NORDIC OPTICAL TELESCOPE

Proposal *65-*

APPLICATION FOR OBSERVING TIME
OBSERVING PERIOD 65
April 1, 2022 October 1, 2022

1. Title of proposal:

Measuring at Intermediate metallicity Neutron Capture Elements

2. Abstract:

The understanding of the physics of the different neutron capture processes (slow, rapid and possibly intermediate) and the comprehension of the Milky Way chemical evolution require precise abundances of n-capture elements in metal-poor stars. The intermediate metallicity range ($-2.5 \leq$ [Fe/H] ≤ -1.5) is particularly interesting because it allows discriminating different models. Surprisingly there are far fewer measurements of n-capture elements abundances in this metallicity range than at lower metallicities. The Measuring at Intermediate metallicity Neutron Capture Elements (MINCE) project aims at filling this gap. Thanks to FIES spectra, we will determine precise chemical abundances in 16 metal-poor giants. This sample will be part of the 5-year MINCE legacy: a catalogue of 1,000 high quality spectra with precise atmospheric parameters and chemical abundances constructed by combining observations from several facilities.

3. Principal Investigator: (**NB:** The P.I. has full responsibility for the content of this proposal!)

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5. If this is a PhD thesis project at a Nordic institute, please give name of student, supervisor and expected time of completion:

6. Observing period(s) and observing mode(s) requested and preferred scheduling:

NB: By applying for observations that require additional services, the P.I. indicates that adequate funds will be available to cover these costs. The home institute of the P.I. takes responsibility for any required contribution

Run	Mode	Instrument	Time	Month(s)/Date(s)	Moon	Seeing	Sky
A	V	FIES	3N	April	N	N	T

7. Number of nights already awarded to project: 7

8. Number of nights needed to complete project: 8

9. Any other special constraints on the scheduling?

10. Scientific justification for the proposal:

In this proposal, we intend to study the nucleosynthetic signatures that can be found in old stars, in particular in a specific class of chemical elements, the neutron-capture elements. Elements with $Z > 30$ are labeled neutron-capture elements: they are mainly formed through multiple neutron captures, and not through stellar fusion. The n-capture process is split in the rapid process (r-process) or slow process (s-process) depending on whether the timescale for n-capture is faster or slower than radioactive beta decay, according to the initial definition by Burbidge et al. (1957). These elements have complex nucleosynthesis and they are not yet deeply investigated as - for example - α elements. The first peculiarity observed for n-capture elements was the spread in halo stars (McWilliam et al. (1998). This was later confirmed by the studies with high-resolution spectra and detailed chemistry of about 30 elements (François et al 2007, Honda et al. 2004). Indeed, it appeared clear that, contrary to other lighter elements such as α elements and iron peak elements, the spread was real. The most recent investigation expanded the number of the stars with detailed chemistry at extremely low metallicity up to approximately a thousand objects (e.g. Roederer et al. 2014, Yong et al. 2013). After this incredible effort in searching and measuring the most extreme metal-poor stars - that is still ongoing - it is natural to think that adding valuable knowledge in this field can be difficult or extremely expensive. However, the search of the lowest possible metallicity have almost completely ignored all the stars in the intermediate range of metallicity between the very metal-poor stars ([Fe/H]< -2.5) and thin or thick disc stars ([Fe/H]> -1.5). In this region, the number of stars with any measurements of the n-capture elements is tiny, only 20% of the stars according to the sample gathered by the JINA database, and only 10% with Eu measurements. According to the metallicity distribution function of the Galactic halo (Schörck et al. 2009) 90% of halo stars are actually in this region, with only 10% percent at lower metallicity, therefore an enormous number of halo stars are yet unexplored as far as the abundances of n-capture elements go. That apart, the more general target of a complete census of the Galactic halo stars, several scientific questions can be addressed thanks to new abundance measurements of n-capture elements for stars in the region. It will be possible to study how the spread in the n-capture elements shrinks. The spread is produced by stochastic process driven by the rarity of the r-process events (Argast et al. 2004, Cescutti 2008), but the way this dispersion shrinks at higher metallicity constrains the rate of the r-process events in the Galactic halo (see Fig. 1). Hidden in this region, we could find also signatures of different types of r-process(es) that can have polluted the interstellar medium at different time scales. This could be the case if both neutron star mergers and magneto rotational driven SNe have contributed to the present amount of r-process material (Cescutti et al. 2015, Cote et al. 2018, Simonetti et al. 2019). Moreover, considering the possibility that a large fraction of the Galactic halo originally evolved in a massive satellite (Haywood et al. 2018, Helmi et al. 2018, Vincenzo et al. 2019), we also expect that the production of s-process elements by AGB stars has left a signature in the chemical abundances at this intermediate metallicity. All this information can be gathered only with a statistically sufficient number of stars for which there are n-capture element measurements from at least the first two s-process peaks but also r-process elements, like Sr - Ba, and Eu, respectively. Present surveys (APOGEE, GALAH) do not aim at providing spectra with sufficient quality to study the n-capture elements in this range of metallicity. In the near future WEAVE survey will certainly produce spectra for these stars in the north. Still, the wavelength range of the high resolution survey is limited, and WEAVE will not deliver all the elements that we can with this proposal at FIES. These elements will be fundamental to disentangle among the different n-capture processes potentially enriching the ISM, such as s-process from massive rotating stars and AGB, i-process, different r-processes from neutron star mergers and magneto-rotational driven SNe. Our proposal is part of the large collaboration MINCE, supported by the European COST Action ChETEC (http://www.chetec.eu/). It targets to gather abundances for n-capture elements of several hundreds stars at this intermediate metallicity using several facilities in a period of five years. Table 1 shows the status of the collaboration after five semester. We expect that our results will be an essential heritage for researchers studying the history of the chemical enrichment in the Galactic halo.

11. Scientific justification *–continued–*

Table 1 Awarded time by MINCE project:

telescope	instrument	time	targets	status
A40-41 TNG	HARPS-N	21 h	31	observed
A42 TNG	HARPS-N	1n	12	observed
A43 TNG	HARPS-N	1n	16	observed
CFHT 2019B+20A	ESPaDOnS	30h	12	observed
CFHT 2020B	ESPaDOnS	24.5h	6	observed
OHP 2019B+20A	Sophie	6n	42	observed
TBL 2020A	NeoNArval	13h	12	observed (reduction problematic)
2019B 2.2m	FEROS	4n	65(72)	observed (2n cancelled)
2020B 2.2m	FEROS	2n	65	observed
Magellan	MIKE	2n	14 (20)	observed (1 night cancelled)
VLT ESO period 105-107	UVES	50h	50	observed
VLT ESO period 106	UVES	50h	50	observed
period 61, NOT	FIES	3n	16	observed
period 62, NOT	FIES	8h	8	observed
ChETEC-INFRA 1, NOT	FIES	3n	16	not taken due to eruption
Moletai 1.65m	VUES	38n	24	observed

References: Anders, F., Khalatyan,

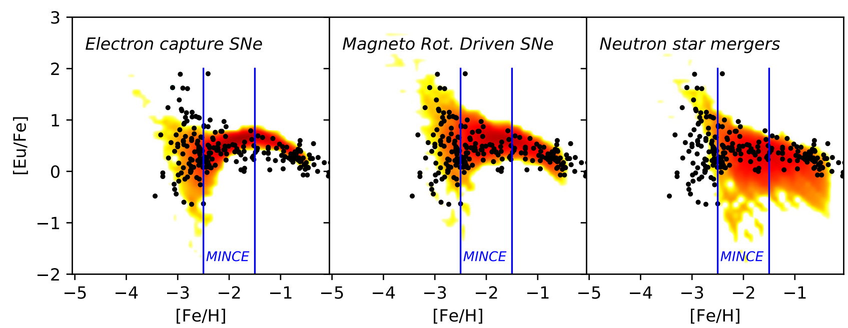

Fig. 1. Abundance ratios in metal-poor stars compared to Galactic chemical evolution models (adapted from Cescutti et al. 2014, Cescutti et al., 2015). It is striking how there are few observed data points in the metallicity interval $-2.5 \leq$ [Fe/H] ≤ -1.5, compared to those at [Fe/H]< -2.5.

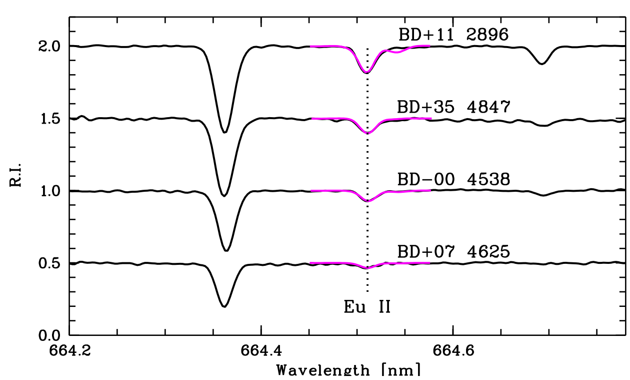

Fig. 2. Spectra of four targets taken by NOT a year ago in the region of an europium line. The magenta lines show preliminary synthetic spectra on this line. Preliminary abundances for BD +11 2896 and BD -00 4538 are available in Table 2 (box 16).

12. Technical description of the observations. (**NB:** Please provide a self-contained case.)

We propose to use FIES at NOT to measure abundances in 16 stars selected using Starhorse (Anders et al. 2019) to be metal-poor ([M/H]< -0.7) and bright (V<10.15) giants (T<5000 K). From the last year, thanks also to our previous results, we decide to add a constrain on the kinematics of the stars ($v_{tot} > 200$km/s) to select halo stars exploting the precise measurements of GAIA satellite. This selection scheme improved the success rate from 70% to almost 100%. For the final sample, we have chosen stars which have no information available in the literature on the abundances of n-capture elements and observable in September. We will measure with extreme quality up to 17 neutron-capture elements (Sr, Y, Zr, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Os, Th, see Fig.2). Clearly, many other elements, covering several nucleosynthetic channels will also be available including CNO, alkali metals (Li, Na), light odd elements (Al, Sc) α elements (Mg, Si, Ti), as well as iron peak elements (V, Cr, Mn, Fe, Co, Ni, Cu, Zn), will be available. The abundances of the elements Na-Zn will be measured with the automatic code MyGIsFoS (Sbordone et al. 2014, A&A 564, A109) that on spectra of S/N$\sim$ 100 at 500 nm has been shown to provide precisions of 0.01 to 0.02 dex (Caffau et al. in preparation). The other elements will be determined using line-profile-fitting, on which the team has ample experience. The goal of this proposal to measure detailed abundances of neutron-capture elements. Most of the transitions of the neutron-capture elements are located in the bluest portion of the spectrum (λ <4200 Å), therefore we request to have a SNR per pixel > 40 in this region. According to the FIES exposure time calculator in Ca II band, we estimate an exposure time of 6000s(4800s) for the faintest (brightest) stars in our sample to guarantee this SNR with an airmass of 1.3 and seeing 1.2 arcsec. With this exposure time a SNR per pixel of 70 will be reached in the reddest part of the spectrum (Band Z). Considering 300s of overheads per target and excluding the operations performed at the beginning of the night, we obtain a total 23.8 hours, so we apply for 3nights.

13. Requested instrument setup(s):

Run	Instrument	Mode	Setup
A	FIES	Spectro-Echelle	High-Res Fiber

14. Target list with coordinates, or intervals in R.A. and Decl. of (sample of) objects:

Run	Name	α_{2000}	δ_{2000}	Magnitude	Diam(′)	Additional Info.
A	TYC 3819-1030-1	10 28 55.02	+55 10 24.58	10.03	point source	vel_{tot}=191. km/s
A	TYC 2040-30-1	15 54 34.02	+29 43 53.89	10.03	point source	vel_{tot}=204. km/s
A	BD+26 2168	11 02 41.84	+25 34 12.61	10.04	point source	vel_{tot}=315. km/s
A	TYC 368-200-1	16 18 33.31	+01 52 13.92	10.04	point source	vel_{tot}=368. km/s
A	BD+64 1121	16 18 02.14	+63 40 58.53	10.05	point source	vel_{tot}=281. km/s
A	BD+62 1133	10 30 39.19	+61 58 09.08	10.07	point source	vel_{tot}=378. km/s
A	BD+42 2293	12 20 26.04	+41 56 28.86	10.09	point source	vel_{tot}=460. km/s
A	BD+38 2298	12 04 14.54	+37 30 21.58	10.1	point source	vel_{tot}=336. km/s
A	TYC 1543-168-1	17 05 29.79	+19 07 36.70	10.11	point source	vel_{tot}=264. km/s
A	TYC 1556-2546-1	17 45 35.30	+17 21 28.99	10.12	point source	vel_{tot}=331. km/s
A	BD+36 2282	12 34 59.39	+35 24 13.97	10.12	point source	vel_{tot}=410. km/s
A	TYC 1444-366-1	12 03 52.66	+21 52 26.49	10.12	point source	vel_{tot}=317. km/s
A	BD+28 2143	12 42 22.88	+27 56 42.36	10.12	point source	vel_{tot}=360. km/s
A	TYC 2035-1577-1	16 01 26.54	+23 04 49.00	10.12	point source	vel_{tot}=435. km/s
A	TYC 327-670-1	14 57 02.60	+01 58 23.58	10.13	point source	vel_{tot}=353. km/s
A	BD+19 3130	16 35 59.44	+19 26 26.47	10.13	point source	vel_{tot}=211. km/s

Remarks:

15. Backup programme (or justification why none is needed).

(**NB:** Also programmes to be done in service mode require a backup programme. The backup programme should also take unfavourable wind conditions into account)

Our project does not need excellent image quality or photometric conditions, but we will also provide stars not selected as best candidates, as alternative targets in case an unfavourable wind speed.

16. List of observing periods, and publications from NOT observations, within the last three years.

NOT61 (PI Spitoni): 3 night awarded, due to pandemic only 12 targets observed. Analysis has been carried out for 7 stars (see below for 2 of them). The quality of the data is excellent, 5 stars are in the MINCE regime, two are only mildly metal poor ([Fe/H]~ -0.3).

Table 2: Preliminary analysis of 2 targets taken in NOT61

BD +11 2896 29 species, 25 elements FeI= -1.48 ± 0.12, 196 lines				BD -00 4538 30 species, 26 elements FeI= -1.91 ± 0.10, 232 lines			
Ion	N(lines)	[X/H]	σ	Ion	N(lines)	[X/H]	σ
Y II	8	–1.54	0.13	Y II	10	–2.21	0.15
Zr I	3	–1.46	0.14	Zr II	2	–1.34	0.07
Mo I	1	–1.07		Mo I	1	–1.62	
La II	10	–1.15	0.11	La II	16	–1.65	0.17
Ce II	8	–1.42	0.12	Ce II	7	–1.80	0.07
Pr II	6	–1.30	0.24	Pr II	4	–1.87	0.06
Nd II	38	–1.11	0.22	Nd II	42	–1.59	0.16
Sm II	6	–0.87	0.30	Sm II	10	–1.37	0.16
Eu II	2	–0.87	0.01	Eu II	1	–1.04	
Lu II	0			Lu II	1	–1.20	

NOT62 (PI Cescutti): 0.7 night awarded, observations done in January 2021, analysis in undergoing.
NOT64 (PI Bonifiacio) 3 nights awarded (ChETEC-INFRA) due in Semptember 2021. Unfortunately, due to the vulcano eruption and the consequent presence of volcanic particles and clouds no data were taken.

17. Additional remarks not covered by the items above, if any:

In the previous six semesters, along with the NOT successful proposals, we have obtained spectra for almost 400 targets at SOPHIE-OHP, ESPADONS-CFHT, UVES-VLT, FEROS-2.2m, Mike-Magellan, VUES at Moletai Astronomical Observatory and HARPS-TNG (for details see Table 1).