A Novel Approach for Identifying Collisional Asteroid Families in the Kuiper Belt

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What is a Collisional Family?

Very little is known about the formation of the Kuiper belt - a circular disc containing KBOs (Kuiper belt objects) located approximately 50 AU from the sun, and the origin of like belts surrounding many similar solar systems. The identification collisional asteroid families - asteroid families endured a collision between multiple objects creating a cluster of KBOs similar in orbital features, has led to the recent discovery of the Haumea asteroid family. This has shed light on the physical processes that have otherwise been neglected e.g., Yarkovsky effect. Furthermore, many new research paper establish the idea that various asteroid collisional families located in the Kuiper belt have traveled to other various parts of the solar system, because the intensity of the collisions have caused major deviations in object velocities. Hence, may Kuiper belt objects have contaminated the both the Main Asteroid belt and the Scattered disk. Discovering the parent bodies of pervious collisions and determining the aftermath would aid in wider knowledge of the evolution and formation of the Kuiper belt. May scientist have disregarded the importance of understating the orbital distributions of KBOs, as the Kuiper belt has mostly been around since the formation of this solar system. Understating the physical properties of these KBOs are essential in understanding the physical of the other regions of solar systems, considering that most solar systems have many asteroid belts.

Question

Can the Haumea asteroid collisional family can be distinguished from the background objects in the Kuiper belt, and which clustering techniques and/or algorithms are the most efficient in identifying the Haumea family? Can these techniques be used to distinguish other families?

Hypothesis

Collisional families located will be able to be distinguished from background objects in the Kuiper belt, and the Hierarchical Clustering method will be the most efficient way in distinguishing the Haumea asteroid collisional family from the background objects in the Kuiper belt.

Methods

Proper Orbital Elements Calculations

This process involves calculation the values of an asteroids position and/or orbit.

Hierarchical Clustering Algorithm

Most common algorithm used for identification of collisional families.

Proper Orbital Elements Plotted

This is was used for visually plotting the data to identify any abnormalities without any analysis.

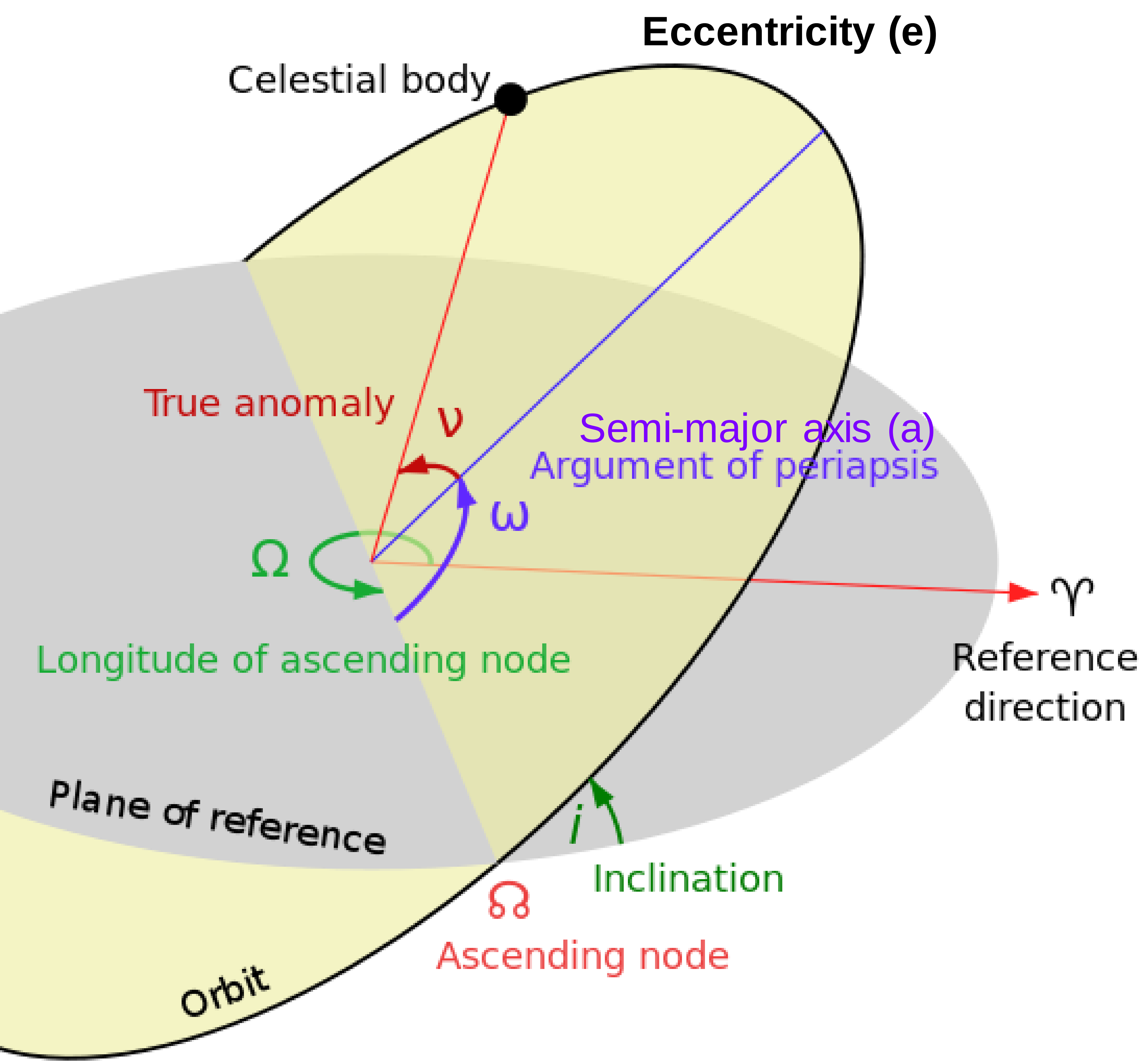
Result Analysis

Analyzing if the algorithms were efficient at identifying collisional families.

K-means Clustering Algorithm

Simple and fast algorithm used for identification clusters in huge datasets.

Proper Orbital Elements Calculations



Eccentricity (e) – elliptical shape of the orbit, described in a range between 0 – 1, where 0 is a perfect circle

Semi-major axis (a) – greater distance from center of an ellipse to the outer.

Inclination (i) – the vertical tilt of the orbit

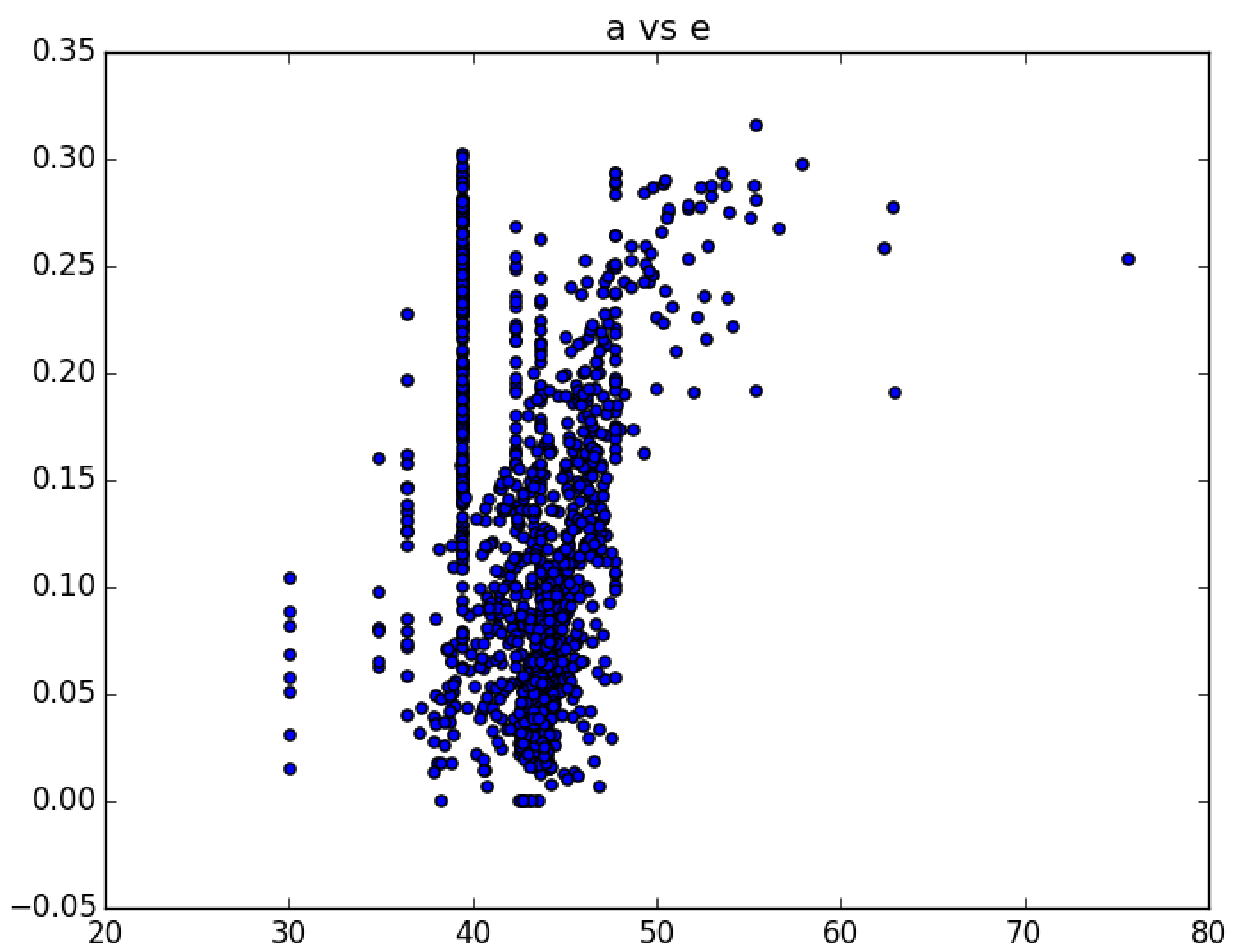
Proper Orbital Elements Calculations (cont.)

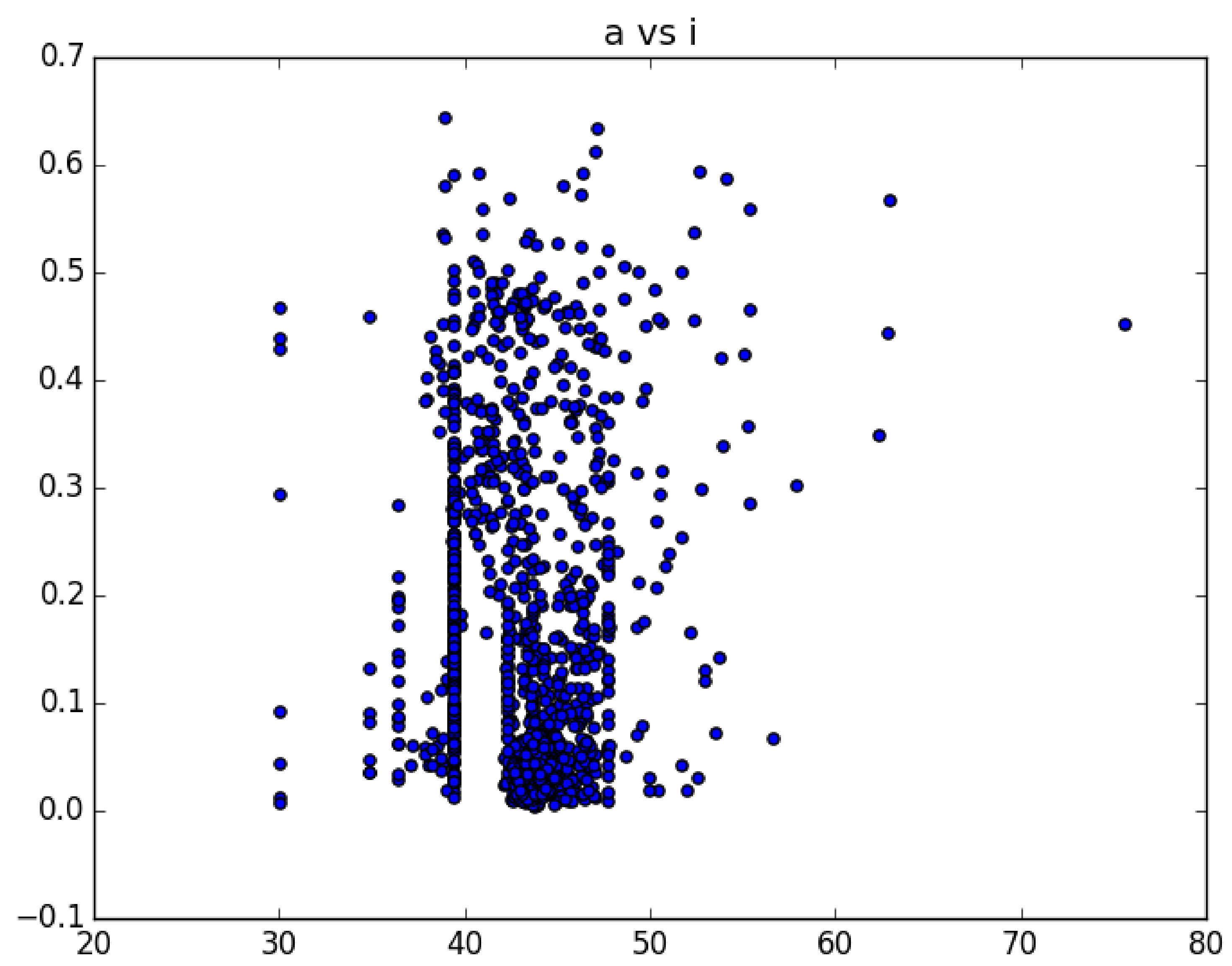
Dataset:

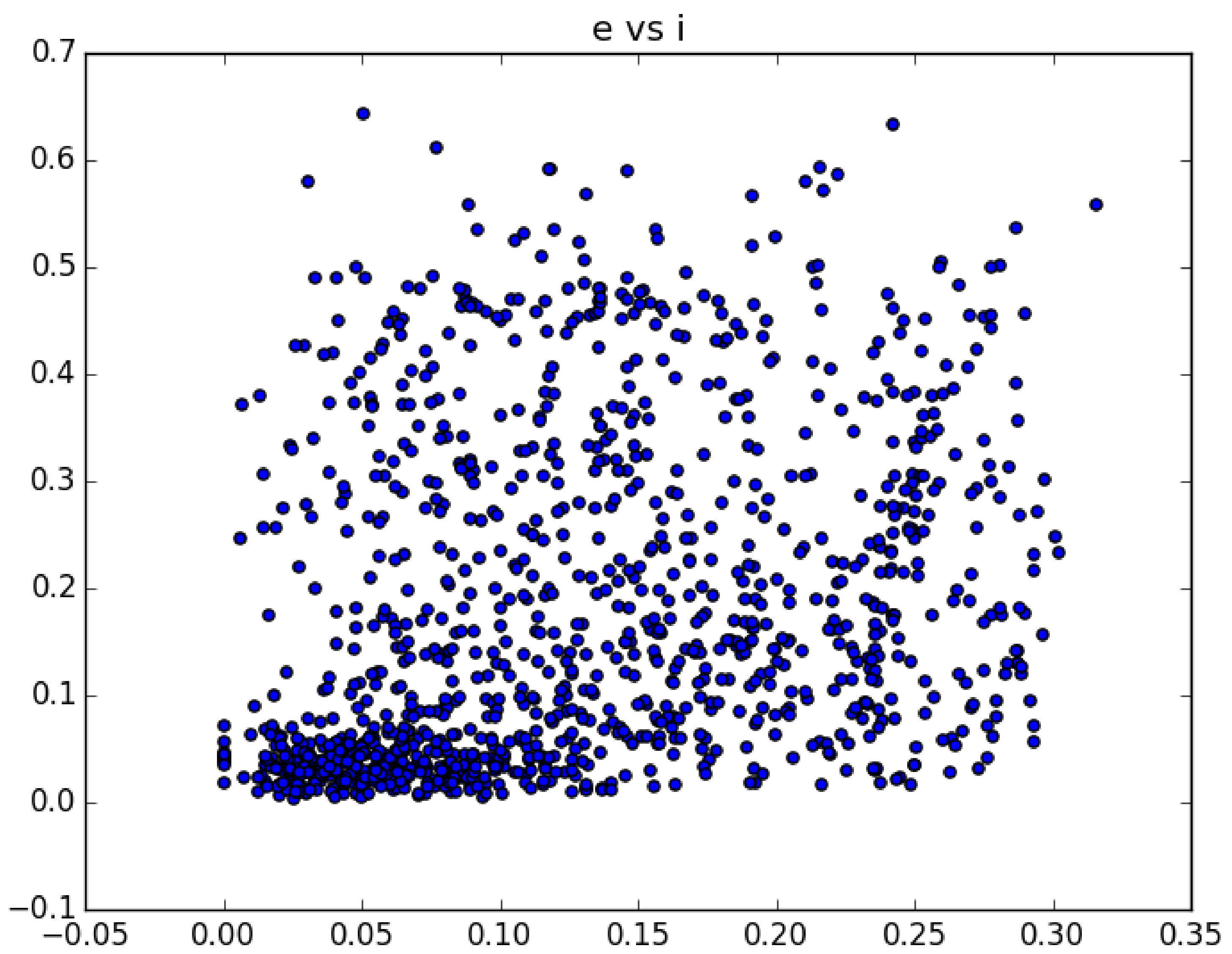
AstDyS provides information on numbered asteroids with a convenient Web-based interface. It is based on a continually and almost automatically maintained database of asteroid orbits.

Name of Object	a	e	i
15760	43.9801085	0.0703557	0.0439968
15789	39.4583336	0.1841545	0.1019159
15807	43.7982074	0.0729767	0.0330139
15809	42.3286792	0.2202312	0.2244278
15810	39.4609541	0.1247105	0.0599178
15836	36.4850721	0.0712616	0.0857137
...			
2015RS24	8.22	40.4187896	0.0988933
2015UK84	49.6112986	0.247131	0.3800829
2016BP81	43.7265793	0.064597	0.0616415
2016FP59	46.6368753	0.1604549	0.090706
2016FW59	43.4338484	0.0762106	0.142732

Result: Proper Orbital Elements Plotted







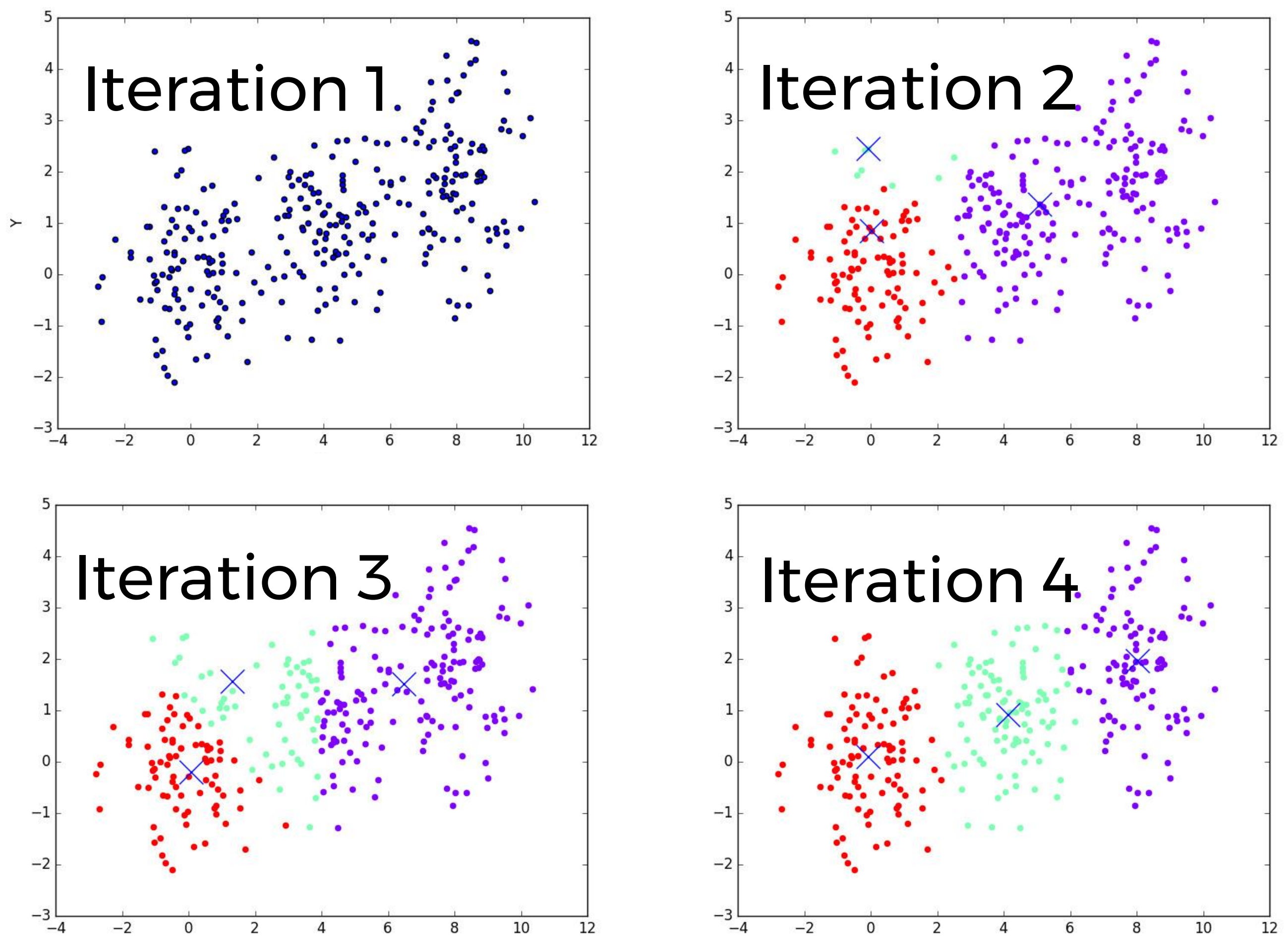
The lines seen in the graphs ‘a vs e’ and ‘a vs i’, are called resonances. Resonances are created when the ratio of an object’s orbit and the orbit of Neptune match up, the object becomes synchronized with Neptune’s gravity. Therefore, the reason why plots graphed with ‘a’ (semi-major axis) display resonances.

K-means Clustering Algorithm

Expiation:

In a center based algorithm, the number of clusters (k) are predefined. The clusters start out at random positions on the graph, the clusters are then moved to and adjusted until each object's distance from the cluster's center is the closest to itself. This iteration is repeated until all objects are located in the cluster closest to their position.

Example:



Algorithm:

$$d = |(k_a - a_P) + (k_e - a_e) + (k_i - a_i)|$$

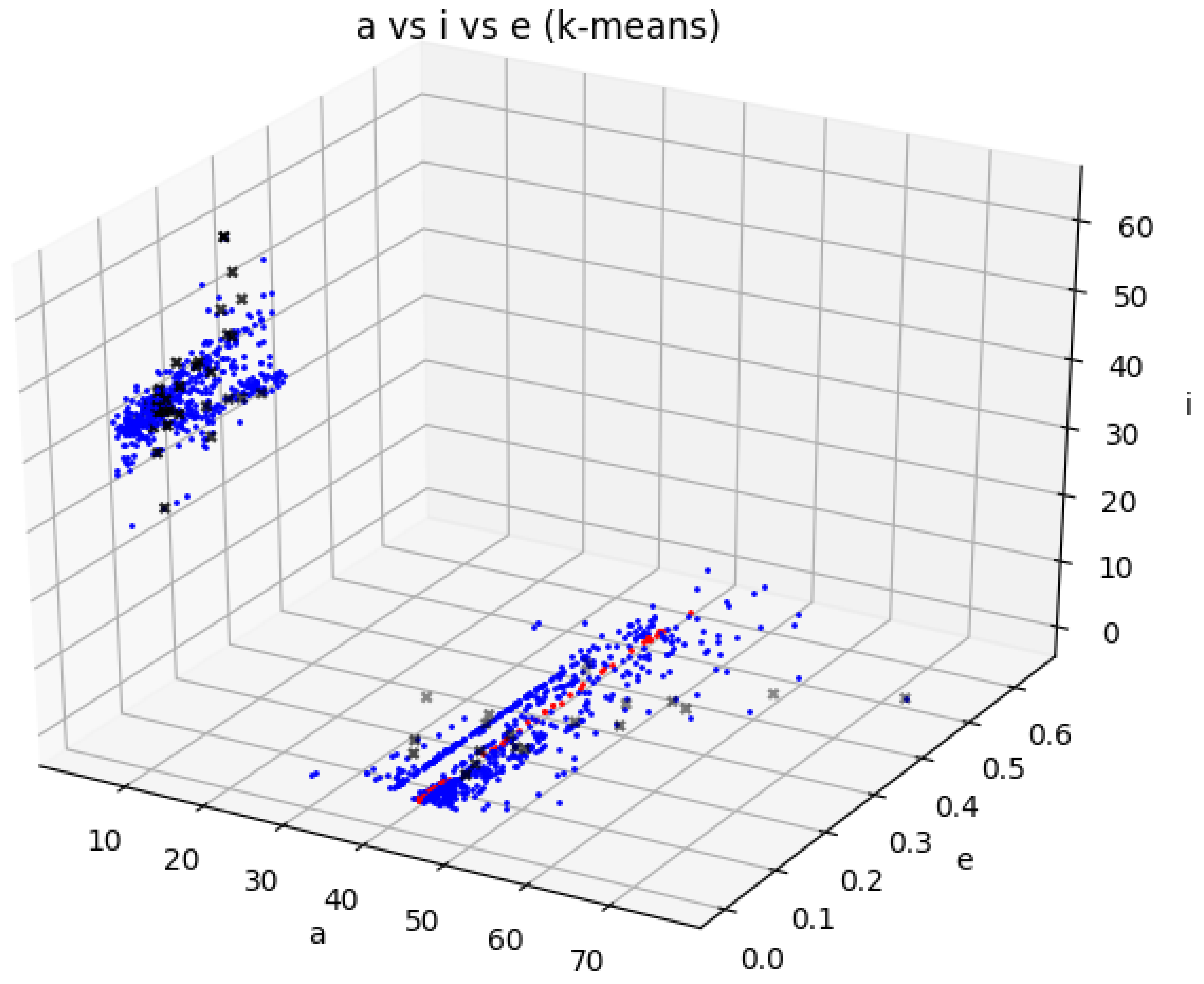
where:

d is the distance from the cluster center
a_P is the semi-major axis of the object (p implies proper)
e_P is the eccentricity of the object (p implies proper)
i_P is the inclination of the object (p implies proper)
k_a is the is the semi-major axis value of center of the cluster
k_e is the is the eccentricity value of center of the cluster
k_i is the is the inclination value of center of the cluster

Implementation (python):

```
dist = np.abs((centroids[labels[i]][0] - X[i][0]) + (centroids[labels[i]][1] - X[i][1]) + (centroids[labels[i]][2] - X[i][2]))
```

Result: K-means Clustering Algorithm



'x' makes are the centers of clusters

The points in red are objects that are grouped containing the planet Haumea.

This method looks promising; however, taking a closer look, many clusters are are just common groupings loosely based on the distance from objects. Hence, most clusters are just created by random chance. This can bee seen as many members of the Haumea family are scatter around in different clusterings.

Objects that are both found in the cluster and in the Haumea family

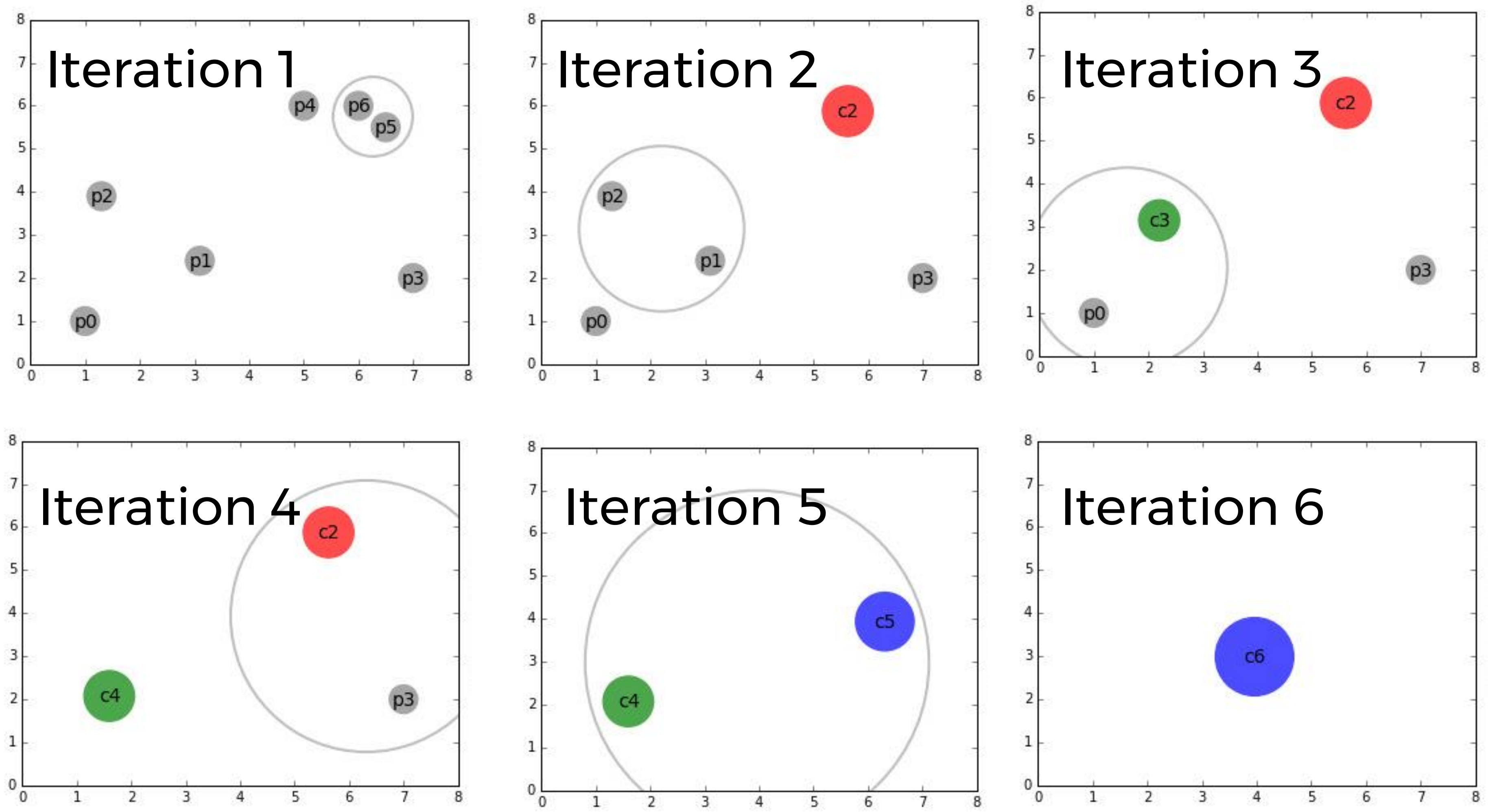
Object	Distance form center
19308	0.330731959129501
55636	0.29394256975858585
120178	0.2820518868809836
145453	0.2915599092512587
308193	0.36074165447900486

Hierarchical Clustering Algorithm

Expiation:

This algorithm is based on the idea that objects closer in distance are more related than others that are farther in distance. Each point essentially becomes the center of its own cluster and from there, the closest point to if becomes apart of the cluster.

Example:



Algorithm:

$$dv^2 = (na_P)^2(k_a(\frac{\delta a_P}{a_P})^2 + (k_e(\delta e_P)^2 + (k_i(\delta i_P)^2$$

where:

dv is the cut of distance
n is the orbital frequency
a_P is the semi-major axis (p implies proper)
e_P is the eccentricity (p implies proper)
i_P is the inclination (p implies proper)
$k_{a,\,e,\,i}$ is the coefficients of the order of unity which in these calculation are constant

$k_a = 5/4$
$k_e = 2$
$k_i = 2$

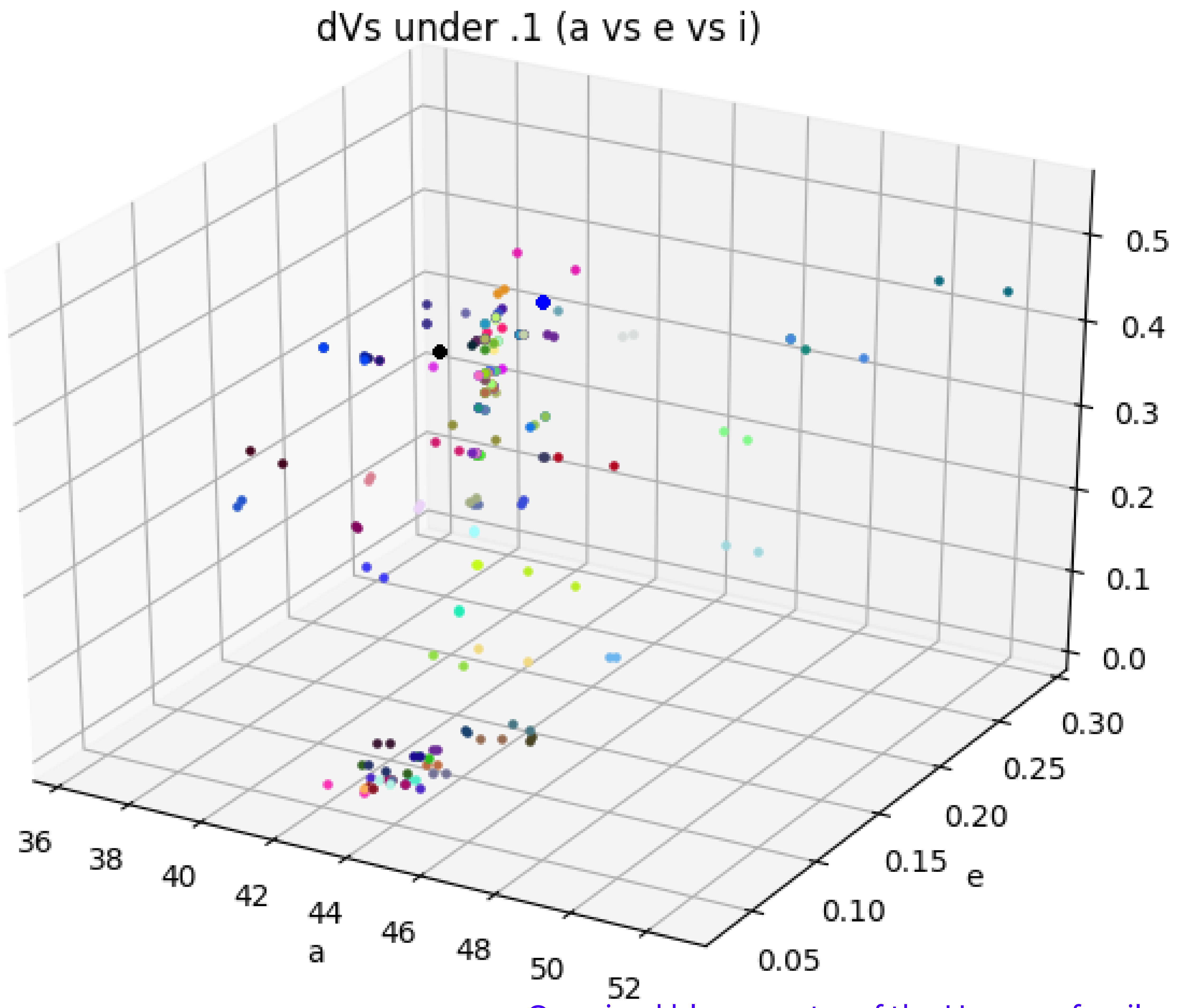
Implementation (python):

dv = abs(2.5*(data[x][2]-data[i][2])/(data[x][2]+data[x][2])) + abs(4*(data[i][3]-data[x][3])/(data[i][3]+data[x][3])) + abs(4*(data[i][4]-data[x][4])/(data[i][4]+data[x][4]))

Result: Hierarchical Clustering Algorithm

The top 100 objects with the least dV are displayed to the right. This graph represents how scattered the Kuiper belt is and how difficult it can be to find collisional families. Using this algorithm, no member of the current Haumea family were found. This implies that additional analysis is needed to identify collisional families.

Object 1	Object 2	dV Value
2004VT75	2007RT15	0.00672402049406887
2014YG50	2011UR41	0.00789975378227958
2011UU41	69986	0.01020990902767570
2014HT19	2014UU22	0.01161328016271370
386723	416400	0.01387207465758520



Oversized blue – center of the Haumea family collision

Oversized black – Haumea planet

Conclusions

- Reject Hypothesis
- Further research is need in development of both Algorithms
- Datasets with more objects are needed
- More computing power is needed in order to test more iterations of the HCA

References

Bolin, B. T., Delbo, M., Morbidelli, A., & Walsh, K. J. (2017). Yarkovsky V-shape identification of asteroid families. *Icarus,282*, 290-312. doi:10.1016/j.icarus.2016.09.029

Delbo', M., Walsh, K., Bolin, B., Avdellidou, C., & Morbidelli, A. (2017). Identification of a primordial asteroid family constrains the original planetesimal population. *Science,357*(6355), 1026-1029. doi:10.1126/science.aam6036

Dermott, S. F., Christou, A. A., Li, D., Kehoe, T. J., & Robinson, J. M. (2018). The common origin of family and non-family asteroids. *Nature Astronomy,2*(7), 549-554. doi:10.1038/s41550-018-0482-4

Levison, H. F., Bottke, W. F., Gounelle, M., Morbidelli, A., Nesvorný, D., & Tsiganis, K. (2009). Contamination of the asteroid belt by primordial trans-Neptunian objects. *Nature,460*(7253), 364-366. doi:10.1038/nature08094

Marcus, R. A., Ragozzine, D., Murray-Clay, R. A., & Holman, M. J. (2011). Identifying Collisional Families In The Kuiper Belt. *The Astrophysical Journal,733*(1), 40. doi:10.1088/0004-637x/733/1/40

Nesvorný, D., Broz, M., & Carruba, V. (2015). Identification and Dynamical Properties of Asteroid Families. *Asteroids IV*. doi:10.2458/azu_uapress_9780816532131-ch016

Novaković, B. (2018). Tracing escapees from collisional families. *Nature Astronomy,2*(7), 528-529. doi:10.1038/s41550-018-0520-2