Gravitational wave spectra from oscillon preheating

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IFAE, Barcelona

UHF-GW online workshop

based on work with: T. Hiramatsu & M. Yamaguchi,
JHEP **03** (2021), 021 [arXiv:2011.12201 [hep-ph]]

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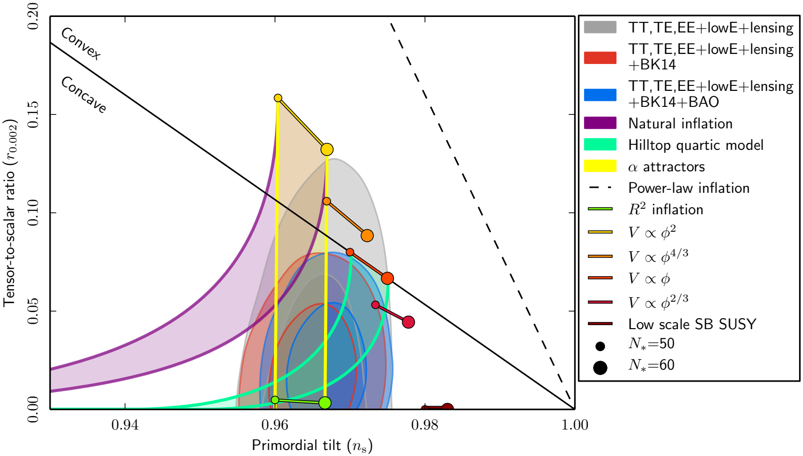
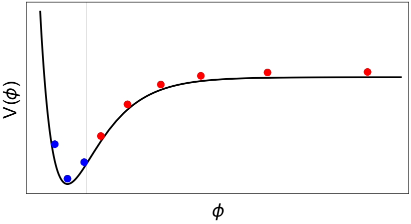
Hints from the sky



Plateau (flat) **potentials** are favored by data.

Inflation must end

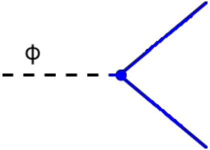
- The inflaton rolls on a flat potential.
- The inflaton oscillates.



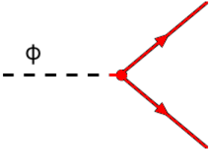
During **reheating** the inflaton transfers its energy to radiative degrees of freedom, setting the stage for BBN.

$\Downarrow$

Parametric resonance (preheating) leads to **exponential amplification**.



The inflaton must couple to bosons or fermions.



Parametric resonance: preheating

Bose enhancement changes the game. Take $\mathcal{L} \subset -\frac{1}{2} g \phi^2 \chi^2$

$$\ddot{\chi}_k + 3H\dot{\chi}_k + \left(\frac{k^2}{a^2} + 2g\phi^2\right)\chi_k = 0$$

Neglect the expansion $(H = 0)$ and take $\phi(t) = \Phi_0 sin(mt)$

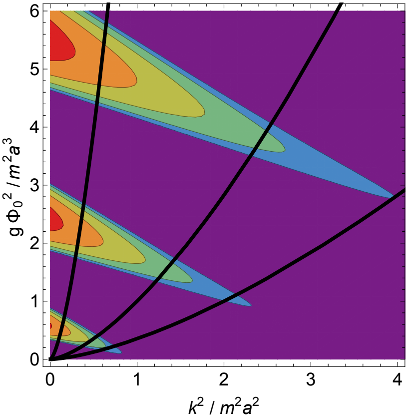
$$\boxed{\ddot{\chi}_k + \left[k^2 + g\Phi_0^2 \sin^2(mt)\right]\chi_k = 0}$$

An equation of the form $\dot{x} = A(t)x$, where $A(t)$ is **periodic**, $A(t+T) = A(t)$, has solutions of the form

$$x(t) = c_1 P(t) e^{\mu t} + c_2 P(t) e^{-\mu t}$$

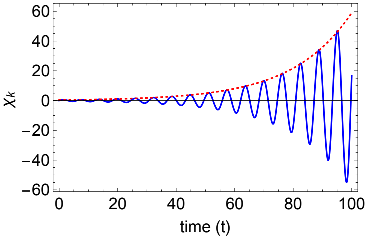
where μ is called the **Floquet exponent**.

Floquet charts

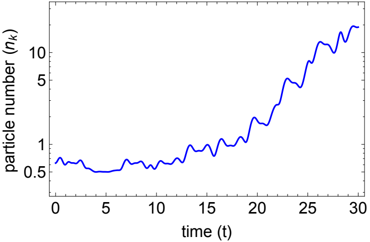


We can read off the regions where the Floquet chart leads to amplification $\chi_k(t) \sim e^{\mu_k t}$.

Exponential growth in static



and expanding universe



non-linear potential $\Rightarrow$ **self-resonance** Take $\mathcal{L} \subset -\frac{1}{4} g \phi^4$

$$\ddot{\phi}_k + 3H\dot{\phi}_k + \left(\frac{k^2}{a^2} + 3g\phi^2 \right) \phi_k = 0$$

Certain wavenumbers of the inflaton field get amplified

$\Downarrow$

fluctuations stop following the linearized equation

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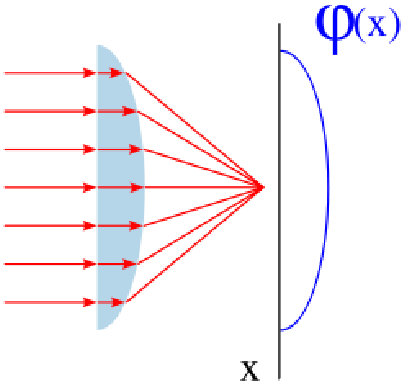
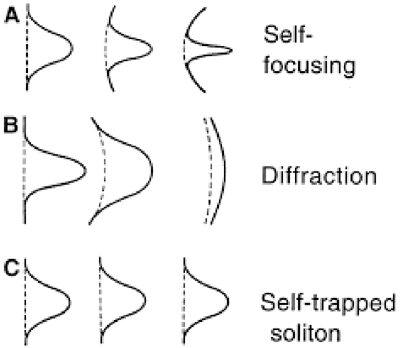
fluctuations probe the non-linear part of the potential.

Amplification, non-linearities & oscillons / solitons



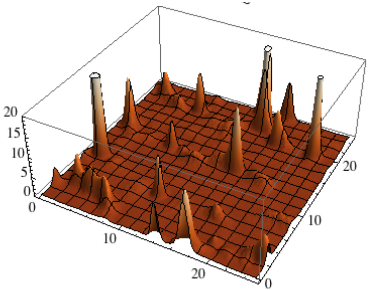


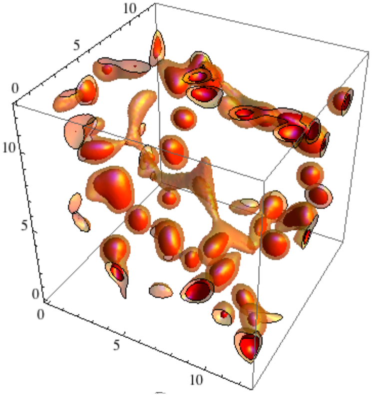
Stegeman & Segev '99

- optics: refractive index $n(I) = n_0 + n_2 I \Rightarrow$ self-focusing
- field theory: self-focusing for $V'(\phi) < m^2\phi$

Oscillon Emergence

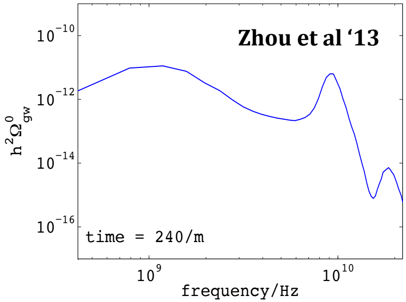
Oscillons have been numerically shown to emerge after inflation.



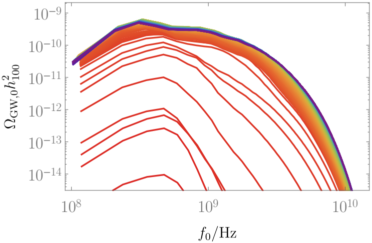


Amin, Easther, Finkel, Flauger, Hertzberg '11

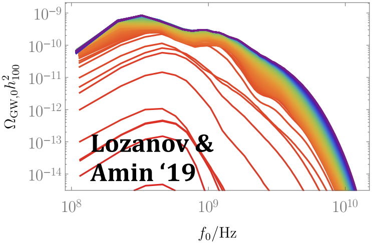
Inflaton fragmentation
in symmetric potentials
with or without oscillons
leads to GW's
$\Downarrow$
¿ shape dependence ?



Oscillons



Transients

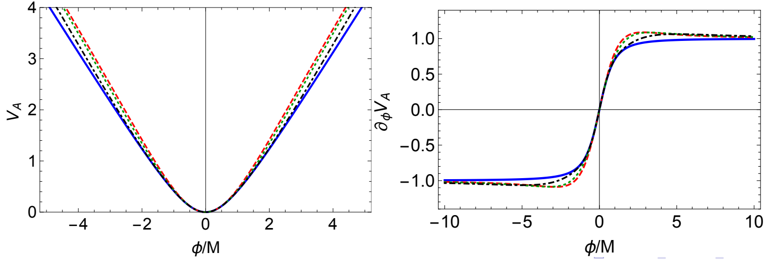


We approximate the axion monodromy potential

$$V_A = m^2 M^2 \left[\sqrt{1 + \phi^2/M^2} - 1\right]$$

using the Padé approximation

$$V_A^{(n)} = m^2 M^2 \frac{x^2}{\sqrt{1+x^2}} \frac{\text{“polynomial”}}{\text{“polynomial”}}$$



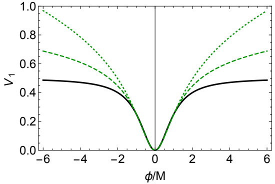
Plateau potential

We deform the plateau potential

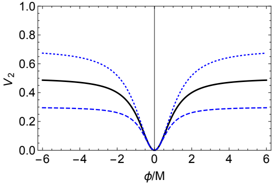
$$V = \frac{m^2 M^2}{2} \frac{(\phi/M)^2}{1+(\phi/M)^2}$$

in slope, height or transition region.

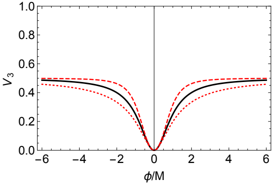
$$\frac{(\phi/M)^2}{1+|\phi/M|^{\alpha_1}}$$



$$\frac{(\phi/M)^2}{1+\alpha_2(\phi/M)^2}$$

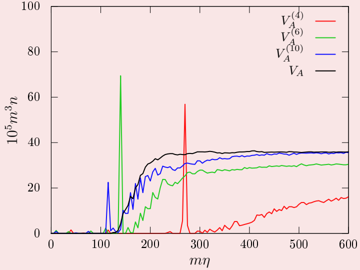


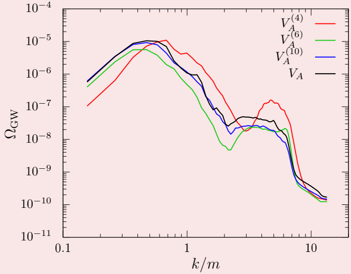
$$\frac{(\phi/M)^2}{\left[1+|\phi/M|^2\right]^{2/\alpha_3}}$$



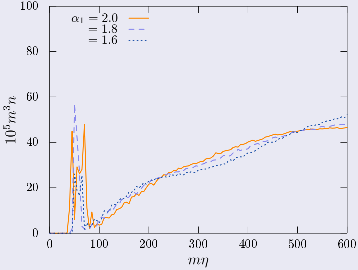
Differences between models / classes

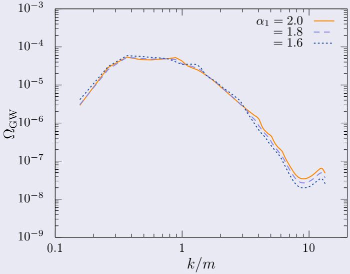
Axion monodromy



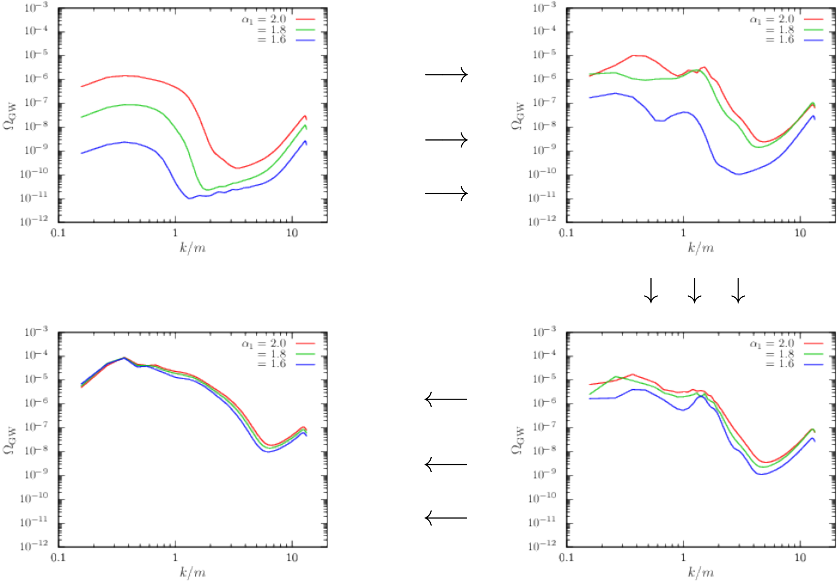


Plateau potential

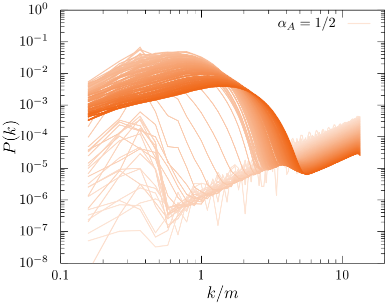


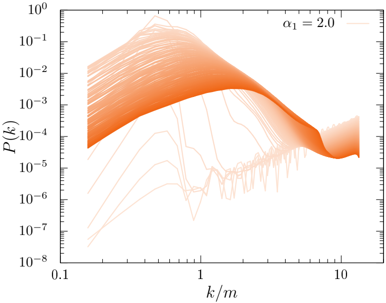


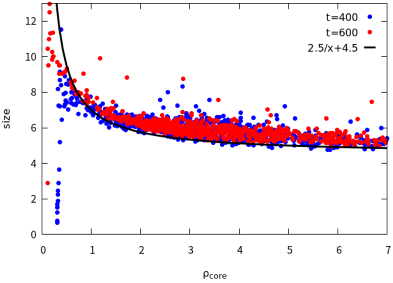
evolution of GW spectra

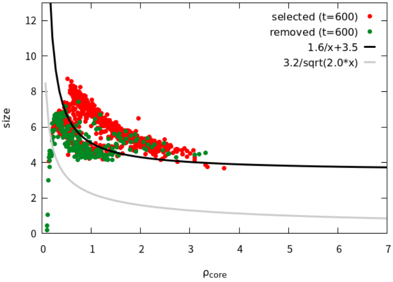


Scalar power spectrum

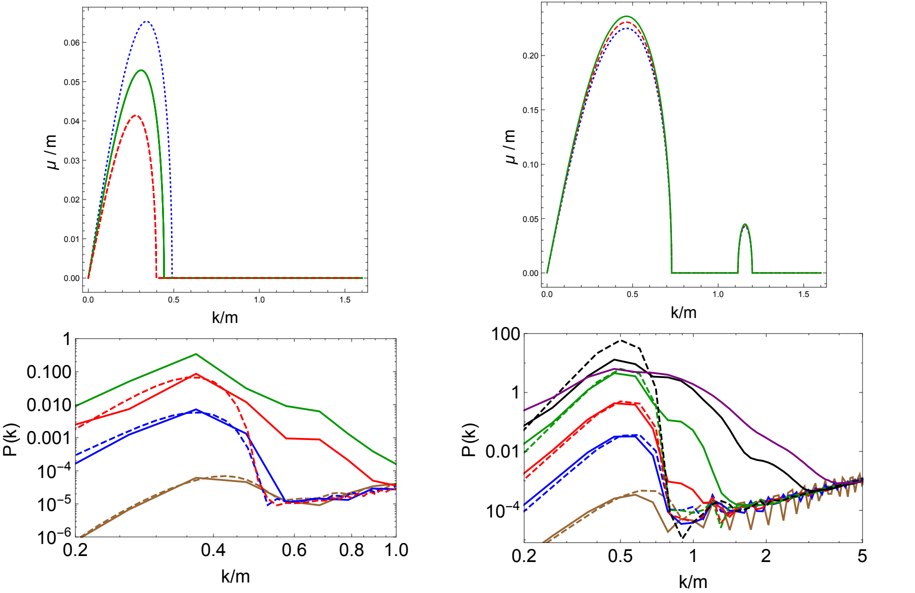






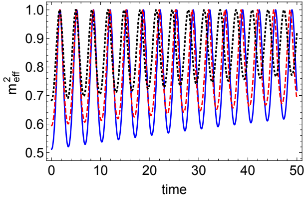


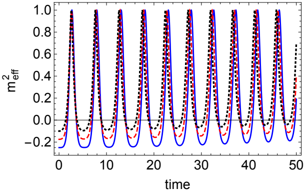
Floquet charts



Results

Potentials exhibiting **efficient self-resonance** tend to give a **featureless GW spectrum** and an earlier oscillon formation time.





Potentials that exhibit a **weaker self-resonance** tend to give a **GW spectrum with peaks and dips** at specific wavenumbers, encoding the **oscillon internal frequencies**.