X-shooter Science Verification Proposal

Probing the nature of the Milky Way outer halo.

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Abstract:

We propose to observe 4 outer halo extremely metal poor stars with X-shooter. Targets have been selected on the basis of spectroscopic [Fe/H] estimates from SDSS/SEGUE DR7 to be the most metal-poor outer halo stars observable from VLT for the periods between June and August 2009. The goal is to obtain medium-resolution observations to measure Fe, C, Mg, Ca, Ti, Sr and Ba abundances with the aim of studying the nucleosynthetic signatures in the outer halo extremely low metallicity population. Observations of two extremely metal poor stars, a giant and a turn off star, with very well studied compositions are also requested, as their spectra will be used to prove the considerable accuracy that can be reached with X-shooter in abundance analysis of metal poor stars.

Scientific Case

The processes that led to the formation of the Galactic halo, its chemical evolution, and the nucleosynthetic mechanisms that contributed to it are key topics in modern astrophysics. The most metal-poor stars are believed to have formed at high z, holding clues on the conditions at the earliest epochs. While nucleosynthetic processes in the first generation of stars cannot be investigated directly, as in our Galaxy primordial stars with masses $> 0.8\mathrm{M}_\odot$ have evolved long ago, low mass, extremely metal-poor (EMP) stars allow to probe indirectly such processes, because their atmospheres carry the fingerprints of the nucleosynthetic processes that contributed to the early chemical evolution in the Milky Way.

In the last few years, considerable observational effort has been put into searching for the most metal poor stars in the Galaxy. A large number of the high-resolution spectroscopic studies have measured a wide set of chemical elements, ranging from Li (Spite et al 2005, A&A 430, 655) to the n-capture species (Sneden et al 2008, ARA&A, 46, 241), providing precious constraints on their formation scenarios and on the nucleosynthetic processes that took place in the early Galaxy.

In spite of this wealth of data, many unresolved issues still exist (e.g. the apparently contradicting findings of extremely uniform α/Fe ratios and highly scattered n-capture elemental abundances). The great variety of peculiar composition stars found among EMP is a challenge for present state-of-the-art stellar nucleosynthesis models, in particular the abundance ratios found in stars with [Fe/H]< -4.0 cannot be fully explained by current metal free SNe or AGB models (Heger & Woosley 2008 arXiv:0803.3161; Lau et al 2007, MNRAS, 378, 563).

One of the main problems in probing these issues is the small number of available objects. No metal-free, first star been found, and the number of detected stars with [Fe/H]< -4 is just five, about an order of magnitude less than what is expected on the basis of the simple, closed box Galactic model (Hartwick 1976, ApJ, 209, 418); possibly suggesting that because of the lack of coolants, the first generation of stars could not form low mass ($\sim 1\mathrm{M}_\odot$) objects, but only now extinct massive stars.

It should be noted that spectroscopic studies have essentially targeted objects belonging to the inner halo population. Given the recent discovery (Carollo et al. 2007 Nature, 450, 1020 and ref therein) that the halo is made of two different subpopulations, with distinct chemical (outer halo ~ 0.4 dex more metal-poor than the inner halo on average) and dynamical characteristics, observations of EMP in the outer halo is of particular current interest.

Hence, the outer halo might well harbor some of the most metal-poor stars in the Milky Way: its observation could allow to find the "missing" [Fe/H]< -4 stars, probing the minimum metallicity (and C abundance) for low mass star formation. Measurements of abundance ratios, in particular for Fe, C, α and Ba in a sample of outer halo stars would allow to shed light on its nature, and probe the hierarchical structure formation process that created the Milky Way. SDSS/SEGUE (Sloan Extension for Galactic Understanding and Exploration) obtained spectra of over 250,000 stars in the Galactic disk and halo, with magnitudes $14 < g < 20$, providing estimates for their metallicity. The reliability of these measurements has been tested by high-resolution follow-ups, making the SEGUE database an ideal mining site for EMP star searches. Its yield is much higher than that found in the two most widely used databases, HK and HES (e.g. Christlieb et al. 2001 A&A,366, 898), but it also reaches further out in the Galactic halo, increasing tremendously the sampled volume. Our team includes the vast majority of the ESO members scientists active in the metal-poor stars community. The present proposal is a joint effort aimed at providing evidence of the tremendous impact that X-shooter can have in our field.

Immediate Objective

We plan to obtain near-UV (330 nm) to near IR (2200 nm) spectra with X-Shooter for 4 outer halo stars. The setup selected uses the IFU, yielding resolving powers of 7900, 12600 and 8800 in the UV, visible and IR arms respectively, allowing measurements of Fe, C, Mg, Ca, Ti, Sr and Ba with an expected typical accuracy better than ∼0.3 dex, which is what is obtained with ESI at Keck (Lai et al 2009, 697, 63). O, Na and N estimates can be obtained from the IR part of the spectra. All targets are selected from SEGUE database DR7 and none of the targets is part of any GTO program.
We also plan to observe two bright metal poor stars: the giant CS 22189-009 (Cayrel et al. 2004 A&A 416, 1117 [Fe/H]=-3.49) and the turn-off star CS 29506-007 (Bonifacio et al. 2009 arXiv:0903.4174v1 [Fe/H]=-2.91) with well studied compositions. While such observations require a modest telescope time investment, they will be used to prove the remarkable accuracy that can be reached in stellar abundance analysis with X-Shooter data.

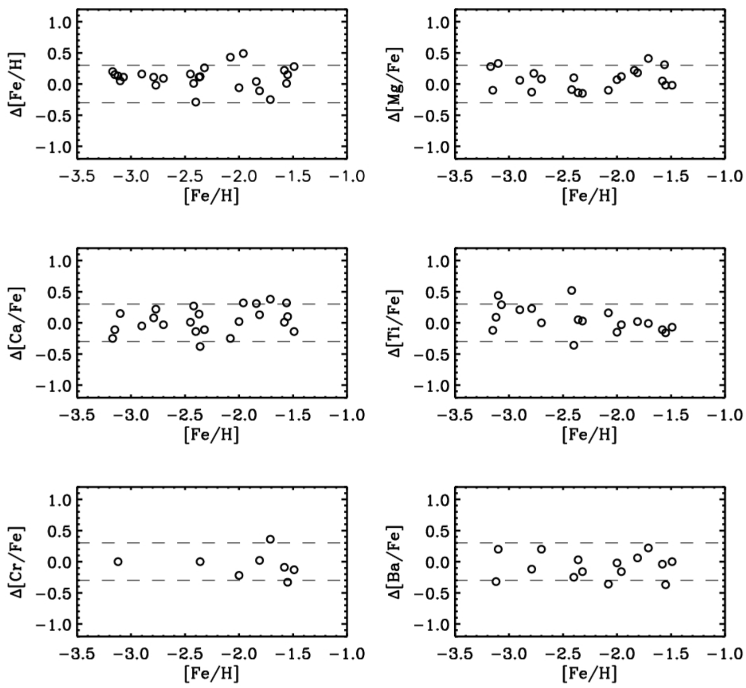

Figure 1: Fig. 1: Adapted from Lai et al. (2004). Abundances for Fe, Mg, Ca, Ti, Cr and Ba from Keck/ESI (R≃7,000) spectra vs literature high-resolution spectroscopy based abundances adopting the same atmospheric parameters as those in the high resolution analyses. Literature data are from Pilachowski et al. (1996, AJ, 111, 1689), Kraft & Ivans (2003, PASP, 115, 143), Sneden et al. (1997, AJ, 114, 1964), and Sneden et al. (2000, AJ, 120, 1351). This shows that with X-Shooter we can expect to measure abundances for these elements with an accuracy better than ∼0.3 dex.

Targets

Target	RA	DEC	V mag	Mode (slit/IFU)	Remarks
CS 22189-009	02 41 42.2	-13 28 15.0	14.00	IFU	Comparison giant star
CS 29506-007	21 20 28.6	-20 46 24.0	14.20	IFU	Comparison turn-off star
1501-53740-75	01 28 27.5	-00 45 12.6	17.74	IFU	SEGUE EMP target
2313-53726-624	01 13 23.60	00 26 31.6	17.10	IFU	SEGUE EMP target
2934-54626-396	14 43 23.88	00 06 50.2	17.84	IFU	SEGUE EMP target
2926-54625-152	13 12 52.39	-00 27 07.5	18.35	IFU	SEGUE EMP target

Time Justification:

Our objects are faint, halo objects. We require a S/N of ∼70 at ∼4600, based on previous experience with Keck/ESI , which has a similar resolution as (but more limited spectral coverage than) X-shooter, yielding a Fe, C, Mg, Ca and Ba abundance with a better than ∼0.3 accuracy (Lai et al 2004 AJ, 128, 2402). Exposure times have been calculated using the X-Shooter ETC version 3.2.8, assuming an airmass of 1.5. Target S/N are 60, 80 and 100 in the UV, Visual and IR arms respectively. Overheads have been estimated using the relevant information in the X-Shooter manual for P84. Total integration time (including overheads) for the 6 targets is of 6 hours.