Bridging the Cosmic Gap: Insights into Modern Cosmology through Fast Radio Bursts

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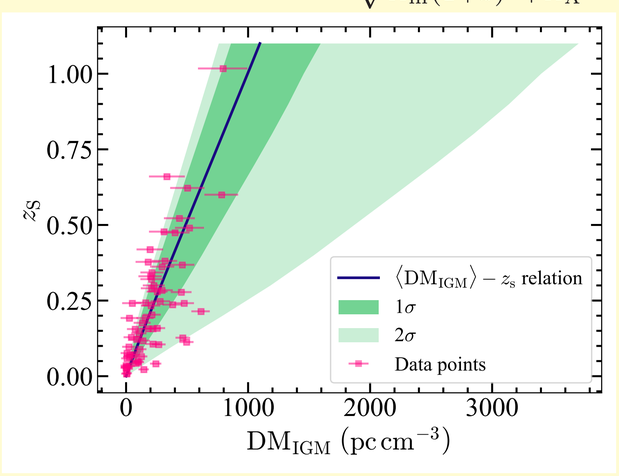
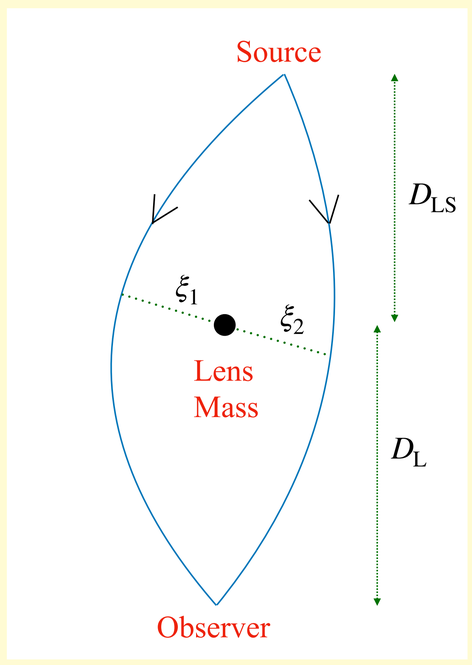
Fast Radio Bursts

- FRBs are radio transient events.
- 838 FRBs have been detected.
- Some are observed to be repeating and some apparently not.
- FRBs have relatively large dispersion measures (DMs) $\implies$ Sources are extragalactic.
- $\mathrm{DM} = \mathrm{DM_{MW}} + \mathrm{DM_{IGM}}(z_\mathrm{S}) + \frac{\mathrm{DM_{Host}}}{1+z_\mathrm{S}}$.

$$\langle \mathrm{DM_{IGM}} \rangle = \frac{3cH_0\Omega_\mathrm{b}}{8\pi G m_\mathrm{p}} \int_0^{z_\mathrm{S}} \frac{f_\mathrm{IGM}(z)\chi(z)(1+z)}{\sqrt{\Omega_\mathrm{m}(1+z)^3+\Omega_\Lambda}}\,\mathrm{d}z\,.$$



Gravitational Lensing



Key Takeaways

- FRBs can be used in estimating the Hubble constant as well as constraining fraction of primordial mass black holes made of dark matter.
- Modified gravity mimics like a scattering screen in the path of light ray, analogous to the scattering effect by plasma on light rays.
- This result will be improved by HIRAX, which will soon be able to detect a lot more FRBs in the Southern sky.

References

1. **S. Kalita**, S. Bhatporia & A. Weltman: *Gravitational lensing in modified gravity: a case study for fast radio bursts*, JCAP 11 (2023) 059 [arXiv:2308.16604]
2. **S. Kalita**, S. Bhatporia & A. Weltman: *Fast Radio Bursts as probes of the late-time universe: a new insight on the Hubble tension*, [arXiv:2410.01974]
3. **S. Kalita** & A. Weltman: *Continuous gravitational wave detection to understand the generation mechanism of fast radio bursts*, MNRAS 520 (2023) 3742 [arXiv:2211.00940]

Hubble Constant estimation using Localized Fast Radio Bursts

- $\mathrm{DM_{exc}} = \mathrm{DM} - \mathrm{DM_{MW}} - \mathrm{DM_{Halo}} = \mathrm{DM_{IGM}}(z_\mathrm{S}) + \frac{\mathrm{DM_{Host}}}{1+z_\mathrm{S}}$.
- Defining $\Delta_\mathrm{IGM} = \mathrm{DM_{IGM}}/\langle \mathrm{DM_{IGM}} \rangle$, the likelihood function is defined as

$$\mathcal{L} = \prod_{i=1}^{N_\mathrm{FRB}} P_i\left(\mathrm{DM_{exc},}i \mid z_\mathrm{S},i\right)$$

where $P_i\left(\mathrm{DM_{exc},}i \mid z_\mathrm{S},i\right) = \int_0^{\mathrm{DM_{exc},}i} P_\mathrm{Host}\left(\frac{\mathrm{DM_{Host}}}{1+z_\mathrm{S},i}\right) P_\mathrm{IGM}\left(\mathrm{DM_{exc},}i - \frac{\mathrm{DM_{Host}}}{1+z_\mathrm{S},i}\right) \mathrm{dDM_{Host}}$, with

$P_\mathrm{IGM}\left(\Delta_\mathrm{IGM}\right) = A\Delta_\mathrm{IGM}^{-\beta_2} e^{-\frac{\left(\Delta_\mathrm{IGM}^{-\beta_1} - C_0\right)^2}{2\beta_1^2\sigma_\mathrm{DM}^2}}$ and $P_\mathrm{Host}\left(\mathrm{DM_{Host}}\right) = \frac{1}{\sqrt{2\pi}\mathrm{DM_{Host}}\sigma_\mathrm{Host}} e^{-\frac{\left(\ln \mathrm{DM_{Host}} - \mu_\mathrm{Host}\right)^2}{2\sigma_\mathrm{Host}^2}}$.

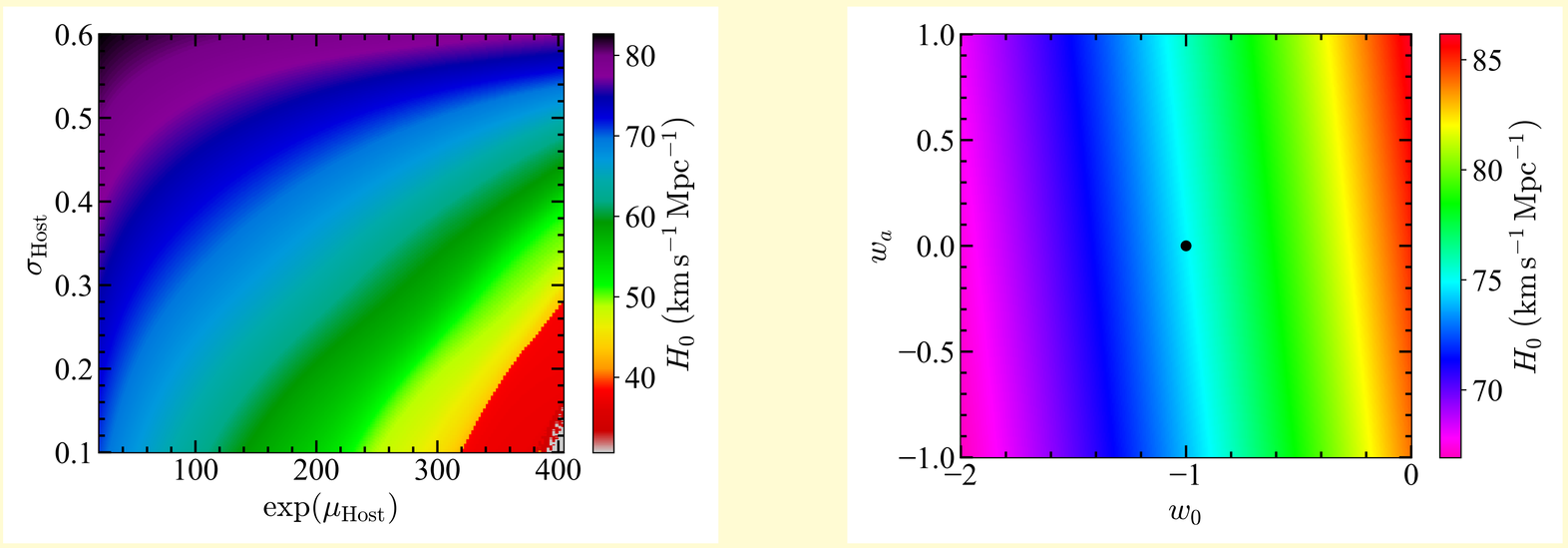


Figure 1: Left panel: H_0 for different host DM contributions under ΛCDM cosmology. Right panel: H_0 for dynamical dark energy model with equation of state $w(z) = w_0 + w_a z/(1+z)$.

Constraints on Fraction of PBHs Made of Dark Matter

- Consider the following modified gravity metric with Ψ is the modified gravity parameter:

$$\mathrm{d}s^2 = \left(1 - \frac{2GM_\mathrm{L}}{c^2 r} + \Psi r^2\right) c^2\,\mathrm{d}t^2 - \frac{1}{1 - \frac{2GM_\mathrm{L}}{c^2 r} + \Psi r^2}\,\mathrm{d}r^2 - r^2\mathrm{d}\theta^2 - r^2\sin^2\theta\mathrm{d}\phi^2,$$

  where M_L is the mass of the lensing object.
- Optical depth:

$$\tau(M_\mathrm{L}, z_\mathrm{S}) = \frac{3}{2} f_\mathrm{PBH}\Omega_\mathrm{c} \int_0^{z_\mathrm{S}} \mathrm{d}z_\mathrm{L} \frac{H_0^2}{cH(z_\mathrm{L})} \frac{D_\mathrm{L} D_\mathrm{LS}}{D_\mathrm{S}} (1+z_\mathrm{L})^2 \left[y_\mathrm{max}^2(\mu) - y_\mathrm{min}^2(M_\mathrm{L}, z_\mathrm{L})\right].$$

  where f_PBH is the fraction of PBHs made up of dark matter.
- Integrated optical depth for all FRBs (636 detected by CHIME):

$$\bar{\tau} = \frac{1}{\mathcal{N}_\mathrm{FRB}} \sum_{i=1}^{\mathcal{N}_\mathrm{FRB}} \tau(M_\mathrm{L}, z_\mathrm{S},i).$$

- Poisson distribution:

$$\mathcal{N}_\mathrm{lensed,FRB} = \left(1 - e^{-\bar{\tau}}\right)\mathcal{N}_\mathrm{FRB}, \quad \bar{\tau} = f_\mathrm{PBH}\tau_1.$$

- No lensed FRB has been confirmed $\implies$

$$f_\mathrm{PBH} < \frac{1}{\tau_1} \ln\left(\frac{\mathcal{N}_\mathrm{FRB}}{\mathcal{N}_\mathrm{FRB} - 1}\right).$$

- Assumption:

$$\langle \mathrm{DM_{Host}} \rangle \approx 100\,\mathrm{pc\,cm^{-3}}.$$

- The left cut-off of f_PBH is determined from the minimum Δt of the telescope ($\approx 10^{-9}$ s for CHIME telescope). The right cut-off is determined from the maximum magnification ratio μ.

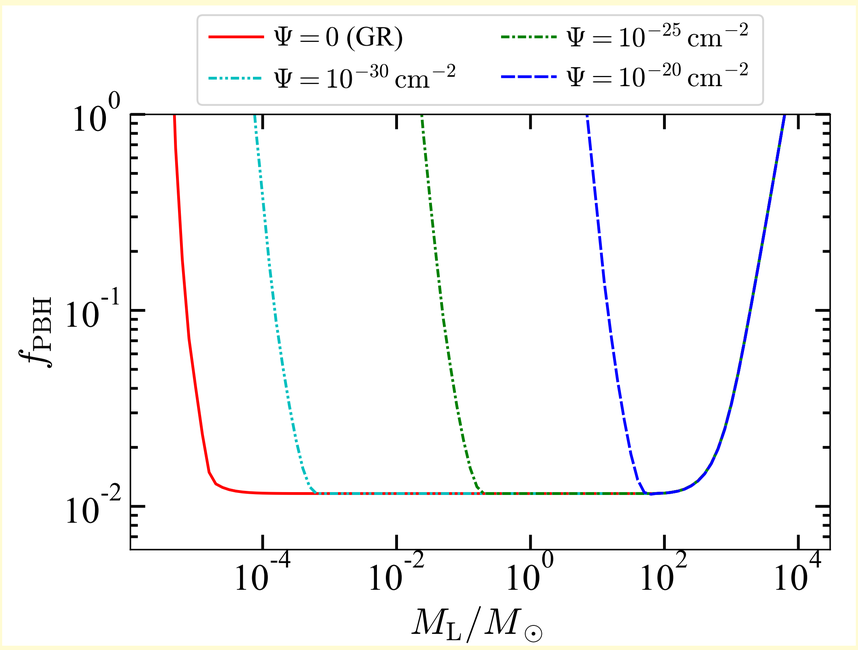


Figure 2: Bounds on the fraction of dark matter made up of primordial black holes for different values of modified gravity parameter Ψ.