AST 25 LABORATORY MANUAL

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INTRODUCTION TO ASTRONOMY LAB

Goals

The goal of this lab course is to allow the student to gain a reasonably broad but detailed knowledge of the night sky and what it contains, along with experience in simple observational methods and the use of a telescope. With this in mind, it is easy to understand that the lab is intended to be somewhat challenging, yet accessible to the student with little or no astronomy experience. By the end of the quarter, the student should know:

1. Major constellations and asterisms (including the signs of the Zodiac) visible this season
2. Bright stars and planets visible this season
3. The basics of using star maps and understanding celestial coordinate systems
4. How the sun, moon, and stars "move" in the sky during the year
5. The use and characteristics of telescopes
6. How to visually observe objects, such as the moon, planets, star clusters, and nebulae

What do I have to do?

The heart of each lab is the **Procedures** section, which describes what the lab leader will be presenting for that night's activities. These contain a combination of lists of activities, data sheets, and some details that have been assigned in the past and **may or may not** be assigned on your specific evening. Our objective is guided observations which should help you to describe clearly what you have seen on the sky in your brief reports. You should interpret the **Procedures** as what will be most helpful in your leaning and practicing the new concepts each week.

After skimming the **Procedures**, you should read that week's **Discussion** if present, and other sources (other parts of the manual, our text, a dictionary or encyclopedia or star atlas, stars charts) for related material that may be necessary for that week's activities. When you then reread the **Procedures,** they should make more sense.

It is crucial that you read over the procedure in advance so you know what you will be trying to do. It's very hard to read in the dark, and running inside to read will mess up your night vision.

Bring Each Week

A **flashlight** with a **red filter** or a red bike light

A **calculator** (you may need this for a few assignments, can share in a group)

A **star wheel** (optional. may be obtained in the UC Davis Bookstore)

Be prepared to go outside **regardless** of how cold it is (i.e. bring a coat and sweater). Even on warm days, expect it to be cold on the open roof after dark.

Grades

The grades assigned are based primarily on:
Participation, attendance, in-lab quizzes -30%
The proper completion of the lab each week (which includes submission of the report sheet) - 70%

The lab grade will comprise part of the class grade, typically in the 15-20% range depending on who is teaching the course in a given year. In particular, **if you fail the lab, you fail the class.**

Lab Reports

Each week, a lab report must be handed in at the end of the lab. These reports, to be done in groups or individually according to the instructions of the lab leader, should follow the format below:

1. **COVER SHEET**
Included in each lab is a cover sheet with spaces for names, date, time of observation, weather conditions, lab title and purpose, equipment, etc., which should be filled in as the conditions apply. The back of the cover sheet may include data table to be used in lab. These should be completed following the lab leader's instructions.

2. **RAW DATA**
Any raw data recorded during the course of the lab must be included. The data should be taken in the provided tables or blank lines.

3. **CALCULATIONS**
If the path from the raw data to the conclusions is not absolutely clear, then any relevant calculations must be shown.

4. **RESULTS AND CONCLUSIONS**
The results are most often in the form of a table or chart and the conclusion should be one or two sentences stating what you learned.

5. **QUESTIONS**
The TA may assign an indoor lab activity involving questions that should be answered and turned in.

Once completed, the lab report should be stapled and turned in to the box outside of the astronomy club room (549 Physics/Geo)

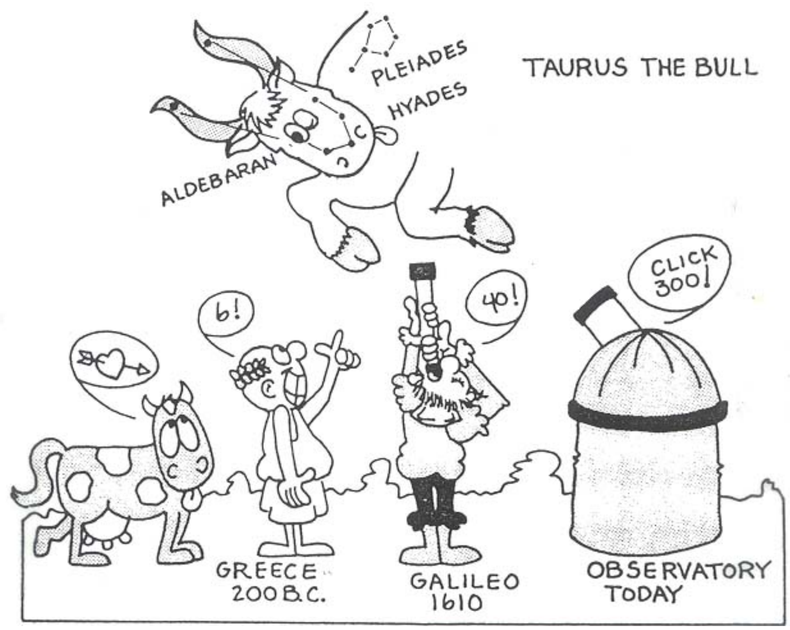
Notes

The Spring Quarter AST 25 lab sections start in 55 Roessler at 9:10 p.m. with a presentation and discussion with the lab leader, plus perhaps data sheet preparation. Based on what we will be doing that evening and the weather conditions, the lab group moves to the roof or 5th floor of the Physics/Geo building or Roessler 158 somewhere around 10 p.m.

You must come to the pre-lab lecture to know when and where we will be for the actual lab! Any observations and written reports should be completed by the end of lab.

It is important that each week you **bring your lab manual**. We will be using some of the stars charts at the end, as well as other maps therein. We may not complete an exercise one week, but rather on a different week, to take advantage of what is happening on the sky. Thus, we will attempt to make lunar and stellar spectra observations when the Moon is up and will be studying “deep sky” (dim fuzzy) objects, such as galaxies and nebulae, when there is no Moon and the sky is dark.

Have fun, stay warm, and hope for clear skies!



STAR NAMES, MAPS, AND CONSTELLATIONS

Except for the last 400 years, all observations of the “universe” were done by naked eye. Surprisingly, there is a great deal that can be learned by simply “stargazing.” In fact, until you’ve become visually familiar with the sky, a telescope will not be of much use, as you won’t know where to point it.

The first stage of any exploration is making a map. The science of mapping is called **cosmography**, where the Greek root word cosmos refers to describing the order and harmony of the universe. The focus of this chapter is to learn about maps of the celestial sphere, how we identify and name stars, and how to find them in the sky.

ASTERISMS & CONSTELLATIONS

On a dark clear night, the sky seems to be random jumble of stars. One of the most basic human traits, however, is to make order out of chaos. We look for patterns. The analytic will see symbolic or geometric grouping (e.g. looks like a “W” or a triangle), the poetic will see epic heroes. These “groupings” of stars are called asterisms. Many are “natural” as evidenced by divergent cultures having many of the same stars grouped together (in some cases, even with similar interpretations).

Historical

The first recorded names for asterisms come from the Babylonians about 3000 BCE. There were originally just four “signs”, associated with the position of the sun for the four seasons: **Taurus** the Bull (spring), **Leo** the Lion (summer), **Scorpius** the Scorpion (fall), and **Aquarius** the Water Bearer (winter). Early man’s agrarian culture was motivated to map the heavens to have a good calendar to know when to plant. Egyptians borrowed the names from Babylonians, with the analogous motivation being to predict the annual flooding of the Nile.

The Greeks (being nomadic shepherds up at night watching the flock) greatly added to the number of asterisms, intertwined with mythological (and spiritual) interpretations, often overlapping. The remaining asterisms (mostly southern sky and some faint ones between major asterisms) were added in the 17th and 18th centuries.

Mythology

Writing, the physical symbolizing of ideas, is a relatively recent invention. Previous to 3000 years ago, most ideas were passed from generation to generation by verbal stories. This is probably the origin of the Greeks’ mapping of the sky via mythological themes. You’ll find nearly all the characters of a mythological legend closely related in their positions in the sky. Indeed, if you know the stories, it becomes easy to remember the meaning and positions of many of the asterisms. As an example, let’s review the “Orion Story’.

Orion, the great hunter, roamed the earth with his two companions, the Big and Little Dogs (**Canis Major** and **Canis Minor**). His egotism offended the goddess Juno, so one day while he was hunting a rabbit (Lepus the Hare) she sent scorpion (**Scorpius**) after him. Orion was stung on the heel and died.

The famous physician **Aesculapius** managed to bring Orion back to life. Also known as **Ophiuchus**, or the "serpent bearer", Aesculapius[1] got his medical secrets from snakes, hence he carries one around with him in the sky (Constellation Serpens). Now the King of the dead (Pluto or Hades) didn't like mere mortals stealing souls back from his underworld kingdom, so he had his brother Jupiter (Zeus) throw a thunderbolt and kill Orion for good.

All the figures of the story were put into the sky by the gods. **Scorpius** is in the summer (evening) sky, with a guard on it in the form of the Archer, **Sagittarius**, just to the East. **Ophiuchus** is just above Scorpius, with his snake around him (in two parts, **Serpens Caput** = head of snake, **Serpens Cauda** = tail of snake). To keep **Orion** safe from Scorpius, he was put in the opposite side of the sky (the winter evening sky). The hare **Lepus** he was hunting is just below him, while his two dogs (**Canis Major** and **Canis Minor**) are to the East.

<u>Division of the Sky into Constellations</u>

A **constellation** contains one or more asterisms (star groups) plus the surrounding region of the dark sky. Much the way that the United States is divided into 50 states, the sky is divided into 88 such constellations (i.e. regions). Each star technically belongs to just one constellation (although traditionally some stars are "shared' by overlapping mythological pictures).

The first really accurate map, the "**Almagest**", which had about 1022 stars grouped into 48 constellations, was drawn by the Greek astronomer Claudius **Ptolemy** (150 CE). It was more than 1500 years before more constellations were "added' to the sky. The German Astronomer Johann **Bayer** (1572-1625) in his famous star chart of 1603, "**Uranometria**", defined 12 more constellations, mostly in southern sky (Apus, Chamaeleon, Hydrus, Musca, Phoenix, Volans, and Triangulum Australis). Three faint constellations in between the major Greek ones were added in 1624 by German Astronomer Jakob Bartsch (Camelopardalis). The German astronomer Johannes Hevelius (noted for mapping of the moon) added 7 more around 1687 (Lynx, Scutum & Lacerta). The French astronomer Nicolas Louis de **Lacaille** was noted for mapping the southern sky and adding 14 southern constellations (Circinus, Caelum, Fornax, Horologium, Mensa, Octans, & Pyxis) in the years 1751-3. The remaining few were named by various astronomers, along with some subdivisions into smaller groups (Ptolemy's Argo Navis, the Argonaut's ship, into Carina the keel, Puppis the stern, Pyxis the compass and Vela the sail).

The final definitions were set by the **IAU** (International Astronomical Union) in a conference in 1930, bringing the total to 88 constellations. Boundary lines were drawn in a zig-zag fashion (to fit the "pictures") along North-South and East-West lines for the year of 1875. Since that time precession has skewed the lines somewhat so that they no longer are aligned NS or EW. The constellations and their standard 3-letter abbreviations are listed in Appendix 1.

The most important constellations for inhabitants of our solar system to learn to recognize are those along the plane of the **Ecliptic**, the so-called circle of the **Zodiac**. These are discussed in the EA (Ecliptic and Annual Motion) lab. Table EA-II on page EA-3 shows that the sun is in Virgo in late September, and therefore the next 6-7 Zodiacal constellations (Libra, Scorpius/Ophiuchus, Sagittarius; Capricornus, Aquarius, Pisces; Aries) will be visible in the sky soon after sunset at the beginning of Fall quarter. Half a

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[1] Aesculapius, Greek god of medicine, can be traced back to the first recorded man of science, the Egyptian physician and architect Imhotep (2900 BCE). This makes it the only constellation representing a real historical person.

year later, in early April, the sun is in Pisces and thus Aries, Taurus, Gemini; Cancer, Leo, Virgo; and Libra will be in the evening sky at the beginning of Spring quarter for AST 25.

STAR NAMES[2]

To identify a certain star, we need some sort of naming system. Since there are a variety of methods employed, it can be rather confusing. It is probably best to summarize them by their chronology.

Ancient Names

Most of the bright stars have individual names. Their names are often related to their part of the "picture." For example, the star **Alhena** in Gemini means "mark", pertaining to a mark on the foot of Gemini twin Pollux. Another example is **Deneb**, which means "tail." Hence **Denebola** is "tail of the Lion" (Leo), **Deneb Algedi** is "tail of the seat goat" (Capricornus), and **Denebokab** is "Tail of the Eagle" (Aquila).

Some names seem to have nothing to do with the constellation. For example, in Cancer (the Crab), the star **Asellus Borealis** means the "Northern Ass" (i.e. donkey). Obviously, this doesn't have anything to do with a crab; it's an alternative (and possibly older) interpretation of the constellation. Oftentimes the name of the star is Arabic, which will have to do then with an Arabic interpretation of the constellation.[3] In fact you'll note that the majority of star names are Arabic in origin. Further a disproportionate number (almost a fourth) being with the letter "A."

Bayer-Lacaille Notation

The first star catalog of **Hipparchus** listed over 1026 stars, designating them by their relative brightness within each constellation (e.g. Leo's brightest star is Regulus) since it was (and is) impractical to use names for the dimmer stars. The method invented by Bayer in 1601 (and still used in visual star maps) designates a star in a constellation by a lowercase Greek letter (see Appendix 2), followed by the genitive form of constellation (see Appendix 1). In general, the letters are assigned in order of brightness beginning with Alpha = α. For example, **Alpha Centauri** (abbreviated α Cen) is the brightest star in the constellation Centaurus, while **Beta Centauri** or "β Cen" is the second brightest. However, in some cases (Ursa Major), Bayer named the stars not in order of brightness, but in order of their relative locations. On some occasions, the star you see in the sky is really a multiple star. When that occurs, an additional suffix is added to the name to denote which star of the multiple is being 'singled out'. This suffix also goes in order of brightness and is given by the Roman capital letters. For example, a-Centauri A is brighter than a-Centauri B, which is in turn a brighter than a-Centauri C, in this imaginary triple star.

What happens when you have more than 24 stars in the constellation? You run out of Greek letters! The astronomer **Lacaille** extended Bayer's notation by using lower case (and some upper case) Latin letters. Although some of Lacaille's notation is still used, mostly you'll see Flamsteed's number notation.

Flamsteed Number Notation

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[2] There has been a recent "scam on star names. Several companies have been "claiming" to officially name (faint) stars after people for a fee. The only official organization to grant star names is the International Astronomical Union.
[Reference: "Tarnished Stars", Sky and Telescope, p. 317 (1985).]

[3] The stars Asellus Australis and Asellus Borealis are the asses ridden by Bacchus and Silenus in their battle with the Titans. The Praesepe of Cancer is then interpreted to be the manger for the asses.

The first Royal Astronomer of England, John **Flamsteed** (1646-1719) published a famous star catalog using his number notation. Starting from the West end of a constellation, he numbered the visible (naked-eye) stars in order of increasing Right Ascension (celestial longitude). For example, **Vega**, the brightest star in **Lyra** the Harp, is denoted **Alpha Lyrae** (α Lyr) in the Bayer notation, or 3 Lyr in the Flamsteed notation. Most modern charts will use the Bayer notation as far as it goes, and then convert to the Flamsteed notation for stars that don't have Greek letters. A few stars that Flamsteed missed will have Lacaille letters.

Some of the stars have notations that seem inconsistent. For example, there is no Gamma Aurigae. The reason is that this star (common name **El Nath**) is shared by **Taurus** and **Auriga**, so Bayer double denoted it as Gamma Aurigae and <u>also</u> as Beta Tauri. The IAU conference of 1930 defined the constellation boundaries such that each star can only belong to one constellation. This star now belongs to Taurus, so there is no longer any Gamma Aurigae. Similar inconsistencies can be found in the Flamsteed numbers.

STAR BRIGHTNESS & MAGNITUDES

Stars are not all the same brightness. The Greek astronomer **Hipparchus** (160-127 BCE) invented the scheme of classifying stars by their brightness where the <u>brightest were first magnitude</u>, the next brightest second magnitude, and the <u>faintest stars were sixth magnitude</u>.

Modern measurements found some stars (e.g. Sirius Altair to be even brighter than first magnitude, so numbers, "less" than 1 have to be used. For example, Vega has a magnitude of 0, meaning it is brighter than a first magnitude star. Sirius, with a -1.5 magnitude, is the brightest star, even brighter than Vega. The moon on this scale is -12.5, the sun -26.8 (see Table SC-VI). Polaris was originally defined to be m=+2, but was later found to be a variable. The magnitude scale was then redefined by a group of northern stars called the "North Polar Sequence."

Herschel showed that the eye does not respond to brightness linearly, i.e. it does not perceive an object twice as bright to be twice as bright. Instead, an object which is 100 times brighter is perceived to be only 5 magnitudes brighter. This has resulted in modern definitions of magnitudes based on a logarithmic scale but corresponding closely to the older magnitudes.

TABLE SC-VI
Apparent Magnitudes of Various Objects

Object Name	**Apparent Magnitude**
Sun	-26.8
Moon	-12.6
Venus	-4.4
Jupiter	-2.4
Sirius	-1.46
Vega	+0.04
Mars	+0.8
Spica (α Vir)	+0.97
Regulus	+1.35
Polaris	+2.02
Zavijava (β Vir)	+3.61
Porrima (γ Vir)	+3.68
Zaniah (η Vir)	+3.98
16 Vir	+4.96
Uranus	+6 (Visual Limit)
Pluto	+15
Kitt Peak Limit	+24.5
Space Tel. Limit	+30

<u>Magnitude Ranges</u>

With telescopes (or cameras) we can see fainter objects due to the light amplification. The practical limit right now is about m=+30, or about 10 billion times fainter than the eye can see. The magnitudes of various common objects are listed in table SC-VI.

There are only 2 stars of magnitude -1, only 5 of m=0, and approximately 20 of m=+1. There are many more stars that are fainter: 65 of m=+2, approximately 200 of m=+3, and 500 of m=+4. The numbers increase or very faint stars, 1,400 for m=+5, more than 5000 for m=+6 and 20,000 for m=+7. The brightness of stars will be represented on maps by the sizes of the dots, like on your star chart. This includes most computer-drawn maps, such as those at the end of this manual. Note that most maps are "negatives", where dark dots represent stars, on a white background.

Note that the eye can see over a tremendous range of about 30 magnitudes from faint star to sunlight; a factor of a trillion times as much light! No man-made instrument can do this (e.g. camera). A good example is viewing Jupiter and its four major moons. The eye can see all, but a camera on short exposure to get a good picture of the planet will not record the moons. Using a longer exposure to get the moons to show up, the planet will be over-exposed ('burnt out").

Limiting Magnitude

The assumed limit of the eye is m=+6. However, for the fainter stars (m=4, 5, 6) "averted" vision must be used. This is because the center of the eye's retina (called the fovea) does not respond to lower light levels. The retina of the eye has two type of receptors, cones (color vision) and rods (night & black & white vision). The cones are concentrated mostly in the center of our field of vision (e.g. the fovea), but don't work well in faint light below 3rd magnitude. The rods work down to 6th magnitude (some eyes can go down to m=+7), but nature has placed them near the edge of our visual field, with nearly none in the fovea. To see a faint star, look slightly above or below (which then uses the rods of your eye).

One confusing point is that a constellation won't look the same under different sky conditions. For example, on a dark clear night in a small town, the constellation Gemini would appear with 4th magnitude stars easily visible. If you were surrounded by more light (street lights, or the moon up in the sky) you might only see down to 3rd magnitude. With a full moon, you might only see first or second magnitudes, making the constellation virtually unrecognizable. You must practice seeing it in all its forms, as sky conditions are seldom ideal. How you visualize the "lines" is up to you.

STAR MAPS

See the end of the manual for a discussion of star maps and **coordinates**, and a useful complete set of amps (including all stars down to 4th magnitude, and others, and other objects of interest) drawn on computer by Dr. William M. Pezzaglia, Jr. You should compare these with other you have including Chandler's or an equivalent circular chart ("star wheel") showing all stars visible from our latitude at any time of the year.

Be aware that these maps are normally oriented **North up (South down)**, as are most road maps. Star charts like these show the correct orientation if you are standing facing the Southern horizon or lying on your back facing up with your feet to the South. In either of these situations **East is to the left and West is to the right**, which is the **opposite** of the orientation of road maps!

INTRODUCTION TO TELESCOPES

Most of the objects astronomers wish to study are very far away in space and time. So much so, that they are quite faint and so small, no detail can be seen with the naked eye. Telescopes are optical instruments designed to magnify these objects to see finer detail and to amplify the light so that faint objects can be seen.

OPTICS

Optics is the science of using lenses and mirrors to manipulate light. Two common optical instruments are the telescope and microscope.

Angular Size

To study an object, you usually get as close as possible. The reason is that the closer the object is, the bigger its image on the retina of the eye. The fine details are spread over more neural receptors, increasing your ability to distinguish. The apparent size of the object is called **angular size**, e.g. the angles of 15˚ and 30˚ in figures 1a and 1b respectively:

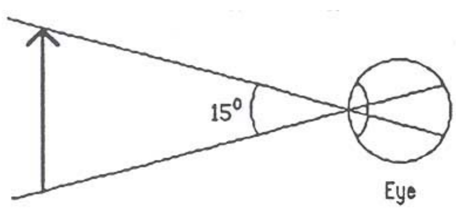

Figure 1a Distant Object Small Image

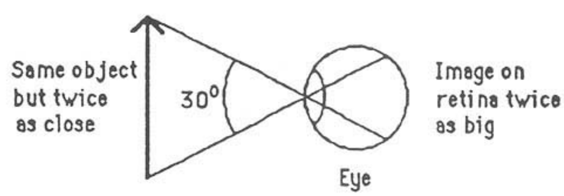

Figure 1b Close Object, Bigger Image

The smallest detail the eye can see, called the **visual acuity**, is about 2' (varies with individuals, anywhere from 1' to 3'), where 1' = 1 arcmin = 1/60 degree. Unfortunately, the apparent angular size of most astronomical objects is quite a bit smaller since they are so far away. For example, the only planet close to this size is Venus at inferior conjunction (1').

Lenses and Mirrors

Telescopes employ lenses and mirrors to make a magnified image of the distant object appear in the observatory, close at hand for study (figure 1c):

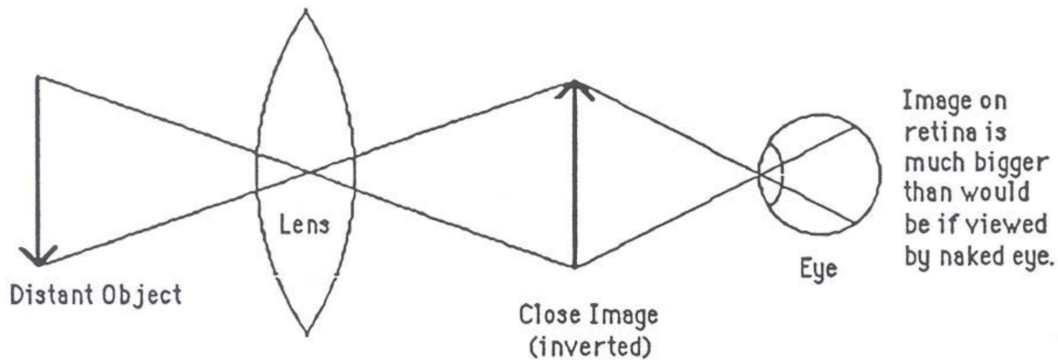

Figure 1c Lens used to construct a close image of a distant object

A (convex) converging lens (figure 2a) is a curved piece of glass such that light from a star "o" is refocused to make an image "i." The common example is a slide projector, where "o" is an illuminated slide and "i" is the image on the screen.

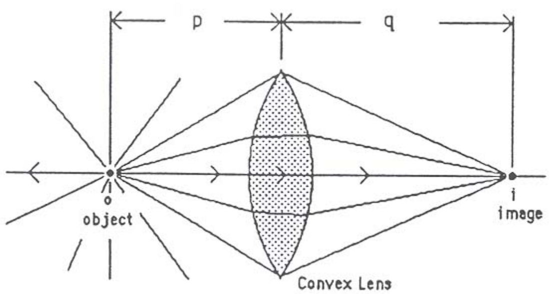

Figure 2a Convex (Converging) Lens

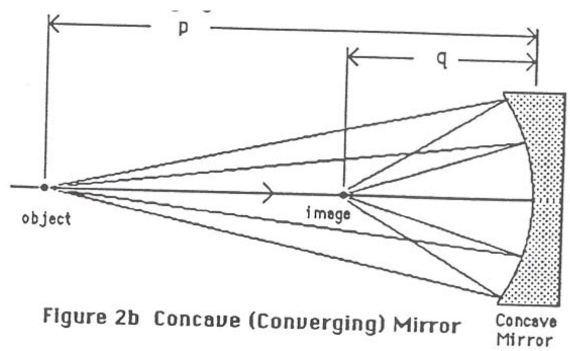

Figure 2b Concave (Converging) Mirror

A (concave) curved mirror has similar behavior (figure 2b). The image is "real" for a convex lens or concave mirror in that if you put a screen at that position, a sharp "picture" of the object would appear and could be captured on film.

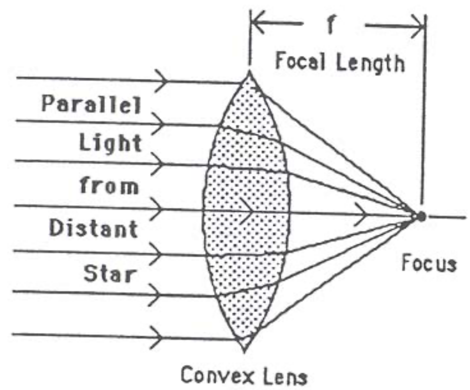

Figure 3 Focal Length of a Lens

Focal Length

If the object is infinitely far away (e.g. a star), then an image will appear at the "focus" of the lens or mirror. The distance to the position of the focus is called the **focal length** "f" (as in figure 3). The focal length of a lens or mirror depends on the curvature of the lens/mirror surface; more highly curved surfaces will have shorter focal lengths.

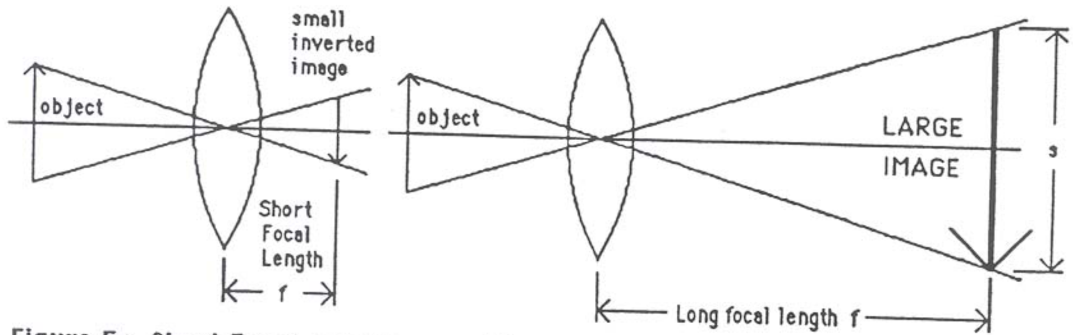

Figure 5a Short Focal Length Figure 5b Long Focal Length

Primary Image

The image will be inverted (i.e. upside down) as in figure 5. The size of the image is determined by the angular size of the object and the focal length. If the focal length is larger, the image will be proportionally larger (figures 5a & 5b). For this reason (and others[4]), focal lengths are often quite large (on the order of several feet).

Eyepieces

Astronomical objects, due to their great distances, are VERY small in apparent angular size (for example, Neptune at its closest is only 2'', i.e. 60 times smaller than the naked eye limit of 2'). Even with a long focal length objective, the prime focus image will often be too small to see any detail (or even too small for the "grain" of film).

An eyepiece (formally known as an ocular) is used like a magnifying glass to make the image appear bigger. The total magnifying power of the telescope depends upon the focal length of both the eyepiece and objective. To get high magnification, you want a long objective focal length and/or a short eyepiece focal length. The magnification will be changed by using a different eyepiece.

The acuity of the eye still limits the smallest detail it can see in the virtual image created by the eyepiece. If, for example, the eyepiece yields a net magnification of 100, the smallest detail you can see with that eyepiece is 100 times smaller than you could with the naked eye, i.e. 2'/100 = 0.02' = 1.2'', enough to barely resolve Neptune into a disk.

Although it might now appear that you could just keep on magnifying to see smaller and smaller detail (e.g. look for houses on Mars), there are optical limits. The most obvious limitation is due to the fluctuations in Earth's atmosphere bending light rather randomly. This is most readily apparent as the "heat waves" when using binoculars to look over a hot field in the summertime. We will also see it here on nights when the air high overhead is clear but turbulent; astronomers refer to this as bad "seeing." A more fundamental limitation (the diffraction limit) is due to the wave nature of light.

LIGHT GATHERING vs. MAGNIFICATION

You know you're talking to a novice if the first thing they ask about is the "magnification" of the telescope. The single number an astronomer finds most impressive is the effective diameter of the lens or mirror objective (e.g. the 36-inch Lick, or 200-inch Hale, or 10-meter Keck). This is formally called the **aperture** in optics, and is the most important parameter, as it determines the faintest stellar object (usually the most distant)

[4] Long focal lengths also have less spherical aberration and, in the case of lenses, less chromatic aberration.

that can be seen. It's the same reason your eye's pupil dilates under dim light conditions: to let in more light.

Light Gathering Power

The main purpose of a telescope is to gather more light than they eye can, i.e. to amplify the light. The amount of light that a mirror/lens collects is called the **light gathering power** and is *proportional to the **area** of the mirror/lens, which is proportional to the square of the aperture (diameter)*.

Limiting Magnitudes

The faintest magnitude star that can be seen with a telescope depends on its aperture. While the naked eye has a limiting magnitude of approximately +6, a 6-meter telescope would push the eye's limit to +21.

Photographic limiting magnitude is greater than visual limiting magnitude since film can be used for time exposures. Compared to the logarithmic response of the eye, film is more linear in its response to intensity of light. However, there is a threshold intensity below which film will not respond regardless of exposure time. Similarly, the limiting magnitude is greater for CCDs (charge coupled devices) used to detect light for electronic imaging.

Focal Ratio (f/stop)

The above arguments are only strictly true for point objects such as stars, which are so far away that they are still points no matter how much they are magnified. For extended objects such as planets, galaxies, or nebulae, the focal length of the objective is also important. Consider observing an object using two telescopes with the same aperture but different focal lengths. The telescope with the longer focal length will magnify the image more, thus "spreading out" the same amount of light and creating a fainter image.

The ratio of focal length to aperture is called the **focal ratio**, **f/stop**, or **f-number** of the objective lens/mirror (as it is for a camera lens). The lower focal ratio, the brighter the image and the **faster** the system (i.e. shorter exposure times can be used). Hence, for nebulae and galaxies, a short focal length (along with large aperture) is desired.

Further magnification by an eyepiece makes the image even fainter. Hence, you would want low magnification (long eyepiece focal length) to view a nebula or galaxy. However, if two telescopes have the same magnification, the aperture determines which has a brighter image.

FIELD OF VIEW

When you look through the eyepiece, you are seeing only a very small part of the sky called the "field." This is the circular area that you observe in the center of the eyepiece that contains the star field, **not** the completely dark region that surrounds the field.

TELESCOPE DESIGN

Telescopes come in many forms, shapes, and sizes. Here we shall review the two major types: **refractors** (which have lens objectives) and **reflectors** (which have mirror objectives).

Refractors

The earliest types of telescopes[5] were made entirely of lenses. However, lenses have trouble with **chromatic aberrations**.

Chromatic Aberrations: Recall that in a prism, each color is bent at slightly different angles (red the least, violet the most). This phenomenon is called "dispersion" and is due to the fact that different colors travel at different speeds in glass (or almost any other material).

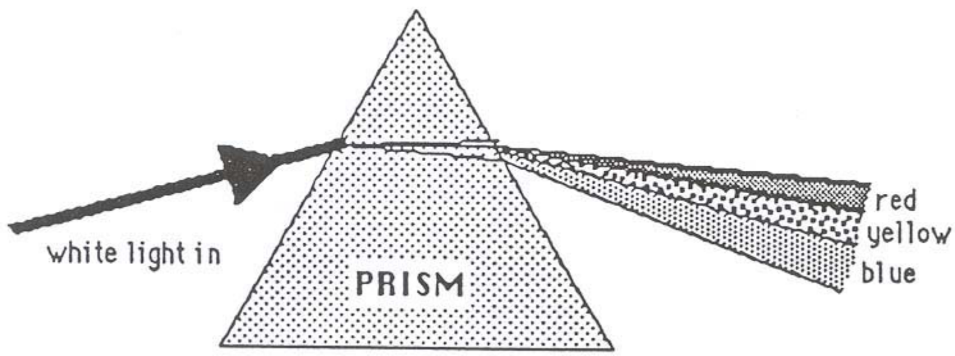

Figure 7 Dispersion in a Prism

Thus, different colors will have slightly different focal lengths, with red the longest. Hence, a well-focused color image cannot be made (e.g. Jupiter might have a purple haze around it). This is a problem in cameras, eyepieces, and the objectives of refractors. The problem is worse for short focal lengths, so long focal lengths (long focal ratios) are used in refractors. (This is at the cost of fainter images; hence the reason nebulae and galaxies were not observed by early telescopes.)

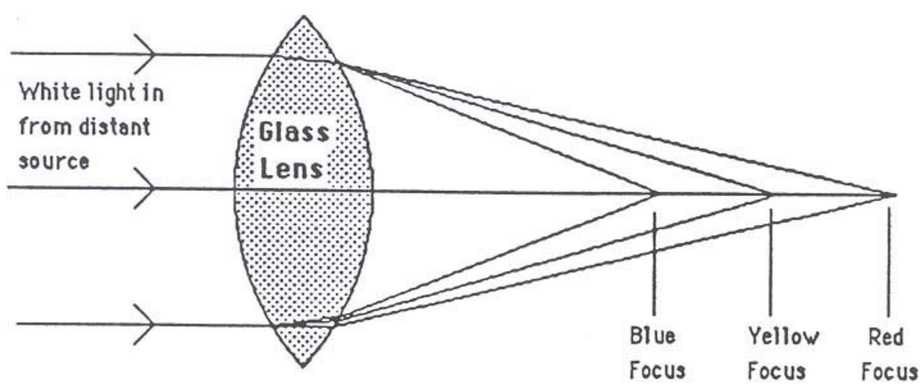

Figure 8 Chromatic Aberration (Exaggerated)

One solution is to insert color filters (e.g. red, yellow, blue) to eliminate all but one color. A color composite can then be constructed from three different images (red, yellow, blue).

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[5] The first telescope was accidentally invented by Hans Lippershey, an eyeglass apprentice. One day he was "fooling around", looking through two lenses at once, and saw the distant church steeple greatly magnified (and inverted). Galileo read about this discovery shortly afterwards and made the first practical use of a telescope for astronomy.

Achromatic Lens: Special compound lenses can be made[6] that eliminate much of the aberration. A converging lens of one type of glass is joined with a diverging lens of a different type of glass. The dispersions of the two lenses cancel out for a wide range of colors. However, it is usually only good over a restricted range (e.g. red through green).

The focal length of an achromatic lens will be quite long (due to the diverging lens part). For example, the Lick 36-inch (i.e. a lens 3 feet in diameter!) has a focal length of about 57 feet. To see objects low in the sky, the astronomer must sit on a high ladder. For objects at zenith (overhead), the floor must be lowered 17 feet.

Advantages/Disadvantages: Due to the large focal length, the focal ratio of a (achromatic) lens will, of course, be quite long. The Lick 36" has a ratio of 19 (compared to reflectors, which are usually less than 10). This is a real problem because a short focal ratio is needed to observe faint nebulae and galaxies (extended objects).

Another problem is the physical size. To see distant galaxies, we want apertures 5 times larger than the lick 36." This would also make the focal length longer, on the order of 300 feet. This creates practical engineering problems, as the telescope is usually supported from a single axis in the center. Also, the lens weight goes up by the cube of the aperture, 125 times more mass, which can only be supported by the thin rim. The lens would crack under its own weight. Further, the thickness becomes a problem, since more and more light would be absorbed in the lens itself.

So why would anyone want to bother with refractors? There are several advantages. First, the generally have a darker field and better definition than a reflector (which has secondary mirrors in the light path, a "central obscuration" which scatters/diffracts light). Hence, refractors are better for resolving double stars and planetary features (which are usually so bright that the long focal ratio is not a problem). They also have a more stable image as they are less sensitive to thermal shock and internal air currents in the tube.

Reflectors

James Gregory (1663) first described the principle of a reflecting telescope using a mirror instead of a lens objective. Curved mirrors have similar optical properties to lenses (see figure 2b), creating an image at the focus. Early mirrors (e.g. Herschel's 48-inch in 1789) were made of metal (e.g. silver), which unfortunately bent easily and tarnished. The process of aluminizing a curved piece of glass around 1880 produced a usable mirror.

Advantages: Mirrors have no chromatic aberrations, so the focal ratios could be made much shorter. The Crossley 36-inch reflector (donated to Lick Observatory around 1895) demonstrated the advantage of reflectors. The short focal ratio allowed for stunning photographs of nebulae and galaxies. Furthermore, mirrors can be supported from the back, so apertures 5 times that of lenses could be constructed. The largest in the world (in Russia) has a 6-meter aperture. The Keck telescope in Hawaii, with 36 separate hexagonal mirrors, has an effective aperture of 10 meters.

Optical Problems: The major problem of a reflector is that the image forms inside the telescope. The photographic plate, or observer, must be inside the telescope, which will block some of the incoming light. Small apertures (under 3 feet) would seem to be physically impossible, since the plate or observer would block all the light.

Newtonian Focus: The trick invented by Newton was to insert a secondary flat mirror, which deflects the light diagonally out the side of the telescope. This configuration is the most common in small telescopes. In any case, the internal observer or photographic plate or diagonal mirror must be supported. The internal parts and their

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[6] First done by Joseph Fraunhofer around 1812.

supports cause diffraction patterns. These appear as “crosses” on the plates, evident on bright stars.

Cassegrain Focus: In this case, a diverging secondary mirror reflects the light back down through a hole in the center of the objective mirror. The viewing instrument (or eyepiece) is contained behind the mirror. You want the mirror size to be small to block the least amount of incoming light (and cause the least amount of diffraction. Hence, it is placed as far away from the objective as feasible. To get the focus behind the objective mirror, the secondary must be diverging, increasing the overall focal length and giving a fainter image.

LAB PROCEDURE

The basic theme of the lab activity is to get you started on using the telescope. As the number of telescopes is limited, you will most likely have to work in groups. There is, unfortunately, a tendency for the most spirited individual to do all the work while the rest simply look through the telescope. **Make sure that you each practice pointing the telescope**: after one person "sights" the object, you should turn the scope away and have the next person sight the same object, then all of you view it and verity that it's the "same one." Remember, you will each be tested **individually** on your skill with the telescope at the end of the quarter.

A written report may be required for this lab exercise. If a report is not required, then a quiz will be given on the discussion material. In the event of cloudy weather, the telescopes will still be set up, but other targets will be used (streetlights, photographs, or projected star fields). In the event of rain, the telescopes may be set up inside, pointed down long hallways with hand-drawn star fields at the other end.

OUTDOOR ACTIVITIES

Before you start the observations, see if you can identify the following parts on the telescope based on the brief introduction from the roof helper: Where/what is the…

Focus knob?	Finder scope?	Aperture?
Declination scale?	Hour angle scale?	Primary mirror?

Place where you insert the eyepieces?

Also, can you name the kind of telescope this is? What kind of mount does the telescope have?

A. MAGNIFICATION OBSERVATION

The finder scopes of each telescope should be properly calibrated/aligned. If it isn't, call a roof helper or TA to align it. To avoid damage to tubes/bolts, ***STUDENTS SHOULD NOT ATTEMPT TO ALIGN FINDER SCOPES***.

Choose an Object: Start with a large but distant object (i.e. a water tower, an illuminated window in a distant building, etc.). Make sure that it is unambiguous (e.g. a window in a building which has many identical windows would be a poor choice; how would you know you were on the right one?). It has to be an "extended" object if you want to observe the effects of magnification. (DO NOT use a point object such as a star, or even a planet, which to the eye looks like a dot. You need SIZE!).

Sighting the Object in Finder scope: DO NOT USE THE FINDER SCOPE OR EYEPIECE AS A HANDLE. Move the telescope tube by grasping the whole tube. Most scopes can be grasped by the end of the tube. HOWEVER, if the telescope has a glass plate at the end, you should NOT grab anywhere near it as you will inadvertently leave fingerprints.

There are two methods you can use to point the telescope at the desired object. Use whichever works for you.

The **one-eye method** involves closing one eye and using the other to sight the telescope like a gun. This is best done by getting behind the mirror and sighting along the tube. For objects overhead, you may be lying on your back on the ground. Then you look through the finder scope and center the object in the crosshairs.

The **two-eye method** will work only if your finder scope is a straight-through finder scope. (Some telescopes have a diagonal eyepiece in the finder scope which will prevent this method from being used.) Look through the finder scope with one eye, and directly at the object with the other. You move the telescope until the two images overlap in your brain. Note one image will be inverted and magnified compared to the other. This process is difficult for some individuals who have left or right eye perception dominance (rather common). Note that a variation of this method is the quickest way to calibrate the finder scope.

<u>Observation</u>

Once you have your object in the field of view of the finder scope, center it (using the crosshairs if you can see them).

Is the image inverted or right-side up? Does the image appear magnified when compared with how it looks with your naked eye? Does it appear brighter than when you observe the object with the naked eye?

Now look at the object through the telescope with the larger focal length (the number in mm written on the eyepiece) eyepiece in place. It should appear magnified.

Is the image dimmer than when you observed it with either your naked eye or with the finder scope? Is the image inverted or right-side up? Compare the field of view between the finder scope and the telescope. Which 'sees' a larger field of view (a larger portion of the object you are looking at)?

Repeat the above observations with the smaller focal length eyepiece and compare its field of view to that of the larger focal length eyepiece.

You should have noted that with each successively smaller focal length eyepiece, the magnification increased, the image became dimmer, and the field of view became smaller. *All* the images should have been inverted!

B. <u>LIGHT GATHERING</u>

The primary purpose of a telescope is to collect more light so you can see fainter objects. We actually explored this a bit in the previous section, but now we can use an actual telescope.

First, point your telescope to a relatively dim star, say magnitude +4 or +5. If the moon is up or some other condition makes it very difficult to visually find stars at those magnitudes, you may use a +3 star instead. After you center the star in the finder scope so that you can see it in the telescope's larger focal length eyepiece, compare your observations between the eye, the finder scope, and the telescope with various eyepieces.

Notice:

1. The star will **not** be magnified (from Earth, they always appear as points because they are so far away). This should appear true whether you are comparing the eye observations to that of the finder scope or of the telescope.
2. The star will appear brighter in the finder scope than with the eye alone. Reason: The aperture, or opening, of the finder scope is about 5 times wider than your eye's dilated pupil.
3. Through the telescope (with the larger focal length eyepiece), the same star will appear brighter still. In fact, the increase in brightness is roughly the same between the finder scope and telescope as it was between the finder scope and your eye. This is because the telescope aperture is about 5 times wider than that of the finder scope.
4. When you increase the magnification of the telescope (by changing the eyepiece from the larger to smaller focal length), you will not see any change in the brightness of the star. Why? (This is a good practical exam question.) The reason is related to the fact that the star continues to appear as a point object, no matter what the magnification. Its brightness is only determined by the amount of light that is gathered, not on the amount of "spread" of the image. Therefore, the only

way to make it brighter is to increase the size of the aperture. No effect on brightness occurs if you hold the aperture fixed and change the magnification.

Aperture Stops

We can look at the effect of changes in aperture on the light gathering power directly by making use of aperture "stops." For stops, just use your hands or a notebook, etc. to block out **some** of the light entering the telescope as another person is looking through the telescope.

Things to note: Does the image get fainter?
Does the field of view change size?
Does the magnification change?
Does the resolution change? (i.e. sharper image?)
Does the aperture stop's position matter? (i.e. centered vs. off-center)

C. RESOLVING POWER AND FIELD

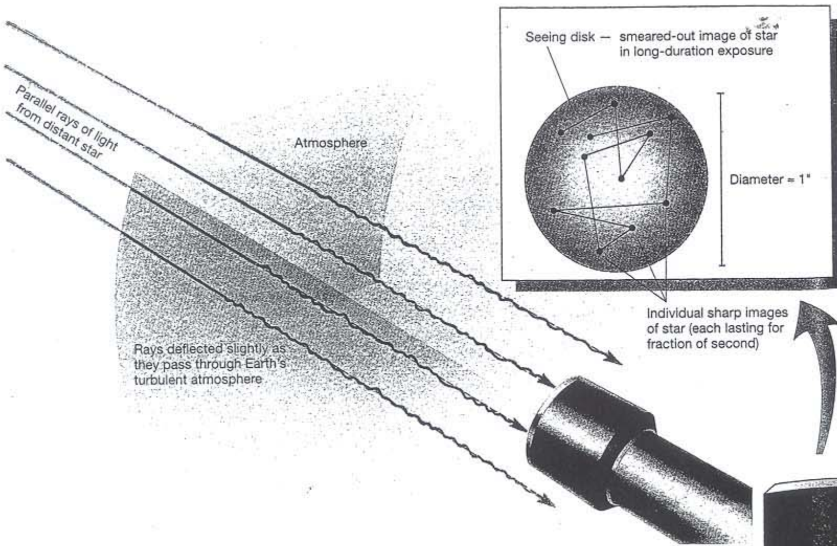
In this last section we will explore the resolving power of the telescope. This is the telescope's ability to separate two closely spaced objects or distinguish detail. To demonstrate this, we will look at some multiple stars, or starts that are in close proximity to each other. Increased aperture size will allow us to see finer detail (refer back to limiting visual resolution).

It is best to use a double star of known separation as an object. Some good doubles are:

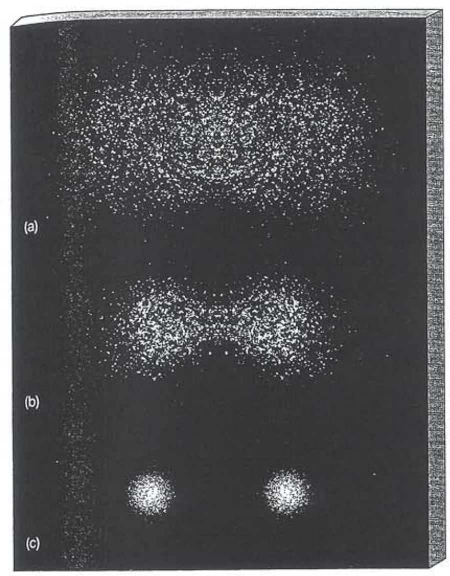
Fall: Albireo (β Cyg = beta Cygni) or ε Lyr = epsilon Lyrae
Winter: Almach (γ And = gamma Andromedae) or ι Cnc = iota Cancri
Spring & Summer: Alcor & Mizar or Mizar AB of Ursa Major

After you have completed the above activities, and if there is still time left, you may want to look at a few other double stars (examples are listed in a table at the end of the Lab or given as a handout). Their colors stand out better in the telescopes and some are quite beautiful.

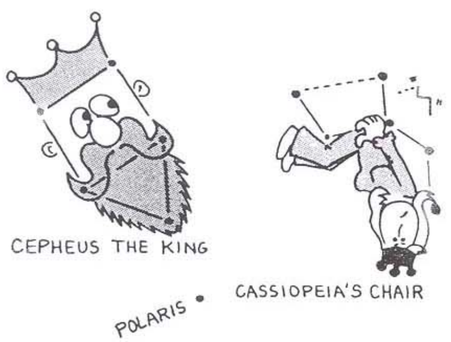
Maybe you could practice your two-eye method (or one-eye method if you are unable to do the two-eye) on some of the brighter stars or planets. A little practice now can make your life easier later. Also, you may want to go over the stars and constellations you learned last week (and add to the number you know). Remember, it is easier to learn a little bit at a time than to try to cram all this stuff at the end of the quarter (a near impossibility!).

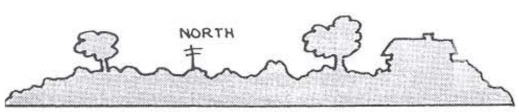


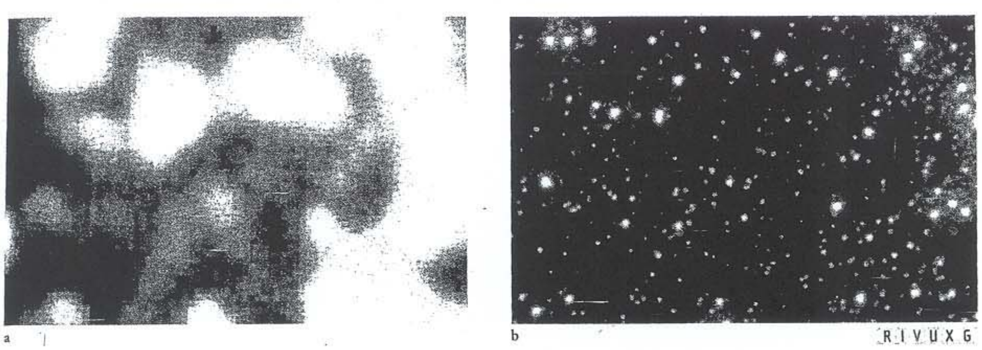
Atmospheric Turbulence Photons from a distant star strike the detector in a telescope at slightly different locations because of turbulence in Earth's atmosphere. Over time, the individual photons cover a roughly circular region on the detector, and even the pointlike image of a star is recorded as a small disk, called the seeing disk.



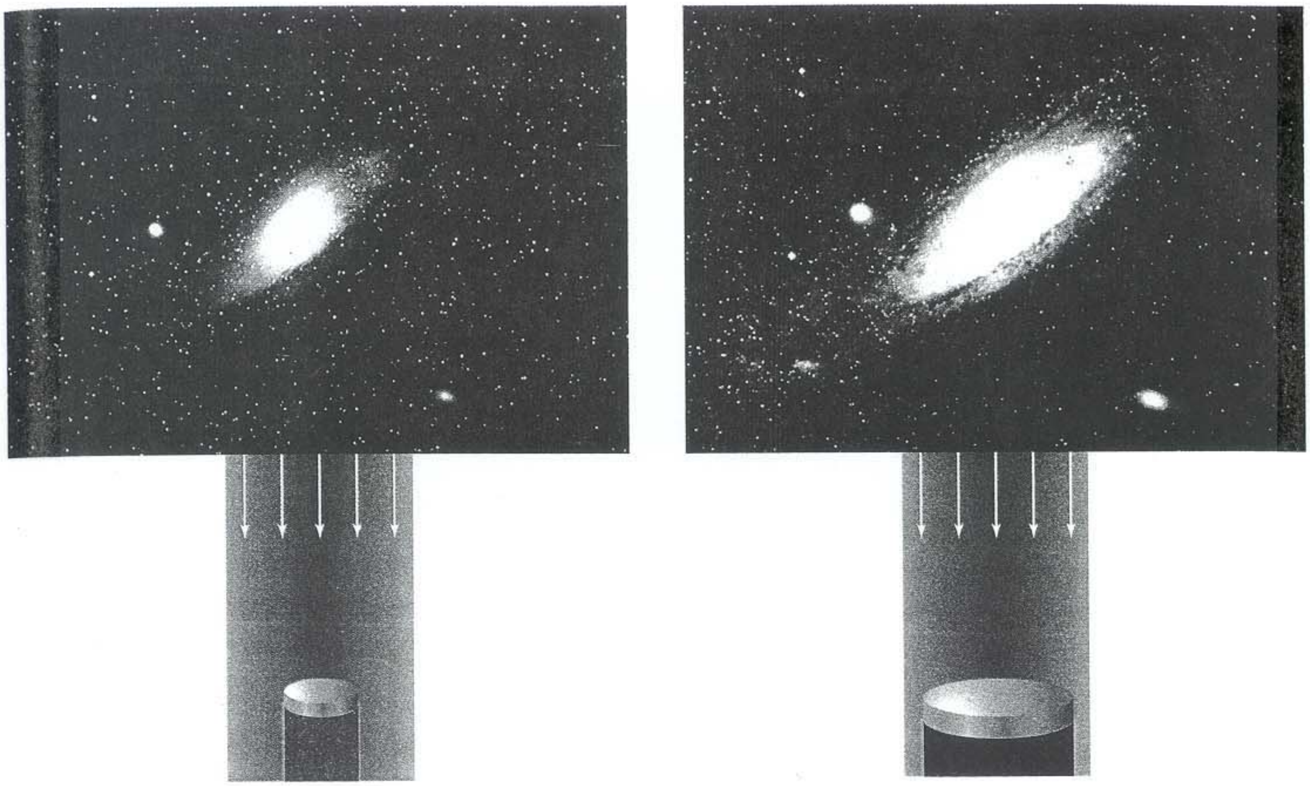
Resolving Power Two comparably bright light sources become progressively clearer when viewed at finer and finer angular resolution. When the angular resolution is much poorer than the separation of the objects, as at the top, the objects appear as a single fuzzy "blob." As the resolution improves, the two sources become discernible as separate objects.



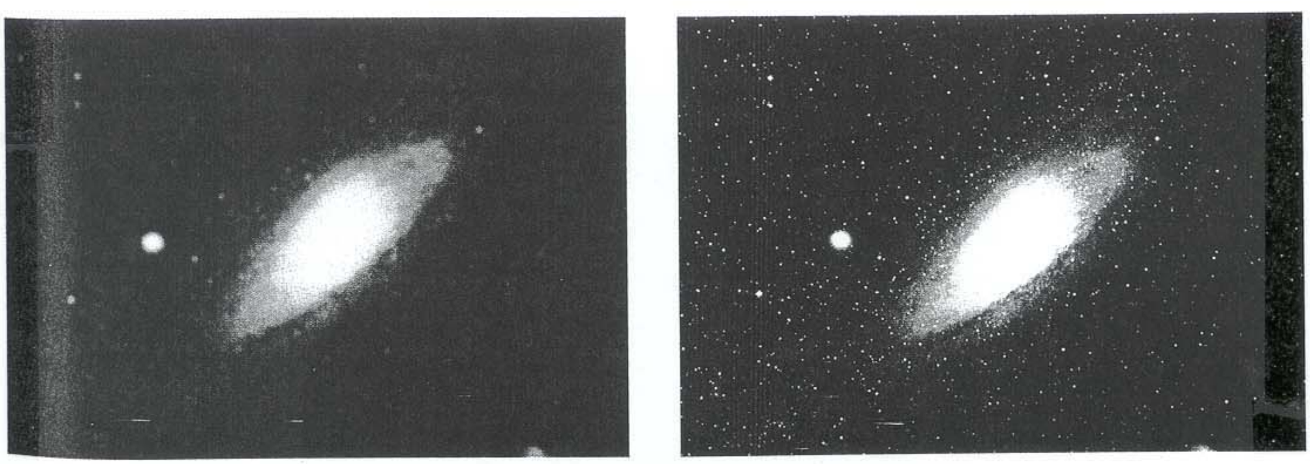




Effects of Twinkling The same star field photographed with **(a)** a ground-based telescope, which is subject to twinkling, and **(b)** the Hubble Space Telescope, which is free from the effects of twinkling. (NASA/ESA)



Light-Gathering Power Because a large lens intercepts more starlight than a small lens, a large lens produces a brighter image. The same principle applies to telescopes that collect light using a primary mirror rather than an objective lens. The two photographs of the Andromeda galaxy were taken through telescopes with different diameters and were exposed for equal lengths of time at equal magnification. (AURA)



Resolution The larger the diameter of a telescope's objective lens or primary mirror, the greater the detail the telescope can resolve. These two images of the Andromeda galaxy, taken through telescopes with different diameters, show this difference. Increasing the exposure time of the smaller diameter telescope (left), will only brighten the image, not improve the resolution. (AURA)

DATE: NAME:

TIME: GROUP MEMBERS:

TELESCOPE #:

LOCATION: Roof? Hallway?

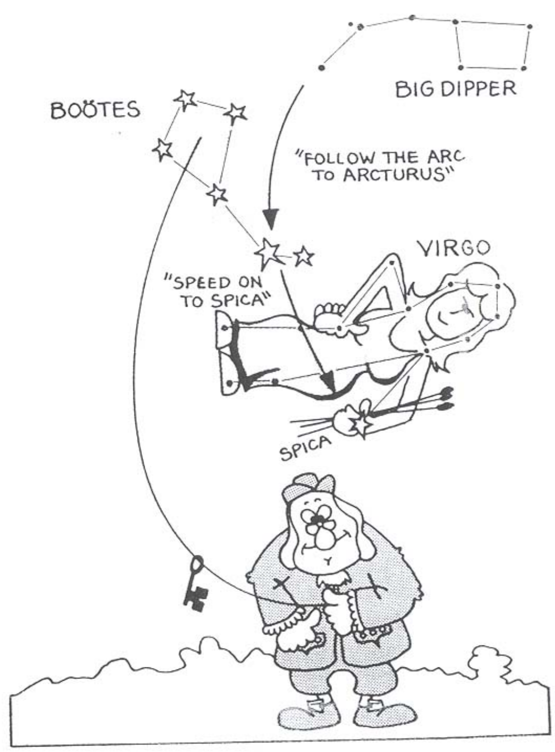
PURPOSE: To understand the operating principles of the lab telescope while targeting various stars and planets.

EQUIPMENT: Lab Telescope: Meade 8-inch Schmidt-Cassegrain
f/8 focal length = 2000 mm

Look at a building or lighted object on campus through both the finder and the telescope eyepiece. Are the images reversed right/left? Up/down? Both?

OBSERVING CONDITIONS:

LIMITING MAGNITUDE:



Name ____________________________

DATA SHEET

Use the fist/finger method to determine altitude and azimuth.
Use the dials on your telescope to determine hour angle.
Hour angle is measured in hours & minutes East and West of your local meridian, e.g. 1:15 E at some time**
Write the star name* in terms of the constellation name and its brightness ranking (α, β, γ, etc.) in the constellation, under the formal name given in the table below.

Please turn this assignment in to one of your roof helpers before you leave the roof.

CHOOSE FIVE OF THE FOLLOWING ELEVEN OBJECTS:

Fall: Polaris, Mizar, Vega, Deneb, Altair, Enif, Kochab, Alpheratz, Algol, Mirphak, Mirach

Winter: Polaris, Kochab, Mirphak, Algol, Betelgeuse, Castor, Pollux, Regulus, Procyon, Capella, Sirius

Spring: Polaris, Betelgeuse, Castor, Pollux, Arcturus, Spica, Denebola, Regulus, Mizar, Capella, Alphard

Summer: Polaris, Mizar, Vega, Deneb, Altair, Enif, Arcturus, Alpheratz, Antares, Alberio, Nunki

Obtain a high-power eyepiece from a roof helper to replace the current eyepiece. What effect does increasing the magnification have on both the field of view and quality of the image?

Star Name	Constellation	Azimuth	Altitude	Time**	Hour Angle**

* As in α U Ma = alpha Ursa Majoris = the brightest star in Ursa Major

TIME AND DIURNAL MOTION

Most of our understanding of gravity and of the motions of the solar system, stars and galaxies comes from using the telescope to make positional (astrometric) measurements. The original motivation was the need for accurate navigational tools. For astronomy we have to know enough about the motions of the sky to know where (and when) to point our telescope to view an object, particularly if it's so faint it can't easily be found. Astronomers use various **coordinate systems** (analogous to latitude and longitude) to define the positions of stars, planets, galaxies etc. Several different interrelated systems are needed and used, which may at first seem a bit confusing. After doing this lab exercise (and also the EA [Ecliptic & Annual Motion] and PM [Planetary Features & Motion] labs), the concepts hopefully will be clear to you.

LOCAL HORIZON COORDINATES (Figure 1a on the next page)

The sky appears to be a big ball (called the Celestial Sphere) surrounding us, with the stars all appearing to be the same (infinite) distance from us, so star maps ignore their actual distances. Maps usually use two angular coordinates (e.g. latitude and longitude, or Declination and Right Ascension) whether on a globe or on a flat map representing part of a globe.

Similarly, we only need two angular coordinates to point a telescope. For an observer standing on the surface of the earth (at a particular latitude), the "Local Horizon System" is the easiest to visualize. Although it is the easiest system in which to make measurements, the apparent positions of given objects are highly dependent on the observer's latitude.

The fundamental circle in the Horizon system is the **horizon** (see figure 1a), from the Greek word 'orizo' (to bound or delimit); the circle around us where the sky meets land/sea. Actually, it's the theoretical or **astronomical horizon** defined by the plane tangent to the surface of the earth at your location. In practice, because the observer sits slightly above the surface of earth, their apparent horizon will "recede" the higher they get (see more "over the horizon" of the earth). The difference between the astronomical and apparent horizons is known as the horizon depression or dip. However, one must also consider all the imperfections of trees, buildings, etc. The true horizon contains all these imperfections, and must be taken into account when you are actually trying to determine if you can see it from your location (i.e. won't do you any good if the object is behind the elevator shaft).

The center of the system is the observer, with one pole directly overhead called the **Zenith**, and the other directly beneath called **Nadir**. Circles parallel to the horizon are called **Almucantars**[7]. Note that due to flat map distortion, on a star wheel (see figure 1b) the Almucantars will appear to be ellipses.

Secondary circles, known as **Vertical Circles**, run perpendicular to the horizon, and all converge at the poles Zenith and Nadir. The origin is the North point of the compass (see figure 1a). The vertical circle that extends north-south is called the **Local Meridian**, while the one that runs east-west the **Local Vertical**.

[7] Alternate spelling: Almucantur. Arabic derived from the sundial. An "almucantar" staff was an instrument having an arc of fifteen degrees, used to take rising and setting observations of the sun.

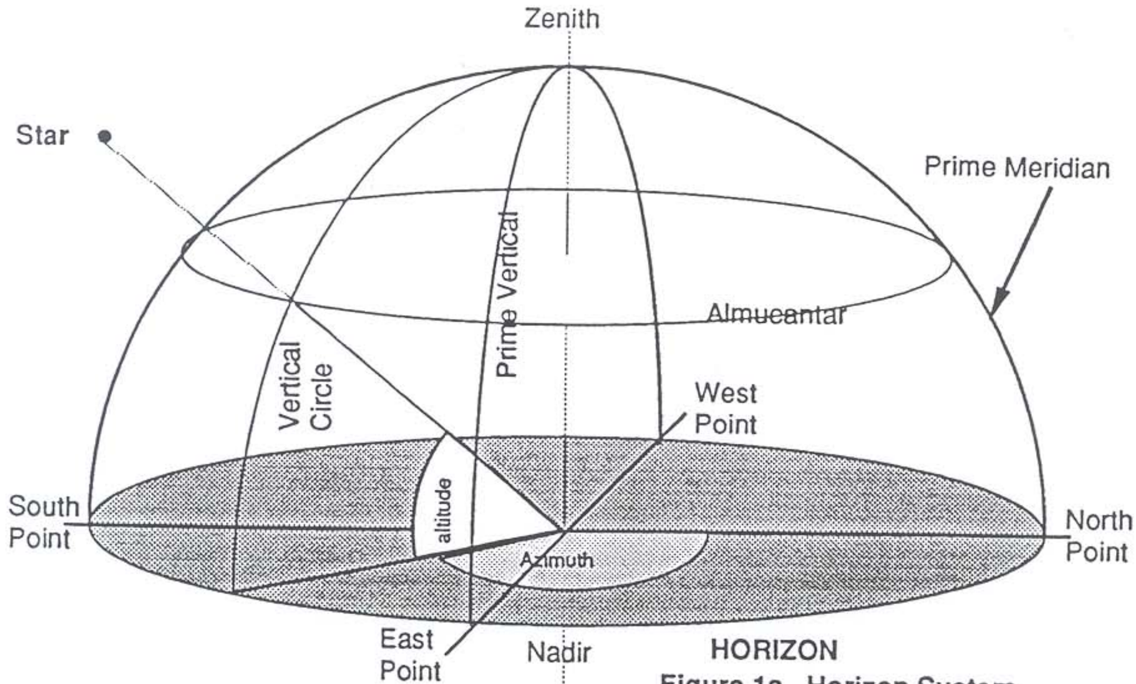


Figure 1a Horizon System

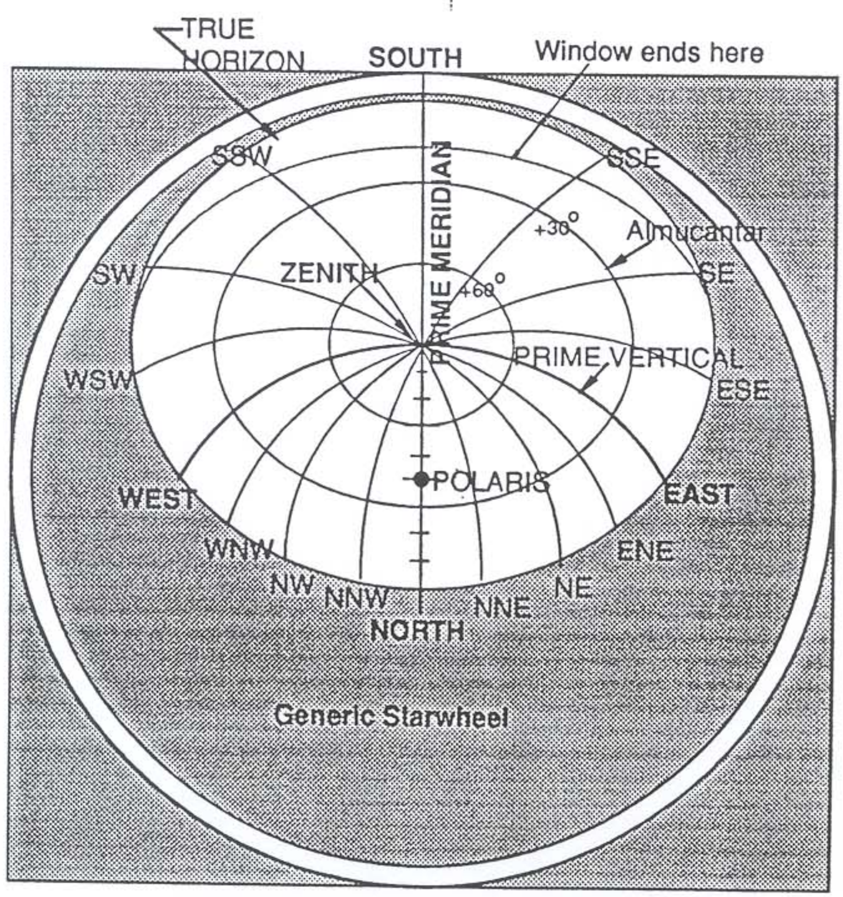


Figure 1b Horizon System on a Starwheel

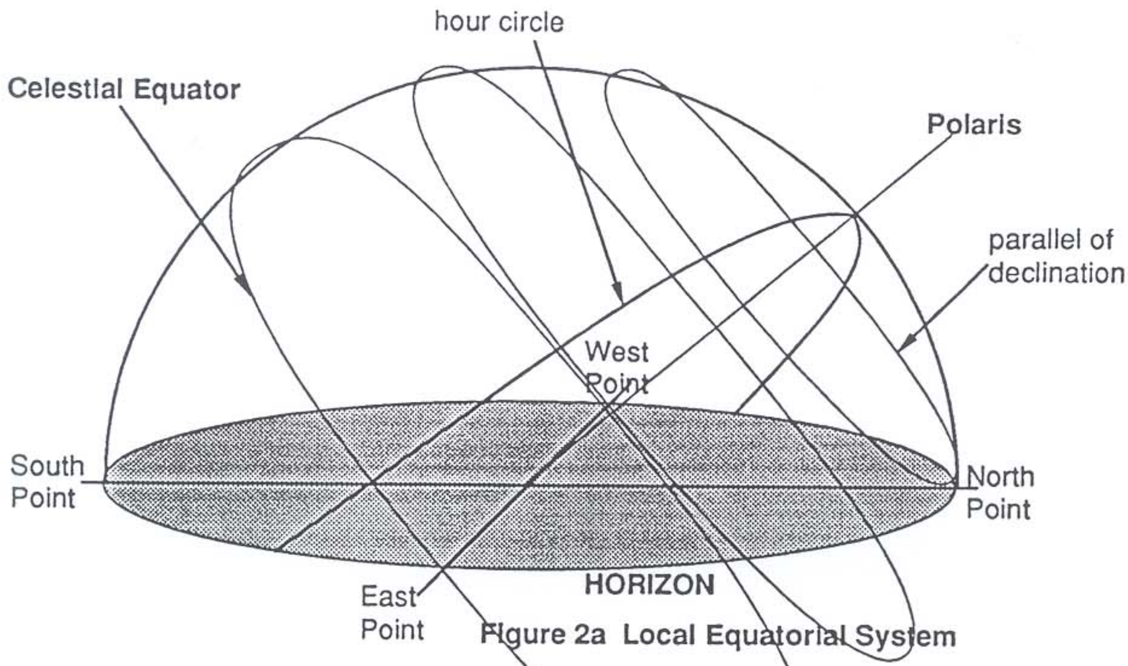


Figure 2a Local Equatorial System

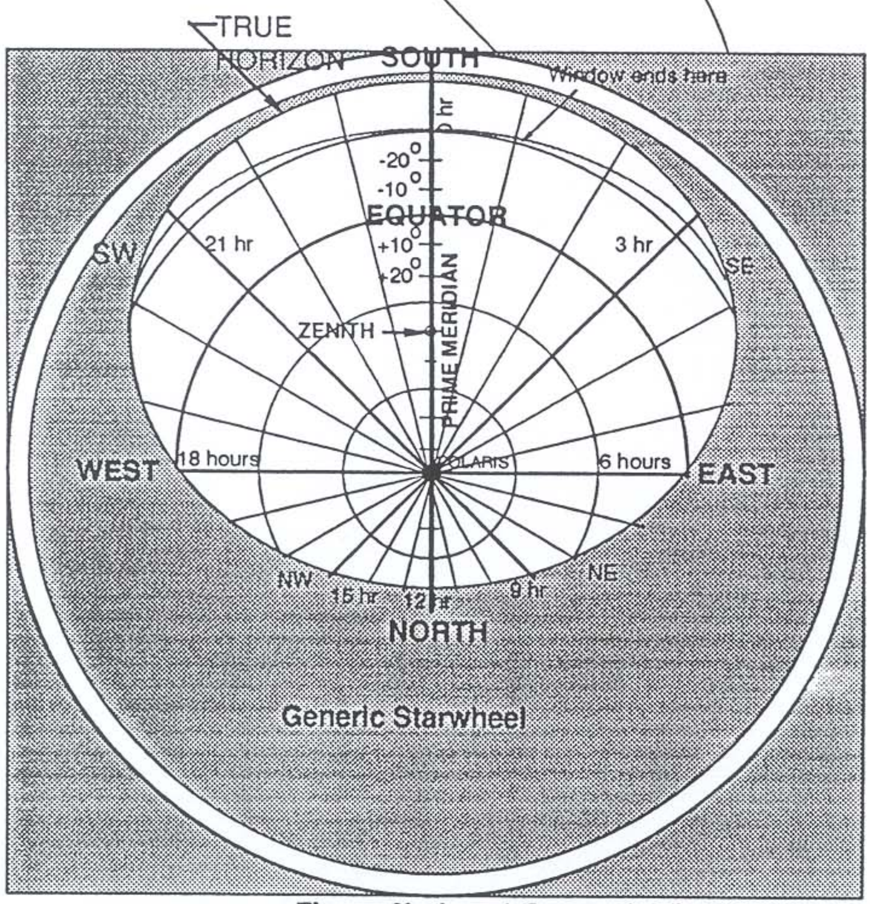


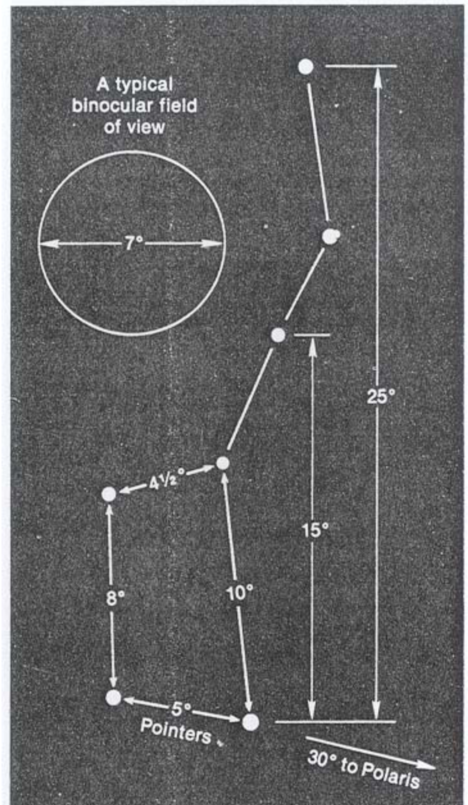
Figure 2b Local Equatorial System on a Starwheel

Coordinates

The coordinate associated with a particular Almucantar is called **altitude** (symbol "h"). In other words, an almucantar is a circle of constant Altitude angle, where the angle is measure along the arc of a vertical circle from the horizon to the almucantar. If instead it is measure down from the Zenith, it is called the **zenith distance** or **zenith angle** (symbol "Z").

The coordinate associated with a particular vertical circle is called **azimuth**, the same as the **compass bearing** the navigators and surveyors use.[8] The azimuth of a vertical circle is measured eastward along the horizon from the north point of the compass. Hence, due north is 0 degrees, due east is 90 degrees, south is 180˚ and due west 270˚ azimuth. [In computation if a negative Azimuth arises, simply add 360˚; for example -90˚ is the same ass 270˚ or due west].

Altitude and azimuth are easily estimated and can be measured to high precision by an altazimuth instrument or a surveyor's transit (a theodolite). These consist essentially of a compass (for azimuth) combined with a level or plumb line and a protractor (to measure the altitude angle from the horizontal to the star).



The Big Dipper

Altazimuth Pros and Cons

Altitude and azimuth are the easiest to use for naked eye directions (e.g. "look about 30˚ above the SE horizon"). For telescopes, altazimuth mounts are the best engineering design (for proper loading, expense, ease of construction etc.). However, it is very difficult to follow the diurnal motion of stars (due to rotation of the earth) because both altitude and azimuth change, and both change at varying rates (very significant when you magnify the sky, since you have magnified the motion too!). In short, computer-controlled tracking is needed for large telescopes.

Horizon coordinates have a more serious drawback in the coordinates for any object not only change with time, but will also be different for every latitude.

THE EQUATORIAL SYSTEM (Figure 2a)

The **equatorial system** is the projection of a geographic system of a latitude and longitude onto the celestial sphere. Hence its pole is the pole of the rotation of the earth, and it easily adapts to the diurnal (daily) motion of the celestial sphere, i.e. the apparent movement of the stars.

The fundamental circle in this case is the **celestial equator** (see figure 2a). The poles are the **North and South poles of rotation**, which, as their name indicates, are defined by the rotation of the earth. The star Polaris (i.e. the "pole star") is almost exactly

[8] In older books, the Azimuth angle was defined as being measured from the Southern Meridian (i.e. from the south point of compass), while bearing was measured from the Northern Meridian (north point of compass).

on the North Pole[9], while there isn't any bright star near the Southern Pole[10]. On a star wheel (see figure 2b) a rivet is usually at the pole.

The **declination** coordinate (symbol δ, abbreviation "dec") is analogous to geographic latitude in definition and units (i.e. measured in degrees). It is $\delta = 0^\circ$ at the Equator, +90˚ at the North Pole, and -90˚ at the South Pole. A circle/arc of constant declination is called a **parallel of declination** (circles parallel to the equator). On the star wheel (fig. 2b) they are concentric circles. The parallel through your local zenith is called the **zenith circle** (and its declination is equal to your latitude).

As time progresses through the night (or day), each star moves along its own parallel at a common rate of 1 revolution per day. This east to west **diurnal motion** is due to the rotation of the earth. When a star passes the prime meridian, it is said to be in **transit**, or **Southing** (since it then to the South of the pole), or **upper culmination** (since it is at its highest altitude) and is in the best position to be observed (through the least air mass).

Time & Hour Angle

The **hour angle** coordinate (symbol η, abbreviation "HA") is a measure of the time (in hours) to or from transit. It originally was defined by sundials, marking the position of the sun with time. The **transit of the sun** is called **noon**, at which time the sun crosses the prime meridian where the hour angle is defined to be 0 hours (not 12, Julian days being at noon!). Although hour angle is sometimes defined as positive to the west (so it will increase as times increases), we define it to be positive to the east (so it will match our telescopes and direction of right ascension). The secondary great circles of constant hour angle are called **hour circles**. The hour circle that runs North-South and passes through local zenith is again the **local meridian**, the same arc as in the horizon system. On a star wheel (Fig. 2b), Hour circles are straight lines passing through the pole.

Telescopes with equatorial mounts can follow stars by driving the telescope about only one axis, the equatorial axis, at a rate equal to the rotation rate of the earth. This is an obvious advantage, although it requires alignment of the equatorial axis parallel to the earth's axis (North-South at an angle from the horizontal equal to the latitude). Small corrections (for atmospheric refraction) are needed only for high precision (such a long exposure photographs or high magnification).

The East point (see Fig. 2b) is at the intersection of the ($\delta=0^\circ$) celestial equator and the HA= 6^h or 6^h East. The West point is on the celestial equator at HA= -6^h or 6^h West (shown at18 hours R.A. on the Star Wheel).

Rising and Setting

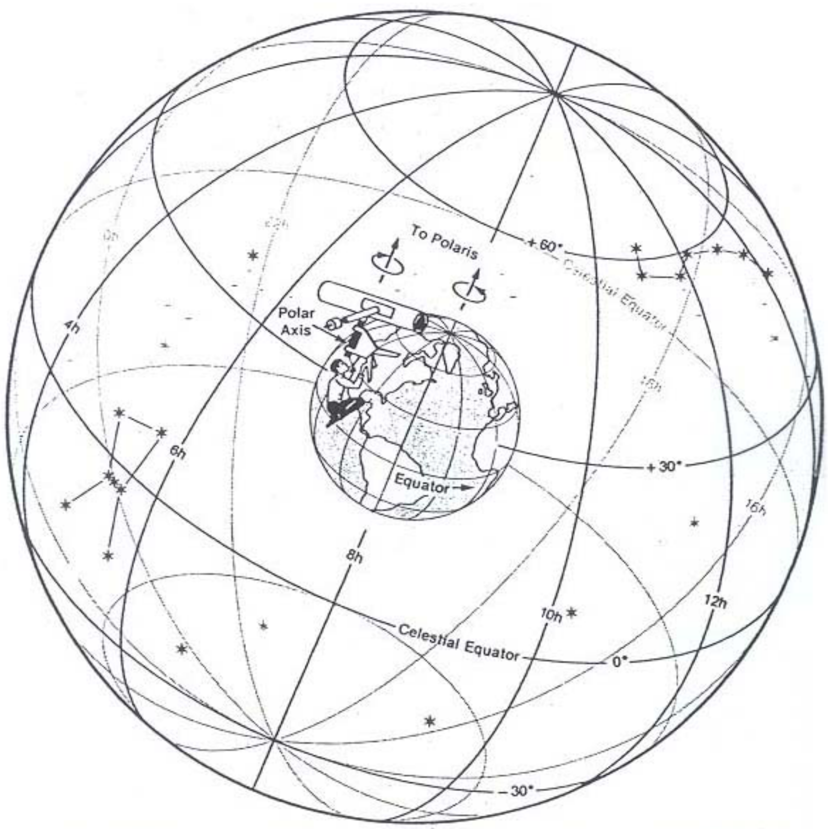
A star on the celestial equator rises at the East point, transits 6 hours later, and sets at the West point in another 6 hours. Stars further north rise earlier and set later. Stars closer to the North Pole than the observer's latitude are circumpolar - they circle the pole without rising or setting (they only have upper and lower culminations). Stars south of the celestial equator stay above the horizon for less than 12 hours. Stars closer to the South Pole than the observing latitude ($\delta < -51.5^\circ$ for UCD) are said to lie below the circle of perpetual occultation since they never rise and thus are never seen at that latitude. Both these features can be demonstrated using a star wheel.

---

[9] Polaris (α or 1 Ursa Minoris) is about 1 degree from the true pole, with 2004.5 coordinates of $\alpha = 2^h37^m00.0^s$, $\delta = 89^\circ17'01''$, and magnitude 2.02 (actually a variable star!)

[10] The 5.47 magnitude star σ Octantis is within 1 degree of the true south pole, with 2004.5 coordinates of $\alpha = 21^h12^m41.4^s$, $\delta = -88^\circ\ 56'17.$"

A star rises if and where it's parallel of declination intersects the east horizon (rising point), and sets where it intersects the west horizon (setting point). To see this with a star wheel, simply rotate until the star runs into the edge of the "window" and disappears. The star wheel also shows the estimated rising and setting times. What the star wheel is doing for you is actually quite complex. It is an analog calculator relating the horizon coordinates (altitude and azimuth) to the equatorial (declination and hour angle). It might seem that it would be easier if we just stuck to one system, but we can't; each deals with a different aspect, and you find that you must convert back and forth between the two systems constantly. For example, it is easy to figure the equatorial position of a star as a function of time, but it won't quickly tell you if it's above your horizon or not, or what time it will rise/set.



On the celestial sphere, declination and right ascension are similar to latitude and longitude on Earth. If a telescope's polar axis is made parallel to the Earth's axis, as shown, the Earth's rotation can be canceled out by turning the telescope in the opposite direction.

SIDEREAL TIME & STAR MAPS

The coordinates on star maps are right ascension (celestial longitude; symbol α; abbreviation RA) and declination (celestial latitude; δ; dec). Declination is the same as in the equatorial system. Right ascension is very much like hour angle (including being measured in hours), but is much simpler since it is constant for a given star.

The fundamental circle (celestial equator) and the poles (North & South poles of rotation) are identical to those of equatorial system. The coordinate for the parallels (declination, symbol δ, abbreviation dec) is also the same.

The difference between the two systems is that the secondary great circles are now fixed to the stars. These celestial meridians are associated with the "celestial longitude”, right ascension, measured in hours eastward form the origin. The origin ($\alpha = 0^h$, $\delta = 0^\circ$) is arbitrarily defined to be the place where the sun crosses the equator at the vernal equinox (known as the First Point of Aries, the intersection of the equator and ecliptic).

Sidereal Time

Our discussions of star positions implied that we were using sidereal time, which advances by 24 sidereal hours as the earth rotates once relative to the stars. (Our usual clocks use mean solar time, which advances by 24 average solar hours as the earth rotates once relative to the sun, and is local solar noon when the sun transits. However, since the earth orbits the sun once a year, sidereal and solar time rates differ by a factor close to 365/366.)

The sidereal time tells us what celestial meridian is transiting, i.e. the star time. For example, the star Betelgeuse (α Ori, RA $=5.9^h$) will transit when the sidereal time is 5.9^h, its Right Ascension. The problem is to know the equivalent solar time, i.e. the relationship between solar and sidereal time. You can approximately read it off of a star wheel. For example, set Betelgeuse such that it is transiting (on the local meridian of the star wheel). The solar time depends upon the date. For example, on January 20, Betelgeuse will transit at about 10 pm. A month later, on February 20, Betelgeuse will transit about 2 hours earlier, at 8 pm.

A solar day is the time between successive transits of the sun, i.e. noon to noon, which is defined to be 24 hours = 86400 seconds. A sidereal day is the time between successive transits of a given star, which is about 4^m short of a solar day. Another way of saying it is that a sidereal day is equal to one complete rotation of the earth (relative to the stars, not the sun). A solar day is slightly more than a complete rotation of the earth, by about 1 degree, due to that apparent 1°/ day eastward annual motion of the sun against the background stars. So, the sun rises 4 minutes later with respect to the stars.

Relationship Between Celestial and Equatorial Coordinates: Diurnal Motion

The term **diurnal motion** is applied to the apparent motion of objects (e.g. stars, moon, sun) across the sky due to the rotation of the earth. It will appear that the whole sky rotates about the Celestial Pole (i.e. the rivet in the star wheel) at the rate of the sidereal clock. Telescopes have a clock drive (first used by Fraunhofer in 1824) which moves the scope at exactly the sidereal rate to track the stars.

Name ______________________________

DATA SHEET

	Positions along the **Meridian**	Hour Angle	Predicted Declination	Measured Declination	Estimated Altitude
B	North Point	12^h	+51.5°		0°
	North Pole	All	+90°	+90°	
	Zenith	0^h	+38.5°		90°
	Celestial Equator	0^h	0°	0°	
	South Point	0^h	-51.5°		0°
C	**Paths from Rising to Transit**		***EASTERN HORIZON***		**Transit**
	Declination	Name	Measured Hour Angle	Estimated Azimuth	Altitude at transit
	-23.5°	Winter Solstice			
	0°	Celestial Equator	6^h E	90°	
	+23.5°	Summer Solstice			
	+40°	+40°			
D	**Paths from Transit to Setting**		**Transit**	***WESTERN HORIZON***	
	Declination	Name	Altitude at transit	Measured Hour Angle	Estimated Azimuth
	-23.5°	Winter Solstice			
	0°	Celestial Equator		6^h W	270°
	+23.5°	Summer Solstice			
	+40°	+40°			

INDOOR ACTIVITIES:

(a) Use the star wheel to predict the constellation at zenith, compare (remember, the star wheel assumes Local Mean Time = PST + 7^m; you can ignore the 7^m and simply use PST, but you should correct for daylight savings as LMT ≈ PST = PDT – 1^h).

(b) Name 3 other constellations that will be transiting at this time.

LUNAR FEATURES AND MOTION

Background

In this lab, students will learn about how lunar features are formed, why they form the way they do, how to observe the Moon, and how to calculate sizes of lunar craters.

Formation and features

Although there still may be some disagreement and dissenting opinions, the most commonly accepted theory for ***lunar formation*** is the collisional ejection theory. Early in the solar system's history, a Mars-sized planetoid named Theia crashed into the proto-Earth, causing material to be ejected near proto-Earth's orbit. Eventually, this material cooled, and because it was massive enough, held itself into a sphere.

The Moon's structure is reminiscent of its turbulent history. As it cooled, due to its proximity to Earth, the Moon's core formed off-center. This had the side effect of making the lunar crust near Earth much thinner than the lunar crust on the far side. This is a good time to note that because the Moon is very close to the Earth, it's *tidally locked*. This means that the same side faces Earth all the time, and why we refer to the moon as having a "far" side and a "close" side. Most large moons in the solar system are tidally locked, too.

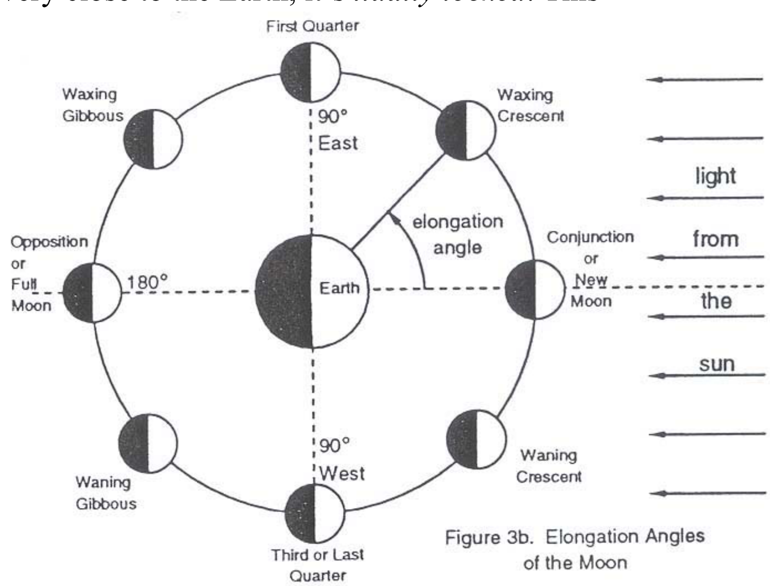


Figure 3b. Elongation Angles of the Moon

These phenomena have differentiated the different sides of the moon. Due to its thinner crust, the near side of the moon was more susceptible to lava fissures when it was geologically active. This igneous rock cooled to form *maria,* the dark "seas" of flat plains visible from Earth (see ***mare***, ***mons***, and ***rima***). They're called maria because ancient astronomers thought they were oceans! Maria have persisted to this day because the Moon's near side is protected by Earth from errant asteroid impacts. On the other hand, the Moon's far side is characterized by few maria and many craters, for the exact and opposite reasons that characterize the near side.

Phases of the Moon

The Moon cycles through its phases once every 29.5 days, called a *synodic month*. At any one time, the Moon has exactly half of its surface illuminated. From Earth, we see the phases change because the side illuminated depends on the Moon's angular distance from the Sun (see ***tides***).

The Moon is *new* when only its dark side is facing Earth, or when it's in between the Earth and the Sun. A *full moon* is when the Moon is showing its entire bright face to the Earth, and it's exactly opposite the Sun. The Moon is in *first quarter* halfway between a new moon and a full moon, and *third quarter* when it's halfway between a full moon and a new moon. The phases in between are named for their percent illumination and their change over time. If the Moon is "growing," or the phase is getting brighter, it's said to be *waxing*. If the Moon is "shrinking" or getting dimmer, it's said to be *waning*. A *crescent* is when the Moon is less than halfway illuminated, and *gibbous* is when the Moon is more than halfway illuminated.

Also, for completeness, the *terminator* is the line that divides the light and dark sides of the moon.

Eclipses

An eclipse is a wonderful sight to see, and something that should be on every astronomer's to-do list. Eclipses come in two different types: *solar eclipses* and *lunar eclipses.*

A solar eclipse is when the Moon is exactly aligned with the Sun such that it blocks light from getting to Earth. By far the most dramatic, solar eclipses are actually a cosmic coincidence. The Sun's and Moon's angular sizes are so alike, that an observer on Earth can experience both total eclipses (when the Sun's disk is completely blocked) and annular eclipses (when the edges of the Sun's disk are able to peak through, in an "annulus," or ring shape) within their lifetime.

A lunar eclipse is when the Earth's shadow is cast on the Moon. Also called "blood moons," total lunar eclipses usually appear a rusty reddish color. The only light able to pass through to the Moon is refracted through Earth's atmosphere, so in essence, all the Earth's sunrises and sunsets are projected onto the Moon.

Why do we not get eclipses every two weeks, then? The Moon's orbital plane is inclined about 5° from the Earth's, so there are only two points in its orbit, called *nodes*, that intersect with Earth's (see ***lunar motion***). In 2022, these nodes are positioned such that eclipses are only able to happen around May and November.

Measuring lunar features

This lab is the most mathematically intense lab in the manual, but AST 10L is meant for all to understand! From some previous labs, you should be relatively familiar with angular sizes and distances. To refresh, an <u>angular size or distance</u> is how big something *appears to be,* which is simply the angle an object's size or distance to another object makes with your eye. For example, you could say, "that crater has an angular size of 2 arcminutes" or "that crater is 45 arcminutes from that other crater."

For this lab, though, we care about <u>*real* distances</u>, not angular ones, so we have to first measure angular sizes or distances and then convert them to physical sizes or distances. As a first step, we can use how long an object takes to move its full width (due to the rotation of the Earth). The rotation of the Earth causes objects in the sky to move at 15" per second, which we can use to find their angular sizes in arcminutes. We convert transit times into arcminutes or radians, using the formulas below. In the formulas t is the transit time in seconds and we use the fact that there are 60 arcseconds in an arcminute and 60 arcminutes in a degree (the symbol " means arcminutes and ′ means arcminutes).

$$\alpha\ (\text{arcmin}) = t * \frac{15''}{\text{sec}} * \frac{1'}{60''} \qquad \alpha\ (\text{radian}) = t * \frac{15''}{\text{sec}} * \frac{1'}{60''} * \frac{1°}{60'} * \frac{2\pi\ \text{rad}}{360°}$$

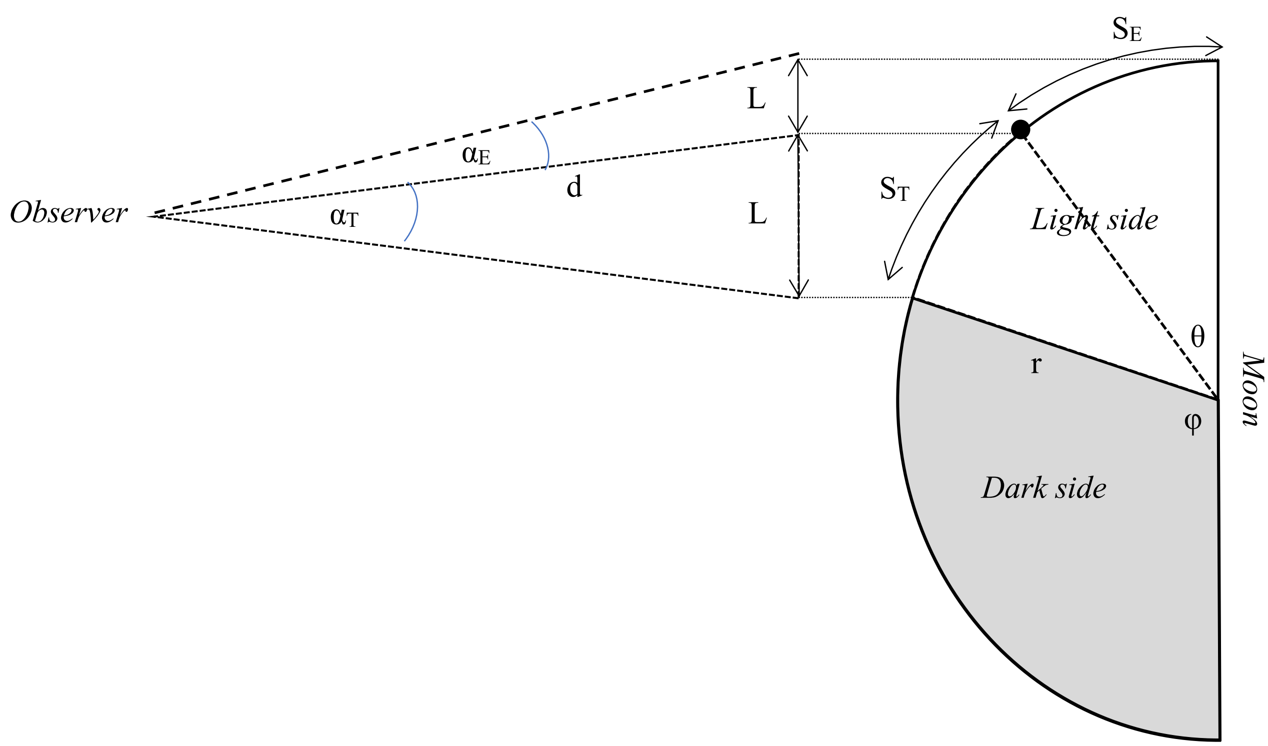
Next, we need to define *subtended distance*. Subtended distance is the distance between two objects when we assume the Moon is flat. The following figure shows subtended distances as L. This can be directly obtained by multiplying angular distance <u>in radians</u>, α, by the distance, d, from the Earth to the Moon, d = 384,000 km.

$$L = \alpha * d. \ \text{(We'll call this the "subtended distance formula")}$$

However, to get the terminator and edge distances you need to take into account the fact that the surface of the Moon is curved. To do this, the angles φ and θ must be calculated as an intermediate step, using the subtended distances (L_T and L_E) and the radius of the Moon (r = 1750 km).

$$\theta = cos^{-1}\left(\frac{r - L_E}{r}\right) \ \text{and} \ \ \varphi = cos^{-1}\left(\frac{L_T + L_E - r}{r}\right)$$

After doing that, the terminator and edge surface distances, S, can be calculated using φ and θ, assuming these *angles are in radians*: $S_E = r * \theta$ and $S_T = r * (\pi - \theta - \varphi)$



In all, the most important takeaway from this lab is the differences between surface and subtended distances. These formulae won't be tested on the final, but the broad concepts will be. As always, if you have any questions, feel free to ask your Roof Helpers.

Procedure

Note that you will need a *calculator* for this lab. Your phone might be alright as simple calculations but doing inverse trig on a phone is very finicky. If you don't have a "real" calculator, work with someone who does.

Part A of this lab consists of estimating the phase of the Moon. Note that the drawing provided is *double inverted*, so be sure to draw what the Moon looks like *through the finder scope* and not your naked eye. A good way to orient yourself is the "lobster claw," also known as Mare Tranquillitatus.

To measure the angular size of the Moon for Part B, position your telescope such that the Moon is just out of view to the right. The Moon will appear to move left to right in the sky, but because your telescope is inverted, we must reverse that motion. Start a stopwatch when the edge of the Moon comes into view, and stop when the other edge comes into view. Note that you should measure the widest part (roughly the Moon's equator). Record that time in seconds, and use the α formula in the previous section (minus the radians part) to convert your units.

Measuring a crater is done the same way. Another way to measure the crater (or the entire Moon for that matter) is to start the timer when the leading edge *exits* your field of view and stop when the trailing edge exits your view. Either way, make sure you're measuring the widest part!

To measure your chosen crater's distances from the terminator or the edge of the Moon, it's the same process as above.

Note that this lab is formatted such that all the observations and calculations are done separately. Don't worry about doing calculations on the roof!

Cover and data sheets

Name:

Group members:

Section: Monday, Tuesday, or Wednesday? (circle one)

Date:

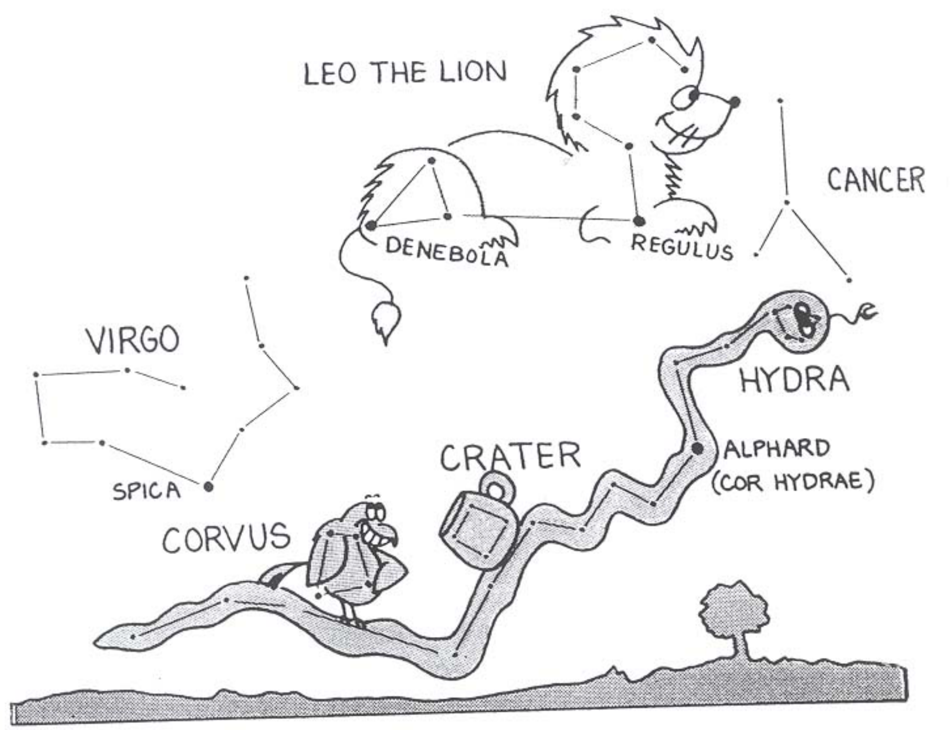
Time:

Location: Roof or Hallway? (circle one)

Telescope number:

Observing conditions:

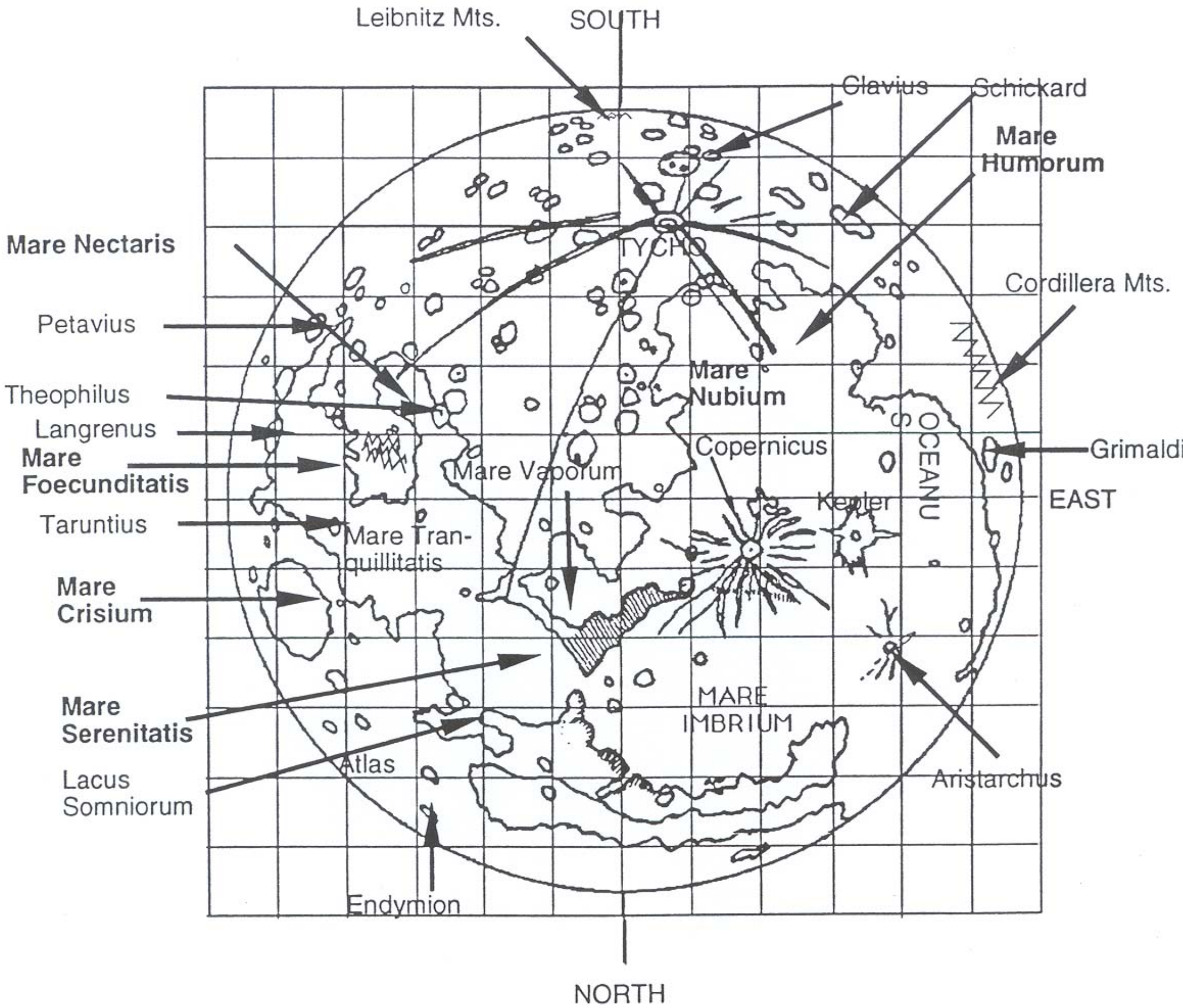
Limiting magnitude:



Data sheet

Part A

Shade in the following *double inverted* diagram of the Moon to the best accuracy you can. This is what the Moon will look like through the *finder scope*.



When you get inside, count the number of shaded squares. Feel free to count fractions of squares, too – but no need to be too precise. As the diagram has squares sized such that the total area of the Moon is 100 squares, the count is exactly equal to the phase.

Calculated Moon phase	%
Phase name	

Part B

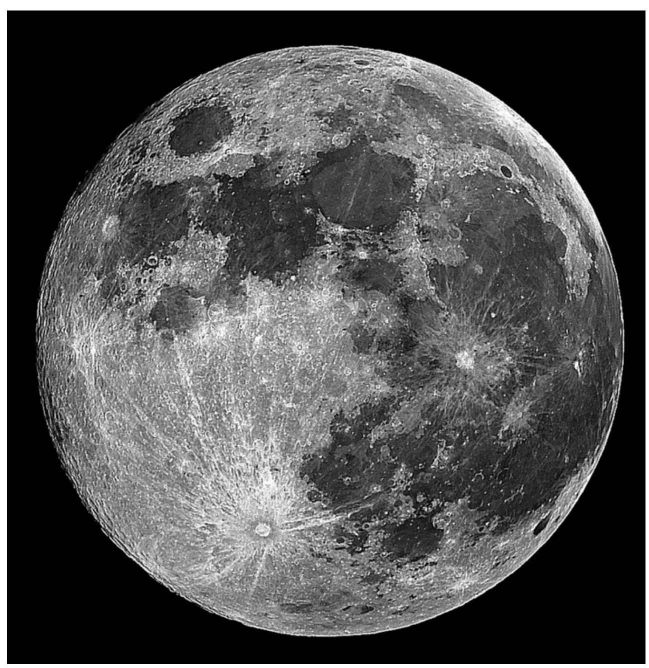
Here is where you'll put your data from measuring the size of the Moon, the size of a chosen crater, and distances from the crater to the *light edge* and terminator. Feel free to use the map in Part A to pick a crater. Many Roof Helpers recommend Theophilus for its proximity to the "lobster claw" and prominent central mountain. Also note that the main scope is *horizontally* inverted, and not doubly inverted. This may make finding your selected crater a bit harder.

Feel free to wait to calculate the angular sizes *indoors*.

Chosen crater	

Object	Time	Avg. time	Angular size
Moon diameter	sec	sec	arcmin
Crater width (measurement 1)	sec		
Crater width (measurement 2)	sec	sec	arcmin
Crater width (measurement 3)	sec		
Angular distance from the crater to the terminator (α_T)	sec	sec	rad
Angular distance from the crater to the light edge (α_E)	sec	sec	rad

Here's a map of the Moon that's *horizontally* inverted to match what you see in the main telescope.



Part C (Physical size of your chosen crater)

In this part, you will calculate physical size of your crater using the measurements from Part B. For this part just assume that you are seeing the crater from above so you can just use the simple subtended distance formula to get the size of the crater

Parameter	Symbol	Calculated value
Angular size of crater in arcmin (from Part B)	α (arcmin)	arcmin
Angular size of crater in radians	α (radian)	radian
Surface size of the crater (just use subtended distance formula)	L	km

Part D (surface distance to light edge)

In this part, you will calculate the surface distance from the crater to the light edge (S_E), using the measurements from Part B. Feel free to reference the formulas in the Background section of this lab.

Parameter	Symbol	Calculated value
Angular distance to light edge (from Part B)	α_E	rad
Subtended distance to light edge (subtended distance formula)	L_E	km
Internal angle from crater to light edge	θ	rad
Surface distance to light edge	S_E	km

Part E (surface distance to terminator)

In this part, you will calculate the surface distance from the crater to the terminator (S_T), using the measurements from Part B and some results from Part C (θ and L_E).

Parameter	Symbol	Calculated value
Angular distance to terminator (from Part B)	α_T	rad
Subtended distance to terminator (subtended distance formula)	L_T	km
Internal angle from crater to dark edge	φ	rad
Surface distance to terminator	S_T	km

Part F

1. Do your calculations match predictions, particularly about the size of the crater? Feel free to look up values from the internet to verify.

2. What are some possible sources of error in your measurements?

3. What percent of the Moon's surface is illuminated at any one time? ____________%

4. Is it possible to figure out if some craters are older than others with just a lunar map? How could you do it? Did your selected crater appear older or younger than its surroundings?

INSTRUCTIONS FOR USING THE STARRY NIGHT PACKAGE

To load ***Starry Night***:

Place the *Starry Night* in your computer's CD ROM drive
Go to My Computer
Click on CD ROM
Click on Set up *Starry Night* Setup
Then follow the accompanying instructions
You will find *Starry Night* under the Programs on your computer

---

●1. You usually do not need to enter an ID number to access the ***Starry Night*** planetarium.
Set your location for **Sacramento**.
When the sky plane appears, right click on your mouse…and click on **Hide Daylight.** The night sky should now appear. Notice that you also see: No Light Pollution, Small City, Large City in the drop down menu when you right clicked.

●2. When the sky panel (about 100 degrees across) appears…
Note the **MAIN CONTROL BAR**.

FILE EDIT VIEW LIVESKY GO WINDOW HELP

And the **tool bar** below this:

Date Time ∨ **1x** ∨ ◄| ◄ █ ► |► ∨∧ **Sacramento Zoom tool**

stop Time step
(controls motion of the sky as a whole)

◄ and ► continuous motion/movie mode
◄| and |► move the sky to the left or right in the intervals you set when clicked on.
This time step can be set/altered by clicking on the ∨ after **1x** and changing the 1x to hours, days etc. and then altering the number using the keyboard.
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⇒The **Zoom** tool on the right allows you to change the field of view in or out, but the maximum sky area is the default of 100 degrees across.

⇒Clicking on the **Date** or **Time** allows to change these directly using the keyboard

⇒Clicking on the ∨ after time produces the drop down menu: now, calendar, sunrise, solar noon, sunset, moonrise, moon transit, moonset. Clicking on these options puts the sky/object where you clicked.

⇒Clicking on **VIEW** produces the drop down panel with: show daylight, show options panel, show/hide Scrollbar, GO HOME
****Show Scroll bar is very important** ⇒ it produces scroll bars on the bottom and right side of the sky Plane. That allows you to move around the sky. You can still click on the hand, but this is neater.
****Show Options Panel is very important** ⇒ this produce a panel of options (Guides, Local View, etc.) down the left side of the screen which controls what you want to see on the sky.
► **Click on the box** in front of Guides, Local View, etc. to make the subset of options boxes drop down so you can see all of the on/off options under each, e.g.

GUIDES→ Celestial Grid (a series of red **horizontal** grid lines appears **every 20º** apart when the **options panel is in place** and every **15º** when the **options panel is removed – this is true on desktops, check the separation on your computer**; in addition, **vertical** grid lines every 2 hrs or **30 degrees apart** in the **east/west** direction), Celestial Poles, Local Meridian, Show Compass, Ecliptic (a green line appears – the path of the sun), Zenith/Nadir, Summer/Winter Solstice, Vernal/Autumnal Equinox.
*** ALL of these should be clicked ON**

LOCAL VIEW→Daylight, Light Pollution

SOLAR SYSTEM→ all of the following have a box for labels to the right
Asteroids, Comets, Meteor Showers, Planets-Moons, Satellites
*** Only Planets-Moons should be clicked ON as well as their LABELS**

STARS→ Milky Way, Stars
***Only the Stars should be clicked ON, not the Labels**

CONSTELLATIONS→ Autoidentifier, Boundaries, Illustrations, Labels, Stick Figures
***Only Boundaries and Labels should be clicked ON.**

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DEEP SPACE→Bright NGC, Messier, NGC/Data base (clicking on the last one produces a list of all kinds of star clusters, nebulae and galaxies, each with different symbols. We may use this later.

⇒If you wish to remove the Horizon, click on your home location (we set to **Sacramento)** on the **TOOL BAR.** A drop down menu will appear. Click on 2X. Watch the changes. You will need to use the hand option to move up in the sky when the process is completed. This process is reversible.

•3. Set Home Location is located in the **TOOL BAR** under **FILE.** **Make sure you set to Sacramento.**

Under **Time Step** – Change to 1 hour
You can now move the entire sky in 1 hour intervals by clicking on either ◄| or |►.

IMPORTANT NOTE: If you really mess up, click **GO Home** under **VIEW** . This will take you to where/when you started originally, but will eliminate all your markers on the sky. You will need to reset Planets, Ecliptic, etc.

⇒ Can you move the sky either with the scroll bars or if necessary with the hand (so that the ecliptic line – the path of the sun on the sky - remains in sight) and find the sun? What sign of the zodiac is the sun located in on the day you did this assignment?

⇒Right click on the sky plane and turn the daylight OFF.
Click **OPTIONS**, then click **Show Options Panel** so that a dropdown panel appears on the left side
of the screen.

- Under Guides, click on all listed **except Local Grid.**
- Under Solar System, click on ONLY Planets and plus their Labels.
- Click the Stars and Milky Way ON, but the labels OFF.
- Under Constellations, click ON labels and boundaries.

Recall that you need to click on the box in front of Guides, etc. to bring down the dropdown panel beneath

⇒You may now click the **Options Panel OFF** to use the full screen to view the sky. You may need to hold the left click down on the fist to bring the horizon up to see the cardinal points.

⇒Use the bottom scroll bar (found under **VIEW**) to place the South point of the horizon in the lower middle of your screen.

STARRY NIGHT 1: Motions and Positions of the Sun, Moon, and Stars During the Year

Name: ____ Date: _______________

1. Set the time to a **1-hour interval** and move the time forward (or backward) till the sun is highest in the sky, i.e. on your local meridian. You may need to use the fist to move up in the sky to see the sun on the green ecliptic line. Note that there should be **15 degrees** between the horizontal red lines of declination on the sky. You should see a Celestial Equator with -15 degrees below it, and there then should be **15 degrees** between the red declination lines. Please check the red declination line labels on the right hand of your screen to make sure these spacings are correct.

► Estimate how far the sun is above the S horizon when it's on the meridian.
_________degrees

►Estimate how far the sun is from the zenith ________________degrees

2. Find the Summer Solstice point on the ecliptic. This is where the sun is located on the first day of summer.

►How far is this point from your zenith when it crosses your local meridian?
_____________degrees

⇒Recall that your local latitude 39° line goes through your zenith when it crosses your local meridian.

►If the celestial equator crosses your local meridian 39 degrees below your zenith, and the sun is 23 ½ degrees north of the celestial equator on the 1st day of summer….does you answer above make sense? Please explain briefly with a sketch below.

```
                              Zenith
                                |
                                |
                                |
                                |
                         ---------------- Celestial Equator
                                |
                                |
                                |
                                |
________________________________|______________________Horizon
                              South
```

►Can the sun ever go through your zenith in Davis, CA? _______________

3. Now, pick a star about 20 degrees above your S horizon when it crosses your local meridian. Move the sky in 1-hour intervals. Let the star rise towards the east and set towards the west. Please sketch out the path of this star between rising and setting in the horizon line below:

```
                              Zenith
                                |
                                |
                                |
                                |
                                |
                                |
------------------------------------------------------------------------------------------
     E           SE             S            SW            W
```

►Does this star rise directly East and set directly West? _________________

►Does this star go through your Zenith? __________________

4. Now move the scroll bar at the bottom of the screen so that you have the **North** point on the horizon centered in the bottom of your screen. Move the sky forward (time increasing) and note the constellations that **NEVER** rise or set. These are the circumpolar constellations.

►Name five of these constellations: ____

►Do the stars move clockwise or counterclockwise around Polaris (circle one)?

►Briefly explain your answer in terms of the directions that stars rise and set on either side of the circumpolar stars:

5. Now, move the horizontal scroll bar back so you are facing the S point on your horizon. Set your date for some time in **December 2018 .** Move the time forward (1-day intervals, then 1-hour intervals) until you find a **full Moon** close to your meridian at midnight. Looking at a **calendar for 2018** that has the Moon's phases might help here.

►Date: ______________________________

►Constellation Moon is in: ___________________________

►How far is the Moon above your South horizon? ________ degrees
►How far is the Moon from your zenith? ________ degrees

Set your date for some time in **June 2018**. Move the time forward until you find a **full Moon** on your local meridian at midnight.

►Date: ____

►Constellation Moon is in: ___________________________________

►How far is the Moon above your southern horizon? _______________ degrees

⇒ Recall that the Full Moon is on the opposite side of the Earth from the Sun and its orbit is within 5 degrees of the ecliptic which includes the signs of the zodiac. So, the Full Moon will be in a constellation that the sun is in 6 months earlier or later, e.g. if the sun is high in the sky during that day then the full Moon will be low in the sky at night.

►Is the Full Moon higher or lower in the sky than the Sun in December?

About the Same Lower Higher

►Is the Full Moon higher or lower in the sky than the Sun in June?

About the Same Lower Higher

►Briefly explain your observations in light of the short paragraph above.

6. Now move the Moon in **1-day** intervals, watch its motion against the background stars. Is this motion <u>East to West</u> or <u>West to East</u> (Circle one)?

►Can you use the background grid (30^{o} between the red **vertical** grid lines) to estimate how far the Moon moves against the background stars in one day?
________________________________ degrees

7. Find the sun and place the sun on your local meridian facing south. Now move the sun in a **two-month** interval. How does the sun move **against the background stars**? East to West or West to East (Circle one)?

►What constellation was initially behind the sun? ____________ Date ___________
►Did this constellation move to the East or West of the Sun after one month (circle one)?

NAME ____

STARRY NIGHT 2: Planetary Motion on the Sky and the Effects of Precession

We shall assume that you have saved all of the original instructions for working the dropdown menus…if not, please review the instructions Starry Night Indoor Lab 1.

Open Starry Night. Set your location for Sacramento. Make sure that in OPTIONS: the cardinal points, celestial coordinates, celestial poles, solstices, equinoxes, ecliptic are on, as well as constellation names & boundaries, plus the planets and their labels.

• 1. Set the time interval for 1 hour. Now move along the ecliptic and try to locate all of the planets.

Date: ______________ Which planets are closest to the Sun? ___________________

Other than Pluto, estimate how far on average (in degrees), the planets lie from the ecliptic. ___________

⇒Set the date for September 15, 2007 at about 5 a.m. and the time interval for 3 *SIDERIAL* days

Make sure that you are pointed between **South and Southeast** along the horizon. You may have to scroll up in the sky to see the ecliptic. Now click the time forward icon and watch the motion of Mars against the background stars until about April 30, 2008. **You may need to change the time to an earlier hour to make sure that Mars stays above the horizon as you scroll west and up (as the days go by).**

NOTE: Be sure to watch the motion of Mars against the background stars, i.e. within one or two constellations.

• 2. What is the general motion of Mars? East to West or West to East?

What constellation was Mars in on October 15?

On approximately what date does Mars reverse its forward motion against the stars? **Look closely in November!** Watch Mars against any nearby stars!

In what constellation is Mars on this date? _________________

In what constellation and on what date did Mars end its retrograde motion?

How long was Mars in Retrograde motion?

What constellation was Mars in on April 30?

Examining the Effects of Precession

Make a note as to whether you have red horizontal declination lines every 15 or 20 degrees apart. Note that the red vertical Right Ascension lines are 30 degrees apart.

Set the date for today. Now go to a location looking at the North Point on your horizon so you can see the Pole Stars. Set the time interval for 900 years.

The star Polaris is very near the **North Celestial Pole (NCP)**, at +90 deg. N declination. The next red horizontal circle should be 15 degrees away (check to be sure it is not 20 deg. As mentioned previously).
NOTE: You can always find Polaris by looking for the brightest star in the constellation Ursa Minor and putting the hand over that star to show its name.

In which constellation is the Vernal Equinox in 2018?

• 3. Click the time interval icon forward in **900-year** steps to about:

2918 – Estimate how far in degrees Polaris is from the NCP.

3818 – Estimate how far Polaris is from the NCP. What constellation is the NCP located in? The Vernal Equinox lies in what constellation?

4718 – Estimate how far Polaris is from the NCP. What named star is closest to the NCP?

5618 – Estimate how far Polaris is from the NCP. The Vernal Equinox lies in which constellation?

6518 - Estimate how far Polaris is from the NCP.

7418 –What very bright star with a real name, e,g, like Sirius, is closest to the NCP, and what constellation lies nearest the NCP?

Is the constellation Cygnus (the Northern Cross) circumpolar In 7405? Is Cygnus circumpolar today?

The Vernal Equinox Lies in which constellation?

8318 – Can you still find Polaris? How far is Polaris from the NCP? The Vernal Equinox lies in which constellation?

9999 – What bright star with a real name is nearest the NCP? Estimate how far in degrees this star is from the NCP.

Can you still find Polaris? Is Polaris circumpolar, never rising or setting?

The Vernal Equinox lies in what constellation?

What can you conclude about the Pole Star? Do they remain the same over time? Do we always have a Pole Star?

• 4. What constellation will the Sun be in on December 31, 9999?

What constellation will the Sun be in on December 31, 2018?

Does the position of the sun with respect to the stars on the same day many years apart remain the same?

Does the position of the Vernal Equinox (the first day of Spring) change with respect to the stars over time? Please describe what you observed in part #3.

Does the Vernal Equinox always remain in the same sign of the Zodiac?

NAME ______________________________

STARRY NIGHT 3: The Sky from the Southern Hemisphere

Open *Starry Night*. Under **VIEW**, click **ON** the **All Objects Under Guide** drop down panel. Click **ON** all options under Guides, Planets & Moons plus their labels, Stars, Constellations & Boundaries. We will now set our home location to Santiago, Chile.

In the top **Tool Ba**r: Under **FILE**, click on **Set Home Location** → Choose Santiago, Chile.

Latitude of Santiago, Chile:

On the **Tool Bar**, click on **Sacramento, USA**. In the dropdown menu, click on **HOME (Santiago**, **Chile).**

•1. Move the scroll bar until the **south point** of your local horizon is in view. You may have to use the hand to pull the horizon down a bit to see more of the sky. Notice the **south celestial pole** and the nearest star. In the dropdown menu on the left side of the screen, **click off** the celestial pole and the meridian. Hide the dropdown panel on the left side of the screen.

What star is closest to the South Celestial Pole? It may not be very bright so look closely. Placing the hand over this star will give you its name.

Approximately how far away in degrees is this star from the Celestial Pole?

In which constellation do we find the South Celestial pole?

How far (in degrees) is the South Point from on the horizon from the South Celestial pole?

How does this value compare to the latitude of Santiago, Chile you noted above?

•2. Now set the time interval to **1 hour** and move the sky in 1-hour intervals. Is the motion around the South Celestial pole Clockwise or Counterclockwise? Is this the **same or different** from the motion of circumpolar stars around the North Celestial Pole?

Can you explain this motion in terms of the rising and setting of the nearby non-circumpolar stars?

•3. Now set the time interval to **200 years**. Click on the **Pole** under **Guides** in the dropdown menu on the left. How far into the future (the year) must you go to find a really bright star with a real name, e.g. like Rigel, almost on top of the South Celestial Pole?

What is the name of this star and in which constellation is this star located?

•4. Place the north point on your horizon in view. Make sure your **local meridian is ON** in the dropdown menu to the left. Set the date for **today** by highlighting the date then entering today's value using the keyboard. Set the time for **noon**. Set the time interval to **1 hour**. **Date: ______________**

How far is the sun from the North Horizon when it crosses your meridian (in degrees)?

How far (in degrees) is the sun from the zenith?

In which direction must you look to see the sun on your local meridian at noon in Santiago, Chile?

In which direction did you look to see the sun on your local meridian in Sacramento, CA?

•5. Place the **east point** of your horizon in view. Move the time in **1-hour i**ntervals until the constellation **Orion (**whose belt lies almost exactly along the Celestial Equator) is rising. Betelgeuse is the bright red star in one corner and Rigel the bright blue star in the opposite corner.

How is this constellation oriented compared to how we view it from Sacramento? Rotated? Right side up? Upside down? You may wish to go back to Sacramento later to look at Orion again.

•6. Now set your time for about 11:30 pm and look toward the South point on your horizon. Make sure the coordinate grids and the constellations are clicked **OFF.** Click **ON** the Milky Way and Bright NGC & Messier (under Deep Space at the bottom of the dropdown panel). Notice the band of light we call the Milky Way (our home galaxy) rising up from the horizon. In Chile, the center of the Milky Way moves directly overhead as opposed to lying low in the southern sky here in California.

Go up in the sky, till slightly north of the zenith, and you see the bulge in the distribution of stars making up the central region of the Milky Way. You may need your room lights **OFF** to see the details of the Milky Way. Now, estimate the thickness of this bulge in degrees:

Turn **ON** the Constellation Labels & Boundaries. In which constellations does the bulge of our galaxy lie? Can we see these constellations from Davis?

Now turn off the Constellation Labels and Boundaries, plus the Coordinates. Move back so the south point of the horizon is in the center of the screen. Looking just above the center of your screen you should see two fuzzy spots in the sky. If you can't find them, click on **Labels** for the Deep Sky Objects at the bottom of the dropdown panel. Placing the cursor over these spots indicates that they are the Large and Small Magellanic Clouds – at a distance of about 180,000 light years, they are the only two galaxies easily visible to the naked eye (though not from the northern hemisphere).

Click **ON** the Constellation Labels & Boundaries. In what constellations do the Small and Large Magellanic Clouds lie?

Small Magellanic Cloud: ____________________

Large Magellanic Cloud: ____________________

ASTRONOMICAL SPECTRA

Stars are so far away in space and time that even through the largest telescopes, they appear as mere dots of light. How, then, do we understand the structure of stars from mere pinpoints of light? By the application of physical laws, a great deal can be deduced just from the properties of the light emitted by different stars. This is the field of **astrophysics**.

Black Body Radiation

From physical laws, it is known that a "hot" body will radiate energy away by emitting "electromagnetic radiation" (EMR), otherwise known as "light." A perfect black body (a body that will absorb all light that falls on it) will radiate energy away proportional to the fourth power of its temperature by a process known as **black body radiation**. Any solid, liquid, or gas under high enough pressure (such as massive stars compressed by gravity) will behave in this manner. (Yes, I know it sounds like a contradiction to say that "bright" luminous stars are "black bodies.")

Temperatures and Colors

How do we know the temperature of stars? One way is from observing the "color" of the star. You know from playing with prisms that sunlight is made up of a rainbow of colors, yet we usually color the sun "yellow" on drawings. Why? The sun radiates a continuous range of colors (including infrared and ultraviolet), but emits the most in yellow (or yellow-green). The amount of each color of light emitted by a black body is described by *Planck's Radiation Law*, basically a range of colors (like a rainbow) around a broad "peak." This color distribution is a function of temperature, so we can deduce a star's surface temperature from its observed **spectrum** (distribution of emitted colors). The hotter a star, the bluer it appears. Conversely, the cooler it is, the redder it appears.

Color is usually measured in terms of the light's **wavelengths** in units of nanometers (nm), one billion times smaller than a meter. (Visible light has wavelengths between 400 and 700 nm, with infrared longer and ultraviolet shorter.) The peak color in Planck's Radiation Law shifts to shorter wavelengths as the temperature increases.

Therefore, if we can measure a star's color, we can get its temperature. This is not as easy as it sounds. In practice, a star's V magnitude m_v (corresponding to visual observations) is measured through a particular yellow-green filter. Its B magnitude (corresponding to relative brightness on blue-sensitive photographic plates) is measured through a particular blue filter. The difference between these two magnitudes is called the star's **color index**, B-V. A bluish star will be brighter in B than in V, and (since brighter is a smaller magnitude) its color index will be a negative number. A reddish star will be brighter in V than in B, and its color index will be a positive number. Examples of some spectral classes and their color indices are tabulated below.

Table1. Color/Temperatures of main sequence stars

Spectral Class	"Color" (perceived)	Temperature (Kelvin)	Color Index
O5	Violet (UV)	47,000	-0.32
B0	Bluish	30,300	-0.29
B5	Blue-white	15,300	-0.16
A0	White	9,410	0.00

A5	Green-white	8,210	+0.14
F0	Green	7,160	+0.31
F5	Green-yellow	6,560	+0.43
G0	Yellow	6,010	+0.59
G5	Yellow-orange	5,780	+0.66
K0	Orange	5,260	+0.82
K5	Orange-red	4,270	+1.15
M0	Red	3,880	+1.46
M5	Deep red	3,260	+1.92
M8	IR	?	?

SPECTRAL LINES

Fraunhofer (1814) found the sun's spectrum to be continuous, but with a number of fine dark lines, i.e. missing colors. Kirchhoff (1860?) called this an **absorption spectrum**. He also found that under low pressure, very hot gasses did the opposite, emitting only a few bright lines – an **emission spectrum**.

Table 2. Some Spectral Lines for Hydrogen

Series Name	**Transition**		**Spectral Notation***	**Wavelength (nm)**	**Color**
	$n_{initial}$ →	n_{final}			
Lyman	2	1	Kα	121	UV
"	3	1	Kβ	102	UV
"	4	1	Kγ	97	UV
Balmer	3	2	Lα	656	Red
"	4	2	Lβ	478	Greenish
"	5	2	Lγ	433	Bluish
"	6	2	Lδ	409	Violet
Paschen	4	3	Mα	1876	IR
"	5	3	Mβ	1282	IR

* Astronomers often use the notation Hα, Hβ, Hγ, etc. for the Balmer series of Hydrogen. These correspond to the C, F, and H Fraunhofer lines.

Atomic Spectra

The explanation of emission and absorption spectra required the discovery of atomic (quantum) physics. An atom has a dense nucleus (of positive charge Z, where Z = atomic number) with negatively charged electrons in orbits about one Angstrom away. Quantum mechanics says that only certain size orbits are allowed, each with a different energy. The bigger the orbit, the higher the energy (until eventually the electron breaks away). The orbits are labeled starting with K at the bottom (see figure 4).

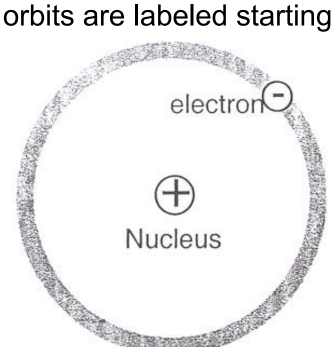


Figure 3. The Atom

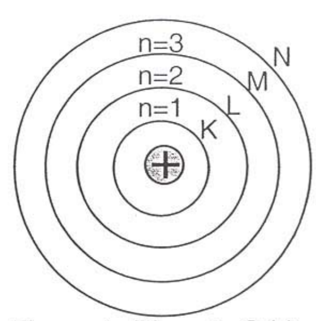
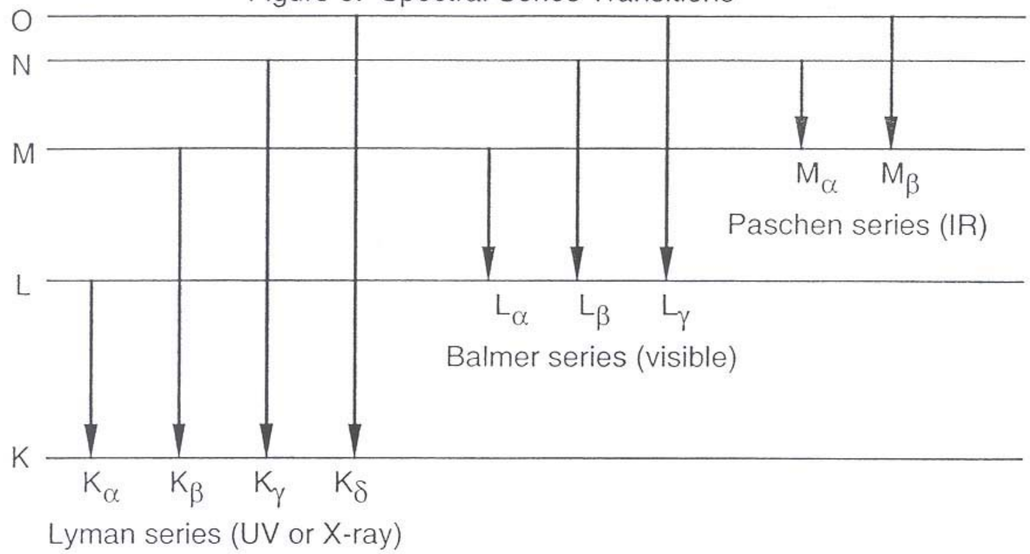


Figure 4. Discrete Orbits

An electron can drop from a high energy orbit to a lower energy orbit, emitting a single photon of light. The color or wavelength of this light will be an exact single color corresponding to the energy difference. Transitions from the n^{th} orbital to the first "K" orbit are known as the Lyman series. These are usually UV (or X-rays) and hence, not visible (see figure 5). Transitions from the n^{th} to the second "L" orbit are called the Balmer series. For hydrogen, one gets four visible colors. The 3 to 2 transition is a bright red line called the **Balmer alpha line**. This red color dominates photos of many nebulae.

Figure 5. Spectral Series Transitions



For the 4 to 2 transition, the energy change is larger, and the color is a shorter wavelength of green, the Balmer beta (β) line. The 5 to 2 and 6 to 2 transitions yield blue and violet lines respectively. All the other possibilities are outside the range of human vision (either IR or UV). What you see is a spectrum with only four colors in it. The relative brightness of each line (called **persistence**) will depend upon the temperature of the gas. If it is not too hot, very few electrons will make it up into the upper orbitals, so the red line will dominate. When the gas is hotter, the other lines will become brighter.

The process can also occur backwards. An electron can absorb one of these special colors (and only these) and go into a higher orbit. This is what creates the absorption spectrum of the sun. The hot photosphere emits a continuous black body distribution of light. The upper atmosphere of the sun (the chromosphere) is cooler, and absorbs the light, but only in specific colors corresponding to the particular atoms present in the sun.

<u>Spectral Classes</u> (see table 1)

Either emission or absorption lines can tell you the elements present in a star. The relative intensities are used to classify the stars. The system is based again on temperature, with type "O" being the hottest, actually an ultraviolet star. Type "M" is the coolest, in the deep red. In between, we have a bunch of letters, but in no rational order: OBAFGKM, traditionally memorized by the phrase **O**h **B**e **A** **F**ine **G**irl **K**iss **M**e. A type "B" is hotter than "A", etc. One can make rough associations with color for each class; see table 6 for a summary. Each class is broken into 10 subclasses. A type "A5" is slightly hotter than "A6." Type "F9" is slightly hotter than "G0."

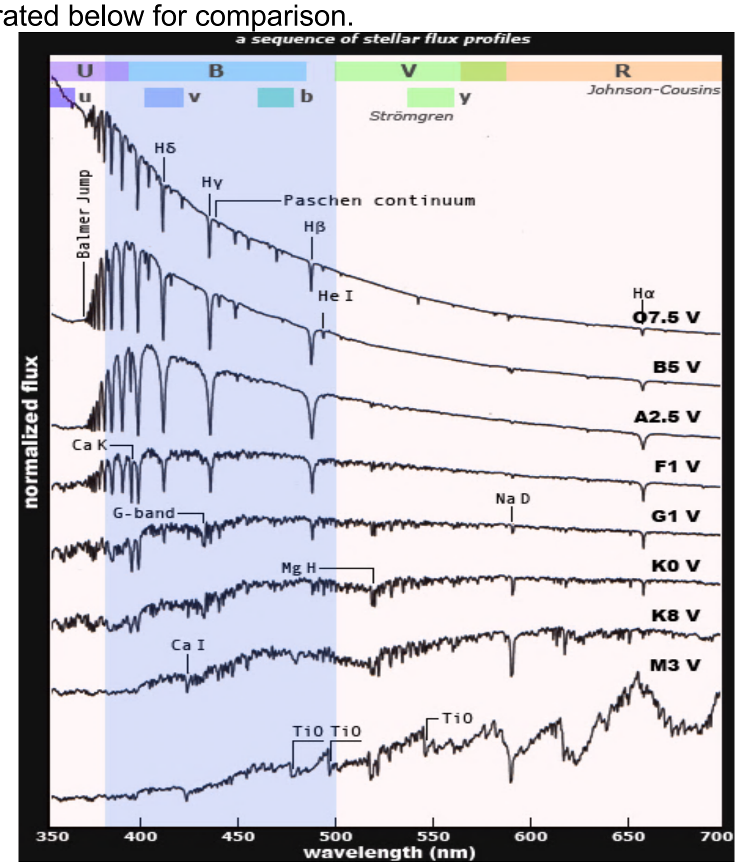
Our sun is a type G2 star. The great majority of stars of the type G2 will be the same as our sun in size, mass, and luminosity. Hence, we can assume all their absolute magnitudes will be about the same, and use their measured apparent magnitudes to estimate their distances. This method of estimating stellar distances is called **spectroscopic parallax**.

Astronomical Spectroscopy

Observatory Observations

Three of the 8" Meade telescopes have been equipped with small grating spectroscopes in lieu of magnifying eyepieces. Instead of a stellar image, the starlight will be spread into a continuous spectrum of colors from violet to red. Note that the stellar image itself provides the spectrum, so depending on the size of the image due to seeing effects, the spectrum will typically be rather narrow. You will be asked to observe the spectra of three different types of stars and note any absorption features (dark lines or bands) that bisect portions of the spectrum. As you go from telescope to telescope, fill in the requested information in **Data Table B** and label any **dark absorption features** seen in the spectra sketched. Be sure to note the color of the star and which colors, **if any**, are brightest in the spectrum. If all the colors in the spectrum appear equally bright, enter **same**. If the Orion or another nebula is visible, note the difference in the appearance of its spectrum as compared to those of the stars. Label the brightest lines seen in **Table B**. One telescope will be set up so that you can observe the Orion nebula directly and note its color.

A photo of several standard stellar spectral types in the red through violet spectral regions is illustrated below for comparison.



While waiting to observe the stellar spectra, there will be 10 hand-held spectroscopes available for you to observe the light emitted by several terrestrial light sources. Try to find at least one incandescent light source and one sodium vapor or mercury vapor street light. In **Data Table A**, label the brightest colors in the incandescent lamp spectrum (if any) and the lines seen in the vapor lamp. Are these similar to any of the light sources seen in your classroom demonstration?

Spectral Standards

Star	RA	Dec	Spectral Type / Stellar Class	Magnitude
Alpha Lyra (Vega)	18h 37m	+38˚ 47’	A0 V	0.03 *
Alpha Aql (Altair)	19h 51m	+08˚ 52’	A7 V	0.76 *
Gamma Cyg	20h 22m	+40˚ 05’	F8 I	2.23
Alpha PsA (Fomalhaut)	22h 58m	-29˚ 37’	A3 V	1.17 *
Beta Peg	23h 04m	+28˚ 06’	M2 III	2.44 *
Beta Cas	00h 09m	+59˚ 10’	F2 III	2.28
Alpha Cas	00h 41m	+56˚ 33’	K0 III	2.24 *
Gamma Cas	00h 57m	+60˚ 44’	B0 IV	2.15 *
Beta And	01h 10m	+35˚ 38’	M0 III	2.07 *
Alpha Ari	02h 07m	+23˚ 28’	K2 III	2.01 *
Alpha Cet	03h 02m	+04˚ 06’	M2 III	2.54
Alpha Tau (Aldebaran)	04h 36m	+16˚ 30’	K5 III	0.87 *
Alpha Aur (Capella)	05h 17m	+46˚ 40’	G6+G2 III	0.08 *
Gamma Ori	05h 25m	+06˚ 21’	B2 III	1.64 *
Alpha Ori (Betelgeuse)	05h 55m	+07˚ 24’	M2 I	0.45 *
Mu Gem	06h 23m	+22˚ 31’	M3 III	2.87
Alpha Gem	07h 35m	+31˚ 53’	A1-A5	1.2 Binary (3” separation) *
Lambda Ursa Majoris	10h 17m	+42˚ 53’	A1 IV	3.45
Mu Ursa Majoris	10h 23m	+41˚ 28’	M0 III	3.06
Beta Ursa Majoris	10h 02m	+56˚ 21’	A0 V	2.34 *
Beta Leo	11h 49m	+14˚ 32’	A3 V	2.14 *
Zeta Ursa Majoris	13h 24.1m	+54˚ 54’	A1 V	2.23 *
Delta Ophiuchus	16h 15m	-03˚ 42’	M1 III	2.73
Alpha Scorpius	16h 30m	-26˚ 27’	M1.5 I	1.06 *
Alpha Hercules	17h 15m	+14˚ 23’	M5 I	2.78

* best spectra

DATE: NAME:

TIME: GROUP MEMBERS:

TELESCOPE #:

LOCATION: Roof? Hallway? Roessler 154?

PURPOSE: To observe and identify emission and absorption spectra using handheld spectroscopes, spectroscopes on the Meade 8-inch telescopes, and using CLEA software.

EQUIPMENT: Meade 8-inch telescope with grating spectroscope, hand-held spectroscope, CLEA stellar spectroscopy software.

OBSERVING CONDITIONS:

LIMITING MAGNITUDE:

Name ____________________________ R.H. Signature __________________________

Data Table A

Incandescent Light Source

Violet Blue Green Yellow Orange Red Brightest Color ___________________

____

Vapor Light Source

Violet Blue Green Yellow Orange Red Brightest Color ___________________

____

Data Table B

Star #1
Name of star ____________ Spectral Class ___________ Color of Star _____________

Sketch in spectral features seen, if any:

Violet Blue Green Yellow Orange Red Brightest color in spectrum ________

____

Star #2
Name of star ____________ Spectral Class ___________ Color of Star _____________

Sketch in spectral features seen, if any:

Violet Blue Green Yellow Orange Red Brightest color in spectrum ________

____

Star #3
Name of star ____________ Spectral Class ___________ Color of Star _____________

Sketch in spectral features seen, if any:

Violet Blue Green Yellow Orange Red Brightest color in spectrum ________

____

Which star is hottest? ___________________

Briefly explain why: ____

Computer Lab – CLEA Software

Part 1: Background and Classification of Stars

First open up the program "Stellar Spectra." Once the program is open, click
File → Log in.
Enter the names of everyone in your lab group, and then click 'OK.' After you have logged in, click on
File → Run → Classify Spectra.

Once the Classify Spectra window is open, click on
File → Unknown Spectrum → Program List.
A window will pop up with several star names in it. The first entry should say "Example 1." Highlight this name and click 'OK'. You should see a graph appear in the middle frame. Click on
File → Preferences → Display → Comb. (Photo & Trace)
Now you should now see the graph on the bottom frame, and in the middle frame you should see a photo of a spectrum. The photo in the middle frame is the same thing that you see with your eyes when you use a prism or diffraction grating on any light. The whiter a point is, the more intense the light is there, and the darker it is, the less intense the light is. The scale of these spectra is in Angstroms, with 3900 Angstroms on the left edge and 4500 Angstroms on the right edge. An angstrom is 10^{-10} m, and 10 Angstroms = 1 nm. The bluer wavelengths are on the left, and the redder wavelengths are on the right.

Now look near 4100 Angstroms. The second frame should have a dark strip, and the third frame should have a 'trough' in the graph. This means the light has a very low intensity at that point. These dark bands are called absorption lines, because the light at these wavelengths is getting absorbed by something and not making it through to us. You should notice three other prominent absorption lines.

Now click on
File → Spectral Line Table
This should open up another window that contains a table of wavelengths and the corresponding elements that create those lines. Move that window off to the side so that it does not cover your spectral window. Move the mouse to the lowest point of the trough at 4100 Angstroms and click on it. The 'Spectral Line Classification' window should jump to the wavelength that you have just clicked. It highlights the wavelength you have clicked on by placing a dotted red line above and below the corresponding wavelength in the table. When you click on the absorption line around 4100, the table should highlight "4101.75 H I (H Delta)." If this is not the line highlighted in your table, make sure the mouse is at the very bottom of the trough and click again, and it should come up.

Now follow the same procedure on the other 3 strong absorption lines. Click on the center of their troughs and write down the wavelength and line identification given by the table.

1. ____

2. ____

3. ____

Two of the absorption lines should have been identified as H lines. H is the chemical symbol for hydrogen, so this means that hydrogen is doing most of the absorbing in this star. The last absorption line, which is not quite as deep as the others, should have been identified as a CA II (K line). Ca is the chemical symbol for calcium, so there is also some calcium in this star that is absorbing some light.

Now let's try and classify this star's spectrum. Go to
File → Preferences → Display → Intensity Trace
This will cause the photograph of the spectrum to disappear and the graph of the spectrum to be put in the middle frame. Next, click on
File → Atlas of Standard Spectra
When the window pops up, select 'Main Sequence' and click 'OK.' Move the window that pops up off to the side so that you can still see your spectra.

On the top and bottom frames, you should see 2 other spectra. These are standard spectra, and we use these standards to classify other stars. But these 2 spectra look pretty different from ours. On the right side of the window, you should see the buttons 'Up' and 'Down'. Scroll through the standard spectra until you find the one that you think most closely matches our spectrum in the middle frame. Once you find the closest match, click the 'Difference' button on the lower right side of the window. The bottom window now subtracts the middle spectrum from the top spectrum and displays the result. Scroll though the standard spectra until you see the smallest difference in the bottom panel. On one of the spectral types, you should see the difference drop to 0 everywhere. This should occur at A5. This means that this star is a perfect match to the spectral type. The spectral type should be written in the table below. The four features we discussed earlier should be recorded there for you.

Now go to
File → Unknown Spectrum → Next on List
This should bring up Example 2 in the middle frame. Now scroll through the spectral types and try to find the spectral type that most closely matches this spectrum. This one is a little tougher. None of the given spectral types make the difference drop to zero. The closest matches are B0 and B6. B6 should have the difference slightly above 0 for most points, and B0 should have the difference slightly below zero for most points. This means that the spectrum for this star is somewhere between B0 and B6. Looking at both B0 and B6, it seems that they are roughly the same distance off, so let's classify this star as B3. Record this in the table below. Now find the most prominent absorption features in the spectrum and use the spectral line identification table to identify the element(s) responsible for the line.

Now let's move on to the unknowns. There are 7 more stars in the list that you need classify. Go through them one by one using the 'Next on List'. There may be more stars in the program than you have on your chart, so make sure you are classifying the correct stars. Classify each star and record your results in the table below. Also, record the wavelengths of the most prominent absorption features in each star, and, using the spectral line identification table, record what element is creating the absorption line.

Name ____

Data Table: Practice Spectral Classification

STAR	SP TYPE	REASONS
HD 124320	A3	H1 lines very strong, Ca(II) line between A0 and A5
HD 37767		
HD 35619		
HD 23733		
O1015		
HD 24189		
HD 107399		
HD 240344		
HD 17647		
BD +63 137		
HD 66171		
HZ 948		
HD 35215		
Feige 40		
Feige 41		
HD 6111		
HD 23863		
HD 221741		
HD 242936		
HD 5351		
SAO 81292		
HD 27685		
HD 21619		
HD 23511		
HD 158659		

Now you have all of your stars classified. Knowing that the spectral classes go through the order OBAFGKM from hot to cold, and, within each group, the lower numbers correspond to hotter stars, arrange your unknown stars in order from hot to cool.

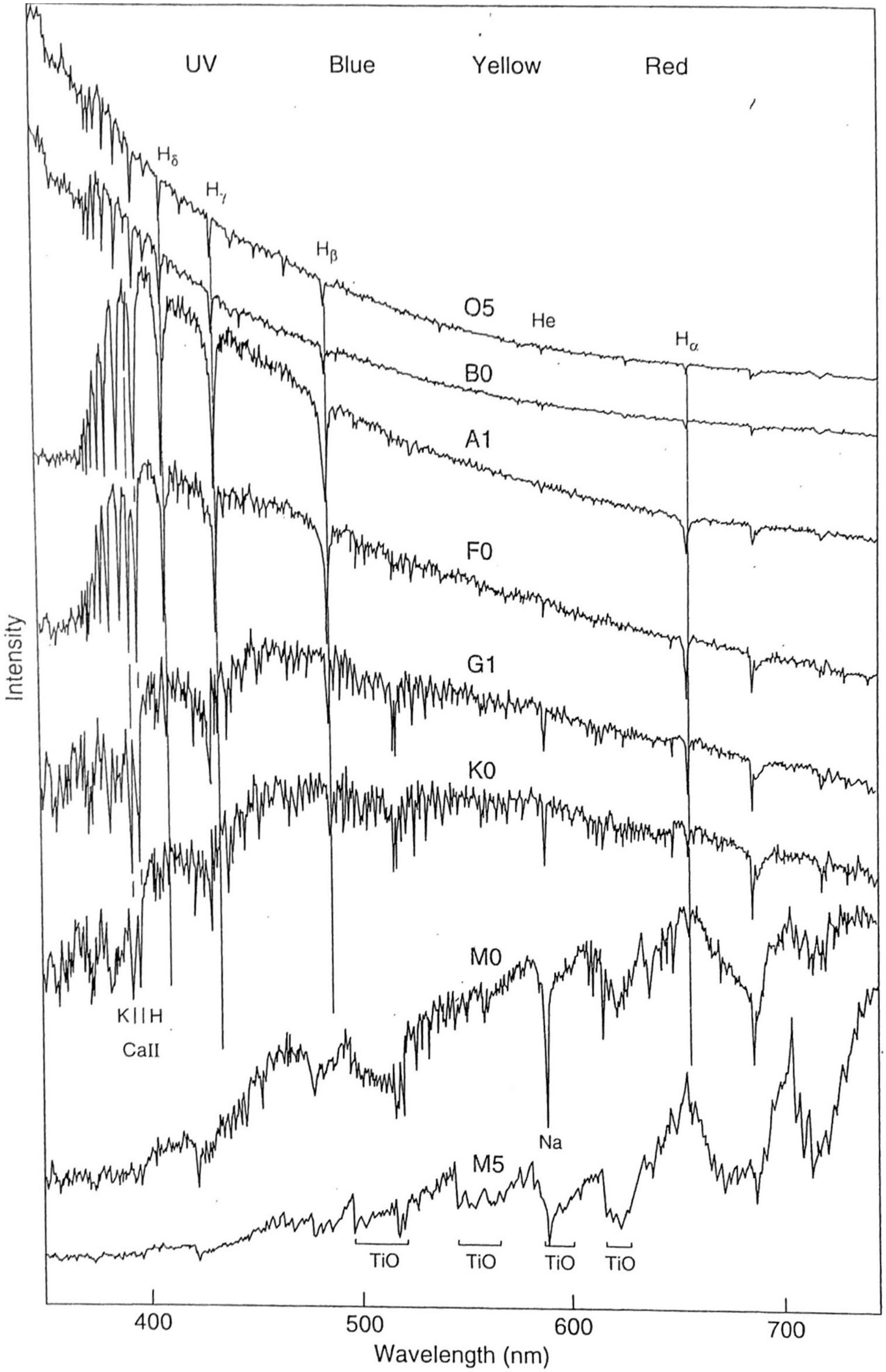
Hottest: ________________________

2:______________________________	14:______________________________
3:______________________________	15:______________________________
4:______________________________	16:______________________________
5:______________________________	17:______________________________
6:______________________________	18:______________________________
7:______________________________	19:______________________________
8:______________________________	20:______________________________
9:______________________________	21:______________________________
10:______________________________	22:______________________________
11:______________________________	23:______________________________
12:______________________________	24:______________________________
13:______________________________	25:______________________________ (coolest)

What element(s) cause the most prominent absorption features in the hot (B, A, F) stars?

What element(s) cause the most prominent absorption features in the cooler (M, K, G) stars?

Stellar Spectra



Part I Spectral Classification Of Main-Sequence Stars

Purpose

To become familiar with the appearance of the spectra of main sequence stars. To learn how to classify the spectra of main sequence stars by comparing a spectrum with an atlas of spectra of selected standard stars.

Method

You will examine the digital spectra of 25 unknown stars, determine the spectral type of each star, and record your results along with the reason for making each classification. The spectra can be compared visually and digitally (point by point) with an representative atlas of 13 standard spectra, and by looking at the relative strengths of characteristic absorption lines, you will be able to estimate the spectral type of unknown stars to about a tenth of a spectral class, even if they lie between spectral types of these stars given in the atlas.

Procedure

1. Select the **Classify Spectra** function from the **File...Run** menu. Answer **no** to any questions the computer may ask at this time about stored spectra (later you may want to examine these spectra, but not now).

   You are now in the classification tool. (See **FIGURE 2** on the following page.) The screen that you see shows three panels, one above another with some control buttons at the right and a menu bar at the top. The center panel will be used to display the spectrum of an unknown star, and the top and bottom panels will show you spectra of standard stars which can be compared with the unknown. Let us now run through the features of the classification tool by classifying the first of the 25 unknown spectra provided for practice.

2. To display the spectra of a practice *unknown* star, select **File**. You will see 3 choices: **Unknown Spectrum**, **Atlas of Standard Spectra**, and **Spectral Line Table**. Choose **Unknown Spectrum**... **Program List**. A window will appear displaying a list of practice stars by name. Highlight the first star on the list — **HD124320** — by clicking the left mouse button (it will be highlighted already), and then click on the **OK** button. You will see the spectrum of HD 124320 displayed in the center panel of the classification screen.

   Look at the spectrum carefully. Note that what you are seeing is a graph of intensity versus wavelength. The spectrum spans a range from 3900 Å to 4500 Å, and the intensity can range from 0 (no light) to 1.0 (maximum light).

The highest points in the spectrum, called the **continuum**, are the overall light from the incandescent surface of the star, while the dips are **absorption lines** produced by atoms and ions further out in the photosphere of the star. You can measure both the wavelength and the intensity of any point in the spectrum by pointing the cursor at it and clicking the left mouse button. The cursor changes from an arrow to a cross, making it easier to center the cursor on the point desired.

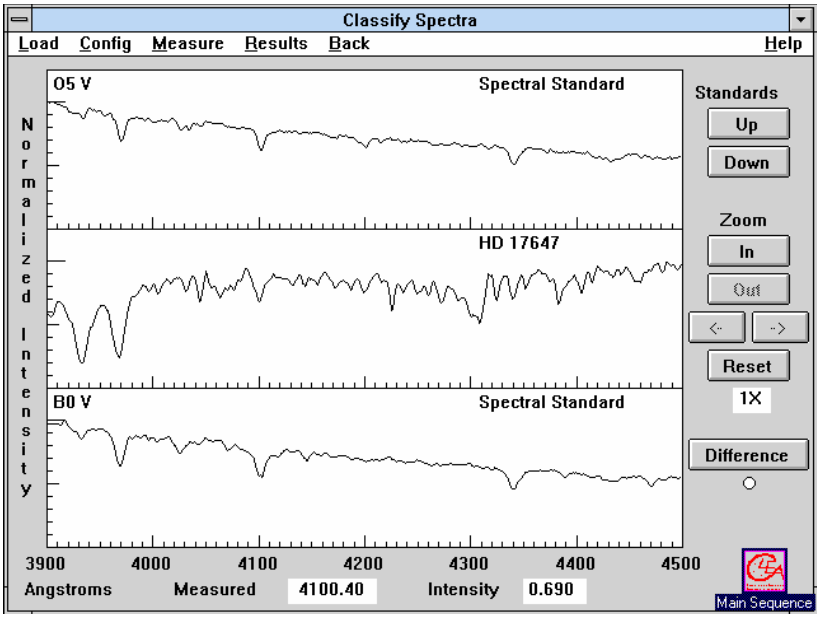


Figure 2: The Classification Window

a. Choose any point on the continuum of HD 124320 and record its wavelength and intensity below.

Wavelength ______________________ Intensity _____________________

b. Measure the wavelength and intensity of the deepest point of the deepest absorption line in the spectrum of HD 124320.

Wavelength ______________________ Intensity _____________________

Note that the spectrum you see here, which is typical of those used for spectral classification, does not cover the entire range of visible wavelengths, but only a limited portion.

c. Question: If you were to look at this range of wavelengths with your eyes, what color would they appear? ____

3. Now you want to find the spectral type of HD 124320 by comparing its spectrum with spectra of known type. Call up the comparison star atlas by selecting the **File...Atlas of Standard Spectra** option. A window will open up displaying numerous choices. Click on **Main Sequence**, the atlas at the top of the list, to select it. Click on **OK** to load the atlas.

4. The 13 spectra in the Atlas will come up in a separate window (see FIGURE 3), but only 4 can be seen at one time. You can look at the entire set by moving the scrollbar at the right of the Atlas window, up and down. Do this, and note that a sequence of representative types, spanning the range from the hottest to the coolest are shown. List the different spectral types that are included in the Atlas in the space provided on the following page, include both the letter of the class and the number of the decimal tenth of a class (e.g. G2, ...). You can ignore the Roman numeral "V" at the end of the spectral type—this just indicates that the standard stars are main sequence stars.

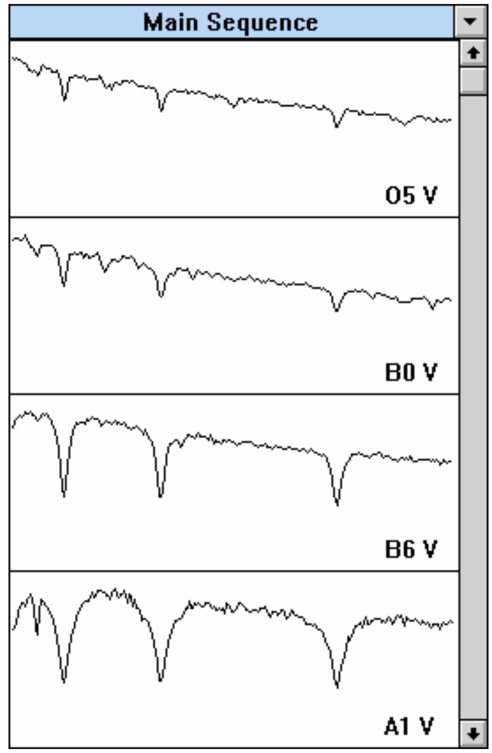
Spectral types in the atlas

____

____

____

Figure 3: The Spectral Window



5. Because the spectral types represent a sequence of stars of different surface temperatures two things are notable:

• the different spectral types show different absorption lines, and

• the overall shape of the continuum changes.

The absorption lines are determined by the presence or absence of particular ions at different temperatures. The shape of the continuum is determined by the blackbody radiation laws. One of these laws, Wein's Law, states that the wavelength of maximum intensity is shorter when the temperature of the object is hotter. This is described mathematically in the equation below:

$$\lambda_{max} = 2.9 \text{ x } 10^7 \, T$$

where λ_{max} = the wavelength of maximum intensity in Angstroms (Å)

T = temperature in degrees Kelvin (°K).

a. As you look through the stars in the Atlas, can you tell from the continuum which spectral type is hottest? Identify the hottest spectral type? ________________________.

Explain your answer. (Remember that, on all these graphs, 3900 Å is at the left, and 4500 Å is at the right).

b. At about what spectral type is the peak continuum intensity at 4200 Å ? (4200 Å is about the middle along the x axis).

____

c. What would be the temperature of this star?

____.

6. Now use the comparison spectra to classify the star. If you look at the panels behind the Atlas window, you will see that two of the comparison star spectra have already been placed in the two panels above and below the spectrum of your unknown star. You can see the three panels more clearly by minimizing the Atlas window. You should see the spectrum of an O5 star is in the top panel, and the spectrum of the next star in the atlas, a B0, in the bottom panel.

If neither of these looks quite like a match to your unknown star, you can move through the Atlas by clicking on the button labeled **down** located at the upper right of the spectrum display. Continue this until you get a close match. You should find that the best match is made with spectral types that have very strong hydrogen lines (more about how to identify these later), and not many other features. The stars with the strongest hydrogen lines are around spectral type A1.

Because not all spectral types are represented in the Atlas, and because you want to get the classification precise to the nearest 1/10 of a spectral type (i.e. G2, not just G), you may have to do some interpolation.

Look at the relative strengths of the absorption lines to do this. For your unknown star, for instance, you should note that it looks most like an A0 type star, but not quite. When the top panel shows an A1 comparison star, the bottom panel will show a A5 star. The strength of the lines in HD124320 lies somewhere between these two. You can therefore make an educated guess that it is about A3.

7. If you want to do this in a more quantitative fashion, click on the button labeled **difference** to the right of the spectrum display. The bottom panel graph will now change, showing the digital difference between the intensity of the comparison spectrum at the top and the unknown spectrum in the center, with zero difference being a straight horizontal line running across the middle of the lower panel.

Look at the dips and valleys on this bottom panel and think about them for a minute. If an absorption line in the comparison star is shallower than the line at the same wavelength in the unknown star, then intensity at those wavelengths in the comparison star will be greater than those in the unknown. So the difference between the two intensities will be greater than zero, and the difference display will show an upward *bum*p. If the top panel is showing an A0 spectra, for instance, and the middle panel HD124320, you should see a small bump at 3933 Å, indicating that the absorption line in the unknown is deeper than that in the A0.

By the same reasoning, if an absorption line in the comparison spectrum is deeper than one in the unknown star, then the difference display will show a downward *di*p. Click on the Standards **down** button to display an A5 comparison spectrum. Note that the 3933 Å difference display now shows a dip, indicating that the absorption line in the unknown is shallower than that of an A5. So it is somewhere in between A0 and A5.

To use the difference display, page through the comparison spectra (using the Up and Down buttons) until the difference between the comparison and unknown star is as close to zero at all wavelengths as possible. To estimate intermediate spectral types, watch to see when the display changes from bumps for some lines, to dips (Since some lines get stronger with temperature, and others get weaker, you will see some lines go from bumps to dips, and some from dips to bumps, as you change comparison spectra). Try to estimate whether the amount of change places the unknown halfway between those two comparison types, or if it seems closer in strength to one of the two comparison types that it lies between.

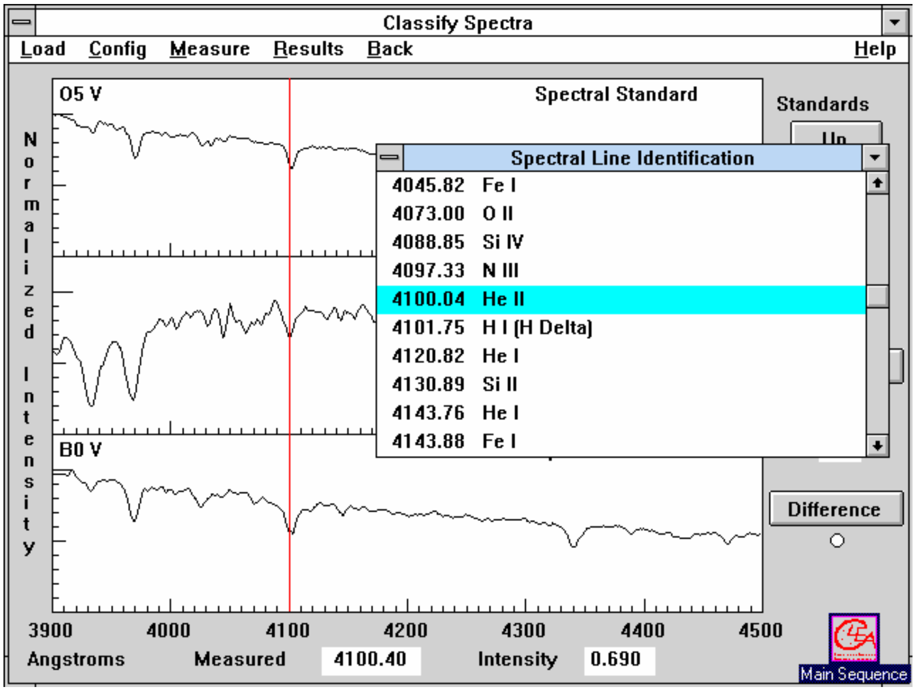
Your estimate of the spectral type of HD124320_________________.

Give reasons for your answer. (For this example: The strength of lines at 4340.4 Å and 4104 Å are almost exactly those of type A1 or A5, and the strength of the 3933 Å line lies somewhere between them.).

8. Record your choice for HD 124320 and your reasons in the computer by selecting **Classification...Record**. This opens up a dialog box where you can record your assigned spectral type and a brief note for your choice. As in the **LogIn** form, you can enter data by Tabbing to the proper box, or clicking the mouse to position the cursor in a box. When you are done recording the classification, click **OK**. You can choose **Review** in this menu if you later want to edit or revise your entry.

9. You have used one or two spectral lines for making a refined classification. But what elements produced them? For reference, you will want to identify the source of the line you are looking at. Select the **File...Spectral Line Table**. You will see a window containing a list of spectral lines. (See FIGURE 4) Adjust the position of the list by pointing the cursor to the blue region of the list window and dragging it in order to view the Classification Window simultaneously. Using the mouse, point the cursor at the center of any absorption line in the spectrum (try the wavelength 4341) and double click the left-hand mouse button. A red line should appear across the screen in the classification window and, if you've centered the crosshairs correctly, a double dashed line on the spectral line list will identify the absorption line at that wavelength.

For instance, the line at 4341 Å is a line from Hydrogen, HI Verify this. Now identify the line at 3933 Å ___________________.



Note: You can minimize the Line Table window until you need it again.

10. Spectra are often displayed as black and white pictures showing the starlight spread out as a rainbow by a diffraction grating or prism. You can view spectra this way using the classification tool. Pull down the menu **File...Preferences...Display...Grayscale Photo**. You are now looking at a representation of what the spectrum might look like if you photographed it. To see the relation between the graphical trace and the photographic representation, select **File...Preferences...Display...Comb. (Photo&Trace)**. The center panel will show the photographic representation of HD124320, and the bottom panel a graph.

Give a physical description of the absorption lines in the photographic spectrum?

____

In the graphical trace? ____.

It is possible to classify stars by looking only at the photographs of the spectra (in fact that is the way it used to be done before computers and digital cameras came along). But you will want to use the trace display for most of your work. Return to this choice by selecting the **File...Preferences...Display...Intensity Trace** menu.

11. You have now classified one spectrum. Call up the next unknown spectrum by pulling down the **File...Unknown Spectra...Next in List**. You do not have to reload the spectral atlas. Use the methods you have practiced above, along with the descriptions of spectral types given in **Appendix I** on page 22 to classify the remaining 24 stars on the list. Use the computer to record your results and your reasons and use **Classification Results...Save to File** to save the results. You may also use the data table on the following page to record your results (and to provide hard-copy backup should the computer fail), and your instructor may request you to print out the record of results from the computer by choosing **Classification Results...Print**.

12. Additional Hints

One quick way to go through the spectral atlas, rather than using the **up** and **down** buttons is to open up the Atlas window and double click on a graph panel of the atlas representing the spectrum you want to insert in the upper comparison panel of the Classification window. The atlas panel selected will be tinted blue to indicate that it is the one selected. You can then iconize the atlas again to see the Classification window more clearly.

You can get close-up views of the spectra by clicking on the **Zoom In** button to the right of the Classification window. In zoom mode, the right and left arrows under the **Zoom** buttons can be used to pan along the spectrum to see wavelengths that are off the edges of the range of view. The **Reset** button returns to full view of the spectrum.

When the Spectral Line List is visible, you can find a particular spectral line on a spectrum by pointing the cursor at an entry on the list and double clicking the *left* mouse button. A red line will appear on the spectrum display at the wavelength of the line.

When the Spectral Line List is visible, pointing the cursor at an entry and double clicking the *right* mouse button will bring up a window with further information on the spectral line in question. In many cases several ions produce spectral lines at about the same wavelength, so it will not be immediately clear what ion is producing a particular absorption line. For instance both CaII and HI produce lines at a wavelength of about 3970 Å . But HI lines are strongest in A stars, while CaII lines are strongest in G and K stars. The notes provided in the spectral line information screens can thus be used to decide what ions are producing what absorption lines if you have a rough idea of the spectral type you are looking at.

Name ____

Astro 25 Lab

Part II: Using spectroscopy to find the distance to a star.

As the telescope records the spectra, it can count the total number of photons that hit the spectroscope and use this to calculate the apparent magnitude of the star (a measure of how bright the star is to us here on Earth). Using other methods, such as stellar parallax, we have measured the distances to other main sequence stars. Using these main sequence stars, we can determine the absolute magnitude (how bright that star would be if it were ten parsecs away) for each spectral type. Using this, it is possible for us to figure out how far away an unknown star is. We will do this for 2 of the stars. First, let us consider Vega. The telescope told us that its apparent magnitude is 0.1. In the previous exercise, you should have found that its spectrum is around A0. Using the table below, we see that the absolute magnitude of an A0 star is 0.7.

To obtain the "distance modulus*", we take
(apparent magnitude – relative magnitude + 5) / 5
For Vega this is:
0.1 – 0.7 + 5 = 4.4
4.4 / 5 = 0.88
So the distance modulus = .88

Then, to find the actual distance, we need to use our calculator. Any scientific or graphing calculator should have a function 10^x on it somewhere. Your calculator may have it as 10^(x) or 10^ . To calculate the distance, all we do is plug in $10^{\text{distance modulus}}$, and this will give us the distance to the star in parsecs.
For Vega this is $10^{0.88}$ = 7.6 parsecs

Now follow this same procedure for Alpha Centauri, which has an apparent magnitude of 0.0

Apparent magnitude – Relative magnitude +5 = ______________________

Now divide this by five to get the distance modulus = ___________________

Now to get distance use the calculator for $10^{\text{distance modulus}}$

Distance = ____

Spectral Type/Absolute Magnitude

O5	-5.8	G0	+4.4
B0	-4.1	G5	+5.1
B5	.1.1	K0	+5.9
A0	+0.7	K5	+7.3
A5	+2.0	M0	+9.0
F0	+2.6	M5	+11.8
F5	+3.4	M8	+16

* The details of where this equation comes from are more mathematically in-depth than what is required for this course, so its derivation has been omitted. If you wish to see this equation derived it can be found in most advanced astronomy texts.

DEEP SKY OBJECTS

At the beginning of the term, we are going to try to locate deep sky objects. You will not have to record anything, but by the end of the term you will be required to find some of these objects on your own and fill in the data below. It requires a degree of practice to become proficient at finding these objects, so don't get discouraged if you don't find this very easy to begin with. You will get some practice every week for the rest of the term, using star maps in the Appendix to help you find these dim objects. You may be asked to find some of these objects from memory as a part of the lab final.

PROCEDURE

You need to know the relative size of the deep sky object in your field of view to identify the object correctly. An object viewed through a telescope will not look like the long exposure photograph of similar objects in your textbook.

To do this we need to find the size of the field of view as seen in the eyepiece of your telescope. First, find a relatively bright star on the celestial equator, (i.e. at declination =0˚). Place this object on the center horizontal line edge (the East side) of your field of view. Now measure the time in minutes and seconds that the object takes to traverse the field of view. If the star disappears immediately, you picked the **WRONG** side.

On the celestial equator: 1 sec (time) = 15 arc seconds
1 minute (time) = 15 arc minutes

A. To find your field of view: Your time (seconds) x 15 arcseconds/second (time) = # arcseconds

Convert this value to arcminutes, knowing that there are 60 arcseconds in one arcminute. Place your values in the **Data Sheet on Line A**.

B. Several lists of deep sky objects (including nebulae, and star clusters) are listed in the appendix. These tables also list the angular size of the objects in arcminutes. Be forewarned…for diffuse nebulae and galaxies, you may not be able to see the light from the outer tenuous gases and/or stars, so these objects will appear smaller than listed when viewed through the telescope. Many double stars of different colors are listed in the complete tables following. Double stars provide a test of the **seeing conditions** at the time of observation based on how well the pair is **resolved**.

Locate at least **FIVE** different objects using the Meade telescope and write the appropriate information/observation in **Table B**.

**Recall that an easy way to locate faint objects on the sky is to set the declination of the object first, then sweep in hour angle in the vicinity of the object.

Data Sheet

R. H Signature ______________________
Telescope #: __________________

Date:
Time:
Observing Conditions:
Limiting magnitude:

Name: _________________________
Group Members:

A. Time for star on the celestial equator to cross the field of view ________seconds

________minutes

Telescope field of view in arcminutes _________arcmin

B. Deep Sky Observations (observations may be continued on the opposite side)

*Appearance = color, relative size to field of view, compactness, etc.

Deep Sky Object Name/Type	Constellation	Angular size (arcmin)	Time of Obs.	Dec.	Hour Angle	Appearance Notes

BINARY STARS

A Test of Telescope Resolving Power and Seeing

The resolution or resolving power of a telescope is its ability to separate objects on the sky and show them as distinct objects. Resolution depends **theoretically on the aperture size** of the telescope but is also degraded by atmospheric effects, i.e. seeing or "twinkling of starlight."

The theoretical formula for the smallest angular separation α resolvable by a telescope of aperture "d" in inches is:

$$\alpha = 4.57/d \quad \text{arcseconds}$$

a) Recall that there are 60 arcseconds in an arcminute. Calculate the theoretical resolution α for the 8-inch aperture Meade telescopes that you are using.

b) What is this number for the 12.5-inch aperture Hutchison telescope?

A way to **experimentally check the resolution** is to observe a double star of KNOWN separation and see if you can distinguish the pair as distinct (i.e. not blurred together as one object).

Far apart	**Close Together**	**Unresolved**
• O	•O	O

From your observations below, try to estimate the actual resolution (in seconds of arc) of the stars seen through the Meade telescopes. If you cannot resolve the objects, which is more at fault, the telescope or the turbulence in the atmosphere? Why did you think this? HINT: Look at your calculation for the theoretical telescope resolution.

Do your stars have different colors? Describe their appearance in the field of view.

Finding charts for all of these stars can be found at the very end of your lab manual and some examples of favorite doubles are listed below. If possible, check out Mizar and Alcor, then observe five other doubles suggested by your roof helpers.

1. Mizar and Alcor

Mizar is the second star from the end of the handle of the Big Dipper. Mizar (zeta Ursa Majoris) and its companion Alcor comprise one of the few doubles to have a separation wide enough to be seen with the naked eye. The magnitude of Mizar is 2.17 while that of Alcor is 4.02. The pair is separated by 12 minutes of arc (12'). This is a good test for your unaided eyes. Can you see both stars without a telescope?

Can you see both stars in the Meade finder telescope? Through the Meade telescope?

Mizar itself should appear as a double when seen through the Meade directly. Mizar B is separated from Mizar A by 14.5 seconds of arc (14"). Make an estimate of the magnitude of Mizar B by knowing that Mizar A is 2.4 mag and Alcor is 4.02 magnitudes. Sketch the relative positions of Mizar A, B, and Alcor.

2. Beta Cygni (Albireo; the Aggie Star)

This is everybody's favorite colored double. Try seeing it in 15x binoculars. With a separation of 34.6", you should easily resolve this pair of very differently colored stars at 3.6 and 5.3 magnitudes.

3. Epsilon Boötes

The components of this binary are separated by 2.8 seconds of arc. At 2.7 and 5.1 magnitudes and with very different colors, this pair is quite spectacular.

Describe the colors and separation of both stars.

4. Epsilon Lyrae

A real double-double (quadruple) star, it is a handy check for seeing conditions near the zenith. Both pairs will be split when the atmosphere is very steady. Both pairs are separated by 208" (over 3 arcminutes), while the stars in each pair are separated by 2.3" (4.9 & 5.2 magnitude) and 2.7" (4.6 & 6.3 magnitude) respectively. Can you resolve the stars in each pair? Can you describe their colors?

5. Alpha Herculis (Ras Algethi)

With components at 3.0 and 6.1 magnitudes, and a separation of 4.8", this is another colorful pair that can be used to check seeing near the zenith. Can you distinguish the color of the fainter component through the telescope?

6. Beta Scorpii

Even though this pair is separated by 13.6", since it is so low in the sky, poor seeing conditions may prevent you from resolving the stars of different colors and very different brightness at 2.0 and 6.0 magnitudes. This is actually a triple system, but the third component is only 0.8" away and very faint at almost 10th magnitude.

Name: __________________________

DATA SHEET

A. Theoretical Calculation of Resolution

8-inch Meade Telescopes **α = ______ arcseconds**

Hutchison 12-inch Telescope **α = ______ arcseconds**

Are the stars "twinkling" very much tonight? ______________________

Does this imply the seeing will be good or fairly poor? ____________________

B. Observations of Double Stars

1. Mizar & Alcor
Distance from the zenith when observed _______________degrees

Can you see both Mizar & Alcor in the finder telescope? _______________

Can you see both Mizar & Alcor looking through the Meade 8-inch telescope? ________

Colors of stars seen ____

Can you see Mizar B? _______ If so, estimate the magnitude of Mizar B _________

Make a sketch of Mizar A & B plus Alcor, showing relative separations and positions:

2. NAME __________________
About how far is this pair from the zenith when observed? _____________ degrees

Can you clearly separate both stars or are they blended? _____________

Colors of both stars? ____

3. NAME ________________________
Distance from the zenith when observed? _________________ degrees

Can you clearly separate them from each other? _____________

Color(s) of star(s) seen? ______________________________________

4. NAME _____________________
Distance from the zenith when observed? _________________ degrees

Can you resolve each of the stars from each other? _____________

Color(s) of star(s) seen? ______________________________________

Sketch of what is seen:

5. NAME ___________________________
Distance from zenith when observed? ____________________ degrees

Can you clearly separate both stars? ___________________

Color(s) of star(s) seen? ______________________________________

6. NAME __________________________
Distance from zenith when observed? ____________________ degrees

Can you clearly separate both stars? ___________________

Color(s) of star(s) seen ______________________________________

<u>Questions</u>
Based on your observations above, do you think the effect of poor seeing on resolution **stays the same, becomes better,** or **becomes worse** as you travel **farther** from the zenith?

If you could not resolve the pairs, do you think the resolving power of the telescope or poor seeing was more to blame? Why do you think this?

List of Colorful Double Stars

This is a list of the most colorful double stars, chosen for resolvability in a small telescope. However, the list includes several of the principal doubles (regardless of color and separation) for reference. Those visible during this quarter's labs are listed in the appendix.

Star	Common Name	Separation (arcsec)	PA (degrees)	Magnitudes	Notes
γ And	Almach	AB=10"	64	2.2, 5.1	Gold, Blue
γ^2 And		BC=0.6"	109	5.5, 6.3	61 year binary, 0.6" max.sep.in 1971
γ Ari	Mesarthim	8.4"	360	4.2, 4.4	Very Pretty
ε Boö	Izar	2.8"	338	3.0, 5.9	Yellow, Green [Pulcherrima of Struve, PA slowly increasing]
ξ Boö		7.2"	334	4.7, 6.6	Yellow, Purple-red [Binary 152 yr, closest (7.2") in 1982]
α Cap	Giedi	376"	291	3.7, 4.5	Both are double:
α^1 Cap	Prime Giedi	45.5"	221	4.5, 9.0	Optical Double
α^2 Cap	Secund Giedi	7.1"	158	3.7, 10.6	fainter is 1.2" binary, mag.11.2 & 11.8
α Cas	Schedar	62.6"		2.2, 9.0	Yellow, Bluish (A=irreg.var.)
η Cas	Achird	11.9"	306	3.7, 7.4	Yellow, Purple (Binary, 480 yr)
ι Cnc		30.7"	307	4.4, 6.5	Yellow, Blue
β Cep	Alfirk	13.7"	250	3.3, 8.0	Green-white, Blue
δ Cep		41"	192	3.6, 7.5	Yellow, Blue [A is Cepheid Var.]
ο Cep		2.7"	208	5.0, 7.5	Green, very Blue
ζ CrB		6.3"	305	4.1, 5.0	Green-white, Green (Pretty)
δ Crv	Algorab	24.2"	212	3.0, 7.5	Yellow, Lilac
α CVn	Cor Caroli	20"	228	2.9, 5.6	
β Cyg	Albireo	34.6"	55	3.0, 5.3	Yellow, Blue
δ Cyg		1.9"	246	3.0, 7.9	Greenish, Ashen (Binary 321 yr)
γ Del		10.6"	269	4.0, 5.0	Gold, Blue-green
ε Dra	Tyl	3.3"	12	4.0, 7.6	Yellow, Blue; slow binary
ε^1 Equ		0.9",	322	5.7, 7.0	Triple, A & B a close binary,
		10.9"	72	7.1	[period of 101 yr.]
α Her	Ras Algethi	4.8"	109	3.0, 6.1	Yellow-Orange, Blue-Green
δ Her	Sarin	11.3"	216	3.0, 8.1	Green, Ashen (decreasing?) optical pair
α Leo	Regulus	176.5"	307	1.5, 8.0	Blue-white, white
γ Leo	Algieba	4.0"	122	2.6, 3.6	Gold, Green-red [binary 407 yr]
α Lib	Zubenelgenubi	4 arcmin		1.2, 5.2	white & green (?)
α Lyr	Vega	56.4"		0.2, 10.5	Blue-White, Orange
ε Lyr		207.8"	172		double-double
		ε^1=2.7"	356	4.6, 6.3	Spectroscopic binary 1200 yr
		ε^2=2.3"	84	4.9, 5.2	Spectroscopic binary 600 yr

Lyra continued on next page

Double Stars continued:

Star	Common Name	Separation (arcsec)	PA (degrees)	Magnitudes	Notes
η Lyr		28.2"	82	4.5, 8.7	
ζ Lyr		43.7"	150	4.4, 5.7	
ε Mon		AB=7.4"	132	5.2, 4.7	Triple star
		AC=2.8"	108	5.6	
β Ori	Rigel	9.4"	206	0.3, 6.7	Yellow-white, Orange
δ Ori	Mintaka	52.8"	0	2.0, 6.8	Green-white,White/Lilac
ζ Ori	Alnitak	AB=2.6"	164	2.0, 5.7	Triple star, yellow, reddish
		AC=57.6"		10.1	Olive
θ1 Ori	Trapezium	cluster		7.0,8.0,4.7	at least 7 stars
				6.3,11.3,...	white, lilac, reddish,...
λ Ori	Meissa	4.2"	42	4.0, 6.0	Yellow, Purple
σ Ori		AB=11.1"		4.0, 10.3	Fine group, striking colors of
		AC=12.9"		7.5, 6.3	Grey, white, blue, red
		AD=41.6"			(8 stars in a 4 inch)
ε Peg	Enif	142.6"		2.7, 8.7	Yellow, Violet
κ Peg		12.9"	296	3.9, 10.8	A is a close binary (11.4 yr)
ε Per		9.0"	9	3.1, 8.3	Green, Blue-white
					[B changes blue to red?]
η Per		28.4"	301	4.0, 8.5	Very yellow, very blue
α Psc	Al Rischa	1.7"	282	4.3, 5.2	Pale green, blue (720 yr period)
α Sco	Antares	3"	274	1.2, 6.5	Red, Green
β Sco	Graffias	AB=13.7"	23	2.0, 6.0	Yellow, Green
		AC=0.8"	105	9.7	triple star
ν Sco		41.5"	336	4.2, 6.5	both A & B are close doubles
	A	1"	2	4.4, 6.4	combined total m=4.2
	B	2.1"	50	6.8, 7.8	combined total m=6.5
θ Ser		22.3"	103	4.0, 4.2	A fine pair
α Tau	Aldebaran	121.7"	112	1.0, 11.2	Gold, Orange
ϕ Tau		52.1"		5.1, 8.5	Red, Blue
ζ UMa	Mizar	14.5"	150	2.2, 3.9	Mizar AB (alias 79 UMa)
g UMa	Alcor, Mizar	12 arcmin	72		Naked-eye double
ξ UMa		2.9"		4.4, 4.9	Binary, 60 yr, widest (2.9") in 1980
ν UMa		7.2"	147	3.7, 10.1	relativelyfixed
α UMi	Polaris	18.3"	217	2.0, 9.0	White, bluish (A is a variable); optical

References: Bernhard, Bennett & Rice **New Handbook for the Heavens** (McGraw-Hill, 1941); **Norton's Star Atlas**; Hirshfeld **Sky Catalog 2000.0**.

THE ROTATION OF SATURN AND ITS RINGS

In this lab we will investigate the Doppler Effect on the spectrum of Saturn and its rings in order to find the rotational period of Saturn and the nature of the rings.

Background

When a light source is moving toward or away from an observer, the lines in its spectrum are displaced by an amount proportional to the speed of approach or recession:

$$\frac{\Delta\lambda}{\lambda} = \frac{v}{c} \qquad (1)$$

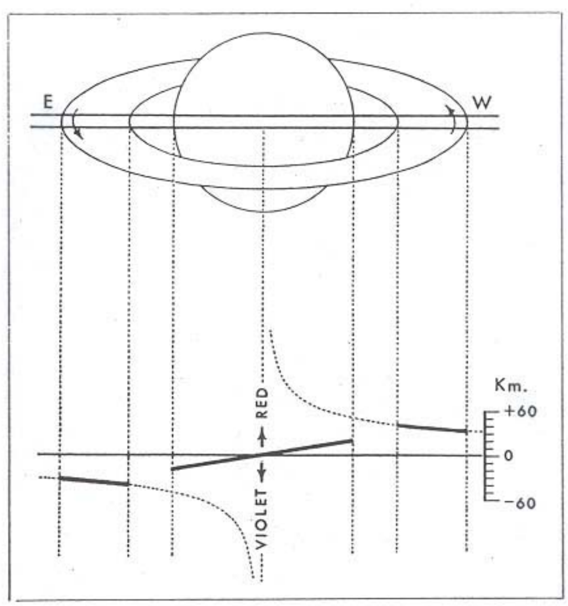
Where λ = wavelength
$\Delta\lambda$ = change in wavelength
v = speed in the direction of motion
c = speed of light = 300,000 km/sec

This is called the **Doppler Effect**. The Doppler Effect is also evident when light is reflected from a moving body. In this case:

$$\frac{\Delta\lambda}{\lambda} = \frac{2v}{c} \qquad (2)$$

The factor of 2 comes in because the light is no longer only emitted by the source, but is going first from the sun as a source to a moving object, which then reflects (behaving like a source) the light back to us. In other words, the object moves into the sun's emitted waves, then while moving, reflects these waves.

The accompanying spectra of Saturn and its rings were taken at Lick Observatory on 19 August, 1964 when the rings were tilted to the line of sight from the earth by 9 degrees. It was a 40-minute exposure with the Coudé spectrograph on the 120-inch



If Saturn rotates as a rigid body and its rings as a swarm of particles, their radial velocities should be as predicted in this diagram by James Keeler. He verified this effect in 1895 with Allegheny Observatory's 13-inch refractor.

reflecting telescope. The spectrograph slit was oriented along the major axis of the rings (as shown below); thus, it fell across the planet's disk and intercepted the rings on each side. The noticeable change in brightness in the outer part of the rings marks the edge of the bright B ring; Cassini's division between this and the outer ring becomes more evident when you sight along the length of the spectrum nearly in the plane of the paper.

The inclined appearance of the dark spectral lines is obvious at once, and its explanation rests on the Doppler principle. One edge of Saturn's disk is rotating **away** from the observer, so light reflected from this edge has a shift toward the **red**, or longer wavelengths of the spectrum. The other edge is rotating **toward** the observer and yields a shift toward the **blue**, or shorter wavelengths.

Sharp-eyed readers will note that not all dark lines show a Doppler tilt, particularly a series near 6280 Angstroms and at longer wavelengths. These are telluric lines, which originate in the Earth's own atmosphere. This particular series arises from molecular oxygen.

Procedure

The letters below the spectra identify chemical elements producing particular absorption lines in the sunlight reflected from Saturn's disk (the central strip) and from its rings (the narrower strips at the top and bottom). The numbers at the top of the spectra are wavelengths in Angstrom units of neon lines, which have been added from a light source at the telescope. Each bright neon **comparison line** at the top of the picture has its counterpart at the bottom. Since these pairs are unaffected by the Doppler shift, they provide standards against which the inclination of Saturn's lines can be measured. For this purpose, **thin sharp lines** have been drawn through each pair of **comparison lines**.

You will measure the distance from a nearby reference line to the upper and lower ends of several well-defined absorption lines in Saturn's spectrum. Try to estimate to at least one-half of a millimeter. **Six lines spaced across the spectrum** should be sufficient. Tabulate the data and calculate the **differences** between the two measurements. Take the **average** of the millimeter differences for all lines measured.

In order to convert these differences from millimeters to Angstrom units, it is necessary to establish the **scale of the photograph in Angstroms per millimeter** by using the labeled comparison lines. Choose two comparison lines that are well separated, measure their separation in millimeters, and then calculate their difference in Angstroms. Find the number of Angstroms/mm. The $\Delta\lambda$'s (changes in wavelength) in mm can now be converted into $\Delta\lambda$'s in Angstroms.

To find the **velocity v** in the Doppler Shift equation, we will choose for a λ a wavelength about **midway** between the extreme values of the measured lines.

As has been mentioned, in the case of a planet shining by reflected light, the displacement of the spectral lines is the sum of the rotation effects with reference to the sun as the source and with reference to the observer. When the planet is in opposition (as is true here), the displacement is just doubled by the reflection which gave us the 2v term in equation (2). Furthermore, since one limb of the planet is **receding** and the other is **approaching** by the same value, the total displacement from one end to the other represents twice the equatorial velocity. Consequently, the measured $\Delta\lambda$ gives a value for v that is now not just 2v but **4v**, or four times the equatorial velocity.

So:
$$\frac{\Delta\lambda}{\lambda} = \frac{4v}{c} \qquad (3)$$

And:
$$v = \underline{\Delta\lambda} \times \underline{c} \qquad (4)$$

λ 4

Knowing the equatorial velocity and the radius of Saturn (60,400 km), we can now find the period of the planet's rotation:

$$\text{Velocity} = \frac{\text{distance}}{\text{time}} = \frac{\text{circumference}}{\text{period}} = \frac{2\pi \text{ x Radius}}{\text{period}} \qquad (5)$$

So:

$$\text{Period} = \frac{2\pi \text{ x Radius}}{\text{velocity}} \qquad (6)$$

Where the velocity v is obtained from (4).

The accepted equatorial period for Saturn is **10 hours 14 minutes.** With our comparatively simple measurements, however, an error of an hour is not unusual. As a side note, Saturn's rotation axis is not perpendicular to our line of sight, so that the limbs of the planet are moving with slightly less than the rotation speed along our line of sight. This will also introduce a small error in our answer.

Saturn's Rings

If the rings rotated as a rigid structure, a given spectral line in the two-ring spectra would fall on a single straight line. When a rigid structure rotates, the velocity increases the farther out we move from the axis of rotation. Clearly, this is not the case, and some other explanation is required.

James Keeler, writing in the first volume of the *Astronomical Journal* (1895), described such an alternative: "The hypothesis that the rings of Saturn are composed of an immense multitude of comparatively small bodies, revolving around Saturn in circular orbits, has been firmly established since the publication of Maxwell's classical paper in 1859. All the observed phenomena of the rings are naturally and completely explained by it, and mathematical investigation shows that a solid or fluid ring could not exist under the circumstances in which the actual ring is placed. I have recently obtained a spectroscopic proof of the meteoric constitution of the ring, which is of interest because it is the first **direct** proof and because it illustrates in a very beautiful manner the fruitfulness of **Doppler's principle**.

Since the relative velocities of different parts of the ring would be essentially different under the two hypotheses of rigid structure and meteoric constitution, it is possible to distinguish between these hypotheses by measuring the motion of the different parts of the ring in the line of sight."

The motion of the matter composing the ring is Keplerian. The inner particles revolve faster than the outer ones, so the spectral lines have the opposite tilt to the lines of the planet itself. This is just how the planets move around the sun, as explained by Kepler's 2nd & 3rd Laws. Obviously, this is conclusive evidence that the ring system cannot be a single solid body, which rotates with greater speed on the outside, but must be composed of separately moving particles."

Name: ___________________________

DATA SHEET

Distance from Neon Reference Line		**Δ D_1D_2**
D_1 top (mm) (± 0.5 mm)	**D_2 bottom (mm) (± 0.5 mm)**	**$\vert D_1 - D_2 \vert$ (mm)**

____
Average Δ D_1 D_2

Scale: 6304.79 Å – 6217.28 Å = _________ 6217.28 Å – 6128.45 Å = ____________

distance in mm = __________ distance in mm = ____________

Å/mm = __________ Å/mm = ____________

Average Å/mm ______________

Look carefully at the diagram on page 1. Is Δ D_1 D_2 a measure of the rotation speed of Saturn or a multiple thereof? What should you have measured to get $\Delta\lambda$? You should make a sketch similar to that on page 1 and note the value of x to place in the conversion equation below.

Conversion of x Δ D_1 D_2 from mm to Angstroms:

Central or mid-wavelength: 6216 Å

Velocity Calculation:

Period Calculation:

Saturn's Rotation Period _______________

NAME ______________________________

STAR CLUSTERS, NEBULAE, AND GALAXIES ON THE SKY (INDOOR)

In this lab, we will project several types of celestial objects (stars, nebulae, open star clusters, globular clusters, galaxies, etc.) to see if we can use their distribution to define the Milky Way – the plane of our home galaxy- across the sky.

BASIC SETUP: The laptops should already be configured as recommended below. Please see the following instruction sheet describing the *REDSHIFT 5* screen and software operation. A snapshot of the screen is also appended.

Make sure your home location is Sacramento.
NOTE: Clicking on the box **in front** of a word, such as STARS, clicks that option **ON** or makes those objects on the sky frame visible.

In the top **Tool Bar**, go to **VIEW** → **Guides** – In the dropdown menu, make sure **Horizontal**, **Celestial**, and **Ecliptic** are clicked **ON**. These may also be found under **Tool Bar** → **PANELS** → **FILTERS**, then click on **Sky Chart** at the top of the panel.

Make sure that **True Sky Color**, **Meteors**, and the **Milky Way** are clicked **OFF** under **Tool Bar** → **VIEW**.

Make sure the Horizon Shading is **Transparent**. Right clicking on the sky frame gives the Horizon Shading.

In the top **Tool Bar**, go to **PANELS** → **VIEW**
In the dropdown panel, click on **Coordinates**, make sure the altitude is about 50 degrees. Change the azimuth to 180 degrees, i.e. pointed South
Also, in **PANELS** → **FILTERS** → **Sky Chart**, click on the word **constellations**. In the action box, click on **ALL** at the top, then **Boundaries** and **Names**

---

1. In the **Tool Bar**, click on **PANELS** → **FILTERS**. In the dropdown panel, click on **Objects** at the top of the panel, then click on the word “**Stars**” (or you can click on the word “**more >>**” at the bottom of the panel). In the action box that appears to the right of the panel, make sure the sliding scale **limiting magnitude** is set to the very end, or about **5.9**. Close the dialog box by clicking on “**Stars**” again. Now click the box in front of the word “**Stars**” to place your objects on the sky frame. A check mark should appear in front of the word “**Stars**.”

Click on **Tool bar** → **Panels** → **Time**. In the dropdown box on the left side of the screen, set the time interval to **1 hour** in the **Time Control Panel** box. Now move the sky around in 1-hour intervals by pressing the Time Forward key |►. You should observe the stars to be slightly concentrated in two different regions of the sky. Name a few **constellations** where you see the densest concentrations of stars.

____

2. Go to **Tool Bar** → **Panels** → **Filters**. Under the dropdown menu on the left side of the screen, click on **Objects**, then the word “**Clusters**” (or **More >>** at the bottom of the panel), then click on **Open Clusters** in the dialog box. Click **ON** the▼ next to Open Cluster and you will see several choices: Real, Area, Icon, Hide. Click on **Icon** (yellow symbol). Click on the “**Filter By**” tab and set the limiting magnitude to the end of the sliding scale, or **10.8**. Make sure the box at the top labeled **Visual Magnitude (zoom dependable)** is **OFF**. Close this dialog box by clicking the word “**Cluster**” (or **Less <<** at the bottom of the panel). Now click on the word “**Nebulae**.” Choose **Bright and Dark Nebulae** in the dialog box that appears. Choose ▼, **icon** for both. Bright nebulae are blue green and dark nebulae are light blue in color. Click on “**Filter By**” at the top of the box, then set the sliding scale limiting magnitude to **10.8** or the end of the scale. Again, make sure that the label **Visual Magnitude (zoom dependable)** at the top of the box is **OFF**. Close the dialog box. Make sure the boxes in front of **Clusters** and **Nebulae** are clicked **ON** so that their icons will be visible on the sky frame.

Now move the sky around in **1-hour intervals** and note that the star clusters and nebulae again concentrate in two different regions of the sky. Name a few constellations where you see the densest concentration of these objects.

____

Are these regions of concentration roughly the same as that of the stars?

____

Can you suggest a reason why this might be so?

____

____

3. Click **OFF** the box in front of both the **Clusters** and **Nebulae**. Click on the word “**Cluster**” and open the dialog box. Click **OFF** the Open Clusters, Click **ON** the Globular Clusters. Click ▼ then on **Icons** (yellow symbol). Leave the limiting magnitudes as previously set to 10.8 under “**Filter By**.” Move the sky around in **1-hour intervals** and note the constellations in which the globular clusters seem to concentrate.

____

Is there **ONE** specific set of constellations where we see the greatest concentration? Please list the constellations where this occurs.

____

How does your answer here compare to those in #1 & #2? ____________________

Can you explain the significance of the single largest concentration of globular clusters?

____

____

4. In the **Tool Bar**, under **VIEW**, click **ON** the Milky Way. How do the constellations that the Milky Way passes through compare to your answers to parts 1 through 3?

____

Does the Milky Way lie along the Ecliptic or Celestial Equator, or at some large angle to them?

____

5. Click **OFF** the box in front of **Clusters** and the **Milky Way**. Click on the word "**Galaxies**" and open the dialog box. Click on ▼, **ICONS** (red) for all types of galaxies. Make sure all types of galaxies are clicked **ON** in the dialog box. Click on "**Filter By**" at the top of the box. Then set the sliding scale limiting magnitude to **14**. Click on the "**Visual Magnitude (Zoom Dependable)"** box at the top. Click **OFF** the dialog box and click **ON** the box in front of Galaxies.

Now move around the sky in 1-hour intervals. Can you find any constellations in which the galaxies seem to be particularly concentrated?

____

Are there any constellations which seem to be particularly devoid of galaxies? Try clicking **OFF** the **Visual magnitude (Zoom Dependable)** option at the top of the **Filter By** mode in the **Galaxy** dialog box, or set the limiting magnitude to **16**.

____

How do these latter regions devoid of galaxies compare to what you found in parts 1 through 4?

____

Can you explain this observation?

____

____

6. Click **OFF** the box in front of Galaxies. Click on the word "**Nebulae**" to open the dialog box. In the box, click **OFF** Bright and Dark Nebulae, click **ON** the Planetary Nebulae. Choose ▼, **ICON**, and leave the limiting magnitude at **10.8**. Click **OFF** the dialog box, click **ON** the box in front of Nebulae.

Recall that planetary nebulae are objects found near the end of a star's life cycle. Would you expect them to be young or old objects, generally speaking?

____

Now move the sky around in 1-hour time intervals. Do they seem to have any particular concentration on the sky?

____

Are they distributed more like galaxies or star clusters and nebulae?

____

Conclusions:

What can you conclude about the location of galaxies, open star clusters, emission nebulae, dark nebulae, and globular clusters with respect to the Milky Way on the sky?

In which constellation does the center of the galaxy lie? Which of these objects are you most likely to find there?

REDSHIFT 5 - Operating Instructions

Sky Panel appears on screen when Redshift 5 is loaded. The all-purpose **Tool Bar** lies along top of the screen. Clicking on these tools gives the options listed below:

View		**Objects**	**Panels**	**Control**	**Tools**
Constellation		Sun	Time	Set Time System	-
Milky Way		Planets	Location	Run Time	-
Meteors		Moons	View	Follow Time System	-
True Sky Color		Stars	Filters	Return Home	Preferences
Guides ►	Horizontal (green)	Star Clusters			
	Celestial (white)	Nebulae			
	Ecliptic (orange)	Galaxies			
	Galactic				
Surface Features					
Quick Start Info					
FOV Indicators – Field of View					
Flip					
Night Vision					
Full Screen					

*Clicking on each of the individual items listed in **PANELS** produces the associated control panel on the left-hand side of the screen. You can also click object/events **ON/OFF** under the **VIEW** and **OBJECTS** Tools.

e.g. **Navigation** appears with the control panels listed below, as

Time Location View - When you click on these, you get the associated sub-panel on the left side of the screen.

Time – Set time or control motion backward/forward in time.

◄	◄|	■	|►	►
Movie	Step	Stop	Step	Movie

Location – Set longitude and/or latitude.

View – Set altitude and/or azimuth.

Also, at very bottom: **Zoom** the field of view in or out - this value should be about 0.4.

1. To find a certain place on Earth, say Sacramento:
Click on **TOOLS** → Preferences → Find Location → drop down menu – Towns and Cities – Sacramento (click OK).
Enter the longitude and latitude in the **LOCATION** box in the panel on the left side of the screen.

2. Right click on sky frame gives: **Horizon Shading** (transparent, opaque, none) as one choice.
Click on Horizon Shading and choose **Transparent**.

When you click on **PANELS** then Filters, you will see a dropdown menu with the control panels: **Objects & Sky Charts** on the left side of the screen below the Navigation drop-down panel.

3. Clicking on **Objects** produces:
▼
□Sun
□Planets
□Moons
□Asteroids ►
□Comets
□Spacecraft
□Stars
□Clusters
□Nebulae
□Galaxies
□Quasars

Clicking on the names of these objects activates an interactive dialog box in which you can change options such as: brightness, name, how indicated on the sky map, etc. Clicking on the name again hides the dialog box. Clicking on the box in front of the name lets you see the objects.

In their interactive dialog boxes:
Planets - make sure all images exhibit **ICONS** and that the **Label is ON**.
Make sure **Stars** are set to magnitude 5, **Star Names OFF**.
Comets, Spacecraft, Clusters, Nebulae, Galaxies, Quasars should be clicked **OFF.**

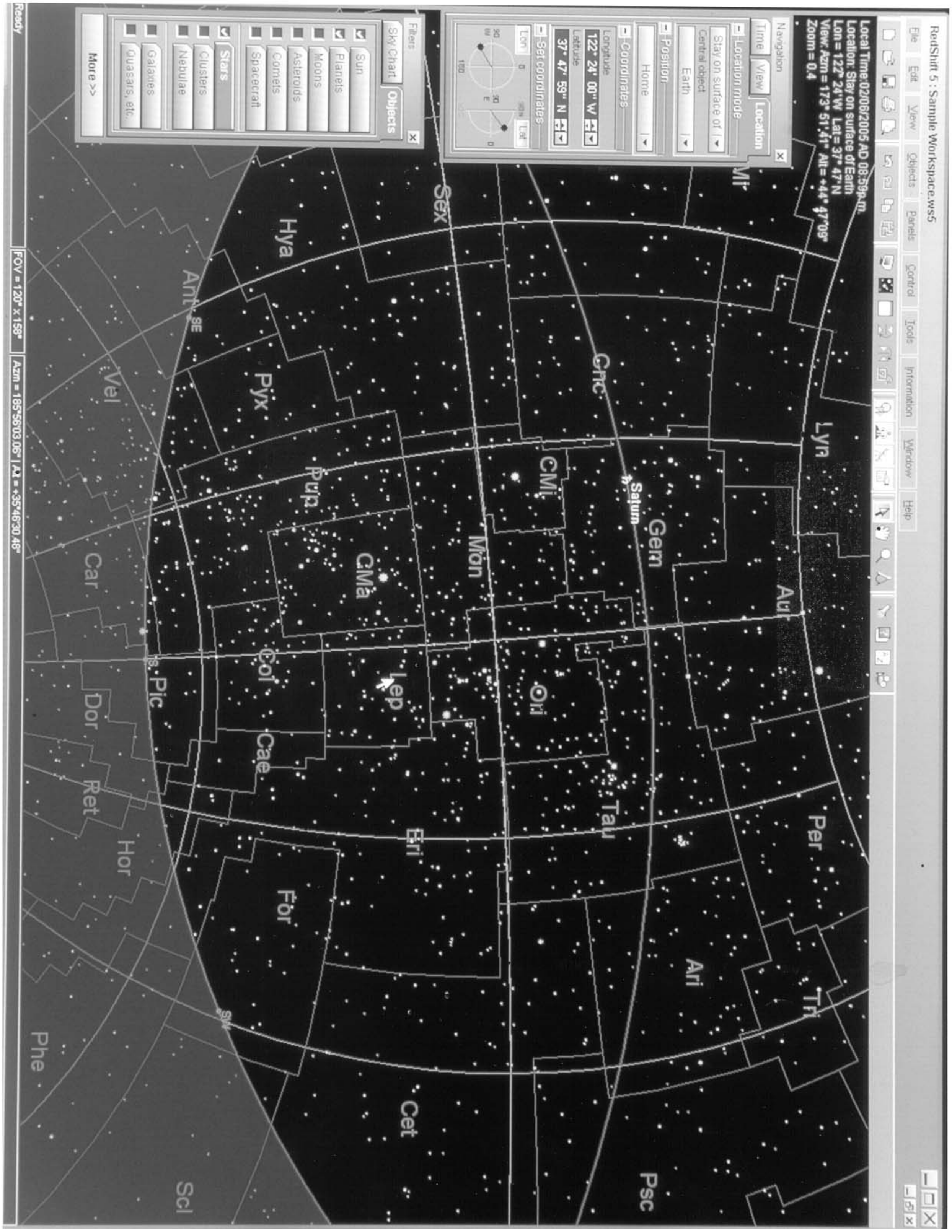
4. Clicking on **Sky Chart** produces:
▼
□Constellations
□Milky Way
□Meteors
□True Sky Color ►
□Night Vision
Guides
□Horizontal
□Celestial
□Ecliptic
□Galactic

As in the objects list, clicking on the words produces an interactive dialog box.

Make sure the Milky Way, True Sky Color, Night Vision, and Meteors are clicked **OFF**.

Click **ON** Horizontal, Celestial, and Ecliptic in the activate box in front of the object.
Clicking on the word “Horizontal” produces an active dialog box. Make sure the cardinal points (compass) and pole are **ON**. All other options should be **OFF**.
Clicking on “Celestial”, make sure all options are **ON**. Celestial coordinates are right ascension and declination. The white declination lines on the screen are located at the celestial equator and at 45 degrees.
Click on “Constellations.” In the interactive box, click on **ALL** at the top, then boundaries and label: Brief Latin.

Just remember that if the screen ever looks odd (e.g. with the horizon at some funny angle), you can always hit the UNDO icon at the top of the screen to undo any mistake!


RedShift 5 : Sample Workspace.ws5
File Edit View Objects Panels Control Tools Information Window Help
Local Time:02/06/2005 AD 08:59p.m.
Location: Stay on surface of Earth
Lon = 122° 24'W Lat = 37° 47'N
Zoom = 0.4
Navigation
Time View Location
Location mode
Stay on surface of
Central object
Earth
Position
Home
Coordinates
Longitude
122° 24' 00" W
Latitude
37° 47' 59" N
Set coordinates
Filters
Sky Chart Objects
Sun
Planets
Moons
Asteroids
Comets
Spacecraft
Stars
Clusters
Nebulae
Galaxies
Quasars, etc.
More >>
Lyn
Cnc
Gem
Saturn
CMi
Aur
Per
Tri
Psc
Ari
Tau
Ori
Mon
Hya
Sex
Pyx
Pup
CMa
Lep
Col
Eri
Cet
For
Cae
Pic
Dor
Ret
Hor
Car
Vel
Ant
Phe
Scl
Ready
FOV = 120° x 158°

GLOBULAR CLUSTERS AND THE DISTANCE TO THE GALAXY M87

One basic method for measuring distances is to use an object of known absolute magnitude M_v, measure its apparent magnitude m_v, and calculate the distance r (in parsecs) from:

$$m_v - M_v = 5 \log r \text{ (pc)} - 5 \qquad (1)$$

The brightest globular clusters in other galaxies have a known M_v = -9.5. Measuring the average apparent magnitude $\langle m_v \rangle$ for four clusters in the giant elliptical galaxy M87 will allow the calculation of the distance of this system from equation (1), rewritten as:

$$\text{Log } r = (m_v - M_v + 5) / 5 \qquad (2)$$

1. Measure the diameters of the **five numbered stars** (members of our galaxy*) of known magnitude on the photograph and record the data in the table below. Square each and enter as S^2.

*Note: You are looking through the outer regions of our galaxy to see galaxies beyond the Milky Way.

Star	m_v	S (in mm)	S^2	Cluster	S (in mm)
1	20.3			1	
2	21.8			2	
3	22.7			3	
4	23.5			4	
5	24.2				

2. **Plot** S^2 versus m_v of the stars on the graph provided and draw a straight line through the points as BEST as you can. This calibrates image area (which goes as S^2) with brightness in the photograph.
3. **Measure** the diameters of **FOUR** globular clusters and record their S^2 (in mm) in the table above. **The globular clusters are the tiny fuzzy dots around M87**.
4. **Add** these cluster S's and divide the sum by 4 to get an average S. **Square** the average to get $\langle S \rangle^2$.
5. Use the **straight line** on your graph to determine the $\langle m_v \rangle$ corresponding to your globular clusters.
6. Use **equation (2)** and the given value for the brightest cl
uster M_v to calculate the distance to M87 in parsecs (pc). Then convert your answer to kiloparsecs (kpc) by dividing by 1000.

For M 87: r = ________________ pc = _________________ kpc

How does your answer compare to the known value 60,000 kpc?

Note: You are using a logarithmic scale for the S^2 axis since S^2 is proportional to the area of the image on the photograph, and the area of the image is proportional to the apparent brightness of the object. Magnitude is a logarithmic function of brightness.

You will notice that your data points for the individual stars $<S^2>$ vs. magnitude do not all fall on your best fit straight line.   Since we have only four cluster data points, the best way to estimate the error is to calculate the mean deviation of the distances for the clusters. Find the distance for each individual cluster, then the average value of the four distances. Find the difference of each value from the average….sum these values.   This value divided by four is the mean deviation.

Add this value to your calculated distance.

Subtract this value from your calculated distance.

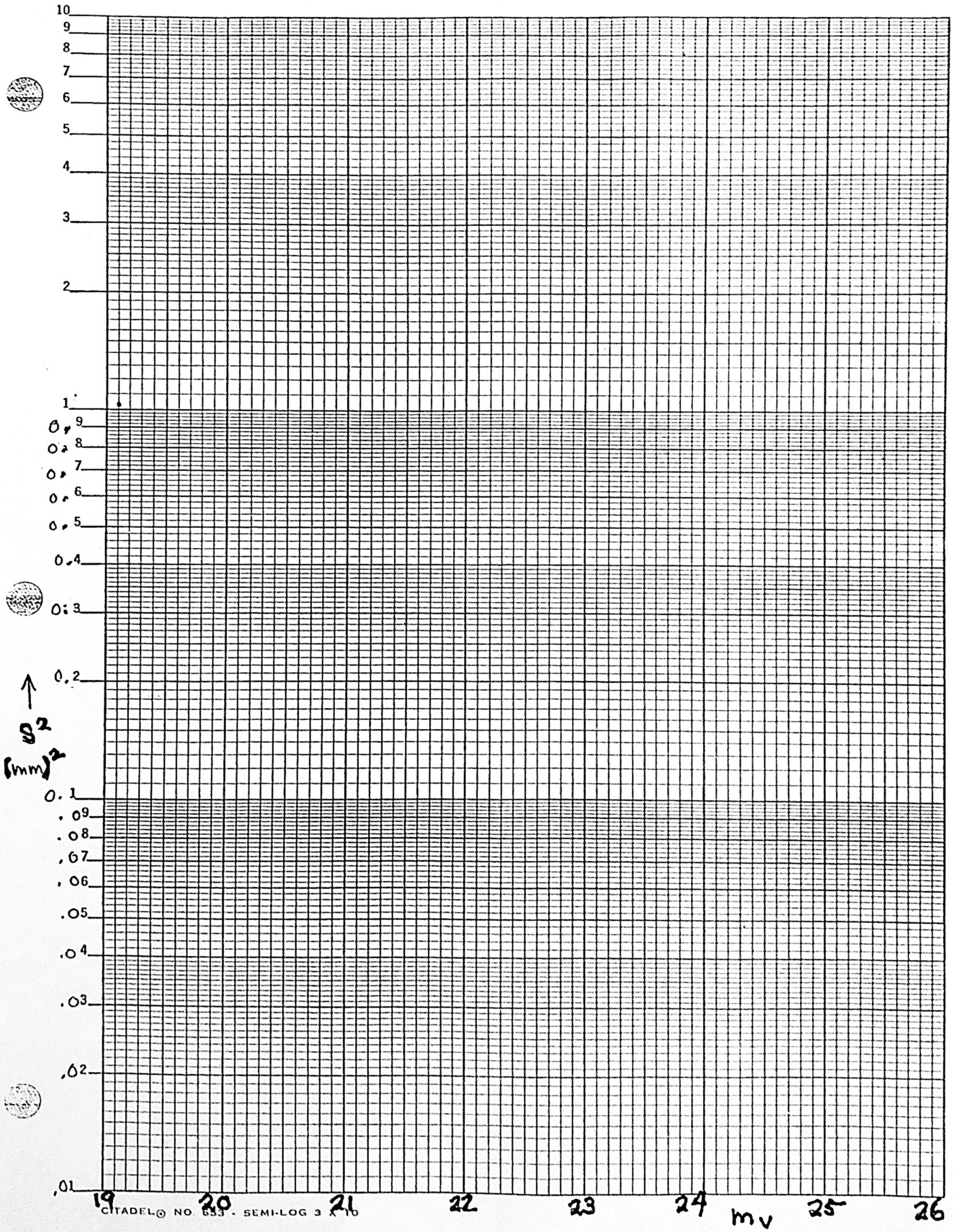
Does the real distance to M87 fall within these values?

If not, then you may have a systematic error in the way you measured the diameters of clusters or the calibrations stars, either too large or too small.

If your diameters are too large…will this make the distance too large or too small?

If your diameters are too small…will this make the distance too large or too small?

Hint: Diameter is related to apparent magnitude and apparent magnitude is related to distance.


10
9
8
7
6
5
4
3
2
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
S^2
$(mm)^2$
0.1
.09
.08
.07
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DYING STARS AND THE BIRTH OF THE ELEMENTS

Stars are born from giant clouds of gas and dust. If these clouds are compressed (perhaps due to a collision with another cloud), they can collapse under gravity. These clouds heat up as they shrink and the temperature and pressure inside the cores of these clouds can become high enough to fuse hydrogen into helium and a star is born.

As a star fuses more and more hydrogen, helium accumulates in its core. If the helium core gets hot enough, it can start to fuse helium into carbon. This puts a large amount of energy into the outer layers of the star, causing it to expand and become a red giant. In low-mass stars like the sun, the outer layers eventually blow off and become a planetary nebula, leaving behind the exposed core, now called a white dwarf. In high-mass stars of about eight or more solar masses, there is enough pressure in the core to fuse carbon into oxygen. This eventually leads to further core collapse as oxygen fuses into magnesium and silicon, and silicon fuses into iron. All of these reactions are exothermic – they release energy when fusion occurs. However, iron requires an *input* of energy to fuse. Iron keeps building up in the core until finally, there is not enough energy to support the star and the outer layers collapse in towards the center. This collapse, combined with an outburst of neutrinos from the core, causes a massive shockwave that blows off the outer layers in what is called a supernova. The gas heated by the shockwave cools off over time, and the gas particles emit electromagnetic radiation in the x-ray band that we can detect here on Earth. This radiation is the key to understanding the physics of the gas in the supernova remnant. By studying the x-ray radiation from these exploded stars, we can investigate the properties of these objects.

To begin, open the program “Dying Stars and the Birth of the Elements”. Click on “File” → “Login”, and then enter the name of everyone in your lab group and click “OK”. It will ask if you have finished logging in, so click “Yes”.

Observing a Target

1. Click on “File” → “Run Exercise”. The program will ask you to set the UT – Local Time Difference. The time difference in Davis is -8.0 hours, so set this value.
2. To begin, the telescope needs to be pointed at the right object. Click on “Slew” → “Hot Lists” → “Objects” and select the object listed. Slew the telescope to the given coordinates and change the “View” option to “Chart”.
3. Manually slew the telescope so that the crosshairs are inside the box labeled “Field 1”. You can change the slew rate of the telescope to slew more quickly or slowly. Once the crosshairs are in Field 1, change the “View” option to “Field”.
4. Click on “Slew” → “Hot Lists” → “Targets” and slew to “Knot 1” to point the telescope at the object we are interested in.

Running the Spectrometer

1. Once the telescope is pointed at one of the objects, click on the “Spectrometer” to bring up the spectrometer window.
2. To begin taking data, click “Go”. When the value of the “Signal to Noise Ratio” is about 15, click on “Stop”.
3. Click on “File” → “Data” → “Save Spectrum” and save the file. Close the spectrometer window.
4. Click on “Tools” → “Spectrum Analysis” to bring up the spectrum analysis window.

5. In the spectrum analysis window, click “File” → “Load Spectrum” and load the spectrum you just took.
6. Click on “Tools” → “Comparison Spectrum” to bring up the comparison spectrum parameters window.
7. In the spectrum analysis window, the top spectrum is your model, the middle spectrum is your data, and the bottom spectrum is the residual, which is the difference between your model and the data. In the comparison spectrum parameters window, you can change various parameters of your model spectrum by moving the slider bars next to each parameter. Changing the parameters will change the model and the residual, as well as the “Quality of Fit” at the top of the window, which represents how well your model matches the data. The lower the value of the “Quality of Fit”, the better your model is. A quality of fit value of 1 is good, but lower is always better. Experiment with the different parameters and try to minimize the quality of fit.
8. When you think you have gotten the best possible fit to your data, go to the spectrum analysis window and click “Tools” → “Analysis of Model Fit”. In the new window, click on “Error Bars”. (If you can’t click on it, your “Quality of Fit” is too high.) Click on “File” → “Print” to print your results. Turn these results in with your lab.
9. Record the values for your parameters in the comparison model spectrum analysis window in Table 1.

Repeat this process for each of the other three objects and record your data in Table 1. Calculate the average of each of the parameters for all four objects and record the data in Table 1. Complete the rest of the data sheet and answer any remaining questions.

NAME______________________________

DATA SHEET

Table 1

Parameter	**Knot 1**	**Knot 2**	**Knot 3**	**Knot 4**	**Average**
kT					
nH					
Fe					
S					
Si					
Ca					
Mg					
Quality of Fit					

For each parameter, calculate the range of the values across the four knots as a ratio of the maximum to minimum values. (i.e. If your range for iron is 1.3 to 2.6, then the ratio of that range is 2.6/1.2 = 2)

Table 2

Parameter	kT	nH	Fe	S	Si	Ca	Mg
Max/Min							

Are the ranges small (e.g. is the max/min within 50% of the average) or large? Describe how they compare and try to explain why this might be the case. In particular, note the range for the temperature (kT) and discuss why it might be large or small.

Studies of supernovae show that the star has less iron before the explosion than after. Where do you think this extra iron might come from?

What do you think will eventually happen to the iron in this region?

How will the supernova affect new stars that will be born in the region? Specifically, how will it affect the chemical composition of these stars?

The Orion Nebula is a star-forming region with several hot, massive stars that will eventually explode. Since there have not yet been any supernovae in the nebula, what does this imply about the abundance of iron in this region?

Our sun has about the same abundance of iron in it as Cas A, the nebula you studied in this exercise. What does this imply about the sun's formation?

Background Information on X-rays and X-ray Spectroscopy

Life and Death in the Universe

Stars, like people, are born, live their lives out, and then die.

Stars are born in giant clouds of gas and dust. Normally, these clouds are supported by their own internal pressure which counteracts their gravity. But if something happens to compress them (such as a collision with another cloud, for example), then they can collapse. Obeying the Ideal Gas Law, the clouds heat up as they shrink, and the density, pressure, and temperature are highest at the center. Eventually, the temperature and pressure in the collapsing core get so high that hydrogen atoms can fuse together, forming helium.

This fusion process releases a huge amount of energy, which heats up the gas and stops the collapse. An equilibrium is reached where the outward pressure generated from this heat balances the inward force of gravity. The resulting object neither expands nor shrinks, and a star is born.

What we think of as normal stars – stars like the Sun – can live for millions, billions or even trillions of years, calmly and steadily fusing hydrogen into helium in their cores. Over time, helium builds up in the core, and the supply of hydrogen available for fusion dwindles.

As this happens, the core of helium contracts and heats up, and if it gets to a high enough temperature and pressure, it may begin to fuse helium into carbon. Around this, in a thin shell, hydrogen will continue to fuse into helium. This process dumps huge amounts of energy into the outer layers of the star, much more than before.

When a gas is heated it expands, and so the star responds to this extra input of energy by swelling up immensely. Ironically, while more energy is generated, the amount of surface area of the star increases so much that the energy emitted per square centimeter is actually *lower* than before it expanded. But there are a lot more square centimeters of star! So while the total amount of energy emitted goes up, the star actually cools off. It becomes red and bloated, so astronomers call this kind of star a “red giant”.

The star has reached a critical junction in its life, and what happens next depends on its mass. In relatively low-mass stars like the Sun, the star is done when the helium runs out. Over time, the outer layers blow off in a hyperactive version of the Sun’s solar wind, leaving the hot core exposed. With no fusion to maintain itself, the naked core, now called a “white dwarf”, will simply cool off. The star, for all intents and purposes, is dead.

But in stars with more than about 8 times the mass of the Sun, the story is very different. The increased mass means that there is more weight crushing the core, which makes it hotter and puts it under more pressure. If the conditions become right, then more fusion can commence. The carbon (left over from the previous fusion of helium) can fuse into oxygen, and then oxygen into magnesium and silicon, and then silicon into iron. After that... well, the word “disaster” means “bad star”. In this case, it can be taken literally.

In all the fusion sequences that have happened in the core so far, the process *releases* energy, which helps support the star against its own gravity. But iron is different: it *absorbs* energy to fuse. Once iron starts to fuse, the energy needed to support the star is removed, sucked up by the iron fusion. Due to this and other processes, once iron fusion starts, the star is doomed.

At this point, things happen quickly. Within milliseconds, with its support taken away, the outer layers of the star's core come crashing down on the inner core. At the same time, the fusion reaction in the core generates vast amounts of particles called *neutrinos*. Almost all the energy generated is pumped into the neutrinos, which immediately rush out of the core. They slam head-on into the infalling matter, and a shockwave of epic proportions is generated, which rams through the material. So much energy is dumped into the collapsing matter that the collapse is actually reversed. Suddenly, all that mass stops, changes direction, and explodes outward at high speed.

At that moment a star dies, but a supernova is created. The matter that used to be the outer layers of the star is now screaming away at a sizeable fraction of the speed of light. Heated and compressed, fusion can still take place in this material. In fact, the explosion is so great that fusion well beyond that of iron is possible, creating all the elements in the periodic table heavier than iron in a process called *explosive nucleosynthesis*.

Over the course of hours, days and weeks, the gas – now called a supernova remnant – expands and cools. Radioactive elements created in the blast (such as cobalt, titanium, and aluminum) heat the material, but the overall cooling continues. Still, even after hundreds of years, gas heated by the shock wave is still quite hot.

When gas is heated, it gives off radiation in the form of electromagnetic energy, generally called "light". The type of radiation emitted depends on many factors, but mostly on the temperature of the gas. At 6000 Kelvin (the surface temperature of the Sun), objects emit visible light. At cooler temperatures, they emit lower-energy light such as infrared, microwave, and radio. At somewhat hotter temperatures, gas emits ultraviolet light.

Gas heated to millions or tens of millions of degrees – such as the gas in the supernova – emits X-rays. This is the key to understand much of the physics in the gas from the exploded star. Iron in the gas, for example, does not emit light in the optical wavelengths, so "normal" telescopes cannot see iron in the supernova; only an X-ray telescope can. So astronomers pointing their X-ray eyes to the sky can investigate the properties of supernovae in ways that are otherwise impossible.

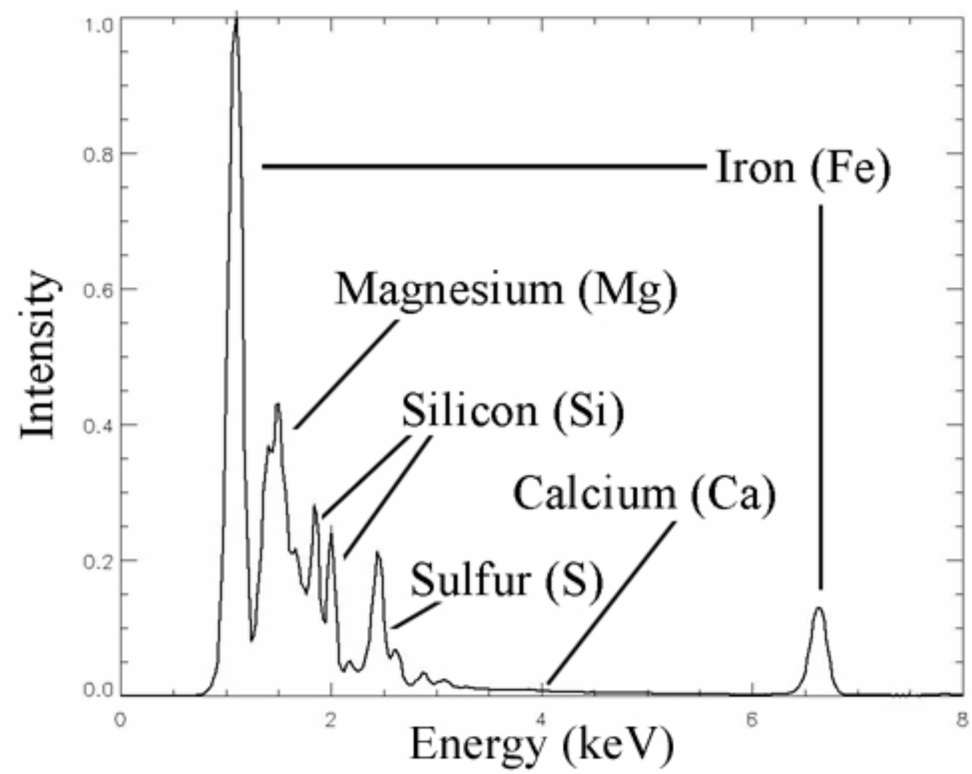
Many other elements in supernova remnants emit X-rays, including magnesium, calcium, silicon, sulfur, and oxygen. By examining the X-rays emitted by these elements, astronomers can determine such properties as the gas temperature, density, and even how much time has elapsed since the gas was hit by the initial supernova shockwave. The tool astronomers use to do this is *X-ray spectroscopy*.

X-ray Spectroscopy

The rainbow is a familiar sight. What may not be so familiar is that it represents a *spectrum* of sunlight: the component colors of the white light from the Sun broken up so we can perceive each one separately. Each color is actually a different wavelength of light. Red has the longest wavelength of visible light, and blue the shortest. The wavelength of light also determines the energy of the light, so red has the lowest energy, and blue the highest.

This goes well beyond the range of visible light, too. Infrared, ultraviolet, radio—all parts of the electromagnetic spectrum can be subdivided and spread out according to the wavelength or energy of the incoming light. Measuring the amount of light versus wavelength is called *spectroscopy*, and is the most powerful tool astronomers have. By analyzing the spectrum of an object it's possible to determine the object's temperature, movement, chemical composition, distance, and even its magnetic field—all without ever coming within light years of the object itself!

X-ray spectroscopy is a relatively new tool available to astronomers. By "spreading out" the X-rays from an object, say a supernova remnant, astronomers can examine how much of the light comes from iron, how much from silicon, etc. (see figure below for a representative X-ray spectrum of a supernova remnant) From that, they can



determine the elemental abundance of the gas; that is, how much of each element is in the gas. They can also find the temperature and density of the gas, and from that they can tell how long ago that bit of gas was struck by the shock wave from the supernova.

To do this, they first must collect the X-ray spectrum, then, using mathematical models of how each element produces X-rays, they fit that model to the observed spectrum by changing the model—they can add more iron to the mix, for example, or lower the temperature somewhat. When the model matches the spectrum, they can then examine the statistics of the fit to make sure they can have confidence in the results. If the results look good, they take that next big step— applying math to the results to calculate the physical characteristics of the gas.

In this CLEA exercise, you will use a (simulated) space-based X-ray observatory to observe the supernova remnant Cas A, the expanding debris from a star that blew up in the year 1680. You will observe several knots of gas, regions where the shock wave from the explosion has compressed the gas. You will take X-ray spectra, plot them, and then use "model-fitting" to determine the composition of the gas, and finally use that information to determine some of the physical characteristics of the gas in the knots.

Overall Strategy: Things to think about when doing the lab

You have been provided with an easy-to-use program which will allow you to point the virtual telescope, aim it at the knots of gas, take spectra, and analyze the results. The details of operating the program will be described later in this write-up, but the basic problem you will be investigating can be understood before you get into the details of the program.

You will find the X-ray spectrum of a knot of gas, and then you will create a model of the physical characteristics of the knot (how hot it is, how much iron is in it, etc.). The X-ray spectrum of the model knot will depend on what parameters you give it. As you adjust the model *parameters*, the model *spectrum* will change. The goal is to get the model spectrum to match the observed one. The model of the knot you have created will then closely match the real characteristics of the observed knot. You will have determined the physical nature of the gas in the supernova remnant!

Software User's Guide

Starting the Program

Your computer should be turned on and running Windows. Your instructor will tell you how to find the icon or menu bar for starting the *Dying Stars and the Birth of the Elements* exercise. Position the mouse over the icon or menu bar and click to start the program. When the program starts, the CLEA logo should appear in a window on your screen. Go to the File menu at the top of that window, click on it, and select the Login option from the menu. Fill in the form that appears with your name (and partner's name, if applicable). Do not use punctuation marks. Press "Tab" to move to the next text block, or click in each text block to enter the next name. Next, if requested by your instructor, enter the Laboratory table number or letter if it is not already filled in for you. Click in the appropriate field to correct any errors.

When all the information has been entered to your satisfaction, click OK to continue, and click "yes" when asked if you are finished logging in. The opening screen of the *Dying Stars and the Birth of Elements* lab will then appear.

Accessing the HELP Files

You may, at any time, select Help from the menu to receive on-line help. Click Help located on the right hand side of the menu bar. Within Help...Topics, there are several options that you can select, covering all the aspects of the software. For example, Log In informs you of the initial steps required to begin the program; Slew Buttons describes how to use the slew buttons to moves the observatory, etc. The topics are different for each window, and specific to the task of that window.

The CLEA X-Ray Telescope Window

Once you have logged in, go to FILE→Run Exercise... to begin the exercise. If a window pops up asking you for your time zone, enter it (for example, Eastern Standard Time is -5).

When you first run the program, a control panel opens which enables you to virtually point and operate a simulation of the orbiting XMM- Newton X-ray telescope.

Window Features

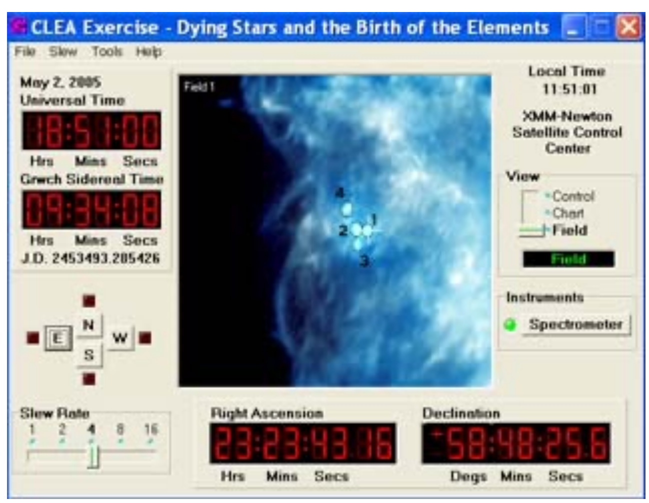
The large numerical displays in the upper left corner give time information.
the lower left allow you to move the telescope and to change the rate of motion (called the "slew rate"). Large numerical displays at the bottom right show the astronomical

coordinates at which the telescope is currently pointed. Controls along the right side allow one to change the view through the telescope monitor screen, and to call up the instrument that records X-rays collected by the telescope, called an X-ray spectrometer, The large square monitor screen viewing area in the center of the control panel allows you to see either the spacecraft or the area in the sky it is looking at. Finally, along the top is a menu bar with drop-down menus that can point the telescope at selected objects (**Slew**), call up screens that help you analyze your data (**Tools**), and access help files for the program (**Help**).

Observing a Target

To start the observation, first point the telescope at the supernova remnant. Go to Slew→Hotlists→ Objects and an "Observation List" window will pop up with a set of coordinates. Double-click on them to move the telescope to the position of the supernova remnant.

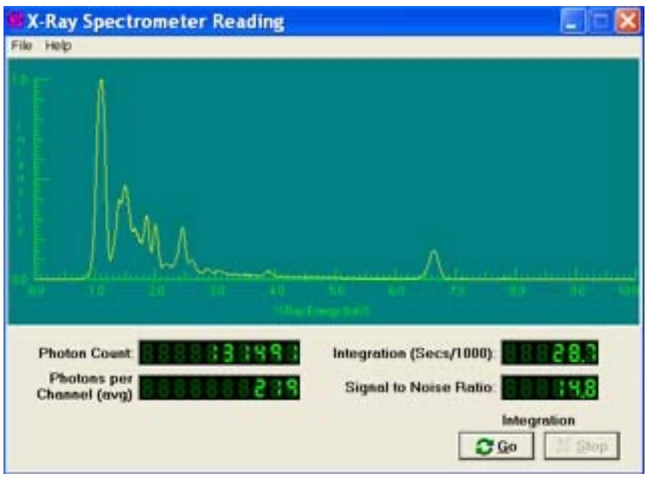
When it has finished slewing, it's time to see where you're pointed. Under the **View** section of the window (on the right), change the field of view to **Chart**. The cursor will show you where you are pointed (the center of the supernova remnant). The actual targets are located in the box labeled "Field 1". To point XMM-Newton at the targets, you can slew it manually by using the **Slew Rate** and direction buttons (N, S, E, W), or go to **Slew→Hotlists→Fields** (note that the "Objects" setting is now greyed out since you're already at the supernova remnant location) and again an "Observation List" window will pop up with coordinates, this time pointing to the center of Field 1. Double click them to slew the telescope.



Once the telescope is in the field, change your **View** to **Field**. This will provide a "close-up" view of the field. Your targets are the four bright clumps of gas near the center of the screen, labeled "1" through "4". As before, you can slew automatically by going to **Slew→Hotlists→ Targets** and choosing one of the four knots to observe. The telescope will slew to the chosen target. To move to a target manually, go to **Slew→Set Coordinates** and enter the coordinates of the particular knot (the coordinates are listed in the Students Guide), and the telescope will slew to the position you designated. You can adjust the position using the NSEW buttons. You may need to adjust the slew rate to center the knot in the window. Make sure your target is centered in the crosshair. If it isn't, then it will take longer to observe because not all the light from the target is getting into the telescope.

Accessing and Running the Spectrometer

Only when the telescope is pointed in the region of interest can you access the spectrometer and take data. Once the target is centered in the crosshair in the **Field** window, click on the **Spectrometer** button to open the spectrometer window.



To take a spectrum, simply click on the **Go** button. The spectrum can be seen building up, photon by photon, as the exposure increases. To stop the exposure, simply click the **Stop** button. Exposures can be continued by simply clicking **Go** again.

The "signal-to-noise ratio" is an indication of how noisy your spectrum is. The higher the number, the "cleaner" the spectrum will be. **You should let the data accumulate until you have a signal-to-noise of about 15.** If it is too much lower than this, you will not get a clean spectrum. Due to the way the mathematical calculations are done in the software, we do not recommend letting the signal-to-noise ratio get much higher than 20. This will make your spectrum harder to fit with the model when you analyze it.

Spectra can be saved to a file by using the **Save** option on the **File** drop-down menu (you **MUST** do this after taking your data, or you will lose it). You can also print out the spectrum on a printer by using the appropriate command on the **File** drop-down menu.

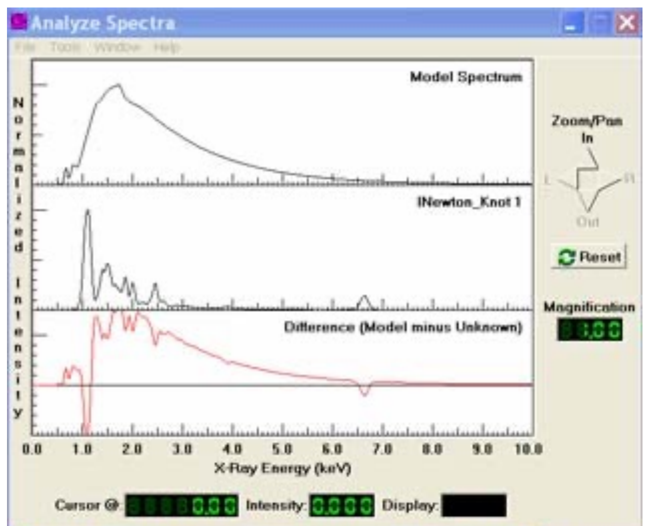
Once you have saved your spectrum, you can close the spectrometer window.

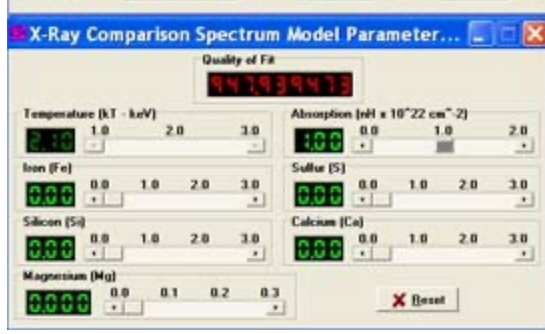
Analyzing Data

Once you have taken a spectrum, you will need to display and analyze it to determine the abundances of elements and other physical properties (temperature and density) of the gas that produced the spectrum. You can access the spectrum analysis tool by going back to the **main telescope control window**, selecting **Tools** from the top menu bar, and choosing **Spectrum Analysis**.

The window that appears, entitled **Analyze Spectra**, has three areas for graphs, which display intensity on the y axis and photon energy on the x axis. The middle graph can be used to display spectra you took. You can load a spectrum you took previously by using the **File→Load Spectrum**... option from the menu bar at the top of the window. The spectrum will appear in the middle plotting area.

To analyze this spectrum, you will want to compare it with a theoretical spectrum whose temperature and chemical abundances can be varied to match the spectrum you took. You load the comparison file by choosing the **Tools→Comparison** Spectrum option from the menu bar. The comparison spectrum is shown on the top plotting area, and the difference between the Comparison Spectrum and the spectrum you took is displayed in the bottom plotting area. In addition, a set of controls titled **X-ray Comparison Spectrum Model Parameters** will appear. You can use these controls to change the chemical composition, temperature, and density of the model (note: your instructor may have turned some of these off, so they are already fixed at their correct values; they appear dimmer in the display). You can use the slider bars to change the values of the parameters, or you can double-click the number itself, and a window will pop up in which you can manually enter a value. As you change these parameters, the model will change accordingly, representing the mathematical model of the spectrum expected from a gas with the parameters you have given it.





The specific parameters are:

Temperature: this is the temperature of the gas (also called kT), measured in units of kilo-electron Volts (keV). This is a standard unit of temperature used by astrophysicists for very hot gases. At these temperatures, electron Volts are not directly convertible to degrees, but one can think of a gas at a temperature of 1 keV being equivalent to about 10 million degrees Celsius—almost as hot as the core of the Sun!

Absorption: This represents the amount of cool, Galactic hydrogen gas between you and the X-ray emitting gas (also called nH). The more gas there is, the more X-rays it absorbs out of the spectrum. The units are 10 /cm , which is the number of atoms per square centimeter. Oddly, that's per unit area! Imagine you are looking through a long tube extending between you and the X-ray source. The atoms could be distributed evenly along the length of the tube, or they could be concentrated all in one spot, but the absorption is still the same. So the length of the tube is not important, just the number of atoms added up along the line-of-sight.

Iron: This is the abundance of the element iron in the gas, relative to the abundance of iron in the Sun. If you take a sample of gas from the Sun, there will be a certain number of atoms from various elements in it; mostly hydrogen, less helium, even less oxygen, and so on. Astronomers measure abundances of cosmic sources relative to their abundance in the Sun. An iron abundance of 1.0 in a sample of supernova gas means it has the same ratio of iron in it that the Sun does. 2.0 means twice as much, and so on.

Sulfur, Silicon, Calcium, Magnesium: Same as iron, but abundances for those elements.

You want to make the model such that the fit of the comparison spectrum to the observed spectrum is best, i.e. the difference between these two spectra is as small as possible. This can be done roughly by eye, watching the difference spectrum (the bottom plotting area in the window) carefully. On the right side of the **Analyze Spectra** window are buttons that allow you to zoom in on various parts of the spectrum, and to pan left and right. By zooming in, you will be able to see the difference spectrum in more detail.

The comparison of your model to the observed spectrum can also be measured mathematically. At the top of the **X-ray Comparison Spectrum Model Parameters** panel is a section labeled "Quality of Fit". This is a statistical parameter that tells you how good your model fit is to the data (the technical name for this number is called the "Chi-Squared parameter", due to the mathematics involved in calculating it). The lower that number is, the better your fit is. You'll see that when you start, the number may be in the hundreds. If it's above 999.999 it will not display a number, and will only start to display numerals when the figure drops below this value. A fit can be called "good" in this instance when the quality of fit drops to or below a value of about 1 (the exact number depends on many factor, like the noise level of your observed spectrum). When that happens, the "Quality of Fit" display turns green letting you know you're getting close. While a value of 1 is good, remember, lower is better.

Your goal is to get as small a value for the "Quality of Fit" as you can.

This next section is for advanced students only:

The difference between the model fit and the actual spectrum is called the "residual". You can display more information about the residuals by going to the **Tools→Analysis of Model Fit** menu on the **Analyze Spectrum** window. A small window will pop up titled **Spectrum Model Fit to Unknown**, which will give you the running numbers for the chi-squared. When the "Quality of Fit" number drops below a value of 3, the **Error Bars** menu becomes accessible in the **Spectrum Model Fit to Unknown** window. This will show you the statistical error bars for each of the physical parameters in your model. These represent the 90% confidence level of your fit. In other words, numbers in this range have only a 10% chance statistically of being incorrect. This in turn means that the smaller your error bars are, the better. If the error bars are small compared to your number, you can be confident the fit is good.

Note: *The error bars are calculated using a sophisticated mathematical process. Sometimes, though rarely, it will not be able to calculate the upper or lower error bar for a parameter. When that happens, it will display "****". This doesn't mean you've done anything wrong! Just make a note of that in your write-up.*

It may take some trial and error to get the best fit of a model spectrum to your data, but with a little patience, some tips given later in the procedure part of this manual, and a little help from the instructor, it can be done with some precision.

When you are done, save and print your results. In the **Spectrum Model Fit to Unknown** window, go to File→Save text and then File→Print. Make sure you save these results and hands them in with your worksheet.

Student Work Guide

Step 1) Prep Work

Before working on this CLEA lab, make sure you have read all the supplemental material and performed any pre-lab activities assigned by your instructor. They will make your life a lot easier when working on this lab. Make sure you read the **Introduction** to this lab!

Read through the **Software User's Guide**, which will tell you how to use the software. Experimenting with the software as you read the Guide will help you feel more comfortable with it.

Step 2) Observing the Cas A Supernova remnant

Fire up the simulated X-ray observatory software. Follow the instructions in the **Software Users Guide**: log in, point the telescope, and choose a knot to observe. You can use the buttons to slew to a knot, or manually enter the coordinates. Below is a table of the coordinates.

KNOT	Right Ascension	Declination
1	23 23 43.18	+58 48 25.6
2	23 23 43.65	+58 48 25.8
3	23 23 43.63	+58 48 21.4
4	23 23 44.05	+58 48 32.3

When you start observing, you will see the spectrum begin to form in the **X-ray Spectrometer Reading** window. Keep your eye on the "Signal to Noise Ratio" (commonly called "S/N") reading. This tells you how clean your spectrum will be; how much real information (signal) you have in the spectrum versus random noise. In general, a S/N of 10 is acceptable, but you want your spectrum to have a S/N of around 15. The trade-off is that a higher S/N takes longer to observe, and may make fitting the spectrum with a model harder. Don't spend all day trying to squeeze out a little more signal!

Once you are satisfied with your spectrum, save it. You *must* save your data to be able to analyze it. Save it using the default name or rename it yourself. You should also print a copy of the spectrum so you can distinguish it from the other spectra you may take later.

Step 3) Analyzing the Spectrum and Model Fitting

Open the **Analyze Spectrum** window and load up your observed and model spectra as outlined in the **Software Users Guide**.

The model spectrum displayed is created using the default settings in the window. The slider bars adjust the parameters that go into the model, and as you adjust them the model spectrum will change.

Start by first adjusting the slider bar for the temperature. Note what happens as you increase and decrease the temperature. Does the overall shape of the spectrum change, or are there specific changes in some places?

Watch the difference spectrum as you change the parameter values with each slider bar. You can do a decent job of fitting just watching it by eye, and trying to get it to zero across the entire range. Once you are close, start paying attention to the "Quality of Fit" value (see the **Software Users Guide** for more information).

Once you think the model is as good as it will get by only adjusting the temperature, move to the absorption bar and adjust it. Continue to do this with all the parameters.

TIP 1: *Every time you adjust a parameter, go back and adjust all the parameters you already adjusted. This way you will converge more rapidly on a good solution. If you simply move down the list of parameters once, you'll never get a good fit.*

As you adjust a parameter, note what is changing. You may find that some things change in similar ways when two different parameters are adjusted.

TIP 2: *You may appear to be getting close to a solution, and then find that you are suddenly not improving. This is normal. Try moving one of the sliders quite a bit, to break out of that impasse. Try again using very different parameter values to start wit, to make sure you don't get locked into those incorrect values again.*

Be patient. This takes some getting used to. It may take a few minutes when you first try it. Remember to open and look at the **Spectrum Model Fit to Unknown** window (see the **Software Users Guide**). It will help you find the best fit.

TIP 3: *Watch the "Quality of Fit" number as you move a slider. When it drops to a minimum value, move to another parameter. When it's again at a minimum, go back to the first parameter and adjust it again. This method will let you converge on a solution more rapidly.*

Once the "Quality of Fit" value drops below about 1 (the specific value is different for every observation depending on the knot you observe and the signal-to-noise ratio you achieved), you are getting close. Note that the display for it turns green, letting you know your fit is getting good. Keep adjusting the sliders to get this value as low as possible.

Step 4) Finalizing the Spectrum

When you think you have found the best fit to a spectrum, it is time to see how close you came. Click the button labeled "Error Bars" on the **Spectrum Model Fit to Unknown** window (remember: the "Quality of Fit" number must be green in the "X-ray Comparison Model Parameters" window or else you cannot display the error bars). This calculates whether the values you found for the parameters make a reliable fit to the data or not. See the last section of the **Software User's Guide** for more information on this.

When you have done that, *save and print the results* as instructed in the **Software Users Guide** (in the Analyze spectrum window, go to Tools→Analysis of Model Fit. In the window that pops up, go to File→Save text and then File→Print).

Now (if told to by your instructor) move on to the next knot, and repeat the procedure. Do this until you have observed, fitted, (for advanced students) found the errors, saved, and printed the results of all four knots.

Step 5) Analysis

Part 1

Note: Your instructor may have only assigned one knot per group of students. If you only observed one knot, then answer the questions that apply to only one knot (5-16). Once the class results are shared, you can answer the remaining questions (1-4).

1) For the four knots (or however many you examined), record in the table below the value of each physical parameter that you found in your model fit, their average values, and the Quality of Fit.

	Knot 1	Knot 2	Knot 3	Knot 4	Average
kT					
nH					
Fe					
S					
Si					
Ca					
Mg					
Quality of fit					

2) For each parameter, look at the values found for each of the four knots of gas (for example, the Fe abundance for Knots 1-4). Calculate the *range* of the values of the parameters across the four knots as a ratio of the maximum to the minimum values (for example, if your range for iron is 1.3 to 2.6, then the ratio of that range is 2.6 / 1.3 = 2).

kT ____
nH ____
Fe ____

S ____
Si ____
Ca ____
Mg ____

3) Examine the values you just found. Are the ranges small (say, the minimum to maximum values for the parameter within +/- 50% of the average) or large? In your own words, describe how they compare and try to think of why this might be. In particular, note the range for the temperature and discuss why it may be large or small.

____
____
____
____
____

4) For advanced students:
The error bars you found for each physical parameter are an indication of the quality of fit you found. A small error bar indicates that the value you found is close to the correct value.

Examine the values for the abundances you found, and their error bars. Are the differences in the abundances between knots significant in the statistical sense? In other words, are the differences much larger than your error bars? Discuss this for each parameter (use extra paper if needed):

kT ____
nH ____
Fe ____
S ____
Si ____
Ca ____
Mg ____

APPENDICES

Appendix 1 – The Constellations

Constellation Name	Genitive Form	I.A.U. Abbrev.	Meaning	Approx. Coordinates α(hr)	δ(deg)
Andromeda	Andromedae	And	Princess of Ethiopea	1	+40
Antlia	Antliae	Ant	Air Pump (of Boyle)	10	-35
Apus	Apodis	Aps	Bird of Paradise	16	-75
Aquarius	Aquarii	Aqr	Water Bearer	23	-15
Aquila	Aquilae	Aql	Eagle	20	5
Ara	Arae	Ara	Altar (of the Centaur)	17	-55
Aries	Arietis	Ari	Ram	3	20
Auriga	Aurigae	Aur	Charioteer	6	40
Boötes	Boötis	Boo	Herdsman (or Bear Driver)	15	30
Caelum	Caeli	Cae	Chisel (of Sculptor)	5	-40
Camelopardalis	Camelopardalis	Cam	Giraffe (=camel-leopard)	6	70
Cancer	Cancri	Cnc	Crab	9	20
Canes Venatici	Canum Venaticorum	CVn	Hunting Dogs (of Boötes)	13	40
Canis Major	Canis Majoris	CMa	Greater Dog (of Orion)	7	-20
Canis Minor	Canis Minoris	CMi	Lesser Dog (of Orion)	8	5
Capricornus	Capricorni	Cap	Sea Goat	21	-20
Carina	Carinae	Car	Keel (of Argo Navis)	9	-60
Cassiopeia	Cassiopeiae	Cas	Queen of Ethiopea	1	60
Centaurus	Centauri	Cen	Centaur	13	-45
Cepheus	Cephei	Cep	King of Ethiopia	22	70
Cetus	Ceti	Cet	Whale (or Sea Monster)	2	-10
Chamaeleon	Chamaeleontis	Cha	Chameleon	11	-80
Circinus	Circini	Cir	Compass (Sculptor's Dividers)	15	-60
Columba	Columbae	Col	Noah's Dove	6	-35
Coma Berenices	Comae Berenices	Com	Berenice's Hair	13	20
Corona Australis	Coronae Australis	CrA	Southern Crown	19	-40
Corona Borealis	Coronae Borealis	CrB	Northern Crown	16	30
Corvus	Corvi	Crv	Crow (or Raven)	12	-20
Crater	Crateris	Crt	Cup (of Bacchus)	11	-15
Crux	Crucis	Cru	Southern Cross	12	-60
Cygnus	Cygni	Cyg	Swan	21	40
Delphinus	Delphini	Del	Dolphin	21	15
Dorado	Doradus	Dor	Swordfish	5	-60
Draco	Draconis	Dra	Dragon	17	65
Equuleus	Equulei	Equ	Little Horse	21	10
Eridanus	Eridani	Eri	River Eridanus	3	-10
Fornax	Fornacis	For	Chemical Furnace	3	-30
Gemini	Geminorum	Gem	Twins	7	25
Grus	Gruis	Gru	Crane	22	-45
Hercules	Herculis	Her	Son of Zeus	17	30
Horologium	Horologii	Hor	Pendulum Clock	3	-60
Hydra	Hydrae	Hya	Water Serpent	10	-20
Hydrus	Hydri	Hyi	Small Water Snake	2	-70
Indus	Indi	Ind	(American) Indian	21	-55
Lacerta	Lacertae	Lac	Lizard	22	45
Leo	Leonis	Leo	Lion	11	15
Leo Minor	Leonis Minoris	LMi	Small Lion	10	35
Lepus	Leporis	Lep	Hare	5	-20
Libra	Librae	Lib	Scales (or Balance)	15	-15
Lupus	Lupi	Lup	Wolf	15	-50

Constellation Name	Genitive Form	I.A.U. Abbrev.	Meaning	Approx. Coordinates α(hr)	δ(deg)
Lynx	Lyncis	Lyn	Lynx	8	45
Lyra	Lyrae	Lyr	Lyre (or Harp)	19	35
Mensa	Mensae	Men	Table Mountain	5	−75
Microscopium	Microscopii	Mic	Microsope	21	−35
Monoceros	Monocerotis	Mon	Unicorn	7	−5
Musca	Muscae	Mus	Fly	12	−70
Norma	Normae	Nor	Square (of Sculptor)	16	−50
Octans	Octantis	Oct	Octant (Hadley's)	22	−85
Ophiuchus	Ophiuchi	Oph	Serpent Bearer	17	0
Orion	Orionis	Ori	Hunter	6	0
Pavo	Pavonis	Pav	Peacock	20	−65
Pegasus	Pegasi	Peg	Winged Horse	23	20
Perseus	Persei	Per	Hero (slayer of Medusa)	3	45
Phoenix	Phoenicis	Phe	Phoenix	1	−50
Pictor	Pictoris	Pic	Painter's Easel	6	−50
Pisces	Piscium	Psc	Fishes	1	10
Piscis Austrinus	Piscis Austrini	PsA	Southern Fish	22	−30
Puppis	Puppis	Pup	Stern (of Argo Navis)	7	−40
Pyxis	Pyxidis	Pyx	Compass (of Argo Navis)	9	−30
Reticulum	Reticuli	Ret	Net (Reticle)	4	−60
Sagitta	Sagittae	Sge	Arrow	20	20
Sagittarius	Sagittarii	Sgr	Archer (Centaur)	19	−25
Scorpius	Scorpii	Sco	Scorpio the Scorpion	17	−30
Sculptor	Sculptoris	Scl	Sculptor	0	−30
Scutum	Scuti	Sct	Shield	19	−10
Serpens (Caput)	Serpentis	Ser	Serpent (Head)	16	10
Serpens (Cauda)	Serpentis	Ser	Serpent (Tail)	18	−10
Sextans	Sextantis	Sex	Sextant	10	0
Taurus	Tauri	Tau	Bull	4	15
Telescopium	Telescopii	Tel	Telescope	19	−50
Triangulum	Trianguli	Tri	Triangle	2	30
Triangulum Australe	Trianguli Australis	TrA	Southern Triangle	16	−65
Tucana	Tucanae	Tuc	Toucan	0	−65
Ursa Major	Ursae Majoris	UMa	Greater Bear	11	50
Ursa Minor	Ursae Minoris	UMi	Lesser Bear	15	75
Vela	Velorum	Vel	Sail (of Argo Navis)	9	−50
Virgo	Virginis	Vir	Virgin (or Maiden)	13	0
Volans	Volantis	Vol	Flying Fish	8	−70
Vulpecula	Vulpeculae	Vul	Fox	20	25

Appendix 2 – The Greek Alphabet

Upper Case	Lower Case	NAME	Upper Case	Lower Case	NAME	Upper Case	Lower Case	NAME
Α	α	alpha	Ι	ι	iota	Ρ	ρ	rho
Β	β	beta	Κ	κ	kappa	Σ	σ	sigma
Γ	γ	gamma	Λ	λ	lamda	Τ	τ	tau
Δ	δ	delta	Μ	μ	mu	Υ	υ	upsilon
Ε	ε	epsilon	Ν	ν	nu	Φ	φ	phi
Ζ	ζ	zeta	Ξ	ξ	xi	Χ	χ	chi
Η	η	eta	Ο	ο	omicron	Ψ	ψ	psi
Θ	θ	theta	Π	π	pi	Ω	ω	omega

Appendix 3 – List of Deep Sky Objects

****An easy way to locate faint objects on the sky (for equatorially mounted telescopes) is to set he declination of the object first, then sweep in hour angle in the vicinity of the object.**

Spring Quarter

Galaxies:

M#	Const.	R.A.	Decl.	Size	Mag.	type	Name	seen?
M32	And	0:40.0	+40°36'	3'×2'	9	El	satellite of M31	
M31	And	0:40.0	+41°0'	160'×40'	4	Sp	Andromeda Galaxy	
M110	And	0:40.4	+41°41'	17'×9.8'	9	El	NGC205; M31,32 companion	
M33	Tri	1:31.1	+30°24'	60'×40'	7	Sp	Triangulum Nebula	
M74	Psc	1:34.0	+15°32'	8'×8'	11	Sp		
M77	Cet	2:40.1	−00°14'	2'×2'	9	Sp		
M81	UMa	9:51.5	+69°18'	16'×10'	8	Sp	same field as M82	
M82	UMa	9:51.9	+69°56'	7'×2'	9	Ir	same field as M81	
M95	Leo	10:41.3	+11°58'	3'×3'	11	Sp		
M96	Leo	10:44.2	+12°5'	7'×4'	10	Sp		
M105	Leo	10:45.2	+12°51'	2'×2'	10	El		
M108	UMa	11:08.7	+55°57'	8'×2'	10	Sp		
M65	Leo	11:16.3	+13°23'	8'×2'	10	Sp		
M66	Leo	11:17.6	+13°17'	8'×2'	9	Sp		
M98	Com	12:11.3	+15°11'	8'×2'	11	Sp		
M99	Com	12:16.3	+14°42'	4'×4'	10	Sp		
M106	CVn	12:16.5	+47°35'	20'×6'	10	Sp		
M61	Vir	12:19.4	+04°45'	6'×6'	10	Sp		
M100	Com	12:20.4	+16°6'	5'×5'	10	Sp		
M84	Vir	12:22.6	+13°10'	3'×3'	10	El		
M85	Com	12:22.8	+18°28'	4'×2'	10	El		
M86	Vir	12:23.7	+13°13'	4'×3'	10	El		
M49	Vir	12:27.3	+08°16'	4'×4'	9	El		
M87	Vir	12:28.3	+12°40'	3'×3'	10	El		
M88	Com	12:29.5	+14°42'	6'×3'	10	Sp		
M89	Vir	12:33.1	+12°50'	2'×2'	11	El		
M90	Vir	12:34.3	+13°26'	6'×3'	11	Sp		
M91	Com	12:34.3	+14°28'	4'×3'	11	Sp	NGC 4548	
M58	Vir	12:35.1	+12°5'	4'×3'	10	Sp		
M104	Vir	12:37.3	−11°21'	7'×2'	8	Sp	Sombrero Galaxy	
M59	Vir	12:39.5	+11°55'	3'×2'	11	El		
M60	Vir	12:41.1	+11°49'	4'×3'	10	El		
M94	CVn	12:48.6	+41°23'	5'×4'	8	Sp		
M64	Com	12:54.3	+21°57'	8'×4'	8	Sp	Blackeye Galaxy	
M63	CVn	13:13.5	+42°17'	8'×3'	10	Sp		
M51	CVn	13:27.8	+47°27'	12'×6'	9	Sp	Whirlpool Galaxy	
M101	UMa	14:01.4	+54°35'	22'×22'	8	Sp	Pinwheel Nebula	

Sp: Spiral Galaxy Ir: Irregular Galaxy El: Elliptical Galaxy

Spring Quarter

Globular Clusters:

M#	Const.	R.A.	Decl.	Size	Magnitude	Spring qtr	found?
M68	Hya	12:36.8	-26°29'	9'	8	transit	
ω	Cen	13:25.0	-47°9'	65'	4.5	transit	
M53	Com	13:10.5	+18°26'	14'	8	transit	
M3	CVn	13:39.9	+28°38'	19'	6	transit	
M5	Ser	15:16.0	+02°16'	20'	6	late	
M80	Sco	16:14.1	-22°52'	5'	7	late	
M4	Sco	16:20.6	-26°24'	23'	6	late	
M107	Oph	16:29.7	-12°57'	8'	9	late	
M13	Her	16:39.9	+36°33'	23'	6	late	
M12	Oph	16:44.6	-01°52'	12'	7	late	
M10	Oph	16:54.5	-04°2'	12'	7	late	
M92	Her	17:15.6	+43°12'	12'	6	late	
M14	Oph	17:35.0	-03°13'	7'	8	late	
M56	Lyr	19:14.6	+30°5'	5'	8	late	
M62	Oph	16:58.1	-30°3'	6'	7	v.late	
M19	Oph	16:59.5	-26°11'	5'	7	v.late	
M9	Oph	17:16.2	-18°28'	6'	7	v.late	
M71	Sge	19:51.5	+18°39'	6'	9	v.late	

Open Clusters:

M#	Const.	R.A.	Decl.	Size	Mag.	Sqtr	Notes, Name	found?
M34	Per	2:38.8	+42°34'	30'	6	v.early		
M45	Tau	3:44.5	+23°57'	120'		v.early	Pleiades	
M41	CMa	6:44.9	-20°41'	32'	6	v.early		
M38	Aur	5:25.3	+35°48'	18'	7	early		
M36	Aur	5:32.8	+34°6'	16'	6	early		
M37	Aur	5:49.1	+32°32'	24'	6	early		
M35	Gem	6:05.8	+24°21'	29'	6	early		
M50	Mon	7:00.6	-08°16'	16'	6	early		

continued on PM-7

Nebulae:

M#	Const.	R.A.	Decl.	Size	Mag.	type	Sqtr	Name	seen?
M42	Ori	5:32.9	-05°25'	66'×60		Di	v.early	Orion Nebula	
M43	Ori	5:33.1	-05°18'			Di	v.early	NW wing of Orion Nebula	
M78	Ori	5:44.2	+00°2'	8'×6'		Di	v.early		
M76	Per	1:39.1	+51°19'	2'×1'	11	Pl	early	Double Nebula, dimmest M	
M1	Tau	5:31.5	+21°59'	6'×4'	10	Sr	early	Crab Nebula	
M97	UMa	11:11.9	+55°18'	3'×3'	11	Pl	transit	Owl Nebula	
M57	Lyr	18:51.8	+32°58'	1'×1'	9.7	Pl	late	Ring Nebula	
M20	Sgr	17:59.6	-23°2'	29'×27'		Di	v.late	Trifid Nebula	
M8	Sgr	18:00.7	-24°23'	90'×40'		Di	v.late	Lagoon Nebula	
M17	Sgr	18:17.9	-16°12'	46'×37'		Di	v.late	Omega\Horseshoe Cluster	
M27	Vul	19:57.5	+22°35'	8'×4'	8	Pl	v.late	Dumbbell Nebula	

Di: Diffuse gaseous nebulae Pl: Planetary nebulae Sr: Supernova remnant

STAR MAPS

Since the sky looks like a giant sphere surrounding the earth (called the **celestial sphere** or **firmament**), making a map of the sky is similar to making a map of the spherical earth. For that reason, celestial star maps have similar features (like an equator, longitude and latitude lines) and similar problems when represented in two dimensions as a flat map (n.b. distortion). There are a few subtle differences. The first is that **East and West are reversed**! Why? Because when you look at the earth, you are looking **down**, but star maps are meant to be held over your head while looking **up**. You will get a chance to use a couple of these types of maps during the quarter, one example being your star wheel or star finder.

Declination (dec or δ) is the celestial latitude, measured in degrees north or south of the celestial equator. Recall that degrees are subdivided into arcminutes and arseconds.

1 circle = 360˚ 1˚ = 60’ 1’ = 60”

Lines (circles) of constant declination are called **parallels**. The 0 parallel is the **celestial equator** or **equinoctial**.

Right ascension (RA or α) is the celestial longitude, measured in hours and increasing in the eastward direction. Hours are subdivided into the usual time divisions of minutes and seconds.

1 circle = 24^h $1^h = 60^m$ $1^m = 60^s$

Lines (circles) of constant RA are called **secondary great circles**. The 0^h circle is called the **equinoctial colure**. On star maps, it passes through the point where the sun crosses the equator on the spring equinox (called the ascending node of the sun, or the **First Point of Aries**).

The sky is divided up into 88 **constellations**, much like the state of California is divided up into counties. Each star, being a “point”, can only technically belong to one. The boundaries were not included on the following maps, but all 88 constellations are named. Lines on the map connecting the major stars in the constellations follow no formal standard, but are relatively generic. Sometimes they traditionally “overlap” two constellations.

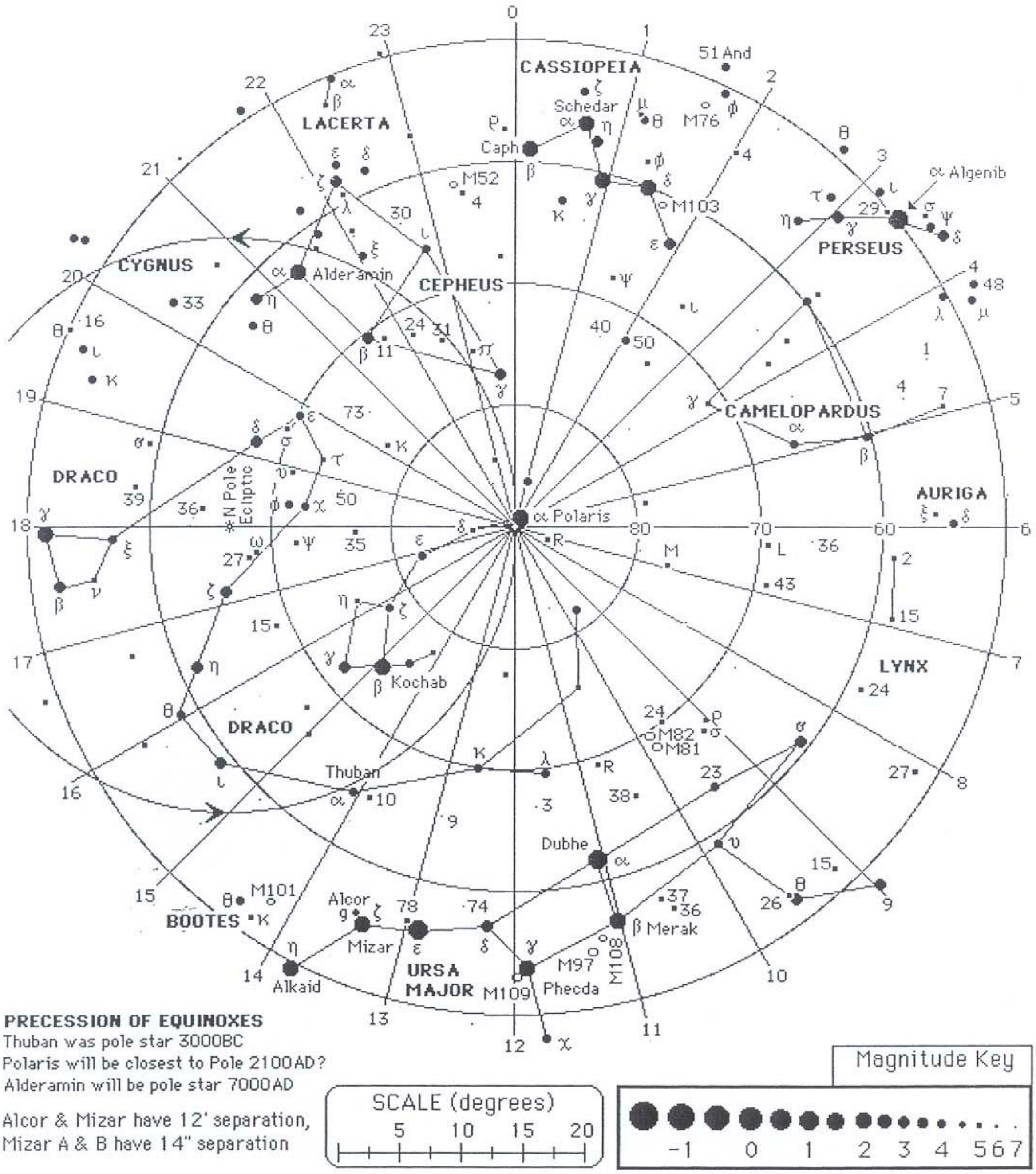
Stars are classified by their **magnitude**. This is represented by the size of the point plotted, with bigger meaning brighter. The brightest star has magnitude -1.5. The faintest star visible to the naked eye under ideal circumstances is 6 or 6.5. These maps have 1482 stars, which include all stars down to 4^{th} magnitude, with selected stars down to 5^{th} and 6^{th} (faintest is 7.4).

Given a map, stars can be referenced by their coordinates. However **precession** of the equinoxes slowly moves our “grid” against the background stars. A map usually will bear an **epoch** date relative to the Julian calendar at which it is correct. New maps use J2000.0 (year 2000); the following maps used J1984.5 (halfway through the year 1984, from the 1984 Nautical Almanac). Considering the scale of the maps, the movement of the grid over the next 15 years will be minimal. The precession circle is shown on both the polar maps, centered at the poles of the **ecliptic**.

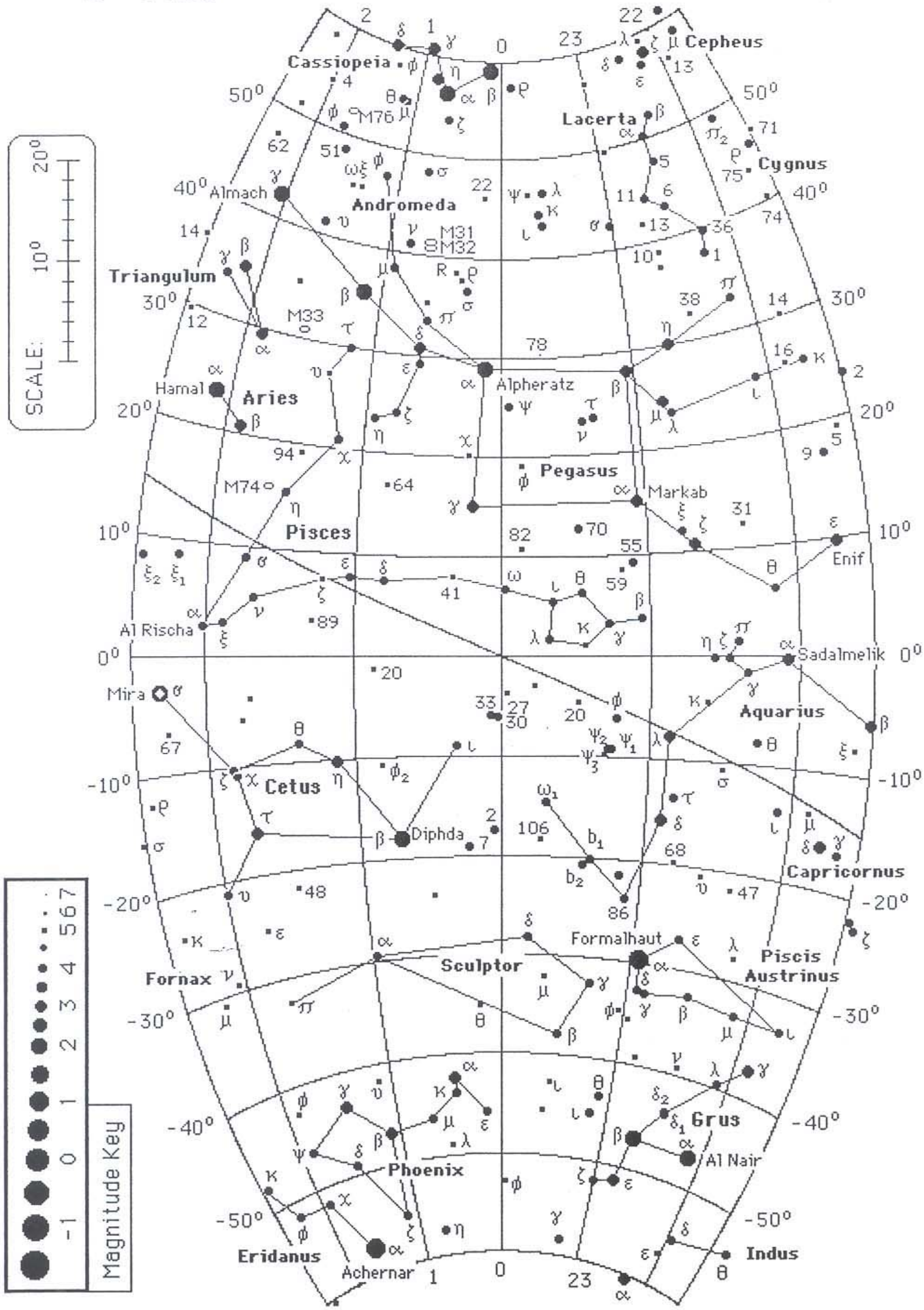
Since coordinates change, stars are usually catalogued by names or numbers. Traditionally, the brightest stars have common names, some of which are included on the map. In the **Bayer** notation, the major stars of a constellation were catalogued by a lowercase Greek letter, approximately in order of brightness. Later, other fainter stars were given a **Lacaille** notation, lowercase Latin letters.

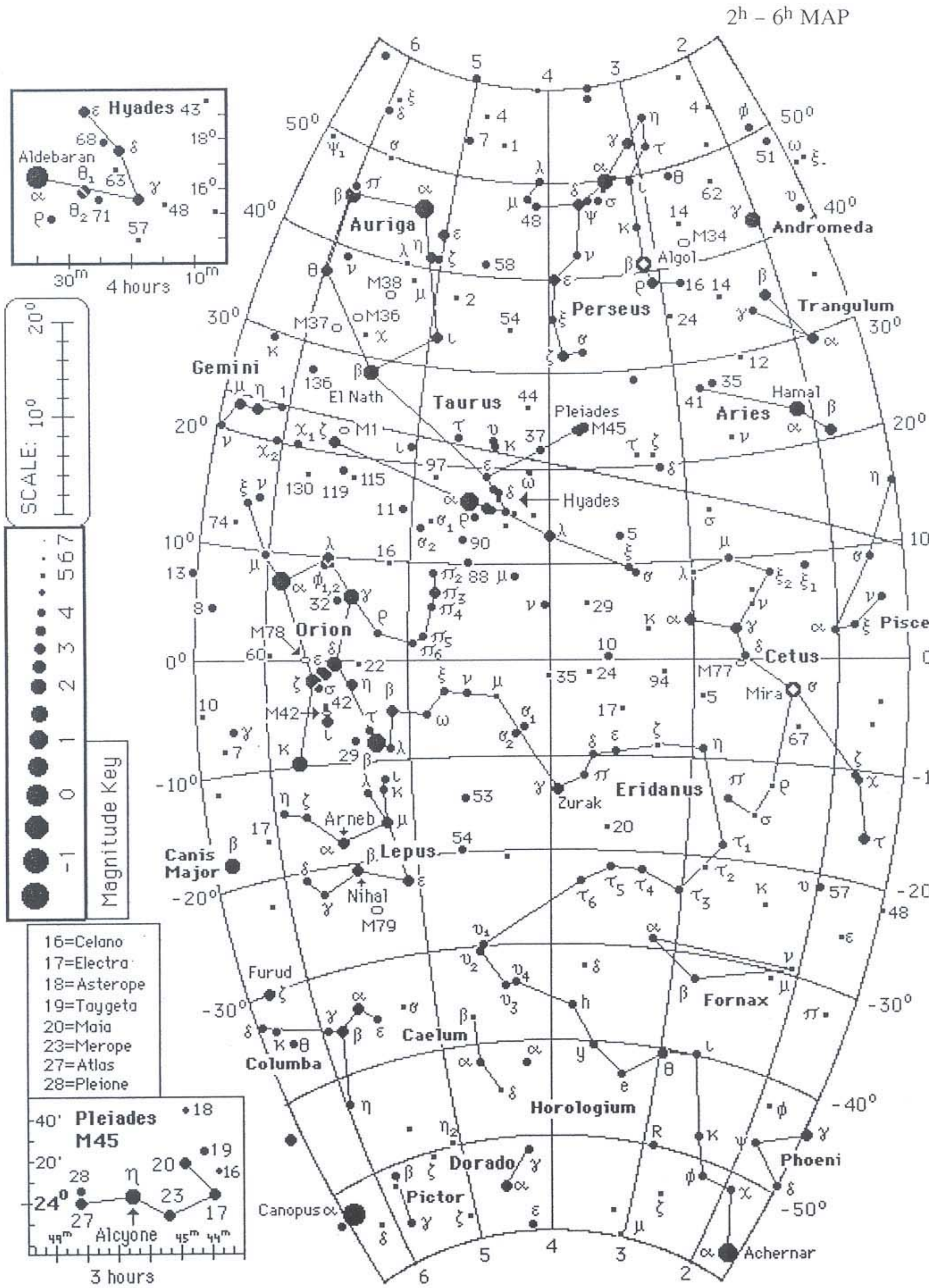
Flamsteed catalogued (most of) the stars in a constellation with numbers, starting at the west end in increasing order of right ascension. Fainter stars have other catalog systems (the next most common is the BS or Bright Star catalog number). A star may have all of the above notations. The brightest star in the constellation Lyra the Harp would be alpha Lyrae (α Lyr) in the Bayer notation, or 3Lyr in the Flamsteed notation.

A capital Latin letter of R, S, T, U, V, W, X, Y, Z (or RR, RS, SS, ST, etc.) is the **Argelander** notation for **variable** stars. Sometimes they are given a special symbol on a map. Bright variables (e.g. Mira, Algol, Polaris) do not follow this system, as they already have notations.

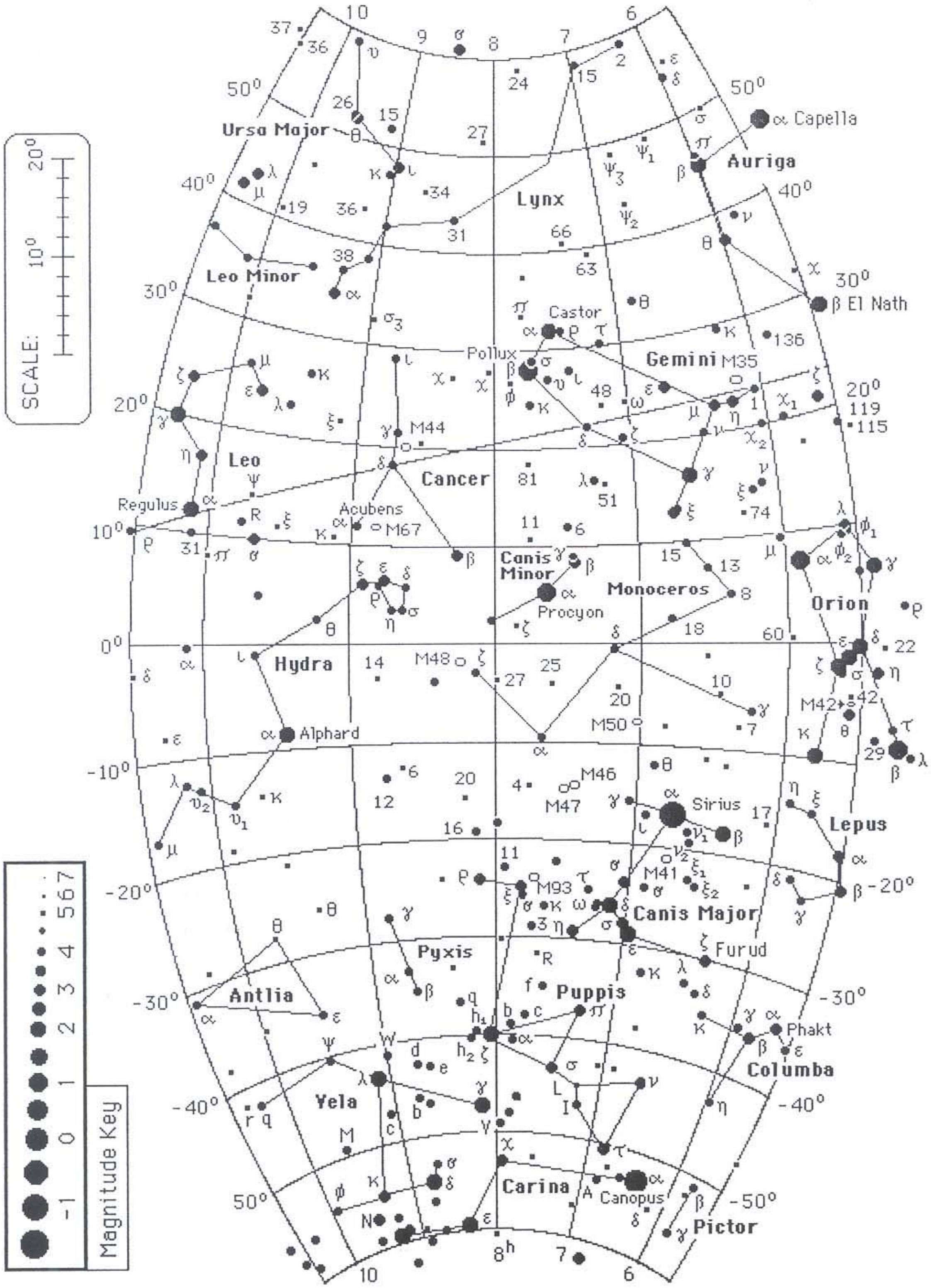

CASSIOPEIA
Schedar
Caph
M52
M103
M76
51 And
LACERTA
CYGNUS
Alderamin
CEPHEUS
PERSEUS
α Algenib
CAMELOPARDUS
AURIGA
LYNX
DRACO
N Pole Ecliptic
α Polaris
Kochab
DRACO
Thuban
M82
M81
Dubhe
β Merak
M101
BOOTES
Alcor
Mizar
Alkaid
URSA MAJOR
M109
Phecda
M97
M108
PRECESSION OF EQUINOXES
Thuban was pole star 3000BC
Polaris will be closest to Pole 2100AD?
Alderamin will be pole star 7000AD
Alcor & Mizar have 12' separation,
Mizar A & B have 14" separation
SCALE (degrees)
5 10 15 20
Magnitude Key
-1 0 1 2 3 4 5 6 7

$22^h - 2^h$ MAP

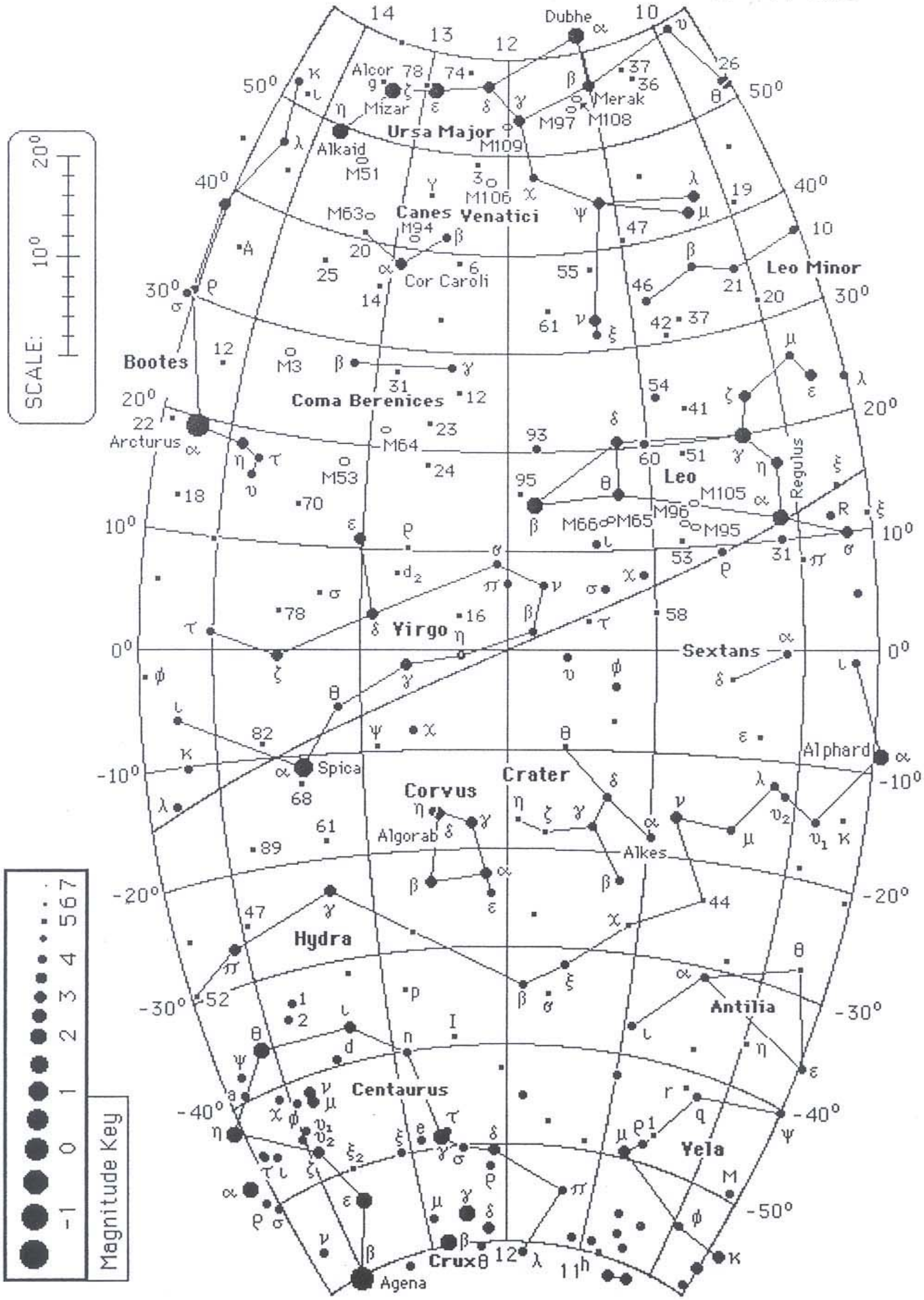

Cassiopeia
Cepheus
Lacerta
Cygnus
Andromeda
Almach
M31
M32
M76
Triangulum
M33
Alpheratz
Hamal
Aries
Pegasus
Markab
M74
Pisces
Enif
Al Rischa
Sadalmelik
Mira
Aquarius
Cetus
Diphda
Capricornus
Fornax
Sculptor
Formalhaut
Piscis Austrinus
Grus
Al Nair
Phoenix
Eridanus
Achernar
Indus
SCALE:
Magnitude Key


2h – 6h MAP
Hyades
Aldebaran
4 hours
SCALE: 10°
Magnitude Key
16=Celano
17=Electra
18=Asterope
19=Taygeta
20=Maia
23=Merope
27=Atlas
28=Pleione
Pleiades
M45
Alcyone
3 hours
Auriga
Andromeda
Algol
M34
M38
M36
M37
Perseus
Trangulum
Gemini
El Nath
Taurus
Pleiades
M45
Hamal
Aries
M1
Hyades
Orion
M78
M42
M77
Cetus
Mira
Pisces
Eridanus
Zurak
Arneb
Lepus
Canis
Major
Nihal
M79
Furud
Fornax
Columba
Caelum
Horologium
Dorado
Pictor
Canopus
Phoeni
Achernar

$6^h - 10^h$ MAP

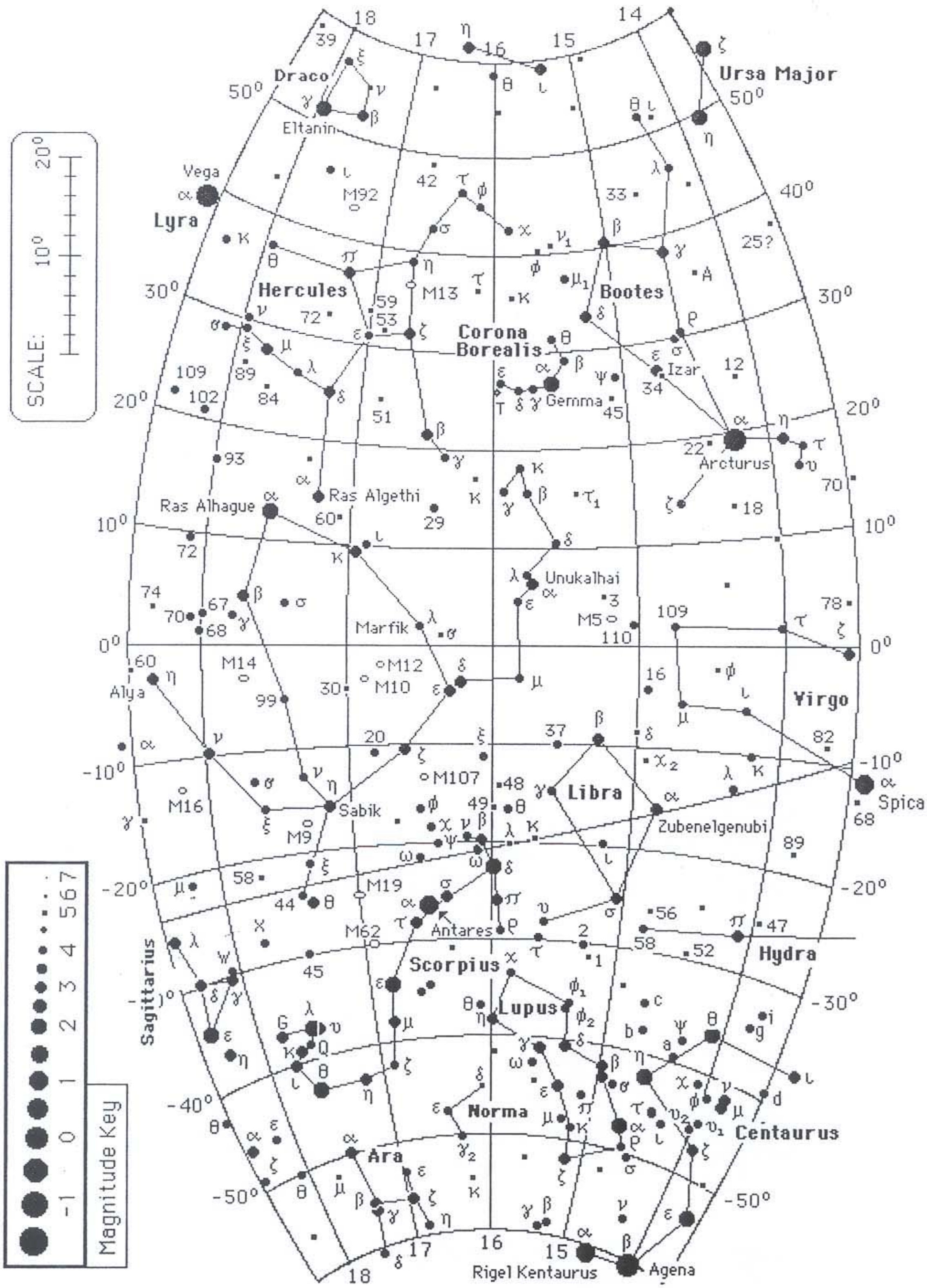

SCALE:
10°
20°
Ursa Major
Leo Minor
Lynx
Auriga
α Capella
β El Nath
Castor
Pollux
Gemini
M35
M44
Leo
Cancer
Regulus
Acubens
M67
Canis Minor
Procyon
Monoceros
Orion
Hydra
M48
M50
M42
Alphard
M46
M47
Sirius
Lepus
M41
M93
Canis Major
Pyxis
Furud
Antlia
Puppis
Phakt
Columba
Vela
Carina
Canopus
Pictor
Magnitude Key
-1 0 1 2 3 4 567

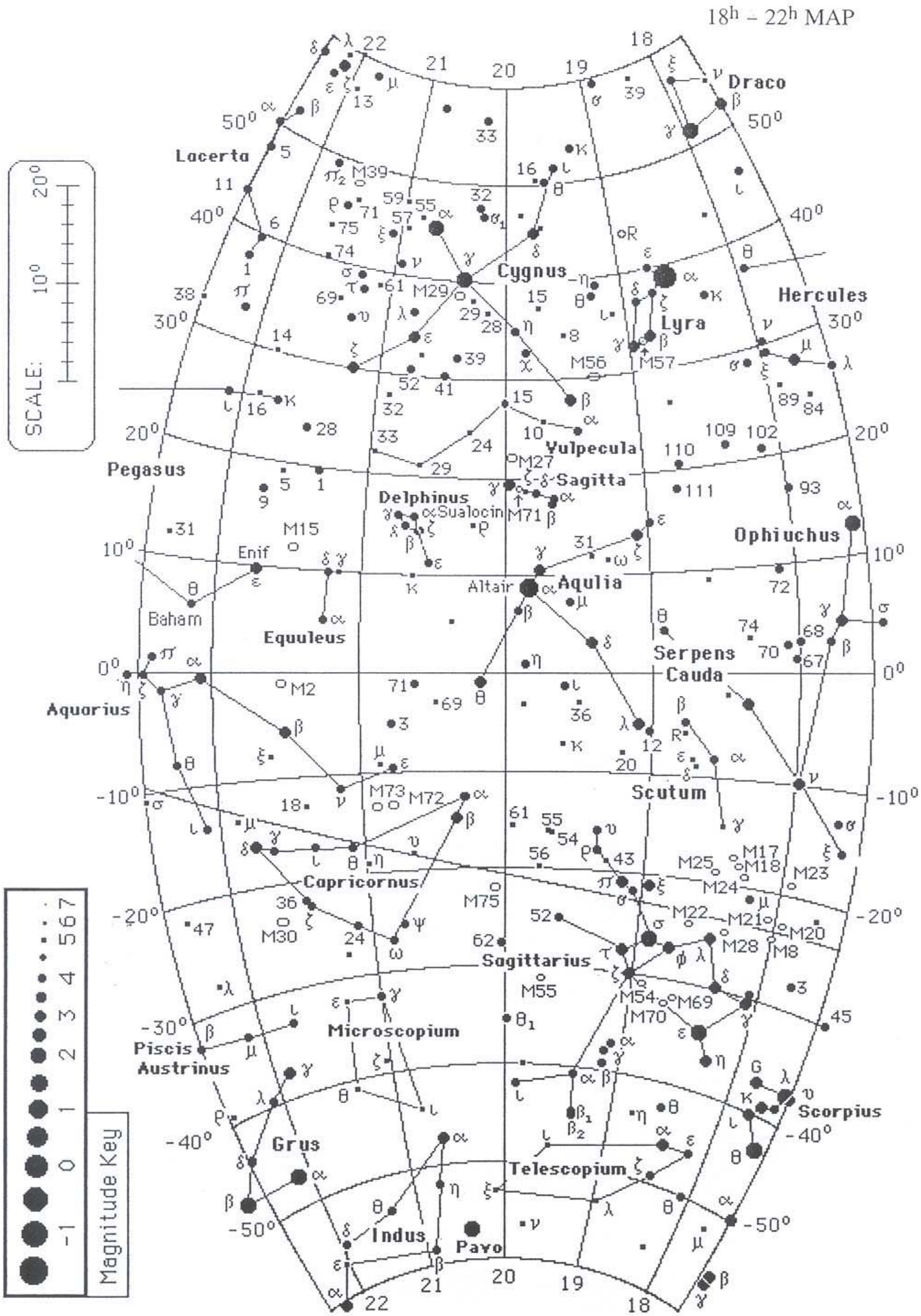
10^h – 14^h MAP



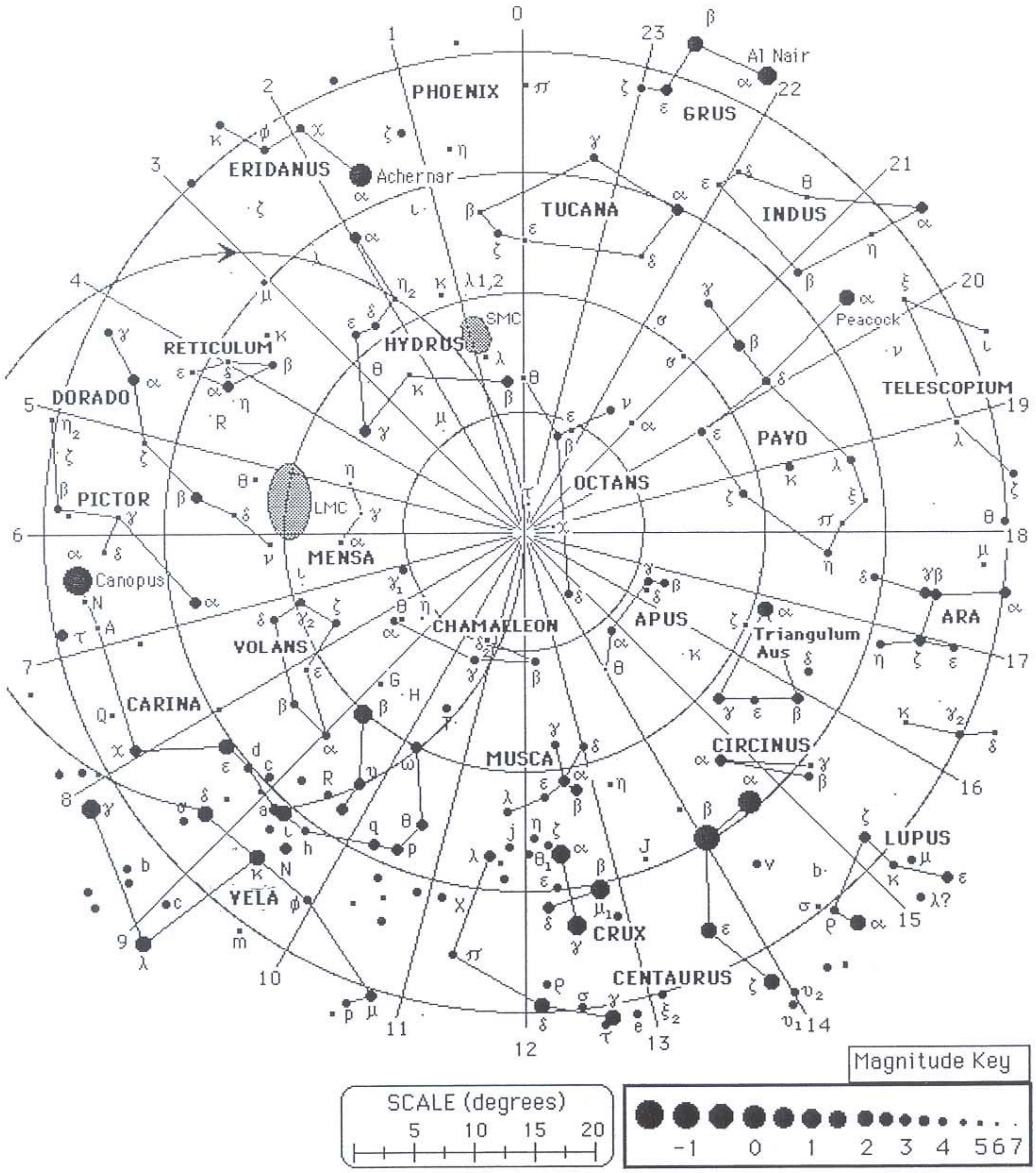
14
13
12
10
Dubhe
Alcor
78
74
37
36
26
50°
Mizar
Merak
M97
M108
Ursa Major
M109
Alkaid
M51
3
M106
40°
19
M63
Canes
Venatici
M94
47
10
20
25
Cor Caroli
6
55
46
21
Leo Minor
30°
14
20
61
42
37
Bootes
12
M3
31
12
Coma Berenices
54
41
20°
22
Arcturus
23
M64
93
51
60
24
M53
Leo
18
70
95
M105
Regulus
M66
M65
M96
M95
R
10°
d2
53
31
78
16
58
Virgo
Sextans
0°
82
Alphard
Spica
Crater
68
Corvus
61
Algorab
89
Alkes
-10°
-20°
44
47
Hydra
52
-30°
1
2
p
I
Antilia
d
n
Centaurus
-40°
r
q
Vela
M
-50°
Crux
12
11h
Agena
SCALE:
10°
20°
Magnitude Key
-1
0
1
2
3
4
5
6
7

$14^h - 18^h$ MAP


Draco
Eltanin
Ursa Major
Vega
Lyra
Hercules
M92
M13
Corona Borealis
Bootes
Gemma
Izar
Arcturus
Ras Algethi
Ras Alhague
Unukalhai
Marfik
M5
M14
M12
M10
Alya
Virgo
Spica
M16
M107
Sabik
Libra
Zubenelgenubi
M9
M19
M62
Antares
Scorpius
Hydra
Sagittarius
Lupus
Norma
Centaurus
Ara
Rigel Kentaurus
Agena
SCALE:
Magnitude Key



18h – 22h MAP
SCALE: 10° 20°
Magnitude Key
-1 0 1 2 3 4 5 6 7
Draco
Lacerta
Cygnus
Lyra
Hercules
Vulpecula
Sagitta
Pegasus
Delphinus
Sualocin
Ophiuchus
Enif
Baham
Altair
Aquila
Equuleus
Serpens Cauda
Aquarius
Scutum
Capricornus
Sagittarius
Microscopium
Piscis Austrinus
Grus
Scorpius
Telescopium
Indus
Pavo
M39 M29 M56 M57 M27 M71 M15 M2 M73 M72 M75 M30 M25 M17 M18 M24 M23 M22 M21 M20 M28 M8 M55 M54 M69 M70

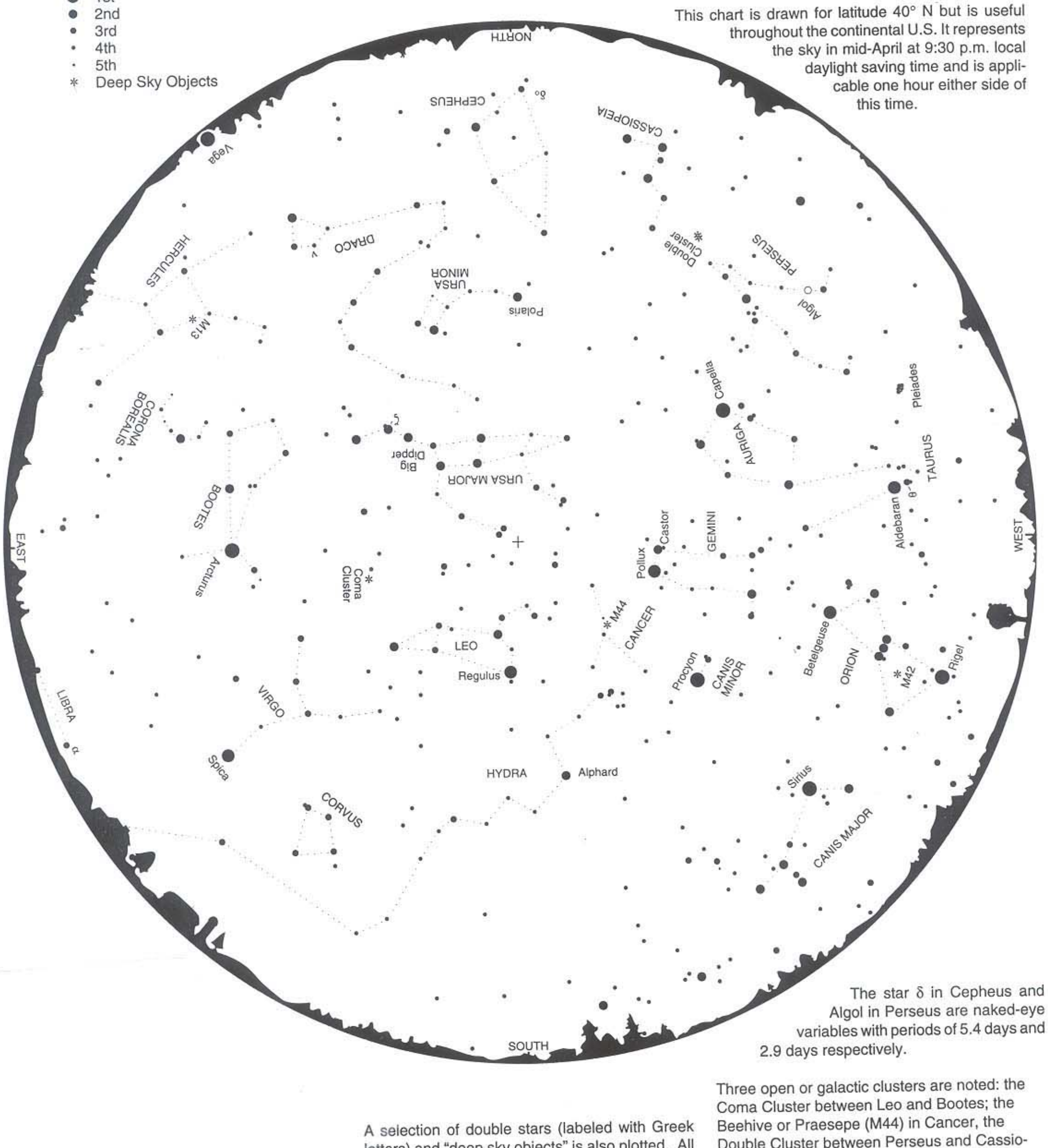

PHOENIX
GRUS
Al Nair
ERIDANUS
Achernar
TUCANA
INDUS
HYDRUS
SMC
Peacock
RETICULUM
DORADO
TELESCOPIUM
PAVO
OCTANS
PICTOR
LMC
MENSA
Canopus
CHAMAELEON
APUS
Triangulum Aus
ARA
VOLANS
CARINA
MUSCA
CIRCINUS
LUPUS
VELA
CRUX
CENTAURUS
Magnitude Key
SCALE (degrees)
5 10 15 20
-1 0 1 2 3 4 567

April Evening Skies

LEGEND
Star Magnitudes

- Zero or brighter
- 1st
- 2nd
- 3rd
- 4th
- 5th
- * Deep Sky Objects

This chart is drawn for latitude 40° N but is useful throughout the continental U.S. It represents the sky in mid-April at 9:30 p.m. local daylight saving time and is applicable one hour either side of this time.



The star δ in Cepheus and Algol in Perseus are naked-eye variables with periods of 5.4 days and 2.9 days respectively.

A selection of double stars (labeled with Greek letters) and "deep sky objects" is also plotted. All are visible with modest equipment; most are within the range of the unaided eye or binoculars.

The double stars, in order of decreasing angular separation, are ζ in Ursa Major, θ in Taurus, α in Libra (just rising), and ν in Draco.

Three open or galactic clusters are noted: the Coma Cluster between Leo and Bootes; the Beehive or Praesepe (M44) in Cancer, the Double Cluster between Perseus and Cassiopeia.

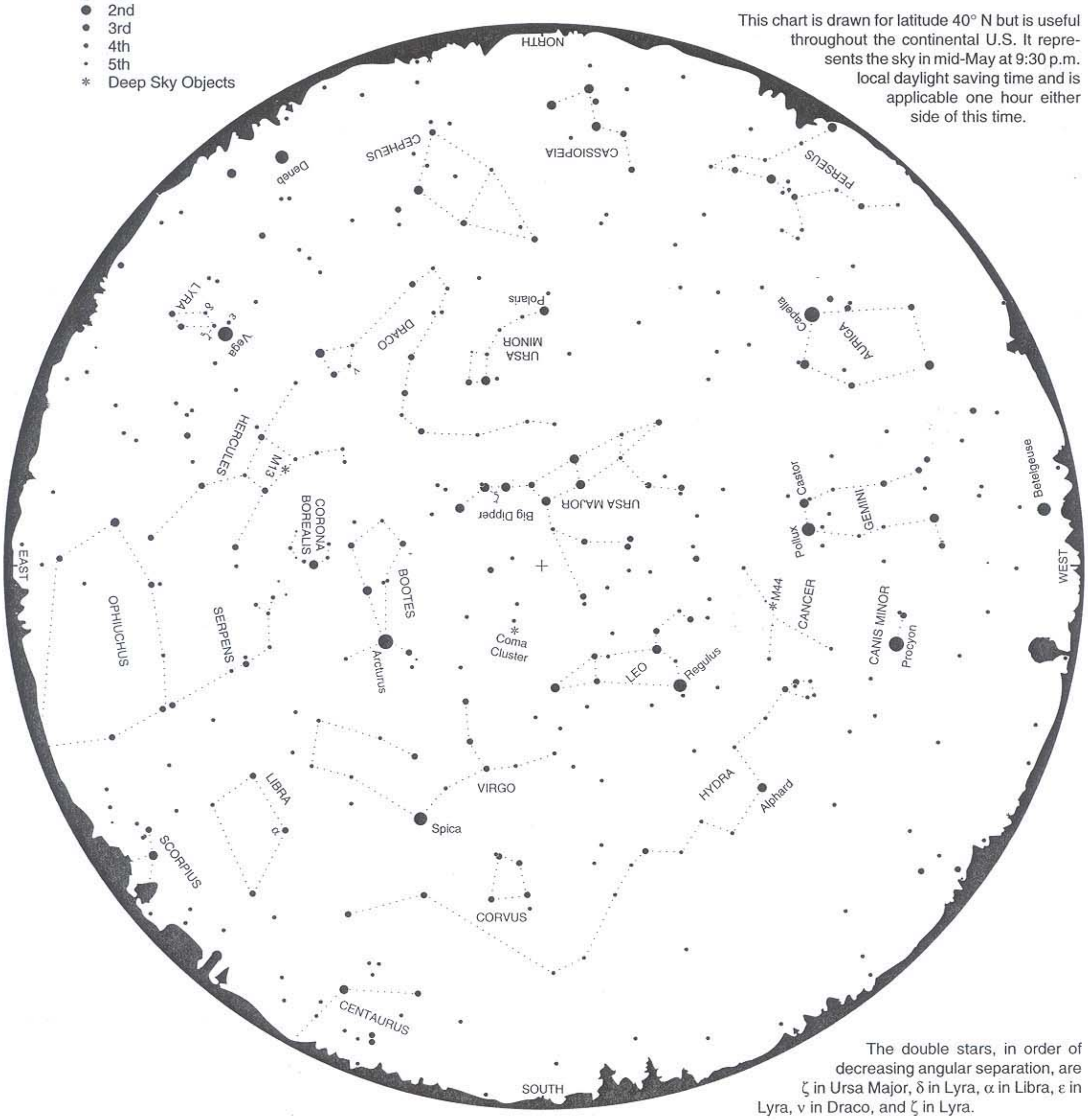
The Hercules Cluster (M13) is a fine example of a globular cluster, and M42, the Orion Nebula, is a gas cloud out of which stars are forming.

May Evening Skies

LEGEND
Star Magnitudes

- Zero or brighter
- 1st
- 2nd
- 3rd
- 4th
- 5th
- * Deep Sky Objects

This chart is drawn for latitude 40° N but is useful throughout the continental U.S. It represents the sky in mid-May at 9:30 p.m. local daylight saving time and is applicable one hour either side of this time.



The double stars, in order of decreasing angular separation, are ζ in Ursa Major, δ in Lyra, α in Libra, ε in Lyra, ν in Draco, and ζ in Lyra.

Two open or galactic clusters are noted. The Coma Cluster is a loose group of naked-eye stars below the handle of the Big Dipper. The Beehive or Praesepe (M44) in Cancer is much more compact, resembling a hazy patch of light.

A selection of double stars (labeled with Greek letters) and "deep sky objects" is also plotted. All are visible with modest equipment; most are within the range of the unaided eye or binoculars.

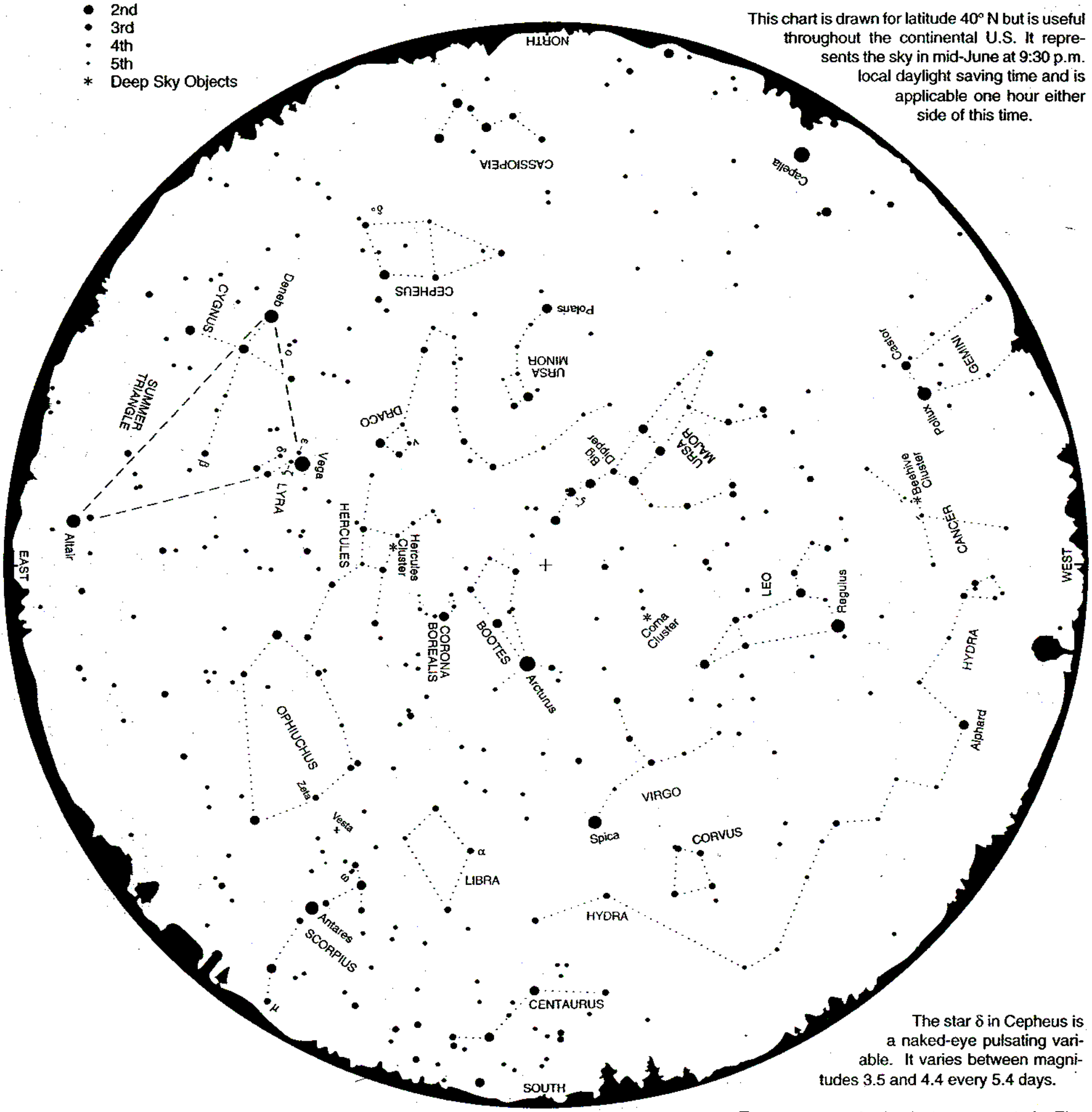
The Hercules Cluster (M13) appears still more compact. It is a fine example of a globular cluster, a dense concentration of about a million stars.

LEGEND
Star Magnitudes

- Zero or brighter
- 1st
- 2nd
- 3rd
- 4th
- 5th
- * Deep Sky Objects

June Evening Skies

This chart is drawn for latitude 40° N but is useful throughout the continental U.S. It represents the sky in mid-June at 9:30 p.m. local daylight saving time and is applicable one hour either side of this time.



The star δ in Cepheus is a naked-eye pulsating variable. It varies between magnitudes 3.5 and 4.4 every 5.4 days.

A selection of double stars (labeled with Greek letters) and "deep sky objects" is also plotted. All are visible with modest equipment; most are within the range of the unaided eye or binoculars.

The double stars, in order of decreasing angular separation, are ω Sco, ζ UMa, δ Lyr, μ Sco, o Cyg, α Lib, ε Lyr, ν Dra, ζ Lyr, β Cyg.

Two open or galactic clusters are noted. The Coma Cluster is a loose group of naked-eye stars below the handle of the Big Dipper. The Beehive or Praesepe in Cancer is much more compact, resembling a hazy patch of light.

The Hercules Cluster appears still more compact. It is a fine example of a globular cluster, a dense concentration of about a million stars.