Non-parametric Type Ia supernova delay-time distributions, tested with IllustrisTNG

Bhavin Joshi

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Collaborators: Lou Strolger, Dahne Pluck, Nico McMahon

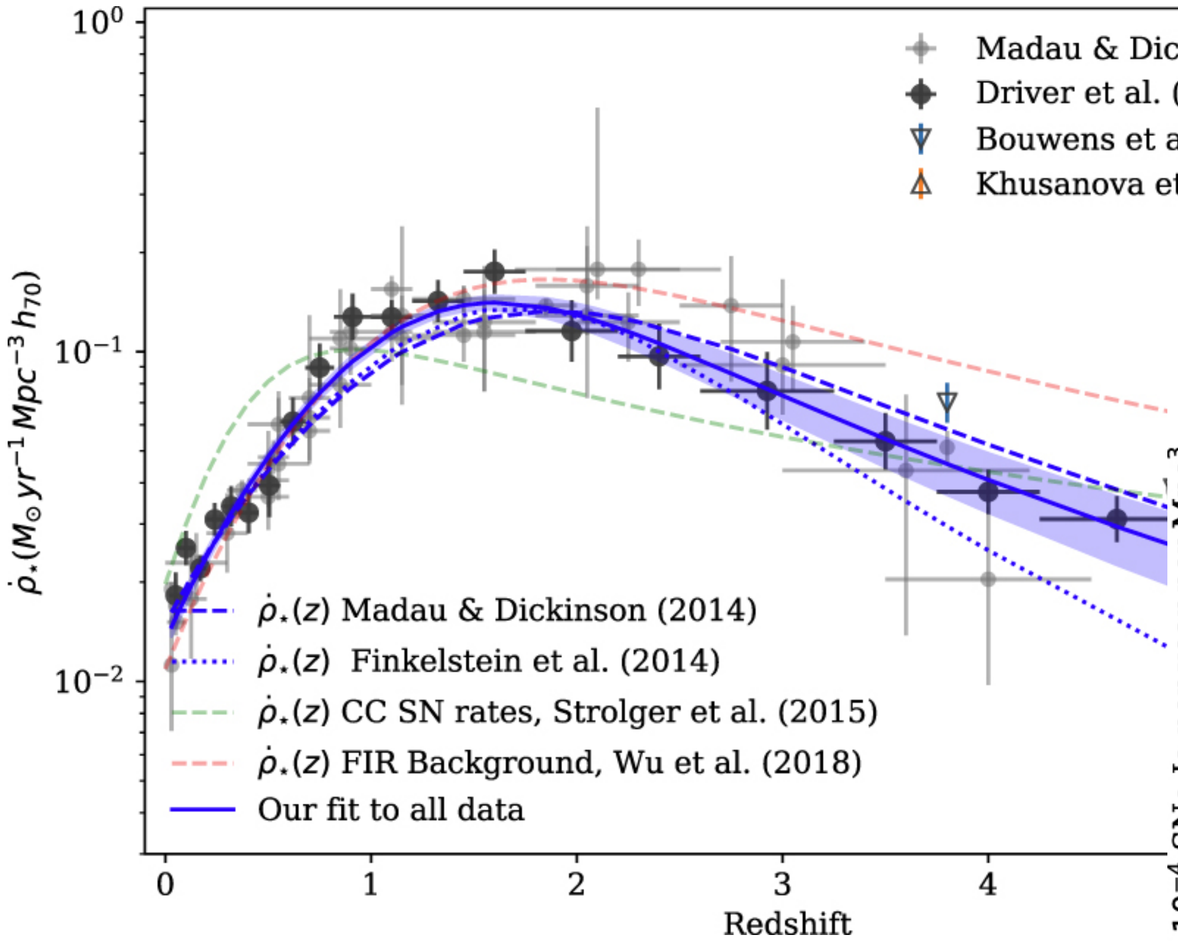
SN Ia Delay Time Distributions (DTDs)

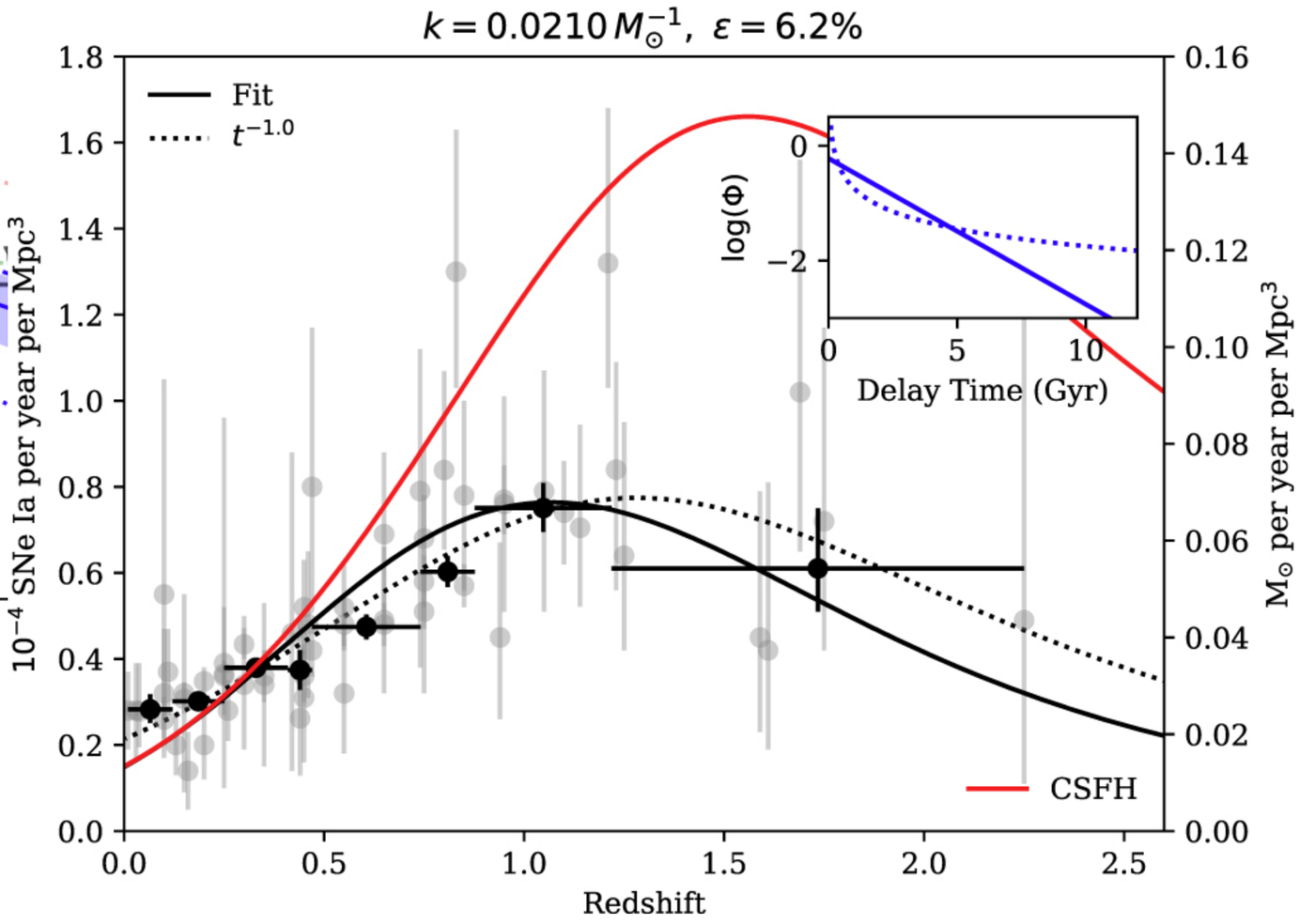
Effectively the distribution of times between formation to explosion for stellar populations. Given the importance of SN Ia for cosmology, understanding DTD is important for understanding progenitors of SNe Ia, explosion physics, and chemical enrichment histories of galaxies.

Inferring SN Ia DTDs from global or individual galaxy SFHS:

I. Compare *global* measured cosmic star-formation density to the observed volumetric SN Ia history to infer DTDs
II. Employ *individual* galaxy SFHs (reconstructed from SED fitting codes) and whether a SN Ia was observed within a galaxy or not, through a likelihood analysis

SN Ia Delay Time Distributions (DTDs)





From Strolger et al. 2020

Reconstructing DTD from individual galaxy SFHs (Maoz et al. 2011)

For any galaxy in a survey the probability of observing SNe follows a Poisson distribution

$$P(n_i|m_i) = \frac{m_i^{n_i} e^{-m_i}}{n_i!}$$

$$L = \prod_i^N P(n_i|m_i)$$

Expected number of SNe ‘m’ in any given galaxy depends on the individual galaxy SFH and the delay time. The SN rate is the convolution of the SFH and the DTD (with some multiplicative constants).

$$m_i \equiv \text{Expected number of SN Ia}$$

$$n_i \equiv \text{Observed number of SN Ia}$$

$$ln\, L = -\sum^N m_i + \sum^N ln\left(\frac{m_i^{n_i}}{n_i!}\right)$$

Hosts + non-hosts

Hosts only

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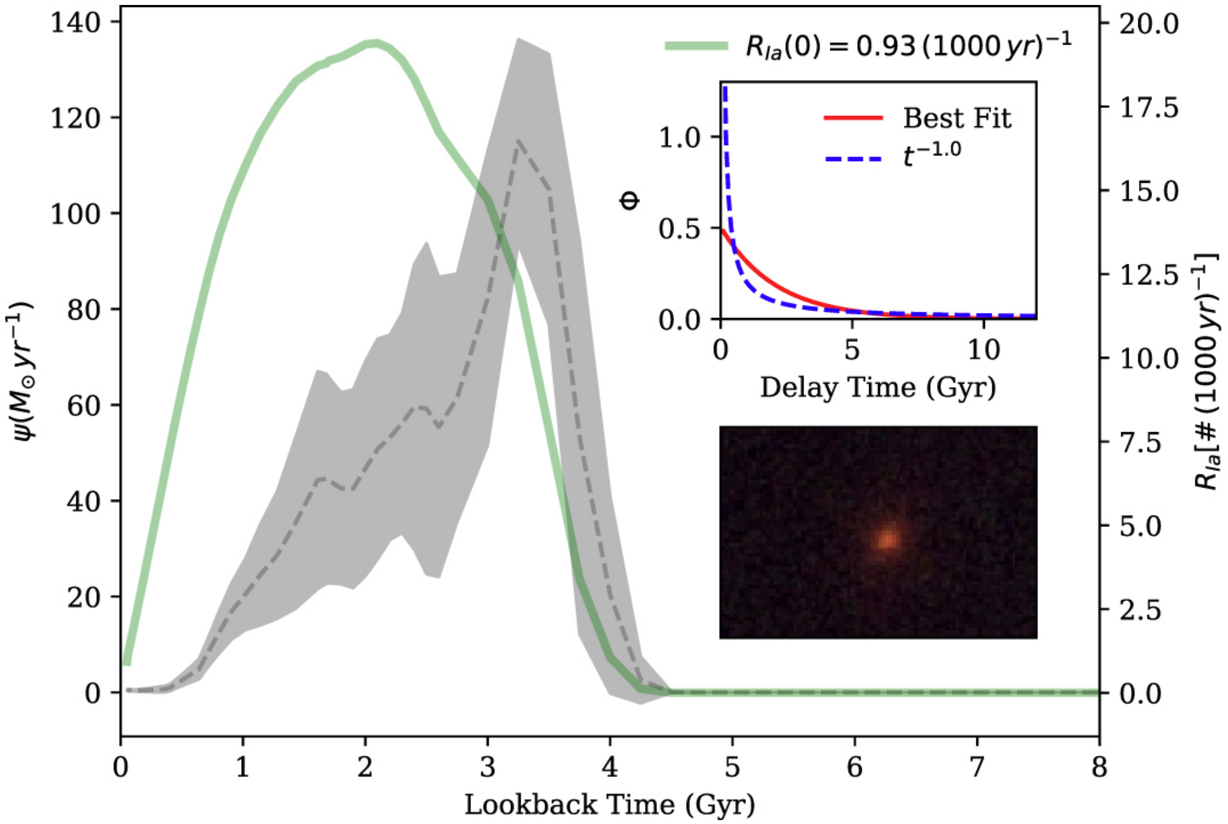
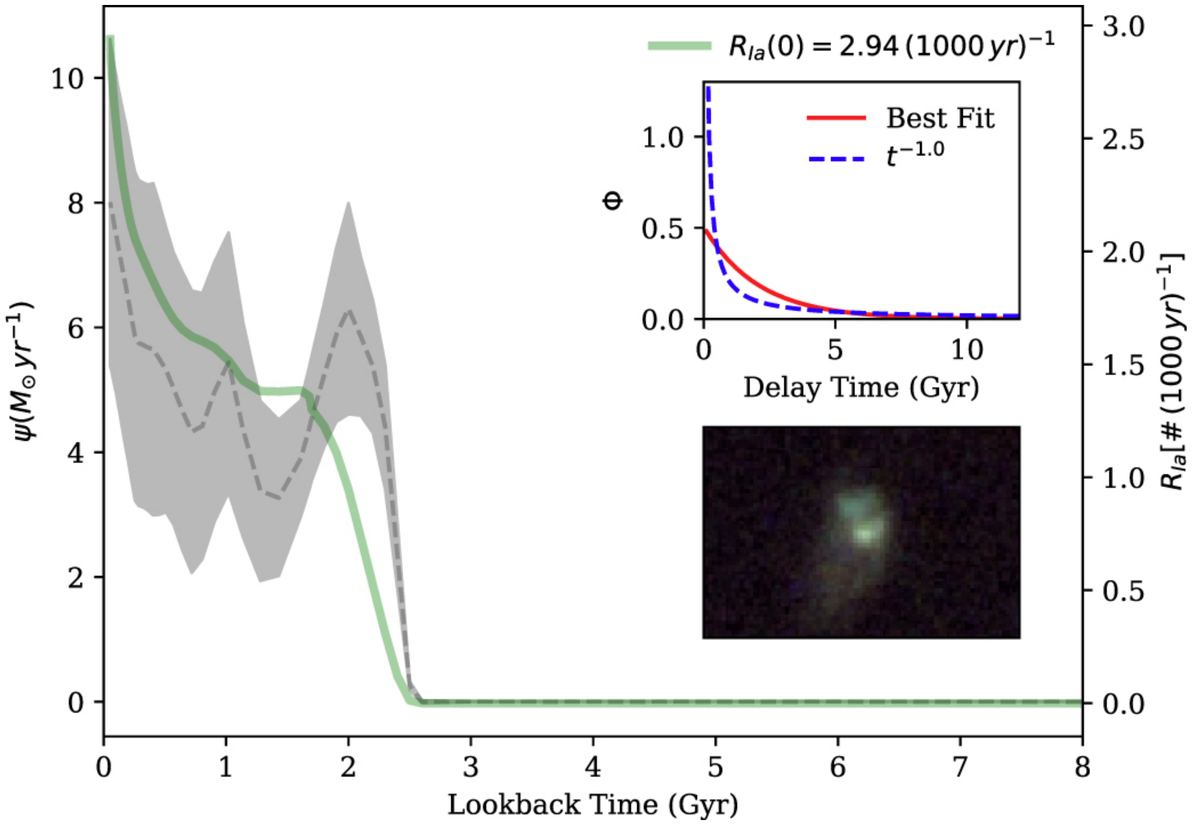
Hosts + non-hosts

Hosts only

(i) Does the number of non-host galaxies within a survey have an effect on the inferred DTD?
(ii) Does the first term in the log likelihood set a minimum floor/threshold of likelihood?

Reconstructing DTDs from individual galaxy SFHs





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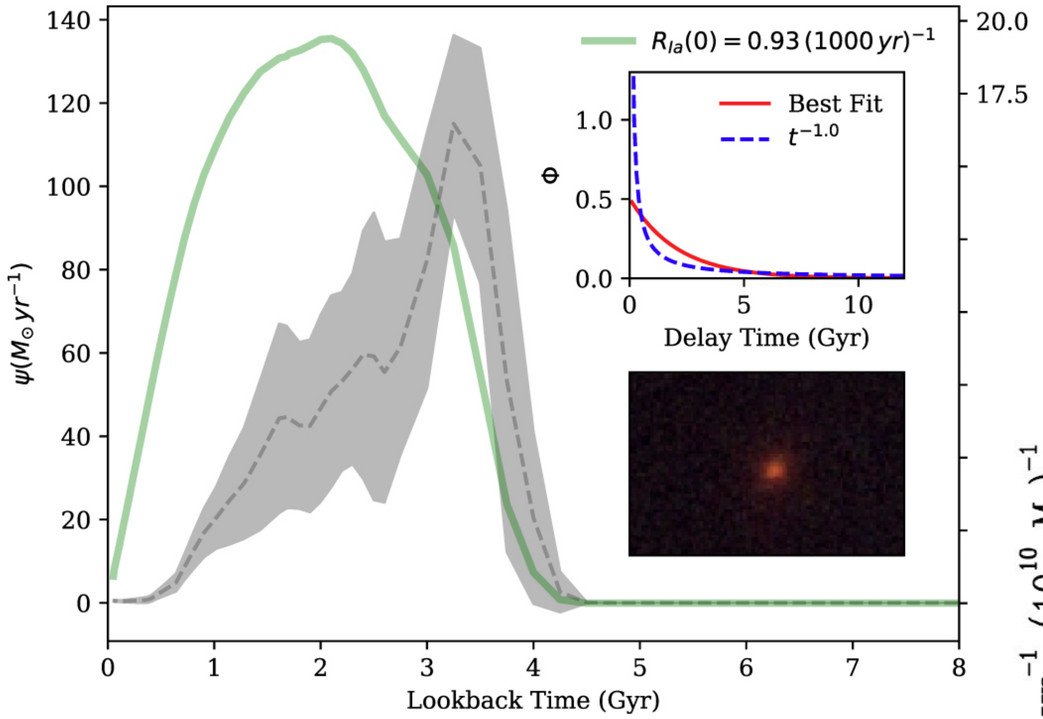
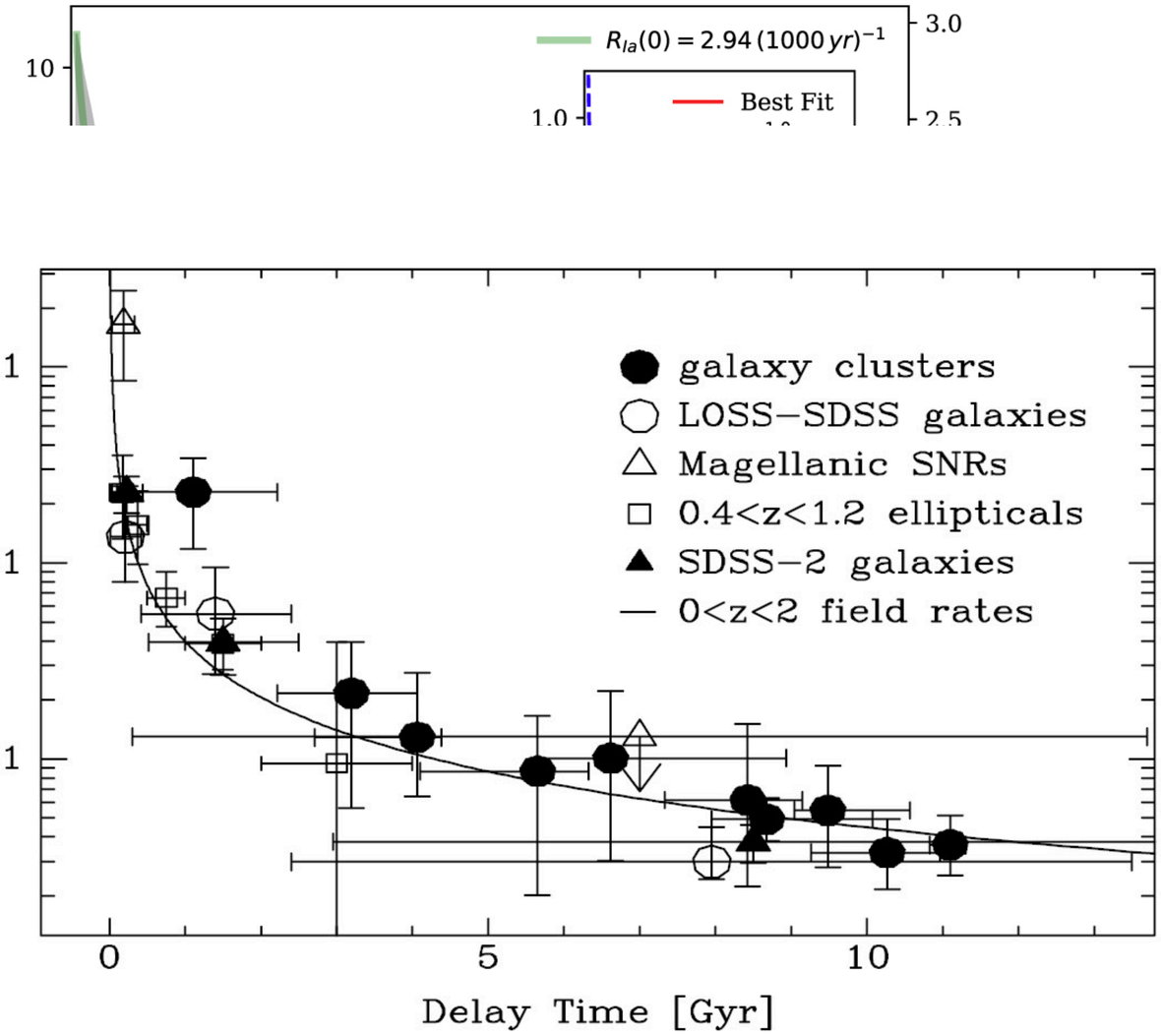




See:
Maoz et al 2011
Maoz & Mannucci 2012
Maoz, Mannucci, & Nelemans 2014
Strolger et al. 2020

The IllustrisTNG Simulation

- Large simulated cosmological volumes at high-resolution
- Volumes (cube side): 50 Mpc, 100 Mpc, 300 Mpc

Why do this analysis with IllustrisTNG? (or any other cosmological simulation)

- No assumptions made on SFHs of individual galaxies
- SFHs are known already and do not need to be inferred (e.g., no assumptions on line-of-sight dust)
- Simulation known to reproduce properties of the observed Universe (e.g., Springel et al. 2018, Nelson et al. 2018, Torrey et al. 2019)

Non-parametric DTDs (or binned DTDs)

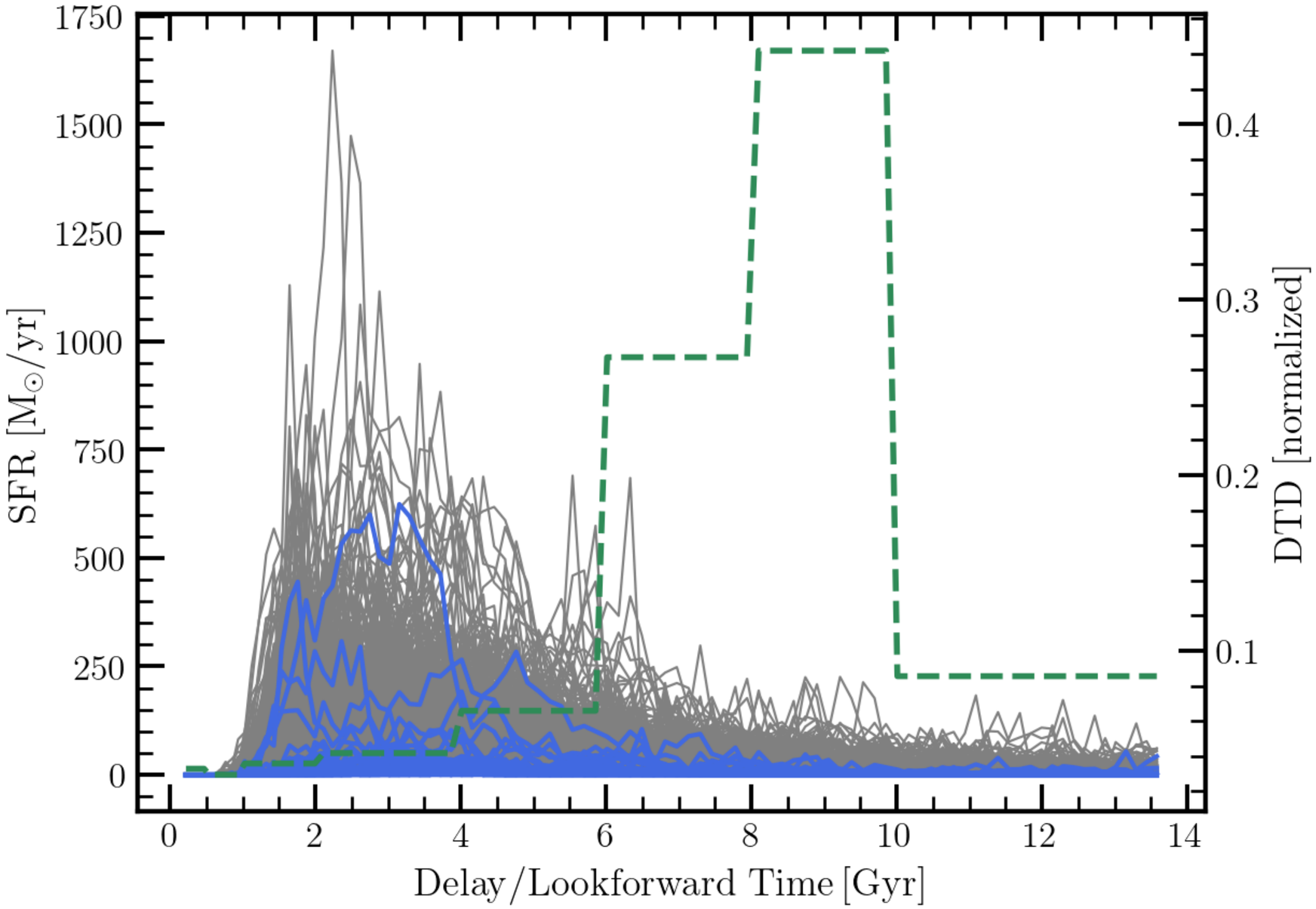
- Similar to non-parametric SFHs for inferring galaxy SFHs — we use piecewise constants combined to form a “non-parametric” DTD
  - No rigid mathematical expression forcing DTD to be a specific shape
  - Constants within each time bin are independent of each other

This flexibility is great for inferring realistic DTDs,

- BUT comes at added computational cost!

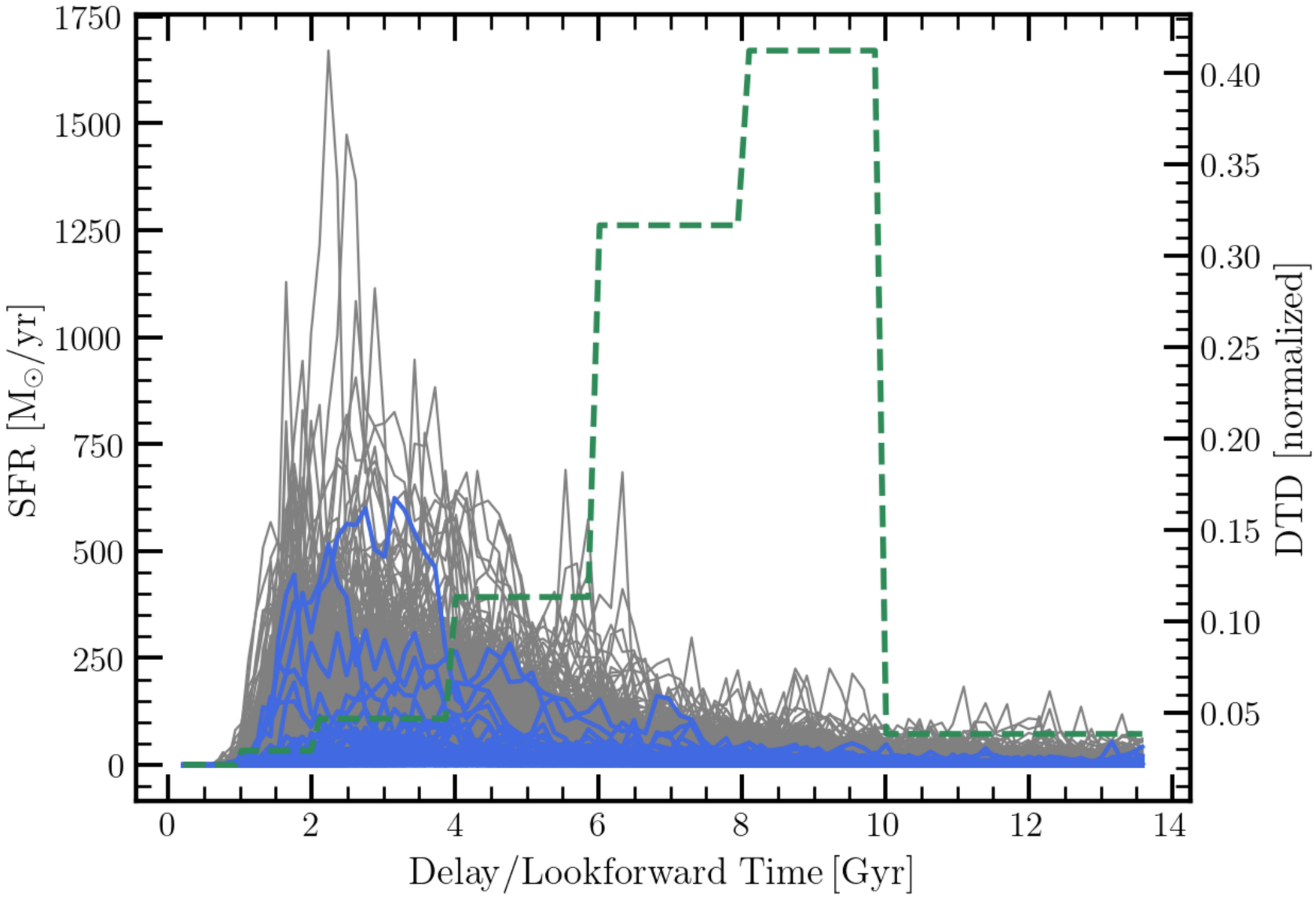
Example 1

- Host galaxies selected randomly
- Total = 10054
- Hosts = 50 (~0.5%)



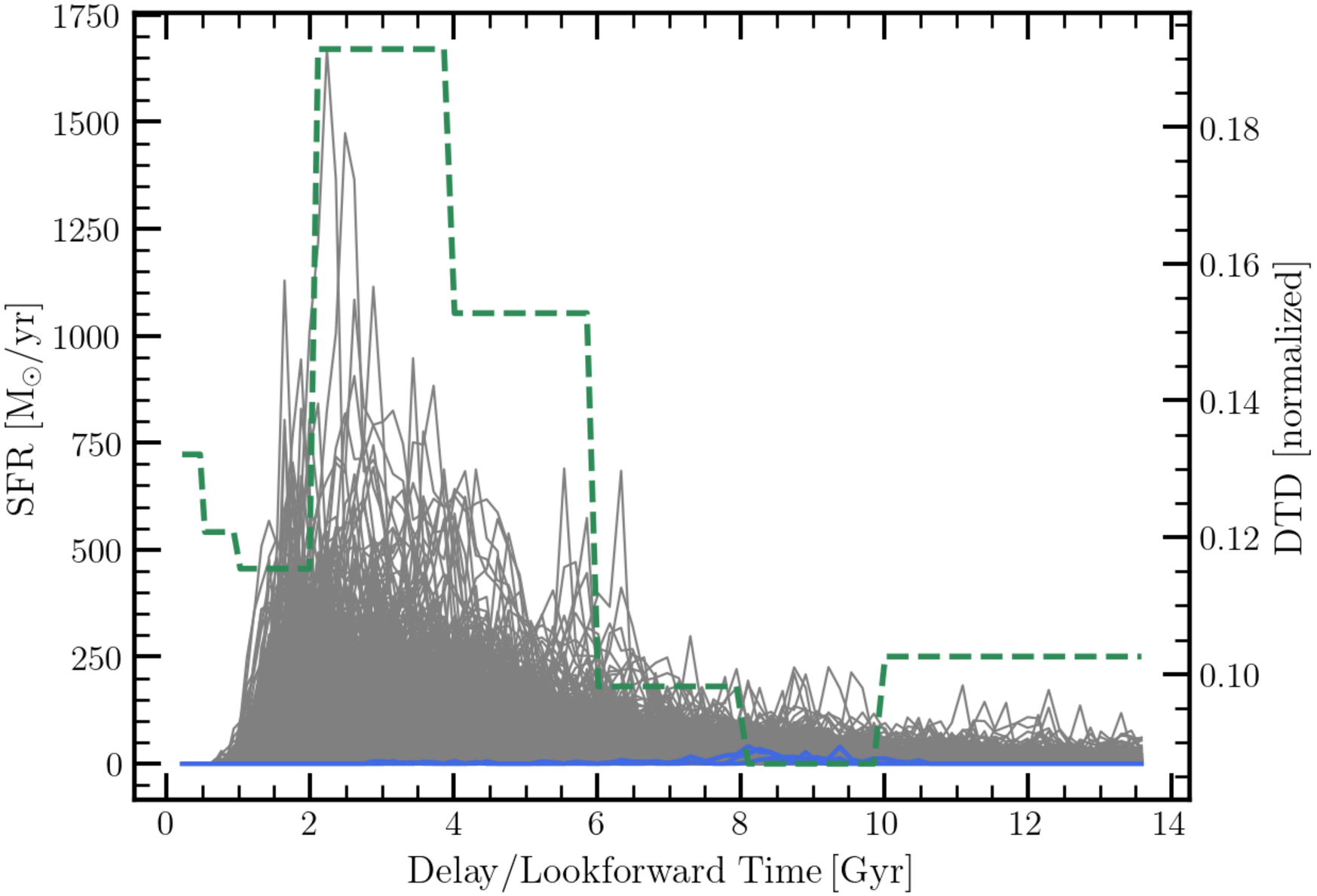
Example 2

- Host galaxies selected randomly
- Total = 10054
- Hosts = 100 (~1%)



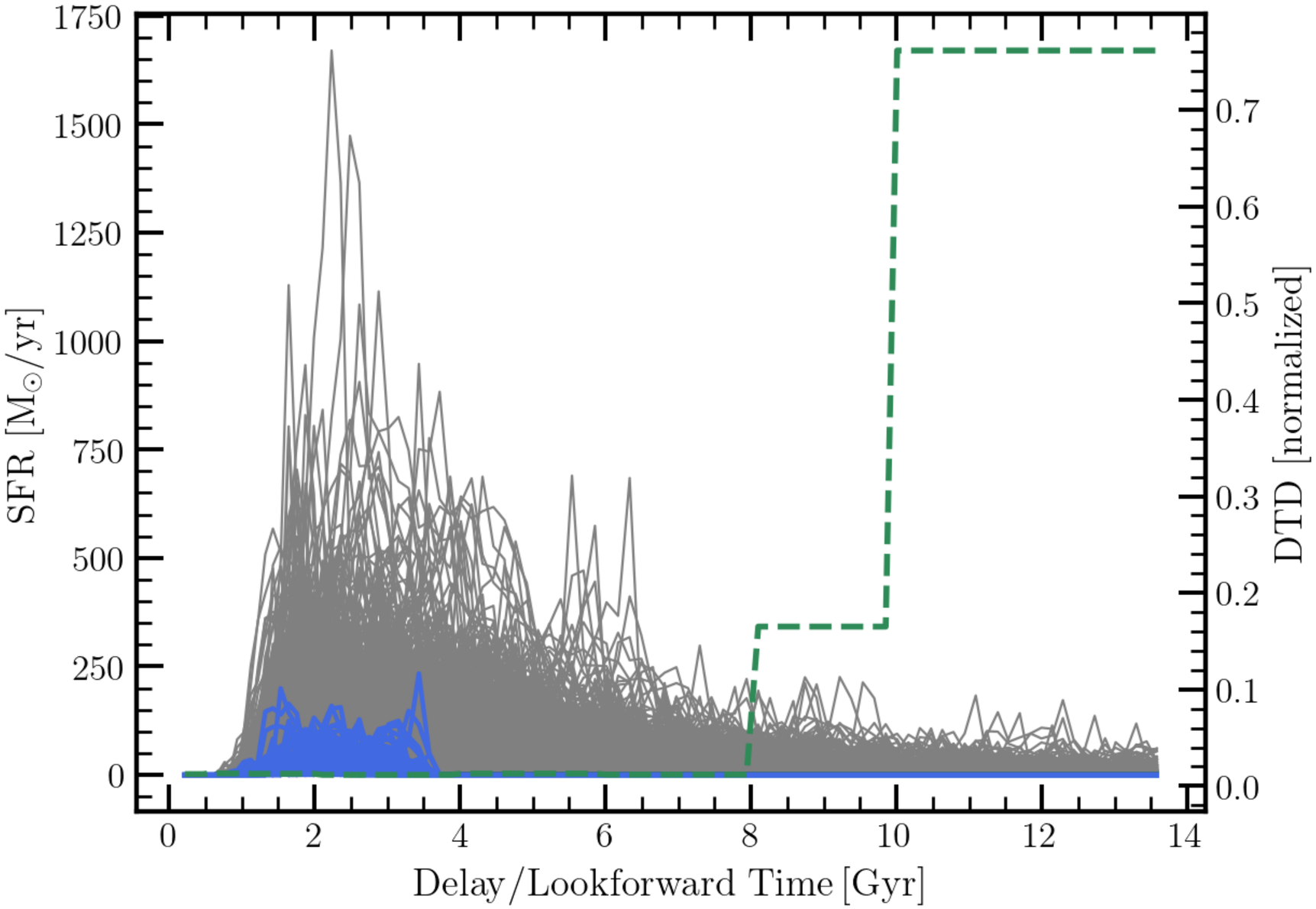
Example 3

- Host galaxies selected to have “burst” in SF ~5 Gyr ago.
- Total = 10054
- Hosts = 3 (~0.03%)



Example 4

- Host galaxies selected to have *zero* star-formation beyond 10 Gyr.
- Total = 10054
- Hosts = 69 (~0.7%)



Next steps

- Increase sizes of simulated surveys — use largest TNG volumes at highest possible resolution
- Present sample at z=0. Probe DTD redshift evolution if any.
- DTD evolution with environment — cluster vs field SN Ia DTD?
- What improvements in SN Ia standardization are possible with improvements in characterizing progenitors?

Thank you!