CS 29497-030: Evidence for s-process operation in the Early Galaxy

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In the course of the ESO Large Programme "First Stars" (P.I. R. Cayrel), we have observed several stars which were classified as Turn Off (TO) on the basis of the medium resolution survey spectra and colours and yet showed a prominent G band, suggesting a strong C enhancement. Among these CS 29497-030 proved to be an exceptional object: it is very metal poor ([Fe/H]=–2.8), hotter than the Halo Turn Off (T_{eff} = 6650K, log$g$ = 3.5) and C, N and O are all strongly enhanced ([C/Fe] = +2.38, [N/Fe]= +1.88, [O/Fe]= +1.67), as well as Na ([Na/Fe]=+0.52) and all of the $n-$ capture elements. Most striking is the large Pb overabundance ([Pb/Fe]= +3.5). This large Pb overabundance and the overall abundance pattern of $n-$ capture elements may be understood as a signature of the $s-$ process in very low metallicity stars. This strongly suggests that the $s-$ process was fully operative at early times in the Galaxy.

Observations and data reduction

The spectra were obtained at the VLT-Kuyen 8.2m telescope, using the UVES spectrograph (Dekker et al 2000) at a resolving power of $R = 43000$. The UVES context within MIDAS was used to reduce the spectra. Equivalent-width measurements were performed by fitting gaussian profiles, using the genetic algorithm code described in François et al. (2003).

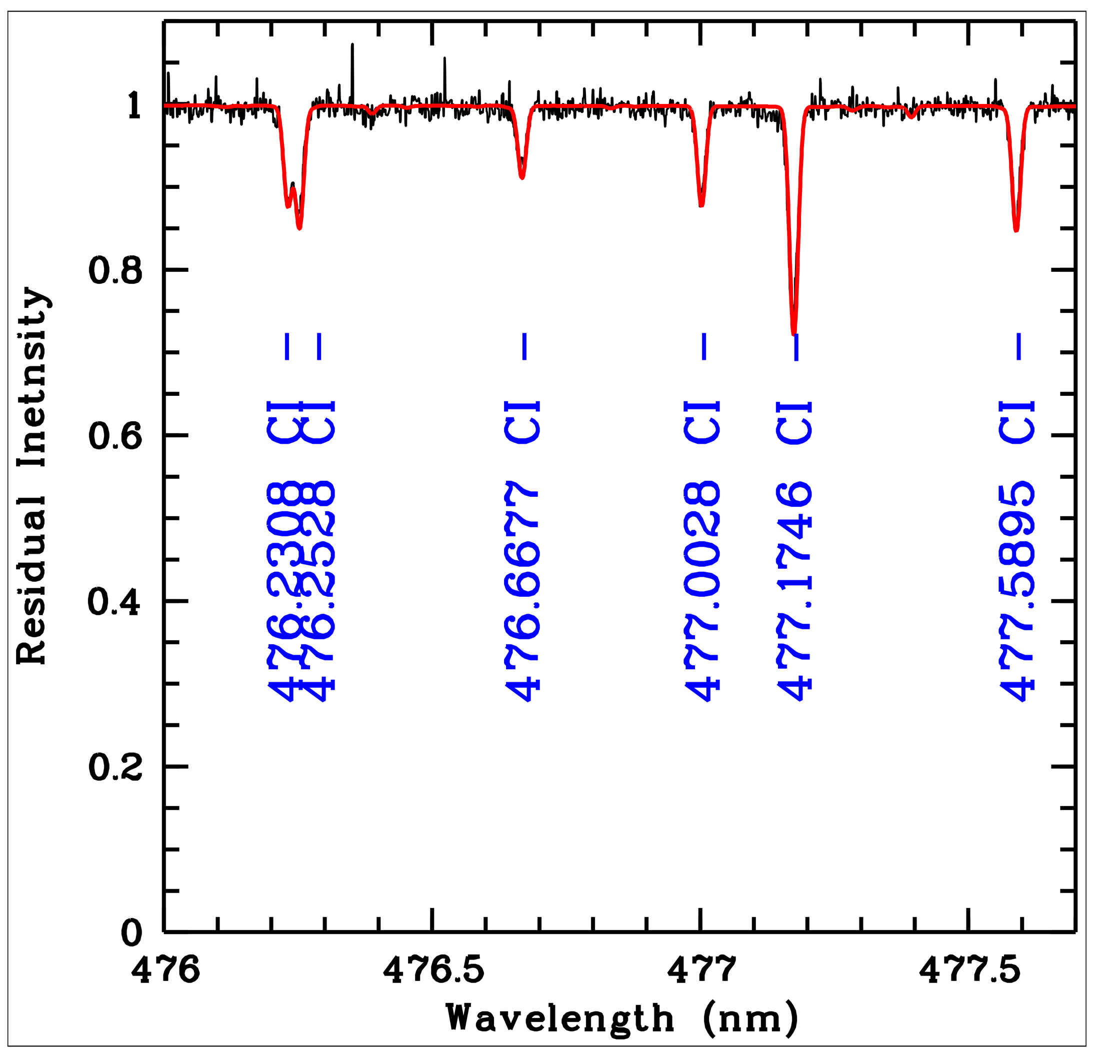

Fig. **1.** Examples of the high-excitation CI lines observed in CS 29497-030. The red line is the synthetic spectrum computed with the fitted C abundance, which is 0.3 dex higher than what is derived from the CH lines.

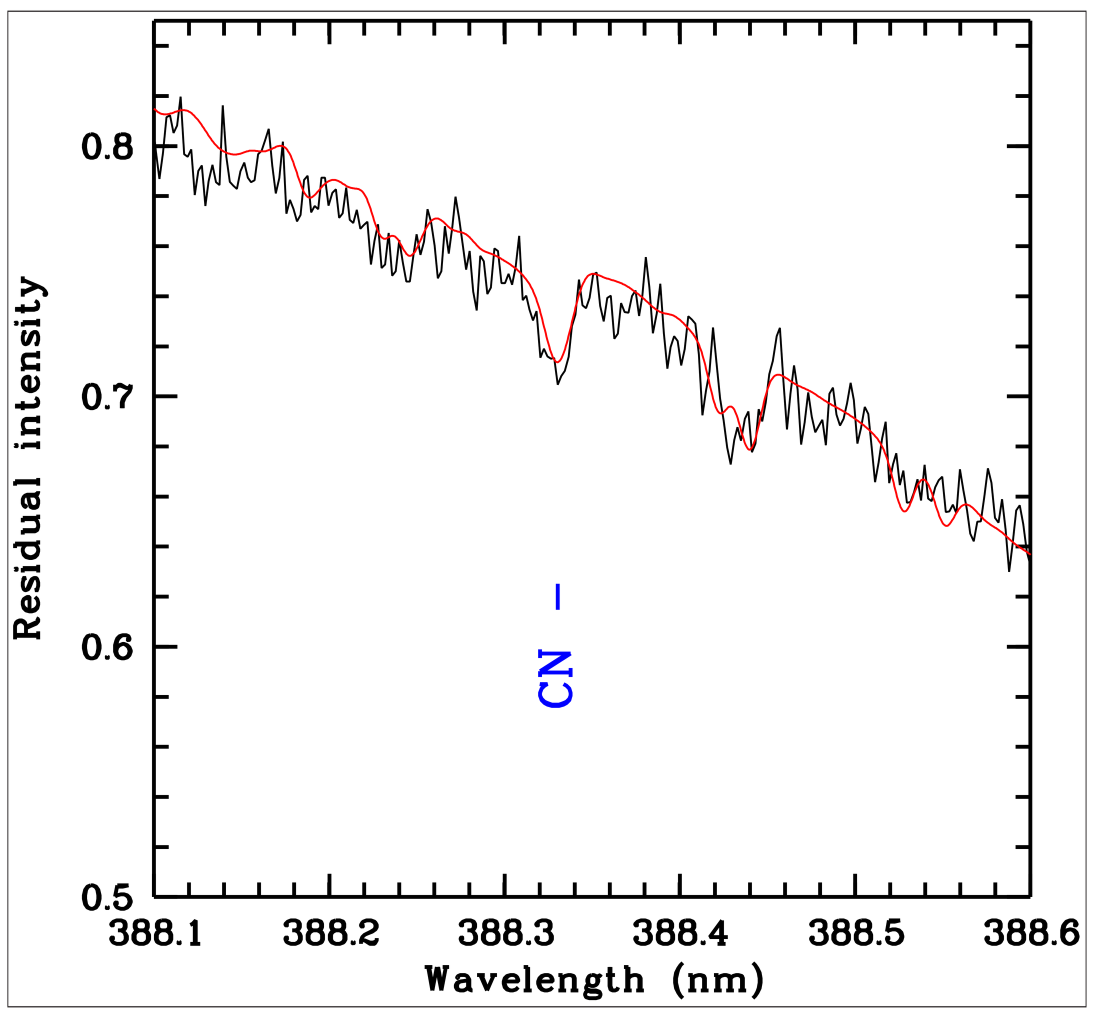

Fig. **2.** The CN 388nm bandhead. The black line is the observed spectrum, while the red line is the synthetic spectrum.

Analysis and results

The analysis was performed using OSMARCS model atmospheres and the TURBOSPECTRUM spectrum synthesis code (by B. Plez). From the Fe I excitation equilibrium we derive T_{eff} = 6650 K, the Fe I/Fe II ionization equilibrium implies log g = 3.5 . From 29 unblende Fe I lines we derive a very low metallicity ([Fe/H]$\simeq -2.8$), as expected from the low resolution spectra. Carbon appears higly enhanced, both from the CH lines and from the high excitation CI lines shown in Fig. 1. However the latter provide an abundance which is 0.1–0.3 dex higher than that derived from the CH lines. We suspect that this is due to NLTE effects and consider the abundance derived from the CH lines more reliable. Also N is found higly enhanced ([N/Fe]=+1.88) from the very weak CN 388nm bandhead, shown in Fig.2

The oxygen abundance was derived from the OI 777.4 nm triplet shown in Fig. 3. Our high [O/Fe]=+1.67 includes an NLTE correction of –0.09 dex as prescribed by Gratton et al. (1999). All the $n-$ capture elements appear to be enhanced and especially Pb, the 405.7 nm line is shown in Fig. 4, which has the record value of [Pb/Fe]=+3.5 .

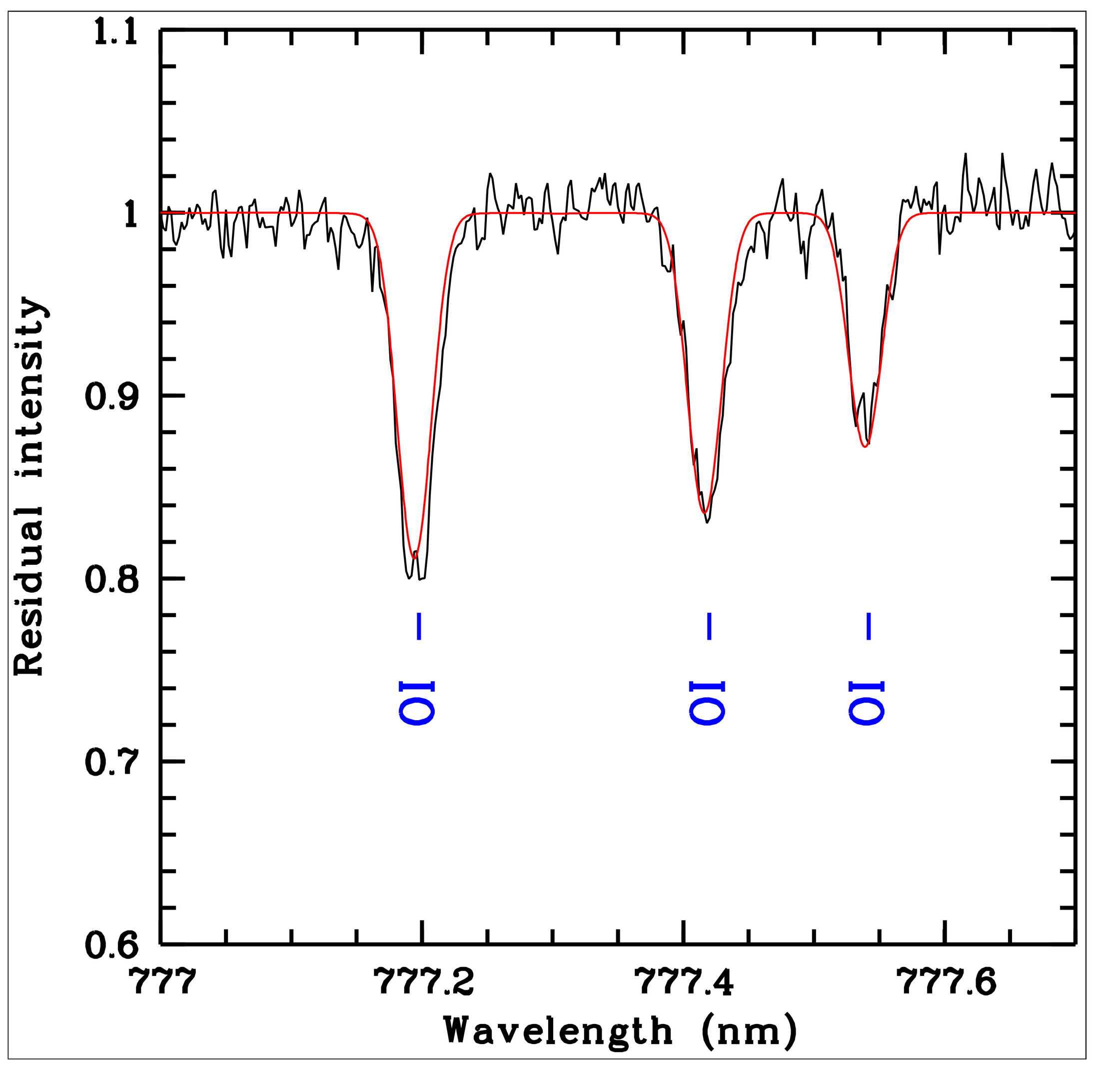

Fig. **3.** The OI 777nm triplet. In red the synthetic spectrum

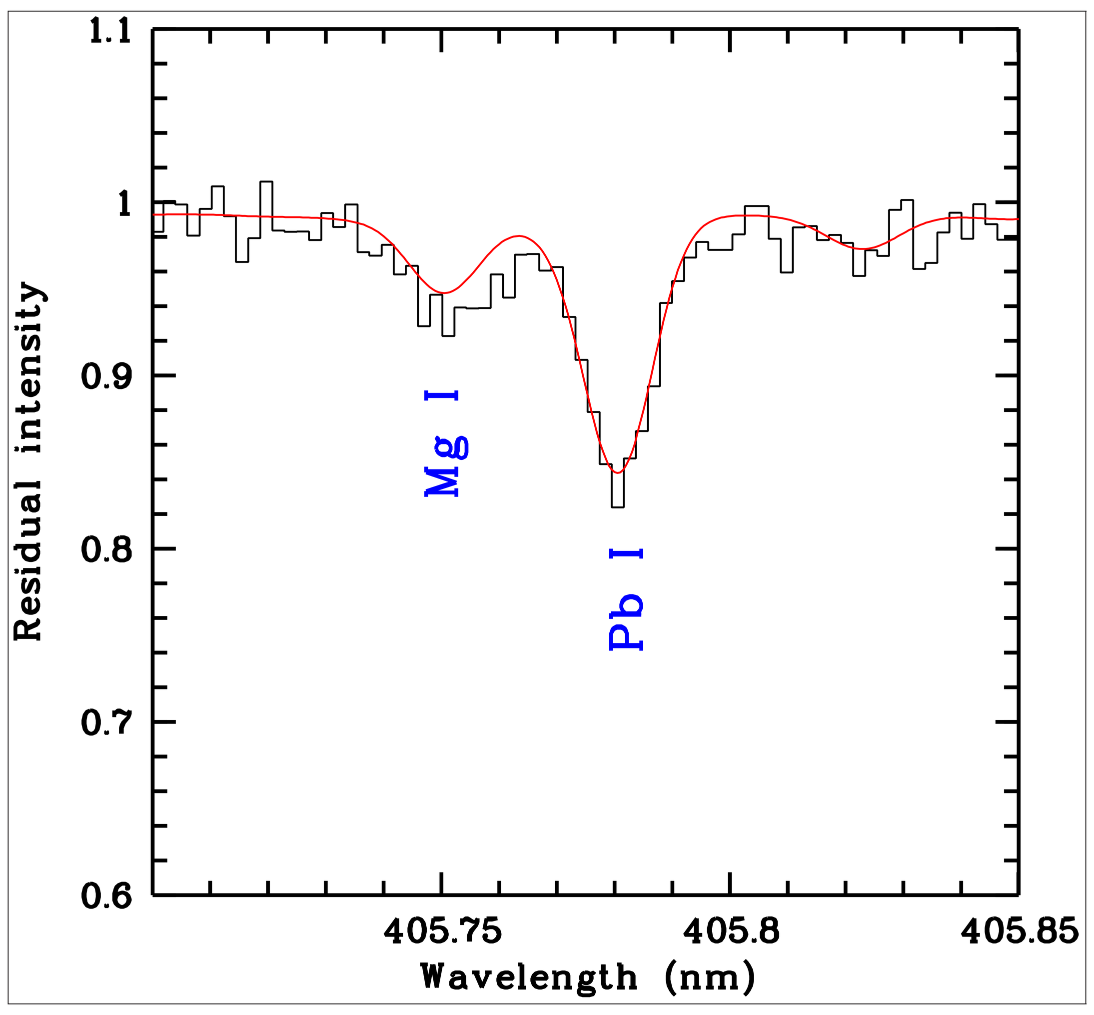

Fig. **3.** The Pb I 405.7nm line. The red line is the synthetic spectrum

Conclusions

The abundance pattern of the n capture elements seems to point unmistakably to the $s-$process. The large overabundance of Pb with respect to the nearby second-peak $s-$process elements (Ba, La, Ce, Nd) is a signature of the $s-$ process in a low metallicity environment, which is characterized by a large neutron-to-seed ratio. The site of the $s-$process is an Asymptotic Giant Branch companion star which has polluted the surface CS 29497-030 with its nucleosynthesis products, including C, N and, perhaps O. CS 29497-030 is a known binary with a period of 242 days (Sneden et al. 2003) but the companion has not been detected either photometrically or spectroscopically, in agreement with the notion that it is presently a white dwarf.

This star is an extreme case of $s-$ process enriched very metal poor star, 25 such stars are known so far. This shows that the $s-$process was operating at early times in the Galaxy. The importance of its contribution to the general evolution of n capture elements needs still to be assessed, however one can safely state that any realistic model of chemical evolution ought to take into consideration both $r-$ and $s-$ process *at all times*. The hypothesis that all the heavy elements are made only through the $r-$ process at low metallicity (Truran 1981) as an *a priori* should be abandoned.

Table 1. Elemental abundances for CS 29497-030

Species	A(X)$_\odot$	[X/H]	[X/Fe]	σ	n
Li I	1.10	< 0.00	<2.7	···	···
C I	8.52	−0.01	2.69	0.24	22
CH	···	−0.32	2.38	···	···
CN	7.92	−0.82	1.88	···	···
O I	8.74	−1.03	1.67	0.1	3
NaI	6.33	−2.18	0.52	0.15	2
MgI	7.58	−2.16	0.54	0.21	4
MgII	···	−2.06	0.64	···	1
Al I	6.47	−3.37	−0.67	···	1
Si I	7.55	−2.75	−0.05	···	1
Si II	7.55	−2.10	0.60	···	2
S I	7.33	−2.30	0.40	···	1
K I	5.12	< −2.00	<0.7	···	···
Ca I	6.36	−2.37	0.33	0.17	9
Sc II	3.17	−2.40	0.30	0.05	3
Ti I	5.02	−2.54	0.16	···	1
Ti II	···	−2.41	0.29	0.28	19
Cr I	5.67	−2.87	−0.17	0.12	6
Cr II	···	−2.75	−0.05	0.07	4
Mn I	5.39	−2.89	−0.19	0.28	3
Mn II	···	−2.87	−0.17	0.00	2
Fe I	7.50	−2.77	−0.07	0.14	55
Fe II	···	−2.70	−0.00	0.10	5
Co I	4.92	−2.28	0.42	0.10	2
Ni I	6.25	−2.91	−0.21	0.22	11
Zn I	4.60	< −2.80	<-0.10	···	···
Sr II	2.97	−1.86	0.84	0.05	2
Y II	2.24	−2.14	0.56	0.10	3
Zr II	2.60	−1.27	1.43	0.15	3
Ba II	2.13	−0.53	2.17	0.25	6
La II	1.17	−0.60	2.10	0.10	11
Ce II	1.58	−0.98	1.72	0.10	4
Nd II	1.50	−0.85	1.85	0.10	8
Eu II	0.51	−1.26	1.44	0.15	6
Pb I	1.95	0.85	3.55	···	1
$^{12}C/^{13}C$			> 10		

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