For the Instructor

Introduction

These labs are introductory astronomy laboratories designed for 100 level liberal arts astronomy students who may have taken their last science and math courses a few years ago. The ambition of these labs is to give those students a flavor of how researchers think, how they experiment, and how they reach their conclusions – and to make them realize that this is something they could do too, provided they learn some techniques of how to think scientifically.

One of the dilemmas of modern day society is that many students have a preconceived idea about what science is and believe that this is not something they could do. In part this is because many of them have never learned (or actually never been taught) how to apply common sense to scientific phenomena. This means we might have to confront the students' attitudes, their way of thinking, and the general fashion in which they have operated so far. The first challenge lies in convincing the students that it would be worthwhile to learn how to do science and think critically, and that this might enrich their lives in ways they may not have imagined before. The second challenge lies in encouraging them to really do the work – and keep at it. Thinking and learning requires an effort and will take energy, and although we will try to provide them with the right tools, we cannot do the thinking and learning for them – they have to do it themselves. The third, and ultimate challenge lies in convincing the students to adopt and integrate the learned scientific methodology and critical thinking into their lives. The question from an educator's point of view is how to go about achieving this goal, how to facilitate this process and assist the students in making this transition.

These labs provide a hands-on approach to learning scientific methodology and critical thinking. They are somewhat different from traditional labs in several ways. On the surface, they look longer, at least in the total number of pages they cover. Rather than letting students merely follow mindless cookbook instructions, the initiative is to encourage the student to make the connection between the objective, the methodology, and the analysis and interpretation of the experiment. While reading the instructions, several leading questions insure that the students "know why they are doing what". Similarly, in the analysis sections the students are asked to suggest and explanation of why they might have been asked to produce a plot of certain data, and what information they might want to extract from those plots – and even discover scientific laws. Furthermore, sometimes when calculations need to be done, formulae are not provided, instead questions are posed in a way that challenge them to figure out by themselves which particular arithmetic function they might want to use. In other cases they might be asked to choose the relevant formula from the toolkit, or they might be asked to express a specific formula in words by writing a sentence or two. Although students are often encouraged to express their results mathematically, the main focus lies in conceptually understanding underlying scientific principles and discovering fundamental laws. In the discussion sections, the students are challenged to reflect on the lab as a whole. Whenever appropriate the students are encouraged to think beyond the lab through questions such as "what might have happened if…" Overall, the aim is to provide the students with some tools of how to do science, and excite them in making discoveries on their own. The following pages demonstrate how each lab addresses these issues.

Suggestions

"The First 15 Minutes of the First Lab"

- General Outline of Course
- Rules, Test, Grading etc… (Please spell them out at the beginning of class – students like to know what to expect; and it makes life easier later…)
- Attendance and "Do-at-home" Versions to replace Missed Labs
- Working in groups is encouraged, but please stress that students will have to use their own words to answer questions. Please encourage discussions among the students themselves.
- Please Explain Philosophy: Doing labs and taking data is totally useless and a waist of your and the students' time if students do not follow the purpose of the lab and understand why they are doing what they are doing – the tests will focus on their understanding of the material.

Prelabs

- The labs are definitely too long if the students come un-prepared!
- These should be done BEFORE arriving to lab. If Pre-Labs have not been done prior to arriving to the lab they should be handed in with the complete report (for only 50% credit).
- It is suggested that Pre-Labs are worth 20% of each Lab grade. If they are worth less, students will often not bother doing the Pre-Labs.

Main Lab

- The questions in the main lab should be answered while doing the lab. (Please mention that blank lines result in "no points", and will affect the grade)
- Comments like "I did not understand this or that, so I left it blank" should be discouraged – the students can ask during the lab hours, and if they do not it's their own problem.
- If the students do not finish the main lab, they will have to complete it at home. Some parts (sometimes even whole labs) can be done at home, but please watch out that the students do as much as they can during the lab itself.

Lab Reports

- Concerning Lab Reports – Please explain why these are important. Also please explain the terms Objective, Experimental Setup, Summary of Results, and Discussion. (Students often have no idea what to write.)
- Please mention that lab reports are not Teamwork! Students can discuss the conclusions, but should always use their own words.
- If the students do not finish the lab report in class, they can complete them at home.
- They should hand in the entire lab (the lab itself and the lab report) at the beginning of the next lab.
- If you like, have the students do a Formal Report (outline is in this manual) instead of the questions at the end of each lab.

Tests and Grading

- Assign one Midterm and one Final – the rational is that student's work in groups (and are encouraged to do so), but partners often do unequal amounts of work. The tests assure that the students who know what they are doing and those who do all the work get rewarded. (This method also helps in singling out those students who focus on copying lab reports.)
- Midterms often tell the students what is expected of them and can give them an indication of their strengths and weaknesses. This seems particularly important in this course since it is somewhat different than traditional laboratories in that it stresses comprehension more than memorization and number crunching.

Lab 1. Measuring Angles

Equipment

- 1m Ruler; small Ruler; Body Parts
- Toolkit
- Optional: Show them instruments to measure angles, like a Cross-Staff, a Starlabe, a Sextant, etc

Mini Lecture prior to Lab

- Explain to the students why we use angles in astronomy
- Explain how the angular size of an object depends on the distance of the object (they all know it yet many of them never thought about that concept)
- Introduce Toolkit and sections on angles & review basic trigonometry (optional)
- Review significant figures and Scientific Notation
- Mention the "one-finger-rule" and make students test it in class.

Procedure and Lab Setup

- This lab can be done anywhere.
- In the first part the students measure the width of their fingers and the length of their arm with the aim of testing the hypothesis that "a finger held at arms length corresponds to 1 degree). Following that they analyze the correlation between angular, linear size, and distance. Part I typically takes about one hour.
- In Part II they test the 1-depree-per-finger rule. (~15min)
- In Part III they measure the distances between various stars using their fist and finger. (~15min)

Notes & Suggestions

- This lab can be shortened considerably. Parts II and III are relatively fast to do and can equally well be assigned as a homework.
- If you intend to do part II, please start the lab with that, then do Part I and have the students complete part II afterwards. Have the students go outside and have them measure either the altitude of the Sun (Option I) or the position or the Sun or a bright star (Option II). [The10-minute-rule for sunsets is cute (they remember it better if you say that it is a good method to impress a date…]
- Part III is very easy, but it's a good illustration of how to measure angles with body parts – and it is rather appropriate for an astronomy lab.

General Concepts & What students might get out of this Lab

- Realizing that separations between objects in the sky are measured in angles
- How to use body parts to measure angles (also refer to toolkit)
- How to calculate distance (or size) from angular size if linear size (or distance) is known

Scientific Methodologies

- How to estimate errors
- How to present data in the form of a graph
- How to use words to describe relationships (which then lead to a formula)

Lab 2. Telescopes

Equipment
- Telescope Kit by Project Star – one per group. [If you no not want the students to start building the telescope, hand out this kit after they have completed part III.]
- 1m ruler and small ruler
- Lenses: a small (2" diameter or so) strong and a small weaker convex lens; a small strong and a small weaker concave lens; a large (4" diameter or so) convex lens. The best strong small lenses have focal lengths of 5, the weaker ones 10 cm (15 or 20 is also fine – as long as the focal length of the concave lens is less than that of the large convex lens).
- The Sun (preferably) or a bright "distant" light bulb. (This exercise tends to become entertaining when students work outside and burn holes into the paper…)
- Optional: A real telescope (as a display at the end of class) to show what's inside a telescope

Mini Lecture prior to Lab
- This lab is self-explanatory. Start with the basics of lenses (Figures 4 and 11 in the Pre-Lab – stress the importance of the Pre-Lab, and that you will not go over the Pre-Labs in the future).

Procedure and Setup
- Please make sure that the student's finish part I in less than half an hour. (If it is a sunny day, they might get carried away burning holes into the paper…)
- In part II students often slow down considerably, but make sure they work solidly – they do not need to measure anything, just describe the image properties.
- If you can spend most time on part III – after all this is where they "discover" telescopes.
- Encourage the students to complete section (d) of part III in class. Please do not tell them how to do the drawings, try to let them figure it out for themselves. The drawing for the Keplerian Telescope is in the book, but the Galilean Telescope is not (this is the most difficult part of the lab and tests whether they understand the properties of lenses and HOW to make a telescope).

Notes & Suggestions
- Handing out the same lenses to the entire class will make the grading much easier
- Part I becomes simpler (and more intuitive) if at least one set of concave and convex lenses have the same focal lengths (when adding 5-cm concave and convex lenses students obtain a piece of glass).
- There is a separate Do-at-Home version of this lab – it does require the telescope kit.

General Concepts & What students might get out of this Lab
- A Feel for different types of Lenses and their Properties – at least qualitatively
- Learn what's inside telescopes; that astronomical telescopes invert images; that a stronger objective gives more magnification – and that they can build simple telescopes by themselves.
- Understand HOW the properties of images seen through a telescope depend on the configuration, alignment, and strengths of the lenses.
- That some telescopes invert (why they do that) and why astronomers prefer this type of telescope
- Never to look at the Sun through a lens

Scientific Methodologies
- How "playing" with lenses can lead to inventing a telescope; and more generally, what thoughts go into experimenting and making discoveries
- That making scientific discoveries depends on understanding concepts, not on using Math and plugging numbers into Formulae (though these are needed for advanced labs…)

Lab 3a. The Sky #1

Equipment
- Celestial Sphere; Color Pens; (and preferably a clear night though this is not essential).

Mini Lecture prior to Lab, Procedure, & Setup
- Please go over the main definitions of RA, Dec, Equator, etc. The students keep the descriptive pages of the pre-lab. These are good for reference and definitions.
- Show them what is where of the Celestial Sphere and how to use it.

General Procedure & Lab Setup
- If this is a night-lab and the sky is clear, please take the students outside and let them find Polaris and a few constellations prior to doing part I.
- In part II, section 1, please demonstrate how to turn the Celestial Sphere.
- In section 2, please have one partner read out the words in capital letters (e.g., horizon, declination, etc.) and the other locate that on the Celestial Sphere. This will make section 3 easier.
- In part III students will often forget to draw the stellar paths, please remind them if they do.
- If the photocopies are not good, you might need a better picture. You can download it from the Anglo-Australian Web-Site. It is one of David Malin's pictures.
- Quiz question #2 can be done at home, if time becomes an issue.

Notes & Suggestions
- If the students have problems with the table, just pick an example (maybe Boston at ~50^{o}) and do the whole row together with the students.
- Sometimes students do not know what to do with the picture in the quiz question. Please have them hold picture at arms length in front of them, and follow the instructions in the text next to the picture.
- The main challenge of this lab is translating the 2-dimensional drawings in the pre-lab to 3-dimensional shapes on the Celestial Sphere, and then visualizing what is really happening in the night sky.

General Concepts & What students might get out of this Lab
- A sense of direction and how to find Polaris and other constellations
- A feeling about stellar motions in the sky, and why and how the sky changes throughout the night.
- An idea about how the night sky changes with location on earth.
- Maybe some basics about coordinate systems, though this is not the main goal

Scientific Methodologies
- Geometrical Visualizations (which is sometimes totally new to students)

Lab 3b. The Sky #2

Equipment

- Sky Charts SC-1 and SC-2 of Esso – Sky Publishing Corporation

Mini Lecture, Procedure, & Setup

- Students should be able to start and complete this lab on their own.
- If you do this lab in class, please go over RA and Dec
- Part II can be illustrated nicely by using an Earth-Sun Demo (This demo may also have the other planets and the Moon). Let the students visualize the meaning of "solar time" by imagining they are on the "lit side of the glob, and by considering the rest of the classroom as background stars – the stars cannot be seen when looking in the direction of the Sun.
- Another nice method is to have four students stand around a student in the center, who represents the Sun. Have them turn of their axis, asking them what time of the day it is, and which stars of which wall they see. To entertain them further you could have them tilt at as 23^{o} angle and then rotate…
- Part III is testing the students' understanding of the general concepts.
- The last question in the lab report really is difficult.

General Concepts & What students might get out of this Lab

- How to read sky charts, and – hopefully – how to translate this exercise from paper to the real sky.
- A sense of how to figure out what's up in the sky and how this depends on the time of the night and on the season.
- A sense of why it takes a year to go though the range of constellations (solar versus sidereal time)
- If they did Part II using a demo (or themselves), they will get a good conceptual understanding of night, day, and the seasons. This really beats and paper and pen exercise.

Notes & Suggestions

- This lab can be omitted – it lab is mainly intended as a continuation of Sky-Lab-#1 (or for extra credit), but can also be done on its own or assigned as the "Do-at-Home" version of Sky-Lab-#1.
- Parts II and III can be done using a star-finder like on the first page. In fact, this exercise will become somewhat easier that way and can be done more quickly. The drawback is that once the students know how to use the star finder, they can just "read off" the answers without really understanding how it works. Nevertheless, after having done Part III from the Sky-Charts, you could show them how to do it with the star finder.
- Even after successfully doing this lab, students often still do not quite know what's up when. A constellation spotting session may help with this.

Lab 4. Astrometry & Kinematics

Equipment
- Transparent Paper; Ruler

Mini Lecture prior to Lab
- Go over small angle formula (SAF)
- Compare SAF to the tangent formula they used in Lab #1 –see also optional part of pre-lab
- Explain how to subtract declination from declination – which has the form of deg-min-sec.
- About Part II – mention stellar streaks (remind them of the Sky Lab)

Lab Setup and Procedure
- No special setup is need – this is a paper and pen exercise.
- Since the photocopies may not be of high quality, please get a good printout of Figure 3 and 4 to show the students that the comet actually looks fuzzy.

Notes & Suggestions
- Please make sure students really do read every sentence in part I. They will want to be told of what to multiply or divide by what, but the purpose of this lab is for <u>them</u> to figure that out.
- There are no complicated calculations in this exercise, only some multiplications, divisions, and unit conversions, but some students will pretend that they are overwhelmed by the math in this exercise, and will not even try. (Not always, but sometimes these students will just sit around hoping copy answers from somebody.) Please spend extra time with those students – oftentimes it is not the number crunching they have problems with, rather it is applying common sense.
- Many students will find it rather challenging to translate the text into algebraic formulae, but it turns out that almost all students will get it if they think about it – if they really have problems, you'll notice in Part II.

General Concepts & What students might get out of this Lab
- Correlation between angles, sizes and distances; the small angle formula, and how to use it
- A sense of how to determine distances to meteors and velocities of anything in the sky. (Sometimes students are surprised by this method)

Scientific Methodologies
- Understanding the connection between words, simple formulae, and arithmetic number crunching
- A step-by-step understanding of why they are doing which calculations

Lab 5. The Sun

Equipment

- Good weather & a telescope (8" or larger)
- White cardboard to project the image of the sun; Ruler
- A solar filter and an H-alpha filter
- A simple light-meter or photon counter (to measure relative fluxes)
- Optional: Sun Glasses; Solar-Eclipse-Glasses

Lab Setup

- This lab really does take some preparation and testing out the equipment prior to the lab. All telescopes should be ready to go once the lab starts.
- It is easiest to set up two telescopes if you have them – one to be used for projecting the Sun onto a cardboard, and another one for direct viewing. Have a stronger eyepiece and the H-alpha filter ready to be put on after the students have observed the whole Sun through the telescope.
- Please make sure solar filter is mounted on the direct-viewing telescope before you let the students to the telescopes.

Mini Lecture prior to Lab

- This lab can be done without any previous knowledge about the Sun, and no big introduction is needed – in fact it can be done on the spot, should it be a nice day (as long as you have an hour of free time to set up the telescopes)
- You can give several mini-lectures about the Sun while students are looking through the telescope.

General Procedure

- Let all students look through the telescope, one after the other
- Let the entire class (or groups of ten) look at the projected cardboard image, have several students measure the diameters of the sun and of sun spots; do the same with flux measurements
- You can give several mini-lectures about the Sun while students are looking through the telescope.
- You could also bring the darkened solar-eclipse-glasses. Sometimes you can Sunspots…

Notes & Suggestions

- This is a less work-intensive, easier, and faster lab than the others (and quite some fun!). If you like, you can require the students to write a "Formal Report".
- Ask the students to bring sun glasses
- Make sure students do not look though the telescope without a filter.

General Concepts & What students might get out of this Lab

- That the Sun is "active" and what happens on the surface of the Sun and why
- A sense of the size of the Sun and of Sun Spots – in relation to the Earth
- Importance of back ground measurements; importance of taking means

Scientific Methodologies

- How "just looking" at the Sun can provide so much information
- The challenge is to describe and draw what they see, and then come up with conclusions from that.
- The need for a deeper understanding of the concepts – like in the case of limb darkening, where the surface temperature of the Sun is the same all over the Sun, yet we "observe" an apparent decrease in temperature when looking at the limb.

Lab 6. Basics of Photometry

Equipment
- Good photocopies of Figure 3 and 4
- Dividers (or protractors if dividers are unavailable)

Mini Lecture prior to Lab
- Make sure the students have covered some of the basics on light and the properties of stars in their lectures. Otherwise you might have to go over definitions of absolute and apparent magnitude, luminosity, and flux (which they should have done in the pre-lab), and review Wien's Law and Stephan-Boltzmann's Law, and correlations between the Luminosities, Temperatures, and Radii. Make sure students know WHY they are measuring the radii of stellar images and more importantly, HOW this provides them with the information on the Luminosities, Temperatures, and Radii of stars.
- Go over black body spectra and demonstrate (using drawings like Plot 4) how the difference between two magnitudes (obtained with different filters), gives information on the color of the star AND its temperature.
- Mention the use of filters in astronomy, how we use them and what information they provide. A neat intuitive demo is to use 3-D glasses (with one red and one blue lens) and have the students look at color pictures. Test the pictures before class and choose some that show the biggest contrasts (red and blue M&M's also work fine – and you'll get brownie points from the students).

General Procedure
- Some students may spend a disproportionate amount of time on Part I – which only includes calibrating standard stars. Please mention that they have to complete parts I to III in class.
- It is possible to gather the data of table II relatively quickly – one student broke the record of doing it in 10 minutes. Budgeting half an hour for this is reasonable.
- Please make sure that each student measures the SAME star in BOTH pictures. This minimizes misclassifications and systematic errors.
- Please encourage the students to plot the HRD in class and ask them to show you the HRD before leaving class. You'll see immediately if something went wrong. Part IV can be done at home.
- Also, please make sure the students label the HRD and write rough numbers on the axis.

Notes & Suggestions
- Please make sure that the students make the connection between measuring radii and plugging numbers into tables, and the overall goal of the lab.
- The second photometry lab uses the data the students obtained from this lab. Both labs are complementary and provide the students with an in-depth laboratory experience and understanding.

General Concepts & What students might get out of this Lab
- How to get information of the colors and magnitudes of stars from black & white pictures
- An intuitive understanding of what magnitudes are and how we measure them using first principles
- How to determine the Luminosities, Temperatures, and Radii of Stars through an analysis of their magnitudes and some correlations.
- The significance and usage of the Herzsprung-Russel-Diagram

Scientific Methodologies
- How to calibrate data and why this is important.
- How doing experiments using first principles (and using old-fashioned methods) can provide them with a deeper understanding of the concepts.

Lab 7. CLEA Photometry

Equipment
- Computer; CLEA Software; One Sheet of transparent paper
- Optional: Excel Spread Sheet

Mini Lecture prior to Lab
- Please explain to the students of observing at national observatories, how to apply for telescope time, how to prepare for the observing run, and how to do the actual observing in the console room.
- The rest of the lab is relatively self-explanatory and students can do it on their own, even at home.

General Procedure & Lab Setup
- Just let the students turn on the computer and follow the instructions.
- Give them half an hour (max) to read the instructions and learn how to use the program. Some students will want to be walked through how to use the program, but this is really not needed – they only need to read the instructions.
- If students work in groups of two, one student could do the plot in Part I, while the other starts reading up on how to run the program of Part II. After a while they could exchange notes and swap tasks. This saves time.
- Please encourage the students (relatively early in the lab) to apply for time on a larger telescope.
- The “Manual” Option in Part III is sometimes faster than the “Excel” Option. The Excel Option is really only meant for students who have some type of computer experience and who seem to have a relatively good grasp on the rest of the lab.
- Please do not let any students leave the lab without having plotted at least a handful of data points into the HRD.

Notes & Suggestions
- This lab CAN be done within the allocated time, provided the students really get on with collecting the data. Some students might take forever, particularly if they do not focus on the lab. Please make sure they use a LARGE telescope.
- Collecting the data can be work-intensive, but like it is with any number crunching exercise, the students will “push bottoms”, sometimes even without knowing what they are doing. If you notice that, please remind them of the purpose of the lab and (almost more importantly) make the connection to the previous photometry lab where they had to do the photometry itself step by step. This might even make them appreciate the current computerized exercise.
- When it looks that the students will not finish the lab in time there are some options (a) Turn on all the computers in the lab and split up partners; (b) Cheat and re-start the program until the students get time on a larger telescope; (c) Split up the labor between two groups, have group 1 do stars 1 to 15, and group 2 stars 15 to 30.

General Concepts & What students might get out of this Lab
- How modern day astronomers use telescopes to obtain their data, and how they “reduce” that data.
- How to interpret the Hertzsprung Russell Diagram
- How to determine the distance to a cluster.

Scientific Methodologies
- Critically thinking about the accuracy of their final result and the suitability of the method they used.

Lab 8. Continuous, Emission, and Absorption Line Formation

Equipment
- Project Star Spectroscopy Kit
- A Light bulb plugged into a Variable Light Switch
- Fluorescent Lamps of unknown gases; Spectral Line poster that will be used to identify the gases (Make sure to use those Fluorescent Lamps which are also on the Spectral Line Poster)
- Black Tape (in addition to the tape provided by Project Star)
- The Sun (well,…), or the Moon (though this is reflected light) – but neither are totally essential

Mini Lecture
- Not much preparation or introduction is needed, but it would make sense to coordinate this lab with the lectures and do it after (or during) the discussion of the properties of light.

General Procedure and Lab Setup
- Please have the spectroscope kits already on the desks when the students arrive. Let them build the Spectroscope, but please give them a time limit. The room will have to be darkened for the remaining part of the lab.
- Use the extra black tape to cover up the two corners of the spectroscope, but make sure the "slit" is not covered.
- Time part II – for part III the room needs to be absolutely dark (you might even want to cover the red light on top of the Fluorescent Lamps as this contaminates the spectrum.
- Parts IV and V can be assigned as homework (Part IV even as an extra credit option) which would make this lab even shorter

Notes & Suggestions
- This is a fully qualitative lab and quite enjoyable
- Part III can be done a little more qualitatively by asking the students to read the scale inside the spectroscope. However sometimes the Fluorescent Lamps are too faint to see the numbers. In that case ask the students to describe the color of the emission lines as precisely as they can.
- What to watch out for: In part II students will often just draw the Black Body spectra they have seen in their book (and drew in the pre-lab), however the main point is to draw this graph totally from first principles (not all colors are equally bright at each setting) and then arrive at a similar curve. They should make the connection between the experiment and that "somewhat theoretical" graph.

General Concepts & What students might get out of this Lab
- Obtain a deeper understanding of Black Body Radiation and the Planck Spectrum
- An understanding of light emitted from different types of gases and how (and why) this is different from black body spectra (i.e., understanding Kirchhoff's law's)
- Get a feel of how astronomers can tell the chemical composition of nebulae and stellar atmospheres though an analysis of their spectra

Scientific Methodologies
- In the case of the Black Body Spectrum, how to make the connection between careful observations, scientific principles and formulae that they have seen before.

Short Lab: Classification of Stellar Spectra

Equipment

- A good image of Figure 1 – preferably from the Web-Site and viewed on the computer with a 200% magnification

Mini Lecture, General Procedure, Notes, & Suggestions

- No introduction is necessary if done together with (or after) Labs 8 or 9.
- Can be assigned either as an extra credit exercise of Lab 8 or Pre-Lab 9.
- It can also be done separately as a "Short Lab" and should take about half an hour.
- If combined with the next lab, please make the students realize that this rather inaccurate and subjective method also has its advantages – such as many spectra with one single observation and much, much less preparation prior to an observing run.

General Concepts & What students might get out of this Lab

- A feeling of how to classify stellar spectra and a sense of how accurately it can be done.
- They might get an appreciation for the work done by Annie Cannon Jump and the Harvard Woman's group.

Scientific Methodologies

- This classification can be rather subjective, but broad classifications are still possible – and science can still be done with this data.

Lab 9. CLEA Spectroscopy

Equipment
- Computer; CLEA Software

Mini Lecture prior to Lab
- If you have not done it for the CLEA photometry lab, please explain to the students of observing at national observatories, how to apply for telescope time, how to prepare for the observing run, and how to do the actual observing in the console room.
- Please compare and contrast photometry and spectroscopy – what information does one obtain with each method? When would you use which one?

General Procedure and Lab Setup
- No Setup is needed, only the computer.
- The lab instructions are relatively self-explanatory (students can do it on their own or at home).
- Part I – obtaining Spectra. Using a large telescope for part I definitely speeds up this lab.
- Part II & III – classifying spectra. If the students do not finish part III, please save their data from part I on disk and let them continue this lab at home. However, this option tends to be rather tedious because the data will have to be transferred into specific subdirectories of the Spectroscopy Program. The Do-at-Home version has instructions on how to install program on the students' home computers – but this will end up being much more work.
- Part IV – determining absolute magnitudes and distances; plotting HRD. Part IV can be done as homework – it is mostly a repeat of the last part of the CLEA photometry exercise (the questions in the Lab Report try to make the connection to the photometry lab).
- Parts I to III involve obtaining and cranking through data. If students have previously done the CLEA photometry exercise they will not need so much overhead time to learn the program. Nevertheless, many students do not like reading instructions. This Lab really is not difficult, but work intensive – the students will need to focus on getting the data.

Notes & Suggestions
- This exercise can be done without much thinking, only through pushing buttons on the keyboard or mouse, so please watch out that the students make a connection to what they are doing and why.
- If you have graded the photometry labs, please return them to the students – it might be a good reference for the CLEA Spectroscopy lab.
- Also, please make the connection between the photometry and spectroscopy labs – all of them deal with plotting an HRD (though the current lab focuses more on the methodology of reducing and classifying spectra)

General Concepts & What students might get out of this Lab
- A sense of how modern day astronomers use telescopes and reduce data.
- Experiencing that cranking through data can get rather monotonous and boring if they lose touch of the bigger picture; yet that cranking through data is a large part and essential to the work of astronomers.

Scientific Methodologies
- A sense of how to use a computer to speed up and simplify stellar classification – this becomes particularly intuitive if they did the previous extra stellar classification (extra credit) lab.
- How to use computer programs to minimize the human subjectivity factor (though this will not have helped significantly with the extra stellar classification (extra credit) lab.

Lab 10. The Origins of the Elements

Equipment
- None; perhaps the textbook for reference; periodic table poster might be useful but is not necessary

Mini Lecture prior to Lab
- Although the formation of the elements is covered in many textbooks, it is not always put into the context of how all elements in the universe are formed.
- If you do this lab in class, please go over regularities in the periodic table. Although this was the main focus of the pre-lab, the students may not have looked very carefully at it.

General Procedure and Lab Setup
- This lab walks the students through the formation of elements, hydrogen burning, the triple alpha process and heavier elements. It is mostly bookwork, i.e., no experiments.

Notes & Suggestions
- It is advisable to assign this lab after the students have covered "energy production in stellar interiors". This lab can also be used as homework for the lecture class.

General Concepts & What students might get out of this Lab
- What happens inside stellar interiors
- A review of the periodic table and an understanding of classifying the elements.
- A sense of how and where elements were created
- The basics of fusion, fission and radioactivity, and the tremendous energies that are produced
- An understanding of some of the basics of particle physics and nuclear physics
- What "$E=mc^2$" really means

Scientific Methodologies
- How do deal with nuclear reactions and in what sense they resemble chemical reactions

Lab 11. The Size & Shape of the Galaxy

Equipment
- Celestial Sphere, preferably with Milky Way drawn onto it.

Mini Lecture prior to Lab
- Maybe start with a picture of a Sb or Sc Spiral Galaxy – Apparently our Galaxy looks like that, but the challenge question is how do we know this? We can only see our Galaxy from within. Show pictures of the Milky Way. How does this tell us the Shape and Size of our own Galaxy?
- Mention the Shapley-Curtis Debate (which was the Pre-Lab) – analyze their data to see how this led us come up with the current model of the shape and size of our Galaxy.
- Maybe remind the students about RA and Dec.

General Procedure and Lab Setup
- With the celestial sphere in front of them, let the students visualize that they are standing on the globe inside the celestial sphere. At any one time RA and Dec would then tell them where on the sky they would see each globular cluster.
- Ask the students to locate the galactic center (and the rest of the Milky Way) on the celestial sphere.
- Please check the students' answers to question 7. If they did not get this right they will not be able to do the drawings of questions 8 and 10.
- After students have done the x/z plot, please quiz them on question 2 of Part IB.
- Part II can be done at home.

Notes & Suggestions
- If you have it bring a toy galaxy, or make one out of clay. Try to have the students visualize what they would see if they were located in the disk.
- Although students will often say they can visualize what they are doing (and they might), it never hurts to check. One method is to ask them to orient the Celestial Sphere like they did in the Sky-Lab (with New York of the Globe pointing to the ceiling, and the N-S axis towards Polaris (a point in the classroom, preferably close to the real position of Polaris). Then ask them to show where they would see the Galactic Center and the rest of the Milky Way if projected onto the classroom walls. Since the Earth spins on its own axis, you might also ask them to show you the apparent path of the Galactic Center projected onto the classroom walls. This will also help them with Figures 4 and 5.
- Interpreting the x-z plot is often a little easier, but here too, some students have problems visualizing that drawing and might copy the location of disk, bulge, and halo from their neighbors. The trick is to really be able to visualize what Figure 1 would look like if inserted into Figure 6 – combined with what we really do see (i.e. the strip of the Milky Way) on the sky (which is also in Figure 6).

General Concepts & What students might get out of this Lab
- A sense of how the Size and Shape of the Galaxy was discovered

Scientific Methodologies
- 3-D visualization techniques
- Analyzing plots, and visualizing what information these plots are providing
- Critically interpreting the data they plotted – are these data consistent with data obtained by others?
- A sense of how science (the methodology) is done, and to decide between right and wrong
- Realizing that there are not always right and wrong answers, rather only "more likely" answers

Lab 12. Galaxy Classification & Evolution

Equipment

- Good photocopies (Hardcopies of the Hubble Tuning Fork and of the examples)
- Access to the Web and/or already downloaded galaxy images and cluster images. The cluster images need to be viewed in magnification.
- Optional: Hubble Atlas, Carnegie Atlas, Arp Atlas

Mini Lecture prior to Lab

- Students can do this lab on their own.
- Having covered the basics of Galaxies and Classifications in the lectures would be useful, but it turns out that students can do this lab reasonably well without having heard much about galaxies. However, fro Part II, they will need to know the basics about stars, their luminosities and colors, and about blue, pink, and dark nebulae.

General Procedure & Lab Setup

- Let the students get on classifying the galaxies, but please watch out that they look at the enlarged images on the computer. If they do no, please pick a galaxy they misclassified and then discuss it while looking at the larger image. (Note that classification from the thumbnails is possible, but only after they have trained themselves a little to know how to recognize what.)
- Initially some students may confuse dust lanes with Spiral arms
- S0's may need additional explanation – they are not ellipticals, they are disk galaxies (with a bulge) but do not show any spiral arms in the disk.
- In part II the students are challenged to think. Please encourage them to do so.
- Check the first tables in parts III and IV. If the numbers are too far off, the interpretation will become rather difficult and confusing. (There should be an increase of ellipticals and decrease of spirals as you go to denser and denser environments; and more Irregulars in the HDF.)

Notes & Suggestions

- If the students have problems classifying galaxies please mention that this is a real problem, particularly at high redshifts.
- When working in groups, please watch out that students do not copy each other's answers, but that every group member does their fair share. Please encourage the students to write the comments during the lab session, i.e., not at home.
- In parts III & IV they are asked to interpret their own results as best as they can. Please do encourage them to interpret their data – the point of this exercise is for them to get the experience of actually doing the research. It is pretty surprising how close the students come to some of the more conventional ideas on galaxy evolution.

General Concepts & What students might get out of this Lab

- A sense of how real research is done
- To what degree they should believe results stated in popular astronomy articles
- That nothing is an error – not even Hubble's "evolutionary interpretation" which we still use, but only for classification purposes.

Scientific Methodologies

- How classification (even if it is not the best scheme) can lead to results
- How to use "subjective" number counts to make quantitative statements
- How statistical uncertainties can affect the interpretations of the results and validity of the arguments

Lab 13. CLEA Hubble Redshift

Equipment
- Computer; CLEA Software

Mini Lecture prior to Lab & General Procedure
- Put Hubble's discovery into the historical perspective – the existence of galaxies outside our own had just been discovered a couple of years ago.
- If students did not do the pre-lab, please make them do it before they start with the main lab. The need to know about Doppler Shifts & Redshift.
- Remind the students about stellar spectra, particularly of late-type stars. Most normal galaxies (excluding starburst galaxies and active galaxies) will therefore show the H and K Lines.
- Maybe go over how difficult it is to measure distances in Astronomy

Procedure and Lab Setup
- Part I is very easy and should take no longer than 10 minutes. The purpose of is to put this exercise into context, and to let the students know a little more about clusters of galaxies and the various assumptions and problems in this area of research. Although the redshifts can be measured relatively accurately, the problem lies in the distance determination (and local motions and...)
- By now the students should have a good idea of how to use the CLEA programs and they should be able to collect the data relatively quickly.
- There a some challenges in Part III since the students have to calculate redshifts, distances, and the Hubble constant. It is all explained step by step, but the students will need to read the (dreaded) instructions… The algebra is pretty easy, but arithmetic slips tend to be rather common.

Notes & Suggestions
- It is absolutely fascinating the have the students discover the expansion of the universe in a 100 level lab, and the students get only marginally excited if this is (specifically!) pointed out to them.
- This exercise can be shortened by having the students only observe ONE galaxy per field (i.e., determine H_o from 5 data points), however they often end up collecting data of 5 galaxies in one field – and that results in rather strange values of H_o.

General Concepts & What students might get out of this Lab
- That it is relatively straightforward to discover the expansion of the universe and the origin of the Big Bang Theory in a two-hour student laboratory.
- A sense of how Hubble himself may have discovered the expansion of the universe
- Some feeling of the uncertainties that go into determining H_o.

Scientific Methodologies
- Using Graphs to present data in Tables
- Thinking about the meaning of certain arithmetic operations – in this case understanding the real meaning of H_o, which was determined by dividing two quantities (i.e., velocity by distance), and finding that this is a constant number.
- Determining some type of subjective estimate of an error by "looking" at a graph and calculating the worst possible slopes that still fit the data

Lab 14. Hubble Deep Field

Equipment

- The Hubble Deep Field Poster
- Or a magnified image of HDF (from Web-Site) – which can be viewed on a computer.
- Ruler; Color Pens to mark Galaxies

Mini Lecture prior to Lab

- Please do this lab after the students covered Galaxies and some Cosmology
- No preparation is necessary; Lab can also be done at home.
- Please stress that Part IV is very important.

Procedure & Lab Setup

- In part I students visualize the size of the picture of the HDF in front of them. Refer the students to the toolkit if they still do not know how to convert degrees to arcseconds.
- The best procedure for part II is to take a subsection of the HDF, and count the number of galaxies in that, then assume the rest of the HDF has the same density… (and then assuming the HDF is representative of the rest of the universe, one can calculate the total number of galaxies)
- Check the total number of galaxies per square arc-minute. Acceptable values are roughly 1000 or more galaxies per square arc-minute.
- Also check what they get for the size of the visible universe. Arithmetic slips tend to be rather common at this point in this exercise.

Notes & Suggestions

- Some students find this lab to be one of their favorites others totally dislike it. It depends on how comfortable they feel about doing algebra. However, the calculations students do in this exercise are division and multiplication only – so generally any 100 level student should be able to do this lab.
- Some students can visualize what billions of galaxies actually mean, however they loose count when determining the mass of the universe in kilograms or the density in grams per cube centimeter.
- Students are often very sloppy with part IV, which however is very important because it demonstrates that this exercise really gives a far too uncertain for the density of the universe. [The uncertainty should turn out to be two to three of orders of magnitude, i.e. $>10^{\pm 2}$]

General Concepts & What students might get out of this Lab

- A sense of how many galaxies there are in the universe
- A sense of just how small the Hubble Deep Field is

Scientific Methodologies

- Educated estimating is a rather useful method.
- Analyzing the uncertainties is extremely important when evaluating the answers.

Lab 15 & 16. CLEA Pulsars, CLEA The Large Scale Structure

Notes & Suggestions

- Please check the original CLEA manuals provided by Gettysburg College