AST 5765: Advanced Astronomical Data Analysis

Fall 2019 Syllabus
Prof. Joseph Harrington

1. Course Vitals

Room:	BA1 126	Lecture:	TR 10:00 – 11:50
Grading:	ABCDF w/ +-	Credits:	3(3,1)
Dates:	27 August – 10 December 2019	Final:	Project due 5 Dec 13:00
Class URL:	WebCourses.ucf.edu, https://planets.ucf.edu/academics/courses/ast-5765/		
Textbooks:	Howell, S. B. 2006. *Handbook of CCD Astronomy,* 2nd Ed. Cambridge, ISBN-13: 978-0521617628. Bevington, P. R., and D. K. Robinson 2002. *Data Reduction and Error Analysis for the Physical Sciences*, 3rd Ed. McGraw Hill, ISBN-13: 978-0072472271.		
Resources, not required to buy (short readings in Press):	Press, W. H., *et al.* 2007. *Numerical Recipes: The Art of Scientific Computing,* 3rd Ed. Cambridge, ISBN-13: 978-0521880688. Lantangen, H. P., 2008. *Python Scripting for Computational Science*, 3rd Ed. Springer, ISBN-13: 978-3540739159.		
Prerequisites:	MAC 2313 (calculus)		
	Ability to write simple computer programs		
	An upper-level course in astronomy or planetary science, or CI		
Required:	Bring a computer to every class. 20 GB free, Linux, MacOS, or Windows, power		

Job:	Instructor	Teaching Assistant
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Contacting:	In case of a computer or other emergency that prevents you from working, call Michael, then Joe. Else, email or text. Email preferred, but text may get a quicker response. Please state name and class in texts.	

2. Objectives

Those who successfully complete this course will be able to:

1. Understand basic statistics and error analysis as used in the physical sciences,
2. Extract physical measurements and error estimates from raw data,
3. Find, educate themselves about, and select appropriate numerical analysis methods,
4. Fit a theoretical model to the measurements,
5. Draw scientifically-valid conclusions from the measurements,
6. Manage and carry out online work with large amounts of data, and
7. Present scientific results.

3. Approach

We cover the following topics in roughly this order:

1. Computers, programming, online management.
2. Introductory statistics and modeling.
3. Array detectors and corrections, image analysis.
4. Photometry and Spectroscopy.
5. Fitting.
6. Project.

In addition, throughout the course, we will read about and discuss a series of advanced topics in computational data analysis.

Data are information, and computers are information manipulators. You should therefore embrace the power of computation and become as expert in computing as in your chosen field. This class approaches the computer as a tool to master and command rather than a black box to fear.

4. Programming Ability and Computer Requirements

We use the Python language. No Python experience is required, but students will need to become functional in Python within the first two weeks of the course, so **general programming ability is required** for success in this course. Students who have taken the course without programming experience have struggled a great deal. Some have failed. **A programming ability evaluation will be given on the first day of class. Students not demonstrating proficiency will be disenrolled.**

Nearly all of the work in this course is done on your computer, including in-class demonstrations. You must **bring a laptop to every class**. We will provide instructions to download and install the course computing environment. The computer you use must have enough free space (at least 5 GB), have a recent-enough operating system to support virtualization in 64 bits, and be fast enough to run the course software. It must also have enough power to run for the two-hour class period. You must be able to install and configure software, following basic instructions. Training to work in the provided computing environment occupies the first three weeks of the course.

5. Video Recording

We video-record each class. This allows students to make up missed classes and to review material. The videos may be posted for the class without redaction. Any videos posted publicly will first be scrubbed of material that shows student faces or grades. Students may not sit in the camera's field of view.

6. Class Format and Grading

Lecture attendance is mandatory. Preparation for and participation in class discussion counts toward the final grade. You must be an active learner by doing the demos and exercises along with the instructor on your computer; don't just watch. The homework assignments are due at the beginning of class on the due date. **No late work will be accepted**, because we discuss the assignments in class, so PLAN AHEAD. Reading should be done **before** the class indicated.

However, you have one homework and one quiz drop to cover unexpected absences (including for jury duty, military service, or illness). This is for our convenience in not giving makeups and is not intended as a form of grading relief. You can choose to spend your drop, but then you have spent your safety net and will take a zero later in the semester if you have to have an unexcused miss. Multiple excused absences will be dealt with according to the Missed Work Policy (below).

We will use peer evaluation (not grading) of homework assignments. Your participation in the peer evaluation counts toward your grade.

Evaluation Weighting	
Homework	45%
Attendance	5%
Discussion participation	5%
Peer evaluation participation	5%
Quizzes	15%
Project results	13%
Project execution	5%
Project paper	7%

Grade Assignment									
		-		straight				+	
A	90	–	93 1/3	93 1/3	–	100			
B	75	–	79.999...	80	–	84.999...	85	–	89.999...
C	60	–	64.999...	65	–	69.999...	70	–	74.999...
D	50	–	53 1/3	53 1/3	–	56 2/3	56 2/3	–	59.999...
F	below 50%								

This is the graduate version of this class. It meets concurrently with the undergraduate version, but has additional problems on homework assignments, a more challenging project, and additional readings assigned during the semester, such as optimal photometric and spectral extraction, spectrum and time-series convolutions, interpolation methods, and wavelet analysis. Undergraduates with programming and data analysis experience may register for the graduate version, with permission of the instructor.

To encourage group participation, grades will not be curved. It is possible for everyone to get an A. It is also possible for everyone to fail (but I hope not!). All reasonable questions regarding grading are welcome.

7. Group Peer Evaluation

Data analysis coding is among the most difficult to do correctly, because there are myriad "moving parts" to track, and because wrong code often does not look much different from correct code. Learning what to do from lists presented in lecture is ineffective; we learn coding experientially. We learn nearly as fast from the experience of others (both positive and negative) as from our own, and with much less effort (we didn't have to write that code!).

Therefore, we use open peer evaluation as a primary learning tool. About once in the semester, each student's homework will be displayed on screen, and we will discuss, with the solutions and grading rubric in hand, how the assignment was coded, and often multiple other ways it could have been coded. Allowing your colleagues to learn from your insights and mistakes will let you learn from theirs, leading quickly to better results for everyone. To date we have never had an incident of disrespect during the peer evaluation, and we expect (and require) this to continue.

Simultaneously, each student will evaluate another's homework, using the grading rubric. Going through the rubric, solutions, and another's code in detail leads to a much deeper understanding and a longer retention of the material. Participation in the peer evaluation is graded. The final homework grades are given by the course staff and frequently differ from the peer evaluation rubrics.

8. Homework Format

Hand in all homework on WebCourses as a single `tar.gz` file per assignment, unless otherwise stated, including prose and math. To make the peer evaluation and grading easier and to promote good coding habits, there are strictly enforced homework format and style rules. See the handout on that topic.

The comments in homework feedback are often about coding style or homework format, so a close reading is important to avoid losing points for the same errors on multiple assignments.

9. Academic Honesty, Sharing, and Information Sources

We will follow the letter and spirit of the UCF Golden Rule. Research in astronomy and physics relies on taking advantage of resources developed elsewhere: software libraries, descriptions of methods, etc. *Unless we state otherwise*, please use such external sources in your work. However, there are several conditions:

1. All math, code, and text answers must be your original work. You may (and should) discuss the relevant general topics with each other, but you may neither give nor receive specific help on nor share assigned work. Sharing code, even to the extent of making it visible on-screen or reading it from someone else's screen, is not allowed, regardless of whether the other party gives permission. This includes help from others not in the class.
2. For coding problems, the portion of the answer relevant to the problem must be your original work. For example, if the question asks you to subtract two images, you must write the code to do the subtraction but you may use third-party code to read the images from files.
3. You must have legal permission to use an external source (assumed if publicly posted).
4. You **MUST** give credit to all external sources **on a problem-by-problem basis**. Credits must include the name of the item, a sentence fragment describing it if it is not obvious from the

name, its author(s), year of authorship, and location (e.g., the name, volume, and pages of a journal article, or the URL of a software package distributed online).

5. As with any scientific research project, you alone are responsible for the output: if you download a package that claims to do something and it has a bug that gives the wrong answer, the answer is wrong and you will be marked accordingly.
6. Work you did prior to the start of the course may not be handed in for grade (talk to the instructor for exceptions).

In addition, see the required statements on academic integrity, below.

10. Working Effectively

There will be approximately weekly homework assignments and project work. It is critical that you do the homework and readings by the beginning of class on the due date, as we discuss answers in class. Your personal understanding is what counts in the discussions, and discussions count toward your final grade. Since answers will be discussed in class, **no late homework will be accepted**.

The **homework solutions** are a critical teaching element. **You must read them**, including all comments in code, each week. They contain discussion of how and why to do important things, knowledge you will need for later assignments.

Not all information needed to do the assignments is covered in lecture or the texts. You must find sources for and read about programming and numerical methods on your own. The Recommended Textbooks are a good place to start, as is the web.

Compared to most physics courses, this course is heavy on skills, methods, and experience. These are taught with practice on real data in the homework assignments. Unlike the “example” datasets of other courses, real data has real problems with it that you will have to overcome. You should budget significant time each week to work on your homework and project. Assignments will depend heavily on prior work done in the class, so skipping work is not very useful: you'll be doing the work anyway in order to do later assignments, so it makes sense to do it in time to get credit for it. Remember that debugging can take a long time, so start your assignments early! While time spent on the class varies a great deal according to students' prior programming experience, you should expect to spend an average of 6-10 hours per week outside of class on this course, and more if this is your first exposure to computing “for real”.

11. Project and Advanced Readings

In October, each student will start a final project based on real data. You will apply the methods learned in the course to produce a measurement and reach a scientific conclusion. Three components of the project together contribute 30% of your final grade: a paper, which will follow the format of *The Astrophysical Journal*, what your coded analysis routines produce (results), and how well your analysis routines are coded and documented (execution).

In addition to the lecture schedule below, there will be readings in numerical analysis from Press *et al.*, and other sources. Topics may include the following list, with additional readings determined in part by class interest and the needs of students:

- Optimal photometric extraction (handout)
- Optimal spectrum extraction (Horne 1986, *PASP* **98**, 609-617)
- Monte Carlo error analysis (Press *et al*.)
- Robust estimation (Press *et al*.)
- Lomb-Scargle periodogram (Press *et al*.)
- Wavelet analysis (Torrence and Compo 1998, *BAMS* **79**, 61-78)

12. Schedule

This is an approximate schedule; pace adjusts to the needs of the class. Formal due dates are as assigned online, not here. The narratives in the homework solutions, demos, and assignment feedback are also required reading. **Quizzes may happen at any time.**

Class	Date		Topic	Reading	Assignment
Tools and Theory					
1	27Aug	T	Introduction	Handout	
2	29 Aug	R	Learning Linux	Handout	1 (Unix)
3	3 Sep	T	First Peer Evaluation	SciPy docs	
4	5 Sep	R	Python Data and Programming	Handout	
5	10 Sep	T	Python Arrays and Image Display	Matplotlib tut., Pydatatut 1-2, readings on handout	2 (SciPy)
6	12 Sep	R	Functions, Coding Style, Measurements, Errors		
Photometry					
7	17 Sep	T	Measurement, Prob., and Stats	Bev. Ch 1,2	3 (programming)
8	19 Sep	R	Prob. Distributions, Error Anal	Handout, Pydatatut 3-4	
9	24 Sep	T	Fitting	Bev. Ch 3,4	4 (stats)
10	26 Sep	R	Fitting and Astronomical Meas.		
11	1 Oct	T	Presenting Data		5 (fitting)
12	3 Oct	R	Presenting Research: Paper Writing		
13	8 Oct	T	CCDs	Bev. Ch 6	6 (S/N,2DGauss)
14	10 Oct	R	Infrared Arrays, Sky, and Corrections	How. Ch 1,2, Press 14.1-14.3, 14.8, Pan-Starrs	
15	15 Oct	T	Combining Frames	Press 15.6, 15.8	7 (setup, dark)
16	17 Oct	R	Flat Fields	How. Ch 3-4.5	
17	22 Oct	T	Coding an Analysis		8 (sky)
18	24 Oct	R	Convolution, Point-Spread Func.	How. Ch 4.6-5	
19	29 Oct	T	Project, PSF, Centering	How. Ch 6	9 (flat field)
20	31 Oct	R	Aperture Photometry	How. Ap C	
21	5 Nov	T	Bad Pixels		10 (centering)
Spectroscopy					
22	7 Nov	R	Coding, Spectroscopy Introduction		
23	12 Nov	T	Spectroscopy	Horne paper	11 (photometry)
24	14 Nov	R	Gratings and Systematics		
25	19 Nov	T	Interpolation and Correlation		
26	21 Nov	R	Wavelength Calibration		
27	26 Nov	T	Spectroscopy Applications		(Project)
	28 Nov	R	Thanksgiving day, **no class**		
Project					
28	3 Dec	T	Bayesian Stats and Markov Chains		(Project)
	4 Dec	W	Project help session (time TBD)	(optional)	(Project)
	5 Dec	R	(in exam week)	(no meeting)	Project Due 1pm
	10 Dec	T	Project discussion 10-12:50	Exam period, required	

13. Disclaimer

This syllabus is a guideline, not a contract. The instructor may alter it at any time.

14. Departmental Policies

Missed Work Policy

It is Physics Department policy that making up missed work will only be permitted for University-sanctioned activities and bona fide medical or family reasons. Authentic justifying documentation must be provided in every case (in advance for University-sanctioned activities). At the discretion of the instructor, the make-up may take any reasonable and appropriate form including, but not limited to, the following: a replacement exam, replacing the missed work with the same score as a later exam, allowing a "dropped" exam, replacing the missed work with the homework or quiz average.

NOTE: Those unable to attend class in person on a particular day may, by arrangement with the instructor, attend via the internet. This is intended mainly to handle mild flu cases and should not be used when it is physically possible for the student to attend class.

Disabilities Policy

The University of Central Florida is committed to providing reasonable accommodations for all persons with disabilities. This syllabus is available in alternate formats upon request. Students with disabilities who need accommodations in this course must contact the professor at the beginning of the semester to discuss needed accommodations. No accommodations will be provided until the student has met with the professor to request accommodations. Students who need accommodations must be registered with Student Accessibility Services, Student Resource Center Room 132, phone (407) 823-2371, TTY/TDD only phone (407) 823-2116, before requesting accommodations from the professor.

Establishing Academic Activity For Financial Aid

All instructors/faculty are required to document students' academic activity at the beginning of each course. In order to document that you began this course, please be present in class, where attendance will be taken, and/or complete the first homework assignment, by the end of the first week of classes or as soon as possible after adding the course. Failure to do so may result in a delay in the disbursement of your financial aid.

15. Required UCF Policies and Statements

The following material is required to be included in all UCF syllabi. It is important information that all students should know and follow. It comes from:
http://www.fctl.ucf.edu/TeachingAndLearningResources/CourseDesign/Syllabus/statements.php

UCF Core Syllabus Statements

See section 8 of UCF Policy 4-403.1, "Required Elements of the Course Syllabus"

Academic Integrity

Students should familiarize themselves with UCF's Rules of Conduct at <http://osc.sdes.ucf.edu/process/roc>. According to Section 1, "Academic Misconduct," students are prohibited from engaging in

1. Unauthorized assistance: Using or attempting to use unauthorized materials, information or study aids in any academic exercise unless specifically authorized by the instructor of record. The unauthorized possession of examination or course-related material also constitutes cheating.
2. Communication to another through written, visual, electronic, or oral means: The presentation of material which has not been studied or learned, but rather was obtained through someone else's efforts and used as part of an examination, course assignment, or project.
3. Commercial Use of Academic Material: Selling of course material to another person, student, and/or uploading course material to a third-party vendor without authorization or without the express written permission of the university and the instructor. Course materials include but are not limited to class notes, Instructor's PowerPoints, course syllabi, tests, quizzes, labs, instruction sheets, homework, study guides, handouts, etc.
4. Falsifying or misrepresenting the student's own academic work.
5. Plagiarism: Using or appropriating another's work without any indication of the source, thereby attempting to convey the impression that such work is the student's own.
6. Multiple Submissions: Submitting the same academic work for credit more than once without the express written permission of the instructor.
7. Helping another violate academic behavior standards.

For more information about Academic Integrity, consult the International Center for Academic Integrity
<http://academicintegrity.org>.

For more information about plagiarism and misuse of sources, see "Defining and Avoiding Plagiarism: The WPA Statement on Best Practices" <http://wpacouncil.org/node/9>.

Responses to Academic Dishonesty, Plagiarism, or Cheating
Students should also familiarize themselves with the procedures for academic misconduct in UCF's student handbook, *The Golden Rule* <http://goldenrule.sdes.ucf.edu/docs/goldenrule.pdf>. UCF faculty members have a responsibility for students' education and the value of a UCF degree, and so seek to prevent unethical behavior and when necessary respond to academic misconduct. Penalties can include a failing grade in an assignment or in the course, suspension or expulsion from the university, and/or a "Z Designation" on a student's official transcript indicating academic dishonesty, where the final grade for this course will be preceded by the letter Z. For more information about the Z Designation, see <http://goldenrule.sdes.ucf.edu/zgrade>.

Course Accessibility Statement

The University of Central Florida is committed to providing access and inclusion for all persons with disabilities. Students with disabilities who need disability-related access in this course should contact

the professor as soon as possible. Students should also connect with Student Accessibility Services (SAS) <http://sas.sdes.ucf.edu/> (Ferrell Commons 185, sas@ucf.edu, phone 407-823-2371). Through Student Accessibility Services, a Course Accessibility Letter may be created and sent to professors, which informs faculty of potential access and accommodations that might be reasonable. Determining reasonable access and accommodations requires consideration of the course design, course learning objectives and the individual academic and course barriers experienced by the student.

Campus Safety Statement

Emergencies on campus are rare, but if one should arise during class, everyone needs to work together. Students should be aware of their surroundings and familiar with some basic safety and security concepts.

- In case of an emergency, dial 911 for assistance.
- Every UCF classroom contains an emergency procedure guide posted on a wall near the door. Students should make a note of the guide's physical location and review the online version at <http://emergency.ucf.edu/emergency_guide.html>.
- Students should know the evacuation routes from each of their classrooms and have a plan for finding safety in case of an emergency.
- If there is a medical emergency during class, students may need to access a first-aid kit or AED (Automated External Defibrillator). To learn where those are located, see <http://www.ehs.ucf.edu/AEDlocations-UCF> (click on link from menu on left).
- To stay informed about emergency situations, students can sign up to receive UCF text alerts by going to <https://my.ucf.edu> and logging in. Click on "Student Self Service" located on the left side of the screen in the toolbar, scroll down to the blue "Personal Information" heading on the Student Center screen, click on "UCF Alert", fill out the information, including e-mail address, cell phone number, and cell phone provider, click "Apply" to save the changes, and then click "OK."
- Students with special needs related to emergency situations should speak with their instructors outside of class.
- To learn about how to manage an active-shooter situation on campus or elsewhere, consider viewing this video (<https://youtu.be/NIKYajEx4pk>).

Campus Safety Statement for Students in Online-Only Courses
Though most emergency situations are primarily relevant to courses that meet in person, such incidents can also impact online students, either when they are on or near campus to participate in other courses or activities or when their course work is affected by off-campus emergencies. The following policies apply to courses in online modalities.

- To stay informed about emergency situations, students can sign up to receive UCF text alerts by going to <https://my.ucf.edu> and logging in. Click on "Student Self Service" located on the left side of the screen in the toolbar, scroll down to the blue "Personal Information" heading on the Student Center screen, click on "UCF Alert", fill out the information, including e-mail address, cell phone number, and cell phone provider, click "Apply" to save the changes, and then click "OK."
- Students with special needs related to emergency situations should speak with their

instructors outside of class.

Make-Up Assignments for Authorized University Events or Co-curricular Activities

Students who represent the university in an authorized event or activity (for example, student-athletes) and who are unable to meet a course deadline due to a conflict with that event must provide the instructor with documentation in advance to arrange a make-up. No penalty will be applied. For more information, see the UCF policy at <http://policies.ucf.edu/documents/4-401.1MakeupAssignmentsForAuthorizedUniversityEventsOrCocurricularActivities.pdf>

Religious Observances

Students must notify their instructor in advance if they intend to miss class for a religious observance. For more information, see the UCF policy at <http://regulations.ucf.edu/chapter5/documents/5.020ReligiousObservancesFINALOct17.pdf>.

Deployed Active Duty Military Students

Students who are deployed active duty military and/or National Guard personnel and require accommodation should contact their instructors as soon as possible after the semester begins and/or after they receive notification of deployment to make related arrangements.