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TMT Science Forum

Stellar Chemical Abundances Exploring Galaxy Evolution

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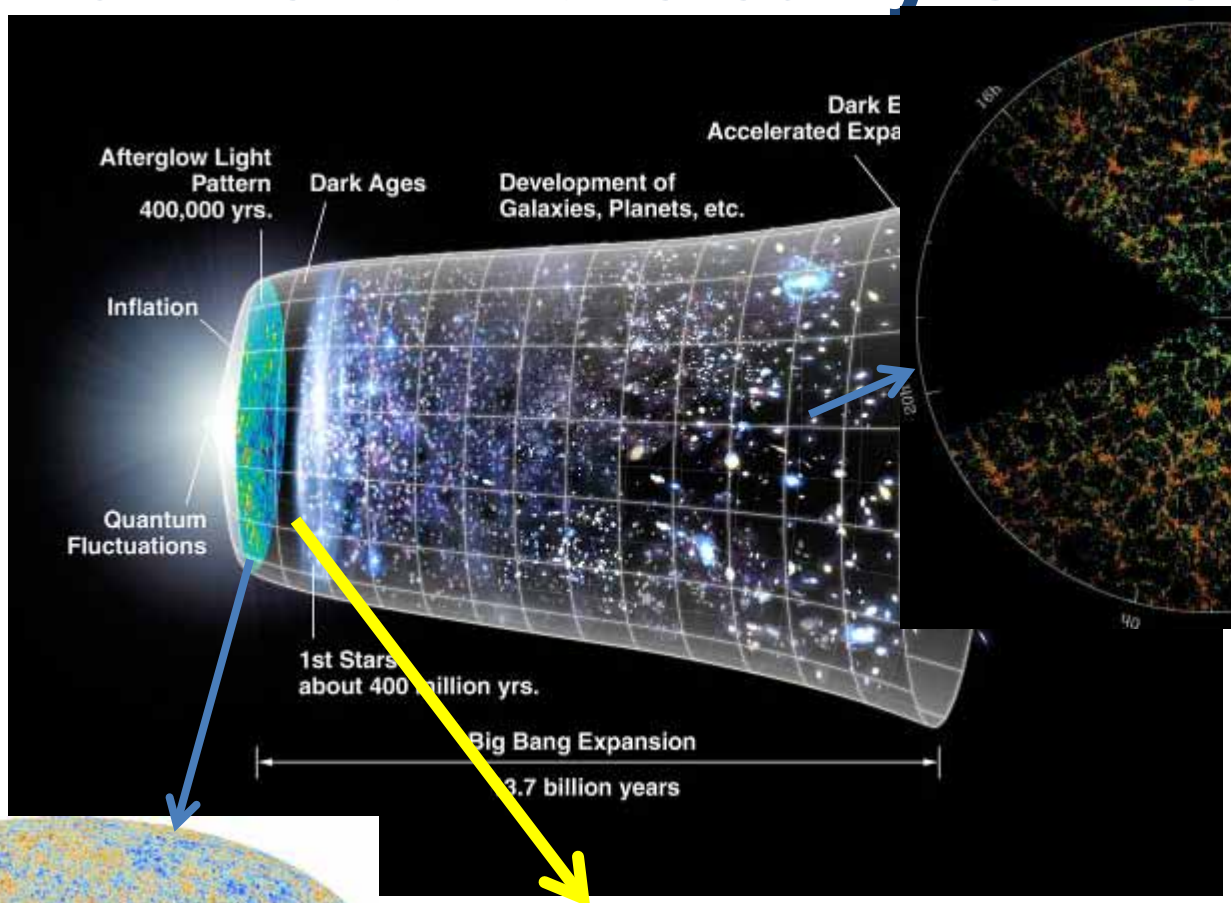
国立天文台TMT推進室
青木和光

Structure formation and chemical enrichment in the early Universe



SDSS

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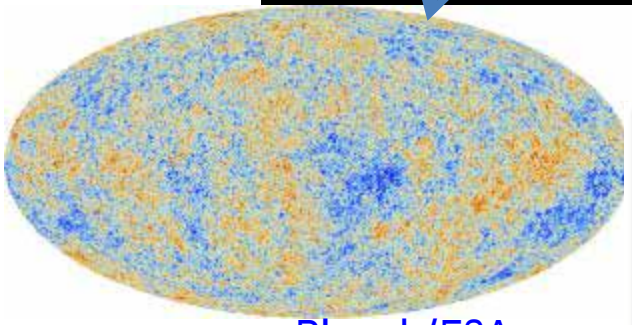
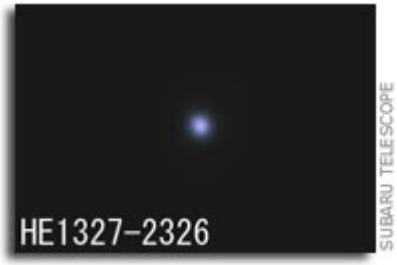
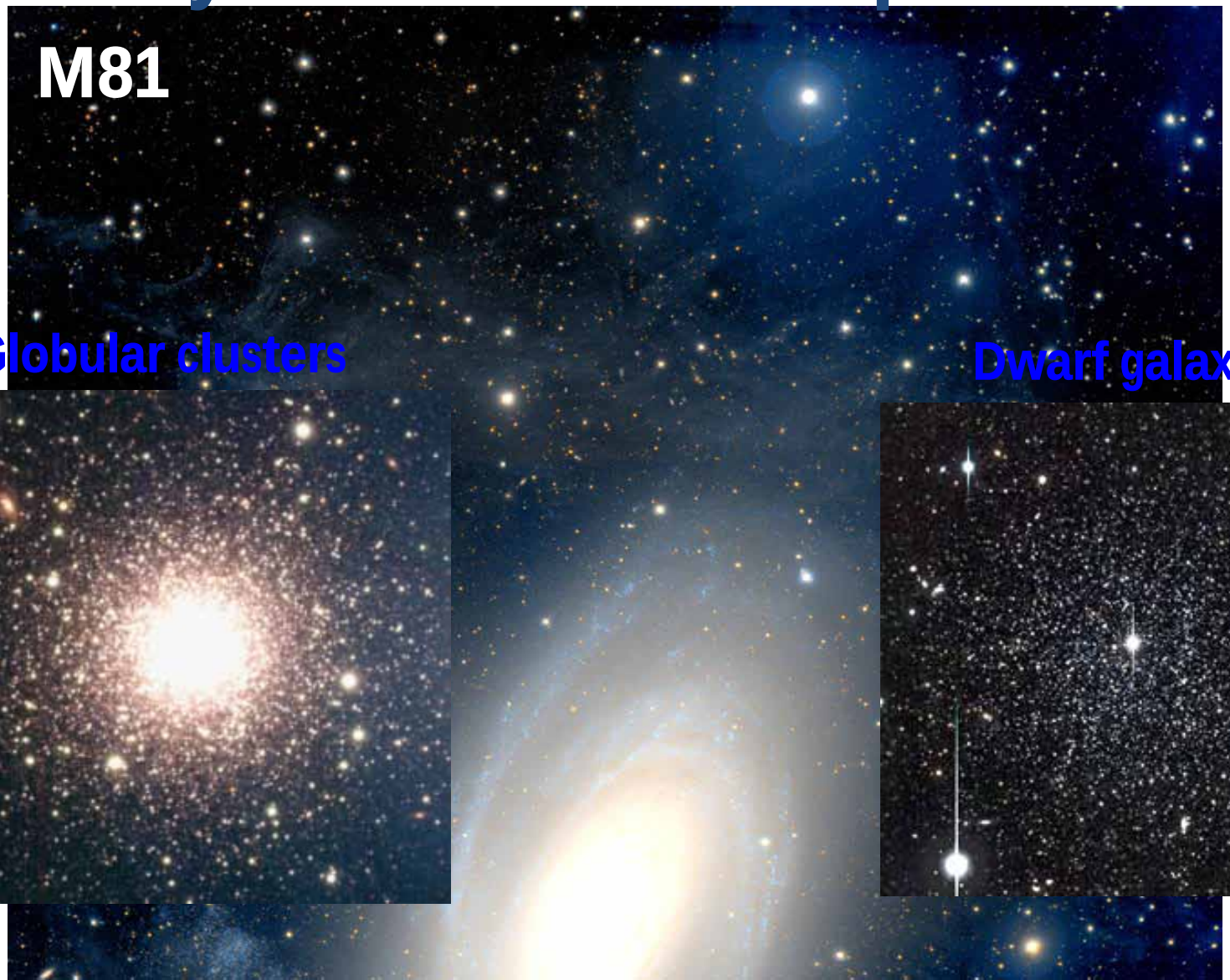


Planck/ESA



Low-mass stars with long lifetime can survive

Early generation stars in the Milky Way … old and metal-poor stars



Globular clusters

Dwarf galaxies

Metal-poor stars in the Galactic halo and dwarf galaxies

- Constraints on the masses of first stars from chemical composition of very metal-poor stars
- Very metal-poor stars beyond the solar neighborhood: dwarf galaxies (and bulge)

- Requirement: optical high-and medium-resolution multi-object spectrograph
- Key program: dwarf galaxies in the local group

Searches for metal-poor stars

- **HK survey (1980s-)**
  ***Beers et al. 1985, 1992*, etc.**
  objective prism survey for Ca II H and K lines (R~800)
- **Hamburg/ESO survey (1990s-)**
  stellar content: *Christlieb et al. 2001* etc.
  → "Hyper Metal-Poor" stars [Fe/H]<-5

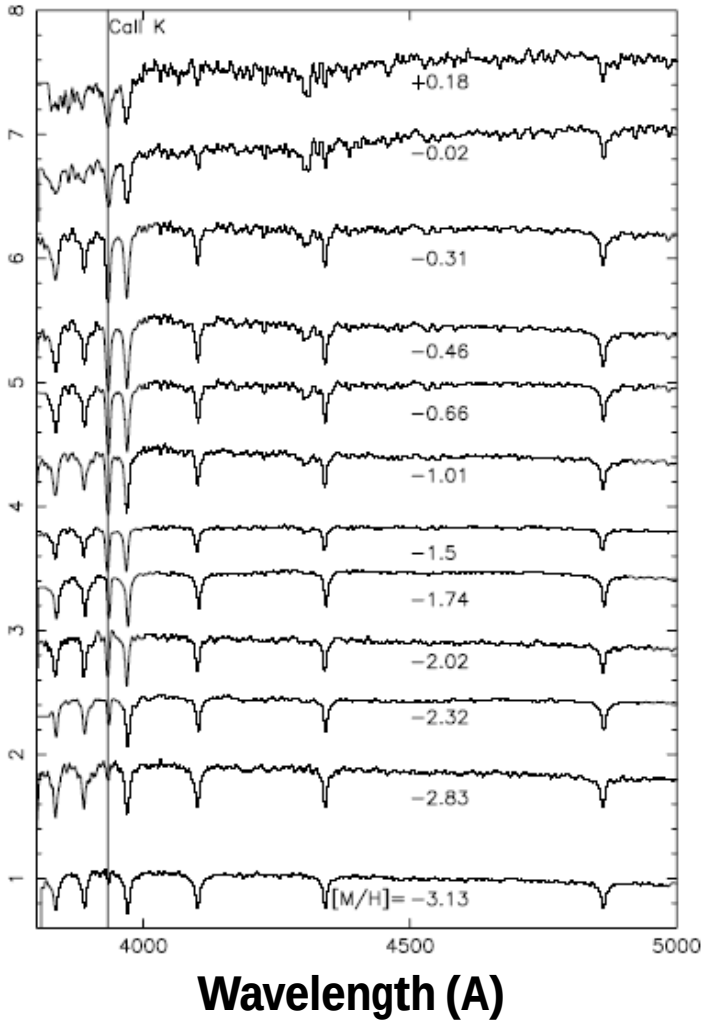
- **SDSS/SEGUE (2006-)**
  ***Yanny et al. (2009)* etc.**
- **LAMOST/LEGUE**
  ***Cui et al. (2012), Zhao et al. (2012)* etc.**
- **Skymapper**
  ***Keller et al. (2012)* etc.**

Searches for very/extremely metal-poor stars with SDSS (SEGUE)

***Yanny et al. (2009)* etc.**

The 2.5m telescope at Apache Point Observatory

- **Imaging/spectroscopic surveys**
- **<u>Surveys of Galactic stars 240,000</u>**

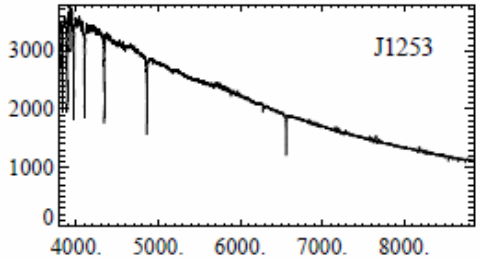


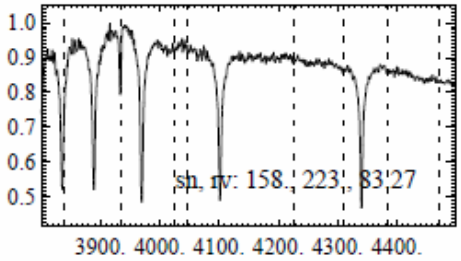
Searches for very/extremely metal-poor stars with LAMOST (LEGUE)

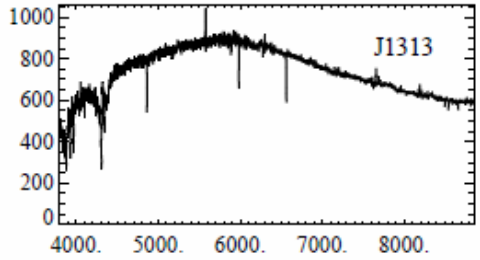
Cui et al. (2012) etc.

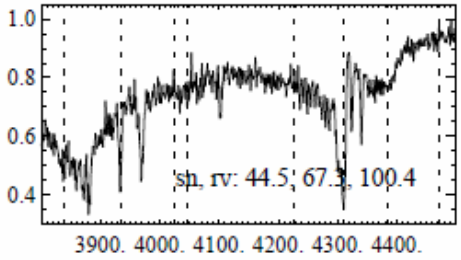
LAMOST
(Guoshoujing Telescope)
- **4m aperture**
- **>1 million stars have been released by DR2**

- **R=1800 spectra**
- **4000 fibers**









Searches for metal-poor stars

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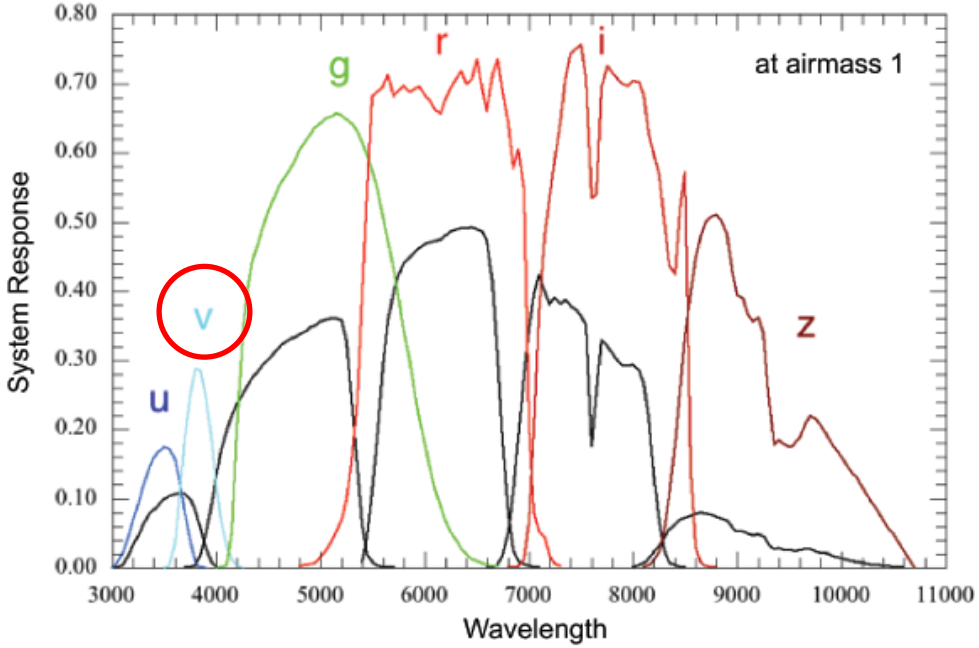
  objective prism survey for Ca II H and K lines (R~800)
- **Hamburg/ESO survey (1990s-)**
  stellar content: *Christlieb et al. 2001* etc.
  → "Hyper Metal-Poor" stars [Fe/H]<-5
  e.g. HE1327-2326
- **SDSS/SEGUE (2006-)**
  ***Yanny et al. (2009)* etc.**
- **LAMOST/LEGUE**
  ***Cui et al. (2012), Zhao et al. (2012)* etc.**
- **Skymapper**
  ***Keller et al. (2012)* etc.**

Photometric searches for very/extremely metal-poor stars with Skymapper

Keller et al. (2012) **etc.**



Skymapper

- **1.35m aperture**
- **2.4 degree field of view**

'v' filter sensitive to metallicity

Abundance studies of extremely/ultra metal-poor stars

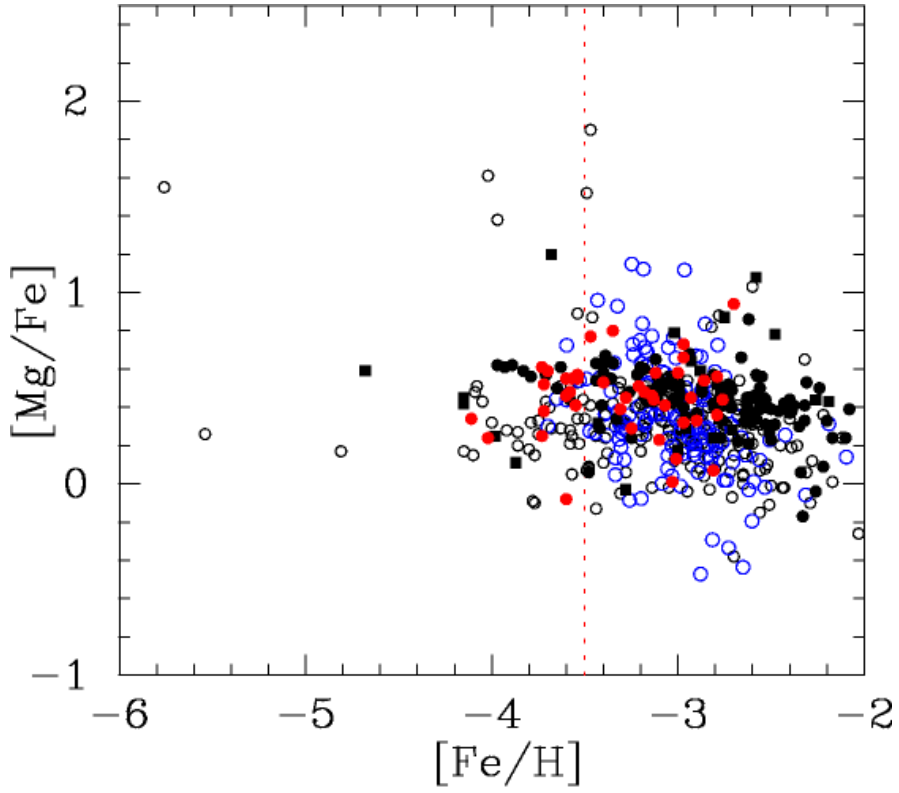
○ *Yong et al. (2013):* Re-analysis of spectra previously obtained +original data

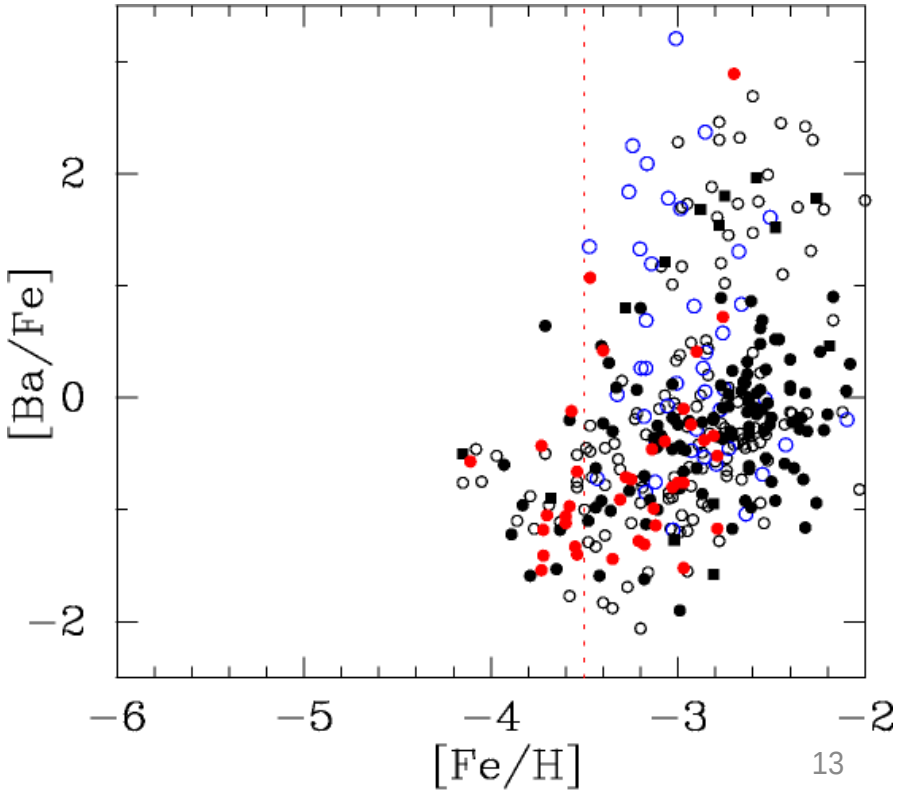
○ *Aoki et al. (2013):* EMP stars from SDSS/SEGUE sample

■ Hansen et al. (2015): HES stars

● Jacobson (2015): sample from Skymapper

● LAMOST + Subaru (*preliminary results*)





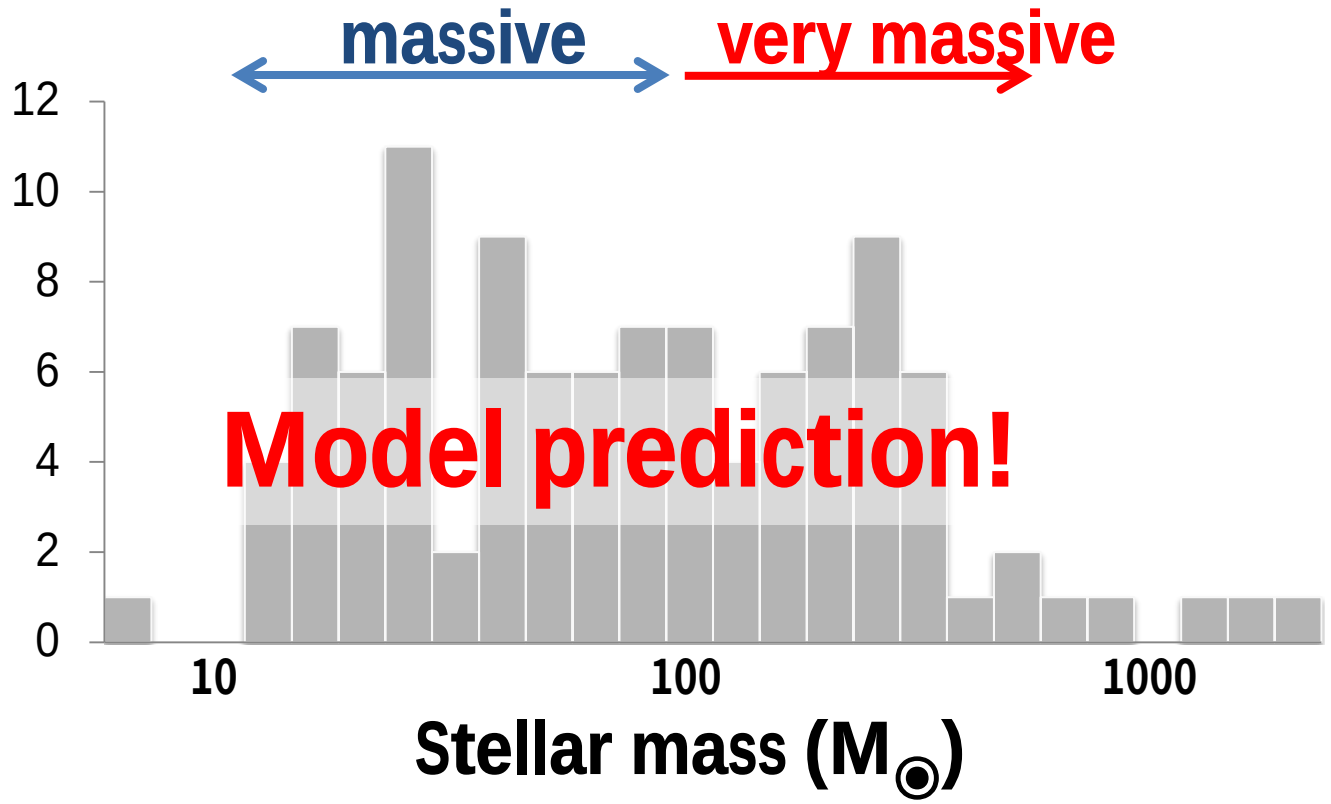
Constraints on masses of first stars

Explosions of first massive stars

formation of next generation low-mass stars

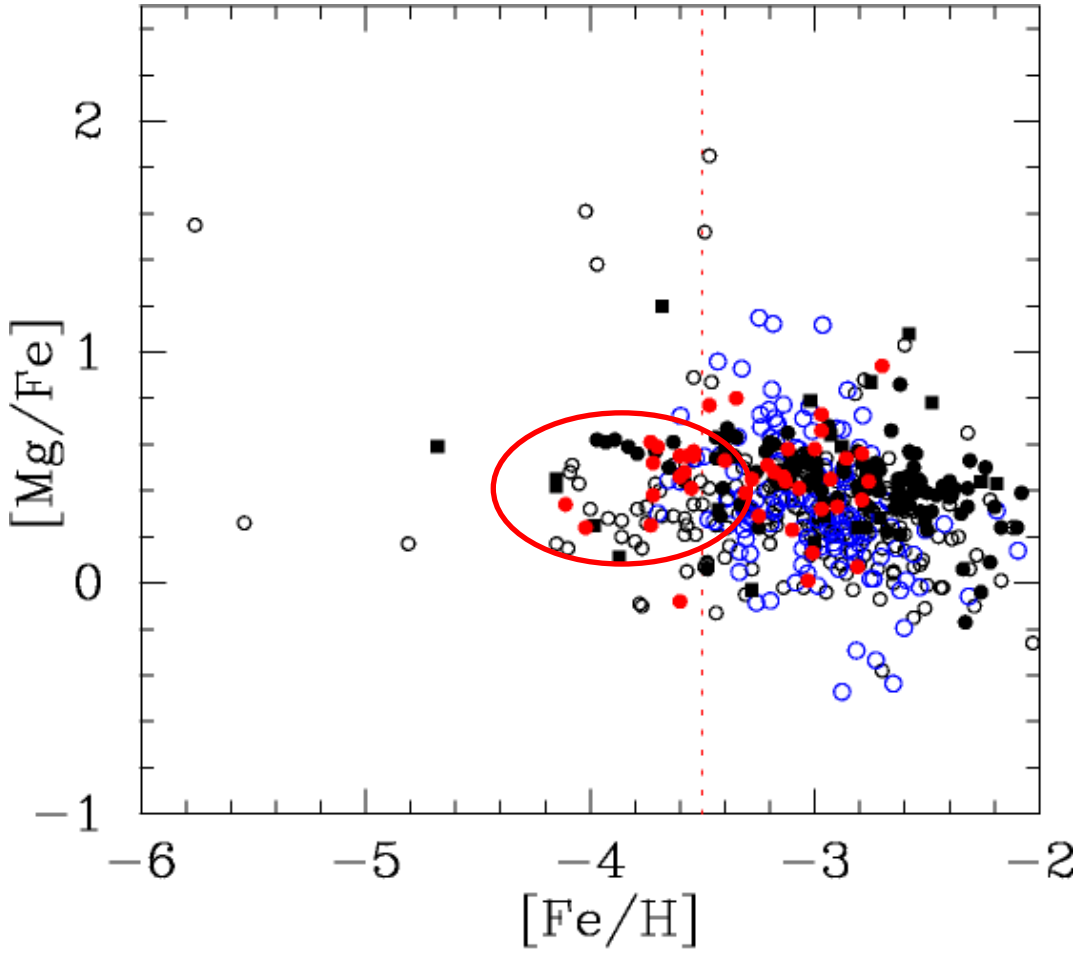
Mass distribution of first stars predicted by numerical simulations

- Majority are massive stars (10-100$M_\odot$)
- some fraction of them are very-massive (>100$M_\odot$)



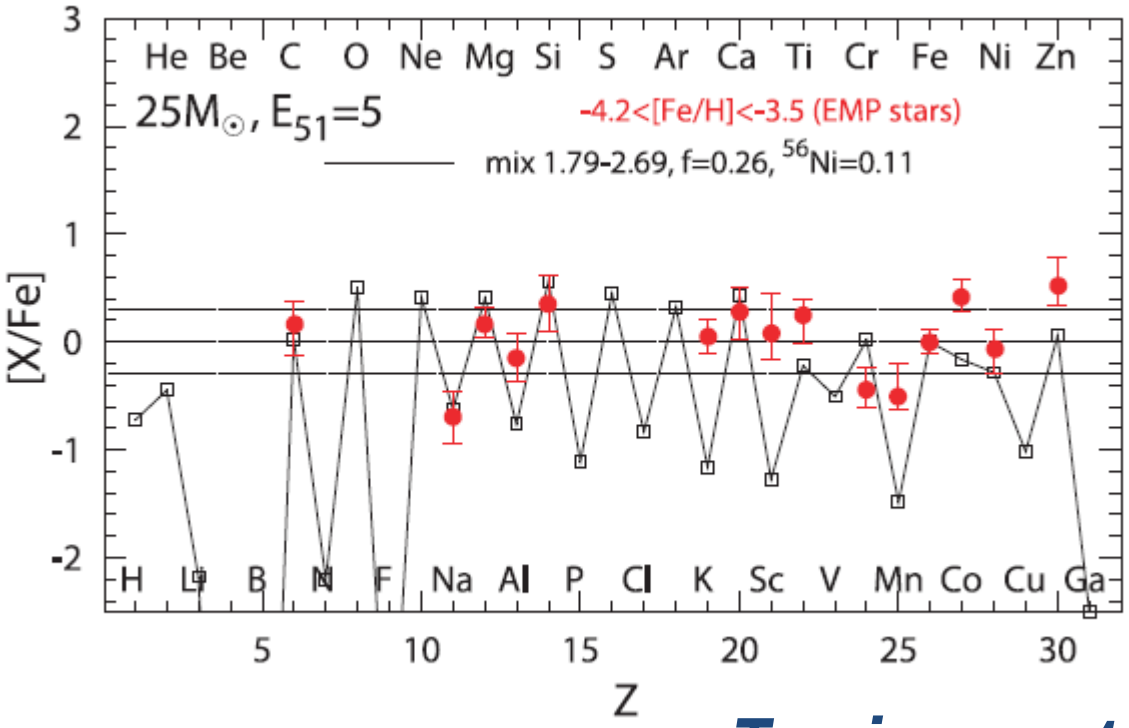
Hirano et al. (2014, Astrophys. J. 781, 60)

Extremely metal-poor stars with “normal” abundance pattern



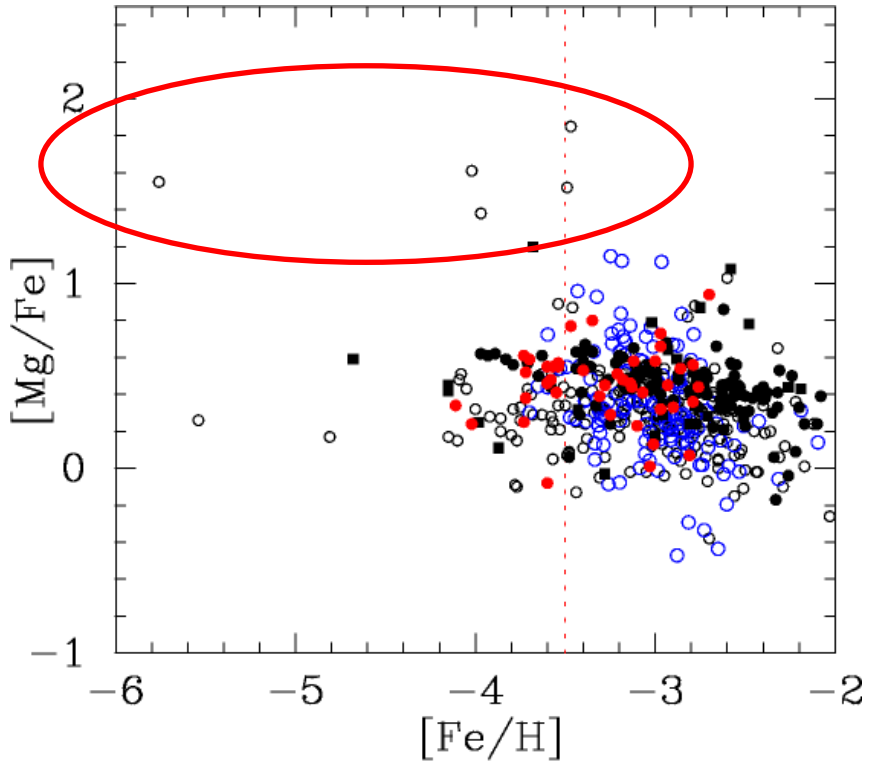
Extremely metal-poor stars with "normal" abundance pattern

→ explained by core-collapse supernovae of stars with several x $10M_{\odot}$



Tominaga et al. (2007)

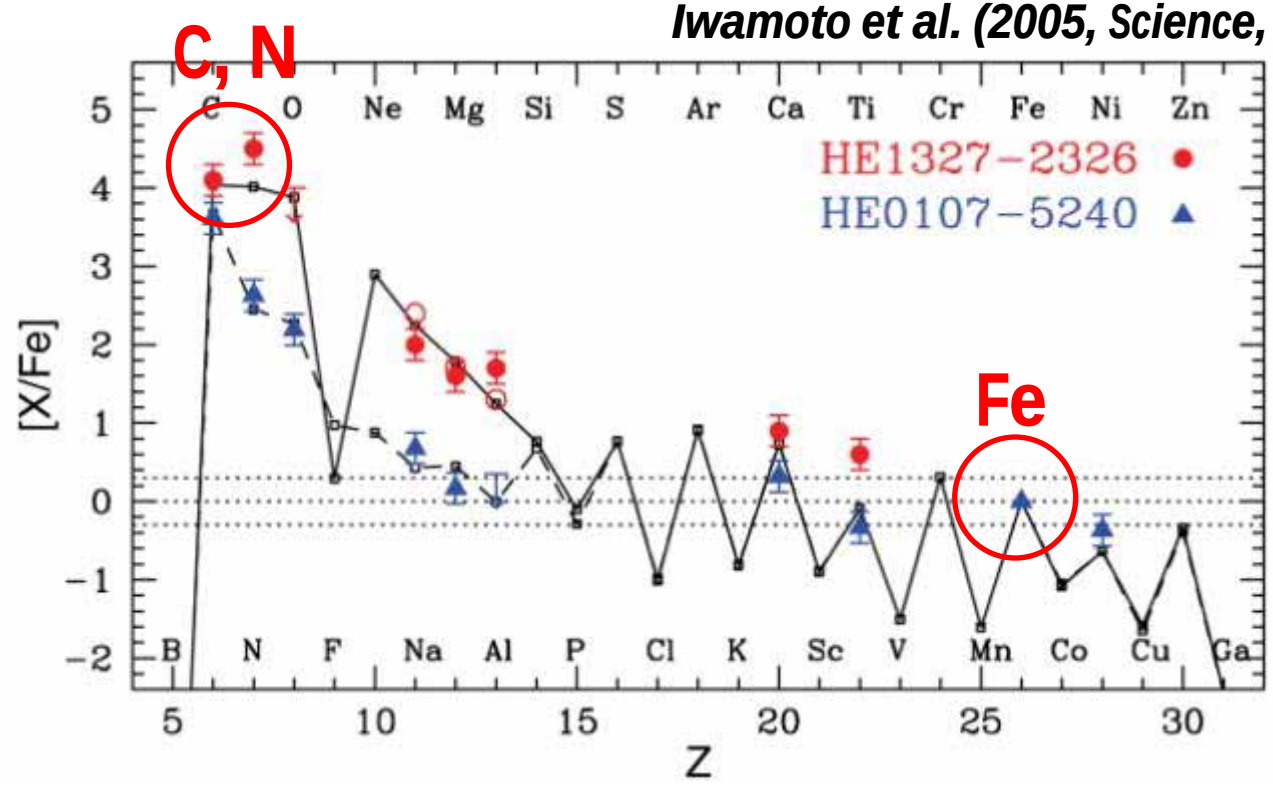
Extremely metal-poor stars with large excess of light elements (C, Mg, …)



Chemical abundance patterns of "Hyper Metal-Poor" stars

- [Fe/H]<-5, [C/Fe]>∼+4
- Faint supernova origin? (several x 10$M_\odot$)

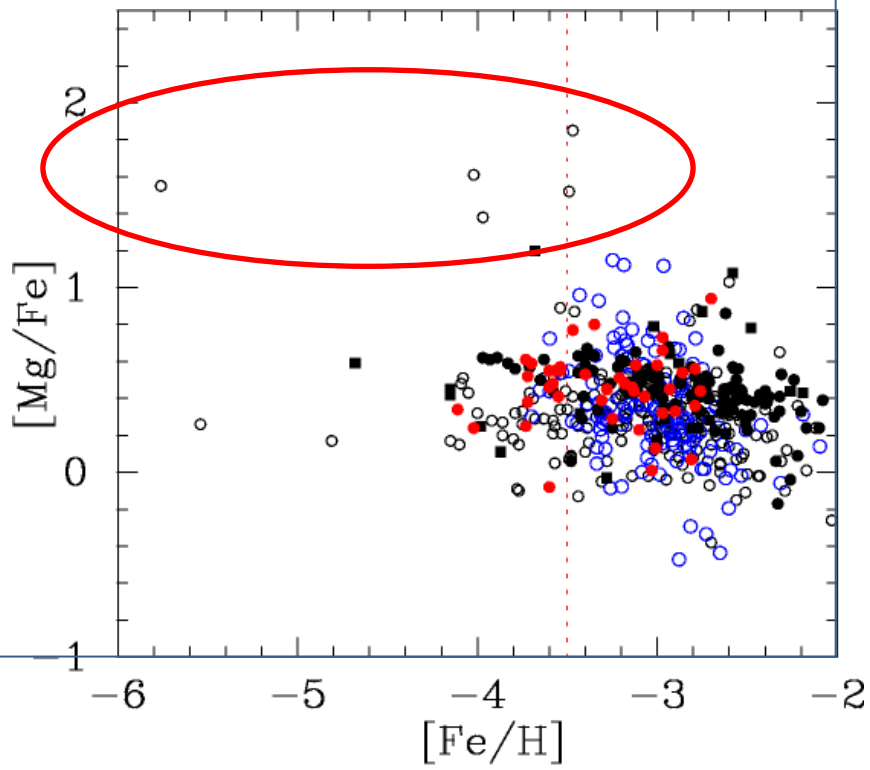
Iwamoto et al. (2005, Science, 309, 451)



Extremely metal-poor stars with large excess of light elements (C, Mg, …)

SMSS J0313-6708

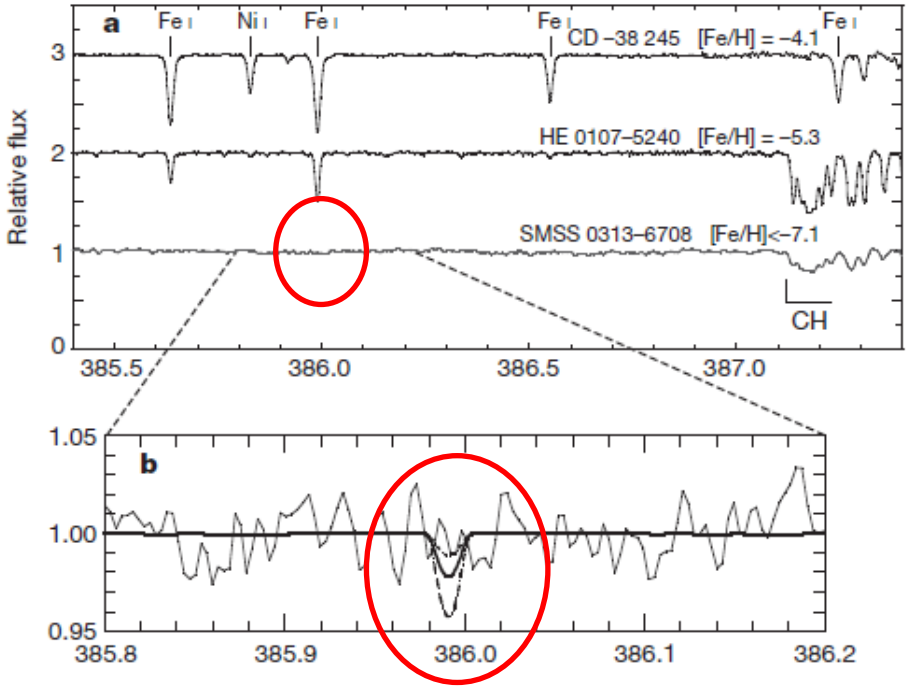
(Keller et al. 2014, Bessell et al. 2015)



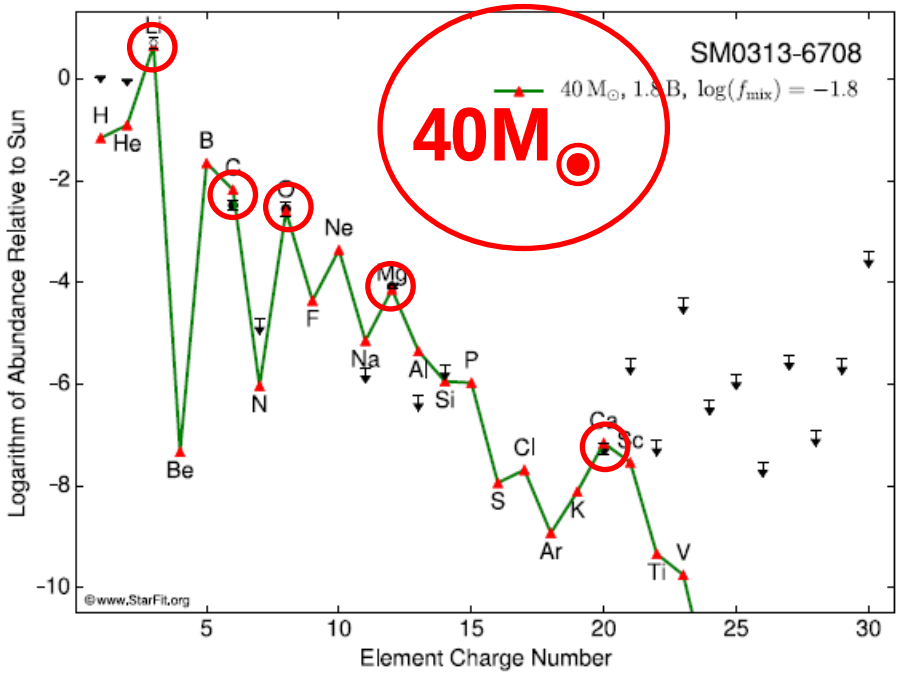
SMSS 0313-6708 : most extreme "carbon-enhanced" star

Keller et al. (2014, Nature)

A red giant with [Fe/H]<-7, but with [C/H]=-2.5



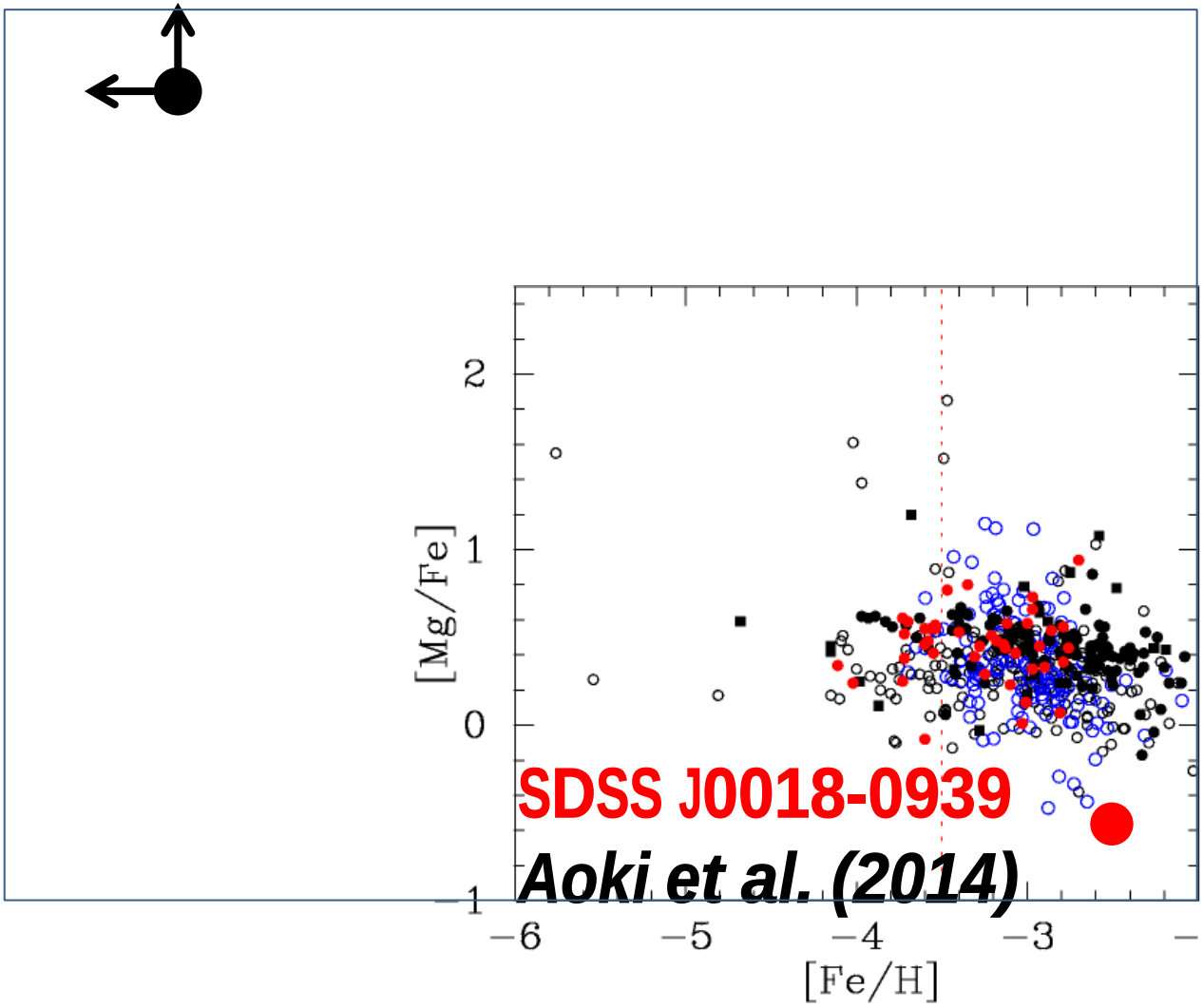
Wavelength (A)



Atomic number

no Fe line detected

Extremely metal-poor stars with low abundance of light elements (C, Mg, ...)

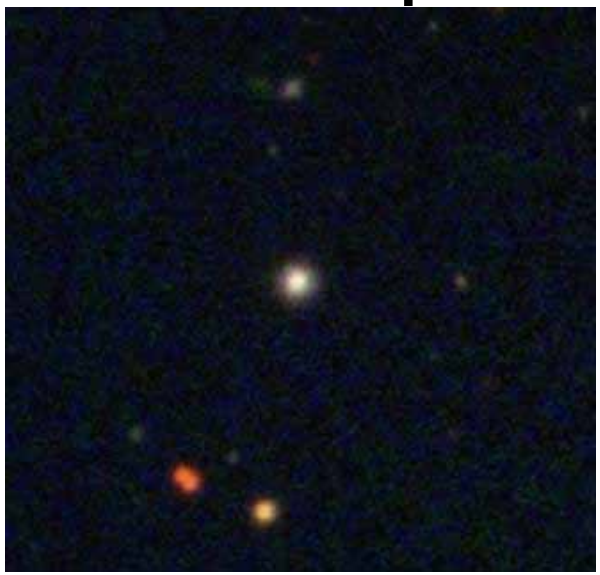


Discovery of a low-mass star with peculiar chemical composition

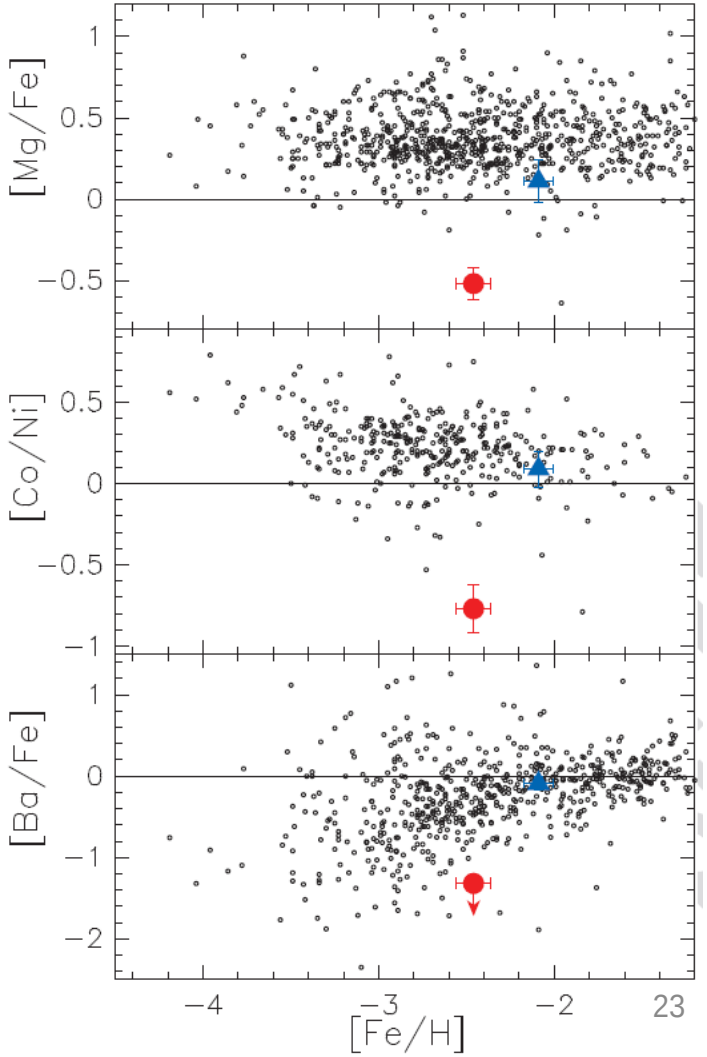
Aoki, Tominaga, Beers, Honda, Lee (2014, Science)

SDSS J001820.51-093939.2

- [Fe/H]=-2.5
- Low C, Mg, Co, Ba etc. abundances
  → excess of Fe
- A low-mass main-sequence star



Taken from SDSS



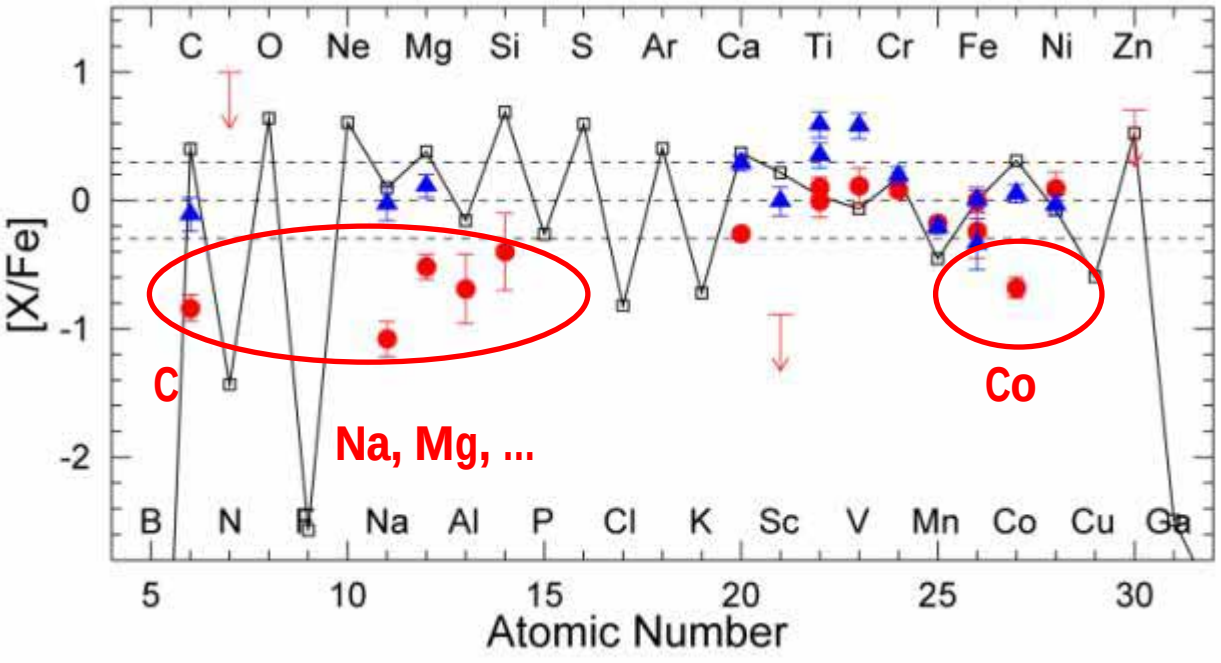
SDSS J0018-0939 -- a low-mass star with a peculiar abundance pattern

The abundance pattern is not explained by normal core-collapse supernovae

Aoki, Tominaga, Beers, Honda, Lee (2014)

● SDSS J0018-0939 ▲ comparison star (G39-36)

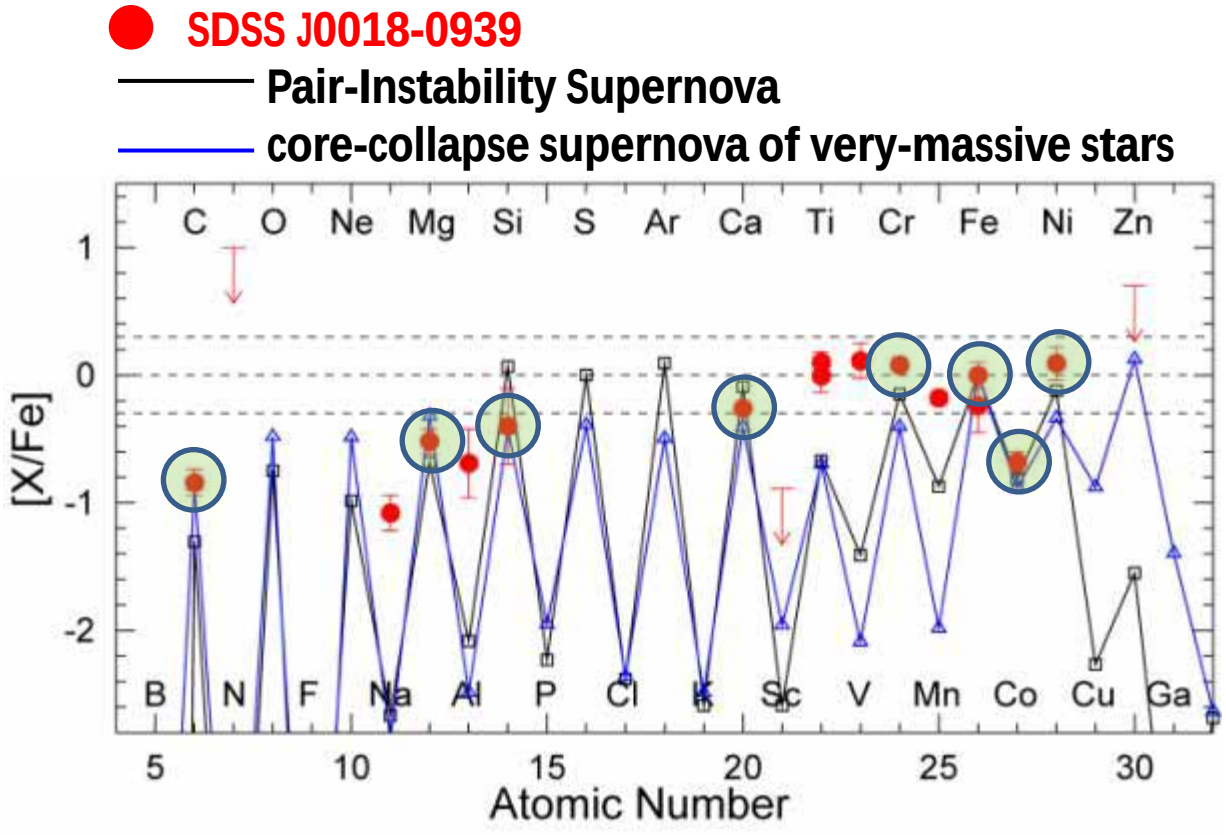
——— core-collapse supernova model



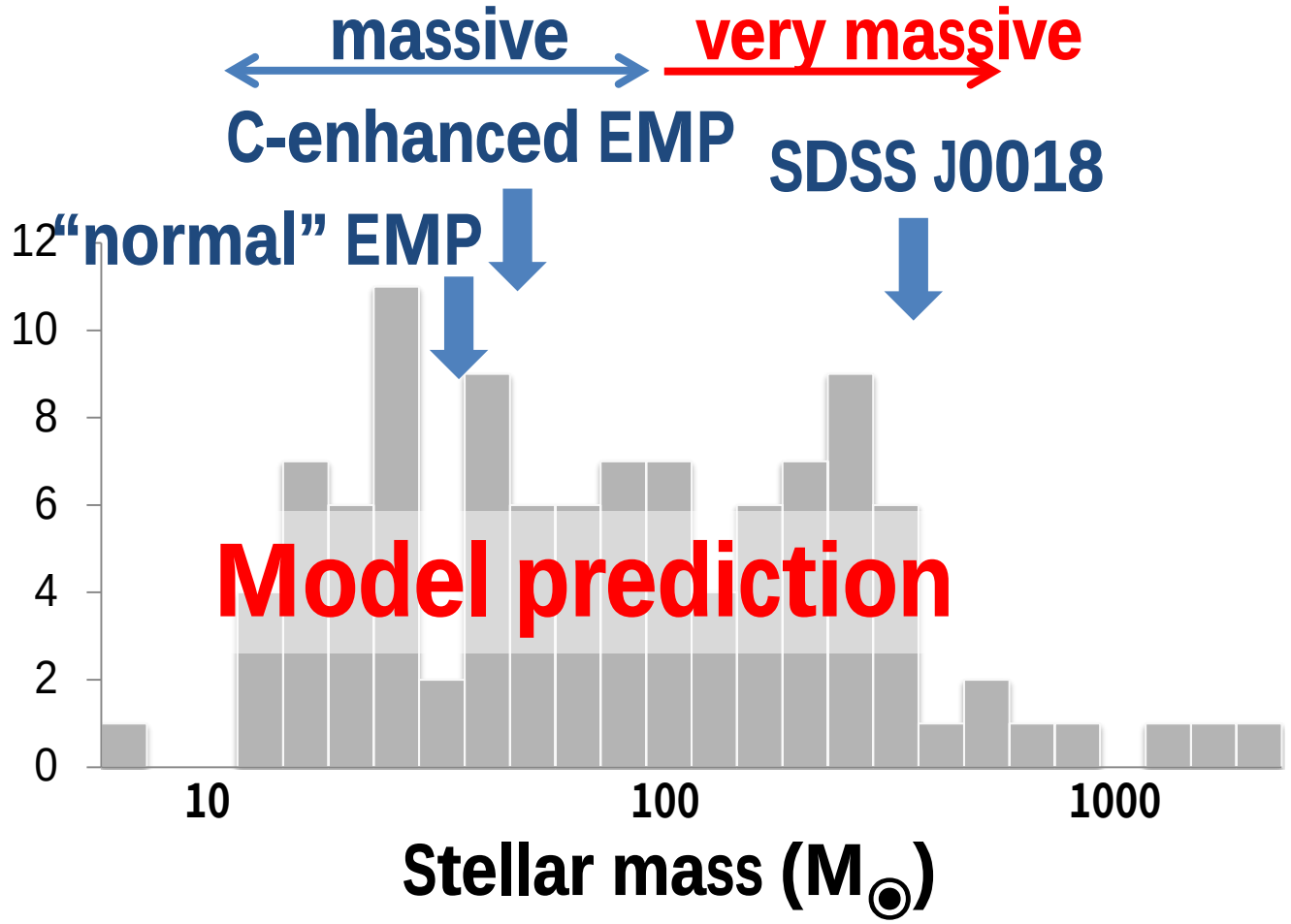
SDSS J0018-0939 -- a low-mass star with a peculiar abundance pattern

Aoki, Tominaga, Beers, Honda, Lee (2014)

Recording yields of a very-massive star?



Mass distribution of first stars predicted by numerical simulations



Hirano et al. (2014, Astrophys. J. 781, 60)

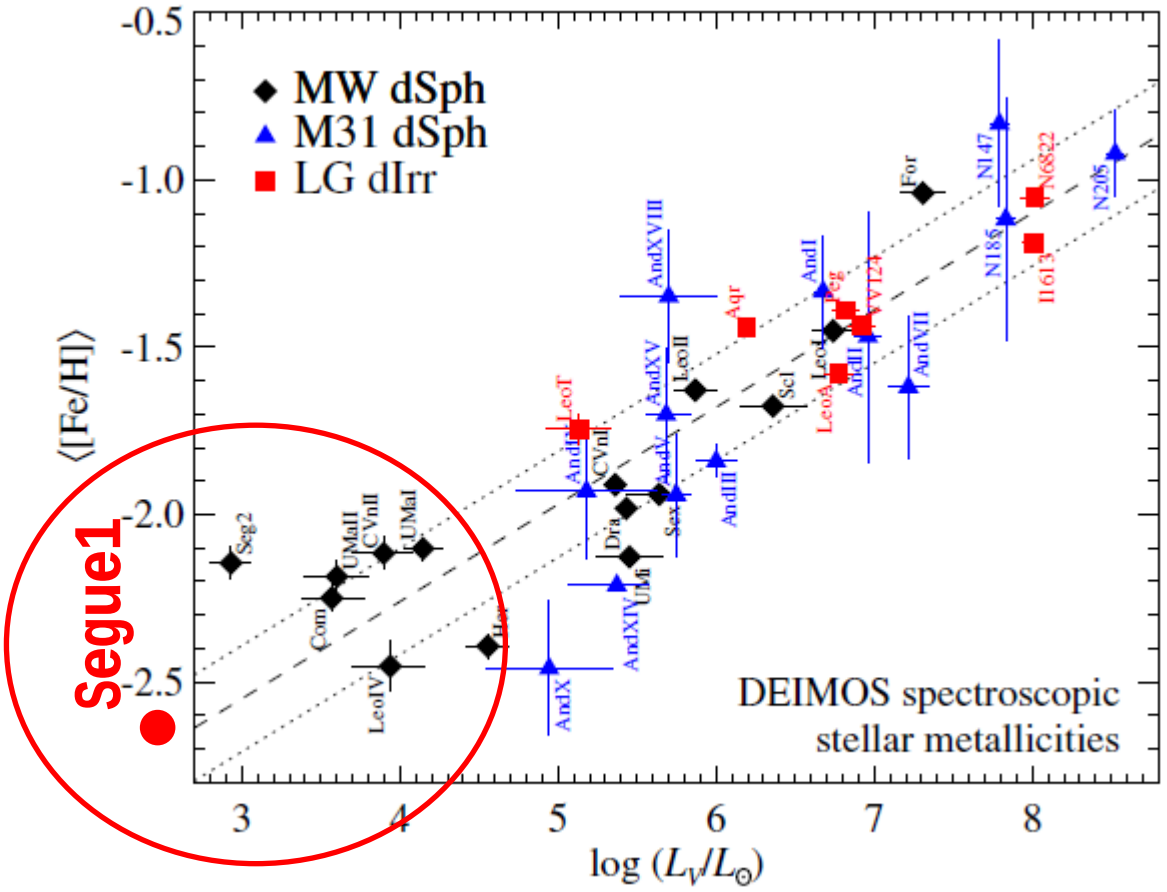
Current understanding of masses of first stars from stellar observations

- ***Massive stars*** **(10-100$M_\odot$) were dominant.**
- ***Very massive stars*** **(>100$M_\odot$) could exist and explode.**
- ***Low mass stars*** **were not formed or they are very rare among first stars.**

To obtain constraints on *mass distribution* of first stars, statistics of very metal-poor stars and understanding of low-mass star formation and evolution are required.

Dwarf galaxies

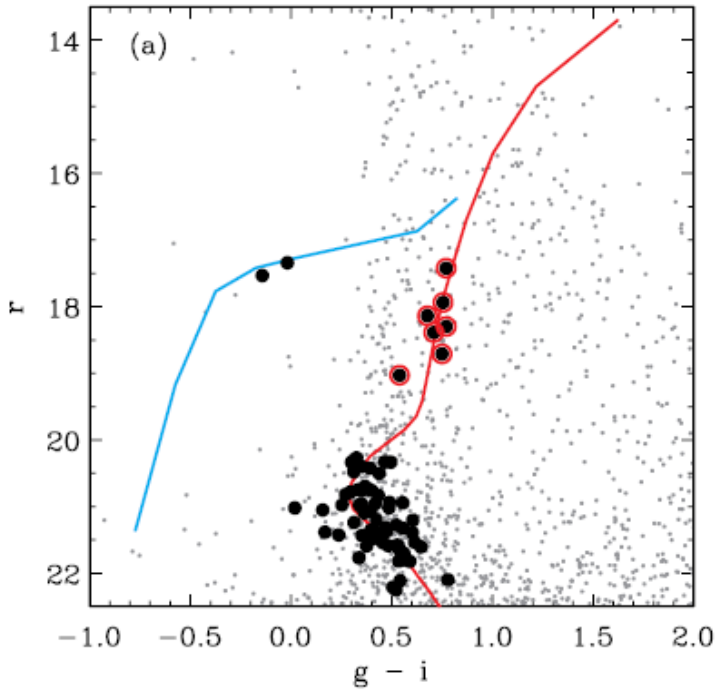
Ultra-faint dwarf galaxies: remnant of first galaxies?

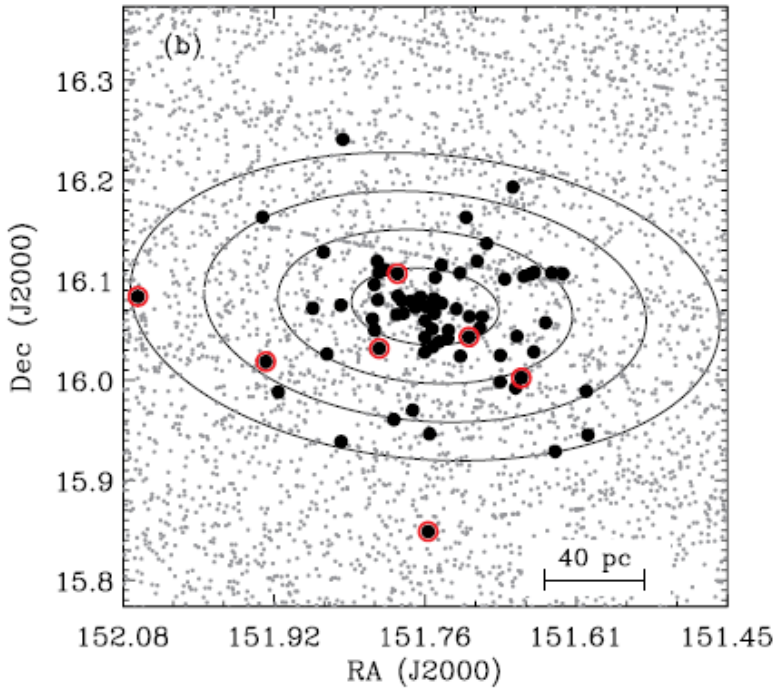


The ultra-faint dwarf galaxy Segue 1

Frebel et al. (2014)

- **70 member stars identified**
- **Only 7 red giants in the galaxy**

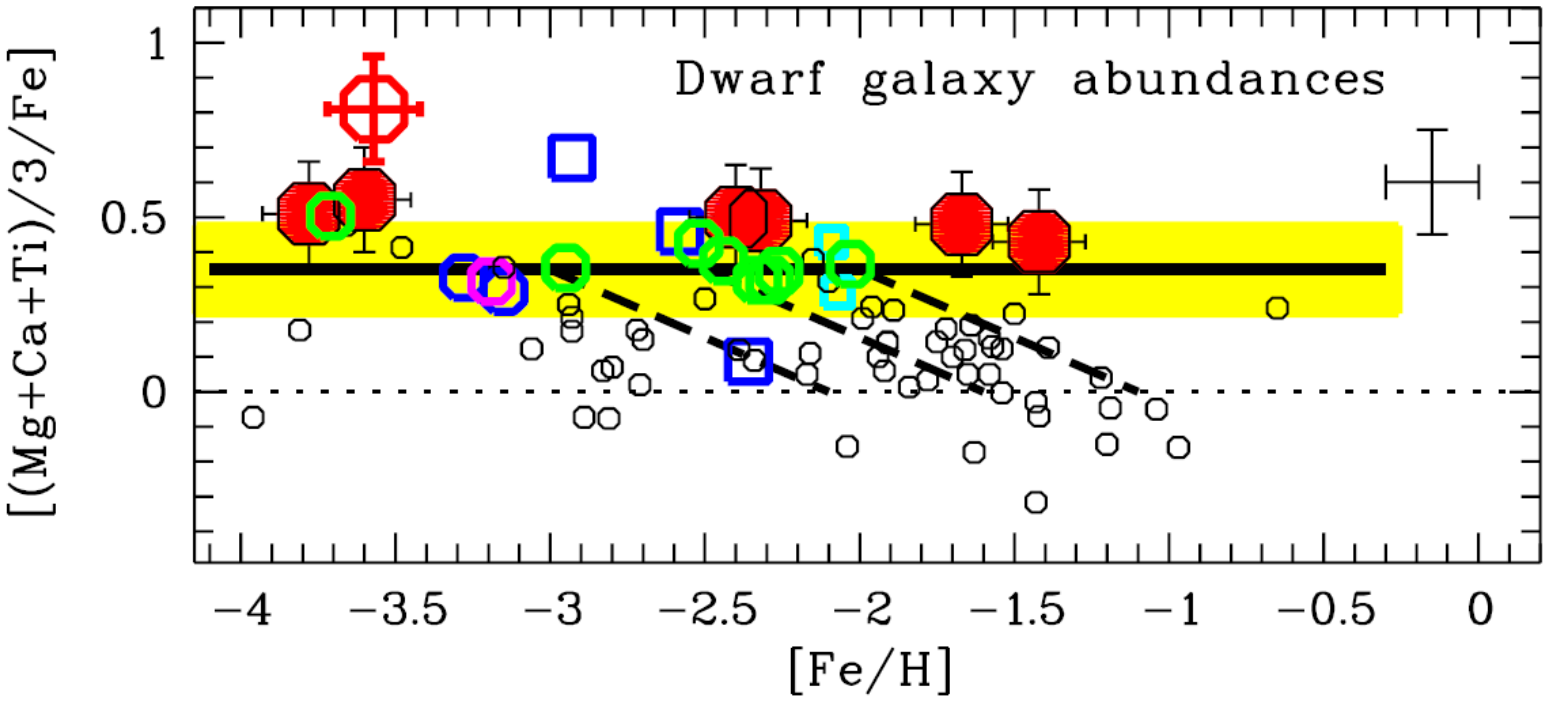




The ultra-faint dwarf galaxy Segue 1

Frebel et al. (2014)

- **Wide metallicity distribution**
- **Constant α/Fe ratios → "one-shot enrichment"**

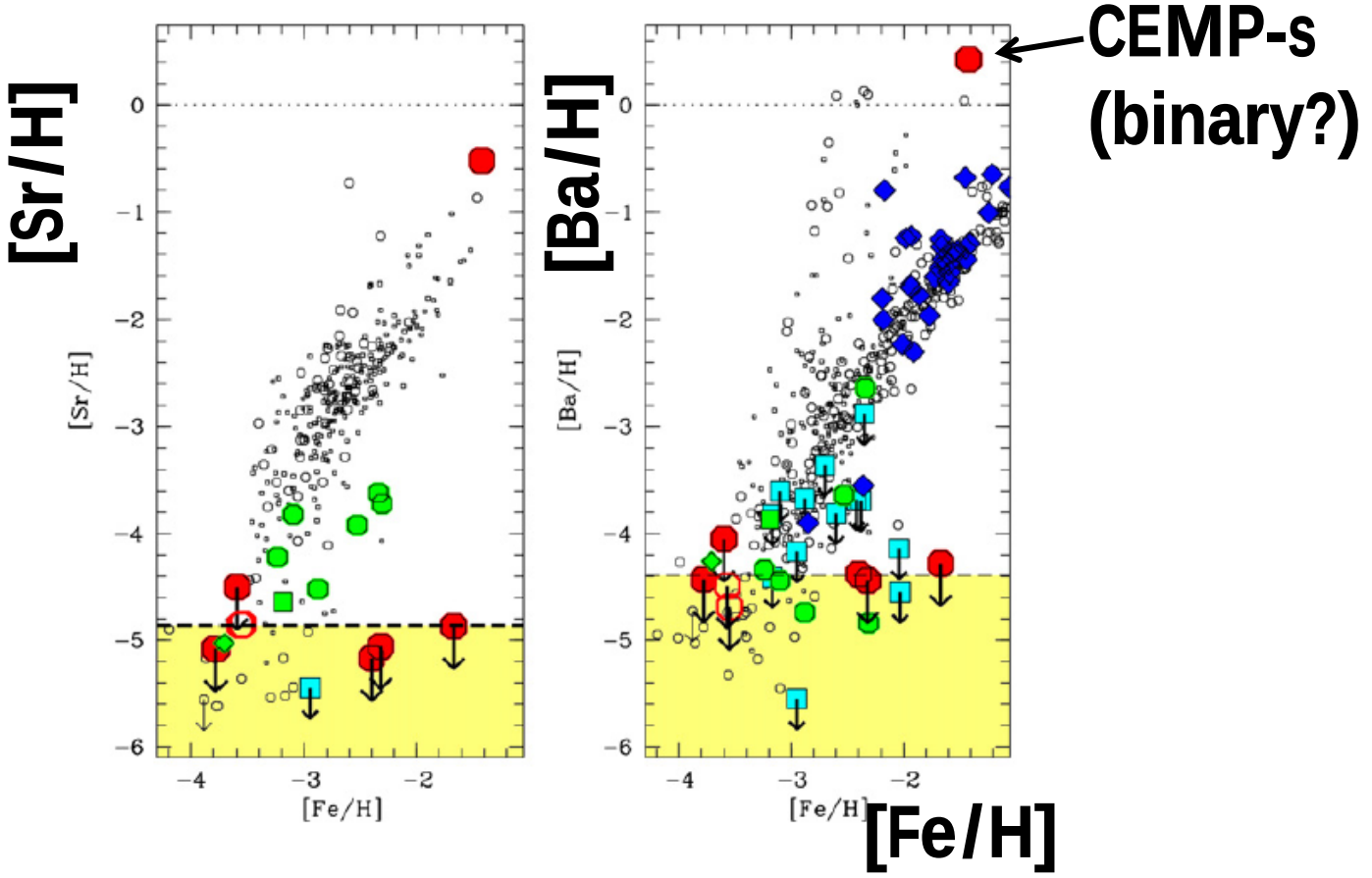


The ultra-faint dwarf galaxy Segue 1

Frebel et al. (2014)

No evolution of heavy elements

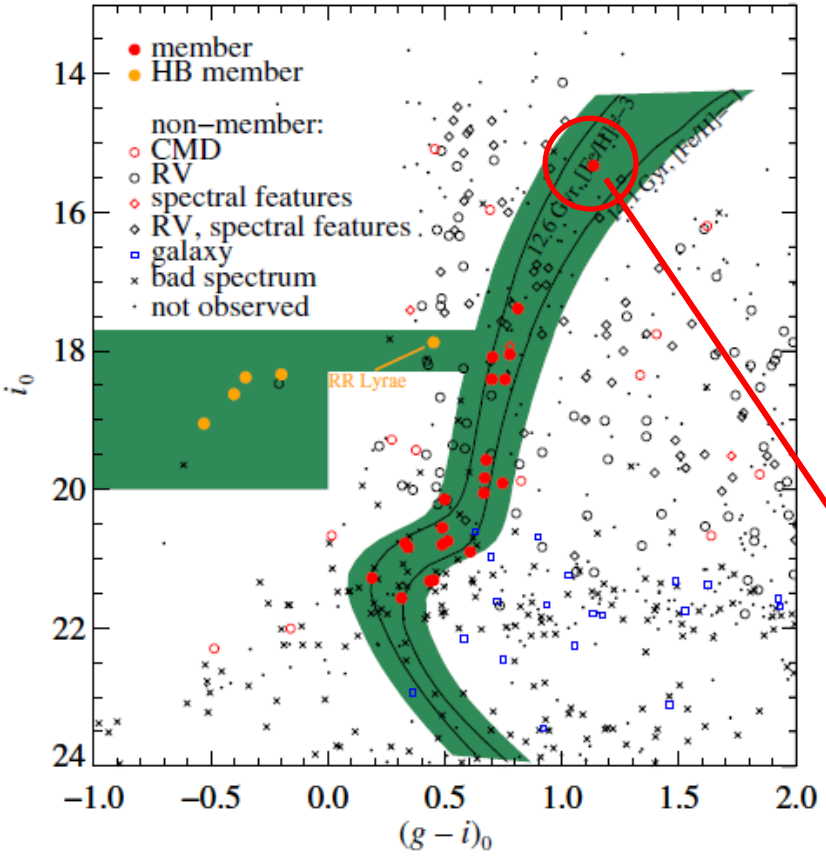
→ "one-shot enrichment" ... remnant of first galaxy?



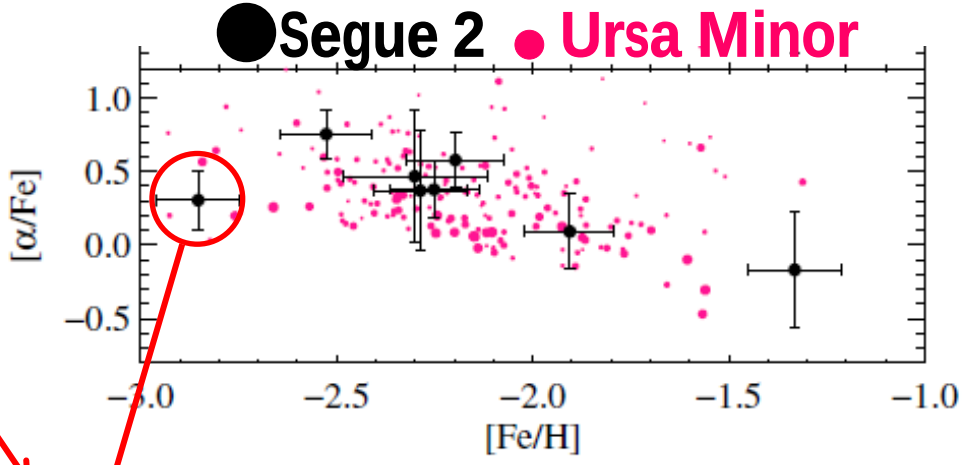
The ultra-faint dwarf galaxy Segue 2

- **25 member stars identified** *Kirby et al. (2013)*
- **Average metallicity higher than expected from luminosity**

→**remnant of a tidally stripped galaxy**?

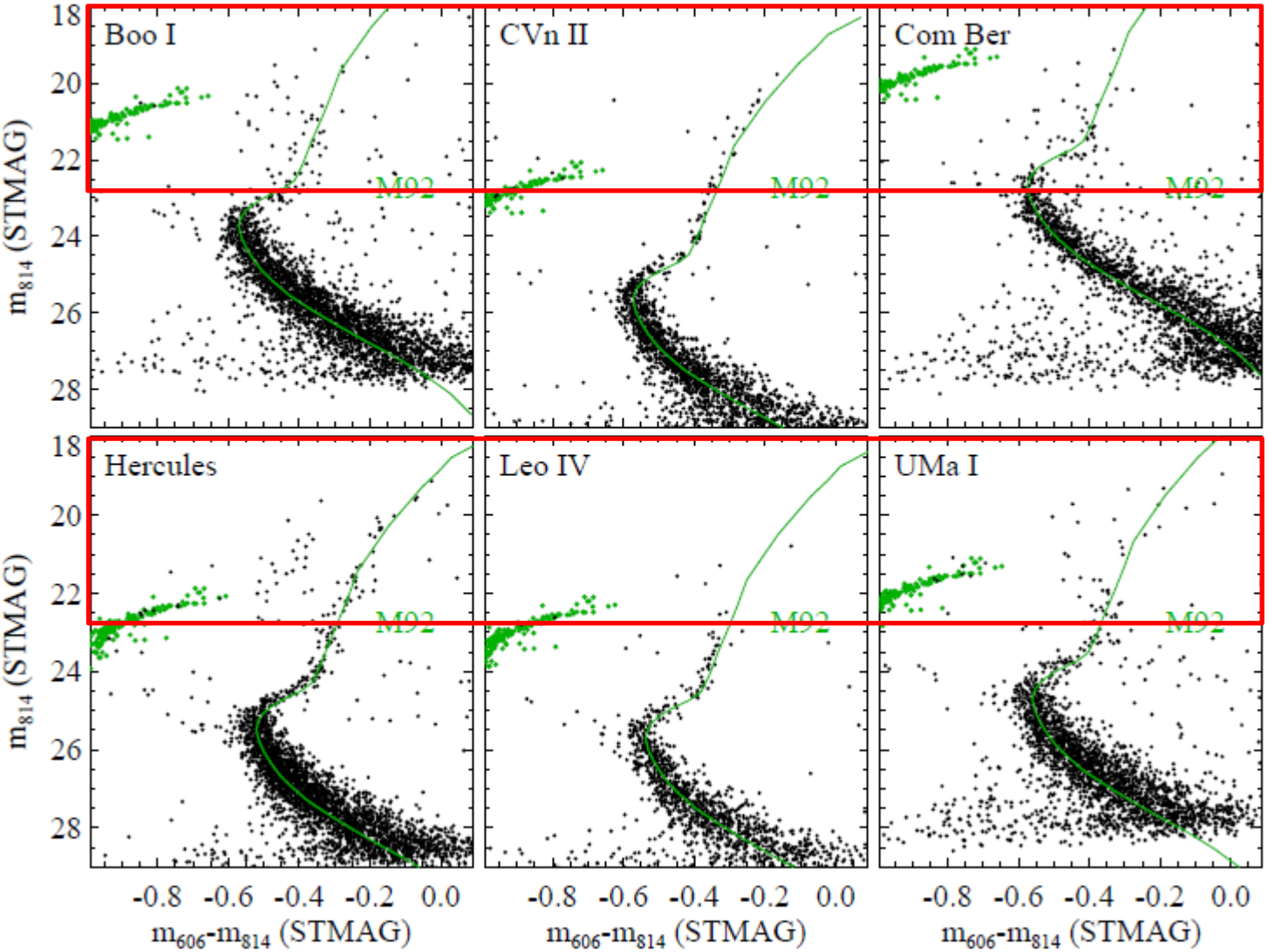


Medium-resolution study with Keck/DEIMOS



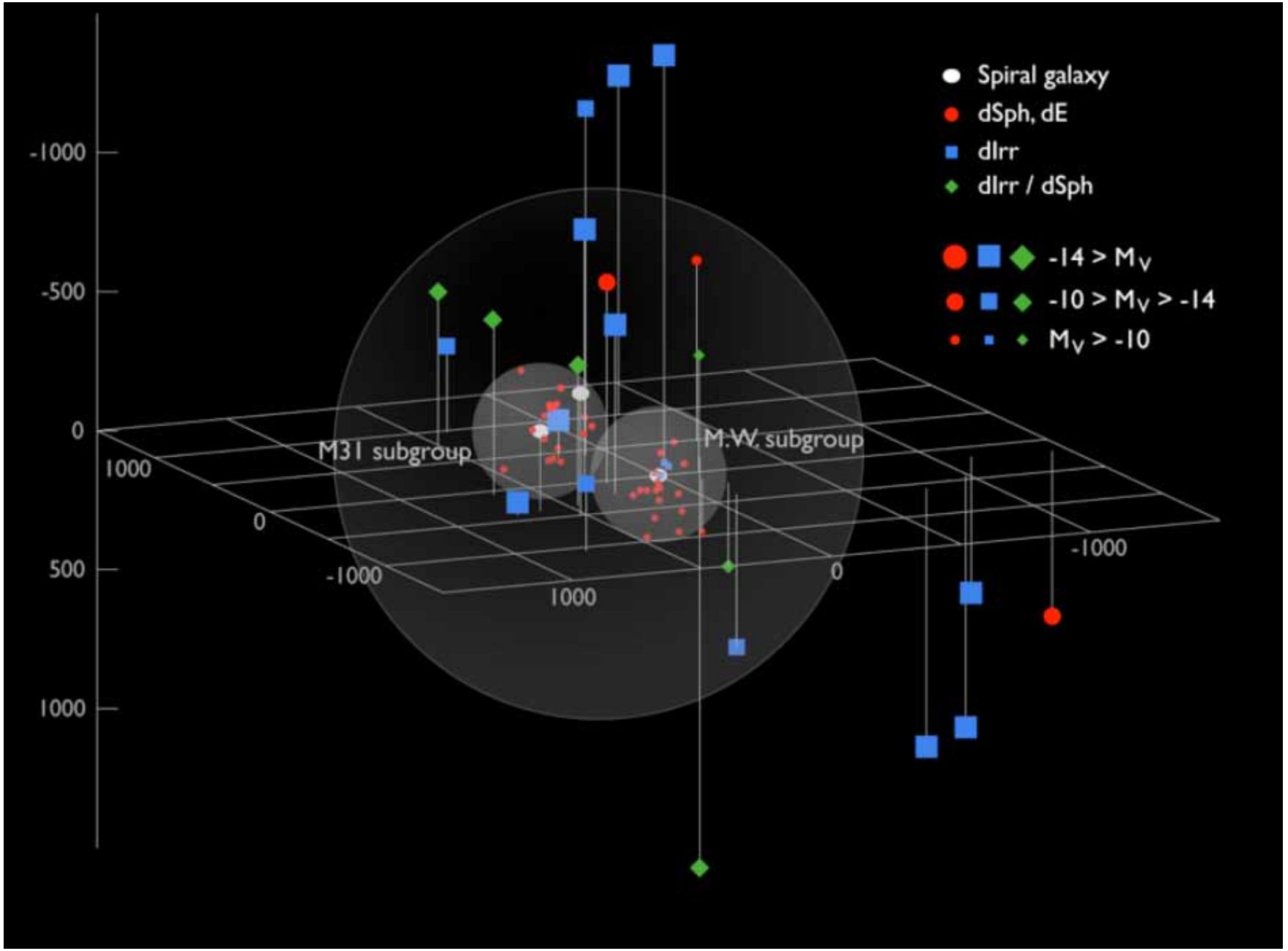
High resolution spectroscopy by *Roederer et al. (2014)*

Ultra-faint dwarfs around the Milky Way



Brown et al.

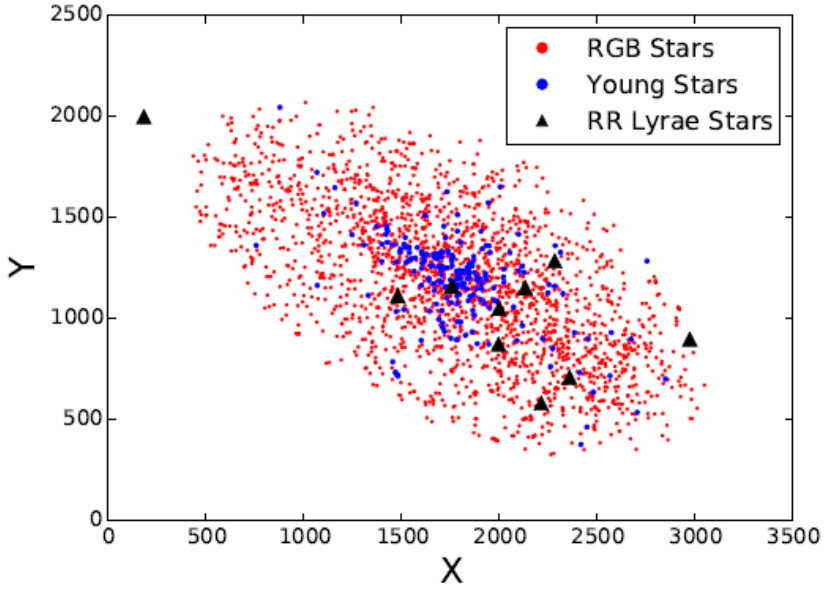
Dwarf galaxies in the local group

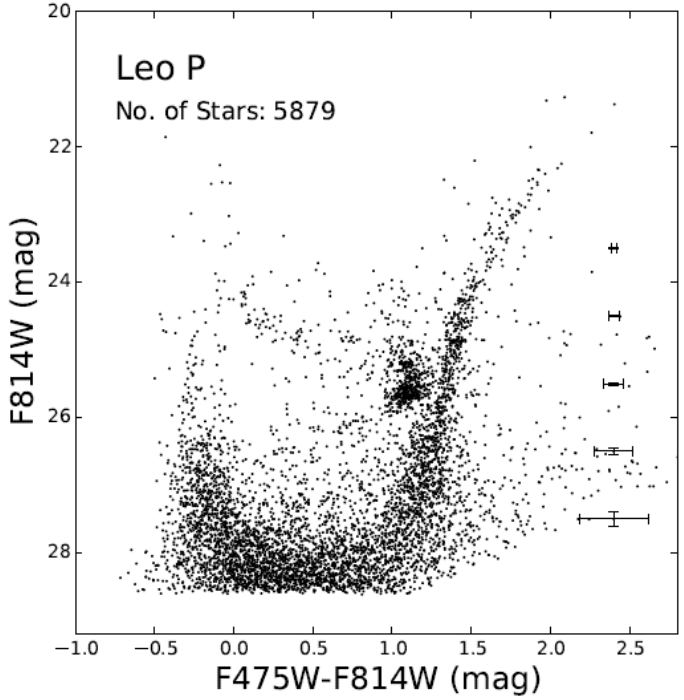


Leo P: an isolated low-mass dwarf galaxy with star formation

McQuinn et al. (2015)

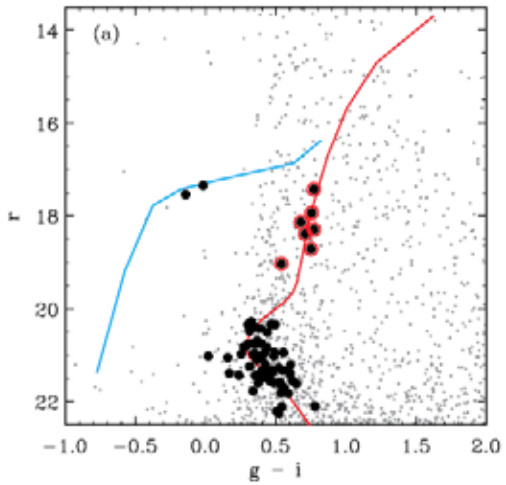
- D~1.6 Mpc
- Low mass: M_*~$10^6 M_\odot$
- Low metallicity ([O/H]=-1.5)

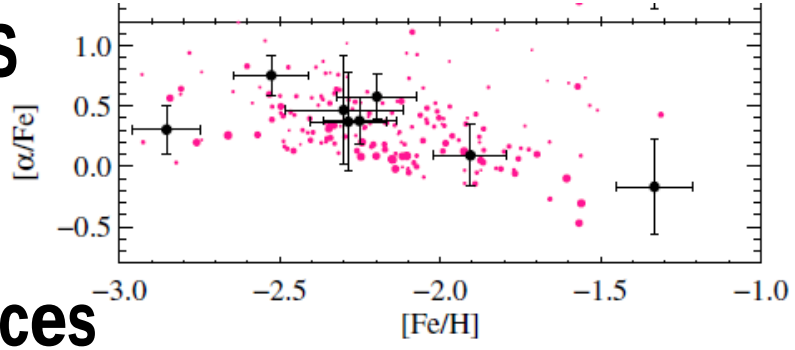




Observing modes to study dwarf galaxies in the local group

- **(Wide-field) imaging → CMD**
  - **→ star formation history, metallicity**
    e.g. Subaru/HSC
- **Medium-resolution spectroscopy**
  - **→ kinematics, galaxy mass, (sub)structure, abundance trend**
    e.g. Keck/DEIMOS , Subaru/PFS
    TMT/WFOS
- **High-resolution spectroscopy**
  - **→ detailed chemical abundances**
    TMT/HROS





Observing modes to study dwarf galaxies in the local group

	MW satellite (<200 kpc)	M31 satellite (~700 kpc)	Isolated dwarfs (>500 kpc)
Imaging →CMD	Subaru/HSC	Subaru/HSC etc.	Subaru/HSC etc.
Medium-res Spectroscopy	Keck/DEIMOS Subaru/PFS	(Keck/DEIMOS) TMT/WFOS	(Keck/DEIMOS) TMT/WFOS
High-res spectroscopy	(Keck, Subaru) TMT/HROS	(TMT/HROS)	(TMT/HROS)

Goal of systematic study of dwarf galaxies with TMT

- **Formation sites and processes of first stars and low-mass stars with very low metallicity.**

- **Formation and early evolution of galaxies – building blocks of Milky Way and large galaxies?**

- **Feedback to nuclear astrophysics**
  e.g. identifying the site of explosive synthesis of heavy elements (r-process)

Synergy with other telescopes and related topics

- **Collaboration with E-ELT and GMT to cover northern & southern objects.**
- **Radio observations for star forming dwarf galaxies.**
- **Proper motion measurements with TMT/IRIS.**