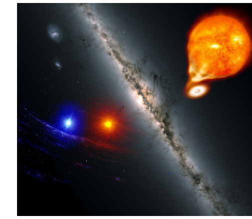
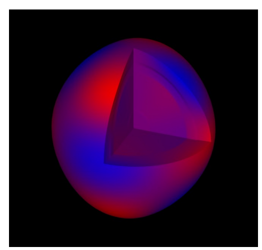
10th Meeting on Hot Subdwarfs and Related Objects



Pulsations in hot subdwarfs (and related objects)

Valérie Van Grootel

(STAR Institute, ULiège, FNRS)



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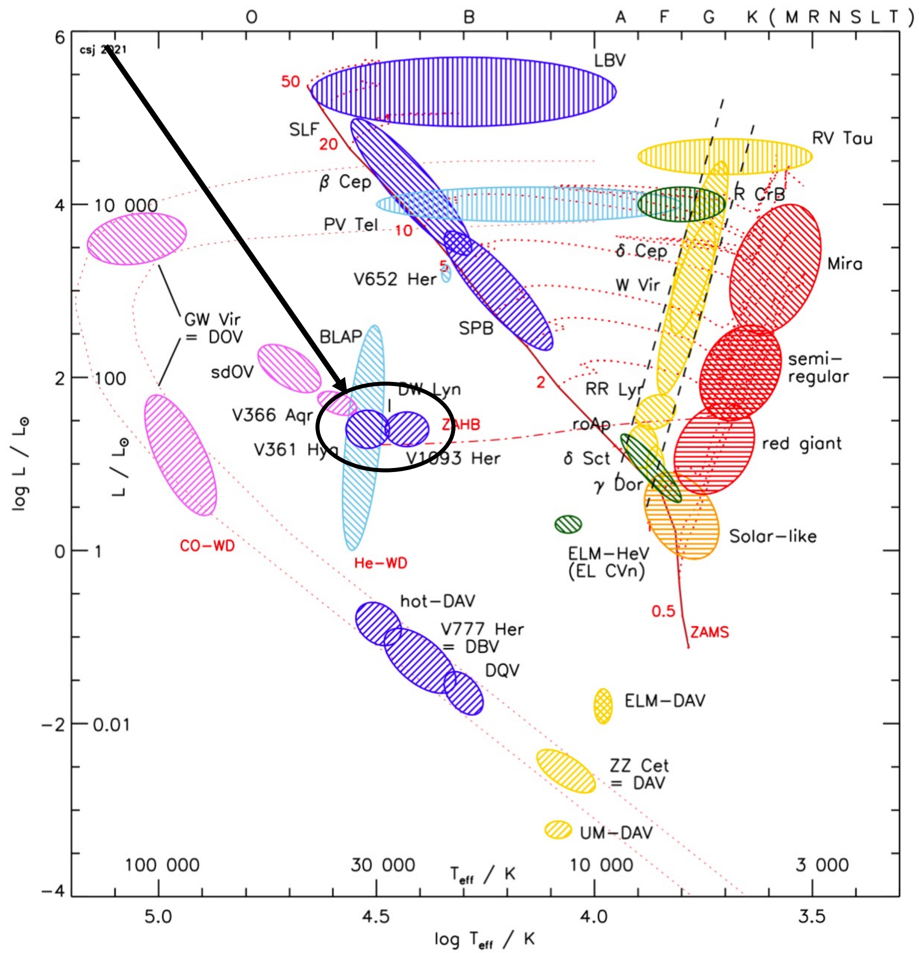
Subdwarf B (sdB) stars

Hot (T_{eff} ~ 20,000 – 40,000 K) and compact stars (log g ~ 5.2-6.2) belonging to Extreme Horizontal Branch (EHB) – He-core burning

Two main classes of multi-periodic sdB pulsators



D. Kurtz/S. Jeffery

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Hot (T_{eff} ~ 20,000 – 40,000 K) and compact stars (log g ~ 5.2-6.2) belonging to Extreme Horizontal Branch (EHB) – He-core burning

Two main classes of multi-periodic sdB pulsators:

> **short-periods** (P ~ 80 - 600 s), A ≤ 1% (EC14026, V361Hya, sdBV_r, **sdBVp** stars)
- Discovered by Kilkenny et al. (1997)
- Rather in the hottest, most compact sdB stars

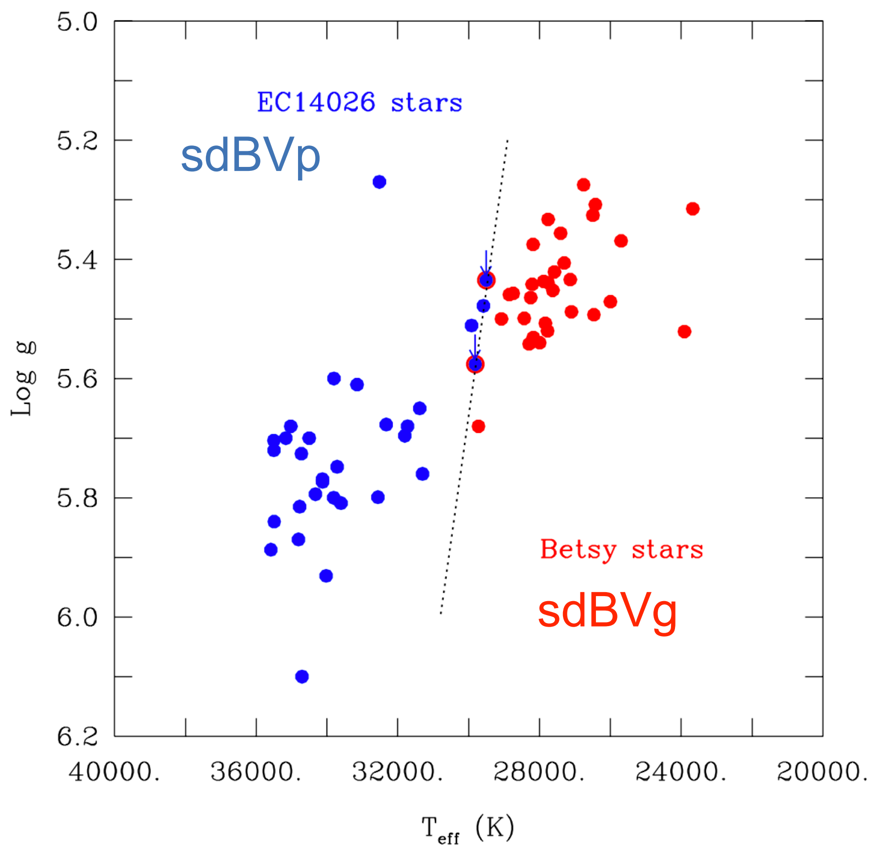
> **long-periods** (P ~ 30 min - 3 h), A ≤ 0.1% (V1093 Her, Betsy stars, sdBV_s, **sdBVg** stars).
- Discovered by Green et al. (2003)
- Rather in cooler, less compact sdB stars

Space observations required !

> **hybrids** (DW Lyn, sdBV_rs). Discovered by Baran et al. (2005), Schuh et al. (2006)

Subdwarf B (sdB) stars

Hot (T_{eff} ~ 20,000 – 40,000 K) and compact stars (log g ~ 5.2-6.2) belonging to Extreme Horizontal Branch (EHB) – He-core burning



But, from Kepler/K2: low-amplitude short-periods in cool sdB stars, or long-periods in hot sdBs, are common (see e.g. Silvotti et al. 2019)

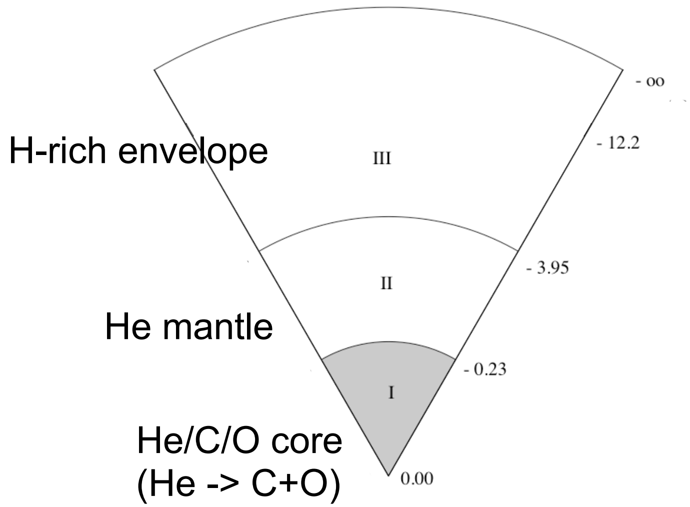
Subdwarf B (sdB) stars

A bit of asteroseismology…

Pulsations are excited and propagate in some regions, and are evanescent in others

p-modes (restoring force : pressure), acoustic waves
g-modes (restoring force : buoyancy), gravity waves

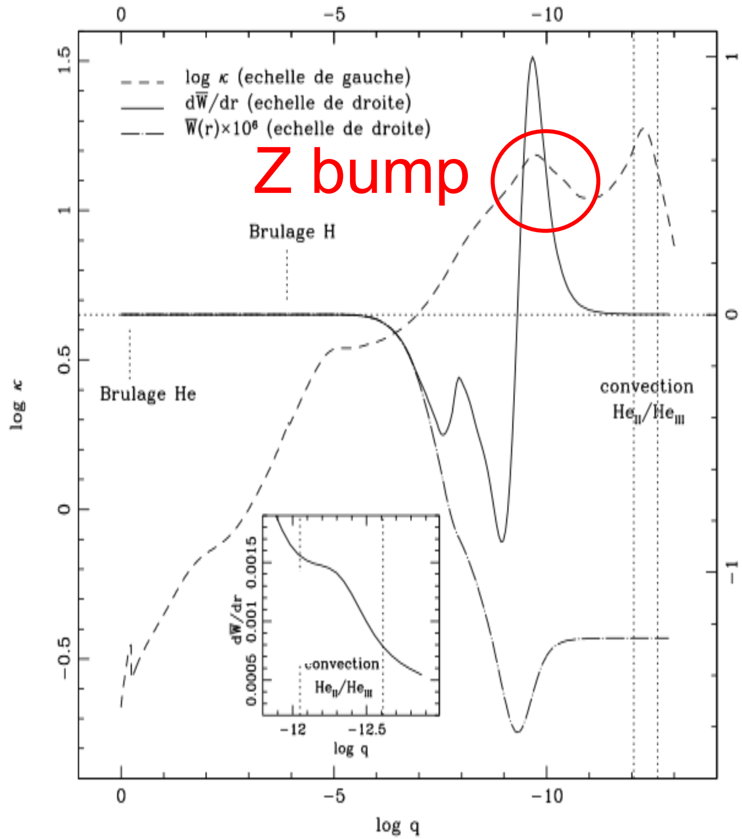
In sdB stars: p-modes propagate in the envelope, g-modes propagate deeper inside the stars



Asteroseismology of sdB pulsators

How pulsations are excited ? Aka « Driving mechanism »

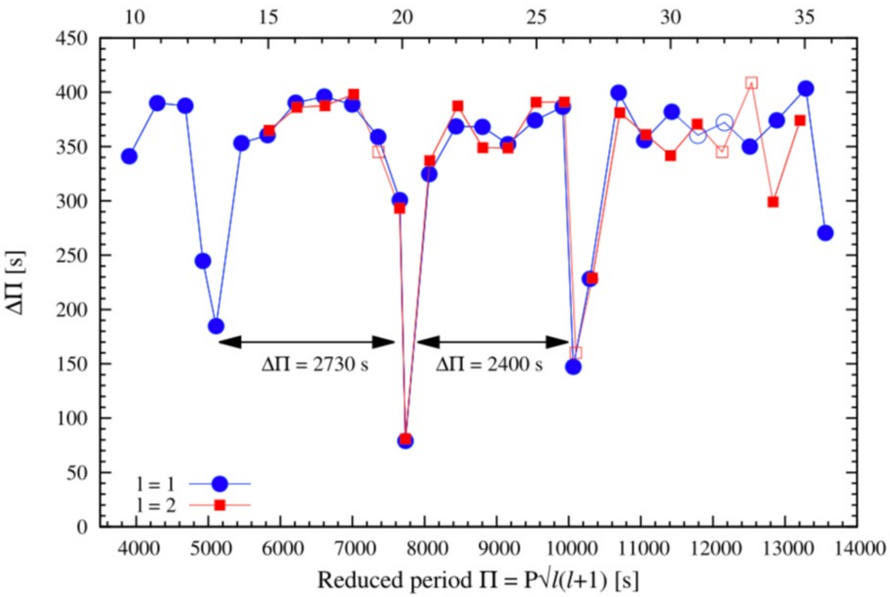
Kappa (opacity) mechanism at work in the envelope: opacity peak due to partial ionization of heavy elements (« Z-bump »)



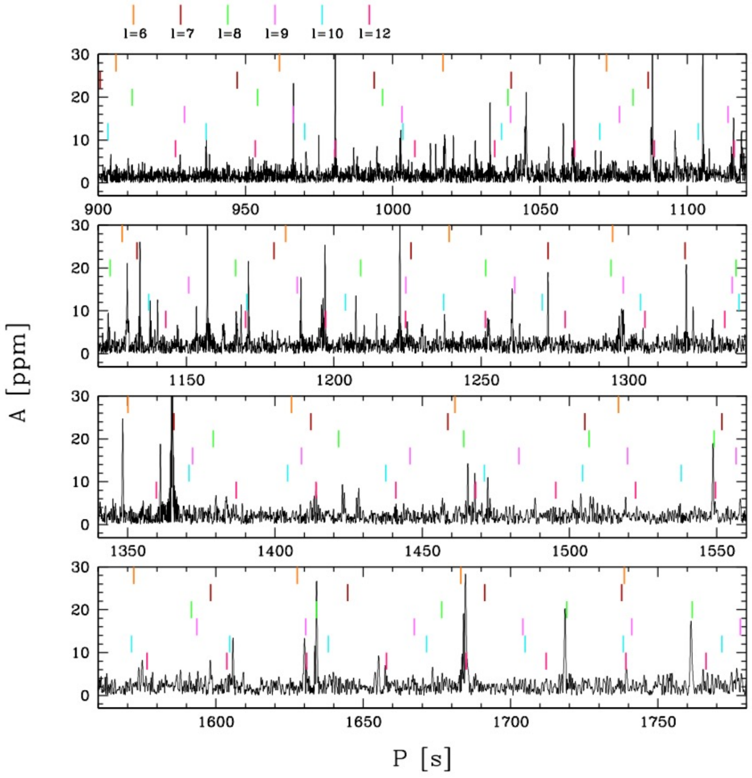
Prediction of sdBVp (p-modes) by Charpinet et al. (1996, 1997)
Also works (qualitatively) for g-modes and sdOV (Fontaine et al. 2003, 2008)

Asteroseismology of sdB pulsators: Marking results

1. Observations of trapped g-modes (Østensen et al. 2014, Uzundag et al. 2017)
2. Observations of g-modes up to l=12 ! (Telting et al. 2014, Kern et al. 2018, Silvotti et al. 2019)



Østensen et al. 2014



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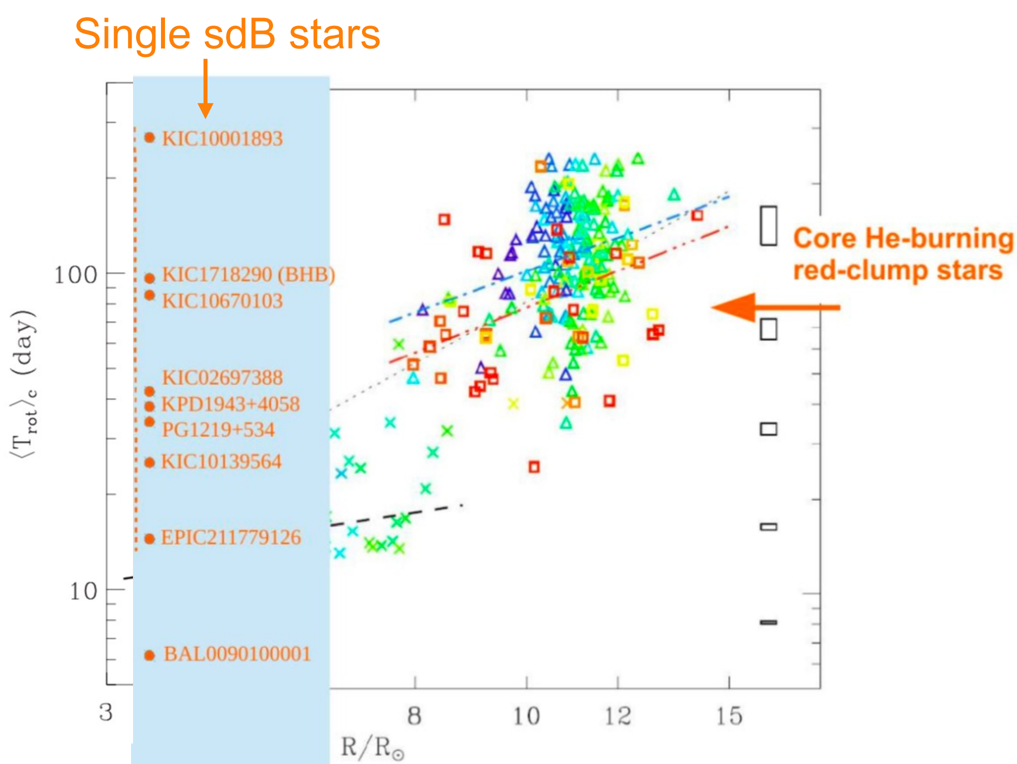
2. Observations of g-modes up to l=12 ! (Telting et al. 2014, Kern et al. 2018, Silvotti et al. 2019)
3. Single sdB stars are (almost) all slow rotators (Charpinet et al. 2018), in direct line with core rotation of Red Clump stars (Mosser et al. 2012) => indication of similar evolution (post-RGB stars)



Mosser et al. 2012
Charpinet et al. 2018

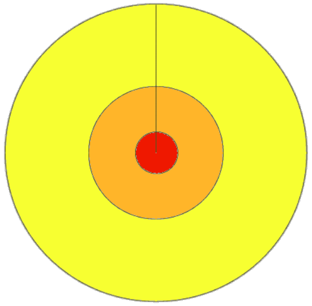
Asteroseismology of sdB pulsators: Marking results

Fontaine et al., Charpinet et al., Van Grootel et al.,…: 18 sdB stars modeled by asteroseismology (mass, radius, H-rich env. thickness, core composition,…)

Two tests of seismic results thanks to GAIA:

1. Possibility to cross-check with **distance** derived based on seismic stellar parameters
2. Combined to spectroscopy, possibility to to cross-check with **mass** derived from asteroseismology

Test 1: Method for deriving asteroseismic distances

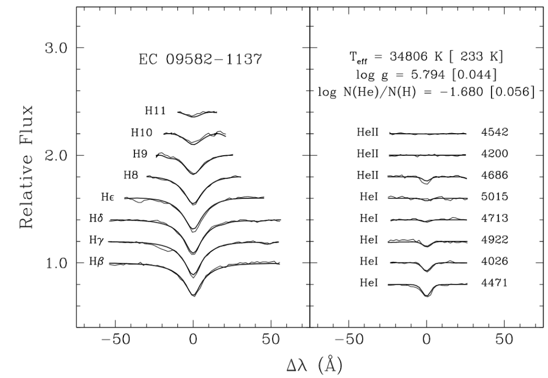


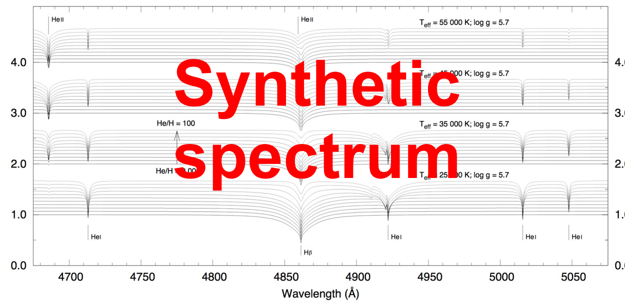
Asteroseismology

- log g
- T_{eff}
- M_*

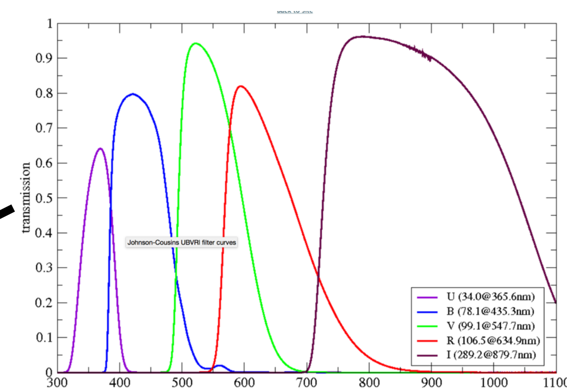
N(He)/N(H)

Spectroscopic fitting





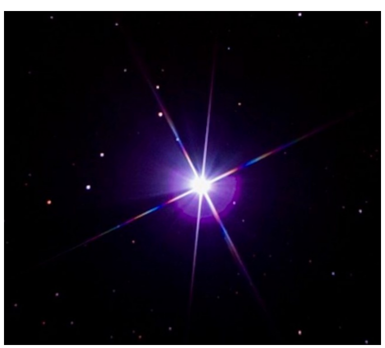
Synthetic spectrum



Absolute magnitude M_a

Bandpass of filter a

Absorption coefficient:
Bandpass+E(B-V)

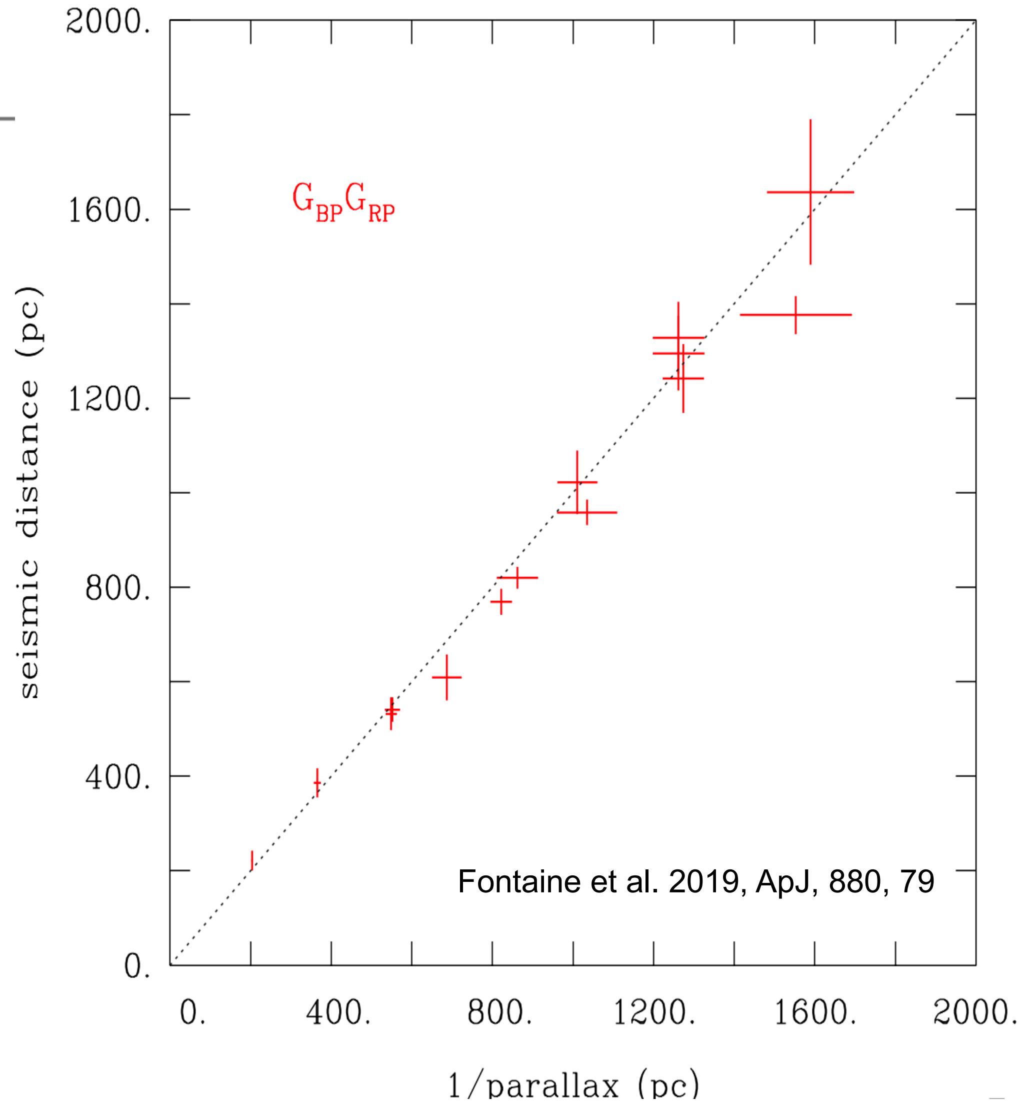


Apparent magnitude a

Asteroseismic distance

Results of test 1: seismic vs GAIA distances

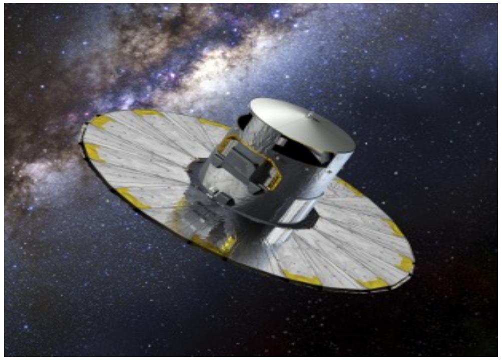
Name	d(Gaia) (pc)	$d(G_{BP}G_{RP})$ (pc)
PG 1047+003	687±37	609±49
PG 0014+067	2794±1037	1812±277
PG 1219+534	549±14	532±35
Feige 48	822±27	769±28
EC 05217−3914	1590±108	1636±154
PG 1325+102	862±51	820±23
PG 0048+091	1058±48	...
EC 20117−4014	587±13	...
PG 0911+456	1035±75	958±27
BAL 090100001	365.6±8.6	386±31
EC 09582−1137	1553±139	1376±40
KPD 1943+4058	1274±51	1242±73
KPD 0629−0016	1011±50	1022±67
KIC 02697388[b]	1262±64	1328±76
KIC 02697388[c]	1262±64	1295±79
PG 1336−018	552±19	541±26
TIC 278659026	203.7±2.1	221±21



All distances agree within 1sigma

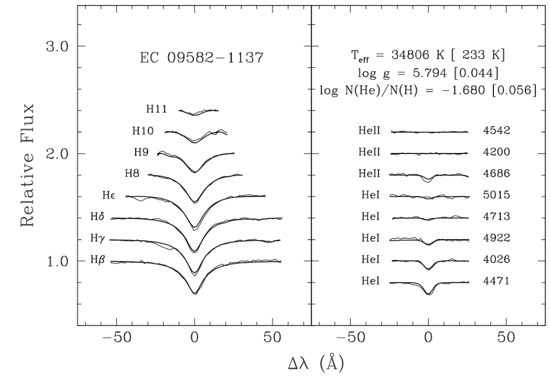
Test 2: Method for deriving "spectroscopic" masses

GAIA



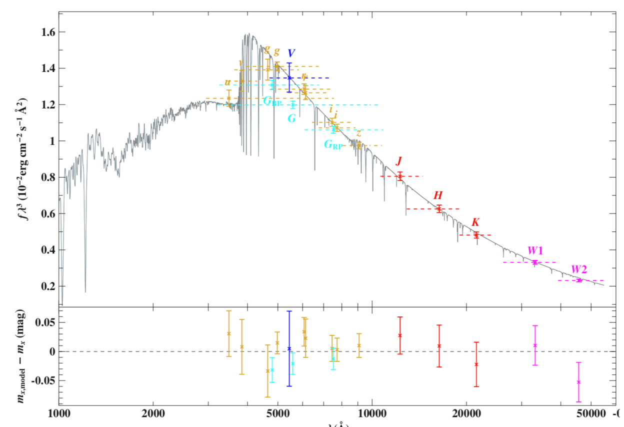
- distance d/parallax ϖ

Spectroscopic fitting



- log g = GM/R^2
- T_{eff}

Spectral energy distribution (SED) fitting to colors (photometry)



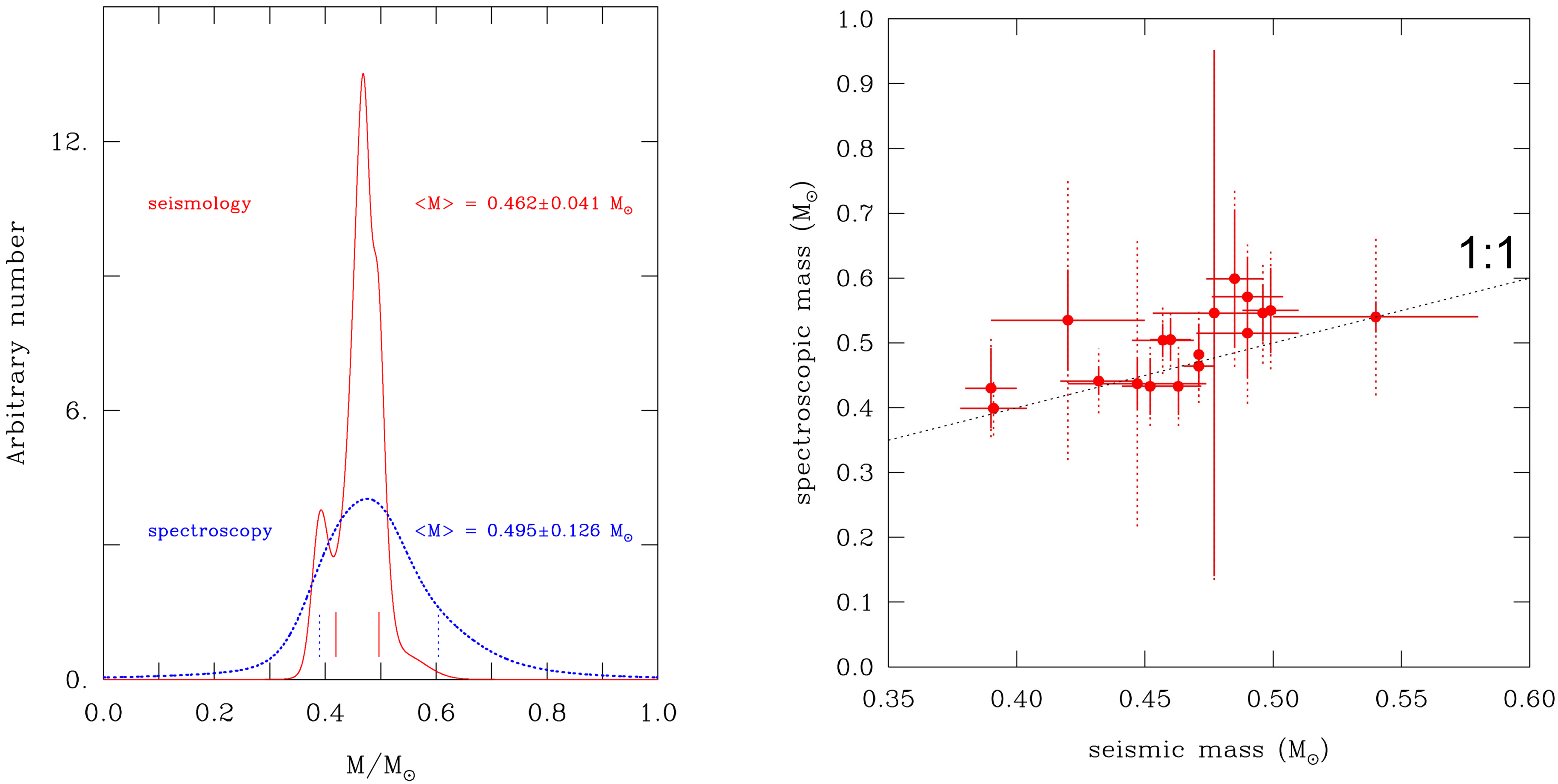
- Angular diameter

θ ≈ 2R/d (if θ<<1)

« Spectroscopic » mass

$$M = g\theta^2 / 4G\varpi^2$$

Results of test 2: seismic vs spectroscopic masses

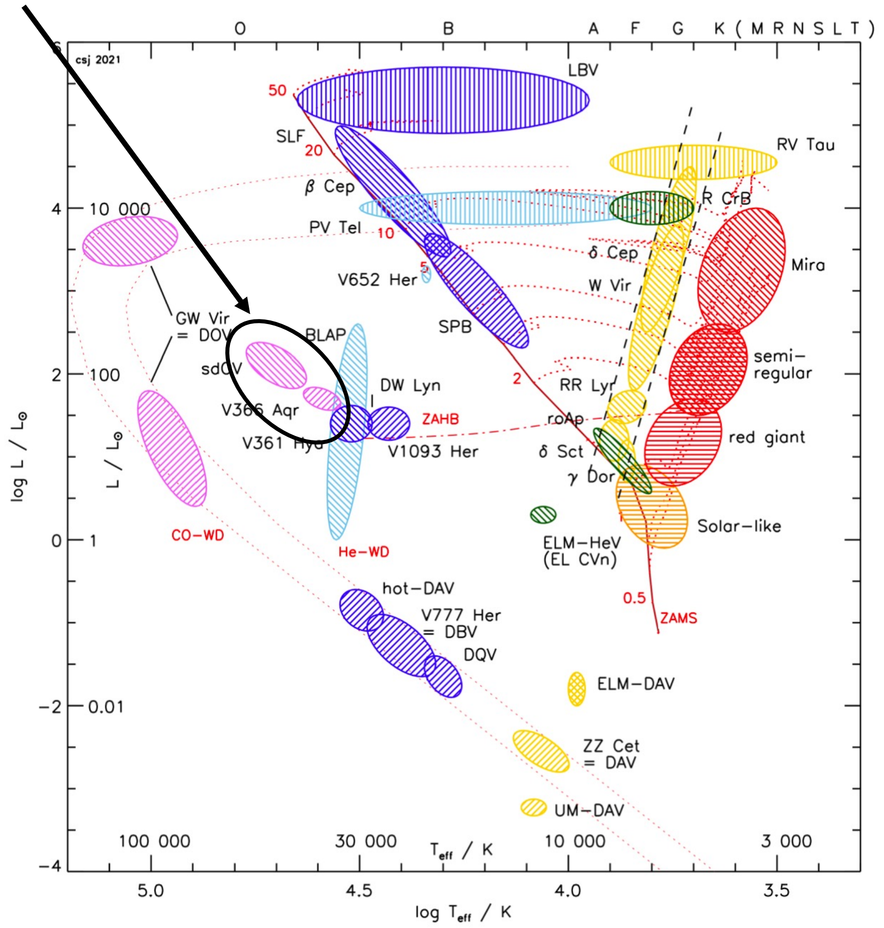


ΔM/M seismology ~ 10%

ΔM/M spectroscopy ~ 25%

Subdwarf O (sdO) stars

Hotter stars (T_{eff} ~ 40,000 – 80,000 K), wide range of log g (4.0-6.2). Some are (would be) post-EHB, some direct post-RGB, some mergers, some post-AGB



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> **Pulsating sdOs in the field:** 3 known (incl. PB 8783) despite extensive search (Rodriguez-Lopez et al. 2007, Johnson et al. 2014)

> A couple of sdOVs identified in **globular clusters** (Omega Cen - Randall et al. 2011, NGC 2808 - Brown et al. 2014)

Very short periods (1-2 minutes), consistent with p-modes (Fontaine et al. 2008)

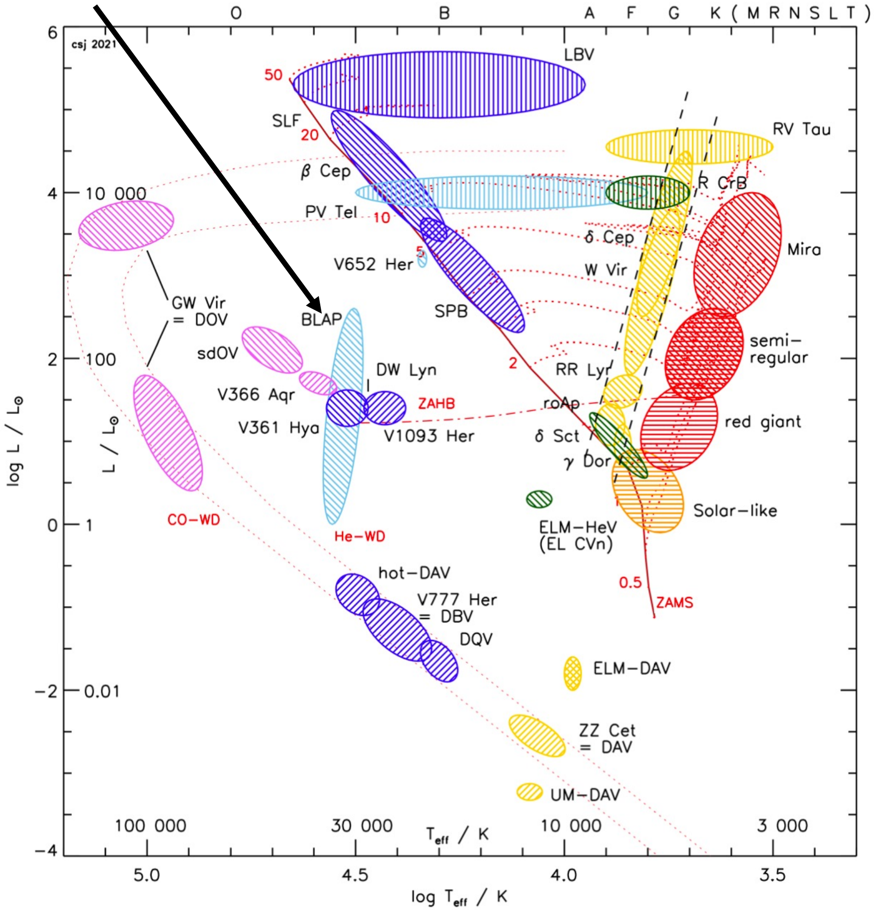
Seismic modeling of sdOVs only tentative (PB8783; Van Grootel et al. 2019)

> V366 Aqr pulsators: 3 g-modes pulsators (periods of ~30 min) in stars with T_{eff} ~ 40,000 K, all intermediate He-rich and extremely enriched in some metal elements.

BLAPs

Blue, Large Amplitude Pulsators, discovered by Pietrukowicz in 2017

- Short-period (3-40 min), radially pulsating (0.2-0.4 mag) H-deficient stars
- Evolutionary path/origin unknown (pre-ELM H-shell burning WDs ? Byrne et al. 2020, 2021) – see Pietrukowicz and Bradshaw's talks



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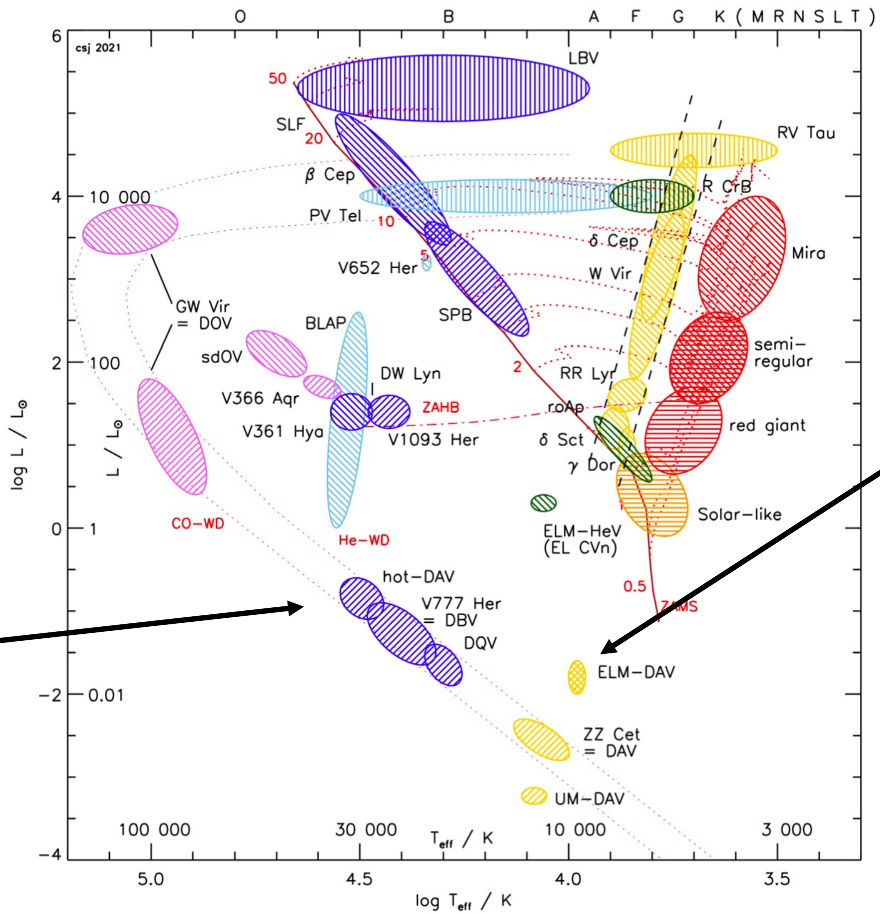
ELM-DAV white dwarfs

Extremely-low-mass (ELM) white dwarfs (He-core)

DA = H-dominant atmospheres (V=variable)

~2-100 min pulsations (g-modes), an extension of the ZZ Ceti instability strip towards low masses (Van Grootel et al. 2013)



+ hot-DAV

See L. Antunes Amaral's talks

D. Kurtz/S. Jeffery

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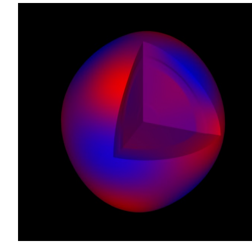


Short-period hot subdwarf pulsators in TESS Southern hemisphere – new and old friends

Valérie Van Grootel

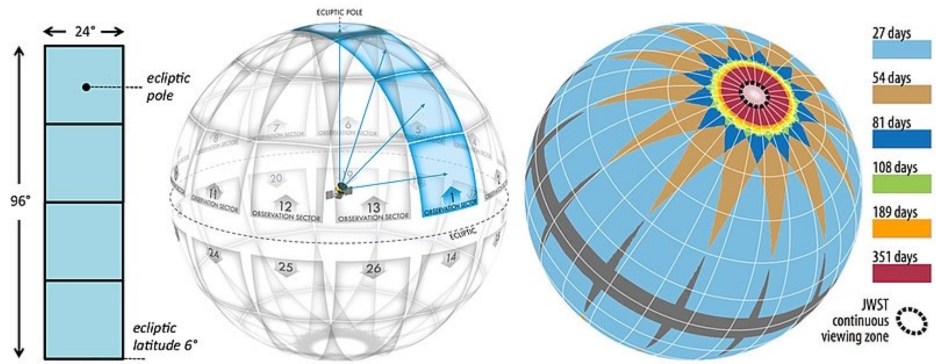
(STAR Institute, ULiège, FNRS)

A. Baran   R.H. Østensen   D. Kilkenny   H. Worters

S. Charpinet, B. Barlow, & TASC WG8 members

The TESS space mission

4 wide-angle cameras (10cm lenses)
2:1 lunar synchronous orbit



Primary mission (2018 - 2019)
- Cycles 1 (south) and 2 (north)
- 2-min cadence data (SC)

Extended mission (2020 - 2022)
- Cycles 3 (south) and 4 (north+ecliptic)
- 2-min and 20s (USC) cadence data

1 cycle = 13 sectors of ~27 days each (= 2 TESS orbits)

Currently in cycle 4

TASC WG8: Evolved compact stars with TESS

~1300 hot subdwarfs observed in primary mission, ~3500 at the end of Cycle 4

Searching for sdBVp in TESS data

- This work: southern hemisphere (Cycle 1+ Cycle 3 + south ecliptic of Cycle 4)

- Importance of 20s cadence data (USC) for p-modes !

- Two independent searches for sdBVp pulsators, by pre-withening technique:
- A. Baran (method: Baran & Koen 2021)
- V. Van Grootel/S. Charpinet with FELIX tool (Charpinet et al. 2010, Zong et al. 2016)

1/ automated search for variations >1500 muHz down to SNR=4.8
2/ individual check if consistent with p-modes pulsations (usually, it's not ☺)

+ check with spectra we have well a hot subdwarf (R. Østensen, D. Kilkenny, H. Worters, P. Németh,…)

RESULTS:
40 p-mode pulsators, confirmed to be hot subdwarfs:

- 17 new detections (10 in SC and 7 in USC)
- 23 known sdBVp (1 in SC and 22 in USC)

New detections

- 7 new sdBVpg (hybrids):
    - TIC 10011123 (3 g-modes and 1 p-modes), 1-sector (S33)
    - TIC 143699381 (3 g- and 2 p-), 1 sector (S13)
    - TIC 366656123 (1 g- and 1 p-), 1 sector (S44)
    - TIC 408147637 (1 g- and 3 p-), 1 sector (S38)
    - TIC 241771689 (6 g- and 35 p-) – seismic modeling potential ! (S38)
    - TIC 273218137 (3 g- and 3 p-), 2 sectors (S10, S37)
    - TIC 169285097 (Sahoo et al. 2020), 37 g- and 6 p-modes, seismic modeling potential ! (S2, S29) (see sdOB9)

- 7 sdBV p-modes only, including 2 with seismic modeling potential (11 p-modes for TIC 295046932 (S39), 10 modes for TIC 409644971 (S13, S39)

- 1 new sdO with p-modes (TIC 387107334), S13. Adding to the three known in the field.

- 4 sdV, need better spectra to determine O/B types

Old friends

- Better data for 4:
  - HE 0230–4323 (Kilkenny et al. 2010), S3
  - EC 09582–1137 (Randall et al. 2009), S35
  - TIC 69298924 (Baran et al. 2011), S44,S45,S46
  - CS 1246 (Barlow et al. 2010, 2011), S38 – TESS detects a g-mode pulsation, so this star is likely a hybrid one.
- No significant improvement for 17:
  - PB8783, sdOV (Van Grootel et al. 2014)
  - EC 03089-6421, sdOV (Kilkenny et al. 2017, 2019);
  - PG 1047+003, TIC 60257911, PG 1315-123, V1405 Ori (K2 data, Reed et al. 2018, 2019, 2020);
  - EPIC 211779126 (K2; Baran et al. 2017)
  - EC 01541-1409 (Randall et al. 2014);
  - EC 11583-2708 (Kilkenny et al. 2006)
  - EC 21281-5010 Kilkenny et al. 2019;
  - PG 1241-084 (Baran et al. 2018);
  - TIC 322009509 (Barlow et al. 2009),
  - EC 20117-4014 (Randall et al. 2006),
  - TIC 366399746 (Boudreaux et al. 2017),
  - 2M 0415+0154 (Oreiro et al. 2009)
  - EC 11275-2504 (Kilkenny et al. 2019)
  - V1835 Ori (Baran et al. 2011)

Conclusions

- TESS is useful and efficient at finding new short-period variables, including a new sdOV.
- Many of these new variables are hybrid pulsators
- Several of these new detections have asteroseismic modeling potential, including 2 hybrid.
- Concerning old friends, 4 have more detected frequencies (but doesn't make them seismic modeling "candidates"), and 17 have no significantly improved pulsation spectra.

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…back at ground-based telescopes to obtain better data on new short-period variables discovered by TESS !!!