Carbon Enhanced Stars in the Sloan Digital Sky Survey (SDSS)

Carbon stars are objects with prominent C2 molecular bands and are studied more than a century (Duner 1884)

Often used as tracers of halo and similar populations in the Milky Way and in nearby galaxies

High luminosity
Prominent C2 features.
Narrow Luminosity function
for giant carbon stars.

Carbon Stars from the SDSS Survey

SDSS DR2 has about 34,998 stars at a resolution R= 1800 from 3800Å to 9000Å

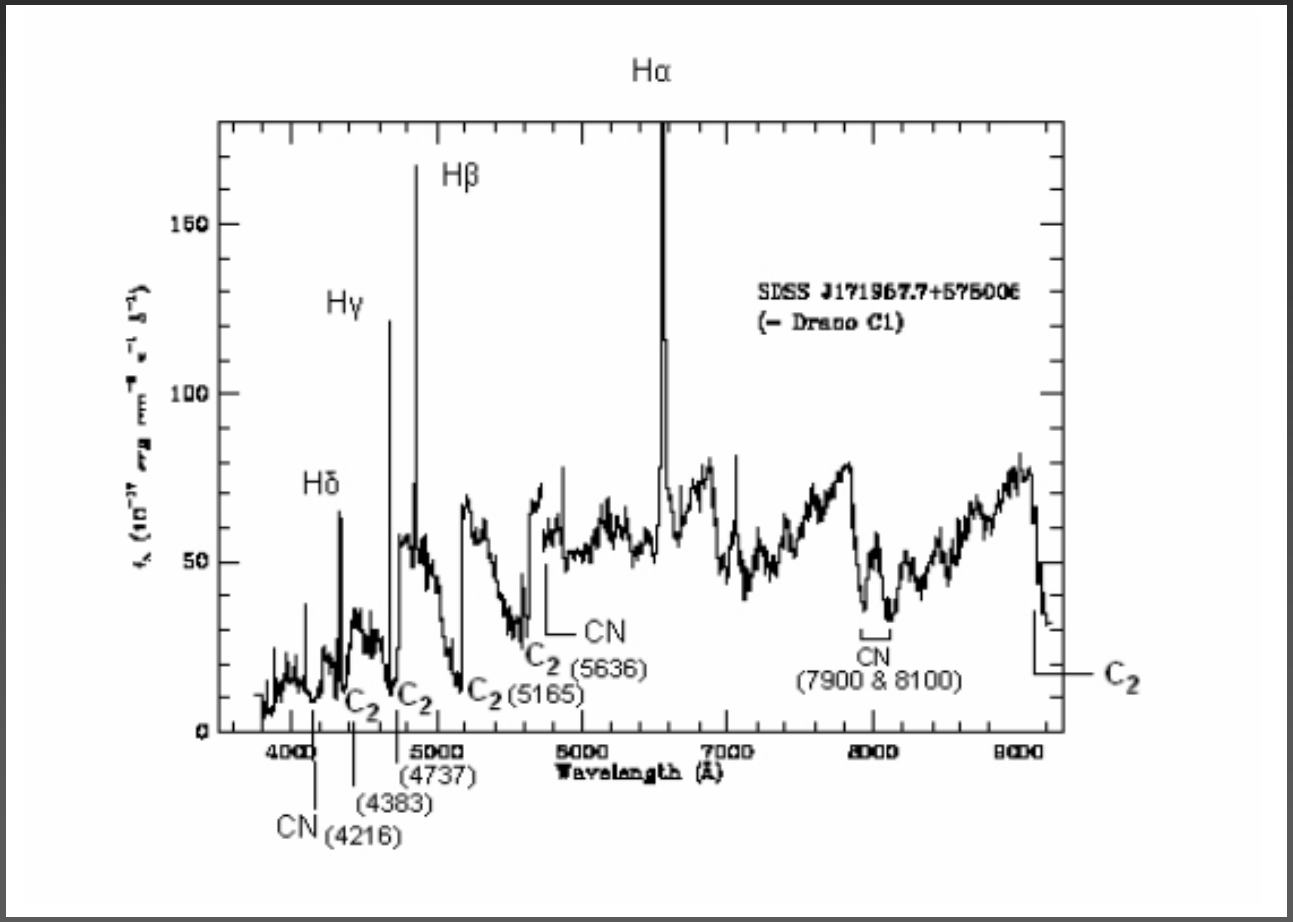
Survey stretegy: 640 fibres for a given field

1. Extra galactic targets
2. Brown dwarfs
3. Carbon stars
4. Standard stars

About 500 carbon stars are identified from SDSS Data release I (DR1) (Margon etal 2002, Downes et al. 2004)

Timothy Beers has identified several hundred new carbon-enhanced stars in the SDSS DR3 below a metallicity of [Fe/H] = -2.0

Carbon Stars



Origin of carbon

AGB at 3rd Dredge up mixing

Evidence for mixing of He core flash products in the RGB phase

Chemical Composition of Carbon Enhanced Metal poor (CEMP) stars

Carbon rich C/O > +1.0

Nitrogen rich at low metallicities.

Most of the carbon stars with solar metallicities have solar Nitrogen abundance.

Some cases exhibit a very high oxygen abundance

CS 29497-030 : [O/Fe]=1.67 from OI triplet lines!

12C/13C ~ 4 – 60

Large frequency of carbon stars at low metallicity. HK I Survey(Beers et al.)

HK II survey (Rhee et al.) and

HES Survey (christlieb et al. (2000)

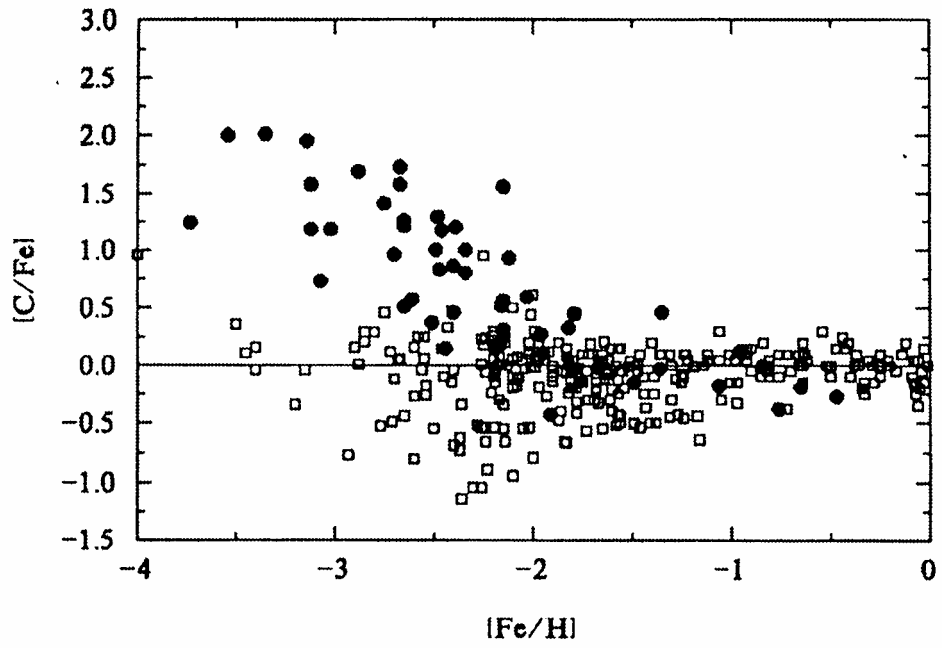


Figure 2. [C/Fe] vs. [Fe/H] for the combined sample of carbon-enhanced stars from Beers et al. (1992) (filled circles) and the literature sample (open squares).

N-capture in CEMP stars

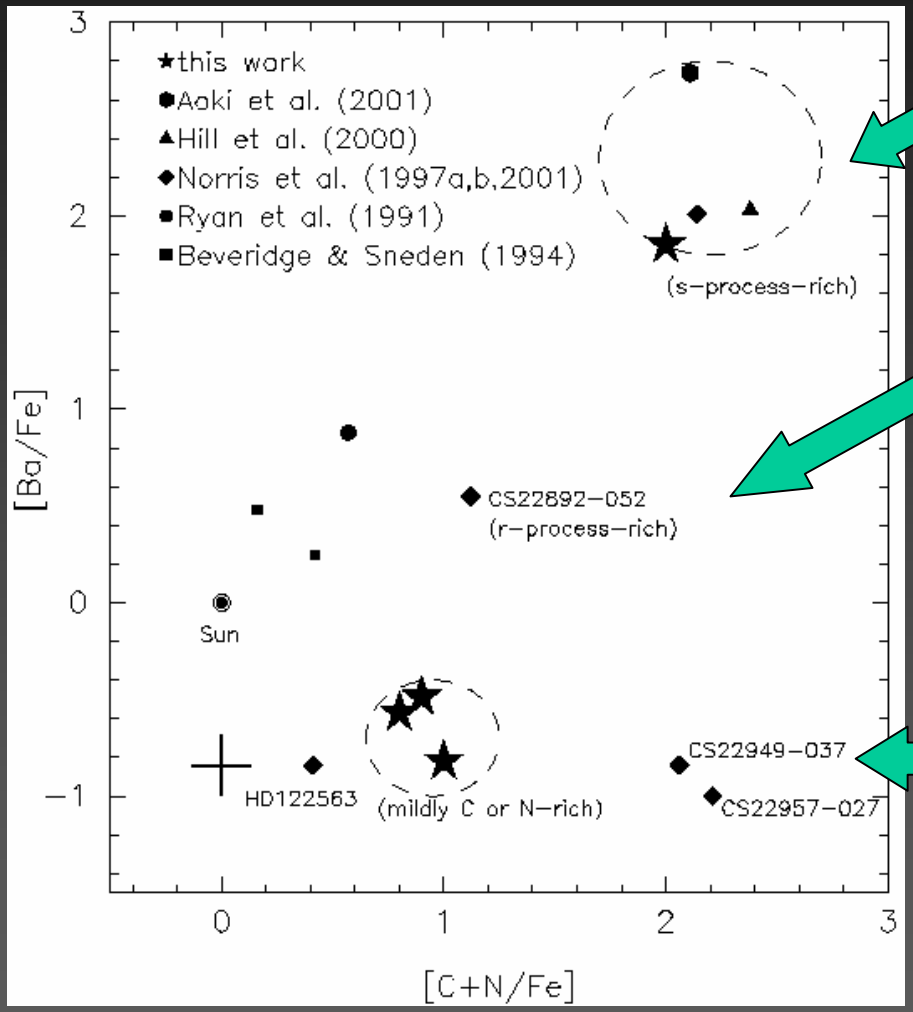


Figure from Ryan et al. (2002)

S-process rich ➔ AGB mass transfer
One with normal Li : LP706-7

CS22892-052
The only r-process rich carbon star
r-only pattern (Sneden et al. 2003)

No n-capture elements
HE 0107-5240 Christlieb et al 2002
CS 22957-027 Aoki et al 2002
HE 0007-1832 Cohen et al 2004
12C/13C ~ 6 – 9 (CNO equilibrium)
Also have high nitrogen abundance
Compared to s-process rich stars.

n-Capture Processes in CEMP stars

r-process rich carbon star
The only known CS 22892-052
r-only pattern (Sneden et al. 2003)

[C/Fe]=0.88, [N/Fe]=1.01, [O/Fe]=0.72
[Mg,Si/Fe] ~ 0.3
[Ba/Fe] = 0.99
[Eu/Fe] = 1.64
[Tb,Dy,Er…./Fe] ~ 1.6

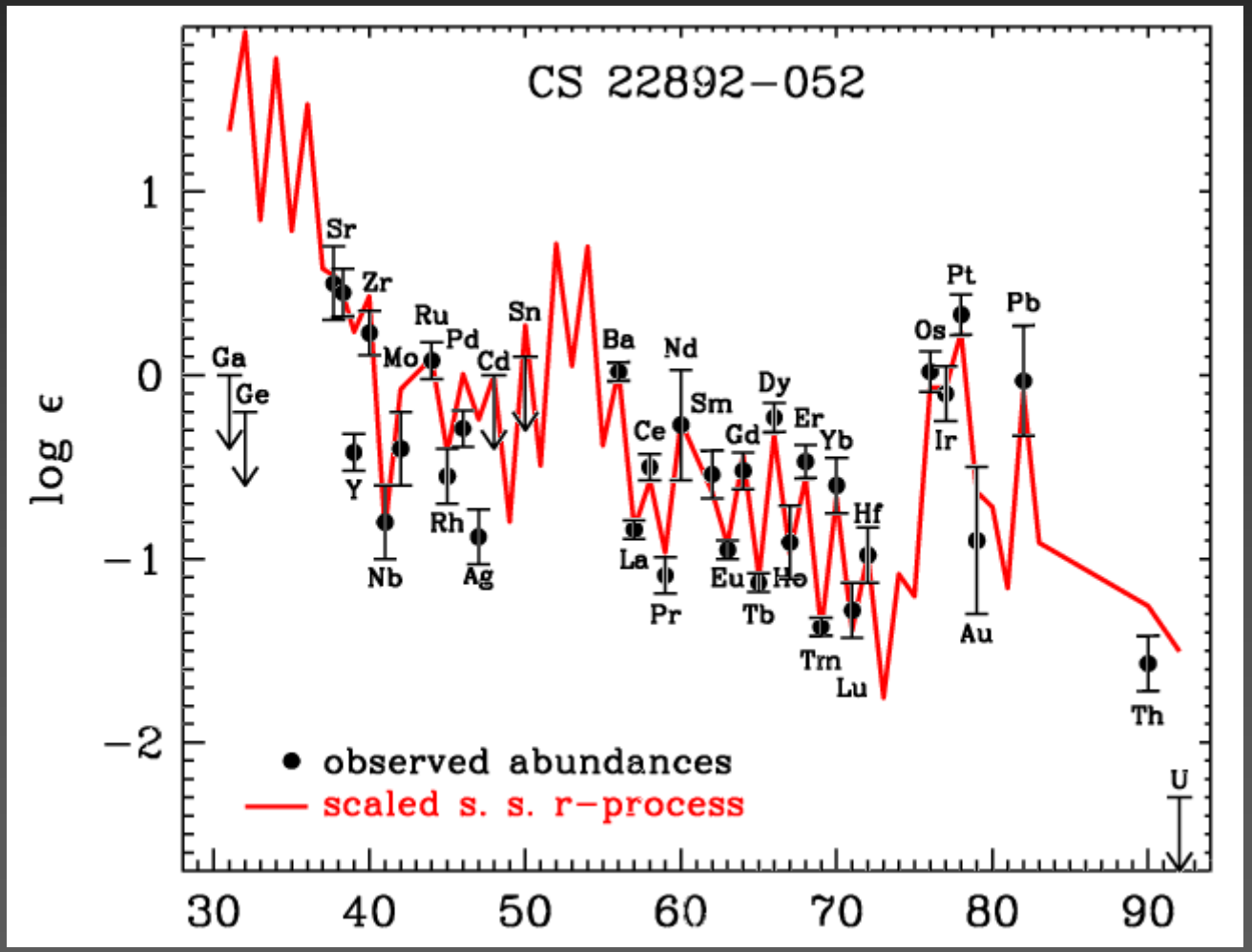
s and r-process
15 objects are known.
High [Eu/Ba] compared to pure s-process

[Ba/Fe] ~ 2.0
[Eu/Fe] ~ 1.5

No n-capture elements
HE0107-5240 Christlieb et al 2002
CS 22957-027 Aoki et al 2002
HE 0007-1832 Cohen et al 2004
12C/13C ~ 6 – 9 (CNO equilibrium)
s-only stars?

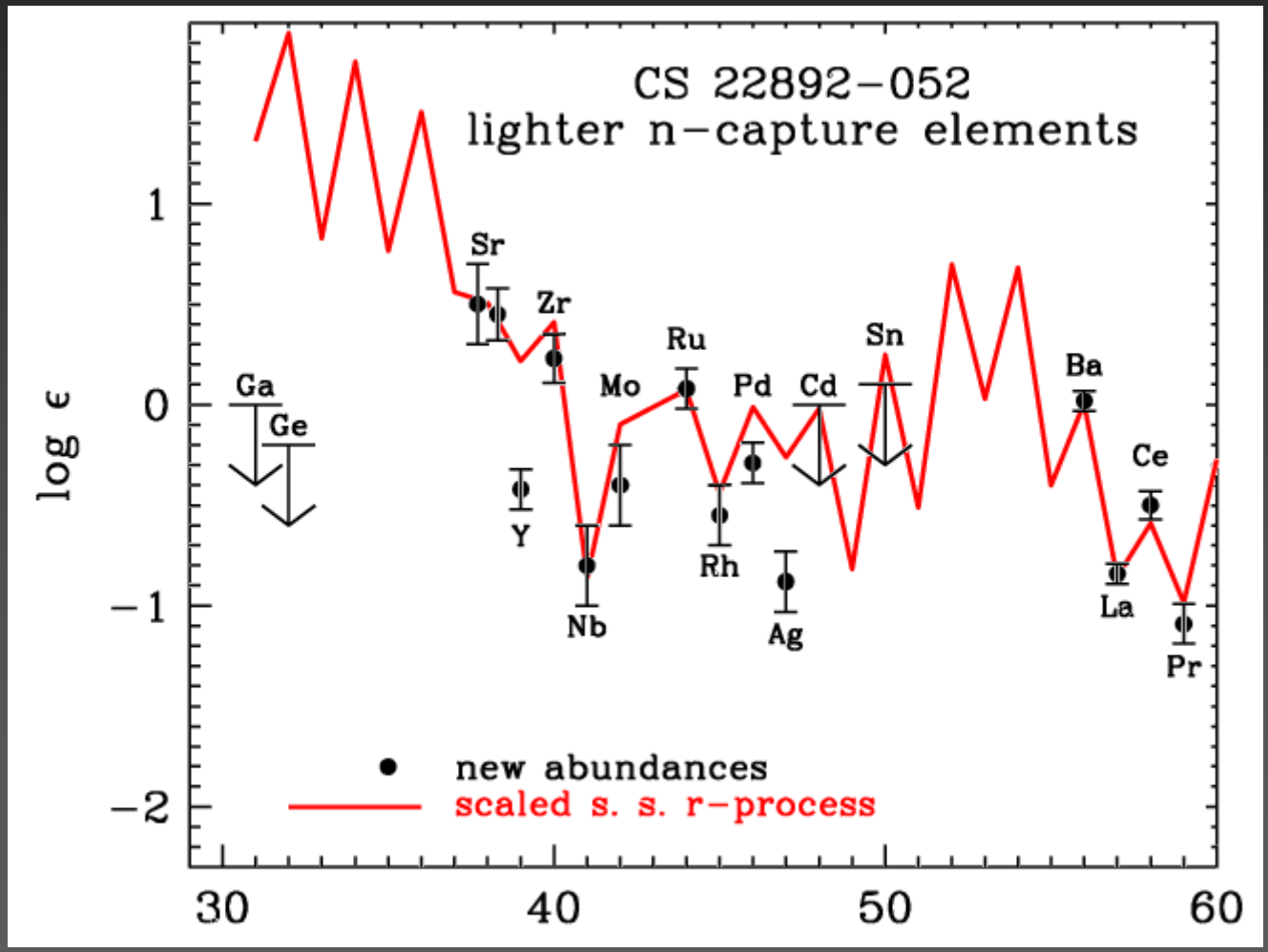
[Ba/Eu] ~ -0.9 ~ pure *r*-process value
at [Fe/H] ~ -3.0

CS 22892-052



Sneden et al. (2003)

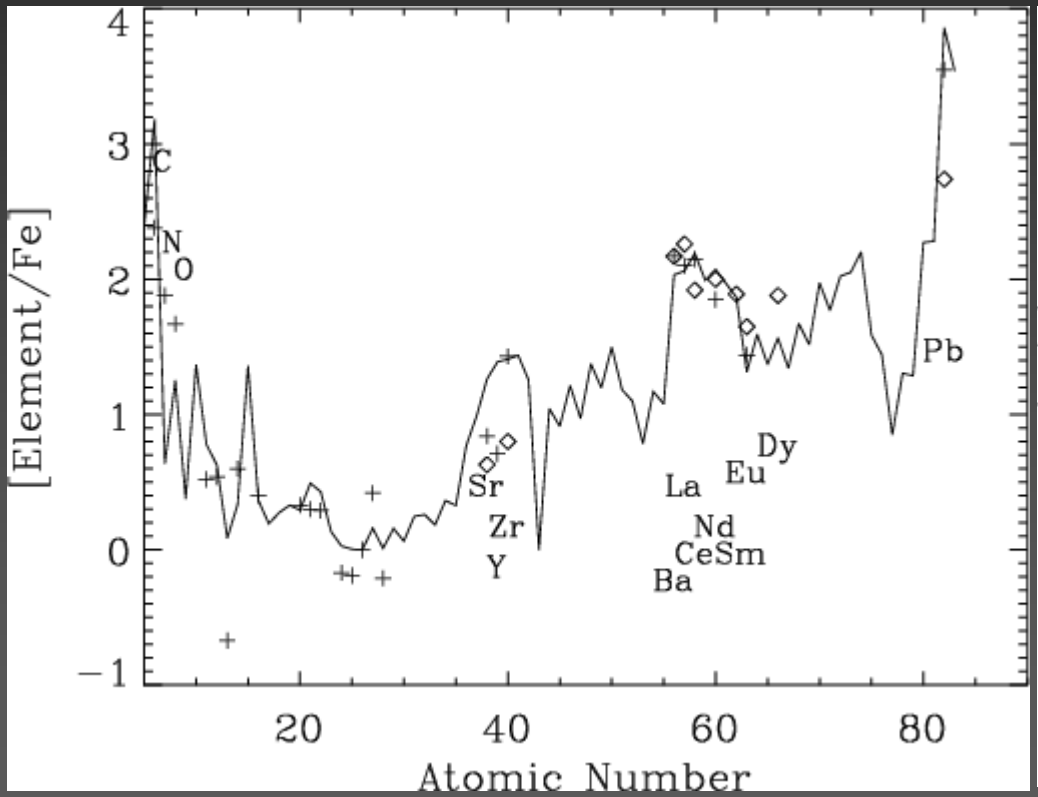
CS 22892-052

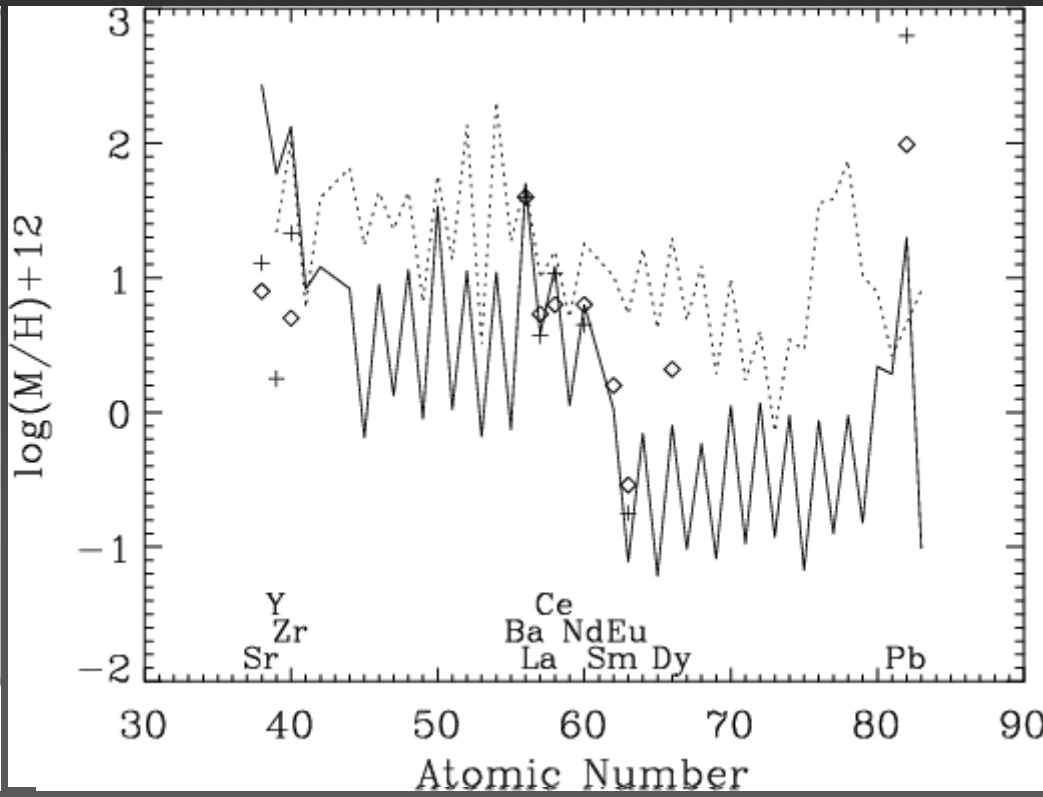


Sneden et al. (2003)

CS 29497-030

Carbon rich s-process rich, Pb rich star

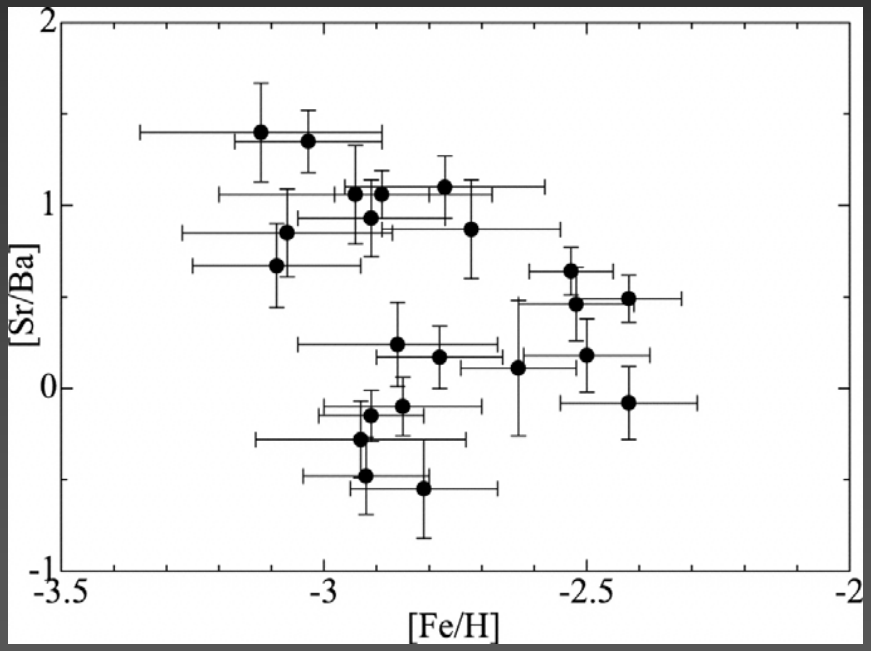




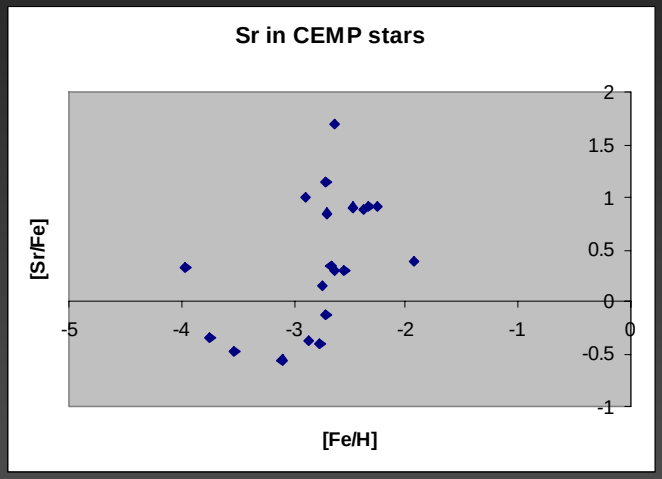
Models by Gallino (Priv. commu)

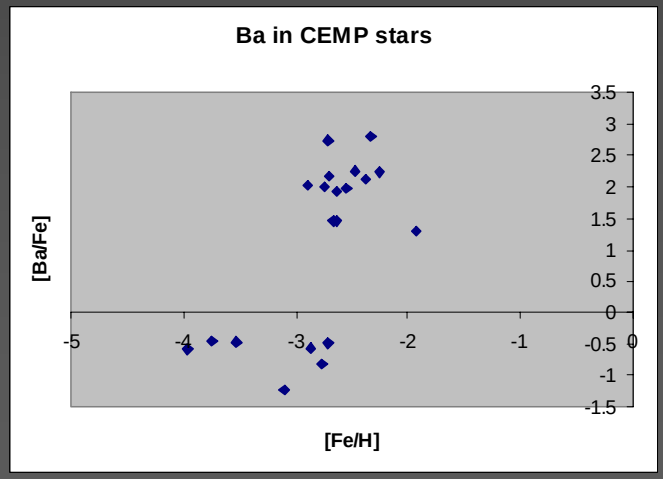
Arlandini et al. (2000)

Sr in Carbon Enhanced Metal poor Stars



Honda et al. (2004)





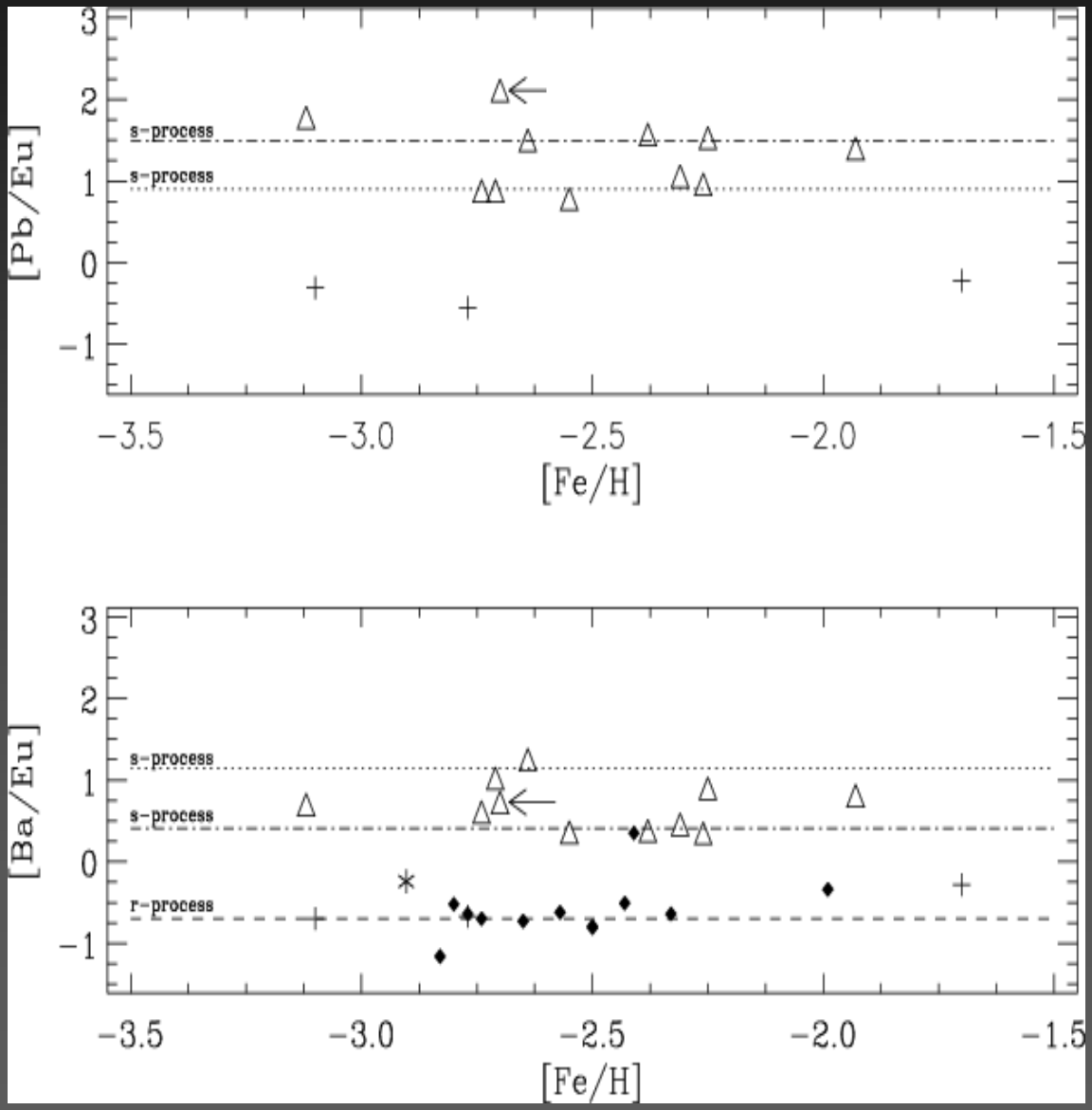
Eu in C Enhanced stars

CS 29497-030 is identified by an arrow.

CS 31082-001, as * Hill et al. (2002)

The dotted line is solar *s-process main component, the dashed line solar r-process value (*Arlandini et al. 1999).

The dash-dotted line represents the surface abundance of an AGB model with *Z=0.001 after 50 thermal pulses (*Goriely & Mowlavi 2000)

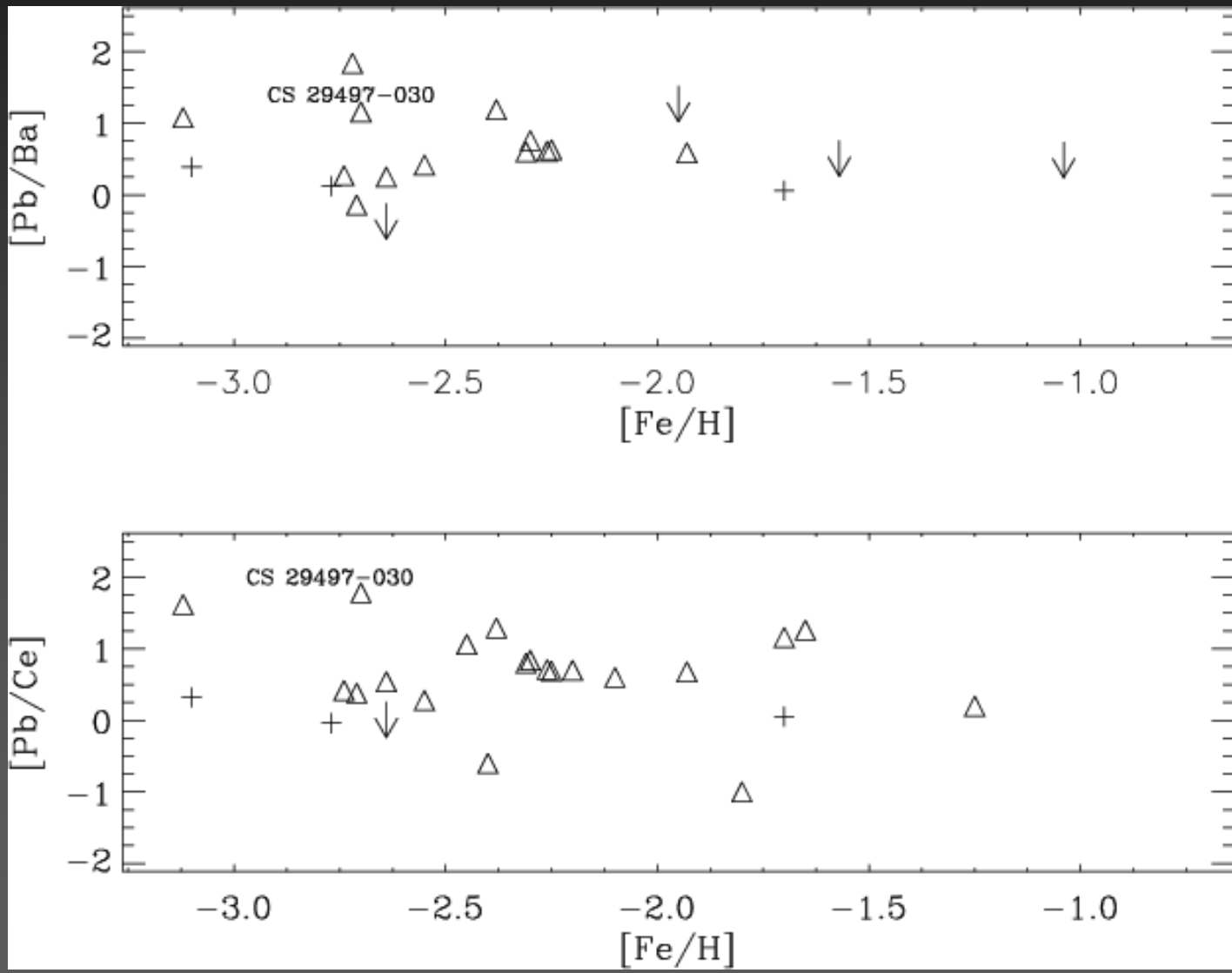


Sivarani et al. (2004)

Pb in Carbon Enhanced Stars

The three *r-process-enhanced stars CS 22892-052, HD 1262238, and HD 115444, are plotted as crosses. Upper limits are shown as downward arrows.*

The scatter is too large to fit with pure r-process stars.



Open Problems Related to n-Capture Elements in Carbon Enhanced Stars

Large frequency of s+r enhanced stars compared to r-only stars

Source of large Eu in s-process rich stars

Large scatter in Sr, Y, Zr

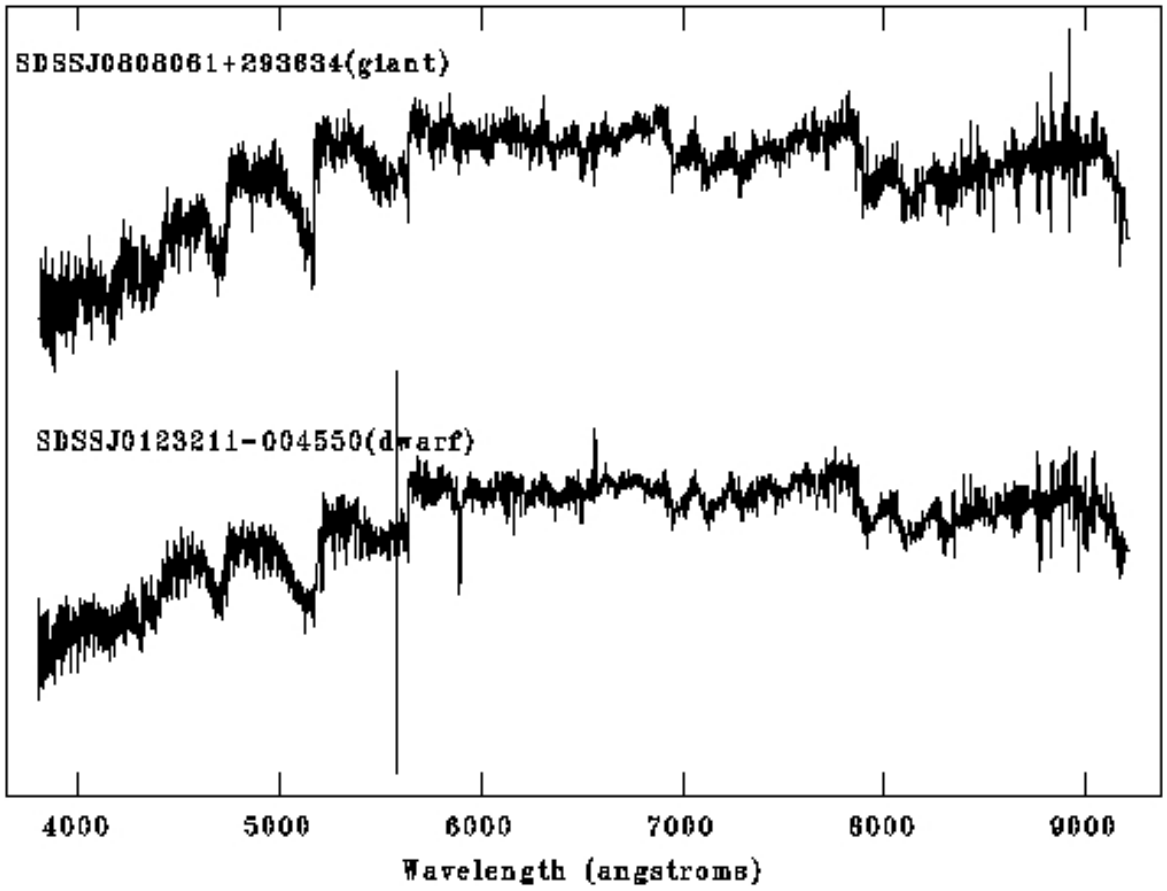
Larger, better understood samples and follow-up high resolution spectroscopy are required for progress. Ideally, one would like to know the frequency of the various phenomena that have been noted with far better accuracy.

Spectroscopy of Carbon stars from SDSS

Long standing problem differentiating Dwarf and Giant carbon stars at low resolution

Range of parameters

Temperature,
surface gravity ,
Metallicity,
Carbon abundance,
Nitrogen abundance



Analysis

MARCS model atmospheres (spherical and plane parallel)

Turbospectrum spectrum synthesis code (Plez)
for computing the theoretical models.

Atomic linelists from VALD and updated with recent values
Molecular linelists CH and CN (Plez)
C2, NH from Kurucz (1993)

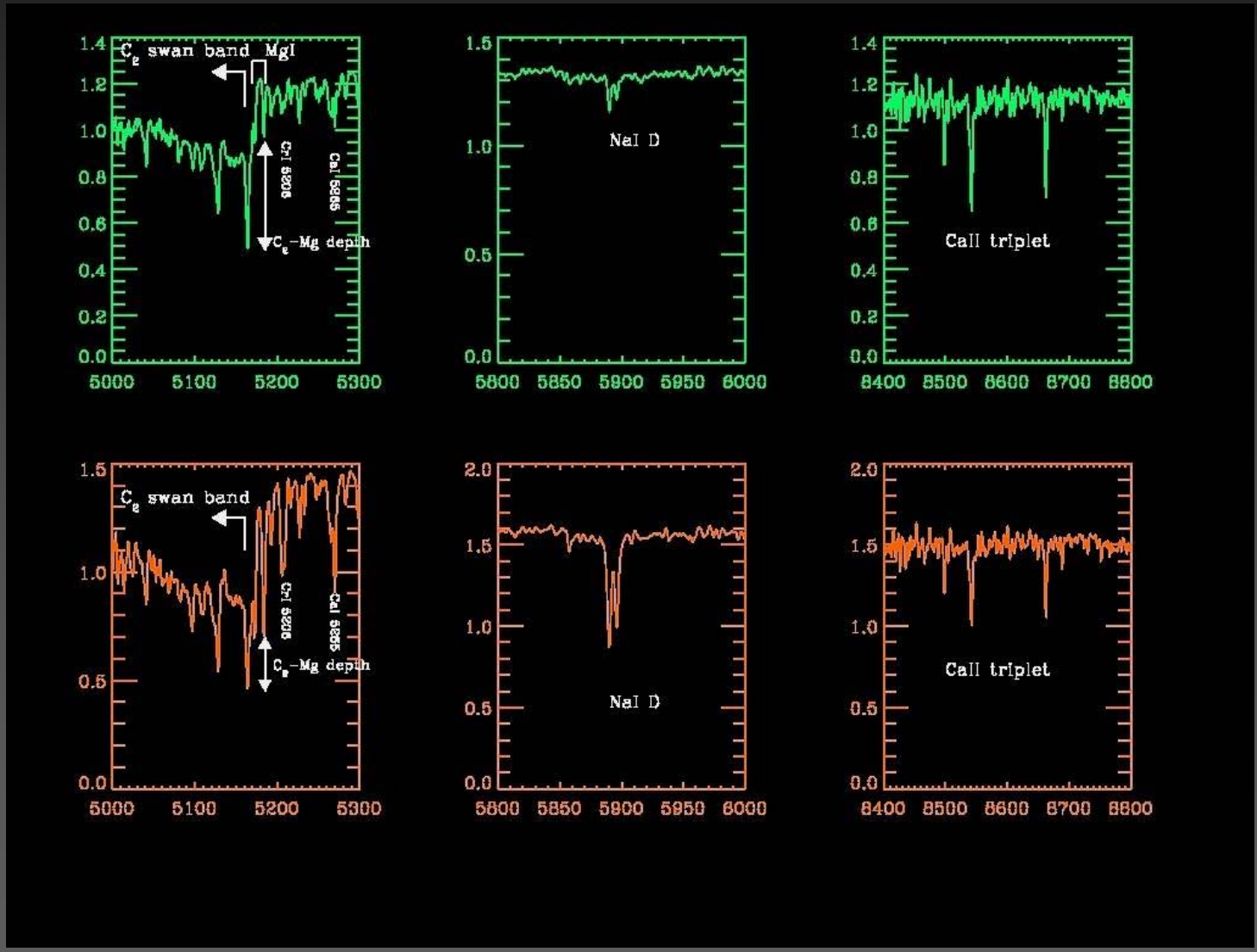
Constructed a grid of synthetic spectra for

Teff = 3500K – 5500K for various carbon abundances, metallicity and nitrogen abundances.

Luminosity Indicators

Teff = 4500K, log g=0.5

Teff = 4500K, log g=4.5



Carbon Stars with Strong C2 Bands

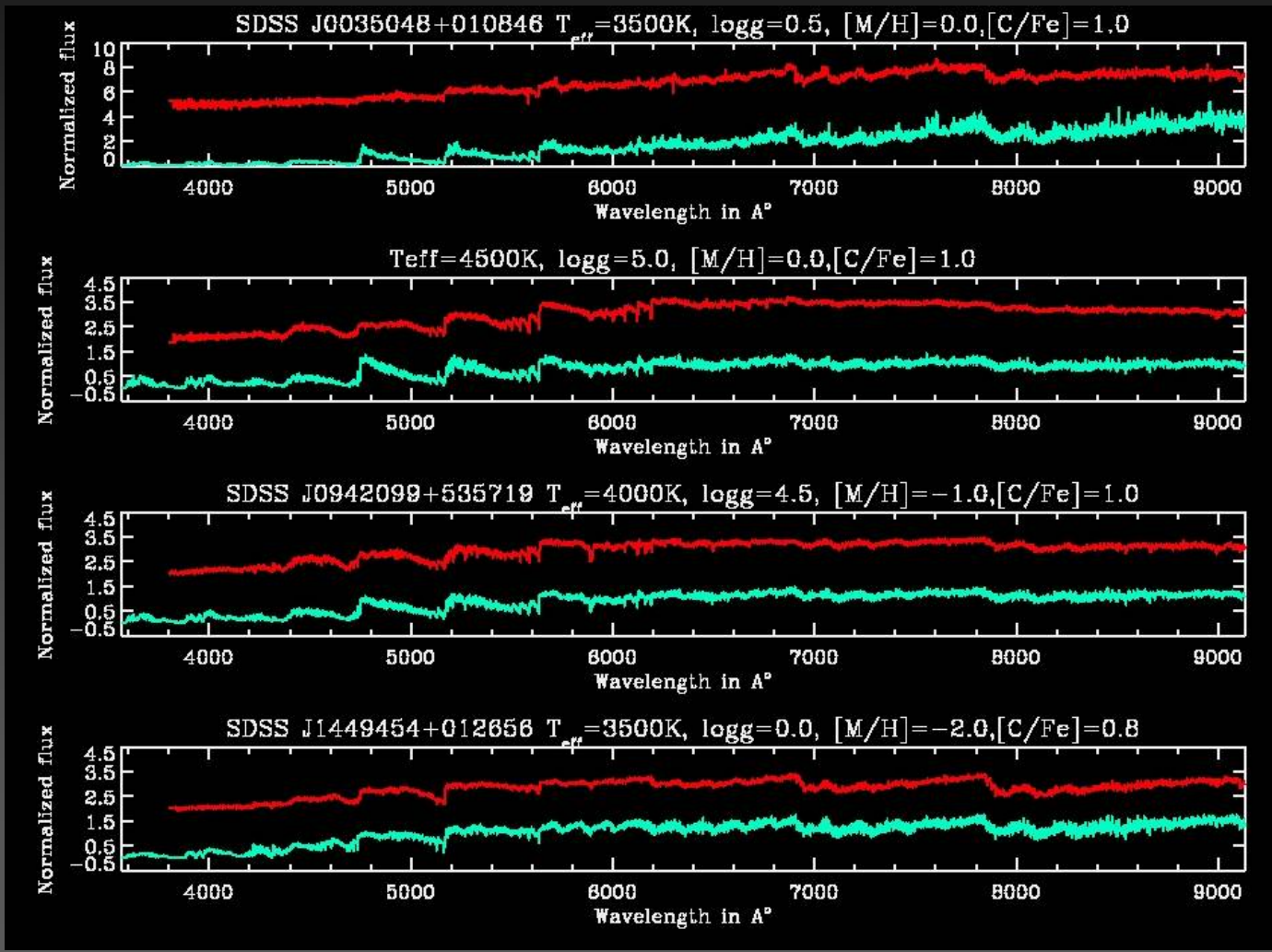
Carbon stars from the Downes et al. (2004) sample (red), along with the best matching theoretical spectra (green).

Solar metallicity stars have strong C2 bands for a given [C/Fe] ratio. Nitrogen abundance is slightly high at low metallicities.

SDSS J0120286-083631
Enhancement in 13C.

SDSS J0942099+535719 is a dwarf that shows no 13C enhancement; Barium is probably enhanced.

SDSS J1449454+012656 is a giant that shows a high 13C abundance and a mild enrichment in Barium.



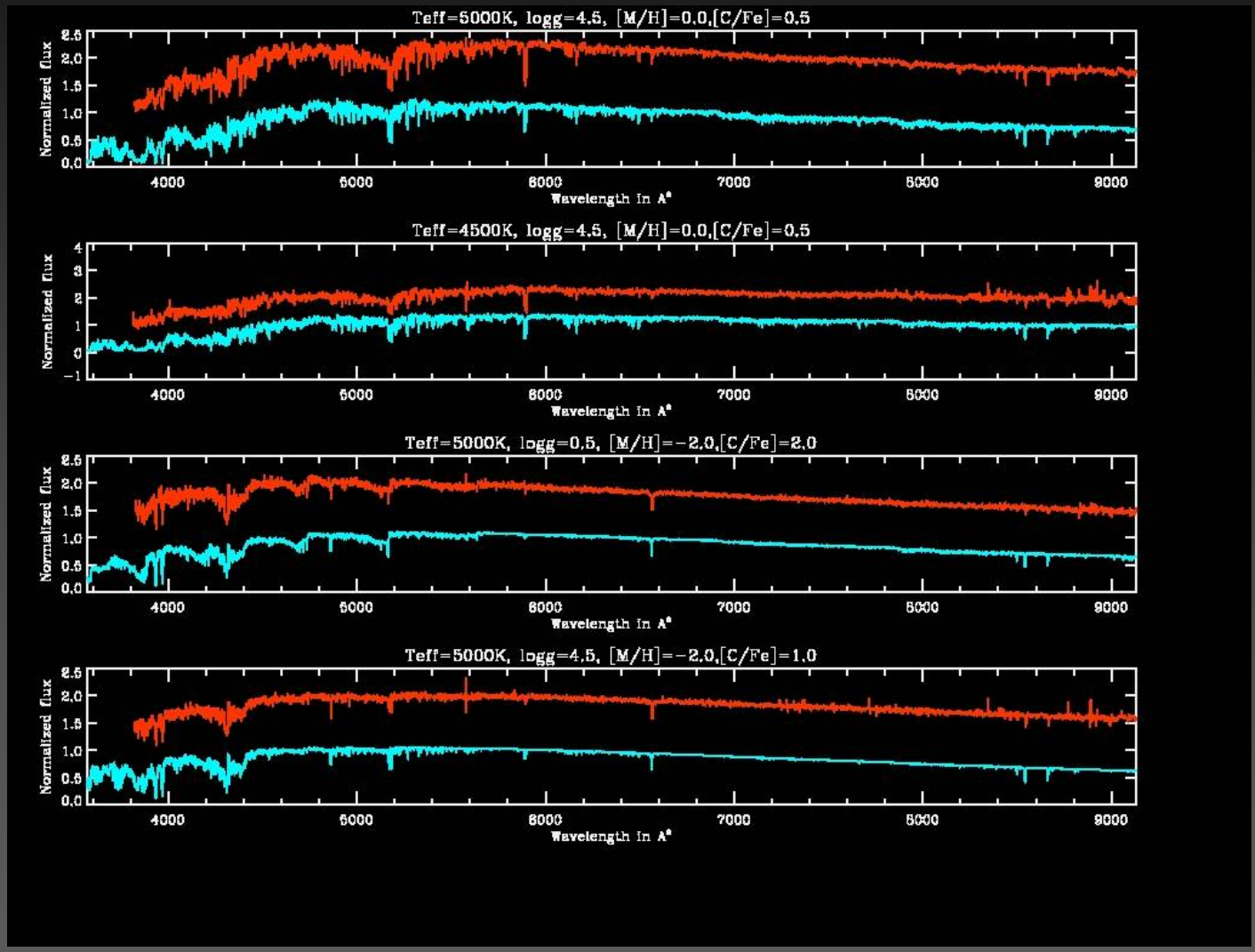
Carbon stars with weak C2 band ➔ low [C/Fe], metal poor

Carbon stars identified from SDSS DR3 (red) . We have compared the SDSS DR3 spectra with theoretical synthetic spectra (green).

At low metallicities the CH band is very prominently seen compared to C2 bands.

SDSS J132615.7-000022 shows a large Barium enrichment and 13C enrichment.

SDSS J121903.7-022812 shows a large 13C enrichment and high nitrogen abundance, and in addition, a probable mild enhancement



Future Work

Classification of carbon stars → useful for kinematics studies (SEGUE will find several thousand suitable stars)

Abundances of carbon stars: [C/Fe], [N/Fe], [Fe/H], [Ba/Fe], [Sr/Fe] and 12C/13C

Automated classification

Follow up high-resolution spectroscopy of the metal poor candidates for abundance studies and radial velocity monitoring