Cosmological imprints of string axions in plateau

Yuko Urakawa (Nagoya university, IAR)

J.Soda & Y.U.(1710.00305)

N. Kitajima, J.Soda,& Y.U.(in progress)

Collaboration in C01

Triggered at annual meeting of 2017

Axions (or ALPs) from string theory

Superstring theory in compact 6D

↓

4D low energy EFT + Axions + Moduli ….

Wide mass ranges → Probe of exDim

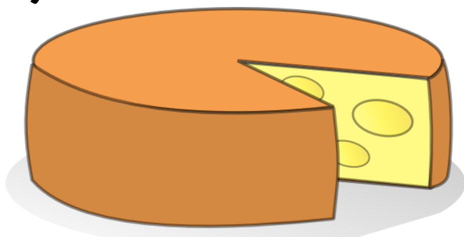
↓

DM candidate (Fuzzy DM)

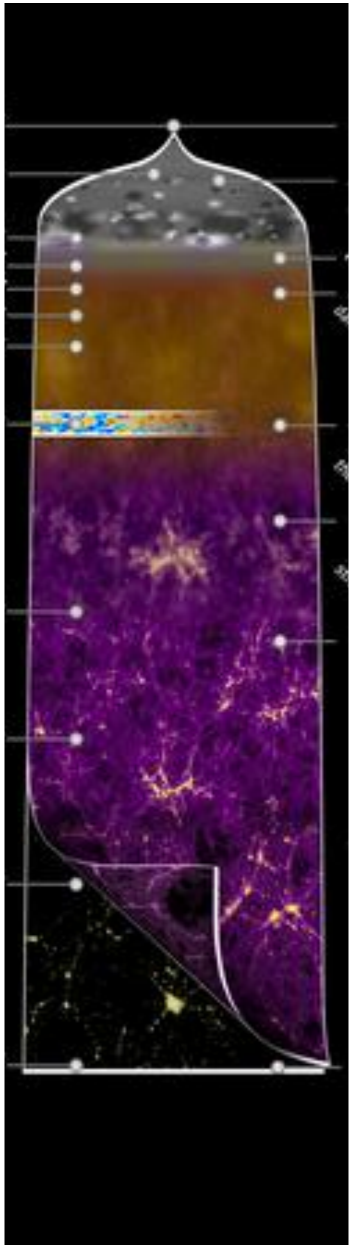
Wu et al.(00), ⋯

ex. Large Volume Scenario *Conlon et al. (05)*

Predicts light mass axions

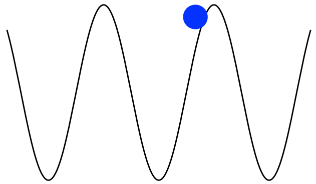


Dreamy bottom-line story

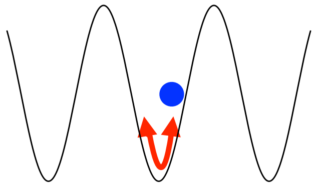


Onset of oscillation

Equal time



$H >> m$



$H << m$

~ DM

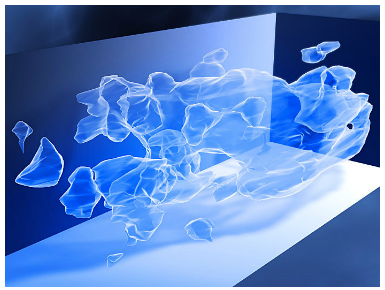


image credit NASA, ESA, R. Massay

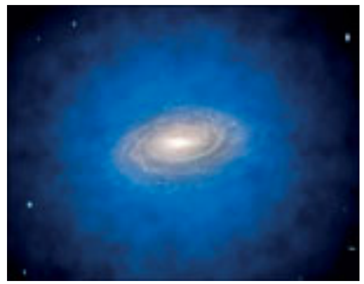
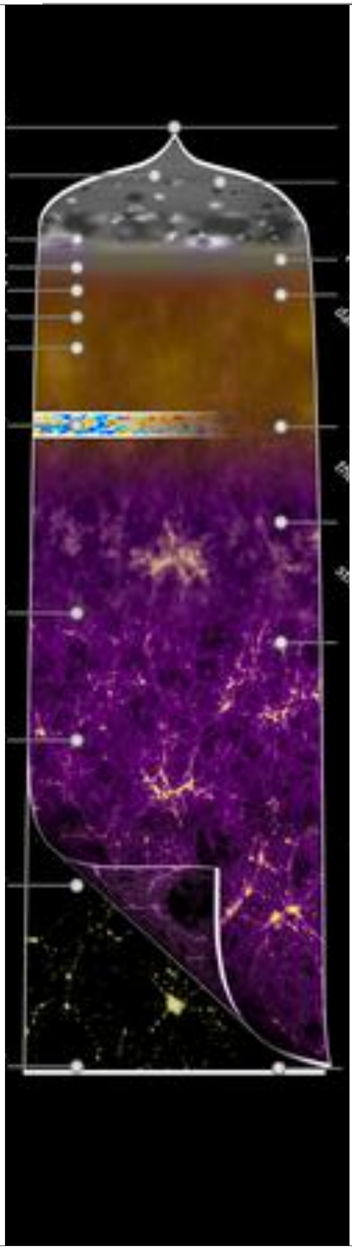


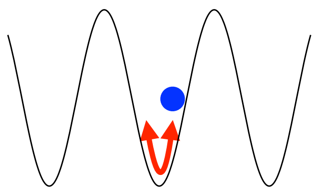
image credit ESO

Dreamy bottom-line story



← Onset of oscillation

← Equal time



~ DM

$\phi(t)$ ⟶ $\delta\phi(t, x)$

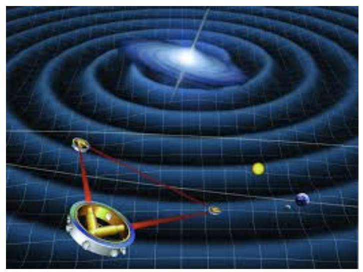
inst.

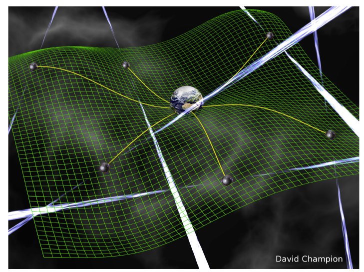
turbulence

(b)GW

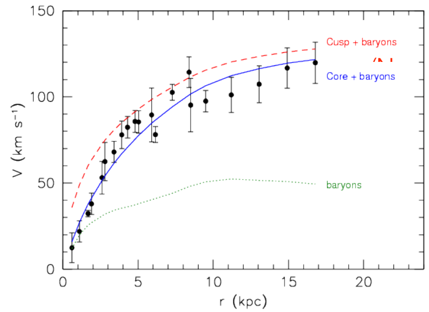
axion

~~bio~~-marker





if $\Omega_c \sim \Omega_{axion}$



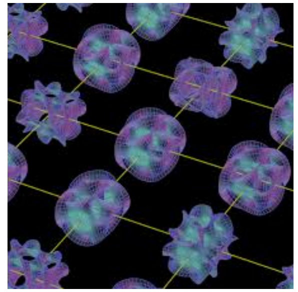
implications to small scales issues?

Why it’s fun?

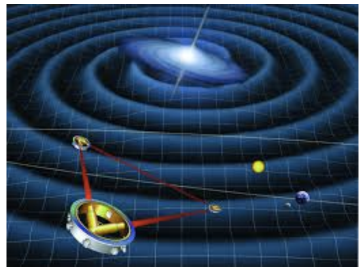
Three perspectives

i) Probe of string axiverse: New window

w/some luck



ii) GW emission, new observational tool.



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iii) Based on basic physics

Kolmogorov turbulence

©V.Gogh

Scalar potential of axion

continuous shift sym.

$\phi \to \phi + c$

NP effects
e.g. instanton effects

$\phi \to \phi + 2\pi n/f$

$n \in \boldsymbol{Z}$

$V(\phi) \sim \Lambda^4 \cos\phi/f$

Potential can be more flatten than $\cos\phi/f$

i) Superposition of multiple cosine terms

e.g., alignment mechanism — *Kim, Nilles, & Peloso (04)*

ii) Non-minimal coupling w/gravity

→ α attractor model — *Kallosh & Linde + (13, 14, ···)*

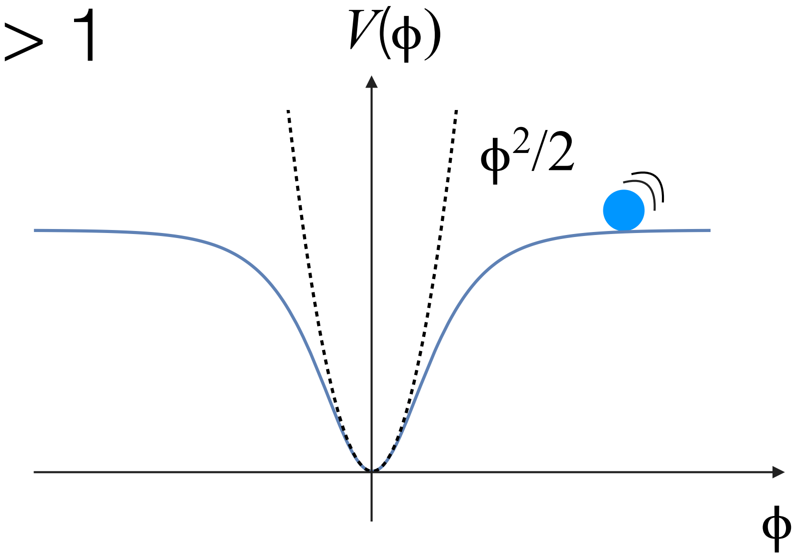
iii) ~~Dilute instanton gas approximation~~

Dubovski et al. (10), Nomura, Watari&Yamazaki(17)

Outline of the story

Soda & Y.U.(17)
Kitajima, Soda & Y.U.(in prep.)

1. Axion slowly rolls down $H_{osc}/m >> 1$



Outline of the story

Soda & Y.U.(17)
Kitajima, Soda & Y.U.(in prep.)

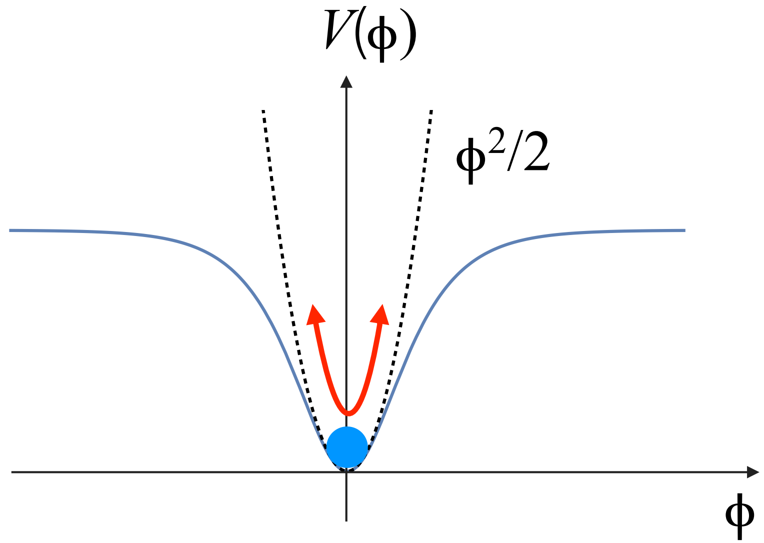
1. Axion slowly rolls in plateau

2. Onset of oscillation $H_{osc}/m < 1$

   Especially w/plateau

   (or $\cos\phi/f$ w/fine tuned IC)

   $H_{osc}/m << 1$



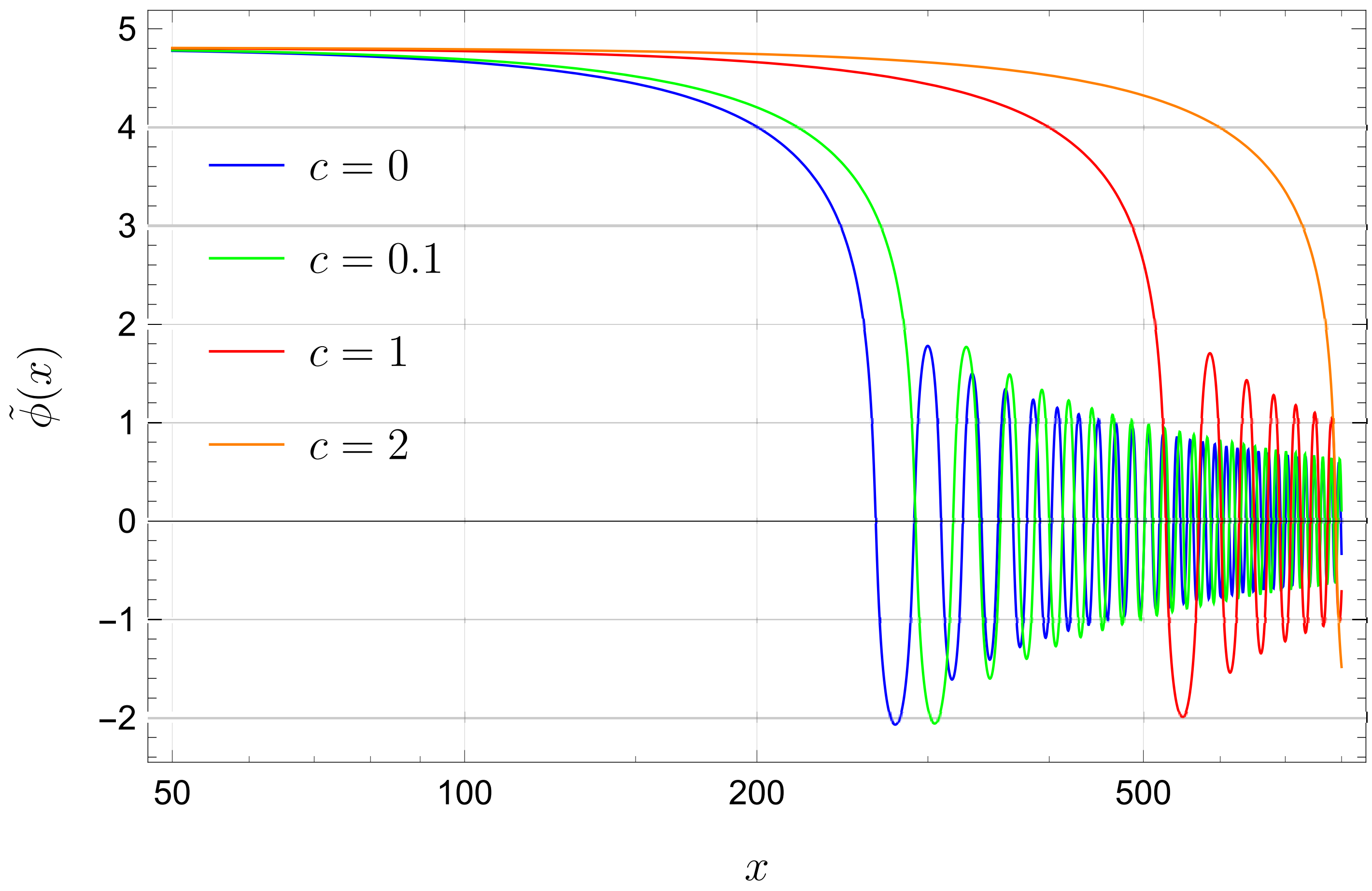
α-attractor

$$V(\phi) = \frac{(m_a f)^2}{2} \frac{(\tanh \frac{\phi}{f})^2}{1 + c(\tanh \frac{\phi}{f})^2}$$

Background evolution

RD

Soda & Y.U.(17)



$x = m/H$

Onset of oscillation is not $m \sim H$, but delayed!

Outline of the story

Soda & Y.U.(17)
Kitajima, Soda & Y.U.(in prep.)

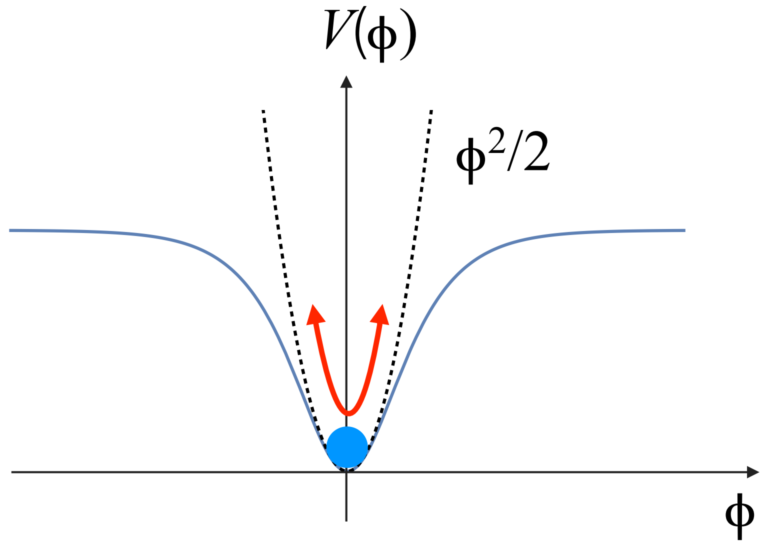
1. Axion slowly rolls in plateau

2. Onset of oscillation $H_{osc}/m < 1$

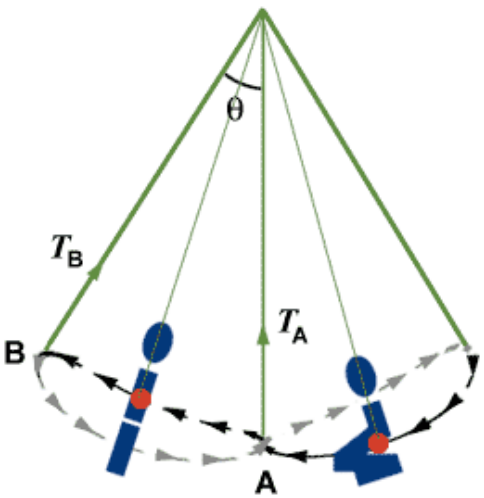
3. Exponential growth due to PR

if $H_{osc}/m << 1$

No disturbance due to cosmic exp.



Parametric resonance



Repeat: Up & Down in a half of osc. period

→ Periodic ext. force

→ Enhancing the amplitude

"Parametric resonance instability"

<u>Mathieu equation</u>

$$\frac{d^2}{dx^2}\tilde{\varphi} + (A - 2q\cos 2x)\tilde{\varphi} = 0$$

resonance band $A \sim n^2$

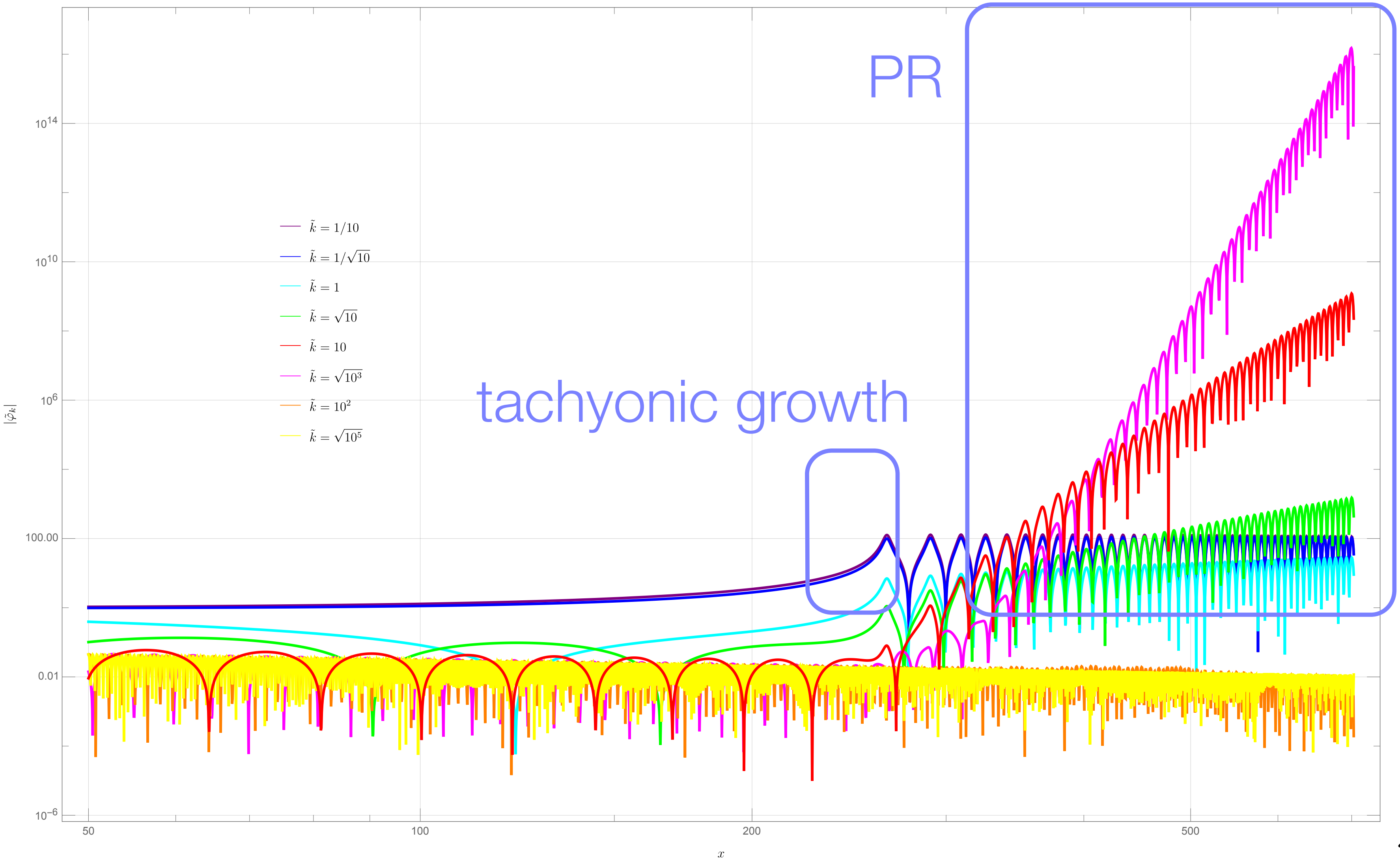
ex. First band $\tilde{\varphi} \propto e^{\gamma x}$ $\gamma \simeq q/2$

Energy transfer $\phi(t) \longrightarrow \delta\phi(t, x)$

Linear perturbation

Soda & Y.U.(17)

PR in $k_r/(a_{osc}\, m) \sim O(1)$, $k_r/(a_{osc}\, H) >> 1$

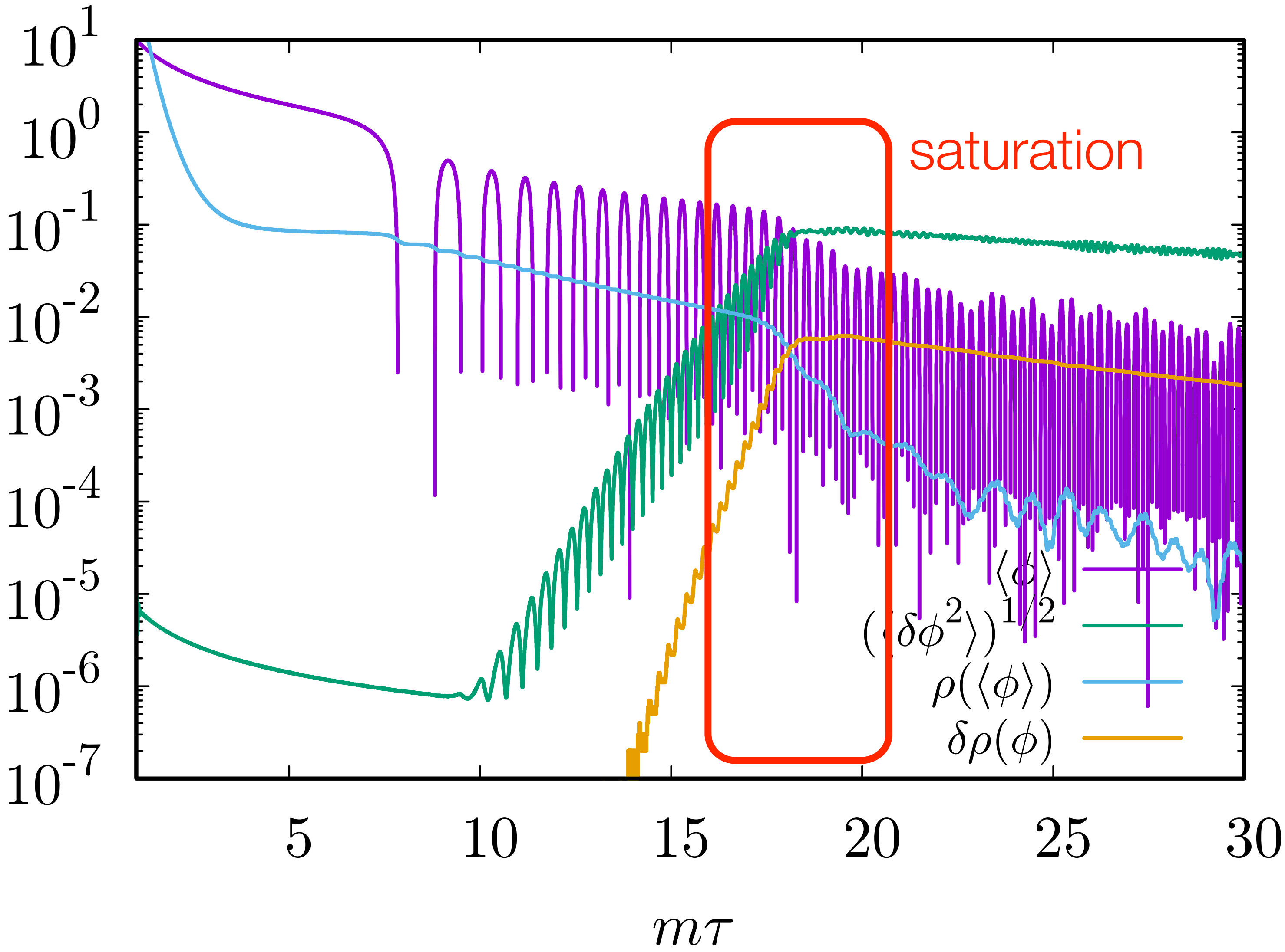


$\tilde{k} = k/(a_i m)$

Energy transfer

Kitajima, Soda & Y.U.(in prep.)

Lattice simulation $N_{grid}=(128)^3$



Outline of the story

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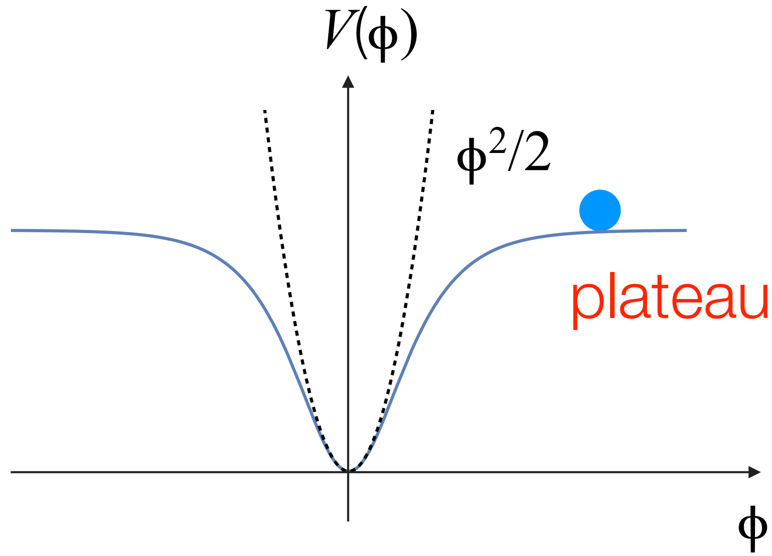


2. Onset of oscillation $\quad H_{osc}/m < 1$

3. Exponential growth due to PR

if $H_{osc}/m < 1$

Energy transfer $\phi(t) \longrightarrow \delta\phi(t, x)$

4. Rescattering → PR becomes inefficient *eg. Kofman, Linde, Starobinsky*

$$\frac{\delta\phi}{\phi},\ \frac{\delta\rho}{\rho} \sim O(1)$$

Outline of the story

1. Axion slowly rolls in plateau

2. Onset of oscillation $H_{osc}/m < 1$

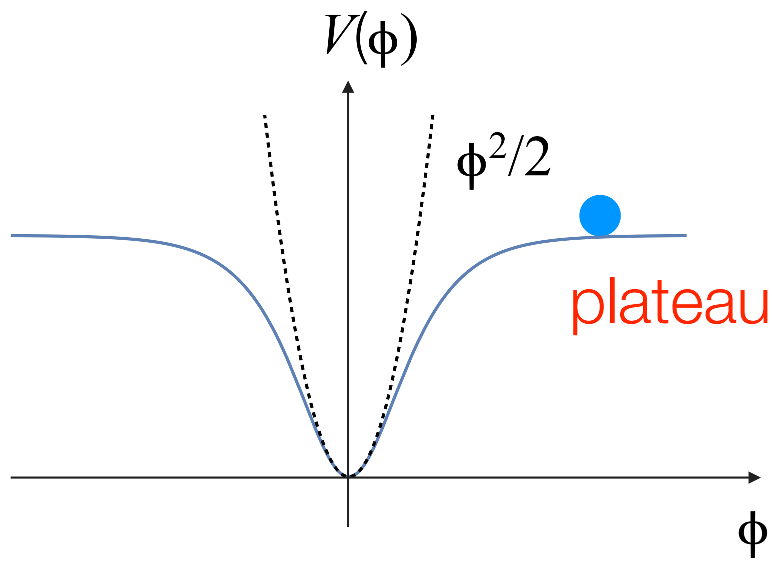
3. Exponential growth due to PR

if $H_{osc}/m < 1$ No disturbance due to cosmic exp.

4. Rescattering → PR becomes inefficient *eg. Kofman, Linde, Starobinsky*

5. Kolmogorov turbulence → GW emission

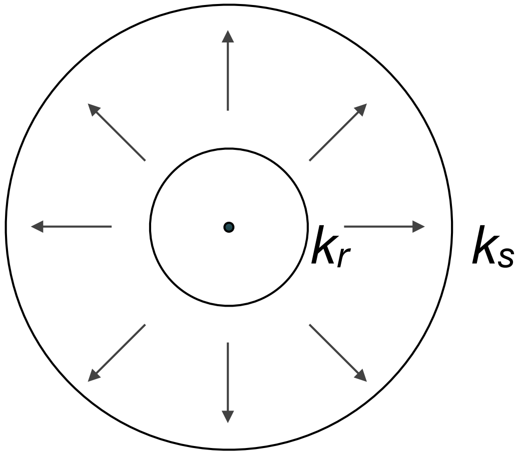
Micha & Tkachev (02,04)



Kolmogorov turbulence

stationary turbulence: source k_r (IR) → sink k_r (UV)

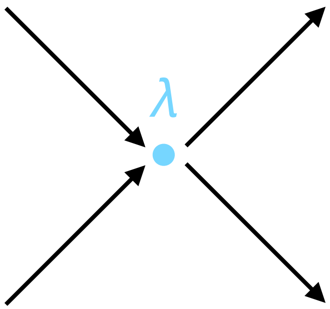
<u>in k-space</u>



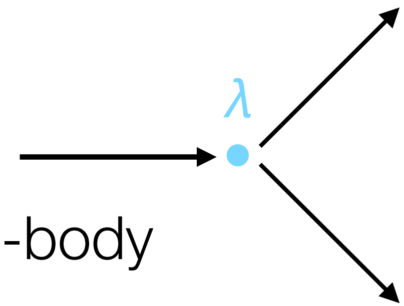
kinetic theory $\quad dn_k/dt = \underline{I_k[n]}$

Collision integral

take $\lambda\phi^4$ theory, now w/ $\phi(t)$



4-body



3-body

assump: const. flux in k for massless ϕ

Micha & Tkachev (02,04)

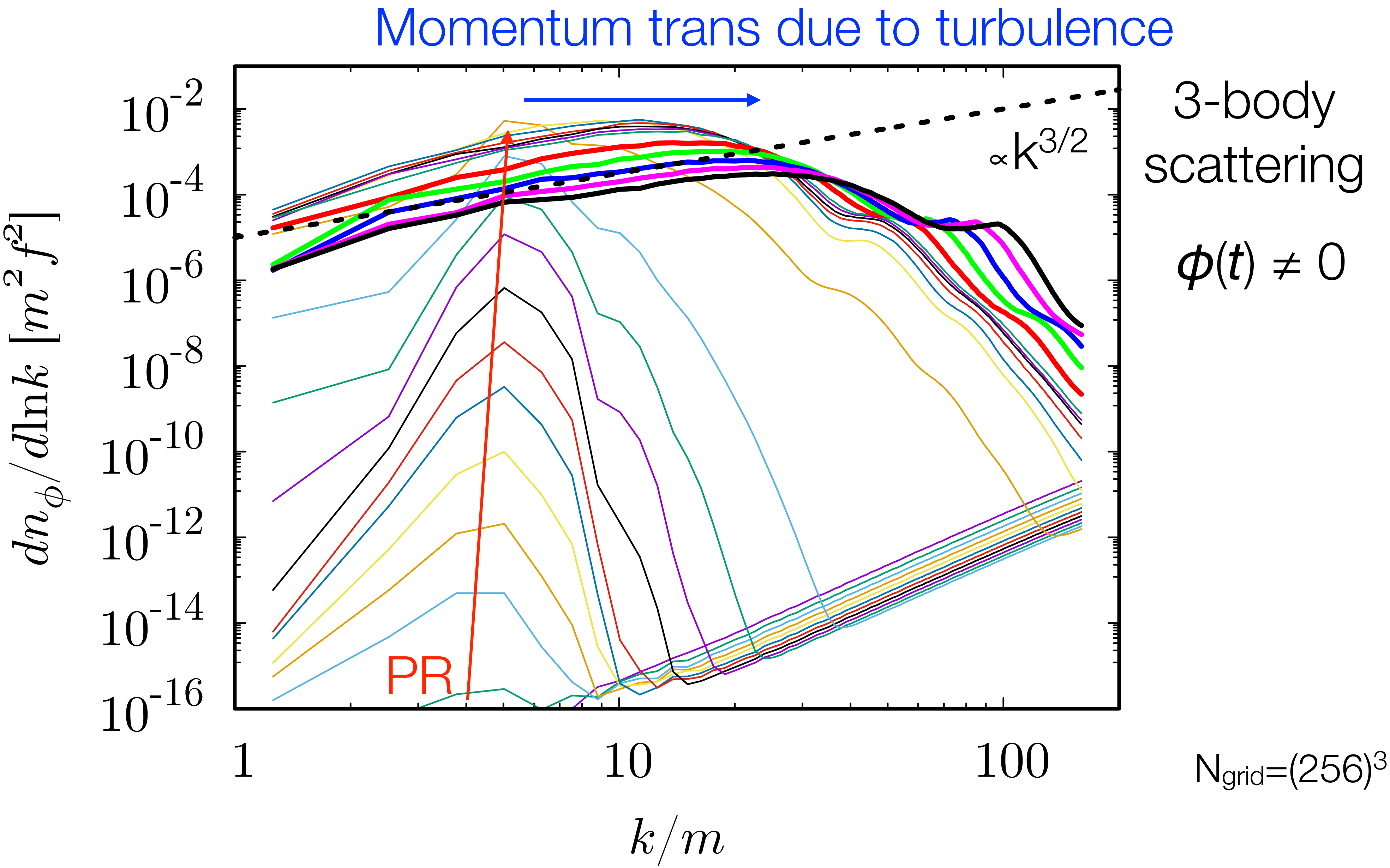
$$dn/d\ln k = k^3 n(k) \propto k^{3-s}$$

$s=5/3$ for 4-body

$s=3/2$ for 3-body

Lattice simulation

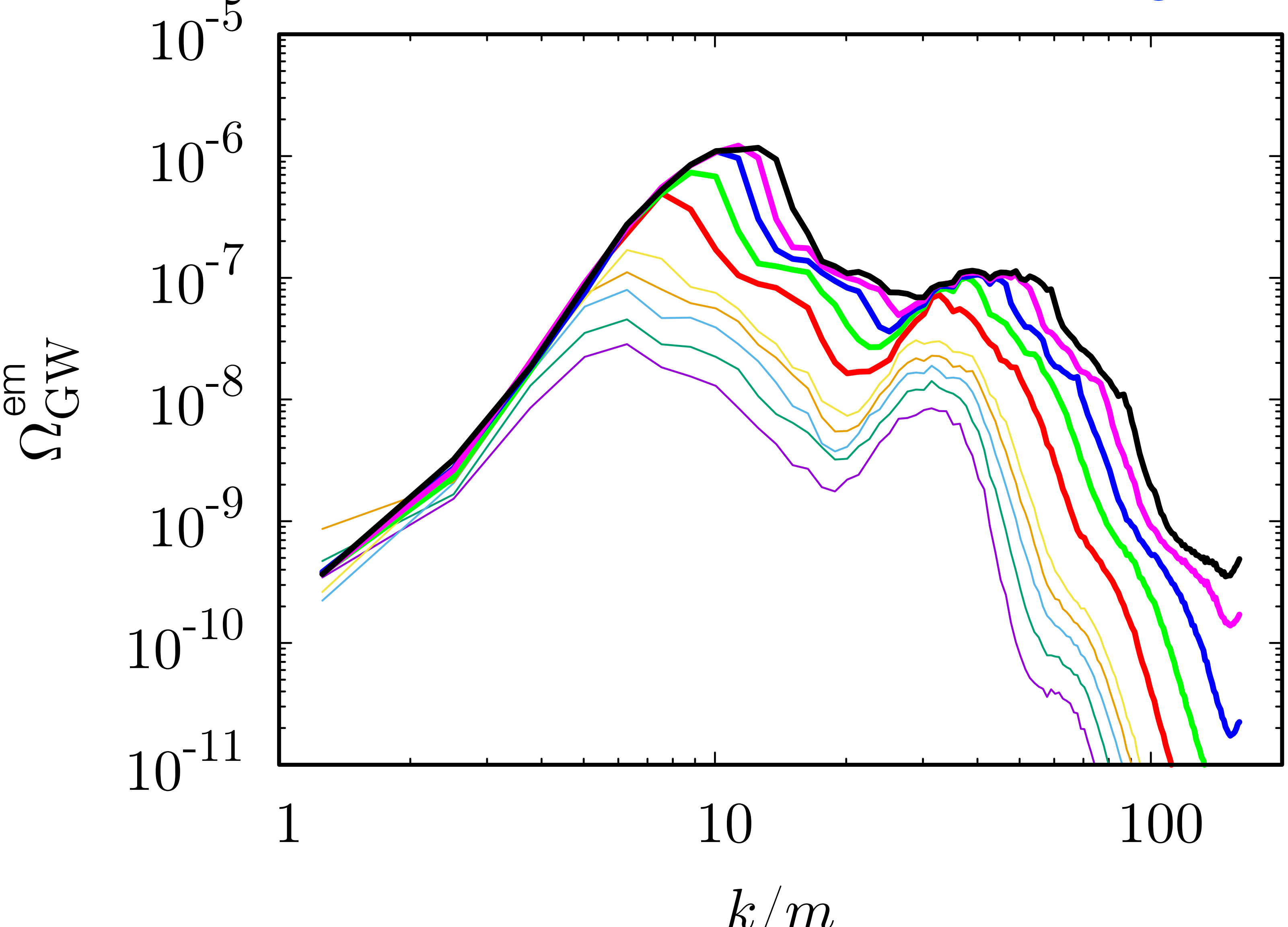
Kitajima, Soda, Y.U. (in preparation)



GW spectrum

Kitajima, Soda, Y.U. (in preparation)

momentum transfer converges earlier for GW



$f \sim 0.01 M_{pl}$

$\times \Omega r$

at present

Outline of the story

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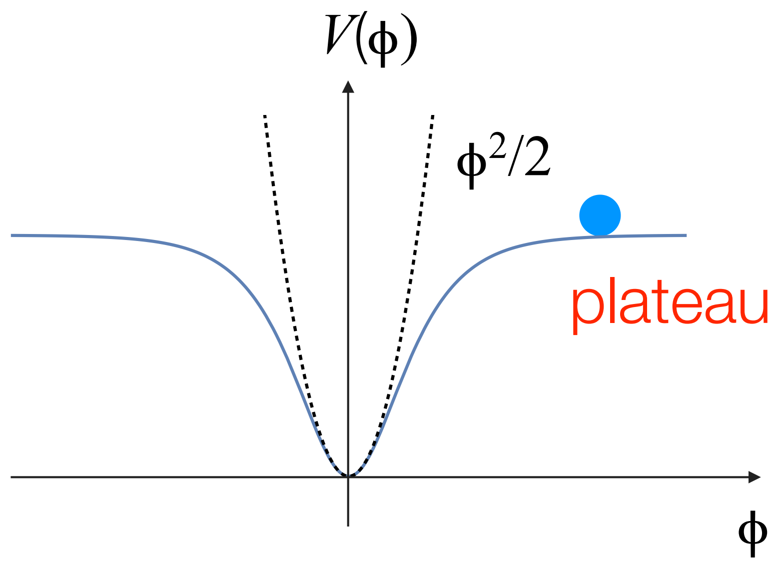


2. Onset of oscillation $H_{osc}/m < 1$

3. Exponential growth due to PR

if $H_{osc}/m < 1$ No disturbance due to cosmic exp.

4. Rescattering → PR becomes inefficient *eg. Kofman, Linde, Starobinsky*

5. Momentum transfer due to turbulence → GW emission

Micha & Tkachev (02,04)

6. GW&ϕ decoupled, Oscillon/I-ball formation

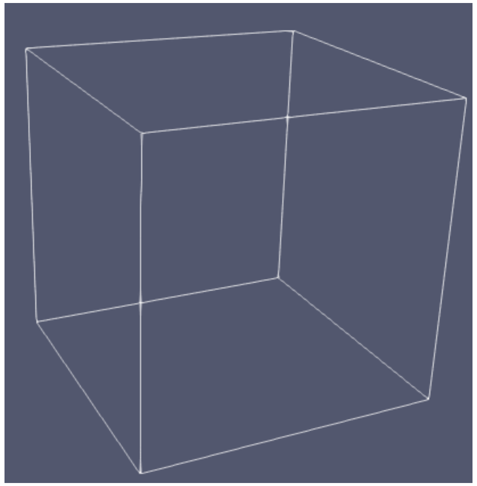
Kasuya+(03),Amin + (10, 12, 17), Zhou(13), Antusch +(17), Kawasaki+(17), ⋯.

Preliminary

Oscillon formation

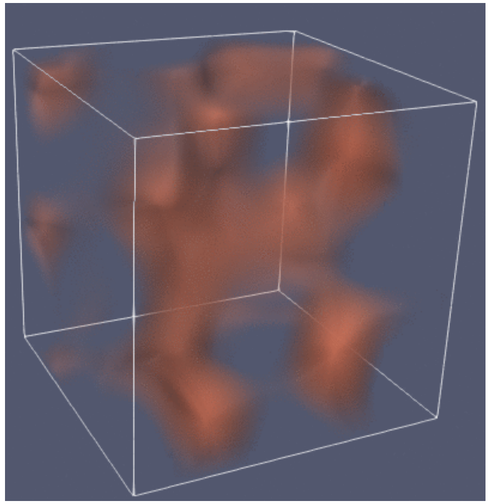
Kitajima, Soda, Y.U. (in preparation)

$a \sim a_0$



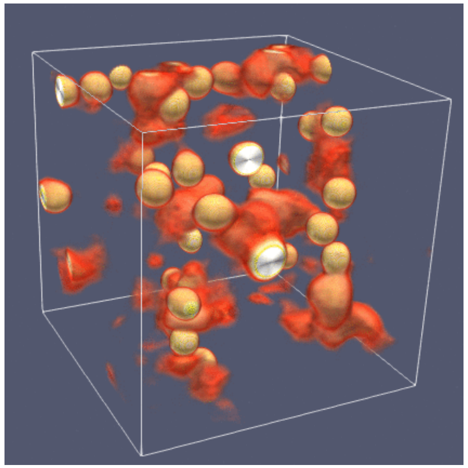
$a \sim 20\, a_0$

rescattering



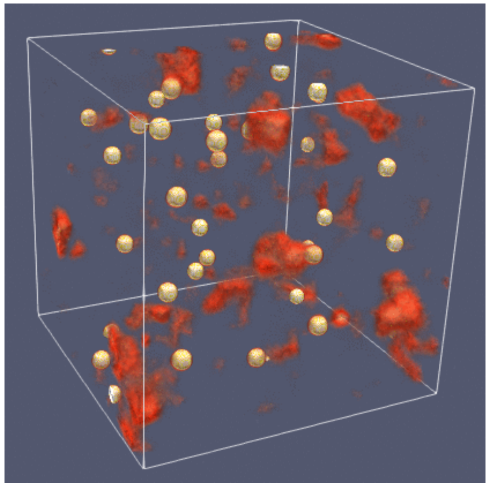
$a \sim 35 a_0$

turbulence



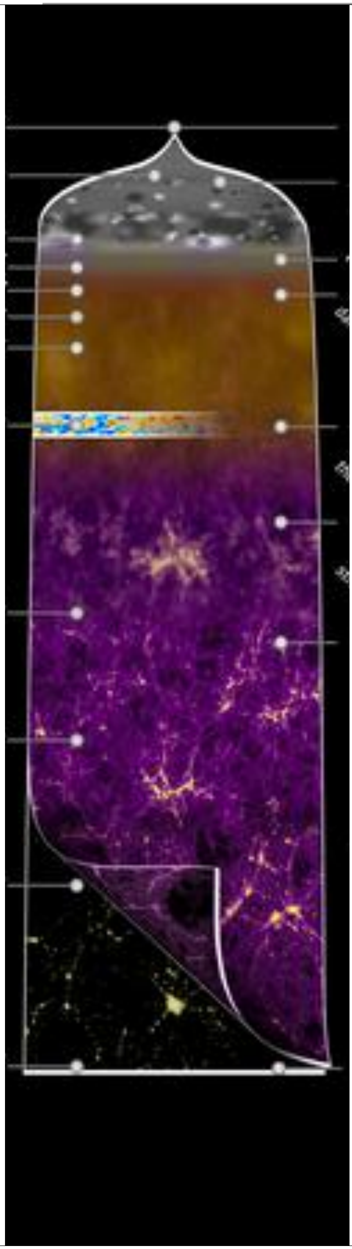
$a \sim 90\, a_0$

oscillon



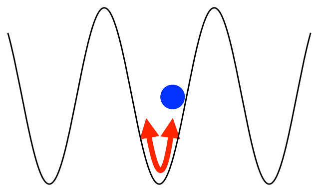
$N_{grid}=(128)^3$

Summary/Future issues



Onset of oscillation

Equal time



~ DM

$\phi(t)$ ⟶ $\delta\phi(t, x)$

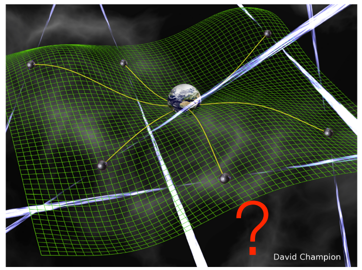
PR

turbulence

(b)GW

ongoing project

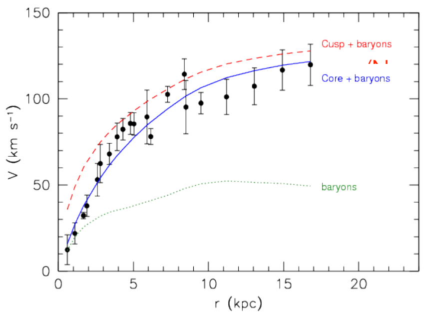
axion-marker



nHz?

or lower

if $\Omega_c \sim \Omega_{axion}$ future project



implications to small scales issues?