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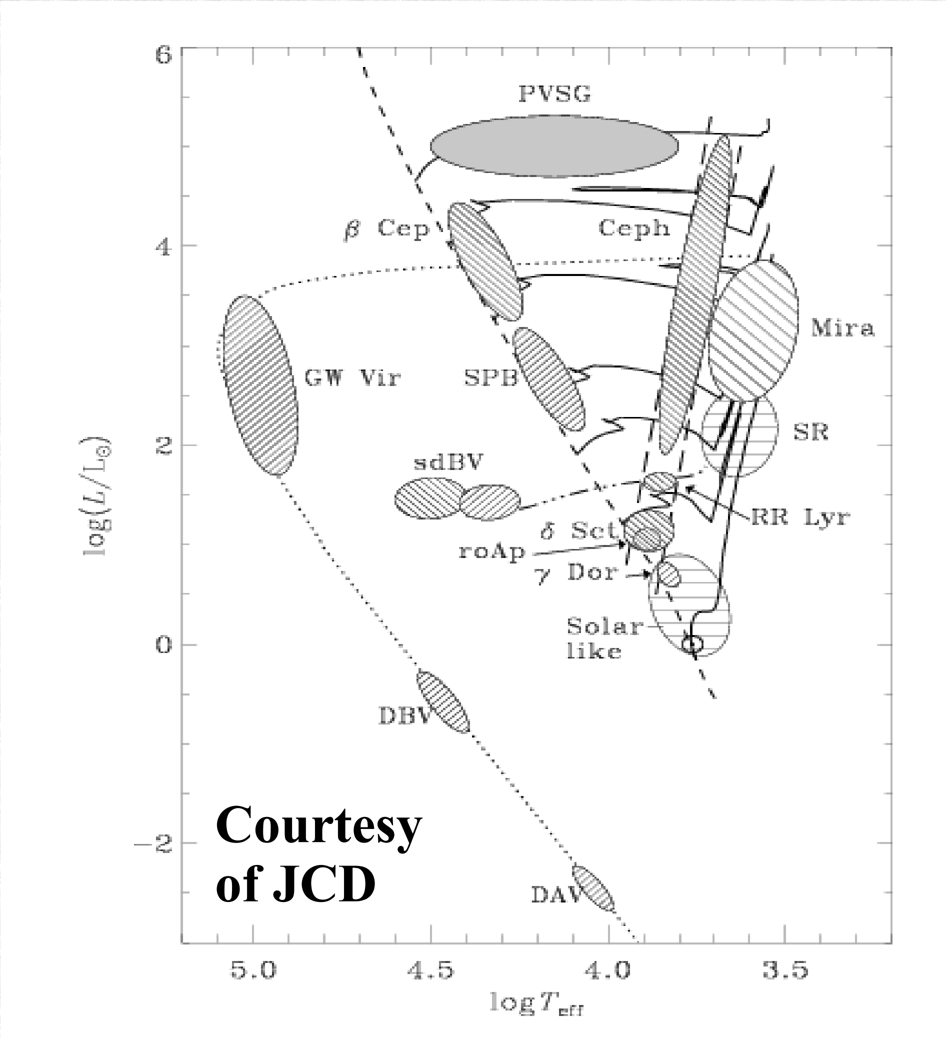
Asteroseismology in the era of the CoRoT space mission

JENAM, 23 April 2009

Why bother?

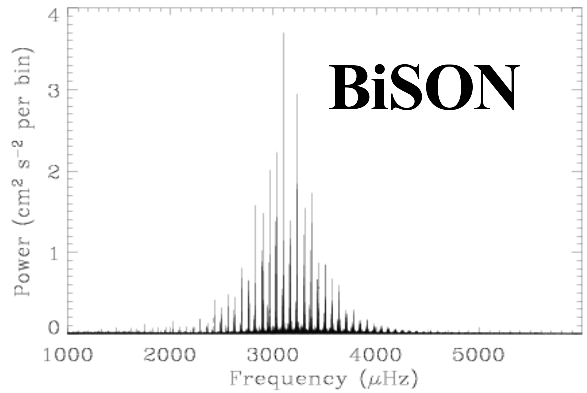
To improve drastically stellar evolution models



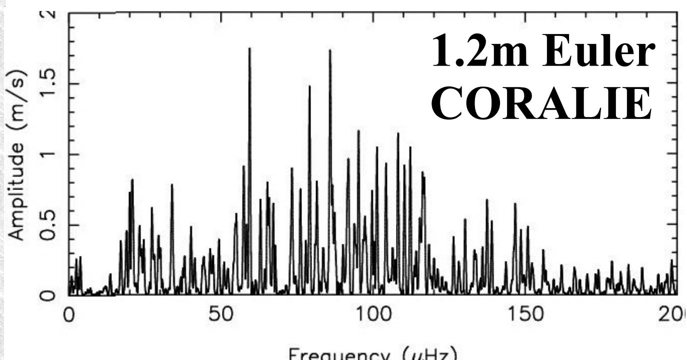
Planet was discovered in light curve of the sdBV star V391 Pegasi (Silvotti et al. 2007)

Frequencies across HRD

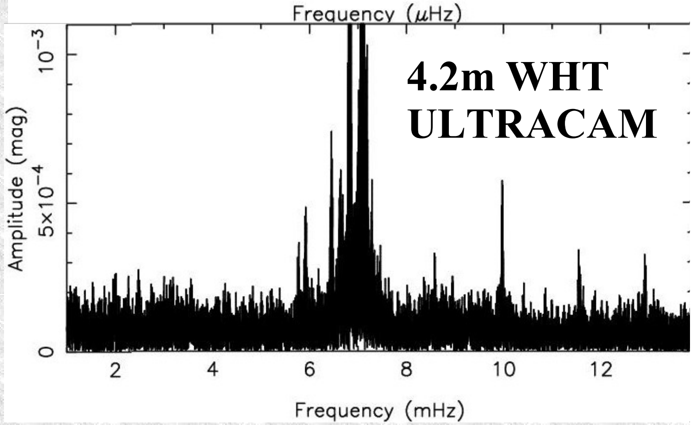
Sun

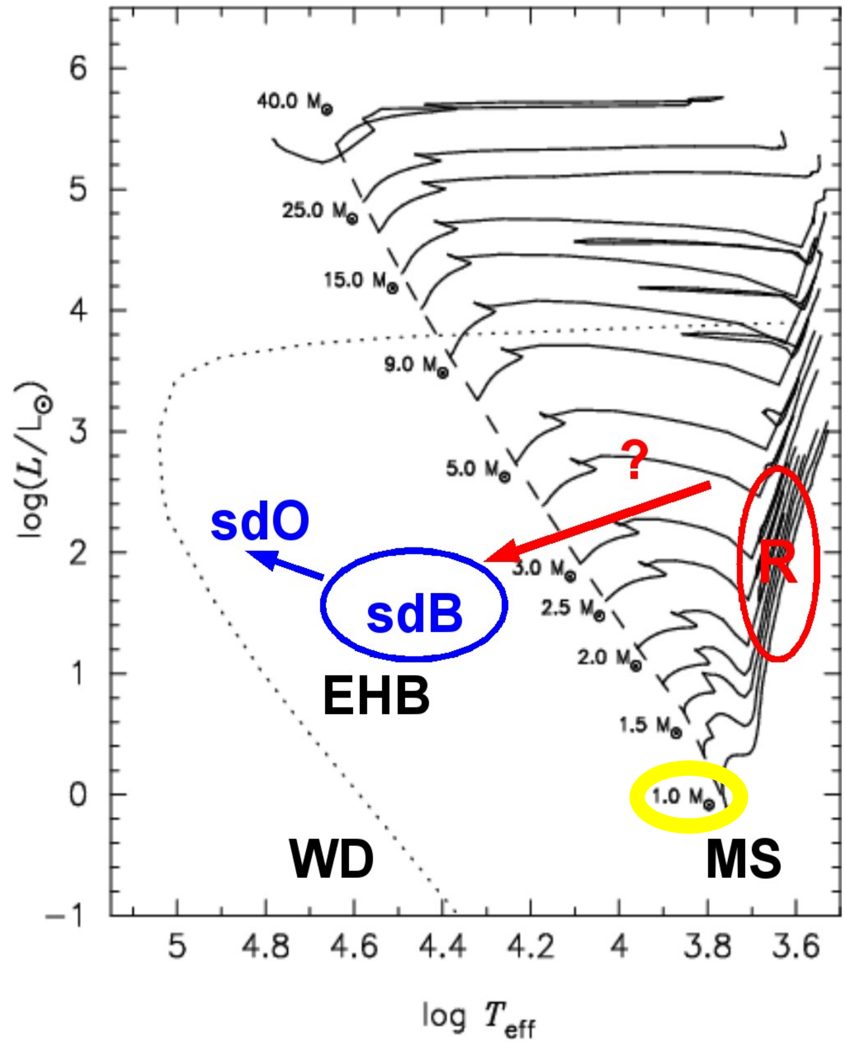


RGB



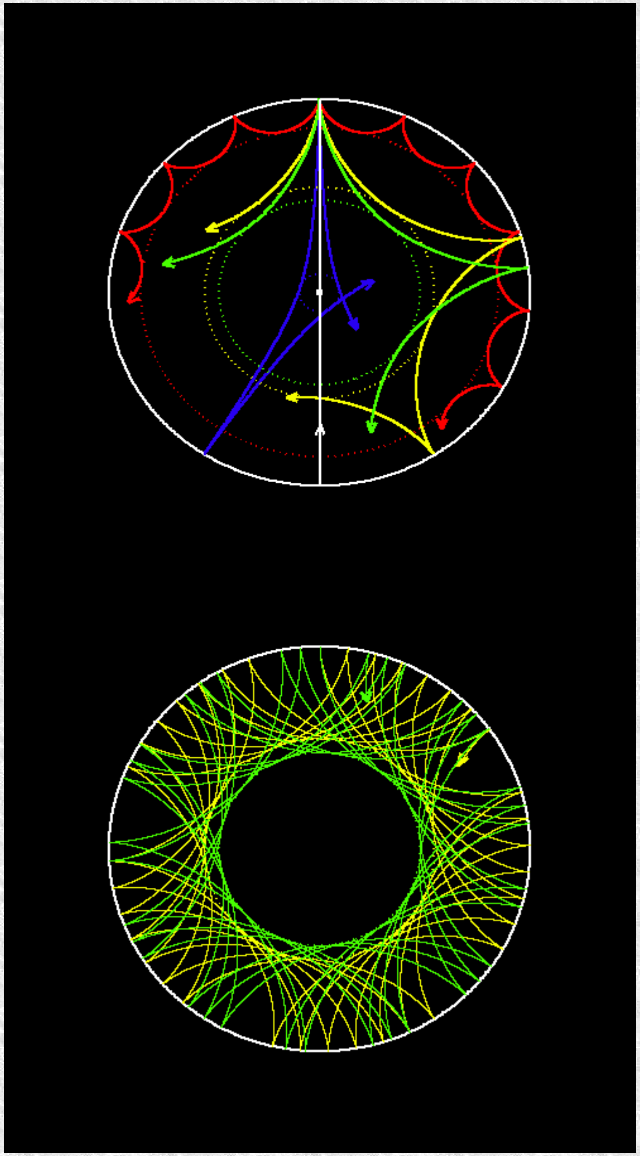
sdB





Why can asteroseismology help?

aster: star
seismos: oscillation
logos: discours, reasoning



The analysis of stellar oscillations allows to study the stellar interior because different modes probe different depths

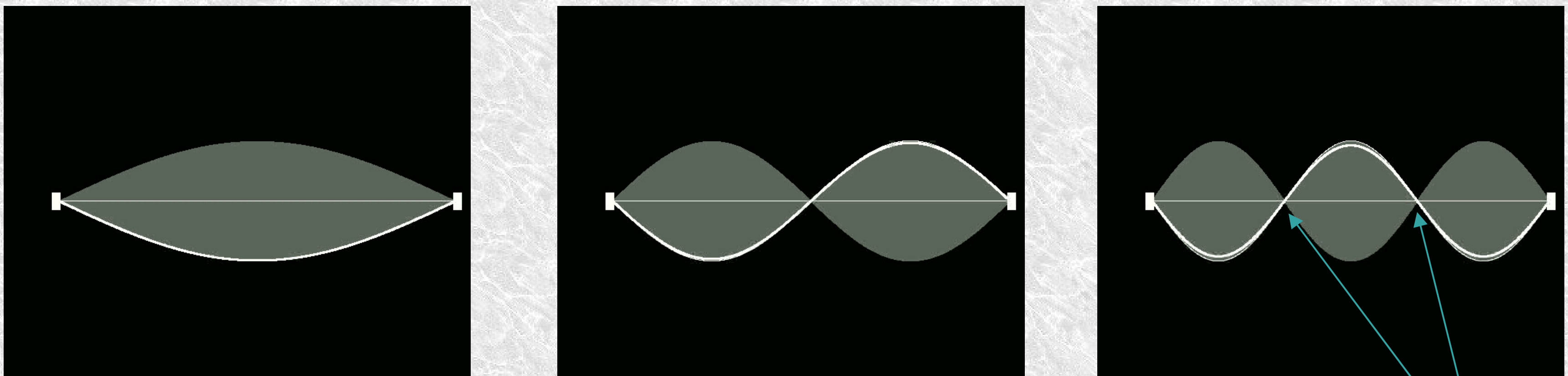
What can asteroseismology give us?

convective overshoot; extent of stellar cores; interior rotation; chemical composition; age; mass; settling; levitation; opacities; EOS;....

classical observations cannot deliver interior structure quantities

Oscillations in 1 dimension

Fundamental | First overtone | Second overtone



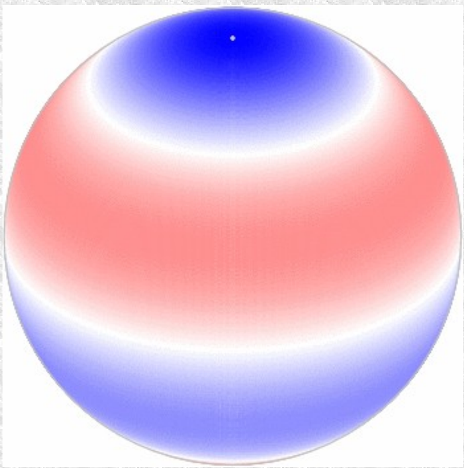
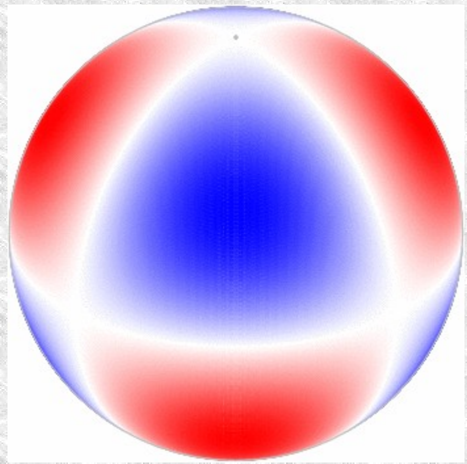
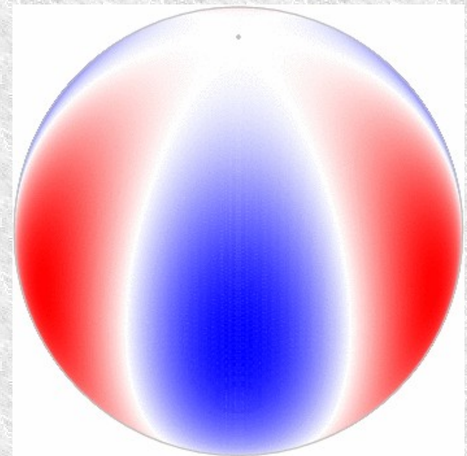
nodes

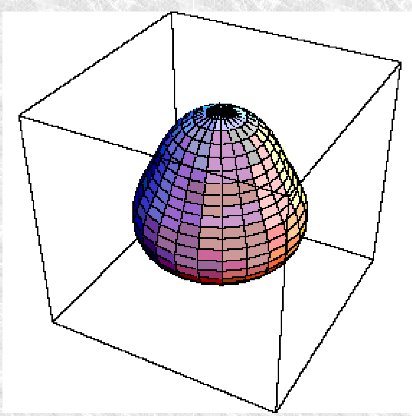
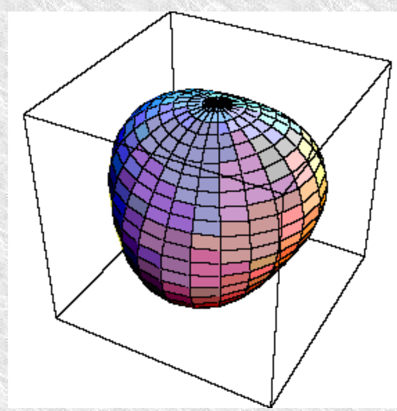
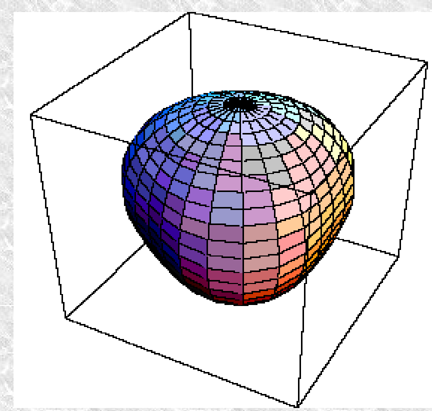
modes

Oscillations in 3 dimensions

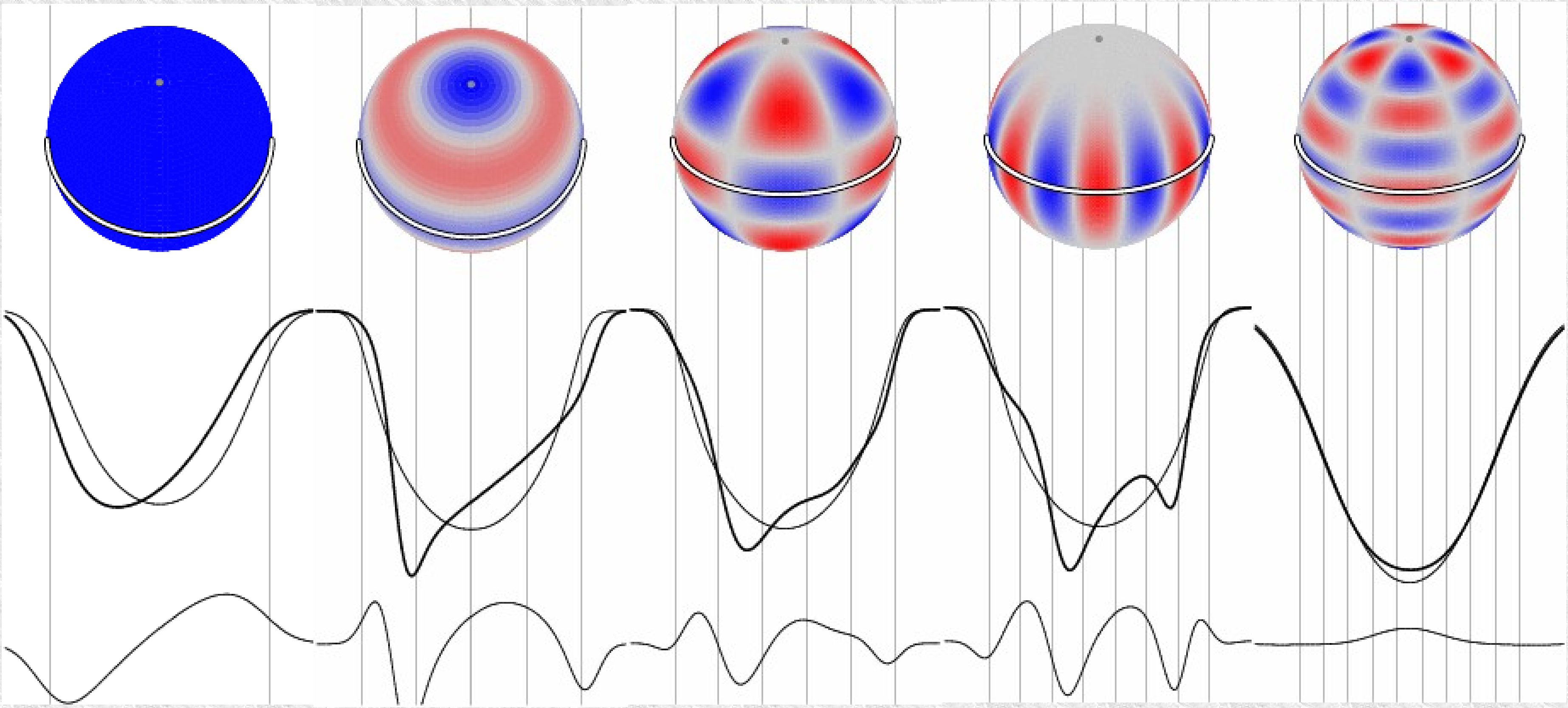
(l,m)=(3,0) axisymmetric *(l,m) = (3,2) tesseral* *(l,m)=(3,3) sectoral*

Blue : Moving towards Observer
Red : Moving away from Observer

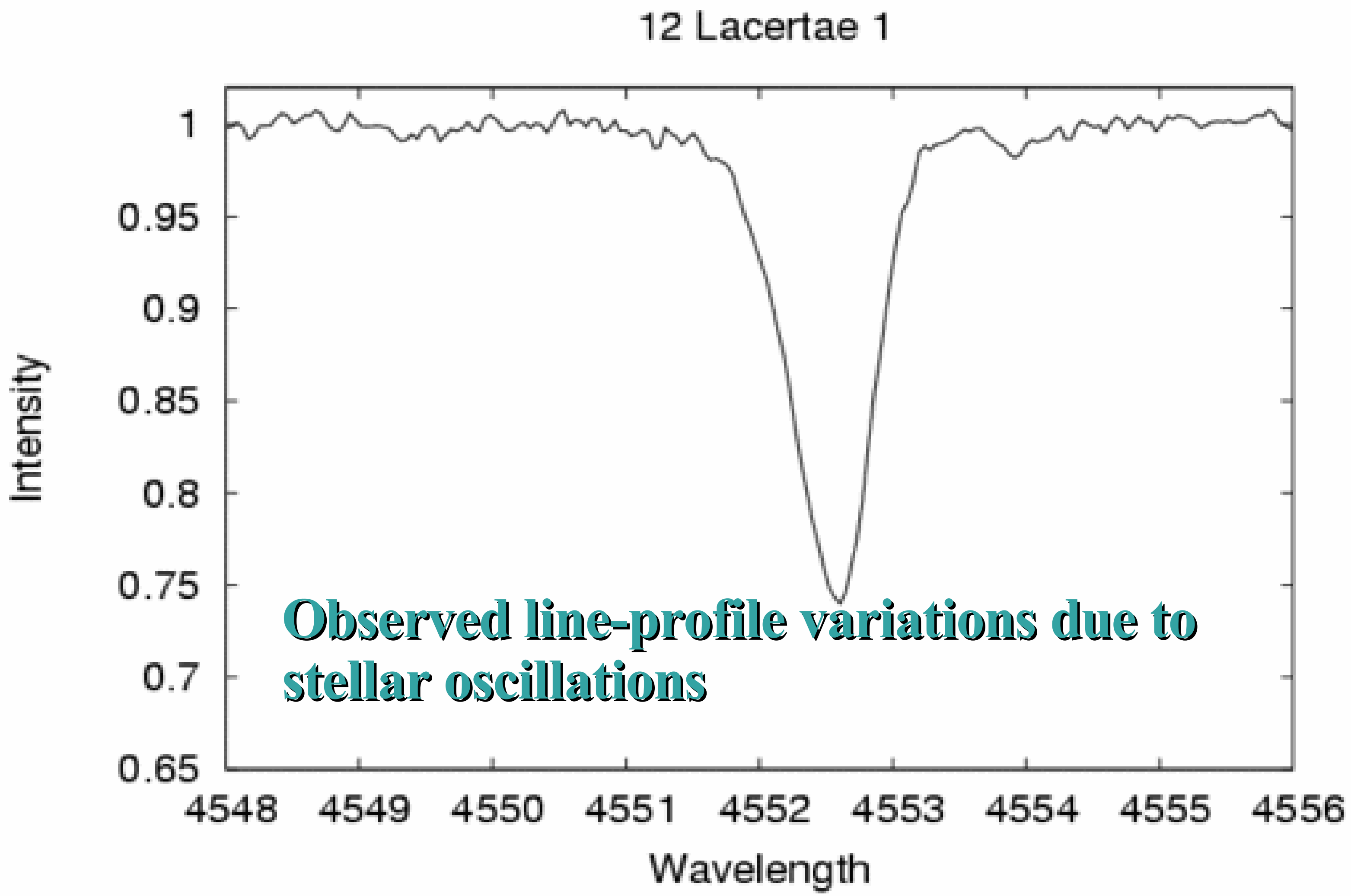
Line-profile variations reveal (l,m,i)



Animations from John Telting and Coen Schrijvers

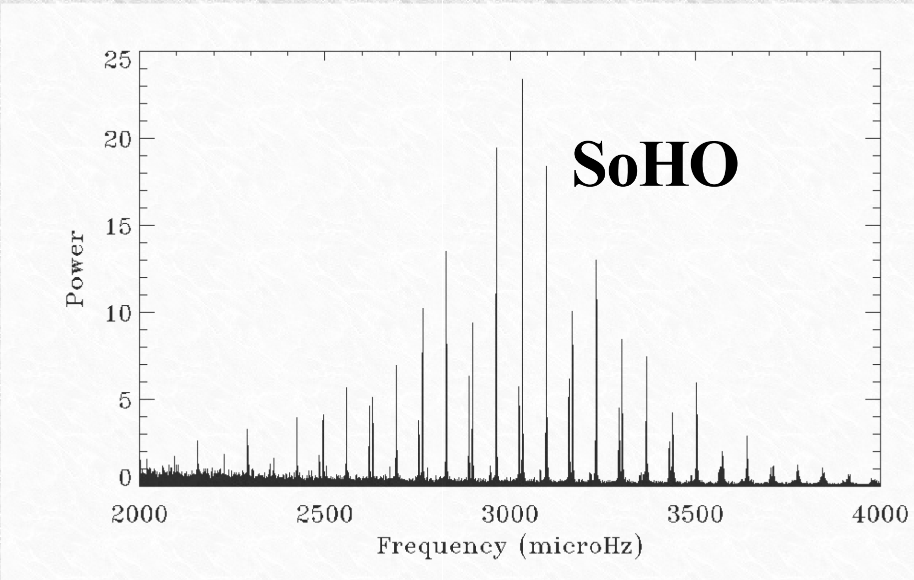
jht@not.iac.es

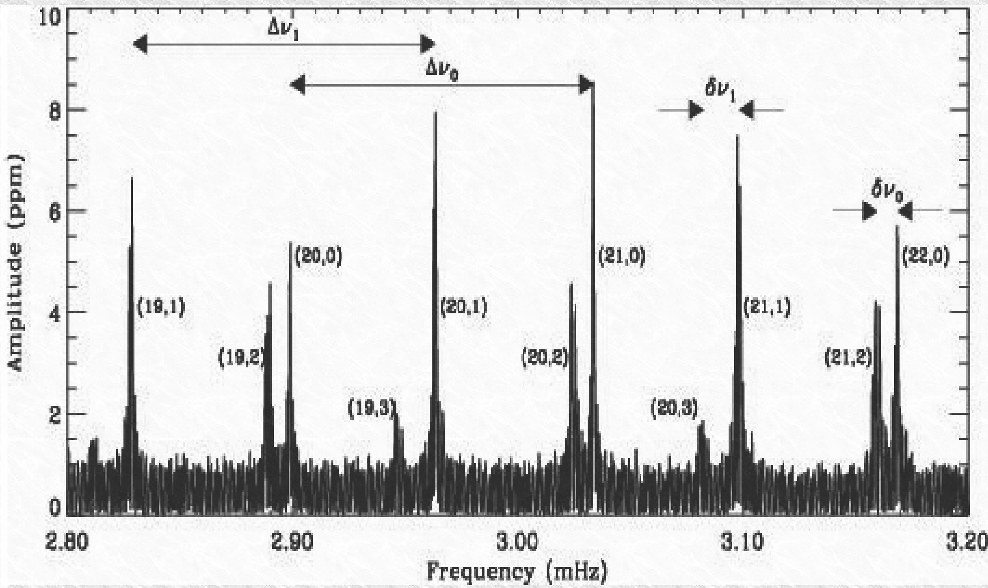
B2IV star 12 Lacertae (Mathias et al. 1994:OHP)



Level of km/s in skewness, moving towards m/s...

How does it work? the Sun...





* Freqs = f (sound speed + boundary effects) +HE
* Ratio of freq separations insensitive to boundary
  = f (density and adiabatic exponent of gas)

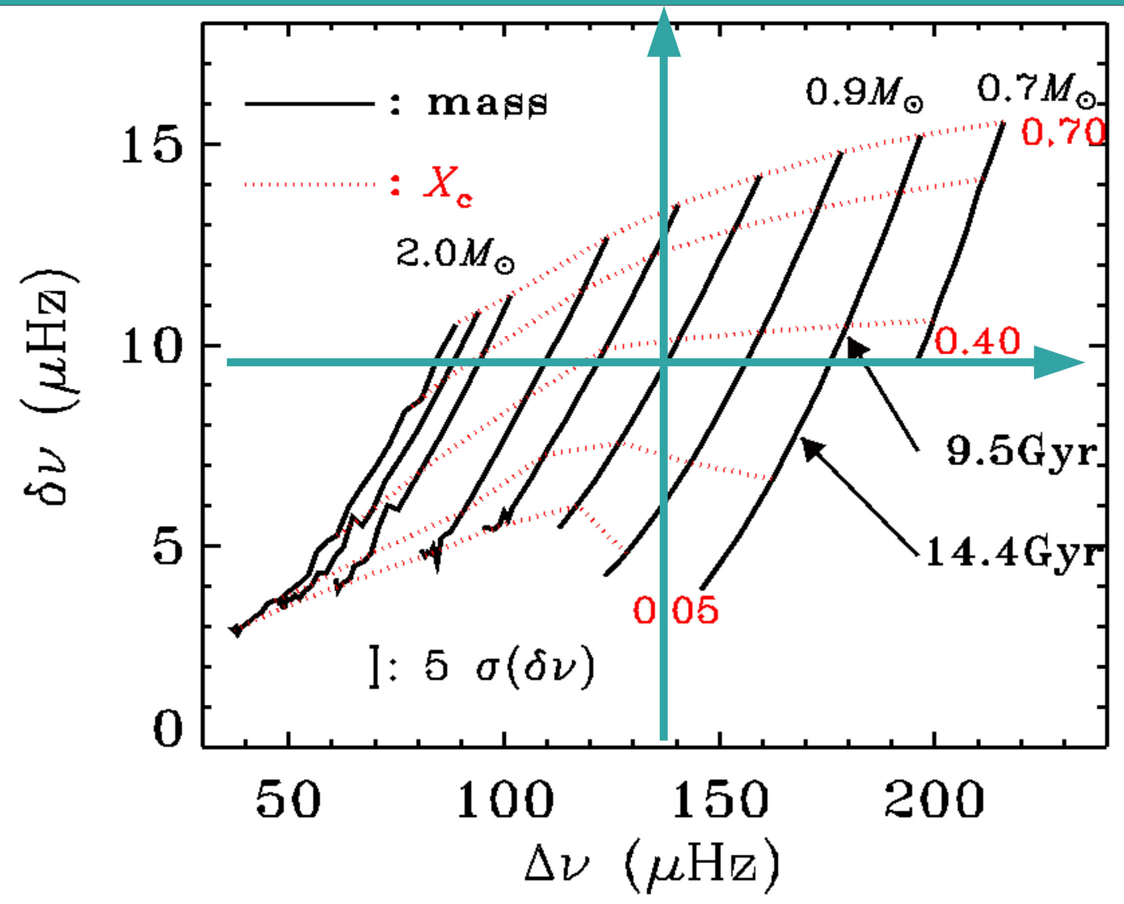
→ model-independent mass if we have an accurate radius (Roxburgh & Vorontsov 2003)

Strategy : forward modelling

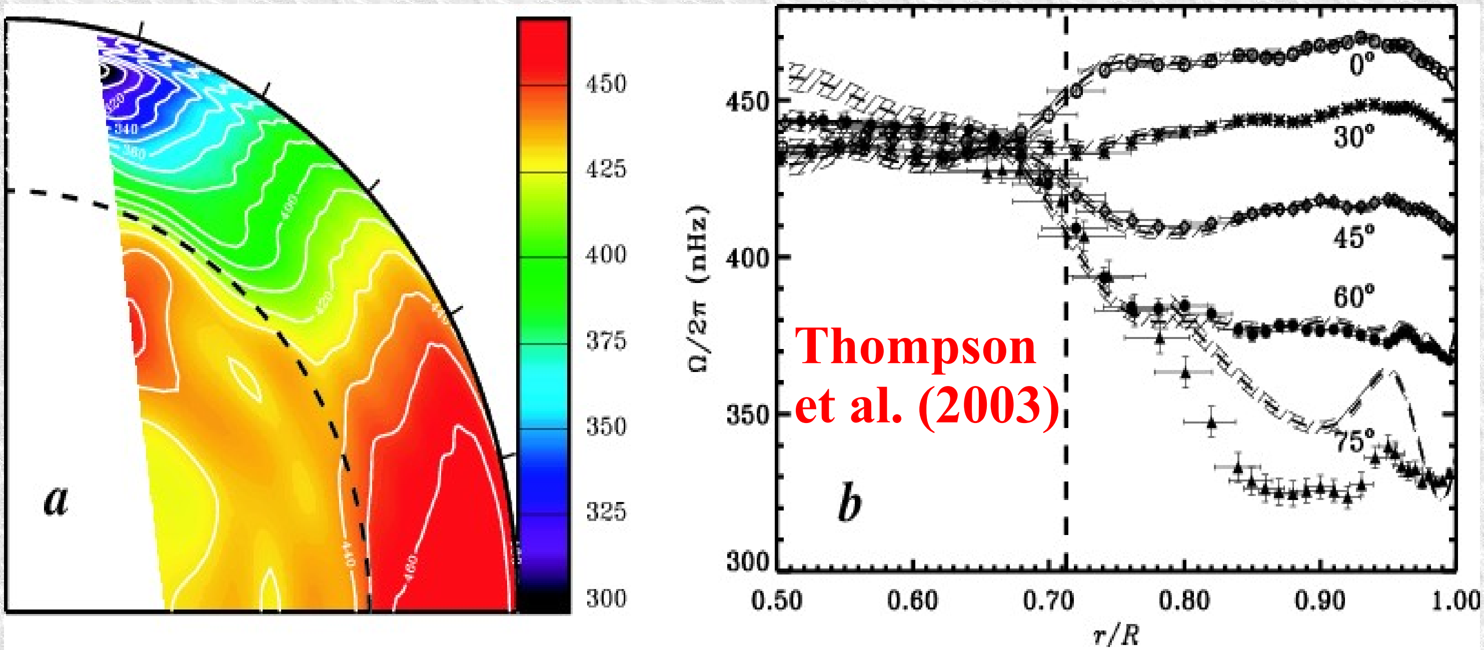
- Derive set of frequencies & separations, MI from data
- Compute stellar models for observed error box (Teff, Z)
  + predict their unstable oscillation modes
  X, Z (or Y), M, age, convective overshoot α_{ov} : 5D
  + effects of atomic diffusion? (settling + levitation)...
  + input: EOS, MLT, metal mixture, opacities,...
- Confrontation: can the models explain the seismic data?
  - if yes: we get very precise stellar parameters (age!!) for the given input physics (i.e. systematic uncertainty)
  - if no: great! Input physics is insufficient and must be upgraded to include additional effects or better descriptions until frequencies can be matched...

Asteroseismic HR (JCD) diagram

Large frequency separation: measure of sound speed
Small frequency separation: measure of sound speed gradient



Rotation inversion for the Sun

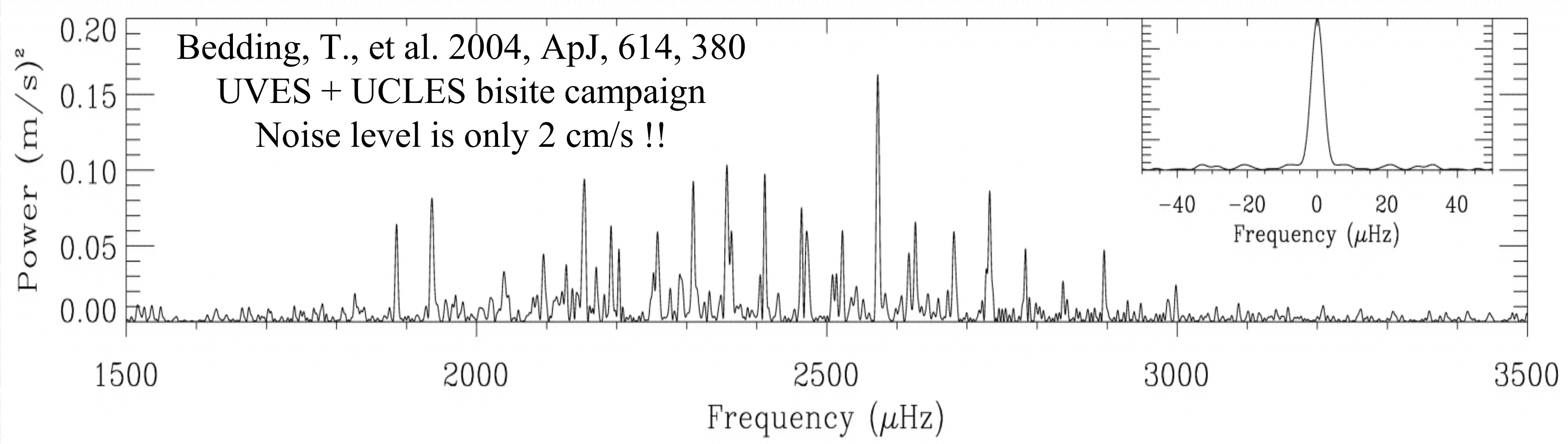


$$\nu_{n,l,m} = \nu_{n,l} - m \int_0^R \int_0^\pi \Omega(r,\theta) K_{n,l}(r,\theta) dr + \Theta\left(\Omega^2\right)$$

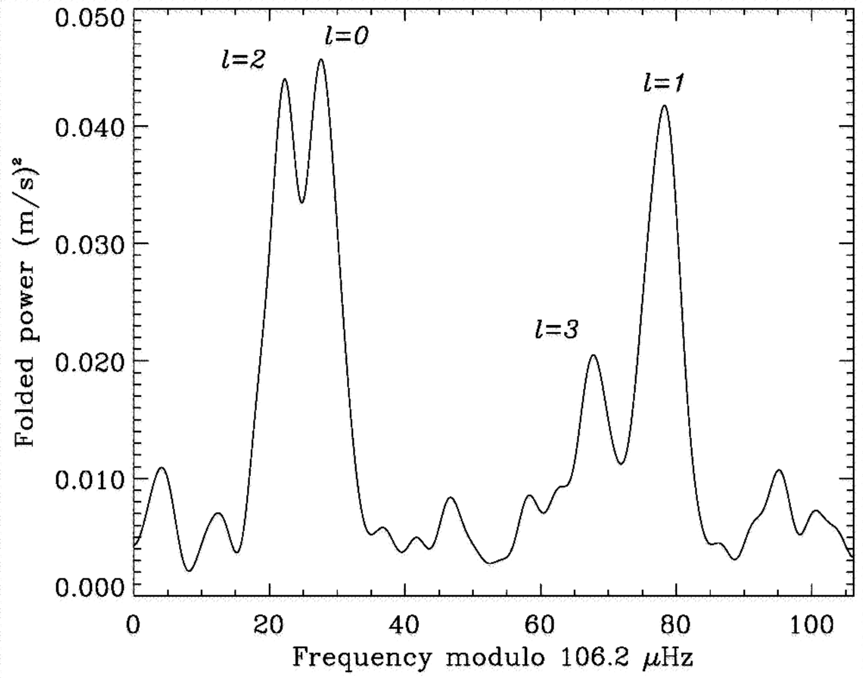
- **Needed to invert this set of equations:**
  1. Numerous observed frequency splittings
  2. Mode identification (l,m,n)

At present: we are able to treat only slow rotation...

Oscillations in α CenA+B (G2V+K1IV)



- **42 freqs of ℓ = 0, 1, 2, 3**
- **M(A)=1.1M☼, no conv. core**
- **Age: 6.7±0.5 Gyr**
- **Too frew freqs to tune metal mixture; Ω(r,θ)**
- **α(A) < α(B) by 5 - 10%**
  e.g. Miglio & Montalban (2005)



Pre-CoRoT status solar-like oscillators

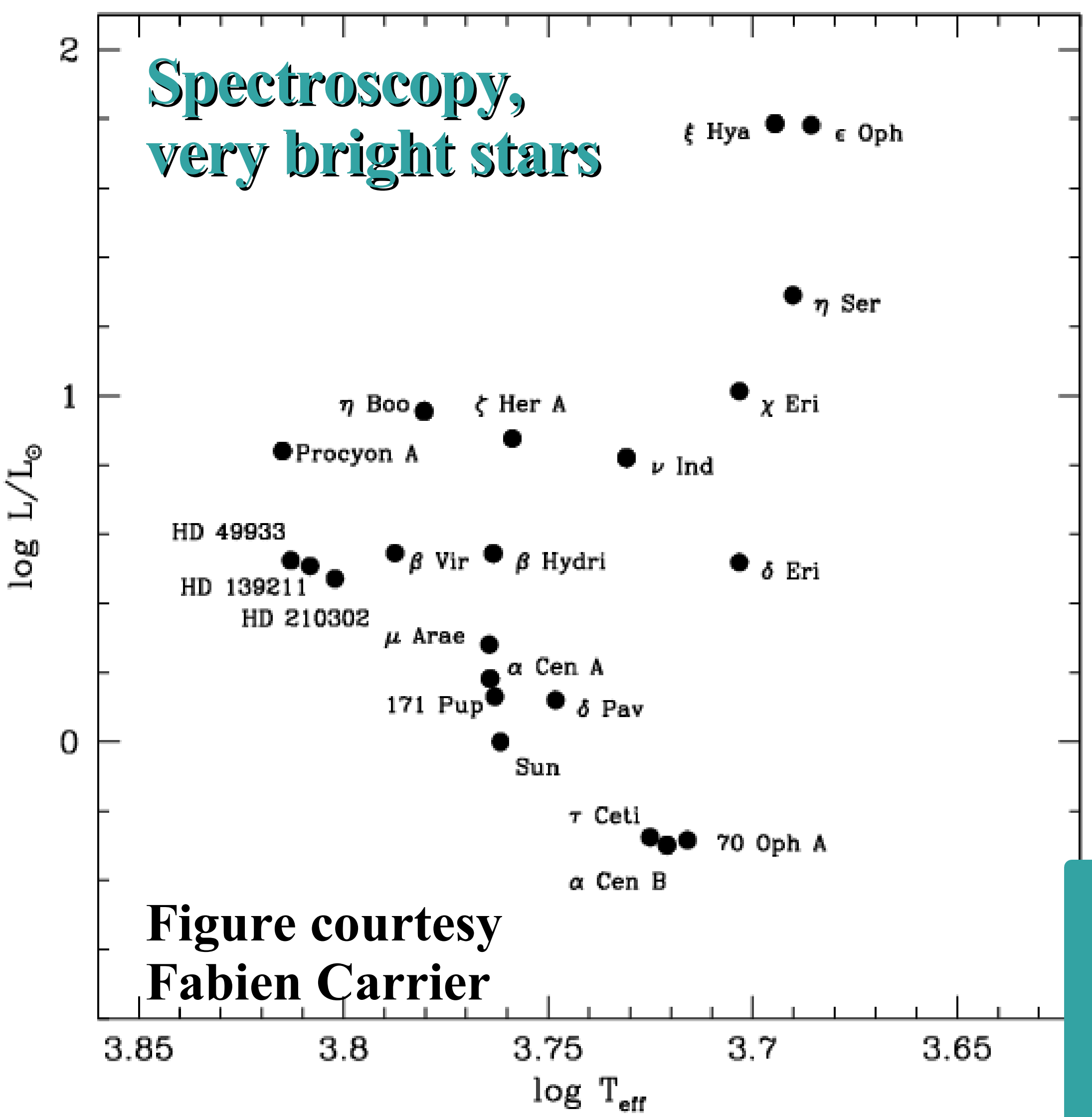


Figure courtesy Fabien Carrier

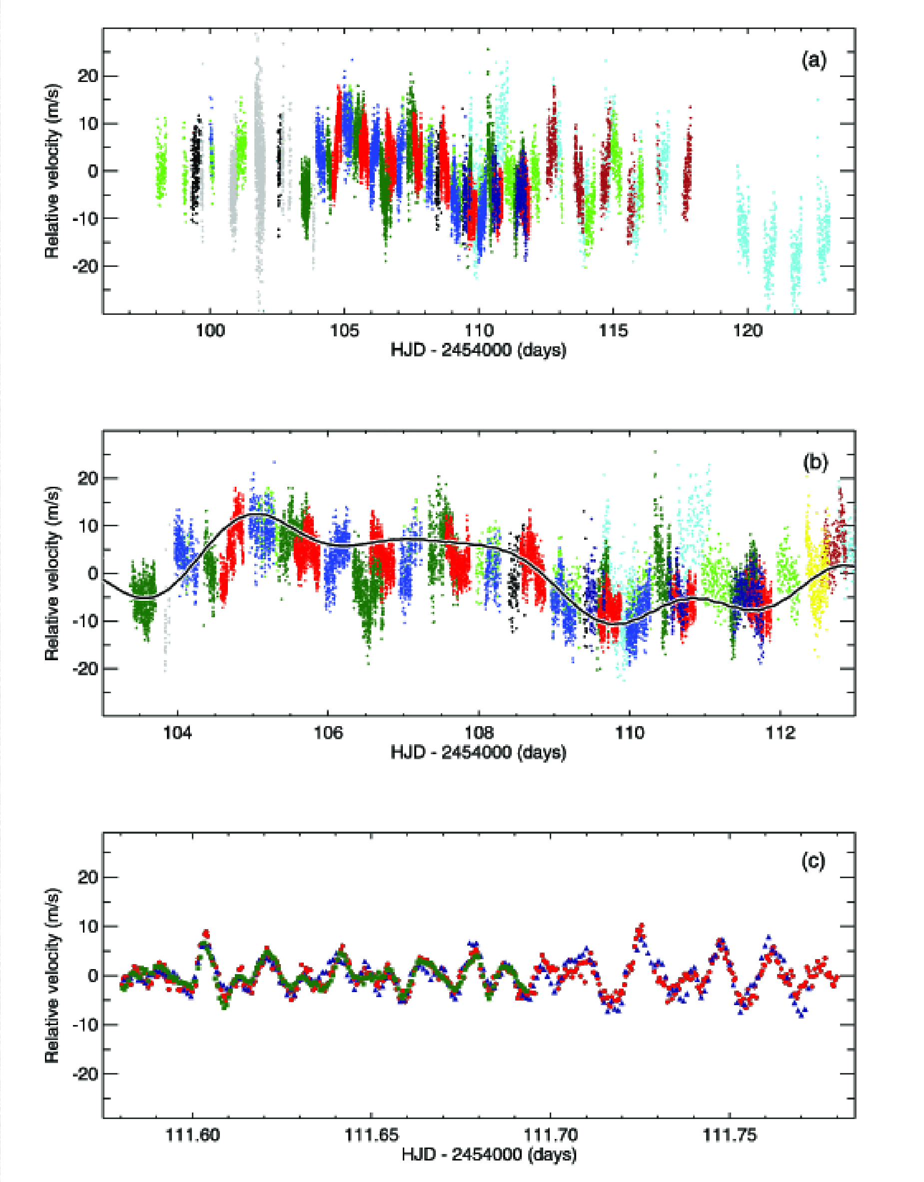
Oscillation frequencies scale ± as expected

Radial or nonradial modes in red giants?

Too few frequencies to map interior rotation or tune mixing processes as in the Sun

Need for long-term monitoring of a few selected targets

Status in RV data of solar-like oscillators



Procyon (F5IV)

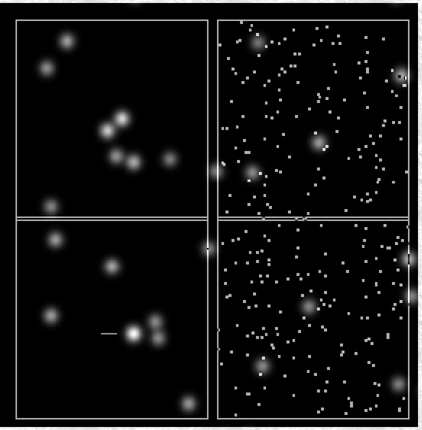
1 WIRE, 2 MOST campaigns (Bruntt et al. 2005, Guenther et al. 2008)

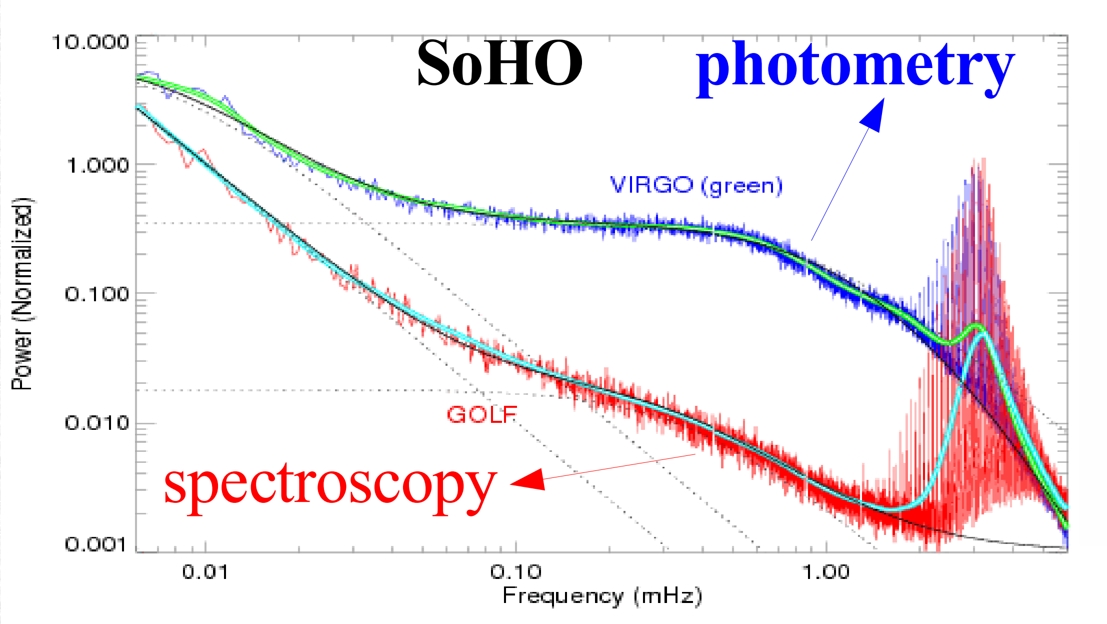
Remarkable multisite m/s spectroscopic campaign: 11 sites @ 8 observatories, 26d (Arentoft et al. 2008)

Stellar oscillations detected, but...

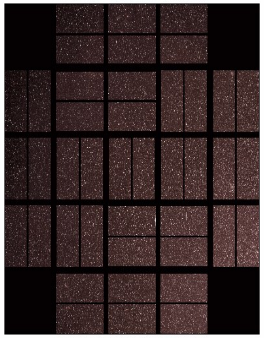
- Far too few frequencies, except for WDs
- Lack of precision in ground photometry (exception: 14 μmag – HR 1217; Kurtz et al. 2002)
- Lack of duty cycle from the ground
- Multisite campaigns in high-precision (m/s) spectroscopy highly exceptional (SONG...)

CoRoT



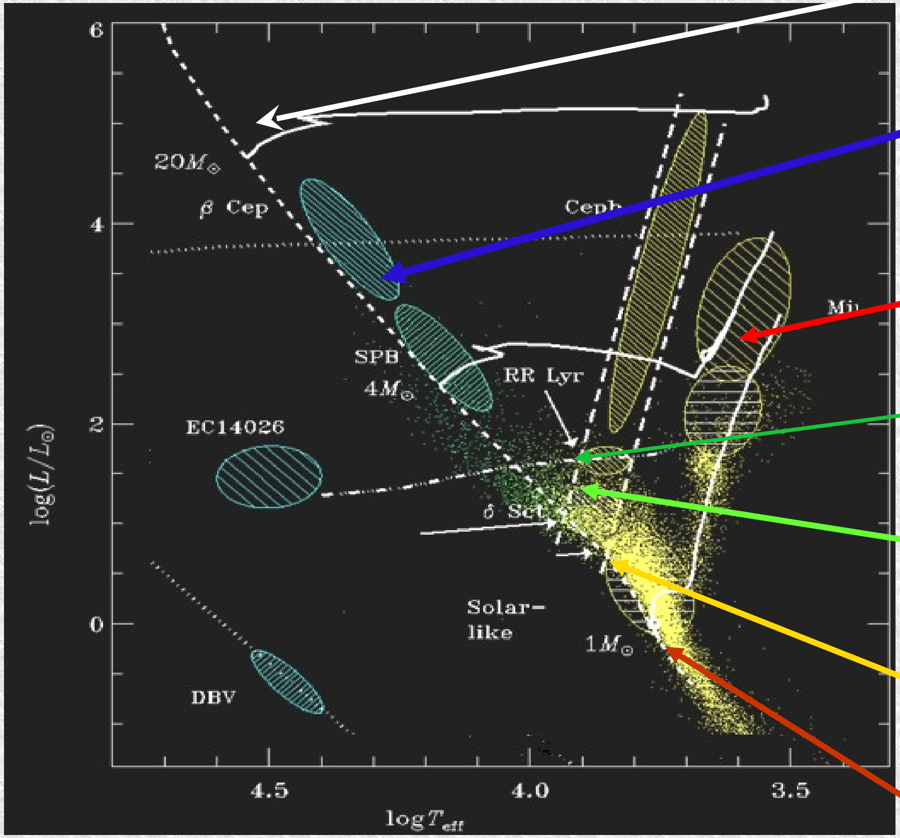


Kepler



Observed CoRoT seismology targets

Slide courtesy: Don Kurtz



7 O

12 B stars,
1 β Cep,
5 Be

10 giants (G,F)

7 δ Scuti,
2 known γ Dor +1

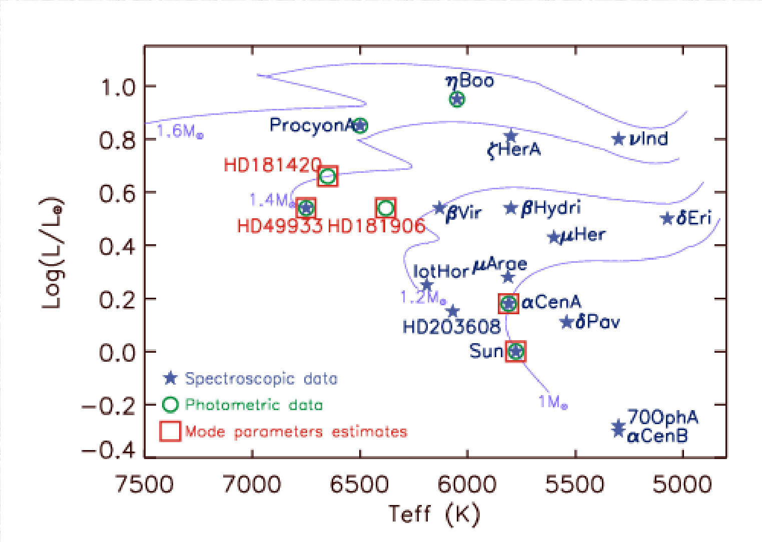
17 A/early F stars ?
3 Am, 7 Ap,

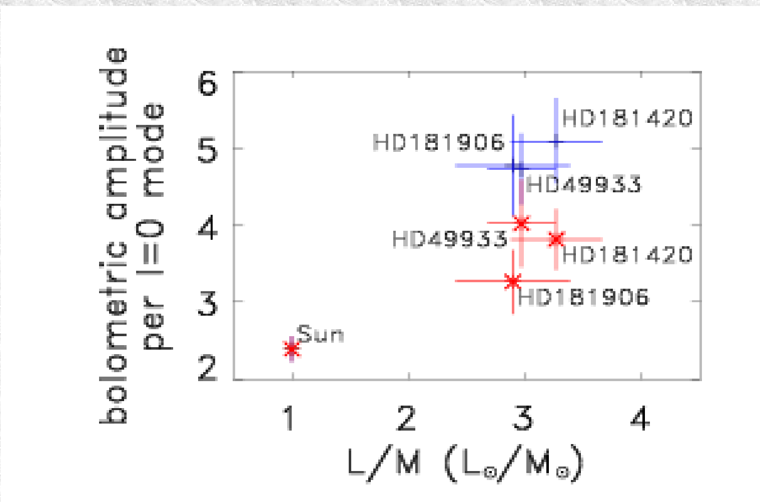
9 solar-like puls. cand.
(one observed twice)

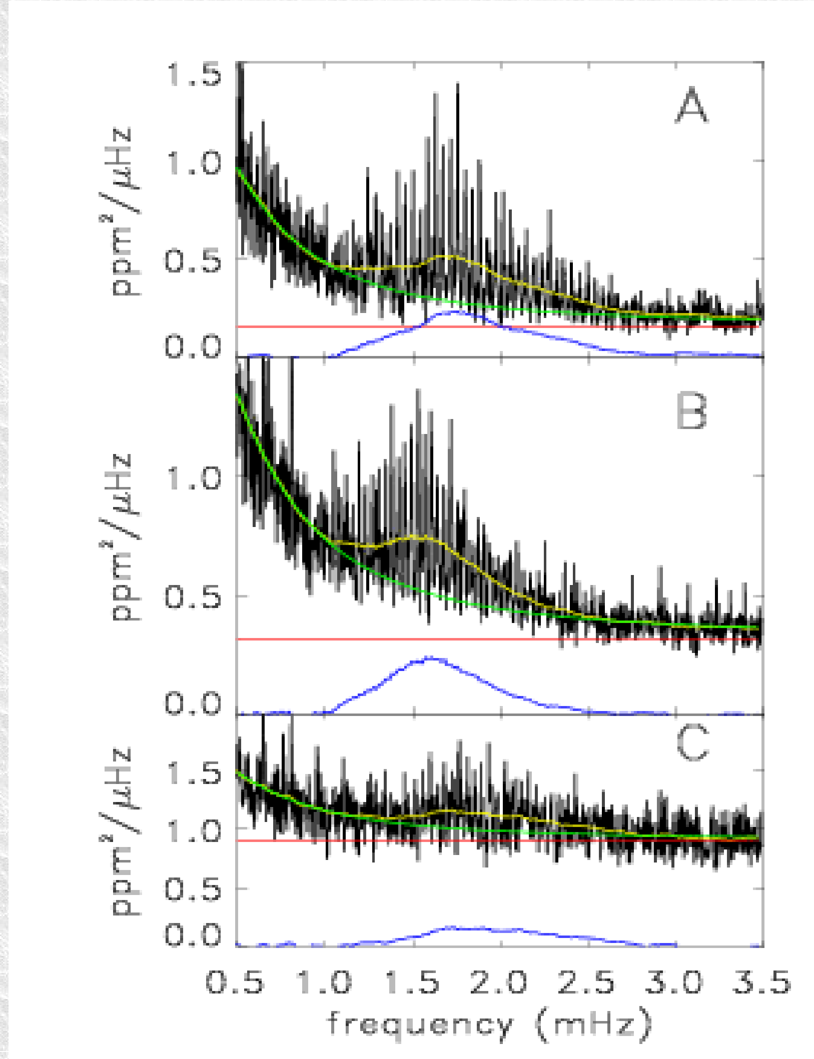
3 KM

Michel et al. (CoAst, 2008): overview

First CoRoT results : F stars







6th

7th

8th

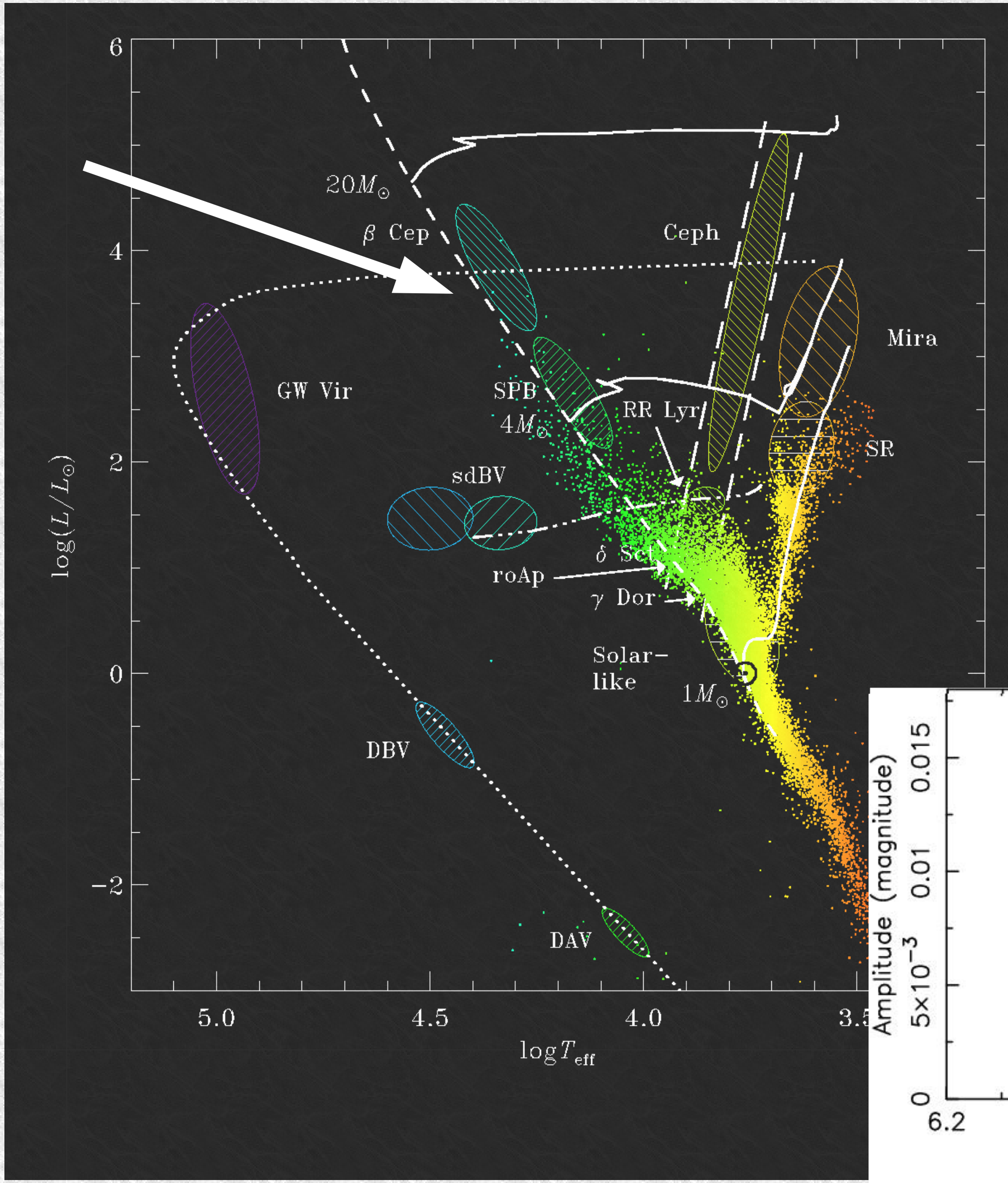
Michel et al. (2008, Science): lower amplitudes, granulation 3x solar

Pre-CoRoT results for B stars

α_{ov} (Hp) ??
Ω(r) ??

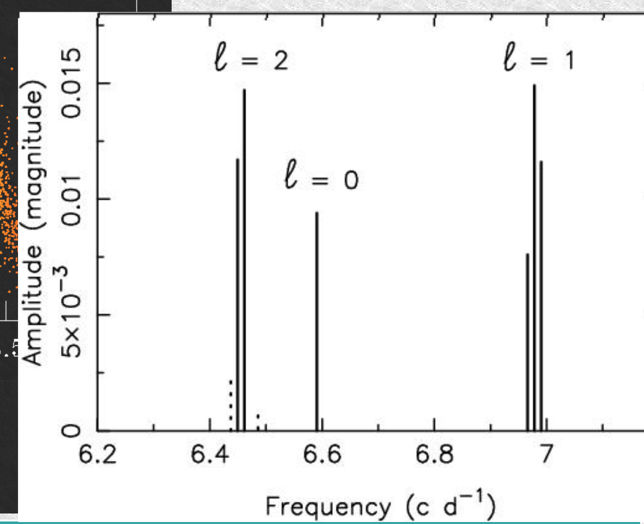
successful for slow rotators

Be stars:NRP detections by LPVs & MOST, but no internal structure parameters



V836 Cen (B3V): 1st proof of core overshoot and of non-rigid internal rotation inside a MS star different from the Sun

(Aerts et al. 2003)



Pre-CoRoT results for B stars

Compatible with EB & isochrone fitting

Ref.	Star	Mass ($M_\odot$)	SpT	α_{ov} (Hp)	ΩR(km/s)	$\Omega_{core}/\Omega_{env}$
(1)	HD 16582	10.2 ± 0.2	B2IV	0.20±0.10	28(14?)	
(2)	HD 29248	9.2 ± 0.6	B2III	0.10±0.05	6±2	~5
(3)	HD 44743	13.5 ± 0.5	B1III	0.20±0.05	31±5	
(4)	HD 129929	9.4 ± 0.1	B3V	0.10±0.05	2±1	3.6
(5)	HD 157056	8.2 ± 0.3	B2IV	0.44±0.07	29±7	~1

(1) Aerts et al. (2006): 20 d MOST photometry + 1 week spectra

(2) Pamyatnykh et al. (2004); Ausseloos et al. (2004):
5 months multisite photometry + spectroscopy

(3) Mazumdar et al. (2006): 4 years high-resolution spectroscopy

(4) Aerts et al. (2003, 2004); Dupret et al. (2004): 20 years photometry

(5) Briquet et al. (2007): 2 years spectroscopy + few months photometry

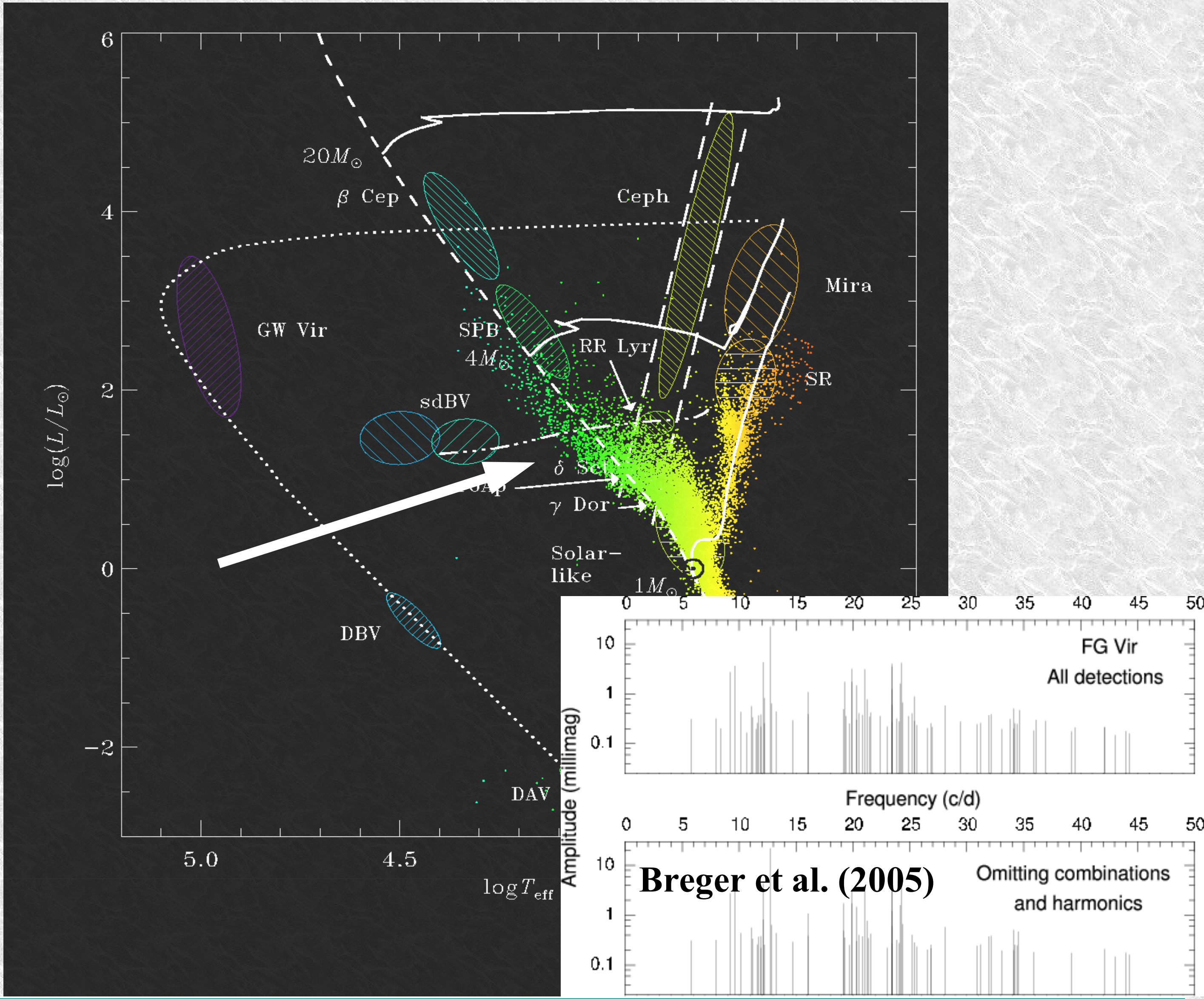
Pre-CoRoT results for AF stars

α_{ov} (Hp) ??

Ω(r) ??

seismic modelling not successful due to lack of mode ident.

numerous frequency detections from ground networks and MOST



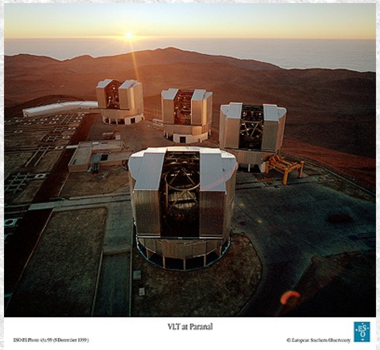
Breger et al. (2005)

Asteroseismology entering its golden age

- Ground-based network data have opened up the field, after helioseismology, particularly for WDs
- MOST as pioneer & CoRoT functioning excellently, they revolutionize observational asteroseismology
- Multisite high-precision spectroscopy for bright stars (cf. Procyon campaign, Arentoft et al. 2008; MOST: Guenther et al. 2008): we need more of those...
- Basic theory is mature; needs refinement for dense cores, rapid rotation, nonlinear mode coupling, outbursts,...
- Ground-based data needed for mode identification and tuning of the models; as well as for fast and/or ultrabright pulsators (roAp, sdOB, WD,...)

Goal 1: better independent constraints

Provide an independent high-precision radius estimate for bright stars Cunha et al. (2007, A&ARev)



ESO
VLTI

Provide an independent high-precision distance estimate: L and Teff → R

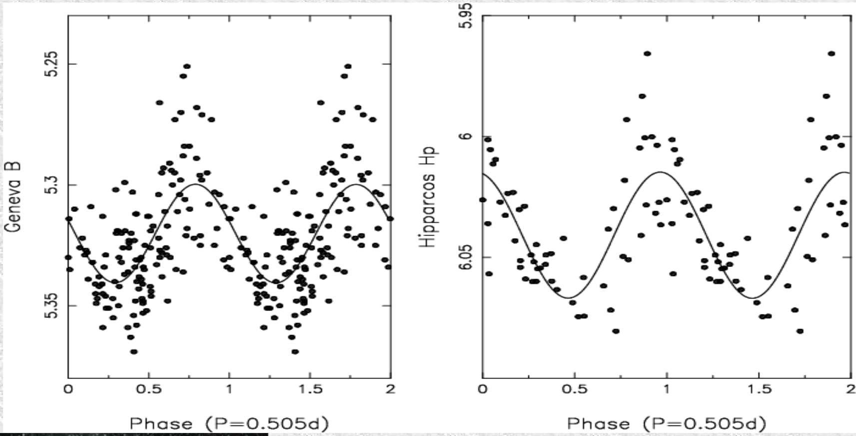
2012-2017
ESA
Gaia

Dedicated instruments for specific stars attached to private telescopes for mode identification

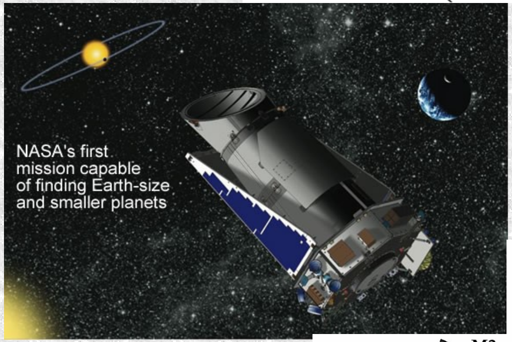
Mercator
ultrafast
MAIA
camera

Goal 2: exoplanet host star seismology

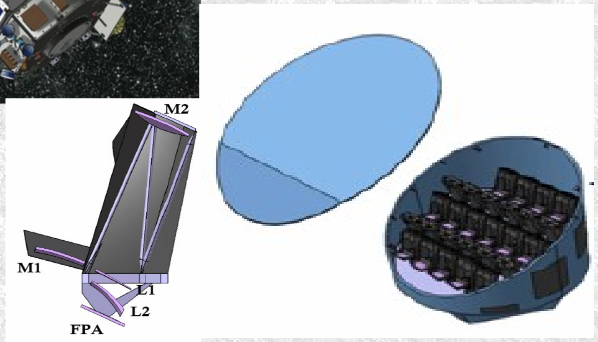
Gamma Dor star HR 8799
SpT A5V, 3 g modes, 3 planets...
(Cuypers et al. 2009)



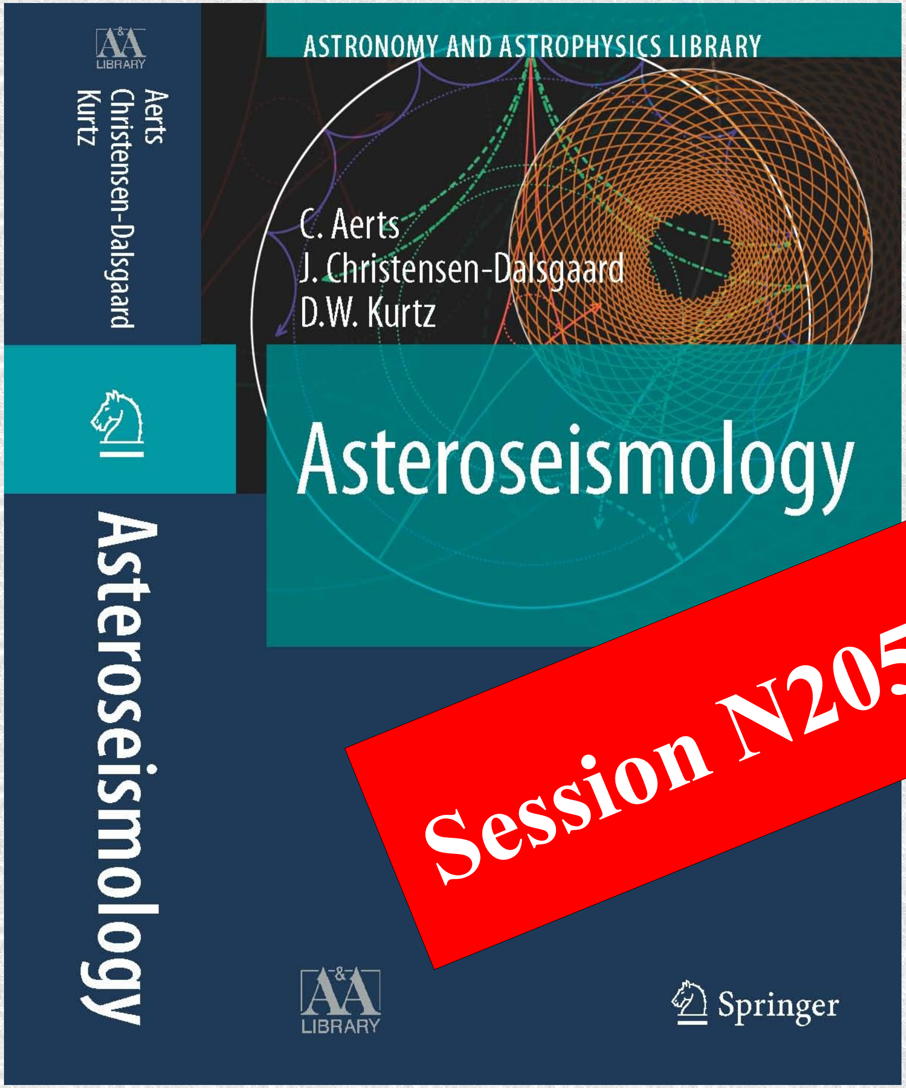
Kepler : NASA mission (95cm), launched 7 March 2009, exoplanets mission with KASC
4 years: 11<V<16



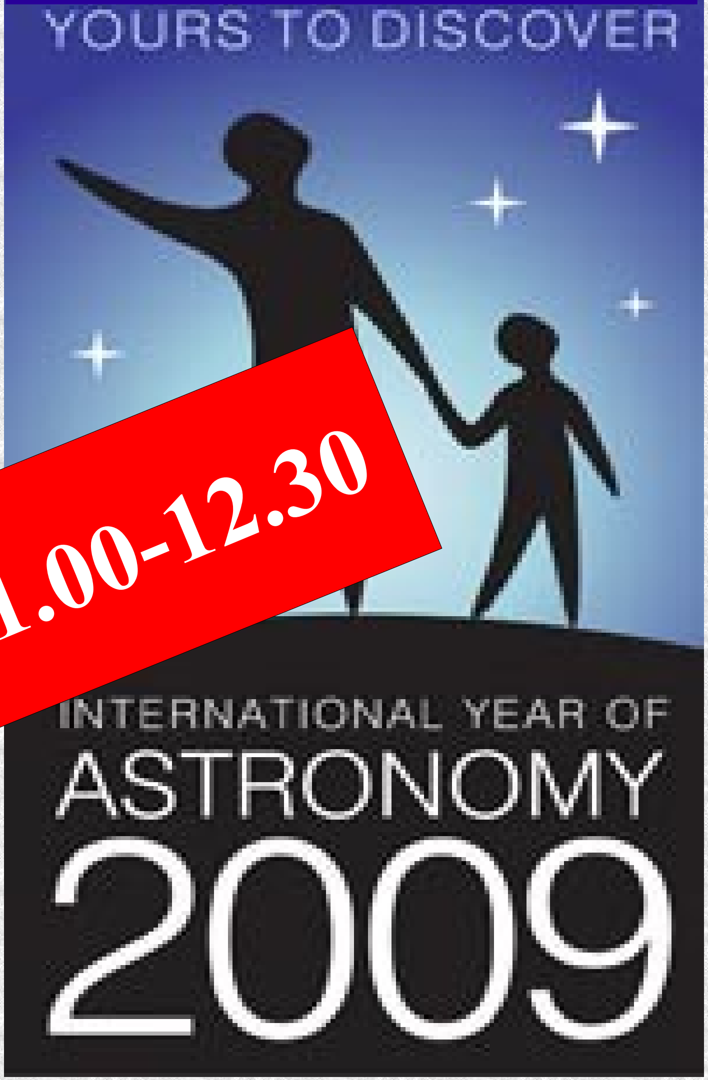
PLATO: exoplanet ESA mission with asteroseismic capabilities pre-selected for CV2015-2025
6 years: 8<V<11



Now is a good time to become an asteroseismologist !!



The CoRoT data



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