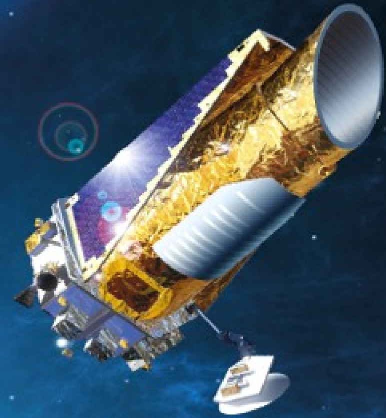
EXTRASOLAR PLANETS

STELLAR STRUCTURE

CoRoT 3 - KASC 7



THE SPACE PHOTOMETRY REVOLUTION

ACTIVITY

July 6 - 11, 2014 - Toulouse, FRANCE

Scientific Organizing Committee

C. Aerts - A. Baglin
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J. Christensen-Dalsgaard - P. De Cat
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D.W. Kurtz - D.W. Latham
T.S. Metcalfe - E. Michel (Co-Chair)
M.J.P.F.G. Monteiro - E. Poretti
H. Rauer - D. Stello
G. Vauclair - W.W. Weiss

ASTEROSEISMOLOGY

ROTATION

Médiathèque José Cabanis, Toulouse

Scientific/business program

Sessions

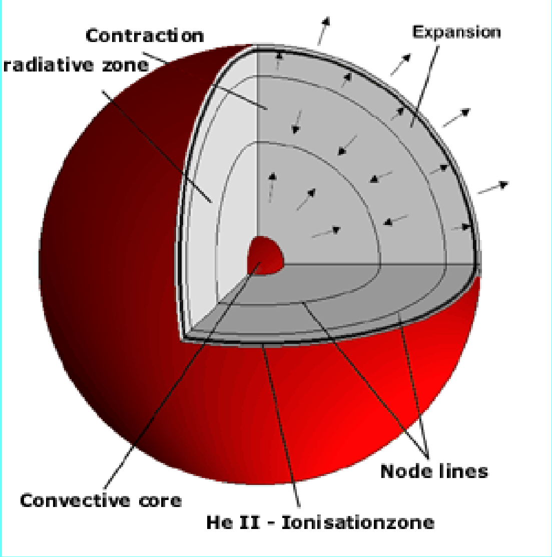
1. Probing stellar structure and evolution with asteroseizmology
2. Extrasolar planets and planet systems
3. Present and future ground-based and space projects
4. Multiple systems and star-planet interactions
5. Stellar activity and rotation

General comments/statistics

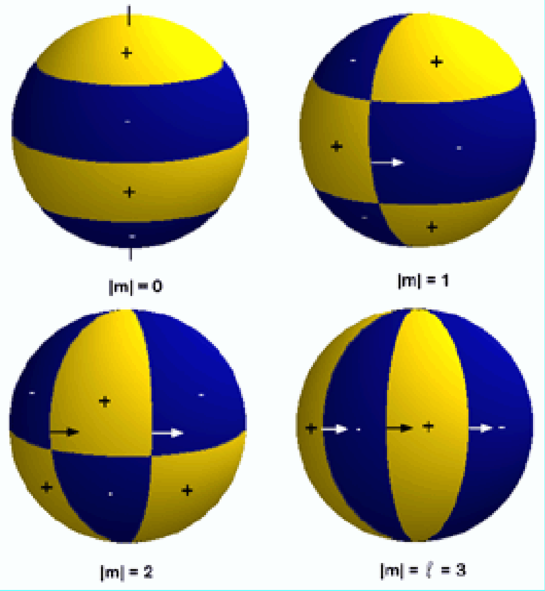
- 245 registered participants, 66 talks, 120 posters
- 4.5 days of scientific sessions + trip
- (almost) all talks recorded and available on YouTube, 62/66 talks as pdf

Stellar pulsations intro

- three quantum numbers to describe the mode:
- n = number of nodal spheres (n=0 fundamental, n=1 first overtone)
- l = number of nodal circles on surface
- m = ±l number of meridional nodal lines (m > 0 for retrograde pulsation)
- p (pressure modes) - large amplitudes in outer layers, restoring force is pressure, equal spacing in frequency
- g (gravity modes) - large amplitude in inner layers, restoring force is gravity, equal spacing in period
- f (gravity) - surface gravity modes - ocean waves
- Surface shape and velocity fields described by Legendre polynomials
- m modes have the same frequency, rotation causes splitting (because of stellar flattening due to rotation) of modes in frequency



Radial mode n=2



Non-radial modes l=3

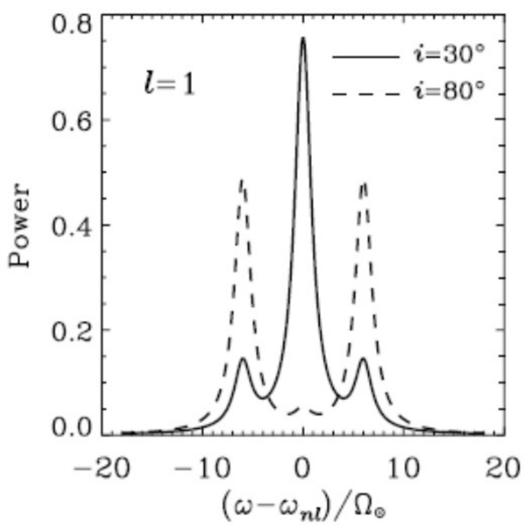
Stellar pulsations intro II

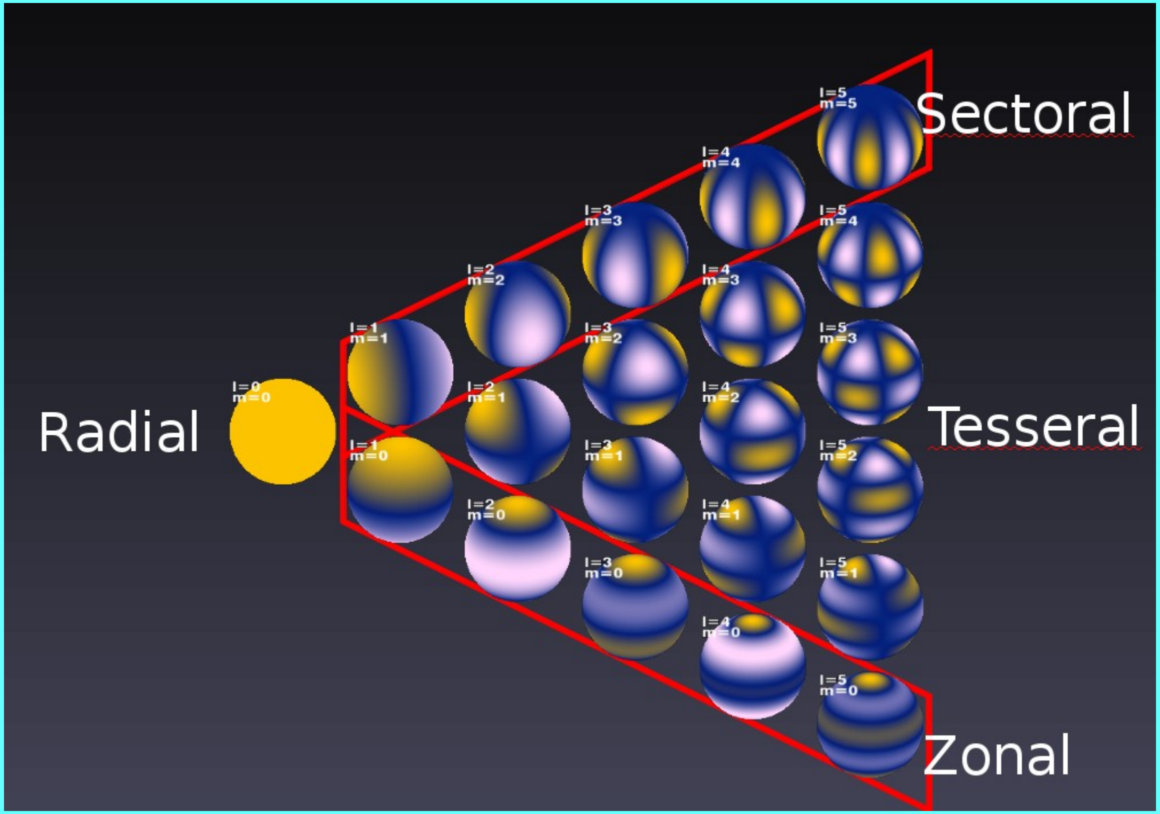
$$\Delta\nu_0 = \left[2\int_0^R \frac{\mathrm{d}r}{c(r)}\right]^{-1}$$

$$L^2 = (k_h c)^2 = l\,(l+1)\left(\frac{c}{r}\right)^2$$

$$N^2 = g\left(\frac{1}{\gamma}\frac{\mathrm{d}\ln P}{\mathrm{d}r} - \frac{\mathrm{d}\ln\rho}{\mathrm{d}r}\right), \quad \gamma = \frac{C_V}{C_P}$$

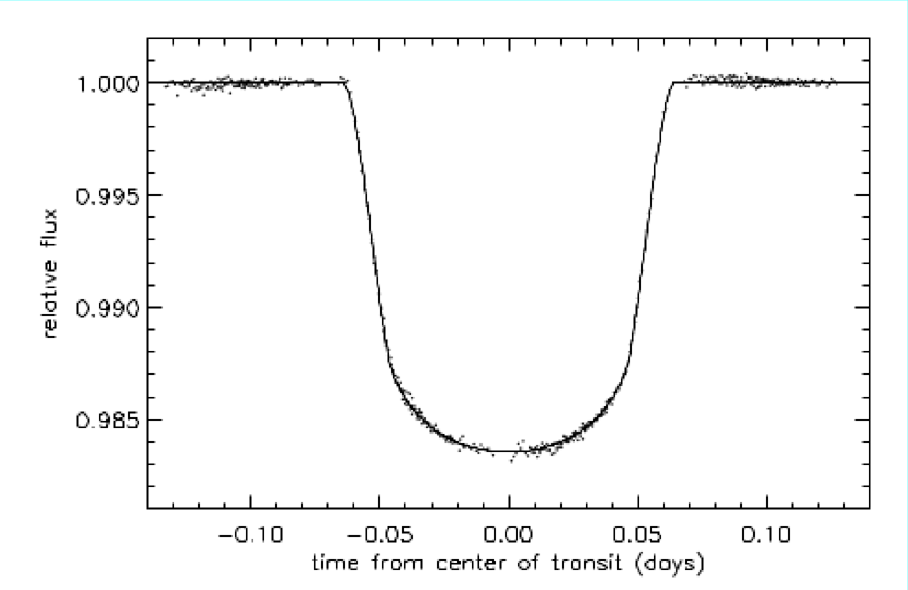
- p-mode frequency spacing = inverse of time sound propagates from center to surface of a star
- p-modes: Lamb frequency
- g-modes: Brunt-Väisälä frequency
- l=0 - radial, l=1 - dipole
- l=2 - quadruple mode
- g-mode γ Dor
- p-mode δ Sct





R. Gillilaland: Prelude to and nature of the Space Photometry Revolution

History:
1995: 51 Peg, spectroscopic discovery
1999: Transits on HD 209458! The exoplanet skeptics silenced.
2001: HST LC of HD 209458, then fantastic, now routine
2001 - 2004: first successes of ground-based asteroseizmology (RVs)
2009: revolution begins with CoRoT data - detection of radial and non-radial pulsations in 300 red giants
Future: TESS & PLATO



Number of discoveries:

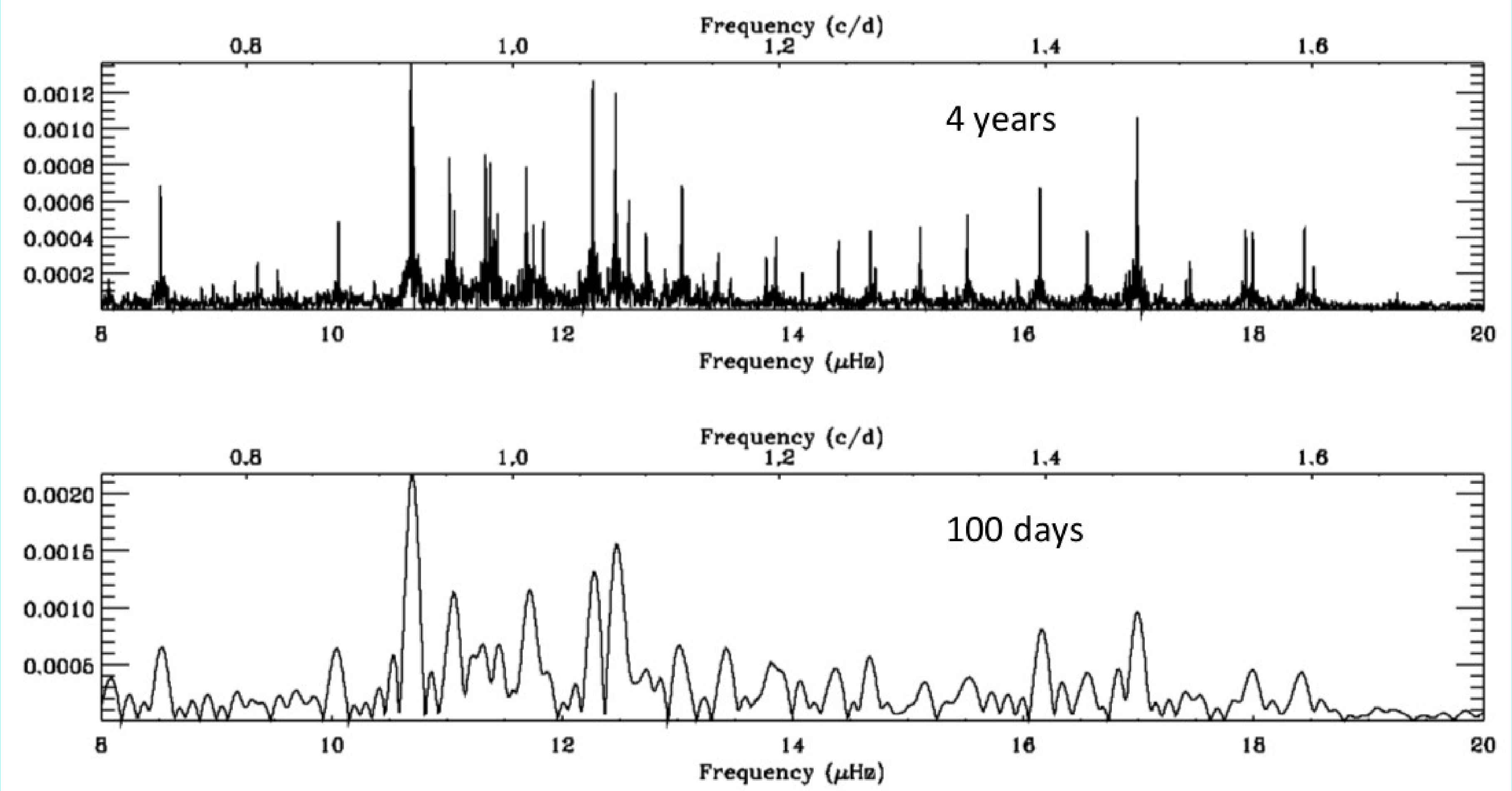
	<1994	1999	2004	2009	2014
Exoplanets	4	25	120	265	1,382
Asteroseismology	0	0	10	380	15,000

1994: quest for discovery, any modestly believable result would do!

2014: a stunningly large number of rock-solid detections in both fields, series of qualitative advances, e.g., discerning the demographics of planets across the rocky/gaseous boundary, probing the internal rotation and deep structural characteristics of red giants, and often results combining exoplanets and asteroseismology to strong interpretive effect.

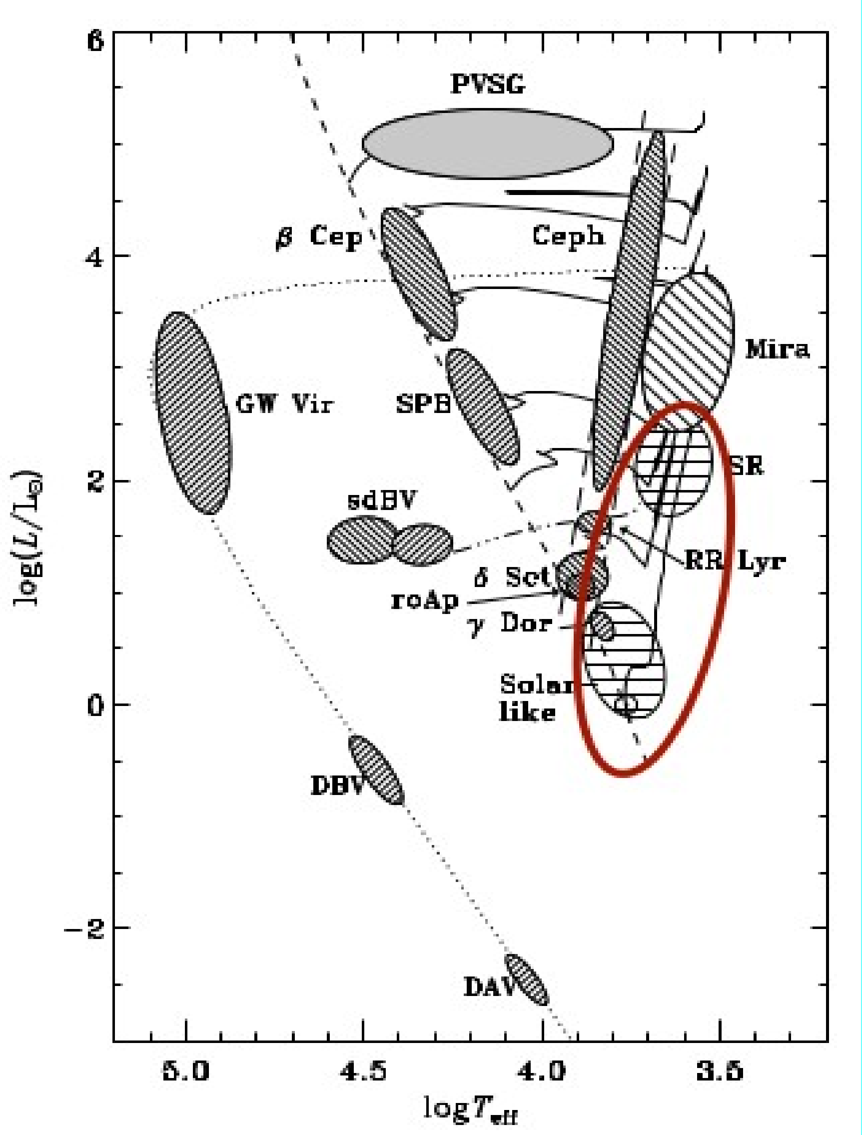
Note on PSF size: sharpest PSF (68% light in the central pixel) provides best photometric accuracy, but requires perfect guiding !

Frequency resolution:



J. Montalban: Ensamble asteroseizmology - scaling laws

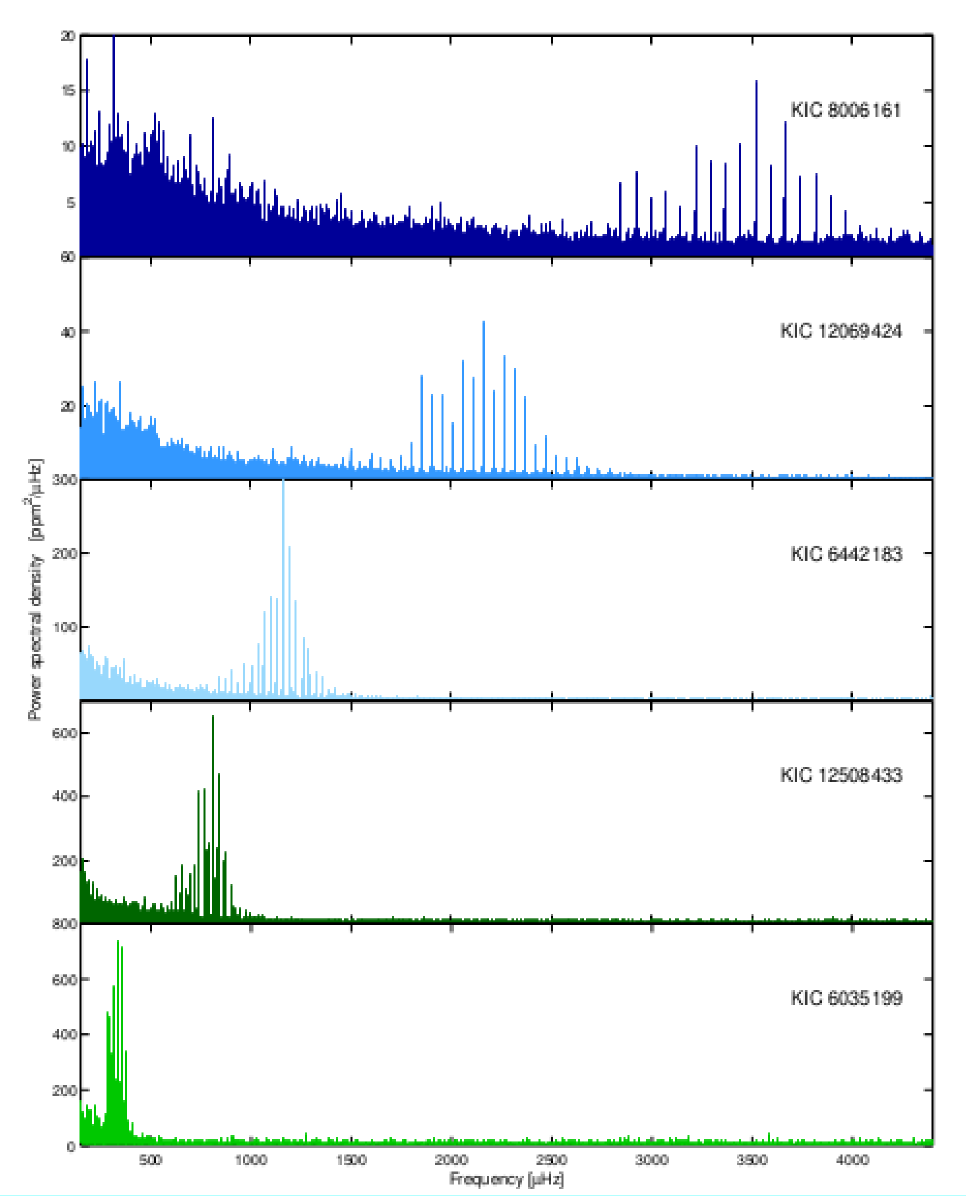
- Solar-like (p-mode) oscillations in other stars: periods: minutes to hours intrinsically damped
- forced by turbulent convection amplitudes:ppm - 10ppm
- acoustic modes: radial and non-radial
- in subgiants/giants: g-p mixed modes



$$\left(\frac{R}{R_\odot}\right) = \left(\frac{\nu_{\max}}{\nu_{\max,\odot}}\right)\left(\frac{\Delta\nu}{\Delta\nu_\odot}\right)^{-2}\left(\frac{T_{\rm eff}}{T_{\rm eff,\odot}}\right)^{0.5}$$

$$\left(\frac{M}{M_\odot}\right) = \left(\frac{\nu_{\max}}{\nu_{\max,\odot}}\right)^{3}\left(\frac{\Delta\nu}{\Delta\nu_\odot}\right)^{-4}\left(\frac{T_{\rm eff}}{T_{\rm eff,\odot}}\right)^{1.5}$$

- Scaling relations must be tested from: eclipsing binaries, interferometry, stars in clusters
- Current accuracy: 4% for radius, 10% for mass
- Chemical composition needed

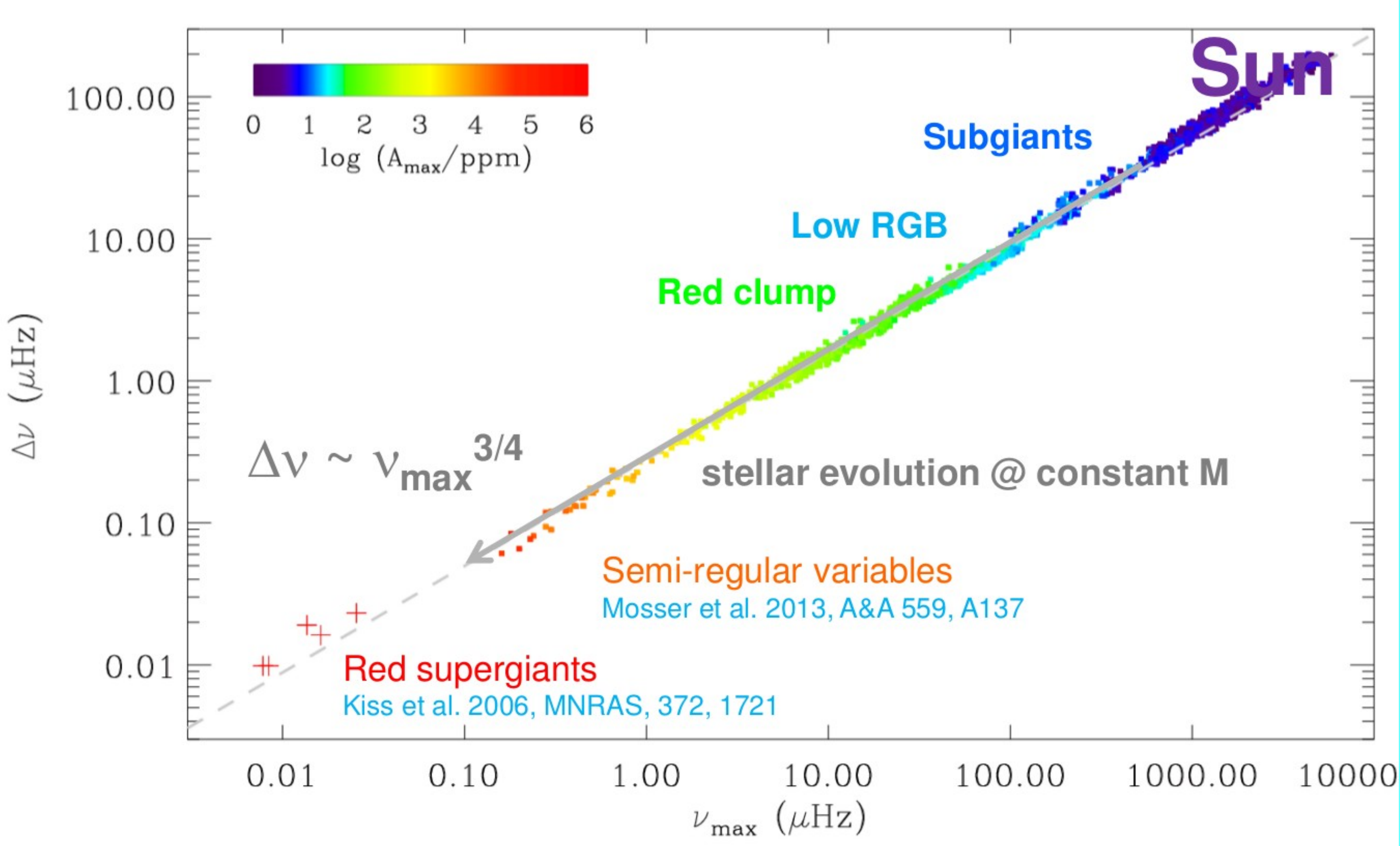


Kepler stars with 1.1 Msun but different surface gravity

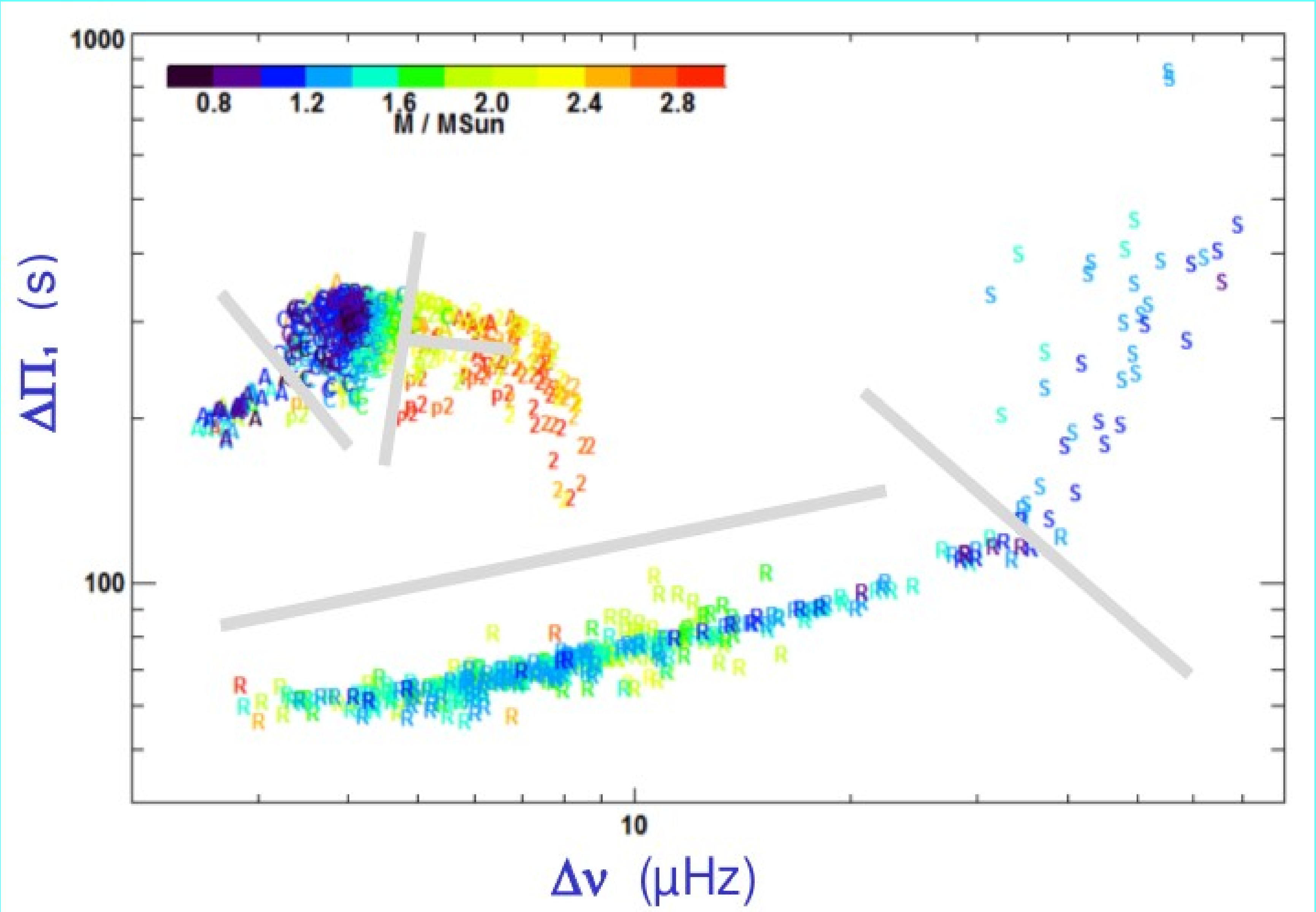
M. Benoît: Monitoring stellar evolution with mixed modes

- mixed modes: have the character of a gravity mode in the core region and of an acoustic mode in the envelope of the star
- they enable to probe deep interiors of subgiants and red-clump stars
- pressure modes: equal spacing in frequency $\Delta\nu$, gravity modes: equal spacing in period $\Delta\Pi$
- some g-modes in the stellar core resonate with p-modes in envelope ==> can be observed and can probe the core !

CoRoT observations

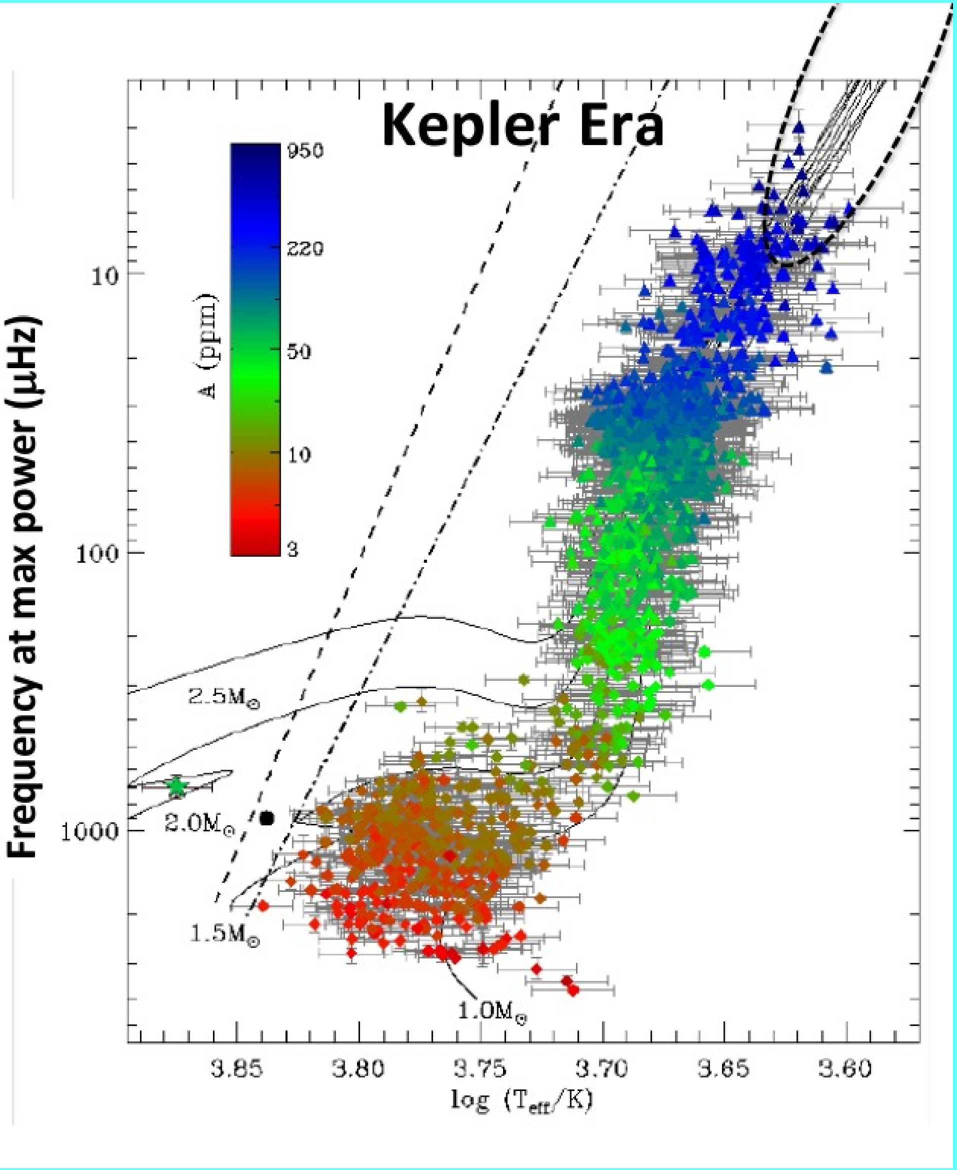


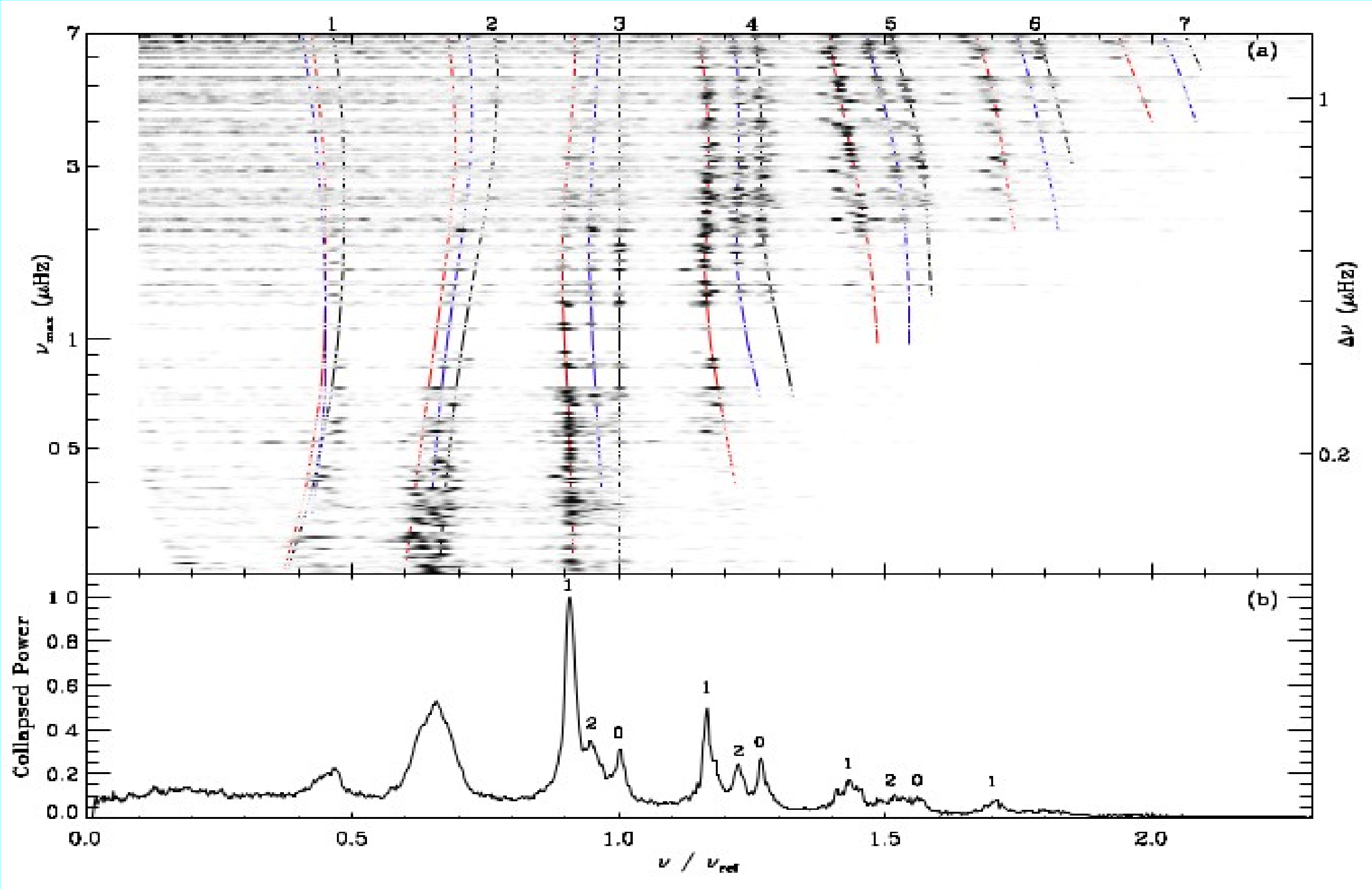
Relation between core and envelope using p and g-modes



D. Stello: Non-radial oscillations in M-giant semi-regular variables

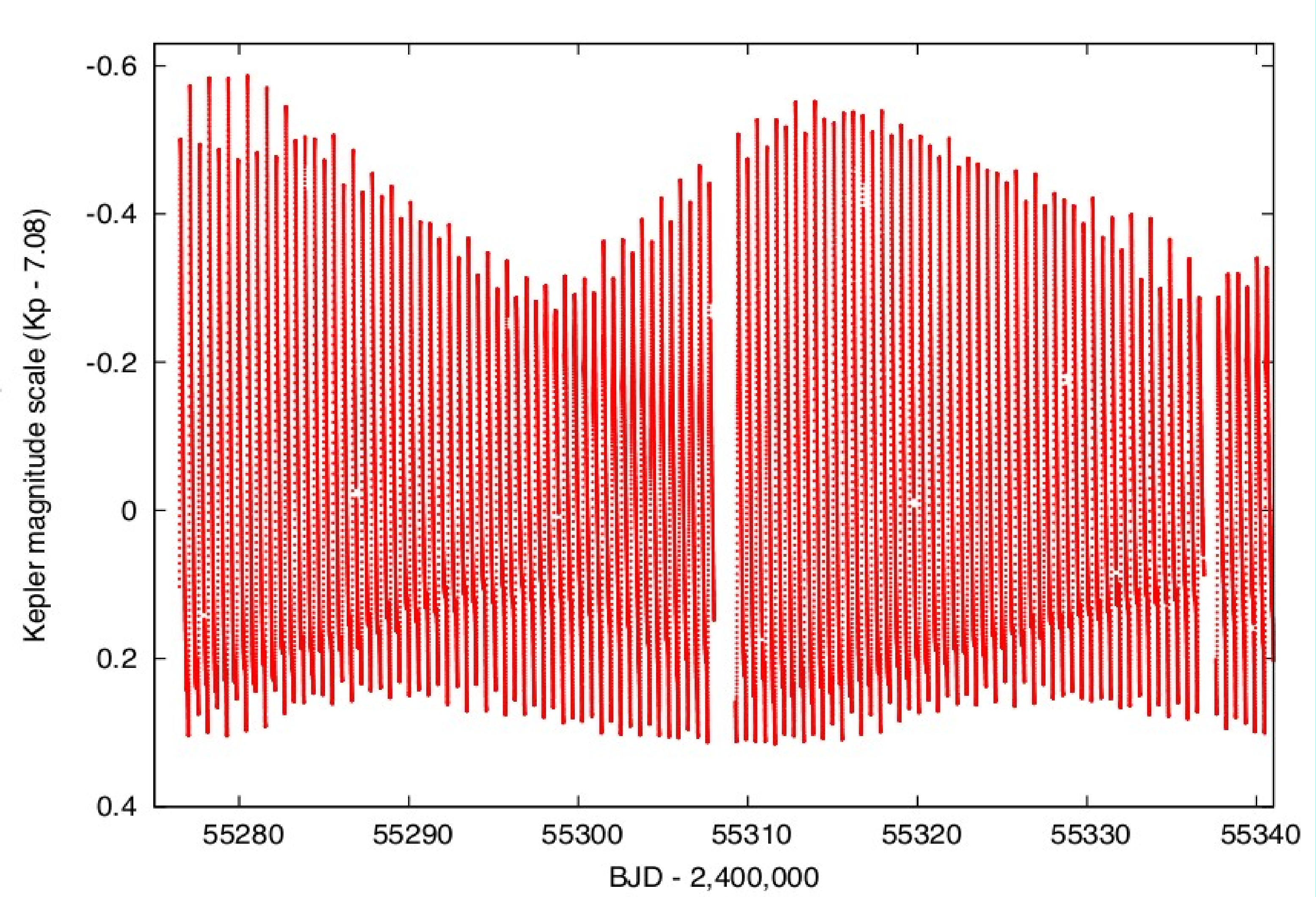
- Periods in M-giants too long
- Theoretical predictions of observed frequencies compared with observations
- First explanations of the Petersen diagram
- Problem: correct identification of modes



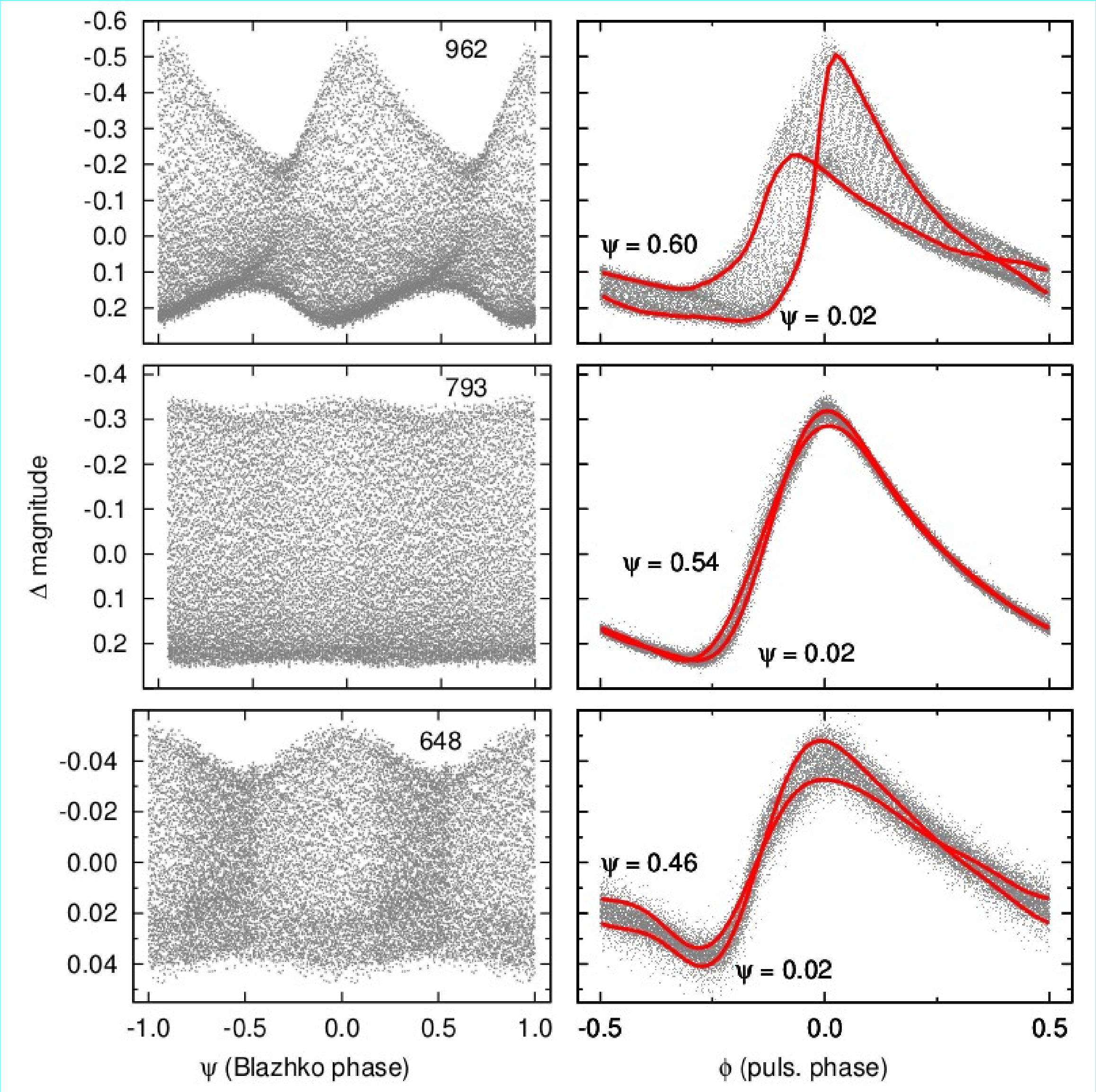


power spectra for 195 Kepler stars sorted with frequency of maximum power (vertical direction) and rescaled to frequency of third radial mode n=3, vertical lines indicate frequencies calculated from evolutionary models for RGs - incredible agreement !!! Dipole mode (l=1) was found to increase in power with luminosity

R. Szabo: The space photometry revolution in our understanding of RR Lyrae stars

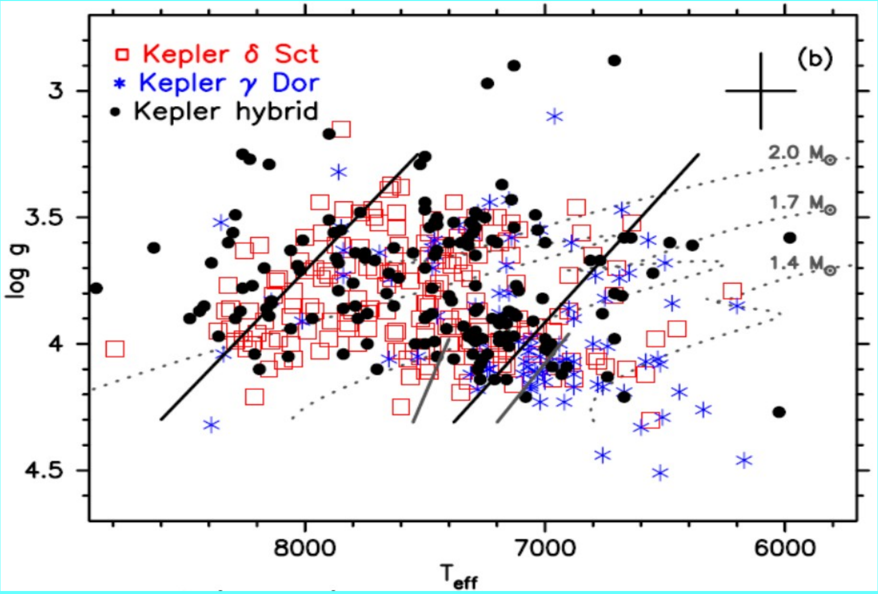


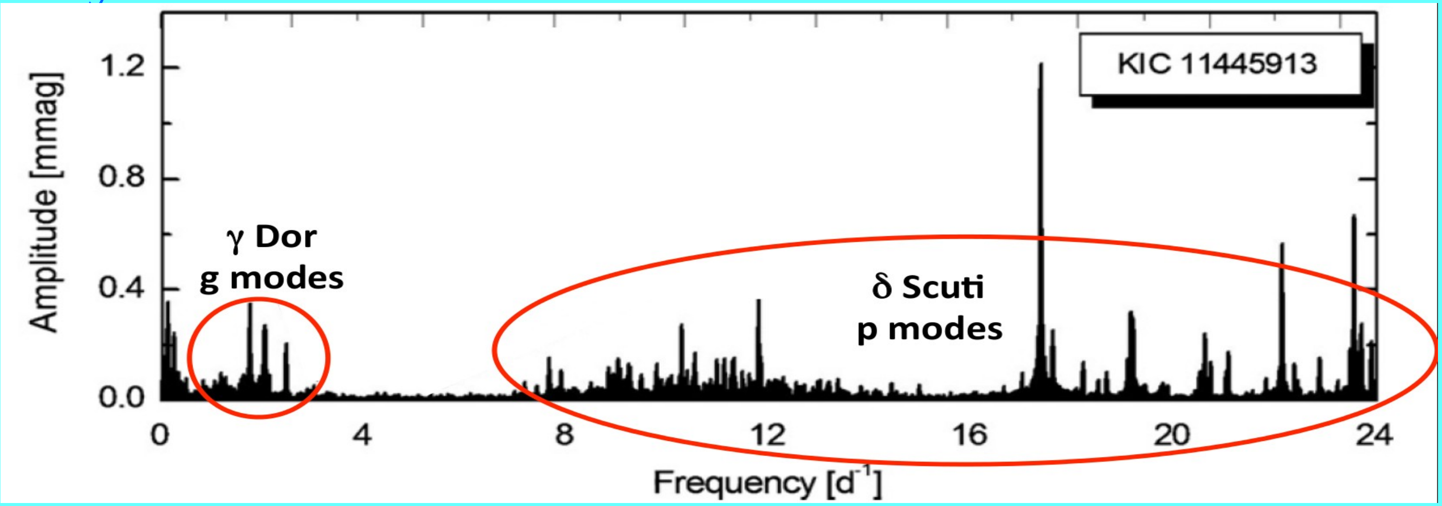
- Blazhko effect = alternating shape and maxima height in part of RR Lyr stars
- RRab (F mode), RRc (O1), RRd (F + O1)
- Period doubling 10/16 Kepler Blazhko stars
- chaos and bifurcation
- Resonance 9:2 between F and 1st overtone radial pulsations
- K2, TESS and Plato: observations of populations with different metalicities



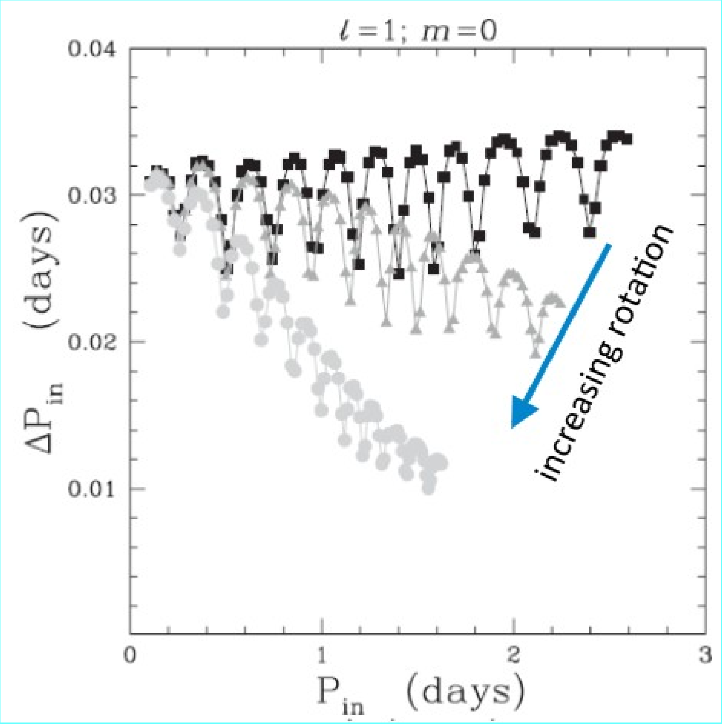
T. Bedding: Unlocking the secrets of gamma Doradus stars using echelle diagrams

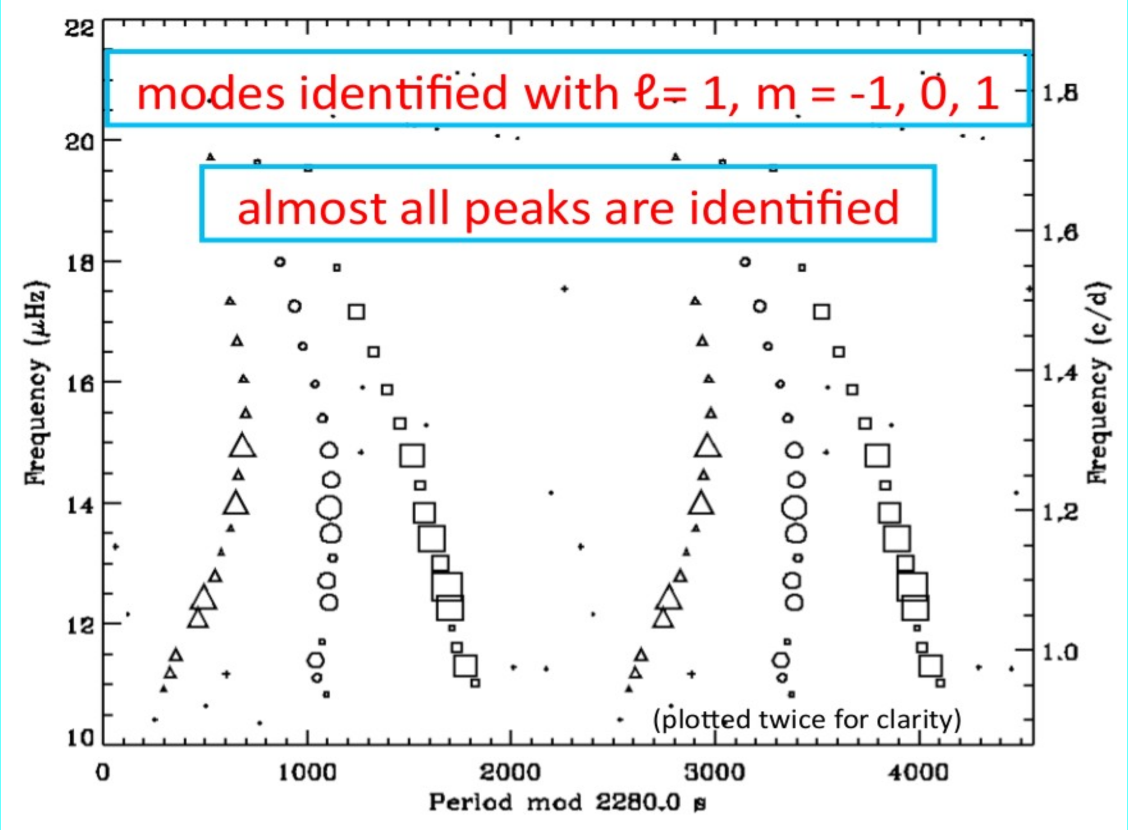
- γ Dor: long-period g-mode oscillators, very difficult from ground (NB: l=0 (radial) g modes do not exist)
- γ Dor: intermediate mass stars
- problem: mode (n,l,m) identification in periodograms
- Kepler: lot of hybrids !!!





- Period spacing depends on l: $\Delta P \approx [l(l+1)]^{-1/2}$ but rot. splitting has equal splitting in frequency...
- Echelle diagram with modulo of period to study the modes
- Irregularities in period spacing: gradients in chemical composition
- In some stars period spacing decreases with period, caused by stellar rotation

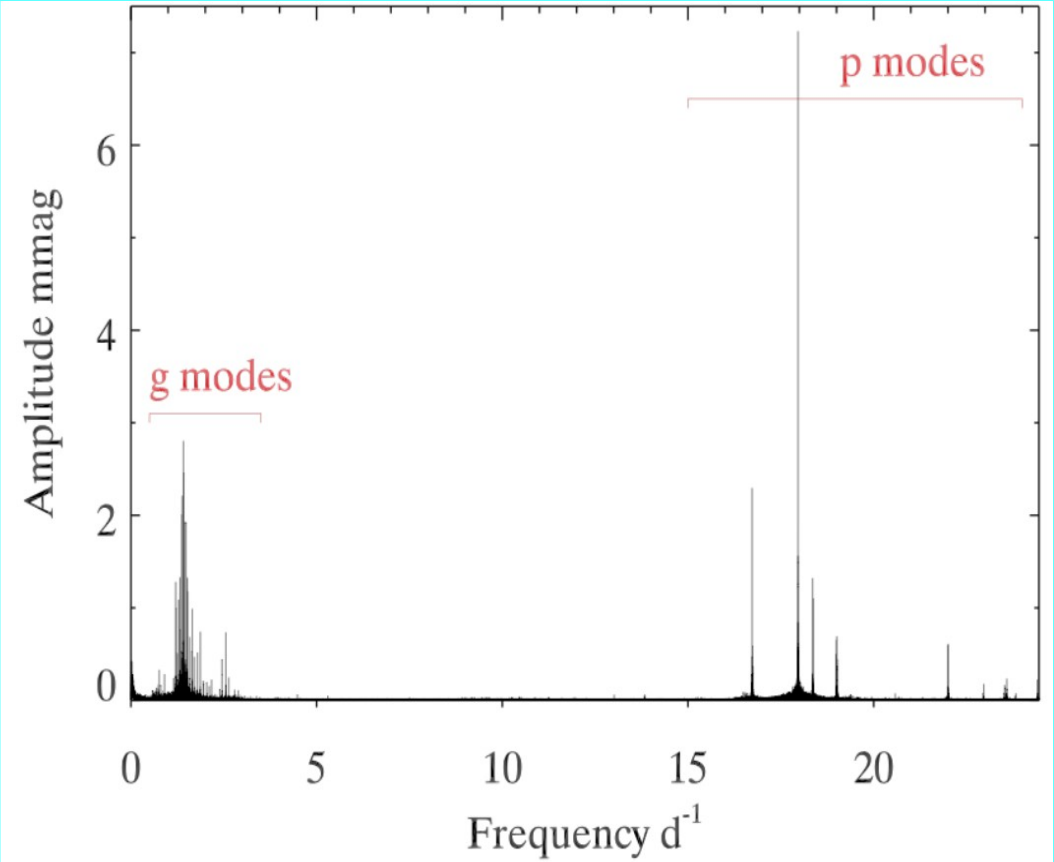




- turbulent mixing removes the irregularities in ΔP vs. P diagram

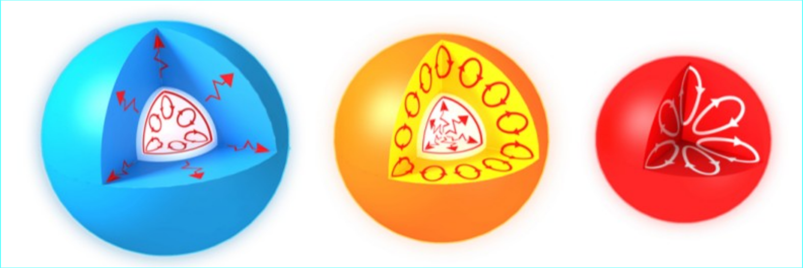
D. Kurtz: Asteroseismic measurements of internal rotation in a MS A star, KIC11145123

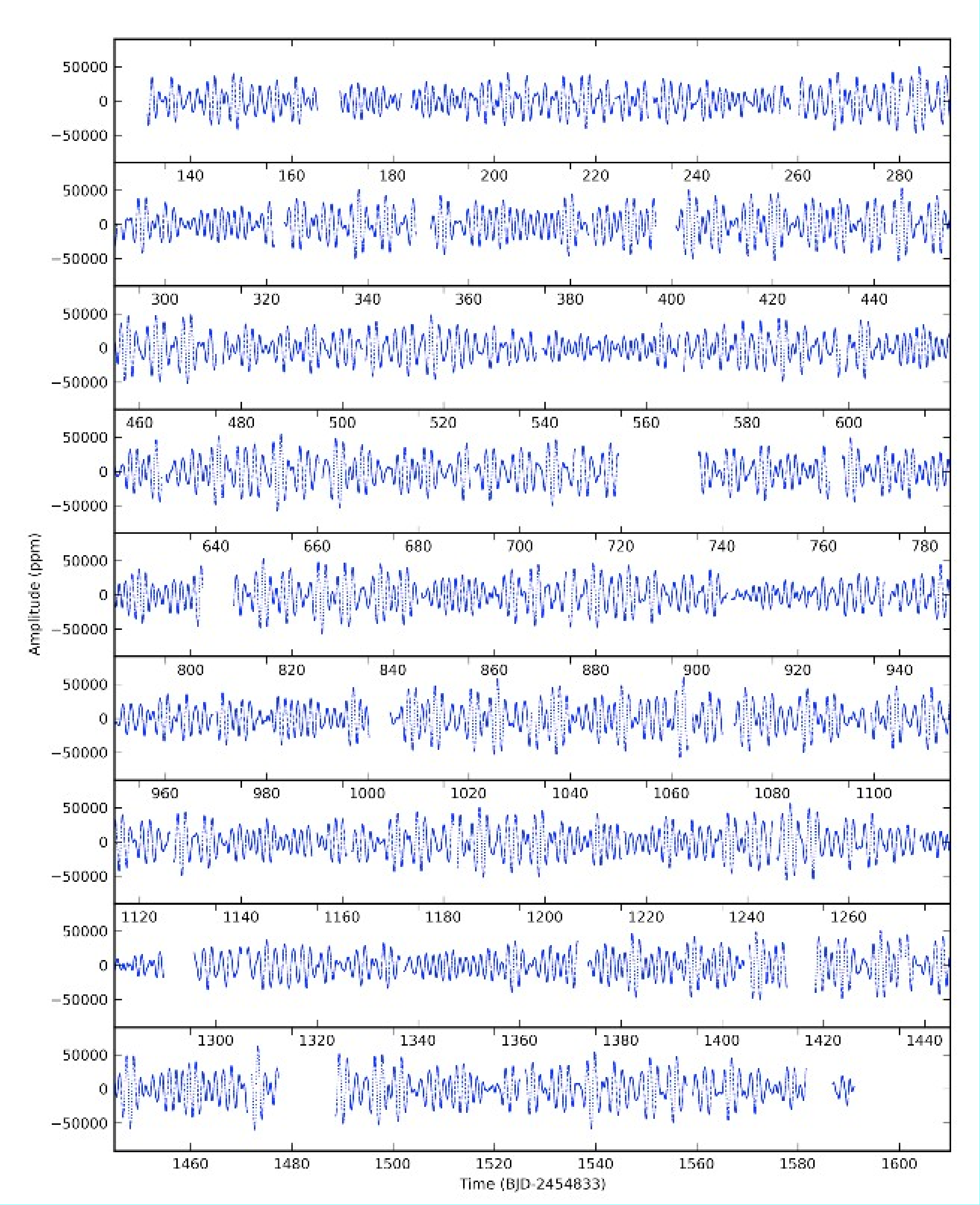
- Internal AM transfer
- spin of stellar cores and envelopes does not evolve independently: angular momentum is transported
- convection prevents g-mode pulsations
- $P_{surface} \leq 98.57$ d
- $P_{core} \geq 105.13$ d
- ==> strong AM transfer mechanism (other than viscosity) must exist !



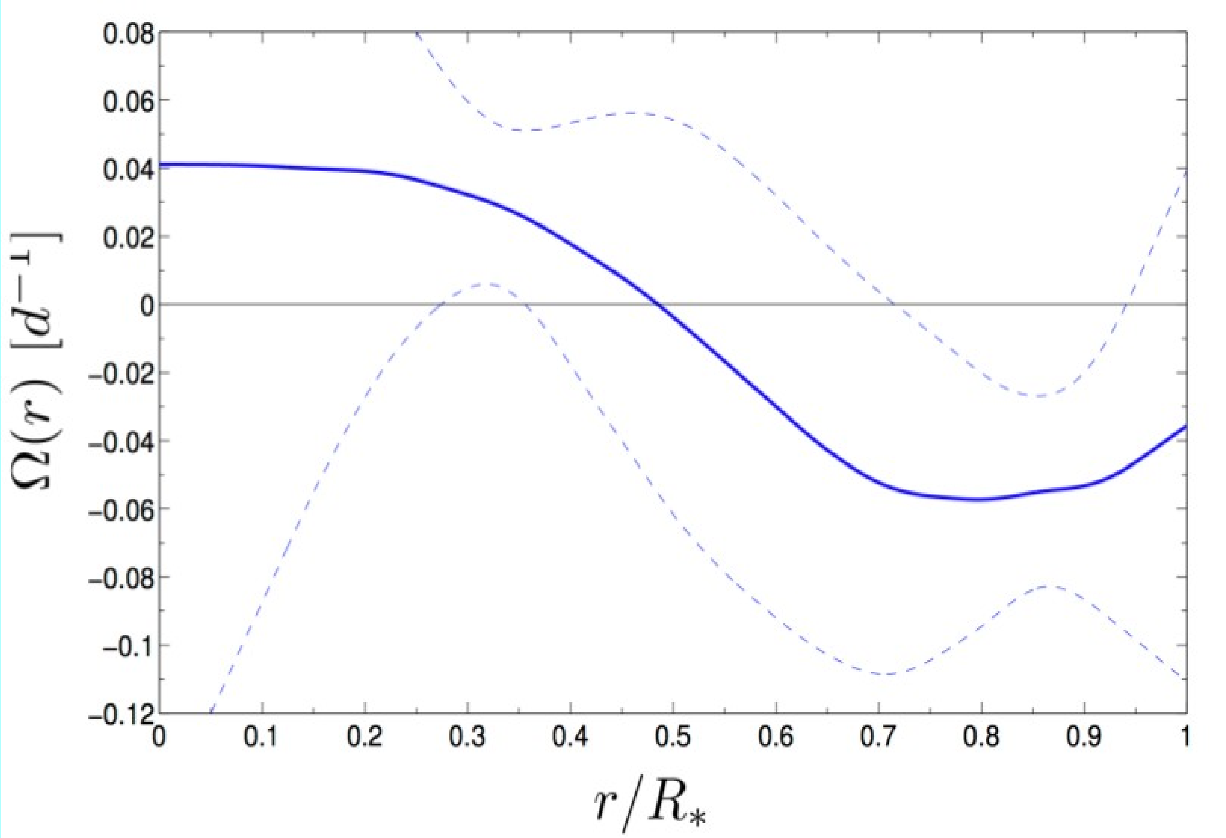
P. Papics: The internal rotation of a g-mode SPB in Kepler LC...

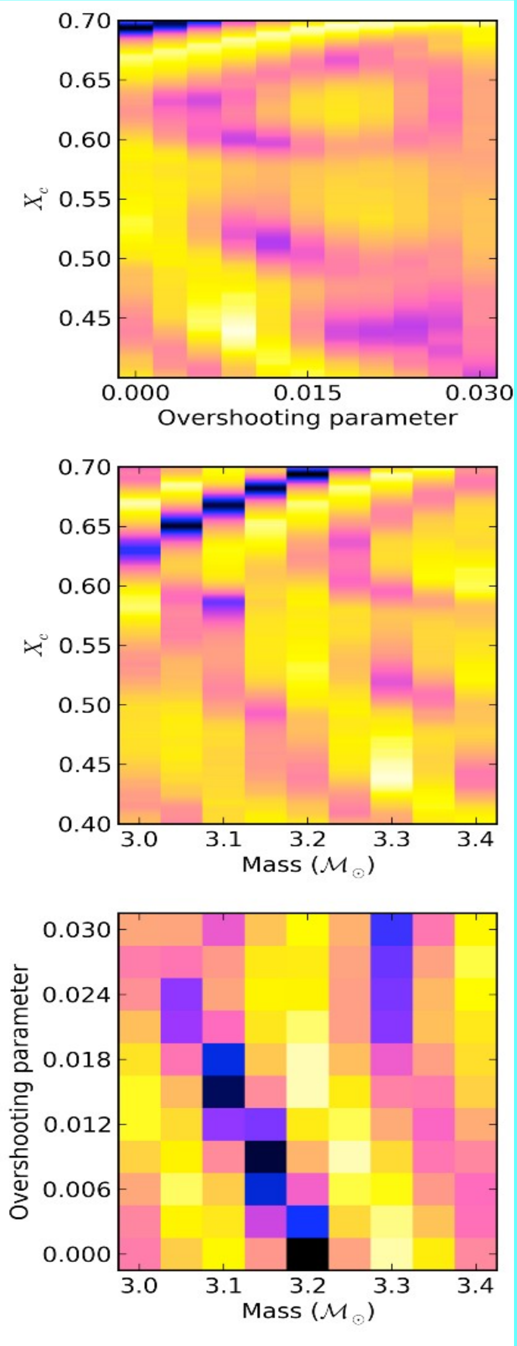
- SPB stars: 11000-22000 K
- high-order gravity modes
  $P \approx 0.5 - 3$ days
- Goals: internal rot. profile, diff. rotations, core overshooting, internal mixing
- Modelling KIC 10526294





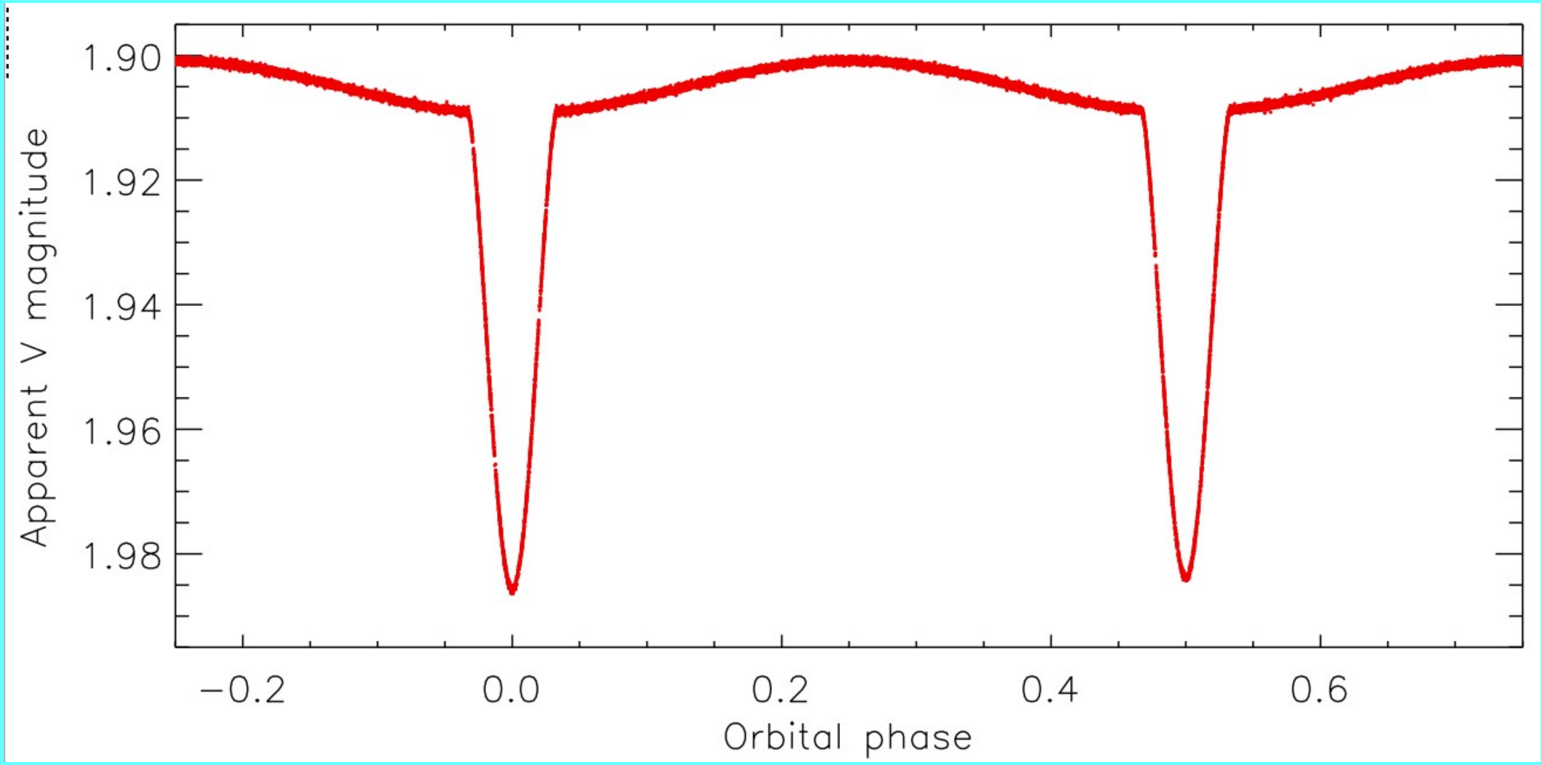
- 19 dipole modes identified
- non-rigid (solid-body) rotational profile
- central hydrogen fraction Xc > 0.64
- The core overshooting parameter α ≤ 0.15
- Ωcore /Ωsurface = −0.53 (counter-rotation)





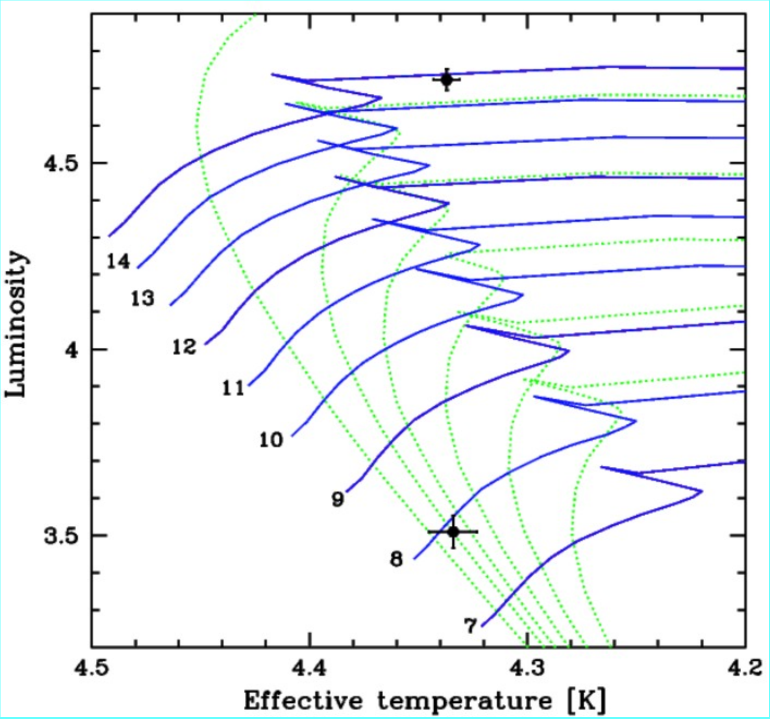
J. Southworth (Taylor): Multiple systems with Kepler and CoRoT

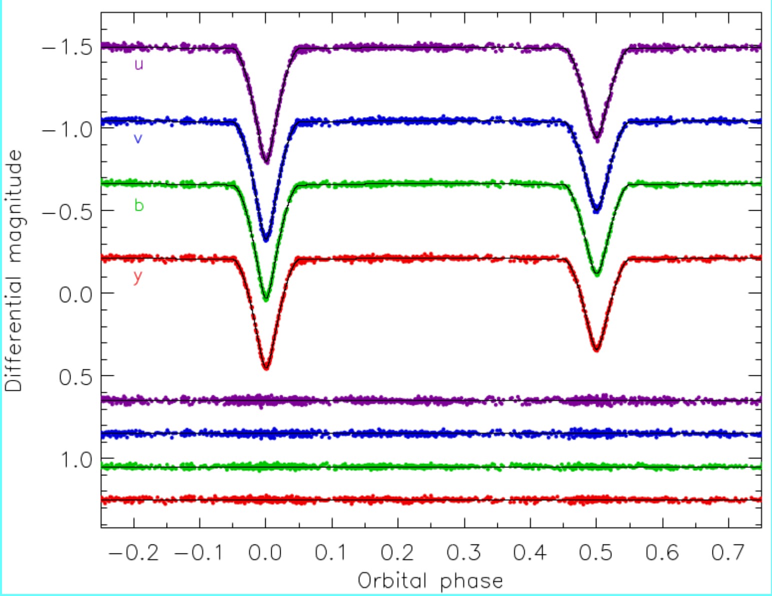
- First extremely precise LCs: star tracker on board WIRE:
- ψ Cen (V=4.0, Bruntt et al., 2006), β Aur (V=1.9, Southworth et al., 2007), CoRoT (2005), Kepler (2009)
- Not sufficient response of the community to the amount of data



EBs in astrophysics:

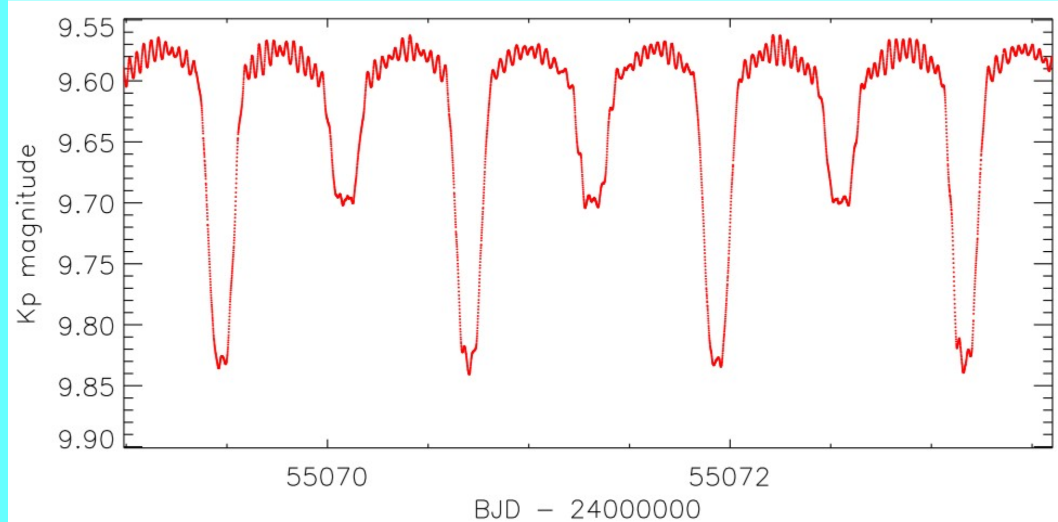
- Test theoretical stellar models (masses,radii, luminosities)
- Apsidal-motion test of stellar structure (k22 constant)
- Test model atmospheres via LD
- Host stars of transiting exoplanets
- Star and binary star formation scenarios (spin-orbit misalignment, circularization, synchronization)
- Chemical evolution of Galaxy
- Direct distance indicators (interferometry and spectroscopy) e.g. to LMC, SMC, M31, M32...

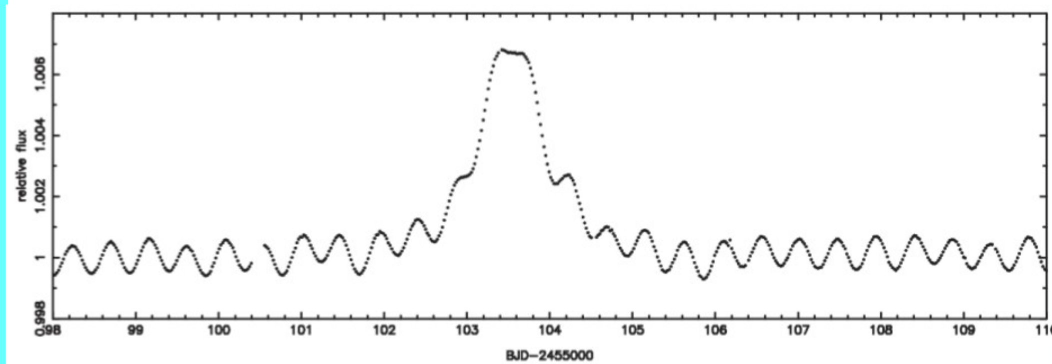


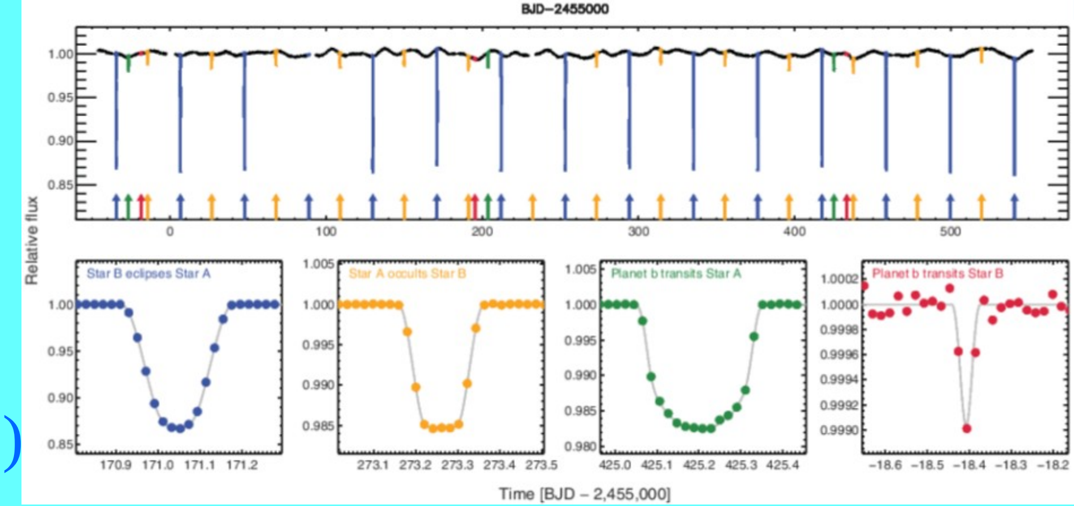


EBs post Kepler & CoRoT

- pulsating red-giant + MS dwarf EBs
- tidally-induced pulsations
- triply eclipsing systems (==> exact parameters)
- δ Sct stars in EBs
- heartbeat stars, eccentric EBs systems without eclipses (KOI-54, 42-days period, 90 and 91 orbit harmonics)
- 8 circum-binary planets (strong constrains on the stellar & planetary params.)

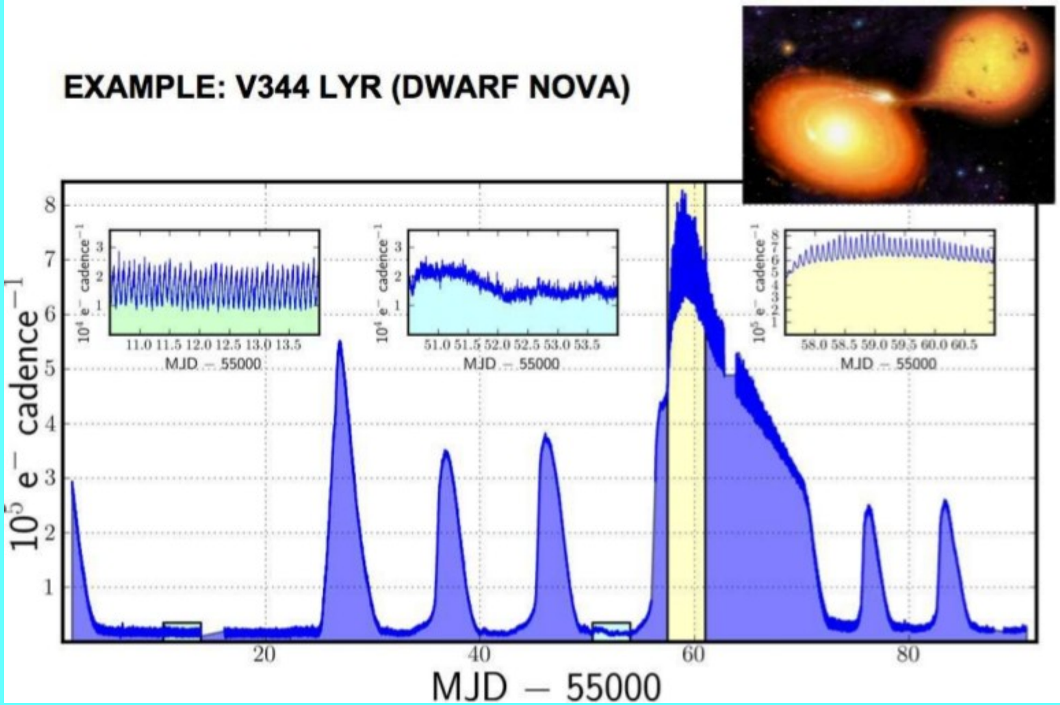


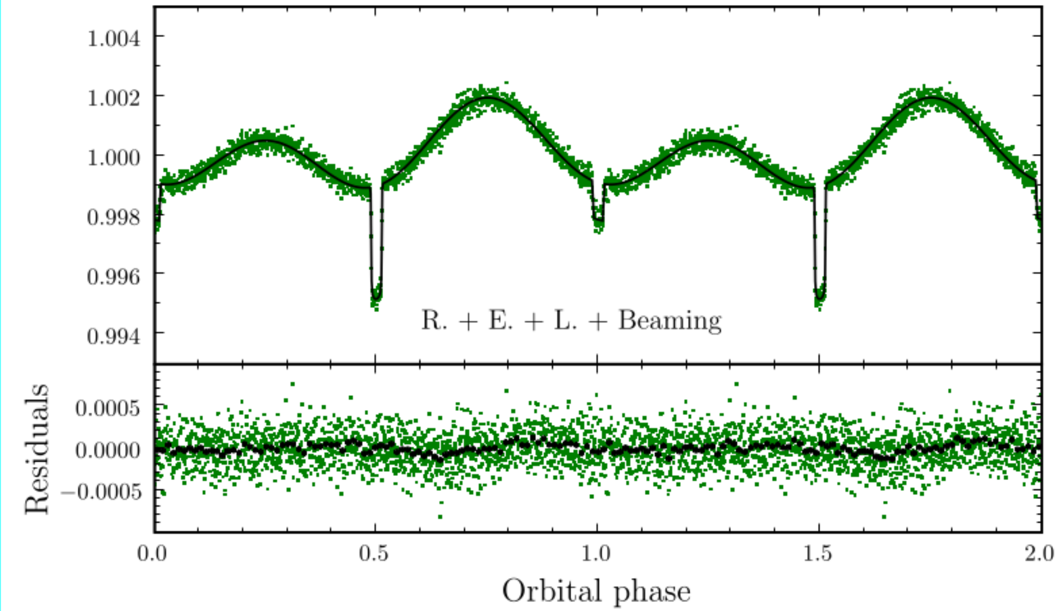




EBs post Kepler & CoRoT

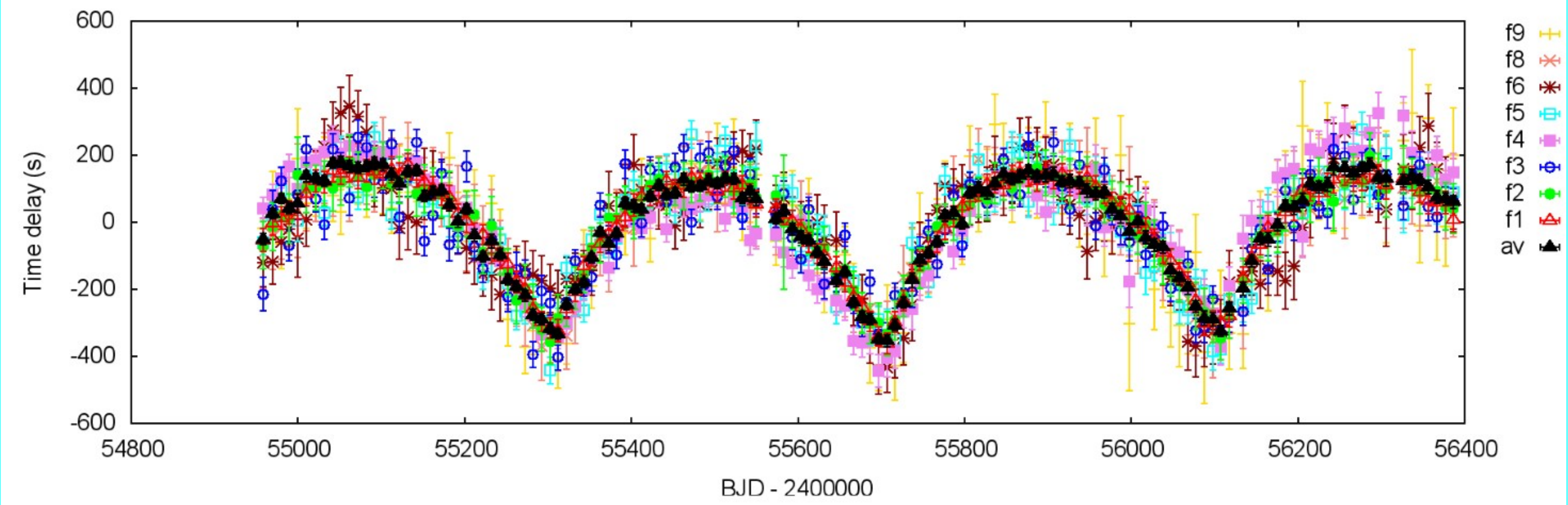
- cataclysmic variables in the Kepler field: V344 Lyr (dwarf nova)
- KPD1946+4340: sdB + WD EB binary - Dopp. beaming and gravitational lensing needed to model the LC
- Better physical models for EBs: fine relativistic effects, more realistic LD, reflection effect,
- Simultaneous modeling of eclipses & asteroseismology

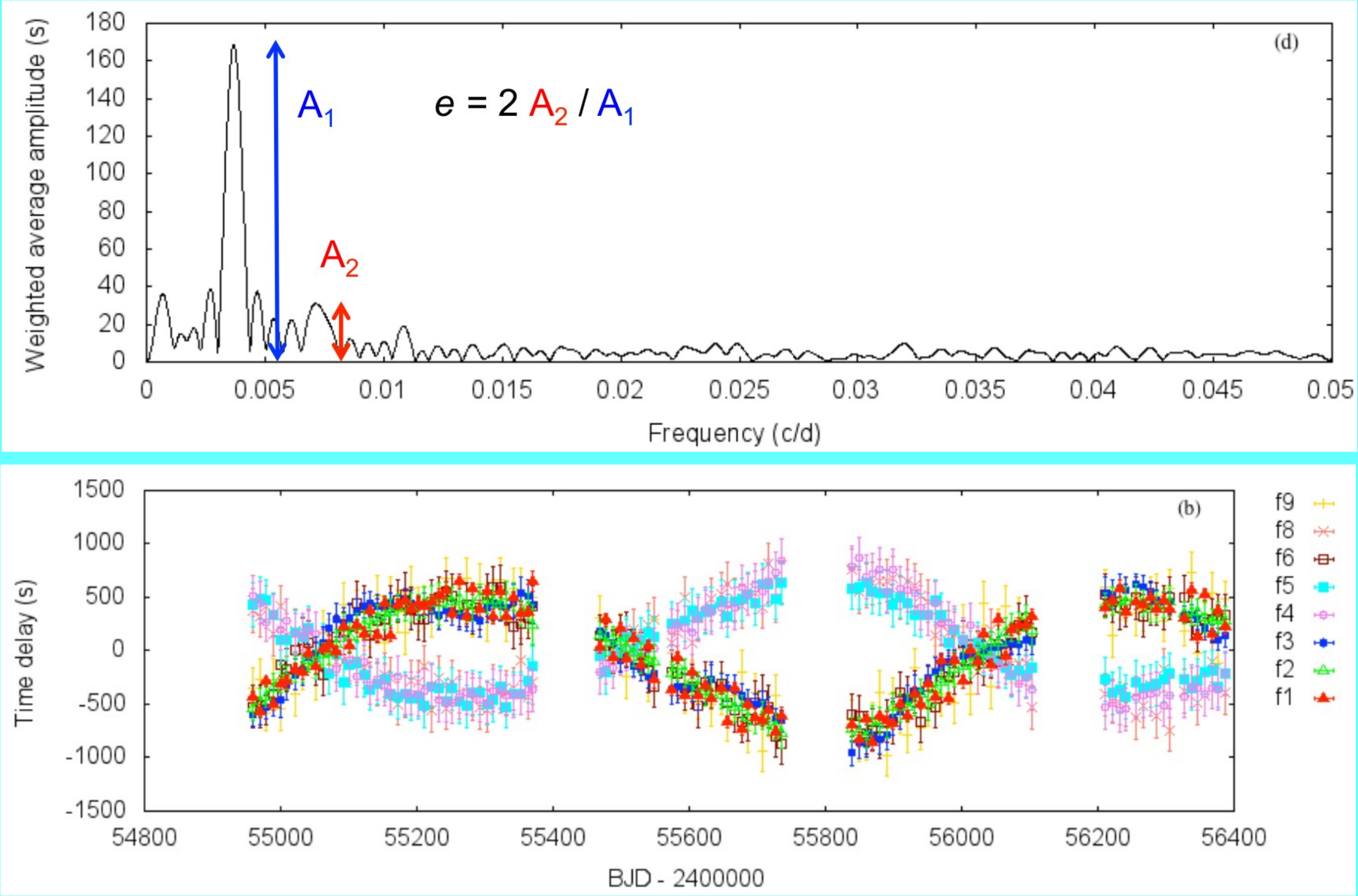




S. Murphy: finding non-eclipsing binaries with from pulsational phase modulation

- Presence of other component leads to phase modulation of puls. frequencies due to LITE
- Power spectrum determined from 10-days samples: frequencies, phases, amplitudes ==> plot of time delays
- Fourier transform of delays ==> orbital period, a sin i, orbital eccentricity estimate
- If all frequencies behave the same the LITE is robust interpretation

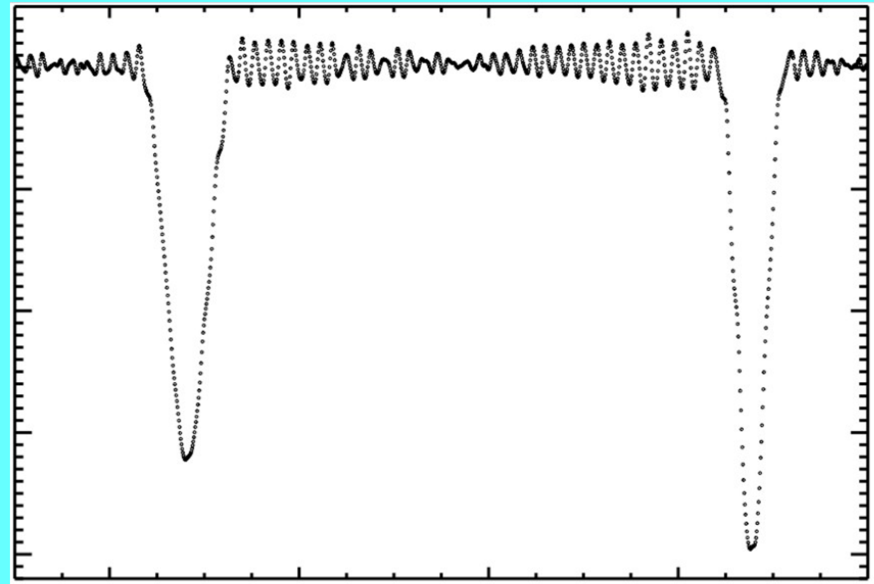


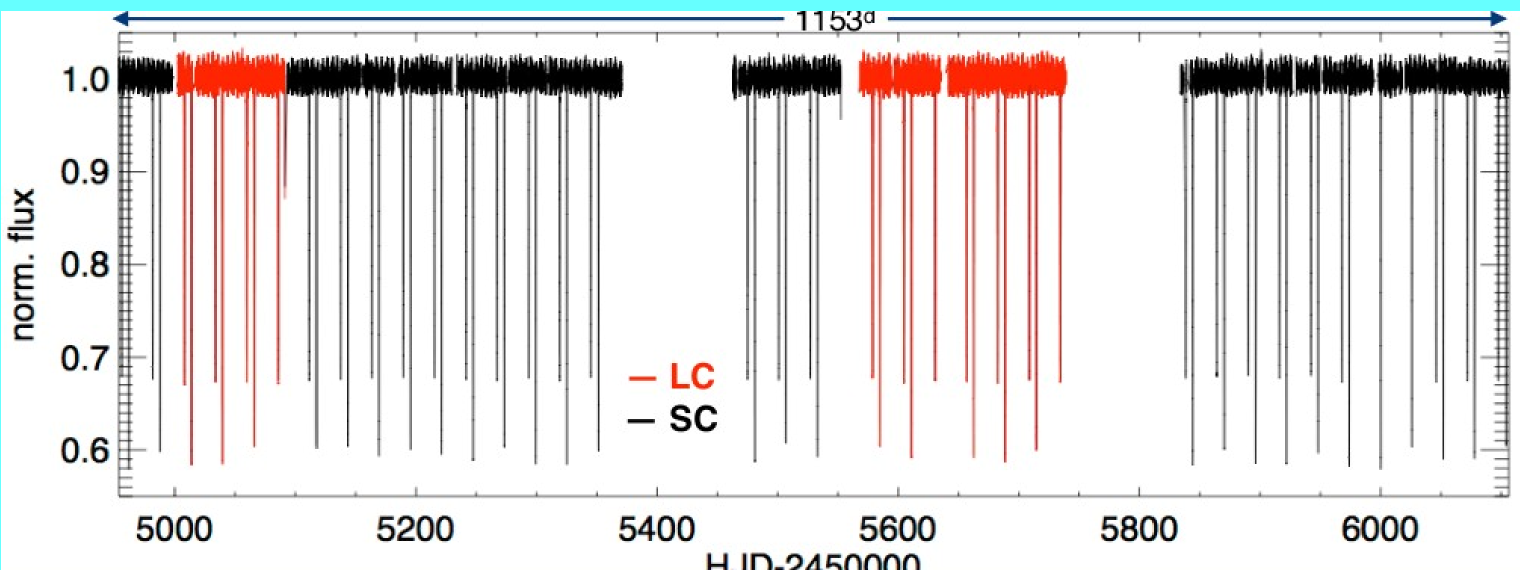


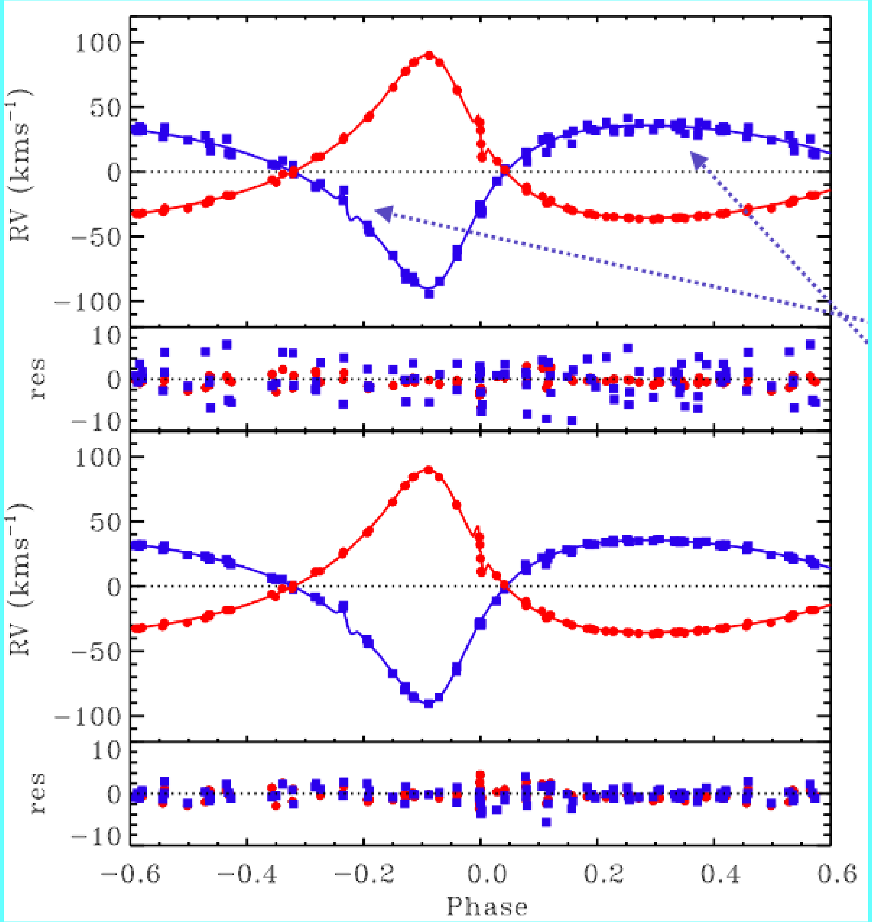
- First results: smallest mass function 4.1±2.0 10^{-7} $M_\odot$, for 2 $M_\odot$ star, the invisible object has minimum mass of 10 Mjup
- most precise eccentricity e=0.113±0.002, 300 PB1 or PB2 analyzed
- PB2 stars: both components pulsate !

C. Maceroni: Pulsations in close binaries

- KIC3858884 (V=9.3, F5, f1=7.231 c/d, f2=7.473 c/d)
- disentangling pulsations and eclipses requires brightness weighting
- lower-order overtones shall not be pre-whitened: eccentricity bump

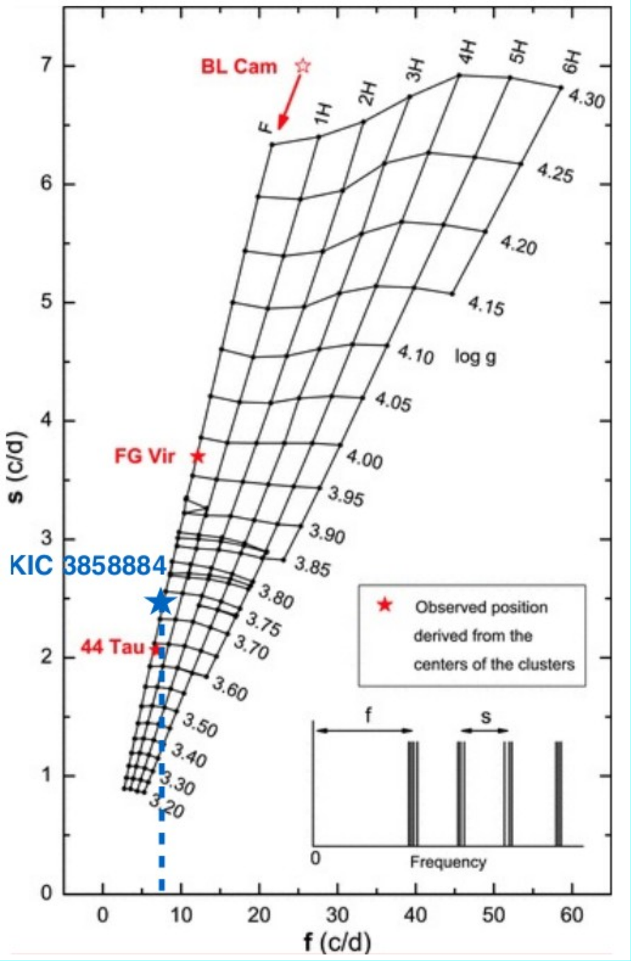


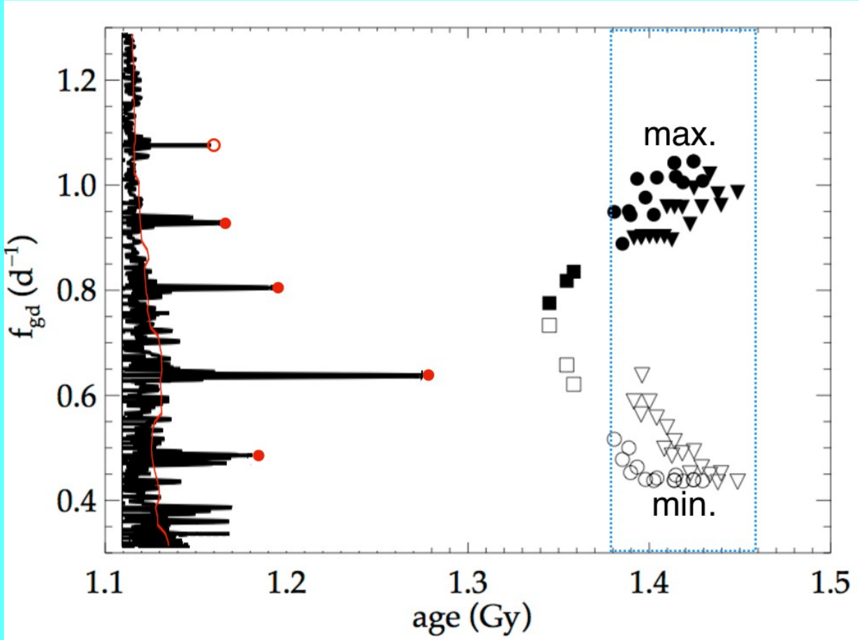




- Spectroscopy: pulsations found in the secondary RVs, RM effect
- Spectra ==> log g, Teff, [m/X]
- RVs + LCs ==> orbital parameters

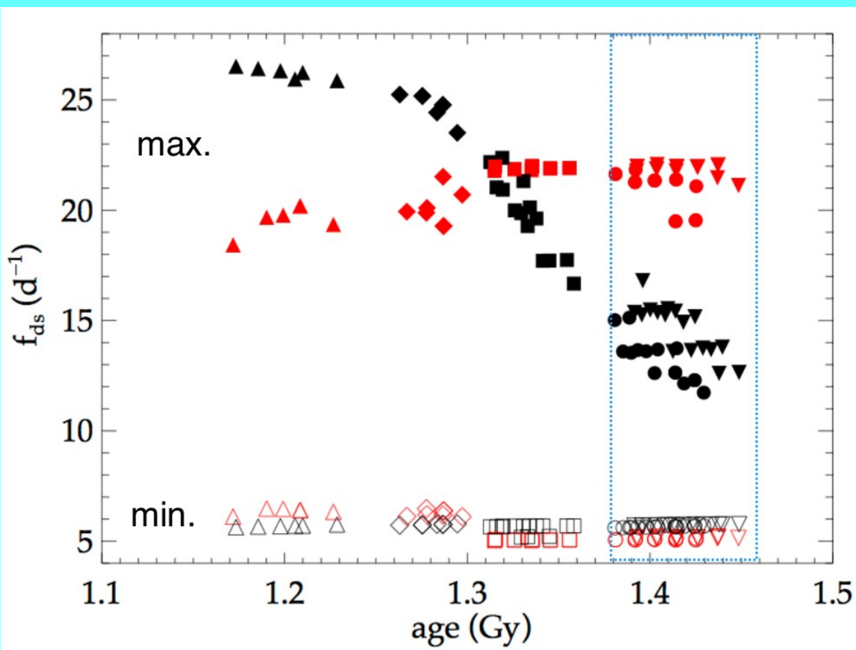
- High-frequency analysis of the δ Sct pulsations: using lowest frequency - frequency spacing diagram, f=7.47 c/d found to be the fundamental radial mode





$$\Im = \int_{r_1}^{r_2} \frac{N}{r} dr$$

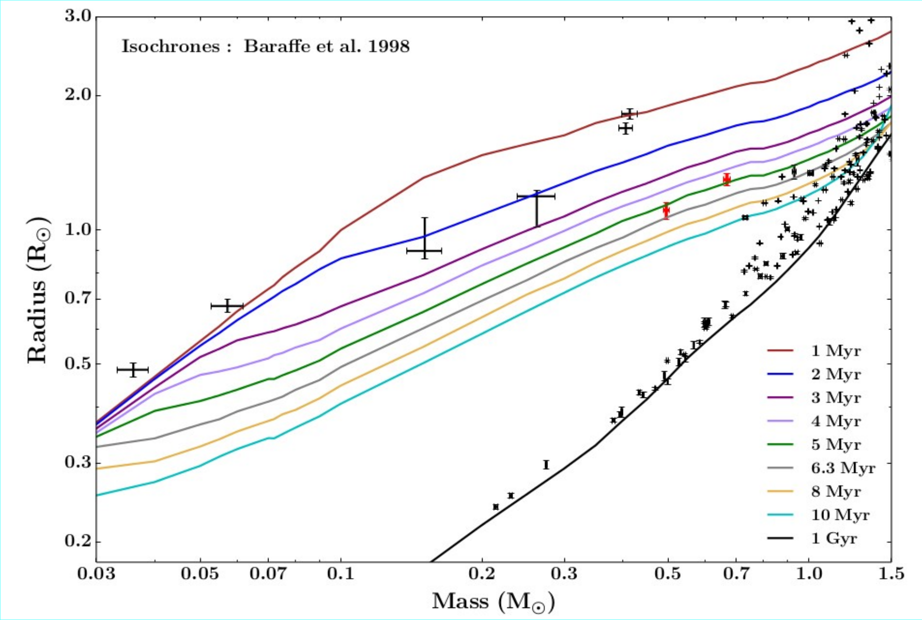
$$\sigma_{n\ell} = \frac{\sqrt{\ell(\ell+1)}}{\pi(n+1/2)} \Im$$

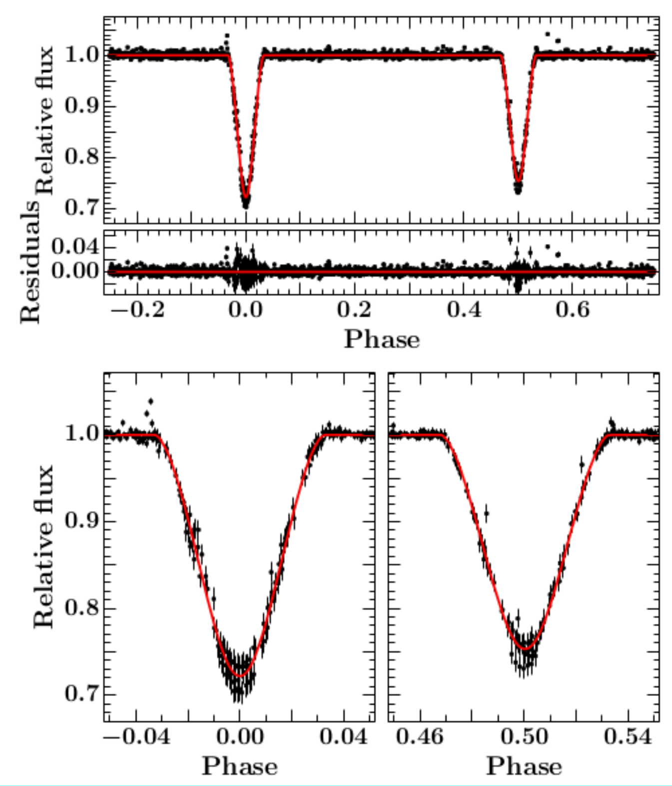


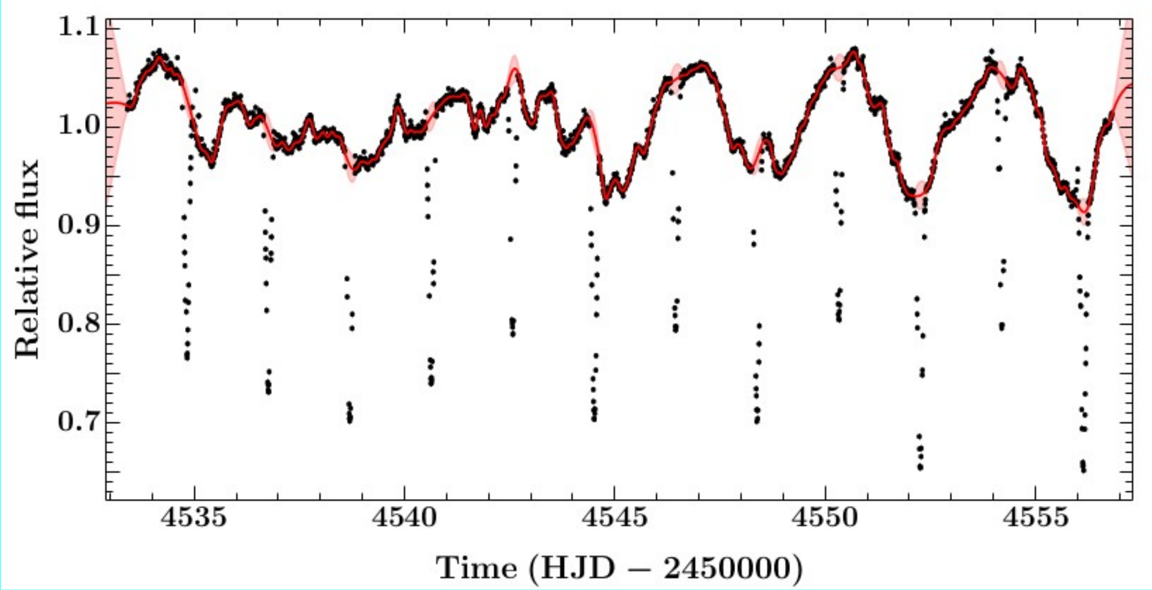
- Comparison of the observed and model-predicted γ Dor and δ Sct frequencies
- Cross-checking of LC-RV parameters and pulsation parameters

E. Gillen: First low-mass, PMS EB with a circumbinary disk

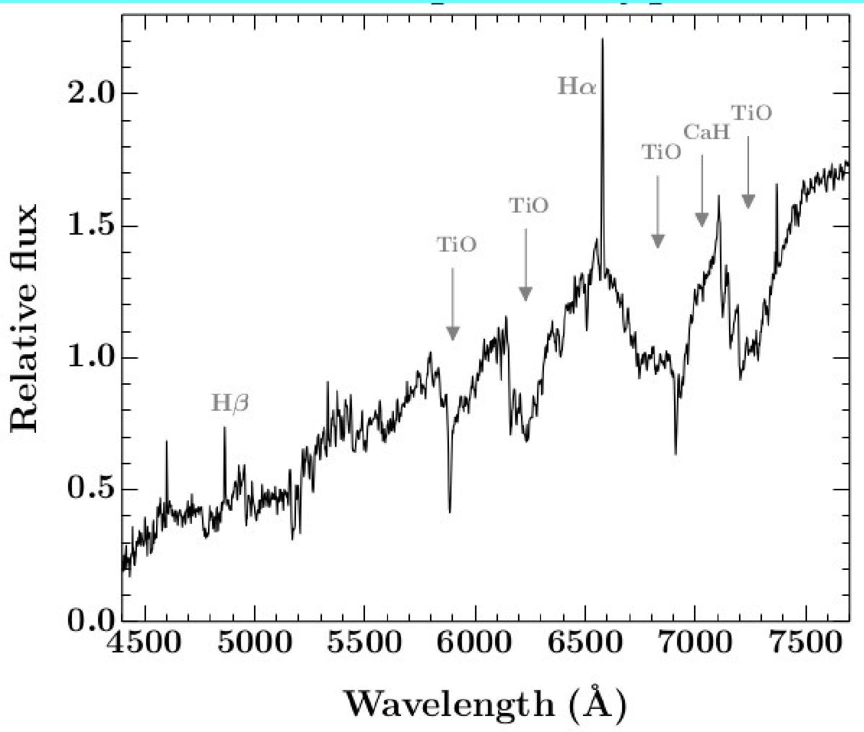
- CoRoT 223992193
- V=16.8, I=14.5, P=3.87457 d
- Member of OC NGC2264
- age 3.5-6 Myr ==> PMS

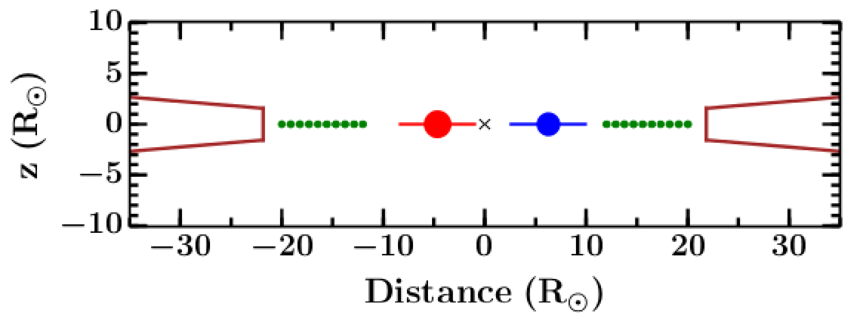


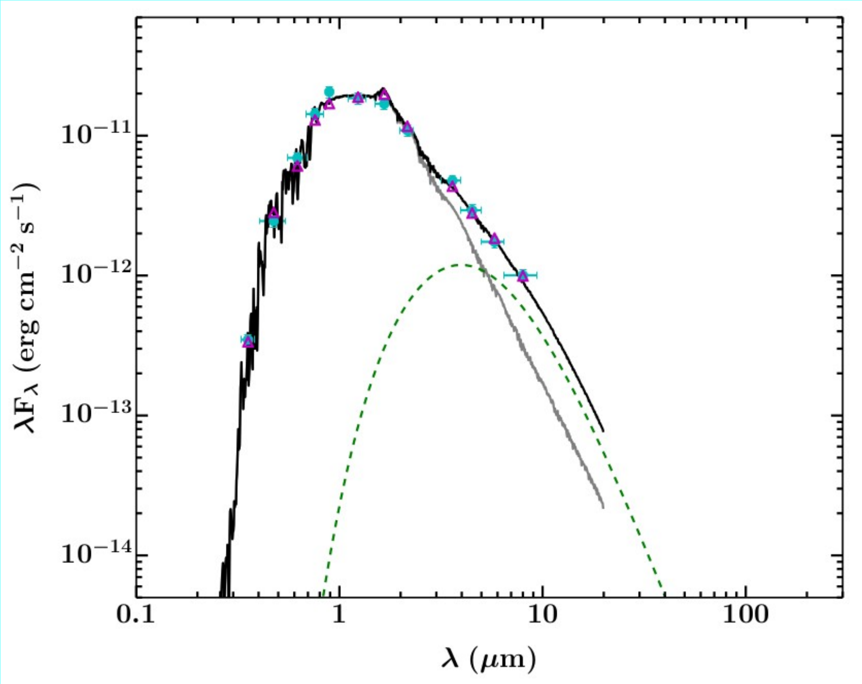




- Gaussian-profile modeling of the out-of-eclipse shape: parameterising of the covariance
- EB modeling - JKTEBOP
- low + medium res. spectra:
- RVs (CCF), lithium, Hα in emission, cluster member, orbital parameters, M2 sp. type

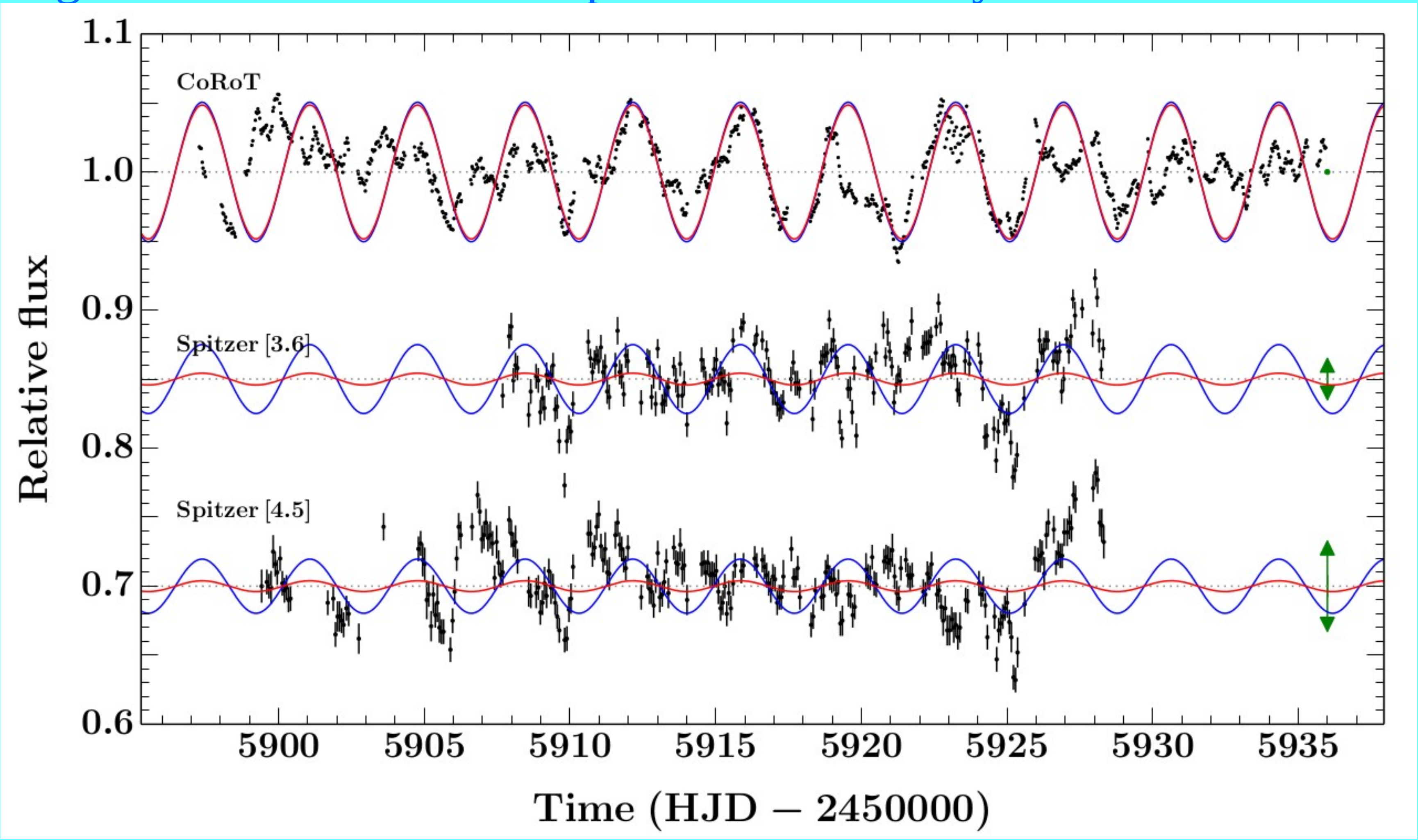


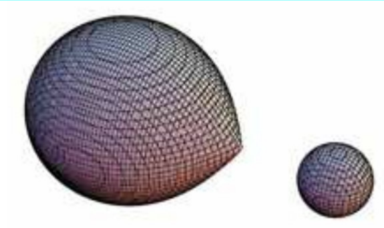




- SED: IR excess - CB disk ?
- mass of the dust 10^{-13} $M_\odot$

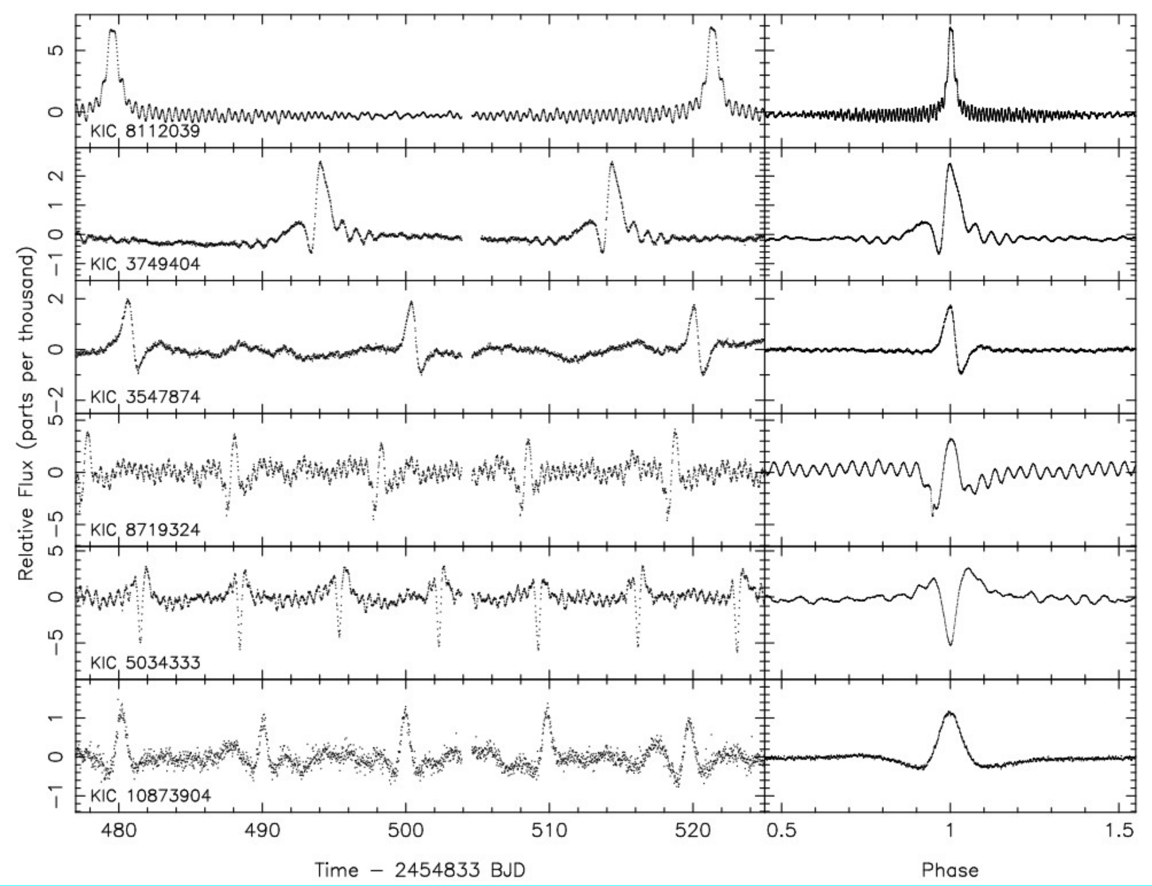
- Cold spot = 3000K, ~15% of stellar surface
- Hot spot = 5000K, ~2% of stellar surface
- Dust obscuration, e.g. ~1μm, dust emission ~1200 K, ~10^{-14} $M_\odot$
- Single mechanism cannot explain the variability in visual and IR

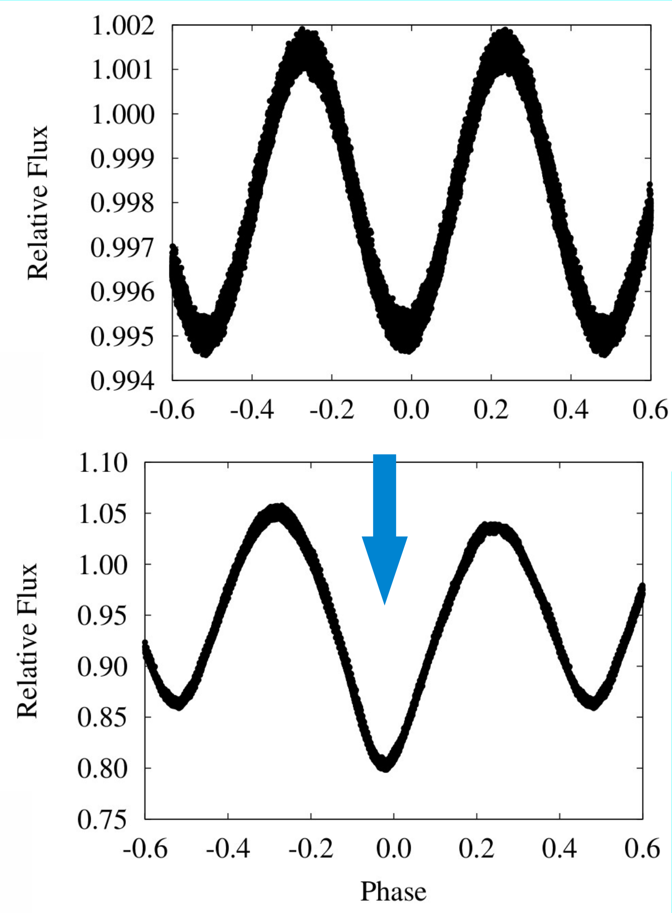




K. Hambleton: Heartbeat stars and the ringing of tidal pulsations

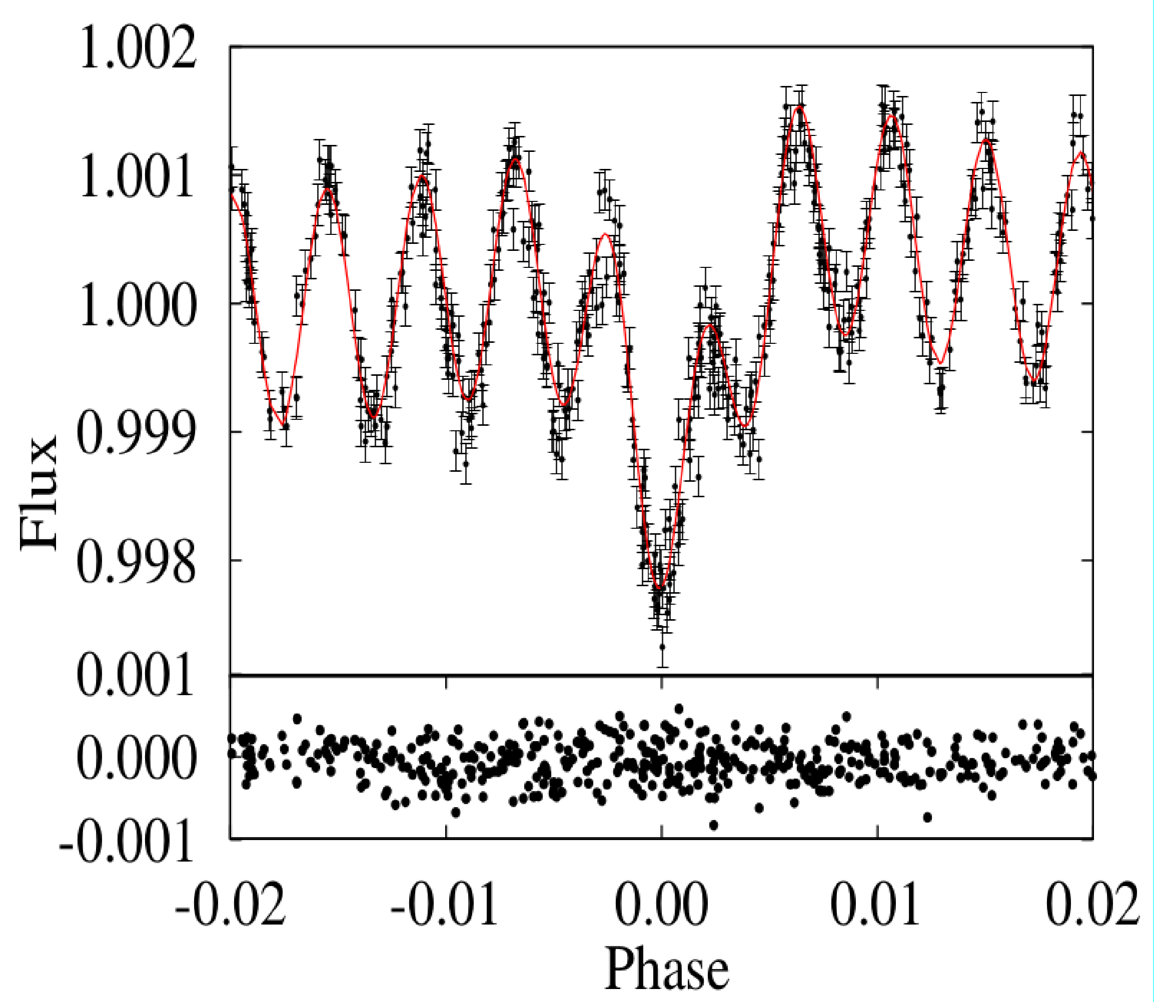
- Result from tidal deform. + eccentric orbit, hypothesised in 1995
- Tidally induced pulsations = harmonics of P_{orb}, l = 2, m = -2,0,2
- amplitude is determined by R_{star}/a





KIC8164262

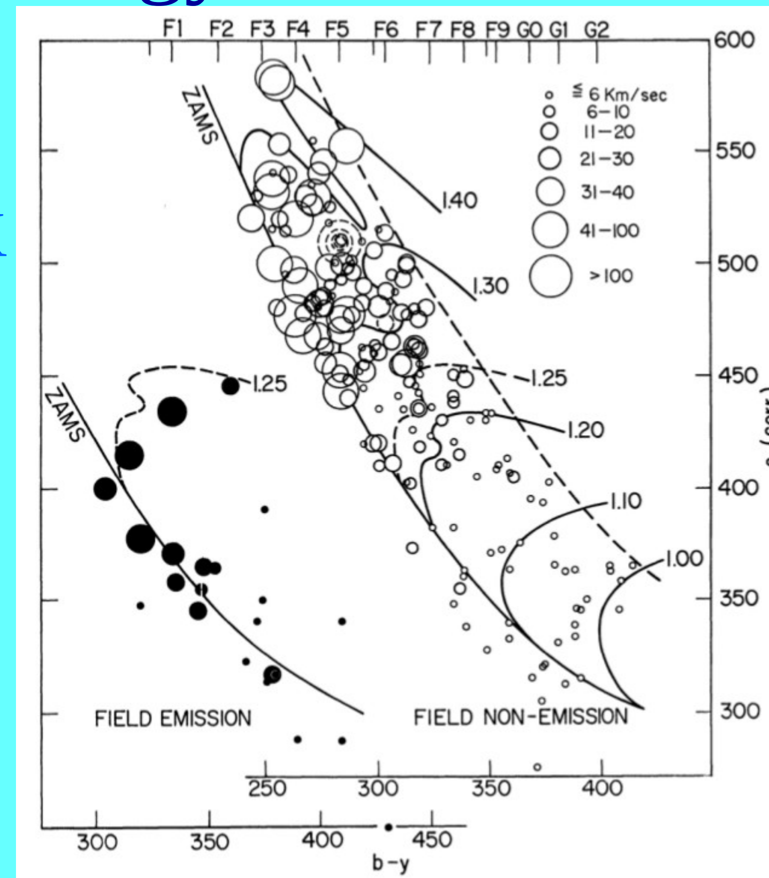
- A star and M dwarf
- P = 87.4549(3) d
- $M_1 = 1.9(1)\ M_\odot$
- $M_2 = 0.21(7)\ M_\odot$
- $R_1 = 2.5(2) R_\odot$
- prominent pulsation 229 ν_{orb}
- two peaks indicating rotation period
- obliquity 21±4 deg



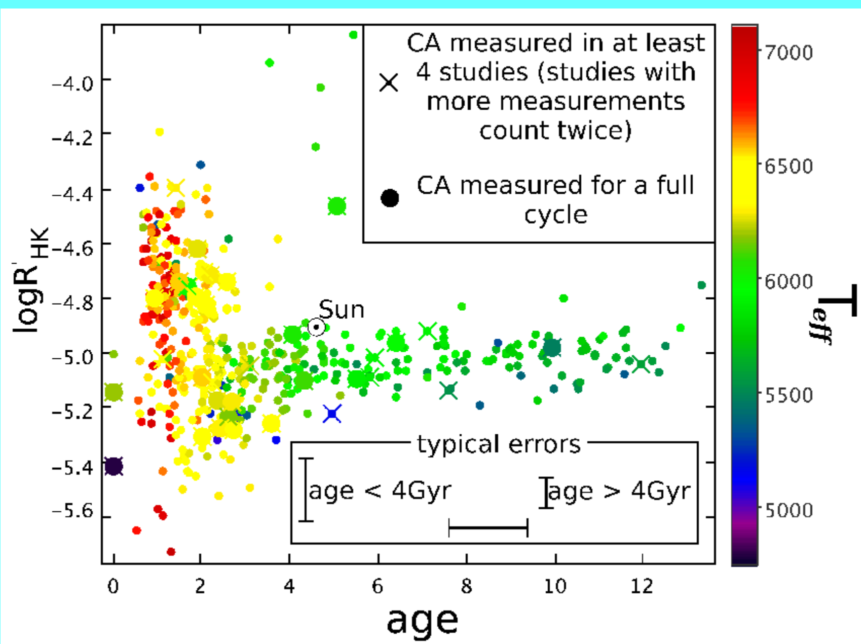
- Resonance locking causes high amplitude modes
- Tidally induced modes appear to affect apsidal motion
- Phases relative to periastron give information about the azimuthal order of a mode

S. Mathur: Towards age/rotation/magnetic activity relation with seismology

- Age: binaries, clusters (isochrone), Li abundance (for low-mass stars), gyrochronology, magn. activity, CaHK Skumanich (1972) law: $P_{rot} \sim \tau^{-1/2}$
- For $M > 1.25\ M_{\odot}$ fast rotation

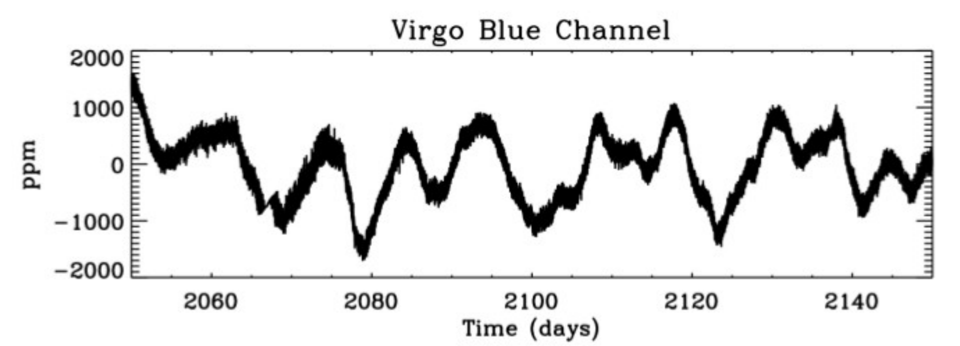


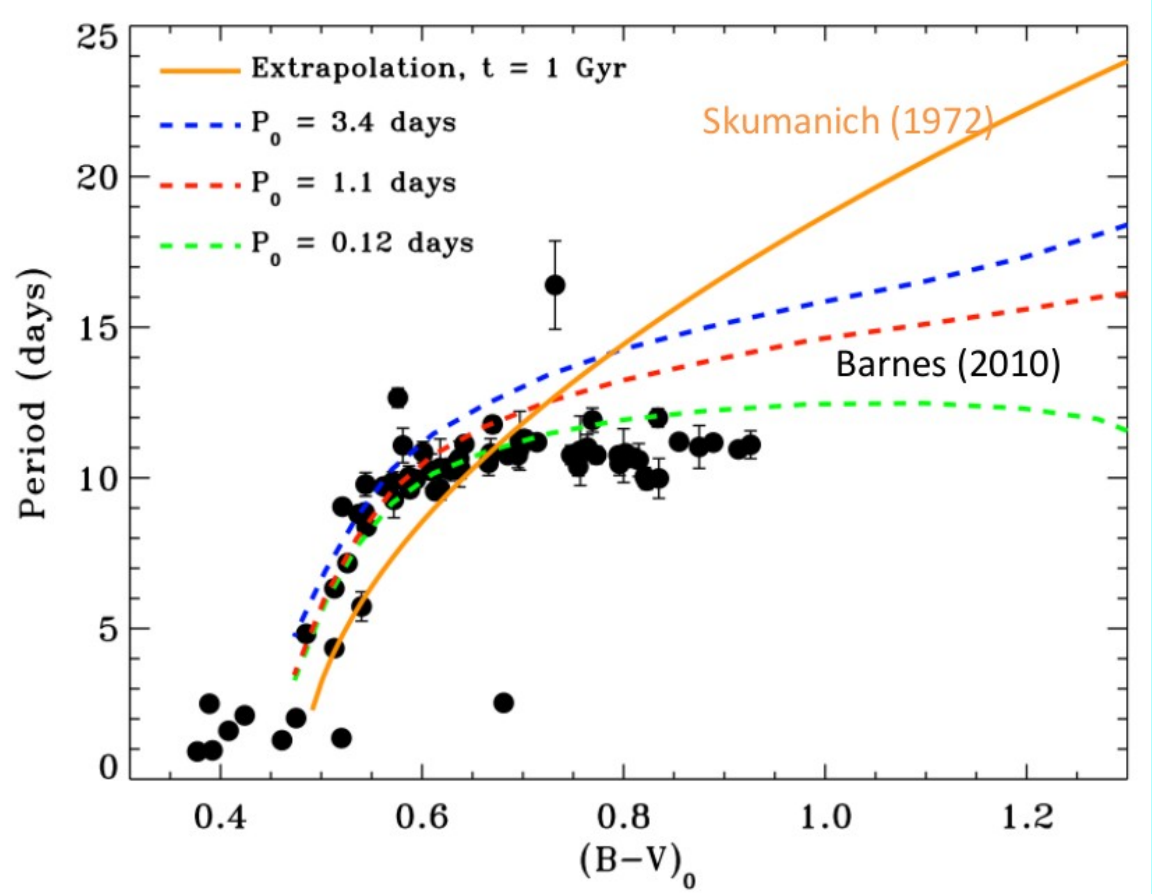
Kraft(1967), for $M > 1.25\ M_{\odot}$ fast rotation (Kraft break)



Pace(2013) RHK limited to 1.5Gyr

- Rotational period: vsin i & changes in Ca II HK, spots modulation of LCs (autocorrelation, wavelet), mode splitting (seismology)





NGC6811, 1 Gyr, 71 Kepler stars

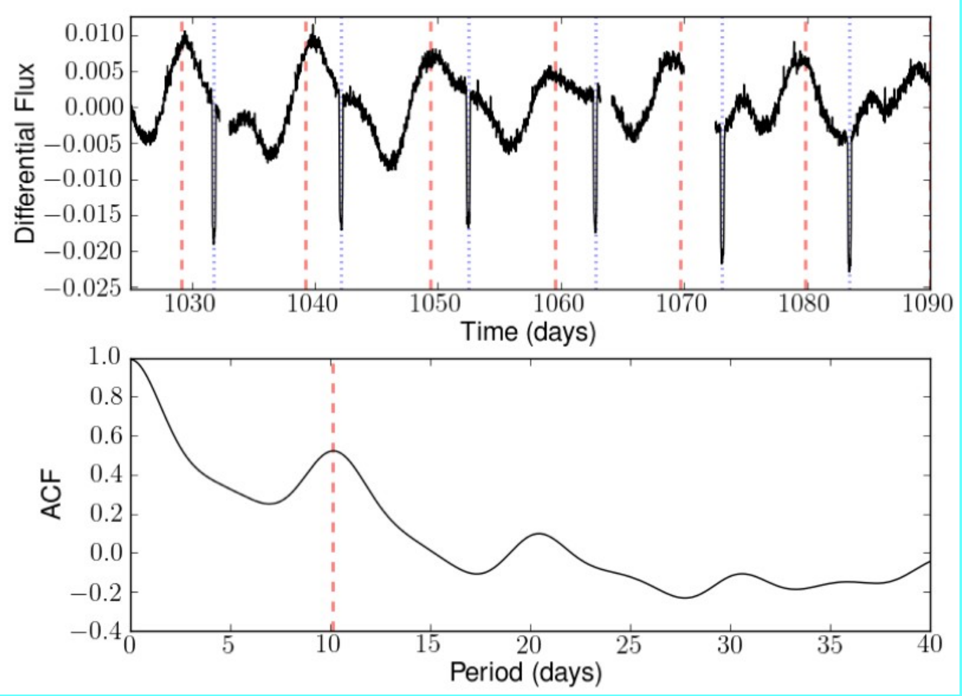
With Kepler:

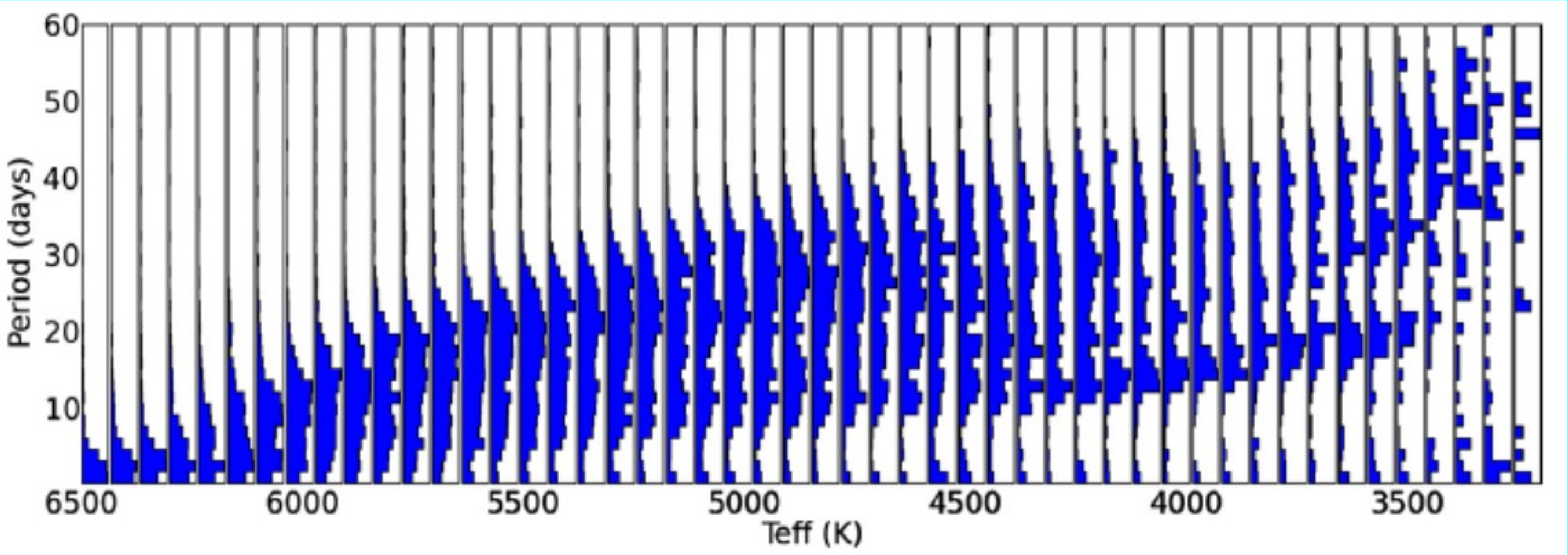
- we can study field stars (seismology constraints)
- determine rotational periods from LCs
- quantify surface activity...

T. Mazeh: Measuring 34030 rotational periods of Kepler field stars...

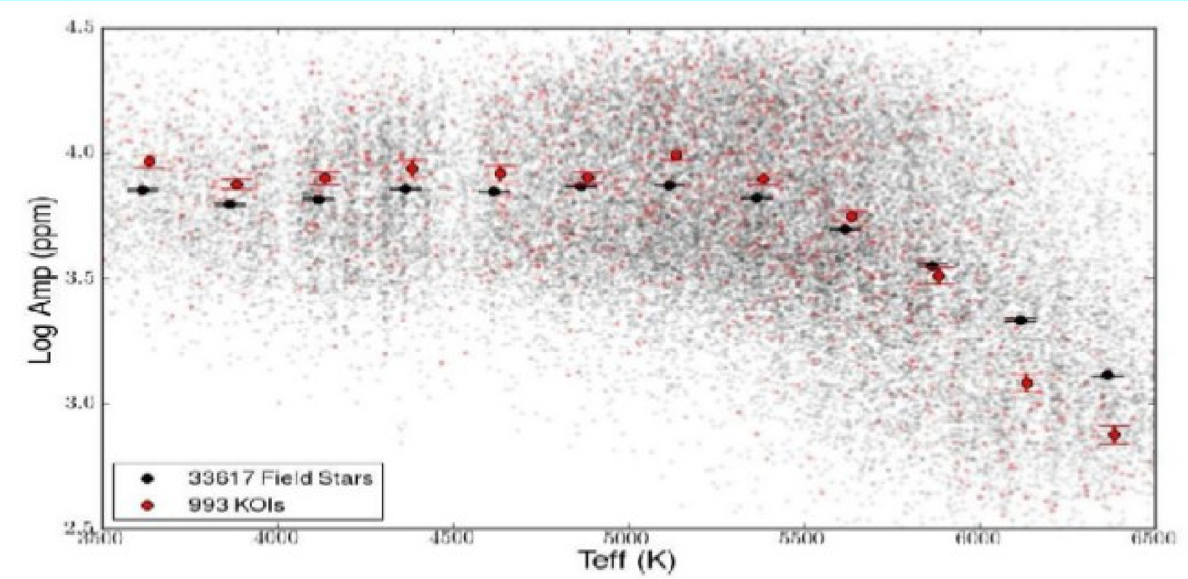
$$r_k = \frac{\sum_{i=1}^{N-k} (x_i - \bar{x})(x_{i+k} - \bar{x})}{\sum_{i=1}^{N} (x_i - \bar{x})^2}$$

- ACF = corelation as function of lag, first bump: period, decrease of bump amplitude: spot decay time - often better than Fourier analysis
- Kepler data: ignoring: giants, EBs, KOIs & Teff > 6500 K
- 133030 stars left, for 34030 period determined





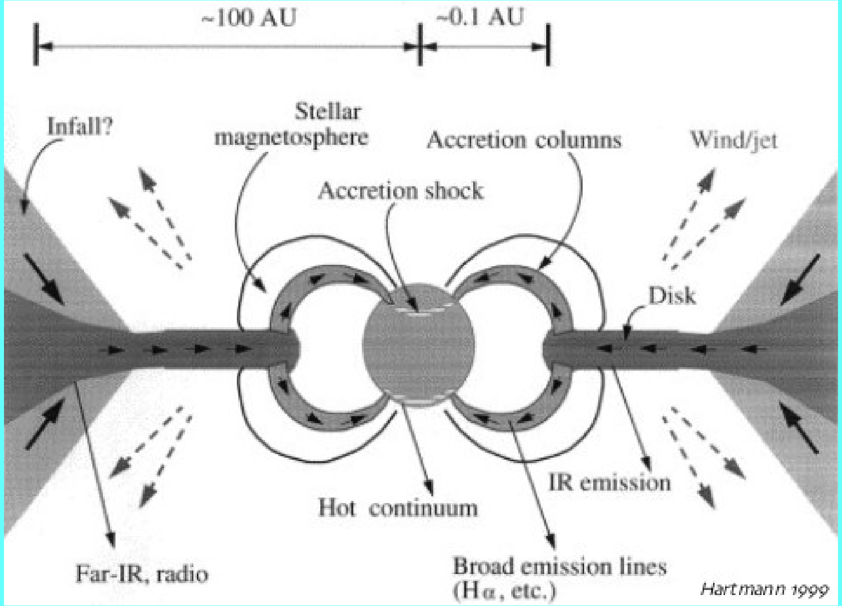
bi-modality for M dwarfs, dip in the upper envelope for Teff < 4000

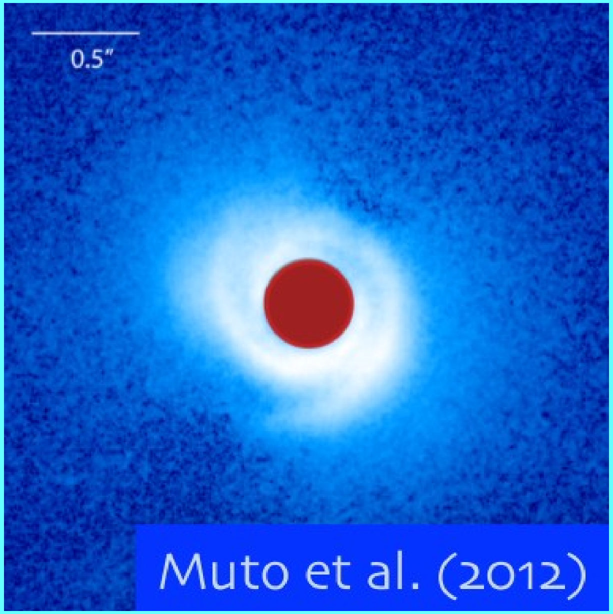


KOIs with T_{eff} > 6000 K show lower photometric variability than field stars => spin orbit misalignment !

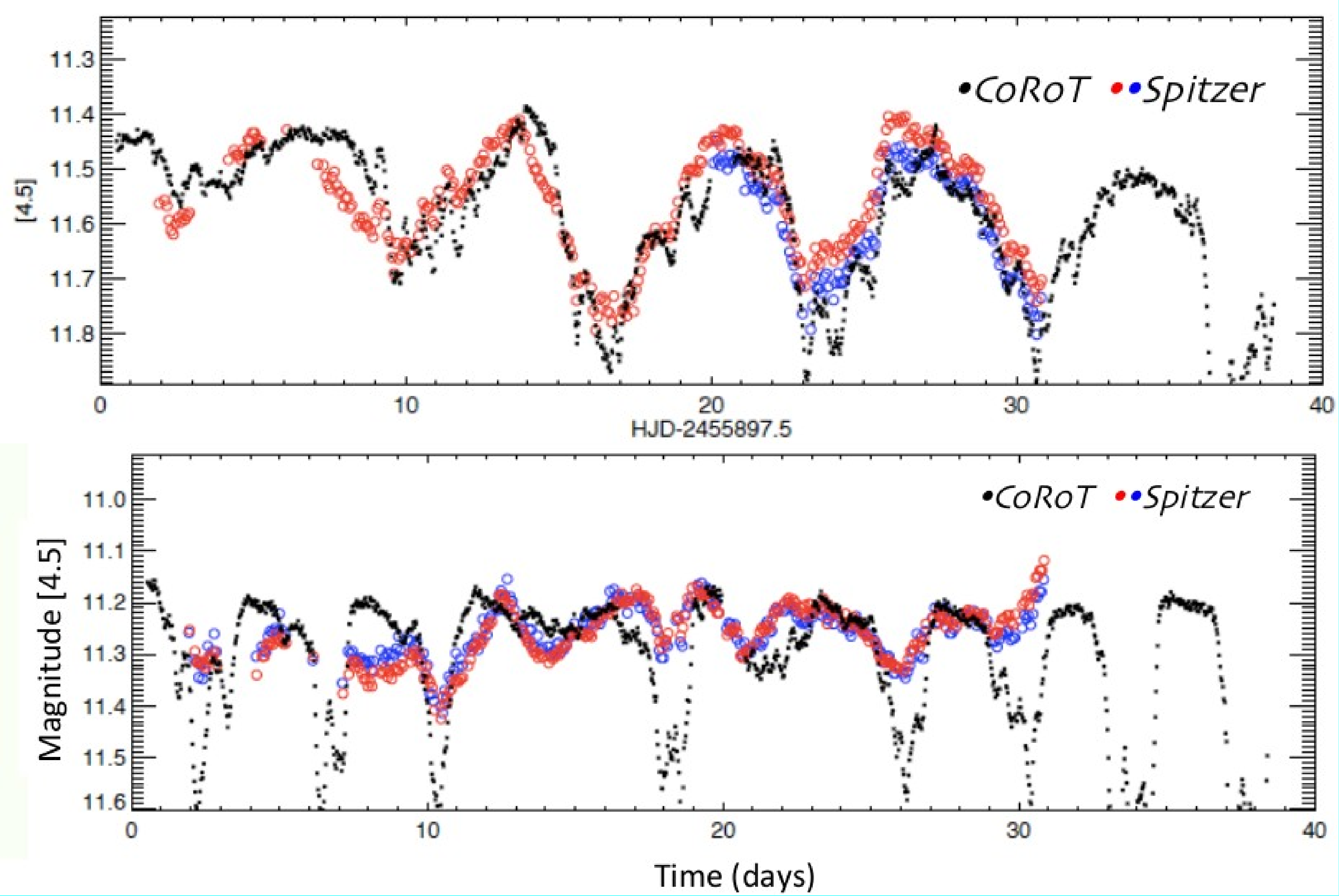
A. Cody: Dynamic young stars and their disks

- PMS - accretion disk: impossible to resolve inner 1 AU, role of magnetic field not clear
- Multifrequency approach
- Photometric variability to tomograph the inner disk to stellar surface
- NGC2264: multi-instrument campaign (CoRoT, Spitzer, MOST) + ground-based spectroscopy for almost 40 days



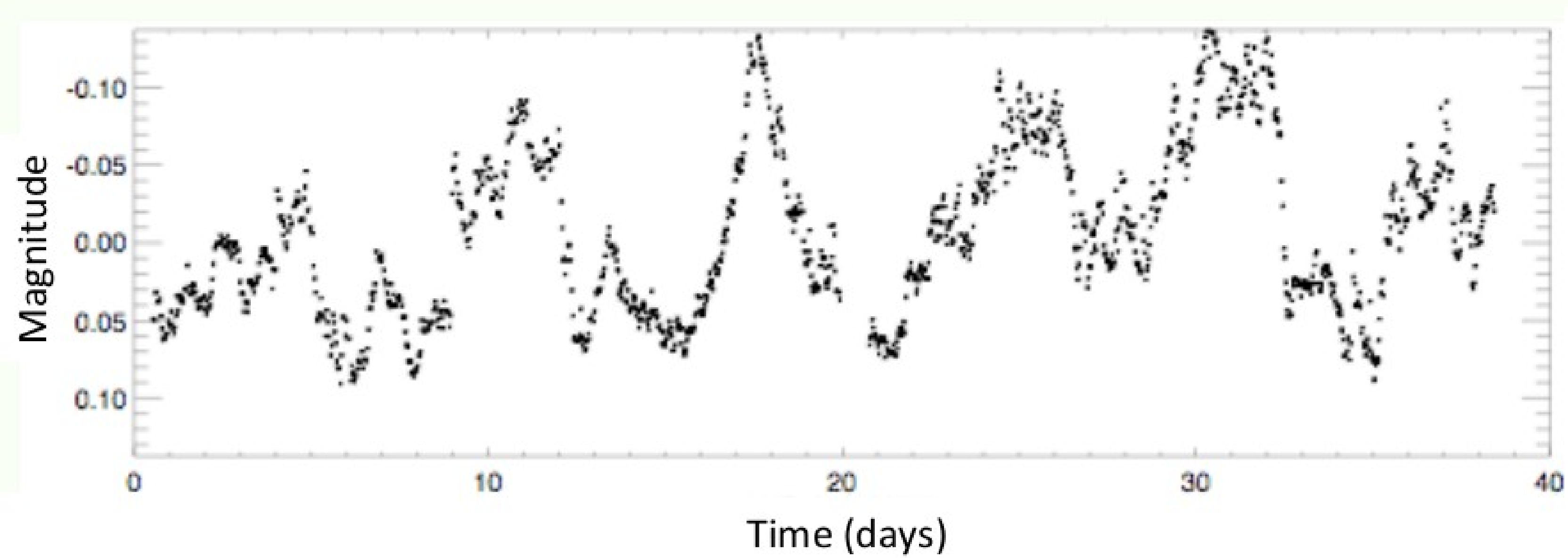


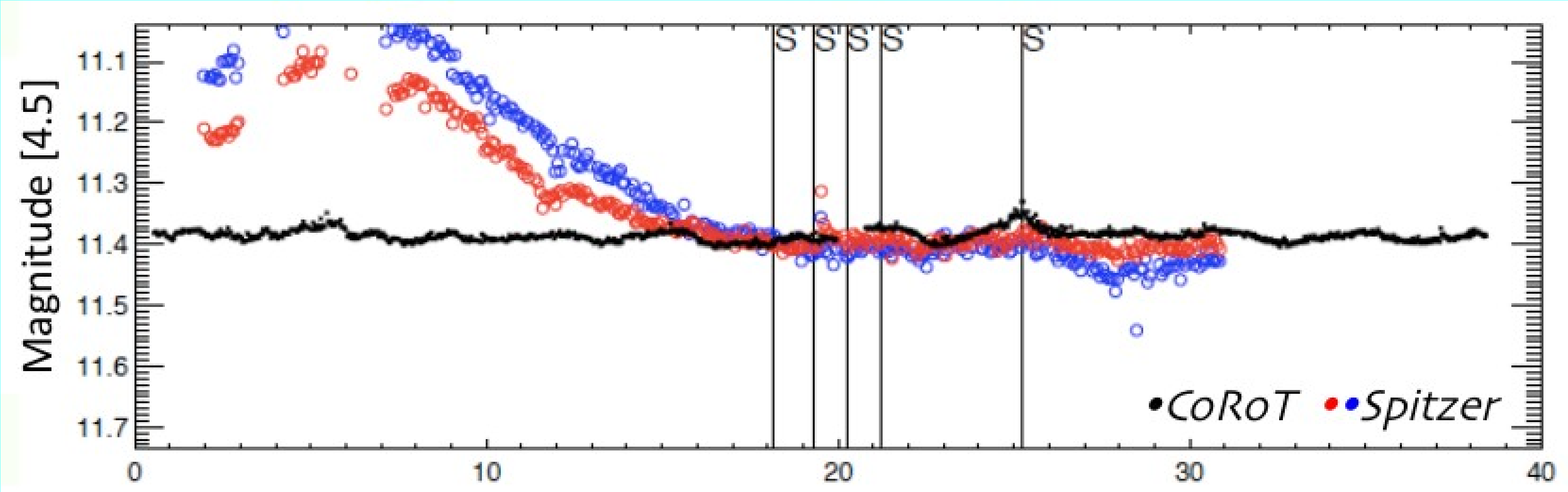
Two PMS objects in NGC 2264



- QP variability: disk blobs or warps, occultation of the central star
- Absorption properties different from ISM, depend on central star

Accretion bursts in some stars ? UV excess, Hα indicates accretion

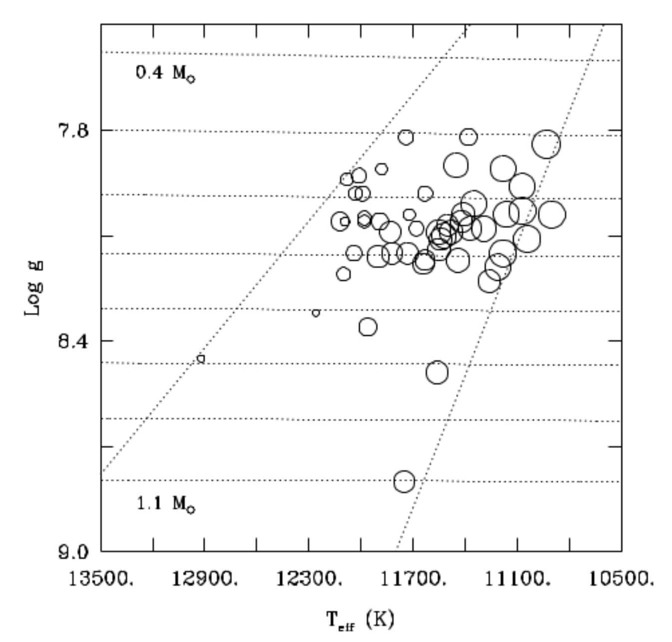




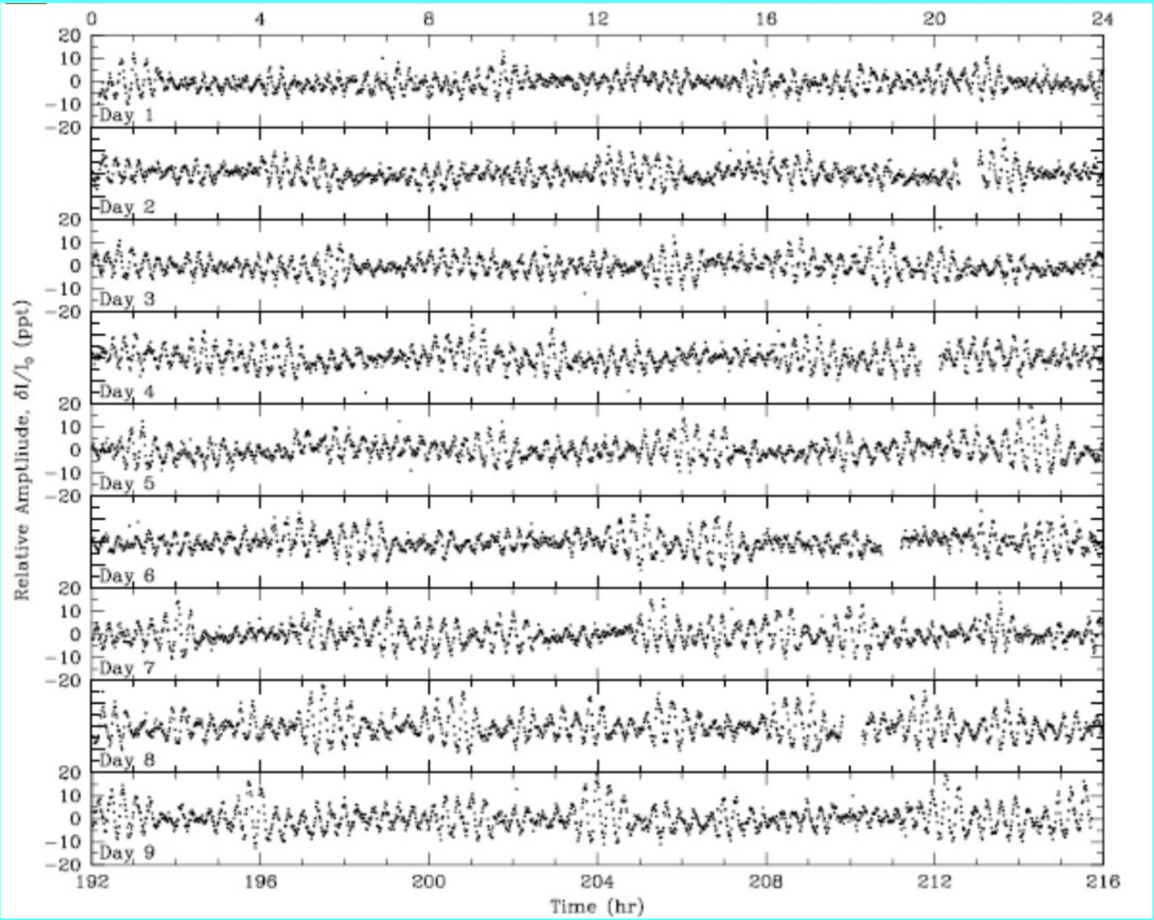
10% stars show enhanced variability in IR only, changing geometry ?

N. Giammichele: GD1212: Probing deep into the interior of a pulsating WD stars

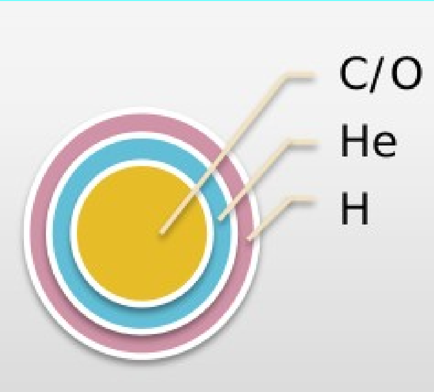
- G1212: ZZ Cet pulsator close to red border of the instability strip, g-mode
- less nonlinear effects



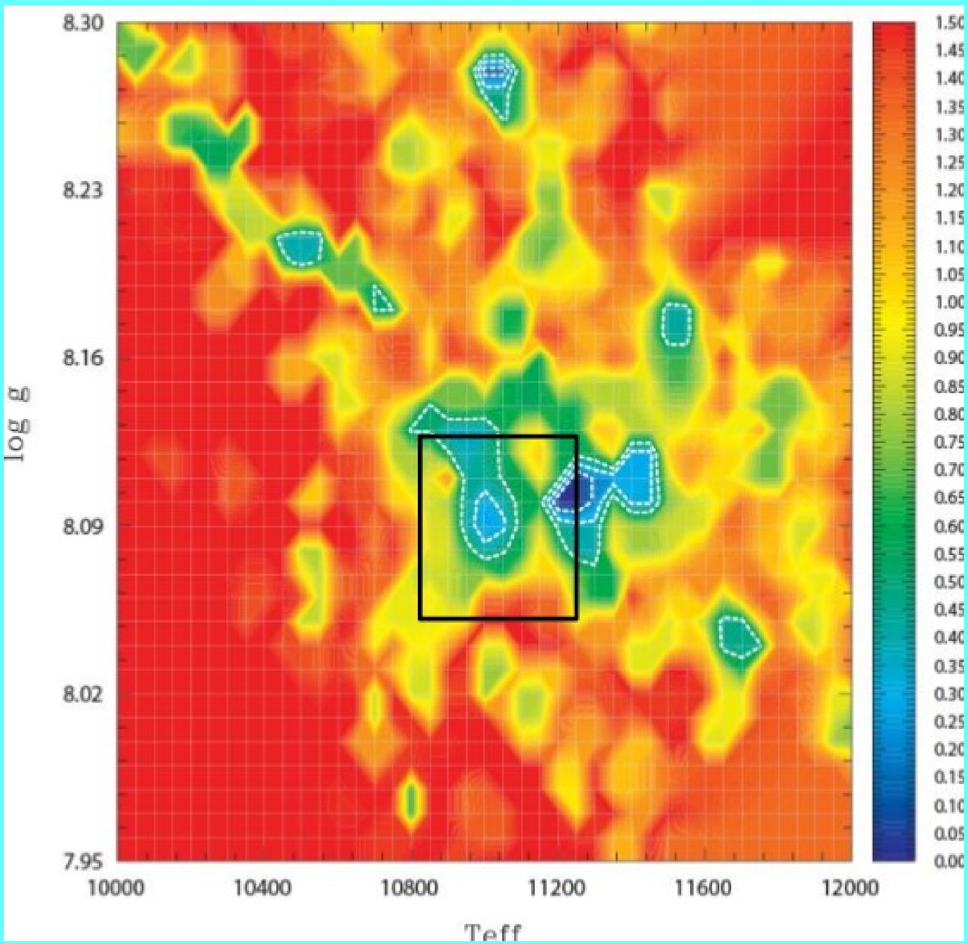
Size of symbol - log (P)



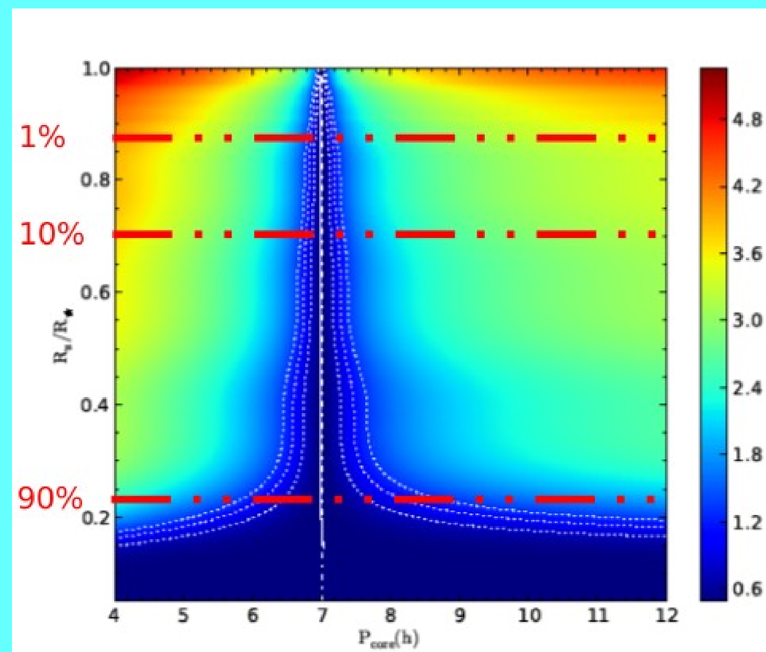
K2 test run, 9 days of data



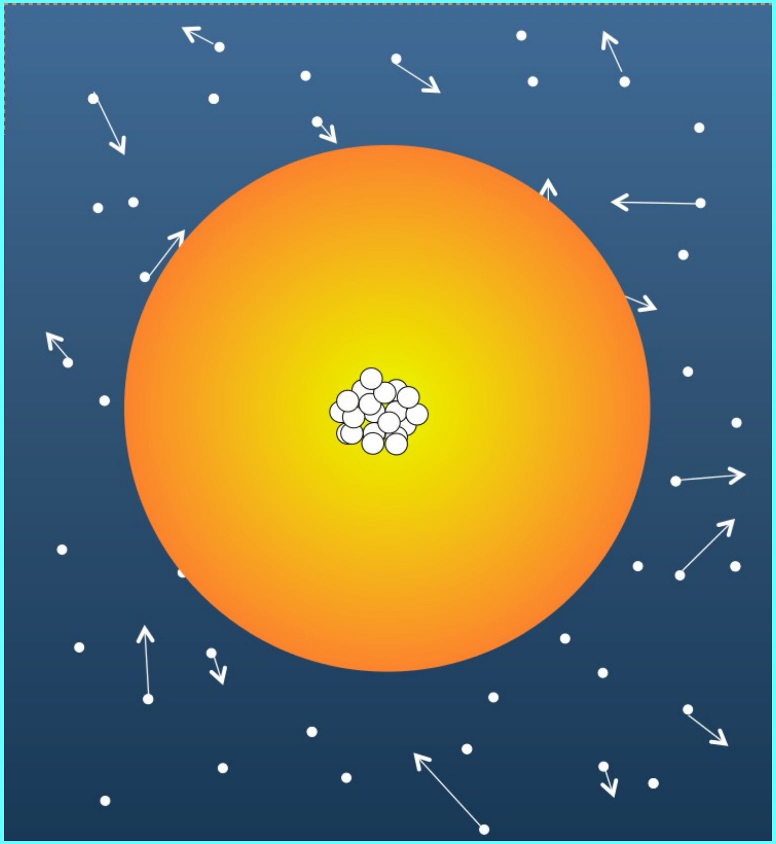
- Forward modeling: frequencies computed from static model: Teff, log g, mass of H, mass of He, core composition… + mode identification
- genetic-algorithm optimization



- seismic-spectroscopic determination of log g, Teff C/O 47-53%
- Mass of H and He layers
- solid-body rotation



J. Casanellas: Constraining dark matter with asteroseizmology



- WIMP: weakly interactive massive particles
- WIMPs are trapped by a star and concentrate in inner 5% of the star
- long mean free path
- new energy transfer mechanism from center to outside !
- strongest in low-mass stars
- we need low degree g-modes to sound the center of the star
- energy transfer in cores can prevent convection
- Problems (i) need accurate stellar parameters, (ii) low-mass MS stars or RGs, (iii) DM-dense environment

Major obstacle: properties of dark-matter particles unknown....

Project Dwarf: ground-based search for circumbinary planets

T. Pribulla, E. Kundra

Astronomický ústav Slovenskej Akadémie Vied, 059 60 Tatranská Lomnica, Slovakia

Circumbinary exoplanets

Circumbinary exoplanets (CBP) are objects simultaneously orbiting both components of a binary. Due to stability requirements, the planetary orbital period must be much longer than that of the binary. Techniques to detect CBP:

- RV measurements to detect the wobble of the binary mass center : the Tatooine project (Konacki et al., 2009): no CBP detected
- photometric detection of transits of the planet(s) across the disk of the inner binary: Kepler satellite photometry - 7 planets in 6 binary systems detected in the Kepler data (see Welsh et al., 2014)
- timing of the inner binary eclipses (successful but not conclusive in PCEBs, see Zorotovic & Schreiber, 2013)

Project Dwarf: precise timing of minima

- The campaign was announced in Pribulla et al. (2012)
- LITE - timing of pulses, eclipses or pulsations
- cyclic period changes of a binary system orbited by a third body due to the finite speed of light
- LITE always gives just an indirect (but good) indication - timing variability can be also interpreted by: (i) magnetic-orbital momentum coupling (ii) apsidal motion in low-eccentricity orbit (iii) perturbations caused by a third body
- enables determination of the orbital parameters similar to spec. elements
- Conroy et al. (2014): timing analysis of Kepler EBs ==> 20% of triple systems, masses in the stellar regime = no planets detected
- All (but AA Dor) PCEBs with timing accuracy better than 10sec observed more than 5 years show cyclic variability (Zorotovic & Schreiber, 2013)

Object rating/target list

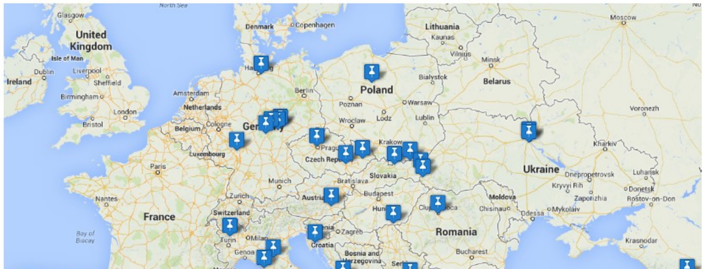
Chances to discover a CBP depend on:

- (i) precision and number of minima
- (ii) semi-amplitude of the LITE caused by the 3rd body
- (iii) intrinsic variability of the binary

Objects with sharp minima included in the campaign:

- (i) K or/and M dwarf binaries
- (ii) systems with a hot subdwarf K/M dwarf component
- (iii) systems with a WD component

At present about 50 EBs observed, new objects searched in the NSVS, ASAS, and FBS databases



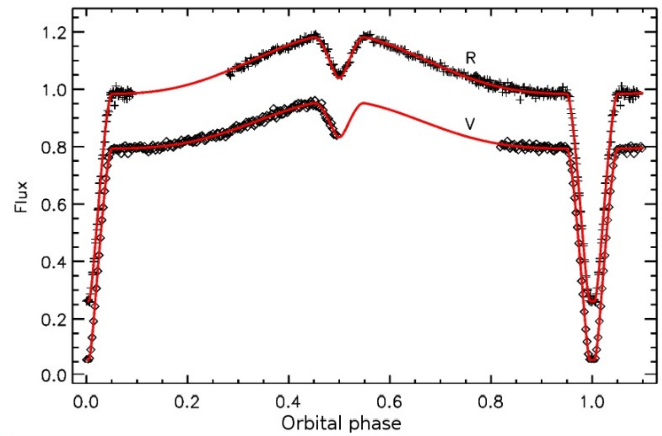


Fig. 2. High-precision VR light-curves of newly-detected sdB+M dwarf eclipsing binary VSX075328+722424 (Pribulla et al., 2013) obtained with 2m telescope of the Rozhen Observatory (Bulgaria).

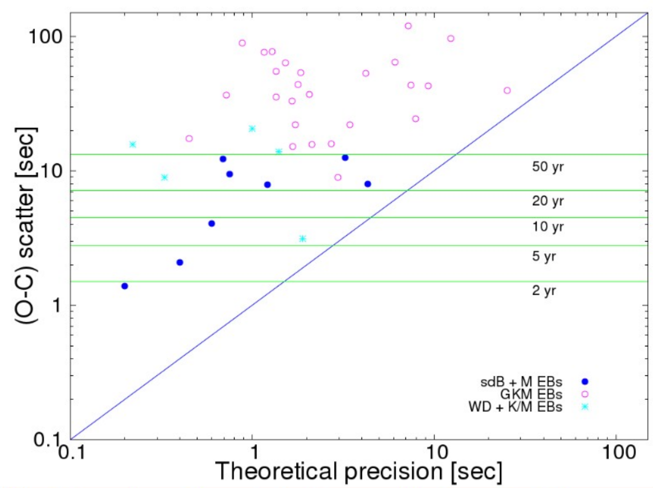


Fig. 3. Comparison of theoretical minima precision for a 60cm telescope and the observed scatter of the timings. Accuracy better than 10 sec is achieved mostly for sdB eclipsing binaries. For WD systems it is limited by the time resolution of the photometry. For K and M-dwarf systems by intrinsic surface variability. Horizontal lines give expected peak-to-peak amplitude of the light-time effect for a 1 solar mass binary orbited by a 1 Jupiter-mass substellar body for orbital periods 2-50 years.