Exploring High-Redshift Compact Binary Evolution with Next-Generation GW Detectors

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Introduction

- BBH mergers can serve as standard sirens, offering an independent means to study cosmic expansion and star formation
- Current GW detectors can probe redshifts upto $z \sim 1$. Current observations suggest a redshift distribution which follows a power law
- Astrophysical models suggest a peak in the star formation rate between redshift of $1 < z < 3$
- With future detectors like Cosmic Explorer and Einstein Telescope, we can probe the high redshift regime
- **Mapping the z_peak:**
    - Closely tied to the star formation rate and metallicity evolution
    - Test competing formation scenarios and astrophysical models

Methodology

BBH population

- Madau Dickinson redshift with time delay
- GWTC-3 mass distribution, precessing spins

Perform PE on detected events

- Fisher matrix analysis (GWBench)
- $\{\log M_c, \eta, \phi_c, t_c, logD_L, \iota, \alpha, \delta, \psi\}$

Convert to multivariate gaussian

- $\{M_c, \eta, \phi_c, t_c, D_L, \iota, \alpha, \delta, \psi\}$
- Construct z posteriors for each event

Population analysis on z

- Redshift model: Madau Dickinson
- Hyperparameters: $\{\gamma, \kappa, z_{peak}\}$

Redshift distribution

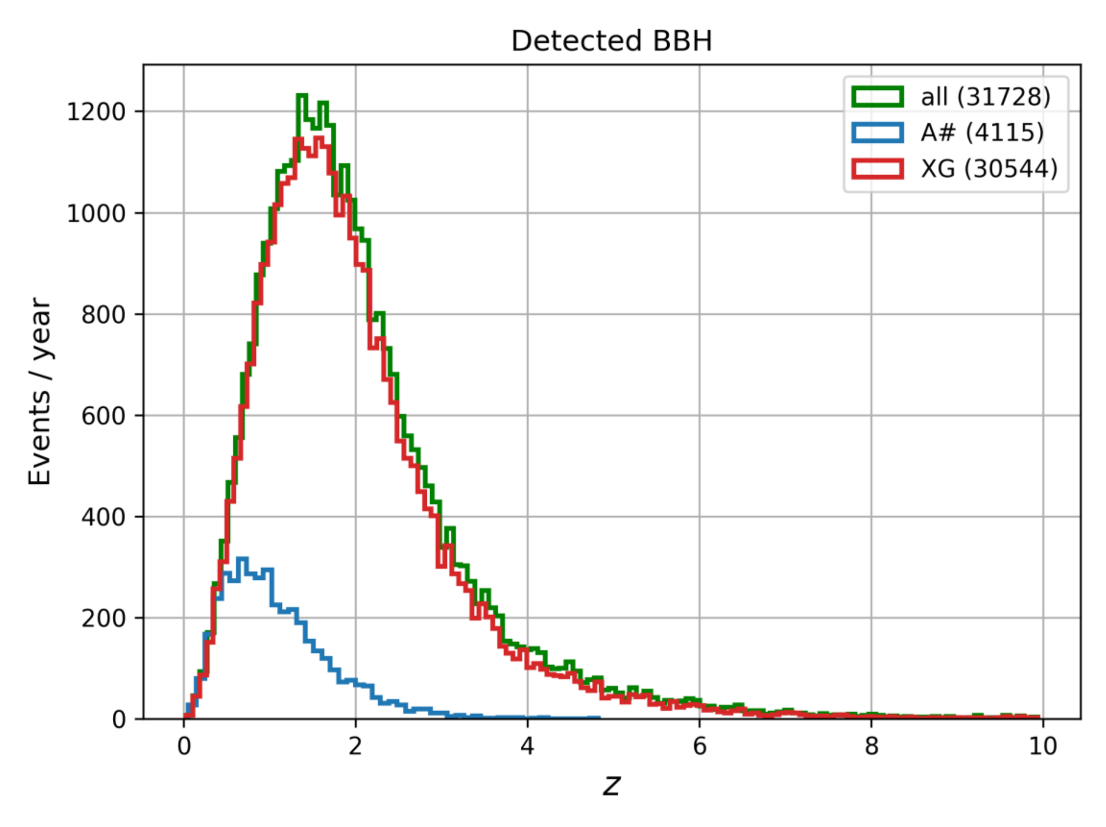
- The Madau-Dickinson star-formation rate, and time delay distribution:
- $$\psi(z) \propto \frac{(1+z)^{\gamma}}{1+\left(\frac{1+z}{1+z_{peak}}\right)^{\kappa}} \quad , \quad p(t_m|t_f,\tau) = \frac{1}{\tau}, t_m < \tau < t_f$$
- The volumetric merger rate in the source-frame:

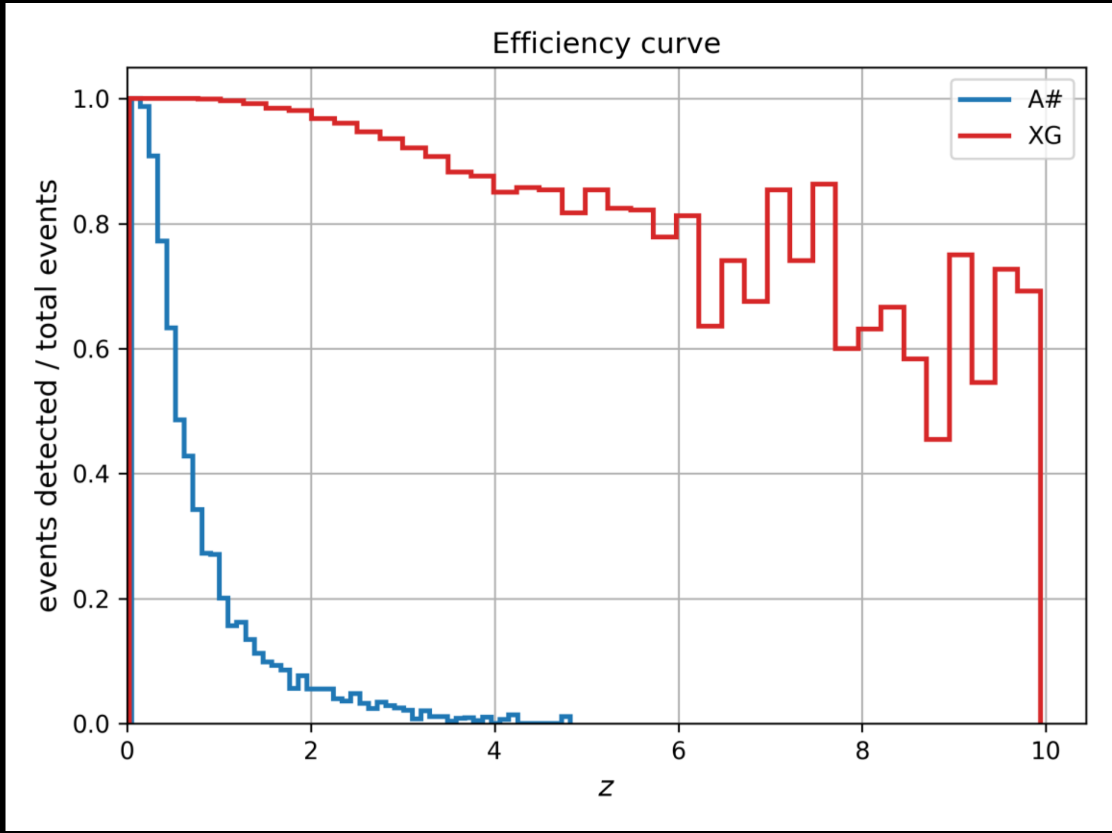
$$\mathcal{R}_m(z_m) \propto \int_{z_m}^{\infty} dz_f \frac{dt_f}{dz_f} \psi(z_f) p(t_m|t_f,\tau)$$

- Redshift distribution:

$$p(z_m) \propto \frac{dV_c}{dz} \frac{1}{1+z} \mathcal{R}_m(z_m)$$

Input BBH population

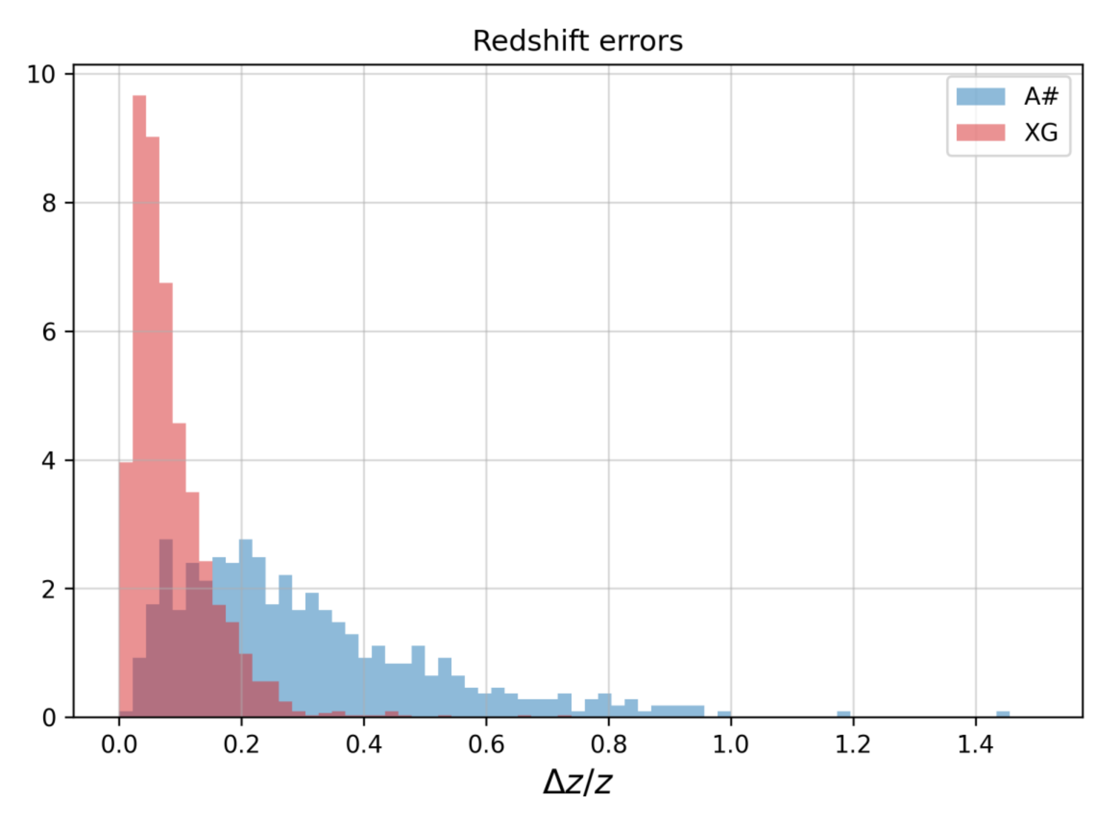


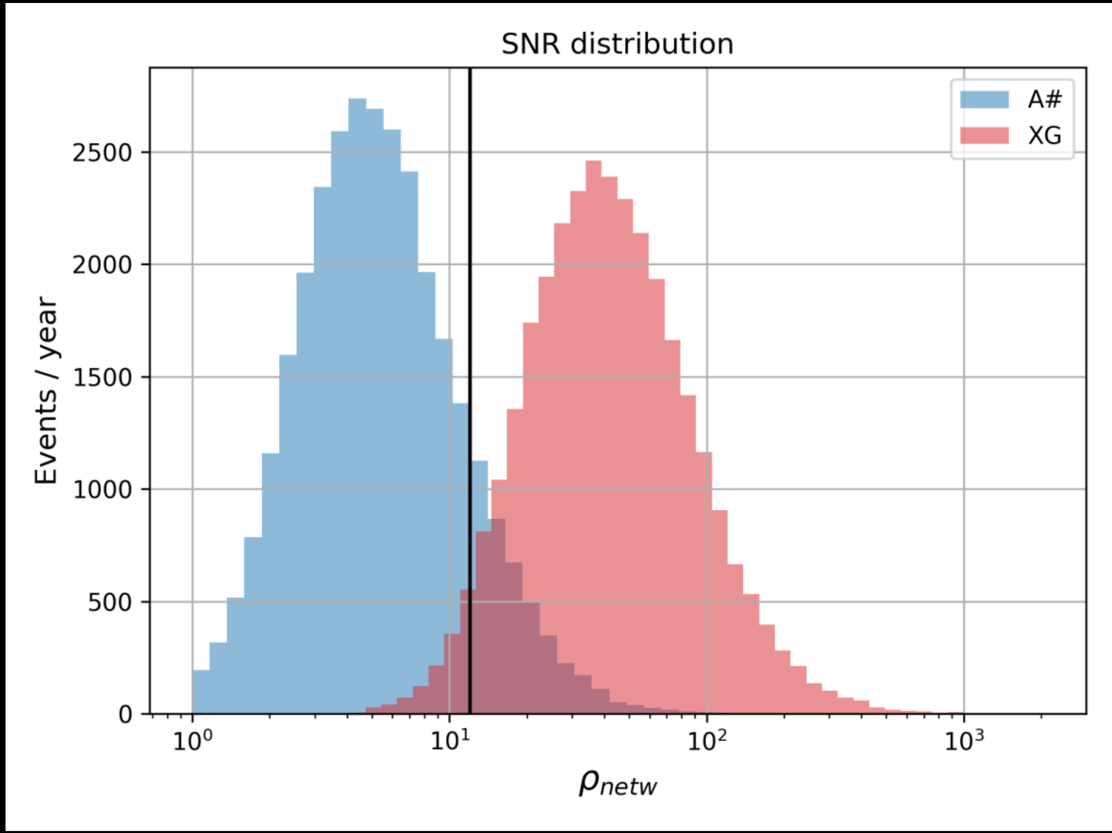


Detection criteria: $SNR_{det} > 5$ for two detectors, $SNR_{netw} > 12$

Networks: A# : L, H, I XG: CE40, CE20, ET (triangle)

Fisher Matrix analysis



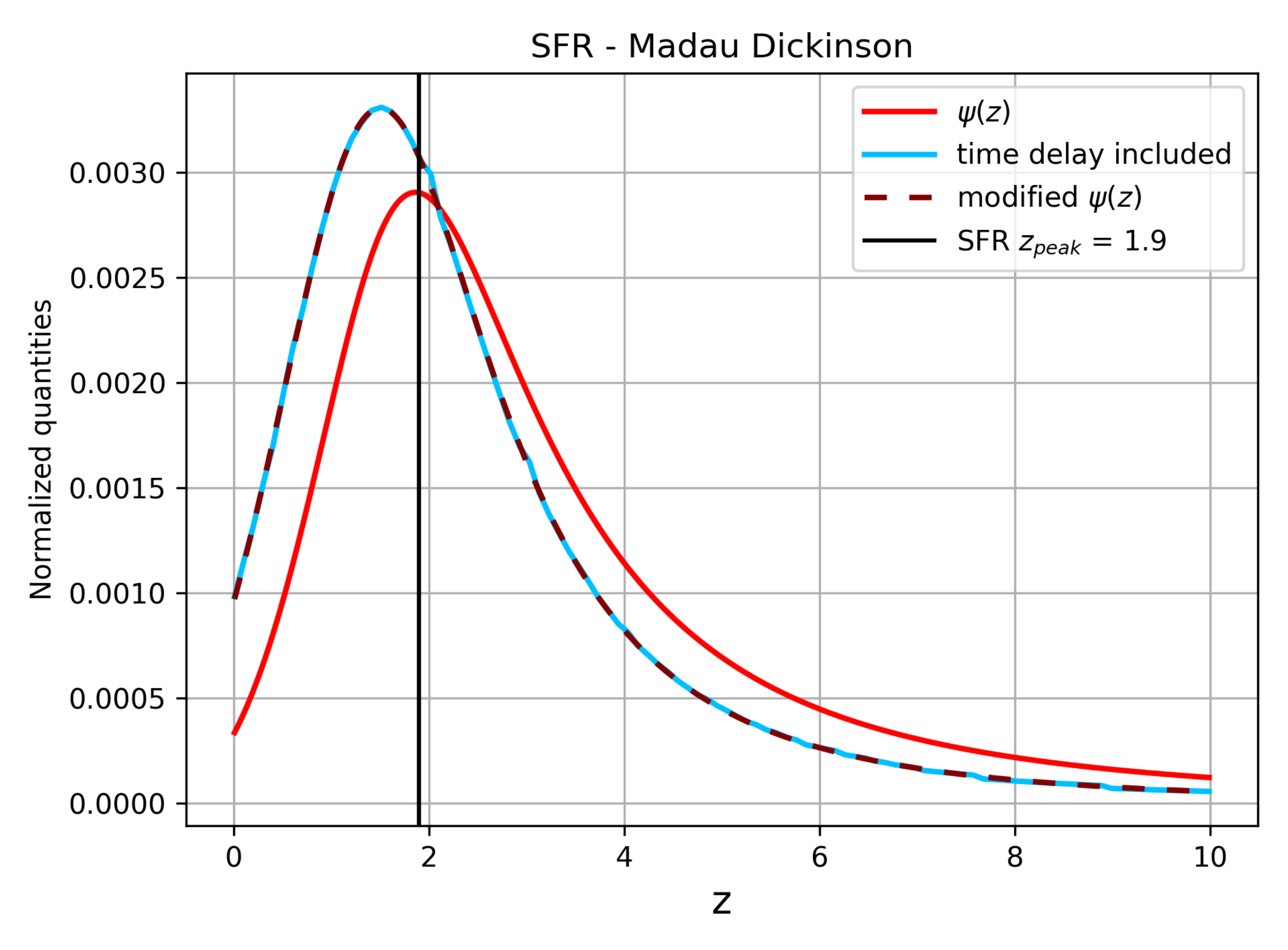


FM analysis dimensions: $\{\log \mathcal{M}_c, \eta, \log D_L, \iota, t_c, \phi_c, \alpha, \delta, \psi\}$

Fitting the redshift distribution

True parameters:

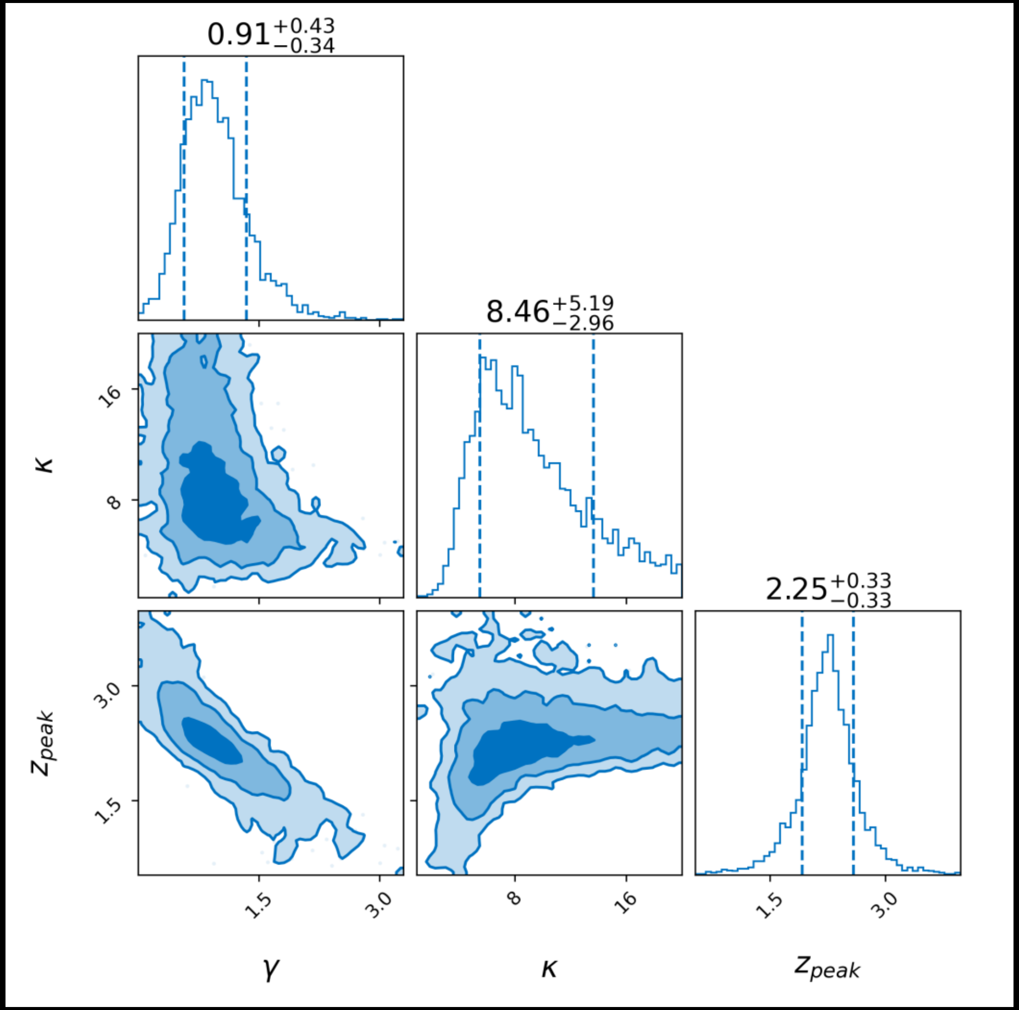
$$\gamma = 2.7,$$
$$\kappa = 5.6,$$
$$z_{peak} = 1.9$$



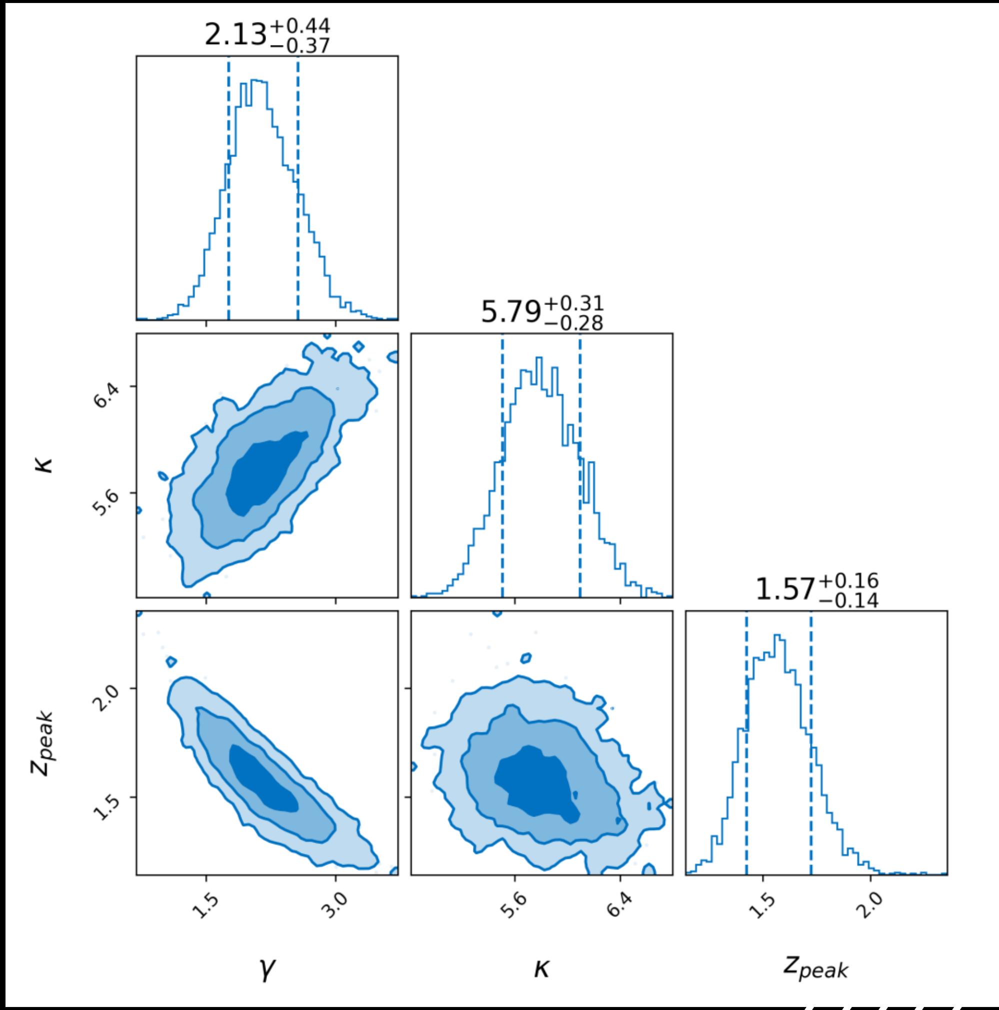
Fitted parameters:

$$\gamma = 1.8032,$$
$$\kappa = 5.3023,$$
$$z_{peak} = 1.8362$$

Population analysis results

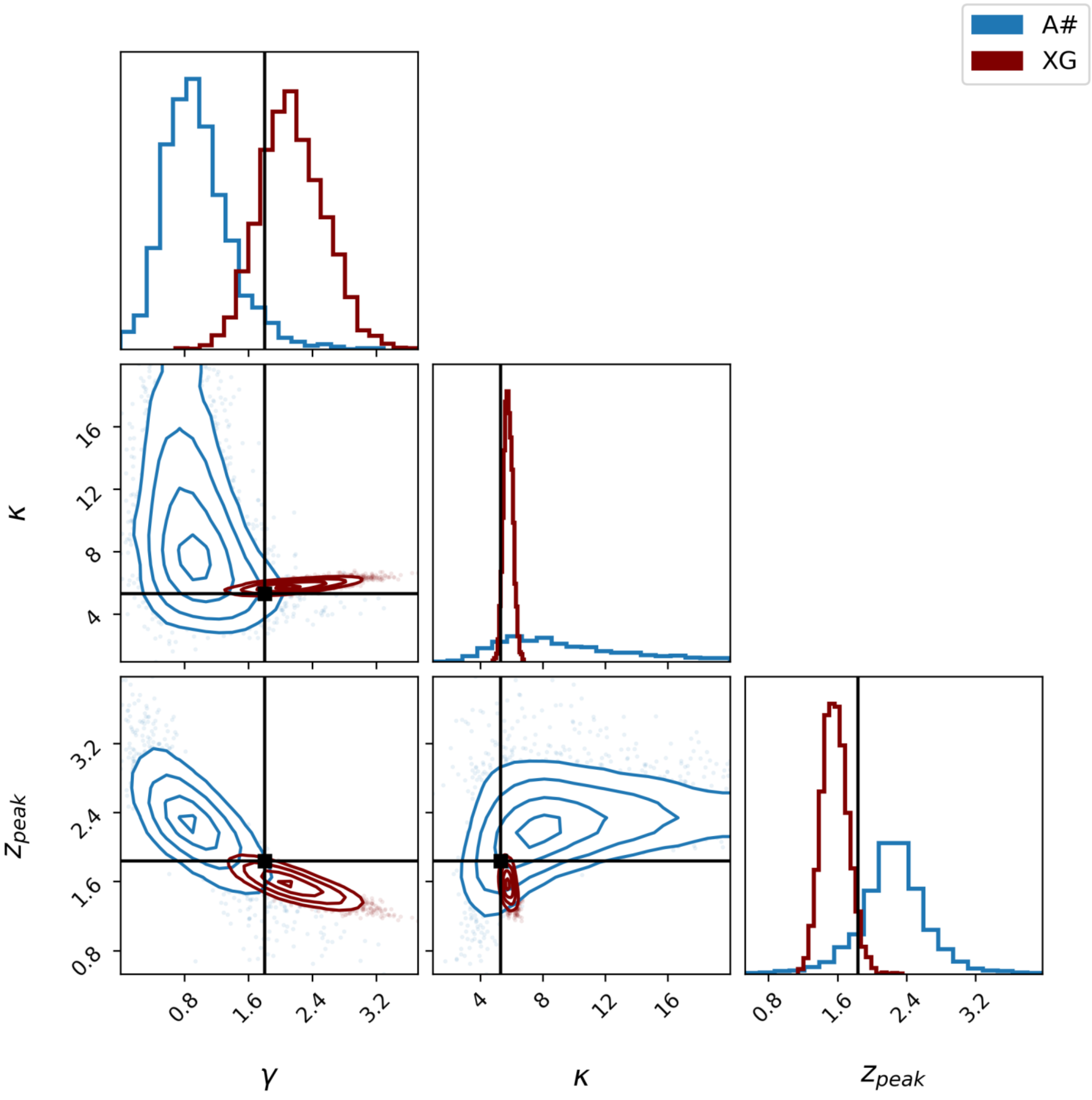


A#

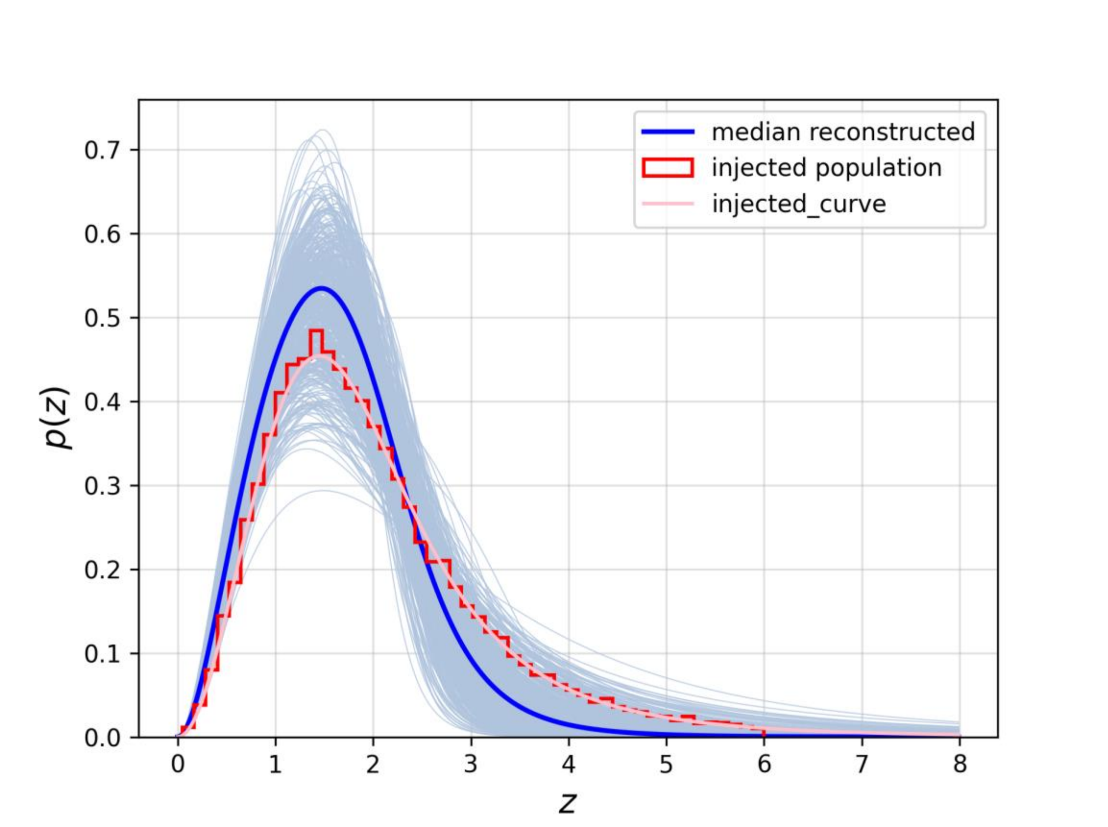


XG

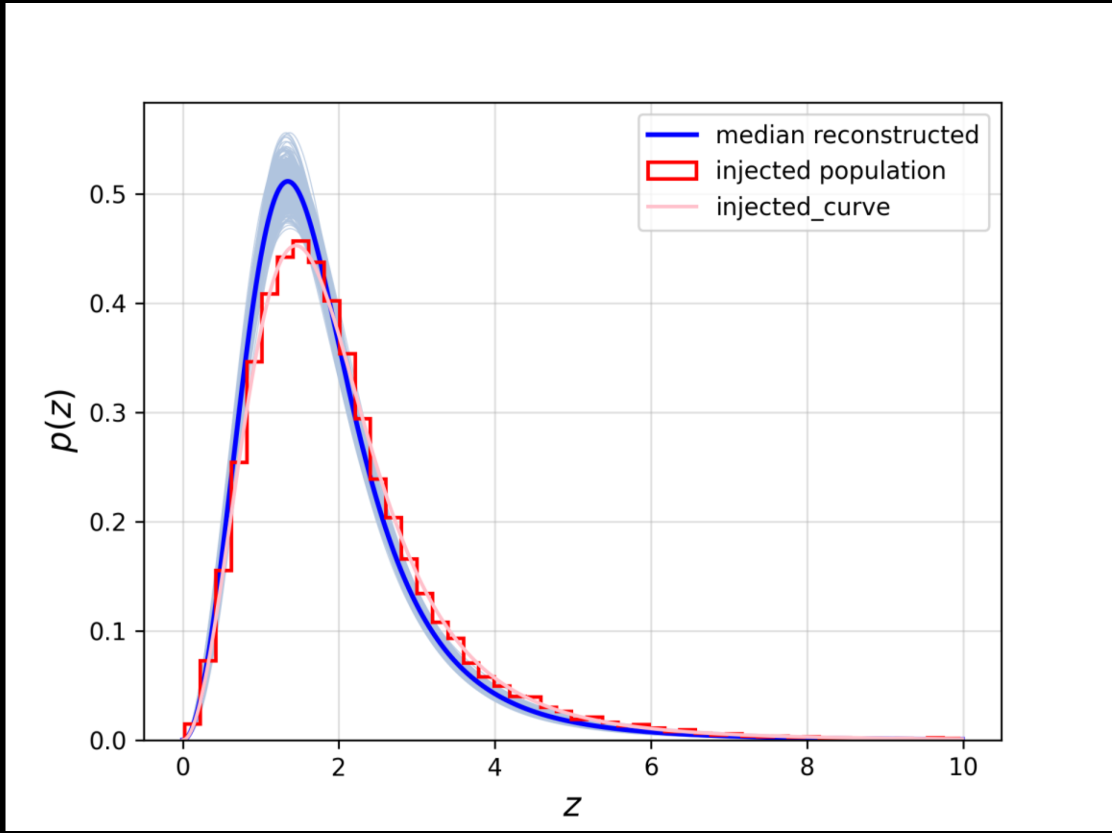
Population analysis results



Population analysis results



A#



XG

Summary and next steps

- A# and next generation detector network can probe the high redshift regime allowing us to look beyond the peak of the star formation
- Currently we analyzed 500 and 1500 events for A# and XG
  - Plan to include more events
- Study the curves for different mass ranges
- Include efficiency factor due to metallicity in the merger rate

Thank you

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