Title: Dark Matter from causal sets

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Collection: Everpresent Lambda: Theory Meets Observations

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Dark Matter from Quantum Gravity

Niayesh Afshordi

original work by *Siavash Aslanbeigi* and *Mehdi Saravani*

1. arXiv:1909.06889 [pdf, ps, other]

Dark matter and nonlocality of spacetime

Mehdi Saravani

Subjects: **General Relativity and Quantum Cosmology (gr-qc)**; High Energy Physics - Theory (hep-th)

2. arXiv:1604.02448 [pdf, other]

Off-shell Dark Matter: A Cosmological relic of Quantum Gravity

Mehdi Saravani, Niayesh Afshordi

Journal-ref: Phys. Rev. D 95, 043514 (2017)

Subjects: **General Relativity and Quantum Cosmology (gr-qc)**; High Energy Astrophysical Phenomena (astro-ph.HE); High Energy Physics - Theory (hep-th)

3. arXiv:1502.01655 [pdf, other]

Dark Matter From Spacetime Nonlocality

Mehdi Saravani, Siavash Aslanbeigi

Journal-ref: Phys. Rev. D 92, 103504 (2015)

Subjects: **High Energy Physics - Theory (hep-th)**; General Relativity and Quantum Cosmology (gr-qc)

A unitary causal non-local field theory?

1. Modes with mass M, called on-shell.
2. A continuum of massive modes with mass higher than M, called off-shell.

- Transition rate of any scattering including one (or more) off-shell mode(s) in the initial state is zero → **Dark Matter!**
- **This is just a phase space factor when**
  - *number of species* → ∞
  - *coupling* → *0*

Review of Off-shell Dark Matter (OfDM)

$$\frac{\Gamma_{1F}}{\Gamma_O} = \frac{\sigma_{1F}}{\sigma_O} = \frac{\int d^4p_1 d^4p_2 2\pi\delta_+(p_1^2)\widetilde{W}(p_2)\delta^4(q-p_1-p_2)}{\int d^4p_1 d^4p_2 2\pi\delta_+(p_1^2)2\pi\delta_+(p_2^2)\delta^4(q-p_1-p_2)} \tag{2.1}$$

where q is the incoming energy-momentum and $\widetilde{W}(p)$ is given in terms of the spectrum of non-local operator $\tilde{\Box}$

$$\widetilde{W}(p) = \frac{2\text{Im } B(p)}{|B(p)|^2}\theta(p^0), \tag{2.2}$$

$$\tilde{\Box}e^{ip\cdot x} = B(p)e^{ip\cdot x}. \tag{2.3}$$

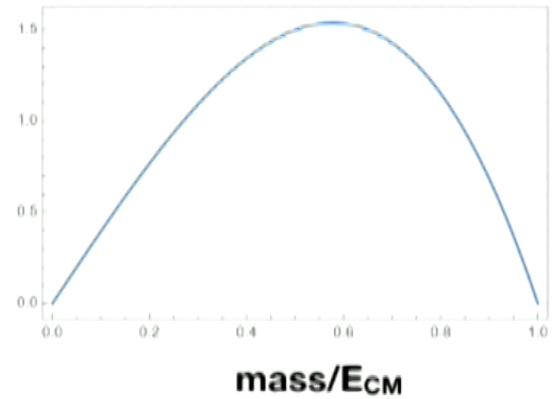
- This is the ratio of the production/decay rate to 1 off-shell vs on-shell particle, when mass << E_{CM} << Λ
- $$B(q) = -q^2 + \mathcal{O}\left(\frac{q^4}{\Lambda^2}\right)$$ $$\text{Im } B(q) = \frac{1}{2}\frac{q^4}{\Lambda^2} + \mathcal{O}\left(\frac{q^6}{\Lambda^4}\right).$$ $$\frac{\Gamma_{1F}}{\Gamma_O} = \frac{\sigma_{1F}}{\sigma_O} = \frac{1}{4\pi}\left(\frac{E_{\rm CM}}{\Lambda}\right)^2,$$

Typical mass of off-shell particles

$$P_{1F}(m) = N \int d^4p_1 d^4p_2 \delta_+(p_1^2)\widetilde{W}(p_2)\delta^{(4)}(q - p_1 - p_2)\ m\delta(p_2^2 + m^2),$$

$$P_{1F}(m) = \frac{4m}{E_{\rm CM}^2}\left(1 - \frac{m^2}{E_{\rm CM}^2}\right) \quad 0 < m < E_{\rm CM},$$

- typical OfDM mass is $0.6E_{CM}$ at production



Dark Matter from Inflation

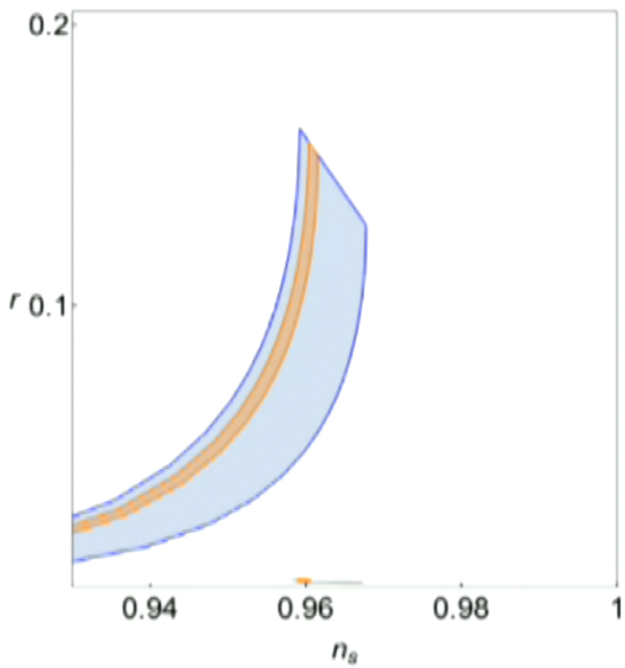
- Fraction of Energy in DM at the end of inflation

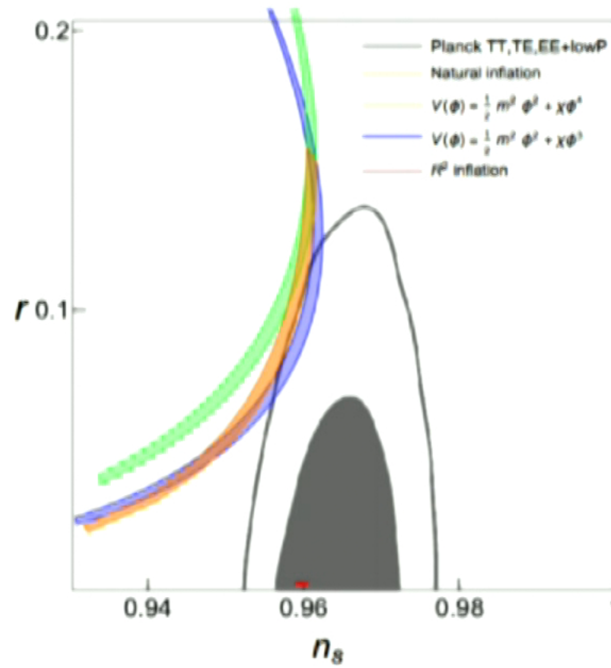
$$f = \frac{1}{4\pi}\left(\frac{m_\phi}{\Lambda}\right)^2 \ll 1,$$

- This fixes the reheating temperature which is the main uncertainty for any given inflation model

- $T_{\text{reheat}} = \dfrac{0.75\ \text{eV}}{f}$

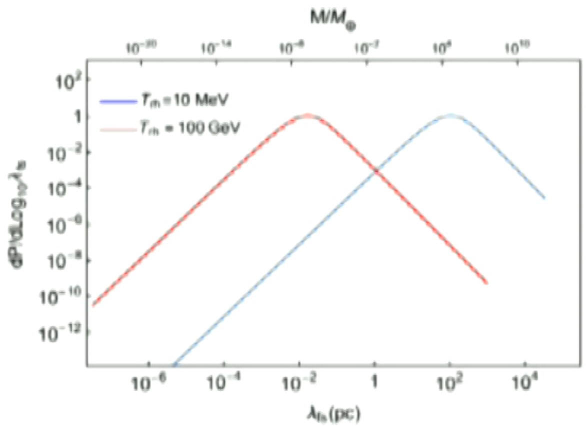
Sharpening Inflationary predictions





$$\Lambda = 0.1 M_{\rm P} - M_{\rm P}$$

Testing OfDM on small scales



(b) Distribution of free streaming distance of OfDM for different reheating temperatures. The top axis shows the characteristic halo mass associated with the free streaming scale, in units of Earth mass.

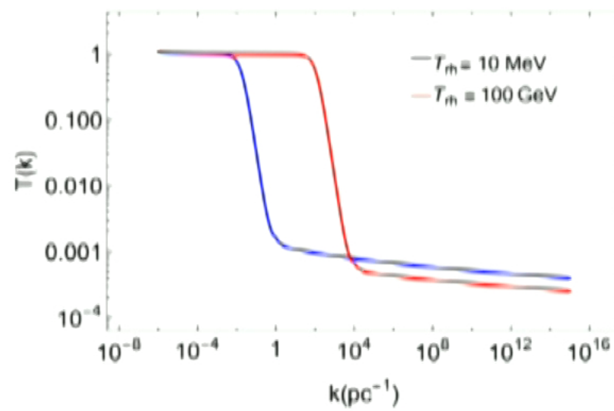
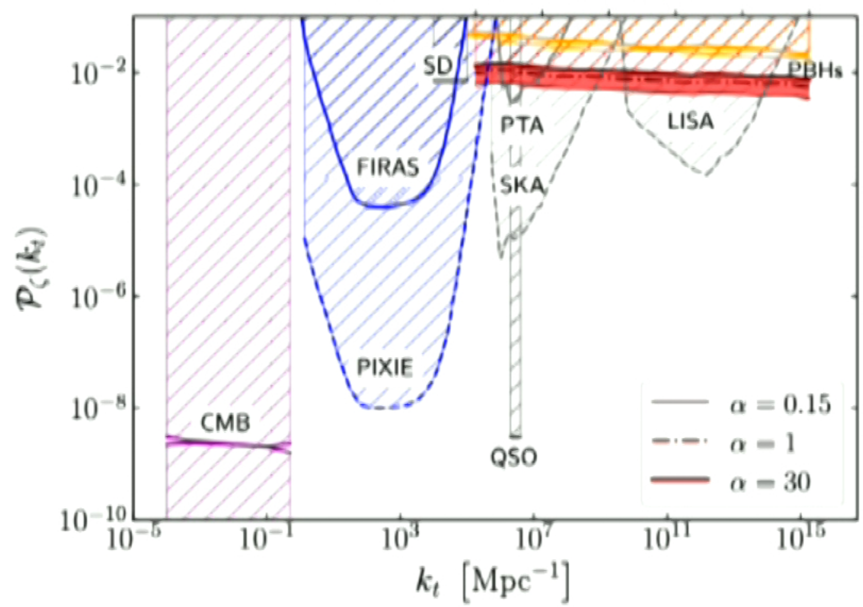


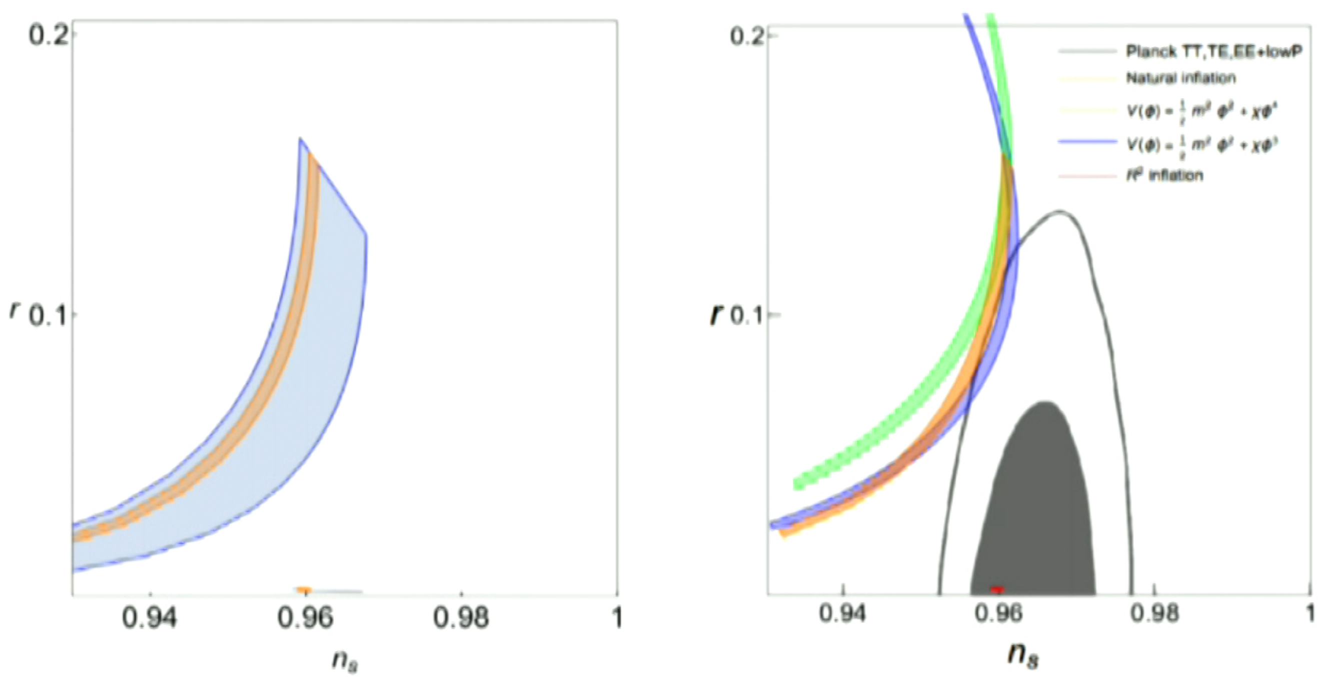
Figure 4: Matter transfer function due to the growth in early matter era and free streaming effect. Instead of an exponential cut-off for large k in thermal scenarios, there is $\propto (\ln k)^{-1}$ drop in OfDM scenario.

Testing OfDM on small scales

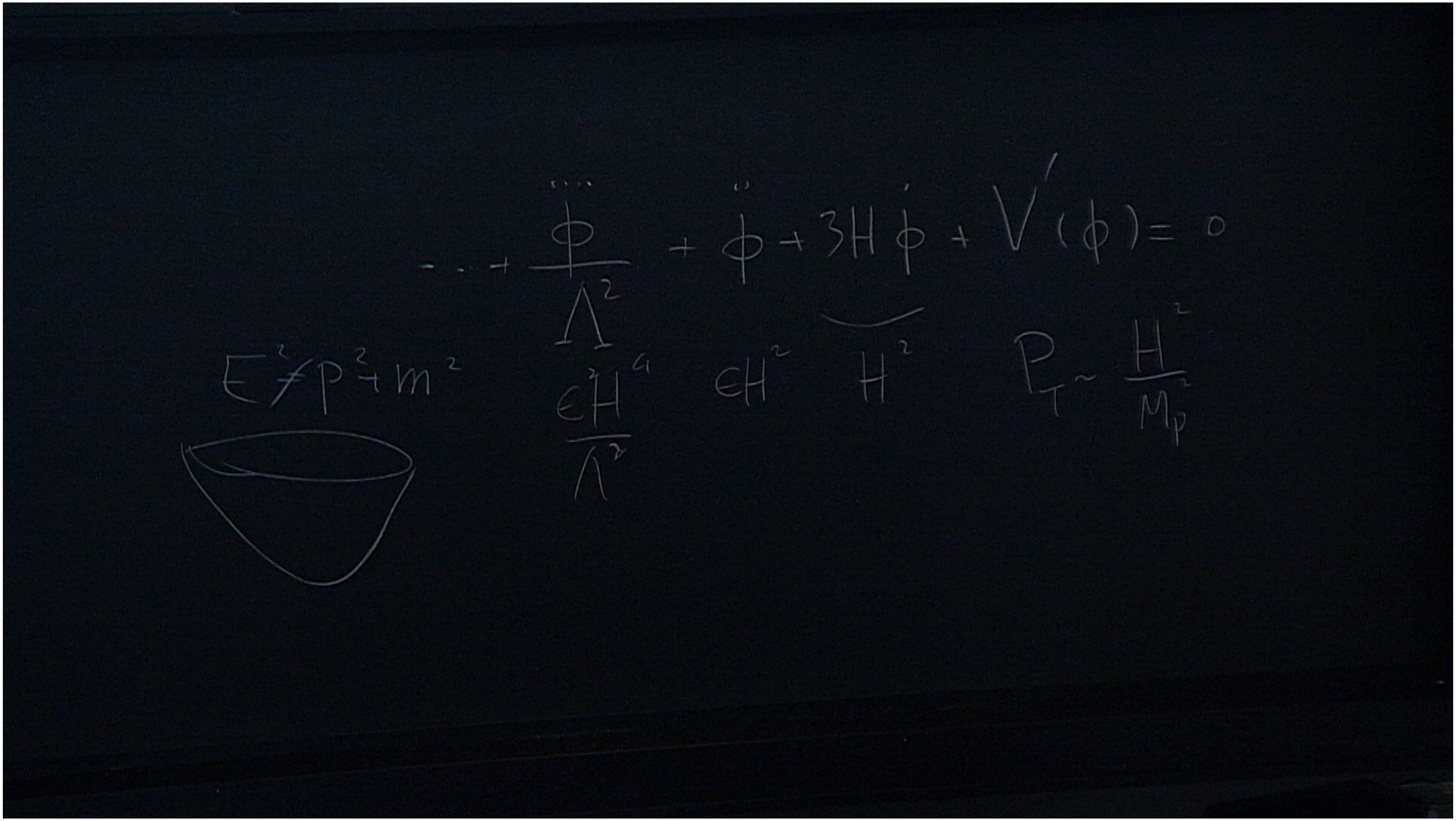
from arXiv:1908.03596



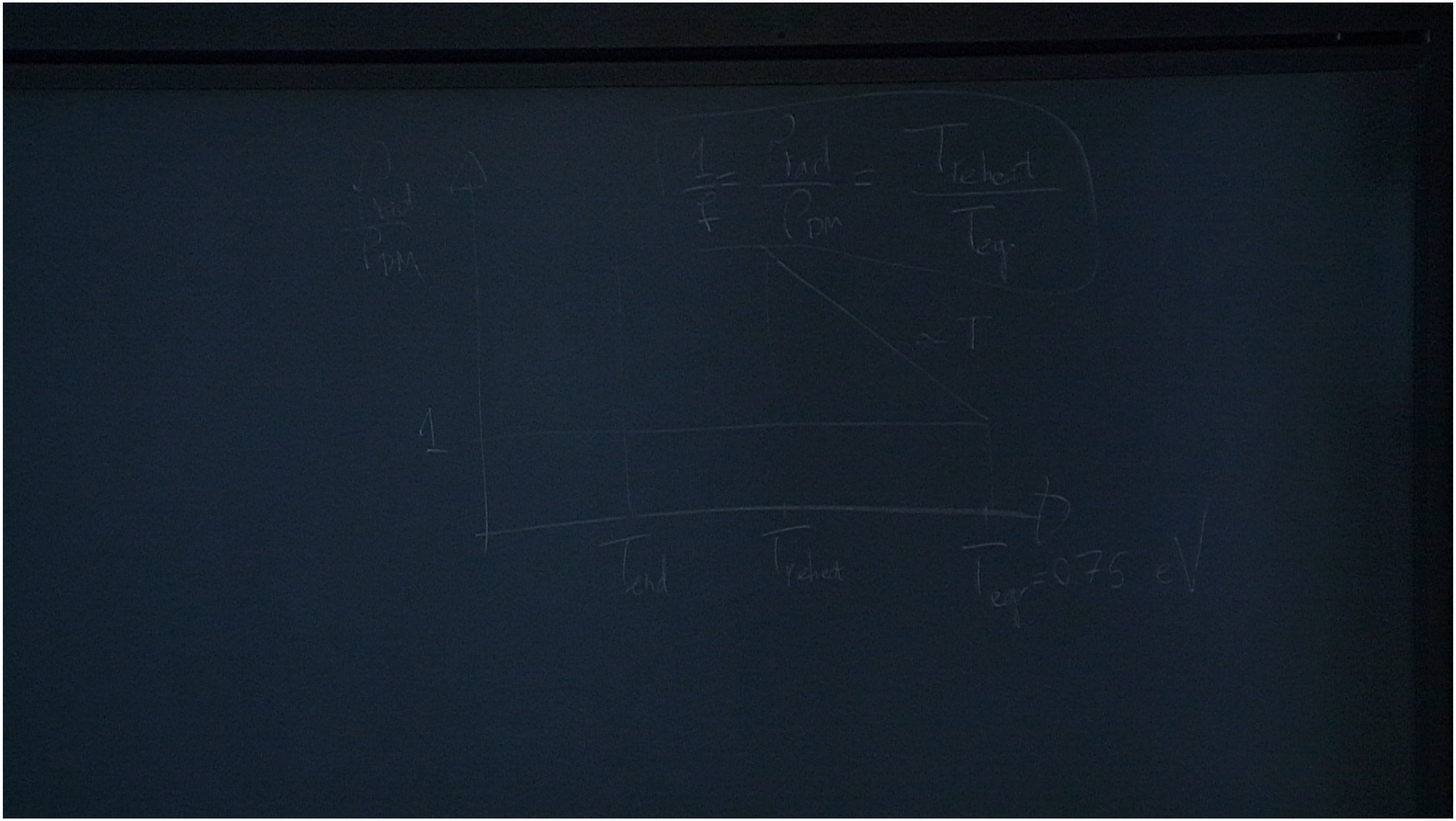
Sharpening Inflationary predictions



$$\Lambda = 0.1 M_{\rm P} - M_{\rm P}$$



... + $\dddot{\phi}/\Lambda^2$ + $\ddot{\phi}$ + $3H\dot{\phi}$ + $V'(\phi) = 0$
$E^2 \neq p^2 + m^2$
$\epsilon H^4/\Lambda^2$
ϵH^2
H^2
$P_T \sim H^2/M_p^2$



$\frac{\rho_{rad}}{\rho_{DM}}$
$\frac{1}{f} = \frac{\rho_{rad}}{\rho_{DM}} = \frac{T_{reheat}}{T_{eq}}$
$\propto T$
1
T
T_{end}
T_{reheat}
$T_{eq} = 0.75$ eV