NORTHERN ARIZONA UNIVERSITY | College of the Environment, Forestry, and Natural Sciences

Exoplanet Science
Course Syllabus – AST 510

General Information:
- Class Times: M/W/F 11:30 am – 12:20 pm
- Location: Biological Sciences Room 224
- Instructor: Prof. Tyler Robinson
    - Email: tyler.robinson@nau.edu
    - Office: Physical Sciences 225 B
    - Office Hours: M 12:30 – 1:30 pm (and by appointment)
    - Digital Office Hours: https://nau.zoom.us/j/2401303038 | Passcode: 486756

Course Pre-Requisites: Students should have graduate or advanced undergraduate standing in Physics, Astronomy, Earth Sciences, or a related field. Familiarity with concepts related to mechanics, thermodynamics, electricity and magnetism, and scientific computing at the advanced undergraduate level are required.

Course Description: This course examines the basic principles in exoplanet detection, atmospheric physics, and exoplanet characterization. Radial velocity, transit, microlensing, and direct imaging approaches to exoplanet detection are described in detail. A strong emphasis is placed on physical and chemical processes that shape the structure of exoplanet atmospheres. Atmospheric characterization through transit, eclipse, and direct imaging spectroscopy are highlighted. Finally, we discuss the feasibility of the search for Earth-like exoplanets, biosignatures, and habitability signatures.

Course Objectives: Students completing this course will gain an in-depth understanding of techniques used to detect worlds around other stars. Additionally, students will gain a mastery of key physical concepts in exoplanet atmospheres, and how observational techniques can be used to characterize these atmospheres. Expertise in these subject areas will be built using observational, theoretical, and computational approaches. Beyond scientific understanding, this course aims to build students into stronger research professionals. Key skills will be developed through data analysis, literature reviews, manuscript refereeing, and giving conference- and colloquium-style presentations.

Textbooks: This course does not require any textbook purchases.

Primary references include:
- Scharf, C. A. (2008) *Extrasolar Planets and Astrobiology*, University Science Books
- Seager, S. (ed.) (2010) *Exoplanets*, University of Arizona Press
- Seager, S. (2010) *Exoplanet Atmospheres: Physical Processes*, Princeton University Press

Secondary references include:

- Catling, D. C. and Kasting, J. F. (2017) *Atmospheric Evolution on Inhabited and Lifeless Worlds*, Cambridge Univ. Press
- Chamberlain, J. W. and Hunten, D. M. (1989) *Theory of Planetary Atmospheres* (2^{nd} Ed.), Academic Press
- de Pater, I. and Lissauer, J. J. (2010) *Planetary Sciences* (2^{nd} Ed.), Cambridge Univ. Press
- Petty, G. W. (2006) *A First Course in Atmospheric Radiation* (2^{nd} Ed.), Sundog Publishing
- Pierrehumbert, R.T. (2011) *Principles of Planetary Climate*, Cambridge Univ. Press

Course Topics Outline:

WEEK	DATES	TOPIC
1	Aug 12 – Aug 14	Exoplanets History & Overview; Data Analysis Overview
2	Aug 17 – Aug 21	Keplerian Orbits; Radial Velocity Technique
3	Aug 24 – Aug 28	Astrometric Detection; Gravitational Microlensing
4	Aug 31 – Sep 04	Transits; Transit Timing Variations; Secondary Eclipse
5	Sep 07 – Sep 11	Exoplanet Direct Imaging
6	Sep 14 – Sep 18	Exoplanet Atmospheres; Atmospheric Structure
7	Sep 21 – Sep 25	Atmospheric Structure; Radiative Transfer
8	Sep 28 – Oct 02	Radiative Transfer & Atmospheric Characterization
9	Oct 05 – Oct 09	Exoplanet Spectroscopy; Transit Spectra
10	Oct 12 – Oct 16	Exoplanet Spectroscopy; Secondary Eclipse & Emission Spectra
11	Oct 19 – Oct 23	Exoplanet Spectroscopy; Direct Imaging
12	Oct 26 – Oct 30	Final Project Hack Week
13	Nov 02 – Nov 06	Future: Discovery and Characterization of Exo-Earths
14	Nov 09 – Nov 13	Final Project Presentations
15	Nov 16 – Nov 20	Final Project Presentations

Grading: Overall course grades will be determined using the following weights:

- Problem Sets (x4) 15%
- Manuscript Peer Review 15%
- Weekly Paper Presentation 15%
- Weekly Paper Questions 5%
- Analysis Project (x2) 20%
- Final Presentation 15%
- Final Paper 15%

Final letter grades will be assigned according to:

A = 90 – 100 : B = 80 – 89 : C = 70 – 79 : D = 60 – 69 : F = 0 – 59

Student grades may be scaled up (but never down) based on overall class performance.

Course Policies: Collaboration with peers on assignments is encouraged. Excepting the final paper, all assignments must be submitted as original work and writing from the student, even if peer discussions led to the final result. Plagiarism in written work will be not be tolerated, resulting in a failing grade for the assignment and, potentially, referral to the University. See policy.nau.edu/policy/policy.aspx?num=100601 for NAU's policies on academic integrity.

Graduate students lead busy lives and are often asked to balance teaching, research, and coursework. Sometimes this balance works better than others. To help accommodate busy schedules, any assignment (excepting the final paper) can be turned in up two **two days** late without penalty. After this grace period, **10%** of the assignment grade will be deducted for **every two additional late days**. Additionally, **once per semester** and excepting the final paper, every student may turn in an assignment **one week late without any penalty**.

Key Due Dates:

DATE	ITEM
AUG 19	Problem Set #1
AUG 28	Problem Set #2
SEP 11	Problem Set #3
SEP 18	Problem Set #4
OCT 09	Analysis Project #1
OCT 23	Manuscript Peer Review
NOV 02	Analysis Project #2
NOV 24	Final Paper

Problem Sets: Problem sets are primarily designed to help students develop the computational and statistical tools required to complete analysis-based projects due later in the semester. Thus, the problem set due dates are all scheduled early in the term.

Manuscript Peer Review: One goal of this course is to help students develop the skills needed to be a professional researcher in astronomy. Unfortunately, seldom are early career scientists taught techniques for effective peer review of scientific manuscripts. Beyond skills for developing and writing manuscripts reviews, another reality of peer review is that reviewers are not always perfect experts in the scientific areas covered by an under-review paper. Thus, peer review often requires familiarizing yourself with topics in which you have not had formal training. In this assignment, students will be given a manuscript for which they must produce a professional-grade review.

Paper Presentations: Each week (roughly) we will read a key paper from the fields of exoplanet detection and exoplanet characterization. Each student is expected to select one of these foundational papers (typically from past issues of *Nature* or *Science*) to give a 12-minute conference-style presentation on that manuscript. The student will also field questions from the audience. Following the presentation and Q&A, the entire class will briefly discuss the paper.

Paper Questions: Prior to the weekly paper presentation, each student must submit (in writing or via email) one question they have from that week's reading. If the Q&A lags, these questions will be used to spur conversation.

Analysis Projects: Following the development of most new topics in this course (e.g., radial velocity exoplanet detection, transit detection, transit spectroscopy, etc.), either real or simulated data will be provided to the students, along with relevant *a priori* parameters. Students are expected to use the analysis techniques developed earlier in the course to perform end-to-end analysis of two of these datasets. Each analysis project will result in a brief write-up that describes the problem, outlines the dataset, presents the relevant theory, and indicates derived constraints on relevant exoplanet parameters.

Final Paper and Presentation: Students will select one analysis project (distinct from the two described above) for which they will do a more in-depth analysis, write-up, and presentation. The write-up is expected to follow the format of a scientific publication, and should be at least 15 double-spaced pages (not counting figures, references, and tables). The student will give a final presentation on this project, wherein background, methods, results, and conclusions will be described. This presentation is expected to be 15 minutes, followed by a brief Q&A. Students may work together on the final project, and can submit a group-written paper. Each student is expected to give their own presentation, however. Each additional student joining the final paper adds 7.5 double-spaced pages to the total required length (again, not counting figures, references, and tables).

Feedback: Unsolicited feedback, either positive or negative, is welcome at any time. I want students to feel safe and secure in my classroom. Additionally, students should feel confident in the material they are being taught and shouldn't feel over-burdened by course requirements. If you are ever feeling concerned, please either: (1) speak to me in person, (2) send me an email, or (3) send me anonymous comments at bit.ly/2wR1aU6.

University Polices: Please see:

http://nau.edu/Curriculum-and-Assessment/_Forms/Curricular-Policy/Syllabus_Policy_Statements/

COVID Policies: Masks are required inside the classroom and for any in-person office visits. Masks must properly cover the mouth and nose, and must provide a sufficiently protective barrier (as determined by the instructor). Students who refuse to wear masks will be asked to leave the classroom. If a student refuses to leave, class will be dismissed and the student will be reported to the Dean of Students for a classroom disruption event. Additional policies specific to measures and practices associated with the institutional response to the COVID-19 outbreak are in place for Fall 2020. Details available in the institutional Syllabus Policy Statements*:*

https://nau.edu/wp-content/uploads/sites/26/Syllabus-Policy-Statements.pdf