Introduction

Since our direct samples of materials from other worlds is very limited, most of our knowledge about planetary surfaces comes from analyzing the light that they reflect. This is the idea behind the science of **remote sensing**. One way to do this is to simply examine images taken in visible light, images much like you would produce with an ordinary camera. Most of the objects you see in such an image (trees, soil, sand, snow, water, concrete . . .) do not emit their own light. Instead, we see them because they reflect sunlight (or moonlight, or light from light bulbs). However, when the light bounces off of them, some colors are reflected and others are absorbed. Things with different compositions will absorb different parts of the spectrum (*i.e.* different colors). Much more information can be obtained by carefully analyzing how much of each different *type* of light is reflected by a surface. It is particularly informative if you look at light outside of the visible spectrum. **Reflectance Spectroscopy** — the analysis of the *spectrum* of reflected light — is a fundamental tool of planetary science. It allows us to determine the properties of planetary surfaces from which we have no direct samples, or even from places on Earth where sampling would be difficult or time consuming.

Rocks are made up of a collection of minerals, and these minerals are made up of a specific collection and structure of elements (usually in a crystal structure). For example, one of the most common minerals in the Earth's mantle is called Olivine (named for its green color). It has the chemical formula [Mg_2SiO_4], meaning that it is made up of the elements Magnesium (Mg), Silicon (Si), and Oxygen (O) all arranged in a specific crystal structure. Olivine has been found in meteorites, the Moon, Mars and in comets.

When light is reflected off a rock, the various crystals in the rocks absorb different wavelengths of light. The specific wavelengths of light they absorb depends on the composition and structure of the crystal. By looking at the reflectance spectrum of a rock we can get an idea of the minerals that make up the rock. This turns out to be a very powerful tool in planetary astronomy. It allows us to determine the composition of a rock by looking at the reflected light. We do not need the have a sample in hand.

The Ground Truth

In this lab we will learn how reflectance spectroscopy can be used to determine the properties of a planetary surface. The world we will explore will be our own: the Earth. We choose the Earth because it is the world we are most familiar with, and it is a place where samples can easily be collected. Collecting samples is a very important part of remote sensing, because it allows us to establish what is called the "ground truth." Before we can recognize a lava flow on the Moon, we have to know the characteristics of light reflected from lava. In order to do that, we need a chunk of lava to bounce light off of and measure.

In order to establish the "ground truth," we are going to be using *reflectance spectrometers* to measure how much light of various colors in the spectrum is absorbed and reflected by objects we might see in images of the Earth taken from space. Instead of shining the whole continuous spectrum at the same time, these spectrometers shine one color of light at a time. Take a minute to look at your spectrometer — **DO NOT** put anything into the hole in the back! Each of the 11 buttons on the front makes a different light shine. You will not be able to see the last two lamps since they are emitting light beyond the visible spectrum. In the middle of the circle of lights is a small photodetector. The display on the front of the spectrometer gives a measure of how much light it detects.

Calibration - Making the Numbers Make Sense

1. Your TF will dim (or turn off) the lights so that you can calibrate your spectrometer without too much contamination. To be extra careful, set the spectrometer on a flat surface so that no additional light is allowed in. Do not press any of the buttons. Notice that the detector does not read zero; rather, it reads a small number. This is called the **dark current**. Write this number in the box below.
2. **Dark Current** = [ ]
3. Set the spectrometer on a flat piece of paper. Press the 600 nm button. Notice that the number you get is different from any other person in the room. This is the instrumental or **raw** number. This number depends on the particular spectrometer you are using, so is not very useful.
4. Next we need to calibrate our spectrometer so that the numbers have some meaning independent of the particular spectrometer we are using. Luckily, photographers also need to do the same type of calibration, so they have made a standard gray card that reflects 18% of the light at all wavelength.
5. Position your reflectance spectrometer flat on the gray card. Turn on the lights one at a time and hold down the button until the numbers in the display stabilize. Record the number on the display in the first column of the **Calibration Table** on the next page.
6. This is not the actual amount of light being reflected by the gray card — remember the dark current. To determine the actual amount of light being reflected by the gray card, subtract the dark offset from each measurement and record the result in the second column.
7. Next we want to find out how much light each of the bulbs is actually emitting (and thus to figure out how much light our samples are reflecting). But we know that the gray card reflects 18% (or 0.18) of the light hitting it, so we can use our previous measurements to calculate this:
8. **Light reflected by gray card = 0.18 × Light emitted from bulb**
9. Therefore, the light emitted is the measurement in the second column divided by 0.18. Record your calculations in the third column.

Collecting Data

- Now place a green leaf on a foam card, and place the spectrometer on top of the leaf. Measure the reflectance of the leaf at each of the wavelengths.
- In the first column of the **Data Table**, record the raw instrumental numbers (raw).
- In the second column of the data table (refl):
  - Take the number from the first column, subtract the dark current.
  - Divide this value by the amount of light the bulb is actually emitting (you calculated this in the last column of **Calibration Table**).
  - The numbers in the "refl" column should be between 0.0 (*i.e.* reflecting no light) to 1.0 (reflecting all the light).
  - Plot your results and connect the points.

- Now observe the rock and other leaf samples. Calculate their reflectance at each wavelength using the procedure above, and record them in the table. Plot your results on the same graph. Please use a different symbol, color, or line style to distinguish each of the lines on your plot.

Table 1: **Calibration Table - Grey Card**

	Raw Instrumental Number	Remove Dark Current (Raw - Dark)	Amount of Light Emitted by Bulb (Raw - Dark) / 0.18)
470 nm			
525 nm			
560 nm			
585 nm			
600 nm			
645 nm			
700 nm			
735 nm			
810 nm			
880 nm			
940 nm			

Table 2: **Data Table**

	Green Leaf (raw)	Green Leaf (refl)	Dead Leaf (raw)	Dead Leaf (refl)	Basalt (raw)	Basalt (refl)	Olivine (raw)	Olivine (refl)	Breccia (raw)	Breccia (refl)
470 nm										
525 nm										
560 nm										
585 nm										
600 nm										
645 nm										
700 nm										
735 nm										
810 nm										
880 nm										
940 nm										

When you take an image with a camera, the film records an image of the entire visible spectrum. Most cameras on spacecraft take images of only a small chunk of the spectra and range far beyond the visible part. To take images of just a piece of the spectrum, filters are placed in front of the camera. Two such filters are indicated by the cross-hatched regions labeled "1" and "2" on your graph.

List the three samples from brightest to darkest as seen through filter #1:

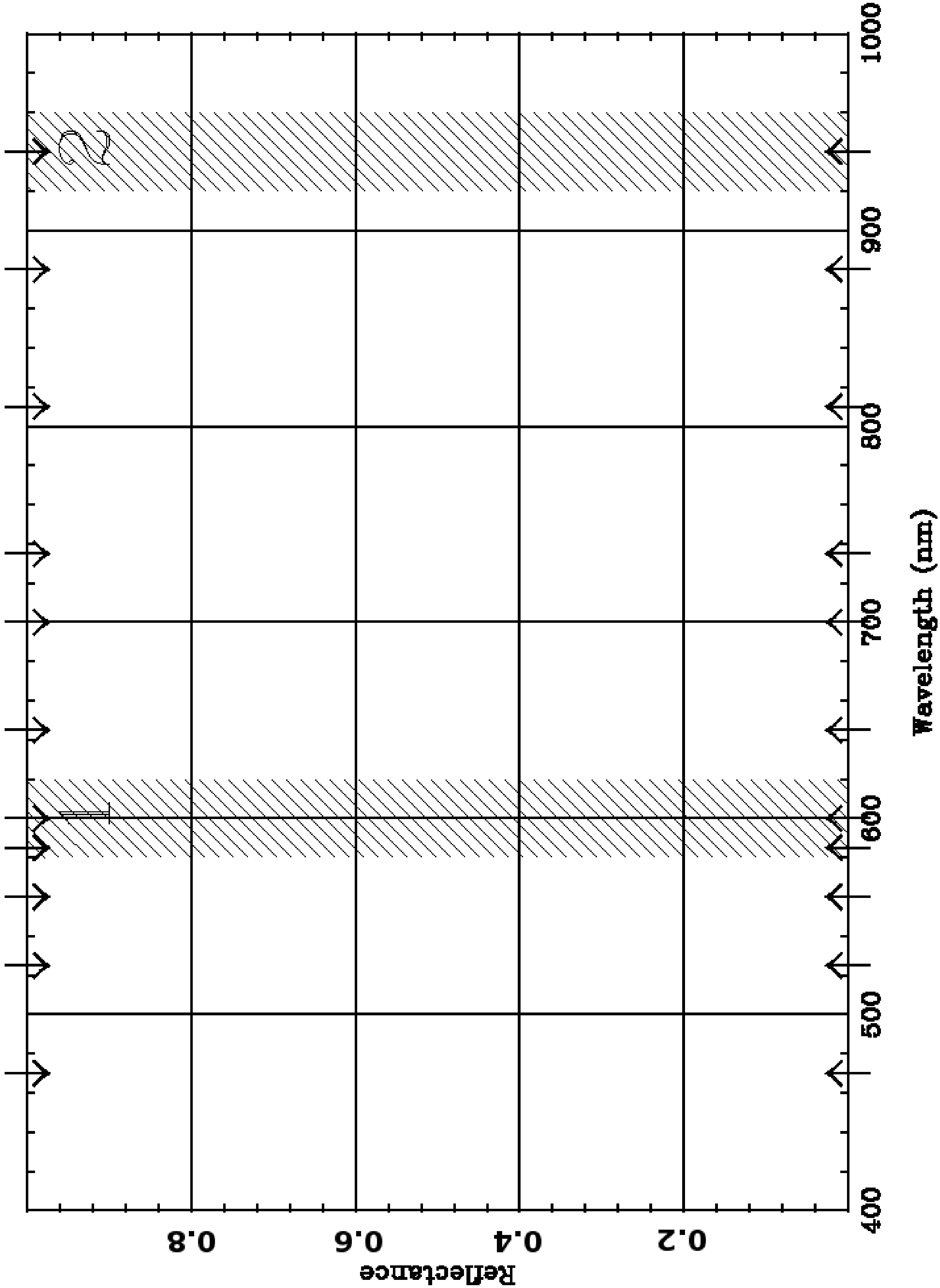
List the three samples from brightest to darkest as seen through filter #2:

Assume that you *only* have data from filters #1 and #2.

How could you distinguish Olivine from Basalt?

How could you distinguish Basalt from a Green Leaf?

How could you distinguish Olivine from Breccia?


Reflectance
0.2
0.4
0.6
0.8
Wavelength (nm)
400
500
600
700
800
900
1000
1
2

Other Worlds

Of course the surfaces of worlds in our solar system are rarely composed of pure basalt, olivine, or breccia. Mostly, they are combination of lots different material, so their reflectance spectra are usually a complicated mess. Actually determining the types and amounts of materials is quite an art. Here is a simple example. The table on the right is data from the two different surfaces made up of the materials you measured the reflectance spectra of in this lab.

Wavelength (nm)	Surface A (refl)	Surface B (refl)
470	0.27	0.08
525	0.37	0.12
560	0.38	0.12
585	0.39	0.12
600	0.39	0.11
645	0.33	0.09
700	0.32	0.11
735	0.35	0.17
810	0.22	0.20
880	0.17	0.19
940	0.16	0.18

Plot and label the data from this table on your data graph. The plot is getting crowed, so try to be neat!

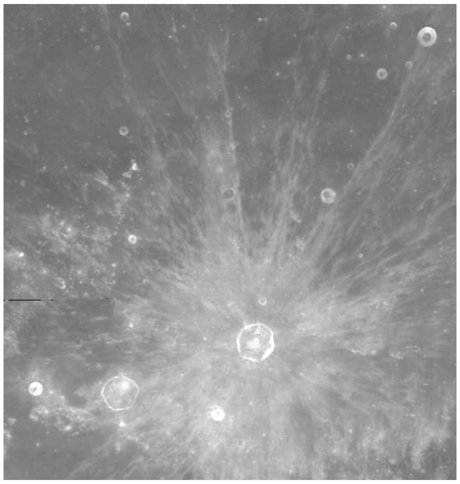
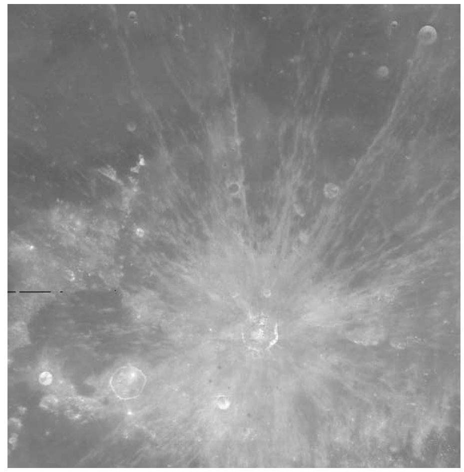
What is the most likely composition of Surface A?

What is the most likely composition of Surface B?

Now assume that you could only image the two surfaces though filters #1 and #2. Discuss if it would be possible to determine the composition of the surfaces.

The Moon

The following images of the Moon were taken with the Clementine spacecraft using filters similar to Filters #1 and #2 (left and right respectively).

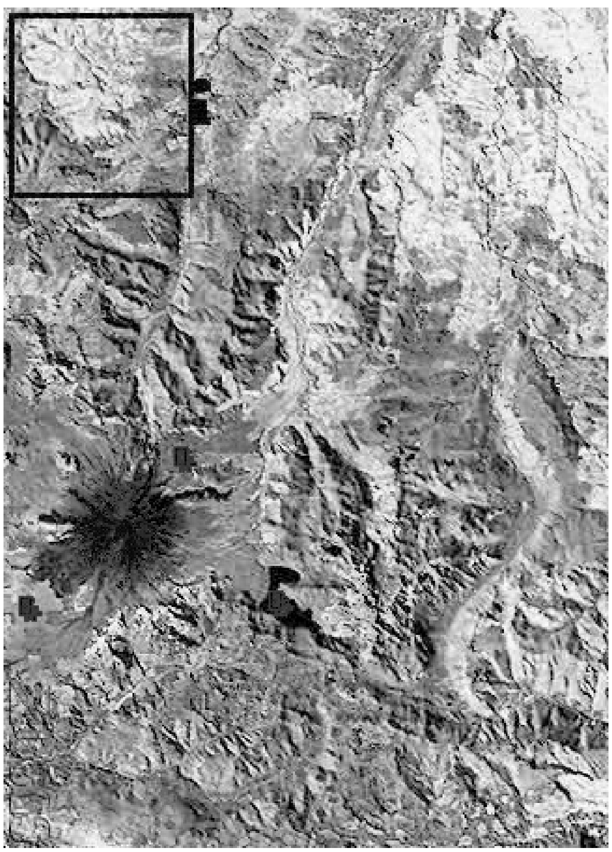
Describe any differences that you see between the two images (be as specific as possible).

Based on your reflectance spectra, what might the composition of some of the surface features be (make sure to list both the features and minerals)?

Landsat Images - Remote Sensing

Landsat are a series of Earth-observation satellites that have fundamentally changed how we look at our world. The first Landsat was launched in July of 1972 and the seventh in the series was launched April 15, 1999. The Landsat satellites image Earth at many different wavelengths, including wavelengths in the infrared. They are essentially orbiting reflectance spectrometers.

Below are two images of Mount St. Helens that were taken by the Landsat satellite through a filter that closely corresponds to our Filter #2. the peak of Mount St. Helens is the dark object near the center of the left edge of each image. The image on the left was taken in 1973 and the image on the right was taken in 1983. Mount St. Helens erupted on May 18, 1980. It is easy to see the the dramatic change between the pre- and post-eruption images.



In the 1973 image, Mount St. Helens is surrounded by material that is bright in Filter #2. Based on the data we collected, what is this material?

In the 1983 image, Mount St. Helens is surrounded by material that is darker in Filter #2. Based on the data we collected, what is this material?

Explain the reason for the change.

Assume it was possible to take a similar Landsat image of the city of Boston 200 years ago. Describe how that image would look different from one taken today, and explain the reason for this difference.