# FRB Two Main Papers Notes

Dispersion measure paper, and energy and redshift distributions paper.

## 1 Arcus et al. 2020

**Abstract.**


1. use ASKAP and Parkes, assume same underlying population is observed.
2. account for detection probability
3. assume DM-$z$ relation is one-to-one
4. best fit is $\hat{\alpha} = 2.2$, $\hat{\gamma} = 2.0$ and strong redshift evolution, but if assume $\hat{\alpha} = 1.5$, then $\hat{\gamma} = 1.5$ and no redshift evolution is best fit.
5. no evidence that FRB is faster than linearly w.r.t. star formation rate


### 1.1 Introduction

$\alpha$ is the spectral index, defined such that $F_\nu \propto \nu^{-\alpha}$

1. e.g. for positive values of $\alpha$, amount of energy released by FRBs is less at higher frequencies
2. $\alpha$ refers to spectral index of population of all FRBs, $\hat{\alpha}$ refers to sample?

$\gamma$ is the energy power-law index, $dN/dE \propto E^{-\gamma}$

1. shows how many FRBs (relatively) are at a particular energy
2. differential, not cumulative distribution

### 1.2 FRB Dispersion Measure Distributions

Equation 1:

$$DM_{\text{obs}} = DM_{\text{MW}} + DM_{\text{Halo}} + DM_{\text{IGM}} + DM_{\text{Host}}/(1+z)$$

1. assumed values: 30 pc cm$^{-3}$, 30 pc cm$^{-3}$, depends, and 50 pc cm$^{-3}$ respectively.
2. use $DM_{\text{obs}}$ and assumed values to find $DM_{\text{IGM}}$, and then use $DM_{\text{IGM}}$-$z$ relation.

$F_0$ is fluence limit at $DM = 0$

1. 1-5 Jy ms for Parkes
2. 21-31 Jy ms for ASKAP

Equation 2: FRB redshift distribution, in a survey of limiting fluence.

$$\frac{dR_F}{dz}(F_\nu > F_0) = 4\pi D_H^5 \left(\frac{D_M}{D_H}\right)^4 \frac{(1+z)^{\alpha-1}}{E(z)} \psi_n(z) \begin{cases} 0 & F_0 > F_{\max} \\ \frac{(1+z)^{2-\alpha}}{4\pi D_L^2} \left(\frac{F_{\max}^{1-\gamma} - F_0^{1-\gamma}}{F_{\max}^{1-\gamma} - F_{\min}^{1-\gamma}}\right) & F_{\min} \le F_0 \le F_{\max} \\ \frac{(1+z)^{2-\alpha}}{4\pi D_L^2} & F_0 < F_{\min} \end{cases}$$

still do not completely understand, but

1. $\psi_n(z)$ is the event rate per comoving volume

2. $F^{1-\gamma}$ comes from integrating $F^{-\gamma}\mathrm{d}\gamma$

Equation 3: FRB DM distribution:

$$\frac{dR_F}{dDM} = \frac{dR_F}{dz} / \frac{d\overline{DM}}{dz}$$

Equation 4: event rate $\propto$ (star formation rate)$^n$:

$$\psi_n(x) = K\left(\frac{0.015(1+z)^{2.7}}{1+((1+z)/2.9)^{5.6}}\right)^n \text{ yr}^{-1}\text{ Mpc}^{-3}$$

Equation 5: $\overline{DM}$-$z$ relation.

$$\overline{DM}(z) = \frac{3H_0 c\Omega_b}{8\pi G m_p}\int_0^z \frac{(1+z')\left[\frac{3}{4}X_{\mathrm{e,H}}(z') + \frac{1}{8}X_{\mathrm{e,He}}(z')\right]}{\sqrt{(1+z')^3\Omega_m + \Omega_\Lambda}}\mathrm{d}z'$$

$\Psi(z)$ is cosmic star formation rate (CSFR). Paper considers $n = 0$, 1, 2, where $\psi(z) \propto (\Psi(z))^n$.

### 1.3 DM Distribution Properties

Equation 6 is not used, as far as I can tell.

Equation 7: estimate efficiency.

$$\eta(DM, w) = \frac{\eta_0}{\sqrt{c_1 2k\mathrm{DM}\nu_r\bar{\nu}_c^{-3} + c_2 t_r + w}}$$

1. first term in denom is smearing of fluence over frequencies due to dispersion
2. second term is time resolution of instrument
3. third term is intrinsic burst width

Equation 8 averages $\eta$ over all widths, using a log-normal distribution in $w$.

#### 1.3.1 Parameter Fitting

They model the observed FRB DM by computing $\bar{\eta}(DM) \cdot dR_F/dDM$, and simulataneously fit the model with ASKAP and Parkes data (on the assumption that they are drawn from same population).

### 1.4 Discussion

Use KS tests to determine final p-values. Broadly, no redshift evolution $n = 0$ is favored and quadratic redshift evolution $n = 2$ is disfavored.

$\gamma$ is expected to impact the DM distribution; $\gamma$ between 2-3 results in excess of FRBs in nearby universe (DM $\sim 0$). This effect is not observed.

Equation 9: expected value of $DM$.

$$\langle DM(F_\nu > F_0)\rangle = \int_0^\infty DM' \frac{dR_F}{dDM'} dDM'$$

## 2 Zhang et al. 2020

**Abstract.**

1. energy, redshift distribution
2. Monte Carlo simulations compared with FRB data constrains models
3. two redshift distribution models: star formation history, and merger (with delay distributions)
4. $-1.8$ power law index for energy confirmed. None of the redshift distributions rejected.

## 2.1 Introduction

Different types of FRB source models.

1. catastrophic (non-repeater): blitzar, star collapse, ...
2. repeaters: magnetars, neutron star interaction, ...

Each source model predicts different redshift distribution.

1. star-related phenomena follow cosmic star formation rate
2. merger-related follow merger redshift distribution

## 2.2 Models

### 2.2.1 Energy Distribution

Equation 1: several groups show FRB distribution is power law:

$$\frac{dN}{dE} \propto \left(\frac{E}{E_c}\right)^{-\alpha} e^{-\frac{E}{E_c}}$$

### 2.2.2 Redshift Distributions

Equation 2-4: Intrinsic event rate density distribution $\frac{dN}{dtdV}(z)$ converts to observed $\frac{dN}{dt_{\text{obs}}dz}(z)$.

$$\frac{dN}{dt_{\text{obs}}dz} = \frac{dN}{dtdV} \cdot \frac{dt}{dt_{\text{obs}}} \cdot \frac{dV}{dz}$$

$$\frac{dt}{dt_{\text{obs}}} = \frac{1}{1+z}$$

$$\frac{dV}{dz} = \frac{c}{H_0} \cdot \frac{4\pi D_L^2}{(1+z)^2\sqrt{\Omega_m(1+z)^3 + \Omega_\Lambda}}$$

### 2.2.3 Star Formation Rate History Model

Equation 5: SFR Model.

$$\frac{dN}{dtdV} \propto \left[(1+z)^{\alpha\eta} + \left(\frac{1+z}{B}\right)^{b\eta} + \left(\frac{1+z}{C}\right)^{c\eta}\right]^{1/\eta}$$

1. $a = 3.4$, $b = -0.3$, $c = -3.5$
2. $B \simeq 5000$, $C \simeq 9$, $\eta = -10$

### 2.2.4 Compact Star Merger Model

Equation 6-8: different models of merger delay distributions.

$$P(\tau)d\tau = \frac{1}{\sqrt{2\pi}\sigma} \exp\left(-\frac{(\tau-\tau_0)^2}{2\sigma^2}\right) d\tau$$

$$P(\tau)d\ln\tau = \frac{1}{\sqrt{2\pi}\sigma} \exp\left(-\frac{(\ln\tau-\ln\tau_0)^2}{2\sigma^2}\right) d\ln\tau$$

$$P(\tau)d\tau = \left(\frac{1-\alpha}{\tau_{\text{max}}^{1-\alpha_\tau} - \tau_{\text{min}}^{1-\alpha_\tau}}\right) \tau^{-\alpha_\tau} d\tau$$

Respectively:

1. Gaussian, $\tau_0 = 2$ Gyr, $\sigma = 0.3$ Gyr
2. log-normal, $\tau_0 = 2.9$ Gyr, $\sigma = 0.2$.
3. power law, $\tau_{\max}$ and $\tau_{\min}$ are max/min merger time scale, and $\alpha_\tau = 0.81$

#### 2.2.5 Others

Steps of Monte Carlo:

1. convert simulated SFR redshift convert to lookback time
2. subtract merger delay time
3. convert back to redshift, derive new event rate
4. convert $dN/(dtdV)$ to $dN/(dt_{\mathrm{obs}}dz)$

Specific Fluence:

$$\mathcal{F}_\nu = \frac{(1+z)E}{4\pi D_L^2 \nu_c}$$

Paper simulates fluence sensitivity threshold $\mathcal{F}_{\nu,\mathrm{th}}$

Dispersion Measure:

$$DM_{\mathrm{IGM}}(z) = \frac{3cH_0\Omega_b f_{\mathrm{IGM}}}{8\pi G m_p} \int_0^z \chi \frac{1+z}{\sqrt{\Omega_m(1+z)^3 + \Omega_\Lambda}} dz$$

$$\mathrm{DM_E} = \mathrm{DM_{IGM}}(z) + \frac{\mathrm{DM_{host}}}{1+z} \text{ (extragalactic DM)}$$

## 3 Data and Simulations