Killer Asteroids Lab #2: Understanding the changing uncertainties of asteroid orbits

GOALS: The goal of this assignment is to understand the uncertainties inherent in the orbits and predicted positions of asteroids, and how these uncertainties change with time and with the inclusion of new data. In the previous lab, you used early observational data for 2007 WD$_5$ to determine its orbit and thousands of alternate possible orbits. From these, you predicted the position of the asteroid on the date that it was observed by the Sloan Digital Sky Survey. Today you will use this prediction to locate the asteroid in the images. You will then add its positional information to the previous observational record and regenerate the possible orbits. Comparison of the "before" and "after" cases will reveal how successive observations improve our knowledge of asteroid orbits.

It is very important that you read this document carefully and follow all of its instructions. Each step depends on those that precede it, and the data you produce now will be used in the weeks that follow.

Remember to login to the computer using the following account, **not** your UAA active directory!
    USERNAME: student
    PASSWORD: labnet

In Lab #1, you learned how to use four important tools that will aid you in your study of asteroid orbits and impact risks:
- Measuring positions in astronomical images using *ImageJ* and the *Polaris Plugin*,
- Determining orbits based on measured positions using *Find_Orb*,
- Understanding how the seven orbital parameters specify an orbit around the Sun, and
- Using *Find_Orb* to predict asteroid positions based on their orbital parameters.

Specifically, you determined the best possible orbit for the asteroid 2007 WD$_5$ based upon 25 positions from November 20th – December 19th, 2007. In addition, you found over 3,000 alternate possible orbits that were also a reasonable fit to that data, which we will now refer to as **clone orbits** or **virtual asteroids**. These data should be stored in your group's folder under *"2007 WD5/Orbit Results/Epoch 1/Data Set A"* with the following filenames:
- *mpc_fmt.txt* – The best orbit solution, in *machine-readable* format.
- *elements.txt* – The best orbit solution, in a more *human-readable* format.
- *mpcorb.dat* – The 3,000+ clone orbits you generated, in the same format as *mpc_fmt.txt*.

In our shorthand notation, the 1st epoch is the date of the SDSS observations (Nov 8, 2007) and the 2nd is the date of the close encounter with Mars (Jan 30, 2008). Next week you will need to recalculate your orbits at Epoch 2 in order to get accurate estimates of the impact probabilities, but this week you will stick with Epoch 1.

Before we make use of the 3 aforementioned files, let's get your computer busy making the *next* set of 3. These will be based on the additional measurements that *you* are about to make of the asteroid's position. So, first things first…

Part I: Adding in the SDSS imaging data

In Question 8 of Lab #1, you predicted the position of 2007 WD$_5$ for the night of Nov 8, 2007 (Epoch 1). You should have come up with the following coordinates:
                    RA: 2h 48m 40.927s
                    Dec: -00° 57' 29.08"
Your next step will be to download the images of this position from the Sloan Digital Sky Survey website. However, to do this you will first have to convert these coordinates from the usual XX:YY:ZZ format into *decimal degrees*. To that end, please open the Excel spreadsheet file **Coordinates-Converter.xls**, which should be in your group's folder within *"Killer Asteroids Project/Student Data/"*.

To convert to the new format, simply enter the RA and Dec values from above into the appropriate cells in the row labeled *Position 1*. Once all seven of the white cells are filled, the two grey cells on the right will contain the RA and Dec in degrees. Now if you select and copy those two cells, you'll be able to paste them directly into the website that follows. *(If you'll be completing your own asteroid orbit refinement project later in the semester, you will use a similar technique to download the necessary images.)*

Next point your browser to the *SDSS Data Archive Server Coordinate List Submission Form*:
http://das.sdss.org/www/html/post_coords.html

Paste your spreadsheet results into the form, put a comma between the two coordinate values, and then delete any other positions that had been entered by default. Click *"Submit Request"*, and you will be presented with a long list of all the images of that position that have been taken by the survey, going all the way back to 1998. Click the link next to Run #7142, which was imaged on the same date and time as our prediction. The images you'll want to download are the **Corrected Frames** files for the **g, r, & i** filters. Right-click each file in turn, saving each one to your group's *"2007 WD5/Images/"* folder. Then, press your browser's "back" button and click the link for Run #2700. Again, download the *Corrected Frames* files labeled *g, r, & i*. These will serve as *reference images*, which were taken of the same position but at a very different date and time. They are guaranteed *not* to contain the asteroid, so they will help you to correctly identify it in the images that *do* contain it.

You should now have the following files saved in your *"2007 WD5/Images/"* folder:
fpC-002700-g1-0147.fit.gz	*fpC-007142-g1-0183.fit.gz*
fpC-002700-i1-0147.fit.gz	*fpC-007142-i1-0183.fit.gz*
fpC-002700-r1-0147.fit.gz	*fpC-007142-r1-0183.fit.gz*

These images have been **g-zipped**, and they will need to be decompressed with a program like *7-Zip* (or *WinZip*) before they can be opened with *ImageJ*. If you select all of them at once, you should then be able to right-click them and select *7-Zip > Extract Here*.

Now you can finally get your hands on the images! Run the image analysis program **ImageJ** by double-clicking its icon on the desktop (or by finding it in the Start Menu). This will open the ImageJ toolbar, which has the traditional Windows pull-down menus along the top. Open the series of images using "File > Import > Image Sequence…" and select any one of the 6 images listed above. When the "Sequence Options" window pops up, just click OK. The images will appear black and almost featureless due to poor contrast settings, but the *Polaris Plugin* will take care of this.

Select "Plugins > Polaris > Polaris Plugin Options" and make sure the settings are as follows.
Checked:	Invert, Align, Hyper-stack, & Auto-contrast images on load	
Unchecked:	Seek brightest pixel & Write to log file	
Output Format:	RWO	
MPC Designation:	K07W05D	*(Those are zeros. All caps, no spaces.)*
RWO Designation:	2007WD5	*(Those are zeros. All caps, no spaces.)*
Observatory Code:	645	
Checked:	Astrometric output only	

Capitalization and spacing do matter! When you click "Apply," it's OK if these preferences cannot be saved for future use, but rest assured that they will be used presently.

Start the plugin using **"Plugins > Polaris > Polaris Plugin."** The screen will flicker a few times as the images are inverted and aligned, and reasonable contrast settings are found. In fact, the images come out a bit dark, so adjust the contrast of the images with "Image > Adjust > Brightness/Contrast…". Click 1-2 times on the second slider's right-arrow to brighten up the first image, and repeat for the remaining images.

The image sequence can now be animated using the backslash (\ ) keyboard shortcut. If they flip by too fast, the speed can be adjusted with "Image > Stacks > Animation Options…". The exposure times and the delays between the images are identical to the asteroid we called *Keanu* that you examined in Lab #1, but 2007 WD$_5$ is fainter and moving slower. However, it is still moving fairly quickly, so it *may* stand out in the animation. Can you see it? It should be near the **predicted position** listed at the beginning of Part I. You can locate this position within ImageJ by watching the RA and DEC coordinates change as you move

the mouse over the image. You may find useful the **Point Selections** tool, which lets you lay a small set of cross-hairs on the image with a click of the mouse. Once you have found the predicted position (to the nearest pixel), jot down its X and Y pixel coordinates so you can find it again quickly later on. Use the ImageJ magnifying glass tool to zoom in on this position. Can you see the asteroid now? *Remember that it should **only** be in the final three images of the animation, and **not** in the first three.* When you have found it, zoom in so that all 3 asteroid streaks as well as the predicted position all fit nicely in the image window. Finally, stop the animation by once again hitting the backslash key (\ ).

 *Warning: The streaks in the 3 images **should not overlap each other!** The asteroid is just a dot of light, which appears as a streak because it moved while the image was being taken. When the shutter opens for the next exposure, the asteroid picks up where it left off. So together, the streaks should look like a dashed line with uneven spaces in between. If your streak doesn't move from image to image, you've probably found yourself a galaxy instead of an asteroid. You should also be able to distinguish between them by consulting your **reference images**: Your asteroid should **not** be present in them, while a galaxy should be at the same location in **all** of your images.*

1. Use the scroll bar at the bottom of the image window to switch to the *final image* of the sequence. *(<u>Scroll all the way to the **right</u>**). How close is the **predicted** position of the asteroid to its **actual** position in the image? (Your answer can be qualitative at this point. Describe it in <u>words</u>, not numbers!)*

Now you will measure the positions as you did in Lab #1. You may want to switch to either the Scrolling (hand icon) or Rectangular Selections tools, to make your clicks more accurate and to avoid unwanted zooming. <u>Make sure that the image window is selected</u>, and move the mouse to the center of the asteroid streak. It is important that you point accurately at the midpoint of the streak, because the position of the mouse is the one that will be measured. When you are happy, press the space bar to record this location. The position will be marked on the image, and the measurement data will appear in the "Measured Magnitudes" box near the bottom of the data panel. (You may have to scroll to the right or detach and widen the panel to see the complete RA and Dec.) Repeat for each of the last three images. If you make a mistake, you can remove the last measurement by clicking the "Clear Last Measured" button, or you can clear all of them with the "Clear All" button. When you're finished, there should be exactly three entries in the "Measured Magnitudes" box.

2. From the "Measured Magnitudes" box, what is the position you measured (RA and Dec) for the asteroid streak in the *final image* of the sequence? *(<u>Scroll all the way to the **right.</u>**)*

In *ImageJ*, underneath the "Measured Magnitudes" box, click the "Copy Results" button to stash the results on the clipboard. Now navigate to your group's folder and open up the following file in a text viewer (by double-clicking):
    2007 WD5/Astrometry/2007 WD5 as of 2007-Dec-28.rwo.txt
This filename references Dec 28th because this was the date that NASA originally acknowledged these new measurements with an updated press release. Paste your new results between the two lines that say "Add new data here" and "End of record." ***If the designations in the first column don't match the others in the file <u>(including capitalization)</u>, you will need to change your new lines to match.*** Save your changes to the file, keeping the filename the same.

You will now repeat the orbit determination for 2007 WD$_5$ based on this new data. In the *"Killer Asteroids Project"* folder, double-click the *"Find_Orb Shortcut"* icon, which looks like a bunch of dots orbiting a yellow sun. Then click the "Open…" button and double-click on *<u>the astrometry file you just saved</u>*.

First, double-check that your newly-measured positions are shown here. ***There should be 3 new lines at the top of the data window, from observatory code 645 on November 8th, 2007. If not, then you need to do some troubleshooting:** Are you sure you opened the correct file? Do you see multiple designations in the box directly below the "Open…" button in Find_Orb? If that's the case, go back and re-read the warning a few paragraphs ago regarding designation-matching (including capitalization). **You will need to resolve these issues before you continue!***

Next, **check all of the boxes in the Perturbers section** at the top of the window, and **change the Epoch value to "2007 11 08"**. Also, you'll need to supply *Find_Orb* with guesses for the asteroid's distance from the Earth on the first and last dates of observation. Try **R1 = 0.1 AU** and **R2 = 0.3 AU**, which were roughly the values found in Lab #1. Then, locate the two inactive observations marked with X's in the astrometry window, and use the "Toggle Obs" button to reactivate them. Finally, click the Auto-Solve button. Notice that the RMS error drops to about 0.7", which indicates that this orbit is a good fit to the observations.

*Warning: At this point, the last line of the "Orbital Elements" box should read: **"From 28 observations 2007 Nov. 8-Dec. 19."** This reflects the addition of your 3 new observations from Nov 8th. In addition, all of the Perturbers should be checked, and the Epoch should be set to the value indicated above. **If any of these are not the case, <u>your orbit will be incorrect.</u> Go back and try again!***

Next, you need to grab the output files from the *Find_Orb* folder before they get overwritten! Drag the *elements* and *mpc_fmt* text files from there to your group's *"2007 WD5/Orbit Results/Epoch 1/Data Set B"* 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.

Go back to Find_Orb and click on the **Monte Carlo** button, which will quickly start counting the number of virtual asteroid orbits that are being generated. Take note of the current time, and remember to come back to collect its output in about 25 minutes, when that number gets above 3,000. At that point, you will *<u>click the Monte Carlo button (now labeled with the running orbit-count) again to stop the process.</u>* You will then drag the *mpcorb.dat* file from the *Find_Orb* folder into your *"2007 WD5/Orbit Results/Epoch 1/ Data Set B"* folder.

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

Part II: Using Starry Night to understand the clone orbits

Last time, you generated files named *mpc_fmt*.txt and *mpcorb.dat*, which should reside in your group's folder under *"2007 WD5/Orbit Results/Epoch 1/Data Set A"*. These files contain the orbital parameters for the best-guess orbit of the asteroid and all of the clones, respectively. Unfortunately, they are in a format that we cannot use directly. First we must convert them to what is called **ASTORB-format**, in order to be able to plug them directly into Starry Night. In the same folder, you should find an empty text file named *Asteroids*. Once you have converted these data to the new format, you will paste them into this file. (Instructions follow.)

Using a web browser, open the following page:
> *http://puck.uaa.alaska.edu/mpcorb2astorb/*

Open the file *mpc_fmt*.txt in a text viewer (by double-clicking), copy its contents, and paste them into the <u>top</u> text box on the webpage. (Use *control-A* to select all contents of a file, *control-C* to copy the selection, and *control-V* to paste.) Repeat these steps for the file *mpcorb.dat*, making sure the contents are pasted in the <u>top</u> text box, but **<u>below</u>** what you've already pasted. *(This is just a text file with a funny extension, so you can use the same text viewer as before to open it.)* Look back over what you've pasted, and make certain that all of the columns line up with each other! A common mistake is to forget to copy a space at the beginning of a line, which would knock off the alignment of that line. Then, from the pull-down menu at the middle of the page, select **"Boost brightness by 5 mags"** to make the asteroids appear brighter in *Starry Night*. Finally, click the **Convert** button, and the bottom text box will fill up with the ASTORB-format data. Copy the entire contents of this bottom text box, paste them into the file *Asteroids* mentioned above, and make sure to save the file! *(If your mpcorb file contains significantly more than 3,000 orbits*

and this conversion seems to take forever, you can trim it down to just over 3,000 lines and you should see better results.)

Now you are ready to add these data to Starry Night. Unfortunately, you can only add a batch of new asteroids to its database by restarting the program, so make sure it is closed before you proceed. In the *"Killer Asteroids Project"* folder on your desktop, open the *"Starry Night Sky Data"* shortcut. Copy your *Asteroids* file from your group's folders, and paste it into this Sky Data folder. (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 Pro Plus 6" from the desktop, but **do not** let Starry Night update its data files at startup. Confirm that your asteroids are loaded by opening the **Find** tab at the left edge of the screen, expanding the **Asteroids** entry, then clicking repeatedly on gray bar at the top of the **Name** column to change the sort order (alphabetical, then reverse alphabetical).

> 3. After sorting alphabetically, what are the names of the **first 2** asteroids on this list? The **last 2**? *(They will probably look something like "K07W05D [123]" or "2007 WD5".)* Do these make sense, given that you expect there to be 3,000 clone orbits loaded?

Next, you'll need to set your viewing location. Select "File > Open…" within Starry Night, navigate to *"Starry Night Scenarios"* in the *"Killer Asteroids Project"* folder, and open the file labeled **"from SDSS telescope."** You will need to change Starry Night's time and date to **"1:53:48am November 8, 2007 AD."** This is the exact moment (in Mountain Standard Time) that 2007 WD$_5$ was imaged by the Sloan Digital Sky Survey, which we are calling Epoch 1.

Note: You can change most parts of the time and date (hours, minutes, seconds, month, day, year) by clicking on the entry and entering the new value from the keyboard. **To change the month, you enter its numerical value from 1 – 12.**

You should also confirm that your **Viewing Location** is now set for either **"SDSS Telescope"**. *If any of the time, date, or location are wrong, your results will be wrong and your grade will suffer for it!* But if they're all correct, the field of view should contain the asteroid's predicted position (marked in red), located near the center of a swarm of greenish-white virtual asteroids. Center on the asteroid by right-clicking it and choosing **"Centre"**, then zoom in using the "+/–" near the upper right corner.

For Questions 4-8, 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.

> 4. Choose the **Angular Separation** tool (to the left of the Time & Date display), then drag your mouse from one end of the swarm to the other. *(If there are a few "stray" points on either end of the swarm, you can ignore them.)* The angle between those two points will be given in degrees, arcminutes, and arcseconds (° ' "). Divide this by 2 and you have a measure of the uncertainty of the predicted position. *(This math can get tricky, but it may help to think in terms of time. If your angle measurement is 3' 10", think of that as a time of 3min 10sec. Half of that would be 1min 30sec + 5 sec = 1min 35sec. Changing back to the correct angular units, your answer would be 1' 35".)*

> 5. Right-click on the asteroid and select "Centre" to make Starry Night track it as it moves. Switch the **Time Flow Rate** to **1 days**, and run time backward to November 1st. What is the value of the uncertainty on this date? *(Remember to "÷2".)* How many times bigger was the swarm on this date, just one week earlier than your previous measurement? *(Write this factor in the margin next to Table 1.)*

> 6. Now run time forward. On what date does the uncertainty *("÷2")* first reach 5" (arcseconds) or less? What is the value of the uncertainty on this date?

7. Continue to run time forward. What is the first date when the uncertainty *("÷2")* once again reaches 5" (arcseconds) <u>or more</u>?

8. Continue to run time forward to January 30, 2008, the date of the asteroid's close approach with Mars. What is the value of the uncertainty *("÷2")* for this date? (January 30, 2008.)

Your answers to Questions 6 and 7 define a range of dates when the uncertainty in the predicted position for 2007 WD$_5$ is particularly small. Compare this with the range of dates for which we have observations of the asteroid (see Question 4 of Lab #1, or the caption for Table 1). These two sets of dates seem pretty similar, don't they?
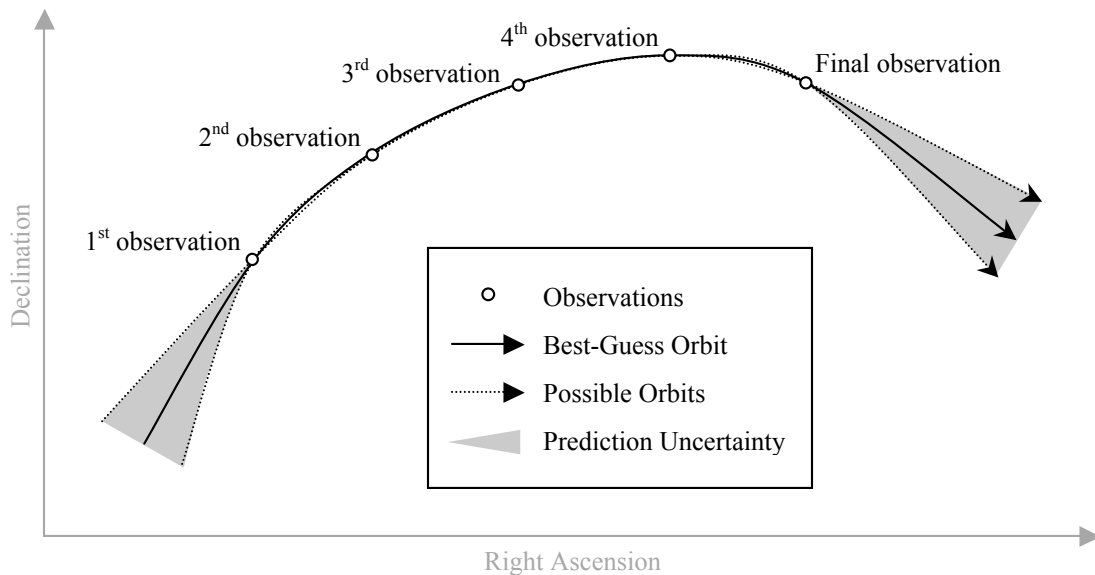
Figure 1 – A sketch of asteroid observations and resulting orbits.

Please refer to Figure 1 above to help you answer Questions 9 and 10.

9. Explain why you think the uncertainty in the predicted position is so small during the range of dates for which we have real observations of the asteroid. *(Give a reason for this behavior.)*

10. Explain why you think the uncertainty grows so much larger when you look beyond the range of dates for which we have real observations. *(Give a reason for this behavior.)*

Part III: Understanding the NEW clone orbits

It is now time to make use of the new orbits you generated in Part I above, which are based on the measurements <u>*you*</u> made of the position of 2007 WD$_5$. If you have not yet stopped the Monte Carlo process in *Find_Orb* or placed the resulting *mpcorb.dat* file in your group's folder, please see the instructions at the end of Part I.

You will now repeat the procedure from the beginning of Part II above. Convert the contents of *mpc_fmt* and *mpcorb* from *"2007 WD5/Orbit Results/Epoch 1/ Data Set B"* to the new format, and paste the results into the empty *Asteroids* text file. Next, copy-and-paste this file into the *"Starry Night Sky Data"* folder (probably overwriting your previous version, which is fine). Finally, close and restart Starry Night.

Select "File > Open…" within Starry Night and open the file labeled **"from SDSS telescope"** as before. Change the time and date to **"1:53:48am November 8, 2007 AD"**, and **confirm that your location** is one of the observatories listed previously. You should notice that the uncertainty region has shrunk considerably.

11. Answer Questions 4-8 again based on these new data. **Please enter your answers in Table 2, where they are labeled Questions 11.4-11.8.**

12. Have your answers to Questions 9-10 changed based on your newfound experience? If so, go back and change them.

13. Compare your results in Table 1 with those in Table 2. What have you accomplished by adding the SDSS data into the orbit solutions, regarding your ability to predict the asteroid's position in the sky?

14. An astronomer asks for your help to find 2007 WD$_5$ in images taken on Nov 1st, 2007. She does not have access to your images from Nov 8th, but you can tell her about your results. Without your help, the uncertainty in her predicted position would be given by Table 1. By helping her, you change her uncertainty to that of Table 2. **Have you made her job easier? If so, how much so?** *(Support your answer with numerical values from Tables 1 & 2.)*

15. In your own words, explain what the swarm of virtual asteroids on your screen represents. *(Look back at the description of the Monte Carlo method from Lab #1, if necessary.)*

Part IV: 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, *but first make sure that you saved a copy in your group's folder!*

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

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Appendix: Organizing your data

Table 1: Results based on observations from Nov. 20th – Dec. 19th, 2007

Date	Uncertainty	Notes
Nov. 1st, 2007		Question 5
Nov. 8th, 2007		Question 4
First below 5": _____ ____ 200__		Question 6
First above 5": _____ ____ 200__		Question 7
Jan. 30th, 2008		Question 8

Table 2: Results based on observations from Nov. 8th – Dec. 19th, 2007

Date	Uncertainty	Notes
Nov. 1st, 2007		Question 11.5
First below 5": _____ ____ 200__		Question 11.6
Nov. 8th, 2007		Question 11.4
First above 5": _____ ____ 200__		Question 11.7
Jan. 30th, 2008		Question 11.8