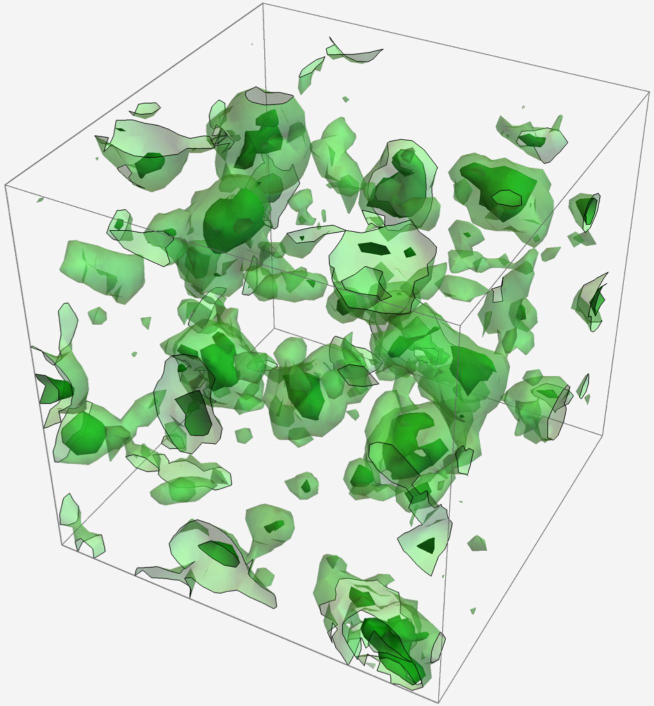
CosmoLattice School 2022

Plotting 3D data with CosmoLattice

Kenneth Marschall
University of Basel

Goal of the lecture

Run a simulation and print snapshots of the energy distributions



Motivation

Consider the potential:

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

with $M = 0.01 m_{\rm pl}$

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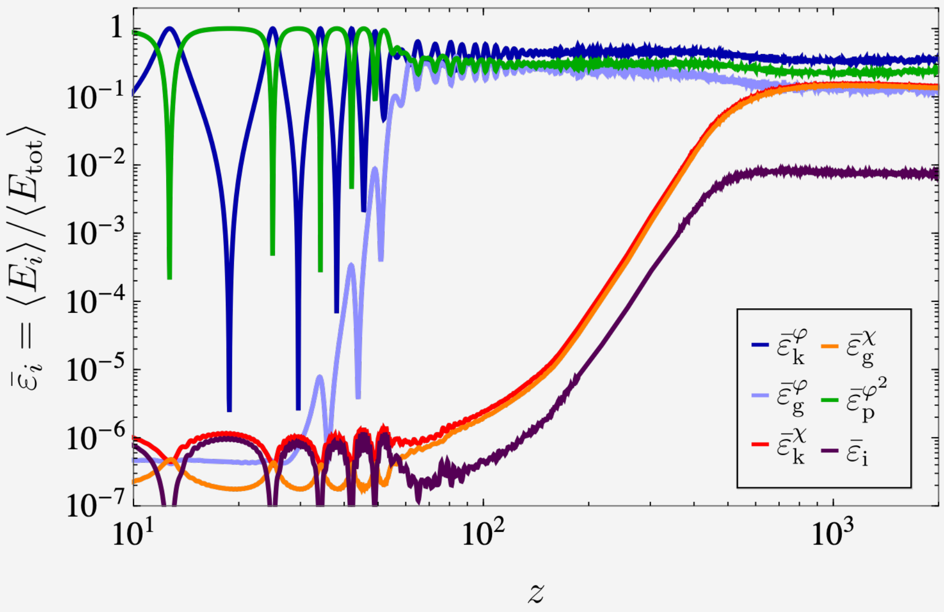

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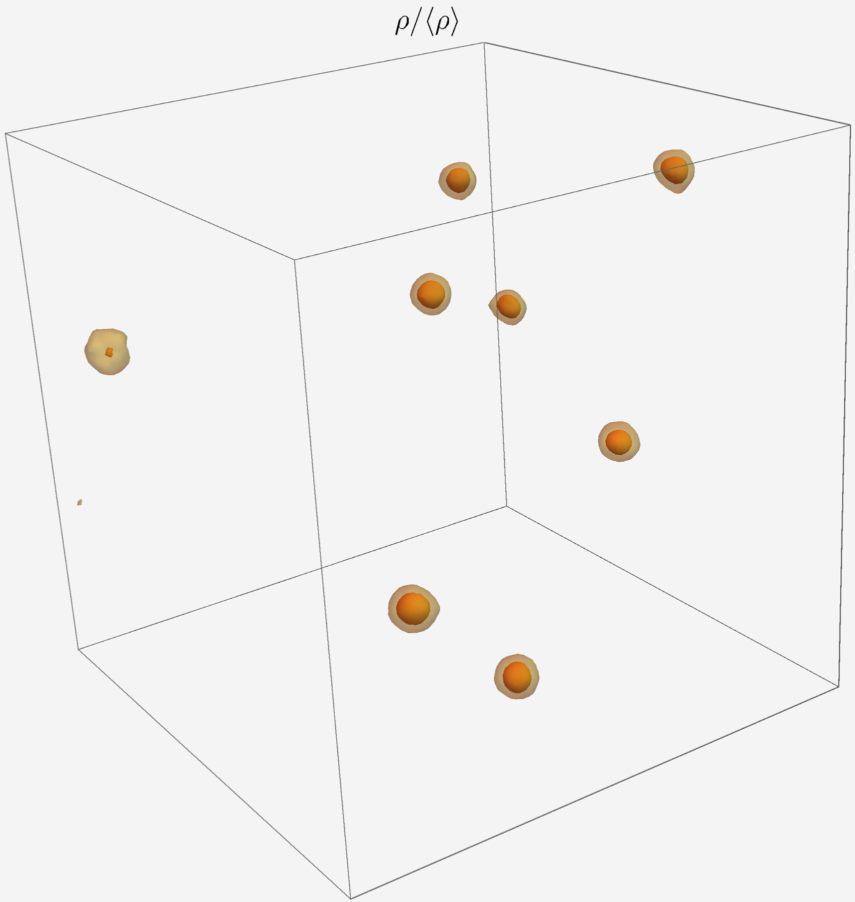

Hierarchical Data Format (HDF5)

CosmoLattice uses the HDF5 library to save snapshots of the three dimensional distributions of the different energy components of the simulated system.

HDF5: Preparation

First, we have to install the HDF5 library by:

```
cd dependencies
bash hdf5.sh MyHDF5                # Only if you also want the serial version
bash hdf5.sh MyHDF5 --parallel     # Only if you also want the parallel version
```

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bash hdf5.sh MyHDF5 --parallel   # Only if you also want the parallel version
```

In CMakeLists.txt we have to set HDF5 from 'OFF' to 'ON' (line 15):

```
set(HDF5 ON CACHE BOOL "Set to ON to build with HDF5 support for saving fields (default = OFF)")
```

(Also, you might need to include the MYHDF5_PATH (line 56) in CMakeLists.txt)

Structure of h5 files in CosmoLattice

Snapshots of the different energy distributions are taken by:

energysnapshotmeasurer.h

- `cosmolattice` :
  - `src` :
    - `tests`
    - `include` :
      - `TempLat` :
        - *cosmolattice.h*
        - `fft`
        - `lattice`
        - `parallel`
        - `parameters`
        - `session`
        - `util`
      - `CosmoInterface` :
        - *CosmoInterface.h* [+ other files]
        - `definitions`
        - `evolvers`
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Structure of h5 files in CosmoLattice

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Snapshots of e.g. the kinetic energy density of a scalar field is 'taken' by:

```
if(saveScalarK) {   // kinetic energy of the scalar singlets
    ForLoop(i, 0, Model::Ns -1,
                    fIO.saver.open( nameScalarK );
                    fIO.saver.save(t, Energies::kineticS(model,FieldFunctionals::pi2S(model,i)),
                        "E_S_K_" + std::to_string(i));
                    fIO.saver.close();
            );
}
```

Structure of h5 files in CosmoLattice

CL saves the different energy components in .h5 files with the name structure:

type_energy_snapshot_fieldtype.h5

	type	fieldtype
Scalars	kinetic, gradient	scalar, complex_scalar, SU2_doublet
Gauge fields	electric, magnetic	U1, SU2

The potential energy is saved in: potential_energy_snapshot.h5

Structure of h5 files in CosmoLattice

If you open a snapshot in e.g a text editor, you'll find weird stuff:

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J∞tÙÓs©?%hÓs©?µËhõÓs©?e¸D˘Ôs©?_¢n/Ìs©?$]Ω˙Îs©?∗PòìÏs©?)‹≥Ïs©?
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7ü~WÎs©?5(/ÕÏs©?ˆ|Ú¸Ïs©?R˘˘Ôs©?,h+®Ós©?∑=µÙÍs©?¸{åçÏs©?‘h„Ïs©?†±!ÔÌs©?£„Ã–
Ìs©?ú çmÌs©?w¨¨ßÏs©?˘sóÌs©?Kƒ·ìÏs©?Å„`±Ìs©?m x«Îs©?ïÙäÌÏs©?Sz@DÓs©? ®ÚÌs©?
∂Ìs©?‰‡∑Ós©?rQwGÔs©?≠Z6<Ìs©? è0PÏs©?ƒyx#Ìs©?tG‘âÏs©?8 ?@4

To read .h5 files use: Mathematica, Matlab, python, gnuplot, etc.

Structure of h5 files in CosmoLattice

HDF5 files are structured in Groups and Datasets.

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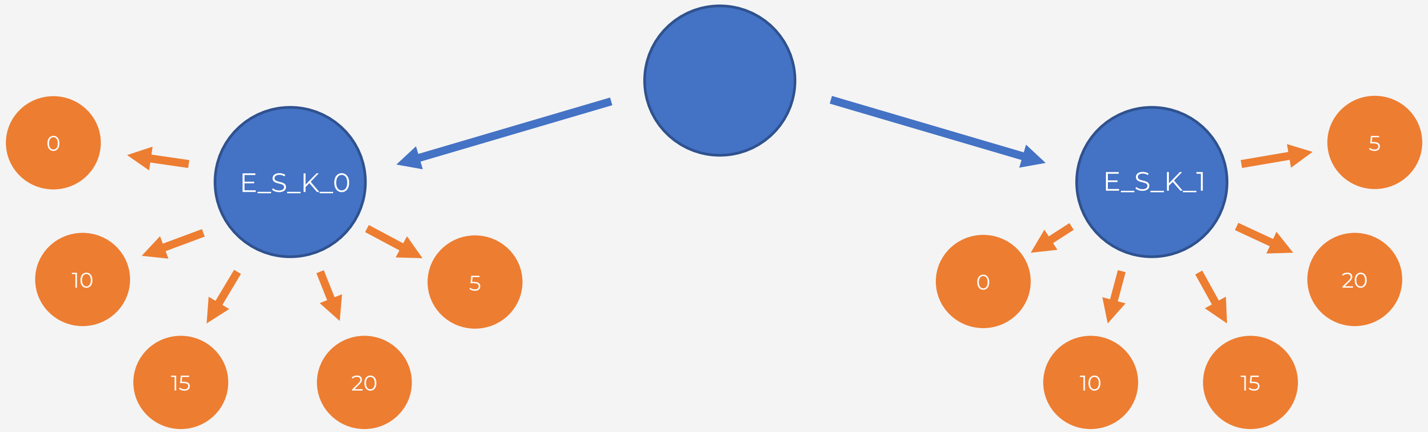
The kinetic_energy_snapshot_scalar.h5 file of a simulation with <u>two</u> real scalar fields is structured as follows:



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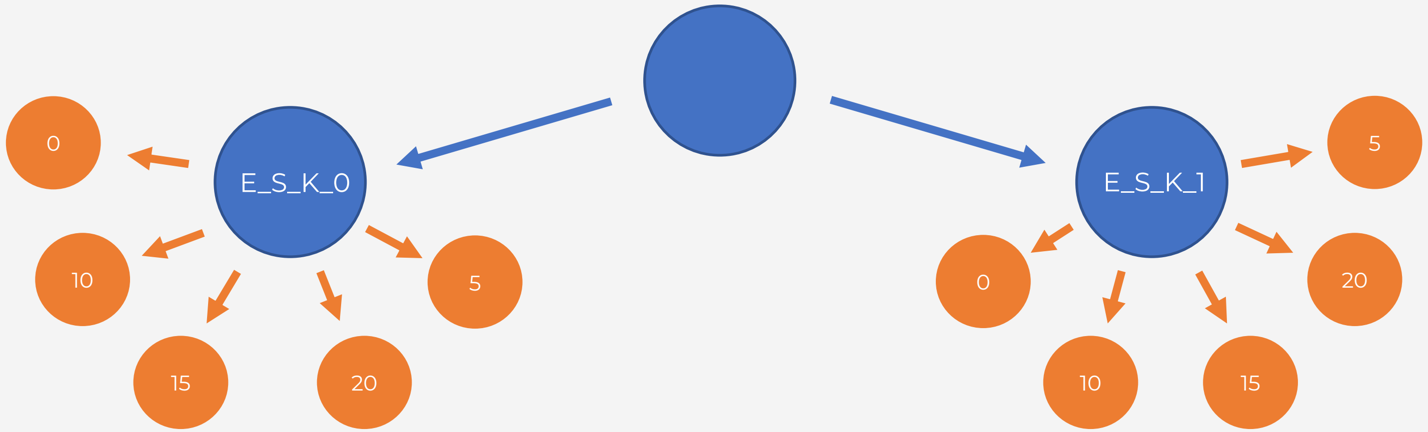

In Mathematica:

```
Import["kinetic_energy_snapshot_scalar.h5", "Summary"]
Import["kinetic_energy_snapshot_scalar.h5", "StructureGraph"]
```

Structure of h5 files in CosmoLattice

The Groups of the different fields are named as follows:

Scalar fields:	kinetic	gradient
Scalar singlet	E_S_K_#	E_S_G_#
Complex scalar	E_CS_K_#	E_CS_G_#
SU(2) doublet	E_SU2D_K_#	E_SU2D_G_#

Gauge fields:	electric	magnetic
U(1)	E_A_K_#	E_A_G_#
SU(2)	E_B_K_#	E_B_G_#

Structure of h5 files in CosmoLattice

We consider a simulation with $N_{\rm grid} = 4$. Snapshots can be imported into Mathematica by:

```
Import["kinetic_energy_snapshot_scalar.h5", {"Data"}]
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Structure of h5 files in CosmoLattice

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```
Import["kinetic_energy_snapshot_scalar.h5", {"Data"}]
```

The first kinetic energy snapshot of the first scalar field is structured as follows:

```
/E_S_K_0/0. →
{{{0.000276042, 0.000275981, 0.000275959, 0.00027602}, {0.000276028, 0.000276077, 0.000275973, 0.000275922},
  {0.000275976, 0.000275983, 0.000276027, 0.000276018}, {0.00027601, 0.000276069, 0.000275992, 0.000275933}},
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 {{0.000275996, 0.000275998, 0.000276003, 0.000276001}, {0.000276074, 0.000276017, 0.000275927, 0.000275985},
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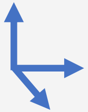

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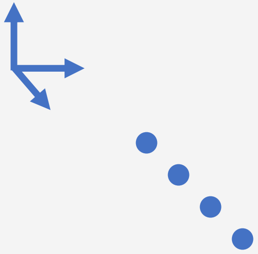

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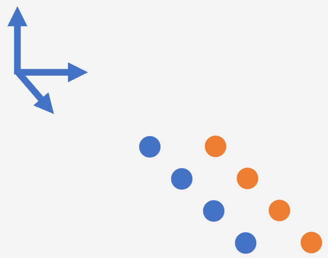

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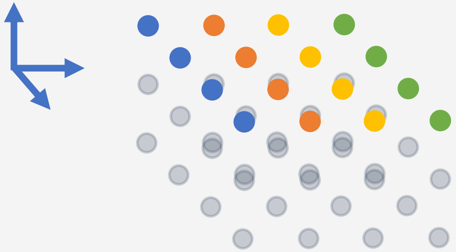

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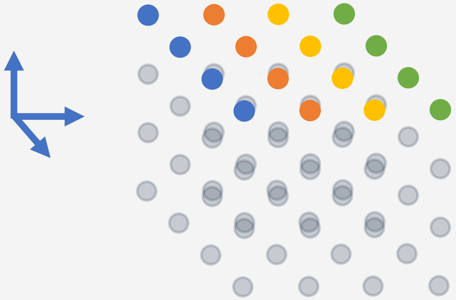

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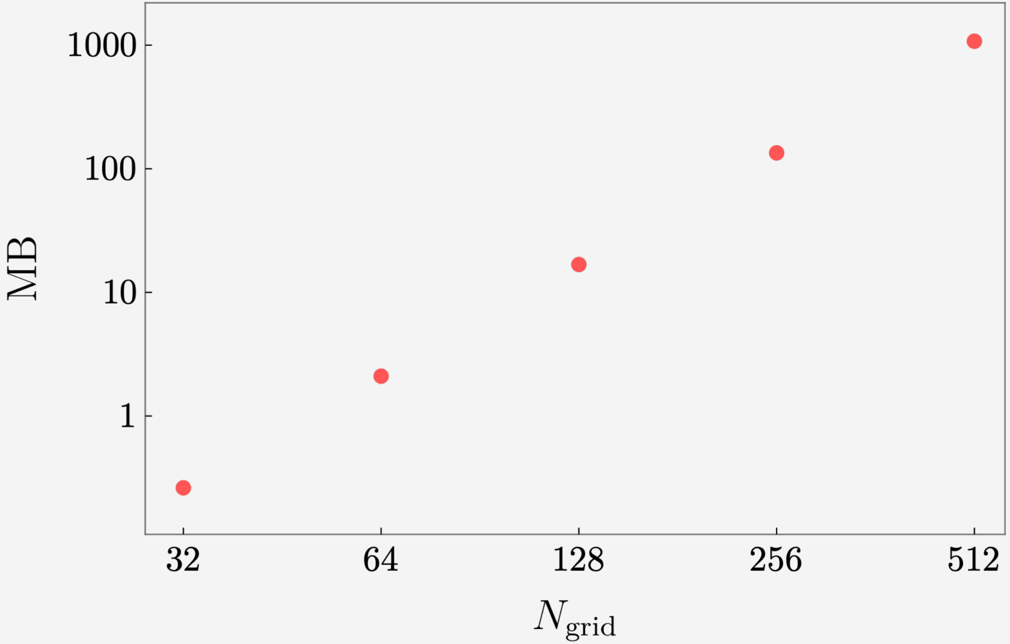
Structure of h5 files in CosmoLattice

A word of caution:

1 slice of a simulation of 1 field with $N_{\mathrm{grid}} = 128$ needs $\sim 17\,\mathrm{MB}$

For a simulation with $N_{\mathrm{grid}} = 256$ you need $8\times$ more space, etc.



Structure of h5 files in CosmoLattice

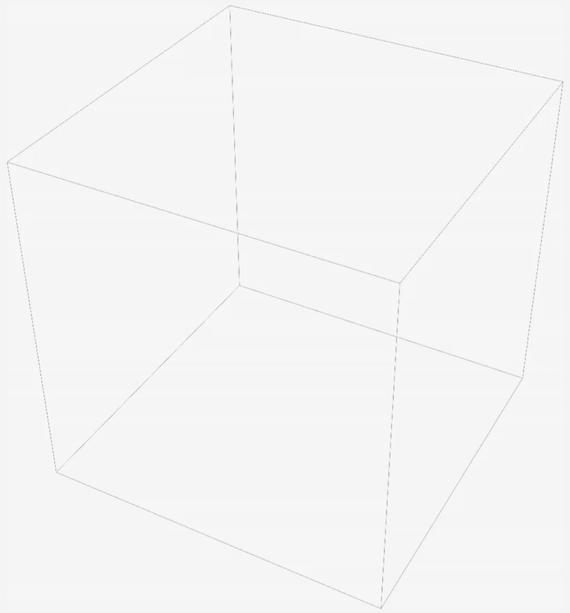
A word of caution:

If your interested in other quantities, e.g. the total energy density of a scalar singlet, you can add it in energysnapshotmeasurer.h to save storage:

```
if(saveScalar) {   // total energy of the scalar singlets
    ForLoop(i, 0, Model::Ns -1,
                    fIO.saver.open( nameScalar );
                    fIO.saver.save(t, Energies::kineticS(model,FieldFunctionals::pi2S(model,i)) +
                        Energies::gradientS(model,FieldFunctionals::grad2S(model,i)) +
                        Potential::potential(model), "E_S_" + std::to_string(i));
                    fIO.saver.close();
            );
}
```

Example

Example

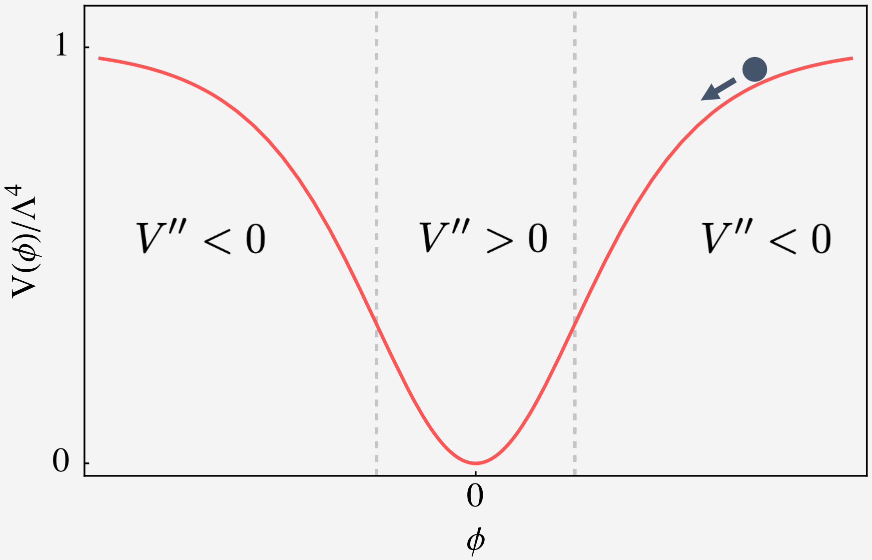


Example: Tachyonic Preheating

Potential we consider:

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

with $M = 0.01 m_{\rm pl}$



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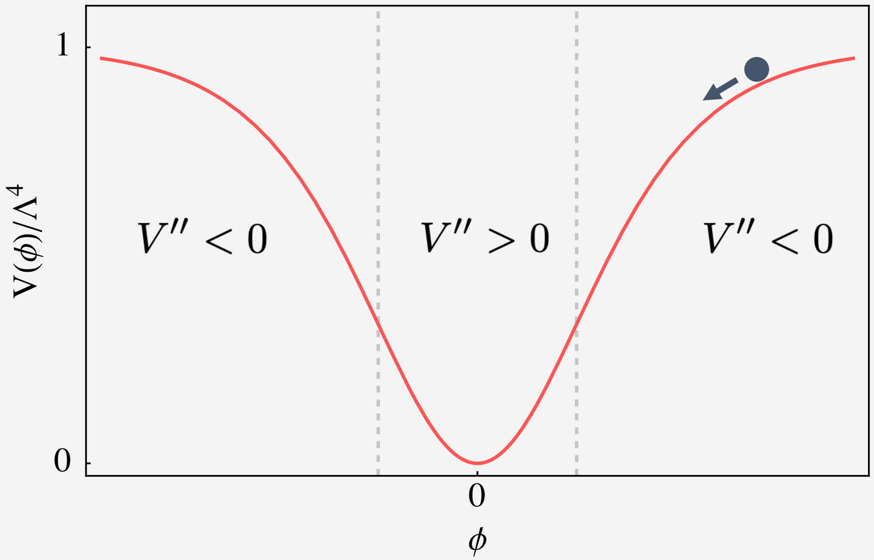
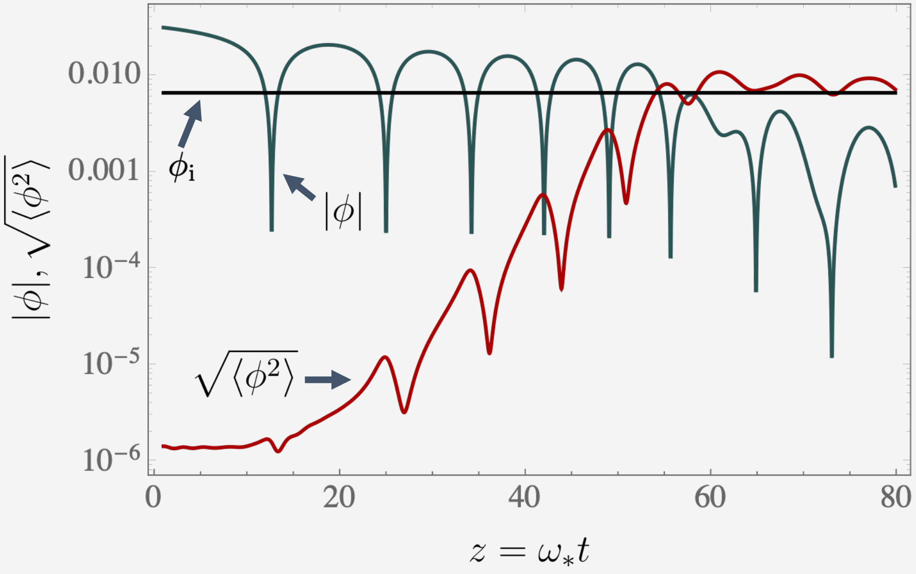
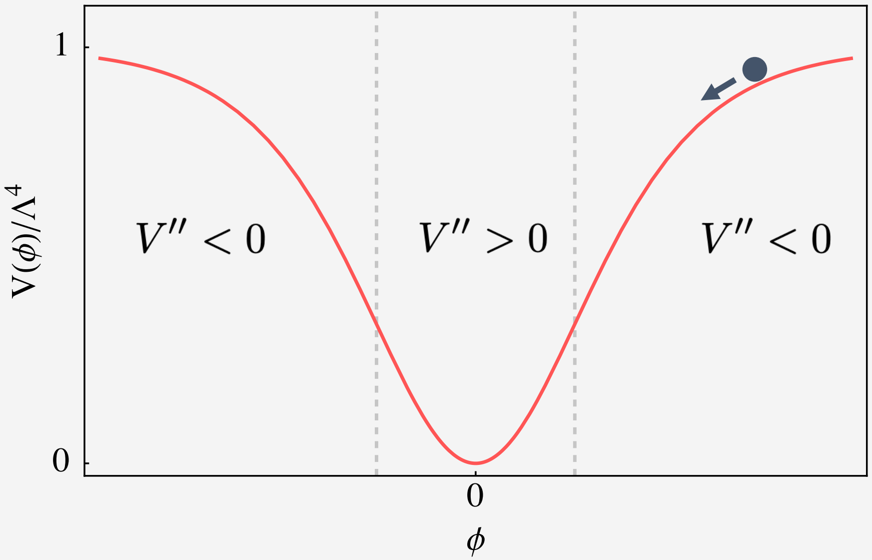
Inflection point:

$$\phi_{\mathrm{i}} = M \operatorname{arcsinh}\left(\sqrt{\frac{1}{2}}\right)$$



Example: Tachyonic Preheating





Example: Preparation

You can download from indico a folder that contains following files:

model file: tanh2hdf5.h
input file: tanh2hdf5.in

Mathematica notebook: SnapshotPrinter.nb

Example: Preparation

You can download from indico a folder that contains following files:

model file: tanh2hdf5.h
input file: tanh2hdf5.in

Put the model file into the models folder and the input file into the parameter-files folder.

cosmolattice :
CMakeLists.txt [+ other files]
dependencies
docs
cosmolattice.cpp [+ other files]
cmake
models
tests
cosmolattice.h
fft

Example: Preparation

You can download from indico a folder that contains following files:

model file: tanh2hdf5.h
input file: tanh2hdf5.in

compile the model:

```
cmake -DHDF5=ON -DMODEL=tanh2hdf5 ../
make cosmolattice
```

Example: Input file

The input file tanh2hdf5.in contains the following simulation:

```
#Output
outputfile = ./

#Evolution
expansion = true
evolver = VV2

#Lattice
N = 32
dt = 0.1
kIR = 0.15
baseSeed = 10
```

```
#Times
tMax = 80
tOutputFreq = 0.1
tOutputInfreq = 10

tOutputRareFreq = 1
energy_snapshot = E_S_K E_S_G E_V

#IC
kCutOff = 2.
initial_amplitudes = 7.717e16
initial_momenta = -2.598e28

#Model Parameters
M = 2.435e16
Lambda4 = 1.217e59
```

Example: Energies

Energy densities

kinetic: $\tilde{K} = \frac{1}{2}(\tilde{\phi}')^2$

gradient: $\tilde{G} = \frac{1}{2}\sum_i(\tilde{\nabla}_i\tilde{\phi})^2$

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CL outputs:

kinetic_energy_snapshot_scalar.h5

gradient_energy_snapshot_scalar.h5

potential_energy_snapshot.h5

Example: Start Simulation

Energy densities

kinetic: $\tilde{K} = \frac{1}{2}(\tilde{\phi}')^2$

gradient: $\tilde{G} = \frac{1}{2}\sum_i(\tilde{\nabla}_i\tilde{\phi})^2$

potential: $\tilde{V}$

CL outputs:

kinetic_energy_snapshot_scalar.h5

gradient_energy_snapshot_scalar.h5

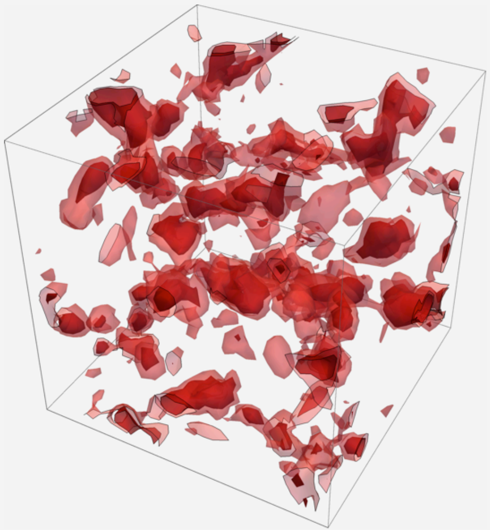
potential_energy_snapshot.h5

Start the simulation with:

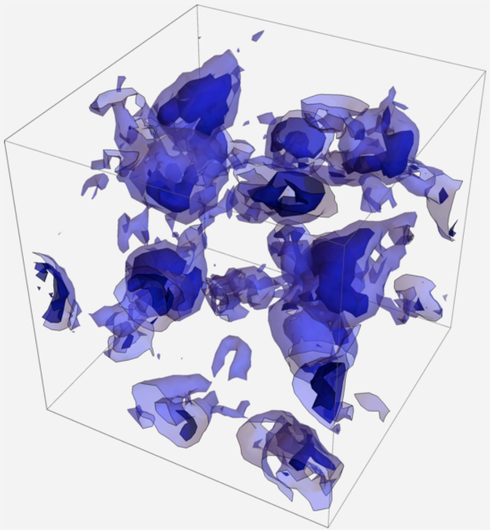
```
./tanh2hdf5 input=../src/models/parameter-files/tanh2hdf5.in
```

Example: SnapshotPrinter.nb

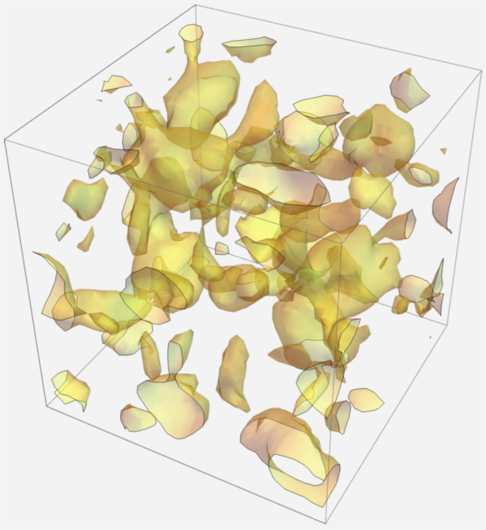
With the provided notebook you can print:



$$\varepsilon_k = \tilde{K}/\langle \tilde{E}_{\mathrm{tot}} \rangle$$



$$\varepsilon_g = \tilde{G}/\langle \tilde{E}_{\mathrm{tot}} \rangle$$



$$\varepsilon_p = \tilde{V}/\langle \tilde{E}_{\mathrm{tot}} \rangle$$

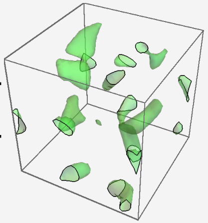
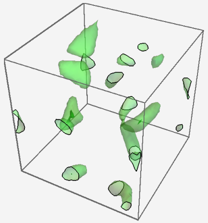
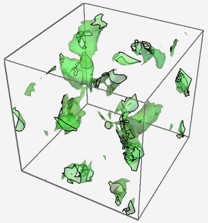
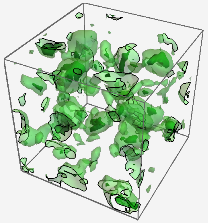
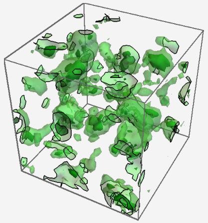
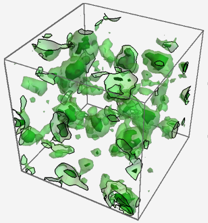
Example: SnapshotPrinter.nb

Save the energy density snapshots in a film reel to make a movie:

```
reel = Table[ListContourPlot3D[(tabKE0[[i, 2]] + tabGE0[[i, 2]] + tabVE0[[i, 2]]) / Etot[tabE0[[i, 1]]],
    Contours → {ContourA, ContourB}, ContourStyle → {ContourStyleA, ContourStyleB},
    PlotRange → All, Mesh -> None, Ticks → None], {i, 1, length}];
```

Example: SnapshotPrinter.nb

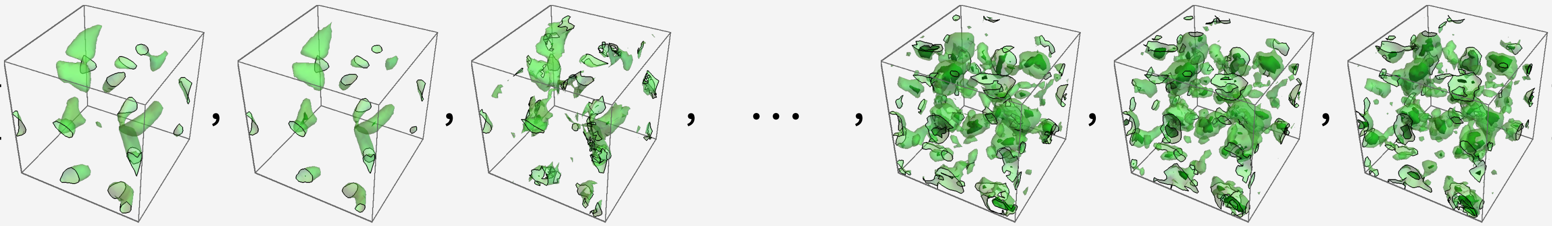
Save the energy density snapshots in a film reel to make a movie:

reel = {  ,  ,  , … ,  ,  ,  }

Example: SnapshotPrinter.nb

Save the energy density snapshots in a film reel to make a movie:

reel = {



}

Which you can export as a movie:

```
Export["movie.avi", reel, "FrameRate" → 4, ImageResolution → 100]
```