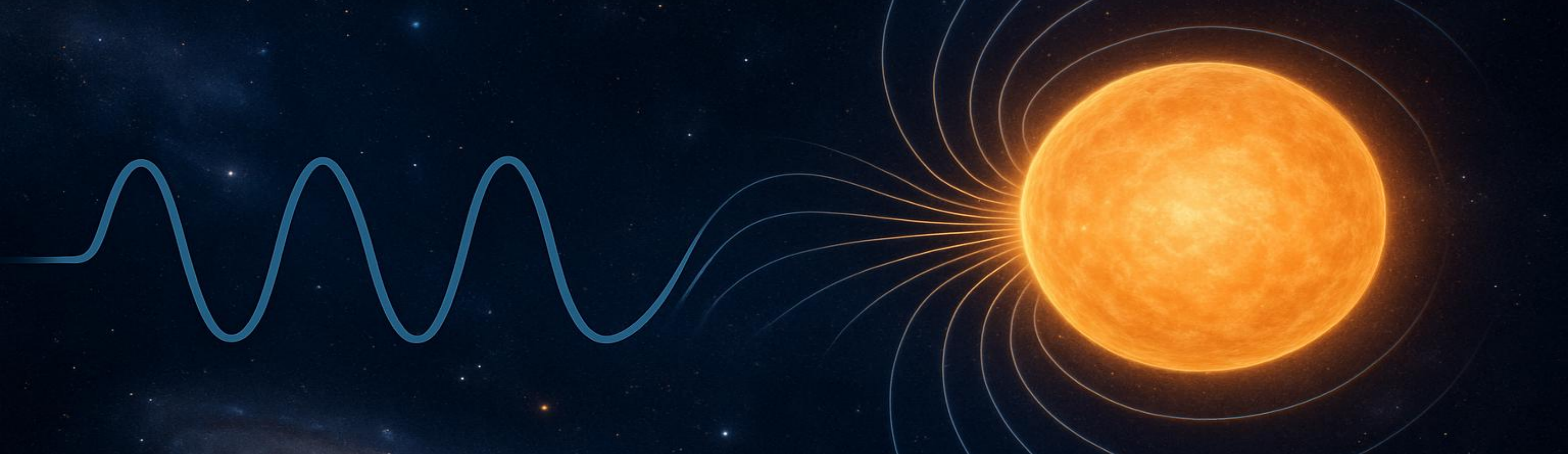
Tunneling in Collapsing ” Boson/ALP” Stars



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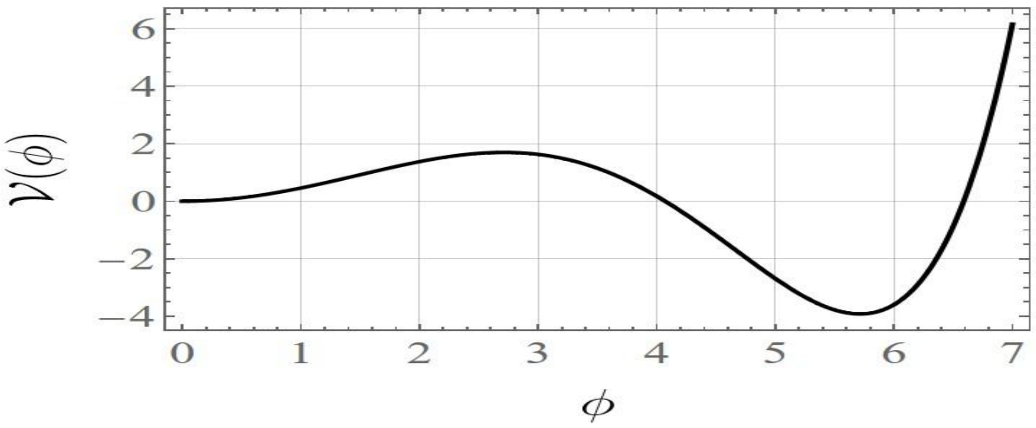
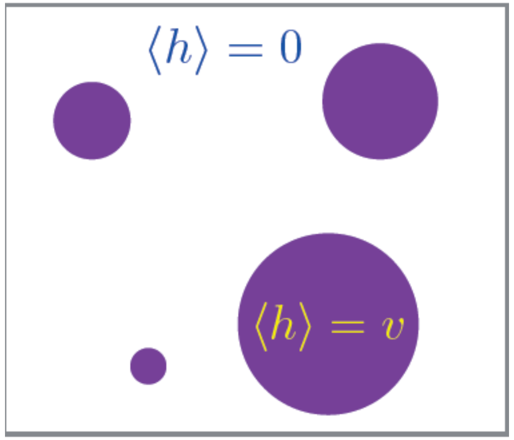
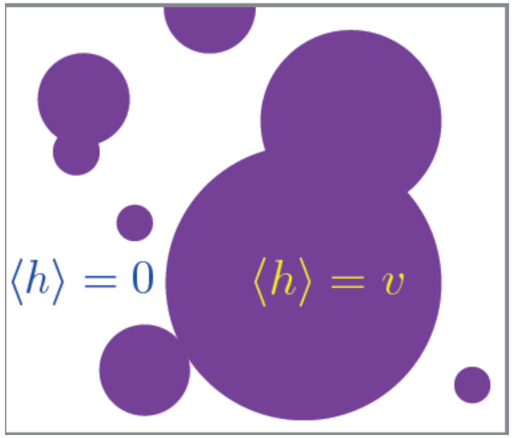
To appear on arxiv soon 250X.XXXXX

First Order Phase Transitions

The Usual Story







The New Story

- Consider a Boson/ALP-like Star in the dense branch.
- During Star Collapse higher order terms in potential become relevant. -> Bosenova
- In the case when the different vacua are non degenerate during star collapse -> Star collapse Induced Tunneling.

” Boson/ALP” Stars

Boson Star Generalities, Consider chunk of bosons of total mass $M = mN$

$$E \sim \frac{N}{8mR^2} - \frac{3}{5}\frac{GM^2}{R}$$

$$\frac{\partial E}{\partial R} = 0 \rightarrow R_{BS} \sim \frac{\alpha_k}{2Gm^2M}$$

ALP Star Considerations

$$\mathcal{L} = \sqrt{-g}\left[\frac{1}{2}g^{\mu\nu}\nabla_\mu\phi\nabla_\nu\phi - V(\phi)\right].$$

$$V(\phi) = \frac{1}{2}m^2\phi^2 + m^2f^2\sum_{n=2}^{\infty} g_n \frac{(-1)^n}{(2n)!}\left(\frac{\phi}{f}\right)^{2n}$$

Decompose field in terms of NR wave function

$$\phi = \frac{f_a}{\sqrt{2}}\left(\psi(\bar{r},t)e^{-imt} + \psi^*(\bar{r},t)e^{imt}\right)$$

$$i\partial_t\psi = -\frac{\Delta\psi}{2m_a} + m\left(\Phi - \frac{g_2|\psi|^2}{8}\right)\psi$$

$$\Delta\Phi = \frac{4\pi\rho}{M_p^2}$$

Self Similar Solution/Bosenova (Tkatchev)

Neglect Gravity and higher order terms in potential in GPP

$$i\partial_t \psi = -\frac{\Delta\psi}{2m_a} - \frac{g_2|\psi|^2}{8} m\psi$$

$$\psi(r,t) \rightarrow \gamma\psi(\gamma r, \gamma^2 t)$$

$$\psi = (-tm)^{-iw} \frac{\chi\left(\frac{rm}{\sqrt{-tm}}\right)}{m\sqrt{g_2}r}$$

Field Value at time t=0 of star collapse

$$\psi_{\text{collapse}} \sim \frac{2.82}{\sqrt{g_2}mr}$$

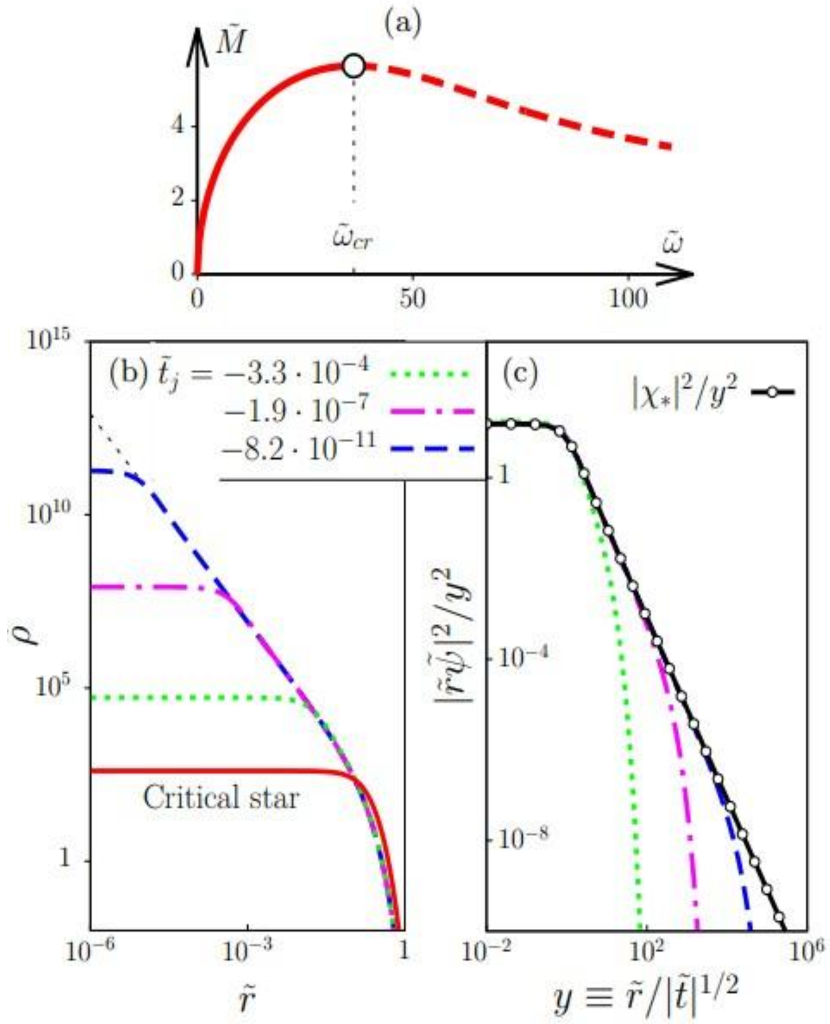


Figure 1 from 1609.03611

Boson Star Collapse Induced Tunneling

Main Question: Can these large field values trigger a phase transition?

Case Study

$$\mathcal{V}(\phi) = \frac{m_a^2}{2!}\phi^2 - \frac{\lambda}{4!}\phi^4 + \frac{\epsilon}{6!}\phi^6$$

Field Value at Collapse

$$\phi_{collapse}(r, t = t_{collapse}) \simeq \frac{2.82\sqrt{2}}{\sqrt{\lambda} r}$$

Condition for growth of bubble

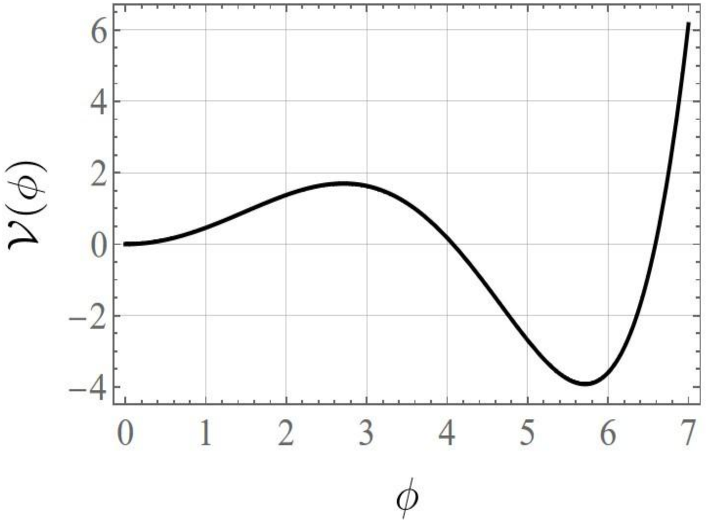
$$\phi_B(R_B) \lesssim \phi_{collapse}(R_B, t = t_{collapse})$$

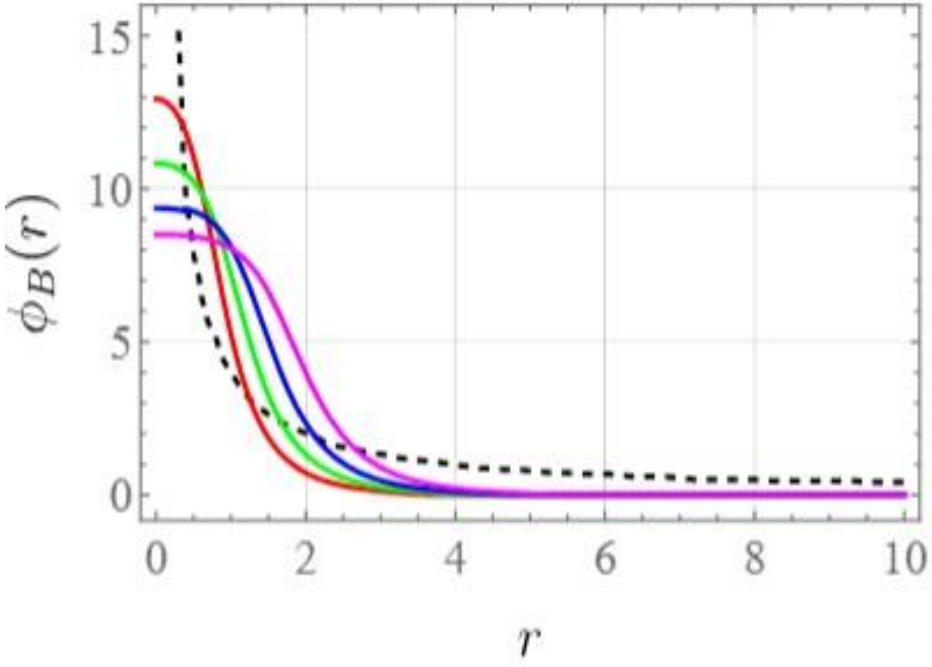
User Case definition of Critical Bubble

$$\phi_B(R_B) = \frac{\phi_B(0)}{2}$$

Naive Collapse Condition

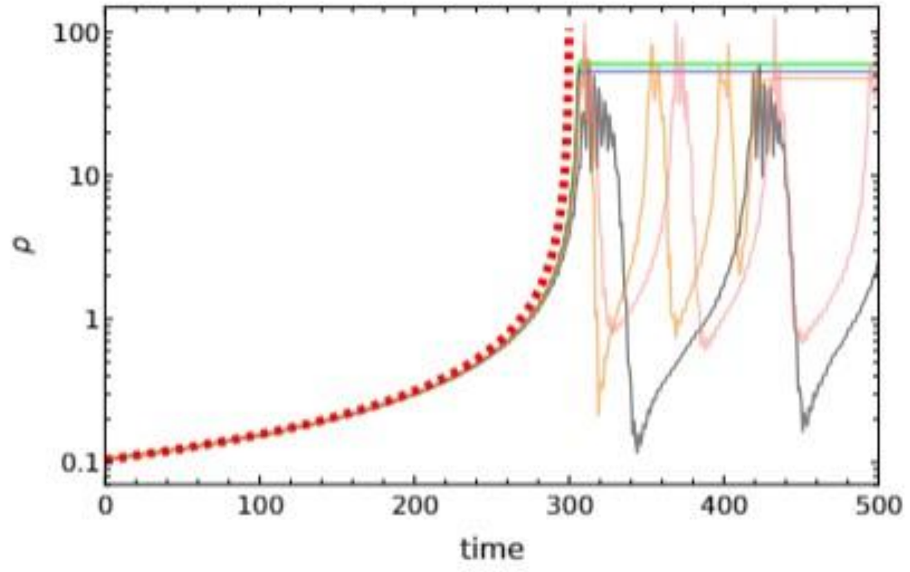
$$\phi_B(0) R_B \sqrt{\lambda} \lesssim 8$$





Field profiles of critical bubbles, O(4) Bounces Black Dashed is Tkatchev solution close to Bosenova

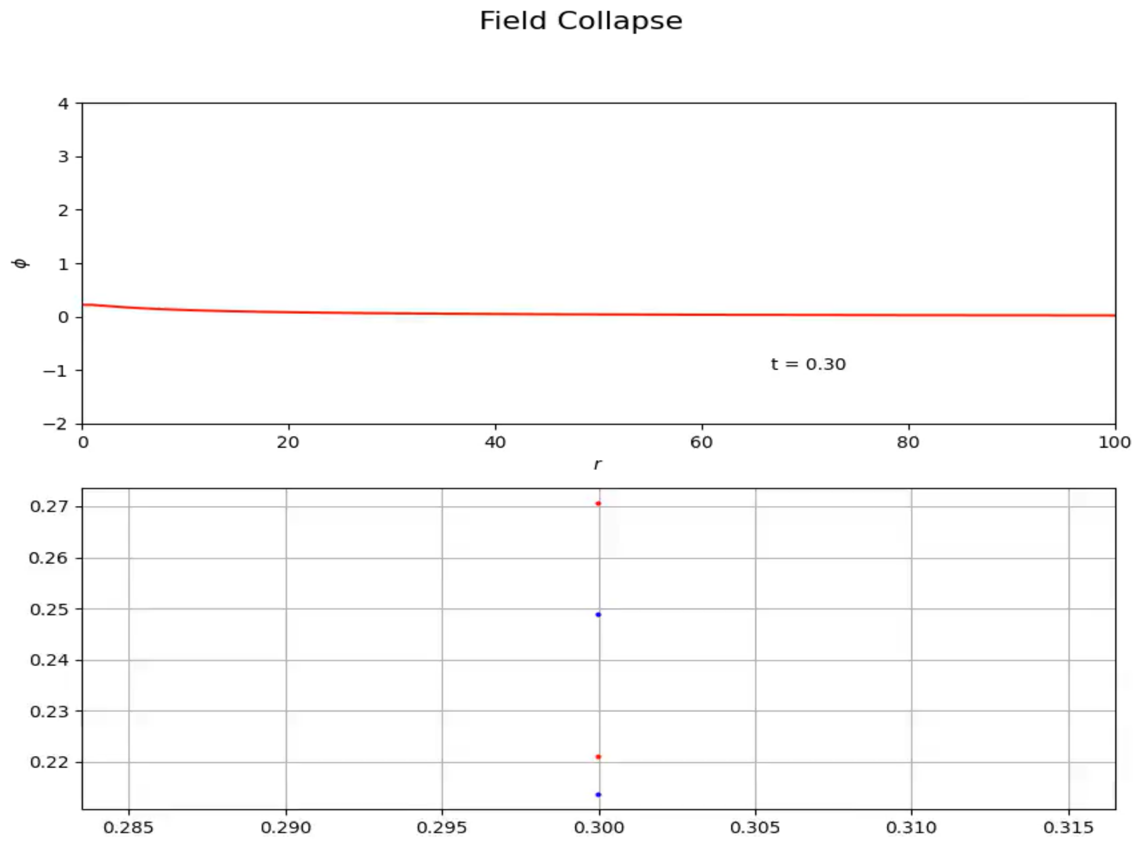
Numerical Results



$$\rho = \frac{\dot{\phi}^2}{2} + \phi^2$$

$$g_{num} = 0.3, 0.33, 0.6$$

Tkatchev Attractor in Red Dashed. Evolution of energydensity starting far away from critical collapse



Field Evolution during collapse g = 0.1 tunneling appears at t=230,

Phenomenological Consequences

- No-Go Theorem for the transition in thin wall limit?

- PT during star collapse -> field in false vacuum, Our current universe in true vacuum.

$$\Delta V \sim \frac{m^4}{\lambda}\left(\frac{5}{g^2}\right)$$

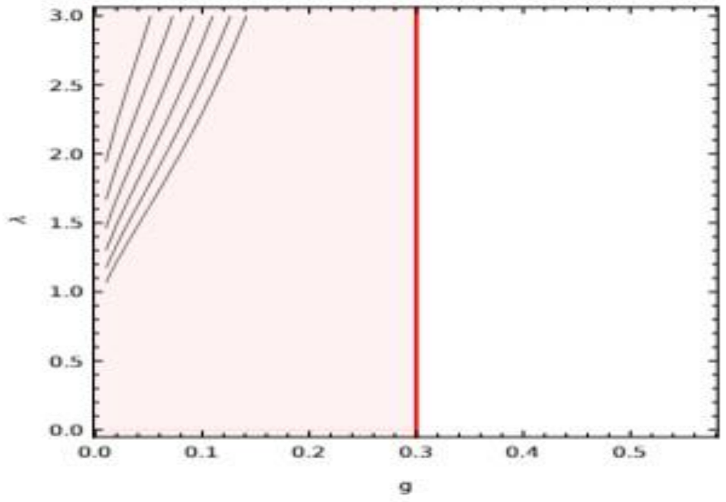
  - Star formation prone in matter domination $\rho \sim m^2\phi^2$

$$\rho_D^m \sim \frac{m^4}{\lambda}\left(\frac{g}{3}\right)$$

- Landscape of ALP models/potentials realizing our setup?

$$V(\phi) = \Lambda_1^4\left(1-\cos\left(\frac{\phi}{f_1}\right)\right) + \Lambda_2^4\left(1-\cos\left(\frac{\phi}{f_2}+\pi\right)\right)$$

- Emergent Dark Energy Model by Ferreira Kobayashi 2018



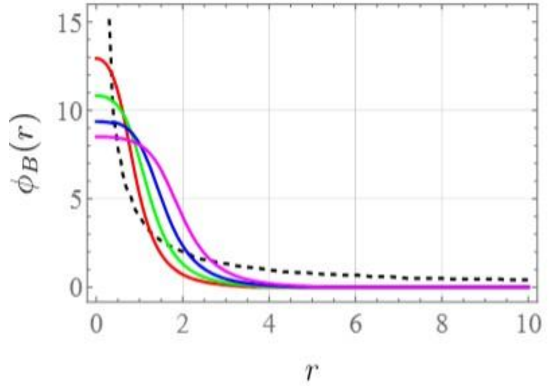
Parameter space where the PT can happen varying m_phi from 1 GeV to 10^10 GeV

- Such UV theory may enable models for CC
- Late Trapping of Axion field ”Up Tunneling”
- Dynamical change in DM particle mass

Conclusions & Outlook

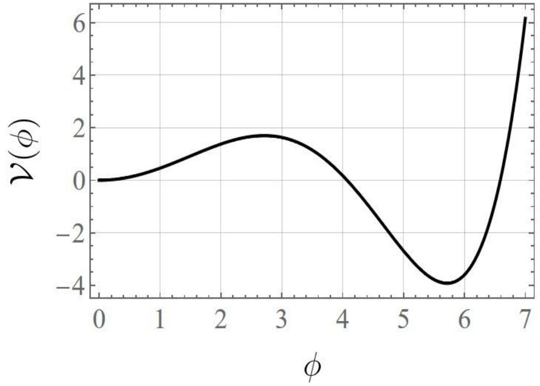
New mechanism for producing bubbles

- Large field excursions
- Core of collapsing stars
- Only Thick bubbles can be produced



The key ingredients

- Non degenerate minima
- Negative quartic coupling
- Relying on Tkachev attractor solution



Phenomonology

- Emergence of cosmological constant
- Constrain Gravothermal collapse
- May also be applicable in BHSR