Modelling the chemical enrichment by Population III supernovae: origins of the metals in near-pristine gas clouds.

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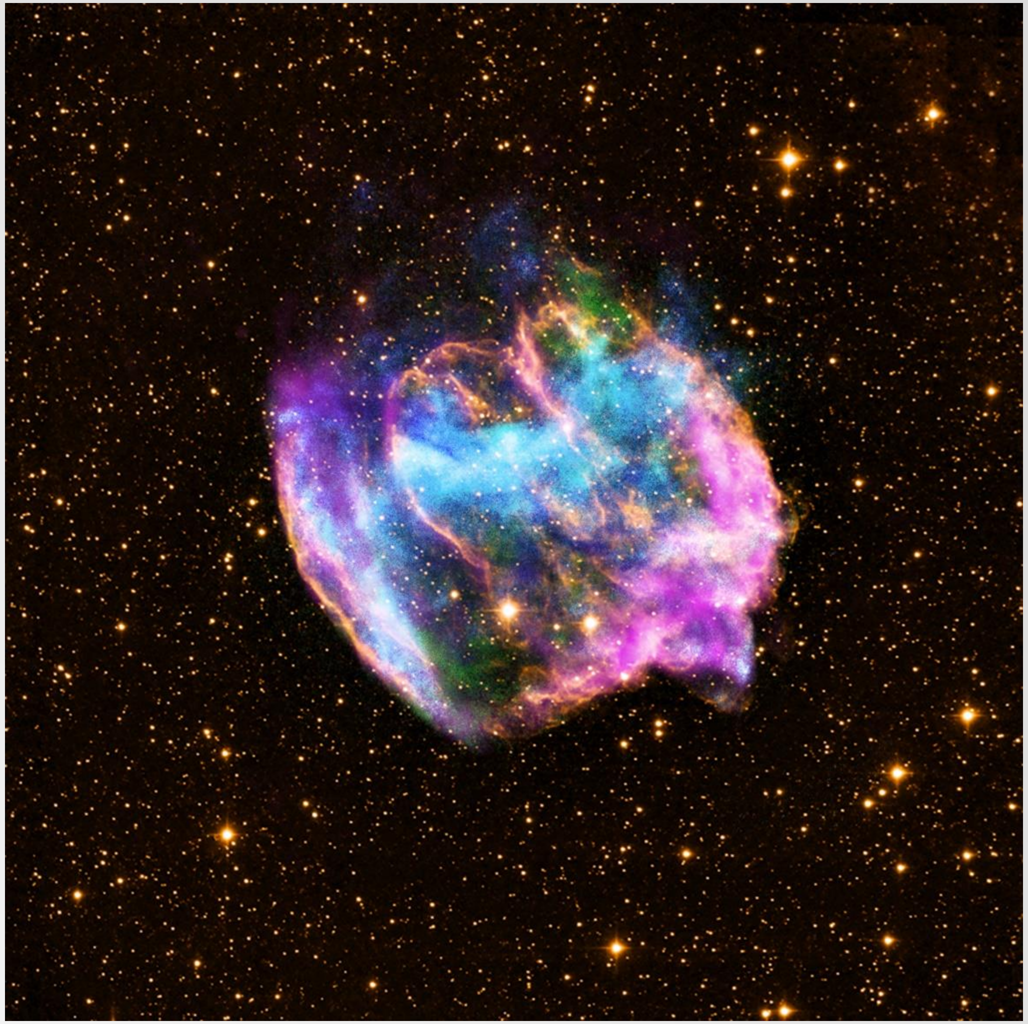
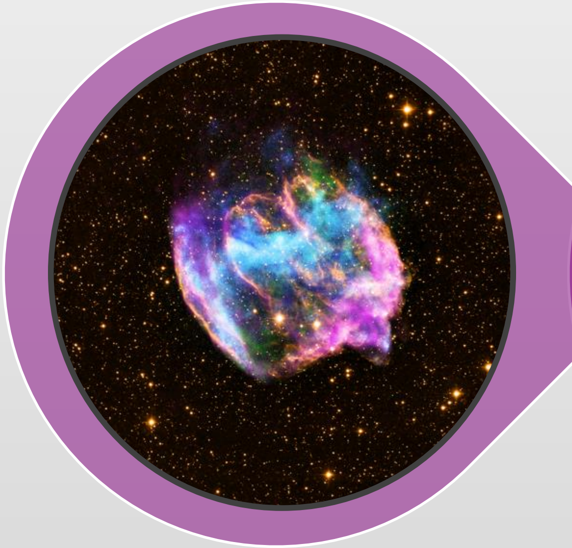


Image credit: X-ray: NASA/CXC/MIT/L.Lopez et al.; Infrared: Palomar; Radio: NSF/NRAO/VLA

In a Nutshell

Population III Properties

- Thought to have formed in small multiples,
- Thought to have formed with higher masses than stars forming from metal-enriched gas,
- Can search for surviving chemical signature in potential Population III relics.



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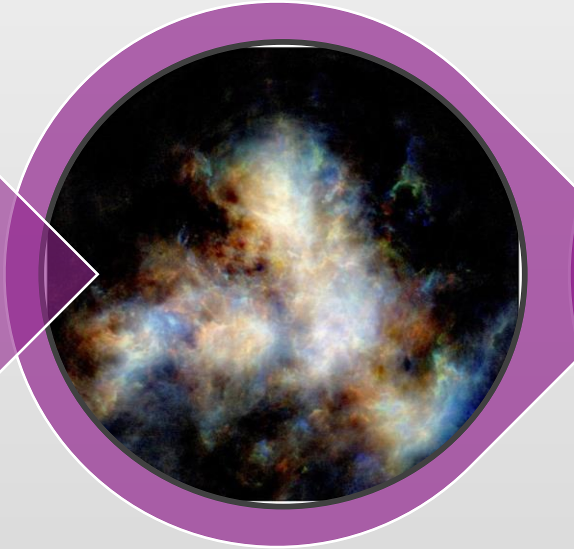


Image credit: Naomi McClure-Griffiths *et al*, CSIRO's ASKAP telescope

Image credit: ESA/NASA

Chemical signature of Population III stars

- 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)

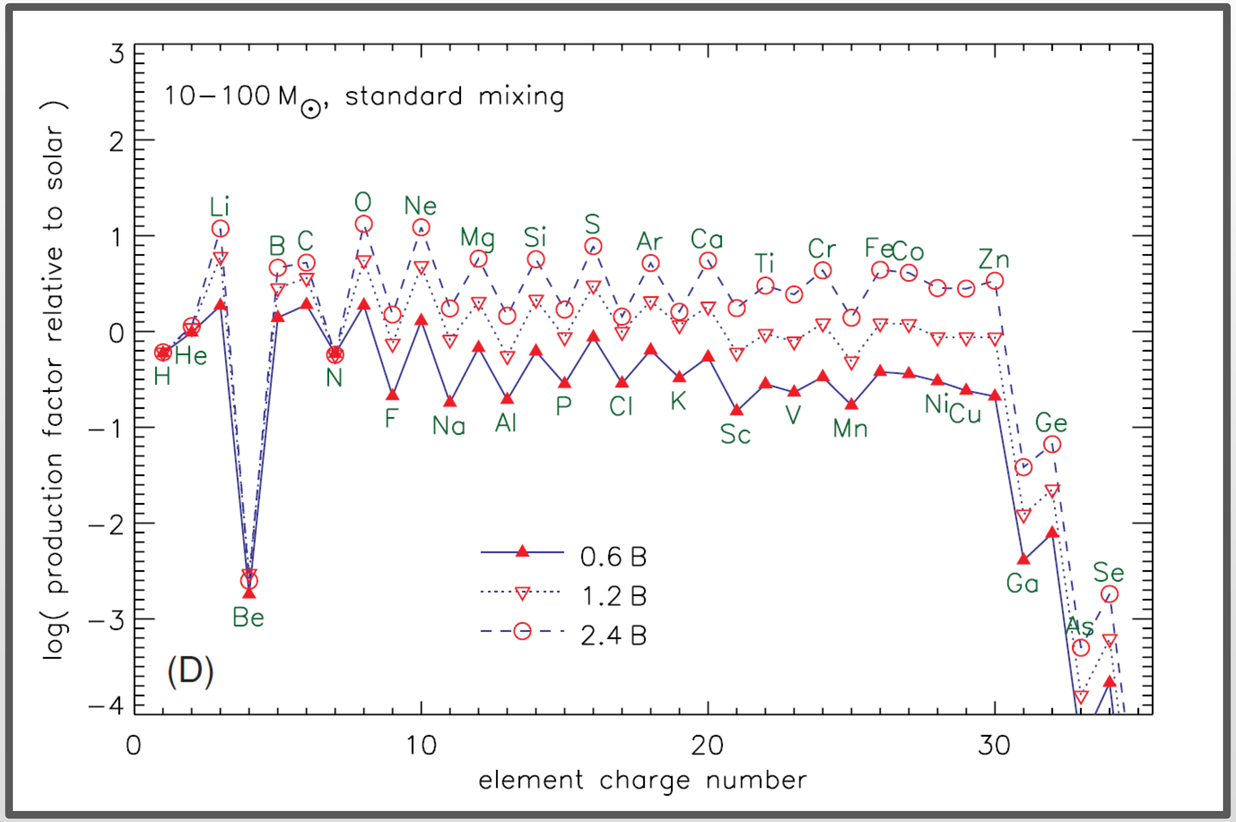
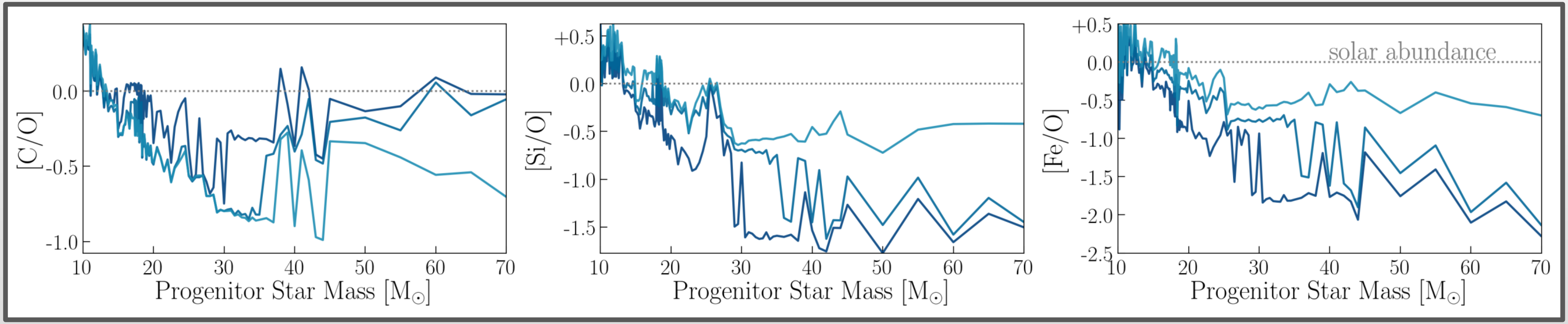


Image Credit: Heger & Woosley (2010)

[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) ≥ 2×10^{20} cm^{-2}

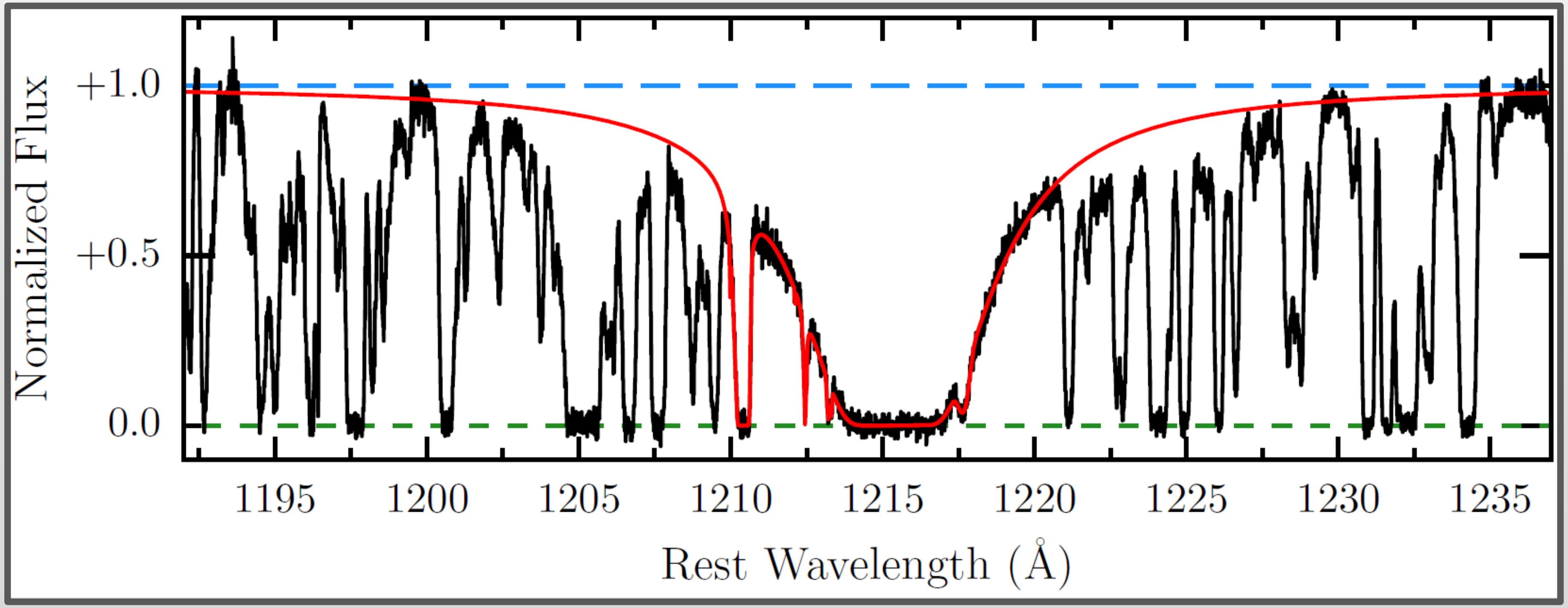
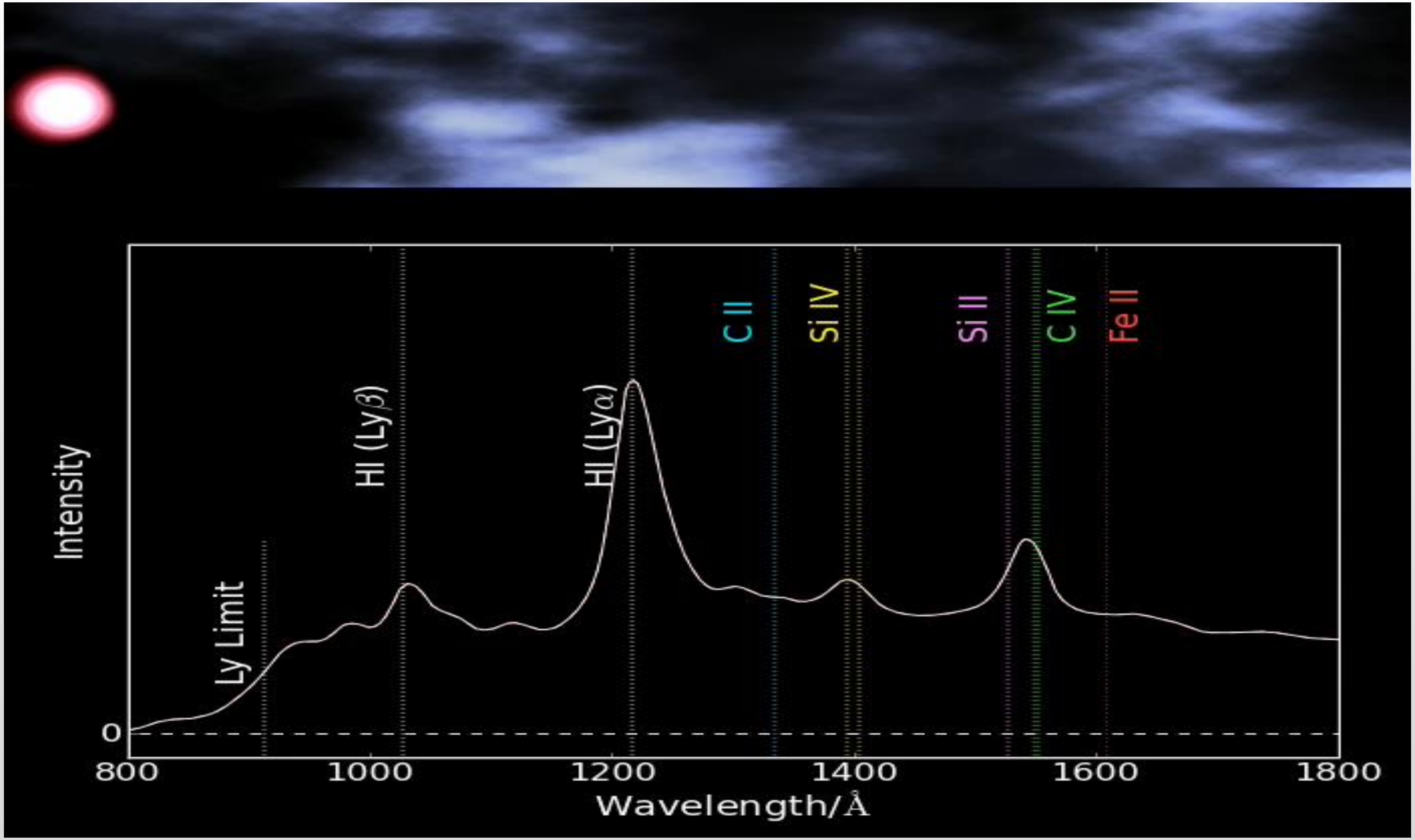
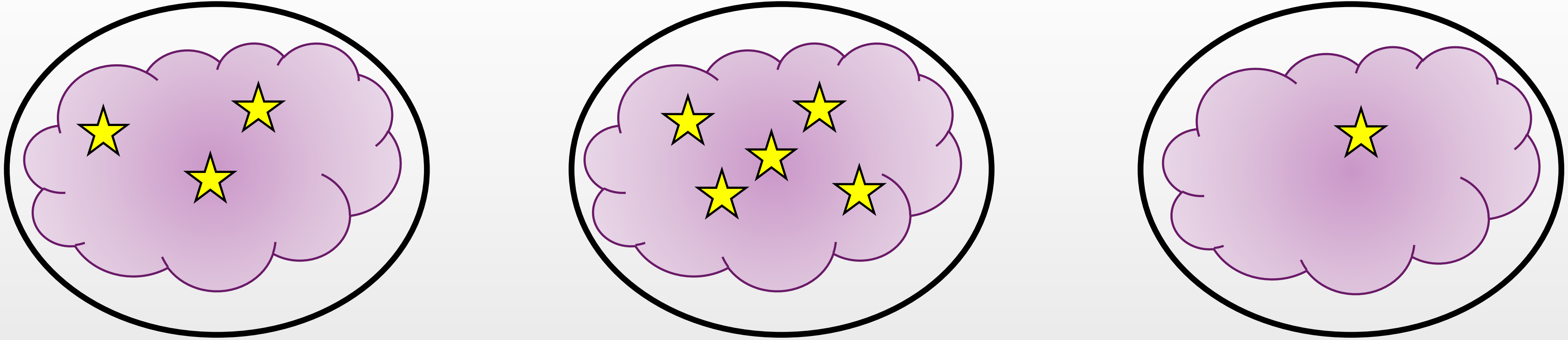


Image Credit: Cooke et al. (2017)

Damped Lyman-alpha systems



Enrichment Model



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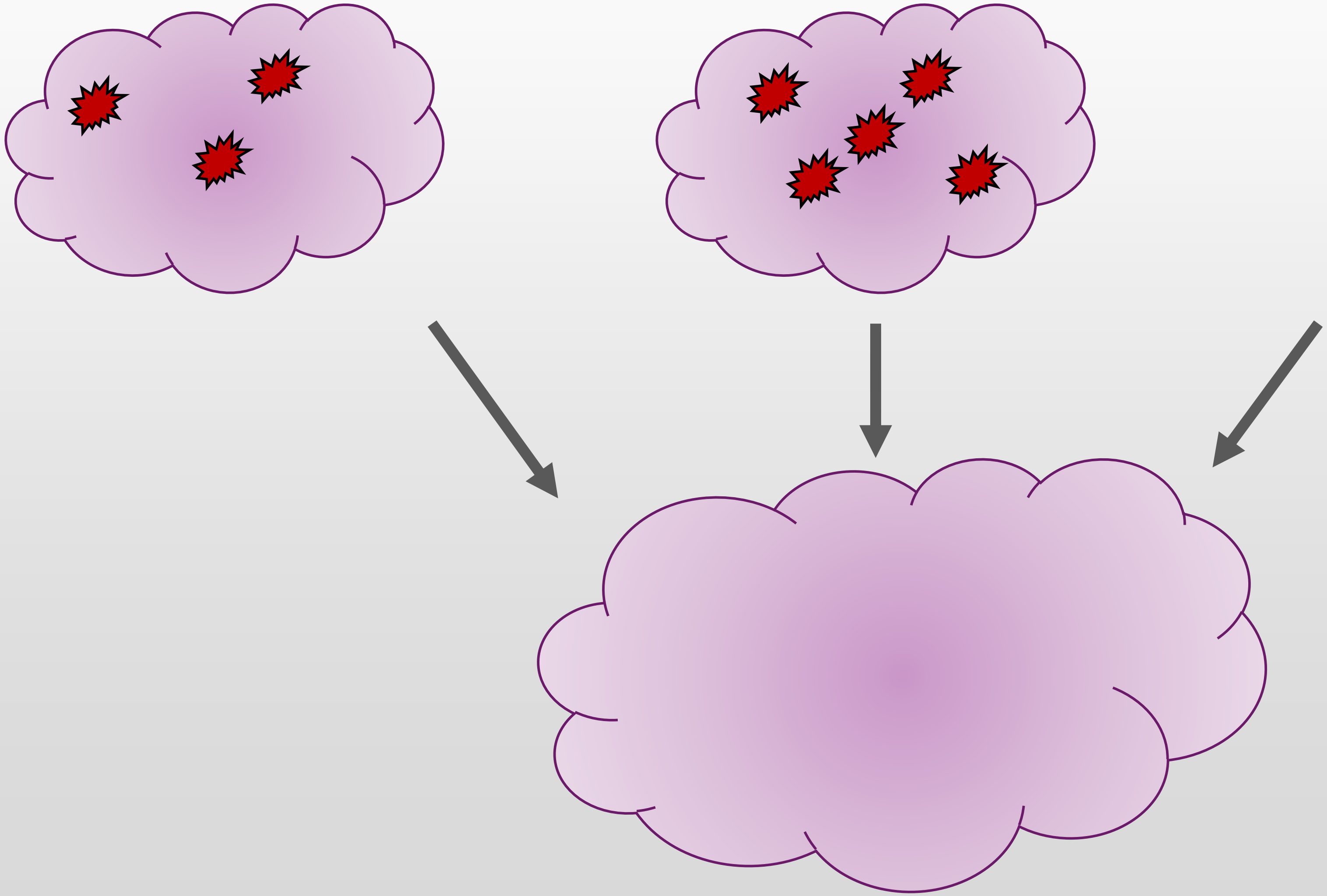

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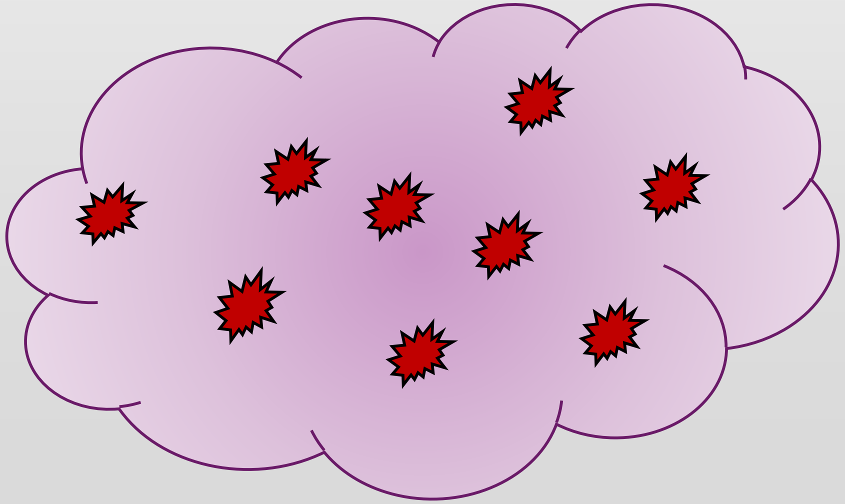

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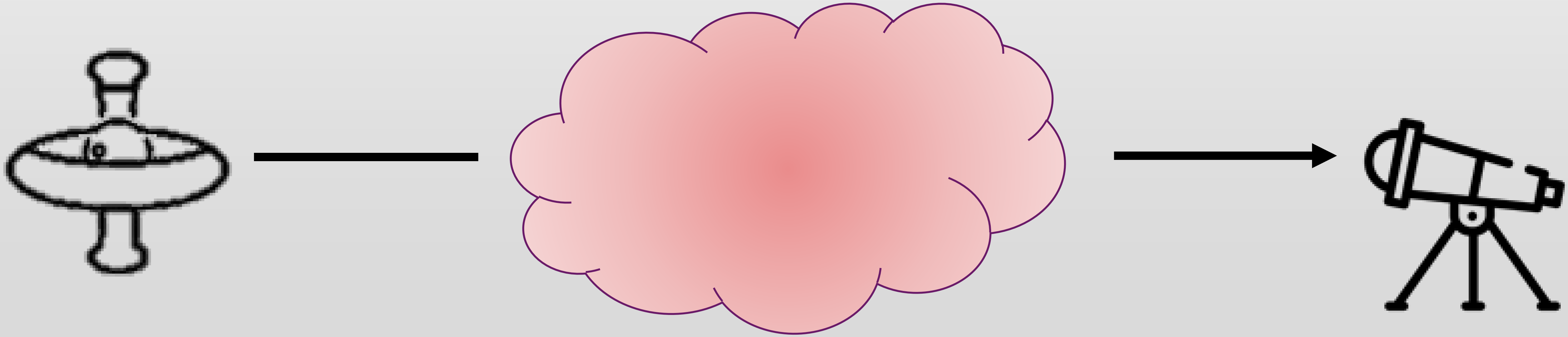


Enrichment model

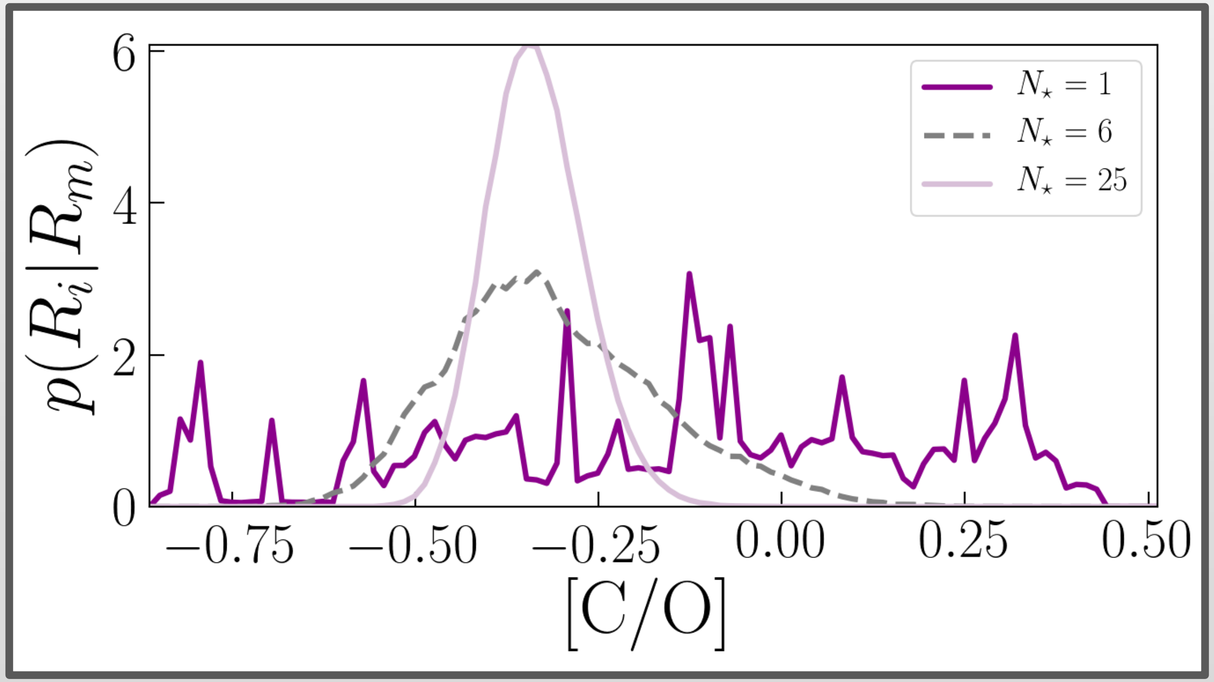
$$N_{\star} = \int_{M_{min}}^{M_{max}} kM^{-\alpha}\,dM$$

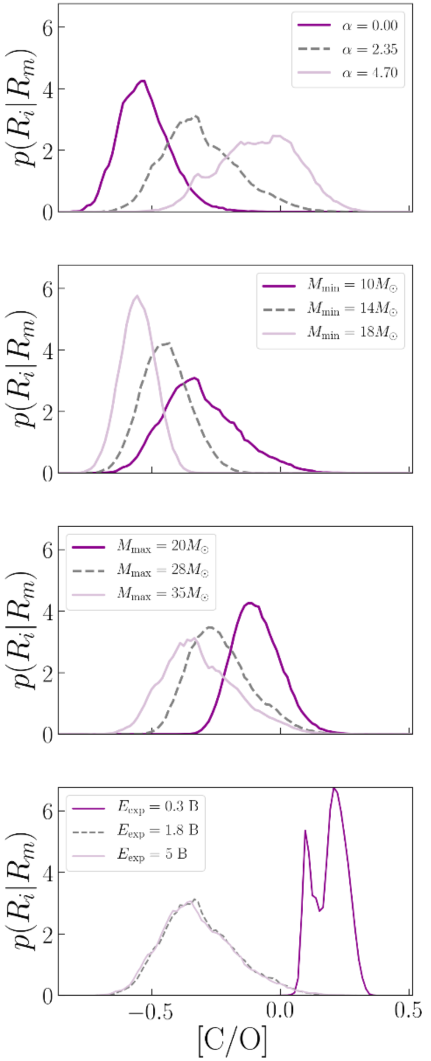
- $N_{\star}$ – number of stars which have contributed to a DLAs enrichment
- M_{min} – minimum mass of enriching stars
- M_{max} – maximum mass of enriching stars
- α – power law mass distribution (Salpeter = 2.35)
- E_{exp} – the energy of supernova explosion at infinity

Probability of [X/Y] given an enrichment model

- Metal-free stars form either individually or in small multiples

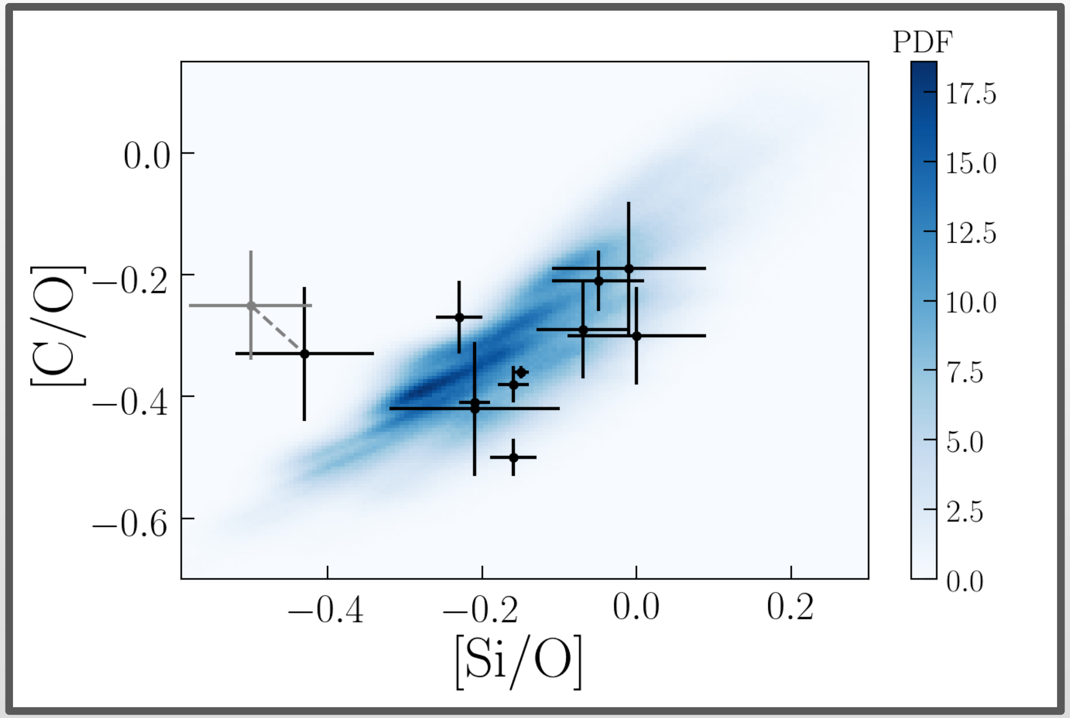
- Underlying IMF is stochastically sampled





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 ~40,000

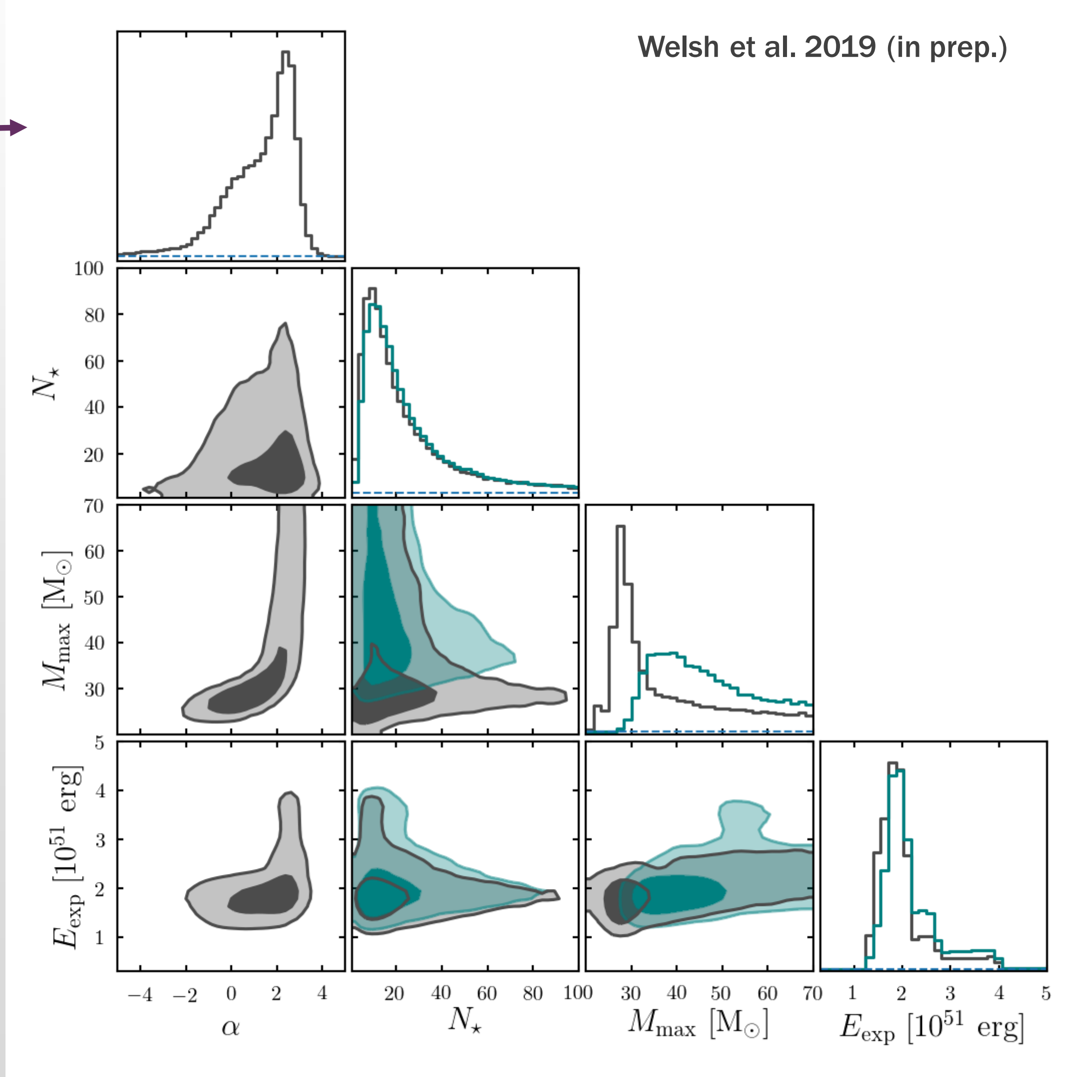


Data from: Dessauages-Zavadsky et al. (2003), Pettini et al. (2008), Ellison et al. (2010), Srianand et al. (2010), Cooke et al. (2011), Cooke, Pettini, & Murphy (2012), Cooke et al. (2014), Dutta et al. (2014), Morrison et al. (2016), Cooke et al. (2017).

Likelihood analysis

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

Consistent with Salpeter distribution. →



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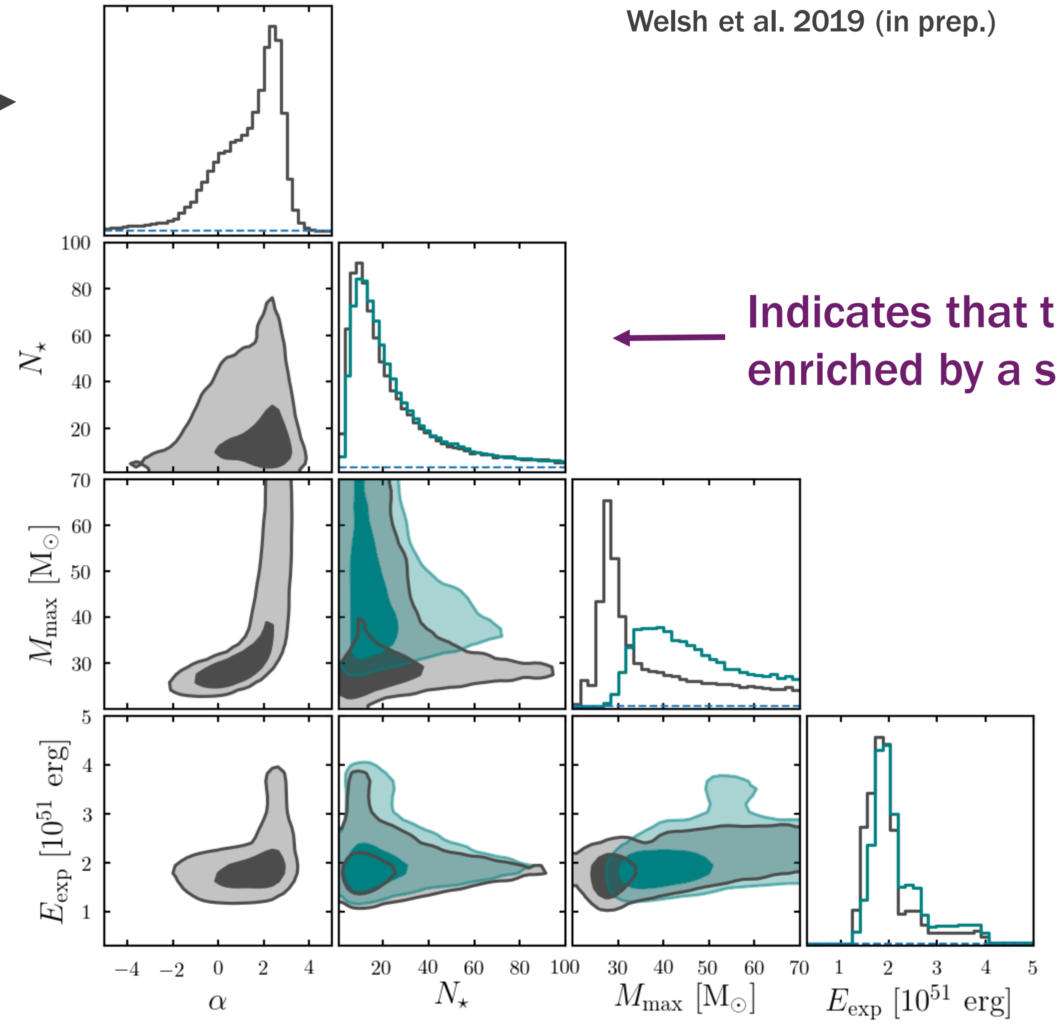

Welsh et al. 2019 (in prep.)

Indicates that these systems have been enriched by a small number of massive stars

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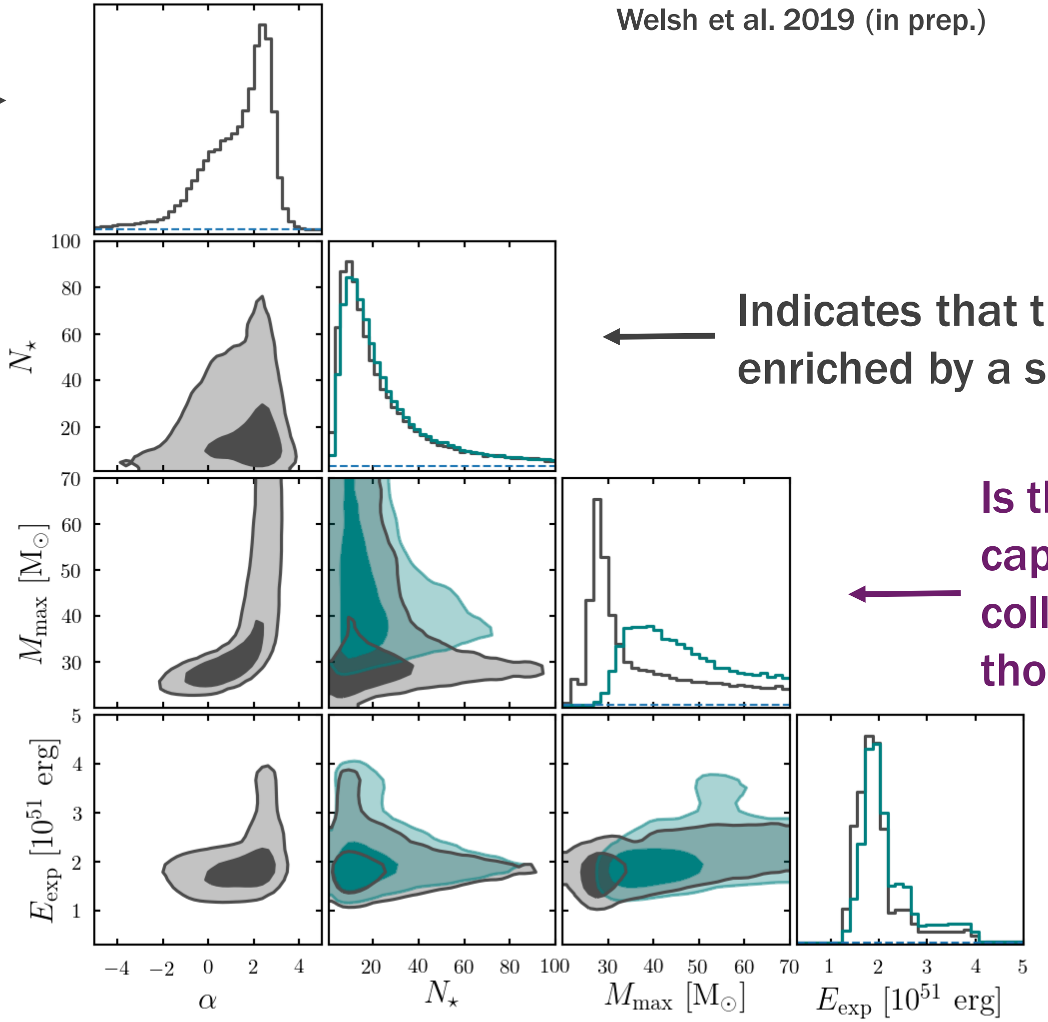

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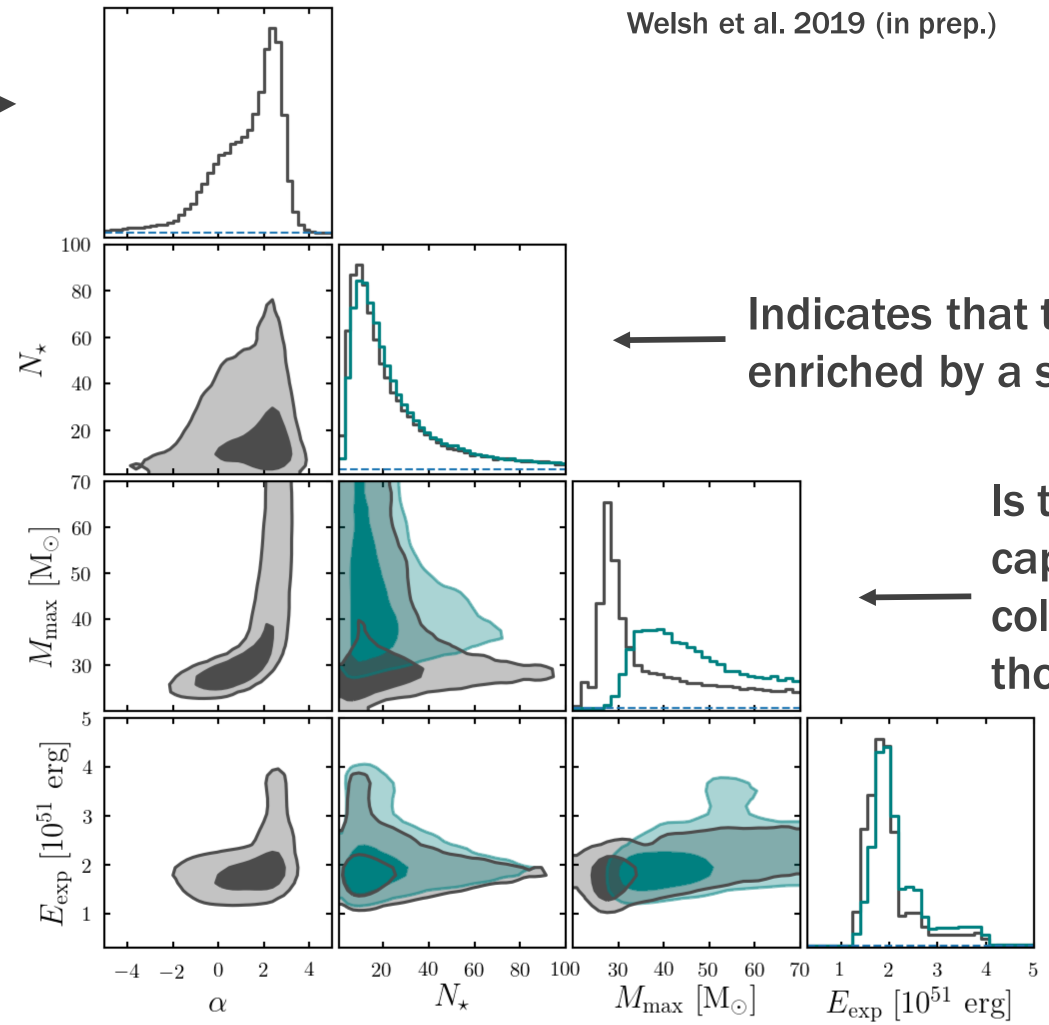

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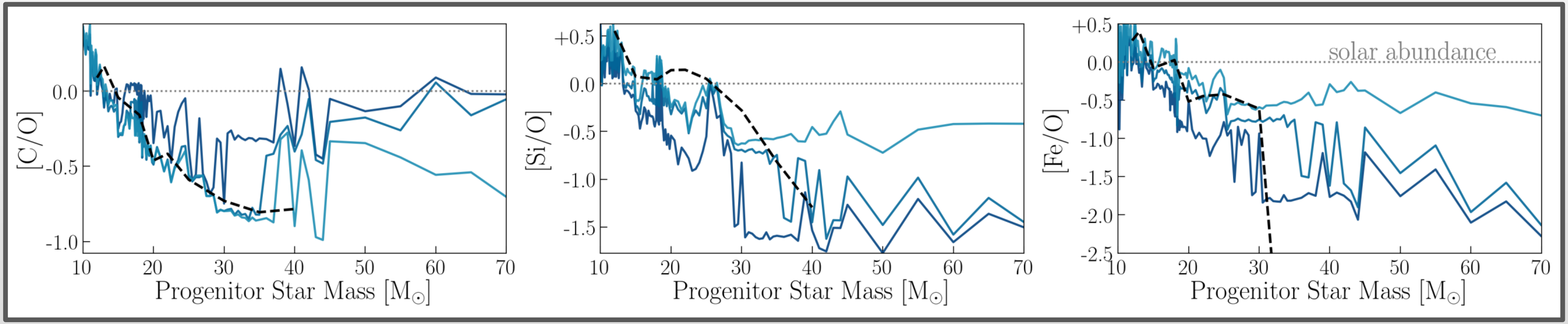
Slightly lower than that found by recent studies studies (e.g. Cooke et al. 2017; Ishigaki et al. 2018)

[X/Y] relationship with initial progenitor mass

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



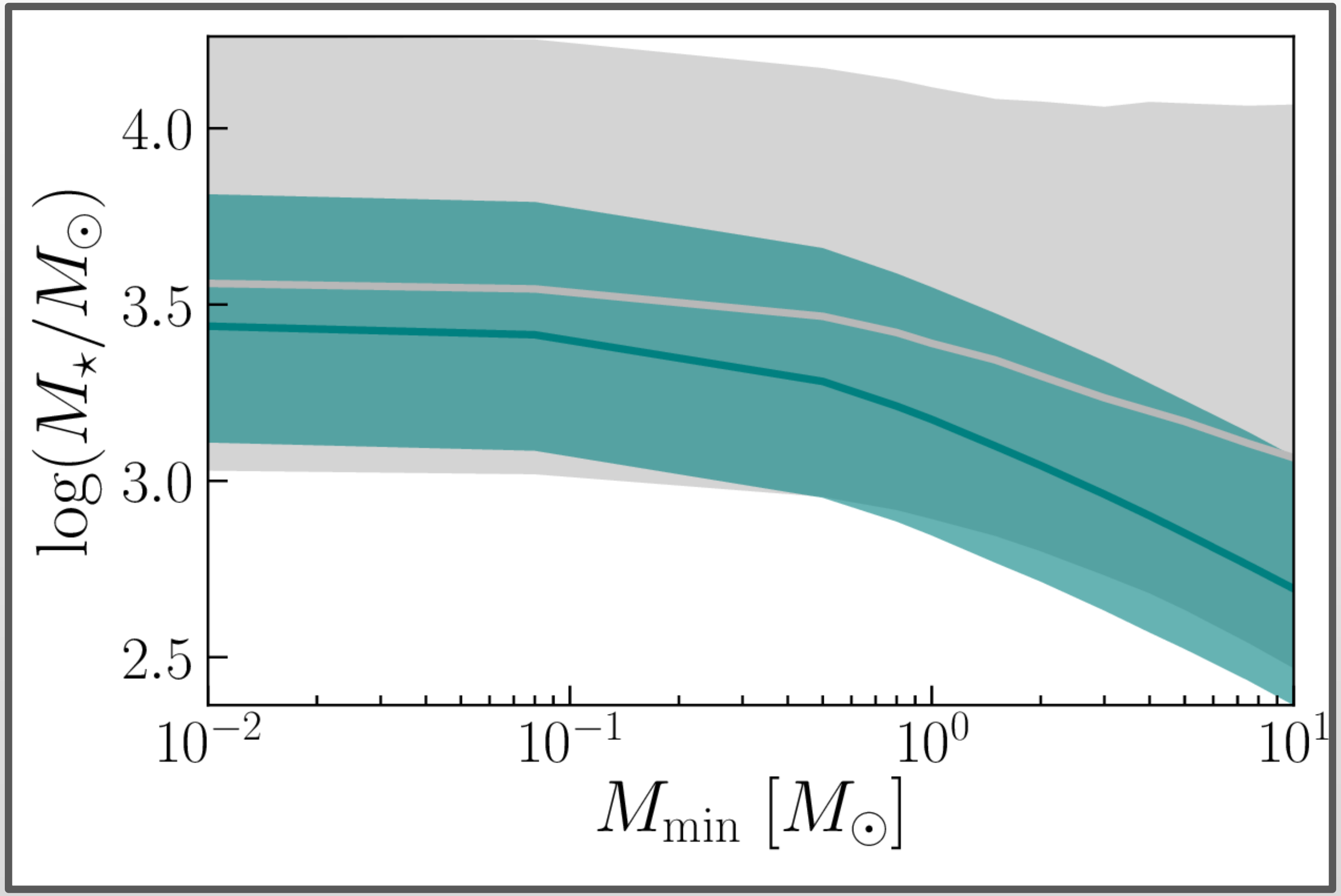
low explosion energy → high explosion energy

What Can We Learn?

Properties of metal-poor DLAs

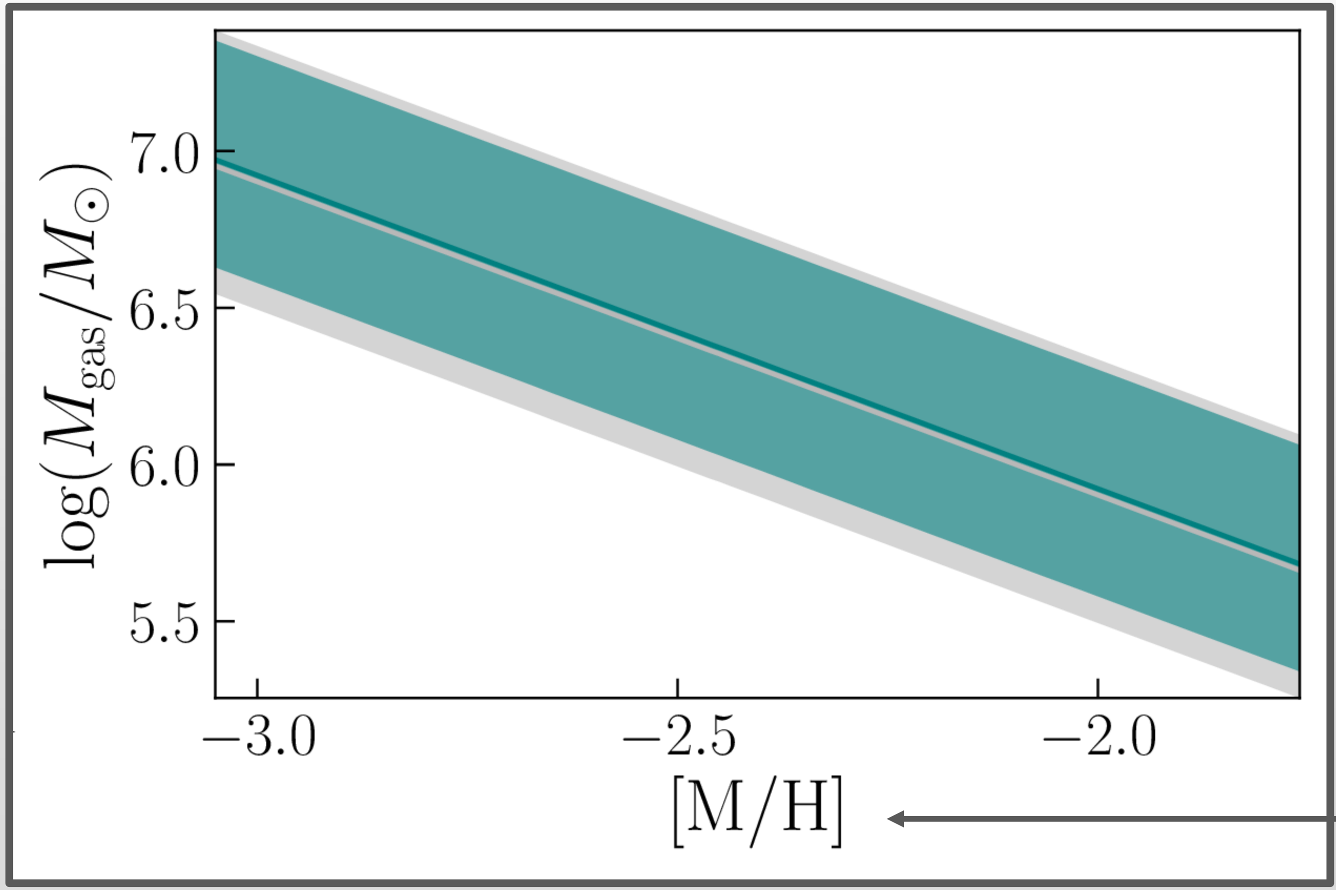
Assuming a log-normal IMF below 1 $M_\odot$ (Chabrier)

$$M_\star = \int_{M_{min}}^{M_{max}} \xi(M) M dM \longrightarrow$$



Properties of metal-poor DLAs

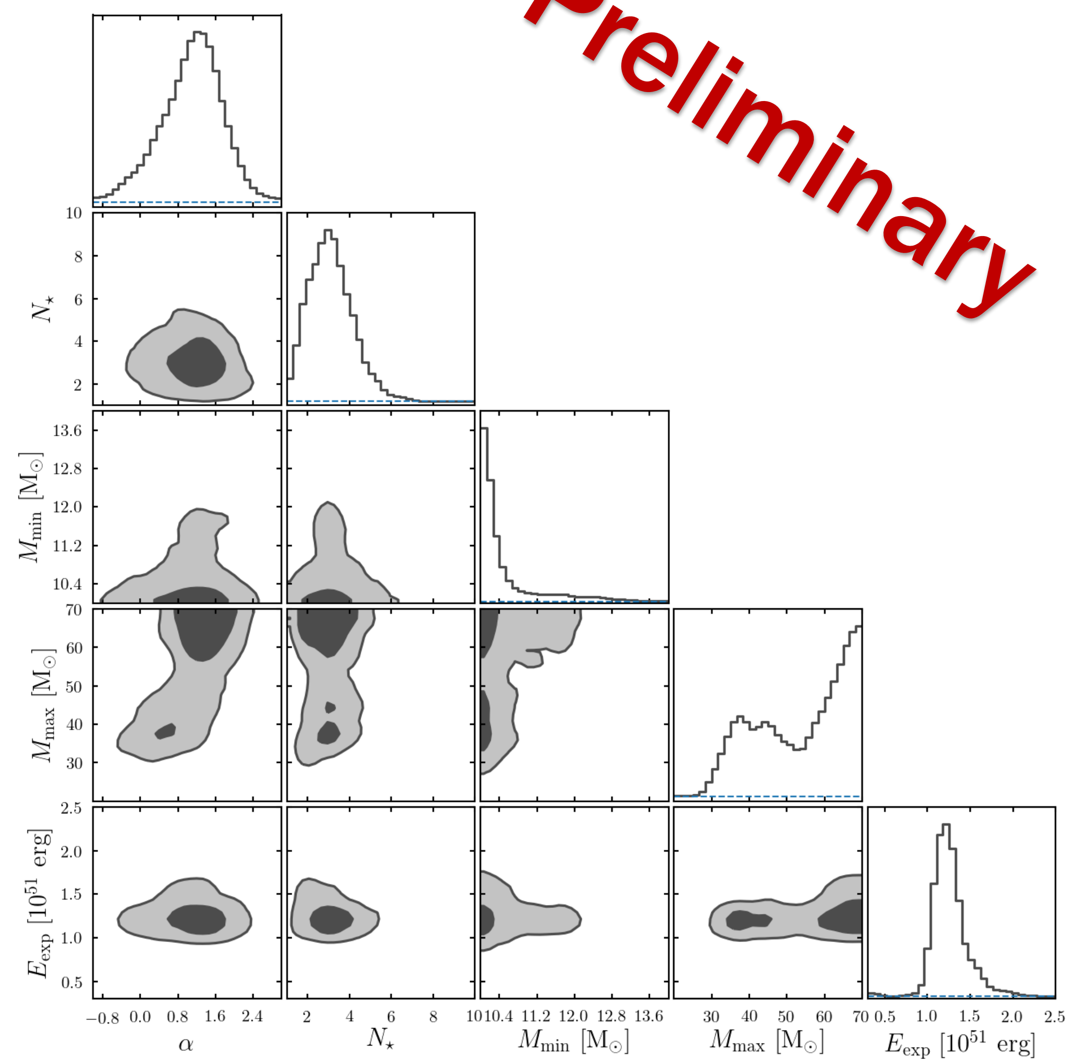
Assuming 100% retention of the metals



Proxies include [C/H], [Si/H] and [O/H]

Applying analysis to metal-poor stars

- Complementary approach
- Far more metal-poor stars currently known than metal-poor DLAs (~20x)
- Abundances are determined for a larger range of elements
- Abundance determinations are less precise
- Preliminary analysis of the 38 survey stars from Yong et al. 2016 show promising results.



Preliminary

Conclusions and Future

Conclusions:

- Early stellar populations can be investigated using the surviving chemical signature left behind by their core-collapse supernovae;
- This enrichment model takes into account the stochastic nature of Population III IMF;
- The most metal-poor DLAs have been minimally enriched by massive stars;
- Investigating the enrichment of these DLAs provides an avenue to explore their typical 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.