Investigating a Collision Between Two Globular Clusters

MARK RYAN
DURHAM UNIVERSITY
DEPARTMENT OF PHYSICS

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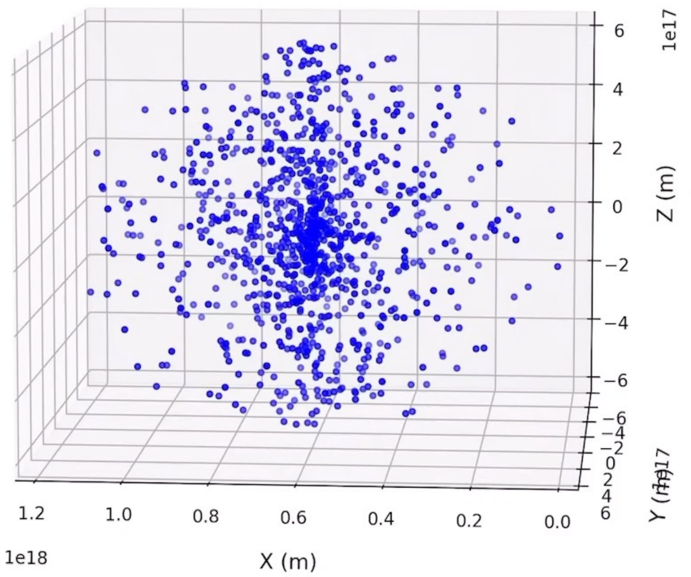
What is a Globular Cluster?

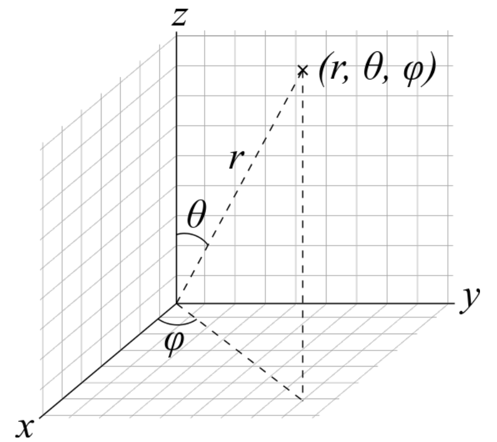
- Centrally concentrated (Beasely, 2020)
- Gravitationally bound
- Contain up to one million stars (Bianchini et al, 2018)
- Spherical appearance
- Radii of a couple of parsec – tens of parsecs

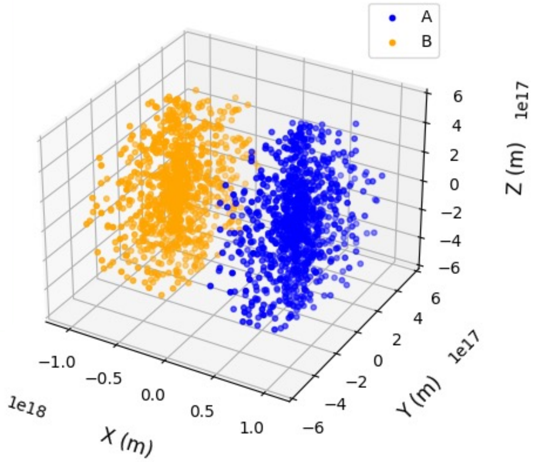

M13 - Ferla, 2019

Modelling the Clusters

- Radial distributions of 1000 particles using spherical coordinates
- $R_{Cluster}$ = 20 pc
- $0 \leq r \leq R_{Cluster}$
- $0 \leq \theta \leq \pi$
- $0 \leq \varphi \leq 2\pi$
- Separation = $2R_{Cluster}$ = 40 pc







Methods of Calculation

Durham University

Newton's Law of Gravitation:

$$F_i = -Gm_i \sum_{j \neq i} m_j \frac{r_i - r_j}{\left[\left|r_i - r_j\right|^2 + \epsilon^2\right]^{3/2}}$$

The Leapfrog Finite Difference Approximation:

$$v_i^{n+1/2} = v_i^{n-1/2} + F_i \frac{dt}{m_i}$$

$$x_i^{n+1} = x_i^n + v_i^{n+1/2} dt$$

Virial Theorem:

$$2E_K + E_{PE} = 0$$

$$\Downarrow$$

$$\frac{2E_K}{E_{PE}} = -1$$

Energy Formulae:

$$E_K = \sum_i^n m_i v_i^2$$

$$E_{PE} = -Gm_i \sum_{j \neq i}^n \frac{m_j}{\left[\left|r_i - r_j\right|^2 + \epsilon^2\right]^{1/2}}$$

$$E_{tot} = E_K + E_{PE}$$

Assumptions

Softening parameter - no actual collisions

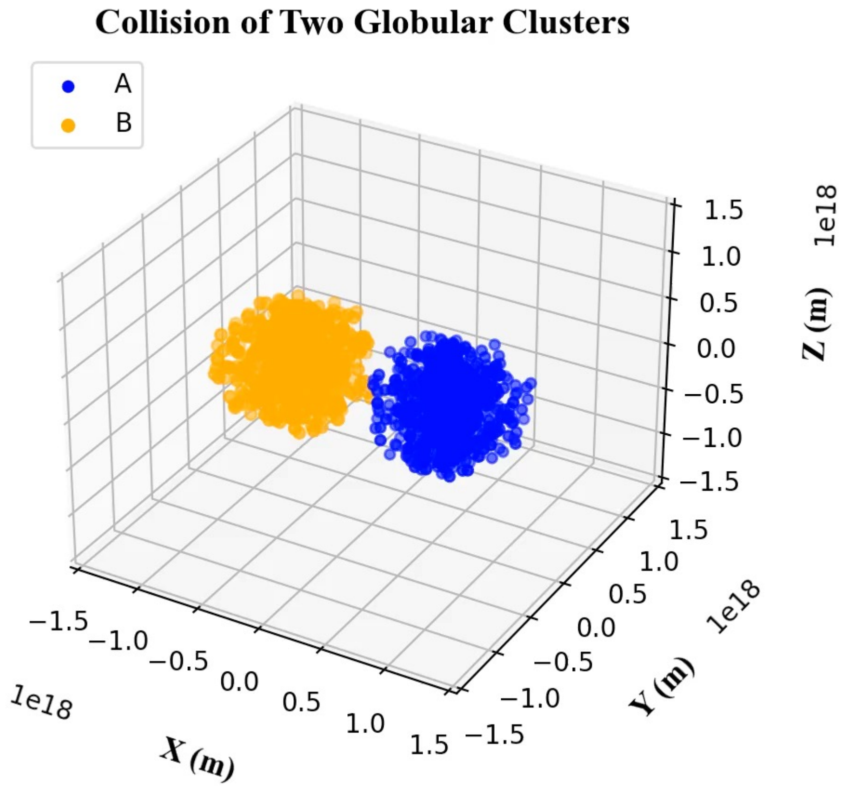
Point masses of mass 1 $M_{\odot}$

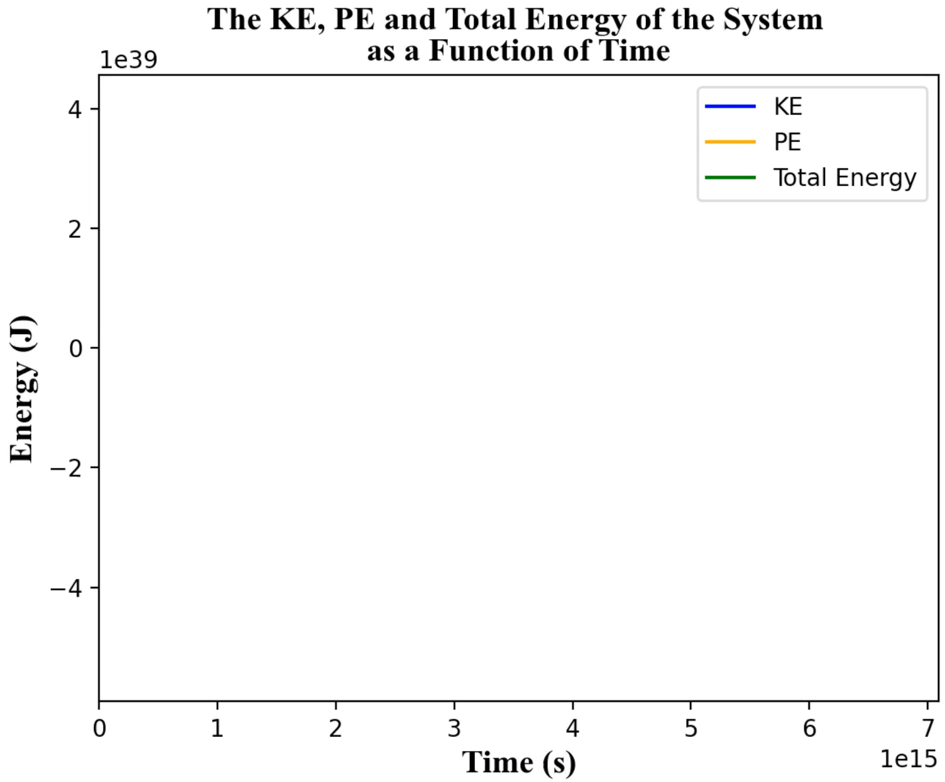
No external forces act on the system

Spherical shape

Radial distribution of stars

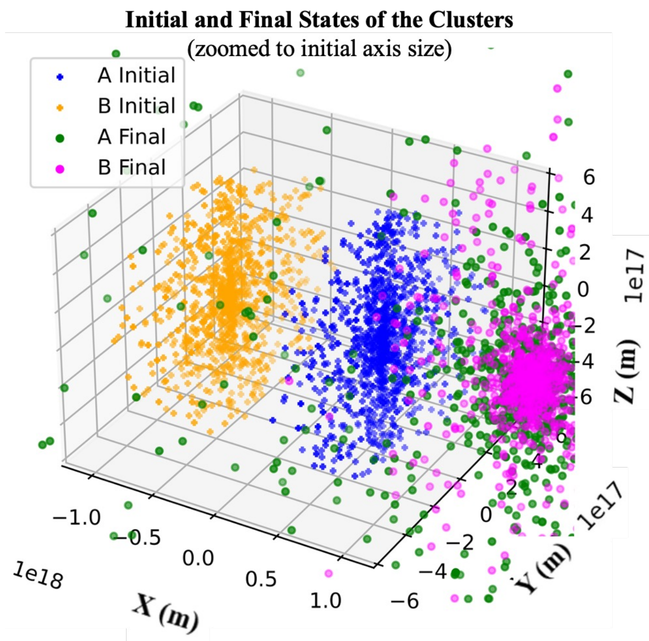
Simulation of the Collision

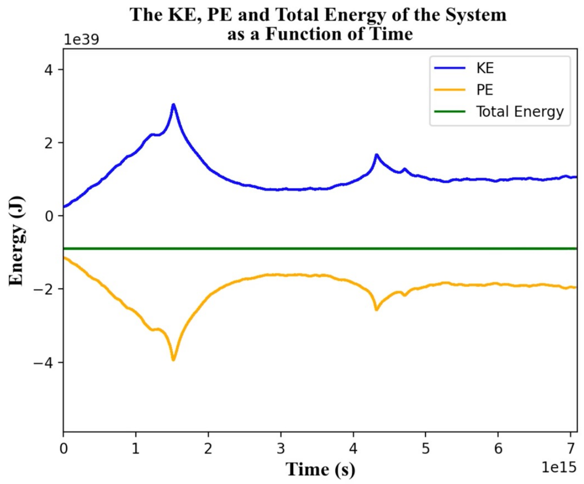


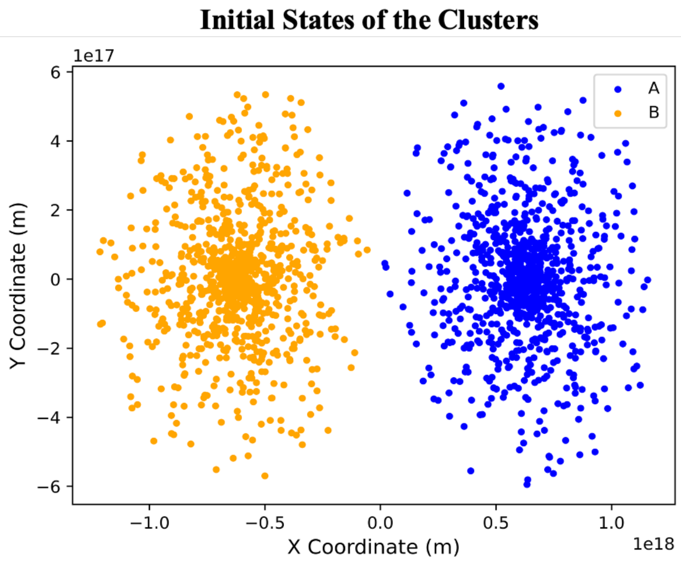


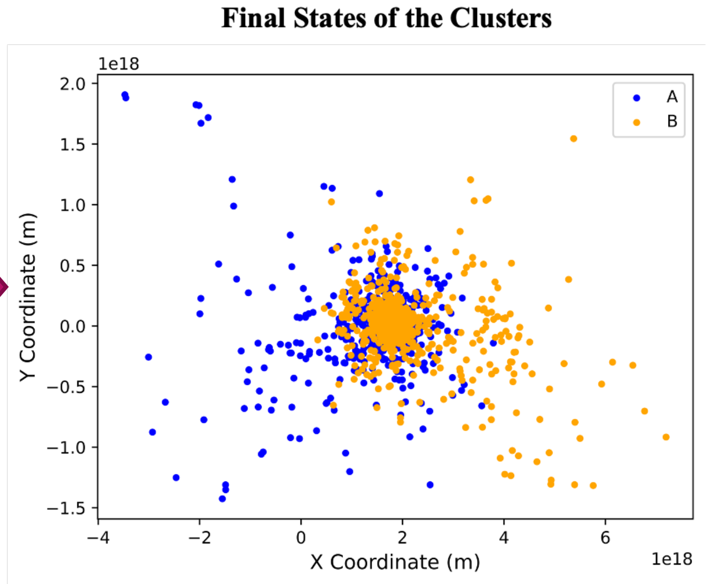
Simulation Results

- Percentage change in total energy = 0.12 % (2SF)
- $\frac{2E_K}{E_{PE}} = -1.1$ (2SF)





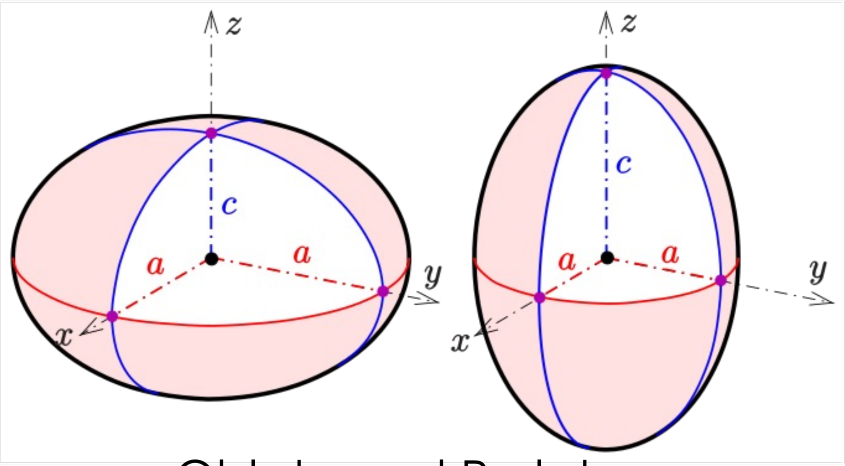




Drawbacks to this Model

- Softening parameter prevents collisions
- In reality stars could collide, merge or break up into debris
- No softening parameter = improved energy conservation?
- Stars in globular clusters likely to orbit the cluster centres (Bianchini et al, 2018)
- Results in spheroidal shape rather than sphere

Sphere



Oblate and Prolate Spheroids

Future Work

Collision of Two Rotating Clusters

- Conservation of angular momentum?
- Net rotation in resultant cluster?
- Shape of resultant cluster?
- How many resultant clusters?

Collision of Two Rotating Clusters with Black Holes at their Centres

- How many stars are absorbed by the black holes?
- Is there a resultant cluster orbiting a merged black hole?
- Net rotation in this resultant cluster?

Conclusions and Summary

- Propagation of numerical errors maintained well
  - Percentage change in total energy = 0.12 % (2SF)
- Large resultant cluster
- Many stars initially ejected
- System stabilises into a state close to virial equilibrium
  - $\frac{2E_K}{E_{PE}} = -1.1$ (2SF))