COSMOLOGICAL FRB SIMULATIONS

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Outline

- Energy, luminosity and redshift distributions
- Contributions to DM
- FRB widths and fluxes
- Simulation procedure
- Results
- Conclusions

Redshift distribution

- Assume FRBs are uniformly distributed
- Generate co-moving distances within a co-moving volume up to $z = 2.5$: $0 < r < 1$

$$D_{\rm c} = \left(V_{\rm max} r \frac{3}{4\pi} \right)^{\frac{1}{3}}$$

- Compute z from $D_c(z)$ (Hogg 1999):

$$D_c(z) = \frac{c}{H_0} \int_0 \frac{dz'}{\sqrt{\Omega_m (1+z')^3 + \Omega_\Lambda}}$$

H_0 = 68.0 km s^{-1} Mpc^{-1} , Ω_m = 0.32, and $\Omega_л$ =0.68

Energy and luminosity distributions

- **Model A**: σ_E, σ_L

  Energy, Luminosity: Gaussian distributions

- **Model B**: E, L_{min}, α

  Energy: Constant

  Luminosity: Power law distribution

$$p(L) = \frac{\alpha - 1}{L_{\min}} \left(\frac{L}{L_{\min}} \right)^{-\alpha}$$

- **Model C**: $\sigma_E, L_{min}, \alpha$

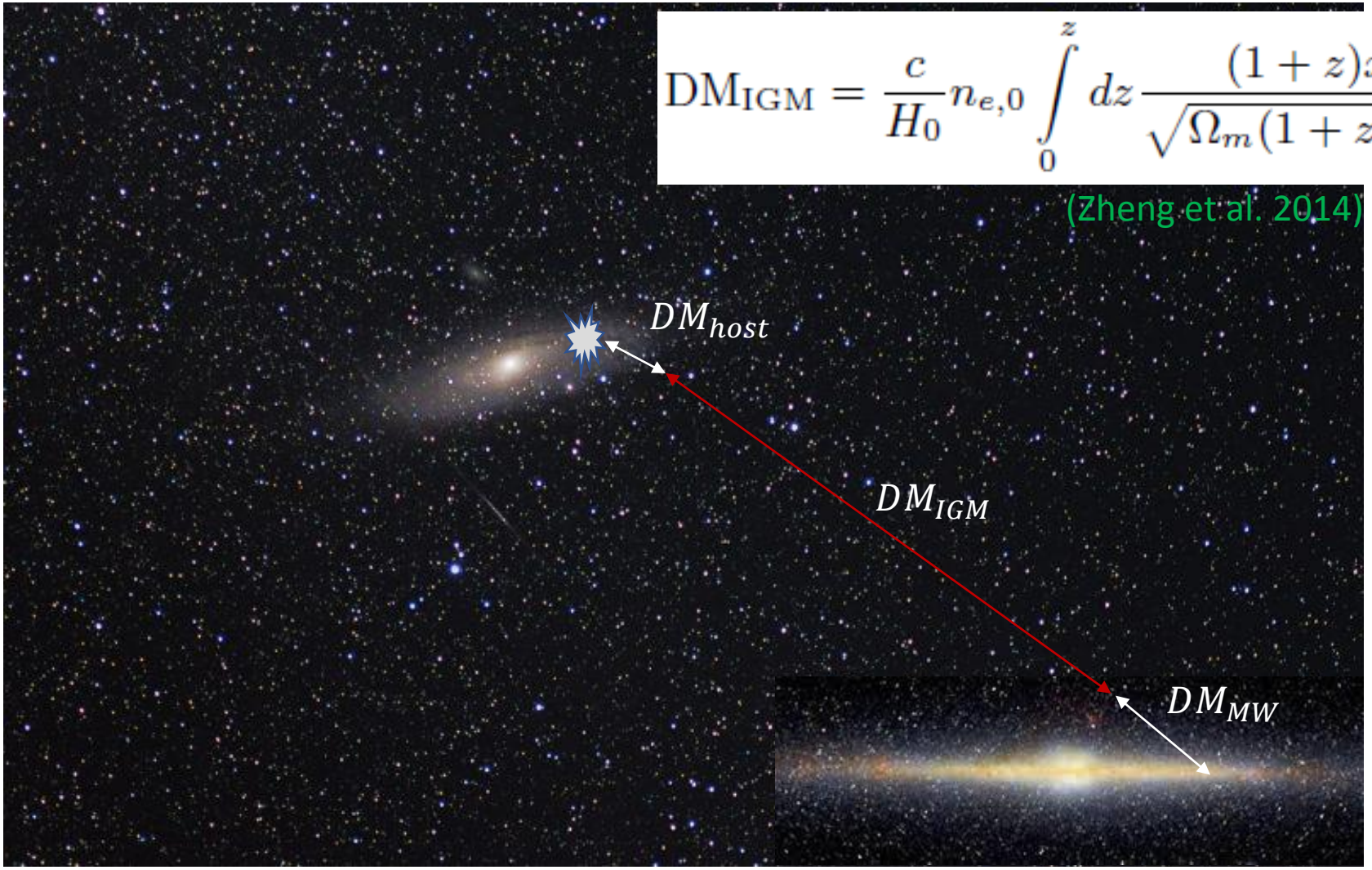
  Energy: Gaussian distribution

  Luminosity: Power law distribution

DM contributions

$$\mathrm{DM_{IGM}} = \frac{c}{H_0} n_{e,0} \int_0^z dz \frac{(1+z)x(z)}{\sqrt{\Omega_m (1+z)^3 + \Omega_\Lambda}}$$

(Zheng et al. 2014)



H_0 = 68.0 km s^{-1} Mpc^{-1} , Ω_m = 0.32, $\Omega_л$ =0.68, $n_{e,0} = 2 \times 10^{-7} cm^{-3}$

FRB widths

- In a simple empirical model:

$$E = LW_{rest} \quad \Rightarrow \quad W_{\rm int} = (1+z)\sqrt{\left(\frac{E}{L}\right)^2 + t^2_{\rm scatt,host}}$$

- The effective observed pulse width (ms):

$$W_{\rm obs} = \sqrt{W^2_{\rm int} + \Delta t^2 + t^2_{\rm scatt,MW} + t^2_{\rm samp}}$$

- Dispersion delay: $\Delta\nu$ and ν in MHz

$$\Delta t \cong 8.3 \times 10^6 {\rm ms} \times {\rm DM} \times \frac{\Delta\nu}{\nu^3}$$

- Scattering:

$$\log(t_{\rm scatt}) = 0.154 {\rm logDM} + 1.07(\log({\rm DM}))^2 - 7$$ (Lorimer et al. 2013)

- Sampling time (Parkes HTRU survey): $t_{samp} = 64\ \mu s$

FRB fluxes

- Peak flux averaged over a certain bandwidth (Following Lorimer et al. 2013):

$$S_{\rm peak} = \frac{L(1+z)^{\alpha-1}}{4\pi D(z)^2(\nu'^{\alpha+1}_{\rm high} - \nu'^{\alpha+1}_{\rm low})} \left(\frac{\nu_2^{\alpha+1} - \nu_1^{\alpha+1}}{\nu_2 - \nu_1}\right) \frac{W_{\rm int}}{W_{\rm obs}}$$

- Peak observed flux:

$$S_{\rm peak,obs} = S_{\rm peak}\delta$$

- Detection criteria: S/N > 9.0

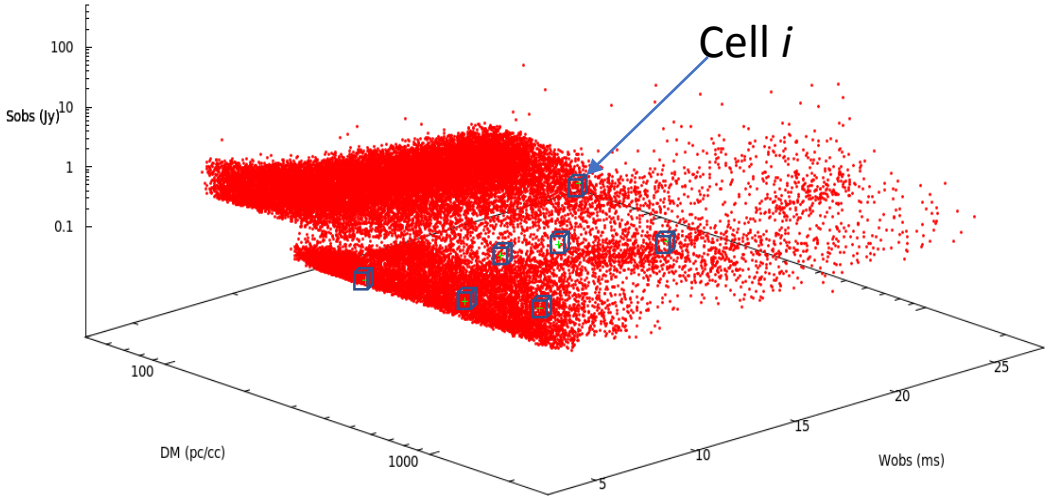
Likelihood

- For every simulated FRB: ***DM, $S_{peak,obs}$, W_{obs}***
- For every known FRB: ***DM, $S_{peak,obs}$, W_{obs}***
- Probability of getting the modeled number of FRBs in cell *i*

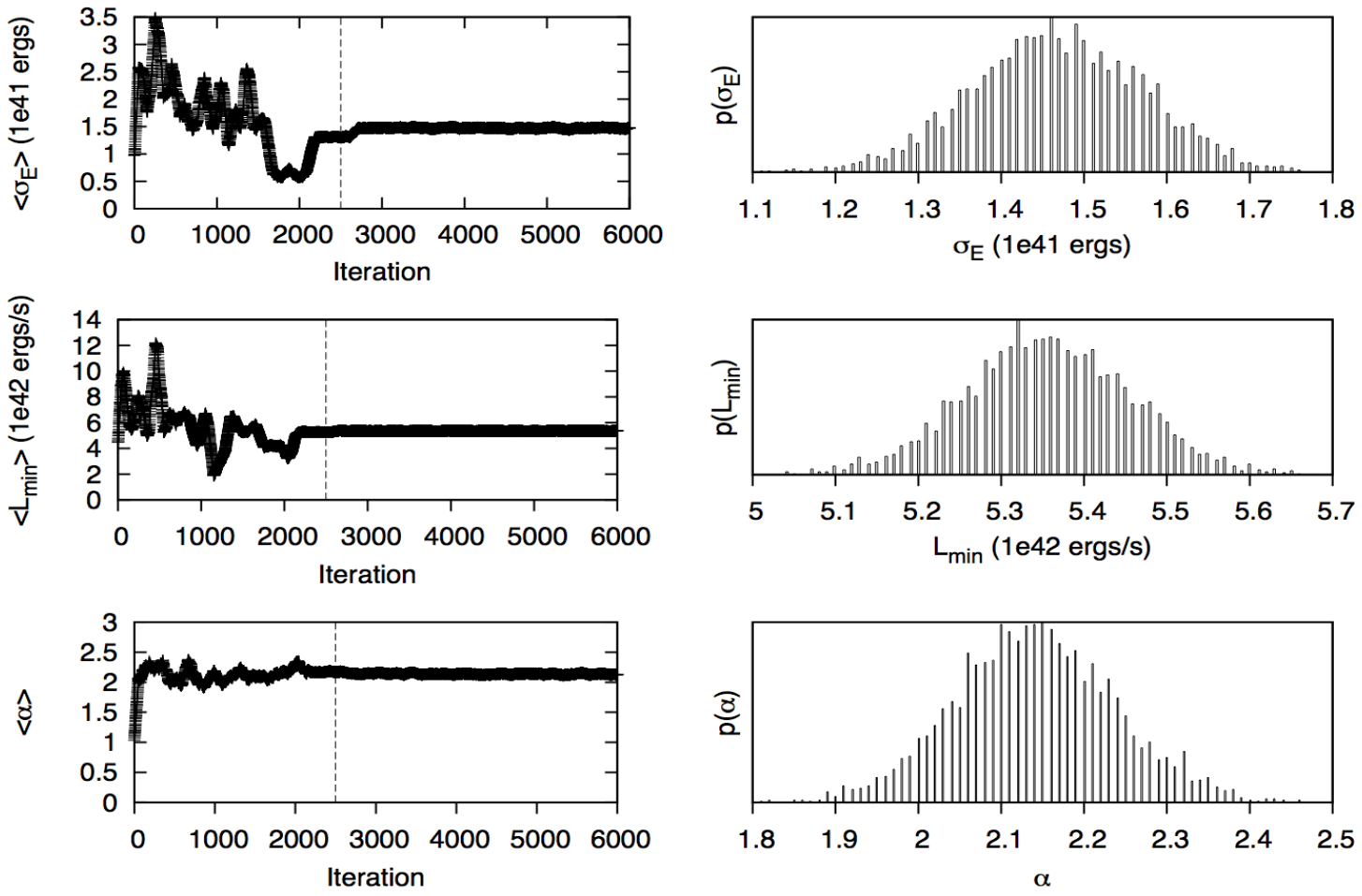
$$p_i = \frac{N_i}{N_{sim}}$$

- The likelihood function

$$\mathcal{L}(\vec{x}|DM, S_{\mathrm{peak,obs}}, W_{\mathrm{obs}}) = \prod_{i=1}^{n} p_{\mathrm{i}}$$



MCMC Results



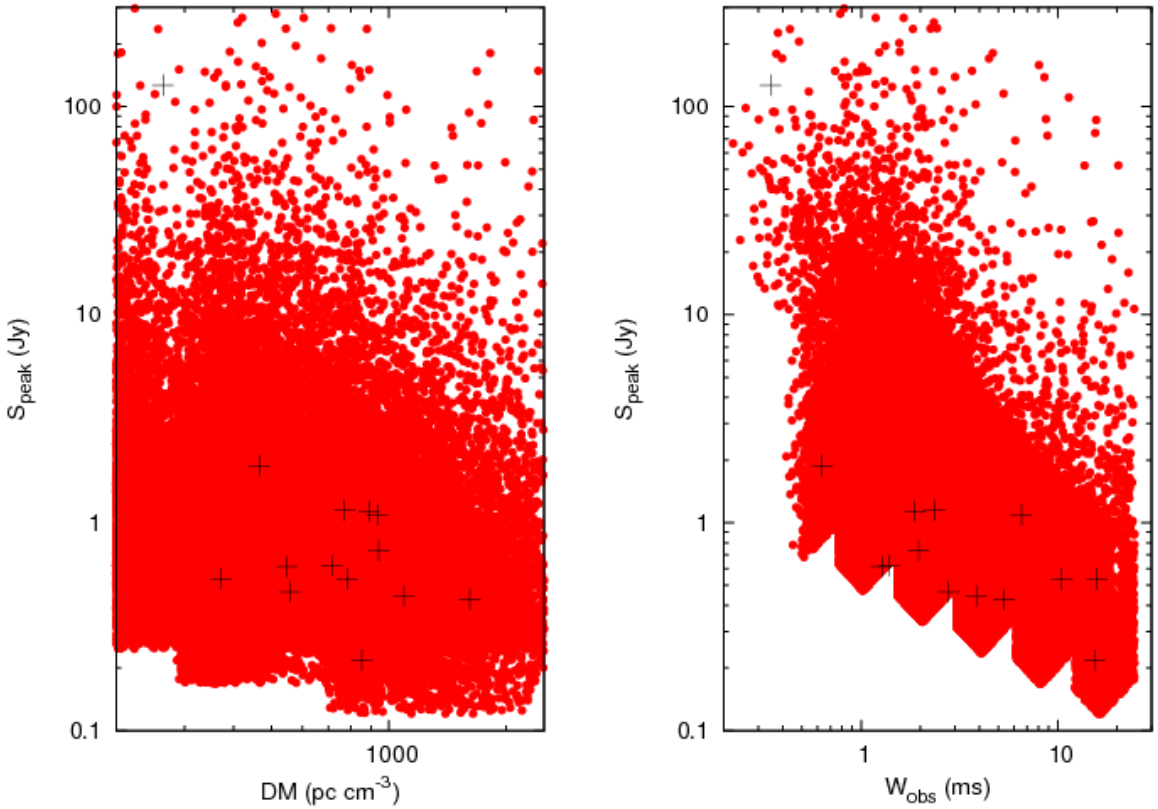
(Rane et al., in prep)

Maximum Likelihood Estimation

Model	Optimal parameters			$\log_{10}(\mathcal{L})$
	$\sigma_{\rm E}(\times 10^{41}{\rm ergs})$	$\sigma_{\rm L}(\times 10^{44}{\rm ergs\ s^{-1}})$		
A1	$20.3^{+0.4}_{-0.3}$	$10.7^{+0.3}_{-0.3}$		-23.1
A2	$20.7^{+0.3}_{-0.4}$	$11.1^{+0.4}_{-0.3}$		-23.6
	$E(\times 10^{41}{\rm ergs})$	$L_{\rm min}(\times 10^{42}{\rm ergs\ s^{-1}})$	α	
B1	$0.7^{+0.4}_{-0.3}$	$4.2^{+0.3}_{-0.3}$	$2.1^{+0.3}_{-0.3}$	-20.2
B2	$0.7^{+0.3}_{-0.3}$	$4.3^{+0.4}_{-0.4}$	$2.1^{+0.3}_{-0.3}$	-20.4
	$\sigma_{\rm E}(\times 10^{41}{\rm ergs})$	$L_{\rm min}(\times 10^{42}{\rm ergs\ s^{-1}})$	α	
C1	$0.6^{+0.3}_{-0.3}$	$4.0^{+0.4}_{-0.3}$	$2.2^{+0.5}_{-0.3}$	-20.4
C2	$1.5^{+0.3}_{-0.4}$	$5.4^{+0.3}_{-0.3}$	$2.1^{+0.3}_{-0.3}$	-20.8

A1-Gaussian distributed E and L around σ_E, σ_L (No Scattering in MW)
A2-Gaussian distributed E and L around σ_E, σ_L (Scattering in MW + host)
B1-Constant E and power law in L with L_{min}, α (No scattering in MW)
B2-Constant E and power law in L with L_{min}, α (Scattering in MW + host)
C1-Gaussian distributed E around σ_E and power law in L with L_{min}, α (No scattering in MW)
C2-Gaussian distributed E around σ_E and power law in L with L_{min}, α (Scattering in MW + host)

Best-fit model

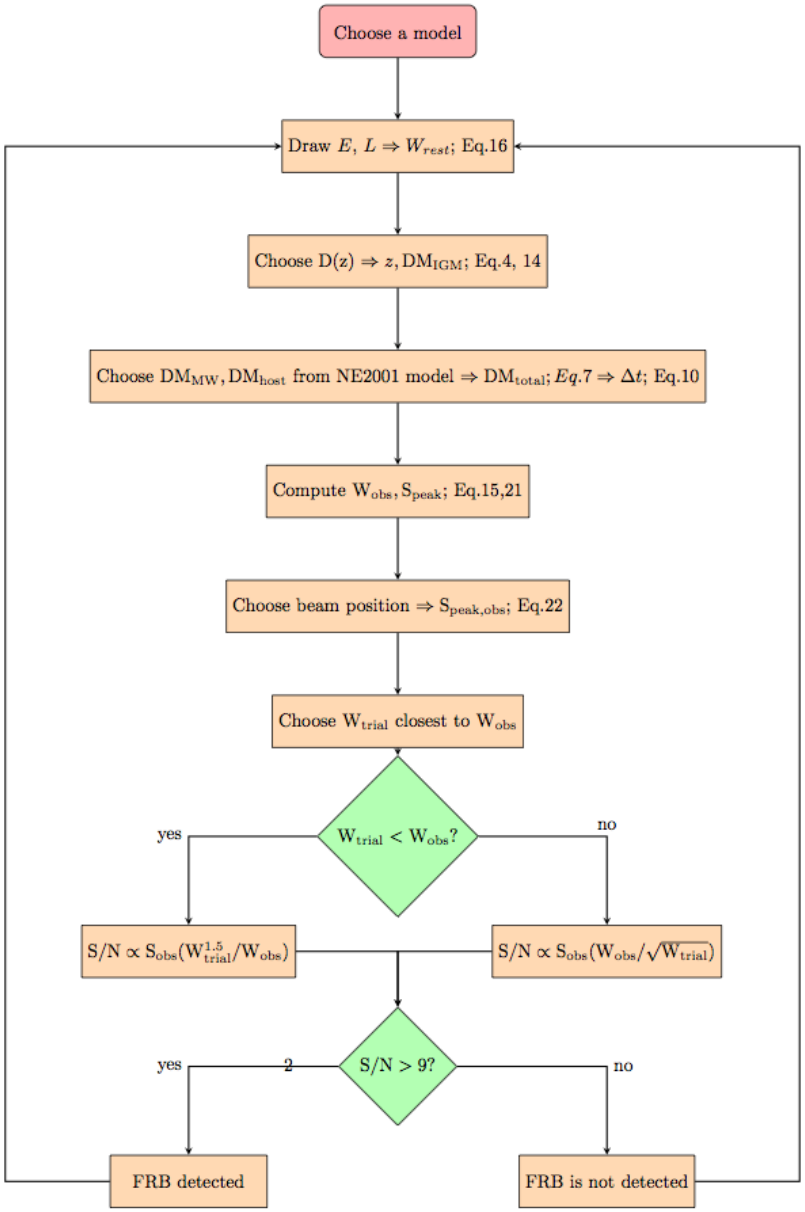


Conclusions

- The observed distributions of DM, flux, and widths are consistent with a distribution of sources at cosmological distances with uniform co-moving density out to z=2.5
- Models with power law in L and constant E and Gaussian distributed E are almost indistinguishable
- The estimated bolometric luminosities for the repeater are consistent with the range of luminosities in our best-fit model
- FRBs unlikely to be standard candles!

Thank you!

Simulation procedure



Detection criteria

- The S/N for optimal detection:

$$S/N = \frac{S_{\rm peak,obs}}{\sigma_{\rm rms}} \qquad \sigma_{\rm rms} = \frac{\beta T_{\rm sys}}{G\sqrt{2{\rm BW}W_{\rm trial}}}$$

- Case 1: $W_{\rm trial} < W_{\rm obs}$

$$S/N = \frac{S_{\rm peak,obs} G\sqrt{2{\rm BW}}}{\beta T_{\rm sys}} \frac{W_{\rm trial}^{1.5}}{W_{\rm obs}}$$

- Case 2: $W_{\rm trial} > W_{\rm obs}$

$$S/N = \frac{S_{\rm peak,obs} G\sqrt{2{\rm BW}}}{\beta T_{\rm sys}} \frac{W_{\rm obs}}{\sqrt{W_{\rm trial}}}$$

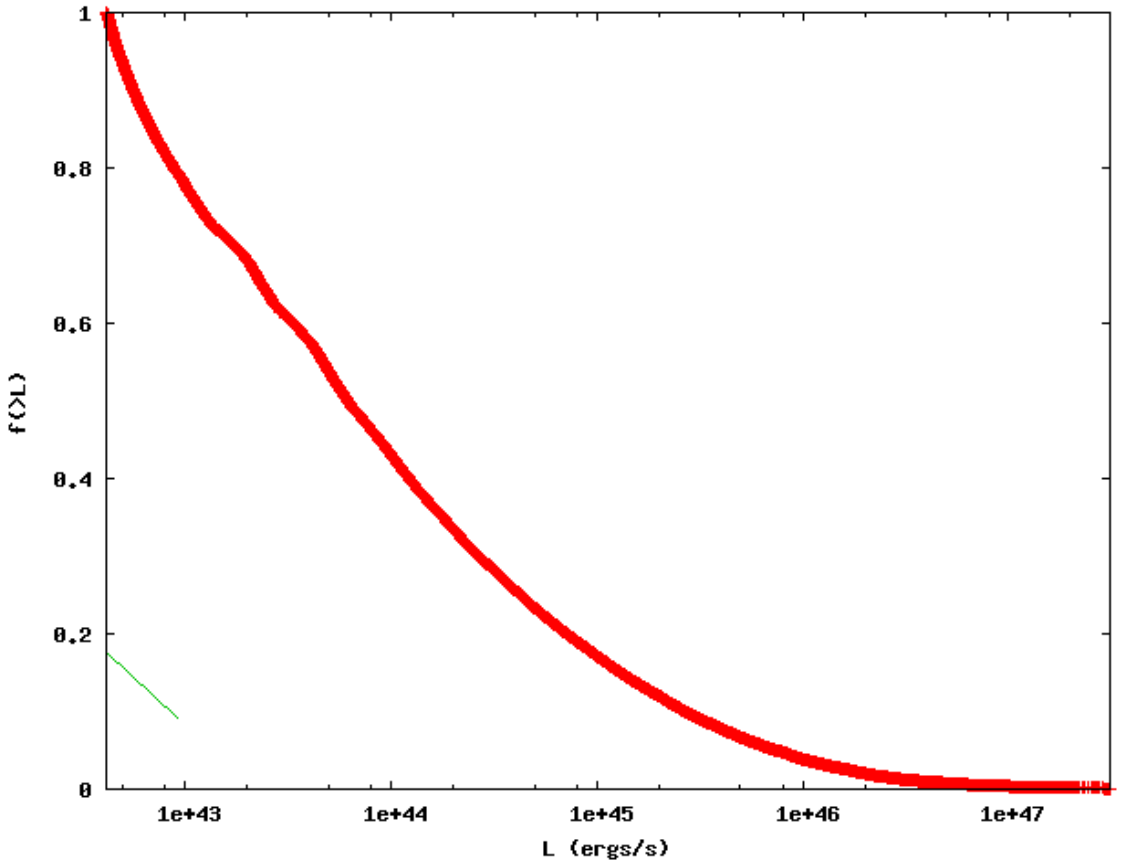
$$G = 0.735, BW = 340{\rm MHz}, T_{\rm sys} = 30{\rm K}, \beta = 1.07$$

Maximum likelihood using MCMC

- Initiate Markov chain with $E = E_1 \;\; L = L_1$ ➡ $\mathcal{L}_1$
- Choose $E_2 \, L_2$ from a Gaussian distribution with σ = 0.1 ➡ $\mathcal{L}_2$
- Compute Metropolis ratio:

$$s = \frac{\mathcal{L}_2}{\mathcal{L}_1}$$

- If $r > s$ stay at current position

- Repeat this process until the chain converges.

Comparing with the repeater