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	May 2020
Received	

APPLICATION FOR OBSERVING TIME

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

1. Telescope: 2.2-m [X] Oct19 [T]

2.1 Applicant

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2.2 Collaborators

H. Lala	ARI-ZAH, Heidelberg
name(s)	institute(s)
Dr. B. Lemasle	ARI-ZAH, Heidelberg
name(s)	institute(s)

2.3 Observers

H. Lala	B. Lemasle
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: [C]

Title : **The early times of the Milky Way as traced by thick disk type II Cepheids**

Abstract : **The thick disk plays a key role for understanding the Milky Way, for instance the possible inside-out evolution or the possible formation of a pseudo-bulge from thick disk populations. This is all the more true after the discovery of the Gaia-Enceladus-Sausage merger event, which may have quenched star formation in the disk and led to the formation of the metal–rich halo. With thick disk type II Cepheids, old (>10 Gyr) pulsating stars which provide accurate distances and abundances for numerous α, iron-peak and neutron-capture elements, we have the perfect tools to probe the early times of the Milky Way.**

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

5. Brightness range of objects to be observed: from **7.22** to **13.07** **V-mag**

6. Number of hours:

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

7. Optimum date range for the observations: .... 15.01.21 – 10.02.21
Usable range in local sideral time LST: .... 12:00h – 23:00h

Astrophysical context

Type II Cepheids (T2Cs) are variable stars whose pulsations are driven by the same processes (κ, γ–mechanisms) as the classical Cepheids. As their progenitors are >10 Gyr old stars with M≈0.5–0.8 $M_{\odot}$, they are considered the old, low-mass counterpart to classical Cepheids (Wallerstein et al., 2002). T2Cs span a wide metallicity range and are located in the bulge, the thick disk, the halo, and globular clusters.

The peak of star formation in the Universe coincides in the Milky Way (MW) with the formation of the thick disk, which may account for half of the MW's stellar content and for the majority of its old population. Studying the thick disk is of paramount importance for the formation and evolution of the MW, in particular for understanding whether our Galaxy has formed inside-out (see e.g., Bovy et al., 2012; Haywood et al., 2015), or for investigating whether the bulge formed from thick disk populations (see e.g., Ness et al., 2013; Di Matteo et al., 2014). Indeed, APOGEE data have shown that the inner disk is older than the outer disk (Ness et al., 2016), supporting the inside–out scenario, but the outer disk also contains old stars and the scale-length of the thick disk did not grow with time (Bovy et al., 2012), which contradicts an inside-out formation. With their >10 Gyr age, *T2Cs are a crucial tool for understanding the early evolution of the thick disk*, especially in a context where most age determinations still rely on chemical clocks like e.g., [α/Fe]. Our current understanding indicates that the thick disk is chemically distinct from the thin disk and had a different chemical evolution (e.g., Haywood et al., 2013; Hayden et al., 2015), but may instead be indistinguishable from the metal–rich halo. In particular, large scale properties such as radial and vertical metallicity gradients are still largely missing, and current scenarios for the formation of the thick disk involving turbulent instabilities (Bournaud et al., 2009), radial migration triggered by spiral arms or merger events (Schonrich & Binney 2009; Minchev et al., 2013) rely mostly on measurements in the solar neighborhood.

After analyzing Gaia DR2, it seems that the halo can be divided in (at least) two populations: the first is the result of the accretion of e.g., the Gaia-Enceladus-Sausage satellite galaxy (Belokurov et al., 2018b; Helmi et al., 2018) while the second one consists of stars formed in-situ in the thick disk and moving in heated orbits by the merger event. In particular, a massive thick disk may be the main contributor to low-metallicity populations ([Fe/H]<–1 dex). *T2Cs are perfect for testing Galactic formation theories, since they have a large range of metallicities e.g., Maas et al., 2007) and show mostly thick disk kinematics (Wallerstein et al., 2018).*

Immediate aim

We set out to probe possible disk formation scenarios using T2Cs as preliminarily shown in e.g., Wallerstein et al., 2018, in particular if some of them turn out to still have cold, disk-like orbits. We will confirm or refute these theories, and in order to do so, we will derive stellar parameters, abundances and compute orbital parameters. The atmospheric parameters are derived directly from the spectra, using for T_{eff} the line depth ratios method (Kovtyukh 2007; Proxauf et al., 2018). A canonical spectroscopic analysis provides abundances for > 30 α, iron-peak and neutron-capture elements. We will use the EW method, and spectral synthesis when lines present an hyperfine structure or are affected by NLTE effects. Distances are derived from the period-luminosity relation for T2Cs and/or Gaia parallaxes. The chemo-dynamical properties of the old thick disk (>10 Gyr) traced by T2Cs will be studied by combining abundances with Gaia kinematics.

Previous work

We have published numerous papers dealing with abundance gradients in the thin disk determined from classical Cepheids (e.g., Lemasle et al., 2007, 2008, 2013, 2018; Genovali et al., 2013, 2014, 2015: da Silva et al., 2016, Inno et al., 2019), including papers about T2Cs (e.g., Lemasle et al., 2015). H. Lala has started a Ph.D. project on type II Cepheids as tracers for Milky Way archaeology in October 2019.

Layout of observations

We will observe 25 T2Cs within 28.1h in the range 7.2< V <13.1. All of these are listed in the Table in Sect. 9. Our targets can be observed (even at relatively low airmass and with mediocre weather: IQ<1,2) over the entire period (in service mode), and ideally between 20.01.2021 and 10.02.2021 in visitor mode.

Strategic importance for MPIA

Our study will provide important information on the spatial distribution of the abundances of the old populations of the thick disk and the halo. Studying the chemodynamical evolution of the different subsystems of the MW (bulge, thin/thick disk, halo) and understanding the nucleosynthetic processes that help galaxies to turn gas into stars are among the key questions posted by the "Galaxies and Cosmology" department at MPIA. In particular, MPIA plays a central role in ongoing and future large spectroscopic surveys aiming at mapping stellar archaeological record (the chemistry and kinematics of large numbers of stars) to study the imprints of chemo-dynamical evolution. Among those, the 4MOST MIlky way Disc And BuLgE survey (4MIDABLE-HR) high resolution survey (co-PI M. Bergemann, MPIA) will target T2Cs located in/towards the Bulge. Comparing their chemical composition to the one of T2Cs in the thick disk from this study will enable one to test scenarios where a large fraction of the Bulge populations originates from secular evolution of the thick disk.

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
2767721700577272448	$0^h\,14^m\,29\overset{s}{.}6072$	$13°\,31'\,08.3406''$	12.144	1
5165896984711852800	$3^h\,13^m\,39\overset{s}{.}1611$	$-10°\,26'\,32.5047''$	11.38	1
3302426196715055616	$3^h\,52^m\,59\overset{s}{.}687$	$9°\,17'\,17.1498''$	12.312	1
3283721030024735360	$4^h\,24^m\,32\overset{s}{.}977$	$4°\,07'\,23.9432''$	9.769	1
3415206707852656384	$5^h\,05^m\,14\overset{s}{.}2591$	$21°\,45'\,48.9253''$	12.964	1
5577329081864722176	$6^h\,48^m\,56\overset{s}{.}4129$	$-37°\,16'\,33.2806''$	10.258	1
3113203642894208128	$6^h\,48^m\,58\overset{s}{.}0459$	$-0°\,37'\,30.7729''$	11.864	1
5511121271942890496	$7^h\,28^m\,44\overset{s}{.}7814$	$-44°\,28'\,16.5996''$	11.334	1
5717854265702401792	$7^h\,52^m\,36\overset{s}{.}509$	$-17°\,23'\,00.7546''$	12.289	1
5643564972301150208	$8^h\,26^m\,11\overset{s}{.}9505$	$-30°\,17'\,08.2387''$	11.078	1
5653136461526964224	$8^h\,54^m\,29\overset{s}{.}643$	$-23°\,31'\,18.1174''$	7.218	1
5311352065144961024	$9^h\,08^m\,24\overset{s}{.}1427$	$-53°\,29'\,40.4375''$	13.027	1
5325604110967001344	$9^h\,12^m\,09\overset{s}{.}6324$	$-50°\,22'\,33.6417''$	12.501	1
5254665166975458944	$10^h\,20^m\,31\overset{s}{.}9835$	$-61°\,14'\,57.3385''$	12.749	1
5335749609693672448	$11^h\,35^m\,47\overset{s}{.}6012$	$-61°\,04'\,45.8918''$	13.075	1
6144045107427693824	$12^h\,01^m\,55\overset{s}{.}2009$	$-46°\,16'\,41.4576''$	12.567	1
6157795870424183552	$12^h\,31^m\,33\overset{s}{.}8498$	$-35°\,29'\,24.0066''$	11.986	1
5855676944429471872	$12^h\,43^m\,14\overset{s}{.}3815$	$-69°\,03'\,23.6319''$	12.422	1
5784674881551467392	$13^h\,02^m\,21\overset{s}{.}1779$	$-79°\,45'\,26.3071''$	12.334	1
3637042116582796544	$13^h\,26^m\,01\overset{s}{.}9887$	$-3°\,22'\,43.414''$	10.349	1
5872414848624226048	$13^h\,52^m\,51\overset{s}{.}2428$	$-56°\,29'\,22.7977''$	11.784	1
6303152720661307648	$14^h\,11^m\,09\overset{s}{.}0412$	$-13°\,18'\,38.4408''$	9.526	1
3640760901131104256	$14^h\,16^m\,48\overset{s}{.}5816$	$-6°\,17'\,15.2326''$	12.511	1
6217308590845895680	$14^h\,46^m\,33\overset{s}{.}6406$	$-32°\,10'\,15.295''$	8.424	1
6241789522177233664	$15^h\,42^m\,00\overset{s}{.}0533$	$-20°\,46'\,45.9407''$	12.333	1

10. Justification of the amount of observing time requested:

We are conducting a survey of all currently known T2Cs. A large number of them is bright enough to be observed with the 2.2m telescope and a spectrograph with a high throughput like FEROS. The large spectral range of FEROS enables the measurement of numerous lines present in the spectra of T2Cs and in turn, to determine the abundances of >30 α, iron peak and neutron-capture elements. Exposures times have been computed using the ETC, increasing the magnitudes by 0.5 mag to take into account that the magnitudes listed in Table 9 are the average magnitude of the variables. Calculations have been made for obtaining a S/N$\geq$50 in order to be able to measure the usually weak lines of neutron-capture elements like e.g., Europium.

We have 4 targets with $12.6< V <13.5$ (4×7200s), 9 targets with $12< V <12.6$ (9×5400s), 3 targets with $11.5< V <12$ (3×3000s), 3 targets with $11< V <11.5$ (3×2100s), 2 targets with $10< V <11$ (2×900s), 4 targets with $V <10$ (5×600s), for a total of 93750s, that is 26 hours. We include 5 min of overheads for the 25 targets, hence 101250s for a grand total of 198700s corresponding to 28.1h

We had been awarded time in Period 105 but no observations were taken due to the shutdown caused by Covid-19.

11. Constraints for scheduling observations for this application:

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

B. Lemasle: Observations at the CFHT+Espadons, TBL+Narval(×2), OHP1.93m+SOPHIE, VLT+Xshooter. 2.2m+FEROS. Very experienced in preparing and reducing service mode observations for e.g., VLT spectrographs. B. Lemasle analyzed FEROS data during his Ph.D.

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	P105	55	NA	Observations lost due to Covid-19 shutdown
2.2m	FEROS	P101	66	90%	Spectra currently analyzed by H. Lala

14. References for items 8 and 13:

Belokurov et al.(2018b): Belokurov, V., Erkal, D., Evans, N. W., et al., 2018b, MNRAS, 478, 611
Bournaud et al.(2009): Bournaud, F., Elmegreen, B. G., Martig, M., 2009, ApJ 707, L1
Bovy et al.(2012): Bovy, J., Rix, H.-W., Liu, C., et al. 2012, ApJ, 753, 148
da Silva et al.(2016): da Silva, R., Lemasle, B., Bono, G., et al. 2016, A&A, 586, A125
Di Matteo et al.(2014): Di Matteo, P., Haywood, M., Gomez, A., et al. 2014, A&A, 567, A122
Genovali et al., 2013: Genovali, K., Lemasle, B., Bono, G., et al. 2013, A&A, 554, A132
Genovali et al., 2014: Genovali, K., Lemasle, B., Bono, G., et al. 2014, A&A, 566, A37
Genovali et al., 2015: Genovali, K., Lemasle, B., da Silva, R., et al. 2015, A&A, 580, A17
Hayden et al.(2015): Hayden, M. R., Bovy, J., Holtzman, J. A., et al. 2015, ApJ, 808, 132
Haywood et al.(2013): Haywood, M., Di Matteo, P., Lehnert, M. D., et al., 2013, A&A, 560, A109
Haywood et al.(2015): Haywood, M., Di Matteo, P., Snaith, O., et al., 2015, A&A, 579, A5
Helmi et al.(2018): Helmi, A., Babusiaux, C., Koppelman, H. H., et al. 2018, Nature, 563, 85
Inno et al., 2019: Inno, L., Urbaneja, M. A., Matsunaga, N., et al., 2019, MNRAS 482, 83
Kovtyukh(2007): Kovtyukh 2007, MNRAS, 378, 617
Lemasle et al.(2007): Lemasle, B., François, P., Bono, G., et al. 2007, A&A, 467, 283
Lemasle et al.(2008): Lemasle, B., François, P., Piersimoni, A., et al. 2008, A&A, 490, 613
Lemasle et al.(2013): Lemasle, B., François, P., Genovali, K., et al. 2013, A&A, 558, A31
Lemasle et al.(2015): Lemasle et al. 2015, A&A, 579, A47
Lemasle et al.(2018): Lemasle, B., Hajdu, G., Kovtyukh, V., et al. 2018, A&A, 618, A160
Maas et al.(2007): Maas et al. 2007: ApJ, 666, 378
Minchev et al.(2013): Minchev, I.; Chiappini, C.; Martig, M., 2013, A&A 558, A9
Ness et al.(2013): Ness, M., Freeman, K., Athanassoula, E., et al. 2013, MNRAS, 430, 836
Ness et al.(2016): Ness, M., Zasowski, G., Johnson, J. A., et al. 2016, ApJ, 819, 2
Proxauf et al.(2018): Proxauf et al. 2018, A&A 616, A82
Schönrich & Binney(2009): Schönrich, R. & Binney, J. 2009, MNRAS, 396, 20
Wallerstein(2002): Wallerstein 2002, PASP, 114, 689
Wallerstein(2018): Wallerstein, G., Farrell, E. M., 2018, AJ 156, 299

Tolerance limits for planned observations:

maximum seeing:	2.0″	**minimum transparency:**	50%	**maximum airmass:**	1.8
photometric conditions:	no	**moon: max. phase / ∠ :**	0.8/30°	**min. / max. lag:**	0/180 nights