Syllabus

ASTR 3510
Astronomical Observations and Instrumentation I: Imaging
Fall 2018

Class: Tu, Th 6:00 – 7:15 PM : ***Sommers-Bausch Observatory classroom (OBSV S175)***
Lab: Tuesdays, 7:30 + : ***SBO computer room and telescopes (OBSV S125)***
http://casa.colorado.edu/~bally

Instructor: *John Bally,* John.Bally@colorado.edu Duane D349, 303 492 5786
Office Hours: Tuesday 3:30, Wednesday 3:00 PM in D349, or by appointment
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Office Hours: or by apt.
Grader: *Suphawit Duangphumek* Suphawit.Duangphumek@Colorado.EDU

Purpose:

ASTR3510/3520 introduce students to the principles of instrumentation used in astrophysics, planetary science, and space physics. The first semester emphasizes imaging while the second semester emphasizes spectroscopy. This course (the first semester) explores the physics and use of telescopes, visual-wavelength imaging with CCDs, photometry, and astrometry. We will also review imaging at other wavelengths including gamma and X-rays, UV, infrared, and radio.

Students will use the SBO 20" and 24" telescopes extensively. Lectures will be held at SBO in the evening, just before labs. Lectures will teach the physical basis of imaging, optics and telescope design, telescope and camera operation, data reduction, and analysis. However, most of the effort in this class will in night-time observing, data reduction, and analysis using PyIRAF, ds9, and Python. Students will do research, write-up, and present their research results.

The class will be subdivided into observing teams of no more than 3 students per team. Each team will be expected to spend 1 to 2 nights per week (weather dependent) observing with either the 20" observing deck scopes (from 10:00 PM when the lower-division classes leave till sunrise) , or the 24" after sunset till sunrise. Student groups will be asked to sign-up for specific time slots to avoid conflicts.

Grading:

The grade will be based on problems sets (**30%**), one paper (**15%,** details will be provided in Week 3), and a combination of lab write-ups and an end-of semester, in-class oral plus written presentation of a student project (**45%**). The remaining **10%** of your grade will be determined by your participation in discussions in class and lab. We will not have exams – your project presentations will serve the purpose of a final. Class and laboratory attendance is mandatory.

There will be multiple instances where the homework will not directly give you all the information required to solve problems. For all of these instances it will be possible to find the relevant information with independent research. Try to see if you can find what you need and cite your sources. If **after searching** you are still unsure of what you need or where to find what you need to solve a problem, cooperate with your classmates and ask your TA or the professor for help. As always, the CU Honor Code applies.

All students are expected to do their own work. It is expected that when collaborating in projects with other students, each student will do a fair share of the work. Cheating, copying, or use of material without proper referencing or attribution is unacceptable.

Observing Projects:

In this class, you will have access to the SBO 24" and 20" telescopes. The end-of semester research project can be based on data acquired with the SBO CCD cameras. All students will be required to submit a formal proposal for an observational research project. The project oral presentation and written report will be due during the last week of the semester.

Projects can be collaborations of up to three students.. In group projects, each student will have to identify specific roles and carry out their tasks on their own. These roles, along with the goals and methodology of your project, will be spelled out in the project proposal (more on this during the first two weeks of class)

No Textbook required: **Useful References*:***

``***To Measure the Sky"***, Frederich R. Chromey

``***Data Reduction and Error Analysis in the Physical Sciences''***, Philip Bevington, & D. Keith Robinson

"An Introduction to Astronomical Photometry Using CCDs," by W. Romanishin.
This manual contains a lot of very useful things that we will be using in this class, though not perhaps in the same order. Use it as a practical guide and a supplement to your class notes.

``***QED; The Strange Theory of Light and Matter",*** Richard P. Feynman, 1985, Princeton University Press

``***Electronic Imaging in Astronomy; Detectors and Instrumentation"***, 1997, Ian S. McLean, John Wiley and Sons, New York

``***Astronomical Observations; An Optical Perspective"***, 1987, Gordon Walker, Princeton University Press, Cambridge

``***Astronomical Optics"***, 1987, Daniel J. Schroeder, Academic Press, Inc., New York

Course Outline:

The schedule is meant to be flexible. The topics to be covered are listed below, but the schedule may vary.

Week 1. Introduction:
Lecture Component:

- Intro to class and logistics. Class overview.
- Introduction to the SBO telescopes & telescopes in general.
- Astronomical coordinates, scales, and time-keeping, angular units and standard conversions (arc-seconds, arc-minutes, degrees, radians, steradians, etc).
  Three electronic handouts: Posted on
  casa.colorado.edu/~bally/Current_Course/ASTR_3510
  Syllabus.pdf
  Form under Useful_documents/ grab
  Constants and Formulae for Majors.pdf)
  CCD_Telescope_Notes.pdf
- Astronomical examples – nebulae, clusters and galaxies.
- Hand out ***Homework 1***

Lab Component:

- Assign students to groups, introduce students to calendar.
- Introduce Palomar sky plates.
- Identify HII regions, spiral and elliptical galaxies, bright stars, planetary nebula, and dark clouds on the negative PSS prints.

Observing: Student groups to start **Lab 1**.

Week 2: (Girish to lecture):
Lecture Component:

- Magnitudes, flux, Jansky as a physical unit.
- Astronomical conventions and coordinates. Sidereal time and relation to Solar and local time.
- Basic telescope properties. Aperture, focal-length, image scale, magnification (when using an eyepiece).
- The diffraction limit and atmospheric turbulence (seeing) limit.
- Hand out ***Homework 2***

Lab Component:

- Introduction to the SBO telescopes.
- Telescope operations. Opening, closing, safety rules.
- Operation of the CCDs.
- Computer access: Intro to Unix, Python, ds9, IRAF. Hand out **Lab 2 Observing:** Each group to open, find a star, focus, take an image, and close.
  Inspect image using ds9. **Complete Lab 1.**

Week 3:
Lecture Component:

- Review properties of light. Light as a wave and light as a particle.
- Continuum and blackbody radiation, emission lines.
- Photo-electric effect and modern imaging devices. History of astronomical imaging.
- Introduction to low-light image acquisition and instrumental artifact removal.
- Hand out ***Homework 3***

Lab Component:

- Intro to calibration frames and basic image processing with IRAF.

Observing: Take images of star fields, clusters, measure image scale and use catalog stars to estimate image scale and orientation. **Complete Lab 2.** Start **Lab 3.** ***Homework 3***

Week 4:
Lecture Component:

- Basic geometric optics: Fermat's principle and image formation.
- Spheres, parabolas, and compound optics (Cassegrain, Ritchey-Chrétien, etc).
- Snell's law and refractive optics.
- Common telescope designs.
- Aberrations.
- Introduction to diffraction. Theoretical limits to resolution.
- Determining the ZPT and photometric calibration.
- Magnitude, Janskys, and estimating limiting magnitude and flux as function of exposure time and instrument parameters.
- Hand out ***Homework 4***

Lab Component:

- Image reduction and analysis using IRAF, ds9, etc.

Observing: **Complete Lab 3.** Start **Labs 4 & 5**:

  - Star, asteroid proper motion imaging
  - Imaging of deep-sky objects.

Week 5:
Lecture Component:

- Overview of modern imaging. Camera design (what's in your SLR or snapshot digital camera?).
- Optical transformers (changing the image-scale and FOV).
- CCD fundamentals.
- Limitation to resolution – the atmosphere. Turbulence, transmission, air-mass.
- Observing practicalities. Focusing, tracking.
- Diagnosing problems (optical alignment, CCD problems, S/N, finding sources, measuring image scales & orientations).
- Use of public-domain resources (USNO, Web-based data bases, etc.). When discussing USNO, note that that images + catalog are directly accessible through DS9 – this saves a good deal of pattern-matching-with-circles pain.
- Hand out ***Homework 5***

Lab Component: Free time to work on analysis for Labs 4 & 5.

Observing: Continue Labs 4 & 5.

***Week 6*:**
Lecture Component:
- Photometry basics. Magnitude systems. Decibels. Janskys.
- CCD gain and how to measure it.
- Introduction to the use and importance of statistics.
- Signal-to-noise. Sources of noise.
- Why and when do we need darks, bias frames, flats? How do we use them?
- Standard stars.
- Exposure time estimation.
- Hand out ***Homework 6***

Lab Component:
- Image reduction and calibration concepts and exercises.
- Discuss student project: possible projects, expectations, format.

***Week 7*:**
Lecture Component:
- Radiative transfer concepts.
- Extinction, reddening.
- Interstellar dust and its effects on stellar and nebular light.
- Color-corrections, measuring the atmosphere.
- Emission vs. absorption as a function of wavelength.
- Hand out ***Homework 7***

Lab Component:
- **Student Project Proposals due.**
- Design observing plan for projects

Observing: Continue Labs 4 & 5

***Week 8*:**
Lecture Component:
- Astrometry basics. Proper motions.
- Distortions in optics.
- Practical astrometry.
- Parallax. (Discuss *Gaia* mission briefly)
- Error estimation.
- Hand out ***Homework 8***

Lab Component & Observing: Start Projects. Continue Labs 4 & 5.

***Week 9. (Girish to lecture)*:**
Lecture Component:
- Deep-sky imaging.
- Planetary imaging.

- Morphological classification of astronomical objects.
- The use of color in astronomy.
- Color-color and color-magnitude diagrams.
- Variability monitoring.
- Variable stars and AGN.
- Synoptic monitoring programs, exoplanet transits, asteroids, gamma-ray bursts, pulsars, and exotic phenomena. (Discuss *LSST* briefly)
- Single-object vs. crowded-field photometry.
- Hand out ***Homework 9***

Lab Component & Observing: Continue Projects, Labs 4 & 5.

***Week 10*:**
Lecture Component:

- Diffraction and interference.
- Depth of focus.
- Measuring the quality of the telescope and seeing.
- Hand out ***Homework 10***

Lab Component:

- Practical observing skills.
- Lab demonstration of interference, diffraction.
- The pinhole camera.
- Multi-aperture interference.

Observing: Continue Projects. **Labs 4 & 5 due.**

Week 11.
Lecture Component:

- Imaging in the UV and near-IR.
- Photometric bands, atmospheric characteristics.
- Detector technologies.
- Optimizing optics and telescopes for each wavelength range.
- Hand out ***Homework 11***

Lab Component:

- Discuss 2020 Decadal proposal missions: Lynx, LUVOIR, WFIRST

Observing: Continue Projects. **Submit Progress Update on Projects.**

***Week 13*:**
Lecture Component:

- Overview of radio astronomy: Discussion interferometric methods and preparation for the field trip.
- Non-thermal / synchrotron emission by electrons.
- The Zeeman effect. Grain alignment. Polarized continua.

Lab Component:

- Discuss the Very Large Array, Atacama Large Millimeter Array, *DKIST*.

Observing: Continue Projects.

***Week 14*:**
Lecture Component:
- Imaging at other wavelengths. Gamma-rays, X-rays.
- Space vs. ground.
- Interferometry.

Lab Component:
- Catch up on lecture material if required. Free time for analysis otherwise.

Observing: Continue Projects. **Resubmission deadline for Labs.**

***Week 15*:**
Lecture Component:
- Applications of imaging in astronomy.
- Overview of the world's observatories.
- Current and future projects. Synoptic surveys.
- Student Project Presentations.

Lab Component:
- Catch up on lecture material if required.
- Student Project Presentations otherwise.

Observing: Final Projects Due.

LABS:

1. Become familiar with the visual sky:
    a. Locate planets, constellations, bright stars with naked eye.
    b. Estimate the diameters setting planets and stellar images by naked-eye timing of how long it takes from first dimming to complete disappearance behind the Flatirons.
    c. Use telescopes to find a planetary nebula, a star cluster, HII region, and a planet. Estimate the visual "seeing" in arcseconds.
    Time: 1 week

2 . Observe with the 20" & 24" telescopes. Find a star, focus, and produce an image.
Analysis: Move the image in directory space using the terminal to a designated folder. Save and submit Terminal output to show your commands used.
Time: 1 week

3. Determine image scale, orientation of camera, zero-magnitude flux (or magnitude @ 1 ADU). Strongly guide observation portion so that students know *exactly* what to look for in image acquisition process. Analysis: Measure "/pix, ADU/Jy, ADU<->mag. Determine telescope optical properties?
Time: 2 weeks

4 Asteroid astrometry and photometry. Assist students with sensitivity estimates but more hands-off w.r.t. finder charts. Determine asteroid proper motion and measure variability using multiple images.
Time: 3 weeks

5 Nebular imaging. We specify a set of targets, leave it to students to determine how best to observe them. Obtain a color image using multi-filter observations.

Proper motion of, e.g., M1, NGC 6888 w.r.t. DSS images.
Stromgren sphere of a planetary nebula. Estimate Q from Ha brightness and radius.
Deep galaxy imaging and mosaic.
Globular and open cluster imaging.
HII region imaging.
Imaging galaxies
Time: 3 weeks

6 Class Project – independent selection *and* observing
Time: 5 weeks. Some possible projects:
Size spectrum of HII regions in a galaxy such as M33, M31.
Color-magnitude and color-color diagrams for open and globular clusters.
QSO photometry – searching for flares that could be observed with HST.
The diameters of transiting exo-planets.
The properties of Algol and similar systems.
Reverberation mapping of variable reflection nebulae; Hubble's Variable Nebula. (NGC 2261), Mc Neil's Nebula in Orion, PV Cep.

CU Mandated section of the Syllabus:

ACCOMMODATION FOR DISABILITIES

If you qualify for accommodations because of a disability, please submit your accommodation letter from Disability Services to your faculty member in a timely manner so that your needs can be addressed. Disability Services determines accommodations based on documented disabilities in the academic environment. Information on requesting accommodations is located on the Disability Services website. Contact Disability Services at 303-492-8671 or dsinfo@colorado.edu for further assistance. If you have a temporary medical condition or injury, see Temporary Medical Conditions under the Students tab on the Disability Services website.

CLASSROOM BEHAVIOR

Students and faculty each have responsibility for maintaining an appropriate learning environment. Those who fail to adhere to such behavioral standards may be subject to discipline. Professional courtesy and sensitivity are especially important with respect to individuals and topics dealing with race, color, national origin, sex, pregnancy, age, disability, creed, religion, sexual orientation, gender identity, gender expression, veteran status, political affiliation or political philosophy. Class rosters are provided to the instructor with the student's legal name. I will gladly honor your request to address you by an alternate name or gender pronoun. Please advise me of this preference early in the semester so that I may make appropriate changes to my records. For more information, see the policies on classroom behavior and the Student Code of Conduct.

HONOR CODE

All students enrolled in a University of Colorado Boulder course are responsible for knowing and adhering to the Honor Code. Violations of the policy may include: plagiarism, cheating, fabrication, lying, bribery, threat, unauthorized access to academic materials, clicker fraud, submitting the same or similar work in more than one course without permission from all course instructors involved, and aiding academic dishonesty. All incidents of academic misconduct will be reported to the Honor Code (honor@colorado.edu); 303-492-5550). Students who are found responsible for violating the academic integrity policy will be subject to nonacademic sanctions from the Honor Code as well as academic sanctions from the faculty member. Additional information regarding the Honor Code academic integrity policy can be found at the Honor Code Office website.

SEXUAL MISCONDUCT, DISCRIMINATION, HARASSMENT AND/OR RELATED RETALIATION

The University of Colorado Boulder (CU Boulder) is committed to fostering a positive and welcoming learning, working, and living environment. CU Boulder will not tolerate acts of sexual misconduct (including sexual assault, exploitation, harassment, dating or domestic violence, and stalking), discrimination, and harassment by members of our community. Individuals who believe they have been subject to misconduct or retaliatory actions for reporting a concern should contact the Office of Institutional Equity and Compliance (OIEC) at 303-492-2127 or cureport@colorado.edu. Information about the OIEC, university policies, anonymous reporting, and the campus resources can be found on the OIEC website.
Please know that faculty and instructors have a responsibility to inform OIEC when made aware of incidents of sexual misconduct, discrimination, harassment and/or related retaliation, to ensure that individuals impacted receive information about options for reporting and support resources.

RELIGIOUS HOLIDAYS

Campus policy regarding religious observances requires that faculty make every effort to deal reasonably and fairly with all students who, because of religious obligations, have conflicts with scheduled exams, assignments or required attendance. See the campus policy regarding religious observances for full details.