Best and Farthest Survey:

Searching for ultra metal-poor stars in the outermost halo

Jinmi Yoon
Department of Physics and JINA-CEE
University of Notre Dame, USA

A Celebration of CEMP & Gala of GALAH workshop

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Timothy Beers , Devin Whitten, Vinicius Placco, Sarah Dietz, Dmitrii Gudin, Kaitlin Rasmussen (Notre Dame), Y. S. Lee (Chungnam Nat'l Univ.) W. Aoki, T. Matsuno (NAOJ), A. Frebel (MIT) , A. Ji (Carnegie Obs.)

JINA-CEE
Center for the Evolution of the Elements

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Notre Dame Galactic Archeology Group

UNIVERSITY OF NOTRE DAME

Timothy Beers

Vinicius Placco

Jinmi Yoon

Sarah Dietz

Dmitrii Gudin

Erika Holmbeck

Kaitlin Rasmussen

Devin Whitten

Collaborators outside ND

Y. S. Lee (Chungnam Nat'l Univ.)
W. Aoki, T. Matsuno (NAOJ)
A. Frebel (MIT)
A. Ji (Carnegie Obs.)

Why are ultra metal-poor stars so important?

Metal-Poor Stars Statistics

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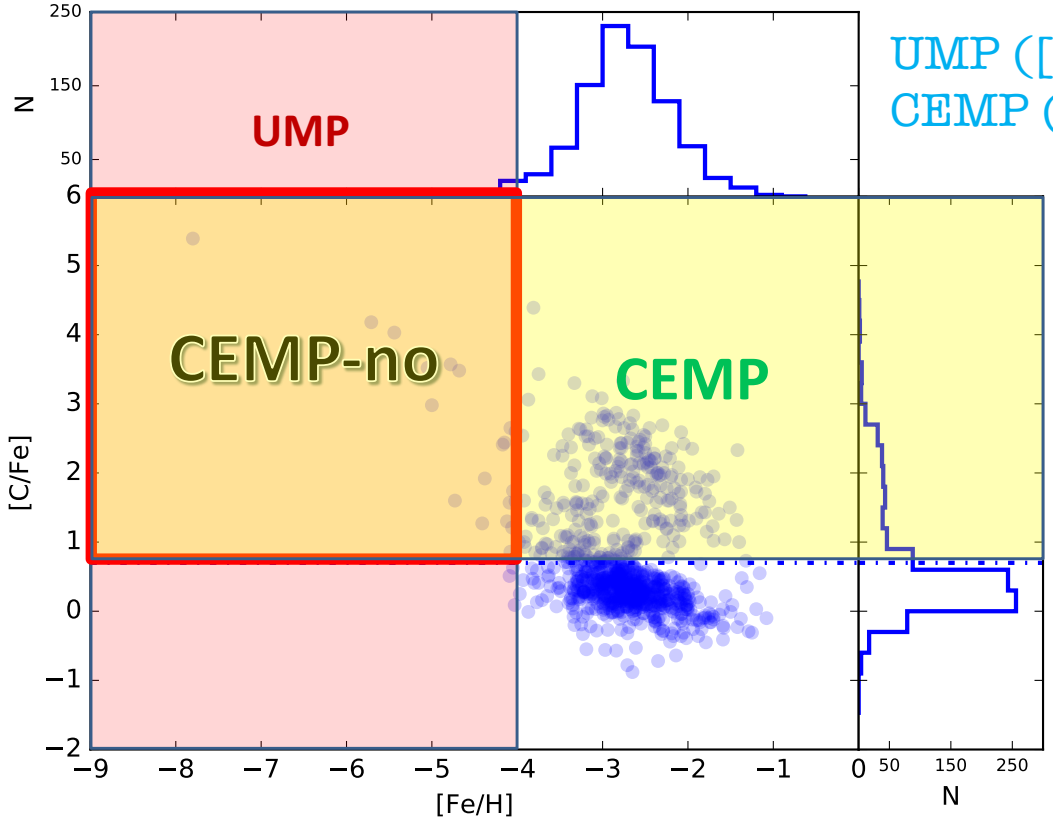

UMP ([Fe/H]<-4.0)
CEMP ([C/Fe]>=0.7)

UMP CEMP-no stars

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- Second-generation stars (e.g.,Cooke & Madau 2014, Frebel &Norris 2015, Hansen+2016a, Placco+2016, Yoon+2016, ...)

- Best Probes for:

UMP CEMP-no stars

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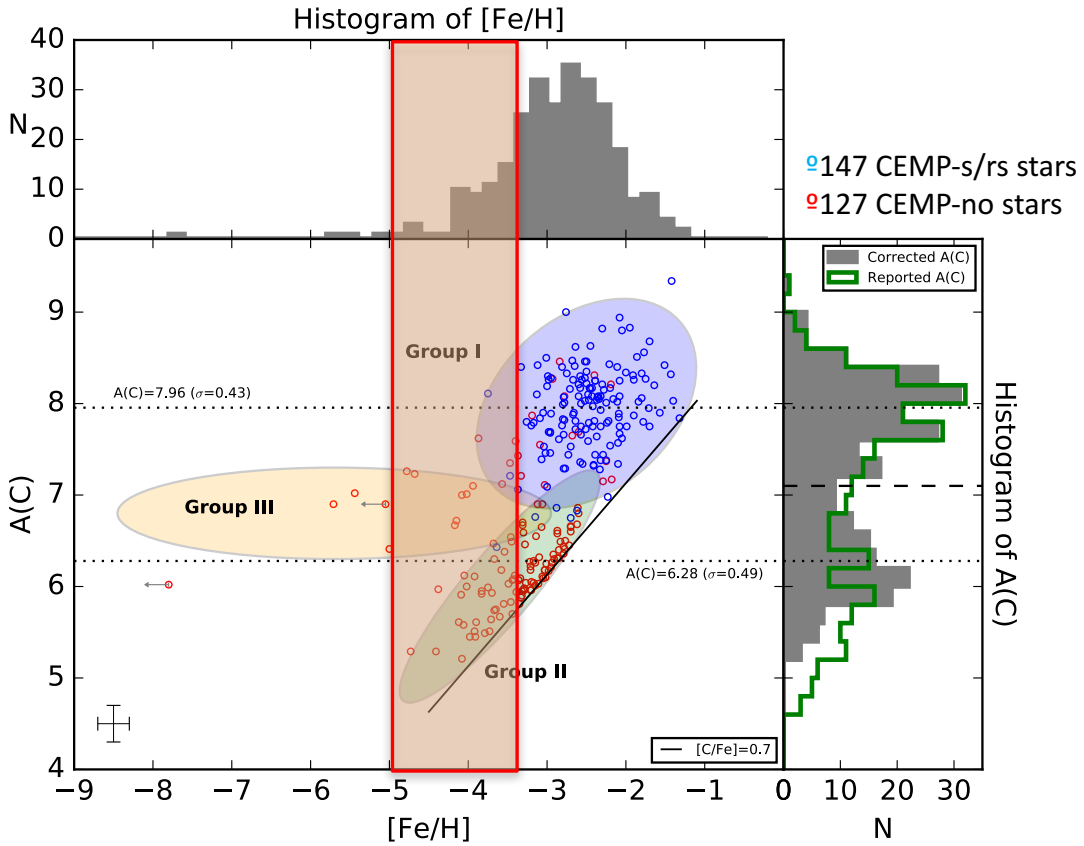
- Best Probes for:
  - ✓ First-star Nucleosynthesis (e.g., de Bennassuti+2014,2016, Salvadori+2016, Yoon+2016, Placco+2016)

Nucleosynthesis (Y-B diagram, Yoon+2016)



- Distinct 3 groups
  - ✓ Group I: CEMP-s
  - ✓ Group II : CEMP-no (A(C) dependence on [Fe/H])
  - ✓ Group III : CEMP-no (A(C) no relation on [Fe/H])
- Origin of 3 groups
  - ✓ Different progenitor masses
  - ✓ Different mixing process with ISM
  - ✓ Different SFH (external vs. internal pollution)
  - ✓ Dust cooling (Chiaki+2017)

UMP CEMP-no stars

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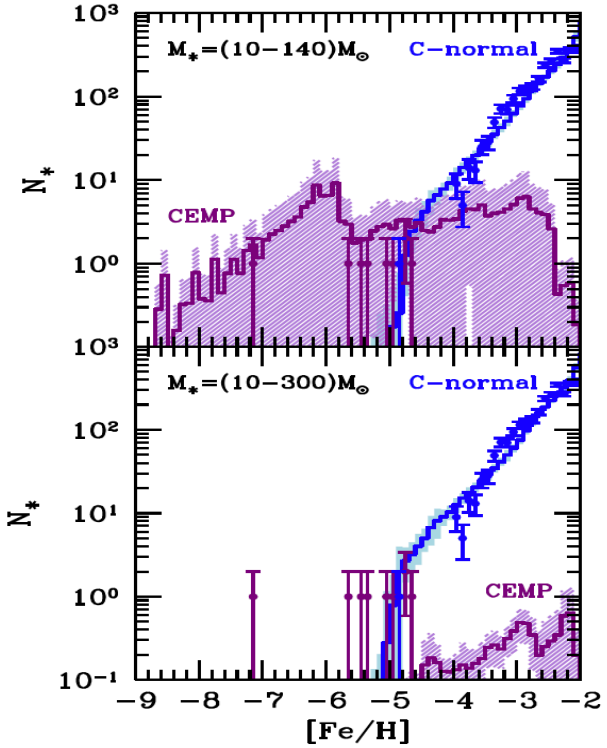
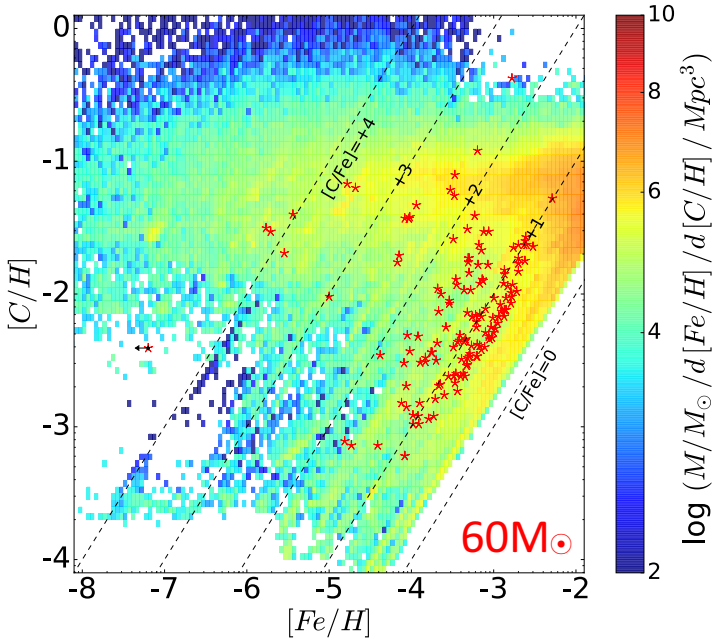
  - ✓ Constraints on First Initial Mass Function (Yoon+2016,Placco+2016)

Initial Mass Function



Salvadori+2016



Credit: Rick Sarmento

UMP CEMP-no stars

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- Second-generation stars (e.g.,Cooke & Madau 2014, Frebel &Norris 2015, Hansen+2016a, Placco+2016, Yoon+2016, ...)

- Best Probes for:
  - ✓ First-star Nucleosynthesis (e.g., de Bennassuti+2014,2016, Salvadori+2016, Yoon+2016, Placco+2016)
  - ✓ Constraints on First Initial Mass Function (Yoon+2016,Placco+2016)
  - ✓ Constraints on chemo-dynamical assembly history of the Galaxy

What is the challenge?

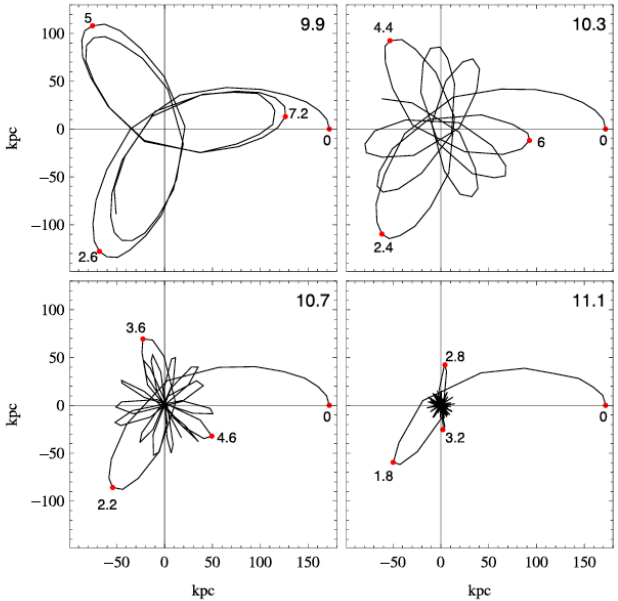
Lack of ultra metal-poor stars known

Where are they ?

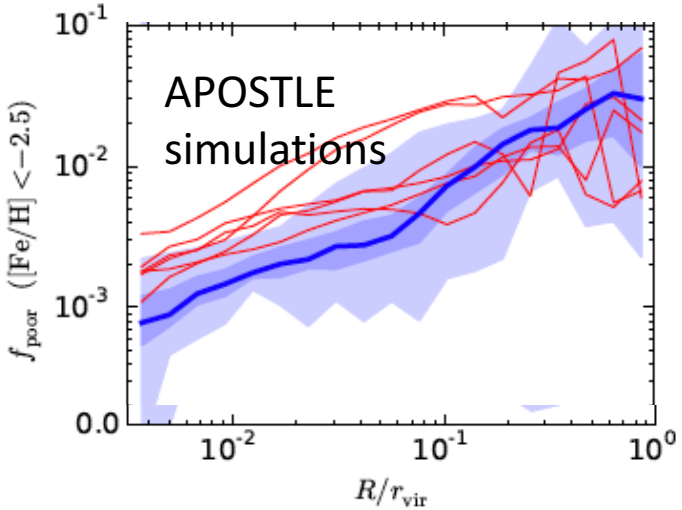
Breakthrough?!

Theoretical studies suggest UMP stars may be found predominantly in the outskirts of the Galaxy (Amorisco 2016, Starkenburg+2016) .

Amorisco 2016



Starkenburg+2016



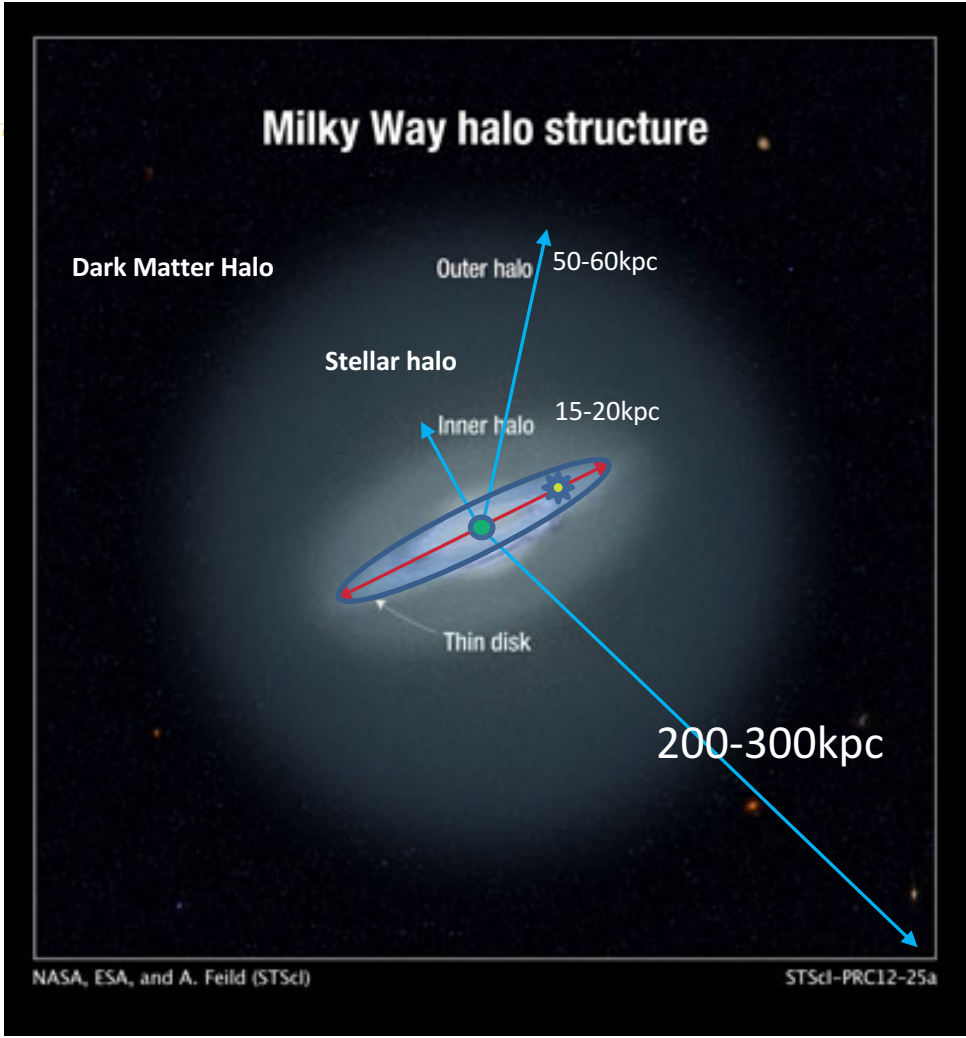
Previous surveys

- HK Survey (Beers et al.) d < 15 kpc
- HES Survey (Christlieb et al.) d < 25 kpc

→ only ~25 UMP stars found over the past quarter century

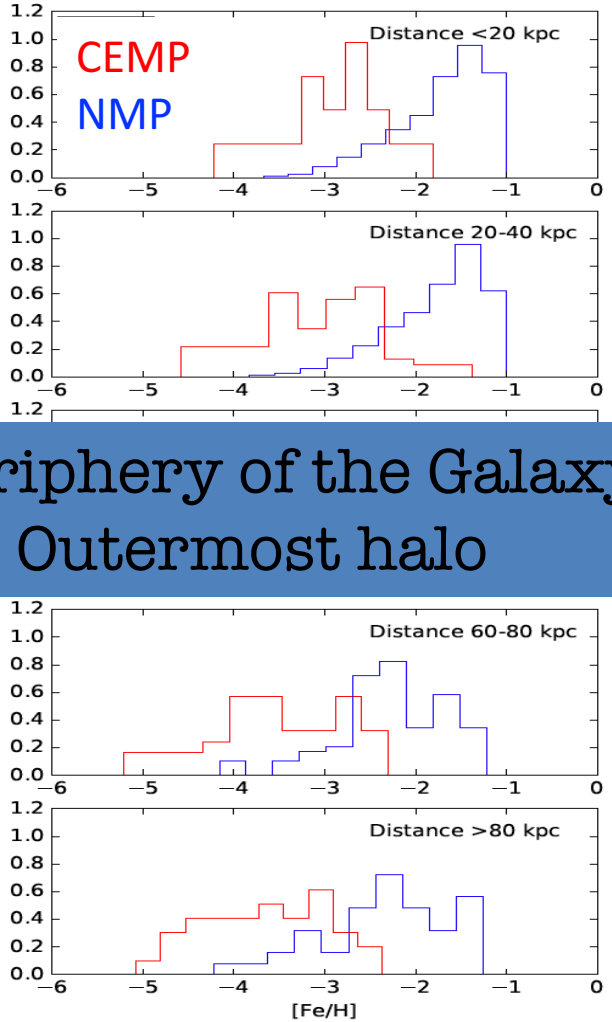
Slow discovery process of UMP stars!!!

Update: look at Miji's poster !



Evidences in Literature samples

- Based on SSPP + n-SSPP pipeline parameters for
- CEMP stars (Green 2013) ~ 230 stars
- Normal MP stars (Janesh+2014) ~ 5,500 stars



We should look at the periphery of the Galaxy.
(beyond 30 kpc) → Outermost halo

Best and Farthest Survey

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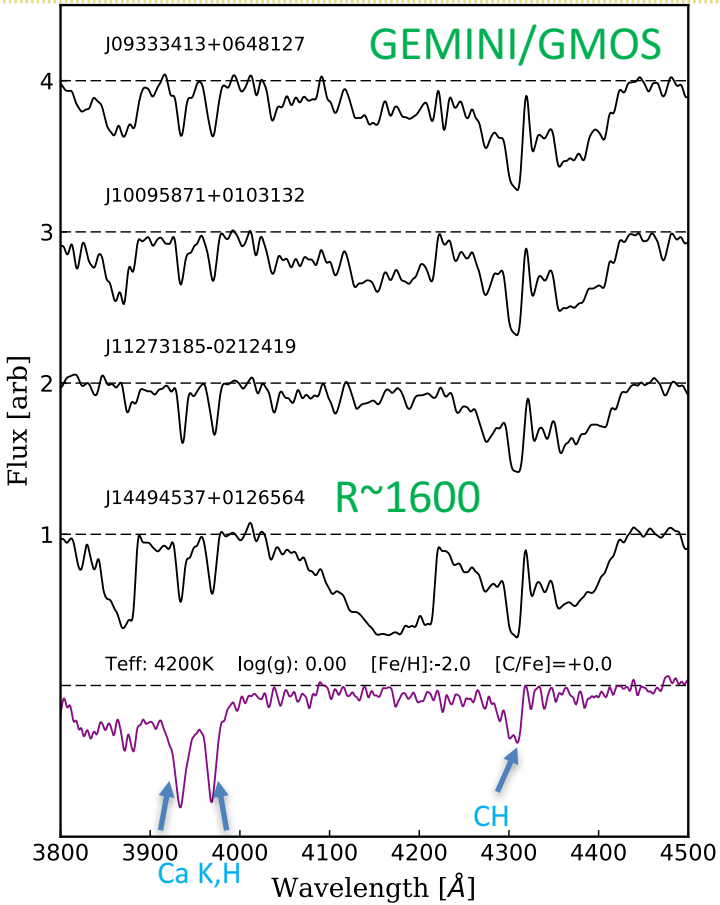
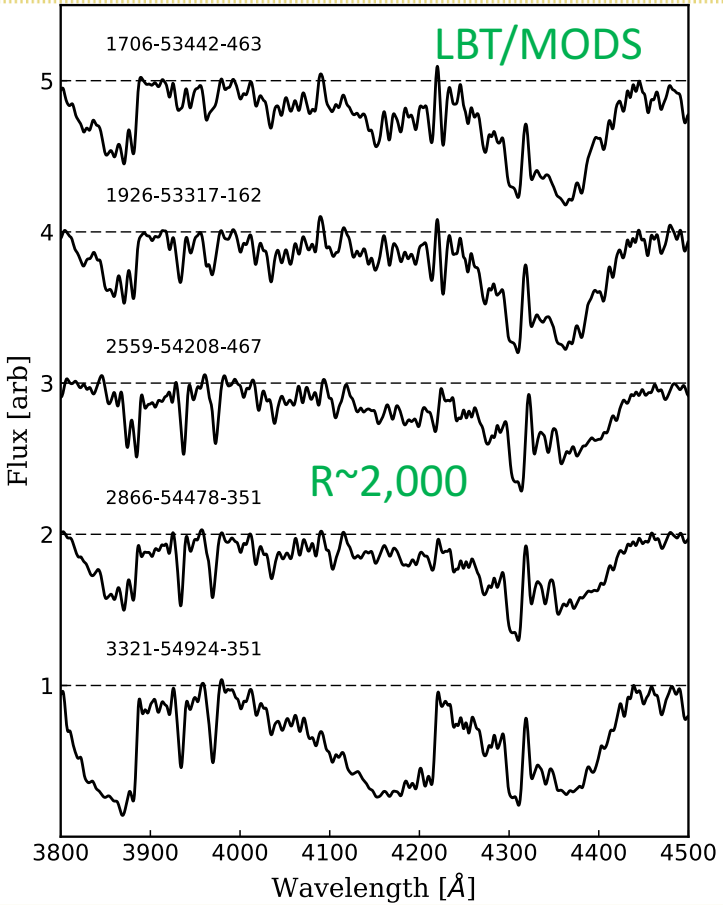
- Created initial candidates
  - Visually inspected spectra of faint CEMP with weak Ca II lines and high proper motions (Green 2013 sample)
  - Rebinned spectra to increase SNR
  - Ran n-SSPP pipeline
- Follow-Up Observation
  - Med-resolution spectroscopic follow-up (SNR ~60-100 at 4000A)
    - ✓ Large Binocular Telescope MODS spectrographs → (5/9) stars
    - ✓ Gemini-S GMOS spectrographs → (4/8) stars

Best and Farthest Survey

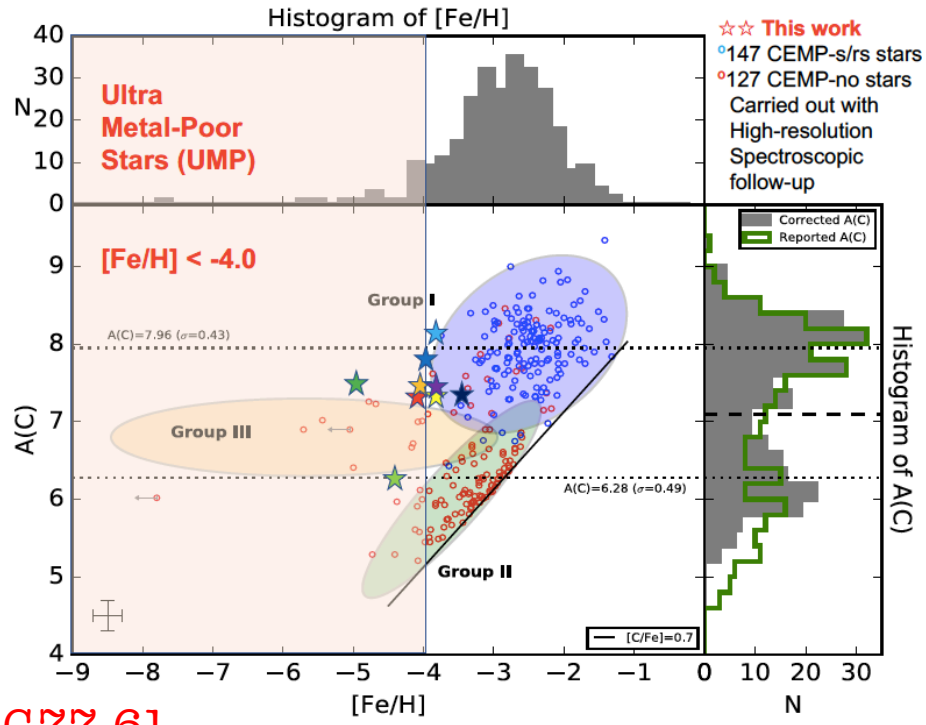




Preliminary Stellar Parameters

	PID-MJD-FIBER	T_{eff} (K)	log g (cm/s^2)	[Fe/H]	[C/Fe]	A(C)[a]	Subclass[b]
★	0502-51957-216	4870	4.8	-4.03	2.84	7.24	Group III
★	0538-52029-310	4086	0.0	-4.00	2.78	7.21 (7.55)	Group III
★	1196-52733-126	4450	5.0	-3.82	2.66	7.27	Group III
★	1706-53442-463	3872	4.0	-4.50	2.80	6.23	Group II/III
★	1926-53317-162	4400	5.1	-5.00	4.14	7.57	Group III
★	2559-54208-467	4836	1.4	-3.82	3.41	8.02 (8.15)	Group I/III
★	2866-54478-351	4984	5.0	-4.02	3.37	7.78	Group I/III
★	3233-54891-206	4880	5.0	-3.59	2.48	7.32	Group I/III
★	3321-54924-351	4128	0.1	-3.80	2.56	7.19 (7.53)	Group III

Yoon-Beers Diagram



✓ Canonical Dwarf CEMP-no stars, eg. G77-61

High-resolution follow-up

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- SDSS J 1449 :
  - Subaru and Magellan
  - Preliminary : [Fe/H]~ -3.5,
    A(C)~ 6.23, A(Ba) ~ 0.68
    [Ba/Fe] ~2.0
  - Huxar & Grebel (2015) : Long period variable in a binary, late R type AGB
  - Aoki+2017 –an EMP post AGB star
- SDSS J 1414 :
  - Subaru (very low quality)
  - Preliminary : [Fe/H] ~ -3.8,
    A(C) ~ 6.33, A(Ba) ~ 0.58
    [Ba/Fe] ~ 2.2
  - Dwarf carbon star with strong Ba
  - Spinstar origin?

Prospect and Future Work

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- ✓ High-resolution spectroscopic follow-up ongoing
- ✓ Increase the number of faint UMP candidates by observing fainter targets (V > 18-19) via Gemini and LBT (8 more stars observed as of today)
- ✓ 30-meter Telescopes :
  - ❖ High-res. spec. follow-up will provide a critical breakthrough to our understanding of first-star nucleosynthesis and constrain the FIMF
- ✓ Gaia DR2 :
  - ❖ Confirm the luminosity status using geometrical distance estimates
  - ❖ Confirm numerous UMPs in the outermost Galactic halo
  - ❖ Advance our understanding of its assembly history using distances and proper motions

Conclusion

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- ✓ BEST: UMP CEMP-no stars are the stellar fossils of the first-generation stars
  - First-star Nucleosynthesis
  - First-star Initial Mass Function (FIMF)
  - Galactic Chemodynamical Assembly of the Milky Way
- ✓ However, only ~25 UMP stars were discovered in the past 25 years.
- ✓ FARTHEST: We started a survey to search for numerous UMP stars in the outskirts of the Galactic halo!
- ✓ Thank You!!!!