# A Window to the First Stars

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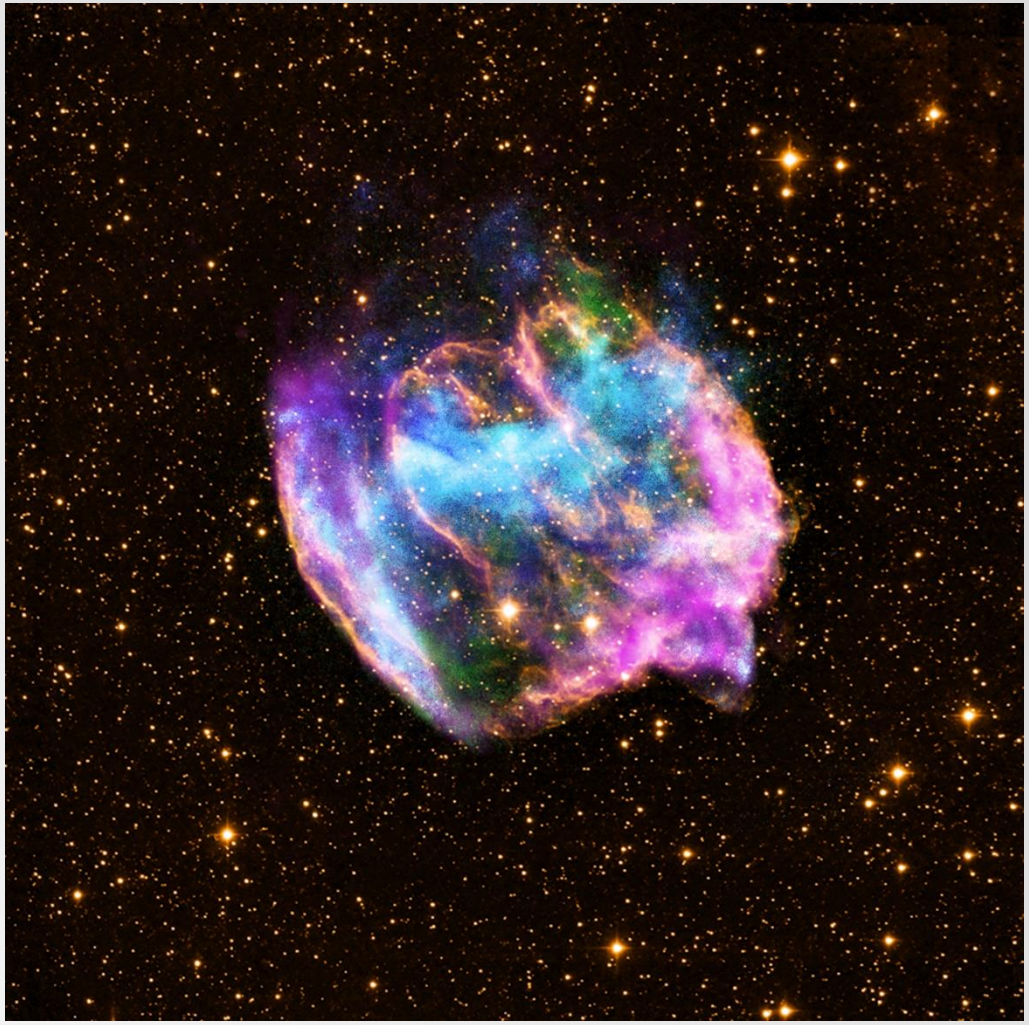

Image credit: X-ray: NASA/CXC/MIT/L.Lopez et al.; Infrared: Palomar; Radio: NSF/NRAO/VLA

Durham Centre for Extragalactic Astronomy

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# In a Nutshell

# Population III stars

- First generation of stars to form in the Universe
- Thought to have formed between a redshift of z~20–30
- Necessarily form from metal-free environment

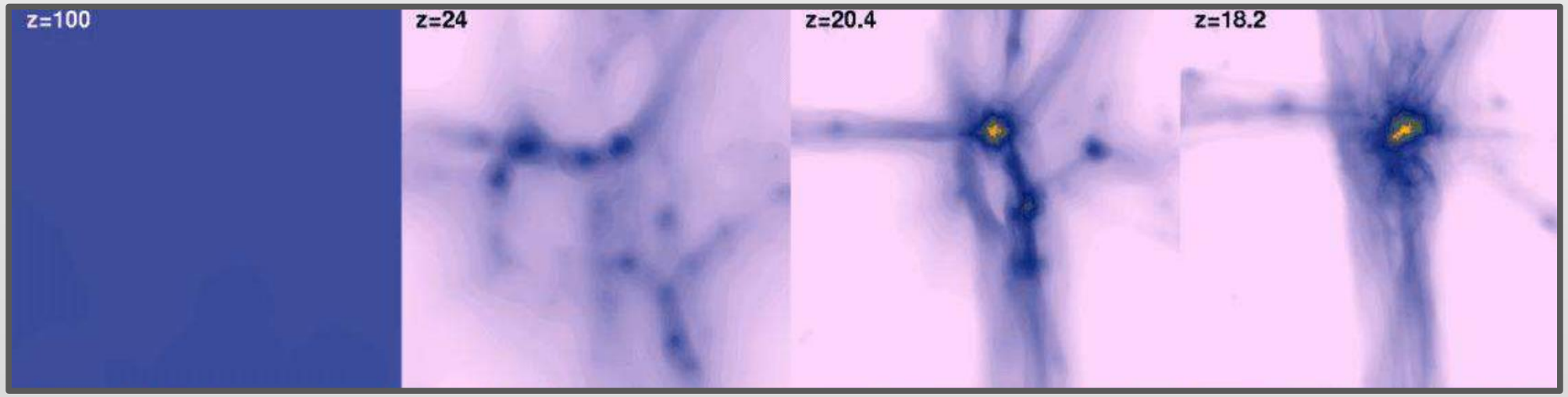
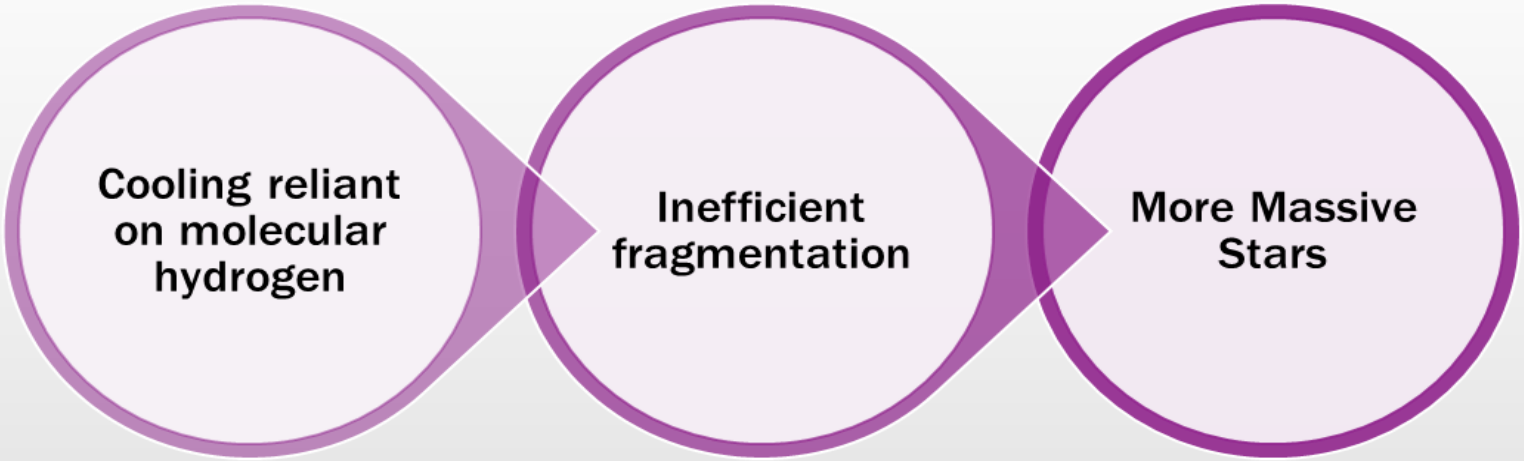



Image credit: Abel, Bryan, and Norman (2001)

# Cooling and Fragmentation



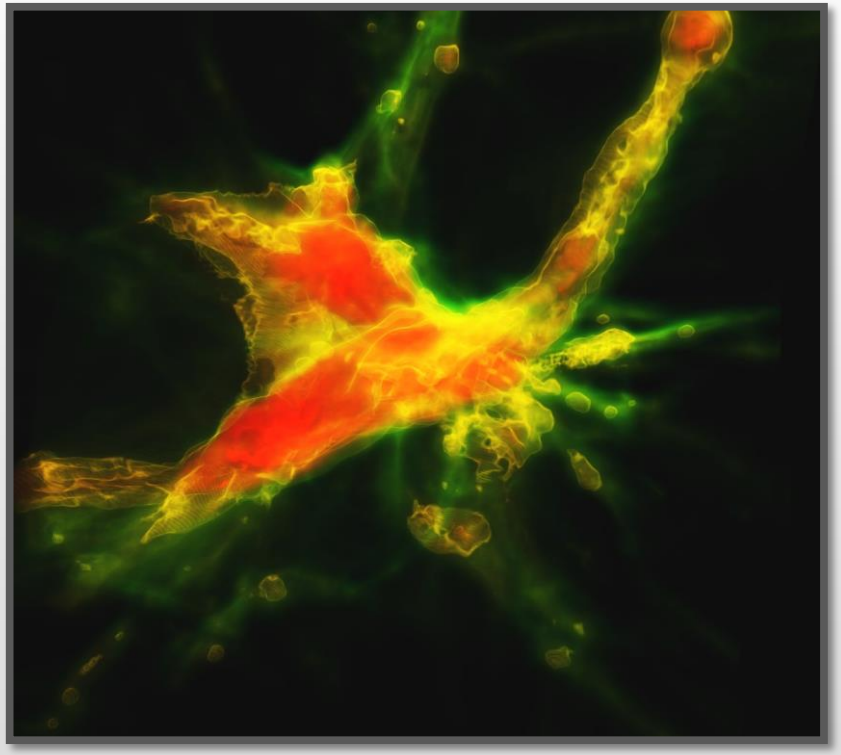



Image credit: T. Greif et al. (2008)

- Characteristic mass: 10 - 100$M_\odot$ (Bromm 2013)
- This mass range is supported by the non-detection of a surviving Population III star

# Chemical signature of Population III stars

- Some metal-free stars ended their lives as core-collapse supernovae
- Simulations of the evolution and ultimate explosion of massive metal-free stars provide expected chemical signature
- Fiducial model uses data from the simulations performed by Heger & Woosley (2010)

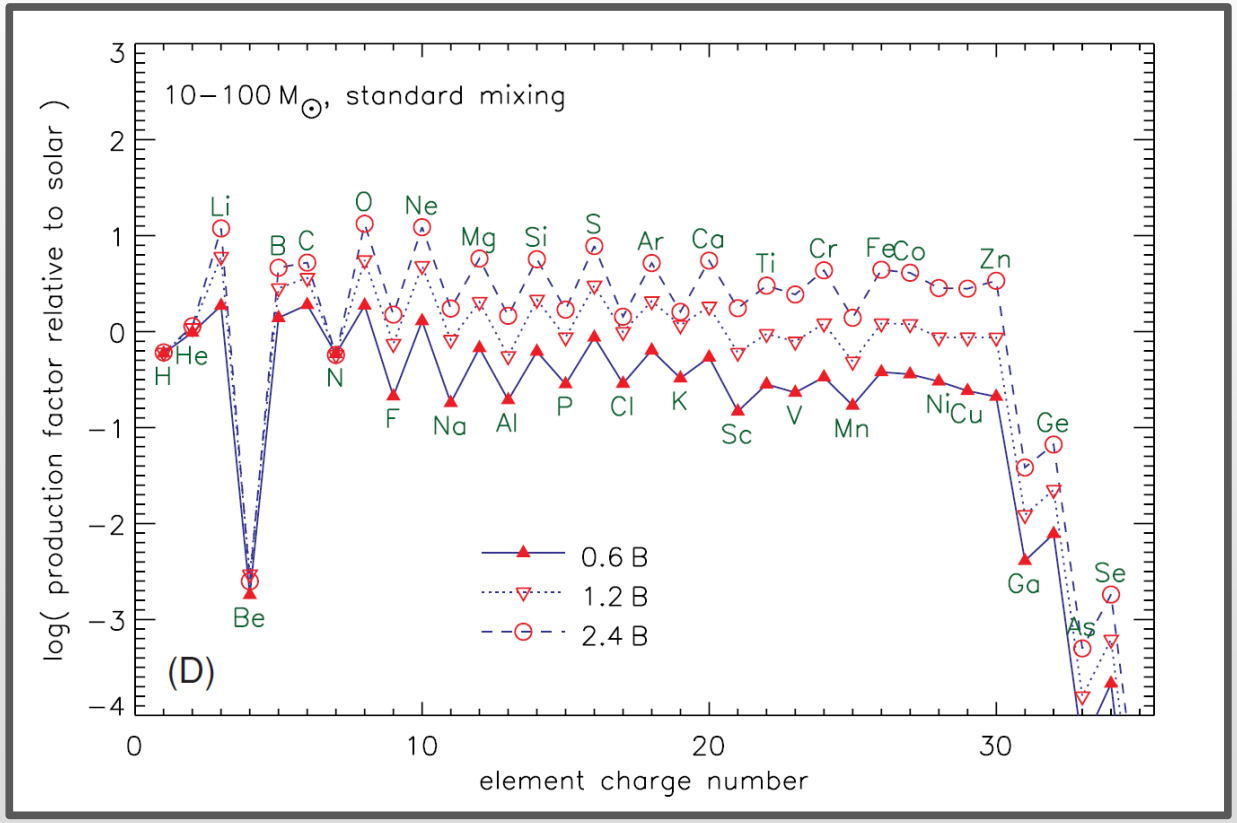
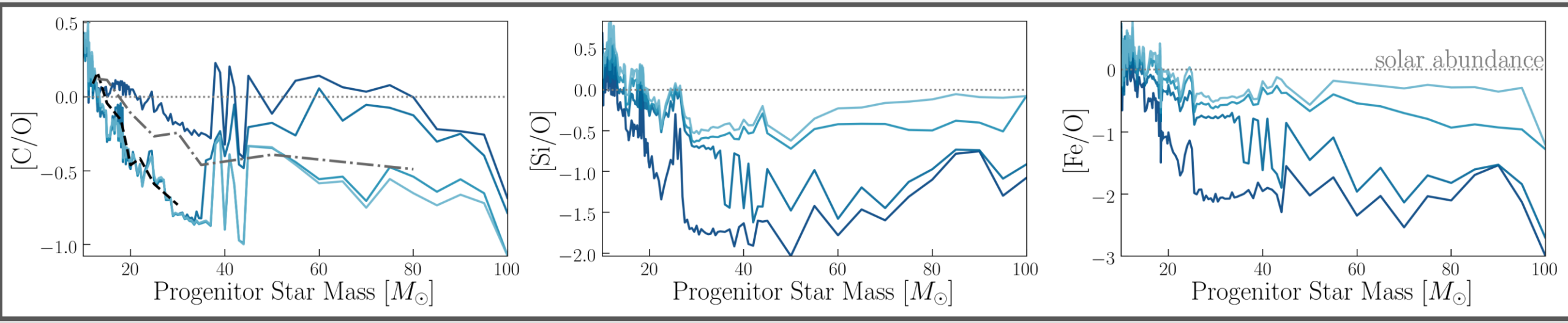



Image Credit: Heger & Woosley (2010)

# [X/Y] relationship with initial progenitor mass

$$[X/Y] = \log(N_X/N_Y)_\star - \log(N_X/N_Y)_\odot$$




**low explosion energy → high explosion energy**

# Damped Lyman-alpha systems (DLAs)

- Clouds of mostly neutral hydrogen found along the line-of-sight towards quasars
- Characterised by a HI column density $N(HI) \geq 2 \times 10^{20} cm^{-2}$

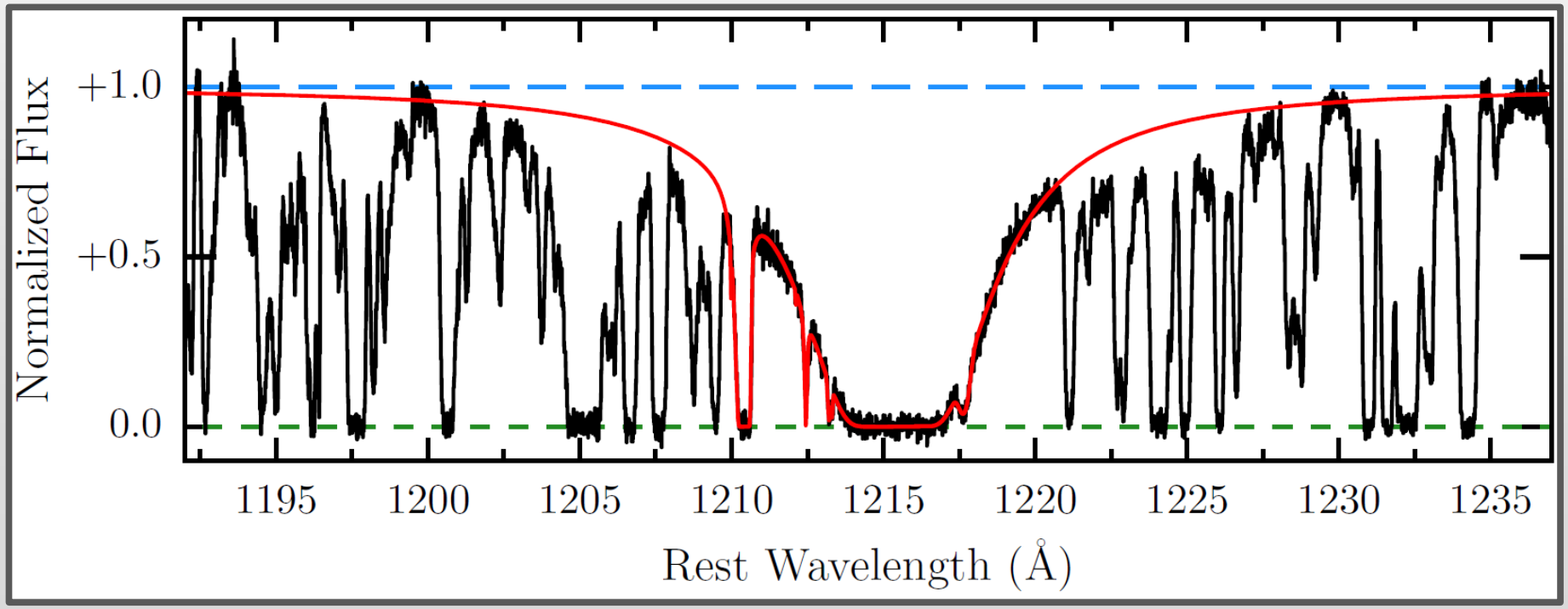
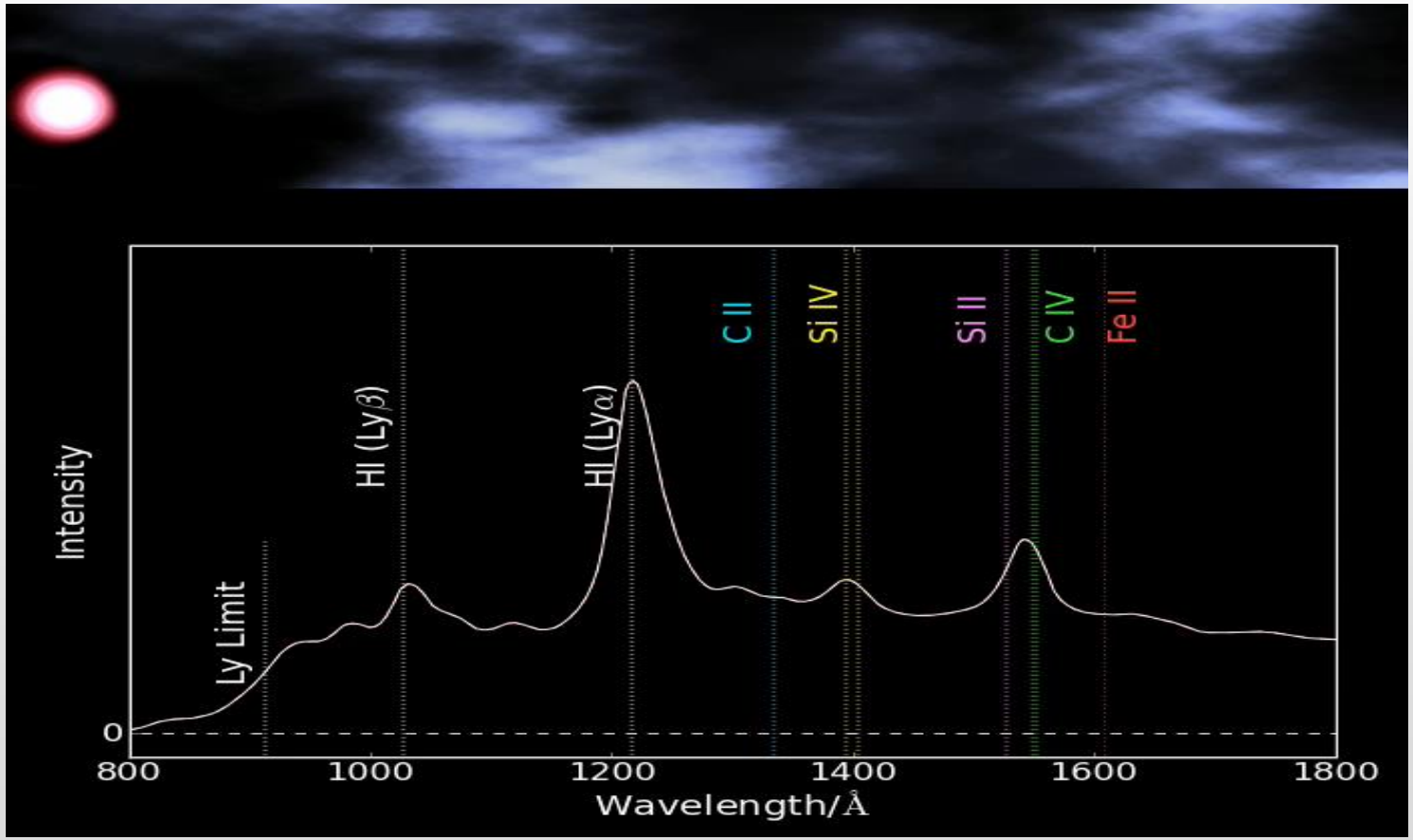



Image Credit: Cooke et al. (2017)

# Damped Lyman-alpha systems



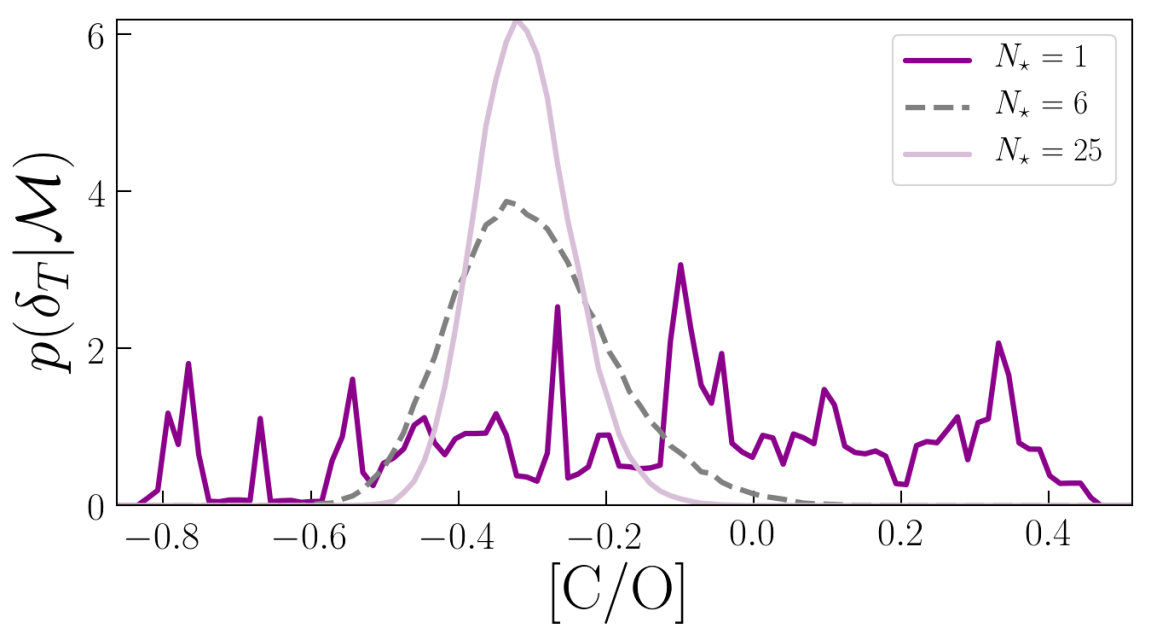
# Enrichment model

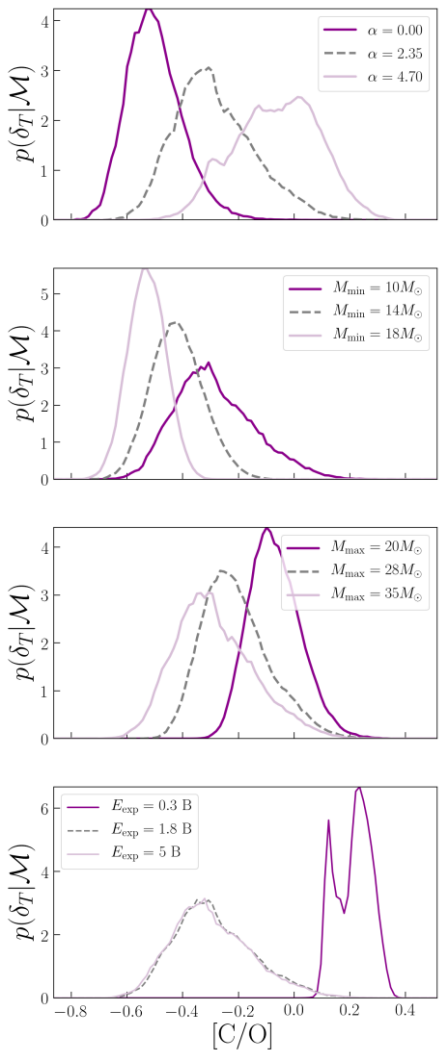
$$N_\star = \int_{M_{min}}^{M_{max}} k M^{-\alpha} dM$$

- $N_\star$ – number of stars which have formed from a given mass distribution (multiplicity)
- $M_{min}$ – minimum mass of enriching stars
- $M_{max}$ – maximum mass of enriching stars
- $\alpha$ – power law mass distribution (Salpeter = 2.35)
- $E_{exp}$ – the energy of supernova explosion at infinity

# Probability of [X/Y] given an enrichment model

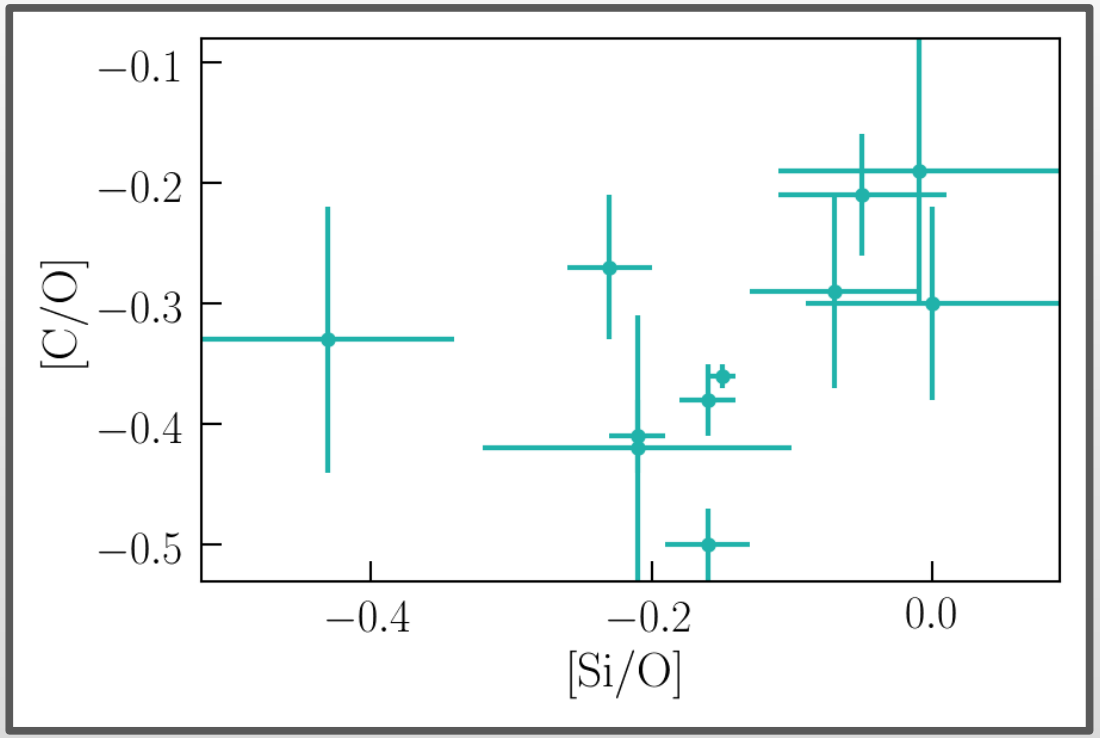
- Metal-free stars form either individually or in small multiples
- Underlying IMF is stochastically sampled



# Current data

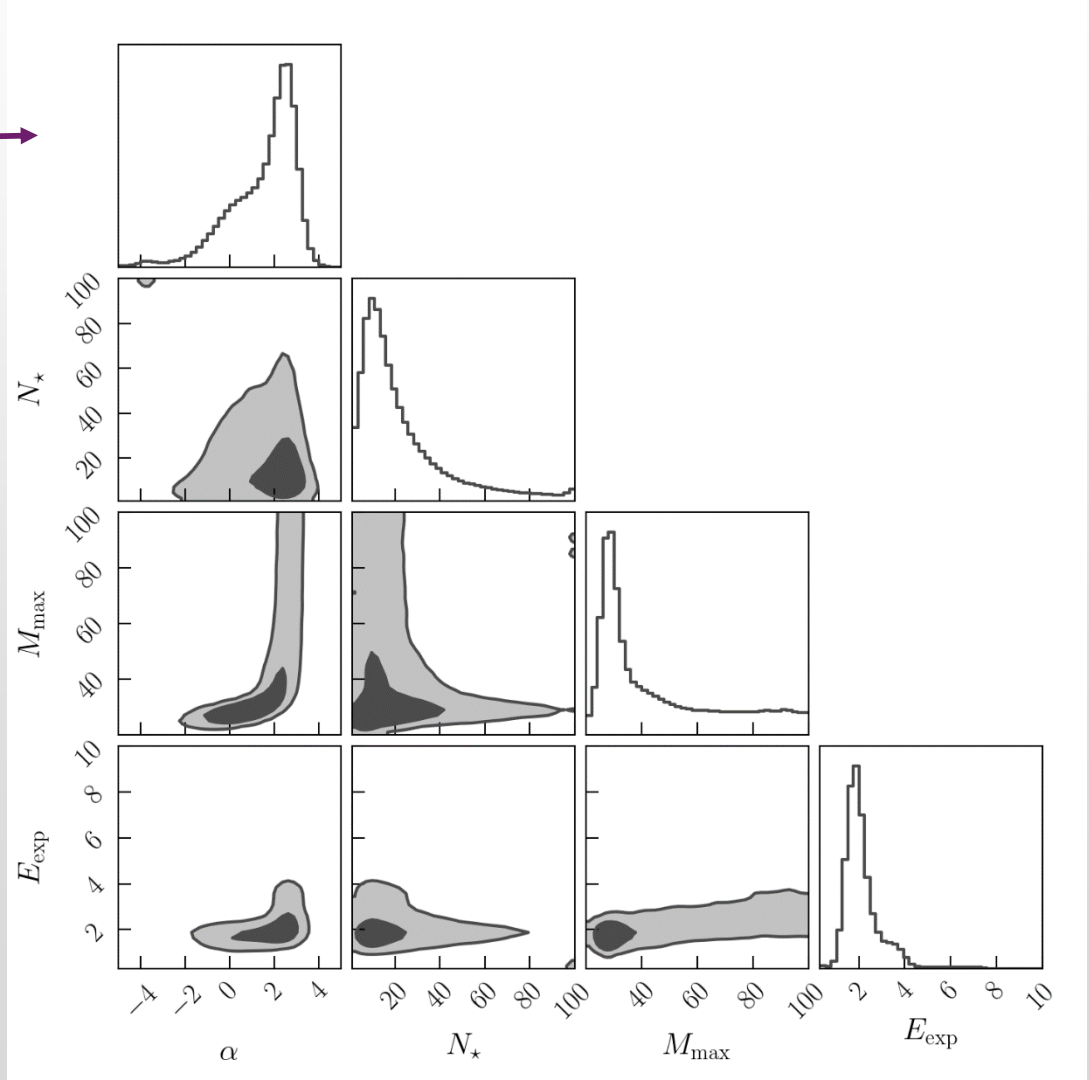
- The 11 most metal-poor DLAs that have been detected beyond a redshift of z=2.6
  - → Contains the most metal-poor DLA currently known (Cooke et al. 2017)
  - → Range of oxygen abundance: -3.05 < [O/H] < -1.8
- All systems have a minimum of 2 number abundance ratios ([C/O] and [Si/O]) – some have an additional [Fe/O] determination
- Observed with ESO Ultraviolet and Visual Echelle Spectrograph (UVES) or Keck High Resolution Echelle Spectrometer (HIRES)
  - → Resolution ~80,000




Data from: Dessauages-Zavadsky et al. (2003), Pettini et al. (2008), Ellison et al. (2010), Srianand et al. (2010), Cooke et al. (2011), Cooke, Pettini, & Murphy (2012), Cooke et al. (2014), Dutta et al. (2014), Morrison et al. (2016), Cooke et al. (2017).

# Likelihood analysis

Consistent with Salpeter distribution.

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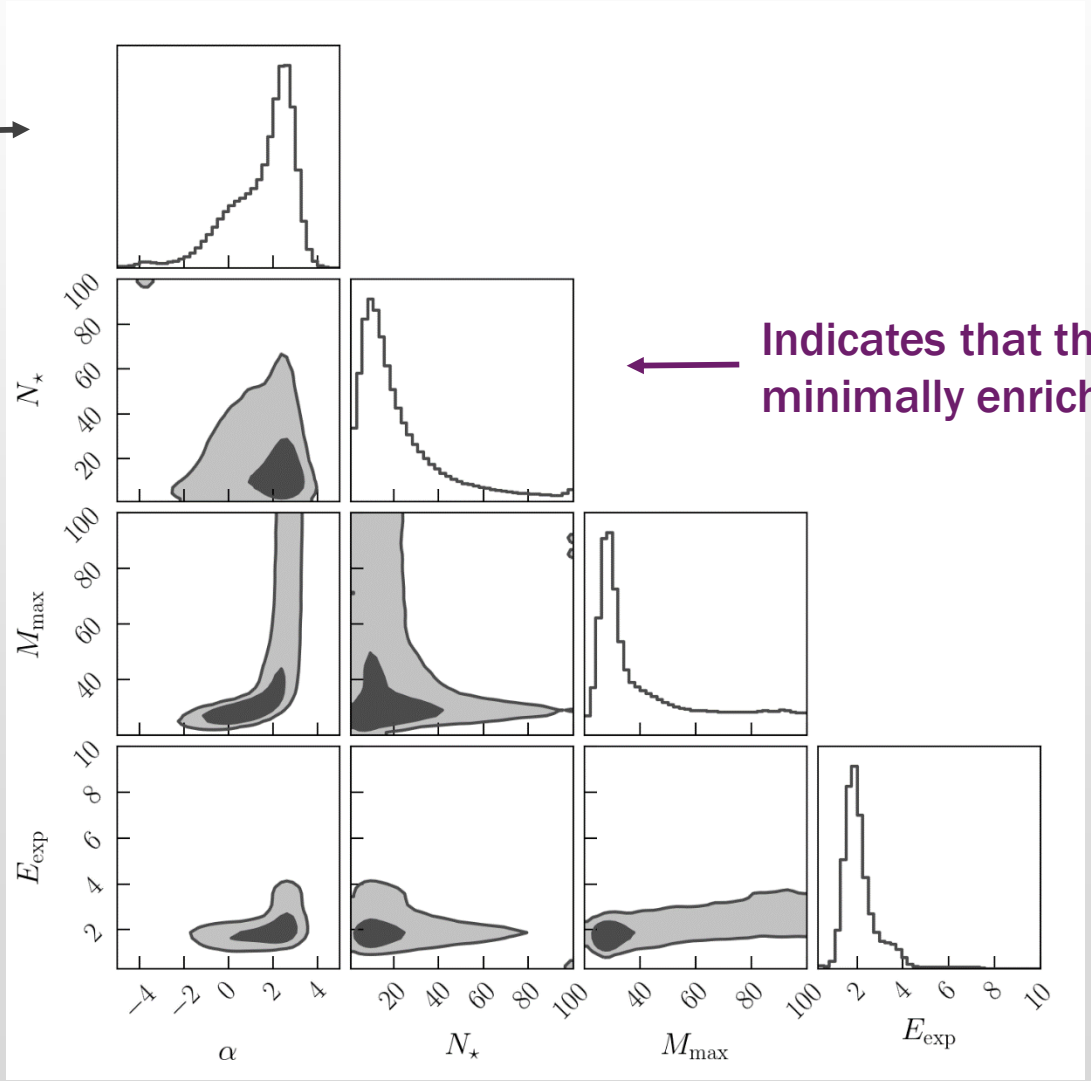


Indicates that these systems have been minimally enriched

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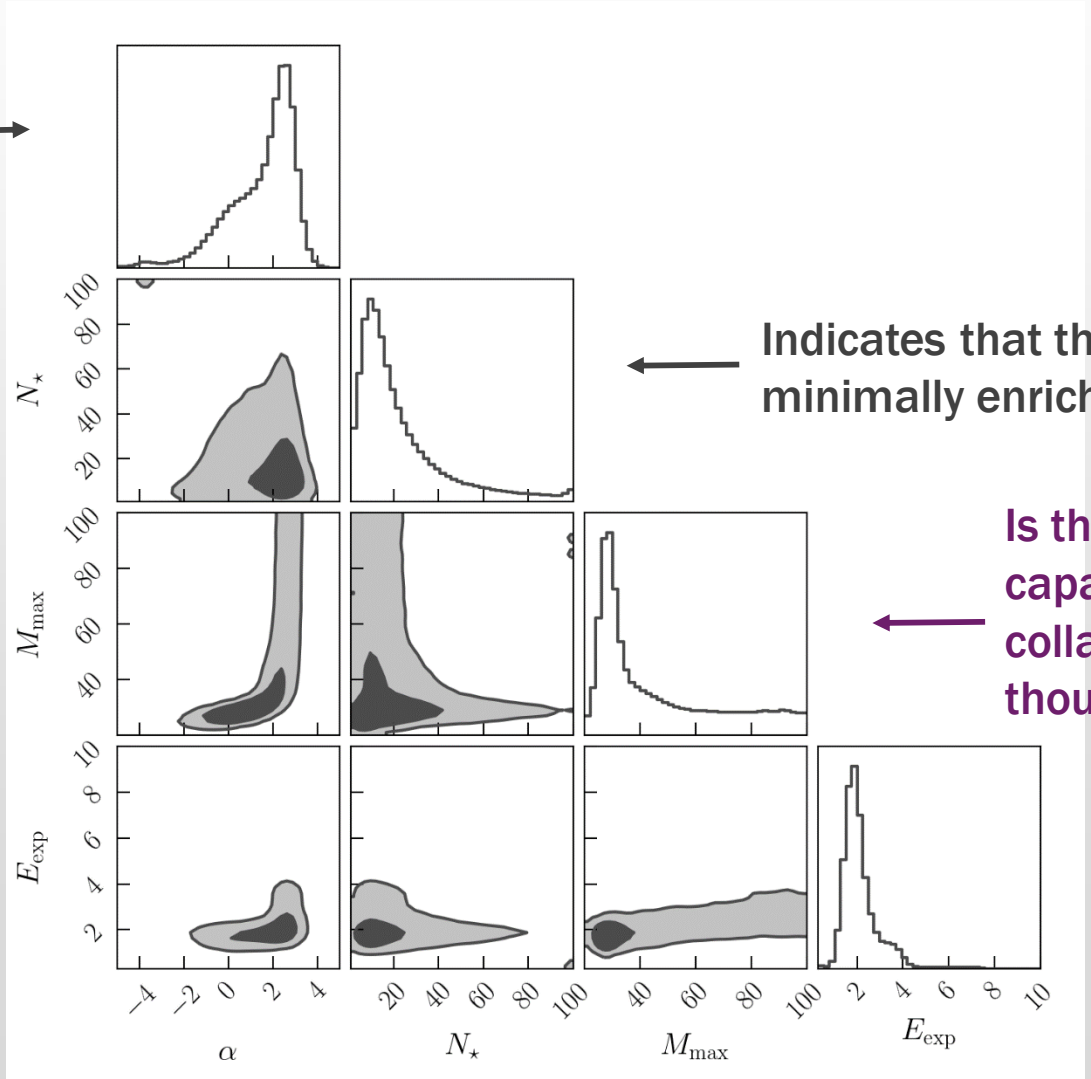


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Is the upper mass limit of stars capable of enrichment via core-collapse SNe lower than previously thought? (See Sukhbold et al. 2016)

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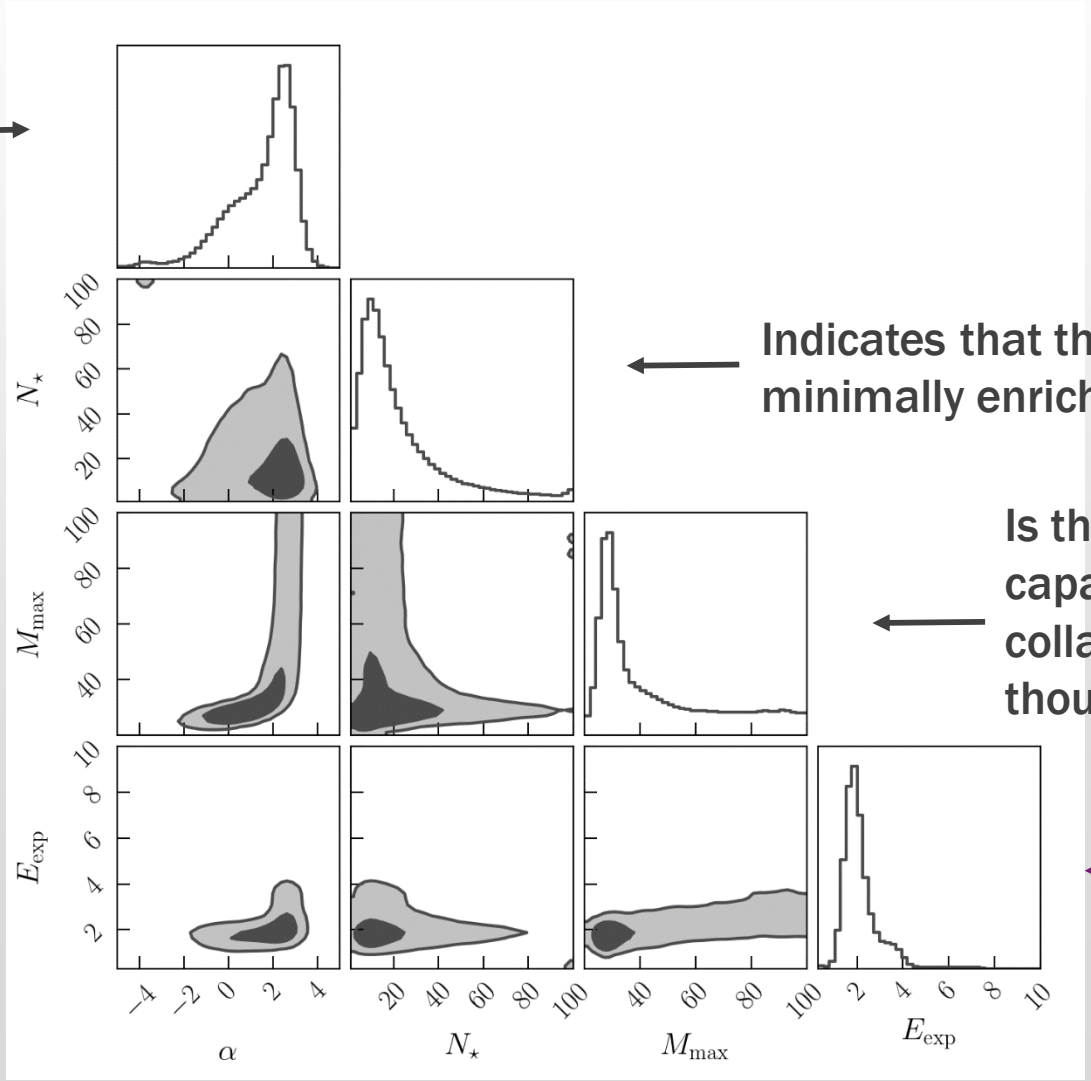


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Slightly higher than that found by previous studies (e.g. Heger and Woosley 2010)

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# Conclusions and Future

Conclusions:

- Early stellar populations can be investigated using the surviving chemical signature left behind by their core-collapse supernovae;
- This technique has promising applications once we can isolate a larger sample of near-pristine gaseous systems;
- Investigating the enrichment of gaseous systems provides an avenue to explore their stellar mass content and other physical properties.

Future:

- Consider these systems in the wider context of galactic evolution;
- Extend this analysis to EMP stars and compare the enrichment histories of these objects.

# Properties of gaseous systems