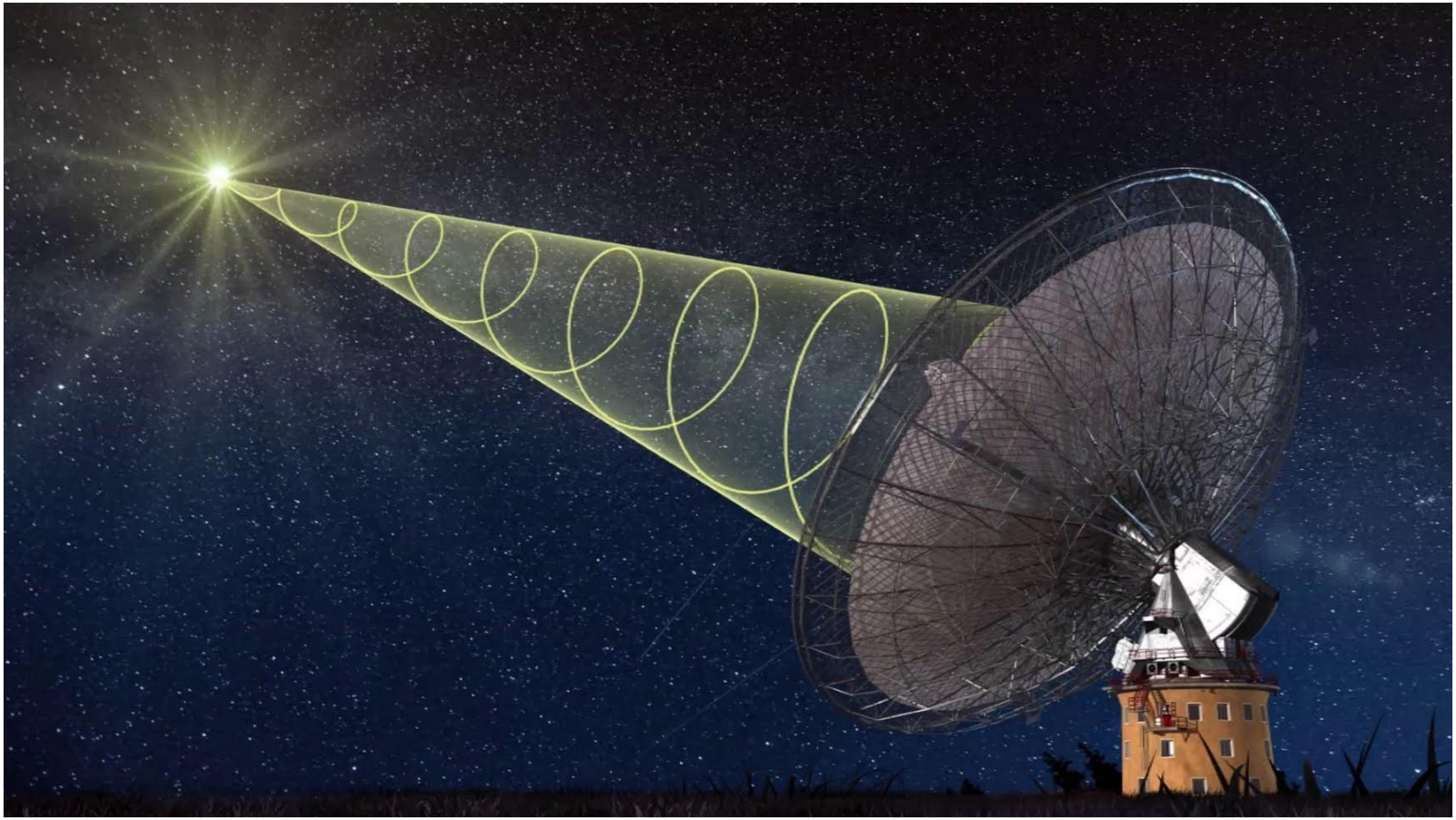

The Scattering and Dispersion Measures of FRBs by the Intergalactic Medium

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Zhu, Feng & Zhang, 2018, ApJ submitted

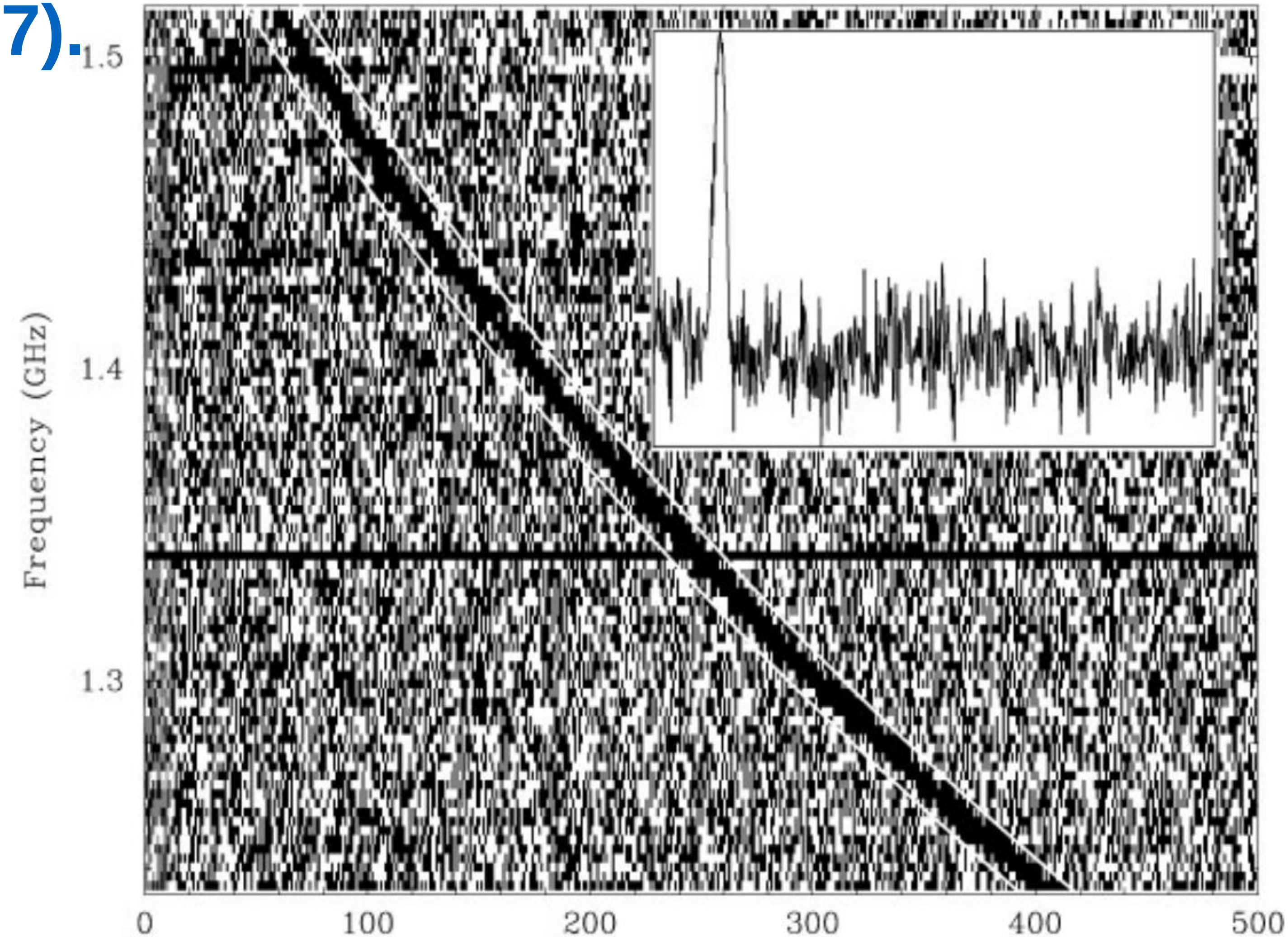
Fast Radio Burst

- Fast radio bursts (FRBs) are a class of millisecond-duration radio transients (Lorimer et al. 2007).

$\triangle t \propto \nu^{-2}$

Dispersion by cold ionized plasma

32 FRBs (2018.6)



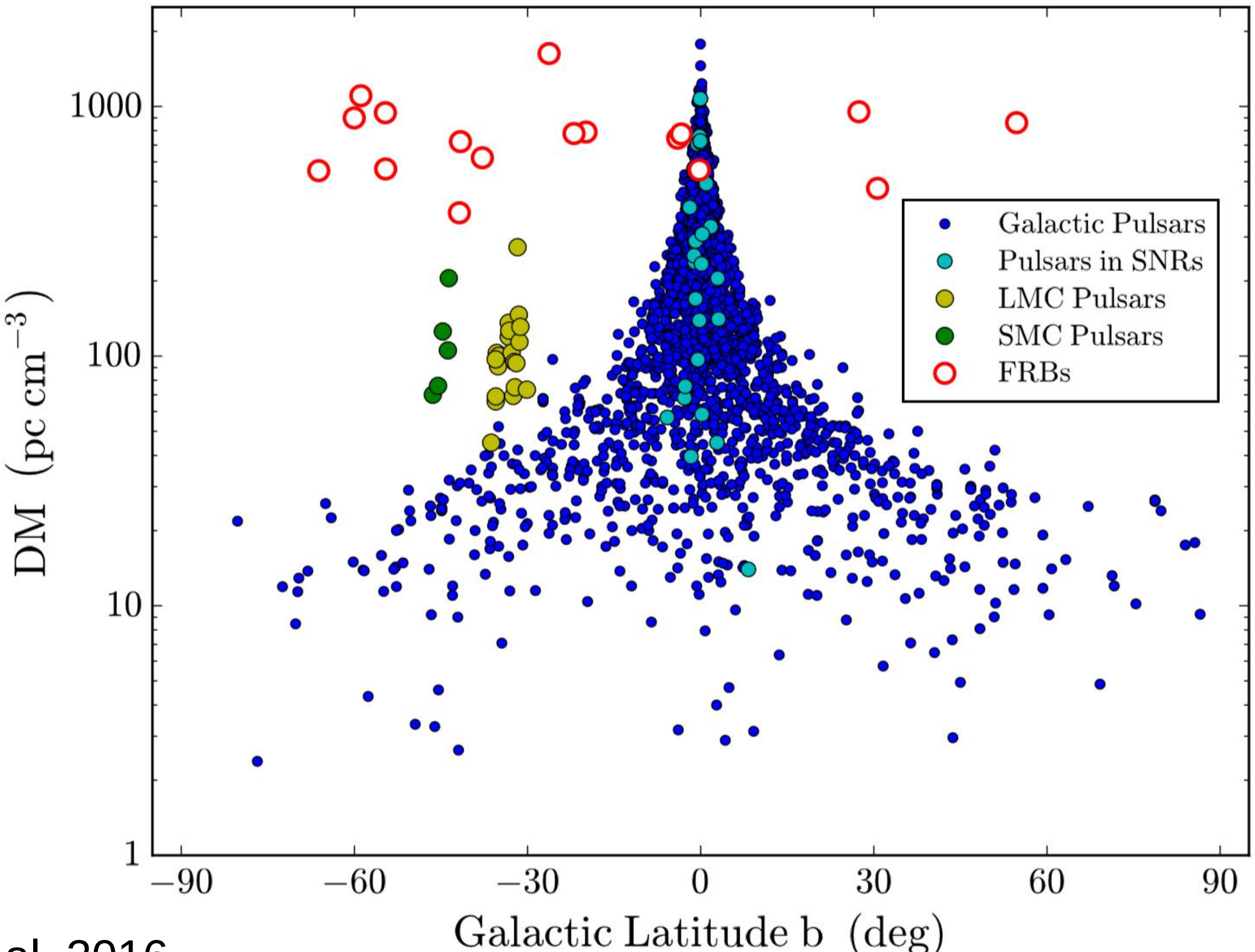
(Lorimer et al. 2007)

Fast Radio Burst: Cosmological Origin

- **Large DM =177–2596pc cm^{-3}: naturally attributed to the intergalactic plasma (Cordes et al. 2016,Ioka 2003; Inoue 2004; Deng & Zhang 2014; McQuinn 2014)**

- **FRB 121102 repeater z~0.193**
(Chatterjee et al. 2017)

- **Isotropic (Bhandari et al. 2018)**



Cordes et al. 2016

Fast Radio Burst: Models

- **Supergiant pulses:**

  Short (us) radio bursts with strong peak (Cordes & Wasserman 2016; Connor et al. 2016)

- **Magnetars**

  Hyperflares of magnetars , similar to Soft Gamma Ray repeaters (Popov et al. 2010, Murase et al. 2016, Lyutikov 2002)

- **Other models**

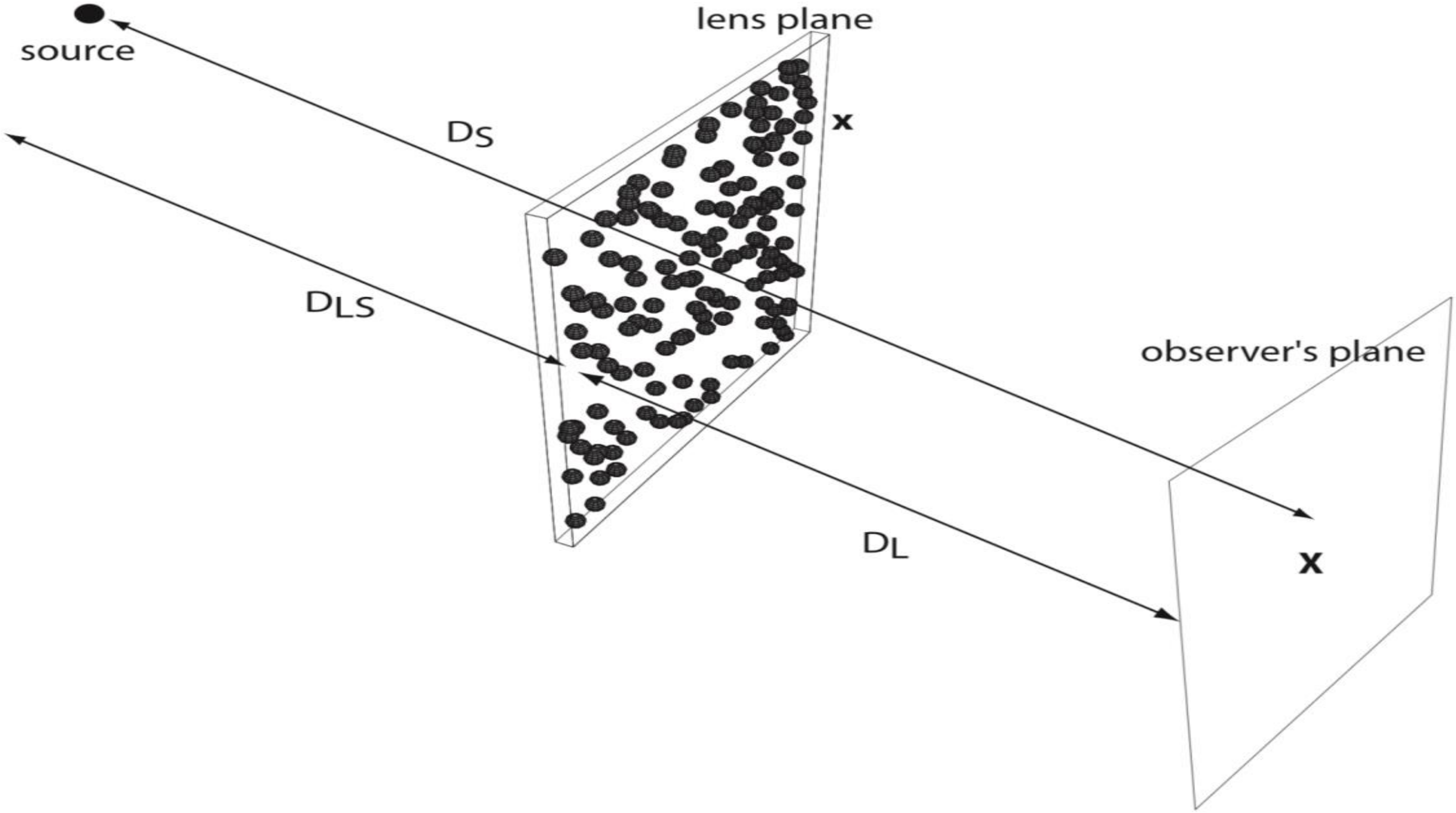
  Merging or colliding neutron stars (Totani 2013)

  Neutron star collapse (Falcke & Rezzolla 2014)

  Collision of asteroids with neutron stars (Dai et al. 2016)

- **The temporal smearing (broadening) of FRB : τ ~1-10 ms at ν ~ 1 GHz (Petroff 2016) τ ∝ ν $^{-4}$**

$$\tau = \frac{D_{\mathrm{L}}\, D_{\mathrm{S}}\, \theta^2_{\mathrm{scat}}}{c\, D_{\mathrm{LS}}\,(1+z_L)}.$$



Kolmogorov turbulence

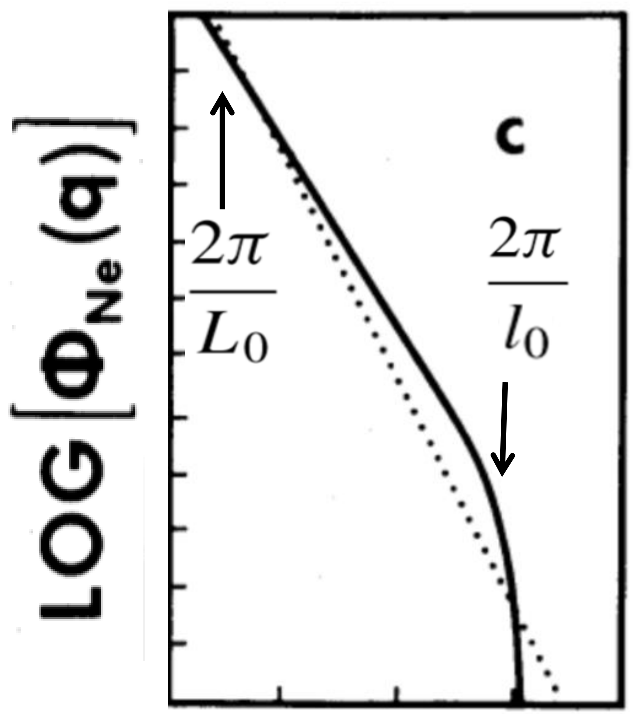
- ***Electron energy power spectrum of turbulence***

$$\Phi_{N_e}(\mathbf{q}; l) = C_N^2(l)\, q^{-\beta} e^{-(q l_0)^2}, \qquad q > \frac{2\pi}{L_0}.$$

- **Outer scale L_0, inner scale l_0**
- **Both simulation and observati can't provide any information between ~10 kpc - 10 AU**

- **The scattering measure of FR**

$$\mathrm{SM_{eff}}(z_s) = \int_0^{z_s} \frac{C_N^2(z) d_H(z)}{(1+z)^3} dz,$$



Coles et al. 1987

The debate of the broadening of FRB

➢Host Galaxy?

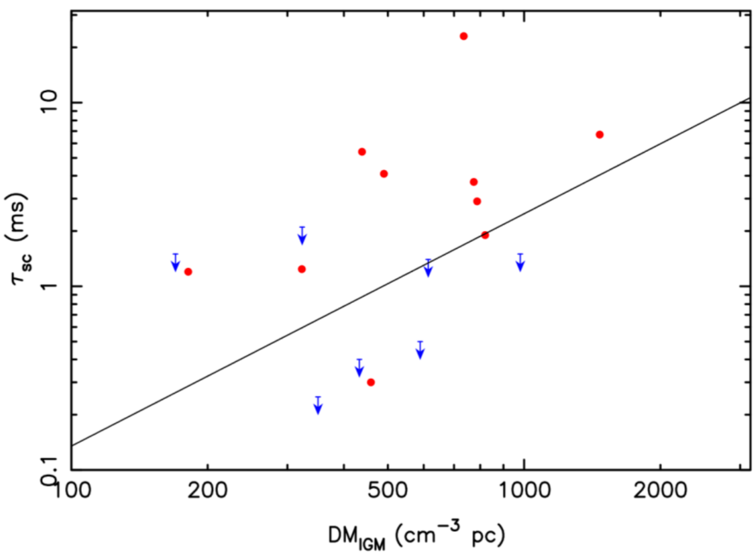
- The host can cause significant broadening to explain the observation (Cordes et al. 2016)

➢IGM?

- **Assuming IGM is uniform,** $L_0 \sim 10^{-2}$ pc (Luan & Goldreich 2014, Xu & Zhang 2016).

✓ But IGM is **not** uniformly distributed

✓ There are significant LOS variations of τ (Macquart & Koay 2013)



Yao et al. 2017

Simulations

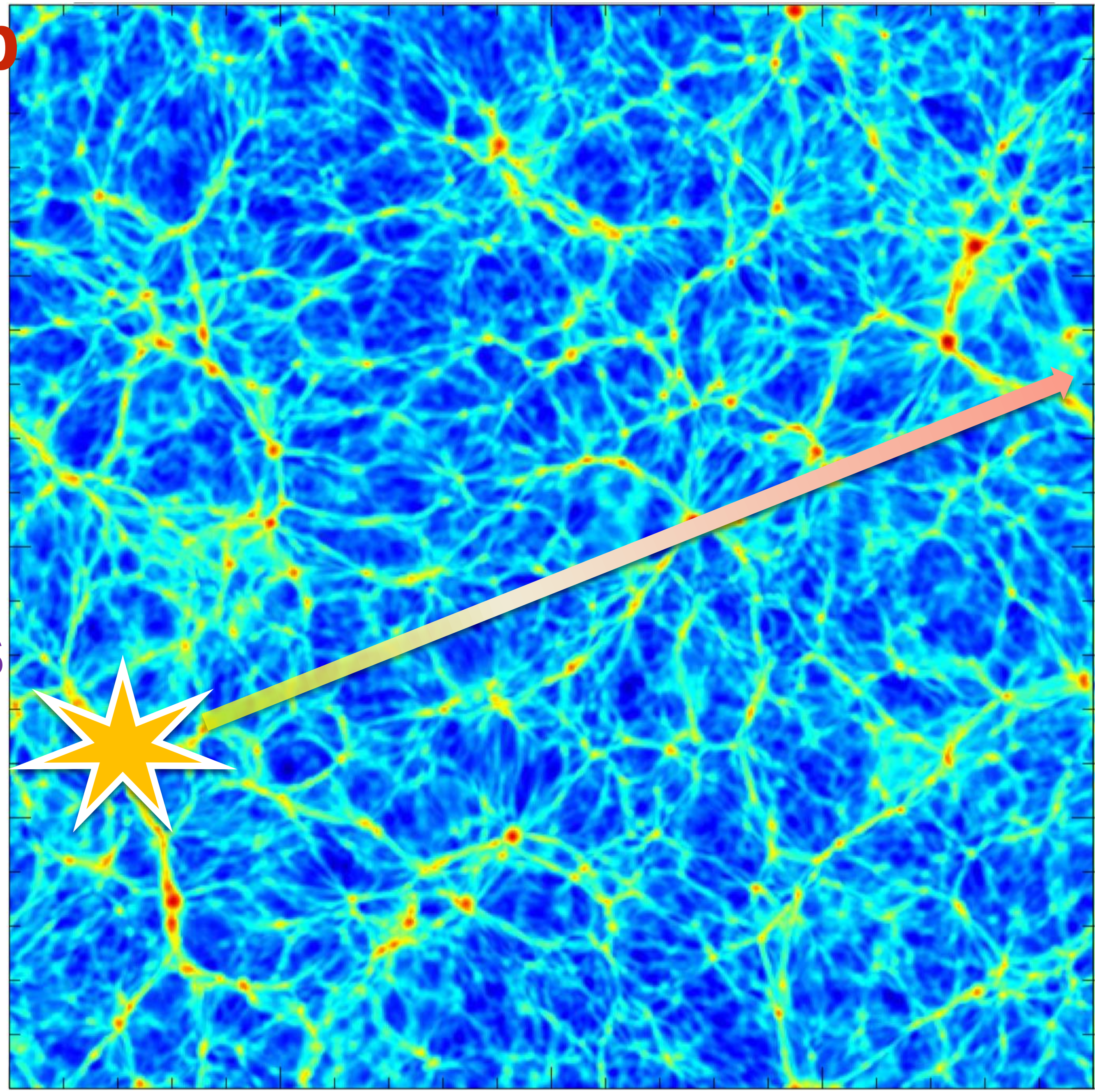
- Fixed-grid cosmological hydrodynamical simulation using the code **WIGEON** (Feng et al. 2004; Zhu et al. 2013)

	Box Size (h^{-1} Mpc)	Spatial Resolution h^{-1} kpc	Grid size
B200	200	195	1024^3
B100	100	97.7	1024^3
B050	50	48.8	1024^3

- Z=2.5~0

Cosmic Web

- Voids
- Walls
- Filaments
- Clusters



Zhu, Feng & Zhang, 2018, ApJ submitted

DM, SM and temporal smearing

$$\mathrm{DM}(z_s) = \int_0^{z_s} \frac{n_e(z)}{1+z} dl,$$

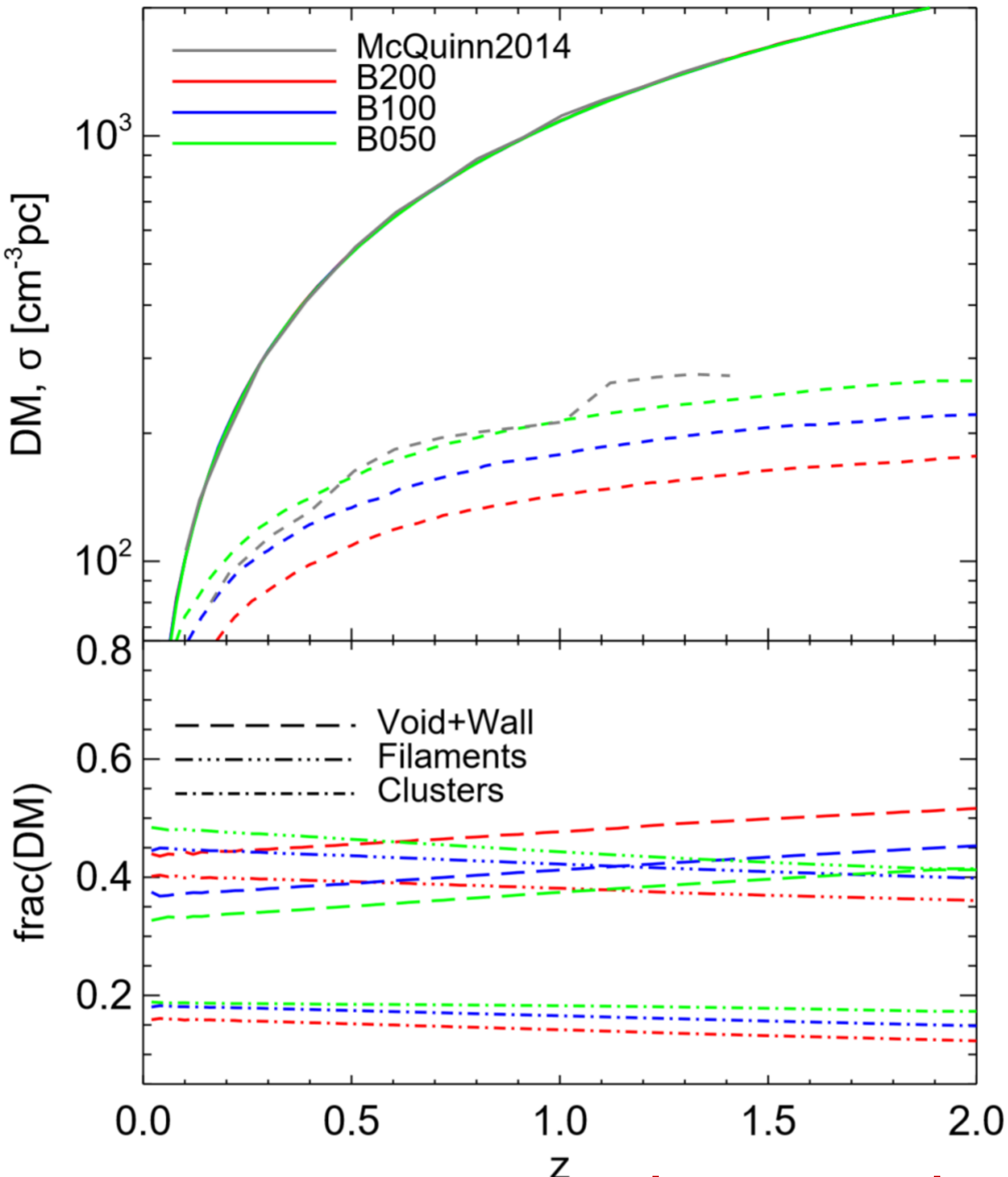
$$\mathrm{SM}_{\mathrm{eff}}(z_s) \approx 1.31 \times 10^{13} m^{-17/3} \cdot \frac{1}{h} (\frac{\Omega_b}{0.049})^2 (\frac{L_0}{1\mathrm{pc}})^{-2/3} \times \int_0^{z_s} (\rho_b(z)/\bar{\rho}_b(z))^2 \frac{(1+z)^3}{[\Omega_\Lambda + \Omega_m (1+z)^3]^{1/2}} dz.$$

$$\tau = 3.32 \times 10^{-4} (1+z_L)^{-1} (\frac{\lambda_0}{30cm})^4 (\frac{D_{\mathrm{eff}}}{1\mathrm{Gpc}}) \times (\frac{\mathrm{SM}_{\mathrm{eff}}}{10^{12} m^{-17/3}}) (\frac{l_0}{1\mathrm{AU}})^{-1/3} ms, r_{\mathrm{diff}} < l_0,$$

R_{diff} diffractive length scale

$$\tau = 9.50 \times 10^{-4} (1+z_L)^{-1} (\frac{\lambda_0}{30cm})^{22/5} (\frac{D_{\mathrm{eff}}}{1\mathrm{Gpc}}) \times (\frac{\mathrm{SM}_{\mathrm{eff}}}{10^{12} m^{-17/3}})^{6/5} ms, r_{\mathrm{diff}} > l_0,$$

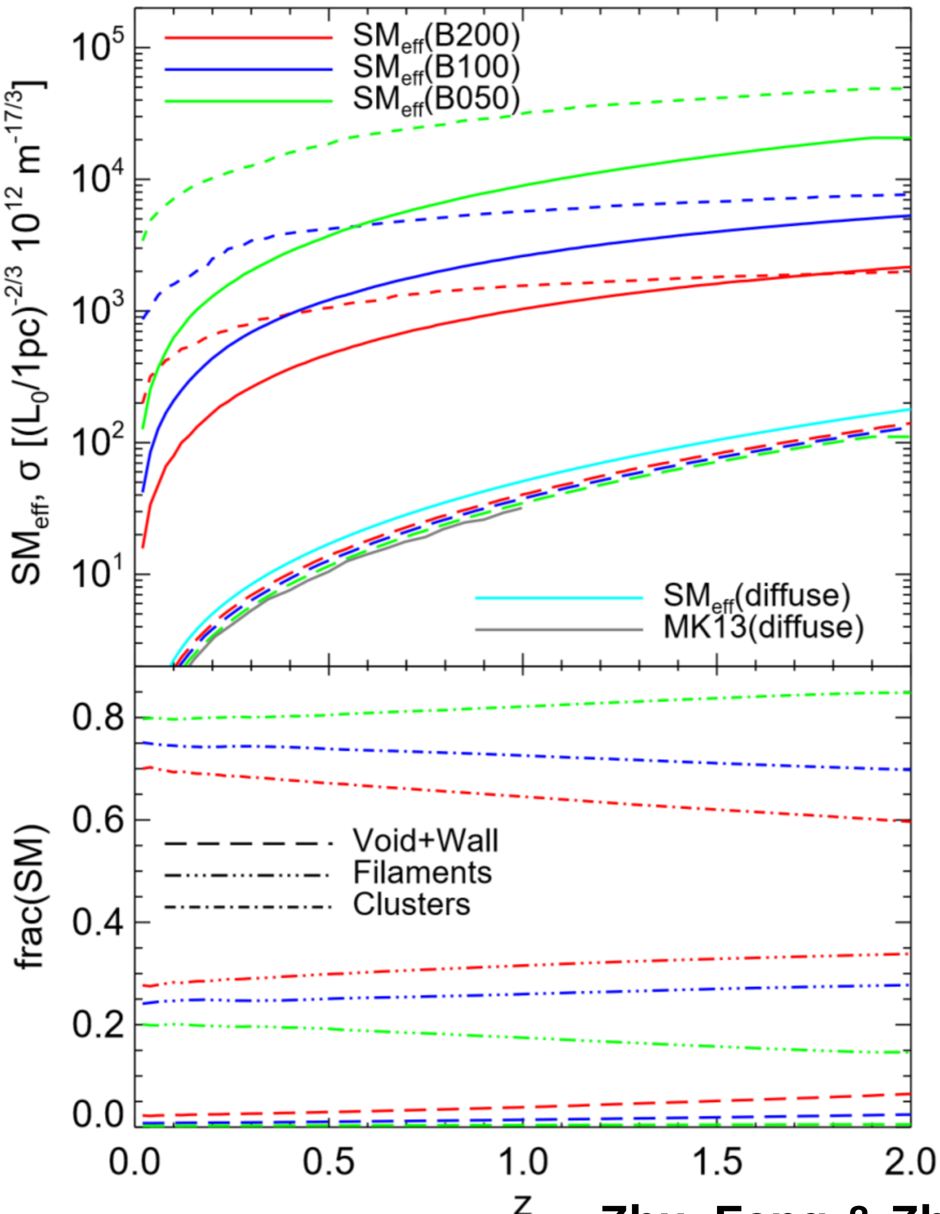
Dispersion Measure of FRB by IGM



- DM increase with z
- Clusters:15%-20%
- Filaments:35-45%
- Voids & Walls: 35-45%

Zhu, Feng & Zhang, 2018, ApJ submitted

Scattering Measure of FRB by IGM



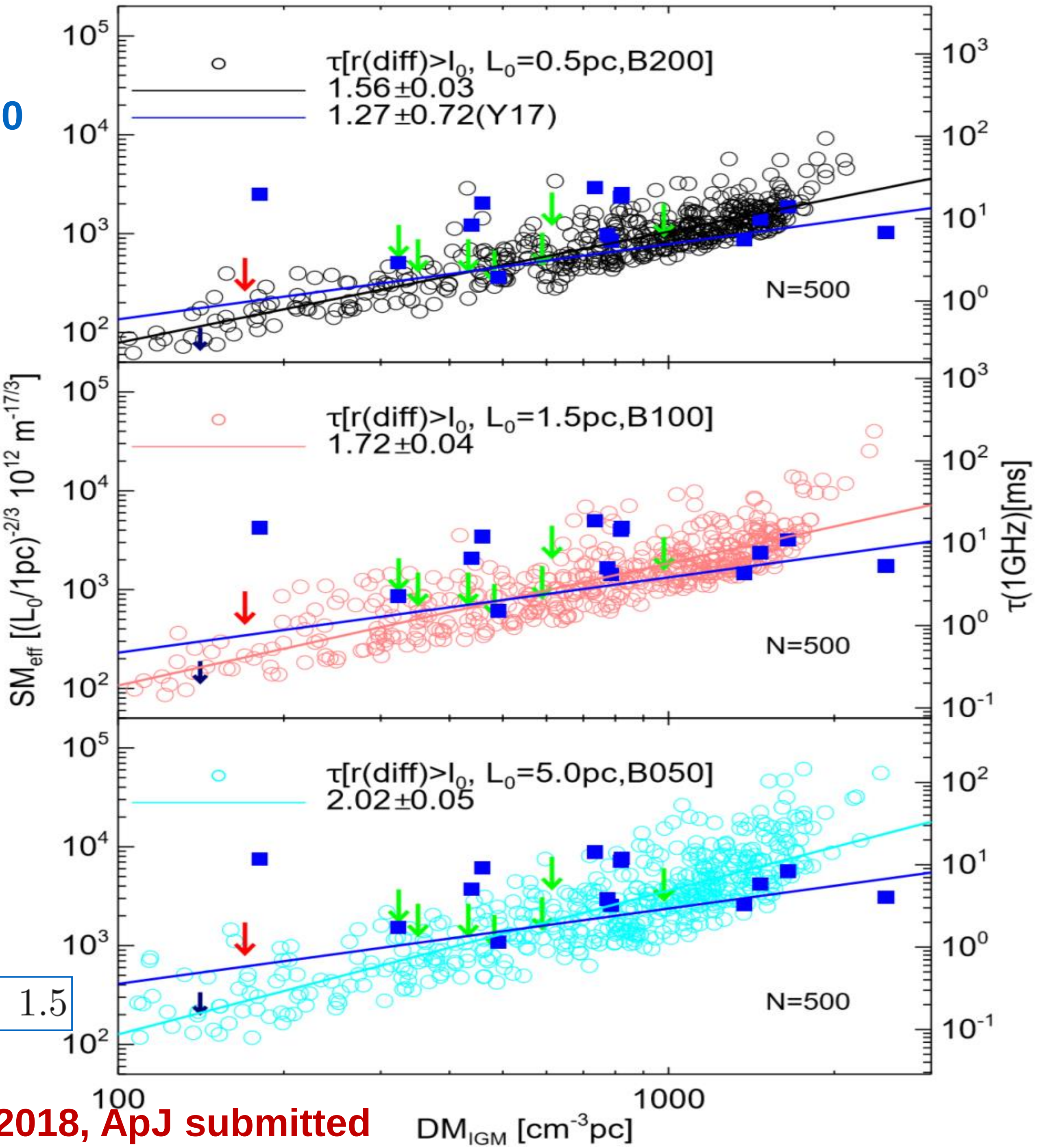
- The SM show significant LOS variations
- Clumpy IGM increase the SM by 20 times
- Increase with resolution

- Void & Wall: 4-5%
- Filaments: 20-30%
- Clusters: 65-80%

Zhu, Feng & Zhang, 2018, ApJ submitted

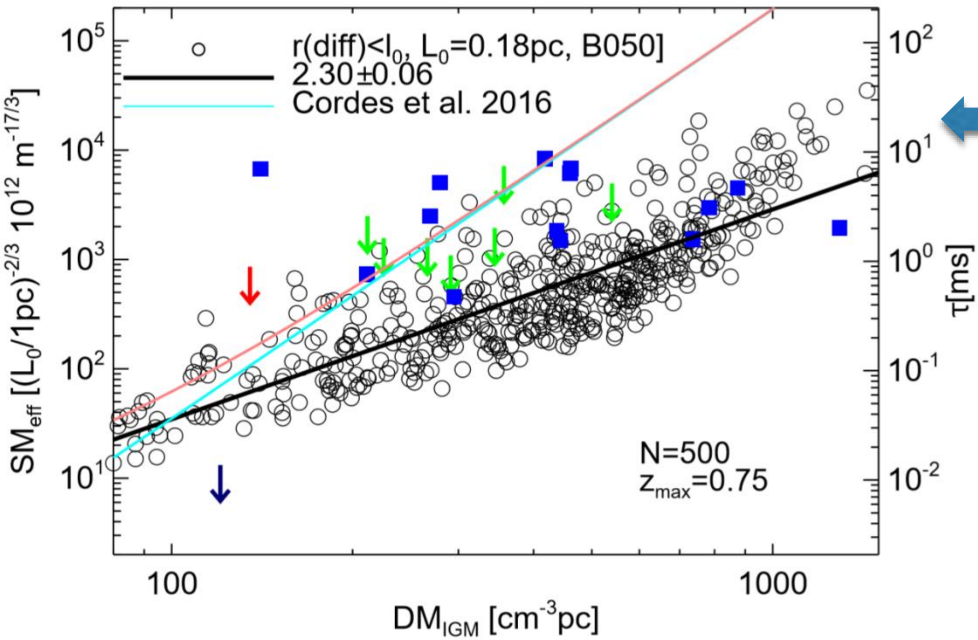
- **The required L_0 0.2-5pc**
- **100 larger than if assuming smoothed IGM**
- **Increase with the resolution**

$\tau_{\rm IGM} \propto {\rm DM_{IGM}}^{\mathbf{1.6\text{-}2.1}}$ at $z < 1.5$



Zhu, Feng & Zhang, 2018, ApJ submitted

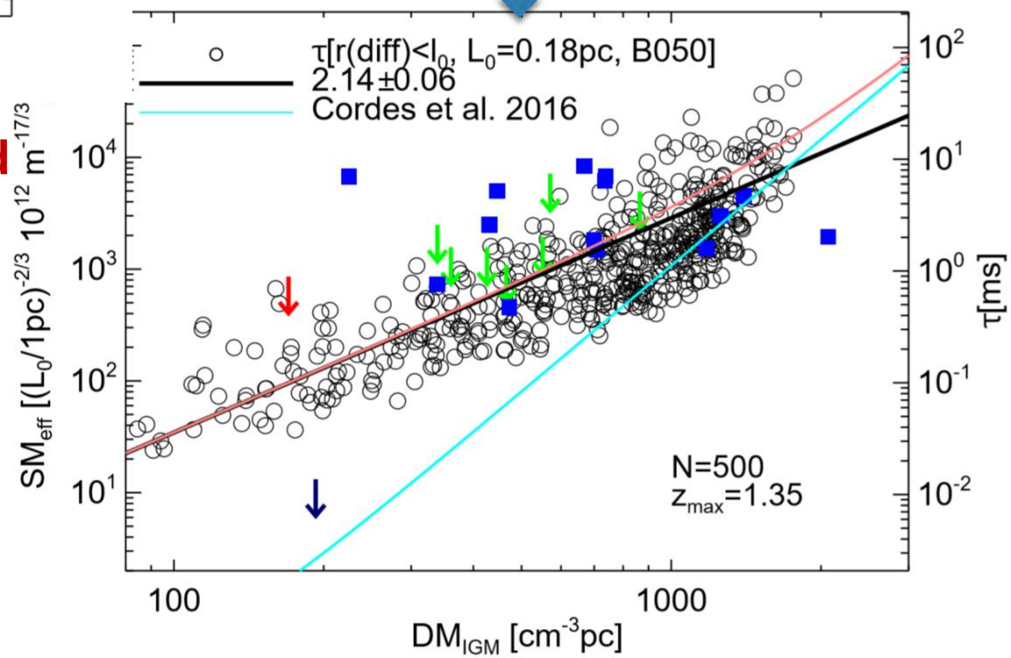
Contribution from host and IGM



DM(Host)=50%

hu, Feng & Zhang, 2018, ApJ submitted

DM(Host)=20%



$$\widehat{\tau}(\mathrm{DM}) = 2.98 \times 10^{-7} \times \mathrm{DM}^{1.4} \times (1 + 3.55 \times 10^{-5} \times \mathrm{DM}^{3.1})\ \mathrm{ms}.$$

Cordes et al. 2016

Conclusions

- The scattering of FRBs by IGM is explored using cosmological hydrodynamical simulations
- Scattering of FRB by IGM
  Voids & walls: weak, filaments & clusters: strong
  Significant LOS variation
  Some FRBs may be explained by IGM, while others by host
- The outer scale L_0~5 pc is required to explain the observed scattering. But it increases with the resolution scale.
- Some FRBs can be useful tools to probe the gas in clusters and filaments.

Thank you!~~

Cosmic Web