The Dark Side of Electric Lights

Forcing remote sensing into a hostile environment

Glen Ritchie[1], Jonathan Frantz[2], Craig Bednarz[3], and Bruce Bugbee[4]

[1]University of Georgia, Tifton, GA
[2]USDA-ARS, Toledo, OH
[3]Texas Tech, Lubbock, TX
[4]Utah State University, Logan, UT

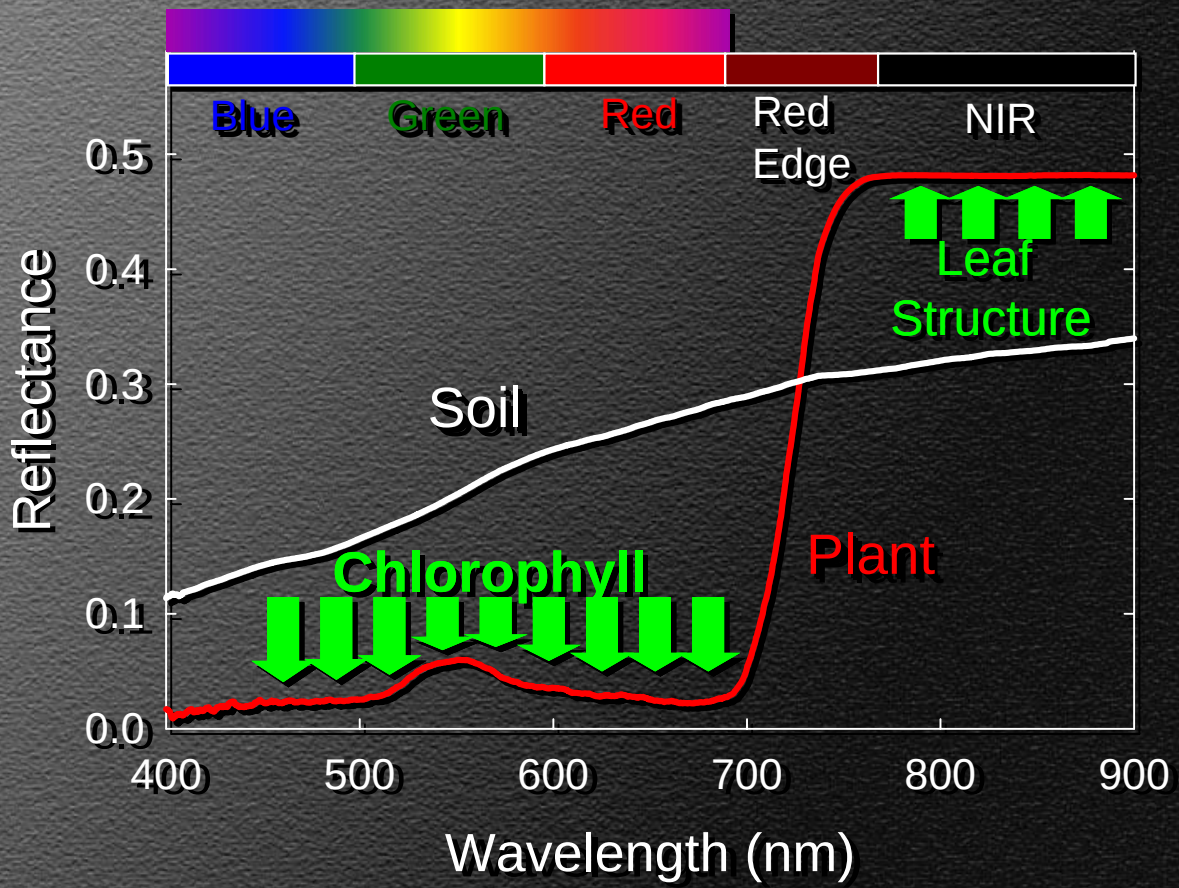
*Disclaimer: Use of trade names does not imply endorsement

Remote Sensing

- Anything you can use without touching the plant
  - Cameras
  - Spectrometers
  - Thermal sensors
  - Radar/Sonar
  - Microwaves
  - Eyes

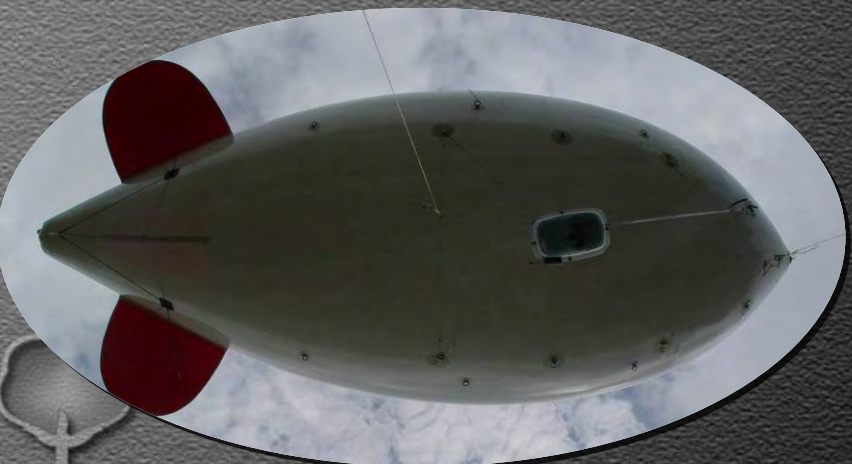
Shortwave Remote Sensing

- Based on reflectance



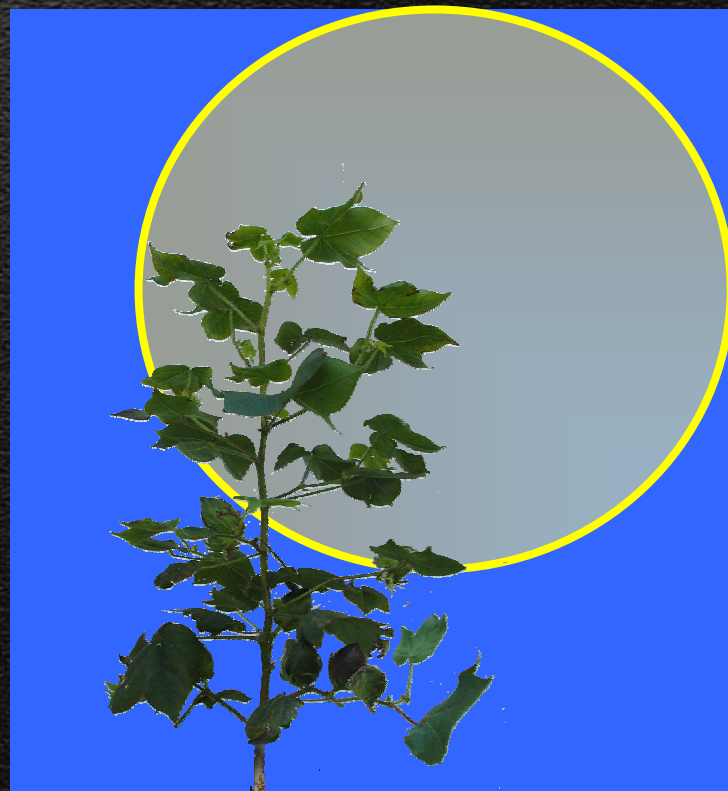
Original Paradigm

- Measuring plants outside
  - Ambient light
  - Soil of varying brightness
  - Difference in reflectance between plants and soil identify plant quantity or color



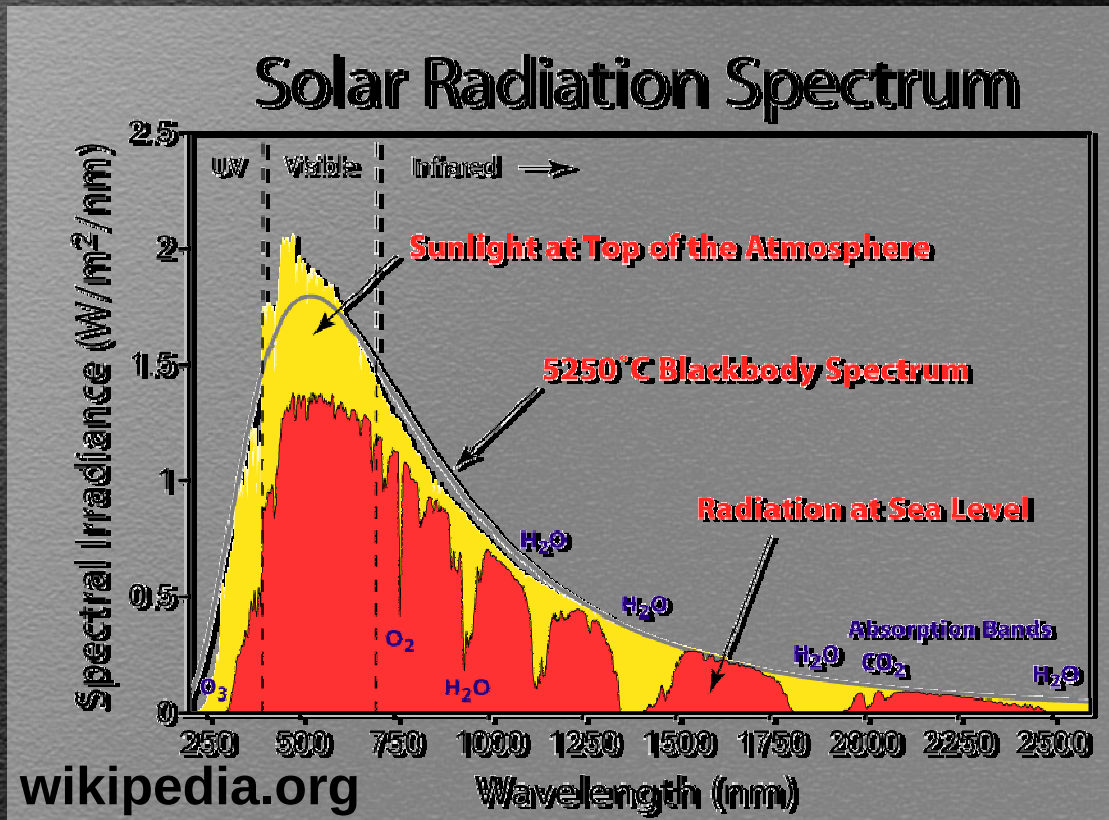
Outside vs. Inside

- Outside
  - Sunlight
  - ~Incandescent
- Greenhouses and growth chambers
  - Fluorescent lamps
  - High Pressure Sodium lamps



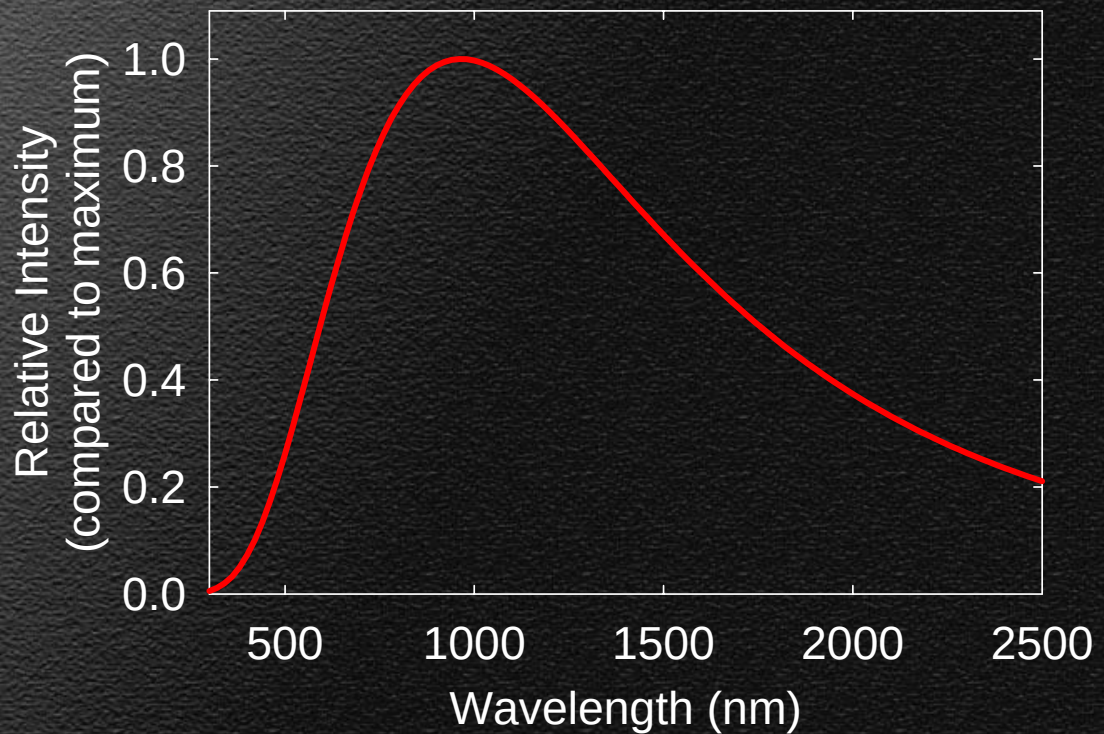
Sunlight

- Incoming radiation from ~280 to 2500 nm
- Some absorption by atmospheric gases and particles
- Direct *or* diffuse
- No cycle
- Clouds…



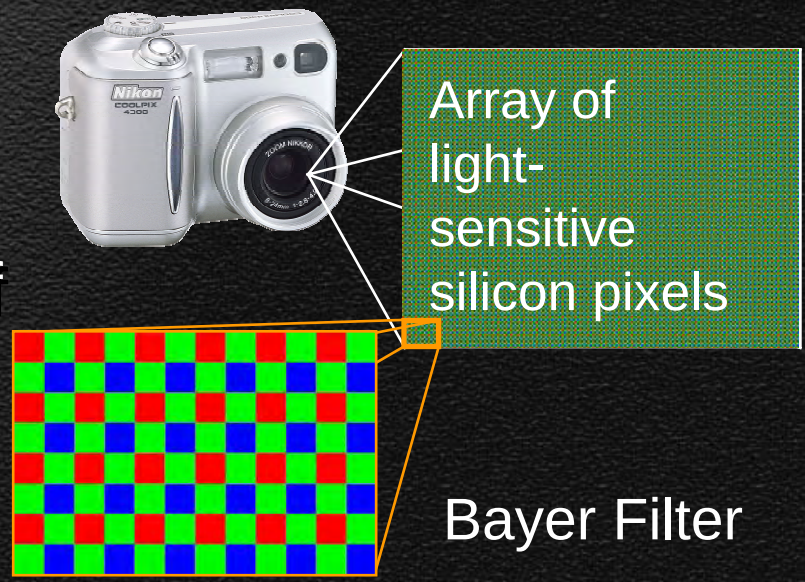
Incandescent

- Terribly inefficient
- Great for remote sensing applications
  - No cycle
  - Smooth spectrum



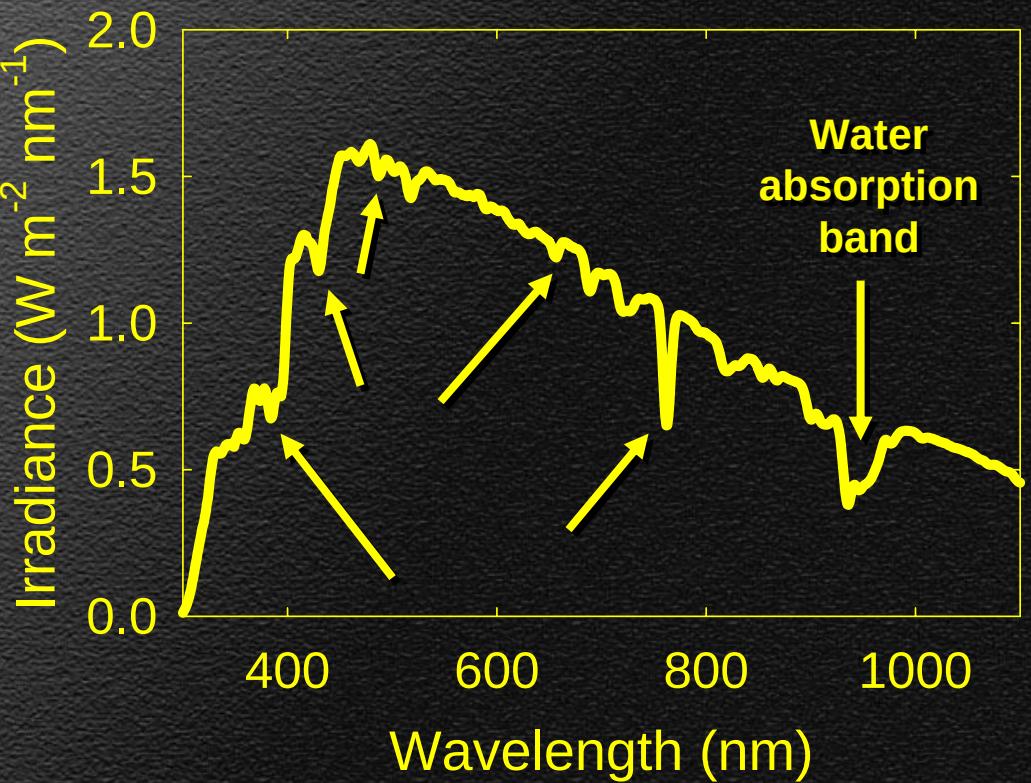
Sensor Systems

- Narrow band
  - High spectral resolution (<20nm)
  - Makes one spot measurement (e.g. spectrometer)
- Broad band
  - Low spectral resolution
  - Can often make an array of measurements (e.g. digital camera)



Fraunhofer Lines

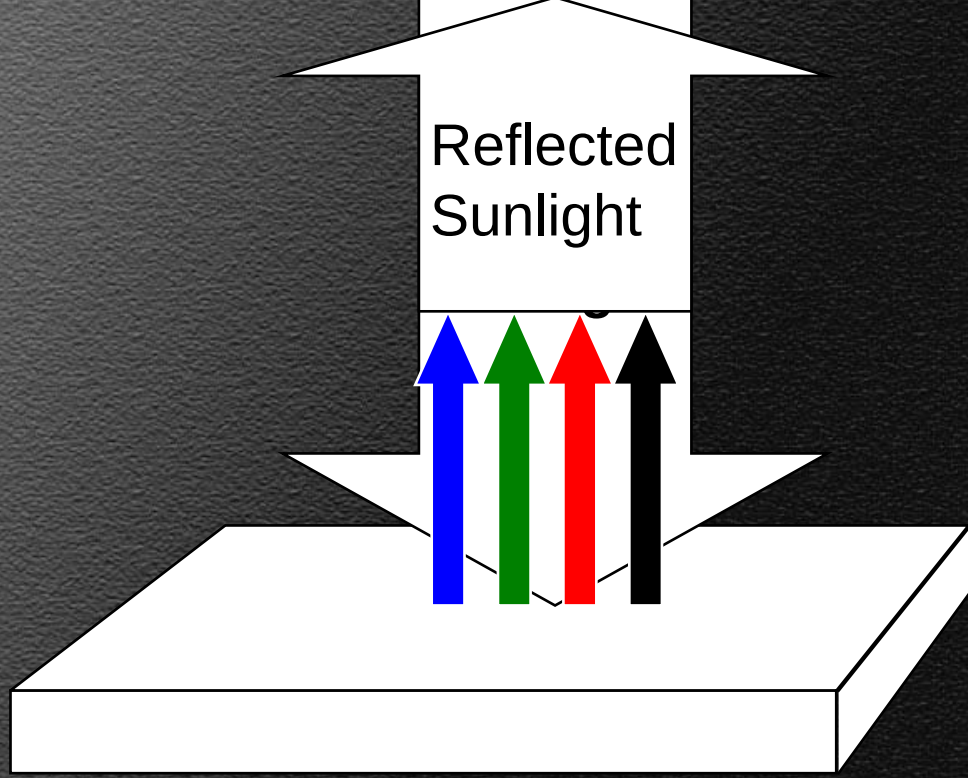
- Lines of atmospheric absorption of sunlight
- Over 1000 lines
- “Noise”

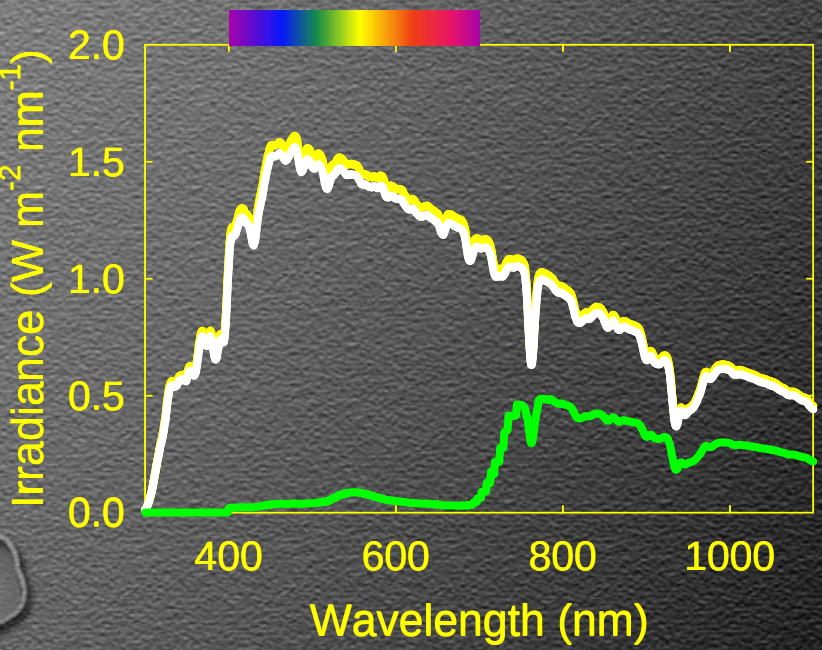


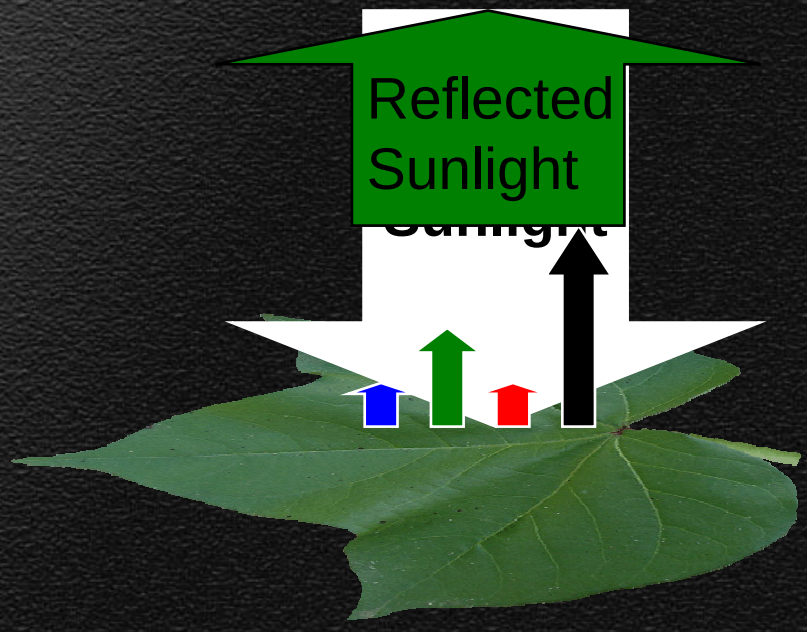
Reflectance

Quantity of light reflected

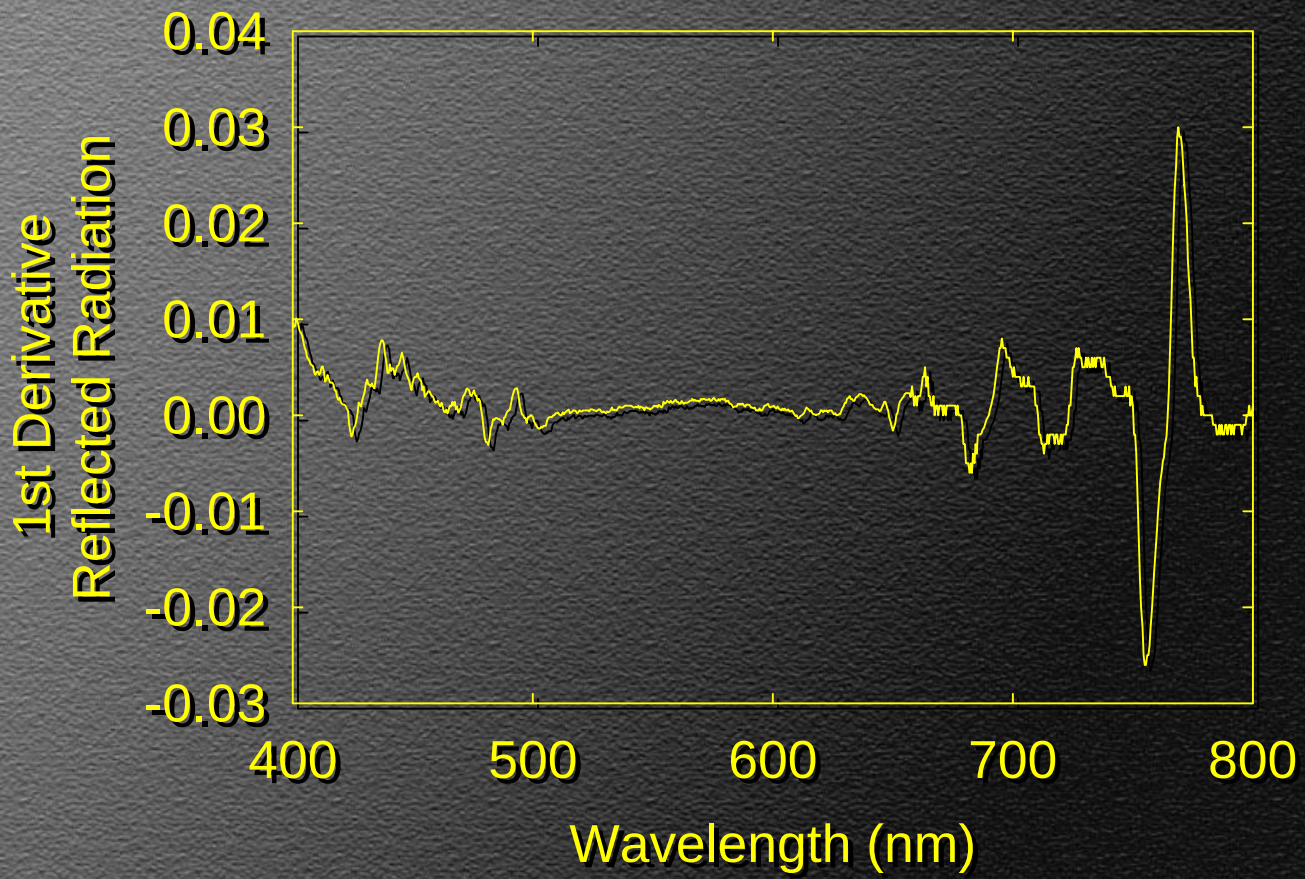
Quantity of light hitting surface







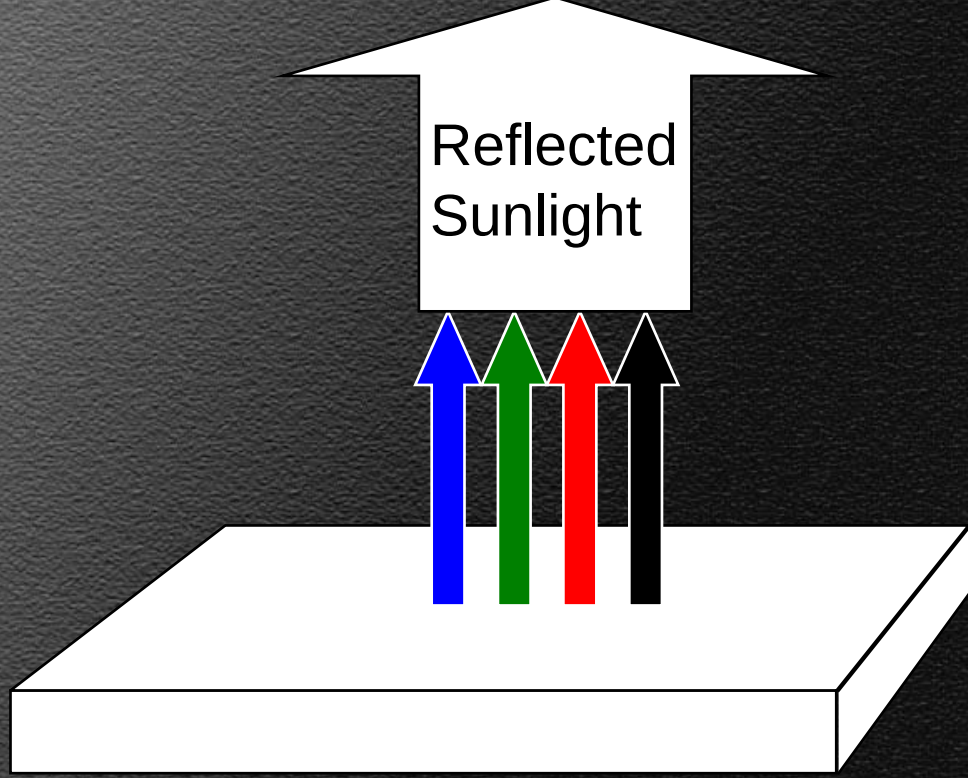
Direct measurement of reflected sunlight - full of noise

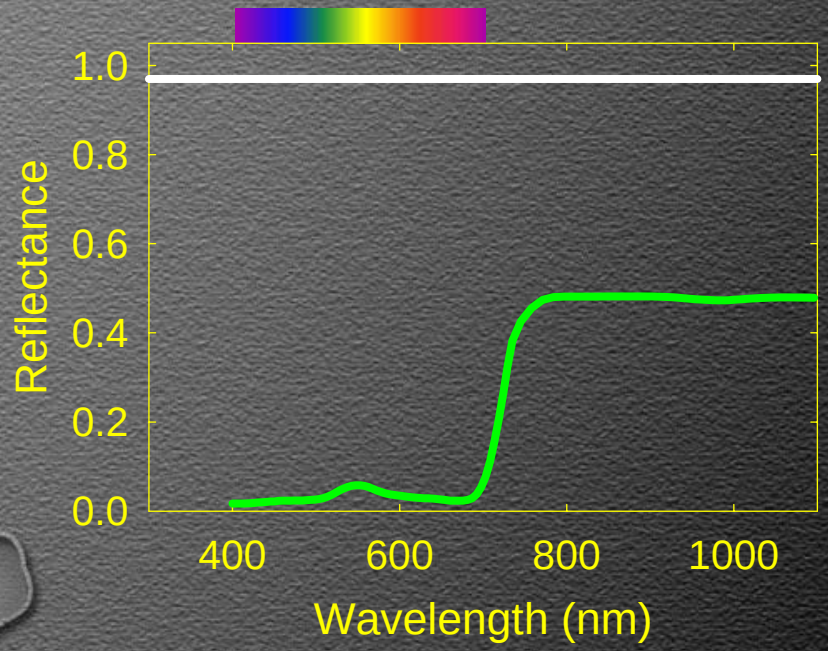


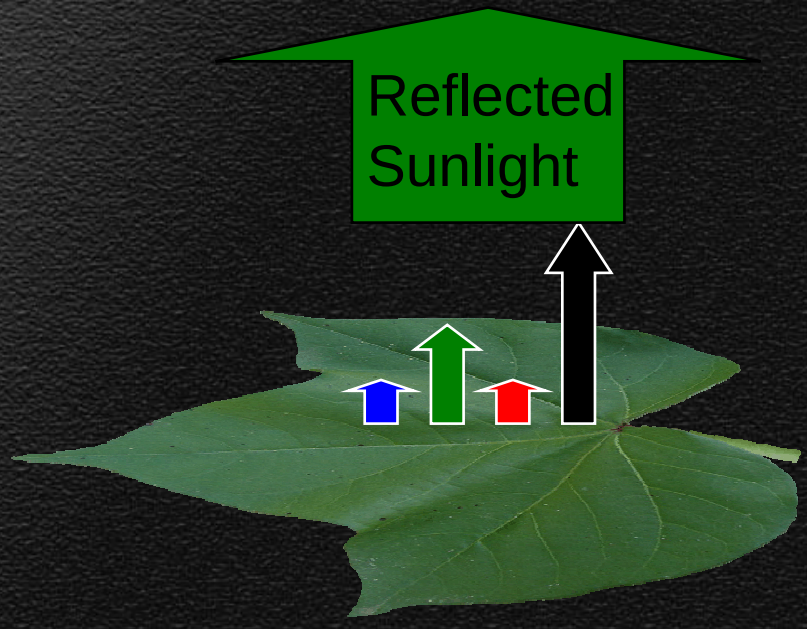
- These big peaks and valleys are related to Fraunhofer and water absorption bands, rather than plant color

Reflectance

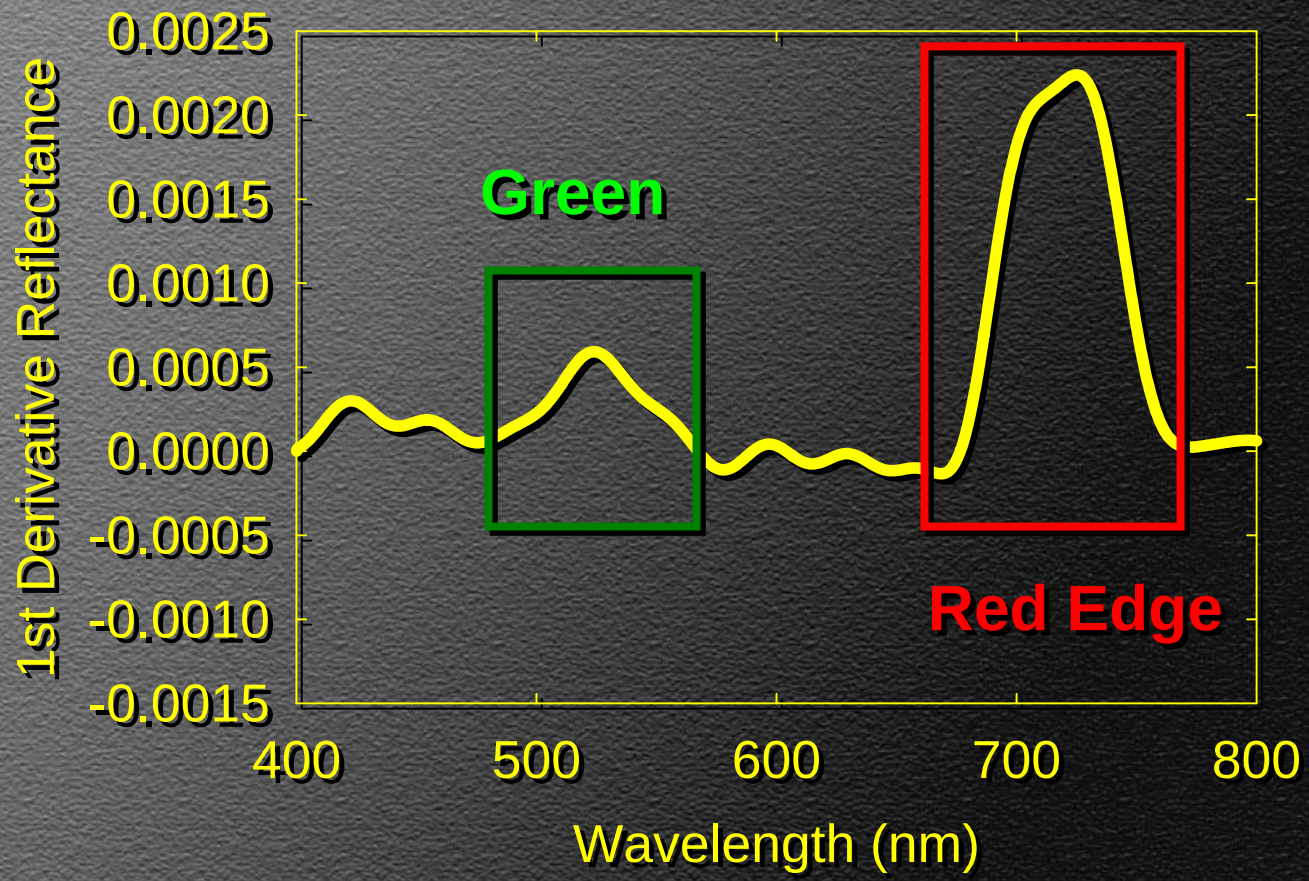
$$\frac{\text{Quantity of light reflected}}{\text{Quantity of light hitting surface}}$$







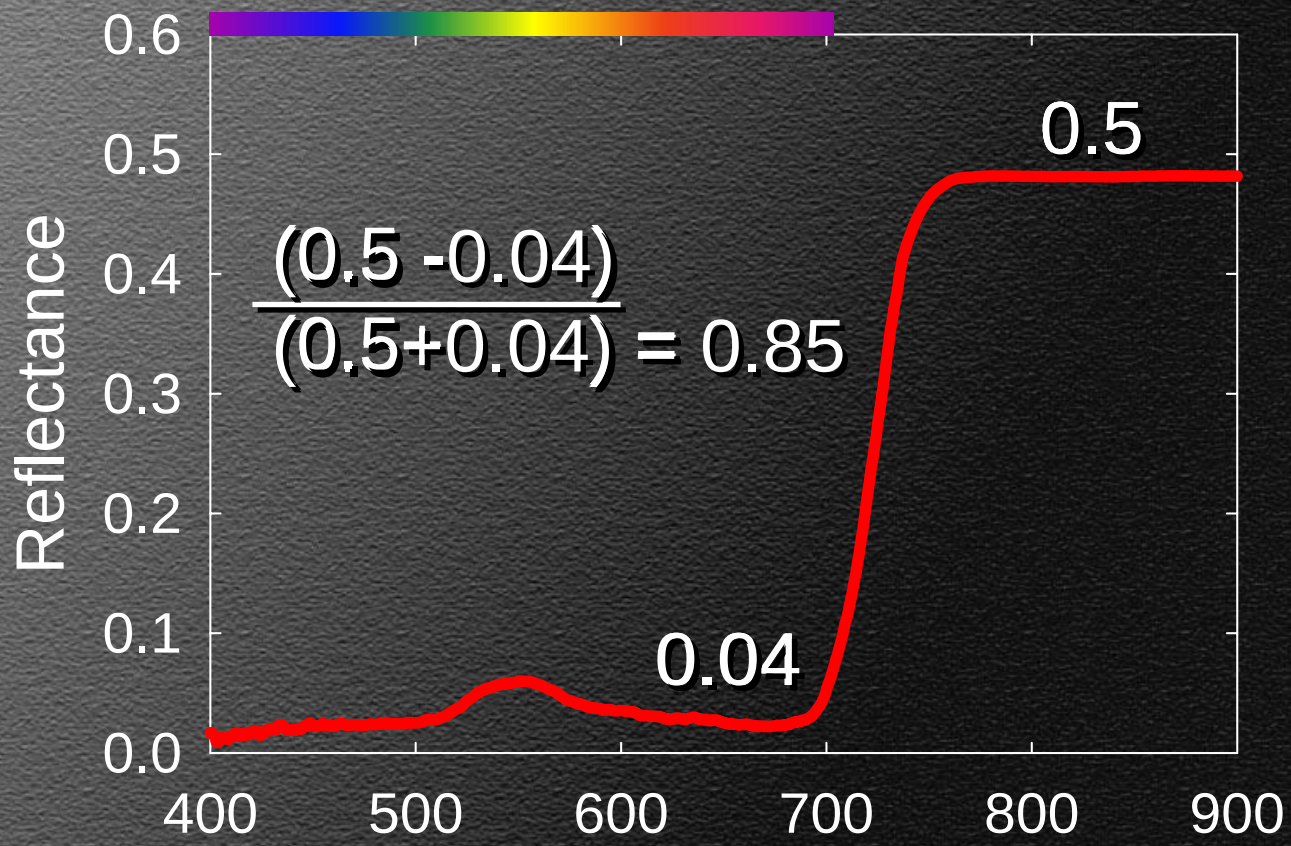
Easier to Analyze



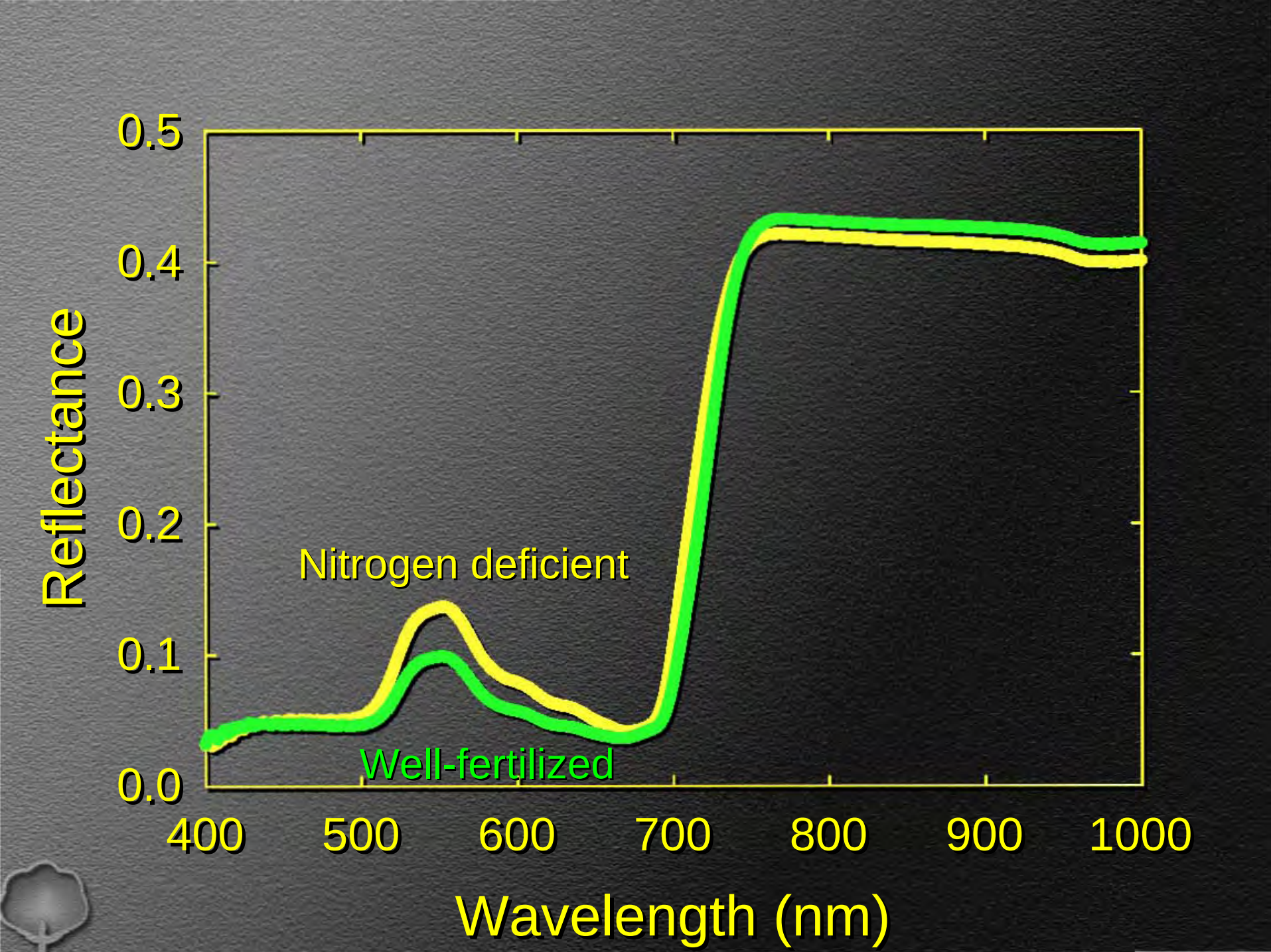
- Peaks and valleys are related to plant color
- Calibration simply requires white reference

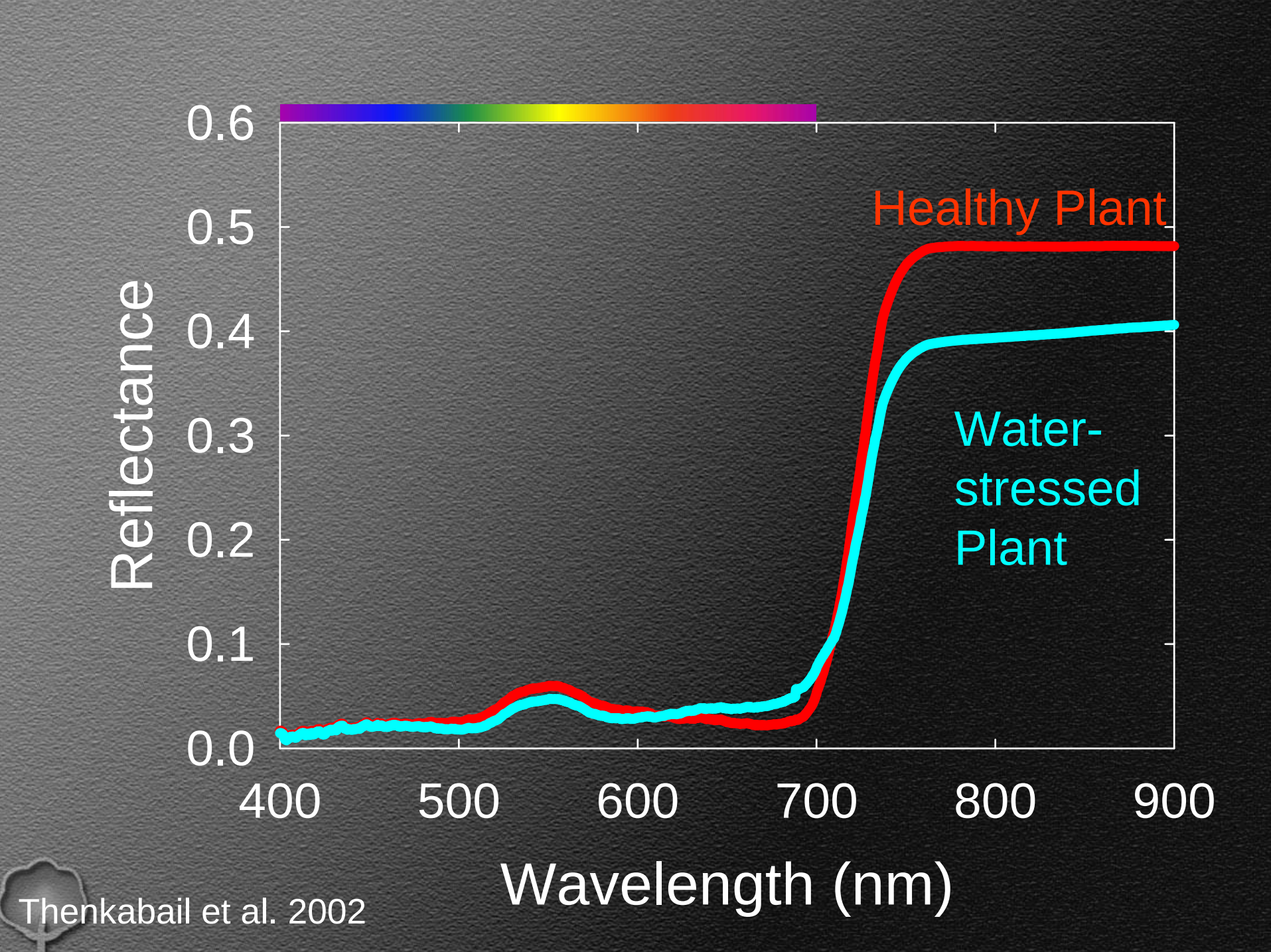
Normalized Difference Vegetation Index (NDVI)

(NIR-R)/(NIR+R)



Jordan, 1969

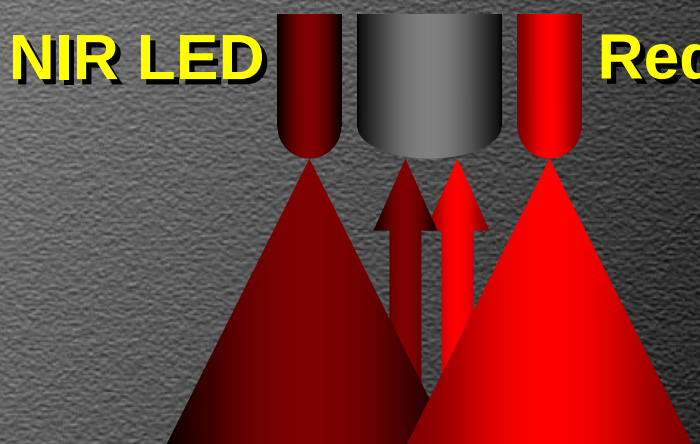

0.5
0.4
0.3
0.2
0.1
0.0
Reflectance
Nitrogen deficient
Well-fertilized
400
500
600
700
800
900
1000
Wavelength (nm)



Thenkabail et al. 2002

Outdoor Solutions

- Soil color – Soil-adjusted vegetation indices
- Clouds – active spectrometry (e.g. GreenSeeker and Crop Circle sensors)
  - Use modulation to decrease solar effects



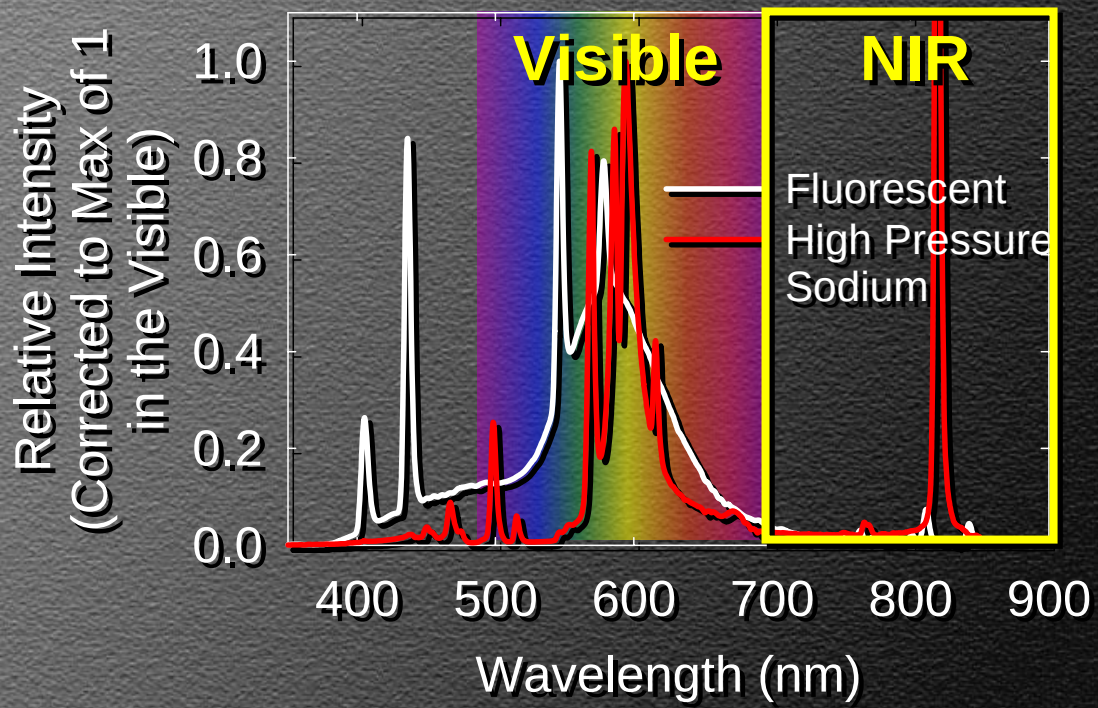
hollandscientific.com

ntechindustries.com

Controlled Environment Monitoring with Remote Sensing

- Electrical lights vs. sunlight
  - Emittance and frequency
- Background effects
- Spectrometer solutions
- Camera solutions

Fluorescent and High Pressure Sodium



- Large phosphor emittance spikes
- Very little NIR radiation (fluorescent)
- NIR is in one spike (HPS)
- High-frequency ballasts

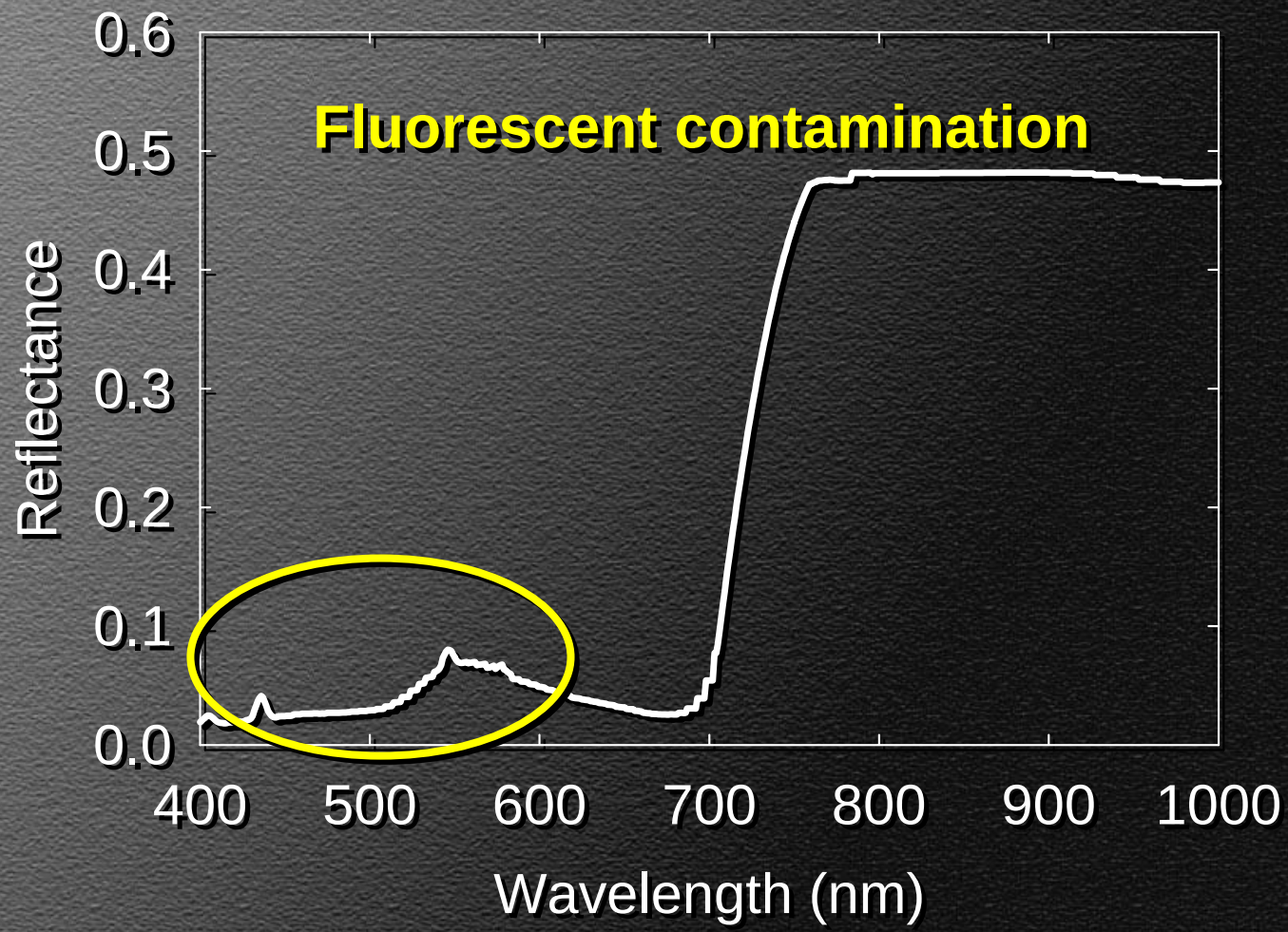
Electric Lighting Systems

- Greenhouse
  - Sunlight + electric lights
- Growth Chamber
  - Only electric lights

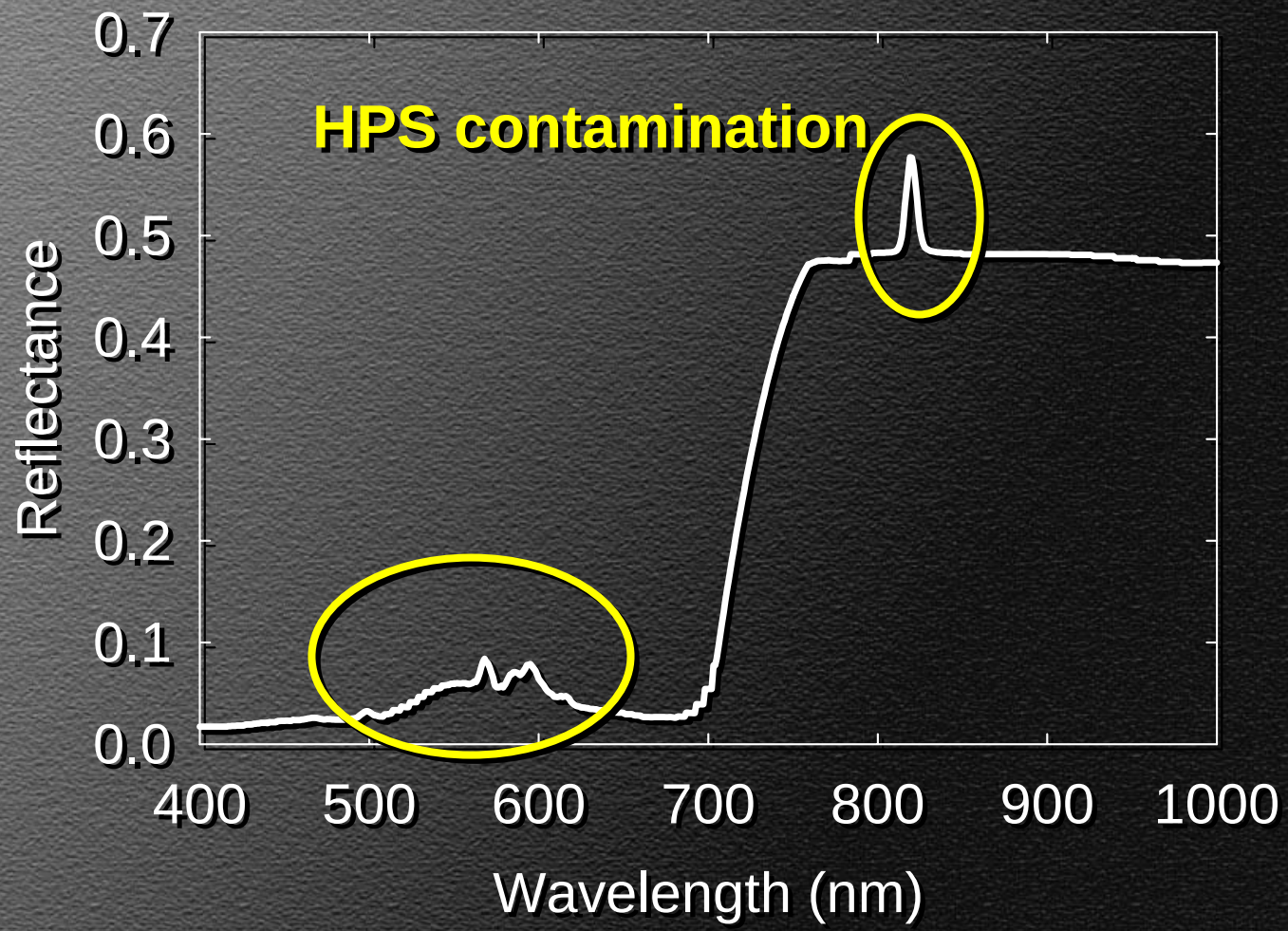
Fluorescent and HPS

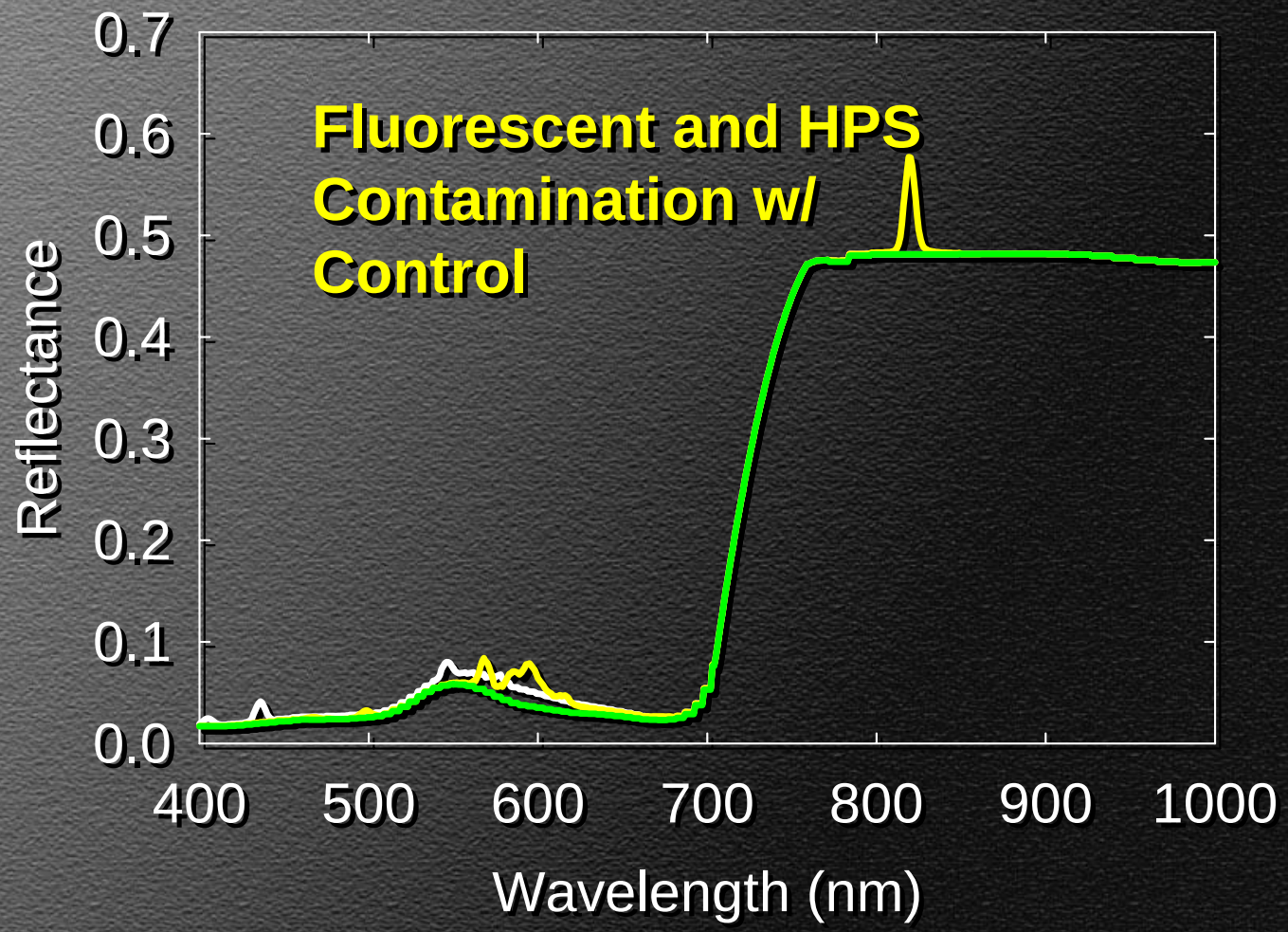
- High efficiency
- Light emittance spikes
- High frequency ballasts
  - Increase efficiency
  - Personal communication with makers of GreenSeeker: High frequency fluorescent lights can affect NDVI measurements

Greenhouse


Fluorescent contamination
Reflectance
0.6
0.5
0.4
0.3
0.2
0.1
0.0
400
500
600
700
800
900
1000
Wavelength (nm)

Greenhouse


HPS contamination
Reflectance
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
400
500
600
700
800
900
1000
Wavelength (nm)


Fluorescent and HPS Contamination w/ Control
Reflectance
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
400
500
600
700
800
900
1000
Wavelength (nm)

Growth Chamber

- No sunlight input
- Little NIR at most wavelengths with fluorescent and HPS lamps
- Low signal-to-noise ratio in NIR for most wavelengths
  - Issue of saturation in the visible

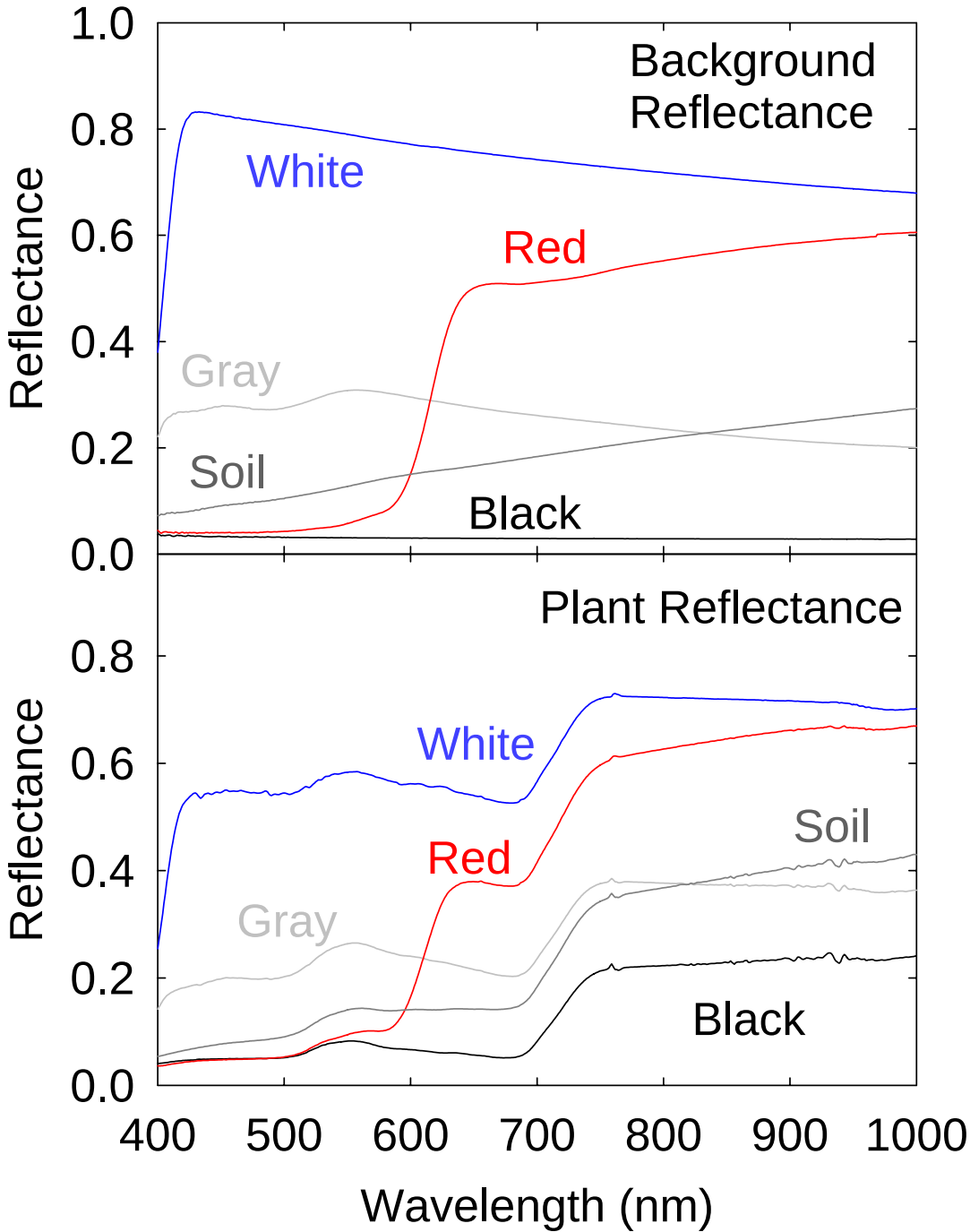
Adapting the System

- What can be done?
  - Broad spectral measurements
  - Reflectance, transmittance, etc. in general terms
- What to be careful of
  - Spikes in narrow band spectral measurements
  - Near -infrared measurements
  - Strange backgrounds

apogeeinstruments.com

Background Effects

- Outside – Soil
  - Different brightness characteristics
  - Spectrally flat
  - Vegetation indices (SAVI, etc.) correct for soil
- Inside
  - Every background will have a different effect


Background Reflectance
White
Red
Gray
Soil
Black
Plant Reflectance
White
Red
Gray
Soil
Black
Reflectance
Reflectance
1.0
0.8
0.6
0.4
0.2
0.0
400
500
600
700
800
900
1000
Wavelength (nm)

Potential Solutions - Background

- Mathematically eliminate background (if you know exactly what the background reflectance is
- Use derivatives (if you have wavelengths you can be confident of)
- Use soil adjusted indices (if your background is spectrally flat)
- ~~Ignore (at your own risk)~~

Potential Solutions - Spectrometer

- Turn off electric lights (watch out for light contamination from adjacent greenhouses!!!)
- Shade plants during measurement
- Select parts of the reflectance spectrum that are less affected by phosphor spikes
- Active spectrometer – watch out for interference
- ~~Ignore (at your own risk)~~

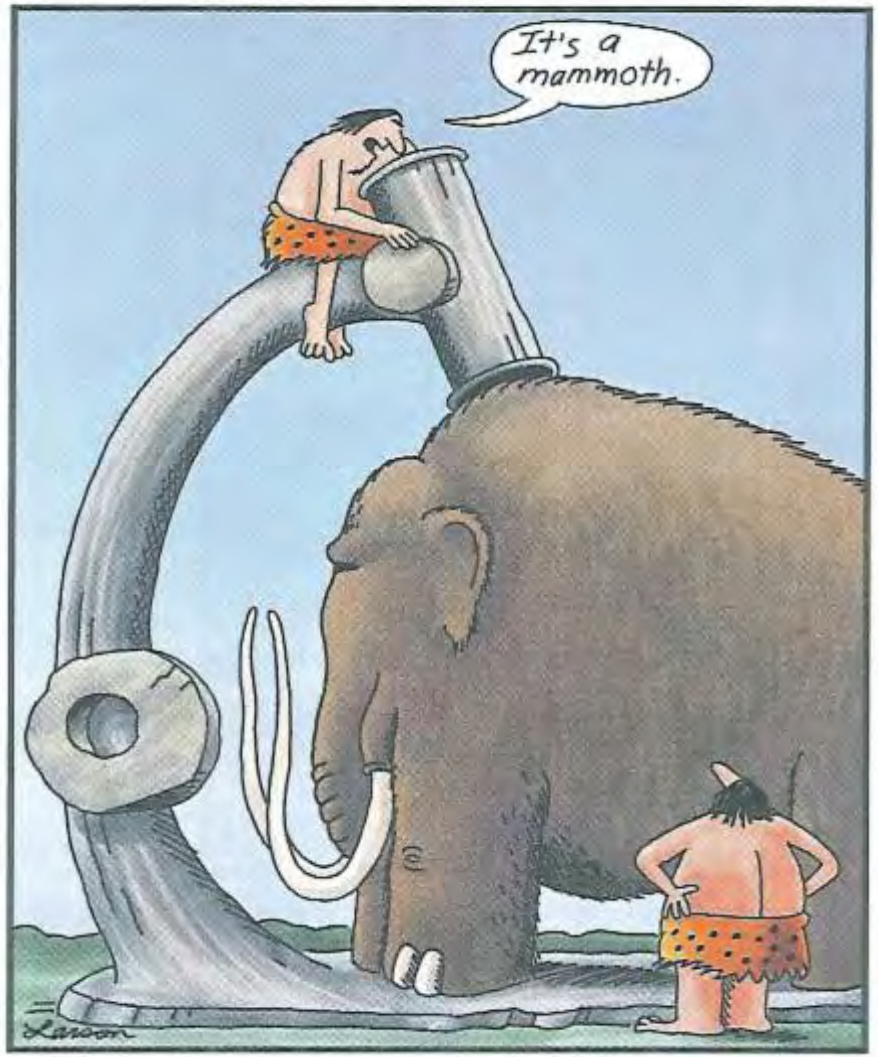
Potential Solutions - Camera

- Calibration panel, such as a gray card
  - Set white balance based on gray card
  - Be careful of changing light characteristics
- Filters
  - Still need to have reference
- Electric light setting on camera
  - Still need to have reference

Potential Solutions - Camera

- Measure ground cover fraction instead of using spectral index (Klassen et al. 2003)
- Relative spectral differences allow discrimination

Questions?



Early remote sensing

Gary Larson