# HROS: A New Window to Stellar Processes

Aruna Goswami
Indian Institute of Astrophysics
Bangalore

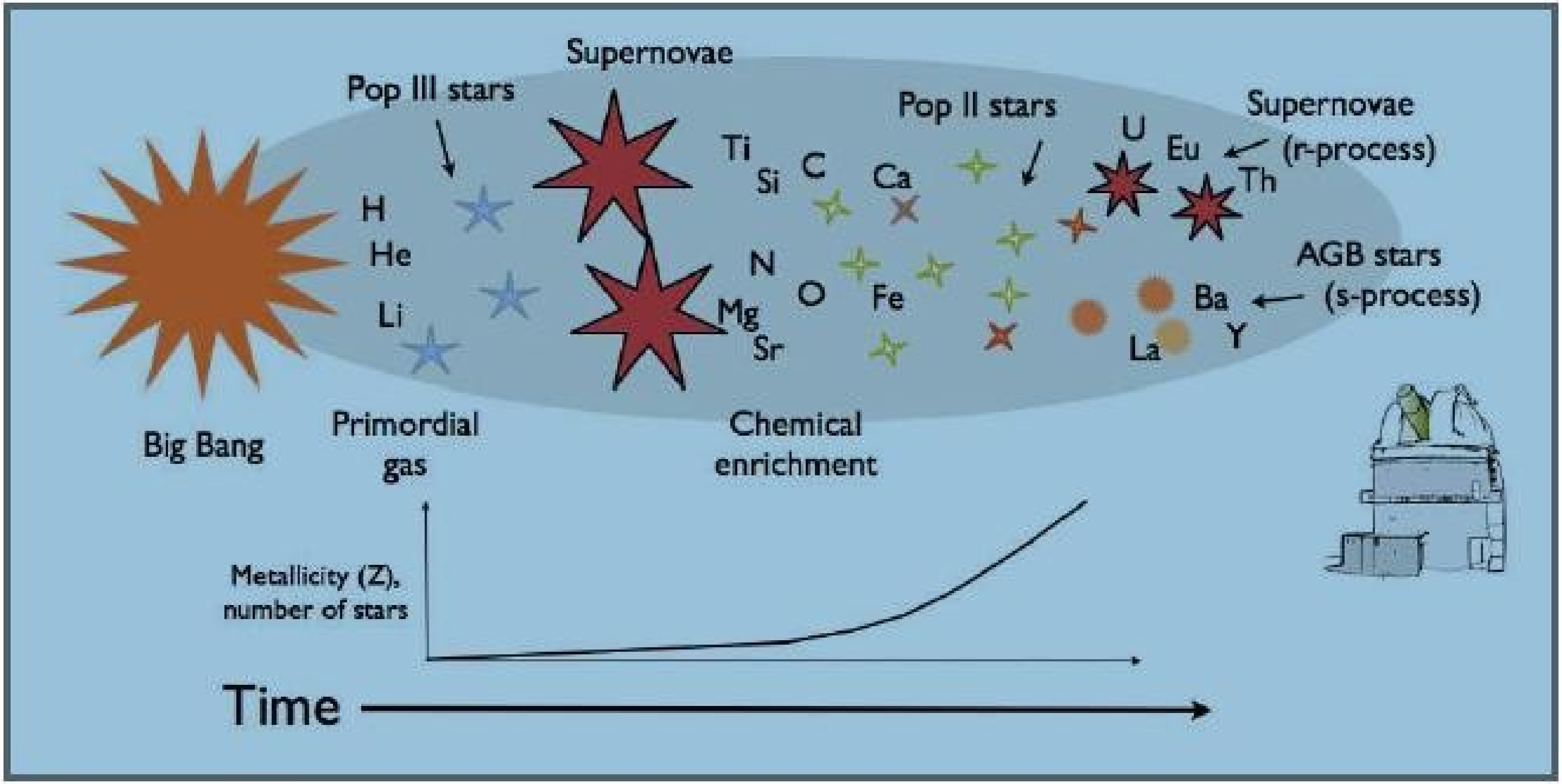
# Scope of Discussion

- Current issues in Stellar Astrophysics
- Observational capabilities required to address these issues
- Current limitations in our investigation of stellar processes
- Most promising observations expected to be enabled by HROS
- What theoretical works are needed to explain the observations ?
- Potential synergies between TMT-HROS and other (TMT) facilities
- Complementary Efforts

- Probing the oldest stars: MW and the Local group
- Stellar nucleosynthesis
- Chemical Evolution: MW, Local Group, Nearby Galaxies
- Stellar Astrophysics

(Validating theories with observations)

# Probing the oldest stars



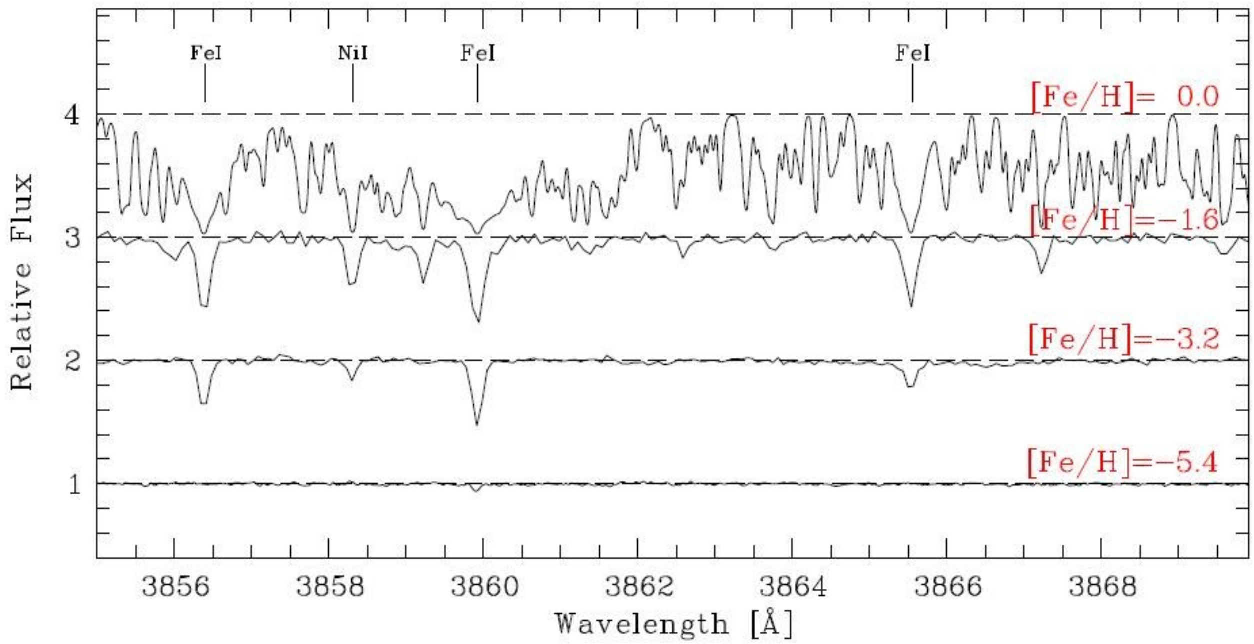

Frebel

# Exploring the Universe with metal-poor stars

- Nature of Pop III stars
- Yields and explosion properties of first SNe
- Are the Yields of first SNe different from today's?
- The primordial stellar mass function
- Critical metallicity for transition from Pop III to Pop II stars
- Early low-mass stars formation and connection to CEMP stars
- Nucleosynthesis processes and sites of elements formation
- Nucleo-chronometry of the oldest stars

- Did the Galactic halo formed from accreted satellite?
- Can we identify accreted dwarf galaxies in Galactic halo?
- Did the first stars formed in dwarf galaxies?
- How did chemical evolution proceed ?

# Current limitations and observational challenges: Examples




Strongest optical Fe line at 3860 Å of the SUN

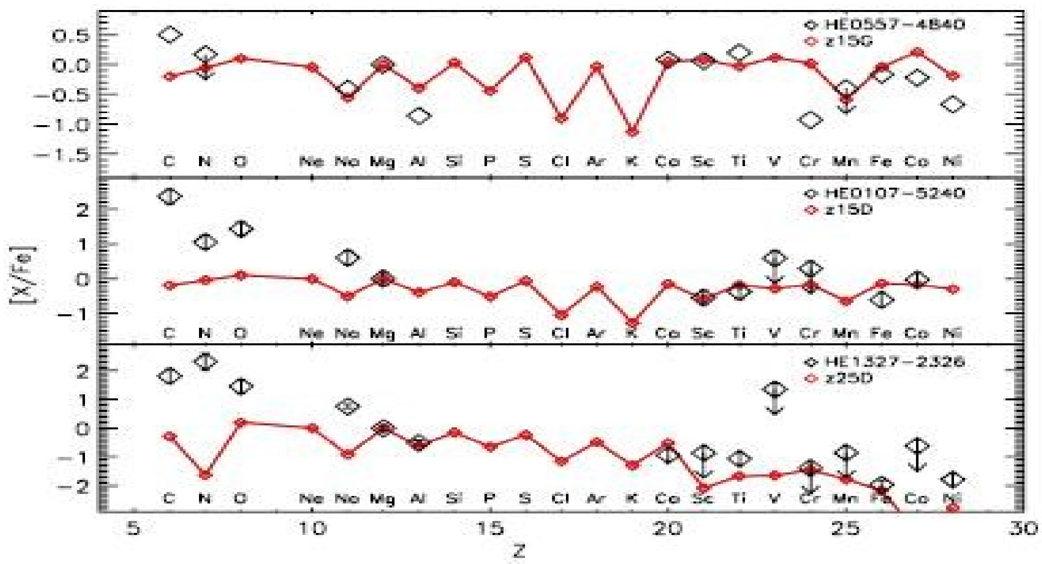
- ❖ Long Exposure time ( ~18 hrs, for HE 1327 -2326 with VLT/UVES)
- ❖ Lowest observable metallicity in the halo, [Fe/H] = -7.3 (Frebel et al.)
- ❖ SMSS J031300.36 – 670839.3 ([Fe/H] = -7.1) (Keller et al. 2014)
- ❖ No Fe lines detected in 3500 – 3800 Å spectrum
- ❖ (R ~ 35000, S/N ~ 120, Exp ~ 13 hrs)
- ❖ Within reach, to find MP stars closest to the First Stars require TMT/HROS

TMT/HROS Spectrum -

- Vmag ~ 21, R ~ 40000, S/N ~ 200 , Exp time ~ 4 hrs.

# Characterizing the oldest stars -

# SNe best-fit yields and observations




Origin of HMP stars -

- Inheriting the ejecta from a single SN II,
- Multiple generations of SN,
- Result of binary mass transfer ?

- Joggerst et al. (2010)

HE 0557-4840

Well reproduced (above Na) by the z15G model yields.

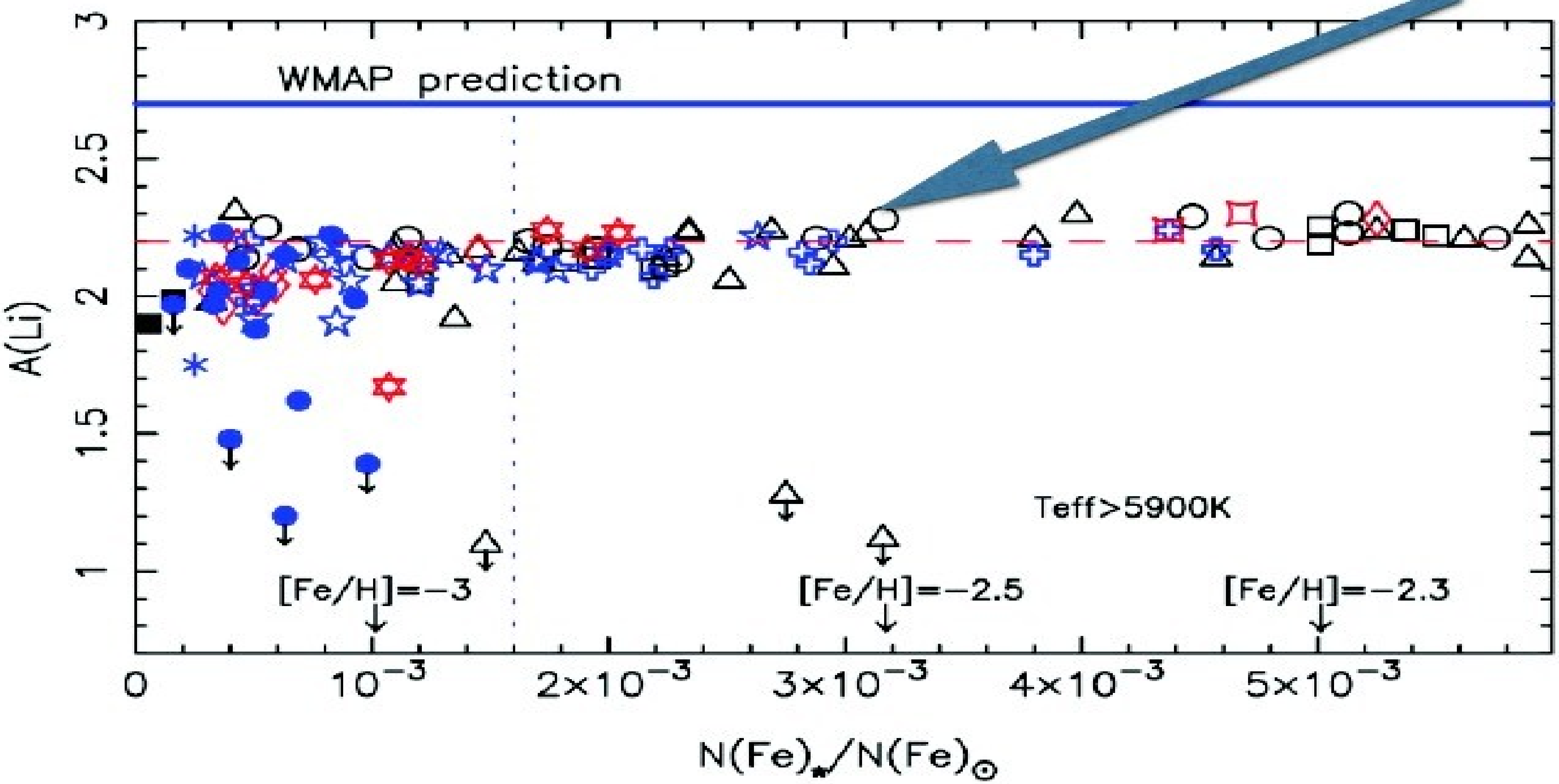
HE 1327-2326 and HE 0107-5240

High C, N, O: Not well reproduced by z15D and z25D models

Detailed measurements of the elemental abundances of metal-poor stars with peculiar abundance ratios, will provide useful constraints on the existence and fraction of very massive stars in the early universe (Karlsson et al. 2008).

# Li Abundance - discrepancy

**Observed Li plateau 2-4 times lower than CMB prediction**




**HE 1327-2326 - Log ε(Li) < 1.6**

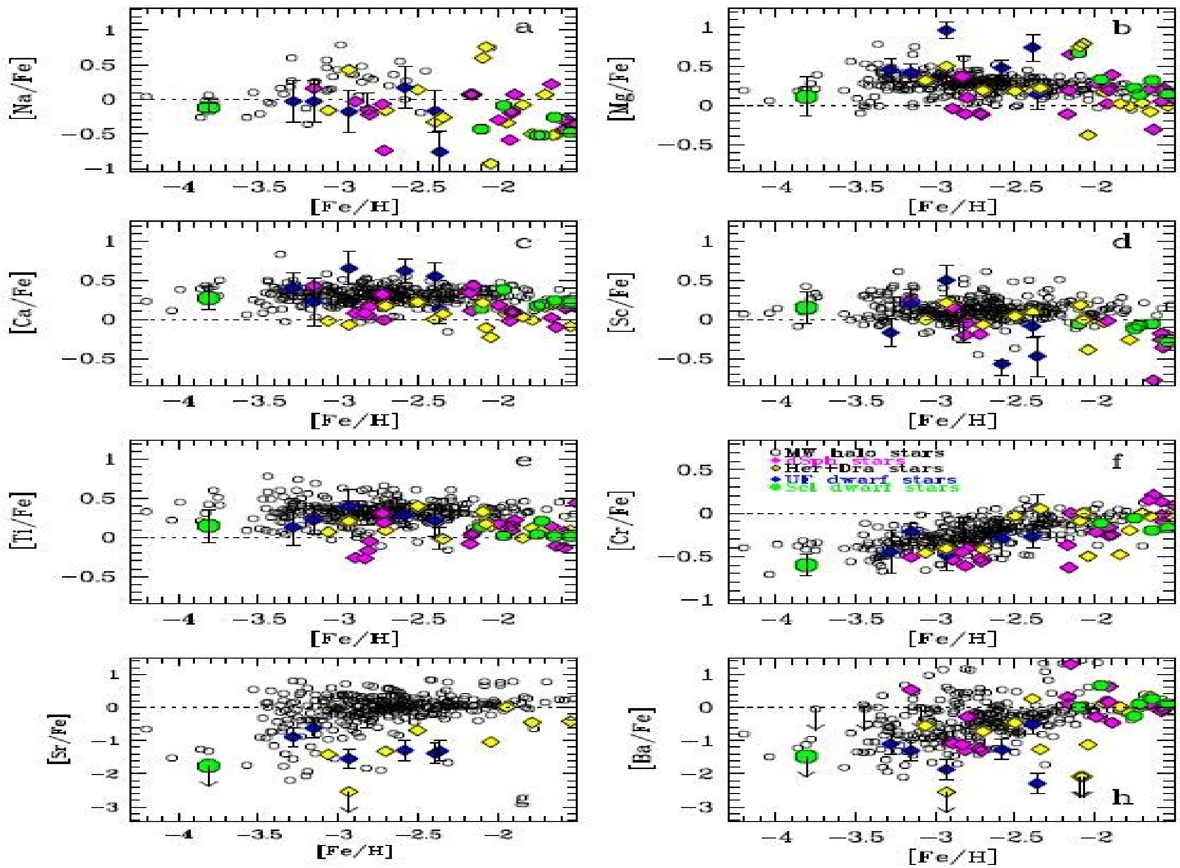
**WMAP Primordial Li - Log ε(Li) =2.6,**

**-- from baryon-to-proton ratio.**

# Chemical evolution: MW and Dwarf galaxies

- Formation of the first low-mass objects
- The formation history of the halo
- Did the Galactic halo formed  from accreted satellite?
- Can we identify accreted dwarf galaxies  in Galactic halo?
- Did the first stars formed in dwarf galaxies?
- How did chemical evolution proceed ?

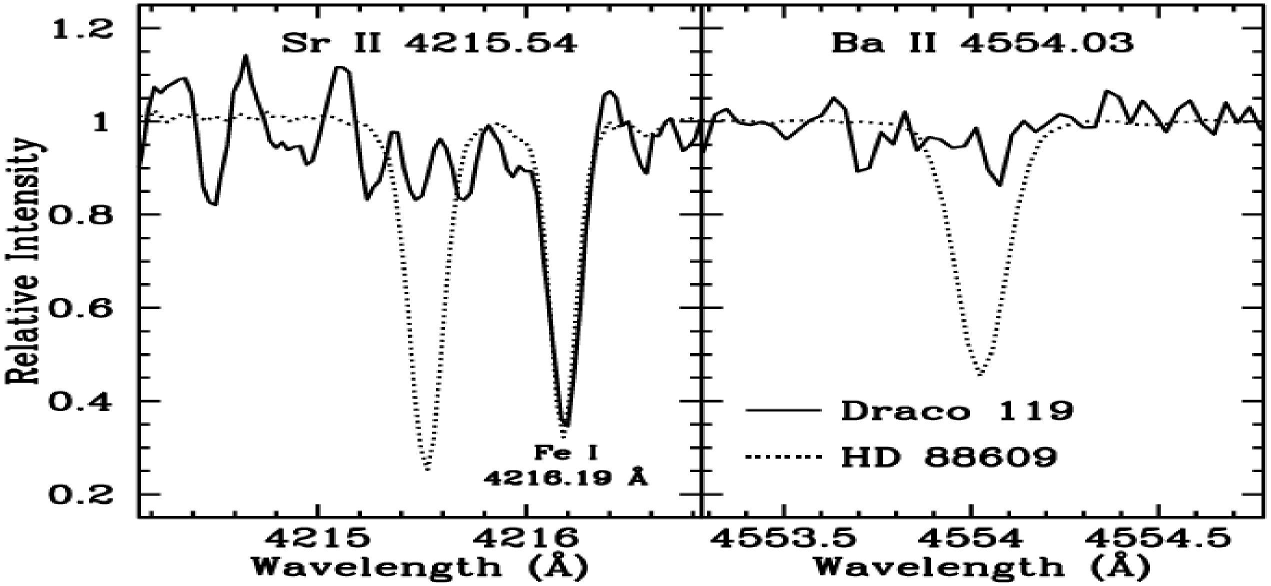
➢ **Are the Galactic building blocks different from surviving dwarfs?**




Abundance ratios as a function of iron abundance in S1020549 and other metal-poor stars. In eight elements, **S1020549 (big green filled circle** at [Fe/H] -3.8) is compared with **halo stars (black circles), ultra-faint dwarf galaxy stars (blue diamonds)** and the **brighter dwarf galaxy stars (pink and yellow diamonds)**. Small green circles indicate higher metallicity Sculptor dwarf galaxy targets (Frebel et al.)

# Neutron-capture Nucleosynthesis : abundance anomalies in Ultra Faint Dwarf galaxies -

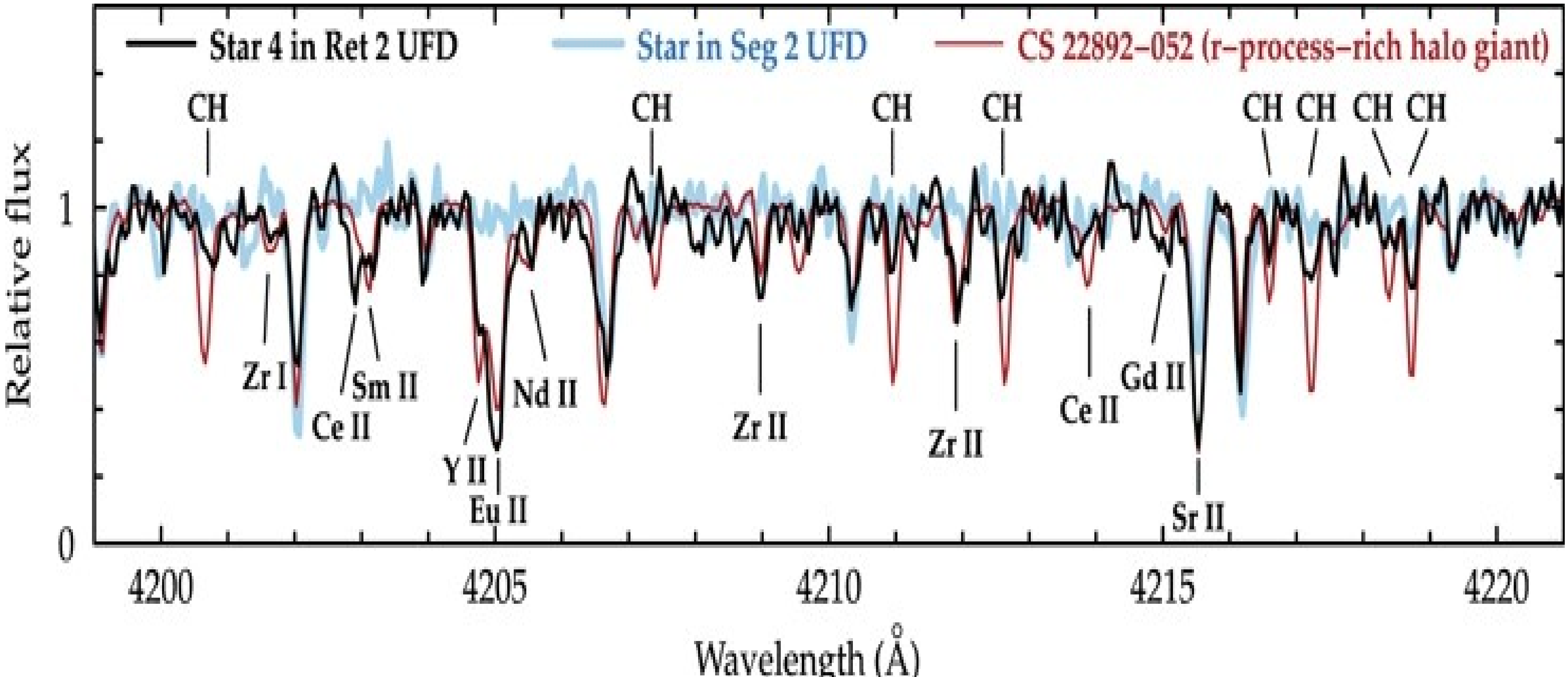
- **Neutron-capture elements are deficient in the Local Group !**



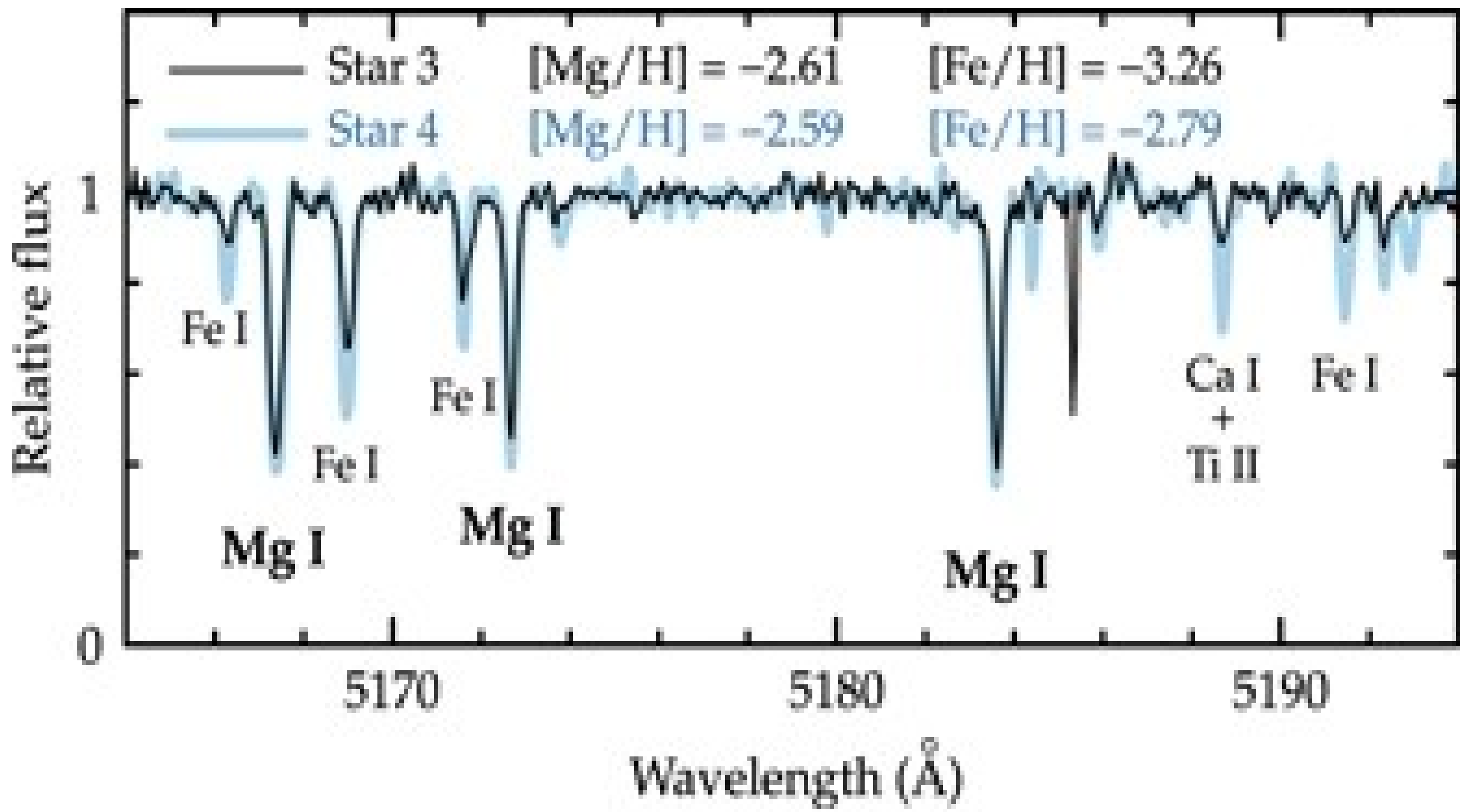

D119: A red giant in the Draco Dwarf Spheroidal galaxy (Fe/H = -2.95);

Dotted lines: HD 88609, of similar metallicity (Fulbright, Rich & Castro 2004).

Hercules dwarf spheroidal galaxy shows similar deficiencies (Koch et al. 2013).




Roederer et al. 2016, AJ,




Roederer et al. 2016, AJ,

# Constrints on r-process from chemical abundances of dwarf galaxies

- MW stars: [Eu/H] increases with increasing [Fe/H];
  r-process enriched stars are found with [Fe/H] < -3.0

- Faint classical dwarf galaxies stars: constant [Eu/H] with respect to [Fe/H] (Tsujimoto & Shigeyama 2014)

- Ultra Faint Dwarf galaxies are found to host r-process rich stars
  Ji et al. 2016, Roederer et al. 2016 (Reticulum II, at d = 32 kpc)

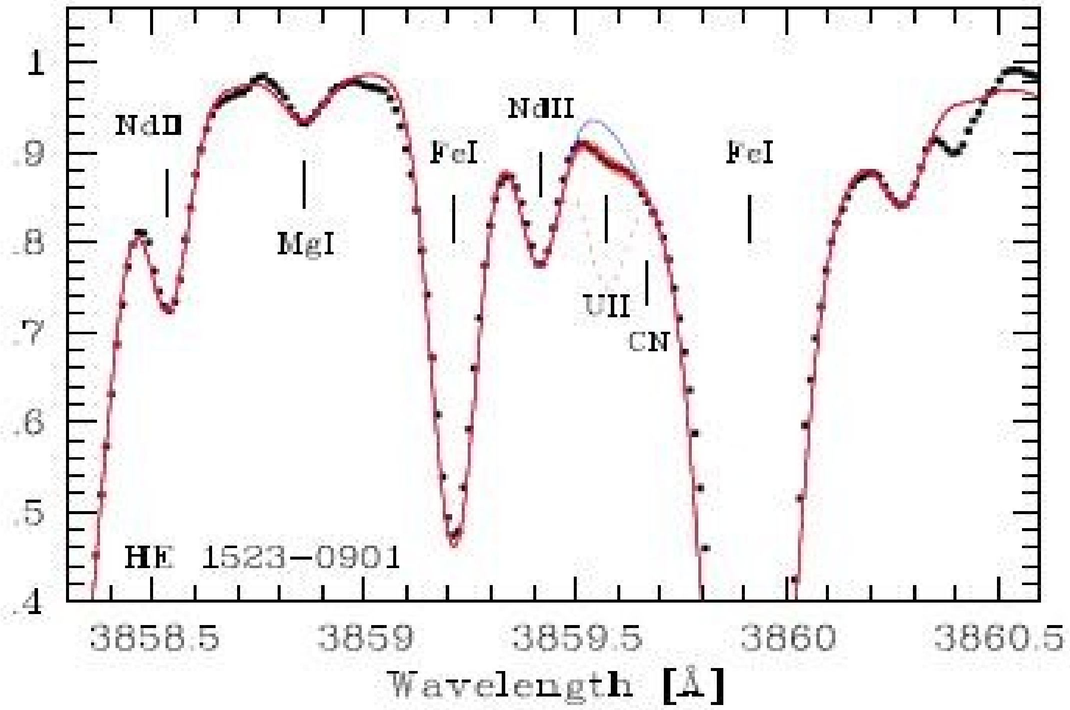
- R-process is a rare process compared to normal core-collapse Supernovae with no (or little) contribution to Fe enrichment

- Proposed sources of r-process: NS-NS mergers;
  Possible to work at very low metallicity, [Fe/H] < -3.0.
  Difficulty in NS- NS merger scenarios?

# Cosmo-chronometry of the oldest stars

**$^{232}$Th (14 Gyr), $^{238}$U (4.5 Gyr):** Radioactive, Long-lived.

CS 22892-052, r II star, (14 Gyr, Th/Eu) Sneden et al. 2003
CS 31082-01, (14 Gyr, Th/U), Cayrel et al. 2001
Ranges from 11 – 14 billion years --
provide a lower limit to the age of the Galaxy.
U (3859 Å), Pb (4057 Å) --- strongest optical transitions
(Blends with CH features in CEMP stars)




Useful chronometers :
Th/U, U/Os, U/Eu, U/Th

R > 60,000, S/N ~ 500
at 4000 Å

# Estimated performance on TMT

## TMT - C-HROS

| Resolution | Seeing (90% encircled) | S/N | Limiting mAB in 6 hrs |
|---|---|---|---|
| 100,000 | 1.0 | 100 | 17.5 |
| 100,000 | 0.5 | 100 | 18.9 |
| 100,000 | 0.2 | 100 | 20.4 |
| 100,000 | 0.5 | 50 | 19.4 |
| 50,000 | 0.5 | 100 | 19.7 |
| 50,000 | 0.5 | 50 | 20.5 |
| 20,000 | 0.5 | 50 | 21.2 |
| 20,000 | 0.5 | 20 | 22.3 |

**Courtesy Cynthia Froning**

## Limiting distances for spectroscopic observations of point sources

| | Mv (mag) | HROS (Mpc) |
|---|---|---|
| Blue Supergiant | - 6.7 | 7.0 |
| Red Supergiant | - 5.9 | 3.5 |
| RGB Tip | - 2.7 | 0.5 |

Assumes 4 hr integrations at $\lambda/\delta\lambda = 50000$,

Corresponding central WL is 5000 A, Slit length: 5”, S/N = 100

(J Cohen)

***Thank you***