Killer Asteroids Lab #3: Changing impact probabilities, and astronomers crying wolf

GOALS: The goal of this assignment is to use the uncertainty in 2007 WD_5's predicted position to estimate that asteroid's probability of impact with Mars on Jan. 30th, 2008. You will repeat this calculation 3 times, based on the observational data that existed on 3 dates: Dec. 21st, Dec. 28th, and Jan. 9th. In the process, you will gain a better understanding of the usual sequence of events that occur when a potential planetary impact is identified.

It is very important that you read this document carefully and follow all of its instructions. Each step depends on those that precede it.

Part I: Generating new orbital elements for a new epoch

In Lab #2, you discovered that the sky position of asteroid 2007 WD_5 could not be predicted absolutely. After generating thousands of possible orbits, you found that your predictions always involved some level of uncertainty. Now, as you estimate this asteroid's probability of colliding with Mars, you'll once again make use of these collections of "virtual" asteroid orbits. However, your previous orbital solutions for 2007 WD_5 won't work as-is.

Why not? Those old orbits had been calculated for the specific date (or "epoch") of Nov. 8th, 2007. But the asteroid passes very close to both Earth and Mars around that date and during the months that follow. Unfortunately, *Guide* doesn't know how to account for the effect of a planet's gravity on the asteroid's path. Fortunately for us, *Find_Orb* does! We will also make use of a small program called *INTEGRAT*, which can quickly update the epochs of all orbits in an *mpcorb.dat* file, without waiting for *Find_Orb* to remake them from scratch. We will take care of this *epochal* change for all of the data sets before moving on to the impact analysis.

<u>*Updating Data Set A:*</u>

Open *Find_Orb* by double-clicking the *"Find_Orb Shortcut"* icon in the *"Killer Asteroids Project"* folder. Then click the "Open…" button, find your group's folder, and double-click the file located at:

2007 WD5/Astrometry/2007 WD5 as of 2007-Dec-21.rwo.txt

Repeat all of the steps from Lab #1 (<u>check</u> all perturbers, <u>set</u> R1=.05 and R2=.15, and <u>toggle-on</u> the two observations marked with an "X"). However, this time you'll also need to <u>**change the Epoch value to "2008 01 30"**</u>, which was the possible collision date. **Now click Auto-Solve.** Check that the last line of the "Orbital Elements" box says: **"From 25 observations 2007 Nov. 20-Dec. 19"**, and confirm that the RMS error is below 1". If that's all true, then it's time to grab the output files from the *Find_Orb* folder. Drag the *elements* and *mpc_fmt* text files from there to your group's *"2007 WD5/Orbit Results/<u>**Epoch 2**</u>/ Data Set A"* folder.

Now, we have a trick up our sleeves. Rather than waiting 25 minutes for *Find_Orb* to produce thousands of alternate possible orbits, we will simply update the epoch values for the orbit files we already have! Open up the folder located at *"Killer Asteroids Project / INTEGRAT"*. You should take note of the following three features:

- The ***Input*** folder, which will hold your original *mpcorb.dat* file,
- The program called ***"Integrate MPCORB to 20080130"***, which does the updating, and
- The ***Output*** folder, which will contain the updated *mpcorb.dat* file.

Use the following steps to update your orbits to the new epoch: (**1**) Copy the *mpcorb.dat* file from your folder *"Epoch 1 / Data Set A"*, and paste it into the *"INTEGRAT / Input"* folder. (**2**) Run the **"Integrate MPCORB to 20080130"** program, and wait a few minutes for it to finish. (**3**) Move the new *mpcorb.dat* file from *"INTEGRAT / Output"* into your *"<u>Epoch 2</u> / Data Set A"* folder. (**4**) Open this new *mpcorb* file, and <u>confirm that the 4th column reads **"K081U"**</u> (meaning 2008/01/30); <u>if not, then this is the wrong file!</u> **(5)** <u>Trim *mpcorb* down to exactly 2,999 lines</u>, and save it. (The best-guess orbit will make an even 3,000.)

Updating Data Set B:

Repeat the same steps for Data Set B: In *Find_Orb*, click the "Open…" button and open the file that contains your group's measurements from Lab #2, named something like:

2007 WD5/Astrometry/2007 WD5 as of 2007-Dec-28.rwo.txt

*(If the first 3 lines in the astrometry box are not from observatory code **645**, then you have the wrong file!)* Repeat all of the steps as before (check all perturbers, set R1=.05 and R2=.15, toggle-on the two observations marked with an "X"), and **change the Epoch value to "2008 01 30"**. **Now click Auto-Solve.** Check that the last line of the "Orbital elements" box says: **"From 28 observations 2007 Nov. 8-Dec. 19"**, and confirm that the RMS error is below 1". If that's all true, then it's time to grab the output files from the *Find_Orb* folder. Drag the *elements* and *mpc_fmt* text files from there to your group's *"2007 WD5/Orbit Results/**Epoch 2/Data Set B**"* folder.

Then update your orbits to the new epoch: (**1**) Copy the *mpcorb.dat* file from your folder *"Epoch 1 / Data Set B"*, and paste it into the *"INTEGRAT / Input"* folder *(replacing the old file if necessary)*. (**2**) Run **"Integrate MPCORB to 20080130"**, and wait a few minutes for it to finish. (**3**) Move the new *mpcorb.dat* file from *"INTEGRAT / Output"* to your *"Epoch 2 / Data Set B"* folder. (**4**) Open this new *mpcorb* file, and confirm that the 4th column reads **"`K081U`"**; if not, then this is the wrong file! (**5**) Trim *mpcorb* down to exactly 2,999 lines, and save it. (The best-guess orbit will make an even 3,000.)

Creating Data Set C:

From Dec. 29th – Jan. 9th, astronomers observed the asteroid 18 more times. These are included in the file:

2007 WD5/Astrometry/2007 WD5 as of 2008-Jan-09.rwo.txt

But that file currently lacks your measurements from Lab #2, which are in the file named something like:

2007 WD5/Astrometry/2007 WD5 as of 2007-Dec-28.rwo.txt

Please open both of these files in text viewers, and copy the appropriate 3 lines of data from one to the other. *(In both files, they should immediately follow the line that says, "Add new data here.")* Save the new Jan. 9th astrometry file, which you will now use to create Data Set C.

In *Find_Orb*, click the "Open…" button and open the file named something like:

2007 WD5/Astrometry/2007 WD5 as of 2008-Jan-09.rwo.txt

*(If the first 3 lines in the astrometry box are not from observatory code **645**, then you have the wrong file!)* Make sure that you **check all perturbers**, and **change the Epoch value to "2008 01 30"**. *No other steps are necessary, because the "bad" measurements that had been marked with an "X" are now excluded, and the program now has enough data that it doesn't require our guesses for R1 and R2.* **Now click Auto-Solve.** Check that the last line of the "Orbital elements" box says: **"From 44 observations 2007 Nov. 8-2008 Jan. 9"**, and confirm that the RMS error is below 1". If that's all true, then it's time to grab the output files from the *Find_Orb* folder. Drag the *elements* and *mpc_fmt* text files from there to your group's *"2007 WD5/Orbit Results/**Epoch 2/Data Set C**"* folder.

While you have the *Find_Orb* folder open, make sure to delete the file there called *mpcorb.dat*, if it exists. You are about to ask the program to put thousands of lines of orbital data into that file, but if the file already exists they will be appended at the end, and that will mean more work for you.

Since you have not used this data set before, you can't use *INTEGRAT* to quickly update the epoch. Go back to Find_Orb and click on the **Monte Carlo** button. Take note of the current time, and remember to come back to collect its output in about 25 minutes, when the number or orbits generated gets above 3,000. At that point, you will *click the Monte Carlo button (now labeled with the running orbit-count) again to stop the process.* You will then drag the *mpcorb.dat* file from the *Find_Orb* folder into your *"2007 WD5/Orbit Results/**Epoch 2/ Data Set C**"* folder. Finally, open up this new *mpcorb* file, trim it down to exactly 2,999 lines, and save it. (The best-guess orbit will make it an even 3,000.)

While you're waiting, please continue with the rest of the lab.
You won't need these Monte Carlo results until Part IV.

Part II: Estimating impact probabilities based on Data Set A (Nov. 20th – Dec 19th)

You'll find all of the data needed for the rest of this lab in the folder *"2007 WD5/Orbit Results/Epoch 2/"*. Begin by opening the folder *"Data Set A"*. Examine the *elements* text file, and confirm that this is the pre-SDSS data. (25 observations over 29 days, from Nov. 20th – Dec. 19th, 2007.)

You will now load the best-guess orbit for the asteroid into *Guide*, along with all of the clone orbits. Open the *"Killer Asteroids Project"* folder in a new window, and then open the *"guide8"* folder within. Copy the *mpcorb.dat* file from your other open folder (*"Epoch 2/Data Set A/"*), and paste it into here. (Replacing an existing copy is OK.) *Do not change its name, and don't put it into a subfolder!* *Guide* is very particular about the name and location of the file from which it loads its asteroids. Copying-and-pasting is important, because you will want to keep a copy of the file in your group's folders for future reference.

Open *Guide* by double-clicking the *"guide8 Shortcut"* icon in the *"Killer Asteroids Project"* folder. Select "Extras > Asteroid options" and click on the "Add MPC comets/asteroids…" button. At the bottom of the new window, click on the red "Add MPC asteroids/comets" hyperlink. Navigate to and select the *elements.txt* file in the *"Epoch 2/Data Set A"* folder mentioned above, then click OK. Finally, go back into "Extras > Asteroid options" and turn off the "Use MPCORB" checkbox, hit OK, and then repeat to turn it back on again. This will guarantee that your new set of clone orbits will replace any that had been previously loaded into *Guide*.

Next, you will load up the view from about 1.5 million kilometers (0.01 AU) above the north pole of Mars at Epoch 2. This is a good vantage point for making a few measurements of the potential impact. Check first that your home location ("Settings > Location…") is set for Mars, then load the mark file using "File > Load Mark…" and select **"Mars – '08 Jan 30 – 2007 WD5 – T."** ("T" stands for "Top View.") Confirm that your location is correct by right-clicking Mars, selecting "More Info," and checking your current distance from Mars. You should see thousands of yellow "×" marks representing all of the virtual asteroids you've loaded, as well as the disk of the planet Mars. Notice that the swarm has now stretched out into a long thin line, but remember that it is still made up of the same number of virtual asteroids as before (3,000).

Your first goal will be to determine the time at which the line of virtual asteroids aligns with the center of Mars. To begin, go to "Animation > Animation dialog…" or just press the " >> " button at the top of the screen. In the animation control window, use the "Faster" and "Slower" buttons to make the time-step button read "1 min." *(Negative time steps such as "-1 min" are nothing to worry about. They just mean that the last time you ran the animation, you had time flowing backwards.)* Make sure that "Locked on: Stars" is selected.

1. Use the " > " and " >> " buttons to find the moment when the line of virtual asteroids aligns with the center of Mars. (Zoom in or out (" * " or " / ") as necessary.) At what time does this occur?

Now zoom out until you can see all of the virtual asteroids at once. Identify two that are at opposite ends of the uncertainty region. *(If there are a few "stray" points on either end, you can ignore them.)* Do this by clicking at one end of the swarm, zooming in (" * " or Shift-8) and then right-clicking the one at the very end of the line. Jot down this object's clone-number, which will be given in the square brackets (" [ ] ") in the new window that pops up. *(If you try to right-click on an asteroid but end up with a background star or some other object instead, try clicking "Next." Repeat until you find the object you meant to click. This happens especially when the asteroid is directly in front of a brighter object, such as the planet Mars.)* Click "OK," zoom out (" / ") and repeat for the opposite end of the line. You will need to know how to find these two virtual asteroids again to answer Question 4.

From the pull-down menus, choose "Go to > Asteroid…" and type "2007 WD5" into the text box, then click OK. This will center the screen on the predicted position of the asteroid, based on our best guess at its orbit. Zoom in until it's obvious which "×" you're centered on, then right-click on it and hit "Center" to keep it from running away once you start the animation.

2. In the animation control panel, select "Locked on: Moving" and hit the ">>" button to start the flow of time. Does the best-guess predicted path for 2007 WD_5 (the yellow "×" at the exact center of the screen) seem to be on a collision course with Mars?

Reset the time and date to match your answer from Question 1, and recenter on 2007 WD_5 if necessary. Zoom in again to find the "×" that you're centered on, then right-click on it and hit "OK". Next, type the less-than sign " < " (Shift-comma), which will transport you to that asteroid as your new home viewing location. You should now see a line in the legend that says "Home = 2007 WD5." Then "Go to > Planet…" and select Mars, zooming out until you can see the whole planet. Finally, right-click on Mars, click "More Info", and use the on-screen info to answer the following question.

For Questions 3, 4, and 7, please enter your answers in Table 1, provided on the last page of this document. Tear that page off and include it with your work when you hand it in.

3. What is the **distance in *kilometers*** between Mars and our best-guess position for 2007 WD_5? *("Dist from home planet" is a handful of lines from the top of the "More info" window. In this case, "home planet" means 2007 WD_5, our current viewing location.)*

Select "Go to > Asteroid…", enter the clone-number of one of the endpoint asteroids you identified previously, and hit "OK". *(If Mars is in the way, you'll need to run time forward or backward until it's just barely out of the way.)* Zoom in until it's obvious which "×" you're centered on, then right-click on it and confirm that it's the one you were looking for. This time, after clicking "OK," type the less-than sign " < " to transport yourself there. You should now see a line in the legend that says "Home = " followed by the object's clone-number. From the pull-down menus, choose "Go to > Asteroid…" and enter the clone-number for the opposite end of the line. *(If Mars is in the way, see above.)* Zoom in until it's obvious which "×" you're centered on, then right-click on it and confirm that it's the one you were looking for. Finally, click "More info" and answer the following question.

4. What is the **distance in *kilometers*** between your "home planet" (the asteroid you are currently viewing *from*) and the other end of the line? Divide this distance by 2 to arrive at the uncertainty in the asteroid's best-guess predicted location in space. **Remember to enter your answer to this question in Table 1.**

Now, switch to the view from 40,000 km above the surface of Mars by loading the mark file **"Mars – '08 Jan 30 – 2007 WD5 – S."** ("S" stands for "Side View.") Right-click on Mars and choose "Center" to keep it from running away. Choose an animation time-step of about "1 min" and make sure "Locked on: Moving" is selected, then click " >> " to set time in motion.

5. Do any of the virtual asteroids seem to hit Mars?

If you answered "Yes" to this last question, then you will need to **count** the number of virtual asteroids that **do** appear to impact Mars. They will disappear as they pass through the surface of the planet! You shouldn't expect to see a bunch of tiny impact craters forming, though. Remember that each of these is just a *possible* predicted location for the asteroid, so there would be **at most** one real impact. Also, notice that some of the clones disappear by **slipping behind Mars from the side**, and **do not impact the surface**. These are not to be counted as impactors. You should also **not** count any "×" that disappears after only its "legs" were in front of the planet; it's the **center** of the "×" that counts! *(To make it easier to see each individual "×", you should probably turn off the labels by right-clicking on any asteroid, hitting the "Display" button, clearing the "Label" checkbox, and hitting "OK.")*

Back up time to before the impact, reduce the time-step to 5-15 seconds, and then click time forward slowly until you see the **rightmost** impactor disappear. Jot down this clone's number as before, then repeat to identify the **leftmost** impactor. Between these two, you should find that **every** clone hits Mars, and that there are no other impactors to be found. Back time up again to before the impact, and count all of these virtual impactors. You may need to zoom in and move slowly along the swarm, so that you don't miss any. *(Unfortunately, the number of virtual impactors <u>is not</u> the same as the difference between the clone-numbers for the leftmost and rightmost impactors. The reason this doesn't work is that the Monte Carlo process that generated these clones is a random process, so the clones are all out of order.)*

6. How many virtual impactors are there, based on these data?

7. Calculate the impact probability by dividing the number of virtual impactors by 3,000. Express this value as a percentage, accurate to at least a tenth of a percent. **Remember to your answer to this question in Table 1.**

8. This time, divide 3,000 by the number of virtual impactors. (This is the *inverse* of your calculation for Question 7). Round your answer to the nearest integer and call it *N*. Finally, write the impact probability as "1-in-*N*". *(This is roughly equivalent to your previous answer: 1-in-N = 1÷N ≈ 1÷(3000/x) = x/3000. Note also that <u>large</u> values of N mean <u>small</u> probabilities: 1-in-10=10%, but 1-in-1000=0.1%.)*

9. Compare your answers above with the estimated 0.033% (1-in-3,030) chance that the asteroid **2007 VK_{184}** will hit the Earth on June 3, 2048. This is currently the object of greatest concern to the folks at NASA who worry about such things. Based on your calculations, should the Martians be worried about 2007 WD_5? *(For the sake of argument, assume that Martians exist.)*

Part III: Repeat based on Data Set B (Nov. 8th – Dec 19th)

You will now repeat all of the steps of Part II, but using the data in the folder **"Epoch 2 / Data Set B"**. When you examine the *elements* text file, confirm that they now include the SDSS data (observatory code 645). There should be a total of 28 observations from Nov. 8th – Dec. 19th, 2007. When you added the 3 SDSS positions, you boosted the time spanned by the observations from 29 days to 41 days.

10. Answer questions 1 – 9 again based on these new data. (Label them as 10.1 – 10.9.) **Remember to enter your answers to Questions 10.3, 10.4, and 10.7 in Table 1.**

11. *Compare 3 & 10.3:* Has the new best-guess path for the asteroid brought it closer to Mars?
Compare 4 & 10.4: Has the uncertainty region gotten smaller since last time?
Compare 7 & 10.7: Has the impact probability increased or decreased? How many times bigger or smaller is it?

12. Consider that the total number of clones has stayed the same, even though the physical size of the uncertainty region has changed. Should this have *increased* or *decreased* the density of virtual asteroids within the swarm? (That is, the number of virtual asteroids within every Mars-sized chunk of the swarm.) Does this explain the change in the impact probability? If so, how so? If not, why not?

Part IV: Repeat based on Data Set C (Nov. 8th – Jan 9th)

Again, repeat all of the steps of Part II, but using the data in the folder **"Epoch 2 / Data Set C"**. When you examine the *elements* text files, notice that there are now a total of 44 observations from Nov. 8th, 2007 – Jan. 9th, 2008. Shortly after the increase in impact probability based on the SDSS data, observatories from across the western hemisphere got into the act, submitting observations to improve the accuracy of the orbit. Eighteen new positions were reported, boosting the time spanned by all the observations to 62 days.

(Two "bad" observations that had been included before have now been dropped: 28 + 18 – 2 = 44.) You will now see how these additional observations affected both the size of the uncertainty region and the estimated impact probability.

13. Examine the file *2007 WD5 as of 2008-Jan-09.rwo*, which is back in your *Astrometry* folder. How many observatories contributed positions after Dec. 25th? How many total observatories were involved in measuring this asteroid? *(Look for the "Obs Cod" column near the end of each line of data.)*

14. Answer questions 1 – 9 again based on these new data. (Label them as 14.1 – 14.9.) **Remember to enter your answers to Questions 14.3, 14.4, and 14.7 in Table 1.**

Note: If you found **no** virtual impactors this time around, please reconsider Questions 14.7 & 14.8. Could you really say that the impact probability has dropped to zero? If you went back and used ten times as many clones, you might end up finding a few impactors. Then the chance of impact might be very small, but it would **not** be zero. Therefore the most you would be able to say is that the impact probability was **less than 1-in-3,000 (< 0.03%)**.

15. *Compare 10.3 & 14.3:* Has the new best-guess path for the asteroid brought it closer to Mars? *Compare 10.4 & 14.4:* Has the uncertainty region gotten smaller since last time? *Compare 10.7 & 14.7:* How has the impact probability changed?

16. Draw 3 diagrams *(roughly to scale)* of the encounter between 2007 WD_5 and Mars, based on your results from Table 1. Each diagram should represent one of the Data Sets (A – C), and should include all of the following:
    - the asteroid,
    - the asteroid's uncertainty region,
    - the planet Mars,
    - a numerical label of the distance between the asteroid and Mars, and
    - a numerical label of the uncertainty in the asteroid's position.

17. Based on your diagrams, explain how the new position (*14.3*) and size (*14.4*) of the uncertainty region have caused this change in the impact probability. ***<u>Provide numerical support for your answer!</u>***

No further observations of 2007 WD_5 were made after Jan. 9th, 2008. In part, this was because it was getting much fainter as it got farther from Earth, and finding it required a 2.2-meter (7.2-foot) diameter telescope on the night of Jan. 9th. However, the largest optical telescope on Earth is **twenty times** more powerful than that, and astronomers could've also pressed the Hubble Space Telescope into service, if necessary. So…

18. Based on your answers to previous questions, why do you think astronomers stopped observing 2007 WD_5 at this point? *(Think about why they were interested in this asteroid in the first place.)*

In the past, astronomers have been accused of "crying wolf" for publicizing impact predictions for asteroids headed toward Earth, when the probabilities later drop to essentially zero. However, astronomers now know that this same sequence of events will recur nearly every time: (1) A potential impact is identified, (2) the odds of impact increase up to some peak value, and then (3) they plummet to nearly zero.

19. The uncertainty region for the date of the potential impact will always *decrease* in size as new observations are made. Smaller uncertainty regions mean that only asteroids passing within a *smaller* distance of the planet will be seen as potentially threatening to that planet. *(See Figure 1 below.)* Eventually, the uncertainties may become *tiny*. Does this explain why <u>most</u> asteroids initially called threats will eventually be seen as non-threats? Justify your answer.

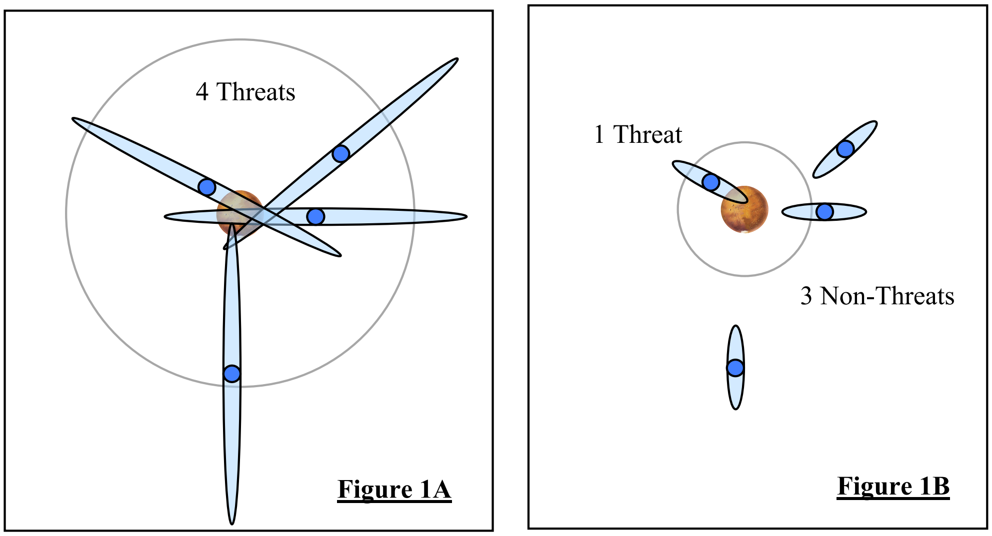

Figure 1 – Four asteroids are predicted to make close approaches with Mars (not necessarily all at the same time). All four are moving *away* from you, perpendicular to the page. The predicted position of each asteroid is shown as a blue dot, each with its own uncertainty ellipse. All uncertainty ellipses within each panel are the same size, but they are 3× smaller in panel B as in panel A. The increased precision leads to a reduced threat to Mars, because only those asteroids passing *closer* to the planet still have the potential to collide with it.

NASA was so confident that the impact probability would eventually become negligible that they said so in nearly every one of their press releases regarding 2007 WD_5. On the other hand, we *know* that these impacts happen periodically. Craters and mass extinctions prove that they've happened on Earth in the distant past, and the collision of Comet Shoemaker-Levy 9 with Jupiter in July 1994 showed that such things are still happening in the Solar System today. Yet, some astronomers believe that these early impact probability estimates should not be publicized, so as to prevent the public from making any rash decisions under the threat of doomsday.

20. *Personal Response:* Do you believe that potential impacts should be publicized as soon as they are discovered, or would you rather see astronomers keep quiet about these early estimates until the uncertainties have been reduced? Justify your answer.

Continued on next page…

Part V: Cleaning Up After Ourselves

As has been mentioned previously, you may be sharing your computer with students in another section of this class. To avoid hassle and confusion for them, please do the following:

- In *Guide*, delete the orbit for 2007 WD_5 that you loaded from the *elements* file. *(Select "Extras > Asteroid options", then click on the "Edit Comet data…" button. If 2007 WD5 is on the list, double-click its name and then click the "Delete" button.)*

- Make sure that you have not left a file named *mpcorb* in the *Find_Orb* folder. Delete it if it exists.

- Make sure all of the files you have saved are in your own group's folder within *"Killer Asteroids Project/Student Data/"*

Appendix: Organizing your data

Table 1: Analysis of the close encounter between 2007 WD_5 and Mars

Which Data?	Distance between Mars and 2007 WD_5	Uncertainty in Predicted Position	Impact Probability
Data Set A (Nov. 20 – Dec. 19)	*Question 3:* ___________ km	*Question 4:* ___________ km	*Question 7:* ___________ %
Data Set B (Nov. 8 – Dec. 19)	*Question 10.3:* ___________ km	*Question 10.4:* ___________ km	*Question 10.7:* ___________ %
Data Set C (Nov. 8 – Jan. 9)	*Question 14.3:* ___________ km	*Question 14.4:* ___________ km	*Question 14.7:* ___________ %