Black Hole Hunter – Jason Hwang and Daniel DuBrow

Purpose

This activity shows the students how a computer simulation may be used to indirectly find information hidden within the observed data. The data is taken from real observations of the stars surrounding the black hole in the middle of the Milky Way Galaxy. In addition the activity reinforces the laws of gravity learned during class, requiring the students to write a program to find the mass of the unseen black hole to compare with the observed stellar orbits. This activity shows the interaction between experiment, theory, and simulation as well as the importance of visualizing data.

Overview

-A day before the activity, give the students a pre-lab to work on, either in class or to take home for homework. The worksheet introduces the essential question (to find the mass of the black hole binding the orbiting stars), the theory behind the simulation, the assumptions to be made in the program and additional conceptual questions to think about. The worksheet prompts the students to think about how the algorithms that will be used to simulate the physics.

-The teacher should either install processing and the initial code onto the available computers or prepare an easily downloadable file with all the necessary files, preferably on a class website.

-At the beginning of the actual activity, we go over the pre-lab, especially the sections that go over the iterations required to update the positions, velocities, accelerations and forces. The students should first show the relations between these qualities through what they know from the physics lectures before converting the equations to computer algorithms.

-The first step for the students is to log into the computers and open processing (or download it if necessary). The students should then open the initial code which has a incomplete version of the finished code but has a basic outline for the needed algorithms.

-The students should then fill in the expressions for calculating distance, accelerations, velocities, and positions at each iteration in time. The expressions on the pre-lab are the physics equations that need to be converted to computer algorithms.

-After the students finish writing the program, the program should be checked by an instructor and then the students should proceed to deducing the black hole's position by changing the corresponding variables in the program. The position of the black hole may be inferred by studying the observed orbits and using what is known about symmetry of orbits.

-When the position has been established, the students should find the mass of the black hole by matching the simulated orbits with the observed orbits.

Student Outcomes

1) Familiarization with processing
2) Use of equations of motion
3) Understanding time stepping
4) Using a simulation fit a model to observed data
5) Indirectly arriving at a solution through a simulation

Applications of learning – The students apply their knowledge of gravity and orbits to solve a problem where the data has already been observed.
Communicating – The students create a program that visualizes the theoretical orbits of their solution and compare the simulated orbits with the observed orbits.
Using technology – The students learn to use processing to simulate the physics behind solving a problem in modern research.
Working on teams – While each student works on their own code, we encourage students to help their neighbors, especially with the wide range of computer programming experience between students.
Making connections – In doing this activity, we hope to show the power behind using computer simulations to fit a model to observed data.

Illinois state science standards met:
Apply scientific inquiry and scientific habits of mind 11A/13A/13Bl.I
How the scientists really work 13A/12A-F/13B.J
Gravitational factors 12D/11B/13A.H

Time

We found that the optimal amount of time for the activity was one class period for the pre-lab and two class periods, preferably together, for the main activity. The activity also runs much smoother if there has been an introduction to programming activity done previously.

Level

This activity works best for students that have had trigonometry and have gone over the laws of gravity in physics class.

Materials and Tools

A computer lab with either processing already installed or an easily downloadable folder with all the files required. A white-board or blackboard is useful for keeping track of the variables the students come up with as well as showing a visual representation of the iterations used in the algorithms.

A pre-lab worksheet given the class period before the lab allows the students to begin formulating ideas on how they will accomplish the activity.

Preparation

The teacher needs to become familiar with the finished code in order to better guide the students along in formulating the algorithm. The teacher should also make sure that the files required to do the activity are either already on each computer or are easily accessible (putting a folder on the teacher website works).

Prerequisites

While no activities are required as a prerequisite, having done an activity introducing processing makes the learning curve much less steep. Having the students go over the algorithms as a class may help solidify any confusing concepts the students may have.

Background

Students should be familiar with the equations of motion and how to apply them with small changes in time (gone over in more detail in the worksheet). Familiarity with excel and organizing scientific data will save time during the activity.

Teaching Notes

The students will work at different paces, be sure to go around the room to ensure that a student is not stuck on a particular step for too long. If the problem is related to a trick in excel rather than a physics concept, showing them the trick is fine. Some students will grasp the concept very quickly and finish much faster. Additional steps for these students are available on the detailed walk through. In the beginning, asking the students to identify the dependent and independent variables helps organize the students' thought processes. Encourage working together, especially because of the large range of computer skills in the class.

Assessment

-The most important part of the assignment is converting the physics equations into a computer algorithm. The completion of the program is the first priority.
-Finding the correct mass and position of the black hole tests the student's understanding of the laws of gravity. The students may compare their found mass with the mass of the black hole as reported by astronomers.
-Filling out the worksheet and answering the 'additional questions' section

Additional Information

-Prior to this activity we had introduced processing and general programming. This step is essential in making sure that the activity is successful.
-While most of the students needed almost the full amount of time to finish the activity, those with previous computer programming experience may finish earlier. There are additional challenges on the worksheet that they may work on.
-While each student should finish their own code, cooperation should be encouraged among the class.