Time Allocation Committee for
MPG time at the ESO 2.2m-telescope
c/o MPI für Astronomie
Königstuhl 17
D-69117 Heidelberg / Germany

Application No.	
Observing period	October 2020
Received	

APPLICATION FOR OBSERVING TIME

from [X] MPIA [ ] MPG institute [ ] other

1. Telescope: 2.2-m [X]

2.1 Applicant

Conny **Aerts**	MPIA & IoA, KU Leuven
Name	Institute
Königstuhl 17	D-69117 Heidelberg
street	ZIP code - city
CAERTS	conny.aerts@kuleuven.be
ESO User Portal username	e-mail

2.2 Collaborators

S. Gebruers & H.W. Rix	MPIA
name(s)	institute(s)
A. Tkachenko & L. IJspeert	KU Leuven
name(s)	institute(s)

2.3 Observers

J. Mombarg	C. Johnston
name	name

By specifying the names under item 2.3 it is obligatory to also send out these observers to La Silla, if required. Correspondence on the rating of this application will be sent to the applicant (P.I.) as quoted under 2.1 above.

3. Observing programme: Category: D

Title : **The unique synergy of binarity and asteroseismology in OB stars**

Abstract : Recent high-precision space photometry has made it strikingly clear that large discrepancies occur between the theory of stellar structure and asteroseismic observations, pointing to poor understanding of stellar interiors. Our project aims to resolve this problem by focusing on the synergy between binarity and asteroseismology for stars with masses above $3\,M_\odot$. The unique conditions to carry out this analysis are met now, with *TESS* data being available, and the accumulation of follow-up spectroscopic data. As announced in our initial FEROS proposal last year, we request a dedicated observing programme to follow-up stars found to be eclipsing binaries. We aim to assemble accurate spectroscopic constraints to exploit the strengths of both binary and asteroseismic modelling in these new binary systems.

4. Instrument: [ ] WFI [X] FEROS [ ] GROND

5. Brightness range of objects to be observed: from 6.1 to 10.4 V-mag

6. Number of hours:

applied for			already awarded	still needed
86.94			none	none
no restriction	grey	dark		

7. Optimum date range for the observations: .... 01.10.2020 – 31.03.2021
Usable range in local sideral time LST: .... 0:50h – 10:50h

Astrophysical context

Stellar evolution is driven by the physical processes at work within the interiors of stars. Understanding these processes is key for the theory of stellar structure and evolution, but also in the areas of study that rely on its outcome, such as galactic evolution and cosmological nucleosynthesis (e.g. Abohalima & Frebel 2018). The interior mixing processes of stars are poorly understood. Therefore, in numerical computations of stellar evolution, a variety of mixing phenomena is included, all having separate free parameters (e.g. Salaris & Cassisi 2017). In fast evolving OB stars with convective cores, mixing near the stellar core leads to more fuel for nuclear burning, increasing the lifetime of the star and altering the way the star evolves. Many of these stars show gravity-mode oscillations in their light curves, making them perfect candidates for asteroseismic analysis of their interiors. The highly suitable space based photometry of the *Kepler* mission covers few OB stars. Now, the perfect conditions are met to expand on this with *TESS* observing bright OB stars.

OB stars are often found in binaries, enabling us to exploit the synergy between FEROS high-resolution spectroscopy and the *TESS* space-based photometry as well as the powerful synergy between binarity and asteroseismology to unveil the mixing properties in the interiors of OB-type stars and simultaneously assess the role of tidal interaction in mixing processes. Johnston et al. (2019 a,b) demonstrated the added benefit of having model-independent mass ratio measurements from spectroscopic binaries with double lined spectra (SB2s) to inform asteroseismic modelling, on top of the constraint that stars in binaries have the same age and initial chemical composition (see Fig. 1). Selecting eclipsing binaries (EBs) from the *TESS* photometry is even more powerful, as EB+SB2s provide individual model-independent masses and radii. Non-pulsating EBs are required targets in assessing the role of pulsational mixing as an important interior process (or not).

Immediate aim

Analogous to our previous FEROS campaign, high-resolution (R≥40 000), high signal-to-noise ratio (S/N≥100) spectroscopic observations are essential to address the above science questions and to meet our immediate goals. The following information will be extracted from the requested spectra of short period (P≤10 days) EB systems:

1. *8 radial velocity measurements* covering the full orbital phase for accurate determination of the orbital parameters and disentangled spectra of binary components;

2. *atmospheric parameters*: precise $T_{\rm eff}$ measurements to place stars in the HR diagram and delimit the parameter space for binary (and asteroseismic) modelling, and measurements of surface abundances.

We take a data-driven approach to estimate the following quantities from asteroseismic and binary modelling: 1) *the interior mixing profile as function of radius:* $D_{mix}(r)$ and 2) *the individual masses* $M_\star$ *and radii* $R_\star$. This is done for a representative sample (in terms of mass, metallicity and rotation) of OB binary stars discovered as EB/SB from TESS data and our 2019-2020 FEROS data in the previous program

Previous work

Coherent gravity-mode oscillations have been found in faint core-hydrogen burning stars with $\mathrm{M} > 3\,\mathrm{M}_\odot$ (e.g. Pedersen 2020). However, synergetic asteroseismic and binary modelling has rarely been achieved for OB stars in the space asteroseismology era, due to lack of spectroscopic monitoring. Schmid & Aerts (2016) showed the proof of concept of iterative binary and asteroseismic modelling in EBs with pulsational signal. Our recent analysis of the *TESS* catalogue has revealed new OB eclipsing binaries, many of which show pulsations (an example is shown in Fig. 2). Since their discovery, *the targets of this FEROS proposal have been analysed and ranked in order of their asteroseismic potential as well as their potential for binary modelling. We request multiple epochs for 30 short period OB eclipsing binaries (*$P_{\rm orb} < 10$ *days), either identified as binary in our previous FEROS programme or newly discovered in the TESS catalogue.*

Layout of observations

The choice of resolving power and S/N is dictated by the requirements to detect spectral lines of the secondary in systems where it contributes ≤10% of the total light and to maintain high S/N of the primary in systems where light contributions are more equal. Two more requirements are to achieve a precision of 3% in $T_{\rm eff}$ as proper constraint for high-precision asteroseismic modelling (Moravveji et al. 2016) and 0.15 dex in individual abundances. The selected short periods will allow us to strategically cover the full orbital period of these targets. The Leuven team has ample experience with the coupling of FEROS spectra to photometric (asteroseismic) space data.

Strategic importance for MPIA

C. Aerts is an external MPS member of MPIA, with the aim to bridge the fields of asteroseismology and galactic structure and evolution. As stated in the previous FEROS application **this new proposal will push the integration forward, focusing on binarity and its synergy with asteroseismology**. Joint MPIA-KU Leuven PhD student S. Gebruers and KU Leuven PhD student L. IJspeert will jointly be involved in analysing the data, and the results will be of paramount importance to the completion of their PhD projects.

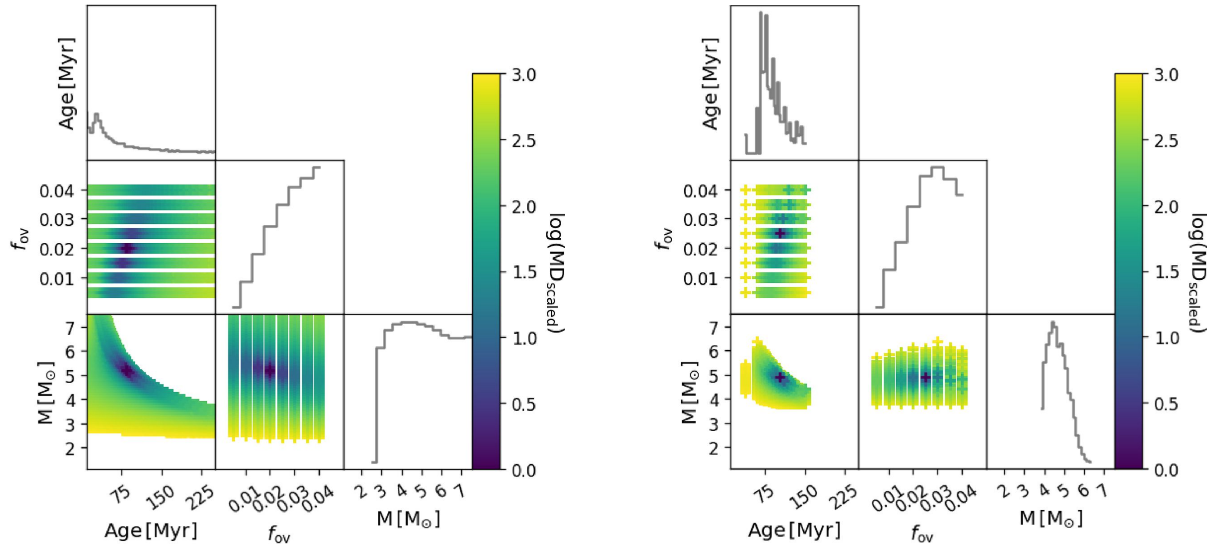

Figure 1: The correlation structure for the age, mass and near-core mixing (f_{ov}) for a grid of models, where the colour indicates the value of the merit function for the star KIC 4930889 A. Only models with a merit function below the 50th percentile are shown. In the left panel, the star is treated as being single, and in the right panel, it is treated as the primary of an SB2. The binary case greatly reduces both the mass-age and mass-mixing degeneracies. Figure reproduced from Johnston et al. (2019a).

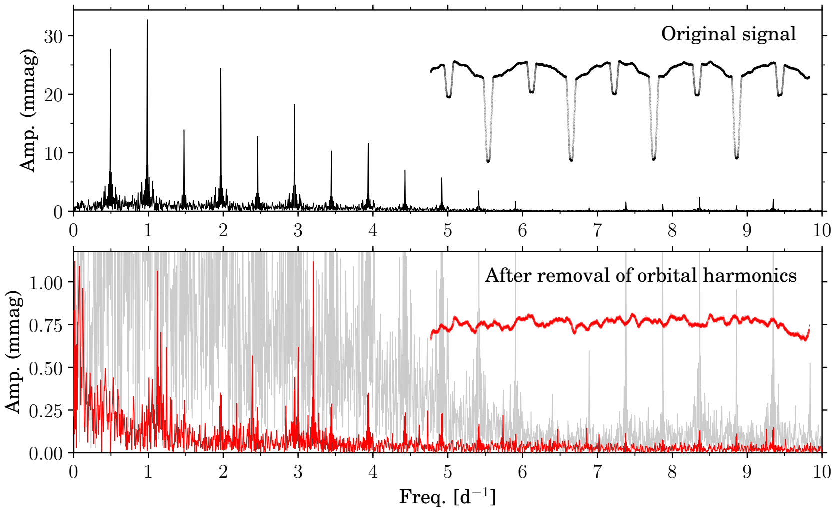

Figure 2: The upper panel shows the Fourier decomposition of the 1 yr *TESS* light curve of the eclipsing binary B2/3V star HD31407, showing many multiples of the orbital frequency $f = 0.49195$ d^{-1}. The inset shows a 10 d cut-out of the light curve. The bottom panel shows the periodogram of the residual light curve (red) after removing 50 harmonics of the orbital frequency from the original signal (light grey). Residual variability intrinsic to one (or two) of the components is still present. The amplitude of the inset light curves is not to scale. Figure courtesy of S. Burssens, unpublished.

9. Objects to be observed

(Objects to be observed with high priority should be marked in last column)

Designation	α (2000)	δ (2000)	magnitude in spectral range to be observed	priority
HD 46792	$6^{h}\,31^{m}\,10^{s}.64$	$-61^\circ\,52'\,46''$	6.1	1a
HD 79365	$9^{h}\,12^{m}\,14^{s}.25$	$-42^\circ\,35'\,32''$	9.0	1b
HD 52349	$7^{h}\,0^{m}\,3^{s}.90$	$-21^\circ\,48'\,17''$	9.4	1b
TYC 8155-1212-1	$8^{h}\,47^{m}\,55^{s}.73$	$-47^\circ\,41'\,45''$	9.7	1b
HD 300344	$9^{h}\,57^{m}\,27^{s}.07$	$-54^\circ\,56'\,33''$	10.3	1b
HD 92741	$10^{h}\,41^{m}\,12^{s}.35$	$-59^\circ\,58'\,25''$	7.2	1b
HD 82110	$9^{h}\,28^{m}\,1^{s}.02$	$-54^\circ\,34'\,10''$	9.0	1b
HD 91141	$10^{h}\,30^{m}\,5^{s}.56$	$-54^\circ\,51'\,46''$	9.4	1b
HD 309317	$11^{h}\,56^{m}\,5^{s}.26$	$-62^\circ\,47'\,22''$	9.9	1b
HD 100737	$11^{h}\,35^{m}\,1^{s}.54$	$-63^\circ\,5'\,15''$	10.0	1b
HD 84493	$9^{h}\,44^{m}\,2^{s}.61$	$-51^\circ\,22'\,3''$	7.7	1b
HD 51981	$6^{h}\,58^{m}\,47^{s}.76$	$-17^\circ\,37'\,56''$	8.2	1b
HD 97966	$11^{h}\,15^{m}\,11^{s}.77$	$-59^\circ\,24'\,58''$	8.9	1b
HD 68340	$8^{h}\,10^{m}\,37^{s}.95$	$-33^\circ\,3'\,24''$	9.1	1b
HD 104233	$12^{h}\,0^{m}\,6^{s}.88$	$-63^\circ\,49'\,8''$	9.3	1b
HD 91154	$10^{h}\,30^{m}\,15^{s}.37$	$-54^\circ\,2'\,13''$	9.5	1b
HD 121776	$14^{h}\,0^{m}\,5^{s}.68$	$-67^\circ\,38'\,30''$	9.7	1b
HD 80627	$9^{h}\,18^{m}\,18^{s}.40$	$-59^\circ\,25'\,36''$	10.2	1b
HD 304241	$11^{h}\,24^{m}\,2^{s}.02$	$-58^\circ\,23'\,40''$	10.2	1b
TYC 8149-3211-1	$8^{h}\,19^{m}\,57^{s}.21$	$-46^\circ\,32'\,58''$	10.3	1b
HD 62738	$7^{h}\,43^{m}\,43^{s}.38$	$-41^\circ\,23'\,9''$	8.7	2
TYC 8151-937-1	$8^{h}\,40^{m}\,51^{s}.80$	$-45^\circ\,30'\,19''$	9.1	2
HD 75872	$8^{h}\,50^{m}\,58^{s}.14$	$-44^\circ\,25'\,9''$	9.5	2
TYC 8972-249-1	$11^{h}\,37^{m}\,7^{s}.67$	$-61^\circ\,48'\,4''$	10.0	2
HD 67025	$8^{h}\,4^{m}\,19^{s}.35$	$-42^\circ\,58'\,43''$	10.2	2
HD 66235	$8^{h}\,0^{m}\,35^{s}.41$	$-45^\circ\,20'\,13''$	7.7	2
HD 28913	$4^{h}\,31^{m}\,59^{s}.79$	$-33^\circ\,53'\,55''$	8.1	2
HD 66673	$8^{h}\,3^{m}\,33^{s}.52$	$-28^\circ\,22'\,59''$	8.3	2
HD 297793	$10^{h}\,7^{m}\,48^{s}.90$	$-49^\circ\,16'\,11''$	10.0	2
TYC 8514-106-1	$5^{h}\,17^{m}\,0^{s}.41$	$-55^\circ\,55'\,26''$	10.4	2

10. `Justification of the amount of observing time requested:`

We request at least 8 spectra per target to optimally derive the 7 free parameters of the orbital fit (K_1, K_2, a, e, i, ω, γ) for each selected O or B type binary with short orbital period ($P_{\rm orb} < 10$ d). We checked the ESO archive and eliminated the stars with HARPS and/or UVES spectra that already meet our needs. Targets were selected to have at least two consecutive sectors of *TESS* observations available, for a total minimum time-base of about 60 days to ensure sufficient oscillation frequency precision for asteroseismology. SB1 systems are included as it is very likely that 8 epochs of high quality spectroscopic data will enable the detection of spectral lines of the secondary, thus turning them into SB2s. We prioritise the targets based on previously obtained spectroscopic information (SB1/SB2) and on the information in the photometric light curves from *TESS* (eclipses/ pulsations), using the following scheme:

(1a) eclipsing binaries with pulsations that were identified as SB1 or SB2;
(1b) eclipsing binaries with pulsations;
(2) eclipsing binaries not pulsating in the photometry.

In all groups, targets with clear secondary eclipses are prioritised. Within the pulsating groups a subdivision is made according to their asteroseismic information (i.e. number of frequencies, identified pulsation patterns, and quality of the photometric data) and finally these priority groups are organised in V magnitude. We include stars up to 11th magnitude over a large area on the sky to cover different Galactic metallicity regimes, which is crucial to test binary (Sana et al. 2012) and pulsation driving physics (Salmon et al. 2012).
To calculate the total observing time, our target list has been grouped in bins of width 1 magnitude in V. The total amount of observing time (including overheads) is computed by multiplying the number of stars by the total observing time (including overhead) of a star representative of the center of the bin. We aim at S/N≈100 and according to the FEROS Exposure Time Calculator (Version P104.1), exposure times of 60 sec (Vmag = 6.5), 120 sec (Vmag = 7.5), 300 sec (Vmag = 8.5), 600 sec (Vmag = 9.5) and 1500 sec (Vmag = 10.5) are required to meet our S/N criterion. The total overhead per exposure is 570 sec, including 1) 360 sec for the telescope pointing, target acquisition and centering on fibre; 2) 60 sec for the FCU + Adapter setup; 3) 150 sec for slow, high-gain read-out (FEROS User Manual, Issue 78.0, Date 15/10/2006).
This results in a **total time request** for the programme of **86.94 hours** of observing time (including overheads) for the close multi-epoch observations of all targets (30 stars).

11. `Constraints for scheduling observations for this application:`

Covering the orbital phase of all short-period binaries is feasible within two 10-d observing runs with 8 spectra.

12. `Observational experience of observer(s) named under 2.3:`
`(at least one observer must have sufficient experience)`

All listed observers are experienced in high-resolution spectroscopy with the FEROS spectrograph and/or the HERMES spectrograph attached to the 1.2-m Leuven Mercator Telescope at La Palma Observatory, whose design and use is based on the FEROS spectrograph.

13. `Observing runs at the ESO 2.2m-telscope (preferably during the last 3 years)`
`and publications resulting from these`

Telescope	instrument	date	hours	success rate	publications
2.2m	FEROS	Dec 2019 to Feb 2020	122.5	97%	Ongoing analysis
This earlier FEROS programme forms the current data set of joint Leuven-MPIA PhD student S. Gebruers, and of Leuven PhD students S. Burssens and L. IJspeert. The binary nature of the stars in this proposal was assessed from the data set by means of visual inspections and radial-velocity measurements. Proper extraction of the spectroscopic parameters needed for asteroseismic modelling is currently ongoing.					

14. References for items 8 and 13:

[1] Abohalima, A. Frebel, A. (2018); *JINAbase — A Database for Chemical Abundances of Metal-poor Stars*; ApJS, **238**, 21

[2] Johnston, C., Tkachenko, A., Aerts, C., et al. (2019a); *Binary asteroseismic modelling: isochrone-cloud methodology and application to Kepler gravity mode pulsators*; MNRAS, **483**, 1231

[3] Johnston, C., Aerts, C., Pedersen, M. G., et al. (2019b); *Isochrone-cloud fitting of the extended main-sequence turn-off of young clusters*; A&A, **632**, A74

[4] Moravveji, E., Townsend, R. H. D., Aerts, C. et al. (2016); *Sub-inertial Gravity Modes in the B8V Star KIC 7760680 Reveal Moderate Core Overshooting and Low Vertical Diffusive Mixing*; ApJ, **823**, 130

[5] Pedersen, M. G. (2020); *Interior Rotation, Mixing, and Ages of a Sample of Slowly Pulsating B stars from Gravity-Mode Asteroseismology*; PhD Thesis, KU Leuven, Belgium

[6] Salaris, M., Cassisi, S. (2017); *Chemical element transport in stellar evolution models*; Royal Society Open Science, **4**, id. 170192

[7] Salmon, S., Montalbán, J., Morel, T., et al. (2012); *Testing the effects of opacity and the chemical mixture on the excitation of pulsations in B stars of the Magellanic Clouds*; MNRAS, **422**, 3460

[8] Sana, H., de Mink, S. E., de Koter, A., et al. (2012); *Binary Interaction Dominates the Evolution of Massive Stars*; Science, **337**, 444

[9] Schmid, V. S., Aerts, C. (2016); *Asteroseismic modelling of the two F-type hybrid pulsators KIC 10080943A and KIC 10080943B* ; A&A, **592**, 15

Tolerance limits for planned observations:

maximum seeing:	2.5″	**minimum transparency:**	50%	**maximum airmass:**	2.0
photometric conditions:	no	**moon: max. phase / ∠ :**	0.8/30°	**min. / max. lag:**	14/30 nights