# Gravity as Portal to (almost) Everything!

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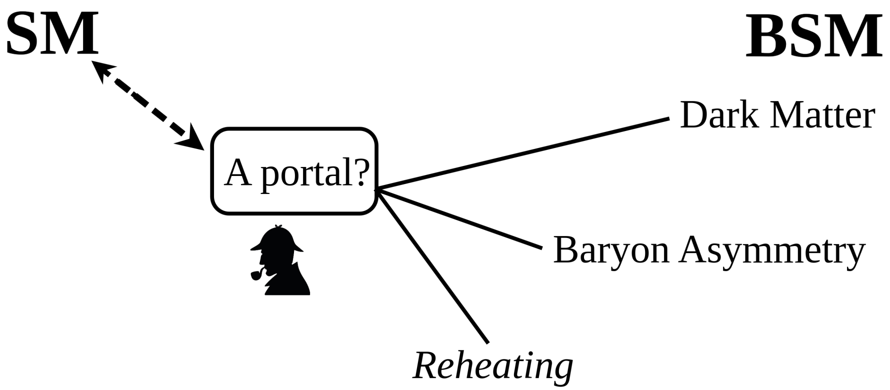
based on

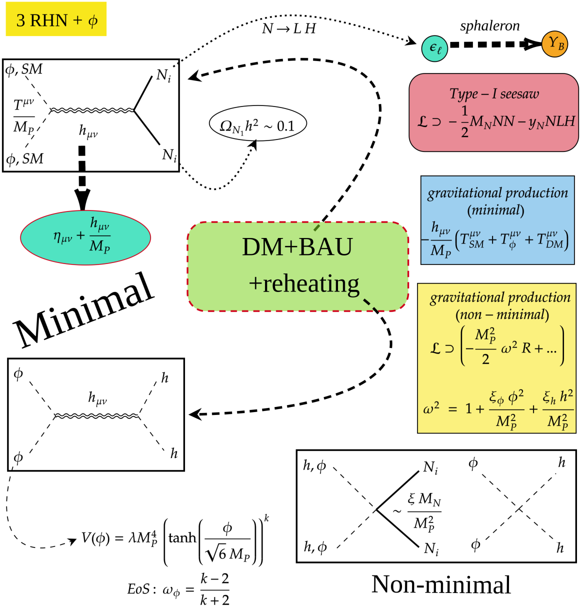
arxiv: 2210.05716 [JHEP12(2022)072], with S.Cléry, R.T.Co, Y.Mambrini & K.A. Olive

arxiv: 23xx.xxxx, with D.Borah, S.Cléry,Y.Mambrini

*"One portal to rule them all"*



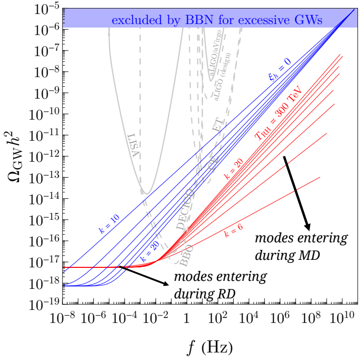
# “One portal to find them”

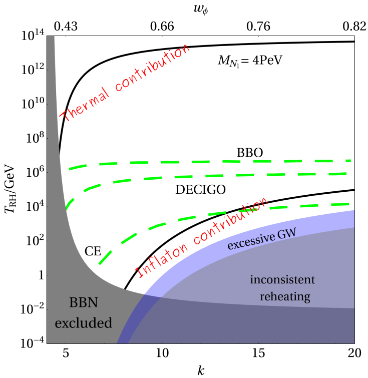


## *“One portal to bring them all”*

$$\underbrace{\Omega_{\mathrm{SM}\to N_1}}_{\text{SM scattering}} + \underbrace{\Omega_{\phi\to N_1}}_{\text{inflaton scattering}} \sim 0.1$$

- Gravitational reheating+$T_{\rm rh} \gtrsim T_{\rm BBN} \implies \omega_\phi \gtrsim 0.65$ (stiff era)
- $\Delta N_{\rm eff}$ forbids excessive blue-tilted *primordial* GW: $\xi_h \not< 0.5$
- Gravity portal naturally provides *PeV-scale decaying DM* → IceCube excess



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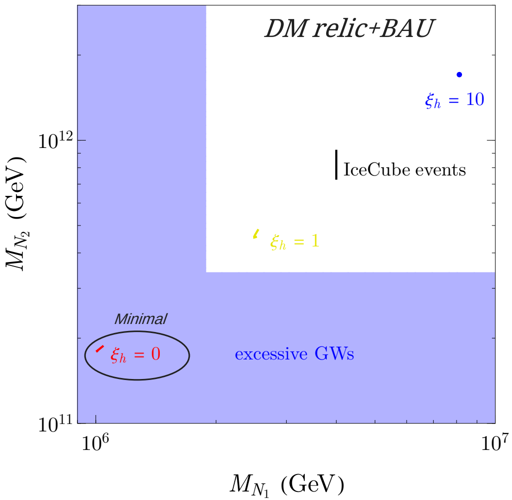


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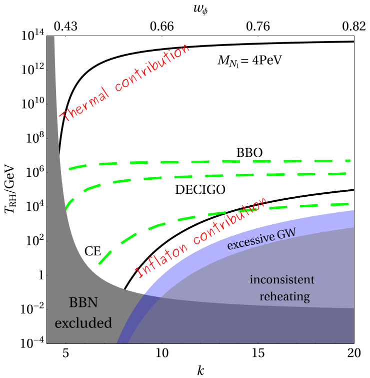

## *"... and (in the darkness) bind them"*

- Minimal gravity mediated DM+BAU+reheating
- Possible explanation to IceCube events
- Testable at future GW detectors

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**Many thanks to the organizers**
**& Thank you for your attention!**

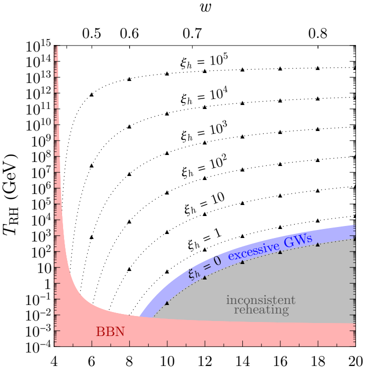
# Backup Slides

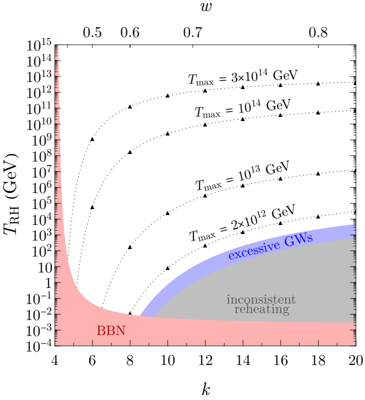
# BBN bound on reheating temperature

$\rho_\phi = \rho_R$ at $T = T_{\rm rh}$

$$\implies 1 = \left.\frac{\rho_\phi}{\rho_R}\right|_{T_{\rm rh}} = \left.\frac{\rho_\phi}{\rho_R}\right|_{T_{\rm BBN}} \frac{(a_{\rm BBN}/a_{\rm rh})^{\frac{6k}{k+2}}}{(T_{\rm rh}/T_{\rm BBN})^4}$$

$$\rho_\phi(T_{\rm BBN}) = \frac{7}{8}\left(\frac{4}{11}\right)^{\frac{4}{3}} \underbrace{\Delta N_\nu}_{<0.226} \frac{\pi^2}{30} T_{\rm BBN}^4$$



# Interactions

$$\mathcal{S}_J = \int d^4x \sqrt{-\tilde{g}} \left[ -\frac{M_P^2}{2} \Omega^2 \widetilde{\mathcal{R}} + \widetilde{\mathcal{L}}_\phi + \widetilde{\mathcal{L}}_h + \widetilde{\mathcal{L}}_{N_i} \right]$$

where

$$\widetilde{\mathcal{L}}_\phi = \frac{1}{2} \partial_\mu \phi \, \partial^\mu \phi - V(\phi)$$

$$\widetilde{\mathcal{L}}_h = \partial_\mu h \, \partial^\mu h^\dagger - V(h h^\dagger)$$

$$\widetilde{\mathcal{L}}_{N_i} = \frac{i}{2} \overline{\mathcal{N}_i} \overleftrightarrow{\nabla} \mathcal{N}_i - \frac{1}{2} M_{N_i} \overline{(\mathcal{N})^c}_i \mathcal{N}_i + \widetilde{\mathcal{L}}_{\rm yuk}$$

$$\widetilde{\mathcal{L}}_{\rm yuk} = -y_{N_i} \overline{\mathcal{N}_i} \widetilde{h}^\dagger \mathbb{L} + \text{h.c.}$$

- Conformal transformation: $\Omega^2 \equiv 1 + \frac{\xi_\phi \, \phi^2}{M_P^2} + \frac{\xi_h \, |h|^2}{M_P^2} \implies g_{\mu\nu} = \Omega^2 \, \tilde{g}_{\mu\nu}$

$$\mathcal{S}_E = \int d^4x \sqrt{-g} \Bigg[ -\frac{M_P^2 \, \mathcal{R}}{2} + \frac{K^{ab}}{2} g^{\mu\nu} \partial_\mu S_a \, \partial_\nu S_b + \frac{i}{2\,\Omega^3} \overline{N_i} \overleftrightarrow{\nabla} N_i - \frac{1}{\Omega^4} \left( \frac{M_{N_i}}{2} \overline{N_i^c} N_i + \mathcal{L}_{\rm yuk} \right) - \frac{3i}{4\Omega^4} \overline{N_i} \left( \overleftrightarrow{\partial} \, \Omega \right) N_i - \frac{1}{\Omega^4} \left( V_\phi + V_h \right) \Bigg],$$

- Field re-definitons: $L \to \Omega^{3/2} L$, $N \to \Omega^{3/2} N$

$$\mathcal{S}_E = \int d^4x \sqrt{-g} \Bigg[ -\frac{M_P^2 \, \mathcal{R}}{2} + \underbrace{\frac{K^{ab}}{2} g^{\mu\nu} \partial_\mu S_a \, \partial_\nu S_b}_{\text{non-canonical kinetic term}} - \frac{1}{\Omega^4} \left( V_\phi + V_h \right) + \frac{i}{2} \overline{N_i} \overleftrightarrow{\nabla} N_i + \frac{1}{\Omega} \mathcal{L}_{\rm yuk}$$

# GW energy density

- Assuming "hc" occurs during inflaton-domination

$$\Omega_{\rm GW}(\tau,k) = \frac{1}{12a(\tau)^2\,H(\tau)^2}\,\mathcal{P}_T(k)\,\left[\chi(\tau,k)'\right]^2$$

$$= \frac{1}{12a(\tau)^2\,H(\tau)^2}\,\mathcal{P}_T(k)\,\frac{k_{gw}^2}{2}\,\left(\frac{a_{\rm hc}}{a_0}\right)^2$$

$$= \frac{\Omega_\gamma\,h^2}{3}\,\frac{\rho_\phi}{\rho_{\rm RH}}\,\left[\frac{g_{\star\rho,rh}}{2}\,\left(\frac{g_{\star\rho,rh}}{g_{\star s,dec}}\right)^{-\frac{4}{3}}\,\left(\frac{a_{\rm hc}}{a_{\rm rh}}\right)^4\right]\,\left(\frac{H_{\rm end}}{2\pi\,M_P}\right)^2$$

$$f = \frac{k_{hc}}{2\pi a_0} = \frac{a_{\rm hc}\,H_{hc}}{2\pi a_0} = \frac{a_{\rm hc}}{a_0}\,\frac{1}{2\pi}\,H_{rh}\,\sqrt{\frac{\rho_{\rm hc}}{\rho_{\rm RH}}} = \frac{\sqrt{\rho_{\rm RH}}}{2\pi\sqrt{3}\,M_P}\,\frac{a_{\rm hc}}{a_0}\,\left(\frac{a_{\rm rh}}{a_{\rm hc}}\right)^{3k/(k+2)}$$

Then

$$\Omega_{\rm GW}\,h^2 = \frac{\Omega_\gamma\,h^2}{3}\,\frac{g_{\star\rho,rh}}{2}\,\left(\frac{g_{\star\rho,rh}}{g_{\star s,dec}}\right)^{-\frac{4}{3}}\,\left(\frac{H_{\rm end}}{2\pi\,M_P}\right)^2\,\left(\frac{a_0}{a_{\rm rh}}\right)^{\frac{k-4}{k-1}}\,\left(\frac{2\pi\sqrt{3}\,M_P}{\sqrt{\rho_{\rm RH}}}\,f\right)^{\frac{k-4}{k-1}}$$

- Assuming "hc" occurs during RD

$$\Omega_{\rm GW}\,h^2 = \frac{\Omega_\gamma\,h^2}{3}\,\frac{g_{\star\rho,rh}}{2}\,\left(\frac{g_{\star\rho,rh}}{g_{\star s,dec}}\right)^{-\frac{4}{3}}\,\left(\frac{H_{\rm end}}{2\pi\,M_P}\right)^2$$

$$\Longrightarrow\ \Omega_{\rm GW}\,h^2 \simeq \Omega_{\rm GW}\,h^2\Big|_{\rm RD} \times \mathcal{W}(f\,,w)$$