Project 1: Multi-Color Imaging of Galaxies and Star Clusters with the McDonald 30"

In this project, you will remotely operate the 30” telescope at McDonald Observatory to obtain images of multiple filters of a nearby bright galaxy and of a star cluster, both of which you will choose. The telescope will be equipped with the SDSS (Sloan Digital Sky Survey) filters ugri, plus a narrowband filter centered on the H-alpha spectral line (Balmer series, n=3-2 transition). For the purposes of this assignment, the broadband filters are probably most important. Your first goal will be to use Python to combine the filtered images of the galaxy into a single multi-color (e.g., RGB) image, and qualitatively interpret what the colors you observe mean. Your second goal will be to again use Python to measure the brightnesses of stars in the star cluster, produce a color-magnitude diagram, and infer the properties of the star cluster.

All coding should take place in a single Jupyter notebook, which you will submit via GitHub following instructions below. You will then write a report, the final version of which will be due at **11:59p on March 3rd.** This document will walk you through the steps you will take to perform this project in the order in which you should perform them.

GitHub Link: https://classroom.github.com/a/L56HX88N

1) Create an observing plan for the time at the telescope. Outline each task (including startup and shutdown), decide how many of each type of file you will need, and estimate how long it will require to obtain all of these observations. Choose an open block of time and schedule your team in the discussion thread on Canvas, requesting the number of hours on the telescope that you think will be needed. **A draft of this section will be due (via email to both instructors and Jackie - one per group) before you observe, and no later than Tuesday Feb 18 at 5pm**, which the instructors will comment on, and then they will synthesize the feedback into a set of common lessons in the next class. This should be written in such a way as to become Section 2 (Observations) of your final report (after modifying it to reflect the actual reality of what occurred).

2) Remotely operate the telescope and obtain the observations you planned for in #2. Note for the purposes of this class, all remote observing should be done from the computer lab in PMA 15.201. Each observation should be recorded in your groups observing log, including notes about relevant events that occurred during the observations (i.e., clouds, software crashes, a mountain lion just walked in front of the telescope and blocked the target). Afterward, create a modified Observations section for your final write-up that reflects on how the implementation differed from the plan, and what lessons were learned which you will apply to future observing runs. You must attend an observing run! For proof of this, while observing, take a selfie of your entire group together, and append it to your project writeup. If you cannot attend with your group, you may attend with another group. If circumstances prevent you from attending, talk to the instructors well in advance of the due date.

3) In the computer lab, process the images in Python. While you won't need to observe calibrations like in Project 0 (observatory staff will take those), you will still need to apply those calibrations to your science observations. For the galaxy, this step will also involve combining the galaxy images into a single three-color (RGB) image.

4) Display your color image of the galaxy, and using what you learned from the papers we've discussed in class, discuss in your report (~a paragraph) what you can learn about the properties of the galaxy from the colors you observe.

5) Analyze the star cluster data in Python. For the star cluster, this will involve figuring out how the pixel positions translate to on-sky positions (which can be done using the Astrometry.net website, which we demoed in class on the Photometry day), and then measuring aperture photometry for a representative set of stars that are part of the cluster. You will also need to calibrate the photometry. To do this, find a set of bright (but not saturated) stars in your images that have known magnitudes (such as from the Sloan Digital Sky Survey or the Pan-STARRS1 survey), measure the difference between your magnitudes and the standard magnitudes, and apply this difference to all of your magnitudes; we also demoed this in class (for our purposes, don't worry about color or airmass terms.)

6) For the star cluster, plot the color-magnitude diagram, and identify the brightness of stars at key locations in its cluster sequence: the tip of the red giant branch, the giant branch clump, and the main-sequence turn-off. Given a set of stellar evolutionary models (which we can help you find, as it depends on your choice of cluster), the distance to the cluster, and the brightness of the MS turnoff, what is the approximate age of the star cluster?

7) Write a project report in LaTeX, using the template provided, which is in the format of the Astrophysical Journal, including (items in gray are not required):

    a) Abstract: This is a high level summary of the paper - look at real papers for examples, and we'll discuss this in class as well.
    b) Introduction: This will be the first full section of your report, which should provide background, supported by citations, on the scientific topic in question. In this project, this should include information on the galaxy and the star cluster you observed, and background on what can be learned from multi-band imaging of both types of targets.
    c) Observations: This should be a description of how you planned your observations, for example, how you decided how many of each type of file you will need. This should include a description of your observing - the date and time, how many images you took, what was different between how you planned and how you executed the observing.
    d) Results: This should be the core of the report. This is a description of how the raw data were processed to yield results that you subsequently interpreted (e.g., how they were reduced, and how measurements were made). This is also where you will discuss (but not yet interpret) these measurements. This

should include well-designed figures and descriptive captions of the required elements from above, to visually demonstrate the key results in a way that is understandable to readers (i.e., your classmates) without necessarily reading the text.

e) Discussion: This is where you interpret your results. For this project, this is where you will put your discussion of what you learned from the galaxy colors, as well as the implications of what you measured from the star cluster. For this project, you need only write ~one paragraph per object (we'll write more in future projects).
f) Conclusions: A high level summary of the key take-away points from this project, If the reader only read the conclusions, what would you want them to know?
g) References: Cite any references used in standard ApJ citation format.
h) Observing Logs: Scan your group's observing log into a PDF, and append it to the end of your report. This is also where you should put the selfie of your group during observing.

8) Submit the final version of your code via Github. The code should be well commented so that the instructors can understand your coding process.

9) Submit the project report via Canvas, uploading as a single PDF. Both the report and the code should be submitted by the time and date at the top of this document.

Tips:

1) If you use Source Extractor to do your photometry, the best way to do this is via two-image mode, where it detects sources in one image, and measures the photometry in a second image. For example, say you have a *g* and *r*-band image, you would run two catalogs, both using one band (say *r*) as the detection image, and once each with the g-band and r-band as the measurement image. You would then have two catalogs, one with the photometry from the *g*-band, and one from the *r*-band, both for positions specified in the *r*-band image. By using the same image as the detection image each time, the catalogs will be the same length and in the same order (e.g., line 257 of both catalogs is for the same object), making it easy to do your analysis.
   a) However, Source Extractor requires the measurement image and the detection image to be on the same pixel-wcs grid, meaning that the RA and Dec of x,y in one image is equal to that in the second image. Since our telescope isn't perfect, this is likely not the case even for sequential images.
   b) To match up your r, g, and b images if the telescope moved, you can use the reproject package, provided you have already added WCS to the headers via astrometry.net: https://reproject.readthedocs.io/en/stable/ which should be installed on all the lab computers. This package reads the WCS information and interpolates one image onto the coordinates of another. One you have "registered" the images in this way, the output of this should be two images of the same size, though double check that this is the case. You can then run Source Extractor in two image mode.

2) If you don't want to reproject, then you can run a g-detection, g-measurement catalog to get your g-band photometry, and a r-detection, r-measurement catalog to get your r-band

photometry. In this case, the catalogs will be different lengths, so you will have to use the measured RA and Dec for each source to match up the two catalogs (there is probably a useful python routine for this, and we also explored this earlier in the semester with the SkyCoord separation function). Be careful - one cannot do a simple r=sqrt(dx^2+dy^2) because the sky is curved! (see back to the earlier lectures).

3) We didn't discuss too much which photometric column to use; if you use a circular aperture that is small, you won't get all the flux, and if its large, you will have very noisy photometry. For this project, I would suggest using MAG_AUTO, which is an adaptable elliptical aperture, which tries to select an aperture size which is a happy medium between the considerations we discussed in class, but does get nearly all of the flux (so you can ignore aperture corrections). Note that MAG_AUTO defines the aperture in the detection image, so if the seeing changed dramatically between the two images, it may not be as accurate, but this is not likely to be the case for you, so it should be fine for both.

4) For making your RGB color image, once you have the registered (matched up) images, any python rgb plotting method should work. One plotting routine specifically built for astronomers is APLPy (http://aplpy.github.io) though we have seen some issues. matplotlib and astropy.visualization both have ways to make an rgb image from three images.

AST376 Project 0: Calibration Data with PMA Rooftop Telescope
Assigned Jan 28, 2020

In this project, you will use the 16” telescope on the roof of the PMA building to obtain standard imaging calibration data. This includes bias images, flat-field images, and dark-current images (with the latter at multiple exposure times, so you can measure the dark current in counts/sec). You will then reduce this data using Python to create the master calibration frames, and perform some measurements on these data. All coding should take place in a single Jupyter notebook, which you will submit via GitHub following instructions below. You will then write a report, the final version of which will be due at **12:30p on Feb 2/13.** This document will walk you through the steps you will take to perform this project in the order in which you should perform them.

You will do the observing in groups, which will be assigned on Thursday. Note that right now the CCD camera is down, but we expect it to be repaired by Friday (if it takes longer, we will provide data to you).

GitHub Link: https://classroom.github.com/a/fEZIB-M9

1) With your group, create an observing plan for the time at the telescope. Outline each task (including startup and shutdown), decide how many of each type of file you will need, and estimate how long it will require to obtain all of these observations. Choose an open block of time and schedule your team on the google doc, requesting the number of hours on the telescope that you think will be needed. **Not needed for Project 0:** **A draft of this section will be due (via email to both instructors and Jackie - one per group) by tomorrow at 5pm**, which the instructors will comment on, and then they will synthesize the feedback into a set of common lessons in the next class. This should be written in such a way as to become Section 2 (Observations) of your final report (after modifying it to reflect the actual reality of what occurred).

2) Go to the telescope and obtain the observations you planned for in #2. Each observation should be described using the standard Observing Log template, including notes about relevant events that occurred during the observations (i.e., clouds, software crashes, I just walked in front of the telescope and blocked the target). Afterward, create a modified Observations section for your final writeup that reflects on how the implementation differed from the plan, and what lessons were learned which you will apply to future observing runs. You must attend an observing run! For proof of this, while observing, take a selfie of your entire group together, and append it to your project writeup. If you cannot attend with your group, you may attend with another group. If circumstances prevent you from attending, talk to the instructors well in advance of the due date.

3) Process the images in Python. For this project, this will involve combining the images to create master calibration frames (a master bias, a master flat, and a

master dark for each dark exposure time). Make figures for your report showing each of the master images.

4) Analyze the data in python. First, create histograms of pixel value distributions in all master images. Then, calculate the mean value and a standard deviation of the pixel values in the various master darks. Make a plot of the mean total dark current versus time, plotting the standard deviations as the error bars. Finally, calculate the dark current (in units of counts/second) by fitting a linear function to the data, be sure to calculate uncertainty on value.

5) Write a project report in LaTeX, using the template provided, which is in the format of the Astrophysical Journal. By the end of the semester, you will be writing a full report with all sections below (including those grayed out). For project 0, the required sections are those not in gray.
   a) Introduction: This should be a version of the text submitted under item 2 above, revised following your instructor's feedback.
   b) Observations: This should be a description of how you planned your observations, for example, how you decided how many of each type of file you will need. This should include a description of your observing - the date and time, how many images you took, what was different between how you planned and how you executed the observing.
   c) Analysis: This is a description of how the raw data were processed to yield results that you subsequently interpreted. This should include well-designed figures and descriptive captions of the required elements from #3 and 4 above.
   d) Results: This should be the core of the report, describing what you measured from your data, supported by well-designed figures and captions to visually demonstrate the key results in a way that is understandable to readers (i.e., your classmates) without necessarily reading the text. Given that this project involves only calibration data, the actual text component of this section may not be large, but you should have a number of figures with descriptive captions.
   e) Discussion/Conclusions. This section should be used to interpret the results and decide what they tell us about how the Universe works, how future observations should be conducted, etc. What were the lessons learned? (For example, what are the quantitative effects of the systematics you see in the dark/flat, and what would be the impact of not correcting them?)
   f) References: Cite any references used in standard ApJ citation format.
   g) Observing Logs: Scan your group's observing log into a PDF, and append it to the end of your report.

6) Submit the final version of your code via Github. The code should be well commented so that the instructors can understand your coding process.

7) Submit the project report via Canvas, uploading as a single PDF. Both the report and the code should be submitted by the time and date at the top of this document.

Name:

AST 376 Project Rubric

Total Grade: ______ / 30

Project Report: Grade _____ / 20

	5	3	1	0	Score
Format	Report is in proper format, with minimal spelling errors, and well-placed figures.	Modest number of spelling errors or poor figure placement.	Major formatting or spelling errors.	Report not divided into sections, major figures not rendering properly, or suffering from major grammar and spelling errors.	
Introduction	Report includes a detailed introduction to the topic, and is revised following instructors comments.	Introduction does not cover all relevant topics.	Introduction missing significant portions of the required topics.	Section is missing.	N/A
Observations	Report includes a complete discussion of the observations, including a discussion of how the observing plan was developed, how it was modified during the run,, and lessons learned for future observing.	Observations section missing one or more of the required elements. The design or observational parameters of one or more datasets is not clear.	The observational design choices and the sequence of events during the observing run are not documented.	Section is missing.	
Analysis	Report includes a detailed description of the data analysis steps used, both for the data reduction, and how any measurements were made.	The description includes all analysis steps, but the analysis progression cannot completely be followed.	The analysis steps in processing the raw data and extracting scientifically meaningful numbers are not described or are described with major factual errors.	Section is missing.	
Figures	All required figures are present. They are simple and easy to interpret, axes are labeled and legible. Figures are accompanied by descriptive captions.	All figures are present, but they are not intuitive to interpret, or the captions do not adequately describe the figures.	Figures contain major inaccuracies, axes are not labeled, points and curves are not labeled. Captions are not used or contain only cursory information.	Figures are absent.	
Results	Report describes in detail what was measured, with each measurement linked to one of the accompanying figures, and discusses potential sources of uncertainty in the analysis.	Report describes the items which were measured, but description is incomplete or does not fully link to figures; some sources of uncertainty not discussed.	The major scientific results are not described or are described in ways that do not follow fundamental principles of physics.	Section is missing.	N/A
Discussion	The report includes an in-depth interpretation of the results, including knowledge of how observations should be conducted, and what lessons were learned.	The report discusses the meaning of the results, but contains substantial logical errors or misunderstanding of physical principles, or does not retrospectively discuss the lessons learned.	The report does not interpret the results and draws no conclusions about how their results agree with or suggest modifications of our understanding of the universe.	Section is missing.	N/A
References	Report includes citations to references where required in the appropriate format.	Some references included, but significant uncited statements.	Significant content from other sources was used without proper citation.	Report contains no references.	

Code Submission: Grade _____ / 10

c	5	3	1	0	Score
Code Formatting	Code is well commented, and one can easily link portions of code to figures in the report	Code can be followed, but the structure is inefficient or important sections are not commented.	Sparse or unhelpful comments, code is difficult to follow.	Code is not commented at all, functionality of code can't be assessed.	
Code Function	Code functions as intended	Code produces all necessary output, but contains errors that result in erroneous results in some cases.	Code only produces part of the output required for the assignment.	Code does not function.	