A STUDENT'S HANDBOOK OF LABORATORY EXERCISES IN ASTRONOMY

(Laboratory Manual for Astronomy 101 and 102)

Second Edition
2010

Astronomy 101 Lab Report

You MUST pass the labs to pass the course. To pass the labs you must write up your own lab and hand it in to the slot for your lab section in the box outside Elliott 403. Write legible full sentences in ink in a "Physics Notes" lab book. If your writing is indecipherable then type the lab report on a computer and print it so your instructor can read it. To maximize your marks you will want to follow this format. Notice that NOT all of the following components will be in every lab; this outline is more of a guideline.

OBJECTIVE/PURPOSE Write one or two sentences about why you are doing the lab.

INTRODUCTION/THEORY Outline what the lab is about and give the historical perspective. You especially want to state what you expect the results to be from previous work. What assumptions are you making?

EQUIPMENT Often a piece of equipment is introduced which allows you to make your measurements. Describe the equipment giving pertinent details.

PROCEDURE In your own words write a brief outline of the steps you used to do the lab. It must not be a copy of the lab manual but it must say more than "See the lab manual". A reasonably knowledgeable person should be able to follow your procedure, complete the lab and get similar results. Use third person past tense: "The galaxy was measured ... " NOT "I measured the galaxy ... ".

OBSERVATIONS Some of the labs require you to sketch something astronomical so record the date, time and sky conditions on the sketch.

TABLES/MEASUREMENTS The data you measure should be put in a table on the white pages of the book with the columns labelled and underlined. Refer to the table in the procedure.

GRAPHS Sometimes we want to show how one thing is related to another and we will do that with a graph. Make sure you print a label on both axes and print a title on the top of the graph. The scale should be chosen so that the points fill the graph paper.

CALCULATIONS When you calculate an answer take note of the significant digits. If you have three digits in the divisor and three digits in the dividend then you should state three digits in the quotient. If you do the same calculation over and over (i.e. for different stars), then show one calculation and then put the other results in a table.

RESULTS The result of a lab is often a number. You must remember to quote an uncertainty for your result. You must also remember to quote the units (kilometres, light years, etc.).

QUESTIONS Usually there are a few questions at the end of the lab for you to answer. These should be answered here.

CONCLUSIONS/DISCUSSION Does your result make sense? Did you get the result you expected within the uncertainty? If not, there is some error and you might want to check it out with your lab instructor! How are your results dependent on your assumptions?

REFERENCES List the books and web sites that you used to write up this lab. Use the text but do not copy it.

EVALUATION Did you like this lab? Did you learn anything?

MARKING In general an average mark is 7 or 8 out of 10. The lab is due approximately 24 hours after you have finished it and one mark is deducted per week that a lab is late. Please hand in the lab to the box in the hall on the fourth floor. It is usually hard but not impossible to get a 10. You need to show that you are interested and to not hold back. Read the lab manual, read the text, visit a few of the suggested web sites and you will learn something to impress the marker and get a better mark.

Contents

1 Visual Observations

OBJECTIVE

The objective of this laboratory exercise is to introduce the student to the essentials of astronomy – planets, stars, galaxies, nebulae, and telescopes – through the observation of the night sky.

EQUIPMENT

Telescopes

At night the brightness of the faintest star which you can see is limited by the size of the pupils of your eyes. Your pupils dilate in the dark so that more photons (bits of light) can get into you eye. In the dark your pupil is about 1 cm in radius and has an area (πr^2) of 3.14 cm^2. If the pupil of your eye were three centimetres radius you could see stars nine times fainter. For this lab we will give you a telescope, which concentrates all the light which falls on a mirror 10 cm in radius into a beam small enough to fit in your eye. These telescopes also magnify about 45 times and have a field of view of 1 degree.

Your instructor will show you the parts of the telescope and explain their function. You will be shown how to use the telescope. Make sure you understand the use of the instrument before you use it in the dark.

- Draw a diagram of the telescope showing the essential parts: primary mirror, secondary mirror, eyepiece, focuser, mount and finder.
- In a sentence or two describe and explain the function of these parts.
- Draw on your diagram the path followed by the incoming light.
- How much brighter will your telescope make the stars appear relative to your unaided eye?

Our telescopes can moved under computer control. The telescopes must be told the accurate time and properly aligned on two stars at the beginning of the night and from then on they will point to any object in the sky. If you turn the power off or bump them then the telescope will need to be realigned by the instructor.

The telescope has a hand control that lets you move the telescope up, down, left and right with the arrow keys. Above the arrow keys are: [Align] never push it, [Enter] to accept an answer, [undo] to not accept an answer or to answer no. Below the arrow keys is the number pad and each number is a command/list of objects. Use the [6=Up] & [9=down] keys to scroll through a list of objects. The [5=planet] key to scroll through the planets and the [8=list] key to see lists of named stars and named objects. The [1=M] key is for a famous list of objects compiled by Charles Messier. The [info] key will give you information about the object you are looking at. There is a list of interesting objects at the end of this lab.

Observations

The Moon

We will start with the Moon since it is the brightest and most easily found object in the sky. To get the moon in the telescope push [undo] a few times; then push [5=planet]; then push [6=Up] until the display says "Moon" and then push [Enter] and the telescope will move to the Moon. Then look into the small finder telescope and centre the image of the moon on the cross hairs by pushing the arrow keys. The moon should now appear in the main eyepiece. Centre the moon in the field of view by pushing on the arrow keys. DO NOT pull or push on the little FINDER telescope.

- Sketch the moon as seen with your eye. Include the time, the horizon
- Sketch the moon as seen through the telescope.

The Planets

People have looked at the night sky with their unaided eye for centuries and have made some interesting observations. The most obvious is that everything in the sky other than the Sun and the Moon seems to be a tiny pin-prick of light. Also, if you measure the moon's position relative to some stars tonight and then do the same thing tomorrow you will find that the moon has moved relative to the stars. The ancients also noticed that some of the brightest "stars" moved; these they called the "planets", which means "wanderers".

The planets are also bright and usually easily identified. Five planets can be seen with the naked eye – Mercury, Venus, Mars, Jupiter, and Saturn.

Depending on their position along their orbit and our position in our orbit around the Sun, some planets may or may not be visible, i.e. above or below the horizon, at the time you are doing this lab.

- Note also the time and date of your observation.
- Use the telescope to observe each visible planet.
  - What colour is the planet?
  - Can you see markings on its surface?
  - Can you see its moons?
  - Is the planet crescent-shape, round, or gibbous (nearly full)?
- Sketch each planet (and its moons, if any) as seen through the telescope.
- If the moons are visible, label them on your sketch.

The Stars

Even if the moon and the planets are below the horizon during the night, there are many very interesting stars to look at.

- Point your telescope at any bright star in the sky. What do you see? In the list of named stars: Vega, Deneb, Altair or Arcturus are probably good choices.

Hopefully you have seen a tiny pin-prick of light that twinkles. Stars look the same through a telescope as they do to your eye, but brighter. They are so far away that they appear to us as *dots* of light – no matter how many times you magnify them, you will always see them as *dots*. The stars are many light years from us (1 ly = 9.46×10^{12} km, the distance a photon of light travels during one year). For comparison, the Moon is about 2 light seconds from us, and the planets are about 20 light minutes from us, the bright stars are about 20 light years from us and the nearby galaxies are about 20 million light years from us.

Some stars have close companions which orbit them, similar to the way our Earth orbits the Sun. These stars are called *double stars* or *binary stars*. The star named Albireo (β Cygni) in the constellation Cygnus is a beautiful double star.

- Point your telescope at Albireo.
- Sketch Albireo.
- What is the colour of each star?
- Which star is the hottest of the two? Explain.
- Note the time and date of your observation.

The Constellations

When you look at the night sky you will probably notice that the stars seem to form lines or simple geometrical shapes. These asterisms are the basis for the constellations. While the origin of our names of the stars and constellations is for most part lost, generally we use names derived from the Arabic names for the stars and the Greek names for the constellations.

constellations of stars. Your instructor will point out the more obvious constellations and bright stars.

- Sketch at least three (3) **new** Constellations that you learnt tonight.
- What is the mythology associated with them.
- Note their approximate positions in the sky, and the time and date of the observations.
- Learn the names of at least three stars and mark them on your constellation sketch.

Deep-Sky Objects : Star Clusters, Nebulae, Galaxies

Plenty of other astronomical objects can be observed such as clusters of stars, gaseous nebulae and galaxies. These objects are generally very distant and thus are quite dim, and therefore harder to see with a small telescope than the planets are. The list of objects compiled by Charles Messier is stored as key [1=M] and you can use this key to move to any of the Messier objects in the table.

- Observe and sketch one of each of these four types of objects :
  - Globular Cluster

  - Open Cluster
  - Planetary Nebula
  - Galaxy

- Describe in a few sentences what these objects are. Do not copy the info button!
- Again, note the time and date of your observations.

If you do not get a chance to see one of these nebulous object due to clouds etc., look them up in your text book or the Internet and write a few sentences about them.

Web Sites
http://skyandtelescope.com/
http://www.heavens-above.com/

INTERESTING FALL OBJECTS

Objects	**R. A.**	**Declination**	**Mag.**	**Comments**
Vega	18:36:56	38°47′	0.0	25 ly A0V
Arcturus	14:15:40	19°11′	0.0	36 ly K2III
Albireo	19:30:44	27°57′	3.1	K3II+B8V
Mizar	13:24	54°56′	2.3	78 ly, Double Star
NGC 869/884	02:20	57°08′	6.6	6000 ly, Double Open Cluster
M11	18:51:06	−6°16′	5.8	6000 ly, Open Cluster
M27	19:59:24	22°43′	7.6	900 ly, Dumbbell Planetary Nebula
M57	18:53:24	33°02′	9.7	1600 ly, Ring Planetary Nebula
M31	00:42:42	41°16′	3.5	2 000 000 ly, Andromeda Galaxy
M13	16:41:42	36°28′	5.9	20 000 ly, Globular Cluster
M15	21:30:00	12°10′	6.3	30 000 ly, Globular Cluster

2 Apparent Positions of the Planets

OBJECTIVE

This exercise is intended to familiarize you with the apparent motions of the bright planets and enable you to predict where and when you might expect to find them in the sky.

INTRODUCTION

In Table 1. you are provided with the heliocentric longitudes of the planets (helio=sun, centric=centred) Venus, Earth, Mars, Jupiter and Saturn. These longitudes, and the radii of the planets' orbits, are used to produce orbits on the graph paper and indicate where the planets are in their orbits for a given time of year.

Materials

- large sheet of polar coordinate graph paper
- protractor
- SC001 constellation chart
- coloured pencils
- planisphere

The Planets' Longitudes

The sun's annual path, through the stars, defines the great circle called the ecliptic. This represents the plane of the earth's orbit projected into space. Since the bright planets are observed to move in paths which closely follow the ecliptic, it follows that all the orbits lie approximately in the same plane (i.e. the plane of the ecliptic). For this lab, we will assume that the orbits are circular, and draw them on a flat sheet of paper.

Table 1. Heliocentric Longitudes from Astronomical Almanac

Date	Venus	Earth	Mars	Jupiter	Saturn
2010-Sep-22	338	000	238	358	187
2010-Oct-22	026	030	254	001	188
2010-Nov-21	074	060	270	004	189
2010-Dec-21	122	090	288	007	190
2011-Jan-19	170	120	306	009	191
2011-Feb-18	218	150	325	012	192
2011-Mar-20	266	180	343	015	193
2011-Apr-19	314	210	003	018	194
2011-May-20	003	240	022	021	195
2011-Jun-21	054	270	040	023	196
2011-Jul-22	104	300	058	026	197
2011-Aug-22	154	330	074	029	199
2011-Sep-22	204	360	090	032	200

Plot the Planets' Positions

Before you plot the positions of the planets for the given time frame, there are some things you need to know. Table 2 gives the radii of the orbits of the planets in question, in astronomical units (AU). The radius of the earth's orbit is defined to be 1 AU (=150 million km).

In order to plot the positions of the planets, the point of zero longitude must be defined. Both heliocentric and geocentric longitudes are measured counterclockwise from $0° - 360°$ the First Point of Aries as zero. The First Point of Aries, assigned the symbol ♈ , is at the vernal equinox, which is the point at which the sun crosses the celestial equator moving north. This is the point in the sky which lies behind the sun at the time of the March equinox.

To plot the positions of the planets, place the sun at the centre of the paper, and use the concentric circles as the orbits. There are 10 heavy black circles; and since the orbit of Saturn is 9.54 AU, each circle can represent 1 AU. Take the large zero at the bottom of the paper to be the First Point in Aries, and read off the longitudes of the planets, moving counterclockwise.

Table 2. Radii and Period of Orbits

Planet	Orbit Radius (A.U.)	Period (years)	Symbol
Sun			☉
Mercury	0.387	0.24	☿
Venus	0.72	0.62	♀
Earth	1.00	1.00	⊕
Mars	1.52	1.88	♂
Jupiter	5.20	11.86	♃
Saturn	9.54	29.46	♄
Uranus	19.218	83.75	⛢
Neptune	30.110	163.73	♆

Mark the planet's positions with a coloured pencil, and label each position with the date. Plot the planet positions for three months.

Conjunctions, Elongations and Oppositions

Figure 1 is a diagram of the sun, earth, an inner planet (like Venus, for example) and an outer planet (like Saturn, for example). On this diagram are labeled various interesting alignments of the planets. Conjunction is when the planet is in line with the sun and generally hard to see like a new moon. Opposition is when the planet is opposite the sun and will stay up all night like a full moon. Greatest Elongation is when an inferior planet is at its greatest distance from the sun as seen in the sky and most easily seen. Quadrature is when the planet is ninety degrees from the sun like a first or third quarter moon. Referring to this diagram and your orbit diagram drawn earlier, for each outer planet state whether it is closest to conjunction, opposition or quadrature. For Venus, state whether it is closest to inferior conjunction, superior conjunction, or greatest eastern or western elongation.

Why does Venus go through phases?

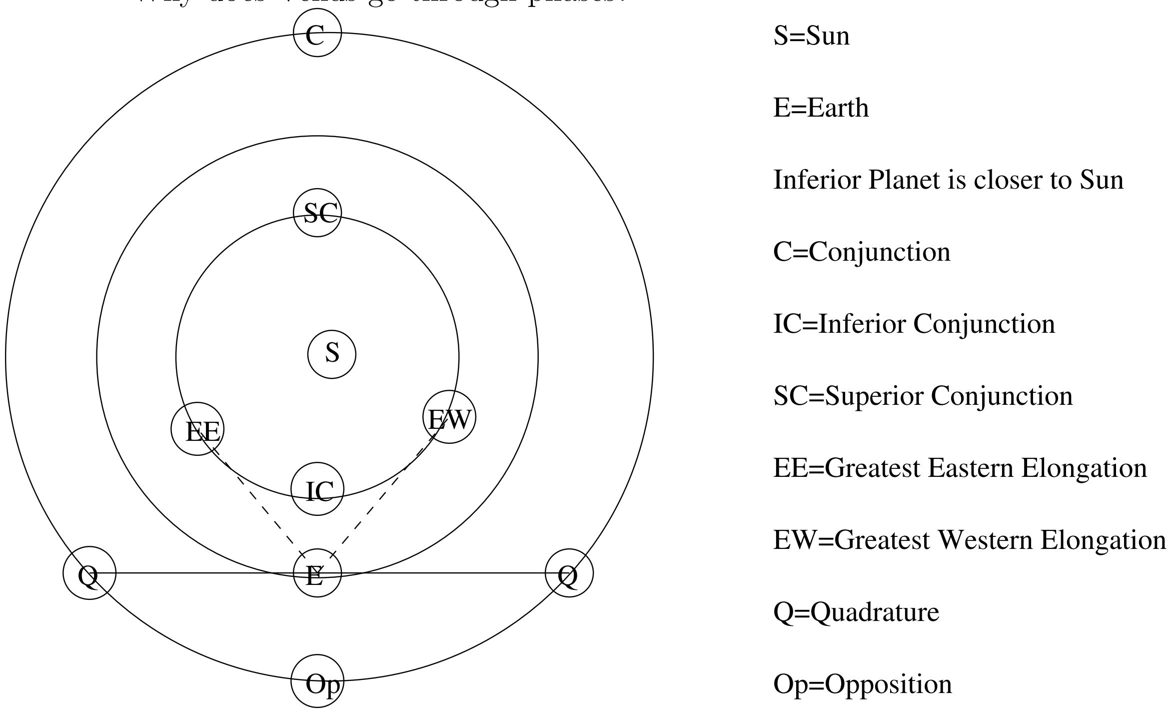


Figure 1. Planetary Configurations

The Planets as Seen from Earth

Now where would Venus, Mars, Jupiter and Saturn be in the sky, as seen from Victoria? You can predict this using your orbit diagram. We know that the earth rotates on its axis counterclockwise, as seen on your diagram. Noon at a particular place on the earth occurs when that place fully faces the sun, midnight is when the earth is turned such that the sun is on the other side of the earth, dusk and dawn are halfway in between. At dusk the sun will be on the western horizon and at dawn the sun will be on the eastern horizon. From Victoria if the sun is “overhead” at noon it is really in the southern part of the sky.

Just like the sun will rise and set once each day so do the planets. For each of the four planets, state whether you would see them at dawn, dusk, noon and midnight and in the eastern or western or southern part of the sky.

Table 3. Planets as seen from the Earth

Planet	Noon	Sunset	Midnight	Sunrise
Venus				
Mars				
Jupiter				
Saturn				

The Geocentric Coordinates of the Planets

Recall that the geocentric ecliptic longitude is the longitude of the planets as measured from the earth (geo=earth). In this part you will be determining the geocentric ecliptic longitude of each of the four planets in question and thus the constellation in which the planet appears.

First measure the geocentric ecliptic longitude of each planet. Note you will have to move your origin from the Sun to the Earth (since we want earth-centred longitudes, not sun-centred ones), and draw a line straight down from the earth to establish a new First Point in Aries from which to measure. This line should be parallel to the original line to the First Point in Aries. Remember to measure from the First Point in Aries around counterclockwise to the planet's location.

Using these geocentric longitudes, plot the positions of the planets and the sun on the ecliptic on the SC001 constellation chart. The zodiac constellations are the 12 constellations which form a band around the celestial sphere, along the ecliptic.

- In which zodiacal constellation is each planet located?
- In which zodiacal constellation is the sun located?
- In which zodiacal constellation was the sun located when you were born? What is your astrological sign? Check with your partners and discuss any discrepancy.

Table 4. Geocentric Equatorial Position of the Planets

Planet	Ecliptic Long.	Constellation	Right Ascension	Declination
Sun				
Venus				
Mars				
Jupiter				
Saturn				

The Geocentric Equatorial Coordinates of the Planets

When we want to move our telescope to see a star or a planet we generally use what are called the equatorial coordinates, called Declination (latitude) and Right Ascension (longitude). The Declination is measured from the equator going north (+) or south (−) in degrees. Right Ascension is measured around the equator in hours and minutes from the First Point in Aries. These coordinates scales are on the constellation chart. What are the Right Ascension and Declination of the planets?

The Use of a Planisphere

A planisphere is a device which displays the stars and sky depending on the time of day and the date in the year. The sky visible from any location of Earth depends on the latitude of the observer so the planisphere has a cutout set for a certain latitude. Here are a number of exercises for you to do which will illustrate how to use the planisphere.

1. Fold and tape together your planisphere as per the instructions on it
2. Turn the dial round and round and round. Which star seems to stay in the middle of the visible area.
3. Along the top dial find the 12 arrow. Turn the inside star dial until the 12 matches up with 01 July.

4. The star in the middle of the visible part of the dial will be the one passing overhead)in the Zenith). What is the name of the star in the Zenith? What constellation is it in?

5. On the right hand side of the planisphere is the "Western Horizon". Which star is on the Western Horizon?

6. Turn the star dial to 15 July at 11pm. Which star is in the Zenith? Which star is on the western horizon?

7. Turn the star dial to 15 August at 11pm. Which star is in the Zenith? Which star is on the western horizon?

8. We can turn the dial until the star Antares is setting on the western horizon. What time will Antares set on the 22 September? What day and month will Antares set at 1am.

9. Turn the dial to 11pm on 01January and find the star Sirius. At what time will Sirius rise on 01 January? At what time will Sirius set on 01Jan? For how many hours will Sirius be above the horizon on 01Jan?

Web Sites
http://www.jpl.nasa.gov/
http://ssd.jpl.nasa.gov/

3 Galaxies, Stars and Nebulae

INTRODUCTION

The photographs that we will be using are reproductions of plates taken by the 1.2 m (48 in) Schmidt telescope on Mount Palomar. Schmidt telescopes are designed specifically for photographing relatively large (by astronomical standards) areas of the sky with very good definition. This particular Schmidt telescope is the largest one in the world and was designed, at least in part, with the idea of compiling an atlas of the entire sky visible from southern California. The atlas took about 10 years to complete, under the auspices of the National Geographic Society, and the Hale Observatories which are run by the Carnegie Institution and California Institute of Technology. It has since been invaluable to astronomers. The telescope was large enough that the pictures include the most distant objects known, and yet the field of view was wide enough (In a large telescope the field of view is usually quite small) that the entire sky is covered by a reasonable number of photographs. Astronomers use the photographs both for survey work in determining the numbers and kinds of different classes of astronomical objects and for discovering and identifying objects that need to be studied further with other types of telescopes.

The original photographs were made on glass, as are most astronomical photographs, because glass is less subject to the stretching, shrinking and warping that can occur with the acetate and other bases used for ordinary photographic film. The original photographs are stored in a vault, but many copies have been made and sold to various observatories and astronomical institutions around the world. All the copies (ours are prints but transparencies are also available) are negative contact copies because, as a matter of practical experience, these preserve more of the details of the original than do any other types of copies. Each print is about 35 cm square and covers an area of the sky of 6^o x 6^o giving a scale of roughly one degree per 6 cm. (The full moon would thus be about 3 cm in diameter.) For each position on the sky, there are two different photographs, one taken originally in blue light and one taken in red light. This lets us estimate the colors of different objects and even, in extreme cases, see objects in one color that are nearly or totally invisible in the other.

These prints are of extremely high quality and are the same ones that astronomers use. They are very difficult to replace so please be extremely careful. Please NO PENS OR PENCILS ANYWHERE NEAR THE PHOTOGRAPHS! DO NOT WRITE ON PAPER THAT IS ON TOP OF THE PHOTOGRAPHS!

BASIC DATA

In the upper left hand corner of each photograph (which corresponds to the northeast corner on the sky) is a block containing the basic information about the photograph. This information includes the plate sensitivity (whether it was sensitive to blue light=O or to red light=E), plate number (the red and blue photographs of the same piece of sky will have the same number), the date on which the original photograph was taken, and the astronomical coordinates (right ascension and declination, which are analogous to latitude and longitude on the earth) which indicate the exact position in the sky of the center of the photograph.

OBJECT

1. To recognize the importance of practice in looking at photographs of astronomical objects.
2. To be able to recognize visually spiral and elliptical galaxies in both face-on and edge-on orientations.
3. To estimate the distance to one cluster of galaxies given the distance to another.
4. To appreciate the usefulness of photographs of more than one color.
5. To recognize the variety of objects visible in the sky.

GALAXIES

INTRODUCTION

The upper left corner of each print has a number which identifies the area of sky it covers. In this exercise you will be using prints 0-83 and 0-1563. Remember that these are negatives, so that light from a star or galaxy appears black on the prints. The spikes and circles around the images of bright stars are an artifact of the telescope structure. All stars, except of course the sun, appear as points of light to even the largest telescopes. The faint circular images which appear here and there are "ghost" images of stars which arise when light from a bright star bounces off the photograph, then gets reflected somewhere inside the telescope and finally returns somewhere else on the photograph.

PROCEDURE

1. Hercules Field

Inspect the print labeled 0-83 for a while. Most of the dots in the print are foreground stars in our Milky Way. This print also shows hundreds of galaxies which are not immediately apparent until you have achieved some experience with the other print.

2. Virgo Cluster

Now study the print 0-1563. You will notice many objects here that are clearly not stars. They are galaxies, mostly belonging to a cluster of galaxies in the constellation Virgo, called the Virgo Cluster of Galaxies. It is the nearest cluster of galaxies to us. We can say that these galaxies are all at approximately the same distance from us (about 51 million light years) and, therefore, any differences we find in the size or brightness between different galaxies are an indication of the intrinsic properties of these galaxies and not due to differences in their distance from us.

Study the print with a magnifier long enough to be able to distinguish:

a) elliptical galaxies (they show no structure, but get fainter from the center out) from spiral galaxies.

b) spiral arms of spiral galaxies that are smooth bands of light from those that are clumpy.

c) spiral galaxies seen edge-on from those seen face-on.

d) spiral galaxies which show a distinct bar across the nucleus (barred spirals).

e) irregular galaxies or peculiar systems like pairs of galaxies which might be colliding or orbiting each other. One of the best ways to look at galaxies carefully is to try to sketch some of them. Sketch at least 6 different galaxies (one from each of the above groups) in boxes about 3 cm square. Classify each galaxy as to which of the above groups it belongs.

3. Dust Lane

Near the upper right corner of 0-1563, just above the giant elliptical galaxy M86, is an elongated galaxy with a white lane across it NGC 4402. Sketch this system. What do you think the white lane is? Why are no stars visible where the white lane is?

Can you see white lanes or patches in any other galaxies? In what type of galaxy is there a tendency for white lanes and patches to occur?

4. Hercules Cluster

Now return to print 0-83. With your new experience, you will be able to find a group of several hundred galaxies clumped in a part of this print. Make a rough sketch of the features in the print showing location and outline of the cluster of galaxies (not the individual galaxies). This is the Hercules Cluster of Galaxies, in the constellation Hercules. Use a magnifier to check whether the Hercules Cluster contains spiral and elliptical galaxies like the Virgo Cluster. What do you find?

5. Distance to Hercules Cluster

Astronomers assume that the larger galaxies in each cluster are in fact very similar in size.

a) Why do the galaxies in the Hercules Cluster look so much smaller than those in the Virgo Cluster?

b) Estimate the distance of the Hercules Cluster, given that the Virgo Cluster is 51 million light years away. (Freedman et al., 1994). To do this, use your magnifier to measure the sizes of the approximately largest galaxies in each cluster, noting the type of galaxy beside each measurement (elliptical, E, or spiral, S). Then use the average size of the brightest galaxies as an indicator of relative distance.

Notes:

i) You will need to think carefully about the criterion you use for measuring size and then try to apply the same criterion to all your measurements.

ii) Estimate roughly the accuracy of your result.

iii) Compare the sizes you measured for the elliptical and spiral galaxies separately and discuss any differences you notice.

STARS AND NEBULAE

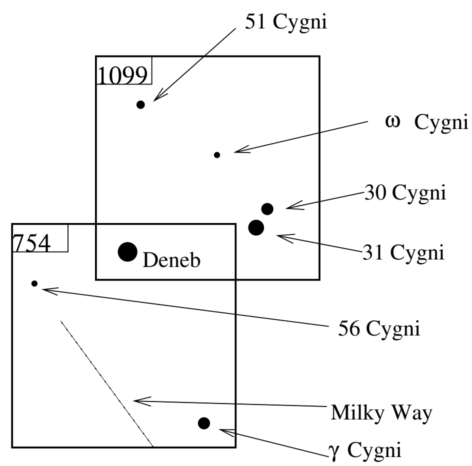
INTRODUCTION

The upper left corner of each print has a number which identifies the area of sky it covers. There is a red (E) print and a blue (O) print for each area.

Prints 1099 and 754 cover adjacent areas of sky and you can arrange them as shown in the diagram. The area covered is 6^o x 12^o, in the constellation Cygnus, where we are looking along a spiral arm of our galaxy. The very bright star Deneb is at the line of overlap as shown in the diagram and the direction of the Milky Way is marked.

The spikes and circles around the images of bright stars are an artifact of the telescope structure. All stars, except of course the sun, appear as points of light to even the largest telescopes. The faint circular images which appear here and there are "ghost" images of stars which arise when light from a bright star bounces off the photograph, then gets reflected somewhere inside the telescope and finally hits somewhere else on the photograph.

Figure 1. The Stars and Nebulae Prints



PROCEDURE

Make a sketch similar to figure 1. in your lab book. Show the outline of the POSS print and mark on a few of the bright stars. Mark the position of the following objects on it.

1. Stars

a) The brighter a star is in the sky, the larger its image on the photograph will be. Would you expect, therefore, the image of a blue star to be larger or smaller on the blue prints than on the red prints?

b) Near the lower right part of the print 1099 there are two fairly bright stars that appear near each other in the sky. 30 Cygni is the star to the north and 31 Cygni is to the south. Which is the bluer of these stars?

c) Find and mark the location of another very blue and another very red star.

2. Planetary Nebula

A planetary nebula appears on print 1099. It contains ionized hydrogen ejected by a dying star, so you would expect its color to be red.

Search on the print of the appropriate color and give its position. Clue: it is small and round, with a sharp boundary.

Search for it on the print of the other color. What do you find? Explain how it is formed.

3. Globule

A globule is a very thick dust cloud, so small that it may soon collapse to form a new star. Since dust absorbs all light emitted by more distant stars and nebulae behind it what color will the globule appear on the prints?

Search on print E-754 for the tiniest dust cloud you can find and mark its position. The globule may look like a speck of dust on the print or a flaw in the film. How can you check that it is a real globule and not merely a flaw?

4. Reflection Nebula

A reflection nebula occurs when dust scatters light from a nearby star. This makes the star redder and the scattered light seems to come from an extended region surrounding the star. The same thing happens in our atmosphere, making our sky blue.

A reflection nebula appears in the right half of 0-754. Search for this reflection nebula, mark its position, and explain how it is formed.

5. Milky Way

The diagram given earlier shows roughly where the Milky Way is located. Now look on the red prints and compare the number of stars in the Milky Way (per square mm) with the number in the upper right part of print 1099. What do you find?

We believe that our Galaxy is a disk of billions of stars, and that most of these are situated in the direction of the Milky Way. Why, then do we not see the greatest number of stars along its central line?

We can make a very rough estimate of the number of stars in our galaxy by counting how many stars there are in a small area and then multiplying by how many small areas there are in the sky. Count the stars in a millimeter by a millimeter square and then multiply by 150 Million to find roughly how many stars there are in the Milky Way galaxy.

6. Dust Clouds

Two dust clouds appear on E-754 at the lower left and lower right. Each is a thick, opaque cloud. Given this information, which cloud is farther away? Explain your reasoning.

7. Bonus

Other things to do if you have time: (no write-up required).

a) Look at E-1099 and E-754 together and notice how the long filamentary structures tend to curve and suggest they may be part of a circular structure with its center on the lower part of E-754. Although it is hard to see on the print, near the center is a group of stars known as the OB association Cygnus OB2. They are very strongly reddened by the interstellar dust between us and them and this dust has also dimmed their light. If this dust were absent, some of the stars would be among the brightest stars visible in the sky. Can you see this association? It is also interesting because there is a source of X-rays as well as a large, strong source of radio waves in the same directions which may have been left by a supernova.

b) Examine anything else that looks interesting and see what you can deduce about it from a comparison of the two prints or from a comparison with other nearby regions.

c) Imagine trying to give a name to each star in the upper right part of print 1099.

Web Site

http://www.stsci.edu/resources/

4 Spectra of Gases and Solids

OBJECTIVE

Our objective is to observe three kinds of spectra, including continuous spectra of opaque filaments, the emission lines of transparent gases, and the solar absorption spectrum. Then we will photograph the spectrum of a gas and identify the lines of Hydrogen and measure the wavelength of the lines.

INTRODUCTION

Wave Nature of Light

In many respects light exhibits a wave-like behaviour. Light has an electric component which undulates up and down, and a magnetic component that oscillates side to side. The distance from one wave crest to the next wave crest is the wave length usually denoted by λ. If you stand in one place and count the wave crests as they go by, the number you count in one second is called the frequency and is denoted by "f" or sometimes ν. See Figure 1. The velocity c of a light wave is the distance it travels in one second. That distance will equal the number of waves passing a point in one second "f" times the length of each wave (λ). Therefore we have a fundamental relation between these three quantities:

$$c = \lambda f \tag{1}$$

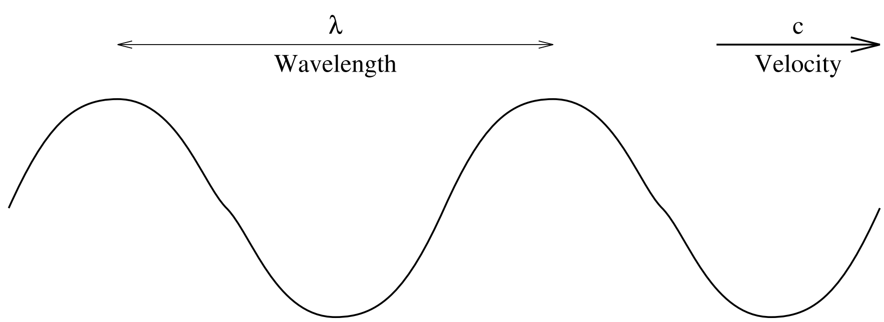


Figure 1. Light Waves

Wavelengths of light waves are often measured in nanometres (1 nm = 10^{-9} m) or Angstroms (1 Å= 10^{-10} m). The wavelength of a light wave determines its colour. Red light has a wavelength of around 6500 Å; green light has a wavelength of 5000 Å; and blue light has a wavelength of 4500 Å. The human eye responds to the wavelength range of around 4000 Å−7000 Å.

Sometimes when it rains you can see a rainbow. The rainbow is formed from sunlight coming over your shoulder and going into the rain drops in front of you. Inside the rain drops the light is broken up into its component colours, red, orange, yellow, green, blue, and violet. The relative brightness of the red to the blue and the yellow to the blue is always the same for rainbows on the earth.

A prism can also form a rainbow, but in this case we call it a spectrum. If we have more than one spectrum then we call them spectra. A spectrum of the sun will have all the colours of the rainbow and in the same relative brightness.

A transmission grating is a piece of transparent glass or plastic ruled with many finely spaced lines. A grating will break up light into a spectrum just like a prism only it will form many little spectra. Some light will go straight through the grating, this is the zero order image. See figure 2. The spectrum formed beside the zero order image is the first order image, and the next is the second order image, et cetera.

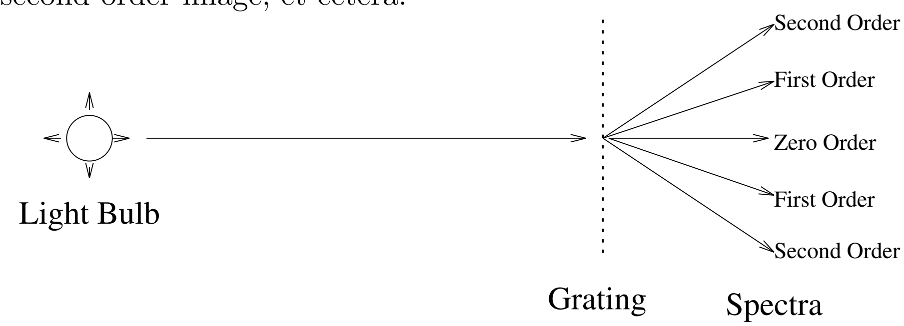


Figure 2. Spectral Orders

EQUIPMENT

We will use a diffraction grating, which is ruled with very fine lines spaced about 600 lines per millimetre.

An ordinary light bulb contains a very thin wire or filament made from solid tungsten. An electric current is forced through the filament making it hot, about 2800 K (=2527 °C). The hotter the solid filament, the brighter it is and the more white its colour. This is an example of Wein's Law and the Stefan-Boltzmann Law.

To make light from various gases we will use gas discharge tubes. These are glass tubes filled with Helium, Hydrogen, Neon, Mercury, and Argon. A high voltage power supply is used to pass an electric current through the gas making it glow. The internal structure of the atoms of the gas make the colour of the light different for each of the different elements. The spectrum of each of the elements is composed of discrete lines of colour. The intensity and position or wavelength of the lines serve as a fingerprint to identify each element.

PROCEDURE

Observe

- Hold the glass grating close to your eye. Look a little to the left or the right of the light source to see the spectrum, which will look like a rainbow.

- Look at the light bulb which is powered through the dimmer switch. As we turn the power to the light bulb up and down, it is the temperature of the filament of the bulb which changes. Is the brightness of the bulb the same with the high and low temperature? Is the bulb's colour the same? Is the spectrum the same with the high and low temperature? Sketch the spectrum at both high and low temperatures. How does this apply to stars?

- Observe the gas discharge tubes. These are tubes of glass where the air has been pumped out and a sample of an element has been put in the tube before it is sealed. A high voltage current is run through the tube to excite the gas and the gas in turn emits light. Turn the box to Neon and look at the first order image. Do you see a lot of red and yellow lines? Make a sketch of the spectra that you see from the gases in the gas discharge tube box (Argon is probably too faint). Colour the lines and comment on the similarity of the different spectra. What is the unknown? Explain two observations about the unknown's spectra, which lead you to this belief. Check your sketches with your neighbour's. Does everyone agree? Explain.

- We can also observe the spectrum of the nearest star, our sun. One of the windows is covered with a board with a slit cut in it. If you stand across the room from that board and look at the spectrum of the slit you will see a continuous spectrum similar to the light bulb. If you look closely in the yellow part of the spectrum you will see a dark line crossing the spectrum. This line is an absorption line due to the element sodium in the sun's atmosphere. What does this tell you about the sun? Can you see other absorption lines? Sketch the sun's spectrum identifying as many lines as you can.

Photograph Helium and Hydrogen Spectra

To make a record of your observations of the spectra of the gases we can replace your eye with a web camera. To start the web cam program, click on [3Com HomeConnect] in the Start menu. Click on [Video Gear] and then [HomeConnect ViViewer]. A window will pop up and the camera will begin taking pictures. We probably need more control over the camera so click on [Controls], [Camera control], and [More] so a camera control window pops up. Set the "Auto Brightness Mode" to "AGC Avg Mode" for good results. You may be able to improve the picture by trying the other options.

Set the gas discharge tube box to Helium. Set up the camera so it is about one meter from the gas discharge box. Focus the camera on the box. Put the grating in front of the lens of the camera so it will make a spectrum to the left and the right of the gas discharge tube. Aim the camera to the right of the gas discharge tube by about 15 degrees, so that the zero order image and the first order image will both be near the centre of the picture. Tilt the camera until the spectrum lines are not tilted and the spectrum runs left to right. Click on [Still Image] and the image will freeze. Save the image.

Without disturbing anything, switch the gas discharge tube box to the Hydrogen gas tube and take another picture. Save the picture.

Measure

The lines of Helium are shown in figure 3 and included is a table of wavelengths of each of the lines. Notice that the red lines have the long wavelengths (6678 Å) and the violet lines have short wavelengths (3889 Å). We want to measure the distance from the zero order image to each of the known lines in the Helium spectrum. Open the Helium picture. Click on the middle of the zero order image and drag the cursor to the middle of the

Helium line. A box will form on the picture and the size of the box will be displayed in the bottom left corner of the window. These "x" values are in pixels. Record these measurements "x" in a table in your lab book along with the known wavelengths.

Reload the Hydrogen picture. Measure the distance from the zero order line to each Hydrogen line. The Hydrogen lines are known by the Greek letters alpha (α), beta (β) and gamma (γ).

Plotting the Graph

Plot the wavelengths of the Helium lines against the "x" measurements of the Helium lines. Draw the best fitting straight line through the Helium measurements. This shows that there is a good relationship between the wavelengths of the lines and the position or "x" values of the lines. We can use this calibration line to find the wavelength of the Hydrogen lines for the "x" values for the Hydrogen lines.

On your graph to find the "x" value for the Hydrogen Alpha line, go up to the calibration line and then across to the wavelength axis to find the wavelength of the line. Repeat this for the other Hydrogen lines.

To find the uncertainty in our measurements of the wavelengths of the Hydrogen lines, we must first estimate how precisely we found the centres of the Hydrogen emission lines. Remeasure a Hydrogen line and find a box that is believable but not identical to the one you found before. Is it a pixel or two different? To what wavelength would it correspond? The accepted wavelengths of the Hydrogen lines are 6563 Å for α, 4861 Å for β, and 4340 Å for γ.

Table 1: TABLE OF HELIUM WAVELENGTHS

Line Number	"x"	Wavelength	Description
1	_	6678	Faint red
2	_	5875	Bright yellowish/green
3	_	5016	Bright green
4	_	4922	Faint Green
5	_	4713	Faint green
6	_	4471	Bright blue-violet
7	_	3889	Faint deep violet

Table 2: TABLE OF HYDROGEN WAVELENGTHS

Line Number	"x"	Wavelength	Description
α	_	_	Bright red
β	_	_	Blue
γ	_	_	faint blue

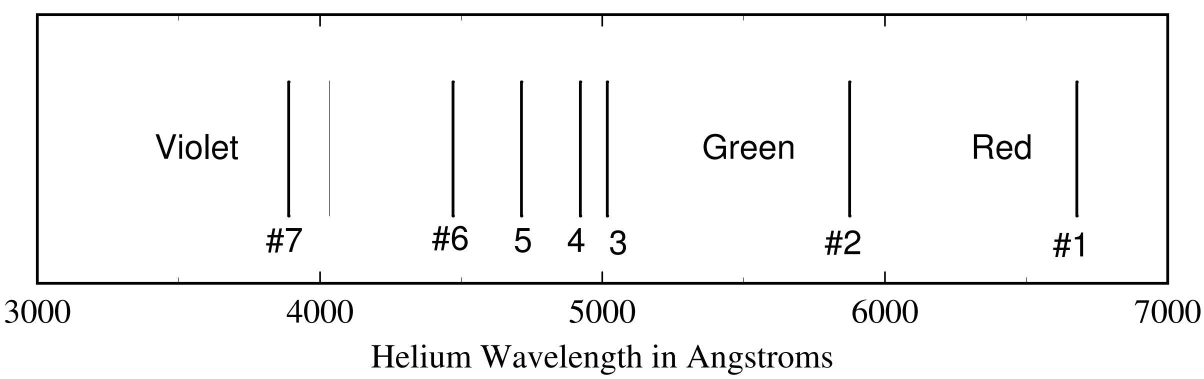


Figure 3. Helium Lamp Spectrum (scale only approximate)

5 Colour-Magnitude Diagrams

OBJECTIVE

To find the distance to and age of both open and globular clusters of stars, using colour-magnitude diagrams.

INTRODUCTION

Stars form from the dust and gas clouds we see silhouetted against the background stars and nebulosity. When one of these clouds collapses, it will form stars in groups or clusters. Therefore the stars in the cluster will all be the same age, same composition and at the same distance from the Earth. Generally a cluster of stars contains a few bright ones and lots of faint ones. If we examine the light from the stars carefully we find they are different colours. The bright ones are generally blue and the faint ones are generally red. Traditionally we measure the brightness through a yellow filter which we denote "V" for visual light and then through the blue or "B" filter. We find the colour by taking the difference of the B and V magnitudes denoted "(B−V)". We then plot the brightness "V" against the color "(B-V)" to make variation of the Hertzsprung-Russell Diagram called the Color-Magnitude Diagram.

To finish the lab on time.

Your instructor will log you into the a120 computers, but the operating system is NOT MS-WINDOWS. It is LINUX-XWINDOWS and so many of the icons and commands, you may be used to, are either nonexistent or will not work the same. Please do not try random commands. They will mostly have no effect, but may lock the terminal and then YOU will have difficulty finishing the lab in a reasonable length of time.

MORPHOLOGY

The program "isochrone" written by James Clem, who was one of our graduate students at the time. It plots the Colour Magnitude Diagram for each cluster on the computer screen. Plotted on the y-axis is the brightness V of each star and the x-axis is the colour of each star (B−V). An example is shown in figure 1. You can see a "Main Sequence" of stars from top left (bright blue) to bottom right (faint red). This is where most of the stars are found.

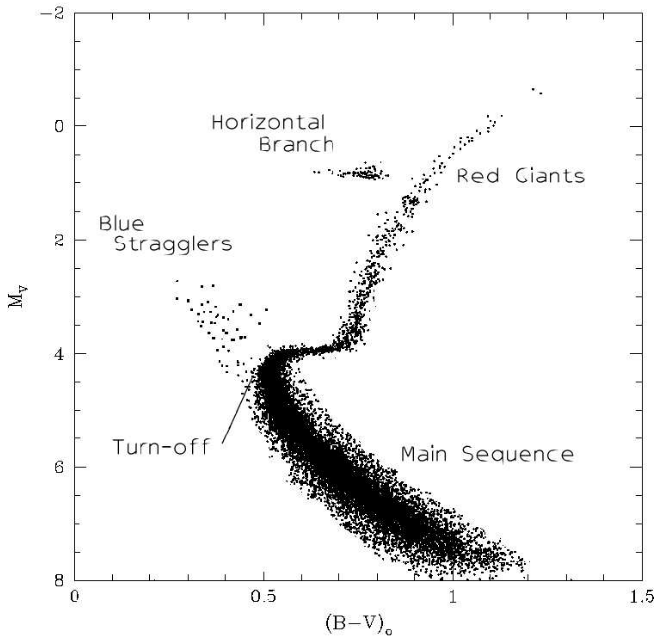


Figure 1. The Morphology of Colour-Magnitude Diagrams

When the cluster stars have burned enough hydrogen in their core, their internal structure changes and as a consequence their brightness and colour change and they will move brighter and redder in the Colour-Magnitude Diagram. The highest mass stars (10 Solar Masses) become Supergiants, then the average sized stars become Red Giants and are found on the Giant Branch. The most massive stars are the hottest in their core so they burn their Hydrogen in millions of years and become Supergiants. The less massive stars, like the sun, burn their Hydrogen in billions of years and become Red Giant stars latter. Since all the stars in a cluster were formed at the same time all the high mass/blue stars will move off the Main Sequence first and the lower mass/redder stars will move off later. Therefore we can tell how long it has been since the cluster formed by how massive/blue the last few stars are that are still on the Main Sequence. The bluest stars still on the Main Sequence are at the "Turn-off Point". Occasionally in very populous clusters a few stars are a bit bluer and brighter than the Turn-off point so they are called “Blue Stragglers”. These stars should have evolved off the Main-Sequence to be come Red Giants, but for some reason(s) they have not. The “Horizontal Branch” is where we find stars which are burning Helium in their core. We can tell they are not foreground or background stars, which we call “Field Stars” because field stars are found randomly sprinkled across the diagram.

Click on “New Cluster” and examine each cluster in turn. Which of the clusters has a “Main-Sequence”, a “Red Giant Branch”, a “Horizontal Branch”, “Field Stars”, “Blue Stragglers”?

THE SUN

Let’s find where the sun would be if it was on this plot. The sun has a (B−V) colour of 0.62 and would lie on the Main Sequence of stars. Put the cursor on the Colour Magnitude Diagram at a (B−V) of 0.62 and on the Main Sequence and click the left button. The V and (B−V) of the clicked point are given on the screen. Load each of the clusters and record what the apparent magnitude V of the sun would be if the sun were in the cluster. Would the sun be visible to the unaided eye, assuming the limit for your eye is V=6?

The absolute magnitude (brightness at 10 parsecs) of the sun is about V=5. Are any of your clusters closer than 10 parsecs?

ISOCHRONE FITTING

The hot bright stars have a larger mass than the small faint red stars. We can calculate the temperature and pressure of the interior of a star and estimate the rate at which it is burning Hydrogen into Helium. When it has burnt a certain fraction of its Hydrogen then it swells and becomes a Red Giant star. The larger the star’s mass the higher its core temperature and the quicker it burns its Hydrogen and the sooner it becomes a Red Giant. Some people at the University of Victoria are world experts in calculating how long it takes a star to burn its Hydrogen etc. They calculate the brightness V and colour (B−V) for a number of stars of various masses for a certain age and plot a line connecting them called an isochrone. Iso means same and chron means time. Since all the stars in the cluster were formed at the same time, we can determine the age of the cluster using the isochrones.

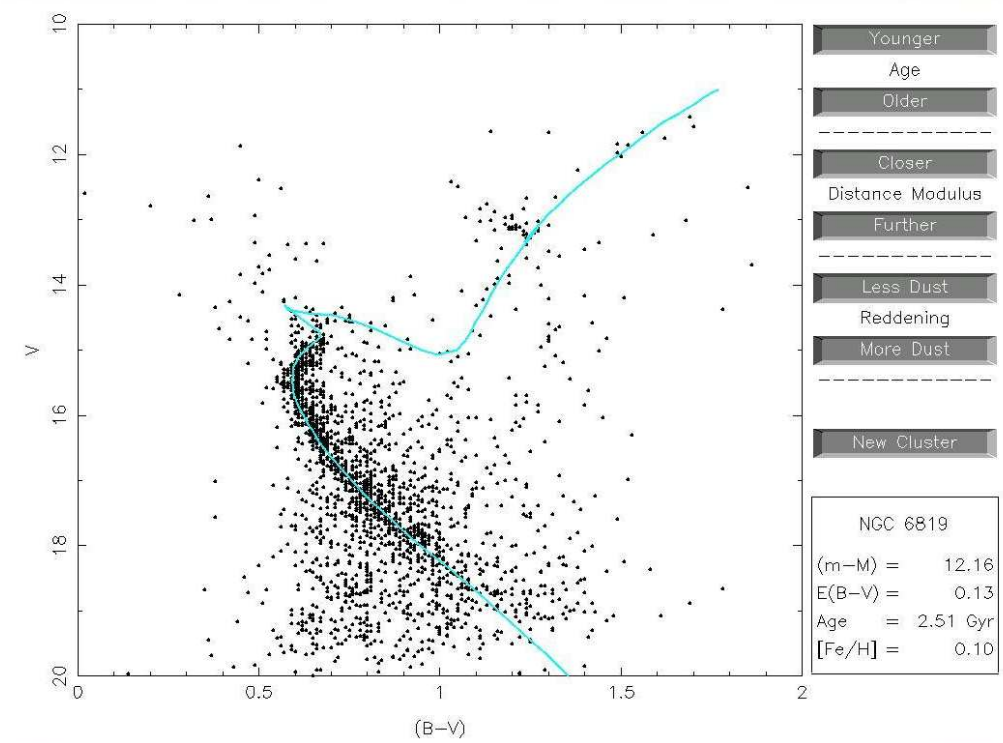


Figure 1. The fitting window

Click on the “Older” button a few times to get an isochrone (red line) for stars of a different age. The age is given in “Gyr”, which means Gigayears, which means billions of years. The isochrone is called the Zero Age Main Sequence (ZAMS) if the stars on it have just formed and not had enough time to evolve significantly. Remember that small, low mass, faint red stars evolve slowly so the isochrone should fit them better than the bright hot blue stars.

Even ignoring evolution the isochrone line will not fit your cluster points because it is set for the wrong distance. Move the isochrone up=closer and down=further by clicking on the “Closer” and “Further” buttons. This changes the distance modulous (m-M) which is the difference between the apparent m and absolute M magnitudes of the stars.

Just like the dust in our atmosphere makes the sun look red at sunset, there is a little dust in space which will make the stars seem redder. The farther the light travels through space the redder it becomes. The amount the stars seem to be reddened by the dust is called the "E(B−V)". The isochrone will move left and right when you click on "Less Dust" and "More Dust".

The fourth parameter is the amount of heavy elements in the star [Fe/H]. The first stars formed were made of only hydrogen and helium, but stars born later were formed from dust enriched in elements other than hydrogen and helium by supernovae. Because the stars in each cluster were all formed from the same dust cloud they will all have the same [Fe/H] We have set this parameter to the currently accepted value for each cluster.

There is some interdependency between these three variables so you will need to do some experimenting to get the range of values which will fit the data. For instance, if you change the age of the cluster you may be able to get nearly as good a fit by changing the distance and reddening. You will need to spend some time varying the parameters to make a good estimate of the uncertainty in each of these parameters.

Make sure you explain in your write up how the Age, Distance and Dust buttons move the isochrone.

DISTANCE

The distance D to the cluster can be found from the distance modulus $(m - M)$ and the formula

$$D = 10^{\frac{(m-M+5)}{5}} \text{ parsecs}$$

Find the distance to each cluster. From your estimate of the uncertainty in the distance modulus estimate the uncertainty in the distance.

Questions

1. Are any of the clusters older than the earth (4.5 billion years), or the universe (13.7 billion years)? Comment.
2. What will be the age of the sun when it reaches the turn-off point? What will happen to the Earth?

3. Two of the clusters - M15 and NGC 104 - are globular clusters (Population II) and look very different from the open clusters (Population I). Compare their distance, age, and [Fe/H] to the open clusters. Why is the [Fe/H] different for the two kinds of clusters?

Web Sites

http://antwrp.gsfc.nasa.gov/apod/ap010223.html

6 How Big is Our Galaxy?

OBJECTIVES

First: using variable stars in the globular cluster M15, determine its distance. Second: find the size of a dozen other globular clusters. Third: find the weighted mean distance to the centre of our galaxy. Fourth: using the distance to the centre of the galaxy and Kepler's Law estimate the mass of the galaxy.

PART ONE

Globular clusters are spherical, compact stellar systems containing between tens of thousands and millions of stars. Of the more than one hundred globular clusters known in the Milky Way, many appear very small (far away) and cannot be resolved into individual stars.

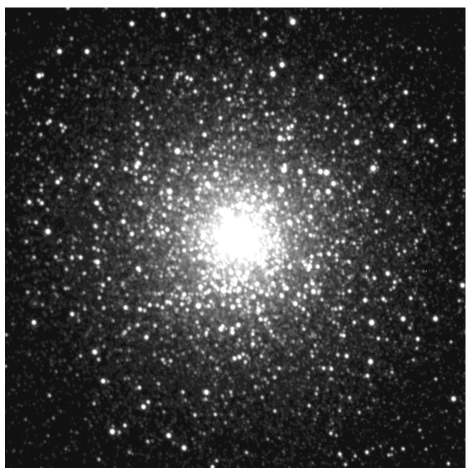


Figure 1. The globular cluster M15

In 1895 Bailey, working at Harvard College Observatory, noticed that three nearby globular clusters contained variable stars. The shape of their light curves identified them as pulsating variables, which was interesting, since it related stars in these unusual objects to stars in the solar neighbourhood.

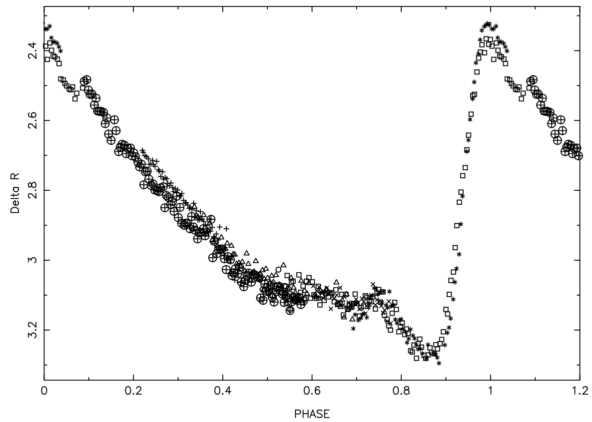


Figure 2. Example light curve of an RR Lyrae star discovered at UVic

The RR Lyrae variable stars all have a period of about half a day and an amplitude of about 0.5 magnitudes. Their light curves usually have the sawtooth shape shown in figure 2, but sometimes the variations will be more sinusoidal.

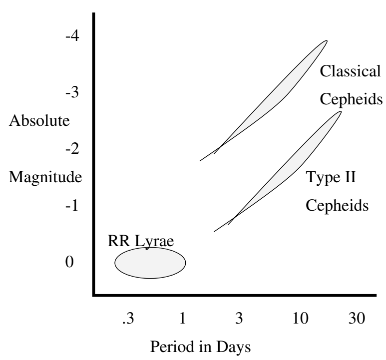


Figure 3. Period Luminosity Relation for RR Lyrae and Cepheid Variables

What makes the RR Lyrae stars very interesting is that within a particular globular cluster all these stars seem to have the same apparent magnitude. This means that all RR Lyrae stars are the same absolute magnitude. After a great deal of effort, which is still continuing, the absolute magnitude of the RR Lyrae and their bigger cousins the Cepheid variable stars have been measured. It is a bit more complicated for the Cepheids, since their intrinsic brightness depends on the period of the brightness variation as plotted in figure 3.

Procedure

Eight photographs of the globular cluster M15 are provided; all taken on a single night. Six RR Lyrae variables in the cluster are identified by letters, and on most of the photographs apparent magnitudes of some non-variable stars are indicated by numbers with the decimal points omitted (i.e. 153 means apparent magnitude 15.3 . The decimal point could be confused with a stellar image.) By comparison to these non-variable stars the magnitudes of the variables are to be estimated on each plate.

The best accuracy is obtained if the comparison stars used are close to the variable, rather than on the other side of the photo, since the emulsion may vary in sensitivity across the plate. Because of different exposure conditions, as well as emulsion differences, it is never possible to use comparison stars on a photograph different from the one on which the variable is recorded. On some plates a variable may be invisible. In that case it is useful to indicate the faintest star in the vicinity of the variable which is recorded, since it then can be said that the variable was fainter than that magnitude. This information may help in drawing a light curve.

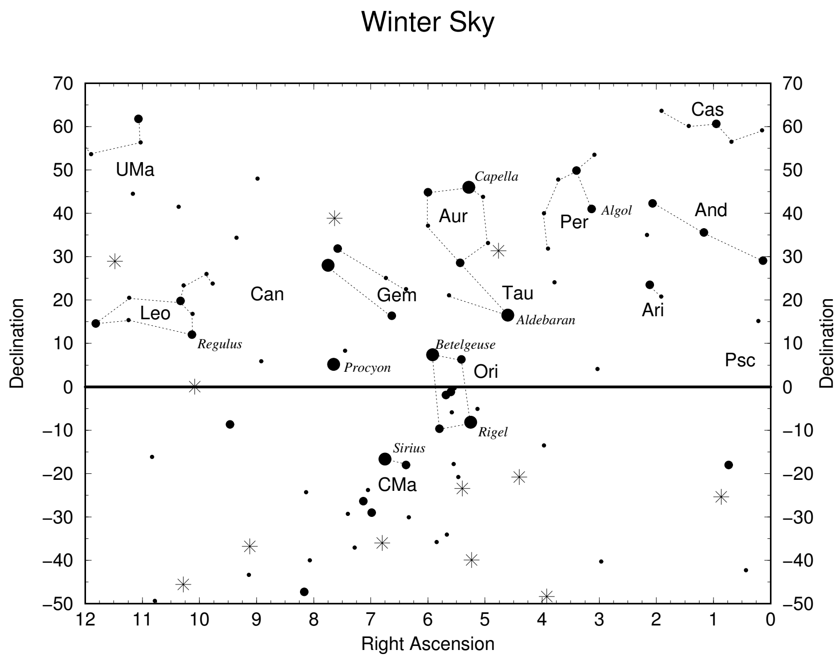
Plot a light curve for each star: apparent magnitude (bright at the top) versus the times in fractions of a day as given on the last page of the handout.

Now we want to estimate the mean magnitude of each star's light curve. If a star goes through a complete cycle, the mean magnitude may be determined as the average between extreme values read from the graph. Note: Even though you may not have an observation exactly at, say, maximum light you can estimate the reading from your sketched-in light curve. Are the mean magnitudes similar? If not, check with your instructor.

Using the accepted absolute magnitude of RR Lyrae stars (M=0.7 for this filter), find the distance D to each of these variable stars using the distance modulus formula.

$$D = 10^{\frac{(m-M+5)}{5}} \text{ parsecs}$$

Find the average distance to the stars and thus the distance to the cluster. Estimate the uncertainty in the distance by finding reasonable upper and lower bounds?



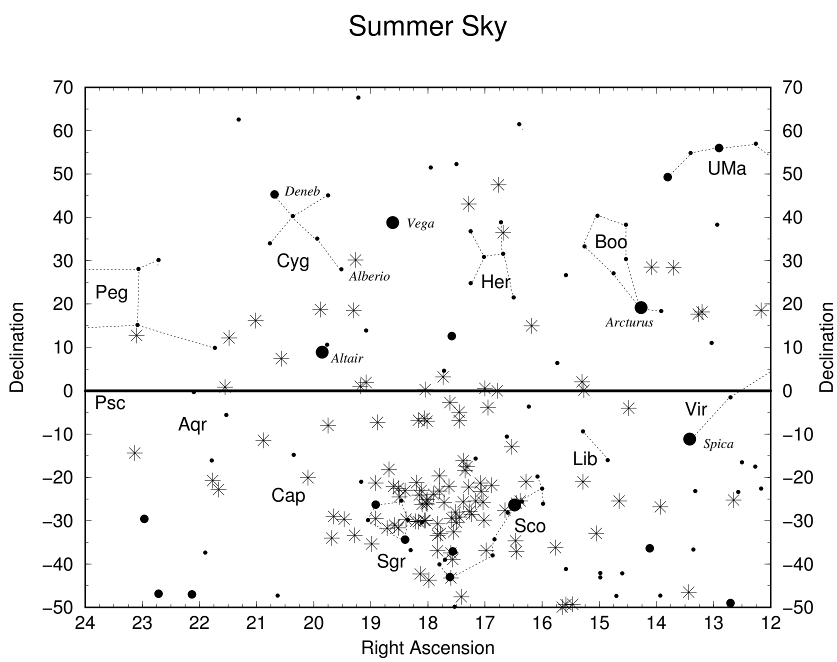


Figure 4. Winter skies above and summer skies below with globular clusters marked as *'s.

PART TWO

The System of the Globular Clusters

In the years 1916-1917, Harlow Shapley had been taking photographs of globular clusters at Mt. Wilson with the 60" reflector. He noticed the marked concentration of these clusters toward the region of the sky near the constellation Sagittarius (Sgr). Can you see a concentration of the globular clusters plotted in figure 4?

Because of the calibration of the Cepheid period-luminosity relation, Shapley was now in a good position to estimate the distances to those clusters in which he could detect Cepheids and measure their periods. This he did for the brighter clusters. In the fainter clusters the Cepheids are below the threshold of detection. But these faint clusters also appeared smaller, thus supporting the hunch that they were of similar construction to the brighter ones but simply at greater distances. The assumption of similar essence could be used to convert the brightness and size data into distance data.

Finally, Shapley accumulated sufficient data to construct a picture of the distribution of the globular clusters with respect to the Milky Way band. The model comprised a more or less spherical distribution of clusters centred far off in the direction of Sagittarius, at a distance estimated by Shapley to be about 16 kpc. The fact that most clusters appear to be in one region of the sky demonstrates that we are outside most of the spherical distribution. This was a real revolution in conception of the size of our stellar system. Supposing the clusters to be symmetrically situated with respect to the Milky Way stars, we would be in a flat, circular system at least thousands of parsecs in diameter.

The Distance to the Centre of the Globular Cluster System

In this exercise we shall carry out a computation of the distance to the centre of the globular cluster system very similar to that done by Shapley. Instead of the 86 clusters Shapley used, we shall use only about a dozen, but that is enough to give a reasonable estimate of the distance. Since, in Shapley's words, "it appears to be a tenable hypothesis that the supersystem of globular clusters is coextensive with the Galaxy itself," by finding the distance to the centre of the cluster system, we shall also find the distance to the centre of the galaxy.

We shall choose a section of sky near to the direction of the apparent centre of the globular cluster system in Sagittarius. In this area of about $15° \times 15°$ (centred on right ascension 19^h00^m and declination $-30°$) there are a dozen globular clusters. We shall find the distance to each one, and then find the distance to the centre of the group by averaging them. In doing so we must make several assumptions:

a) The angular size of a cluster is inversely proportional to its distance. This is tantamount to presuming that all clusters are of more or less the same intrinsic size.

b) We see in this limited region a representative selection of globular clusters, both near and far.

Procedure

We want to measure the apparent diameter of each globular cluster on the photo of (19^h00^m, $-30°$). We have downloaded pictures of each of the clusters and we can view them with the **skycat** program using the lab computers. Click on [File] [Open] and then double click on each cluster. Choose a suitable criterion for measuring size, such as the diameter of the brightest part of the image. Use the same criterion when measuring all the clusters. Right click and drag the cursor across the cluster from side to side or top to bottom. The numbers displayed are distance across the cluster in arc minutes and seconds. Convert the minutes to seconds by multiplying the minutes by 60.

Go back and measure M15 a second time and make certain you get the same answer. If you do not get nearly the same measurement you may want to continue measuring the globular clusters until you are consistent.

PART THREE

Volume Correction

When we take a photograph of a section of sky, the volume of space recorded on the picture increases very rapidly with distance (see figure 5). The first kiloparsec of distance from us a narrow wedge of space (volume A) is photographed. At a great distance away, however, an extra kiloparsec of distance includes a much larger slice of space (volume B).

Clearly we should expect to see more clusters in volume B than in volume A just because of its greater size. That means we shall see an anomalously great number of distant clusters and an anomalously small number of nearby clusters.

We must account for this effect before averaging cluster distances, or else the preponderance of distant clusters will yield a lopsided result. The area of the beam covered by the photograph increases as the square of the distance, and this is the correction factor needed.

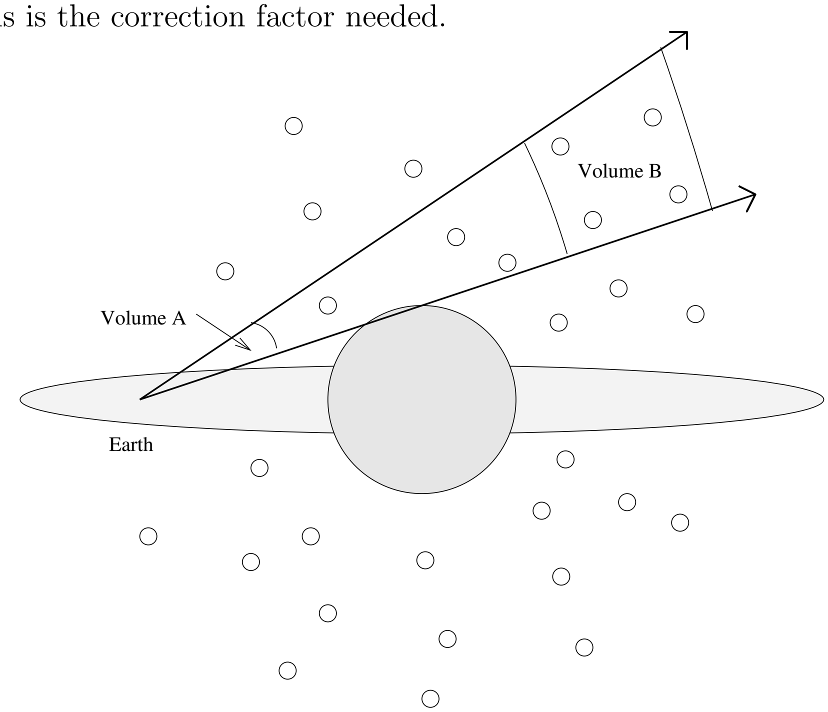


Figure 5. Globular Cluster Distribution about the Galaxy. The wedge represents the region of clusters seen on one photographic plate.

Procedure

A computer program has been written to solve the weighted mean equation, correcting for the increasing volume observed. Enter your measurements to find the distance to the centre of the galaxy. The computer can be used to estimate the uncertainty in this distance by modifying your measurements and running the program again.

PART FOUR

1. To try and get feel for how far it is to the centre of our galaxy, calculate how long it takes for light to get to the sun from the centre of the galaxy. There are 3.26 light years in one parsec.

2. The sun orbits the centre of the galaxy just like the earth orbits the sun. Now that we have found the distance to the centre of the galaxy we know the radius of the orbit. Calculate the distance the Sun travels around the centre of the galaxy. (the circumference= $2\pi r$).

3. From observations of other galaxies we measure that the sun travels around the centre of the galaxy at a speed of $\sim 220\frac{km}{sec} = 0.00021\frac{parsec}{year}$. How long does it take the sun to orbit the centre of the galaxy?

4. Kepler's Third Law relates the period P and the distance A separating two orbiting bodies to the sum of the masses of the bodies. Since we have the sun orbiting the centre of the galaxy, find the mass of the galaxy. If we use years for the period and parsecs for the radius of the orbit, the mass will be:

$$Mass\,in\,Solar\,Masses = 8.8 \times 10^{15} \times \frac{A^3}{Period^2} \tag{2}$$

5. Assuming each star has a mass the same as the sun (one solar mass), how many stars are in our galaxy?

   If you are looking for life in our galaxy, and you spend 1 second looking at each star, how many years would it take to check out our galaxy? 1 year $= 3 \times 10^7$seconds

An interesting URL concerning the great debate is:
http://antwrp.gsfc.nasa.gov/diamond_jubilee/debate.html

7 What is the Age and Size of the Universe?

> "With the 200-inch," Hubble said in a BBC broadcast in London," we may grasp what now we can scarcely brush with our fingertips." "What do you expect to find with the 200-inch?" he was asked, and he replied, "We hope to find something we hadn't expected."

OBJECTIVE

To determine the size and age of the observable universe, by measuring the distance and recession velocity of some galaxies.

INTRODUCTION

The lab uses one of the "Contemporary Laboratory Experiences in Astronomy" developed by Larry Marshall's group at the Department of Physics, at Gettysburg College. This exercise simulates the operation of a telescope and an electronic spectrometer which adds up (or integrates) the light it receives from faint objects until a measurable signal has been recorded. We will use the spectrometer to record the spectra of the brightest galaxies in a number of clusters of galaxies. Using two prominent spectral lines in the galaxy's spectrum, we will calculate the amount each spectrum has been redshifted, and from this calculate the recession velocity of the galaxy.

Brightest cluster galaxies have been chosen because they can be assumed to all have approximately the same absolute magnitude, $M=-22.0$. We shall use this information and the apparent magnitude of each galaxy to determine the distance to each galaxy. A plot of Recession Speed vs. the Distance will give us the value of the Hubble constant.

Making Observations

Begin by selecting *Log In* on the main menu, and fill in the requested information. After completing the log-in, select *Start* from the main menu.

A control panel window will appear as in Figure 1. The telescope controls and readouts are positioned to the left, the spectrometer control is on the right, and the sky field will be displayed in the centre.

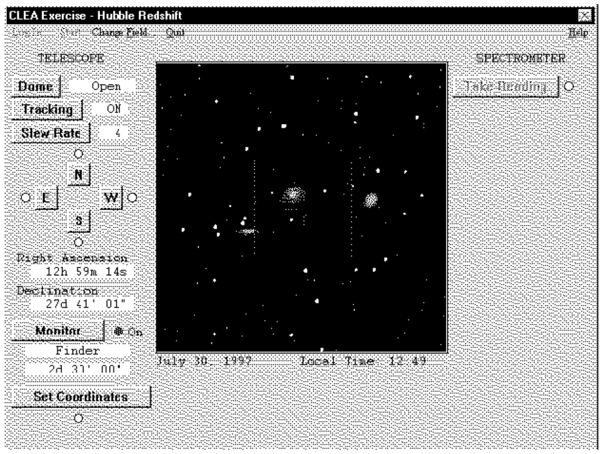


Figure 1. Control Panel

At the beginning of the exercise, the telescope dome is closed and the sky cannot be seen. Click on the button labelled *Dome* to open the telescope dome slit. You will be able to see stars and galaxies through the open door. Before observations can made, you must start the telescope tracking motor by clicking on the *Tracking* button.

The *Slew Rate* button adjusts how fast you can move the telescope. The four buttons below it indicate the directions to move the telescope. Use these buttons to put one of the galaxies in the telescope cross-hairs.

Once a galaxy is within the cross hairs, you must switch on the Monitor of the Spectrometer. Click on the *Monitor* button to get a magnified view of the telescope's field of view, and a pair of red lines, simulating the spectrometer "slit" will appear in the new view. The "slit" is a small hole which lets light from the galaxy into the spectrograph. The "slit" is surrounded by a mirror which reflects the light from the surrounding galaxies into the TV monitor. Use the four slewing buttons to position the centre of the galaxy on the slit. Click on the *Take Reading* button.

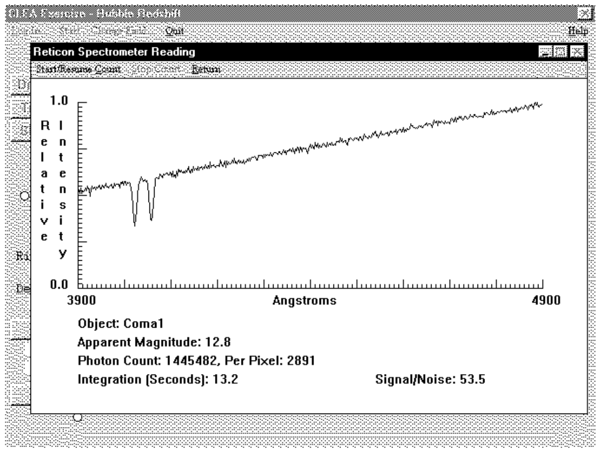


Figure 2. Spectrometer Control Window

The Reticon Spectrometer window will appear as in Figure 2. Click on *Start Resume* on the menu bar. If the galaxy has been correctly centred on the slit, you will see the counts build up and a spectrum will begin to appear on the Relative Intensity vs. Wavelength plot of the spectrometer. You will notice that for the brighter galaxies the spectrum builds up quite quickly, and two absorption lines, the K and H lines of ionized calcium, are apparent very soon after the integration begins. The spectra of the fainter galaxies build up more slowly and the spectral lines cannot be distinguished from noise for some time.

You may select *Stop/Count* from the menu at any time. This causes the integration to pause and the spectrum which has been collected up to this point to be displayed. Click on *Start/Resume* to continue the integration. You should integrate each spectrum until the Signal/Noise ratio is at least 15.0, click on *Stop/Count* and measure the spectrum. If the left mouse button is pressed when the cursor is on the graph, the cursor will change to cross-hairs. While still pressing the left mouse button, carefully position the cross-hairs at the centre of the K line, and record the wavelength of the line position shown on the screen. Repeat for the H line. Record the Signal/Noise value.

When you have finished measuring a galaxy spectrum, select *Return* from the tool bar menu. You can then continue to another galaxy. Be sure you have recorded all the information you require before returning from the spectrometer window - the information is not saved by the program

Table 3: Hubble Redshift Distance Relation

Galaxy ID	Apparent Mag	Distance (Mpc)	λ' in Å		Recession Speed	
			K Line	H Line	K Line	H Line

Measure two or three galaxies from each cluster of galaxies. To move to a different cluster of galaxies, you first need to return to the telescope monitor by clicking on it. Then select *Change Field* from the toolbar menu, select a new cluster and click on **OK**.The telescope will move to that field and you can select the galaxies to measure as above. Continue until you have completed five clusters of galaxies.

When you have finished your observing, turn off the tracking, close the dome, and quit the program.

Analysis

Using the following steps complete table 3.

1. If the galaxies were not receding, the **K** and **H** lines would be at their rest wavelengths, λ. The rest wavelength for the K line is 3934 Å and for the H line it is 3968 Å. Calculate the wavelength difference for each of the K and H lines for each galaxy, $\Delta\lambda = \lambda' - \lambda$, where λ' is the redshifted wavelength you measured.

   Find the Recession Speed v by multiplying the change in wavelength $\Delta\lambda$ for each galaxy by the speed of light, c = **300,000km/sec** and then dividing by the rest wavelength for the line λ.

$$v = c\frac{\Delta\lambda}{\lambda} \tag{3}$$

2. Determine the distance, D to each galaxy using its recorded apparent magnitude, m and the assumed absolute magnitude, M=−22.0 We want the distance to be in Megaparsecs so we modify the usual distance modulus formula to be:

$$D = 10^{\frac{m-M-25}{5}} \tag{4}$$

   If you are not certain how to use this equation be sure to ask.

3. Plot the Recession Speed=V (km/sec) vs. Distance=D (Mpc) for each of the galaxies on graph paper in your lab book. Draw a best-fit straight line through the points including the origin and determine the slope of this line. The slope is the Hubble Constant=H. If there is time try to find the uncertainty in the slope by fitting another line which is as flat as is reasonable, but still goes through the points. Find the slope of this second line and compare it to the best line. The equation describing this is :

$$V = HD \tag{5}$$

   There is still a great debate over the "real" value of the Hubble Constant. Generally astronomers are finding near 70 km/sec/Mpc, but values from 40 to 100 km/sec/Mpc have also been reported. More recently the WMAP satellite (see website below) has confirmed that H=71 km/sec/Mpc

4. As the galaxies become more distant, the observed speeds of the galaxies can not increase without bound. As the speeds increase towards the speed of light, the redshift increases to the point where the galaxies are no longer visible. Nothing can be seen past this horizon. Neglecting some subtleties we can estimate this distance to the edge of the observable universe by asking at what distance will the velocity of a galaxy be equal to the speed of light. Convert this distance to billions of light years, knowing there is 3.26 light years in a parsec.

5. Since we know how far it is to one of these galaxies, and we know how fast the galaxy is going, we can estimate where it was last year,

a thousand years ago or a billion years ago. In fact by dividing the distance to a galaxy by the speed with which it is moving, we can find how long it took to get there.

$$Time = \frac{Distance}{Velocity}. \tag{6}$$

If we rearrange the Hubble Constant equation $V = HD$ to be $\frac{D}{V} = \frac{1}{H}$ and change the km to Mpc and the seconds into billions of years to get more convenient units we find that the age of the universe in billions of years is:

$$T = \frac{D}{V} = \frac{1000}{H}. \tag{7}$$

Divide 1000 by your Hubble constant to get the number of Billions of Years since the galaxies started moving apart due to the Big Bang. Compare it to the age of the earth (4.5 Billion Years) and the oldest stars (13 Billion Years). What is your estimate of the uncertainty in the age of the universe?

Web Sites
http://map.gsfc.nasa.gov/ (WMAP website)

8 Search for Extraterrestrial Intelligence

OBJECTIVE

An important part of science is to look for phenomena which are expected, but have not yet been observed. Here we can use a very simple theory, a little astronomical knowledge and a few reasonable(?) assumptions to estimate the chances we will find evidence of extraterrestrial intelligent beings.

Drake Equation

The first person to set out the parameters used to estimate the number of civilizations in a galaxy was Frank Drake, when he was preparing for a conference on SETI in 1961. Obviously the number of civilizations N_c will depend on the number of stars in the galaxy N_*; the more stars, the more places for aliens to live. It also depends on the fraction of stars that have planets f_p, since the aliens probably do not live right on the stars. The planets have to be warm; not too hot or too cold like the Earth n_e. Life must evolve on the planet f_L and it must then produce intelligent beings f_i, who broadcast their presence in some manner we can detect. Lastly, for us to know about the alien civilization, they must last long enough to exist at the same time as us F_S.

Our version of the Drake equation is:

$N_c = N_* f_p n_e f_L f_i F_S$

Let's estimate N_c by examining each of these parameters in more detail.

N_* = Number of Stars in Our Galaxy

We found the number of stars in our galaxy in the "Size of the Galaxy" lab from the mass of the galaxy. Look back in your lab book and see what number you measured. Check with your partners and see if they found approximately the same number. This number of stars in the galaxy is too large because it includes dust and gas which has not formed into stars. It also includes the "Dark Matter" and no one knows what that is.

A second way of estimating the number of stars is by counting the number in a small area of the sky and scaling it to the whole sky. More than half the sky was photographed by the Palomar Sky Survey project and we have copies of one of these pictures for you to use. The scale of the pictures is one minute of arc per millimetre. Count the stars you see in a square a millimetre on a side and multiply it by 150 million to get another estimate of the number of stars in our galaxy. This number is probably too small since lots of stars will be too faint and lots more will be obscured by dust.

From these two methods estimate the number of stars in our galaxy, $N_* = \Box$**.**

Discovering Planets

The first extrasolar planet discovered was in 1995, when Mayor et al. announced the discovery of a planet orbiting the star 51 Peg. Mayor very precisely measured the spectra of 51 Peg and found that the star moved towards us and then away from us. He found that its movement was very predictable and varied in a sinusoidal shape with a period of 4.2293 days. The fact that the period was constant and the shape of the variations was a sine curve led him to conclude that something was orbiting 51 Peg. The amplitude of the star's motion gave him an estimate of the mass of the orbiting body, which was so small that he concluded that the orbiting body was a planet.

Characterization of Extrasolar Planets

A spectrum of the star HD209458 shows that it is slightly bigger in radius and slightly more massive than our sun. The Hipparcos satellite has measured its parallax and found the distance to HD209458 to be 47 parsecs. Geoff Marcy discovered a planet orbiting HD209458 with an orbit which is tilted just right for the planet to pass in front of the star. When the planet blocks part of the light from the star we see the star become a bit fainter.

A modeling program has been written by J. Clem to help us visualize the situation and find the mass and radius of the planet orbiting the star HD209458. The modeling program allows us to simulate the planet orbiting the star, the eclipse of the star by the planet, and also the variations in the radial velocity of the star. We can change the planet's mass, period, radius and the orbital inclination by clicking on the buttons in the button panel seen in Figure 1.

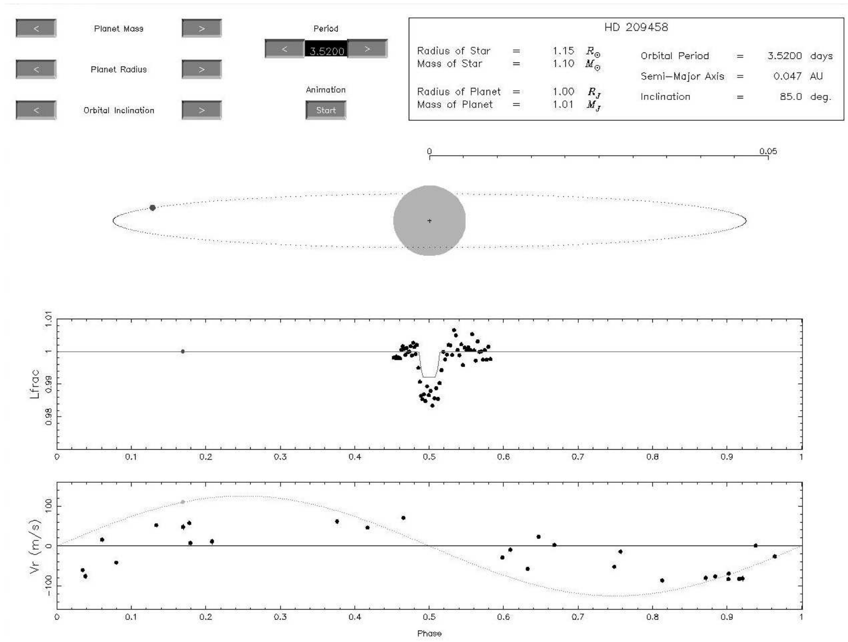


Figure 1. The modeling program.

The second panel shows the blue planet orbiting the red star. The ellipse is the path of the planet around the star. Click on the [Orbital Inclination] button to change how much the orbit is inclined to the line of sight. If the inclination is just right, the planet will pass in front of the star and block out part of the star's light making the star appear fainter.

The third panel shows a plot of how the brightness of HD209458 changes as a function of time. Every 3.525 days the star becomes very slightly fainter. We watched the dimming of HD209458 one summer with our 20 inch telescope and our observations are the points plotted in the third panel. The depth of the eclipse depends on the size of the planet; the bigger the planet, the more light it blocks and the deeper the eclipse. We can find the radius of the planet from the depth of the eclipse. Change the radius of the planet using the [Planet Radius] buttons so that the line agrees with the data. Change the inclination of the orbit to get the observations of the edges of the eclipse to agree with the model.

Record the radius of the planet and the inclination of the orbit.

The bottom panel is a plot of the radial velocities of HD209458 as observed by Geoff Marcy with the world's largest telescope. A sine curve has been drawn through the data points, but it does not quite agree with them. The more massive the planet the larger the reflex motion of the star and the larger the amplitude of the radial velocities. So we can measure the mass of the planet by measuring the amplitude of the radial velocity variations. Change the amplitude of the radial velocity curve by clicking on the [Planet Mass] button.

We can also change the position of the data points along the graph by changing our guess of the period of the planet's orbit around the star. Change the period by clicking on the [Period] buttons and you will find that the observed points move left or right a little bit. From Kepler's Law we know the semimajor axis of the orbit of the planet around the star depends on the period of the orbit. Change the period and see that the Radius of the Orbit changes as well. Change the planet mass and the period to best fit the data points.

Record your best estimate of the mass, period, and semimajor axis of the orbit of the planet.

Would you be able to detect a Jupiter mass planet in a one year orbit? Click on the [Stop] animation box and then click on the Period value and change it from 3.52 to 365 days. Click [Start] twice and the animation will start again with the planet at about 1 Astronomical Unit from the star. Increase the mass of the planet until it is at 1 Jupiter mass. Increase the radius of the planet until it is at 1 Jupiter radius. Set the Inclination to 90 degrees so that eclipses must occur.

Would you be able to observe radial velocity variations (uncertainty of $\pm 4\frac{m}{sec}$) or eclipses for a Jupiter sized planet in an Earth like orbit?

Would it be possible to detect planets like the Earth? Set the Period in the simulator to 365 days and the radius of the planet to 0.1 Jupiter and the mass of the planet to 0.01 Jupiter Masses.

f_p = Fraction of Stars with Planets

A few groups are now surveying the bright stars in the sky looking for stars with the tell-tale small amplitude, periodic variations in their radial velocities. At the present time there are about 500 extra-solar planets that have been found after surveying about 4000 F, G, and K main sequence stars. The latest results can be found at the last two web sites listed at the end the end of this lab, or we can use the diagram:

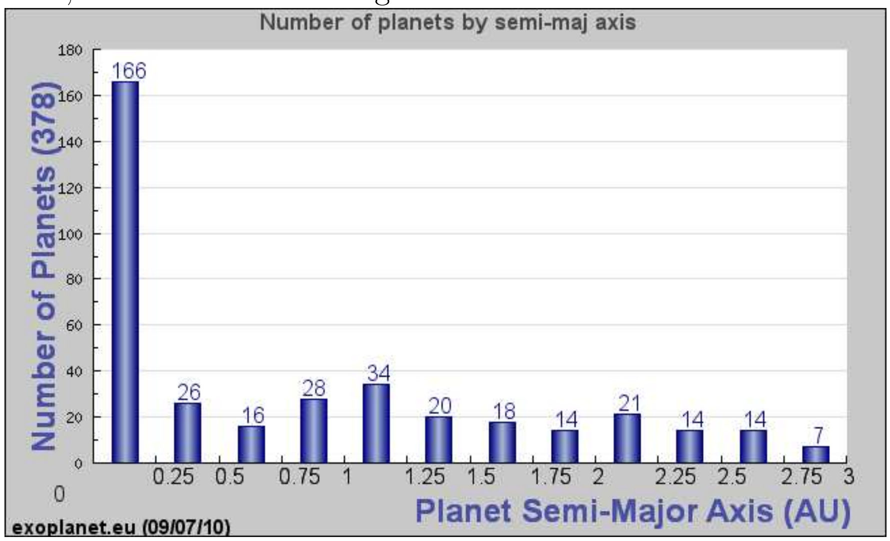


Figure 2. Number of extrasolar planets as a function of their distance from their star (Jean Schneider and Cyril Dedieu 2010).

Remember these surveys are only sensitive to planets of Jupiter's mass or greater and are more sensitive to planets that are orbiting close to their stars, so there will be lots of planets like the Earth that will be missed.

What is your best guess as to the Fraction of Stars with Planets? $f_p = \Box$

n_e = Number of Habitable Planets in Each Solar System

The number of Earth-like planets is a difficult question. While it is possible to imagine, alien life which does not need liquid water to exist, it is probably more interesting to look for life which has more in common with us. In order for life as we know it to exist there must be liquid water, therefore the temperature of the planet must lie between 273 K=0 °C and 373 K=100 °C for a pressure at sea level. One planet (Gliese 581c) has already been found which is about 5 times the mass of the Earth and probably at the correct distance for liquid water to be found on its surface.

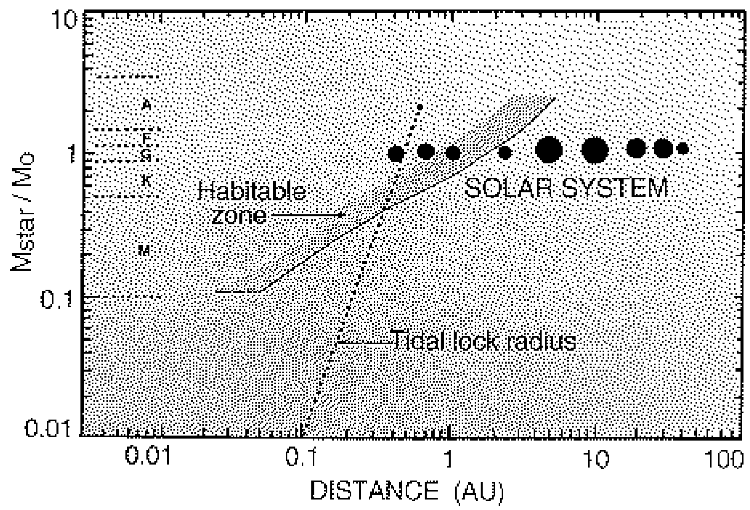


Figure 3. Limits to the habitable zone.
http://www.astro.sunysb.edu/fwalter/AST101/habzone.html

Let's investigate how these temperature limits are found. A planet orbiting a star will intercept some light and become warm. The warm planet must radiate this heat away or it will become hotter and hotter. Thus the planet will need to radiate all the energy it receives to be in equilibrium.

Energy Absorbed = Energy Radiated

The "Energy Absorbed" will depend on the planet-star distance D and the luminosity of the star L and the radius of the planet r. The "Energy Radiated" by the planet will depend on the temperature T of the planet and the radius of the planet r.

$$\frac{Lr^2}{D^2} \propto r^2 T^4$$

We can can see that the radius of the planet r will cancel and if we solve for L we get:

$$L \propto T^4 D^2$$

For another planet orbiting the same star we have the same luminosity of the star and a different distance D and temperature T.

$$L \propto T_P^4 D_P^2 = T_E^4 D_E^2$$

For a star with the same luminosity as the sun we can find the temperature T_P of any planet once we know the distance D_P of the planet from the star, assuming that the temperature T_E of the Earth is 288 K(15 °C) and its distance D_E is 1 AU.

$$T_P^4 D_P^2 = (288)^4 (1.0)^2$$

Square Root of both sides:

$$T_P^2 D_P = 82944$$

What would be the temperature of the planet orbiting the star HD209458, assuming the star has the same luminosity as the Sun and that the planet is at the distance you found in the last section?

Find the distances a planet would need to be from a star like the sun to have a surface temperature of 373 K and 273 K.

In our Solar System the Earth orbits in the habitable zone with an orbital radius of 1 Astronomical Unit. The orbital radius for Mercury is 0.387 AU, Venus is 0.723 AU, Mars is 1.524 and Jupiter is 5.203 AU. In the Ups Andromedae system the planets are at distances of 0.06, 0.83 and 2.51 AU. In the 55 Cancri system the planets are found at 0.04, 0.11, 0.24, 0.78 and 5.77 AU. In the HD160691 system the planets semimajor axes are 0.09, 0.92, 1.5 and 4.17 AU.

What is your estimate of n_e, the number of habitable planets in each solar system? $n_e = \square$

f_L = Fraction of Habitable Planets with Life

The fraction of planets which do have life given that they are in the habitable zone is difficult to estimate since we have only our Solar System to use for data. How long it took for life to form on the earth gives us some indication of how likely it is for life to form given the right conditions. If it is easy for life to start then generally it will form right away and if it is very difficult for life to start then it will take a long time for life to form. It is about 4.5 Billion years since the Earth first formed and during the first few million years the

Earth was continually bombarded with asteroids which heated the surface to incandescence. The Earth did not cool enough to allow liquid water on its surface until about 4 Billion years ago. The oldest fossils of living organisms are 3.9 Billion years old so life must have originated almost as soon as it was possible.

Since it originated, life has spread to cover the surface of the earth and even thrives far underground and deep in the ocean. There even exist life forms which do not need light. They live near "black smokers" on the ocean floor.

What is your best guess as to the fraction of habitable planets on which life originates?$f_L = \square$

f_i = Fraction of Life Systems with Intelligence

Assuming that there is a habitable planet and life originates on it, we need to guess whether or not intelligent life will evolve. Frank Drake originally defined intelligent life, as life which built radio telescopes, but this is debatable definition. In the competition for food and habitat mankind has managed to spread across the Earth, eliminating many of the animals inhabiting our ecological niche or preying upon us. This is probably mostly due to our intelligence, but also due to our ability to pass our knowledge on to successive generations. Humans have only existed for the last few million years so at least for the Earth intelligence has taken a long time to evolve.

If you think intelligence has a large survival value guess 1.0 and if you think intelligence is not likely to evolve guess something closer to 0.0.$f_i = \square$

F_S = Lifetime fraction

Civilizations will ultimately have a great deal of difficulty lasting longer than their home star. The sun will become warmer as it evolves and in a billion years the Earth will not be habitable. Astronomical disasters like comet impact, supernova or Gamma Ray Bursts will set limits of millions of years.

Historically the civilizations of the Egyptians, Greeks, Romans, Mayans, Incas and Aztecs have all come and gone. Some lasted a few hundred years and some lasted a few thousand. If civilizations last only a few years, there will be fewer in the galaxy at any one time than if civilizations generally last a long time. Of course, if you are pessimistic, humankind could be wiped out by nuclear war, plague, etc at any time.

Choose an average Lifetime for a Civilization.

To find the civilization lifetime as a fraction of a star lifetime we need to estimate how long a star like the sun exists. Eventually the sun will become a red giant and swell so that the Earth will be orbiting at its surface. In the Colour-Magnitude Diagram lab, we estimated the ages of the clusters of stars so check back and see how old a star like the sun is when it leaves the Main Sequence.

Divide the civilization lifetime by the age of a star like the sun and you have the lifetime fraction.$F_S = \Box$

The Number of Civilizations in Our Galaxy

From your previous answers (best guesses) find the number N_c of intelligent life forms in our galaxy.

Obviously this is a very crude answer so round it off to one significant figure.

The Distance to the Nearest Civilizations in Our Galaxy

Even if there is a lot of civilizations, the galaxy is so large we may never detect them. The distance to the next alien civilization depends not only on how many civilizations there are but also on how big the galaxy is. In the "Size of the Galaxy" lab you found the distance from us to the centre of the Milky Way galaxy to be approximately 30,000 light years.

If the sun is two thirds of the way to the edge of the galaxy what is the radius of the disk of the galaxy?

Find the area of the galaxy ($Area = \pi R^2$).

If the civilizations are evenly distributed across the disk of the galaxy, each will have its own neighbourhood surrounding its star.

To find the average area of the neighbourhood occupied by a civilization divide the area of the galaxy by the number of civilizations.

If we imagine the neighbourhood of a civilization to be a square then we can find the length of a side of the neighbourhood by taking the square root of the area of the neighbourhood.

Find the length of the side of a square with the area of the average neighbourhood.

The length of the side of a square will be the average distance to the next civilization. Obviously if the next civilization is 100 light years distant, and we say "Hello" today then they will not hear it until 100 years from now. If they answer right away we will not receive the answer until another hundred years have elapsed. So a conversation will have to be between civilizations, assuming the civilization lasts for a much longer time than the light time between the two civilizations.

Compare the average distance between civilizations to the lifetime of a civilization.

Detecting the Message

We have been broadcasting our presence to the universe for more than 50 years. Every radio, TV, RADAR, and cell phone signal has leaked a little radio noise into space. These signals would not be easy to detect because they are at many different frequencies and both AM and FM coding.

Would our earliest radio signals have made it to the nearest civilization yet?

Astronomers are looking for these stray signals by listening to "random" locations in the sky and analyzing the radio noise to look for periodic signals. This is very computing intensive and so some astronomers have appealed to the people of the world to become involved in the Search for Extraterrestrial Intelligence. These astronomers have written a screen saver which will analyze the radio data whenever the computer owner is not using it. More than a million people are helping with the search. For more info:

http://setiathome.berkeley.edu/

Over the next decade the Allen Radio Telescope array will scan the sky looking for radio emissions produced by intelligent extraterrestrial creatures. The array will cost approximately the same as our new science building ($\sim$60million) and has been made possible by a donation to UC Berkeley by Paul Allen. One million stars within 1000 light years will be surveyed and a radar transmitter as powerful as the most powerful on Earth should be detected. If the Allen radio telescope array can detect civilizations emitting powerful radio signals out to about 1000 light years:

Do you expect it to detect any civilizations?

Decoding the Message

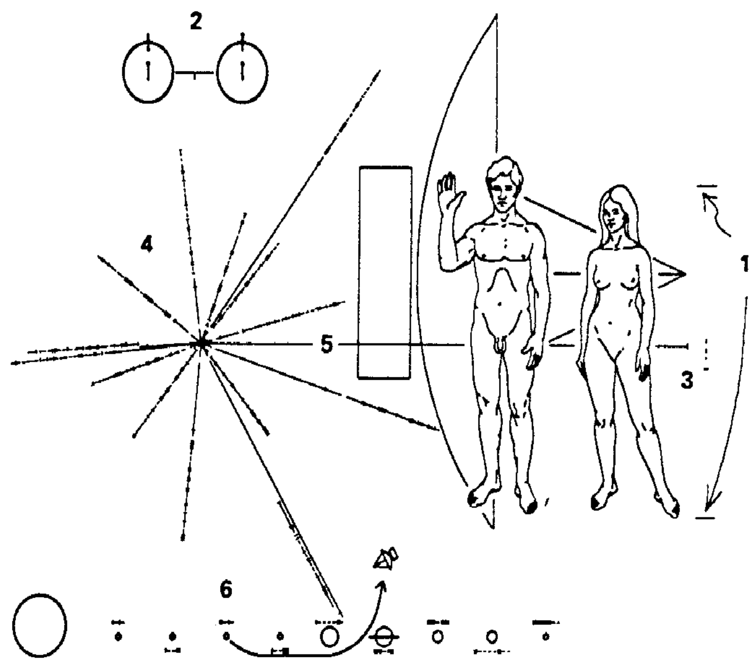


Figure 5. The Pioneer 10 and 11 plaques.

In 1976 the USA launched the spaceships Pioneer 10 and 11. Their main mission was to photograph Jupiter and Saturn, but they are now on a trajectory which will take them out of the Solar System never to return. A message was engraved on a plaque attached to the space craft. This spaceship and plaque will probably outlast not only our civilization but also the Earth. The plaque has been reproduced in Figure 5 with the numbers added to aid you in referring to different parts.

What can you decipher about the creatures that made this plaque? Explain what you base it on.

to find the answer see: http://en.wikipedia.org/wiki/Pioneer_plaque

Web Sites

http://www.seti-inst.edu/
http://exoplanet.eu/
http://exoplanets.org/index.html

9 Lunar Imaging

> "The Moon certainly isn't pretty. It was exotic and it was different and it was challenging...I don't think it's forbidding" Gene Cernan
>
> "nothing but a ball of rocks and dirt" Paul O'Neil

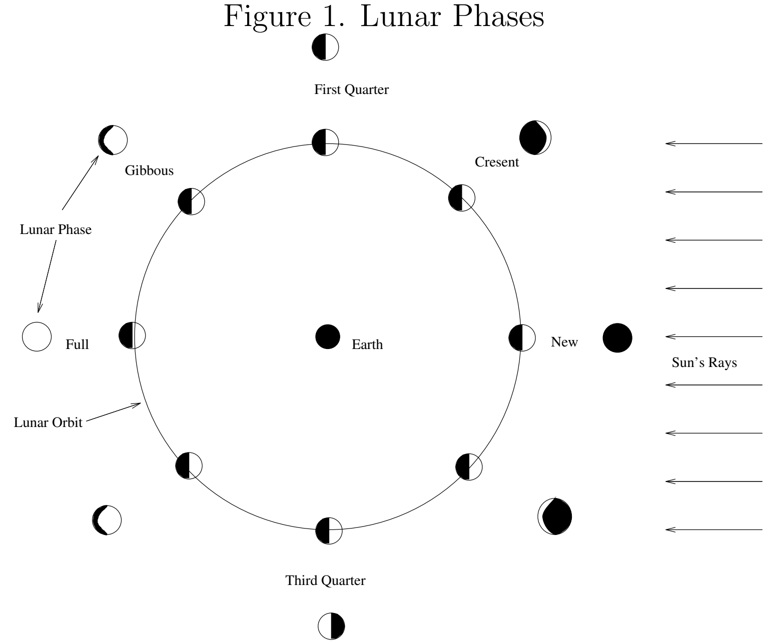
OBJECTIVE

To image the moon using a telescope and to study the craters on its surface.

INTRODUCTION

Early civilizations regarded the Moon with wonder and awe. It was a source of light, and its changing phases provided a convenient method of tracking time. Figure 1 shows the different phases of the Moon, and where the Moon is in relation to the Sun. The lunar cycle of 29.53 days is the basis for the size of our months.

Figure 1. Lunar Phases



The amount of illuminated lunar surface visible from Earth changes from none at New Moon to 100% at Full Moon. The small lunar figures show what the Moon looks like from the Earth at that time. The direction of the Earth's rotation in this diagram is counter-clockwise, from which it follows that the First Quarter is visible in the early evening and the Third Quarter in the early morning.

The Moon had other strange properties, in particular, it would occasionally block out the Sun in a solar eclipse, and at times it would be eclipsed by the Earth (a lunar eclipse). As these events were taken as being powerful portends, being able to predict when an eclipse would occur was considered very important, and was a driving force in the development of early astronomy. The Babylonians were able to make lunar eclipse predictions by the seventh century BC. The first recorded prediction of a solar eclipse was by the Greek Thales in 585 BC, and was only accurate to within a year. Thales also determined that moonlight is actually reflected sunlight.

While the Moon itself would change, first waxing and then waning, the patterns on the Moon's surface did not change. In these patterns many early cultures saw the images of people (the Man in the Moon), the face of a god or goddess, or animals. Aristotle thought that the markings seen on the Moon were actually reflections of the Earth, and that the Moon itself was a perfect crystal sphere. Further determinations as to what these markings were would have to await the development of the telescope.

Galileo may not have been the first person to use a telescope to look at the moon, but he was the first to record what he observed. Far from being the perfect sphere that Aristotle had claimed, Galileo saw a rough surface with varying terrain. He saw mountain ranges (by measuring the lengths of the shadows they cast he found that these mountains were similar in height to mountains on Earth), craters, and large areas of darker material that seemed to be fairly level which he called maria (Latin for seas). His observations of the Moon as well as other astronomical observations were published as Siderius Nuncius (Messenger from the Skies) in 1610.

The fact that the Moon's features do not change implies that we can only see one side of the Moon from the Earth. For this to be the case, the Moon's rotation must be locked to the Earth, so that the Moon rotates exactly once on its axis during each complete orbit of the Earth. This can be seen in Figure 1. If the same side of the Moon is facing the Earth at both first and third quarter, the Moon must have rotated by 180^o. The Moon's rotation being locked to the Earth is a consequence of the gravitational interaction of the Earth and the Moon.

Johanes Hewelcke published the first map of the Moon in 1647. He gave mountain ranges the names of terrestrial mountain ranges, and named craters after cities and countries. While his names for the mountain ranges were adopted, the crater names were changed by Giovanni Riccioli and his student Francesco Grimaldi in Grimaldi's map which appeared in Almagestum Novum in 1651. They named craters after famous scientists and Philosophers (the craters Riccioli and Grimaldi are among the largest).

These names are still in use, although Johann Schrvter and later J. Heinrich von Middler extended the naming system to include subsidiary craters labeled with capital letters.

The development of photography allowed the production of even more accurate maps. The first photograph was a daguerreotype taken by Louis Daguerre in 1839, but it was of poor quality. The first true photograph was obtained in 1857, and a photographic lunar atlas was published by the Paris Observatory in 1896. The Photographic Atlas of the Moon, published in 1903 by the Harvard College Observatory, used photographs taken at different phases. This is important, because the different light angles highlight different features. For example, craters and mountains are best seen when they are near the terminator (the line separating the light and dark sides of the Moon), where they cast the largest shadows. Shadowless features, like the maria and rays extending from craters, are seen most easily at full Moon as this provides more contrast.

Photography from ground based telescopes remained the best way to examine the Moon until the development of rockets allowed missions to the moon. The Luna program of the Soviet Union was the first to send rockets to the Moon. In 1959 Luna 1 passed within 6000 km of the Moon, Luna 2 successfully crash landed and Luna 3 provided the first pictures of the Far side of the Moon. While the Soviets also had the first soft lunar landing and the first spacecraft to orbit the Moon, the American Apollo program landed the first astronauts on the Moon. On July 20, 1969 the Command Module Eagle landed on the Sea of Tranquillity, and Neil Armstrong became the first person to stand on the Moon. There were a total of six manned space craft that landed on the Moon between 1969 and 1972, vastly increasing our knowledge of the Moon.

When looking at the Moon, perhaps the most striking feature is the large number of craters on its surface. The craters range in size from centimetres to hundreds of kilometres, and are all over the Moon's surface. Even in areas that have few craters, evidence of cratering abounds in the form of mixed dust, small rocks and glass beads that result from impact events. Early observers believed that the craters were volcanic in origin, but the craters do not look like terrestrial volcanoes. Volcano's on the Earth consist of a cone rising above the surroundings with a bowl-like indentation at the centre while the craters on the Moon have elevated rim walls surrounding the crater depression and a small peak in the middle. In 1873 Richard Proctor suggested that the craters on the Moon were the results of impacts rather than volcano's. This idea gained strength with the discovery of the Barringer impact crater in Arizona, which looks similar to craters on the Moon.

The question then arises, if the Moon is covered with impact craters, why do we see so few of them on Earth? There are three reasons for this:

1. The Earth is geologically active while the Moon is not. Material on the Earth's surface is constantly being replaced by new material.

2. Surface features on the Earth are subject to erosion and mountains are worn down by wind and rain, while depressions are filled in by sediments. As the Moon lacks an atmosphere, only solar wind and meteorites cause erosion, and they are much slower processes.

3. The Earth's atmosphere protects it from some cratering events.

The Earth's atmosphere has two effects on objects falling onto the Earth. The first is that, due to the high speeds with which objects fall, the atmosphere acts somewhat like a sandblaster. The friction with the air strips away the outermost layers of the object. If it is small, nothing will be left, and it will have 'burned up'. For larger meteorites, only the outer few millimetres are lost, and from reports of people who have seen a meteorite strike, it was immediately cool to the touch. The second effect of the atmosphere is that the atmosphere can act like a solid wall. Small meteorites pass fairly easily through the air, but for larger objects (the size of the Elliott Building, for example) the air builds up in front of it, while there is no time for the atmosphere to flow in behind it. The resulting pressure difference can cause a massive explosion, in which the meteor is totally destroyed. This happened over Revelstoke in 1965 and the explosion had as much energy as the first atomic bombs.

Meteorites that are even bigger, or that are made of iron rather than rock, do not get destroyed in the atmosphere. The atmosphere is only a very thin covering over the Earth; about two-thirds of the atmosphere lies below the height of the peak of Mt. Everest. As meteorites travel very fast (about 40 km/s), they are only in the atmosphere for about one second. If you imagine a large asteroid, say ten times the size of Mt. Everest, hitting the Earth, the first part of it would hit the ground before the last had even entered the atmosphere. Fortunately, such large meteorites are very rare. For example, over the land area of the Earth it is predicted that about 6000 meteorites of 0.1 kg or larger will fall in a given year, but only about 250 objects of 10 kg or more will hit. For even larger objects, such as the asteroid or comet that presumably killed off the dinosaurs, tens or hundreds of millions of years can pass between impacts.

PROCEDURE

The 0.5 meter telescope on the roof will be used to take the pictures of the Moon. Your instructor will help you to find the Moon in the telescope and take the picture. The telescope does not use film, but a CCD (Charged Couple Device) that records the image electronically. The image is sent to a computer, and then printed out. The image of the Moon projected by the telescope is too large to fit on the CCD, so it is necessary to get several images if all of the Moon's visible surface is to be recorded. After all of the images have been obtained, you will combine them by taping them together, cutting out anything not needed. With the aid of a Lunar map, you will then examine your picture and note interesting features.

EXERCISES

1. Combine all the different pictures of the moon into a mosaic.

2. Identify on your picture of the moon three craters, three Maria, and three landing sites of spacecraft. Note whether or not there are central peaks in the middle of the crater.

3. Craters which come later are going to overlay craters, which were there originally. Find and indicate an example of a crater, which was formed after another crater. We know that the dark Maria are about 3.5 Billion years old. Find a crater which formed after this. Find one that formed before 3.5 Billion years ago. Mark these on your mosaic and explain your reasoning.

Table 4: Selected Meteorite Impact Craters

Name, Location	Diameter (km)	Age in Million years	Features
Barringer, Arizona	1.2	0.049	shocked sandstone
Manicouagan, Quebec	100	214	circular lake
Chicxulub, Mexico	180	64.98	dinosaur killer

The sun produces a wind, which blows continuously against the moon and turns the lunar rock very black. When new craters form the explosion blasts the underlying lighter coloured rock across the surface. Can you find some lighter coloured craters? Can you find some lines (rays) of lighter coloured material emanating from a crater? or an ejecta blanket?

4. Are the craters on the moon like craters found on the earth? Measure the diameter of a big and a little crater and convert them to kilometres assuming a diameter of the moon of 3476 km. Compare them to the craters listed in the table. The diameter of a crater is about 10 to 50 times the diameter of the meteorite depending on the mass and velocity of the meteorite. How big was the meteorite, which made these lunar craters, assuming the craters are 25 times bigger than the meteorite?

5. The dinosaurs became extinct 65 million years ago at the Cretaceous-Tertiary boundary, probably due to an impact by a comet or asteroid. From the high concentration of Iridium found world wide at this strata, it has been estimated that the asteroid was 10 km. in diameter. In the Yucatan peninsula a crater has now been identified which is 180 km in diameter and 65 million years old. Is this crater about the right size? This impact is roughly the equivalent of an explosion of 100 million megatons of TNT or 10,000 times the combined arsenals of the U.S. and Russia.

   It has been estimated that most of the people on the earth would be killed by the impact of a much smaller 1 km. diameter object. This is the equivalent of a 1 million megaton explosion and would make a

Table 5: Crater and Tsunami Size for Various Impact Energies

Crater Diameter (km)	150	50	10
Energy (ergs)	1×10^{30}	6×10^{28}	2.6×10^{26}
Distance (km)	Tsunami Height (meters)		
10000	100 m	15 m	1 m
3000	250 m	40 m	3 m
1000	540 m	90 m	5 m
300	1300 m	200 m	15 m

crater about 25 km. across. To estimate how often this happens we can examine our nearest neighbour, the moon. There are 29 ± 5 craters bigger than 25 km in diameter on the lunar Maria. The maria are 3.5 billion years old, so how often do craters of this size form on the maria? To estimate how often this happens on the earth we need to know how much bigger the earth is compared to the lunar maria. If the area of the maria is about 5 million sq. km, and if the area of the earth is 500 million sq. km, how often would you expect a crater of this size to be formed on the earth and end civilization.

6. Every year on the 12 August the Perseid Meteor shower occurs. This meteor shower is caused by bits of gravel lost from comet Swift-Tuttle, but still traveling in almost the same orbit. The Earth's orbit intersects the comet's orbit at the place that the Earth is on 12 August. If the date of perihelion of the periodic comet Swift-Tuttle changes by +15 days (it changed by several years in its last orbit), it will hit the earth on August 14, 2126. It has a diameter of about 2 km, and would hit the earth with a speed of about 50 km/s. How big a crater would it make? There would be a 75% chance that it would land in an ocean. From the table, how large would the tidal wave be 300 km from the impact sight? Would you be safe on Mt. Doug (altitude=210 m)?

Web Sites

http://impact.arc.nasa.gov/
http://www.nineplanets.org/

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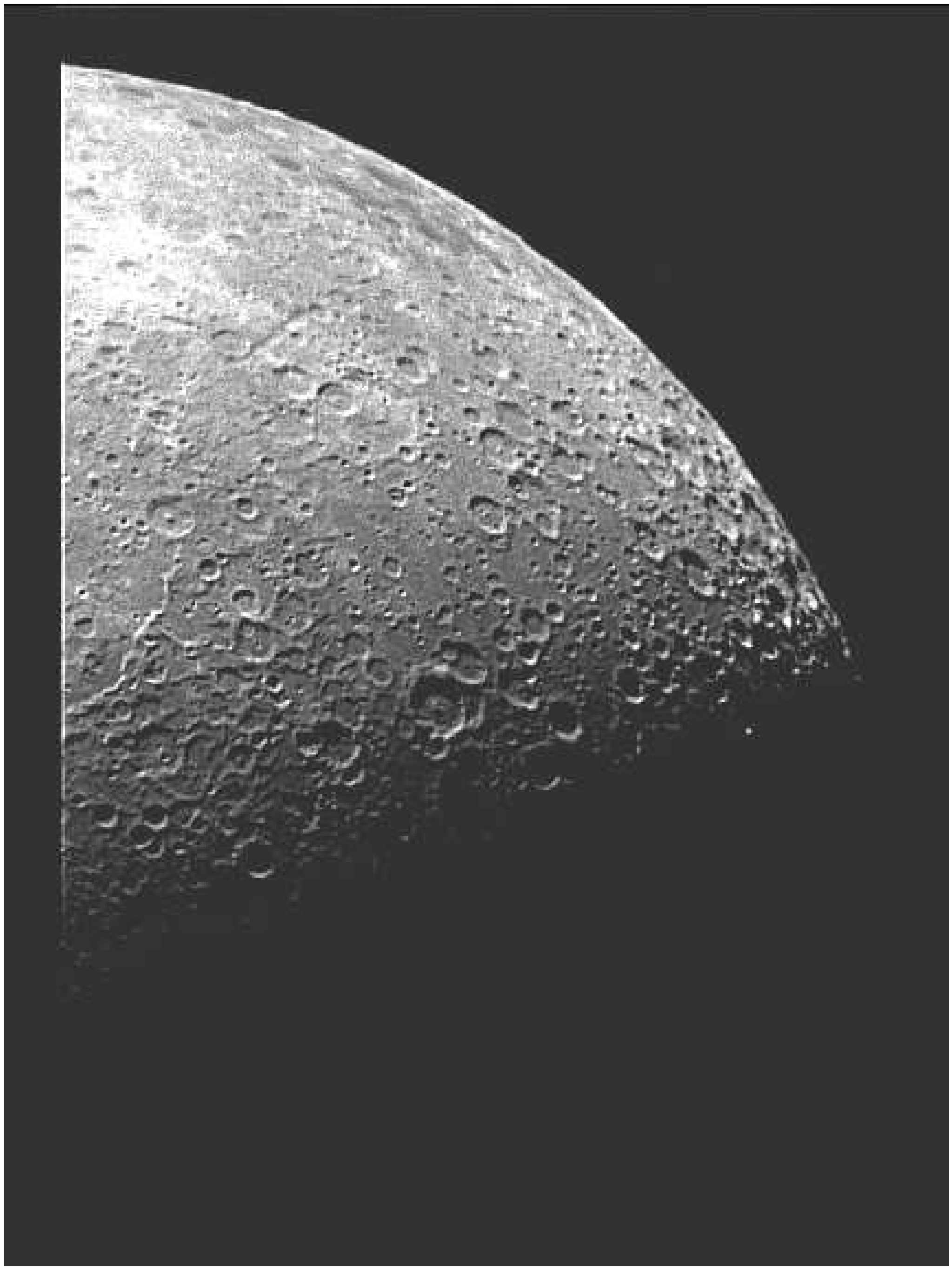

Figure 2a. Lunar Photo 1

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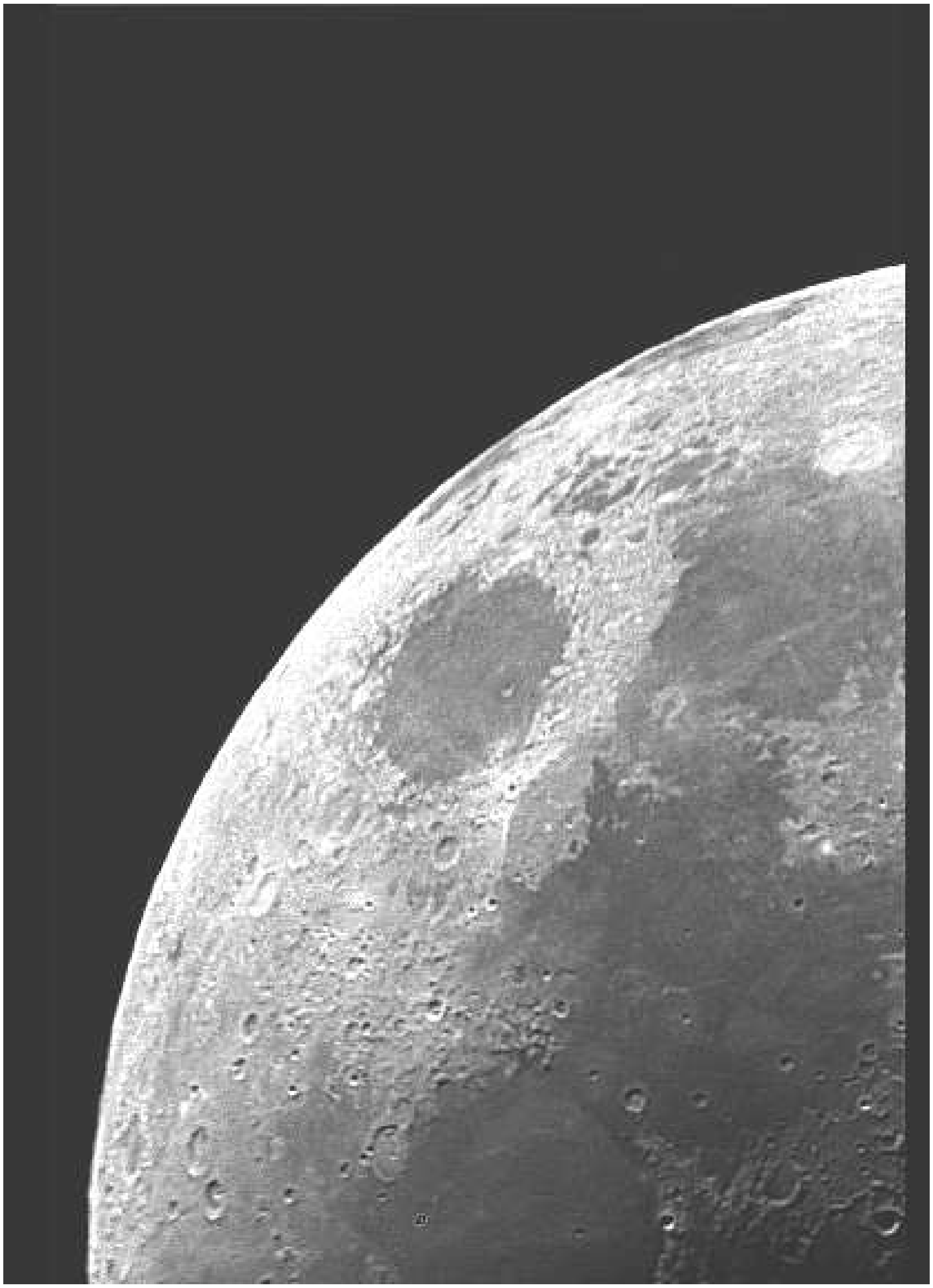

Figure 2b. Lunar Photo 2

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Figure 2c. Lunar Photo 3

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10 Constellation Imaging

> "Plato thought that God, after having created the heavenly bodies, assigned them the proper and uniform speeds with which they were forever to revolve; and that He made them start from rest and move over definite distances under a natural and rectilinear acceleration such as governs the motion of terrestrial bodies. He added that once these bodies had gained their proper and permanent speed, their rectilinear motion was converted into a circular one, the only motion capable of maintaining uniformity, a motion in which the body revolves without either receding from or approaching its desired goal."
>
> ...Galileo Galilei, 1629, Dialogues
>
> Concerning Two New Sciences, P.283

OBJECTIVE

To photograph your favourite constellation and to learn about some of the constituent stars.

TAKING THE PICTURE

Generally you will take the picture one night and analyze it on another lab period a couple of weeks later.

The camera will be mounted so you can point the camera to the constellation you are interested in. Your instructor will help you check that the camera is focused at infinity.

The camera is controlled by a computer, which will allow you to set the exposure to about 10 seconds and to name the file etc. Note the date, time, length of exposure, focal length of the camera, and constellation name in the log book.

EQUIPMENT

We will use a Santa Barbara Instruments Group - ST8 CCD camera with a fisheye lens of 15 mm focal length and a sturdy tripod to hold the camera during the time exposure. This camera is a very sensitive digital camera, which is cooled to decrease the noise inherent in this equipment. The detector is a Charge Coupled Device (CCD), which is composed of 1530×1020 pixels each 9 microns in size. The picture elements or pixels can be binned or added together to make pictures with 2 or 3 times less elements but still cover the same area on the sky. Generally we use it binned 2×2. The pictures can be enhanced and stored in a computer.

Field of View

In order to identify stars on the picture we need to know how much of the sky is included in our picture. This is called the field of view "FOV" and is usually measured in degrees. The field of view depends on the size of the picture (s) and the focal length (f) of the lens. See figure 1. The bigger the picture, the more sky you will see. A short focal lens length has a small radius of curvature and will make a small picture. Using the small angle formula, the distance (s) on the picture is equal to the focal length of the lens (f) times the angle (θ), on the sky measured in radians:

$$s = f\theta,$$

and for an angle θ in arc seconds we get the familiar:

$$\frac{s}{f} = \frac{\theta}{206265}.$$

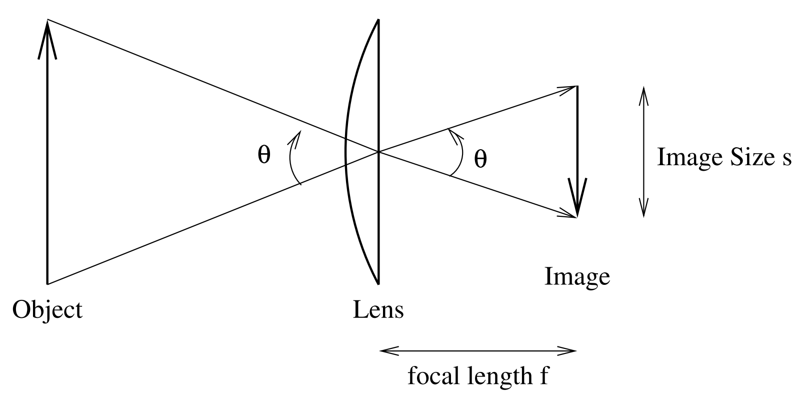

Figure 1. The focal length, image size and angular diameter relationship

There are 57.3 degrees in one radian so if you measure θ in degrees the relation becomes:

$$s = f\theta/57.3,$$

$$\theta = 57.3s/f.$$

The focal length (f) of the camera's lens is 15 mm and the CCD has a length (s) 13.77 mm and width 9.18 mm. What is the length and width (θ) of the picture in degrees?

Theoretical Scale

Closely related to the "field of view" is the scale of the picture. This term refers to the number of degrees per millimetre on the picture. The illuminated region of the CCD does not quite go to the edge of many of our pictures, but usually the width is about 206 mm. To find the scale, divide the number of degrees your picture is on a side by the length of that side in millimetres as measured on your print.

Resolution

If you look very closely at your picture with a magnifier you can see that the picture is made up of tiny pixels. The smallest detail you can see in your picture is called the "resolution" and depends on the size of these pixels. The pixels on our CCD are 9 microns on a side, but usually we bin the data by 2 or 3 times so the pixels are effectively 2 or 3 times larger. If two stars appear very close together on the sky, then the light from both stars may land on a single pixel and we will record them as one star. Such a star is β Cygni (=Albireo), which appears to have a separation of 0.01 degrees (= 30 arc seconds) in the sky.

- Using our lens of 15 mm focal length, how far apart will the two images of the stars be? Will this angle be resolved by our CCD if the pixels are 9 microns (0.009 mm) on a side?
- What would you need to change to enable us to resolve the star into its two components?

Table 6: Greek Letters

α	Alpha	η	Eta	ν	Nu	τ	Tau
β	Beta	θ	Theta	ξ	Xi	υ	Upsilon
γ	Gamma	ι	Iota	o	Omicron	ϕ	Phi
δ	Delta	κ	Kappa	π	Pi	χ	Chi
ϵ	Epsilon	λ	Lambda	ρ	Rho	ψ	Psi
ζ	Zeta	μ	Mu	σ	Sigma	ω	Omega

OBSERVATIONS

Constellations

Of the 88 constellations in the sky only a few will be visible in your picture. Some of these constellations such as those of the Zodiac are very ancient and have referred to the same stars since the time of the Babylonians. Some of the constellations are rather recent inventions of the 1700's by Lacaille and Hevelius.

Sketch on your picture, connecting the bright stars to show the constellation(s) visible in your picture. What mythological figure does your constellation(s) represent?

Star Data

Only the brightest stars such as Betelgeuse were named by the Arabs and the Greeks. To include fainter stars Bayer introduced in 1603 the system of identifying each star by a Greek letter and the name of the constellation so Betelgeuse = α Orion. These designations generally go in order of brightness with the brightest star designated α and the second brightest designated β etc.

To include even fainter stars, in 1725 the Astronomer Royal John Flamsteed introduced a system of numbering the stars from West to East in a constellation. Therefore the bright star Betelgeuse is also called α Orion or 58 Orion. The Henry Draper Catalogue (HD) was compiled in about 1900 and was the first big catalogue to include the spectral types of the 359,000 stars to 9 magnitude. The Smithsonian Astrophysical Observatory (SAO) catalogue was made in about 1950 and it included accurate positions and spectral types for 300,000 stars brighter than 9 magnitude. The Guide Star

Catalogue (GSC) was compiled for the the Hubble Space Telescope contains 19 million “stars” to about 15 magnitude. The Hipparcos catalogue (HIP) was made from data from the Hipparcos satellite which measured the accurate positions and brightnesses of 118,218 nearby stars. The problem of naming stars continues today as we want to refer to more and more, fainter and fainter stars, galaxies and other objects.

The “Sky” computer program has been included with your textbook and we have installed it on the lab computers. Click on the icon and the program should show you the sky with the constellations and stars named. If not check with the instructor.

To find your constellation, right click and choose [Find]. Choose Constellation labels and then choose your constellation. Click on [Centre and Frame] and the program will zoom to your constellation. Click on the magnifying glass to see more or less sky.

Click on a star to see more about the star. Record the name, magnitude/brightness, distance in light years and spectral class of a few bright stars.

You will learn much more about spectral classes in later labs and lectures but for now all you need to know is that it tells us the temperature and size of a star. The spectral class of a star tells us its temperature - from hottest to coolest the spectral classes go O,B,A,F,G,K,M. Each spectral class is divided into ten subclasses so they go B8, B9, A0, A1, A2, A3 ... A8, A9, F0, F1, ... M9. Usually then there is a Roman numeral to tell whether a star is a dwarf (=V), a giant (=III) or a supergiant (=I or II). Our sun is a G2V type star and has a temperature of 5000 degrees. Vega is an A0V type star and has a temperature of 10000 degrees.

The distance to a star is measured in parsecs or light years and 3.26 light years equals a parsec. The brightness of a star is measured in magnitudes. Astronomers use blue (B) and yellow (visual = V) filters to measure the brightness and colour of a star. Remember that the small magnitudes 0, 1, 2 ... are bright and big magnitudes 5, 6, 7, ... are faint.

Nebulae

Charles Messier was the first to catalogue some nebulae in 1771 and we still use his list today, M1, M2, M3, etc. Are there any fuzzy objects in your picture? Can you find any clusters, emission nebulae, or galaxies? If you find a fuzzy spot, check another picture of the same region to see if it is a real object or if it is a plate flaw such as scattered light from the moon or a bright star.

Limiting Magnitude

Astronomers love to talk about "Who can 'see' the faintest star?". In the star atlas the brightness of a star is indicated by the size of the dot representing the star. The faintest star in the atlas that you can detect on your picture is the limiting magnitude. What is the limiting magnitude of your picture? How could you get a picture with a fainter limiting magnitude?

Right Ascension and Declination

Just as the Earth is divided into a grid of latitude and longitude lines, the sky is divided into Declination and Right Ascension. Declination measures North and South of the equator in degrees just like latitude and is given by the numbers going up the side of the star chart. Right Ascension measures east and west in hours, minutes and seconds and is given by the numbers on your star atlas going across the top of the chart. Note that the Right Ascension increases towards the East. Find the Right Ascension and Declination of the Centre of your picture. Use the "Sky" program and click a few times to see how precisely you can measure this quantity.

Observed Plate Scale

We can now confirm the theoretical plate scale. Find two stars which are quite far apart in the picture and which you can identify unambiguously in the star atlas or SKY program. On the picture measure with your ruler the distance between the stars in millimetres. Using the SKY program, left click on the first star and then left click on the second. Scroll down to the bottom of the data window and it will tell you how many degrees separate the two stars.

Find the scale of your picture in degrees per millimetre by dividing the distance between the stars that you measured on the picture into the number of degrees from the SKY program. Does this agree with the theoretical scale you calculated from the focal length of the camera lens? Comment on the accuracy of this procedure.

Alternatively we can use the atlas to measure the distance between the same two stars in degrees. The easiest way to do this is to align the edge of a piece of paper with the two stars and mark their positions on the paper. Then align the paper with the Declination scale on the edge of the atlas and just read off the number of degrees between the marks.

Star Counts

The limiting magnitude of your picture is approximately what you would see from a very dark place with your unaided eyes. Many people think that the number of stars you can see is uncountable, but we can estimate it from your picture. You can count the number of stars in a small square and then multiply it by the number of small squares in the whole sky.

Draw a small square on your picture 25 mm by 25 mm and count the stars in it. Draw a couple of similar squares in other parts of the picture and count the stars in the square to measure the uncertainty. Use your observed scale to find the area of the square in square degrees. It should be close to 41 square degrees. If there are 41,253 square degrees on a sphere, roughly how many stars are there in the sky that you could photograph with this camera?

Web Sites

http://www.astro.uiuc.edu/∼ kaler/sow
http://en.wikipedia.org/wiki/Constellation

11 Solar Rotation

OBJECT

To observe the rotation of the sun as evidenced by sunspot motion, and to determine the period of rotation.

INTRODUCTION

Would we expect the sun to rotate? There are several reasons which lead us to anticipate a positive answer to that question.

a) The general dynamical state of the solar system as exemplified by planets and satellites is one of rotation. We should therefore not be particularly surprised to find similar behaviour on the part of the sun.

b) The condition of zero rotation is unique among all possible rotational states. If rotational states were randomly chosen, the chances of obtaining precisely zero are vanishingly small.

c) If a body as massive as the sun is initially endowed with a certain amount of rotation, astrophysicists are quite hard put to think of ways in which that rotation might be entirely lost. Cosmogonists do not offer any help, since most models for the formation of stars include rotation as an intimate part of the process.

How might we go about determining the rotation of the sun? In 1611 Galileo Galilei, in the course of examining the heavens with his newly invented telescope, noticed sunspots and detected their motion across the solar disk. Assuming them to be part of the solar surface, Galileo cited this as evidence proving the sun rotates in about 27 days.

It was established in about 1861 by an English amateur astronomer, Carrington, that the period of solar rotation determined from a sunspot varied with the latitude of the spot; at higher latitude the period was greater. This was the first indication that the sun, or at least its surface, does not rotate as a solid body.

PROCEDURE

1. To find the period of rotation of the sun from the sunspots you need observations of the sun every day or two for a week. A sketch of the sun

can be made by projecting an image of the sun onto a piece of paper using a telescope and a projection screen. Carefully mark the edge of the sun and the positions of all the sunspots. Turn off the drive for the telescope and the image of the sun and the spots will drift across the field of view. The spots are drifting across the field of view because the Earth keeps turning and the telescope is not moving to follow the apparent westward motion of the sun. Mark on your sheet an arrow showing the direction that one of the spots has moved. The sun seems to be moving to the West so mark the end of the arrow with a W. Record the date and time that you made the sketch.

2. Back in the lab you will be given observations of the sun made on a few other days. To easily see the motion of the spots from day to day trace your diagram onto a sheet of lined paper. Make the lines of the paper parallel to the arrow, i.e. the motion of the spot when the drive was turned off. Trace the other days' diagrams onto the same paper to form a composite diagram. Be very careful to align each arrow with the lines on the paper. Label each of the spots with the date it was observed.

3. To help clarify the situation we will make a three dimensional diagram showing the surface of the sun and the spots. Connect the different observations/days of the same spot with a line of latitude going east-west across the sun. Tape a piece of paper along the latitude line. This piece of paper will be a cross-section of the sun. On the paper draw a semi-circle with a radius equal to half the length of your latitude line. If you now draw lines perpendicular to the latitude line from the spots to the semi-circle, you can see where the spots were on the curved surface of the sun. Draw lines connecting the centre of the semi-circle with the spots.

4. With a protractor you can now measure the angle that the spot moved through from observation to observation. Make a table with all the angle and time differences for each pair of observations of a spot.

5. From the differences calculate the period of rotation for each pair of observations and average the periods.

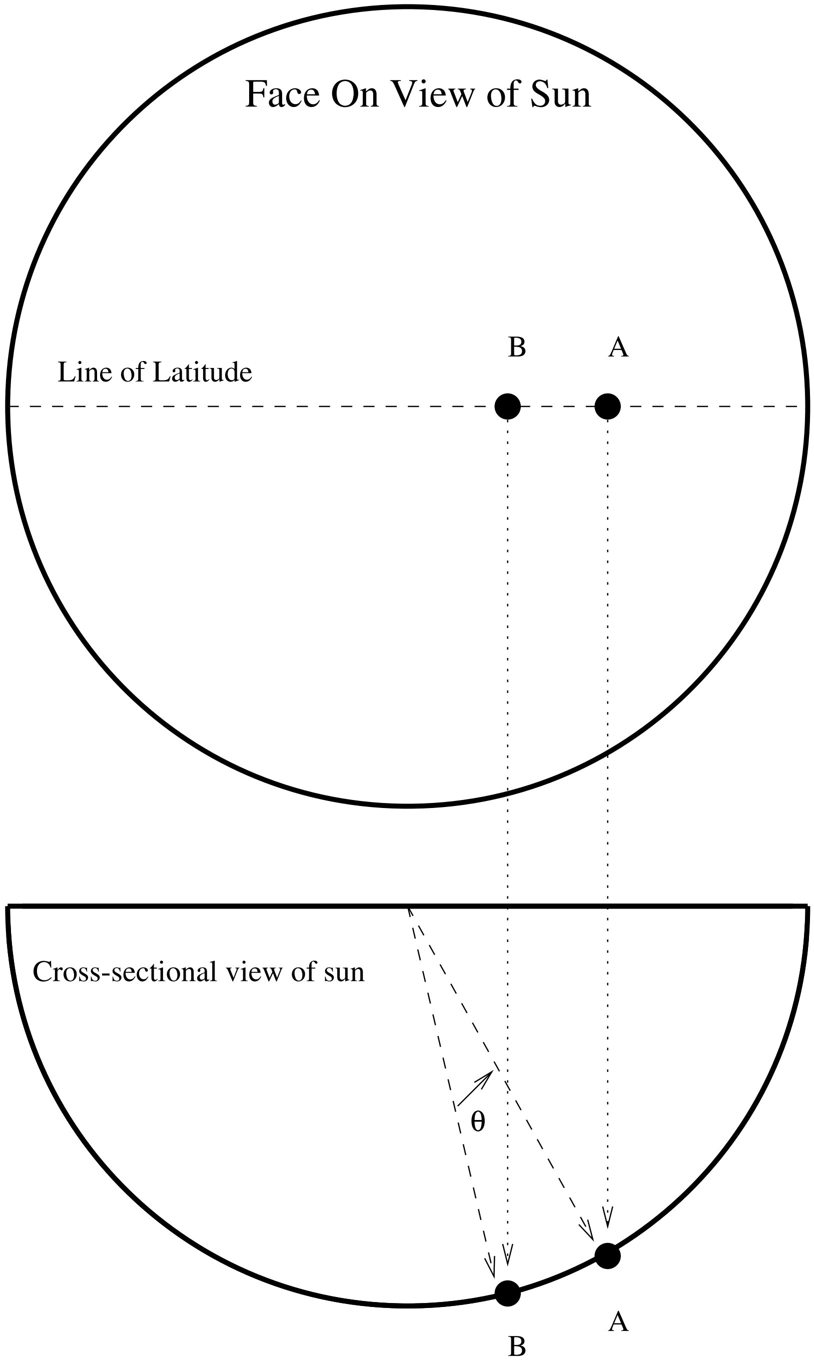

Figure 1. Face-on and Cross-sectional views of the sun.

QUESTIONS

1. The accepted value of the observed rotation period of the sun is 27 days at the equator and 28 days at 30 degrees latitude. Compare your determination of the period with these values, giving your best estimate of the uncertainty in your determination.

2. What are we assuming about sunspots, which is fundamental to determining the rotation of the sun by this method? How might you investigate the validity of this assumption?

3. In a paragraph describe how the sunspots change in size, shape and number over the few days of observation.

4. Assuming the diameter of the sun is 1,392,500 km, how big is a sunspot? Compare it to the diameter of the Earth (12,756 km).

Web Sites
http://www.bbso.njit.edu/
http://sohowww.nascom.nasa.gov/
http://www.spaceweather.com/