Cosmological-model independent limits on photon mass from FRB and SNe data

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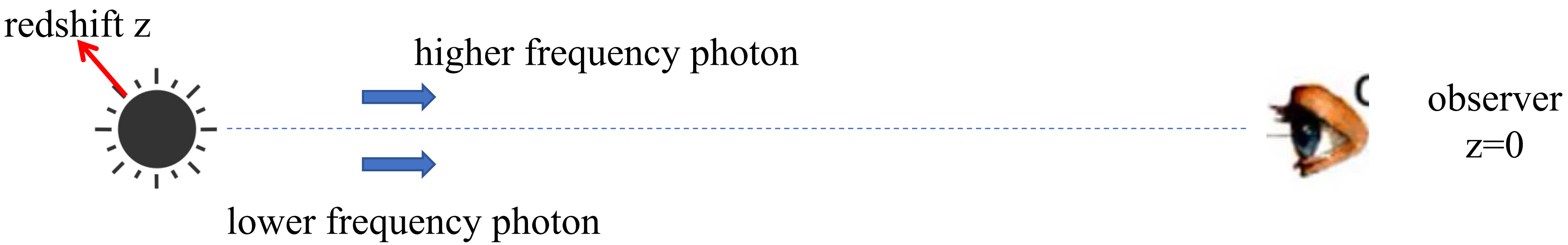
The time delay induced by the nonzero photon mass



- lower frequency.
- longer distance.
- shorter arrival time

$$\Delta t = \frac{D}{v_l} - \frac{D}{v_h}$$

So, it is possible to write the total time delay as the contribution from plasma dispersion and non-vanishing photon mass

$$\Delta t_{\rm obs} = \Delta t_{\rm DM} + \Delta t_{\gamma}$$

The observed DM of an extragalactic FRBs

The observed DM of FRBs includes

$$\mathrm{DM}_{\mathrm{obs}} = \mathrm{DM}_{\mathrm{astro}} + \mathrm{DM}_{\gamma} = \mathrm{DM}_{\mathrm{MW}} + \mathrm{DM}_{\mathrm{halo}} + \mathrm{DM}_{\mathrm{IGM}} + \frac{\mathrm{DM}_{\mathrm{host},0}}{1+z} + \mathrm{DM}_{\gamma}$$

$$\mathrm{DM}_{\mathrm{IGM}}(z) = \frac{3c\Omega_b H_0^2}{8\pi G m_p} \int_0^z \frac{(1+z')\, f_{\mathrm{IGM}}(z')\, \chi(z')}{H(z')} dz'$$

$$\mathrm{DM}_{halo} = 50\mathrm{pc/cm}^3$$

$$\mathrm{DM}_{\gamma}(z) = \frac{\varepsilon_o m_e e^5}{\hbar^2 e^2} m_{\gamma}^2 \int_0^z \frac{(1+z')^{-2}}{H(z')} dz'$$

To perform a statistical comparison $\mathrm{DM}_{\mathrm{ext}}$

- observational data

$$\mathrm{DM}_{ext}^{obs}(z) \equiv \mathrm{DM}_{obs}(z) - \mathrm{DM}_{ISM} - \mathrm{DM}_{halo}$$

- theoretical data

$$\mathrm{DM}_{ext}^{th}(z) \equiv \mathrm{DM}_{host}(z) + \mathrm{DM}_{IGM}(z) + \mathrm{DM}_{\gamma}(z)$$

$$\sigma_{\mathrm{tot}}^2 = \sigma_{\mathrm{obs}}^2 + \sigma_{\mathrm{MW}}^2 + \sigma_{\mathrm{IGM}}^2 + \left(\frac{\sigma_{\mathrm{host},0}}{1+z}\right)^2 + \delta^2$$

$$\sigma_{\mathrm{host},0} = 30\mathrm{pc/cm}^3 \quad \delta = 230\sqrt{z}\mathrm{pc/cm}^3 \quad \sigma_{\mathrm{IGM}} = A f_{\mathrm{IGM},0}\left[\frac{\sigma_{d_L}^2}{c^2} + \frac{\sigma_{\mathrm{I}}^2}{c^2}\right]^{1/2}$$

- Sample:68 well-localized FRBs

A Cosmological-Model Independent Approach for DM_{IGM}&DM_{γ}

- Luminosity Distance Calculation

$$\mu(z) = m_B - M_B = 5\log_{10}\left[\frac{d_L(z)}{1\mathrm{Mpc}}\right] + 25 \quad \sigma_{d_L} = \frac{\ln 10}{5} d_L \cdot \sqrt{\sigma_{m_B}^2 + \sigma_{M_B}^2}$$

z-dL relation:Gaussian Process (GP) reconstruction(Gapp package)

$$\mathrm{DM}_{\mathrm{IGM}}(z) = A f_{\mathrm{IGM},0}\left[\frac{d_L(z)}{c} - \frac{1}{c}\int_0^z \frac{d_L(z')}{(1+z')} dz'\right] \quad \int_0^z \frac{d_L(z')}{(1+z')} dz' = \frac{1}{2}\sum_{i=1}^{N}(z_{i+1} - z_i) \times \left[\frac{d_L(z_{i+1})}{(1+z_{i+1})} + \frac{d_L(z_i)}{(1+z_i)}\right]$$

$$\mathrm{DM}_{\gamma}(z) = B m_{\gamma}^2\left[\frac{d_L(z)}{(1+z)^3} + \frac{2}{c}\int_0^z \frac{d_L(z')}{(1+z')^4} dz'\right] \int_0^z \frac{d_L(z')}{(1+z')^4} dz' = \frac{1}{2}\sum_{i=1}^{N}(z_{i+1} - z_i) \times \left[\frac{d_L(z_{i+1})}{(1+z_{i+1})^4} + \frac{d_L(z_i)}{(1+z_i)^4}\right]$$

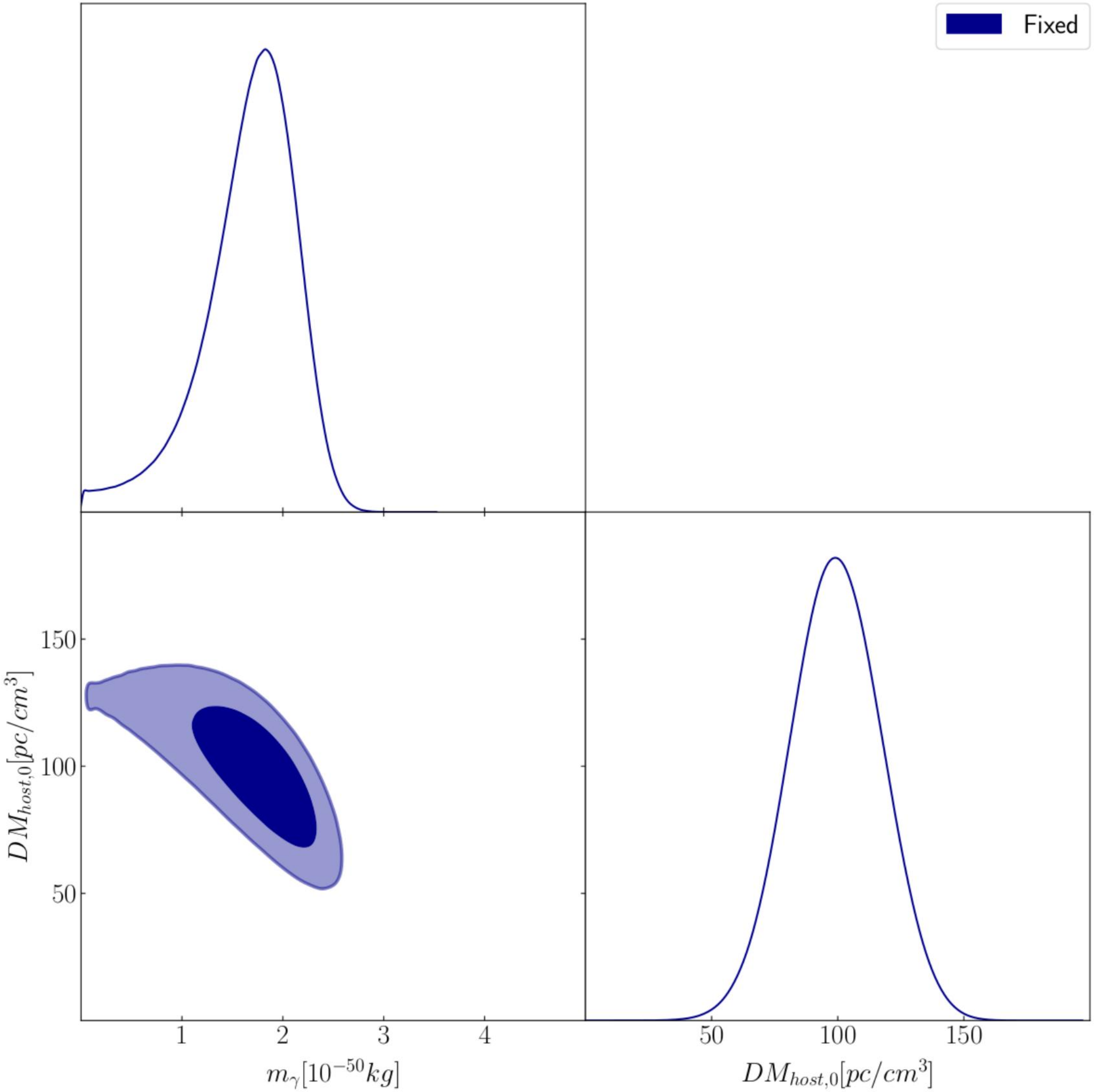
where $A = \frac{3c\Omega_b H_0^2}{8\pi G m_p}, B = \frac{\varepsilon_o m_e c^5}{\hbar^2 e^2}$

Results

Constant parameterizations:
fixed value $f_{IGM,0} = 0.83$

$$m_\gamma = (18.2^{+2.7}_{-5.9}) \times 10^{-51} kg$$

$$\mathrm{DM_{host,0}} = 100 \pm 18 pc/cm^3$$



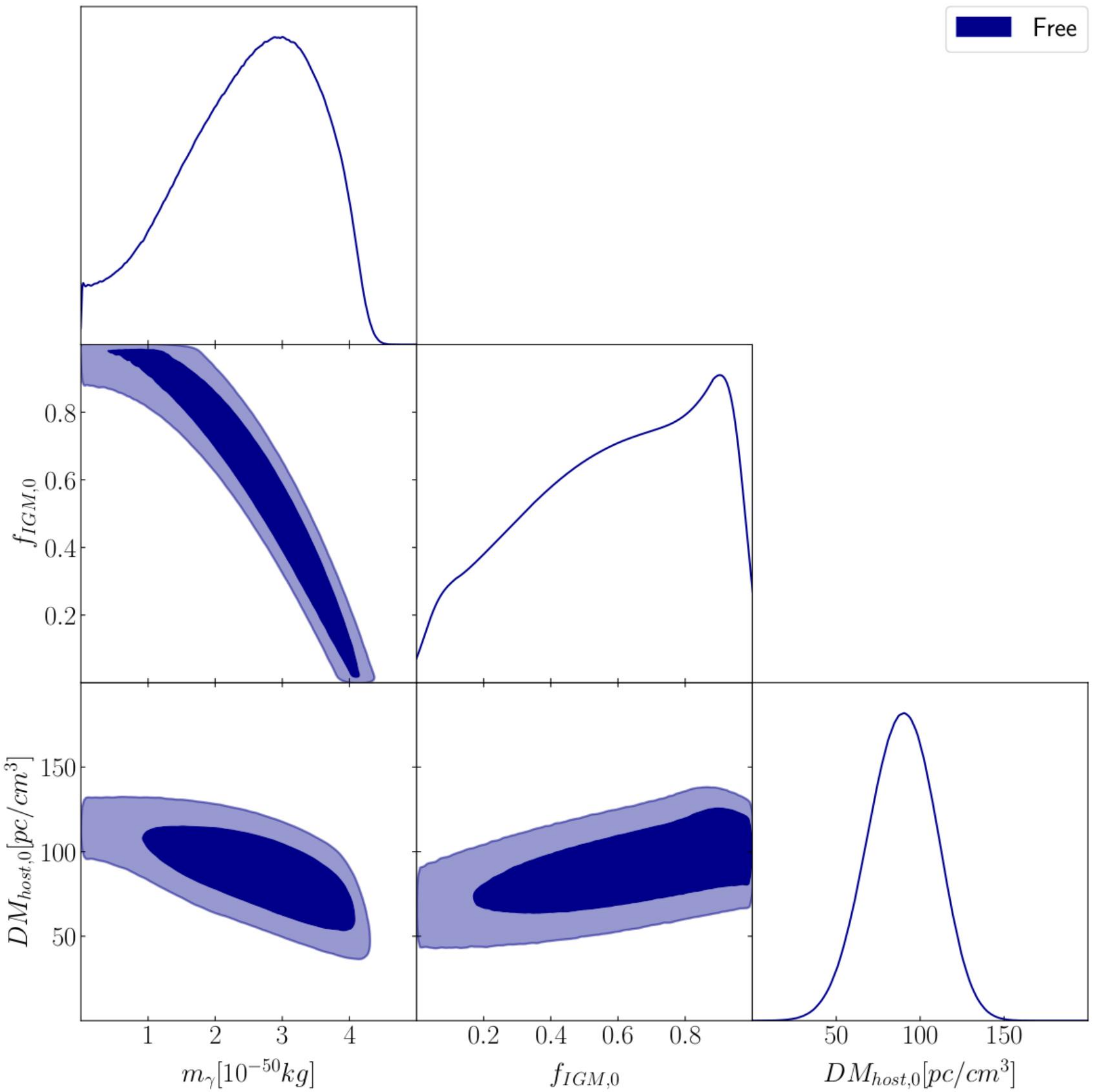
Results

free parameter：

$$m_\gamma = (29.4^{+5.8}_{-15.5}) \times 10^{-51} kg$$

$$\mathrm{DM_{host,0}} = 90^{+19}_{-22} pc/cm^3$$

$$f_{\mathrm{IGM,0}} = 0.902^{+0.034}_{-0.631}$$



Summary

- The method provides robust limits on photon mass without relying on any specific cosmological model.

Fixed $f_{IGM,0}$=0.83: $m_\gamma = (18.2^{+2.7}_{-5.9}) \times 10^{-51}$

Free $f_{IGM,0}$ parameter: $m_\gamma = (29.4^{+5.8}_{-15.5}) \times 10^{-51} kg$

- A strong anti-correlation between m_γ and f_{IGM}, indicating that better constraints on the baryon content of the IGM would directly improve photon mass limits.

Thanks for your listening!

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