FA25-PHYS780-001 ST: Solar and Solar-Terrestrial Physics

PHYS 780 - Solar and Solar-Terrestrial Physics – Fall 2025

Time	Days	Where	Date Range	Instructor
2:30 - 3:50 pm	Monday	FMH319	09/02-12/02/25	Alexander G. Kosovichev alexander.g.kosovichev@njit.edu
10:00 -11:20 am	Tuesday	FMH319		

In addition to the classroom, the course is delivered synchronous-online:
https://njit-edu.zoom.us/j/2763710797?pwd=K0w0aHZCSmcrM0FkeXRKSklZUjZvZz09

Course materials are available in Canvas.
Primary textbooks:
Stix, M. "The Sun: An Introduction", 2nd edition, Springer 2002
"Introduction to Space Physics", ed. M.G. Kivelson & C.T. Russell, Cambridge Univ. Press, 1995
Grading: 40% homework assignments, 20% quizzes, 40% final presentation
Office hours: by appointment

Lecture plan

1. September 2, Tuesday. Introduction. Course overview. "Big problems of heliophysics": solar neutrinos, rotation, dynamo, magnetic energy release, coronal heating, solar wind.
2. September 8, Monday. The Sun as a star. General properties, place in the Hertzsprung-Russell diagram. Distance, mass, radius, luminosity, composition, age, evolution, spectral energy distribution.
3. September 9, Tuesday. Tools for solar observations I. Solar telescopes. Resolution, MTF, and seeing. High-resolution telescopes.
4. September 15, Monday. Tools for solar observations II. Spectrographs. Measurements of the line shift.
5. September 16, Tuesday. Tools for solar observations III. Zeeman effect. Magnetic fields and polarimetry.. Solar space missions: SOHO, TRACE, STEREO, Hinode, RHESSI, SDO, IRIS. Neutrino telescopes.
6. September 22, Monday. Internal structure of the Sun I. Stellar Scaling Laws. Standard model. Evolution. Nuclear reactions. Equation of state. Radiative transfer. Quiz #1 (Lectures 1-5).
7. September 23, Tuesday. Internal structure of the Sun II. Stability. Convective energy transfer. Non-standard models. Solar neutrinos, neutrino transitions, MSW effect.
8. September 29, Monday. Solar oscillations. Observations. Excitation mechanisms.
9. September 30, Tuesday. Theory of solar oscillations. Theory of p-, and g-modes.

10. October 6, Monday. Principles of helioseismology I. Global helioseismology. Asymptotic inversion. Variational principle, perturbation theory. Inversions, sound speed, and rotation inferences.
11. October 7, Tuesday. Principles of Helioseismology II. Local-area helioseismology. Ring diagrams, acoustic imaging, time-distance tomography. Far-side imaging. Meridional circulation. Emerging magnetic flux. Active region dynamics.
12. October 13, Monday. Convection. Granulation, supergranulation, giant cells. Energy balance. Superadiabatic layer. Rotational and magnetic effects. Numerical simulations.
13. October 14, Tuesday. Differential rotation. Observations. Heliographic coordinates. Oblateness, quadrupole moment, and the test of general relativity. Rotational history. Models of differential rotation.
14. October 20, Monday. Solar MHD I. Particle Motion in Electric Field, Magnetic Effects, Ohm's Law, MHD Equations. Quiz #2 (Lectures 6-13).
15. October 21, Tuesday. Solar MHD II. Magnetic Field Diffusion, Frozen Magnetic Flux Approximation, Magnetic Forces, MHD Waves
16. October 27, Monday. The Solar Cycle and dynamo theory. 11-year sunspot cycle, butterfly diagram, mean-field electrodynamics, dynamo models, 3D MHD simulations.
17. October 28, Tuesday. Magnetic energy release. Reconnection. Particle acceleration. Observations. Theories of reconnection, current sheets, MHD, and plasma instabilities. Acceleration mechanisms.
18. November 3, Monday. Solar atmosphere. The structure of the solar atmosphere, photosphere, chromosphere, and corona. Transition region. Chromospheric network, filaments, prominences, spicules.
19. November 4, Tuesday. Sunspots. Active regions. Flux tubes. Observations. Static models. Flows, Evershed effect. Formation and decay of sunspots. Theories of emerging flux tubes, magnetic buoyancy.
20. November 10, Monday. Flares. Observations. Radiation, radio-, X-, and gamma-rays. Energetic particles. Thin- and thick-target models, evaporation, heat conduction. Radiative and MHD shocks. Moreton waves, "sunquakes".
21. November 11, Tuesday. Corona. CME. Observations, eclipses. White light corona, Thompson scattering. Coronal heating, heat conduction. Large-scale structures and changes with the solar cycle. Coronal mass ejections, shocks.
22. November 17, Monday. Solar wind. Observations. Expansion, Parker's model, high- and low-speed wind. Composition, first-ionization potential effect. Sector structure, current sheet. Quiz #3 (Lectures 14-21).
23. November 18, Tuesday. Magnetosphere. Interaction of solar wind with the Earth's magnetosphere and planets. Geomagnetic effects.
24. November 24. Monday. Ionosphere. Radiation belts. Auroras, substorms. Space weather.
25. December 1. Monday, Presentation of projects
26. December 2, Tuesday. Presentation of projects
27. December 8, Monday. Presentation of projects
28. December 9, Tuesday. Presentation of projects

Learning Objectives and Outcomes

The purpose of the course is to introduce the students to several areas of solar and space physics, applied physical principles, and observational methods. This course covers electromagnetic, plasma, and nuclear processes from the center of the Sun to the Earth's surface. It will include the solar radiation, the evolution, and structure of the Sun, solar activity cycles, cosmic rays, the heliosphere, solar wind, magnetosphere, radiation belts, ionosphere, geomagnetic effects, and space weather.

Upon successful completion of this course, the student will be able to

1) Demonstrate comprehensive knowledge and understanding of observational and data analysis methods, theoretical principles, and applications of solar and solar-terrestrial physics. Students will be able to: understand the basic principle of remote sensing by using spectroscopy (e.g. Doppler-shift, line depth, magnetic field, and continuum intensity measurements); understand the basic principles of helioseismology, mechanisms, and impacts of sunspot cycles, solar flares, and eruptions.

2) Describe the additional concepts that are necessary to understand the physical processes ion the Sun and other stars, and their variations with the magnetic activity. Explain the basic concepts of the solar dynamo mechanisms, describe the characteristic features of the solar differential rotation, such as the tachocline, and the near-surface rotational shear layer; understand the structure of the meridional circulation, and its role in the solar cycles.

3) Demonstrate skills in locating, digesting, and presenting the contents of published research papers and monographs at the cutting edge of solar and solar-terrestrial physics, and clearly describe the issues at hand.

4) Apply such newly-acquired concepts to heliophysics, astrophysics and space weather research, as well as to broader applications based on observational and theoretical methods, attempt a clarification or synthesis of the latest results in the field.

Academic Integrity

Academic Integrity is the cornerstone of higher education and is central to the ideals of this course and the university. Cheating is strictly prohibited and devalues the degree that you are working on. As a member of the NJIT community, it is your responsibility to protect your educational investment by knowing and following the academic code of integrity policy that is found at: http://www5.njit.edu/policies/sites/policies/files/academic-integrity-code.pdf. Please note that it is my professional obligation and responsibility to report any academic misconduct to the Dean of Students Office. Any student found in violation of the code by cheating, plagiarizing or using any online software inappropriately will result in disciplinary action. This may include a failing grade of F, and/or suspension or dismissal from the university. If you have any questions about the code of Academic Integrity, please contact the Dean of Students Office at dos@njit.edu

Any student who is disruptive in the classroom will be in violation of the Academic Honor Code and will be reported to the Dean of Student Services. Any student who cheats during a quiz or an examination will be in violation of the Academic Honor Code. The student will automatically fail the course and will be reported to the Dean of Student Services so that further action may be taken. Examples of cheating during a quiz or an examination include, but are not limited to, talking with another student, copying work from another student's work, allowing another student to copy work from your own work, or use of any materials besides the examination paper and a writing utensil.

Missed Quiz or Exam

Students who miss a common quiz or exam will receive a score of zero for that exam unless they present a valid excuse within 7 days of the exam. Students with two or more missing, unexcused common exams automatically fail the course. Students expecting to be absent from a common exam should discuss their situation with their instructor PRIOR TO their absence. In order to qualify for a (rare) "make-up" common exam, a student needs to document the reason for not being able to take the test as scheduled (for example, due to an exam conflict or documented illness). Under NJIT policy, the documentation should be presented to the student's instructor AND to the Dean of Students, both of whom must agree to permit a "make-up" exam.