The Role of GR and Tidal Effects in Dense Stellar Systems

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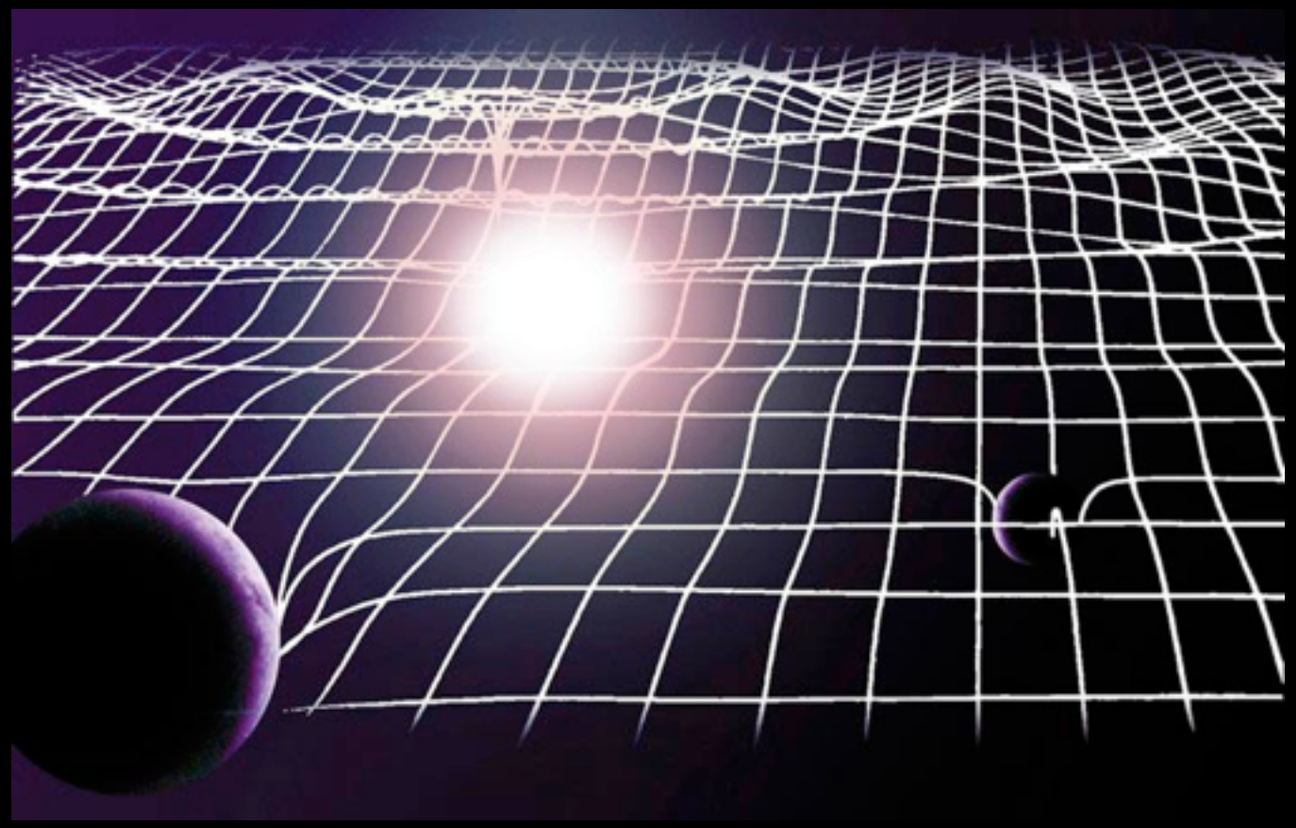


Moved to **Princeton** last xmas from **Denmark**

- Einstein, Spitzer fellow.
- Member of the Princeton Society of Fellows.
- Wife and daughter (2 months!!)

Princeton, Peyton Hall

New Home

Main Project:

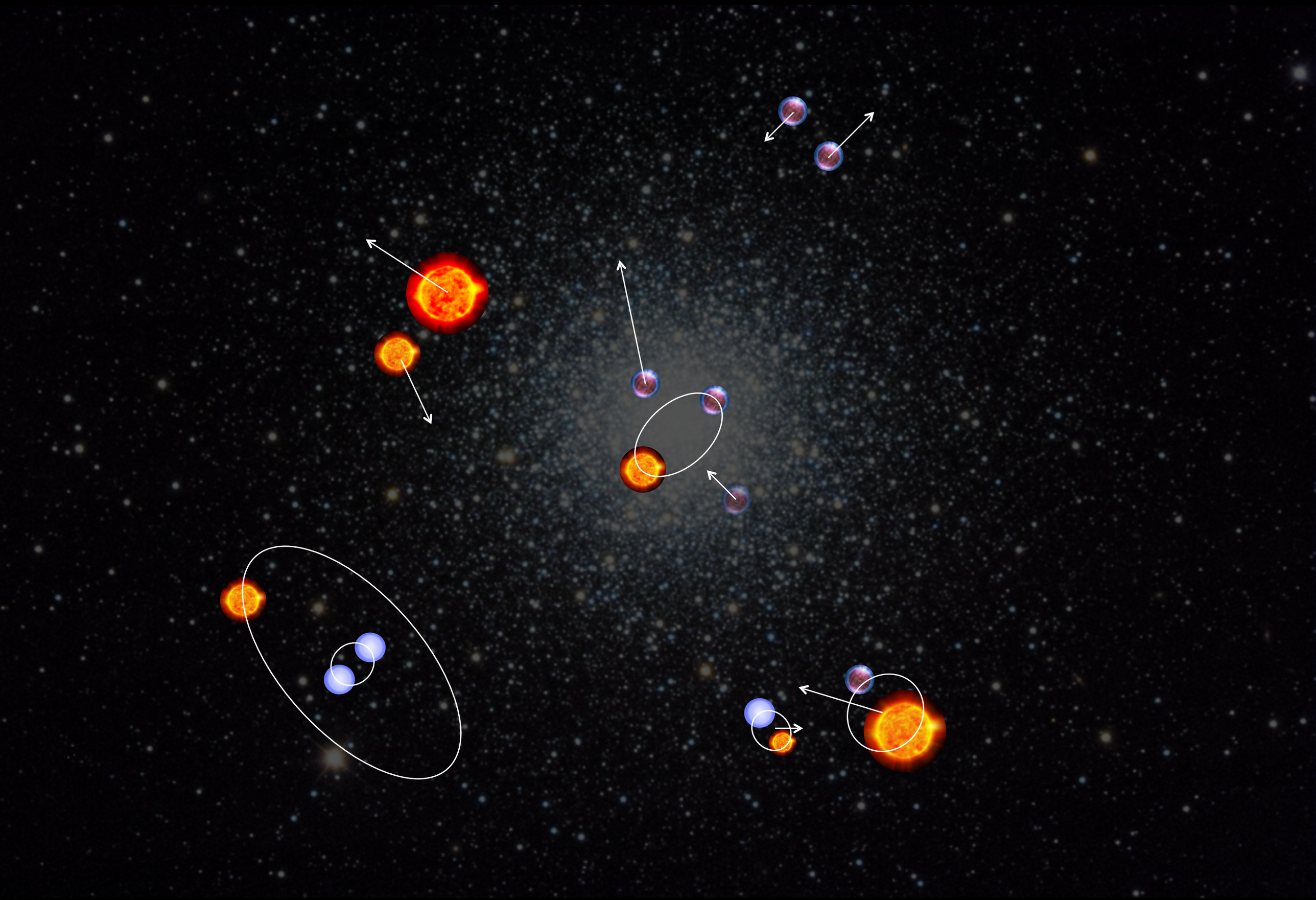
Study the role of GR and Tides in few body interactions.

Tools:

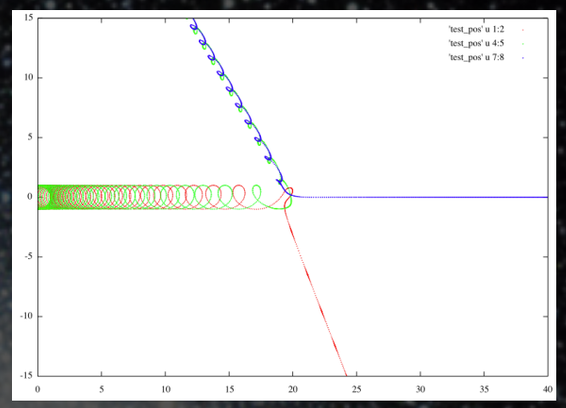
I wrote a parallel N-body code with equations of motion including dynamical GR and nonlinear Tides.

First goals:

- Identify tidal outcomes (i.e. whats going on ?)
- Calculate cross sections for tidal outcomes.
- Observable consequences.



Bin, mergers (SN)

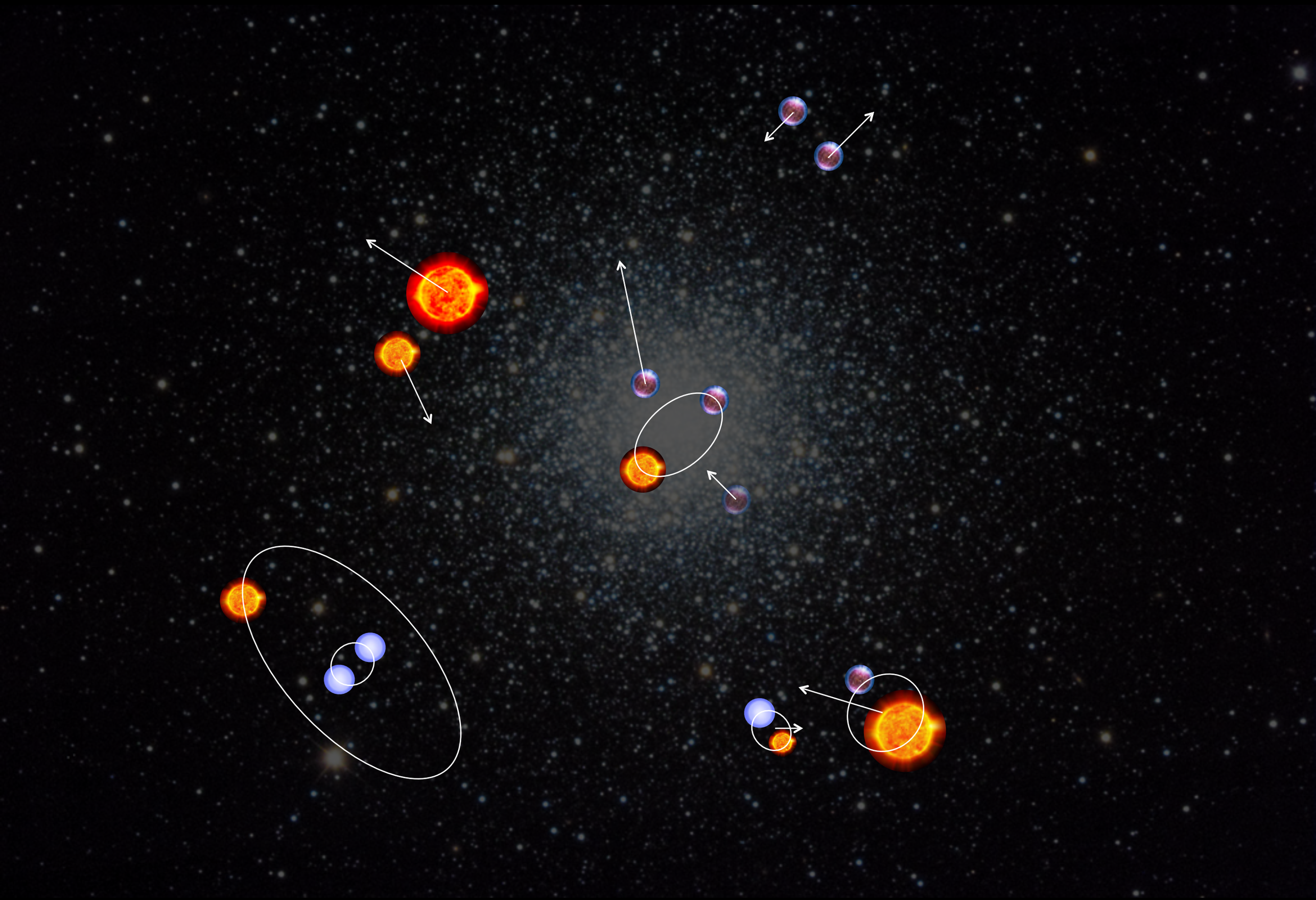


- GW inspirals
- Super novae(SN)
- Blue Stragglers
- LMXB
- HV stars
- Black Holes
- ….

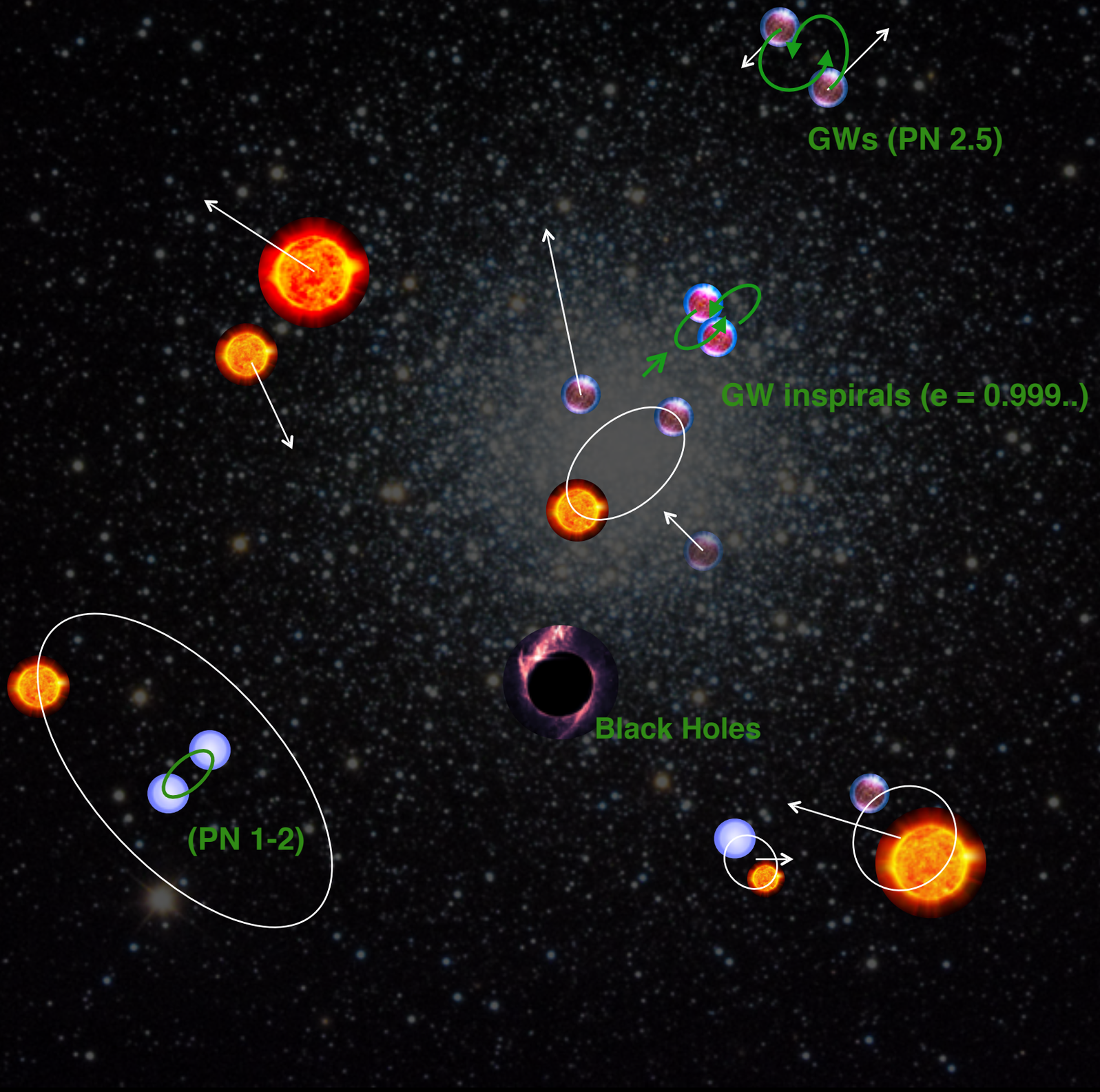
NS-NS (GW),
GC ‘heat source'

Compact bin, mergers (SN, GW)

Kozai-Triples

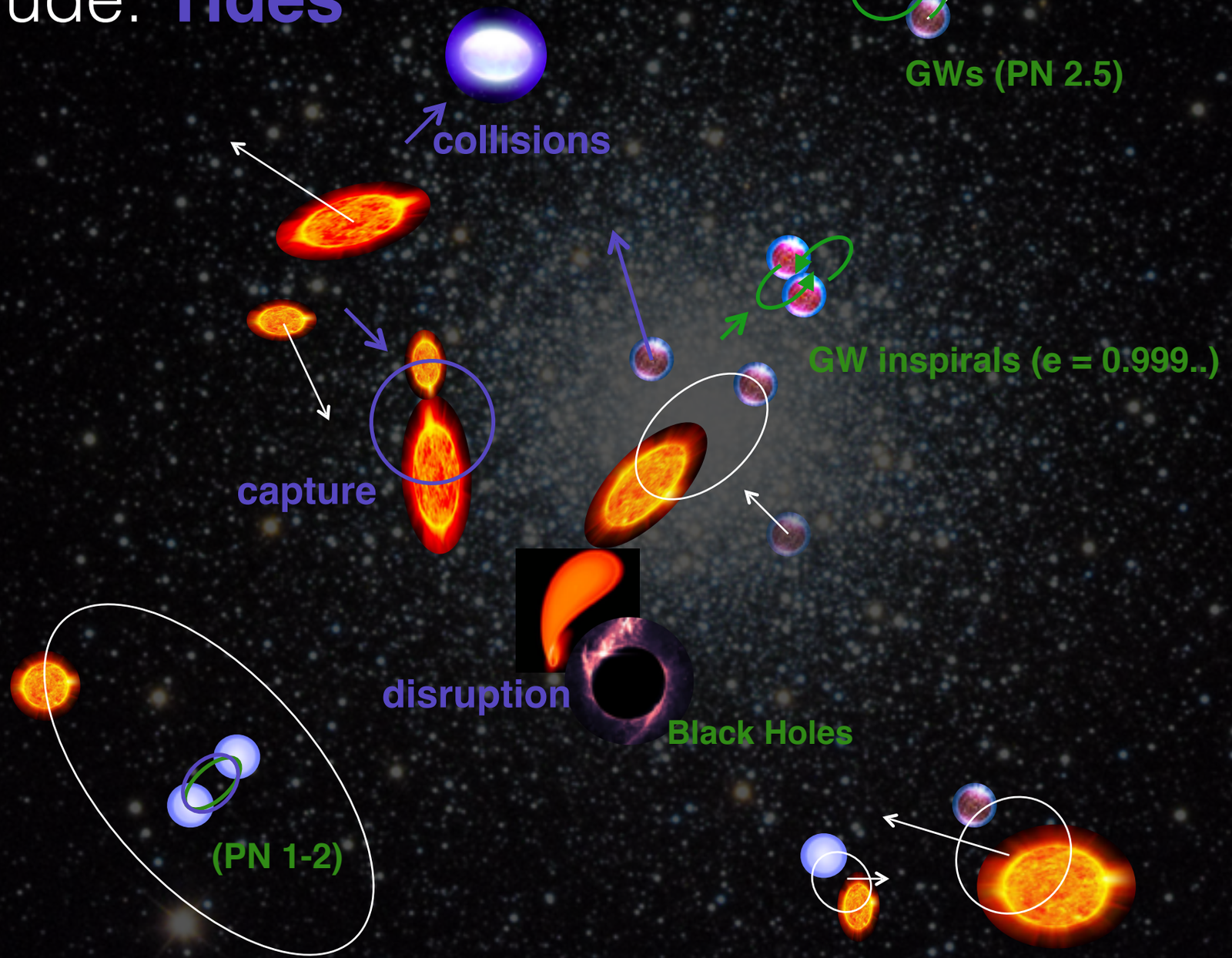


Include: **GR**



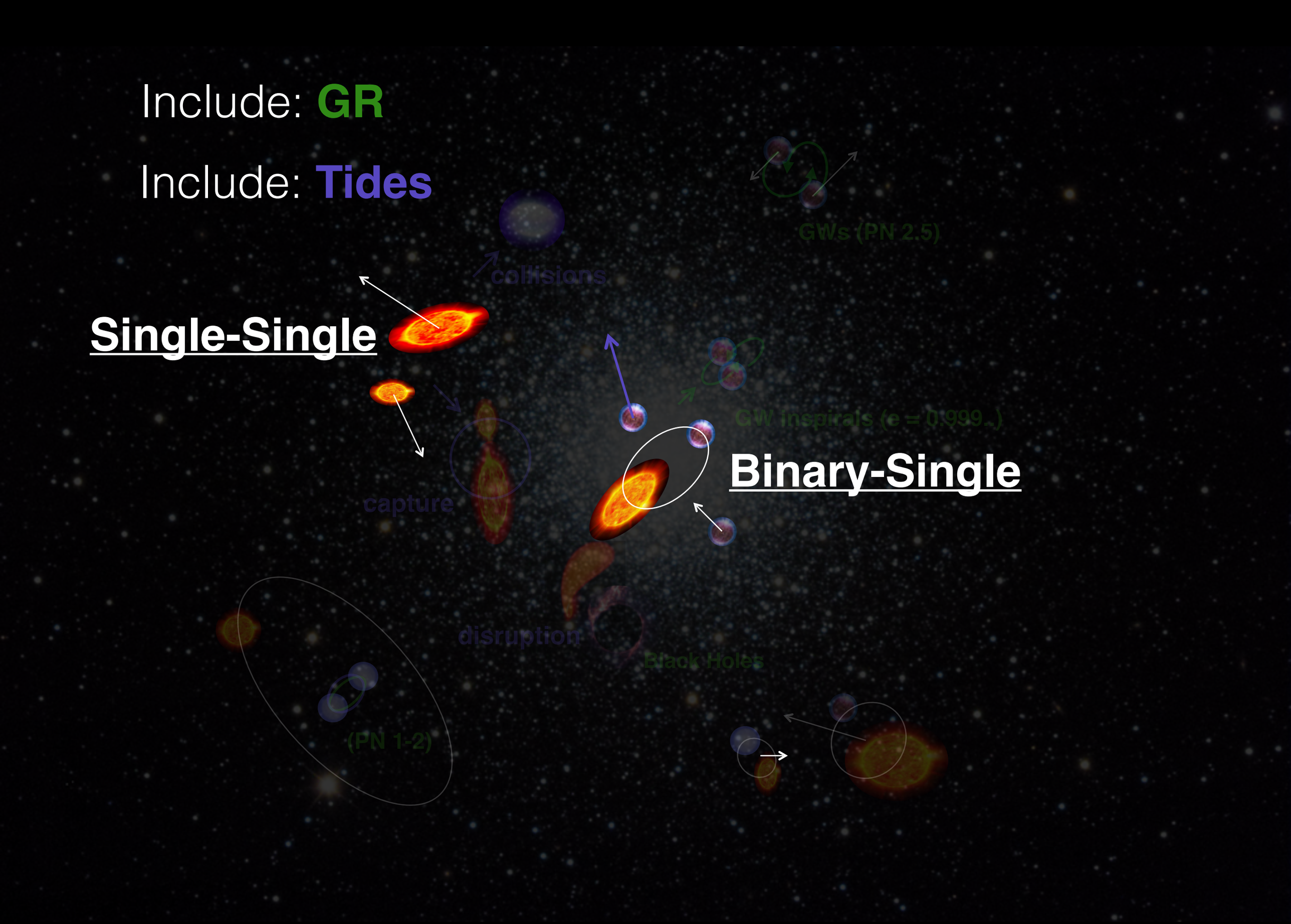
Include: **GR**

Include: **Tides**

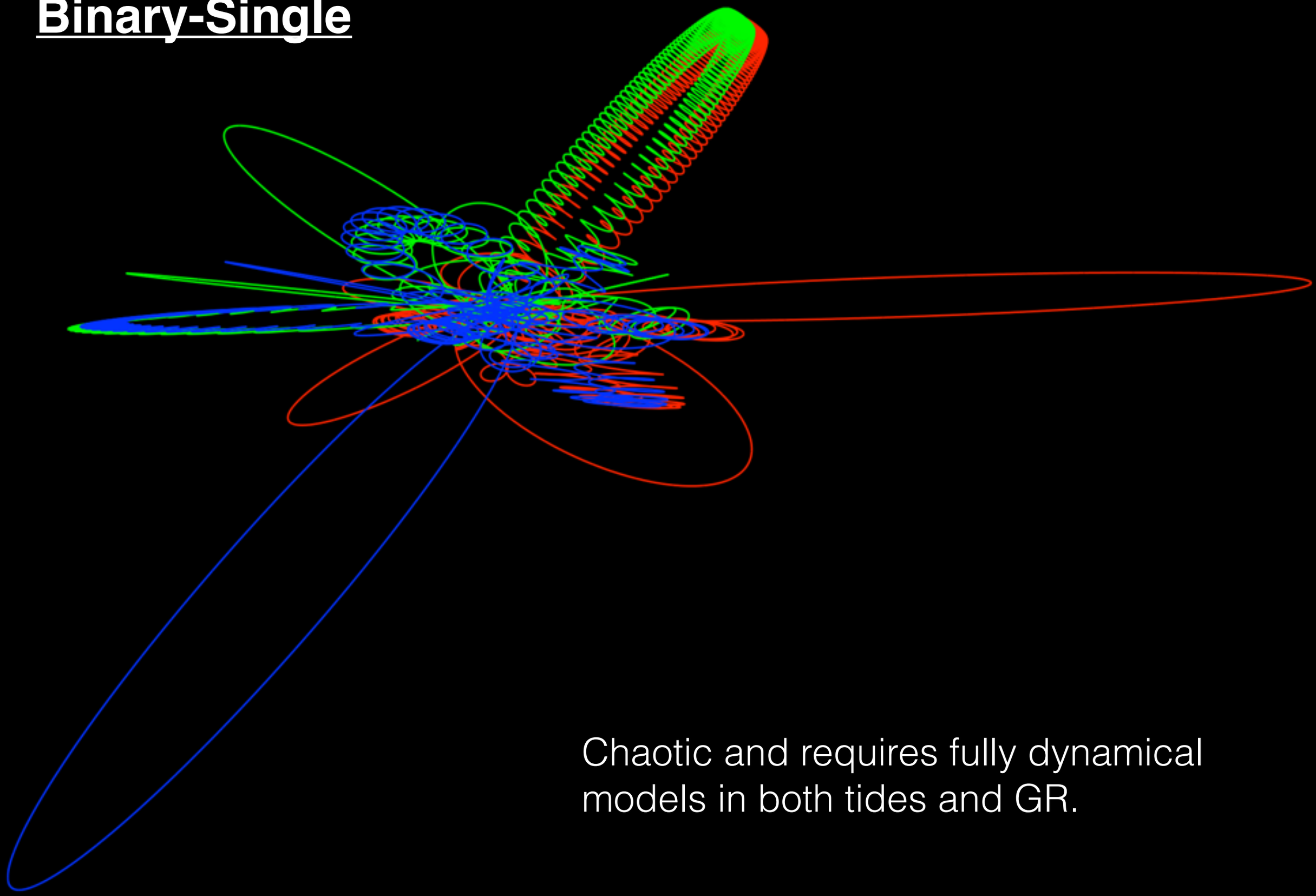


Include: **GR**

Include: **Tides**



Binary-Single



Chaotic and requires fully dynamical models in both tides and GR.

N-body Code:

Equations of motion:

- Write out total energy of the system (internal, external) assuming the stars a self-similar ellipses and then apply Euler-Lagrange equations.

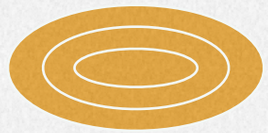
My version:

- Fast parallel Fortran version.
- Hundreds of chaotic orbits in 5-10 sec.
- Single and statistical studies.
- Can never be done with full hydro!!

GR model

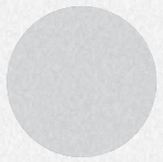
- PN expansion (v/c)
- 1PN ,2PN ,2.5PN(GWs) order
- Added as modified acc

Affine Model:



$$r_i = q_{ia}\hat{r}_a$$

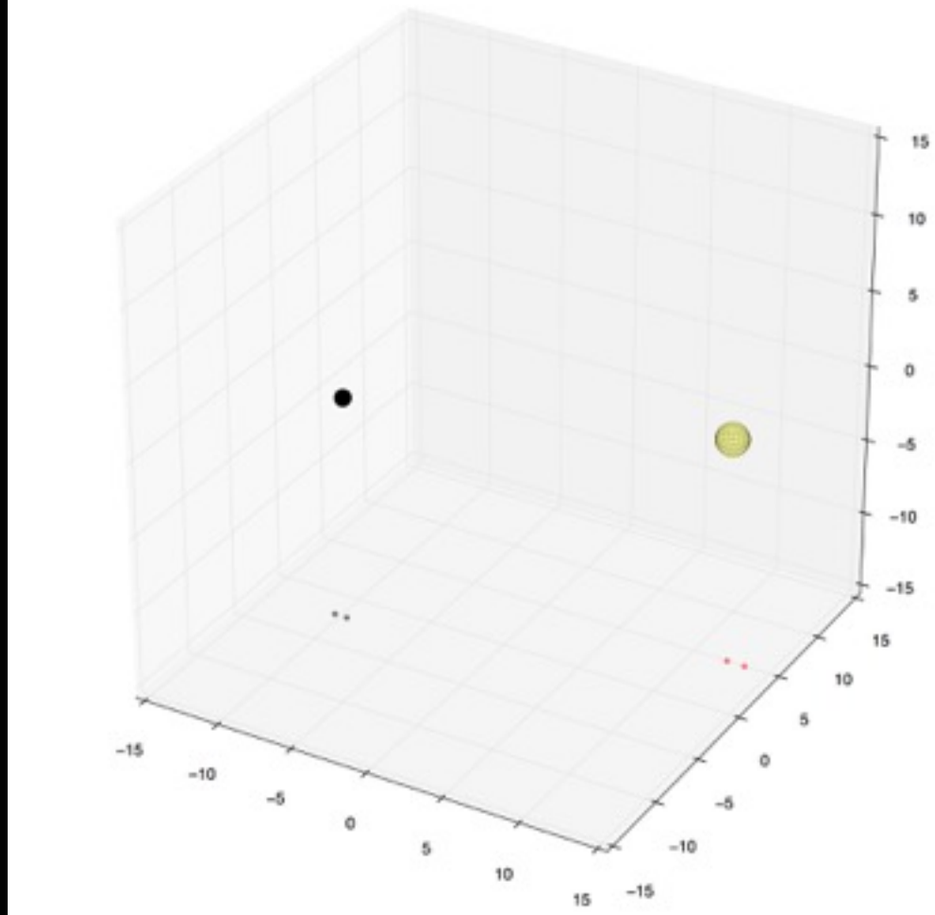
$$\dot{r}_i = \dot{q}_{ia}\hat{r}_a$$



- Self-similar ellipses
- Allow non-linear variations
- Polytropic stars
- Fully dynamical
- Easy to add viscosity and GR.
- effectively l=2 (see PT).

2-body studies by:

- Carter, Luminet (1985)
- Lai, Rasio, Shapiro (1-4)
- Kochanek (91)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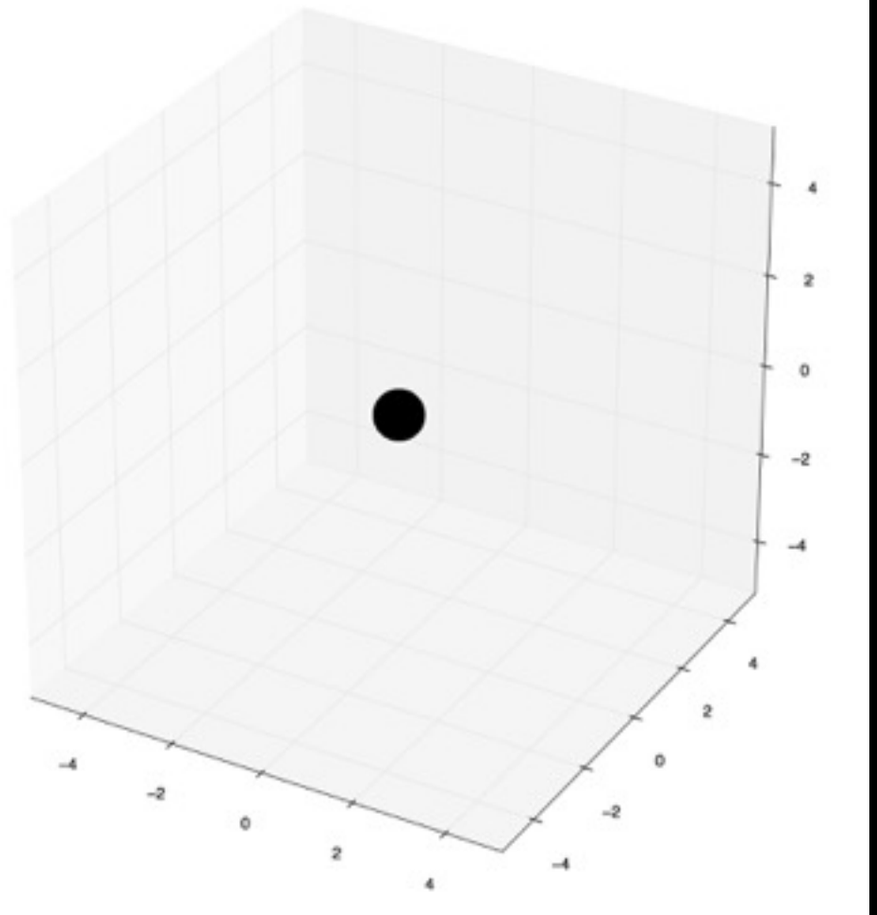
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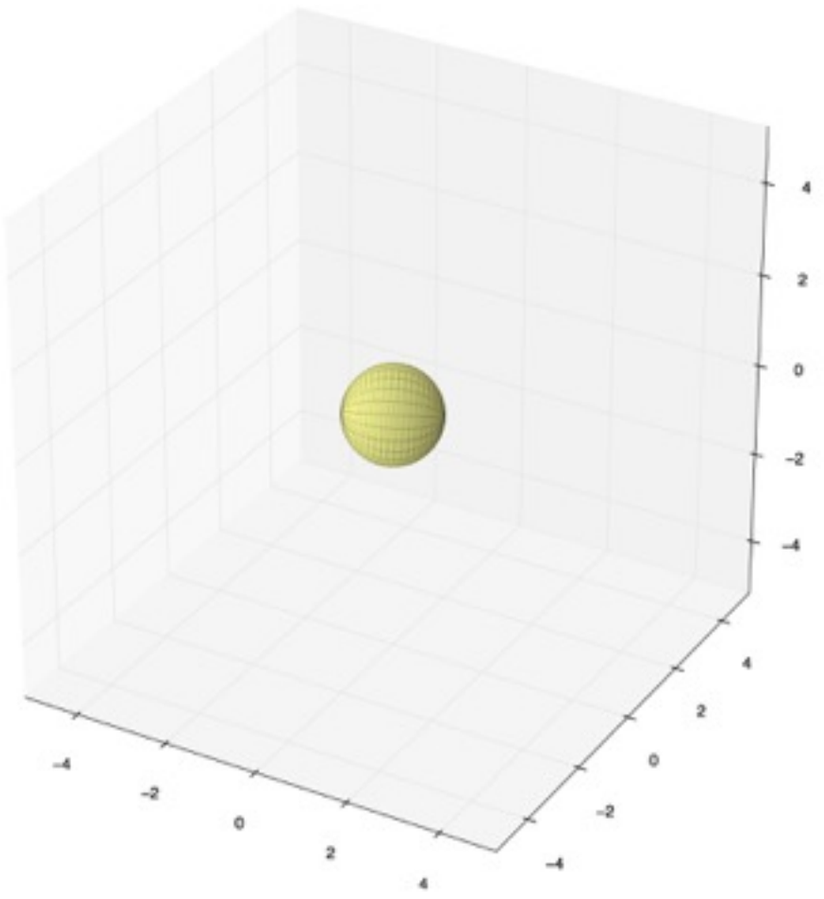
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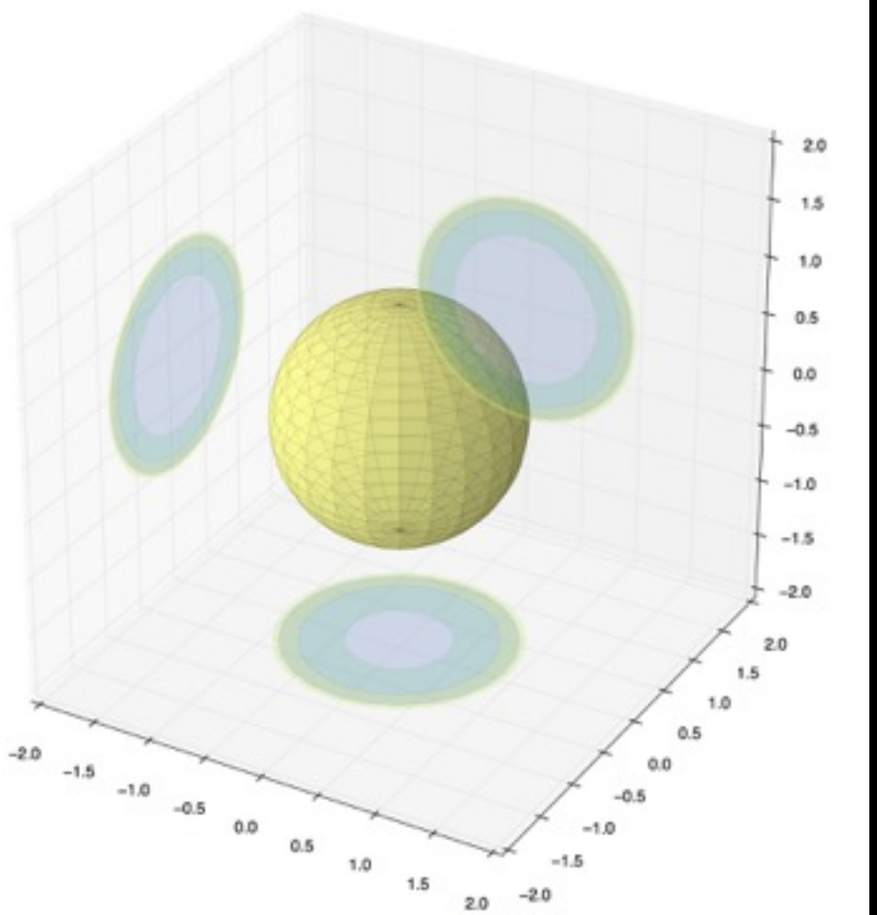
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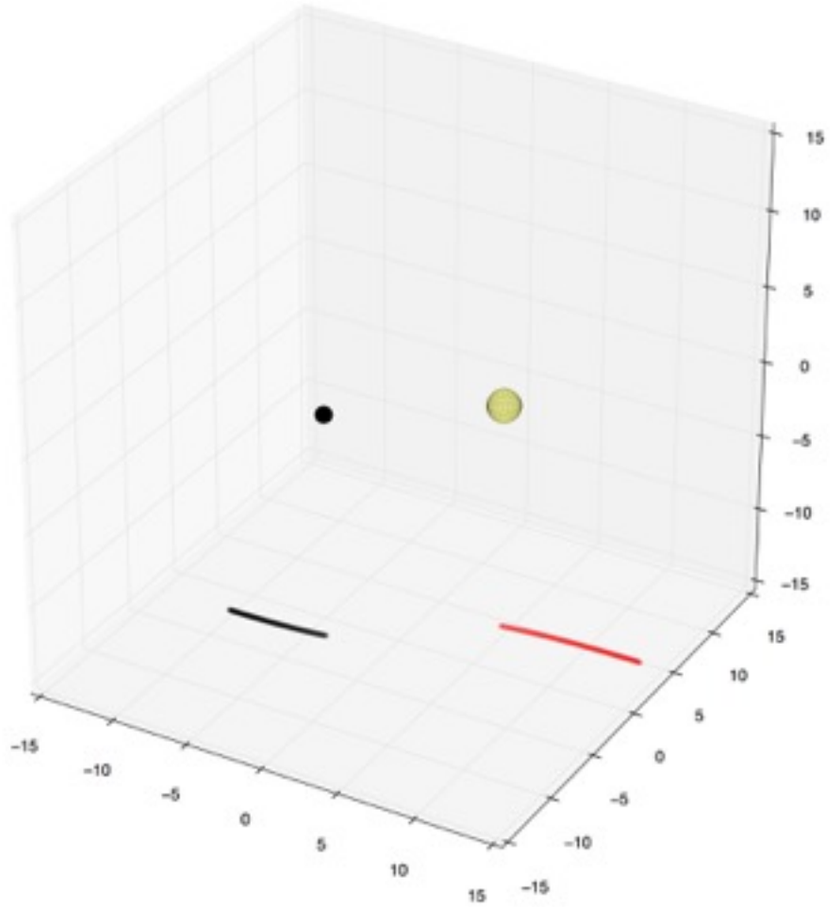
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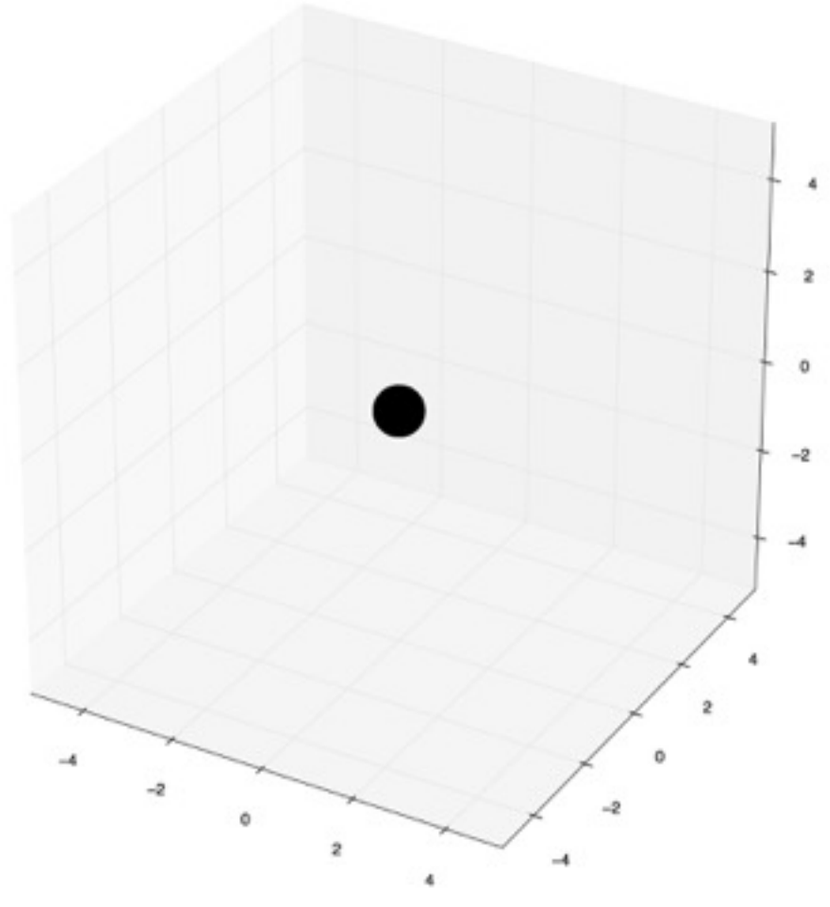
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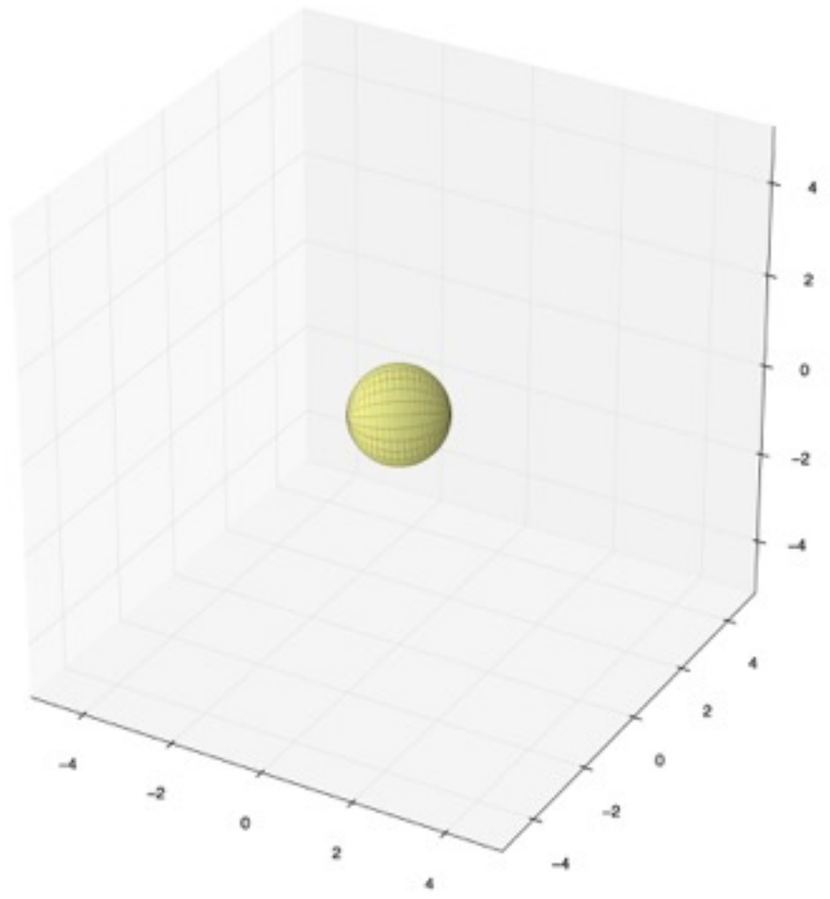
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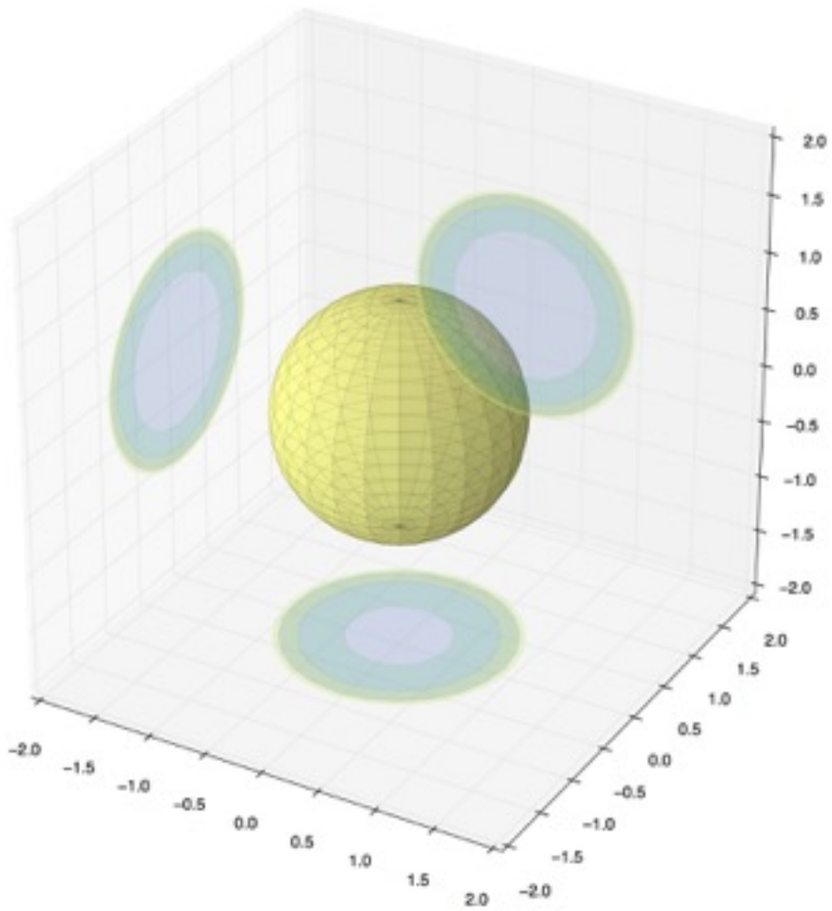
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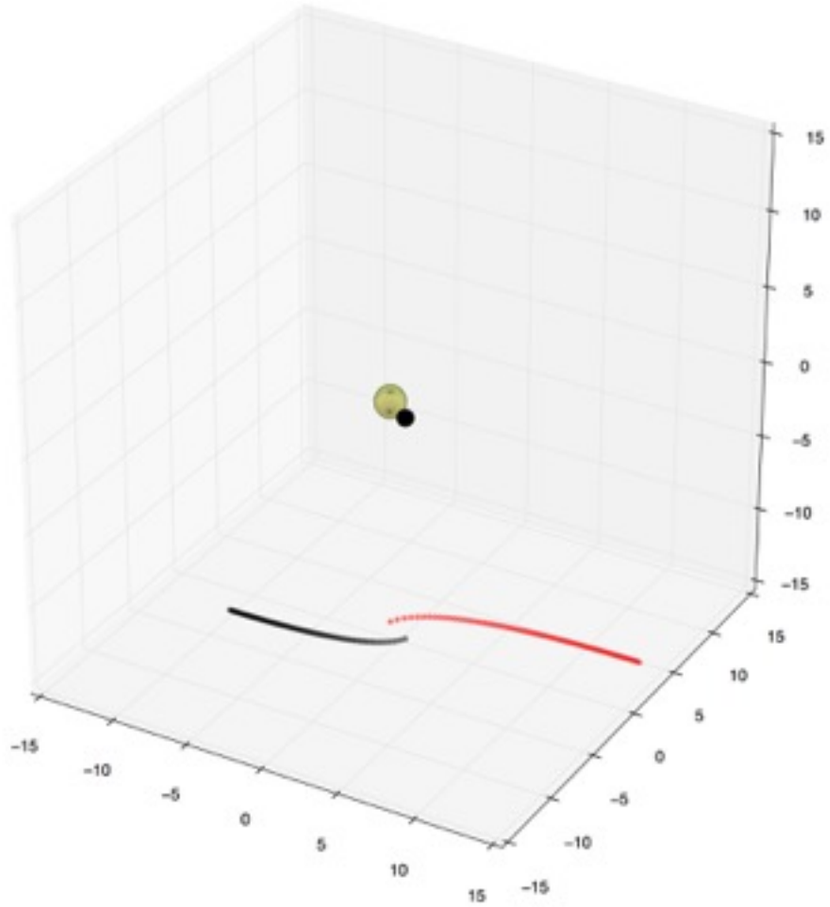
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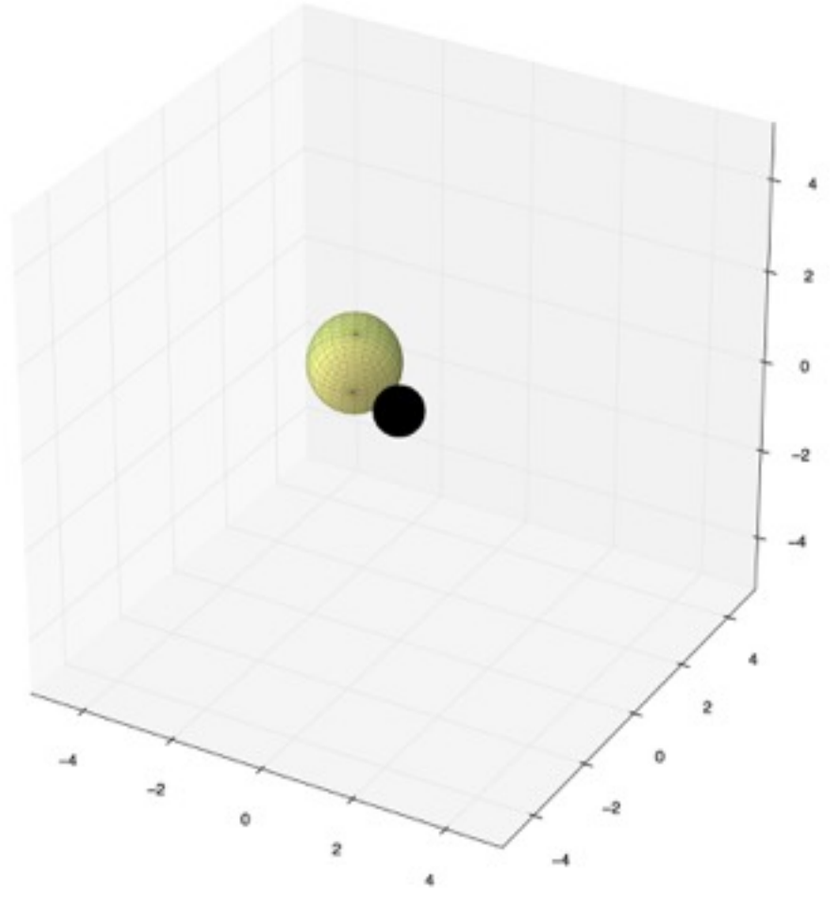
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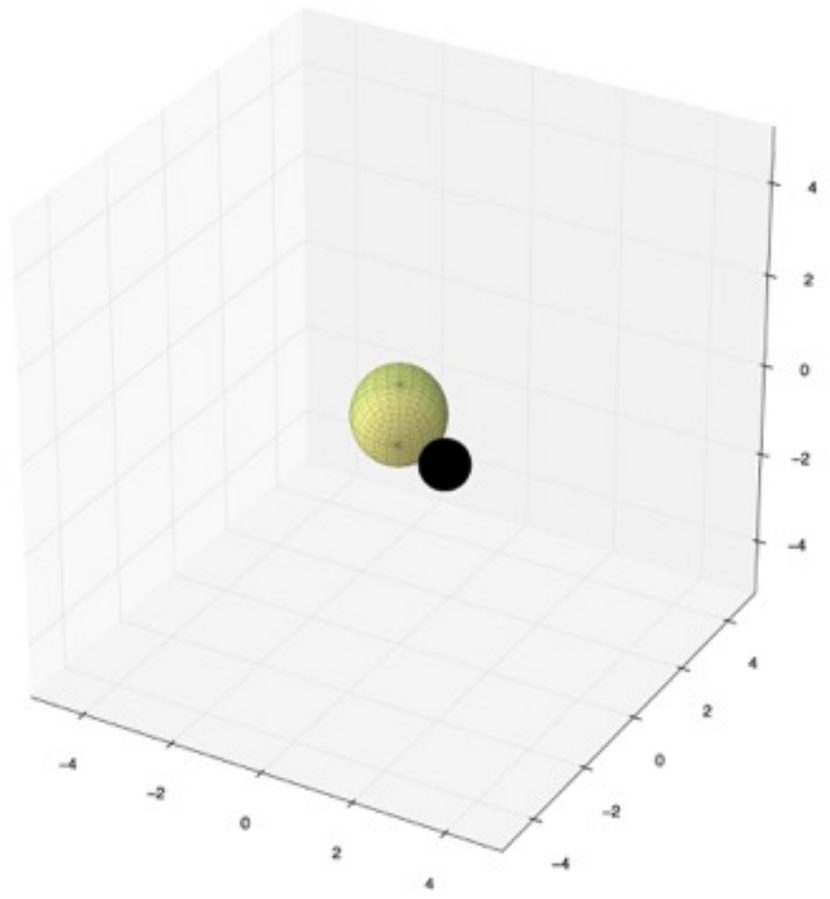
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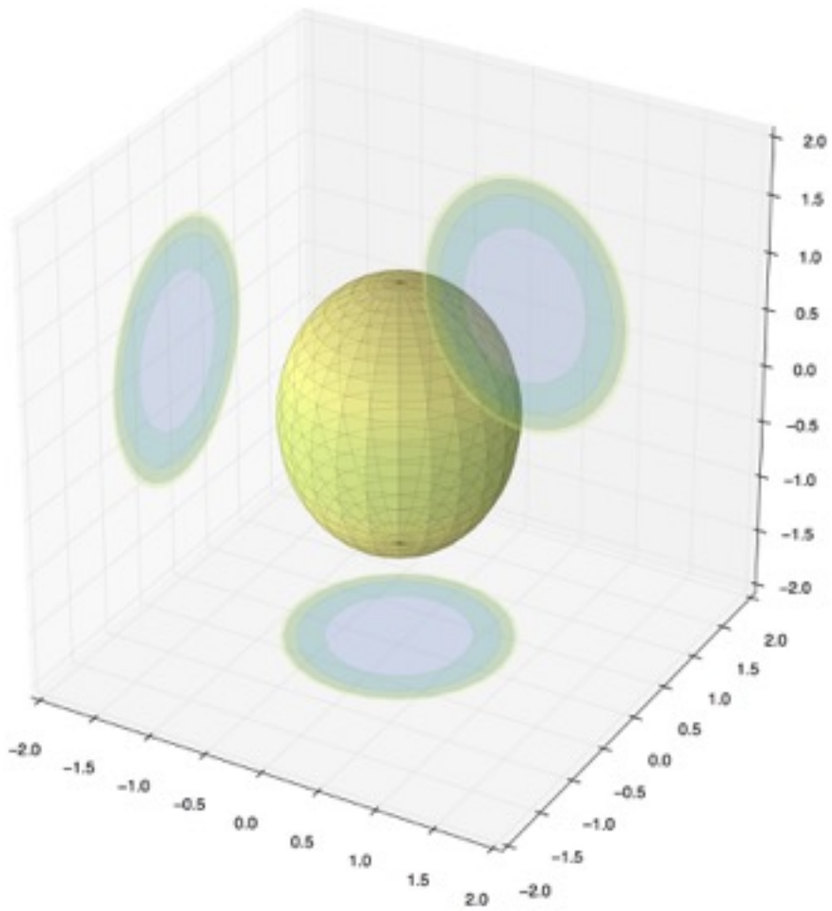
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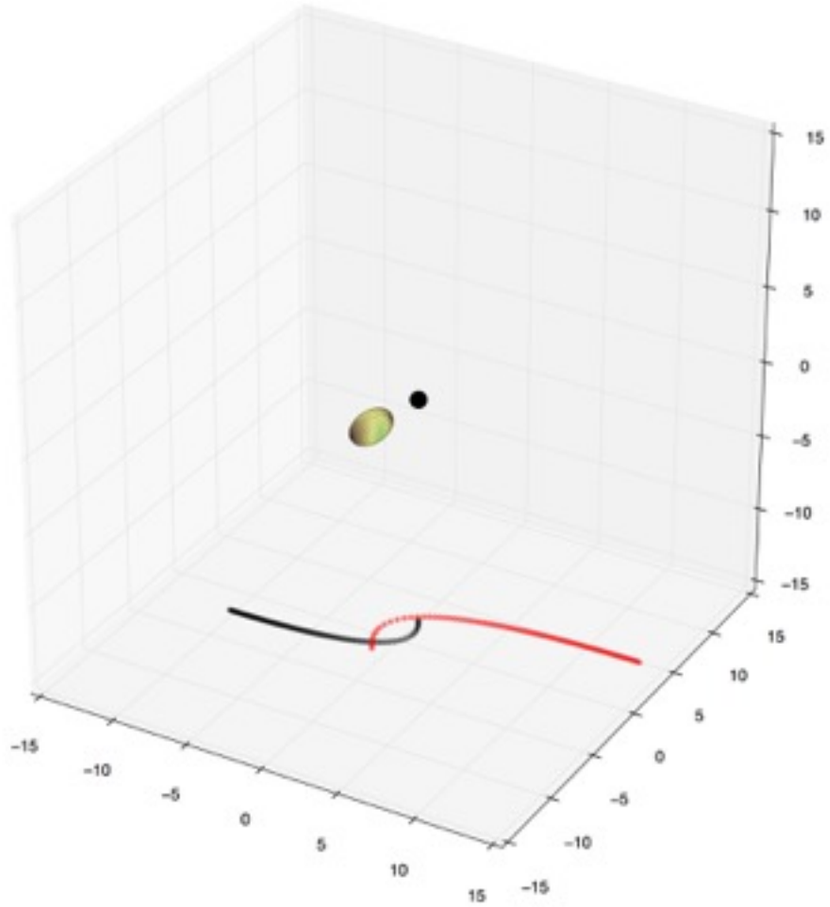
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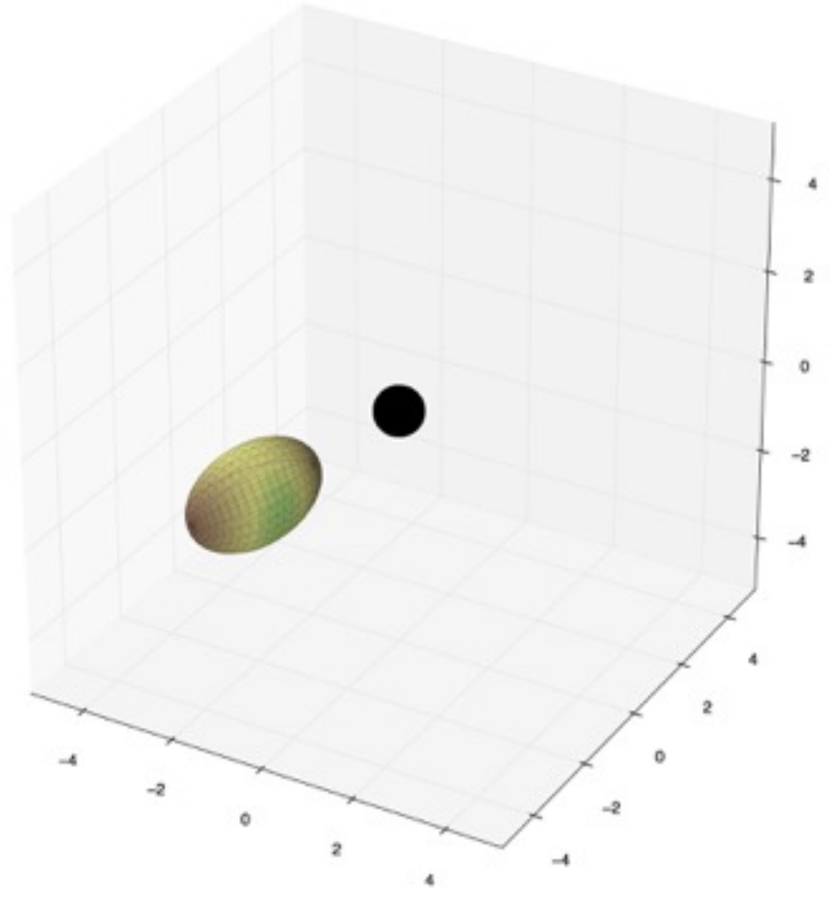
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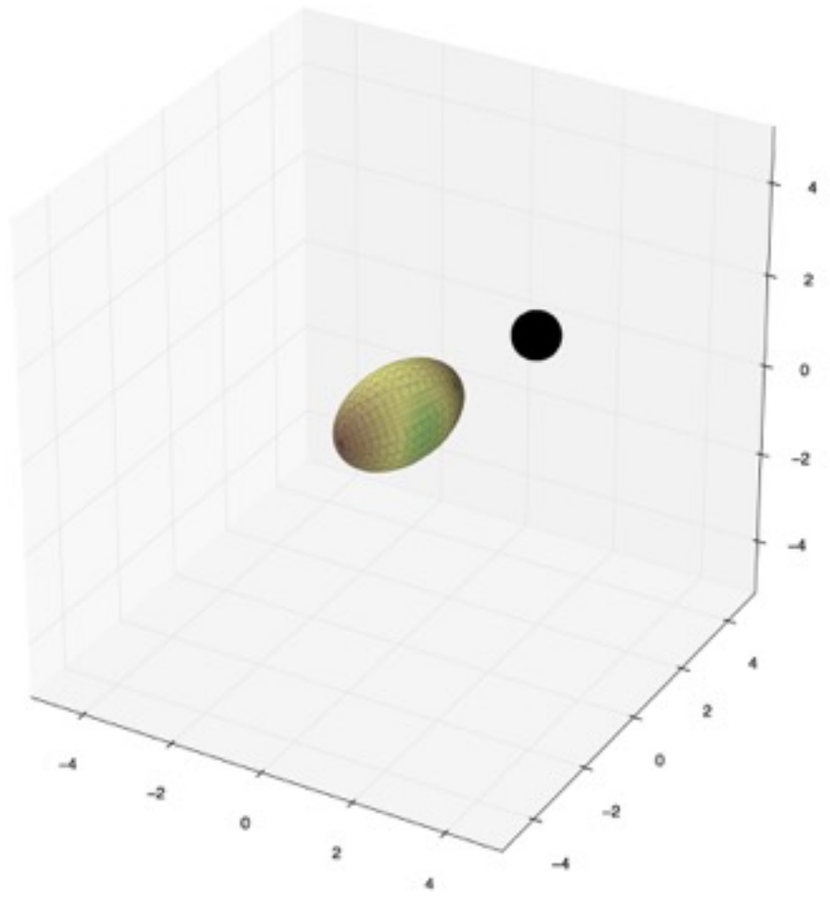
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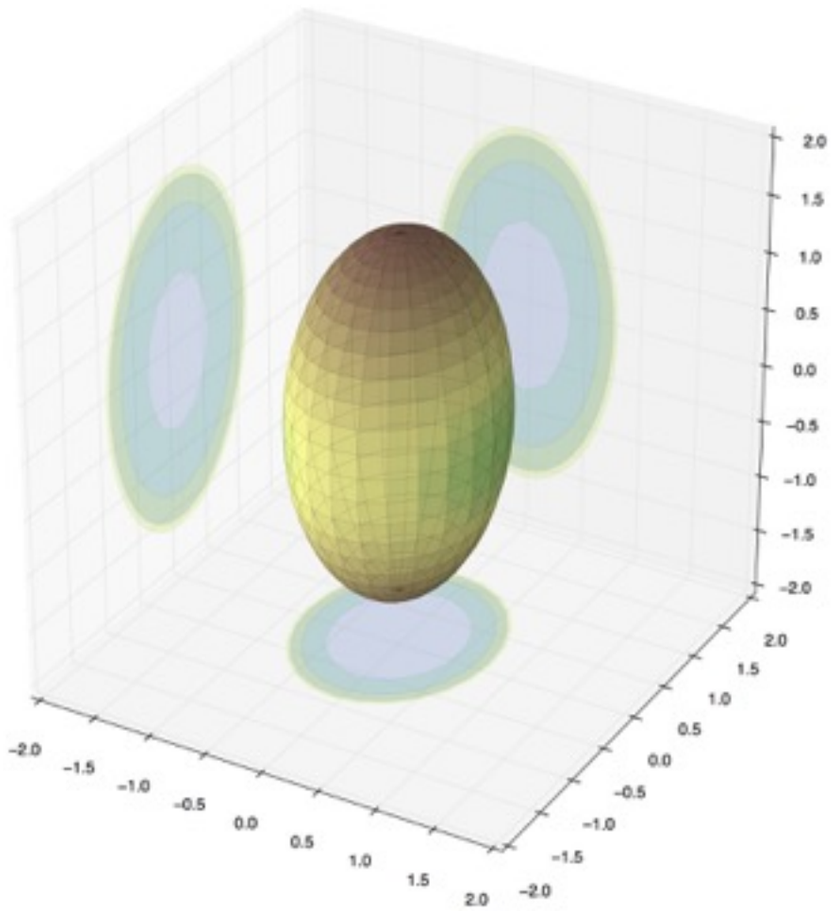
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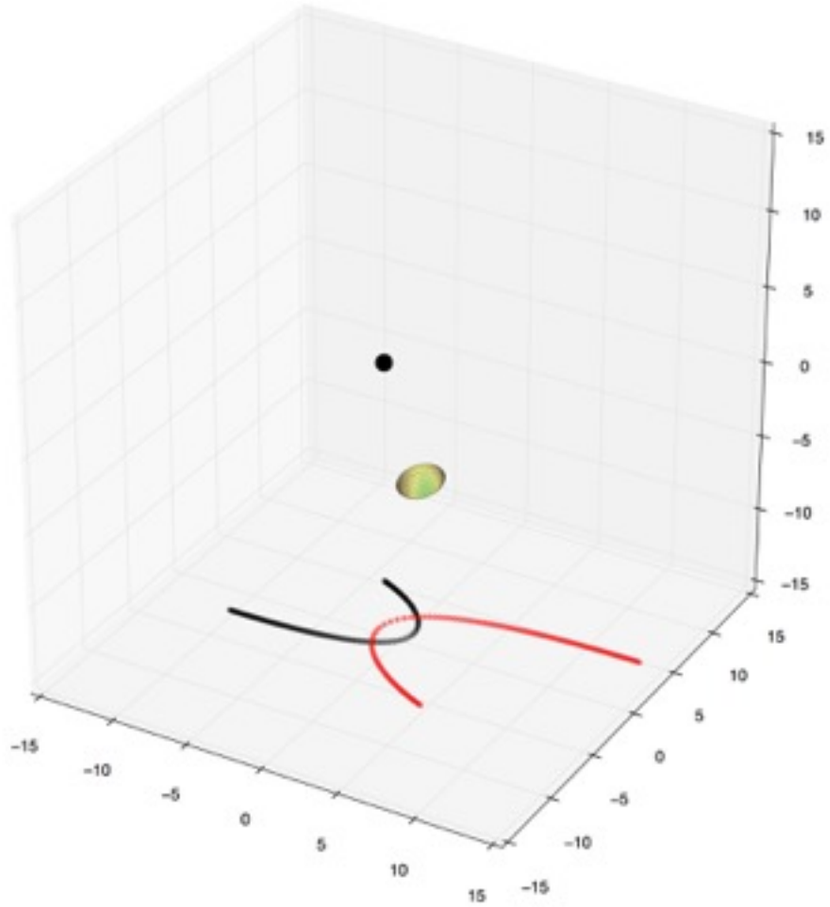
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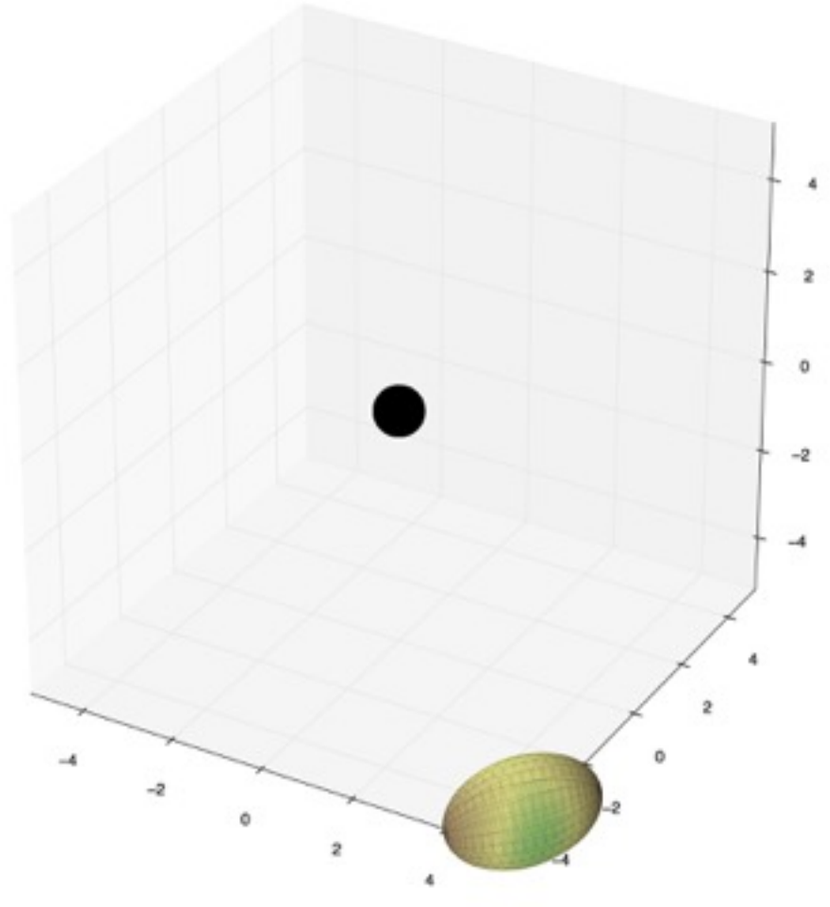
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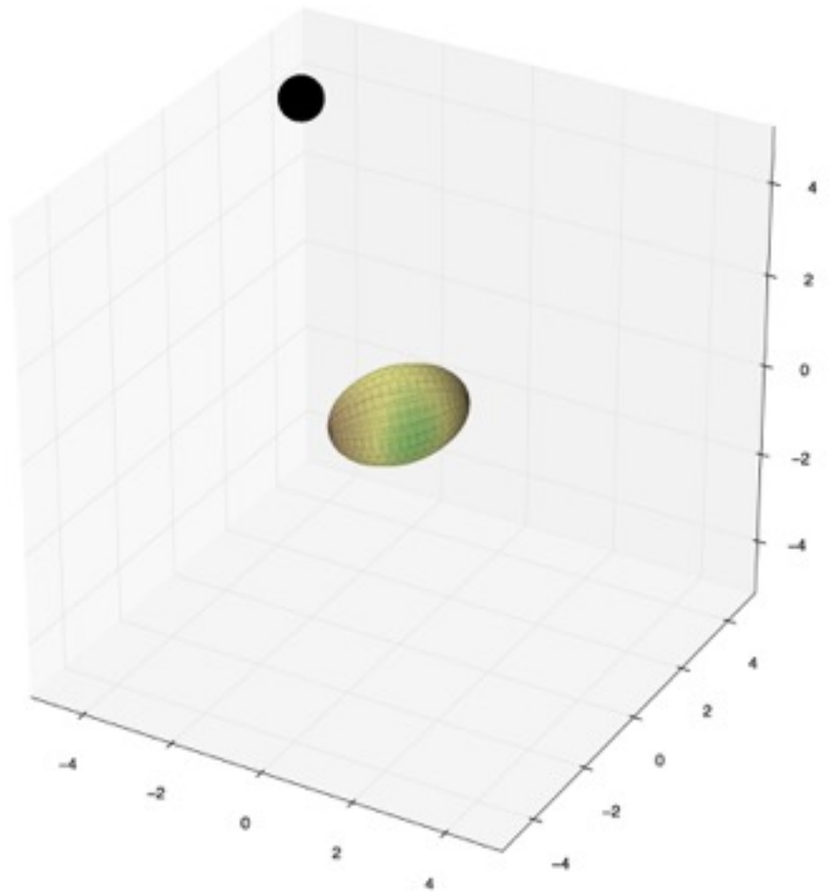
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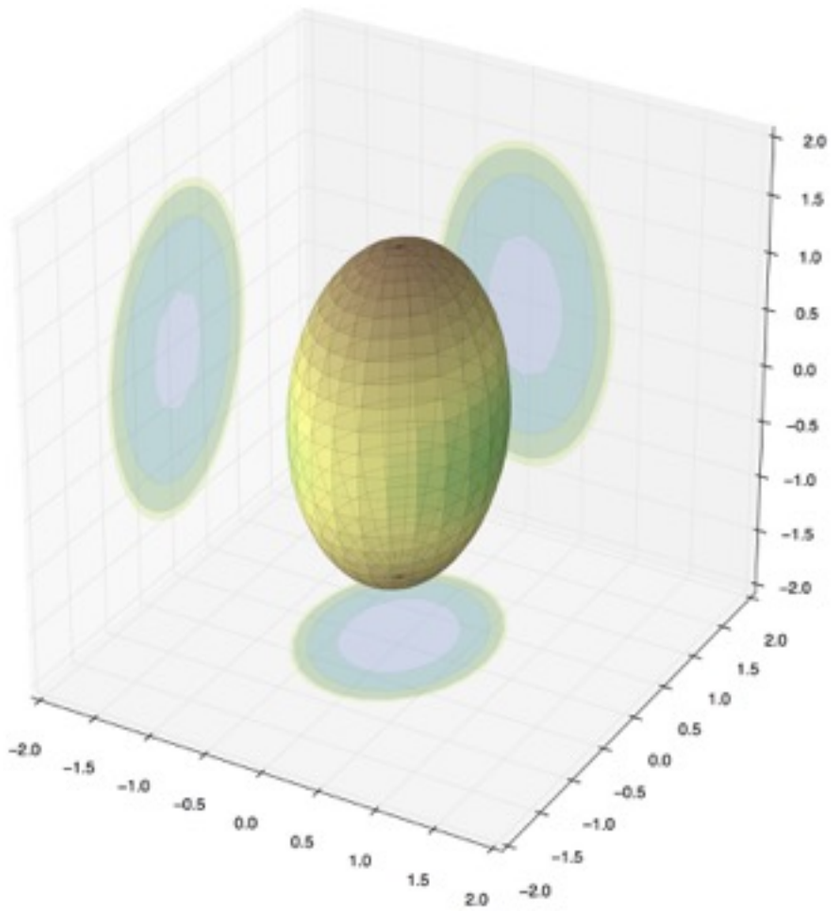
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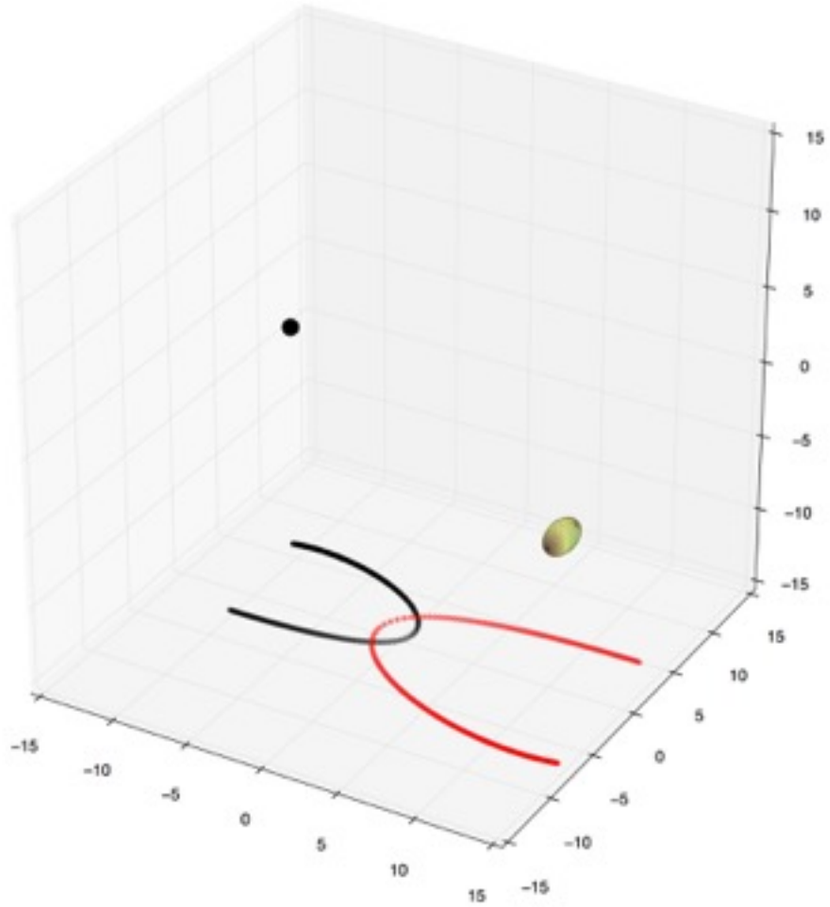
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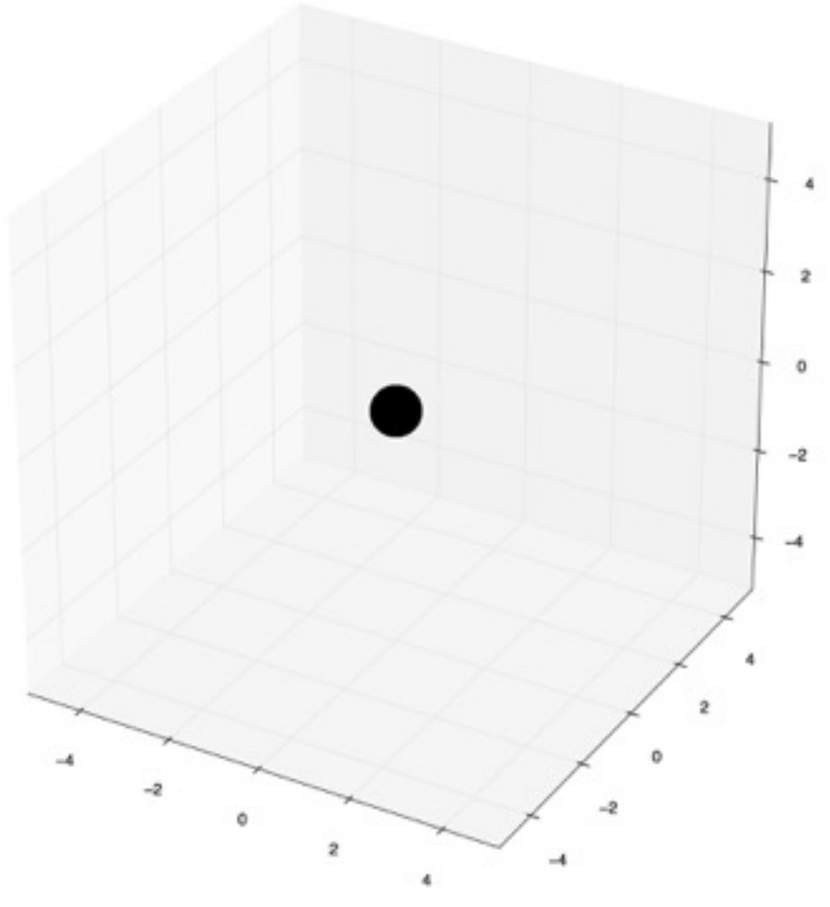
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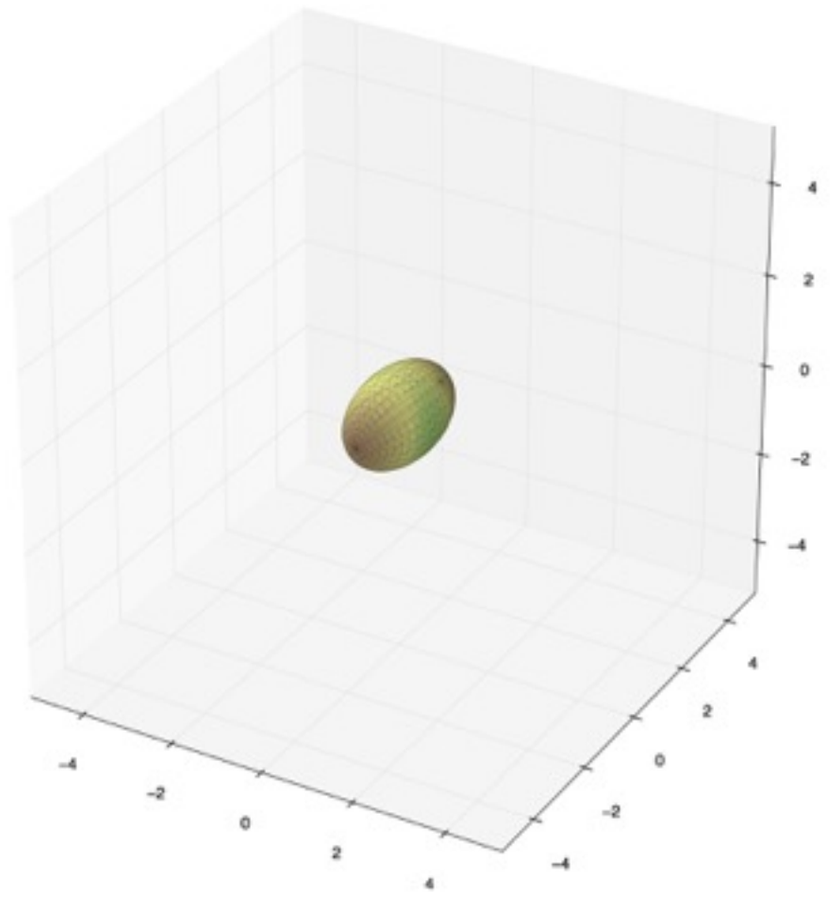
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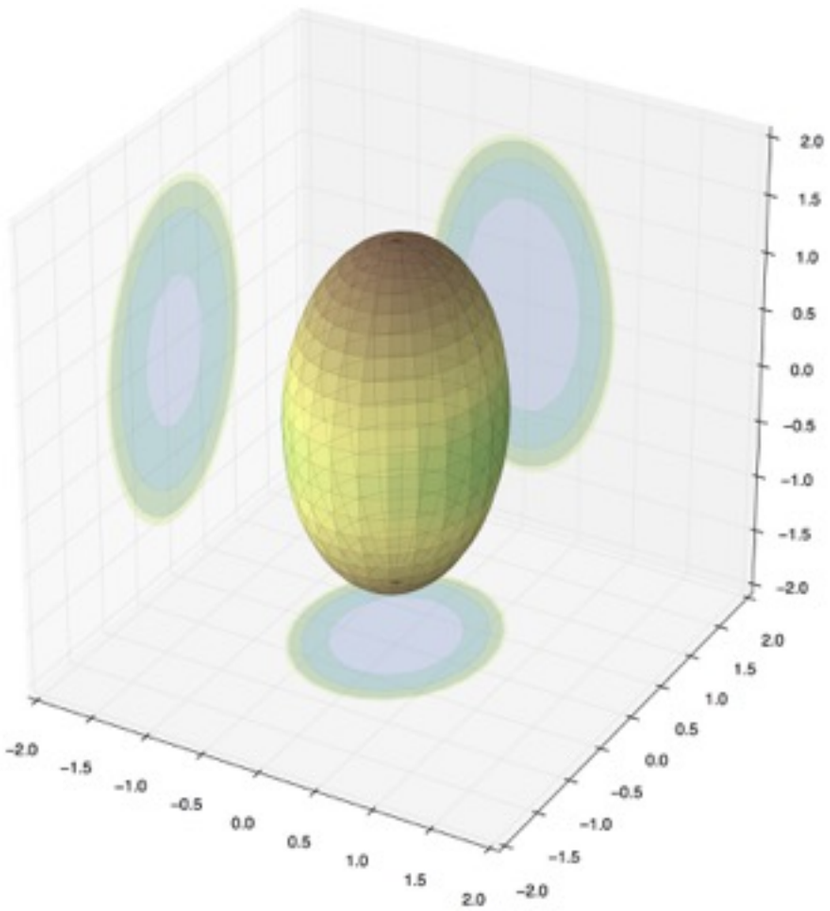
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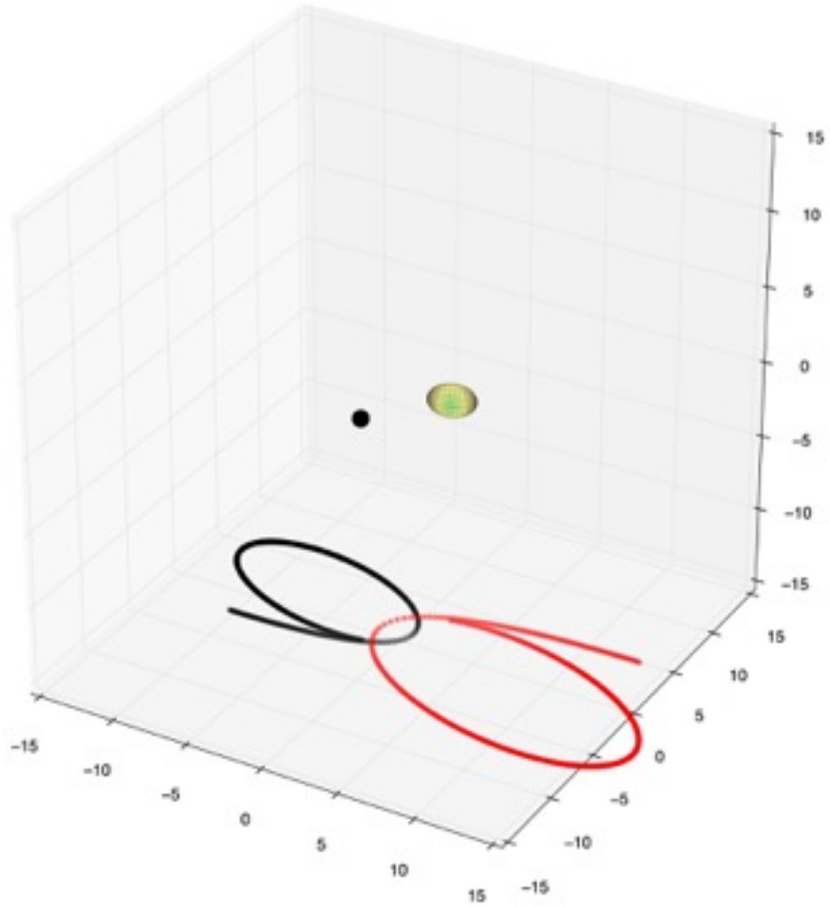
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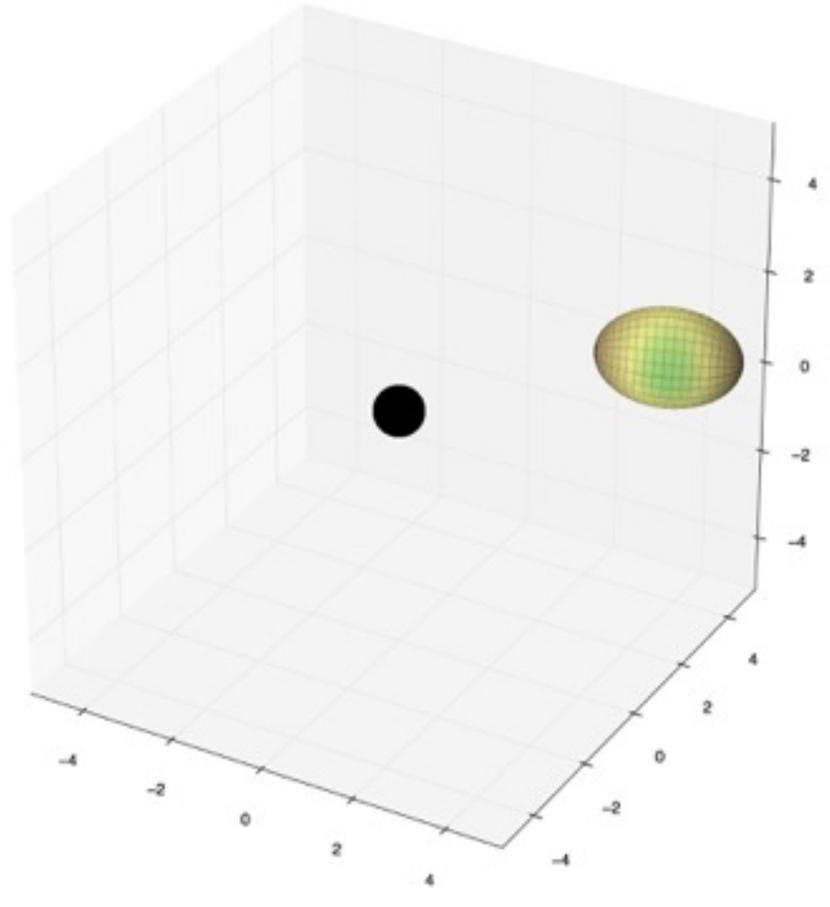
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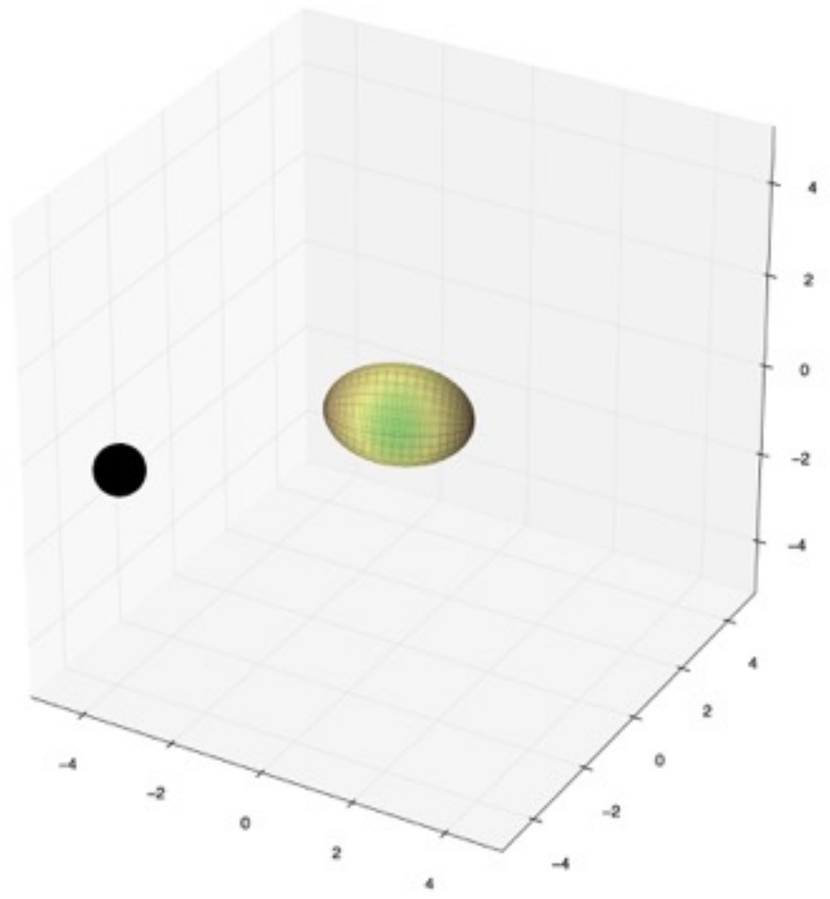
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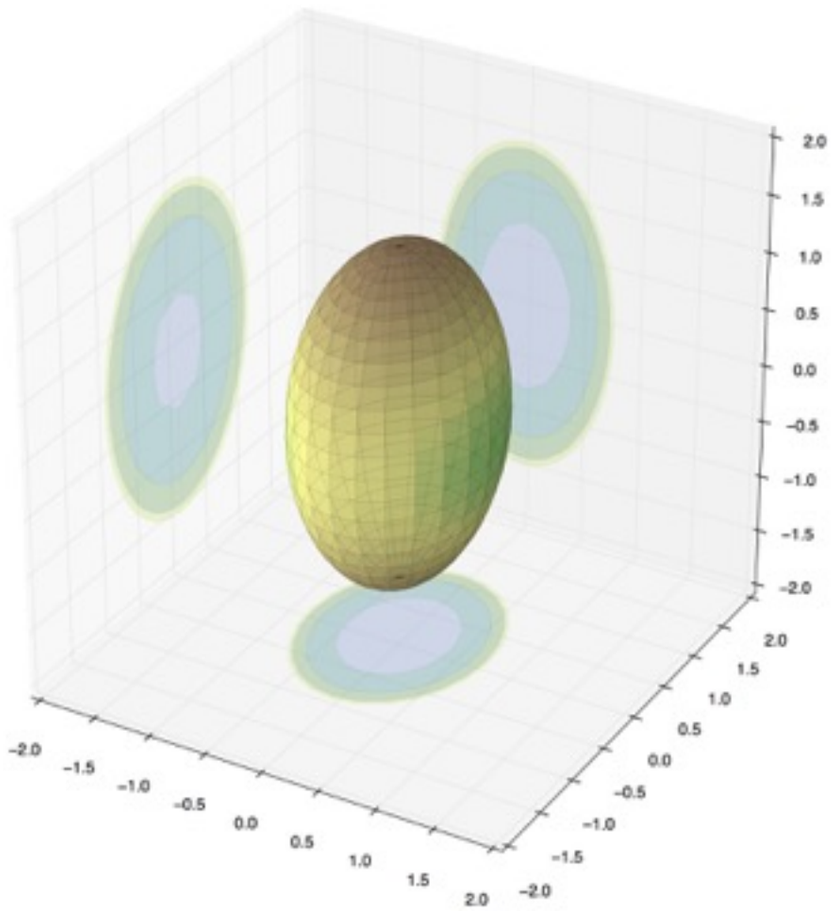
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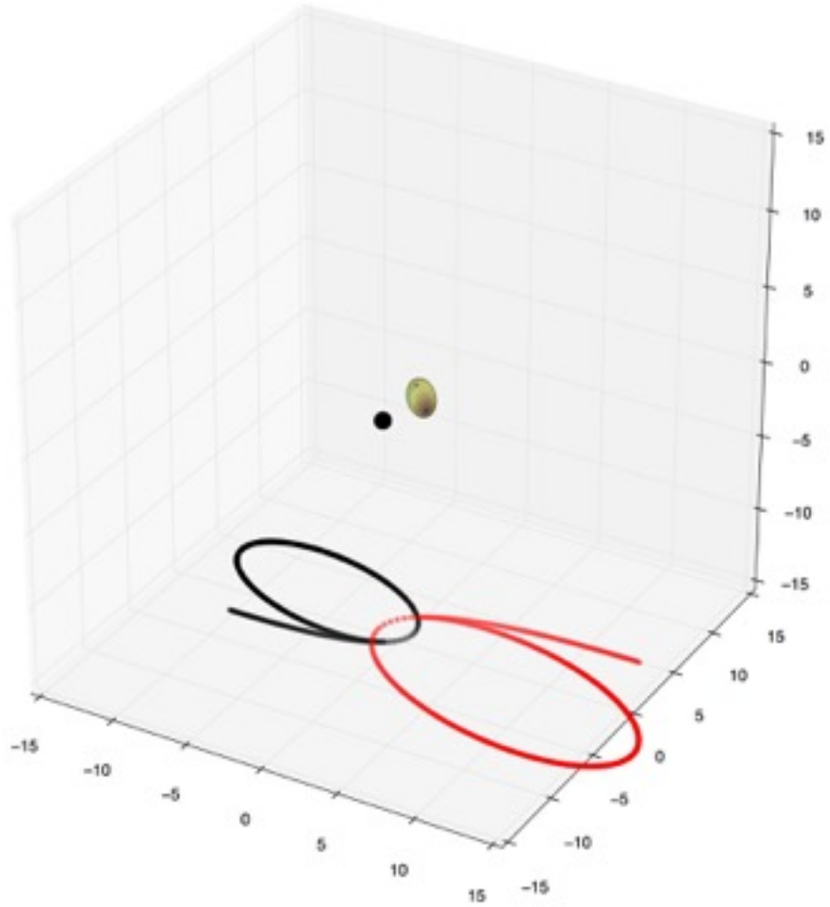
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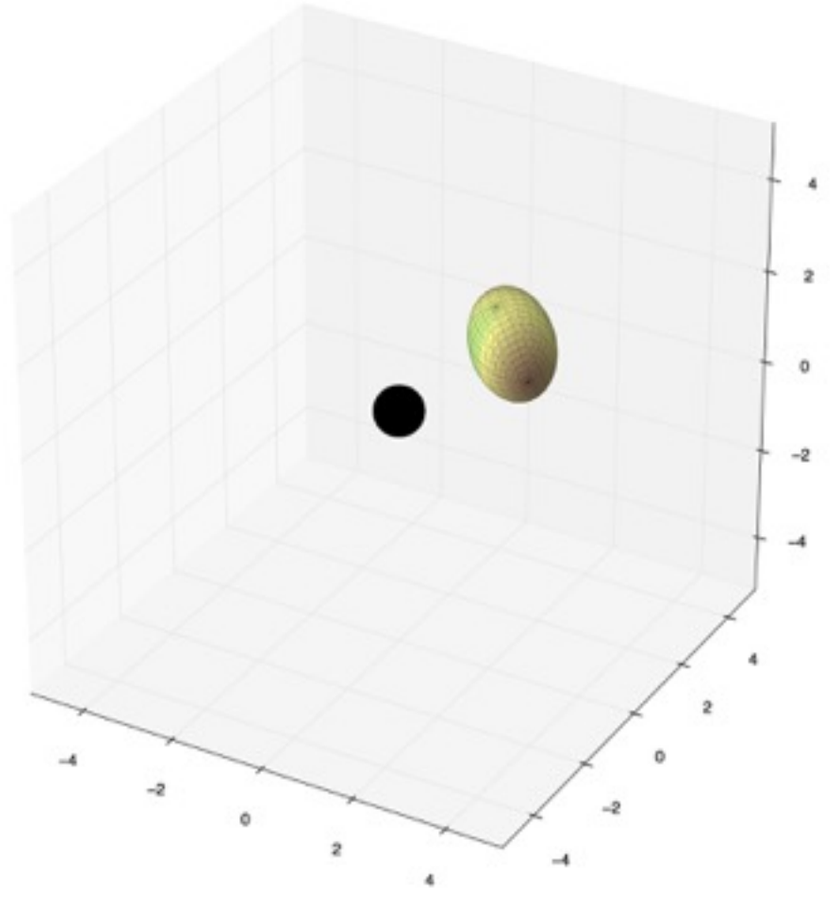
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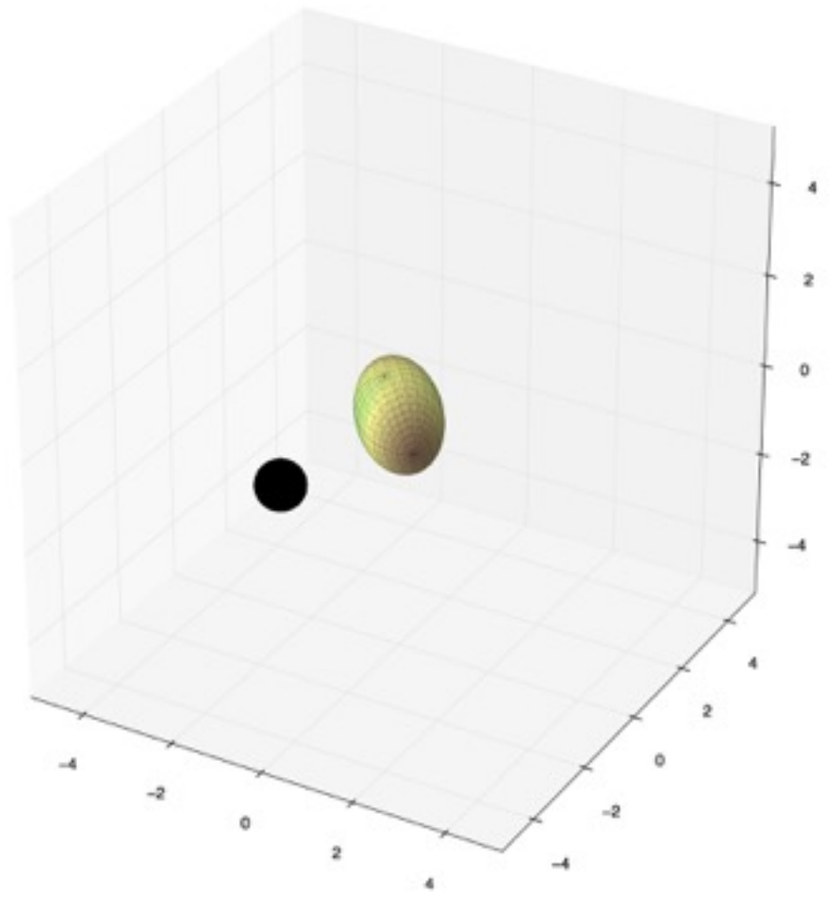
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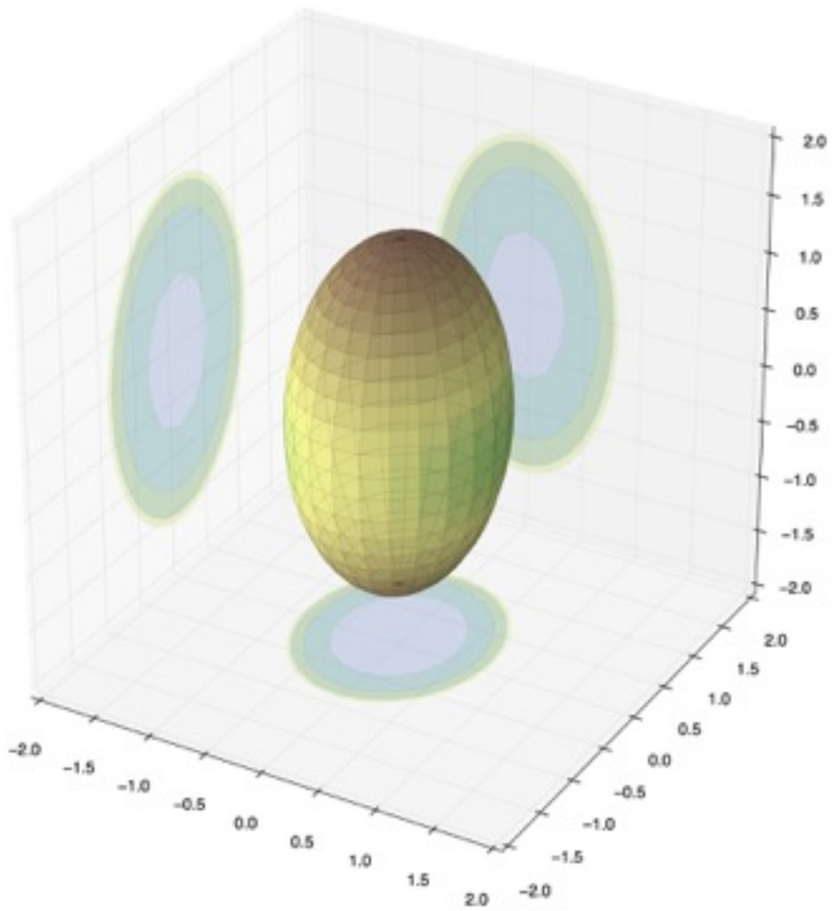
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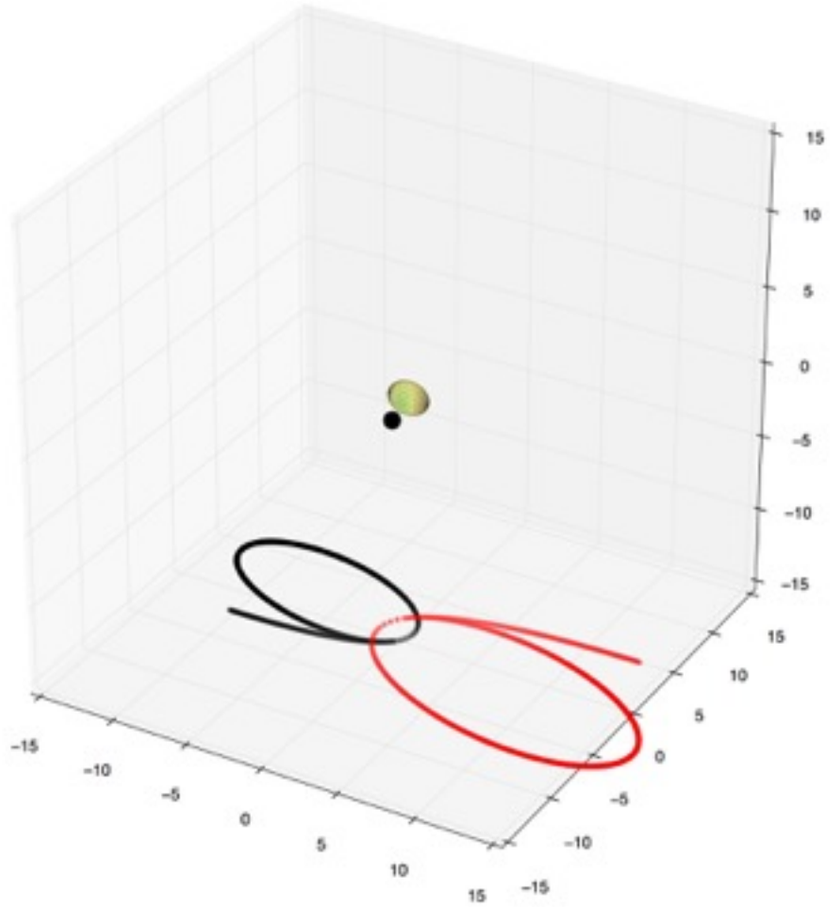
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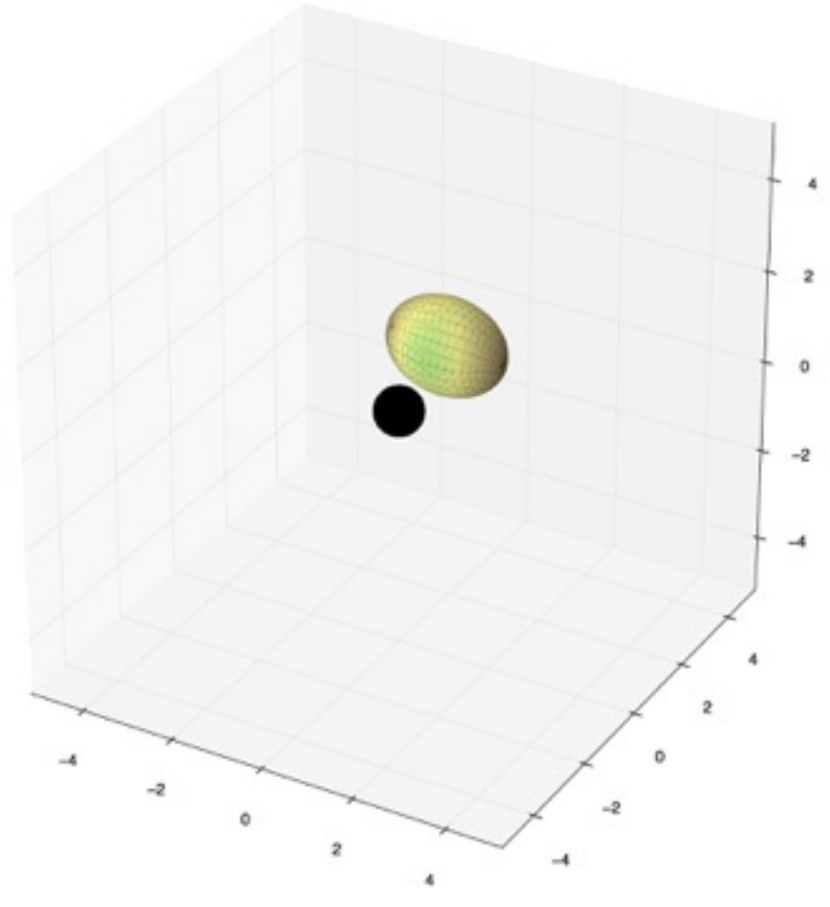
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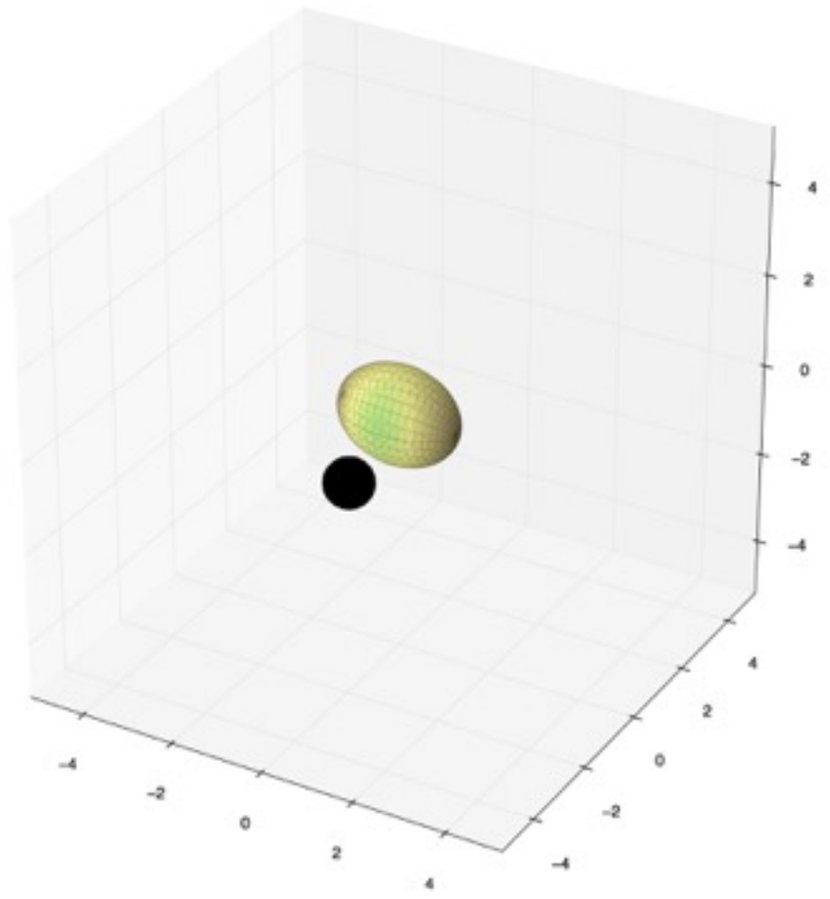
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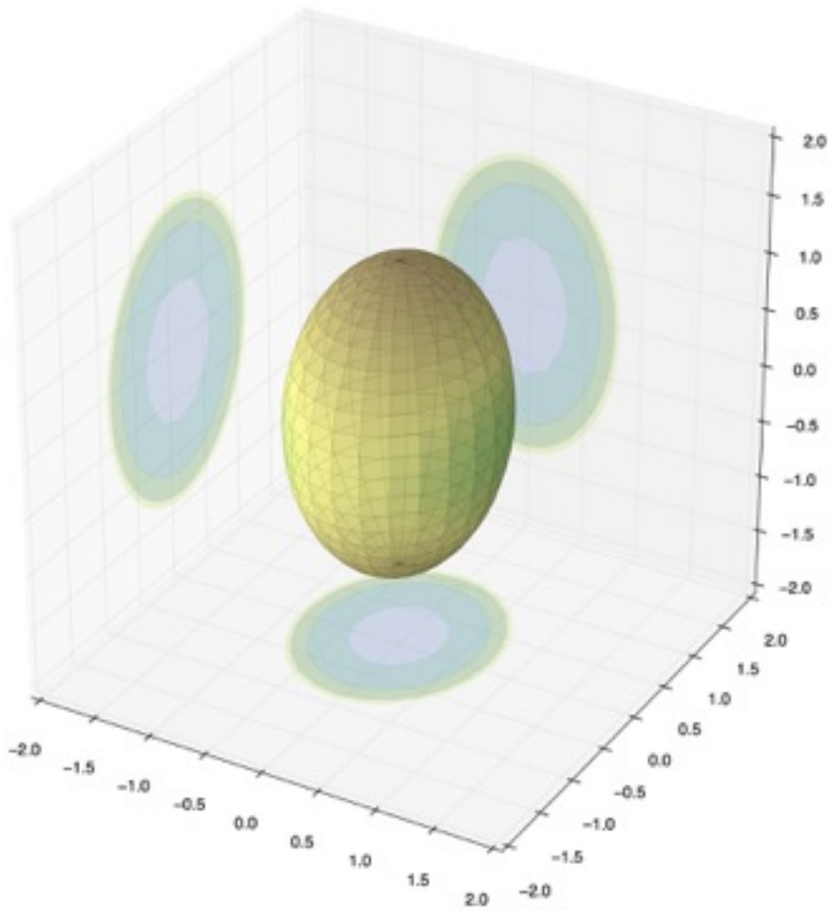
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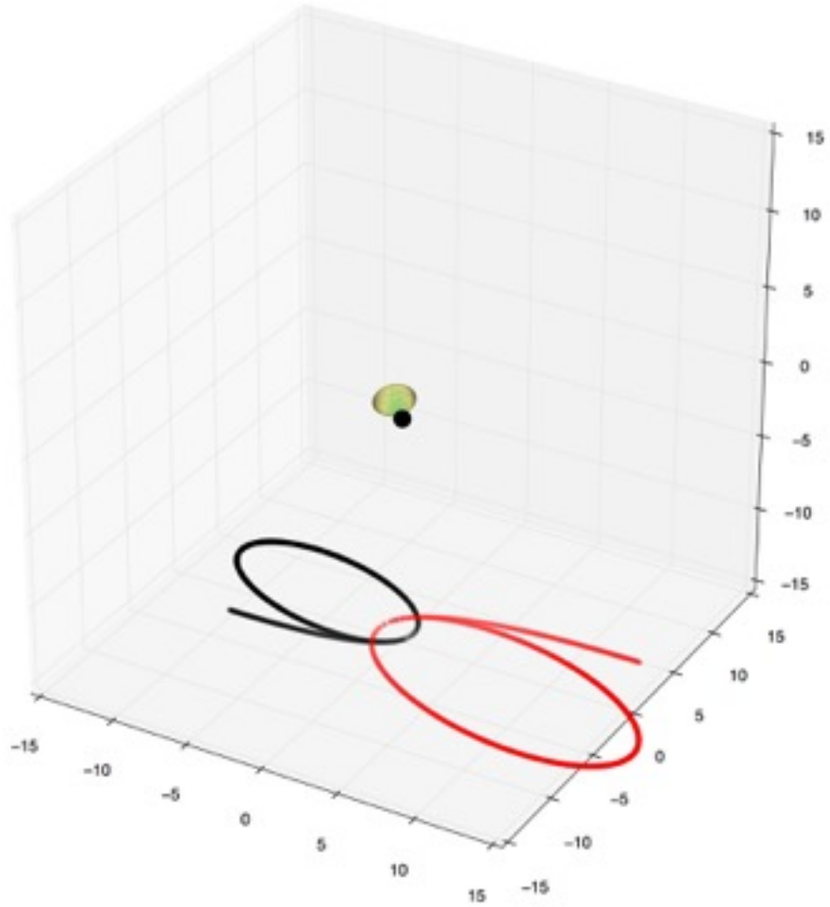
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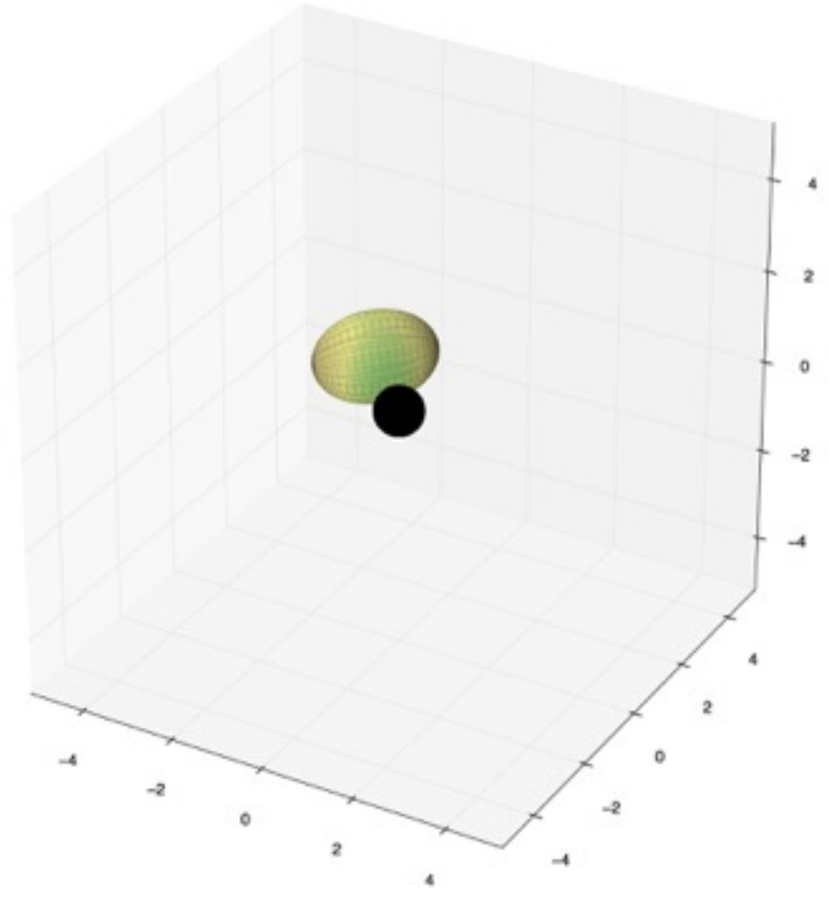
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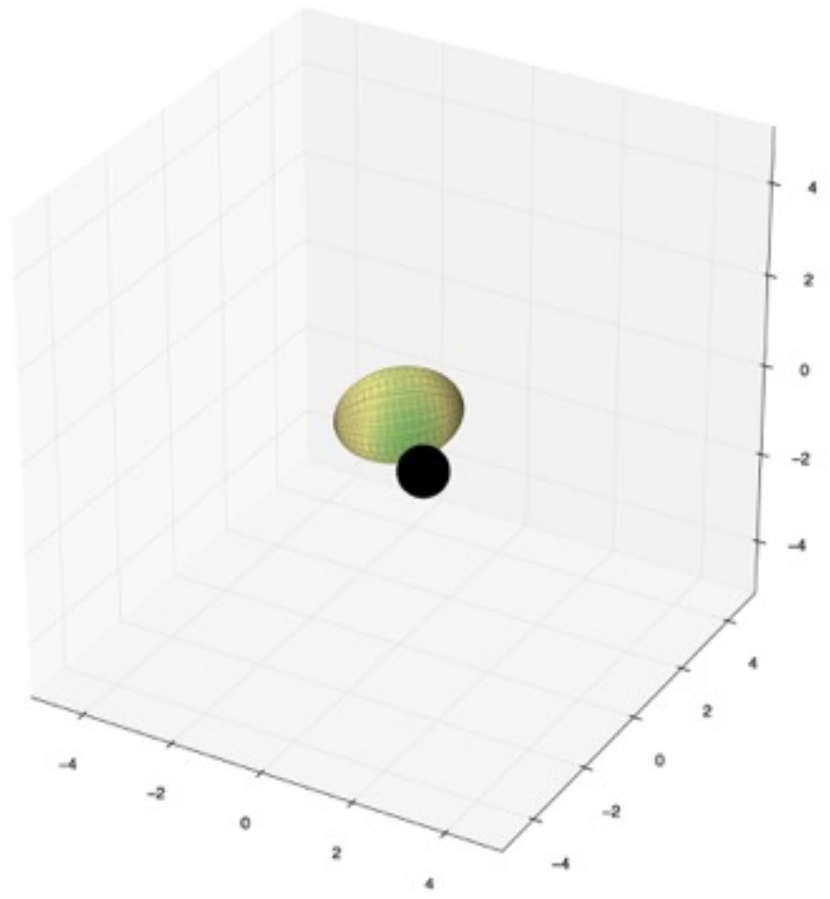
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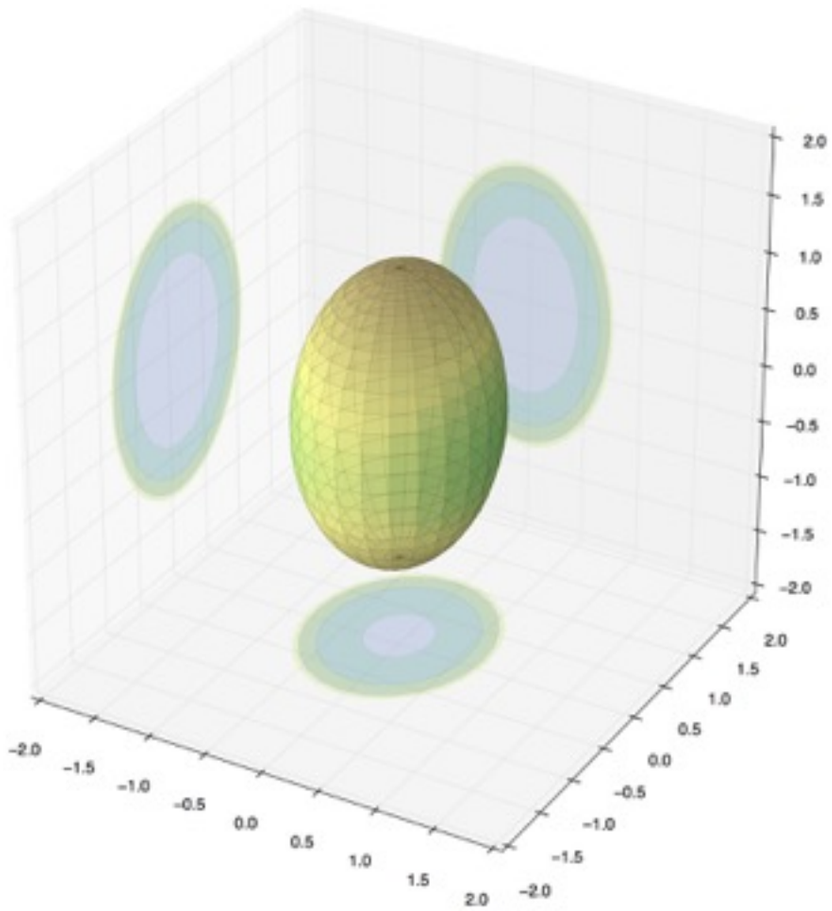
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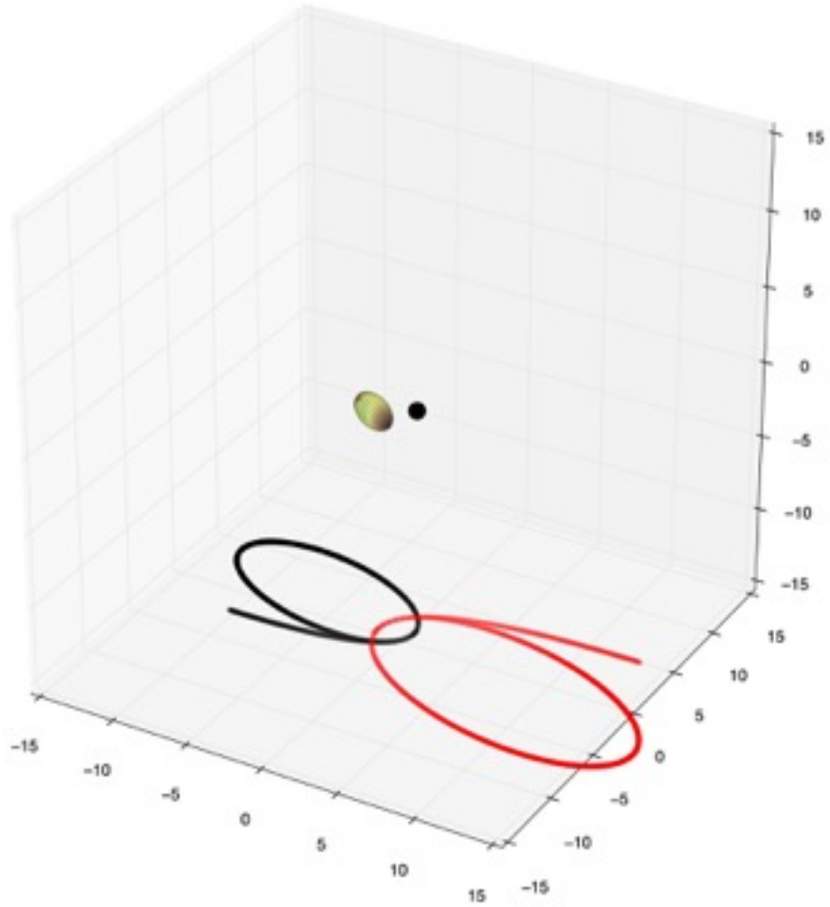
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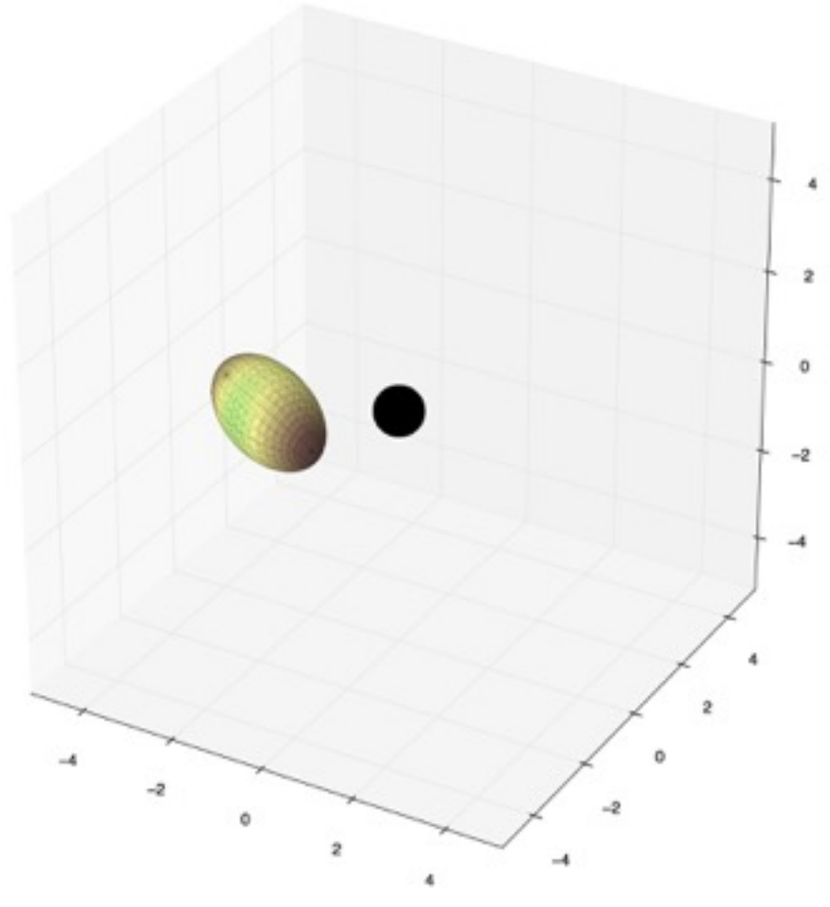
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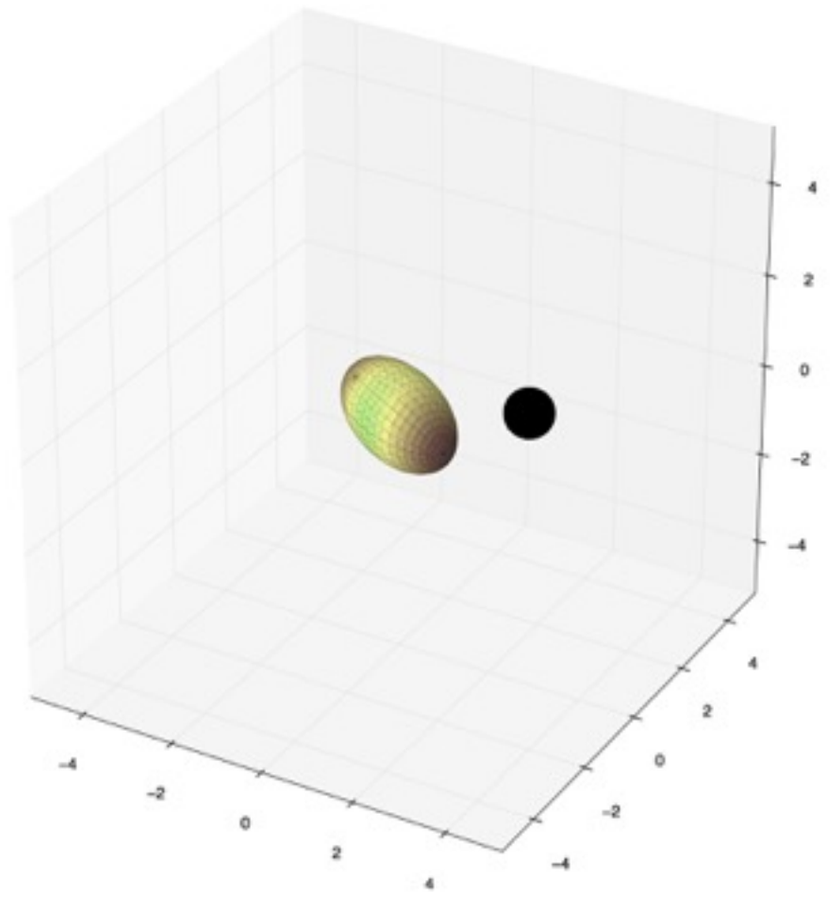
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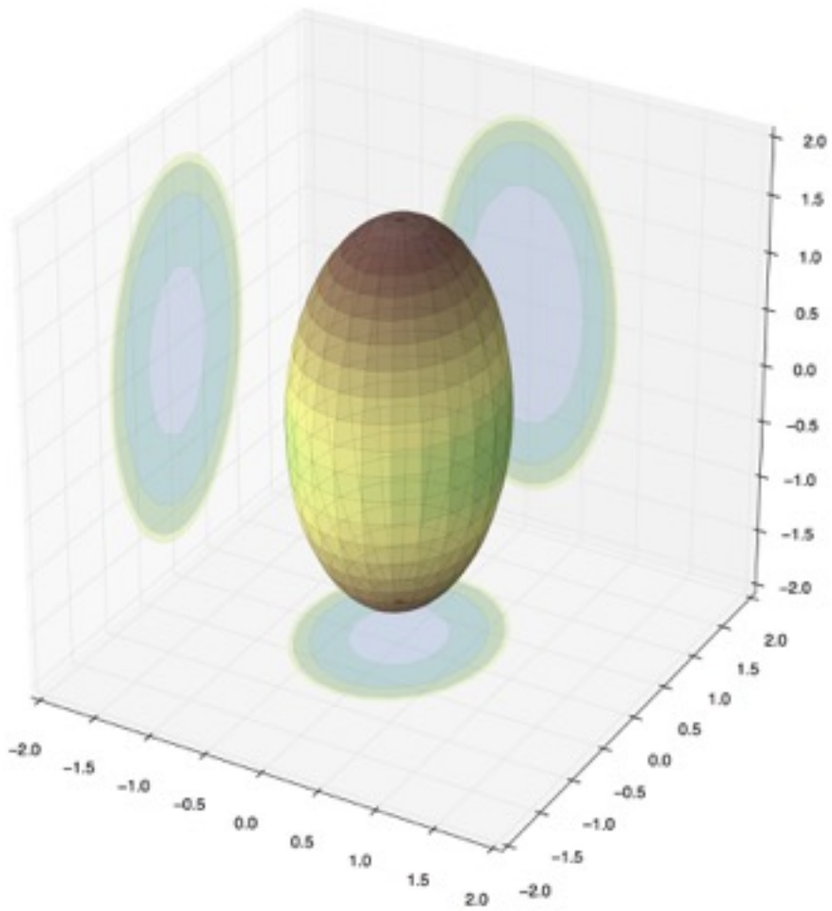
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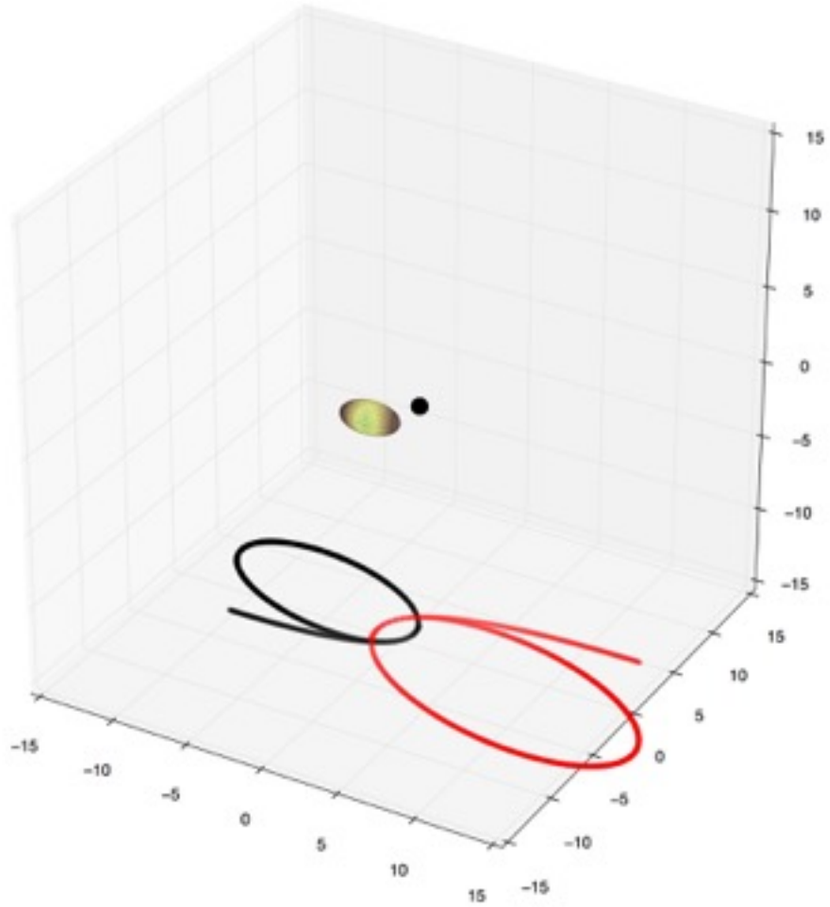
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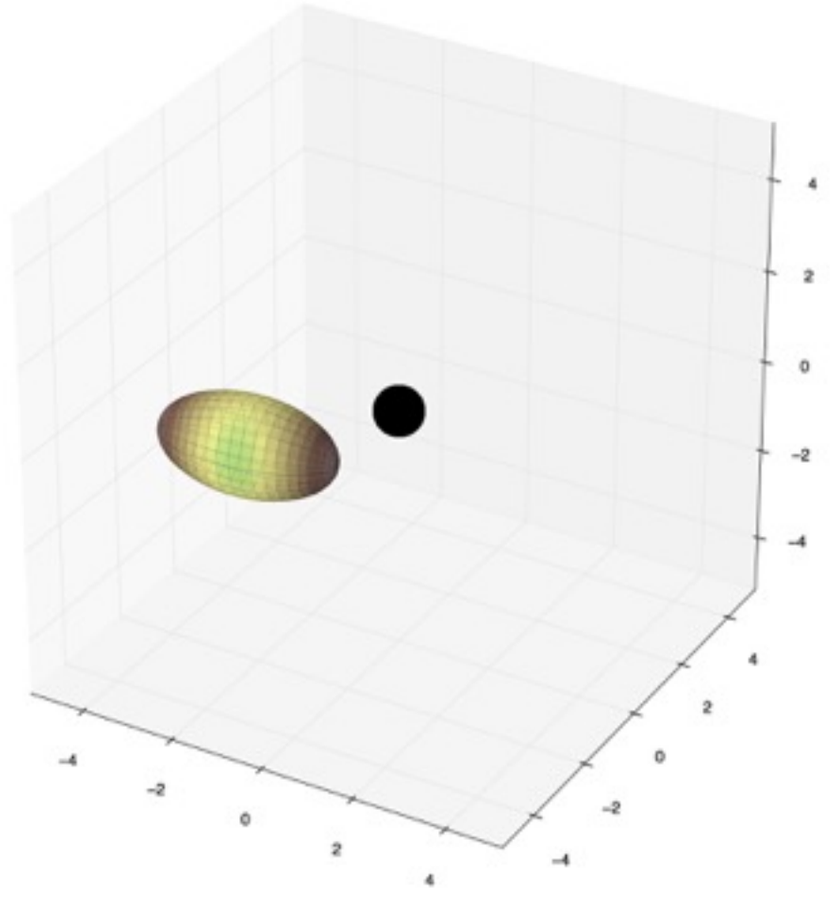
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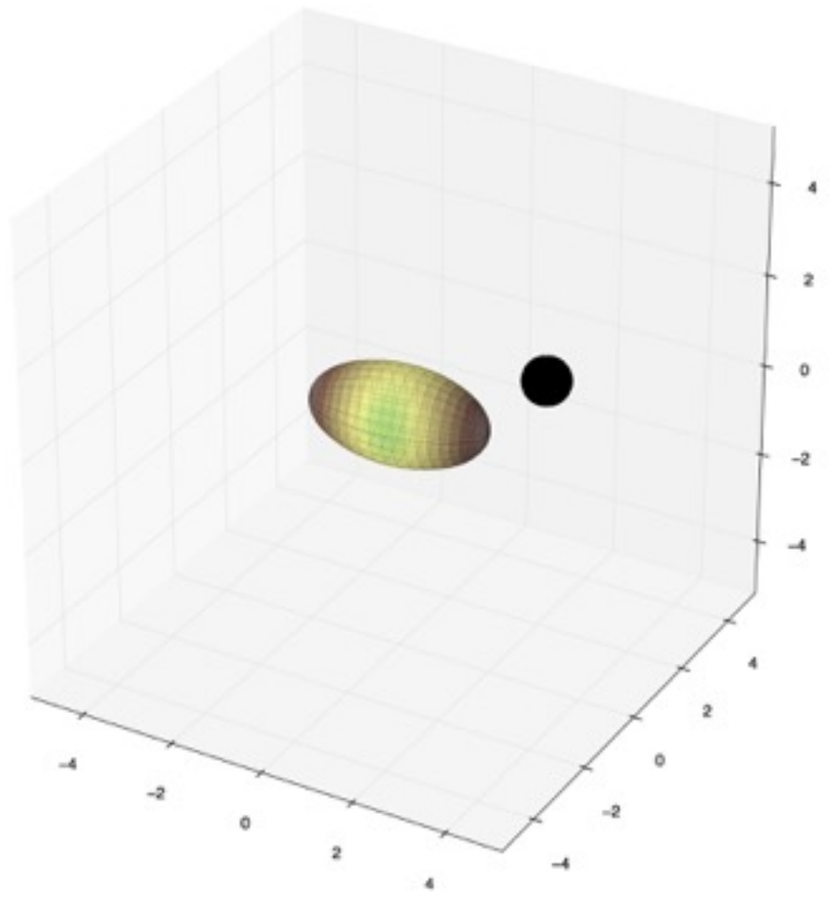
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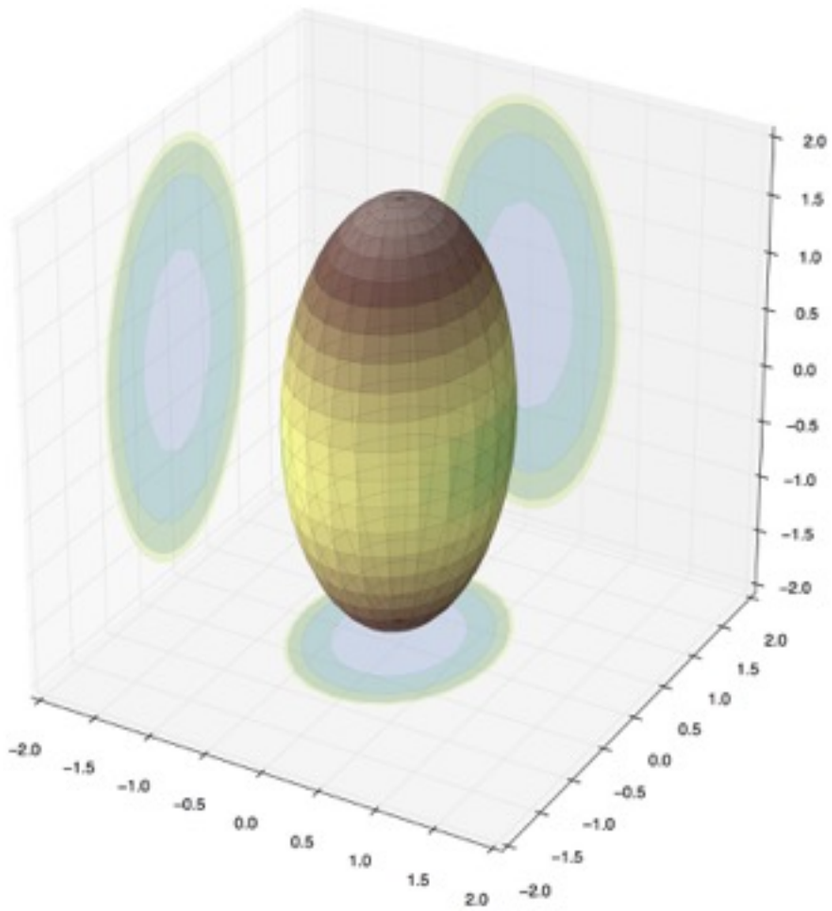
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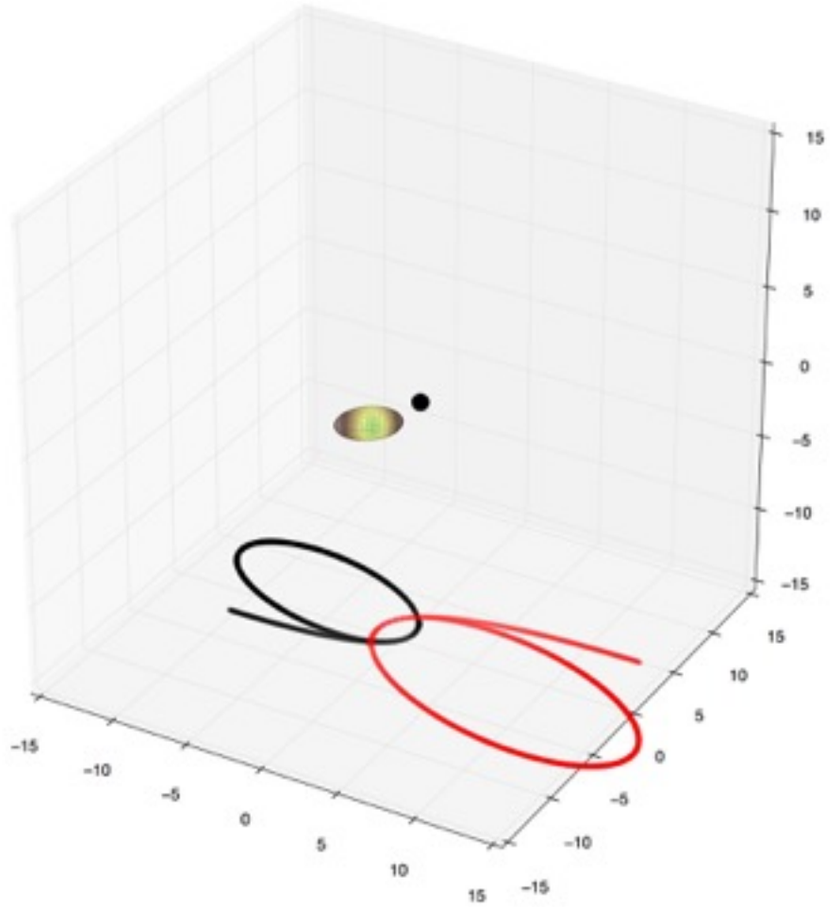
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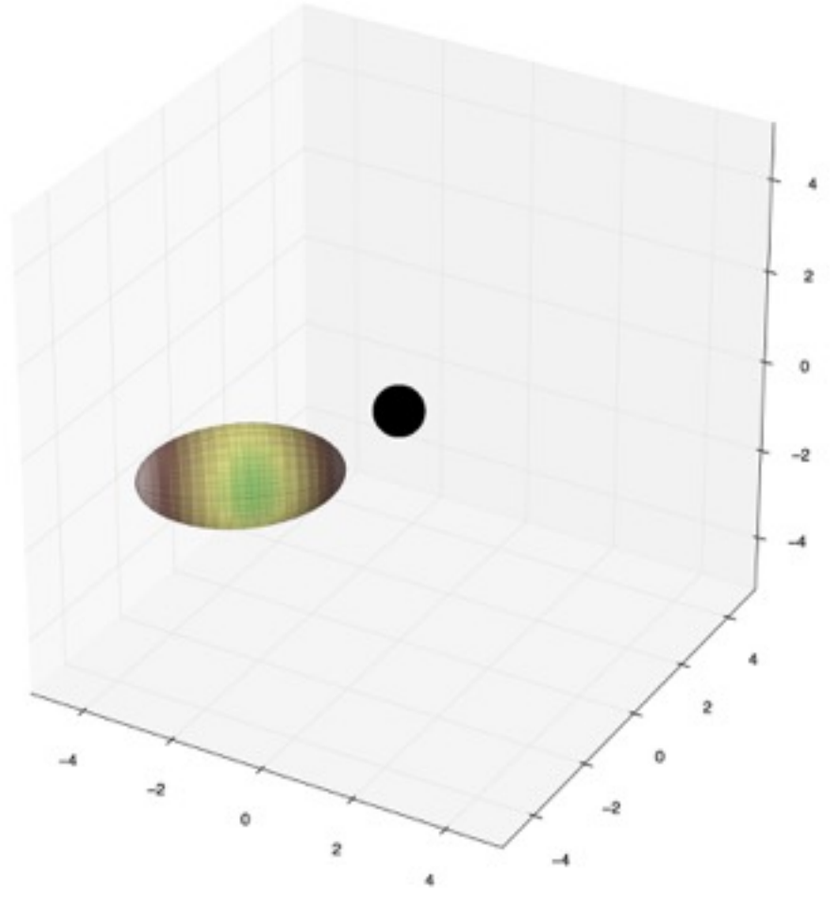
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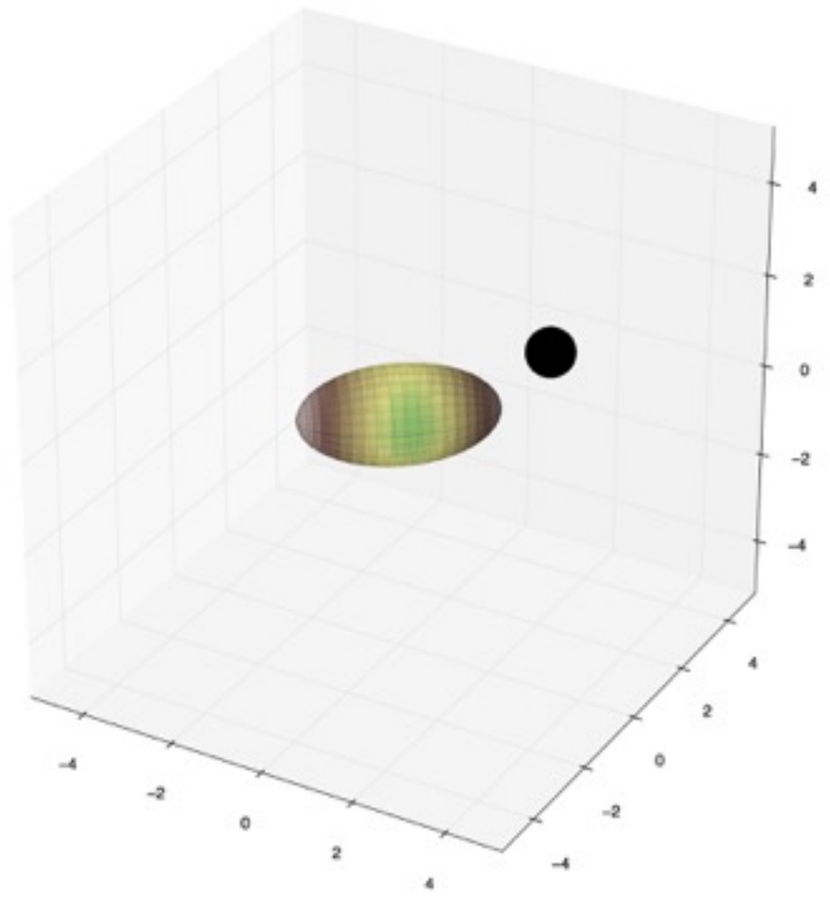
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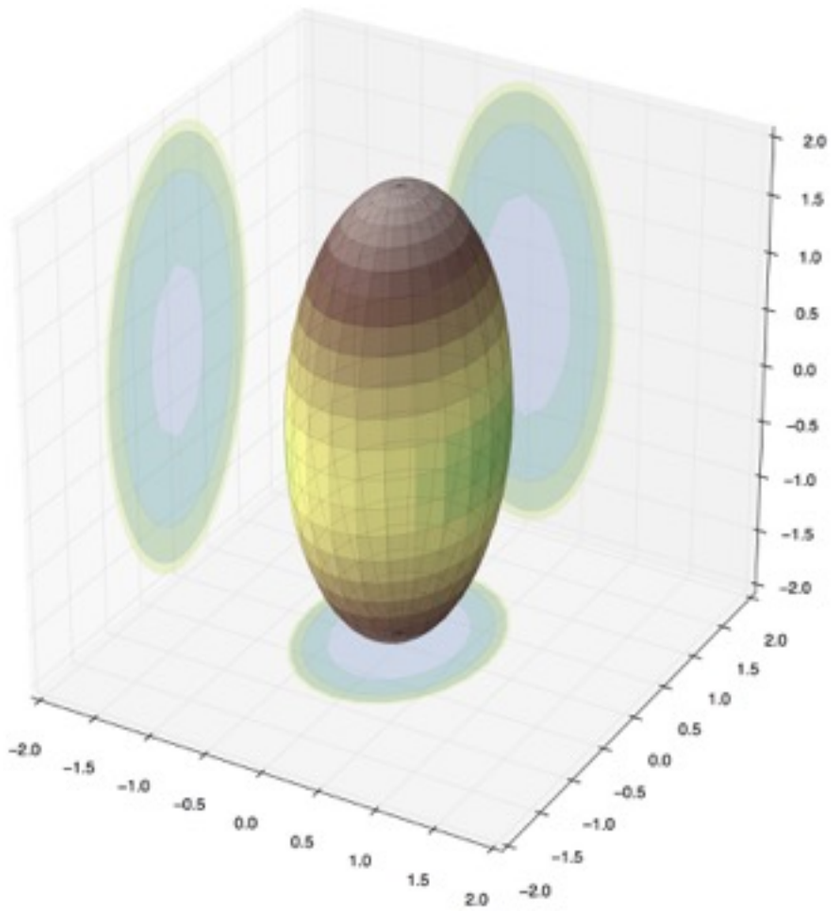
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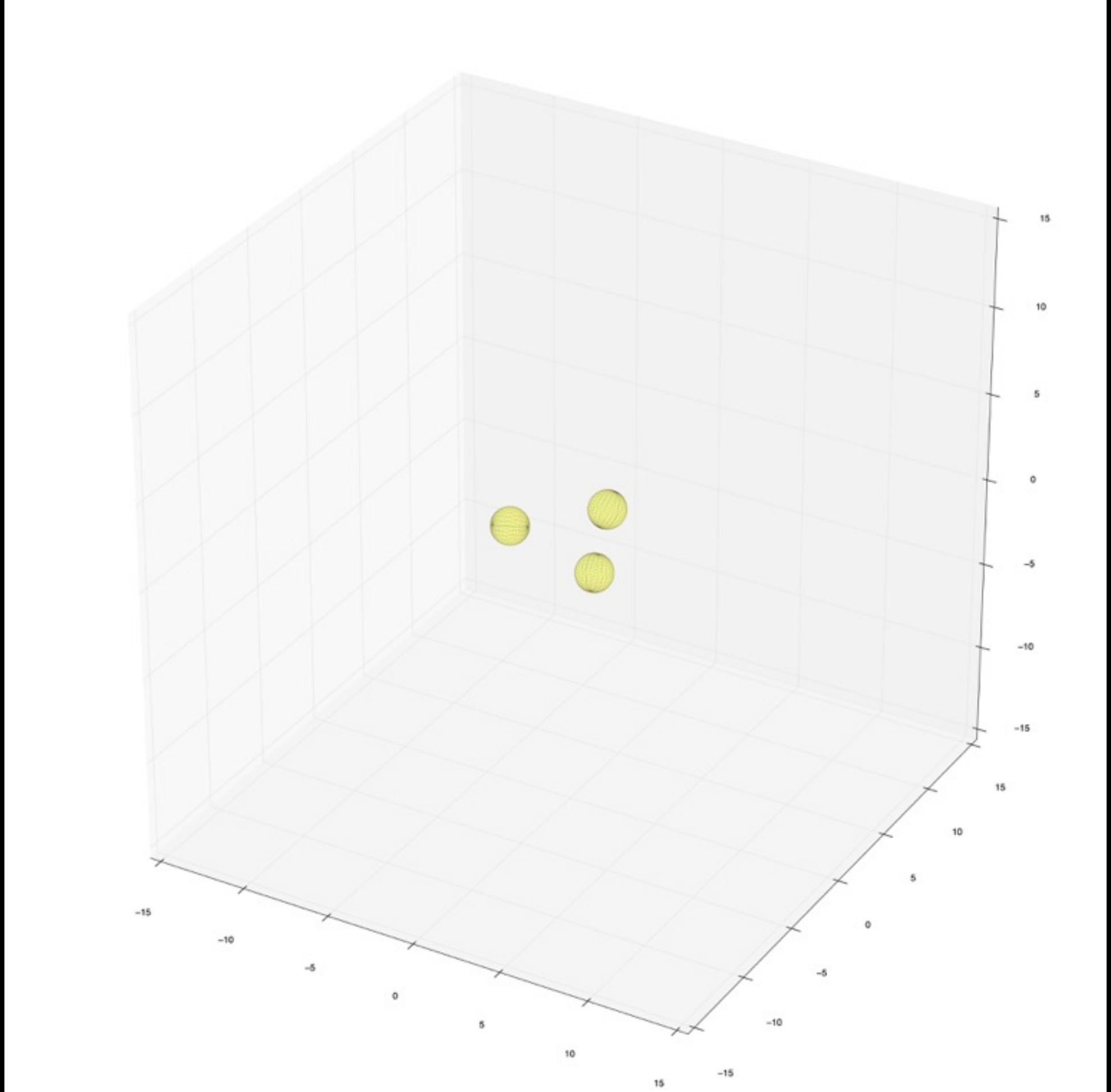
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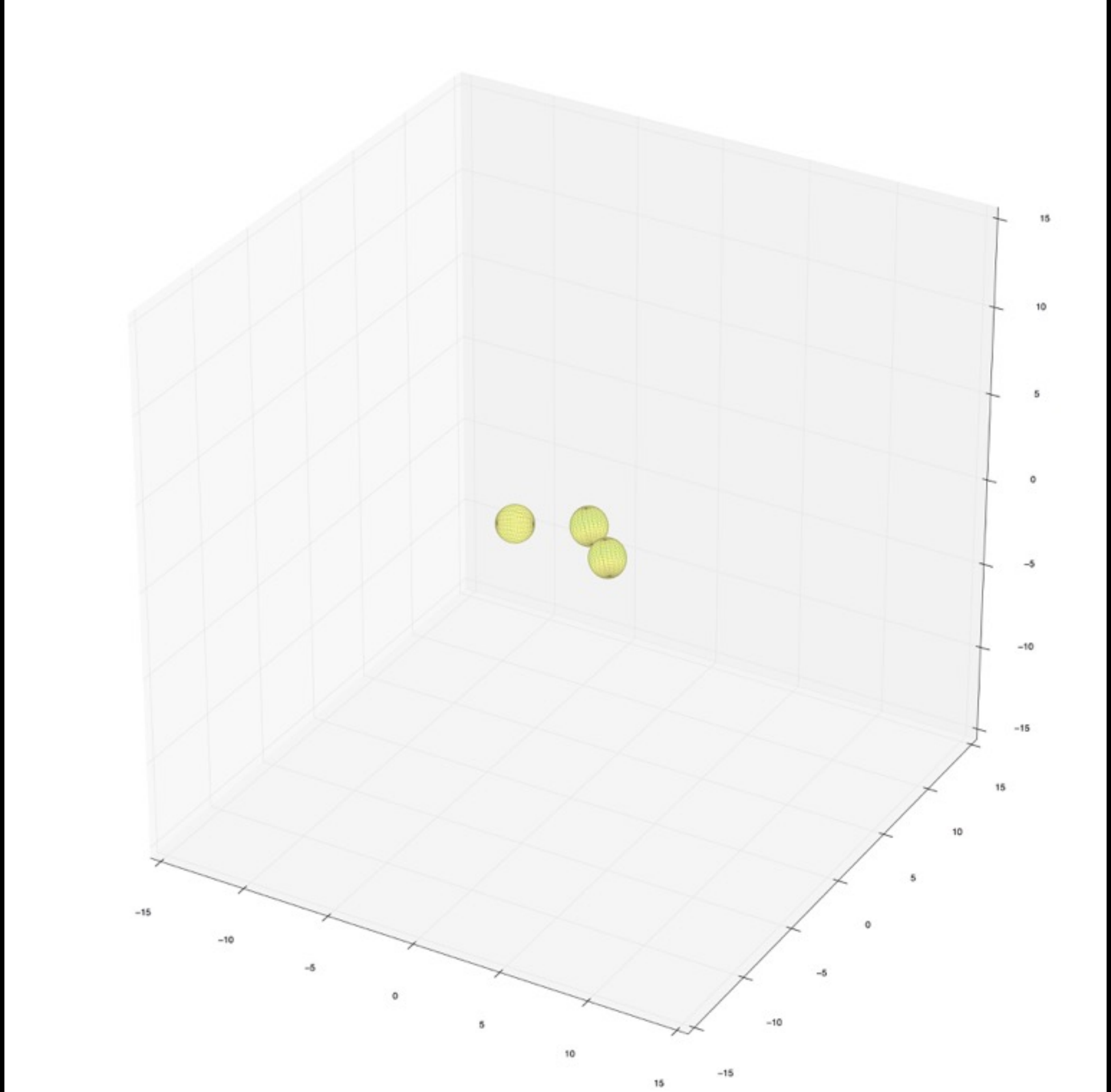
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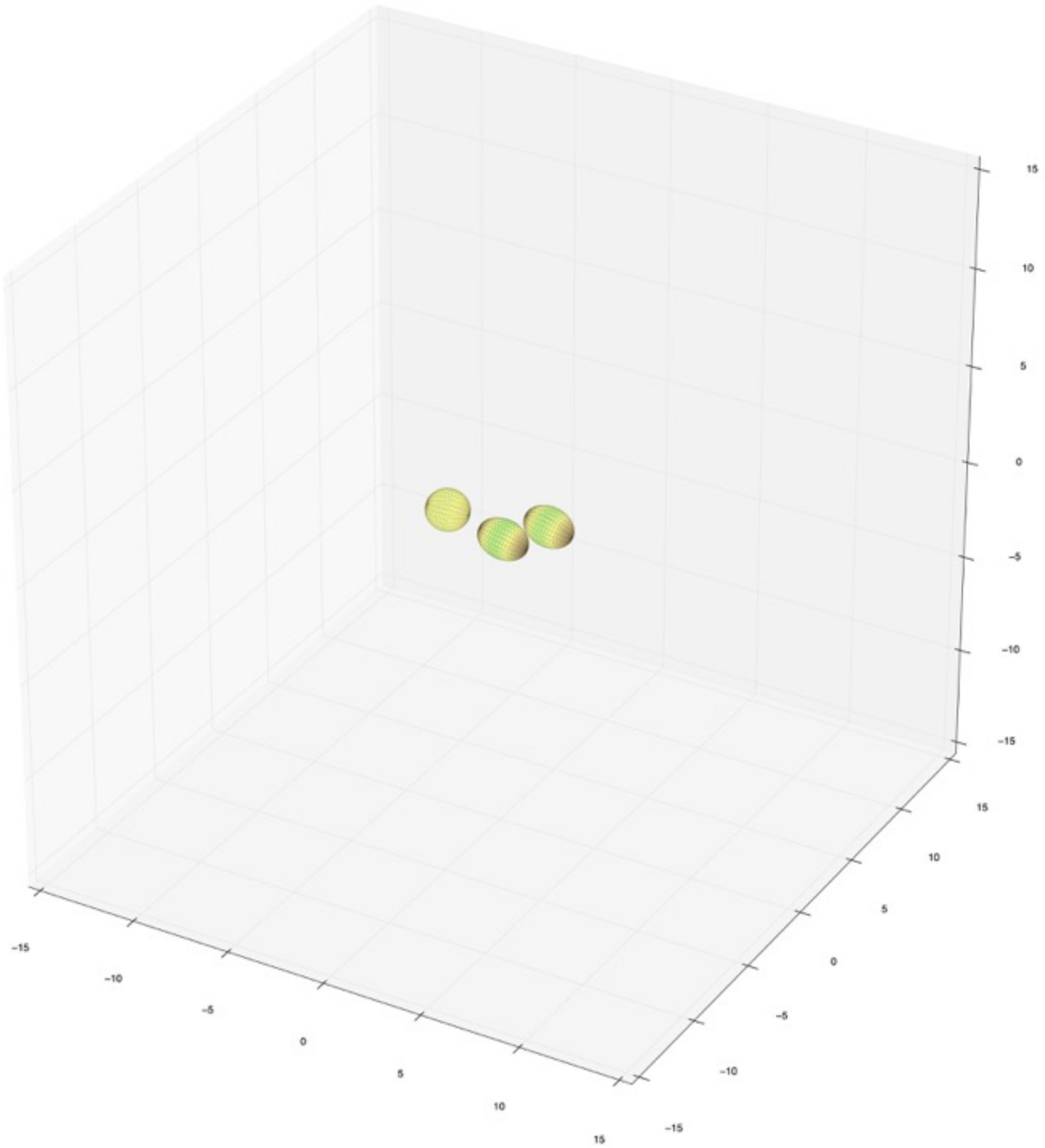
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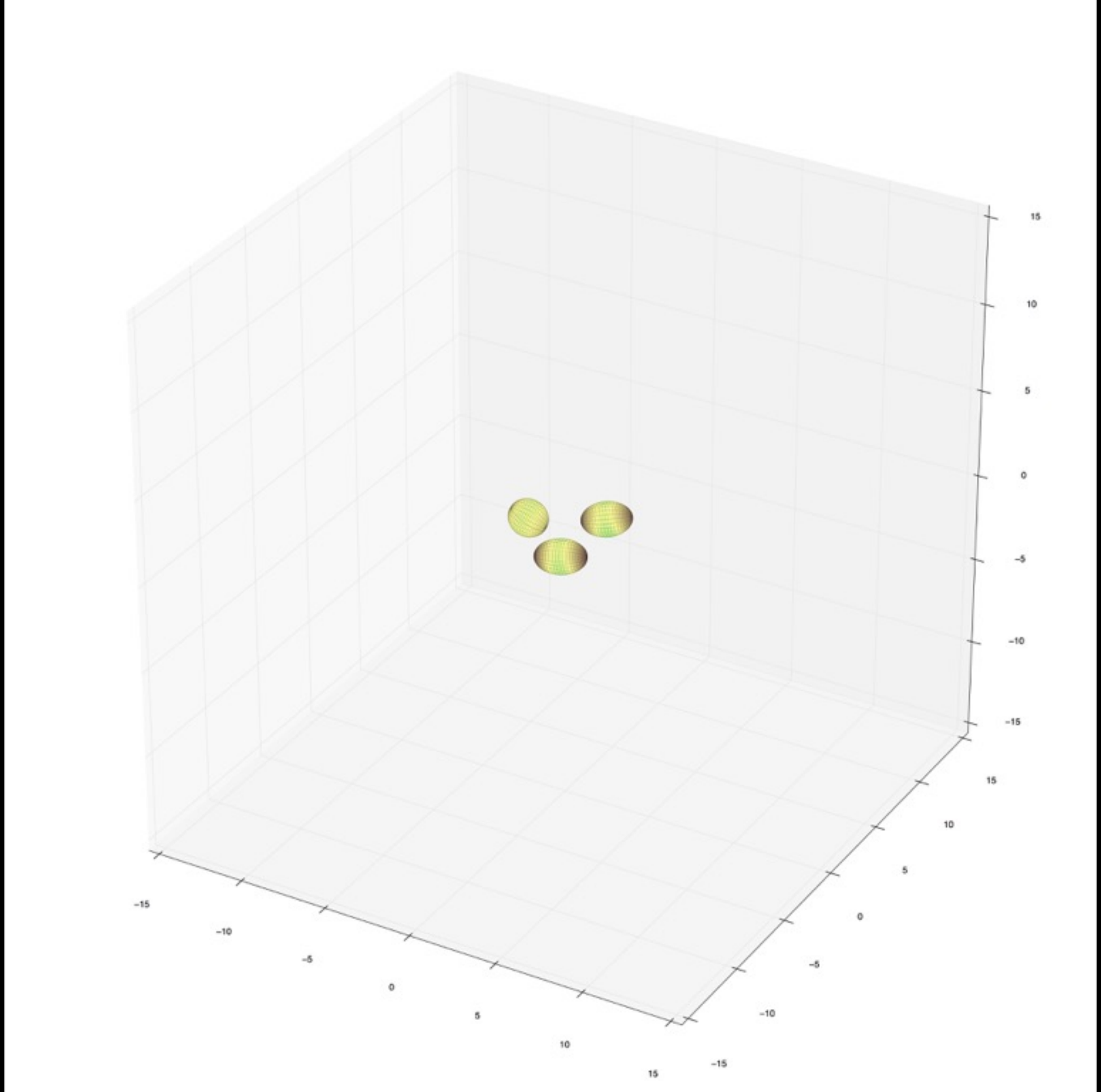
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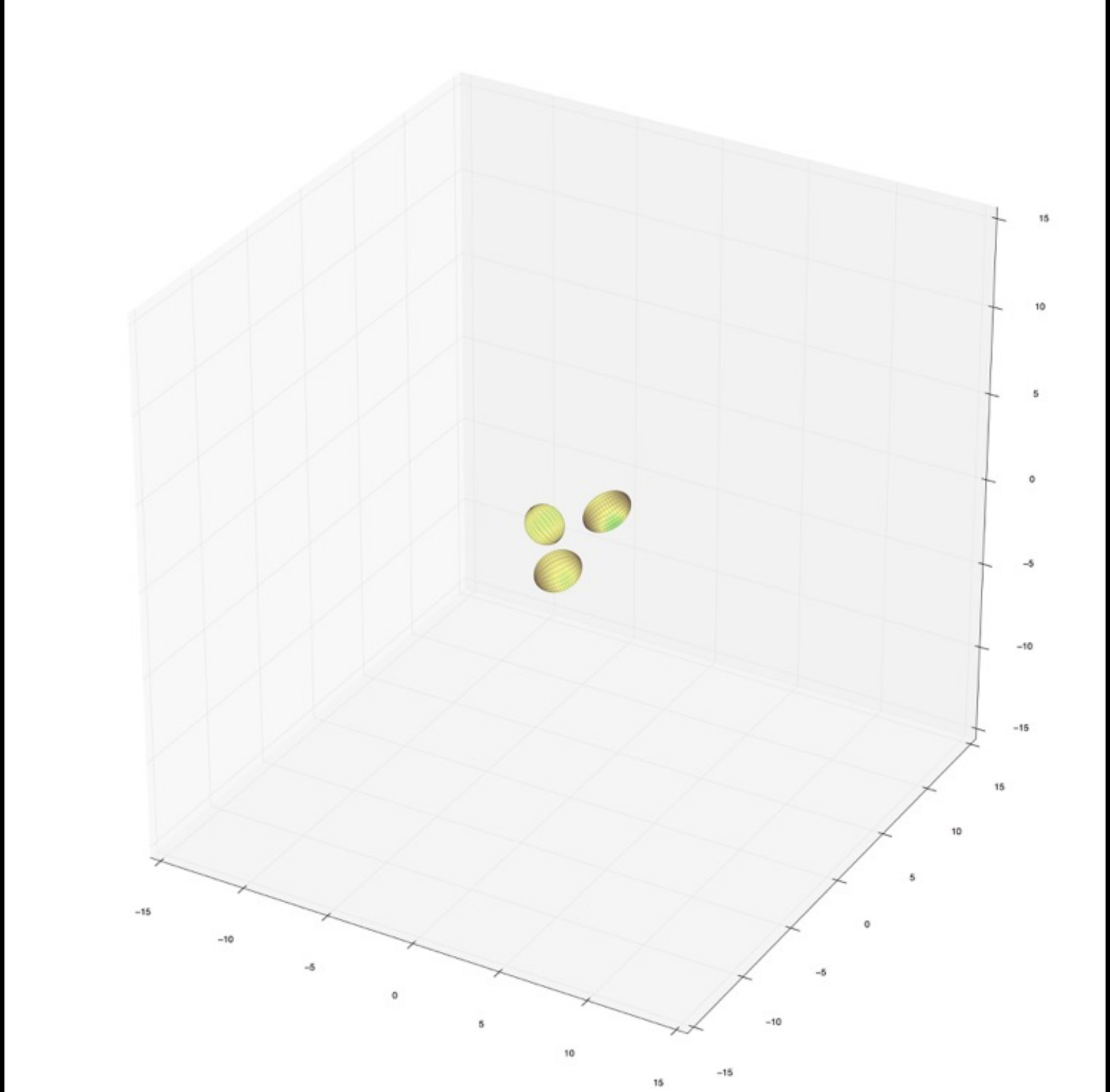
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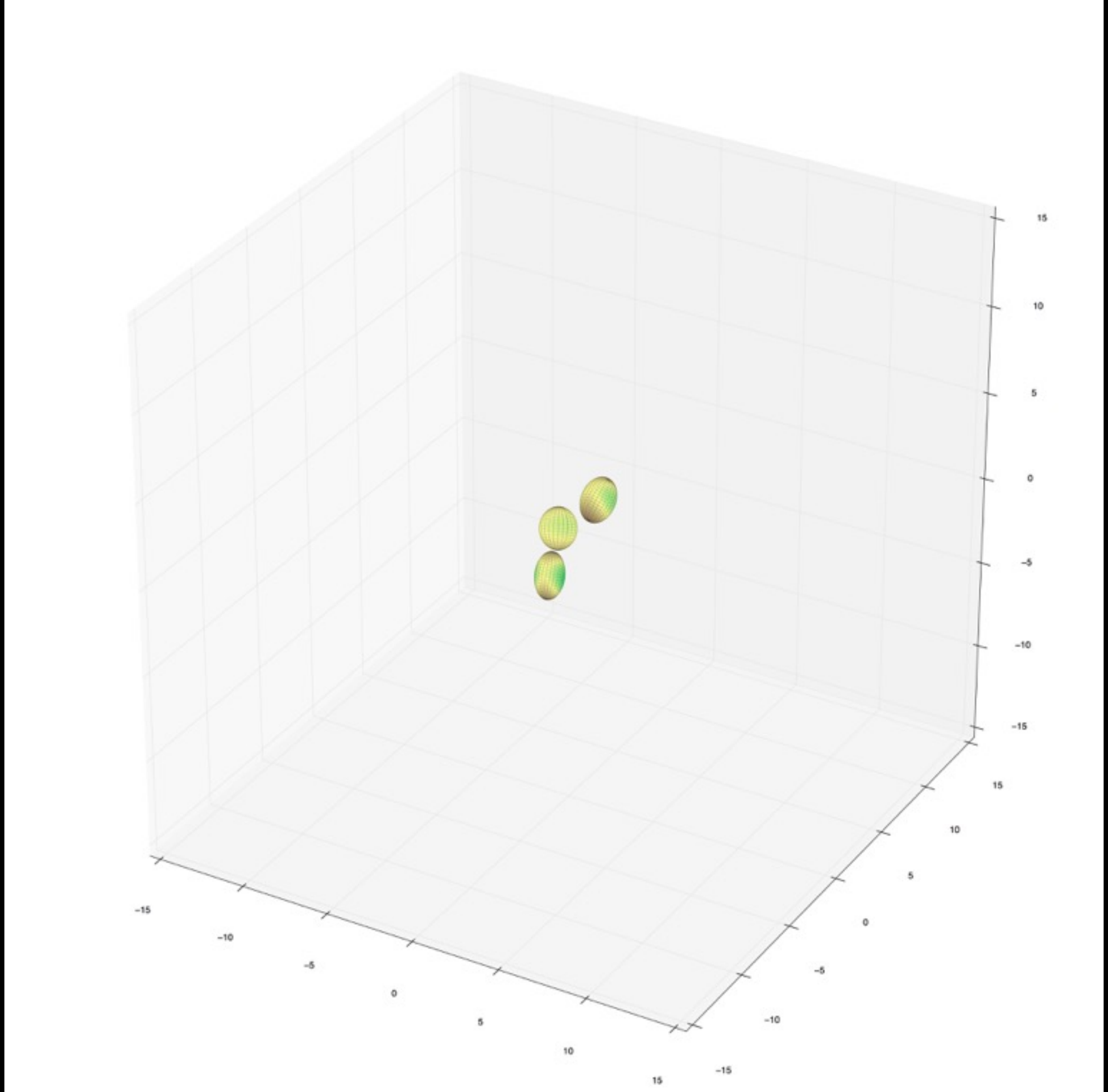
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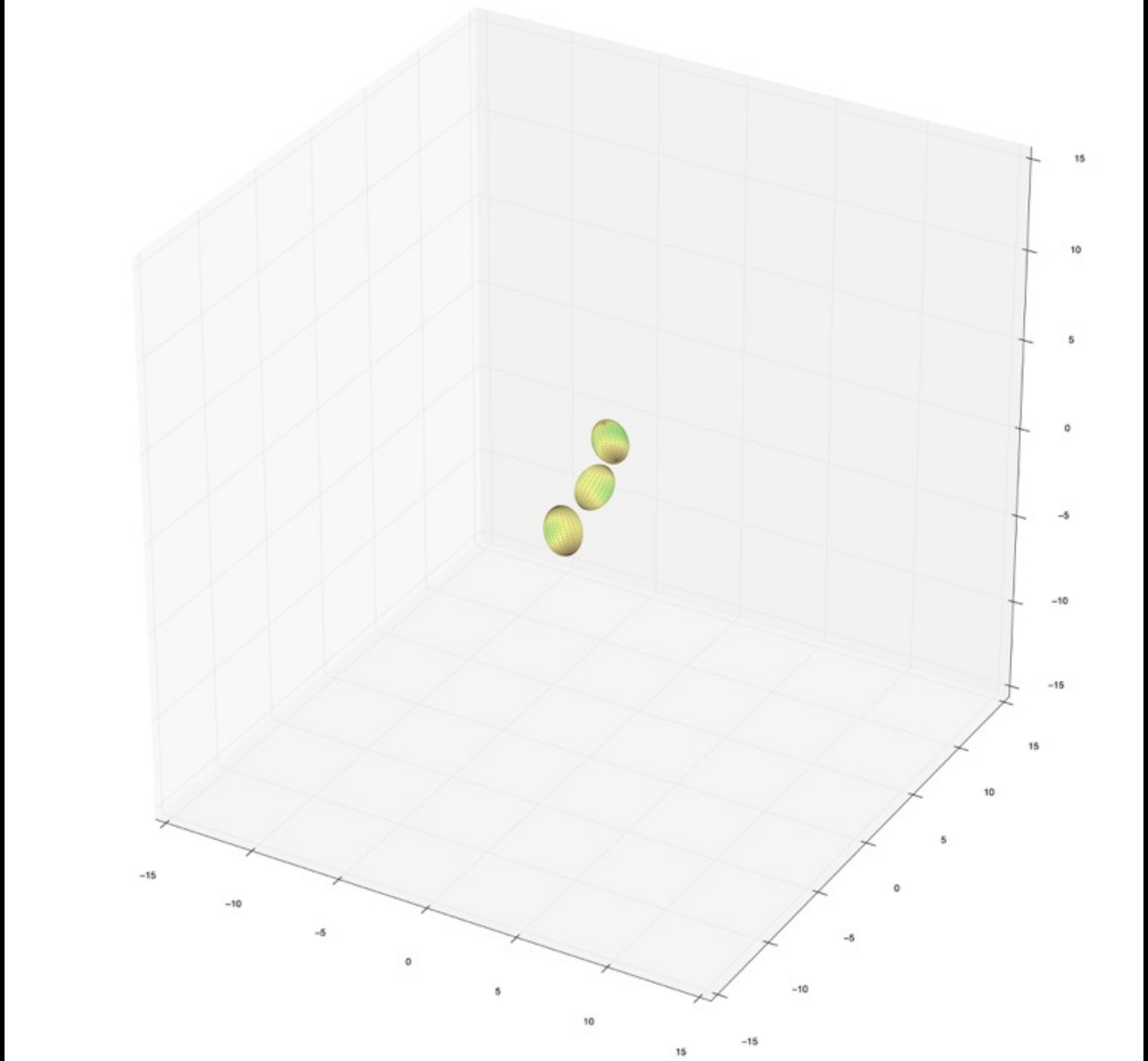
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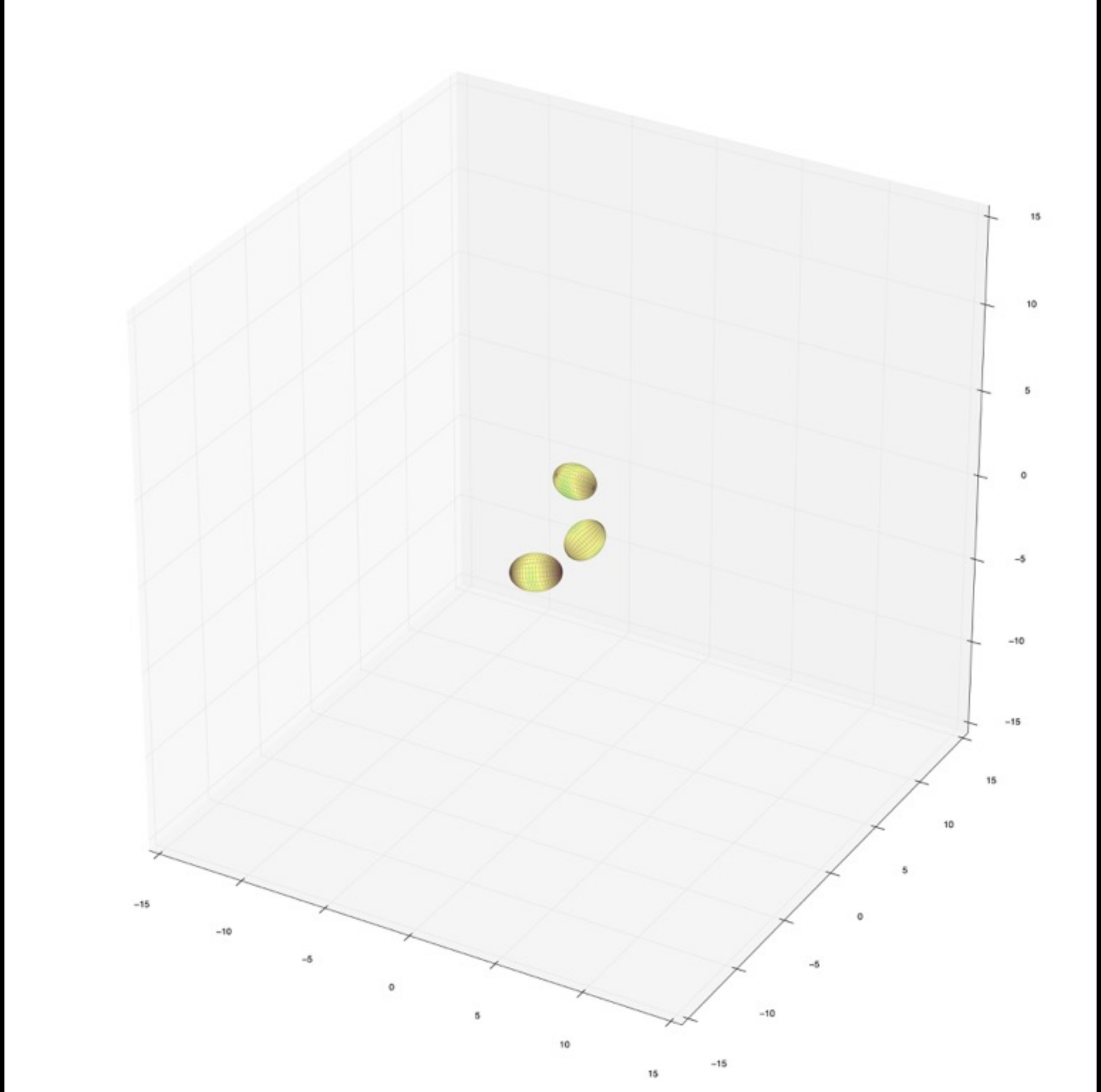
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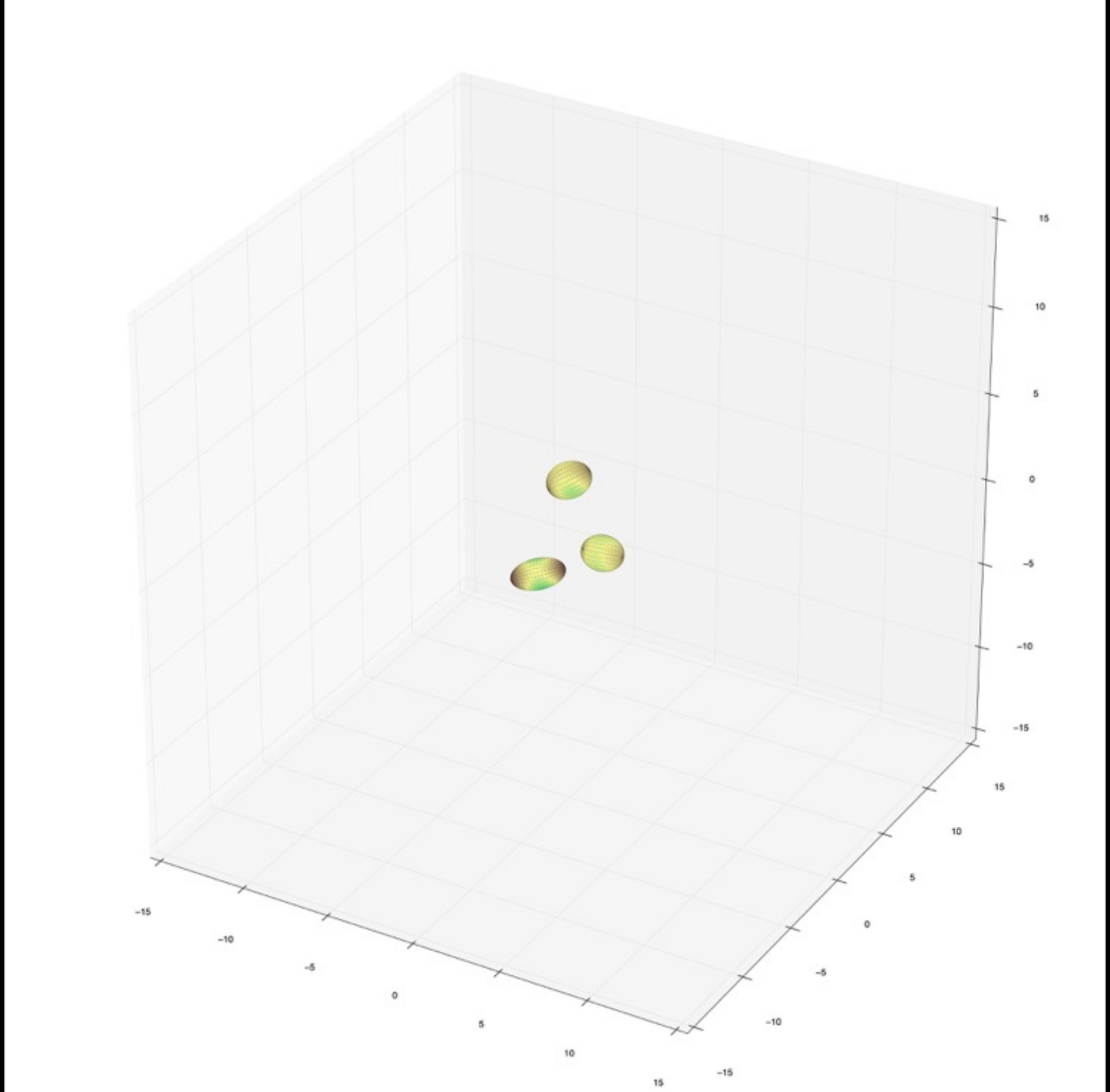
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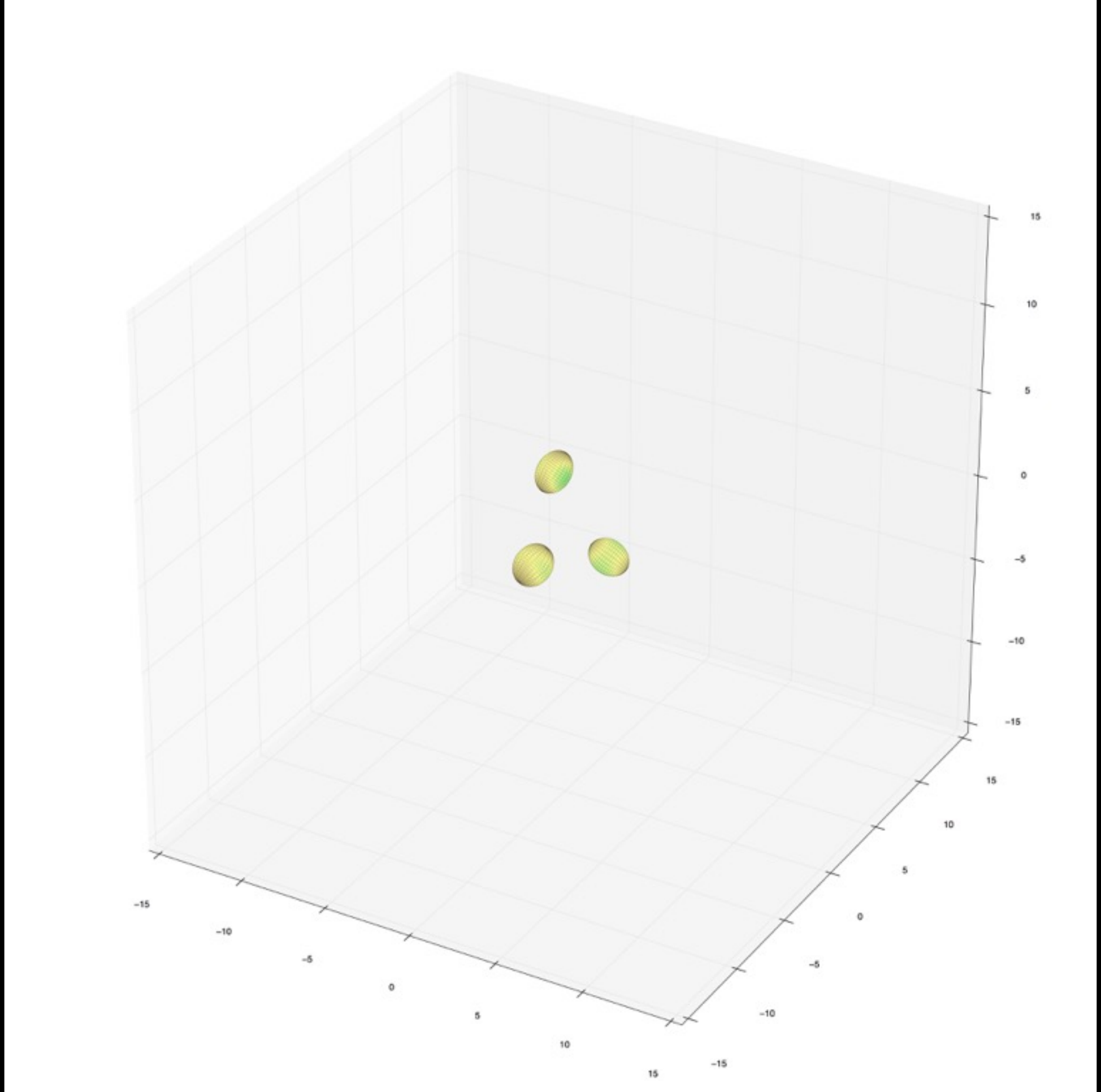
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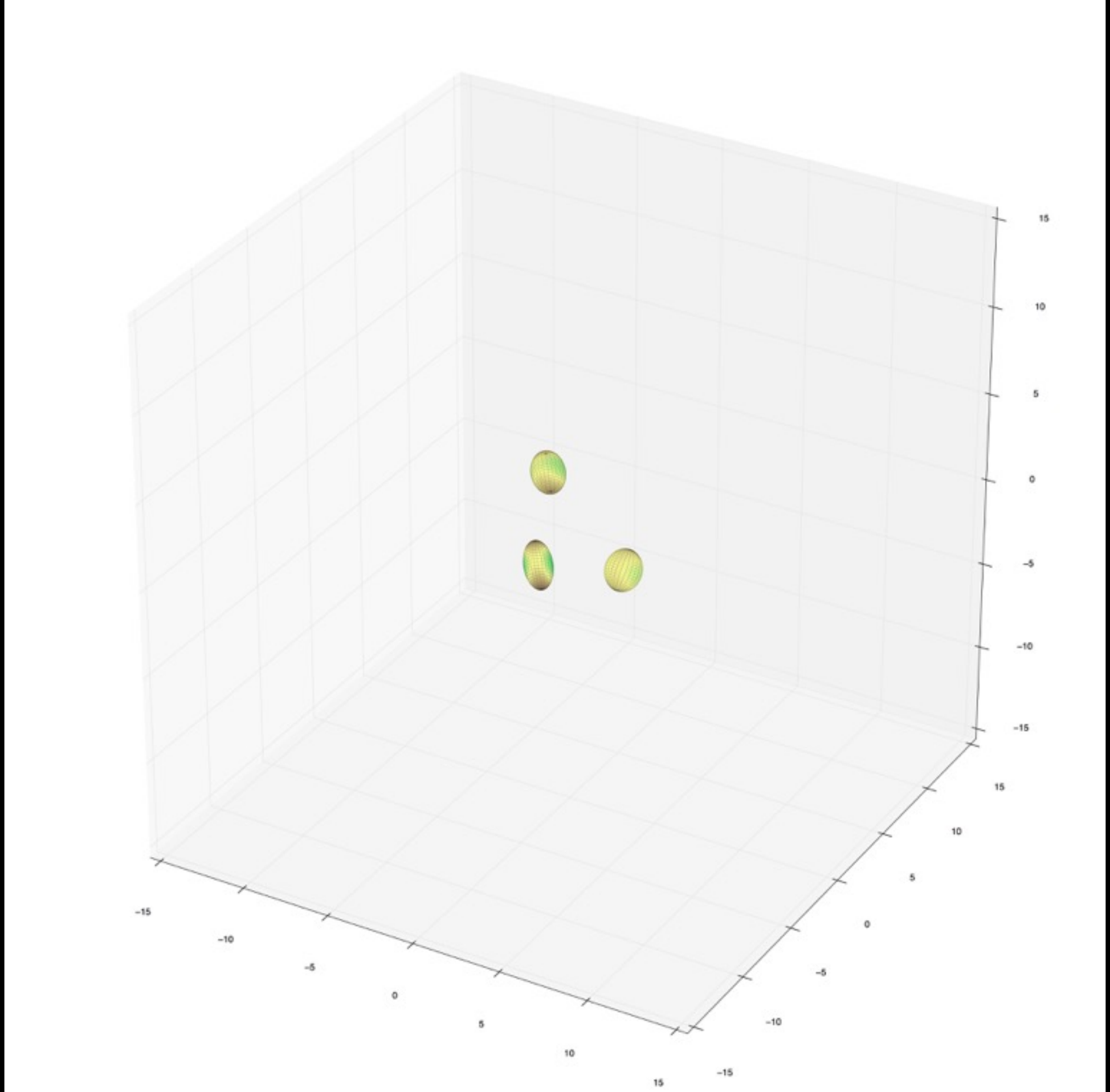
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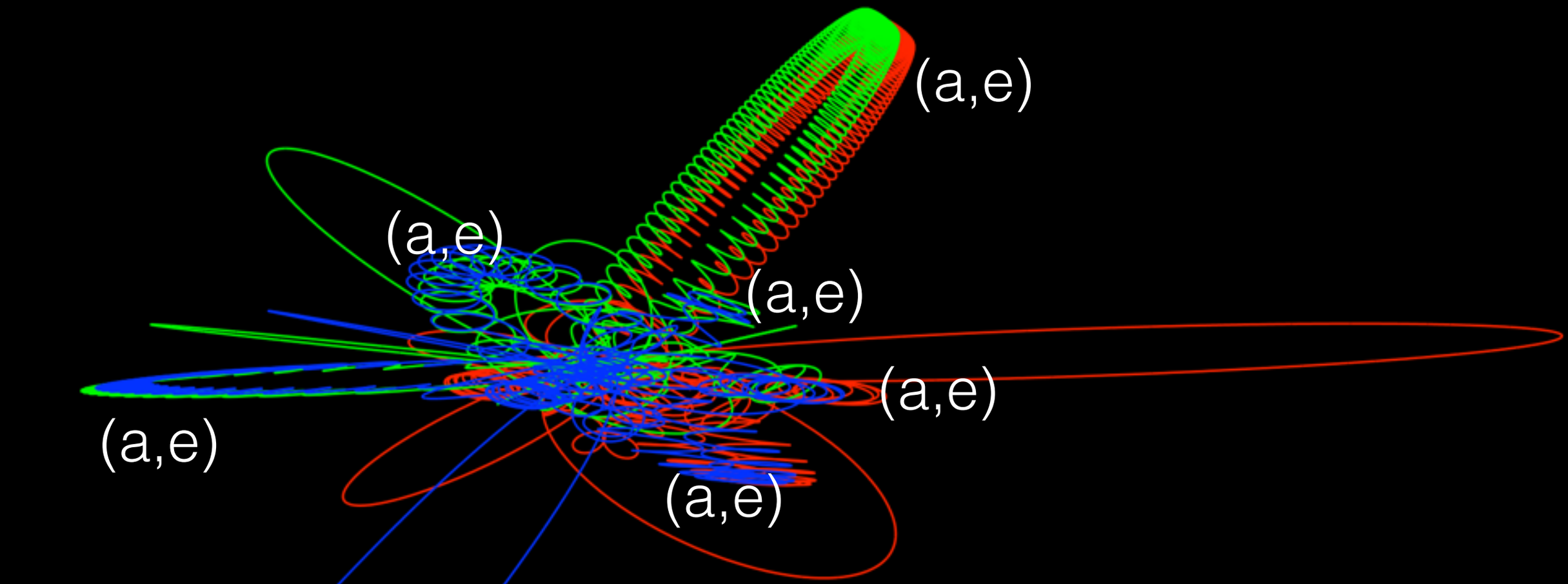
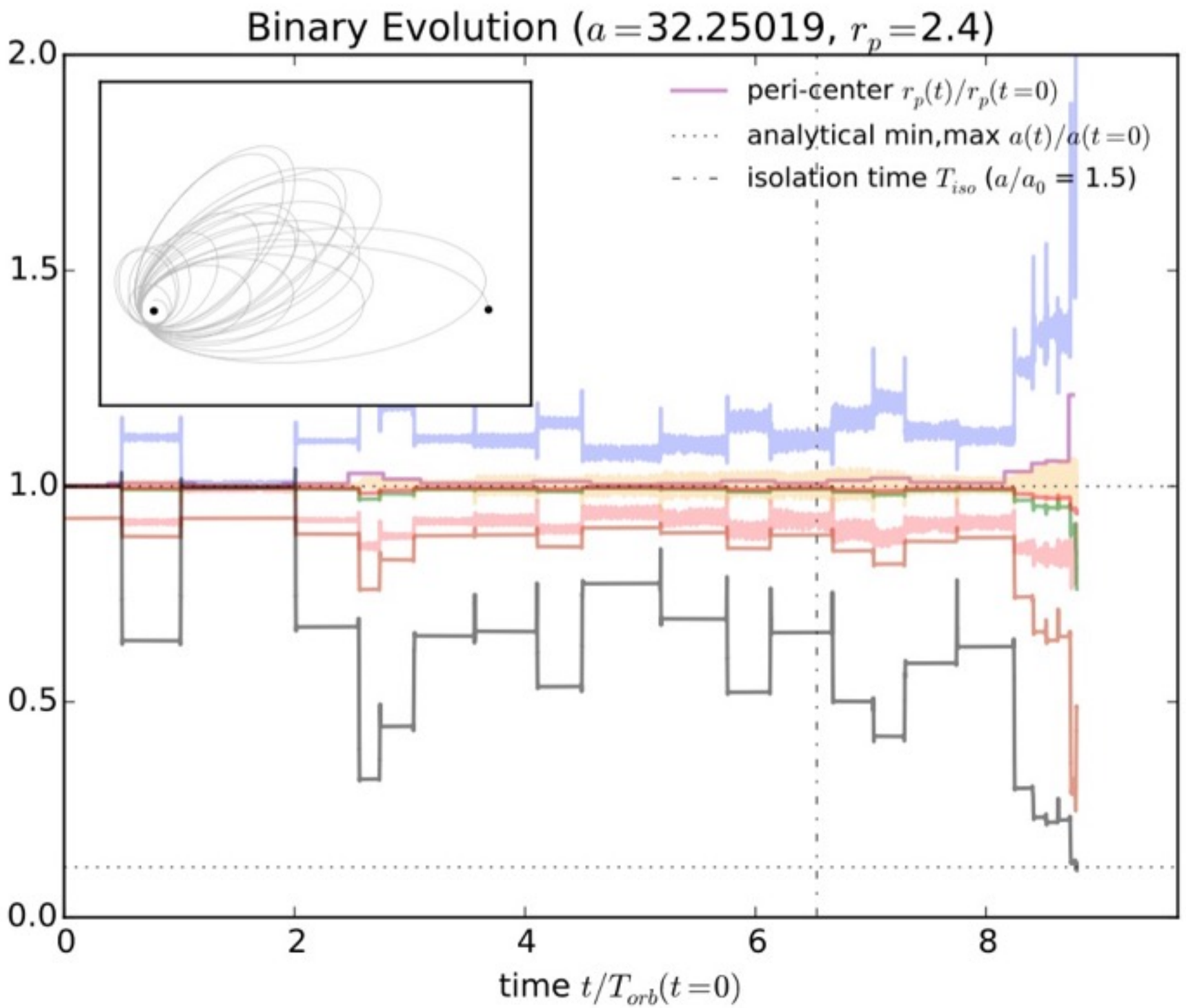
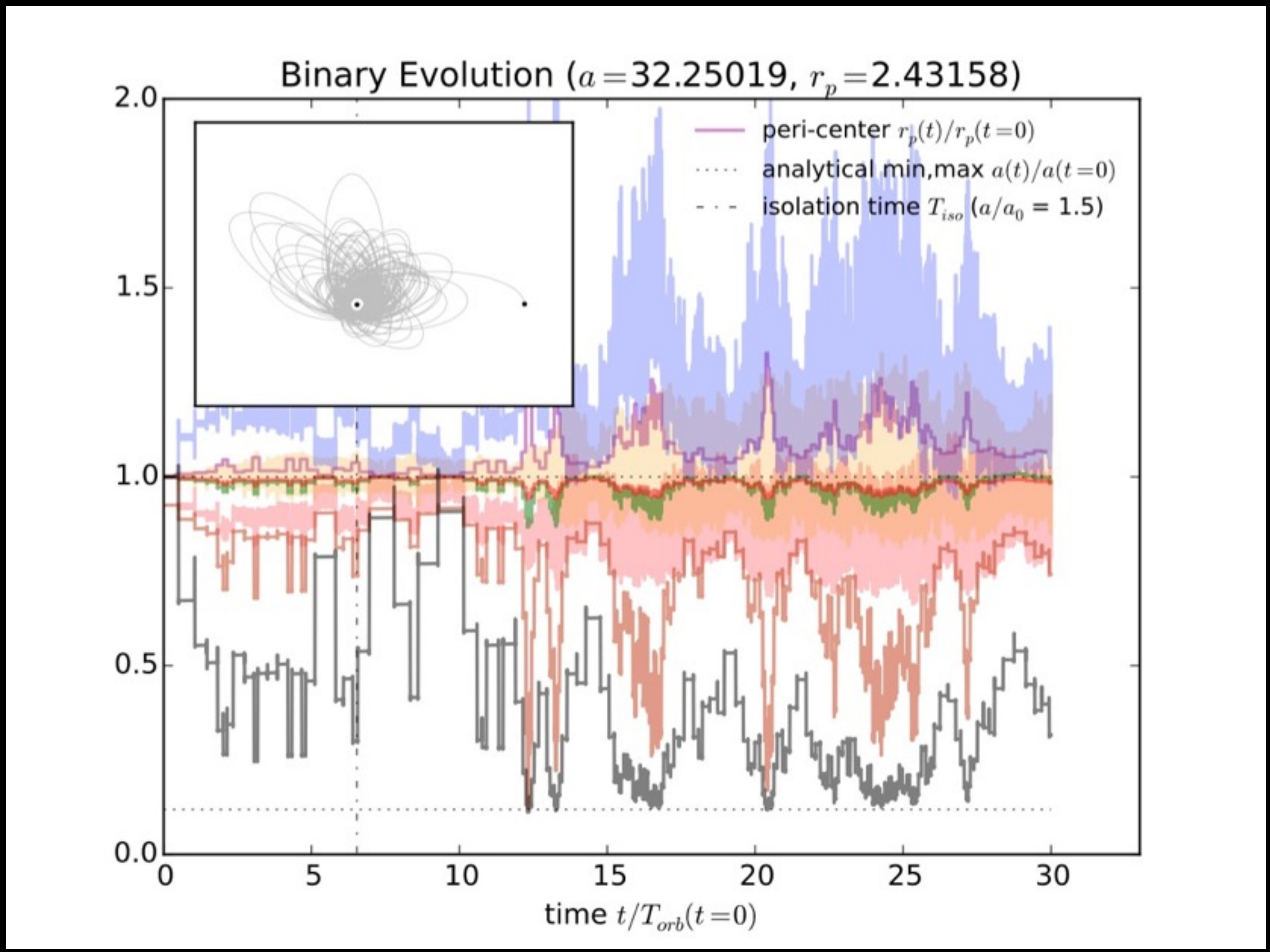
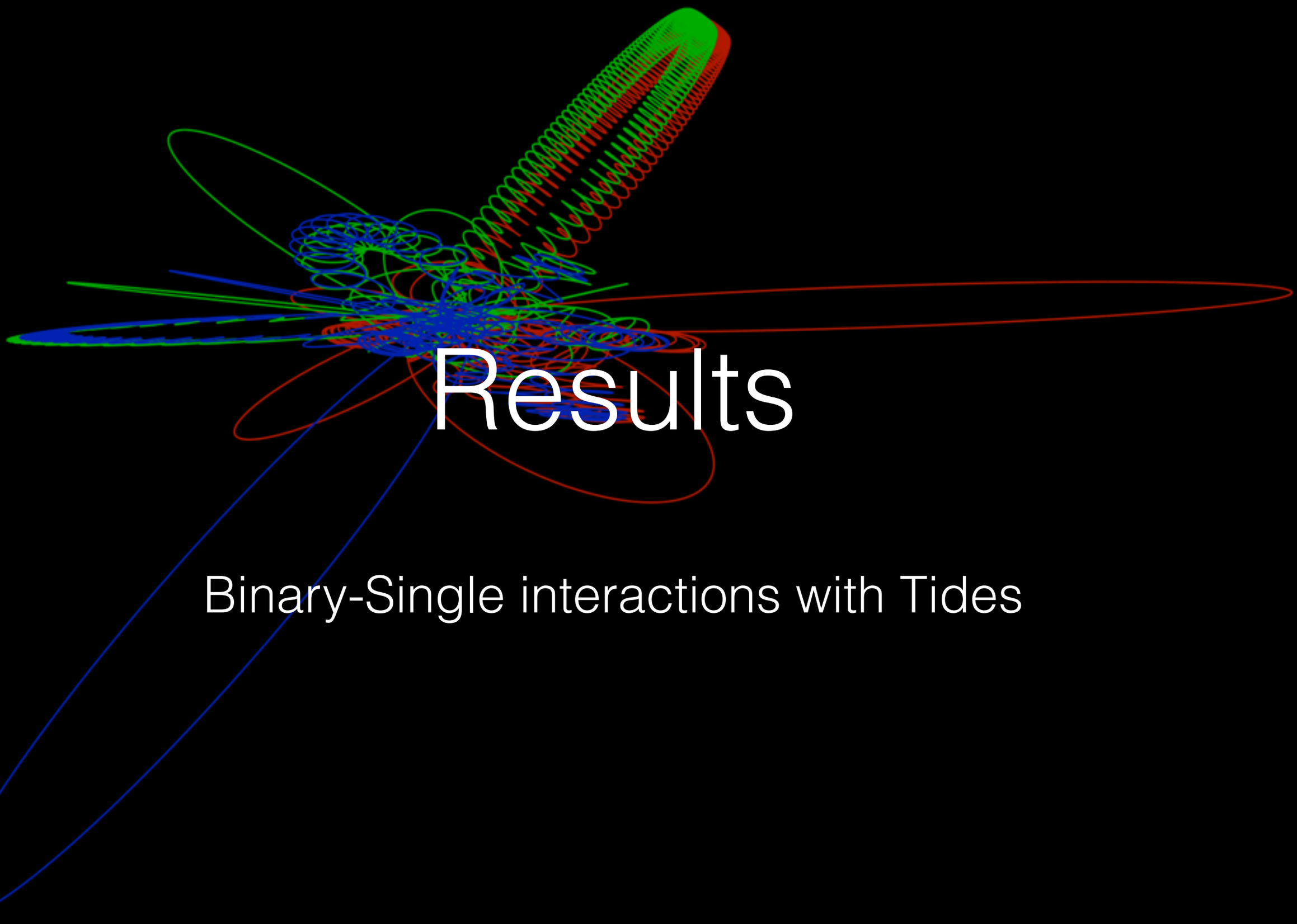


Chaotic interactions can be decomposed into a binary with a bound single

The key is therefore to understand the evolution of isolated binaries


Binary Evolution ($a=32.25019$, $r_p=2.4$)
peri-center $r_p(t)/r_p(t=0)$
analytical min,max $a(t)/a(t=0)$
isolation time T_{iso} (a/a_0 = 1.5)
2.0
1.5
1.0
0.5
0.0
0
2
4
6
8
time $t/T_{orb}(t=0)$


Binary Evolution ($a=32.25019$, $r_p=2.43158$)
peri-center $r_p(t)/r_p(t=0)$
analytical min,max $a(t)/a(t=0)$
isolation time T_{iso} (a/a_0 = 1.5)
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
30
time $t/T_{orb}(t=0)$

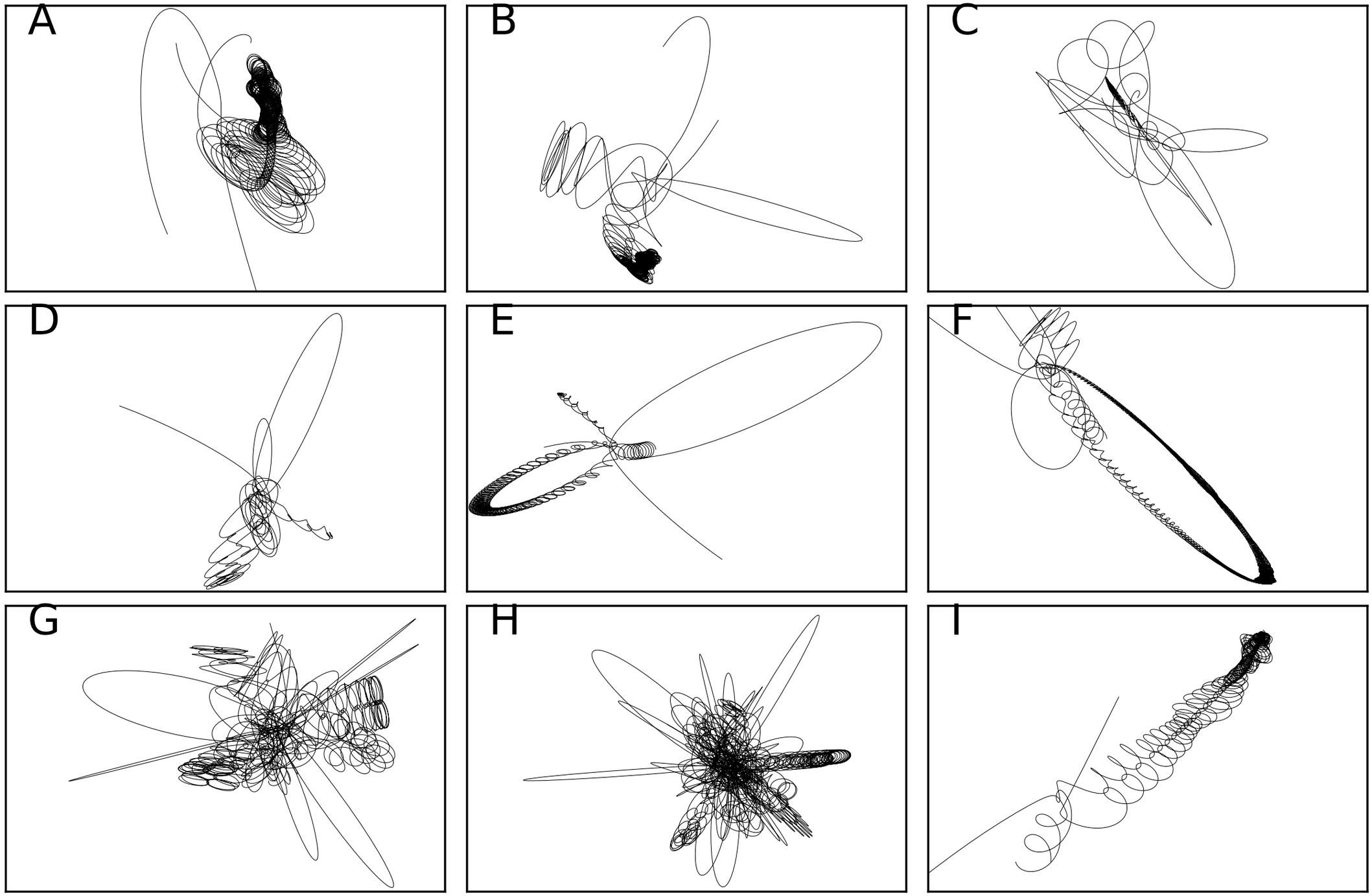


Results

Binary-Single interactions with Tides

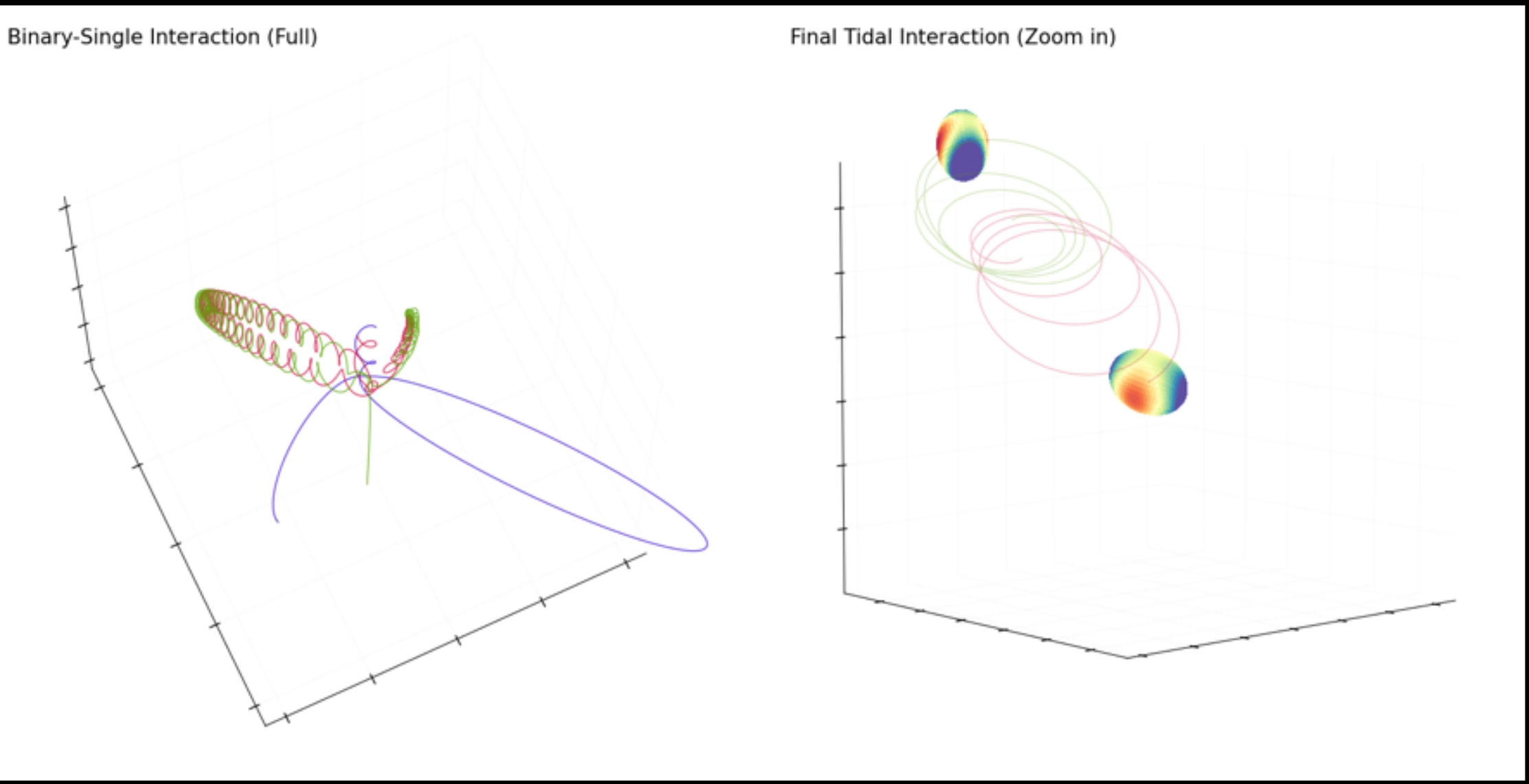
Formation of Tidal Inspirals

- Never appear without tides

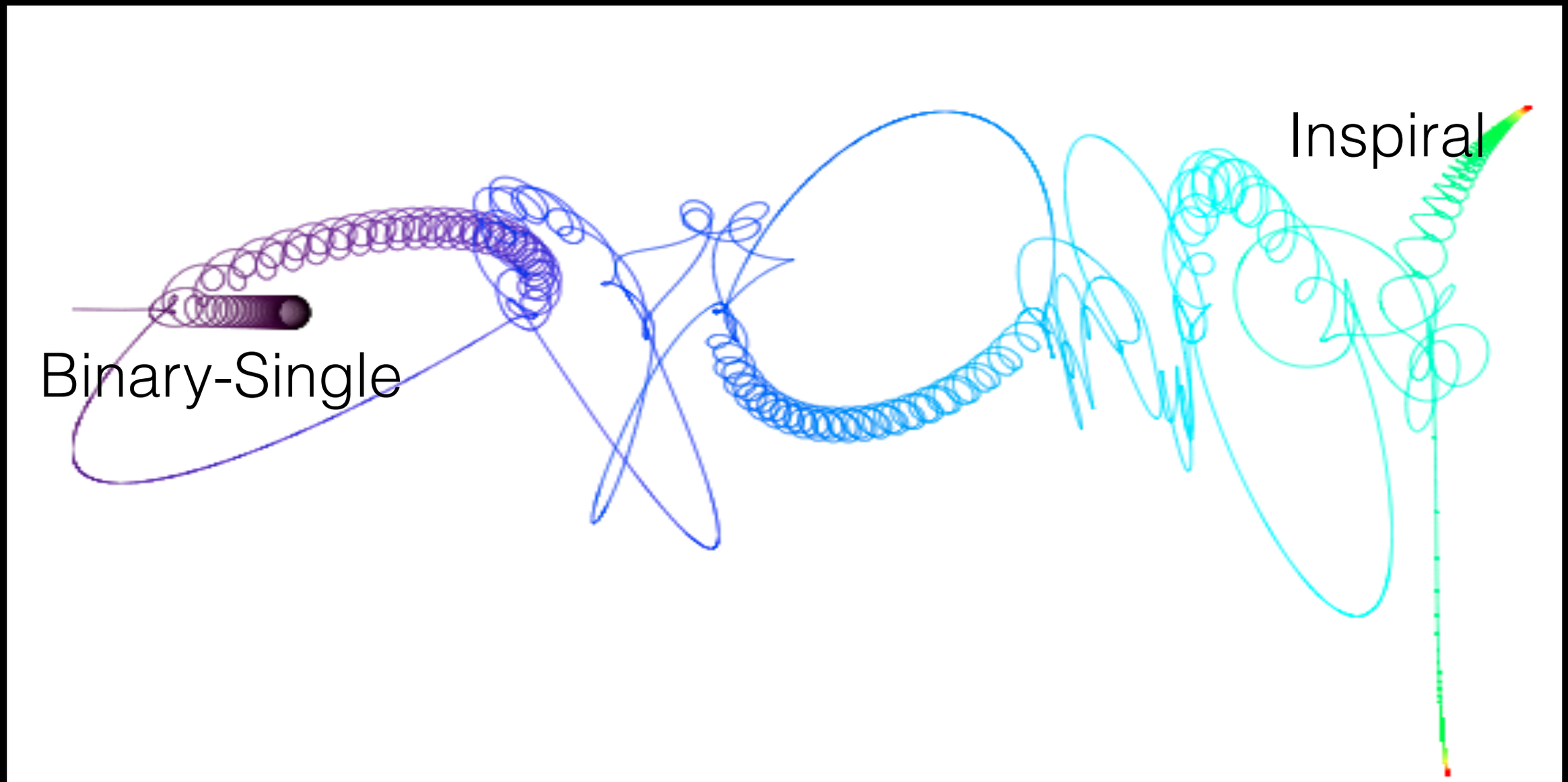


Formation of Tidal Inspirals

- Never appear without tides

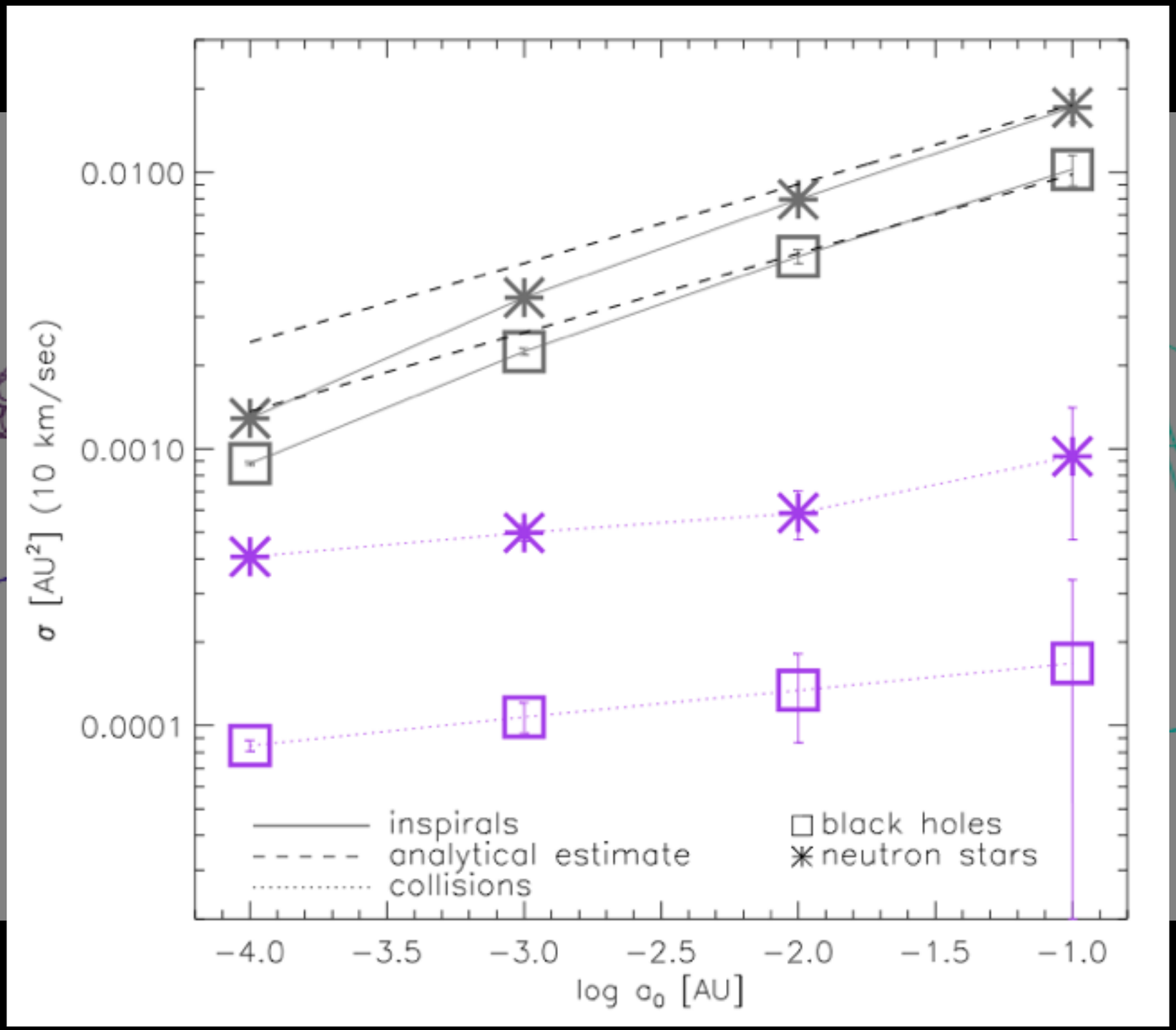


Similar to GW inspirals



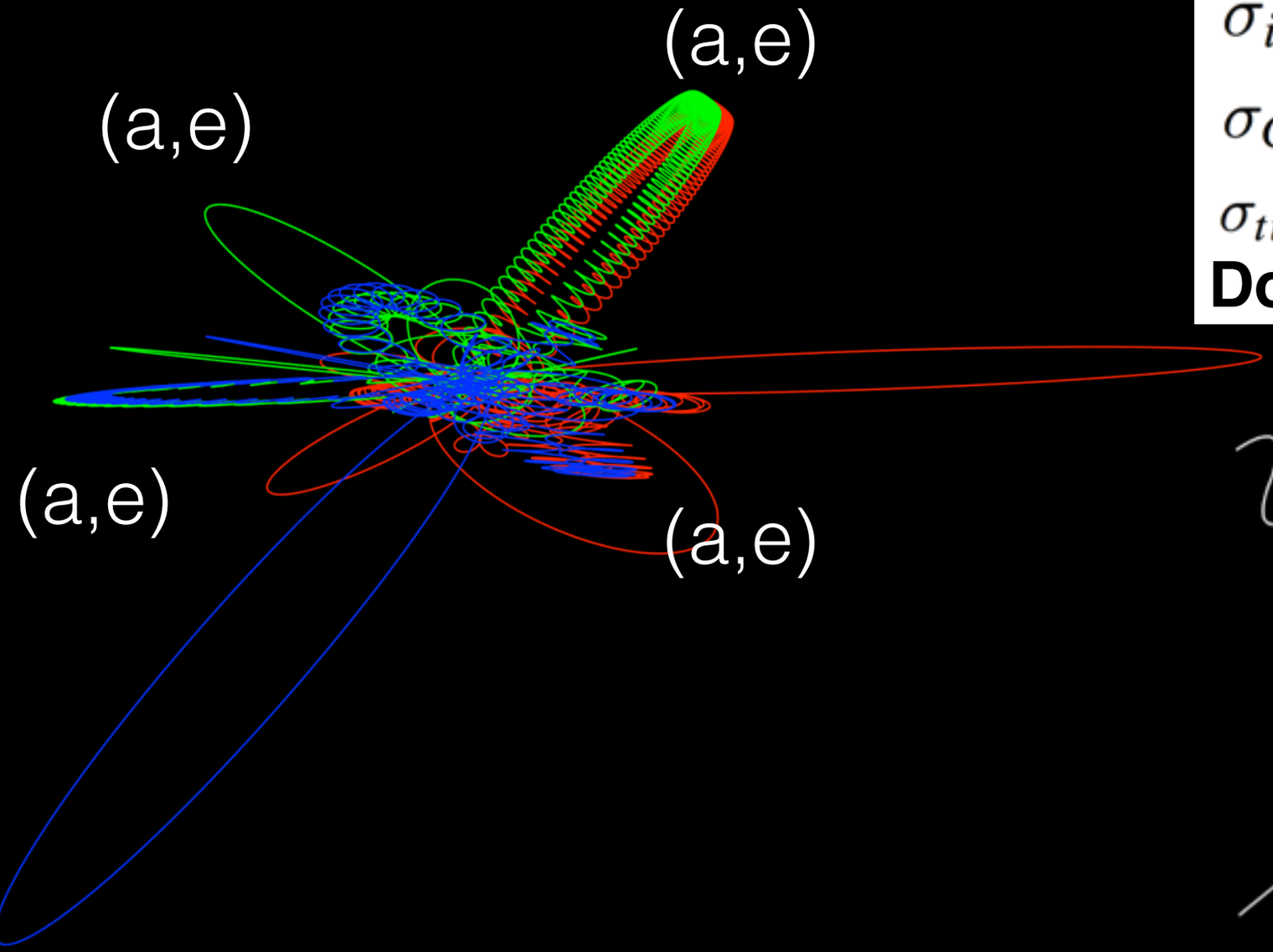
Cross section increases with SMA!

Same for Tidal inspirals?



A hint from analytical estimates

- Calculate inspiral time (t_insp) vs isolation time (t_iso).
- Identify in phase space where t_insp<t_iso.



Hard Binary limit:

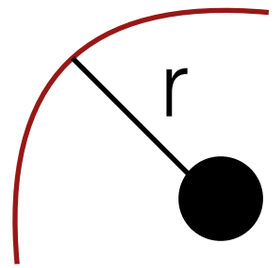
$$\Delta E \propto 1/r_p^{\beta}$$

$$P(insp|bin-sin) \propto a_0^{(1/\beta-1)}$$

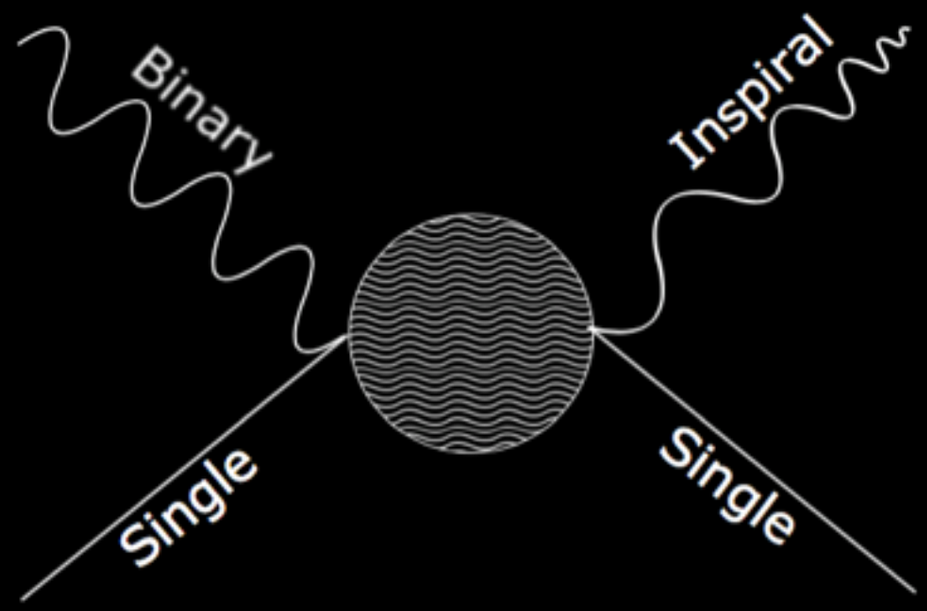
$$\sigma_{insp} \propto a_0^{1/\beta}$$

$$\sigma_{GW} \propto a_0^{2/7}$$

$$\sigma_{tides} \propto a_0^{1/3}(?)$$



Dominate over collisions!!!



Thank you