INAF – TIME ALLOCATION COMMITTEE

Application for observing time **Category: D**

Period AOT39 (April 2019 – September 2019) **Submit using: www.tng.iac.es/submit.html**

1. Title

Spectroscopy of benchmark M dwarfs for PLATO

2. Abstract

In the search for exoplanets M dwarfs are attractive targets. Multiple space missions are designed to look for exoplanets, among them the future ESA mission PLATO. To be able to determine the habitability of the planets stellar parameters need to be determined, which is difficult in the case of M dwarfs due to their faintness and low effective temperature. By observing M dwarfs in the J band over a large wavelength range, atmospheric parameters and abundances of individual elements can be determined. This is done through fitting of synthetic spectra. We propose to use TNG-GIANO-B spectra to determine the effective temperature, surface gravity, metallicity and individual element abundances of benchmark M dwarfs in order to develop and test our methods. The result of this analysis will be used for testing parameter determination methods, which will be applied to PLATO M dwarf targets.

3a. Number of requested hours per telescope and instrument

TNG					REM	
DOLORES	DOLOR.+MOS	NICS	HARPS-N	GIANO-B	ROSS	REMIR
				16		

3b. Observing modes

TNG:	X	Visitor		Service		ToO
REM:		Rapid Response		Queuing		ToO

4a. Preferred months

first choice: May second choice: April

4b. Other scheduling constraints (use also box 14)

5a. Past and future of the project

a) Hours already awarded to the project: 0

b) Hours foreseen to complete the project: 0
(not including this request)

6. Principal investigator (Nordic Time)

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7. Co-investigators (name and institution)

Ulrike Heiter, Department of Physics and Astronomy (Uppsala, Sweden)
Oleg Kochukhov, Department of Physics and Astronomy (Uppsala, Sweden)

8. Status of the project

Telescope	Instrument	Date	Hours	Notes

Description

Publications

9a. If this proposal is a part of a PhD thesis, write here the name of the student, the thesis title and briefly describe the relevance of these observations for the thesis goals.

Terese Olander, preliminary title of the thesis: *Characterisation of cool stellar atmospheres for PLATO*. PLATO is a future ESA mission which will search for exoplanets in the habitable zone, in the sample M dwarfs can be found. Before this projects starts an M dwarf benchmark sample needs to be built. To do this multiple M dwarfs need to be observed.

9b. Is this, or a similar application submitted to other time allocation committees (e.g. ESO, TNG-CAT, ITP)? If yes, please specify which and explain if and why the proposals should be considered complementary.

10. Description of the programme (max. 3 pages, including references, tables, and figures.)

A) Scientific rationale

In the search for exoplanets, M dwarfs are prime targets. This is partly due to that M dwarfs are very common, they constitute 70% of the stars in the local Galaxy. Furthermore their small radius and mass increases the probability of finding exoplanets by both transit and radial velocity methods. Additionally because of the low luminosity the habitable zone is closer to the star which increases the probability of finding a planet in the habitable zone. The likelihood of finding an exoplanet around a M dwarf is also large. Dressing & Charbonneau (2015) estimate an occurrence rate of about 2.5 planets with a radius of 1-4 R_E per M dwarf, the occurrence rate of habitable planets with a radius of 1-2 R_E around M dwarfs is about 0.43.

To evaluate the habitability of planets around M dwarfs, stellar parameters of the host star need to be determined. The abundances of chemical elements in the photosphere of a main-sequence star is believed to be the same as the chemical abundances of the material from which both planet and star were formed. By determining the abundances in the photosphere of the star we can determine the composition of possible planets (Santos et al. 2015). This is also needed for a better understanding of planet formation.

In addition, 2026 will mark the launch of the European Space Agency's mission PLATO, a space telescope dedicated to the search for terrestrial exoplanets in the habitable zone of their host stars. A significant part of its sample will consist of M dwarfs. One of the scientific objectives of PLATO is to analyse the correlation of planet properties and their frequencies with stellar parameters (e.g. stellar metallicity, stellar type). To prepare for this mission, it is crucial to develop a reliable methodology to infer accurate stellar parameters and chemical abundances of M dwarfs. Additionally, since M dwarfs do not have intrinsic brightness variations due to pulsations stellar parameters cannot be determined using asteroseismology, which is what PLATO is using for the warmer targets. Other (spectroscopic) methods are needed.

However, it is notoriously difficult to determine accurate stellar parameters for M dwarfs. Due to their low effective temperatures, their optical spectrum is contaminated by a forest of molecular lines that is effectively blending into atomic spectral lines (Gustafsson 1989). For this reason spectroscopic studies of M dwarfs in the optical are extremely challenging. Observations in the near infrared are better suited for M dwarfs since much of the flux can be found at these wavelengths. Additionally in the J band there are fewer molecular transitions, hence there is less blending making a continuum rectification possible (Lindgren & Heiter 2017).

Lindgren et al. (2016, 2017) have successfully made metallicity determination using high-resolution spectroscopy but their studies were based on observations with limited wavelength coverage. With a more extended wavelength coverage the determination of individual element abundances is possible which has not been done up to now. This has to be tested by observing benchmark stars. Benchmark stars are stars which ideally have known angular diameters and bolometric fluxes (Pancino et al. 2017) so that their effective temperatures can be derived independently from spectroscopy.

Our proposal is to build on the methodology developed by Lindgren et al (2016, 2017), who used observations from the CRIRES spectrograph at VLT. We will make use of the large wavelength coverage of GIANO-B and its excellent efficiency, to perfect the methods and verify their reliability on a set of known benchmark stars. This would give us the confidence to apply the method next to the host stars of the future PLATO sample. The large simultaneous wavelength coverage of GIANO-B and its high resolution makes it ideal for this project and it is the only available instrument which give sufficient resolution and wavelength coverage.

B) Scientific aim

We propose to use spectra obtained with the GIANO-B spectrograph to perform a chemical abundance analysis of a sample of M dwarfs, with the goal to determine each stars overall metallicity [M/H] and the abundance of several individual elements. Based on an extraction from the VALD database (http://vald.astro.uu.se) using an atmospheric model for a solar-metallicity M4 dwarf and a minimum central line depth of 0.1, we estimate at least 100 useful, unblended atomic lines in the J-band region (1100-1360 nm). Most of these lines are from neutral Fe, Cr, Ti, Ca, Na, Si and Mn, but there are also a few lines of K, Al, Mg, V, Ni, and Ba. We will also explore line visible in the H band and assess their usefulness for abundance analysis and stellar parameter determination.

The chosen targets are spread in effective temperature and metallicity. The stars were chosen from the Gaia-ESO benchmark stars (Pancino et al. 2017) and complemented with stars from Boyajian et al. (2012) and Mann et al. (2015).

High-resolution observations in the infrared, combined with large wavelength coverage are vital requirements in order to perform accurate abundance determination. We aim to achieve an uncertainty of $<$ 0.1 dex for [M/H] and elemental abundances and 150 K for effective temperature. To meet these goals we estimate that a S/N of 150 is needed. This is higher than the median S/N of the M dwarf spectra analysed in Lindgren et al. (2016). Taking into account the difference in sampling between CRIRES and GIANO-B this should allow accurate determination of abundances of individual elements in addition to the overall metallicity. For the abundance determination we plan to follow a similar approach as was established by Valenti & Fischer (2005), adjusting $T_{\rm eff}$, log g, [M/H], and the abundances of several elements simultaneously. For this we will employ automatic spectrum synthesis, using the SME package (Piskunov & Valenti 2017). Routines for continuum rectification, accurate wavelength calibration using telluric features and telluric rectification are already in place from previous/ongoing projects (see Figure 1).

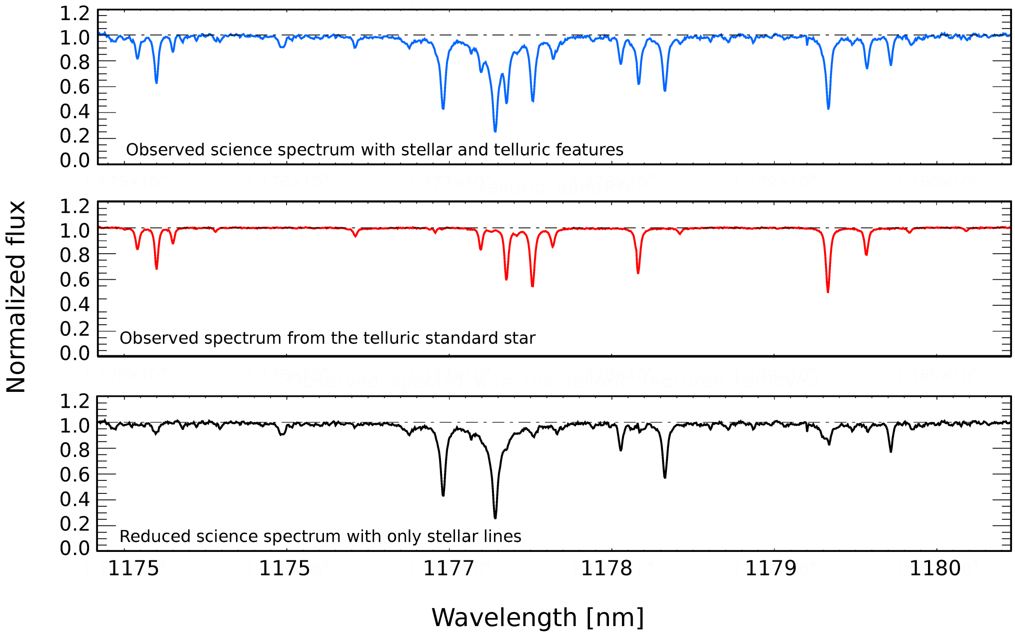

Figure 1: An example of a continuum rectified and wavelength corrected spectrum in a short wavelength interval for the star GJ 179. The science spectrum can be seen in the top panel, in the middle panel shows the spectrum of the telluric standard star and the bottom panel shows the science spectrum where the telluric lines have been removed. The continuum can be seen as the dashed line. Figure from Lindgren et al. (2017).

References:

Boyajian T. S., 2012, ApJ, 757, 112
Dressing, C. D. & Charbonneau, D., 2015, ApJ 807, 45
Gustafsson, B., 1989. ARA&A, 27, 701
Lindgren, S., Heiter, U., & Seifahrt, A., 2016, A&A, 586, A100
Lindgren, S., &Heiter, U., 2017, A&A, 604, A97
Mann, A. W., Feiden, G. A., Gaidos, E., Boyajian, T., & von Braun, K., 2015, ApJ, 804, 64
Pancino, E., et al., 2017, A&A, 598, A5
Piskunov, N.,& Valenti, J.A., 2017, A&A, 597, A16
Santos N.C., et al., 2015, A&A 580, L13
Valenti, J. A. & Fischer, D. A., 2005, ApJS, 159, 141

11. List of targets (note that the absence of a proper object list and information may weaken the proposal)

Name	α	δ	Epoch	Mag.	Time	Additional Information
GJ 436	11 42 11.09	+26 42 23.66	J2000	J6.9	1200s	M3.0
GJ 526	13 45 43.78	+14 53 29.47	J2000	J5.18	200s	M1.5
GJ 581	15 19 26.83	-07 43 20.19	J2000	J6.706	1200s	M2.5
GJ 699	17 57 48.50	+04 41 36.11	J2000	J5.244	300s	M4.0
GJ 338A	09 14 22.78	+52 41 11.79	J2000	J4.89	200s	M0.0
GJ 411	11 03 20.19	+35 58 11.57	J2000	J4.13	100s	M2.0
GJ 412A	11 05 28.58	+43 31 36.39	J2000	J5.56	300s	M1.0
GJ 687	17 36 25.90	+68 20 20.90	J2000	J5.37	300s	M3.0
GJ 725A	18 42 46.71	+59 37 49.41	J2000	J5.19	200s	M3.0
GJ 725B	18 42 46.89	+59 37 36.72	J2000	J5.72	300s	M3.5
GJ 809	20 53 19.79	+62 09 15.81	J2000	J5.52	300s	M0.5
GJ 514	13 29 59.79	+10 22 37.78	J2000	J5.902	600s	M1.0
GJ 649	16 58 08.85	+25 44 38.97	J2000	J6.448	600s	M2
Gl 806	20 45 04.0	+44 29 56	J2000	J7.317	1800s	M2.0
Gl 752A	19 16 55.2	+05 10 08	J2000	J5.543	300s	M2.1
Gl 745 B	19 07 13.2	+20 52 37	J2000	J7.291	1800s	M2.1
Gl 745 A	19 07 05.5	+20 53 17	J2000	J7.321	1800s	M2.1
Gl 740	18 58 00.1	+05 54 29	J2000	J6.257	600s	M0.7
Gl 729	18 49 49.3	+23 50 10	J2000	J6.225	600s	M4.1
Gl 701	18 05 07.5	+03 01 52	J2000	J6.180	600s	M1.3
Gl 694	17 43 55.9	+43 22 43	J2000	J6.845	1200s	M2.6
Gl 686	17 37 53.3	+18 35 29	J2000	J6.382	600s	M1.2
Gl 685	17 35 34.4	+61 40 53	J2000	J6.908	1200s	M0.8
Gl 678.1 A	17 30 22.7	+05 32 54	J2000	J6.307	600s	M0.5
Gl 649	16 58 08.8	+25 44 39	J2000	J6.495	600s	M1.3
Gl 628	16 30 18.0	+12 39 44	J2000	J5.952	600s	M3.6
Gl 625	16 25 24.5	+54 18 14	J2000	J6.625	1200s	M2.1
Gl 555	14 34 16.8	+12 31 10	J2000	J6.861	1200s	M4.0
Gl 505 B	13 16 51.5	+17 00 59	J2000	J6.546	600s	M0.7
Gl 471	12 31 15.8	+08 48 38	J2000	J6.821	1200s	M0.3
Gl 447	11 47 44.3	+00 48 17	J2000	J6.568	600s	M4.3

12. Observational strategy and justification of requested time, including overheads.

Our aim is to observe a sample of M dwarf benchmark stars. The selected stars have known bolometric flux and effective temperature estimated from photometry. We aim to achieve an uncertainty of < 0.1 dex for [M/H] and elemental abundances and 150 K for effective temperature. To meet these goals we estimate that a S/N of 150 is needed. Given exposure times are calculated using the GIANO-B Exposure Time calculator, with the goal of achieving S/N $\sim$ 150 in the J-band for each target. The table lists the time on target. We estimate an additional overhead of 11.5 min per target according to the information on the GIANO-B web page. This amounts to about 14 hours.

Given the importance of telluric correction, we plan to observe rapidly rotating, early-type telluric standard stars several times during the night. Flat field, darks, and wavelength calibration will be needed and acquired during daytime. We require three observations of telluric standard stars per night. Assuming typical early-type stars with J magnitude of 5, it amounts to about 2 hours. In total the requested observation time is about 16 hours, that is two nights of observations.

Note that we do NOT apply for simultaneous observations with HARPS-N (GIARPS). Our targets are much fainter in the optical wavelength region than in the infrared, and obtaining a similar S/N in the optical would require twice as much observing time. Furthermore, current tools do not allow us to extract useful information from the optical spectra of M dwarfs.

11a. Additional list of targets

Name	α	δ	Epoch	Mag.	Time	Additional Information
GJ 1230 A	18 41 09.7	+24 47 14	J2000	J7.511	1800s	M4.3
Gl 436	11 42 11.0	+26 42 24	J2000	J6.911	1200s	M2.8
Gl 406	10 56 28.9	+07 00 53	J2000	J7.074	1200s	M5.9
Gl 388	10 19 36.2	+19 52 12	J2000	J5.502	300s	M3.4
Gl 382	10 12 17.6	+03 44 44	J2000	J5.904	600s	M1.9

13. Requested instrument(s) setup

Id	Instrument	Binning	Filter(s)	Slit	Grism	Time	Additional Information
	GIANO-B		none			16hr	

14a. Moonlight constraints

Max. # of days from new moon ☐

14b. Scheduling constraints, special requirements and other remarks
(please include justification of constraints in 14a)

Not between June 18 and June 25.

15. Observational background of the applicants

Name of the observer(s) at TNG: Terese Olander, Ulrike Heiter, Oleg Kochukhov

Experience of the observer(s) with the requested TNG instrument(s)
O. Kochukhov has contributed a science case to the GIANO white book. He obtained some commissioning spectra for hot magnetic stars in collaboration with E. Oliva and L. Origlia. The analysis of these spectra is currently ongoing. O. Kochukhov has also observed with GIANO-B in 2017 in visitor mode.

Experience of the observer(s) with other telescopes/instruments
Oleg Kochukhov has done visitor mode runs with FIES@NOT, HARPS@ESO3.6m, UVES@VLT, CRIRES@VLT, SARG@TNG, and other high-resolution spectrometers.
The observing experience of Ulrike Heiter includes about 100 visiting observing nights at European Southern Observatory (ESO, La Silla), Observatoire de Haute Provence, Osservatorio Astronomico di Padova, Kitt Peak National Observatory (Tucson, Arizona), McDonald Observatory (Fort Davis, Texas), and the CHARA Array (Mt. Wilson, California, remote operations from Nice, France). Also, more than 100 hours of service observing time have been obtained at ESO (Paranal) and Télescope Bernard Lyot (Pic du Midi).