

# Deviation from MBC under slow oscillations

#2D

#circular\_island

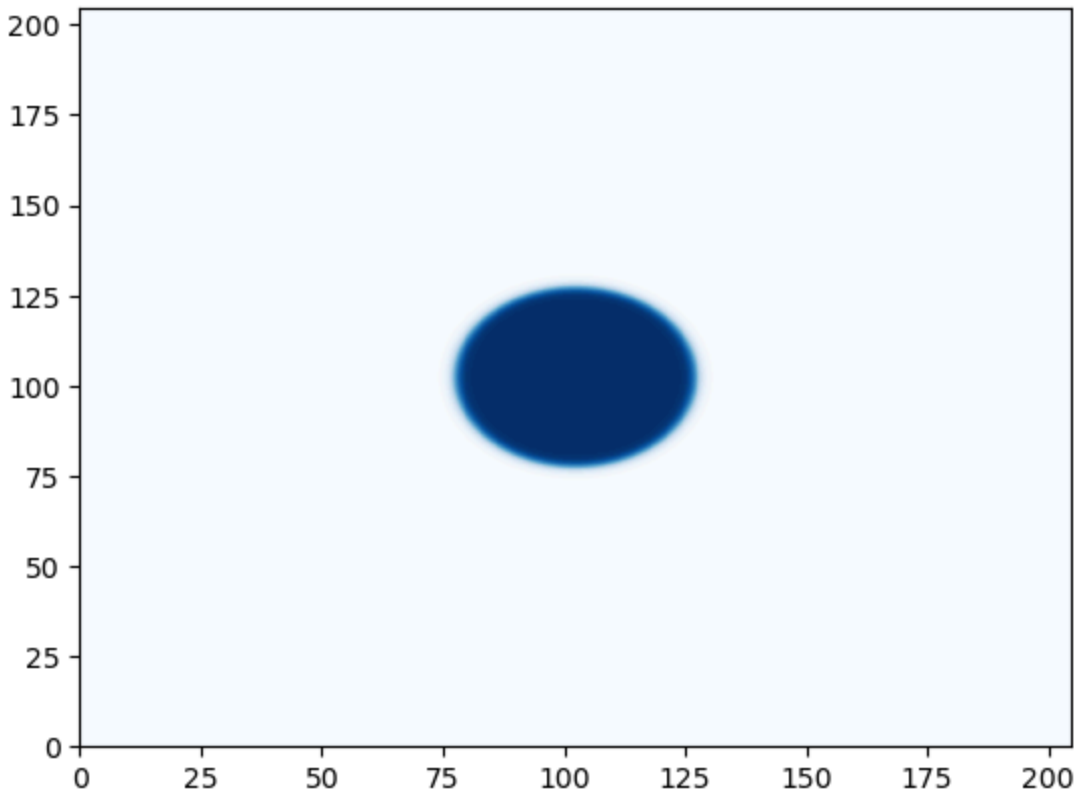
#mbc

Here we ran simulations of the 2D TDGL equation considering the initial state to be a circular island of radius  $R_0$

$$u(x, y, t = 0) = \tanh \left( (R - R_0) \sqrt{\frac{1}{2}} \right)$$

we considered the simulation box length

$$L = 204.8 \quad R_0 = 25$$



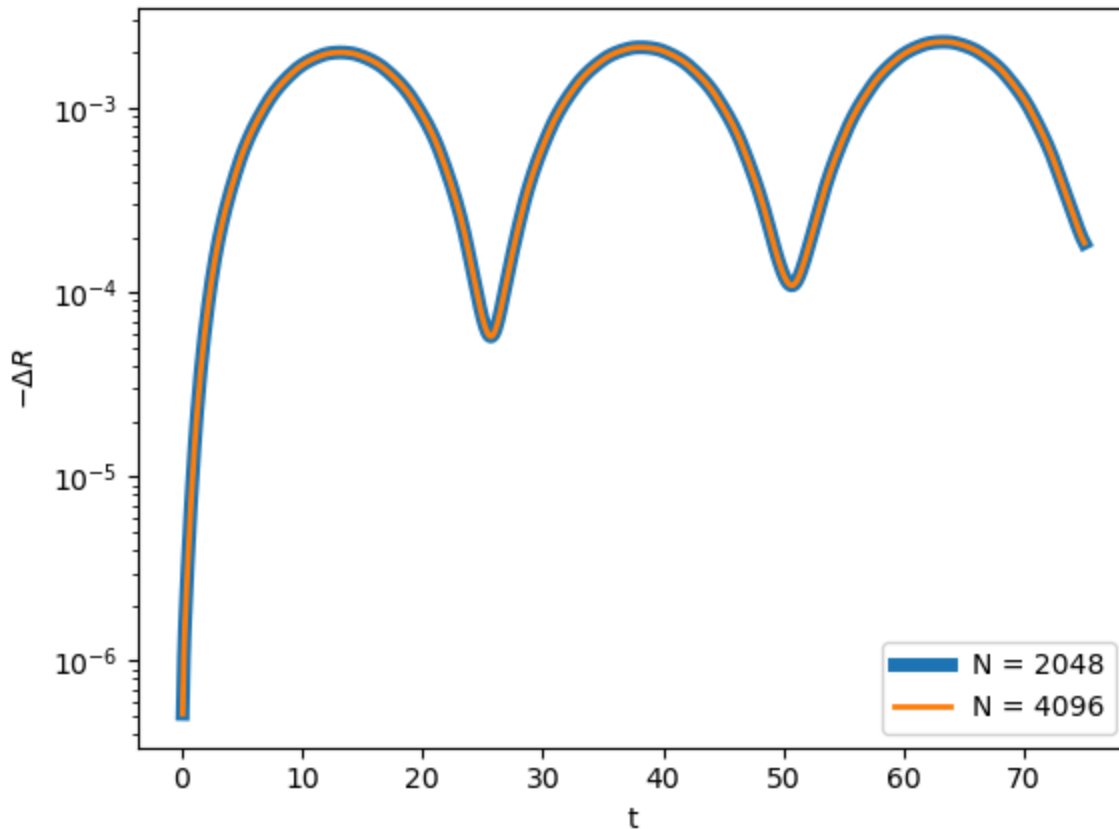
such that there is no interaction between opposite kinks due to the PBC conditions.

The size of the **simulation box is big enough** for this radius as you can see from here:

$$\Delta R = R_{C(t)} - R_{C=1}$$

$$C(t) = 1 + 0.2\sin(2\pi t/25)$$

$$R_0 = 25, L = N * dx, dx = 0.1$$



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## How we measure things

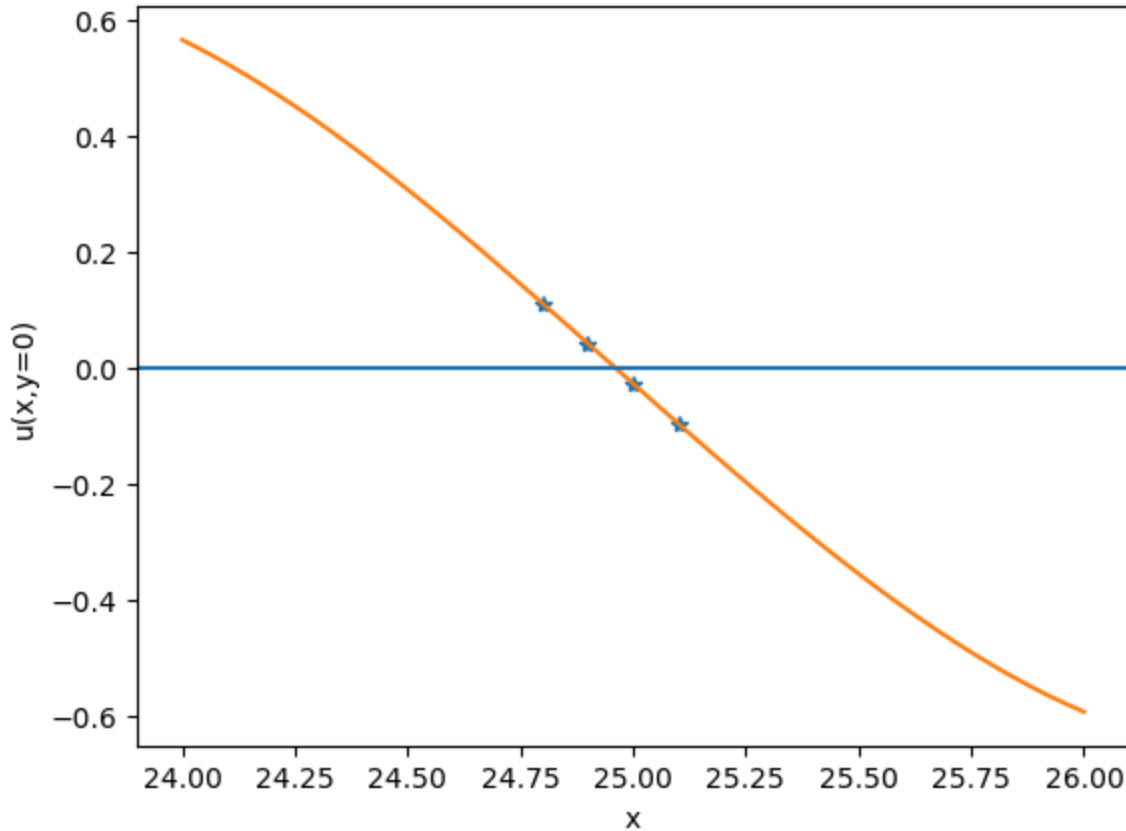
### How Radius is measured

The radius, as a function of time  $R(t)$ , has been measured by looking at the sections of  $u(x, y)$  along the line  $y = 0$ . Then we focus on the  $x > 0$  semi-axis, where there is a kink.

The position of the kink is **estimated** by finding the discrete  $x_n$  where  $u$  changes sign. Then **4 points** around  $x_n$  are considered and a **spline cubic interpolation** is made.

**CubicSpline**: "piecewise cubic polynomial which is twice continuously differentiable"

The position of the kink is represented by the central root of the polynomial and this is our estimate for the radius  $R$ .



## How constant C and C(t) data is compared

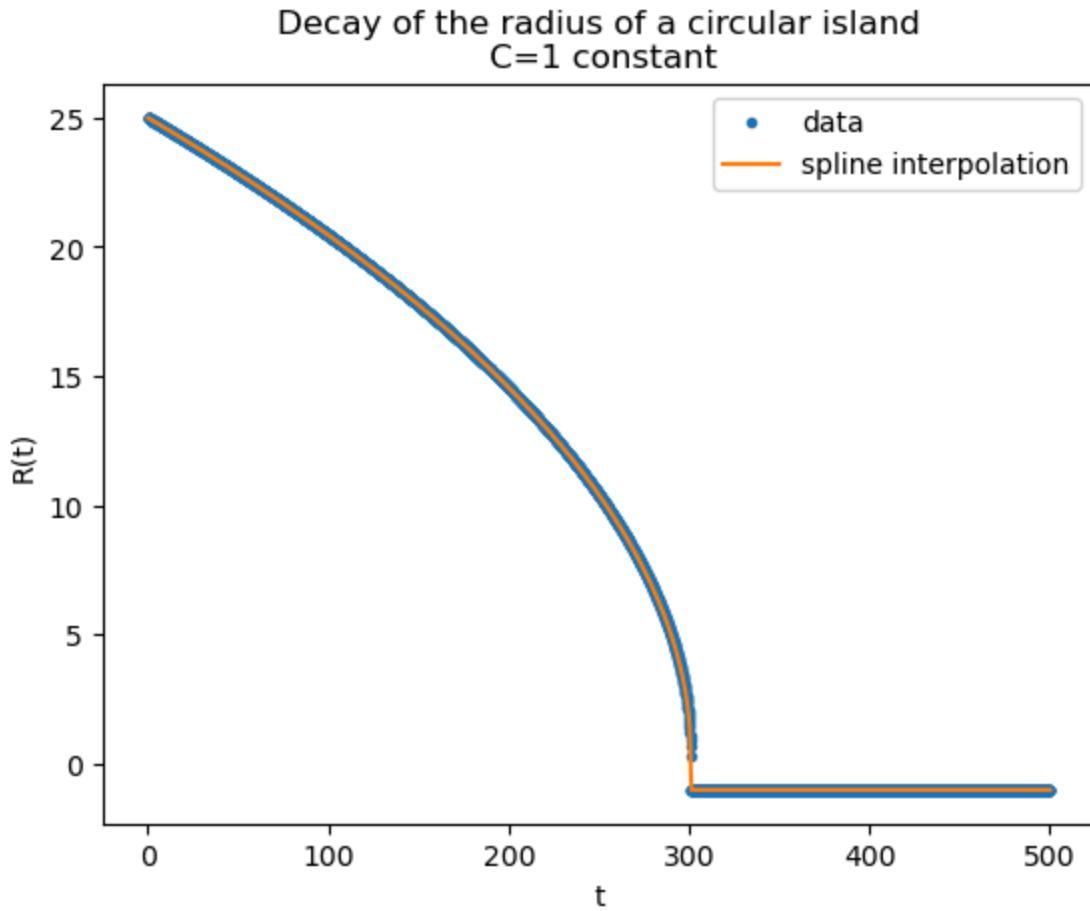
As time passes, the curve  $R(t)$  deviates more and more from the curve  $R_{C=1}(t)$  curve.

If we want to compare  $\partial_t R_{C=1}$  and  $\partial_t R$  at the **same value of R**, this is a problem, because this **does NOT mean** to compare the two derivatives at the **same time t**.

### Solution

We interpolate with a **spline** of degree  $k = 4$  (**UnivariateSpline**) the data  $R_{C=1}(t)$ . Obtaining a **continuous** function

$$f : t \rightarrow R_{C=1}(t)$$



Then we compute the **analytical derivative**

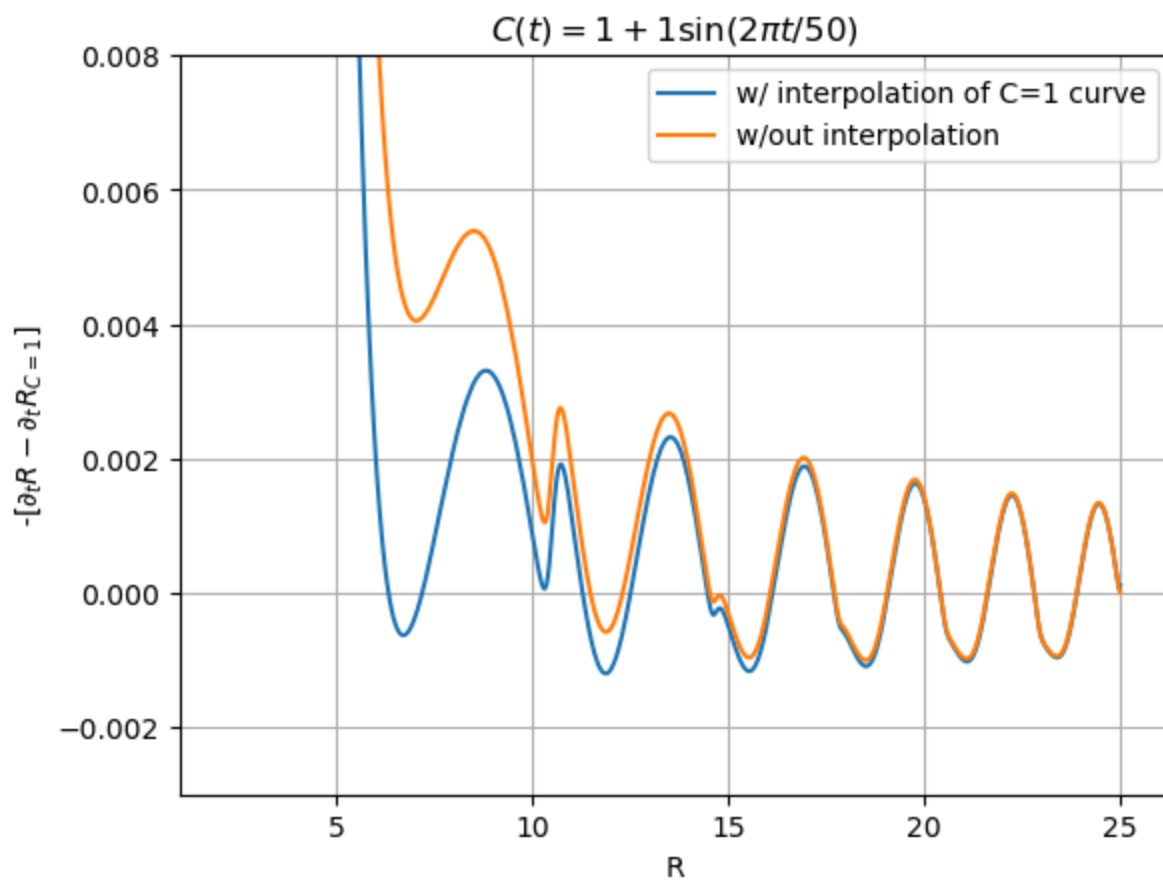
$$g : t \rightarrow \partial_t R_{C=1}(t)$$

Then we can find the inverse respect to  $f$  of an image  $R$  by looking at the root of  $f(t) - R$ .  
And we can compose those functions to obtain

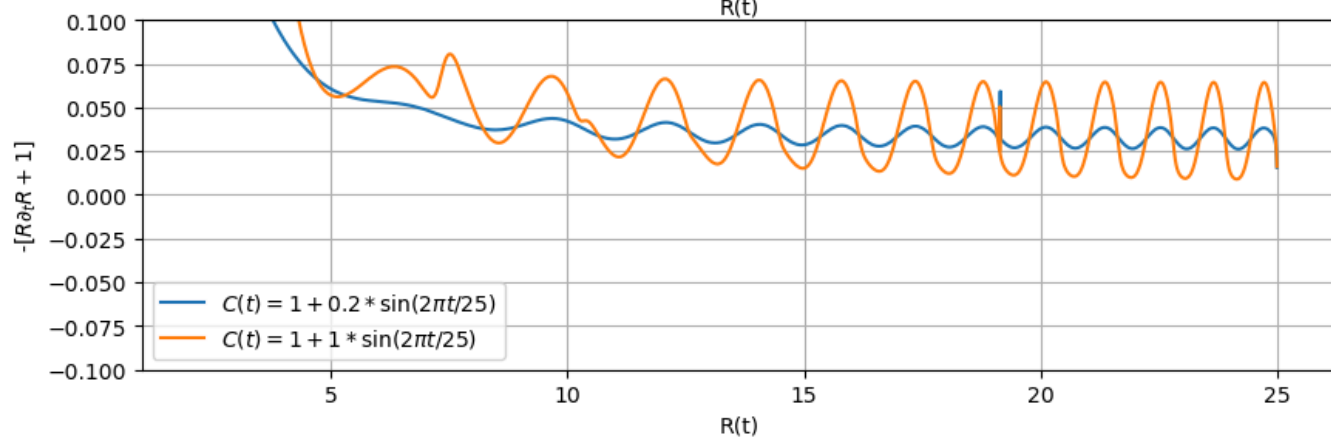
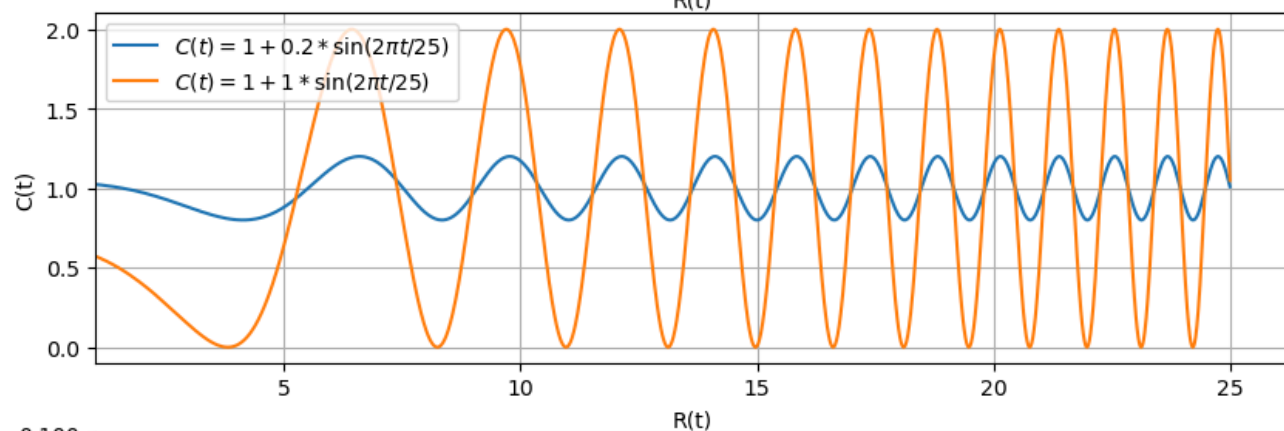
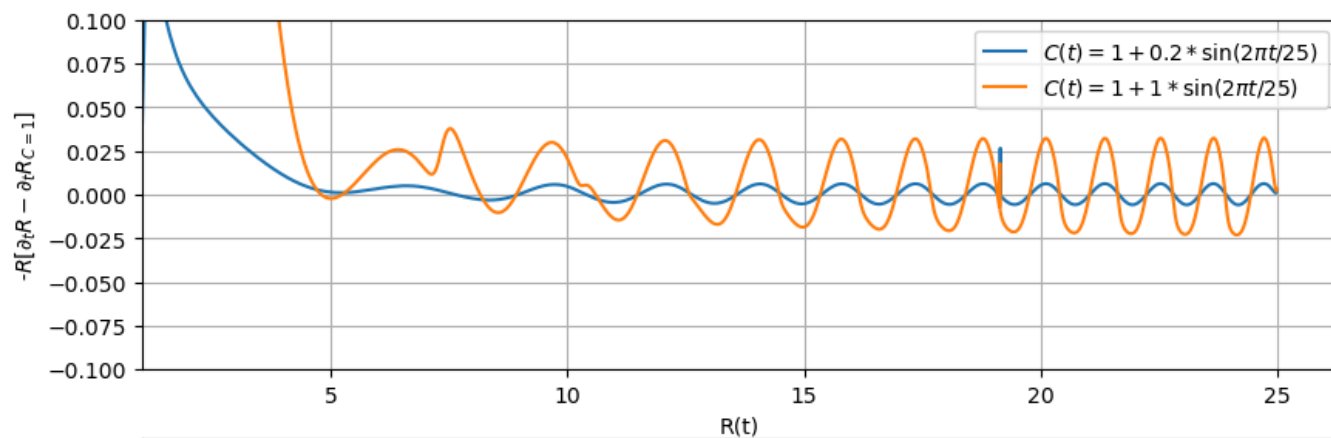
$$\gamma = g(f^{-1}(R)) : R \rightarrow \partial_t R_{C=1}$$

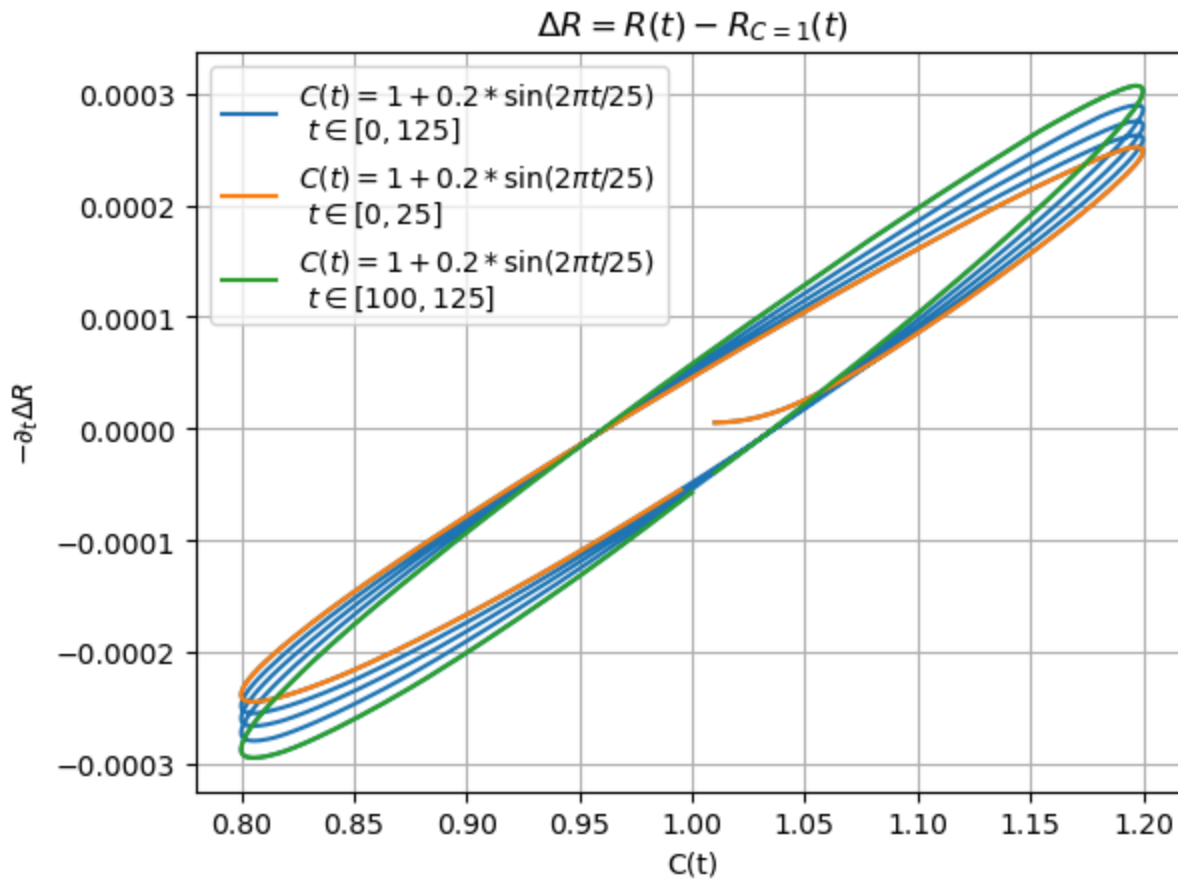
Now this function is defined **for any value of  $R$** , so we can compare it with the **numerical derivative** of  $R(t)$  such that  $R$  is the same for each datapoint compared.

In the plot below, the blue line represent the difference obtained using the interpolation, while the orange curve represents the difference obtained subtracting data points with the same time  $t$  (and on x-axis is plotted the radius of the simulation with  $C(t)$ ).



Here I show that the two interpolations we make, at different levels, give **smooth** plots:





## Analysis

Here we investigate how MBC is affected by the oscillations of  $C$ .

We will in this order

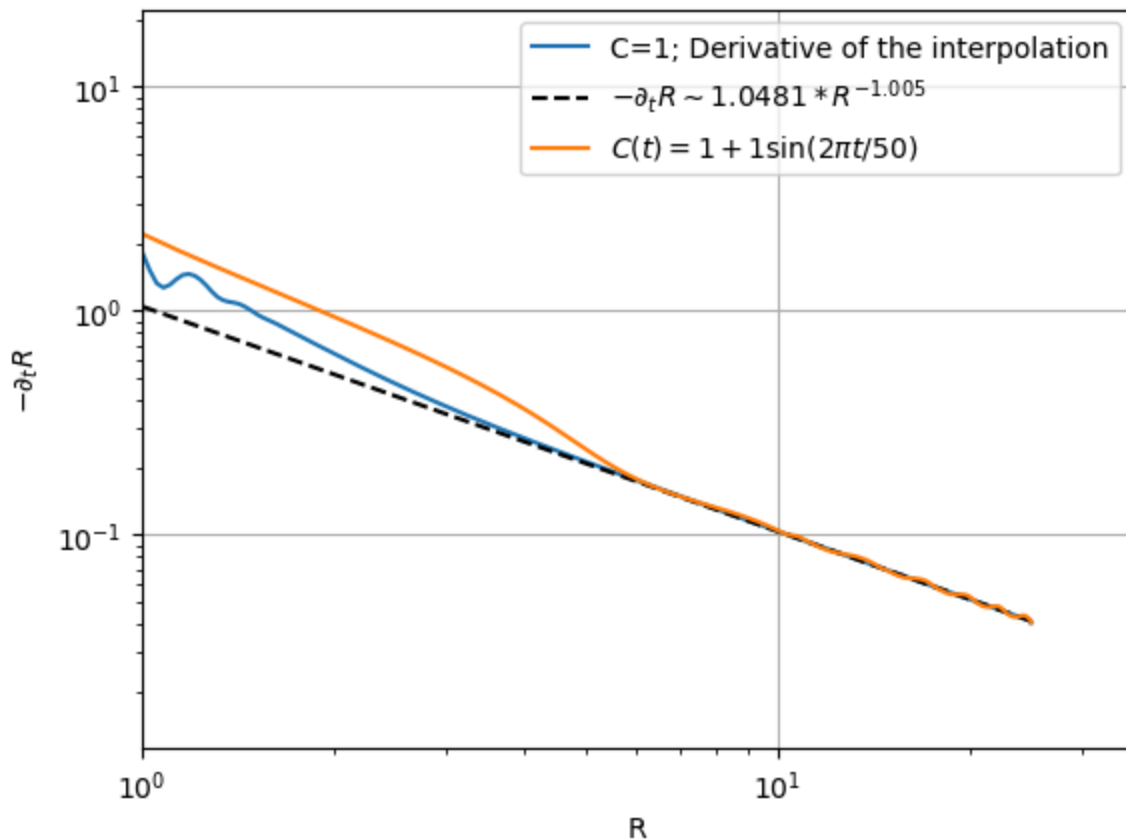
- Verify that, up to leading order, MBC is true
- Remove the leading order contribution and seek for the  $R$  and  $C(t)$  dependence of the next leading effect.

## Leading order effect (Motion by curvature)

The MBC law for a circular island

$$\dot{R} \simeq -\frac{1}{R} \quad R \gg 1$$

can be verified for a  $C = 1$  simulation



Now the question is what happens if  $C = C(t)$  and the oscillations are slow

$$\epsilon \sim \frac{1}{T}$$

## Next-to-leading order effect

Now we advance **two hypothesis** about the next order effect

- $\dot{R} = -\frac{1}{R} + \frac{f(C(t))}{R}$
- $\dot{R} = -\frac{1}{R} + \frac{f(C(t))}{R^2}$

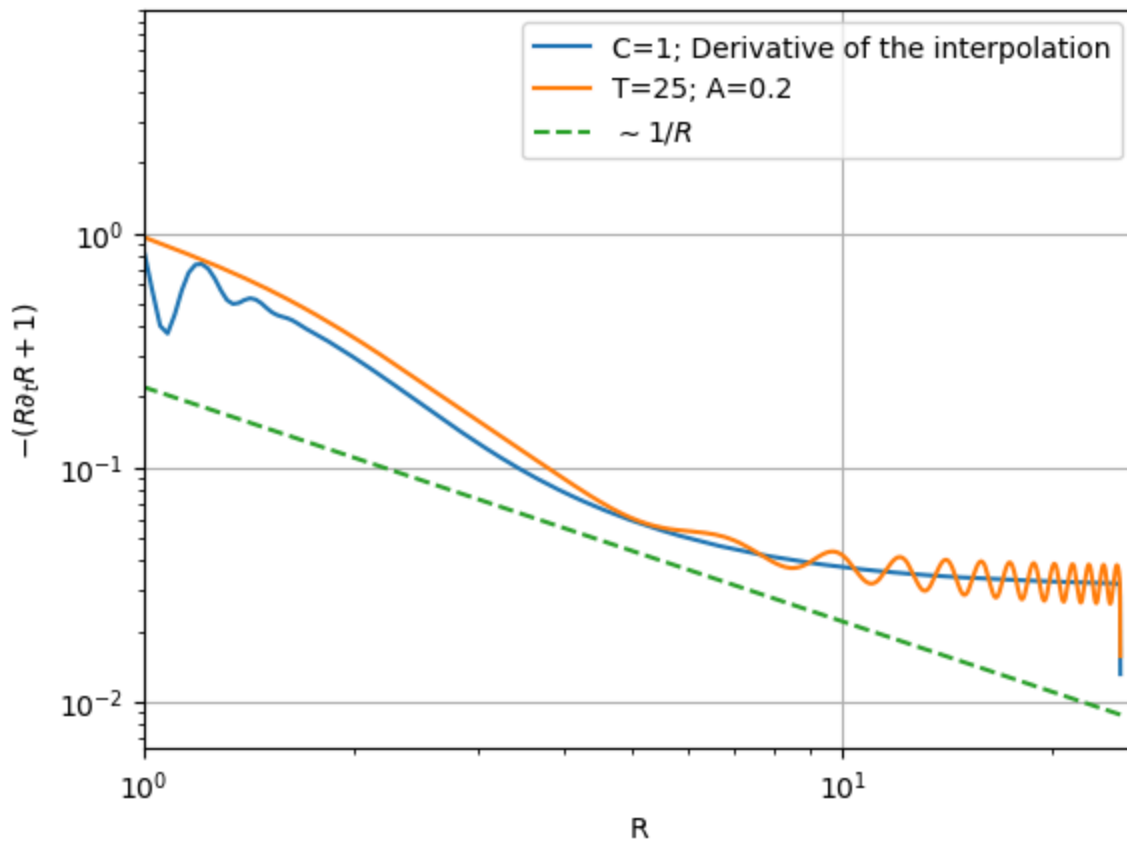
If the second model is true, it means that  $(R\dot{R} + 1) \sim \frac{f(C(t))}{R}$ .

If, instead, the first is true  $(R\dot{R} + 1) \sim f(C(t))$ .

So we can **exclude** one model or the other by plotting, in **log-log** scale,  $(R\dot{R} + 1)$  v.s.  $R$ .

## Small amplitude $A=0.2$





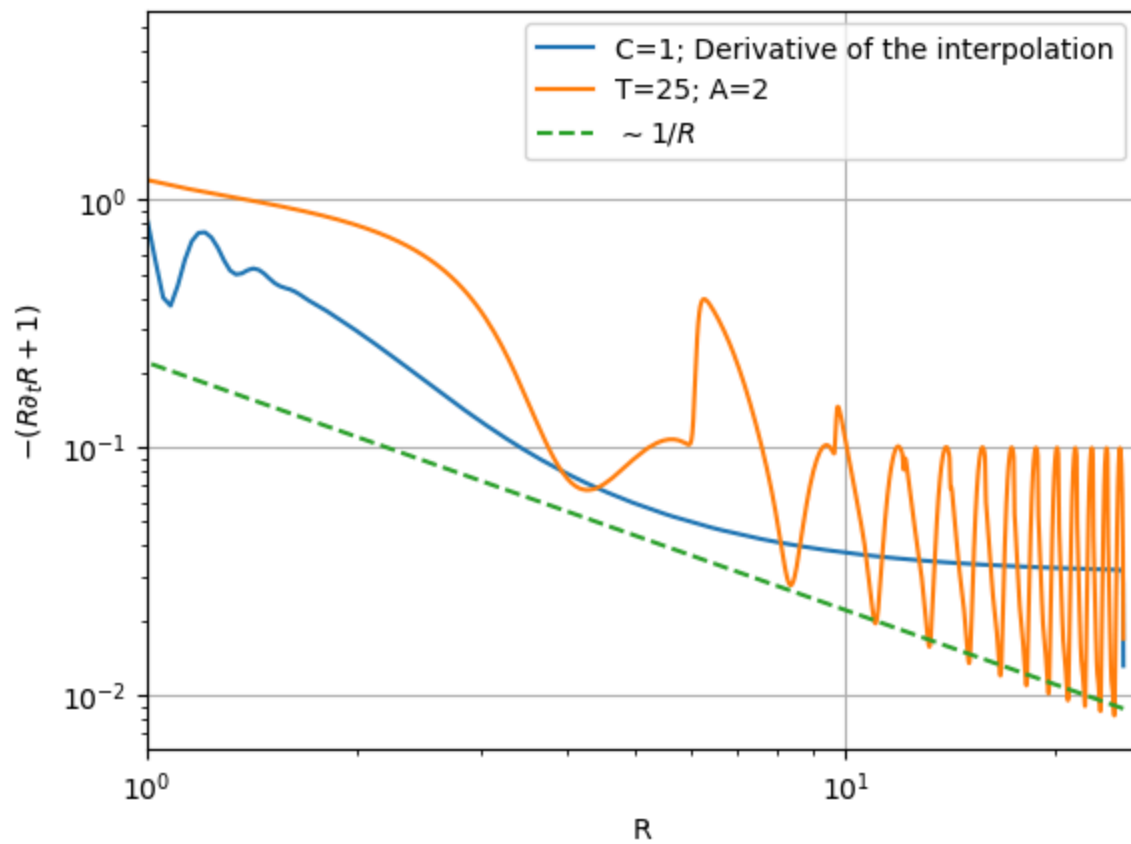
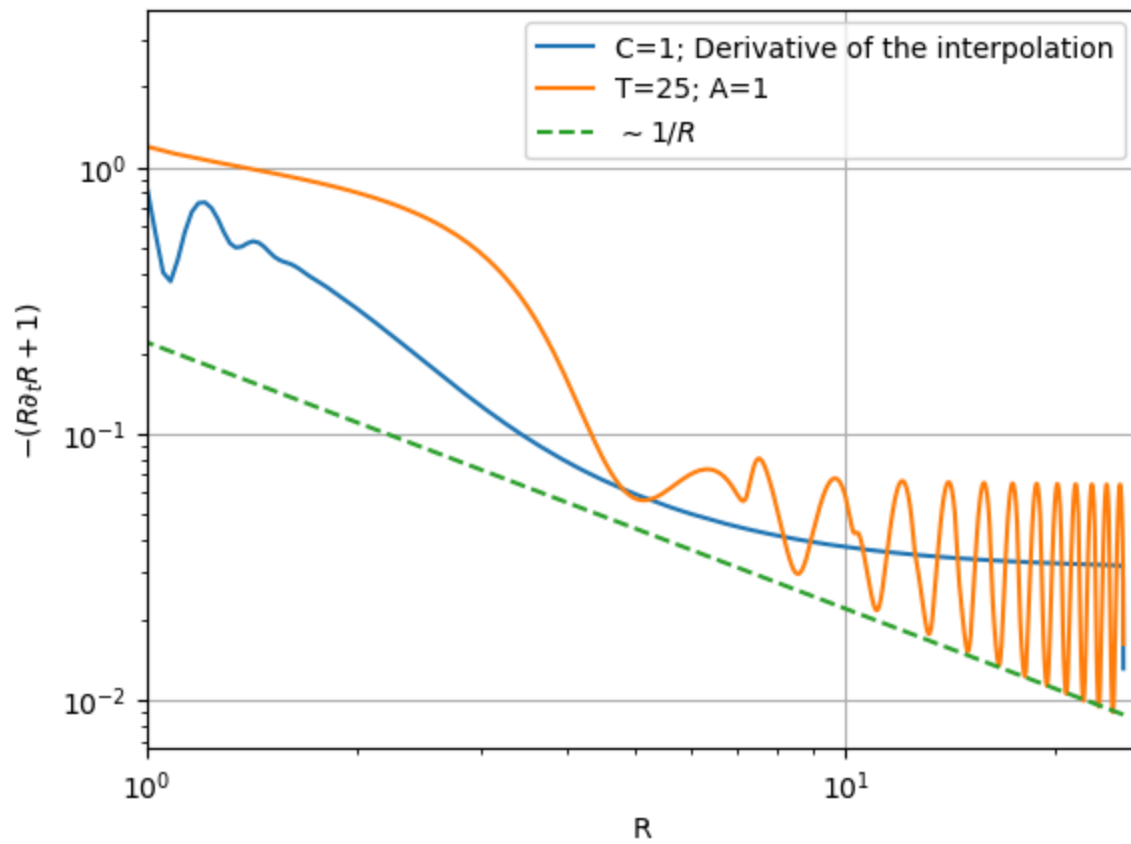
By adding oscillations,  $-(R\dot{R} + 1)$  decays slower than a power law  $\sim \frac{1}{R}$ , so the second model is false and the **first model** is more suitable.

## Large amplitude $A \geq 1$

By increasing the amplitude of  $C(t)$ , we see that

- The maximas of the oscillation do not depend on  $R$

- The minimas decays as a power-law  $R^{-1}$



**How the correction scales with  $\epsilon$**

For small amplitude oscillations, it seems that the model is

$$\dot{R} = -\frac{1}{R} + \frac{f(C(t))}{R}$$

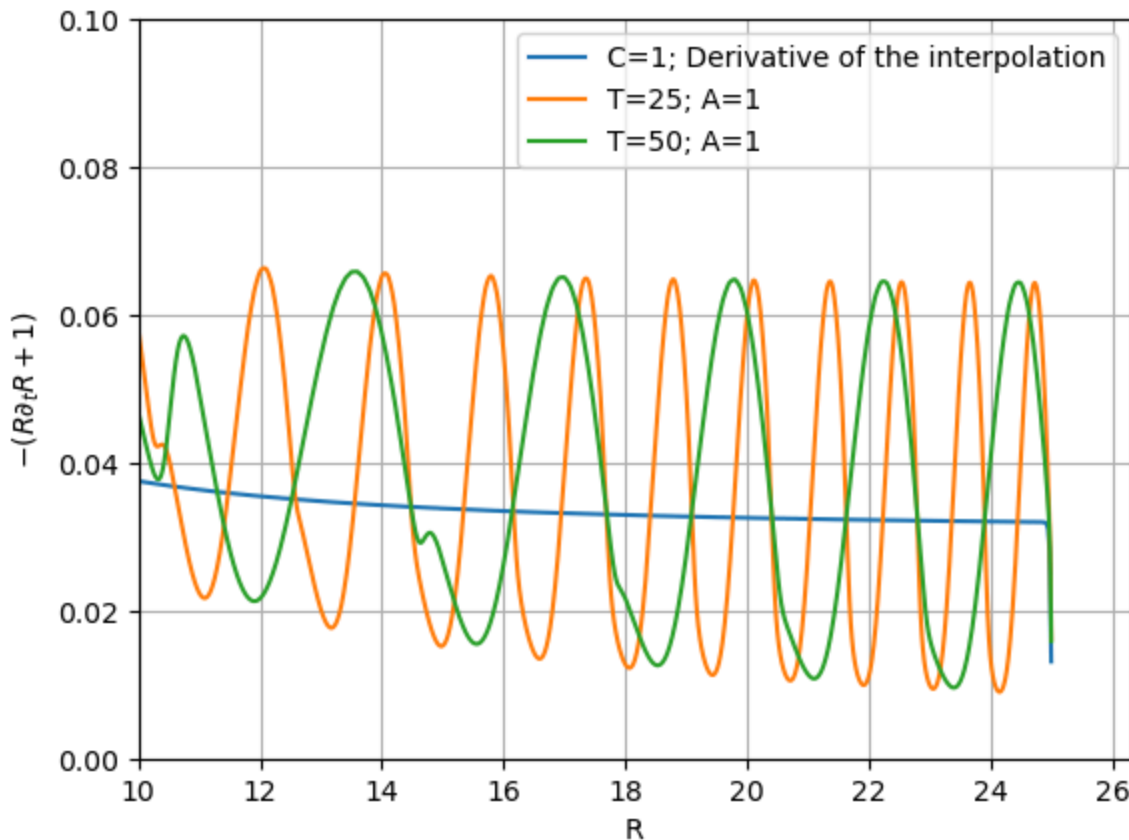
In order for this model to be coherent with our result on slow oscillations

$$\dot{R} = -\frac{1}{R} + O(\epsilon^2)$$

as  $\kappa = \frac{1}{R} \sim \epsilon$  (because  $R_0 = 25 = T \sim \epsilon^{-1}$ ) we should see that

$$f(C(t)) = (R\dot{R} + 1) \sim \epsilon^n \quad n \geq 1$$

and NOT of order 1!



This plot shows experimental curves associated to two values of the period that are one the double of the other. So  $\epsilon_{orange} = 2\epsilon_{green}$ .

So the next-to-leading order contribution of the green line should be smallest than the half of the contribution of the orange line, but it is not so!

## Dependence on C

We have plot how the leading and next-to leading contributions to  $\dot{R}$  behave with R. But what about C?

Following the idea that the previous plots show a weak dependence on R of the next-to-leading order contribution (for sure slower than a power law  $R^{-1}$  for small amplitudes), then we can look

for the dependence on C comparing data **at different R** (assuming there is no dependence on R)

