PHYSICS 123-253   Observing Guide

v1.4 November 2013

TEAMWORK

Working in pairs or groups is quite common in science labs, and this lab is no exception. Teamwork can be quite effective; it's often possible to figure things out faster if you work with another person, and some experiments are much easier with two pairs of hands. In a real team, everybody is involved and contributes to the group effort. While you will obtain your data as a small team at the telescope, your data processing and analysis will be done individually. To insure that everybody is involved, we require you to *use your own words* in writing up your results.

OBSERVING

Your group will be assigned a number of observing nights [just like professional astronomy]. We will try to observe every night the weather seems reasonably good, and meet indoors only when bad weather rules out any kind of observation. This means that your group may have several attempts at an observing session. Do not be discouraged – this is the life of an astronomer!

Observing is like working on any experiment in physics -- you must come with a plan, you must carefully manage your time, you must understand all your equipment before observing begins, and you must continuously check for systematic error while taking data. Come to the telescope with your observing plan for the night fully laid out. Allot needed time for each step: bias frames, zeroing the telescope coordinate system, flat field frames, calibration stars, object exposures. Check your images to see if they have the expected number of counts in the pixels that matter to you. When doing observational astronomy, patience is necessary. For example, the weather may be bad when we go out to observe. The best course of action may be to wait until conditions improve, or try again another night.

Safety

Astronomy is generally a safe activity. Unlike some science labs, we have little need for hazardous materials or equipment. We will be working outdoors at night, mostly in the dark (see note below re flashlights). You will be up on the roof of Hutchison Hall in the dark. Do not walk outside the catwalk and narrow pathway guard rails. There is no guard railing at the edge of the roof! Follow your instructor's orders at all times. Stay inside the dome. There is plenty of room, and chairs.

It is likely that you will be at the observatory during daylight, to test your equipment and familiarize yourself with it operation. There is one safety rule which must be emphasized, even though it may not seem all that relevant to this class: **never look at the sun through any telescope** unless you are using a professionally-designed solar filter! It's important that the filter cover the **entire** aperture of the telescope and that it is securely attached and **can't** fall off by accident.

Comfort

We will be observing outside at night for several hours at a time, and you should plan to dress appropriately. It can get cold in the evenings, and clothes which were comfortable in mid-afternoon will not keep you warm enough at night. Wear loose-fitting warm clothes you can move around in easily, and bring a sweater or jacket. Other than a light snack such as trail mix and water, *do not bring food to the dome*.

EQUIPMENT

Below is a summary of the equipment you will be using. However, before going to the observatory you should read carefully the descriptions of each component of the instrumentation which have been uploaded to the 123 web page for this observing project. Be particularly familiar with the CCD Camera, the filters, and the software.

1. **14-inch Celestron Reflecting Telescope.** This is robust and simple to operate. It is controlled by *The Sky* software from Software Bisque.
2. **Apogee U-6 1024x1024 pixel CCD camera.** This is a research grade CCD camera with a filter wheel attached with 7 filters, 4 broadband and 3 narrowband. The broadband filters cover the spectral range 4000 – 9000 Angstrom in four filters B, V, R, I. The three narrowband filters are used for emission line imaging: H-alpha, Oxygen-III, Sulfur-II.
3. **Precision fork mount, computer controlled.** This is a professional observatory fork mount, drive, and controller. It is interfaced with the telescope software package.
4. **Observing Flashlights.** Ordinary flashlights are too bright to use while observing, and white light temporarily impairs your ability to see faint stars. We will use special red LED flashlights when observing; we have one for every student.
5. **Observing software.** CCD-Soft5 by Software Bisque, controls the CCD camera.
6. **Dome.** The telescope dome is atop Hutchison Hall and is accessed via the east elevator to the 5th floor, then up to the roof, and special keys that the instructor will have. No smoking allowed.

   You will need to bring a few things:

1. Your lab book.
2. Pencil, eraser, pen.
3. Warm clothing. Shorts not allowed.
4. A scientific calculator.
5. A small flashlight for getting around outside the dome.

PRE-LAB ASSIGNMENTS

Some required materials are posted to the web page. A copy of Chromey "To Measure the Sky" [Cambridge, 2010] will be available in the lab or you can get a used copy at the bookstore or Amazon for about $30.

Part 1. Read and understand Chromey chapter 3 (see course website). When you get access to Chromey read chapters 5, 6.1-6.2, 8, 9, and 10. **At that time do exercises 6, 7, and 8 at the end of chapter 9** and *hand in prior to your first observing run*. Your grade in this course will depend in part on how well you follow these directions and your demonstrated teamwork. Be operationally familiar with the camera control software. You will have an opportunity to do this in the Roessler 154 lab before going to the observatory. The TA will certify you for observing. There is a complete CCD imaging camera set up there, with the same software that you will be using at the telescope; Hubble Space Telescope images of M51 in the same four bands can be displayed on a laptop screen and re-imaged onto the CCD.

Part 2. This is even more important than the background knowledge you demonstrate in Part 1. Before your first observing night you must develop a schedule for your CCD exposures (what objects, when, what bands) and estimate the required exposure time so that you obtain the needed signal-to-noise (S/N) level in each band. In a long exposure, most of your noise will come from the Gaussian variance of your night sky photon flux. You must also calibrate your observations: Do not forget to include exposures in all your bands on your calibration stars. To estimate the required exposure, you need to know the flux of photons per pixel from your object, the flux from the background sky, and the read noise of the CCD. This estimate of the required total integration time, given your estimated S/N, is critical. This is always part of an observing proposal to an observatory; you must show that you can achieve your science goals with the instrumentation available and the background noise (discussed below). Put all this in your lab book, and when you write your report, describe this planning and show the calculations.

For a rough estimate of the photon flux from an object of apparent magnitude m_V in the V band, you can use the approximation that a 6th magnitude star produces about 10^6 photons per second at the focal plane of a 6-inch diameter telescope. Scale to your 14-inch telescope. Divide by 2 for a rough correction due to the 50% quantum efficiency of your CCD. If you are imaging a diffuse source such as a galaxy or nebula, then you need to estimate the effective number of pixels this flux will be spread over, and correct the photon flux per pixel for this dilution. This should yield an estimate of the number of photo-electrons per pixel per second. You then must convert to ADUs (analog-to-digital units) because the output of the camera is digital data. For this, you need to know the so-called gain of the camera electronics. For our Apogee U-6 CCD camera this is 1.4 electrons/ADU. Dividing by this gives you an estimate of the *signal* in ADU counts per pixel per second. It is the statistics of these counts relative to the noise that matters.

You must also estimate the *noise* per pixel, in order to calculate your S/N. The noise will likely be dominated by the relatively bright night sky, even if the moon is down [you may wish to avoid observing in broadband filters in bright moon]. Night sky brightness is normally expressed in units of magnitudes per square arcsecond (a measure of surface brightness). So you

will have to convert to magnitudes per pixel, and then to ADU per pixel per second as above. This is your sky background level per second in that filter (the sky brightness varies with wavelength). Then multiply times the number of seconds integration in your individual exposure. Since these photons are arriving randomly, your noise per exposure is then the square root of this sky count. Finally, then you can estimate the total integration time to reach a desired S/N using the knowledge you gained in the first week of this course. Signal increases proportional to integration time, and of course the noise increases like sqrt integration time since it is a random Gaussian process. All the above is described adequately in Chromey.

A useful review of sky glow is at:
http://www.skyandtelescope.com/howto/visualobserving/35614744.html

Below is a dark night sky spectrum. Beware that your sky can be brighter due to campus lighting and moonlight as discussed in the above article. 19th V magnitude per square arcsecond sky surface brighness is typical at the UC Davis site. There is a portable meter in the dome.
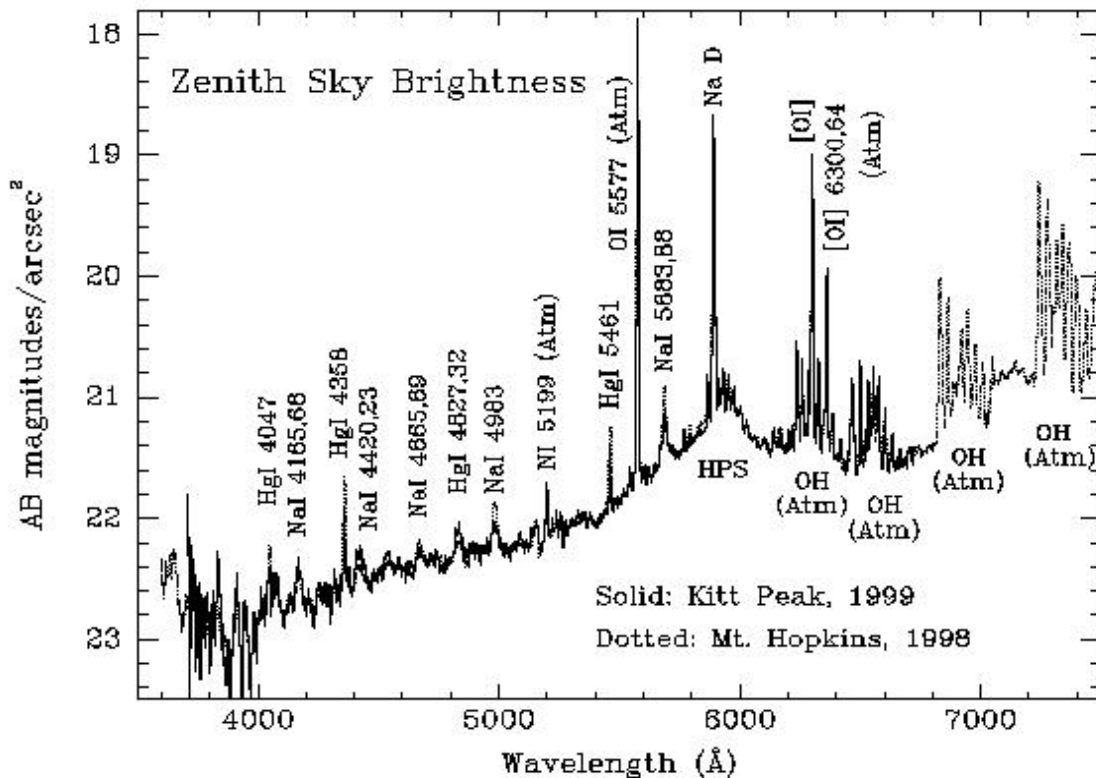
Knowing what to expect. Finally, you must prepare an observing chart showing what objects are in and around your selected field in the sky. To do this you can enter the name or coordinates of your object and the size of your field of view (about 24 arcminutes) into the astronomical database GUI: http://ned.ipac.caltech.edu/forms/byname.html

You can view an image or -- better -- download a FITS format image which you can display and manipulate using (for example) DS9 (free download from http://hea-www.harvard.edu/RD/ds9/) as well as your own python image processing code. Become completely familiar with this image processing well in advance of your data run.

OBSERVING PROJECT

Your observing project for fall 2013 will be to undertake calibrated narrow band photometry and generate a deep multi-color image of an emission line object, analyzing the data to extract information on the physical processes in play. Ionized plasmas play an important role in many aspects of astrophysics. H II regions and planetary nebulae, ionized by hot stars, provide opportunities to measure chemical abundances and other quantities that are central to the process of star formation, stellar evolution, and the chemical evolution of galaxies.

An emission spectrum consists only of radiation at a number of discrete wavelengths, appearing as bright lines against a dark background. This type of spectrum is produced by hot diffuse gases, such as in a gas discharge tube or in clouds of interstellar gas heated by hot young stars nearby. Electrical energy or heat supplied to the gas is absorbed by atoms or ions in the gas, raising the energy level of electrons. As the electrons fall back to their normal energy state, they give up a quantum of energy as a photon corresponding to one of the observed wavelengths. The emission spectrum is made up of lines corresponding to all the possible electron transitions. The relative intensity of each line depends on the composition of the gas. Emission nebulae are regions of hot gas, mainly hydrogen, and dust heated by the radiation from nearby young stars. As excited electrons in the atoms and ions within the nebula drop to lower energy levels, line spectra are produced with emission lines in the ultraviolet, visible, infrared and radio bands, characteristic of the elements that make up the nebula.

You will do this by taking many deep exposures in five filters: B,V, H-alpha, O-III, S-II. See related material "Filter transmission curves". The object will be chosen from the list below, depending on observing time, date and weather. The list includes nebulae in our own Galaxy as well as another galaxy with star forming emission regions. The science you will pursue is a study of either the emission line regions for the nebula, or the stellar populations (from their broadband colors) and the hot star forming regions (via their excited hydrogen-alpha line emission) for the galaxy. These objects will be well within the 24 arcminute CCD field of view.

M57   18 53.6 +33 02   8.8 mag   3.8x3.8'   http://apod.nasa.gov/apod/ap130605.html

M27   19 59.6 +22 43   7.5 V mag   8x5.7'   http://apod.nasa.gov/apod/ap050603.html

M76   01 42.4 +51 34   12 V mag   2.7x1.8'   http://apod.nasa.gov/apod/ap100723.html

M33   01 34 +30 39   5.7 V mag   67' x 42' Sc galaxy with knots of H alpha in the arms

http://apod.nasa.gov/apod/ap121220.html

Note M57 is small by comparison to some of the other objects on your list, so you may want to spend most of your time on M27 or the 60 times fainter M76. We recommend taking a number of 300 sec exposures, correcting for telescope drift in between if necessary. If you use the offset guider system, you may not have to adjust the position on the sky between exposures.   The faintest object may require shift-and-stare imaging [chopping on the sky].   Be sure to shift the object off itself in your multiple exposures.

Remember to start your observing when your object is to the east, because it will take you several hours to take your data, and you cannot observe very far to the west. Plan your session so that your most difficult imaging is done close to the zenith (where there is minimum absorption in the atmosphere).   Be alert for clouds; do not take data through clouds. After your eyes dark adapt you will be able to detect clouds by how they obscure the stars.

Calibration

You will need to calibrate your observations by taking shorter exposures of several Landolt calibration stars before and after your exposures.   The Landolt catalog can be found on-line, and there is a list of Landolt UBVRI calibration stars in the 3-ring binder in the dome. See below for details on standard star calibrations of flux and color.   In order to derive fluxes in the emission lines you will have to calibrate the camera-telescope-filter on a spectroscopic calibration star of known flux per unit wavelength. Chose from list at

 http://www2.keck.hawaii.edu/inst/deimos/flux_stds.html

Be sure to observe calibration stars at about the same airmass as your main science observations. This will take some planning prior to your observing night.

Finally, be sure to take CCD camera calibration images. You can do most of this system sensitivity calibration and systematics data collection while you are waiting for the sky to get dark:

1. Take ten "bias" frames [zero sec exposure with shutter closed] Some CCD cameras exhibit a low level repeatable systematic error due to the electronics clocking signals and electrical pickup. You will take the median average of these images during image reduction.

2. Take ten "dome flats" with the telescope pointed at the dome screen – illuminated by the special projector. You will use the median average of these to correct for the pixel-to-pixel sensitivity variations. Check that your counts per pixel are not too high (else the CCD becomes non-linear), or too low (which would give you poor statistics). Adjust exposure time to give about 5-10 times the night sky background counts that you have on your sky exposures (to get good statistics per pixel). You don't want to divide your nice galaxy data by a noisy flat field image!

Color and Magnitude Corrections:

There are a few points we will need to consider since here we need to calculate an actual magnitude as opposed to a magnitude difference:

Recall that $m(1) – m(2) = 2.5 \log (F_2 /F_1)$, where F is the flux.

Atmospheric extinction:

The atmospheric extinction changes as a function of airmass and wavelength.   We will try to observe M51 close to the zenith, so you could use typical atmospheric extinction values from Kitt Peak: B ~ 0.3 mag, V ~ 0.2 mag, R ~ 0.15 mag, I ~ 0.1 mag. But you need to correct for extinction from the airmass of your observations. The correct values for our UCD site can be found by observing a standard star at several zenith angles in all of the filters. You may not have the time to make these measurements. The best approach would be to use the values for the extinction coefficients in your filters from Palomar.

You will need to correct for total extinction in each filter (A).   See the file on extinction coefficients for Palomar (in the 123 web page on Observing). Use these extinction coefficients for UC Davis.

Be sure to convert your instrumental magnitudes to actual magnitudes using the Landolt standard star zero points before you apply these extinction corrections.

http://www.eso.org/sci/observing/tools/standards/Landolt.html

Science Data Analysis

Once you have preprocessed your images as discussed in class by subtracting a median bias from all the other images (including all your calibration and science exposures) and then dividing by your flat field image normalized, you are set to do the photometry required for your science. You may have many exposures in a given color, and they may be dithered in position. First register and then co-add your good exposures into a final deep exposure, one for each filter band. Register by tagging a number of bright isolated stars in DS9 and using the output list of xy positions as input to a python routine for offset measurement and shifting. Co-add registered images by median filtering (average via median) to eliminate outlier pixel values (cosmic rays, for example). Read the posted material on the 123 web page. In the following, be sure to calibrate your "apparent magnitudes" or integrated ADU, by using your extinction corrected calibration stars.

Read chapter 10 in Chromey on photometry. The photometry you will perform takes two basic forms: surface photometry (flux per area from your object integrated over a large number of pixels), and stellar photometry (flux in a small number of pixels). In both cases what you measure is the integrated flux in some (usually circular) aperture from your object plus the underlying flux from sky emission and also underlying flux from diffuse emission from objects unrelated to your object (such as diffuse starlight from the galaxy if your object is a HII region). You must subtract this background because it is also in your photometry aperture.

To measure the sky level you need to estimate the sky level outside the region of your object. In the case where the object of your photometry is the diffuse flux, you may have to make this sky measurement well outside the object. This means that you are relying on having made a precise flat field correction. If you are observing in the narrow band H-alpha filter and you are trying to photometer a compact HII region, then you must subtract the background in an annular area around this HII region. For isolated star precision photometry, it is best to use an annular region around the star (inner radius sufficiently beyond the tail of the stellar point spread function). Devote some thought to your choice of object and sky apertures. Be sure to correct for the different areas of your sky annulus and your photometry area.

Now that you have reduced your data and have calibrated fluxes, you can answer the question: which emission line is the strongest in your object [most flux]. You may also want to estimate the rest-frame luminosity in H-alpha using the known distance to your object. Express in units of solar luminosities.

Finally, include in your report a color image (for this you need three input "RGB" images) made from H-alpha, V, B or some other combination of filters. Be sure to subtract sky in each filter. [you are not interested in the sky's color, and it will swamp your object]. Leave one sigma of sky noise.

In your report introduce your science problem, then discuss your detector, S/N considerations, your observing, your data calibration and reduction, and photometric analysis. Scientific writing style is very important [see Reports tab].