CHEMICAL ABUNDANCES OF INDIVIDUAL STARS FROM SIMULATED DWARF GALAXIES

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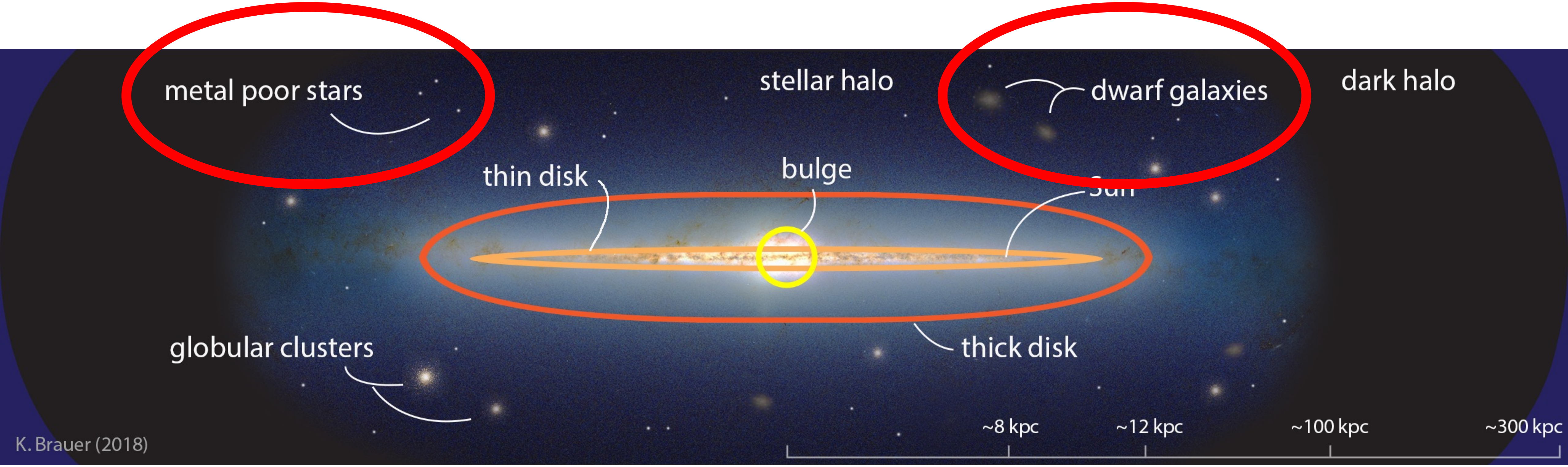
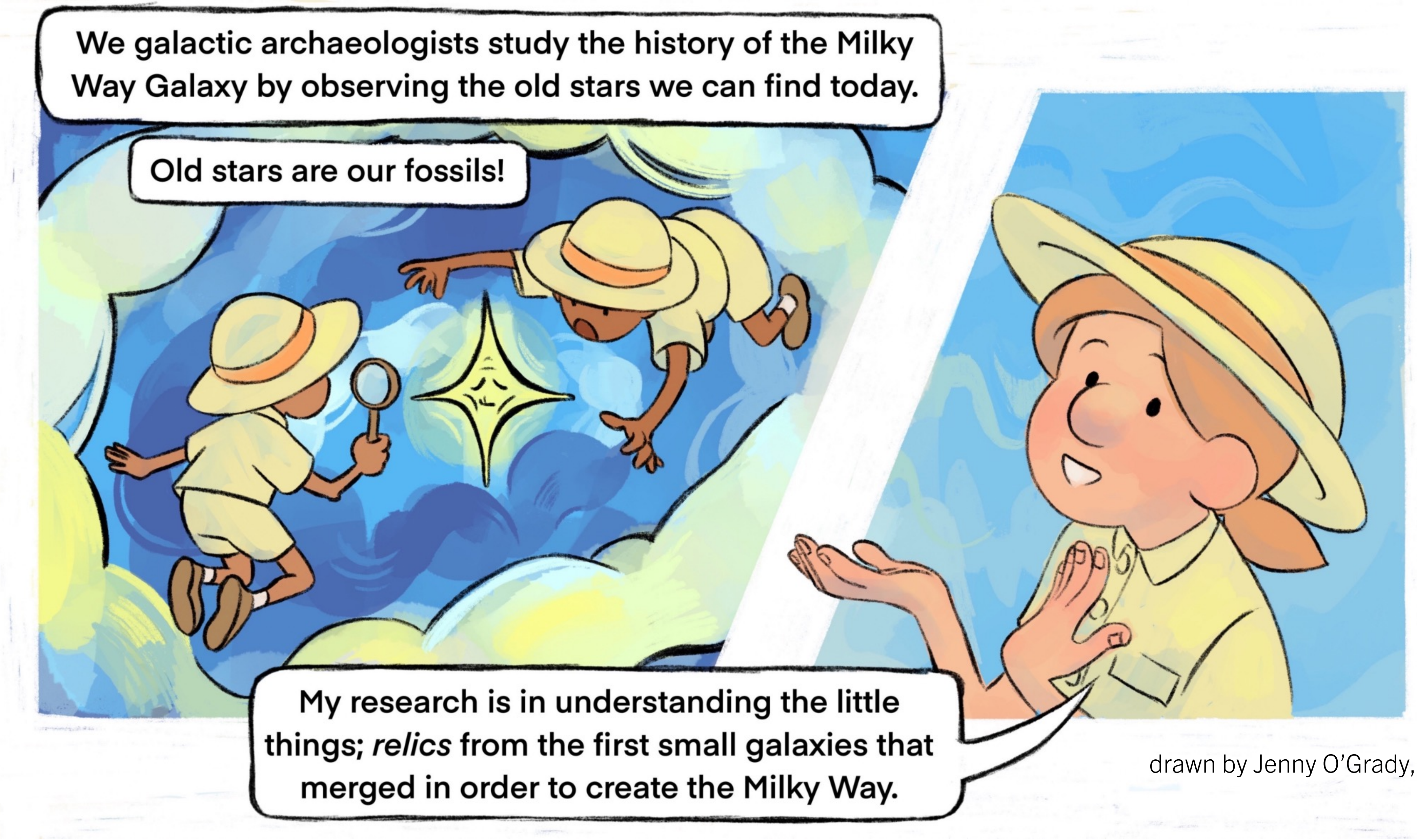
HARVARD & SMITHSONIAN

THE MILKY WAY



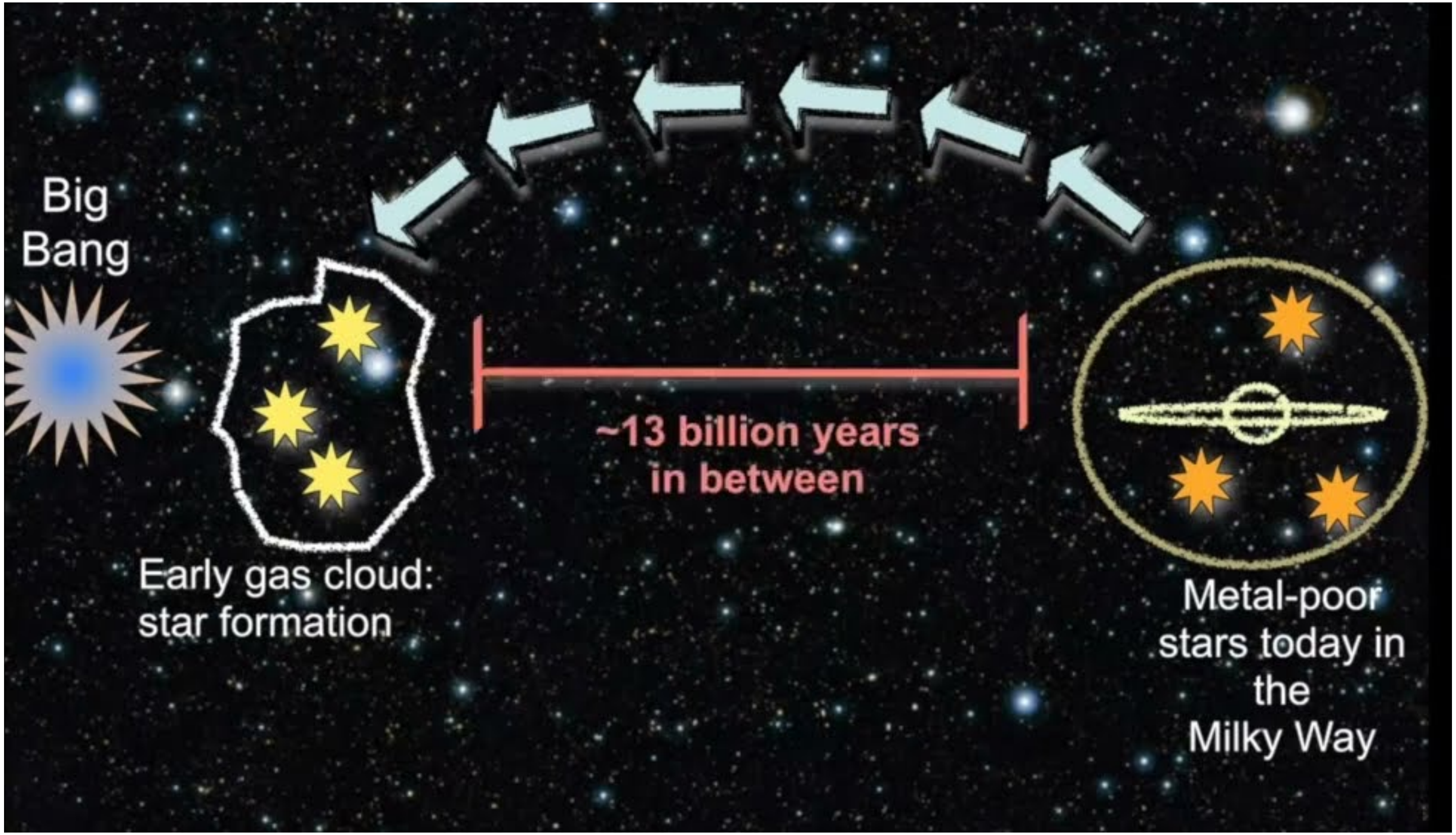
The Milky Way grew through dozens of mergers over billions of years.

How can we precisely study its formation history, from the first small galaxies until today?



drawn by Jenny O'Grady, MassArt

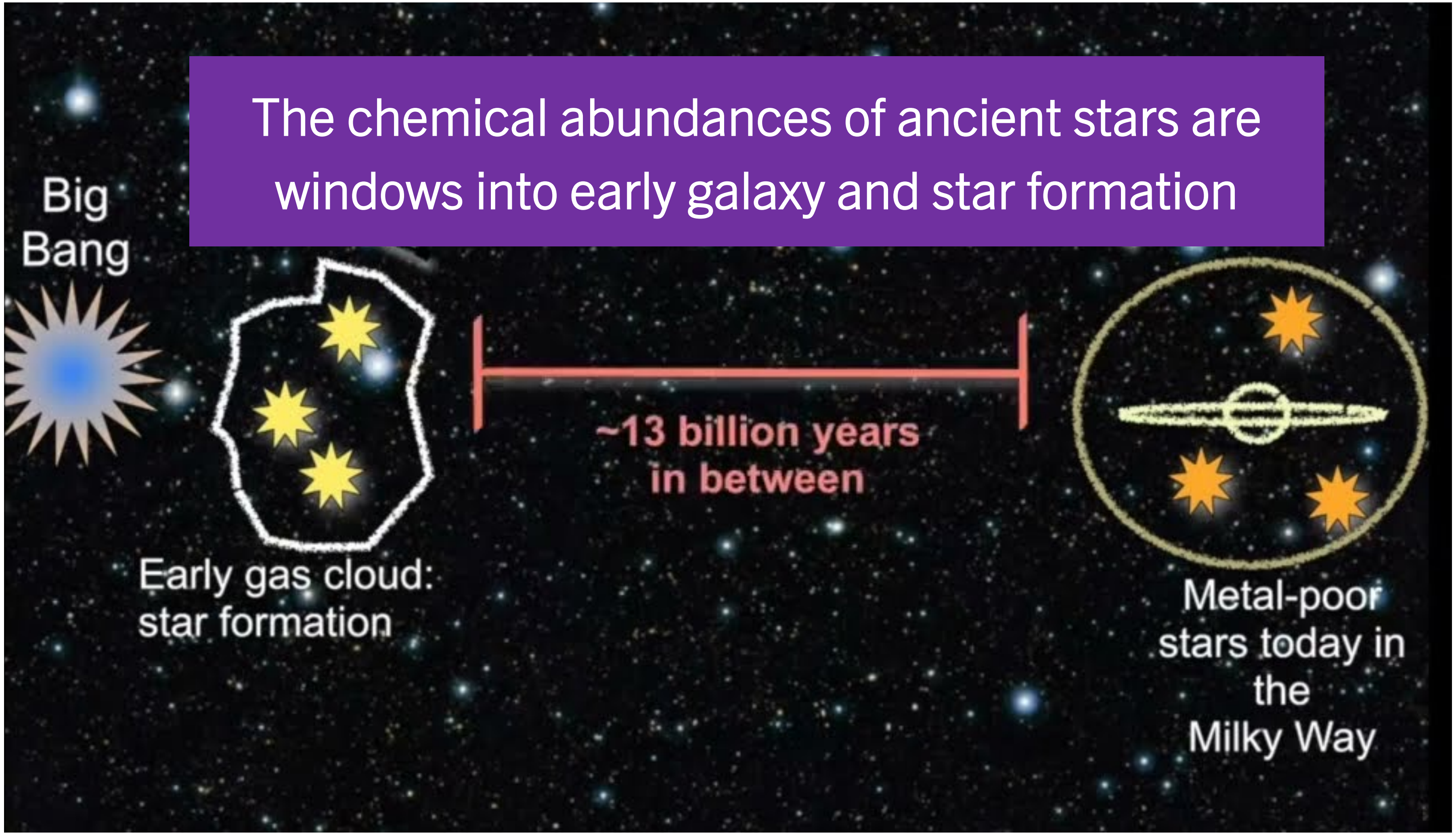
13 billion year old stars can be found in the Milky Way today



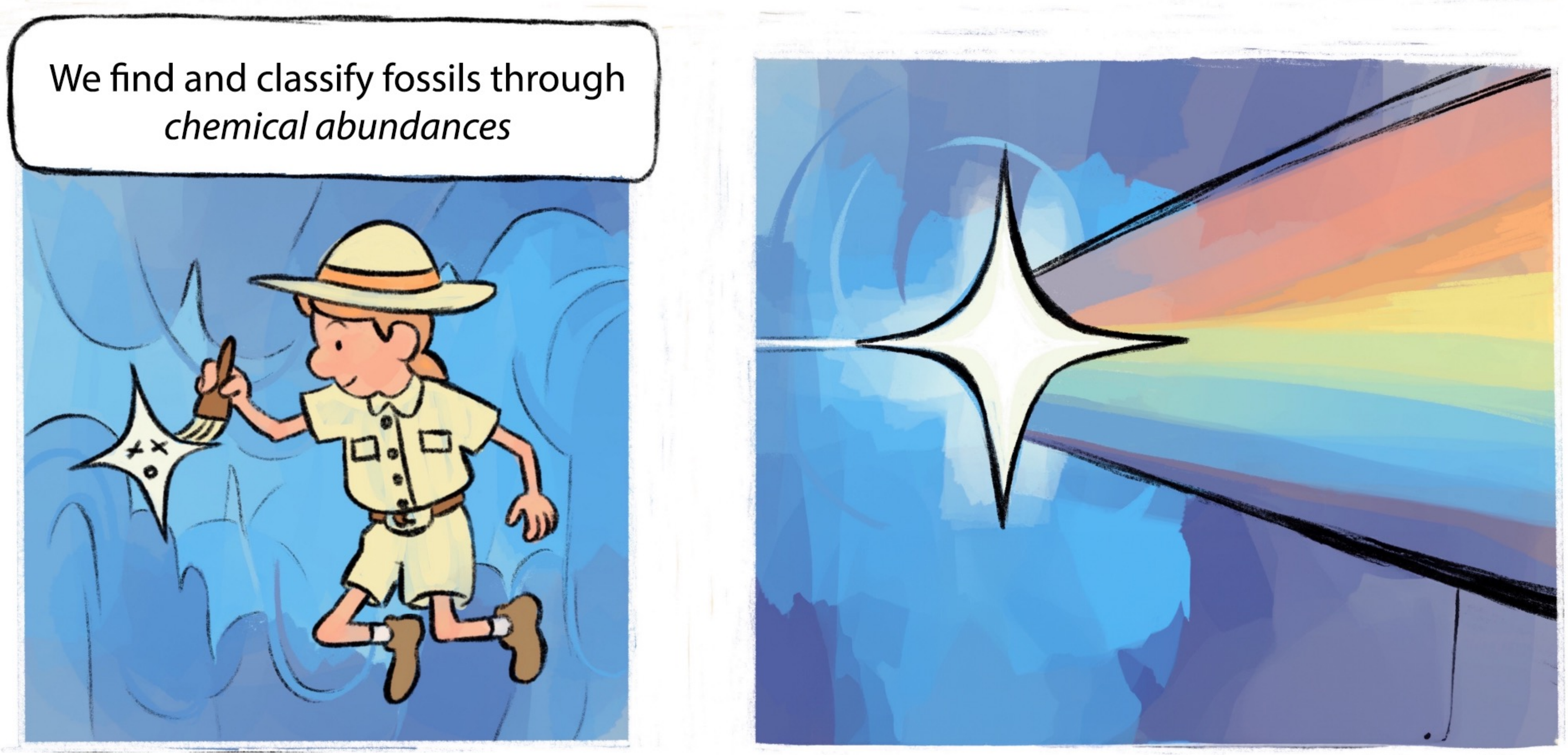
credit Anna Frebel

13 billion year old stars can be found in the Milky Way today

The chemical abundances of ancient stars are windows into early galaxy and star formation



credit Anna Frebel



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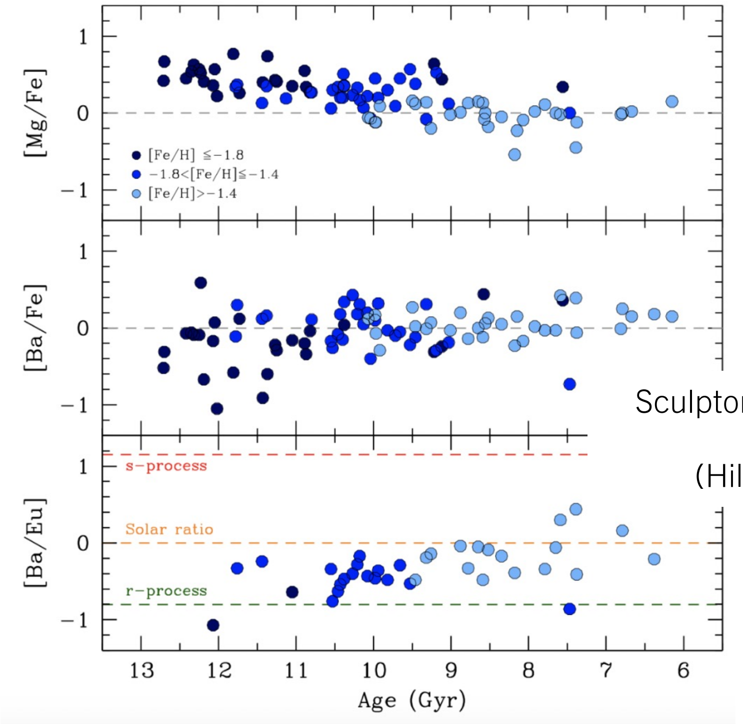
Stellar chemical abundances of old stars contain information about early galaxy formation and chemical enrichment



Sculptor age-abundance relations
(Hill et al. 2019)

stellar chemical abundances are a promising method to identify and study stars from the smallest, earliest galaxies

(e.g., Brauer et al. 2019, 2022, Ji et al. 2019)

but current simulations can't explain the scatter and star-by-star distributions of observed chemical abundances

-> we need simulations with more detailed stellar chemical abundances

High-resolution spectra for 1000s of stars with much more to come!

GALAH
GALactic Archaeology
with HERMES

H3

DARK ENERGY SPECTROSCOPIC INSTRUMENT

LAMOST Survey

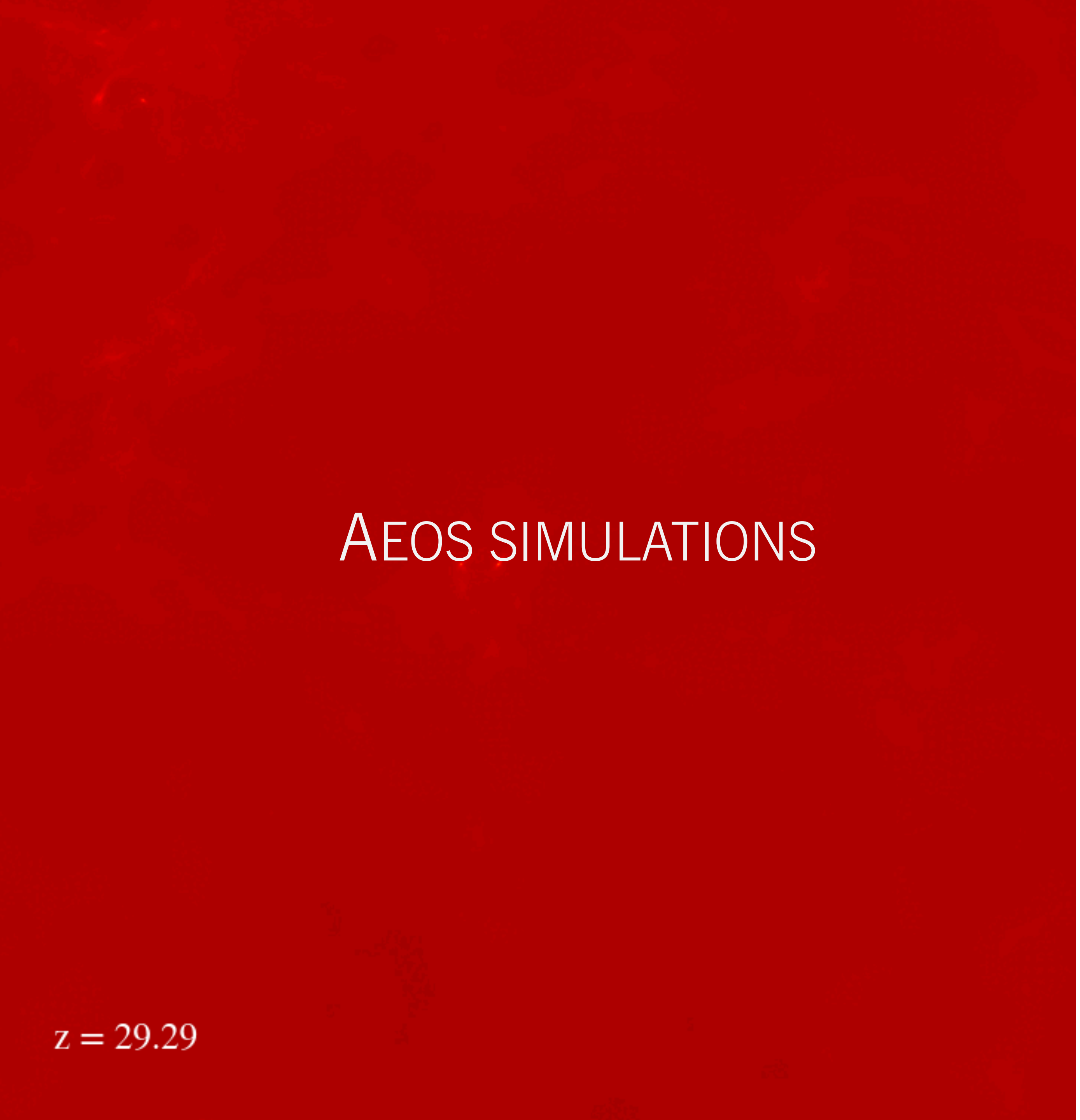
WEAVE

4MOST

SDSS

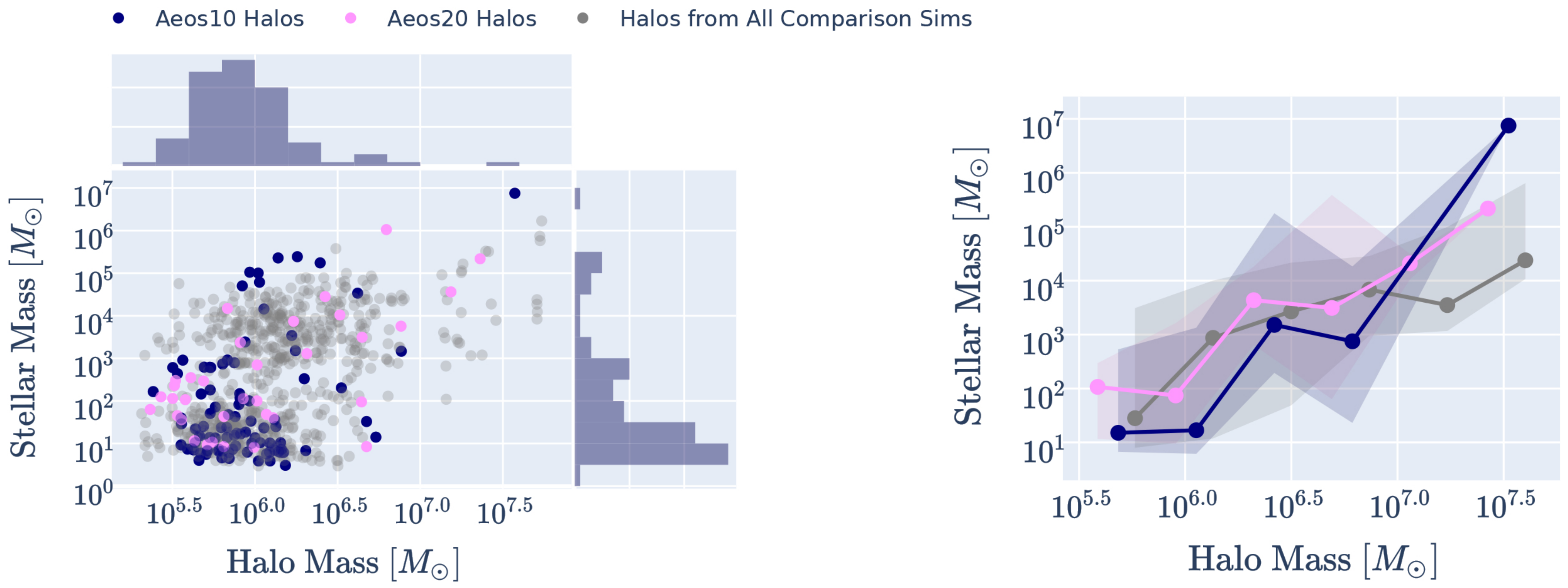
RAVE
RADIAL VELOCITY EXPERIMENT

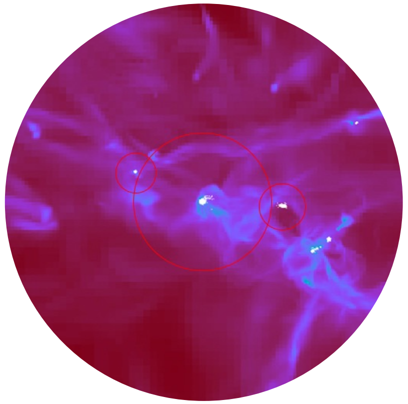
AEOS SIMULATIONS

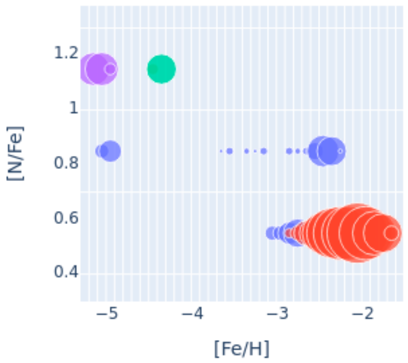


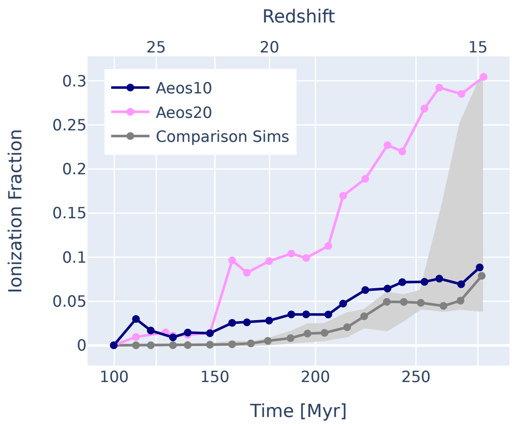
Aeos, one of the horses that pulls the Sun god across the sky

Detailed evolution of ~100 simulated galaxies from the first few hundred Myr of the universe

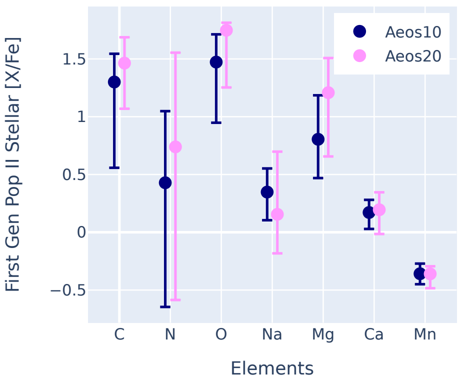


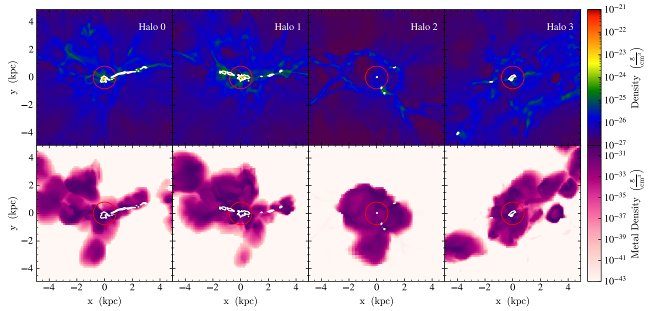


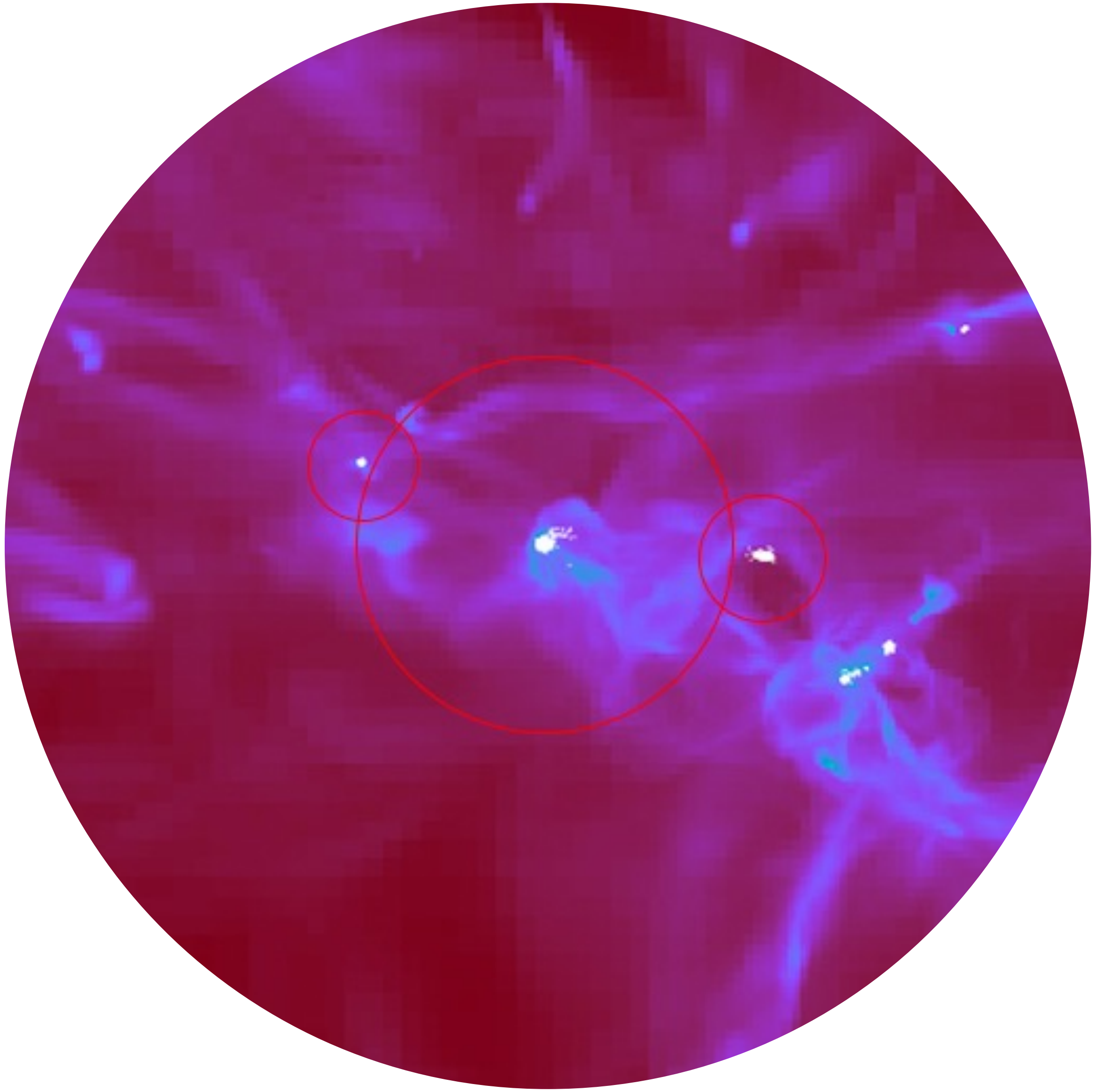




SOME SELECTED RESULTS FROM THE FIRST AEOS SIMULATIONS





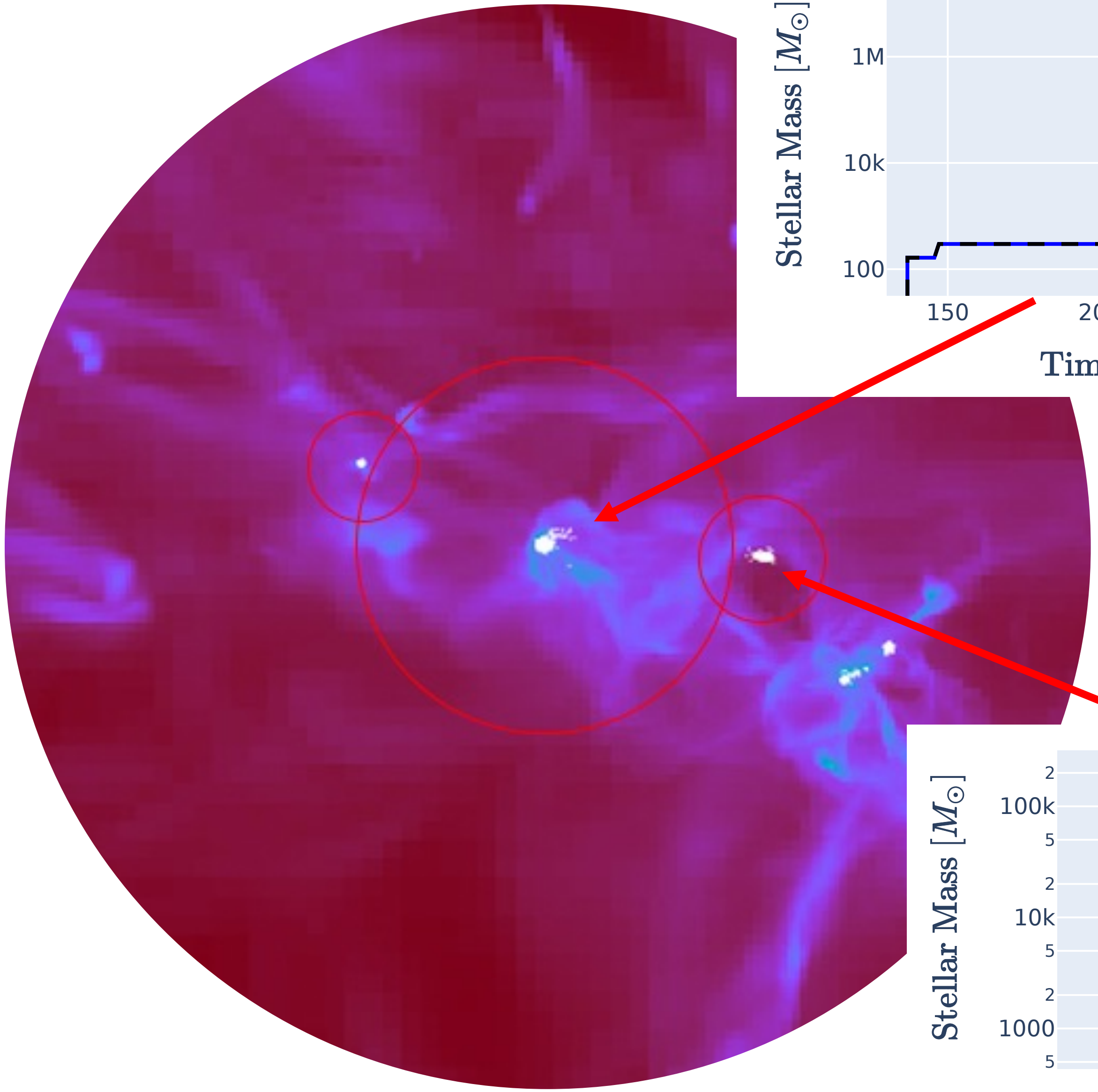


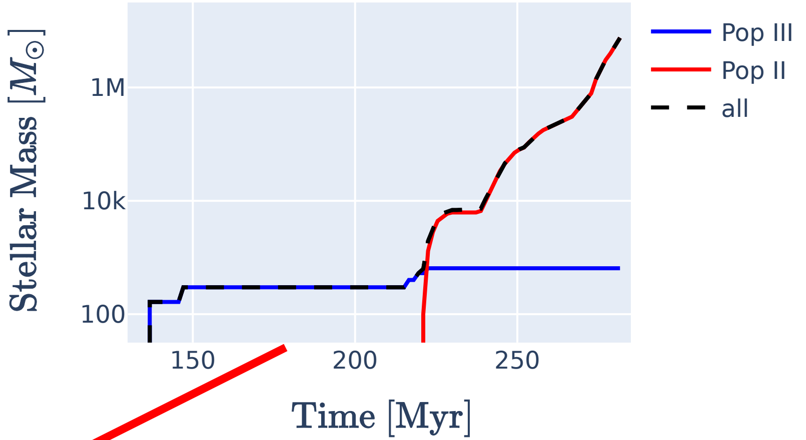
External enrichment

Early, small galaxies have very small potentials -> struggle to retain their gas and metals

Galaxies in cluster environments freely share gas and function like a larger system rather than individual galaxies

Brauer et al. (2024)





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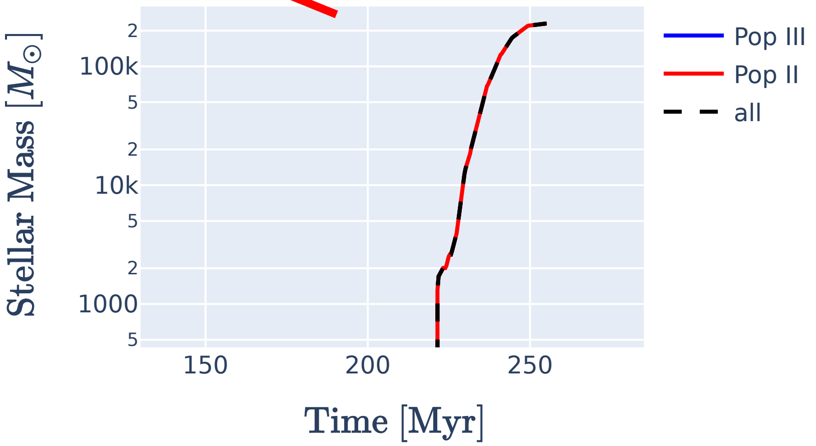


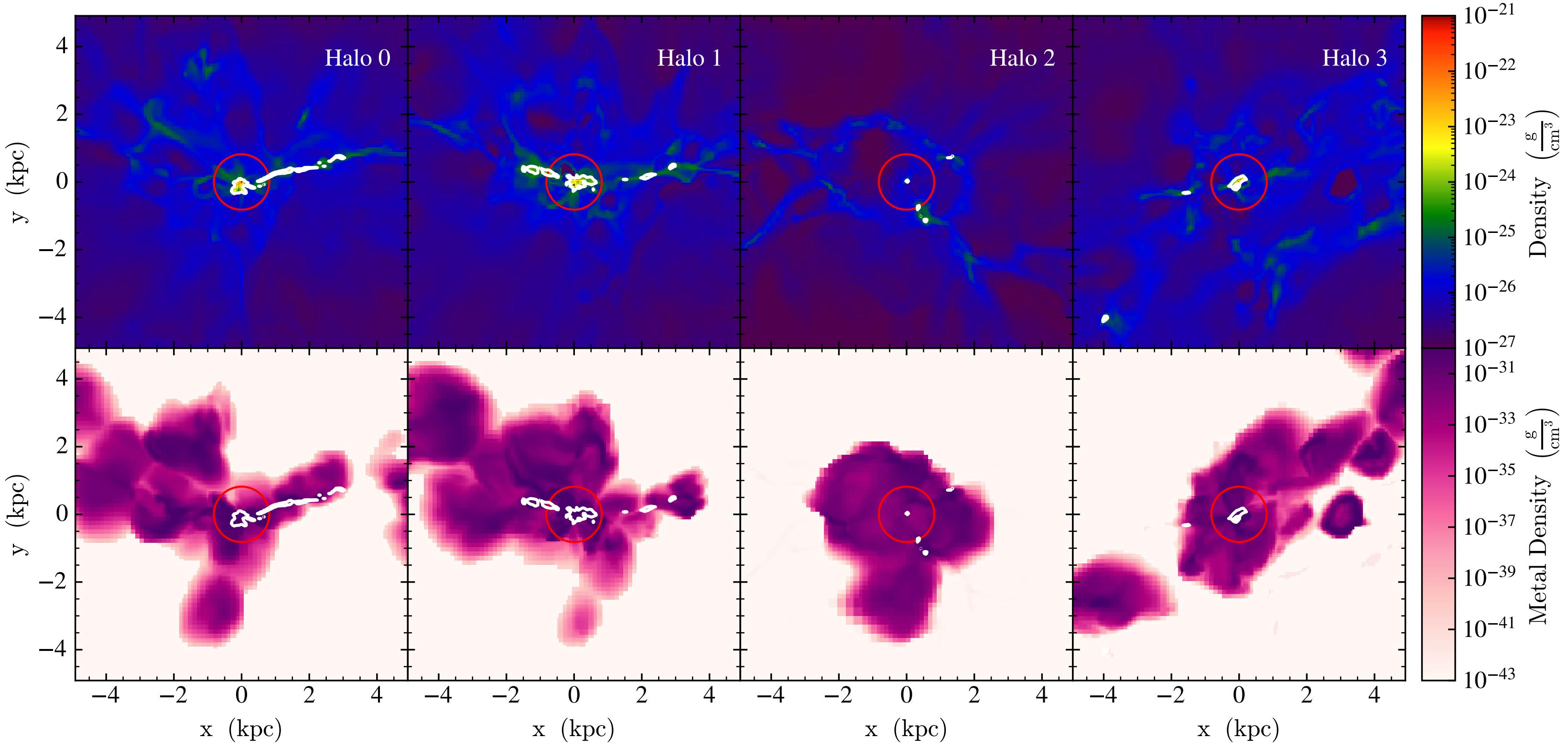
-onments freely

like a larger

vidual galaxies

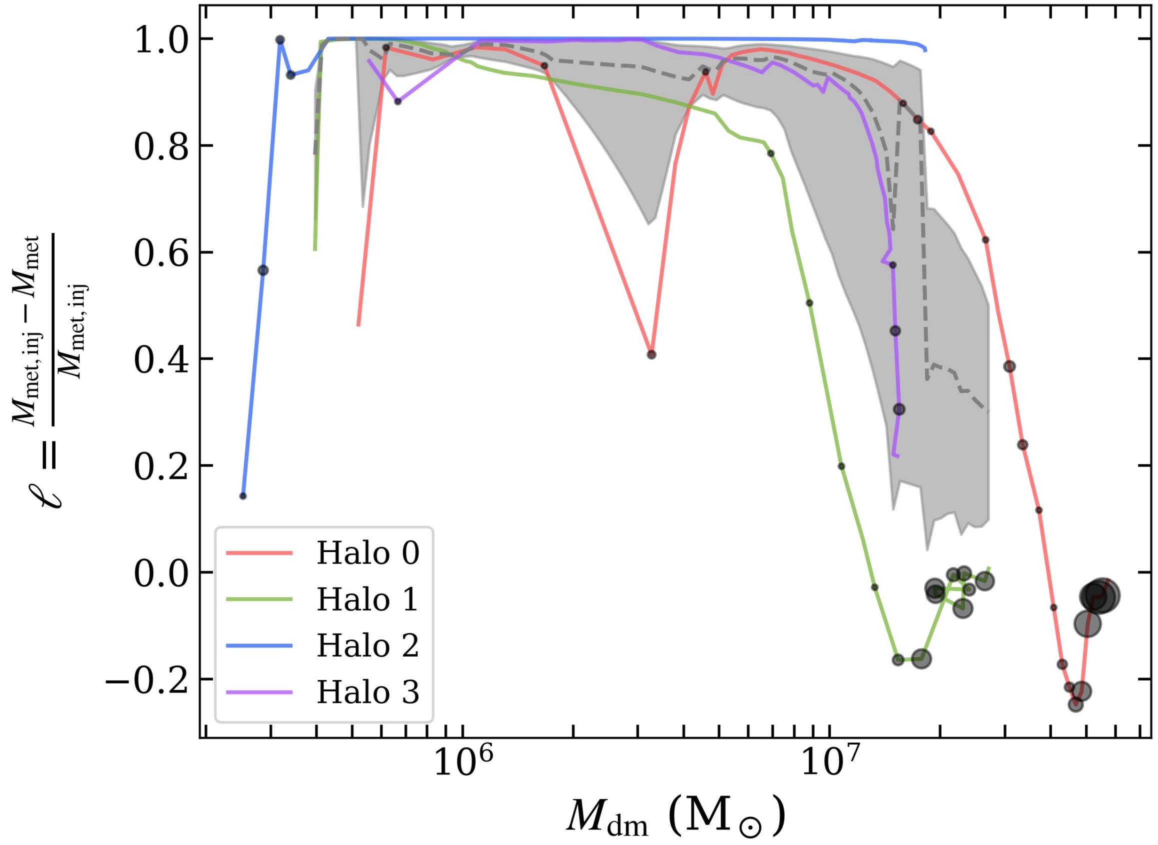
Brauer et al. (2024)

METALS EXTEND FAR BEYOND VIRIAL RADIUS



Mead, Brauer et al. (submitted)

SIGNIFICANT METAL LOSS IN HALOS < 10^7 $M_\odot$

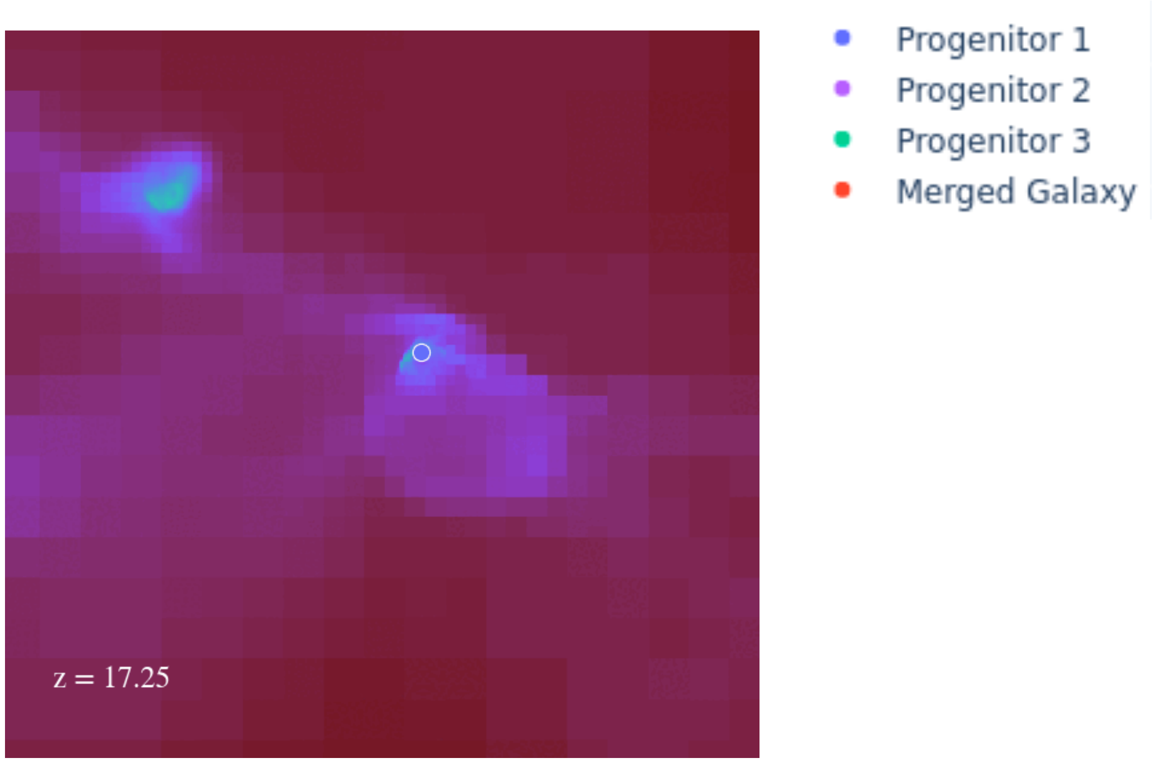


Minihalos lose **ALL** their metals after supernovae feedback

Galaxies do not retain their metals until $M_{halo} \sim 10^7$ $M_\odot$

Mead, Brauer et al. (submitted)

the chemical abundances of the stars in the simulation trace their origins



gas projection showing a merger of three systems at z~15

Brauer et al. (2024)

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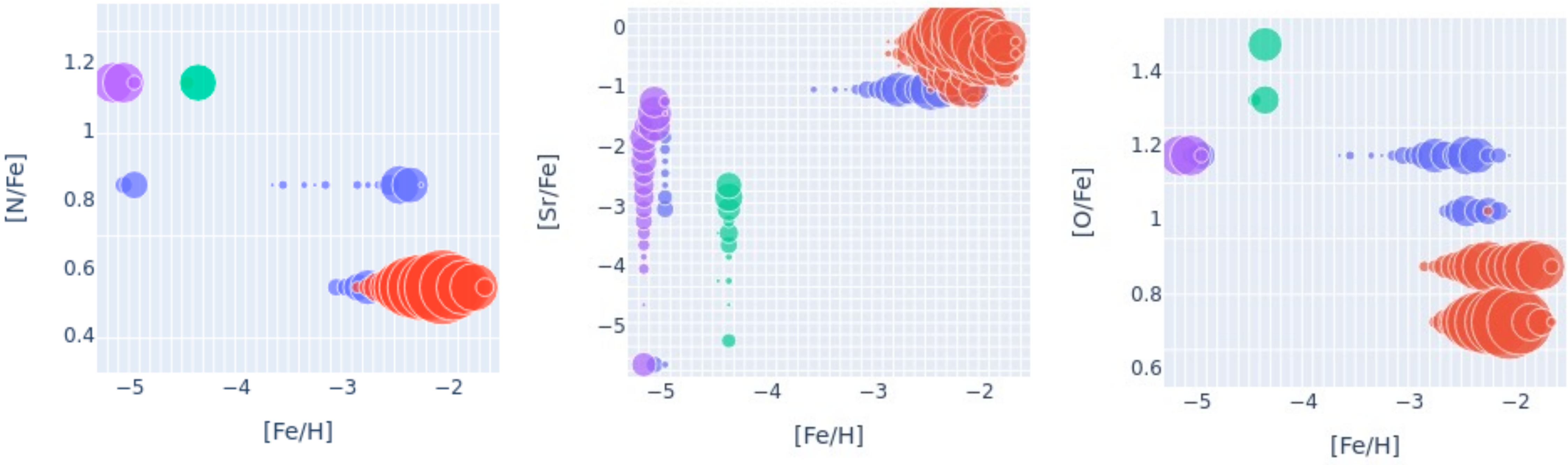
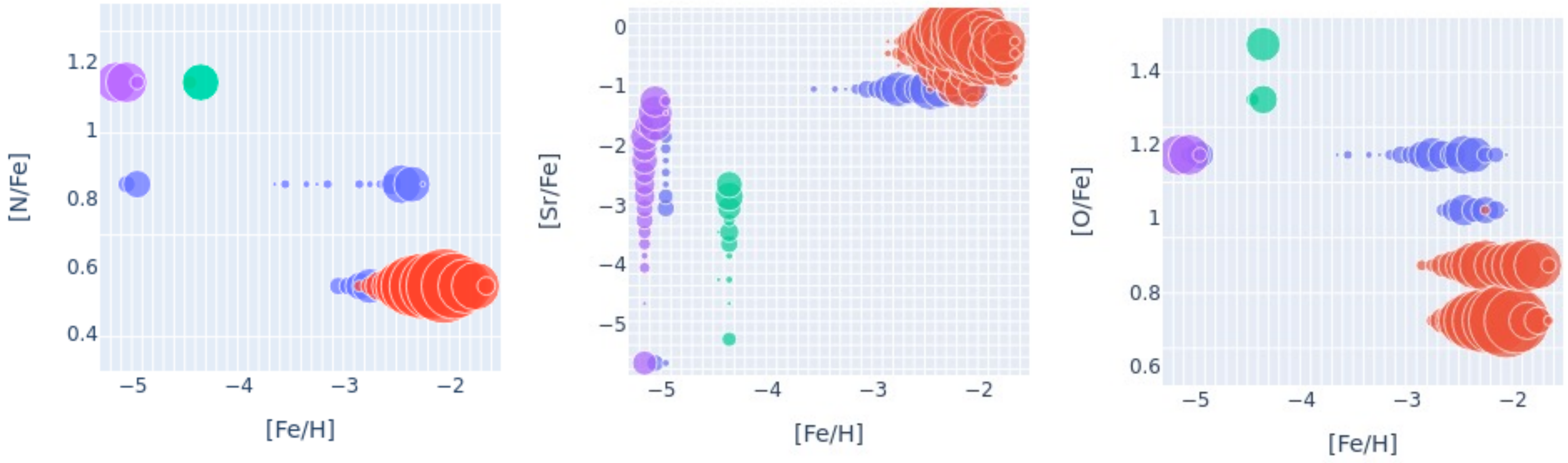


Brauer et al. (2024)

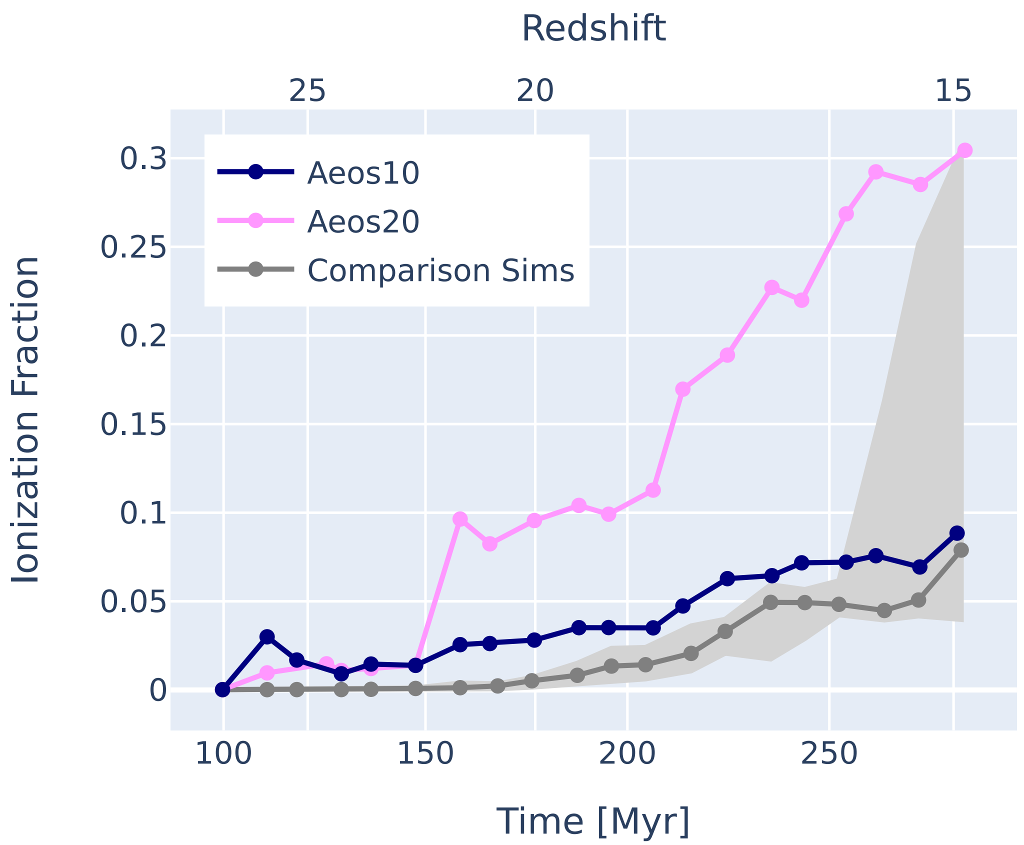
scatter also exists within galaxies from different nucleosynthetic sources and inhomogeneous mixing



-> next steps: untangle how much observed scatter we expect to originate from galaxy mergers vs. different nucleosynthetic sources

Brauer et al. (2024)

Impact of Pop III Initial Mass Function (IMF)



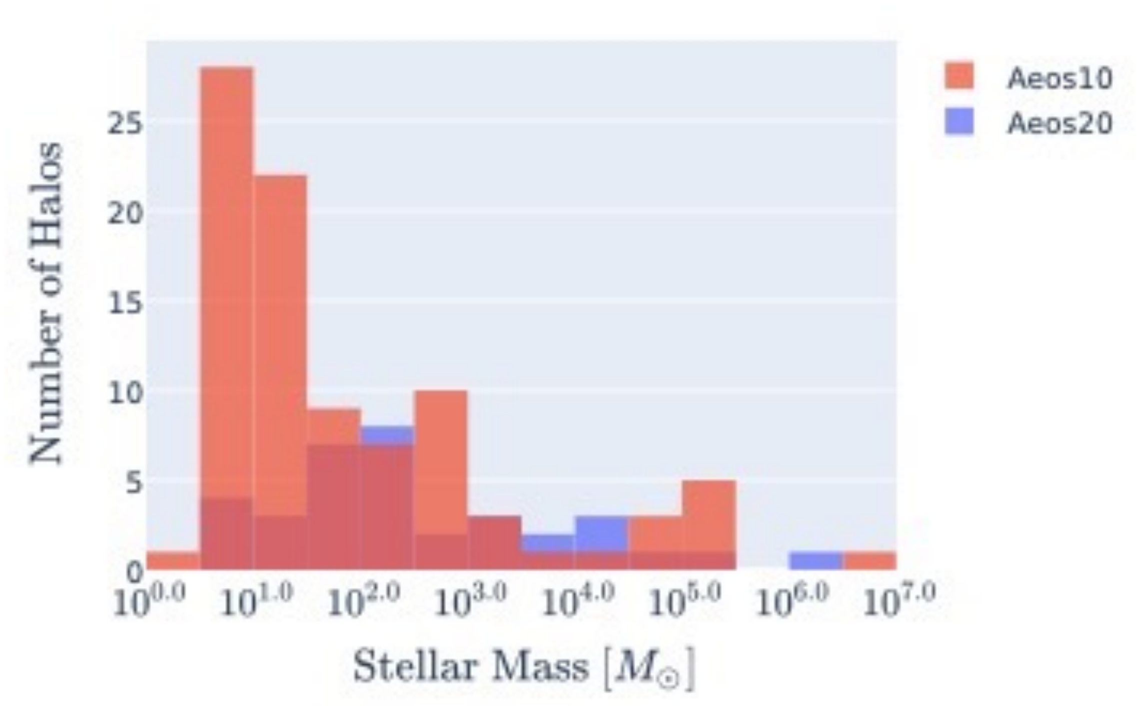
We also ran simulations with different Pop III IMFs:

Aeos10: $M_{char} = 10\ M_\odot$, up to $100\ M_\odot$

Aeos20: $M_{char} = 20\ M_\odot$, up to $300\ M_\odot$

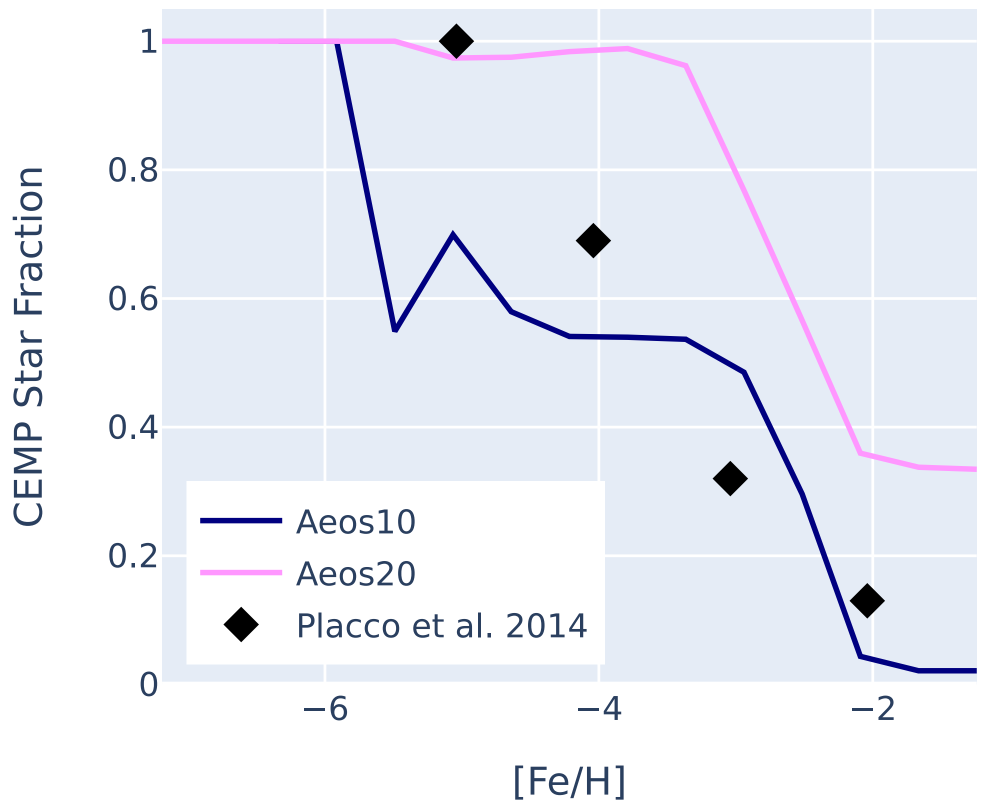
This resulted in the simulation volume of Aeos20 ionizing **much faster** than Aeos10, mostly due to the contributions of a few extremely massive Pop III

Impact of Pop III Initial Mass Function (IMF)



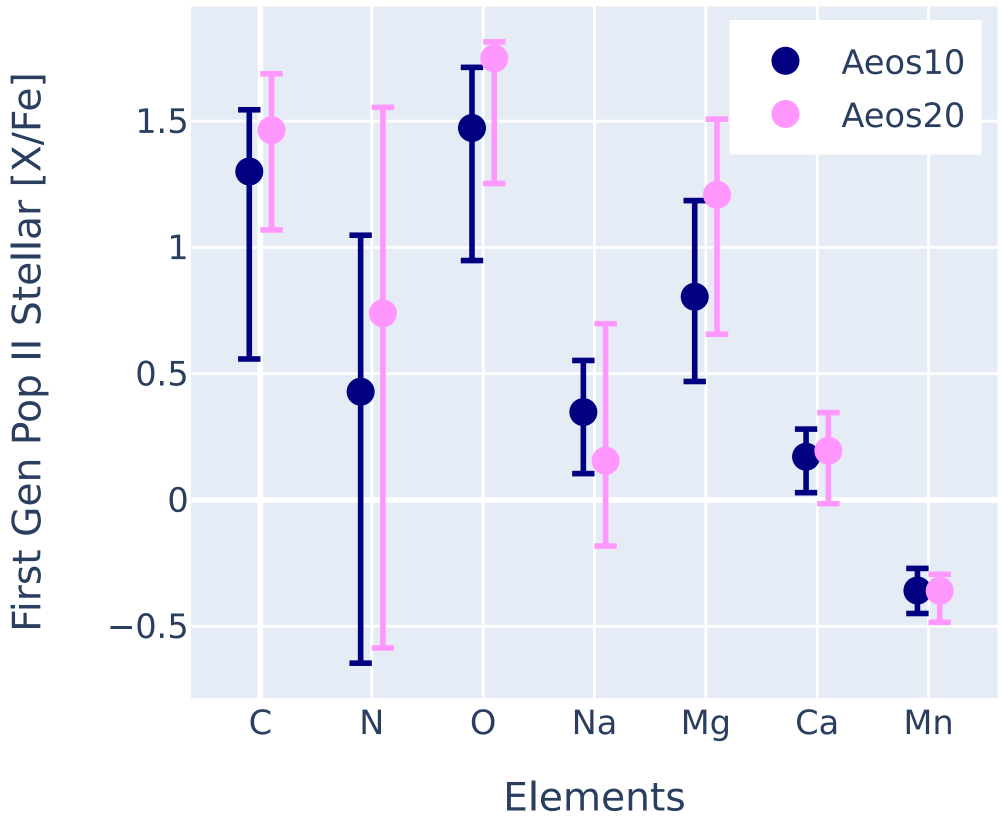
The higher ionization suppressed the formation of the smallest galaxies, so Aeos20 has far fewer galaxies of <=100 solar masses

Impact of Pop III Initial Mass Function (IMF)



The mass distribution of Pop III significantly affects the fraction of CEMP stars

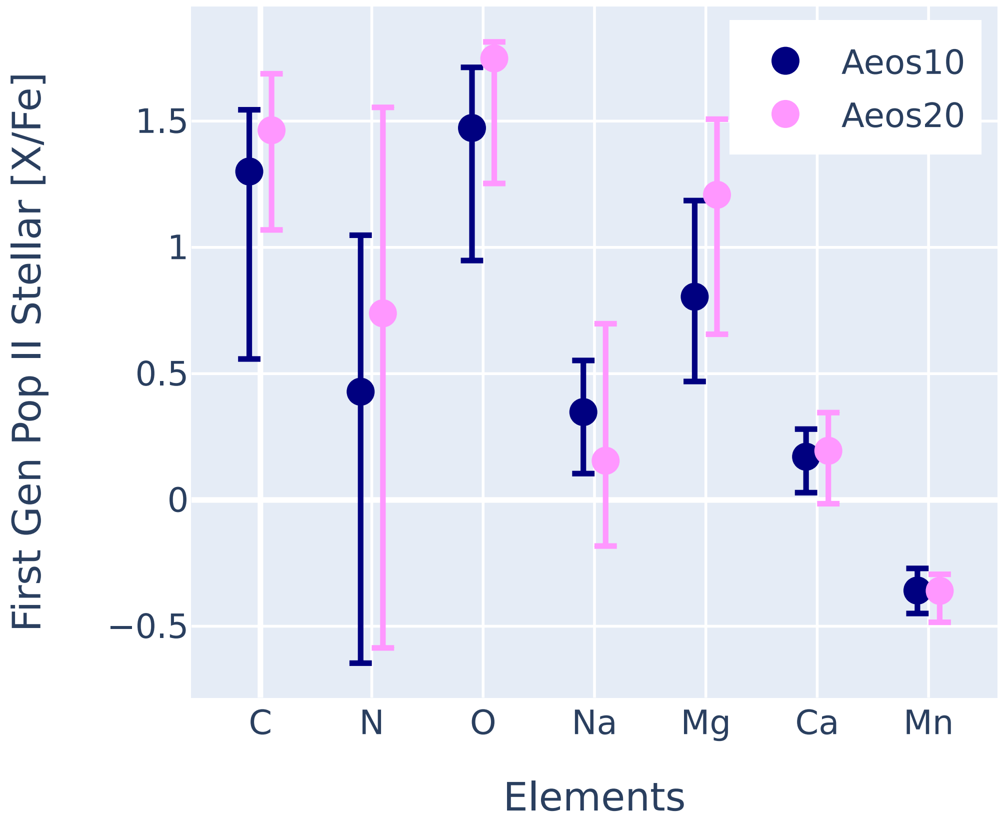
Metals from Pop III enrichment



How does Pop III enrichment translate into the chemical abundances of the first-generation Pop II stars?

← ~20 galaxies have begun Pop II at the end of the sims, shown here at the abundances of the first-gen low-mass Pop II stars.

Metals from Pop III enrichment



How does Pop III enrichment translate into the chemical abundances of the first-generation Pop II stars?

← ~20 galaxies have begun Pop II at the end of the sims, shown here at the abundances of the first-gen low-mass Pop II stars.

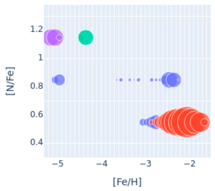
Alpha elements (CNO) increased, even-odd differences (Mg vs Na)

Significant scatter! Lots of variation between different first-gen Pop II galaxies

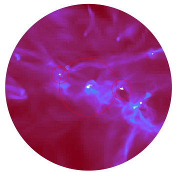
SUMMARY OF THE FIRST AEOS SIMULATIONS

star-by-star cosmological galaxy simulations tracing 10 metals + 10 additional metal tracer fields; Pop III enrichment; metal mixing

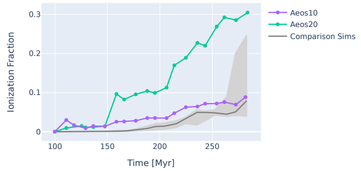
- the chemical abundances of stars trace their origins in different galaxies



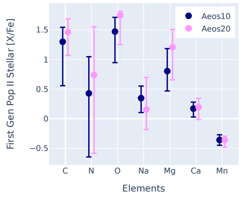
- early galaxies frequently share gas and metals, leading to examples of external enrichment (galaxies that start star formation with Pop II)



- small galaxies are significantly suppressed by increased amounts of ionizing radiation, making them sensitive to different Pop III initial mass functions



- Pop III enrichment & how this leads to the abundances of first-gen Pop II stars



SUMMARY OF THE FIRST AEOS SIMULATIONS

star-by-star cosmological galaxy simulations tracing 10 metals +
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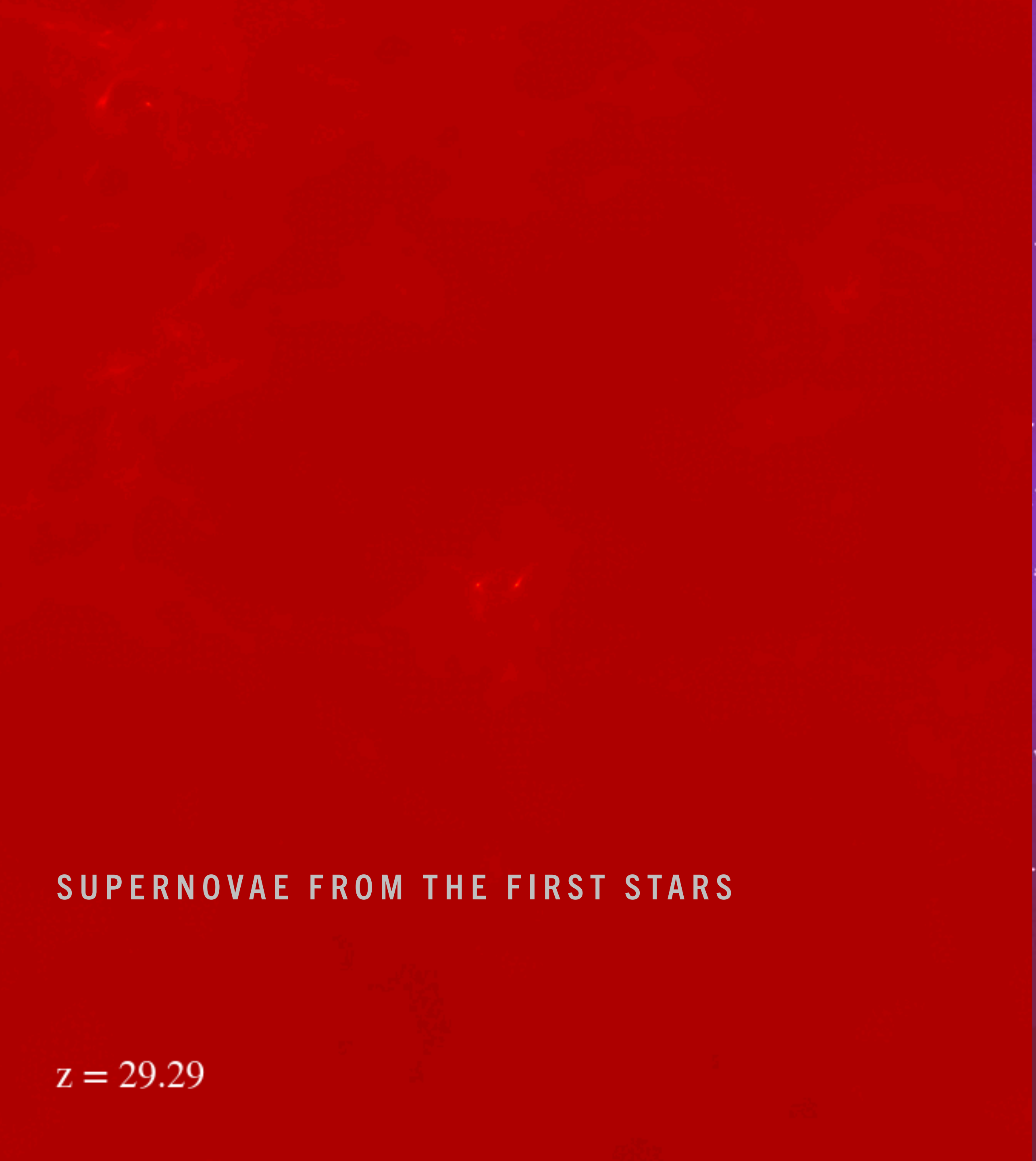
UPCOMING:

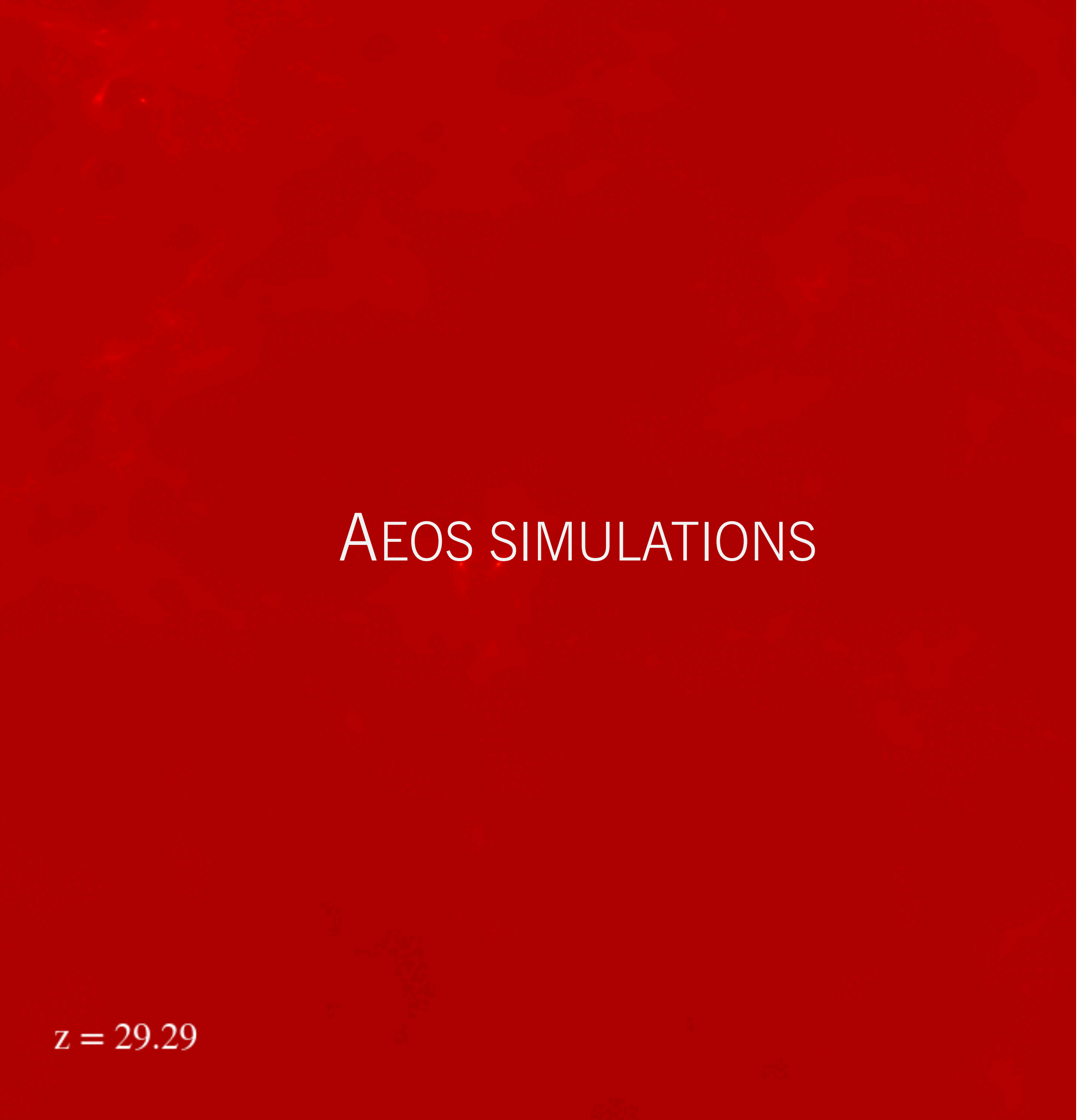
- Zoom simulations of a suite of ultra-faint dwarf galaxies
- Comparisons with stellar halo abundance data and dwarf galaxy abundance data
    - Origins of observed abundance scatter
    - Estimates of low-mass end of Milky Way assembly history
    - Origins of different metals in metal-poor stars

AEOS


SUPERNOVAE FROM THE FIRST STARS
z = 29.29


DETAILED MERGERS & INDIVIDUAL STARS
z = 15.02

AEOS SIMULATIONS



Running with modified version of Enzo

(Bryan et al., 2014; Brummel-Smith et al., 2019)

Fiducial cosmological simulation:

1 Mpc box,
gas resolution up to 1 pc,
individual particle for every star >2 $M_{\odot}$,
Pop III stars & enrichment,
redshift = 130 to 14 (300 Myr)
zooms that will run to redshift 6,
~100 star forming halos

Tracing 10 Metals:
C (CCSNe, AGB winds), N (AGB winds), O (CCSNe), Na (CCSNe), Mg (CCSNe), Ca (CCSNe), Mn (Type Ia), Fe (CCSNe, Type Ia), Sr (AGB winds), & Ba (AGB winds)
+ additional metal tracer fields including an r-process field

20 total metal fields for each star particle and gas cell