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
Received

APPLICATION FOR OBSERVING TIME

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

1. Telescope: 2.2-m [X]

2.1 Applicant

Zdenek Prudil	Astronomisches Rechen-Institut
Name	Institute
Mönchhofstrasse 12-14	69120 Heidelberg
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ESO User Portal username	e-mail

2.2 Collaborators

Andreas Koch, Camilla Hansen	ARI, MPIA
name(s)	institute(s)
Hitesh Lala, Giuliano Iorio	ARI, University of Padova
name(s)	institute(s)

2.3 Observers

Zdenek Prudil	Bertrand 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: E

Title : **Exploration of the Milky Way disk components with RR Lyrae stars**

Abstract : Our current understanding of the two Milky Way (MW) disk components (both distinct in their kinematical and chemical distribution) relies on two prominent periods of star formation, being traced by a dynamically hot, metal-poor, α-rich, stellar population with ages ~ 10 Gyr, and another younger (~ 8 Gyr), kinematically cold, metal-rich, α-poor population. Our proposal focuses on the formation timescale aspect of the MW disk, and is *motivated by recent discoveries of the metal-rich, α-poor **old** population (above 10 Gyr) of pulsators associated with the presumably **young** (< 8 Gyr) α-poor disk.* This RR Lyrae sub-population challenges our understanding of the MW disk formation and the single-star evolutionary models of horizontal branch giants.

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

5. Brightness range of objects to be observed: from 8.9 to 13.0 G-mag

6. Number of hours:

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

7. Optimum date range for the observations: .... 15.5.21 – 15.08.21
Usable range in local sideral time LST: .... 21:00h – 7:00h

Astrophysical context

The exploration and understanding of the MW disks are currently undergoing turbulent development thanks to the large-scale spectroscopic and astrometric surveys [1, 2, 3, 5] which subsequently will foster the theoretical framework of the disk formation and evolution. Our present understanding is that the two components of MW disk [7] differ in their chemical (metallicity [Fe/H] and α-element abundances, e.g., [Ca/Fe], [Mg/Fe]), and kinematic properties (their orbits' eccentricity and inclination to the Galactic plane.

The current disk formation paradigm includes two prominent periods of star formation that lead to the formation of the old, metal-poor, α-rich old disk component ($8 - 13$ Gyr, [14]) and a younger, metal-rich, α-poor disk (< 8 Gyr, [14]). Stars associated with the presumably younger α-depleted disk are dynamically cold with almost circular prograde orbits. On the other hand, stars associated with the old α-rich disk exhibit a higher velocity dispersion and a larger lag behind the Galactic rotation than the younger α-poor disk stars.

In our project, we focus on the MW disk formation using the RR Lyrae variables. RR Lyrae stars are old (ages > 10 Gyr) pulsating horizontal branch variables, serving as standard candles within the Local Group. Our interest in the Galactic disk and RR Lyrae stars is motivated by recent chemo-dynamical studies of RR Lyrae stars in the Solar neighborhood (3 kpc from the Sun, [21, 27]), Galactic bulge [22], and Galactic halo [16]. In the aforementioned studies, **a small fraction (around 7 %) of local RR Lyrae variables have been found exhibiting chemo-dynamical features prototypical for stars associated with the α-poor presumably young disk**, namely with a small velocity dispersion in the vertical direction ($\sigma_{v_{\mathrm{Z}}} = 16\,\mathrm{km\,s^{-1}}$), low [Ca/Fe] abundance (on average [Ca/Fe]$= 0.04$ dex) while being metal-rich ([Fe/H]~ 0.60 dex), see the [Ca/Fe] vs. [Fe/H] distribution in Fig. 1.

Our focus is on the nature and association of the old RR Lyrae variables with the presumably young α-poor disk. If this is true, it would shift the age of the young, α-poor disk from the current 8 Gyr to $>$ 10 Gyr.

Immediate aim

Our goal with this spectroscopic follow-up is to probe the detailed chemistry of 80 RR Lyrae stars with disk-like kinematics to revise or confirm their association with the old/young disk. To this end, we will use Gaia astrometric products.

We expect the majority of our survey stars will be chemo-dynamically connected with the α-poor MW disk (based on, e.g., [Ca/Fe] abundance, see Fig. 2. We will explore obtained spectra for traits that could potentially explain their kinematical and chemical link to the α-poor Galactic disk, e.g., the result of binary evolution where the mass exchange between both components pushed one of them toward the horizontal branch. The clues of binary evolution can be found as imprints on the chemical composition [19] of an RR Lyrae star where the more evolved companion already passed through an asymptotic giant branch and, through mass transfer, polluted the atmosphere of an RR Lyrae star. The pulsator would then exhibit over-abundance, e.g., carbon [17], and in n-capture elements [19] (e.g., Barium, see Fig. 3). Therefore, one of the two expected outcomes can arise:

- Kinematically cold, metal-rich RR Lyrae stars are part of the α-poor Galactic disk, and their origin cannot be explained by binarity. Thus the timescale of the α-poor disk formation should be revisited, ***or*** a new formation mechanism of RR Lyrae stars proposed (with ages below 8 Gyr).
- The presence of RR Lyrae stars in the α-poor disk is a result of their co-existence in binary systems. Such systems are extremely rare among RR Lyrae stars. To this day, we know of only one RR Lyrae star (out of 150k known RR Lyrae stars in MW [6]) residing in a binary system.

Previous work

Our project is building upon our pilot study [21] where we collected literature data for local RR Lyrae stars and found that a small portion can be associated with the α-poor disk [22, 21, 16]. PI and Co-PIs have previously worked on chemo-dynamical studies [8, 9] in the MW substructures and have extensive experience in stellar spectroscopy and MW dynamics [10, 11, 20, 21].

Layout of observations

We chose 80 RRab-type RR Lyrae stars to be observed in this project, for which we expect the prevailing majority to be chemo-dynamically associated with the young Galactic α-poor disk. This will provide a sufficient sample to explore their possible origin. We picked pulsators that exhibit α-poor disk properties based on tangential velocities but do not have any chemical information in the literature. The full abundance pattern will permit comparison among disk spectroscopic studies and allow probing the possible mass transfer enrichment. We will observe each variable with 20 minute exposures. Obtained spectra will be processed using standard spectroscopic techniques to determine systemic velocities [23] of each object and associated abundances [4, 9] by measuring the equivalent widths of spectral lines and spectral synthesis.

Strategic importance for MPIA

Our data will serve as a legacy survey for large spectroscopic surveys like 4MOST and SDSS V, integral to several groups at MPIA. Our sample can serve as a training set for RR Lyraes processing pipelines of the aforementioned surveys that will contain tens of thousands of RR Lyrae variables.

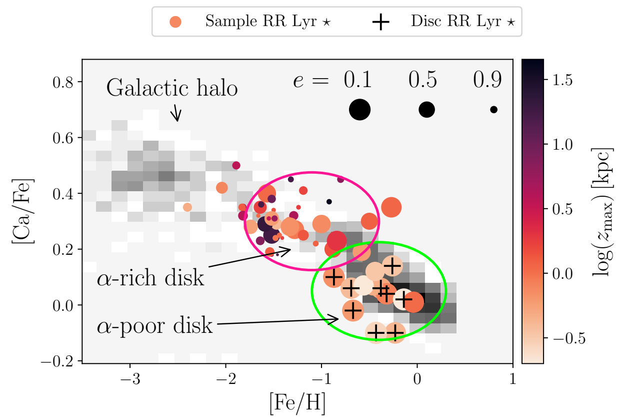

Figure 1: The [Ca/Fe] vs. [Fe/H] dependence of sample used in [21] study. The color-coding of individual points represent their maximal distance from the Galactic plane. The black pluses represent stars kinematically associated with the Galactic disk. The solid green and pink lines stand for the approximate separation between presumably young α-poor and old α-rich disk, respectively.

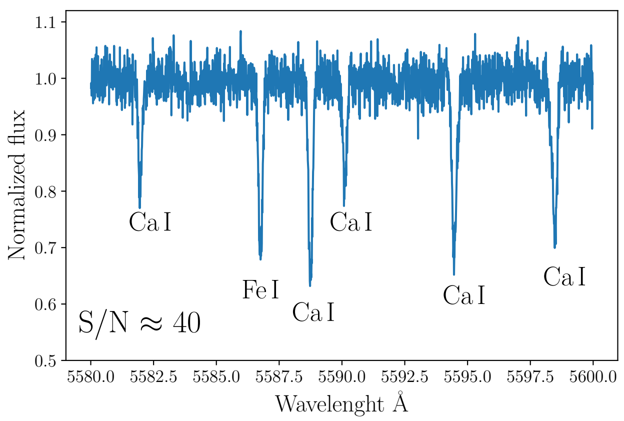

Figure 2: Synthesized spectrum with the stellar parameters typical for a survey RR Lyrae star with added noise to mimic signal-to-noise ratio (S/N) ≈ 40 achieved with a 20 minutes exposure for a $G = 13$ mag star. With this setup we expect to achieve $\sigma_{\mathrm{[Ca/Fe]}}$ ≈ 0.1 dex similarly to a comparable S/N as in [9].

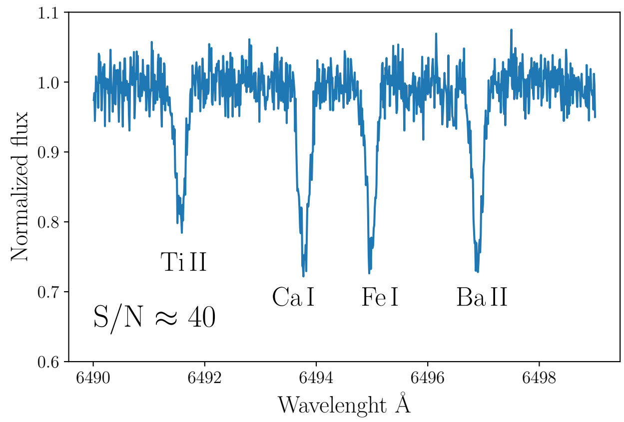

Figure 3: Synthesized spectrum with the stellar parameters typical for a survey RR Lyrae star with added noise to mimic S/N ≈ 40 achieved with a 20 minutes exposure for a $G = 13$ mag star. With this setup, we expect to reach Barium lines at 5853 Åand 6496 Å.

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
6005656897473385600	$15^{h}\ 22^{m}\ 25.38^{s}$	$-40^\circ\ 55'\ 36.5''$	8.912790	high
1760981190300823808	$20^{h}\ 47^{m}\ 28.37^{s}$	$+12^\circ\ 27'\ 50.8''$	9.917064	high
6750122648534747392	$19^{h}\ 54^{m}\ 01.93^{s}$	$-30^\circ\ 15'\ 10.5''$	10.196107	high
4039386574037718528	$18^{h}\ 13^{m}\ 35.45^{s}$	$-34^\circ\ 19'\ 02.2''$	10.302418	high
6730211038418525056	$18^{h}\ 47^{m}\ 57.57^{s}$	$-37^\circ\ 44'\ 22.9''$	10.477429	high
6771307454464848768	$19^{h}\ 32^{m}\ 20.78^{s}$	$-23^\circ\ 51'\ 13.6''$	10.487098	high
4039655477775501440	$18^{h}\ 12^{m}\ 00.89^{s}$	$-33^\circ\ 20'\ 44.6''$	10.547496	high
6547228908864323968	$22^{h}\ 47^{m}\ 34.72^{s}$	$-39^\circ\ 03'\ 33.4''$	10.630246	high
5947570591534602240	$17^{h}\ 59^{m}\ 10.69^{s}$	$-49^\circ\ 26'\ 00.6''$	10.841574	high
4352084489819078784	$16^{h}\ 24^{m}\ 41.21^{s}$	$-06^\circ\ 32'\ 29.8''$	10.901791	high
5926543599916531584	$17^{h}\ 08^{m}\ 01.89^{s}$	$-49^\circ\ 53'\ 13.4''$	10.976112	high
4124594086640564352	$17^{h}\ 31^{m}\ 54.05^{s}$	$-16^\circ\ 53'\ 09.6''$	11.214932	high
5815008831122635520	$17^{h}\ 00^{m}\ 46.67^{s}$	$-66^\circ\ 39'\ 50.1''$	11.296361	high
5854531253311879936	$14^{h}\ 17^{m}\ 57.51^{s}$	$-61^\circ\ 28'\ 52.3''$	11.325402	high
4161418414667076480	$17^{h}\ 35^{m}\ 02.52^{s}$	$-13^\circ\ 55'\ 58.9''$	11.368602	high
4055098870077726976	$17^{h}\ 40^{m}\ 48.48^{s}$	$-31^\circ\ 32'\ 31.9''$	11.371429	high
6046836528519375232	$16^{h}\ 51^{m}\ 26.21^{s}$	$-24^\circ\ 34'\ 58.0''$	11.433043	high
4090995249027736192	$18^{h}\ 24^{m}\ 25.66^{s}$	$-21^\circ\ 34'\ 20.4''$	11.491250	high
6787617919184986496	$21^{h}\ 16^{m}\ 22.72^{s}$	$-30^\circ\ 17'\ 03.2''$	11.497036	high
4136943255792306304	$17^{h}\ 22^{m}\ 02.47^{s}$	$-15^\circ\ 25'\ 00.1''$	11.633010	high
6210360364551400192	$15^{h}\ 35^{m}\ 03.84^{s}$	$-28^\circ\ 09'\ 04.9''$	11.639576	high
4118543955178309376	$17^{h}\ 48^{m}\ 48.87^{s}$	$-21^\circ\ 52'\ 51.8''$	11.714892	high
5899911190569392640	$15^{h}\ 04^{m}\ 27.64^{s}$	$-52^\circ\ 48'\ 45.6''$	11.743967	high
5891984987370441216	$14^{h}\ 23^{m}\ 30.35^{s}$	$-57^\circ\ 53'\ 04.4''$	11.754058	high
5978413228421896448	$17^{h}\ 02^{m}\ 58.85^{s}$	$-33^\circ\ 46'\ 28.1''$	11.799692	high
5801111519533424384	$17^{h}\ 35^{m}\ 41.26^{s}$	$-76^\circ\ 13'\ 15.9''$	11.808372	high
6788454544456587520	$21^{h}\ 03^{m}\ 16.62^{s}$	$-29^\circ\ 33'\ 08.3''$	11.818446	high
6265633363833063552	$15^{h}\ 28^{m}\ 02.09^{s}$	$-15^\circ\ 40'\ 04.4''$	11.842353	high
5996105366938238336	$15^{h}\ 55^{m}\ 53.24^{s}$	$-40^\circ\ 41'\ 44.1''$	11.868291	high
5903483783039264640	$15^{h}\ 03^{m}\ 27.42^{s}$	$-47^\circ\ 56'\ 04.1''$	11.893089	high
6047898927316091648	$16^{h}\ 40^{m}\ 14.39^{s}$	$-23^\circ\ 42'\ 32.8''$	11.947209	high
4224859720193721856	$20^{h}\ 38^{m}\ 15.07^{s}$	$-02^\circ\ 53'\ 25.2''$	11.992696	high
4344296958198114688	$16^{h}\ 25^{m}\ 11.10^{s}$	$-10^\circ\ 31'\ 25.7''$	12.033117	high
4387211137548084352	$17^{h}\ 23^{m}\ 13.39^{s}$	$+01^\circ\ 51'\ 50.6''$	12.072227	high
4099676060763820032	$18^{h}\ 42^{m}\ 19.47^{s}$	$-16^\circ\ 31'\ 33.1''$	12.084250	high
2668973015098185088	$22^{h}\ 01^{m}\ 55.52^{s}$	$-05^\circ\ 36'\ 02.6''$	12.088913	high
4373335399587661184	$17^{h}\ 23^{m}\ 36.09^{s}$	$-01^\circ\ 11'\ 27.7''$	12.104453	high
6321161342439508480	$15^{h}\ 18^{m}\ 21.89^{s}$	$-08^\circ\ 27'\ 42.7''$	12.107064	high
5806921716937210496	$16^{h}\ 20^{m}\ 51.49^{s}$	$-71^\circ\ 40'\ 15.9''$	12.120746	high
4375522225138690560	$17^{h}\ 40^{m}\ 38.62^{s}$	$+01^\circ\ 36'\ 25.8''$	12.150750	high
4304943959593306240	$19^{h}\ 54^{m}\ 21.14^{s}$	$+12^\circ\ 49'\ 42.8''$	12.171536	high
4101181223464611328	$19^{h}\ 00^{m}\ 17.12^{s}$	$-15^\circ\ 06'\ 07.1''$	12.175774	high
6762676112087595520	$19^{h}\ 06^{m}\ 28.45^{s}$	$-27^\circ\ 50'\ 11.8''$	12.186201	high
4539889008646053888	$17^{h}\ 17^{m}\ 59.68^{s}$	$+11^\circ\ 04'\ 28.1''$	12.205187	high
4511030504912231296	$18^{h}\ 50^{m}\ 32.19^{s}$	$+16^\circ\ 31'\ 50.9''$	12.205501	high
6767877356142698752	$19^{h}\ 33^{m}\ 21.06^{s}$	$-25^\circ\ 17'\ 31.3''$	12.248424	high
6660781556341189888	$19^{h}\ 33^{m}\ 20.28^{s}$	$-45^\circ\ 39'\ 49.3''$	12.251117	high
...	$...^{h}\ ...^{m}\ ...^{s}$	$...^\circ\ ...'\ ...''$	...	...

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

The goal of our program is to obtain spectra of 80 RR Lyrae stars selected based on their kinematical properties. From this number targets, we estimate that above 50 % of the survey stars exhibit features of peculiar RR Lyrae population associated with the α-poor MW disk. Such a yield will allow, through detailed spectroscopical analysis, clear separation between both *α-poor* and *α-rich* RR Lyrae population, and will be sufficient enough to explore the origin of α-poor RR Lyrae variables with respect to their n-capture elements. To fulfill the above-stated plan we need a 2m class telescope with a high-resolution spectrograph, that will allow us to obtain spectra with $S/N \approx 40$ in 5600Å.

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

All our targets are observable from mid-May to the first half of August while fulfilling the minimum observing requirements, and can be all observed in a single run. We emphasize that our monitoring program requires observation at specific phases of the pulsation period, therefore, the visitors' mode is required.

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

Bertrand Lemasle:
ESPaDOnS: High-resolution spectrograph on CFHT (4m), Mauna Kea, Hawaii - 3 nights
NARVAL: High-resolution spectrograph on TBL (2m), Pic du Midi, France - 14 nights
SOPHIE: High-resolution spectrograph on T193 (2m), OHP, France - 7 nights
XShooter: medium-resolution spectrograph on VLT (8m), Chile - 2 nights
FEROS: High-resolution spectrograph on ESO/MPG 2.2m (2m), La Silla, Chile - 10 nights
WFI: Wide Field Imager on ESO/MPG 2.2m (2m), La Silla, Chile - 10 nights
GROND: Gamma-Ray Burst Optical/Near-Infrared Detector on ESO/MPG 2.2m (2m), LaSilla, Chile - 10 nights

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	Aug 19	10		Postdoc from spring 2021

14. References for items 8 and 13:

[1] Adibekyan V. Z., Santos N. C., Sousa S. G., Israelian G., 2011, A&A, 535, L11

[2] Ahumada R., Prieto C. A., Almeida A., Anders F., Anderson S. F., Andrews B. H., Anguiano B., et al., 2020, ApJS, 249, 3

[3] Buder S., Lind K., Ness M. K., Asplund M., Duong L., Lin J., Kos J., et al., 2019, A&A, 624, A19

[4] For B.-Q., Sneden C., Preston G. W., 2011, ApJS, 197, 29

[5] Gaia Collaboration, Brown A. G. A., Vallenari A., Prusti T., de Bruijne J. H. J., Babusiaux C., Bailer-Jones C. A. L., et al., 2018, A&A, 616, A1

[6] Clementini G., Ripepi V., Molinaro R., Garofalo A., Muraveva T., Rimoldini L., Guy L. P., et al., 2019, A&A, 622, A60

[7] Gilmore G., Reid N., 1983, MNRAS, 202, 1025

[8] Hansen C. J., Nordström B., Bonifacio P., Spite M., Andersen J., Beers T. C., Cayrel R., et al., 2011, A&A, 527, A65

[9] Hansen C. J., Rich R. M., Koch A., Xu S., Kunder A., Ludwig H.-G., 2016, A&A, 590, A39

[10] Hansen C. J., Hansen T. T., Koch A., Beers T. C., Nordström B., Placco V. M., Andersen J., 2019, A&A, 623, A128

[11] Hansen C. J., Koch A., Mashonkina L., Magg M., Bergemann M., Sitnova T., Gallagher A. J., et al., 2020, arXiv, arXiv:2009.11876

[12] Haschke R., Grebel E. K., Duffau S., 2012, AJ, 144, 106

[13] Haschke R., Grebel E. K., Duffau S., 2012, AJ, 144, 107

[14] Haywood M., Di Matteo P., Lehnert M. D., Katz D., Gómez A., 2013, A&A, 560, A109

[15] Hernitschek N., Sesar B., Rix H.-W., Belokurov V., Martinez-Delgado D., Martin N. F., Kaiser N., et al., 2017, ApJ, 850, 96

[16] Iorio G., Belokurov V., 2020, arXiv, arXiv:2008.02280

[17] Kennedy C. R., Stancliffe R. J., Kuehn C., Beers T. C., Kinman T. D., Placco V. M., Reggiani H., et al., 2014, ApJ, 787, 6

[18] Layden A. C., 1995, AJ, 110, 2312

[19] Preston G. W., Thompson I. B., Sneden C., Stachowski G., Shectman S. A., 2006, AJ, 132, 1714

[20] Prudil Z., Dékány I., Grebel E. K., Catelan M., Skarka M., Smolec R., 2019, MNRAS, 487, 3270

[21] Prudil Z., Dékány I., Grebel E. K., Kunder A., 2020, MNRAS, 492, 3408

[22] Savino A., Koch A., Prudil Z., Kunder A., Smolec R., 2020, A&A, 641, A96

[23] Sesar B., 2012, AJ, 144, 114

[24] Sesar B., Hernitschek N., Dierickx M. I. P., Fardal M. A., Rix H.-W., 2017, ApJL, 844, L4

[25] Szabó R., Kolláth Z., Molnár L., Kolenberg K., Kurtz D. W., Bryson S. T., Benkő J. M., et al., 2010, MNRAS, 409, 1244

[26] Taam R. E., Kraft R. P., Suntzeff N., 1976, ApJ, 207, 201

[27] Zinn R., Chen X., Layden A. C., Casetti-Dinescu D. I., 2020, MNRAS, 492, 2161

Tolerance limits for planned observations:

maximum seeing:	1.5″	**minimum transparency:**	50%	**maximum airmass:**	1.5
photometric conditions:	no	**moon: max. phase / ∠ :**	1.0/30°	**min. / max. lag:**	1/1 nights