Revisiting well-known pulsating B-type stars
the combination of ground-based spectroscopy and multi-colour photometry with TESS

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ABSTRACT Asteroseismology is the study of pulsating stars in which a sufficient number of modes occur such that the stellar interior can be probed from oscillation studies. A better knowledge of the physical processes ongoing in the stellar interior is mandatory to improve our understanding of stellar evolution. Hence, it is of utmost importance to perform detailed studies for a wide variety of pulsating stars. Massive stars deserve special attention as they are potential progenitors of supernovae explosions that enrich the universe with the building blocks of the next generation of stars.

For the project "Gravity-mode Asteroseismology of Stars with a convective core" (GAS), we have selected a sample of 30 bright slowly pulsating B (SPB) stars that we have studied in the past based on time series of ground-based multi-colour photometry and high-resolution spectroscopy. We are now adding the ultra-precise space-based photometric observations gathered with the TESS mission to the archival data to optimize the observed frequency spectrum (both the number and accuracy of the pulsation frequencies) with the ultimate goal to derive their internal rotation profile Ω(r) and the chemical transport D_{mix}(r). These are two uncalibrated physical parameters for models of evolution that have an impact on the further life of stars. The study of gravity modes allows to estimate them, but this has only been done for two SPB stars so far (Moravveji et al., 2015, A&A 580, A27; Moravveji et al., 2016, ApJ, 823, 130). This project has therefore the potential to significantly increase the sample and hence to provide important clues for the improvement of the theoretical description of the internal physics of SPB stars.

In this poster, we present (very) preliminary results obtained for two stars of our sample to highlight the strengths of this approach.

HD74195

SPB star prototype
(Waelkens, 1991, A&A 246, 453)

Only few new spectra after previous study
(De Cat & Aerts,, 2002, A&A 393, 965)

Best ground-based dataset: photometry
(Geneva photometry)

Previously known pulsation frequencies:
f_1 = 0.35475(9) d^{-1}
f_2 = 0.35033(9) d^{-1}
f_3 = 0.34630(9) d^{-1}
f_4 = 0.39864(9) d^{-1}

RESULTS
Frequencies De Cat & Aerts (2002) confirmed
No new frequencies but slightly different f_3
Buoyancy radius Π_0 ~ 10 000 s

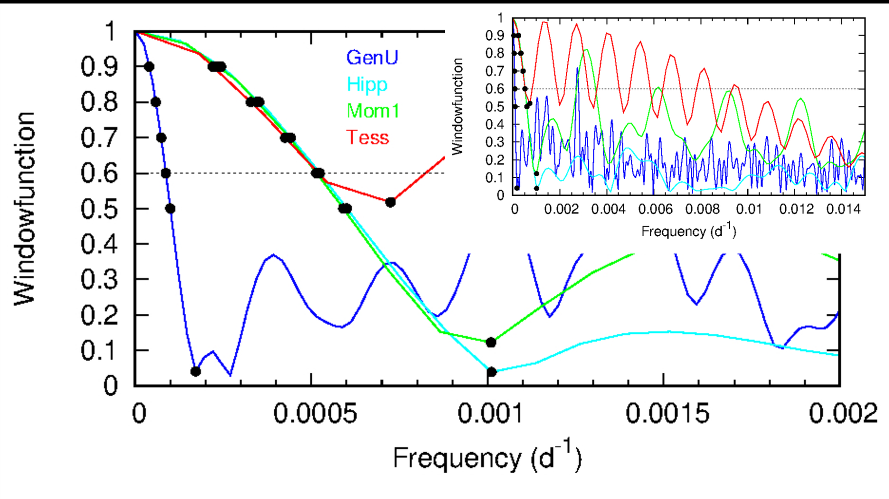

Fig 1a: The weights used for the frequency analysis of HD74195 are based on the half-width of the central peak of the window function at a height of 60% (dotted line). The largest weight is attributed to Geneva photometry (GenU).

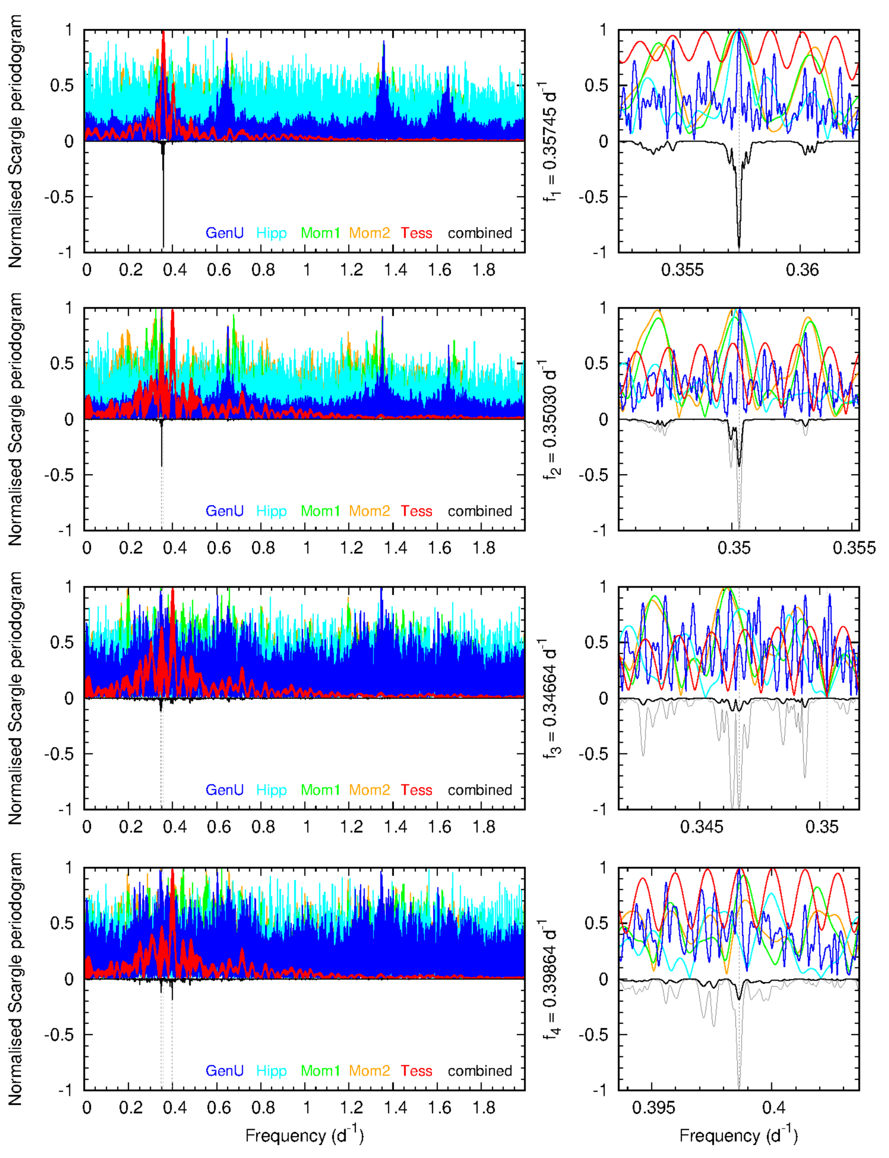

Fig 2a: Different steps for the combined frequency analysis of the time series of HD74195. Top half of the panels: individual, normalized Scargle periodograms. Bottom half of panels: combined Scargle periodograms (normalised version in gray in the right panel to increase the visibility of the peaks). The vertical dotted lines indicate the accepted frequencies (darkest gray for last frequency). No new frequencies are detected for HD74195 but the value for f_3 differs slightly from the value known in the literature (De Cat & Aerts, 2002, A&A 393, 965).

RESULTS from poster 1903 (Timothy Van Reeth)

Alternative frequency analysis

HD74195
(combination GenU and TESS time series)
f_1 = 0.357449(4) d^{-1} f_2 = 0.350328(6) d^{-1}
f_3 = 0.34359(2) d^{-1} f_4 = 0.39863(2) d^{-1}

HD215573
(combination Mom1 and TESS time series)
f_1 = 0.56537(1) d^{-1} f_2 = 0.54394(3) d^{-1}
f_3 = 0.35143(2) d^{-1} f_4 = 0.87747(2) d^{-1}

INPUT

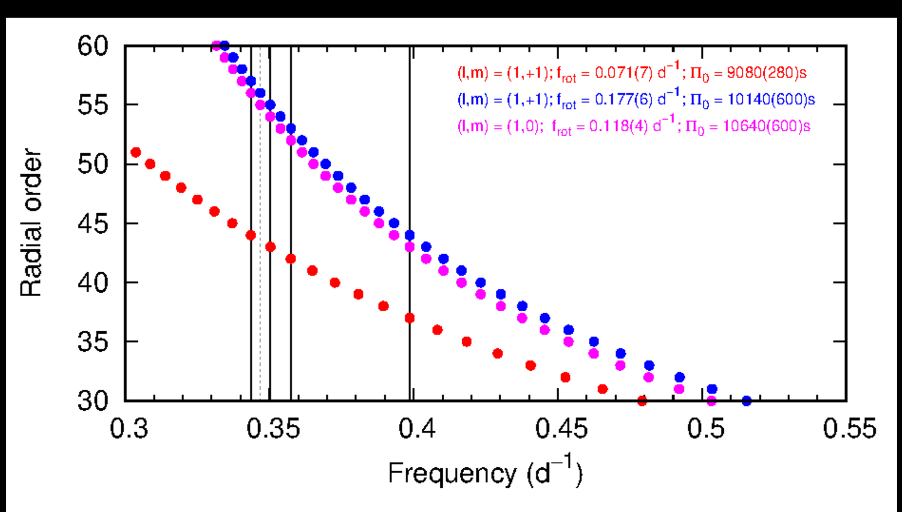

Fig 3a: Modeling of the pulsation frequencies of HD74195. The theoretical frequency patterns for the 3 best fitting models are shown (from top to bottom in the upper right corner). The frequencies that were used during the fitting procedure are indicated by the full vertical lines. The alternative value for f_1 is given by the dashed vertical line and matches perfectly with a mode from the frequency patterns of models 2 and 3.

1 SAMPLE

Slowly pulsating B stars

massive main-sequence stars
(convective core with radiative envelope)

gravity mode pulsators
(high radial order n)

temporal variations in light and line profiles

multiperiodic with periods ranging from ~0.3 to ~3 days

Previously studied with ground-based data

SPB prototypes
(discovery papers: Waelkens, 1991, A&A 246, 453; Waelkens, 1996, A&A 311, 873)

Hipparcos SPB stars
(discovery paper: Waelkens et al., 1998, A&A 330, 215)
(description southern sample: Aerts et al., 1999, A&A 343, 872)
(description northern sample: De Cat et al., 2007, A&A 463, 243)

2 DATA

Ground-based photometry

Geneva photometry (U, B1, B, B2, V1, V, G) → GenU

Ground-based spectroscopy

→ Mom1
Mom2

CAT@LaSilla/1.4-m (411.5-413.5 nm)
CORALIE@LaSilla/1.2-m (390-680 nm)
ELODIE@HauteProvence/1.93-m (390-570 nm)
NEW SOPHIE@HauteProvence/1.93-m (400-680 nm)
FEROS@LaSilla/2.2-m (380-680 nm)
HERMES@LaPalma/1.2-m (380-900 nm)
⇓
Least-Squares Deconvolution profiles
Velocity moments

Space-based photometry

HIPPARCOS mission → Hipp
NEW TESS mission → Tess

3 FREQUENCY ANALYSIS

Individual modified Scargle periodograms
(Horne & Baliunas, 1986, ApJ 302, 757)

Frequency step:
minimum 10 times oversampling of time series with longest time base

Highest frequncy:
fixed to 24 d^{-1}
(requirement Tess data in cycles 1 & 2)

Normalisation:
variations in each time series at same level

+

Weightning scheme (Figs. 1)

Relative to width of central peak of window function
(same % of height for each time series)

Product of weights put at unity
(normalisation of product)

⇓

Combined Scargle periodgram (Figs. 2)

Weighted multiplication
(efficient removal of alias peaks thanks to TESS data)

Selection of highest peak

Acceptance criterion:
amplitude above 4 signal-to-noise level in at least one of the individual Scargle periodograms

Iterative prewhitening of accepted frequencies

4 ASTEROSEISMIC PARAMETERS

Modelling of pulsation frequencies

Assumption:
All pulsation frequencies have the same mode identification (l,m)

Estimation minimum value rotation rate f_{rot}
based on *vsini* measurement from spectroscopy

Theoretical frequency patterns for range of rotation rates f_{rot}
Optimization of buoyancy radius Π_0 and radial orders n
for each (l,m) combination

⇓ χ^2_{red} evaluation

First estimation of asteroseismic parameters (Figs. 3)

HD215573

Southern Hipparcos SPB star
(Aerts et al., 1999, A&A 343, 872)

Many new spectra after previous study
(De Cat et & Aerts,, 2002, A&A 393, 965)

Best ground-based dataset: spectroscopy
(line profile variations)

Previously known pulsation frequencies:
f_1 = 0.5654(6) d^{-1}
f_2 = 0.5439(6) d^{-1}

RESULTS
Frequencies De Cat & Aerts (2002) confirmed
Up to five new candidate frequencies detected
Buoyancy radius Π_0 ~ 14 000 s

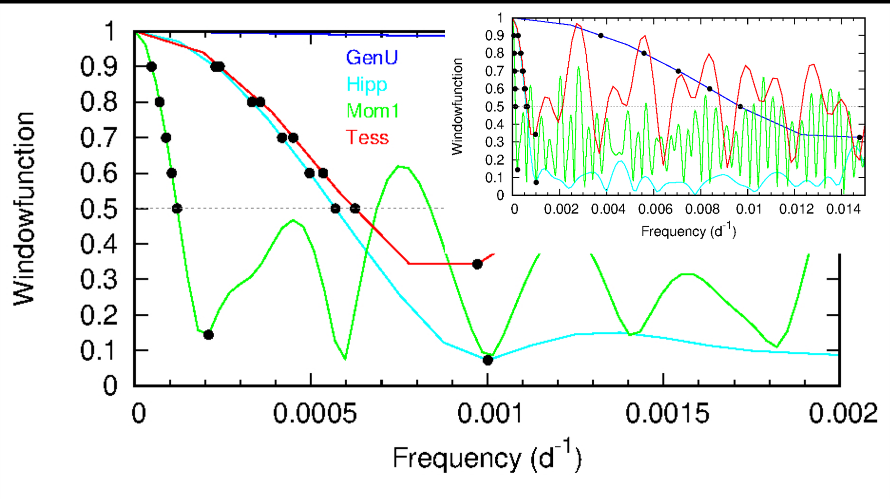

Fig 1b: The weights used for the frequency analysis of HD215573 are based on the half-width of the central peak of the window function at a height of 50% (dotted line). The largest weight is attributed to the spectroscopic data (Mom1 & Mom2).

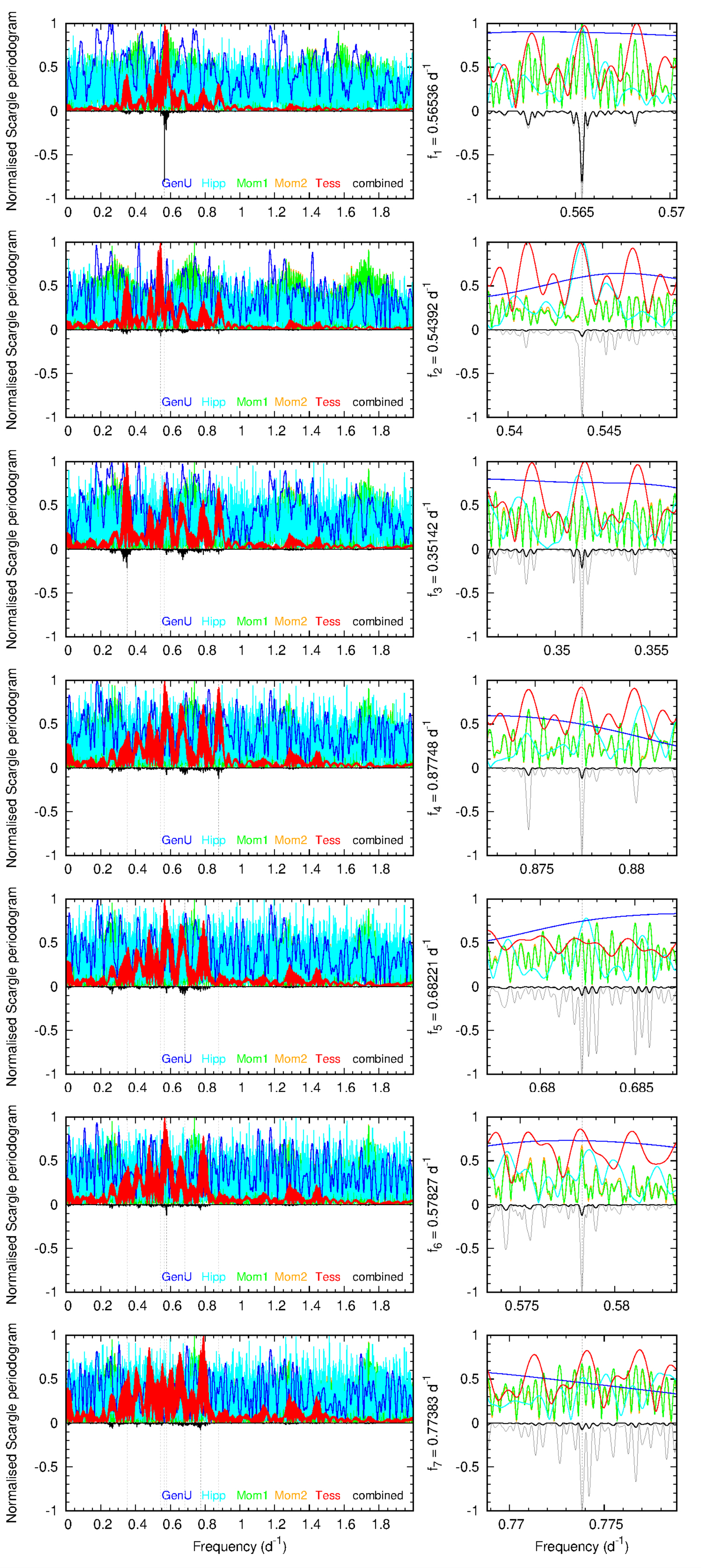

Fig 2b: Same as Fig. 2a but for HD215573. The frequencies f_1 and f_2 as known in the literature are confirmed (De Cat & Aerts, 2002, A&A 393, 965) and up to five new candidate frequencies are detected.

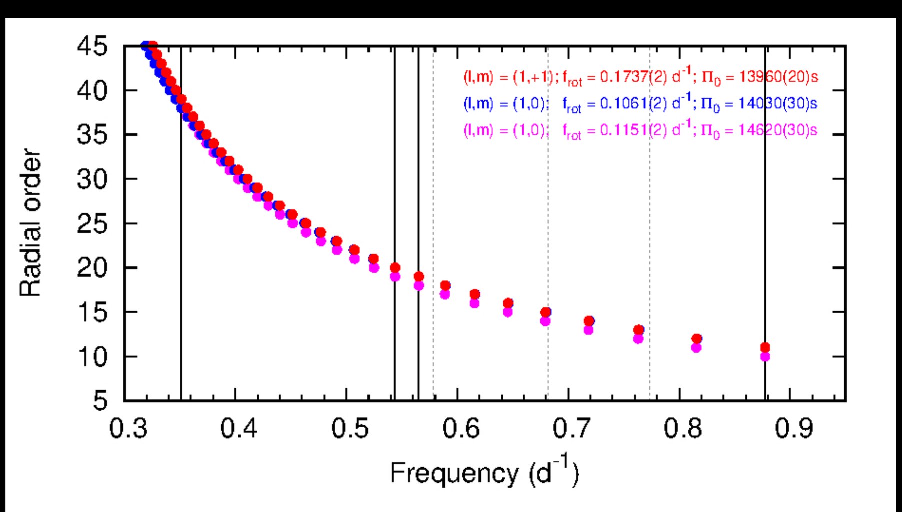

Fig 3b: Same as Fig. 3a but for HD215573. The candidate frequencies that were not taken into account during the modeling are given by the dashed vertical lines. They are in good agreement with the theoretical frequency patterns.

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