DiseaseModelPINN_notebook_noSingLoss

December 16, 2022

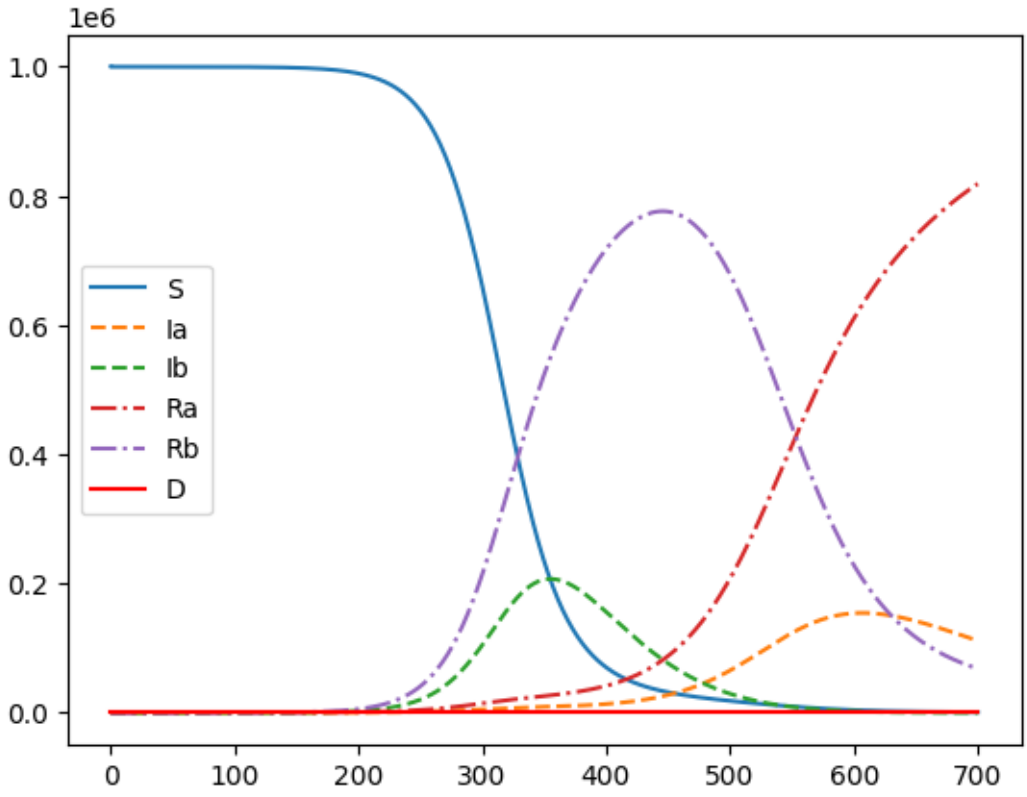
[ ]:
```
import deepxde as dde
from deepxde.backend import pytorch
import torch
import matplotlib.pyplot as plt
import numpy as np

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)
```

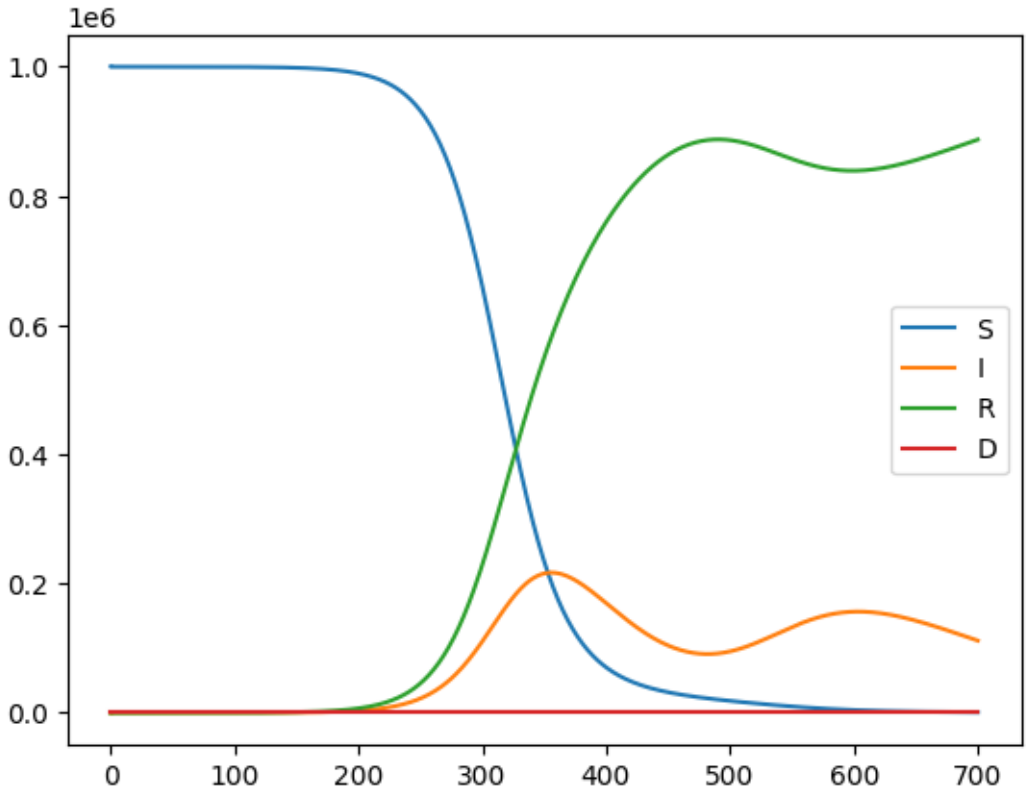
```
Using backend: pytorch


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()
```


1e6
1.0
0.8
0.6
0.4
0.2
0.0
0
100
200
300
400
500
600
700
S
Ia
Ib
Ra
Rb
D



[ ]:
```
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=3)
```

```
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',
'observe_Im_a', 'observe_Im_b', 'smooth_S', 'smooth_Ia', 'smooth_Ib',
'smooth_Ra', 'smooth_Rb', 'smooth_D', 'smooth_Im_a', 'smooth_Im_b',
'L1_norm_Ia', 'L1_norm_Ib', 'L1_norm_Ra', 'L1_norm_Rb', 'L1_norm_D',
'L1_norm_Im_a', 'L1_norm_Im_b']
Compiling model…
'compile' took 0.000080 s
```

[ ]:
```
TOTAL_ITER = 2000
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
12000     [1.18e-06, 1.20e-05, 1.96e-07, 7.85e-06, 6.17e-06, 4.16e-06, 6.65e-06,
7.83e-06, 1.66e-07, 3.22e-06, 1.22e-06, 4.54e-07, 1.97e-05, 3.43e-06, 3.74e-07,
8.04e-07, 1.92e-04, 2.73e-04, 1.85e-04, 2.19e-05, 9.20e-06, 2.16e-04, 1.82e-04,
0.00e+00, 1.48e-06, 3.95e-07, 1.29e-06, 4.34e-07, 1.41e-05, 4.44e-05, 1.44e-08,
5.04e-06, 3.42e-06, 3.82e-06, 5.85e-06, 9.01e-06, 2.74e-05, 1.29e-05]
[1.18e-06, 1.20e-05, 1.96e-07, 7.85e-06, 6.17e-06, 4.16e-06, 6.65e-06, 7.83e-06,
1.66e-07, 3.22e-06, 1.22e-06, 4.54e-07, 1.97e-05, 3.43e-06, 3.74e-07, 8.04e-07,
```

1.92e-04, 2.73e-04, 1.85e-04, 2.19e-05, 9.20e-06, 2.16e-04, 1.82e-04, 0.00e+00,
1.48e-06, 3.95e-07, 1.29e-06, 4.34e-07, 1.41e-05, 4.44e-05, 1.44e-08, 5.04e-06,
3.42e-06, 3.82e-06, 5.85e-06, 9.01e-06, 2.74e-05, 1.29e-05] []
12100 [1.15e-06, 1.00e-05, 3.73e-07, 7.22e-06, 5.45e-06, 2.31e-06, 5.97e-06,
6.58e-06, 1.53e-06, 1.56e-06, 1.49e-07, 8.91e-07, 4.73e-06, 1.21e-05, 1.81e-08,
6.78e-07, 1.02e-04, 2.37e-04, 1.51e-04, 8.86e-06, 5.73e-06, 1.56e-04, 1.41e-04,
0.00e+00, 6.10e-08, 3.67e-07, 9.98e-08, 7.42e-07, 9.18e-06, 1.91e-05, 0.00e+00,
3.35e-06, 4.52e-07, 2.38e-06, 2.75e-06, 1.80e-06, 1.81e-05, 6.47e-06]
[1.15e-06, 1.00e-05, 3.73e-07, 7.22e-06, 5.45e-06, 2.31e-06, 5.97e-06, 6.58e-06,
1.53e-06, 1.56e-06, 1.49e-07, 8.91e-07, 4.73e-06, 1.21e-05, 1.81e-08, 6.78e-07,
1.02e-04, 2.37e-04, 1.51e-04, 8.86e-06, 5.73e-06, 1.56e-04, 1.41e-04, 0.00e+00,
6.10e-08, 3.67e-07, 9.98e-08, 7.42e-07, 9.18e-06, 1.91e-05, 0.00e+00, 3.35e-06,
4.52e-07, 2.38e-06, 2.75e-06, 1.80e-06, 1.81e-05, 6.47e-06] []
12200 [1.15e-06, 8.08e-06, 5.56e-07, 7.10e-06, 5.01e-06, 1.54e-06, 5.66e-06,
6.23e-06, 1.81e-07, 1.42e-06, 4.56e-07, 5.80e-08, 1.96e-06, 9.31e-06, 1.52e-07,
3.28e-07, 6.23e-05, 2.25e-04, 1.37e-04, 6.51e-06, 4.61e-06, 1.34e-04, 1.29e-04,
0.00e+00, 7.77e-09, 7.17e-07, 2.40e-09, 7.75e-07, 6.40e-06, 1.16e-05, 0.00e+00,
4.06e-06, 4.17e-07, 8.74e-07, 1.97e-06, 1.05e-06, 8.32e-06, 3.09e-06]
[1.15e-06, 8.08e-06, 5.56e-07, 7.10e-06, 5.01e-06, 1.54e-06, 5.66e-06, 6.23e-06,
1.81e-07, 1.42e-06, 4.56e-07, 5.80e-08, 1.96e-06, 9.31e-06, 1.52e-07, 3.28e-07,
6.23e-05, 2.25e-04, 1.37e-04, 6.51e-06, 4.61e-06, 1.34e-04, 1.29e-04, 0.00e+00,
7.77e-09, 7.17e-07, 2.40e-09, 7.75e-07, 6.40e-06, 1.16e-05, 0.00e+00, 4.06e-06,
4.17e-07, 8.74e-07, 1.97e-06, 1.05e-06, 8.32e-06, 3.09e-06] []
12300 [1.11e-06, 6.59e-06, 6.27e-07, 7.16e-06, 4.71e-06, 1.13e-06, 5.65e-06,
6.07e-06, 1.56e-06, 1.44e-07, 3.64e-07, 1.36e-08, 1.50e-06, 3.16e-06, 1.20e-07,
5.73e-08, 4.68e-05, 2.20e-04, 1.32e-04, 5.96e-06, 4.46e-06, 1.29e-04, 1.27e-04,
0.00e+00, 3.76e-07, 1.84e-07, 7.75e-11, 1.07e-06, 4.40e-06, 8.03e-06, 4.63e-09,
6.88e-07, 7.49e-07, 7.65e-07, 1.67e-06, 7.18e-07, 3.95e-06, 1.60e-06]
[1.11e-06, 6.59e-06, 6.27e-07, 7.16e-06, 4.71e-06, 1.13e-06, 5.65e-06, 6.07e-06,
1.56e-06, 1.44e-07, 3.64e-07, 1.36e-08, 1.50e-06, 3.16e-06, 1.20e-07, 5.73e-08,
4.68e-05, 2.20e-04, 1.32e-04, 5.96e-06, 4.46e-06, 1.29e-04, 1.27e-04, 0.00e+00,
3.76e-07, 1.84e-07, 7.75e-11, 1.07e-06, 4.40e-06, 8.03e-06, 4.63e-09, 6.88e-07,
7.49e-07, 7.65e-07, 1.67e-06, 7.18e-07, 3.95e-06, 1.60e-06] []
12400 [1.04e-06, 5.66e-06, 6.76e-07, 7.13e-06, 4.51e-06, 9.03e-07, 5.75e-06,
5.97e-06, 7.56e-07, 9.65e-07, 5.58e-09, 1.16e-07, 7.15e-07, 1.99e-09, 4.40e-06,
7.24e-06, 3.99e-05, 2.19e-04, 1.30e-04, 5.41e-06, 4.21e-06, 1.28e-04, 1.26e-04,
0.00e+00, 9.22e-07, 1.77e-07, 1.44e-09, 1.44e-06, 3.40e-06, 6.59e-06, 1.74e-07,
3.63e-07, 1.33e-06, 7.40e-07, 1.56e-06, 9.45e-07, 2.58e-06, 1.02e-06]
[1.04e-06, 5.66e-06, 6.76e-07, 7.13e-06, 4.51e-06, 9.03e-07, 5.75e-06, 5.97e-06,
7.56e-07, 9.65e-07, 5.58e-09, 1.16e-07, 7.15e-07, 1.99e-09, 4.40e-06, 7.24e-06,
3.99e-05, 2.19e-04, 1.30e-04, 5.41e-06, 4.21e-06, 1.28e-04, 1.26e-04, 0.00e+00,
9.22e-07, 1.77e-07, 1.44e-09, 1.44e-06, 3.40e-06, 6.59e-06, 1.74e-07, 3.63e-07,
1.33e-06, 7.40e-07, 1.56e-06, 9.45e-07, 2.58e-06, 1.02e-06] []
12500 [9.98e-07, 5.24e-06, 6.65e-07, 7.06e-06, 4.36e-06, 7.73e-07, 5.86e-06,
5.91e-06, 1.41e-07, 5.29e-08, 4.46e-07, 1.07e-08, 1.10e-06, 3.09e-06, 2.72e-09,
6.85e-10, 3.71e-05, 2.19e-04, 1.29e-04, 4.91e-06, 4.23e-06, 1.27e-04, 1.26e-04,
0.00e+00, 6.20e-07, 1.60e-07, 1.33e-11, 1.22e-06, 2.75e-06, 3.15e-06, 5.84e-09,
6.71e-07, 1.71e-07, 5.70e-07, 1.53e-06, 5.87e-07, 1.59e-06, 6.89e-07]

[9.98e-07, 5.24e-06, 6.65e-07, 7.06e-06, 4.36e-06, 7.73e-07, 5.86e-06, 5.91e-06,
1.41e-07, 5.29e-08, 4.46e-07, 1.07e-08, 1.10e-06, 3.09e-06, 2.72e-09, 6.85e-10,
3.71e-05, 2.19e-04, 1.29e-04, 4.91e-06, 4.23e-06, 1.27e-04, 1.26e-04, 0.00e+00,
6.20e-07, 1.60e-07, 1.33e-11, 1.22e-06, 2.75e-06, 3.15e-06, 5.84e-09, 6.71e-07,
1.71e-07, 5.70e-07, 1.53e-06, 5.87e-07, 1.59e-06, 6.89e-07] []
12600 [9.66e-07, 4.80e-06, 7.05e-07, 6.94e-06, 4.21e-06, 6.82e-07, 5.97e-06,
5.87e-06, 3.47e-08, 5.54e-07, 6.86e-08, 1.24e-07, 5.75e-07, 1.75e-07, 1.68e-06,
3.08e-06, 3.52e-05, 2.19e-04, 1.28e-04, 4.33e-06, 4.14e-06, 1.26e-04, 1.26e-04,
0.00e+00, 8.99e-07, 1.64e-07, 2.05e-09, 1.32e-06, 2.41e-06, 2.76e-06, 8.76e-08,
3.84e-07, 3.25e-07, 4.95e-07, 1.35e-06, 6.14e-07, 1.23e-06, 5.64e-07]
[9.66e-07, 4.80e-06, 7.05e-07, 6.94e-06, 4.21e-06, 6.82e-07, 5.97e-06, 5.87e-06,
3.47e-08, 5.54e-07, 6.86e-08, 1.24e-07, 5.75e-07, 1.75e-07, 1.68e-06, 3.08e-06,
3.52e-05, 2.19e-04, 1.28e-04, 4.33e-06, 4.14e-06, 1.26e-04, 1.26e-04, 0.00e+00,
8.99e-07, 1.64e-07, 2.05e-09, 1.32e-06, 2.41e-06, 2.76e-06, 8.76e-08, 3.84e-07,
3.25e-07, 4.95e-07, 1.35e-06, 6.14e-07, 1.23e-06, 5.64e-07] []
12700 [1.07e-05, 2.58e-05, 7.87e-06, 3.05e-05, 1.00e-05, 1.35e-06, 2.70e-05,
1.46e-05, 6.79e-05, 3.11e-04, 1.78e-05, 4.44e-04, 2.12e-03, 8.82e-04, 1.45e-03,
4.48e-05, 1.38e-03, 1.05e-03, 3.17e-03, 4.79e-04, 1.17e-03, 4.10e-03, 3.77e-03,
0.00e+00, 2.45e-04, 2.49e-05, 6.86e-07, 1.85e-05, 5.10e-04, 4.43e-04, 2.54e-04,
2.48e-04, 2.03e-05, 4.16e-04, 8.07e-06, 4.57e-04, 4.24e-04, 2.27e-04]
[1.07e-05, 2.58e-05, 7.87e-06, 3.05e-05, 1.00e-05, 1.35e-06, 2.70e-05, 1.46e-05,
6.79e-05, 3.11e-04, 1.78e-05, 4.44e-04, 2.12e-03, 8.82e-04, 1.45e-03, 4.48e-05,
1.38e-03, 1.05e-03, 3.17e-03, 4.79e-04, 1.17e-03, 4.10e-03, 3.77e-03, 0.00e+00,
2.45e-04, 2.49e-05, 6.86e-07, 1.85e-05, 5.10e-04, 4.43e-04, 2.54e-04, 2.48e-04,
2.03e-05, 4.16e-04, 8.07e-06, 4.57e-04, 4.24e-04, 2.27e-04] []
12800 [2.93e-05, 2.28e-05, 1.08e-06, 1.16e-05, 7.34e-06, 1.10e-06, 2.97e-05,
1.32e-05, 5.67e-06, 3.77e-05, 2.72e-08, 8.02e-06, 7.74e-06, 1.20e-07, 3.33e-10,
1.64e-05, 1.43e-04, 3.03e-04, 1.68e-04, 4.03e-05, 1.42e-05, 1.66e-04, 1.82e-04,
0.00e+00, 2.19e-05, 0.00e+00, 1.05e-09, 3.09e-07, 2.24e-06, 9.57e-06, 2.58e-08,
1.88e-05, 1.39e-05, 6.02e-06, 8.86e-06, 6.50e-07, 1.55e-05, 2.03e-05]
[2.93e-05, 2.28e-05, 1.08e-06, 1.16e-05, 7.34e-06, 1.10e-06, 2.97e-05, 1.32e-05,
5.67e-06, 3.77e-05, 2.72e-08, 8.02e-06, 7.74e-06, 1.20e-07, 3.33e-10, 1.64e-05,
1.43e-04, 3.03e-04, 1.68e-04, 4.03e-05, 1.42e-05, 1.66e-04, 1.82e-04, 0.00e+00,
2.19e-05, 0.00e+00, 1.05e-09, 3.09e-07, 2.24e-06, 9.57e-06, 2.58e-08, 1.88e-05,
1.39e-05, 6.02e-06, 8.86e-06, 6.50e-07, 1.55e-05, 2.03e-05] []
12900 [2.37e-05, 1.29e-05, 6.62e-07, 9.30e-06, 6.69e-06, 5.61e-07, 2.44e-05,
1.34e-05, 3.74e-06, 2.23e-05, 4.01e-06, 1.30e-07, 6.96e-07, 4.14e-09, 2.10e-06,
9.75e-06, 9.63e-05, 2.39e-04, 1.45e-04, 1.17e-05, 3.98e-06, 1.48e-04, 1.50e-04,
0.00e+00, 1.01e-05, 0.00e+00, 2.61e-06, 4.99e-09, 6.78e-07, 8.13e-06, 8.34e-07,
1.98e-06, 4.99e-06, 4.00e-06, 1.96e-05, 1.85e-06, 9.09e-06, 9.89e-06]
[2.37e-05, 1.29e-05, 6.62e-07, 9.30e-06, 6.69e-06, 5.61e-07, 2.44e-05, 1.34e-05,
3.74e-06, 2.23e-05, 4.01e-06, 1.30e-07, 6.96e-07, 4.14e-09, 2.10e-06, 9.75e-06,
9.63e-05, 2.39e-04, 1.45e-04, 1.17e-05, 3.98e-06, 1.48e-04, 1.50e-04, 0.00e+00,
1.01e-05, 0.00e+00, 2.61e-06, 4.99e-09, 6.78e-07, 8.13e-06, 8.34e-07, 1.98e-06,
4.99e-06, 4.00e-06, 1.96e-05, 1.85e-06, 9.09e-06, 9.89e-06] []
13000 [1.79e-05, 9.58e-06, 8.35e-07, 7.86e-06, 5.80e-06, 4.53e-07, 2.01e-05,
1.21e-05, 9.11e-07, 1.40e-05, 2.98e-06, 7.38e-07, 3.29e-07, 5.52e-07, 3.93e-07,
2.24e-06, 7.04e-05, 2.25e-04, 1.36e-04, 6.34e-06, 1.82e-06, 1.37e-04, 1.37e-04,

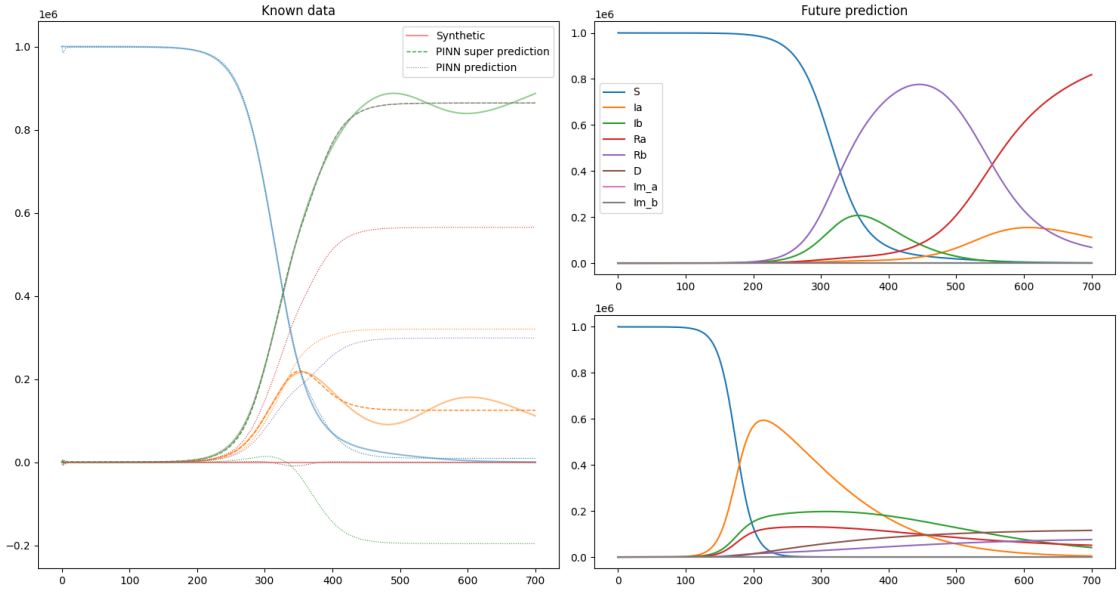
0.00e+00, 1.00e-05, 0.00e+00, 9.48e-07, 2.84e-08, 6.73e-07, 4.91e-06, 1.37e-06,
3.71e-06, 7.76e-06, 1.51e-06, 8.43e-06, 2.62e-06, 6.41e-06, 5.88e-06]
[1.79e-05, 9.58e-06, 8.35e-07, 7.86e-06, 5.80e-06, 4.53e-07, 2.01e-05, 1.21e-05,
9.11e-07, 1.40e-05, 2.98e-06, 7.38e-07, 3.29e-07, 5.52e-07, 3.93e-07, 2.24e-06,
7.04e-05, 2.25e-04, 1.36e-04, 6.34e-06, 1.82e-06, 1.37e-04, 1.37e-04, 0.00e+00,
1.00e-05, 0.00e+00, 9.48e-07, 2.84e-08, 6.73e-07, 4.91e-06, 1.37e-06, 3.71e-06,
7.76e-06, 1.51e-06, 8.43e-06, 2.62e-06, 6.41e-06, 5.88e-06]   []
13100   [1.33e-05, 8.08e-06, 1.04e-06, 6.82e-06, 4.95e-06, 3.99e-07, 1.64e-05,
1.04e-05, 1.74e-07, 1.44e-05, 1.33e-08, 4.41e-06, 4.04e-09, 2.52e-06, 1.14e-06,
1.64e-07, 5.52e-05, 2.20e-04, 1.31e-04, 5.00e-06, 1.10e-06, 1.31e-04, 1.31e-04,
0.00e+00, 8.25e-06, 0.00e+00, 1.34e-07, 2.96e-07, 5.40e-07, 3.39e-06, 1.60e-06,
4.09e-06, 7.51e-06, 1.88e-06, 1.08e-06, 3.32e-06, 4.58e-06, 3.42e-06]
[1.33e-05, 8.08e-06, 1.04e-06, 6.82e-06, 4.95e-06, 3.99e-07, 1.64e-05, 1.04e-05,
1.74e-07, 1.44e-05, 1.33e-08, 4.41e-06, 4.04e-09, 2.52e-06, 1.14e-06, 1.64e-07,
5.52e-05, 2.20e-04, 1.31e-04, 5.00e-06, 1.10e-06, 1.31e-04, 1.31e-04, 0.00e+00,
8.25e-06, 0.00e+00, 1.34e-07, 2.96e-07, 5.40e-07, 3.39e-06, 1.60e-06, 4.09e-06,
7.51e-06, 1.88e-06, 1.08e-06, 3.32e-06, 4.58e-06, 3.42e-06]   []
13200   [1.02e-05, 7.12e-06, 1.18e-06, 6.15e-06, 4.34e-06, 3.60e-07, 1.37e-05,
9.22e-06, 3.07e-07, 9.78e-06, 1.35e-06, 9.57e-07, 3.75e-08, 5.11e-07, 2.65e-07,
1.67e-06, 4.64e-05, 2.18e-04, 1.29e-04, 4.40e-06, 1.19e-06, 1.29e-04, 1.28e-04,
0.00e+00, 6.10e-06, 0.00e+00, 9.48e-07, 2.02e-07, 5.79e-07, 3.38e-06, 2.23e-06,
3.00e-06, 4.36e-06, 1.01e-06, 4.47e-06, 2.95e-06, 3.37e-06, 2.41e-06]
[1.02e-05, 7.12e-06, 1.18e-06, 6.15e-06, 4.34e-06, 3.60e-07, 1.37e-05, 9.22e-06,
3.07e-07, 9.78e-06, 1.35e-06, 9.57e-07, 3.75e-08, 5.11e-07, 2.65e-07, 1.67e-06,
4.64e-05, 2.18e-04, 1.29e-04, 4.40e-06, 1.19e-06, 1.29e-04, 1.28e-04, 0.00e+00,
6.10e-06, 0.00e+00, 9.48e-07, 2.02e-07, 5.79e-07, 3.38e-06, 2.23e-06, 3.00e-06,
4.36e-06, 1.01e-06, 4.47e-06, 2.95e-06, 3.37e-06, 2.41e-06]   []
13300   [8.14e-06, 6.38e-06, 1.26e-06, 5.71e-06, 3.91e-06, 3.27e-07, 1.19e-05,
8.42e-06, 5.75e-07, 8.30e-06, 4.63e-07, 8.94e-07, 1.24e-09, 1.00e-06, 8.05e-07,
8.68e-07, 4.16e-05, 2.18e-04, 1.27e-04, 3.88e-06, 1.29e-06, 1.27e-04, 1.27e-04,
0.00e+00, 5.28e-06, 0.00e+00, 7.74e-07, 3.69e-07, 4.88e-07, 2.97e-06, 2.19e-06,
2.86e-06, 3.38e-06, 5.61e-07, 2.55e-06, 3.31e-06, 2.62e-06, 2.11e-06]
[8.14e-06, 6.38e-06, 1.26e-06, 5.71e-06, 3.91e-06, 3.27e-07, 1.19e-05, 8.42e-06,
5.75e-07, 8.30e-06, 4.63e-07, 8.94e-07, 1.24e-09, 1.00e-06, 8.05e-07, 8.68e-07,
4.16e-05, 2.18e-04, 1.27e-04, 3.88e-06, 1.29e-06, 1.27e-04, 1.27e-04, 0.00e+00,
5.28e-06, 0.00e+00, 7.74e-07, 3.69e-07, 4.88e-07, 2.97e-06, 2.19e-06, 2.86e-06,
3.38e-06, 5.61e-07, 2.55e-06, 3.31e-06, 2.62e-06, 2.11e-06]   []
13400   [5.16e-06, 5.90e-06, 1.73e-06, 4.02e-06, 3.59e-06, 3.44e-07, 8.88e-06,
6.88e-06, 1.68e-06, 1.24e-05, 7.26e-05, 8.15e-05, 9.08e-07, 1.70e-04, 1.55e-04,
8.34e-05, 1.88e-03, 6.86e-04, 3.13e-03, 1.43e-05, 3.97e-05, 2.94e-03, 2.75e-03,
0.00e+00, 2.00e-04, 0.00e+00, 4.47e-04, 2.37e-04, 1.08e-06, 1.25e-03, 1.23e-03,
1.92e-04, 6.80e-05, 4.31e-04, 2.34e-04, 1.42e-06, 1.23e-03, 1.21e-03]
[5.16e-06, 5.90e-06, 1.73e-06, 4.02e-06, 3.59e-06, 3.44e-07, 8.88e-06, 6.88e-06,
1.68e-06, 1.24e-05, 7.26e-05, 8.15e-05, 9.08e-07, 1.70e-04, 1.55e-04, 8.34e-05,
1.88e-03, 6.86e-04, 3.13e-03, 1.43e-05, 3.97e-05, 2.94e-03, 2.75e-03, 0.00e+00,
2.00e-04, 0.00e+00, 4.47e-04, 2.37e-04, 1.08e-06, 1.25e-03, 1.23e-03, 1.92e-04,
6.80e-05, 4.31e-04, 2.34e-04, 1.42e-06, 1.23e-03, 1.21e-03]   []
13500   [3.17e-06, 6.21e-06, 2.97e-07, 6.96e-06, 4.63e-06, 1.23e-06, 5.59e-06,

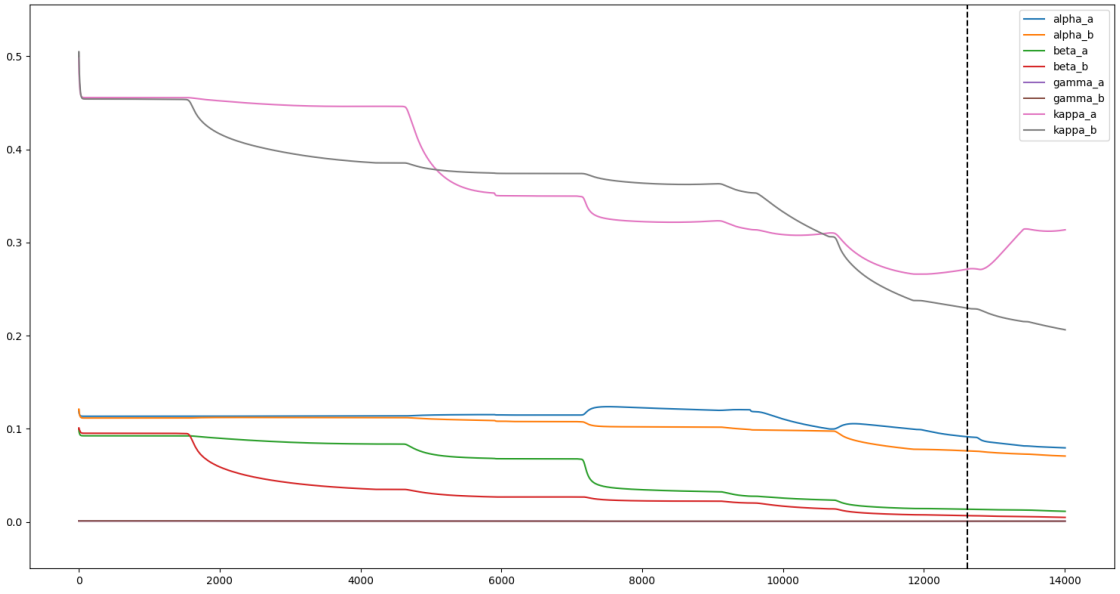
6.73e-06, 4.50e-06, 2.12e-07, 9.43e-08, 1.45e-07, 2.23e-06, 1.66e-06, 3.08e-07,
7.24e-06, 1.07e-04, 2.28e-04, 1.60e-04, 9.03e-06, 1.74e-06, 1.65e-04, 1.76e-04,
0.00e+00, 3.17e-06, 2.75e-06, 1.44e-06, 0.00e+00, 1.76e-06, 1.39e-05, 8.69e-06,
4.47e-06, 1.96e-06, 1.60e-06, 7.60e-06, 2.07e-06, 1.55e-05, 1.96e-05]
[3.17e-06, 6.21e-06, 2.97e-07, 6.96e-06, 4.63e-06, 1.23e-06, 5.59e-06, 6.73e-06,
4.50e-06, 2.12e-07, 9.43e-08, 1.45e-07, 2.23e-06, 1.66e-06, 3.08e-07, 7.24e-06,
1.07e-04, 2.28e-04, 1.60e-04, 9.03e-06, 1.74e-06, 1.65e-04, 1.76e-04, 0.00e+00,
3.17e-06, 2.75e-06, 1.44e-06, 0.00e+00, 1.76e-06, 1.39e-05, 8.69e-06, 4.47e-06,
1.96e-06, 1.60e-06, 7.60e-06, 2.07e-06, 1.55e-05, 1.96e-05]   []
13600   [4.69e-06, 5.02e-06, 3.05e-07, 6.28e-06, 4.94e-06, 1.03e-06, 5.89e-06,
6.26e-06, 3.60e-06, 4.65e-07, 7.40e-06, 9.67e-07, 1.25e-06, 3.11e-08, 1.84e-06,
1.28e-06, 7.06e-05, 2.22e-04, 1.44e-04, 3.63e-06, 6.42e-07, 1.46e-04, 1.51e-04,
0.00e+00, 3.68e-06, 1.85e-06, 1.38e-06, 0.00e+00, 1.39e-06, 3.46e-06, 3.97e-06,
4.81e-06, 6.09e-06, 5.70e-07, 8.45e-06, 9.32e-07, 7.71e-06, 8.64e-06]
[4.69e-06, 5.02e-06, 3.05e-07, 6.28e-06, 4.94e-06, 1.03e-06, 5.89e-06, 6.26e-06,
3.60e-06, 4.65e-07, 7.40e-06, 9.67e-07, 1.25e-06, 3.11e-08, 1.84e-06, 1.28e-06,
7.06e-05, 2.22e-04, 1.44e-04, 3.63e-06, 6.42e-07, 1.46e-04, 1.51e-04, 0.00e+00,
3.68e-06, 1.85e-06, 1.38e-06, 0.00e+00, 1.39e-06, 3.46e-06, 3.97e-06, 4.81e-06,
6.09e-06, 5.70e-07, 8.45e-06, 9.32e-07, 7.71e-06, 8.64e-06]   []
13700   [5.09e-06, 4.32e-06, 3.29e-07, 5.80e-06, 4.99e-06, 8.82e-07, 5.99e-06,
6.15e-06, 1.53e-06, 2.10e-07, 1.43e-06, 8.27e-08, 1.66e-08, 1.83e-07, 5.75e-07,
7.81e-07, 5.78e-05, 2.21e-04, 1.37e-04, 2.64e-06, 6.96e-07, 1.38e-04, 1.41e-04,
0.00e+00, 5.17e-06, 8.18e-07, 4.68e-07, 3.18e-09, 1.62e-06, 2.89e-06, 3.38e-06,
5.61e-06, 6.26e-06, 1.21e-06, 2.38e-06, 2.65e-07, 5.92e-06, 5.89e-06]
[5.09e-06, 4.32e-06, 3.29e-07, 5.80e-06, 4.99e-06, 8.82e-07, 5.99e-06, 6.15e-06,
1.53e-06, 2.10e-07, 1.43e-06, 8.27e-08, 1.66e-08, 1.83e-07, 5.75e-07, 7.81e-07,
5.78e-05, 2.21e-04, 1.37e-04, 2.64e-06, 6.96e-07, 1.38e-04, 1.41e-04, 0.00e+00,
5.17e-06, 8.18e-07, 4.68e-07, 3.18e-09, 1.62e-06, 2.89e-06, 3.38e-06, 5.61e-06,
6.26e-06, 1.21e-06, 2.38e-06, 2.65e-07, 5.92e-06, 5.89e-06]   []
13800   [5.21e-06, 4.03e-06, 3.37e-07, 5.46e-06, 4.93e-06, 7.80e-07, 6.05e-06,
6.12e-06, 1.77e-07, 1.33e-07, 3.03e-07, 1.04e-06, 1.55e-06, 5.62e-07, 9.46e-08,
5.37e-07, 5.12e-05, 2.21e-04, 1.33e-04, 2.11e-06, 5.51e-07, 1.34e-04, 1.36e-04,
0.00e+00, 1.95e-07, 1.39e-06, 1.90e-07, 7.77e-08, 9.48e-07, 2.72e-06, 2.83e-06,
3.50e-07, 8.42e-07, 2.18e-06, 4.62e-07, 1.18e-06, 4.76e-06, 4.59e-06]
[5.21e-06, 4.03e-06, 3.37e-07, 5.46e-06, 4.93e-06, 7.80e-07, 6.05e-06, 6.12e-06,
1.77e-07, 1.33e-07, 3.03e-07, 1.04e-06, 1.55e-06, 5.62e-07, 9.46e-08, 5.37e-07,
5.12e-05, 2.21e-04, 1.33e-04, 2.11e-06, 5.51e-07, 1.34e-04, 1.36e-04, 0.00e+00,
1.95e-07, 1.39e-06, 1.90e-07, 7.77e-08, 9.48e-07, 2.72e-06, 2.83e-06, 3.50e-07,
8.42e-07, 2.18e-06, 4.62e-07, 1.18e-06, 4.76e-06, 4.59e-06]   []
13900   [5.26e-06, 3.72e-06, 3.82e-07, 5.15e-06, 4.80e-06, 7.15e-07, 6.12e-06,
6.12e-06, 7.82e-08, 3.28e-08, 4.56e-07, 1.60e-06, 2.61e-08, 3.36e-07, 6.19e-08,
1.55e-06, 4.69e-05, 2.21e-04, 1.31e-04, 1.89e-06, 7.06e-07, 1.32e-04, 1.33e-04,
0.00e+00, 8.99e-07, 5.34e-07, 2.20e-07, 1.33e-07, 1.36e-06, 2.59e-06, 2.41e-06,
1.00e-06, 1.48e-06, 1.66e-06, 3.57e-07, 2.77e-07, 3.89e-06, 3.87e-06]
[5.26e-06, 3.72e-06, 3.82e-07, 5.15e-06, 4.80e-06, 7.15e-07, 6.12e-06, 6.12e-06,
7.82e-08, 3.28e-08, 4.56e-07, 1.60e-06, 2.61e-08, 3.36e-07, 6.19e-08, 1.55e-06,
4.69e-05, 2.21e-04, 1.31e-04, 1.89e-06, 7.06e-07, 1.32e-04, 1.33e-04, 0.00e+00,
8.99e-07, 5.34e-07, 2.20e-07, 1.33e-07, 1.36e-06, 2.59e-06, 2.41e-06, 1.00e-06,

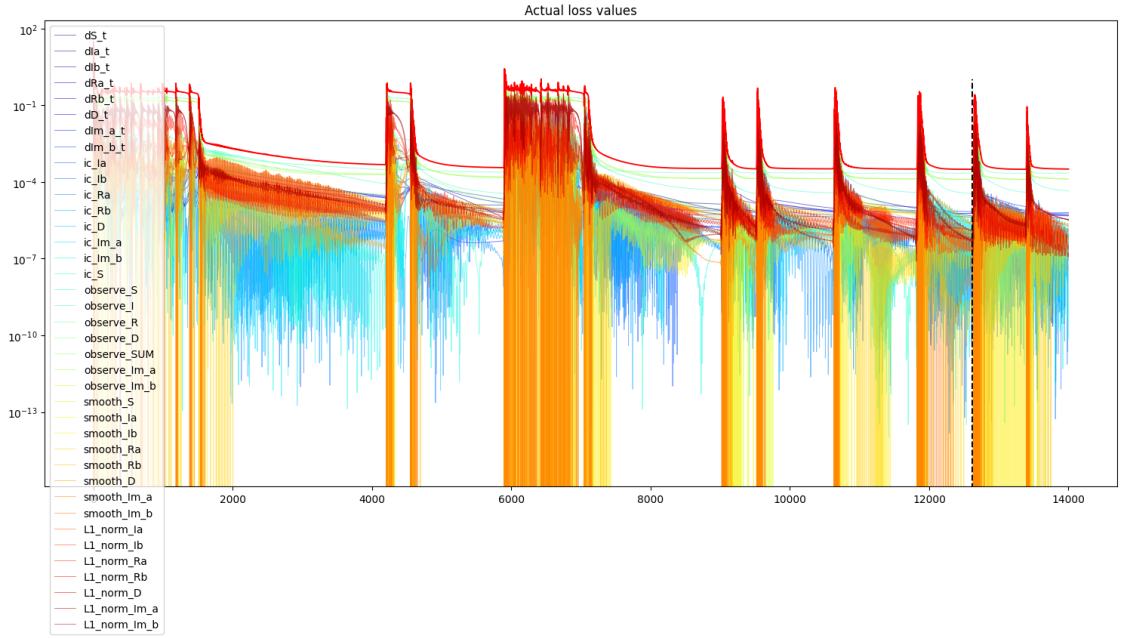
```
1.48e-06, 1.66e-06, 3.57e-07, 2.77e-07, 3.89e-06, 3.87e-06]    []
14000     [5.22e-06, 3.48e-06, 4.24e-07, 4.91e-06, 4.67e-06, 6.61e-07, 6.17e-06,
6.14e-06, 3.79e-07, 2.30e-07, 7.32e-07, 4.51e-07, 1.59e-07, 9.14e-07, 5.48e-08,
4.40e-07, 4.40e-05, 2.20e-04, 1.29e-04, 1.48e-06, 5.31e-07, 1.30e-04, 1.31e-04,
0.00e+00, 1.67e-07, 6.05e-07, 2.47e-07, 1.03e-07, 1.11e-06, 2.13e-06, 1.84e-06,
2.37e-07, 5.66e-07, 1.27e-06, 3.39e-07, 1.71e-07, 3.30e-06, 3.25e-06]
[5.22e-06, 3.48e-06, 4.24e-07, 4.91e-06, 4.67e-06, 6.61e-07, 6.17e-06, 6.14e-06,
3.79e-07, 2.30e-07, 7.32e-07, 4.51e-07, 1.59e-07, 9.14e-07, 5.48e-08, 4.40e-07,
4.40e-05, 2.20e-04, 1.29e-04, 1.48e-06, 5.31e-07, 1.30e-04, 1.31e-04, 0.00e+00,
1.67e-07, 6.05e-07, 2.47e-07, 1.03e-07, 1.11e-06, 2.13e-06, 1.84e-06, 2.37e-07,
5.66e-07, 1.27e-06, 3.39e-07, 1.71e-07, 3.30e-06, 3.25e-06]    []

Best model at step 12621:
  train loss: 6.87e-04
  test loss: 6.87e-04
  test metric: []

'train' took 89.533464 s
```

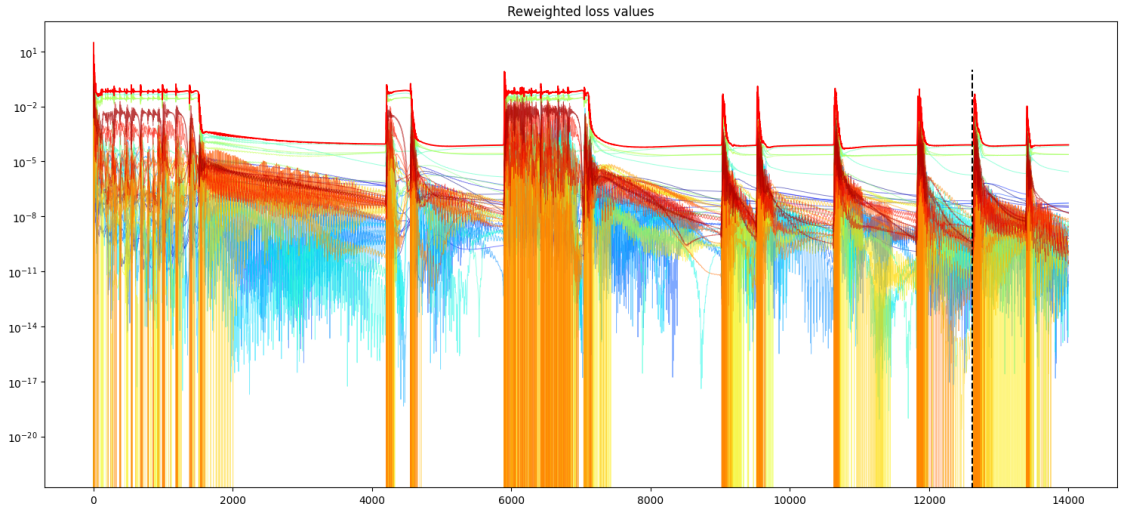
[ ]:
```python
params_nn = model.get_best_params(out_func=np.exp) # parameters need to be␣
 ↪extracted with the exponential functino as they have been modelled in␣
 ↪logspace
t_nn_param, wsol_nn_param, wsol_sird_nn_param = solver(*params_nn)
# params_nn= tuple(np.exp([*params_nn]))
# print(*params_nn)
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: 12621
alpha_a: 0.09129657174765073
alpha_b: 0.07621637457799292
beta_a: 0.013464823568164518
beta_b: 0.006611352100200285
gamma_a: 0.0005507601060147573
gamma_b: 0.0007294955804116339
kappa_a: 0.2714961301773914
kappa_b: 0.22922587915891235
{'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}
```


Known data
Future prediction
1e6
Synthetic
PINN super prediction
PINN prediction
S
Ia
Ib
Ra
Rb
D
Im_a
Im_b


alpha_a
alpha_b
beta_a
beta_b
gamma_a
gamma_b
kappa_a
kappa_b


Actual loss values
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
observe_Im_a
observe_Im_b
smooth_S
smooth_Ia
smooth_Ib
smooth_Ra
smooth_Rb
smooth_D
smooth_Im_a
smooth_Im_b
L1_norm_Ia
L1_norm_Ib
L1_norm_Ra
L1_norm_Rb
L1_norm_D
L1_norm_Im_a
L1_norm_Im_b
10^{2}
10^{-1}
10^{-4}
10^{-7}
10^{-10}
10^{-13}
2000
4000
6000
8000
10000
12000
14000


Reweighted loss values
10^{1}
10^{-2}
10^{-5}
10^{-8}
10^{-11}
10^{-14}
10^{-17}
10^{-20}
0
2000
4000
6000
8000
10000
12000
14000

[ ]:

[ ]: