

# Lorenz\_PINN\_baseline

March 27, 2024

```
[16]: # import numpy, scipy, and matplotliblib
import numpy as np
import scipy as sp
import matplotlib.pyplot as plt

from sklearn.model_selection import train_test_split

import torch
%matplotlib widget

import os
import tempfile

# torch random seed
torch.manual_seed(0)
```

```
[16]: <torch._C.Generator at 0x7fc00a44f8b0>
```

## 1 Lorenz PINN baseline

In this notebook we apply the same method as the DHO baseline to the Lorenz system. After some preliminary test, here we show what append if we limit the train time span between (0,0.25) training the short\_lorenz\_baseline. In a second part we will train the long\_lorenz\_baseline with the time span (0,1).

### 1.1 Useful func

```
[17]: def lorenz(t, Y):
      """
      This function returns the right-hand side of the Lorenz system of ordinary_
      ↪differential equations.
      Parameters:
      t (float): time
      Y (array): state vector [x, y, z]

      Returns:
      array: [dxdt, dydt, dzdt]
```

```

"""

x, y, z = Y
dxdt = 10 * (y - x)
dydt = x * (28 - z) - y
dzdt = x * y - 8/3 * z

return [dxdt, dydt, dzdt]

def seq_lorenz(Y):
    """
    This function returns the right-hand side of the Lorenz system of ordinary
    ↪ differential equations.
    Parameters:
    Y (array): state vector [x, y, z]

    Returns:
    array: [dxdt, dydt, dzdt]
    """

    x, y, z = Y[:, 0], Y[:, 1], Y[:, 2]
    dxdt = 10 * (y - x)
    dydt = x * (28 - z) - y
    dzdt = x * y - 8/3 * z

    return np.array([dxdt, dydt, dzdt]).T

```

```

[18]: def plot_components(X, Y):
    """
    This function plots the components of the state vector Y as a function of
    ↪ time X.
    """
    plt.figure(figsize=(15, 10))
    plt.subplot(131)
    plt.plot(X, Y[:,0], label='x')
    plt.ylabel('x')
    plt.xlabel('time')
    plt.grid()

    # do all the same for y
    plt.subplot(132)
    plt.plot(X, Y[:,1], label='y')
    plt.ylabel('y')
    plt.xlabel('time')
    plt.grid()

```

```

    # do all the same for z
    plt.subplot(133)
    plt.plot(X, Y[:,2], label='z')
    plt.ylabel('z')
    plt.xlabel('time')
    plt.grid()

def plot_compare_components(X, Y, Y_pred):
    """
    This function plots the components of the state vector  $Y$  and  $Y_{pred}$  as a
    function of time  $X$ .
    """
    plt.figure(figsize=(15, 10))
    plt.subplot(131)
    plt.plot(X, Y[:,0], label='x')
    plt.plot(X, Y_pred[:,0], label='x_pred')
    plt.ylabel('x')
    plt.xlabel('time')
    plt.legend()
    plt.grid()

    # do all the same for y
    plt.subplot(132)
    plt.plot(X, Y[:,1], label='y')
    plt.plot(X, Y_pred[:,1], label='y_pred')
    plt.ylabel('y')
    plt.xlabel('time')
    plt.legend()
    plt.grid()

    # do all the same for z
    plt.subplot(133)
    plt.plot(X, Y[:,2], label='z')
    plt.plot(X, Y_pred[:,2], label='z_pred')
    plt.ylabel('z')
    plt.xlabel('time')
    plt.legend()
    plt.grid()

def show_history(history, name=None):
    """
    This function plots the loss and learning rate as a function of epoch.
    """
    history = np.array(history)

```

```

fig, ax = plt.subplots(figsize=(15, 10))

# plot the loss
ax.plot(history[:, 0], label='loss')
ax.legend(loc='upper left')
ax.set_yscale('log')
ax.set_xlabel('epoch')
ax.set_ylabel('loss')
plt.grid()

# plot the learning rate
ax2 = ax.twinx()
ax2.plot(history[:, -1], label='lr', color='r')
ax2.set_yscale('log')
ax2.set_ylabel('lr')
# legend to the right
ax2.legend(loc='upper right')
plt.grid()
plt.title('history' + name)

# history to list
history = history.tolist()

# def a function called ode_loss
def lorenz_loss_ode(model, X):
    """
    This function calculates the loss of the ode for the Lorenz system
    as a function of the input tensor X (time).
    Parameters:
    model (torch.nn.Module): the model
    X (torch.tensor): the input tensor
    """

    X.requires_grad = True
    Y_pred = model(X)

    # get the derivatives
    dx_dt_pred = torch.autograd.grad(Y_pred[:, 0], X, grad_outputs=torch.
    ↪ones_like(Y_pred[:, 0]), create_graph=True)[0]
    dy_dt_pred = torch.autograd.grad(Y_pred[:, 1], X, grad_outputs=torch.
    ↪ones_like(Y_pred[:, 1]), create_graph=True)[0]
    dz_dt_pred = torch.autograd.grad(Y_pred[:, 2], X, grad_outputs=torch.
    ↪ones_like(Y_pred[:, 2]), create_graph=True)[0]

    # get true derivatives, using the lorenz parameter

```

```

dx_dt_ode = 20 * (Y_pred[:,1] - Y_pred[:,0])
dy_dt_ode = Y_pred[:,0] * (28 - Y_pred[:,2]) - Y_pred[:,1]
dz_dt_ode = Y_pred[:,0] * Y_pred[:,1] - 8/3 * Y_pred[:,2]

# loss ode
loss_ode = (dx_dt_pred[:,0]- dx_dt_ode)**2 + (dy_dt_pred[:,0]-
↳dy_dt_ode)**2 + (dz_dt_pred[:,0]- dz_dt_ode)**2

return loss_ode

def plot_propagation(X, Y_true, Y_pred, Y0_index):
    """
    This function compare predicted and true solution of the lorenz system,
    in addition there is the solution (with solve_ivp) propagated from the
    ↳predicted state at the Y0_index.
    Parameters:
    X (array): time
    Y_true (array): true state
    Y_pred (array): predicted state
    Y0_index (int): index of the predicted state to be used as initial condition
    """

    # get the predicted state for the maximum index
    Y0 = Y_pred[Y0_index]

    # evolve with the lorenz function, use scipy ivp_solve
    sol = sp.integrate.solve_ivp(lorenz, [X[Y0_index], 1], Y0,
    ↳t_eval=X[Y0_index:])

    # plot the solution
    plt.figure(figsize=(15, 10))
    plt.subplot(131)
    plt.plot(sol.t, sol.y[0], label='x_prop', marker='o')
    # plot the predicted solution
    plt.plot(X, Y_pred[:,0], label='x_pred')
    # plot x real
    plt.plot(X, Y_true[:,0], label='x_real')
    # red dot in the maximum index
    plt.plot(X[Y0_index], Y_pred[Y0_index,0], 'ro')
    plt.ylabel('x')
    plt.xlabel('t')
    plt.grid()
    plt.legend()

    # do all the same for y

```

```

plt.subplot(132)
plt.plot(sol.t, sol.y[1], label='y_prop', marker='o')
plt.plot(X, Y_pred[:,1], label='y_pred')
plt.plot(X, Y_true[:,1], label='y_real')
plt.plot(X[Y0_index], Y_pred[Y0_index,1], 'ro')
plt.ylabel('y')
plt.xlabel('t')
plt.grid()

# do all the same for z
plt.subplot(133)
plt.plot(sol.t, sol.y[2], label='z_prop', marker='o')
plt.plot(X, Y_pred[:,2], label='z_pred')
plt.plot(X, Y_true[:,2], label='z_real')
plt.plot(X[Y0_index], Y_pred[Y0_index,2], 'ro')
plt.ylabel('z')
plt.xlabel('t')
plt.grid()

```

## 1.2 Load data

```

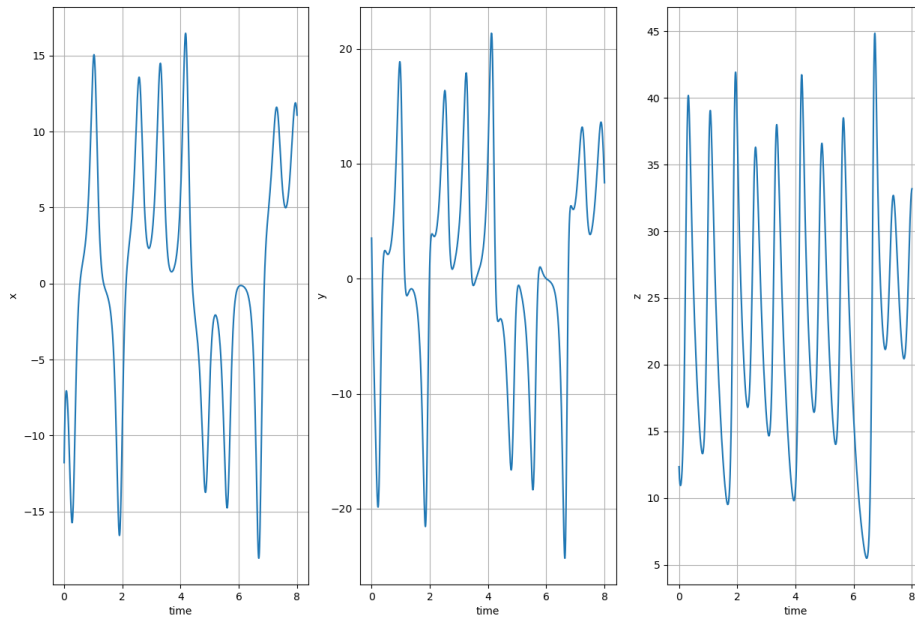
[19]: # import data
# data are generated by "src/DHOscillator_data_gen.py"
data = np.load('../data/Lorenz_data.npy')
# Y is the state, X is the time, Y is made of x, y, z
X = data[:,0]
Y = data[:,1:]

```

```

[20]: # plot components
plot_components(X, Y)

```



### 1.3 Define the model

This is inspired by the tuned model on DHO

```
[21]: # Model class
class FFNN(torch.nn.Module):
    def __init__(self, n_layers, n_neurons):
        super(FFNN, self).__init__()
        layers = []
        for i in range(n_layers):
            if i == 0:
                layers.append(torch.nn.Linear(1, n_neurons))
            else:
                layers.append(torch.nn.Linear(n_neurons, n_neurons))
                layers.append(torch.nn.Tanh())
            layers.append(torch.nn.Linear(n_neurons, 3))
        self.model = torch.nn.Sequential(*layers)
    def forward(self, x):
        return self.model(x)
```

```
[22]: n_layers = 4
n_neurons = 28
n_epochs = 10000
```

```
# create model
short_model = FFNN(n_layers, n_neurons)
```

## 1.4 Short model

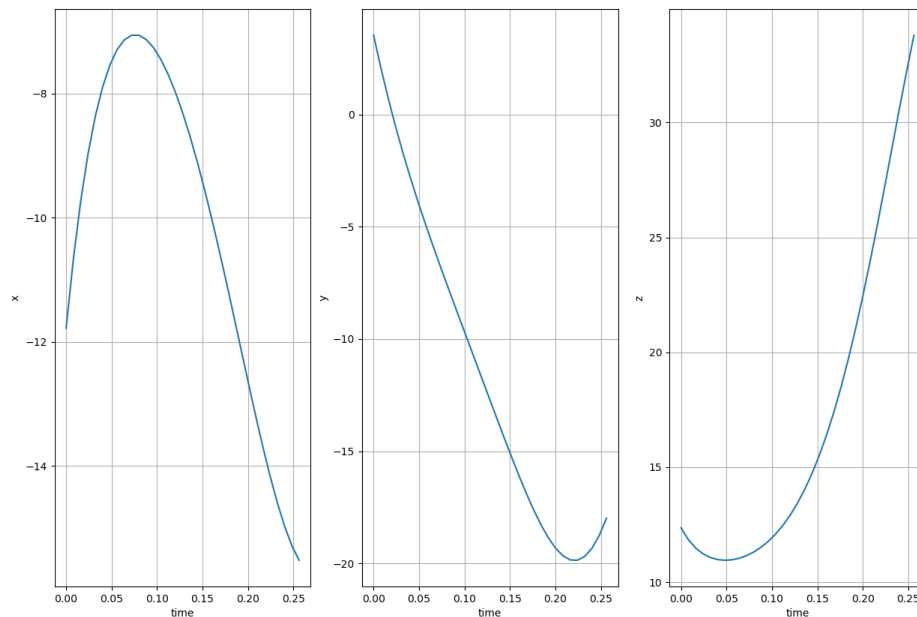
```
[23]: history_PINN = []
```

```
[24]: # define the optimizer
optimizer = torch.optim.Adam(short_model.parameters(), lr=0.001)
# add minimun to lr
scheduler = torch.optim.lr_scheduler.ReduceLROnPlateau(optimizer, 'min',
↪factor=0.8, patience=1000, min_lr=1e-5)

# define the loss function, L2
loss_fn = torch.nn.MSELoss()
```

```
[25]: # select only time < 2
X_sub = X[X<0.26]
Y_sub = Y[X<0.26]
```

```
[26]: # plot components
plot_components(X_sub, Y_sub)
```





```
[27]: # to torch
X_sub_t = torch.tensor(X_sub, dtype=torch.float32).view(-1, 1)
Y_sub_t = torch.tensor(Y_sub, dtype=torch.float32)
```

3\*250000

```
[38]: %%time

for epoch in range(3*250000):
    optimizer.zero_grad()
    X_sub_t.requires_grad = True
    Y_pred = short_model(X_sub_t)

    # get the derivatives
    dx_dt_pred = torch.autograd.grad(Y_pred[:,0], X_sub_t, grad_outputs=torch.
    ↪ones_like(Y_pred[:,0]), create_graph=True)[0]
    dy_dt_pred = torch.autograd.grad(Y_pred[:,1], X_sub_t, grad_outputs=torch.
    ↪ones_like(Y_pred[:,1]), create_graph=True)[0]
    dz_dt_pred = torch.autograd.grad(Y_pred[:,2], X_sub_t, grad_outputs=torch.
    ↪ones_like(Y_pred[:,2]), create_graph=True)[0]

    # get true derivatives, using the lorenz parameter
    dx_dt_ode = 10 * (Y_pred[:,1] - Y_pred[:,0])
    dy_dt_ode = Y_pred[:,0] * (28 - Y_pred[:,2]) - Y_pred[:,1]
    dz_dt_ode = Y_pred[:,0] * Y_pred[:,1] - 8/3 * Y_pred[:,2]

    # loss ode
    loss_ode = loss_fn(dx_dt_pred[:,0], dx_dt_ode) + loss_fn(dy_dt_pred[:,0],
    ↪dy_dt_ode) + loss_fn(dz_dt_pred[:,0], dz_dt_ode)

    # add loss ic
    loss_ic = torch.mean((Y_pred[0] - Y_sub_t[0])**2)

    loss = 20*loss_ode + loss_ic

    loss.backward()
    optimizer.step()
    scheduler.step(loss)

    history_PINN.append([loss.item(), loss_ode.detach().numpy(), loss_ic.
    ↪detach().numpy(), optimizer.param_groups[0]["lr"]])

    if epoch % 1000 == 0:
        print(f'Epoch {epoch}, Loss {loss.item()}, lr {optimizer.
        ↪param_groups[0]["lr"]}')

```

Epoch 0, Loss 0.26342737674713135, lr 0.00040960000000000001

Epoch 1000, Loss 0.484549343585968, lr 0.00040960000000000001  
Epoch 2000, Loss 0.2737593352794647, lr 0.00040960000000000001  
Epoch 3000, Loss 0.3397865891456604, lr 0.00040960000000000001  
Epoch 4000, Loss 0.2481081336736679, lr 0.00040960000000000001  
Epoch 5000, Loss 0.26107338070869446, lr 0.00040960000000000001  
Epoch 6000, Loss 0.6151490807533264, lr 0.00040960000000000001  
Epoch 7000, Loss 0.310327410697937, lr 0.00040960000000000001  
Epoch 8000, Loss 0.41346481442451477, lr 0.00040960000000000001  
Epoch 9000, Loss 0.23382900655269623, lr 0.00040960000000000001  
Epoch 10000, Loss 0.8320176005363464, lr 0.00040960000000000001  
Epoch 11000, Loss 0.25102561712265015, lr 0.00040960000000000001  
Epoch 12000, Loss 0.35422852635383606, lr 0.00040960000000000001  
Epoch 13000, Loss 0.25925007462501526, lr 0.00040960000000000001  
Epoch 14000, Loss 0.5006727576255798, lr 0.00040960000000000001  
Epoch 15000, Loss 0.542710542678833, lr 0.00040960000000000001  
Epoch 16000, Loss 0.20863153040409088, lr 0.00040960000000000001  
Epoch 17000, Loss 0.2256685197353363, lr 0.00040960000000000001  
Epoch 18000, Loss 0.4553592801094055, lr 0.00040960000000000001  
Epoch 19000, Loss 0.23574163019657135, lr 0.00040960000000000001  
Epoch 20000, Loss 0.5307074785232544, lr 0.00040960000000000001  
Epoch 21000, Loss 0.20027029514312744, lr 0.00040960000000000001  
Epoch 22000, Loss 0.20147134363651276, lr 0.00040960000000000001  
Epoch 23000, Loss 0.19673770666122437, lr 0.00040960000000000001  
Epoch 24000, Loss 0.49799203872680664, lr 0.00040960000000000001  
Epoch 25000, Loss 0.2607436776161194, lr 0.00040960000000000001  
Epoch 26000, Loss 0.1820361614227295, lr 0.00032768000000000001  
Epoch 27000, Loss 0.5748018026351929, lr 0.00032768000000000001  
Epoch 28000, Loss 0.2440687119960785, lr 0.00032768000000000001  
Epoch 29000, Loss 0.17857778072357178, lr 0.00032768000000000001  
Epoch 30000, Loss 0.2394225150346756, lr 0.00032768000000000001  
Epoch 31000, Loss 0.46871814131736755, lr 0.00032768000000000001  
Epoch 32000, Loss 0.47121661901474, lr 0.00032768000000000001  
Epoch 33000, Loss 0.18561848998069763, lr 0.00032768000000000001  
Epoch 34000, Loss 0.1880175769329071, lr 0.00032768000000000001  
Epoch 35000, Loss 0.24631918966770172, lr 0.00032768000000000001  
Epoch 36000, Loss 0.1812141090631485, lr 0.00032768000000000001  
Epoch 37000, Loss 0.3718787431716919, lr 0.00032768000000000001  
Epoch 38000, Loss 0.15920551121234894, lr 0.00032768000000000001  
Epoch 39000, Loss 0.2409868836402893, lr 0.00032768000000000001  
Epoch 40000, Loss 0.2605553865432739, lr 0.00032768000000000001  
Epoch 41000, Loss 0.23022834956645966, lr 0.00032768000000000001  
Epoch 42000, Loss 0.1855393499135971, lr 0.00032768000000000001  
Epoch 43000, Loss 0.16501949727535248, lr 0.00032768000000000001  
Epoch 44000, Loss 0.13774622976779938, lr 0.00032768000000000001  
Epoch 45000, Loss 0.46258407831192017, lr 0.00032768000000000001  
Epoch 46000, Loss 0.18900667130947113, lr 0.00032768000000000001  
Epoch 47000, Loss 0.1326463222503662, lr 0.00032768000000000001  
Epoch 48000, Loss 0.17300331592559814, lr 0.00032768000000000001

Epoch 49000, Loss 0.13285943865776062, lr 0.0003276800000000001  
Epoch 50000, Loss 0.15686339139938354, lr 0.0003276800000000001  
Epoch 51000, Loss 0.2058541476726532, lr 0.0003276800000000001  
Epoch 52000, Loss 0.1405266374349594, lr 0.0003276800000000001  
Epoch 53000, Loss 0.12706151604652405, lr 0.0003276800000000001  
Epoch 54000, Loss 0.6432791948318481, lr 0.0003276800000000001  
Epoch 55000, Loss 0.18401701748371124, lr 0.0003276800000000001  
Epoch 56000, Loss 0.13966165482997894, lr 0.0003276800000000001  
Epoch 57000, Loss 0.136574387550354, lr 0.0003276800000000001  
Epoch 58000, Loss 0.11922416090965271, lr 0.0003276800000000001  
Epoch 59000, Loss 0.11427754163742065, lr 0.0003276800000000001  
Epoch 60000, Loss 0.10878102481365204, lr 0.0003276800000000001  
Epoch 61000, Loss 0.22299078106880188, lr 0.0003276800000000001  
Epoch 62000, Loss 0.11129612475633621, lr 0.0003276800000000001  
Epoch 63000, Loss 0.28143104910850525, lr 0.0003276800000000001  
Epoch 64000, Loss 0.42254719138145447, lr 0.0003276800000000001  
Epoch 65000, Loss 0.13530588150024414, lr 0.0003276800000000001  
Epoch 66000, Loss 0.11001910269260406, lr 0.0003276800000000001  
Epoch 67000, Loss 0.0997278243303299, lr 0.0003276800000000001  
Epoch 68000, Loss 0.17189809679985046, lr 0.0003276800000000001  
Epoch 69000, Loss 0.38982340693473816, lr 0.0003276800000000001  
Epoch 70000, Loss 0.3315889835357666, lr 0.0003276800000000001  
Epoch 71000, Loss 0.10215266048908234, lr 0.0003276800000000001  
Epoch 72000, Loss 0.1920560896396637, lr 0.0003276800000000001  
Epoch 73000, Loss 0.09354259073734283, lr 0.0002621440000000001  
Epoch 74000, Loss 0.8761094212532043, lr 0.0002621440000000001  
Epoch 75000, Loss 0.09607982635498047, lr 0.0002621440000000001  
Epoch 76000, Loss 0.10870647430419922, lr 0.0002621440000000001  
Epoch 77000, Loss 0.08530294895172119, lr 0.0002621440000000001  
Epoch 78000, Loss 0.08172337710857391, lr 0.0002621440000000001  
Epoch 79000, Loss 0.08590124547481537, lr 0.0002621440000000001  
Epoch 80000, Loss 0.07879370450973511, lr 0.0002621440000000001  
Epoch 81000, Loss 0.09440170228481293, lr 0.0002621440000000001  
Epoch 82000, Loss 0.07650494575500488, lr 0.0002621440000000001  
Epoch 83000, Loss 0.08417562395334244, lr 0.0002621440000000001  
Epoch 84000, Loss 0.17601770162582397, lr 0.0002621440000000001  
Epoch 85000, Loss 0.07261036336421967, lr 0.0002621440000000001  
Epoch 86000, Loss 0.07149993628263474, lr 0.0002621440000000001  
Epoch 87000, Loss 0.08705708384513855, lr 0.0002621440000000001  
Epoch 88000, Loss 0.06909097731113434, lr 0.0002621440000000001  
Epoch 89000, Loss 0.20833326876163483, lr 0.0002621440000000001  
Epoch 90000, Loss 0.07758616656064987, lr 0.0002621440000000001  
Epoch 91000, Loss 1.0804251432418823, lr 0.0002621440000000001  
Epoch 92000, Loss 0.06620381772518158, lr 0.0002621440000000001  
Epoch 93000, Loss 0.06543199717998505, lr 0.0002621440000000001  
Epoch 94000, Loss 0.08157793432474136, lr 0.0002621440000000001  
Epoch 95000, Loss 0.9649913311004639, lr 0.0002621440000000001  
Epoch 96000, Loss 0.06957219541072845, lr 0.0002621440000000001

Epoch 97000, Loss 0.21804893016815186, lr 0.0002621440000000001  
Epoch 98000, Loss 0.06308673322200775, lr 0.0002621440000000001  
Epoch 99000, Loss 0.07656940817832947, lr 0.0002621440000000001  
Epoch 100000, Loss 0.08038856089115143, lr 0.0002621440000000001  
Epoch 101000, Loss 0.06358902901411057, lr 0.0002621440000000001  
Epoch 102000, Loss 0.15820108354091644, lr 0.0002621440000000001  
Epoch 103000, Loss 0.366810142993927, lr 0.0002621440000000001  
Epoch 104000, Loss 0.058468978852033615, lr 0.0002621440000000001  
Epoch 105000, Loss 0.05932345241308212, lr 0.0002621440000000001  
Epoch 106000, Loss 0.0894792228937149, lr 0.0002621440000000001  
Epoch 107000, Loss 0.053481586277484894, lr 0.0002621440000000001  
Epoch 108000, Loss 0.20286208391189575, lr 0.0002621440000000001  
Epoch 109000, Loss 0.05369500070810318, lr 0.0002621440000000001  
Epoch 110000, Loss 0.05316320061683655, lr 0.0002621440000000001  
Epoch 111000, Loss 0.04751544073224068, lr 0.0002621440000000001  
Epoch 112000, Loss 0.11623938381671906, lr 0.0002621440000000001  
Epoch 113000, Loss 0.04811007156968117, lr 0.0002621440000000001  
Epoch 114000, Loss 0.06126664578914642, lr 0.0002621440000000001  
Epoch 115000, Loss 0.10194414854049683, lr 0.0002621440000000001  
Epoch 116000, Loss 0.14897501468658447, lr 0.0002621440000000001  
Epoch 117000, Loss 0.042873725295066833, lr 0.0002621440000000001  
Epoch 118000, Loss 0.6193925738334656, lr 0.0002621440000000001  
Epoch 119000, Loss 0.06313852965831757, lr 0.0002621440000000001  
Epoch 120000, Loss 0.043494585901498795, lr 0.0002621440000000001  
Epoch 121000, Loss 0.08471044152975082, lr 0.0002621440000000001  
Epoch 122000, Loss 0.03931733965873718, lr 0.0002621440000000001  
Epoch 123000, Loss 0.08183515816926956, lr 0.0002621440000000001  
Epoch 124000, Loss 0.05959685146808624, lr 0.0002621440000000001  
Epoch 125000, Loss 0.04716525971889496, lr 0.0002621440000000001  
Epoch 126000, Loss 0.42861008644104004, lr 0.0002621440000000001  
Epoch 127000, Loss 0.1851668357849121, lr 0.0002621440000000001  
Epoch 128000, Loss 0.035716865211725235, lr 0.0002621440000000001  
Epoch 129000, Loss 0.04278714209794998, lr 0.0002621440000000001  
Epoch 130000, Loss 0.16943910717964172, lr 0.0002621440000000001  
Epoch 131000, Loss 0.0348145067691803, lr 0.0002621440000000001  
Epoch 132000, Loss 0.03484645485877991, lr 0.0002621440000000001  
Epoch 133000, Loss 0.12609632313251495, lr 0.0002621440000000001  
Epoch 134000, Loss 0.05929030478000641, lr 0.0002621440000000001  
Epoch 135000, Loss 0.7828461527824402, lr 0.0002621440000000001  
Epoch 136000, Loss 0.03312527388334274, lr 0.0002621440000000001  
Epoch 137000, Loss 0.030649175867438316, lr 0.0002621440000000001  
Epoch 138000, Loss 0.09419586509466171, lr 0.0002621440000000001  
Epoch 139000, Loss 0.03066711127758026, lr 0.0002621440000000001  
Epoch 140000, Loss 1.0074344873428345, lr 0.0002621440000000001  
Epoch 141000, Loss 0.05498269945383072, lr 0.0002621440000000001  
Epoch 142000, Loss 0.028648968786001205, lr 0.0002621440000000001  
Epoch 143000, Loss 0.02764841541647911, lr 0.0002621440000000001  
Epoch 144000, Loss 0.027545727789402008, lr 0.0002621440000000001

Epoch 145000, Loss 0.03709838539361954, lr 0.0002621440000000001  
Epoch 146000, Loss 0.03262490779161453, lr 0.0002621440000000001  
Epoch 147000, Loss 0.03938364237546921, lr 0.0002621440000000001  
Epoch 148000, Loss 0.061363376677036285, lr 0.0002621440000000001  
Epoch 149000, Loss 0.4333343505859375, lr 0.0002621440000000001  
Epoch 150000, Loss 0.03631962090730667, lr 0.0002621440000000001  
Epoch 151000, Loss 0.04981212317943573, lr 0.0002621440000000001  
Epoch 152000, Loss 0.02416454814374447, lr 0.0002621440000000001  
Epoch 153000, Loss 0.063046894967556, lr 0.0002621440000000001  
Epoch 154000, Loss 0.02413662150502205, lr 0.0002621440000000001  
Epoch 155000, Loss 0.022798193618655205, lr 0.0002621440000000001  
Epoch 156000, Loss 0.11627843230962753, lr 0.0002621440000000001  
Epoch 157000, Loss 0.1316903680562973, lr 0.0002621440000000001  
Epoch 158000, Loss 0.02188270352780819, lr 0.0002621440000000001  
Epoch 159000, Loss 0.022371631115674973, lr 0.0002621440000000001  
Epoch 160000, Loss 0.2542214095592499, lr 0.0002621440000000001  
Epoch 161000, Loss 0.020654721185564995, lr 0.0002621440000000001  
Epoch 162000, Loss 0.022517507895827293, lr 0.0002621440000000001  
Epoch 163000, Loss 0.19074806571006775, lr 0.0002621440000000001  
Epoch 164000, Loss 0.15665706992149353, lr 0.0002621440000000001  
Epoch 165000, Loss 0.019437385722994804, lr 0.0002621440000000001  
Epoch 166000, Loss 0.06331805139780045, lr 0.0002621440000000001  
Epoch 167000, Loss 0.018901929259300232, lr 0.0002621440000000001  
Epoch 168000, Loss 0.6142215132713318, lr 0.0002621440000000001  
Epoch 169000, Loss 0.018568653613328934, lr 0.0002621440000000001  
Epoch 170000, Loss 0.0462939627468586, lr 0.0002621440000000001  
Epoch 171000, Loss 0.022159110754728317, lr 0.0002621440000000001  
Epoch 172000, Loss 0.029190707951784134, lr 0.0002621440000000001  
Epoch 173000, Loss 0.01813674345612526, lr 0.0002621440000000001  
Epoch 174000, Loss 0.016871076077222824, lr 0.0002621440000000001  
Epoch 175000, Loss 0.06066199019551277, lr 0.0002621440000000001  
Epoch 176000, Loss 0.07939990609884262, lr 0.0002621440000000001  
Epoch 177000, Loss 0.01746118813753128, lr 0.0002621440000000001  
Epoch 178000, Loss 0.2232891023159027, lr 0.0002621440000000001  
Epoch 179000, Loss 0.016223708167672157, lr 0.0002621440000000001  
Epoch 180000, Loss 0.015954598784446716, lr 0.0002621440000000001  
Epoch 181000, Loss 0.02123374119400978, lr 0.0002621440000000001  
Epoch 182000, Loss 0.19318941235542297, lr 0.0002621440000000001  
Epoch 183000, Loss 0.029873037710785866, lr 0.0002621440000000001  
Epoch 184000, Loss 0.0161479152739048, lr 0.0002621440000000001  
Epoch 185000, Loss 0.023748308420181274, lr 0.0002621440000000001  
Epoch 186000, Loss 0.01475602574646473, lr 0.0002621440000000001  
Epoch 187000, Loss 0.17973726987838745, lr 0.0002621440000000001  
Epoch 188000, Loss 0.030416522175073624, lr 0.0002621440000000001  
Epoch 189000, Loss 0.02109741047024727, lr 0.0002621440000000001  
Epoch 190000, Loss 0.014070150442421436, lr 0.0002621440000000001  
Epoch 191000, Loss 0.013902915641665459, lr 0.0002621440000000001  
Epoch 192000, Loss 0.024248741567134857, lr 0.0002621440000000001

Epoch 193000, Loss 0.013181398622691631, lr 0.0002621440000000001  
Epoch 194000, Loss 0.12373608350753784, lr 0.0002621440000000001  
Epoch 195000, Loss 0.026585083454847336, lr 0.0002621440000000001  
Epoch 196000, Loss 0.06436893343925476, lr 0.0002621440000000001  
Epoch 197000, Loss 0.01234772801399231, lr 0.0002621440000000001  
Epoch 198000, Loss 0.012582866474986076, lr 0.0002621440000000001  
Epoch 199000, Loss 0.05864425003528595, lr 0.0002621440000000001  
Epoch 200000, Loss 0.5011572241783142, lr 0.0002621440000000001  
Epoch 201000, Loss 0.020714737474918365, lr 0.00020971520000000012  
Epoch 202000, Loss 0.05881894752383232, lr 0.00020971520000000012  
Epoch 203000, Loss 0.06317640095949173, lr 0.00020971520000000012  
Epoch 204000, Loss 0.03362848237156868, lr 0.00020971520000000012  
Epoch 205000, Loss 0.01436963677406311, lr 0.00020971520000000012  
Epoch 206000, Loss 0.21991980075836182, lr 0.00020971520000000012  
Epoch 207000, Loss 0.01054384745657444, lr 0.00020971520000000012  
Epoch 208000, Loss 0.3197035789489746, lr 0.00020971520000000012  
Epoch 209000, Loss 0.01027323305606842, lr 0.00016777216000000001  
Epoch 210000, Loss 0.010629920288920403, lr 0.00016777216000000001  
Epoch 211000, Loss 0.011924466118216515, lr 0.00016777216000000001  
Epoch 212000, Loss 0.1604505032300949, lr 0.00016777216000000001  
Epoch 213000, Loss 0.017744502052664757, lr 0.00016777216000000001  
Epoch 214000, Loss 0.08050897717475891, lr 0.00016777216000000001  
Epoch 215000, Loss 0.09089109301567078, lr 0.00016777216000000001  
Epoch 216000, Loss 0.011052665300667286, lr 0.00016777216000000001  
Epoch 217000, Loss 0.016173619776964188, lr 0.00016777216000000001  
Epoch 218000, Loss 0.1432618498802185, lr 0.00016777216000000001  
Epoch 219000, Loss 0.020542819052934647, lr 0.00016777216000000001  
Epoch 220000, Loss 0.010114668868482113, lr 0.00016777216000000001  
Epoch 221000, Loss 0.06625279784202576, lr 0.00016777216000000001  
Epoch 222000, Loss 0.008148003369569778, lr 0.00016777216000000001  
Epoch 223000, Loss 0.11220139265060425, lr 0.00016777216000000001  
Epoch 224000, Loss 0.008150261826813221, lr 0.00016777216000000001  
Epoch 225000, Loss 0.011674610897898674, lr 0.00016777216000000001  
Epoch 226000, Loss 0.17097532749176025, lr 0.00016777216000000001  
Epoch 227000, Loss 0.09613525122404099, lr 0.00016777216000000001  
Epoch 228000, Loss 0.007489650510251522, lr 0.00016777216000000001  
Epoch 229000, Loss 0.009380893781781197, lr 0.00016777216000000001  
Epoch 230000, Loss 0.023070745170116425, lr 0.00016777216000000001  
Epoch 231000, Loss 0.0071346210315823555, lr 0.00016777216000000001  
Epoch 232000, Loss 0.007527247071266174, lr 0.00016777216000000001  
Epoch 233000, Loss 0.007607749197632074, lr 0.00016777216000000001  
Epoch 234000, Loss 0.10259037464857101, lr 0.00016777216000000001  
Epoch 235000, Loss 0.0330854132771492, lr 0.00013421772800000008  
Epoch 236000, Loss 0.022737840190529823, lr 0.00013421772800000008  
Epoch 237000, Loss 0.011105815880000591, lr 0.00013421772800000008  
Epoch 238000, Loss 0.1959734708070755, lr 0.00013421772800000008  
Epoch 239000, Loss 0.006762959994375706, lr 0.00013421772800000008  
Epoch 240000, Loss 0.022140245884656906, lr 0.00013421772800000008

```
Epoch 241000, Loss 0.006216241046786308, lr 0.00013421772800000008
Epoch 242000, Loss 0.014357908628880978, lr 0.00013421772800000008
Epoch 243000, Loss 0.010585037060081959, lr 0.00013421772800000008
Epoch 244000, Loss 0.0060417731292545795, lr 0.00013421772800000008
Epoch 245000, Loss 0.006413214839994907, lr 0.00013421772800000008
Epoch 246000, Loss 0.009185083210468292, lr 0.00013421772800000008
Epoch 247000, Loss 0.009743203409016132, lr 0.00013421772800000008
Epoch 248000, Loss 0.1916225105524063, lr 0.00013421772800000008
Epoch 249000, Loss 0.022759824991226196, lr 0.00013421772800000008
CPU times: user 17min 52s, sys: 3.9 s, total: 17min 56s
Wall time: 17min 57s
```

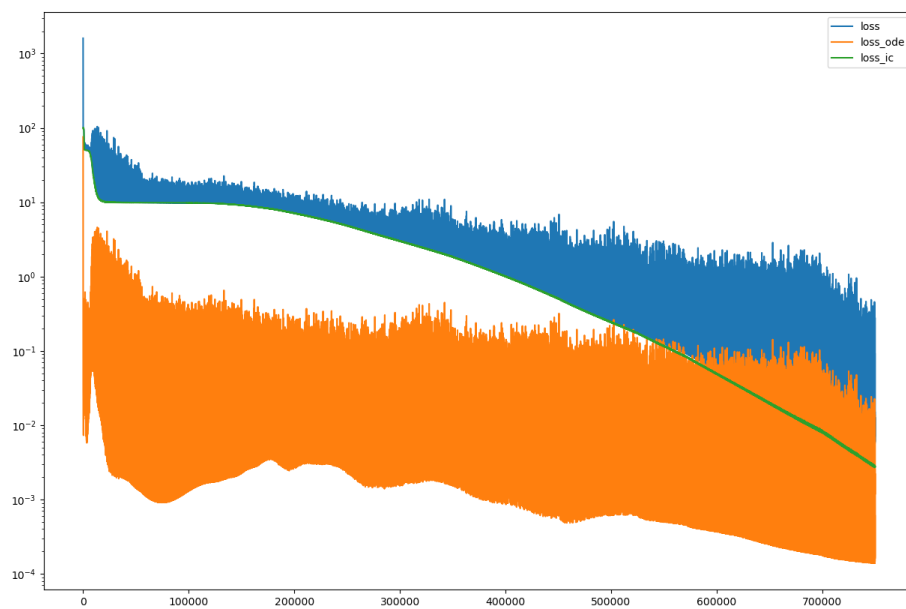
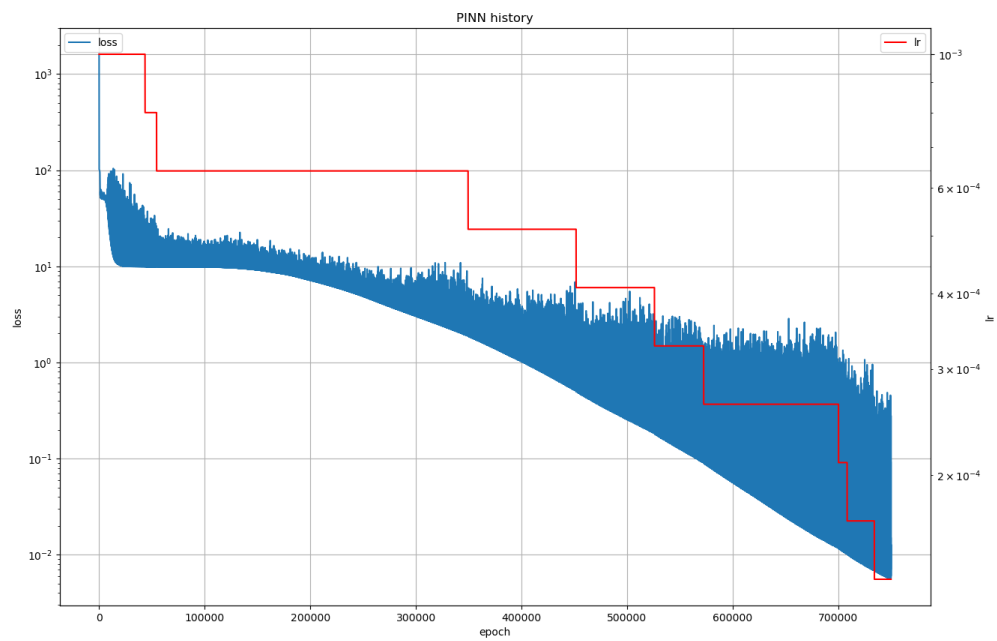
```
[39]: # plot history_PINN loss and lr in two subplots
history_PINN = np.array(history_PINN)

fig, ax = plt.subplots(figsize=(15, 10))
# plot the loss
ax.plot(history_PINN[:, 0], label='loss')
ax.legend(loc='upper left')
ax.set_yscale('log')
ax.set_xlabel('epoch')
ax.set_ylabel('loss')
plt.grid()

# plot the learning rate
ax2 = ax.twinx()
ax2.plot(history_PINN[:, -1], label='lr', color='r')
ax2.set_yscale('log')
ax2.set_ylabel('lr')
# legend to the right
ax2.legend(loc='upper right')
plt.grid()
plt.title('PINN history')

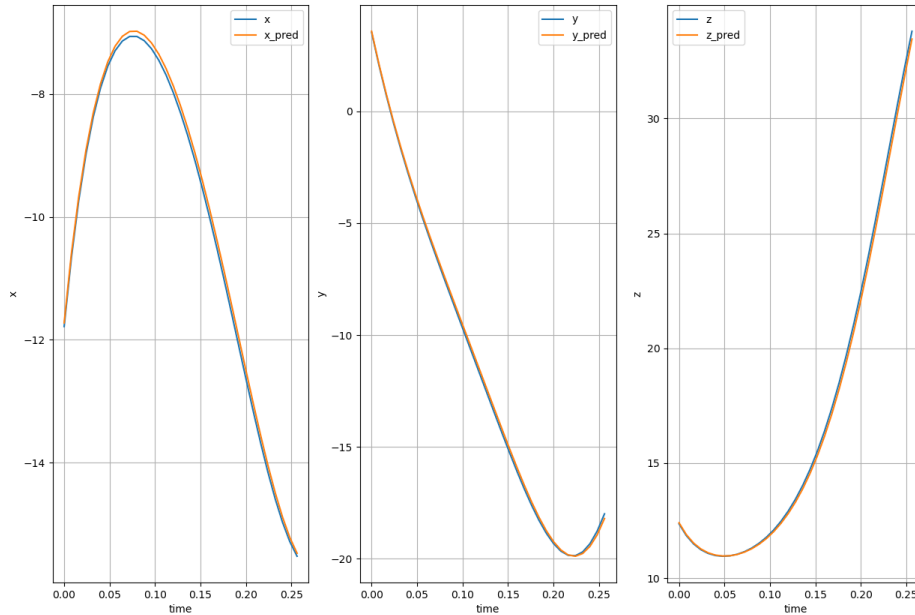
# plot losses
plt.figure(figsize=(15, 10))
plt.plot(history_PINN[:, 0], label='loss')
plt.plot(history_PINN[:, 1], label='loss_ode')
plt.plot(history_PINN[:, 2], label='loss_ic')
plt.legend()
plt.yscale('log')

# history to list
history_PINN = history_PINN.tolist()
```





```
[40]: # get prediction and plot compare
Y_pred = short_model(X_sub_t).detach().numpy()
plot_compare_components(X_sub, Y_sub, Y_pred)
```



```
[ ]: # save model in ../models/Lorenz_PINN_baseline/Lorenz_short_baseline.pt
## torch.save(short_model, '../models/Lorenz_PINN_baseline/
↳Lorenz_short_baseline.pt')
```

## 1.5 Long model

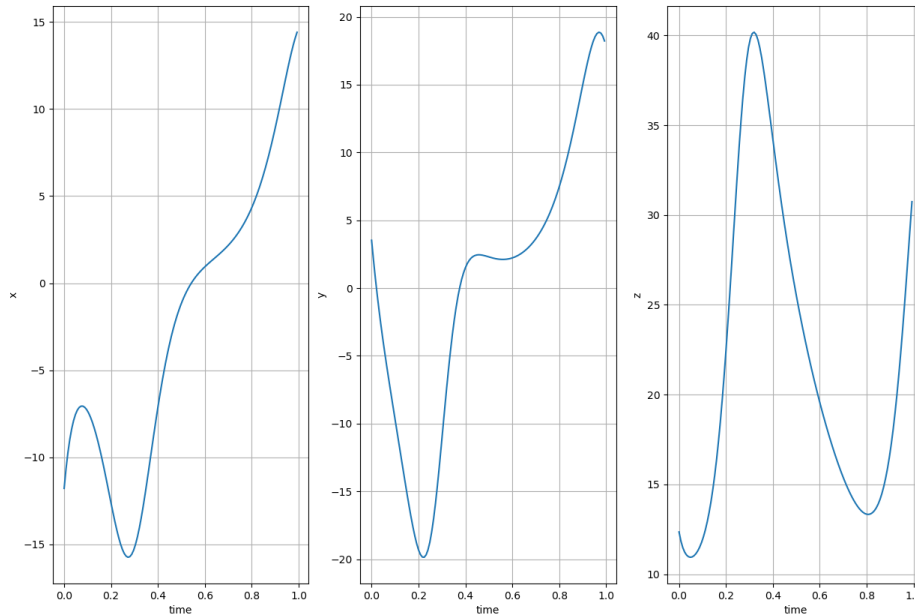
Starting with the same model, already trained on the short time span, we will train the model on the time span (0,1). Note that the epochs are 3x the short model.

```
[42]: # define the optimizer
optimizer = torch.optim.Adam(short_model.parameters(), lr=0.001)
# add minimun to lr
scheduler = torch.optim.lr_scheduler.ReduceLROnPlateau(optimizer, 'min',
↳factor=0.8, patience=1000, min_lr=1e-5)

# define the loss function, L2
loss_fn = torch.nn.MSELoss()
```

```
[56]: # select only time < 2
X_sub = X[X<1]
Y_sub = Y[X<1]
```

```
[57]: # plot components
plot_components(X_sub, Y_sub)
```



```
[58]: # to torch
X_sub_t = torch.tensor(X_sub, dtype=torch.float32).view(-1, 1)
Y_sub_t = torch.tensor(Y_sub, dtype=torch.float32)
```

```
[46]: %%time

for epoch in range(9*250000):
    optimizer.zero_grad()
    X_sub_t.requires_grad = True
    Y_pred = short_model(X_sub_t)

    # get the derivatives
    dx_dt_pred = torch.autograd.grad(Y_pred[:,0], X_sub_t, grad_outputs=torch.
    ↪ones_like(Y_pred[:,0]), create_graph=True)[0]
    dy_dt_pred = torch.autograd.grad(Y_pred[:,1], X_sub_t, grad_outputs=torch.
    ↪ones_like(Y_pred[:,1]), create_graph=True)[0]
```

```

    dz_dt_pred = torch.autograd.grad(Y_pred[:,2], X_sub_t, grad_outputs=torch.
↪ones_like(Y_pred[:,2]), create_graph=True)[0]

    # get true derivatives, using the lorenz parameter
    dx_dt_ode = 10 * (Y_pred[:,1] - Y_pred[:,0])
    dy_dt_ode = Y_pred[:,0] * (28 - Y_pred[:,2]) - Y_pred[:,1]
    dz_dt_ode = Y_pred[:,0] * Y_pred[:,1] - 8/3 * Y_pred[:,2]

    # loss ode
    loss_ode = loss_fn(dx_dt_pred[:,0], dx_dt_ode) + loss_fn(dy_dt_pred[:,0],
↪dy_dt_ode) + loss_fn(dz_dt_pred[:,0], dz_dt_ode)

    # add loss ic
    loss_ic = torch.mean((Y_pred[0] - Y_sub_t[0])**2)

    loss = 20*loss_ode + loss_ic

    loss.backward()
    optimizer.step()
    scheduler.step(loss)

    history_PINN.append([loss.item(), loss_ode.detach().numpy(), loss_ic.
↪detach().numpy(), optimizer.param_groups[0]["lr"]])

    if epoch % 1000 == 0:
        print(f'Epoch {epoch}, Loss {loss.item()}, lr {optimizer.
↪param_groups[0]["lr"]}')

```

```

Epoch 0, Loss 626389.5, lr 0.001
Epoch 1000, Loss 145.3151092529297, lr 0.001
Epoch 2000, Loss 125.38775634765625, lr 0.001
Epoch 3000, Loss 119.87185668945312, lr 0.001
Epoch 4000, Loss 111.70367431640625, lr 0.001
Epoch 5000, Loss 104.68612670898438, lr 0.001
Epoch 6000, Loss 99.33305358886719, lr 0.001
Epoch 7000, Loss 85.5203857421875, lr 0.001
Epoch 8000, Loss 82.61097717285156, lr 0.001
Epoch 9000, Loss 80.74768829345703, lr 0.001
Epoch 10000, Loss 81.3205795288086, lr 0.001
Epoch 11000, Loss 74.30023193359375, lr 0.001
Epoch 12000, Loss 68.00859832763672, lr 0.001
Epoch 13000, Loss 59.172706604003906, lr 0.001
Epoch 14000, Loss 51.27915573120117, lr 0.001
Epoch 15000, Loss 40.913787841796875, lr 0.001
Epoch 16000, Loss 33.425106048583984, lr 0.001
Epoch 17000, Loss 27.24936866760254, lr 0.001
Epoch 18000, Loss 22.314571380615234, lr 0.001

```

Epoch 19000, Loss 18.15882682800293, lr 0.001  
Epoch 20000, Loss 16.817596435546875, lr 0.001  
Epoch 21000, Loss 11.265545845031738, lr 0.001  
Epoch 22000, Loss 9.260003089904785, lr 0.001  
Epoch 23000, Loss 7.8487396240234375, lr 0.001  
Epoch 24000, Loss 7.520223140716553, lr 0.001  
Epoch 25000, Loss 6.988001823425293, lr 0.001  
Epoch 26000, Loss 5.0305280685424805, lr 0.001  
Epoch 27000, Loss 10.02731704711914, lr 0.001  
Epoch 28000, Loss 4.007084369659424, lr 0.001  
Epoch 29000, Loss 3.4510767459869385, lr 0.001  
Epoch 30000, Loss 7.5396575927734375, lr 0.001  
Epoch 31000, Loss 12.425554275512695, lr 0.001  
Epoch 32000, Loss 2.769685745239258, lr 0.001  
Epoch 33000, Loss 2.6396472454071045, lr 0.001  
Epoch 34000, Loss 5.023177146911621, lr 0.001  
Epoch 35000, Loss 2.063999652862549, lr 0.001  
Epoch 36000, Loss 2.0849881172180176, lr 0.001  
Epoch 37000, Loss 1.876191258430481, lr 0.001  
Epoch 38000, Loss 2.5863776206970215, lr 0.001  
Epoch 39000, Loss 1.7494056224822998, lr 0.001  
Epoch 40000, Loss 1.7089989185333252, lr 0.001  
Epoch 41000, Loss 3.5138206481933594, lr 0.001  
Epoch 42000, Loss 1.64840829372406, lr 0.001  
Epoch 43000, Loss 1.757177710533142, lr 0.001  
Epoch 44000, Loss 1.6318395137786865, lr 0.001  
Epoch 45000, Loss 1.6043781042099, lr 0.001  
Epoch 46000, Loss 2.407886505126953, lr 0.001  
Epoch 47000, Loss 1.652109146118164, lr 0.001  
Epoch 48000, Loss 3.2537426948547363, lr 0.001  
Epoch 49000, Loss 1.579786777496338, lr 0.001  
Epoch 50000, Loss 1.604350209236145, lr 0.001  
Epoch 51000, Loss 8.528993606567383, lr 0.001  
Epoch 52000, Loss 1.4880053997039795, lr 0.001  
Epoch 53000, Loss 1.7631347179412842, lr 0.001  
Epoch 54000, Loss 1.8400765657424927, lr 0.001  
Epoch 55000, Loss 1.4840478897094727, lr 0.001  
Epoch 56000, Loss 1.8940573930740356, lr 0.001  
Epoch 57000, Loss 8.815999984741211, lr 0.001  
Epoch 58000, Loss 1.500179648399353, lr 0.001  
Epoch 59000, Loss 3.505702495574951, lr 0.001  
Epoch 60000, Loss 1.650827169418335, lr 0.001  
Epoch 61000, Loss 3.988633632659912, lr 0.001  
Epoch 62000, Loss 6.318777084350586, lr 0.001  
Epoch 63000, Loss 1.4340779781341553, lr 0.001  
Epoch 64000, Loss 1.4650520086288452, lr 0.001  
Epoch 65000, Loss 2.45967960357666, lr 0.001  
Epoch 66000, Loss 1.5560120344161987, lr 0.001

Epoch 67000, Loss 6.815795421600342, lr 0.001  
Epoch 68000, Loss 5.103592872619629, lr 0.001  
Epoch 69000, Loss 2.4808530807495117, lr 0.001  
Epoch 70000, Loss 2.4526309967041016, lr 0.001  
Epoch 71000, Loss 5.260627746582031, lr 0.001  
Epoch 72000, Loss 2.333016872406006, lr 0.001  
Epoch 73000, Loss 1.7401859760284424, lr 0.001  
Epoch 74000, Loss 2.3862695693969727, lr 0.001  
Epoch 75000, Loss 1.392557144165039, lr 0.001  
Epoch 76000, Loss 1.338659644126892, lr 0.001  
Epoch 77000, Loss 1.8375523090362549, lr 0.001  
Epoch 78000, Loss 1.3348872661590576, lr 0.001  
Epoch 79000, Loss 3.5249340534210205, lr 0.001  
Epoch 80000, Loss 1.3182835578918457, lr 0.001  
Epoch 81000, Loss 1.3580042123794556, lr 0.001  
Epoch 82000, Loss 1.5853897333145142, lr 0.001  
Epoch 83000, Loss 1.3320057392120361, lr 0.001  
Epoch 84000, Loss 3.483884811401367, lr 0.001  
Epoch 85000, Loss 1.3101462125778198, lr 0.001  
Epoch 86000, Loss 1.3403804302215576, lr 0.001  
Epoch 87000, Loss 2.171982765197754, lr 0.001  
Epoch 88000, Loss 3.9505772590637207, lr 0.001  
Epoch 89000, Loss 1.3788288831710815, lr 0.001  
Epoch 90000, Loss 1.310186743736267, lr 0.001  
Epoch 91000, Loss 1.3216558694839478, lr 0.001  
Epoch 92000, Loss 1.2824398279190063, lr 0.001  
Epoch 93000, Loss 5.928512096405029, lr 0.001  
Epoch 94000, Loss 1.4147697687149048, lr 0.001  
Epoch 95000, Loss 1.5043785572052002, lr 0.001  
Epoch 96000, Loss 6.18107271194458, lr 0.001  
Epoch 97000, Loss 1.325878381729126, lr 0.001  
Epoch 98000, Loss 1.2356747388839722, lr 0.001  
Epoch 99000, Loss 1.3912160396575928, lr 0.001  
Epoch 100000, Loss 1.2605819702148438, lr 0.001  
Epoch 101000, Loss 1.221770167350769, lr 0.0008  
Epoch 102000, Loss 1.4451391696929932, lr 0.0008  
Epoch 103000, Loss 3.073535919189453, lr 0.0008  
Epoch 104000, Loss 2.072439193725586, lr 0.0008  
Epoch 105000, Loss 6.119832992553711, lr 0.0008  
Epoch 106000, Loss 1.2162717580795288, lr 0.0008  
Epoch 107000, Loss 1.5024852752685547, lr 0.0008  
Epoch 108000, Loss 1.2148667573928833, lr 0.0008  
Epoch 109000, Loss 2.2979226112365723, lr 0.0008  
Epoch 110000, Loss 1.2116453647613525, lr 0.00064  
Epoch 111000, Loss 1.2181575298309326, lr 0.00064  
Epoch 112000, Loss 1.2872580289840698, lr 0.00064  
Epoch 113000, Loss 1.2086822986602783, lr 0.00064  
Epoch 114000, Loss 1.4042097330093384, lr 0.00064

Epoch 115000, Loss 1.2054996490478516, lr 0.0005120000000000001  
Epoch 116000, Loss 1.23091721534729, lr 0.0005120000000000001  
Epoch 117000, Loss 2.2758336067199707, lr 0.0005120000000000001  
Epoch 118000, Loss 2.7117958068847656, lr 0.0005120000000000001  
Epoch 119000, Loss 1.2072994709014893, lr 0.0005120000000000001  
Epoch 120000, Loss 1.5968704223632812, lr 0.0005120000000000001  
Epoch 121000, Loss 5.246935844421387, lr 0.0005120000000000001  
Epoch 122000, Loss 1.3233318328857422, lr 0.0005120000000000001  
Epoch 123000, Loss 1.4000325202941895, lr 0.0005120000000000001  
Epoch 124000, Loss 1.2164220809936523, lr 0.0005120000000000001  
Epoch 125000, Loss 2.497387647628784, lr 0.0005120000000000001  
Epoch 126000, Loss 1.1885995864868164, lr 0.0005120000000000001  
Epoch 127000, Loss 1.2427334785461426, lr 0.0005120000000000001  
Epoch 128000, Loss 1.3806394338607788, lr 0.0005120000000000001  
Epoch 129000, Loss 1.1920337677001953, lr 0.0005120000000000001  
Epoch 130000, Loss 1.1817562580108643, lr 0.0005120000000000001  
Epoch 131000, Loss 1.419372320175171, lr 0.0005120000000000001  
Epoch 132000, Loss 1.1868972778320312, lr 0.0005120000000000001  
Epoch 133000, Loss 1.2261446714401245, lr 0.0005120000000000001  
Epoch 134000, Loss 1.2442688941955566, lr 0.0005120000000000001  
Epoch 135000, Loss 1.3836758136749268, lr 0.0005120000000000001  
Epoch 136000, Loss 1.5069284439086914, lr 0.0005120000000000001  
Epoch 137000, Loss 1.1781060695648193, lr 0.0005120000000000001  
Epoch 138000, Loss 1.1711751222610474, lr 0.0005120000000000001  
Epoch 139000, Loss 1.5451934337615967, lr 0.0005120000000000001  
Epoch 140000, Loss 1.447336196899414, lr 0.0005120000000000001  
Epoch 141000, Loss 1.2657616138458252, lr 0.0005120000000000001  
Epoch 142000, Loss 1.1707221269607544, lr 0.0005120000000000001  
Epoch 143000, Loss 1.2243263721466064, lr 0.0005120000000000001  
Epoch 144000, Loss 1.2462763786315918, lr 0.0005120000000000001  
Epoch 145000, Loss 1.3654108047485352, lr 0.0005120000000000001  
Epoch 146000, Loss 1.33060884475708, lr 0.0005120000000000001  
Epoch 147000, Loss 1.1447683572769165, lr 0.0005120000000000001  
Epoch 148000, Loss 1.141907811164856, lr 0.0005120000000000001  
Epoch 149000, Loss 1.1496058702468872, lr 0.0005120000000000001  
Epoch 150000, Loss 2.1650314331054688, lr 0.0005120000000000001  
Epoch 151000, Loss 1.1372848749160767, lr 0.0005120000000000001  
Epoch 152000, Loss 1.1686309576034546, lr 0.0005120000000000001  
Epoch 153000, Loss 1.7935656309127808, lr 0.0005120000000000001  
Epoch 154000, Loss 1.2859222888946533, lr 0.0005120000000000001  
Epoch 155000, Loss 1.1406781673431396, lr 0.0005120000000000001  
Epoch 156000, Loss 1.1511677503585815, lr 0.0005120000000000001  
Epoch 157000, Loss 3.0807037353515625, lr 0.0005120000000000001  
Epoch 158000, Loss 2.199831485748291, lr 0.0005120000000000001  
Epoch 159000, Loss 1.2345495223999023, lr 0.0005120000000000001  
Epoch 160000, Loss 1.2398576736450195, lr 0.0005120000000000001  
Epoch 161000, Loss 1.8000762462615967, lr 0.0005120000000000001  
Epoch 162000, Loss 1.1879634857177734, lr 0.0005120000000000001

Epoch 163000, Loss 1.1186044216156006, lr 0.0005120000000000001  
 Epoch 164000, Loss 1.2457433938980103, lr 0.0005120000000000001  
 Epoch 165000, Loss 1.0937097072601318, lr 0.0005120000000000001  
 Epoch 166000, Loss 2.315643787384033, lr 0.0005120000000000001  
 Epoch 167000, Loss 1.1606276035308838, lr 0.0005120000000000001  
 Epoch 168000, Loss 1.122793197631836, lr 0.0005120000000000001  
 Epoch 169000, Loss 1.1259853839874268, lr 0.0005120000000000001  
 Epoch 170000, Loss 1.081575870513916, lr 0.0005120000000000001  
 Epoch 171000, Loss 1.0754796266555786, lr 0.0005120000000000001  
 Epoch 172000, Loss 2.441585063934326, lr 0.0005120000000000001  
 Epoch 173000, Loss 1.1260011196136475, lr 0.0005120000000000001  
 Epoch 174000, Loss 1.0898998975753784, lr 0.0005120000000000001  
 Epoch 175000, Loss 1.131210207939148, lr 0.0005120000000000001  
 Epoch 176000, Loss 1.095670223236084, lr 0.0005120000000000001  
 Epoch 177000, Loss 3.011202335357666, lr 0.0005120000000000001  
 Epoch 178000, Loss 1.1051896810531616, lr 0.0005120000000000001  
 Epoch 179000, Loss 2.7689743041992188, lr 0.0005120000000000001  
 Epoch 180000, Loss 1.5103236436843872, lr 0.0005120000000000001  
 Epoch 181000, Loss 1.0645984411239624, lr 0.0005120000000000001  
 Epoch 182000, Loss 1.3870649337768555, lr 0.0005120000000000001  
 Epoch 183000, Loss 1.1562526226043701, lr 0.0005120000000000001  
 Epoch 184000, Loss 1.0348846912384033, lr 0.0005120000000000001  
 Epoch 185000, Loss 2.2737598419189453, lr 0.0005120000000000001  
 Epoch 186000, Loss 1.0967646837234497, lr 0.0005120000000000001  
 Epoch 187000, Loss 1.0234932899475098, lr 0.0005120000000000001  
 Epoch 188000, Loss 1.014581561088562, lr 0.0005120000000000001  
 Epoch 189000, Loss 1.0118184089660645, lr 0.0005120000000000001  
 Epoch 190000, Loss 1.926274061203003, lr 0.0005120000000000001  
 Epoch 191000, Loss 1.2408385276794434, lr 0.0005120000000000001  
 Epoch 192000, Loss 1.1370962858200073, lr 0.0005120000000000001  
 Epoch 193000, Loss 1.3653676509857178, lr 0.0005120000000000001  
 Epoch 194000, Loss 1.172474980354309, lr 0.0005120000000000001  
 Epoch 195000, Loss 0.9910038113594055, lr 0.0005120000000000001  
 Epoch 196000, Loss 0.9949862360954285, lr 0.0005120000000000001  
 Epoch 197000, Loss 0.9803063869476318, lr 0.0005120000000000001  
 Epoch 198000, Loss 0.9998416900634766, lr 0.0005120000000000001  
 Epoch 199000, Loss 0.969569742679596, lr 0.0004096000000000001  
 Epoch 200000, Loss 0.9720639586448669, lr 0.0004096000000000001  
 Epoch 201000, Loss 1.0242429971694946, lr 0.0004096000000000001  
 Epoch 202000, Loss 1.0453859567642212, lr 0.0004096000000000001  
 Epoch 203000, Loss 1.1250983476638794, lr 0.0004096000000000001  
 Epoch 204000, Loss 0.9458605051040649, lr 0.0004096000000000001  
 Epoch 205000, Loss 0.9347525835037231, lr 0.0004096000000000001  
 Epoch 206000, Loss 1.1711018085479736, lr 0.0004096000000000001  
 Epoch 207000, Loss 0.9226886034011841, lr 0.0004096000000000001  
 Epoch 208000, Loss 1.3527979850769043, lr 0.0004096000000000001  
 Epoch 209000, Loss 0.915057361125946, lr 0.0004096000000000001  
 Epoch 210000, Loss 0.9439575672149658, lr 0.0004096000000000001

Epoch 211000, Loss 0.9107749462127686, lr 0.0004096000000000001  
Epoch 212000, Loss 0.9600318670272827, lr 0.0004096000000000001  
Epoch 213000, Loss 1.4003877639770508, lr 0.0004096000000000001  
Epoch 214000, Loss 1.2989593744277954, lr 0.0004096000000000001  
Epoch 215000, Loss 0.8896918892860413, lr 0.0004096000000000001  
Epoch 216000, Loss 1.127147912979126, lr 0.0004096000000000001  
Epoch 217000, Loss 0.8703666925430298, lr 0.0004096000000000001  
Epoch 218000, Loss 0.912285327911377, lr 0.0004096000000000001  
Epoch 219000, Loss 1.1285452842712402, lr 0.0004096000000000001  
Epoch 220000, Loss 0.8421017527580261, lr 0.0004096000000000001  
Epoch 221000, Loss 2.7344233989715576, lr 0.0004096000000000001  
Epoch 222000, Loss 0.813353419303894, lr 0.0004096000000000001  
Epoch 223000, Loss 1.3608278036117554, lr 0.0004096000000000001  
Epoch 224000, Loss 1.0293068885803223, lr 0.0004096000000000001  
Epoch 225000, Loss 0.7852129340171814, lr 0.0004096000000000001  
Epoch 226000, Loss 0.8736746311187744, lr 0.0004096000000000001  
Epoch 227000, Loss 0.7519655227661133, lr 0.0004096000000000001  
Epoch 228000, Loss 0.7928658723831177, lr 0.0004096000000000001  
Epoch 229000, Loss 0.7511227130889893, lr 0.0004096000000000001  
Epoch 230000, Loss 0.8708597421646118, lr 0.0004096000000000001  
Epoch 231000, Loss 0.7000936269760132, lr 0.0004096000000000001  
Epoch 232000, Loss 2.47249698638916, lr 0.0004096000000000001  
Epoch 233000, Loss 2.0619008541107178, lr 0.0004096000000000001  
Epoch 234000, Loss 0.6787962913513184, lr 0.0004096000000000001  
Epoch 235000, Loss 0.9601268768310547, lr 0.0004096000000000001  
Epoch 236000, Loss 0.6202864646911621, lr 0.0004096000000000001  
Epoch 237000, Loss 0.6095873713493347, lr 0.0004096000000000001  
Epoch 238000, Loss 0.6467689275741577, lr 0.0004096000000000001  
Epoch 239000, Loss 0.7112449407577515, lr 0.0004096000000000001  
Epoch 240000, Loss 0.5118167400360107, lr 0.0004096000000000001  
Epoch 241000, Loss 0.4964398443698883, lr 0.0004096000000000001  
Epoch 242000, Loss 0.4495795965194702, lr 0.0004096000000000001  
Epoch 243000, Loss 0.5208935737609863, lr 0.0004096000000000001  
Epoch 244000, Loss 0.6453901529312134, lr 0.0004096000000000001  
Epoch 245000, Loss 0.3812394440174103, lr 0.0004096000000000001  
Epoch 246000, Loss 0.3708001375198364, lr 0.0004096000000000001  
Epoch 247000, Loss 0.9181734323501587, lr 0.0004096000000000001  
Epoch 248000, Loss 0.2977672517299652, lr 0.0004096000000000001  
Epoch 249000, Loss 0.28573501110076904, lr 0.0004096000000000001  
Epoch 250000, Loss 0.2560464143753052, lr 0.0004096000000000001  
Epoch 251000, Loss 0.6953340768814087, lr 0.0004096000000000001  
Epoch 252000, Loss 0.24762243032455444, lr 0.0004096000000000001  
Epoch 253000, Loss 0.24835534393787384, lr 0.0004096000000000001  
Epoch 254000, Loss 0.181606262922287, lr 0.0004096000000000001  
Epoch 255000, Loss 0.7001481652259827, lr 0.0004096000000000001  
Epoch 256000, Loss 0.671523928642273, lr 0.0004096000000000001  
Epoch 257000, Loss 0.6264956593513489, lr 0.0004096000000000001  
Epoch 258000, Loss 0.10751501470804214, lr 0.0004096000000000001



Epoch 259000, Loss 0.1621362268924713, lr 0.0004096000000000001  
Epoch 260000, Loss 0.08759450912475586, lr 0.0004096000000000001  
Epoch 261000, Loss 0.07223936170339584, lr 0.0004096000000000001  
Epoch 262000, Loss 0.25787287950515747, lr 0.0004096000000000001  
Epoch 263000, Loss 0.3445201516151428, lr 0.0004096000000000001  
Epoch 264000, Loss 0.06823373585939407, lr 0.0004096000000000001  
Epoch 265000, Loss 0.13063165545463562, lr 0.0004096000000000001  
Epoch 266000, Loss 0.05121387913823128, lr 0.0004096000000000001  
Epoch 267000, Loss 0.03345160186290741, lr 0.0004096000000000001  
Epoch 268000, Loss 0.03363065421581268, lr 0.0004096000000000001  
Epoch 269000, Loss 0.02916637435555458, lr 0.0004096000000000001  
Epoch 270000, Loss 0.43919289112091064, lr 0.0004096000000000001  
Epoch 271000, Loss 1.3495646715164185, lr 0.0004096000000000001  
Epoch 272000, Loss 0.020931944251060486, lr 0.0004096000000000001  
Epoch 273000, Loss 0.3222789466381073, lr 0.0004096000000000001  
Epoch 274000, Loss 0.06331896036863327, lr 0.0004096000000000001  
Epoch 275000, Loss 1.0602017641067505, lr 0.0004096000000000001  
Epoch 276000, Loss 0.0221739262342453, lr 0.0004096000000000001  
Epoch 277000, Loss 0.5123036503791809, lr 0.0004096000000000001  
Epoch 278000, Loss 0.01899797096848488, lr 0.0004096000000000001  
Epoch 279000, Loss 0.015599176287651062, lr 0.0004096000000000001  
Epoch 280000, Loss 0.028569841757416725, lr 0.0004096000000000001  
Epoch 281000, Loss 0.047520481050014496, lr 0.0004096000000000001  
Epoch 282000, Loss 0.018560927361249924, lr 0.0004096000000000001  
Epoch 283000, Loss 0.023758849129080772, lr 0.0004096000000000001  
Epoch 284000, Loss 0.027642350643873215, lr 0.0004096000000000001  
Epoch 285000, Loss 0.45895475149154663, lr 0.0004096000000000001  
Epoch 286000, Loss 0.009778081439435482, lr 0.0003276800000000001  
Epoch 287000, Loss 0.013939562253654003, lr 0.0003276800000000001  
Epoch 288000, Loss 0.008650949224829674, lr 0.0002621440000000001  
Epoch 289000, Loss 0.018763812258839607, lr 0.0002621440000000001  
Epoch 290000, Loss 0.09451590478420258, lr 0.0002621440000000001  
Epoch 291000, Loss 0.058183204382658005, lr 0.0002621440000000001  
Epoch 292000, Loss 0.011192314326763153, lr 0.0002621440000000001  
Epoch 293000, Loss 0.008321128785610199, lr 0.0002621440000000001  
Epoch 294000, Loss 0.016718965023756027, lr 0.00020971520000000012  
Epoch 295000, Loss 0.009603231213986874, lr 0.00020971520000000012  
Epoch 296000, Loss 0.02760561741888523, lr 0.00020971520000000012  
Epoch 297000, Loss 0.0829557254910469, lr 0.00020971520000000012  
Epoch 298000, Loss 0.20157741010189056, lr 0.00020971520000000012  
Epoch 299000, Loss 0.006698776036500931, lr 0.00016777216000000001  
Epoch 300000, Loss 0.00684118177741766, lr 0.00016777216000000001  
Epoch 301000, Loss 0.007588492706418037, lr 0.00016777216000000001  
Epoch 302000, Loss 0.0070170569233596325, lr 0.00016777216000000001  
Epoch 303000, Loss 0.006415293551981449, lr 0.00016777216000000001  
Epoch 304000, Loss 0.018589520826935768, lr 0.00016777216000000001  
Epoch 305000, Loss 0.0062210438773036, lr 0.00016777216000000001  
Epoch 306000, Loss 0.006091175135225058, lr 0.00016777216000000001

Epoch 307000, Loss 0.021311365067958832, lr 0.0001677721600000001  
 Epoch 308000, Loss 0.006778843235224485, lr 0.0001677721600000001  
 Epoch 309000, Loss 0.005852074362337589, lr 0.00013421772800000008  
 Epoch 310000, Loss 0.060162503272295, lr 0.00013421772800000008  
 Epoch 311000, Loss 0.005927193909883499, lr 0.00013421772800000008  
 Epoch 312000, Loss 0.0057054380886256695, lr 0.00013421772800000008  
 Epoch 313000, Loss 0.027884578332304955, lr 0.00013421772800000008  
 Epoch 314000, Loss 0.006487750913947821, lr 0.00013421772800000008  
 Epoch 315000, Loss 0.006808639969676733, lr 0.00013421772800000008  
 Epoch 316000, Loss 0.005419840104877949, lr 0.00010737418240000007  
 Epoch 317000, Loss 0.010750727728009224, lr 0.00010737418240000007  
 Epoch 318000, Loss 0.016176898032426834, lr 0.00010737418240000007  
 Epoch 319000, Loss 0.05281651392579079, lr 0.00010737418240000007  
 Epoch 320000, Loss 0.005532432813197374, lr 0.00010737418240000007  
 Epoch 321000, Loss 0.013511965982615948, lr 0.00010737418240000007  
 Epoch 322000, Loss 0.005437001585960388, lr 0.00010737418240000007  
 Epoch 323000, Loss 0.01678963005542755, lr 0.00010737418240000007  
 Epoch 324000, Loss 0.009493157267570496, lr 0.00010737418240000007  
 Epoch 325000, Loss 0.006083987187594175, lr 0.00010737418240000007  
 Epoch 326000, Loss 0.004987194202840328, lr 8.589934592000007e-05  
 Epoch 327000, Loss 0.006216835230588913, lr 8.589934592000007e-05  
 Epoch 328000, Loss 0.005207521375268698, lr 8.589934592000007e-05  
 Epoch 329000, Loss 0.006840800866484642, lr 8.589934592000007e-05  
 Epoch 330000, Loss 0.026988161727786064, lr 8.589934592000007e-05  
 Epoch 331000, Loss 0.004829414654523134, lr 8.589934592000007e-05  
 Epoch 332000, Loss 0.006216632202267647, lr 8.589934592000007e-05  
 Epoch 333000, Loss 0.005884192883968353, lr 8.589934592000007e-05  
 Epoch 334000, Loss 0.024642402306199074, lr 8.589934592000007e-05  
 Epoch 335000, Loss 0.009398265741765499, lr 8.589934592000007e-05  
 Epoch 336000, Loss 0.019133349880576134, lr 8.589934592000007e-05  
 Epoch 337000, Loss 0.020110279321670532, lr 6.871947673600006e-05  
 Epoch 338000, Loss 0.004471004940569401, lr 6.871947673600006e-05  
 Epoch 339000, Loss 0.005184597335755825, lr 6.871947673600006e-05  
 Epoch 340000, Loss 0.00498213293030858, lr 6.871947673600006e-05  
 Epoch 341000, Loss 0.004548275843262672, lr 6.871947673600006e-05  
 Epoch 342000, Loss 0.00430485513061285, lr 5.497558138880005e-05  
 Epoch 343000, Loss 0.004982106853276491, lr 5.497558138880005e-05  
 Epoch 344000, Loss 0.004279655404388905, lr 5.497558138880005e-05  
 Epoch 345000, Loss 0.00466420641168952, lr 5.497558138880005e-05  
 Epoch 346000, Loss 0.004539113026112318, lr 5.497558138880005e-05  
 Epoch 347000, Loss 0.004185250960290432, lr 5.497558138880005e-05  
 Epoch 348000, Loss 0.02907913736999035, lr 5.497558138880005e-05  
 Epoch 349000, Loss 0.007900087162852287, lr 5.497558138880005e-05  
 Epoch 350000, Loss 0.0109163923189044, lr 5.497558138880005e-05  
 Epoch 351000, Loss 0.004049945622682571, lr 5.497558138880005e-05  
 Epoch 352000, Loss 0.00416214857250452, lr 5.497558138880005e-05  
 Epoch 353000, Loss 0.007363531272858381, lr 5.497558138880005e-05  
 Epoch 354000, Loss 0.003971772734075785, lr 5.497558138880005e-05

Epoch 355000, Loss 0.0274693313986063, lr 5.497558138880005e-05  
Epoch 356000, Loss 0.008428693749010563, lr 5.497558138880005e-05  
Epoch 357000, Loss 0.004049315582960844, lr 5.497558138880005e-05  
Epoch 358000, Loss 0.00382498512044549, lr 5.497558138880005e-05  
Epoch 359000, Loss 0.007631488144397736, lr 5.497558138880005e-05  
Epoch 360000, Loss 0.0068350667133927345, lr 5.497558138880005e-05  
Epoch 361000, Loss 0.009270492941141129, lr 5.497558138880005e-05  
Epoch 362000, Loss 0.00396099966019392, lr 5.497558138880005e-05  
Epoch 363000, Loss 0.003718802472576499, lr 5.497558138880005e-05  
Epoch 364000, Loss 0.0038913015741854906, lr 5.497558138880005e-05  
Epoch 365000, Loss 0.0056329164654016495, lr 5.497558138880005e-05  
Epoch 366000, Loss 0.003724193898960948, lr 5.497558138880005e-05  
Epoch 367000, Loss 0.003741663880646229, lr 5.497558138880005e-05  
Epoch 368000, Loss 0.003614387707784772, lr 5.497558138880005e-05  
Epoch 369000, Loss 0.004390812944620848, lr 5.497558138880005e-05  
Epoch 370000, Loss 0.003736278973519802, lr 5.497558138880005e-05  
Epoch 371000, Loss 0.0035822901409119368, lr 5.497558138880005e-05  
Epoch 372000, Loss 0.00655954796820879, lr 5.497558138880005e-05  
Epoch 373000, Loss 0.008069518953561783, lr 5.497558138880005e-05  
Epoch 374000, Loss 0.004028995055705309, lr 5.497558138880005e-05  
Epoch 375000, Loss 0.007608945947140455, lr 5.497558138880005e-05  
Epoch 376000, Loss 0.006319028325378895, lr 5.497558138880005e-05  
Epoch 377000, Loss 0.01438602153211832, lr 5.497558138880005e-05  
Epoch 378000, Loss 0.005965610034763813, lr 5.497558138880005e-05  
Epoch 379000, Loss 0.003404933726415038, lr 5.497558138880005e-05  
Epoch 380000, Loss 0.00930856354534626, lr 5.497558138880005e-05  
Epoch 381000, Loss 0.005138135049492121, lr 5.497558138880005e-05  
Epoch 382000, Loss 0.0034249830059707165, lr 5.497558138880005e-05  
Epoch 383000, Loss 0.0039094421081244946, lr 5.497558138880005e-05  
Epoch 384000, Loss 0.0033616172149777412, lr 5.497558138880005e-05  
Epoch 385000, Loss 0.00530760595574975, lr 5.497558138880005e-05  
Epoch 386000, Loss 0.0034349351190030575, lr 5.497558138880005e-05  
Epoch 387000, Loss 0.012822096236050129, lr 5.497558138880005e-05  
Epoch 388000, Loss 0.00490918941795826, lr 5.497558138880005e-05  
Epoch 389000, Loss 0.003606132697314024, lr 5.497558138880005e-05  
Epoch 390000, Loss 0.003271473338827491, lr 5.497558138880005e-05  
Epoch 391000, Loss 0.0031443960033357143, lr 5.497558138880005e-05  
Epoch 392000, Loss 0.003257154021412134, lr 5.497558138880005e-05  
Epoch 393000, Loss 0.0032088966108858585, lr 5.497558138880005e-05  
Epoch 394000, Loss 0.0054768952541053295, lr 5.497558138880005e-05  
Epoch 395000, Loss 0.0033786799758672714, lr 5.497558138880005e-05  
Epoch 396000, Loss 0.0037737898528575897, lr 5.497558138880005e-05  
Epoch 397000, Loss 0.0030805866699665785, lr 5.497558138880005e-05  
Epoch 398000, Loss 0.0047267163172364235, lr 5.497558138880005e-05  
Epoch 399000, Loss 0.00489960890263319, lr 5.497558138880005e-05  
Epoch 400000, Loss 0.0033511074725538492, lr 5.497558138880005e-05  
Epoch 401000, Loss 0.003146121511235833, lr 5.497558138880005e-05  
Epoch 402000, Loss 0.00700058788061142, lr 5.497558138880005e-05

Epoch 403000, Loss 0.0029411951545625925, lr 5.497558138880005e-05  
Epoch 404000, Loss 0.0029251647647470236, lr 4.3980465111040044e-05  
Epoch 405000, Loss 0.003723705420270562, lr 4.3980465111040044e-05  
Epoch 406000, Loss 0.0028997096233069897, lr 4.3980465111040044e-05  
Epoch 407000, Loss 0.023789720609784126, lr 4.3980465111040044e-05  
Epoch 408000, Loss 0.0028659794479608536, lr 4.3980465111040044e-05  
Epoch 409000, Loss 0.004040635656565428, lr 4.3980465111040044e-05  
Epoch 410000, Loss 0.00290012639015913, lr 4.3980465111040044e-05  
Epoch 411000, Loss 0.002852069213986397, lr 4.3980465111040044e-05  
Epoch 412000, Loss 0.023867454379796982, lr 4.3980465111040044e-05  
Epoch 413000, Loss 0.0028617046773433685, lr 4.3980465111040044e-05  
Epoch 414000, Loss 0.006339071784168482, lr 4.3980465111040044e-05  
Epoch 415000, Loss 0.0029720717575401068, lr 4.3980465111040044e-05  
Epoch 416000, Loss 0.0050066933035850525, lr 4.3980465111040044e-05  
Epoch 417000, Loss 0.00424719974398613, lr 4.3980465111040044e-05  
Epoch 418000, Loss 0.0032447688281536102, lr 4.3980465111040044e-05  
Epoch 419000, Loss 0.005476980470120907, lr 4.3980465111040044e-05  
Epoch 420000, Loss 0.0027677146717906, lr 4.3980465111040044e-05  
Epoch 421000, Loss 0.0028953205328434706, lr 4.3980465111040044e-05  
Epoch 422000, Loss 0.0027371651958674192, lr 4.3980465111040044e-05  
Epoch 423000, Loss 0.005180024076253176, lr 4.3980465111040044e-05  
Epoch 424000, Loss 0.002764312783256173, lr 4.3980465111040044e-05  
Epoch 425000, Loss 0.01621202565729618, lr 4.3980465111040044e-05  
Epoch 426000, Loss 0.0026118482928723097, lr 4.3980465111040044e-05  
Epoch 427000, Loss 0.003610845422372222, lr 4.3980465111040044e-05  
Epoch 428000, Loss 0.002977518830448389, lr 4.3980465111040044e-05  
Epoch 429000, Loss 0.003459539031609893, lr 4.3980465111040044e-05  
Epoch 430000, Loss 0.0025800953153520823, lr 4.3980465111040044e-05  
Epoch 431000, Loss 0.002648971974849701, lr 4.3980465111040044e-05  
Epoch 432000, Loss 0.007306086830794811, lr 4.3980465111040044e-05  
Epoch 433000, Loss 0.0025581801310181618, lr 4.3980465111040044e-05  
Epoch 434000, Loss 0.0025476994924247265, lr 4.3980465111040044e-05  
Epoch 435000, Loss 0.005066477227956057, lr 4.3980465111040044e-05  
Epoch 436000, Loss 0.0025593603495508432, lr 4.3980465111040044e-05  
Epoch 437000, Loss 0.004910273011773825, lr 4.3980465111040044e-05  
Epoch 438000, Loss 0.002516750246286392, lr 3.5184372088832036e-05  
Epoch 439000, Loss 0.0024887220934033394, lr 3.5184372088832036e-05  
Epoch 440000, Loss 0.002601718995720148, lr 3.5184372088832036e-05  
Epoch 441000, Loss 0.003599751740694046, lr 3.5184372088832036e-05  
Epoch 442000, Loss 0.002471747575327754, lr 3.5184372088832036e-05  
Epoch 443000, Loss 0.0024568450171500444, lr 3.5184372088832036e-05  
Epoch 444000, Loss 0.00477920426055789, lr 3.5184372088832036e-05  
Epoch 445000, Loss 0.0045435247011482716, lr 2.814749767106563e-05  
Epoch 446000, Loss 0.0025380365550518036, lr 2.814749767106563e-05  
Epoch 447000, Loss 0.005016154143959284, lr 2.814749767106563e-05  
Epoch 448000, Loss 0.002904146909713745, lr 2.814749767106563e-05  
Epoch 449000, Loss 0.002520598005503416, lr 2.814749767106563e-05  
Epoch 450000, Loss 0.002375867683440447, lr 2.814749767106563e-05

Epoch 451000, Loss 0.0052051544189453125, lr 2.814749767106563e-05  
Epoch 452000, Loss 0.0046694171614944935, lr 2.814749767106563e-05  
Epoch 453000, Loss 0.002623249776661396, lr 2.814749767106563e-05  
Epoch 454000, Loss 0.007438083179295063, lr 2.814749767106563e-05  
Epoch 455000, Loss 0.0036321417428553104, lr 2.814749767106563e-05  
Epoch 456000, Loss 0.0035500202793627977, lr 2.814749767106563e-05  
Epoch 457000, Loss 0.0026481961831450462, lr 2.814749767106563e-05  
Epoch 458000, Loss 0.0026987760793417692, lr 2.814749767106563e-05  
Epoch 459000, Loss 0.0022761900909245014, lr 2.814749767106563e-05  
Epoch 460000, Loss 0.004199034068733454, lr 2.814749767106563e-05  
Epoch 461000, Loss 0.004538432694971561, lr 2.814749767106563e-05  
Epoch 462000, Loss 0.002242594724521041, lr 2.814749767106563e-05  
Epoch 463000, Loss 0.0028360607102513313, lr 2.814749767106563e-05  
Epoch 464000, Loss 0.0022243403363972902, lr 2.814749767106563e-05  
Epoch 465000, Loss 0.002203692914918065, lr 2.814749767106563e-05  
Epoch 466000, Loss 0.0027053903322666883, lr 2.814749767106563e-05  
Epoch 467000, Loss 0.004155338741838932, lr 2.814749767106563e-05  
Epoch 468000, Loss 0.002306669019162655, lr 2.814749767106563e-05  
Epoch 469000, Loss 0.0021927307825535536, lr 2.2517998136852506e-05  
Epoch 470000, Loss 0.0022848141379654408, lr 2.2517998136852506e-05  
Epoch 471000, Loss 0.00216804351657629, lr 2.2517998136852506e-05  
Epoch 472000, Loss 0.002145363949239254, lr 2.2517998136852506e-05  
Epoch 473000, Loss 0.0021543875336647034, lr 2.2517998136852506e-05  
Epoch 474000, Loss 0.0022853887639939785, lr 2.2517998136852506e-05  
Epoch 475000, Loss 0.0023803350050002337, lr 2.2517998136852506e-05  
Epoch 476000, Loss 0.002147600520402193, lr 2.2517998136852506e-05  
Epoch 477000, Loss 0.004076060838997364, lr 2.2517998136852506e-05  
Epoch 478000, Loss 0.003206780645996332, lr 2.2517998136852506e-05  
Epoch 479000, Loss 0.0024189671967178583, lr 2.2517998136852506e-05  
Epoch 480000, Loss 0.0025112668517977, lr 2.2517998136852506e-05  
Epoch 481000, Loss 0.0020764183718711138, lr 2.2517998136852506e-05  
Epoch 482000, Loss 0.002238375134766102, lr 2.2517998136852506e-05  
Epoch 483000, Loss 0.00236406153999269, lr 2.2517998136852506e-05  
Epoch 484000, Loss 0.004186152946203947, lr 2.2517998136852506e-05  
Epoch 485000, Loss 0.0025661580730229616, lr 2.2517998136852506e-05  
Epoch 486000, Loss 0.0020504777785390615, lr 2.2517998136852506e-05  
Epoch 487000, Loss 0.0025702714920043945, lr 2.2517998136852506e-05  
Epoch 488000, Loss 0.0028541770298033953, lr 2.2517998136852506e-05  
Epoch 489000, Loss 0.002013533841818571, lr 2.2517998136852506e-05  
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Epoch 492000, Loss 0.0019997465424239635, lr 2.2517998136852506e-05  
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Epoch 494000, Loss 0.001988132018595934, lr 2.2517998136852506e-05  
Epoch 495000, Loss 0.00201651849783957, lr 2.2517998136852506e-05  
Epoch 496000, Loss 0.0019709919579327106, lr 2.2517998136852506e-05  
Epoch 497000, Loss 0.003369369311258197, lr 2.2517998136852506e-05  
Epoch 498000, Loss 0.001963577698916197, lr 2.2517998136852506e-05

Epoch 499000, Loss 0.001977351261302829, lr 2.2517998136852506e-05  
Epoch 500000, Loss 0.001969053875654936, lr 2.2517998136852506e-05  
Epoch 501000, Loss 0.005739108193665743, lr 2.2517998136852506e-05  
Epoch 502000, Loss 0.0019332834053784609, lr 2.2517998136852506e-05  
Epoch 503000, Loss 0.0019899148028343916, lr 2.2517998136852506e-05  
Epoch 504000, Loss 0.001922817318700254, lr 2.2517998136852506e-05  
Epoch 505000, Loss 0.0019369315123185515, lr 2.2517998136852506e-05  
Epoch 506000, Loss 0.001896855654194951, lr 2.2517998136852506e-05  
Epoch 507000, Loss 0.0036267228424549103, lr 2.2517998136852506e-05  
Epoch 508000, Loss 0.0027923265006393194, lr 2.2517998136852506e-05  
Epoch 509000, Loss 0.0029761611949652433, lr 2.2517998136852506e-05  
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Epoch 513000, Loss 0.002574038691818714, lr 2.2517998136852506e-05  
Epoch 514000, Loss 0.003041099291294813, lr 2.2517998136852506e-05  
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Epoch 519000, Loss 0.0019037688616663218, lr 1.8014398509482006e-05  
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Epoch 524000, Loss 0.0018993691774085164, lr 1.8014398509482006e-05  
Epoch 525000, Loss 0.0018089769873768091, lr 1.8014398509482006e-05  
Epoch 526000, Loss 0.0018412107601761818, lr 1.8014398509482006e-05  
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Epoch 528000, Loss 0.0017721449257805943, lr 1.8014398509482006e-05  
Epoch 529000, Loss 0.0017758650938048959, lr 1.8014398509482006e-05  
Epoch 530000, Loss 0.0025727928150445223, lr 1.4411518807585605e-05  
Epoch 531000, Loss 0.0027065924368798733, lr 1.4411518807585605e-05  
Epoch 532000, Loss 0.0020077726803719997, lr 1.4411518807585605e-05  
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Epoch 535000, Loss 0.001762291183695197, lr 1.4411518807585605e-05  
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Epoch 538000, Loss 0.0017287163063883781, lr 1.4411518807585605e-05  
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Epoch 543000, Loss 0.00274060876108706, lr 1.4411518807585605e-05  
Epoch 544000, Loss 0.0022736797109246254, lr 1.4411518807585605e-05  
Epoch 545000, Loss 0.0017585231689736247, lr 1.4411518807585605e-05  
Epoch 546000, Loss 0.0018043933669105172, lr 1.4411518807585605e-05

Epoch 547000, Loss 0.0016708967741578817, lr 1.1529215046068485e-05  
Epoch 548000, Loss 0.0016961547080427408, lr 1.1529215046068485e-05  
Epoch 549000, Loss 0.0017439591465517879, lr 1.1529215046068485e-05  
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Epoch 551000, Loss 0.0017636035336181521, lr 1.1529215046068485e-05  
Epoch 552000, Loss 0.0016955651808530092, lr 1.1529215046068485e-05  
Epoch 553000, Loss 0.0016523061785846949, lr 1.1529215046068485e-05  
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Epoch 555000, Loss 0.001696927472949028, lr 1.1529215046068485e-05  
Epoch 556000, Loss 0.0016510406276211143, lr 1.1529215046068485e-05  
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Epoch 559000, Loss 0.001901953830383718, lr 1.1529215046068485e-05  
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Epoch 572000, Loss 0.0015771993203088641, lr 1.1529215046068485e-05  
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Epoch 574000, Loss 0.0015775068895891309, lr 1.1529215046068485e-05  
Epoch 575000, Loss 0.0016389029333367944, lr 1.1529215046068485e-05  
Epoch 576000, Loss 0.001547542866319418, lr 1.1529215046068485e-05  
Epoch 577000, Loss 0.0016680684639140964, lr 1.1529215046068485e-05  
Epoch 578000, Loss 0.001681795227341354, lr 1.1529215046068485e-05  
Epoch 579000, Loss 0.0015533260302618146, lr 1.1529215046068485e-05  
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Epoch 581000, Loss 0.0015294959302991629, lr 1.1529215046068485e-05  
Epoch 582000, Loss 0.0015261585358530283, lr 1.1529215046068485e-05  
Epoch 583000, Loss 0.001736836158670485, lr 1.1529215046068485e-05  
Epoch 584000, Loss 0.0015143275959417224, lr 1.1529215046068485e-05  
Epoch 585000, Loss 0.0016680961707606912, lr 1.1529215046068485e-05  
Epoch 586000, Loss 0.0018172330455854535, lr 1.1529215046068485e-05  
Epoch 587000, Loss 0.0015097861178219318, lr 1.1529215046068485e-05  
Epoch 588000, Loss 0.0018740653758868575, lr 1.1529215046068485e-05  
Epoch 589000, Loss 0.0018717909697443247, lr 1.1529215046068485e-05  
Epoch 590000, Loss 0.0015816749073565006, lr 1.1529215046068485e-05  
Epoch 591000, Loss 0.0017917593941092491, lr 1.1529215046068485e-05  
Epoch 592000, Loss 0.001500020152889192, lr 1.1529215046068485e-05  
Epoch 593000, Loss 0.0015021871076896787, lr 1.1529215046068485e-05  
Epoch 594000, Loss 0.001507224515080452, lr 1.1529215046068485e-05

Epoch 595000, Loss 0.0015260549262166023, lr 1.1529215046068485e-05  
Epoch 596000, Loss 0.0014783181250095367, lr 1.1529215046068485e-05  
Epoch 597000, Loss 0.0015110739041119814, lr 1.1529215046068485e-05  
Epoch 598000, Loss 0.0014801116194576025, lr 1.1529215046068485e-05  
Epoch 599000, Loss 0.0014596028486266732, lr 1.1529215046068485e-05  
Epoch 600000, Loss 0.0014620778383687139, lr 1.1529215046068485e-05  
Epoch 601000, Loss 0.0014750309055671096, lr 1.1529215046068485e-05  
Epoch 602000, Loss 0.0014754466246813536, lr 1.1529215046068485e-05  
Epoch 603000, Loss 0.0014582239091396332, lr 1.1529215046068485e-05  
Epoch 604000, Loss 0.0015198918990790844, lr 1.1529215046068485e-05  
Epoch 605000, Loss 0.0016430019168183208, lr 1.1529215046068485e-05  
Epoch 606000, Loss 0.0015642765210941434, lr 1.1529215046068485e-05  
Epoch 607000, Loss 0.0014421861851587892, lr 1.1529215046068485e-05  
Epoch 608000, Loss 0.0014298234600573778, lr 1.1529215046068485e-05  
Epoch 609000, Loss 0.00155895936768502, lr 1.1529215046068485e-05  
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Epoch 613000, Loss 0.0017477727960795164, lr 1.1529215046068485e-05  
Epoch 614000, Loss 0.0014110564952716231, lr 1.1529215046068485e-05  
Epoch 615000, Loss 0.0015430139610543847, lr 1.1529215046068485e-05  
Epoch 616000, Loss 0.0014864621916785836, lr 1.1529215046068485e-05  
Epoch 617000, Loss 0.0014119634870439768, lr 1.1529215046068485e-05  
Epoch 618000, Loss 0.0014593643136322498, lr 1.1529215046068485e-05  
Epoch 619000, Loss 0.0016915430314838886, lr 1.1529215046068485e-05  
Epoch 620000, Loss 0.001428518327884376, lr 1.1529215046068485e-05  
Epoch 621000, Loss 0.0013850508257746696, lr 1.1529215046068485e-05  
Epoch 622000, Loss 0.0016381287714466453, lr 1.1529215046068485e-05  
Epoch 623000, Loss 0.0014899030793458223, lr 1.1529215046068485e-05  
Epoch 624000, Loss 0.0013758809072896838, lr 1.1529215046068485e-05  
Epoch 625000, Loss 0.0013845096109434962, lr 1.1529215046068485e-05  
Epoch 626000, Loss 0.0013764831237494946, lr 1.1529215046068485e-05  
Epoch 627000, Loss 0.0013932620640844107, lr 1.1529215046068485e-05  
Epoch 628000, Loss 0.0014856591587886214, lr 1.1529215046068485e-05  
Epoch 629000, Loss 0.0013927664840593934, lr 1.1529215046068485e-05  
Epoch 630000, Loss 0.0013588505098596215, lr 1.1529215046068485e-05  
Epoch 631000, Loss 0.001408852287568152, lr 1.1529215046068485e-05  
Epoch 632000, Loss 0.001611025771126151, lr 1.1529215046068485e-05  
Epoch 633000, Loss 0.0013474199222400784, lr 1.1529215046068485e-05  
Epoch 634000, Loss 0.0014406880363821983, lr 1.1529215046068485e-05  
Epoch 635000, Loss 0.0013486796524375677, lr 1.1529215046068485e-05  
Epoch 636000, Loss 0.0013391651445999742, lr 1.1529215046068485e-05  
Epoch 637000, Loss 0.001627246499992907, lr 1.1529215046068485e-05  
Epoch 638000, Loss 0.0014781220816075802, lr 1.1529215046068485e-05  
Epoch 639000, Loss 0.002800806425511837, lr 1.1529215046068485e-05  
Epoch 640000, Loss 0.0013992461608722806, lr 1.1529215046068485e-05  
Epoch 641000, Loss 0.0013795794220641255, lr 1.1529215046068485e-05  
Epoch 642000, Loss 0.0013194674393162131, lr 1e-05



Epoch 643000, Loss 0.0013462709030136466, lr 1e-05  
Epoch 644000, Loss 0.0014274473069235682, lr 1e-05  
Epoch 645000, Loss 0.0013253227807581425, lr 1e-05  
Epoch 646000, Loss 0.0014782504877075553, lr 1e-05  
Epoch 647000, Loss 0.0015958475414663553, lr 1e-05  
Epoch 648000, Loss 0.0013119364157319069, lr 1e-05  
Epoch 649000, Loss 0.0013047942193225026, lr 1e-05  
Epoch 650000, Loss 0.0014104453148320317, lr 1e-05  
Epoch 651000, Loss 0.001444969791918993, lr 1e-05  
Epoch 652000, Loss 0.0015001328429207206, lr 1e-05  
Epoch 653000, Loss 0.0015419957926496863, lr 1e-05  
Epoch 654000, Loss 0.0012887446209788322, lr 1e-05  
Epoch 655000, Loss 0.0015264900866895914, lr 1e-05  
Epoch 656000, Loss 0.0013210256583988667, lr 1e-05  
Epoch 657000, Loss 0.0014045408461242914, lr 1e-05  
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Epoch 660000, Loss 0.0012856462271884084, lr 1e-05  
Epoch 661000, Loss 0.0012698618229478598, lr 1e-05  
Epoch 662000, Loss 0.0014959537656977773, lr 1e-05  
Epoch 663000, Loss 0.001278413343243301, lr 1e-05  
Epoch 664000, Loss 0.0012787224259227514, lr 1e-05  
Epoch 665000, Loss 0.001260412740521133, lr 1e-05  
Epoch 666000, Loss 0.0012834537774324417, lr 1e-05  
Epoch 667000, Loss 0.0013841523323208094, lr 1e-05  
Epoch 668000, Loss 0.0012736953794956207, lr 1e-05  
Epoch 669000, Loss 0.0012529721716418862, lr 1e-05  
Epoch 670000, Loss 0.0012501954333856702, lr 1e-05  
Epoch 671000, Loss 0.0012554967543110251, lr 1e-05  
Epoch 672000, Loss 0.001256271032616496, lr 1e-05  
Epoch 673000, Loss 0.0012446357868611813, lr 1e-05  
Epoch 674000, Loss 0.0012352943886071444, lr 1e-05  
Epoch 675000, Loss 0.0012320197420194745, lr 1e-05  
Epoch 676000, Loss 0.001395287923514843, lr 1e-05  
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Epoch 678000, Loss 0.0013507959665730596, lr 1e-05  
Epoch 679000, Loss 0.001260170596651733, lr 1e-05  
Epoch 680000, Loss 0.0014006723649799824, lr 1e-05  
Epoch 681000, Loss 0.001262247795239091, lr 1e-05  
Epoch 682000, Loss 0.0012489622458815575, lr 1e-05  
Epoch 683000, Loss 0.0012446398613974452, lr 1e-05  
Epoch 684000, Loss 0.0012115811696276069, lr 1e-05  
Epoch 685000, Loss 0.0012089662486687303, lr 1e-05  
Epoch 686000, Loss 0.0012484262697398663, lr 1e-05  
Epoch 687000, Loss 0.001237493590451777, lr 1e-05  
Epoch 688000, Loss 0.0013963555684313178, lr 1e-05  
Epoch 689000, Loss 0.0012484616599977016, lr 1e-05  
Epoch 690000, Loss 0.001316772191785276, lr 1e-05

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Epoch 694000, Loss 0.0011934916255995631, lr 1e-05  
Epoch 695000, Loss 0.0011867942521348596, lr 1e-05  
Epoch 696000, Loss 0.0012855909299105406, lr 1e-05  
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Epoch 704000, Loss 0.0012008651392534375, lr 1e-05  
Epoch 705000, Loss 0.0011892731999978423, lr 1e-05  
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Epoch 969000, Loss 0.0007906669052317739, lr 1e-05  
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Epoch 973000, Loss 0.0008456251816824079, lr 1e-05  
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Epoch 975000, Loss 0.0008644790505059063, lr 1e-05  
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Epoch 977000, Loss 0.0007763347239233553, lr 1e-05  
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Epoch 982000, Loss 0.0007709584897384048, lr 1e-05  
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Epoch 988000, Loss 0.0007951486622914672, lr 1e-05  
Epoch 989000, Loss 0.0007694483501836658, lr 1e-05  
Epoch 990000, Loss 0.0007661054842174053, lr 1e-05  
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Epoch 1279000, Loss 0.0006136275478638709, lr 1e-05  
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Epoch 1281000, Loss 0.0005665125208906829, lr 1e-05  
Epoch 1282000, Loss 0.0005741306813433766, lr 1e-05  
Epoch 1283000, Loss 0.0005730452248826623, lr 1e-05  
Epoch 1284000, Loss 0.000559810025151819, lr 1e-05  
Epoch 1285000, Loss 0.0005684210336767137, lr 1e-05  
Epoch 1286000, Loss 0.0006929515511728823, lr 1e-05  
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Epoch 1289000, Loss 0.0005863239639438689, lr 1e-05  
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Epoch 1292000, Loss 0.0007267281762324274, lr 1e-05  
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Epoch 1295000, Loss 0.0005683234194293618, lr 1e-05  
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Epoch 1298000, Loss 0.0010357595747336745, lr 1e-05  
Epoch 1299000, Loss 0.000570852542296052, lr 1e-05  
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Epoch 1587000, Loss 0.0006008780328556895, lr 1e-05  
Epoch 1588000, Loss 0.0004727500199805945, lr 1e-05  
Epoch 1589000, Loss 0.0004335609555710107, lr 1e-05  
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Epoch 1592000, Loss 0.0004312874807510525, lr 1e-05  
Epoch 1593000, Loss 0.00044558668741956353, lr 1e-05  
Epoch 1594000, Loss 0.00045871216570958495, lr 1e-05  
Epoch 1595000, Loss 0.0004360679886303842, lr 1e-05  
Epoch 1596000, Loss 0.00046536128502339125, lr 1e-05  
Epoch 1597000, Loss 0.0004489518469199538, lr 1e-05  
Epoch 1598000, Loss 0.00044404383515939116, lr 1e-05  
Epoch 1599000, Loss 0.0004398596938699484, lr 1e-05  
Epoch 1600000, Loss 0.0004749290528707206, lr 1e-05  
Epoch 1601000, Loss 0.0004830133111681789, lr 1e-05  
Epoch 1602000, Loss 0.0004288842901587486, lr 1e-05

Epoch 1603000, Loss 0.000526321935467422, lr 1e-05  
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Epoch 1607000, Loss 0.0005327881081029773, lr 1e-05  
Epoch 1608000, Loss 0.0004302735615056008, lr 1e-05  
Epoch 1609000, Loss 0.000444041914306581, lr 1e-05  
Epoch 1610000, Loss 0.00044032407458871603, lr 1e-05  
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Epoch 1612000, Loss 0.00047006591921672225, lr 1e-05  
Epoch 1613000, Loss 0.0004408666572999209, lr 1e-05  
Epoch 1614000, Loss 0.00045557672274298966, lr 1e-05  
Epoch 1615000, Loss 0.00042296777246519923, lr 1e-05  
Epoch 1616000, Loss 0.0004491420404519886, lr 1e-05  
Epoch 1617000, Loss 0.0005374241154640913, lr 1e-05  
Epoch 1618000, Loss 0.000431492633651942, lr 1e-05  
Epoch 1619000, Loss 0.0006365058943629265, lr 1e-05  
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Epoch 2201000, Loss 0.00035351584665477276, lr 1e-05  
Epoch 2202000, Loss 0.00028968387050554156, lr 1e-05  
Epoch 2203000, Loss 0.00034312010393477976, lr 1e-05  
Epoch 2204000, Loss 0.00031746417516842484, lr 1e-05  
Epoch 2205000, Loss 0.0002880616520997137, lr 1e-05  
Epoch 2206000, Loss 0.0008027168223634362, lr 1e-05  
Epoch 2207000, Loss 0.0006790585466660559, lr 1e-05  
Epoch 2208000, Loss 0.0003092016850132495, lr 1e-05  
Epoch 2209000, Loss 0.0004371600516606122, lr 1e-05  
Epoch 2210000, Loss 0.0007807846996001899, lr 1e-05  
Epoch 2211000, Loss 0.0002994177339132875, lr 1e-05  
Epoch 2212000, Loss 0.0002906238951254636, lr 1e-05  
Epoch 2213000, Loss 0.00029680097941309214, lr 1e-05  
Epoch 2214000, Loss 0.0002989704080391675, lr 1e-05  
Epoch 2215000, Loss 0.0002904111461248249, lr 1e-05  
Epoch 2216000, Loss 0.00038233044324442744, lr 1e-05  
Epoch 2217000, Loss 0.0002941972343251109, lr 1e-05  
Epoch 2218000, Loss 0.0005295415176078677, lr 1e-05  
Epoch 2219000, Loss 0.00043880249722860754, lr 1e-05  
Epoch 2220000, Loss 0.0005561222787946463, lr 1e-05  
Epoch 2221000, Loss 0.0002995882532559335, lr 1e-05  
Epoch 2222000, Loss 0.00034803018206730485, lr 1e-05  
Epoch 2223000, Loss 0.00044401935883797705, lr 1e-05  
Epoch 2224000, Loss 0.00029394772718660533, lr 1e-05  
Epoch 2225000, Loss 0.00028970290441066027, lr 1e-05  
Epoch 2226000, Loss 0.00030446937307715416, lr 1e-05

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Epoch 2227000, Loss 0.0003360686532687396, lr 1e-05
Epoch 2228000, Loss 0.000333078351104632, lr 1e-05
Epoch 2229000, Loss 0.0006499770097434521, lr 1e-05
Epoch 2230000, Loss 0.0020763117354363203, lr 1e-05
Epoch 2231000, Loss 0.0008150915964506567, lr 1e-05
Epoch 2232000, Loss 0.0005858680815435946, lr 1e-05
Epoch 2233000, Loss 0.0003119510365650058, lr 1e-05
Epoch 2234000, Loss 0.00029497986542992294, lr 1e-05
Epoch 2235000, Loss 0.00032173970248550177, lr 1e-05
Epoch 2236000, Loss 0.00029048151918686926, lr 1e-05
Epoch 2237000, Loss 0.00028910551918670535, lr 1e-05
Epoch 2238000, Loss 0.0002831359743140638, lr 1e-05
Epoch 2239000, Loss 0.0003362601564731449, lr 1e-05
Epoch 2240000, Loss 0.00028339045820757747, lr 1e-05
Epoch 2241000, Loss 0.0002865550632122904, lr 1e-05
Epoch 2242000, Loss 0.0003025620826520026, lr 1e-05
Epoch 2243000, Loss 0.000391858397051692, lr 1e-05
Epoch 2244000, Loss 0.0006418225821107626, lr 1e-05
Epoch 2245000, Loss 0.0003131130652036518, lr 1e-05
Epoch 2246000, Loss 0.00028307962929829955, lr 1e-05
Epoch 2247000, Loss 0.0003386775788385421, lr 1e-05
Epoch 2248000, Loss 0.0003064009943045676, lr 1e-05
Epoch 2249000, Loss 0.00037372150109149516, lr 1e-05
CPU times: user 12h 1min 39s, sys: 6min 37s, total: 12h 8min 16s
Wall time: 3h 4min 13s

```

```

[77]: # plot history_PINN loss and lr in two subplots
history_PINN = np.array(history_PINN)

fig, ax = plt.subplots(figsize=(15, 10))
# plot the loss
ax.plot(history_PINN[:, 0], label='loss')
ax.legend(loc='upper left')
ax.set_yscale('log')
ax.set_xlabel('epoch')
ax.set_ylabel('loss')
plt.grid()

# plot the learning rate
ax2 = ax.twinx()
ax2.plot(history_PINN[:, -1], label='lr', color='r')
ax2.set_yscale('log')
ax2.set_ylabel('lr')
# legend to the right
ax2.legend(loc='upper right')
plt.grid()
plt.title('PINN history')

```

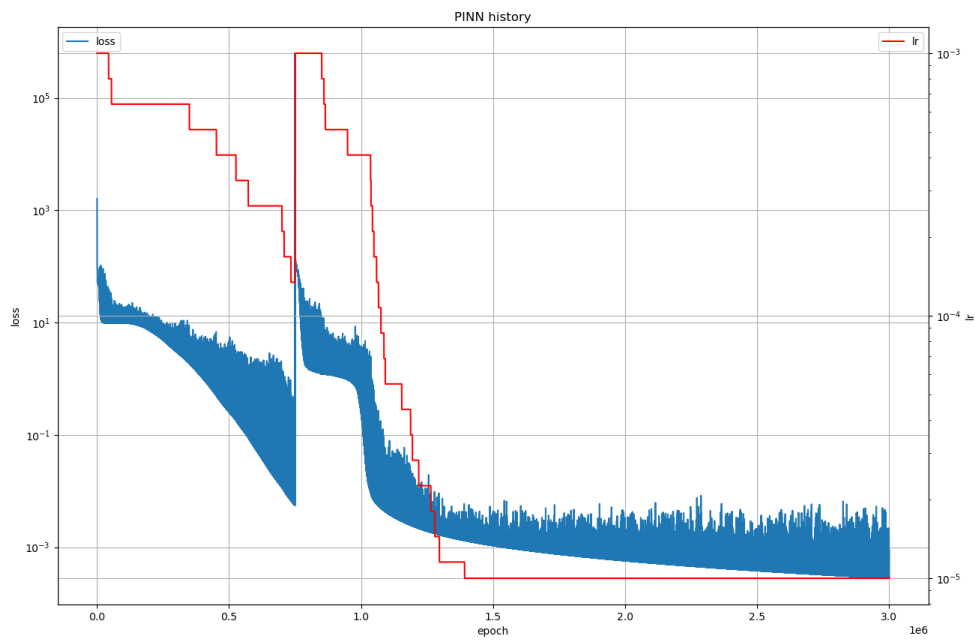
```

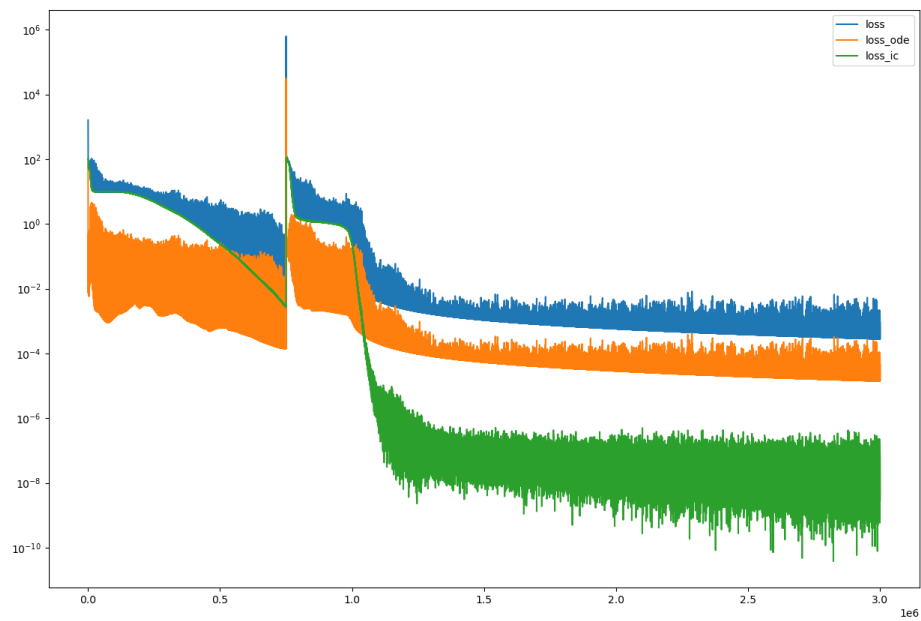
# save fig
plt.savefig('../plot/lorenz_long_history.pdf')

# plot losses
plt.figure(figsize=(15, 10))
plt.plot(history_PINN[:, 0], label='loss')
plt.plot(history_PINN[:, 1], label='loss_ode')
plt.plot(history_PINN[:, 2], label='loss_ic')
plt.legend()
plt.yscale('log')

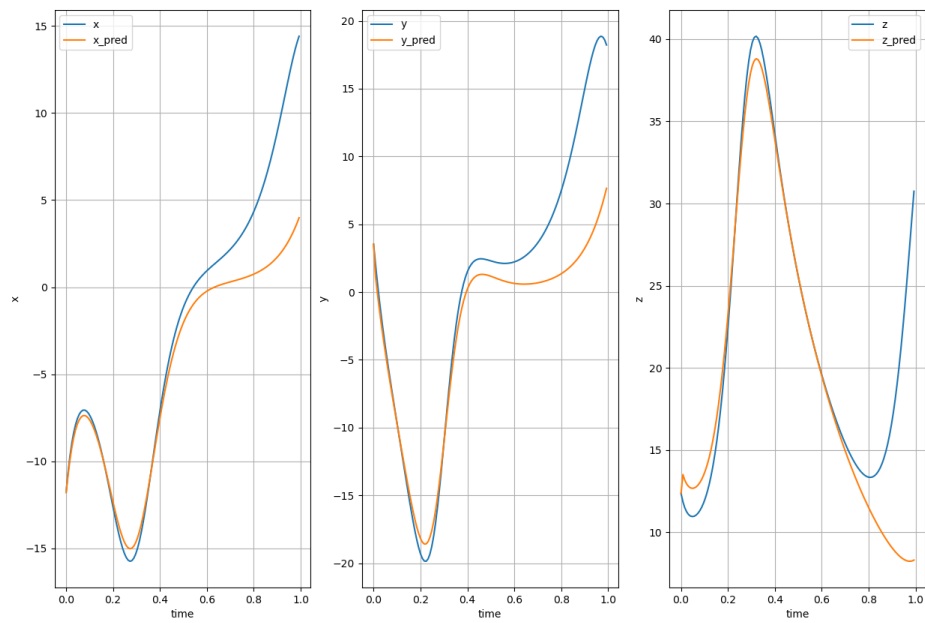
# history to list
history_PINN = history_PINN.tolist()

```





```
[48]: # get prediction and plot compare
Y_pred = short_model(X_sub_t).detach().numpy()
plot_compare_components(X_sub, Y_sub, Y_pred)
```



```
[ ]: # save model in ../models/Lorenz_PINN_baseline/Lorenz_long_baseline.pt
    ## torch.save(short_model, '../models/Lorenz_PINN_baseline/Lorenz_long_baseline.
    ↪ pt')
```