New Jersey Institute of Technology
College of Science and Liberal Arts
Department of Physics
Introduction to Helioseismology
PHYS 747-001
Fall 2016

Monday **1:00PM – 2:20PM**	**GITC 1403**	
Wednesday **1:00PM – 2:20PM**	**GITC 1403**	

NJIT Webex: https://njit.webex.com/join/sasha
URL: http://sun.stanford.edu/~sasha/PHYS747

Instructor

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Textbook

M, Stix, The Sun: an Introduction. Second Edition, Springer, 2004.
C. Aerts, J. Christensen-Dalsgaard, D. W. Kurt, Asteroseismology, Springer, 2010

Additional sources:
A.G. Kosovichev, Advances in Global and Local Helioseismology: An Introductory Review, Lecture Notes in Physics, Volume 832, 2011
Extraterrestrial Seismology, V. Tong, R. Garcia (eds), Cambridge Univ. Press, 2015

Grade

Your final grade will be based upon homework (20%), quizzes (20%), class participation (20%), and one Final Presentation (40%).
The grades you earn will determine your final grade based on the following table.

85% to 100%	A
80% to 84%	B+
70% to 79%	B
65% to 69%	C+
50% to 64%	C
40% to 49%	D
0% to 39%	F

The homework grades will not be "curved," nor will the quiz grades be "curved." The homework, the quizzes, and the presentations will cover topics discussed in class and/or topics discussed in the textbooks. Each quiz will be "closed book" and "closed notes." No "formula sheet" or "cheat sheet" will be provided, nor will either be permitted.

Academic Integrity

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.

Syllabus

Week 1
Observations and basic properties of solar oscillations. Brief history of helioseismology.
Week 2.
Oscillation power spectrum. Excitation by turbulent convection. Line asymmetry and pseudo-modes.
Week 3
Magnetic effects: sunspot oscillations and acoustic halos. Helioseismic response to solar flares: sunquakes.
Week 4
Global helioseismology. Basic equations; JWKB solution; Dispersion relations for p- and g-modes.
Week 5
Frequencies of p- and g-modes. Asymptotic ray-path approximation; Duvall's law. Asymptotic sound-speed inversion.
Week 6
Surface gravity waves (f-mode). The seismic radius. Solar-cycle variations.
Week 7
General helioseismic inverse problem. Variational principle; Perturbation theory; Kernel transformations
Week 8
Solution of inverse problem. Optimally localized averages method. Inversion results for solar structure
Week 9
Regularized least-squares method. Inversions for solar rotation. Results for solar rotation.
Week 10
Local-area helioseismology. Basic principles. Ring-diagram analysis. Time-distance helioseismology; Acoustic holography and imaging.
Week 11
Solar tomography. Time-distance diagram. Wave travel times. Deep- and surface-focus measurement schemes.
Week 12
Sensitivity kernels. Ray-path approximation. Born approximation.
Week 13
Inversion results of solar acoustic tomography. Diagnostics of supergranulation. Structure and dynamics of sunspots.
Week 14
Large-scale and meridional flows. Solar dynamo.
Week 15
Presentation of student's projects.

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Learning Objectives and Outcomes

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 helio- and asteroseismology. Students will be able to: understand the basic principle of remote sensing by using spectroscopy (e.g. Doppler-shift, line depth, continuum intensity measurements); analyze stochastic time series of solar and stellar oscillations; calculate and investigate the oscillation power spectra using spherical harmonic and Fourier transforms; identify branches of acoustic, surface and gravity modes; understand mechanisms of turbulent wave excitation and the origin of pseudo-modes; calculate the eigenfrequencies and eigenfunctions of normal oscillation modes using the asymptotic JWKB theory; explain the effect of avoided crossing in oscillation power spectra; identify the normal modes in the observed oscillation spectra; measure parameters of the oscillation modes by using the maximum likelihood estimator; understand the influence of magnetic field and rotation on the oscillation spectrum; calculate the rotational frequency splitting; investigate effects of the differential rotation; understand and explain the origin of helioseismic response to solar flare (sunquakes); understand the basic principles of the acoustic noise imaging; calculate the local wave dispersion (ring) diagrams by using 3D Fourier transform; calculate time- distance diagrams by using the cross-covariance analysis; derive and calculate the acoustic wave paths in the solar interior by using the ray-theoretical approximation; understand the basic principle of acoustic tomography; solve the helioseismic inverse problems by using the method of Abel integral equations and the variational principle; calculate the sensitivity and localized averaging functions; use observational data from space missions and ground-based networks; estimate the resolving power, errors and uncertainties of helioseismic inferences.
2) Describe the additional concepts that are necessary to understand the physical processes inside the Sun and other stars, and their variations with the magnetic activity. For example, students will be able to define the relationship between the helioseismic inferences and the structure and dynamics of the solar interior; describe variations of the oscillation frequencies with the solar activity cycle; understand the principles of the far-side imaging; explain the basic concepts of the solar dynamo mechanisms and the role the interior flows inferred by helioseismology; recognize and describe the characteristic features of the solar differential rotation, such as the tachocline, the near-surface rotational shear layer, and the torsional oscillations; understand the structure of the meridional circulation, and its role in the solar cycles; recognize the advances and limitations of the local helioseismology techniques; understand the basic principles and results of asteroseismology.
3) Apply such knowledge to calculate the observational and theoretical properties of solar and stellar oscillations, and infer the interior structure and dynamics by solving inverse problems of helioseismology. For example, students will be able to: calculate the observational and theoretical frequency-wavenumber diagram; interpret the normal mode parameters in terms of the angular degree and order; identify oscillation modes in the power spectra; determine the acoustic cut-off frequency; estimate the mode frequencies, amplitudes, line width and asymmetry, and observational uncertainties by using the observational data; calculate the ring and time-distance diagrams; describe methods and results of local helioseismology.
4) Demonstrate skills of locating, digesting, and presenting the contents of published research papers and monographs at the cutting edge of helioseismology and the solar structures modeling to clearly describe the issues at hand.
5) Apply such newly-acquired concepts to heliophysics, astrophysics and space weather research, as well as to broader applications based on remote sensing, inverse theory, normal mode analysis, and ambient noise imaging, attempt a clarification or synthesis of the lat