Primordial Black Holes generated from SUSY Breaking in Non-oscillatory Inflation Models

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Outline

Sgoldstinoless Model

$$W = \left(1 - \frac{S}{\sqrt{3}}\right)^3 f(Z)$$

$$K = K_1\left(Z, \overline{Z}\right) - 3\log\left[1 - \frac{|S|^2}{3} + \frac{|S|^4}{\Lambda^2}\right],$$

(L. Heurtier, A.M., L. Wacqwez, 2023)

- $f(Z)$ is a holomorphic function: $\overline{f(Z)} = f(-\overline{Z})\,, \qquad f(0) \neq 0\,,$
  S is the goldstino superfield. (Dall'Agata and Zwirner 2014)
- The nilpotent limit: $S^2 = 0 \Rightarrow$ scalar potential $V_{\rm nil}(z)$.
- Inflaton effective potential after integrating out S

$$V_{\sf eff}(z) = V_{\sf nil}(z) - \frac{\Lambda^2\, V_{\sf nil}(z)^2}{2\left[6m_{3/2}^2 + \Lambda^2 V_{\sf nil}(z)\right]}\,.$$

Sgoldstinoless Model

- The gravitino mass: $m_{3/2}^2 \simeq f\,(i\,z)^2$.
- Sgoldstino mass

$$m_s^2 \;=\; \frac{36\, m_{3/2}^2 + 6\,\Lambda^2\, V_{\mathsf{nil}}}{\Lambda^2}\,,$$

- Large UV scale, integrate out the sgoldstino with:

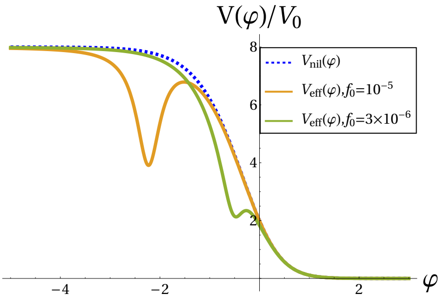
$$\langle s \rangle = \frac{\Lambda^2\, V_{\mathsf{nil}}}{2\sqrt{3}\left[\Lambda^2\, V_{\mathsf{nil}} + 6\, m_{3/2}^2\right]}\,.$$

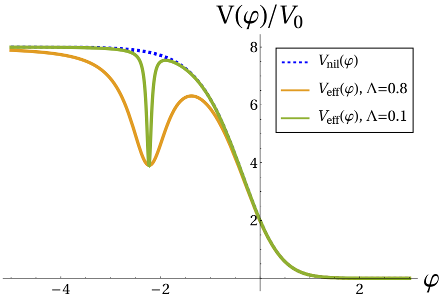
- The nilpotent limit is equivalent to sending the UV scale $\Lambda \to 0$
- The nilpotent limit: $S^2 = 0 \Rightarrow$ scalar potential $V_{\rm nil}(z)$.

Model: Canonical Kähler

$$K_1 = \frac{1}{2}\left(Z+\overline{Z}\right)^2 , \qquad f(Z) = f_0 - \sqrt{V_0}\,\log\left(1+e^{2\sqrt{2}\,i\,b\,Z}\right) .$$

$$V_{\mathsf{nil}} = -f'\left(iz\right)^2 = \frac{8\,b^2 V_0}{\left(e^{2b\varphi}+1\right)^2} .$$





Features

- *Cosmological Seesaw Mechanism*: Two different plateaus with a hierarchical difference $\sim V_0$, .
- Inflation tail: $\varphi \ll -1 \Rightarrow H^2 \sim V_0/3$
- DE tail: $V \ll 1$ as $\varphi \gg 1$, and $m_{3/2} \sim f_0$
- Corrections due to integrating out the sgoldstino
  - Bumps, dips or inflection points in the inflation tail.
  - These Corrections (proportional to Λ^2) vanish as $\varphi \gg 1$
  - Corrections depend on SUSY breaking f_0 and the UV scale Λ
  - For specific values of these two parameters in order to obtain Ultra Slow Roll (USR) phase, during inflation, leading to the formation of PBHs and GWs.

Cosmological History

- Inflation phase: along the Inflation tail $\varphi \ll -1$, for 50-60 efolds.
- Reheating Mechanism: Gravitational Reheating

$$\rho_{\rm grav}\big|_{t=t_{\rm end}} = \frac{g_{\star,{\rm end}} q}{1440\pi^2} \left(\frac{H_{\rm end}}{M_{\rm Pl}}\right)^2 \rho_{\rm end}\,, \tag{1}$$

- Kination era: Energy density dominated almost entirely by the kinetic energy of φ. $w_{\rm kin} \approx 1$, $\rho_{\rm kin} \propto a^{-6}$, $a \propto t^{1/6}$ and $H = \dfrac{1}{3t}$.

$$\varphi(N) = \varphi_{\rm kin} + \sqrt{6}\, M_{\rm Pl}\, (N - N_{\rm kin})\,,$$

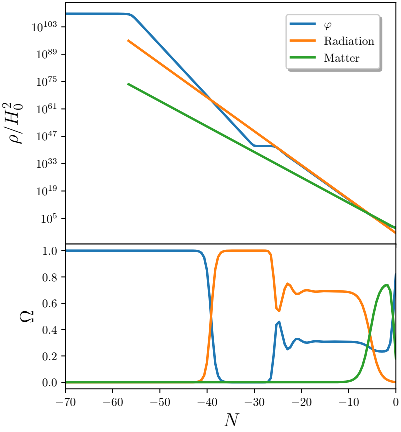
- Radiation Domination: SM radiation starts dominating over the scalar field energy density.

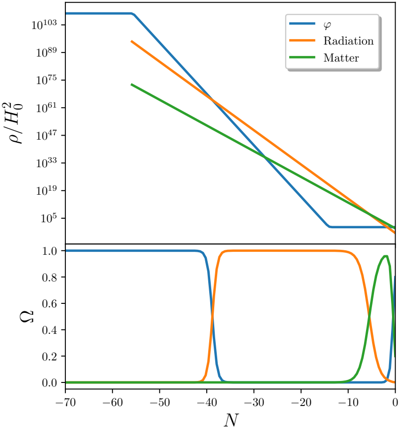
$$\varphi_{\rm rad} = \varphi_{\rm kin} + \sqrt{\frac{2}{3}}\, M_{\rm Pl}\, \ln\left(\frac{H_{\rm kin}}{H_{\rm rad}}\right)\,, \qquad H_{\rm rad}^2 = \frac{2\rho_{\rm rad}}{3M_p^2}. \tag{2}$$

- Matter Domination: Matter-radiation equality at $N_{\rm eq} = \log\left(\dfrac{\Omega_{\rm rad,0}}{\Omega_{\rm m,0}}\right)$, where the matter energy density begins to dominate the universe.

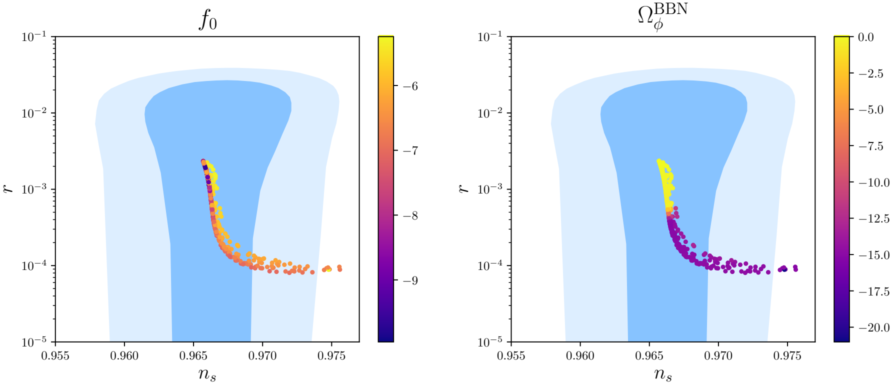
Cosmological History and Observables

$$\Gamma_{\text{track.}} \equiv \frac{V''V}{(V')^2} \geq 1 \quad \text{and} \quad \left| \frac{d\ln(\Gamma_{\text{track.}} - 1)}{d\ln a} \right| \ll 1\,, \quad [\text{Wang, etal}\,(1999)]$$



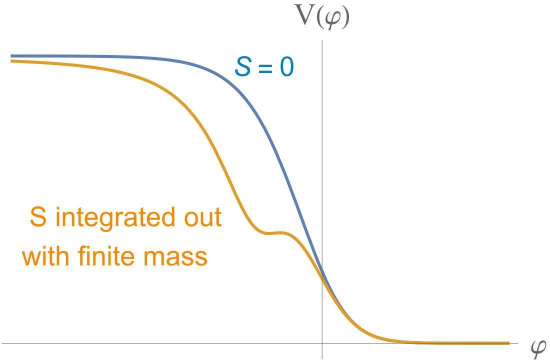


- We have scanned over f_0, Λ, V_0, b
- Large SUSY breaking scale $f_0 > 10^{-8}$ in order to avoid long tracking regime.



Primordial Black Holes

- Breaking of SUSY at a scale comparable to the inflation scale typically produces inflection points along the inflation potential.
- We are interested in USR regime around inflection point: $V' \approx 0$, $V'' = 0$.



f_0	b	Λ	V_0	M[g]
1.1190938×10^{-5}	0.84	1.392	3.25×10^{-11}	5.5×10^{20}

Primordial Black Holes

- The mass of a PBH that forms during the kination dominated era

$$M(k) = 4\pi\gamma \left(\frac{\pi^2 g_*^{\mathsf{eq}}}{45}\right)^{\frac{1}{1+3w}} \left(\frac{g_s^{\mathsf{eq}}}{g_s(T_{kin})}\right)^{\frac{3w-1}{3(3w+1)}} T_{kin}^{-\frac{3w-1}{3w+1}} \left(\frac{a_{\mathsf{eq}} T_{\mathsf{eq}}}{k}\right)^{\frac{3(1+w)}{3w+1}}$$

- The fractional abundance of PBHs

$$f_{\mathsf{PBH}}(M) = \frac{\Omega_{\mathsf{PBH}}(M)}{\Omega_c}$$
$$= \frac{\gamma}{T_{\mathsf{eq}}} \left(\frac{g_s(T_{\rm kin})}{g_s(T_{\mathsf{eq}})}\right)^{1/3} \left(\frac{\Omega_m h^2}{\Omega_c h^2}\right) \left(\frac{90}{\pi^2 g_*(T_{\rm kin})}\right)^{\frac{w}{1+w}} (4\pi\gamma)^{\frac{2w}{1+w}} T_{\rm kin}^{\frac{1-3w}{1+w}} \beta(M) M^{-\frac{2w}{1+w}}\,.$$

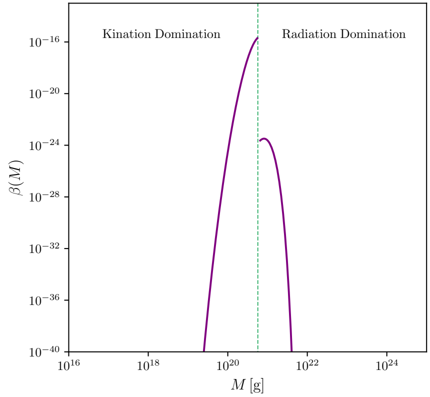
- Modes that re-enter the horizon then form black holes with the usual mass and dark matter fraction spectrum: sending $T_{\rm kin} \to T_{\rm eq}$ and $w \to 1/3$.

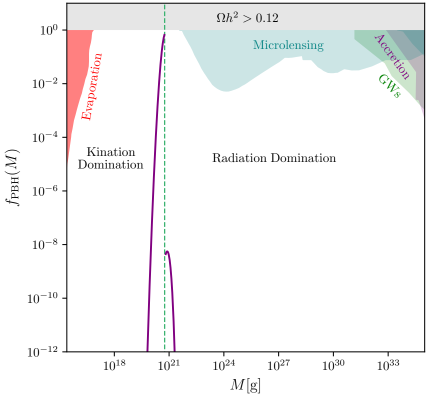
Primordial Black Holes

Mass Fraction: $\beta(k) = 2\int_{\delta_c(k)}^{\infty} \frac{1}{\sqrt{2\pi\sigma^2(k)}} e^{-\delta^2/2\sigma^2(k)} \mathrm{d}\delta\,,$

$$\delta_c(k) = \frac{3(1+w)}{5+3w}\sin^2\left(\frac{\pi\sqrt{w}}{1+3w}\right).$$

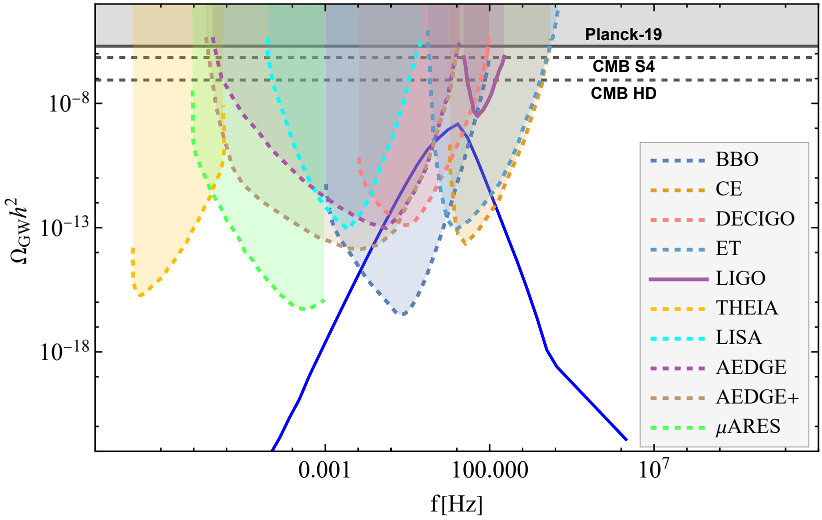
$$\text{The variance}: \sigma^2(k) = \int_{k_*}^{k_{end}} 4\left(\frac{1+w}{5+3w}\right)^2 \mathcal{P}_{\mathcal{R}}(q)\left(\frac{q}{k}\right)^4 e^{-q^2/k^2} T\left(\frac{q}{k\sqrt{3}}\right) \mathrm{d}\ln q\,,$$





Scalar Induced Gravitational Waves (SIGW)

Preliminary Results



Conclusions

- Sgoldstinoless models of non-oscillatory inflation provide an intersting framework that can combine Infation, SUSY breaking and DE.
- Integrating out the sgoldstino with a finite mass, has many interesting cosmological implications.
- SUSY breaking effects with finite sgodstino mass can generate an inflection point in the inflation tail, that may feature an ultra slow roll phase before the end of inflation.
- This may be translated into an enhancement in the primordial power spectrum, that may generate primordial Black Holes with reasonable abundnace accounting for a DM fraction and can source gravitational waves.
- Kination phase has interesting implications where the PBH mass fraction is enhanced more than fractions formed during radiation.

Thank you