PreFRBLE:
Predictions of FRBs & Likelihood Estimates

Stefan Hackstein

2nd year PhD student @

shackste@physnet.uni-hamburg.de

Supervisors: Marcus Brüggen, Franco Vazza

Collaborators: Bryan Gaensler

2019-02-19

Overview

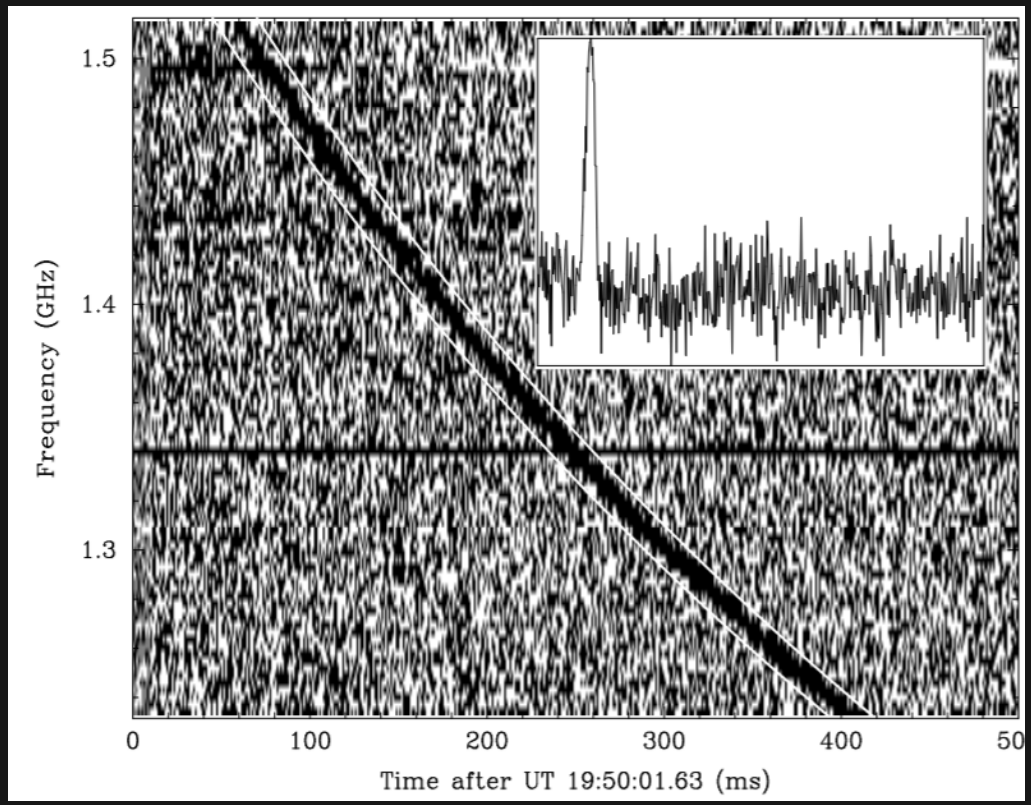
Fast Radio Bursts
Extra-Galactic Magnetic Fields
PreFRBLE

Outline

Fast Radio Bursts

- bright ms bursts $\sim 1\mathrm{GHz}$
- Very short duration
  $\Rightarrow$small source ~ 10 km
- dispersion consistent with

$$v_\gamma \propto \nu^2$$



Lorimer'07

$$DM = \int \frac{n_e}{1+z} dl$$

$$RM = \int B_{\parallel} \frac{n_e}{1+z} dl$$

Outline

Extra-Galactic Magnetic Fields

Extra-Galactic Magnetic Fields

LSS ($\approx 20\%$ of volume)

galaxies $\sim 5 - 15\ \mu\mathrm{G}$

clusters $\sim \mu\mathrm{G}$

filaments $\lesssim 0.1 \mu\mathrm{G}$

e. g. *Beck+ 2016, Feretti+ 2012, Brown+ 2017*

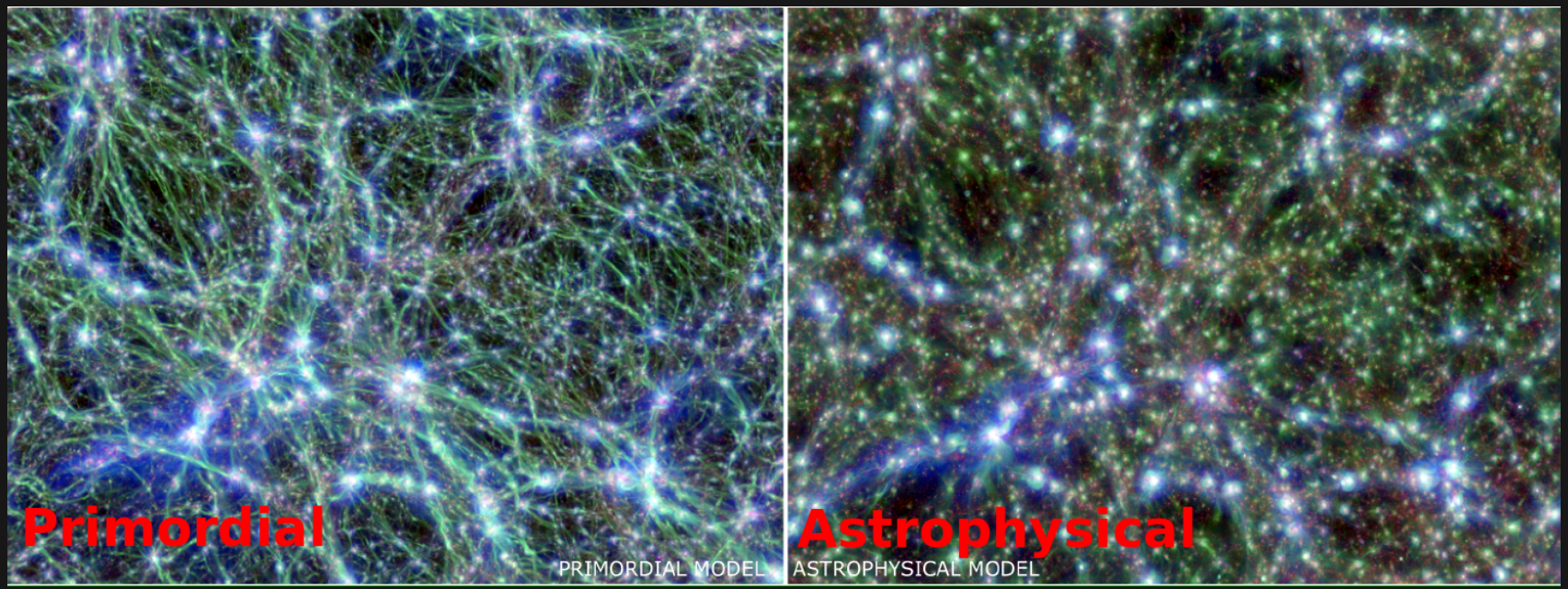
Voids ($\approx 80\%$ of volume)

$B_0 \lesssim 1\ \mathrm{nG}$

Planck 2015

$B_{\mathrm{void}} \gtrsim 10^{-7}\mathrm{nG}$

Neronov & Vovk 2010



Vazza et al. 2018

Can FRBs tell us about IGMFs and their origin?

Outline

PreFRBLE

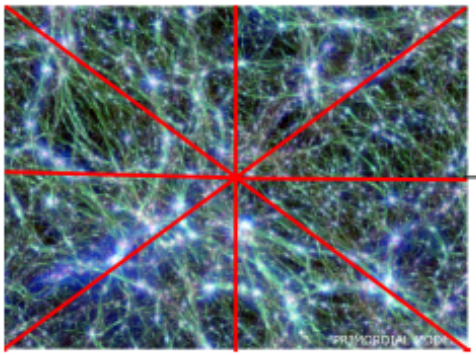
PreFRBLE

Predict FRBs →Likelihood Estimates

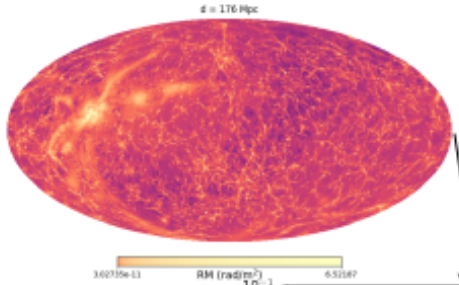
- predict outcome of several models of all contributors (progenitor, Host galaxy, IGM, Milky Way)
- combine to full measurement
- compare to observations
- quantify corroboration of models (Bayesian inference)

Derive Probability: Monte Carlo method

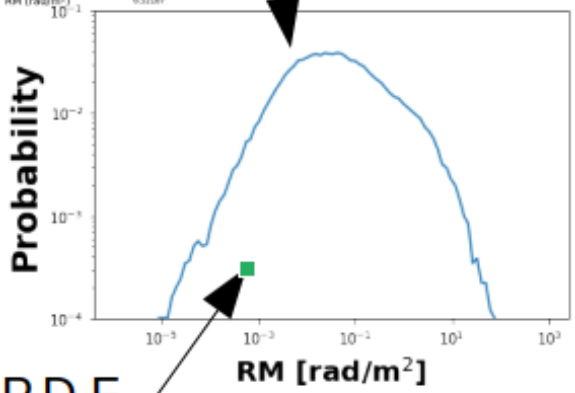
Simulation



LoS-Path Integral



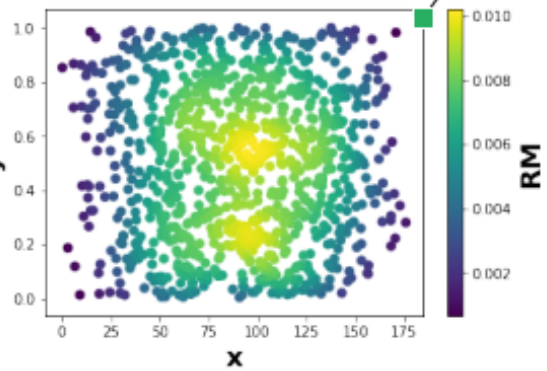
P.D.F



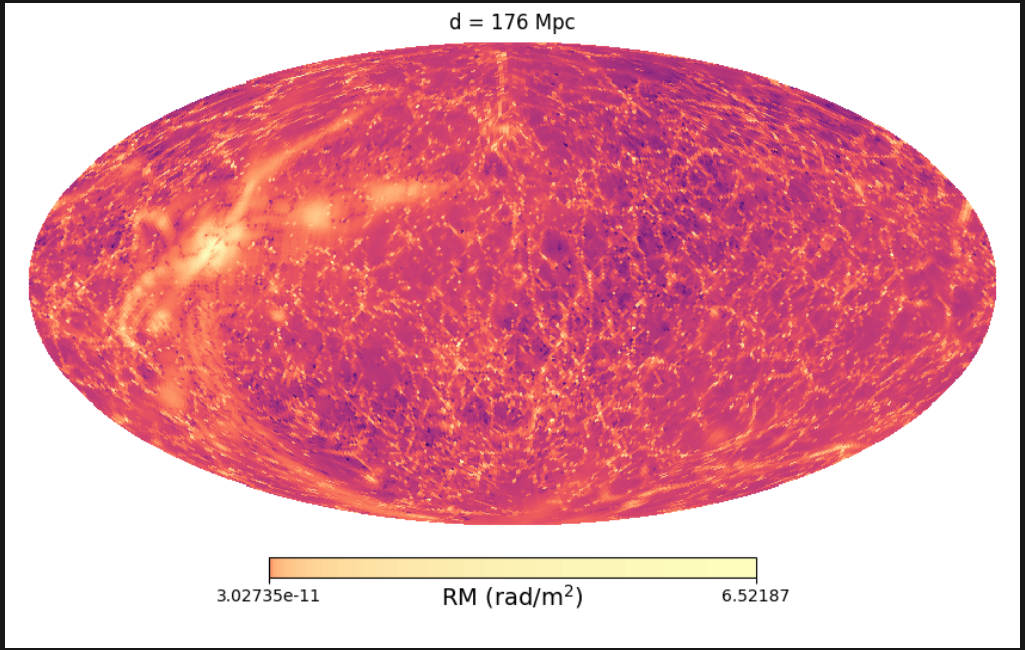
Analytic Prediction

RM(x,y) Sample

P.D.F



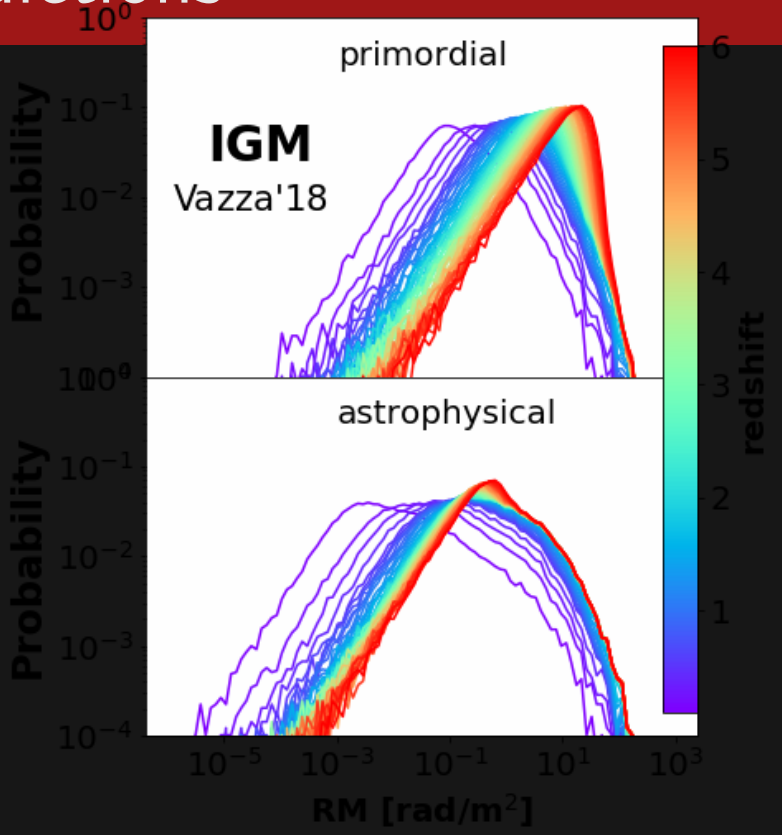
Predictions

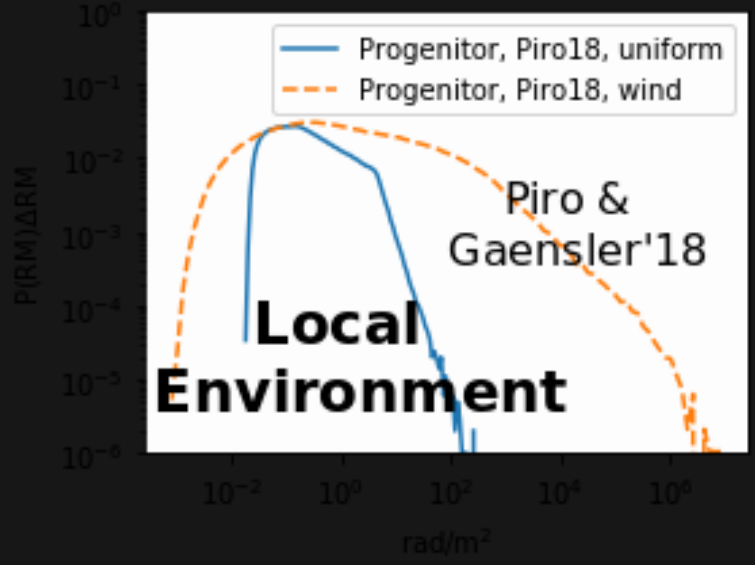


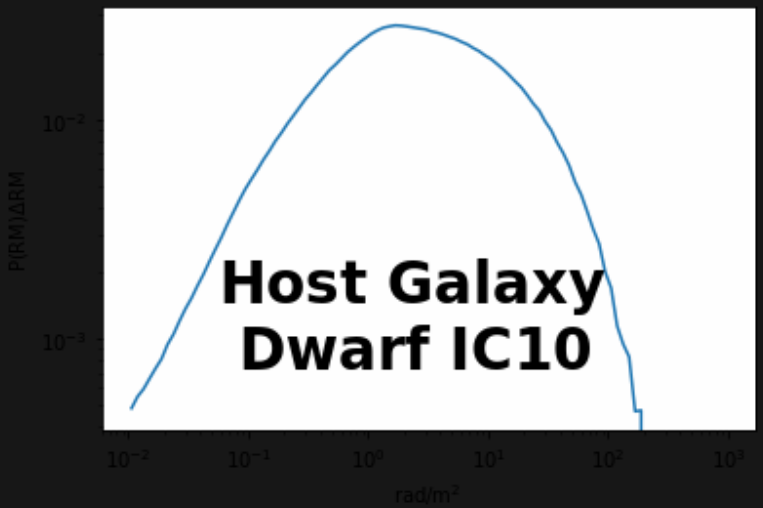
Strategies

1. **LoS** through **constrained numerical MHD simulation** $\rightarrow$**IGM** *(Vazza'18)*
2. **LoS** through **analytical model** $\rightarrow$**MW** *(NE2001 & JF12)* & **Host** *Dwarf IC10 (Heesen'11)*
3. **analytical predictions**, sample parameter space $\rightarrow$**progenitor** *(Piro & Gaensler'18)*

Predictions



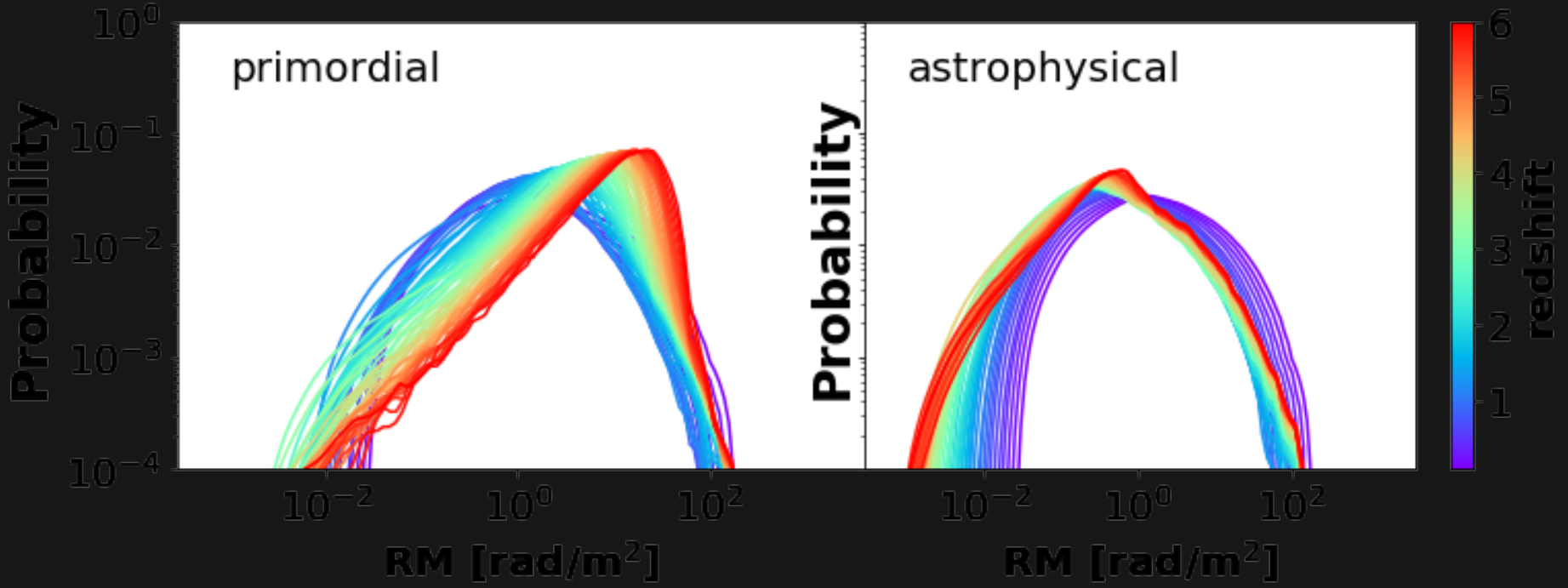




Combine Predictions

preliminary

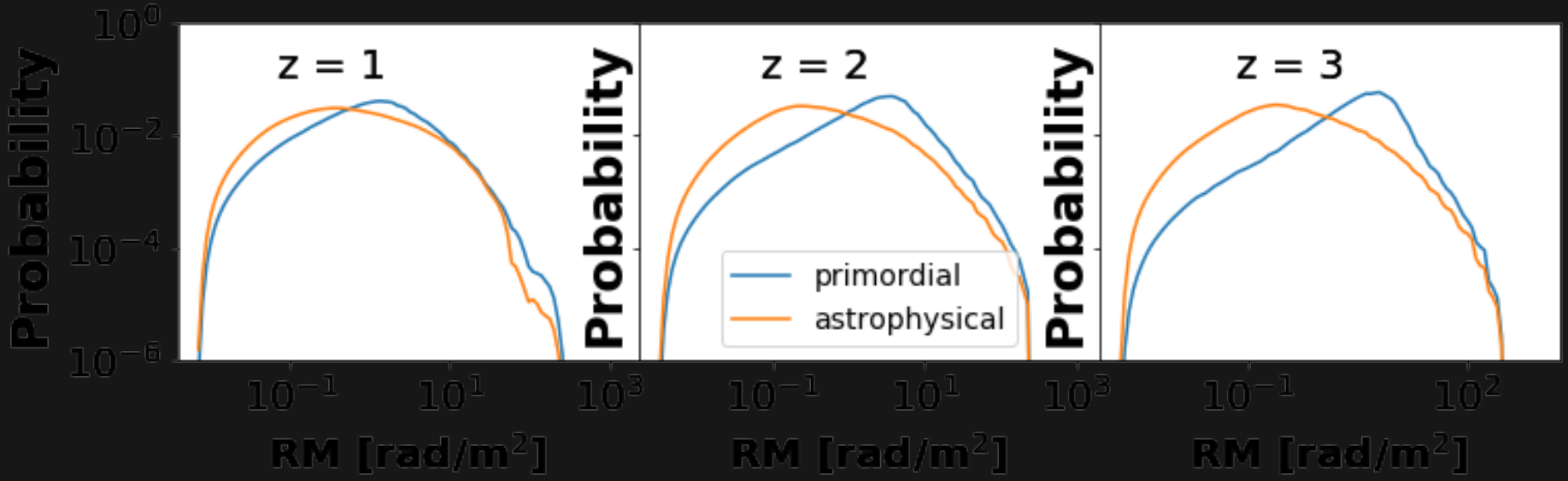
$$P_{\mathrm{exc}} = P_{\mathrm{IGM}} * P_{\mathrm{Host}} * P_{\mathrm{Progenitor}}$$



Combine Predictions

preliminary

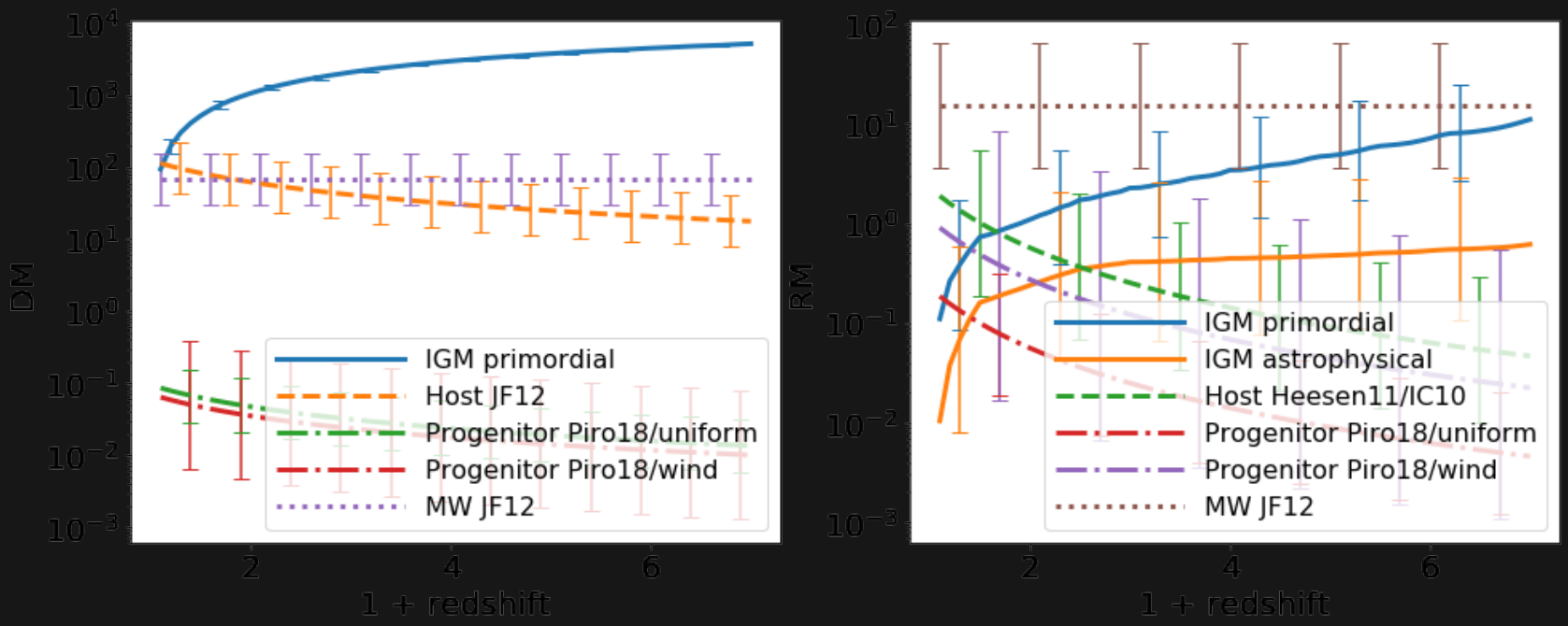
$$P_{\mathrm{exc}} = P_{\mathrm{IGM}} * P_{\mathrm{Host}} * P_{\mathrm{Progenitor}}$$



Redshift dependence

preliminary

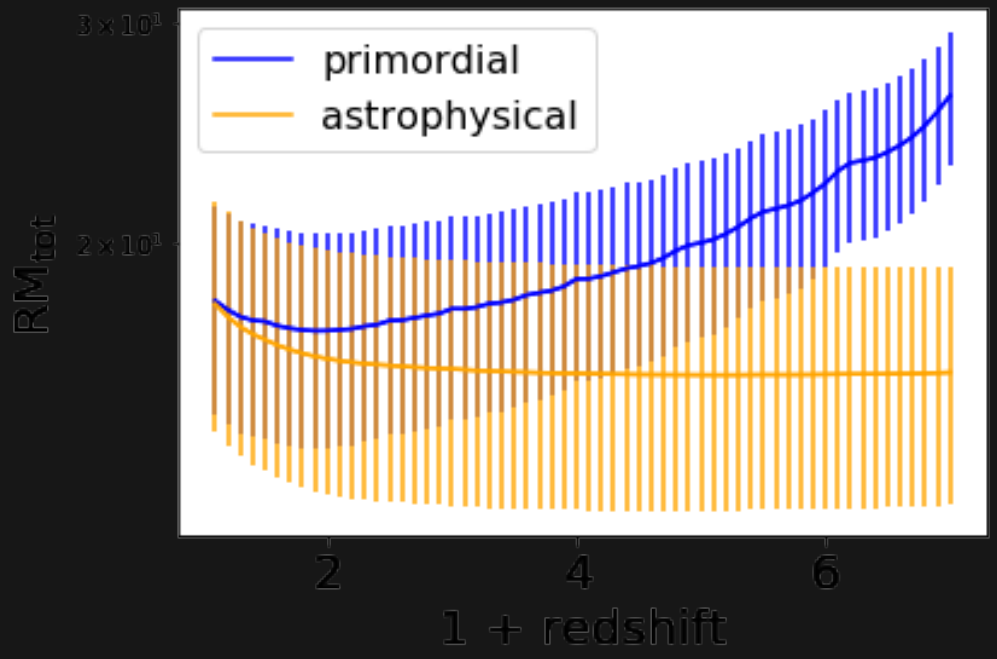
- DM strongly dominated by IGM ($z > 0.1$)
  $\longrightarrow$measure host redshift *(e. g. Dolag'15)*
- RM overshadowed by MW
  $\longrightarrow$remove or restrict to high latitude
- $\mathrm{RM_{exc}}$ dominated by Host galaxy for $z \lesssim 1$
  higher z: strong IGM dominates



Redshift dependence

preliminary

- DM strongly dominated by IGM ($z > 0.1$)
  $\longrightarrow$measure host redshift *(e. g. Dolag'15)*
- RM overshadowed by MW
  $\longrightarrow$remove or restrict to high latitude
- $\mathrm{RM}_{\mathrm{exc}}$ dominated by Host galaxy for $z \lesssim 1$
  higher z: strong IGM dominates
  $z > 5$: $\langle RM \rangle$ $\longrightarrow$**IGMF**



Redshift dependence

preliminary

- DM strongly dominated by IGM ($z > 0.1$)
  $\longrightarrow$measure host redshift *(e. g. Dolag'15)*
- RM overshadowed by MW
  $\longrightarrow$remove or restrict to hi
- $\mathrm{RM}_{\mathrm{exc}}$ dominated by Host
  higher z: strong IGM domi
  $z > 5$?!? $\longrightarrow$**IGMF**

Bayes Theorem

model Likelihood $\leftarrow$prediction(measurement) & prior

$$L(M|v) \propto P(v|M)\pi(M)$$

$$\textbf{Bayes-factor (Model}_2 \xrightarrow{\textbf{corroboration}} \textbf{Model}_1 \textbf{)}$$

$$B(M_1, M_2|v) = \frac{P(v|M_1)}{P(v|M_2)}$$

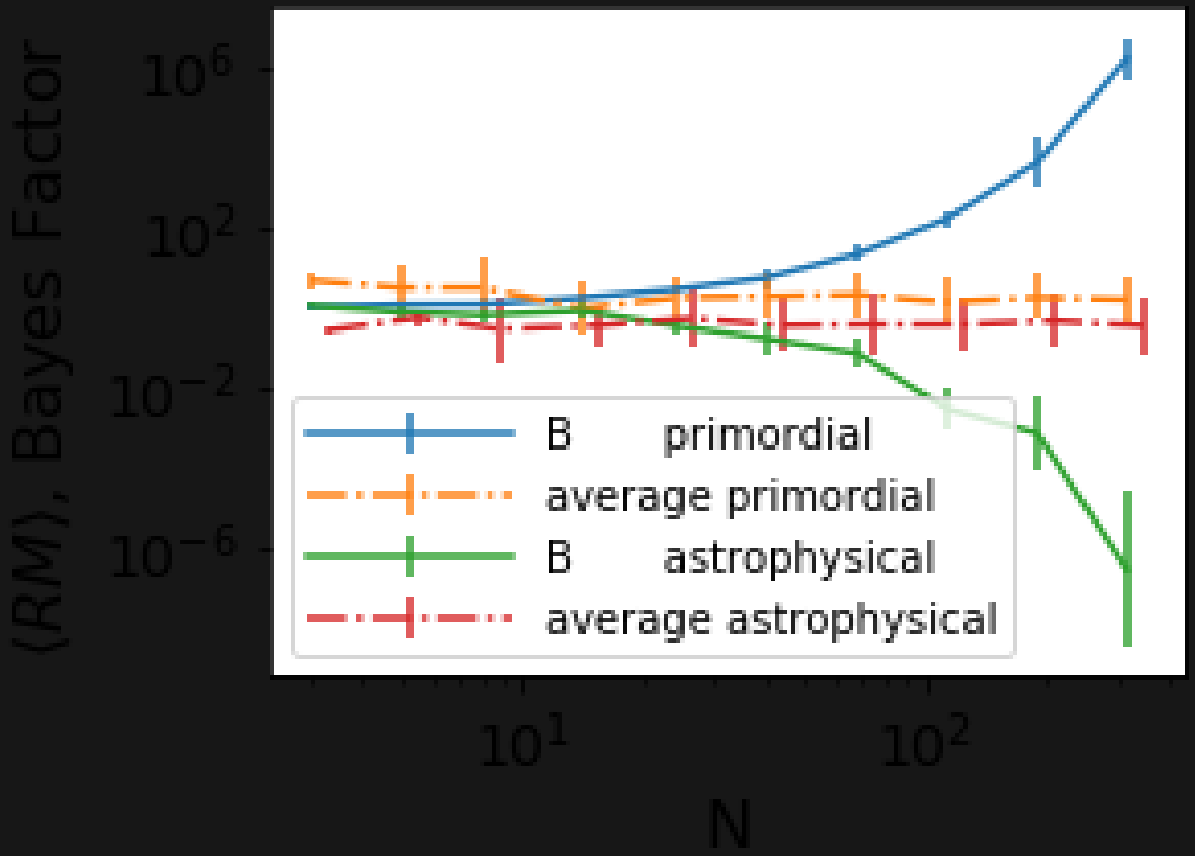
Combine several measurements

$$P(\vec{v}|M) = \prod_{v \in \vec{v}} P(v|M)$$

fake test-group

preliminary

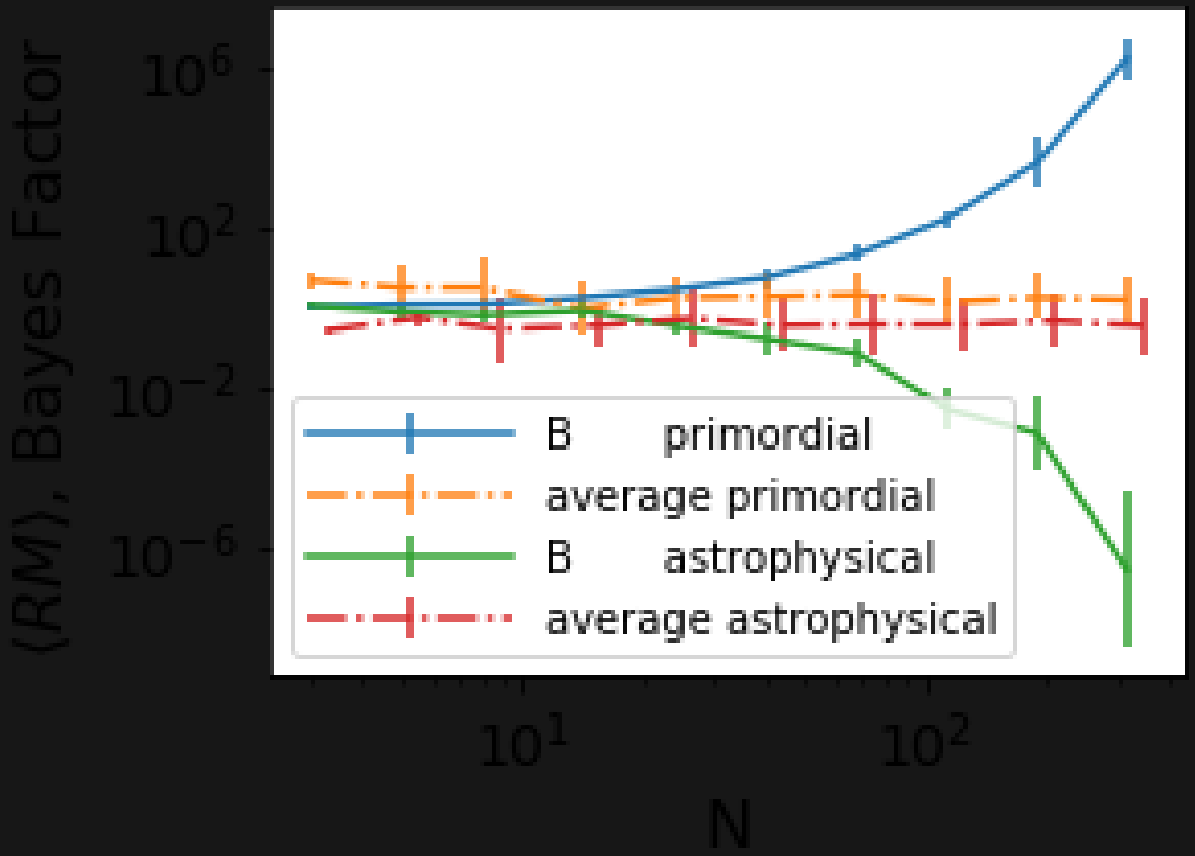
- sample DM & RM prediction for both IGMF models at $\mathbf{z = 1}$
- compare $\langle RM \rangle$ and $B = \frac{P(\vec{v}|\text{primordial})}{P(\vec{v}|\text{astrophysical})}$



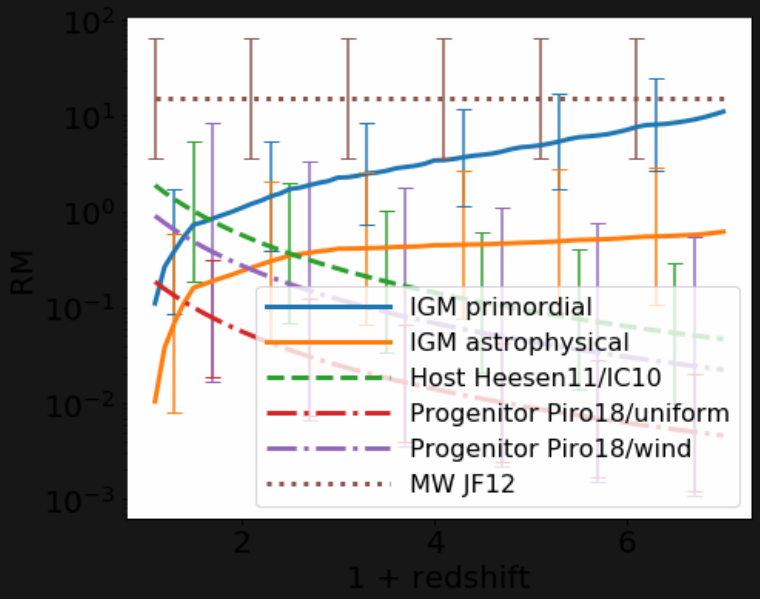
fake test-group

preliminary

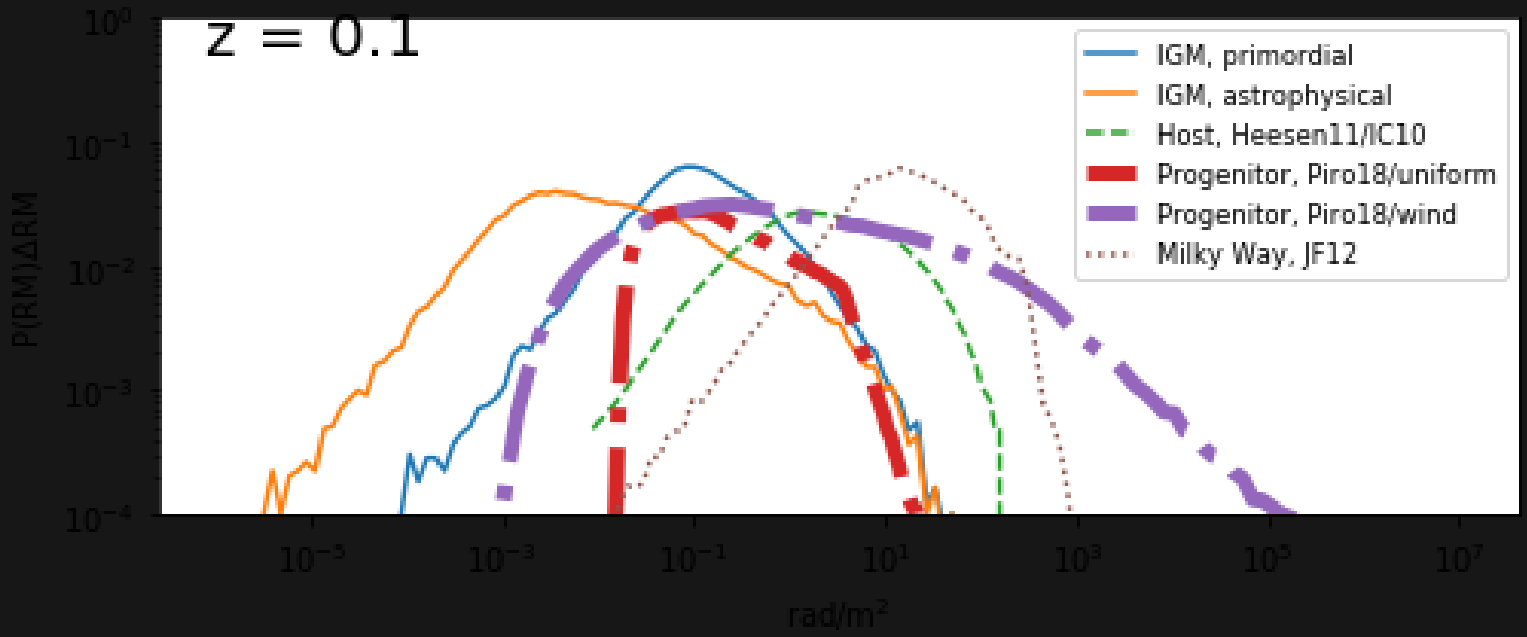
- sample DM & RM prediction for both IGMF models at $\mathbf{z = 1}$
- compare $\langle RM \rangle$ and $B = \frac{P(\vec{v}|\text{primordial})}{P(\vec{v}|\text{astrophysical})}$
- $\Rightarrow$**100 events suffice to identify origin of IGMFs**
- **if** host is dwarf galaxy



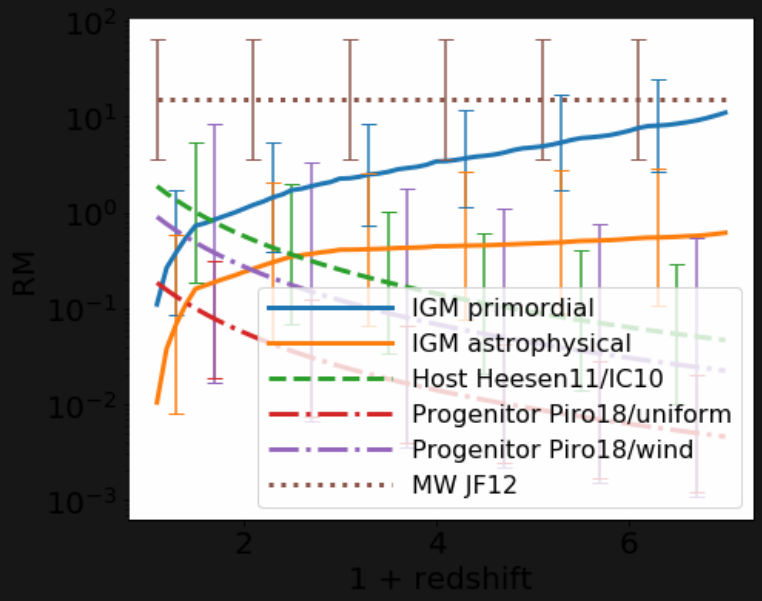
What about the Progenitor?



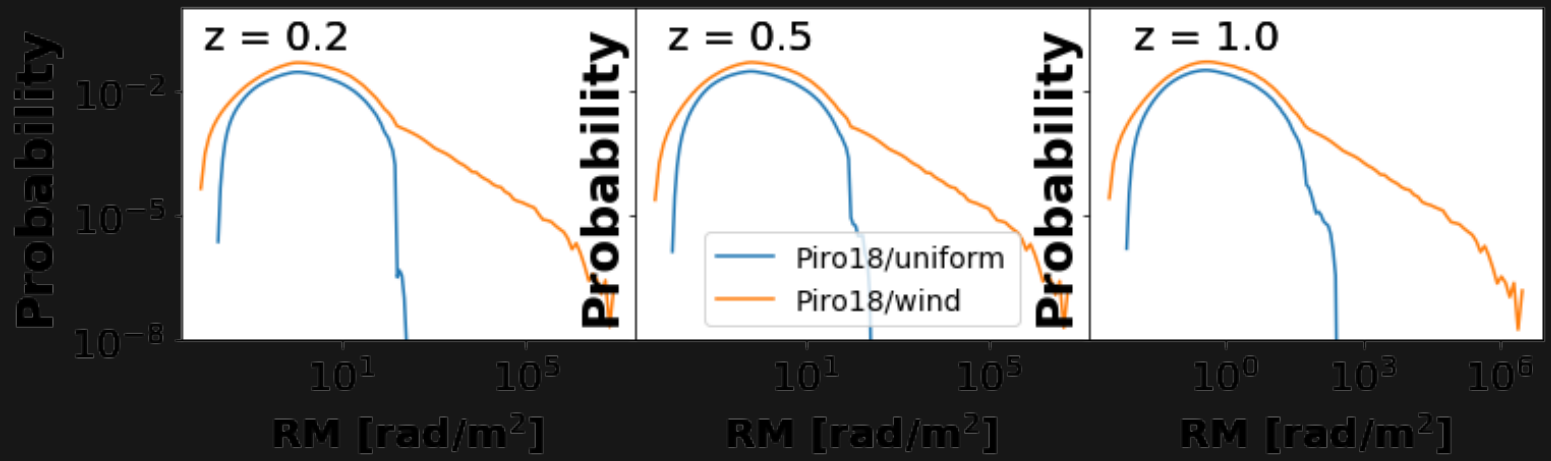
- $\langle RM_{\rm Prog} \rangle << \langle RM_{\rm exc} \rangle$
- BUT highest values $\Rightarrow$constrain progenitor using highest RMs



What about the Progenitor?



- $\langle RM_{\rm Prog} \rangle << \langle RM_{\rm exc} \rangle$
- BUT highest values $\Rightarrow$constrain progenitor using highest RMs
- high RM of FRB121102 ($\gtrsim 10^5$ rad m^2) probably due to local environment



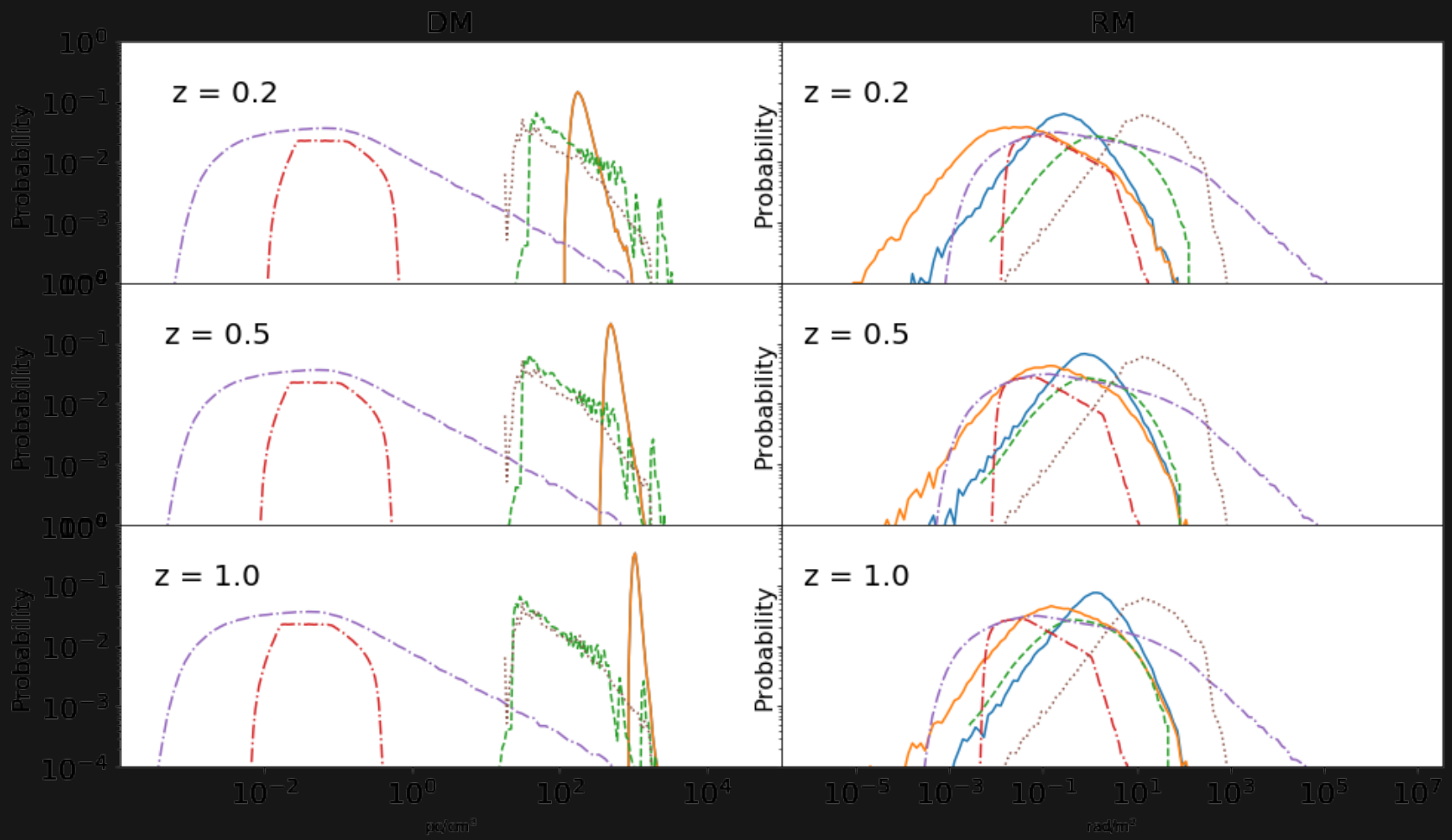
Conclusions

- **$\mathrm{RM}_{\mathrm{exc}}$ of FRBs $z \gtrsim 1$: information on magnetic fields in voids and origin of cosmic magnetic fields**
  FRBs hosted by dwarf galaxies
- **$N_{RM} \lesssim$100 suffice to demarcate origin of IGMF (Bayesian)**
- **quantify likelihood of different (sets of) models**
  $\Rightarrow$one vs. multiple source classes

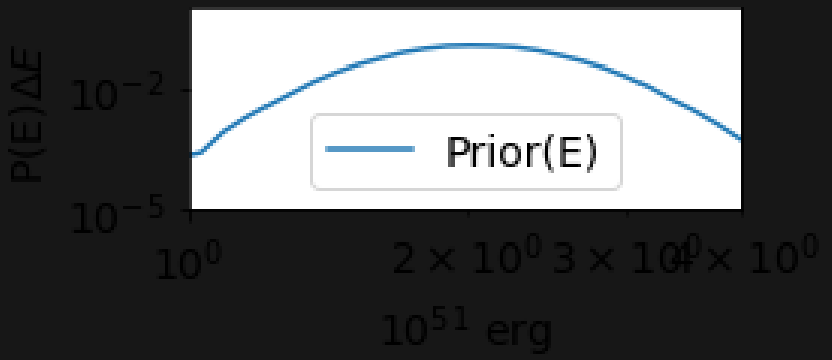
- PREFRBLE: easy-to-use PYTHON-package to interpret DM and RM of FRBs and obtain Likelihoods for different (combinations of) models, even for single bursts
- free download on github soon ...
- current status: low number of models included, more to come.

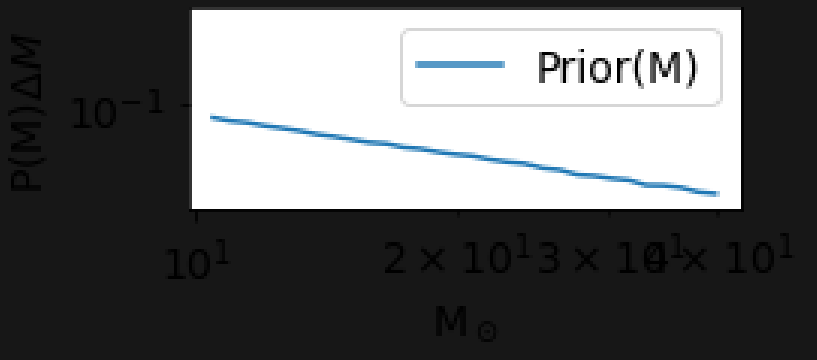
Yours, maybe?

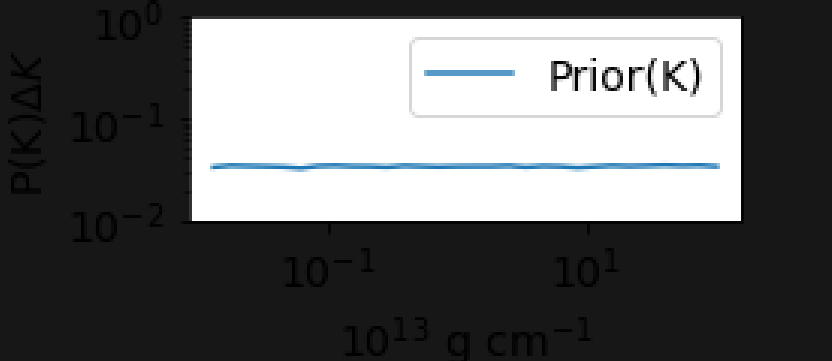
Compare Predictions

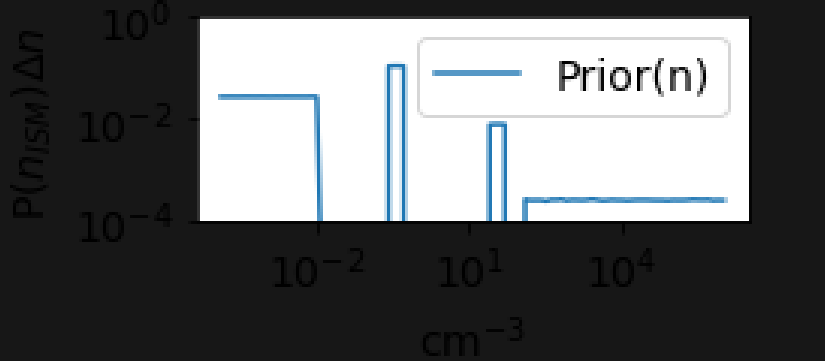


Priors

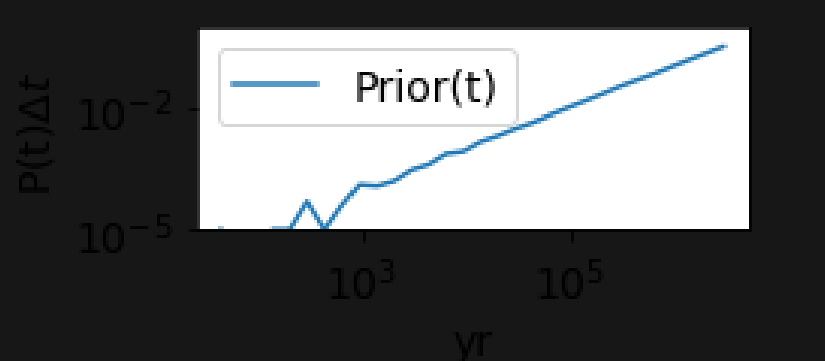

Prior(E)
P(E)ΔE
10^{-2}
10^{-5}
10^{0}
2×10^{0}
3×10^{0}
4×10^{0}
10^{51} erg


Prior(M)
P(M)ΔM
10^{-1}
10^{1}
2×10^{1}
3×10^{1}
4×10^{1}
$M_\odot$


Prior(K)
P(K)ΔK
10^{0}
10^{-1}
10^{-2}
10^{-1}
10^{1}
10^{13} g cm^{-1}


Prior(n)
$P(n_{ISM})\Delta n$
10^{0}
10^{-2}
10^{-4}
10^{-2}
10^{1}
10^{4}
cm^{-3}


Prior(B)
P(B)ΔB
10^{0}
10^{-1}
10^{-2}
10^{2}
10^{3}
10^{4}
G


Prior(t)
P(t)Δt
10^{-2}
10^{-5}
10^{3}
10^{5}
yr