Killer Asteroids Lab #1: Learning how to measure positions and determine orbits

GOALS: The goal of this assignment is to learn how to measure asteroid positions in digital images, and how to use these positions to determine the orbit of the asteroid. You will also learn what parameters are necessary to specify an orbit, and the effect of each on the shape and orientation of the orbit. Finally, you will learn how to generate alternate possible orbits for a given asteroid.

You will use these skills over the coming weeks to study the asteroid 2007 WD_5, which narrowly missed hitting Mars on January 30, 2008. In particular, you will estimate the probability of impact based upon what was known about this object's orbit at various points between its discovery and the date of the possible impact. You should then understand why every "impact scare" to date has followed the same pattern: Odds first go up, but then they fall quickly to near zero. You'll also get the "bigger picture": Science involves uncertainty, and it takes time and hard work to get good results.

Part I: Measuring Asteroid Positions with ImageJ

The first goal of this assignment is to teach you how to measure the positions of celestial objects in digital images. In particular, you will be measuring the position of an asteroid as it streaks through a field of background stars. (The measurement of positions of cele stial objects is known as **astrometry**.) Of course, since the asteroid is moving, it is also important to accurately note the **time** at which it was found at a particular position. Tracking an asteroid's motion across the sky allows us to estimate its orbital path around the Sun, and more data provides a better estimate. This, in turn, allows us to predict the future position of the asteroid, and to determine whether or not it is likely to hit Earth or Mars.

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.

Locate the "Shared Documents" folder on your computer's Desktop, then navigate down to the folder:

Shared Documents/LSIS A202/Killer Asteroids Project

This will be your "command center" for this sequence of asteroid labs. This project will involve a fair amount of electronic data, and it is important that you keep it organized. In particular, you may be sharing your computer with students in another lab section! **Double-click** on "Student Data", then create a new copy of the "GROUP TEMPLATE" folder you find there. (First copy it, then paste a new copy alongside it.) Finally, rename this new folder with some clever name to represent your group. This will contain all of our group's data, images, and results over the next three labs.

Let's begin by examining three images of an unidentified asteroid, taken by the 2.5-meter telescope of the Sloan Digital Sky Survey (SDSS) on February 12, 2000. This is a relatively fast-moving NEO (Near-Earth Object), so let's call it ***Keanu***. Run the image analysis program ImageJ by clicking on 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…", navigate to your group's folder, and select the file:

Keanu/Images/fpC-001140-g4-0122.fit

When the "Sequence Options" window pops up, just click OK. The images will appear black and almost featureless due to poor contrast settings, but this will be taken care of shortly.

The software that will allow you to examine astronomical images is the Polaris Plugin, which requires some setup before you begin. 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:	UNK0001
RWO Designation:	UNK0001

Observatory Code: 645
Checked: Astrometric output only

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. Move between the three images in the sequence by using the scroll bar at the bottom of the image. To adjust the brightness and contrast (B&C) of each image manually, use "Image > Adjust > Brightness/Contrast…". For instance, you may find that the last image in the sequence is darker than the rest. You can brighten it up by clicking a handful of times on the right arrow of the Maximum slider (2nd from the top). Changes will take effect immediately, so there's no need to click Apply. If you'd like to reset the B&C settings, you can always restart the plugin by reselecting it from the Plugins menu.

Animate these three images with "Image > Stacks > Start Animation," or you can toggle the animation on/off using the backslash (\ ) keyboard shortcut. If they flip by too fast, the speed can be adjusted with the "Animation Options…" selection in that same pulldown menu. The asteroid should be immediately obvious, streaking across the image from left to right. (In reality it streaked from right to left, because ImageJ opens the images in alphabetical order, which happens to be reverse chronological order for these SDSS filenames.) Note that the asteroid itself is not pencil-shaped! In a much shorter exposure it would look like a point of light, just like the stars do. However, each of these images had an exposure time of roughly 54 seconds. The shutter was left open to collect light for that amount of time, during which the asteroid moved the length of the streak. (Imagine taking a long exposure of a racetrack as a single car speeds by.) Use the ImageJ magnifying glass tool to zoom in (left-click) on the asteroid, so that all three streaks are visible together on the screen. (Right-click if you need to zoom out.) At this point, you may stop the animation by hitting the " \ " key.

The panel on the right displays the *celestial coordinates* (RA = Right Ascension, Dec = Declination) of each pixel as you move the mouse over the image. You can think of these coordinates as extensions of the longitude and latitude coordinates we use here on Earth. It may help if you imagine that we are at the center of a giant *celestial sphere*, with all of the stars and galaxies of the night sky painted on the inside. That sphere appears to rotate around the *north celestial pole* (Declination = +90°), which is directly above the Earth's north pole. It also has a *celestial equator* (Declination = 0°), which is directly above the Earth's equator. **Right Ascension is measured <u>around</u> this equator (east/west), while Declination is measured <u>perpendicular</u> to this equator (north/south).** *(In other words, Right Ascension is like Earth Longitude, and Declination is like Earth Latitude.)*

Right Ascension and Declination are each usually written as three numbers separated by colons, such as *12:34:56*. If this looks like a *time* to you, it should! The celestial sphere appears to revolve around the Earth once every 24 hours, so the night sky can be used as a rudimentary clock. For this reason, Right Ascension is traditionally measured in *hours*, where 24 hours make up a full 360° circle. Each hour is then subdivided into 60 *minutes*, and each minute into 60 *seconds*, just as with time. The format for writing RA is thus *hours : minutes : seconds*. Declination is measured in the usual *degrees*, which are similarly divided into 60 *arcminutes* ('), and those into 60 *arcseconds* ("). The format for writing Declination is thus *degrees : arcminutes : arcseconds*. Note that 1 hour of RA = 15°, 1 min of RA = 15', & 1 sec of RA = 15".

You will now make your first measurement of Keanu's position in an image. First, you may want to switch to either the Scrolling (hand icon) or Rectangular Selections tools. Next, <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. It 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 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. Click the "Copy Results" button to stash the results on the clipboard. In your group's folder, locate the file:

Keanu/Astrometry/Keanu Astrometry.rwo.txt

Open the file, paste in the results below the 2 lines of column headers, and save the file. You will see 3 long lines of data in RWO format, which are compatible with the data downloadable from the Asteroid Dynamics (AstDys) and Near Earth Object Dynamics (NeoDys) websites. If you're interested, you can visit those sites at:

AstDys – http://hamilton.dm.unipi.it/cgi-bin/astdys/astibo
NeoDys – http://newton.dm.unipi.it/cgi-bin/neodys/neoibo

(You do not need to visit either of these sites to complete this project.)

Take a look at the following sample of data in this format, along with column headers. Each line is too long to be printed here on a single line, so this sample will be split up into four parts.

```
! Object   Obser ============= Date =============
! Design   K T N YYYY MM DD.dddddddddd   Accuracy
 2007WD5   O C   2007 11 20.32652        1.000E-05

================== Right Ascension =================
HH MM SS.sss  Accuracy      RMS  F     Bias    Resid
04 13 56.060  1.500E-01    1.000 F    0.000    0.027

 ================= Declination =====================
sDD MM SS.ss  Accuracy      RMS  F     Bias    Resid
+17 21 43.00  1.000E-01    1.000 F    0.000   -0.694

==== Magnitude ==== Obs  Residual SEL
Val  B   RMS  Resid Cod       Chi A M
20.0 V  0.70  -0.26 G96      0.71 1 1
```

There's a lot of information here that you won't need to understand, but the parts you should be aware of have been italicized and underlined. Let's go through them one by one.

- The *Object Designation* is the asteroid's "name." In the above sample, the name is **2007 WD$_5$**. This value is specified to the Polaris Plugin by setting the "RWO Designation" in the Polaris Plugin Options. *(You do not need to set this option now, but whenever you do, **it is important that you use the correct capitalization and spacing!** Even slightly different designations are considered to be different asteroids by the software you will be using.)*

- The Observation *Date* is given in an odd decimal-days format that bears explaining. In this sample, the first two parts are what you would expect: **2007** is the year, and **11** is the month. What the third part tells you is that **20.32652** *decimal days* have elapsed since the beginning of the month, taking into account the exact time of day that the observation was made. You can figure out what time of day that was by multiplying the decimal part by 24 hours: **0.32652 days × 24 hrs/day = 7.83648 hrs**, or **roughly 7:50am**. The Earth is round, so you also need to know what time zone this is in. The convention in astronomy is to use **Universal Time (UT)**, which is effectively the same as **Greenwich Mean Time (GMT)** of Greenwich, England.

- The *Right Ascension* coordinate is displayed without its customary colons. Putting them back in, we have RA = **04:13:56.06** (hr : min : sec). You might also see this written as **4h 13m 56.06s**.

- The *Declination* coordinate is also displayed without colons. Putting them back in, we have Dec = **+17:21:43.0** (deg : arcmin : arcsec). You might also see this written as **+17° 21' 43.0"**.

- The *Observatory Code* ("Obs Cod") is a 3-character code that tells you which observatory made these observations. This value is specified to the Polaris Plugin by setting it in the Plugin Options. *(You do not need to set this value now.)* In this example it is **G96**, the code for the Mt Lemmon Survey observatory north of Tucson, AZ. If you're interested, a list of observatory codes is at:

  http://cfa-www.harvard.edu/iau/lists/ObsCodesF.html

  (You do not need to visit this site to complete this project.)

- Note that the plugin will always leave the *Residual* and *Chi* values blank. Your results will also lack any of the *Magnitude* information, because you have chosen the "Astrometry Only" option.

1. From your own measurements in *Keanu Astrometry.rwo.txt*, identify which line of data represents the *first* observation made on that day. What was the full decimal date (year, <u>name of month</u>, and decimal days)? What were the RA and Dec?

2. **At roughly what time of day was this image of Keanu taken?** Give your answer in both Universal Time (UT) and Mountain Standard Time (MST), to the nearest 10-15 minutes. (MST = UT - 7 hours.) *(Start by converting the decimal part of the days into hours, as outlined above. Next, estimate the minutes from the decimal part of the hours. Together, the hours and minutes give you a time in UT on a 24-hour clock. Finally, convert to MST.)* **Also, given that the SDSS telescope keeps Mountain Standard Time in February, would it have been dark at the telescope at this time?**

3. If a celestial globe is available in the lab, use it to locate the (RA, Dec) coordinates from your answer to Question #1. **In which constellation are these coordinates located?** *(If you find the globe confusing, please go back and re-read the coordinate descriptions on page 2. Also, note that <u>both a second and an arcsecond are smaller than 1/2,000th of an inch</u> on a 12-inch globe, so you can ignore these parts of the RA and Dec for this question.)*

You are finished with ImageJ for today, so it can now be closed.

Part II: Finding Orbits with Find_Orb

You will now begin your investigation of the asteroid 2007 WD_5, which gained notoriety over Christmas break 2007 because it had the potential to hit Mars in late January with the energy of a nuclear blast. To see the astrometric record for this object as of 2007 Dec 21, go to your group's folder and open the file:

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

The format of the file is the same as that described above, so you should already be an expert at reading it.

4. What were the first and last dates on which this asteroid was observed? How many total **observa<u>tions</u>** (measured positions) were there? How many different **observa<u>tories</u>** (observatory codes) were involved?

You will now use this astrometric record to make a "best guess" at the orbit for this asteroid, based on the available 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, navigate back to your group's folder, and open the astrometry file mentioned above, in the first paragraph of Part II.

Warning: *Every time you use the "Open…" button, most of Find_Orb's checkboxes and text boxes will return to their default values for that asteroid. So if you have to re-open the astrometry file, you should plan to re-enter all of your settings as well.*

First, take a moment to learn your way around the Find_Orb window. At the top are check-boxes and text inputs that control how the orbits will be calculated. A box in the middle labeled "Orbital Elements" displays the parameters that define the current guess at the orbit. Near the bottom is a large text box with a scroll bar, which displays a summary of the contents of the astrometry file that is currently open. If one or more of the observations in this box is selected, then the space at the bottom of the window will display further information on that particular observation(s).

An important point to notice about the initial orbit displayed by Find_Orb is just how *horrible* it is as a fit to the data. You can see this by first examining the astrometry box that has the scroll-bar. Each line shows first the date, observatory code, RA, and Dec of the observation. The final two columns then give the differences in RA and Dec between the position predicted by the current orbital solution and the actual observed position. These *residuals* or *errors* will normally be given in arcseconds, but when they get too large, a "d" will indicate that they have switched over to degrees. A good residual for each observation would be less than about 1 arcsecond, so you can see how bad this current solution is! A good way to summarize the quality of a particular solution is to calculate some sort of statistical average of all of these residuals. Find_Orb does this in the form of the *root-mean-square* (RMS) error, shown directly above the astrometry box's scroll-bar. A good value would once again be less than 1 arcsecond, but in this case it is more than 3,000 arcseconds, or almost a whole degree! You can do much, much better.

Click on the "Settings" button at the right-center of the Find_Orb window. Make sure that the "Heliocentric orbits only" option is checked, and that the "Element precision" is set to 7, then click OK. This will force your solutions to orbit the Sun instead of the Earth, Moon, or Mars. Next, **check all of the boxes in the Perturbers section** at the top of the window. This tells Find_Orb to take into account the gravity of all of these planets, asteroids, and moons as it calculates the orbit of your asteroid. Finally, ask for the orbit for a specific date by **changing the Epoch value to "2007 11 08"**. The significance of this particular date will become clear in Lab #2. Now click the Auto-Solve button once or twice.

Ordinarily you'd be done at this point, but as you can see, the RMS error value isn't getting any better. In fact, it has gotten worse! That's because these observations were made over a fairly short period of time, when 2007 WD_5 was making a particularly close approach to the Earth. Fortunately, there's something else we can try. The astrometry file also includes measurements of the brightness of the asteroid, which astronomers measure in terms of **magnitudes**. This particular asteroid got fainter by about 2 magnitudes over the course of these observations. From this information, it's possible to estimate that on the last of these dates, the asteroid was about 3 times farther away from the Earth than on the first date. So suppose we take a guess and say that this distance grew from a mere 0.05 astronomical units (AU) to a slightly more comfortable 0.15 AU. (The Earth is 1 AU from the Sun.) Plug these values into *Find_Orb* as follows:

R1: 0.05 AU
R2: 0.15 AU

Once again click the Auto-Solve button. *(Notice that the values of R1 and R2 get revised based on the specifics of the new best-guess orbit. While our specific guesses were not correct, the ratio of 3 between them ends up being pretty accurate.)* **Confirm that your RMS error value is now less than 1 arcsecond.** *(If it isn't, then you missed something, and you need to go back and fix it!)*

Congratulations, you've found an excellent guess at the asteroid's orbit! (*Jot down the RMS error, which will be part of your answer to Question 5.)* However, in this case we are going for historical accuracy, so a few more steps are required. Scroll down in the astrometry window until you find the two observations with an X between the date and the observatory code. These two observations are not currently being used in the orbit solution, but they *were* being used in the predictions back in mid-December 2007. As more observations have been made, it has become clear that something went wrong with these two. To make them active, select these two rows and click the Toggle Obs button. Now click Auto-Solve again, and you can see that the RMS error has gotten a bit larger, but not too bad. Again, we are going for historical accuracy here.

Warning: *At this point, the last line of the "Orbital Elements" box should read:* ***"From 25 observations 2007 Nov. 20-Dec. 19."*** *These should match your answers to Question 4 above. 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!***

5. What was the RMS error before you included these two observations? What was it after?

The parameters that describe the orbit are listed in the "Orbital elements" box, but they have also been saved in a pair of text files. You'll want to save these for later, so please open up the *Find_Orb* folder in the *"Killer Asteroids Project"* directory and locate the files *elements.txt* & *mpc_fmt.txt*. In a new window, navigate to your group's folder and then on to *"2007 WD5/Orbit Results/Epoch 1/Data Set A."* (There may also be some dates in parentheses, to help you keep the epochs and data sets straight.) Drag the two files mentioned above from *Find_Orb* to the "*Data Set A"* folder. You will come back to these momentarily. Also, while you have the *Find_Orb* folder open, please delete the file *mpcorb.dat*, if it exists. (Find_Orb will create all of these files again later when needed.)

Find_Orb has another trick up its sleeve: We may now have a best-guess orbit for the asteroid, but how certain are we that it's accurate? One way to find out would be to try *thousands* of possible orbits that fit the observations, and see how much they differ. Let's do that! First, click on the Settings button and change the "Monte Carlo noise" value to 0.5, then click OK. **Also, check that all of your other settings have not changed since you set them above.** Now click the "Monte Carlo" button, and its label will be replaced with a series of numbers. Find_Orb will chug along in the background as you continue working on this lab. Take note of the current time, and remember to come back to collect its output in about 25 minutes, when the number gets above 3,000.

What's going on here? According to Wikipedia, "a **Monte Carlo** method is a computational algorithm that relies on repeated random sampling to compute its results." (The randomness and repetitiveness of this method made the Manhattan Project scientists of the 1940s think of casino games, so they named it after a famous casino in Monaco.) Find_Orb randomly changes the RA and Dec coordinates of each of the observations in the astrometric data file by some small amount (the "Monte Carlo noise" value, which you previously set to 0.5 arcseconds). Each set of freshly altered data produces a new orbit, which is then stored in the file *mpcorb.dat* and the number on the Monte Carlo button increases by 1.

Why are we doing this? The positions in the astrometric data file are not absolute, but may have some uncertainty associated with them. Calculating thousands of orbits based on these randomly-altered data will allow you to estimate the uncertainties in the positions you will predict for the asteroid, based on the uncertainties in all of its positions measured to date. *Uncertainties are unavoidable in science, and minimizing them is an important part of scientific research.*

After about 25 minutes, when you've generated at least 3,000 alternate orbits, you will *click the Monte Carlo button (now labeled with the running orbit-count) again to stop the process.* You will also need to grab the resulting *mpcorb.dat* file that was mentioned above. For further instructions, see Part IV.

While you're waiting, please continue with the rest of the lab.
You won't need these Monte Carlo results until Lab #2.

Now, go back to *"2007 WD5/Orbit Results/Epoch 1/Data Set A"* in your group's folder and open the *elements.txt* file, which contains the results of your best-guess orbit for 2007 WD_5 based on the available observations. **Within that file, locate the following seven orbital parameters.** *(You don't need to write them down, you should just learn where to find them in the file.)*

a	= mean distance (or semimajor axis)	[AU]
e	= eccentricity	[unitless]
Incl.	= inclination (*i*)	[degrees]
Node	= (longitude of the) ascending node	[degrees]
Peri.	= arg(ument) of pericentre/perihelion (*w*)	[degrees]
M	= mean anomaly (*L*)	[degrees]
Epoch	= arbitrary reference date	[date, or Julian Days]

The seventh and final orbital parameter is the ***epoch***, or the moment in time at which all of the other parameters apply. You will find this listed two different ways in the elements text file:

"Epoch 2007 Nov 8.0 TT = JDT 2454412.5"

For Part III, you will be interested in the part of the Epoch that comes after the "JDT," which gives the "Julian date," or the number of days elapsed since noon UT on January 1, 4712 BC. You will be entering these parameters into another program shortly, and it is important that you enter all seven values correctly.

Part III-A: Understanding Orbits with Starry Night

You will now explore how these seven orbital parameters specify the shape and orientation of the asteroid's orbit, as well as its position along that orbit. Open the planetarium program "Starry Night Pro 5" from the desktop. (If it asks about checking for updates, click "Cancel." If it asks about OpenGL, try "Keep.") Begin by selecting "File > New Asteroid Orbiting Sun…" from the pulldown menus. At the top of the window, change the asteroid's name from "Untitled" to "2007 WD5". At the top-right, try zooming in and out with the "\/" and "/\" buttons. Also try clicking and dragging in the orbit display window to change your viewpoint. The three beige-colored orbits shown here are, from smallest to largest: Mercury, Earth, and Jupiter. (You will need to zoom out to see Jupiter.) The red orbital path is the asteroid you are currently adding.

6. **Match each of the 6 parameters on the left below with the description of its effect on the asteroid's orbit on the right.** *Your answers should be submitted as a list of matches: "Mean Distance = Description X," "Eccentricity = Description Y," etc.* Determine the matches by playing with each of the 6 orbit-parameter sliders in *Starry Night* to get a feeling for what each one does. <u>When you get to the last 3 sliders, it will help if the eccentricity is set around 0.5 and the inclination is near 45°.</u>

<u>Orbit Parameters</u>

- mean distance
- eccentricity
- inclination
- ascending node
- argument of perihelion
- mean anomaly

<u>Descriptions of Effects</u>

- Angle between the asteroid's orbit and the Earth's orbit **(jumping rope)**
- Shape of the asteroid's orbit **(rubber band)**
- Orientation of the elliptical orbit within its orbital plane **(hula hoop)**
- Placement of the asteroid along its orbital path **(car on a track)**
- Size of the asteroid's orbit **(shrink or grow)**
- Where the asteroid goes from below Earth's orbit to above it **(spinning coin)**

Now, use the following steps to enter the parameters for 2007 WD_5 from your *elements.txt* file into *Starry Night*. First enter the epoch (in Julian-date format), which specifies the moment in time at which all of the remaining parameters apply. (Look back at the previous page if you need help finding the epoch value in the text file.) Next, using the sliders again, approximately enter the other 6 parameter-values from the text file. Just get as close as you can on each of them, using only the sliders, and watch what effect each has on the orbit. Change the zoom and the perspective if necessary! Next, go back through and set them exactly, using either the keyboard or copy-and-paste from the elements text file.

7. Do you think that this asteroid could currently be classified as "potentially hazardous" to the Earth? Why or why not? *(We have not defined what it means for an asteroid to be "potentially hazardous," so you will need to think about what that might mean to you.)*

8. What criteria do you think an asteroid's orbit needs to satisfy in order for a collision with the Earth to be possible?

You can now close the add-an-asteroid window by clicking on the red "X" in the upper-right corner. When it asks, **make sure NOT to save your changes**! You can also close Starry Night itself.

Part III-B: Working with Asteroids in Guide

While *Starry Night* is a full-functioning planetarium program, we will instead be using the competing software *Guide*, which provides far greater positional accuracy for our purposes. Open the *Guide* program by double-clicking the *guide8* icon in the "Killer Asteroids Project" folder. You will be presented with a view of the night sky, as seen from some location in our Solar System (probably the surface of the Earth). The particulars of your initial viewing location and the patch of sky you see will depend on what the previous user was doing, because *Guide* remembers these settings from one use to the next. (It always starts up using the current date and time, though.) Aside from the stars and galaxies that you would see with your eyes, a host of additional information is presented as well. Green dashed lines connect stars into *constellations*, and orange dashed lines show boundaries between those constellations. More importantly for our project, you may see planets marked by a purple "+", and asteroids marked by a yellow "×". A *legend* describing these elements appears in the corner of the screen. In that legend, you will also find the RA and Dec of the mouse's current position, as well as the date and time of the current display. You can zoom in by pressing "*", zoom out by hitting "/", and recenter on a position by simply clicking there.

Now, a little backstory. On 2007 Dec 21, the asteroid 2007 WD_5 made the national news when its predicted odds of impact with Mars were upgraded from 1-in-350 (0.3%) to 1-in-75 (1.3%). You can read NASA's original press release here:

http://neo.jpl.nasa.gov/news/news151.html

In it, they said that "the asteroid is becoming increasingly difficult to observe," and that they would only be able to improve their impact predictions once it "became observable again in early January." But what if some observatory had already taken a picture of it, but didn't realize it? That data could be used to improve those predictions immediately, without waiting weeks for more observations. Fortunately, the Sloan Digital Sky Survey (SDSS) telescope *did* happen to image this asteroid on 2007 Nov 8, as it was searching for supernovae in distant galaxies. What's amazing about these images is that *they were taken 12 days before the asteroid had even been officially discovered!*

You will now use *Guide* to predict the position of 2007 WD_5 in these SDSS images, based on your best orbit solution to the prior observational data. *Guide* will need to know the time and date of the observation, as well as the location of the SDSS telescope on the Earth's surface. To simplify matters, all of these settings have been saved in a **mark file**. First, make sure that you are observing from Earth by clicking "Settings > Location…", then select "Earth" and click OK. Then click on "File > Load Mark…", select "SDSS - '07 Nov 8 - 2007 WD5" and click OK. *Guide* will load up the view from that location on the night of 2007 Nov 8^{th}, when the SDSS happened to observe 2007 WD_5.

Next, you will load your orbit. 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 and open the *elements.txt* file in the "Epoch 1 / Data Set A" part of your group's folder, then click OK. You should see the predicted position of the asteroid as a single yellow "×". (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.)

9. Right-click on the asteroid's position, then choose "More info". **What are its RA and Dec at that moment?** *(In this case, they can be found immediately below the orbital elements. <u>Do not</u> use the values underneath the phrase "Mean position at current epoch.")* **Also specify the date and time *(with time zone!)***, which can be found in the main *Guide* legend.

10. Using this same "More info" help window, what is the distance *in kilometers (km)* between the observer and the asteroid? (Look for the "Dist from home planet" entry.)

11. If a celestial globe is available in the lab, use it to locate the (RA, Dec) coordinates from your answer to Question #8. In which constellation are these coordinates located? *(If you find the globe confusing, please go back and re-read the coordinate descriptions on page 2.)*

Part IV: Cleaning Up After Yourself

As was mentioned previously, you may be sharing your computer with students in another section of this class. To avoid confusion and potential loss of data, please do the following:

- In *Guide*, delete the orbit for 2007 WD_5 that you loaded from the *elements* file. To do this, go to "Extras > Asteroid options" and click the "Edit Comet data…" button. Select 2007 WD5 from the top of the list, then "Delete" it and hit OK. *(No, 2007 WD_5 is **not** a comet. For some reason, Guide lumps objects loaded in this way with the comets. The software's author plans to fix this in an upcoming version.)*

- If the "Find_Orb" program is still running its "Monte Carlo" process, turn it off by clicking the button labeled with the running orbit count. Then click "OK" to turn off the program.

- Move the "mpcorb.dat" file from the "Find_Orb" folder to "Epoch 1/Data Set A" in your group's folder. You will use it next time. Do not leave a copy in the "Find_Orb" folder. The program will append to the end of the file if it exists, which can get confusing when there are 100s or 1000s of entries.

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