A Window to the First Stars.

LOUISE WELSH

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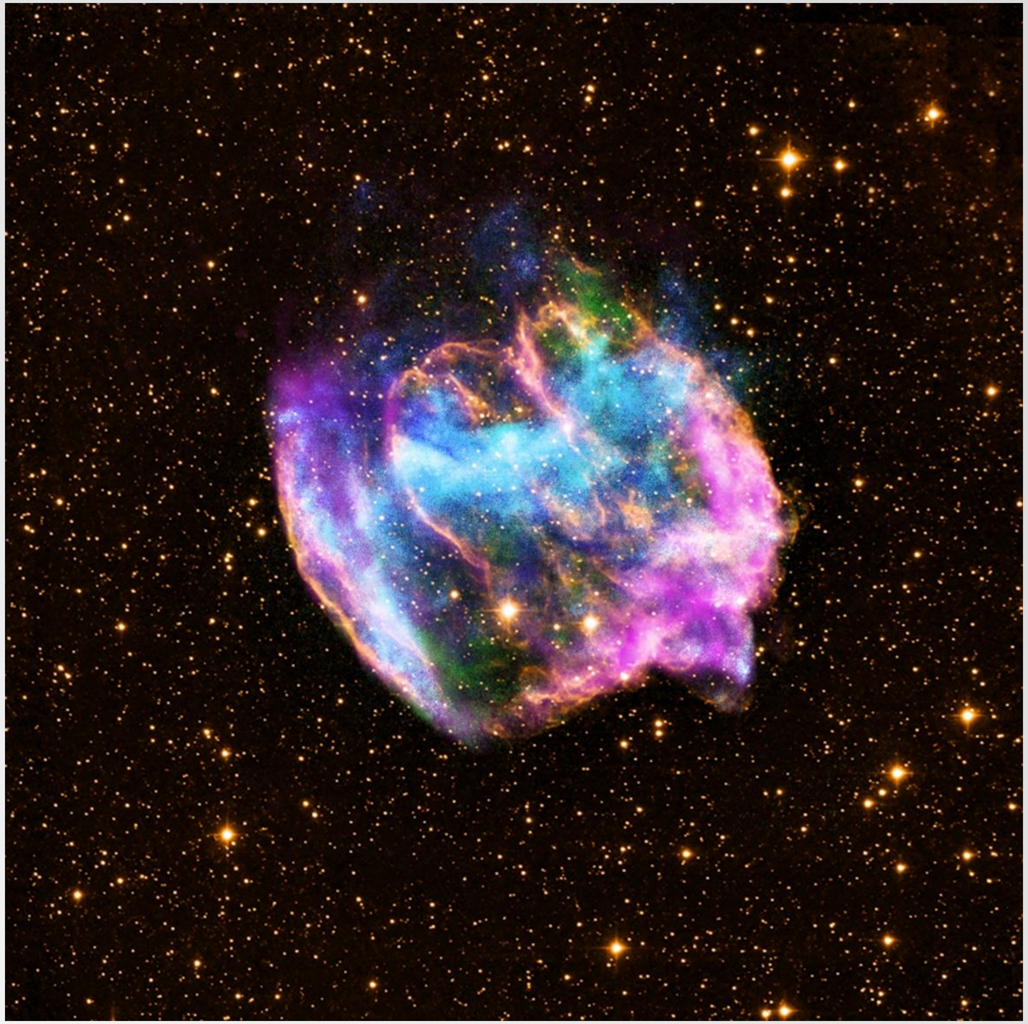

Image credit: X-ray: NASA/CXC/MIT/L.Lopez et al.; Infrared: Palomar; Radio: NSF/NRAO/VLA

In a Nutshell

Population III Properties

- Necessarily form from metal-free environment,
- 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.

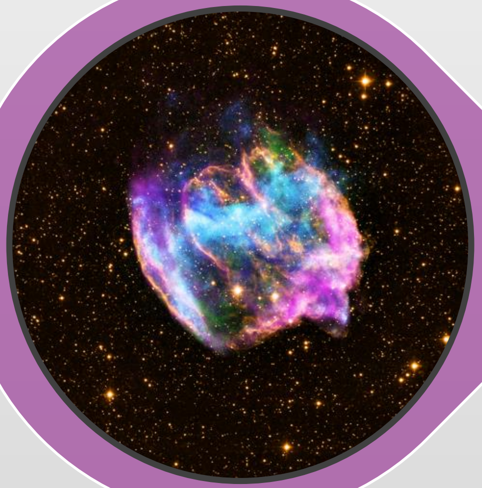

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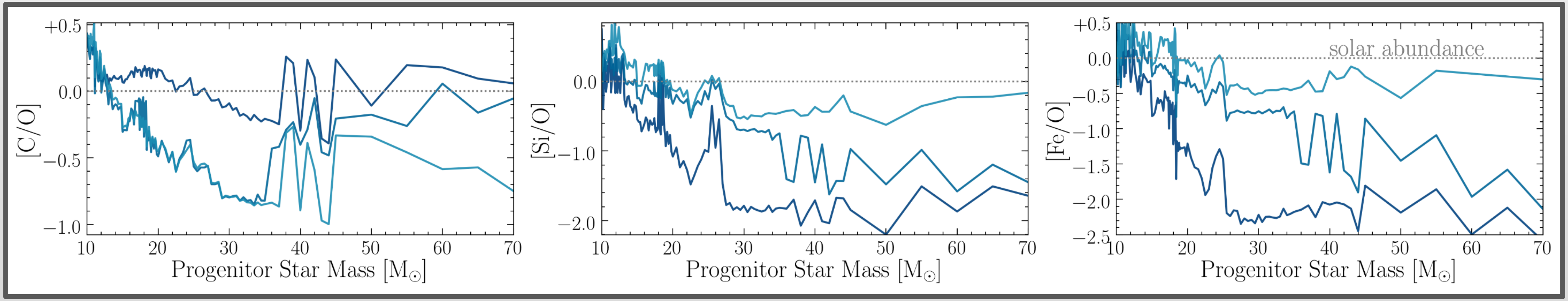
Image credit: Naomi McClure-Griffiths *et al*, CSIRO's ASKAP telescope

Image credit: ESA/NASA

Chemical Signature of Population III stars

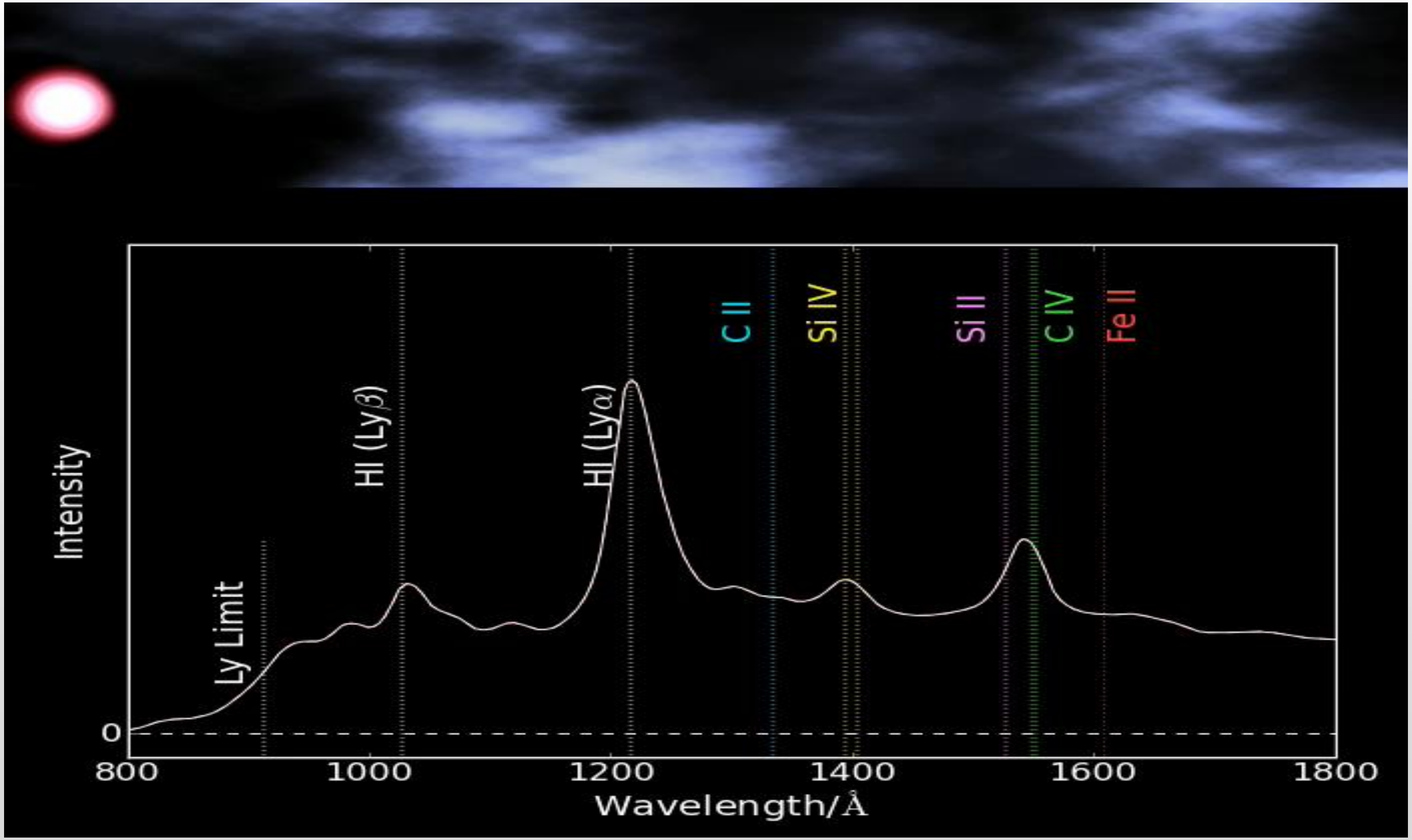
- Simulations of the evolution and explosion of massive metal-free stars provide expected chemical signature (I use those of Heger & Woosley 2010)

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

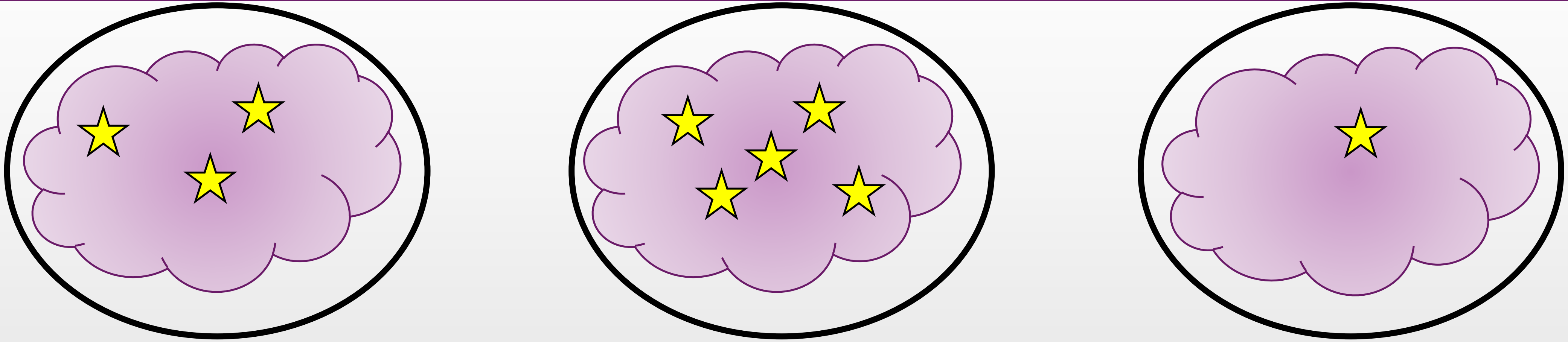


low explosion energy → high explosion energy

Damped Lyman-alpha systems (DLAs)



Stochastic Enrichment Model



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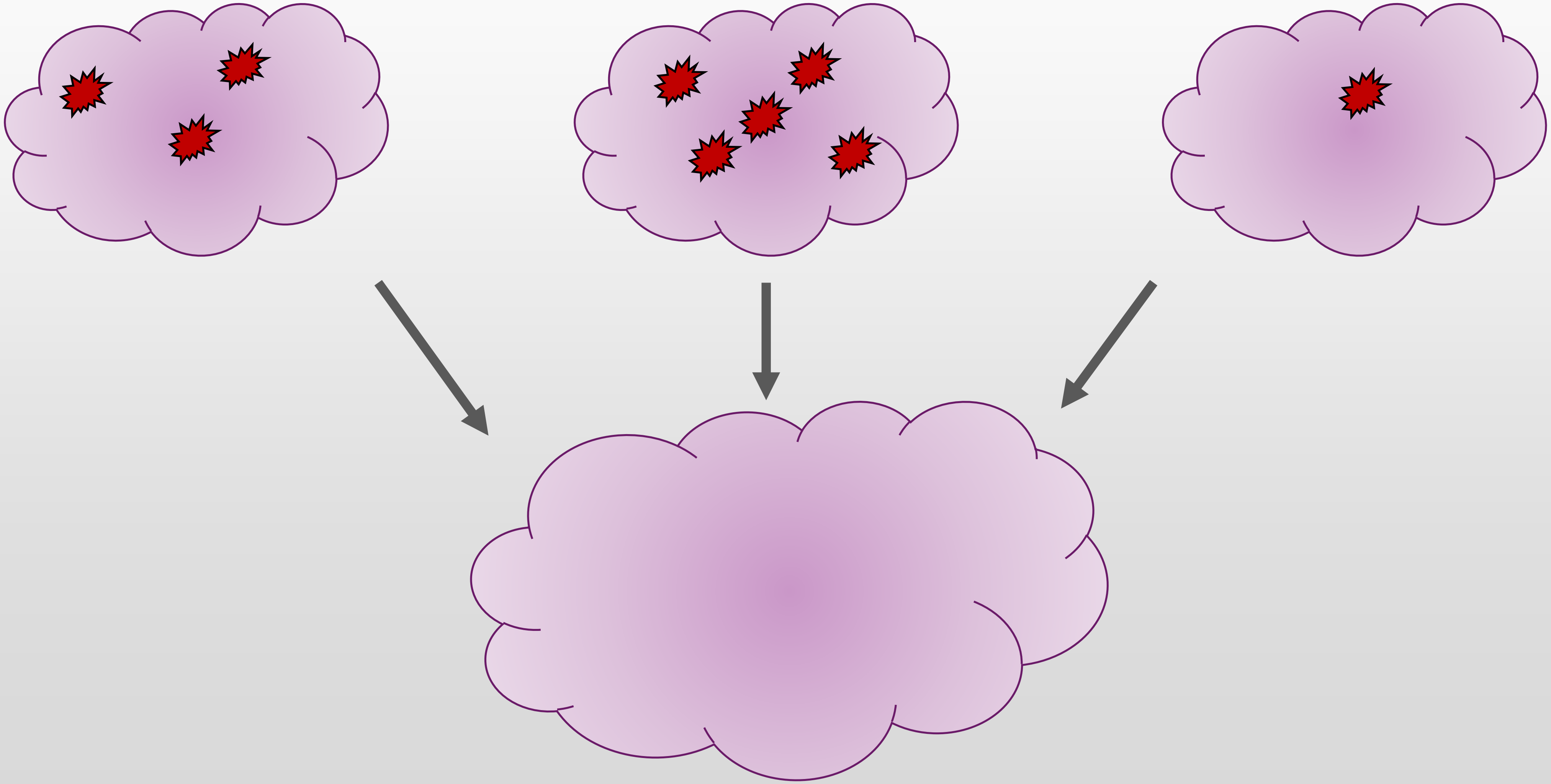

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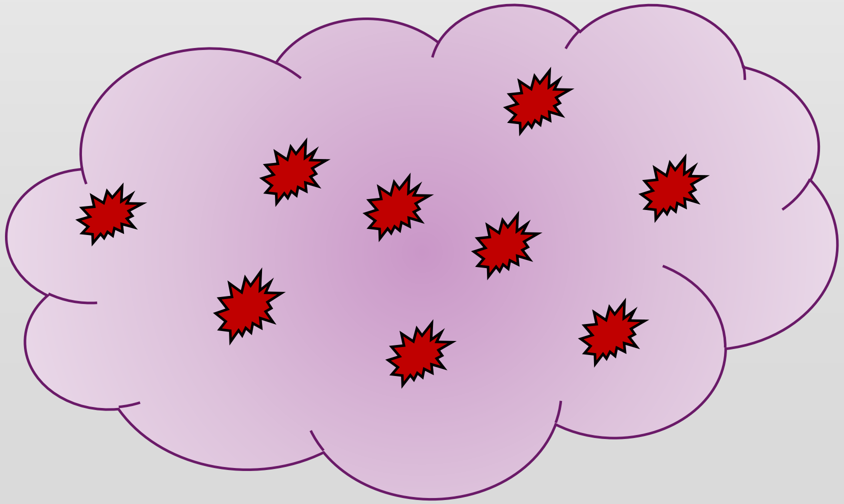

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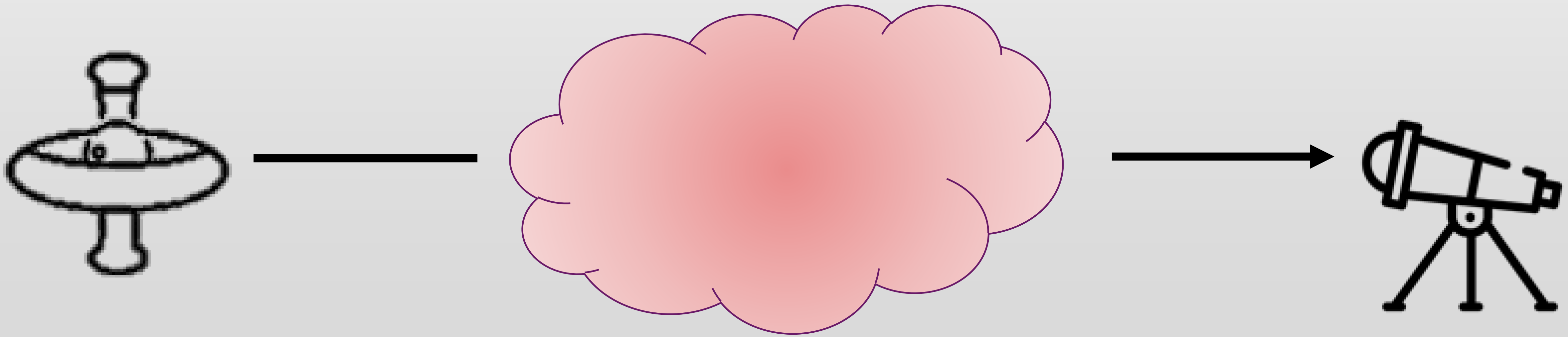


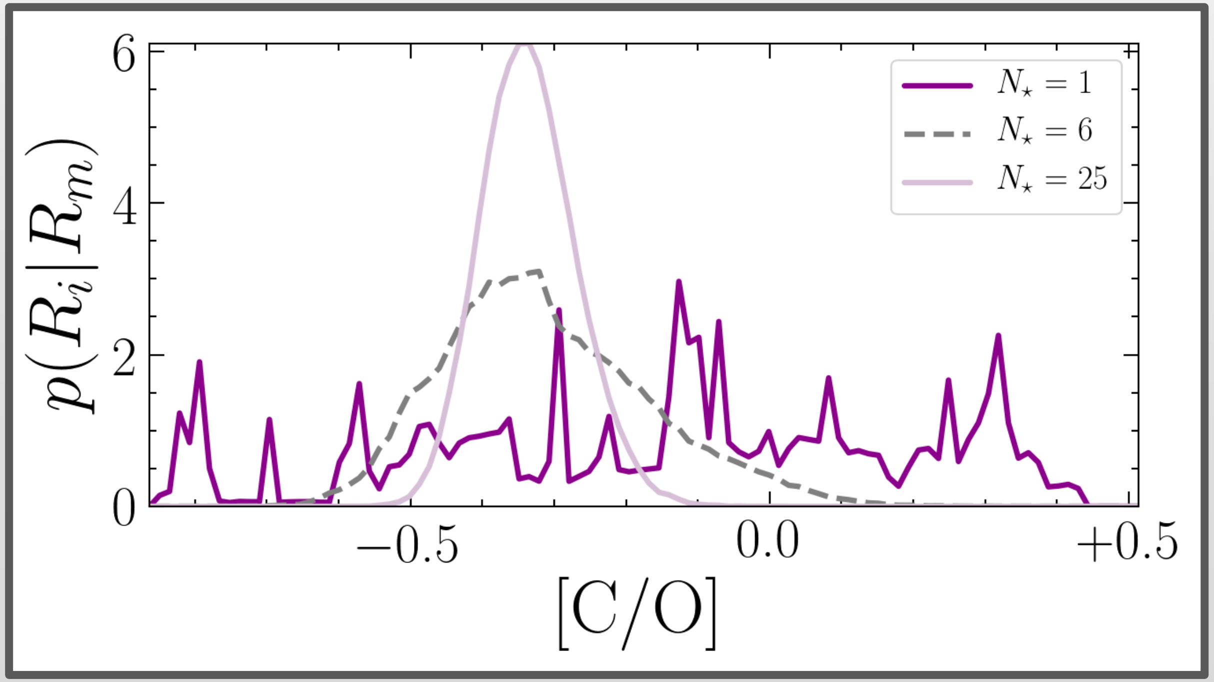
Stochastic Enrichment Model

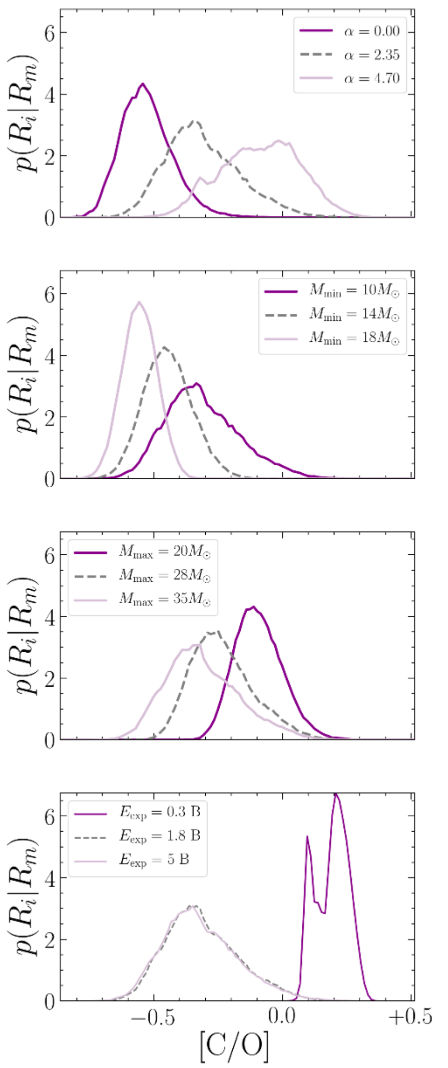
$$N_\star = \int_{M_{min}}^{M_{max}} kM^{-\alpha} dM$$

- $N_\star$ – number of stars which have contributed to 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

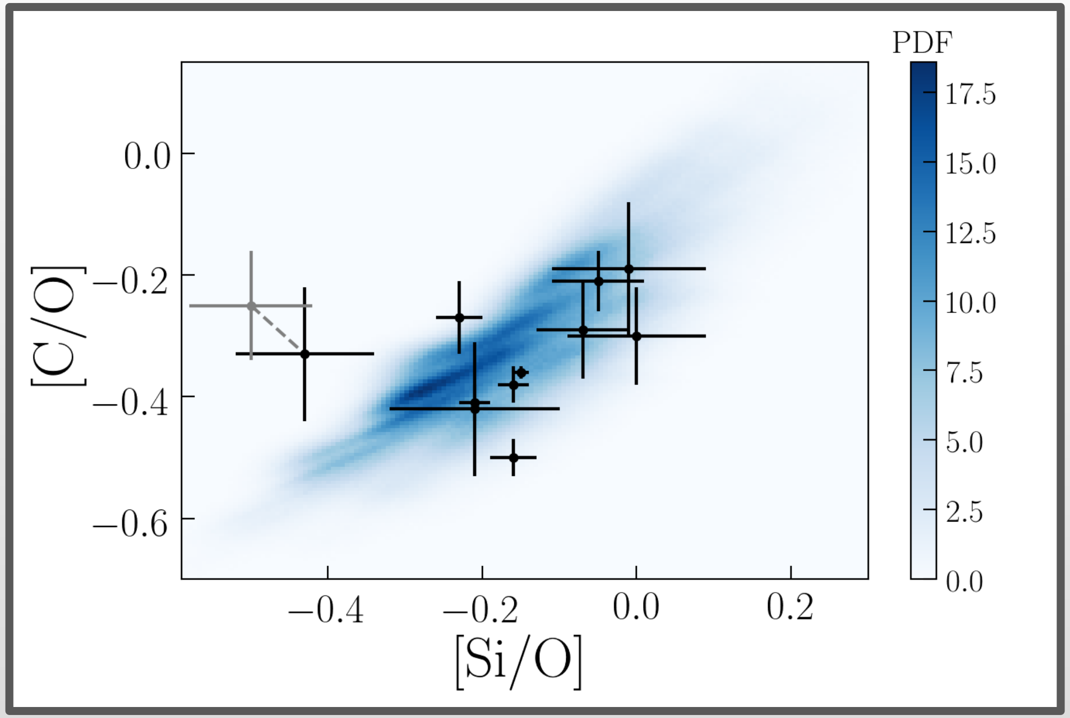
- Metal-free stars form either individually or in small multiples
- Underlying IMF is stochastically sampled





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 iron abundance: -3.45 < [Fe/H] < -2.15
- All systems have a minimum of 2 number abundance ratios ([C/O] and [Si/O]) – most 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

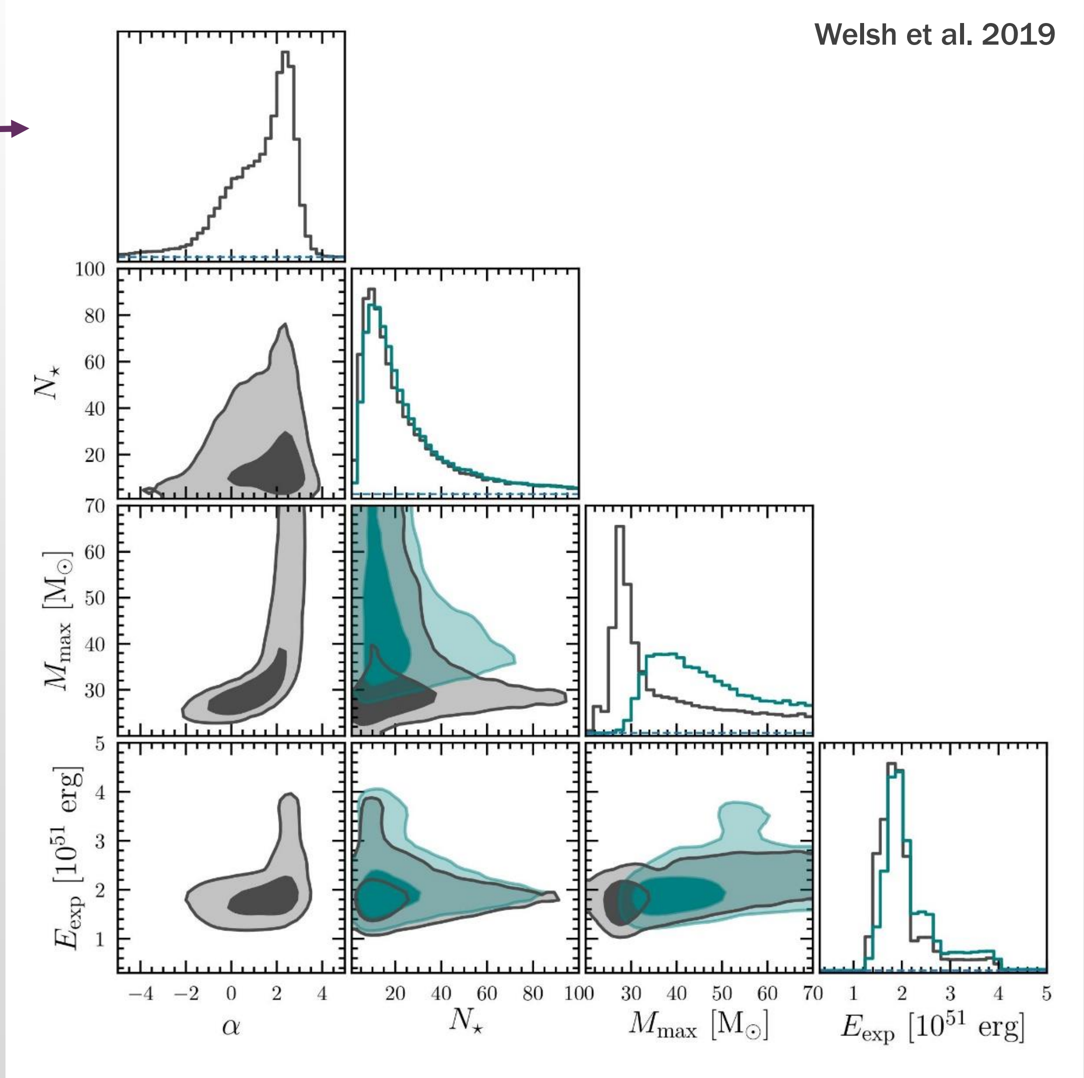


Data from: Dessauages-Zavadsky et al. (2003), Pettini et al. (2008), Ellison et al. (2010), Srianand et al. (2010), Cooke et al. (2011), Cooke, Pettini, & Murphy (2012), Cooke et al. (2014), Dutta et al. (2014), Morrison et al. (2016), Cooke et al. (2017).

Likelihood analysis

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

IMF slope consistent with Salpeter distribution →



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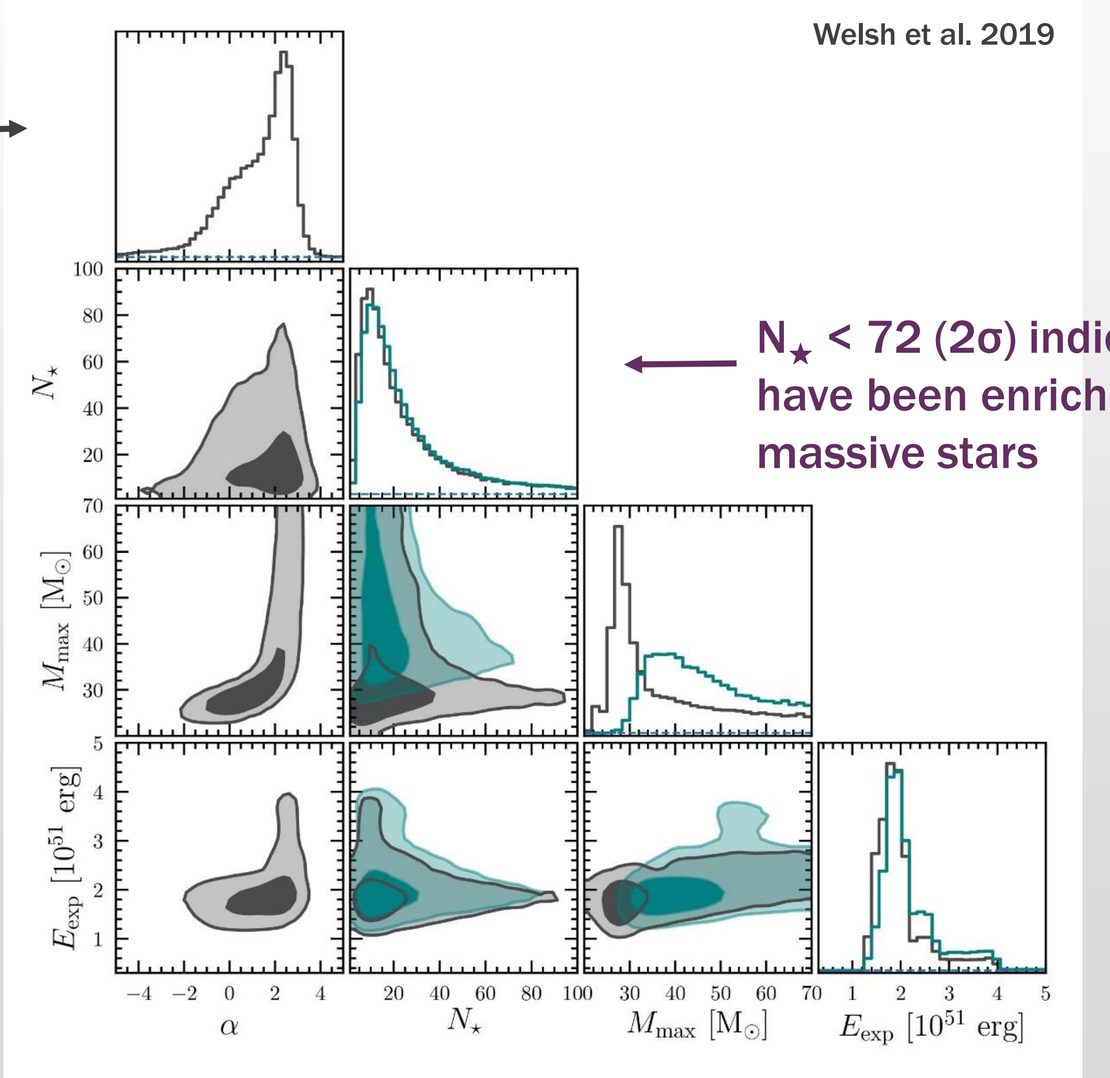

$N_\star$ < 72 (2σ) indicates that these systems have been enriched by a small number of massive stars

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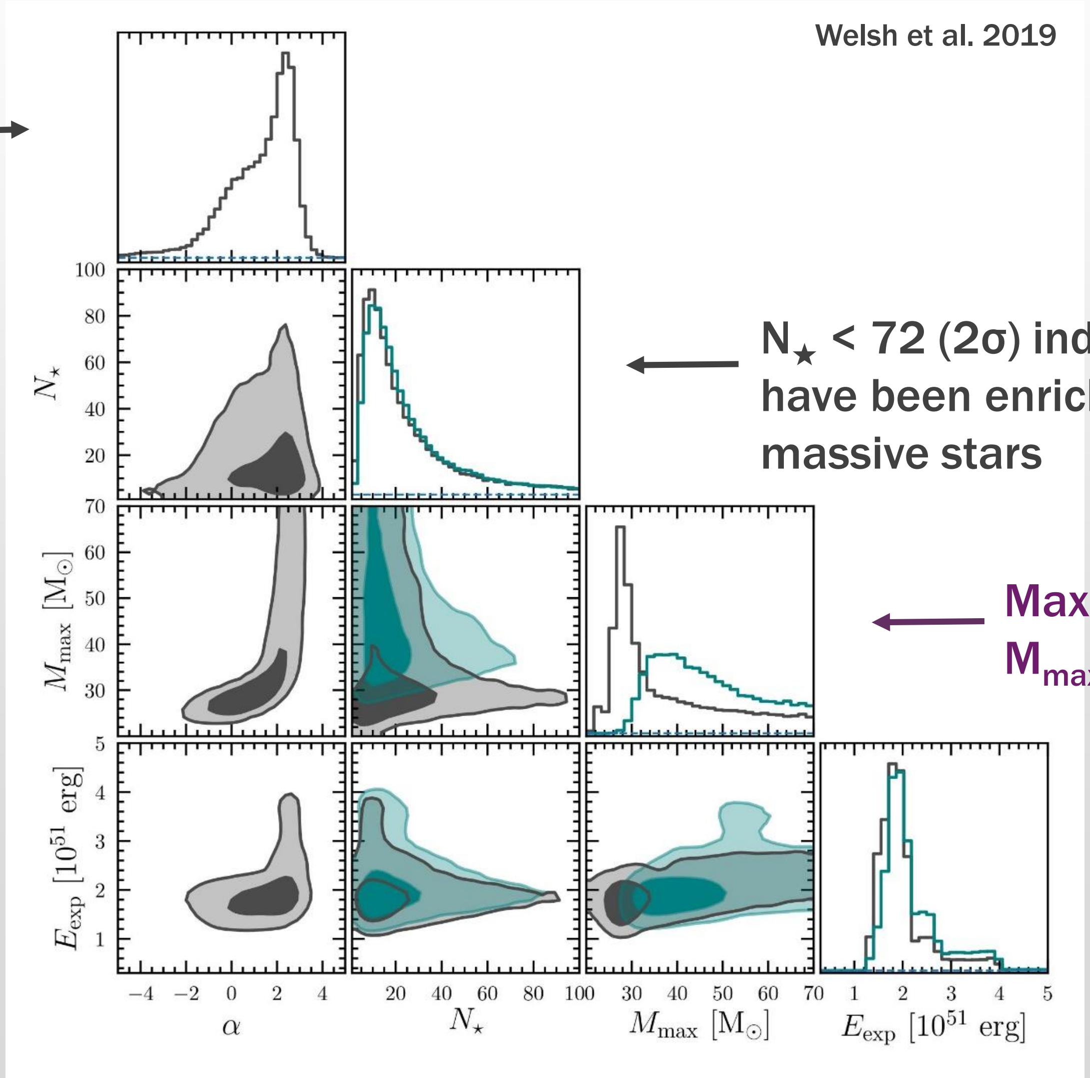

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Maximum mass of enriching stars

$M_{max} < 40\ M_\odot$ (See Sukhbold et al. 2016)

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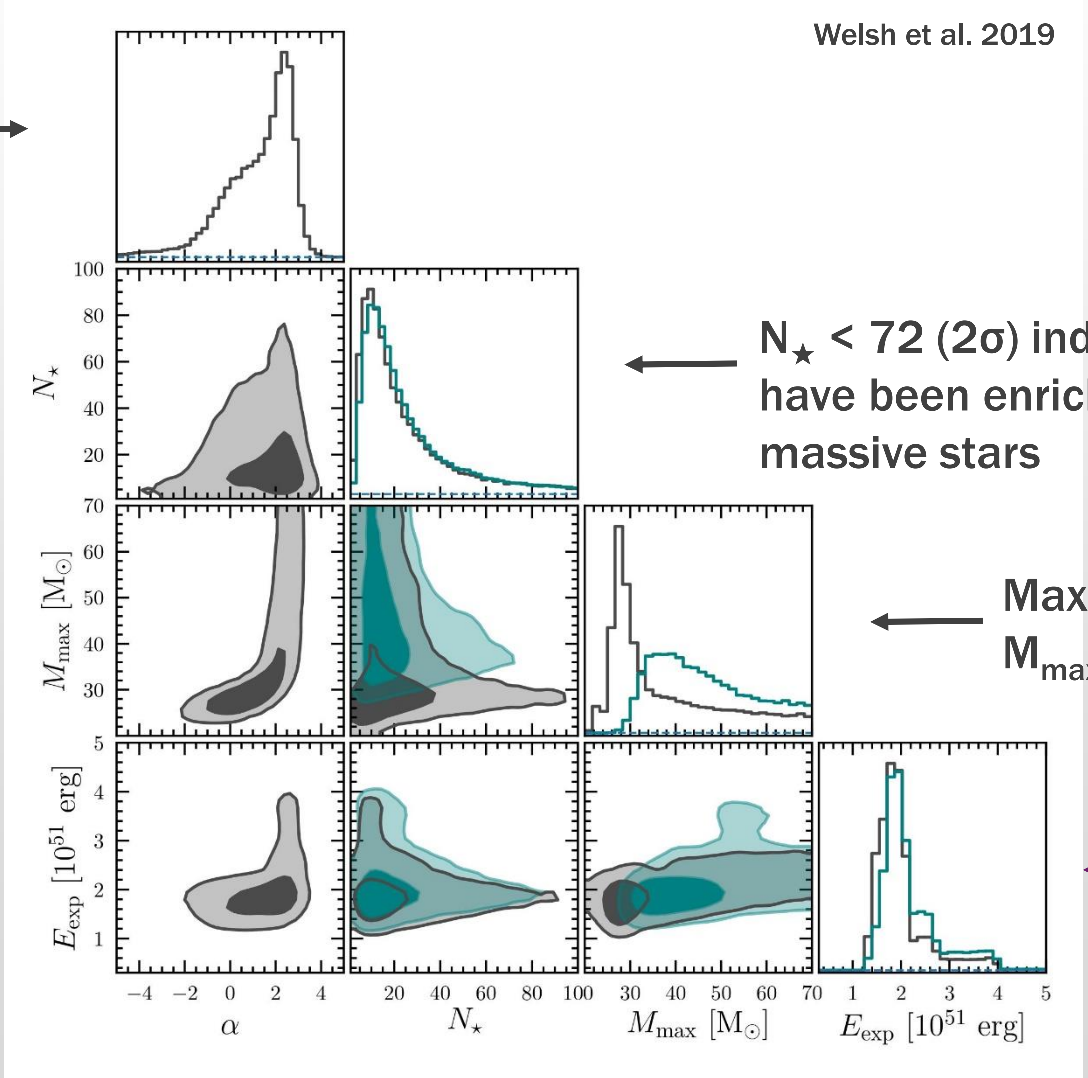

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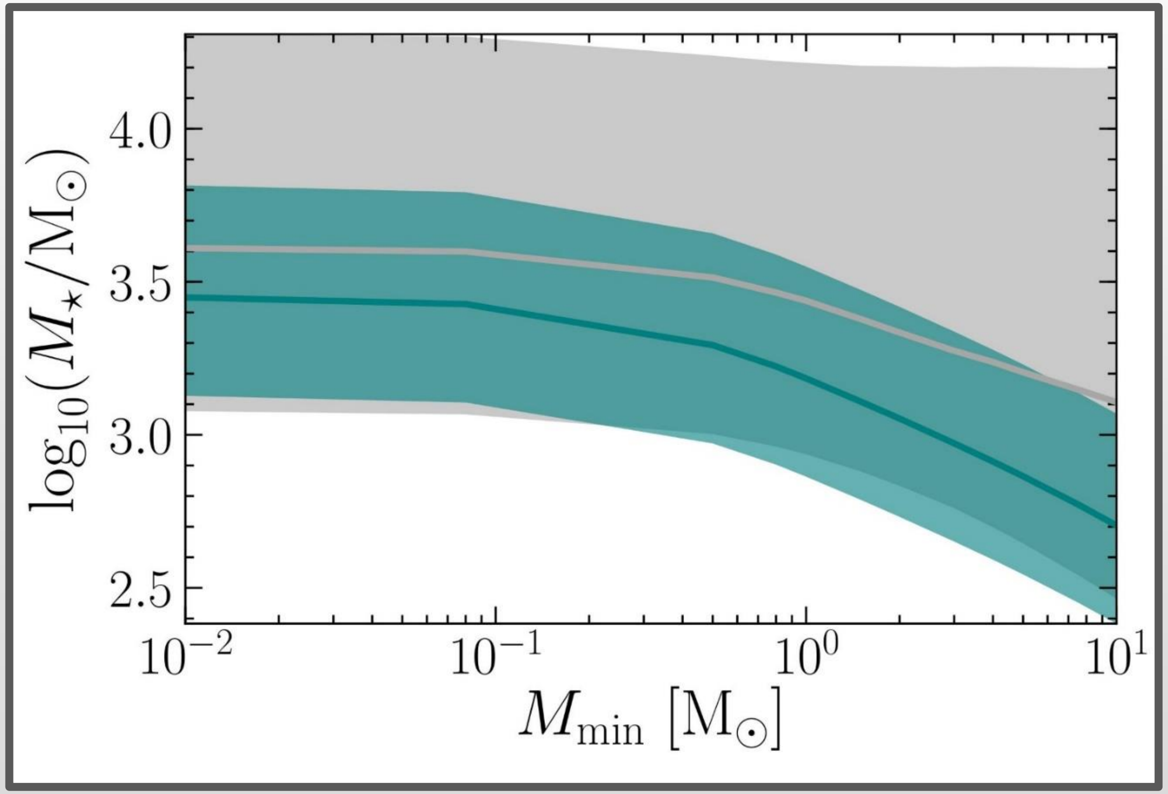
Maximum mass of enriching stars $M_{max} < 40\ M_\odot$ (See Sukhbold et al. 2016)

Higher than typical explosion energy expected from CCSNe

What Can We Learn?

Total Stellar Mass

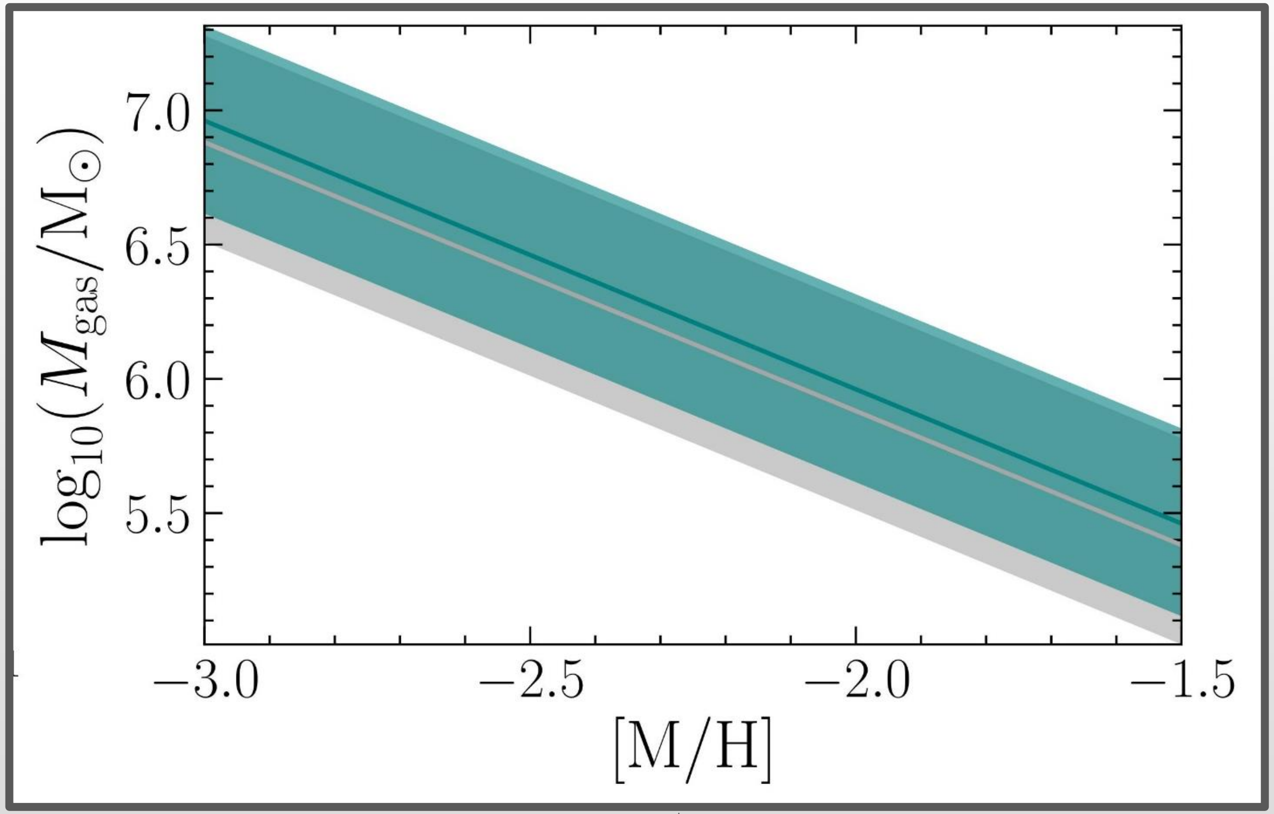
$$M_{\star} = \int_{M_{min}}^{M_{max}} \xi(M) M dM$$



- Know the mass distribution of massive stars from enrichment model;
- Assume this relationship holds for lower mass stars (> 1 $M_{\odot}$) and adopt a log-normal IMF below 1 $M_{\odot}$ (Chabrier 2003);
- Calculate the total stellar mass expected within these systems as a function of the minimum mass with which stars can form;
- Comparable to stellar content of the faint Milky Way satellite population (Martin et al. 2008; McConnachie 2012)
- These typically span a mass range of $\sim (10^2 - 10^5)\ M_{\odot}$

Total Gas Mass

- Know total mass of metals in these systems from enrichment model;
- Assume 100% retention of these metals;
- Calculate the amount of pristine gas necessary to produce a given [M/H];
- Stars may constitute ~0.03 per cent of the mass fraction of the most metal-deficient DLAs;
- UFD galaxies still expected to contain gas at redshift ~3 (Wheeler et al. 2018).



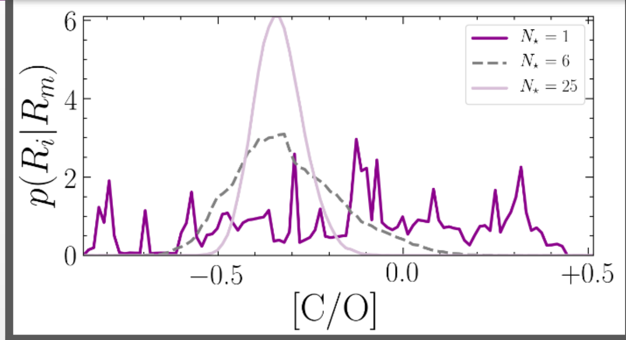
Proxies include [C/H], [Si/H] and [O/H]

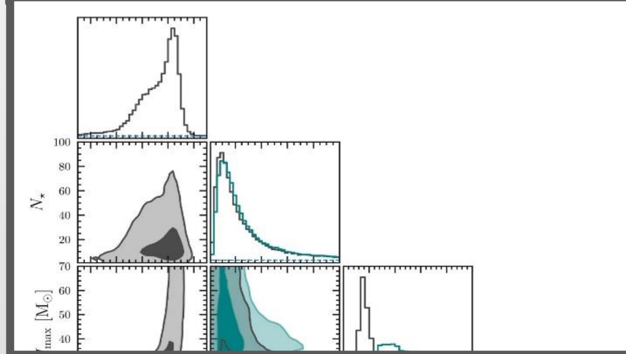
What are the descendant of these systems?

Conclusions and Future

Conclusions:

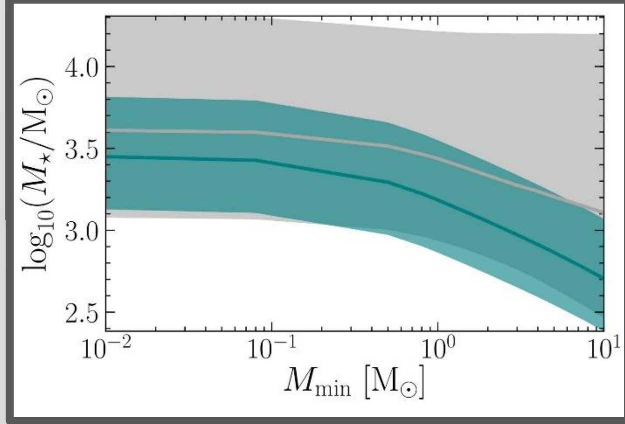
- **Early stellar populations can be investigated using the surviving chemical signature left behind by their core-collapse supernovae;**
- My enrichment model takes into account the stochastic nature of Population III IMF;
- The most metal-poor DLAs have been minimally enriched by massive stars;
- Exploring the physical properties of these systems allows us to compare with those of UFD galaxy population.





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.



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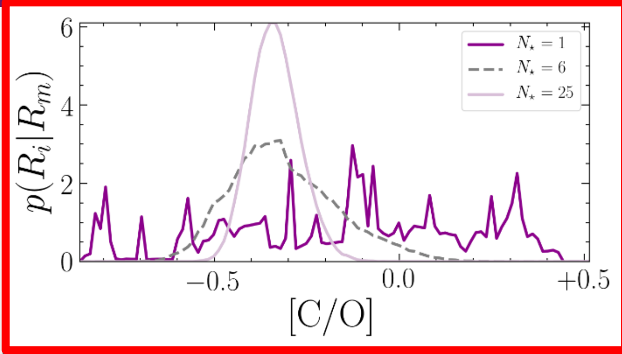

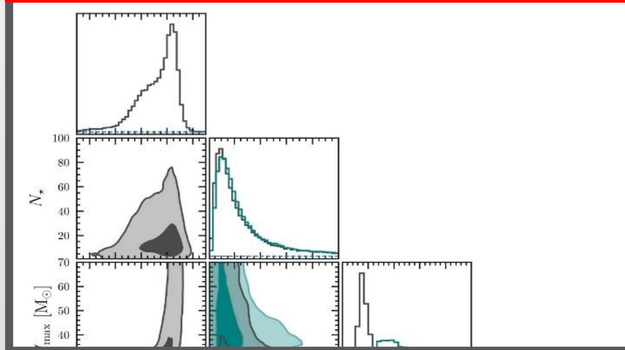

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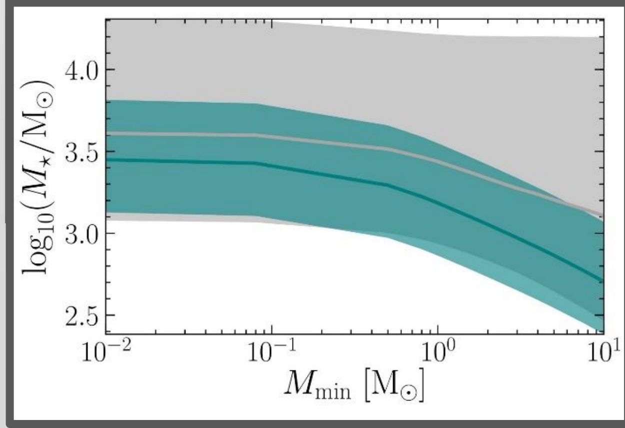

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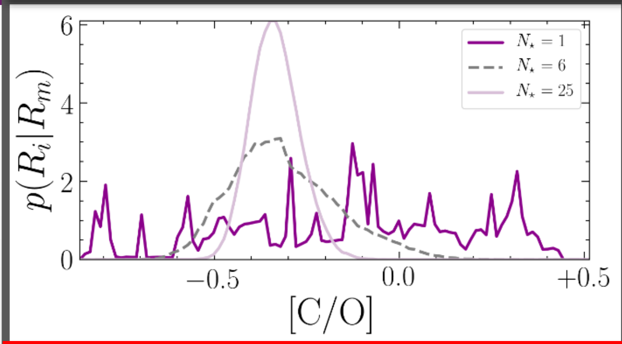

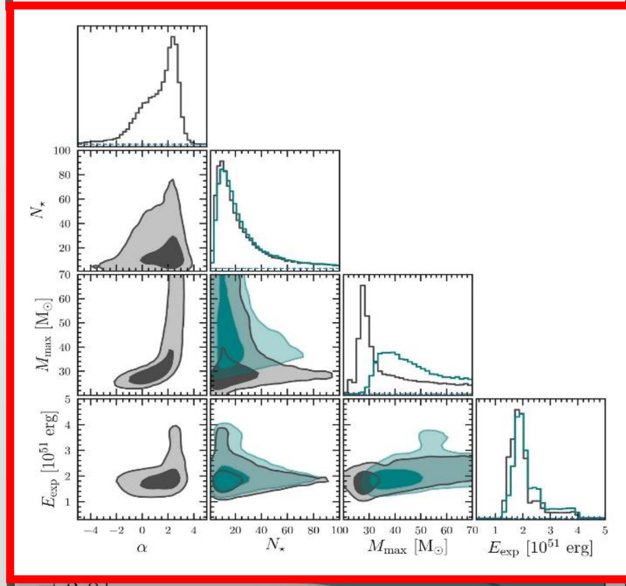

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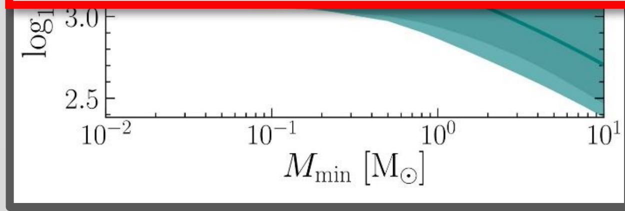

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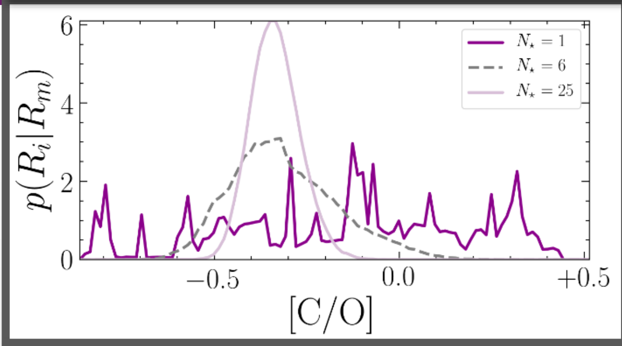

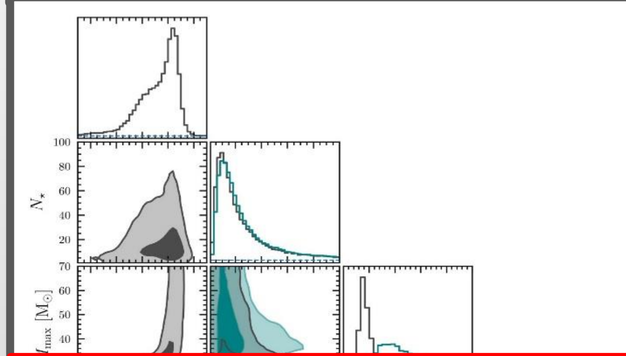

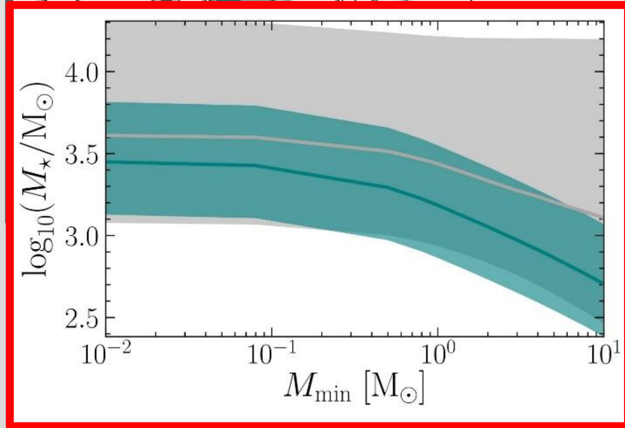

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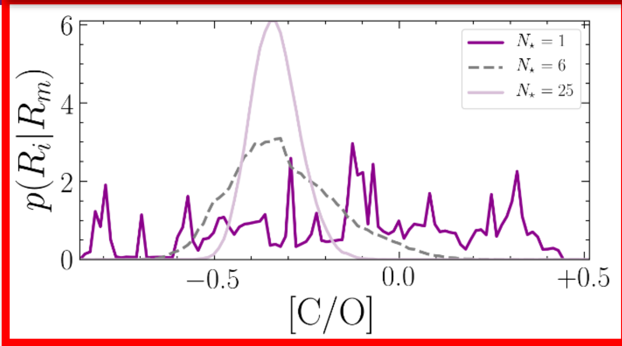

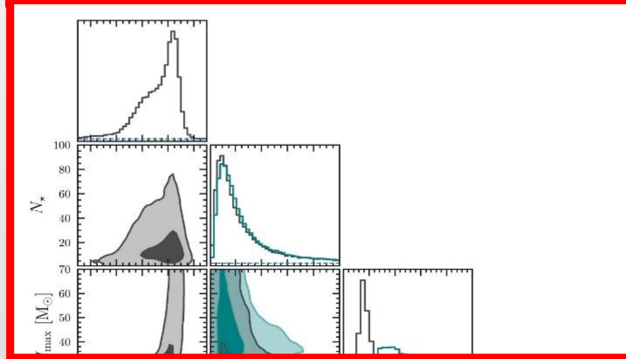

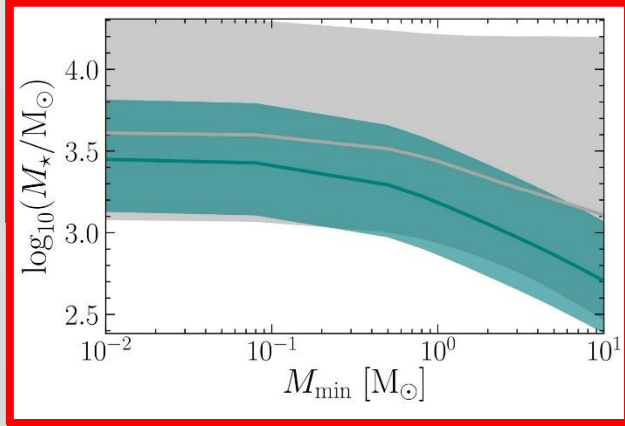

Far Future

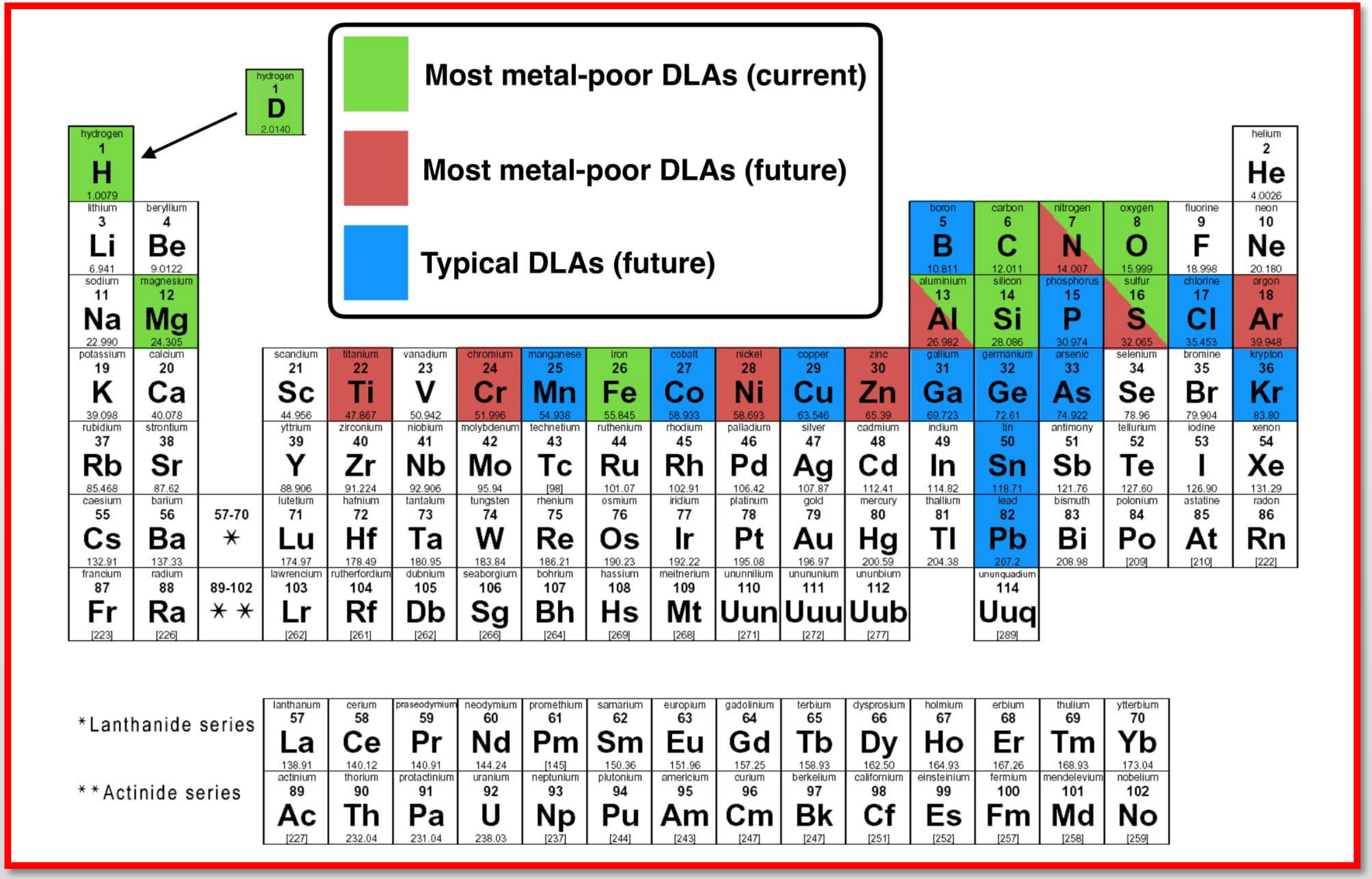

Image credit: Ryan Cooke