Term Information

Effective Term	Autumn 2025
Previous Value	*Autumn 2022*

Course Change Information

What change is being proposed? (If more than one, what changes are being proposed?)

Change 1. Change from a 3-credit course to a 4-credit course with a laboratory component.

Change 2. Update prerequisites to include coursework in computer programming.

Change 3. Remove the GE designation from the course.

What is the rationale for the proposed change(s)?

Change 1. Provide astronomy majors and minors with an astronomy-focused laboratory experience. Currently, our majors are meeting their laboratory coursework requirements within physics (specifically through Physics 3700).

Change 2. To formally require the completion of computer programing coursework as part of our major. Currently, this requirement is being met through Physics 3700 which has a programming prerequisite. However, should students take Astronomy 3350 instead (which this application would allow), there is currently no programming requirement within the existing prerequisites.

Change 3. Astronomy 3350 is not attracting GE enrollments due to its prerequisites. We would therefore like to remove the GE designation to avoid any GE-related administration.

What are the programmatic implications of the proposed change(s)?

(e.g. program requirements to be added or removed, changes to be made in available resources, effect on other programs that use the course)?

No major programmatic implications are anticipated:

Change 1. Additional resources include the venue, TA and scheduling requirements needed to add a 2-hour lab with two sections to the course. In addition to resources, Astronomy majors will be able to take Astronomy 3350 instead of Physics 3700. Since Physics 3700 is typically full and waitlisted, this may help alleviate this bottleneck. We anticipate at most a 10% reduction in Physics 3700 enrollments (roughly 12 out of 120 enrollments).

Change 2. This change will require all students, majors and minors, taking Astronomy 3350 to have taken computer programming as a prerequisite. We don't anticipate a problem with this as all majors are currently required to have taken programming as a prerequisite for Physics 3700, and our records show that almost all minors enter Astronomy 3350 with previous programming experience.

Change 3. No implications are anticipated as students are currently not selecting this course as a GE.

Is approval of the requrest contingent upon the approval of other course or curricular program request? No

Is this a request to withdraw the course? No

General Information

Course Bulletin Listing/Subject Area	Astronomy
Fiscal Unit/Academic Org	Astronomy - D0614

College/Academic Group	Arts and Sciences
Level/Career	Undergraduate
Course Number/Catalog	3350
Course Title	Methods of Astronomical Observation and Data Analysis
Transcript Abbreviation	Obs & Data Anly
Course Description	Overview of observational methods and quantitative analysis in astronomy with applications to the large datasets produced by modern astronomy surveys. Students will apply commonly used methods to reproduce major astronomical results in a collaborative setting. The course prepares students for advanced undergraduate research in astronomy and introduces broadly-applicable data analysis tools.
Previous Value	*Astronomical observational techniques and quantitative analysis of astronomical data; practical experience with modern astronomical instrumentation and computer-based reduction, analysis, and interpretation of astronomical data.*
Semester Credit Hours/Units	Fixed: 4
Previous Value	*Fixed: 3*

Offering Information

Length Of Course	14 Week, 12 Week
Flexibly Scheduled Course	Never
Does any section of this course have a distance education component?	No
Grading Basis	Letter Grade
Repeatable	No
Course Components	Laboratory, Lecture
Previous Value	*Lecture*
Grade Roster Component	Lecture
Credit Available by Exam	No
Admission Condition Course	No
Off Campus	Never
Campus of Offering	Columbus, Lima, Mansfield, Marion, Newark, Wooster

Prerequisites and Exclusions

Prerequisites/Corequisites	Astron 2292; and Math 1152 or 1172 or higher; and CSE 1222, 1223, 1224, Astron 1221, Engr 1221, or 1281H; or permission of the instructor. Previous coursework or experience with statistical analysis and linear algebra are useful but not required.
Previous Value	*Astron 162, H162, 292, 1162, 1162H, or 2292 and Math 153 or 1152 and Physics 133 or 1251*
Exclusions	
Previous Value	Not open to students with credit for Astron 350.
Electronically Enforced	No

Cross-Listings

Cross-Listings

Subject/CIP Code

Subject/CIP Code	40.0202
Subsidy Level	Baccalaureate Course
Intended Rank	Sophomore, Junior, Senior

Requirement/Elective Designation

Required for this unit's degrees, majors, and/or minors

Previous Value

Required for this unit's degrees, majors, and/or minors
General Education course:
Data Analysis; Mathematical and Quantitative Reasoning (or Data Analysis)

Course Details

Course goals or learning objectives/outcomes

- Gain a functional knowledge of the methods of astronomical data acquisition and curation.
- Become proficient in the analysis of large data collections.
- Gain experience with sample selection and sample bias.
- Create models using data to inform us about astronomical quantities of interest, including least-squares and Bayesian parameter estimation.
- Be able to estimate random and systematic errors and their effect on data models.
- Master basic programming in Python in a cloud computing environment.
- Compose informative, well-referenced laboratory reports in the form of computational essays, mastering documentation and visualization skills widely used in astronomy and industry.
- Work effectively in groups to complete projects.

Previous Value

Content Topic List

- Light and energy: Plan an observing program
- Transiting exoplanets: Determine orbital period and planet radius
- Properties of star clusters: Determine the age of a cluster
- Measure the age of the Universe: Assess errors in the local value Hubble constant

Previous Value

- *Measurements and uncertainties*
- *Spherical astronomy: celestial coordinates and time*
- *Statistical treatment of experimental data*
- *Astronomical data analysis*

Sought Concurrence No

Previous Value

Attachments

- Astro3350L-Syllabus.pdf: New Syllabus
  (Syllabus. Owner: Westraadt,Lindsay)
- A3350_Syllabus.pdf: Old Syllabus
  (Syllabus. Owner: Westraadt,Lindsay)
- Astro3350L-Syllabus - Revised.pdf: Revised Syllabus
  (Syllabus. Owner: Westraadt,Lindsay)
- AstronomyCurriculumMap.xlsx: Curriculum Map
  (Other Supporting Documentation. Owner: Westraadt,Lindsay)

Comments

- Revised syllabus attached together with curriculum map if needed.

  Hi Bernadette, I don't have a copy of the original (2012) syllabus. However, I have attached the current (2024) syllabus for reference. I suspect that the original syllabus corresponded to the blue "previous values" highlighted above. Thanks, Lindsay *(by Westraadt,Lindsay on 11/12/2024 12:16 PM)*
- Please see Subcommittee feedback email sent 11/8/24. *(by Neff,Jennifer on 11/08/2024 09:02 AM)*
- Lindsay, could you please also upload the old syllabus so that the reviewing faculty can see the before and after? *(by Vankeerbergen,Bernadette Chantal on 10/07/2024 11:14 AM)*

Workflow Information

Status	User(s)	Date/Time	Step
Submitted	Westraadt,Lindsay	10/02/2024 11:55 AM	Submitted for Approval
Approved	Thompson,Todd Alan	10/07/2024 08:54 AM	Unit Approval
Revision Requested	Vankeerbergen,Bernadette Chantal	10/07/2024 11:14 AM	College Approval
Submitted	Westraadt,Lindsay	10/07/2024 11:52 AM	Submitted for Approval
Approved	Thompson,Todd Alan	10/10/2024 10:02 AM	Unit Approval
Approved	Vankeerbergen,Bernadette Chantal	10/20/2024 09:18 PM	College Approval
Revision Requested	Neff,Jennifer	11/08/2024 09:02 AM	ASCCAO Approval
Submitted	Westraadt,Lindsay	11/12/2024 12:18 PM	Submitted for Approval
Approved	Thompson,Todd Alan	11/12/2024 12:52 PM	Unit Approval
Approved	Vankeerbergen,Bernadette Chantal	11/12/2024 01:11 PM	College Approval
Pending Approval	Jenkins,Mary Ellen Bigler Hanlin,Deborah Kay Hilty,Michael Neff,Jennifer Vankeerbergen,Bernadette Chantal Steele,Rachel Lea	11/12/2024 01:11 PM	ASCCAO Approval

Astronomy 3350
Methods of Astronomical Observation and Data Analysis

Instructor

Name: Donald Terndrup (he/him)
Office: 4059 McPherson Lab (4th floor), mailbox in 4055 McPherson Lab
Phone: 614-292-4579
Office Hours: Fridays 12:30 – 2:00 p.m., or by appointment
Email: Terndrup.1@osu.edu
Preferred mode of communication: email

Course Information

Lecture: MWF 03:00 – 03:55 p.m.
Laboratory: Tuesdays or Thursdays 12:40 – 2:30 p.m.
Credit Hours: 4
Format of instruction: Three in-person lectures and one laboratory session, for 5 contact hours per week.
Web Page: Available through http://carmen.osu.edu
Classroom and lab location: TBD

Course description

Astronomy 3350 is an overview of observational methods and quantitative analysis in astronomy with applications to the large datasets produced by modern astronomy surveys. The course will cover methods in common use by researchers. Students will learn to apply these methods to reproduce several major astronomical results in collaborative research projects. The goal of the course is to better prepare students for advanced undergraduate research in astronomy and to introduce many of the tools of data analysis for students interested in other careers that use these methods.

Prerequisites

Astron 2292; and Math 1152 or 1172 or higher; and CSE 1222, 1223, 1224, Astron 1221, Engr 1221, or 1281H; or permission of the instructor. Previous coursework or experience with statistical analysis and linear algebra are useful but not required.

Expected Learning Outcomes

Successful students will be able to apply quantitative or logical reasoning and/or mathematical/statistical methods to understand and solve problems and will be able to communicate their results. In the context of astrophysics, students will:

- Gain a functional knowledge of the methods of astronomical data acquisition and curation.
- Become proficient in the analysis of large data collections.
- Gain experience with sample selection and sample bias.
- Create models using data to inform us about astronomical quantities of interest, including least-squares and Bayesian parameter estimation.
- Be able to estimate random and systematic errors and their effect on data models.
- Master basic programming in Python in a cloud computing environment.
- Compose informative, well-referenced laboratory reports in the form of computational essays, mastering documentation and visualization skills widely used in astronomy and industry.
- Work effectively in groups to complete projects.

More generally, the skills acquired in this course will have broad applications to data analysis in any subject. Students will:

- Use logical, mathematical and/or statistical concepts and methods to represent real-world situations.
- Use diverse logical, mathematical and/or statistical approaches, technologies and tools to communicate about data symbolically, visually, numerically and verbally.
- Draw appropriate inferences from data based on quantitative analysis and/or logical reasoning.
- Make and evaluate important assumptions in estimation, modeling, and logical argumentation and/or data analysis.
- Evaluate social and ethical implications in mathematical and quantitative reasoning.

Astronomy 3350 will satisfy these learning objectives through detailed case studies in astrophysics, exploring the key stages of data analysis (sampling, acquisition, cleaning, curation, documentation), deep grounding in widely used statistical methods, and readings/discussions on the ethics of information sharing in data analysis and workflows.

Required materials

All reading and study resources are available online, either through Carmen or freely available on the Web.

Required computing equipment

You will need laptop, PC, or large-format tablet (*not* a phone) that provides internet access with a modern web browser. Writing and programming will be done in the browser using cloud computing resources such as sciserver.org or the Ohio Supercomputer Center. You should have a device with a sufficiently large screen and a keyboard for easy editing of jupyter notebooks in the Python language. If you do not have a device that you can bring to class and laboratory, please inform the instructor as soon as possible at the start of the semester.

Grading Information

The course will have weekly laboratory assignments designed to reinforce material covered in class. Each of these assignments will have equal weight and the total will correspond to 40% of the course grade. These assignments can usually be completed in lab time, but if editing is required the reports may be submitted within 48 hours of the completion of each laboratory session.

There will be four group assignments in which teams of students will work together to apply the methods of the course to modern research questions in astronomy. These assignments can be done individually with permission of the instructor. Group work will mostly occur outside of class, except for orientations to the projects during class time. These four group assignments will together compose of 60% of the course grade. Grades on these group assignments will be based on the evaluation of the team's written report (33%), application of designated computational or statistical methods (33%), and mastery of astronomical concepts (33%).

We will have no midterms nor a final exam.

Class attendance and workload

Students are expected to attend all lectures (three per week) and laboratory sessions (one per week). There will be modest flexibility in assignment deadlines for those needing accommodations for religious reasons (below) or to attend important personal or professional events, with advance notice to the instructor.

The total expected workload is 12 hours per week, divided according to:

- Three hours attending lecture,
- Two hours attending laboratory,
- Up to six hours outside class for reading and study of the materials presented in lecture and working on computational essays, and
- One hour per week outside lab time preparing for labs and editing reports.

The laboratory reports will consist of written descriptions of methods and conclusions, which generally amount to about 1-2 pages of text. Interspersed with the written material are blocks of Python code, tabular or graphic output, and other computational techniques. Time will be allocated during lab to compose first drafts of these reports, and in most cases the laboratory exercises will be in the form of partially completed notebooks which will guide students through the lab activities.

The four team computational essays will generally require 4-5 pages of written material plus accompanying codes, graphics, and tables.

Grading Scale

93–100: A
90–92.9: A-
87–89.9: B+
83–86.9: B
80–82.9: B-
77–79.9: C+
73–76.9: C
70–72.9: C-
67–69.9: D+
60–66.9: D
Below 60: E

Weekly Topical Course Outline

The course will begin with an overview of common statistical methods used in data analysis, as well as data access and visualization, and then introduce different data analysis methods in an astronomy context. The schedule below is an approximate outline of the topics and when they are likely to be covered.

Many of the lab exercises will be in the form of partially completed computational essays. These should be uploaded to SciServer and thoroughly studied in advance of each lab session.

Instructions for the team computational essays will be issued during the second week of each module. They will be due, via file upload to Carmen, on the Friday one week after the completion of each module. For example, the first essay will be issued in week 2 and due at the end of week 5. The last computational essay will be due the Friday of finals week (there will be no final exam).

Week	Astrophysical / statistical concepts	Programming skills with lab activities
Module 1: Light and energy **Group assignment: plan an observing program**		
1	Introduction to Astronomy 3350 Astronomy, statistics, and computing Individual and team work / shared workspaces Ethical considerations for sharing data and workflows	Getting started with SciServer Data types and basic math
2	Specific intensity / flux density Photons and detectors Unit analysis	Formatted printing The Markdown language Basics of LaTeX
3	Imaging and spectroscopy Exposure time estimates Signal to noise	Lists and simple list comprehensions / for loops Introduction to functions
4	The magnitude system Coordinate and time systems Observation planning	Constructing computational essays

Module 2: Transiting exoplanets **Group assignment: Determine orbital period and planet radius**		
5	Astronomical time systems / reference frames Orbits and scaling relations for planet detection	Advanced list comprehension methods: slicing, index lists, values selection, conditional tests Conditional tests Function keyword arguments
6	Descriptive statistics / probability distributions Errors and error assessment Data cleaning	Initial exploration of transiting planet data Designing analysis methods
7	Analysis of periodic signals	The Lomb-Scargle periodogram
Module 3: Properties of star clusters **Group assignment: determine the age of a cluster**		
8	Distances, radial velocities, proper motions	Introduction to Pandas
9	Stellar evolution and isochrones	Data selection Data views and copies
10	Interstellar extinction and isochrone fitting	Functions and computations Advanced plotting techniques
Module 4: Measure the age of the Universe **Group assignment: Assess errors in the local value Hubble constant**		
11	What the expansion of the Universe looks like Standard candles / galaxy distances	Apply the Cepheid P-L relation
12	Theory of linear least-squares modeling Homoscedastic and heteroscedastic errors	Estimate the local Hubble constant The idea of an error model
13	Conditional probabilities and Bayes' Theorem The How and the Why of Monte Carlo Markov Chain modeling Prior and posterior probability distributions	Concept building exercises in MCMC
14	Large cosmological surveys	Construct an MCMC model for the local expansion rate

Academic Misconduct

It is the responsibility of the Committee on Academic Misconduct to investigate or establish procedures for the investigation of all reported cases of student academic misconduct. The term "academic misconduct" includes all forms of student academic misconduct wherever committed; illustrated by, but not limited to, cases of plagiarism and dishonest practices in connection with examinations. Instructors shall report all instances of alleged academic misconduct to the committee (Faculty Rule 3335-5-48.7 (B)). For additional information, see the Code of Student Conduct.

Disability Services

The university strives to maintain a healthy and accessible environment to support student learning in and out of the classroom. If you anticipate or experience academic barriers based on your disability (including mental health, chronic, or temporary medical conditions), please let me know immediately so that we can privately discuss options. To establish reasonable accommodations, I request that you register with Student Life Disability Services. After registration, make arrangements with me as soon as possible to discuss your accommodations so that they may be implemented in a timely fashion.

If you are ill and need to miss class, including if you are staying home and away from others while experiencing symptoms of a viral infection or fever, please let me know immediately. In cases where illness interacts with an underlying medical condition, please consult with Student Life Disability Services to request reasonable accommodations. You can connect with them at slds@osu.edu; 614-292-3307; or slds.osu.edu.

Religious Accommodations

Ohio State has had a longstanding practice of making reasonable academic accommodations for students' religious beliefs and practices in accordance with applicable law. In 2023, Ohio State updated its practice to align with new state legislation. Under this new provision, students must be in early communication with their instructors regarding any known accommodation requests for religious beliefs and practices, providing notice of specific dates for which they request alternative accommodations within 14 days after the first instructional day of the course. Instructors in turn shall not question the sincerity of a student's religious or spiritual belief system in reviewing such requests and shall keep requests for accommodations confidential.

With sufficient notice, instructors will provide students with reasonable alternative accommodations with regard to examinations and other academic requirements with respect to students' sincerely held religious beliefs and practices by allowing up to three absences each semester for the student to attend or participate in religious activities. Examples of religious accommodations can include, but are not limited to, rescheduling an exam, altering the time of a student's presentation, allowing make-up assignments to substitute for missed class work, or flexibility in due dates or research responsibilities. If concerns arise about a requested accommodation, instructors are to consult their tenure initiating unit head for assistance.

A student's request for time off shall be provided if the student's sincerely held religious belief or practice severely affects the student's ability to take an exam or meet an academic requirement and the student has notified their instructor, in writing during the first 14 days after the course begins, of the date of each absence. Although students are required to provide notice within the first 14 days after a course begins, instructors are strongly encouraged to work with the student to provide a reasonable accommodation if a request is made outside the notice period. A student may not be penalized for an absence approved under this policy.

If students have questions or disputes related to academic accommodations, they should contact their course instructor, and then their department or college office. For questions or to report discrimination or harassment based on religion, individuals should contact the Office of Institutional Equity. (Policy: Religious Holidays, Holy Days and Observances).

Mental health

As a student you may experience a range of issues that can cause barriers to learning, such as strained relationships, increased anxiety, alcohol/drug problems, feeling down, difficulty concentrating and/or lack of motivation. These mental health concerns or stressful events may lead to diminished academic performance or reduce a student's ability to participate in daily activities. The Ohio State University offers services to assist you with addressing these and other concerns you may be experiencing. If you or someone you know are suffering from any of the aforementioned conditions, you can learn more about the broad range of confidential mental health services available on campus via the Office of Student Life's Counseling and Consultation Service (CCS) by visiting ccs.osu.edu or calling 614-292-5766. CCS is located on the 4th Floor of the Younkin Success Center and 10th Floor of Lincoln Tower. You can reach an on-call counselor when CCS is closed at 614-292-5766 and 24 hour emergency help is also available 24/7 **by dialing 988 to reach the Suicide and Crisis Lifeline**.

Sexual misconduct and relationship violence

Title IX makes it clear that violence and harassment based on sex and gender are Civil Rights offenses subject to the same kinds of accountability and the same kinds of support applied to offenses against other protected categories (e.g., race). If you or someone you know has been sexually harassed or assaulted, you may find the appropriate resources at http://titleix.osu.edu or by contacting the Ohio State Title IX Coordinator at titleix@osu.edu.

Diversity

The Ohio State University affirms the importance and value of diversity of people and ideas. We believe in creating equitable research opportunities for all students and to providing programs and curricula that allow our students to understand critical societal challenges from diverse perspectives and aspire to use research to promote sustainable solutions for all. We are committed to maintaining an inclusive community that recognizes and values the inherent worth and dignity of every person; fosters sensitivity, understanding, and mutual respect among all members; and encourages each individual to strive to reach their own potential. The Ohio State University does not discriminate on the basis of age, ancestry, color, disability, gender identity or expression, genetic information, HIV/AIDS status, military status, national origin, race, religion, sex, gender, sexual orientation, pregnancy, protected veteran status, or any other bases under the law, in its activities, academic programs, admission, and employment. (To learn more about diversity, equity, and inclusion and for opportunities to get involved, please visit: https://odi.osu.edu/ or https://cbsc.osu.edu).

Chapter 0

Introduction to Astronomy 3350

0.0. Overview

Astronomy 3350 is a fast and broad survey of observational astronomy, emphasizing computation and data analysis. We will dive into several case studies, and along the way we will cover several fundamental ideas in statistics that are needed in astrophysics or any other data-driven discipline. We will pay special attention to the measurement process and associated errors, and learn how data get into astronomical catalogs. A key part of the course is creating informative representations of data and how these can be useful guides to the underlying physics of any situation. We'll take a deep dive into programming with the Python language and learn how to write effective analysis reports.

These notes have a narrow text width to make reading easier on small-screen electronic devices. Definitions, reminders, remarks, and other important ideas will be in margin notes. You will be directed to margin notes with a ⇒ symbol in the text. Starting with chapter 0 is a joke about the way python numbers items in a list.

0.1. Goals for today

(See side note ⇒).

- Present my teaching approach and the themes we'll cover.
- Outline requirements and expectations for your participation.

- Explain the grading scheme I will employ.
- Sketch how and when we will engage in cooperative activities.

0.2. Prerequisites

This is a course designed for any student who is interested in a technical introduction to astrophysical data analysis. Your group this semester mostly includes majors and minors in Astronomy & Astrophysics, Physics, Earth Sciences, and Data Sciences.

Prerequisites: Astronomy 2291 or 2292, Physics 1251, plus second-semester calculus (1152 or equivalent). No prior programming experience is needed.

Note: While Astronomy 1162 is technically allowed as a prerequisite, Astronomy 2292 will be assumed for most students. The Math and Physics prerequisites will assume a mastery of (not just familiarity with) calculus and classical physics.⇒

Important: Notify the instructor immediately if you have not taken Astronomy 2292 or you lack the calculus preparation. We will work out a plan so you can still get the most out of this course.

It will be helpful if you have studied linear algebra and are proficient with complex numbers, but we'll be sure to cover these topics with plenty of background information if you need a refresher.

0.3. What this course is about

The course has three main goals:

- How we learn about the Universe's history and the properties of planets, stars, and galaxies.
- How astronomical observations are made, what we measure, and what we can learn from those measurements.
- How to create physically-based data models that employ common statistical tools.

Our study of astronomy will center on the ideas of measurements, error, and inference. This is the true core of this course. I hope that the statistical methodology sticks with you the longest, and serves you well whatever career you pursue. Competence in data analysis is increasingly a *must have* for jobs in the academic or commercial fields. Most enlightened employers heed the advice of Lord Martin Rees, Astronomer Royal of the United Kingdom. When asked, “Is there a particular field of study you would recommend?”, Rees replied,[1]

> *Do any subject in biology or physical sciences, but also become adept in computation I would say.*

0.4. Becoming adept in computation

So how do we achieve what Martin Rees advocates? In this course, we'll get there by carefully stepping through the basics of the Python programming language and by using various numerical and statistical packages that are easily linked to Python codes.

If you haven't yet used Python, have no worries: we will assume no knowledge of the language. It will, of course, be helpful if you have already done some work in Matlab, C++, Java, or any other programming language, but even if you have never coded before you will get by just fine in this course.

If you already know a lot of Python, or if you have previously taken Astronomy 1221, then I want you to back up a long ways and pretend – as much as possible – that you are starting over. Python is a really good language for learning the principles of coding, especially *object-oriented programming*, but is popular mainly because there are dozens of easily-available code libraries which enable you to do powerful stuff with only a little effort. Many astronomers use Python all the time, mainly through these libraries, but knowing how to call numerical and statistical tools within Python is definitely not the same as mastering the language and knowing how to take advantage of its features.⇒ Increasingly, commercial and industrial data applications are written in real Python (not astronomer Python), and employers want to hire people who actually know what they are doing when they program. So we are going to spend time focusing on how Python works,

> A lot of astronomical codes written in Python are really terrible from a computer-science point of view.

[1]Blue text indicates an active hyperlink in the notes, pointing you to resources for additional reading. I will also repeat the link in a footnote with the link URL explicitly spelled out. If your PDF reader does not support hyperlinks, you may copy the URL into your browser. Readings in footnotes will be listed as required or optional. The Rees link is at `https://youtu.be/U9DYtGncrI8` (optional reading).

concentrating on fundamentals of the language, to learn how to use it as a way of solving data problems. Our treatment of Python will be much more sophisticated than in Astronomy 1221.

Important: this course is not a programming class, nor is it mainly about statistics. It is principally a course in *how to think about data problems and communicate results* using interesting bits of astrophysics and a particular technique for computation (Python). The main idea is not to program computers, but to program your brain about the *idea* of data analysis. In this course, computation is a tool for learning about the Universe, not a goal in itself. True, the best users of tools are those who know how they really work. More importantly, the best data analysts are those who know how to ask questions and have the tool-using (and tool-*making*) skills to answer them.

Some of my resources in designing this course come from specialists in Physics Education Research who use computation as a method for teaching physical intuition and statistical reasoning. Consider this idea from Stephen Wolfram:[2]

> *Computational thinking . . . is about formulating things with enough clarity, and in a systematic enough way, that one can tell a computer how to do them.*

0.5. Logistics

Reading: A lot of the instruction in this course will be done asynchronously. Reading assignments will be posted on Carmen, and you are expected to do the readings by the dates specified in the assignment. That way you will be prepared for the in-person class sessions.

Class sessions: Everyone is expected to appear in person during all our regular class times. ⇒

Read this in an encouraging tone: Showing up is half the battle. You will miss out on important ideas and chances for interactive learning if you skip class. Emergencies and important professional or personal obligations can be accommodated. Missing sessions was one of the biggest sources of difficulty for some students in previous incarnations of this class. The other was waiting too long to get going on assignments.

Class times are MWF from 15:00 – 15:55. (All times in this syllabus are for the eastern time zone of the United States.) We will meet in room 40 Jennings Hall.[3]

[2] https://www.wired.com/2016/09/how-to-teach-computational-thinking/ (optional reading).

[3] https://www.osu.edu/map/building/014

Open collaboration time: Our classroom will be open to us on Fridays from 13:50 – 15:00. There will always be at least one member of the teaching staff present. Come by to work on your assignments, get help and advice on your coursework, study with your classmates, or relax a little! The time will be completely unstructured. Attendance is optional but is encouraged. We will begin on the second week of classes, namely on Friday, September 1.

Instructor office hours: I will hold office hours each week in room 4030 McPherson Laboratory.[4] These will be from 13:00 – 14:30 on Thursdays, starting on August 31. Office hours can be whatever you want them to be. The highest priority, naturally, will be to discuss the assignments and to help one another learn the material, but you are welcome to stop by just to chat or to hang out and listen to what others have to say.

During regular office hours, you may stop by without any advance notice, but if you have a chance to email me before you join in I would appreciate it. That way I'll know what you want and get any necessary items ready. You may also write for a special appointment if you need to see me outside these hours (these special appointments can be over Zoom). I want every one of you to stop by office hours at least once during the semester, just to say hello and get acquainted. Office hours are *not* private – several students can attend at once at once – so if you want a meeting to discuss anything in confidence, just let me know.

Contacting me: Email is best, to **terndrup.1@osu.edu**. I usually do not respond to email between the hours of 20:00 and 08:00. My office phone number is 614-292-4579. Since I will not always be in my office to pick up the phone and I generally do not answer if I do not recognize the number, please leave a voice message. I'll get an email right away with your voice mail attached, so I can respond soon from anywhere.

Teaching assistants: Our student staff will be announced early in the semester.

0.6. Organization of the course

The course is divided into four modules. The first three are case studies of important astronomical issues, while the 4th module is to prepare you for

[4] `https://www.osu.edu/map/building/053`

an end-of-semester research project.

I. Scaling relations and computational essays (August 23 – September 8)

Effective communication of research is far more than creating graphs and tables. Here we will learn the valuable technique of writing a computational essay, and become proficient at making simple notebooks.

1. The electromagnetic spectrum, wavelength/frequency/energy, intensity and flux density
2. Physical quantities and unit systems
3. Magnitudes and colors
4. Scaling relationships
5. Order of magnitude calculations

Skills:

- Creating, editing, and presenting work in `jupyter` notebooks
- Making effective use of the markdown language
- Writing simple equations in LaTeX

II. Photometry and the detection of exoplanets (September 11 – 29)

Astronomical catalogs list the brightness of objects in the sky in various different ways. How do we measure how bright an object is? How can we detect exoplanets via transits, and learn about their physical sizes? How well do we know the accuracy of our measurements?

1. Poisson statistics, means and variance
2. Angular resolution and astronomical seeing
3. Noise in measured and derived quantities
4. Exposure time calculations
5. Data types, lists, and list comprehensions

6. Control structures
7. Functions
8. File input/output

Skills:

- Effective plotting
- Interpreting graphical data in terms of underlying physics
- Writing well-documented Python lab notebooks that include computations and data plots

III. Stars and their planets (October 2 – 20)

Stellar theory requires certain physical values to be determined by observational data. How well do we know the masses and orbital periods of exoplanets from observations of stellar radial velocities? How do these values depend on our knowledge of the properties of the host stars?

1. Stellar motions
2. Exoplanet orbits
3. Catalog mining and data curation
4. Values-based data slicing
5. Theory and observation of periodic signals

Skills:

- Effective analysis and manipulation of large databases
- Incorporating derived quantities in data analysis
- Advanced graphical techniques

IV. How fast is the universe expanding? (October 23– November 8)

The rate of expansion of the Universe informs us about how old the Universe is. One key value in determining the age is the Hubble constant. At present there is a significant tension between the value of the Hubble constant derived from relatively nearby galaxies and that found from analysis of the cosmic microwave background. How well do we know the local value?

1. Classical linear least-squares
2. Introduction to probabilistic modeling
3. Bayesian linear regression, priors and posteriors
4. Homoscedastic and heteroscedastic errors
5. MCMC probability sampling, and why it works
6. Random and systematic errors and their effects on model building

Skills:

- Error assessment
- Model specification and evaluation

V. Research projects (November 13 – December 8)

There are a number of open-ended questions that are excellent ways to give you a feel for how research works. Here you will use your analytic skills to investigate a project of your own choosing. You will present your results at a mini-conference on Friday, December 8.

1. How to give a good short talk
2. How to create an effective conference poster

This is a topical list, and won't line up one to one with our class meetings.

Once introduced, each topic or skill you learn will be employed over and over again throughout the course. This class is definitely cumulative, meaning that each area builds upon the previous material. As a result, it will be difficult if you fall behind; it won't, however, be impossible to recover since we'll constantly be repeating ideas and looking at them from new angles.

I want to make one key point as early as possible this semester. During this course, we'll cover the usual statistical tools that you need to learn in order to do research in (astro)physics, chemistry, materials research, etc. It's pretty important to note that astronomy differs from many other sciences in that it is *not* a laboratory science. Mother Nature conducts the experiments for us without enabling us to control for the effects we want to uncover. We do, however, have a lot of control over what we observe and how we do it. We have to be very careful to design observational campaigns that have a good chance of telling us what we want, and we have to take the data in a way that allows proper testing of hypotheses, but we usually don't get to set up things to isolate particular phenomena as can be done in many other fields of research.

0.7. Requirements

You are required to:

1. Complete frequent short assignments given in these class notes or on Carmen. Often these will help you get ready for the larger problem sets.

2. Complete all assigned computational essays. These are to be submitted individually, though you are always free to study together and discuss the problems before you write out your own solutions. When discussing the assignment with others in the class, please be careful to discuss ideas but not copy each other's work.

3. Participate in discussions and in small-group problem-solving exercises conducted during class sessions.

4. Complete an end-of-semester research project, write an informative report on your research, and present your principal results either in a short talk or with a digital poster. We will have a mini-conference with research talks on Friday, December 8, from 12:00 - 13:45. Attendance is required. (This was the scheduled time for the final exam in this course.)

There will be no midterm exams nor will there be a final exam.

Class participation: This will mainly occur in two forms:

- Small-group discussions: Our classroom is furnished with tables where small groups can gather. Most days during the semester I will pose a problem and ask you to spend a little time thinking about it and talking it over with the people at your table. Then I'll direct a discussion of the problem, in which I expect active interaction. It is perfectly acceptable to ask questions of me or the other teaching staff, or request a more detailed explanation, or simply to say "I don't know." Science is a collaborative activity, and in this course you are not in competition with anybody else. I want these discussions to help everybody along. Statistical analysis is above all *a way of thinking*, and it takes a lot of talking and questioning to develop it.
- Worked problems: Frequently I will spend time in lecture working through problems that are like the ones on the homework assignments, meaning that they require the same skills as you will need to solve assigned problems. During this, I will ask for suggestions about how to proceed, with questions like these: What is the best way to solve this problem? What sort of answer are we expecting? What might be the best way to present the results? What is a good way to write code to get the desired result?

Optional and required reading: Many lectures will have some links to web pages or documents that you can download. I'll note whether these are optional or required reading.

Textbook: There is no required text for this course. See the information about required computer resources below.

0.8. Types of sessions

This course is designed in a format called Studio Teaching.[5] This method focuses on problem/project work and experimentation in a hands-on studio environment. It is traditionally found in the arts and architecture, but

[5] See `https://serc.carleton.edu/introgeo/studio/what.html` (required reading).

is increasingly used in other fields such as Instructional Technology and the sciences. In studio learning, the teaching staff is available to clarify issues and help solve problems, but most of the work comes from student-led inquiry and small-team exploration.

To get the most out of the course, you will need to read the background and preparatory material on your own *ahead of class time*. That way we can focus on small-group work where you can discuss ideas and techniques and to help one another along.

Naturally any masking and social distancing we must practice will affect how cooperative learning works.

We'll have three different types of sessions:

1. **Traditional lectures**: These will generally happen only during the first session or two of each course module. I will present a thorough discussion of the goals and methods for each section, and include a number of example problems. Questions and discussion are encouraged, but sometimes we might need to defer a long answer to the next lecture.

2. **Exploration**: Most days we will take at least half the class time to work in groups to solve example problems. I will usually give a quick overview (say 10–15 minutes) to start us off, and then I will give you a problem or two to work on. If you are inexperienced with this type of teamwork during class time, I hope you will find it helpful.

3. **Open discussion**: Sometimes we will spend the entire class time in discussion of the homework assignments and other problems. This will be your chance to ask questions of one another and of the instructor, and to discuss the approach you are taking to the various problems. The goal here is to imitate the cooperative give-and-take that all scientists use when they are doing research.

In order to free up time for discussion, I will avoid long mathematical derivations in class. You should realize, however, that the mathematics is important, and that effective use of statistical tools requires a deep understanding of their mathematical basis. Quite often I will present a full derivation in these notes (or give you a link to on-line material), with commentary to help you understand what each statistical tool is good for and what assumptions went into it. With easy access to downloadable computer codes and packages, it's common to grab an inappropriate analysis tool and draw the wrong conclusions from it. Therefore understanding the basis of each method will be important.

0.9. Grading

I will employ a method called Competency-Based Grading.[6] This method establishes clear goals for each assignment, in which the goals are explicitly tied to proficiencies or competencies that I want you to learn. Both for in-class activities and for homework assignments, I will not only tell you what problem I want you to solve, but *how* I want you to solve it. For example, a homework or in-class problem might be stated as, "Using a list comprehension, compute the orbital period of a planet from size of the orbit using the data in Table 2." Competency-based grading is perfect for this course or for any other class that emphasizes methods and techniques.

The grading will work like this: You will get binary credit (0 or 1 point) if you get the right answer *and* you use the stated technique. You will not receive credit, even if you have the right answer, if you use a technique other than that which is requested.⇒ There is no partial credit. If there are 10 required questions on an assignment, then there will be 10 points possible. The competencies are also designed to build confidence. Usually I will set up the competencies so you first demonstrate that you get a stated result for a test problem. That way you will know that you have the right answer for longer computations.

It will do you no good if you use fancy Python techniques if they have not yet been called for in the course.

In addition, there will often be optional problems which can be used for extra credit. In these, you will be permitted to use any analysis technique you wish.

We'll use the standard OSU grading scale, computed by the percentage of competencies that you demonstrate: $\geq 93\%$ (A), 90% (A–), 87% (B+), 83% (B), 80% (B–), 77% (C+), 73% (C), 70% (C–), 67% (D+), 60% (D), and ($< 50\%$) E.

At the end of the semester, 60% of your final grade will come from the problem sets, 20% from the completion of various short reflection or competency-

[6] See https://www.competencyworks.org/analysis/what-is-the-difference-between-standards-based-grading/ (optional reading).

building exercises, and 20% from the final research project.

Instead of due dates, we will have *submission windows* and *target dates* for each assignment. The submission window opens whenever an assignment is published. Carmen will show that an assignment is due on some date, but this is actually a target date. I would like you to do your best to complete the work by the target date, but you can always have a little extra time to complete things. A submission window closes at a time shown as "Available until," which will typically be 48 hours after the target date. The target dates permit us to start grading the bulk of the assignments and to give you feedback as soon as possible after the target date.

Special extensions: Life happens. It is far better to ask for a delay than to rush your work and do a bad job of it. You may obtain a 48-hour delay for the major assignments (the computational essays) by informing me that you need an extension. Specifically, you can extend the close of a submission window by 48 hours upon request. Your delay will be automatically granted *with no questions asked and no explanation required.* You may take one such delay during the semester. ⇒

Pay special attention to this.

0.10. Expectations

I have high expectations for professionalism in this course. The following items are minimum standards for behavior in this class:

1. Join the class sessions in person at all scheduled times, and please be punctual.
2. Download the lecture notes and go over them at least once before each lecture. Most of these will have a short question or two that you are to answer before the next lecture or by some stated date. Answers for these may be submitted through Carmen.
3. Review any assignment as soon as possible after it is available to you. Begin work when practical, leaving time for you to overcome any unexpected difficulties or to review important concepts. Do not wait until the last minute to start your work.
4. Treat everyone with respect and with politeness. In addition to issues of diversity (see below), there is another that is important: your col-

leagues may have greater or less experience with astrophysics, statistics, or programming than you do. I want everybody to help one another so we all grow and advance. You are not in competition with your fellow students, since everybody can get a top grade in the course. As we move through the semester, the problems we'll face will get more and more complex and will require a lot of collaboration and cooperation.

5. Questions and discussion are welcomed and encouraged. There are no silly questions. Some of the concepts we will discuss will require a deep understanding of various subtleties, and I would rather slow down and make sure you grasp the concepts than plow ahead and leave you behind. If you have a question, then maybe a dozen others in the class probably do too. I expect that all discussions will be conducted with the highest level of mutual respect.

6. Written material should be clean and explanatory, without sentence fragments, poor punctuation, sloppy paragraphing, etc. I am not interested in getting a draft of a homework assignment, but the final product. Your name goes on it, after all, and you should be proud of your work. I will *always* be willing to look at a draft homework solution, as long as you give me enough time to comment and you leave sufficient time to incorporate those comments.

Much of our class time will be devoted to concept development and to the discussion of statistical methods, the problem sets, and the longer analysis projects. As a result, you will have to do a considerable amount of studying on your own in addition to any time you spend on your assignments. In designing this class, I assume that your independent study time will be about 3 hours a week, with another 4–5 hours a week (averaged over the semester) on your assignments and projects.

0.11. Presenting your work

You will spend a lot of time solving problems in this course, either for homework assignments or to prepare for class discussions or presentations. This section outlines my expectations for written work in this course.

Here are some rules to follow:

1. Describe what you are doing in clear written English, interspersed with any equations, and define every symbol that you use even if you think the definition is obvious. I want you to do this even if you think that the equation you present is obviously the right one. Being in the habit of defining everything will really help you in the future.

2. Wherever possible, carry your calculations forward algebraically as far as possible. Put in numbers only near the end.

3. Label the axis of every graph you present, and include a caption explaining what the graph shows.

4. Be careful to show units everywhere, in particular to evaluate units with the numbers, and to double check that expected unit comes out at the end (e.g., if you are calculating a time, all the units had better multiply and divide so the final answer is in *seconds*).

My notes and class presentations will give you many examples of how you should compose your work.

0.12. Computing requirements

At minimum, you will need access to a computer which can:

- Read PDF documents.
- Access the web using a modern browser.
- Download and upload files.

It will not be necessary to download any software to your own computer. All (or almost all) of your computing will be done on an external hosting site, on which you can create and run Python notebooks, store data, and share your work with me and with others.

Computer use in class: If you have a laptop computer or a good tablet (not your phone), I encourage you to bring it to class *as long as you use it for class business only.* We will spend a lot of time on computing techniques and solving example computational problems, and it will be most efficient if you can engage in these exercises during class time.

0.13. Other important matters

Academic integrity: Academic integrity is essential to maintaining an environment that fosters excellence in teaching, research, and other educational and scholarly activities. Thus, The Ohio State University and the Committee on Academic Misconduct (COAM) expect that all students have read and understand the universitys Code of Student Conduct (studentconduct.osu.edu), and that all students will complete all academic and scholarly assignments with fairness and honesty. Students must recognize that failure to follow the rules and guidelines established in the university's Code of Student Conduct and this syllabus may constitute "Academic Misconduct."

The Ohio State Universitys Code of Student Conduct (Section 3335-23-04) defines academic misconduct as: Any activity that tends to compromise the academic integrity of the university or subvert the educational process. Examples of academic misconduct include (but are not limited to) plagiarism, collusion (unauthorized collaboration), copying the work of another student, and possession of unauthorized materials during an examination. Ignorance of the university's Code of Student Conduct is never considered an excuse for academic misconduct, so I recommend that you review the Code of Student Conduct and, specifically, the sections dealing with academic misconduct.

If I suspect that a student has committed academic misconduct in this course, I am obligated by university rules to report my suspicions to the Committee on Academic Misconduct. If COAM determines that you have violated the university's Code of Student Conduct (i.e., committed academic misconduct), the sanctions for the misconduct could include a failing grade in this course and suspension or dismissal from the university.

If you have any questions about the above policy or what constitutes academic misconduct in this course, please contact me.

Other sources of information on academic misconduct (integrity) to which you can refer include:

- Committee on Academic Misconduct[7]
- Ten Suggestions for Preserving Academic Integrity[8]

[7] See `https://go.osu.edu/coam`
[8] See `https://go.osu.edu/ten-suggestions`

- Eight Cardinal Rules of Academic Integrity[9]

Copyright for Instructional Materials The materials used in connection with this course may be subject to copyright protection and are only for the use of students officially enrolled in the course for the educational purposes associated with the course. Copyright law must be considered before copying, retaining, or disseminating materials outside of the course.

Students with individual needs: The University strives to make all learning experiences as accessible as possible. If you anticipate or experience academic barriers based on your disability (including mental health, chronic or temporary medical conditions), please let me know immediately so that we can privately discuss options. To establish reasonable accommodations, I request that you register with Student Life Disability Services. After registration, make arrangements with me as soon as possible to discuss your accommodations so that they may be implemented in a timely fashion. SLDS contact information – email: slds@osu.edu; phone: 614–292–3307; web: slds.osu.edu; location: 098 Baker Hall, 113 W. 12th Avenue.

Statement on Title IX: All students and employees at Ohio State have the right to work and learn in an environment free from harassment and discrimination based on sex or gender, and the university can arrange interim measures, provide support resources, and explain investigation options, including referral to confidential resources.

If you or someone you know has been harassed or discriminated against based on your sex or gender, including sexual harassment, sexual assault, relationship violence, stalking, or sexual exploitation, you may find information about your rights and options on Ohio States Title IX website (titleix.osu.edu) or by contacting the Ohio State Title IX Coordinator at titleix@osu.edu. Title IX is part of the Office of Institutional Equity (OIE) at Ohio State, which responds to all bias-motivated incidents of harassment and discrimination, such as race, religion, national origin and disability. For more information, visit the OIE website (equity.osu.edu) or email equity@osu.edu.

Staying healthy: As a student you may experience a range of issues that can cause barriers to learning, such as strained relationships, increased anxiety, alcohol/drug problems, feeling down, difficulty concentrating and/or lack of motivation. These mental health concerns or stressful events may

[9] See `https://go.osu.edu/cardinal-rules`

lead to diminished academic performance or reduce your ability to participate in daily activities. The Ohio State University offers services to assist you with addressing these and other concerns you may be experiencing. If you or someone you know are suffering from any of the aforementioned conditions, you can learn more about the broad range of confidential mental health services available on campus via the Office of Student Life's Counseling and Consultation Service (CCS) by visiting ccs.osu.edu or calling 614–292–5766. CCS is located on the 4th Floor of the Younkin Success Center and 10th Floor of Lincoln Tower. You can reach an on call counselor when CCS is closed at 614–292–5766 and 24 hour emergency help is also available through the 24/7 National Suicide Prevention Hotline at 1–800–273–TALK or at suicidepreventionlifeline.org.

Diversity and respect for one another: The Ohio State University affirms the importance and value of diversity in the student body. Our programs and curricula reflect our multicultural society and global economy and seek to provide opportunities for students to learn more about persons who are different from them. We are committed to maintaining a community that recognizes and values the inherent worth and dignity of every person; fosters sensitivity, understanding, and mutual respect among each member of our community; and encourages each individual to strive to reach his or her own potential. Discrimination against any individual based upon protected status, which is defined as age, color, disability, gender identity or expression, national origin, race, religion, sex, sexual orientation, or veteran status, is prohibited. More generally, don't be a jerk: treat all people with the respect you wish for yourself.

Accessibility Accommodations for Students with Disabilities

Requesting Accommodations: The university strives to make all learning experiences as accessible as possible. If you anticipate or experience academic barriers based on your disability including mental health, chronic or temporary medical conditions, please let me know immediately so that we can privately discuss options. To establish reasonable accommodations, I may request that you register with Student Life Disability Services (SLDS). After registration, make arrangements with me as soon as possible to discuss your accommodations so that they may be implemented in a timely fashion.

Disability Services Contact Information

- Phone: 614-292-3307

- Website: slds.osu.edu
- Email: slds@osu.edu
- In person: Baker Hall 098, 113 W. 12th Avenue

Accessibility of Course Technology

This online course requires use of CarmenCanvas (Ohio State's learning management system) and other online communication and multimedia tools. If you need additional services to use these technologies, please request accommodations with your instructor.

- CarmenCanvas accessibility (go.osu.edu/canvas-accessibility)
- Streaming audio and video
- CarmenZoom accessibility (go.osu.edu/zoom-accessibility)
- Collaborative course tools

Required Courses (offered by the unit)	Astron 2895: Seminar
	Astron 2291: Intro Astrophys I
	Astron 2292: Intro Astrophys II
	Astron 3350: Methods of Observation
Required 5000-level course (pick one)	Astron 5205: Planetary Science
	Astron 5681: Stellar Evolution
	Astron 5682: Cosmology
Required Courses (offered outside the unit)	Math 2415: ODEs and PDEs
	Math 2568: Linear Algebra
	Physics 2300: Mechanics I
	Physics 2301: Mechanics II
	Physics 5400: Int. E&M I
	Physics 5500: Quan. Mech I
	Physics 5600: Stat Mech
Only one of these is required	Physics 5401: Int. E&M II
	Physics 5501: Int E&M II
Elective	Astron 5550: Adv. Astro Analysis
	Astron 3810: Order of Magnitude I (submitted for approval)
	Astron 4810: Order of Magnitude II (submitted for approval)

Credits	Acquire a basic mastery of fundamental physics and astrophysics, including motion and structure through classical mechanics, electromagnetism, and modern physics	Develop analytical and problem solving skills involving physics and mathematics
1		
3	Advanced	Advanced
3	Advanced	Advanced
3	Beginning	Advanced
3	Advanced	Advanced
3	Advanced	Advanced
3	Advanced	Advanced
3		Advanced
3		Advanced
4	Advanced	Advanced
4	Advanced	Advanced
4	Advanced	Advanced
4	Advanced	Advanced
4	Advanced	Advanced
4	Advanced	Advanced
4	Advanced	Advanced
3	Beginning	Advanced
1	Advanced	Advanced
1	Advanced	Advanced

Astronomy & Astrophysics Major Learning Goals

Acquire a basic mastery of experimental methods	Acquire a basic mastery of data analysis	Learn to effectively communicate professionally and colloquially (orally and in writing)
		Beginning
Advanced	Advanced	Advanced
Intermediate		
Beginning		
Beginning		
Beginning		
Beginning		
Advanced	Advanced	Advanced
		Intermediate
		Intermediate

Learn about and participate in research and outreach activities consistent with their interest, ability, and postgraduate plans
Beginning
Intermediate
Intermediate
Beginning
Beginning