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金属欠乏星・矮小銀河の星の観測からの制限

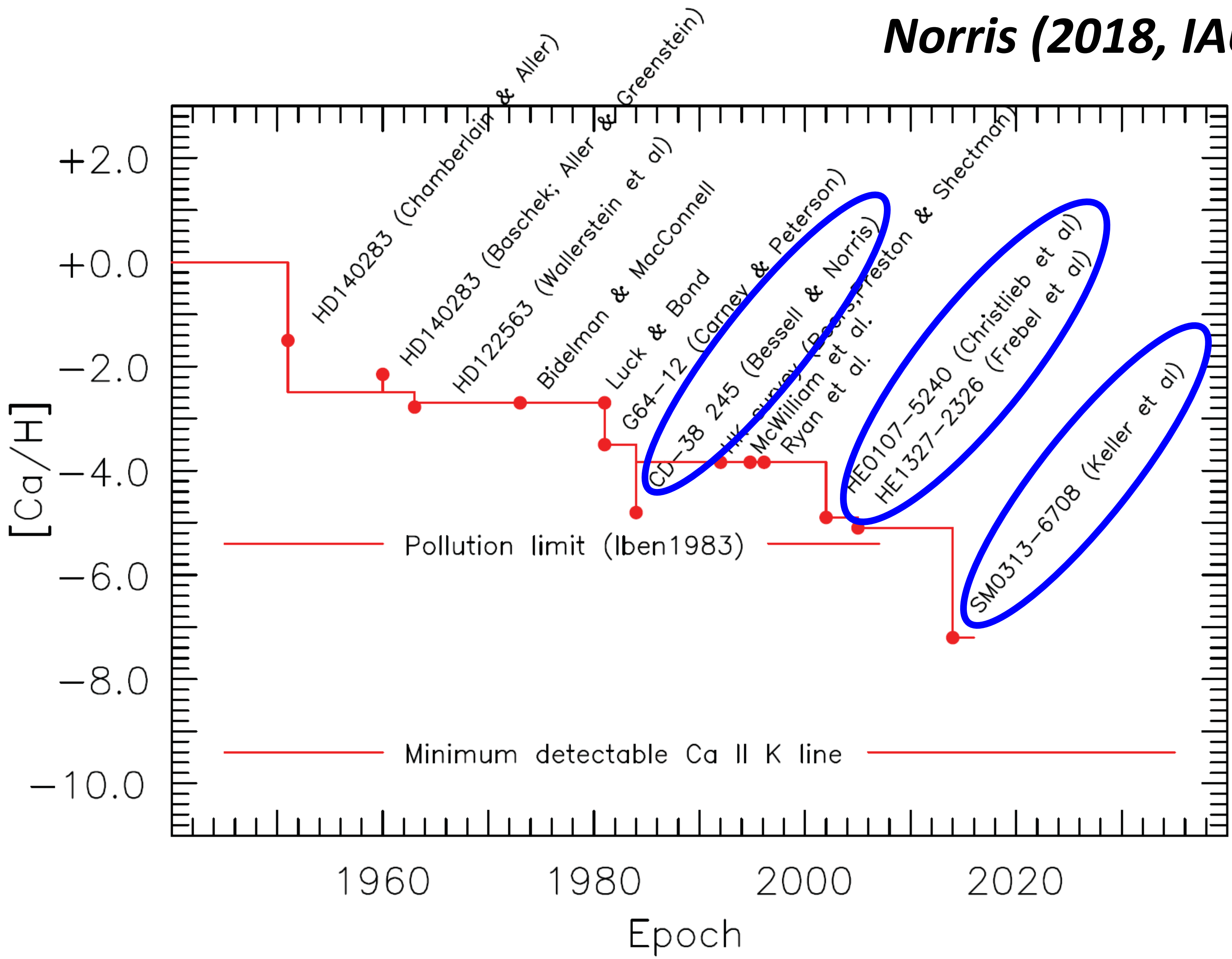
国立天文台
青木和光

金属欠乏星・矮小銀河の星の観測からの制限

- Most Metal-Poor stars
- Li abundances in the lowest metallicity range
- Classification of CEMP stars and their origins
- Ultra-faint dwarf galaxies
- Neutron-capture elements

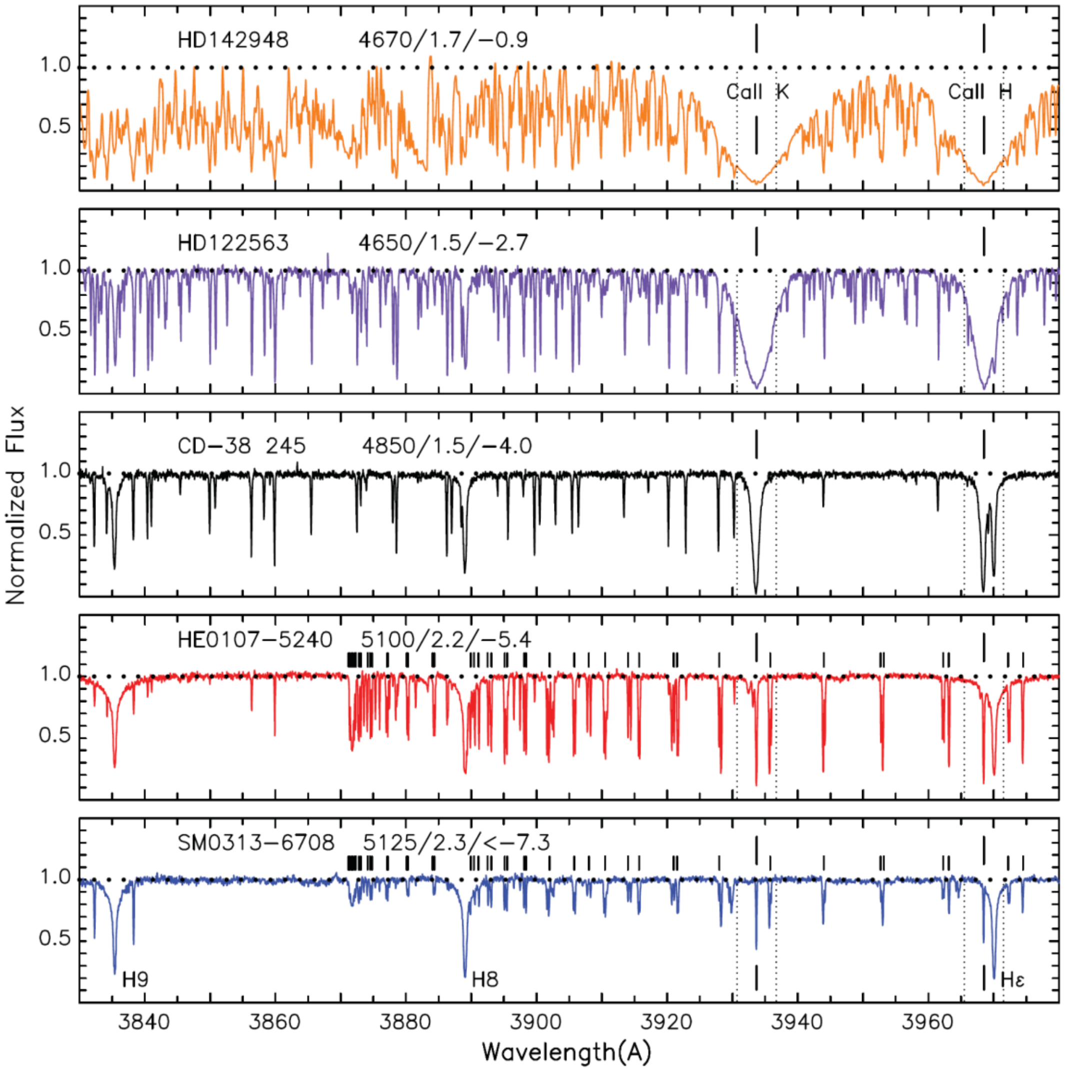
Discoveries of most metal-poor stars

Norris (2018, IAUS334)



Spectra of most metal-poor giants

- **Fe lines are not detected in SMSS0313-6708 ([Fe/H]<-7.3)**
- **Ca II HK lines are detectable for [Ca/H]=-7 (or lower)**

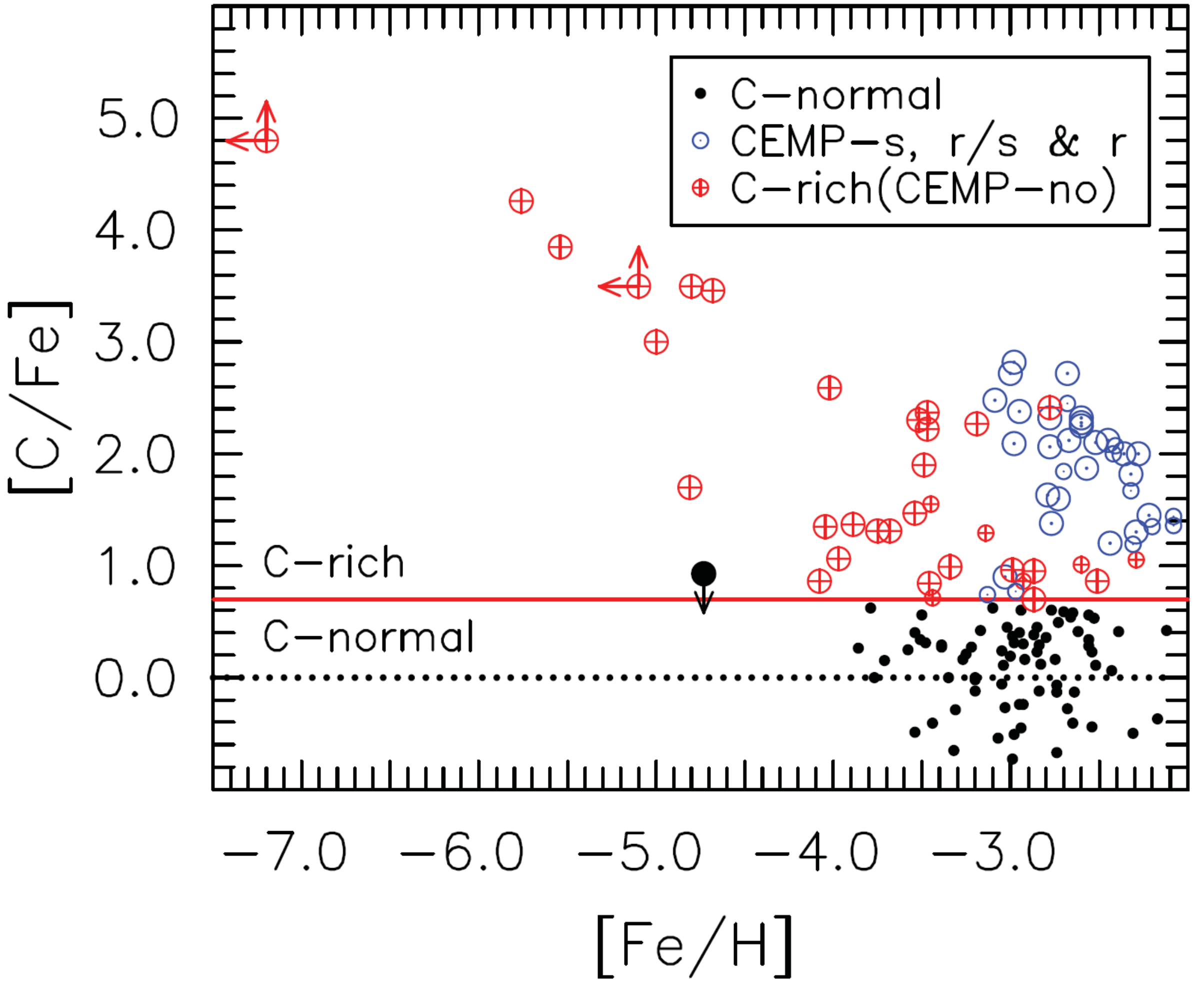


Norris (2018, IAUS334)

[Ca/H]=-7

Carbon-excess in most metal-poor giants

- **All stars with [Fe/H]<-4.5 but one (HE1029+1729) are carbon-enhanced**



Norris (2018, IAUS334)

Stars with [Fe/H]<-4.5

object	Mag.	Teff	log g	[Fe/H]	[C/Fe]	A(Li)	[Mg/Fe]	[Ca/Fe]	Ref.
SM0313-6708	*V*=14.7	5125	2.3	<-7.3	>4.9	0.7	>4.0	>0.1	1
J0023+0307	*g*=17.9	5997	4.6	<-6.3*	>3.76	1.7	>3.33	>0.53	2
HE1327-2326	*V*=13.6	6180	3.7	-5.66	4.3	<0.7	1.65	0.25	3
HE0107-5240	*V*=15.1	5100	2.2	-5.39	3.7	<1.12	0.15	-0.09	4
SD1035+0641	*g*=18.65	6262	4.0	<-5.07	>3.5	1.9		>0.42	5
SD1313-0019	*V*=16.9	5200	2.6	-5.00	3.0	<0.8	0.44	0.25	6
SD1742+2531	*g*=18.9	6345	4.0	-4.80	3.6	<1.8	<0.27	0.26	5
HE0557-4840	*V*=15.45	4900	2.2	-4.75	1.6	<0.7	0.25	0.25	7
SD1029+1729	*g*=16.9	5811	4.0	-4.73	<0.9	<1.1	0.40	0.72	8
HE0233-0343	*V*=15.4	6100	3.4	-4.68	3.5	1.77	0.59	0.34	9

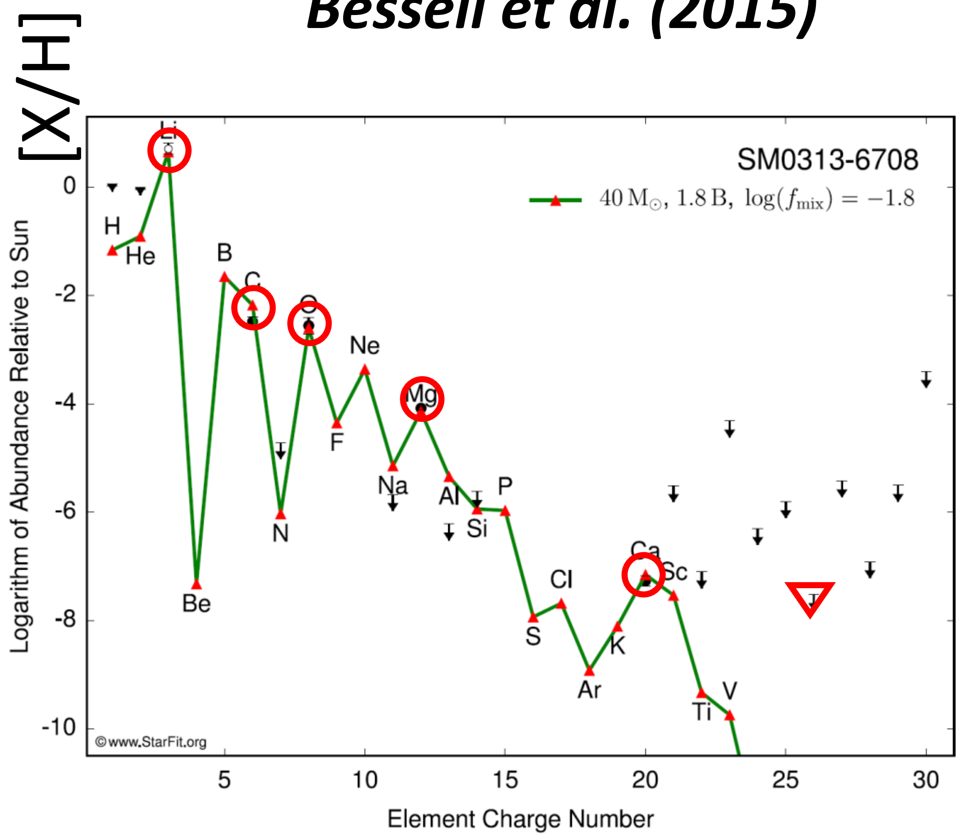
*The value estimated from Ca abundance. [Fe/H]<-5.8 is derived from Fe I lines.

(1)Keller et al. (2014); (2)Frebel et al. (2018); (3)Frebel et al. (2005); (4)Christlieb et al. (2004); (5)Bonifacio et al. (2014); (6)Frebel et al. (2015); (7)Norris et al. (2007); (8)Caffau et al. (2011); (9)Hansen et al. (2014)

SMSS 0313-6708: most Fe-poor giant

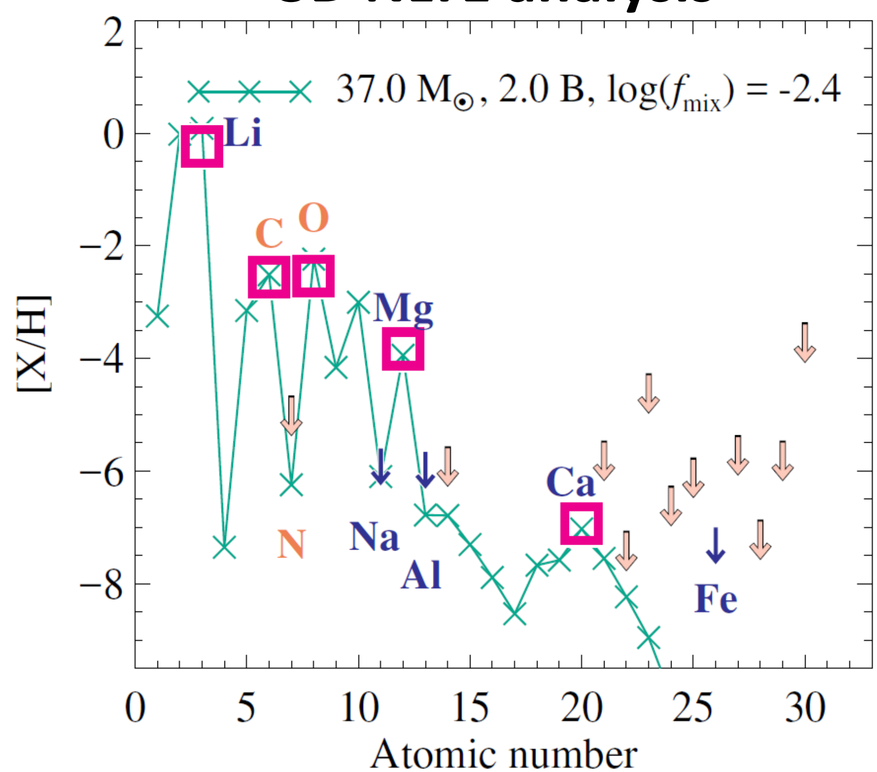
- Only five elements are detected (Li, C, O, Mg and Ca)
- Large excesses of C, O, and Mg with respect to Fe

Bessell et al. (2015)



Atomic number

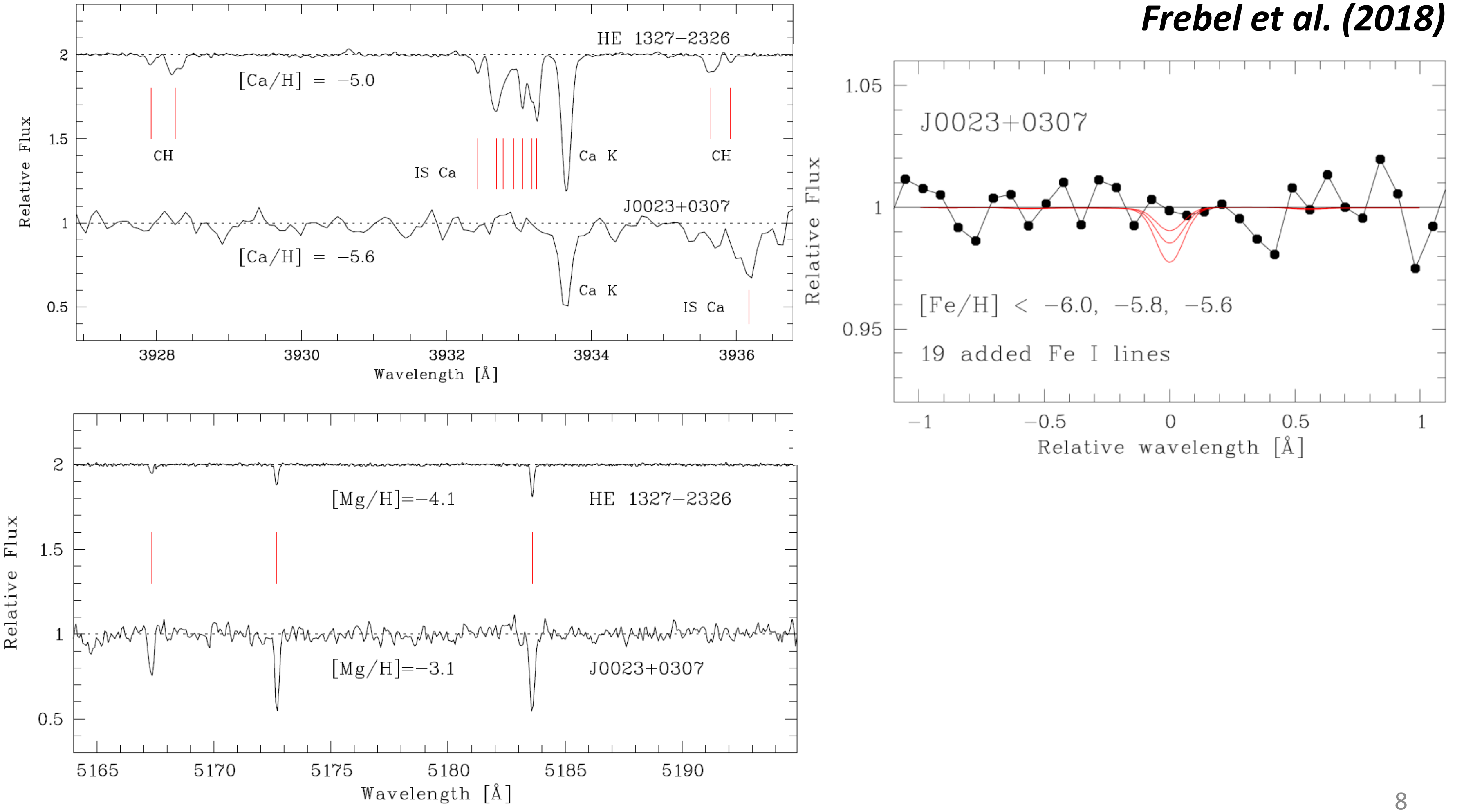
Nortland et al. (2017)
3D NLTE analysis



J0023+0307: Most Fe-poor main-sequence star

- Very weak Ca II features. No detection of Fe lines.
- A faint object (*g*=17.9) … difficulty in follow-up studies

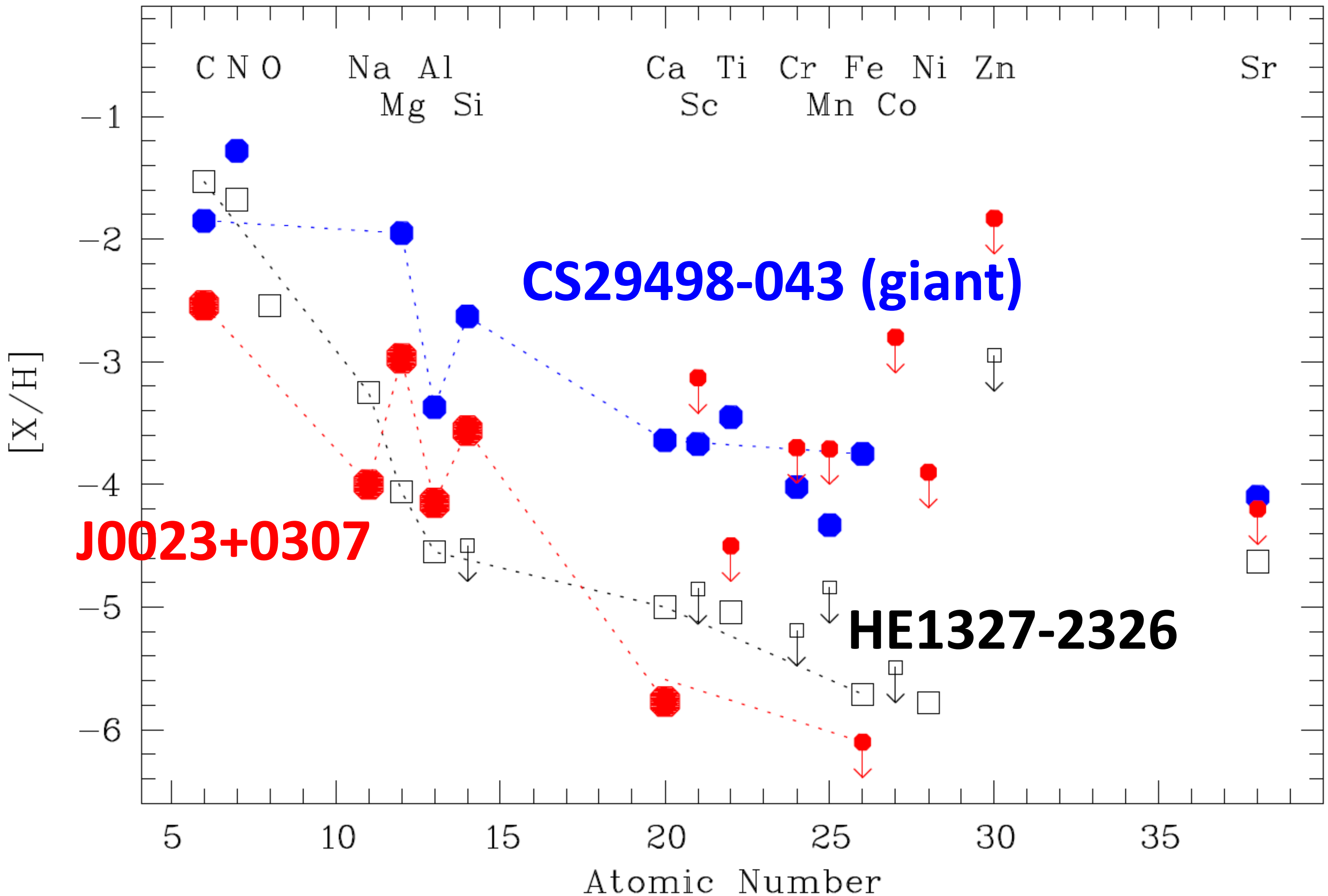
Frebel et al. (2018)



J0023+0307: Most Fe-poor main-sequence star

- **Abundances are measured only for 6 elements (C, Na, Mg, Al, Si, and Ca)... weak constraint on models**

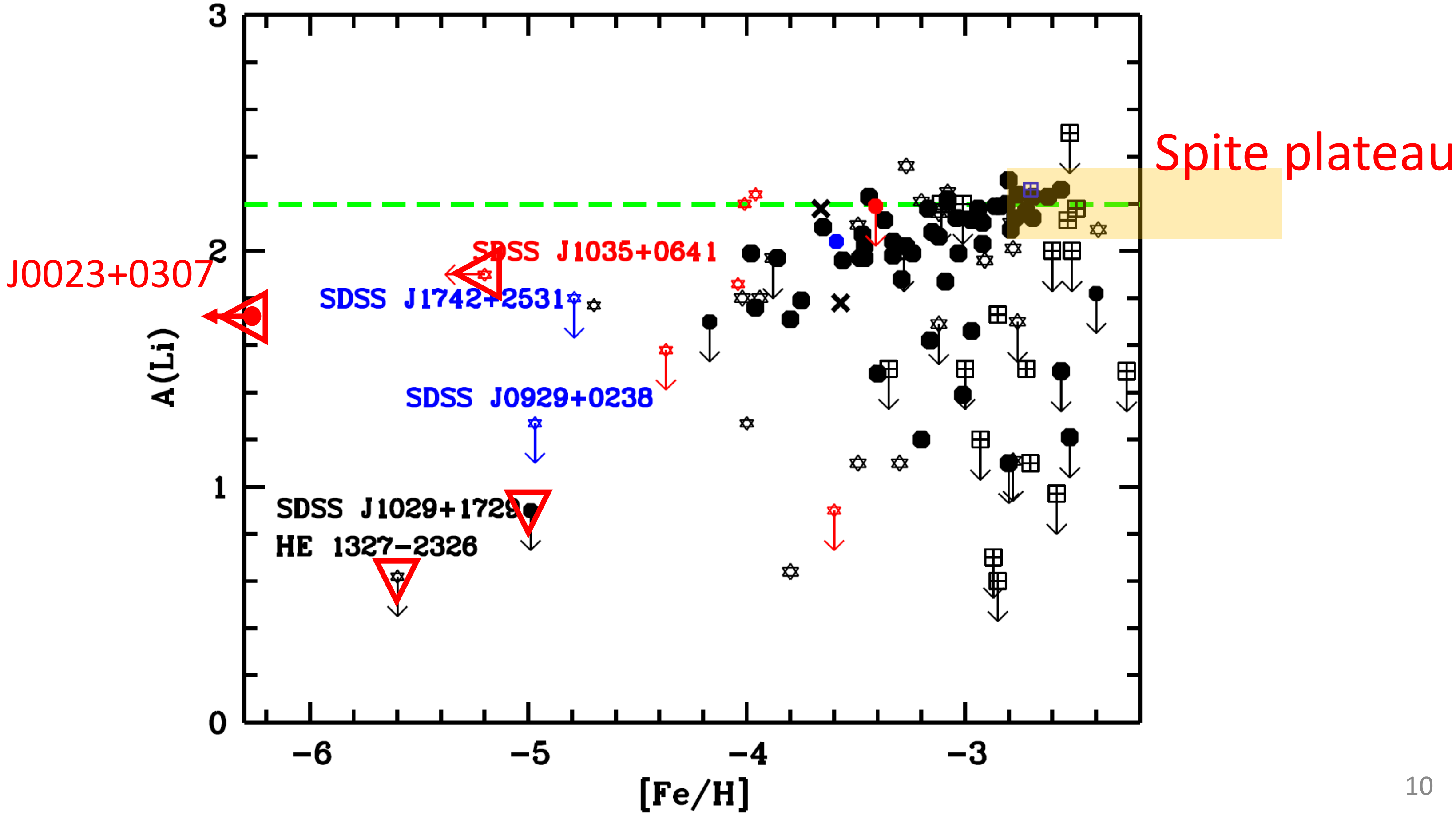
Frebel et al. (2018)



Li abundances

- Lower Li at lower metallicity (lower Fe abundance)?
- No correlation between C-excess and Li

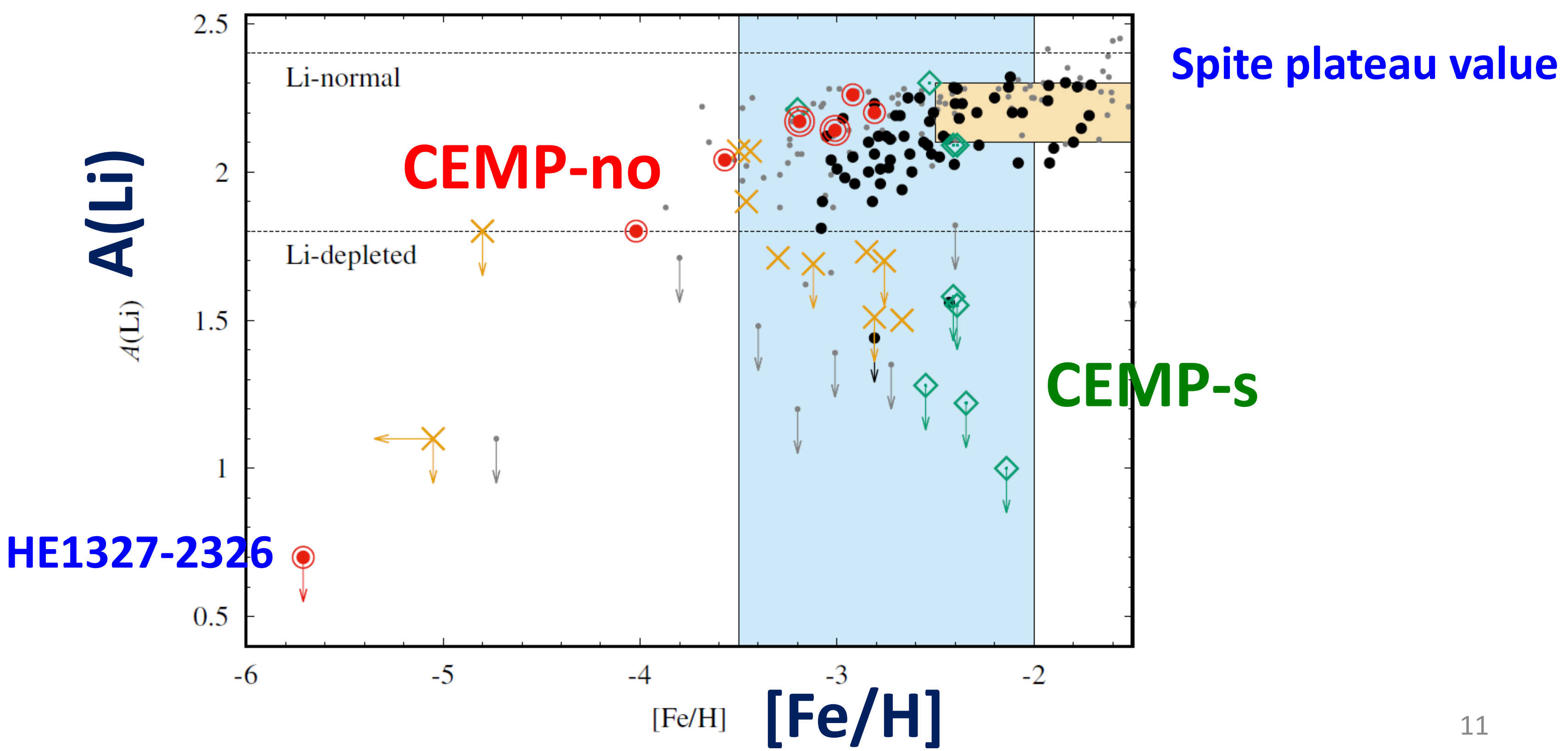
Bonifacio et al. (2018) *+ Frebel et al. (2018)*



Li in CEMP-no stars

- CEMP-no stars with -4<[Fe/H]<-3 have *normal* Li abundance
  cf. Li in CEMP-s stars is depleted
- Li in two Ultra/Hyper metal-poor stars is depleted

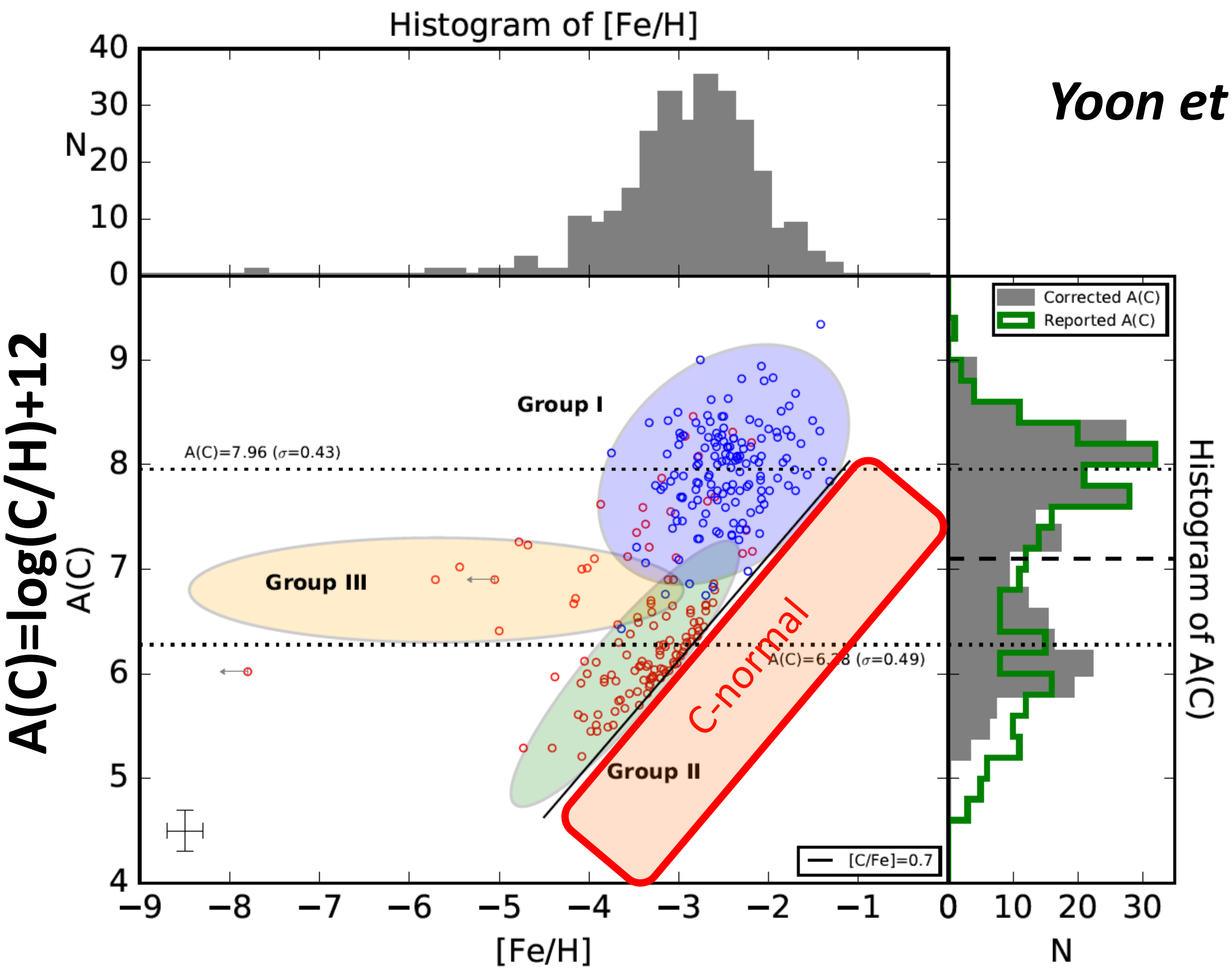
Matsuno et al. (2017)



Classification of CEMP stars

- CEMP-s (s-process excess) and CEMP-no (no excess of s-process)
- Two groups in CEMP-no stars?

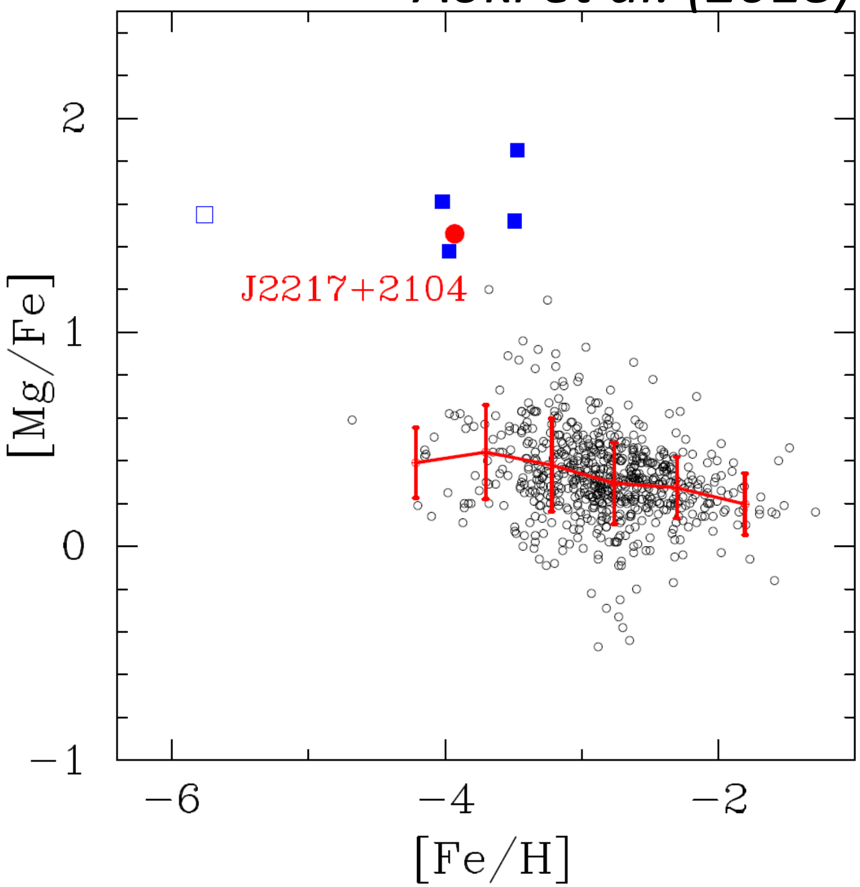
Yoon et al. (2017)



CEMP-no stars with large excesses of Mg and Si

- [α/Fe]～[Mg/Fe]>0 →core-collapse supernovae
- Extremely metal-poor stars with high [Mg/Fe]
  → specific type of first generation supernovae

Aoki et al. (2018)



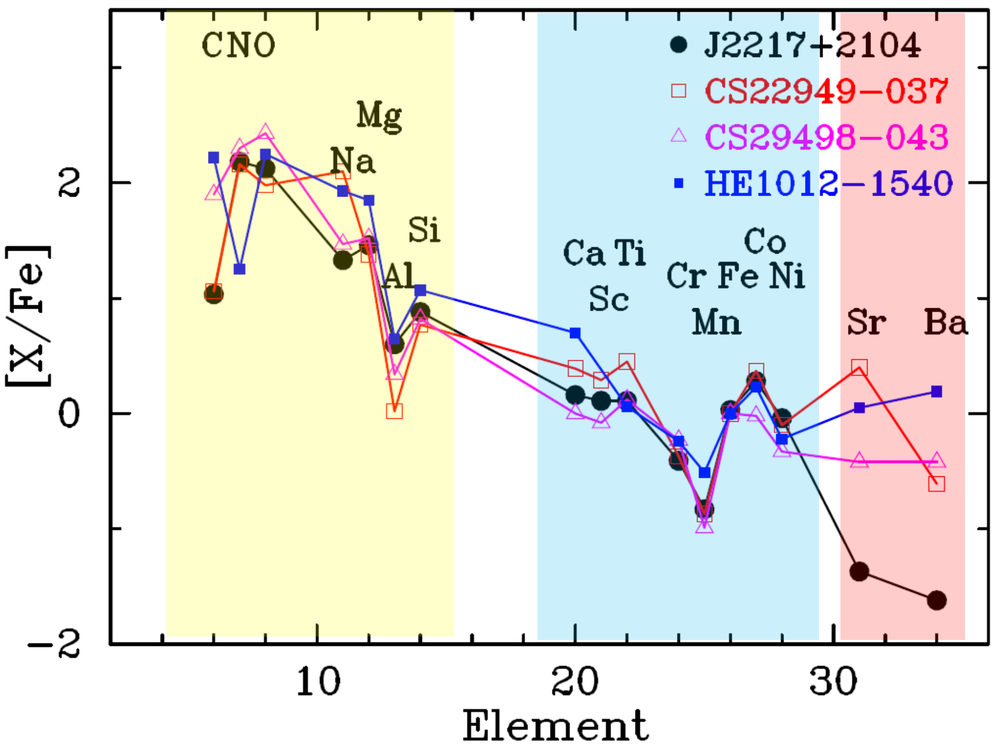
- J2217+2104 ([Fe/H]=-4.0)
  (Aoki et al. 2018)
- CS22949-037 ([Fe/H]=-4.2)
  （McWilliam et al. 1995, Norris et al. 2001, Depagne et al. 2002）
- CS29498-043 ([Fe/H]=-3.5)
  (Aoki et al. 2002, 2004)

cf. HE1327-2326 ([Fe/H]=-5.6)
(Frebel et al. 2005, Aoki et al. 2006)

Abundance patterns of CEMP-no stars with excesses of Mg and Si

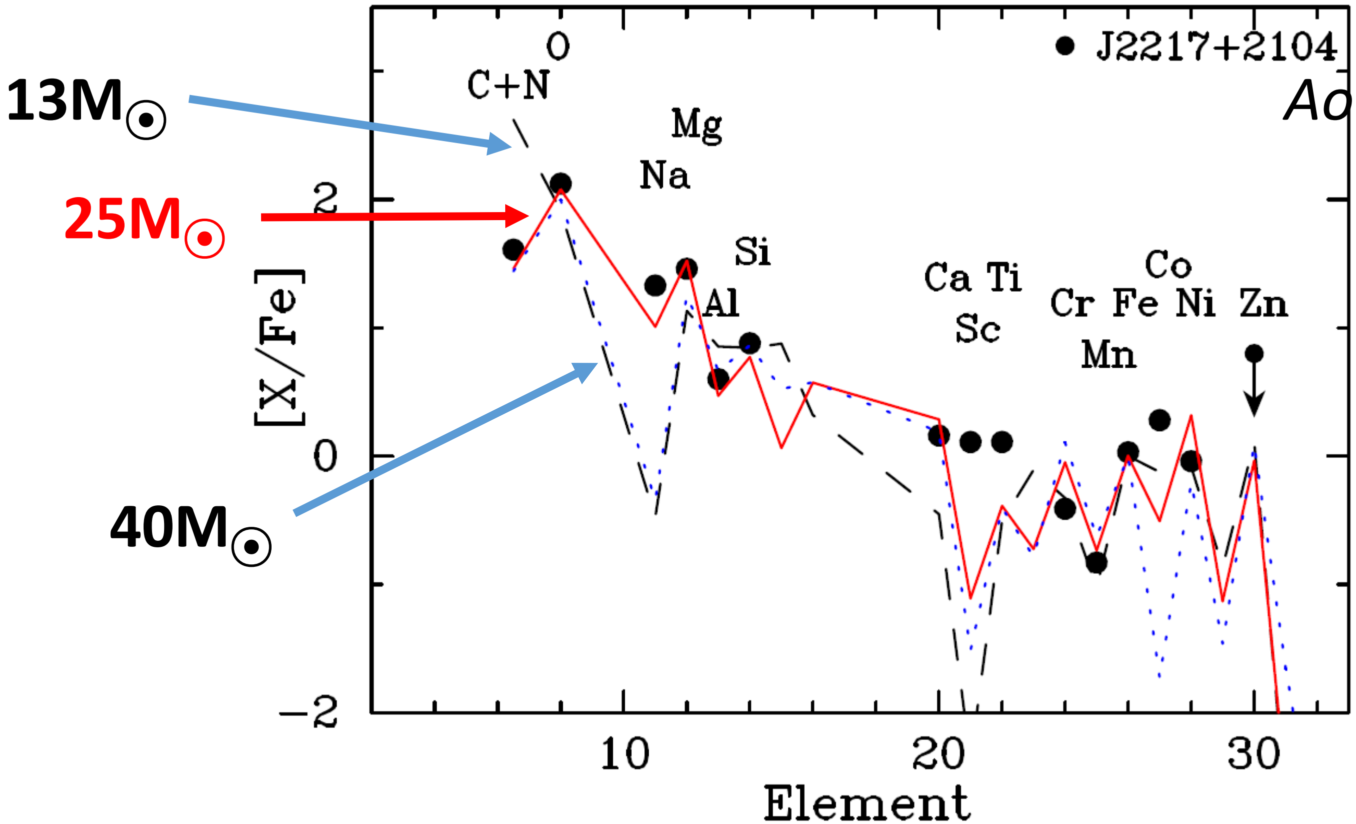
- Abundance patterns of the four well-studied objects are very similar each other (except for Sr and Ba)
- Enhancement in C-Si, no anomaly in abundances for Ca-Ni.
- Scatter in C/N, but similar in (C+N)/O

Aoki et al. (2018)



Constraints on supernova models: ～best explained by explosion of a 25M$_\odot$ model

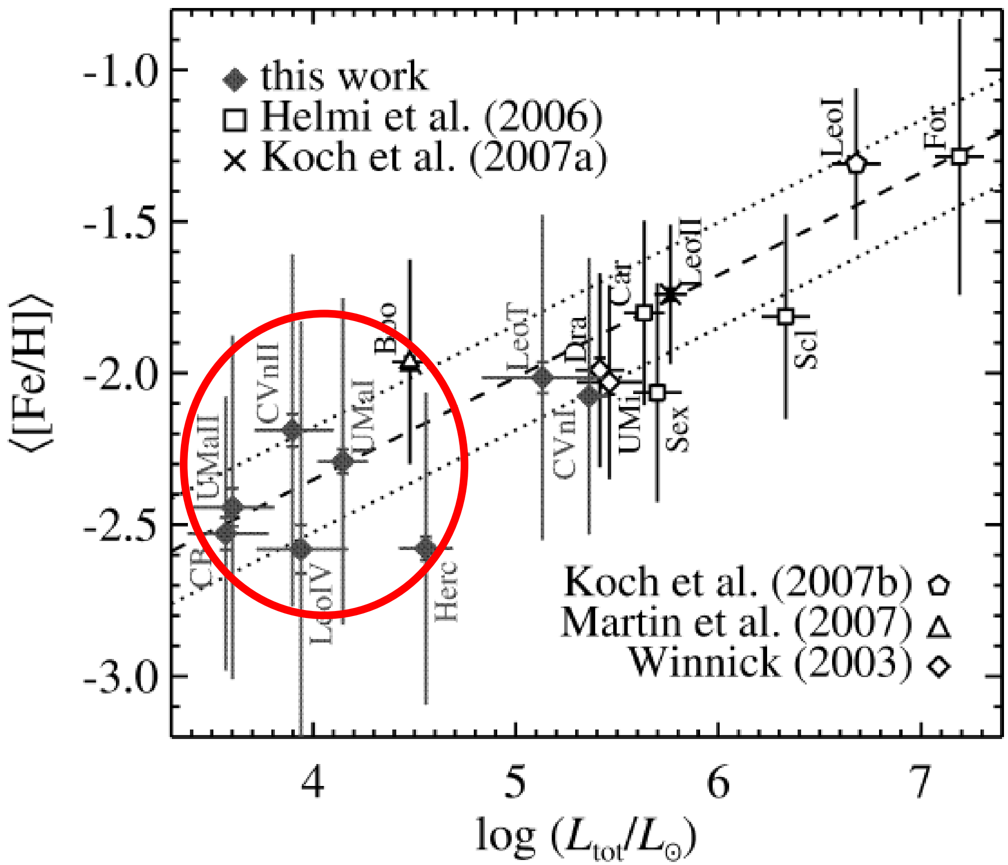
- (C+N)/O and Na/Mg are sensitive to progenitor masses (Ishigaki et al. 2018)
- 25M$_\odot$ is a typical mass estimated for C-normal stars. The cause for excesses of C, Mg and Si would be characteristics of the progenitor other than mass (rotation? Binarity?)



Aoki et al. (2018)

Ultra-faint dwarf galaxies

Ultra-faint dwarf galaxies involve extremely metal-poor stars with high frequency

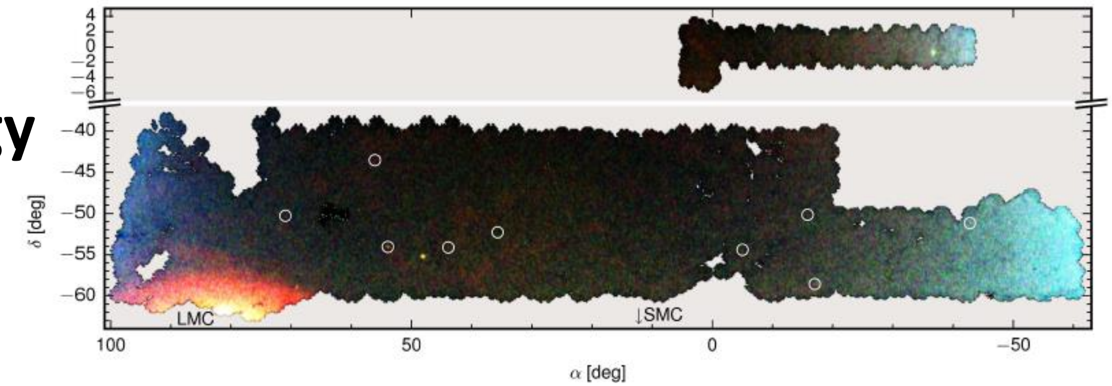


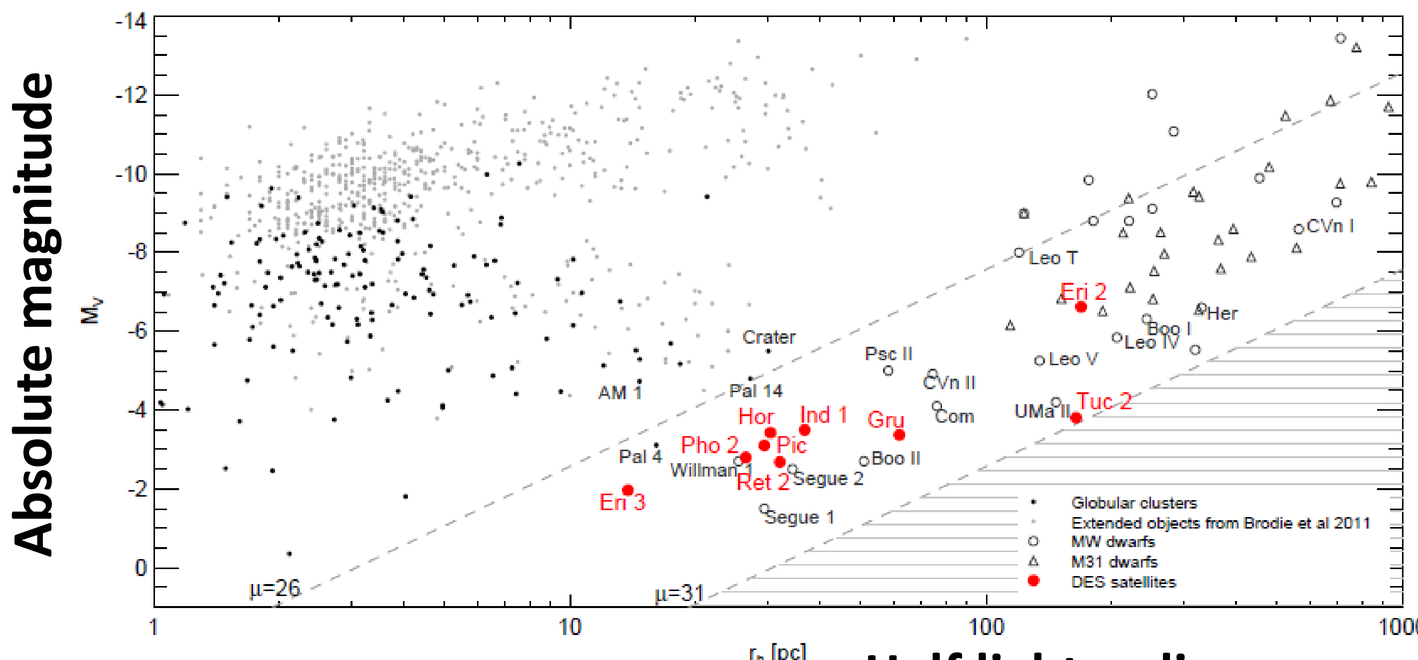
Kirby et al. 2008

Discoveries of new ultra-faint dwarf galaxies

Koposov , Belokurov et al. (2015)

Over density search in data of DES (Dark Energy Survey) by Blanco 4m telescope at CTIO

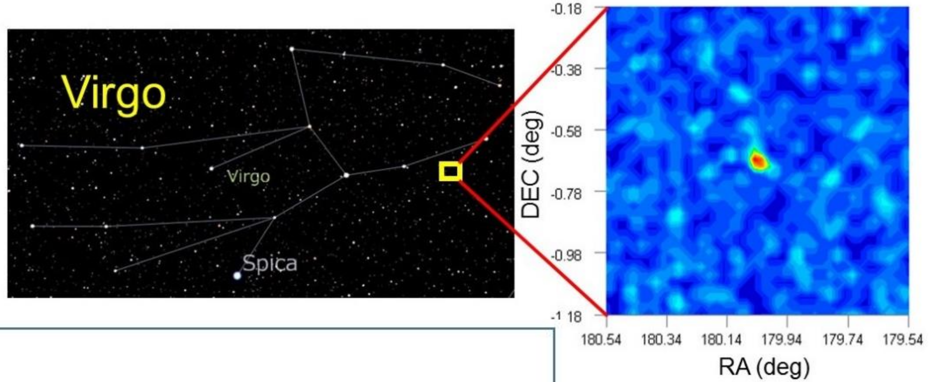


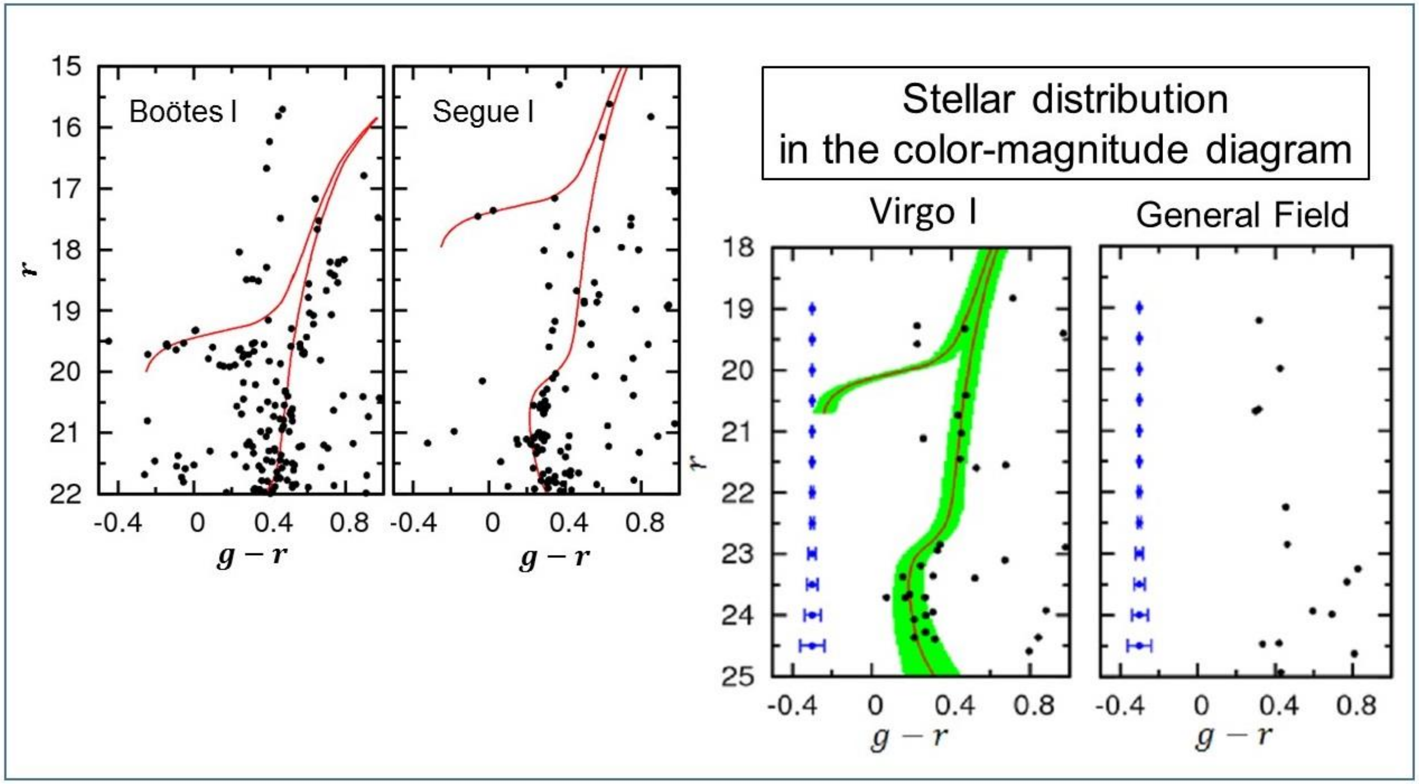


Discoveries of new ultra-faint dwarf galaxies: Virgo 1

Honma et al. (2016)

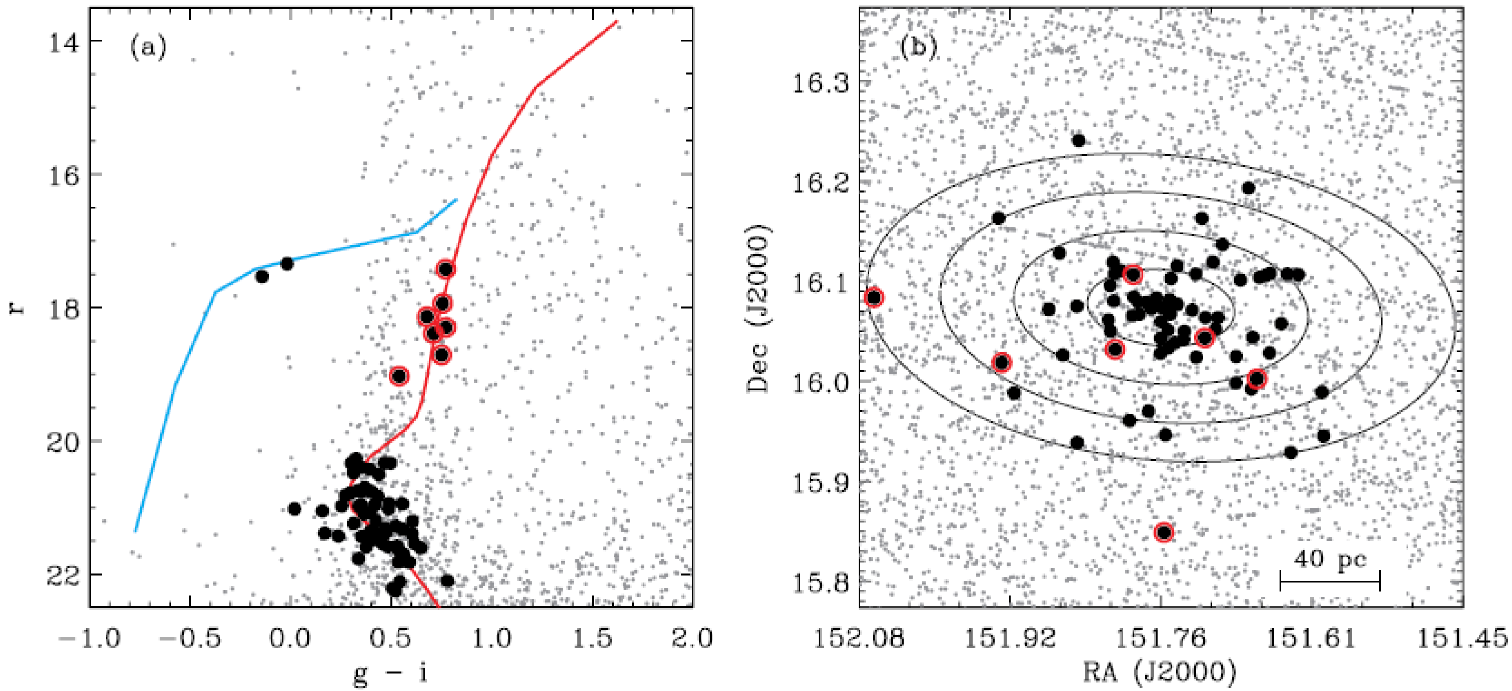
M_V=-0.8





The ultra-faint dwarf galaxy Segue 1

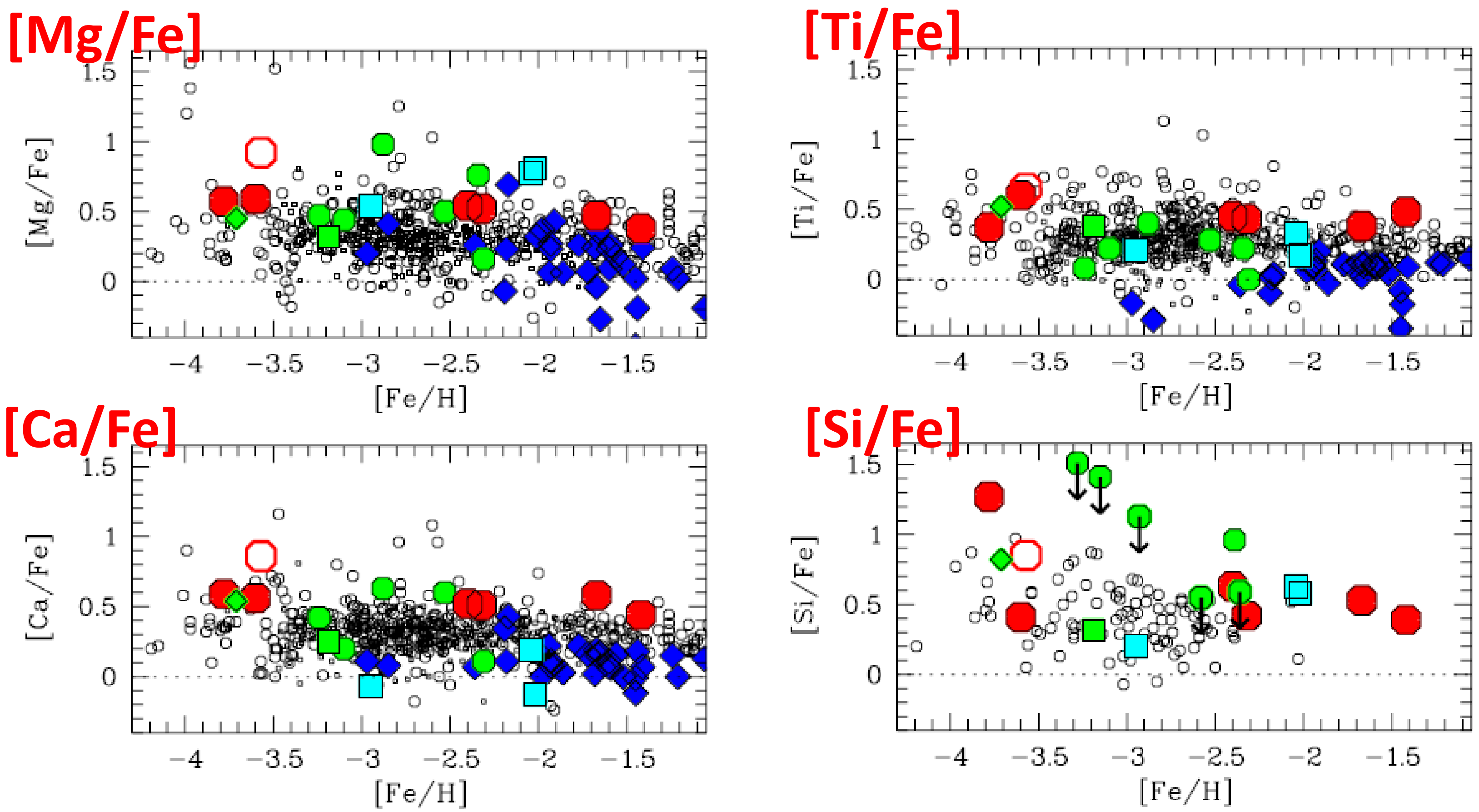
Frebel et al. (2014)



The ultra-faint dwarf galaxy Segue 1

Frebel et al. (2014)

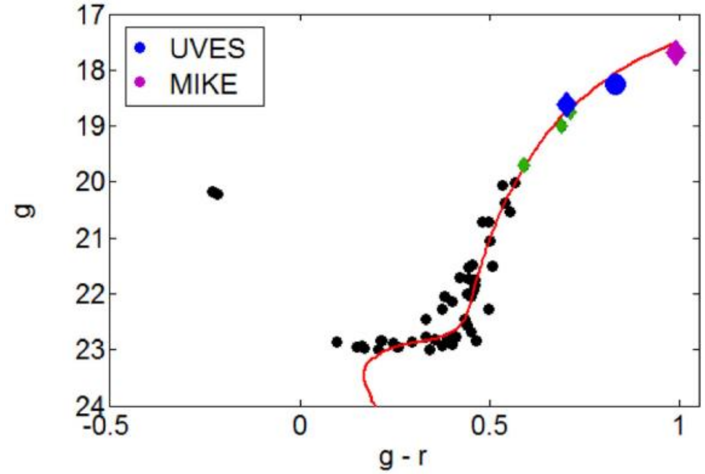
- Wide metallicity range (-4<[Fe/H]<-1.5)
- Constant α/Fe ratios

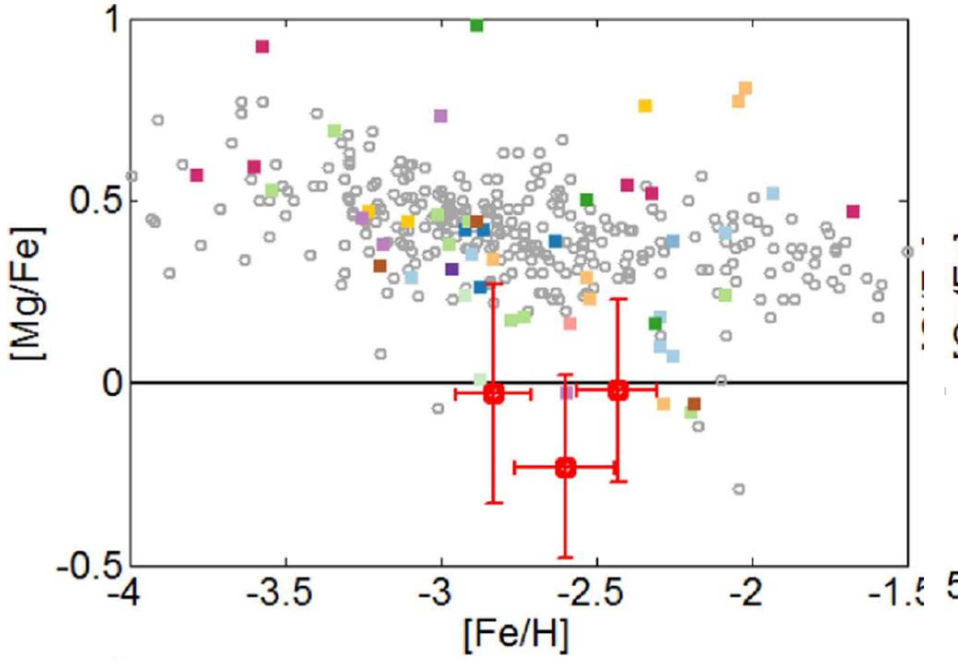


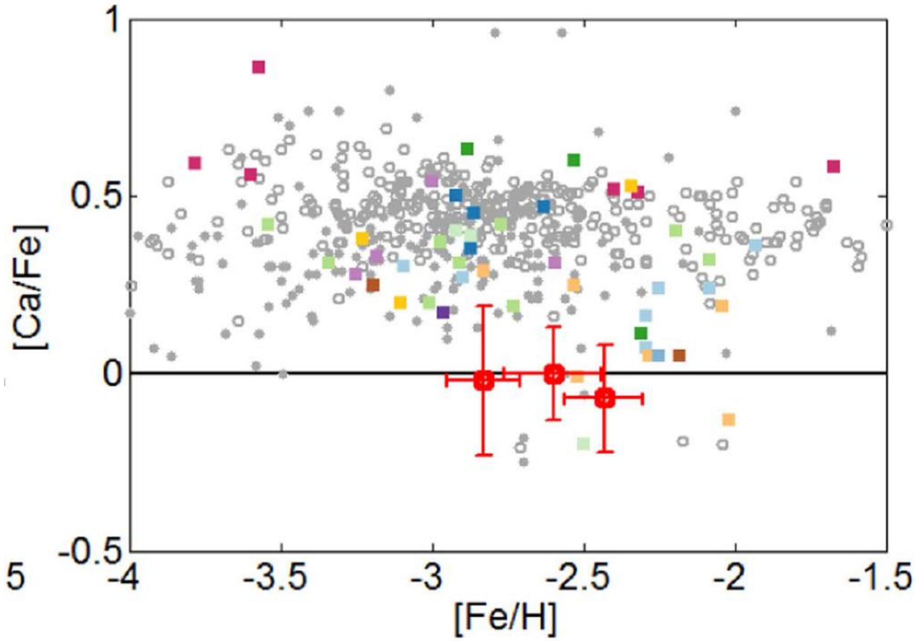
Low α/Fe stars in a ultra-faint dwarf galaxy

Nagasawa et al. (2018)

- Horologium I: three giants with [Fe/H]～-2.6 with [α/Fe]～0
- Same origins of low α/Fe stars in the field halo?







r-process-enhanced stars in the ultra-faint dwarf galaxy Reticulum 2

- Most stars in the galaxy show r-process excess
- No excess in stars with lowest metallicity?

Ji et al. (2016b)

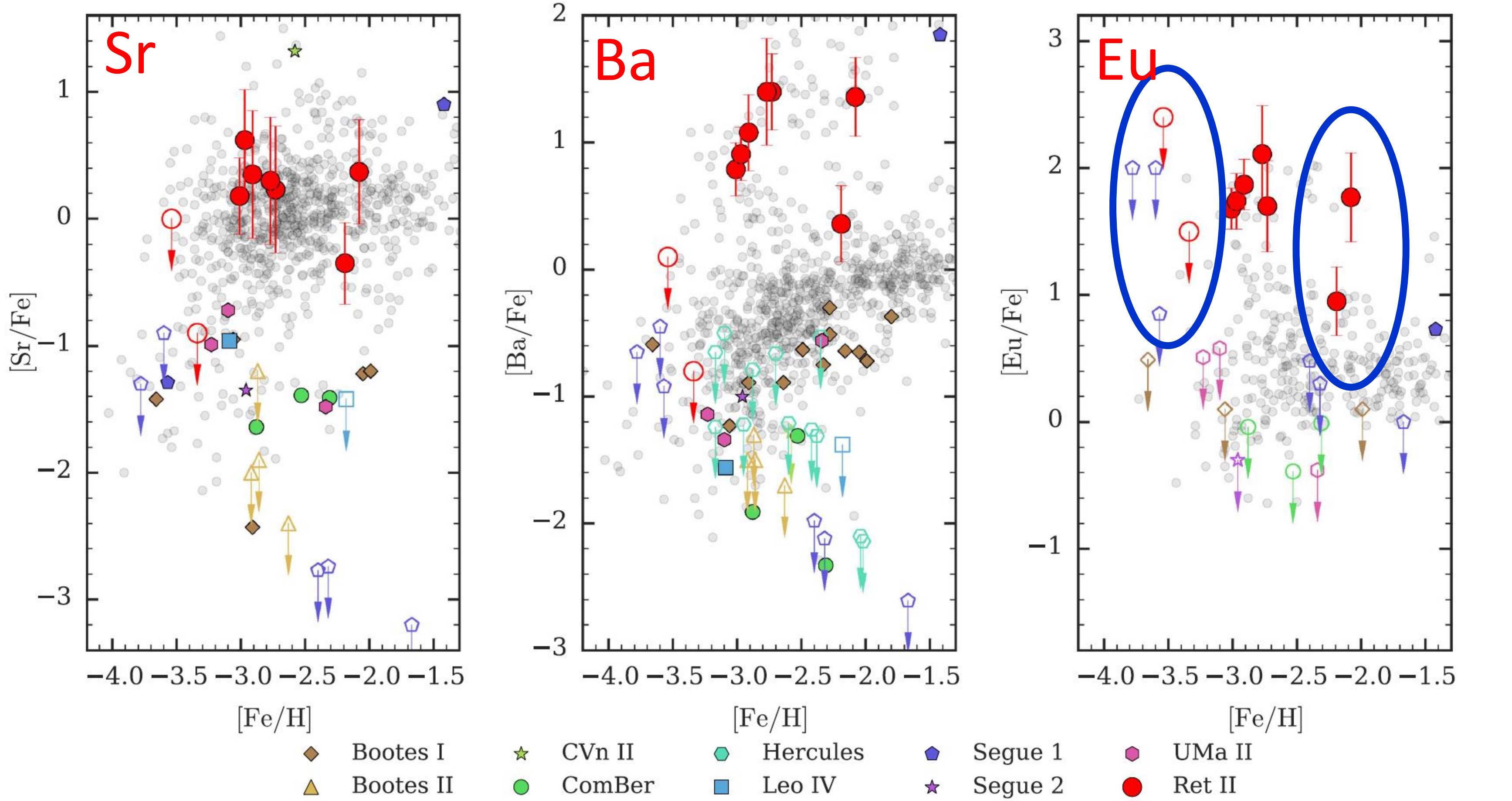
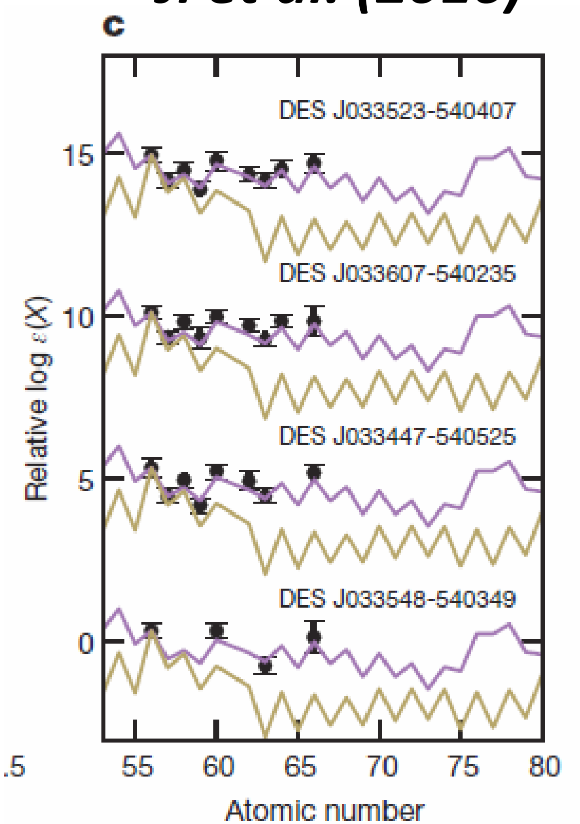


Figure 3. Neutron-capture element abundances for Sr, Ba, and Eu. Symbols are the same as in Figure 2. DES J033531−540148 and DES J033556−540316 have only upper limits that are consistent with other UFD stars. Note that DES J033531−540148 has a [Sr/Fe] = −1.73 detection (Roederer et al. 2016b). The other seven stars have extremely enhanced neutron-capture abundances, although DES J033548−540349 is less enhanced. CVn II has a star with very high [Sr/Fe] but no detectable Ba (François et al. 2016). The star in Segue 1 with high neutron-capture abundances has experienced binary mass transfer (Frebel et al. 2014).

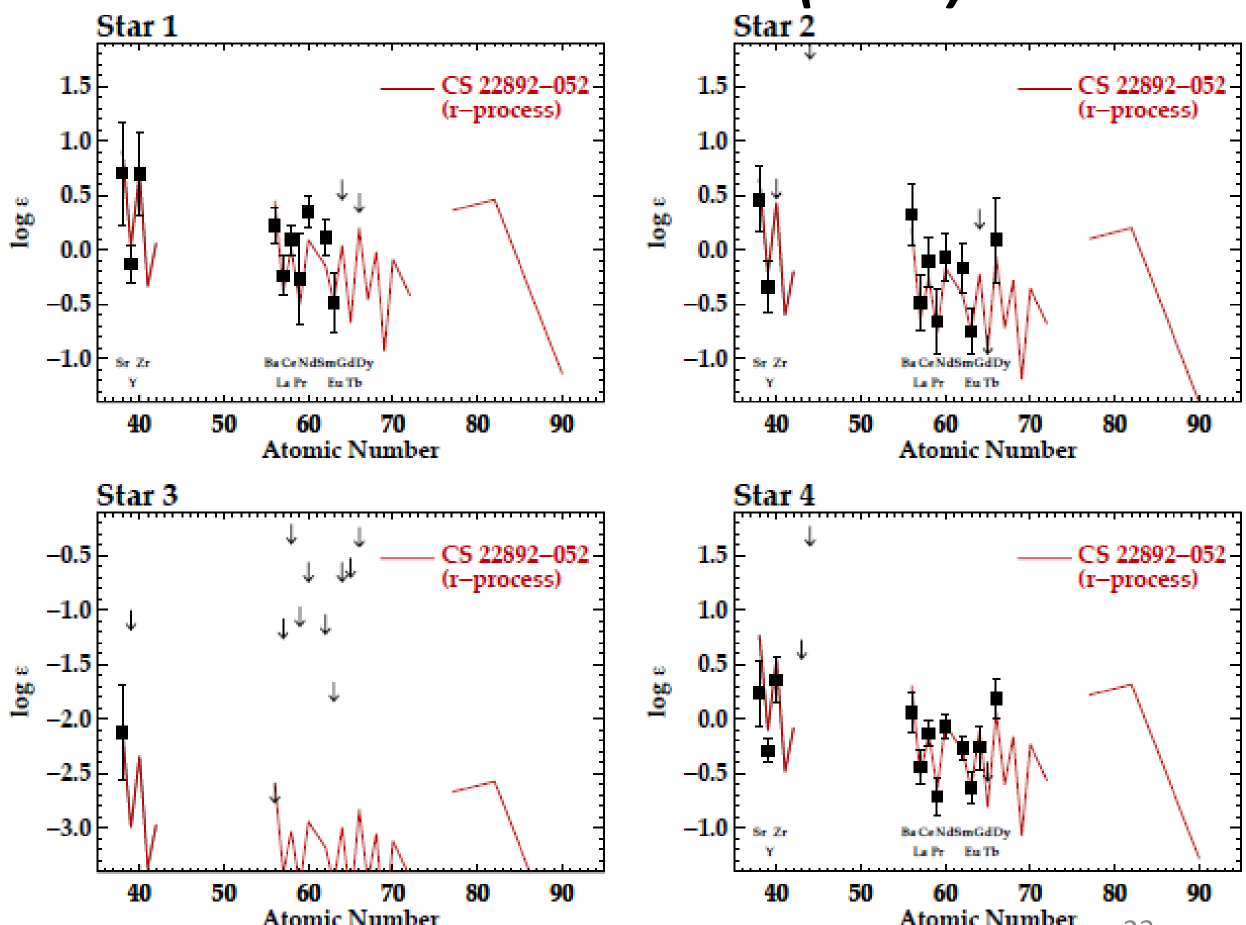
r-process-enhanced stars in the ultra-faint dwarf galaxy Reticulum 2

- Heavy elements trace the solar-system r-process abundance pattern

Ji et al. (2016)



Roederer et al. (2016)



Enrichment of r-process elements in the dwarf galaxy Reticulum 2

Ji et al. (2016)

- [Eu/H]=-1 → $M_{Eu}/M_{H}=10^{-10.3}$

  Galaxy mass ∼ $10^6 M_\odot$ (10^5- $10^7 M_\odot$)

  → M_{Eu} ~ $10^{-4.3} M_\odot$

  Cf. Expected Eu production:

  -Neutron stars merger: $10^{-4.5} M_\odot$

  -Magnetrotationally driven supernova: $10^{-5} M_\odot$

- Event rate:

  -r-process event is only once

  -Galaxy mass ~ $10^6 M_\odot$ →1000-2000 supernovae

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- 10 objects with [Fe/H]<-4.5:
  - 9 are C-enhanced.
  - Large variation in Li abundances in the 4 main-sequence turn-off stars.
- Abundance patterns well determined for EMP stars ([Fe/H]>~-4) are still useful to constrain the progenitors
- Abundance ratios of dwarf galaxy stars (combined) show similar abundance trend/scatter in field stars. Abundance ratios of stars *in each galaxy* are homogeneous (?).
- r-process-excess in a ultra-faint dwarf galaxy (Reticulum 2) might be a signature of merging of binary neutron stars… are they first generation massive (<20$M_{\odot}$) stars?