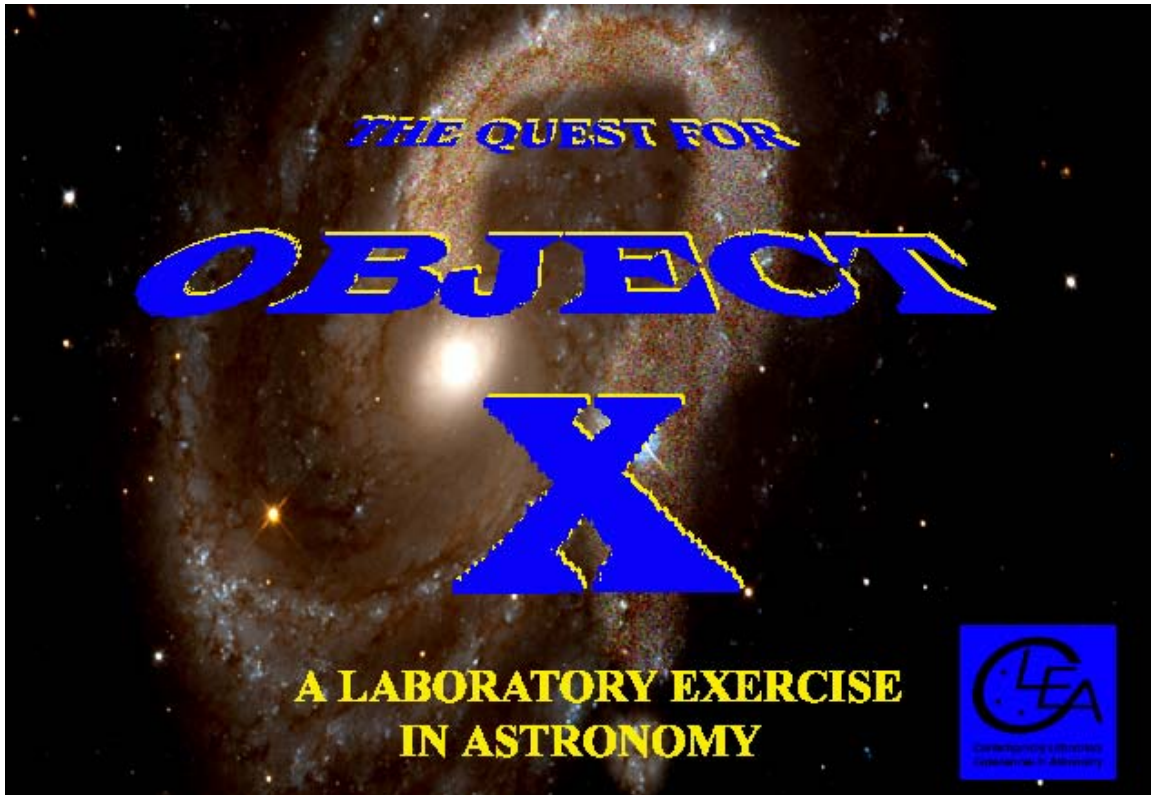


The Quest for Object X

Student Manual



A manual to Accompany Software for the
Introductory Astronomy Lab Exercise
Document SM10: Version 1

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Goals

Given the celestial coordinates of a celestial object, you should be able to use observations with a variety of astronomical instruments at a variety of wavelengths and times to determine what kind of an object it is . You should also be able to use observations to determine some of its physical properties such as temperature, distance, velocity, etc. (depending on the type of object). Ultimately, you should get a better appreciation of the distinction between *observations*—which produce data --- and *interpretations*, which are conclusions about the characteristics of an object drawn from the data.

Objectives

If you learn to...

- Operate CLEA’s simulated optical and radio telescopes.
- Locate objects using celestial coordinates.
- Take spectra, images, and photometric measurements.
- Recognize the identifying characteristics of stars, galaxies, asteroids, pulsars, and other objects in the heavens.
- Understand which types of measurements yield useful information about celestial objects.
- Calculate the properties of celestial objects from various types of measurements.

You should be able to...

- Identify what kind of an object you have been given by your instructor.
- Make additional measurements that will enable you to identify at least some of these properties: size, temperature, distance, velocity, period of rotation, age, composition.
- Developing an understanding of what astronomers do when they conduct research.
- Appreciate some of the difficulties and limitations in making astronomical discoveries.

Useful terminology you should review in your notes and textbook

Absolute Magnitude	Absorption line	Apparent magnitude	Asteroid	Astronomical Unit
Brightness	CCD Camera	Declination	Distance modulus	Doppler shift
Emission line	Frequency	Galaxy	HR Diagram	Hubble relation
Infrared	Light Year	Parsec	Photometer	Pulsar
Radial velocity	Radio Telescope	Red shift	Right Ascension	Spectral type
Spectrometer	Spectrum	Star	Transverse velocity	Universal time
Wavelength				

THE QUEST FOR OBJECT X

Introduction

What does it mean to say that an astronomer has “discovered” something? In many fields of science, discovery implies finding something that is hidden out of sight, such as digging up a fossil hidden under layers of clay, discovering the chemical structure of an enzyme, or traveling to the heart of the rainforest to photograph a previously unknown species of songbird.

But how does this apply to astronomy? The skies are in full view, with the exception of objects that lie below the horizon. If you are willing to wait for the earth to turn and if you are able to travel to a different hemisphere, you can see the entire sky. If you take a longer exposure or use a larger telescope, you can see fainter and fainter things. Nothing can be really hidden.

There are so many things in the sky, however, that what may be in full view may not be easy to distinguish. The main task of astronomical discovery, in short, is to recognize a few objects of interest among the billions and billions of points of light we detect up there. It’s like the puzzles in the “Where’s Waldo?” books, which ask the reader tries to find one person in a crowd of thousands—you can stare straight at the object you’re looking for, yet fail to find what’s right before your eyes.

To appreciate the difficulty of discovering something of interest among the multitude of lights in the sky, consider the following: On a dark moonless night, a good observer can see about 3000 stars at any given time with the naked eye. The telescopes and electronic cameras used by astronomers today increase this number immensely. If you count stars as down to one ten thousandth the brightness of those just barely visible to the naked eye, the number is about 20 million, and the number rises quickly into the billions as one goes still fainter. Long exposures with the best telescopes can see things a million times fainter still, and no one has attempted to make a complete count of the billions and billions of objects visible at that level.

Most of the things in the sky look like dots or smudges of light. Even through the biggest telescopes only a few objects, like the large planets, a few galaxies and nebulae, show distinguishing details. It takes careful observation—with spectrometers, photometers, imaging cameras at a wide range of wavelengths to distinguish one smudge from another. Just as an analytical chemist works with white powders, trying to figure out what they’re made of, so an astronomer takes data on little dots and smudges of light in order to “discover” their true nature.

This is an exercise in astronomical discovery. It’s simple in concept: you will be given the celestial coordinates (Right ascension and Declination) of a mystery object, the “unknown”, Object X. Using the techniques of observational astronomy, you will identify the object and find out all you can about its physical characteristics (e.g. the distance, temperature, and luminosity of a star in the Milky Way, or the speed and distance of a remote galaxy.)

YOUR UNKNOWN OBJECT

Write down in the space below the celestial coordinates of the unknown object assigned by your instructor.

THE COORDINATES OF OBJECT X					
RIGHT ASCENSION			DECLINATION		
H	M	S	'	"	"

PROCEDURES FOR IDENTIFYING ASTRONOMICAL OBJECTS

The General Idea

As an astronomer you are presented with an unknown object. All you know are its celestial coordinates, Right Ascension and Declination, which tell you where in the sky to point your telescope. How do you figure out what the object is?

To understand the basic method, consider a more familiar situation: You are a chemist, and someone gives you a white powder. What do you do to find out what it is made of? The general technique is to run the powder through a series of standard procedures to see what results it produces. A chemist may place the powder in a mass spectrometer, which will produce a graph indicating the presence of various chemical elements. A teaspoon of the powder might be weighed on a sensitive balance to see how dense it is. Or the chemist may put the powder in a test tube and add another reactive substance to see what happens---a solution might change colors, or a precipitate might form.

Astronomers analyze the light from an unknown object in similar fashion—they run it through a series of tests. The first thing an astronomer might do is to point a telescope at the unknown object and take a picture of it. That might immediately settle what it is---if the object looks like a large extended spiral of light, then it's a relatively nearby spiral galaxy. But suppose it looks like a *point source*---a little dot of light---then the decision is not as clear. It could be an asteroid in our own solar system; it could be a star a few light years away; it could be a distant galaxy hundreds of millions of light years distant (which is too far away for its shape to be visible); it could even be a quasar (a small source of intense radiation, powered by a super-massive black hole), billions of light years away.

To settle the question, you would perform an additional test. You could attach a spectroscope to your telescope and take a spectrum of the light from the unknown object. Suppose the spectrum looked like this (figure 1), with only a few broad spectral lines visible, and the distinctive pattern of two close lines (from ionized Calcium atoms) at the short wavelength end of the spectrum:

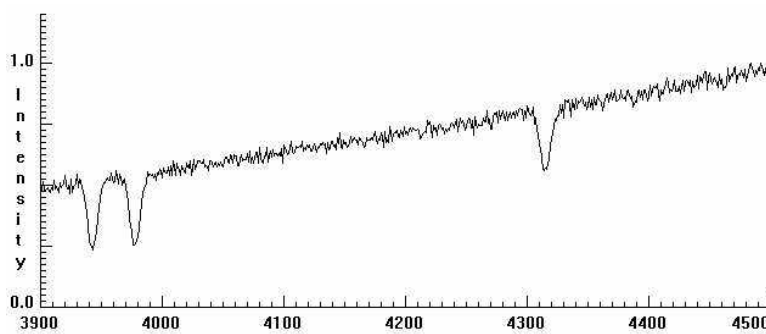


Figure 1:
Spectrum of
a Galaxy

This is a typical galaxy spectrum, as distinct from the spectrum of a star, say, which might look like the spectrum below (figure 2) , which has a different and distinctive pattern of spectral lines.

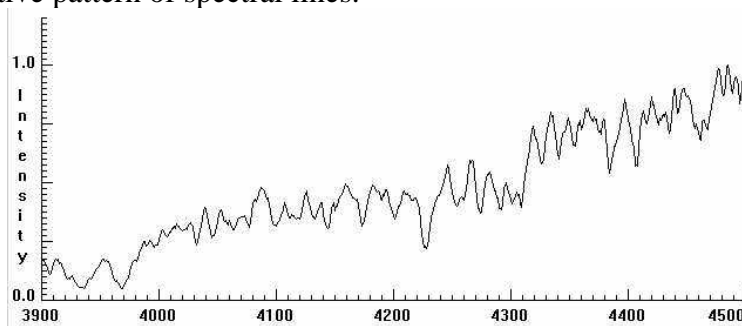


Figure 2:
Spectrum
of a Star

While galaxy spectra look pretty much the same (because they are the average of millions of stars of different kinds), the spectra of stars differ from one spectral type to the other. Here's another star spectrum (figure 3) of a different spectral type.

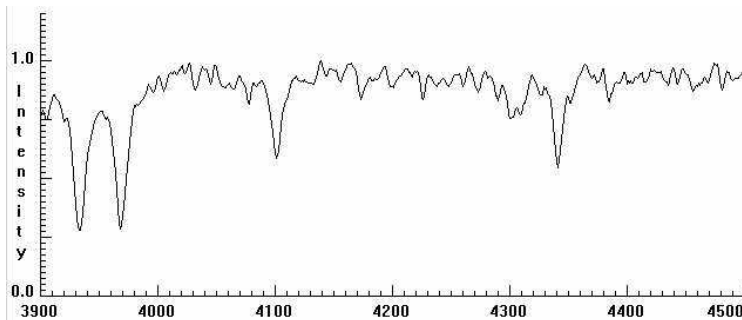


Figure 3:
A star spectrum of a
different spectral
type from that in
figure 2

For an exercise on spectral types of stars, see the CLEA lab “Spectral Classification of Stars”.

Since *our* unknown object in this case has the spectrum of a galaxy, we identify it as such, and can then proceed to determine some of its properties from the spectrum, notably its redshift, its speed of recession from us, and its distance (see CLEA’s exercise: “The Hubble Redshift-Distance Relation”).

If the spectrum of the object had been that of a star, we would have been able to determine its spectral type and its absolute magnitude from its spectrum. We might have gone on to determine the apparent magnitude of the star using a photometer (see CLEA’s

exercise: “Photoelectric Photometry of the Pleiades”). Then from the absolute and apparent magnitudes we could have determined the distance of the star.

Sometimes it’s just that simple. If we classified the spectrum and found that it was a B5 main-sequence star, we could rest assured that the object was indeed a star, and we could go ahead and determine its properties from tables of the properties of various types of stars.

Sometimes it’s not that simple, however, and additional observations are necessary to reach a firm identification. Suppose the unknown spectrum was that of a G2 main-sequence star, which happens to be the spectral type of our own sun. Though there are plenty of G2 stars in the sky, it’s also possible that the object might *not* be a star at all but an asteroid in our solar system, reflecting the light of our sun.

How could we decide whether it was a nearby asteroid or a distant star? The simplest way is to note that an asteroid is in orbit around the sun, and moves noticeably against the background of much more distant stars in just a few minutes time. So if we take two pictures of the unknown object several minutes apart and we notice that the object has moved from one picture to the next, then it is an asteroid, not a star. Consequently, before we can conclude that the pointlike object with the G2 spectrum is a star, we need to take two pictures of it spaced several minutes apart and compare them to make sure that it has not moved. (This method of identifying asteroids is presented in CLEA’s “Astrometry of Asteroids” exercise.)

Some General Hints

There is no quick cookbook recipe for identifying unknown objects, and one of the goals of this exercise is for you to develop your own strategy of astronomical discovery. But the example in the previous section should give you some idea of what is involved. The CLEA software provided with this exercise gives you access to a wide range of telescopes, instruments, and analysis software that you can use to analyze the light from an unknown celestial object. You can use these facilities to perform tests that will help you uncover the object’s most likely nature

Here are some of the questions you may want to ask yourself as you design and implement your observing strategy:

- Is the object visible at some wavelengths and not at others? Normal stars, for instance are visible through an optical telescope, while pulsars (with one or two exceptions) are invisible, because they emit very little light. On the other hand pulsars are strong emitters of radio radiation, and can be detected with radio telescopes, while stars (with the exception of our Sun, because it is so close) emit too little radio radiation to be detected.
- Is the object a *point source* or an *extended source*? Point sources look like featureless dots of light, no matter how much they are magnified, while extended sources exhibit detail and spread out over a measurable area of the sky. Stars (again except for the sun) appear as point sources. So do asteroids and quasars. Nearby galaxies appear as extended sources---diffuse blobs or pinwheels of light. But very distant galaxies may be so far away that they appear as no more than dots of light, and can be mistaken for stars. Some objects that appear as point sources on short

exposures, reveal extended features when very long exposures reveal their faint outer regions.

- Does the object show an absorption spectrum or an emission spectrum? Stars and galaxies show absorption spectra, though as we have seen the spectrum of a star is distinct from that of a galaxy. Thin clouds of gas heated by nearby stars show emission spectra. Some examples of these gas clouds include HII regions, like the Orion Nebula, and planetary nebulas, like the Ring Nebula (M57). Quasars often show emission spectra, too.
- Does the object move? Most objects outside of our solar system show such small motions that they appear stationary, except over periods of thousands or millions of years. But objects in the solar system, since they are in orbit around the sun, appear to move relatively quickly among the stars. The motion of an asteroid, for instance, can usually be noticed on pictures taken just a few minutes apart.
- Assuming I've identified my object correctly, which of its properties can I derive from observations with the instruments I have available? If it is a star, for instance, I can determine its spectral type from observations with my spectrograph, and knowing its spectral type, I can look up its temperature and absolute magnitude. I can also measure its apparent magnitude with my photometer, and from its apparent and absolute magnitudes, determine its distance. If it is a pulsar, however, I can't see it with my optical telescope at all. Instead, I'll have to use my radio telescope, and I can then determine its period, which tells me how fast the neutron star that produces the pulsar is spinning. Further by observing the difference in arrival times of its pulses at different frequencies, I can determine how far away the pulsar is. (See CLEA's *Radio Astronomy of Pulsars* exercise.)

In the table on the next page we've listed some of the distinguishing characteristics of a number of types of astronomical objects, along with some of the properties you can measure with your observations. They may be a help in designing your own strategy for identifying your unknown object.

Criteria for Identifying Astronomical Objects		
TYPE OF OBJECT	OBSERVATIONAL CHARACTERISTICS	PHYSICAL QUANTITIES DERIVABLE FROM OBSERVATIONS
Star	<ul style="list-style-type: none"> • Optical: Point Source Absorption Spectrum Matches Stellar Spectral atlas type. Radio: Not Detectable 	<ul style="list-style-type: none"> • Spectral Type Temperature Luminosity Distance Galactic Coordinates Age (if in cluster)
Asteroid	<ul style="list-style-type: none"> Optical: Point Source Moves with respect to background stars. G2V Absorption spectrum. Radio: Not Detectable 	<ul style="list-style-type: none"> • Position Transverse component of velocity Distance (if parallax measurements available). Color and type
Normal Galaxy	<ul style="list-style-type: none"> Optical: Extended Source. But may appear as Point Source if sufficiently distant Absorption Spectrum, late type composite. H, K lines and G band prominent. Notable red-shift. Radio: Weak or non-detectable. 	<ul style="list-style-type: none"> • Radial velocity Distance (assuming H_0) or using an independent standard candle such as Cepheids or Type Ia Supernova.
Quasi-Stellar Object	<ul style="list-style-type: none"> Optical: Point Source Emission Spectrum High Red Shift. Radio: May be strong or weak.. 	<ul style="list-style-type: none"> • Radial Velocity Distance (assuming H_0) Luminosity
Pulsar	<ul style="list-style-type: none"> Optical: Not detectable except for a very few of the youngest (e.g. Crab, Vela) Radio: Short duration, periodic bursts Period $\sim 10^{-3}$ to 10 sec. 	<ul style="list-style-type: none"> • Rotation period Distance (assuming interstellar electron density). Age
Planetary Nebula	<ul style="list-style-type: none"> Optical Extended source. Small and distant ones may appear as point sources. Emission Spectrum: Nebular lines prominent Radio Not detectable 	<ul style="list-style-type: none"> • Temperature Gas Density Distance

THE CLEA VIRTUAL EDUCATIONAL OBSERVATORY (VIREO)

Once you have written down the coordinates of your unknown object, you'll want to run the VIRTUAL Educational Observatory (VIREO), available on your laboratory computer. This software gives you access to a variety of telescopes and measuring instruments which you can use to examine and analyze the radiation from Object X. You can then think over what you want to use first, and begin to develop a strategy for identifying the unknown. You don't have to lay out your entire strategy all at once: you can make some measurements and then decide what to do next on the basis of your first results. But keep track of what you're doing, so that you can summarize your overall strategy in your final report.

Here is a summary of the instruments you have available through the VIREO software:

Optical Telescopes: There are three optical telescopes available for your use, one with a small mirror (0.4 meters in diameter), one with a medium-size mirror (1.0 meters in diameter), and one with a large mirror (4.0 meters in diameter.) You can choose the telescope you want in the main observatory window of the program (figure 4). Which telescope you choose, of course, will influence how much light you collect and how much time it will take to collect data with the telescopes. For very faint objects, therefore, the largest telescope is best. For brighter objects, a smaller telescope may be sufficient.

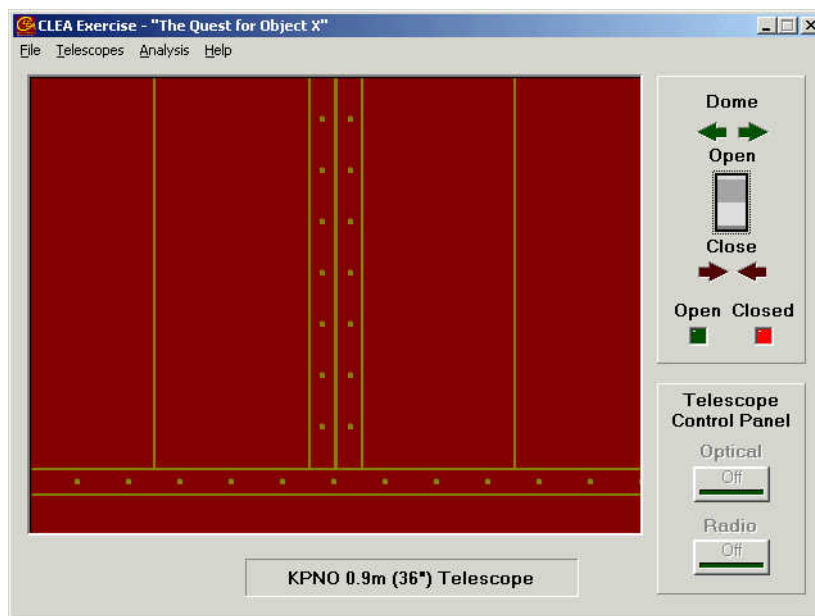


Figure 4: The Main Observatory Window

Once you have selected a telescope, you can open up the dome and turn on the telescope control window, which will open a window like that in Figure 5.

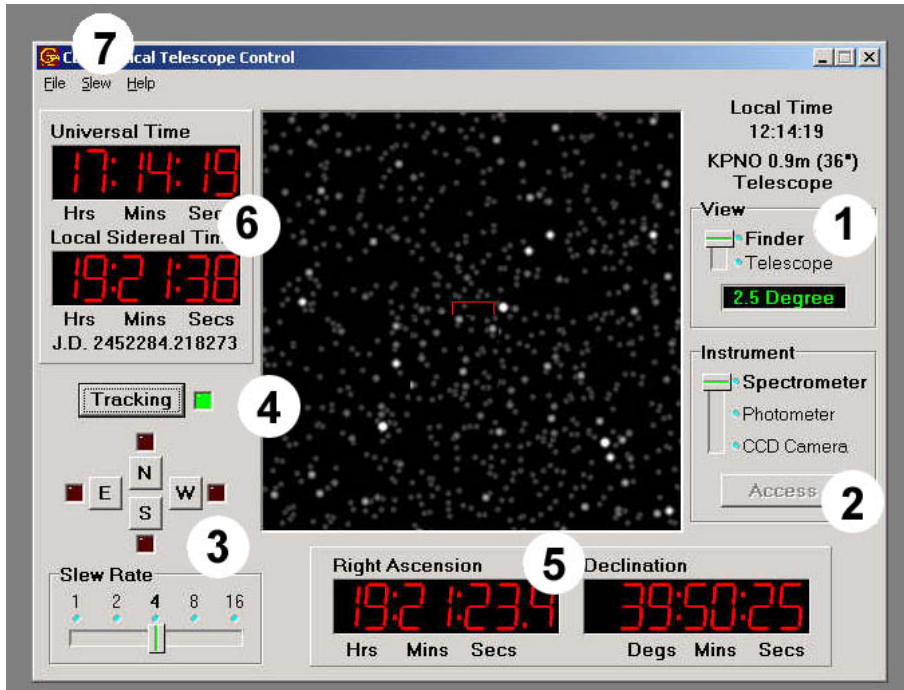


Figure 5: The telescope control window

In addition to the TV screen in the center that shows the view through the telescope, there are:

1. Controls to zoom in from a wide field (“Finder”) view to a magnified narrow-field (“Telescope”) view.
2. Controls to select instruments to attach to the telescope.
3. Controls to move (“slew”) the telescope.
4. A control to turn on the telescope so that it tracks the stars. (NOTE: tracking must be turned on in order to use the other features of the telescope. If the tracking is off, the stars will appear to move through the TV viewer as the earth turns).
5. Displays of the coordinates in the sky that the telescope is pointed at.
6. Displays of time.
7. A pull down menu in which you can enter the exact. coordinates of stars you want the telescope to move to.

You’ll want to turn on the tracking by pushing the tracking button (the green tracking light goes on and the stars stop drifting westward on the TV). You may want to slew the telescope to the coordinates of your unknown object. You will want to get a magnified view of the object by switching to the narrow field (“telescope”) view. You can then select the instrument you want to use to analyze the light of the object.

Instruments for the Optical Telescopes:

The CCD Camera: The CCD camera takes a digital picture of the sky the telescope is pointing at. A typical exposure, takes a minute or two, and you can make longer exposures to pick up fainter objects. There are two filters, the astronomical B (blue) and V (yellow-green) filters that you can put in front of the camera, or you can use none (“NF”). You can save your digital images to view and analyze later. The camera instrument control window looks like this (figure 6). Be sure to save any pictures you take, using the “File” menu to name and save your image file.

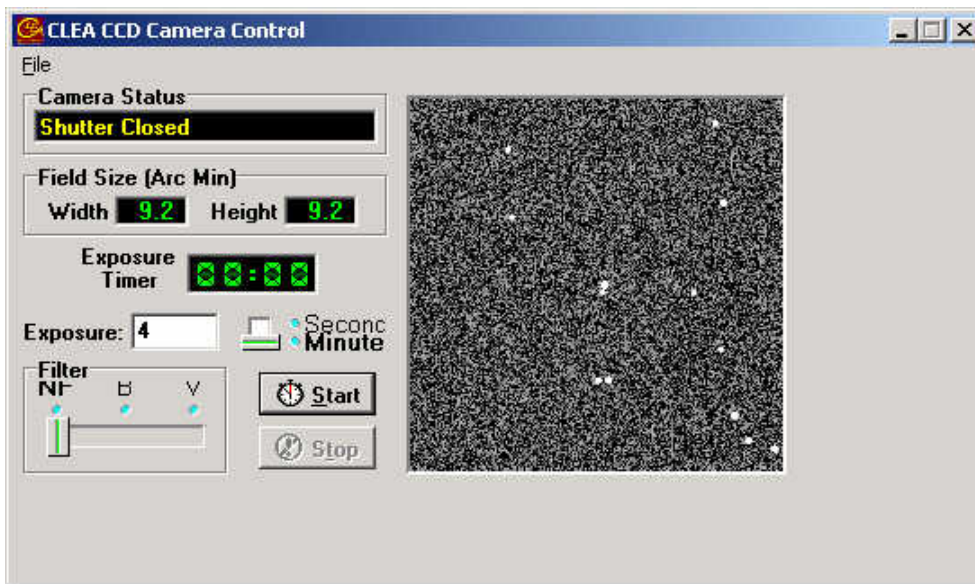


Figure 6:
The CCD
control
window

The Aperture Photometer: The photometer measures the brightness of light coming in through a small circular hole positioned in the image plane of the telescope. Filters can be placed between the hole and the photomultiplier tube that counts the photons of light as they come in. The telescope can be pointed at a star and all the light from the star, which goes through the photometer hole will be counted---as well as some background light from the night sky as well (caused by reflected city lights, emission of molecules in the atmosphere, etc.). The photometer should first be pointed at some blank sky to measure the background level--it will not calculate stellar magnitudes if you don't do this first. Once it has recorded the sky background, you can then point it to stars you want to measure. (See CLEA's *Phototelectric Photometry of the Pleiades* exercise for details).

Since photons of light come in at random times, you also need to make sure to collect about 10000 photons to make sure you have enough for a good statistical estimate of the brightness of the star. You can increase the exposure (“integration”) time, or the number of trials the photometer takes, to reach this number. For very faint stars, you may not be able to get 10000 photons in a reasonable time, but your results will therefore not be as reliable.

The photometer window, with all its controls, is shown in figure 7.

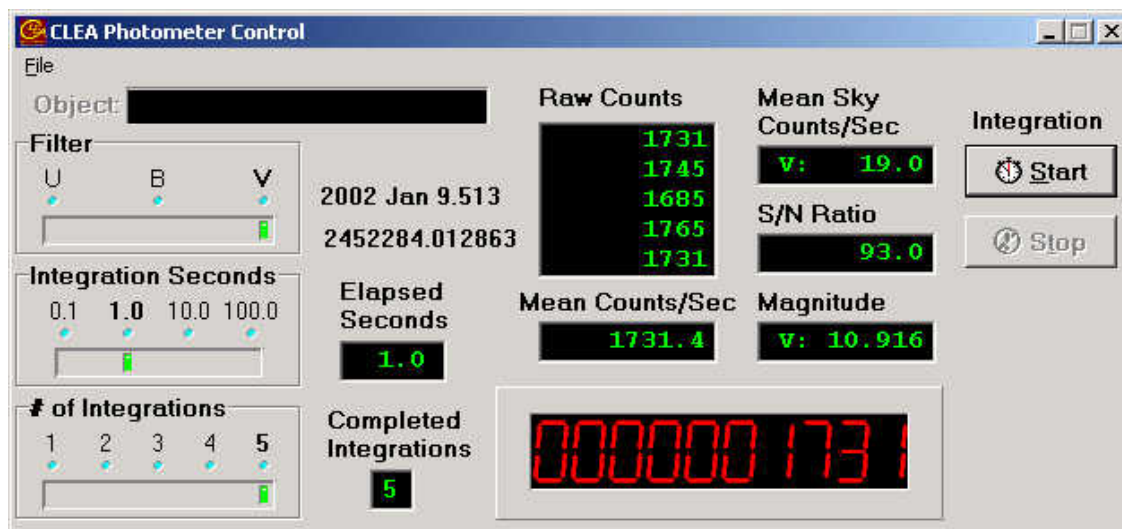


Figure 7: The Photometer Window

The Photon-Counting Spectrometer: The photon-counting spectrometer takes light that falls on a small slit in the image plane of the telescope and uses a grating to spread the light out into a spectrum, a graph of intensity versus wavelength. The longer you expose the spectrum, the clearer and more detailed it the graph will be. The intensity and wavelengths of points on the graph can be measured by pointing the mouse at the graph. The spectrum can also be saved for later analysis and measurement. For instance there is a classification tool that can be used to compare an unknown spectrum to a series of known comparison spectra.

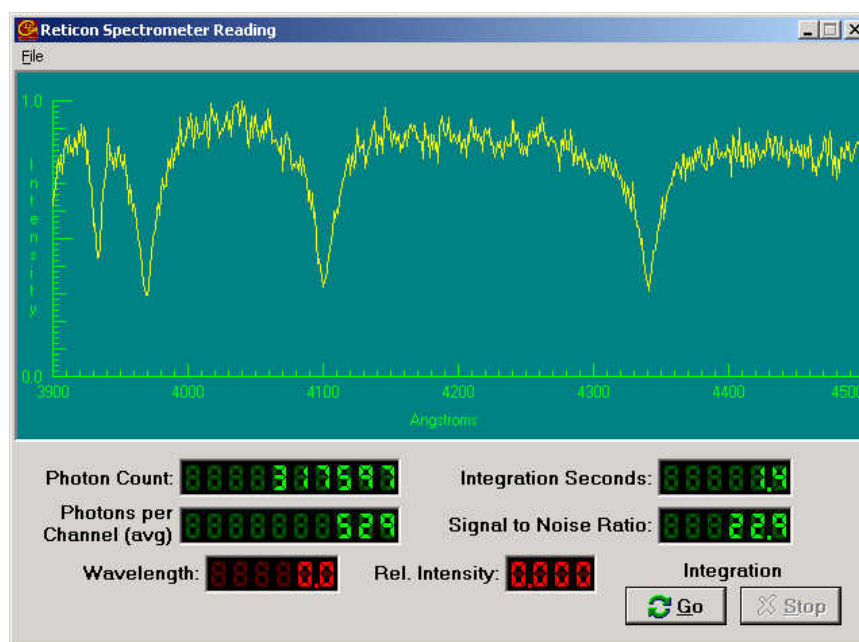


Figure 8: The Spectrometer window.

The Radio Telescope: Many objects in the heavens emit more at radio wavelengths than in visible light, and can best be detected with a radio telescope. You can access the CLEA radio telescope from the main window. The radio telescope control window (Figure 9) looks very much like the optical telescope window. However it controls a large radio dish antenna which can collect radio waves and send them to a radio receiver. Like the optical telescope, the antenna can track objects as they move across the sky. It can also be left stationary, picking up objects as the rotation of the earth moves the sky in front of it. (Astronomers call this “transit” mode of operation).

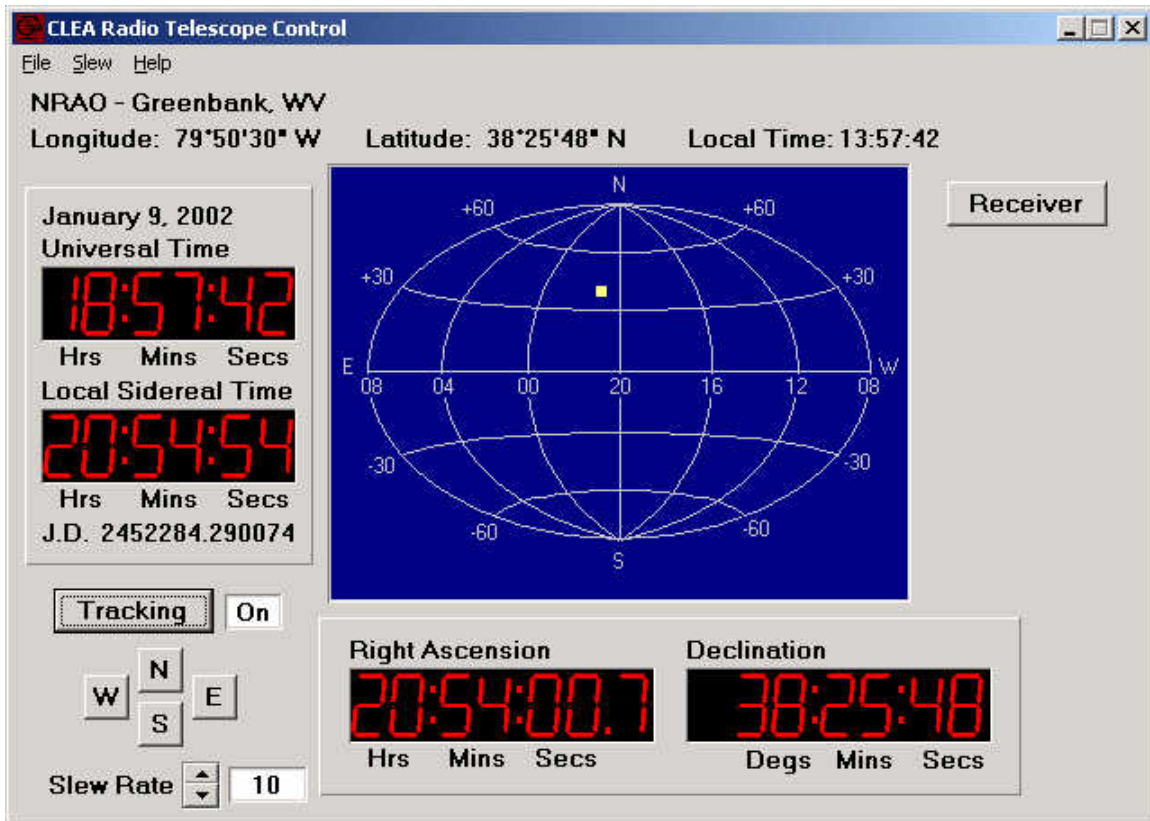


Figure 9: The Radio Telescope Control Window

The radio telescope window controls the telescope motion and has time, and coordinate displays like the optical telescope. The only difference is that, since it cannot actually see stars, there is no TV in the center to display starlight. Instead a map indicates where in the sky the telescope is pointed. There is a button in the upper right that turns on the instruments attached to the dish once the telescope is pointed to an object; these instruments are called radio receivers.

Instruments for the Radio Telescope:

Tunable Radio Receivers. (3 available) : Radio radiation collected by the dish antenna is fed to a radio receiver which can be actuated by the “receiver” button on the radio

telescope control window. The receiver control window that appears is shown in figure 10.

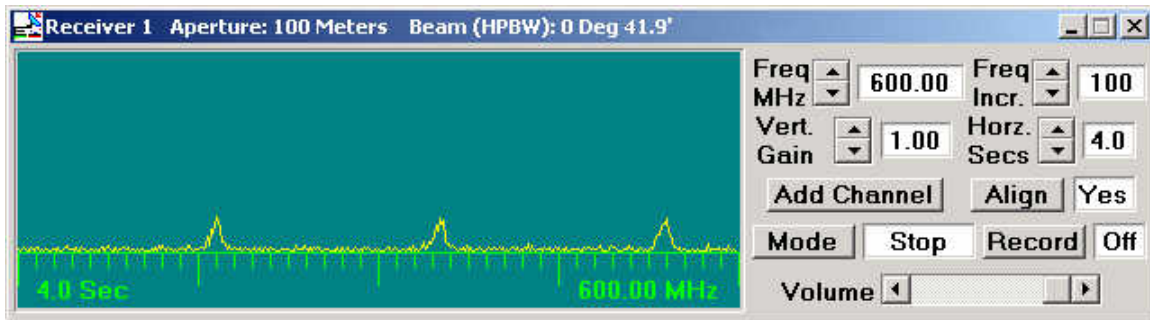


Figure 10: The Tunable Radio Receiver

The radio receiver takes an incoming signal and graphs it versus time on the screen. The controls on the radio receiver are like those on an ordinary radio. You can tune the receiver between 400 and 1400 MHz using the buttons at the top. The vertical gain control adjusts how high signals appear on the screen. The horizontal seconds control adjusts the speed of the graph across the screen---it can be adjusted to spread out quickly varying signals so they are more visible. To turn on the graph, the mode switch is pressed. To stop the graphing, press it again, and the graph will stop when it has finished the current sweep across the screen. Data can be recorded and stored on files for later playback. The sound of the incoming signals can even be heard, if your computer has a sound card, by adjusting the volume control.

By pushing the “add channel” button, additional receivers can be displayed, up to three in all. These can be tuned to different frequencies as desired. Comparing signals at different frequencies is most useful in determining the distance of pulsars (see the CLEA lab “Radio Astronomy of Pulsars” for an example).

Additional Analysis Tools:

Software tools for analyzing the data collected with the various telescopes are accessed through the *analysis* menu on the main observatory page.

Spectrum Analysis Tool

Spectra collected by the optical spectrometer are saved as files with an extension .CSP. The spectra can be displayed in the spectrum tool window. This window allows you to magnify the spectra, measure intensity and wavelength at any point, and measure the amount of absorption (called the “equivalent width”) of spectral lines. To aid in spectral classification, it is also possible to display spectra of standard stars of various spectral types in windows directly adjacent to the spectrum of the unknown.

Figure 11 shows the appearance of the spectrum analysis tool.

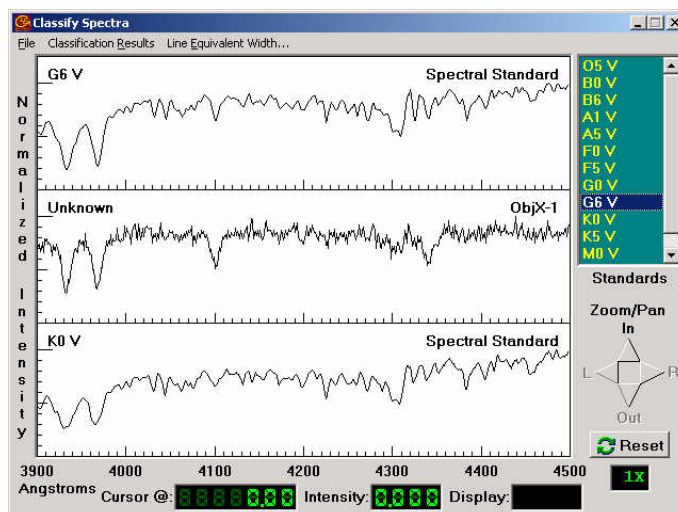


Figure 11: The spectral analysis tool

Toolkit for Astrometry

Images collected by the CCD camera and the infrared camera are saved as files with an extension .FIT. (This stands for “Flexible Image Transport System”, the standard format used by astronomers.). Up to 4 images may be loaded into the Astrometry Toolkit, (Figure 12) a self-contained program that can be run from the main menu of the Virtual Observatory, or can be run alone from the “programs” menu of your PC. The toolkit allows you to display images, manipulate brightness and contrast, and zoom in on features of interest. It also lets you blink images, measure coordinates of objects on the images against a catalog of reference stars, and predict the future positions of asteroids on the basis of their measured motions. For details see CLEA’s *Astrometry of Asteroids* exercise.

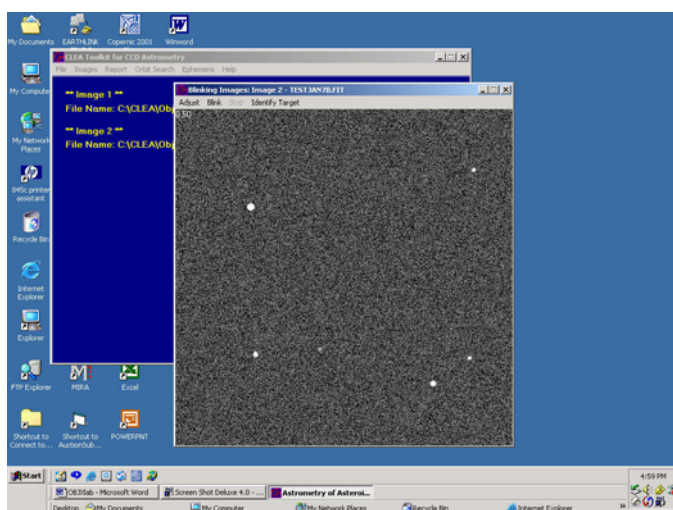


Figure 12: The Astrometry Toolkit for displaying, blinking, and measuring images.

Radio Pulsar Analysis Tool

Signals recorded by the radio receivers are saved as files with extension .PLR. These radio data files, which represent radio intensity versus time, can be examined with the radio analysis tool, figure 13. The radio analysis tool has features for magnifying the scale of the display, for measuring time and intensity, and for comparing signals from up to three receivers. Cursors can be used to mark important points in both the horizontal and vertical axes by clicking the mouse buttons. For details see CLEA's *Radio Astronomy of Pulsars* exercise.

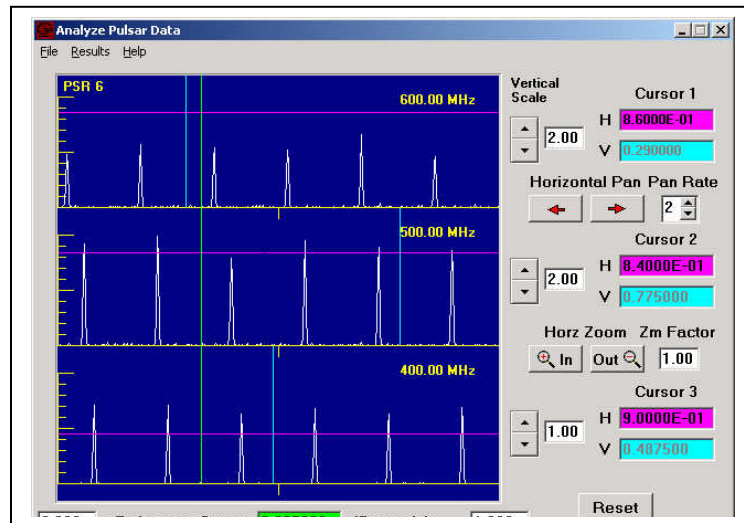


Figure 13: The Pulsar analysis tool.

Spectra/Photometry, Line Measurement, and Pulsar Results editors

Numerical data derived from measurements can be stored in text files. These files can be reviewed, edited, edited, and printed using editors built in to the Virtual Observatory program.

Spreadsheets

Text data files for CLEA exercises are written in a format that can be imported into most popular spreadsheet programs such as Excel®. The spreadsheet can be run independently, or can be called from the menu bar of the Virtual Educational Observatory.

REPORTING YOUR RESULTS

There are many ways to write up your report, and your instructor may specify a particular format. Some suggested ways are:

1. As a scientific notebook.
2. As a scientific journal article.
3. As a popular science essay.

1) A Scientific Notebook.

A scientific notebook is a careful record—made as you go along --- of the procedures you followed, the instruments you used, the numbers you read from the instruments (*data*), the techniques you used to analyse the data (*analysis*), and the conclusions you reached from your data (*interpretation*). To a scientist, it is meant to be a resource for writing more formal articles submitted to journals and magazines at a later date. It is also meant to be a source of information for further work and a way for others to check the work and perhaps reproduce it. Even though it doesn't have to follow the strict format of a journal article, it should be presented so that it will be clear when read at a later date or by another reader---a notebook is useless if it is so jumbled and chaotic that it can't be understood even by the person who did the work!

- Descriptions of instruments and procedures can be written in brief outline form; complete sentences aren't even necessary---but be careful to make the descriptions clear and understandable nonetheless.
- The organization of the notebook can simply follow the sequence in which you performed the data taking and analysis. References to outside sources need not be collected at the end, as in a paper, but can be placed wherever appropriate. Scientists to take notes as they occur to them. But if notes are simply strung out without any organization, it can be hard to make sense of them---so as you go be sure to use bold and underlined headings to indicate important pieces of information as you go along. Remember, your instructor will have to read the report, and won't know what you have in mind unless you write it clearly and explicitly. In real life, scientists want to be able to read their notebooks months or years later without being confused by a lack of clarity. All the following suggestions are aimed at making the notes as clear as possible to future readers.
- Raw data should be organized in clearly labeled tables. Printouts from the computer can be stapled or taped onto the pages to record this data, or it can be copied by hand.
- Images taken by the instruments should be included, where appropriate, and they should be clearly labeled.
- Graphs can be included, clearly labeled, from computer printouts.
- The formulas and programs used for analysis should be clearly stated, along with any constants.
- Clearly specify any assumptions made. (e.g. "We assume that all giant elliptical galaxies have absolute magnitude -22 and use this, along with the measured apparent magnitude, to determine the distance of the galaxy.")
- Conclusions can be summarized in a table and a few brief sentences. Include the identification of the object, the reasons for your identification, a summary of supporting data, and a summary of the properties of the object. Any sources of

ambiguity or uncertainty should be noted, along with suggestions for further observations, if any, that might help in further understanding the object.

2) A Scientific Journal Article

Scientific journal articles are more formal ways of organizing and presenting the observations and analysis that are recorded first in notebooks. The raw data, analysis, conclusions, and reference sources are all presented in separate sections. The journal article contains full paragraphs with complete sentences, and the narrative tries to make clear the logic, assumptions, and conclusions of the work in clear, though sometimes technical, language. Here's a sample outline of a journal article. Your instructor may want to provide a specific example of the format he or she has in mind:

- **Title and author:** A few words that give identifying information about the work.
- **Abstract:** A short paragraph describing what was done, what data was taken, and what was concluded.
- **Introduction:** A few short paragraphs setting the work in context and describing related work by others.
- **Observations:** A description of the techniques and instruments used to take the data, a listing of the objects studied, and data tables recording the observations made and data collected. For instance, if your unknown object looked like a star you might describe the telescope and instruments you used to observe it, and then present the image, spectrum, and a table of photometric measurements of the U,B,V magnitudes of the object. You would also specify how long your exposures were and other information about the exact methods you used to get the data.
- **Data Reduction and Analysis:** A description of techniques, formulas, and programs used to analyze the data. This section also includes tables of quantities derived from the observed data, and descriptions of some of the logical steps you made to arrive at your conclusions. If you were observing a star, for instance, this section might include comparison of the spectrum to others, to determine the spectral type of the star. It might also include a reference to the temperatures and absolute magnitude of stars of similar spectral type and a calculation of the distance of the star from the photometric data. It might also have a discussion of how reasonable the results seem and what they might imply. (If your calculations showed the star was closer to earth than the moon, you'd have some further explaining to do!).
- **Conclusions:** A summary of the work, similar to the abstract but more specific, describing what you did and what you concluded. The conclusion gathers together the important points made in previous sections---may readers of journal articles just read the conclusions and then refer back to the previous sections if they have any questions about specifics.

- **References:** Any outside sources used for information---for instance the references used to assign temperatures and absolute magnitudes to spectral types---should be collected at the end of the article. In the article itself, these references are usually noted as parenthetical notes with author and date. For instance in the text of the article you might say “For the value of the Hubble constant we use a value of 60 km/sec/mpc, an average of the best available measurements at the present time. (Wyzotzky and Yertle, 2002)”. In the list of references at the end you list the full reference: “Emma Wyzotzky and Geoffrey Yertle, *Monthly Reviews of Astrophysical Science*, Volume 27, p. 245, 2002” . The exact format of the notes and references may be specified by your instructor.

3) A Popular Science Essay

Popular science essays, which appear in newspapers like the *New York Times* and magazines like *Scientific American*, *Discover*, *Sky and Telescope*, and *Astronomy*, are written to explain scientific discoveries to non-specialists. A popular science essay tries to avoid as much technical language as possible. It tells a story, more often than not, placing the work in a human context, with references both to other scientific work and also to the people doing the work.

Though there is no strict format for a popular science essay, it can be more challenging than a straight journal article. It is meant to inform and entertain, not just to record technical details for an audience of specialists. When writing a popular science essay, it's a good idea to imagine you're trying to explain the science to your parents or friends. They may have no interest in the subject to begin with, so you have to make them feel how interesting the subject is, as well as helping them to understand what was done.

You may want to look at some popular astronomy articles in newspapers or magazines before you attempt to write up your results in this fashion. Your instructor may have some suggestions of popular essays that will be particularly helpful for your class.

USEFUL REFERENCES

This exercise presumes familiarity with the several of the other CLEA Exercises: Manuals and software for these exercises are available on the CLEA webpage: <http://www.gettysburg.edu/academics/physics/clea/CLEAhome.html>

- Photoelectric Photometry of the Pleiades
- The Classification of Stellar Spectra
- The Hubble Red-Shift Distance Relation
- Radio Astronomy of Pulsars
- Astrometry of Asteroids

Appendix A: USEFUL ASTRONOMICAL CONSTANTS AND INFORMATION

<i>Time</i>	
Number of seconds in an hour	3600
Number of seconds in a year	3.1×10^7
<i>Density and Mass</i>	
Density of water	1 kg/m^3 or 1 g/cm^3
Mass of the sun (One Solar Mass)	$1.99 \times 10^{30} \text{ kg}$
Mass of the earth	$5.98 \times 10^{24} \text{ kg}$
<i>Length</i>	
Ångstrom unit	$10^{-10} \text{ m} = 10^{-8} \text{ cm} = 10 \text{ nanometers}$
kilometer	$10^5 \text{ cm} = 10^3 \text{ m}$
Astronomical Unit (AU)	$1.5 \times 10^8 \text{ km}$
light year	$9.5 \times 10^{12} \text{ km} = 9.5 \times 10^{17} \text{ cm}$
parsec	$3.09 \times 10^{13} \text{ km} = 206265 \text{ AU} = 3.26 \text{ ly}$
Radius of the sun	$7 \times 10^5 \text{ km}$
<i>Velocity</i>	
Velocity of light	$c = 3 \times 10^5 \text{ km/sec} = 3 \times 10^{10} \text{ cm/sec}$
<i>Angular Measure</i>	
Degree (°)	60 arcminutes (′) = 3600 arcseconds (″)
1 Hour of Right Ascension	15 degrees
<i>Miscellaneous Astronomical Constants</i>	
Hubble Constant	$65 \pm 5 \text{ km/sec/mpc}$
Mean angular size of the moon	$\sim 1800 \text{ arcseconds}$

Appendix B: USEFUL FORMULAS

Relation between distance, absolute magnitude and apparent magnitude

Log D = (m-M-5)/5	Where D is the distance in Parsecs, m is the apparent magnitude, and M is the absolute Magnitude
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Relation between time of arrival of two pulses at two different frequencies from the same pulsar, and the distance of the pulsar.

D = $\frac{T_2 - T_1}{124.5 \left\{ (1/f_2)^2 - (1/f_1)^2 \right\}}$	Where T ₁ is the arrival time of the pulse at frequency f ₁ , and T ₂ is the arrival time of the pulse at frequency f ₂ .
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The Hubble Redshift-Distance Relation

V = HD	Where V is the velocity of the galaxy in km/sec, D is the distance of the Galaxy in megaparsecs (mpc), and H is the Hubble constant in km/sec/mpc. Use the value 65 km/sec/mpc for the Hubble constant.
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Appendix C: DISTINGUISHING FEATURES OF MAIN SEQUENCE SPECTRA

Spectral Type	Surface Temperature	Distinguishing Features (absorption lines unless noted otherwise)
O	28000-48000	Ionized atoms especially singly ionized helium, He II
B	10000-28000	Neutral helium, He I, and some neutral hydrogen, HI, in cooler types
A	8000-10000	Strongest HI Balmer lines at A0. Ionized calcium, CaII increasing at cooler types. Some other ionized metals
F	6000-8000	CaII stronger; HI weaker; ionized metal lines appearing, including iron, Fe
G	4900-6000	CaII very strong; Fe and other metals strong with neutral metal lines appearing, H weakening. Our Sun is G2
K	3500-4900	Neutral metal lines strong; CH and CN molecular bands beginning to develop in the cooler types.
M	2500-3500	Very many lines; TiO and other molecular bands prominent. Neutral Calcium, CaI, prominent. S stars show Zr) and N stars show C ₂ lines as well.
L	1300-2500	Neutral potassium, K, cesium, Cs, Rubidium, Rb, and hydrides of metals (molecules with one H atom). Strong infrared continuum.
T	Below 1300	Some water (H ₂ O) and strong KI; Strong infrared continuum
WR (Wolf-Rayet)	40000+	Broad Emission of He II; WC stars show doubly and triply ionized Carbon: CII and CIV; WN stars show NII prominently

Appendix D: ABSOLUTE MAGNITUDE AND B-V VERSUS SPECTRAL TYPE

(From C.W. Allen, *Astrophysical Quantities*, The Athlone Press, London, 1973)

Main Sequence Stars, Luminosity Class V		
Spectral Type	Absolute Magnitude, M	Color Index, B-V
O5	-5.8	-0.35
B0	-4.1	-0.31
B5	-1.1	-0.16
A0	+0.7	0.0
A5	+2.0	0.13
F0	+2.6	0.27
F5	+3.4	0.42
G0	+4.4	0.58
G5	+5.2	0.70
K0	+5.9	0.89
K5	+7.3	1.18
M0	+9.0	1.45
M5	+11.8	1.63
M8	+16.0	1.80

Giants, Luminosity Class III	
Spectral Type	Absolute Magnitude, M
G0	+1.1
G5	+0.7
K0	+0.5
K5	-0.2
M0	-0.4
M5	-0.8

Supergiants, Luminosity Class I	
Spectral Type	Absolute Magnitude, M
B0	-6.4
A0	-6.2
F0	-6
G0	-6
G5	-6
K0	-5
K5	-5
M0	-5

