Origin of CEMP-no morphology in the Milky Way halo

(A holistic approach)

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Collaboration with
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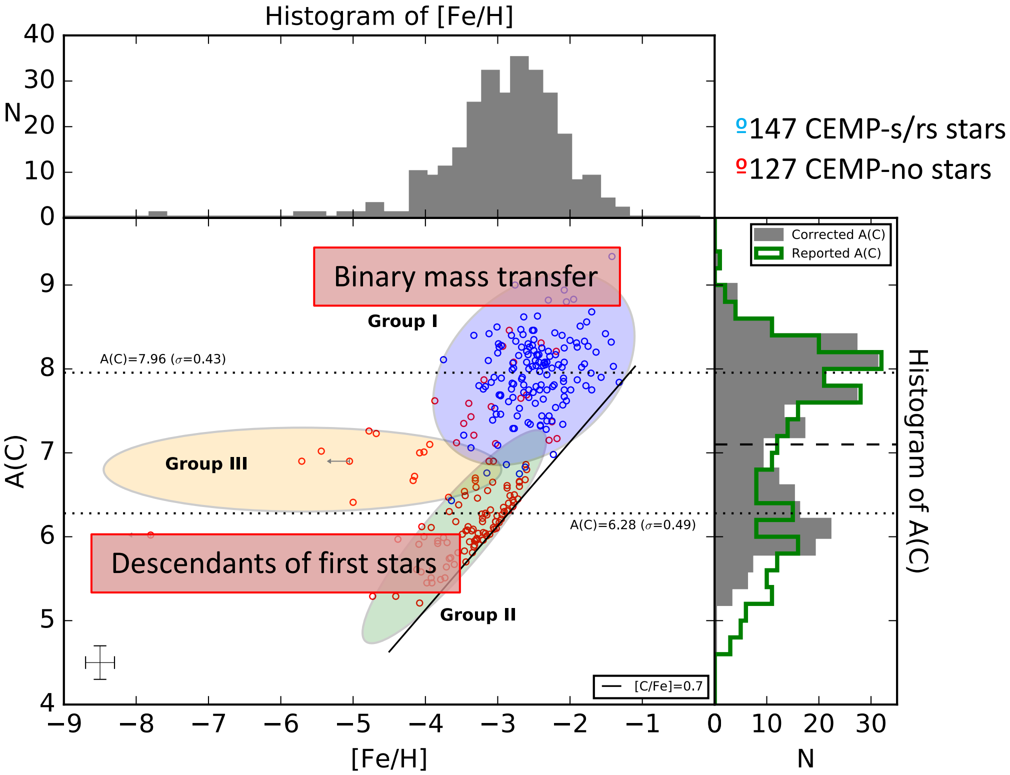
Nucleosynthetic origin of CEMP-no Stars

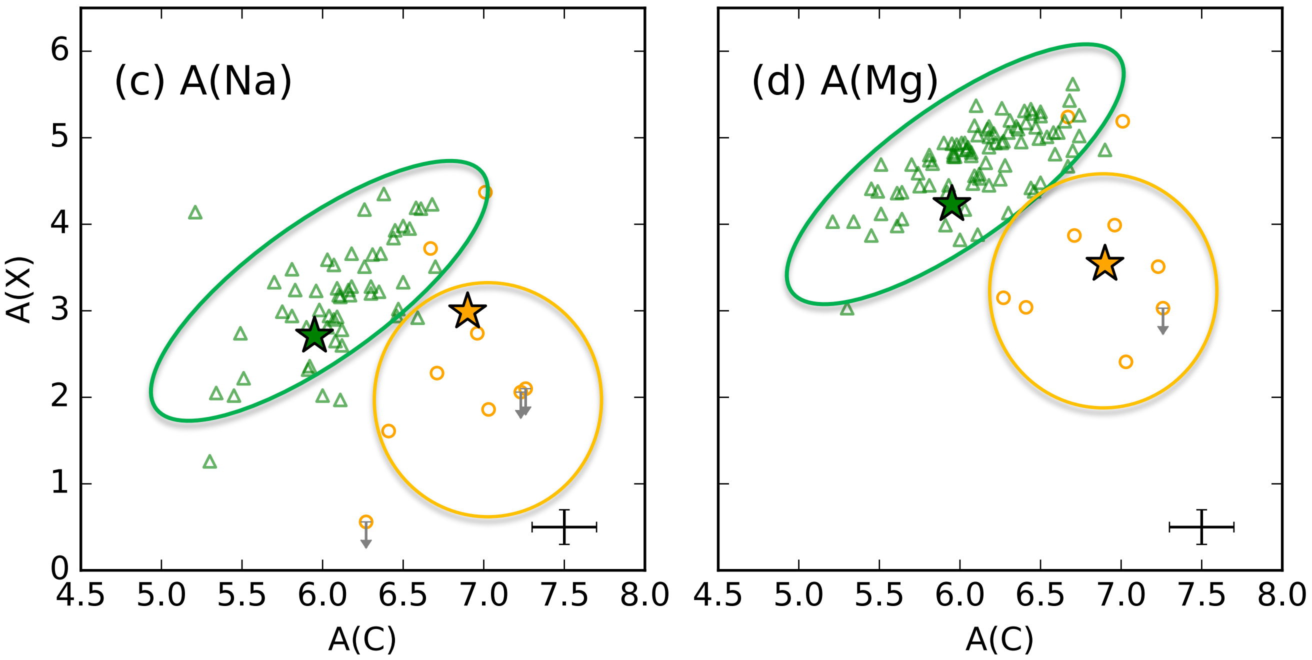
Halo CEMP Morphology –A(C)-[Fe/H]



Yoon et al. 2016, ApJ 833,20

- **Distinct 3 CEMP groups**
  - Group I: CEMP-s (majority)
    CEMP-no (~13%)
  - Group II : CEMP-no
    strong correlation of A(C) -[Fe/H]
  - Group III : CEMP-no
    no correlation of A(C) -[Fe/H]

Halo CEMP Morphology –A(Na, Mg)-[Fe/H]



△ Group II CEMP-no
★ BD+44 493

○ Group III CEMP-no
★ HE 1327-2326

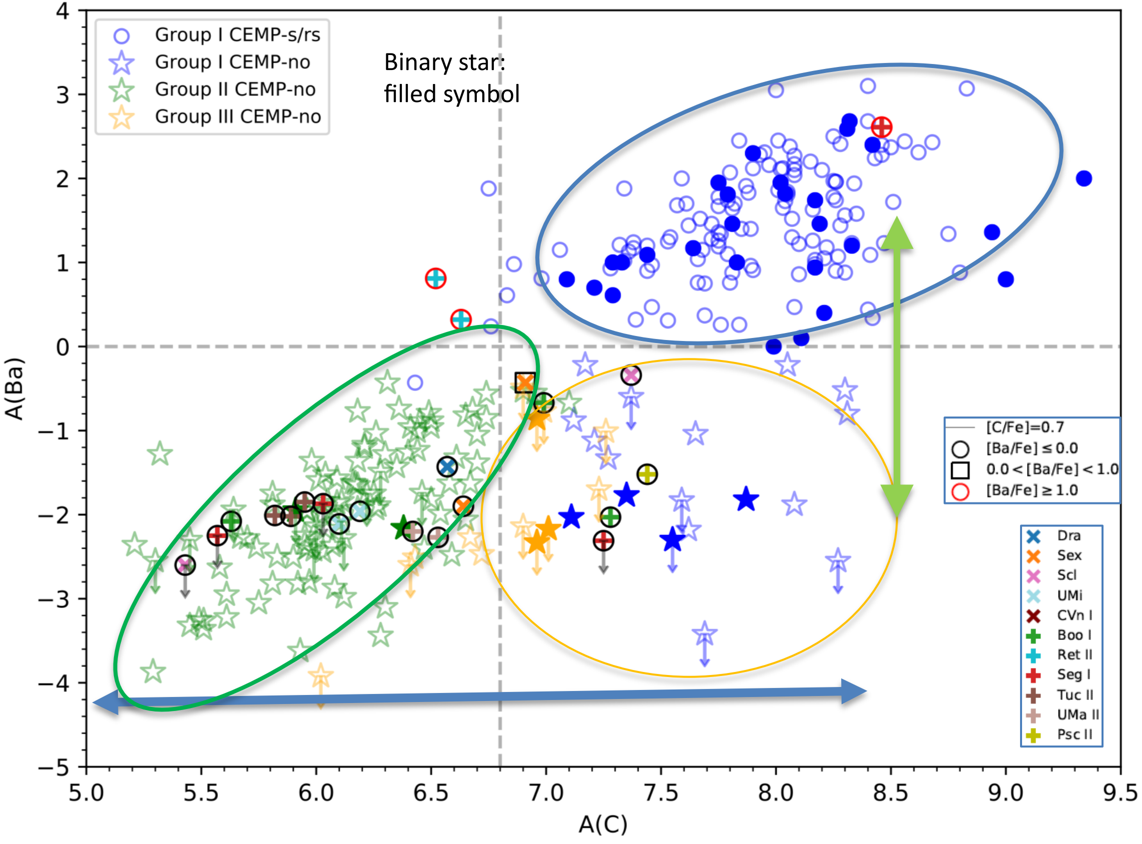
Yoon, Beers, Placco et al. 2016, ApJ 833,20

Origin of Group I CEMP-no

- GI CEMP-no and G III have a higher binary fraction than G2 → mass transfer?
- But G I CEMP-no and G III CEMP-no have similar A(Ba) and lower Ba (>~4 dex) from G I CEMP-s

→ Perhaps different nucleosynthetic origin from the rest of CEMP-no stars

→ **multiple Faint SNe or spinstars contribution – favorable ?**



Yoon, Beers, Tian, & Whitten (2019)

Host galactic environments of CEMP-no Stars (Accretion origin)

Another Perspective

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A(X), [X/H]

X : nucleosynthesis
H : Galactic formation /star formation/metal-mixing

Reflecting the dilution of stellar yields due to mixing with pristine interstellar medium
(Galactic/natal environments)

CEMP groups of the dwarf galaxies

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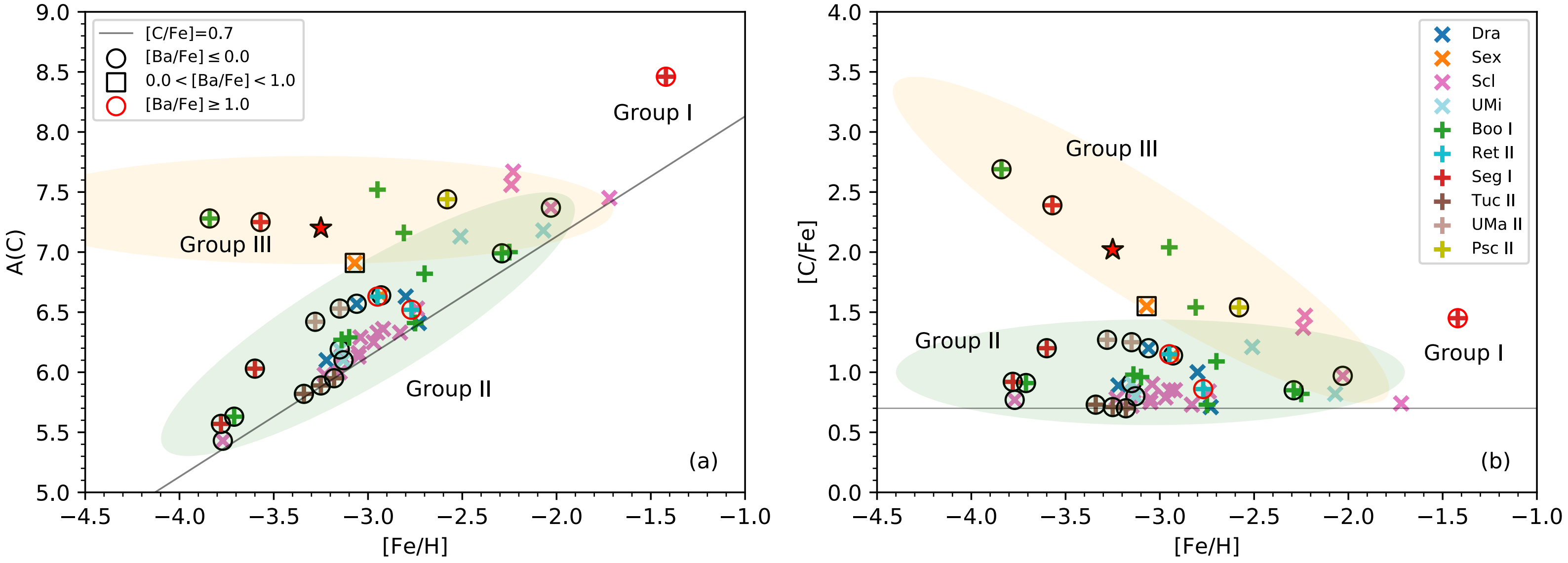
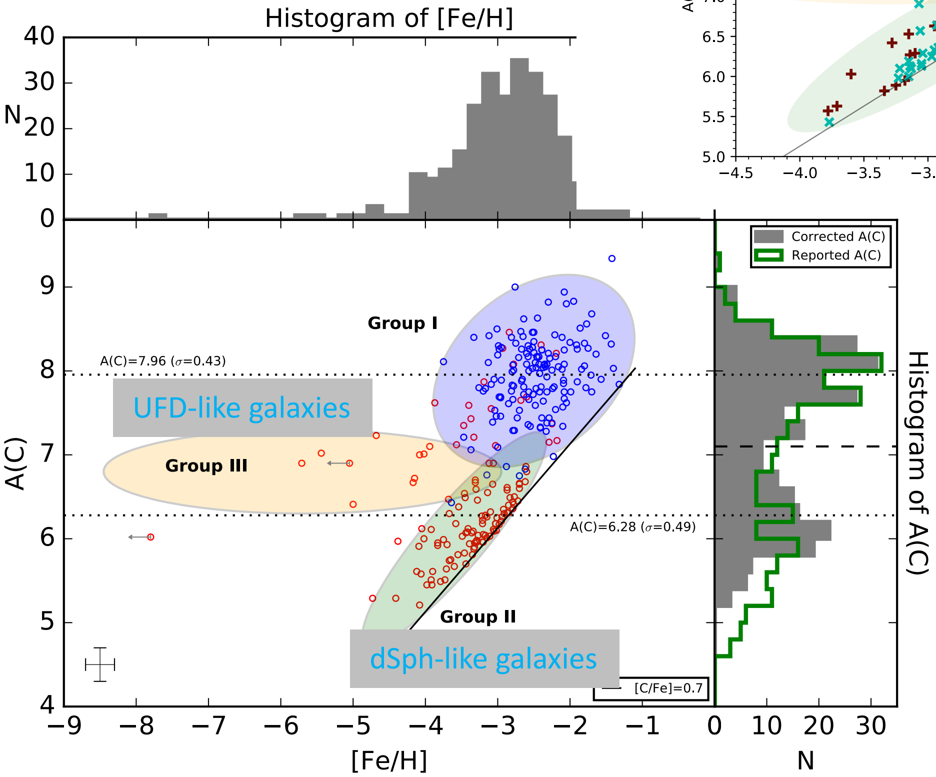
★ SDSS 1327+3335, CVn I Group III CEMP star (Yoon, Whitten, Beers, Placco, & Lee, 2019, ApJ submitted)



Data: cohen+2010,frebel+2010,tafelmeyer+2010,honda+2011, lai+2011,shetrone+2013, frebel+2014,Kirby+2015,skuladottir+2015, lardo+2016, ji+2016d,chiti+2018a,chiti+2018b, spite+2018

Yoon, Beers, Tian, & Whitten (2019)

Accretion origin



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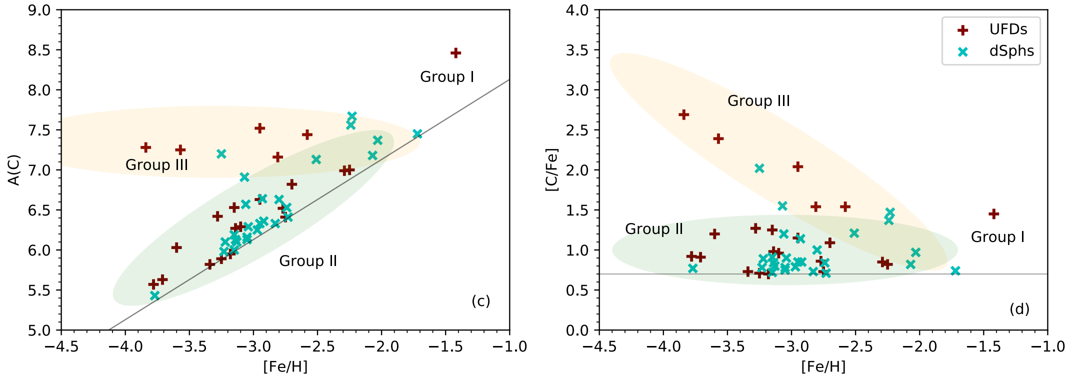


- **Distinct 3 CEMP groups**
  - Group II : CEMP-no

    strong correlation of A(C) -[Fe/H]

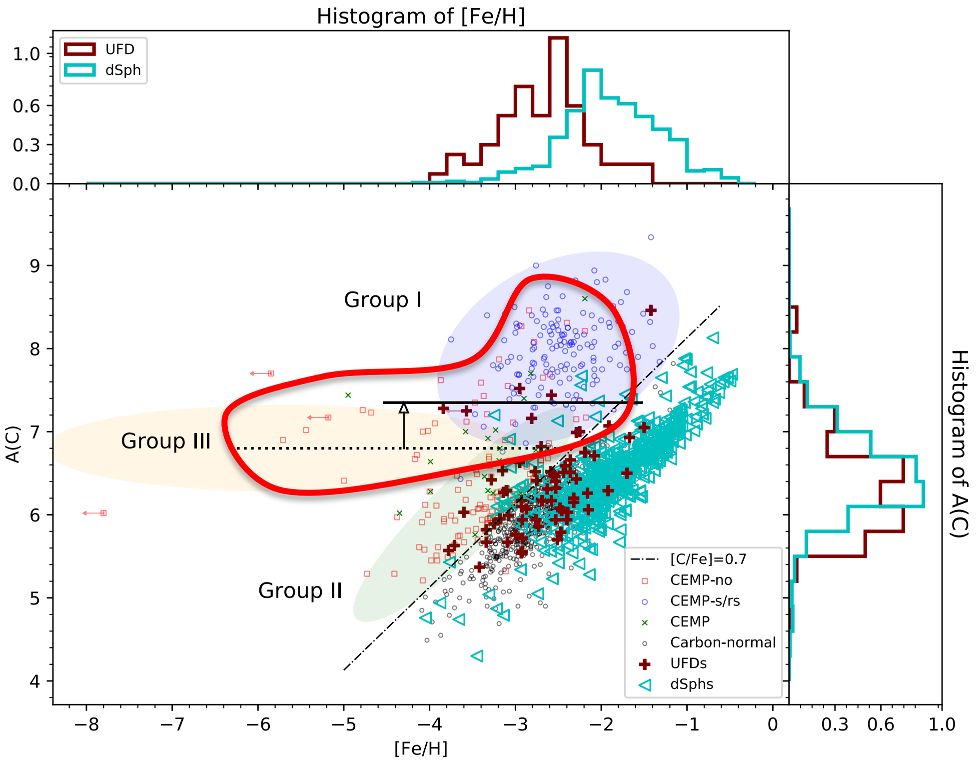
    → Formed in more massive dwarf galaxies (classical dSph-like glaxies)
  - Group III : CEMP-no

    no correlation of A(C) -[Fe/H]

    → Formed in least massive dwarf galaxies (ultra-faint dwarf (UFD)-like galaxies)
  - Group I: CEMP-s (majority)

    CEMP-no (~13%)

Accretion origin



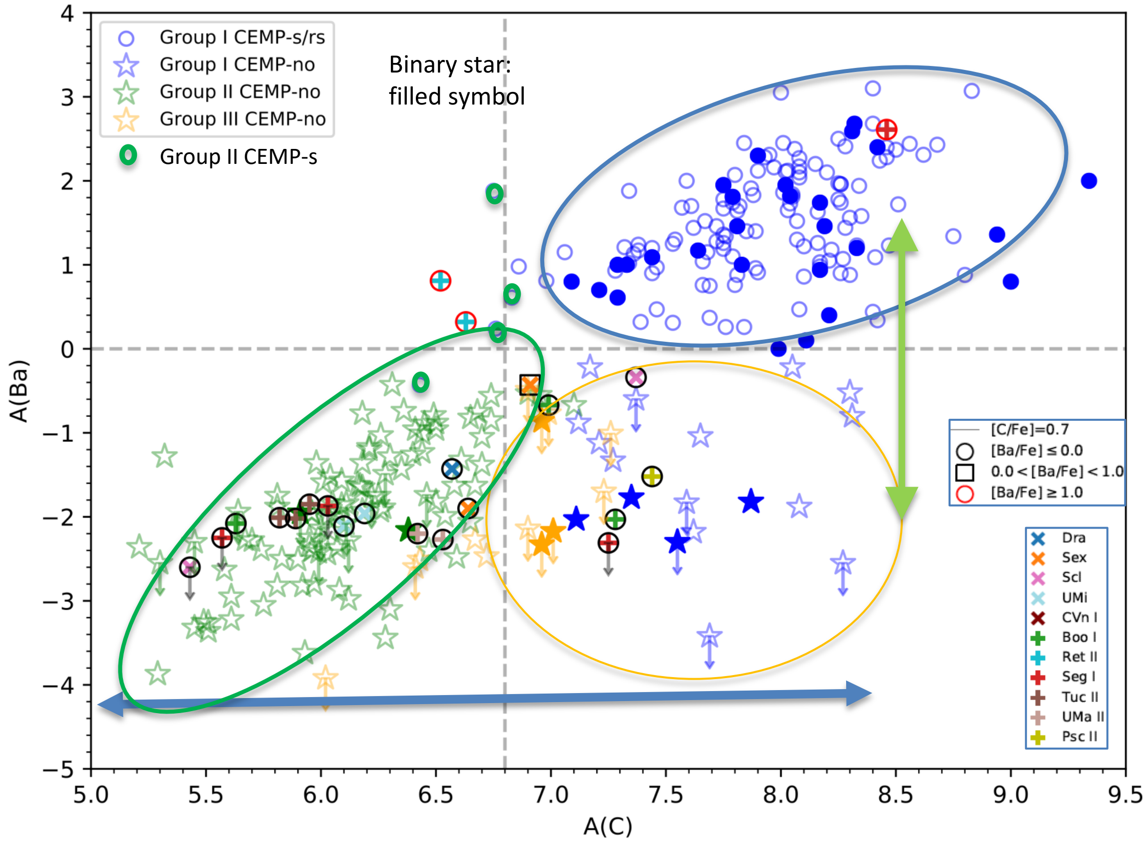
- ## Distinct 3 CEMP groups
  - Group I: CEMP-s (majority)
    CEMP-no (~13%)

Based on the morphological Connection between the halo CEMP-no Group I and 3 and dwarf galaxy Group3,

Halo Group I **CEMP-no** stars could have the same origin with the Group III **CEMP-no** stars

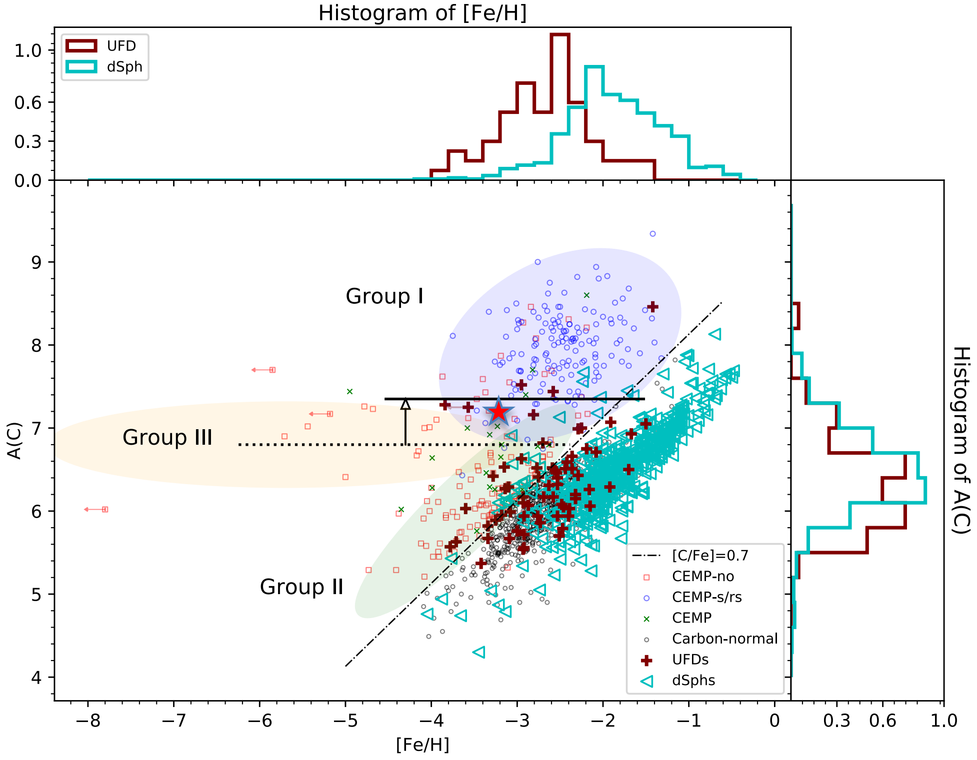
Yoon, Beers, Tian, & Whitten (2019)

Origin of Group I CEMP-no



Yoon, Beers, Tian, & Whitten (2019)

CEMP Fractions



	UFDs	dSphs
<[Fe/H]>	-2.69	-1.88
<A(C)>	6.33	6.49
CEMP frequency	~28%	~3%

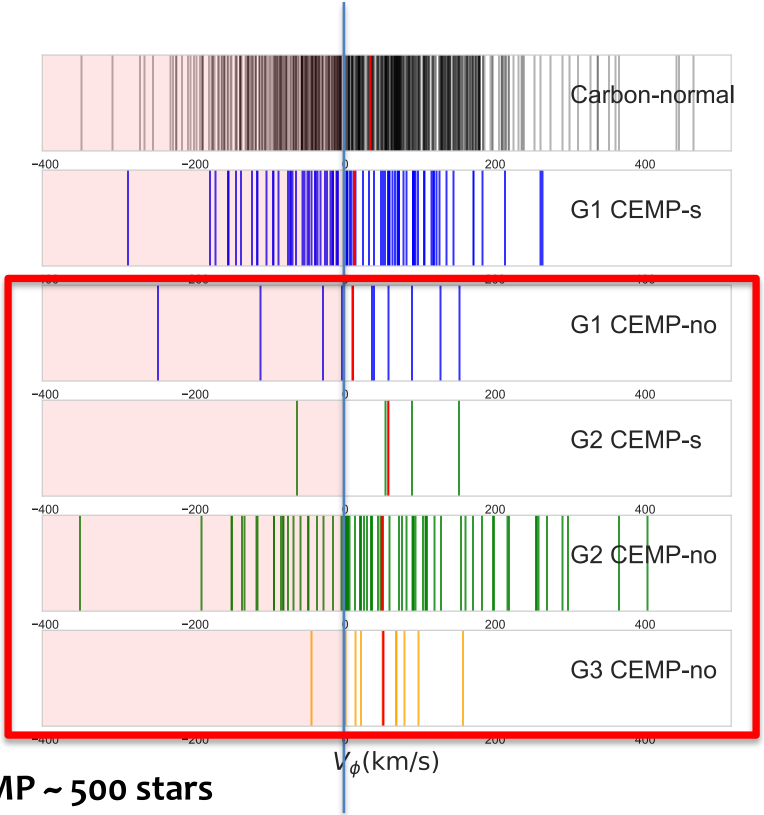
See e.g., Salvadori+15

Data: literature data, SAGA database

Yoon, Beers, Whitten, & Tian(2019)

Kinematic origin of CEMP Stars

Kinematical Analyses



NMP ~ 500 stars
CEMP ~ 180 stars

V_ϕ =0

- Higher fraction of **prograde** stars among **CEMP-no stars (G1, G2 and G3)**
- **G3** + **G1 CEMP-no** stars share **similar** $\mathbf{V_\phi}$ range → **Similar** kinematic origin
- **G 3** +**G 1** CEMP-no may have **different origin** from the most of **G2 CEMP-no** stars

Kinematical Analyses

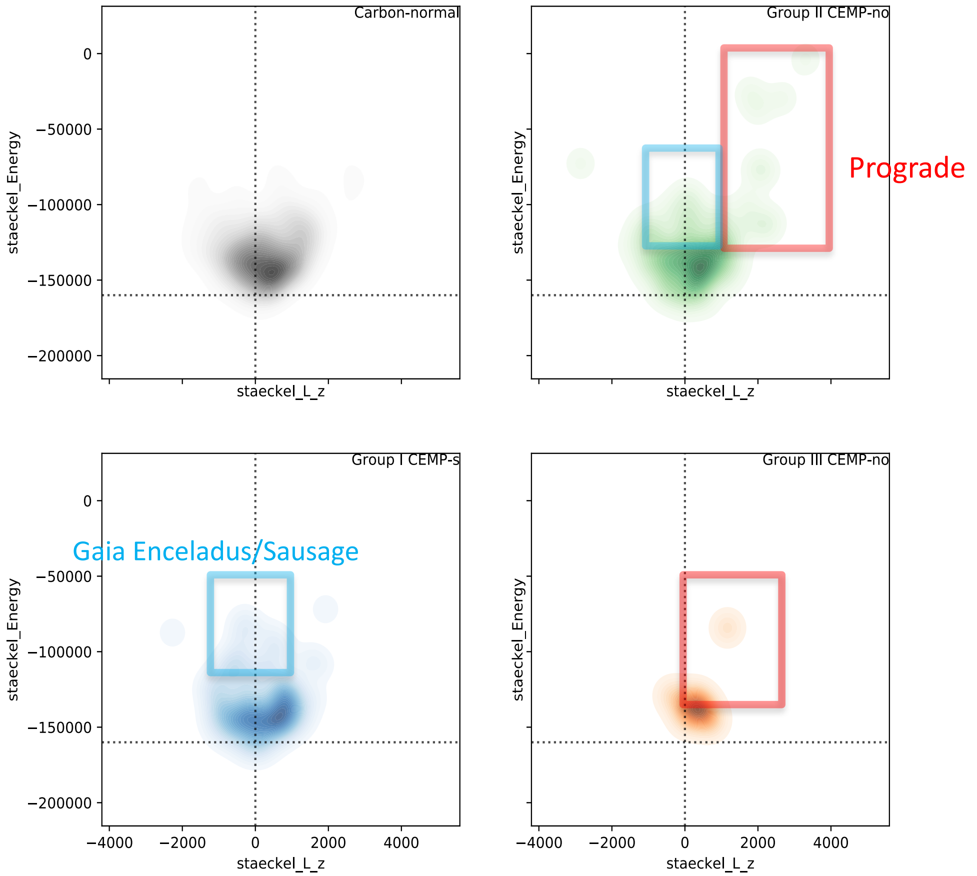
- **CEMP-s** stars and some of the **G2 CEMP-no** stars have the plume feature

  → **Gaia Enceladus/Sausage event.**

- Also there are stars with **prograde** motion among G2 CEMP-no and G3 → **minor accretion**

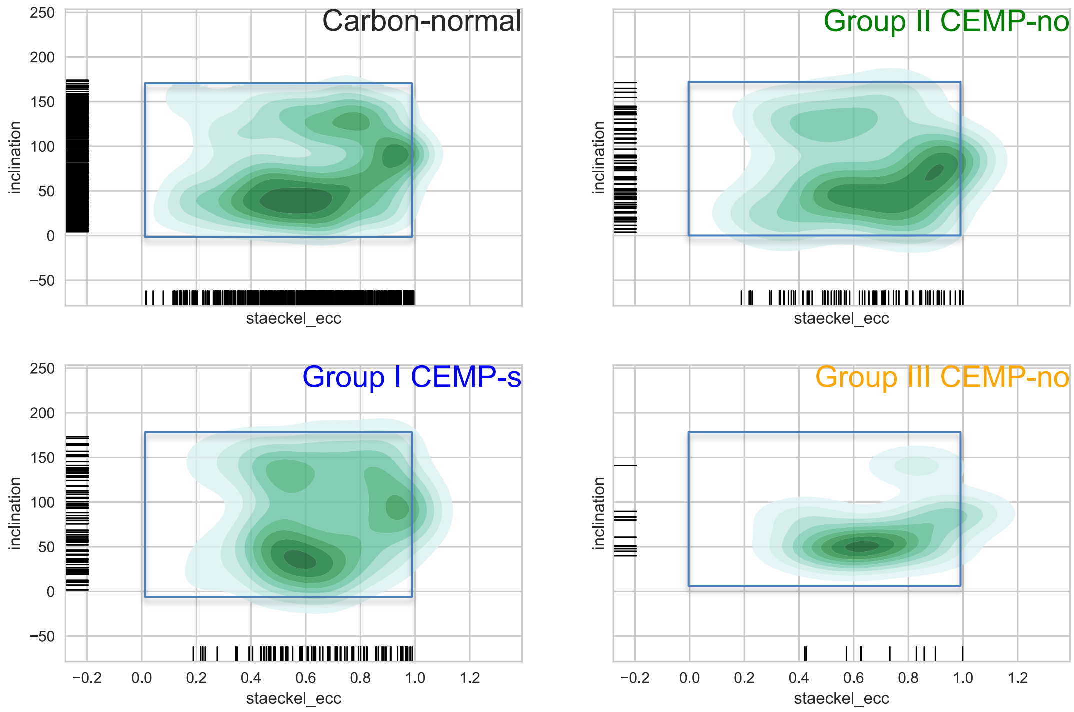
NMP ~ 500 stars

CEMP ~ 180 stars



Inclination angle vs. Eccentricity

0 = prograde in-plane, 90 = polar orbit, 180 =retrograde in-plane



- **G3 CEMP-no** is different from the rest of them
- **Three** (/w **Polar ~ another_merger?**) different preferred **orbits** among others
- **Carbon-normal (NMP)** share some orbits with **G2 CEMP-no**, however, **G 2** has more stars **close to polar orbit**
- **Retrograde NMP** have very **eccentric** orbit, while **G2 retrograde** stars rather **low eccentricity.**
- **G2 CEMP-no retrograde** share the same region of **CEMP-s retrograde**

Future Work

- Detailed abundance analysis of G I CEMP-no and **Carbon-normal** stars
- Theoretical modeling needed to explain the origin of G I/G3 CEMP-no
- Look for signature of binary mass transfer
- More CEMP stars from the dwarf galaxies
- Further understanding of kinematical analysis (is there clear separation among carbon-normal if G 2 does not exist?)
- CEMP stellar pipeline for very cool stars

Summary

CEMP-no morphology

- **multiple** nucleosynthetic pathways for **CEMP-no stars**
- **star forming and galactic environment**
- possible **accretion origin**
- **Mass of host galaxies** is important for **CEMP formation/fraction.**
- Kinematic origin -- each class of stars have **complex accretion** history
  - **CEMP-no** stars have preferentially **prograde motion.**
  - A substantial fraction of CEMP-no stars have **polar orbits** → indicates **another merger** event?

- **Thank you!**

Impact of masses of galactic environment

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Table 1. Characteristics of Group II and Group III CEMP-no Stars

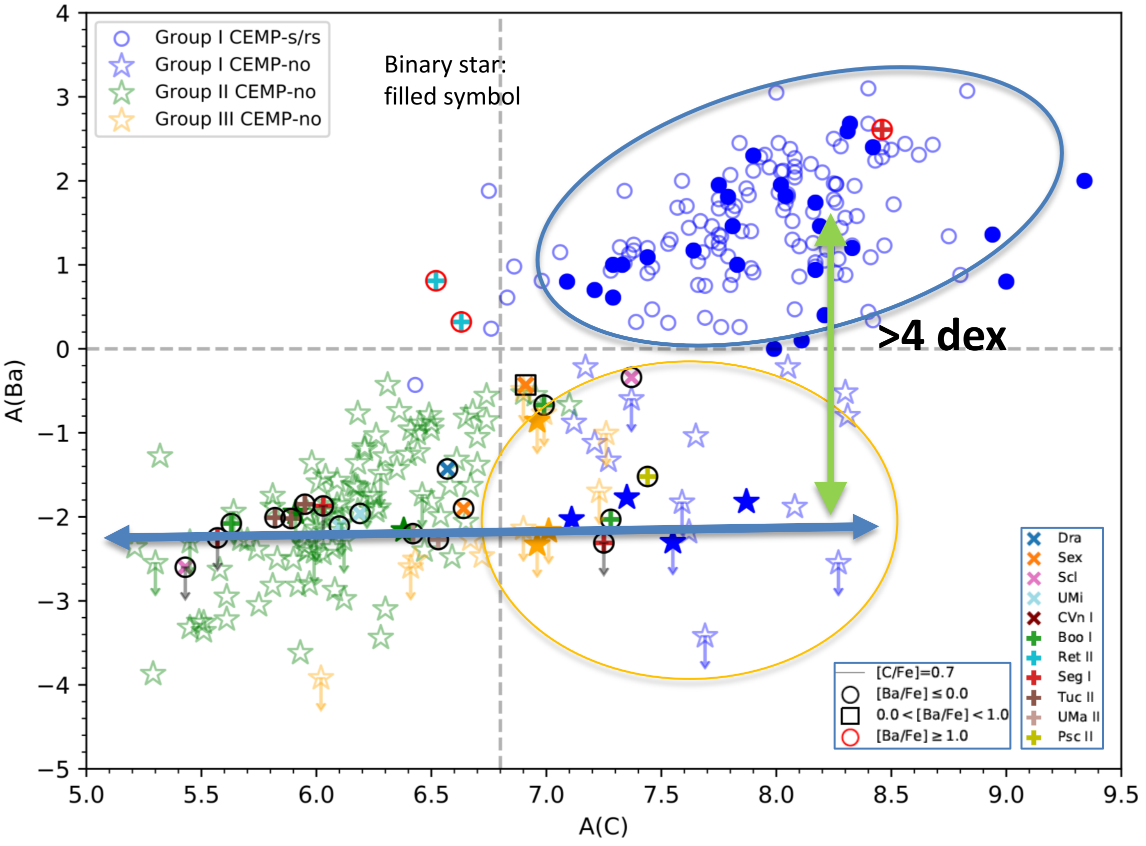
Characteristic	Group II	Group III	References
	Chemical signatures		
A(C)-[Fe/H] correlation	yes	no & higher A(C)	(1), (2)
A(C)-A(Na, Mg) correlation	yes	no & lower A(Na,Mg)	(1)
A(C)-A(Ba) correlation	yes	no & lower A(Ba)	(2)
	Galactic environment		
Galaxy type	dSphs (& UFDs)	UFDs	(2)
Galaxy total mass	$\sim 10^9 M_\odot$	$\sim 10^6 M_\odot$	(3), (4), (5), (6)
Star-formation history	prolonged (chemically evolved)	truncated (stoschastic, inhomogeneous)	(6), (7)
	Star-forming environment		
Progenitor SN	normal CCSNe	faint SNe	(8)
Gas cooling agents	silicate grains	carbon grains	(8)
Dominant Pop. contribution	Pop. II	Pop. III	(9), (10), (11)
Number of progenitors	multiple (multi-enrichment)	single (mono-enrichment)	(12)
Natal-gas enrichment	internal pollution (self-enrichment)	external & internal pollution	(13), (14), **(15)**

NOTE—Some of the characteristics are drawn from inferences based on the results from the listed references; only the dominant source is emphasized in the table. References: (1) Yoon et al. (2016), (2) this work, (3) Mateo (1998), (4) Walker et al. (2009), (5) McConnachie (2012), (6) Simon (2019), (7) Tolstoy et al. (2009), (8) Chiaki et al. (2017), (9) de Bennassuti et al. (2017), (10) Sarmento et al. (2017), (11) Sarmento et al. (2019), (12) Hartwig et al. (2018), (13) Smith et al. (2015), (14) Chiaki et al. (2018), **(15) Chiaki & Wise (2019).**

Yoon, Beers, Tian, & Whitten (2019)

Origin of ubiquitous Ba abundance

- **r-process** production events via NSM, collapsar, magneto-driven supernovae
- **weak-s process** in rapidly rotating massive stars
- **Existence of AGB stars with [Fe/H]<-3.0** that produce little if any s-process elements. → r-process might not be the only producers for Ba
- Require theoretical understanding of this phenomenon

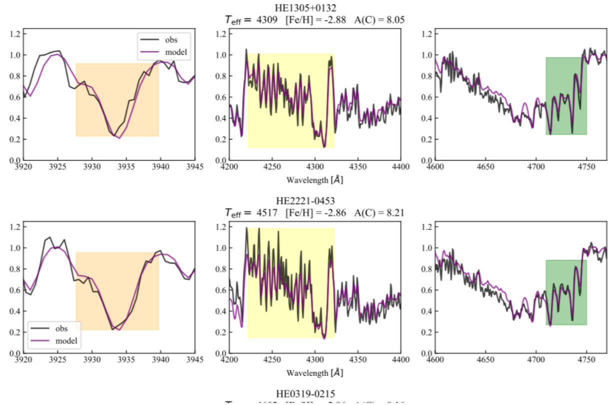


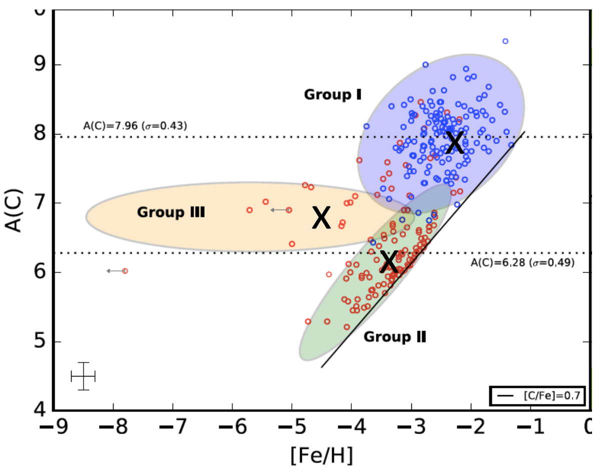
Yoon, Beers, Tian, & Whitten (2019)

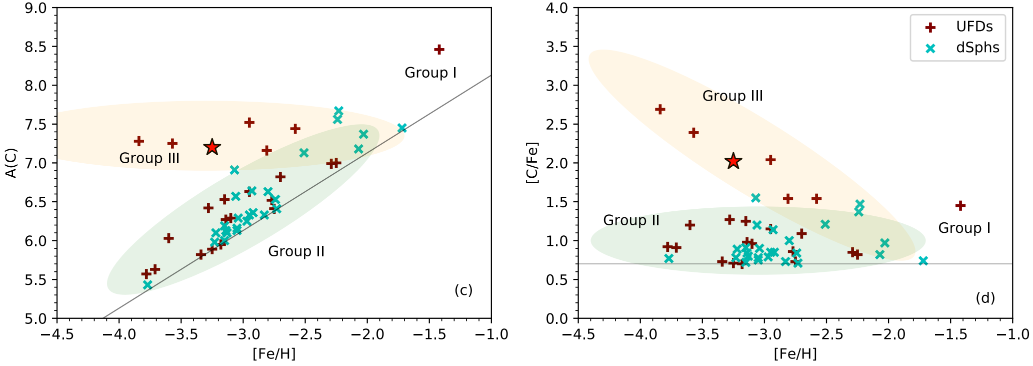
Archetypal fitting to CEMP groups

3 archetypes of parameters representing CEMP groups.

Devin Whitten







Yoon, Whitten, Beers, Lee, & Placco, 2019, ApJ, submitted