The dispersion measure and scattering of Fast Radio Bursts: contributions from multi-components, and clues for the intrinsic properties

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Abstract

Based on a model with mixed FRB population, intrinsic Schechter energy distribution, contributions to dispersion measure (DM) and scattering time (τ) from multi-components, we identify optimal parameters that can reproduce the joint distribution of DM and τ in the CHIME/FRB catalog by MCMC simulations. Our model suggests around 60% of FRBs have young progenitors, while the characteristic energy cut-off is $\log_{10} E_* [erg] = 42.41^{+1.10}_{-1.26}$ and the differential power-law index is $\gamma = -1.62^{+0.10}_{-0.12}$ in the Schechter function. Using the optimal model, we estimate FRB redshifts through DM-only and combined DM-τ methods. Examination with localized events suggests no improvement by incorporating τ. When comparing host galaxy properties of localized FRBs with our model, we find good agreement, further validating our model's fidelity.

Introduction

FRB: Bright, milliseconds-duration and predominantly extragalactic radio transients. Physical origin are still unclear.

(Lorimer, et al., science, 2007)

(Bochenek, et al., nature, 2020)
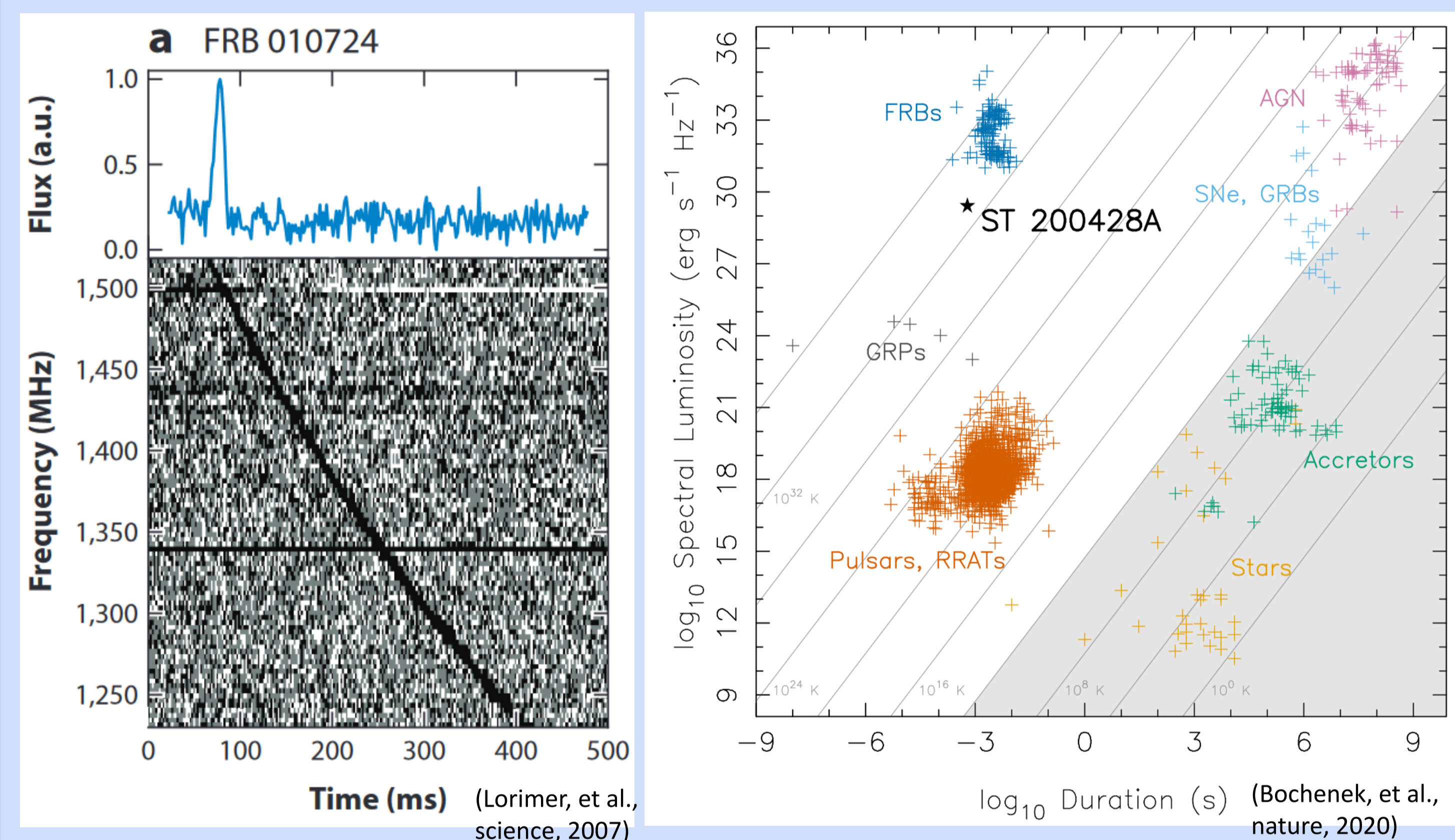
Up to now, ~800 FRBs have been reported, while ~50 are localized.
DM($DM \equiv \int n_e dl$): related to time delay.
Scattering time: related to pulse broadening.
Motivation: reproduce the joint distribution of DM and τ in the CHIME/FRB catalog to constrain the FRB population, energy distribution and host galaxy properties.
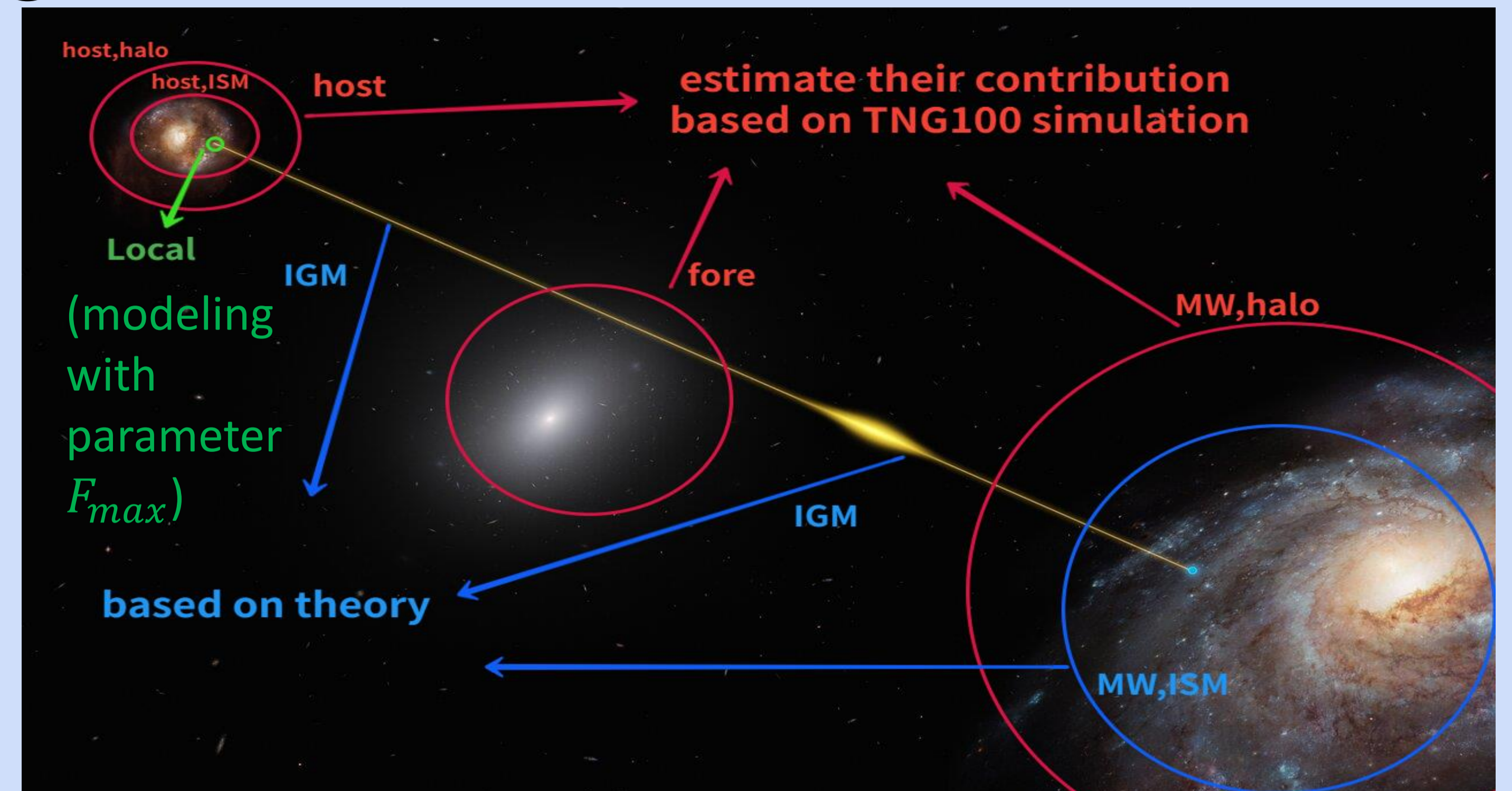
Methodology

① Generate FRB redshift distribution by a mixed population model with parameter of f_{PSFR}, i.e., the fraction of tracing cosmic star formation rate density.
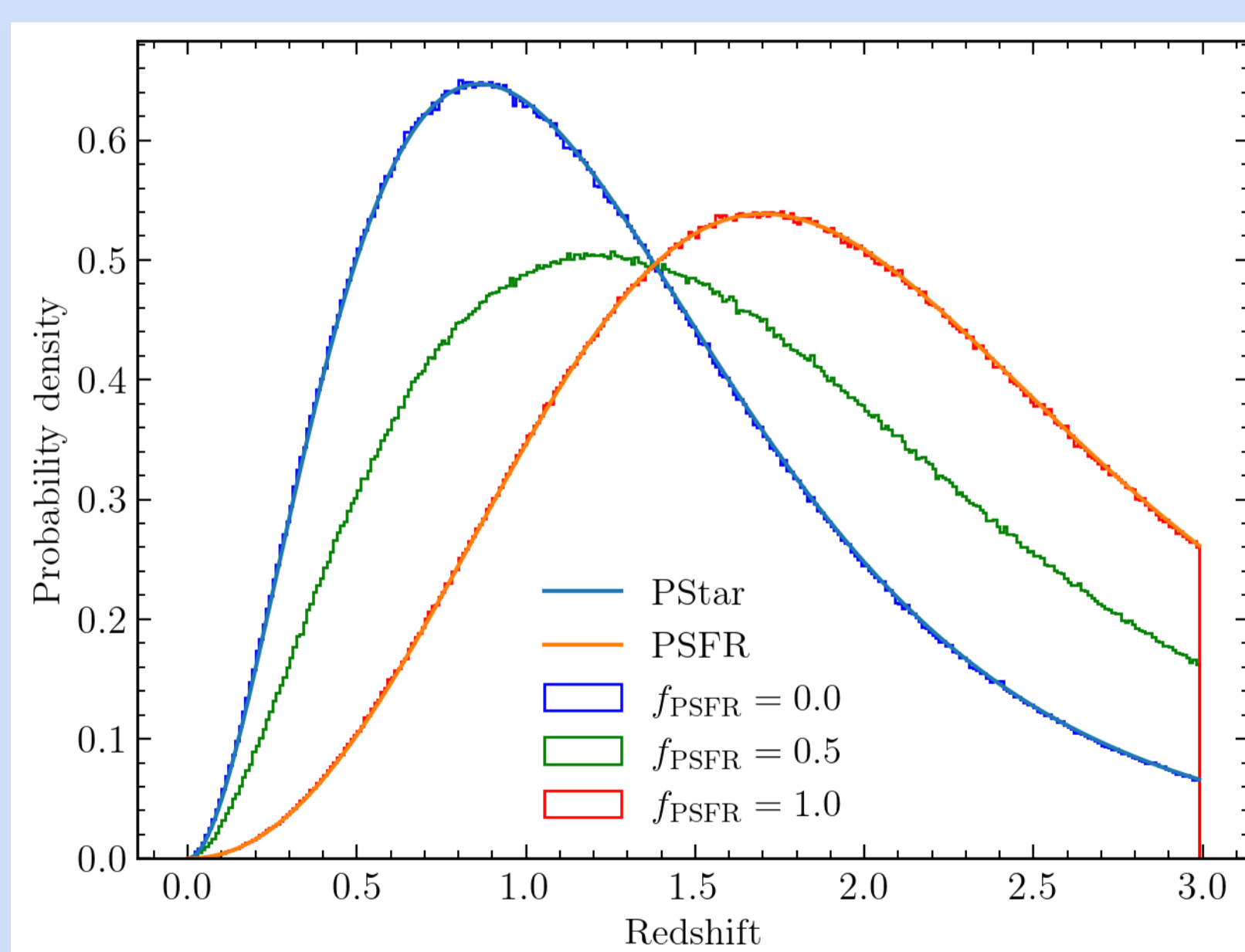
② Generate FRB energy distribution by Schechter function:
$$P(E)dE \propto \left(\frac{E}{E_*}\right)^{\gamma} \exp\left(-\frac{E}{E_*}\right) dE$$
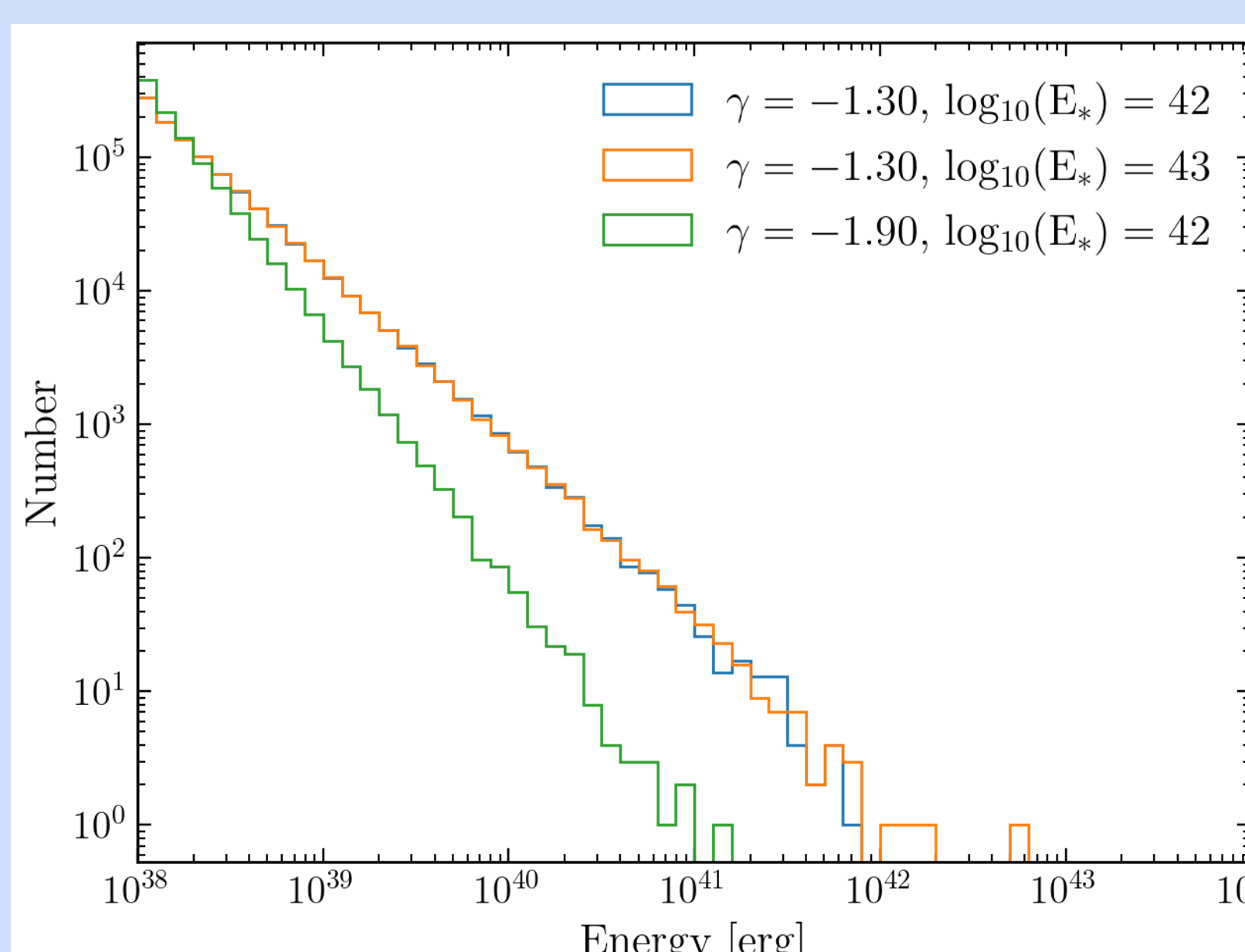
③ Estimate multi-components' contributions to DM and τ

estimate their contribution based on TNG100 simulation
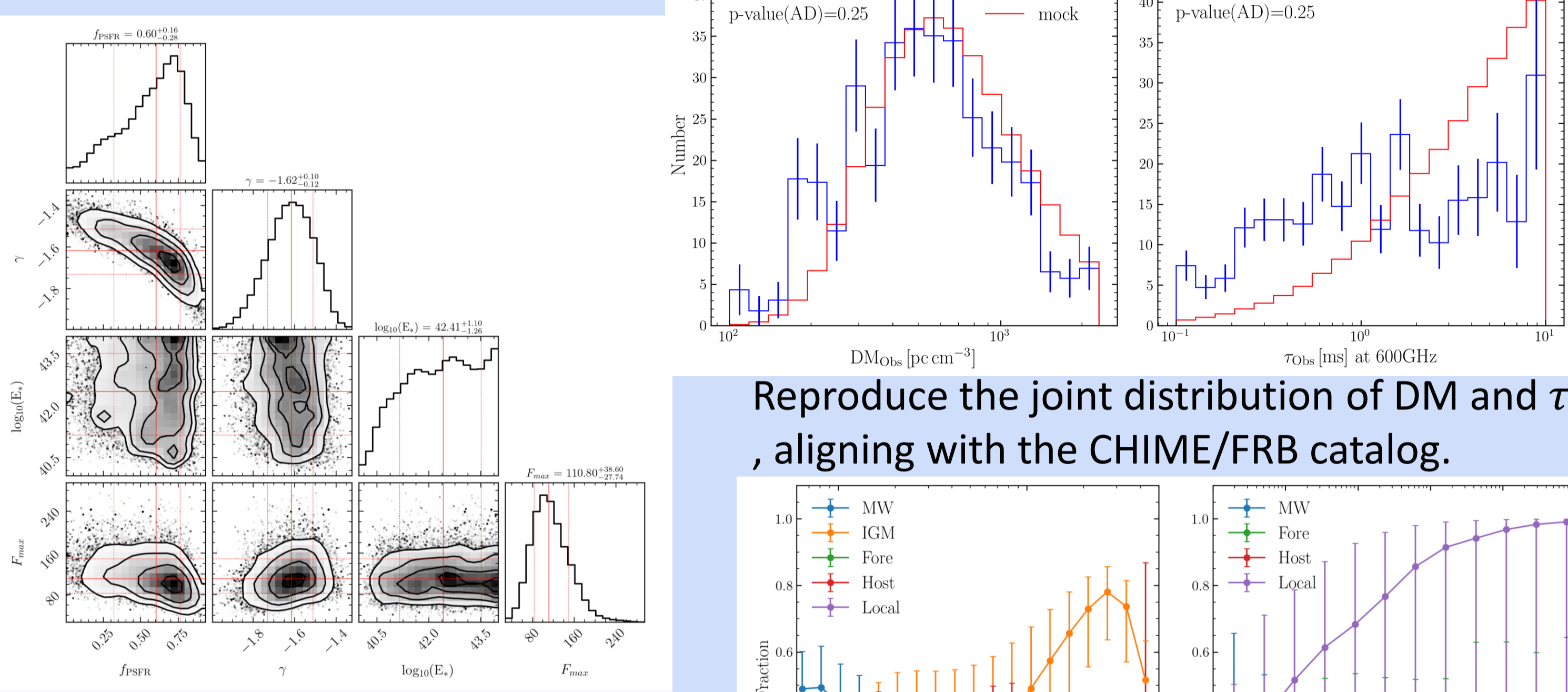
based on theory

$$DM_{obs} = DM_{MW} + DM_{IGM}(z_h) + \frac{DM_{fore}}{1+z_f} + \frac{DM_{host}}{1+z_h} + \frac{DM_{Local}}{1+z_h}$$

$$\tau_{obs} = \tau_{MW} + \frac{\tau_{fore}}{(1+z_f)^{x_\tau-1}} + \frac{\tau_{host}}{(1+z_h)^{x_\tau-1}} + \frac{\tau_{Local}}{(1+z_h)^{x_\tau-1}} . (x_\tau \simeq 4)$$

④ Select fluence > 0.4 Jy ms as mock FRBs, and run MCMC simulations to get the optimal parameters (f_{PSFR}, γ, E_*, F_{max}) that can reproduce the joint distribution of DM and τ, aligning with the CHIME/FRB catalog.
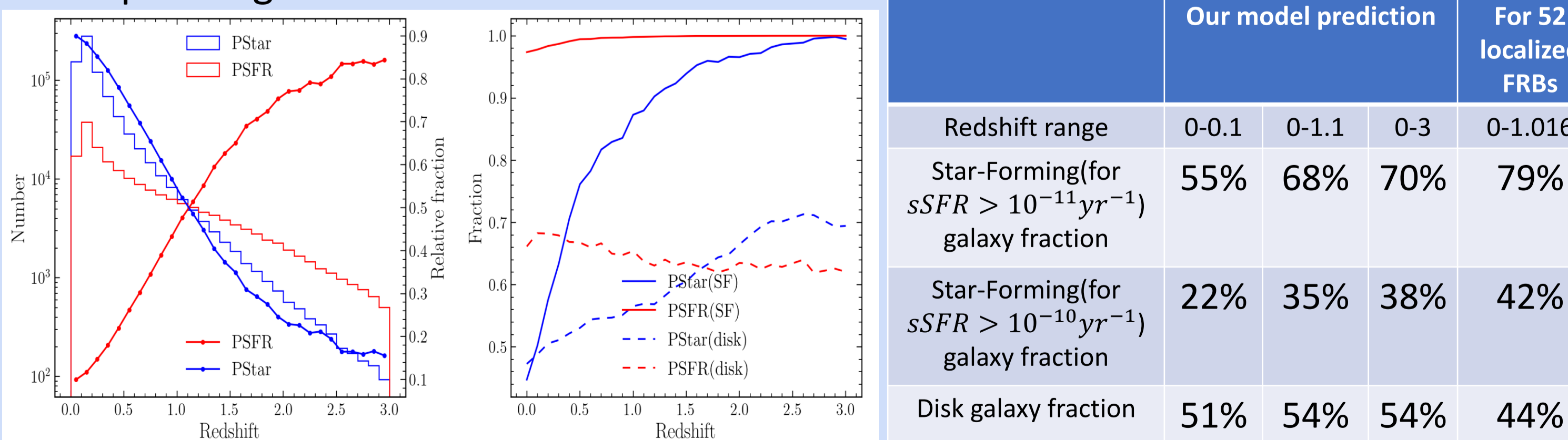
Results

Reproduce the joint distribution of DM and τ, aligning with the CHIME/FRB catalog.

Using the optimal parameters → Generate mock FRBs
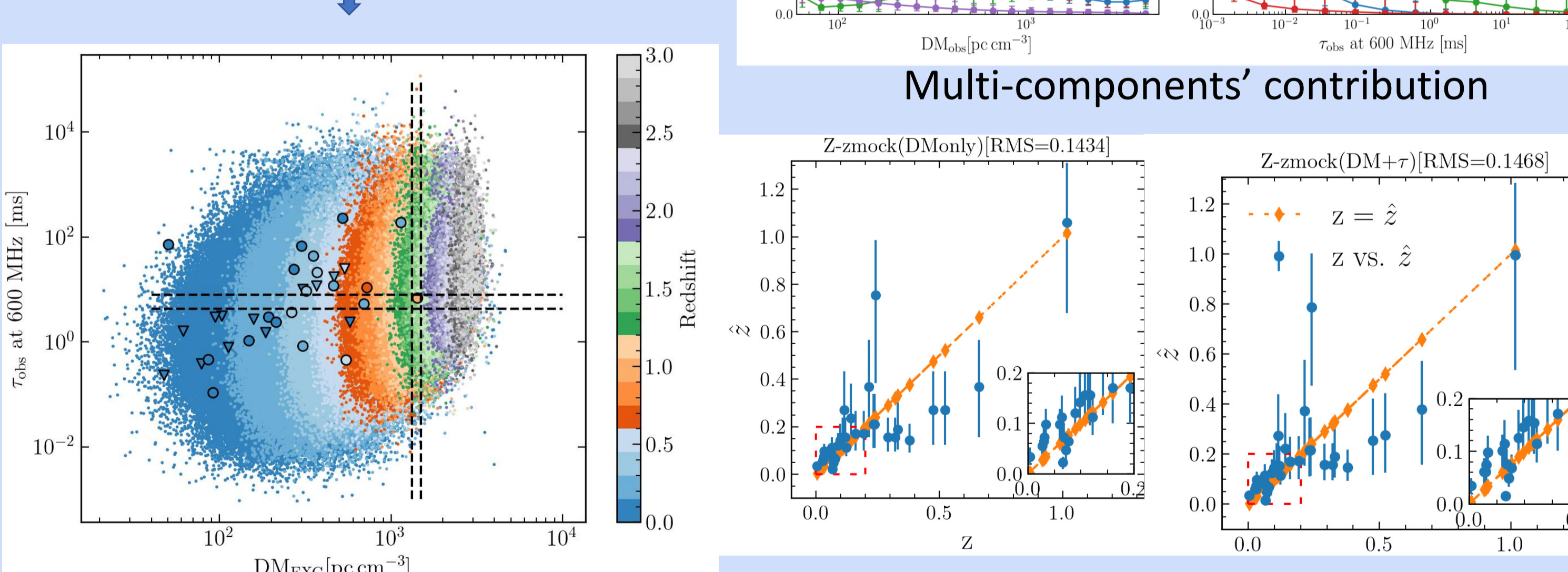
Multi-components' contribution

Using the optimal model, we estimate FRB redshifts through DM-only and combined DM-τ methods. Examination with localized events suggests no improvement by incorporating τ.

	Our model prediction			For 52 localized FRBs
Redshift range	0-0.1	0-1.1	0-3	0-1.016
Star-Forming(for $sSFR > 10^{-11} yr^{-1}$) galaxy fraction	55%	68%	70%	79%
Star-Forming(for $sSFR > 10^{-10} yr^{-1}$) galaxy fraction	22%	35%	38%	42%
Disk galaxy fraction	51%	54%	54%	44%

Based on the optimal parameters, we can predict the properties of host galaxy, e.g., the fraction of Star-Forming and disk galaxy. Localized FRBs observations agree with our prediction.

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