𝒞osmoℒattice School:

Practice session 2: Let's play with scalar fields!

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Practice Session 2: Goals

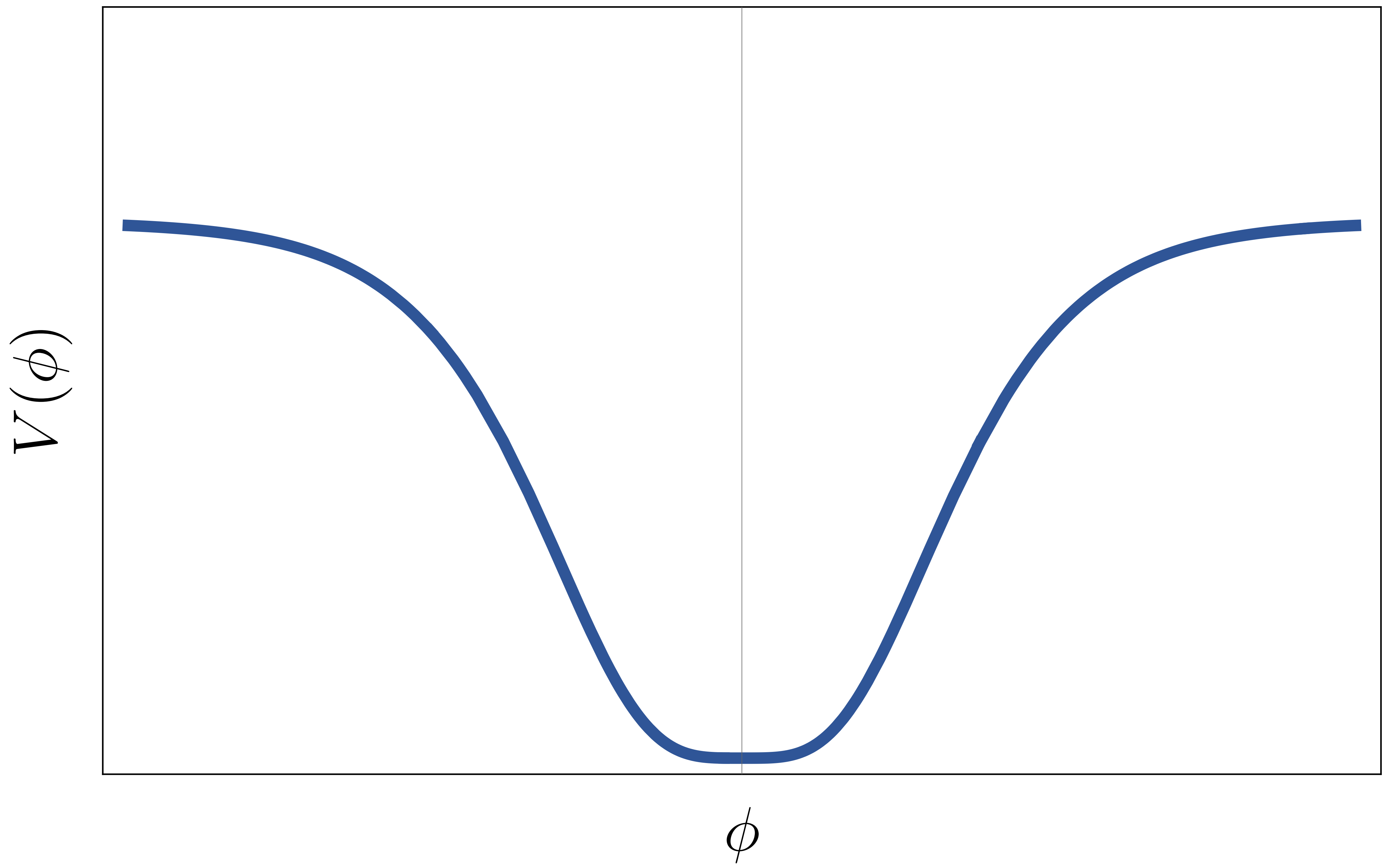
- Implement and modify a model in CosmoLattice
- Compile and run a simulation of your model
- Analyse the data and adapt lattice parameters if needed

Preheating after α-attractor inflation

Model:

$$V(\phi,\chi) = \frac{1}{4}\Lambda^4 \tanh^4\left(\frac{\phi}{M}\right)$$

(inspired by α-attractor T-Model: 1306.5220)



α-attractor inflation model

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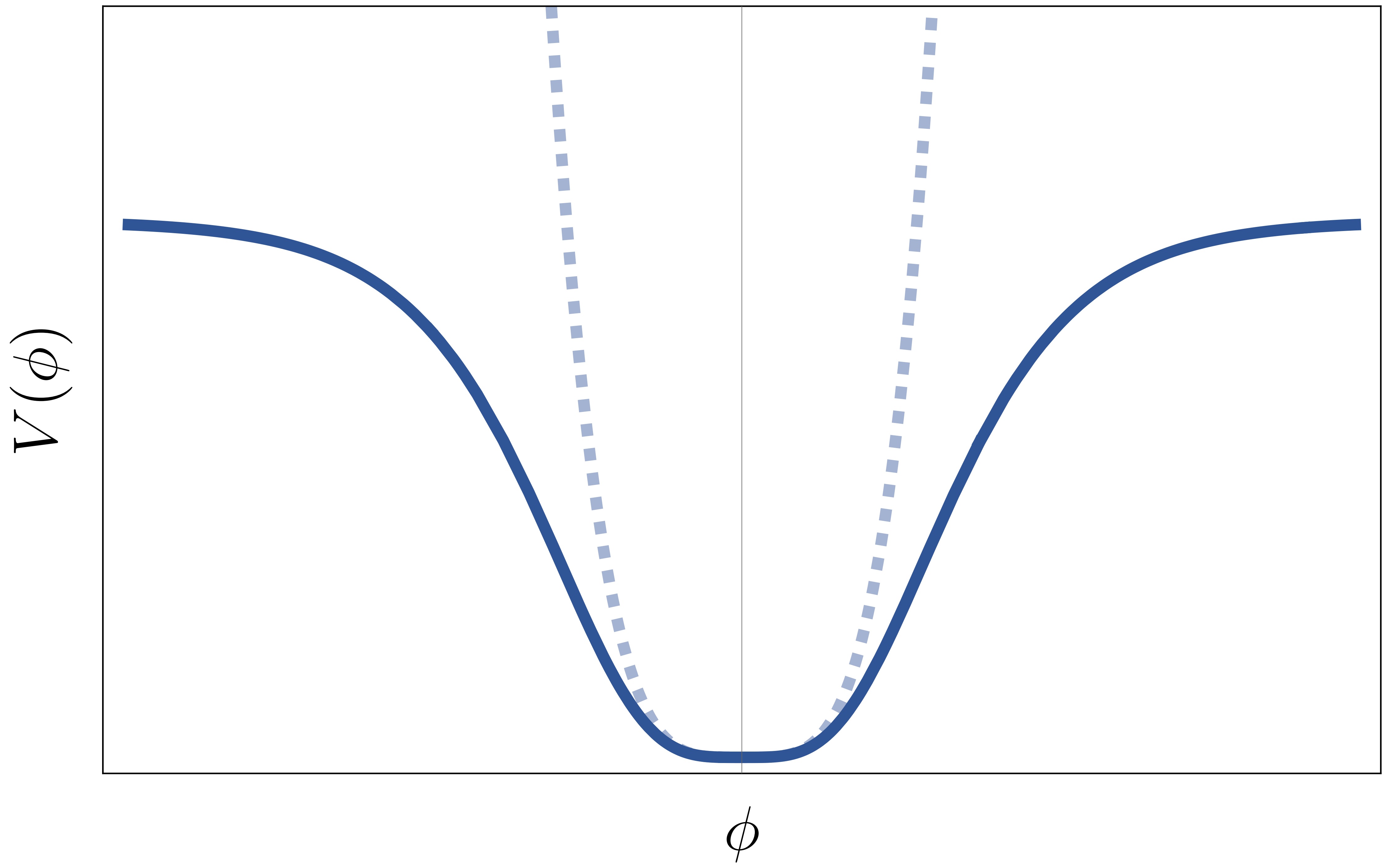
- We consider: $M = 10 m_{\rm pl}$



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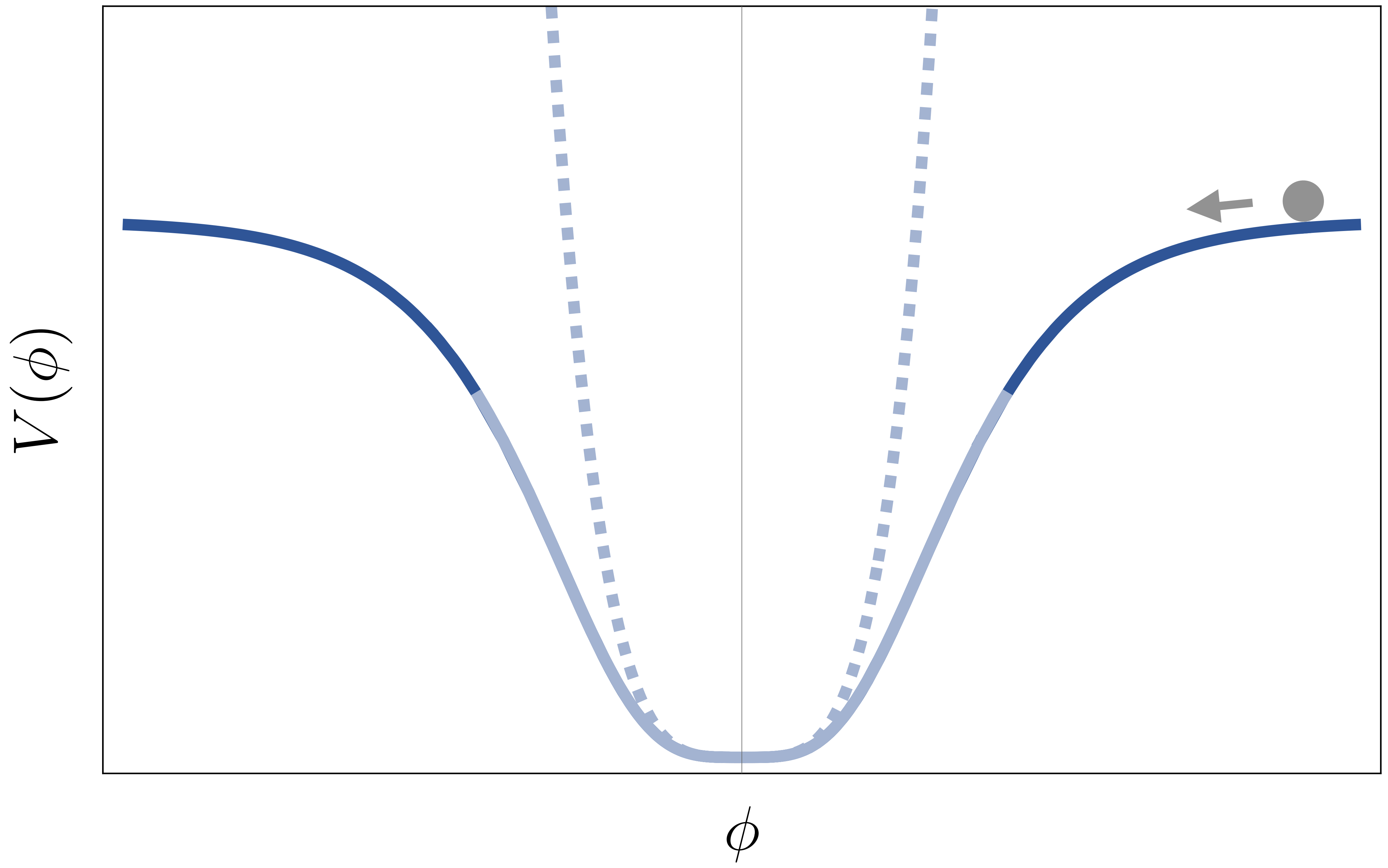
- Inflation ends at: $\phi_{\rm e} \simeq 2.696 m_{\rm pl}$

Inflation



Reheating after α-attractor inflation

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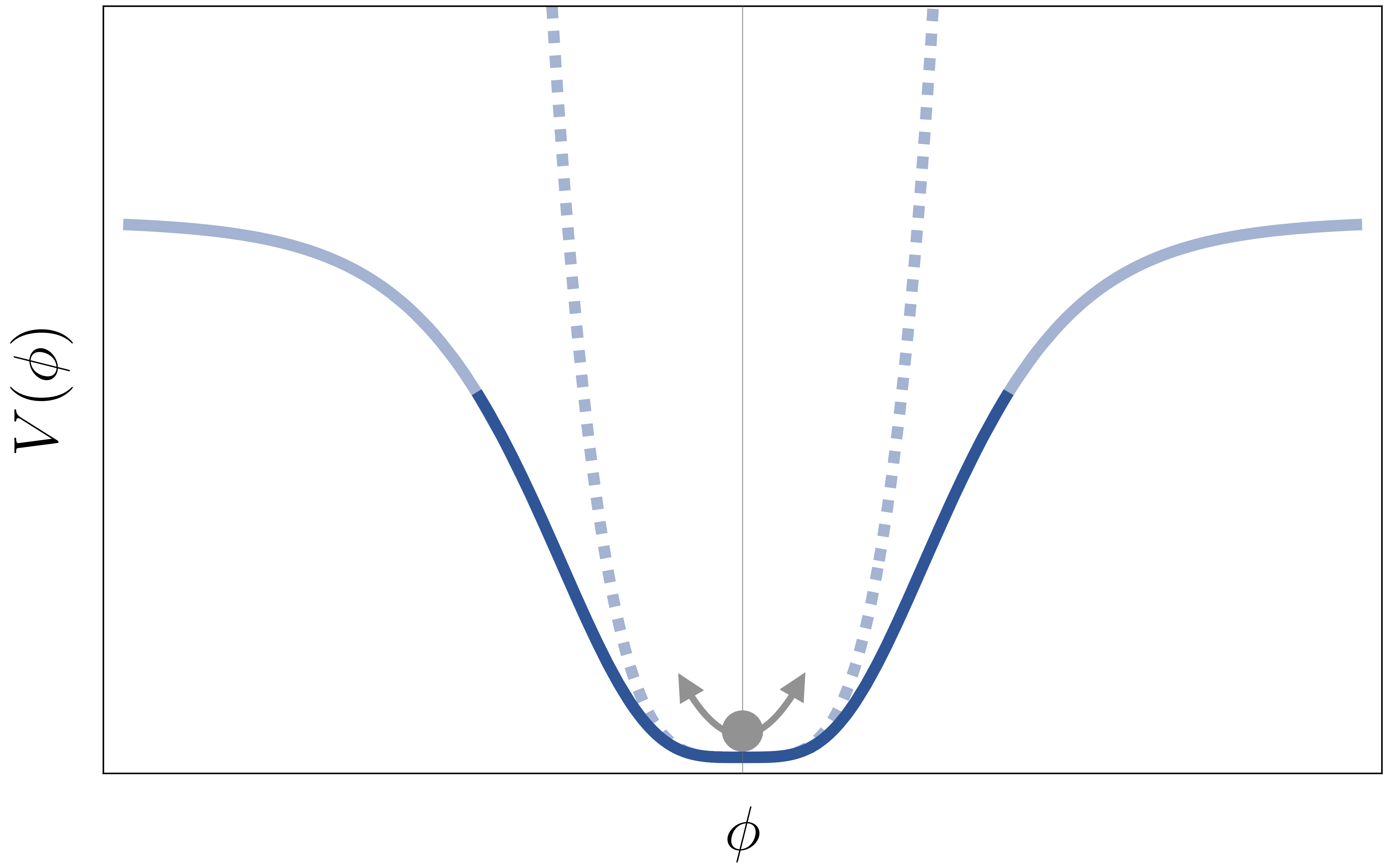

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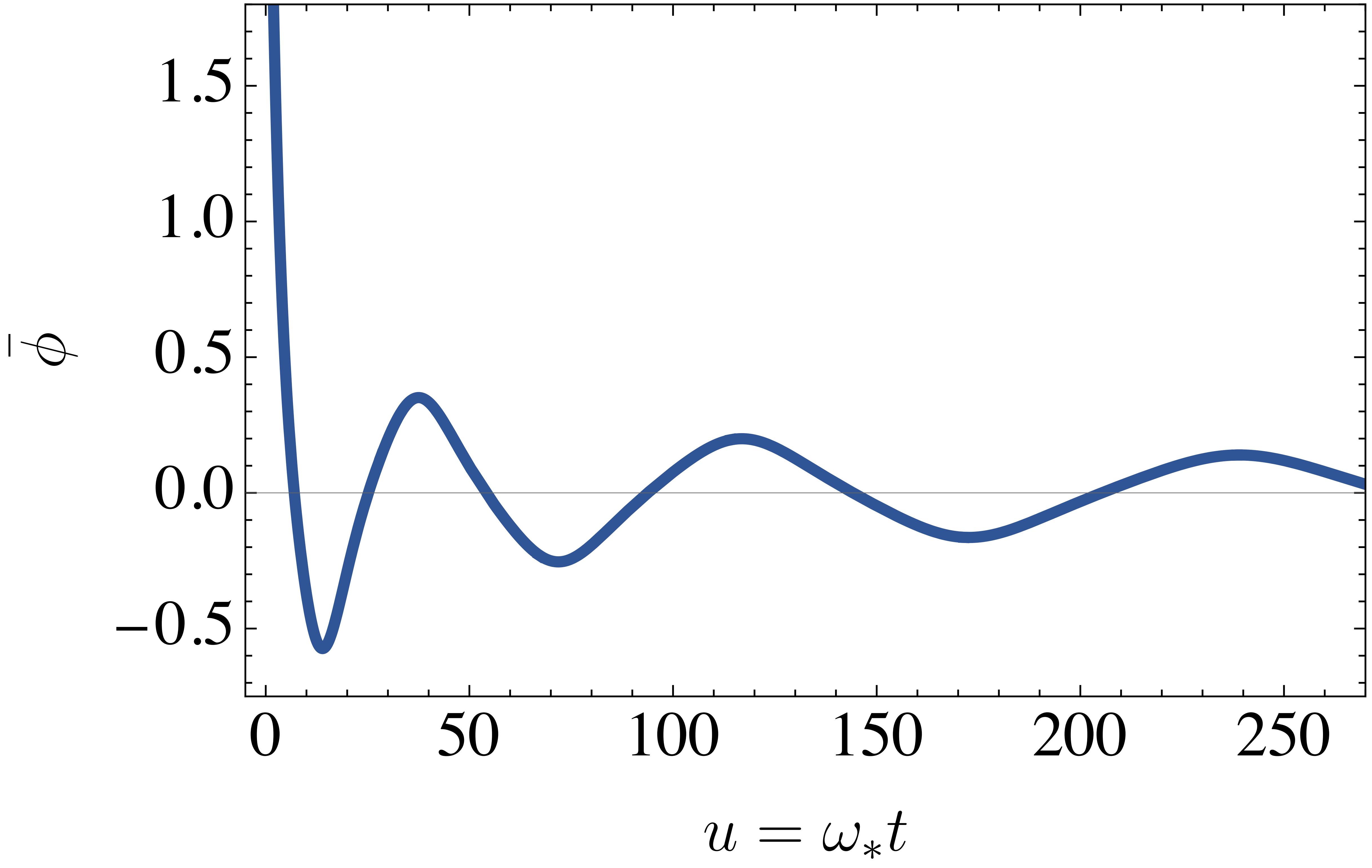

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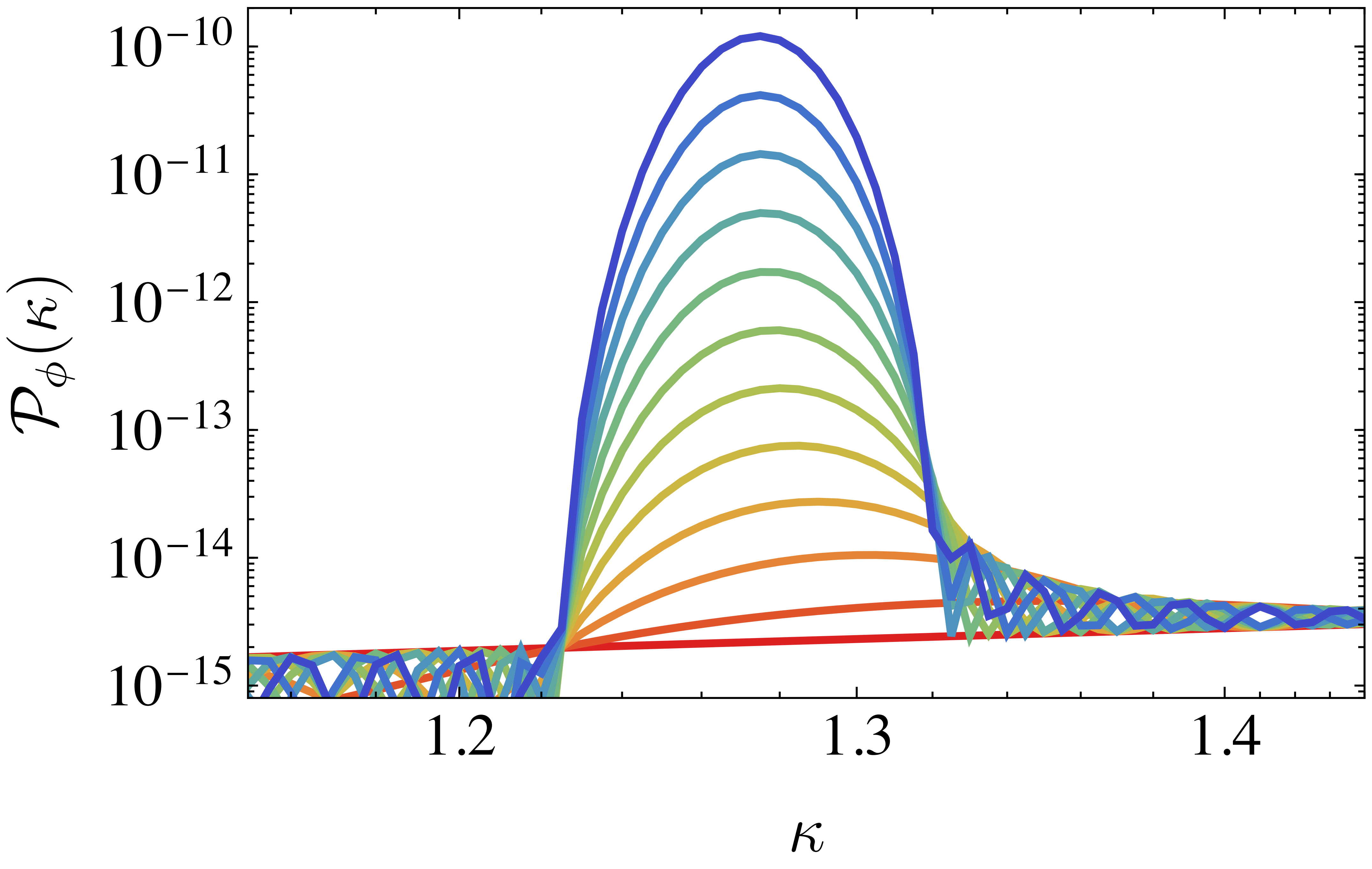
Self-Resonance

$$\tilde{\phi}_k'' + \left(\kappa^2 + m_\phi^2(\tilde{\phi})\right)\tilde{\phi}_k = 0$$



Program variables

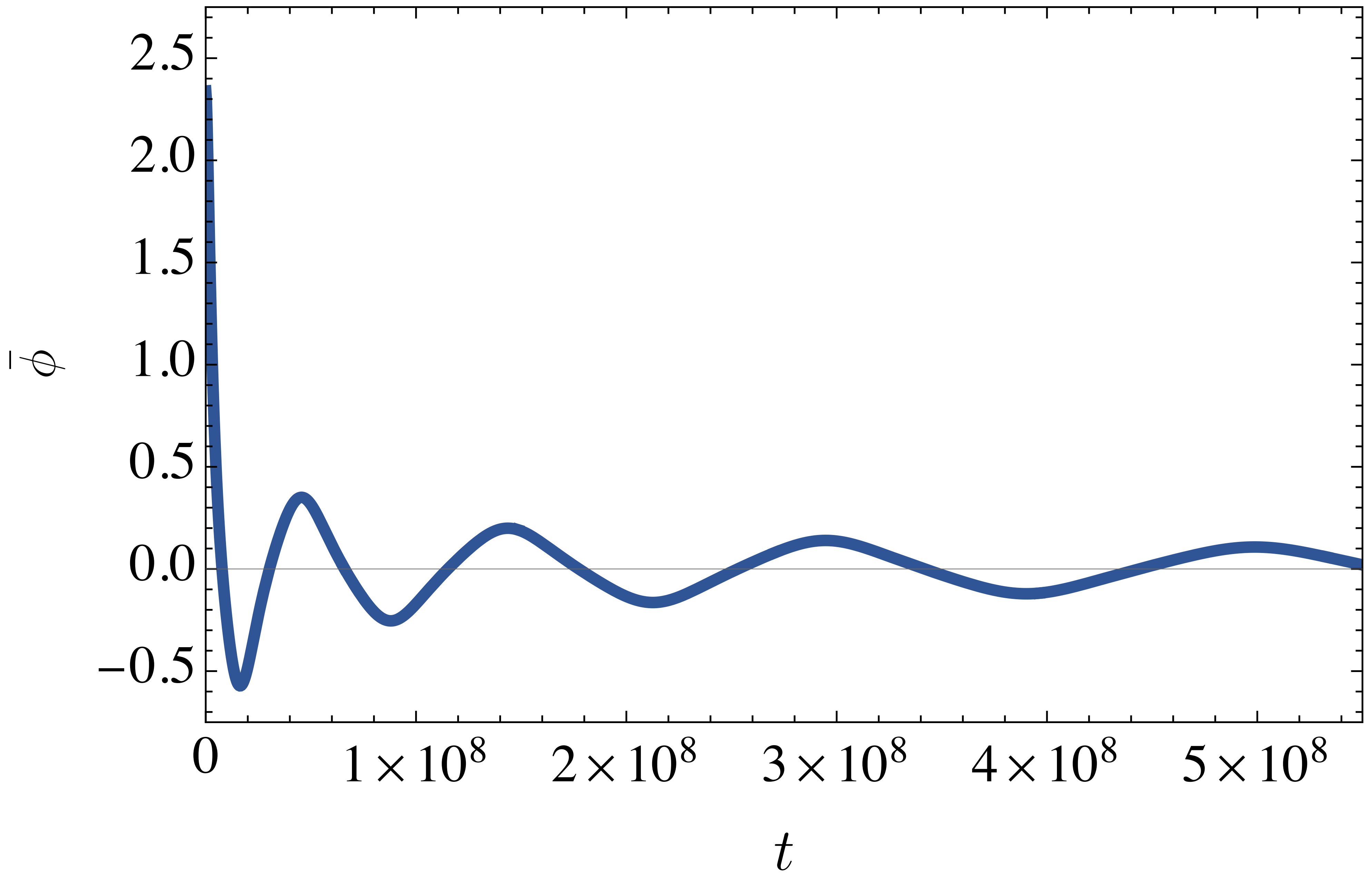
Program variables:

$$f_* = \phi_* \qquad \omega_* = \frac{\Lambda^2}{M^2}\phi_* \qquad \alpha = 1$$

$$\rightarrow$$

$$d\tilde{\eta} \equiv \frac{\Lambda^2}{M^2}\phi_* a^{-1} dt \qquad \tilde{\phi} = \frac{\phi}{\phi_*}$$

$$d\tilde{x}^i \equiv \frac{\Lambda^2}{M^2}\phi_* dx^i \qquad \tilde{\chi} = \frac{\chi}{\phi_*}$$



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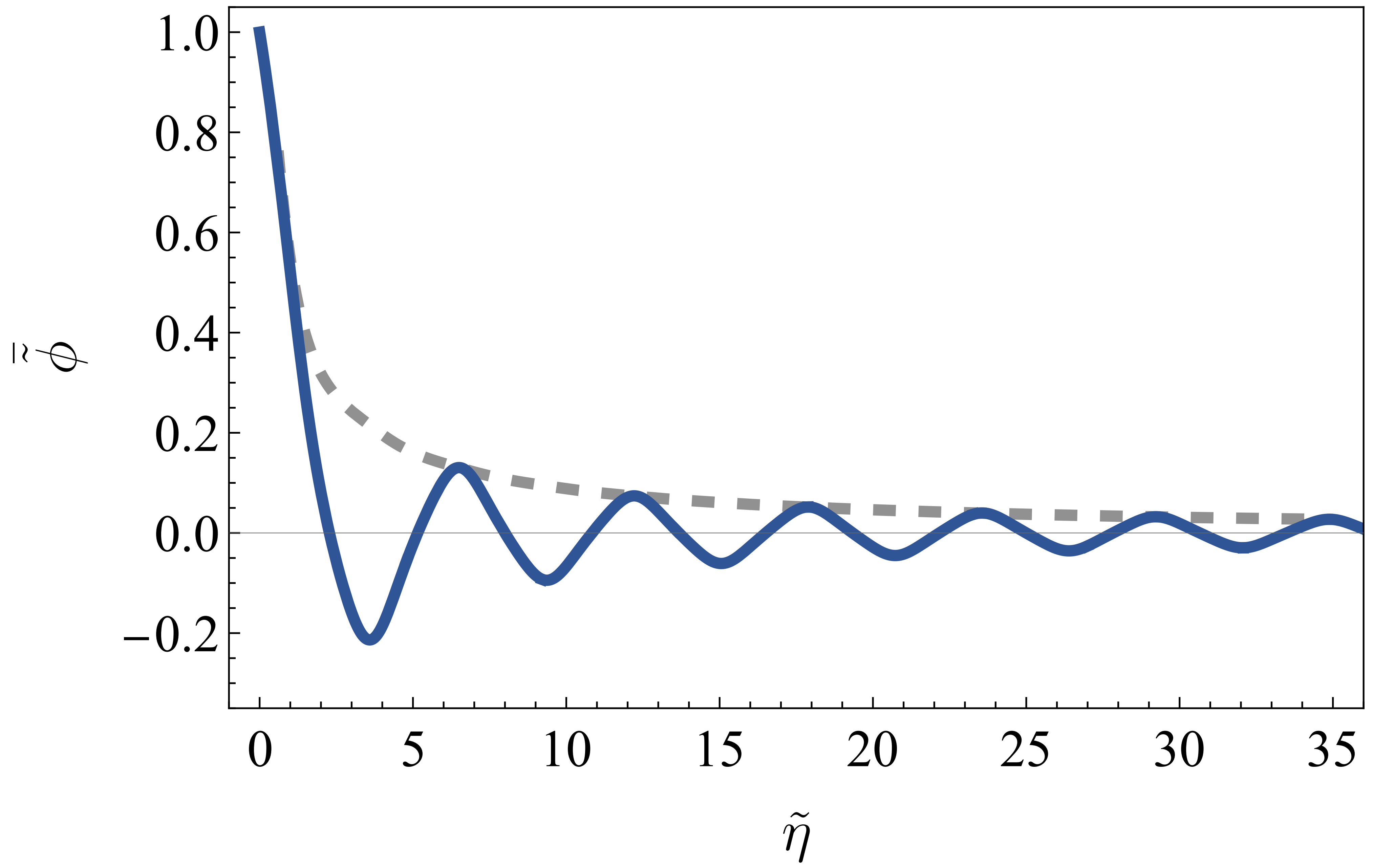

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Program potential and derivatives:

- $$\tilde{V}(\tilde{\phi}) \equiv \frac{V(f_*\tilde{\phi})}{f_*^2\omega_*^2} = \frac{1}{4}\left(\frac{M}{\phi_*}\right)^4 \tanh^4\left(\frac{\phi_*\tilde{\phi}}{M}\right)$$
- $$\frac{\partial\tilde{V}(\tilde{\phi})}{\partial\tilde{\phi}} = 2\left(\frac{M}{\phi_*}\right)^3 \frac{\tanh^4\left(\phi_*\tilde{\phi}/M\right)}{\sinh(2\phi_*\tilde{\phi}/M)}$$
- $$\frac{\partial^2\tilde{V}(\tilde{\phi})}{\partial\tilde{\phi}^2} = 4\left(\frac{M}{\phi_*}\right)^2 \left(4 - \cosh\left(\frac{2\phi_*\tilde{\phi}}{M}\right)\right) \frac{\tanh^4\left(\phi_*\tilde{\phi}/M\right)}{\sinh(2\phi_*\tilde{\phi}/M)}$$

Exercise 1

1. Download the **tanh4_Ex1.h** model and the **tanh4_Ex1.in** files and add them to the models and parameter-files folders. The **tanh4_Ex1.in** contains a simulation with M=10mpl

2. The potential and derivative terms are missing, add them! For example, the potential term should look as follows

```
auto potentialTerms(Tag<0>) // Inflaton potential energy
{
  return pow<4>(M/phii) * pow<4>(tanh(fldS(0_c)*phii/M)) / 4;
}
```

3. Go to your build folder, and compile and run the simulation

```
cd build
cmake -DMODEL=tanh4_Ex1 ../
make cosmolattice
./tanh4_Ex1 input=../src/models/parameter-files/tanh4_Ex1.in
```

4. Analyse the volume-averaged field amplitudes and variances, energy components, and field spectra with the Mathematica or Python notebooks that is provided for this practice session.

Exercise 2: Add a scalar daughter field

Model

$$V(\phi,\chi) = \frac{1}{4}\Lambda^4 \tanh^4\left(\frac{\phi}{M}\right) + \frac{1}{2}g^2\phi^2\chi^2$$

Inflaton is coupled to a scalar singlet daughter field via scale free interaction.

Program potential:

$$\tilde{V}(\tilde{\phi},\tilde{\chi}) = \frac{1}{4}\left(\frac{M}{\phi_*}\right)^4 \tanh^4\left(\frac{\phi_*\tilde{\phi}}{M}\right) + \frac{1}{2}q\tilde{\phi}^2\tilde{\chi}^2$$

with resonance parameter: $q \equiv \frac{g^2}{\Lambda^4/M^4}$

The potential derivatives are given by:

- $$\frac{\partial\tilde{V}(\tilde{\phi},\tilde{\chi})}{\partial\tilde{\phi}} = 2\left(\frac{M}{\phi_*}\right)^3 \frac{\tanh^4\left(\phi_*\tilde{\phi}/M\right)}{\sinh(2\phi_*\tilde{\phi}/M)} + q\,\tilde{\chi}^2\tilde{\phi}$$
- $$\frac{\partial\tilde{V}(\tilde{\phi},\tilde{\chi})}{\partial\tilde{\chi}} = q\,\tilde{\phi}^2\tilde{\chi}$$
- $$\frac{\partial^2\tilde{V}(\tilde{\phi},\tilde{\chi})}{\partial\tilde{\phi}^2} = \frac{\partial^2\tilde{V}(\tilde{\phi})}{\partial\tilde{\phi}^2} + q\,\tilde{\chi}^2$$
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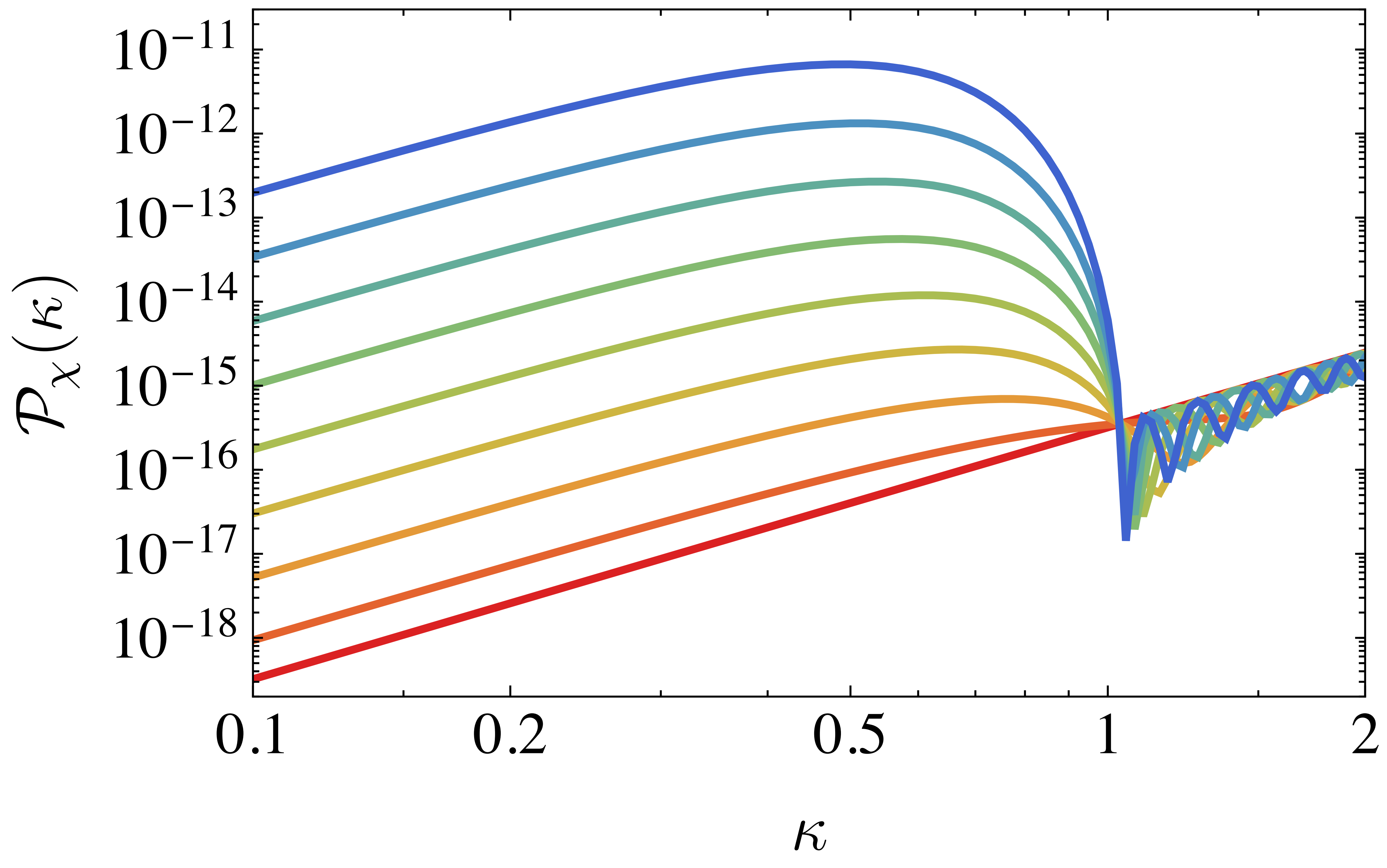
$$\tilde{\chi}_k'' + \left(\kappa^2 + m_\chi^2(\tilde{\phi})\right)\tilde{\chi}_k = 0$$



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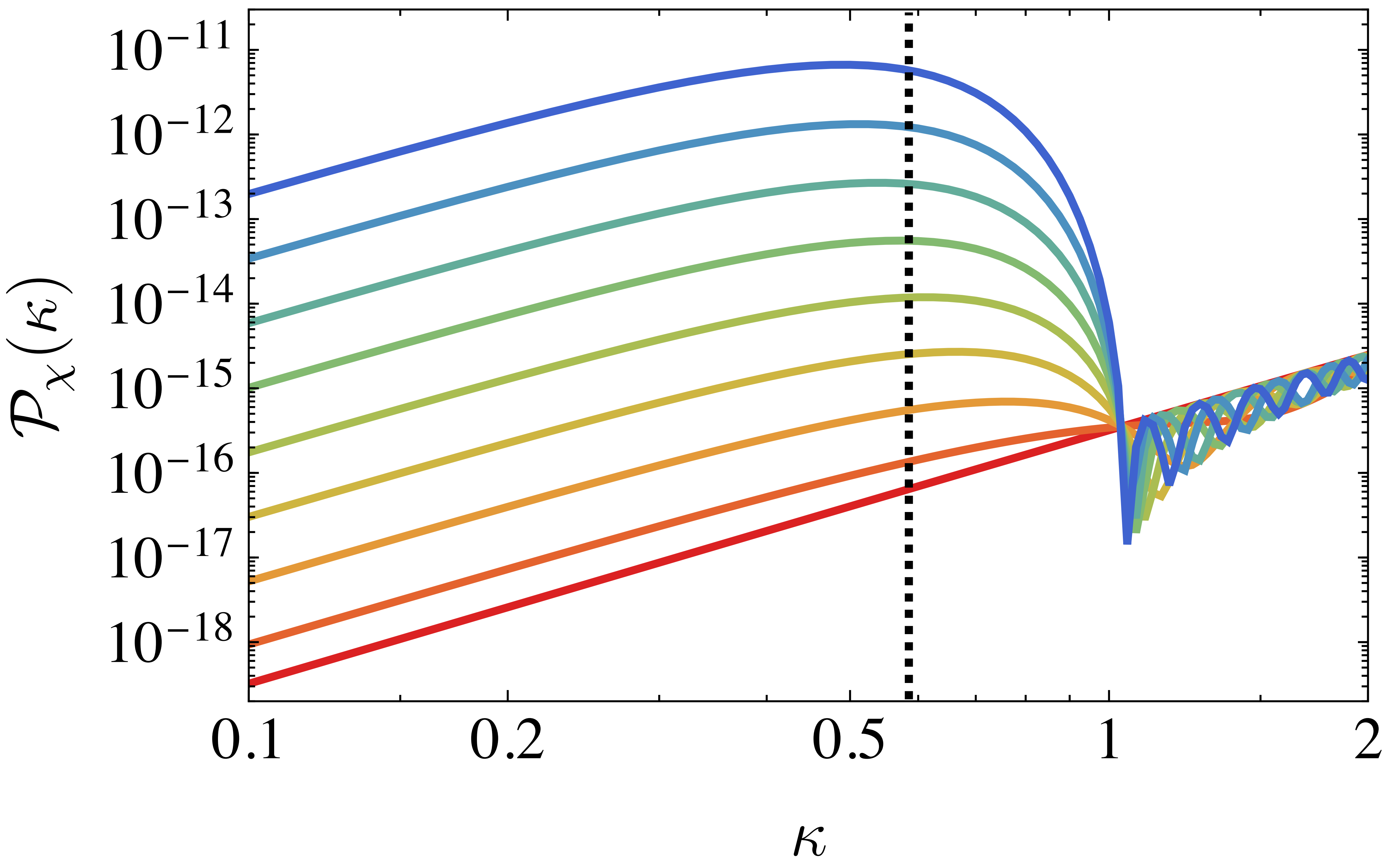

Exercise 2

1. Download the **tanh4_Ex2.h** model and the **tanh4_Ex2.in** files and add them to the models and parameter-files folders.

2. Go through the model file and add/modify the missing parts. It should include a second scalar field and the appropriate potential and derivative terms.

3. Go through the **tanh4_Ex2.in** file and choose appropriate values for the missing lattice parameters. (You may need to do several test runs to figure out which values work best)

4. Go to your build folder, and compile and run the simulation

```
cd build
cmake -DMODEL=tanh4_Ex2 ../
make cosmolattice
./tanh4_Ex2 input=../src/models/parameter-files/tanh4_Ex2.in
```

5. Analyse the volume-averaged field amplitudes and variances, energy components, and field spectra with the Mathematica or Python notebooks that have been provided in Practice Session 1.

Thank you!