MSc Project - Modelling a Double Barred Galaxy as a Double Binary

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Abstract

TODO

Keywords: TODO

1 Introduction

The aim of this project was to create a simple model of a double barred galaxy using a double binary.

2 Methods

Fortran 90 was selected as the language of choice in order to avoid the fixed line limitations of Fortran 77. The model was created using OdeInt from Numerical Recipes. I first converted OdeInt to Fortran 90 for this purpose. Please see the Compilers subsection for a few notes on compilers - may or may not be relevant to the project.
The classical equations of motion for an n-body problem are:

$$m_i \ddot{\mathbf{r}} = \sum_{i \neq j} \frac{m_i m_j}{r_{ij}^3} \mathbf{r_{ij}} \qquad i = 1, 2, 3... \tag{1}$$

where $\mathbf{r_i} = (x_i, y_i)$ and $\mathbf{r_{ij}} = \mathbf{r_j} - \mathbf{r_i}$. So for a four body problem this equation results in the following:

$$\ddot{\mathbf{r_1}} = \frac{m_2 \mathbf{r}_{12}}{r_{12}^3} + \frac{m_3 \mathbf{r}_{13}}{r_{13}^3} + \frac{m_4 \mathbf{r}_{14}}{r_{14}^3} \tag{2}$$

$$\ddot{\mathbf{r_2}} = \frac{m_1 \mathbf{r}_{21}}{r_{21}^3} + \frac{m_3 \mathbf{r}_{23}}{r_{23}^3} + \frac{m_4 \mathbf{r}_{24}}{r_{24}^3} \tag{3}$$

$$\ddot{\mathbf{r}}_{\mathbf{3}} = \frac{m_1 \mathbf{r}_{31}}{r_{31}^3} + \frac{m_2 \mathbf{r}_{32}}{r_{32}^3} + \frac{m_4 \mathbf{r}_{34}}{r_{34}^3} \tag{4}$$

$$\ddot{\mathbf{r}}_{\mathbf{4}} = \frac{m_1 \mathbf{r}_{41}}{r_{41}^3} + \frac{m_2 \mathbf{r}_{42}}{r_{42}^3} + \frac{m_3 \mathbf{r}_{43}}{r_{43}^3} \tag{5}$$

The above equations were encoded into Fortran. A full code listing is supplied in a separate file.

2.1 Initial Conditions

As a starting point both the outer binary and inner binary were placed in circular orbits and tested separately and then combined to ensure a stable starting point. The inner binary had initially a neglible mass. The outer binary initial conditions were:

```
m1=.5, m2=.5, x1=-.5, x2=.5, y1=0, y2=0,
vx1=0, vx2=0, vy1=-.5, vy2=.5
```

and for the inner binary:

```
m3=.001, m4=.001, x3=-.001, x4=.001, y3=0, y4=0,
vx3=0, vx4=0, vy3=-.5, vy4=.5
```

Plots of the two initial binaries are shown in Fig. 1 and 2. The scale of the inner binary is so small that it is difficult to see in GnuPlot.

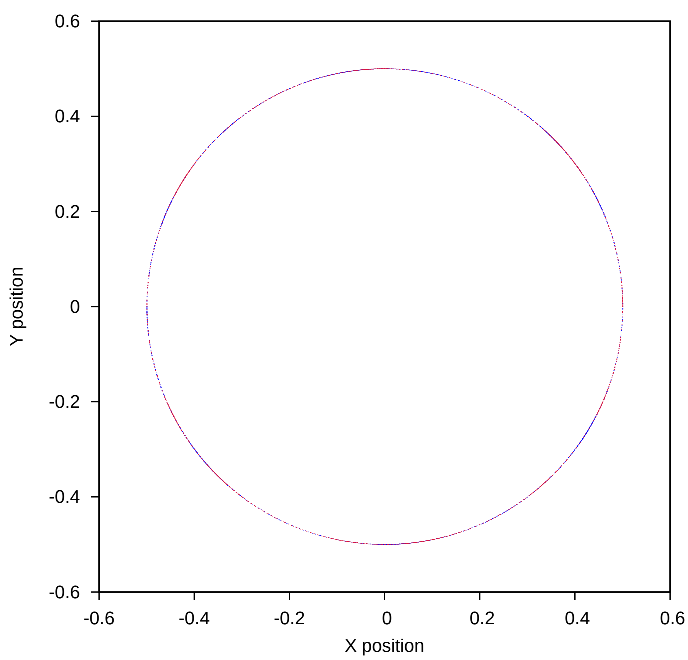


Figure 1: Outer Binary

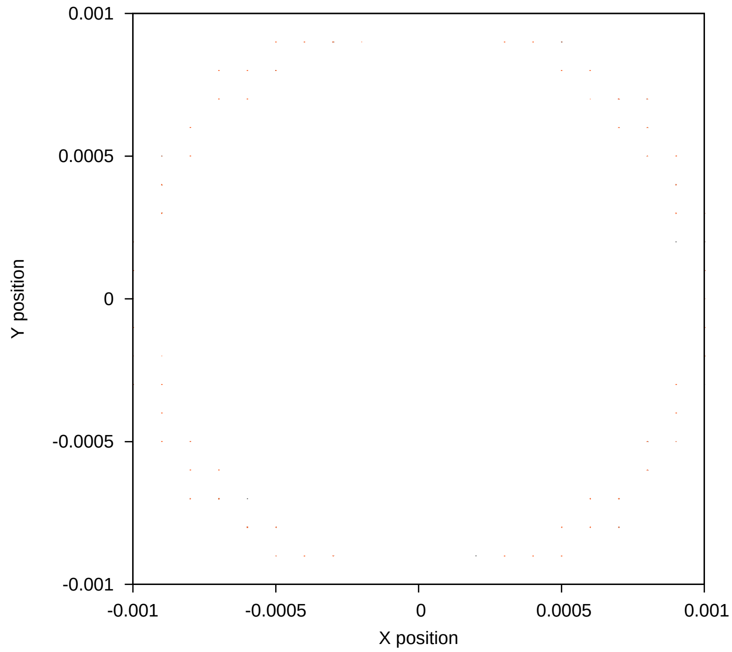


Figure 2: Inner Binary

I then proceeded to perturb the system by gradually increasing the mass of the inner binary. As the system became unstable I componensated for the increasing mass of the inner binary by increasing the velocity of the outer binary and also decreasing the velocity and increasing the binary separation of the inner binary. In many of the configurations the systems were inherently unstable and produced collisions with some or all of the bodies being ejected from the system. These were rejected and only 'stable' configurations were considered. Table 1 shows the perturbations made to the system - only the variables in this table changed and all the other initial conditions remained the same.

2.2 Compilers

As I had converted OdeInt into Fortran 90 I wanted to make sure I hadn't introduced any errors. I therefore compared the output of the Numerical Recipes version of OdeInt with mine. I was compiling with GFortran and the Fortran 77 version was compiled with g77. They were different! So naturally concerned I then compiled the Fortran 77 version with GFortran. The results were identical to mine, which satisified me that I hadn't introduced any errors.

Table 1: Configurations

Config.	m3	m4	vy1	vy2	x3	x4	vy3	vy4
1	.001	.001	-.5	.5	-.001	.001	-.5	.5
2	.002	.002	-.5	.5	-.001	.001	-.5	.5
3	.003	.003	-.5	.5	-.001	.001	-.5	.5
4	.004	.004	-.5	.5	-.004	.004	-.5	.5
5	.004	.004	-.55	.55	-.004	.004	-.5	.5
6	.004	.004	-.57	.57	-.004	.004	-.5	.5
7	.005	.005	-.58	.58	-.005	.005	-.3	.3
8	.005	.005	-.58	.58	-.005	.005	-.4	.4
9	.005	.005	-.58	.58	-.005	.005	-.35	.35
10	.006	.006	-.6	.6	-.006	.006	-.3	.3
11	.025	.025	-.65	.65	-.02	.02	-.5	.5
12	.025	.025	-.7	.7	-.025	.025	-.5	.5
13	.03	.03	-.7	.7	-.03	.03	-.5	.5
14	.035	.035	-.75	.75	-.04	.04	-.4	.4
15	.04	.04	-.75	.75	-.045	.045	-.4	.4
16	.05	.05	-.75	.75	-.045	.045	-.4	.4
17	.05	.05	-.75	.75	-.05	.05	-.35	.35
18	.05	.05	-.75	.75	-.05	.05	-.3	.3
19	.06	.06	-.8	.8	-.06	.06	-.25	.25
20	.08	.08	-.9	.9	-.08	.08	-.15	.15
21	.09	.09	-.95	.95	-.09	.09	-.1	.1
22	.1	.1	-1	1	-.1	.1	-.05	.05
23	.1	.1	-1	1	-.1	.1	-.04	.04
24	.1	.1	-1	1	-.1	.1	-.03	.03
25	.1	.1	-1	1	-.1	.1	-.02	.02
26	.12	.12	-1.05	1.05	-.11	.11	-.015	.015
27	.12	.12	-1.1	1.1	-.11	.11	-.015	.015
28	.12	.12	-1.1	1.1	-.115	.115	-.015	.015
29	.12	.12	-1.1	1.1	-.12	.12	-.015	.015
30	.1	.1	-1	1	-1.	.1	-.1	.1

3 Results

As can be seen from Fig. 3 even a neglible mass inner binary causes the outer binary to begin to separate and become less tightly bound. Figures Fig. 3 to 38 show plots of the double binary using the parameters given in Table 1. In many cases the inner binary is only visible as a point at the centre of the outer binary. As the mass of the inner binary increased the system became increasingly unstablle and the effect on the outer binary became more pronounced. Even the 'stable' configurations listed in Table 1 hold for only a few orbits. I was unable to recreate a stable system for a mass > .08 for the inner bar. The plots below reveal that increasing the mass of the inner binary causes the outer binary to separate and form wider orbits.

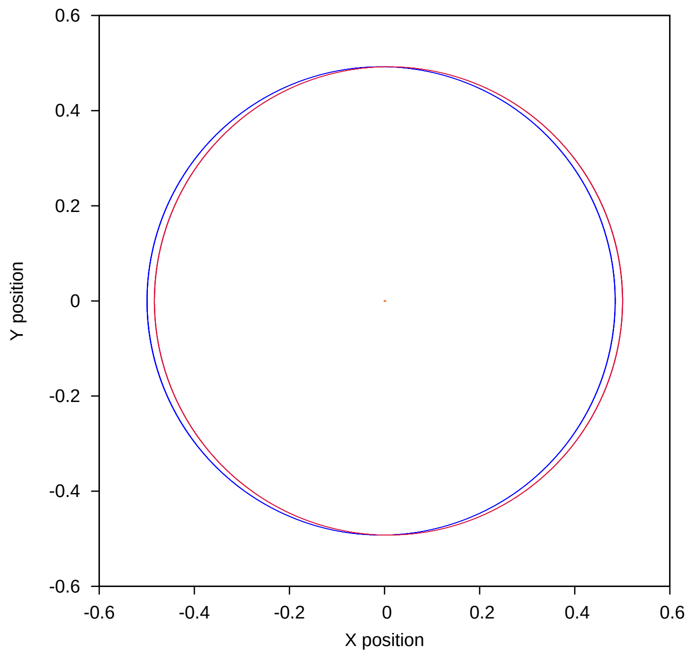


Figure 3: Configuration 1

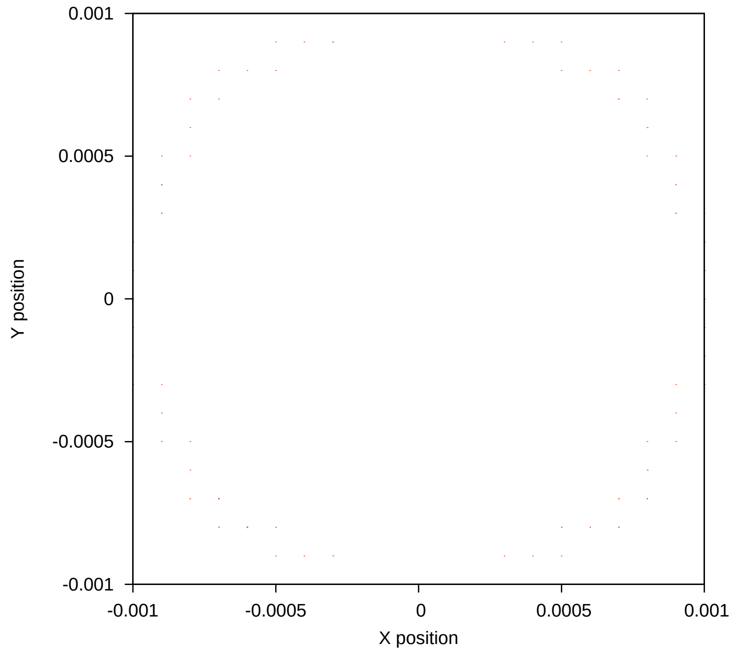


Figure 4: Configuration 1 - Inner Bar

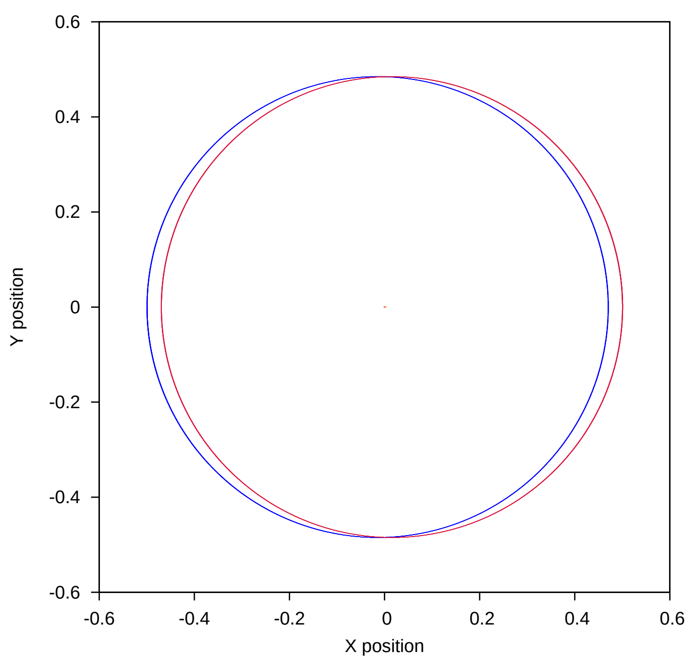


Figure 5: Configuration 2

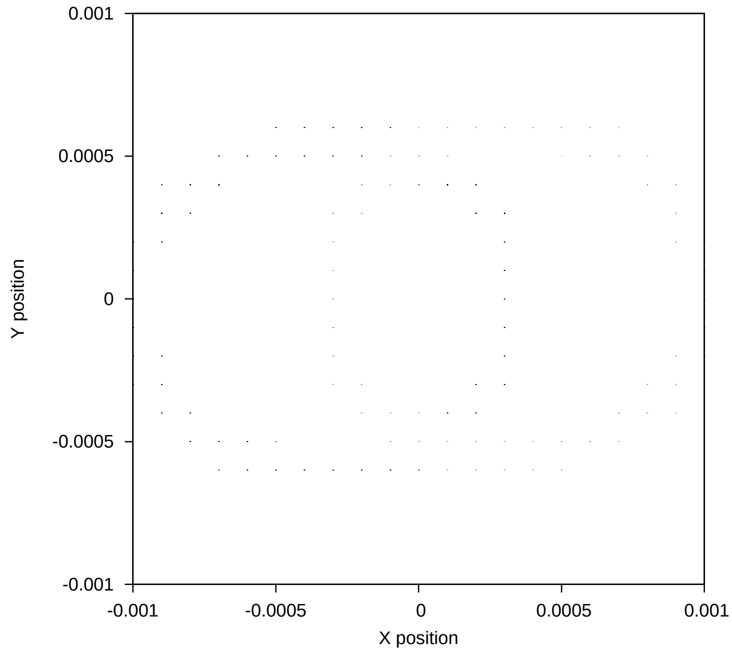


Figure 6: Configuration 2 - Inner Bar

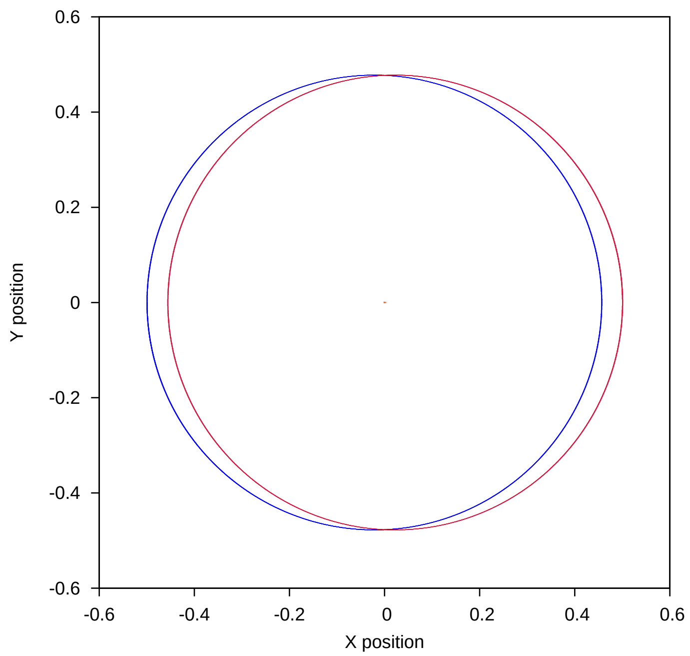


Figure 7: Configuration 3

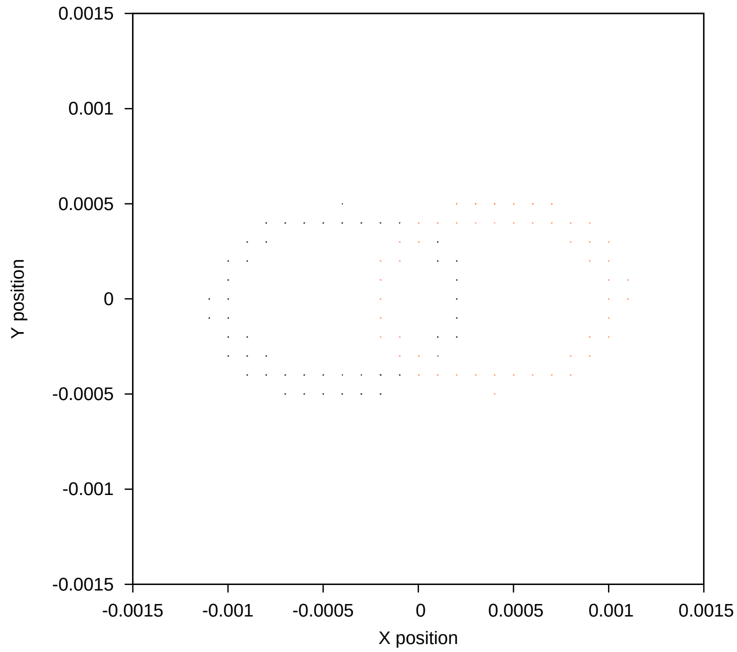


Figure 8: Configuration 3 - Inner Bar

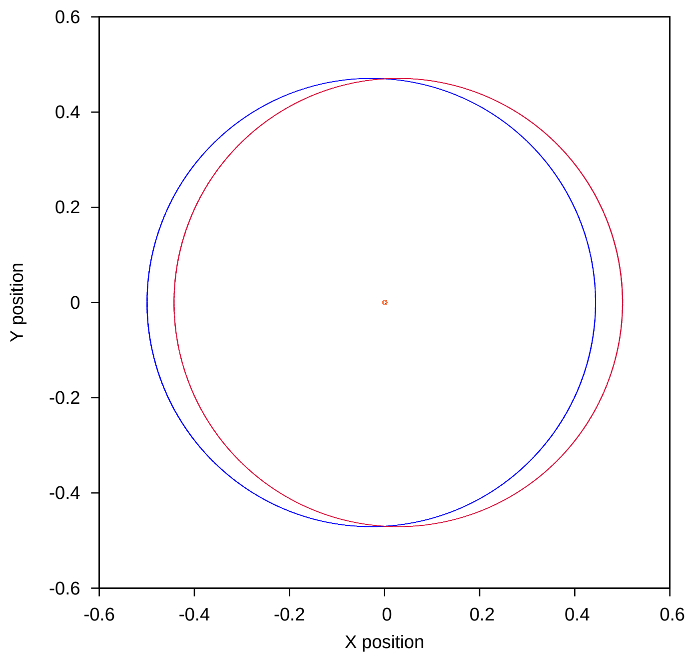


Figure 9: Configuration 4

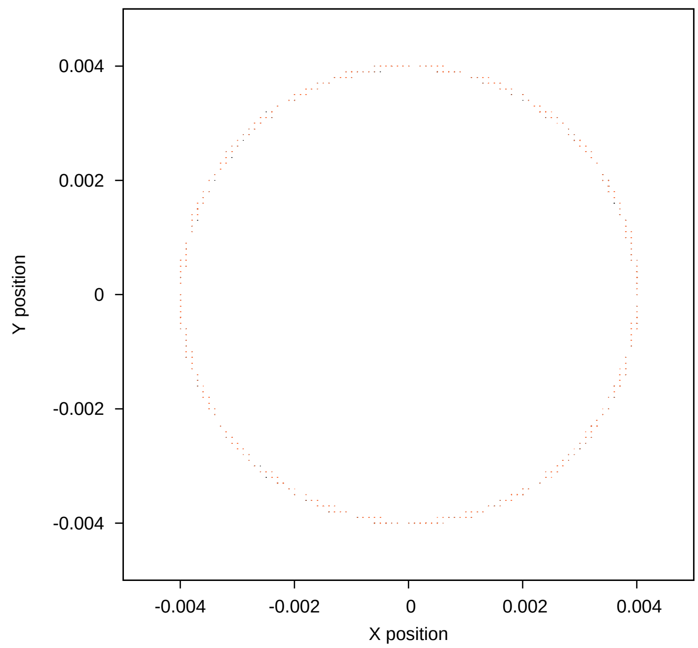


Figure 10: Configuration 4 - Inner Bar

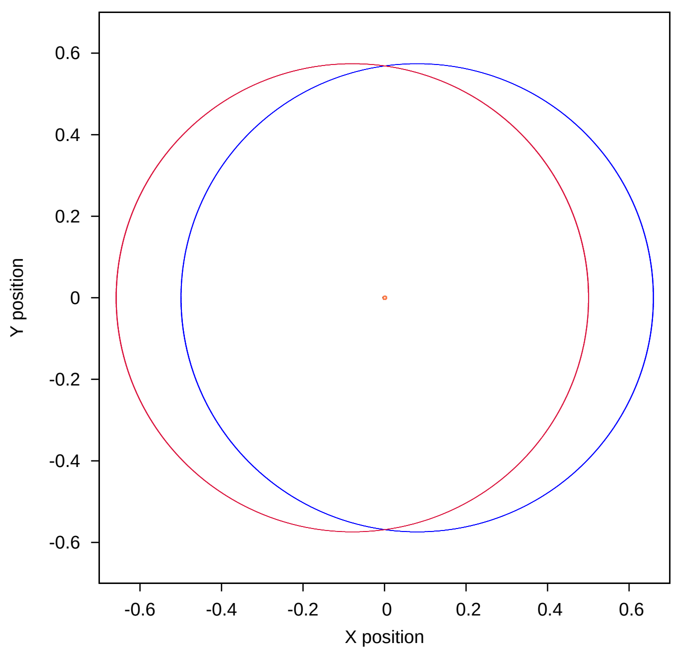


Figure 11: Configuration 5

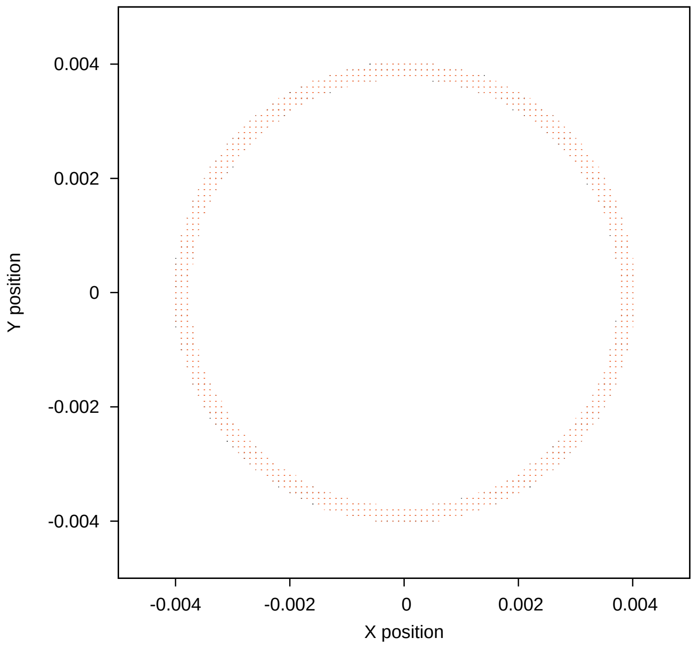


Figure 12: Configuration 5 - Inner Bar

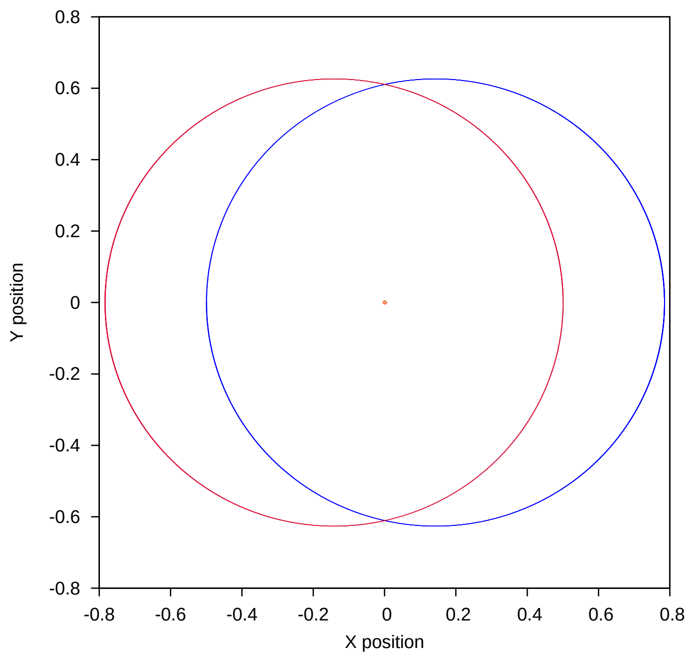


Figure 13: Configuration 6

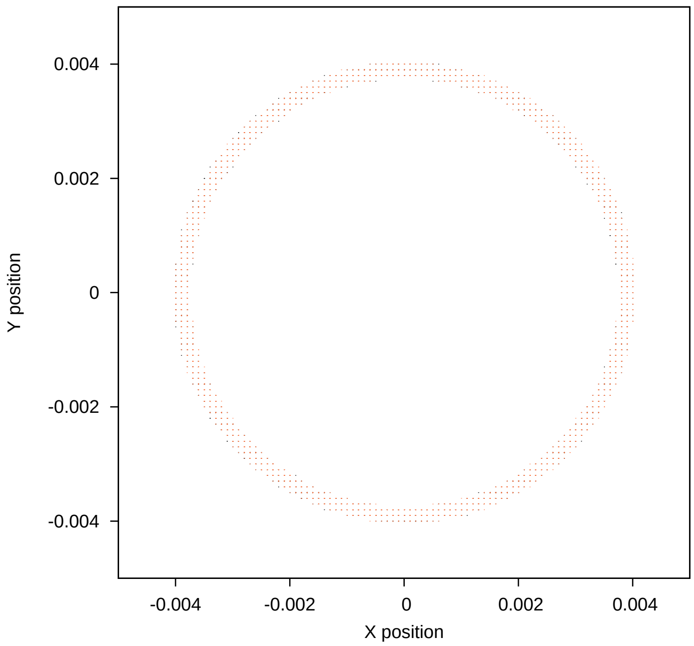


Figure 14: Configuration 6 - Inner Bar

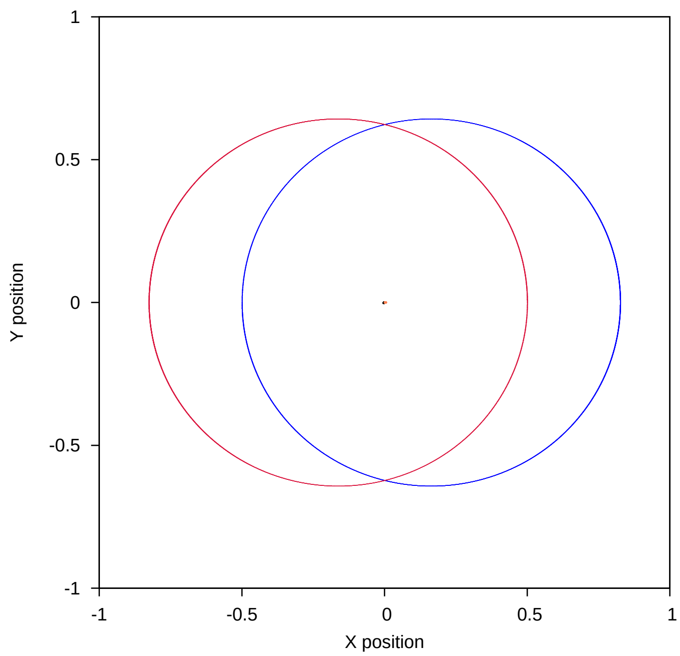


Figure 15: Configuration 7

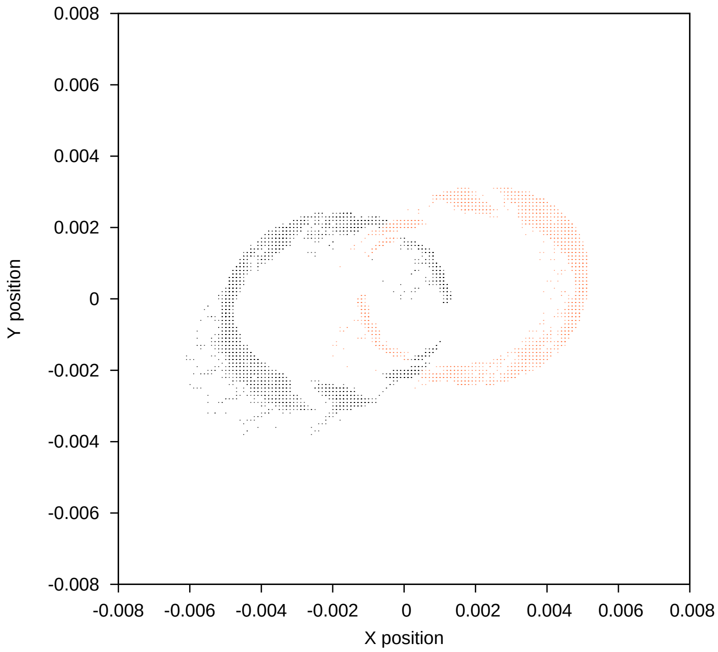


Figure 16: Configuration 7 - Inner Bar

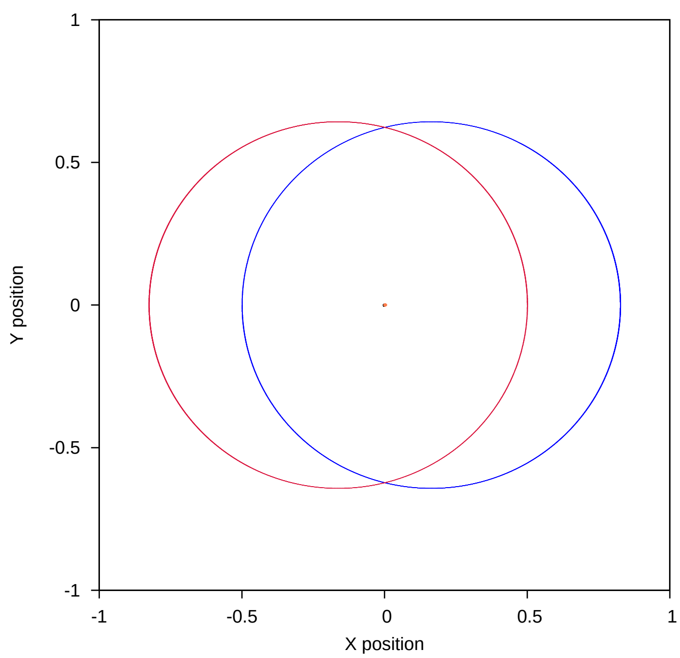


Figure 17: Configuration 8

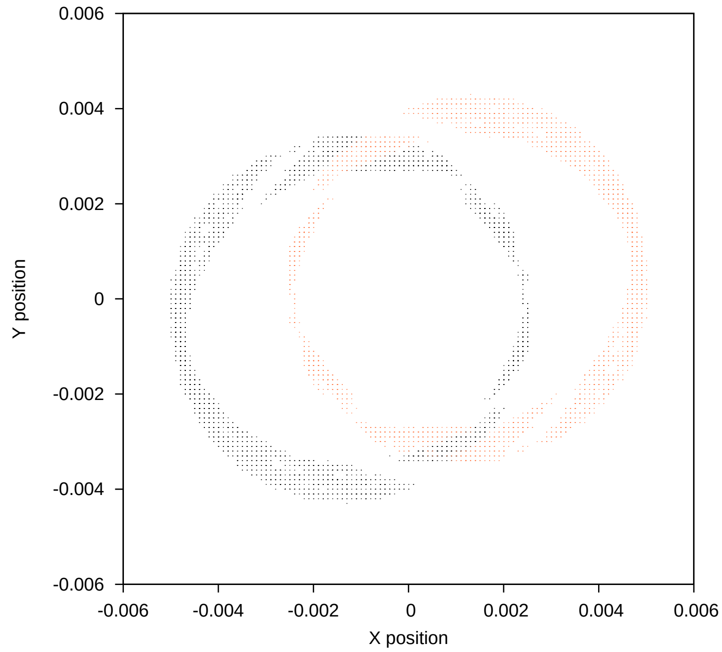


Figure 18: Configuration 8 - Inner Bar

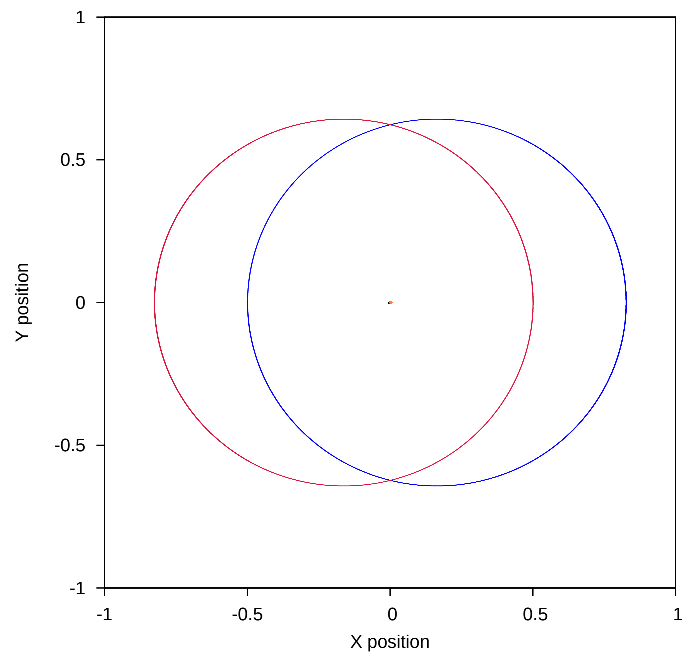


Figure 19: Configuration 9

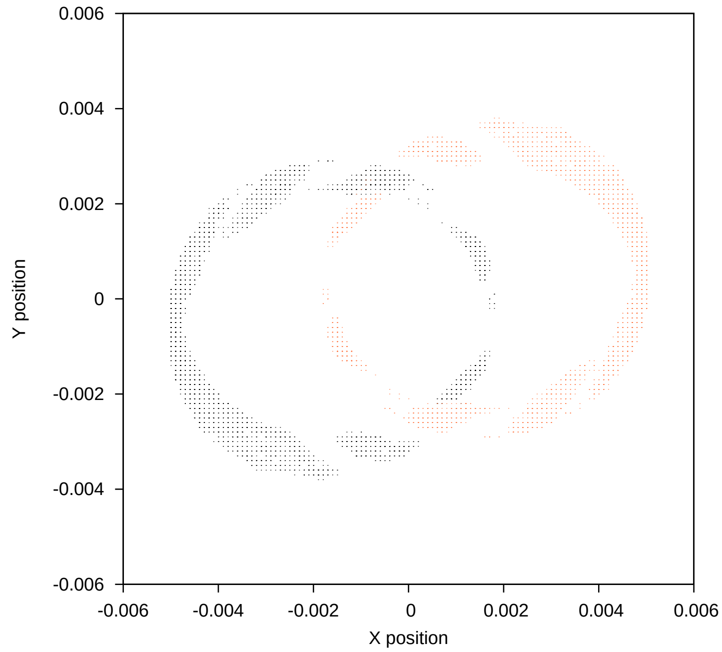


Figure 20: Configuration 9 - Inner Bar

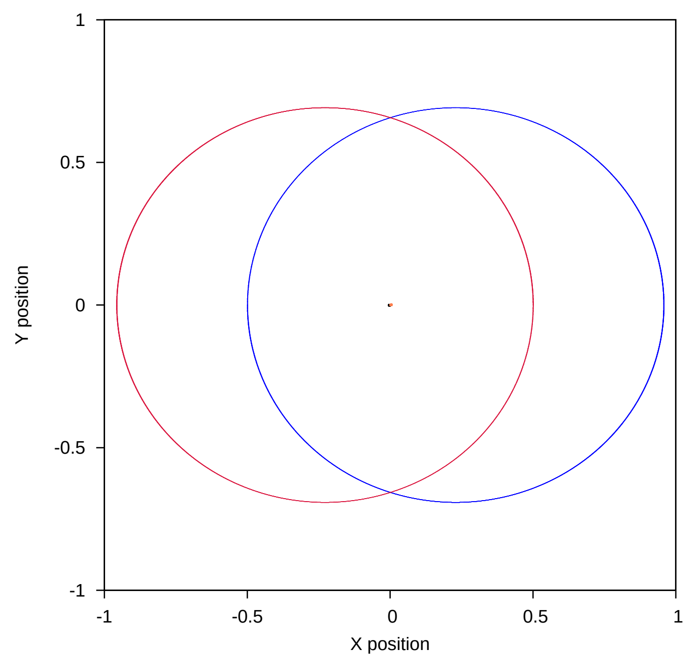


Figure 21: Configuration 10

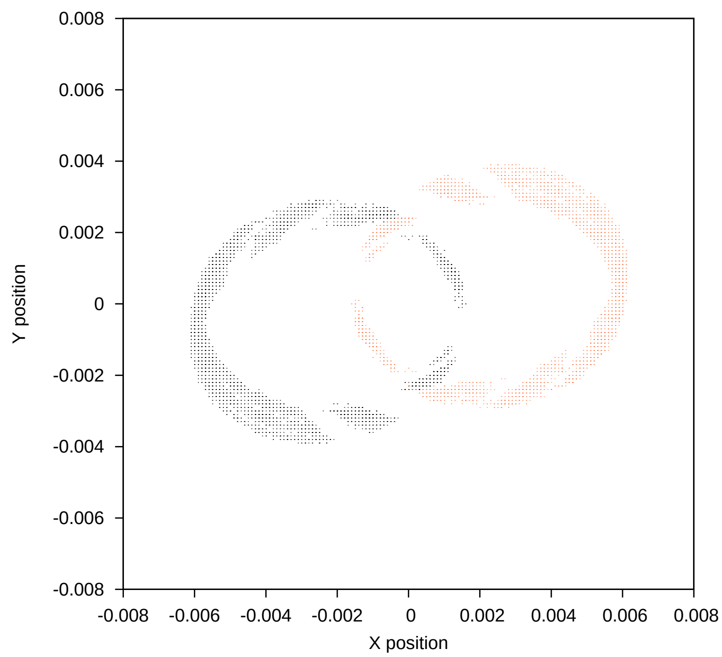


Figure 22: Configuration 10 - Inner Bar

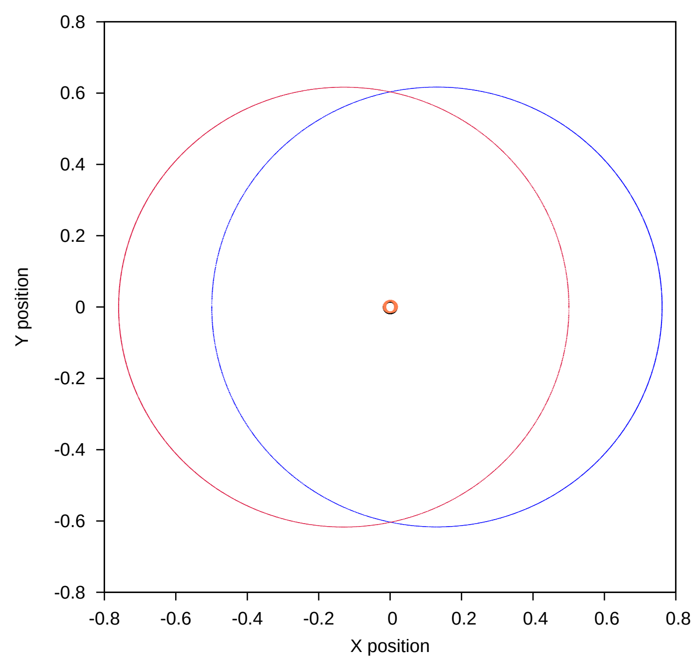


Figure 23: Configuration 11

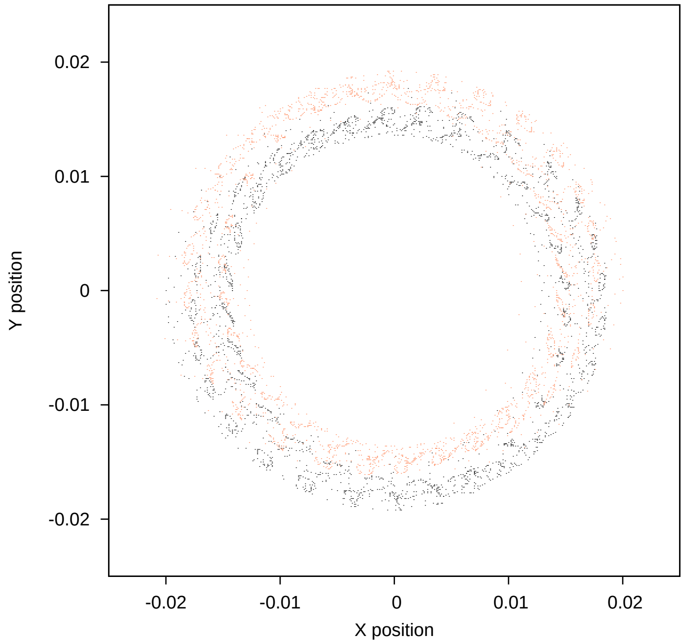


Figure 24: Configuration 11 - Inner Bar

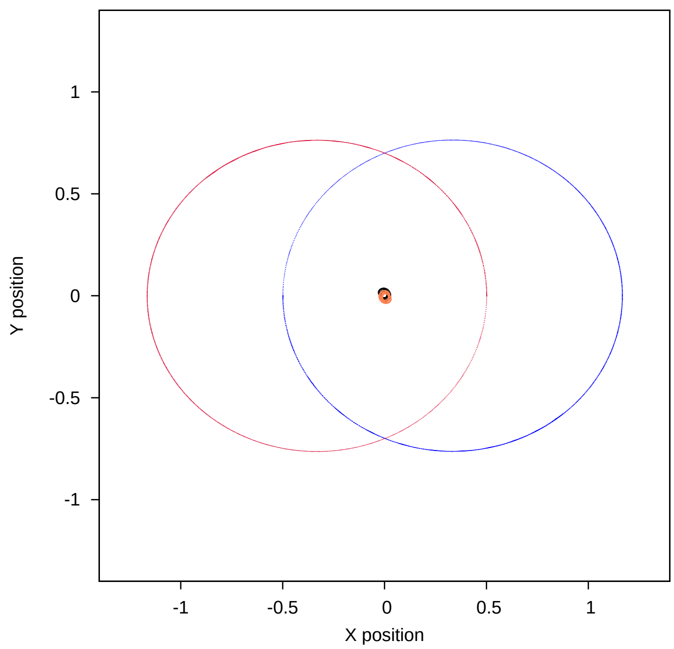


Figure 25: Configuration 12

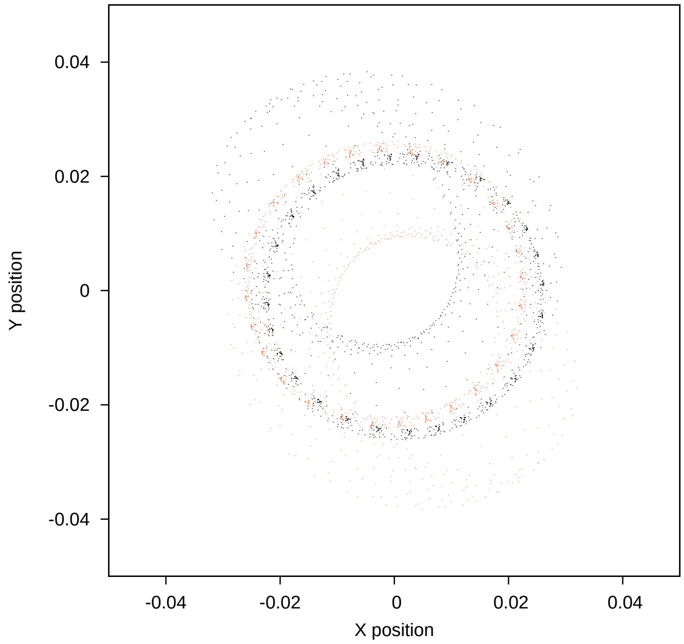


Figure 26: Configuration 12 - Inner Bar

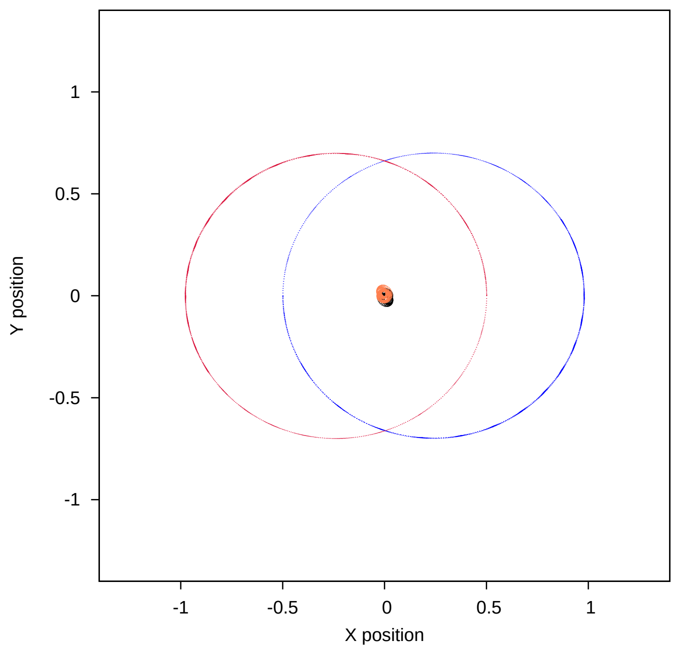


Figure 27: Configuration 13

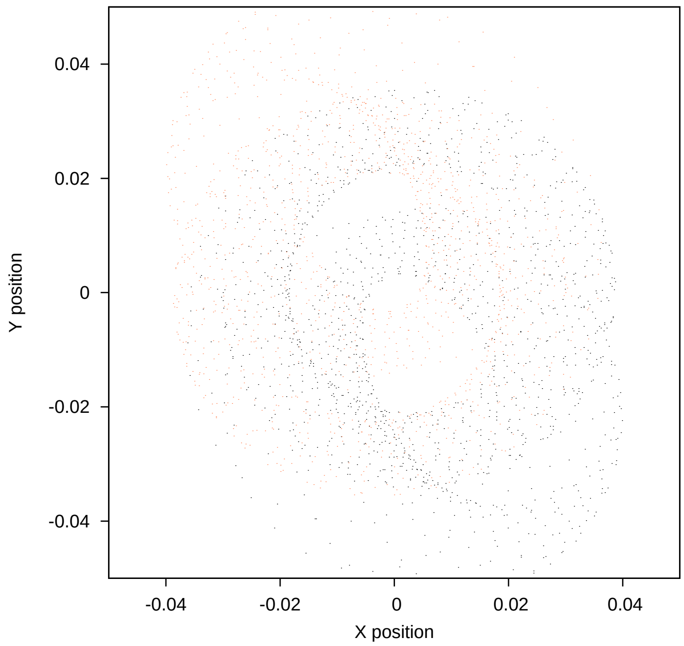


Figure 28: Configuration 13 - Inner Bar

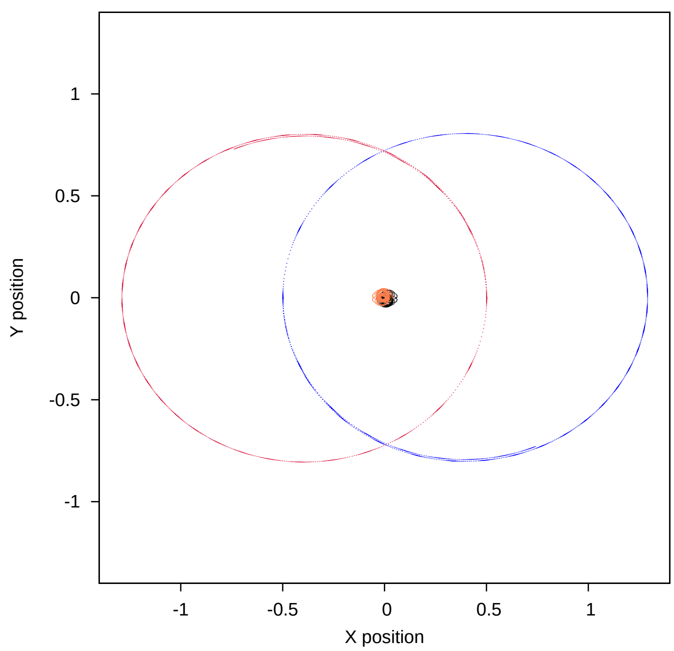


Figure 29: Configuration 14

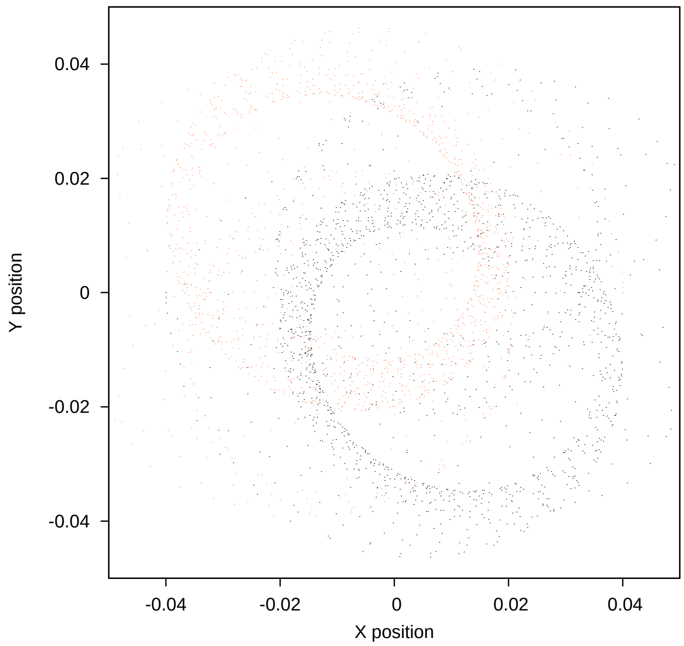
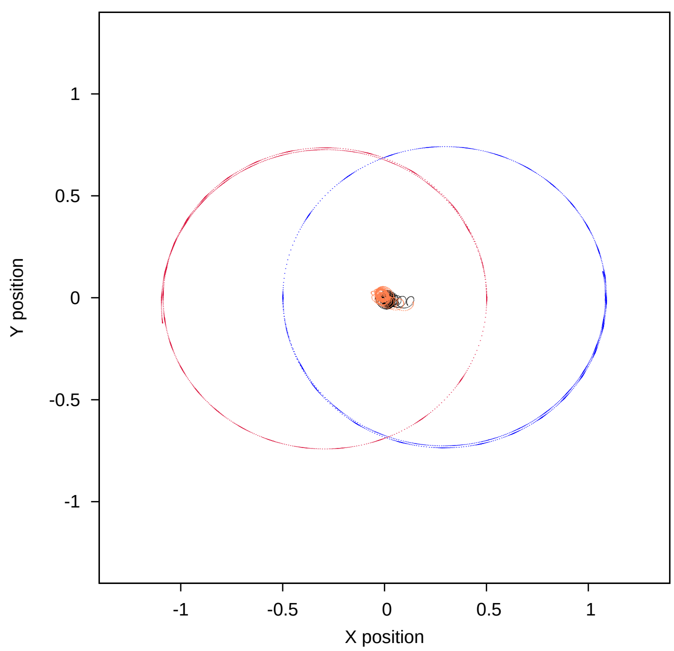


Figure 30: Configuration 14 - Inner Bar



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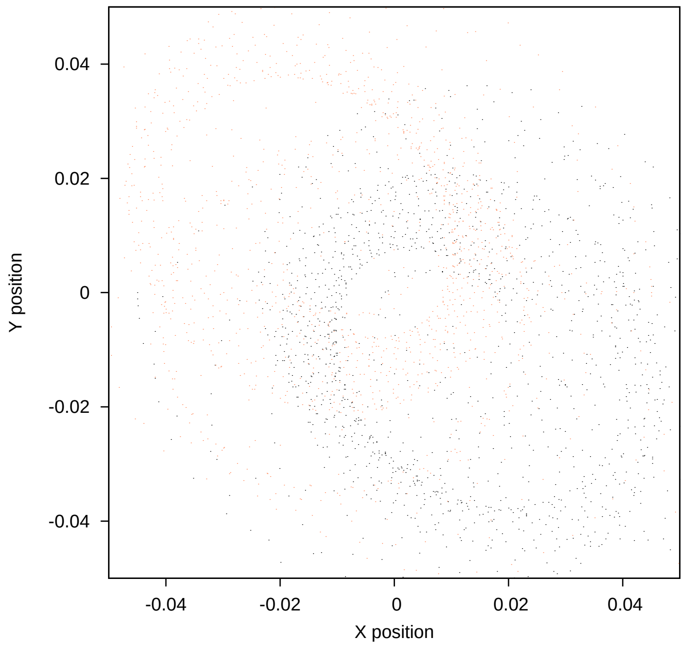

Figure 32: Configuration 15 - Inner Bar

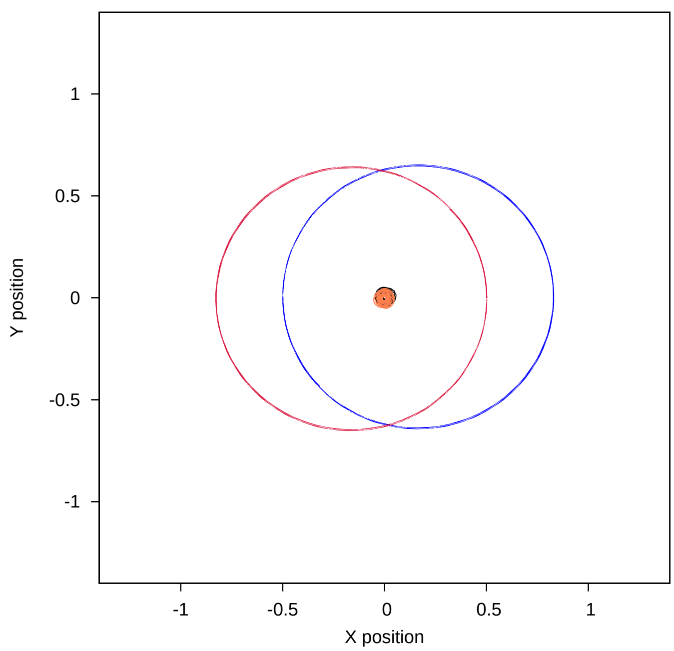

Figure 33: Configuration 16

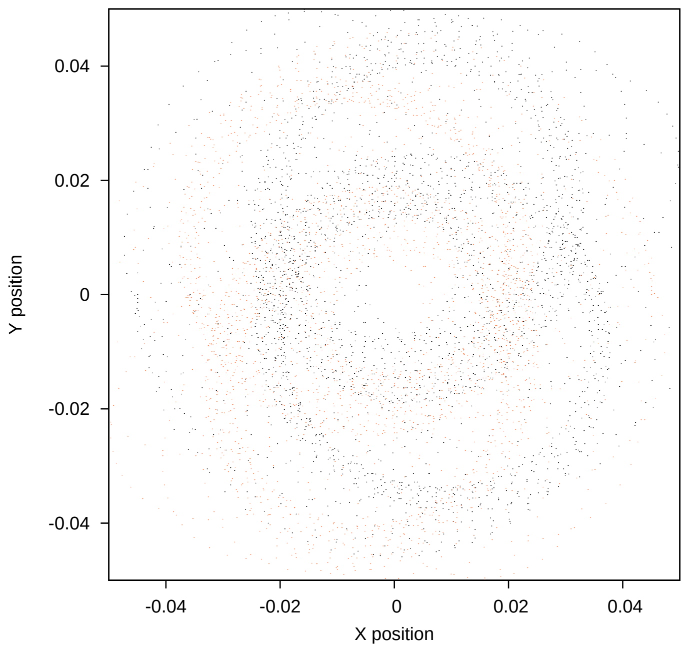

Figure 34: Configuration 16 - Inner Bar

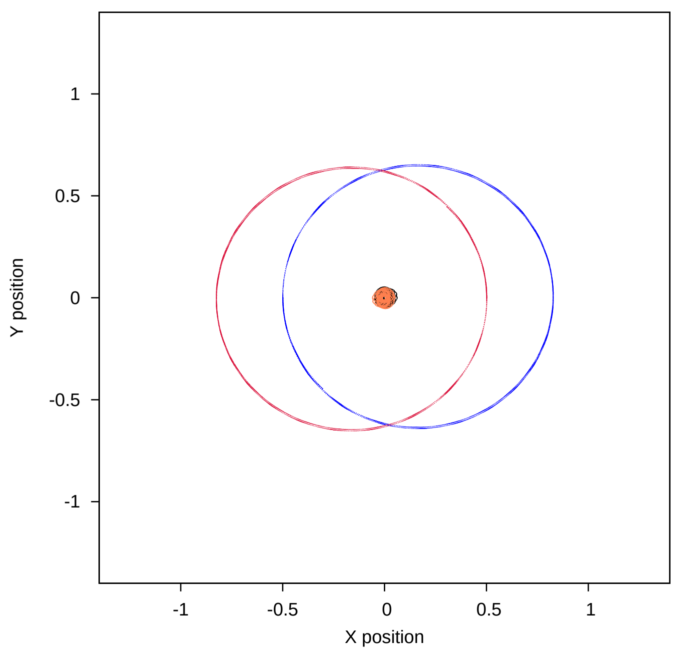

Figure 35: Configuration 17

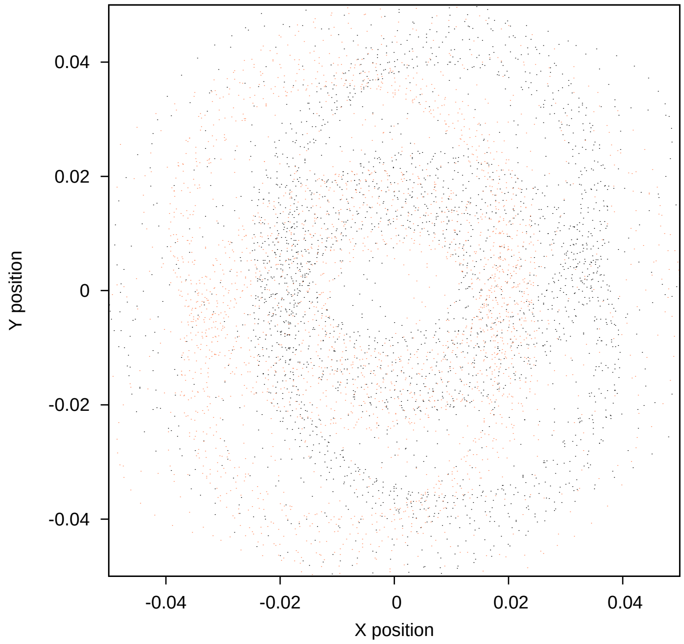

Figure 36: Configuration 17 - Inner Bar

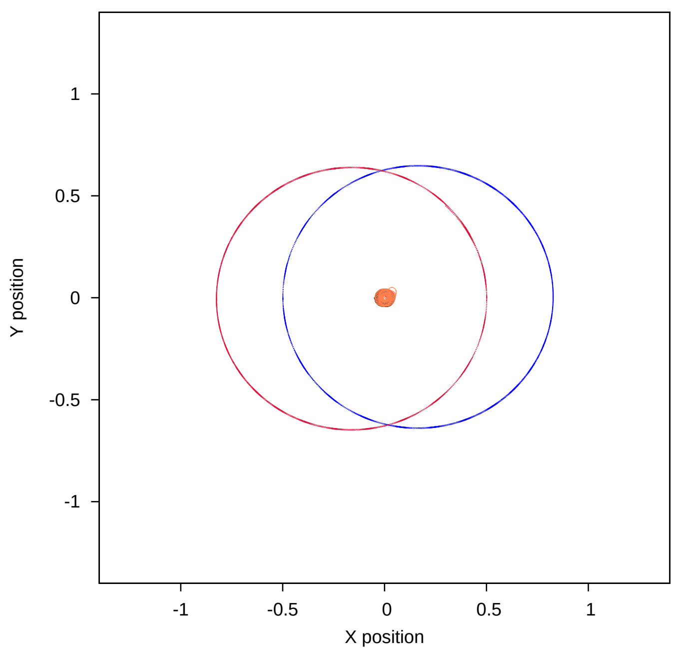

Figure 37: Configuration 18

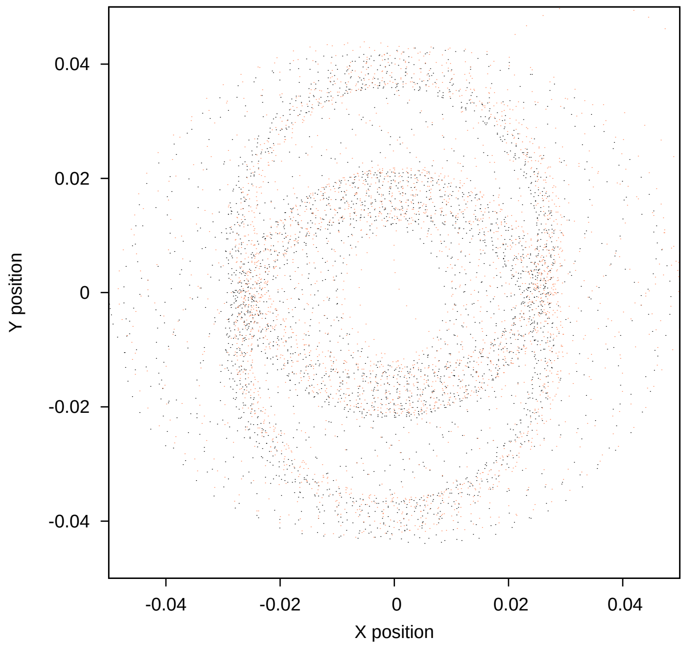

Figure 38: Configuration 18 - Inner Bar

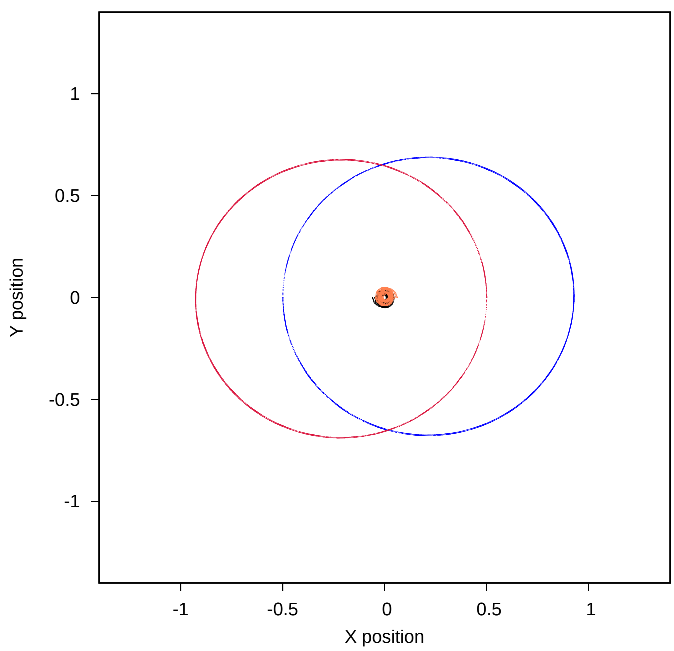

Figure 39: Configuration 19

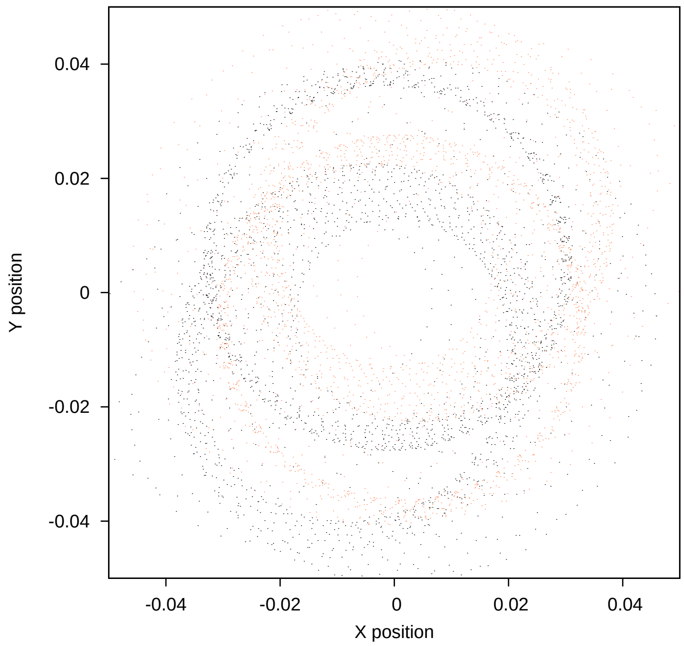

Figure 40: Configuration 19 - Inner Bar

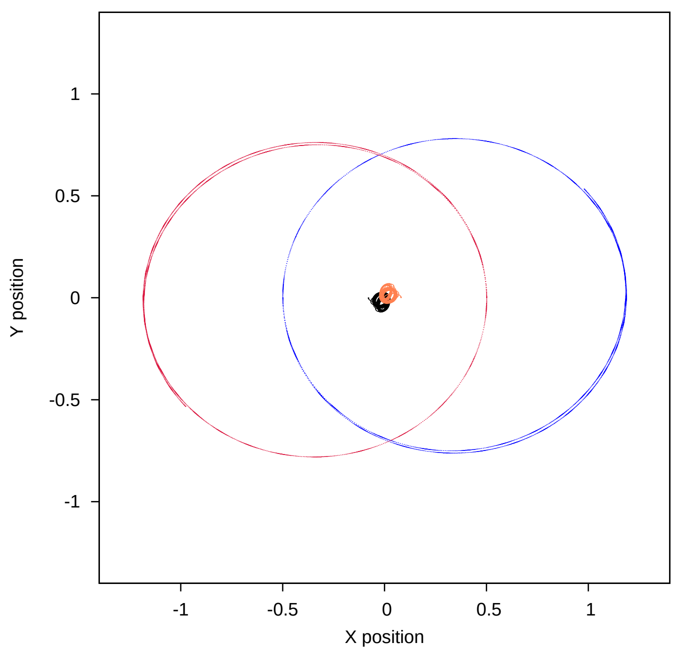

Figure 41: Configuration 20

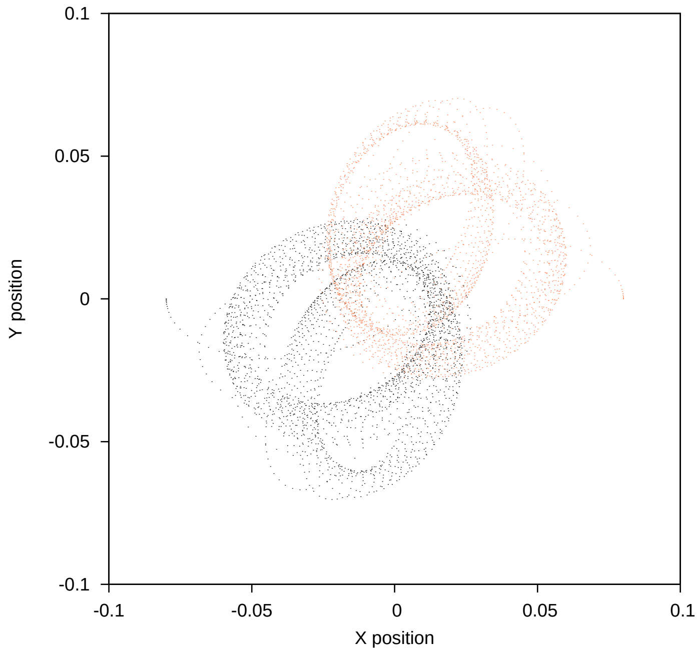

Figure 42: Configuration 20 - Inner Bar

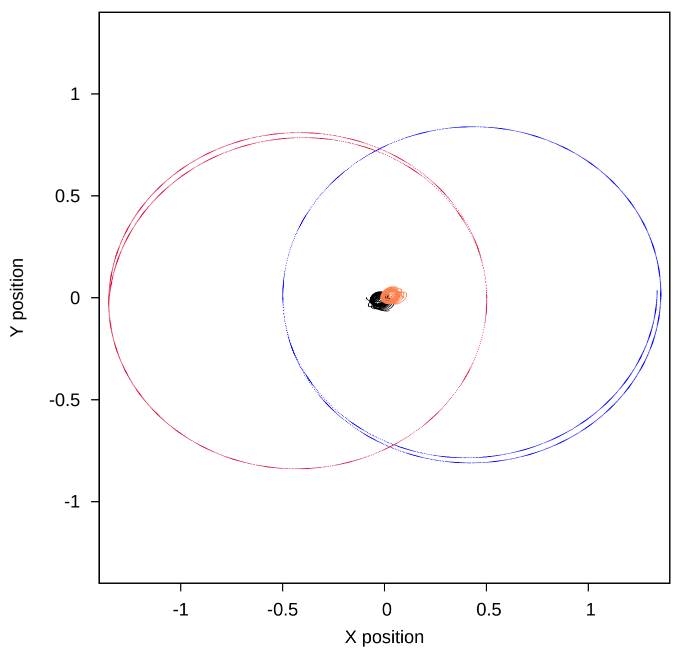

Figure 43: Configuration 21

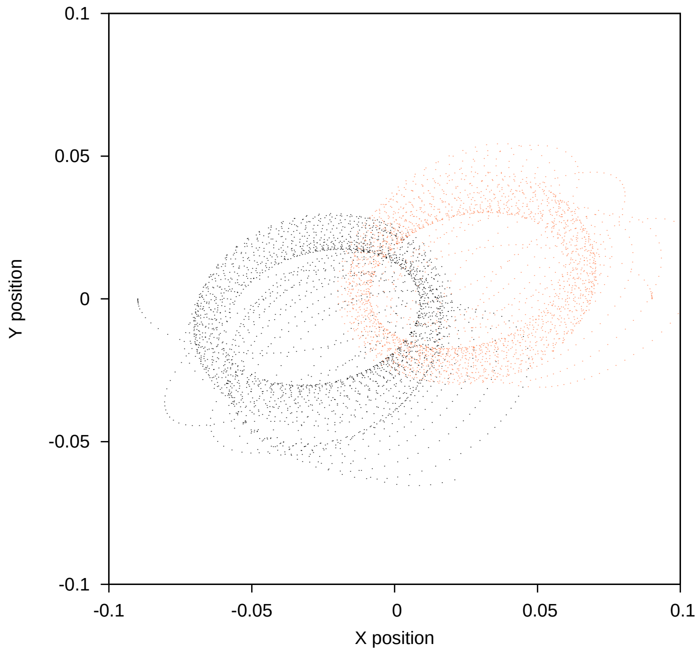

Figure 44: Configuration 21 - Inner Bar

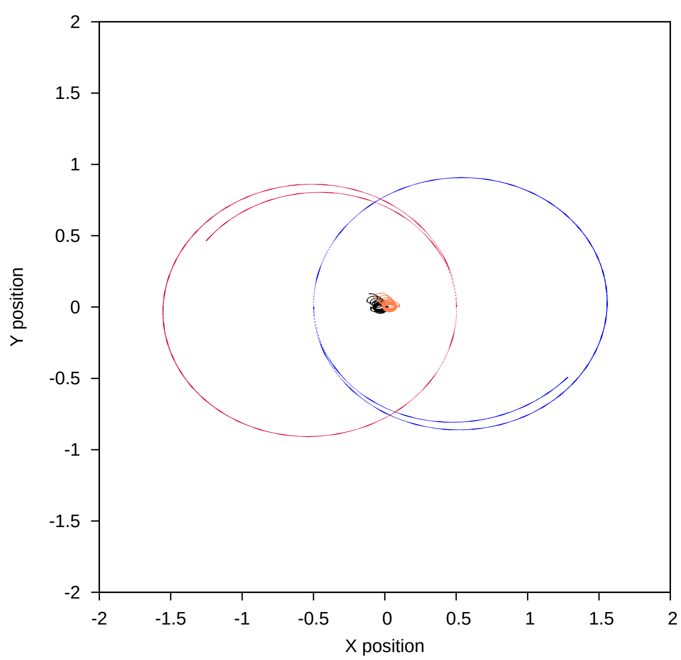

Figure 45: Configuration 22

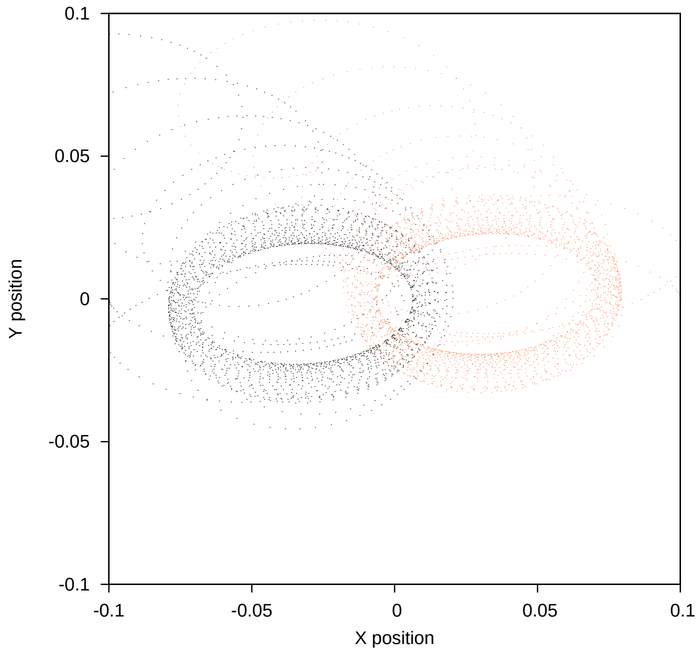

Figure 46: Configuration 22 - Inner Bar

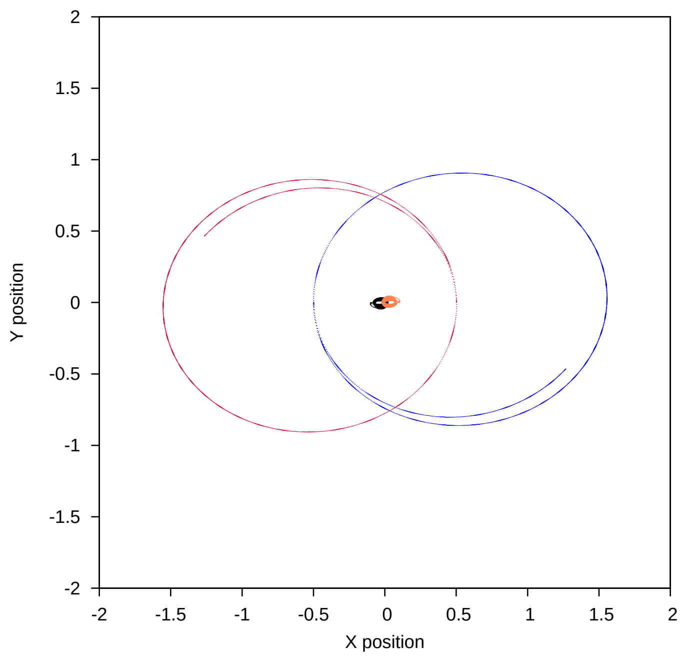

Figure 47: Configuration 23

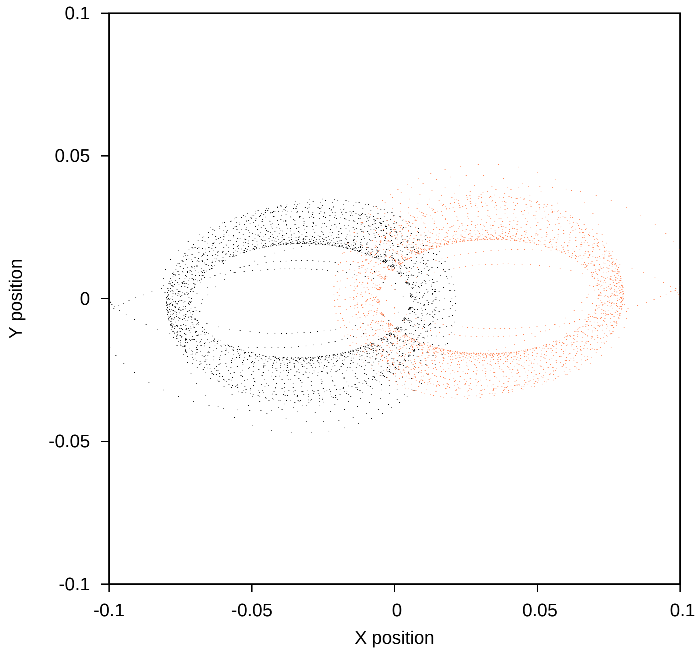

Figure 48: Configuration 23 - Inner Bar

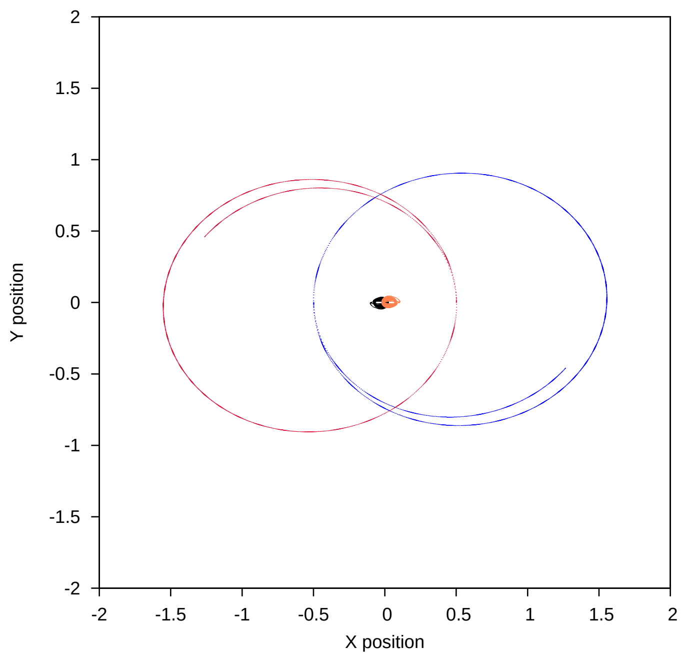

Figure 49: Configuration 24

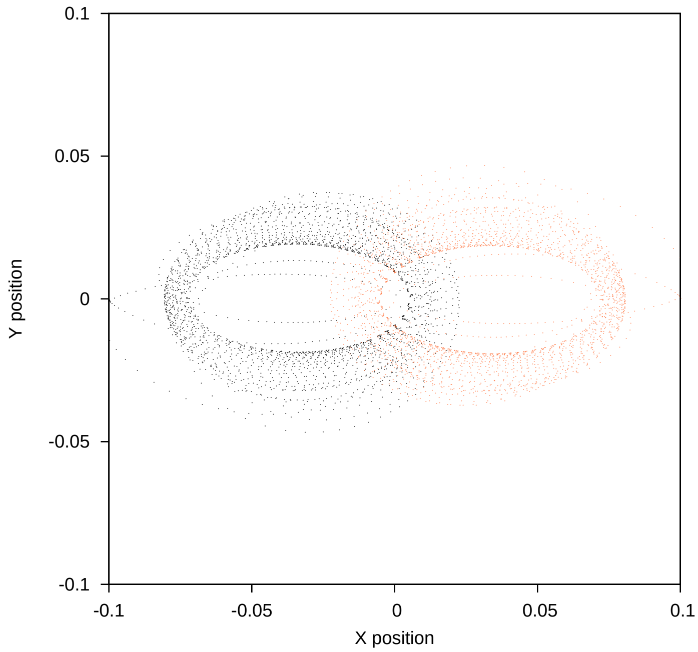

Figure 50: Configuration 24 - Inner Bar

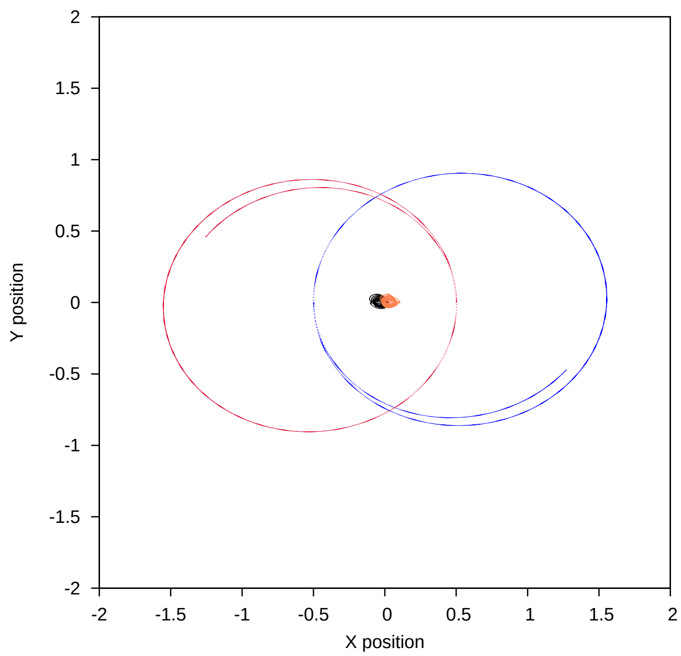

Figure 51: Configuration 25

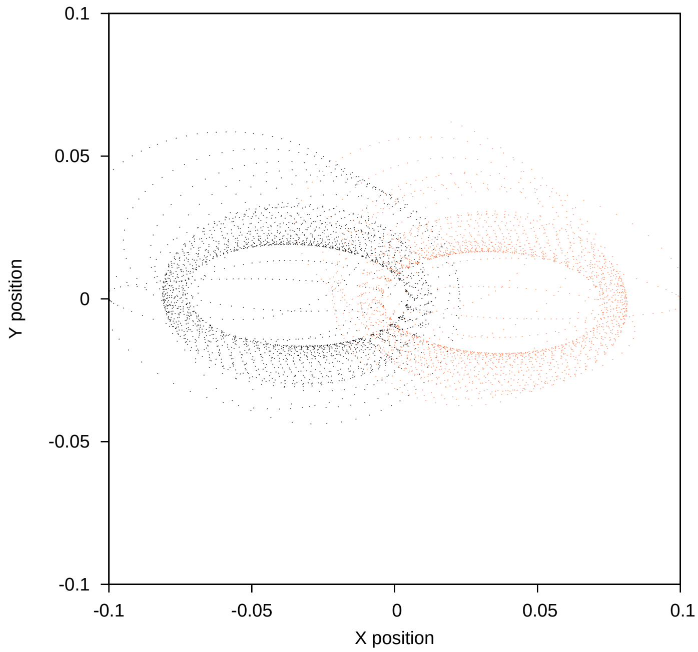

Figure 52: Configuration 25 - Inner Bar

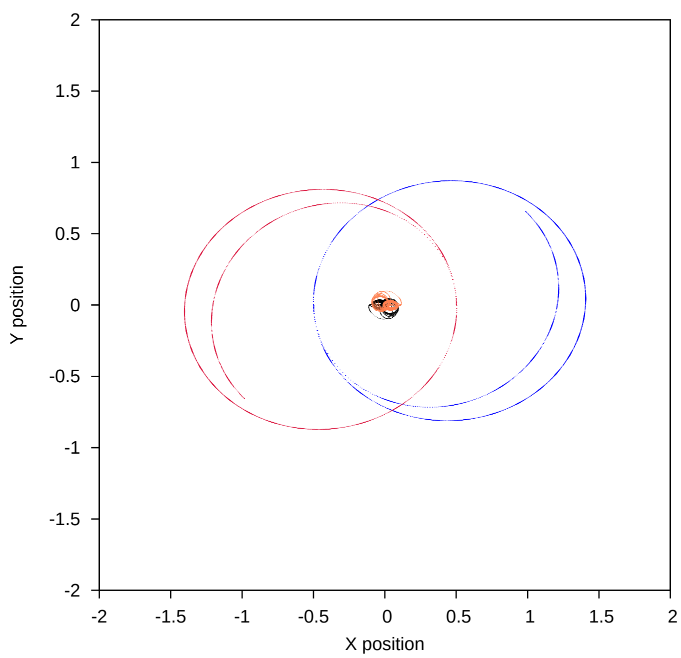

Figure 53: Configuration 26

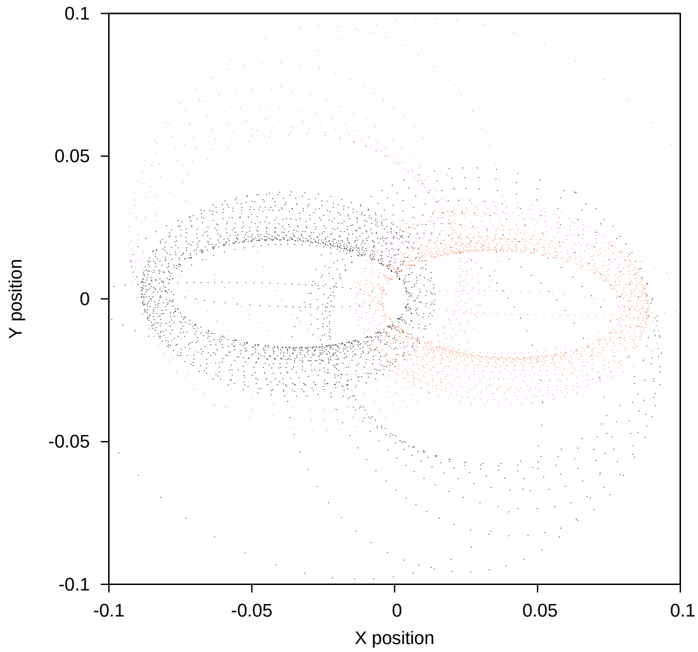

Figure 54: Configuration 26 - Inner Bar

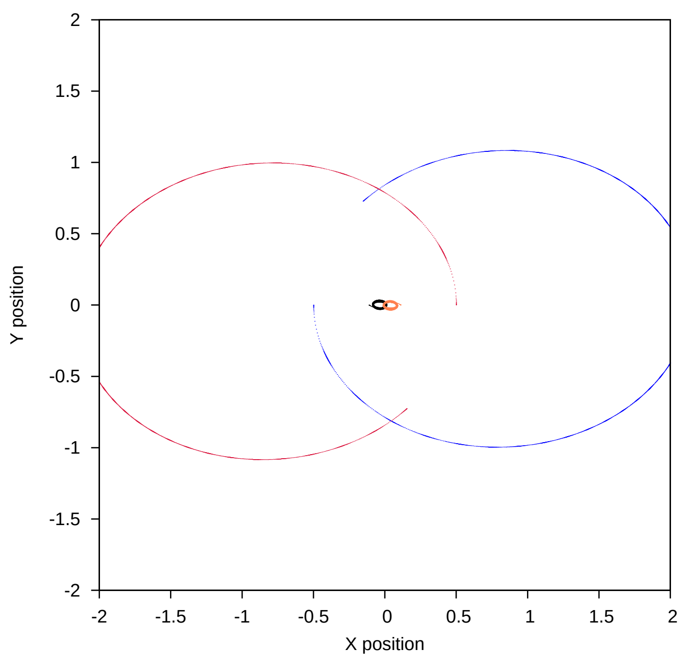

Figure 55: Configuration 27

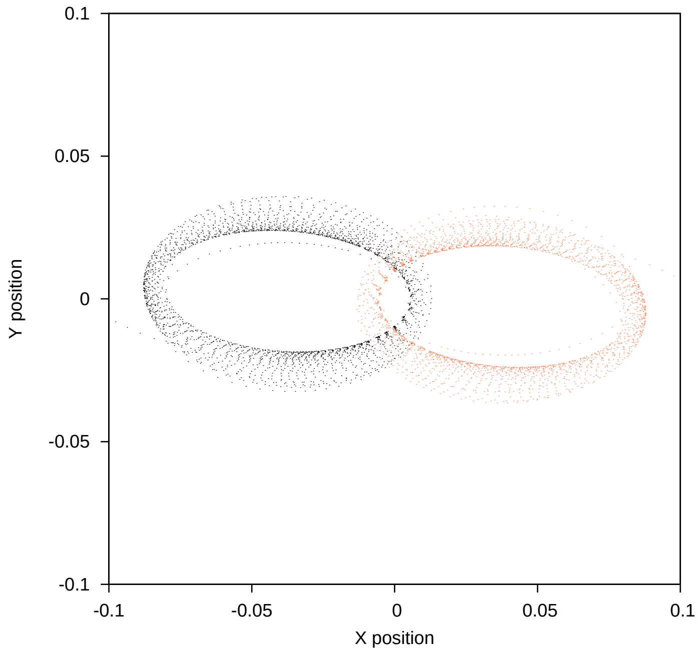

Figure 56: Configuration 27 - Inner Bar

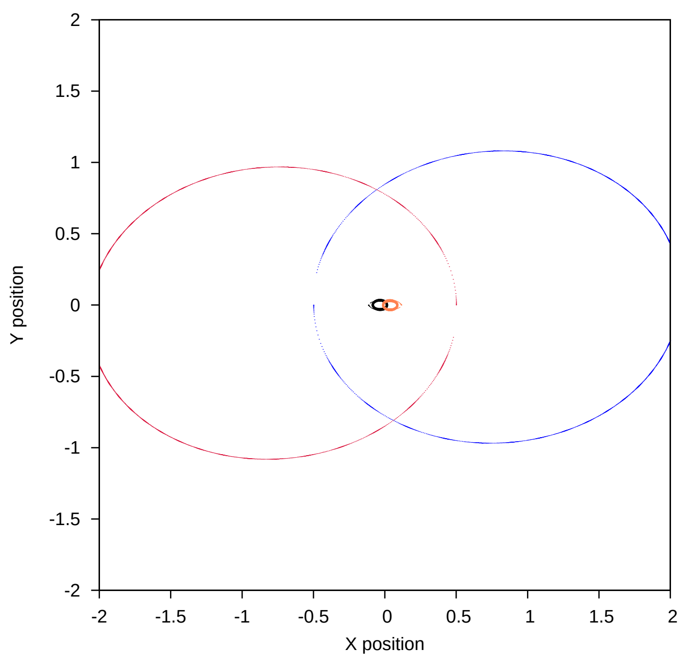

Figure 57: Configuration 28

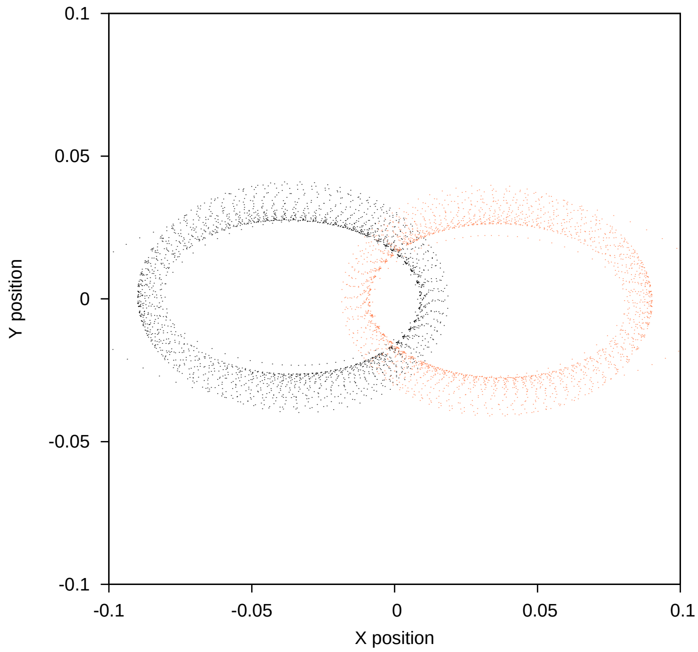

Figure 58: Configuration 28 - Inner Bar

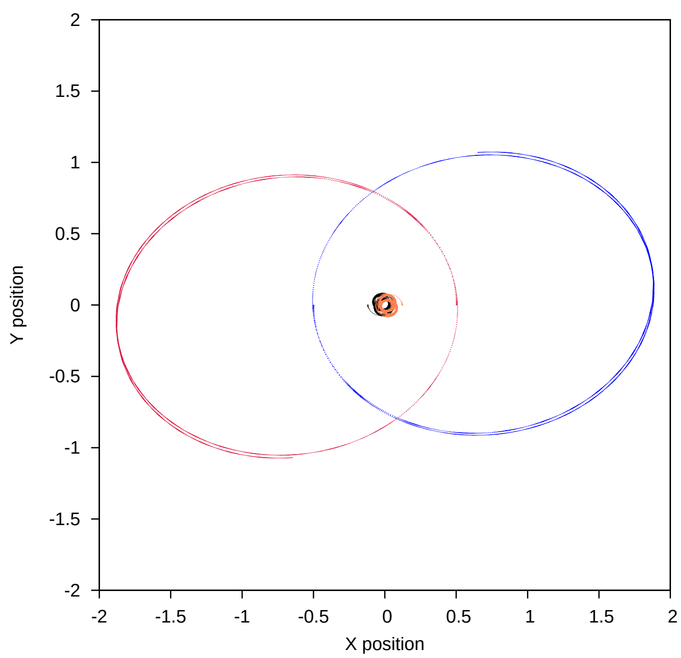

Figure 59: Configuration 29

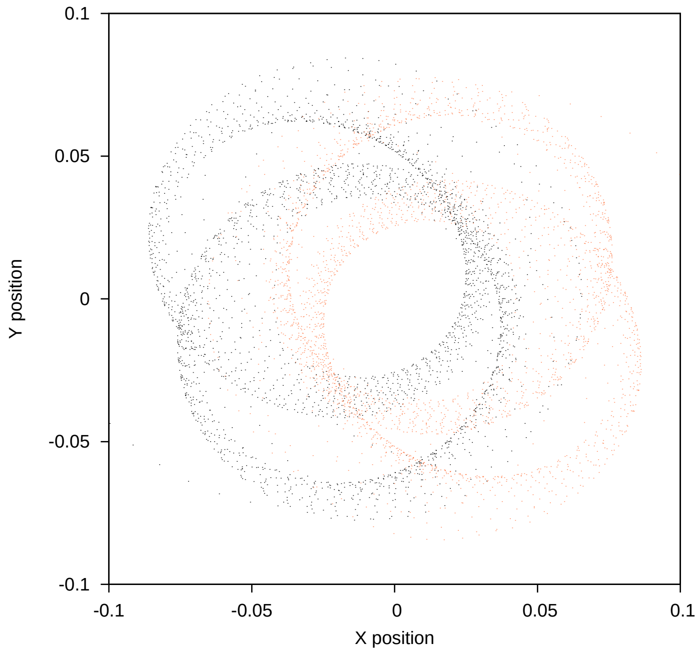

Figure 60: Configuration 29 - Inner Bar

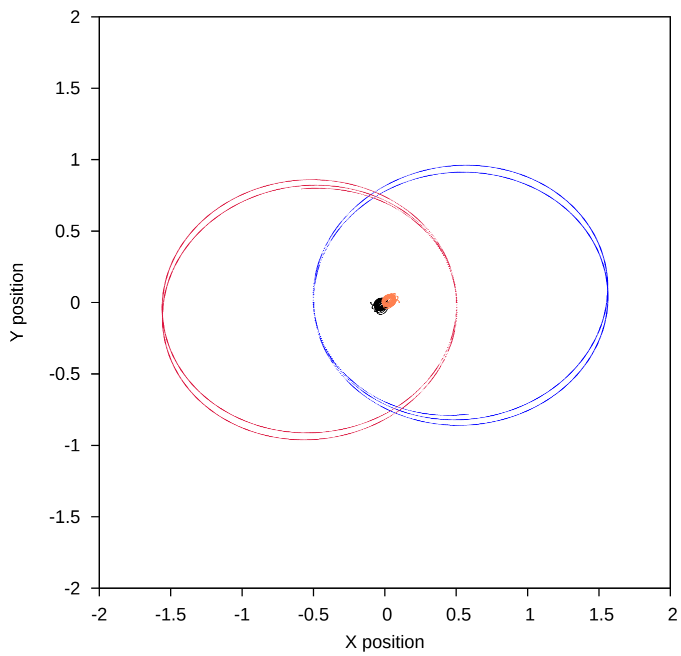

Figure 61: Configuration 30

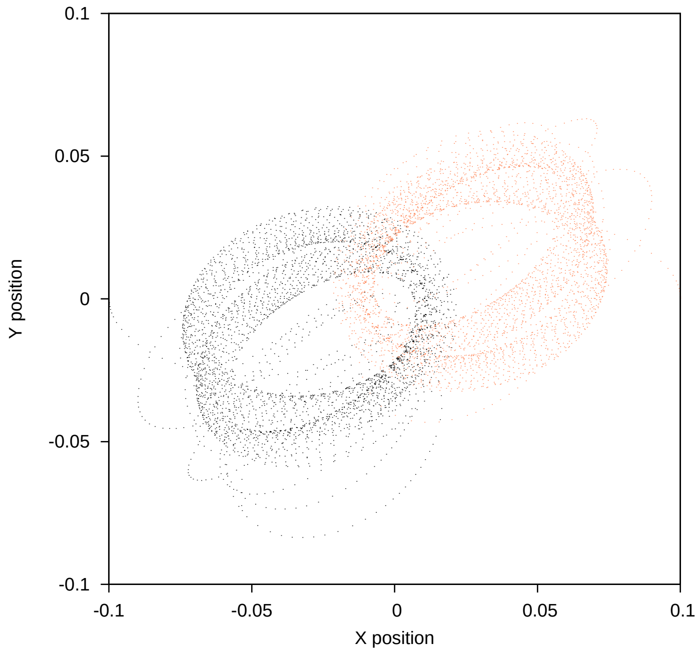

Figure 62: Configuration 30 - Inner Bar

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