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 2021
Received	

APPLICATION FOR OBSERVING TIME

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

1. Telescope: 2.2-m [X]

2.1 Applicant	Sarah **Gebruers** (Name)	MPIA & IoA, KU Leuven (Institute)
	Königstuhl 17 (street)	D-69117 Heidelberg (ZIP code - city)
	sarahg (ESO User Portal username)	sarah.gebruers@kuleuven.be (e-mail)
2.2 Collaborators	H. -W. Rix, M. Xiang, E. Zari (name(s))	MPIA (institute(s))
	A. Tkachenko (name(s))	Institute of Astronomy, KU Leuven (institute(s))
2.3 Observers	S. Gebruers (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 : **A gold-standard sample of BA(F)-stars with FEROS spectra**

Abstract : We need good spectral modelling for stars across the CMD to constrain theoretical models of stellar and galactic structure and evolution. Large-scale all-sky spectroscopic surveys such as LAMOST and SDSS-V are obtaining spectra for millions of stars, but at low resolution. To derive precise stellar parameters, these low-resolution spectra must be calibrated with data from high-resolution spectra. Spectral 'gold standards' exist for cool (GK) stars, but not for the hotter BA(F) stars. Here we propose to use FEROS to create the first such sample of spectra and derive high-precision atmospheric parameters and chemical composition for 96 BA(F) stars with Gaia parallaxes better than 10% and TESS data.

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

5. Brightness range of objects to be observed: from 8 to 12 Gmag

6. Number of hours:

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

7. Optimum date range for the observations: .... 01.12.2021 – 01.03.2022
Usable range in local sideral time LST: .... 1:00h – 13:00h

Astrophysical context

Large spectroscopic surveys, such as SDSS-V and LAMOST, are obtaining low-resolution spectra for millions of stars over the whole sky. These spectra and their stellar parameters and abundances are being used in different fields of astronomy such as stellar physics, star-formation physics and Galactic research. Low-resolution spectra are informative but tricky to model because many of the spectral lines are blended. Therefore, the parameters derived from low-resolution spectra must be calibrated with a sample of reference stars for which also high-resolution spectra are available, with precise and accurate atmospheric parameters and surface abundances. Such a reference sample should have information from high-precision (TESS) space-based photometry and (Gaia) astrometry such that the surface parameters from spectroscopy can be better constrained. Additionally, photometry delivers information about interior properties of stars (through asteroseismology) and/or about their true surface rotation rates (from rotational modulation), while distances to stars can be obtained from Gaia, all of which can thus be calibrated as well. Such 'golden samples' exist or are being constructed for cool stars (FGK) [1] and for the hottest stars (O and early B) [1,2]. But BA(F) stars have been ignored thus far. This proposal aims to fill this spectral type/stellar mass gap. We require high-resolution, high signal-to-noise FEROS spectra for a sample of 96 BA(F) stars (7000 K $< T_{\mathrm{eff}} <$ 25 000 K and $1.3\,\mathrm{M}_{\odot} <$ mass $< 9\,\mathrm{M}_{\odot}$) that are targets of the SDSS-V and LAMOST surveys, and for which there are Gaia astrometry data available, along with variability information from TESS photometry. We will derive stellar parameters and abundances for this gold sample from the FEROS spectra, space-based photometry and astrometry, and then use a neural net approach for 'label transfer' [2] to all low-resolution spectra of BA(F) stars in the SDSS-V and LAMOST surveys, with a precision approaching that of the golden sample (Xiang et al., in prep.).

Immediate aim

We have constructed a sample of 96 BA(F) stars by cross-matching the LAMOST catalogue of some 300 000 OBA stars constructed by us (Xiang et al., in prep.) with the SDSS-V target catalogue [3] and subsequently selecting targets with Gmag < 12, precise Gaia parallaxes ($\sigma_{\varpi}/\varpi < 0.1$) and TESS light curves that show photometric variability that we attributed to either stellar pulsations or rotational modulation.

With the FEROS spectrograph we can obtain high-resolution (R > 40 000) and high signal-to-noise (S/N > 150) spectra for these BA(F) golden sample stars located in the Southern Hemisphere ($\delta < +10°$). For each target we need at least two observations separated by more than a month in order to observe radial velocity differences between the different epochs and unravel possible binary systems. High S/N spectra are required to be able to derive precise atmospheric parameters (T_{eff}, $\log g$, $v \sin i$ and [M/H]) and surface abundances [4]. For hot and evolved stars the abundance analysis will be done in NLTE. The precision with which these parameters and abundances are obtained from the FEROS spectra will define how precise they can be derived for low-resolution spectra. From Figs. 1 and 2 we expect that the precision of the parameters will more than double for high- versus low-resolution spectra and the accuracy will increase as well, especially for $v \sin i$. The parameters and abundances will be used as labels in a data-driven neural net approach to predict these quantities for all BA(F) stars in the SDSS-V and LAMOST surveys.

Previous work

More and more spectral analysis approaches, such as The Cannon [5] and The Payne [6], are using machine learning techniques to derive stellar parameters from spectroscopic data. In recent work by Straumit et al. (in prep.), The Payne has been adapted to also include spectrum continuum normalisation. This allows to homogeneously analyse whole samples of spectroscopic data without having to manually normalise the spectra, which influences the shape of spectral lines and causes wrong stellar parameter predictions. This updated version of The Payne has been successfully applied to a sample of 111 F- and B-type stars observed with the high-resolution HERMES spectrograph attached to the Mercator telescope in [7]. Currently we are generalising the framework such that it can be used for hot stellar spectra at any resolution.

Layout of observations

For each target we require two epochs maximally separated in time and at least by one month to detect RV differences and probe for binarity. The multiple epochs of single stars and SB1 systems will be shifted to the same RV and co-added to obtain spectra with higher S/N. We request co-added spectra with S/N > 150 to derive T_{eff} with a precision of < 3%, $\log g$ with an uncertainty ~ 0.15 dex, $v \sin i \sim$ 5-10% and individual abundances precisions of ~ 0.15 dex for H, He, C, N, O, Mg, Si, S and Fe for B-type stars and for H, C, Na, Mg, Si, Ca, Fe and Ni for A(F)-type stars.

Strategic importance for MPIA

MPIA has leading involvement in the SDSS-V and 4MOST spectroscopic surveys. The research based upon these surveys will need to rely on the golden sample observations that will be obtained with this proposal. The requested data is also a central part of the PI's PhD research.

[1] https://ullyses.stsci.edu/
[2] https://massivestars.org/xshootu/

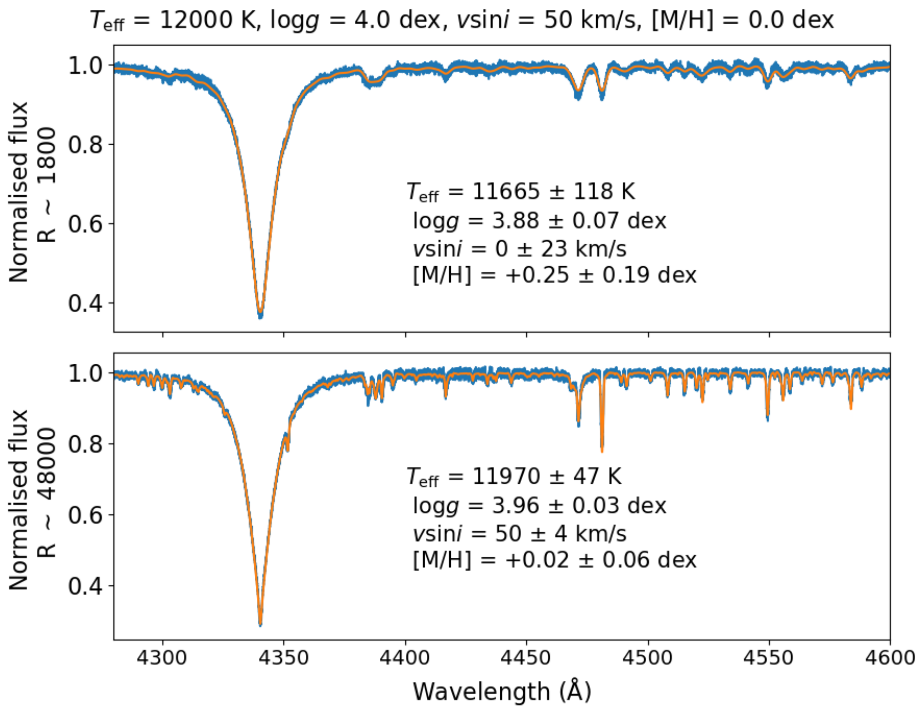

Figure 1: **Spectral resolution effects:** synthetic spectra computed with the stellar parameters given in the title for R $\sim$ 1800 (*top*) and R $\sim$ 48 000 (*bottom*) at S/N $\sim$ 150 are plotted in blue. The best fitting spectra from The Payne are shown in orange and the corresponding best fitting parameters are given in each panel.

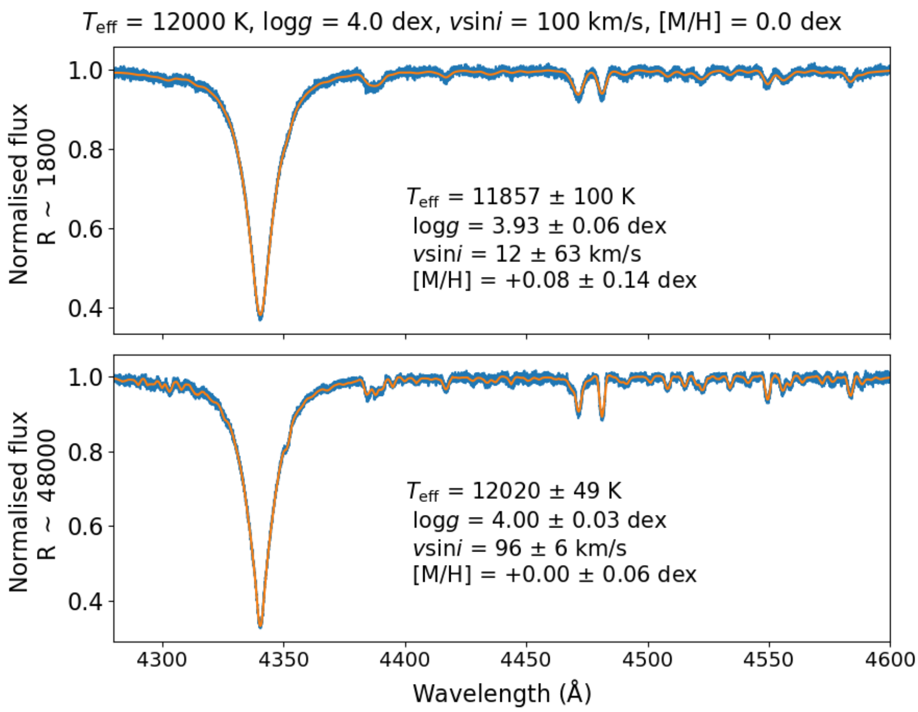

Figure 2: Same as in Fig. 1 but for $v \sin i$ = 100 km/s.

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
TIC88690729	$08^h\,08^m\,42^s.00$	$-01^\circ\,24'\,07''$	8.9	1
TIC32791149	$06^h\,57^m\,27^s.16$	$-00^\circ\,07'\,39''$	8.9	1
TIC37159285	$06^h\,32^m\,41^s.68$	$-04^\circ\,26'\,59''$	9.0	1
TIC234735877	$06^h\,28^m\,51^s.67$	$+02^\circ\,08'\,21''$	9.1	1
TIC149739056	$08^h\,40^m\,56^s.16$	$-04^\circ\,10'\,22''$	9.2	1
TIC88977680	$08^h\,13^m\,08^s.55$	$-05^\circ\,38'\,36''$	9.2	1
TIC169197614	$08^h\,29^m\,56^s.38$	$-00^\circ\,30'\,11''$	9.3	1
TIC231229686	$06^h\,44^m\,17^s.53$	$+07^\circ\,25'\,44''$	9.4	1
TIC234768553	$06^h\,29^m\,36^s.01$	$+04^\circ\,28'\,08''$	9.4	1
TIC373102309	$04^h\,32^m\,09^s.20$	$+09^\circ\,04'\,16''$	9.5	1
TIC393093100	$06^h\,39^m\,38^s.62$	$+03^\circ\,06'\,52''$	9.7	1
TIC281531451	$06^h\,37^m\,30^s.63$	$+05^\circ\,55'\,22''$	9.7	1
TIC167391268	$06^h\,21^m\,00^s.47$	$+08^\circ\,25'\,40''$	9.7	1
TIC234853418	$06^h\,32^m\,16^s.40$	$+01^\circ\,10'\,29''$	9.7	1
TIC270559856	$09^h\,04^m\,32^s.23$	$+00^\circ\,55'\,29''$	9.8	1
TIC281531590	$06^h\,37^m\,21^s.99$	$+05^\circ\,58'\,18''$	9.9	1
TIC220135104	$06^h\,36^m\,05^s.62$	$+09^\circ\,53'\,11''$	10.0	1
TIC301388739	$06^h\,41^m\,10^s.67$	$+03^\circ\,25'\,10''$	10.0	1
TIC232171729	$06^h\,05^m\,03^s.37$	$+03^\circ\,22'\,57''$	10.0	1
TIC234224257	$06^h\,47^m\,26^s.07$	$+01^\circ\,54'\,24''$	10.1	1
TIC281314912	$06^h\,37^m\,06^s.59$	$+05^\circ\,34'\,58''$	10.3	1
TIC237648444	$06^h\,54^m\,14^s.56$	$+01^\circ\,08'\,09''$	10.4	1
TIC220224072	$06^h\,38^m\,32^s.77$	$+06^\circ\,08'\,24''$	10.5	1
TIC65673481	$07^h\,35^m\,54^s.68$	$-02^\circ\,49'\,04''$	10.5	1
TIC220215892	$06^h\,37^m\,49^s.74$	$+09^\circ\,27'\,11''$	10.6	1
TIC234818376	$06^h\,30^m\,47^s.41$	$+03^\circ\,37'\,07''$	10.7	1
TIC235275641	$06^h\,51^m\,54^s.27$	$+09^\circ\,15'\,02''$	10.7	1
TIC237535461	$06^h\,51^m\,41^s.04$	$+01^\circ\,17'\,45''$	10.7	1
TIC237557897	$06^h\,52^m\,13^s.95$	$+01^\circ\,28'\,28''$	10.7	1
TIC235121479	$06^h\,48^m\,29^s.84$	$+08^\circ\,13'\,06''$	10.7	1
TIC235208724	$06^h\,49^m\,58^s.79$	$+06^\circ\,12'\,51''$	10.7	1
TIC235493785	$06^h\,57^m\,13^s.79$	$+07^\circ\,08'\,46''$	10.8	1
TIC234420890	$07^h\,34^m\,24^s.79$	$+08^\circ\,40'\,47''$	10.8	1
TIC234062453	$06^h\,44^m\,06^s.87$	$+00^\circ\,09'\,46''$	10.8	1
TIC234257600	$06^h\,48^m\,12^s.65$	$+03^\circ\,11'\,08''$	11.0	1
TIC237463998	$06^h\,50^m\,34^s.33$	$+01^\circ\,41'\,36''$	11.0	1
TIC220298408	$06^h\,39^m\,44^s.90$	$+06^\circ\,27'\,36''$	11.1	1
TIC220275285	$06^h\,39^m\,17^s.47$	$+06^\circ\,58'\,22''$	11.1	1
TIC237557504	$06^h\,52^m\,10^s.36$	$+01^\circ\,36'\,19''$	11.1	1
TIC264086251	$07^h\,13^m\,03^s.19$	$+06^\circ\,29'\,43''$	11.3	1
TIC177956652	$07^h\,31^m\,54^s.52$	$-02^\circ\,44'\,59''$	11.4	1
TIC61846963	$07^h\,19^m\,27^s.43$	$-00^\circ\,38'\,05''$	11.5	1
TIC235497698	$06^h\,57^m\,38^s.79$	$+06^\circ\,36'\,01''$	11.5	1
TIC257072889	$07^h\,47^m\,38^s.22$	$+05^\circ\,23'\,30''$	11.5	1
TIC235329357	$06^h\,53^m\,15^s.87$	$+06^\circ\,31'\,13''$	11.7	1
TIC274318529	$06^h\,16^m\,14^s.80$	$+08^\circ\,40'\,53''$	11.9	1
TIC64260226	$07^h\,24^m\,52^s.64$	$-02^\circ\,14'\,55''$	11.9	1
TIC66314414	$07^h\,41^m\,29^s.80$	$-03^\circ\,06'\,60''$	12.0	1
[a]				

[a] This is only half of the sample. The full sample is listed in the accompanying ASCII file.

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

Our sample consists of all bright (Gmag < 12) BA(F) stars that overlap between the LAMOST and SDSS-V surveys and are located in the Southern Hemisphere ($\delta < +10°$). They also have precise Gaia parallaxes ($\sigma_{\varpi}/\varpi < 0.1$) and TESS light curves in which variability due to pulsations or rotational modulation is detected by us. We checked the ESO archive for FEROS high-resolution spectra and eliminated those stars from the sample that already have spectra.
For the other targets we request two epochs with the high-resolution FEROS spectrograph, maximally separated within the observing semester to detect possible binaries. We require S/N $\sim$ 100 at 5000 Å for each epoch in order to have a co-added spectrum with S/N $\sim$ 150. Following the FEROS exposure time calculator, we computed the exposure times needed to achieve the required S/N for different magnitude bins. These are 300 sec (Vmag = 8 - 9), 600 sec (Vmag = 9 - 10), 1500 sec (Vmag = 10 - 11) and 2400 sec (Vmag = 11-12). The total overhead per target is $\sim$ 570 sec, including 1) 360 sec for the telescope pointing, target acquisition and centring 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 of **100.9 hours** of observing time, including two epochs for all the 96 BA(F) golden sample stars and overhead.

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

The different epochs of each target should be maximally separated within the semester and at least by one month to be able to detect binaries.

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

All the observers have experience with the FEROS spectrograph.

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

Telescope	instrument	date	hours	success rate	publications
2.2m	FEROS	Dec 2019	122.5	97%	Paper in prep.
2.2m	FEROS	March 2021	26.5	60%	Data analysis ongoing

The data from December 2019 are currently being analysed and a paper is in preparation. The analysis of the data from March 2021 is ongoing.

14. References for items 8 and 13:

[1] Heiter, U.; Jofré, P.; Gustafsson, B.; Korn, A. J.; Soubiran, C.; Thévenin, F., 2015: *Gaia FGK benchmark stars: Effective temperatures and surface gravities*, A&A, **582**, A49

[2] Ho, A. Y. Q.; Ness, M. K.; Hogg, D. W., et al., 2017: *Label Transfer from APOGEE to LAMOST: Precise Stellar Parameters for 450,000 LAMOST Giants*, ApJ, **836**, 5

[3] Zari, E.; Rix, H. -W.; Frankel, N., et al., 2021: *Mapping Luminous Hot Stars in the Galaxy*, A&A, in press (arXiv:2102.08684)

[4] Przybilla, N.; Nieva, M. -F.; Butler, K., 2008: *A Cosmic Abundance Standard: Chemical Homogeneity of the Solar Neighborhood and the ISM Dust-Phase Composition*, ApJL, **688**, L103

[5] Ness, M.; Hogg, D. W.; Rix, H. -W.; Ho, A. Y. Q.; Zasowski, G., 2015: *The Cannon: A data-driven approach to Stellar Label Determination*, ApJ, **808**, 16

[6] Ting, Y. -S.; Conroy, C.; Rix, H. -W.; Cargile, P., 2019: *The Payne: Self-consistent ab initio Fitting of Stellar Spectra*, ApJ, **879**, 69

[7] Gebruers, S.; Straumit, I.; Tkachenko, A., et al., 2021: *A homogeneous spectroscopic analysis of a Kepler legacy sample of dwarfs for gravity-mode asteroseismology*, A&A, in press (arXiv:2104.04521)

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:**	30/90 nights