NORTHERN ARIZONA UNIVERSITY

College of the Environment, Forestry, and Natural Sciences

# AST 391 – Astrophysics: Stars

Fall 2024

## Course Information

- Location: Adel Mathematics Rm 148
- Meeting time: T/Th 2:20-3:35 pm
- Total Units of Course Credit: 3
- Prerequisites: AST 280 and PHY 263 (PHY 265 preferred)

## Instructor Information

- Instructor: Prof. Jonathan Jackson
- Email: jonathan.jackson@nau.edu
- Office: Physical Sciences Rm 225A
- Student Hours: M/W 2-3:30 pm
- Grader: Hunter Brooks (hcb98@nau.edu)

## Course Description

This is an upper-level undergraduate course in stellar astrophysics covering stellar atmospheres and stellar interiors. These topics will contain an introduction to stellar spectra, line formation, and radiative transfer, which are useful in all areas of astrophysics. This is a lecture course that includes group activities and small quizzes, reading assignments, homeworks with small coding/plotting components, and exams.

## Student Learning Objectives

At the end of this course, students should be able to:
**SLO1.** Explain the key concepts of stellar properties, atmospheres, and interiors;
**SLO2.** Derive and/or apply fundamental equations that describe stellar phenomena;
**SLO3.** Write, or use, programs to explore and illustrate key diagrams, and interpret the output to demonstrate physical principles and phenomena;
**SLO4.** Explore and analyze real/theoretical stellar data and derive scientific results or conclusions;
**SLO5.** Create simple Concept Maps or diagrams to express or relate to complicated physical properties of stars, as a practice of effective science communication.

## 100% Career Ready

One of the primary goals of this course is to provide skills that are in-demand from STEM employees to help NAU CEFNS students pursue careers of confidence and lives or purpose. Below is a list of in-demand career-ready competencies (CRC) from the

National Association of Colleges and Employers (NACE) that students may be able to practice in this course:

**CRC1.** Career & Self-Development: Proactively develop oneself and one's career through continual personal and professional learning, awareness of one's strengths and weaknesses, navigation of career opportunities, and networking to build relationships within and without one's organization.
**CRC2.** Communication: Clearly and effectively exchange information, ideas, facts, and perspectives with persons inside and outside of an organization.
**CRC3.** Critical Thinking: Identify and respond to needs based upon an understanding of situational context and logical analysis of relevant information.
**CRC4.** Equity & Inclusion: Demonstrate the awareness, attitude, knowledge, and skills required to equitably engage and include people from different local and global cultures. Engage in anti-racist practices that actively challenge the systems, structures, and policies of racism.
**CRC5.** Leadership: Recognize and capitalize on personal and team strengths to achieve organizational goals.
**CRC6.** Professionalism: Knowing work environments differ greatly, understand and demonstrate effective work habits, and act in the interest of the larger community and workplace.
**CRC7.** Teamwork: Build and maintain collaborative relationships to work effectively toward common goals, while appreciating diverse viewpoints and shared responsibilities.
**CRC8.** Technology: Understand and leverage technologies ethically to enhance efficiencies, complete tasks, and accomplish goals.

## Textbook and Materials

- ***An Introduction to Modern Astrophysics,*** 2nd ed. by Carroll and Ostlie
- ***Foundations of Astrophysics,*** by Ryden and Peterson (Chapter 15, will be provided)
- **Calculator**
- **Laptop** or an accessible computer
- **Programming/graphing software of your choice** (Python, IDL, MATLAB, Mathematica, Microsoft Excel, etc.)

## Evaluation and Grading System

| Absences | Effect on grade |
|---|---|
| 0 – 3 | None |
| 4 – 6 | Lowered by 5% |
| 7 or more | Lowered by 10% |

| Assessment | Points |
|---|---|
| Homework | 175 |
| Activities | 140 |
| Reading Quizzes | 60 |
| Midterm Exam | 60 |
| Final Exam | 65 |
| **Total** | **500** |

| Grade | Points |
|---|---|
| A | 450 or more |
| B | 400 – 449 |
| C | 350 – 399 |
| D | 300 – 349 |
| F | 0 – 299 |

## Homework

- **Homework should be submitted in class on the day it is due**. If you need to miss class on the day a homework assignment is due, you may email your solutions to the instructor AND the grader prior to class starting. Any homework submitted by email should be in high-resolution pdf format. No homework points will be dropped.
- In order to receive full credit for computing/plotting problems, **you must turn in both your plots AND your code**. Any plots must have 1) *a title,* 2) *axes labeled with units,* and 3) *legends if needed.* Your code must be *commented* – at minimum, your comments should include your name and the date, and what units each variable is carrying.
- **Late assignments will be accepted only with prior permission**. You may ask for a 2-extension with no questions asked! For longer extensions, please communicate the reason for the extension in your request. Once the solutions are posted, you can no longer submit an assignment.
- **I encourage you to work with your classmates**! Science is a collaborative endeavor and this class will reflect that. However, your solutions must be written and submitted in your own words, *including any programming/plotting codes.* Homework that is copied or suspiciously similar to another student will receive a zero for *all students involved*.
- **You may correct and resubmit your work for half the missing points!** Corrections must be submitted within one week and should be completed on your own!

## Homework Outline

| Ch | | SLO | CRC | Question 1 | | Question 2 | | Question 3 | | Points |
|---|---|---|---|---|---|---|---|---|---|---|
| 3 | HW 1 | 1, 2 | 3 | Solar irradiance | 4 | Magnitude and flux | 6 | | | 10 |
| | HW 2 | 1, 2, 3 | 3, 8 | Blackbody curves* | 11 | Rayleigh-Jeans Law* | 12 | Wien's Displacement Law* | 5 | 28 |
| 5 | HW 3 | 1, 2 | 3 | Electronic transitions | 8 | Series limits | 6 | | | 14 |
| 7 | HW 4 | 1, 2, 4 | 3 | Mass, luminosity, and radius determination of Sirius A & B | 17 | | | | | 17 |
| | HW 5 | 1, 2, 4 | 3 | Mass determination of zeta the binary | 10 | | | | | 10 |
| | HW 6 | 1, 2, 3, 4 | 3, 8 | Eclipsing Binary Simulator | 28 | | | | | 28 |
| 8 | HW 7 | 1, 2, 3 | 3, 8 | Maxwell-Boltzmann distribution* | 13 | Boltzmann Equation* | 14 | | | 27 |
| | HW 8 | 1, 2, 3, 4 | 3, 8 | He I partial ionization zone in a pure He atmosphere* | 15 | Balmer absorption strongest in A-type stars at T = 9900 K* | 6 | Extra Credit: He II partial ionization zone in a pure He atmosphere* | (7) | 21 |
| 9 | HW 9 | 1, 2, 3, 4 | 3, 8 | Curve or growth and abundance of elements, Part II* | 20 | | | | | 20 |
| *Coding and/or plots required | | | | | | | | | | 175 |

## In-class Activities

- Each week, we will have an activity in class. Most will be group activities with some individual activities mixed in. These activities will be completed with in-class materials or on Canvas. No activity points will be dropped.
- If you will be absent, you must reach out to Professor Jackson ASAP to schedule a time to make up the activity.
- In-class activities will address SLO 1-5 and CRC 2, 3, 7, and 8.

## Reading Quizzes

- All reading quizzes will be administered and submitted on Canvas. Quizzes will be 20 minutes in length and will be open book/open notes. You are *strongly encouraged* to read carefully and thoroughly – the textbook may be difficult to parse at times, but if you are able to absorb everything in the readings, you will likely be very successful in this class. No reading quiz points will be dropped.

## Exams

- Both the Midterm and Final Exam will be administered and submitted on Canvas. You can enter your answers directly on Canvas, write them on paper and take high-resolutions pictures, or turn them into PDFs for submission.

- Exams will consist of both qualitative and quantitative questions. Makeup exams are not given except with official university excuses. If you need a makeup exam, please communicate with me as early as possible.
- Exams will be **open book/open notes** – your memorization skills will not be tested, but having well-organized notes will be key to succeeding on the exams. Search engines and AI tools will NOT be allowed and any plagiarism will result in zero points for the entire exam.
- The Midterm Exam (on chapters 3, 5, and 7) will be due on 10/24 and the Final Exam (on chapters 8, 9, and 15 in R&P) will be due on 12/12

## University Policies

- **ACADEMIC INTEGRITY:** NAU expects every student to firmly adhere to a strong ethical code of academic integrity in all their scholarly pursuits. The primary attributes of academic integrity are honesty, trustworthiness, fairness, and responsibility. As a student, you are expected to submit original work while giving proper credit to other people's ideas or contributions. Acting with academic integrity means completing your assignments independently while truthfully acknowledging all sources of information, or collaboration with others when appropriate. When you submit your work, you are implicitly declaring that the work is your own. Academic integrity is expected not only during formal coursework, but in all your relationships or interactions that are connected to the educational enterprise. All forms of academic deceit such as plagiarism, cheating, collusion, falsification or fabrication of results or records, permitting your work to be submitted by another, or inappropriately recycling your own work from one class to another, constitute academic misconduct that may result in serious disciplinary consequences. All students and faculty members are responsible for reporting suspected instances of academic misconduct. All students are encouraged to complete NAU's online academic integrity workshop available in the E-Learning Center and should review the full *Academic Integrity* policy available at https://www9.nau.edu/policies/Client/Details/1443?whoIsLooking=Students&pertainsTo=All
- **ARTIFICIAL INTELLIGENCE:** Artificial intelligence (AI) technologies bring both opportunities and challenges. Ensuring honesty in academic work creates a culture of integrity and expectations of ethical behavior. The use of these technologies can depend on the instructional setting, varying by faculty member, program, course, and assignment. Please refer to course policies, any additional course-specific guidelines in the syllabus, or communicate with the instructor to understand expectations. NAU recognizes the role that these technologies will play in the current and future careers of our graduates and expects students to practice responsible and ethical use of AI technologies to assist with learning within the confines of course policies.
- **COPYRIGHT INFRINGEMENT:** All lectures and course materials, including but

not limited to exams, quizzes, study outlines, and similar materials are protected by copyright. These materials may not be shared, uploaded, distributed, reproduced, or publicly displayed without the express written permission of NAU. Sharing materials on websites such as Course Hero, Chegg, or related websites is considered copyright infringement subject to United States Copyright Law and a violation of NAU Student Code of Conduct. For additional information on ABOR policies relating to course materials, please refer to ABOR Policy 6-908 A(2)(5).

- **COURSE TIME COMMITMENT:** Pursuant to Arizona Board of Regents guidance (ABOR Policy 2-224, *Academic Credit*), each unit of credit requires a minimum of 45 hours of work by students, including but not limited to, class time, preparation, homework, and studying. For example, for a 3-credit course a student should expect to work at least 8.5 hours each week in a 16-week session and a minimum of 33 hours per week for a 3-credit course in a 4-week session.
- **DISRUPTIVE BEHAVIOR:** Membership in NAU's academic community entails a special obligation to maintain class environments that are conductive to learning, whether instruction is taking place in the classroom, a laboratory or clinical setting, during course-related fieldwork, or online. Students have the obligation to engage in the educational process in a manner that does not interfere with normal class activities or violate the rights of others. Instructors have the authority and responsibility to address disruptive behavior that interferes with student learning, which can include the involuntary withdrawal of a student from a course with a grade of "W". For additional information, see NAU's *Disruptive Behavior in an Instructional Setting* policy at https://nau.edu/university-policy-library/disruptive-behavior.
- **NONDISCRIMINATION AND ANTI-HARASSMENT:** NAU prohibits discrimination and harassment based on sex, gender, gender identity, race, color, age, national origin, religion, sexual orientation, disability, veteran status and genetic information. Certain consensual amorous or sexual relationships between faculty and students are also prohibited as set forth in the *Consensual Romantic and Sexual Relationships* policy. The Equity and Access Office (EAO) responds to complaints regarding discrimination and harassment that fall under NAU's *Nondiscrimination and Anti- Harassment* policy. To report a concern related to possible unlawful discrimination or harassment or to request a time to meet, please use the Report an Issue Form. To file a complaint, please submit the online Complaint Form. EAO also assists with religious accommodations. To request a religious accommodation, please use the Religious Accommodation Request Intake Form. EAO additionally provides access to lactation spaces, and please use to the Lactation Space Request Form to request use of a location. For additional information about nondiscrimination or anti-harassment, contact EAO at EquityandAccess@nau.edu, or visit the EAO website at https://nau.edu/equity-and-access. The EAO is located in Old Main on the first floor.
- **TITLE IX:** Title IX of the Education Amendments of 1972, as amended, protects individuals from discrimination based on sex in any educational program or activity operated by recipients of federal financial assistance. In accordance with Title IX,

Northern Arizona University prohibits discrimination based on sex or gender in all its programs or activities. Sex discrimination includes sexual harassment, sexual assault, relationship violence, and stalking. NAU does not discriminate on the basis of sex in the education programs or activities that it operates, including in admission and employment. NAU is committed to providing an environment free from discrimination based on sex or gender and provides a number of supportive measures that assist students, faculty and staff employees, and covered guests. One may direct inquiries concerning the application of Title IX to either or both the university Title IX Coordinator or the U.S. Department of Education, Assistant Secretary, Office of Civil Rights. You may contact NAU's Title IX Coordinator at titleix@nau.edu or by phone at 928-523-5434 . In furtherance of its Title IX obligations, NAU promptly will investigate or equitably resolve all reports of sex/gender-based discrimination, harassment, or sexual misconduct and will eliminate any hostile environment as defined by law. To submit a report, please use the File a Report Form. The Office for the Resolution of Sexual Misconduct (ORSM): Title IX Institutional Compliance, Prevention & Response addresses matters that fall under the university's Sexual Misconduct Policy. ORSM also facilitates reasonable modifications for pregnant or parenting individuals. Additional important information and related resources, including how to request help or confidential support following conduct covered by the Sexual Misconduct Policy, is available on the ORSM web site, and you also may contact the office at titleix@nau.edu. The ORSM is located in Gammage on the third floor.

- **ACCESSIBILITY:** Professional disability specialists are available at Disability Resources to facilitate a range of academic support services and accommodations for students with disabilities. If you have a documented disability, you can request assistance by contacting Disability Resources at 928-523-8773 (voice), ,928-523-8747 (fax), or dr@nau.edu (e-mail). Once eligibility has been determined, students register with Disability Resources every semester to activate their approved accommodations. Although a student may request an accommodation at any time, it is best to initiate the application process at least four weeks before a student wishes to receive an accommodation. Students may begin the accommodation process by submitting a self-identification form online at https://nau.edu/disability-resources/student-eligibility-process or by contacting Disability Resources. The Director of Disability Resources, Jamie Axelrod, serves as NAU's Americans with Disabilities Act Coordinator and Section 504 Compliance Officer. He can be reached at jamie.axelrod@nau.edu.
- **RESPONSIBLE CONDUCT OF RESEARCH:** Students who engage in research at NAU must receive appropriate Responsible Conduct of Research (RCR) training. This instruction is designed to help ensure proper awareness and application of well-established professional norms and ethical principles related to the performance of all scientific research activities. More information regarding RCR training is available at https://nau.edu/research/compliance/research-integrity.
- **MISCONDUCT IN RESEARCH:** As noted, NAU expects every student to firmly adhere to a strong code of academic integrity in all their scholarly pursuits. This

includes avoiding fabrication, falsification, or plagiarism when conducting research or reporting research results. Engaging in research misconduct may result in serious disciplinary consequences. Students must also report any suspected or actual instances of research misconduct of which they become aware. Allegations of research misconduct should be reported to your instructor or the University's Research Integrity Officer, Scott Pryor, who can be reached at scott.pryor@nau.edu or 928-523-5927. More information about misconduct in research is available at https://nau.edu/university-policy-library/misconduct-in-research.

- **SENSITIVE COURSE MATERIALS:** University education aims to expand student understanding and awareness. Thus, it necessarily involves engagement with a wide range of information, ideas, and creative representations. In their college studies, students can expect to encounter and to critically appraise materials that may differ from and perhaps challenge familiar understandings, ideas, and beliefs. Students are encouraged to discuss these matters with faculty.

## Tentative Course Schedule

| Week | Date | Ch | Topic | Reading Quiz | Activity | Homework Due |
|---|---|---|---|---|---|---|
| | 8/27 | | | | | |
| 1 | 8/29 | | | | #1 Stellar Properties Concept Map | |
| | 9/3 | | | | #2 Parallax Exercise | |
| 2 | 9/5 | 3 | Class introduction & The continuous spectrum of light | Ch 3 | #3 Blackbody Radiation and You | |
| | 9/10 | | | | #4 Star Map | |
| 3 | 9/12 | | | | | Homework 1 |
| | 9/17 | | | | #5 Color-Color Diagram | |
| 4 | 9/19 | 5 | The interaction of light and matter | Ch 5 | | |
| | 9/24 | | | | | |
| 5 | 9/26 | | | | #6 Mass of Spectroscopic Binaries | Homework 2 |
| | 10/1 | | | | | |
| 6 | 10/3 | | | | #7 Light Curves of Eclipsing Binaries | Homework 3 |
| | 10/8 | | | | | |
| 7 | 10/10 | 7 | Binary systems & Stellar parameters | Ch 7 | | Homework 4 |
| | 10/15 | | | | | |
| 8 | 10/17 | | | | #8 Hydrogen Atom's Electron Orbitals | Homework 5 |
| 9 | 10/22 | 8 | The classification of stellar spectra | | | |
| | 10/24 | | **MIDTERM – Ch 3, 5, & 7** | | | |
| | 10/29 | | | | #9 Mini H-R Diagram | |
| 10 | 10/31 | 8 | The classification of stellar spectra | Ch 8 | | Homework 6 |
| | 11/5 | | | | #10 Stellar Temperatures | |
| 11 | 11/7 | | | | | Homework 7 |
| | 11/12 | | | | #11 Photon-Particle Interactions | |
| 12 | 11/14 | | | | | Homework 8 |
| | 11/19 | 9 | Stellar atmospheres | Ch 9 | #12 Curve of Growth & Abundance of Elements | |
| 13 | 11/21 | | | | #13 Modeling Stellar Interiors, Part I | Homework 9 |
| | 11/26 | 15 | Stellar interiors (Ryden & Peterson) | | #14 Modeling Stellar Interiors, Part II | |
| 14 | 11/28 | | *THANKSGIVING BREAK – NO CLASS* | | | |
| | 12/3 | | | | #15 Modeling Stellar Interiors, Part III | |
| 15 | 12/5 | 15 | Stellar interiors (Ryden & Peterson) | Ch 15 | | |
| 16 | 12/12 | | **FINAL EXAM – Ch 8, 9, & 15** | | | |