instituto de astrofísica
e ciências do espaço

SpaceInn.eu

ρ and logg for δ Scuti stars using "$\Delta\nu$"

Antonio García Hernández (IA-CAUP), M. J. P. F. G. Monteiro, S. Martín, Z. Guo, D. R. Reese, J. C. Suárez, J. Pascual-Granado, R. Garrido

Joint TASC2 & KASC9 Workshop – SPACEINN & HELAS8 Conference
11-15 July 2016, Angra do Heroísmo, Terceira-Açores, Portugal

δ Scuti stars

- A-F type, main sequence stars (bright and numerous)
- Convective core
- *p* modes around F0 (and *g* modes) = no asymptotic regime
- κ mechanism/turbulent pressure (Antoci's talk)
- Precursors of some RG (M = [1.5, 3] M_{sun}) with planets
- Rapid rotators (> 100 km/s or > 0.3 Ω_K) (Ouazzani's talk)

Dealing with rotation

- Non-validity of spherical approximation
- Displacement of frequencies
- Increase the number of modes (new categories)
- Destroy the rotational splitting pattern

- Models limited to:
  - spherically symetric 1D
  - time-consuming 2D

Patterns

- Breger (histogram)
- Handler (Fourier)
- García Hernández (Fourier)
- Paparó (visual/SSA)
- Zwintz (histogram)
- Antoci (visual)
- Brunsden (histogram)

- What kind of pattern?
  - Large separation
  - Rotational splitting
  - Other
- How to avoid modelling?

Eclipsing binaries with δ Sct

- Inspired by:
  - Suárez et al. 2014 using non-rotating models
  - Theoretical predictions with 2D realistic rotating models (Lignières, Reese, Ouazzani, etc)

- 6 EB + 1 binary with optical interferometry (Rasalhague)
  - Space observations > pulsation frequencies
  - Mass
  - Volume using the equatorial & polar radii (Roche's model)

Eclipsing binaries with δ Sct

Table 1
Characteristics of the Systems Taken from the Literature

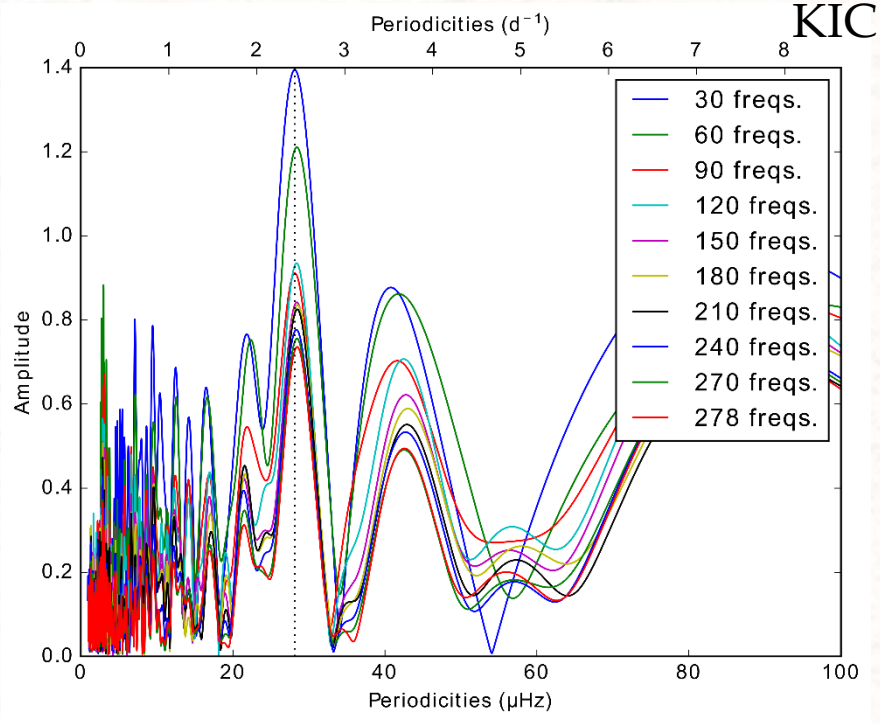
System	$\Delta\nu$ (μHz)	M ($M_\odot$)	R ($R_\odot$)	$\bar{\rho}$ ($\rho_\odot$)	$v \cdot \sin i$ (km s^{-1})	i (∘)	Ω/Ω_K
KIC 3858884[a]	29 ± 1	1.86 ± 0.04	3.05 ± 0.01	0.0657 ± 0.0021	25.7 ± 1.5	88.176 ± 0.002	0.0754
KIC 4544587[b]	74 ± 1	1.61 ± 0.06	1.58 ± 0.03	0.414 ± 0.039	75.8 ± 15	87.9 ± 3	0.172
KIC 10661783[c]	39 ± 1	2.100 ± 0.028	2.575 ± 0.015	0.1255 ± 0.0039	78 ± 3	82.39 ± 0.23	0.200
HD 172189[d]	19 ± 1	1.78 ± 0.24	4.03 ± 0.11	0.0283 ± 0.0061	78 ± 3	73.2 ± 0.6	0.281
CID 1008669999[e]	56 ± 1	1.8 ± 0.2	1.9 ± 0.2	0.262 ± 0.112	⋯	80 ± 2	⋯
CID 105906206[f]	20 ± 2	2.25 ± 0.04	4.24 ± 0.02	0.02986 ± 0.00095	47.8 ± 0.5	81.42 ± 0.13	0.152
HD 159561[g] *(Rasalhague)*	38 ± 1	$2.40^{+0.23}_{-0.37}$	$R_{eq} = 2.858 \pm 0.015$ $R_{pol} = 2.388 \pm 0.013$	0.123 ± 0.021	239 ± 12	87.5 ± 0.6	0.88

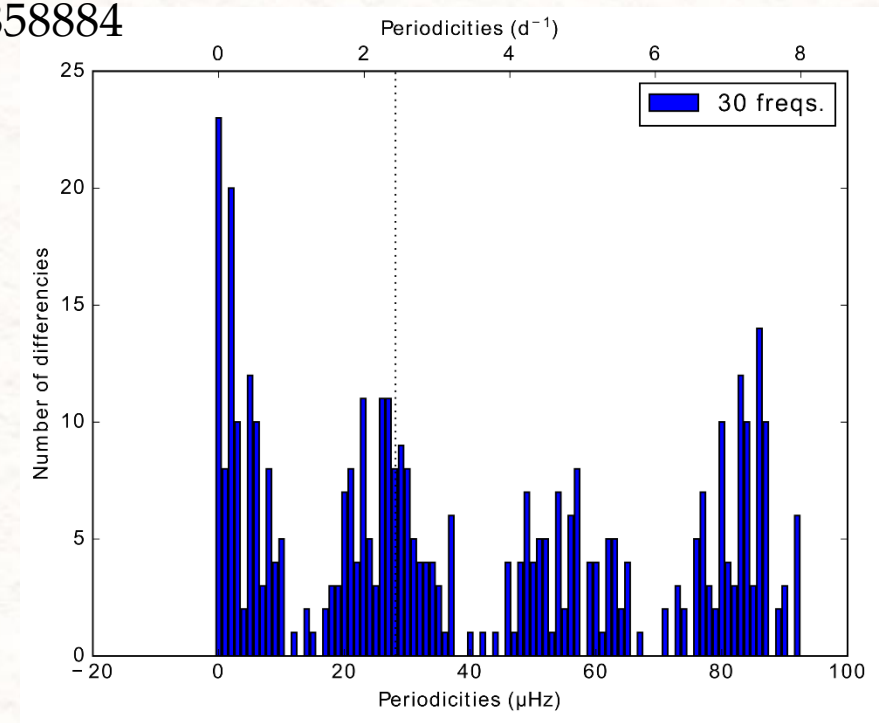
Star	**P_{orb} (d) / ν_{orb} (d^{-1})**	**ν_{rot} (d^{-1})**	**$\Delta\nu$ (d^{-1})**
KIC 3858884	25.953 / 0.0385327	0.1667	2.5056
KIC 4544587	2.1890951 / 0.457	0.95	6.3936
KIC 10661783	1.2313622 / 0.812	0.605	3.3696
HD 172189	5.70198 / 0.1754	0.4	1.6416
CID 100866999	2.80889 / 0.356	--	4.8384
CID 105906206	3.69457080 / 0.271	0.226	1.728
HD 159561	3148.4 / 0.00032	1.803	3.2832

Pattern: methodology

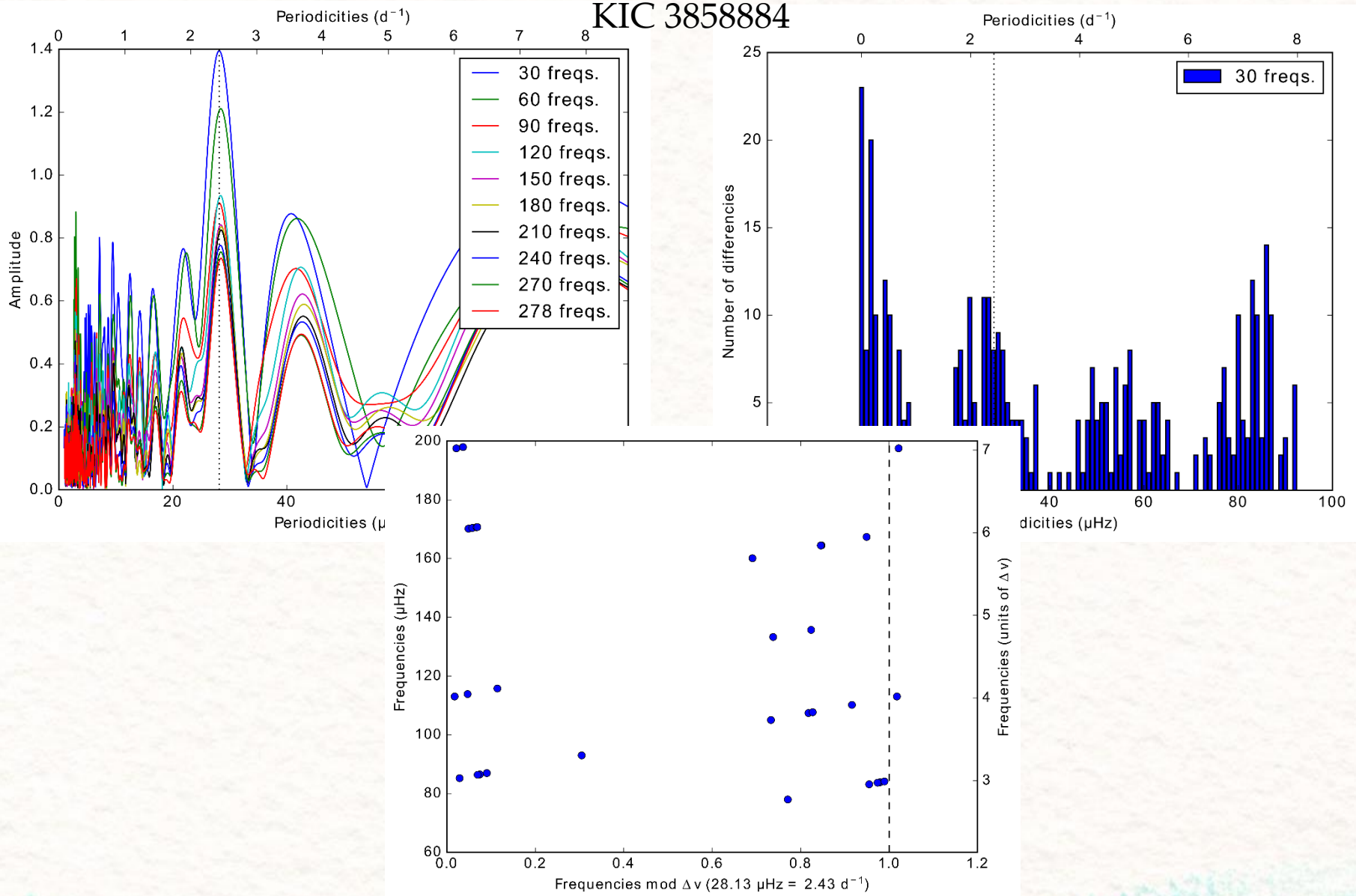
- No harmonics, combinations, rotation period of the system
- No *g* modes (> 50 μHz or > 4.32 d^{-1})
- Taken different subsets (30, 60 frequencies) of highest amplitude modes
- Fourier transform of the frequencies:
  - All amplitudes = 1
  - High peak and submultiples
  - Search for persistent peaks
- Histogram of frequency differences:
  - High peak and multiples
- Echelle diagrams

KIC 3858884

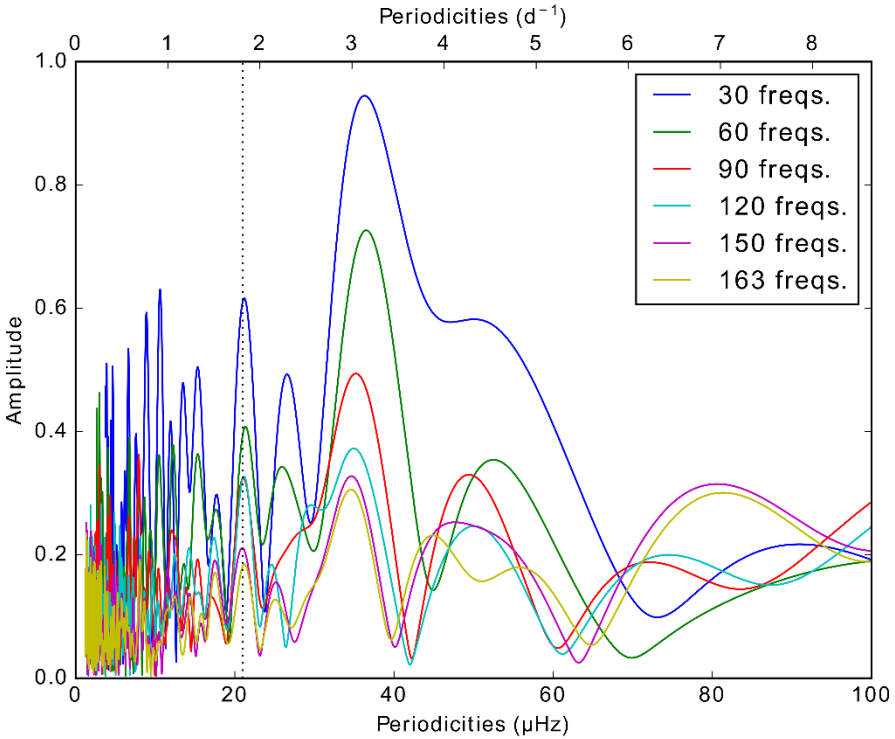

Periodicities (d^{-1})
Amplitude
Periodicities (μHz)
30 freqs.
60 freqs.
90 freqs.
120 freqs.
150 freqs.
180 freqs.
210 freqs.
240 freqs.
270 freqs.
278 freqs.

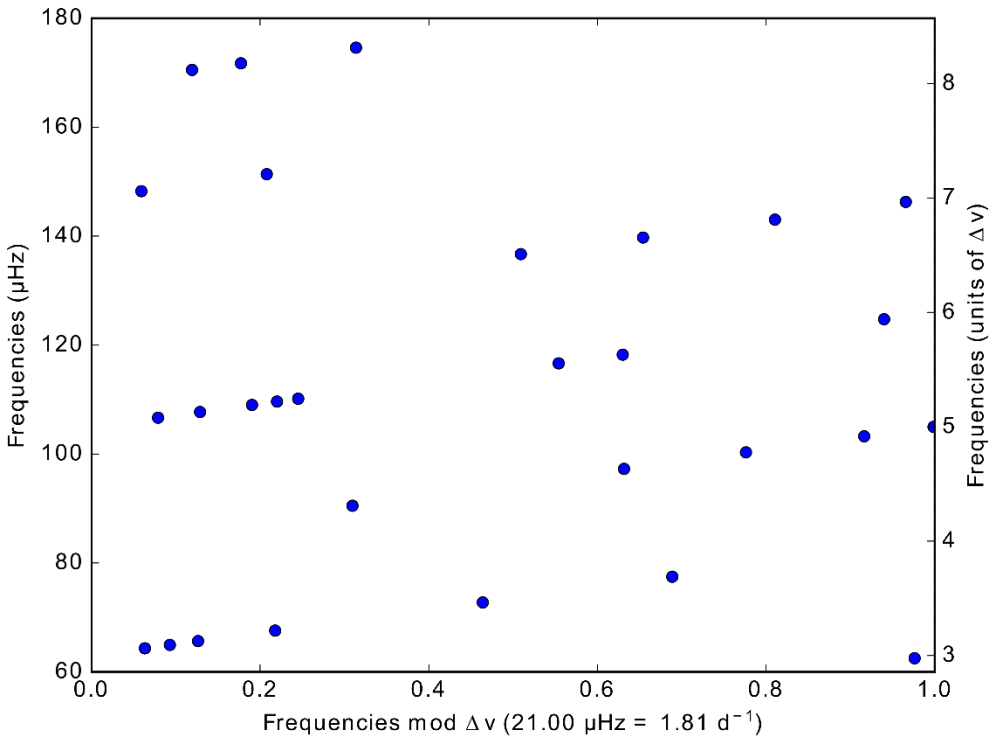

Periodicities (d^{-1})
Number of differencies
Periodicities (μHz)
30 freqs.

KIC 3858884


Periodicities (d^{-1})
Amplitude
30 freqs.
60 freqs.
90 freqs.
120 freqs.
150 freqs.
180 freqs.
210 freqs.
240 freqs.
270 freqs.
278 freqs.
Periodicities (μ
Periodicities (d^{-1})
Number of differencies
30 freqs.
dicities (μHz)
Frequencies (μHz)
Frequencies (units of Δ ν)
Frequencies mod Δ ν (28.13 μHz = 2.43 d^{-1})

CID105906206



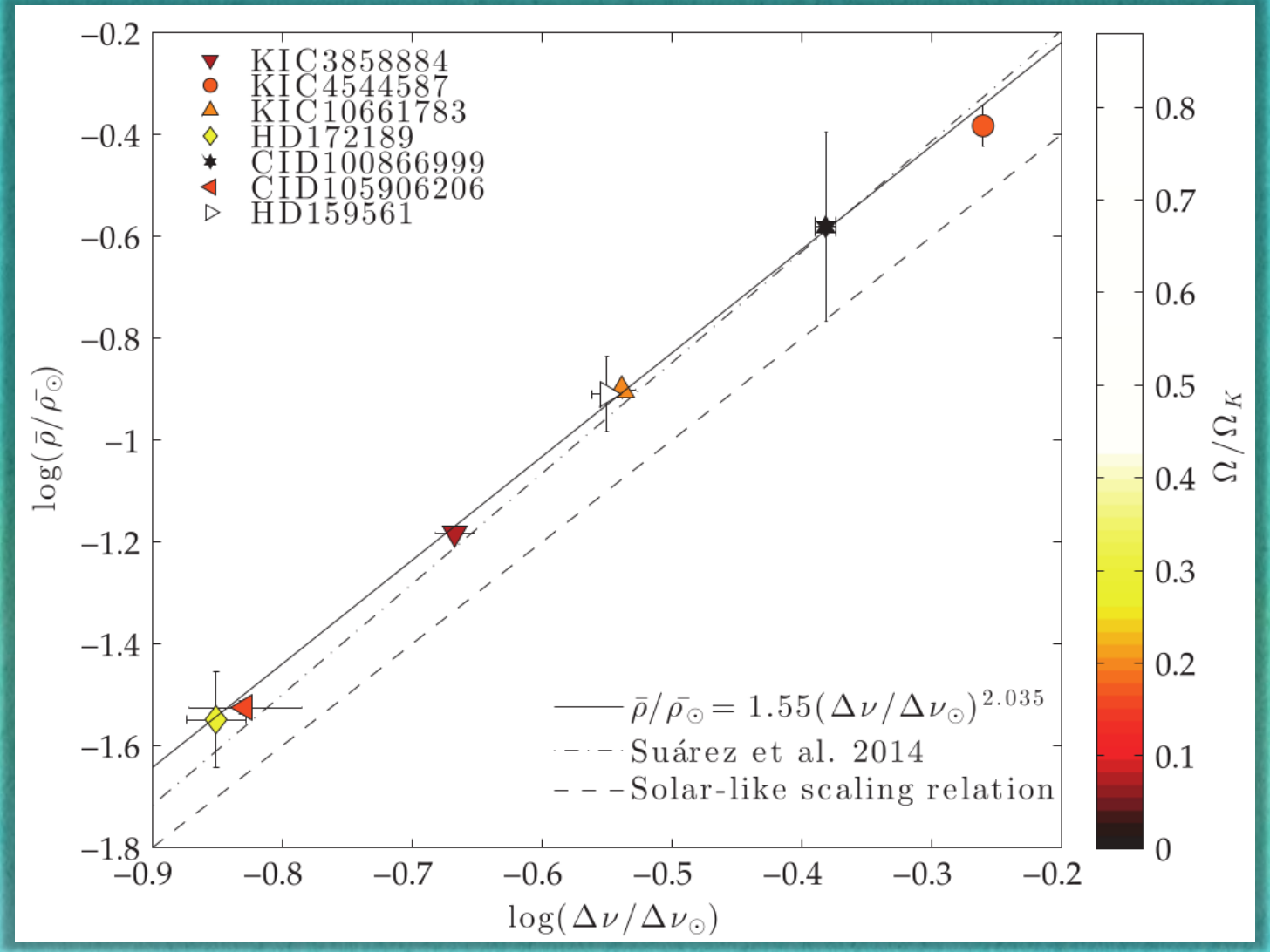


Some considerations

- Periodicity appears as $\Delta\nu/2$:
  - HD 172189
  - HD 159561 (Rasalhague)
- Periodicity appears as $\Delta\nu/4 \approx 2\nu_{rot}$:
  - KIC 4544587

- Expected from the theory! (Reese 2008, Lignières et al. 2010)

García Hernández et al. 2015 ApJL 811, L29



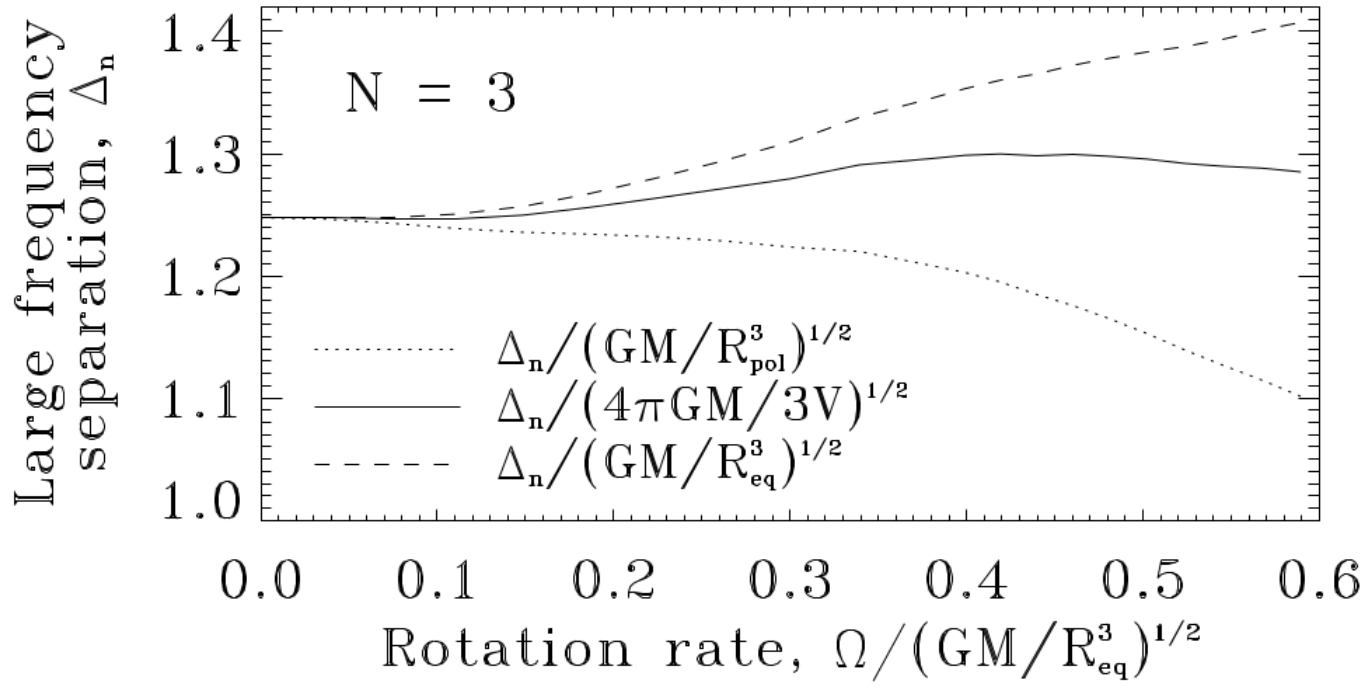
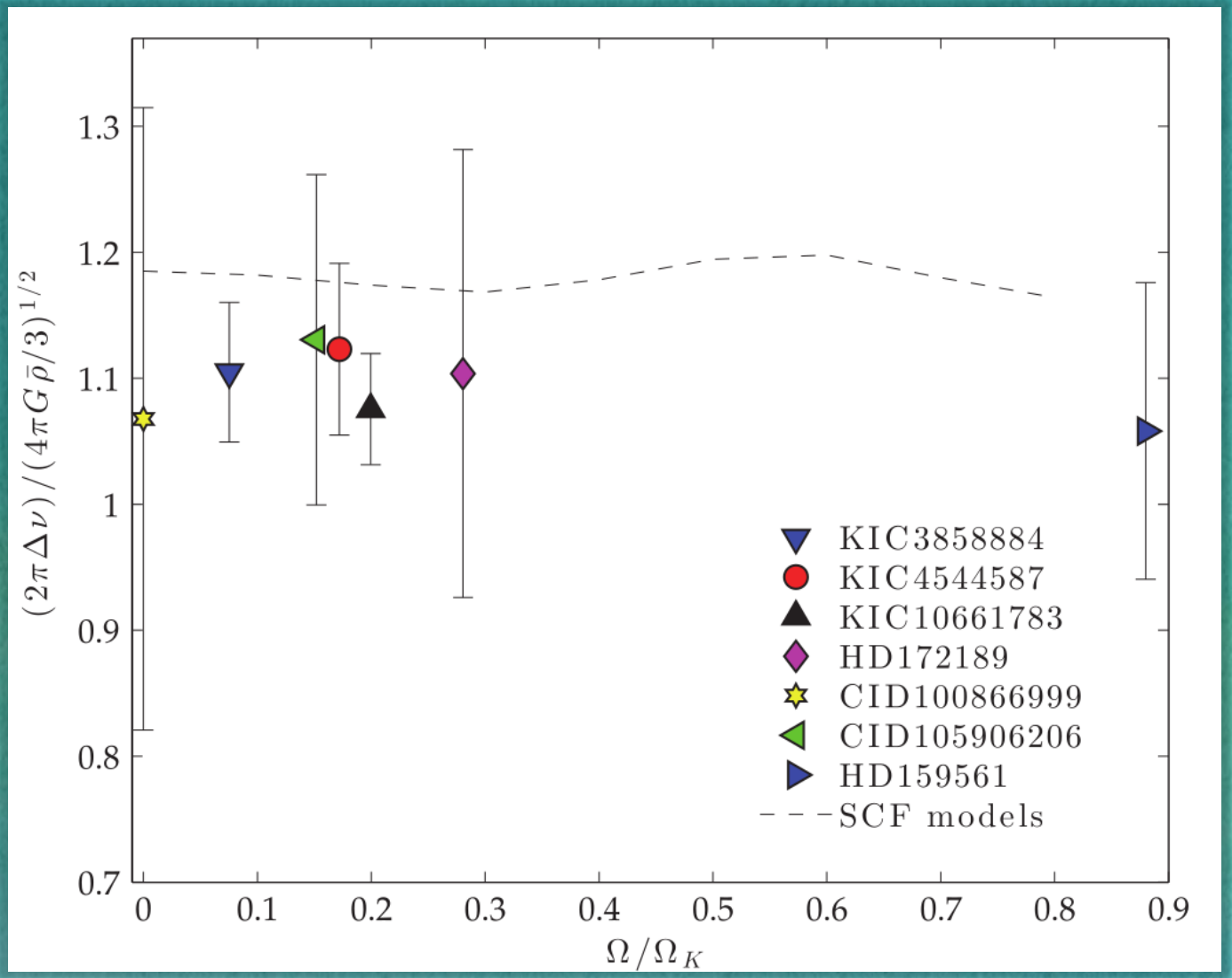


Fig. 2. The large frequency separation Δ_n as a function of the rotation rate Ω. Δ_n has been scaled with different quantities so as to show which other stellar quantity best matches this frequency separation. As can be seen, Δ_n is roughly proportional to the square root of the mean density of the star.

Reese et al. 2008 A&A 481, 449

García Hernández et al. 2015 ApJL 811, L29



$\Delta\nu$-ρ relation

- Periodic pattern is not accidental/artifact
- It's a large separation-like structure (i. e., related to stellar ρ)
- It's independent on the rotational velocity…
- … although there is a "relation" between $\Delta\nu$ and ν_{rot}
- Indicative of the evolutionary state
- Help in determining rotational splitting? (Paparó et al. 2016)
- Mode identification?
- And…

Paparó et al. 2016 ApJS, 224, 41P

Δν-ρ

- Periodic
- It's a larg
- It's indep
- Help in c
- Mode id
- And…

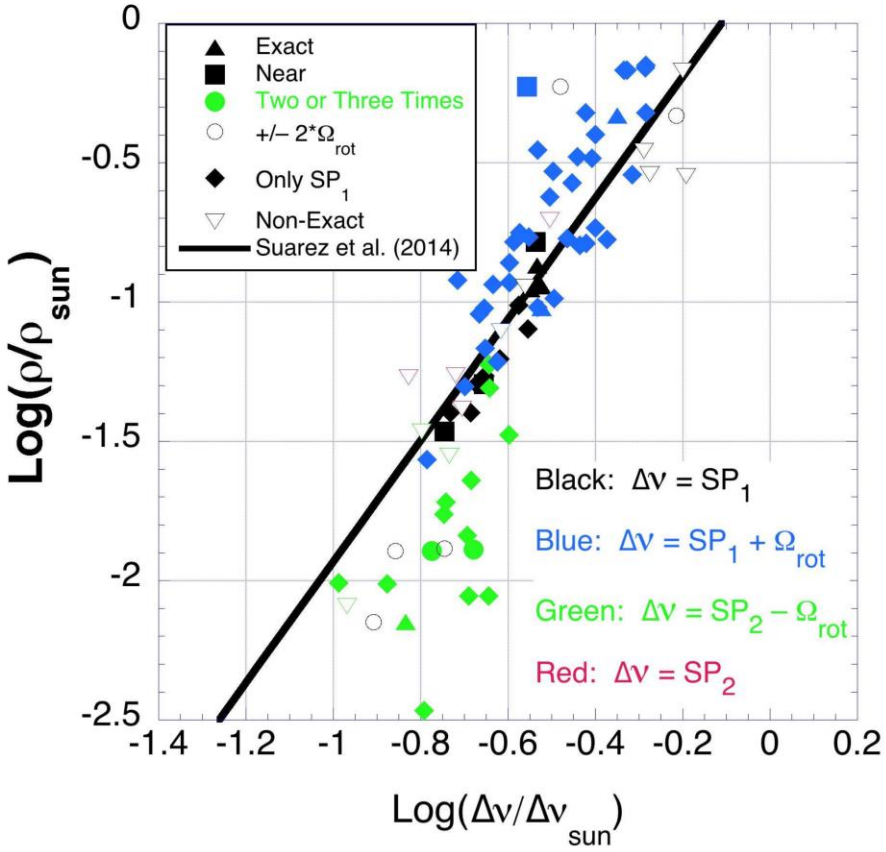
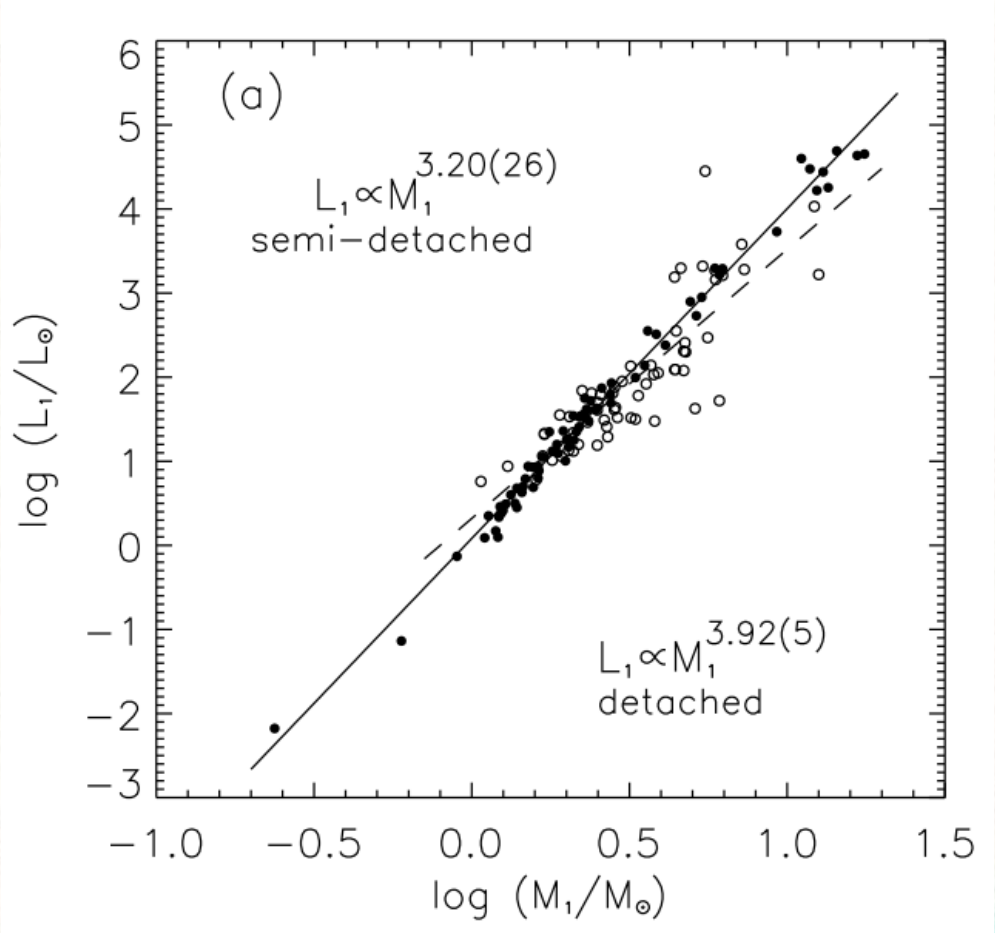


FIG. 16.— Location of the whole sample on the log mean density vs. log large separation diagram, along with the relation based on stellar models from Suárez et al. (2014). The new symbols represent the stars for which there is no agreement between the rotational frequency and the difference of the spacings (inverted triangle) or the stars with only one spacing (diamonds). The color code is the same as in the previous figure, with the addition of the red color corresponding to $\Delta\nu = SP_2$.

et al. 2016)

One step further: log *g*

- Estimating the mass (Gaia)



İbanoğlu et al. 2006

One step further: log *g*

From true L:

- HD 159561
- CID 105906206
- KIC 10661783

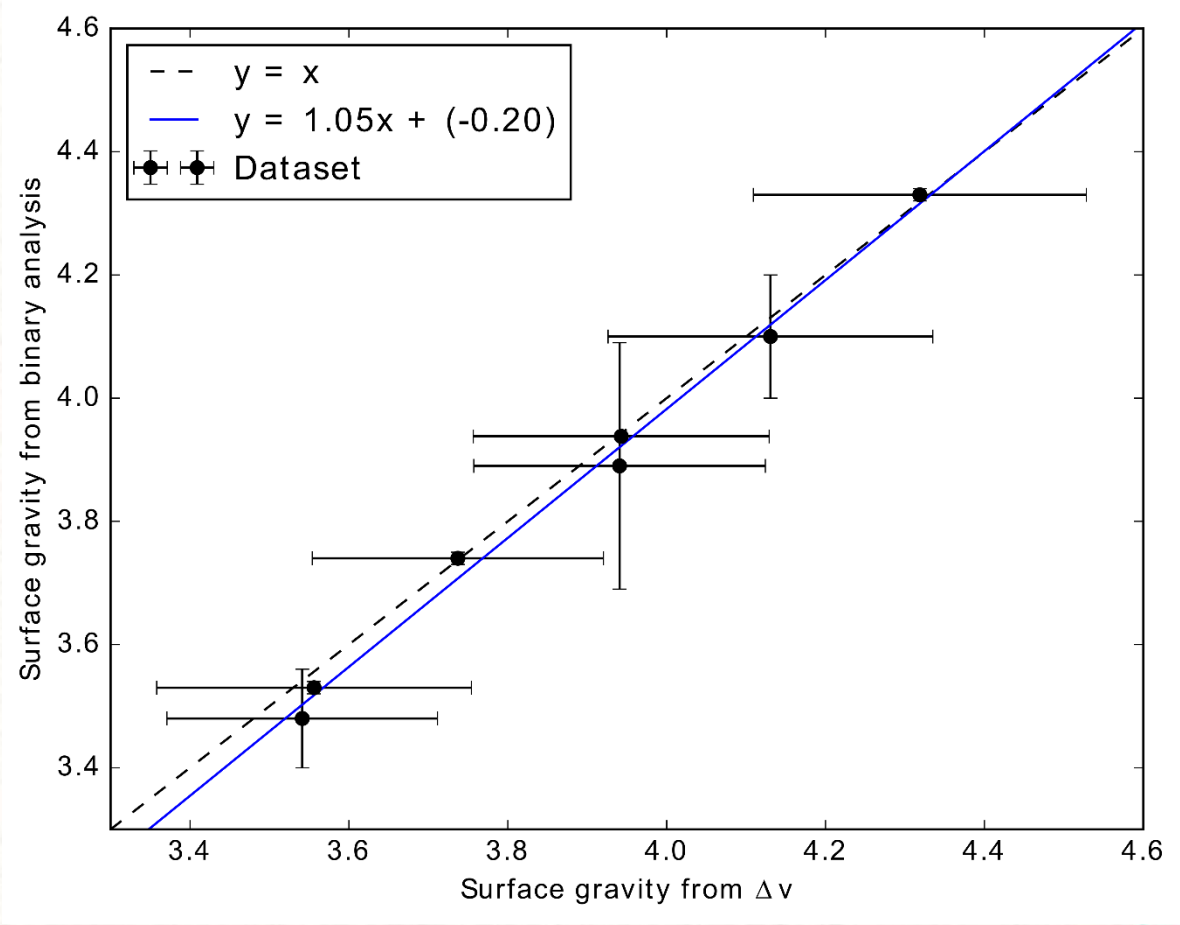
From Mb:

- HD 172189
- CID 100866999
- KIC 4544857

From parallax:

- KIC 3858884

One step further: log *g*



Conclusions

- $\Delta\nu$ as seismic index
- Accurate ρ
- "Accurate" log*g*
  - *Less uncertainty in $\Delta\nu$-ρ relation*
- Indepent of rotation
- Reveal rotational splitting
- First step for mode ID
- δ Sct hosting planets (WASP33)?

- Keep obserbing EB with a δ Sct!!