Lab 2
Astronomical Coordinates, Time, Focal Length, Messier List and Open Clusters

Name: ____

Partner(s): ____

Boxes contain questions that you are expected to answer (in the box). You will also be asked to put computer output into special directories, so it can be graded. If you need more room for an answer, put it on the back of a page, with a pointer to it.

To do this lab, you should have read the link on the class website to "Celestial Coord Tutorial". If you have not done so, do it now. You may also find it useful to read the Wikipedia entries for "Right ascension", "Declination", and "Sidereal time".

The basic idea is that objects in the sky have "equatorial" coordinates just as do objects on the Earth. But instead of "longitude" for the E-W coordinate, astronomers say "right ascension" (or "RA"), and instead of "latitude" for the N-S coordinate, they say "declination" (or "δ"). Also, right ascension is often measured in hours, not degrees. Dividing the full circle of the celestial equator into 24 hours, each hour corresponds to 15 degrees.

There are a lot of special terms related to where things are in the sky. On the next page, sketch a sphere representing the sky as seen from Santa Barbara, and on it sketch and label the following:

Horizon with cardinal points NSEW
Celestial equator
N. celestial pole
Zenith and nadir
Meridian
A few lines of constant Right Ascension (hour circles)
A few lines of constant Declination

Make your sketch as big as the page will hold. Do it freehand. Do not trace something from a book. Computer-generated graphics are right out. You may find that it helps to look at the celestial globe (in the classroom) while you are doing this.

Put your celestial
sphere sketch on
this page.

On your computer, get into the **images** subdirectory of your home directory, start **ds9**, and open the file **lab001.fit**. Display the header, by clicking on "file/display_header". Notice that two of the entries have comments mentioning "Right Ascension" and "Declination". These are the coordinates in the sky where the telescope was requested to point, before taking the image. Also notice the entry commented "… observation start…". This is the Date and Time (in Universal Time, or UT) when the shutter opened for the CCD image. UT corresponds to the local time on the *prime meridian* (longitude = 0 degrees), which passes through the observatory at Greenwich, England. This time zone is 8 hours ahead of Pacific Std Time, and 7 hours ahead of Pacific Daylight Time.

On a certain day, the Sun crossed the meridian at 12:00 noon UT in Greenwich, England. Santa Barbara lies at 119.7 degrees W. longitude. On that same day, what is the UT time when the Sun crosses the meridian in Santa Barbara?

Using **ds9** to get information from the headers, list the requested RA, δ, date, and UT for each of the following images:

Image	**RA**	**δ**	**Date**	**UT**
lab001.fit				
lab004.fit				
lab006.fit				
lab009.fit				
lab010.fit				

On the next page, sketch a map of the part of the sky where these images were taken. Use only as much range in RA and δ as you need. Note that RA is defined so that as the Earth turns, the RA of objects on the meridian *increases* with time. Draw your map with N up and E to the left (as it would appear if you were facing the southern horizon). Does RA increase to the right, or to the left?

Put your map sketch in this box.

Find this area of the sky on the celestial globe. In what constellations do these fields lie?

Because astronomical objects of interest are scattered all over the sky, we need their **RA** and **δ** coordinates to find them. But because the Earth is always turning, objects that we care about are not always visible from out location. So we also need to concern ourselves with a special notion of time.

Sidereal Time

The word "sidereal" means "with respect to the stars". The current **Local Sidereal Time** (LST) is the value of the RA in the equatorial coordinate system that is crossing your meridian at the moment. Since the coordinates of stars are essentially constant over very long times, at a given LST you will always find the stars in the same apparent positions in the sky. Sidereal time is not the same as solar time (which we normally use) -- at a given solar time (such as noon), we find the *Sun* in the same position, not the stars. Because the Earth orbits the Sun once per year, the sidereal day is about 4 minutes shorter than the solar day. Thus, measuring by solar time, a given star rises and sets about 4 minutes earlier every day.

Make a labeled sketch to illustrate why the solar day is about 4 minutes longer than the sidereal day.

You are in Goleta (long = 120 degrees W, lat = +34:30) and the LST is 07:30. At the same instant, what is the LST in Boulder, CO (long = 105 degrees W, lat = +40:00)? (hint: remember 15 degrees per hour)

What bright star (bright as in "with a name") is most nearly overhead in Goleta? (Check a star map on the web or the celestial globe.)

You are in Urumqi, China (long = 87 degrees E, lat = +44:00) and the LST is 07:30. What bright star is most nearly overhead?

Look at the header for image **lab009.fit**. Notice that the telescope's longitude and latitude are given. What was the local mean solar time (Pacific Standard Time) when this image was taken?

What was the local sidereal time when **lab009.fit** was taken?

The Messier Catalog

In the late 1700s, Charles Messier and his colleague Pierre Mechain compiled a catalog of astronomical objects that do not look like stars, and that confused them in their main work, which was comet-hunting. Over the years, this catalog has come to be recognized as, in effect, a list of everybody's favorite astronomical objects. Most of the objects that we will observe with the Sedgwick telescope appear in this catalog, and we will refer to them by their Messier numbers, eg **M67**. A full list (with pictures) may be found on Wikipedia under "List of Messier Objects". Useful lists of the Messier objects sorted in various ways (by type of object, by location in the sky, etc) may be found at http://www.maa.clell.de/Messier/indexes.html

The answers to many of the following questions can most easily be found by looking at an appropriate web site. I will provide some suggestions, but it is best if you poke around and find your own favorite sources of information. If you use a web page in answering a question, write down a link to it as part of your answer.

We will be looking mostly at objects identified as "open clusters". How many open clusters are there in the Messier catalog? Get the answer to this in the cleverest way you know (ie, the least work, consistent with doing it yourself), and explain how you did it.

Suppose you live on a planet circling a star in a distant galaxy, but your planet and galaxy are similar in all important respects to our own. Say your astronomer Reissem Selrachc makes a list of the 110 brightest non-stellar objects in your sky. How many of them should you expect to be open clusters? What is the uncertainty in this estimate?

At the bottom of the Wikipedia entry mentioned above, there is a nice map of the sky coordinates of the Messier objects. The blue sinusoidal band across the map is the Milky Way.
What is the Milky Way, anyhow? (In physical terms)?

Why does it appear as a (more or less) sinusoidal band on the map?

Open Clusters and Galaxies have different (from each other) distributions in the sky, with respect to the Milky Way. What is the difference? What is the reason for this difference?

What is the northernmost Messier object, and what is its declination?

What fraction of the area of the celestial sphere lies between this declination and the north celestial pole (ie, at higher declination)? Given that there are 110 Messier objects in the sky, and supposing that they are randomly distributed, how many would you expect to find in this area? What is the uncertainty in this estimate? Is it surprising to find none in this polar cap? Show your work.

What is the southernmost Messier object, and what is its declination? Answer the same questions as above, only for the southern polar cap that contains no objects. How do you explain the difference in the sizes of the two empty polar caps?

When it is dark enough to begin our observations using the Sedgwick telescope on April 12, the local solar time (PDT) will be about 20:40. What is the corresponding UT date and time?

What is the corresponding LST, accurate to a few minutes? (Take the longitude of Sedgwick to be 120 degrees W.) There are a lot of web sites for calculating sidereal time, but many of them do not work. Try www.go.ednet.ns.ca/~larry/orbits/jsjdetst.html. Be careful about "local time", which is not the same as Standard Time (PDT) for this time of year.

At the time just stated, an object with RA = LST will be on the local meridian at Sedgwick. An hour later, the same object will have moved west of the meridian by 1 hour = 15 degrees. The angle in RA by which an object is east or west of the meridian is thus the difference between the local sidereal time and its RA. This is called the *hour angle* or HA. Thus, HA = LST – RA. A positive HA means the object lies west of the meridian, negative means east.

At the time and place stated above, what is the HA of the open cluster M37?

The mechanics of the Sedgwick telescope mount will allow observations only in the HA range [-5 hours <= HA <= +5 hours]. On April 12, say that we will start observing real objects at 21:00 PDT, and continue until 23:59. Make a list of the open clusters in the Messier catalog that are placed in the sky so that we can observe them on that night. Please list them in order of increasing RA.

Focal Length and Image Scale

The size of an astronomical image on the CCD detector depends on the **effective focal length** (usually abbreviated "focal length") of the telescope. There is an explanatory page "Focal length and f/# explained" linked on the course web page. If you have not read this already, then do so now.

To get quantitative, an angle of 1 arcsec on the sky maps into a distance **d = fl / 206264.80**… measured in the focal plane of a telescope having focal length **fl.**

Explain the origin of the magic number 206264.80….

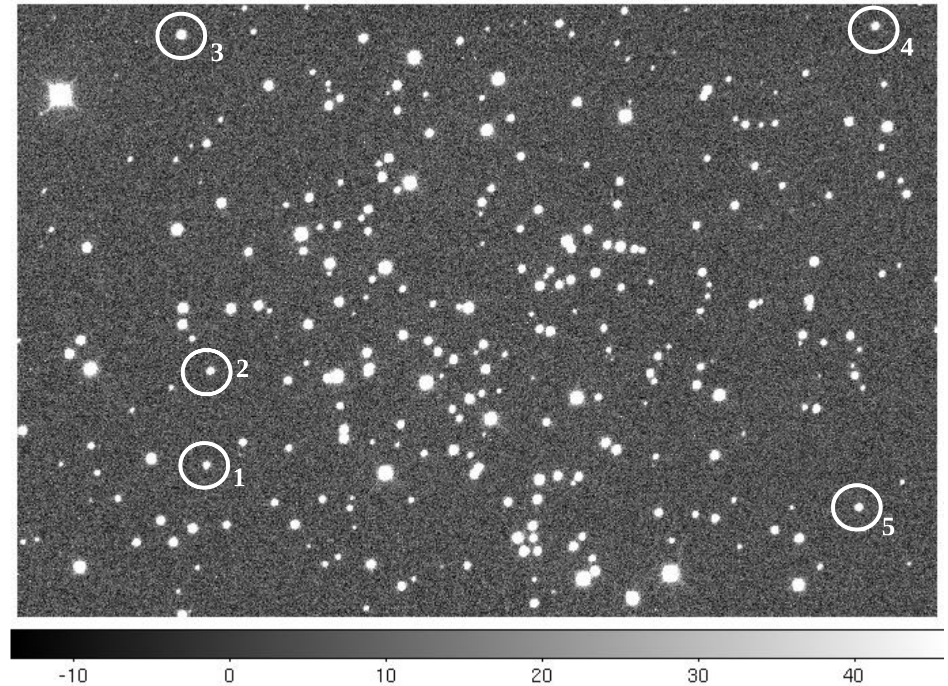
The FITS header of any image taken with the Sedgwick telescope has a keyword FOCALLEN that gives an estimate of the telescope's focal length. The mean angular diameter of the Moon is about ½ degree, or 1800 arcsec. What is the diameter of an image of the Moon made by this telescope, in mm?

Other keywords give the widths and the number of detector pixels, in the x- and y- directions. What is the (x,y) size of the detector as projected on the sky, in arcsec? Will the entire image of the full Moon fit on it?

How do we know if the header value for the image scale of the telescope is correct? Can we measure it? Yes. Let's do so.

Use **ds9** to open the image **lab014.fit**. Click on "scale" and "zscale" so you can see faint stars. Display the header, and write down the **RA, δ** coordinates to which the telescope is pointing.

After doing a Y-invert (see below),
your image should look like this, except for the little circles and numbers.



By no coincidence at all, this is the center of an open cluster in the Messier catalog. By matching coordinates in one of the Messier catalog lists that you have already used, identify which open cluster it is. Write down the name.

In the **ds9** "Zoom" tab (not the Zoom button), click "Invert Y" to flip the image upside down. This will facilitate comparison with other images that are in a more standard format. (Notice, for future reference, that other flip and rotate operations are possible.)
Now open a browser and go to http://www.sky-map.org. This is a nice piece of planetarium software. Go to "Home", and enter the name of the cluster in the "Find Object" window. When the map comes up, point to the small elliptical icon in the upper left called "DSS", and select "DSS2 All Sky Survey". Zoom in 3 or 4 clicks on the size scale, and you should see a familiar star cluster (a bit off center). Drag it to the center of the window, and zoom it to whatever degree makes you comfortable. Now when you drag the cursor over a star image you will see lots of information about each star, including a long catalog number, and (most importantly) the star's equatorial coordinates.

Identify the 5 numbered stars on the star-map.org site, and list their RA, δ values in a table, 1 row per star. Also measure the {x,y} coordinates of each star on **lab014.fit**, using the cursor to pick out the brightest point in each star. Do this carefully, zooming so that setting the cursor is easy, and adjusting the "scale" options so you can easily see the brightness variations inside the star images.
Make a subjective guess about the error (in pixel units) with which you can measure the star positions. Put this in the table too, under error_g.

Star	**RA**	**δ**	**X_pos**	**Y_pos**	**error_g**
1					
2					
3					
4					
5					

What do you think is your largest source of error (the one that dominates your estimate of error_g)?

Now compute the distances between various pairs of stars, as given below. Do this first by using the difference in RA and δ that you obtained from sky-map.org. Formally this is an exercise in spherical trigonometry, but because all of these stars are very close together on the sky, we may use small-angle approximations. In this case we get sufficient accuracy by taking

$$dr = \mathrm{sqrt}\left(d\delta^2 + [d(RA)\cos(\delta)]^2 \right),$$

where dr is the angular separation between two stars, dδ is the separation in Declination, and d(RA) is the separation in Right Ascension, with all angles are expressed in units of angle (use arcsec). *Remember that RA is normally expressed in units of time, not angle -- one second of RA (the difference between RA = 08:30:00 and 08:30:01, for instance) equals 15 arcsec.* You should consider where the factor cos(δ) comes from.
Also compute the separation between these pairs of stars in units of pixels, using your measured values of X_pos and Y_pos. In this case the normal Pythagorean law may be used, with no cos(δ) factor. (Think about why.) Use your estimates of error_g and the propagation-of-error rules in Taylor to estimate the errors in these separations which we will call error_p. Put all of this in the table on the next page.

Star Pair	dr (arcsec)	dp (pixel)	Error_p (pixel)	Scale (arcsec/pixel)	Error_s (arcsec/pixel)
{1,2}					
{1,3}					
{3,4}					
{3,5}					
{1,4}					

Show the formula(s) you used for calculating the error_p values.

For each star pair, compute the image scale dr/dp in units of arcsec/pixel, and enter this value in the table. Use Taylor's error propagation rules, starting from your estimates of error_p, to estimate the error in your derived value for the image scale (which we will call error_s). Assume that the star separations derived from www.sky-map.org positions have negligible errors. Put your error_s values in the table.

Now you have 5 not-quite-independent measurements of the image scale. Do they agree with each other, within the plausible errors? If not (and especially if the disagreement is very large), the most likely explanations are (a) there is a mis-identified star, or (2) there is an error in computation. In either of these cases, you should go back and correct the error before proceeding.

Do your image scale estimates now agree (within reasonable error estimates)?

If yes, then average your results (we will do weighted averages later), and estimate the uncertainty of this mean value, again using the rules described in Taylor's book. From the image scale, compute the telescope focal length and its uncertainty. Compare this to the focal length value found in the FITS image header. Show your work.

Is your focal length estimate consistent with that reported in the image header? If not, what do you make of that fact?

Finally, it would be good to have a more objective measure of the error in estimating x- and y-positions of stars. To get one, measure the x- and y- coordinates of the same stars on the image **lab013.fit**, which is an image of the same field of view, taken at a slightly different time. Notice that the star coordinates are *systematically* different between these images, because the telescope pointing changed slightly in the time between taking these images. We can isolate the effect of random errors by concerning ourselves only with the separations between stars on a single image. Fill out the following table, which contains differences between separations measured on images **lab014.fit** and **lab013.fit**.

Star pair	**dx(014 – 013)(pixel)**	**dy(014 – 013)(pixel)**
{1,2}		
{1,3}		
{3,4}		
{3,5}		
{1,4}		

Compute the square root of the mean-squared values of dx and dy, taken as one set of 10 numbers. This is an estimate of your typical error in estimating star positions along either axis. Write it down. How does it compare with your subjective guess error_g from earlier?