MODELING ENERGY OF COLLIDING BLACK HOLES

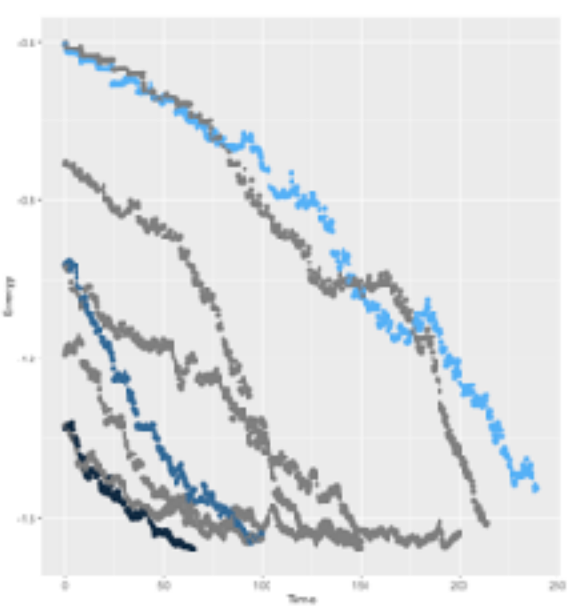
Abhishek Singh - aasingh@indiana.edu
Astronomy Dept Mentor- Dr. Jeremy Webber
SOIC Mentor- Dr. David Wild

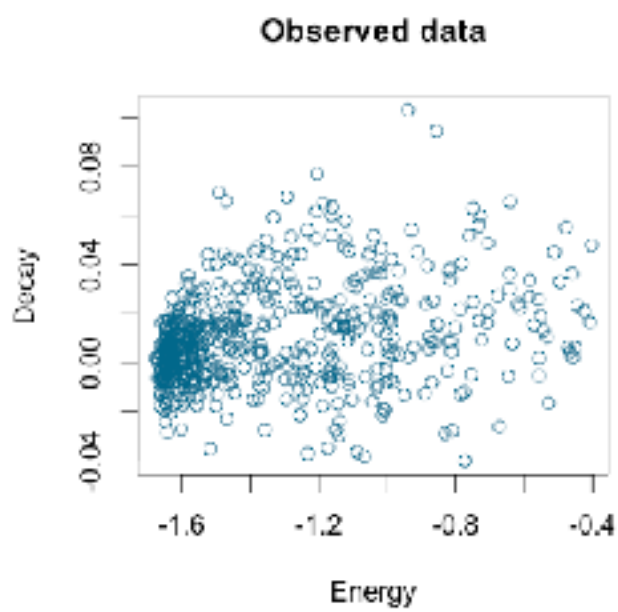
INTRODUCTION:

Recent numerical relativity simulations have shown that emissions of gravitational waves during the merger of two massive blackholes delivers a kick to the final supermassive black hole ((SMBH) , with a magnitude as large as 4000 km/s. Once this SMBH is created, such high magnitude of kick velocity displaces it from it's original position in the star cluster. Depending on the initial kick velocity, the SMBH might leave the star cluster on an elliptical orbit or may get completely ejected from the cluster. In case where the SMBH doesn't get ejected, it follows an elliptical orbit until it loses all its energy as a result of friction and interaction from other stars in the cluster. We studied the motion of these SMBHs ejected from galaxy cores by such kicks and the effects on the stellar distribution. Our goal was to model the position/energy of the black hole as a function of time for a given set of black hole masses and kick velocities. Traditional approach utilizes massive computation on compute clusters for a long period of time to model black hole mergers with a specific mass and kick velocity. Although this approach gave results which were accurate to a higher degree, but not very robust in terms of quickly creating datasets. To solve this problem, a data driven approach using machine learning and data analysis was necessary.

DATASET:

We ran simulations for a super massive blackhole with five different kick velocities. The kick velocities determine the orbit amplitude, radius and time before the blackhole becomes stable again. Following are the models of all the different datasets that we have:





Our dataset looks as follows:

Time	Radius	Energy	Orbital_Amplitude	Orbital_Period	Velocity	Decay
0.0000010	1.253749e-10	-1.366770	0.42932920	1.825000	0.00189052	-4.000900e-02
0.2500153	1.896864e-01	-1.376951	0.42005873	1.803239	0.67947465	-1.334640e-03
0.5000153	3.306853e-01	-1.377265	0.41975460	1.805364	0.43994325	2.393760e-02
0.7500153	4.053430e-01	-1.371381	0.42520755	1.736708	0.18668255	3.401280e-03
1.0000153	4.215003e-01	-1.370458	0.42590253	1.813347	0.09029622	-6.161500e-03
1.2500153	3.644523e-01	-1.371991	0.42457885	1.746883	0.36260411	9.368280e-03
1.5000153	2.409918e-01	-1.369674	0.42669025	1.817164	0.62297267	2.361300e-02

We calculated and added decay since it seems as the most important feature affecting the SMBH motion. We also aggregated time into orbits, since SMBH lost most of it's energy towards the end of an orbit, thus leading to the assumption of average decay per orbit.

Modified training data looks as follows:

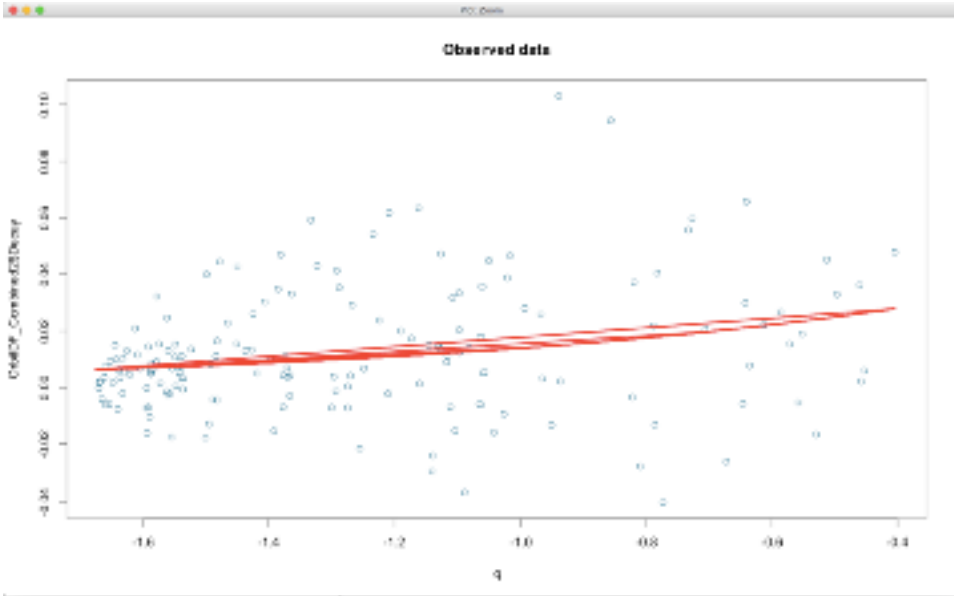
row.names	Time	Energy	PreviousEnergy	Decay
1	8.500015	-0.4521151	-0.4042221	0.047892950
2	16.500215	-0.4580806	-0.4521151	0.005965590
3	23.750215	-0.4601604	-0.4580806	0.002079720
4	30.500808	-0.4962816	-0.4601604	0.036121250
5	37.250215	-0.5291170	-0.4962816	0.032835380

Note: row.names corresponds to orbit number.

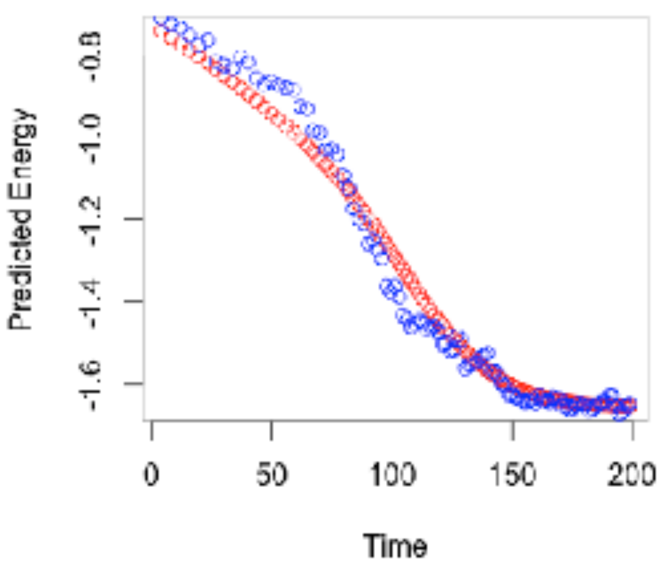
The decay is measured at every orbit of the black holes motion. Once we had the decay for each separate dataset, we combined the dataset to create one huge table containing values for all the different black holes. This dataset served as the training data to model our polynomial regression model as follows :

Decay ~ a+b(Energy)+c(Energy)^2

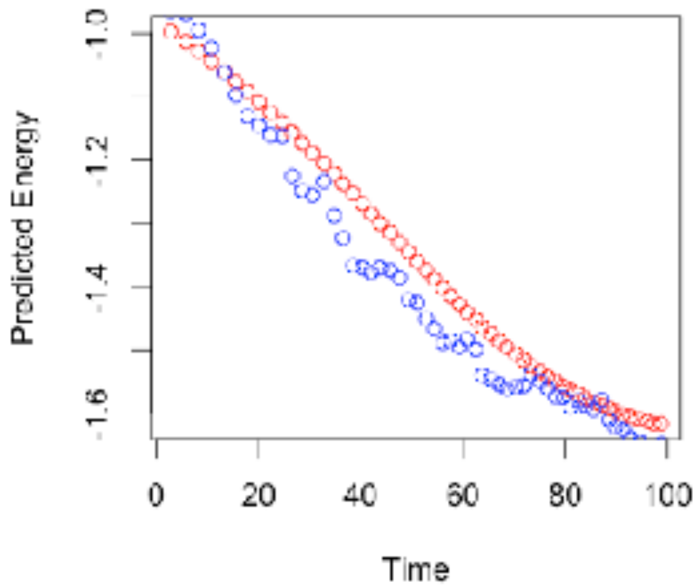
This model is third order polynomial which models something closest to what we see in the Decay vs Energy plot. Following is a plot showing the lines of the predicted points:



RESULTS:
The model has predicted very accurate decay values which were used to calculate the Energy of the SMBH at a specific kick velocity. Following are some of the results from the model showing predicted functions:



Energy function for kick velocity of -0.767 for SMBH going for 200 million years.



Energy function for kick velocity of -0.966 for SMBH going on for little less than 100 million years.

The above plots are the overlay results from original dataset (blue) and our predicted function (red). As we can see a third order polynomial function is able to successfully model the behavior of an SMBH with given mass and variable initial kick velocity.

The current work will be further expanded to account for random encounters with other stars in the cluster (currently we are ignoring them) and include SMBH with different masses, which will lead to a much more complex model.