# Syllabus: Remote Sensing with Applications from Planetary Fluids to the Cosmos

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## I. COURSE DESCRIPTION

This is a 4 credit semester long course on remote sensing for undergraduate senior-year students in the engineering and technology program.

### A. Overview

The course introduces the science of remote sensing that emphasizes methods to detect weak signals from a distant source. The class material is presented in a way that gives the students a physical perspective of the topics. Observing physical systems from a great distance and from a spatially remote location only became possible in the last part of the twentieth century. Recently, in the early part of the twenty first century, remote sensing has become a rapidly expanding field of science. Viewing physical systems from afar provides a unique global perspective of the large-scale dynamical behavior of those systems. So the tools of remote sensing have become indispensable to scientific exploration of our world at the largest scales, ranging from the study of the Earth to the Universe at large.

### B. Applications

Remote sensing began with defense applications such as stand-off data collection and early warning, first with aircraft and then with space-based satellites. Instead of reviewing the history of remote sensing, this course places its emphasis of the study on the scientific principles upon which remote sensing is based. This course begins with a review of the satellites used to study the geophysics of the Earth, which became particularly useful for the application of meteorology with the launch of the geosynchronous satellite that can fix its view over long periods of time over a particular region of the Earth. Yet, in the last couple decades, remote sensing has undergone a revolution by pointing the satellite's detector (or an Earth-based detector not necessarily based on light detection) away from the Earth. Today remote sensing also includes detecting different kinds of weak signals, for example including gravitational waves from the collision of a pair of black holes in addition to weak electromagnetic waves that fill the cosmos and left as a remnant of the formation of the universe. So this course reviews some new remote sensing applications to study the world at large, including those useful for understanding black holes and the cosmology of the Universe. In addition to studying the Earth, reviews of remote sensing applications for the heliophysics of the Sun and planetary physics (particularly that of Mars) are addressed too. This course spans subject matter from remote sensing of the Earth to sensing at the cosmological frontiers.

A main theoretical objective of this course is to help the student begin to grasp the phenomena of electromagnetism, fluid dynamics and gravitational radiation from a remote sensing perspective. To this end, this course reviews Maxwell's equations, the electromagnetic radiation field and wave spectrum, the electromagnetic wave equation, photon polarization, Planck's blackbody radiation, the Stefan-Boltzmann law, and cosmic microwave background radiation. Then, the course reviews the interaction of light and matter, on the small scale including the scattering of light by atoms (e.g. Raman scattering and Mie scattering as parametric processes, and Rayleigh scattering and Brillouin scattering as nonparametric processes), nonlinear optics, and light propagation through the atmosphere. Next, the course introduces the concepts of incompressible and compressible flow, diffusion, viscosity, convection, Reynolds number, and laminar and turbulence flow. An accessible derivation of the Navier-Stokes equations for incompressible flow is presented, followed by a derivation of the fluid equations for compressible momentum Navier-Stokes equations as they pertain to the behavior of the atmospheric as observable by remote sensing satellites. Finally, the course introduces the concept of the gravitational metric field and and the phenomenon of gravitational radiation, and gives an accessible derivation of the Einstein equation for gravitational radiation as a first introduction to the theory of gravity. This course highlights the similarities between electromagnetic and gravitational radiation.

In passive remote sensing, the detection of extremely weak signals from a distant source depends on ultra sensitive detectors. So, the course also reviews electromagnetic detection devices (e.g. photometers, radiometers, aperture arrays, charge coupled devices) and gravitational detection devices (e.g. laser interferometers as gravitometers). In active remote sensing the source of the radiation is man made. For this purpose, this course reviews laser technology (stimulated emission of monochromatic and directed radiation) with applications to LiDAR and laser interferometry. Time-permitting, this course also introduces a new quantum interferometry technique based on atom lasers that presently serve as one of the newest remote sensing technologies based on matter wave interferometry (e.g. accelerometers based on atomic matter waves).

Overall, the course provides laboratory hands-on applications of the concepts and theories presented in each class throughout the semester. The course uses technologies and physical analysis relevant to Hawaii's high-tech industries and scientific communities.

### C. Course plan

Students should have facility with Signals and Systems and Digital Signal Processing as well as the ability to carryout symbolic mathematical calculations on a computer. Demonstrations in the class will use Mathematica and this symbolic mathematics software application is highly recommended for the students as an aid to accomplishing the assigned weekly problem sets.

Each student will select a remote sensing topic of their choosing for a Final Project.

The Final Project will entail:

1. reviewing an existing remote sensing system that is in the public domain
2. obtaining experimental discrete time series image data from the respective open access database
3. analyzing the digital data or imagery with tools and methods presented in the class
4. and reviewing the scientific progress achieved with respect to the comparison of analytical predictions with the observed behavior of the large physical system.

Each student will summarize his or her remote sensing study in written Technical Report form for turn in as a final project.

A basic review/refreshers for vector calculus is provided at the outset as needed.

The class meets Monday 12:45-3:30pm and Wednesday 12:45-3:30pm (via VTC).

Office Hours: Immediately following class Monday and Wednesday and by appointment

Prerequisites: ETRO 360 and ETRO 450 with grade C or better. — This prerequisite cannot be waived.

### D. Mathematical skill set

Signals and systems, digital signal processing, and symbolic computation.

## II. PROSPECTUS

1. Introduction
   - Introduction to remote sensing
2. Introduction to electromagnetic radiation
   - Maxwell's equations, electric and magnetic fields, complex electromagnetic field of radiation
   - Wave equation, vector calculus identities, solenoidal (divergence free) fields, and plane-wave solutions
   - Photon polarization, spin-1 representation, Stokes parameters
   - Stefan-Boltzmann law, radiant exitance, thermodynamic temperature, Planck's constant, radiance, emissivity, luminosity, effective temperature, and irradiance
3. Interaction of light and matter
   - Interaction of electromagnetic radiation and matter with an introduction to scattering theory and dielectric polarization
   - Light-atom scattering, including Rayleigh and Mie scattering as parametric processes, and Raman and Brillouin scattering as nonparametric processes
   - Nonlinear optics processes, including frequency-mixing processes, self-focusing, and optical solitons
   - Light propagation through the atmosphere, Fresnel free-space optical transfer function in the paraxial approximation, and optical turbulence in the troposphere
4. Introduction to fluid dynamics
   - Mass density, flow velocity, pressure, diffusion, viscosity, convection and Reynolds number
   - Navier-Stokes equation for incompressible flow
   - Stream function for 2D equations for laminar flow and 3D laminar and turbulent flow regimes
   - Hydrothermal equations for compressible flow
   - Atmospheric physics, multiphase flow and tropospheric weather
5. Midterm
   - Midterm exam (and compilation of assigned Problem Sets up to middle of the semester)
   - In-class review of the solution set
6. Introduction to gravity
   - Gravity field of the Earth and Sun, Kepler orbits, satellite orbits and numerically-computed orbits of central bodies
   - Gravitational metric field, transformations between coordinate systems, the Jacobian and calculation of the metric tensor in terms of the Jacobian
   - Example manifolds in 1+1 dimensions, hyperbolic coordinate and the Minkowski metric
   - Friedmann-Lemaître-Robertson-Walker metric, Einstein's equation, gravitational waves, and polarization tensors of transverse-traceless gravitational plane waves
7. Sources of radiation
   - Solar electromagnetic radiation
   - Cosmic rays and Cherenkov radiation from air showers generated by cosmic rays
   - Lasers, stimulated emission of monochromatic electromagnetic radiation
   - RADAR, LiDAR, and Synthetic aperture array RADAR

8. Applications
    - Satellite systems for geophysics, e.g. Landsat, AVHRR, MODIS, GOES, ASTER
    - Systems for cosmic microwave background (CMB), e.g. COBE, WMAP and Planck experiments
    - Systems for weak gravitational waves, e.g. LIGO
9. Final project
    - Final exam (May — complete compilation of assigned Problem Sets) and Student Project submitted in Technical Report format

## III. PROBLEM SETS

Problem sets are assigned as needed and tailored to the students' progress. Students generally have one week to complete any given assigned problem set.

Selected Problem Sets will be submitted in Technical Report format using scientific typesetting software. Students should be familiar with technical and scientific writing.

## IV. COURSE REQUIREMENTS AND EVALUATION

Labs, written exercises, and computer problems: 30%
(e.g. assigned Wednesday and due the following Wednesday)
Midterm examination: 30%
Final project: 30%
Class participation: 10%

## V. METHOD OF INSTRUCTION

- "Space: The New Frontier" video series
- Scientific presentations
- Internet-based video teleconference
- Mathematica demonstrations
- Class discussions
- Weekly office hours following the class end and can be scheduled on a weekly basis by e-mail request

## VI. RESOURCES

- Text book:
  There is no assigned textbook for this course.
- Additional reference book:
  W.G. Rees, "Physical Principles of Remote Sensing," 3rd Edition, Cambridge University Press (2013)
- Wikipedia provides many helpful overviews, including for the respective lectures presented in the course:
    1. Maxwell's equations
    2. Electromagnetic radiation
    3. Planck's law
    4. Cosmic microwave background

5. Stefan-Boltzmann law
6. Kepler's laws
7. Fluid dynamics
8. Navier-Stokes equations
9. Numerically-computed orbits in an inverse-square potential
10. Metric tensor field
11. Einstein's equation
12. Friedmann-Lemaître-Robertson-Walker metric
13. Friedman equation
14. Gravitational radiation
15. Interaction of radiation with matter
16. Linear optics
17. Nonlinear optics

- Mathematical physics developments will be provided in class tailored to the skill of the students.

## VII. DISABILITY STATEMENT

1. If you have a disability and have not voluntarily disclosed the nature of your disability and the support you need, you are invited to contact Lisa Deneen - Disabilities Coordinator at 984-3227 or Telecommunication Device for the Deaf (TDD) 984-3325 or the Text Telephone (TT) replay service at 643-8833.

2. Reasonable accommodations will be provided for students with documented physical, sensory, systemic, cognitive, learning and psychiatric disabilities. If you believe you have a disability requiring accommodations, please notify Lisa Deneen - Disabilities Coordinator at 984-3227 or Telecommunication Device for the Deaf (TDD) 984-3325 or the Text Telephone (TT) replay service at 643-8833. The Disabilities Coordinator will verify your disability and provide the course instructor with recommendations for appropriate accommodations.