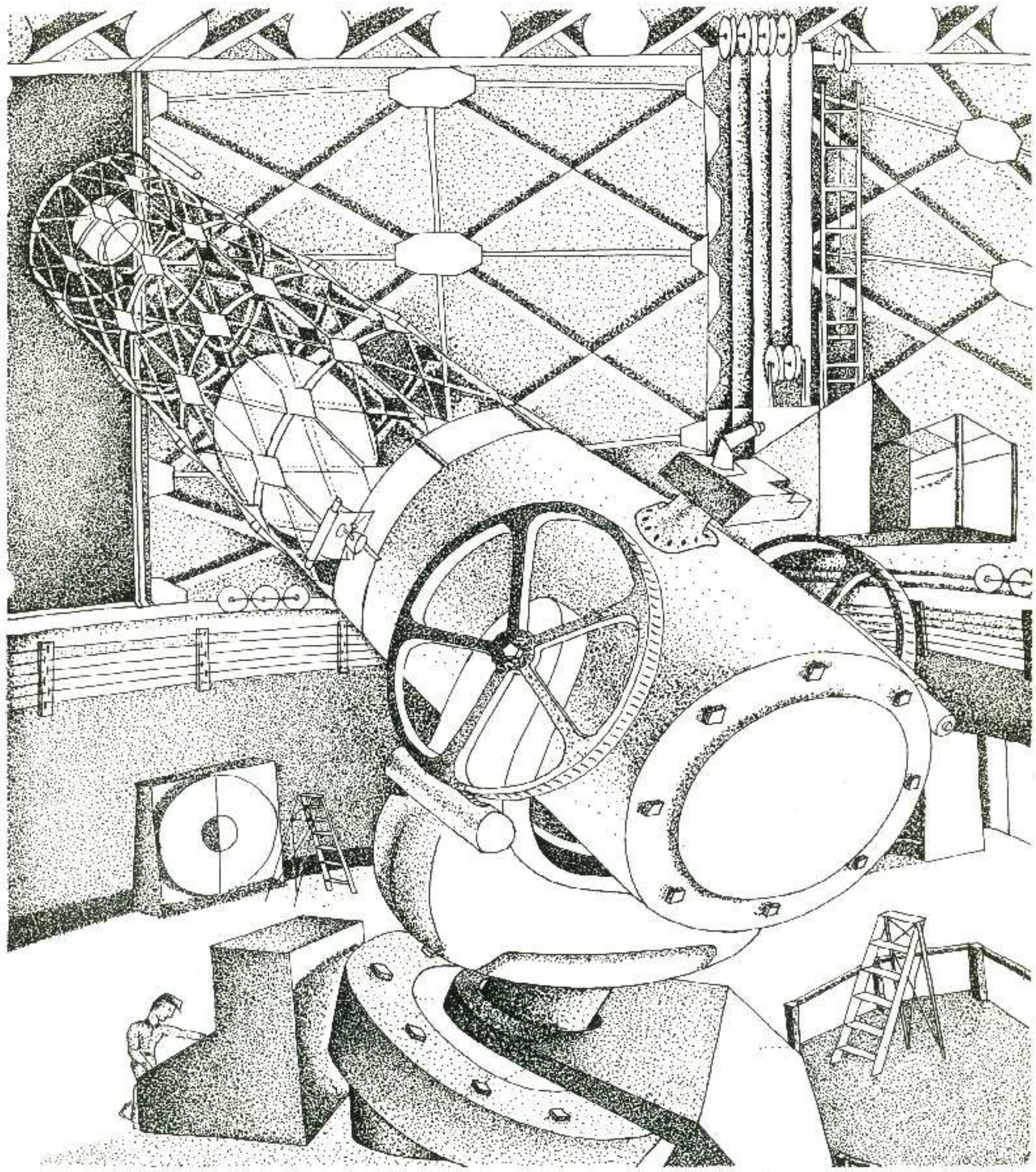
A STUDENT'S HANDBOOK OF LABORATORY EXERCISES IN ASTRONOMY

(Laboratory Manual for Astronomy 102)

First Edition
July 2014



Astronomy 102 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 what key quantity you have measured or what key concept you have demonstrated.

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 labeled and underlined. For any quantity you have measured include an estimate of the uncertainty in the measurement. Refer to the table in the procedure.

GRAPHS Sometimes we want to show how one quantity 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 Night Lab

OBJECTIVE

The objective of this laboratory exercise is to introduce the student to the essentials of astronomy – telescopes, planets, stars, nebulae, and galaxies – through the observation of the night sky. Generally there are four stations: one for the parts of the telescope, one for the constellations, one for the small telescopes and one for the large telescope.

EQUIPMENT

Parts of the Telescope

Light is composed of little bits called photons and a star looks brighter because you see more photons from it. You can not see faint stars because your eyes do not detect enough photons. Your pupils dilate in the dark, because the larger the area of your pupil the more photons your eye collects and the fainter the stars you can see. 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.

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. 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 sketches.

The Small Telescopes

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 date, time, terminator and 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.

Large Telescope

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. Charles Messier made a catalog of 110 nebulous objects and we use his catalog - M1-M110.

- Observe and sketch one of each of these four types of objects :
  - Globular Cluster - Fall M13, M15 - Summer M3
  - Open Cluster - Fall M11, NGC 869 - Summer M67
  - Planetary Nebula - Fall NGC 7662, M57 - Summer M57
  - Galaxy - Fall M31, M32 - Summer M82
- Describe in a few sentences what these objects are. Do not copy Wikipedia.
- 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://www.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
NGC 7662	23:25:54	$42°32'$	8.6	Blue Snowball 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 Stars, Clusters, Nebulae and Galaxies

INTRODUCTION

The objective of this lab is to acquaint the student with the many interesting objects in the sky and the way that astronomers use to record their images.

The images that we will be using are images from scans of photographic plates taken by the 1.2 meter (48-inch) 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 some of 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.

BASIC DATA

We will use Google-sky for our investigations. So start googleearth and click on the Saturn image at the top and choose Sky. Google-sky uses the digitized photographic plates from the first Palomar Observatory Sky Survey called the DSS for most of the sky. The sky was surveyed with this telescope again in the 1990's using three different filters (=RGB colors). This second survey is called the POSS II. About a quarter of the sky was surveyed using digital cameras by the "Sloan Digital Sky Survey" SDSS. Google-Sky will switch from one survey to another as you move about the sky. It tells you which survey is displayed using in the copyright message at the bottom of the screen.

The Google-sky display shows the position of the cursor at the bottom of the screen. The astronomical coordinates displayed are Right Ascension (RA) in hours, minutes and seconds and Declination (Dec) in degrees, minutes and seconds of arc. They are analogous to latitude and longitude. You can also drag the screen to the left, right, up, down (East, West, North and South).

In the right hand corner is the size of the Field Of View (FOV) of the screen in degrees, minutes and seconds of arc. Roll the thumb wheel back and forth or click the zoomer to see the FOV change.

In the Layers section we will need the Backyard Astronomy and the Sky Community = information flags. Inside Backyard we need to have checked Constellations, Messier, New General and Yale Bright Star catalogs; at least to start with. Uncheck the Featured observatories section to cut down on the clutter. We will turn them on later.

We can type the name of the object or the RA and Dec of the object in the box under Search on the left and the program will zoom over to put the object on the middle of the screen.

STARS

a) Go to Vega by typing Vega in the Search box and click Search. The brighter a star is in the sky, the larger its image on the photograph will be. Zoom out until the Field of View is about 1 degree. The stars are infinitesimal dots which can not be resolved and only appear to have a size due to the blurring effects of the atmosphere and diffraction in the telescope. Look at all the spikes and circles around Vega. They are caused light diffracting around the optics inside the telescope. Pick a faint star just to the left of Vega. Center it and Zoom in until you can see that it is a few pixels across. Put your cursor at the top of the star's image and read the Declination Scale and then put your cursor at the bottom of the star and read the scale again. The difference is how big a star image is and tells you the resolution of the picture.

Zoom out to a Field of View of about 10 degrees. Can you find a roundish glow just above and left of Vega that is about the same size as the over exposed image of Vega? It is called a ghost and is caused by the light reflected off the film back into the telescope and then back onto the film but out of focus. Watch out for ghosts and imperfections in these images.

b) Go to 30 Cygni. Because the original pictures were taken through blue and red filters and in the computer they are superimposed, we can tell what color the stars are. The color of the star tells us its temperature - hot stars are blue stars and red stars are cooler stars. Which is the bluer star? Which is the hotter of these stars? Click on the circle to see the information about the star. What are the names and distances of the two stars?

c) The Sun is located inside the Milky Way Galaxy which is shaped like a plate or a Frisbee. We can very roughly estimate the number of stars in the galaxy by counting the number of stars in a small area and then, assuming that area is typical, we can multiply the number of stars by the number of small areas it would take to cover the whole sky. Unfortunately the density of stars you see varies depending on whether you are looking at the center of the Milky Way or up out of the Galaxy. So while no area is typical we can get a upper and lower limit by looking in the most dense and least dense regions. Look up, out of the galaxy at the North Galactic Pole by typing 12:51:26 +27:07:42 into the search box. Set the Field of View (FOV) to 5 arc minutes. How many stars can you count? Since it would take 6 million of these small areas to cover the whole sky, multiply this by 6 million to get how many stars in the galaxy. This is a lower limit.

The densest star region I found was at 17:58:59 -29:12:14, near the center of the Milky Way Galaxy. Set the Field of View to 5 arc minutes and obviously you have so many stars you could never count them. The high resolution square in the middle is an image taken by the Hubble Space Telescope so the stars are not blurred by the atmosphere and the resolution is set by diffraction in the telescope. Set the Field of View to about 5 arc seconds and guess/count the stars. Since it would take 22 Billion of these small areas to cover the sky, multiply your number by 22 Billion to get the number of stars in the galaxy. This is the upper limit to the number of stars in the Milky Way galaxy.

To emphasize the effect of resolution pan over to see the edge of the Hubble Space Telescope picture (HST). Zoom out to have a FOV of about 30” and measure the size of a star image on the Hubble picture and the size of a star image on the DSS picture. How much bigger is the seeing disk of the DSS picture compared to the HST picture?

CLUSTERS

Some stars are congregated together in clusters. We find two kinds of clusters in the Milky Way. The generally young, loose Open Clusters and the old, more concentrated Globular clusters.

1. Open Clusters

Go to M67. Click on the red circle and record how old the cluster is.

Look at the bright stars; are there more red stars or blue stars or about the same number? Set the field of view to 4 degrees to see how the cluster stands out from the background stars. You can also see some of the weird artifacts/ghosts around some of the bright stars.

2. Globular Cluster

Go to M13. Set the FOV to about a degree. Click on the red circle and record how many stars are in this cluster and how far away it is. Again looking at the brightest dozen stars are there more red stars or blue stars?

3. Classify Them

Go to M92. Is this cluster a globular or open cluster? Record something interesting about it.

Go to the Pleiades (FOV 5 degrees) and record whether it is a globular or an open cluster and something interesting about it.

NEBULAE

1. Reflection Nebula

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

Go to the Pleiades and set the Field of View to about 3 degrees. In the layers section click on the Spitzer Showcase to turn on the infrared picture. If you click on the Big red "S" then you will get an information window. How far is it to the Pleiades? Who was chasing them? Can you see them with your naked eye?

2. Emission Nebula

Hydrogen gas in the interstellar medium can be ionized (=HII region) by a star hotter than B2V. This glowing gas should appear sort of red-green-violet, but in googlesky it appears sort of yellow orange.

Go to North America Nebula and have the field of view at 4 degrees. Find the Pelican Nebula just to the right.

3. Dark Nebula/Globule

A Giant Molecular Cloud is a very cold, relatively dense, cloud of dust and molecules. Parts of a Giant Molecular Cloud will contract and form globules, protostars and eventually stars. 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 images?

Search on the North America and Pelican Nebula for the tiniest dust cloud you can find and record its position. Do not be fooled by the tiny black squares; they are artifacts.

Maybe you have noticed that there are a different number of stars per square inch on the different parts of this picture. Compare the number of stars per square inch you see on the regions New Mexico/Texas, Gulf of Mexico and on the Pelican Nebula near 56 Cygni. If the stars are uniformly distributed in space, then the foreground star density will tell us how far away the different nebulae are. Which nebula is the furthest and which is the closest nebula?

GALAXIES

Galaxies are huge collections of billions of stars, dust and gas. There are four different classifications of galaxies and it would be interesting to have look at an example of each kind and then try to classify some unknowns.

1. Elliptical Galaxies

Go to M89. Notice how it is brighter in the center and becomes fainter smoothly toward the edge. It contains no dust or gas. What color is it? Go to M87 - it is also an elliptical galaxy. Zoom in on the center to see a jet coming from the center. What color is the jet?

2. Spiral Galaxies

Go to the Whirlpool Galaxy. This is a nice example of a face-on spiral galaxy. Notice the spiral arms swirling away from the central bulge. What color are the arms of this galaxy? What color is the bulge? Click on it to find the distance. Go to M31 and comment on its colors. Notice how it is inclined to the line of sight. Go to NGC4594. This is a nice example of an edge-on spiral galaxy. Notice how it is even more inclined and the disk/arms are now edge on. Notice the thin dust lane superimposed on the bulge.

3. Barred Spiral Galaxies

Go to NGC 1300. Notice here that the spiral arms start from a bar which extends from the bulge of the galaxy. What is the distance to this galaxy?

4. Peculiar/Interacting Galaxies

Go to “The Mice”. Many galaxies do not fit into the Elliptical/Spiral Classification and we put them all into the Peculiar/Interacting classification.

What is happening here? Comment on the colors and dust in this/these galaxy(s).

5. Galaxies Classification

Go to M101, M89, NGC 4565, M105, M95, M96 and The Antennae and classify these galaxies.

6. Hubble Ultra-Deep Field

The Hubble Space Telescope was pointed to an area of the sky devoid of bright stars for few months in 2003-04. Four filters were used to make a color image, which records objects as they were 13 Billion years ago. Go to the Hubble Ultra Deep Field. Notice the blank areas surrounding it where the DSS does not record many objects. Zoom in and notice all the galaxies. All the stars have the plus sign on them and everything else is a galaxy. How many could there be in the whole sky? Let's count the galaxies in a square area 20 arc seconds on a side and then multiply by one billion to find out how many galaxies the Hubble Telescope could take pictures of if it could cover the whole sky.

MISCELLANEOUS

Planetary Nebula

At the end of a star's lifetime it will eject its atmosphere leaving a very dense, very hot white dwarf as the remnant of its core. An example of a planetary nebula is M57. Go to M57. Zoom in and see if you can find hot white dwarf at the exact center of the nebula. What color is it?

Asteroid Track

Straight lines in the images which are only one color are made by asteroids. They moved along in their orbit during the exposure and because the exposure was made in three colors, red, green and blue at three different times, the track will be a single color. The Sloan Digital Survey takes the red, green, and blue pictures one right after the other so the asteroid tracks will line up. Go to 13:28:33 +61:09:53. What color(s) is the asteroid track? Check out 13:40:00 +54:30:00 - what color tracks can you find here?

Supernova Remnant

Really large stars will explode at the end of their lifetime and the gas which is expelled is sometimes still visible. Go to the Crab nebula. Turn on the "Featured Observatories" one at a time to see what the Crab Nebula looks like in the different parts of the Electromagnetic Spectrum. When did astronomers observe the supernova which made the Crab Nebula? How far away is the Crab Nebula? In the center of the nebula what is left of the star that exploded?

Quasar

Some galaxies have a supermassive black hole at their center. The Black Hole is always black, but when a star or gas come close to the black hole, the gas whirls around in a disk before falling in and becomes hot and bright. The Black Hole and its disk are so small that they look like a star to us. These bright stellar objects are called quasars. The closest quasar is 3C273 and its position is 12:29:07 +02:03:09. Notice the faint jet which seems to originate at the quasar. Check Wikipedia to find out how far away it is and how long is the jet. Quasars are among the most distant objects we know. One of the most distant quasars is APM 08279 +5255 which is at RA and DEC of 08:31:41.6 +52:45:17. What color is it? Check Wikipedia to find out how far away it is.

Black Hole

Go to 19:58:22 +35:12:06. What is the HD number of this star? This is the star which orbits the nearest black hole. We can not really see the black hole; but check Wikipedia to find out: How massive is it? How far is it? Do we need to worry about falling in?

Barnard's Star

The second closest star system is Barnard's star. Go to 17:57:49 +04:39:34 . Zoom out until the FOV is about 7 arc minutes. It looks blue, but it should have been red since Barnard's star is a cool red dwarf. Turn on the "Sky Community" i tags in "Layers". The i tag is actually about 2 arcminutes north of Barnard's star, since the picture was taken in the 1990's and Barnard's star has moved north since that time. What is Barnard's Star's distance?

BONUS

Find some object that you think looks interesting and record its position and what you think it is.

OBJECTS

Objects	**R. A.**	**Declination**
Vega	18:36:56	38:47:15
30 Cygni	20:13:18	46:49:03
North Galactic Pole	12:51:26	27:07:42
Dense Region	17:58:59	-29:12:00
M67	08:51:24	11:49:00
M13	16:41:41	36:27:37
M92	17:17:01	43:08:11
M57	18:53:24	33:01:45
Pleiades	03:47:24	24:07:00
North American	20:59:18	44:31:00
M89	12:35:40	12:33:23
M87	12:30:49	12:23:28
Whirlpool	13:29:53	47:11:43
M31	00:42:44	41:16:10
NGC 4594	12:39:59	-11:37:23
NGC 1300	03:19:41	-19:24:41
The Mice	12:46:10	30:43:55
M101	14:03:13	54:20:57
M89	12:35:40	12:33:23
NGC 4565	12:36:21	25:59:16
M105	10:47:50	12:34:54
M95	10:43:58	11:42:14
M96	10:46:46	11:49:12
Antennae	12:01:53	-18:52:10
Hubble Ultra	03:32:39	-27:47:29
Crab Nebula	05:34:32	22:00:52

3 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

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.

We can learn a great deal about the stars, planets, galaxies and the Universe from studying the spectra of these celestial objects.

Wave Nature of Light

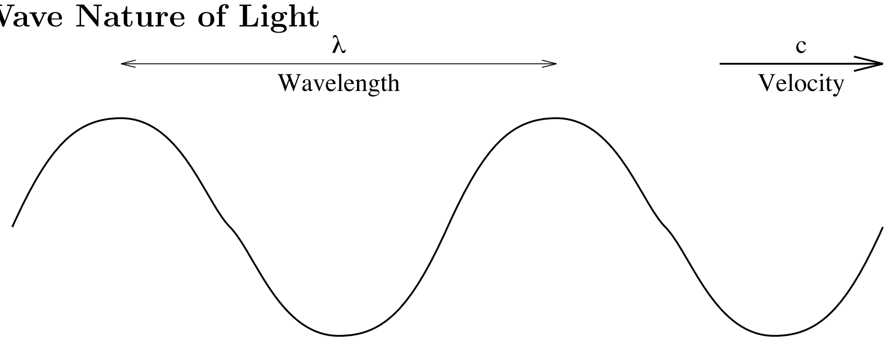


Figure 1. Light Waves

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 velocity 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:

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

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.

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.

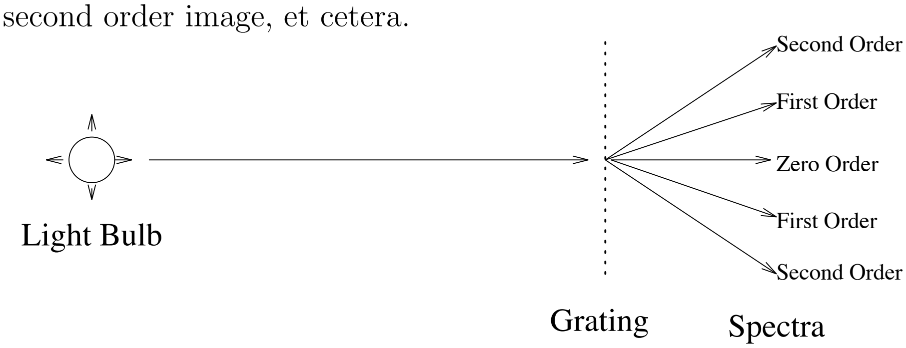


Figure 2. Spectral Orders

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. In the next three sections comment on whether the spectrum is a continuous, an emission or an absorption spectrum.

- 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?

- Look at the flourescent light. Sketch the spectrum Do you see bands of colour as well as a continuous background?

- We can also observe the spectrum of the nearest star, our sun. One of the windows is covered with a blind, which is closed until only a slit of light shows. If you stand across the room from that window 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.

- 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. Make a sketch of the spectra that you see from the gases in the gas discharge tube box for Hydrogen, Helium, Mercury and the unknown. 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.

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. You may need to use a black book to shield the camera from light from the computer monitors. 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)(red), beta (β) and gamma (γ)(violet).

Plotting the Graph

Plot the wavelengths of the Helium lines against the "x" measurements of the Helium lines. With a ruler 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 Å	Description
1	_	6678	Bright Red
2	_	5875	Bright yellowish
3	_	5016	Bright green
4	_	4922	Faint Green
5	_	4713	Faint Blue
6	_	4471	Bright blue-violet
7	_	3889	Deep violet

Table 2: TABLE OF HYDROGEN WAVELENGTHS

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

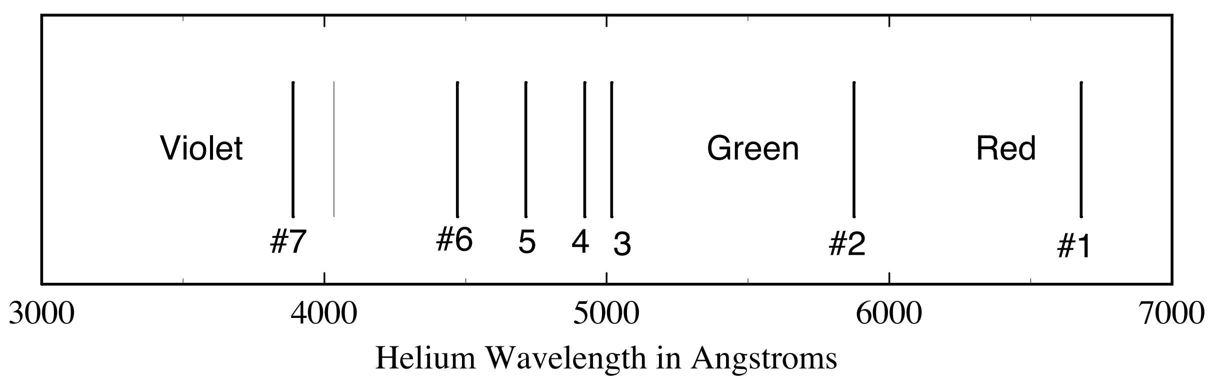


Figure 3. Helium Lamp Spectrum (scale only approximate)

4 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.

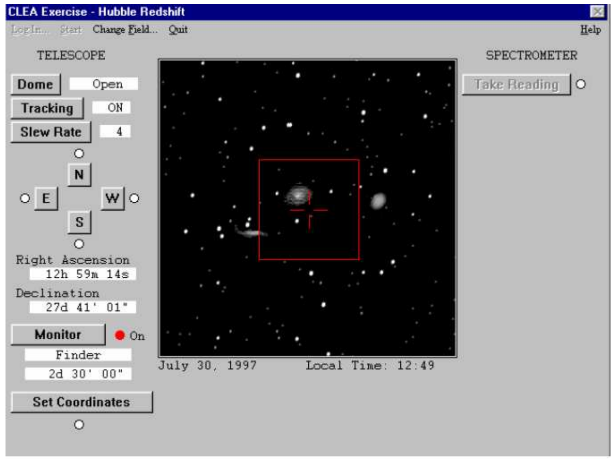


Figure 1. Control Panel

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.

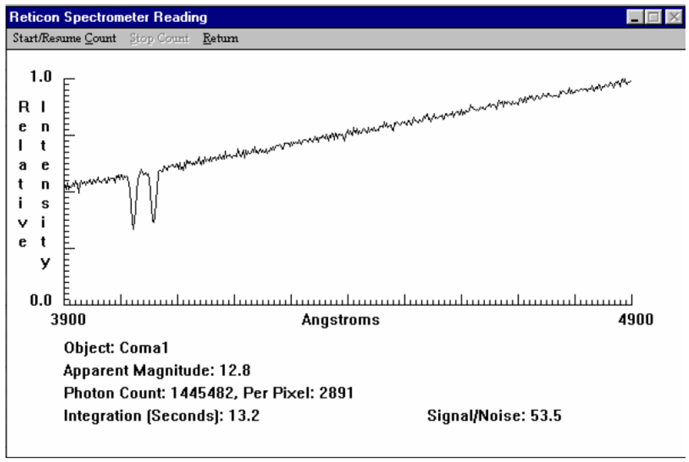


Figure 2. Spectrometer Control Window

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 km/sec	
			K Line	H Line	K Line	H Line

Measure one or two galaxies from each cluster of galaxies and lots from the "Sagittarius Cluster". 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.

You may want to apply for time on a big telescope. Time on a big telescope is restricted so you might want to think about which clusters to use the big telescope on.

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.

$$v = c\frac{\Delta\lambda}{\lambda} \tag{2}$$

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:

$$D = 10^{\frac{m-M-25}{5}} \tag{3}$$

   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. The equation describing the line is :

$$V = HD \tag{4}$$

   Determine the slope H of the line. The slope is the Hubble Constant. 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.

   There was 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 were also reported. More recently the WMAP satellite and supernovae observations (see website below) have 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.

$$Time = \frac{Distance}{Velocity}. \tag{5}$$

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:

$$T = \frac{D}{V} = \frac{1000}{H}. \tag{6}$$

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). Estimate your uncertainty in the age of the universe by using your second slope from your graph.

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

5 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.

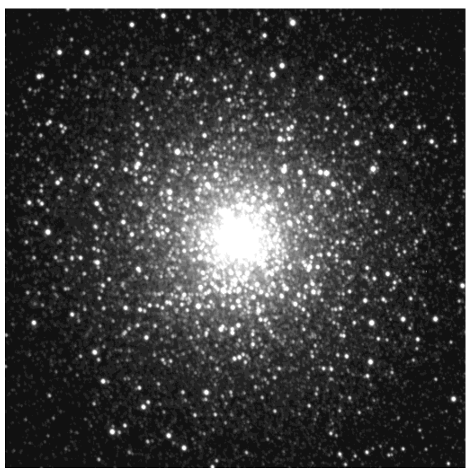


Figure 1. The globular cluster M15

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.

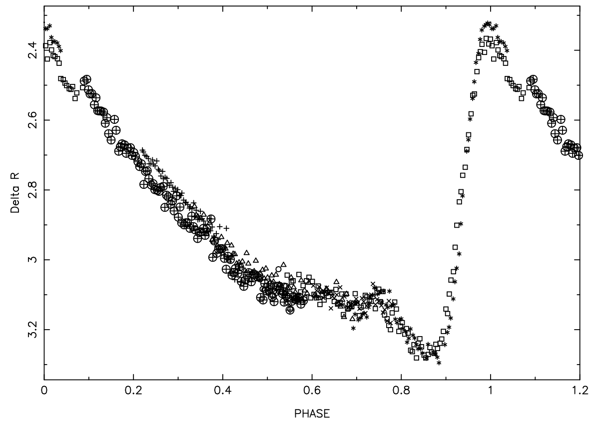


Figure 2. Example light curve of an RR Lyrae star discovered at UVic

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.

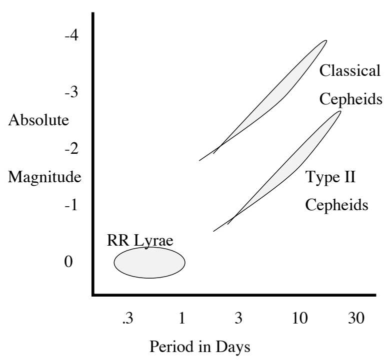


Figure 3. Period Luminosity Relation for RR Lyrae and Cepheid Variables

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=1.0 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.

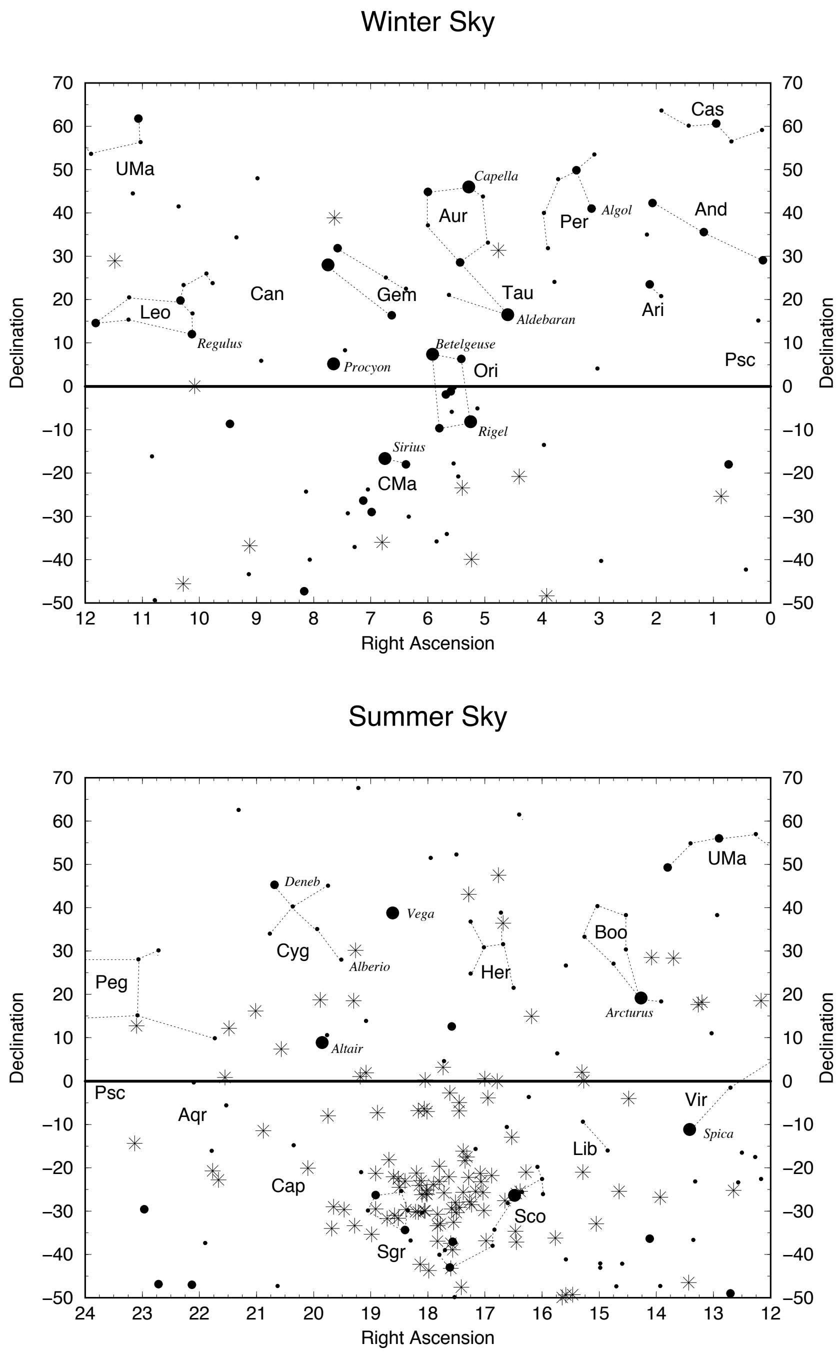


Figure 4. Winter skies above and summer skies below with globular clusters marked as *'s.

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 inch 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.

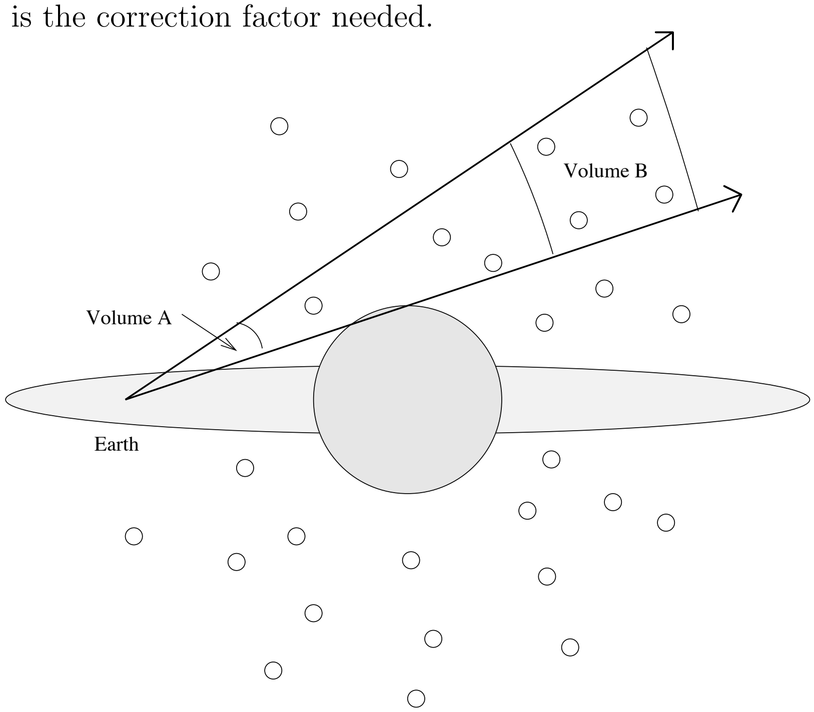


Figure 5. Globular Cluster Distribution about the Galaxy. The wedge represents the region of clusters seen on one photographic plate.

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:

$$Mass\,in\,Solar\,Masses = 8.8 \times 10^{15} \times \frac{A^3}{Period^2} \tag{7}$$

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://apod.nasa.gov/diamond_jubilee/debate20.html

6 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 lab 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.

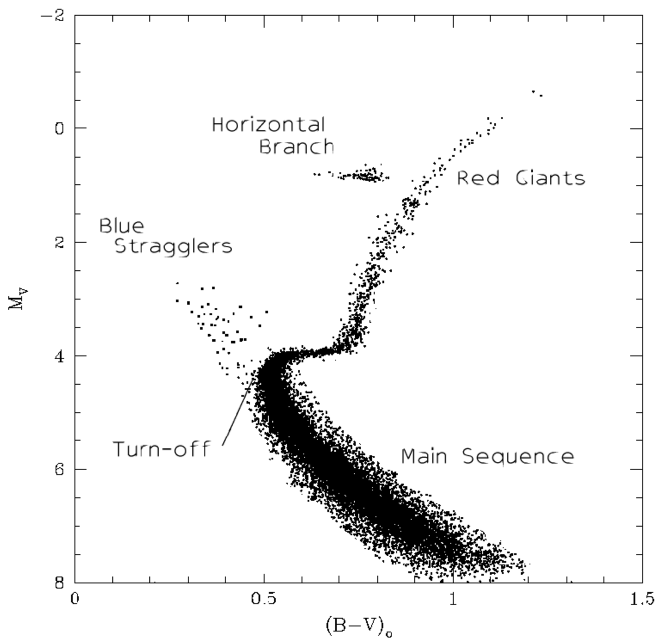


Figure 1. The Morphology of Colour-Magnitude Diagrams

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. In which clusters, if any, 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.

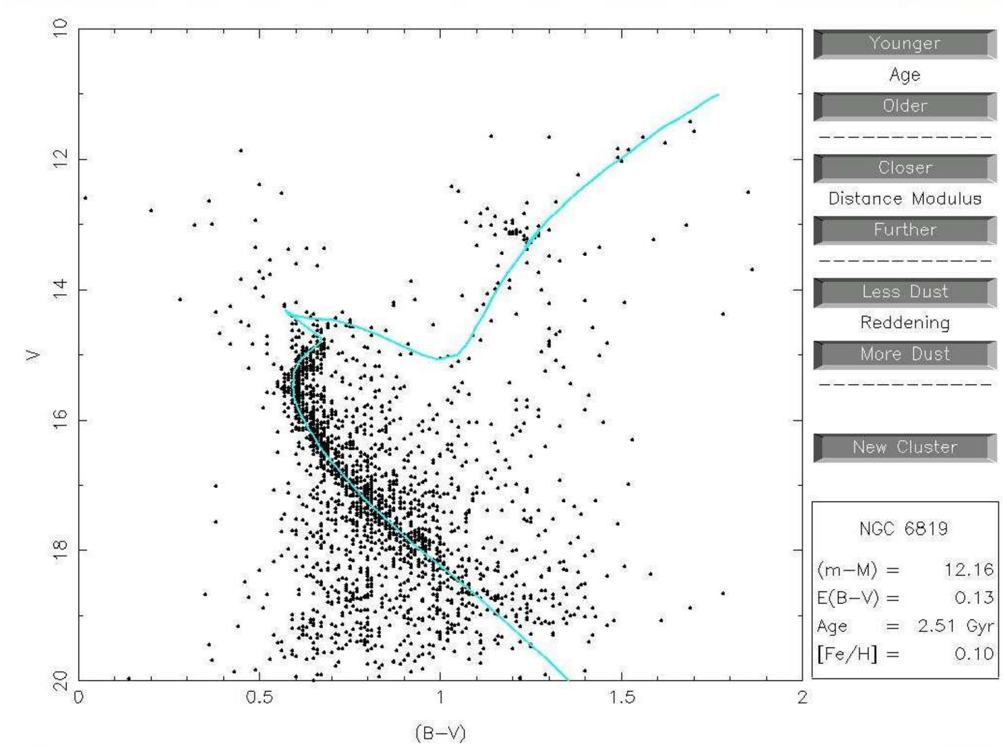


Figure 1. The fitting window

Age

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.

Distance Modulus

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 modulus (m-M) which is the difference between the apparent m and absolute M magnitudes of the stars.

Reddening

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”.

This interstellar dust will cause the stars to look fainter as well as redder. The more dust the more reddening and the more interstellar extinction. We can use the reddening E(B−V) to correct for this interstellar extinction as follows:

$$(m - M)_o = (m - M) - 3.1 \times E(B - V)$$

Heavy Elements

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

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

A graph has been plotted to show the relationship between distance and distance modulus and your instructor will show you how to use it if this formula is daunting.

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

Questions

1. How does the isochrone change when you increase the distance? Why?
2. How does the isochrone change when you increase the dust? Why?
3. How does the isochrone change when you increase the age? Why?
4. Do the clusters with age=0 years have a red giant branch? Why or why not?
5. Are any of the clusters older than the earth (4.5 billion years), or the universe (13.7 billion years)? Comment.
6. What will be the age of the sun when it reaches the turn-off point? What will happen to the Earth?
7. 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] generally different for the two kinds of clusters?

Web Sites
http://apod.nasa.gov/apod/ap010223.html