ngCFHT workshop
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Extremely Metal-Poor Stars

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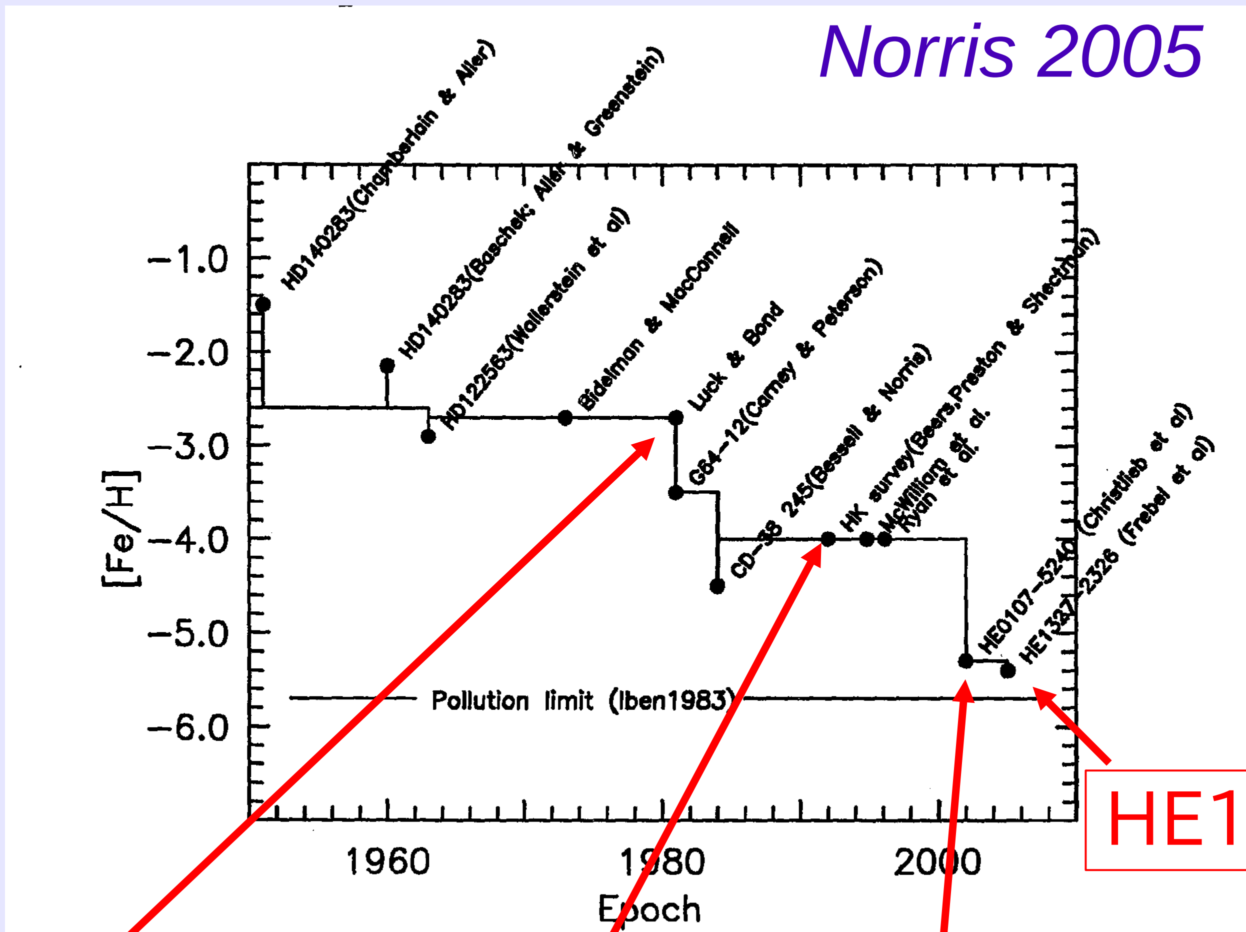
Extremely Metal-Poor (EMP) Stars

•Chemical composition of EMP stars
→Nucleosynthesis of first generation stars
→Mass and evolution of first generations of (massive) stars/supernovae.

•Statistics of EMP stars
→low-mass star formation in the early Galaxy
Mechanism of gas cooling, binary formation, etc.

Search for metal-deficient stars in the Galaxy



HE1327-2326

Bond (1981)
"Where is Population III"

HK survey

Discovery of HE0107-5240
([Fe/H]=-5.3)

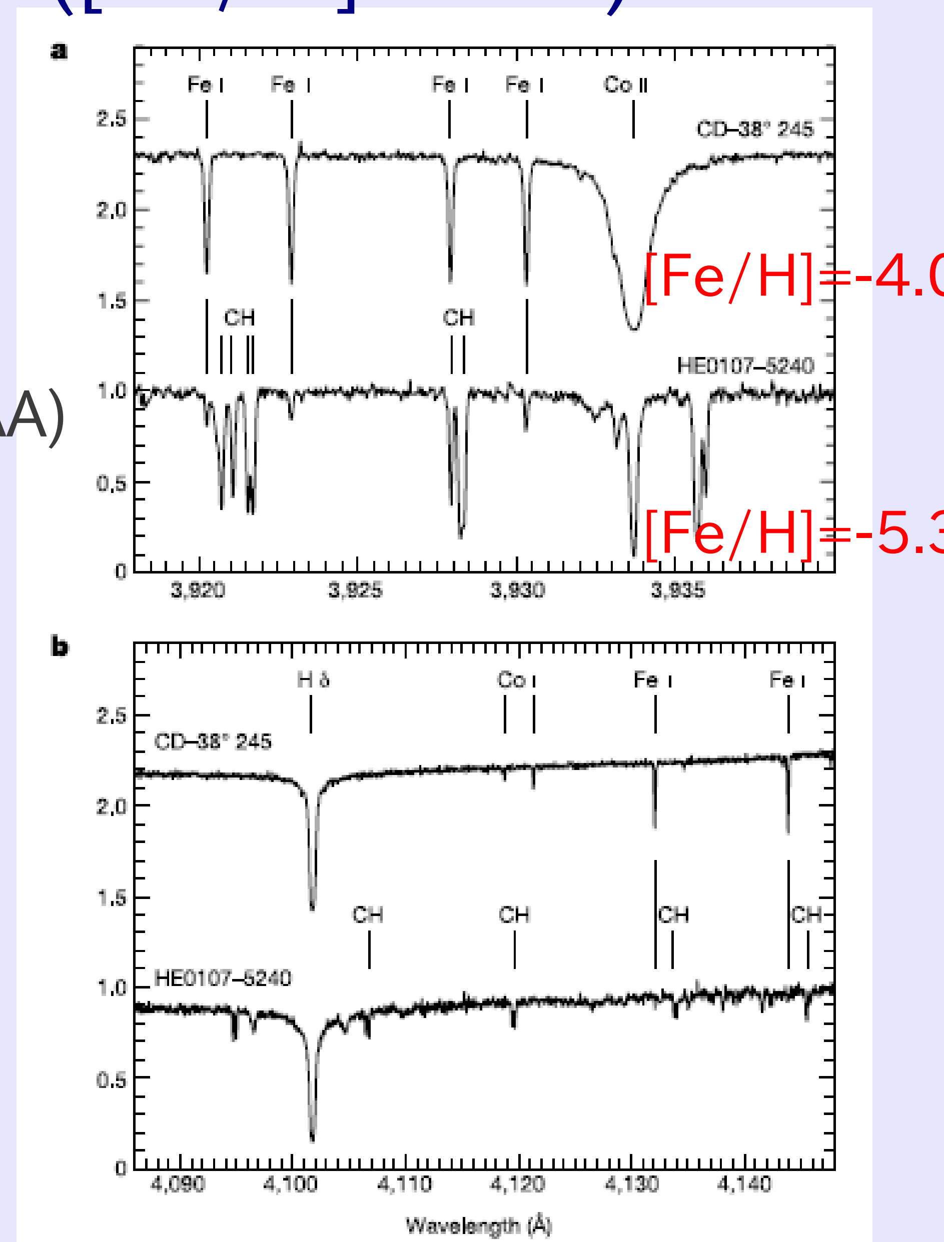
10 years from the discovery of HE0107-5240 ([Fe/H]=-5.3)

The first "Hyper Metal-Poor" (HMP) star
Christlieb et al. (2002)

Beers & Christlieb (2005, ARAA)

TABLE 1 Nomenclature for stars of different metallicity

[Fe/H]	Term	Acronym
> +0.5	Super metal-rich	SMR
~0.0	Solar	—
< −1.0	Metal-poor	MP
< −2.0	Very metal-poor	VMP
< −3.0	Extremely metal-poor	EMP
< −4.0	Ultra metal-poor	UMP
< −5.0	Hyper metal-poor	HMP
< −6.0	Mega metal-poor	MMP

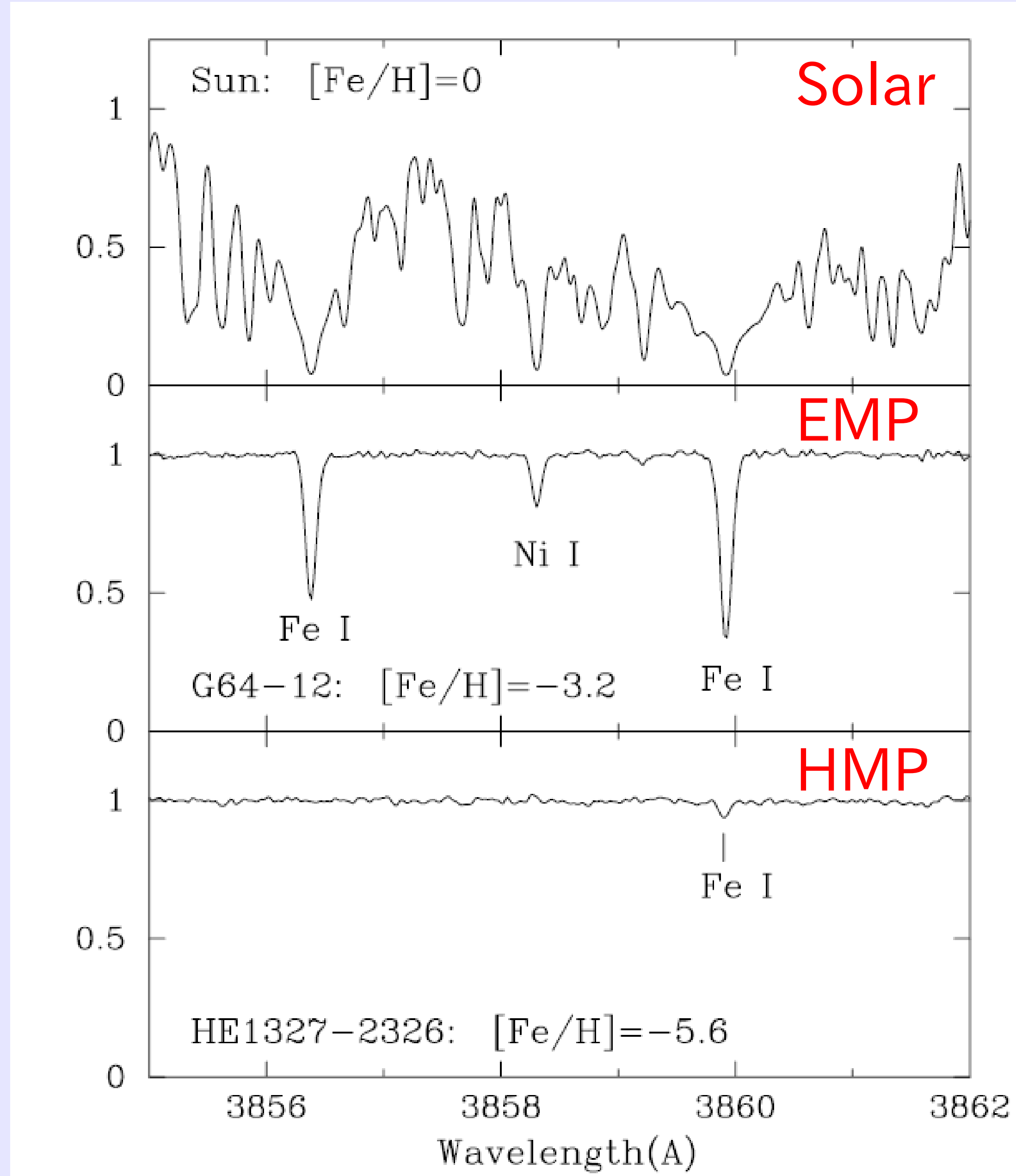


The 2nd HMP star HE1327-2326

Frebel et al. (2005)

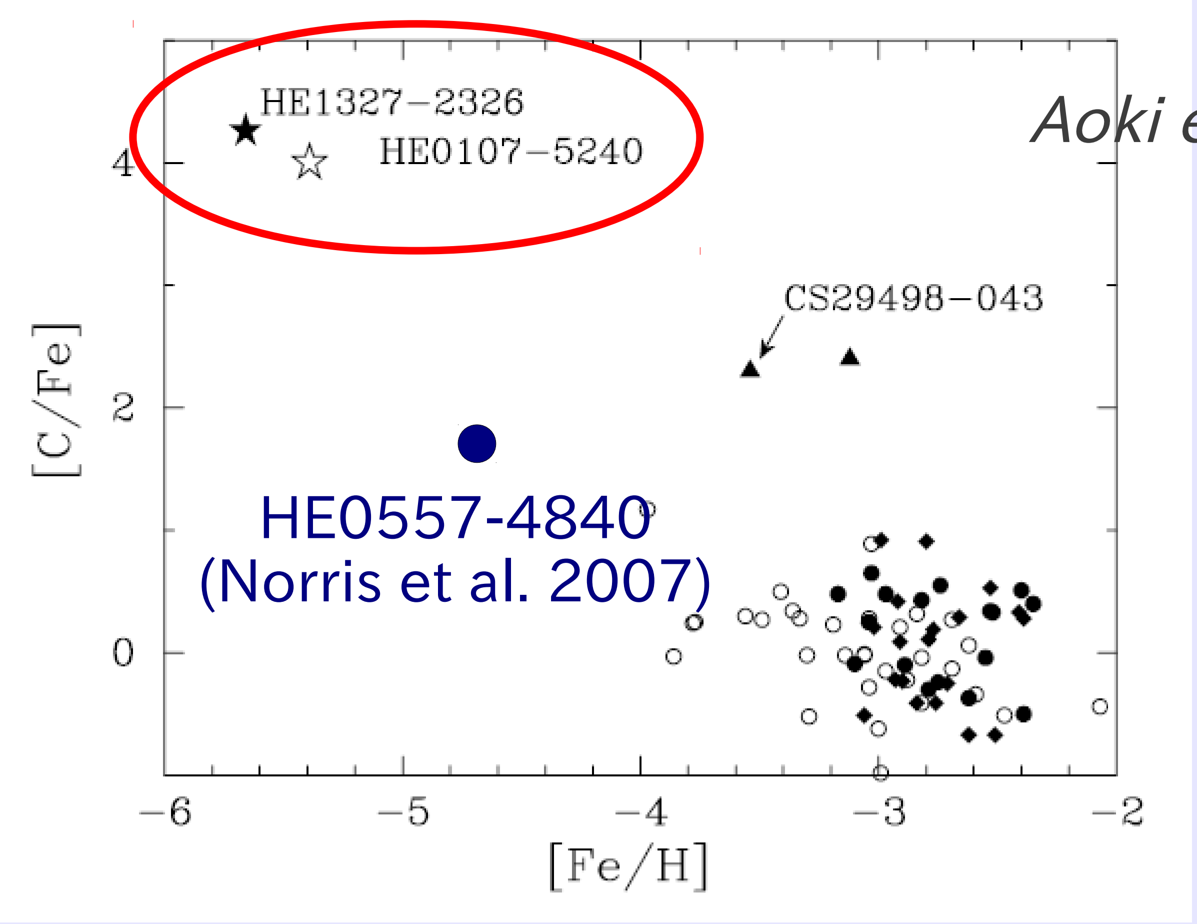
very weak Fe lines
→[Fe/H]=-5.4

detection of CH molecular bands
→excess of carbon



Carbon-enhancement in HMP stars

The two HMP stars show large excesses of C, (N) and O …
low-mass star formation from C and O-rich cloud?

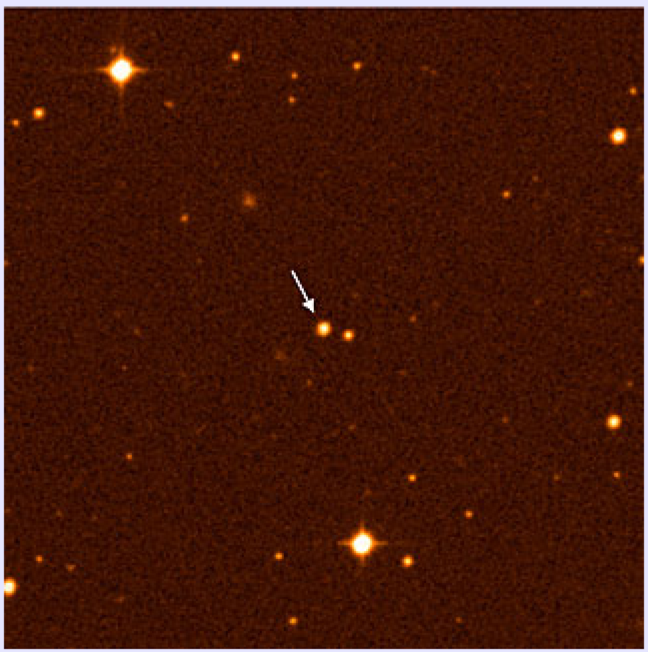


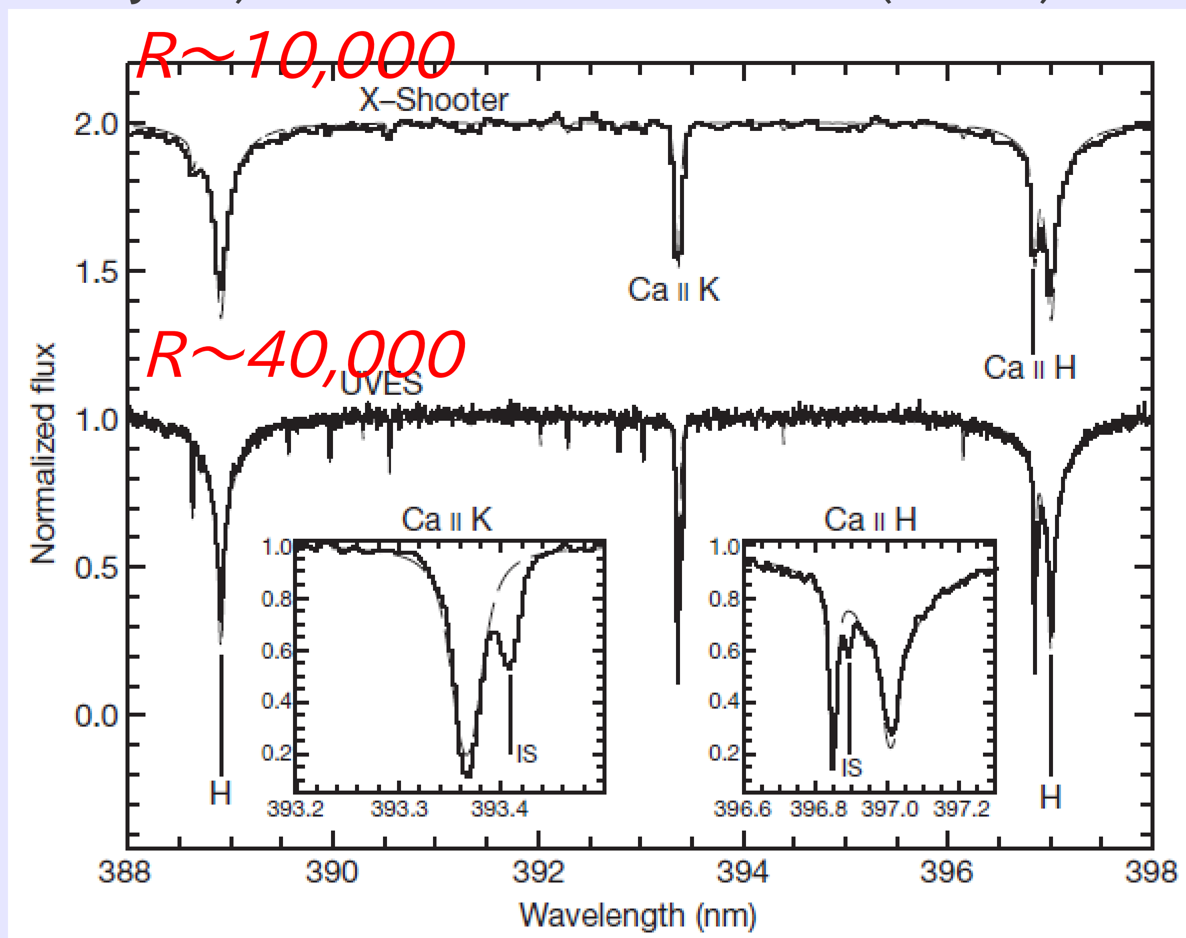
Aoki et al. (2006)

Discovery of the [Fe/H]～-5 star with normal C abundance SDSS J1029+1729

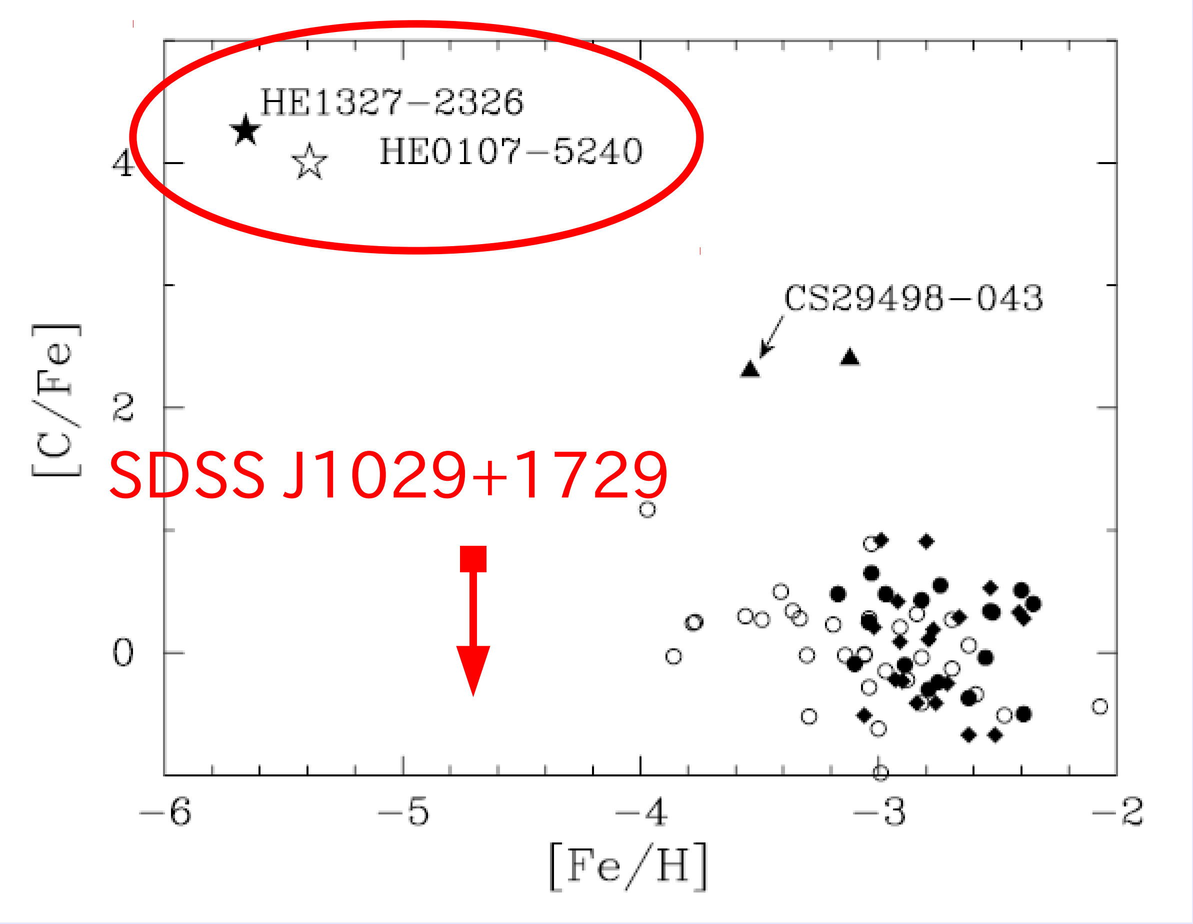
Caffau et al. (2011, 2012)

[Fe/H]=-4.7 (1D LTE analysis) → Ultra-Metal-Poor (UMP) star





Normal C abundance of the UMP star SDSS J1029+1729

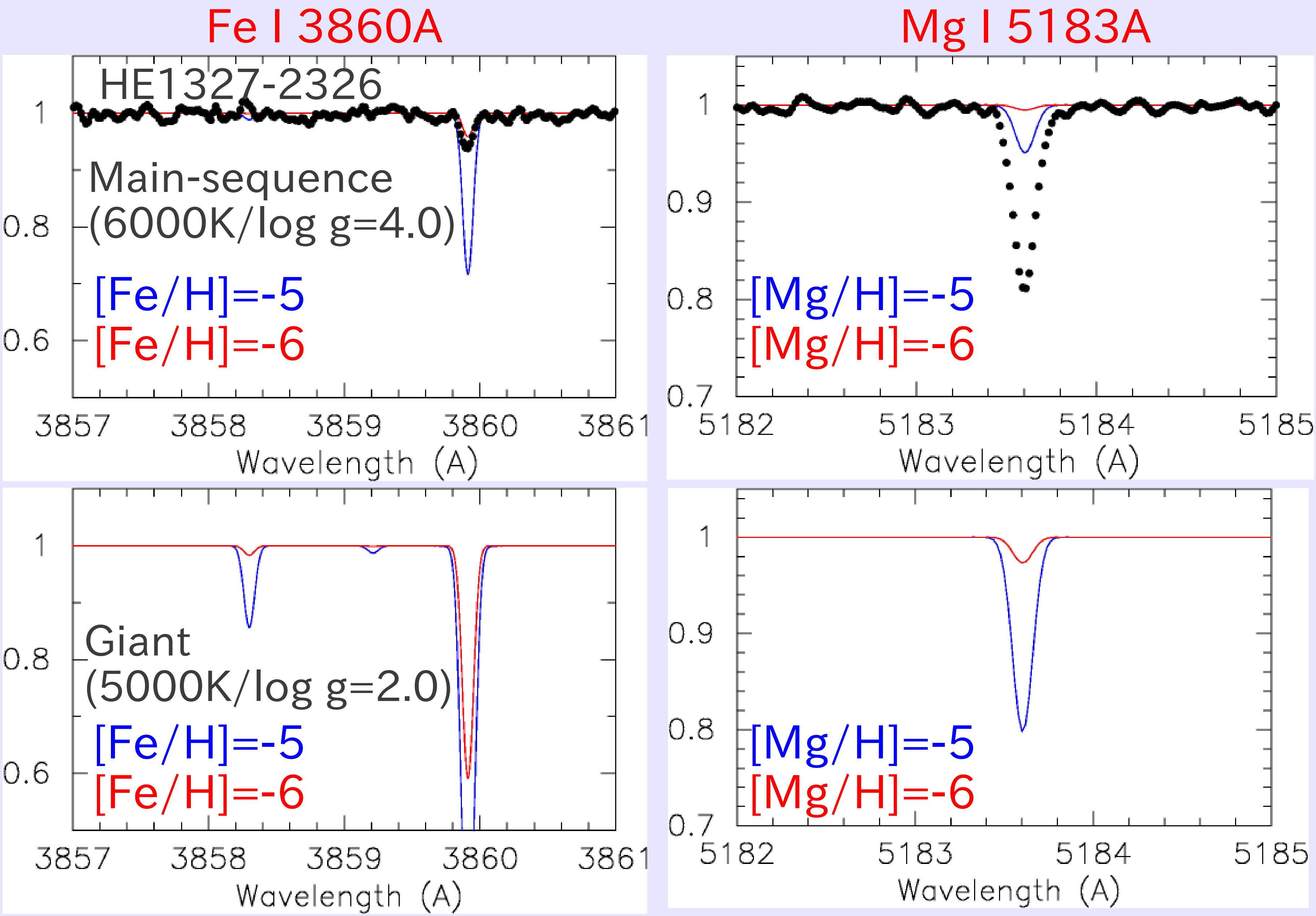


UMP/HMP stars ([Fe/H]<-4) found in the past decade

Object	V	[Fe/H] (1D-LTE)	[C/Fe]	Teff	type	
HE0107-5240	15.2	-5.3	4.0	5100	Giant	
HE1327-2326	13.5	-5.6	4.2	6180	MSTO*	
HE0557-4840	15.5	-4.8	1.6	4900	Giant	
SDSS J1029+1729	g= 16.9	-4.7	<0.9	5810	MSTO*	

* MSTO: main-sequence turn-off

Absorption lines in HMP/UMP stars



Growing sample of EMP stars

The sample of EMP stars studied based on high resolution spectroscopy becomes larger.

•Yong, Norris et al. (2013) → 86 EMP ([Fe/H]<-3) stars, including re-analysis of objects previously studied

•Aoki et al. (2013) → 70 new EMP stars from SDSS sample

→statistics
  -Metallicity distribution function
  -Fraction of carbon-enhanced objects
  -Binary frequency

→"rare" objects
  Cool main-sequence stars, RR Lyr, ...

Search for metal-poor stars by Sloan Digital Sky Survey (SDSS)

The 2.5m telescope at Apache Point Observatory

- SDSS spectroscopy:
  R˜1800
  Covering 3900-9000A
  14<V<20
- Metallicity estimate from Ca II HK lines
- Standard stars in SDSS-I
- New surveys in SDSS-II (SEGUE)→240,000 stars

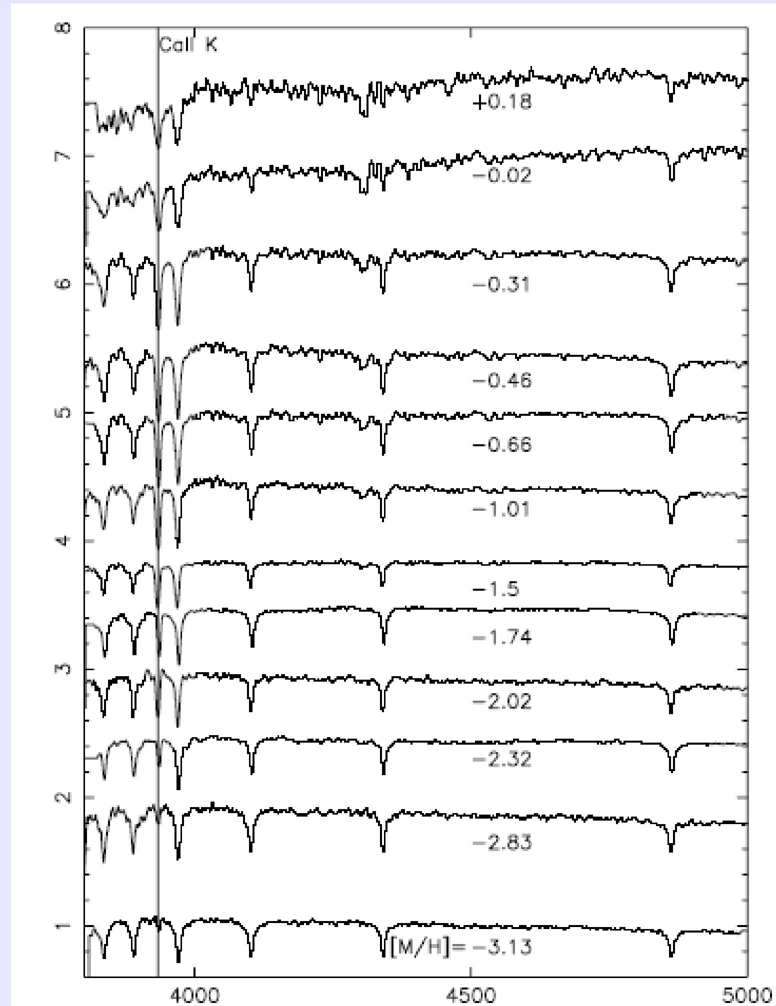


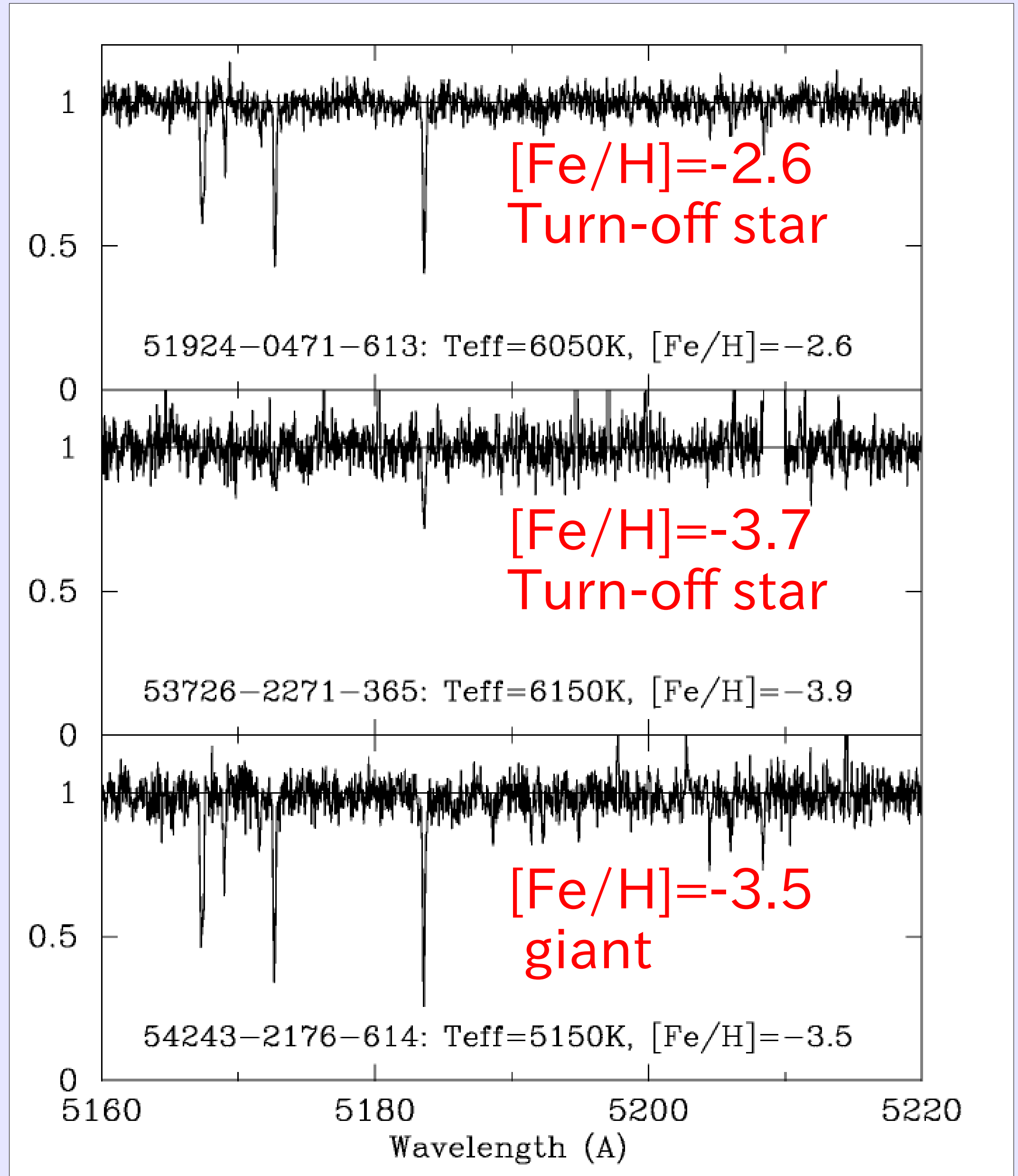
Figure 7. F star metal sequence—a set of SEGUE F stars, selected to show the range of metallicities sampled by the F subdwarf, F/G, spectrophotometric standard and reddening standard categories. All 13 stars have similar effective temperatures, near 6500 K, but the strength of the Ca K line at λ3933 indicates metallicities ranging from less than 0.001–1.5 times Solar.

High-resolution follow-up spectroscopy with Subaru/HDS

Snap-shot spectroscopy
- R=36,000
- 4030-6800A
- S/N～25-30
- ～150 objects with V<16.5

→Aoki et al. (2013, AJ)

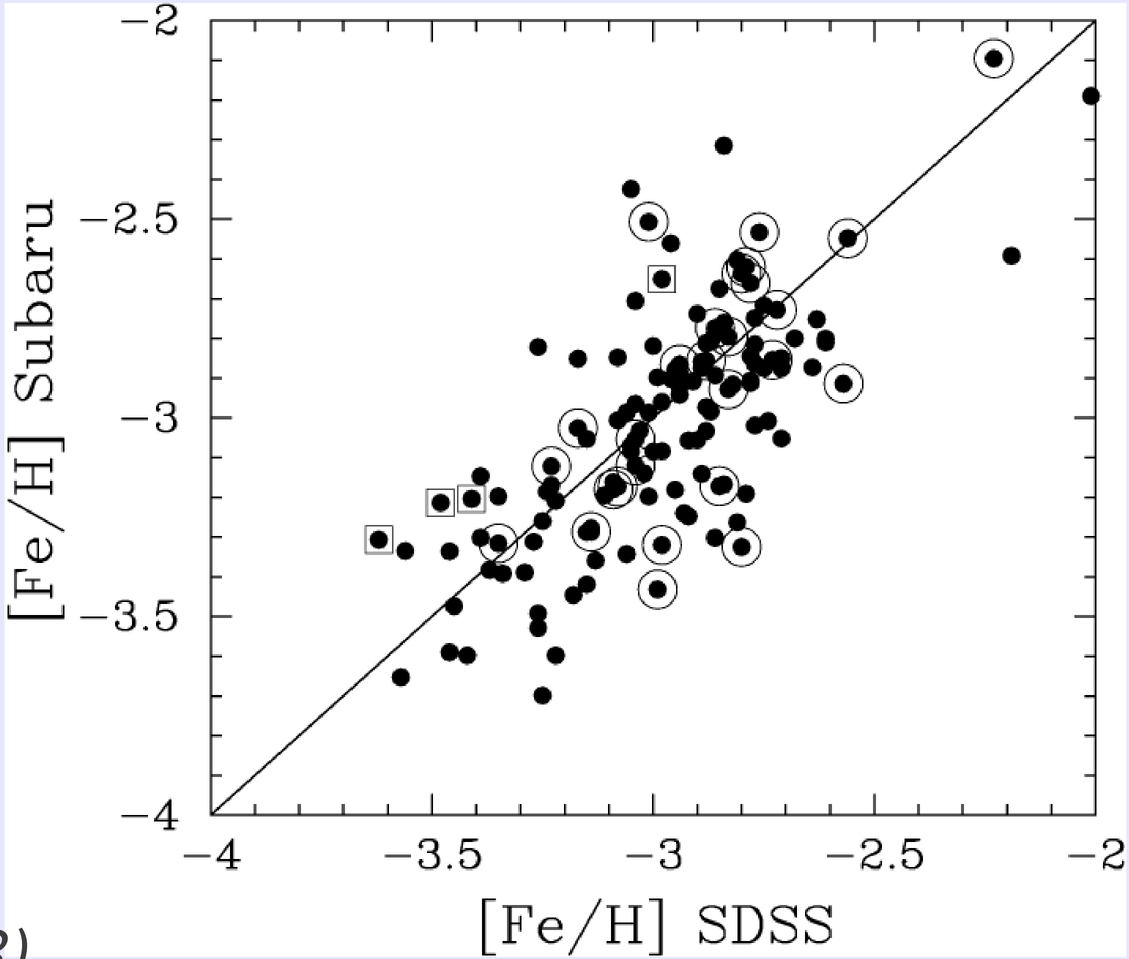
Example: Mg triplet around 5170A →



High S/N spectra with R=60,000 for ~15 selected stars have been obtained.

Metallicity ([Fe/H]) from Subaru spectra and comparison with SDSS estimates

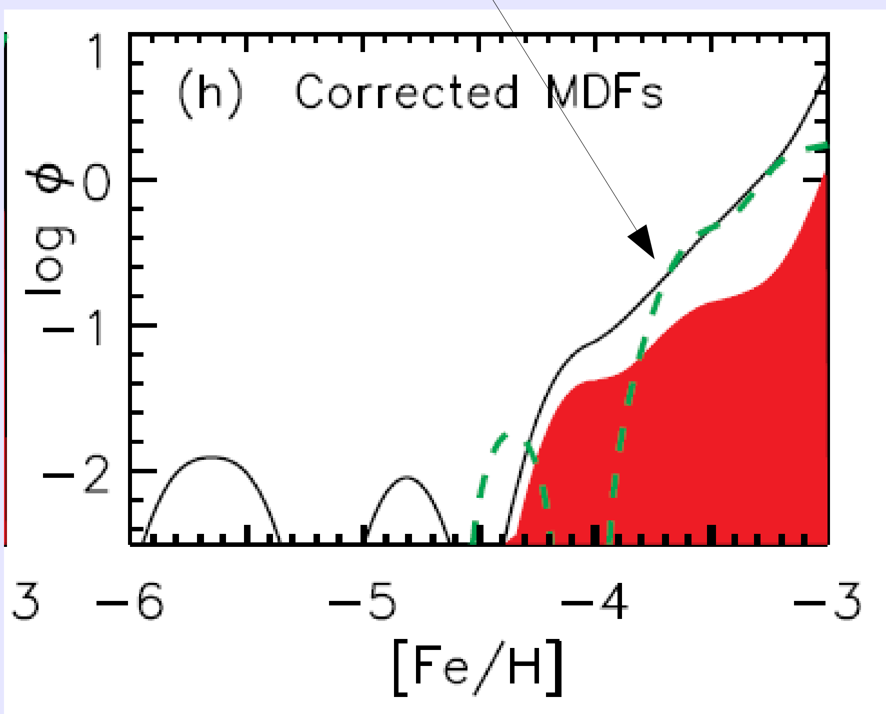
The metallicity estimated by the pipeline SSPP agrees with the estimate from high resolution spectroscopy with Subaru (no systematic offset). However, significant scatter remains in EMP stars.



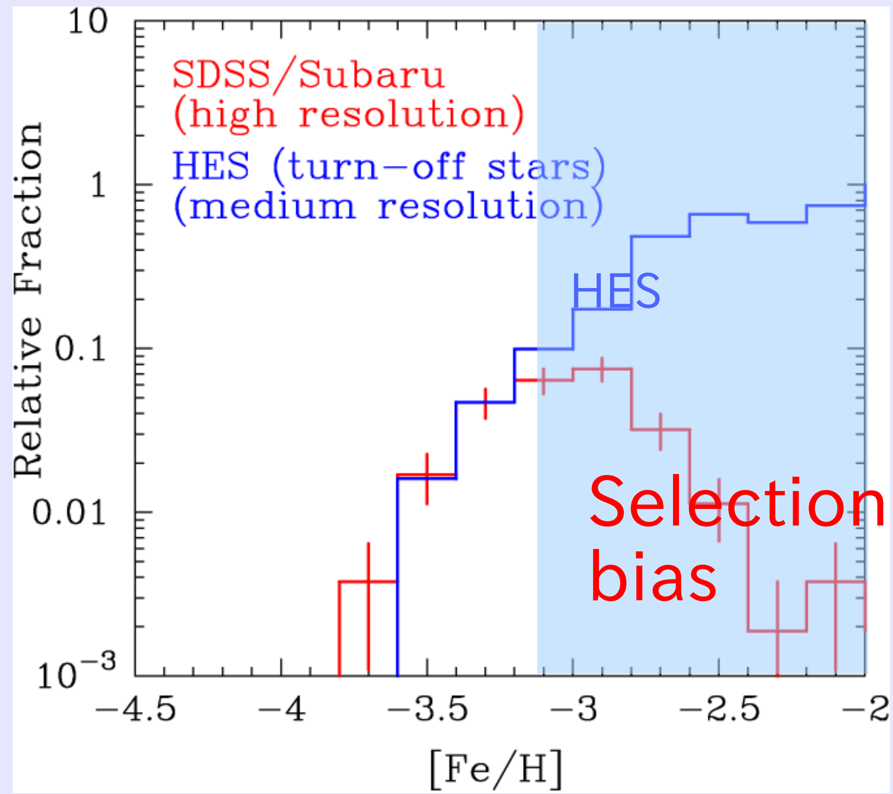
Aoki et al. (2013)

Metallicity Distribution Function (MDF) of EMP stars

Yong et al. (2013)
Whole sample (190stars)



SDSS/Subaru sample
(70 stars with [Fe/H]<-3)



Tail of MDF in [Fe/H]<-3.6? (or Drop at [Fe/H]=-3.8?)

Fraction of C-rich stars and their nature

- SDSS/Subaru sample: 9 of the 25 giants are carbon-rich
  →fraction of C-rich stars is 36% at [Fe/H]～ -3 (Aoki et al. 2013)

- Norris, Yong et al. (2013) estimate fraction of C-rich stars at [Fe/H]～-3.1 to be 28%.

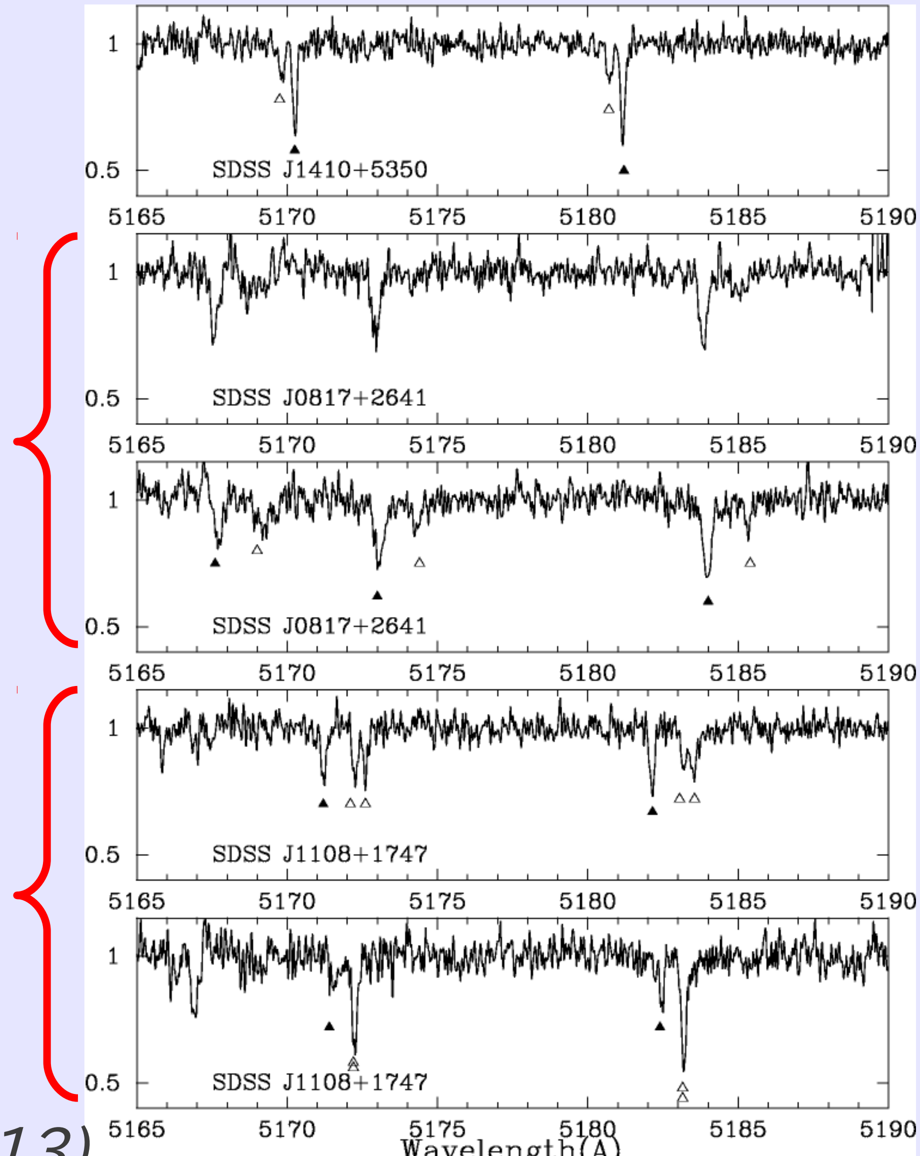
→two channels of gas cooling for low-mass star formation:
  - -fine structure lines of CII and OI (C-rich case)
  - -dust (C-normal case)

Double-lined spectroscopic binaries in the SDSS/Subaru sample

- 3 double-lined spectroscopic binaries among 109 turn-off stars (main-sequence + subgiant; Teff>5500K)

- One of them (SDSS J1108+1747) is a triple system!

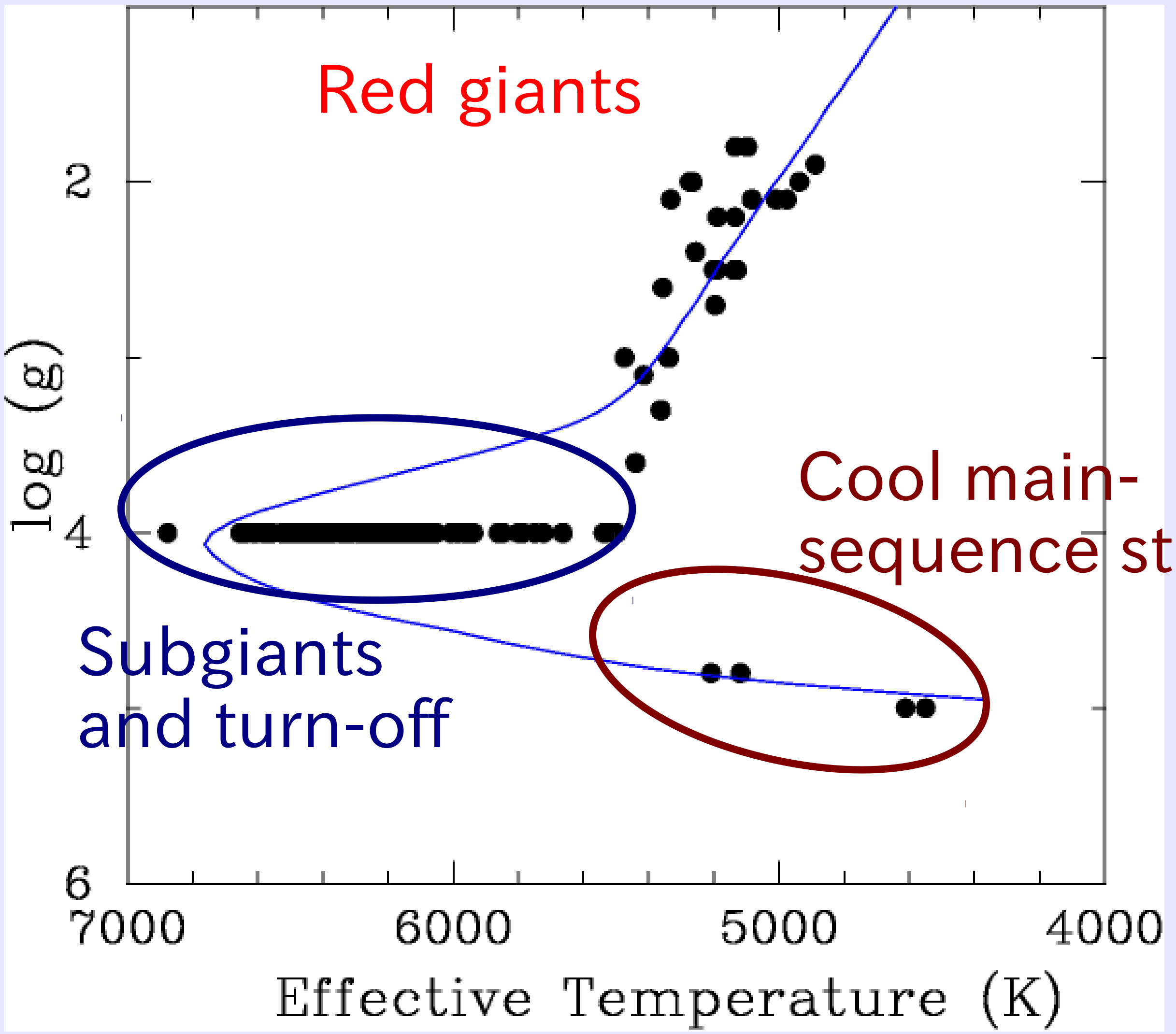
- Taking the detection probability into account, fraction of low-mass star binaries (with short separation) could be as high as 10%.



Aoki et al. (2013)

Cool main-sequence EMP stars

*T*eff-log(*g*) diagram of the SDSS/Subaru sample



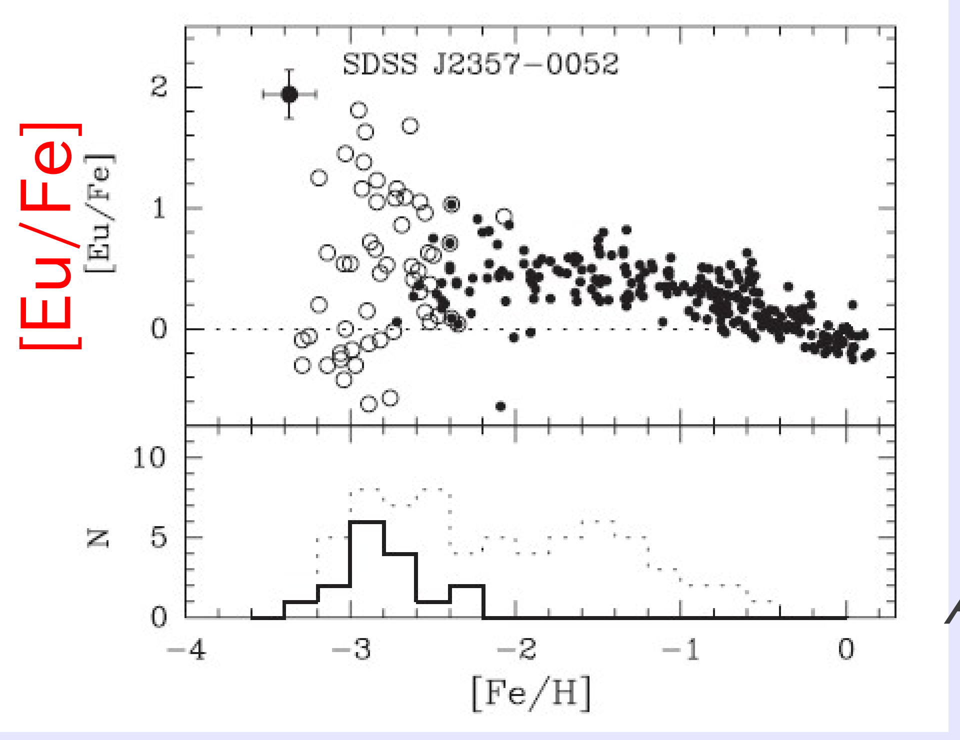
Cool main-sequence EMP stars

Two of the four cool main-sequence EMP stars show peculiar abundance patterns:

•SDSS2357-0052: extremely large excess of r-process elements

•SDSS0018-0939: deficiency of carbon and alpha-elements (Aoki et al., in prep.)

(The other two stars show normal abundance patterns.)



Aoki et al. (2010)

Extremely Metal-Poor stars summary

- Candidates of EMP stars ([Fe/H[<-3) can be selected from medium resolution spectra (e.g., SDSS). High resolution spectra (R>～20,000) is required to determine metallicity ([Fe/H]) and chemical abundance ratios for individual EMP stars.

- Large sample of EMP stars will provide more useful constraints on the (low-mass) star formation at low (zero) metallicity.