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# GRAVITATIONAL PARTICLE CREATION FOR DARK MATTER AND REHEATING

SH and Jun’ichi Yokoyama, *Phys. Rev. D* **99**, 043008 (2019)

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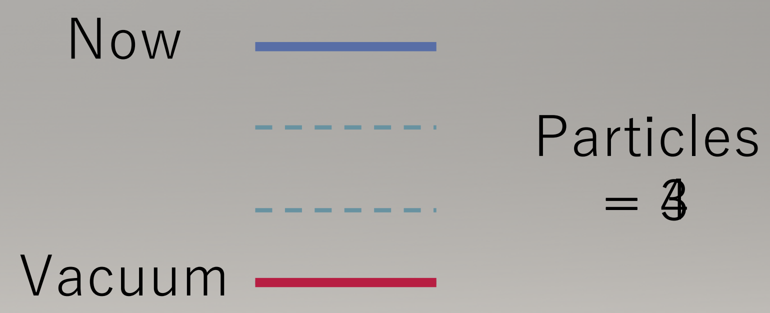
# GRAVITATIONAL PARTICLE CREATION

(L. Parker 1969)

- Vacuum state itself can change in **curved spacetime**
  → Particle number increases
  **Gravitational particle creation**
- This occurs when the conformal symmetry of particle is violated



# CONFORMAL SYMMETRY

- Symmetry under the conformal transformation.

$$g_{\mu\nu} \mapsto \Omega^2 g_{\mu\nu}$$

This symmetry is broken by

- Mass term

  $\frac{1}{2} m^2 \phi^2$ $\phi$: scalar field

  We use this

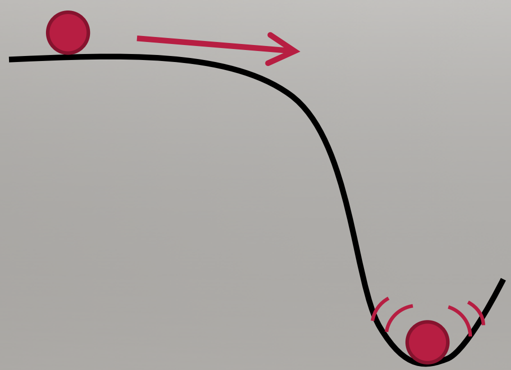
- Non-conformal coupling

  $\frac{1}{2} \xi R \phi^2$ $R$: scalar curvature, $\xi \neq 1/6$

# INFLATION AND REHEATING

- **Potential-driven**

  (L. F. Abbott+ 1982 *etc.*)

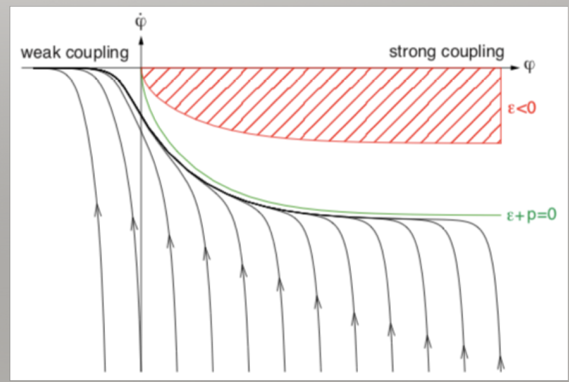


Inflaton oscillates after inflation and decays into SM particles

VS.

- **Kinetically driven +**

  (C. Armendariz-Picon+ 1999)

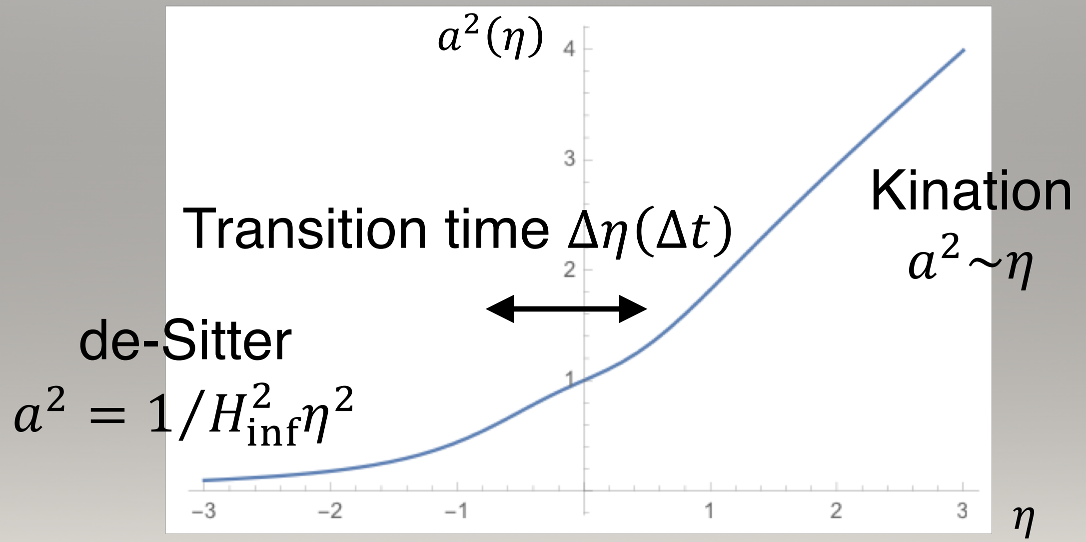



No inflaton oscillation after inflation

⇒ **Gravitational reheating**

# PARAMETERS

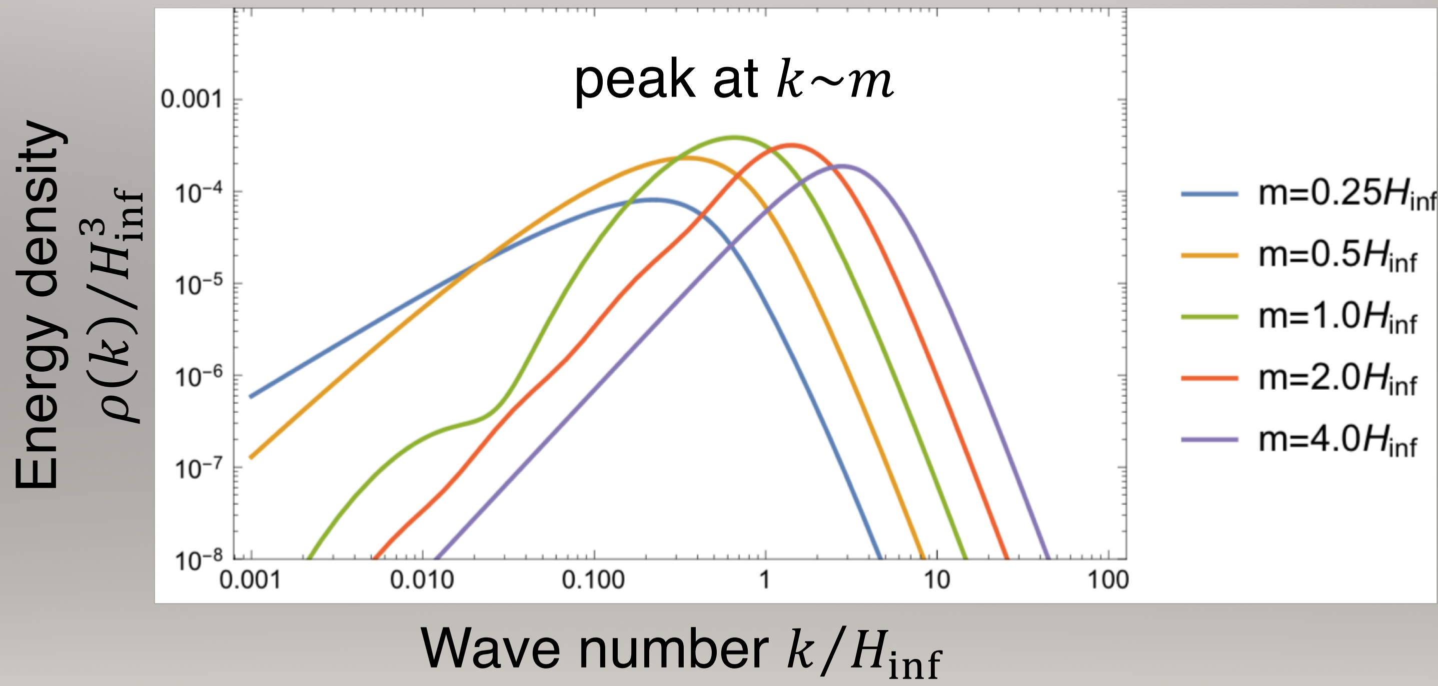
- Hubble parameter during inflation: $H_{\mathrm{inf}}$
- Transition time scale: $\Delta t$
- Mass of produced scalar particle: $m$



# NUMERICAL RESULT 1/2

(SH and J. Yokoyama 2019a)

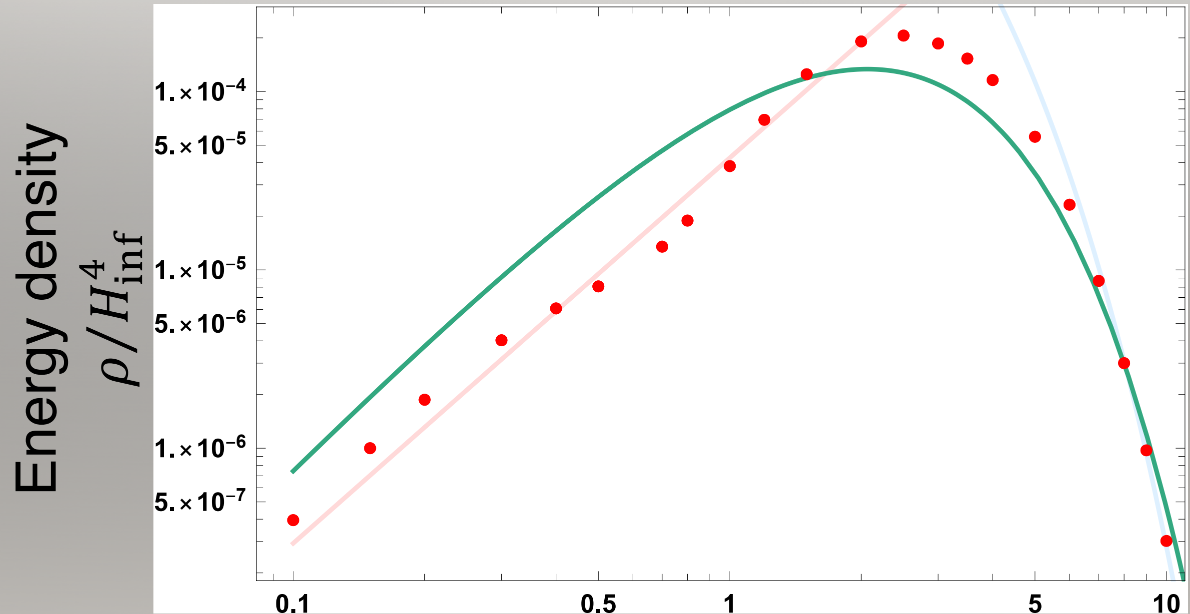
- Power spectrum of produced particles



# NUMERICAL RESULT 2/2

(SH and J. Yokoyama 2019a)

- Produced total energy densities




$(\Delta t = 0.3 H_{\rm inf}^{-1})$

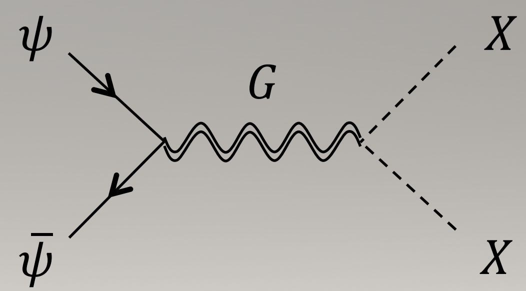
$$\boxed{\rho \approx 2\times10^{-4} e^{-4m\Delta t} m^2 H_{\rm inf}^2}$$

# PURELY GRAVITATIONAL DARK MATTER (PGDM)

(M. Garny+ 2016, Y. Tang and Y.-L. Wu 2016, Y. Ema+ 2018)

- Dark matter which interacts with SM particles ONLY gravitationally (no weak interaction)
- Its extremely feeble interaction makes it difficult to produce PGDM thermally

Can gravitational particle creation produce enough PGDM?



# OUR MODEL

- 2 massive scalar particles conformally coupled to gravity
  - Particle $A$

    mass: $m_A$,   decay rate: $\Gamma = \alpha m_A$

    → Decay into radiation and realize reheating
  - Particle $X$

    mass: $m_X$

    → Behave as PGDM

Both are produced gravitationally

# CONDITIONS TO BE SATISFIED

(Planck Collaboration 2018 VI)

- Present (cold) dark matter abundance

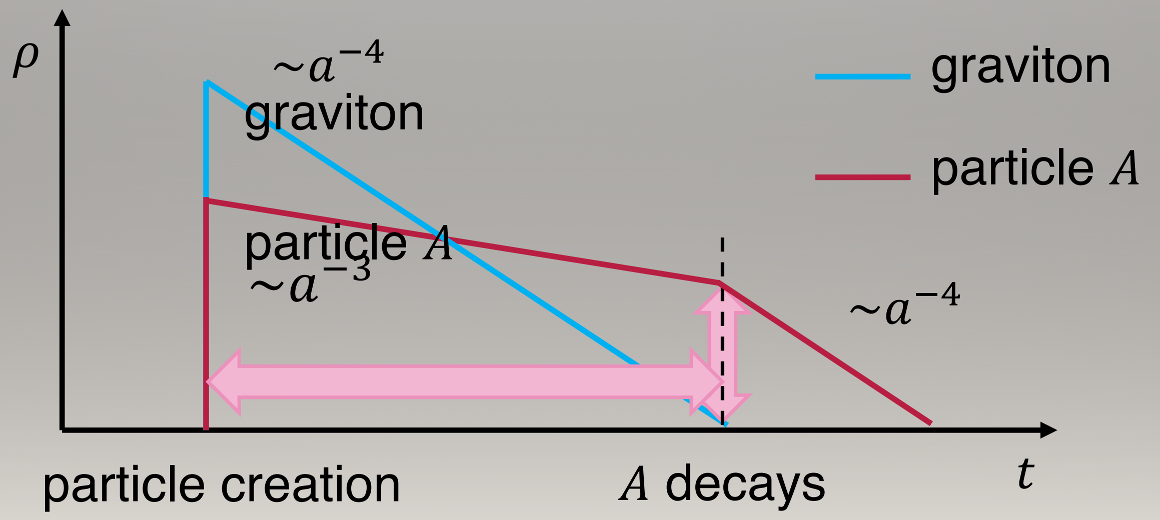
$$4\times10^{-2}\alpha^{1/4}e^{(3m_A-4m_X)\Delta t}\frac{m_X^2 H_{\rm inf}^{1/4}}{m_A^{5/4}} = 4\times10^{-10}\ \mathrm{GeV}$$

- Graviton's effective degree of relativistic freedom

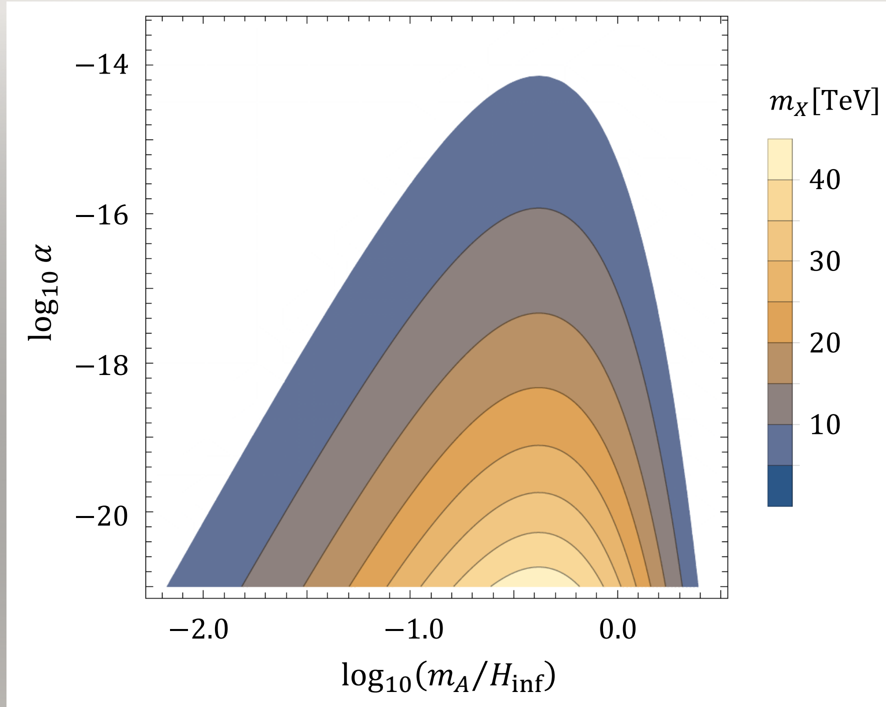
$$\alpha^{-1/3}e^{-4m_A\Delta t}\left(\frac{m_A}{H_{\rm inf}}\right)^{5/3} > 2.3\times10^3$$

# SUPPLEMENTARY EXPLANATION TO 2ND COND.

- Gravitons are also gravitationally produced
- They affect CMB spectrum and BBN (abundance of $^4\mathrm{He}$)
- Hence, they should be “concealed” by radiation



# CALCULATION RESULT




- $\alpha$ takes max. value $7.0\times10^{-15}$ when $m_A = 0.42H_{\rm inf}$
- $m_X$ takes min. value $5.8$ TeV on the border

# PLANCKIAN INTERACTION ?

- Smallness of $\alpha$

  CMB observation gives $\alpha < 7.0\times10^{-15}$

  If interactions between particle $A$ and SM particles are Planck suppressed such as

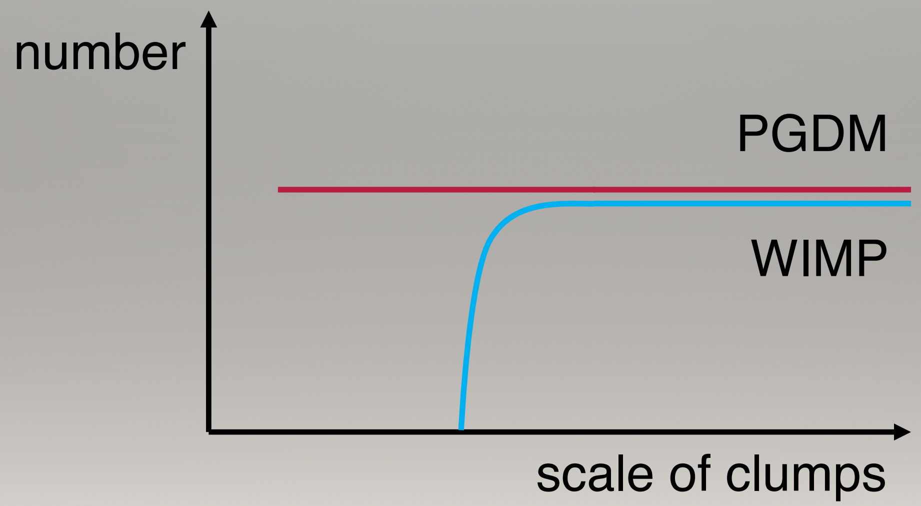
$$\mathcal{L}_{\rm int} = \tilde{\lambda}\frac{m_A}{M_G}\bar{\Psi}\Psi$$

$$\Rightarrow \alpha = \frac{\tilde{\lambda}^2}{32\pi^2}\left(\frac{m_A}{M_G}\right)^2 \sim \underline{10^{-16}\tilde{\lambda}^2}$$

$\alpha < 7.0\times10^{-15}$ means $\tilde{\lambda} < \mathcal{O}(1)$

# TESTABILITY OF PGDM

- Too feeble interaction to be detected directly
- Search for their resultant structure?
  PGDMs are out-of-equilibrium throughout the history
  ⇒ They can form **quite small-scale** clumps



# SUMMARY

- Sufficient amount of PGDMs can be gravitationally produced after inflation

  → Gravitational particle creation can explain reheating and dark matter simultaneously!

- Scalar particle which decays into radiation must have a very small decay rate

  → Planckian interaction?