

*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<sub>5</sub> 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.**

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 *Guide* to predict asteroid positions based on their orbital parameters.

Specifically, you determined the best possible orbit for the asteroid 2007 WD<sub>5</sub> based upon 25 positions from November 20<sup>th</sup> – December 19<sup>th</sup>, 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 1<sup>st</sup> epoch is the date of the SDSS observations (Nov 8, 2007) and the 2<sup>nd</sup> 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<sub>5</sub> for the night of Nov 8, 2007 (Epoch 1). You should have come up with the following coordinates:

RA: 2h 48m 40.816s  
Dec: -00° 57' 29.60"

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. If you now select and copy those two cells, you can 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](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:

<i>fpC-002700-g1-0147.fit.gz</i>	<i>fpC-007142-g1-0183.fit.gz</i>
<i>fpC-002700-i1-0147.fit.gz</i>	<i>fpC-007142-i1-0183.fit.gz</i>
<i>fpC-002700-r1-0147.fit.gz</i>	<i>fpC-007142-r1-0183.fit.gz</i>

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<sub>5</sub> 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. (*Scroll all the way to the **right**.*) 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 words, 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. Make sure that the image window is selected, 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? (*Scroll all the way to the **right**.*)

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 28<sup>th</sup> 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 (including capitalization), 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<sub>5</sub> 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 the astrometry file you just saved.

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 8<sup>th</sup>, 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 Perturbbers 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 8<sup>th</sup>. 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, your orbit will be incorrect. 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 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 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 Guide to understand the clone orbits*

Last time, you generated files named *elements.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. You will now load these data into *Guide*.

In the "*Killer Asteroids Project*" folder, double-click the "*guide8 Shortcut*" icon, which looks like the constellation of Orion. Select "Extras > Asteroid options", then 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 "2007 WD5/Orbit Results/Epoch 1/Data Set A" in your group's folder, and select the *elements.txt* file found within. Click "OK" and this best-guess orbit will be loaded into the program.

Next, bring up the view from the telescope at Epoch 1, which is the exact moment (in Universal Time) that 2007 WD<sub>5</sub> was imaged by the Sloan Digital Sky Survey. Check first that your home location ("Settings > Location...") is set for Earth, then load the mark file using "File > Load Mark..." and choose "**SDSS - '07 Nov 8 - 2007 WD5.**" You should see the predicted position of the asteroid as a single yellow "x". (If you see a lot more than one asteroid, try going to "Extras > Asteroid options" and making sure that "Use MPCORB" isn't selected. If you don't even see one, then there's something wrong with your *elements* file.)

Now let's load in your 3,000+ clone orbits. There is no way to do this from within *Guide* itself, so you will need to place a copy of your *mpcorb.dat* file into *Guide*'s program folder. First, navigate to "2007 WD5/Orbit Results/Epoch 1/Data Set A" in your group's folder. Open the file *mpcorb.dat* in a text viewer, and determine how many orbits it contains.

3. Counting the best-guess orbit, how many total orbits are you loading into *Guide*?

Copy *mpcorb.dat*, and paste it into the “*Killer Asteroids Project / guide8*” folder. (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.

In the *Guide* program, go to “Extras > Asteroid options,” turn on “Use MPCORB,” then hit OK. You should now see a cloud of your “virtual asteroids,” probably labeled with their Monte Carlo orbit number. (You can turn off the labels by right-clicking on any asteroid, hitting the “Display” button, clearing the “Label” checkbox, and hitting “OK.”) Using the “\*” and “/” keys to zoom and left-clicks of the mouse to recenter, make the cloud of virtual asteroids fill the screen (without losing any asteroids off the edge).

**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. Measure the angular separation from one end of the swarm to the other: Right-click on the endmost asteroid at each end, and hit OK immediately afterwards. (*If there are a few “stray” points on either end of the swarm, you can ignore them.*) Hitting the *Insert* key will then pop up a window giving the length on the top line in both arcminutes (′) and arcseconds (″). Divide the arcsecond result by 2 and you have a measure of the uncertainty of the predicted position.

Next you will start the flow of time. Right-click near the center of the swarm, then hit the “Center” button to center the nearest clone on the screen. Go to “Animation > Animation dialog…” or just press the “>>” button at the top of the screen. In the animation control window, select “Locked on: Moving” to make *Guide* track the clones as they move. Click the “Faster” button a few times until the time-step button reads “1 day.” You can now change the date by one-day intervals by clicking either the “<” or “>” buttons, or start the animation with the “<<” or “>>” buttons. Note that your start-date was “8 Nov 2007.”

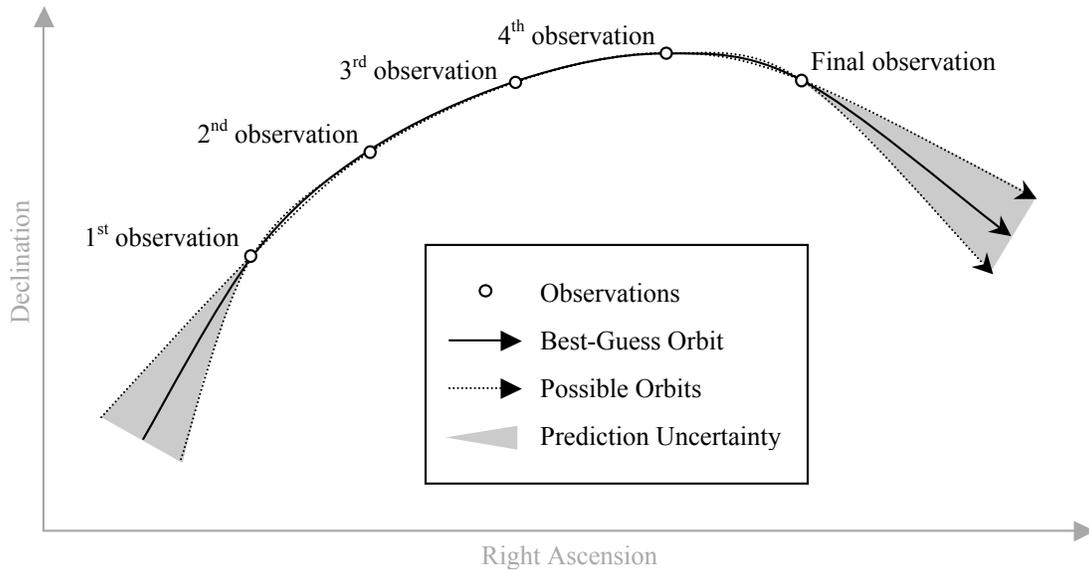
5. Run time backward to November 1<sup>st</sup>, zooming out as necessary. What is the value of the uncertainty on this date? (*Remember to “÷2”.*) How many times bigger was the swarm on this date, just one week earlier than your previous measurement? (*Write this factor in the margin next to the Table 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? (*A quick-and-dirty way to measure angular separations is to right-click-and-drag between two points, but the Insert method described above is more accurate.*)
7. Continue to run time forward. What is the first date when the uncertainty ( “÷2” ) once again reaches 5” (arcseconds) or more?
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<sub>5</sub> 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?

Please refer to Figure 1 below 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.*)



**Figure 1** – A sketch of asteroid observations and resulting orbits.

*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 you made of the position of 2007 WD<sub>5</sub>. If you have not yet stopped the Monte Carlo process in *Find\_Orb* or placed the resulting *mpcorb* file in your group’s folder, please see the instructions at the end of Part I.

In *Guide*, go to “Extras > Asteroid options” and load up the new *elements.txt* and *mpcorb.dat* files from “2007 WD5/Orbit Results/Epoch 1/ Data Set B”, following instructions similar to those at the beginning of Part II above. Once you have the 3,000+ clone orbits loaded, 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<sub>5</sub> in images taken on Nov 1<sup>st</sup>, 2007. She does not have access to your images from Nov 8<sup>th</sup>, 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 *Guide*, delete the orbit for 2007 WD<sub>5</sub> that you loaded from the *elements* file. Follow the instructions in the last full paragraph above.
- 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. 20<sup>th</sup> – Dec. 19<sup>th</sup>, 2007**

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

**Table 2: Results based on observations from Nov. 8<sup>th</sup> – Dec. 19<sup>th</sup>, 2007**

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