Oscillons from Higgs Inflation

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Based on *arXiv:2304.13056* with Javier Rubio

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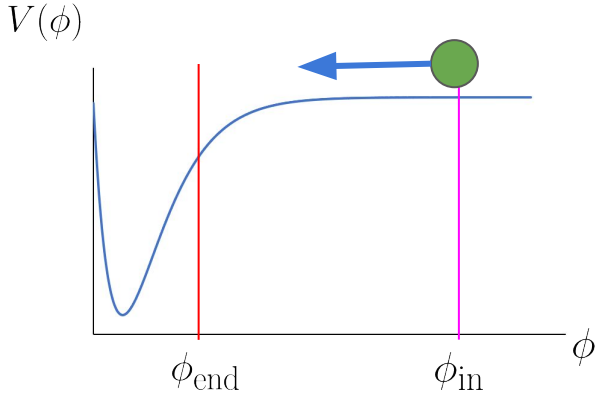
Inflation, and then what?

A scalar field to solve problems of standard cosmology and seed the perturbations leading to structure formation



- Accelerated expansion
- Generation of primordial density perturbations

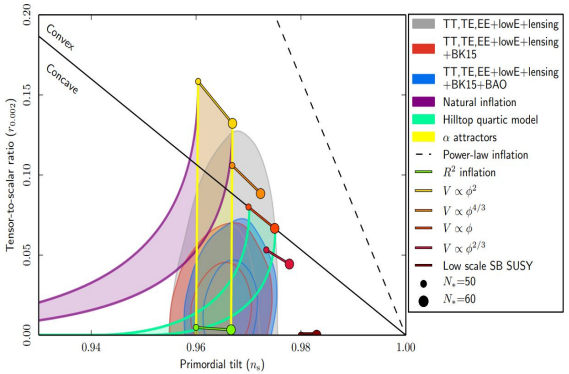
Inflation alone would leave the Universe COLD and EMPTY

Post-Inflationary to-do list:

1. Fill the Universe with SM particles(Preheating)
2. Reach thermal equilibrium (Reheating)

Connecting what we know

Inflation



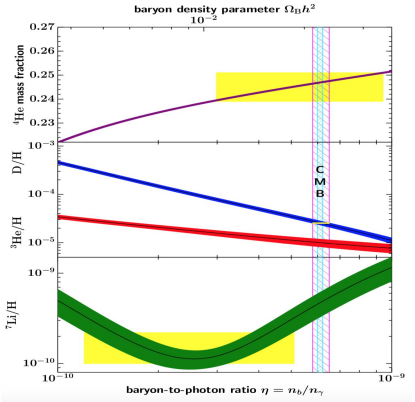
Planck collaboration, Astron.Astrophys. 641 (2020)

(P)Reheating

Knowledge required
Inflaton couplings with SM

Phenomenological signatures
Gravitational waves signal
Modified cosmic evolution

Big Bang Nucleosynthesis



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Choose your inflaton: The SM Higgs

Encyclopædia Inflationaris

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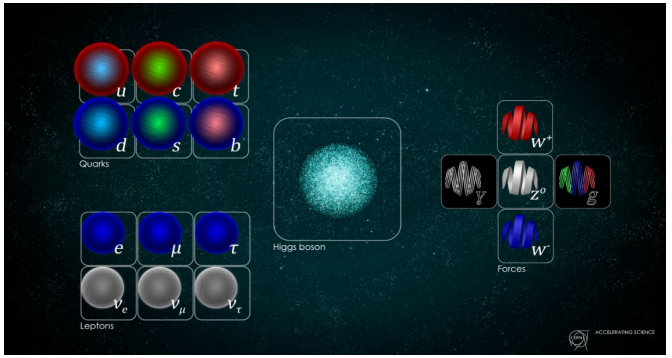
Let's use the only scalar we know

$$U(h) = \frac{\lambda}{4}(h^2 - v^2)^2$$



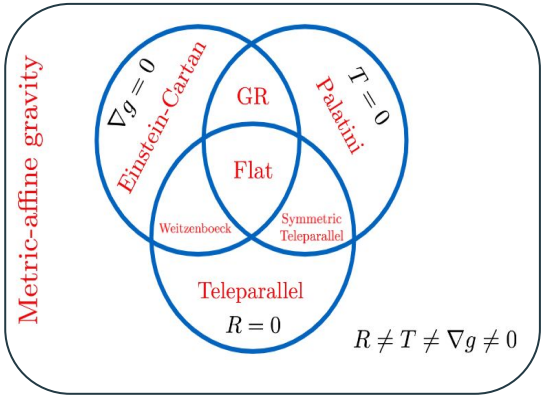
Gravity enters the game

Non-minimal coupling

$$\frac{\xi h^2}{2} R$$

- Allowed by symmetries
- Necessary for consistency

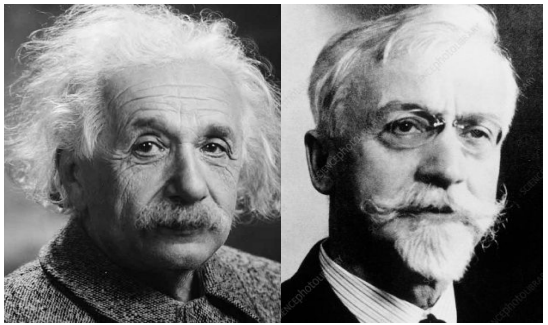
Choose your gravity: Einstein-Cartan



$$g_{\alpha\beta} = e^A_\alpha e^B_\beta \eta_{AB} \ , \quad \eta_{AB} = e^\alpha_A e^\beta_B g_{\alpha\beta}$$

$$\Gamma^\kappa_{\nu\mu} = e^\kappa_A \left(\partial_\mu e^A_\nu + \omega^A_{\mu B} e^B_\nu \right)$$

You know him — Élie Cartan



- Tetrads and spin-connection are the fundamental variables
- Obtained by gauging the Poincaré group
- Non-vanishing torsion
- Fermions are naturally introduced in the theory

The connection is not assumed to be symmetric *a priori* → $T^\mu{}_{\nu\rho} = \Gamma^\mu{}_{\nu\rho} - \Gamma^\mu{}_{\rho\nu}$

Avoiding the Einstein-Cartan Multiverse

Many extra operators are allowed, we focus on a representative one

Nieh-Yan Topological Invariant

$$-\frac{1}{4}\int \mathrm{d}^4x\, \xi_\eta h^2 \partial_\mu \left(\sqrt{-g}\epsilon^{\mu\nu\rho\sigma}T_{\nu\rho\sigma}\right)$$

Einstein-Frame: original recipe

1. **Remove the coupling to curvature with a Weyl rescaling of the metric**
2. **Solve the equation of motion for the non-dynamical anti-symmetric part of the connection**
3. **Plug back the solution into the action**
4. **Make the field canonical**

$$S = \int d^4x\sqrt{-g}\left[\frac{R}{2} - \frac{1}{2}(\partial\chi)^2 - V(\chi)\right]$$

Fixed by CMB

$$c = \xi + 6\xi_\eta^2$$

$$c = \frac{2}{5}\lambda N^2 \cdot 10^7$$

$$V \simeq \frac{\lambda}{4\xi^2}\left[1 - \exp\left(-\frac{2\xi|\chi|}{\sqrt{c}}\right)\right]^2$$

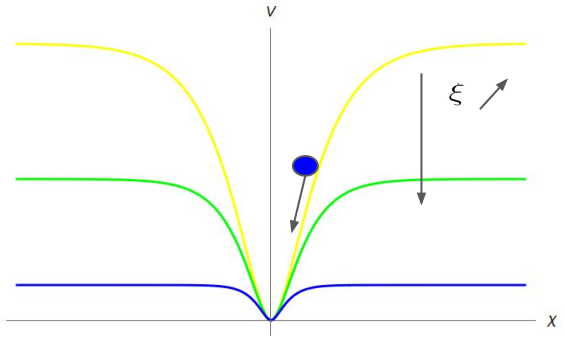
The model only has 1 free parameter

Preheating

At first order in perturbation theory we get

$$\ddot{\delta\chi}_{\mathbf{k}} + 3H\dot{\delta\chi}_{\mathbf{k}} + \left(\frac{\mathbf{k}^2}{a^2(t)} + \frac{\mathrm{d}^2 V(\chi)}{\mathrm{d}\chi^2}\bigg|_{\chi=\overline{\chi}(t)} \right) \delta\chi_{\mathbf{k}} = 0$$

Possible tachyonic instability



Rapid growth of perturbations at low momenta → **Backreaction** → **Fragmentation**

Formation of non-linear structures of fixed physical size called **oscillons**.

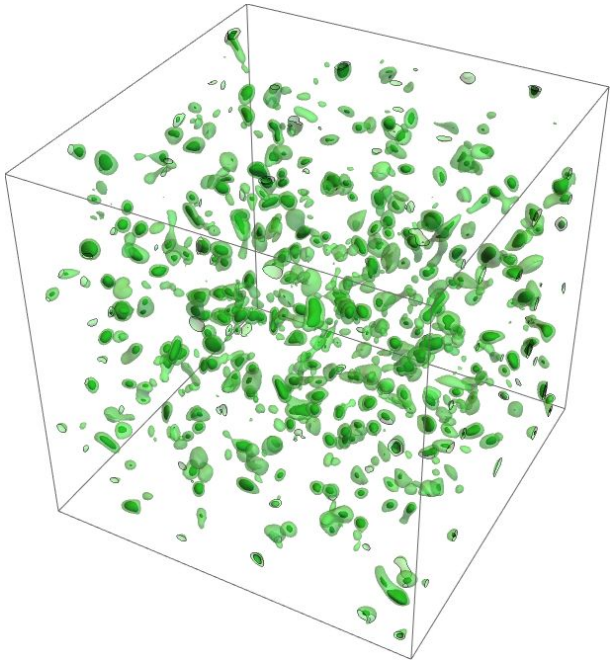
Oscillons

- Pseudo-solitonic objects
- Quasi-spherical shape
- Similar to boson stars (and Q-balls)

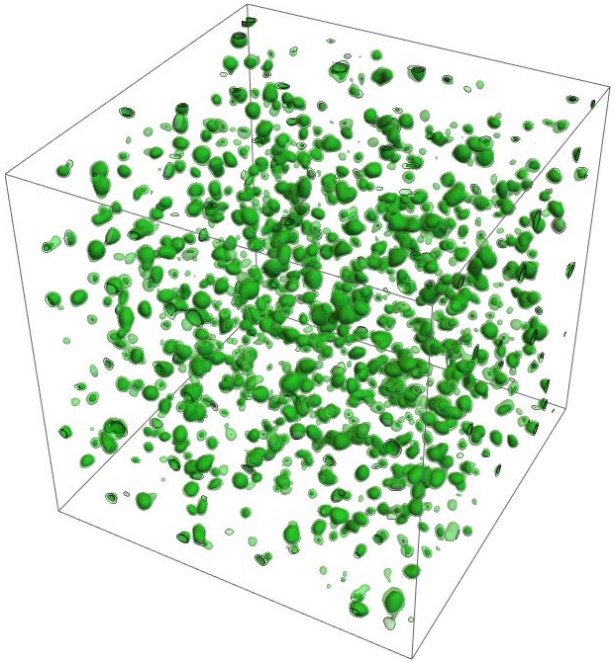
Related phenomena

- Production of sizeable amount of gravitational waves
- Non-standard expansion history
- Change of the inflationary observables

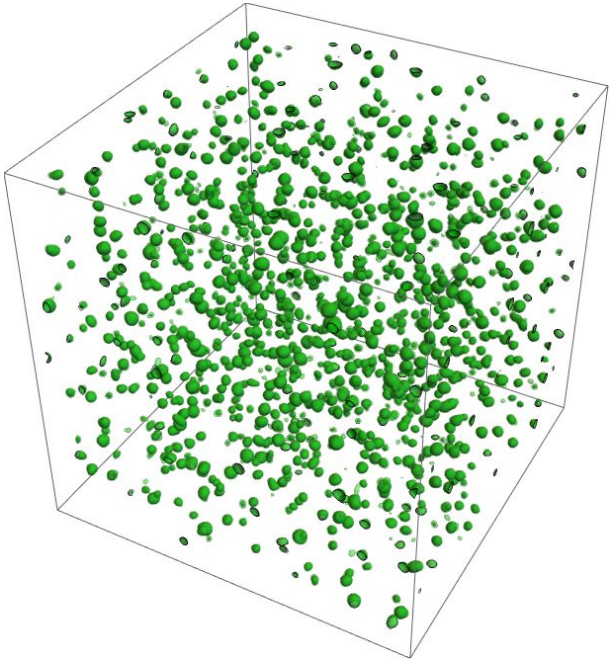
Results from the lattice



$\Delta N = 1$



$\Delta N = 1.5$



$\Delta N = 2.0$

Gravitational waves production

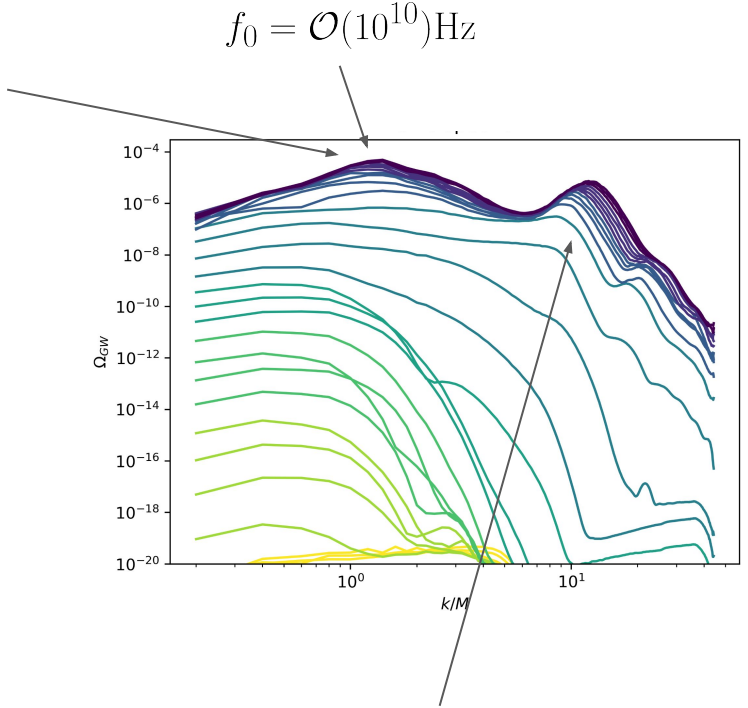
The fragmentation of the condensate can lead to the generation of a stochastic gravitational wave background

$$\ddot{h}_{ij} + 3H\dot{h}_{ij} - a^{-2}\nabla^2 h_{ij} = 2a^{-2}\Pi_{ij}^{\mathrm{TT}}$$

$$\Pi_{ij}^{\mathrm{TT}} = (\partial_i\chi\partial_j\chi)^{\mathrm{TT}}$$

Strong signal 😄

High frequency 😢



Oscillons themselves can source a secondary peak at larger frequencies

Conclusions

- For the first time we have observed the presence of oscillons in the context of Higgs-Inflation
- Oscillons can appear for a wide range of parameters
- Their presence can source a sizeable amount of GWs, providing an extra observational channel besides inflation
- Fermions and gauge bosons are not expected to spoil oscillons formation, but can play a role once they have formed

Thank you!