EUROPEAN SOUTHERN OBSERVATORY

Organisation Européenne pour des Recherches Astronomiques dans l'Hémisphère Austral
Europäische Organisation für astronomische Forschung in der südlichen Hemisphäre

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APPLICATION FOR OBSERVING TIME — PERIOD: **78A**

Important Notice:

By submitting this proposal, the PI takes full responsibility for the content of the proposal, in particular with regard to the names of COIs and the agreement to act according to the ESO policy and regulations, should observing time be granted

1. Title — Category: **B–3**

First Stars relics in the Milky-Way and satellites

2. Abstract

There are two basic ways to probe the very first stellar formation events: look for pop III stars at high redshift, or observe, locally, the nucleosynthetic imprints of these first stars. Searches for the most metal-poor stellar content of the galactic halo are advancing fast and in the coming decade, we expect to have large samples of extremely metal-poor stars identified throughout the Milky-Way halo and the nearby galaxies (Magellanic Clouds and closest dwarf spheroidal galaxies). These stars still display in their atmospheres the imprints of metal-enrichement by pop III stars, and allow to gain insight on the nature and nucleosynthesis of the earliest chemical enrichement processes, provided that the detailed abundance patterns of these stars can be derived (eg Cayrel et al. 2004). This DRM reviews what major steps could be taken by a 42m ELT, examining the wavelength domains needed for various applications.

3.

Run	Period	Instrument	Time	Month	Moon	Seeing	Sky Trans.	Obs.Mode
A	79	UVES	20h	any	d	$\leq 0.8''$	PHO	v

4. Number of nights/hours	Telescope(s)	Amount of time
a) already awarded to this project:		
b) still required to complete this project:		

5. Special remarks:

6. Principal Investigator: Vanessa Hill (Observatoire de Paris, F, Vanessa.Hill@obspm.fr)

CoI(s):

7. Is this proposal linked to a PhD thesis preparation? State role of PhD student in this project

8. Description of the proposed programme

A) Scientific Rationale: There are two basic ways to probe the very first stellar formation events: look for pop III stars at high redshift, or observe, locally, the nucleosynthetic imprints of these first stars. This latter approach, often referred to as stellar archeology, has been so far persued in the Milky-Way halo.
Searches for the most metal-poor stellar content of the galactic halo have yielded significant samples of low-mass stars, that have lived close to a Hubble time, and still display in their atmospheres the imprints of metal-enrichement by pop III stars. They allow to gain insight on the nature (masses in particular) and nucleosynthesis of the earliest chemical enrichement processes, provided that the detailed abundance patterns of these stars can be derived (eg Cayrel et al. 2004).
So far, both the extremely metal-poor stars (EMPS) searches, and even more strikingly the high resolution spectroscopic follow up needed to derive accurate elemental abundances, have foccussed on a small volume around the solar neighborhood. Typically, main-sequence stars are confined within ∼XX kpc of the sun while giants can typically reach out to ∼XX kpc. In the coming decade, these sample will be enlarged and deepened (to V∼20), finally reaching to the full galactic halo (out to ∼80-100kpc). These will also includes the most metal-poor stars outside of the Milky-Way galaxy, in nearby satellite galaxies such as the Magellanic Clouds and the most nearby dwarf spheroidal galaxies. With this major step forward, one can hope to adress numerus questions that are today hampered by the lack of statistics and volume confined in the inner halo:

- what is the true lowest-Z boundery for low-mass stars ?
- and its corollary: how does star-formation proceeds close to zero metallicity ?
- what is the role of extremely massive popIII stars in the metal build-up ?
- is the outer halo preferentially populated by EMP stars (as has been suggested by the finding of the first [Fe/H]=-5 star in the HES sample, a category of stars that was absent from more nearby survey)
- does the population of most ancient stars (lowest-metallicity) vary upon the host-galaxy (or DM halo) they reside in (as has been suggested by Helmi et al. 2006) ?
- can the Lithium abundances (^{6}Li and ^{7}Li) observed in dwarf EMP stars be reconciled with Big Bang Nucleosynthesis under the concordance cosmological model ?
- what is the age of the most metal-poor stars (radioactive age-dating using Th and U, eg Cayrel et al. 2001, Hill et al. 2002, Frebel et al. 2007). What is the astrophysical site for the r-process neutron captures ?
- what are the role of cosmic ray spallation in the early galaxy (production of Be and ^{6}Li)

Below is an outline of the near future searches for EMPS that will be in need of high spectral resolution follow-up in the coming decade, together with the number of stars below [Fe/H]< -3 and < -5 expected to be found from these searches.

Survey	Hemisph.	Start	Eff. sky coverage	Eff. mag limit	$N < -3.0$ (EMP)	$N < -5.0$ (HMP)
HES	South	1989	6400 deg^2	$B < 17.0$	400	4
SEGUE	North	2005	1000 deg^2	$B < 19.0$	1000	10
LAMOST	North	2007	10,000 deg^2	$B < 19.0$	10,000	100
SSS	South	2007	20,000 deg^2	$B < 18.0$	5000	50

The estimated numbers of stars expected to be discovered in ongoing and near-future surveys for metal-poor stars, extrapolating the current results from the HES. [Courtesy N. Christlieb.]
By the time of the operation of an ELT, searches for EMPS will have been further extended to yet larger volumes and depth, reaching B=20-21. This is a very significant step, since it means that they will have *reached significant samples outside of the Milky-Way*, in the closest small galaxies: LMC, SMC and a few dSph galaxies. This will provide with the first strong test on the similarities / differences of the metallicity distribution function of the oldest stars in large (Milky-Way) and small (MC and dSph) galactic systems, a *direct constraint to galaxy formation and assembly scenarios at the earliest times.*

B) Immediate Objective:
To perform these detailed analyses of the genesis of the most ancient populations in the Milky-Way and nearby systems, one needs to perform high-resolution spectroscopy to measure accurately the elemental abundance patterns in stars of magnitudes down to B=19 to 20.
Because EMPS are very metal-poor, many atomic and molecular transitions in the V, R and IR bands are exeedingly weak, and the UV becomes a very important wavelength domain where instrisically strong lines are still detectable. Below is a short list of unique oportinities to be gained, at a resolution R 40000-70000 (single object, no requirement on spatial resol) for the study of EMPS with metallicities < -3 and down to < -5.
1) in the blue (370nm-520nm):
Most of the elements in very metal-poor stars can only be measured in the blue. This includes:

- numerous lines of Fe (two ionisation stages to constrain the stellar gravity -or luminosity and hence distance, aswell as microturbulent velocity)
- α elements (Mg, Ca, Ti) iron peak elements (Mn, Co, Ni), Zn, that allow to constrain the nucleosynthetic origin of the metal-enrichment and hence the nature and metal-production of pop III stars.

8. Description of the proposed programme (continued)

• heavy neutron capture elements (r-process elements). The radioactive elements Th and U that can be used for age-dating the stars fall in that category, whith theit most proeminent lines at 401.9nm and 386nm respectively (each extremely weak, Thλ401.9 can reach some 30mÅwhile Uλ385.96 reaches at most a few mÅ). This make radioactive age-dating will become possible for almost all the very metal-poor stars with r-process enhancements that will be detected by LAMOST for example (several hundred candidates expected) provided B=18 can be reached.

2) in the UV (310nm-370nm):

• Berylium (310nm) probes cosmic-ray spallation in the earliest phases of galaxy evolution. Reaching B=15-15.5 will turn the current handfull of stars ([Fe/H]<-2.5) where Be is measurable into a whole population (some 100 turnoff stars are currently known in the galactic halo with [Fe/H]<-3 at that magnitude limit)

• the r-process is still at loss of a production site, and, because of its rare nature, a very good probe of mixing of SNe products in the early galactic gaz. Many r-process elements can only be detected bluer than 3700A, most notably among the heaviest and lightest (Nb, Mo, Ru, Ag and Ir, Pt, Bi)

• Oxygen has other transitions (in V, R and H bands) but all of them become undetectable at the lowest metallicities, leaving the OH bands in the UV (310nm) the *only* probe of oxygen abundance in these stars. Oxygen is the most abundant element after He, and yeilds very important clues on the nature of popIII stars since it's production is mass-dependant

• similarly, Nitrogen is only detectable at the lowest metallicities from the NH bands around 336nm. Nitrogen is one of the current major puzzles for early nucleosynthesis (secondary element that should therefore be underabundant in metal-poor stars but instead shows a primary behaviour, and is even enhanced in the reccord-holders -5 metallicity stars).

3) The case of Li (670.7nm)

Lithium in old stars can give constraints on Big-Bang Nucleosynthesis and Ω_{baryon}. So far, its abundance has only been measured in the Milky Way. The ELT will give for the first time the opportunity to measure it in another galaxy (other DM halo). It is detected by its 670.7nm doublet, and will be measurable in the Sagittarius dwarf galaxy dwarf (turnoff) stars. (LMC will still be too faint, even for a 42m ELT).

C) Telescope Justification: We need the ELT because of the photon collecting power. Similar observations could be done with EXPRESSO in its 4-UT combined mode, **provided it goes all the way to UV** which is technically very difficult given the light-path to the common focus. Even in the (unlikely) event that the combined 4-UT mode reaches a 16m equivalent telescope, the limiting magnitudes that would be reachable there would be too shallow to reach the outer galactic halo stars and the nearest satellite galaxies (LMC, SMC, Sgr, Scl, Draco..).

D) Observing Mode Justification (visitor or service): visitor mode is preferred as we just love to sit in tin boxes and would like to see the Eiffeltower on its side.

E) Strategy for Data Reduction and Analysis: In parallel to the increasing accuracy of the observations of spectra, the corresponding stellar atmosphere modelling is also expected to progress significantly in the coming decade. Most notably, radiative transfer in 3D hydrodynamical stellar atmospheres is now starting to emerge, and will become the norm in the coming decade(s). Similarly, NLTE modelling is becoming feasible for numerou atoms. This has a strong impact especially in metal-poor stars where the UV flux is high and collisions are few (and LTE more easily violated).

8. Attachments (Figures)

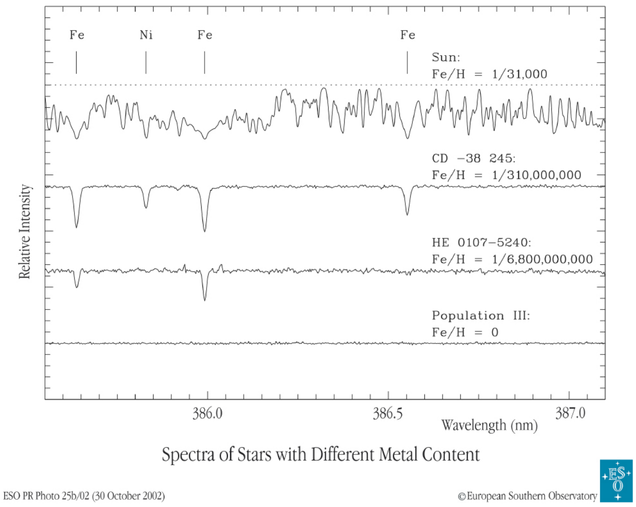

Fig. 1: Metal-lines in stars of various metallicities, in the blue wavelength. The stars targetted here are of [Fe/H]<-3 to -4. In the red wavelength domain, only very few and exceedingly weak lines persist at these metallicities.

9. Justification of requested observing time and lunar phase

Lunar Phase Justification: -

Time Justification: (including seeing overhead) The requirement for such a science case is a visual (and UV) single-object spectrograph with resolution R= 20000 - 70000 (around 40000-50000 being the best compromise), with no particular requirement on the spatial resolution (seeing limited is fine).
Using the ELT- Experimental ETC (Version 2.7WG) (integrated over 0.8" in a seeing limited observation with seeing=0.8"). These numbers wer checked and refined (at various wavelength) scaling up the current performances of VLT+UVES to a 42m telescope (1247m^2 vs 45.24m^2 collecting area):
1) Blue and UV
• Detailed abundance analysis of extremely metal-poor giants down to B=20 (i.e. reaching down to the level of the horizontal branch in the LMC): S/N=80-100 per resolution element is achieved in 2h in the B band at R=50000
• Uranium detection (& r-process elements) S/N=200 @386nm at R=70000 in 9h for a B=18 magnitude [Fe/H]=-3 giant.
2) Extreme UV • Nitrogen detection S/N=40 @336nm at R=50000 (or S/N=70 336nm at R=20000, since the bandhead is wide) in 3h for a B=19 [Fe/H]=-4 lower-RGB giant or turnoff star.
• Oxygen detection R=50000 S/N=50 @310nm in 10h for a B=17.5 [Fe/H]=-4 giant.
• Berylium detection R=50000, S/N=150 @310nm in 10h for a B=15.5 turnoff star at [Fe/H]<-3.
3) Red • Lithium detection S/N=60 @670.7nm in 7h for a V=21.5 turnoff star in the Sgr Galaxy.

Calibration Request: Standard Calibration

10. Report on the use of ESO facilities during the last 2 years

11. Applicant's publications related to the subject of this application during the last 2 years

12. List of targets proposed in this programme

Run	Target/Field	α(J2000)	δ(J2000)	ToT	Mag.	Diam.	Additional info	Reference star
A	name	RA	DEC	time(hrs)	mag	DM	ang diam(')	note

12b. ESO Archive - Are the data requested by this proposal in the ESO Archive (http://archive.eso.org)? If yes, explain why the need for new data.

13. Scheduling requirements

14. Instrument configuration

Period	Instrument	Run ID	Parameter	Value or list
79	UVES	A		