. Weiss)**
  - Activity & rotation (J. Renan de Medeiros)
  - Be stars (C. Neiner)
  - Convection and short time scale activity (S. Aigrain)
  - γ Doradus stars (P. Matthias)
  - Eclipsing binaries (C. Maceroni)
  - Pre-main sequence stars (K. Zwintz)
  - Pulsating G and K giants (J. de Ridder)

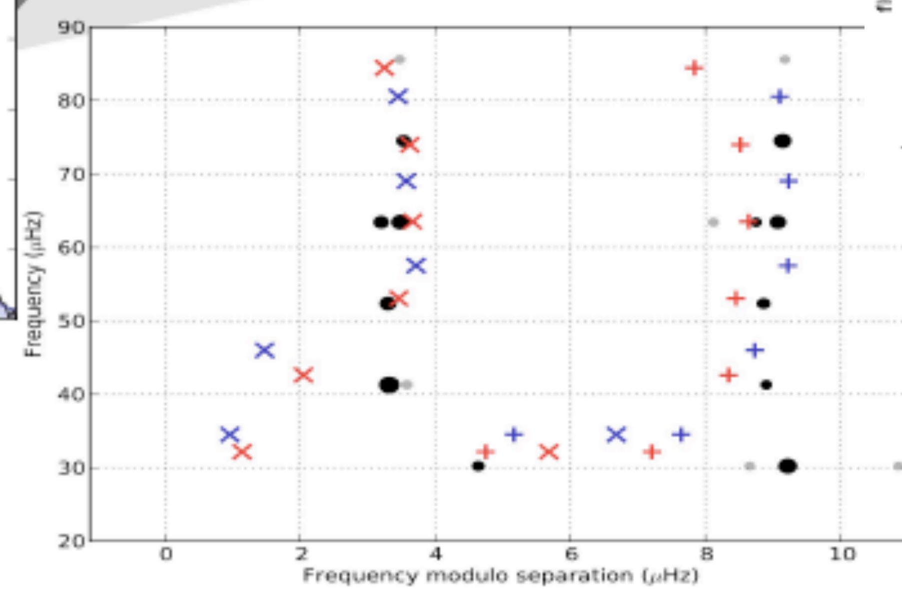


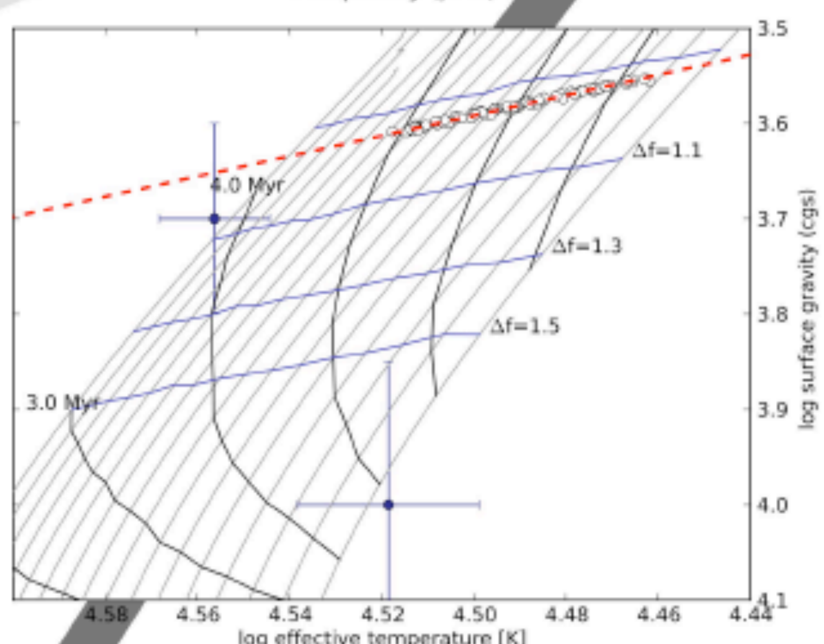
CoRoT Additional Program: Solar-like oscillations in the O8.5V star HD 46149





Degroote et al., A&A, 2010a





l=0 & l=1 p-modes

Outside instability strips, but frequencies according to eigenmodes of star with $\sim 30 M_\odot$

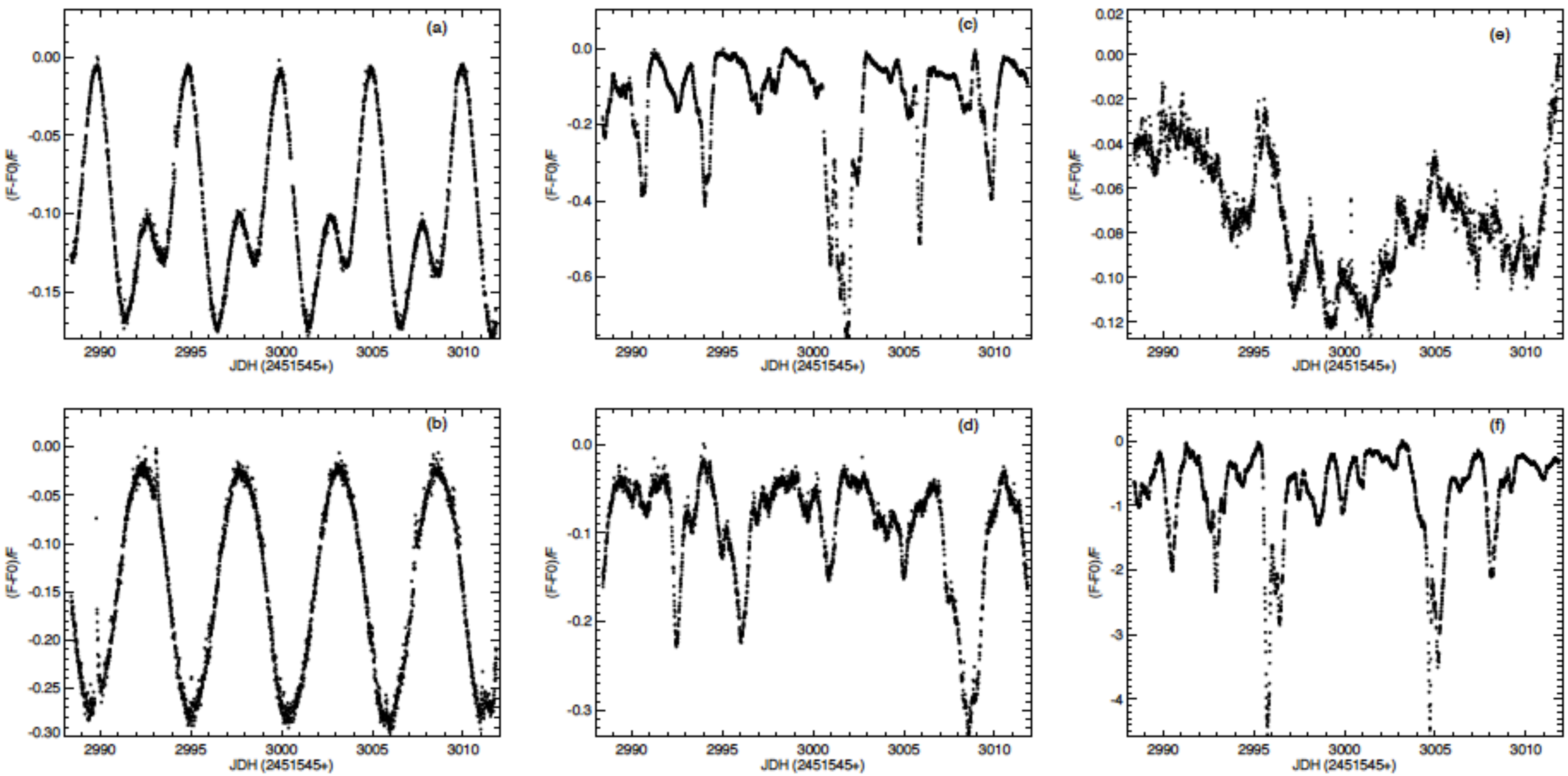
Stochastically-excited oscillations with finite life times were unexpected

Slide courtesy of Pieter Degroote

CoRoT Additional Program: The young cluster NGC 2264

Alencar et al. (2010)

NEW CLASS



28 spot-like
- sinusoidal-like
- stable shape

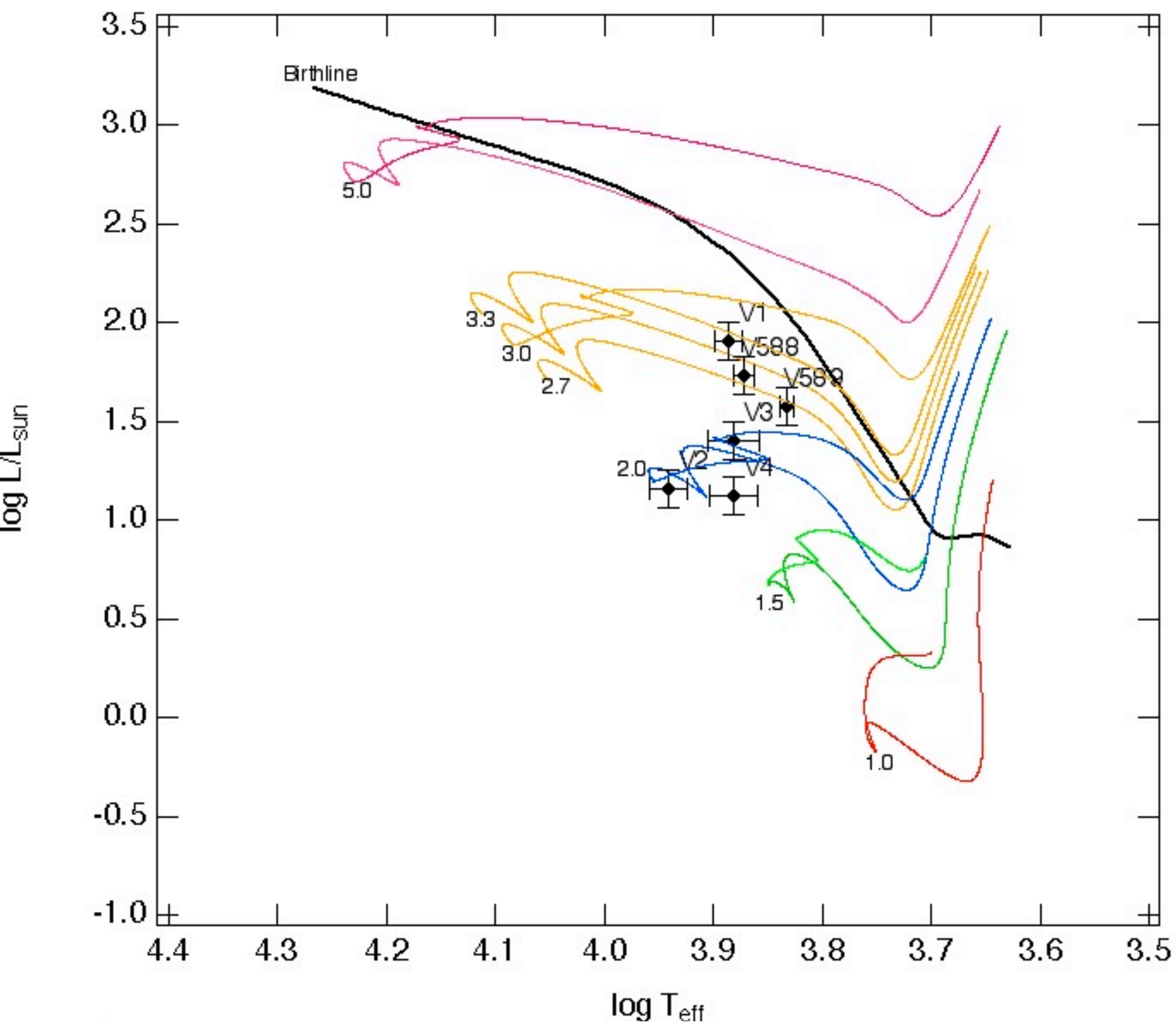
23 AA Tau like
- semi-regular
- 28% of all CTTSs

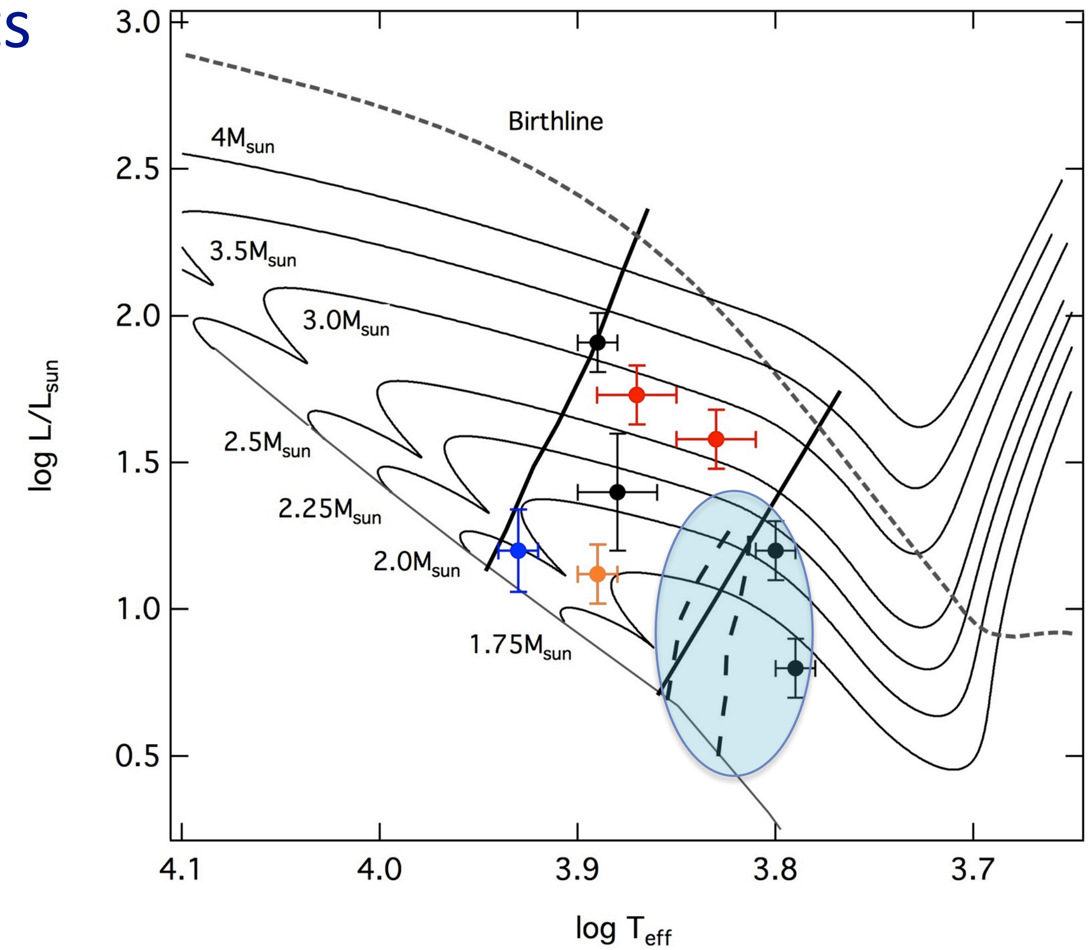
32 irregular
- obscuration
- non-steady accretion

CoRoT Additional Program: The young cluster NGC 2264

6 PMS δ Scuti stars (Zwintz et al. 2009)

- closer to ZAMS: good asteroseismic model fits
- closer to Birthline: models not appropriate





First 2 PMS γ Doradus stars

(Zwintz et al. 2013)

- Theoretical instability strip

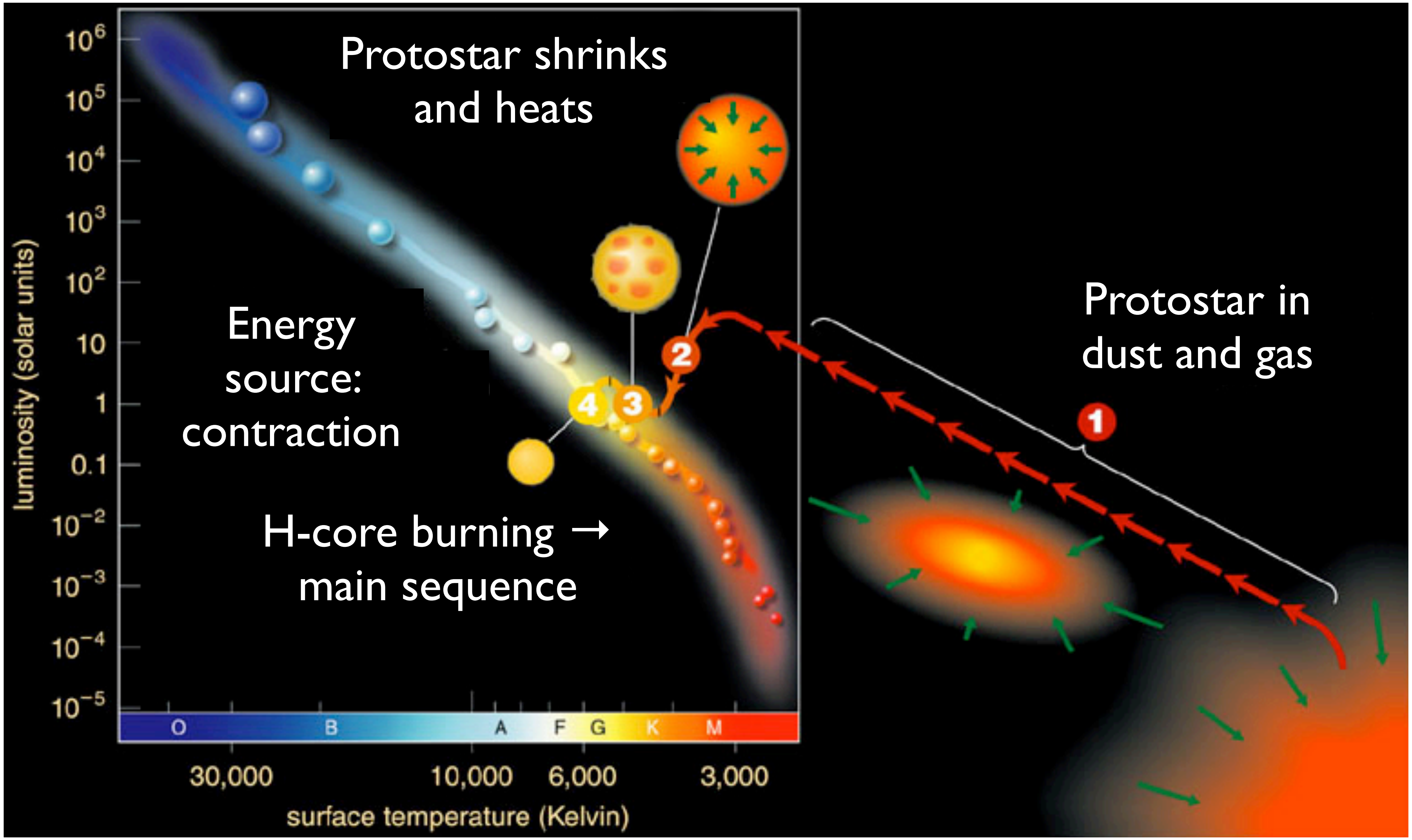
(Bouabid et al. 2011)

PLATO Legacy Science

- Any topic that is not a main science goal!
- Highlights
  - pre-main sequence stars: T Tauri, Herbig Ae/Be, young cluster members
  - clusters: open or globular
  - massive stars: pulsations, rotational effects
  - classical pulsators: δ Scuti, γ Doradus, RR Lyrae & Cepheids (**see talk by Robert Szabo**)
  - binaries
  - red giants: **see talk by Andrea Miglio**
  - asteroseismology of sdB stars

Pre-main sequence (PMS) stars

- Birth of stars and births of planets are connected



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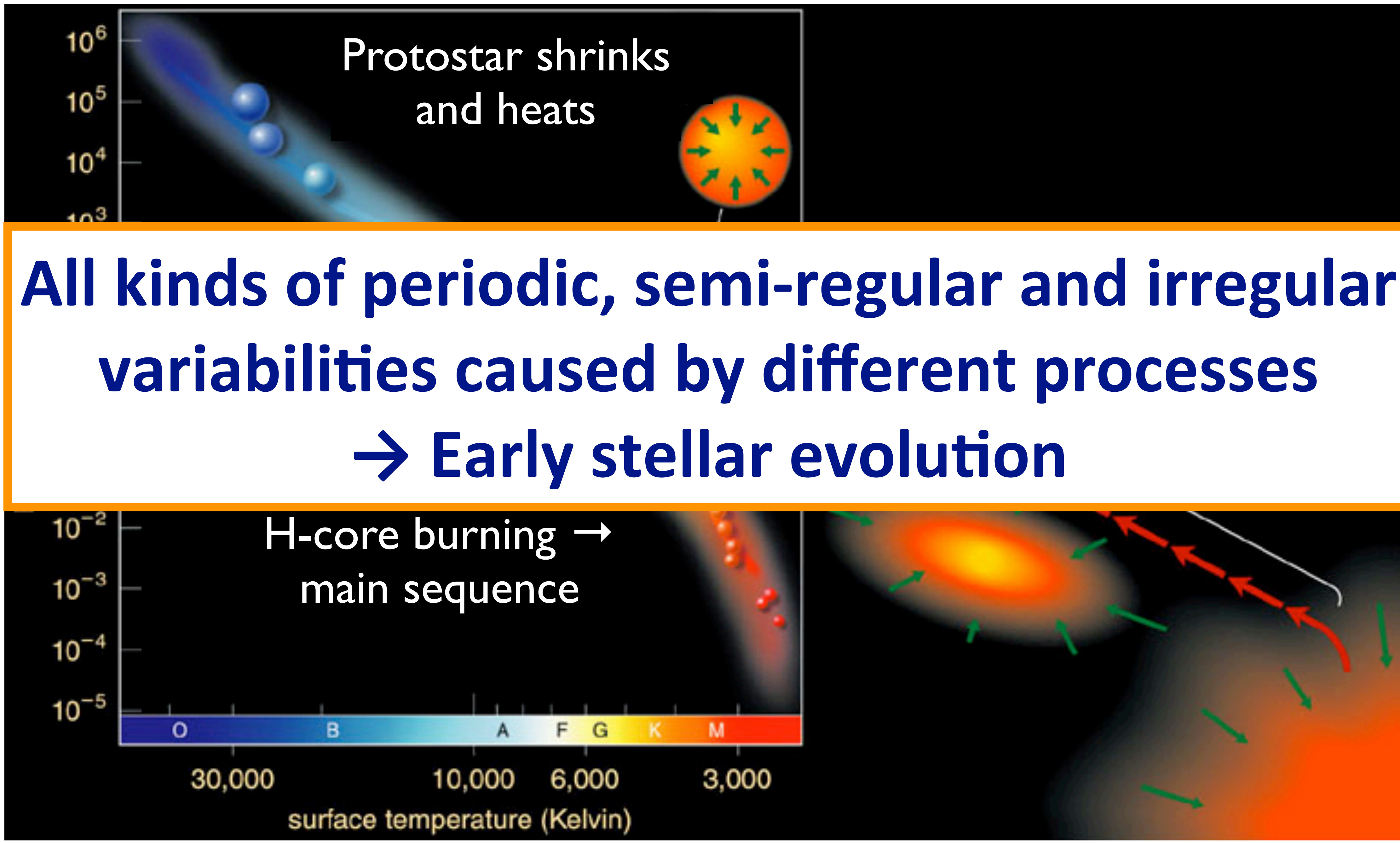
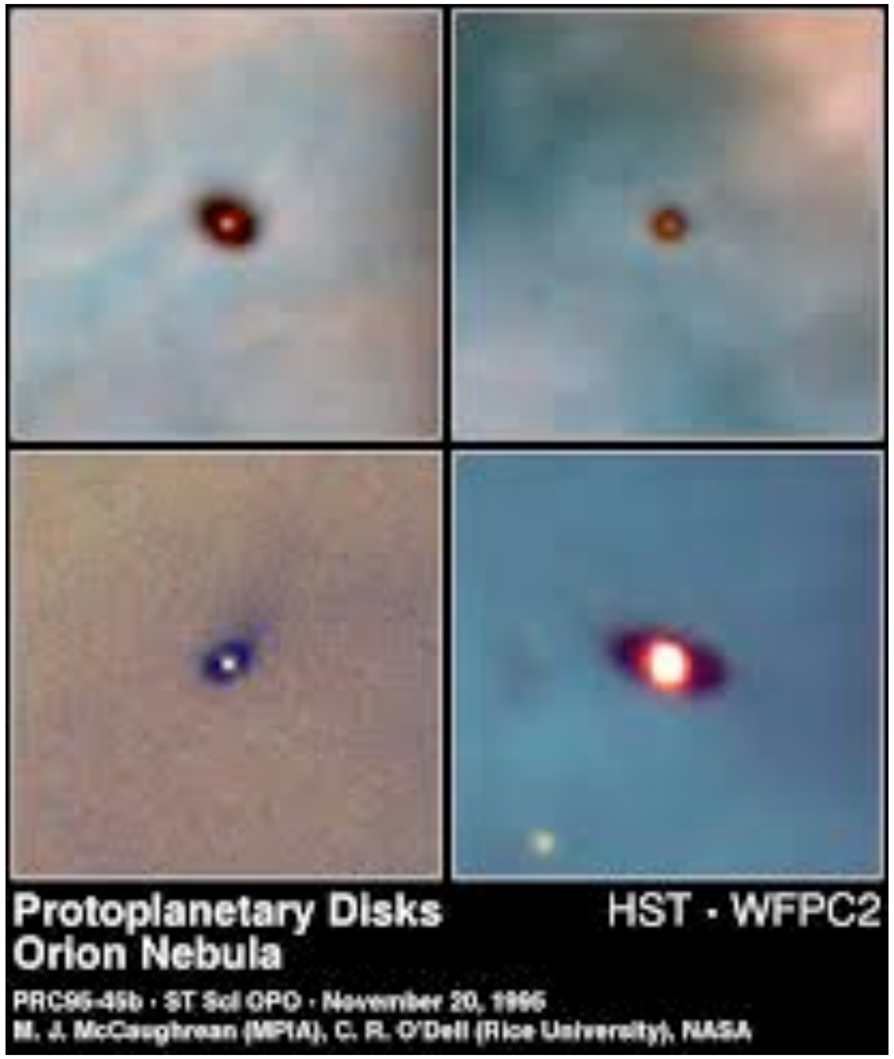


All kinds of periodic, semi-regular and irregular variabilities caused by different processes
→ Early stellar evolution

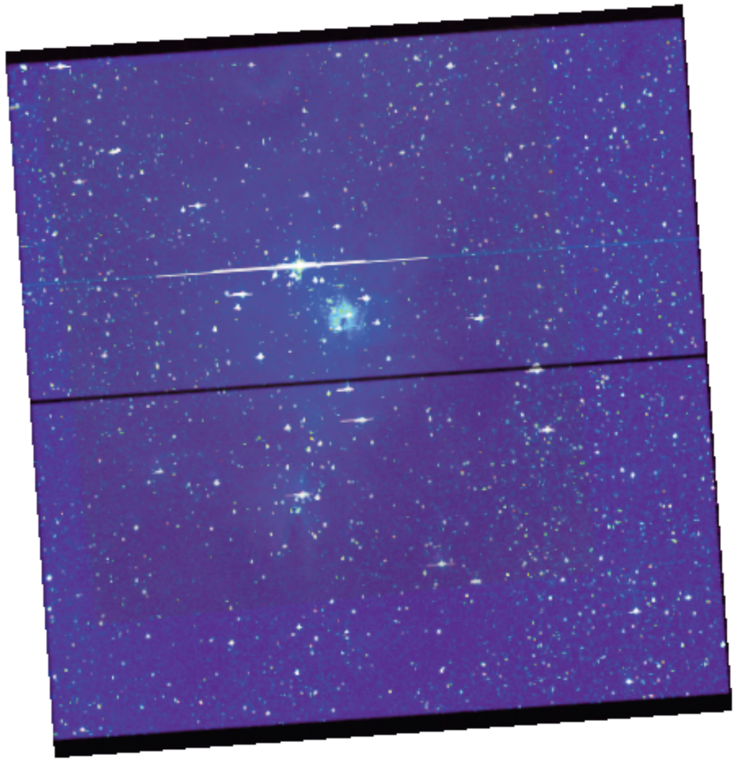
Young stars as planet hosts

- **CoRoT**: no planets in NGC 2264 (time base ~23 & 39 days)
- **Kepler**: no access to young stellar population
- **PLATO**: very complementary topic to the main science goals!
  - **asteroseismology of PMS planet-host stars**
  - early stellar evolution AND planet formation → beneficial for both topics!
  - **leading role for PLATO**



Clusters

- **MOST**: limited field-of-view, few parts of clusters observed
- **CoRoT**: few clusters → major breakthroughs in different topics
- **Kepler**: four open clusters → red giant asteroseismology
  BUT: narrow range of ages: 0.4 Gyr to ~8 Gyr
- **PLATO**: large-sky accessibility & step-and-stare phase
  - **full cluster asteroseismology**
  - testing **stellar evolution theory** through asteroseismology most successful if applied for extremes of evolutionary stages
  - from **youngest (i.e. few Myrs) to oldest (globular) clusters**



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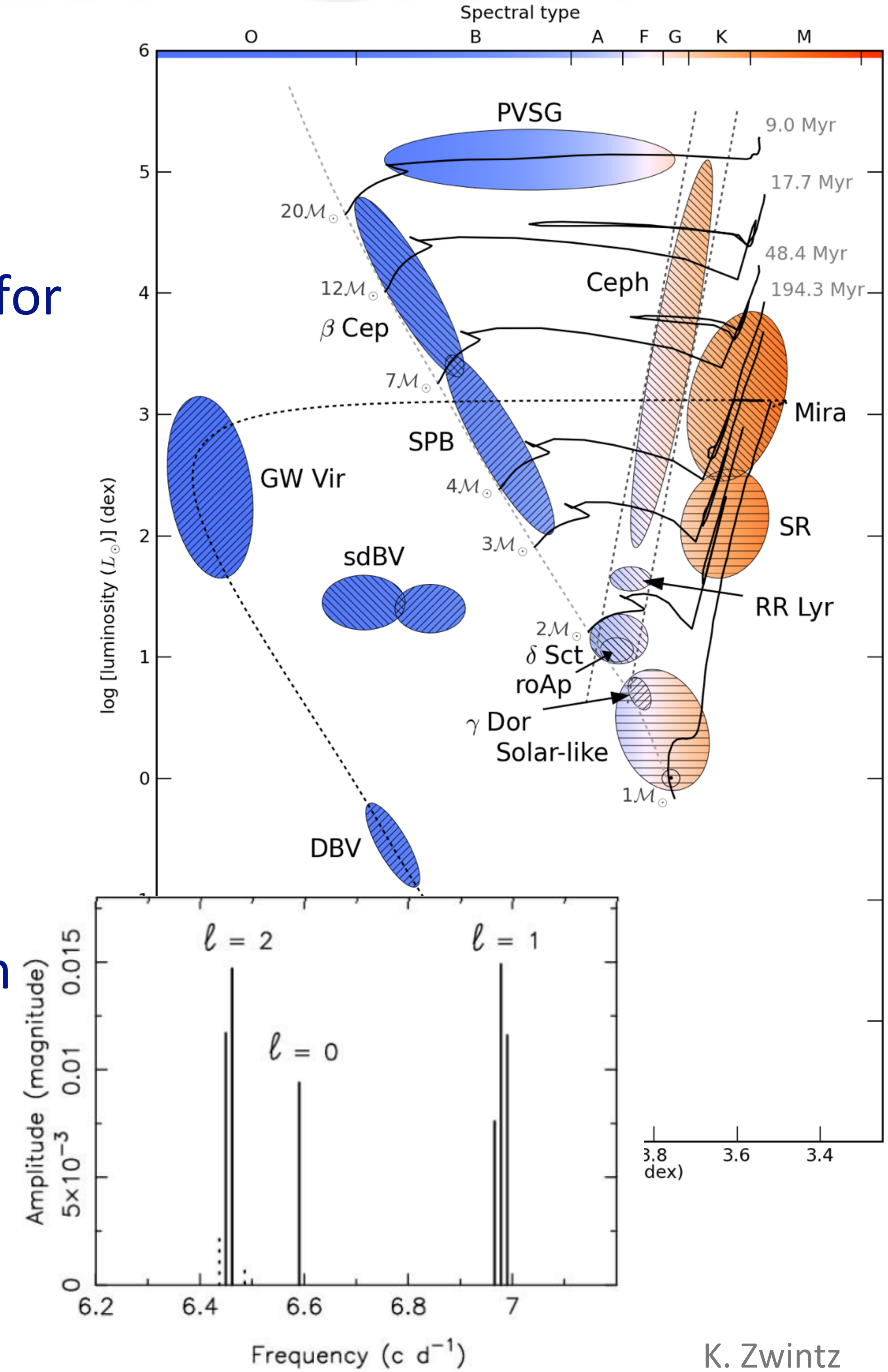
Asteroseismology of core-H burning B stars

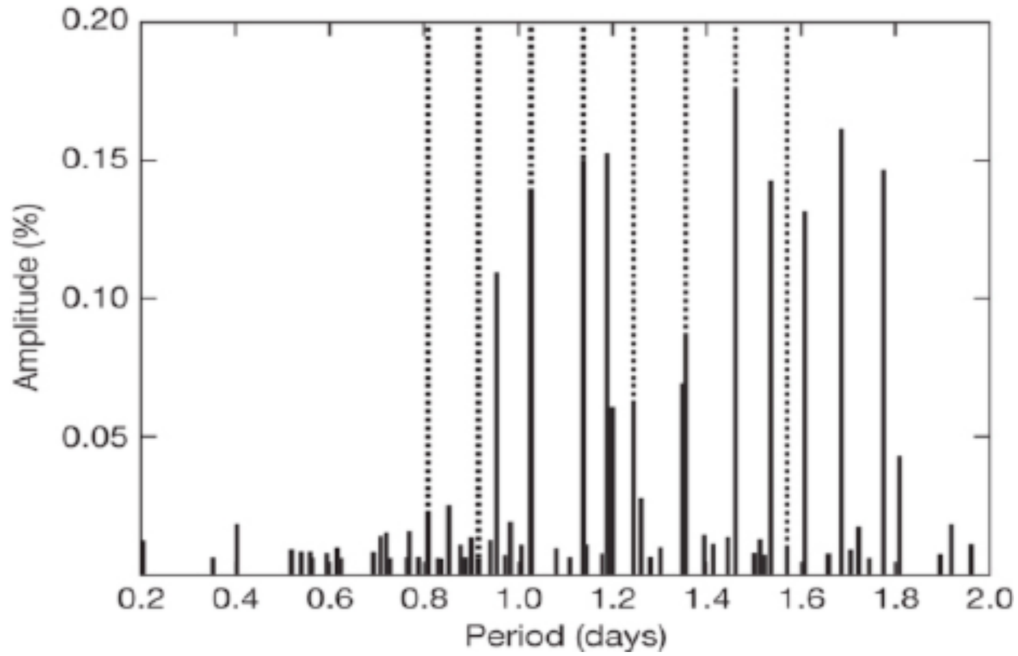
- **pulsating B stars**:
  - low-order p- and g-modes with periods of hours for SpT O9-B3,
  - high-order g-modes with periods of days for SpT B3-B9;
  - can reach mmag & km/s in amplitude
- Modes excited by **heat-mechanism** acting on Fe opacity bump (e.g., Dziembowski & Pamyatnykh 2008; Briquet et al. 2011)
- **Sparse oscillation spectra** but well separated frequencies (multiplets): forward seismic modelling & probing of inner core regions from identification of (l,m) of detected modes

Aerts et al. (2003)
Dupret et al. (2004)

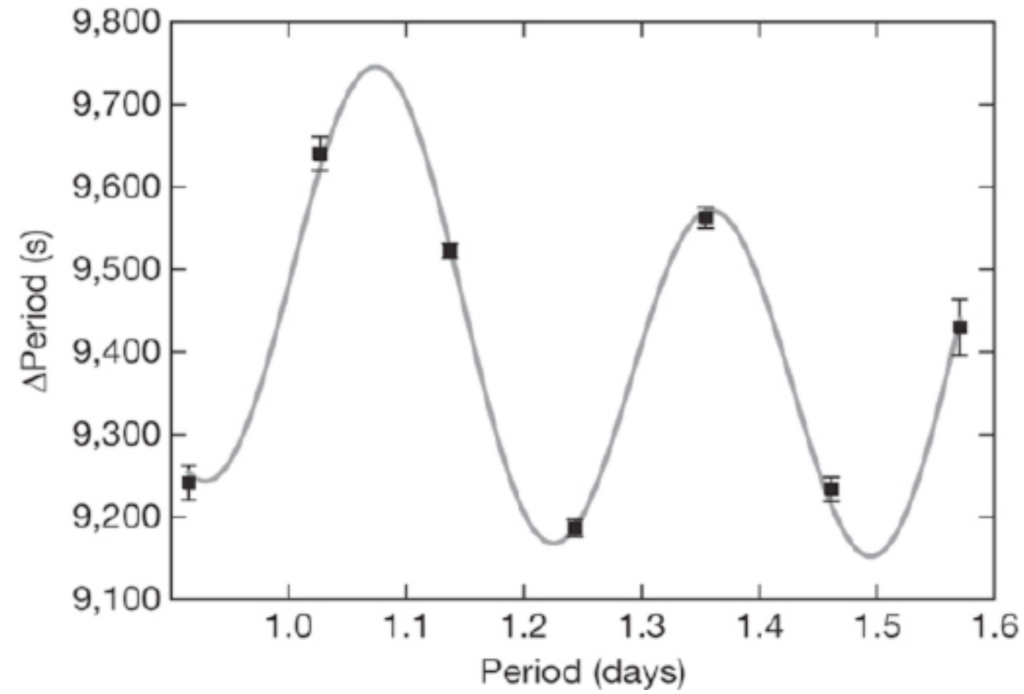


Massive stars: g-mode core probing

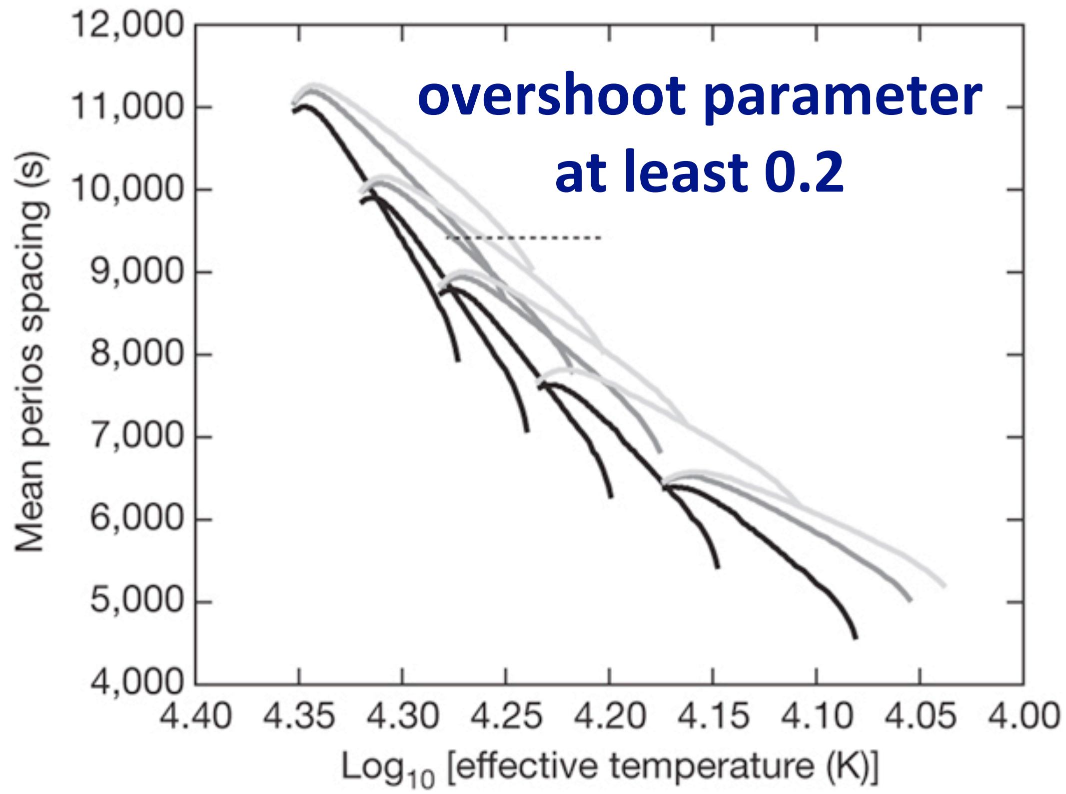
Degroote et al. (2010)



Theoretical treatment: Miglio et al. (2008)

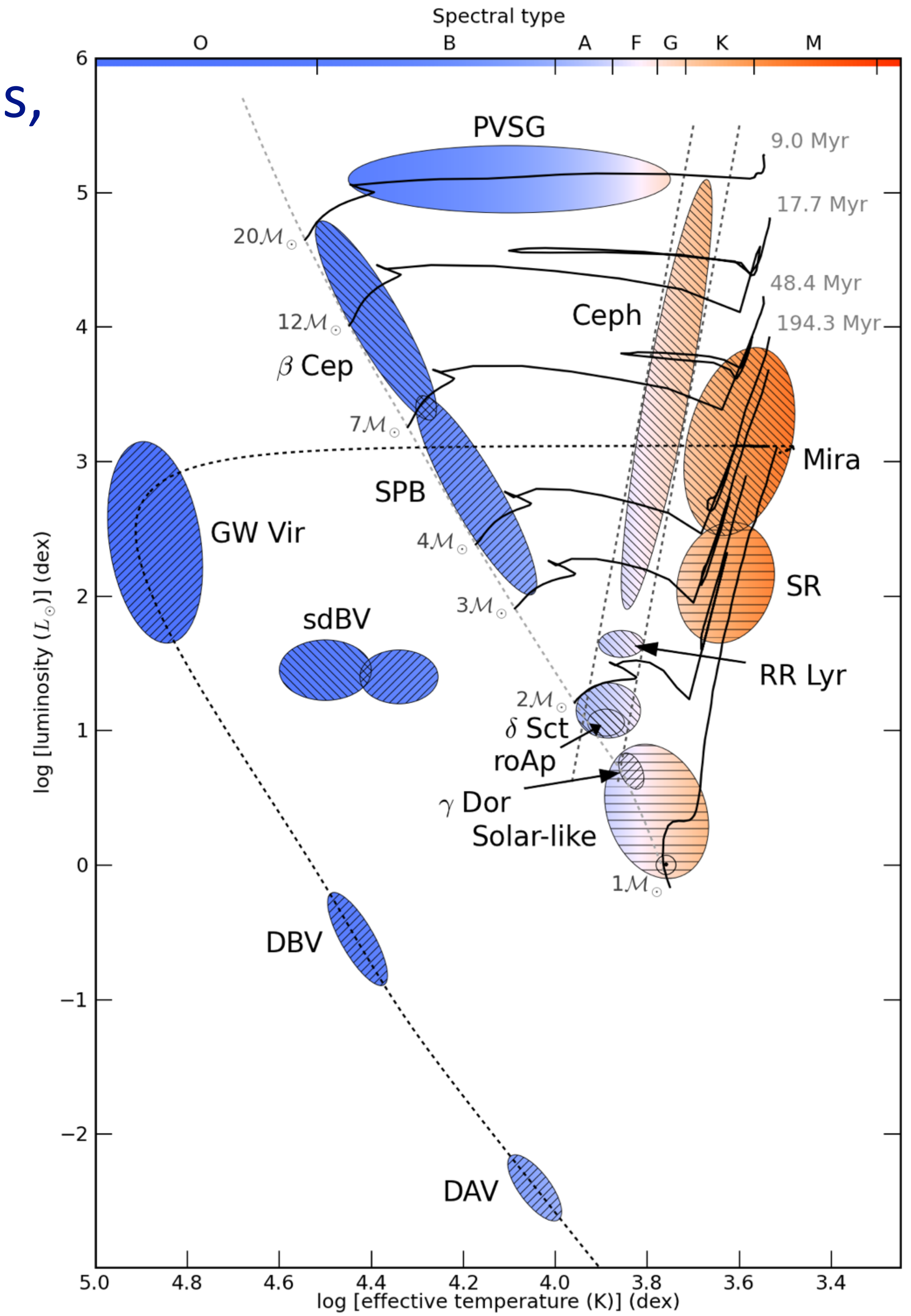


- **HD50230**, B3V, vsini<10 km/s
  - gravity modes: 0.5d < P < 5d
  - almost constant P spacing: **9418s** with deviations up to **200s**
  - region of varying chemical composition outside the convective core
  - **inhomogeneous diffusive near-core mixing in addition to overshooting**



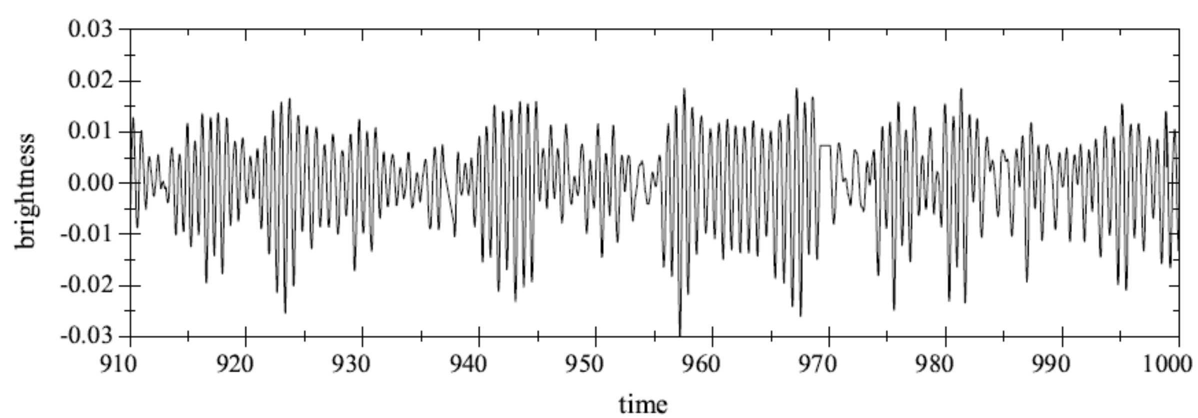
Classical Pulsators

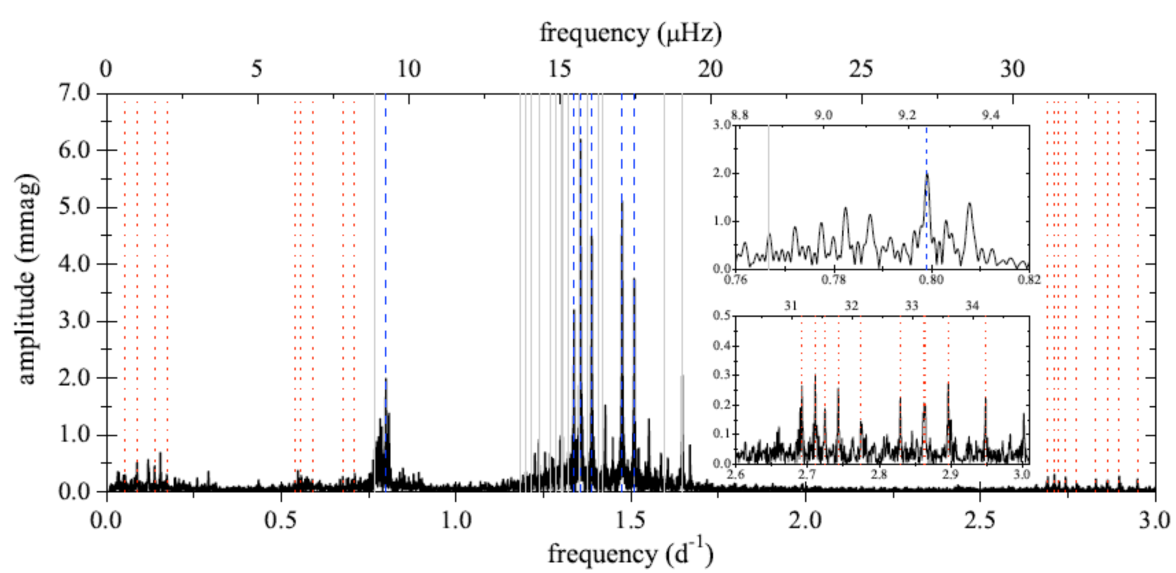
- **Pulsation periods** range from seconds to months, beat periods of many years
- **Amplitudes** from several mag to µmag, or from tens of km/s to cm/s
- Very **different oscillation mode physics**: pressure versus gravity dominated & mixed, various mode lifetimes
- Various **excitation mechanisms**: heat-driven, stochastically excited, convective flux blocking, tidally excited, non-linear resonant excitation,...
- If observations allow it, asteroseismology can be applied to **many regions in HRD**

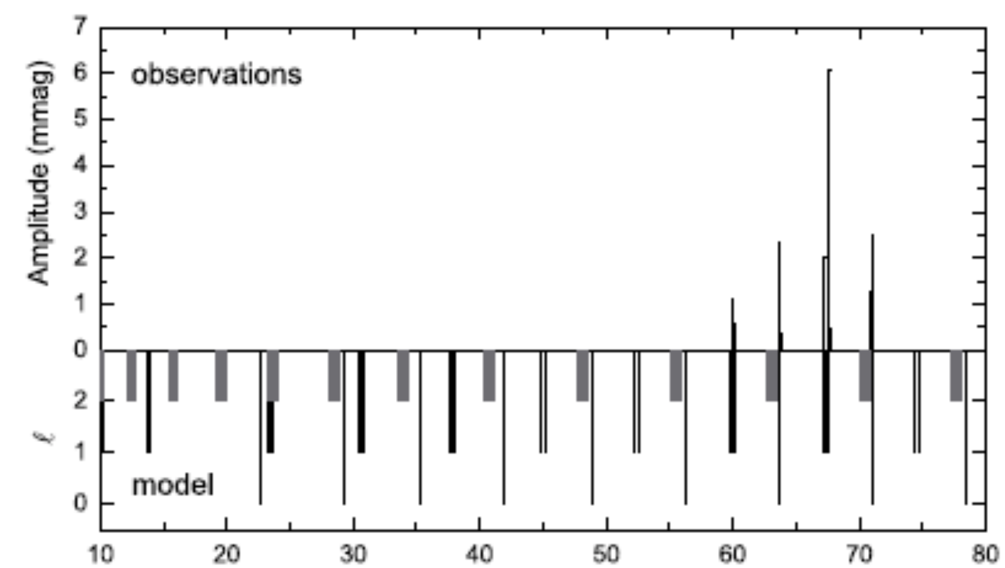


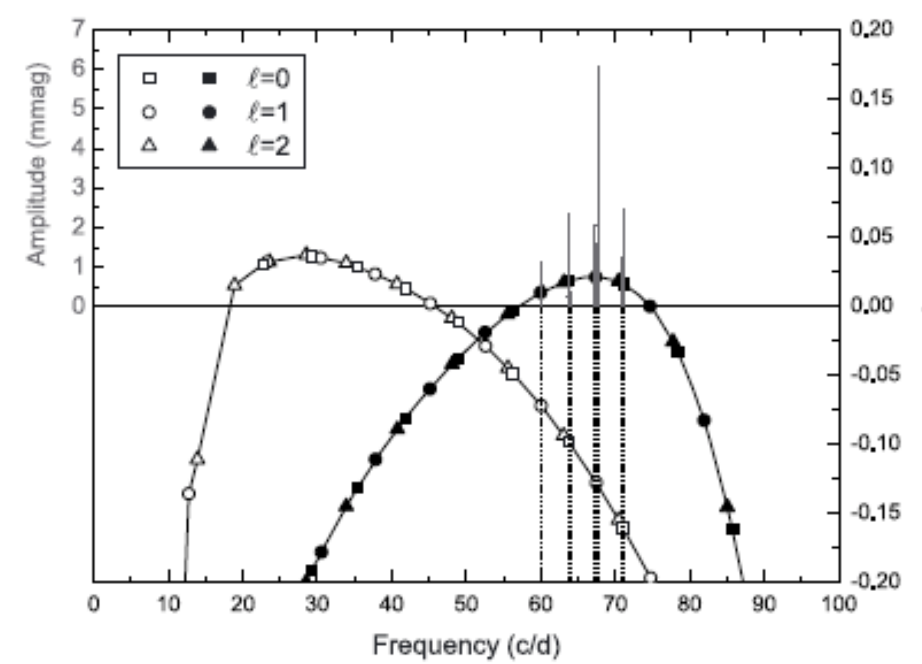
Asteroseismology of AF-type stars

- **Challenges**: fast rotation spoils equidistant multiplets, no mode identification, models to start with not good enough, treatment of convection...
- **Hopes**: moderately-rotating γ Doradus stars with period spacings & splittings (Tkachenko et al. 2013), regular frequency patterns in δ Scuti stars (Breger et al. 2011; Zwintz et al. 2013), ...









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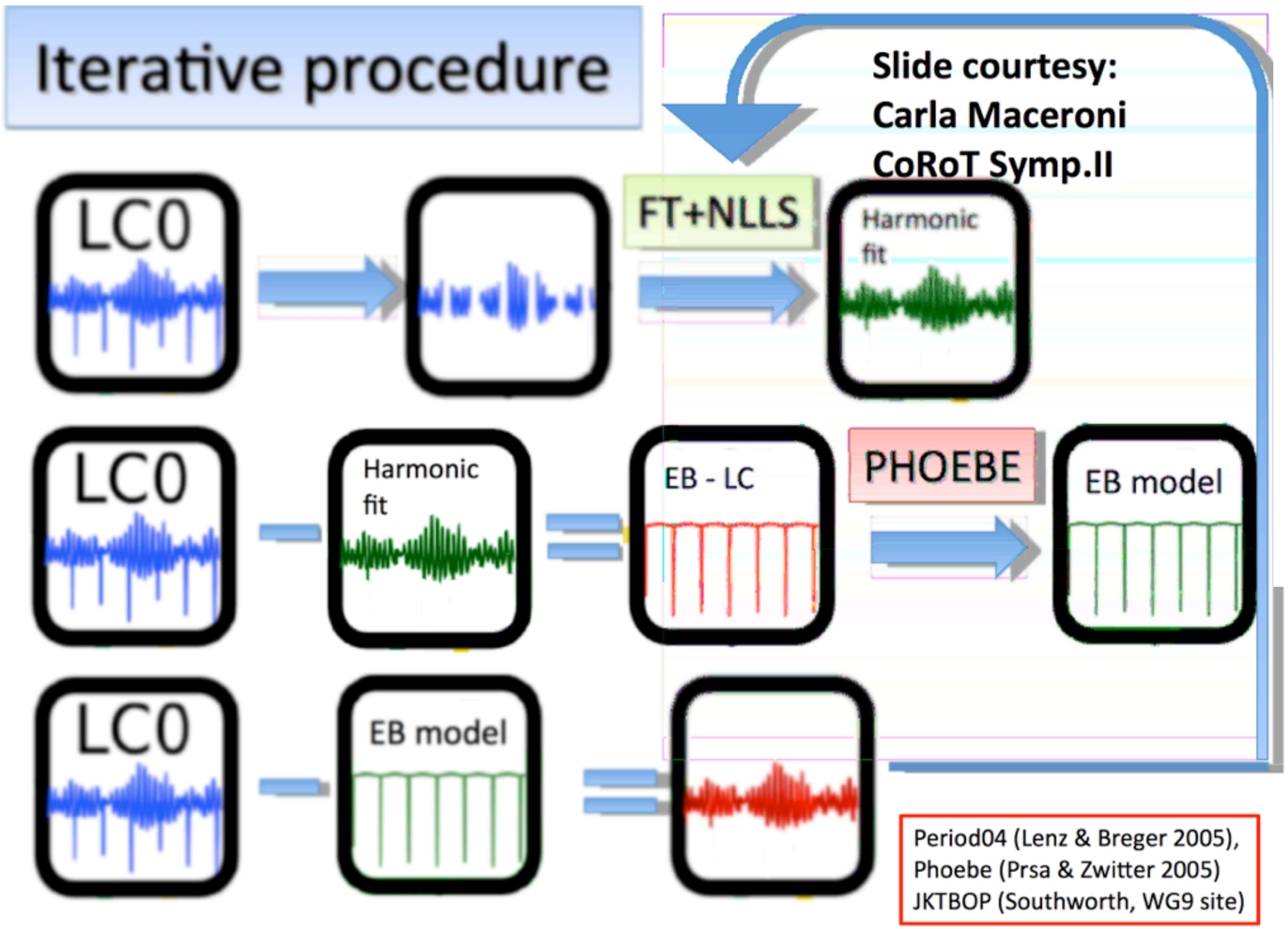
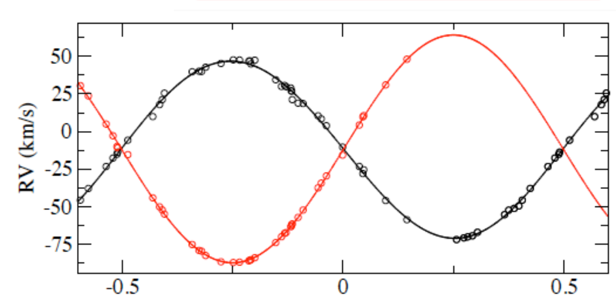
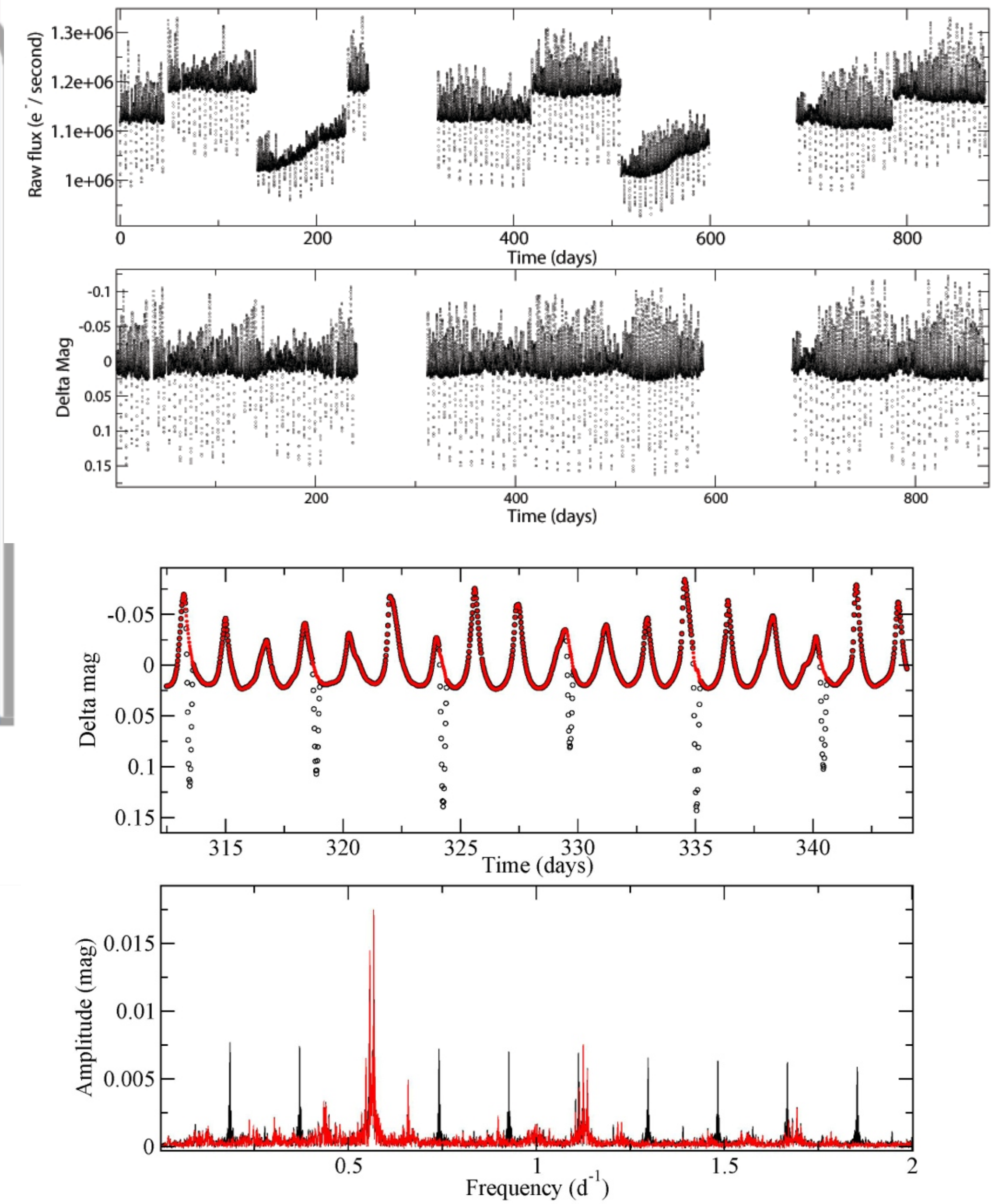
Asteroseismology of unevolved EBs



	System	
Orbital period P (days)	10.790492±0.000003	
Eccentricity e	0.005 ± 0.003	
Inclination i (degrees)	85.32 ± 0.02	
Semi-major axis a ($R_\odot$)	28.8 ± 0.1	
Light ratio L_1/L_2	0.38 ± 0.01	
System RV γ (km s^{-1})	-11.7 ± 0.2	
	Primary	Secondary
Mass M ($M_\odot$)	1.543 ± 0.013	1.200 ± 0.016
Radius R ($R_\odot$)	2.123 ± 0.010	1.472 ± 0.014
log g	3.973 ± 0.006	4.18 ± 0.01





Tidally affected g modes in an SB2 (Debosscher et al. 2013)

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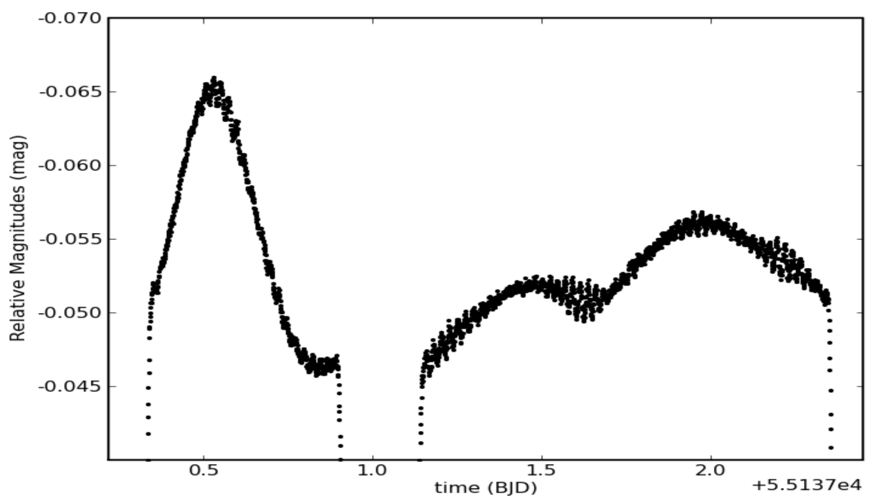
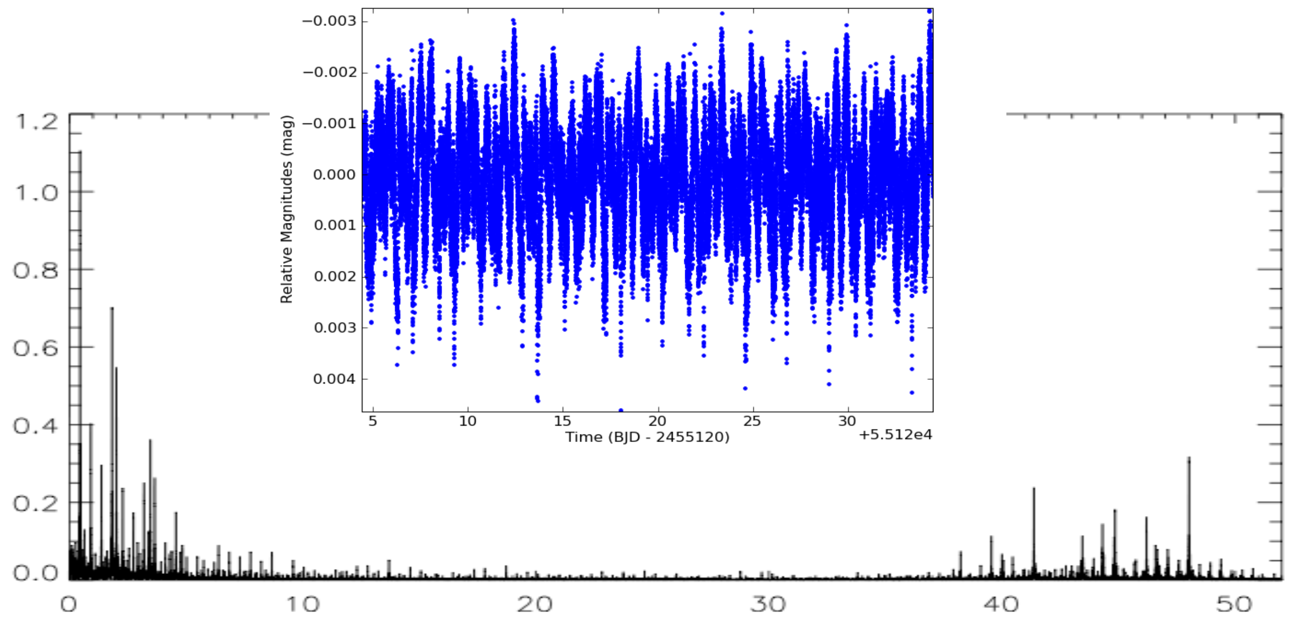
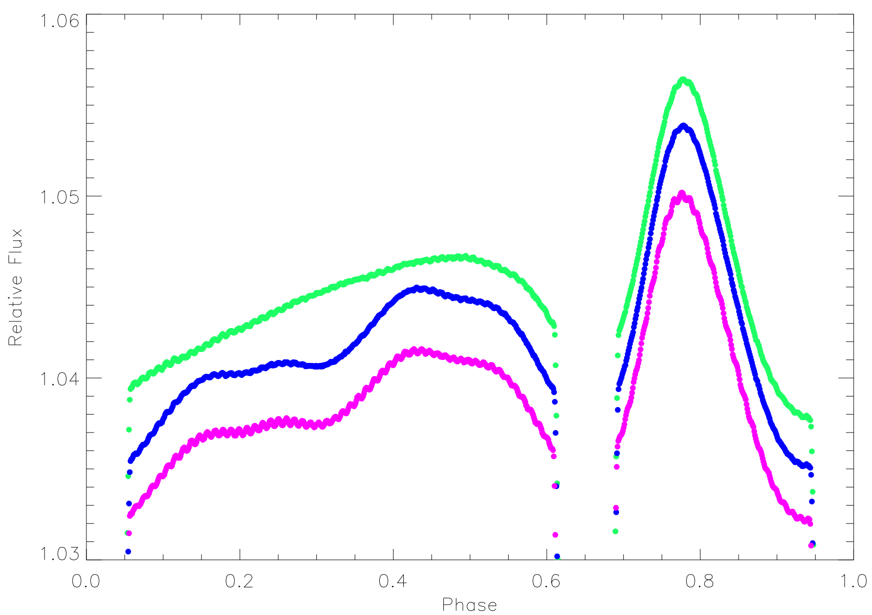
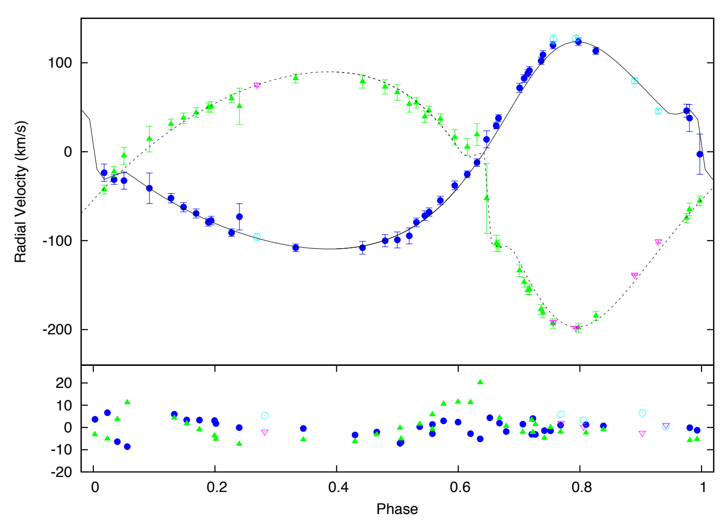
Asteroseismology of A pulsators in EBs

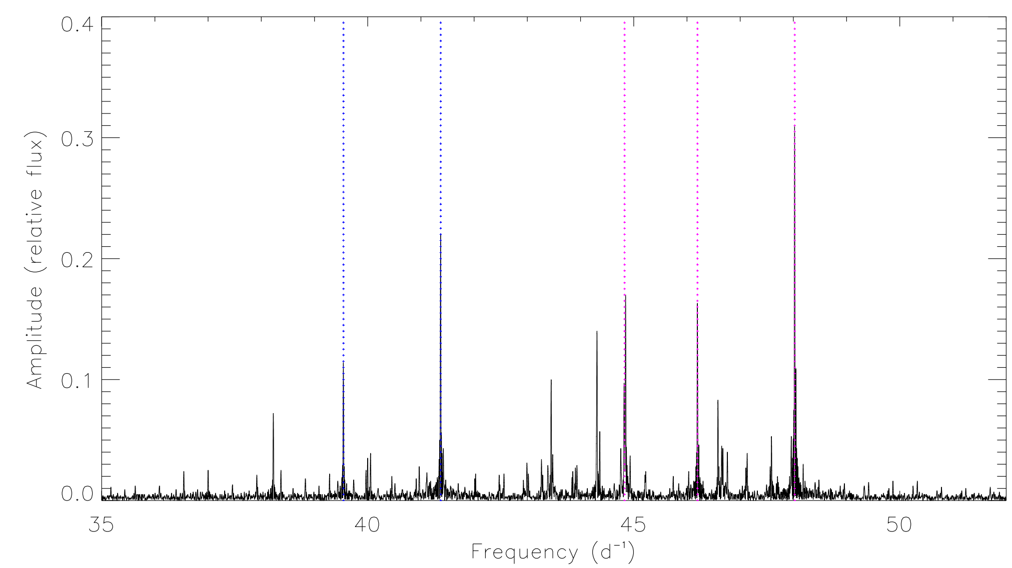




Porb=2.189d
e=0.288
M1=1.98M⊙
M2=1.60M



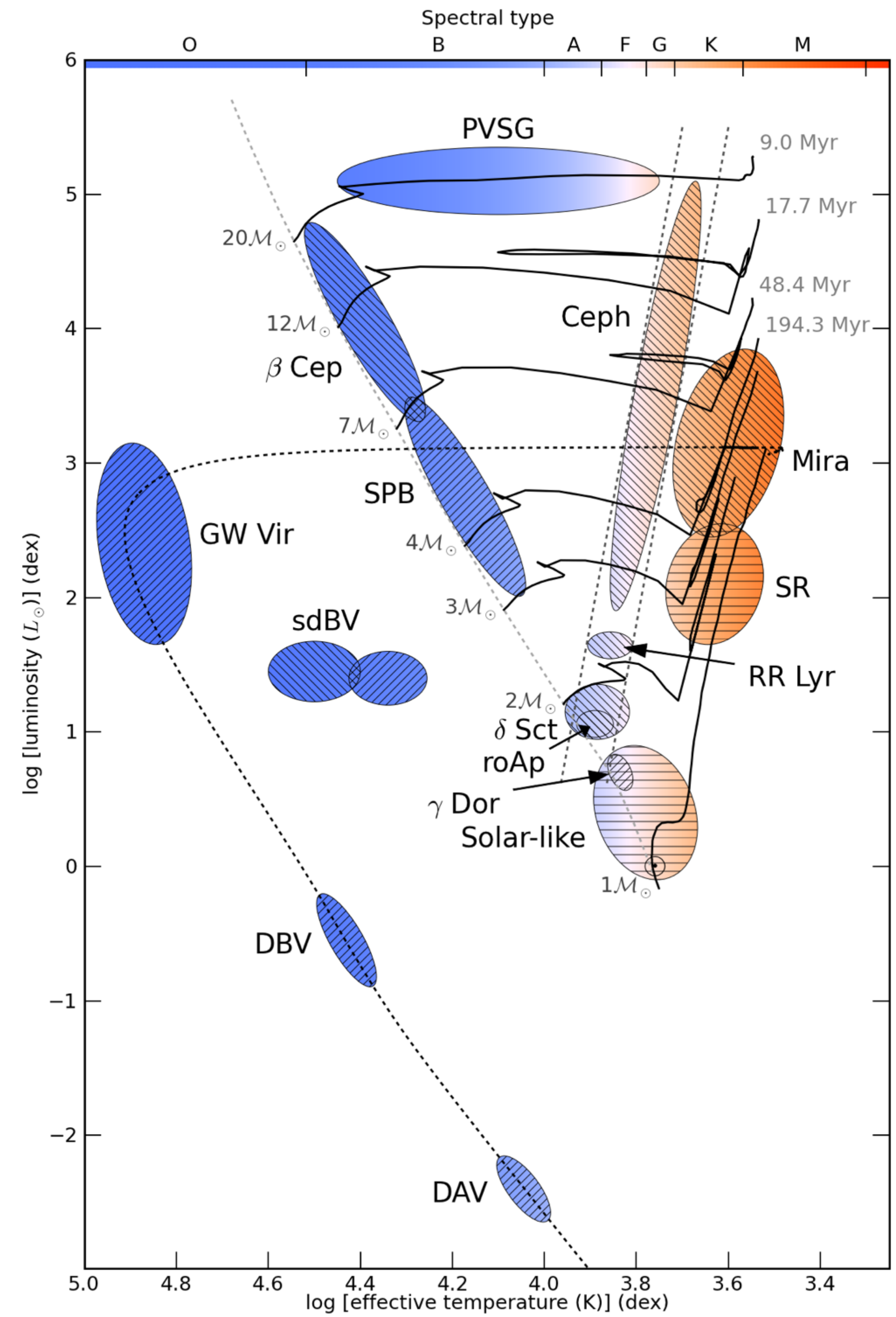




EB with δ Sct primary: 31 modes in total, of which 8 tidally excited g modes + combination p-modes in this, A+F SB2 (Hambleton et al. 2013)

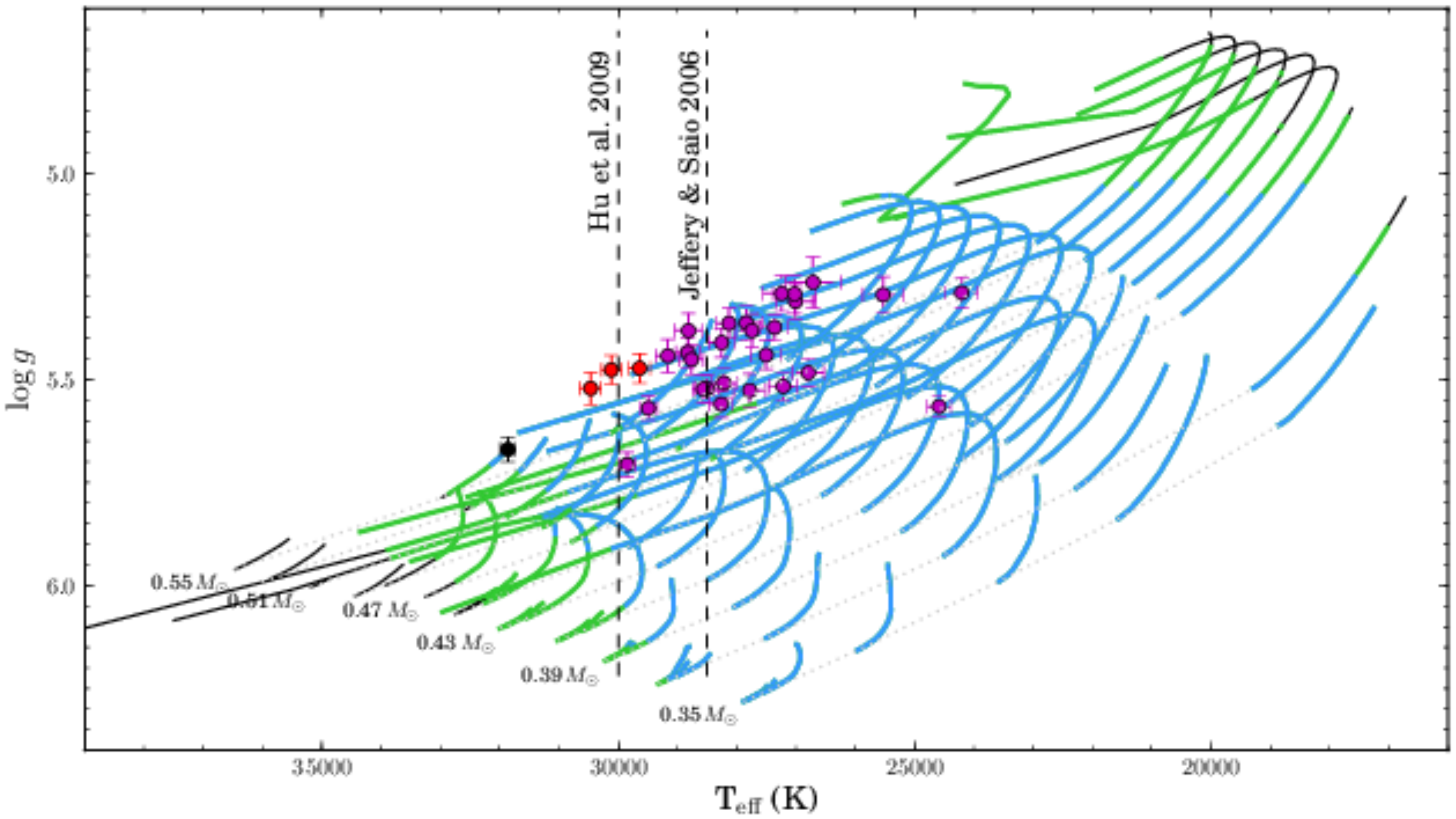
Asteroseismology of sdB stars

- **pulsating subdwarf OB stars**: p- and g-mode pulsators with periods of minutes to hours
- Modes excited by **heat-mechanism acting on Fe/Ni opacity bump**, interplay between gravitational settling & radiative levitation (Charpinet et al. 1996, Fontaine et al. 2003, Jeffery & Saio 2006), but **observed blue edge is problematic...**
- Very **rich oscillation spectra**: seismic modelling & probing of inner core regions, but from static models, e.g., Van Grootel et al. (2011), Charpinet et al. (2010, 2012),...
- Note: exoplanets have been claimed from O-C Kepler data (Charpinet et al. 2011)



Instability region of sdB stars

- Inclusion of gravitational settling, concentration & thermal diffusion+radiative levitation by solving diffusion equations for H,He,C,N,O,Ne,Mg,Fe,Ni **along evolution** with STARS (Eggleton) code + coupled to MAD (Dupret) code by Hu et al. (2009,2011,2012): **excitation of g-modes at observed Teff for one track**



- Bloemen et al. (2013): computation of new IS strip: **blue edge problem solved!**
- **But: only one target in the blue region.... PLATO can find more!**

Conclusions: PLATO's Legacy Science

- Observations in **many directions of the sky**
  - sampling a **wider variety of time-variable phenomena** in various populations of the Galaxy
- **Asteroseismic characterization of stellar ensembles**
  - significant **addition to Gaia** for about 50% of the sky
- **Rich legacy** for stellar and galactic physics expected

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Lessons learned from MOST, CoRoT, Kepler

➡ Be prepared for the unexpected!

➡ Surprises in Legacy Science of all space missions