

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

GOALS: The goal of this assignment is to use the uncertainty in 2007 WD₅'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.

Remember to login to the computer using the following account, **not** your UAA active directory!

USERNAME: student
PASSWORD: labnet

Part I: Generating new orbital elements for a new epoch

In Lab #2, you discovered that the sky position of asteroid 2007 WD₅ 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 WD₅ 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, *Starry Night* 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.

Updating Data Set A:

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 (check all perturbers, set R1=.05 and R2=.15, and toggle-on the two observations marked with an "X"). However, this time you'll also need to **change the Epoch value to "2008 01 30"**, 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/Epoch 2/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 “*Epoch 2 / Data Set A*” folder. (4) Open this new *mpcorb* file, and confirm that the 4th column reads “**K081U**” (meaning 2008/01/30); if not, then this is the wrong file! (5) As before, use the website <http://puck.uaa.alaska.edu/mpcorb2astorb/> to combine the *mpc_fmt* and *mpcorb* files from *Data Set A* into a single *Asteroids.txt* file, remembering to: (a) skip or delete the first 6 lines of *mpcorb*, which contain extraneous info added by *INTEGRAT*, and (b) use the option to “Boost brightness by 5 mags”.

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) As before, use the website <http://puck.uaa.alaska.edu/mpcorb2astorb/> to combine the *mpc_fmt* and *mpcorb* files from *Data Set A* into a single *Asteroids.txt* file, remembering to: (a) skip or delete the first 6 lines of *mpcorb*, which contain extraneous info added by *INTEGRAT*, and (b) use the option to “Boost brightness by 5 mags”.

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 of 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, you'll use the website <http://puck.uaa.alaska.edu/mpcorb2astorb/> to combine the *mpc_fmt* and *mpcorb* files from *Data Set C* into a single *Asteroids.txt* file, remembering to use the option to "Boost brightness by 5 mags".

**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 *Starry Night*, along with all of the clone orbits. Open the "*Killer Asteroids Project*" folder in a new window, and then open the "*Starry Night Sky Data*" shortcut within. Copy the *Asteroids* file from your other open folder ("*Epoch 2/Data Set A*"), and paste it here. (Replacing an existing copy is OK.) Do not change its name, and don't put it into a subfolder! *Starry Night* 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 *Starry Night* (or close and restart it, if it was open) by double-clicking on "*Starry Night Pro Plus 6*" on the desktop. Remember **not** to let it update its data files from the internet, if it asks. Confirm that the asteroids have been loaded by opening the **Find** tab, expanding the **Asteroids** entry, then clicking repeatedly on the gray bar at the top of the **Name** column to change the sort order (alphabetical, then reverse alphabetical). **Confirm that you have exactly 3,000 asteroids listed here.**

Next, you will load up the view from about 1.5 million kilometers (0.01 AU) above the north pole of Mars. This is a good vantage point for making a few measurements of the potential impact. Select "File > Open..." within *Starry Night*, navigate to "*Starry Night Scenarios*" in the "*Killer Asteroids Project*" folder, and open the file labeled "**above Mars.**" Confirm that the Viewing Location box at the top of the screen says you are "0.010 au from Mars." Next, reset the date to "**January 30, 2008.**" 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).

1. Set the time-flow rate to "1 minute", and step time forward until the line of virtual asteroids aligns with the center of Mars. (Zoom in or out, as necessary.) At what time does this occur?
2. Zoom out until you can see both Mars and the asteroid labeled "2007 WD5". This predicted position for the asteroid is based on our best guess at its orbit. Does this best-guess position seem to be on a collision course with Mars? (*You may need to continue to run time forward to convince yourself of the answer.*)

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. Reset the time and date to match your answer from Question 1. Using the **Angular Separation** tool, draw a line between Mars and 2007 WD₅. Underneath the **red** text that says “Angular separation,” there will be **blue** text that gives the distance between them. What is the **distance (in AU or km)** between 2007 WD₅ and Mars at this time?
4. Zoom out further, until you can see the entire line of virtual asteroids. Use the Angular Separation tool again, this time to measure the **distance (in AU or km)** from one end of the line to the other. (*If there are a few “stray” points on either end, you can ignore them.*) What is the uncertainty (in AU or km) in the asteroid’s best-guess predicted location in space? (*Remember to “÷2”.*)

Now, “File > Open...” to load the scenario file labeled **“beside Mars.”** This will change your location to roughly 40,000 km above the potential impact zone on the planet’s surface. (Confirm this with the Viewing Location info at the top of the screen.)

Warning: *As soon as you load up this scenario file, you should immediately switch over to the Hand tool. (The Tool Selector is in the upper-left corner, to the left of the Time and Date controls.) The tool that comes up by default is the Adaptive Hand, which automatically changes to other “useful” tools depending on what you are doing. Unfortunately, in this case it likes to turn into the Location Scroller, which will rotate Mars beneath you. Due to the limitations of Starry Night, changing your perspective in this way drastically changes your impact probability estimates! So stick with the regular Hand tool.*

Now, when you reset the date to **“January 30, 2008”** you should see the virtual asteroids come back into view. Right-click on Mars and choose “Center” to keep it from running away. Choose a Time Flow Rate of “30 seconds” and set time in motion.

5. Do any of the virtual asteroids look like they might 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.

Back up time to before the impact, and then click time forward slowly until you see the **rightmost** impactor disappear. Keep stepping time forward until you see the **leftmost** impactor disappear. (It may help to mark them both in red using the checkboxes in the **Find** tab. Jot down their names, then alphabetize the list to find them more easily.) 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 dots that overlap. (*Unfortunately, the number of virtual impactors is not 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: $1\text{-in-}N = 1 \div N \approx 1 \div (3000/x) = x/3000$. Note also that large values of N mean small 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 VK₁₈₄** 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 WD₅? (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?
(It may help to compare distances if you convert using $1 \text{ AU} = 150 \text{ million km}$.)
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?
(It may help to compare distances if you convert using $1 \text{ AU} = 150 \text{ million km.}$)
16. **Draw 3 diagrams (*roughly to scale*)** of the encounter between 2007 WD₅ 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. **Provide numerical support for your answer!**

No further observations of 2007 WD₅ 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 WD₅ 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 most asteroids initially called threats will eventually be seen as non-threats? Justify your answer.

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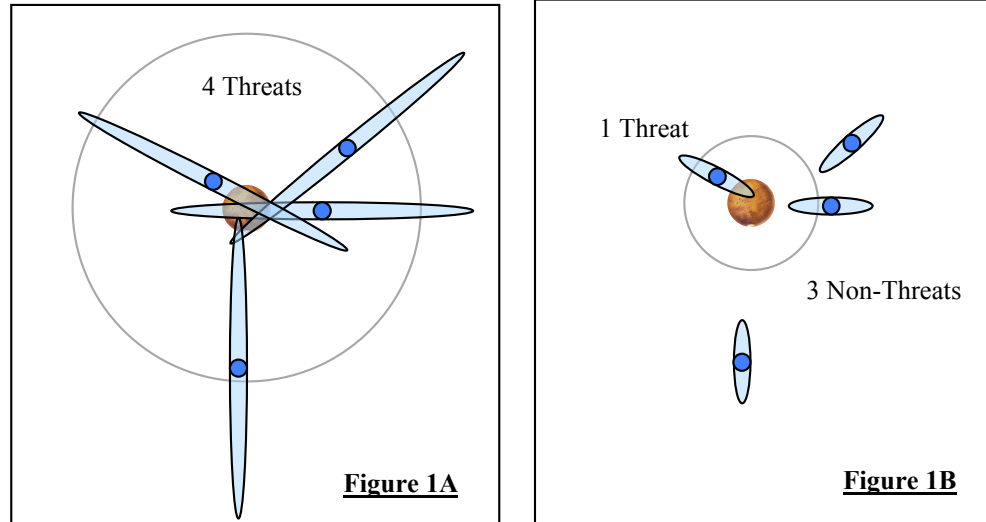


Figure 1 – Four asteroids are predicted to make close approaches with Mars (not necessarily all at the same time). All four are moving *away* from you, perpendicular to the page. The predicted position of each asteroid is shown as a blue dot, each with its own uncertainty ellipse. All uncertainty ellipses 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 WD₅. 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.

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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 the “*Starry Night Sky Data*” folder, locate your *Asteroids* text file. Delete it, *but first make sure that you saved a copy in your group’s folder!*)
- 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 WD₅ and Mars

Which Data?	Distance between Mars and 2007 WD₅	Uncertainty in Predicted Position	Impact Probability
Data Set A (Nov. 20 – Dec. 19)	<i>Question 3:</i> _____ AU _____ km	<i>Question 4:</i> _____ AU _____ km	<i>Question 7:</i> _____ %
Data Set B (Nov. 8 – Dec. 19)	<i>Question 10.3:</i> _____ AU _____ km	<i>Question 10.4:</i> _____ AU _____ km	<i>Question 10.7:</i> _____ %
Data Set C (Nov. 8 – Jan. 9)	<i>Question 14.3:</i> _____ AU _____ km	<i>Question 14.4:</i> _____ AU _____ km	<i>Question 14.7:</i> _____ %