CARBON-ENHANCED METAL-POOR STARS AND EARLY GALACTIC CHEMICAL EVOLUTION

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HK survey:

Survey areas : 2800 deg^2 in the Northern Hemisphere

4100 deg^2 in the Southern Hemisphere

Used objective prism plates, 0.6m Burrell and Curtis Schmidt telescope

Yielded ~ 1000 stars with [Fe/H] < -2.0; ~ 100 stars with [Fe/H] < -3.0

(strength of Ca II K lines)

HES survey: Hamburg/ESO survey

Reaches apparent magnitudes 10.0 < B < 17.5

(11.0 < B < 15.5 HK survey)

Covers regions - not covered by HK survey

Expected to increase the number of EMP stars by almost an order of magnitude with respect to HK survey

HERES survey: Hamburg/ESO R-process enhanced stars

High resolution spectra with R=20000, S/N = 30-50 are obtained to identify r-II stars amongst candidate HES giants with [Fe/H] < -2.5

Discovered the most metal-poor stars known at present

HE 0107-5240 and HE 1327-2326

Effective yields of Metal-poor stars

Survey	N	[Fe/H] < -2.0	[Fe/H] < -2.5	[Fe/H] < -3.0
HK Survey/no B-V	2614	11%	4%	1%
HK Survey/with B-V	2140	32%	11%	3%
HES (Faint turnoff stars)	571	59%	21%	6%
HES (Faint Giants)	643	50%	20%	6%
Goswami 2005	91		38% (35 objects)	

Details of detection procedure, spectral criteria, spectral description, atmospheric parameters (T_{eff}), carbon isotopic ratios are given in

Goswami 2005, MNRAS, 359, 531

Subclasses of metal-poor stars

Neutron capture-rich stars

r-I	0.3 < [Eu/Fe] < + 1.0 and [Ba/Eu] < 0
r-II	[Eu/Fe] > +1.0 and [Ba/Eu] < 0
s	[Ba/Fe] > +1.0 and [Ba/Eu] > +0.5
r/s	0.0 < [Ba/Eu] < +0.5

Carbon-enhanced metal-poor stars

CEMP	[C/Fe] > +1.0
CEMP-r	[C/Fe] > +1.0 and [Eu/Fe] > +1.0
CEMP-s	[C/Fe] > +1.0, [Ba/Fe] > +1.0, and [Ba/Eu] > +0.5
CEMP-r/s	[C/Fe] > +1.0 and 0.0 < [Ba/Eu] < +0.5
CEMP-no	[C/Fe] > +1.0 and [Ba/Fe] < 0.0

Ref element: Eu, mainly produced by r-process in solar system material; its abundance is among the most readily measurable in optical spectra

[Ba/Eu] < 0.0 ; $[Ba/Eu]_s$ = +1.5 ; $[Ba/Eu]_r$ = -0.8

Numerous questions remain as to the nucleosynthetic histories and astrophysical sites of these classes.

It already seems clear that a single mechanism for the production of the enhanced carbon in these stars would be unlikely to lead to such a diversity of heavy-element abundance patterns.

To obtain insight into the possible origins of the CEMP stars & to place additional constraints on the nucleosynthesis of s-process and r-process elements at low metallicity it is thus necessary to conduct high-resolution spectroscopic analysis of as many types of CEMP stars as possible.

C plays a central role in the nucleosynthesis reactions that drive the post main sequence evolution of stars, one might hope to gain some insight into the evolutionary processes which have formed CEMP stars by studying their carbon abundances and carbon isotope ratios.

Results from HR spectroscopic studies

High-resolution spectroscopic study of the CEMP stars from Goswami (2005) with additional targets from Goswami (2006, in preparation)

A Case Study

HE 1305+0007, HE 1152-0355
(candidates from Goswami 2005)

(Collaboration: Aoki Wako, J E Norris, S G Ryan, Tim Beers, N Christlieb, Tsangarides, H Ando)

Photometric parameters of HE 1305+0007 & HE 1152-0355

Stars	V	B-V	V-R	V-I	E(B-V)	J	H	K
HE 1305+0007	12.22	1.459	0.682	1.152	0.0379	10.247	9.753	9.6
HE 1152-0355	11.43	2.459	0.816	1.194	0.0259	9.339	8.665	8.429

E(B-V) values from Schlegel et al. (1998)

OBSERVATIONS

HDS at 8.2 m SUBARU (Noguchi et al. 2002)

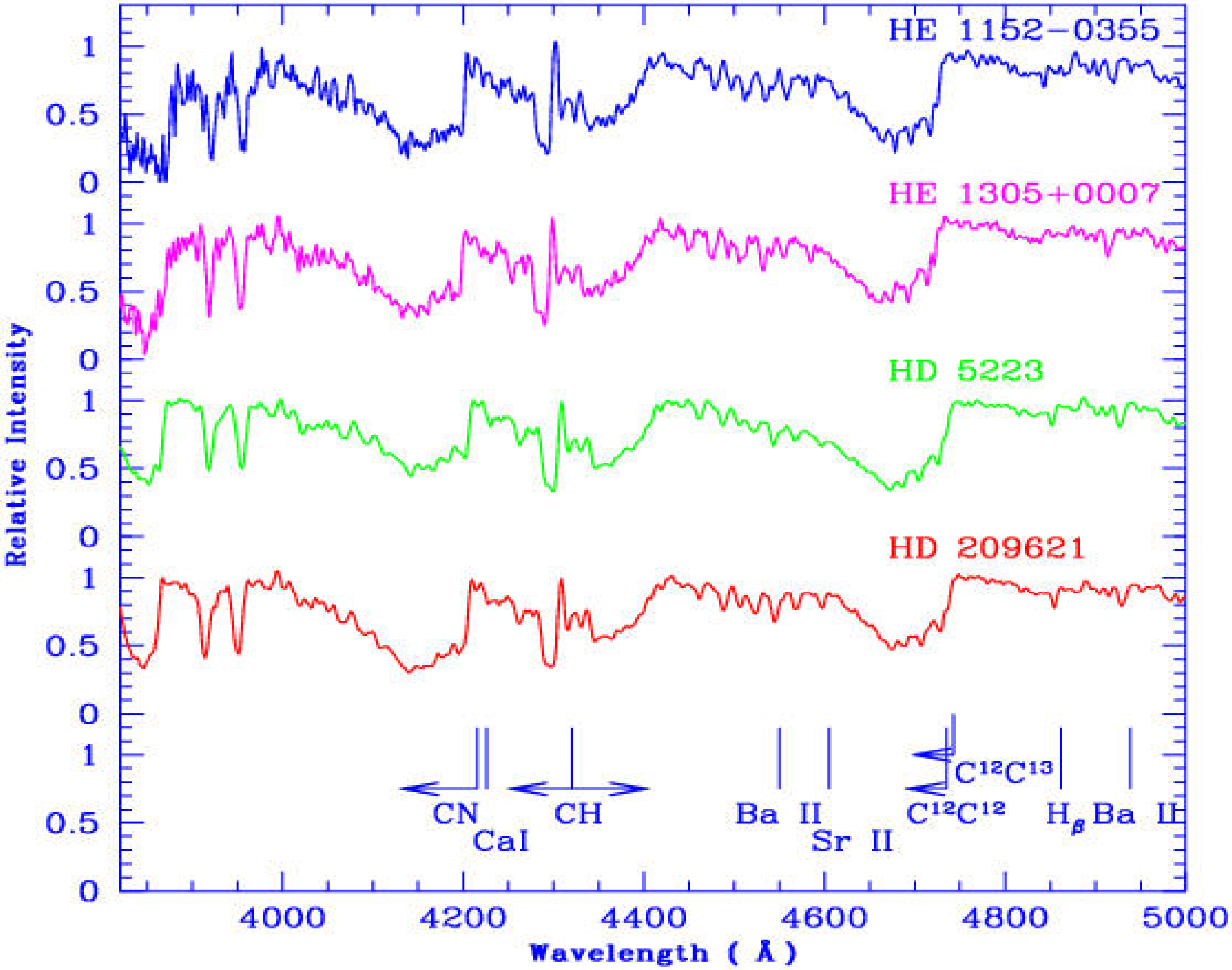
Spectral Resolution ~ 50,000

Observed bandpass 4020 - 6775 A

Gap of 75 A from 5335 – 5410 A

WL calibration : Th+Ar hollow cathod lamp

Comparison stars : HD 5223, HD 209621, CS 22948-027



Low-resolution spectra of HE 1305+0007 & HE 1152-0355 in the wavelength region 3850 – 5000 A. G-band of CH is strong; the secondary P- branch head around 4342 A is quite distinct. Narrow atomic lines are blended with contributions from Molecular bands. Ca I at 4226 A is not noticed. Prominent features are indicated.

Radial Velocities: Mean Heliocentric radial velocities

+ 217.8 km/s	(HE 1305+0007)	HJD 2452784.95121
+ 431.3 km/s	(HE 1152-0355)	HJD 2452784.83629
-244.9 km/s	(HD 5223)	HJD 2453544.12049

Uncertainties +/- 1.5 km/s

No other estimates on radial velocities of the two HE stars are available in the literature. At present it is not known whether these two stars are radial velocity variables.

Atmospheric parameters using model atmospheres

Employed the standard routine procedure

Effective temperatures : method of excitation balance

slope of the abundances from Fe I lines vs E.P. ~ 0

Surface gravities : Fe I/ Fe II ionization equilibrium

Derived atmospheric parameters

Stars	T_{eff}	logg	V_t km/s	[Fe I/H]	[Fe II/H]
HE 1305+0007	4750	2.0	2.0	-2.03	-1.99
HE 1152-0355	4000	1.0	2.0	-1.27	-1.30
HD 5223	4500	1.0	2.0	-2.06	-2.04
CS 22948-027	4750	1.5	2.0	-2.50	-2.40

Chemical compositions in HD 5223

Element	Z	Solar abun	Abun	[X/H]	[X/Fe]
C I	6	8.39	7.90	-0.49	+1.57
Na I D_1	11	6.17	4.57	-1.60	+0.46
Na I D_2	11	6.17	4.57	-1.60	+0.46
Ca I	20	6.31	6.05	-1.48	+0.58
Ti II	22	4.90	3.35	-1.50	+0.49
Fe I	26	7.50	5.39	-2.06	
Fe II	26	7.50	5.41	-2.04	
Ni I	28	6.23	3.70	-2.53	-0.47
Sr I	38	2.92	2.00	-0.92	+1.14
Y II	39	2.21	0.80	-1.41	+0.63
Zr I	40	2.59	2.10	-0.49	+1.57
Ba II	56	2.17	1.95	-0.22	+1.82
La II	57	1.13	0.85	-0.28	+1.76
Ce II	58	1.58	1.75	-0.27	+1.87
Nd II	60	1.45	1.06	-0.39	+1.54
Sm II	62	1.01	0.70	-0.31	+1.68

Chemical compositions of HE 1152-0355

Elements	Z	Solar ε	log ε	[X/H]	[X/Fe]
C	6	8.39	7.7	-0.69	+0.58
Ti II	22	4.9	4.15	-0.75	+0.52
Fe I	26	7.45	6.18	-1.27	
Fe II	26	7.45	6.15	-1.30	
Y II	39	2.21	0.85	-1.36	-0.06
Zr I	40	2.59	1.32	-1.27	0.00
Ba II	56	2.17	2.45	+0.28	+1.58
La II	57	1.13	1.40	+0.27	+1.57
Nd II	60	1.45	0.58	-0.87	+0.43
Sm II	62	1.01	0.58	-0.43	+0.87

Chemical compositions in HE 1305+0007

Element	Z	Solar abun	Abun	[X/H]	[X/Fe]
C I	6	8.39	8.20	-0.19	+1.84
Na I D2	11	6.17	4.40	-1.77	+0.26
Na I D1	11	6.17	4.57	-1.60	+0.43
Mg I	12	7.53	5.75	-1.78	+0.25
Ca I	20	6.31	4.41	-1.90	+0.13
Sc II	21	3.05	1.15	-1.90	+0.09
Ti II	22	4.90	3.70	-1.20	+0.79
Mn I	25	5.39	3.50	-1.89	+0.14
Fe I	26	7.45	5.42	-2.03	
Fe II	26	7.45	5.46	-1.99	
Ni I	28	6.23	3.95	-2.28	-0.25
Sr I	38	2.92	1.75	-1.17	+0.86
Y II	39	2.21	0.95	-1.26	+0.73
Zr I	40	2.59	2.65	+0.06	+2.09
Ba II	56	2.17	2.50	+0.33	+2.32
La II	57	1.13	1.70	+0.57	+2.56
Ce II	58	1.58	2.12	+0.54	+2.53
Pr II	59	0.71	1.10	+0.39	+2.38
Nd II	60	1.45	2.05	+0.60	+2.59
Sm II	62	1.01	1.62	+0.61	+2.60
Eu II	63	0.52	0.50	-0.02	+1.97
Pb I	82	2.00	2.38	+0.38	+2.37

Impact of CEMP stars on early Galactic chemical evolution

Over the metallicity range $-4.0 < [Fe/H] < -2.0$, there exists an upper limit to the level of carbon enhancement amongst CEMP stars at $[C/H] \sim -1.0$; suggests carbon was produced by

(i) a primordial mechanism from massive stellar progenitors,

(ii) intrinsic production by low-mass stars of extremely low [Fe/H],

(iii) extrinsic production by stars of intermediate mass, which can be prodigious manufacturers of carbon during their AGB stages followed by mass transfer to a surviving lower-mass companion.

It remains possible that all three sources have played a role

S-process enhanced stars

Because of the (possibly) required presence of iron-peak seed nuclei for the operation of the s-process, it was believed that there might be little or no evidence of element production from this source in the early Galaxy

Recent studies of metal-deficient stars have identified stars that exhibit clear s-process signatures indicating that the s-process could indeed operate even at very low metallicities, as low as [Fe/H] = -3.5   CS 29528-041,   Masseron et al. (2006)

The nature of s-process at very low metallicities is still very uncertain it is not even clear that the requirement of iron-peak seeds applies as it appears to for intermediate and solar-metallicity stars.

The two CEMP_s stars HE 1152-0355 and HD 5223 that we have studied recently have metallicities -1.3 and -2.0 respectively Goswami et al. (2006, communicated)

Lead stars

s-process nucleosynthesis in AGB stars

Efficient production of the 3rd-peak s-process element Pb can occur in very metal-poor environments; the lack of seed nuclei leads to the very high neutron-to-seed ratios needed for its manufacture (Gallino et al. 1998, Goriely & Mowlavi 2000, Busso et al. 2001)

First detection of lead in LP 625-44 ([Fe/H] = -2.7); Wako et al. (2000)

Extreme [Pb/Fe] ratio reported to date is found in CS 29497-030, [Pb/Fe] = +3.5, 3000 times > than the solar ratio

Lead stars now include more than 20 well-studied examples

Our contribution

Added one more object to this group
HE 1305+0007, [Pb/Fe] = 2.37, [Fe/H] = -2.1
Goswami et al. (2006, communicated)

r-process enhanced stars

The prototype r-II star is CS 22892-052, an EMP star with [Fe/H] = -3.1

Elemental abundances in the range $56<Z<76$ closely track a scaled solar-system r-process abundance pattern

Produced heavy elements with astounding consistency from the earliest times in the Galaxy upto the formation of the solar system

CS 31082-001, ([Eu/Fe] = +1.6), r- II star, but not carbon enhanced

calls into question any causal connection between the enhancement of carbon and the r-process-enhancement phenomenon

log*e*(Pb) = -0.55 +/- 0.15 Plez et al. (2004)

If the solar inventory of r-process elements are due to the same nucleo-synthesis process that enriched CS 31082-001, the fraction of lead in the solar system that has its origin in the r-process could be as low as a few percent, the remaining lead must have been produced by s-process

Open-questions

The discovery of r-process enhanced, metal-poor stars has focused attention on a number of critical questions – answers are required to place strong constraints on the operation of early r-process and on their astrophysical sites

What is the frequency of r-I, r-II, and r/s stars as a function of [Fe/H] ?

r-II stars, all have [Fe/H] = -3.0

r-I, and r/s stars cover a wider range [Fe/H] = -3.0 to [Fe/H] = -1.5

Suggests, large enhancements with pure r-process elements might be associated with the earliest r-process-generating events

Distribution of r-process enhancements for r-I, r-II and r/s stars?

How stable is the pattern of r-process-element abundances in the range $56 < Z < 76$?

Star-to-star scatter of the abundances of elements must be quantified

The range of r-process enhancement for the 3rd r-process peak elements $Z > 76$ and for the actinides Th and U?

Application of cosmo-chronometers involving the actinides

Techniques that directly address these questions are now available

CEMP_r/s stars

CS 22948-027, CS 29497-034, HE 2148-1247
(Hill et al. 2000, Aoki et al. 2002, Cohen et al. 2003)

HE 1305+0007 makes a member of CEMP_r/s group showing double enhancement of r- and s-process elements
(Goswami et al. 2006 communicated)

The abundance anomalies particular to CEMP_s stars (CH stars) are generally explained as a result of the mass transfer to a normal star from a companion undergoing its second ascent of the giant branch

This could not be generalized to HE 1305+0007 in which double enhancement r-process and s-process are noticed with [Eu/Fe] = 1.97 & [Pb/Fe] = 2.37

Offers a challenge towards the formation mechanism of these stars

HMP stars:

The lowest metallicity stars currently known

HE 0107-5240, [Fe/H]$_{NLTE}$ = -5.3

HE 1327-2326. [Fe/H]$_{NLTE}$ = -5.4

Dwarf C-star G 77-61 [Fe/H]$_{NLTE}$ = -5.5 (logε(Fe)=2.0 Liebert 1988)

High quality Keck/HIRES spectrum results [Fe/H] = -4.03 +/- 0.15 (Plez)

Abundance patterns of HMP stars

HE 0107-5240: [C/Fe] = +4.0, [N/Fe] = +2.3

HE 1327-2326 : [C/Fe] = +4.0, [N/Fe] = +4.2

Ca, Ti, Fe abundances relative to H are same in both

Na, Mg, Al abundances relative to H are 1dex higher in HE 1327-2326

Two Sr lines are detected in Subaru/HDS spectrum of HE 1327-2326

[Sr/Fe] = +1.2 ; Ba absent ; [Sr/Ba] > -0.6 (Lower limit)

Sr – not produced by main s-process

Possible origins : weak s-process, r-process

Observational challenges presented by HMP stars

Absorption lines of elements other than diatomic molecules involving C & N are extremely weak in HMP stars

Strongest Fe I lines in HE 1327-2326 : 5.9 mA, 6.8 mA

O abundance from OH lines (several nights of observing time at VLT/UT2)

Already approaching the limit of feasibility for conducting detail abundance analysis of HMP stars

Lowest metallicity stars to be found, in new, deeper surveys can be studied once the next generation of large ground-based telescopes are available

[Fe/H] does not necessarily refer to the total metal content of a given stellar atmosphere, which might not in fact be significantly less than the solar value, e.g. when the stars under consideration also exhibit large overabundances of elements such as C, N and O

Question still remains an open question- do they represent the first stars?

Important tool for studying the 1st generation of stars and SN

Models for abundance pattern

Self enrichment, pollution from an AGB, pre-enrichment by SN or ISM

Issues that cannot yet be addressed with the existing databases of MP stars

The nature of the MDF throughout the Galactic halo

MP stars located within 20kpc of the SUN
Representative of the inner-halo population
Whether or not MDF remains similar at larger distances?
Provides important constraints on the formation history of the Galaxy

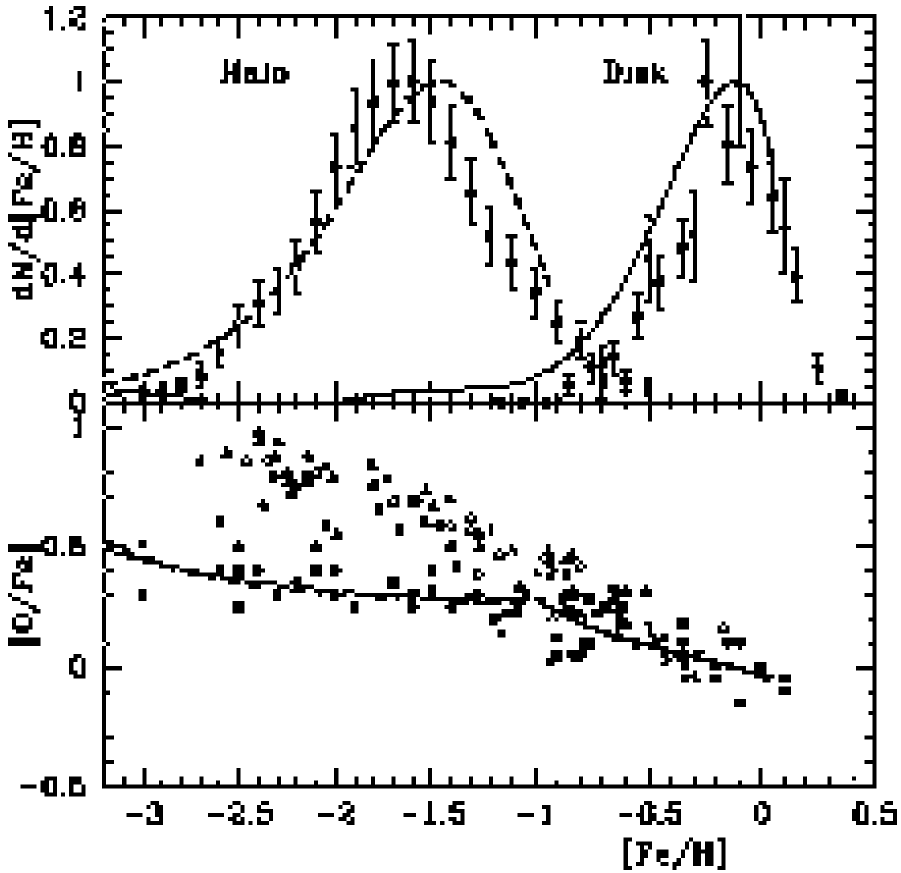
Better populating the VMP tail of the MDF one can test whether the MDF is a continuous function OR as previous hints have suggested it might contain structure that could be associated with bursts of star formation at various metallicities

Is there a real gap in the MDF between [Fe/H] = -4.0 & -5.0?
If so, what might account for its presence?

How low can we go? Existence of a lower limit to the MDF?

Results: Metallicity distribution and O vs Fe in the halo and the disk

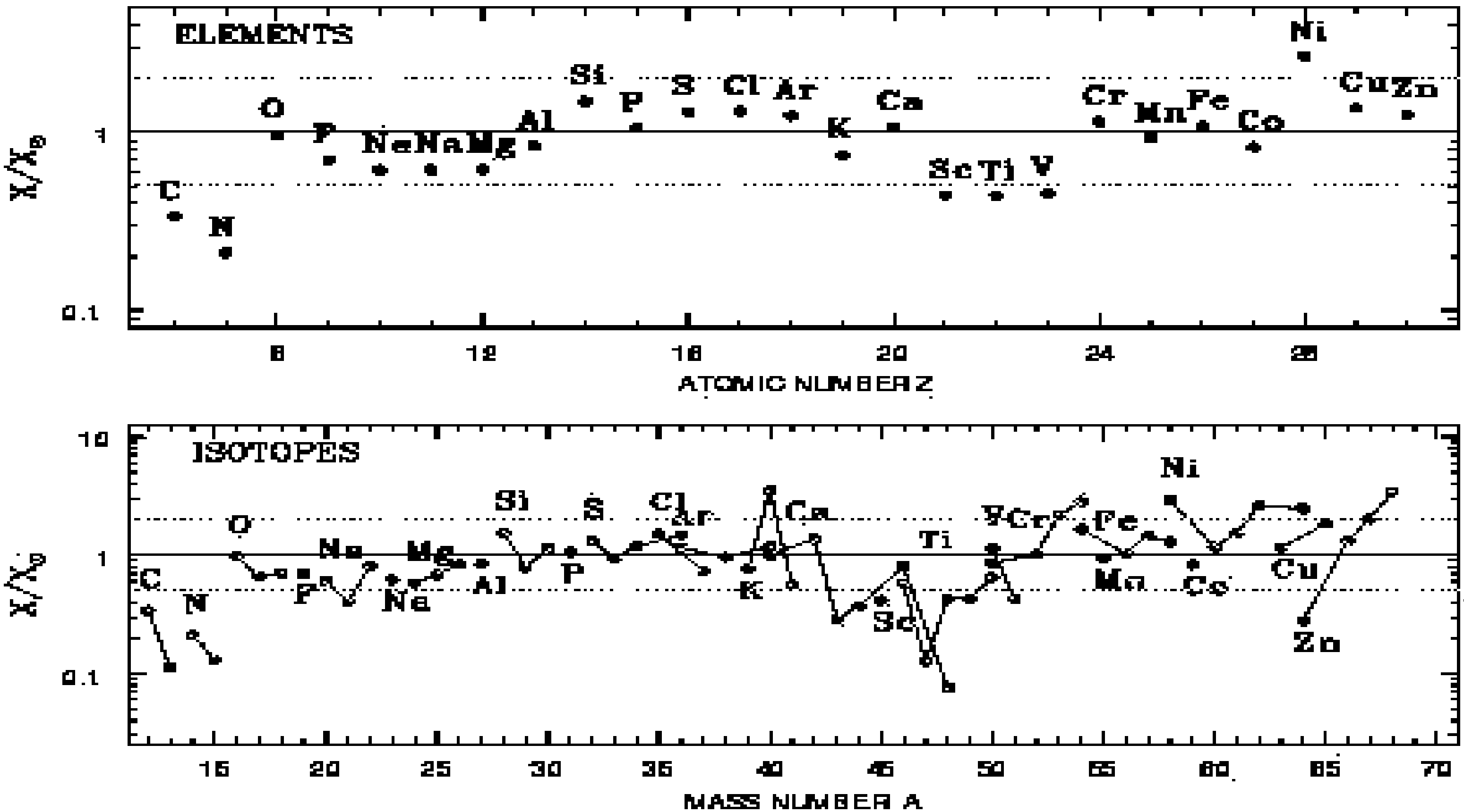
Goswami & Prantzos, (2000), A&A, 359, 191



Upper Panel: Model metallicity distribution (MD) of the Galactic halo (dashed curve) and the local disk (solid curve). The traditional disk population at [Fe/H] > -1, is indicated by the thick curve. Lower Panel: [O/Fe] vs. [Fe/H] in the halo and the disk (thick for [Fe/H] > - 1 and thin for [Fe/H] < - 1.

- Lower panel: Evolution of O vs Fe
- Virtually identical in the two models, up to [Fe/H] = -1
- Both O and Fe are primaries, produced in the same site (massive short-lived, stars)
- Abundance ratios are independent of infall or outflow
- The observed decline of O/Fe in the disk is reproduced by the delayed appearance of SN Ia, producing ~ 2/3 of the solar Fe

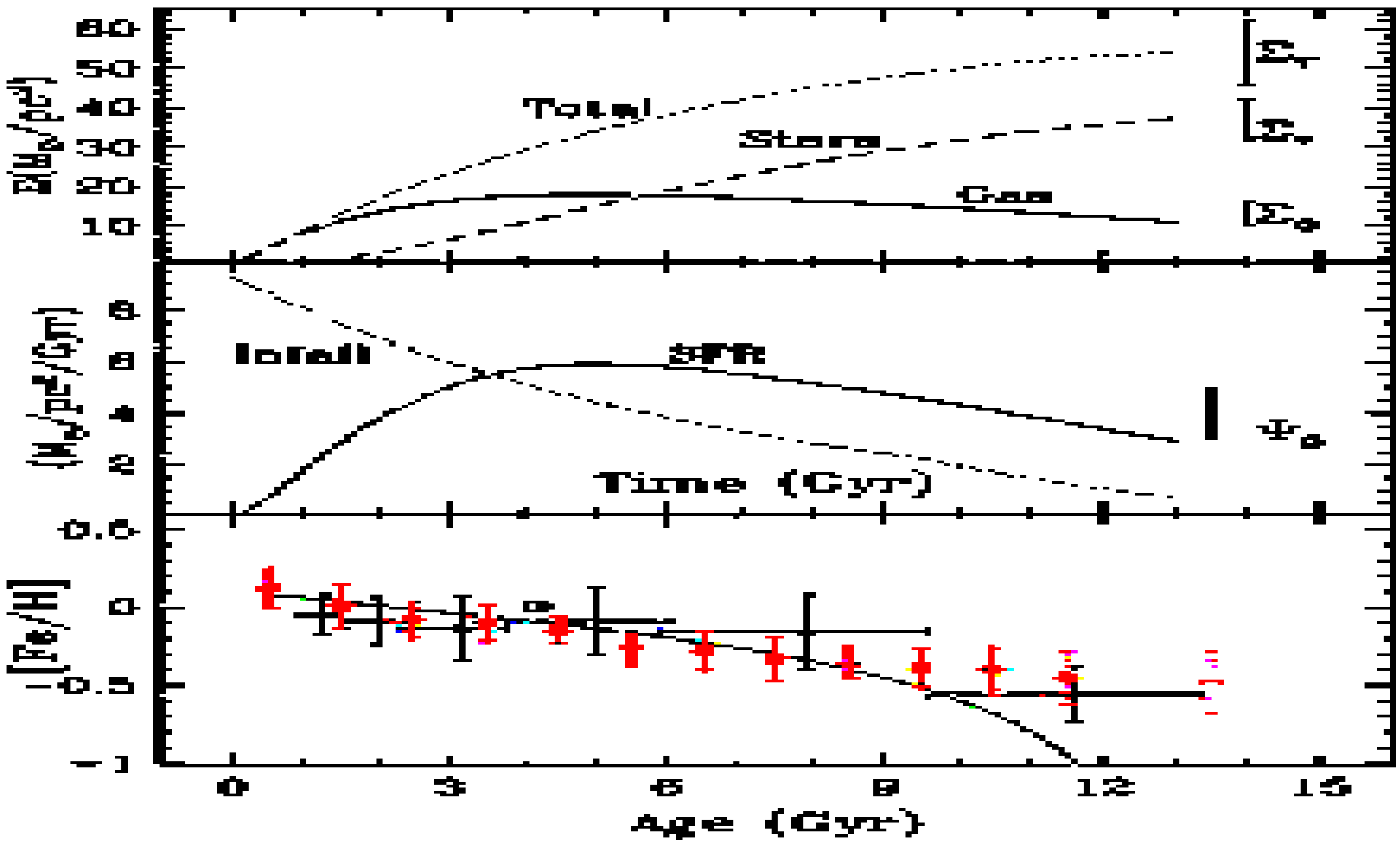
➢Solar compositions



Ratio of the calculated and the observed solar abundances of elements C to Zn (Upper panel) and their stable isotopes (Lower Panel). The model results correspond to Disk age of 8.5 Gyr (Sun's formation).

Dotted lines mark deviations by a factor of 2 from the solar composition.

➢Evolution of the Local disk



Comparison of the main observables of the local disk to our model predictions.

Upper panel : Surface densities of stars, gas and total amount of matter as a function of time. Vertical error bars represent present day values.

Middle panel: The star formation rate and infall rate

Lower panel : Solid curve shows the derived age-metallicity relation

Early Galactic Chemical Evolution : Implications

Elemental abundances in halo stars :   Spite & Spite (1978)

Ba & Y over deficient with respect to Fe
Ba abundance increases as fast as Fe at low metallicity
Suggests a common origin in massive short-lived stars

" r-only" hypothesis : (Truran 1981)   In the early Galaxy the n-capture elements were formed exclusively through the r-process, assumed to occur in core-collapse type II SN

In addition to many theoretical propositions there now exists observational evidence that suggests, in contrast to the r-only hypothesis, the s-process could indeed operate even at very low metallicities, as low as [Fe/H] = -3.5
CS 29528-041,   Masseron et al. (2006)

Their impact on the chemical evolution of n- capture elements throughout the early Galaxy is still an open question

Depends on the IMF of early-generation stars

Future surveys

RAVE : Radial Velocity Experiment for 50 Million stars in the Northern and Southern Hemispheres (accuracy ~ 1km/s)

R=10000, WL range 8400-8750A, S/N =20 V_limit =16

The siding spring/Hamburg Survey (SSHS)

To concentrate on the portions of sky not covered by HES in the Southern hemisphere

SDSS- Sloan Digital Sky Survey

Spectra for 75000 Galactic stars (R=1800)

Expected, the database will reveal 5000-10000 VMPs & 500-1000 EMPs

SEGUE- Sloan Extension for Galactic Understanding and Exploration

Medium resolution spectroscopy for 250,000 stars, as deep as V=20

Expected to detect ~ 25,000 VMPs (HR spectroscopic follow-up may not be possible with 8-10 m but tractable with 30 – 100 m telescope)

LAMOST: Large Sky Area Multi-Object fibre Spectroscopic Telescope

Planned to be a 4m telescope capable of simultaneously observing 4000 objects in the Northern Hemisphere sky

Can go as deep as V=20,

R=1000-3000, S/N = 10, WL regions 370-620 & 600-900nm

First light ~ Mid-2006

GAIA astrometric satellite: To be launched by ESA in mid-2011

V=20, R=11,500, WL 8480-8740A, will creat database for 10^9 objects

Complementary ground-based follow-up observations will be needed to identify the most metal-poor stars observed with GAIA

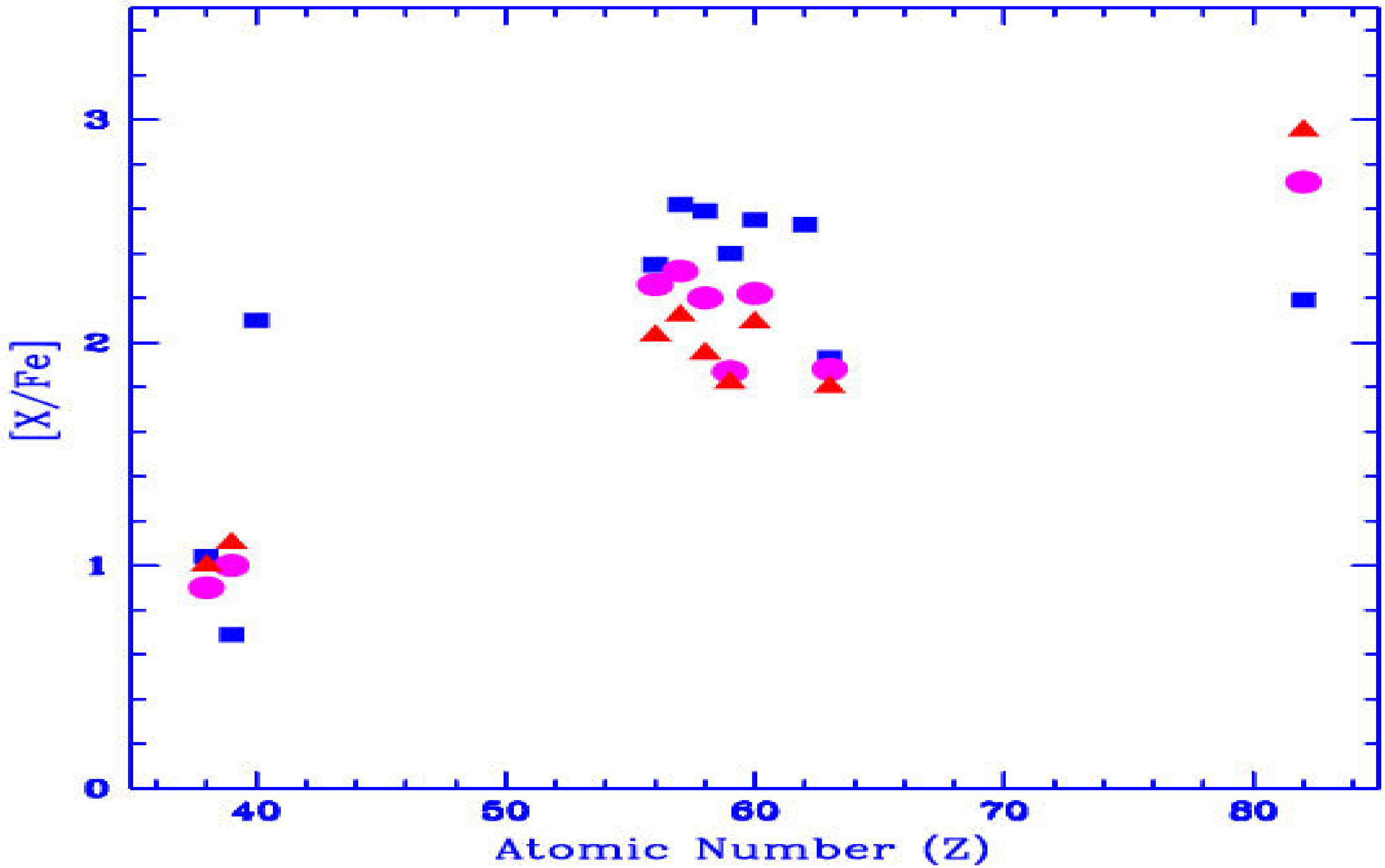
Proposed scenarios:

Cohen et al. 2003: A scenario invoking triple system, one component polluting with r- elements, another polluting with s-elements was considered. Discarded– Such a system may not be dynamically stable

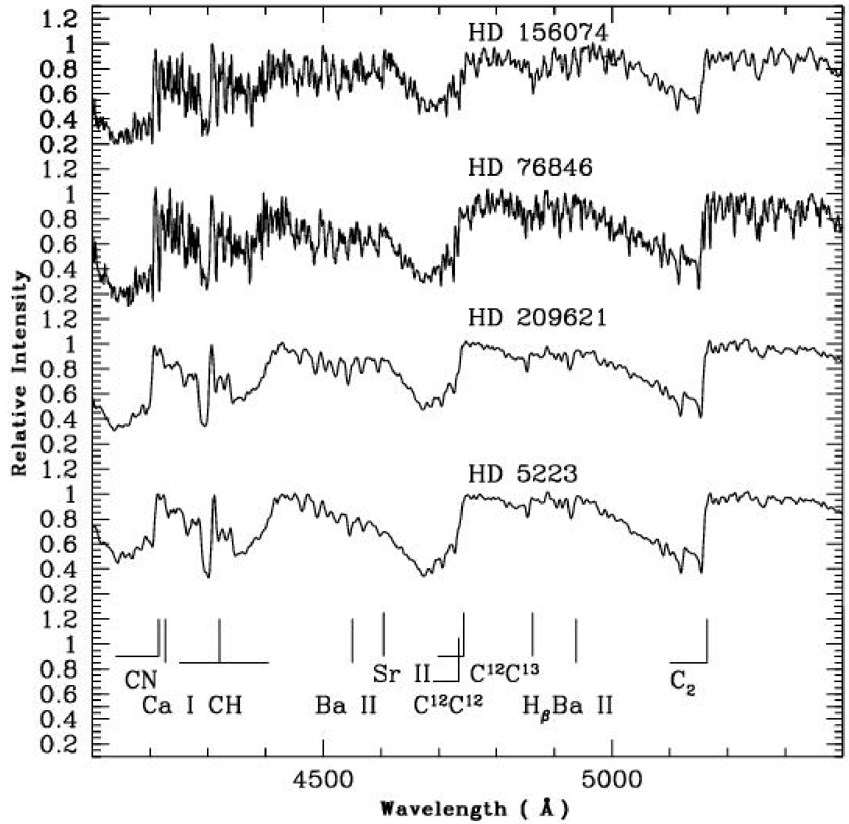
Qian & Wasserburg 2003: Due to the s-process occurring in an AGB star member of a binary system, followed by the r-process taking place in a subsequent accretion induced collapse (AIC) of the white dwarf remnant of the former AGB.
Drawback: Occurrence of AIC in the Galaxy is rare and highly uncertain
The rarity cannot justify the observed number of CEMP(r+s) stars

Zijlstra 2004: The primary (evolved as an AGB) transfers s-rich matter to the observed star but does not suffer a large mass loss owing to its low metallicity. At the end of the AGB phase the degenerate core explodes as an AGB supernova
Drawback: r-processing in such a scenario is not significant
The dominant role played in this scenario is the assumed mass loss.

The possibility of s-processing occurring in a 10 solar mass star !
More quantitative studies are needed to make a definitive conclusion



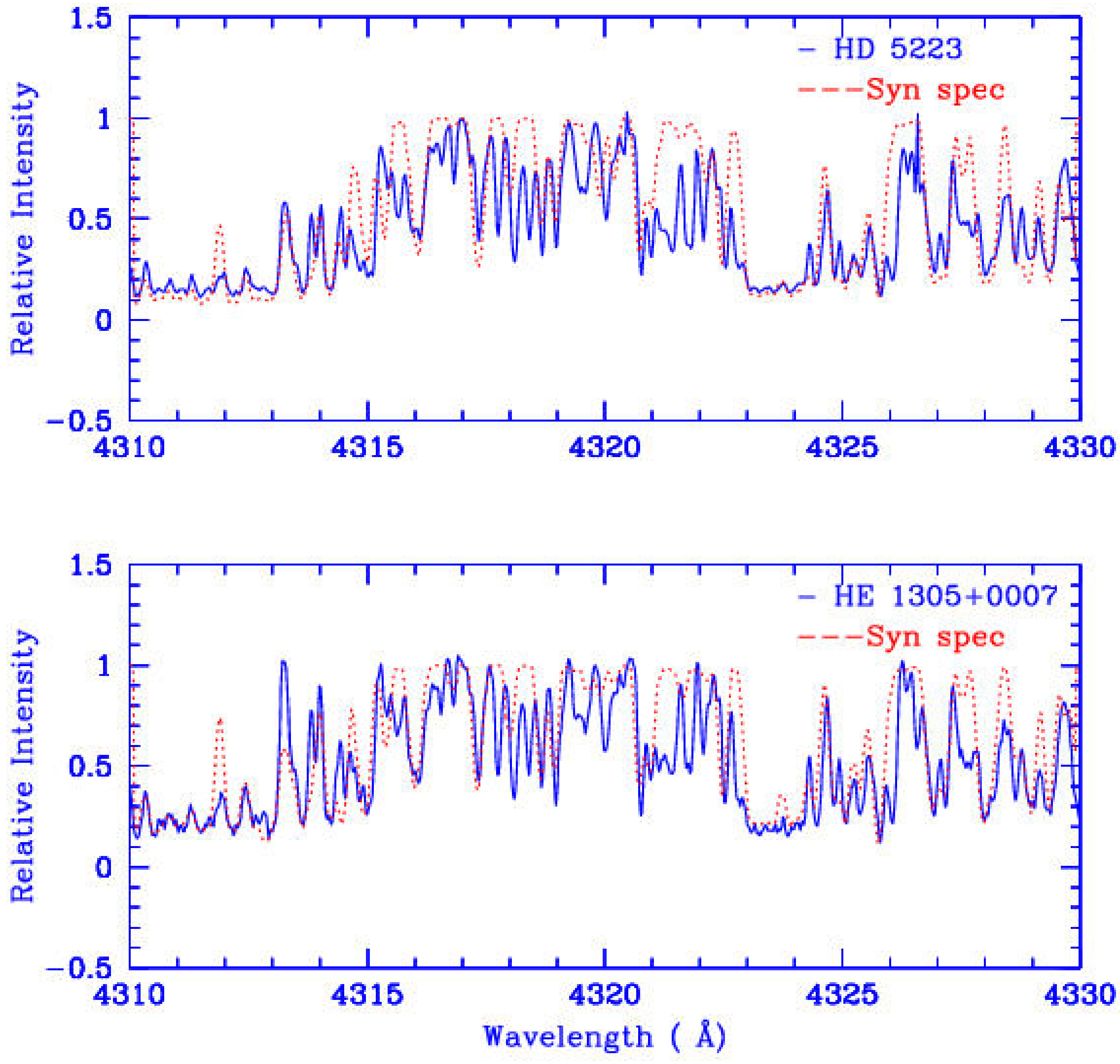
A comparison of the abundances in HE 1305+0007, CS 22948-0027 & CS 29497-0034 . Similarity indicates that they have been formed in similar astrophysical environments and form a homogeneous group.



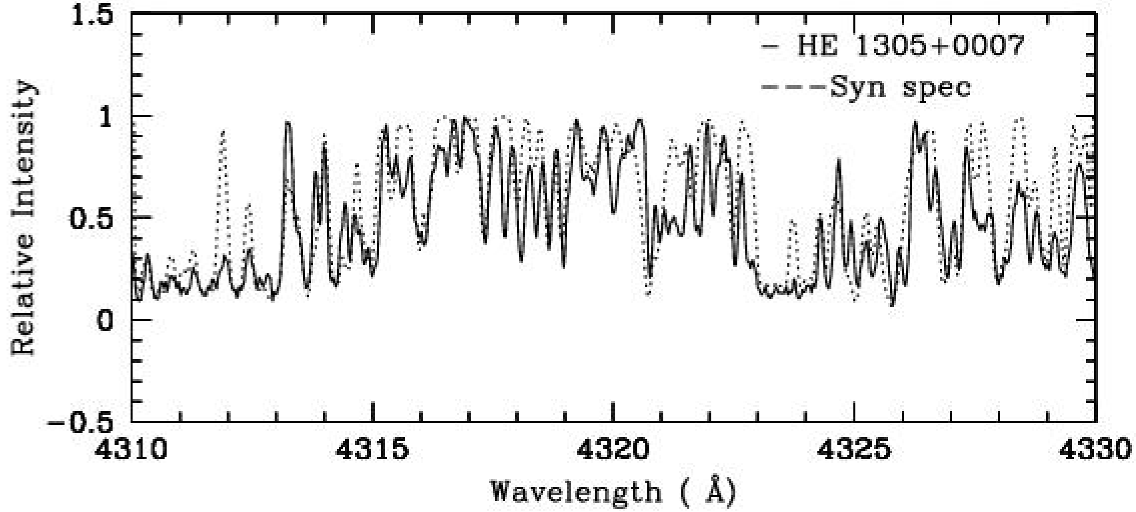
A comparison of known C-R and CH stars spectra. Secondary P-branch head around 4342 A is distinctly seen in the CH stars spectra. In C-R stars, the Ca I at 4226 A line depth is almost equal to the CN band depth at 4215 A. This line is marginally noticed in CH stars spectra. Hβ and Ba II at 4554 A are the two features clearly noticeable in the CH stars. In C-R stars this region is a complex combination of atomic and molecular lines.

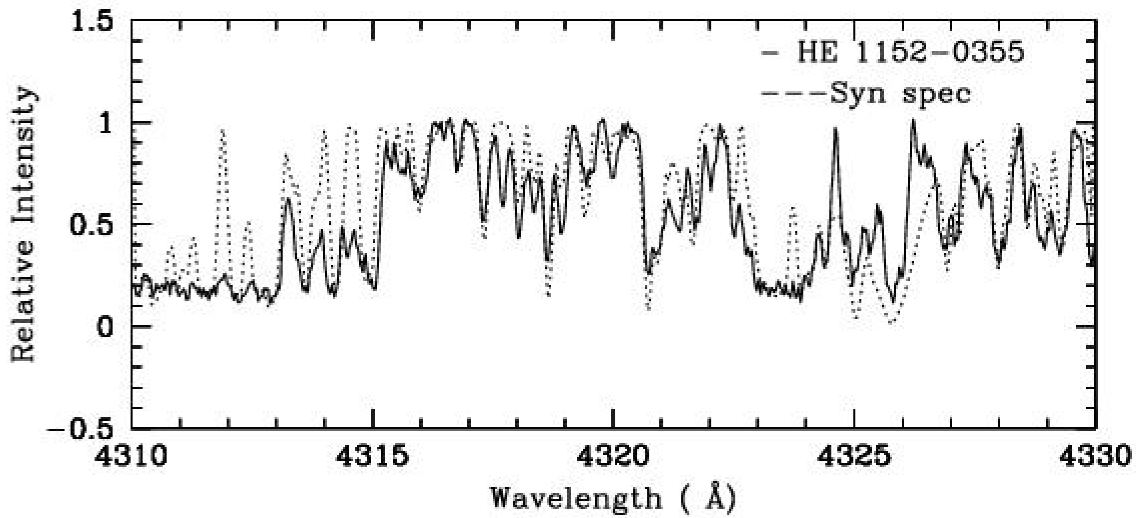
Table 9: Abundances of HE 1305+0007 compared with CS 22948-027 and CS 29497-034

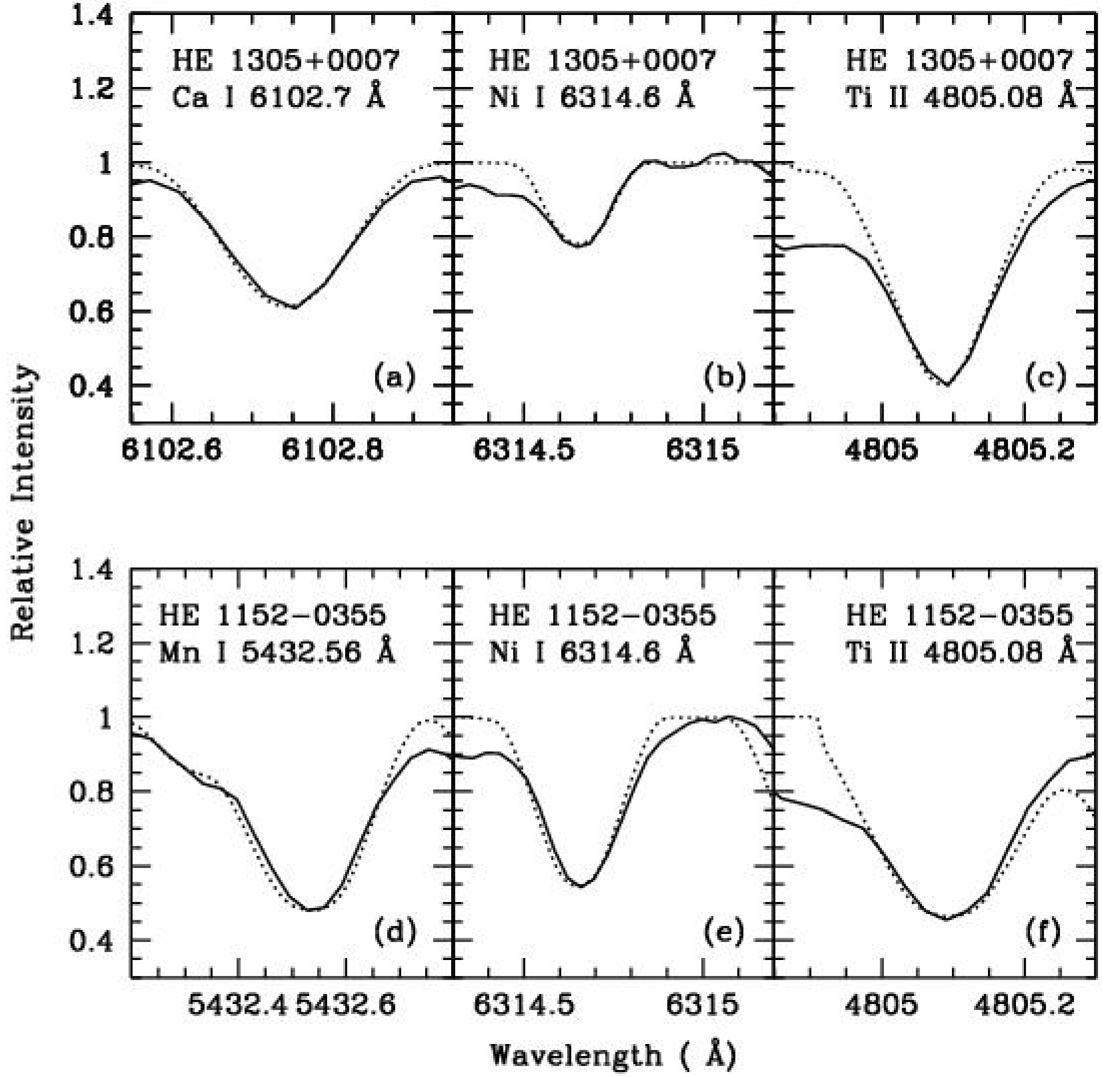
Elements X	Z	log ϵ Solar	[X/Fe] HE 1305+0007 [Fe/H] = -2.0 [hs/ls] = 1.22 $^{12}C/^{13}C = 10$	[X/Fe] CS 22948-027 [Fe/H] = -2.45 [hs/ls] = 0.97 $^{12}C/^{13}C = 14$	[X/Fe] CS 29497-34 [Fe/H] = -2.9 [hs/ls] = 1.28 $^{12}C/^{13}C= 12$
C I	6	8.39	+2.97	+2.43	+2.63
Na I	11	6.17	+0.20 (D_2)	+0.57	+1.18
Na I	11	6.17	+0.37 (D_1)	+0.57	+1.18
Ca I	20	6.31	+0.22	+0.54	+0.45
Sc II	21	3.05	+0.32		
Ti I	22	4.90		+0.34	+0.29
Ti II	22	4.90	+0.95	+0.54	+0.44
Cr I	24	5.64		-0.15	-0.23
Mn I	25	5.39	+0.08		
Fe I	26	7.50			
Fe II	26	7.50			
Ni I	28	6.23	-0.26	-0.01	+0.01
Zn I	30	4.60		+0.36	+0.46
Sr I	38	2.92	+1.00		
Sr II	38	2.92		+0.90	+1.00
Y II	39	2.21	+0.69	+1.00	+1.10
Zr I	40	2.59	+2.06		
Ba II	56	2.17	+2.35	+2.26	+2.03
La II	57	1.13	+2.62	+2.32	+2.12
Ce II	58	1.58	+2.59	+2.20	+1.95
Pr II	59	0.71	+2.38	+1.65	+1.65
Nd II	60	1.45	+2.55	+2.22	+2.09
Sm II	62	1.01	+2.53	+1.70	+2.00
Eu II	63	0.52	+1.93	+2.10	+2.25
Dy II	66		+1.60	+1.50	
Pb I	82	2.00	+2.15	+2.72	+2.95

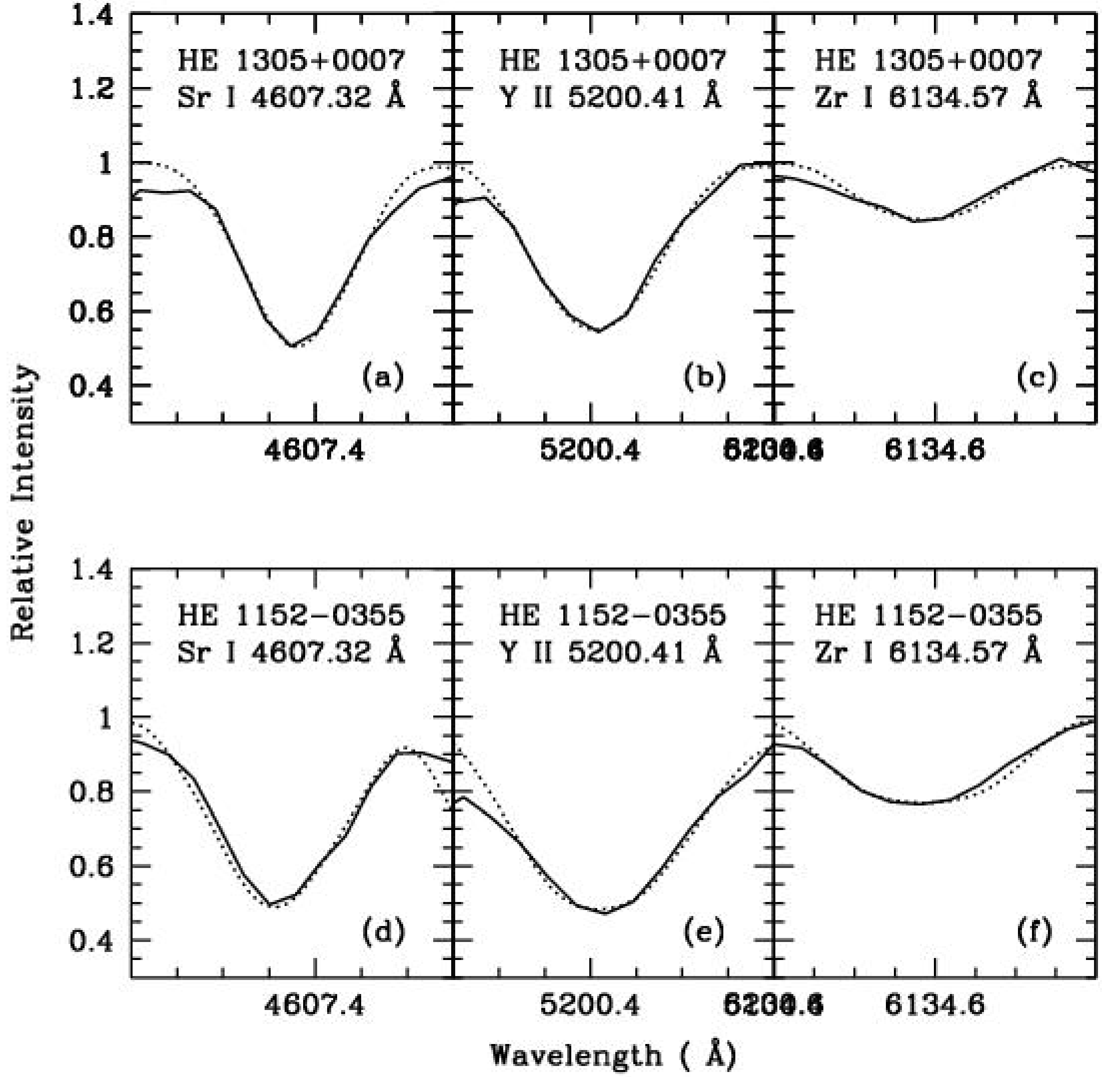


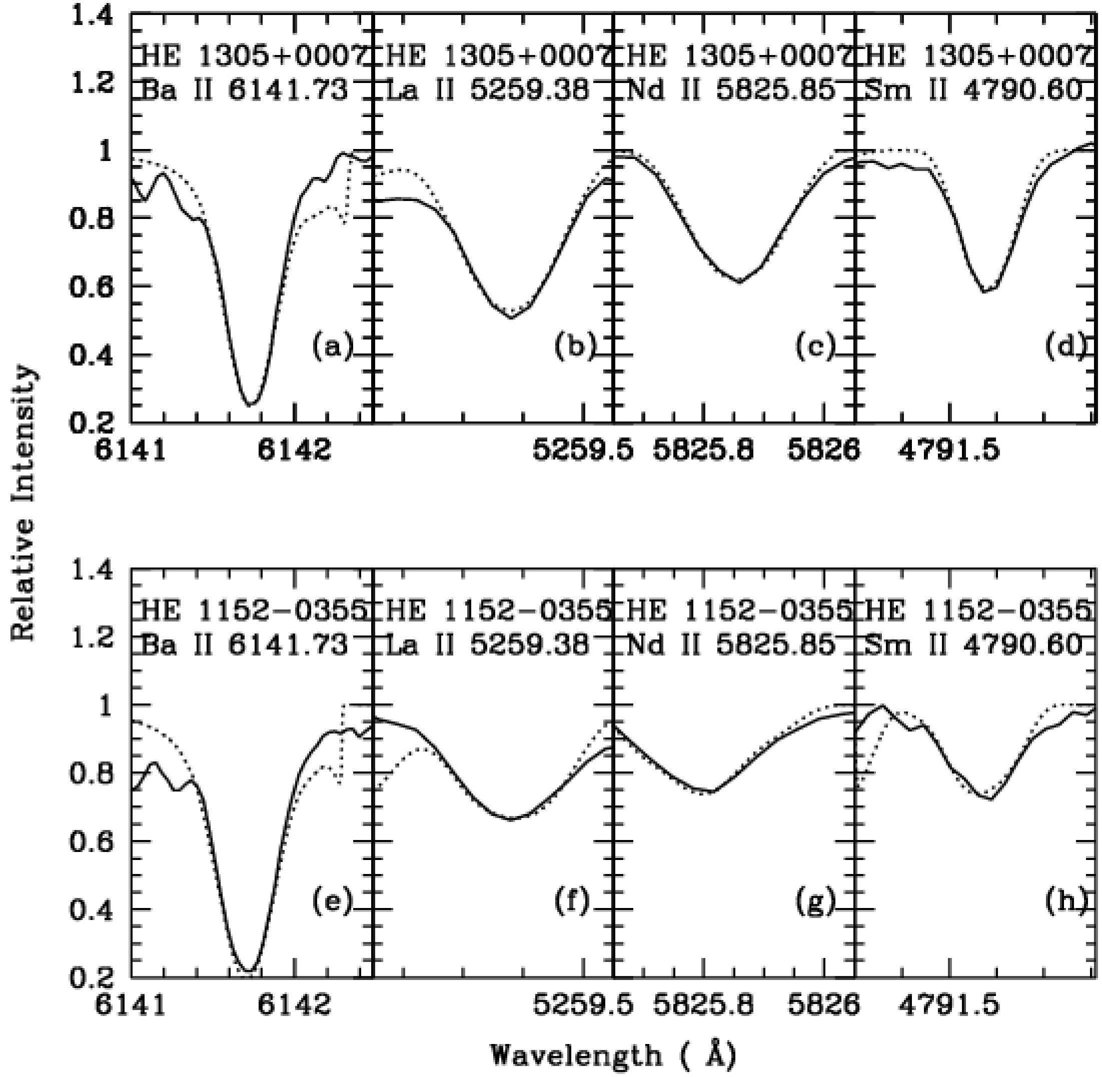
HD 5223
Syn spec
HE 1305+0007
Syn spec
Relative Intensity
Wavelength (Å)
1.5
1
0.5
0
−0.5
4310
4315
4320
4325
4330

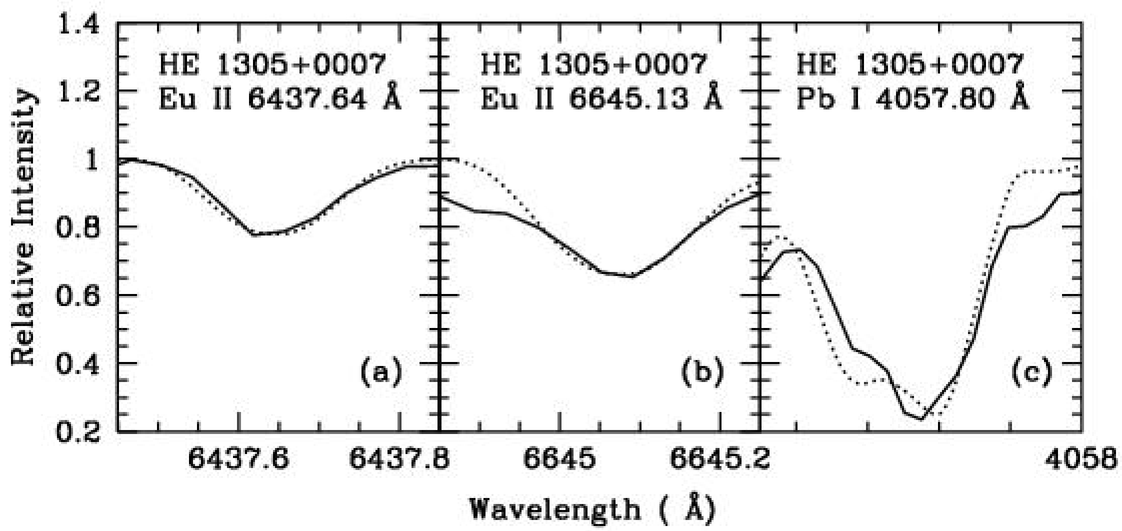

HE 1305+0007
---Syn spec
Relative Intensity
Wavelength (Å)
1.5
1
0.5
0
−0.5
4310
4315
4320
4325
4330

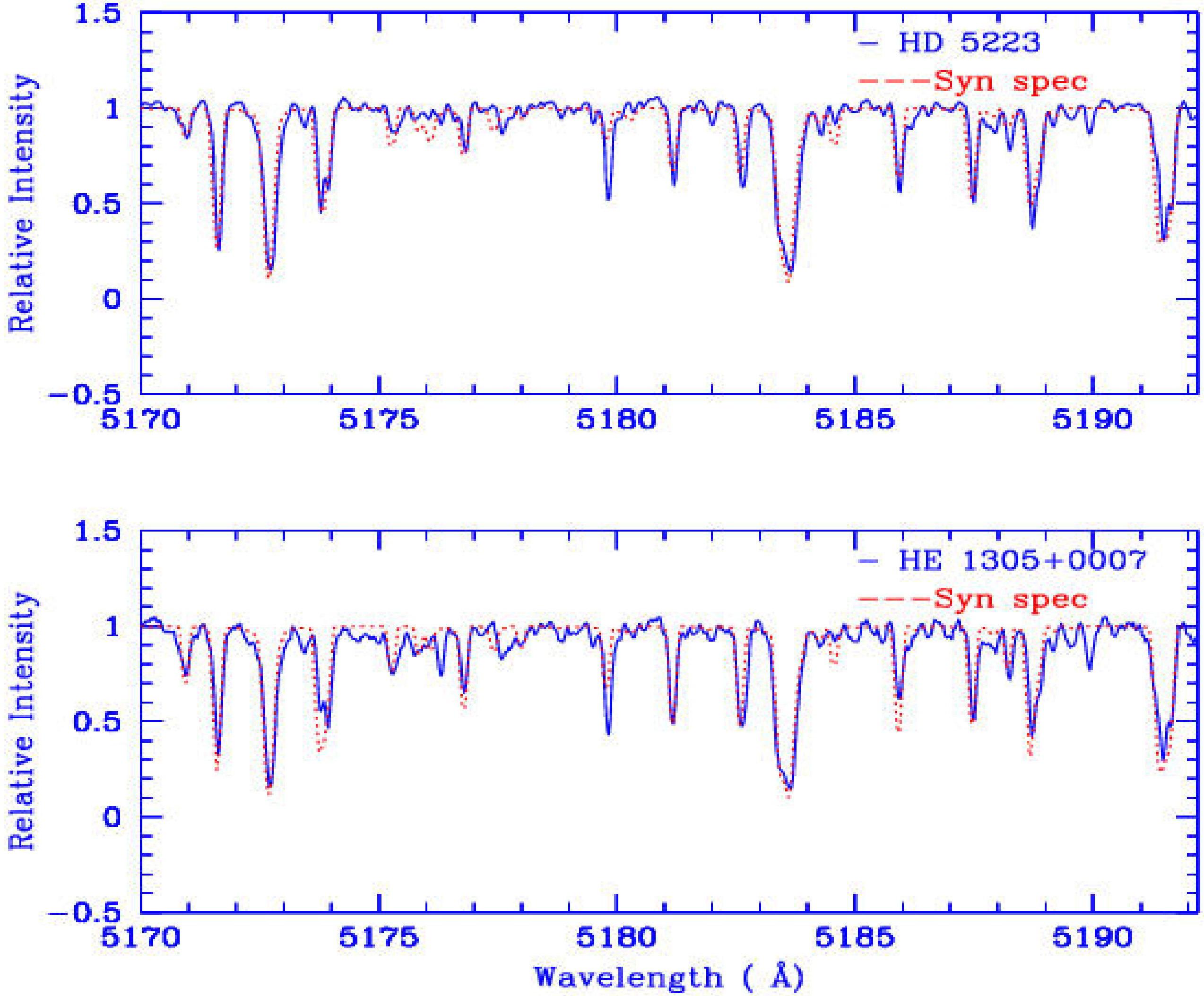

HE 1152-0355
---Syn spec
Relative Intensity
Wavelength (Å)
1.5
1
0.5
0
−0.5
4310
4315
4320
4325
4330


HE 1305+0007
Ca I 6102.7 Å
(a)
HE 1305+0007
Ni I 6314.6 Å
(b)
HE 1305+0007
Ti II 4805.08 Å
(c)
HE 1152−0355
Mn I 5432.56 Å
(d)
HE 1152−0355
Ni I 6314.6 Å
(e)
HE 1152−0355
Ti II 4805.08 Å
(f)
Relative Intensity
Wavelength (Å)
1.4
1.2
1
0.8
0.6
0.4
6102.6
6102.8
6314.5
6315
4805
4805.2
5432.4
5432.6


HE 1305+0007
Sr I 4607.32 Å
HE 1305+0007
Y II 5200.41 Å
HE 1305+0007
Zr I 6134.57 Å
(a)
(b)
(c)
HE 1152-0355
Sr I 4607.32 Å
HE 1152-0355
Y II 5200.41 Å
HE 1152-0355
Zr I 6134.57 Å
(d)
(e)
(f)
Relative Intensity
Wavelength (Å)
4607.4
5200.4
6134.6
1.4
1.2
1
0.8
0.6
0.4


HE 1305+0007
Ba II 6141.73
(a)
HE 1305+0007
La II 5259.38
(b)
HE 1305+0007
Nd II 5825.85
(c)
HE 1305+0007
Sm II 4790.60
(d)
HE 1152-0355
Ba II 6141.73
(e)
HE 1152-0355
La II 5259.38
(f)
HE 1152-0355
Nd II 5825.85
(g)
HE 1152-0355
Sm II 4790.60
(h)
Relative Intensity
Wavelength (Å)
0.2
0.4
0.6
0.8
1
1.2
1.4
6141
6142
5259.5
5825.8
5826
4791.5


HE 1305+0007
Eu II 6437.64 Å
HE 1305+0007
Eu II 6645.13 Å
HE 1305+0007
Pb I 4057.80 Å
(a)
(b)
(c)
Relative Intensity
Wavelength (Å)
1.4
1.2
1
0.8
0.6
0.4
0.2
6437.6
6437.8
6645
6645.2
4058



HD 5223
---Syn spec
Relative Intensity
1.5
1
0.5
0
−0.5
5170
5175
5180
5185
5190
HE 1305+0007
---Syn spec
Relative Intensity
1.5
1
0.5
0
−0.5
5170
5175
5180
5185
5190
Wavelength (Å)

Future works and challenges

Yields of low mass zero metal SN II
Yields of metal-poor massive AGB stars

Final phase of the metal-poor massive AGB stars

Observations & analysis of a larger sample of CEMP stars

Determination of the orbit of each binary

Could provide with the mass of the evolved companion (remnant)

Could provide with some useful constraints on the problems of the r-process sites in these binaries