Particle production during inflation and the Swampland Distance Conjecture

Joaquin Masias

in collaboration with Dieter Luest,
Mauro Pieroni, Marco Scalisi

Max-Planck-Institut
für Physik

07/07/2022

21st STRING PHENOMENOLOGY
Conference LIVERPOOL | 4 - 8 JULY 2022

Swampland Distance Conjecture

- The Swampland Distance Conjecture (SDC) predicts that for large distances in the field space of a scalar, the mass scale of an **infinite tower of states becomes exponentially light**:

$$M_{tower} \propto e^{-\alpha d(\phi)}$$

- Since inflation may deal with **superPlanckian displacements** ($\sim \mathcal{O}(10 M_P)$ for power law potentials) it may be interesting couple the inflaton to such a tower of states.

- What observational consequences can arise from having and infinite tower of states coupled to the inflation via an exponential mass term before the **breakdown of the EFT**?

Swamplands Distance Conjecture

- The breakdown is due to a drop off of the QG cut-off which goes below the Hubble scale. This is given by the **species scale**.
- For an **infinite tower of scalars**, with linear mass separation (e.g. KK-modes, winding modes):

$$m_n = n \cdot M e^{-\alpha d(\phi)} \qquad \Lambda_{QG} = \frac{M_P}{\sqrt{N}} \simeq e^{-\frac{\alpha}{3} d(\phi)}$$

- Where N is the maximum number of states that can be below the cutoff.

Scenario I

- For slow roll inflation, a very **flat potential** is required, which is generally difficult to achieve.
- Introducing friction in terms of **particle production** can be used to relax the flatness of the potential:

$$\mathcal{L} = \frac{1}{2}\partial_\mu\varphi\partial^\mu\varphi - V(\varphi) + \sum_i \frac{1}{2}\partial_\mu\chi_i\partial^\mu\chi_i - \frac{g^2}{2}e^{-\alpha\varphi}(\varphi - \varphi_{0i})^2\chi_i^2$$

[Silverstein et al. 2009, Peloso et al. 2016]

- The quantua are only produced when $\varphi \simeq \varphi_{0i}$, when the χ_i are massless.

Scenario I

- We fix the distance between two consecutive points

$$V(\varphi, \chi_i) = \frac{g^2}{2} e^{-\alpha\varphi} (\varphi - \varphi_{0i})^2 \chi_i^2 \qquad \Delta = |\varphi_{0i+1} - \varphi_{0i}|$$

- In order to deduce the scaling of the states we look at the tower when

$$\varphi = \varphi_{00}$$

- The masses of the tower, and the scale of QG are then:

$$m_i = ige^{-\alpha\varphi/2}\Delta \qquad \Lambda_{QG} = \frac{M_P}{\sqrt{N}} \simeq e^{-\frac{\alpha}{6}\varphi}$$

Scenario I

- We have three distinct timescales:

$$t_p = \frac{1}{\sqrt{g|\dot{\varphi}_{0i}|e^{-\alpha\varphi_0/4}}} \qquad t_H = \frac{1}{H} \qquad t_{QG} = \frac{6}{\alpha\dot{\varphi}}$$

- One of the assumptions of Trapped Inflation is:

$$t_p \ll t_H$$

- We want inflation to occur before the breakdown of the EFT

$$t_p \ll t_H \ll t_{QG} \qquad \frac{|\alpha\dot{\varphi}|}{H} \ll 1$$

Scenario I

- Because of the vast difference in scales, we treat the exponential as a rescaling of the coupling $g^2 \to g^2 e^{-\alpha\varphi}$, when computing $\langle : \chi_i^n : \rangle$

- We can compute the background solution $\varphi_0(t)$ and the correlation functions for the perturbations $\langle : \delta\varphi_1(t,\vec{x})\delta\varphi_1(t,\vec{x}) : \rangle$

$$\dot{\varphi}_0 \simeq -\frac{\exp\left(\alpha\varphi_0/2\right)}{g}(24\pi^3 H\Delta V')^{2/5}\left(1+\frac{1}{6}\frac{\alpha}{H}\frac{\exp\left(\alpha\varphi_0/2\right)}{g}(24\pi^3 H\Delta V')^{2/5}\right)$$

- And the scalar power spectrum:

$$P_\zeta \simeq P_{\zeta_s} = 5.7\cdot 10^{-4}\,\frac{g^{9/4}e^{-9\alpha\varphi_0/8}\,H}{\Delta^{1/2}\,|\dot{\varphi}_0|^{1/4}}\left(1+\frac{10}{7}\frac{\alpha\dot{\varphi}_0}{H}\right)$$

Scenario I

- The spectral tilt takes the form:

$$n_s - 1 = \varepsilon\left(-\frac{7}{10} - \frac{1}{5p} + \frac{5}{2p}\alpha\varphi_N\right) + \varepsilon^2\left(-\frac{5}{7p}\alpha\varphi_N + \frac{20}{7p^2}\alpha\varphi_N\right)$$

- We have considered a potential of the form:

$$V(\varphi) = \frac{\mu^{4-p}}{p!}\varphi^p$$

- For p=1, p=2 we have:

$$n_s - 1_{(p=1)} = -0.0058 + 3.73 \cdot 10^4 \alpha g^{2/3}\mu$$

$$n_s - 1_{(p=2)} = -0.011 + 4.91 \cdot 10^7 \alpha g\mu$$

Scenario I

- We have 5 parameters:

$$N_e \qquad \Delta \qquad g \qquad \mu \qquad \alpha$$

- The number of e-folds has to be around 50 $\quad N_e = 60$

- The value of Δ can be fixed in term of the other parameters

Scenario I

- We have 5 parameters:

$$N_e \qquad \Delta \qquad g \qquad \mu \qquad \alpha$$

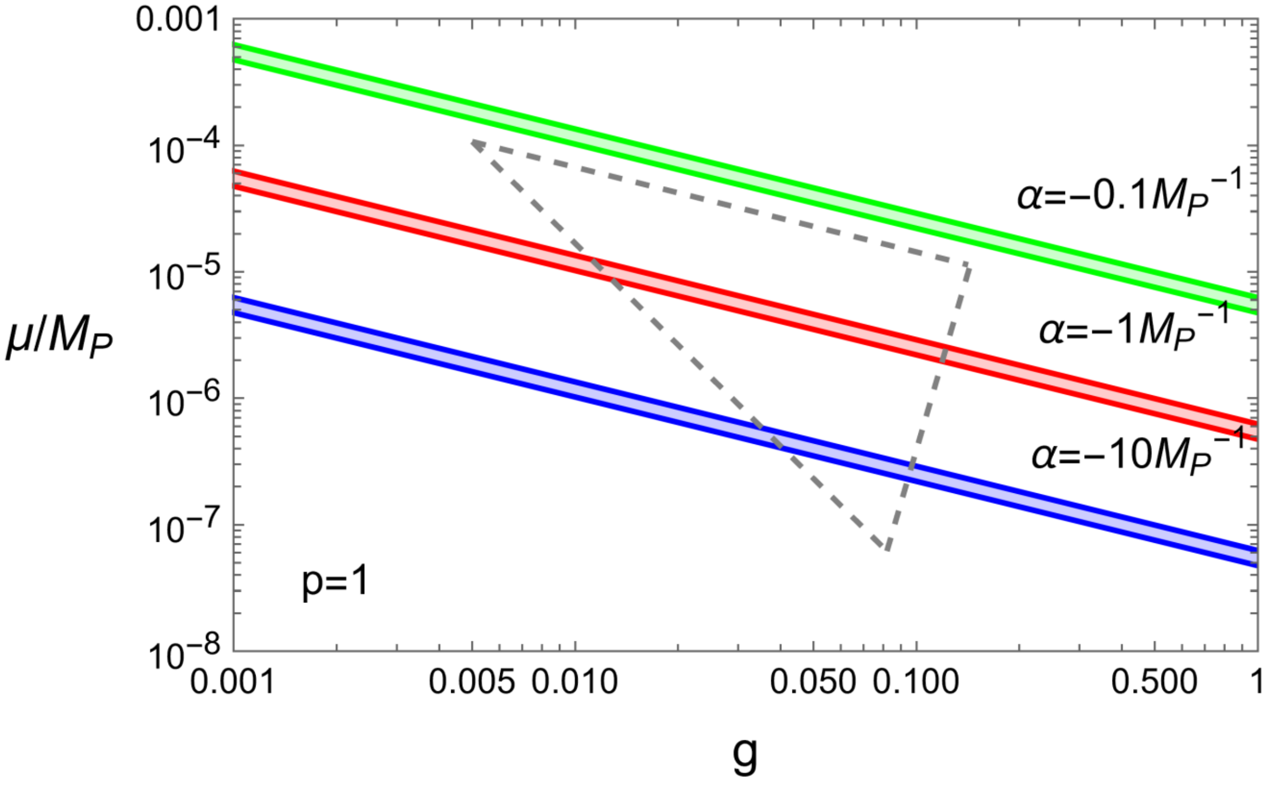
- The number of e-folds has to be around 50 $\quad N_e = 60$

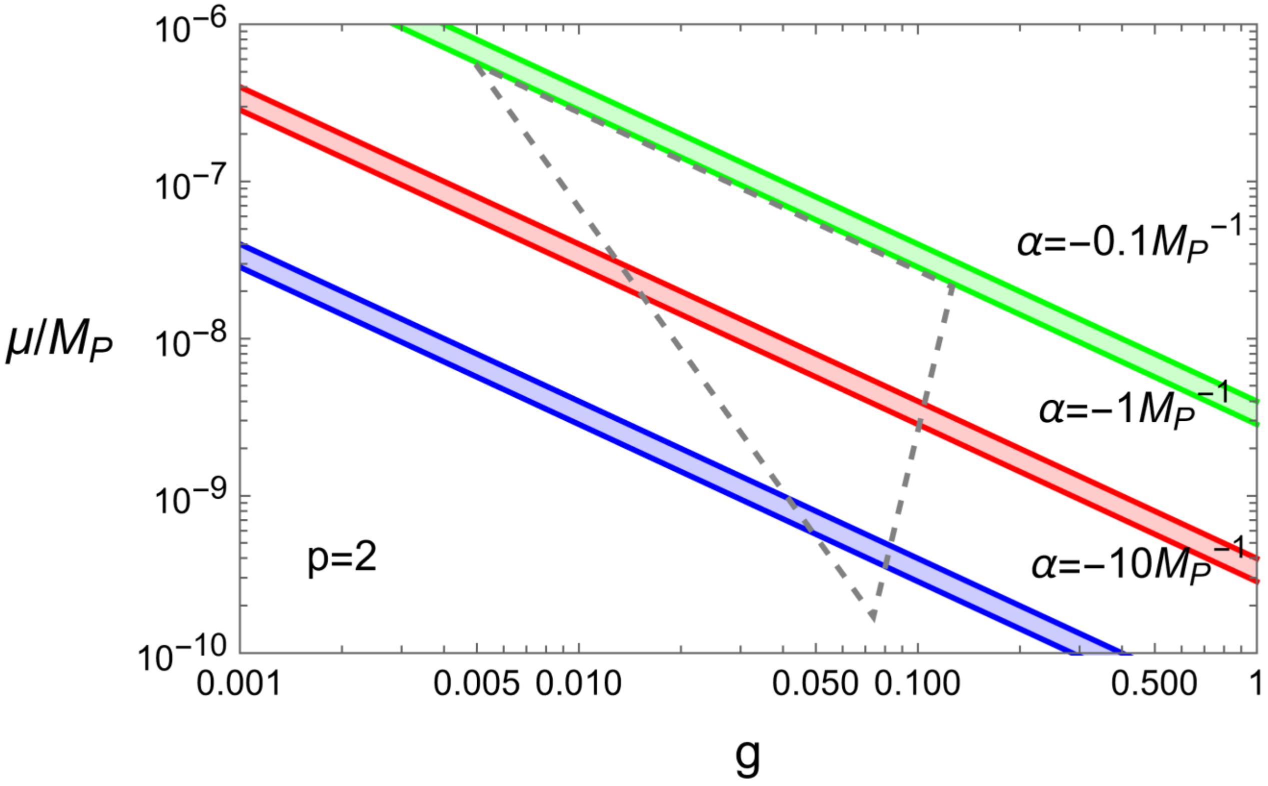
- The value of Δ can be fixed in term of the other parameters

Scenario I

- Given the measured value $n_s - 1 = -0.035 \pm 0.004$:

$$V(\varphi) = \frac{\mu^{4-p}}{p!}\varphi^p$$





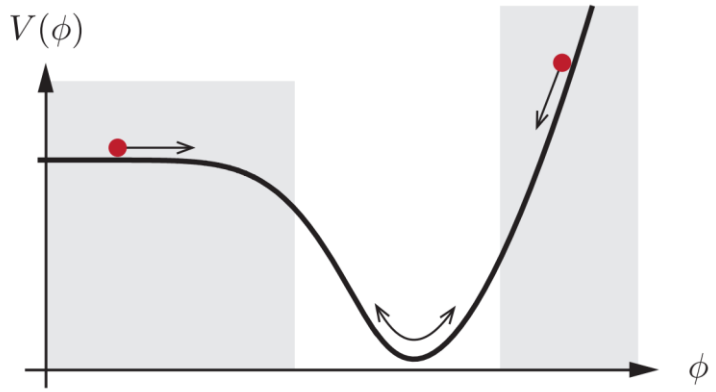
- This is in agreement with the SDC, which predicts $\alpha \sim \mathcal{O}(M_P^{-1})$

Scenario I

- Positive or negative values of alpha correspond to a tower of states, or its dual.

- We are considering $\varphi > 0, \dot{\varphi} < 0$, in order to have a tower with decreasing mass scale α must be negative.

- We have defined the distance $d(\varphi) = \varphi$, if we instead define it as $d(\varphi) = \varphi_i - \varphi$ we would have positive values of α .



Scenario I

- The tensor power spectrum is dominated by the unsourced term.

$$P_T = \frac{2H^2}{\pi^2 M_p^2}\left[1 + 0.062\beta^2 \frac{|\dot{\varphi}_0|}{g M_p^2} \ln^2\left(\frac{\sqrt{g \exp\left[-\alpha\varphi\right]\dot{\varphi}_0}}{H}\right)\right]$$

- The scalar power spectrum receives large contributions from particle production.

- This brings down the tensor to scalar ratio.

Scenario II

- We consider the inflaton coupled to an infinite tower of states

$$V(\varphi, \chi_n) = \frac{m_n^2}{2} e^{-\alpha\varphi} \chi_n^2$$ [Reece et al. 2022]

$$m_n = n \cdot m_1$$

- The inflaton rolls down slowly, such that higher order derivatives are negligible:

$$\varphi(t) \simeq \varphi_{t_0} + \dot{\varphi} t \simeq \varphi_{\tau_0} - \frac{\dot{\varphi}}{H} \log\left(\tau/\tau_0\right)$$

- We once again compare the scales of inflation and quantum gravity, such that:

$$\frac{|\alpha\dot{\varphi}|}{H} \ll 1$$

Scenario II

- The fields in the tower have e.o.m.'s:

$$\chi_n''(\tau,\vec{k}) + \left[k^2 + \frac{m_n^2}{H^2\tau^2}\exp\left(-\alpha\varphi\right) - \frac{2}{\tau^2}\right]\chi_n(\tau,\vec{k}) = 0 \qquad \frac{|\alpha\dot{\varphi}|}{H} \ll 1$$

$$\sum_n^N \frac{m_n^2}{2} e^{-\alpha\varphi}\langle : \chi_n(\tau,\vec{x})\ \chi_n(\tau,\vec{x}) : \rangle = \frac{1}{a^2}\frac{3}{8\pi^2}\frac{H^2}{\sqrt{2}\tau^2}N \qquad N = \frac{M_P^2}{\Lambda_{QG}^2}$$

- The background solution is:

$$\dot{\varphi}_0 = \frac{1}{3H}\left(\alpha\frac{3}{8\pi^2}\frac{H^4}{\sqrt{2}}N - \frac{\mu^{4-p}}{(p-1)!}\varphi^{p-1}\right)$$

Scenario II

- We can then compute the power spectra from the inflaton perturbations:

$$P_\zeta \simeq \frac{H^2}{\dot{\varphi}_0^2} \frac{\alpha^2 m_1^4 e^{-2\alpha\varphi_0} \left(\frac{N}{10}\right)^5}{2\pi^2}$$

$$P_T \simeq \frac{2\,H^2}{\pi^2\,M_P^2}\left[1 + 3.55\frac{H^2 N}{M_p^2 \pi^3}\right]$$

$$H < \Lambda_{QG}$$

$$N < \frac{Mp^2}{H^2}$$

$$V(\varphi) = \frac{\mu^{4-p}}{p!}\varphi^p$$

$$n_s - 1 = \left(-\frac{4}{p} - \left[0.018\frac{p+1}{p^2}\alpha\varphi_N + 0.012\left(\frac{\alpha\varphi_N}{p}\right)^2\right]\frac{H^2}{\Lambda_{QG}^2} + \frac{2}{3p}\alpha\varphi_N\right)\varepsilon$$

Scenario II

- We have 4 parameters:

$$N_e \qquad m_1 \qquad \mu \qquad \alpha$$

- The number of e-folds has to be around 50 $\quad N_e = 60$

- The value of m_1 can be fixed in term of the other parameters

Scenario II

- We have 4 parameters:

$$N_e \qquad m_1 \qquad \mu \qquad \alpha$$

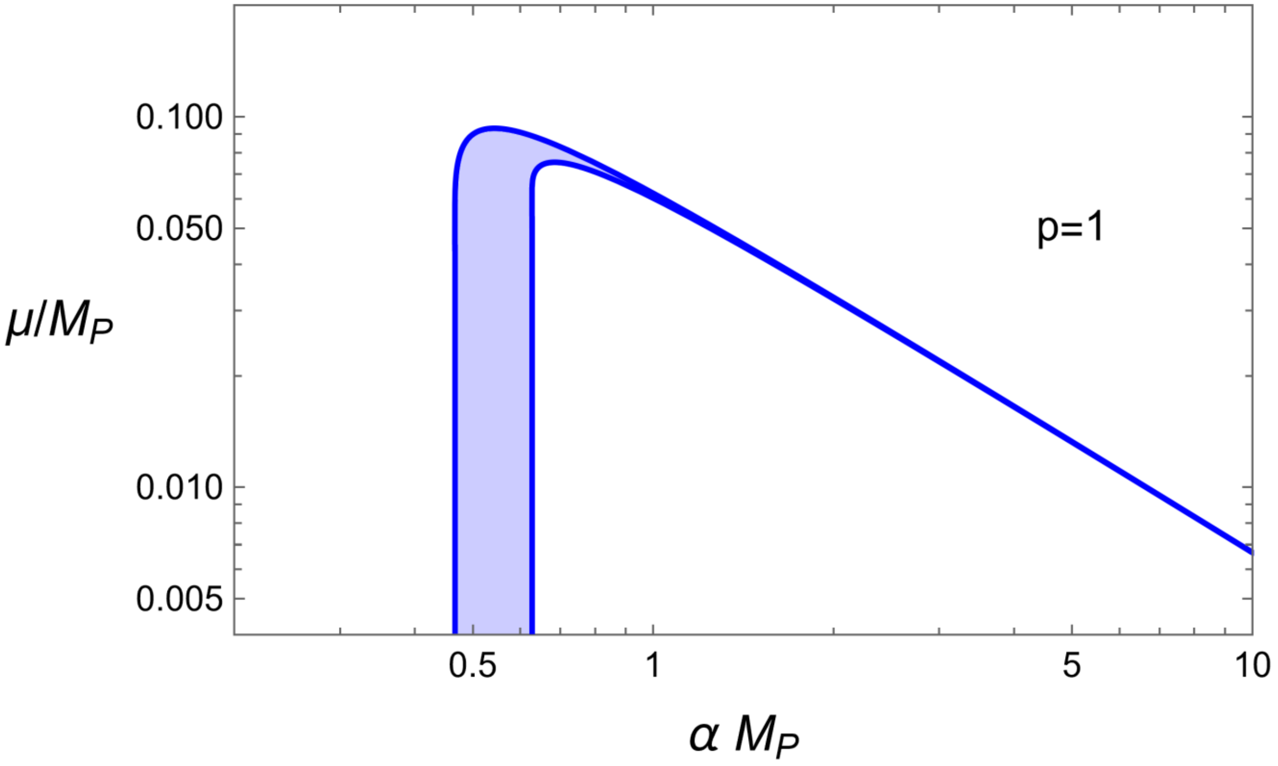
- The number of e-folds has to be around 50 $\quad N_e = 60$

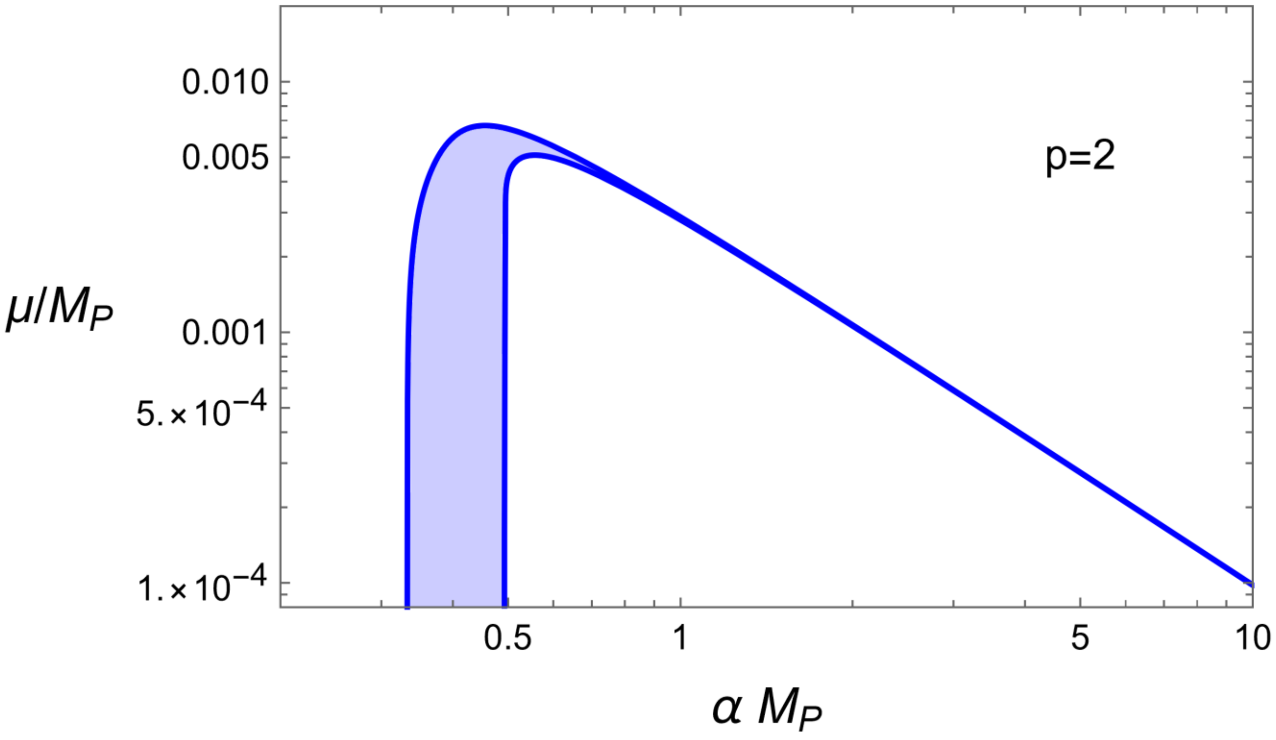
- The value of m_1 can be fixed in term of the other parameters

Scenario II

- Given the measured value $n_s - 1 = -0.035 \pm 0.004$:

$$V(\varphi) = \frac{\mu^{4-p}}{p!}\varphi^p$$





- When $\alpha \sim \mathcal{O}(M_P^{-1})$ we can have arbitrarily small potential.

Conclusions and Outlook

- During Inflation the inflaton can have **field excursion** $\sim \mathcal{O}(10 M_P)$.
- This motivates the appearance of an **infinite tower of states.**
- We have computed the effect of such tower with two different exponential couplings
- The effects of particle production during inflation can strongly modify the predictions

What's next…

- Compute the non-Gaussianities for both models from the second order inflaton perturbations
- Study this models in the regime in which the inflation and QG scales are close
- Explore the possibility of generating primordial blackholes