

DiseaseModelPINN_notebook_withSignLoss

December 16, 2022

```
[ ]: import deepxde as dde
from deepxde.backend import pytorch
import torch
import matplotlib.pyplot as plt
import numpy as np

from SIRD_deepxde_DiseaseModel import SIRD_deepxde_net
from DiseaseModel import SIR,SIRD,SIRDim,SIRDimRel, SIRDimRelSimple, SIRD2Var,
↳GeneralModelSolver
from Plot import Plot

# %matplotlib widget

seed = 1
np.random.seed(seed)
dde.config.set_random_seed(seed)
```

Using backend: pytorch

default Torch device: cpu

```
[ ]: time_delta = [0,2*350] # use three values here for intro time of second variant

# initial_conditions = {
#     "S": 1000000,
#     "I": 1,
#     "R": 0,
# }
# static_parameters = {
#     "alpha": (0.15),
#     "beta": (0.07),
# }
# sird_model = SIR(initial_conditions, static_parameters, time_delta)

# initial_conditions = {
#     "S": 1000000,
#     "I": 1,
```

```

#     "R": 0,
#     "D": 0,
#     }
# static_parameters = {
#     "alpha": (0.2),
#     "beta": (0.05),
#     "gamma": (0.001),
#     }
# sird_model = SIRD(initial_conditions, static_parameters, time_delta)

# initial_conditions = {
#     "S": 1000000,
#     "I": 15,
#     "R": 0,
#     "D": 0,
#     "Im": 0, # should be between 0 and 1
#     }
# static_parameters = {
#     "alpha": 0.12,
#     "beta": 0.07,
#     "gamma": 0.02,
#     "kappa": 0.2,
#     }
# sird_model = SIRDIm(initial_conditions, static_parameters, time_delta)
# initial_conditions = {
#     "S": 1000000,
#     "I": 15,
#     "R": 0,
#     "D": 0,
#     "Im": 0, # should be between 0 and 1
#     }
# static_parameters = {
#     "lambda_": 1.5,
#     "gamma": 0.000,
#     "kappa": 0.2,
#     }
# sird_model = SIRDImRel(initial_conditions, static_parameters, time_delta)
# initial_conditions = {
#     "S": 1000000,
#     "I": 15,
#     "R": 0,
#     "Im": 0, # should be between 0 and 1
#     }
# static_parameters = {
#     "lambda_": 1.5,
#     "kappa": 0.2,
#     }

```

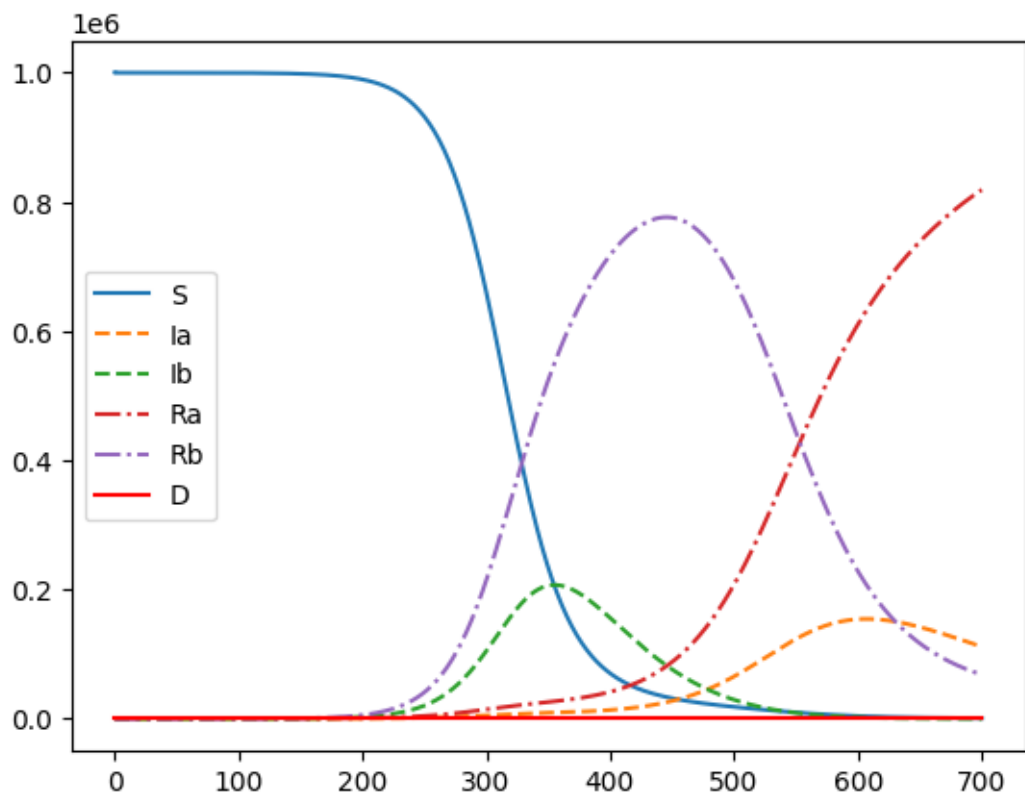
```

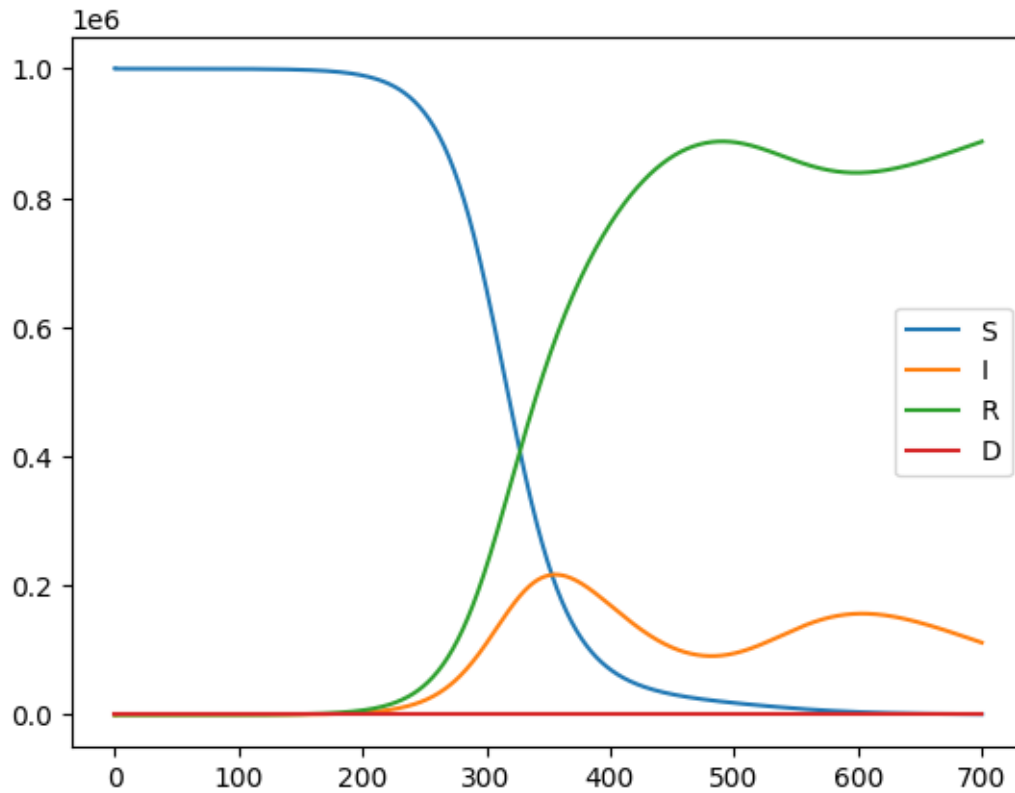
# sird_model = SIRDimRelSimple(initial_conditions, static_parameters,
    ↪time_delta)

initial_conditions = {
    "S": 1000000,
    "Ia": 1,
    "Ib": 0,
    "Ra": 0,
    "Rb": 0,
    "D": 0,
    "Im_a": 0, # should be between 0 and 1
    "Im_b": 0, # should be between 0 and 1
}
static_parameters = {
    "alpha_a": 0.11,
    "alpha_b": 0.12,
    "beta_a": 0.08,
    "beta_b": 0.08,
    "gamma_a": 0.00,
    "gamma_b": 0.00,
    "kappa_a": 0.1,
    "kappa_b": 0.2,
}
sird_model = SIRD2Var(initial_conditions, static_parameters, time_delta)

t_synth, solution_synth_full = sird_model.simulate()
t_synth, solution_synth = sird_model.get_solution_as_sird()
sird_model.plot_solution()
sird_model.plot_sird()

```





```
[ ]: print(sird_model)
```

A Disease Model with description: 'A model that simulates two concurrent diseases and natural herd immunity as a factor of the amount of recovered for each variant':

Parameters:

```
alpha_a = 0.11
alpha_b = 0.12
beta_a = 0.08
beta_b = 0.08
gamma_a = 0.0
gamma_b = 0.0
kappa_a = 0.1
kappa_b = 0.2
```

PDE groups and initial conditions:

```
S = 1000000
Ia = 1
Ib = 0
Ra = 0
Rb = 0
```

```

D = 0
Im_a = 0
Im_b = 0

```

PDE equations:

```

dS/dt = -(alpha_a/N)*Ia*S -(alpha_b/N)*Ib*S
dIa/dt = (alpha_a/N)*S*Ia + (alpha_a/N)*(1 - Im_a)*(Ra + Rb - D)*Ia -
beta_a*Ia - gamma_a*Ia
dIb/dt = (alpha_b/N)*S*Ib + (alpha_b/N)*(1 - Im_b)*(Ra + Rb - D)*Ib -
beta_b*Ib - gamma_b*Ib
dRa/dt = beta_a*Ia - (alpha_a/N)*(1 - (Im_a))*(Ra)*(Ia) - (alpha_b/N)*(1
- (Im_b))*(Ra)*(Ib)
dRb/dt = beta_b*Ib - (alpha_a/N)*(1 - (Im_a))*(Rb)*(Ia) - (alpha_b/N)*(1
- (Im_b))*(Rb)*(Ib)
dD/dt = gamma_a*Ia + gamma_b*Ib
dIm_a/dt = kappa_a*beta_a*Ia/N
dIm_b/dt = kappa_b*beta_b*Ib/N

```

PINN PDE loss equations:

```

dS_t - (-(alpha_a/N)*Ia*S -(alpha_b/N)*Ib*S)
dIa_t - ((alpha_a/N)*S*Ia + (alpha_a/N)*(1 - Im_a)*(Ra + Rb - D)*Ia -
beta_a*Ia - gamma_a*Ia)
dIb_t - ((alpha_b/N)*S*Ib + (alpha_b/N)*(1 - Im_b)*(Ra + Rb - D)*Ib -
beta_b*Ib - gamma_b*Ib)
dRa_t - (beta_a*Ia - (alpha_a/N)*(1 - (Im_a))*(Ra)*(Ia) - (alpha_b/N)*(1
- (Im_b))*(Ra)*(Ib))
dRb_t - (beta_b*Ib - (alpha_a/N)*(1 - (Im_a))*(Rb)*(Ia) - (alpha_b/N)*(1
- (Im_b))*(Rb)*(Ib))
dD_t - (gamma_a*Ia + gamma_b*Ib)
dIm_a_t - (kappa_a*beta_a*Ia/N)
dIm_b_t - (kappa_b*beta_b*Ib/N)

```

```
[ ]: # keep this even if not subsetting
```

```
t = t_synth
```

```
wsol = solution_synth
```

```
solver = GeneralModelSolver(sird_model)
```

```
# subset
```

```
# max_timestep = 300
```

```
# t_bool = t_synth < max_timestep
```

```
# t = t_synth[t_bool]
```

```
# wsol = wsol_synth[t_bool]
```

```
[ ]: model = SIRD_deepxde_net(t, wsol,disease_model=sird_model, with_neumann=False,
```

```
    ↪model_name="diseasemodel_test", with_softadapt=True)
```

```
print(model)
```

```
hyper_print_every = 100
```

```
model.init_model(lr=0.01, print_every=hyper_print_every, activation="tanh",  
↳nn_layers=4)
```

PINN model:

```
Parameters: ['alpha_a', 'alpha_b', 'beta_a', 'beta_b', 'gamma_a', 'gamma_b',  
'kappa_a', 'kappa_b']  
Loss measures: ['dS_t', 'dIa_t', 'dIb_t', 'dRa_t', 'dRb_t', 'dD_t', 'dIm_a_t',  
'dIm_b_t', 'ic_Ia', 'ic_Ib', 'ic_Ra', 'ic_Rb', 'ic_D', 'ic_Im_a', 'ic_Im_b',  
'ic_S', 'observe_S', 'observe_I', 'observe_R', 'observe_D', 'observe_SUM',  
'sign_Ia', 'sign_Ib', 'sign_Ra', 'sign_Rb', 'sign_D', 'sign_Im_a', 'sign_Im_b']  
Compiling model...  
'compile' took 0.000063 s
```

```
[ ]: TOTAL_ITER = 10000  
plot_every=500  
# for n in range(TOTAL_ITER//plot_every):  
model.train_model(iterations=TOTAL_ITER, print_every=hyper_print_every,  
↳use_LBFGSB=False)  
# params_nn = model.get_best_params()  
# params_nn= tuple(np.exp([*params_nn]))  
# print(*params_nn)  
# t_nn_param, wsol_nn_param = solver(*params_nn)  
  
# model.set_synthetic_data(t_synth, solution_synth_full)  
# model.set_nn_synthetic_data(t_nn_param, wsol_nn_param)  
# plot = Plot(model, values_to_plot=sird_model.initial_conditions_keys) # class  
↳that contains plotting functions  
# plot.show_known_and_prediction()  
# plot.plot_param_history()  
# plot.plot_loss_history()
```

Training model...

Step Train loss

Test loss

Test metric

```
20000      [1.06e-05, 1.69e-06, 1.04e-07, 7.85e-07, 8.09e-06, 8.08e-08, 1.31e-06,  
2.70e-06, 6.40e-09, 1.25e-05, 4.54e-04, 3.83e-06, 2.17e-05, 8.15e-07, 1.34e-07,  
1.87e-05, 1.84e-04, 2.40e-04, 2.55e-04, 9.45e-06, 1.38e-05, 2.92e-08, 1.60e-05,  
8.93e-05, 1.09e-07, 5.23e-06, 1.82e-08, 8.85e-06]      [1.06e-05, 1.69e-06,  
1.04e-07, 7.85e-07, 8.09e-06, 8.08e-08, 1.31e-06, 2.70e-06, 6.40e-09, 1.25e-05,  
4.54e-04, 3.83e-06, 2.17e-05, 8.15e-07, 1.34e-07, 1.87e-05, 1.84e-04, 2.40e-04,  
2.55e-04, 9.45e-06, 1.38e-05, 2.92e-08, 1.60e-05, 8.93e-05, 1.09e-07, 5.23e-06,  
1.82e-08, 8.85e-06]      []  
20000      [1.06e-05, 1.69e-06, 1.04e-07, 7.85e-07, 8.09e-06, 8.08e-08, 1.31e-06,  
2.70e-06, 6.40e-09, 1.25e-05, 4.54e-04, 3.83e-06, 2.17e-05, 8.15e-07, 1.34e-07,
```

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 2.07e-06, 4.23e-06, 3.37e-06, 4.50e-08, 3.83e-07, 1.87e-06, 3.22e-05, 1.07e-05,
 5.27e-05, 3.33e-06, 1.84e-04, 2.02e-08, 4.46e-08, 2.16e-05, 9.10e-04, 4.51e-04,
 1.03e-03, 1.18e-04, 2.72e-04, 0.00e+00, 0.00e+00, 5.27e-07, 2.94e-08, 4.47e-05,
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 21000 [3.73e-06, 5.32e-07, 1.24e-06, 4.03e-06, 1.47e-06, 1.02e-08, 2.72e-07,
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 8.71e-06, 1.66e-04, 2.24e-04, 1.87e-04, 5.29e-06, 1.03e-05, 2.11e-09, 2.34e-09,
 2.65e-08, 2.57e-08, 4.43e-06, 1.09e-11, 4.05e-10] [3.73e-06, 5.32e-07,
 1.24e-06, 4.03e-06, 1.47e-06, 1.02e-08, 2.72e-07, 8.38e-07, 2.59e-07, 2.28e-07,
 2.98e-06, 2.74e-06, 8.53e-07, 3.83e-09, 5.33e-08, 8.71e-06, 1.66e-04, 2.24e-04,
 1.87e-04, 5.29e-06, 1.03e-05, 2.11e-09, 2.34e-09, 2.65e-08, 2.57e-08, 4.43e-06,
 1.09e-11, 4.05e-10] []
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 3.22e-06, 1.19e-04, 2.13e-04, 1.47e-04, 2.94e-06, 1.83e-06, 0.00e+00, 0.00e+00,
 1.32e-07, 7.82e-08, 7.23e-07, 1.26e-07, 0.00e+00] [1.13e-06, 2.79e-07,
 4.33e-07, 3.93e-07, 1.37e-06, 4.65e-09, 7.19e-07, 8.06e-07, 2.40e-11, 1.60e-10,
 1.02e-05, 6.24e-06, 3.14e-06, 4.60e-08, 3.78e-09, 3.22e-06, 1.19e-04, 2.13e-04,
 1.47e-04, 2.94e-06, 1.83e-06, 0.00e+00, 0.00e+00, 1.32e-07, 7.82e-08, 7.23e-07,
 1.26e-07, 0.00e+00] []
 29000 [1.17e-06, 2.86e-07, 3.64e-07, 4.85e-07, 1.46e-06, 5.60e-09, 7.10e-07,
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9.76e-06, 1.32e-04, 2.11e-04, 1.54e-04, 3.02e-06, 1.27e-05, 2.70e-08, 2.34e-08,
 2.08e-07, 1.71e-07, 1.78e-06, 1.34e-07, 0.00e+00] [1.17e-06, 2.86e-07,
 3.64e-07, 4.85e-07, 1.46e-06, 5.60e-09, 7.10e-07, 9.32e-07, 1.76e-06, 1.77e-06,
 1.44e-05, 1.19e-05, 3.32e-06, 5.67e-08, 1.14e-09, 9.76e-06, 1.32e-04, 2.11e-04,
 1.54e-04, 3.02e-06, 1.27e-05, 2.70e-08, 2.34e-08, 2.08e-07, 1.71e-07, 1.78e-06,
 1.34e-07, 0.00e+00] []
 29100 [9.54e-07, 2.18e-07, 2.51e-07, 4.71e-07, 1.33e-06, 4.98e-09, 6.77e-07,
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 3.58e-08, 1.25e-04, 2.14e-04, 1.44e-04, 1.89e-06, 2.92e-06, 0.00e+00, 0.00e+00,
 4.17e-08, 1.41e-07, 1.30e-06, 1.15e-07, 0.00e+00] [9.54e-07, 2.18e-07,
 2.51e-07, 4.71e-07, 1.33e-06, 4.98e-09, 6.77e-07, 8.10e-07, 2.44e-07, 2.41e-07,
 3.36e-06, 9.28e-06, 1.24e-06, 4.85e-08, 3.60e-09, 3.58e-08, 1.25e-04, 2.14e-04,
 1.44e-04, 1.89e-06, 2.92e-06, 0.00e+00, 0.00e+00, 4.17e-08, 1.41e-07, 1.30e-06,
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 29200 [4.56e-05, 3.32e-06, 1.11e-05, 1.28e-06, 3.15e-06, 4.27e-09, 8.96e-08,
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 1.16e-02, 3.90e-01, 1.03e-02, 3.21e-01, 1.89e-02, 1.10e+00, 0.00e+00, 0.00e+00,
 0.00e+00, 0.00e+00, 0.00e+00, 5.49e-04, 0.00e+00] [4.56e-05, 3.32e-06,
 1.11e-05, 1.28e-06, 3.15e-06, 4.27e-09, 8.96e-08, 6.85e-07, 3.12e-04, 1.98e-02,
 2.00e-01, 1.70e-01, 1.89e-02, 5.47e-04, 4.94e-02, 1.16e-02, 3.90e-01, 1.03e-02,
 3.21e-01, 1.89e-02, 1.10e+00, 0.00e+00, 0.00e+00, 0.00e+00, 0.00e+00, 0.00e+00,
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 1.37e-01, 2.33e-01, 8.76e-03, 1.56e-01, 3.17e-03, 1.99e-04, 0.00e+00, 0.00e+00,
 0.00e+00, 0.00e+00, 3.17e-03, 0.00e+00, 2.95e-06] [9.60e-07, 1.27e-08,
 1.08e-10, 6.61e-07, 1.35e-08, 2.25e-10, 3.88e-08, 6.08e-09, 1.79e-04, 1.73e-04,
 4.86e-02, 3.75e-02, 3.17e-03, 3.61e-09, 2.95e-06, 1.37e-01, 2.33e-01, 8.76e-03,
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 29400 [5.20e-06, 5.57e-08, 2.14e-10, 8.62e-07, 1.41e-06, 1.20e-09, 2.04e-07,
 3.31e-08, 9.43e-04, 9.45e-04, 2.31e-01, 3.46e-03, 1.11e-03, 3.13e-09, 3.01e-07,
 1.33e-01, 2.35e-01, 5.80e-03, 1.55e-01, 1.11e-03, 7.32e-03, 0.00e+00, 0.00e+00,
 0.00e+00, 3.46e-03, 1.11e-03, 0.00e+00, 3.01e-07] [5.20e-06, 5.57e-08,
 2.14e-10, 8.62e-07, 1.41e-06, 1.20e-09, 2.04e-07, 3.31e-08, 9.43e-04, 9.45e-04,
 2.31e-01, 3.46e-03, 1.11e-03, 3.13e-09, 3.01e-07, 1.33e-01, 2.35e-01, 5.80e-03,
 1.55e-01, 1.11e-03, 7.32e-03, 0.00e+00, 0.00e+00, 0.00e+00, 3.46e-03, 1.11e-03,
 0.00e+00, 3.01e-07] []
 29500 [6.29e-06, 1.18e-07, 1.05e-09, 1.39e-05, 2.24e-06, 1.81e-09, 3.03e-07,
 5.05e-08, 1.41e-03, 1.44e-03, 1.24e-02, 3.78e-01, 9.76e-04, 1.77e-09, 1.36e-07,
 1.84e-01, 2.17e-01, 5.29e-03, 1.57e-01, 9.76e-04, 1.40e-02, 0.00e+00, 0.00e+00,
 1.24e-02, 0.00e+00, 9.76e-04, 1.77e-09, 0.00e+00] [6.29e-06, 1.18e-07,
 1.05e-09, 1.39e-05, 2.24e-06, 1.81e-09, 3.03e-07, 5.05e-08, 1.41e-03, 1.44e-03,
 1.24e-02, 3.78e-01, 9.76e-04, 1.77e-09, 1.36e-07, 1.84e-01, 2.17e-01, 5.29e-03,
 1.57e-01, 9.76e-04, 1.40e-02, 0.00e+00, 0.00e+00, 1.24e-02, 0.00e+00, 9.76e-04,
 1.77e-09, 0.00e+00] []
 29600 [5.52e-06, 1.35e-08, 3.91e-09, 1.09e-06, 1.85e-06, 1.73e-09, 2.77e-07,
 4.96e-08, 1.33e-03, 1.42e-03, 2.31e-01, 1.56e-03, 1.24e-03, 1.28e-07, 8.93e-06,

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2.02e-01, 2.13e-01, 5.33e-03, 1.54e-01, 1.24e-03, 9.52e-04, 0.00e+00, 0.00e+00,
0.00e+00, 1.56e-03, 1.24e-03, 1.28e-07, 0.00e+00] [5.52e-06, 1.35e-08,
3.91e-09, 1.09e-06, 1.85e-06, 1.73e-09, 2.77e-07, 4.96e-08, 1.33e-03, 1.42e-03,
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3.88e-06, 2.70e-06, 8.74e-07, 3.03e-09, 7.56e-08, 3.71e-08, 1.42e-03, 5.08e-03,
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0.00e+00, 1.51e-02, 3.87e-03, 2.08e-05, 7.86e-06] [2.31e-05, 3.78e-06,
7.51e-06, 2.39e-06, 4.26e-06, 7.29e-09, 2.90e-07, 4.21e-08, 5.60e-03, 5.94e-03,
3.70e-01, 1.51e-02, 3.87e-03, 2.08e-05, 7.86e-06, 1.43e-01, 2.31e-01, 9.46e-03,
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2.07e-01, 2.12e-01, 6.08e-03, 1.56e-01, 1.82e-03, 1.34e-02, 0.00e+00, 0.00e+00,
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3.37e-06, 1.09e-05, 8.60e-06, 4.32e-09, 1.74e-07, 2.42e-08, 3.37e-03, 3.41e-03,
2.04e-02, 4.09e-01, 1.82e-03, 5.91e-06, 1.83e-06, 2.07e-01, 2.12e-01, 6.08e-03,
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5.91e-06, 1.83e-06] []
30000 [7.35e-06, 8.55e-07, 2.14e-06, 9.63e-07, 1.80e-06, 2.82e-09, 1.12e-07,
1.63e-08, 2.17e-03, 2.29e-03, 3.87e-01, 1.88e-02, 3.52e-04, 7.25e-06, 8.21e-06,
1.84e-01, 2.17e-01, 5.24e-03, 1.55e-01, 3.52e-04, 1.75e-02, 0.00e+00, 0.00e+00,
0.00e+00, 1.88e-02, 3.52e-04, 7.25e-06, 0.00e+00] [7.35e-06, 8.55e-07,
2.14e-06, 9.63e-07, 1.80e-06, 2.82e-09, 1.12e-07, 1.63e-08, 2.17e-03, 2.29e-03,
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1.55e-01, 3.52e-04, 1.75e-02, 0.00e+00, 0.00e+00, 0.00e+00, 1.88e-02, 3.52e-04,
7.25e-06, 0.00e+00] []

```

Best model at step 28461:

train loss: 3.83e-04

test loss: 3.83e-04

test metric: []

'train' took 661.277568 s


```
[ ]: params_nn = model.get_best_params(out_func=np.exp) # parameters need to be
      ↪ extracted with the exponential function as they have been modelled in
      ↪ logspace
t_nn_param, wsol_nn_param, wsol_sird_nn_param = solver(*params_nn)
# params_nn= tuple(np.exp([*params_nn]))
# print(*params_nn)
model.set_synthetic_data(t_synth, solution_synth_full)
model.set_nn_synthetic_data(t_nn_param, wsol_nn_param, wsol_sird_nn_param)
print(static_parameters, sep="\n")
plot = Plot(model, values_to_plot=sird_model.initial_conditions_keys) # class
      ↪ that contains plotting functions
plot.show_known_and_prediction()
plot.plot_param_history()
plot.plot_loss_history()
```

Best train step: 28461

alpha_a: 0.18333618492652734

alpha_b: 0.028846205243505292

beta_a: 0.12614254776948966

beta_b: 0.01726116706101004

gamma_a: 0.0007519516824799706

gamma_b: 0.00037296339047424026

kappa_a: 0.21812370271097062

kappa_b: 0.16713655025076637

{'alpha_a': 0.11, 'alpha_b': 0.12, 'beta_a': 0.08, 'beta_b': 0.08, 'gamma_a': 0.0, 'gamma_b': 0.0, 'kappa_a': 0.1, 'kappa_b': 0.2}

