# Lab 1: Learning the System

*(Due: 2017 February 08)*

## 1.1 Finding Out About Your Star

You have each been assigned a star from the Luyten Half-Second (LHS) catalog.  These stars have proper motions greater than ½ arcsec/y.  Your main task is to accurately measure the position of your star, and verify through calculation that it is where it is predicted to be, within the uncertainty of your measurement.  You will also do some basic calculations to determine the distance to the star, based on published values for its spectral type, color, and magnitude.

You will use the *Aladin* java viewer (these instructions refer to v. 9.0) to learn more about your assigned star.  It is assumed that you have a laptop computer to use for the course.  Go to the Aladin web page (http://aladin.u-strasbg.fr/AladinJava?frame=downloading), and download and install the *Aladin* java-based software.  Once you start the software, you will see a window with some text (e.g Quick start…) where images will go, and along the right side an area where the "image plane stack" will be.  We are now going to display an image from the Palomar Optical Sky Survey 2 (POSS2).  To load it, choose the menu item (slashes are submenus)

> File/Load Astronomical Image/DSS…/DSS from STScI.

This will open a "Server selector" window with the target coordinates blank.   We will use the star LHS 1858 for this example, so the figure below shows the result of typing "LHS 1858" in the box.  But go ahead and type LHS and your assigned star's number, then hit Enter or select the SUBMIT button at the bottom of the window.   After a few moments, you should see a white image with black stars.  You should now see an image of the sky around your star, but it may not be clear which star is yours.  The image you are looking at is from the second Palomar Optical Sky Survey (POSSII).

We will now add a second image. In the Sky Survey drop-down list of the "Server selector" window, choose POSS1_Red and click the SUBMIT button.  Finally, add a "Simbad" overlay of objects by clicking on the Simbad icon to the right in the "Server selector" window, and under "Display filter" choose "Star," then click the SUBMIT button.  At this point, your display should look like the one in Figure 1.  The green overlay is from Simbad, and there should be a line extending from near your star (it may not be exactly on the star).  Make sure the bottom plane (the image for POSS2) is highlighted in the main *Aladin* window, and click on the properties icon as shown in Figure 1.  In the window that opens, click "Get original header."  This opens the FITS header window.  FITS stands for Flexible Image Transport System, and is an image/data format that we will be using extensively in this class.  Find DATE-OBS.  For LHS 1858, it is 1990-12-16T08:50:00, which means the date the image was taken was Dec. 16, 1990, at 8:50:00 UT (Universal Time).  This is called the EPOCH.  Write down the epoch for your star in your lab notebook—you will need this information later.

Now click the checkbox of the other image (POSS1), and look at the date it was taken (by again clicking on the properties icon).  For LHS 1858, the new Date-Obs is 1955-11-

10T10:88:00.  The time is messed up (there is no such thing as 10:88:00 UT), but this will not concern us.  Write down the epoch of the POSS1 image for your star.  You can see that this POSS1 image was taken 61 years ago, while POSS2 was taken 26 years ago.
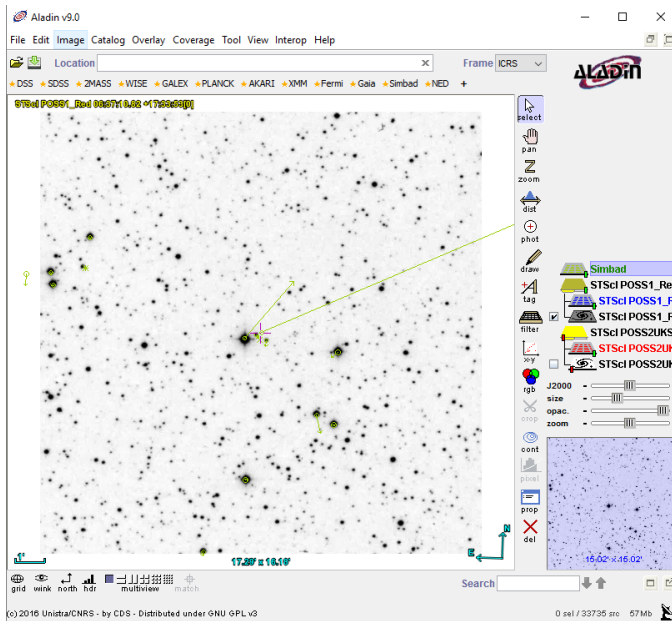


Fig. 1: *Aladin* multiview window, showing the POSS2 image and the location of the properties button.

Let's blink these two images to see how the star may have changed in the 35 years between the two images. To do that, select the menu item Image/Blink…, choose the two images to blink in the pop-up window, and click "CREATE".  In a moment you will see the two images blink, showing you the rather large proper motion of your star.  Notice that the blink image is now in layer seven of the Plane stack.

Click the checkbox next to the POSS2 icon in the Plane stack (the bottom layer of the stack) to display it. Once you have your POSS2 image displayed, click on the circle closest to your star (at the end of the line extending from your star, and you should have some information about your star, listed on a single line below the image.  In the case of LHS 1858, there are two objects shown by Simbad near the same location, but by selecting different ones in turn, you can find out which is LHS 1858.  If you put the mouse over the different cells in the line of information, you will see the meaning of each cell.  **Write down in your lab book the following information from these cells:**

- MAIN ID
- RA (Right Ascension coordinate)
- DEC (Declination coordinate)
- PMRA (Proper motion in RA)
- PMDEC (Proper motion in Dec)
- B (Blue magnitude)
- V (Visual magnitude)
- SP TYPE (Spectral Type)

Some of the information may be off the screen, so use the scroll bar along the bottom. Now click on the MAIN ID link (HD 260655 in the example), and you will go to a web page listing the information you just wrote down, and some additional information.

- Write down the information in the Parallaxes line. For LHS 1858, it says Parallaxes mas: 102.60 (ignore the other text on that line)
- Scroll down and you will also see a list of other identifiers for your star. Find the identifier that starts with TYC, and write down that number. For LHS 1858, the number is TYC 1333-1683-1.

This is all of the information we will need for now, and we are ready to observe!

## 1.2 Installing Cartes du Ciel

We are using a "planetarium" program called *Cartes du Ciel*, which is a very capable freeware program, to control the telescope. You can download this program yourself, and are encouraged to do so, especially if you have a laptop that you can bring to class. To download, go to: http://www.ap-i.net/skychart/ and click on "download" in the menu at the left. You will need to download Skychart 3.10 (the program) and the Additional Catalog (Stars catalogs). Download the appropriate ones for your system, either Windows, Mac, or Linux. *Cartes du Ciel* uses the Tycho-2 star catalog of the 2.5 million brightest stars: (http://www.astro.ku.dk/~erik/Tycho-2/). If you wish, you can download the UCAC4 catalog (up to 2.7 GB), which provides fainter stars, but you should not need it for the course. The installation should proceed in the usual manner for your system.

You will use *Cartes du Ciel* to find your star by using its Tycho-2 (TYC) identifier. In *Cartes du Ciel*, click on the "Find" icon (the little binoculars, as shown in Fig. 3, below), click on the "Stars" tab, and select the "TYC" button, then type your number in the blank, exactly as TYC 1333-1683-1 (including the dashes). When you click OK, the star will be placed in the center of the screen. Zoom in to 1 degree field of view, and re-center the star if necessary. If you lose it, you can always find it again in the new zoomed view by using the Find icon. You will be shown in class how to tell the telescope to go to this location.
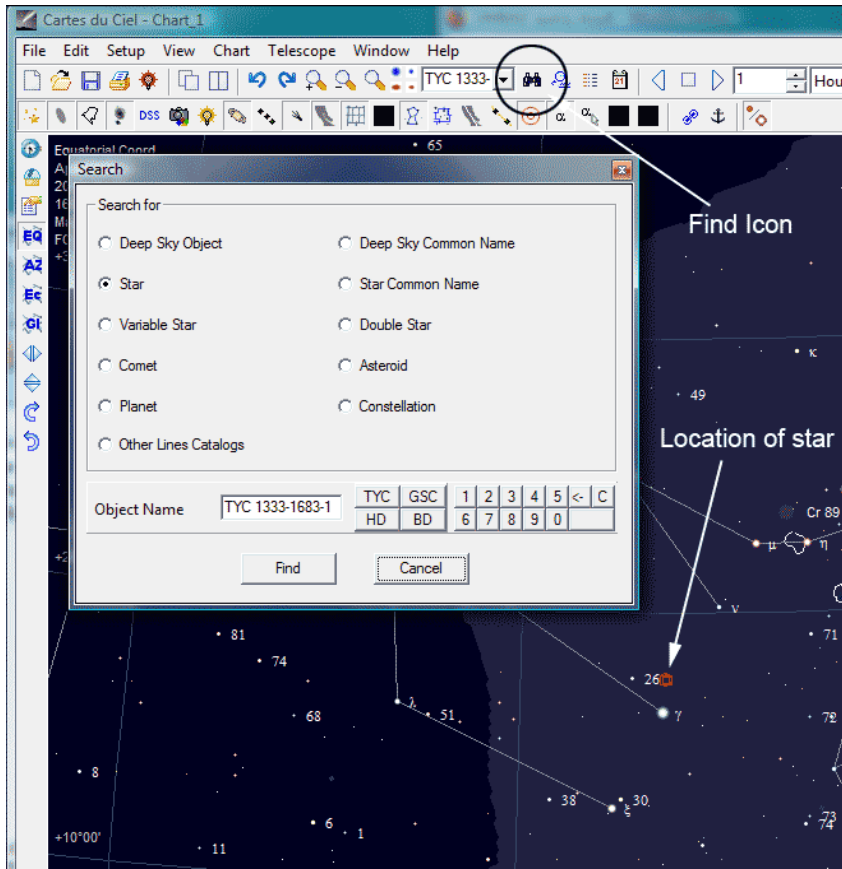
Fig. 2: *Cartes du Ciel* window, showing the use of the Find icon.

## 2.1 Focusing the Telescope

Once you know where your star is, you need to find a nearby star of 4th or 5th magnitude, on which to focus. Zoom out to a 15 degree field of view and click on some of the larger stars until you find one nearby that is between magnitude 4.0 and 5.99. (To find the magnitude, click on the star, then click on the star's name, and in the pop-up box read the Visual Magnitude value.) Verify that this star is above the horizon, and not too close to the pole (no more than 73° Dec). If everything is okay, click on the star and click "Goto" to send the telescope there. Go up to the roof and check that the telescope is pointing at clear sky, and not at a cloud or building, and move the dome slit so that the area of sky where the telescope is pointing is in view.

Once the telescope is on the star, bring up *Focusmax* and *MaxIm DL* (*Focusmax* will normally start up *MaxIm DL* when it starts). Click on "Find" in the *Focusmax* window, and see if it finds your star. If so, you can go ahead and click "Focus" to do the focus routine. If not, you will have to take a full-frame exposure with *MaxIm DL* and try to figure out where the telescope is pointing. Write down in your logbook the size of the star found at the best focus, and the value of the focus readout.

## 2.2 Taking an Image

Now send the telescope back to your star, and zoom in again to 1 degree field of view. We are now ready to take an image with *MaxIm DL*.  First, make sure that *MaxIm DL* is connected to the telescope (you will be shown how to do this).  When the telescope is connected, *MaxIm DL* will read the RA and Dec of the telescope and add it to your image, so that we can do astrometry.  In *MaxIm DL* take a 20 s exposure, and carefully compare the stars in your image with the stars in *Cartes du Ciel*, until you can identify which is your star.  You should be able to find your star with certainty.  Once you know which is your star, center it by right-clicking on the star in the image, and selecting "Point telescope here" from the pop-up menu.  Wait for the telescope to stop slewing, and give it another 10 s to settle down, then take another 20 s image.  Save your image as a file with your star's LHS designation (LHS_1858.fit in this example). **Write down in your log book the file and folder name, the exposure duration, and the filter.**

## 3.1 Precision Astrometry

We will use the wonderful web resource at http://nova.astrometry.net, to "plate solve" our images.  Each of you should sign up for your own free account.  For this lab, it should be enough to just upload the image directly to your account and get a solution, without giving further information.  If the image is not very good, perhaps due to clouds or other problems, it may be possible to get a solution by providing additional information, such as the center coordinates.  After the upload, wait while the image is submitted for processing, and the job completes (usually just a minute or two.  If the solution is successful, click on "Go to the results page."  There, you will see the image, overlaid with known sources, and some information along the right side, including links to some to the outputs of the processing. Feel free to explore the page.

When you are done with your exploration, click on the link "new-image.fits" to download the new image created by the processing. **Take a screen shot of your image overlaid with the solution, for inclusion in your report. Write the information in the first 7 lines of the "Calibration" output into your log book.**

This concludes your planning, data taking, and image reduction.  We have one more step, which is to accurately determine the coordinates of your star.  To do this, we will use Aladin again.  If you do not have Aladin loaded as in Section 1.1, do so again, so that the POSS1 and POSS2 data are loaded.  Now select the menu item "File/Load local file…" and find and load the file new-image.fits that you downloaded from astrometry.net.  You can set up a 3-way blink comparison if you wish.  Notice that by doing the plate solution, Aladin now knows how to coalign it with the POSS images.  To make your measurement, click the checkmark next to your new-image plane, select the photometric tool ("phot" icon), and carefully click on your star.  Zoom in with the mouse for more clarity.   Write down the measured RA and DEC position of your star (ICRS coordinate system).

Now all that is left is to go through your results and analyze them to see how accurately your position measurement compares with the predicted location for your date and time, and then write it all up in a lab report.

## 3.2 Analysis

The analysis is very simple.  Take the J2000 coordinates that you obtained for your star from *Aladin*, add the motion that took place from 2000 Jan 1 until the date of your measurements (based on the proper motion you obtained from *Aladin*), and then compare this corrected position with your measured one.  In practice, you have a couple of things to worry about—units and time.  The date of your observations is called the epoch, but you want to represent it in the form of decimal years.  If you took your observations on 2006 Jan 1, the epoch would be 2006.0.  However, on Jan 2 it is 1 day later, or 1/365 of a year, i.e. 2006.00274.  In general, you should also take account of the time of day, so at midnight the time is 0, at noon it is 0.5 of a day, etc.  Once you have the difference between the J2000 epoch (2000.0) and your epoch, in years, multiply by the proper motion and add it to the J2000 RA and Dec coordinates.  But notice that the proper motion is given in milliarcsec (mas), so you need to divide by 1000 to get arcsec.  You also need to take account of the fact that RA is expressed in hours, while Dec is in degrees.  Nothing is easy!  And be careful with signs—the proper motion may be negative in one or both axes.

When you are done with this calculation, you should find that your measured RA and Dec agrees to within the uncertainty (0.23" in RA and 0.25" in Dec, for my example).  Give the $\sigma$ of the error (actual difference divided by the uncertainty—$\sigma$ will be discussed in class).  Your measurement should be well within $3\sigma$.  If it is not, recheck your measurements and/or your math.

## 3.3 Further Analysis

We have not used the other four bits of information that you wrote down for your star, namely the $B$ magnitude, the $V$ magnitude, the spectral type, and the parallax.  From the first three of these, it should be possible to determine the distance to your star, and hence determine the parallax.  The difference in magnitudes, $B - V$, is called the color index, and for main sequence stars (ordinary stars burning hydrogen to helium in their cores), one can determine the spectral type directly from their color index.  Find the paper by H. L. Johnson and W. W. Morgan (1953) at http://adsabs.harvard.edu/abstract_service.html, and look up both Table 14 (to convert $B - V$ to spectral type) and Fig. 5 (to convert $B - V$ to absolute magnitude).  Does the spectral type you get from Johnson & Morgan agree with the one from *Aladin*?  Determine the distance to your star, in pc, using the distance modulus formula ($m_V - M_V = 5 \log d - 5$; see pg. 87 of the text).  Then determine the parallax, $\pi$, in arcsec, from $\pi = 1/d$.  Discuss the agreement of predicted parallax with the measured one given by *Aladin*?

## Bulletized Synopsis

### Purpose: Image a star and do astrometry to determine proper motion

- You have been assigned a rather faint star from the Luyten catalog.  Find out as much as you can about your star (J2000 RA and Dec, other designations, proper motion, $B$ and $V$ magnitude, spectral type, parallax) using *Aladin*.
- Find your assigned star in *Cartes du Ciel*.

- Find a nearby 4th or 5th magnitude star and point the telescope at this star
- Run *FocusMax* to focus the camera
- Now point the telescope at your assigned star, and take a single 20 s image of the star field, with the telescope connected in *MaxIm DL*.
- Identify the stars in the image with the stars shown by *Cartes du Ciel*, and verify that you are pointed at the right place.
- Center the star in the field of view, using "Point Telescope Here"
- Take another 20 s image and save the image. Upload it to astrometry.net to get a "plate solution."
- Download the solved image and read it into *Aladin* again. Use the photometry tool to measure the star position. Write down results.
- Compare your coordinates with the J2000 coordinates for the star
- Correct for proper motion and compare with your coordinates
- Use $B - V$ to get spectral type, compare with listed spectral type
- Use $B - V$ to get $M_V$, determine distance and parallax, compare with listed parallax