REMOTE SENSING OF THE EARTH & PLANETS
Morning Exercises!

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• Does all matter emit radiation/light/energy/photons?
• What is Light?

• How is light produced?

• How does light propagate through space?
• **What is Light?**
  
  – Energy: either wave or particle

• **How is light produced?**
  
  – Energizing atomic particles: electrons orbiting an atom's nucleus or protons neutrons in the nucleus.
  
  – chemiluminescence

• **How does light propagate through space?**
  
  – Self-propagating wave: Energizing or accelerating a charge produces a change in the electric field which in turn produces a change in the magnetic field, etc.

All matter has an internal property of energy, remember $e=mc^2$
Wavelengths can be smaller than an atom, like gamma rays or larger than skyscrapers, like radio waves. Shorter wavelength and high energy radiation is most harmful. Radiation on left side of the spectrum can interact with cells and can even alter DNA.
Amplitude: The height of a wave from the average center.
Wavelength: Length from one peak to the next in a wave.

Frequency: The number of waves in some length.
Light can be described by the wavelength or frequency.
**Electromagnetic Spectrum**

**Electromagnetic** means energy is carried in form of rapidly fluctuating electric and magnetic fields.

Changing electric and magnetic fields creates a self-sustaining **electromagnetic wave**.

The self-sustaining wave, **allows light to travel through space**. A medium like air is not needed to carry it.

Electromagnetic wave = transverse wave
Transverse means at right angles
Transverse waves get their name from how the electric and magnetic components of the electromagnetic spectrum are at right angles.
Common spectroscopy techniques and their origin:

\( \gamma \text{-ray} \): Rearrangement of elementary particles in nucleus

\( X \text{-ray} \): Transition of inner electrons in atoms

\( \text{UV-Visible} \): Transition of valence electrons

\( \text{Raman & Infrared} \): Vibrational transitions

\( \text{Microwave} \): Rotational transitions

\( \text{ESR (Electron spin resonance)} \): electronic spin transition in magnetic field

\( \text{NMR (Nuclear magnetic resonance)} \): Nuclear spin transitions in magnetic field.
Electromagnetic Radiation

Because different wavelengths of energy are sensitive to different materials, it is important to define the science objectives of a planetary mission.

- do you want to study the atmosphere of a planet?
- do you want to study the near-surface of a planet?
- do you want to study the structure of the upper crust of a planet

Missions typically carry multiple instruments that as a whole are designed to provide the most knowledge about a place in order to meet the specified science objectives.
Categories of remote Sensing

Instrument Types
- Active – Energy is sent and received by instrument
  - Name a few
- Passive – Instrument only receives incoming (natural) energy
  - Name a few

Proximity
- Contact
- Standoff
- Orbital (remote)
Visible & Near Infrared (VIS-NIR) Spectroscopy

Visible-Near Infrared (VIS-NIR) spectrometers measure the amount of sunlight reflected off of an object at visible wavelengths & beyond into the near-infrared.

Different materials will reflect or absorb light in different ways, and we can use these differences to estimate what the surface is made of.

Light is commonly absorbed in this wavelength range due to the presence of transition elements (Fe, Ti, etc.), in which electrons can jump orbital shells, or by vibration of molecules (H₂O, CO₂, etc.).

VIS-NIR spectrometers are probably the most common instrument used on Earth satellite systems. They have been used for many decades and can provide images that are equivalent to what the human eye can see.

Earth examples include Landsat, MODIS, Ikonos, GeoEye-1, etc.
The current method of VIS-NIR spectroscopy for remote sensing is to acquire images of the surface at many different wavelengths of light.

A terrestrial example is the AVIRIS instrument, which is a VIS-NIR hyperspectral imaging system that flies on an airplane and measures reflected sunlight.

A plot of reflected light versus wavelength is known as a reflectance spectrum, and an image cube will have one for each and every pixel.
Visible & Near Infrared (VIS-NIR) Spectroscopy

The VIS-NIR region of ‘light’ carries diagnostic information about surface composition.

Different minerals absorb or reflect light at different wavelengths, dependent on their chemistry and structure. Therefore, the spectrum of a mineral is like a ‘fingerprint’.

We can get a ‘fingerprint’ from each image pixel and then try to back out what minerals are in that location.
We also have VIS-NIR ‘image cubes’ for the Moon (Moon Mineralogy Mapper). Again, each pixel provides a spectrum that tells us about the reflectance properties of the lunar surface.

We can calculate the wavelength position and strength of absorption features and then link these features to different types of minerals.
The Sun’s energy directly warms Earth’s Atmosphere.

A) True
B) False
C) Don’t know
In addition to measuring the sunlight that is reflected off of the surface, we can also measure the energy that is emitted by a surface. This occurs at longer wavelengths (planetary objects are colder than the Sun) and if we want to observe the surface then we need to make sure the surface is warmer than the atmosphere (otherwise the warmer atmosphere would emit more energy and dominate the energy from the surface).
Measurements in the **Thermal Infrared (TIR)** can be used to:

- estimate surface temperature and atmospheric temperature
- estimate the abundances of minerals on the surface, allowing mapping of rock types (this requires modeling of the measured signal and can be non-unique!)

Warmer objects will emit more energy, but the exact amount of energy emitted at a given wavelength will also depend on the properties of that material.

The pattern of emission versus wavelength is an *emissivity spectrum.*
TIR measurements can be made at different times of day over the same spot.

Different materials will absorb and release energy at different rates (sand heats up fast, but larger rocks heat up slowly), thus we can use these types of measurements to estimate the physical properties of surface materials and better understand how the surface responds to temperature variations.
As with many spectroscopic techniques, geologists want to use TIR data (emissivity spectra) to learn about the rock types and minerals that make up the surface of a planet.

These maps can then be used to inform us about how the crust of a planet has evolved. (Is it basaltic? Are there more evolved, silica-rich, lava flows? Is there evidence of water?)

This is a map created from several TIR images acquired by the THEMIS instrument on the Mars Odyssey satellite.

In this false-color image the bright pink and blue-purple tones represent olivine-rich deposits, likely olivine-rich basalt flows.
Another spectroscopic technique is to measure the gamma rays and neutrons produced by interaction of cosmic rays with planetary surfaces.

Cosmic rays hit a surface and produce neutrons when they collide with elements. Neutrons are ejected and/or scattered at different energies, and some result in the production of γ-rays.
Gamma-ray and Neutron Spectroscopy

- These types of instruments have been used for Mercury, the Moon, Mars, Vesta and Ceres.
- γ-rays typically measure elements such as Fe, Mg, Al, Ti, Si, K, Th, S, Cl, and O.
- Technique is sensitive to upper ~1 meter.
- The accuracy/resolution of the elemental abundances is linked to the spatial resolution and to the number of counts by the detector.
- Therefore, some elements require long counting times/many orbits.

Lunar Prospector data for the Moon Gillis et al., 2004

Lawrence et al., 2002
Gamma-ray and Neutron Spectroscopy

- Neutrons are particularly useful for detecting hydrogen.
- Neutron detectors measure the relative counts of ‘fast’ thermal, and epithermal neutrons.
- When hydrogen is present it will count fewer epithermal neutrons.
- H and neutrons have similar mass, so when they collide with neutrons are slowed down.
Another useful and relatively simple measurement technique for planetary geologists is altimetry.

Laser altimetry provides information on the topographic relief, elevation, and roughness of a planet’s surface using an active system (it sends out a signal).

A laser is sent from the spacecraft, a clock starts, the laser bounces off of the surface and comes back to the detector, and the clock stops.

The travel time of the laser signal can then be used to estimate the distance to the ground, which can be converted to elevation if you know the position of the spacecraft with great precision.

This technique is relatively simple and can provide very accurate information on elevation (~10 cm or less vertical accuracy).
Elevation map of Mars from the Mars Orbiter Laser Altimeter (MOLA) instrument.
Elevation maps of the Moon from the LOLA instrument on the Lunar Reconnaissance Orbiter spacecraft.

This instrument has recently provided a whole new look at the topography of the Moon, which will help us to identify geographic features and assess the safety of landing spots for future astronauts.

More detailed information about the size and number of craters also helps us to estimate the age of planetary surfaces.
Radar is an active system (sends a signal out) that uses relatively long wavelengths of EM radiation to either examine surface properties (roughness, changes in composition) or to probe into the subsurface of a planet.

A technique known as synthetic aperture radar (SAR) is often used to create radar images of a surface and can provide information about topography. This technique was used to peer beneath the clouds of Venus during the Magellan mission and is also being used to image the surface of Saturn’s moon Titan.

It is a very useful technique for imaging the surface of planets/moons that have thick atmospheres which prohibit the penetration of shorter wavelengths (that is, places where visible or infrared light can’t reach the surface).
A SAR system was critical for imaging and mapping the surface of Venus.

Different rock types and surface types will reflect the radar signal in different ways, and these measurements can then be modeled to make estimates about surface properties.
More recently, radar systems (SAR) have been used to image the surface of Titan.

These data have revealed the presence of lakes at high latitudes and dark linear features called ‘cat scratches’, which are interpreted as dunes.

This type of radar system is excellent for looking at the surface of a planet, but many corrections must be made for the geometry of the observation and the topography of the surface, and trying to determine rock type with this technique can be rather non-unique.
Longer wavelength radar systems can penetrate beneath the surface and provide information about the stacking of rocks or layers of ice in the subsurface.

This provides important information about the geometry of layers of rock/ice, which can be used to understand how they were deposited. This technique has been particularly useful for understanding the composition and layering in the polar caps of Mars.
Different materials will reflect the radar signal in different ways, and layers of ice or buried aquifers with liquid water produce very strong reflections.

Therefore, radar systems are useful for searching for buried ice or liquid water.
Laser-induced breakdown spectroscopy (LIBS) is a technique for measuring the chemical constituents of materials.

The technique uses a high energy laser to effectively ‘melt’ a small spot on the target (such as a rock). This creates a plasma that emits energy (photons) that can be measured by a detector.

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However, LIBS is not a direct measurement of mineralogy.

It detects elements.

For the LIBS instrument on the Curiosity rover (called ChemCam), it is necessary to take along a suite of samples that will act as calibration targets.
This is an active measurement technique and it is capable of providing information about the chemical composition (not mineralogy) of materials.

A target is bombarded with alpha particles that are generated by a radioactive source (often Cu$^{244}$). It requires contact with the target (rock, soil, etc.).
The alpha particles hit the nuclei in the target and are scattered back to a group of detectors.

The energy of the scattered particles can be related to the mass of the nucleus they hit, and we can use the position and intensity of the measured signal (see graph below) to determine the abundance of different elements.

This technique is not sensitive to all elements, including very light elements, and it has a lifetime that is driven by the lifetime of the radioactive source.

This technique has been used since Lunar Surveyor landed on the Moon in 1967 and is a trusted, proven instrument for flight.

An APXS instrument is also on the Mars Science Lab rover (Curiosity).

The instrument does not measure mineralogy directly, but trends in the elemental data can be combined with other data to place constraints on which minerals may or may not be present.
In class we added the following instruments

• Mössbauer absorption spectrometry (Mars: both MER rovers)
  – In this technique a solid sample is exposed to a beam of gamma radiation, and a detector measures the intensity of the beam transmitted through the sample.
  – Used to measure state of iron Fe$^0$, Fe$^{2+}$, Fe$^{3+}$ in rocks.
• X-ray diffraction (Mars: Curiosity – CheMin)
  – X-rays generated by a cathode ray tube, filtered to produce monochromatic radiation, collimated to concentrate, and directed toward a sample
  – In a crystalline sample, minerals are identified based on constructive interference of the monochromatic X-rays.
In class we added the following instruments

• Radar used in SETI – Search for ExtraTerrestrial Intelligence
  – SETI uses Radar to listen for aliens.

• Mass spectrometry (Mars: Viking and Phoenix; Titan: Huygens probe; Comet: Rosetta; Moon: LADEE)
  – This technique that identify the amount and type of molecules present in a sample by measuring the mass-to-charge ratio and abundance of gas-phase ions.