

COURSE SYLLABUS – Spring 2003

GEOLOG 702u – Advanced Photogrammetry – Remote Sensing Measurements For Geologic Applications I – Reflectance Spectroscopy

Course Credits: 3 semester hours

Dr. James V. Taranik, Regents Professor
Arthur Brant Chair of Geophysics
Arthur Brant Laboratory for Exploration Geophysics
Laxalt Mineral Research Center – 356A
775-784-4258, E-mail: jtaranik@mines.unr.edu, jvtaranik@cs.com (home)

Classroom: LMR 356

Time: 1:00 Lectures: MW LMR 356,

**Laboratory: Days and Hours by Arrangement in LMR 360, Arthur
Brant Laboratory for Exploration Geophysics**

COURSE DESCRIPTION

This course reviews fundamental principles of aerospace remote sensing in the visible, near-infrared and short-wave infrared portions of the electromagnetic spectrum. Students are expected to gain an understanding of the energy-path concept that provides a model for understanding the properties of the principal source of electromagnetic radiation (EMR), the Sun. Students learn the concepts of frequency and wavelength and the properties of EMR from the Sun entering the top of the Earth's atmosphere. The phenomenology of atmospheric effects is reviewed so students will develop an understanding of the effects of atmospheric scattering and absorption on the spectral properties of solar energy reaching the Earth's surface.

Students gain an understanding of the physics of surface scattering, reflection, selective absorption of EMR by major classes of earth surface materials with emphasis on the spectral properties of minerals and consolidated rocks, unconsolidated rock-weathering products, soils, and coatings and alteration products that occur with these materials. The science of spectral measurement is reviewed including: photon flux, ground instantaneous field of view, integration of spectral response, and spectral end-members. Students learn how atmospheric scattering and absorption effect EMR reflected from the Earth's surface and the models used to correct for their effects in aerospace remote sensing data.

Sensor technology is reviewed in terms of optical physics and focal plane technology. Students learn models used to characterize detector response to understand how EMR measured by detectors is formatted to data. Concepts of radiometric and geometric adjustments to raw sensor data are learned and models for correcting remote sensing imagery in multispectral and hyperspectral analysis are applied by students. Students evaluate sensor systems and platforms for their utility for evaluation of natural resources.

Students learn how to make ground-based field and laboratory spectral measurements of common rock materials and their associated rock alteration products, soils, coatings and vegetation to develop an appreciation of the spectral attributes of natural resource themes that can be effectively measured with aerospace remote sensing techniques. Multispectral and hyperspectral data analysis techniques are introduced over geological sites of interest in the Great Basin. The cost-effectiveness of aerial imagery, multispectral imagery and hyperspectral imagery for natural resources applications is reviewed.

COURSE EMPHASIS

Course Notebook: 15%, constitutes the textbook for the course.

Mid-Term Examination: 10%, an examination with open book and open notes.

Term Project: 35%

Oral Presentation on term project: 15%

Final Examination: 25%, a take home examination.

COURSE NOTEBOOK

This course has no course textbook, however students are expected to develop their own course textbook through lecture notes taken in class, notes taken from assigned readings and notes taken from reference materials that students wish to include on their own initiative. Please **do not** just copy references from this course for your notebook! Your interpretations of the key points in these references are what should constitute most of your notebook. An important part of the notebook is a comprehensive list of references, appropriate to each major subject, and including references you may find beyond those assigned during class. The notebook will be professionally prepared, including carefully illustrated diagrams. It will be appropriately footnoted to acknowledge sources of information, and it will be organized in a three-ring binder. These notebooks will be graded for completeness and neatness. Notebooks submitted by students may be retained by the instructor and the information contained in the notebooks will not be subject to copyright by the student. The instructor reserves the right to use materials from the submitted notebooks for future classes. Some of the material in the submitted course notebooks may be placed, in condensed form, on the World Wide Web for the use of all students.

TERM PROJECT

The term project will involve a combined class project but will culminate in independent student research on a geological remote sensing problem. This class project will develop an understanding of the kinds of spectral attributes that can be detected and mapped with aerospace remote sensing data. Students will use high-altitude and low-altitude AVIRIS, HyMap, Hyperion and HyperSpecTIR image data over the same area in the Great Basin of Nevada. AVIRIS, HyMap and Hyperion data are radiance data and must be corrected for atmospheric effects prior to analysis. HyperSpecTIR data are furnished in three formats: radiance data, reflectance data and reflectance polished data

for a small scene on western edge of the Cuprite hydrothermal system. ENVI software will be used for analysis. The first goal of the term project will be to compare the various the various types of hyperspectral image data in terms of the scales, formats, coverage and accuracies of landscape information that can be extracted by analysis of the data. The second goal of the term project will be define optimal characteristics of an advanced airborne sensor for commercial applications in terms of its spatial, spectral and radiometric resolution; swath width, formats of data, data delivery, accuracy, etc. Each step of your analysis, including failed trials and errors, should be carefully documented. Documentation can take the form of screen saves of processing steps used, outlines of procedures, etc. This documentation should appear as an appendix to the report. A goal will be collaborative publication of the results of the term project as a publication suitable for peer review.

The methodology for term projects will take the form of identification of suitable data, development of pertinent references, meetings with the instructor to review the tentative project, conduct of the research leading to preliminary results, submitting a topic sentence outline for the proposed project report and including key references. The topic sentence outline and bibliography will be evaluated for completeness and they will be graded. When the project is well underway, the class will meet regularly as a group to review results and chart new courses of research. The final project report is due in professional style on the last day of the course. Late reports will be downgraded accordingly. Incompletes are strongly discouraged and must be adjudicated with the instructor. CD ROMs, are to be left with the instructor containing the original raw hyperspectral image used, any image data developed as intermediate analysis products, final image data product, the PowerPoint presentation used in the oral report and the final report. Software developed and applied during the project should be included as an appendix. This disk will become a part of the Arthur Brant Laboratory archive and may be used by faculty and students in the future.

ORAL REPORT

The oral report will be a professionally prepared talk that uses “MS PowerPoint” is required for original figures and diagrams. Figures and diagrams from reference sources must be carefully documented. The oral report will be presented as a 20 minute PowerPoint presentation with 5 minutes for questions and answers, in a manner similar to that in a professional association meeting. The class will participate in the evaluation of the presentation, in terms of its organization, style and content. These talks are designed to improve student communication skills and to prepare students for professional life. The oral reports will be given at the end of the course and students may invite guests to attend.

CLASS SCHEDULE – Spring 2003

Refer to Course Outline

January 22 - Wednesday – Class Organizational Meeting, hand-out Syllabus and reading list.

January 24 – Friday - Introduction to Term Project Problem. Begin learning ENVI.

Reading assignments (Copies found in Arthur Brant Laboratory):

1. Goetz, A.F.H, et. al., 1985, Imaging spectrometry for earth remote sensing: Science, Vol. 228, pp. 1147-53.
2. Schott, J. R., 1997, Remote Sensing, The Image Chain Approach, Chapter 3, Radiometry and Radiation Propagation, pp. 47 – 88, Oxford University Press, N. Y.
3. Slater, P. N., 1980, Remote Sensing, Optics and Optical Systems, Chapter 4, Electromagnetic Theory and Chapter 5, Radiometric Concepts, Definitions and Laws, pp. 31-60 and 88-110 Addison-Wesley Publishing Company.

Please respect copyright laws in using this material.

January 27 – Monday – Overview of Imaging Spectroscopy. History of the development of imaging spectroscopy.

January 29 – Wednesday – No class. Jim in Denver for Newmont Board meetings.

January 31 – Friday - Begin registration of hyperspectral remote sensing data sets.

Reading assignment:

4. Elachi, C., 1987, Introduction to the Physics and Techniques of Remote Sensing: John Wiley and Sons, Chapter 3, pp. 46 – 71.

Please respect copyright laws in using this material.

February 3 – Monday – Introduction to the physics of electromagnetic radiation. Solar radiation. Concepts of particles and waves. Concepts of wavelength, wavenumber, frequency and electromagnetic spectrum.

Reading assignment:

5. Hunt, G. R., 1980, Electromagnetic Radiation: The Communications Link in Remote Sensing: in Remote Sensing in Geology, John Wiley and Sons, pp. 13 – 35.

Please respect copyright laws in using this material.

February 5 - Wednesday – Concepts of energy path. Transmittance, absorptance, reflectance and albedo. Concept of refraction, refractive indices and reflection. Types of reflectance: specular, diffuse and mixed.

February 7 – Friday – Continue registration of hyperspectral data sets.

Reading assignment:

6. Clark, R. N., 1999, Spectroscopy of Rocks and Minerals and Principles of Spectroscopy: in Remote Sensing for the Earth Sciences, Manual of Remote Sensing, 3rd Ed., Vol. 3, Chapter 1, pp. 3 – 58. John Wiley and Sons, Inc.

February 10 – Monday – Physics of spectra. Electronic processes: Crystal field effects, Charge Transfer, Conduction Bands, and Color Centers. Vibrational Processes: fundamentals, overtones and combinations.

Reading Assignments:

7. Clark, R. N., et. al., 1990, High Spectral Resolution Reflectance Spectroscopy of Minerals: Jour. Geophys. Res., Vol. 95, No. B8, pages 12-653 to 12-680.

8. Hunt, G. R., and Salisbury, J. W., and Lenhoff, C. J. (later), 1970 – 1976, in Modern Geology, Visible and near infrared spectra of minerals and rocks:

- I. Silicate Minerals, Vol. 1, pp. 283 -300.
- II. Carbonates, Vol. 2, pp. 23 – 30.
- III. Oxides and Hydroxides, Vol. 2, pp. 195 – 205.
- IV. Sulphides and Sulphates, Vol. 2, pp. 1 – 14.
- V. Halides, Phosphates, Arsenates, Vanadates and Borates, Vol. 3, pp. 121 -132.
- VI. Additional Silicates, Vol. 4, pp. 85-106.
- VII. Acidic Igneous Rocks, Vol. 4, pp. 217 -224.
- VIII. Intermediate Igneous Rocks, Vol. 4, pp. 237 -244.
- IX. Basic and Ultrabasic Igneous Rocks, Vol. 5, pp. 15 -22.
- XI. Sedimentary Rocks, Vol. 5, pp. 211 – 217.
- XII. Metamorphic Rocks, Vol. 5, pp. 219 – 228.

9. Hunt, G. R., and Ashley, R. S., 1979, Altered rock spectra in the visible and near infrared: in Econ. Geology, Vol. 74, 1613 – 1329.

10. Lee, and Raines, G. L., 1984, Reflectance spectra of some alteration minerals (iron oxides and sulfates notably): Chart in U. S. Geol. Survey, Open File Report 84 – 96.

11. Taranik, D. L., and Kruse, F. A., 1989, Iron mineral reflectance in geophysical and environmental research imaging spectrometer (GERIS) data: in Proc. 7th Thematic Conference on Remote Sensing for Mineral Exploration Geology, Environmental Research Institute of Michigan, Ann Arbor, MI. With accompanying term paper.

12. Kruse, F. A., and Tarantik, D. L., 1990, Mapping hydrothermally altered rocks with the Airborne Imaging Spectrometer (AIS) and Airborne Visible/Infrared Imaging Spectrometer (AVIRIS): in Proc. 8th Thematic Conference on Remote Sensing for Mineral Exploration Geology, ERIM, Ann Arbor, MI.

13. Miller, N. L., and Elvidge, C. D., 1985, The Iron Absorption Index: A comparison of ratio-based and baseline-based techniques for the mapping of iron oxides: in 4th Thematic Conference on Remote Sensing for Exploration Geology, ERIM, Ann Arbor, MI.

14. Thompson, A. J. B., Hauff, P. L. and Robitalle, A. J., 1999, Alteration mapping in exploration: application of short-wave infrared (SWIR) Spectroscopy: in SEG Newsletter, no. 39, pp. 1 continued to 16 – 27.

February 12 – Wednesday – Scattering Processes, Introduction to Mixtures, Grain Size Effects. Continuum and Band Depth. Continuous-Removed Spectral Features.

Reading Assignment:

15. Kruse, F. A., 1999, Visible-Infrared Sensors and Case Studies: in Remote Sensing for the Earth Sciences: Manual of Remote Sensing, 3rd Ed., Vol 3. pp. 567 – 611. John Wiley and Sons. Also go to the Web, type in hyperspectral and surf for the latest information.

16. Green, R. O., et. al., 1998, Imaging Spectroscopy and the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS): in Remote Sensing of the Environment, vol. 65, pp 227 -248. Elsevier Science Inc., New York. Also see: Inflight Validation of AVIRIS Calibration, Calibration of the Airborne Visible/Infrared Imaging Spectrometer in the laboratory, FLAASH, A MODTRAN4 atmospheric correction package for hyperspectral data retrievals and simulations, and surface and atmospheric parameter retrieval from AVIRIS data: The importance of non-linear effects. (These papers from proceedings of the annual AVIRIS conferences).

February 14 – Friday – Begin hyperspectral analysis of data sets. Jim at Rice University for evaluation of Graduate Professional Degree Programs.

Reading Assignment:

17. Ben-Dor, Irons, J. R., and Epema, G. F., 1999, Soil Reflectance: in Remote Sensing for the Earth Sciences, Manual of Remote Sensing, 3rd Ed., Vol. 3, Chapter 3, pp. 111 – 188. John Wiley and Sons.

February 17 – Monday – PRESIDENTS DAY HOLIDAY, NO CLASS

February 19 – Wednesday – Reflectance spectra of rocks and soils

18. Ustin., S. L., et. al., 1999, Geobotany: Vegetation Mapping for Earth Sciences: in Remote Sensing for the Earth Sciences, Manual of Remote Sensing, Vol. 3, Chapter 4, pp. 189 – 248. John Wiley and Sons.

19. Elvidge, C. D., 1988, Vegetation Reflectance Features in AVIRIS data: in Proc. 6th Thematic Conference on Remote Sensing for Exploration Geology, ERIM, Ann Arbor, MI.

February 21 – 28 – AVIRIS Meeting at JPL. Class to attend meeting voluntarily.

March 3 – Monday – Reflectance spectra of vegetation.

20. Mustard, J. F., and Sunshine, J. M., 1999, Spectral Analysis for Earth Science: Investigations Using Remote Sensing Data: in Remote Sensing for the Earth Sciences: Manual of Remote Sensing, 3rd Ed, Chapter 5, pp. 251 – 306. John Wiley and Sons.

21. Adams, J. B., Smith, M. O. and Gillespie, A. R., 1989, Simple models for complex natural surfaces: A strategy for the hyperspectral era of remote sensing: in Proc., IGARSS '89, the International Geoscience and Remote Sensing Symposium of IEEE.

22. van der Meer, F., 1996, Spectral mixture modeling and spectral stratigraphy in carbonate lithofacies mapping: in Photogrammetry and Remote Sensing, Vol. 51 – 150 – 162.

23. van der Meer, F., 1995, Spectral Reflectance of Carbonate Mineral Mixtures and Bidirectional Reflectance Theory: Quantitative analysis techniques for application in remote sensing: in Remote Sensing Reviews, Vol. 13, pp. 67 – 94.

24. van der Meer, F., 1994, Extraction of mineral absorption features from high-spectral resolution data using non-parametric geostatistical techniques: in Int. J. Remote Sensing, Vol., 15, no. 11, 2193 – 2214.

25. van der Meer, F., 1996, Classification of remotely-sensed imagery using an indicator kriging approach; application to the problem of calcite-dolomite mineral mapping: in Int. J. Remote Sensing, 1996, vol. 17.

26. Adams, J. B., Smith, M. O., and Gillespie, 1989, A mixing-model strategy for analyzing and interpreting hyperspectral images: in Remote Geochemical Analysis, Elemental and Mineral Composition, Pieters and Englert, Editors.

27. Possolo, A., Adams, J. B., and Smith, M. O., 1989, Mixture Models for Multispectral Images: in Jour. Geophysical Research. Unknown date of actual publication.

March 5 – Wednesday – Spectral variability and spectral mixtures.

March 7 – Friday – Continue laboratory work.

March 10 – Monday – Take Home Mid-Term Examination Handed Out.

March 12 – Wednesday – Work on Mid-Term Examination

March 14 – Wednesday – Mid-Term Examination Due at beginning of Class. Enjoy your Semester Break. Jim in Washington, D. C. for Space Grant and NASA Meetings.

Reading Assignment:

28. Harris, J. R., Viljoen, D. W., and Rencz, A. N., 1999, Integration and Visualization of Geoscience Data: in Remote Sensing for the Earth Sciences, Manual of Remote Sensing, Vol. 3, Chapter 6, pp. 307 – 354. John Wiley and Sons.

March 24 - Monday – Review of Mid-Term Examination

Reading Assignment:

29. Salisbury, J. W., Spectral Measurements Field Guide: Earth Satellite Corporation.

30. Clark, et. al., 1999, Surface Reflectance Calibration of Terrestrial Imaging Spectroscopy Data, a Tutorial using AVIRIS, USGS Open File Report. Available on the Web at speclay.cr.usgs.gov/Papers.

March 26 – Wednesday – Introduction to field measurement of spectral reflectance

March 28 – Friday – Review of progress on Lab Projects

March 31 – Monday - Field measurement of spectral reflectance lab.

31. Cudahay, T. J., et. al., 1999, Mapping surface mineralogy and scattering behavior using backscattered reflectance from a hyperspectral mid-infrared airborne CO₂ Laser System (MIRACO2LAS): in IEEE Transactions on Geoscience and Remote Sensing, Vol 37, no. 4 July 1999. pp. 2019 – 2034.

April 7 – Monday – Atmospheric Correction of Hyperspectral Data – MODTRAN

April 8 – Wednesday – Atmospheric Correction of Hyperspectral Data – ATREM

April 10 – Friday – Review of Progress on Term Projects

April 14 – Monday – Atmospheric Correction of Hyperspectral Data ACORN.

April 16 – Wednesday – Atmospheric Correction of Hyperspectral Data FLAASH

April 18 – Friday – Review of Progress on Term Projects

April 21 – Monday – Review of Current Airborne Hyperspectral Systems

April 23 – Wednesday – Review of Current Spaceborne Hyperspectral Systems

April 25 – Friday – Review of Progress on Term Projects

April 28 – Monday – Hand Out Take Home Final Examination

April 30 – Wednesday – Student Talks on Term Projects

May 5 – Monday – Review of Material, Hand in Term Projects

May 7 – Wednesday – Finals Preparation Day

May 12 – Monday – Hand in Take Home Final Examination

December 10 – Monday Student Oral Papers Presented.

December 14 – TERM PAPERS DUE! Turn in to Lori Rountree NLT 4:30 PM

December 17 – Monday – FINAL EXAMINATION 12:00 NOON – 2:00PM

December 21 – Thursday – Grades Due, Faculty released until January 15th

**TOPICAL OUTLINE – REMOTE SENSING FOR GEOLOGIC APPLICATIONS –
REFLECTANCE SPECTROSCOPY**

I. INTRODUCTION TO ELECTROMAGNETIC REMOTE SENSING

Electromagnetic Radiation (EMR)

1. Review of Theories for Electromagnetic Radiation
 - a. Wave Theory
 - (1) Characteristics of Electromagnetic waves
 - (2) Maxwell's Electromagnetic Field Equations
 - (a) Wave behavior of EMR described by Maxwell's Equations
 - (b) Electric Vector, Induction Vector, specific conductivity
 - (c) Magnetic Vector, Displacement Vector, Current Density
 - (d) Induction Vector, permeability and permittivity
 - (e) Wave propagation equations
 - (3) Concepts of wavelength and frequency

f = Frequency = in cycles per second

Note: 1 Hertz = 1 cycle per second

w = Wavelength= distance in nanometers or micrometers between two consecutive like elements in a wave representation (peak to peak, trough to trough)

(4) Concept of wavenumber: number of waves in 1 cm.

b. Quantum Theory

(1) Photons:

- elementary particle with zero mass
- travel at the velocity of light
- transport energy and momentum
- energy transported is proportional to wavelength

(2) Concept of Quanta. Discrete packets of energy: **Photon Energy**

Planck's constant

(3) Number and spectral makeup of photons gives: **Total energy**

(4) Rate at which energy is propagating: **Radiant Flux or Power**

Units: watts (**w**)

(5) Rate at which the radiant flux is delivered to a surface: **Irradiance**

Units: **w** per meter squared

(6) Radian, unit solid angle (steradian):

(7) The radiant flux exiting a surface: **Radiant Emittance**

Units: **w** per meter squared

(8) Flux per unit solid angle in a direction: **Radiant Intensity**

Units: watts per meter squared per steradian

(9) Flux per unit projected area per unit solid angle from a surface:
Radiance

2. Sources of EMR

a. The Sun

(1) Origin of EMR from the Sun

(2) Internal constitution of the Sun

- Core, intermediate interior, convection zone,
- Photosphere
- 500 km thick

--Photons emitted have only a small probability of being absorbed or scattered and therefore exit the photosphere and travel through the chromosphere, through free space to the Earth's outer atmosphere

--Most of radiation received at Earth is emitted from the surface of the Photosphere down to 100km.

--Temperature at top of Photosphere = 4300 degrees Kelvin

--Effective temperature for whole layer = 5780 degrees K

- Chromosphere
- Corona

(3) Physics of EMR from the Sun

(a) Concept of a perfect radiator and absorber: **Blackbody**

(b) Planck blackbody radiation equation for the spectral radiant exitance from a surface:

T = temperature in Kelvin degrees

(c) Concept of spectral emissivity: **Radiant Spectral Emittance**

(d) Ability of a material to allow radiant flux to pass through it:

Transmissivity, spectral transmittance

(e) Ability of a material to reflect incident flux incident upon it:

Reflectivity, spectral reflectance

(f) Ability of a material to convert incident flux incident upon it to another form of energy: **Absorptivity, spectral absorptance**

(g) Conservation of energy: **Kirchoff's Law**

(h) Emissivity must be numerically to the absorptance for surfaces in thermodynamic equilibrium:

(i) Total exitance from a blackbody at all wavelengths, **Stephan Boltzmann Equation:**

(j) Determination of the wavelength at which peak radiance occurs: **Wein's Displacement Law**

(4) Properties of EMR from the Sun

- Blackbody curve for 5780 Kelvin Degrees Solar radiation
- Spectral distribution of solar radiation outside of the Atmosphere
 - Fraunhofer absorption lines
 - Solar irradiance curve outside the atmosphere

(5) Radiometric concepts, definitions and units

- Inverse-Square Law for Irradiance from a point source
 - (a) The irradiance from a point source at a distance r:
- Concept of Sun angle, solar incidence angle
- Concept of a Lambertian surface
 - (a) A Lambertian reflector is characterised by:

A Lambertian surface shows a decrease in intensity that approaches zero at incidence angles of 90 degrees.

(b) The radiance along the normal from a Lambertian surface:

The radiance from a Lambertian surface is the same in all directions because as the incidence angle increases the projected area increases.

(c) For a Lambertian surface the radiance and radiant exitance are related by:

- b. Introduction to atmospheric effects on EMR
 - (1) Exoatmospheric solar irradiance:
 - (2) Atmospheric path transmission:
 - (3) Direct solar spectral irradiance at sea level:
 - (4) Downwelled radiance from the atmosphere (Skylight)
- c. Reflected background radiance from adjacent landscape features
- d. The Earth
 - (1) Sources for EMR from the Earth
 - The Earth's Natural Radiation
 - Reflectance from the Earth
 - Concepts of reflection, refraction, absorption and transmission of EMR, Kirchoff's Law reviewed
 - Blackbody curve for a 300 degree Kelvin Earth
 - Spectral distribution for EMR from the Earth
 - Overlap of Earth and Solar Radiation
- e. The Moon and Starlight
- f. Artificial Sources

Concept of the Electromagnetic Energy Spectrum

- 1. Classification Scheme for the Electromagnetic Energy Spectrum
 - a. Units, micrometers, microns, nanometers, Angstroms
 - b. Solar Reflected Energy Spectrum
 - Ultraviolet Spectrum (UV)
 - Visible Spectrum (VIS) – 50% of solar energy received
 - Near-Infrared Spectrum (NIR)
 - Short-Wave Infrared Spectrum (SWIR)
 - c. Emitted Infrared Energy Spectrum
 - Mid-Wave Infrared (MIR)
 - Overlap Region between Short-Wave IR and Mid-Wave IR
 - Long-Wave Infrared (LWIR)
 - d. Microwave Electromagnetic Spectrum
 - Millimeter Wave
 - Microwave Radiometry
 - Radio Detection and Ranging (Radar)
 - X - Band
 - C - Band
 - L - Band

- P - Band

Energy Path Concept

1. Source
 - a. The Sun and its relationship to the Earth
 - Concept of Solar Constant, solar variability and sunspots
 - Effects of variations in distance of the Earth to the Sun
 - Effects the Earth's orbital attitude with respect to the Sun
 - b. Effects solar insolation.
2. Transmitting Media
 - a. Effects of space environment on Solar radiation
 - b. Interactions from the top of Earth's atmosphere to Earth's surface
 - (1). Concept of atmospheric path length and incidence angle
 - (2) Physics of atmospheric absorption
 - (a) Theory for absorption by gases in atmosphere
 - (b) Effects of absorption by water vapor
 - (c) Effects of other gases in reflected solar energy spectrum
 - (3). Physics of atmospheric scattering
 - (a) Rayleigh Scattering
 - Symmetric in both forward- and back- scatter

Note: Scattering varies inversely as the fourth power of wavelength. Shorter wavelengths are scattered more.
 - (b) Mie and Non-selective scattering
 - Mie scattering is highly forward-scattered, and interaction is mostly by wavelengths about the same size as the particles. (e.g. dust, looks brown)
 - Non-selective scattering involves particles very much larger than the incident wavelengths of energy (e.g., clouds, looks white)
 - (4) Concepts of Sunlight, Daylight, Skylight and Scattered light
 - (5) Concept of upwelled radiance, Haze
3. Interactions of Solar reflected radiation at the Earth's Surface
 - a. Possible irradiance conditions at the Earth's Surface
 - b. Bidirectional reflectance distribution function
 - (1) Specular, diffuse, and mixed reflectors
 - c. Reflected Solar Radiation
 - d. Fluorescence – Fraunhofer line luminescence
 - e. Concept of Surface Cover
 - (1) Surface cover types
 - (a) Minerals
 - (b) Consolidated rocks, aggregates of minerals
 - (c) Unconsolidated rock weathering products
 - (d) Soils
 - (e) Coatings on rocks and soils
 - (f) Vegetation
 - (g) Water, snow and ice
 - (h) Culture
 - (i) Mixtures of surface cover types
 - f. Concept of surface cover patterns
 - g. Concept of surface topography
 - h. Concept of topographic patterns
 - Concept of landform pattern

- Concept of drainage pattern
- h. Adjacency effects of topography and surface cover
- 4. Solar radiance at the sensor
 - a. Path radiance, upwelling solar scattered radiance
 - b. Haze revisited
- 5. Sensor Energy Path
 - a. Effects of Optics
 - (1) Transmission
 - (2) Polarization
 - (3) Newton's Diffraction limit for optics
 - b. Properties of solid-state detectors and focal planes
 - (1) Concept of Radiometric Resolution
 - (2) Concept of Detectivity
 - (3) Chopping frequency and Modulation Transfer Function
 - (4) Concept of Detector Gain and Offset
 - (5) Concept of Spectral Detectivity
 - c. Formatting sensor measurements to radiometric data

Concepts of Measurement, Data and Spectral Information

1. Concept of Ground Instantaneous Field of View
 - a. Units of measurement
2. Concept of Spatial Resolution in Image Data
 - a. Concept of Test Object Contrast (TOC), camera and film resolution
 - b. Concept of solid-state sensor resolution
 - Detector resolution and GIFOV
3. Concept of reflection
 - a. Concept of specular reflection
 - b. Concept of diffuse reflection
 - c. Concept of mixed reflection
 - d. Concept of diffuse hemispherical reflection
4. Introduction to the concept of spectral reflectance
 - a. Minerals (molecules) have discrete energy levels and can absorb only specific amounts of energy, photons with specific wavelength
 - b. Processes that cause photons to be absorbed:
 - (1) **Electronic processes**, interactions between electrons and crystal fields:
 - **Crystal Field Effects** in Minerals
 - Energy level of ion split and displaced in crystal field
 - Determined by:
 - Valence state
 - Coordination Number
 - Symmetry
 - Iron the most important mineral (Fe²⁺ and Fe³⁺ substitute for Mg²⁺ and Al³⁺)
 - **Electronic Charge Transfer**
 - Electrons transfer from one atom to another
 - Fe->O transfer responsible for broad absorption band in visible blue.

- Color Centers

- Electrons trapped in structural defects in crystal lattice
- Fluorite, CaF₂ where fluorine atom is missing and replaced by an electron

- Conduction bands in metals

(1) Vibrational processes

- Fundamental vibrations
 - Absorbed energy from photons causes molecular vibration
 - Molecules vibrate at different frequencies depending on their structure and number of atoms
 - For minerals, absorptions occur beyond 2.5 μ m (Si-O, Al-O)
- Overtones – multiples of the fundamental frequency, 2 ν ₁, 3 ν ₂
- Combinations – sums and differences of fundamental or overtone frequency ν ₁ + ν ₂, 2 ν ₁ + ν ₃
Frequencies add (not wavelengths)

(2) Water Vapor Vibrations

- Absorption Fundamental Vibrations
 - Symmetric Stretch ν ₁ = 2.734 μ m
 - Bend ν ₂ = 6.271 μ m
 - Asymmetric stretch ν ₃ = 2.663 μ m
- Water Vapor Combination Absorptions in VNIR and SWIR
 - ν ₂ + ν ₃ = 1.865 μ m
 - ν ₁ + ν ₃ = 1.379 μ m
 - ν ₁ + ν ₂ + ν ₃ = 1.135 μ m
 - 2 ν ₁ + 3 ν = 0.942 μ m

(3) Liquid Water Vibrations

- | | | |
|-------------|---|-----------------|
| Fundamental | ν ₃ | = 2.903 μ m |
| | ν ₂ | = 6.08 μ m |
| Overtones | 2 ν ₃ | = 1.4 μ m |
| Combination | ν ₂ + ν ₃ | = 1.9 μ m |

(4) Hydroxyl Vibration (OH)

5. Common absorption features and their cause
6. Mineral spectral absorption bands
7. Introduction to mineral absorption features
8. Introduction to soil spectral features
9. Introduction to vegetation spectral features
10. Introduction to spectral features of culture
11. Concept of spectral resolution
12. Concept of spectral signature, spectra

13. Correction for atmospheric effects on spectral signatures
 - a. Radiative transfer models
 - b. Atmospheric correction models

II. BASIS FOR HYPERSPECTRAL REMOTE SENSING IN GEOLOGY

Spectral Libraries for Earth Materials

1. Laboratory instrumentation and software
 - a. Calibration
 - b. Concepts of mineral and spectral purity
2. USGS spectral library
3. JPL spectral library
4. Other spectral libraries

Reflected Spectral of Minerals and Rocks

1. Spectra of Silicates
2. Spectra of Carbonates
3. Spectra of Oxides and Hydroxides
4. Spectra of Sulphides and Sulphates
5. Spectra of Halides, Phosphates, Arsenates, Vanadates and Borates
6. Spectra of Acidic Igneous Rocks
7. Spectra of Intermediate Igneous Rocks
8. Spectra of Basic and Ultrabasic Igneous Rocks
9. Spectra of Sedimentary Rocks
10. Spectra of Metamorphic Rocks
11. Spectra of Alteration Minerals

Soil Spectra

1. Properties affecting reflectance spectra of soils
 - a. Nature of the surface
 - b. Organic material present
 - c. Size of constituents
 - d. Presence of oxide minerals, iron, manganese, etc.
 - e. Presence of clays and carbonates
 - f. Moisture content

Vegetation Spectra

1. Vegetation constituents affecting spectra
 - a. Water content
 - b. Chlorophyll content
 - c. Cellulose and lignin

- d. Plant structure, wood, bark
 - e. Nitrogen components, pigments, proteins
 - f. Presence of acids, waxes, sugars and starch
 - g. Density of canopy
 - h. Plant litter under canopy
2. Photon interactions within leaves
 3. Importance of EMR interaction geometry
 4. Vegetation spectral properties
 5. Stressed vegetation

Concepts of spectral purity, spectral variability and spectral mixtures

1. Concept of integration of spectral response in the sensor GIFOV

Definitions and units of Measurement

1. Multispectral, hyperspectral and ultraspectral sensors
2. Wavenumbers, Micrometers, Microns, Nanometers and Angstroms

Concepts of radiometric measurement, spectral data and spectral information, spatial data and spatial information

E. Concepts of Landscape Information, Geological Information and Geological Models

1. Concept of landscape information
2. Models and assumptions used in interpretation of spatial and spectral information to landscape information.
 - a. Spatial distribution of surface cover patterns
 - b. Spatial distribution of topographic patterns
3. Interpreting landscape information to deduce geologic information.
 - a. Surface cover, landform and drainage = lithology, structure, and process.
 - b. Rock sequence, sequence geometry, discontinuities = structure
 - c. Inferred movement picture and emplacement sequence = geodynamics
 - d. 3-D Geologic models of the crust
4. Types of Geological Information
5. Development of exploration models from geologic information

III. FIELD MEASUREMENT OF SPECTRAL REFLECTANCE

A. Principles and Practice of Field Spectrometry

1. Effects of the environment on spectral measurements
 - a. Solar variability
 - b. Atmospheric effects
 - c. Secondary effects
 - d. Effects of clouds and haze

- e. Wind
- 2. Effects of the environment on field instruments
 - a. Temperature, including wind chill
- 3. Comparison of available field spectrometer instruments
 - a. ASD FieldSpec FR
 - b. GER 3700
 - c. GER Mark V
 - d. Pima II
- 4. Methodologies for field investigations
- 5. Analysis of field spectrometer data
- 6. Laboratory exercises with the ASD FieldSpec FR
- 7. Field exercises with the ASD FieldSpec FR

IV. SENSORS AND SYSTEMS FOR HYPERSPECTRAL REMOTE SENSING

A. Hyperspectral sensors

- 1. History of the development of aerospace spectral measurements
 - a. NASA Airborne Multispectral Scanners – Silver Bell Case History
 - b. NASA Landsat Multispectral Scanner – Goldfield Case History
 - c. GER Airborne Spectroradiometer – Virginia City Case History
 - d. JPL Shuttle Multispectral Infrared Radiometer
 - e. NASA Satellite Thematic Mapper – Goldfield Case History
 - f. JPL Airborne Imaging Spectrometer – Cuprite Case History
Virginia City Case History
Tybo Mining District Case History
 - g. GER Imaging Spectrometer – Cuprite Case History
- 2. Current and planned hyperspectral sensors
 - a. Advanced Visible and Infrared Imaging Spectrometer (AVIRIS)
Bodie Case History
Cuprite Case Histories
Virginia City Case Histories
 - b. ITRES Research CASI
 - c. GEOSCAN
 - d. HYDICE, MIVIS
 - e. Texaco
 - f. ESSI Probe 1
 - f. Hyperspectral Imager, Lewis
 - g. ARIES
 - h. Warfighter, OSC

B. Hyperspectral Measurement Science

- 1. Spectrometer conceptual design
- 2. Linear array imaging
- 3. Areal array imaging
- 4. Attributes of hyperspectral imagers
 - a. Spatial Resolution and Ground Sample Resolution

- b. Modulation Transfer Function
- c. Point Spread Function
- d. Spectral Range and Spectral sampling interval
- e. Spectral Resolution
- f. Spectral point spread function
- g. Spectral MTF
- h. Noise Equivalent Radiance
- i. Signal to Noise Ratio
- j. Atmosphere
- k. Optics
- l. Dark current of detector
- m. Quantization

V. ANALYSIS OF SPECTRAL DATA

A. Nature of Hyperspectral Data

B. Calibration of Hyperspectral Data

1. Radiometric Calibration
 - a. Bad lines and bad pixels
 - b. Bad bands
 - c. Detector gain and offset problems, striping
2. Wavelength Calibration
3. Reflectance Calibration
 - a. Empirical
 - b. Model Based
 - c. Measured Radiance
 - d. Empirical methods
 - (1) Residual Images
 - (2) Flat Field Correction
 - (3) Internal Average Relative Reflectance
 - (4) Log Residuals
 - (4) Empirical Line Method
 - e. Model based methods
 - (1) ATREM
 - (2) ATREM plus ground spectra
 - (3) Green's Atmospheric Model, MODTRAN3
 - f. Empirical Flat Field Optimal Reflectance Transformation (EFFORT)

C. Standard Radiometric and Geometric Processing of Hyperspectral Data

1. Processing to a Data Cube, Level 1 (Cube Generation Model)
2. Radiometric Calibration of Data Cube, Level 1R1 (Cube Calibration Model)
3. Correction for bad data lines, Level tmp (Pixel Quality Assurance Model)
4. Atmospherically corrected surface reflectance data cube, Level 1R2 (Atmospheric Removal Model)
5. Geocoded data cube, Level 1G1, (Geocoding Model)

D. N-dimensional nature of hyperspectral data

1. 2-d scatterplots
2. N-dimensional visualization of hyperspectral data

E. Introduction to Environment of Visualizaing Images (ENVI)

1. Data Reduction to Apparent Surface Reflectance
2. Spectral/Spatial Browsing
3. Using spectral libraries
4. Using color images in spectral analysis
5. Spectral Data Reduction and Noise Segregation (MNF)
6. Spatial Data Reduction, pixel purity (PPI)
7. Selection of Endmembers
8. Identification of Endmembers
9. Mapping of Endmember distributions and abundances
 - a. Spectral similarity, Binary Encoding, Spectral Angle Mapper (SAM)
 - b. Semi-quantitative Mineral Abundances and Spectral Unmixing
 - c. Concept of Convexity and Convex Geometry
 - d. Spectral matching and Spectral Feature Fitting (SFF)
 - e. Partial unmixing, Class Collapsing and Matched Filtering
 - f. Mixture-Tuned Matched Filtering