Non-Standard Primordial Clocks from induced Mass in Alternatives to Inflation Scenarios

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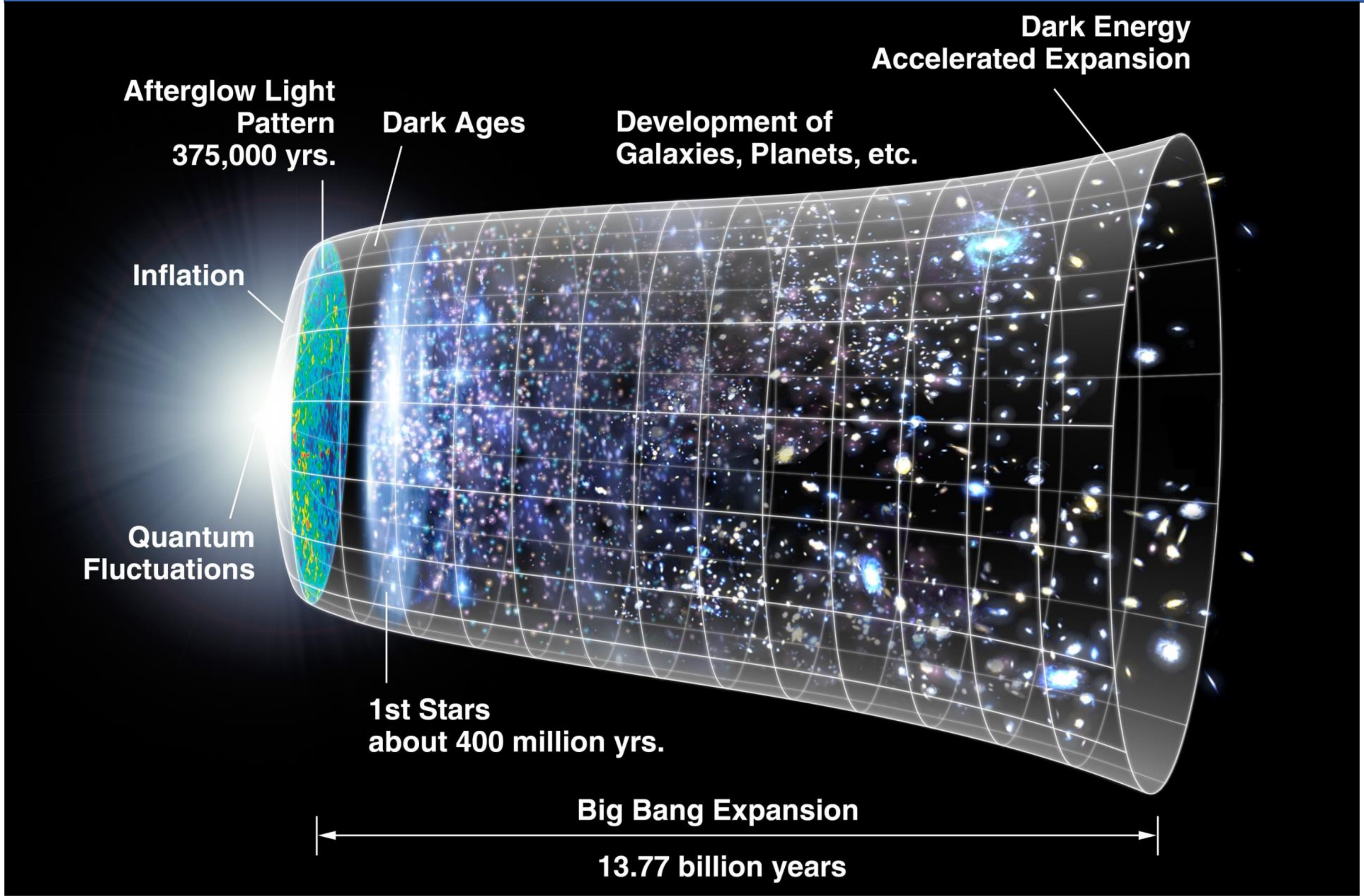
Reference:

1. Xingang Chen, Mohammad Hossein Namjoo and Yi Wang, 1509.03930
2. Yi Wang, Zun Wang and Yuhang Zhu, 2007.09677

Universe evolution



-Expanding?

-Contracting?

How Fast?

How to describe it?

Alternative scenarios of the inflation

The relative expansion of the universe is parametrized by a dimensionless scale factor a.
In an expanding or contracting FLRW universe, starting from time t_0 to any arbitrary time t, it should be:

$$d(t) = a(t)\, d_0(t_0),$$

where $d(t)$ refers to the proper distance at t and d_0 is the distance at the reference time t_0.

And we usually use conformal time τ but not physical time t for calculation simplification which is defined as:

$$dt = a(\tau)\, d(\tau),$$

where the cosmological conformal time is the proper time reconciled by the fundamental observers.

Cosmological scale factor and conformal time

Four possibilities for alternatives scenarios $a = a_0 \left(\frac{t}{t_0}\right)^p = a_0 \left(\frac{\tau}{\tau_0}\right)^{p/(1-p)}$	
fast expansion	$\|p\| > 1$
fast contraction	$0 < p \sim O(1) < 1$
slow contraction	$0 < p \ll 1$
slow expansion	$-1 \ll p < 0$

Figure 1. Four possibilities for alternatives scenarios with power law scale factor $a \sim t^p$. Each coefficient p represents different alternatives of cosmic evolution.

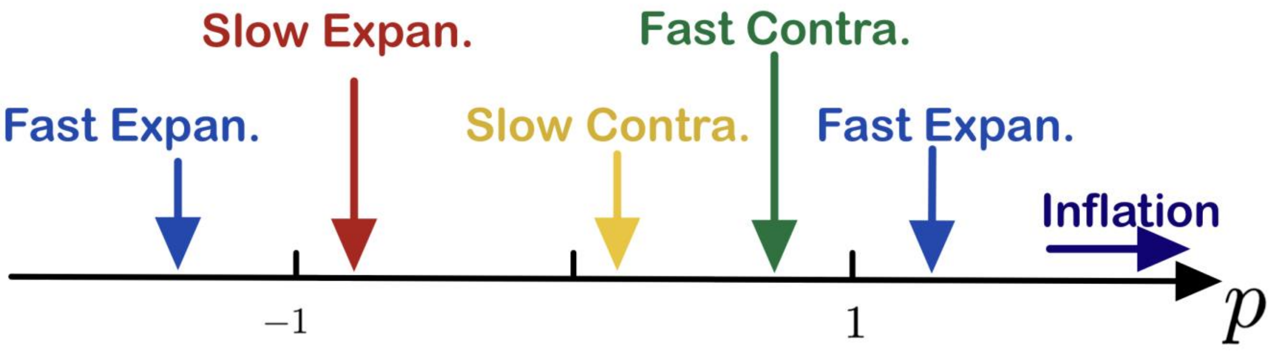


Figure 2. Axial Schematic diagram to explain four possibilities for alternatives scenarios with power law scale factor $a \sim t^p$.

Alternative scenarios of the inflation

We know fluctuations as functions of scales (k) very well that

$$k \sim -1/\tau \text{ (conformal time).}$$

Thus we know that: fluctuation ←→ conformal time

But the problem is that: fluctuation ←→ physical time

<u>Classical Standard Clock (Massive Oscillations)</u> <u>(X. Chen, 1104.1323, 1106.1635)</u>

$$\int d\tau f(\tau) e^{-ik\tau} e^{imt} \,,$$

Saddle point approximation:

inverse function of a(t)

$$\Delta P_\zeta \sim sin\left[\frac{p^2}{p-1}\frac{\omega}{H_0}\left(\frac{k}{k_r}\right)^{1/p} + \text{phase}\right].$$

Classical Standard Clock

Reference:

"Primordial Features as Evidence for Inflation" arxiv: 1104.1323

"Fingerprints of Primordial Universe Paradigms as Features in Density Perturbations " arxiv: 1106.1635

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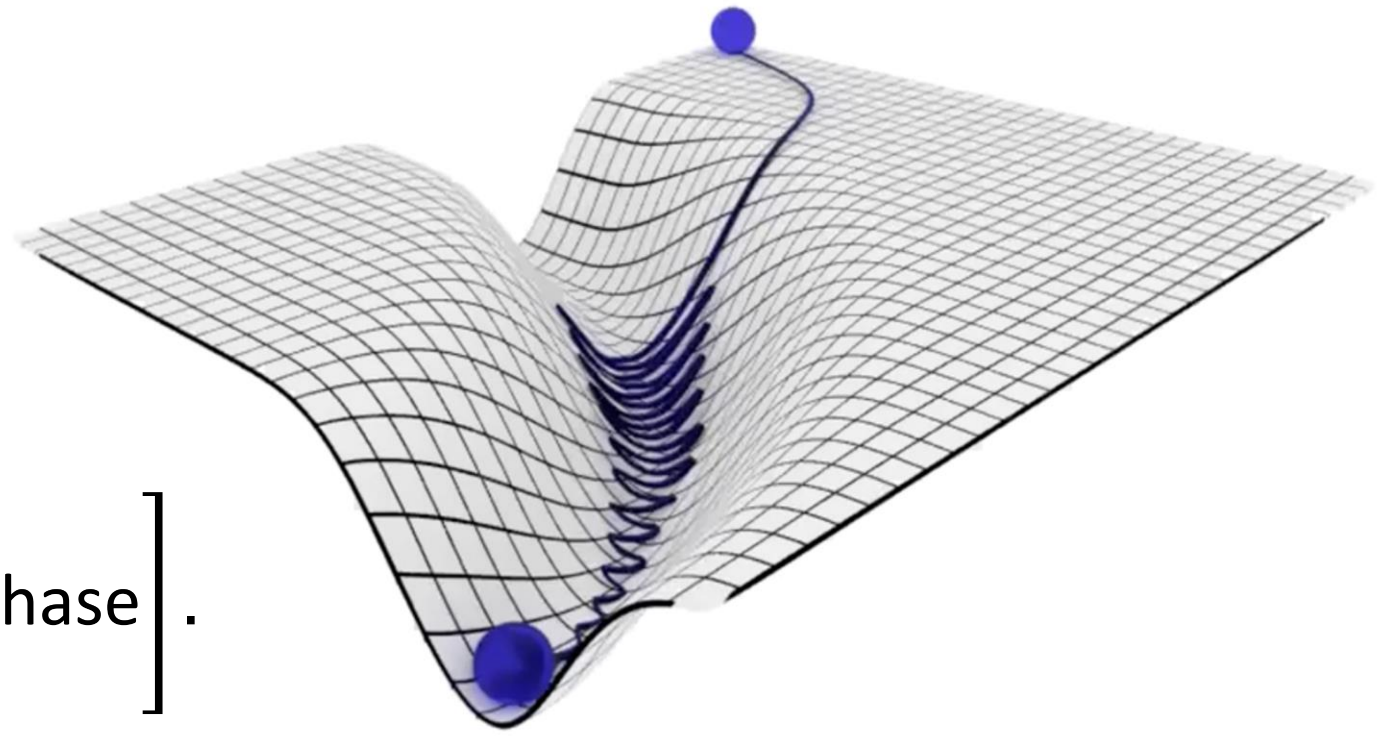

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Non-standard Classical Clocks (Chen,1104.1323; Huang&Pi, 1610.00115| Domnech, Rubio&Wons, 1811.08224)

Couplings:

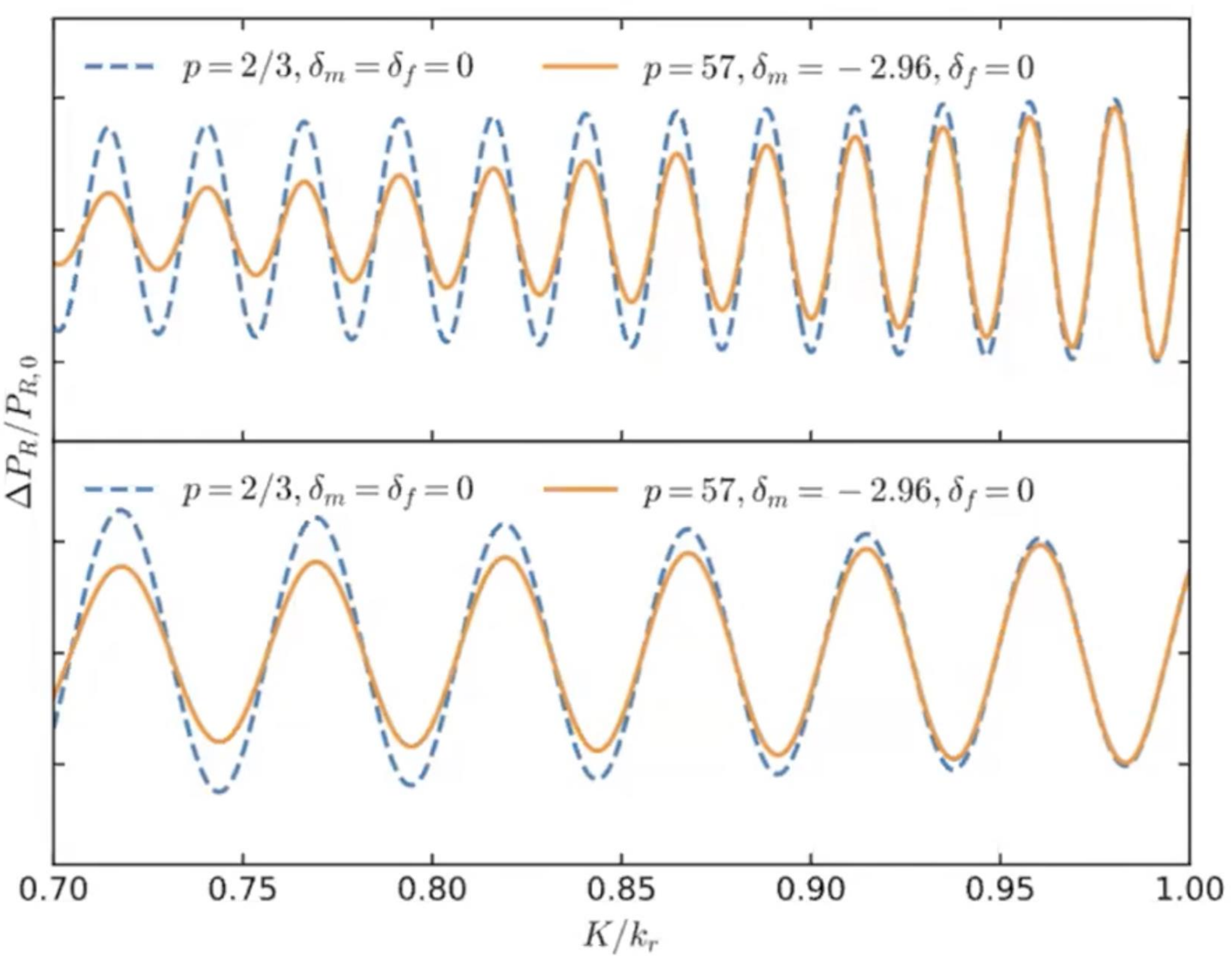
$$\frac{-L}{\sqrt{-g}} = \frac{M_p^2}{2} r - \frac{1}{2}\omega^2(\chi) g^{\mu\nu}\partial_\mu\phi\partial_\nu\phi - V(\phi)$$

$$-\frac{1}{2} f^2(\phi) g^{\mu\nu}\partial_\mu\chi\partial_\nu\chi - \frac{1}{2} m^2(\phi)\chi^2$$

where

$$\delta_f \equiv \frac{d\, ln\, f}{dN}$$

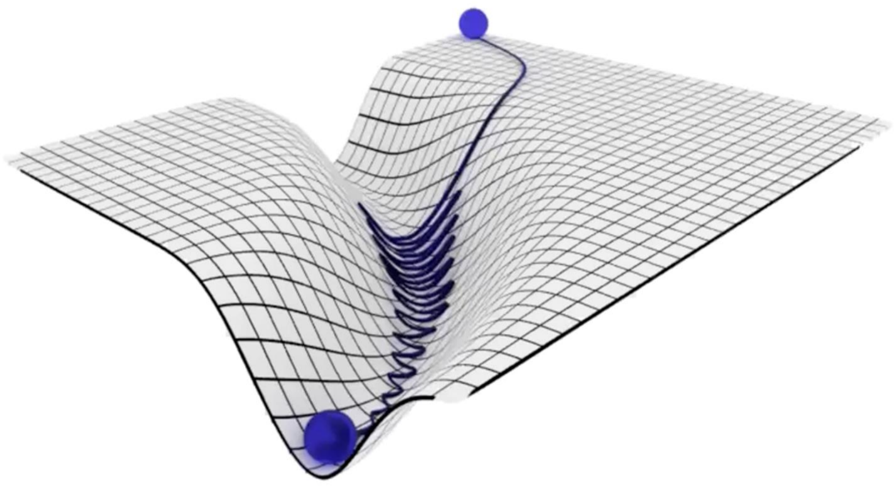
$$\delta_m \equiv \frac{d\, ln\, m}{dN}$$

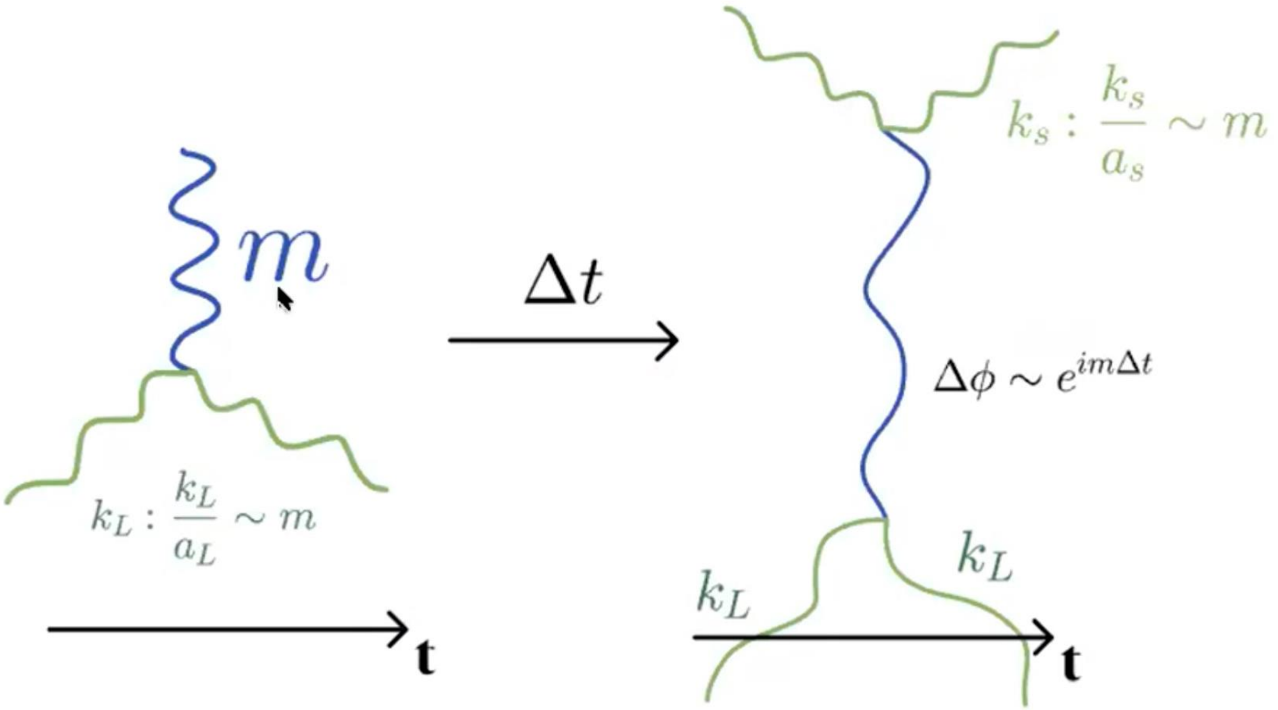


Classical Clock to the Quantum Clock

Classical Clock Signal: Large signal, but fortune needed

Quantum Clock Signal: One single-particle needed, existence, large signal if lucky





$$\text{corr.f.} \sim \exp[im(t_s - t_L)]$$

$$\sim \exp\left[i\frac{m}{H}(log(k_s/m)) - log(k_L/m)\right]$$

$$\sim \left(\frac{k_s}{k_L}\right)^{im/H} \quad \text{(inflation)}$$

Non-standard quantum clocks (Yi Wang, Zun Wang and Yuhang Zhu, 2007.09677)

1. Time-dependent effective mass from coupling to the Ricci curvature

$$\mu^2 = m^2 + \xi R = m^2 + 6\xi \frac{p(2p-1)}{t^2} \;\rightarrow\; \mu \sim t^{-1} \;\rightarrow\; H$$

2. Time-dependent effective mass from nonlinear corrections ($V = \frac{1}{4}\lambda\phi^4$)

$$\dot{\sigma} = -\frac{\lambda}{3p} t\sigma^3 + \frac{\sqrt{\Lambda}}{3p} t^{(-3/2)}\eta(x,t) \Rightarrow \mu \sim t^{-1} \;\rightarrow\; H$$

Standard/ Non-standard Quantum Clock Signal

$$m \sim H \sim t^{-1}: \quad S^{\text{clock}} \sim f(p,\xi,k_3)\left(\frac{2k_1}{k_3}\right)^{\frac{1+p}{2(1-p)}} sin\left\{S\, log\left[\left(\frac{2k_1}{k_3}\right)^{-1}\right] + \phi(p,\xi,k_3)\right\}$$

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Inflation $|p| > 1, \frac{1+p}{2(1-p)} < 0 \;\Rightarrow$ decreasing with k_1

Alternative scenarios $|p| < 1, \frac{1+p}{2(1-p)} > 0 \;\Rightarrow$ increasing with k_1

Conclusion

If we find the quantum clock signal from the power spectrum:

- $sin\left(\sim k^{1/p}\right)$ with |p|<1: alternative scenarios;
- $sin(\sim \log(\ldots k))$:

  - correlation function increases with k: alternative scenarios

  - correlation function decreases with k: inflation

(other nice non-standard clocks caused by others can be studied…)

Reference

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Thank you