PI: M. Bolte, U128NS,"Fluorine in the early Galaxy"

SCIENTIFIC JUSTIFICATION:

The chemical history of the Galaxy is written in the stars. In particular, the atmospheres of low-mass, extremely-metal-poor (EMP) stars carry the fingerprints of the nucleosynthetic processes which contributed to the early chemical evolution in the Milky Way: nucleosynthesis in early supernovae, in the first Asymptotic Giant Branch (AGB) stars, and in Pop III objects.

The last decade has seen a renaissance in this area, fueled by the discovery of a large number of EMP star candidates (Beers et al. 1992; Christlieb et al 2001) and high-spectral-resolution followup studies including those from our group (e.g. Lai et al. 2008). Measurements of chemical elements ranging from Li to the n-capture species have provided tests of nucleosynthesis pathways, physical conditions in stars, the initial mass function of the first stars in the Galaxy, new estimates of the age of the Universe and other wide-ranging topics. Most of the high-resolution studies have been carried out using optical spectra and as a result there are some potential important diagnostic elements about which little is known. One of these is Fluorine (F).

Fluorine is a particularly interesting element, as its abundance is very sensitive to the physical conditions in stars. It is one of the few elements for which we do not have a clear understanding of its principal source(s). Models suggest three possible sites for F production: Wolf-Rayet stars, Type II supernovae, and low-mass AGB stars. The modeling of the latter has received the most attention, and the prediction is that low-metallicity, low-mass (M<3-4Msun) AGB stars synthesize enormous quantities of F (see e.g. Straniero et al. 2004; see also Fig 1). It is noteworthy that F can be produced early in the AGB phase, prior to the synthesis of the s-process elements. On the other hand, massive AGB stars are expected to destroy F via Hot Bottom Burning (HBB, see Smith et al. 2005). However, there are still many remaining uncertainties in the details of the AGB modeling at low metallicity.

Cunha et al. (2003), on the basis of observations of HF in stars in the LMC and in Omega Centauri, argued that AGB stars are unimportant producers of F, and instead proposed the neutrino process in supernovae or winds from massive Wolf-Rayet stars as the main sites of F production. Models show however that both SN and WR F yields should be metallicity dependent, decreasing to very low (SN) or essentially zero (WR) at low metallicities (see Alibes, et al. 2001;Meynet & Arnould 2000). Renda et al. (2004) showed that the inclusion of a non-negligible contribution from AGB stars to F production is necessary to reconcile the discrepancy existing between Galactic chemical evolution models and the F abundances measured in Milky Way field stars. Moreover, there is now mounting observational evidence (Jorissen et al 1992; Werner & Herwig 2006) that at solar metallicities AGB stars are important sources of F.

It was recently shown (Lucatello et al. 2005) that likely *all* C-rich, EMP stars (CEMP) with s-process enhancement (the CEMP-s stars) belong to a binary system. CEMP-s are then the metal poor analogies to the classical CH and Ba stars: low-mass stars whose intermediate mass (between 1.5 to 4 Msun) companion, now a faint white dwarf, dumped material processed during its AGB phase on their surfaces, leaving its chemical fingerprints in the composition of their envelopes. Therefore, the nucleosynthetic processes taking place in EMP, intermediate-mass stars, now long extinct, can be investigated directly through the study of CEMP-s stars characteristics. These are an excellent laboratory for exploring F production in AGB stars.

So far, only a handful of measurements of F abundance in EMP stars have been obtained. Schuler et al. (2007) measured an enormous F overabundance in one CEMP-s star HE 1305+0132 ([F/Fe]=+2.9) apparently verifying model predictions. On the other hand, we recently collected VLT CRIRES spectra for ten CEMP stars and only two F measurements could be obtained (the highest F abundance being [F/Fe]=+1.5 Lucatello et al. 2008 in prep), while for the rest of the sample only upper limits could be placed, suggesting that perhaps, at least in most cases, F production in AGB stars is not as large as predicted in the current models.

The comparison of the model predictions with the set of elemental abundances that have already been measured (C, alpha and n-capture), with the addition of F, N, O and C isotopic ratios (measured respectively from the CN and CO bands in the same spectral region as HF) can shed light on the source of F in the early Galaxy and provide strong constraints on the quantitative reliability of the nucleosynthetic AGB models. This understanding is of particular importance--given the mounting evidence for a primordial stellar population particularly rich in intermediate-mass stars (see e.g. Abia et al. 2001).

OUR PROGRAM

Given the handful of existing studies of F abundances, the obvious next step is to obtain observations for a sample of cooler CEMP stars (Teff < 4700) to improve our ability to make actually measurements rather than deriving upper limits. We plan to use NIRSPEC to observe a sample of eleven CEMP stars measuring F from the only strong, clean HF line in the K-band, at 2.335μm, and O and C isotopic ratios from the CO lines scattered all over the range. Our sample is comprised of cool C-rich objects for which optical spectra analysis are either published in the literature or available to our group. The HF lines will be clearly detectable down to [F/H]=-1.0 (see e.g. Fig 2). CO bands are plentiful in cool, C-rich stars such as those in the present sample. This will allow the measurements (or determination of useful upper limits) of F, O, and Na abundance as well as C isotopic ratios. On the basis of the F, O and Na abundance measured in CEMP-s stars, together with the information obtained from the optical (alpha-elements, C, N, n-capture abundances) we will be able to shed light on the origin of F in the Early Galaxy and set strong constraints on the AGB models.

Na is predicted to be produced, in different amounts, in AGB stars (see Fig 2) by n-capture nucleosynthesis in the He-shell flash, therefore its abundance provides crucial anchor for the physical conditions of the n-capture. It probes the ^{22}Ne source, whereas the bulk of the trans-iron s-process elements, at least in the standard model that is valid for moderately metal-poor stars, comes from radiative ^{13}C burning.
O production in low metallicity AGB is still controversial. Some models predict large intershell O abundances (see Herwig 2004), and this is partly supported by post AGB star observations. CEMP provide the ideal testing ground, the (absolute) amount of O present in the envelope is low allowing detection of the presence of a O enhancement due to the accreted material. At higher metallicities the enhancement would be negligible with respect to the original O content in the envelope of the accreting star.

The proposed measurements will provide important information to address a range of questions: AGB star structure, AGB star evolution, nucleosynthesis at low metallicity, the origin of F, and ultimately the early chemical enrichment of the Galaxy.

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FIGURES:

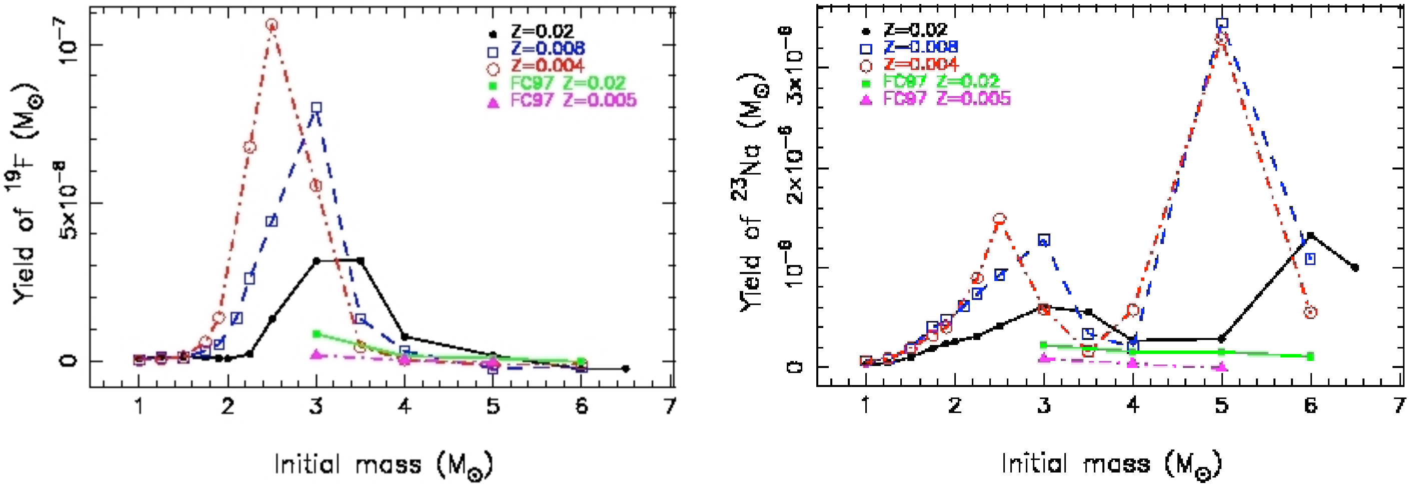

Figure 1: F (left panel) and Na (right panel) in AGB stars as a function of stellar mass, plotted for different metallicities (Karakas 2003).

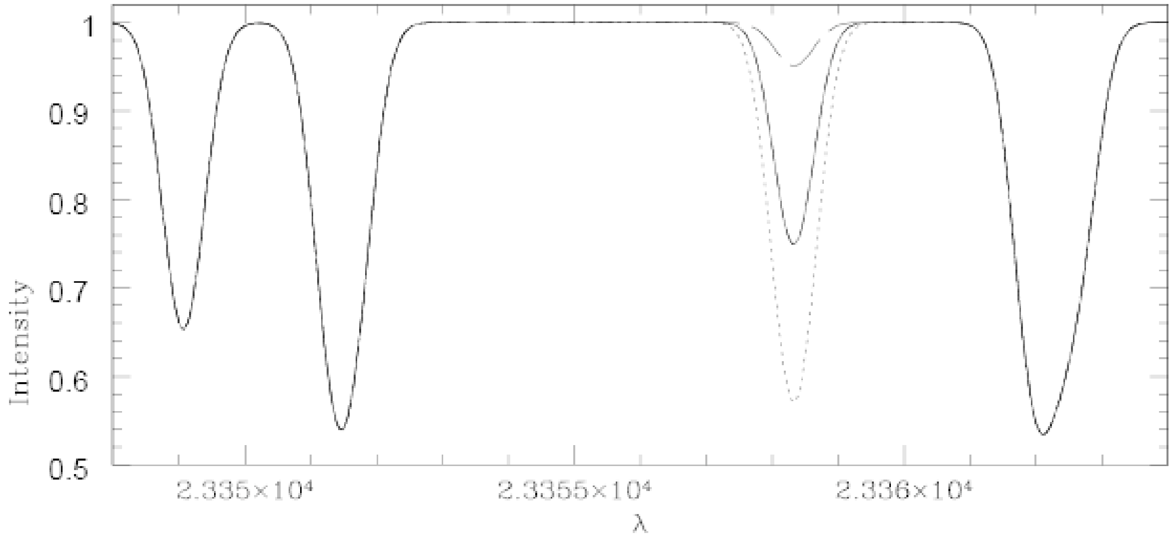

Figure 2: HF line synthesis, with R=35,000, for a star with Teff=4400, log g=1.0, [Fe/H]=-2.5 and [C/Fe]=1.5, typical values for our sample. The F values used are [F/H]=-1.0,0.0,1.0.

Technical Remarks:

We require a resolution of R≈35,000 attainable with a slit width of 0”.29.

To attain accurate background subtraction, we will follow the standard nodding procedure ABBA sequence. The setup adopted will center the HF line at 23358.3 Å in the central order (#33) . The resulting wavelength range encompasses a very large number of ^{12}CN, ^{12}CO and ^{13}CO (including the bandhead at ~24150 Å), as well as two Na lines at 23360 and 23380 Å.
To meet the accuracy requirements of our scientific goal (0.2 dex in abundance determinations) we require a signal-to-noise ratio of 120 per pixel for the program stars. In the case of exceptionally bad seeing or transparency, we will focus on the brighter targets, and take longer exposures.

Targets and Exposures:
The targets have been selected among CEMP cool stars (Teff <4700 K) to allow the measurement of F down to low abundances ([F/H]=-1, see Fig 2). These are rare objects and only a handful are accessible in the northern hemisphere. For comparison sake, we also include two objects we already observed with CRIRES for which F has been measured , HE1152-0355 and HD5223. A number of early type stars will also be observed for accurate telluric features subtraction. The stars labeled with * are for 2009B.
The required signal-to-noise ratio for our purposes is of ~120 per pixels and the exposure times have been computed accordingly, on the basis of the sensitivities values provided on the NIRSPEC webpage, including for each object the overhead for the nodding cycles and the telluric calibration spectra acquisition.

Name	**RA**	**DEC**	**V**	**K**	**Teff**	**[Fe/H]**	**exptime(h)**
HE5223	00 54 14.0	+24 04 01	8.47	5.670	4500	-2.0	0.4
V Ari	02 15 00.1	+12 14 23	8.52	4.364	3580	-2.4	0.4
HE0319-0215	03 21 46.3	-02 04 34	13.60	11.063	4502	-2.3	1.5
HE0322-1504	03 24 40.1	-14 54 24	13.80	11.340	4467	-1.7	2.0
G 77-61	03 32 38.1	+01 58 00	13.90	10.480	4000	-4.0	1.0
*HE1152-0355	11 55 06.1	-04 12 24	11.43	8.429	4000	-1.3	0.5
*HE1204-0600	12 07 11.6	-06 17 06	14.00	10.703	4100	-2.0	1.2
*HD 122956	14 05 13.0	-14 51 25	7.25	4.563	4510	-1.95	0.5
*HE1429-0551	14 32 31.3	-06 05 00	12.61	10.066	4700	-2.47	0.8
*CS30301-15	15 08 56.9	+02 30 19	13.04	10.738	4750	-2.63	1.2
*HD135148	15 13 17.5	+12 27 25	9.40	6.368	4100	-2.07	0.5
*HD187216	19 24 18.4	+85 21 57	9.56	6.025	3500	-2.48	0.4
*HD 189711	20 01 03.8	+09 30 51	8.42	3.804	3500	-1.8	0.4
*CS22892-52	22:17:01.5	-16 39 26	13.29	10.929	4700	-2.8	2.0
*HE2221-0453	22 24 25.7	-04 38 02	13.65	10.815	4400	-2.20	1.8
*HE2228-0137	22 31 26.2	-01 21 42	14.70	11.589	4570	-2.4	2.5

Path to Science: We will use the REDSPEC software package to reduce the spectra. The team includes experts in IR abundance analysis who will use state-of-the art spectral synthesis code to conduct the analysis. We will include the effects of the C-richness of our sample on the model atmospheres.

Status of previously approved Keck proposals related to this program: This is our first NIRSPEC proposal, however we have been assigned a total of 16 ESI or HIRES nights on stellar abundance related program since Aug 2000. Twelve of those nights were clear enough to get useful data. This is resulted in eight journal articles with two additional papers near completion.

Johnson, J. & Bolte, M., 2001, ApJ, 554, 888, ``Th Ages for Metal-poor Stars''.
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