Estimating the IGM Baryon Mass Fraction Using Fast Radio Bursts

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Introduction to Fast Radio Bursts (FRBs)

- **Definition**

Fast Radio Bursts are millisecond-duration, intense radio pulses originating from extragalactic sources.

- **Characteristics**

- Some FRBs repeat, enabling detailed study.
- Possible origins include neutron stars or magnetars, though the exact mechanism remains unclear.

- **Utility**

FRBs produce a dispersion measure (DM), reflecting electron density along the line of sight, ideal for probing the intergalactic medium (IGM).

$$\mathrm{DM} = \int n_e \, \mathrm{d}l$$

where n_e is the electron density, useful for inferring IGM baryon content.

The Intergalactic Medium and the Missing Baryon Problem

- FRBs' Role in Addressing the Missing Baryon Problem

By measuring the dispersion measure (DM), FRBs can estimate the electron density in the IGM, helping quantify the baryon fraction (f_{IGM}) and address the missing baryon problem.

$$\mathrm{DM}_{\mathrm{obs}}(z) = \mathrm{DM}_{\mathrm{MW,ISM}} + \mathrm{DM}_{\mathrm{MW}}, halo + \mathrm{DM}_{\mathrm{IGM}}(z) + \frac{\mathrm{DM}_{\mathrm{host}}}{1+z}$$

Objective: Isolate DM_{IGM} to compute (f_{IGM}), the fraction of baryons in the IGM.

Challenges in Estimating (f_{IGM})

- Traditional Methods

Traditionally, DM_{IGM} is related to redshift (z) using a cosmological model:

$$\mathrm{DM}_{\mathrm{IGM}}(z) = \frac{3cH_0\Omega_b f_{\mathrm{IGM}}}{8\pi G m_p} \int_0^z \frac{f_e(z')(1+z')\,dz'}{H_0\sqrt{\Omega_m(1+z')^3+\Omega_\Lambda}}$$

High sensitivity to cosmological parameters

This relation depends on cosmological parameters such as ：H_0(Hubble constant),Ω_m(Matter density), Ω_λ(Dark energy density),$f_e(z)$(ionization fraction).

⚠ Key Issues

- Model sensitivity: Small changes in model assumptionslead to significant differences in f estimates.
- Parameter degeneracy: Different combinations of parameters can yield similar DM values.
- Circular reasoning: Using cosmological parameters to constrain IGM properties, which in turn affect these parameters.

Cosmology-Independent Method

Source: arXiv:1904.08927 and arXiv:2004.08393

- 💡Key Idea：

Utilize the ratio (d_L /DM_{IGM}), where (d_L) is the luminosity distance, which is nearly independent of cosmological parameters (e.g., dark energy equation of state).

$$d_{\rm L}/{\rm DM}_{\rm IGM} = R$$

Methodology

- Methodology

➢ Parameterize $f_{\rm IGM}(z) = f_{\rm IGM,0}(1 + \alpha z/(1+z))$ to model redshift evolution.

➢ Model the host galaxy's DM contribution (DM_{host}) as a function of star formation rate (SFR).

$$\sigma_{\rm IGM}^2 = \sigma_{\rm obs}^2 + \sigma_{\rm MW}^2 + \sigma_{\rm int}^2$$

σ_{int} This systematical scatter might originate from the diversity of host galaxy contribution or the IGM fluctuation.

Application to Five Localized FRBs

- Data:Five localized FRBs with known redshifts and DMs

◎Repeating FRBs:

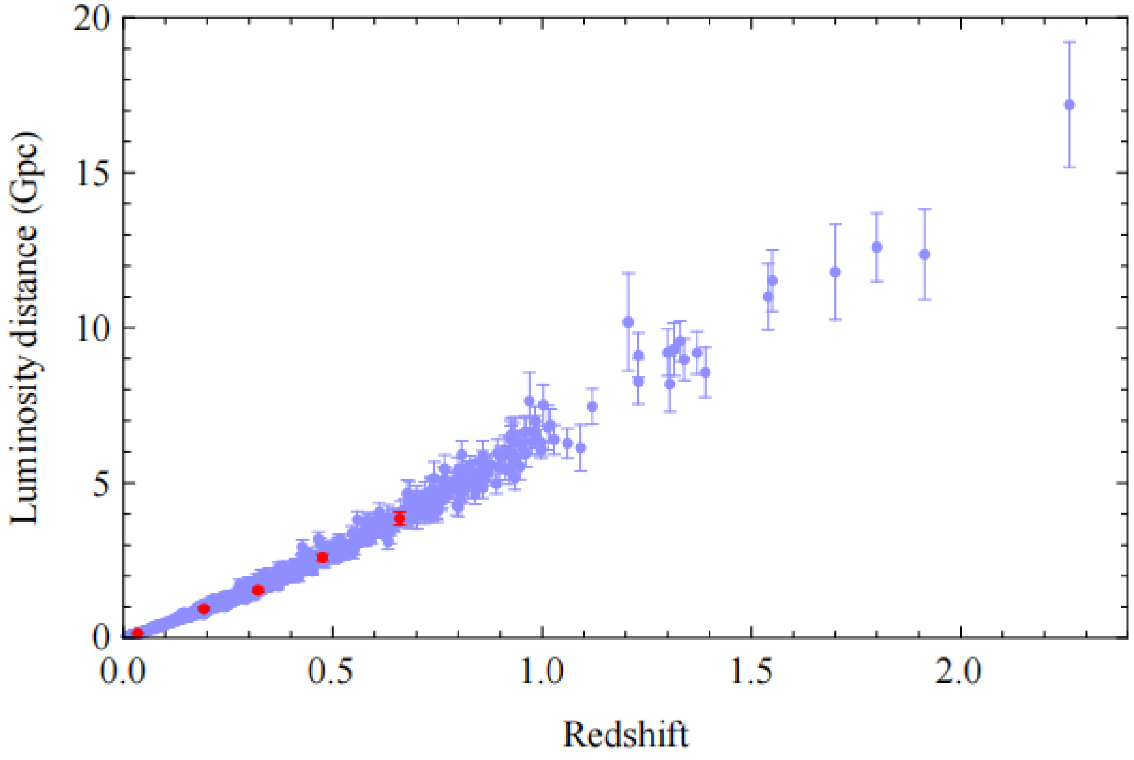
- FRB 121102
- FRB 180916.J0158+65

Non-repeating FRBs:

- FRB 180924
- FRB 181112
- FRB 190523

Results

Luminosity distances (d_L) inferred from redshifts and type Ia supernova data.

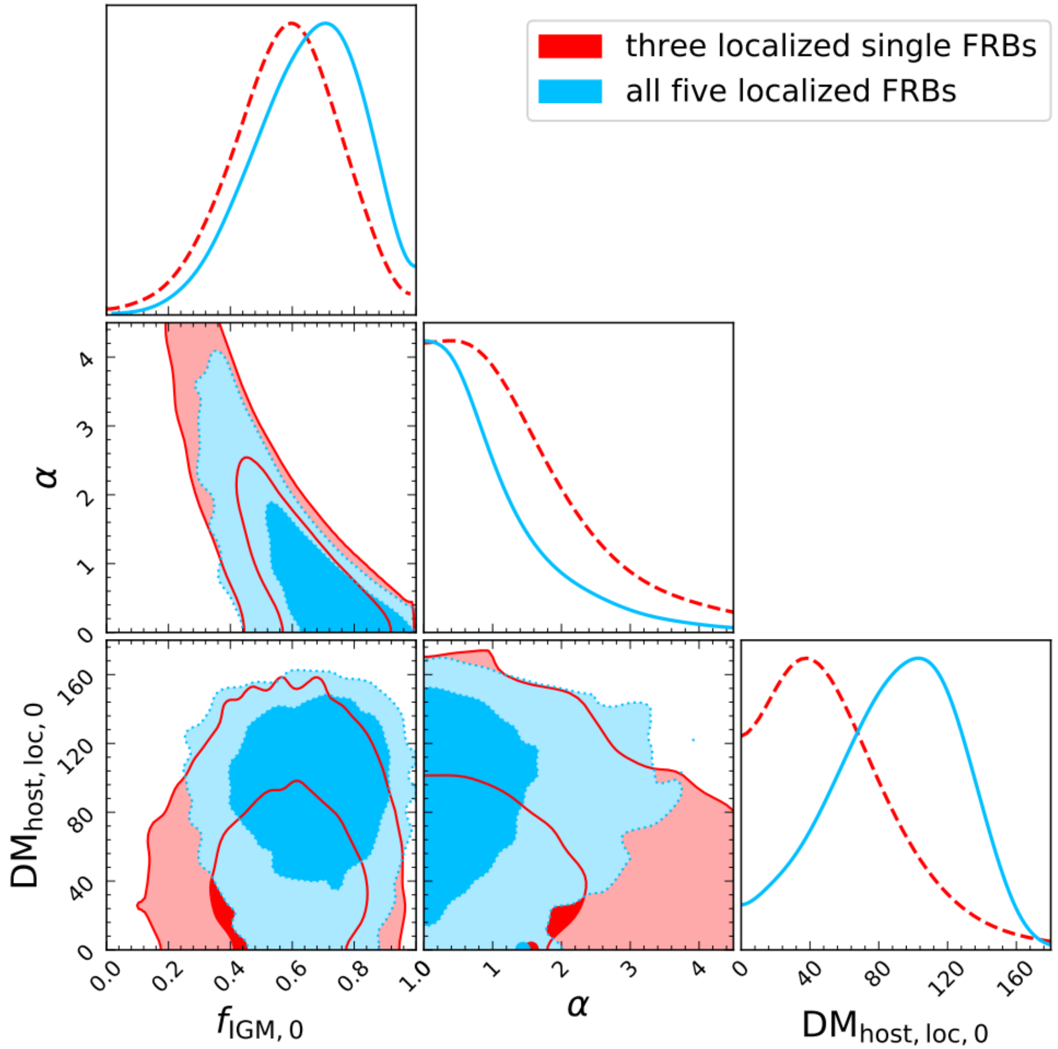


Results

Sample	$f_{IGM,0}$	$DM_{host,loc,0}$(pc cm^{-3})
All Five Localized FRBs	$0.84^{+0.16}_{-0.22}$	107^{+24}_{-45}
Three Non-Repeating FRBs	$0.74^{+0.24}_{-0.18}$	34^{+39}_{-45}

Key Observations

- Both analyses yield consistent values around 0.7-0.85, suggesting most baryons reside in the IGM.
- Non-repeating FRBs show a lower host galaxy DM contribution, possibly indicating different environments.
- The results support constraints from other cosmological probes while challenging the assumption that $f_{IGM,0}=1$.



Comparison and Implications

Results challenge earlier assumptions of f = 1.0, suggesting a more complex baryon distribution.note:Previous models (e.g., Inoue 2004, Ioka 2003) assumed all baryons reside in the IGM, but our findings indicate a significant fraction (~15-20%) may be in other forms.

Limitations

- Limited sample size:Five FRBs lead to relatively large uncertainties.
- Host galaxy modeling: DM_{host} relies on star formation rate assumptions.
- Systematic errors:Potential biases in luminosity distance measurements.

Future Prospects:

- Increasing the number of local fast radio bursts and improving precision.
- Better redshift measurements and refined DM_{host} models will reduce systematic uncertainties.
- Larger samples will allow constraints on $f_{IGM}(z)$, shedding light on IGM evolution.

Summary

- FRBs provide a novel tool for studying the IGM and addressing the missing baryon problem.
- The cosmology-independent method using the dL/DM ratio yields robust f_{IGM} estimates.

Thanks for your listening!

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