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Remote Sensing of Algae Growth in Waterways



PRESENTED BY

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Outline

Motivation

Overview of Optical Spectroscopy/Optical Detection

Future vision: Drones/UAVs/UASs

Technology overview:

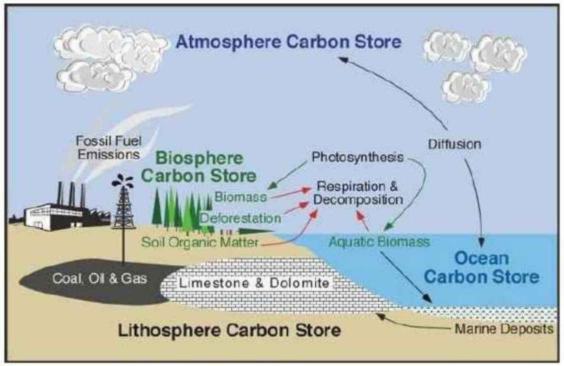
- The sensors
- The data
- The tradeoffs
- The challenges

SNLs approach to monitoring algal biomass

Additional applications

Why Measure Algae in Waterways?

Global Carbon Cycle (simple view)



EoE- http://www.eoearth.org/article/Carbon_cycle

- Algae are ubiquitous in outdoor waterways; play a large role in the global C cycle.
- Algae are at the bottom of the food chain. Changes in their populations over time can lead to changes throughout in the ecosystem.
- Monitor & predict ecosystem fluctuations, harmful algal blooms
- Improve algal production of fuels and high value chemicals
- Detect environmental release of harmful chemicals and effluents

Image courtesy of: Ocean River Institute

Image courtesy of cdc.gov

Ways Researchers Monitor Algae in Waterways

Grab samples & return to lab

- Molecular analysis: Sequencing & PCR
- Colorimetric assay
- Optical density
- Flow cytometry

Advantage: Can measure anything you want

Drawbacks: Requires a la personnel, limited time p consuming

Stick something in water

- Colorimetric
- Optical density
- Chlorophyll fluorescence
- pH

Advantage: Easy, quic required, can be auto

Drawbacks: Limited to points, submerged pro person for most cases

Observe remotely based on optical signatures

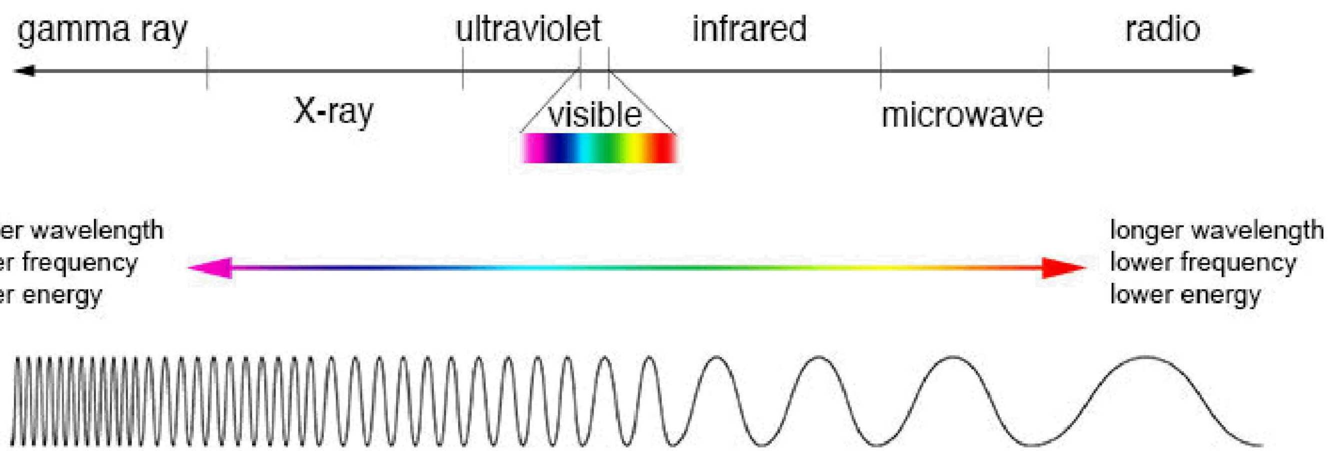
- Optical density
- Algal concentration
- Algal species
- Population dynamics

Advantages: Can be continuous, real-time and autonomous, no fouling of sensors

Drawbacks: Requires development to correlate optical properties to algal properties

Basics of Optical Spectroscopy

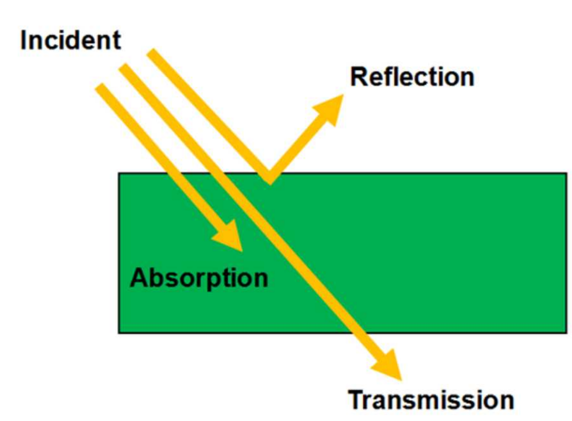
The study of the interaction of light with matter



Comparison of wavelength, frequency and energy for the electromagnetic spectrum. (Credit: NASA's Imagine the Universe)

Three things can happen when light hits a sample:

- Transmission
- Absorption
- Reflection



Absorption

- If frequency of incoming light is near the energy levels of the electrons in the matter they will absorb the energy of the light and change their state
- Light absorbed has many different fates depending on material and wavelength
  - Remission – fluorescence, phosphorescence
- Beer-Lambert Law: Absorbance is directly proportional to the concentration

Reflection

- When light waves encounter a surface that does not absorb the energy, the wave "bounces" from the surface.
- Dependent on the texture of the surface
- Scattering is a type of reflection

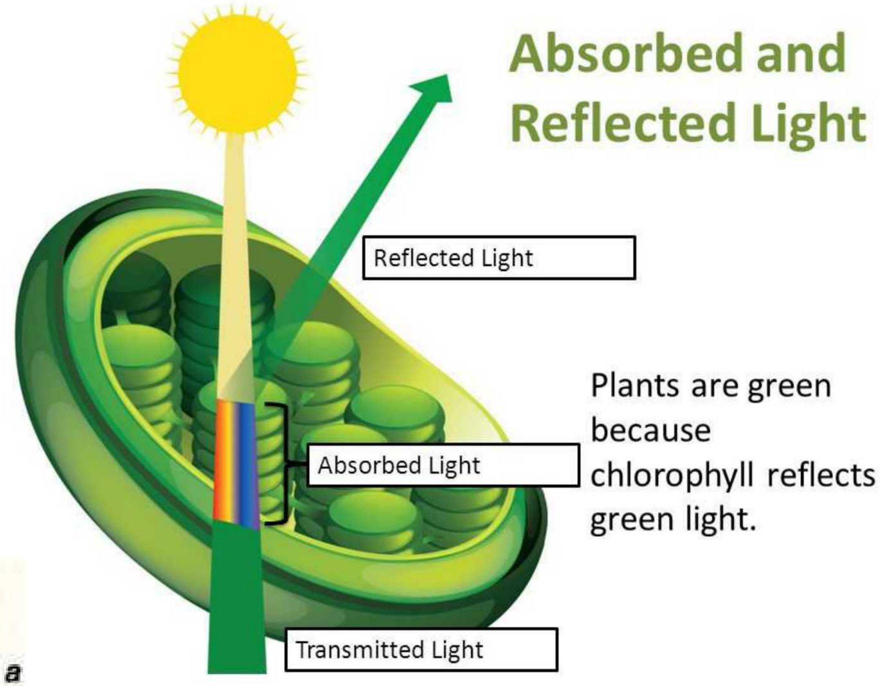
It's all about the molecules!

Many biological molecules have unique optical signatures when they interact with different wavelengths of light.

Photosynthetic organisms have pigments with distinct properties

This makes it possible to distinguish between different plants, algae, and photosynthetic microbes by the way they interact with light

Pigments also change depending on environment making it possible to determine stress and health of an organism



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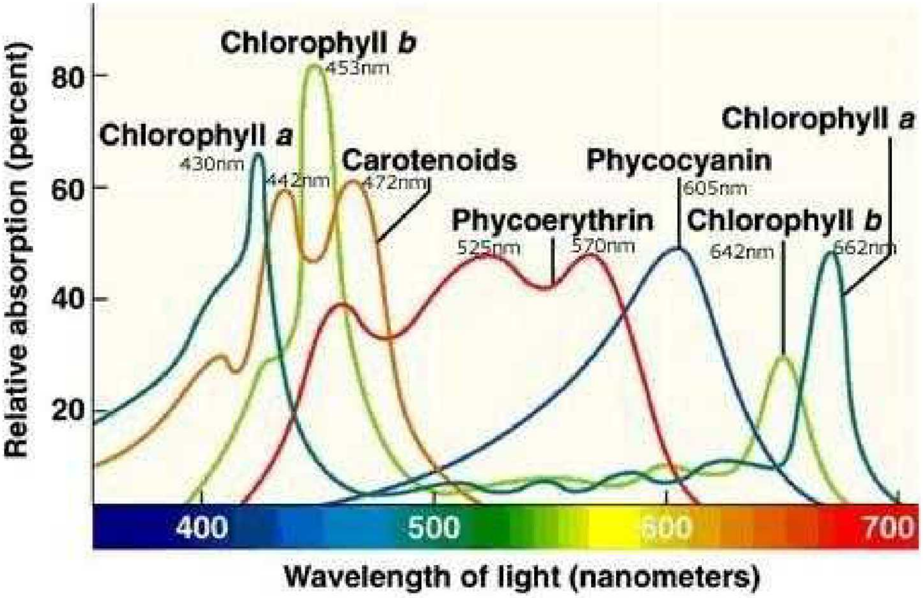
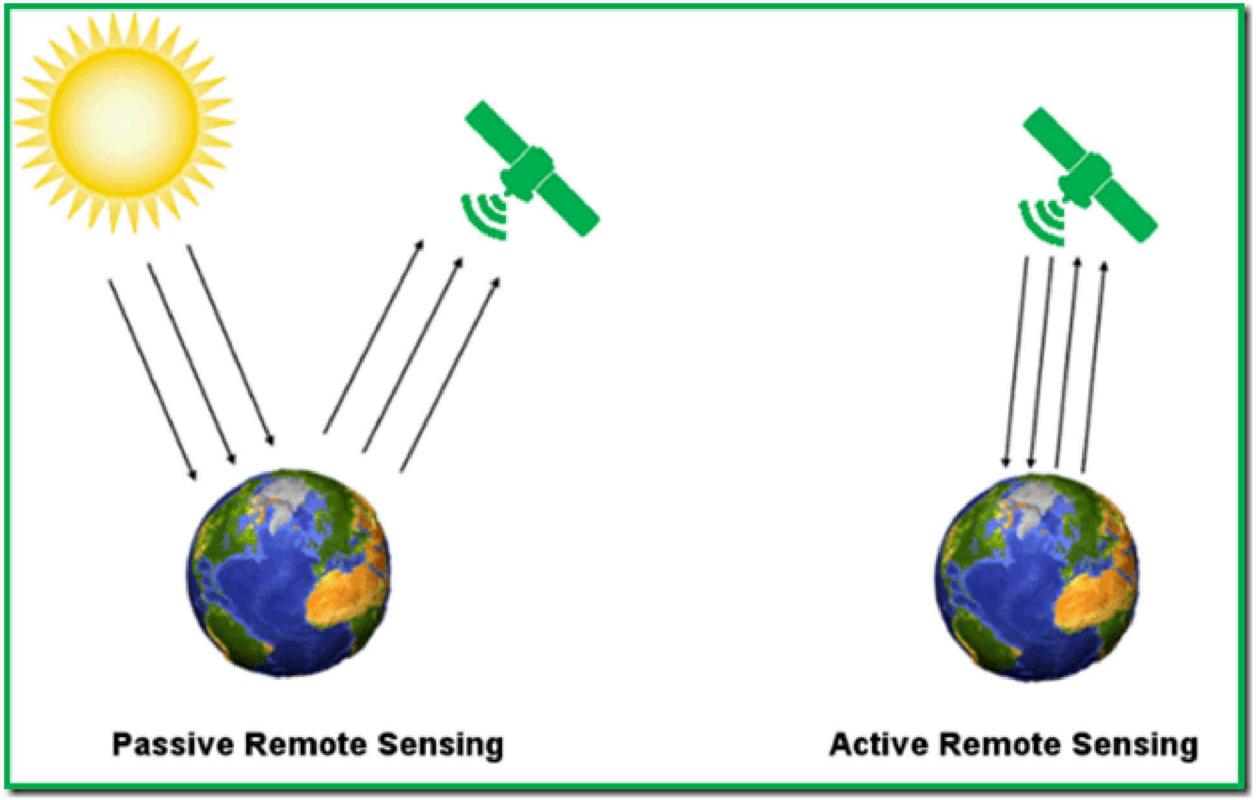


Remote Optical Sensing

Many optical properties and phenomena can be measured

- Wide spectral range UV, VIS, NIR, SWIR, IR

Active vs. Passive



From A to Z Remote Sensing

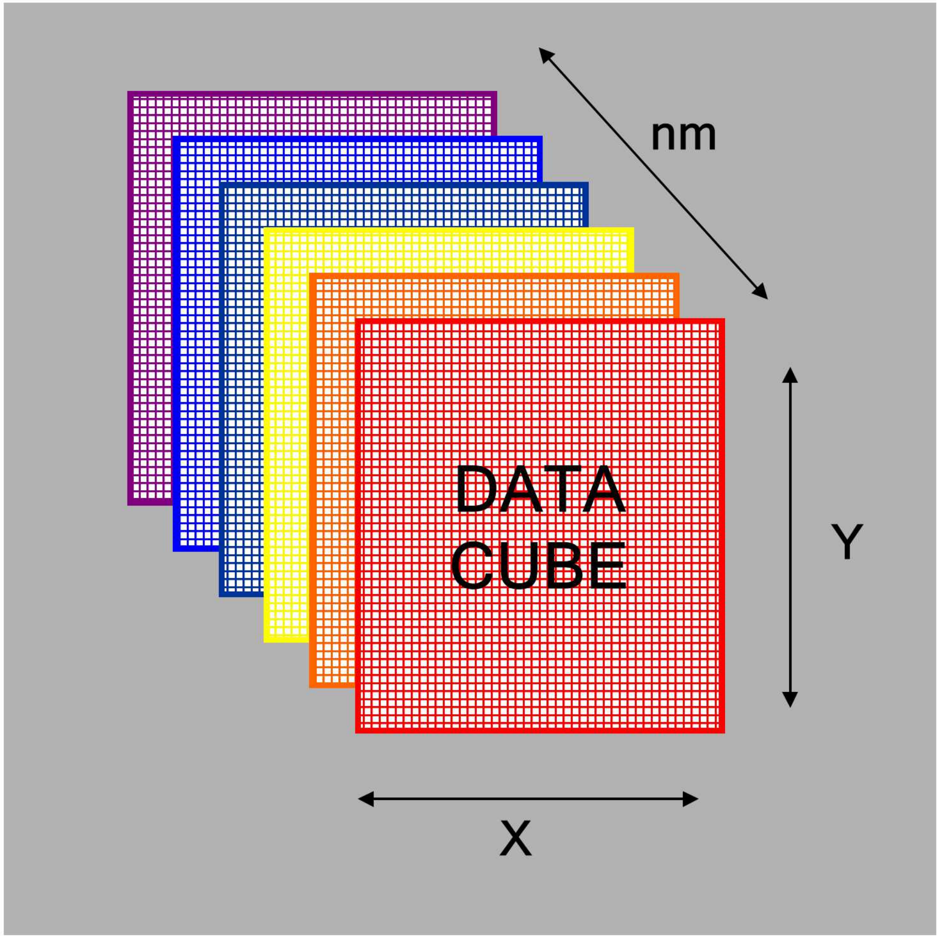
Advantages of Remote Optical Sensing of Algae

- **Rapid** (~5 min) measurement times
- ***In situ*** measurement based on inherent algal optical properties
- **No physical sampling**, only optical line-of-sight required
- **Non-contact**, no fouling
- **Functional** information about algal pigments and other pests including competitors, pathogens and predators
- **No pre-calibration**, analysis via light-transport physics
- Signatures are **fully scalable** from beaker to satellite
- **Autonomous** operation

Future Vision: Drones/UAVs/UASs

Smartphone spectrometer from Allied Scientific Pro (Canada)

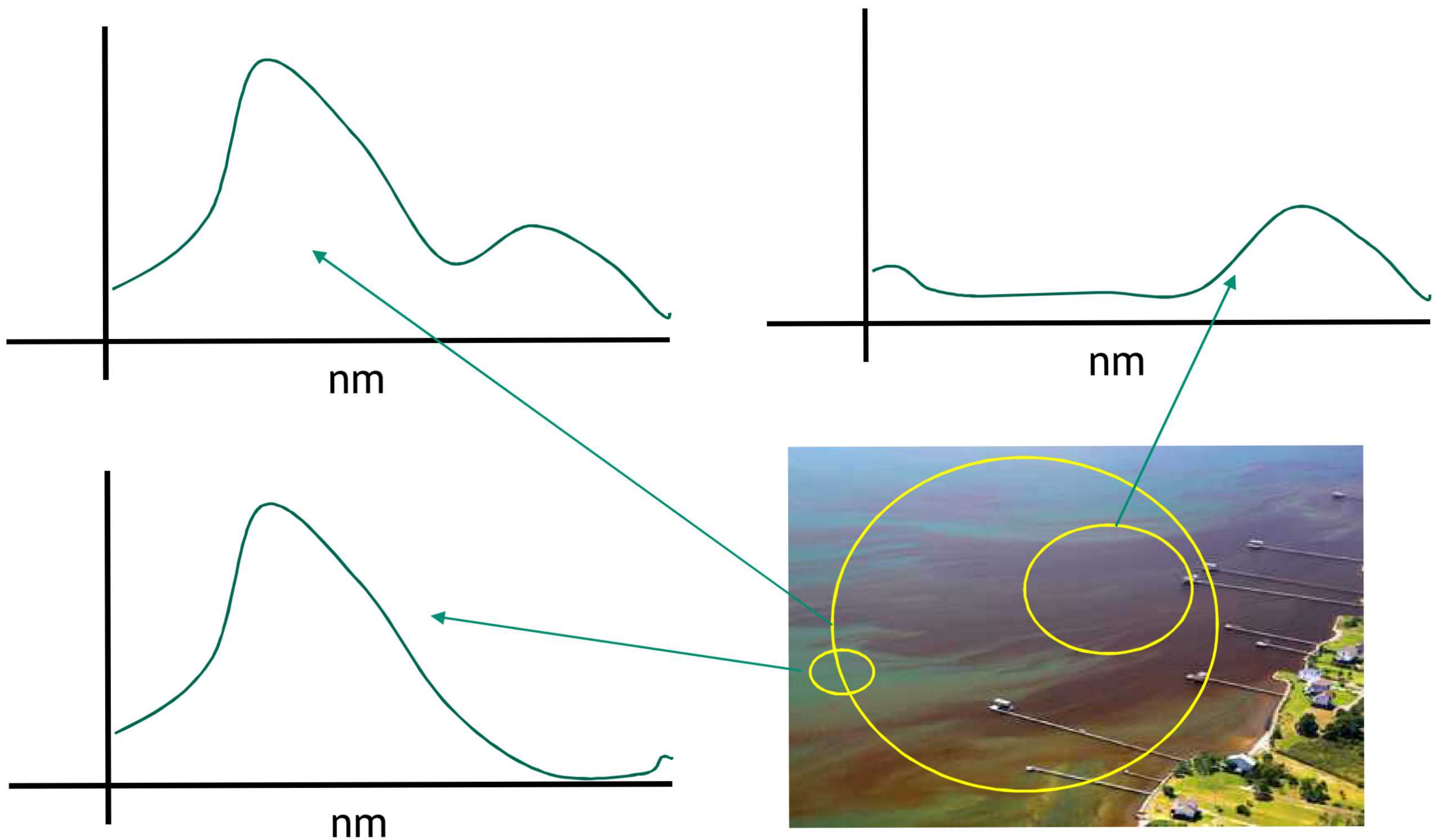
The Spectral Data Cube



In general sensors operate in three modes:
Spectroscopy --- Multispectral ---Hyperspectral

Spectroscopy

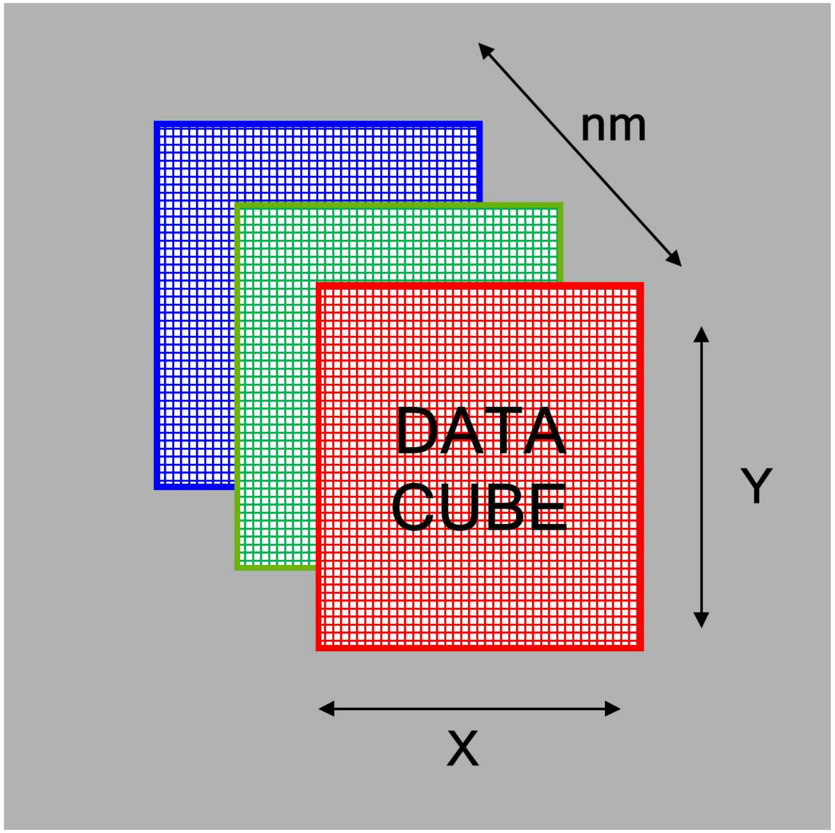
Spectroscopy = bulk or one spatial location, many spectral bands

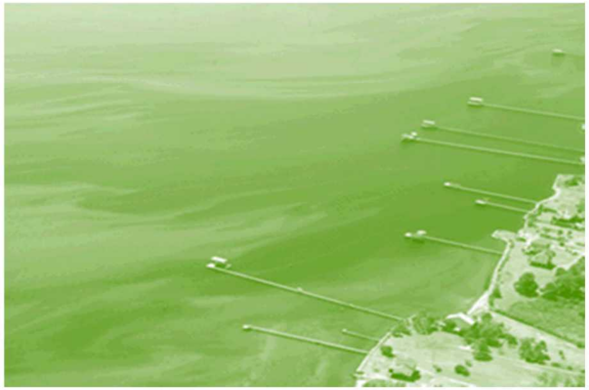


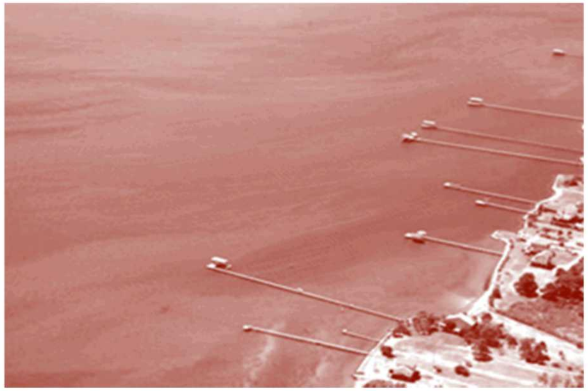
Multispectral

Multispectral = 2- 9 spectral bands (colors), many spatial locations

Broadband imaging is a special case (SWIR, LWIR)



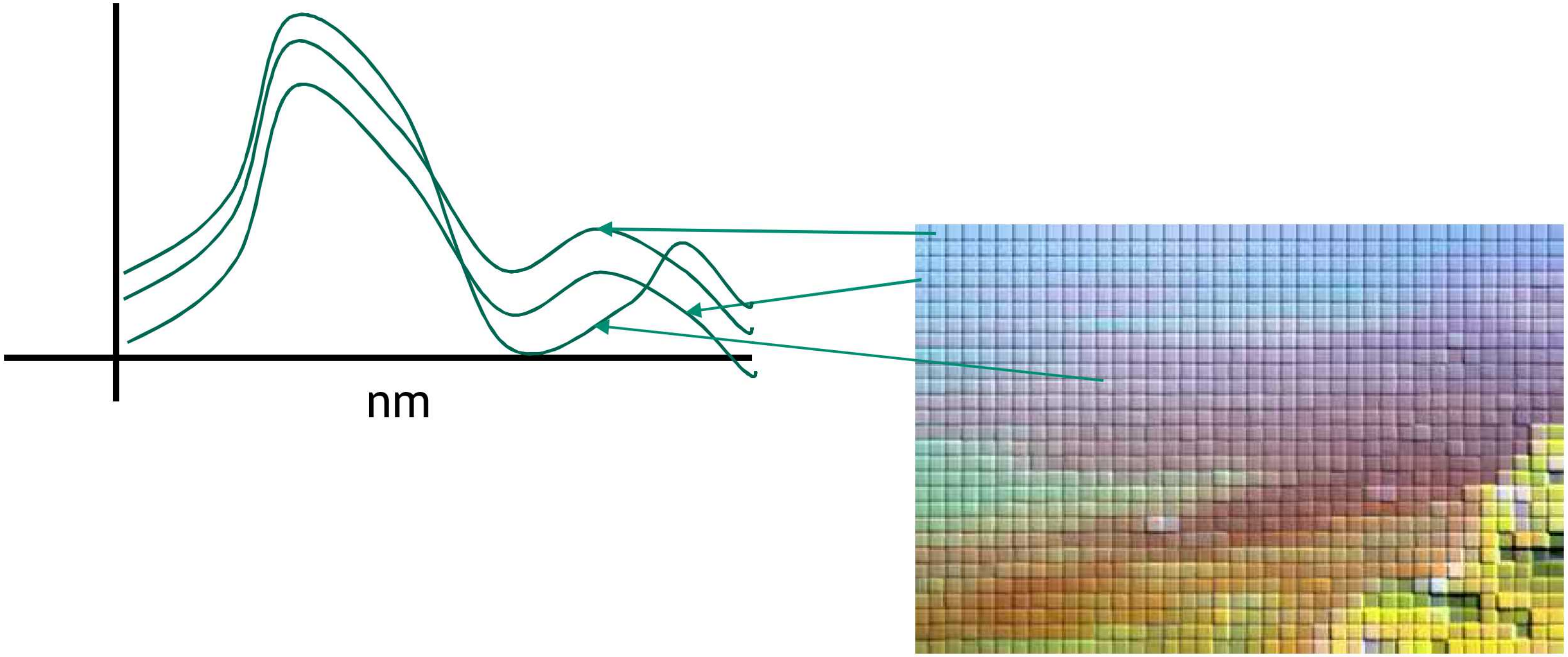




Hyperspectral

Hyperspectral - >10 spectral bands (colors), many spatial locations

Every image pixel has a spectrum of >10 bands …



The Trade-offs

Spectral resolution vs. Spatial resolution

Spatial resolution vs. speed

Sensitivity vs. speed

Resolution (spatial or spectral) vs. cost

Interestingly these don't really change from a laboratory based instrument as compared to a drone platform

Technology Comparison

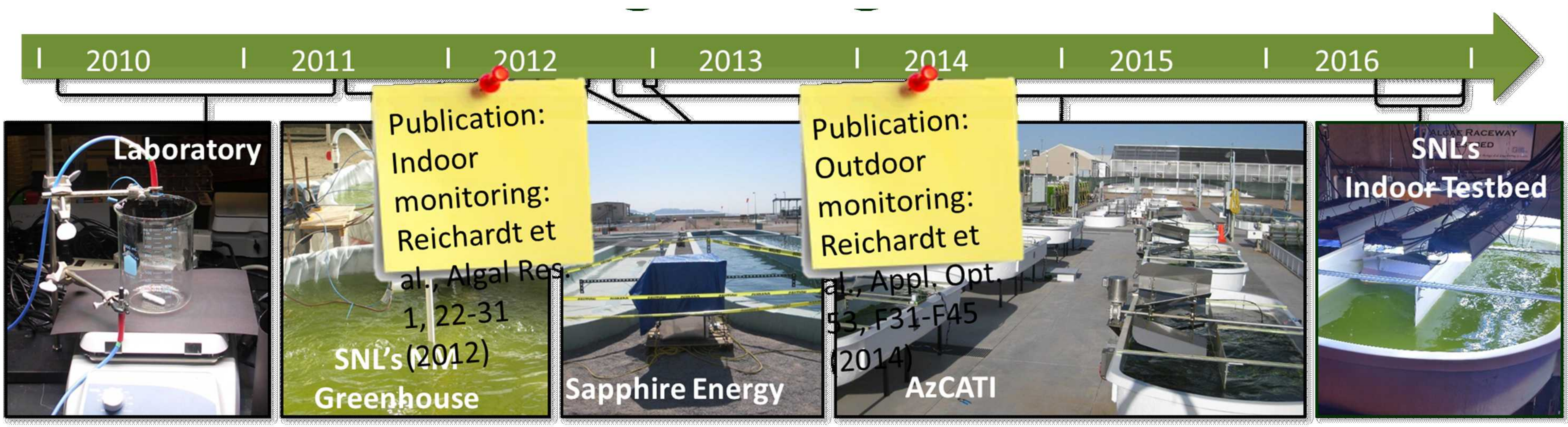
	Spectral sensor	Multispectral Sensor	Hyperspectral Sensor
# of Spectral bands	Up to 1000's	2-9	10s to 100s
Spatial resolution	Not inherent, is possible w/motion	Yes (microns to meters)	Yes (microns to meters)
Potential information content	High	Low	Moderate
Amount of Data	Low - moderate	Low - moderate	Huge
Level of math required for analysis	Moderate to advanced	Basic	Moderate to advanced
Cost	$2k – 5k	$5k – 15K	>$25K

Sandia's Approach to Algal Monitoring

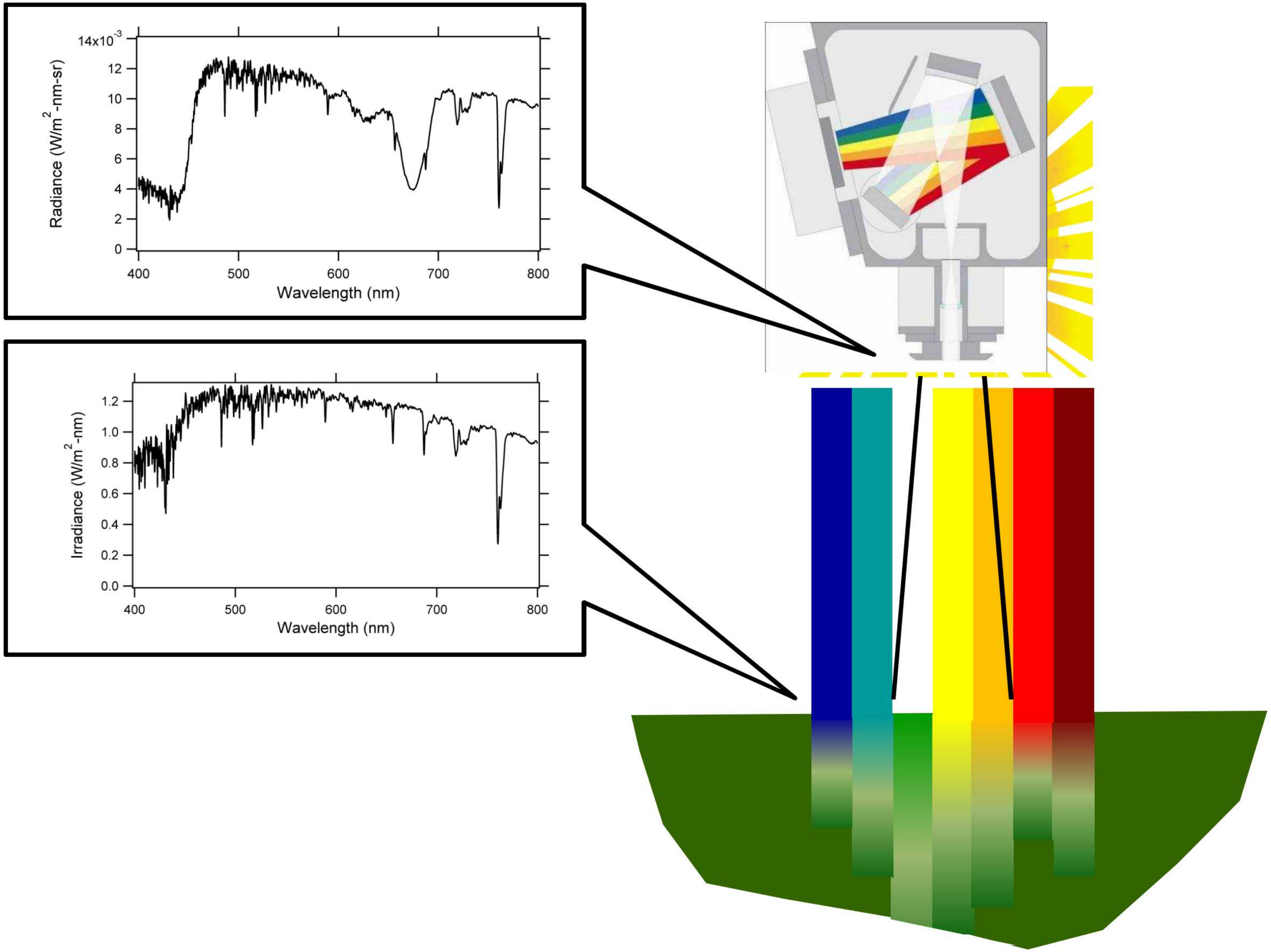
Passive measurement of reflected light
- Spectroradiometric monitoring

No spatial resolution
- Not informative for well-mixed ponds

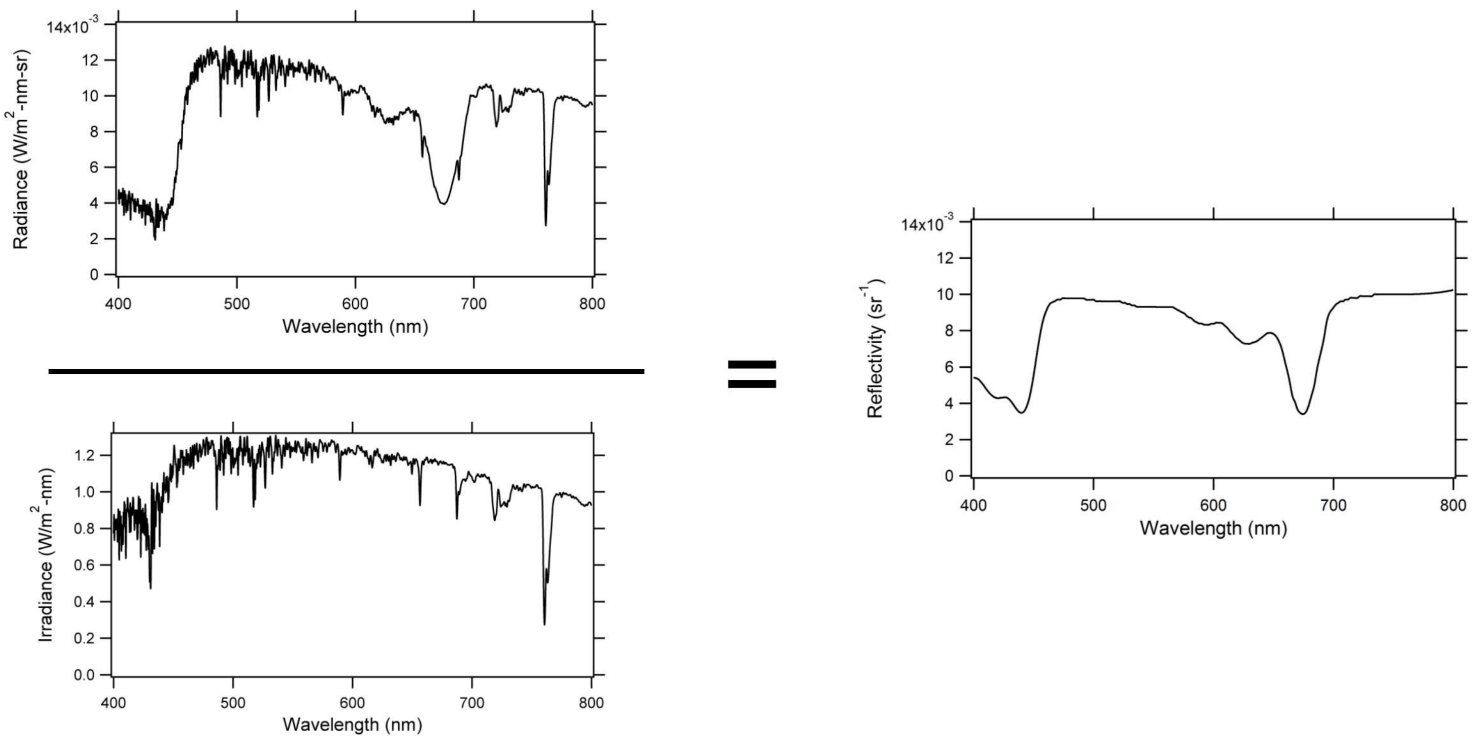
Radiometric transfer model to determine optical properties



Spectroradiometric Monitoring



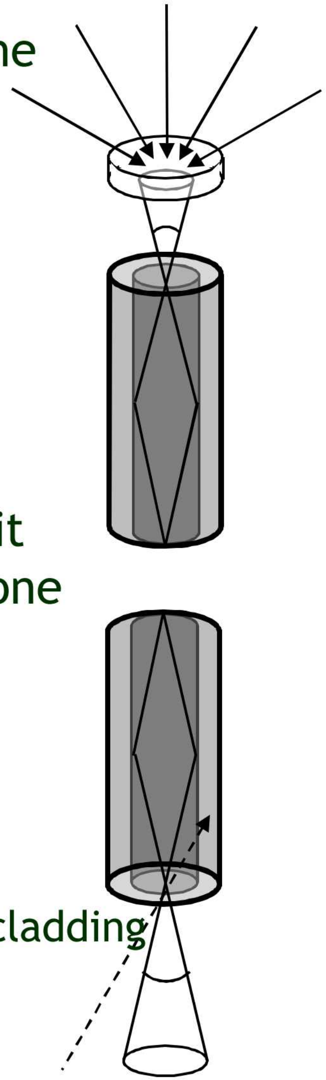
Spectroradiometric Monitoring



Dual-channel Spectrometer

- Diffuser randomizes the direction of incoming light
- Fiber captures light from all downwelling angles

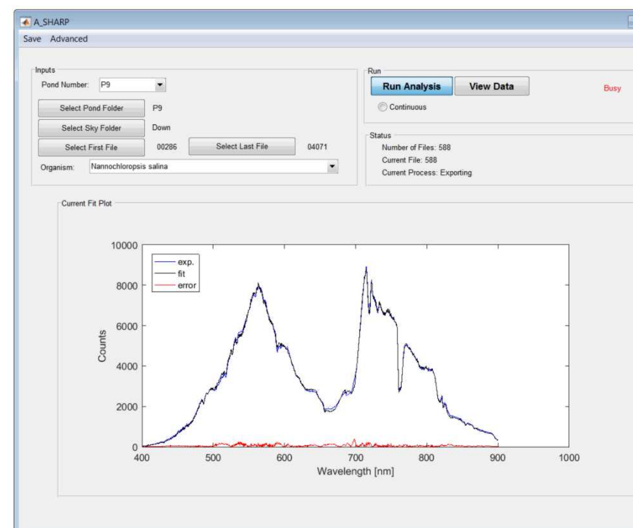
- Refractive indices of core and cladding limit field-of-view to 25° cone of light



Building on a physics-based light transport model from oceanography community

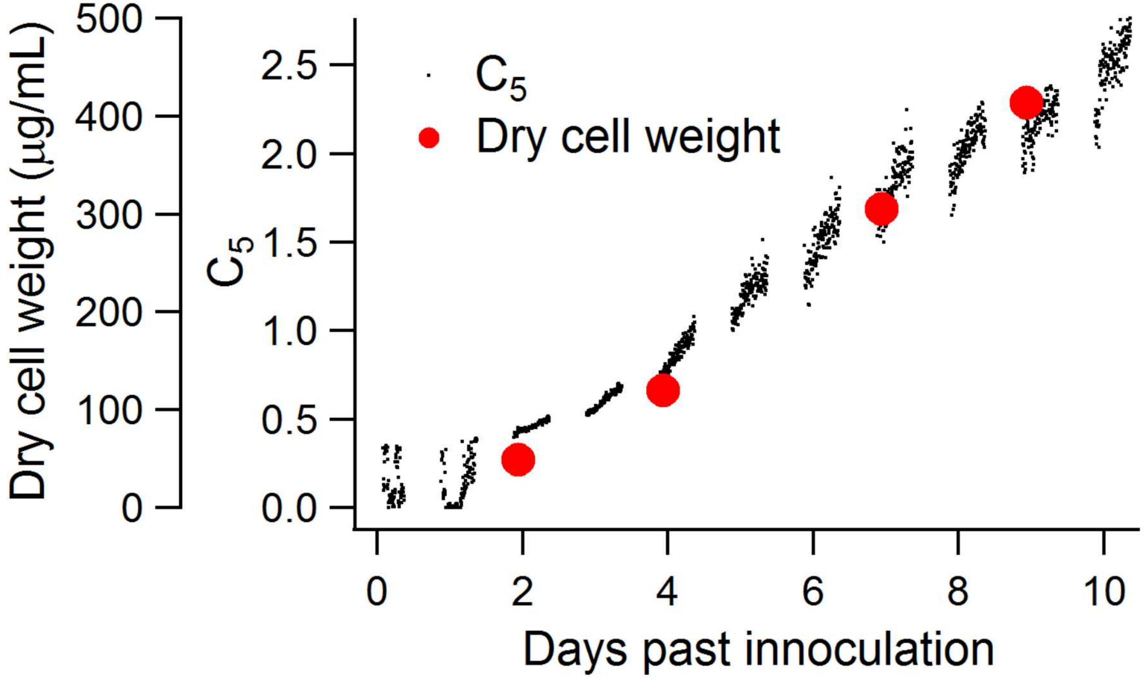
Many parameters (12!!!)

- **Absorbance**
  - Absorption $a(\lambda)$: Algae, dissolved organic matter (DOM), and water
- **Backscattering**
  - Absorbance features impact backscatter
  - Backscatter $b_b(\lambda)$: Approximated with the Hilbert transform
- **Water surface reflection**
  - Variable position of the sun
  - Different downwelling light fields from the sun and sky
- **Chl a fluorescence**



A-SHARP (Analysis-Software for Hyperspectral Algal Reflectance Probes) provides our partners the capability to perform real-time analysis

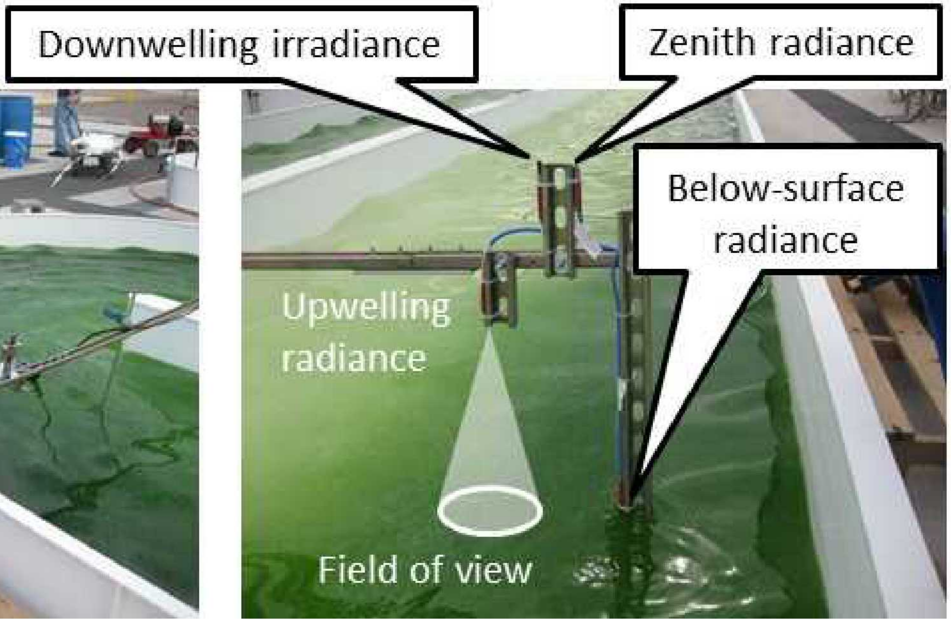
First in the Laboratory



The algal backscatter coefficient scales with algal dry cell weight, while pigment absorption provides information on algal state-of-growth

Next in the Field

Photos by Aaron Collins, Sandia (2012)



Collected all four spectra at 5 minute intervals

- 2-20 ms integration times, 1000 averages

Converted counts to spectrally resolved intensity (W/cm^2-nm) via calibrated lamp measurements

Stared at Spectralon target for calibration of reflectance

Lesson #1: It's hot in the desert

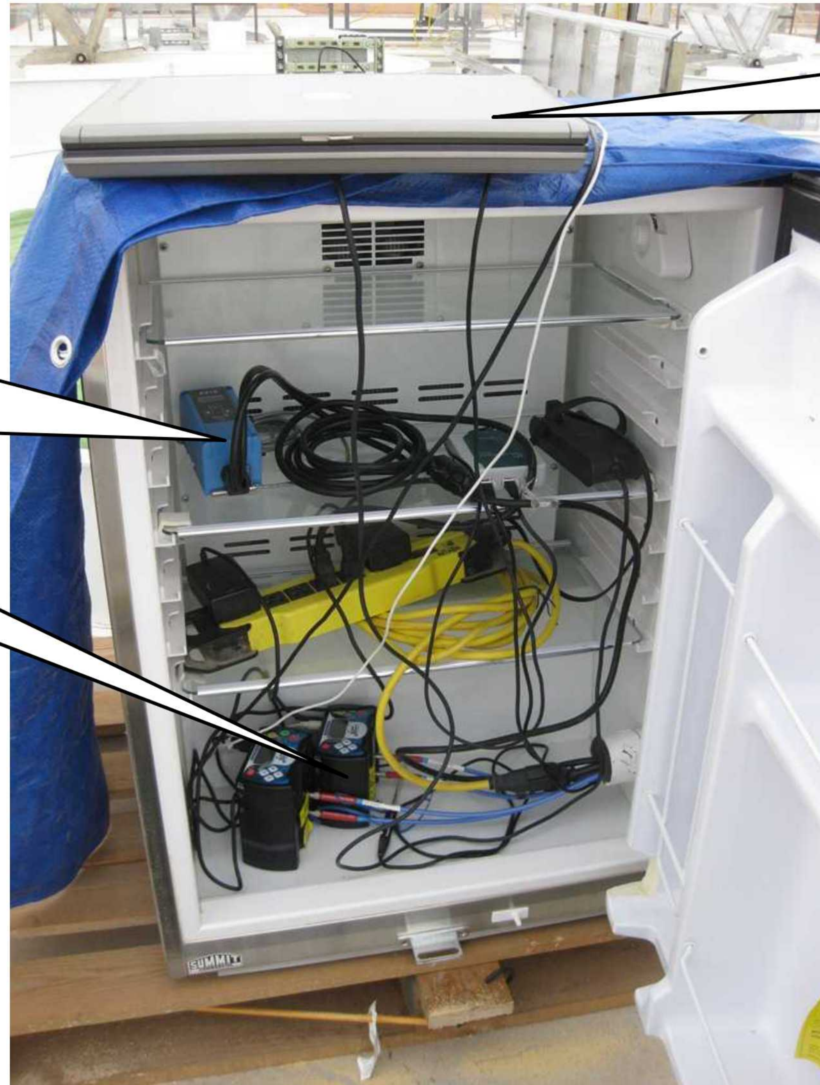
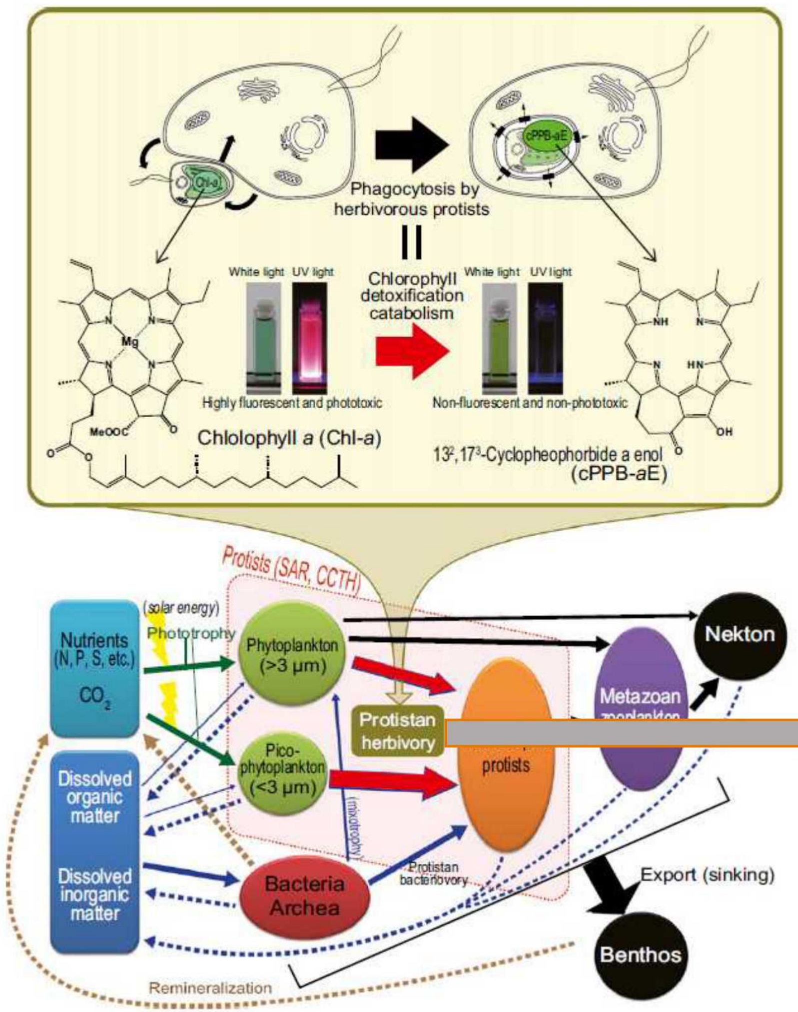


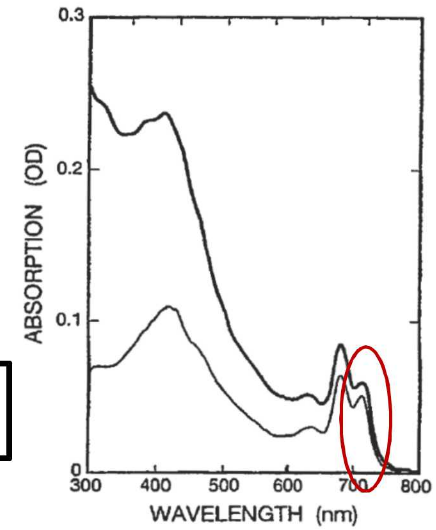
Photo by Aaron Collins, Sandia (2012)

Lesson #2: The Circle of Life… Under the Sea

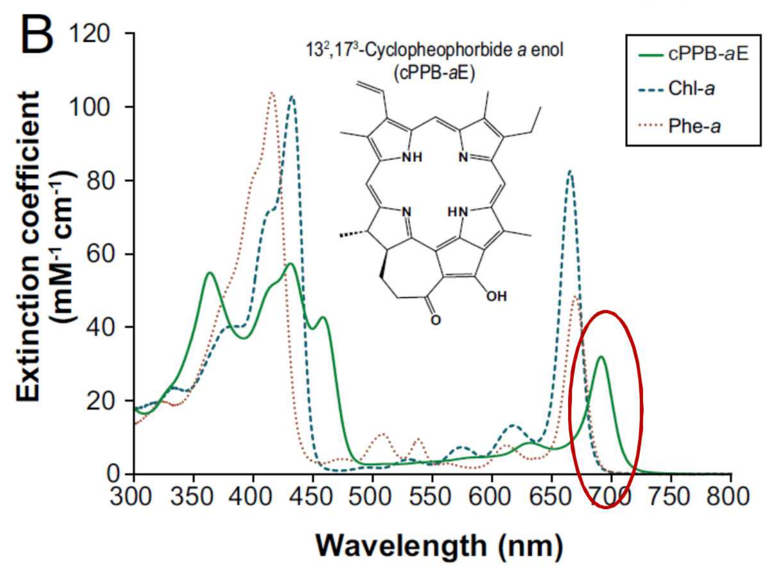


Y. Kashiyama et al. “Ubiquity and quantitative significance of detoxification catabolism of chlorophyll associated with protistan herbivory,” PNAS **109**, 17328-17335 (2012).

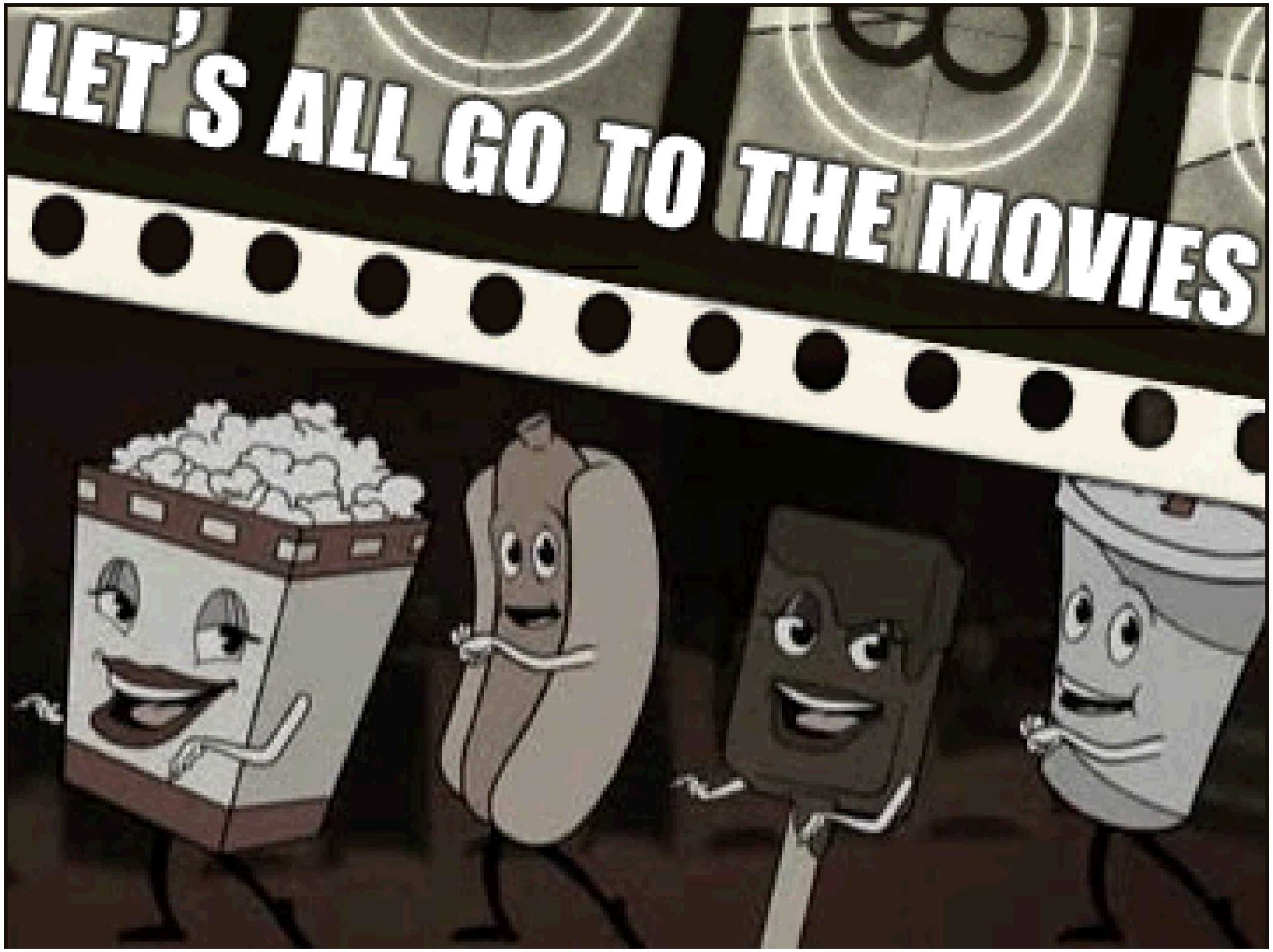
M. Vernet et al. “Evidence for a novel pigment with in vivo absorption maximum at 708 nm associated with *Phaeocystis* cf. *pouchetii* blooms,” Mar. Ecol. Prog. Ser. **133**, 253-262 (1996).



C_{a3}



Algae and a catabolite can be measured



Papers

Reichardt, TA, Collins, AM, Garcia, OF, Ruffing, AM, Jones, HDT and Timlin, JA, "Spectroradiometric monitoring of nannochloropsis salina growth," *Algal Research*, 2012, 1:1, 22-31.

Reichardt, TA, Collins, AM, McBride, RC, Behnke, CA and Timlin, JA, "Spectroradiometric monitoring for open outdoor culturing of algae and cyanobacteria," *Applied Optics*, 2014, 53:24, F31-F45.

Paper in preparation on monitoring predators/pathogens/competitors

Design Criteria Relevant for UAVs

Resolution: spatial & spectral

Sensitivity

Area

Speed

Calibration

Others: weight, battery life/power requirements

Our thoughts about approach: Mount spectrometer on UAV (not a hyperspectral camera) and let UAV motion build up the image pixels.

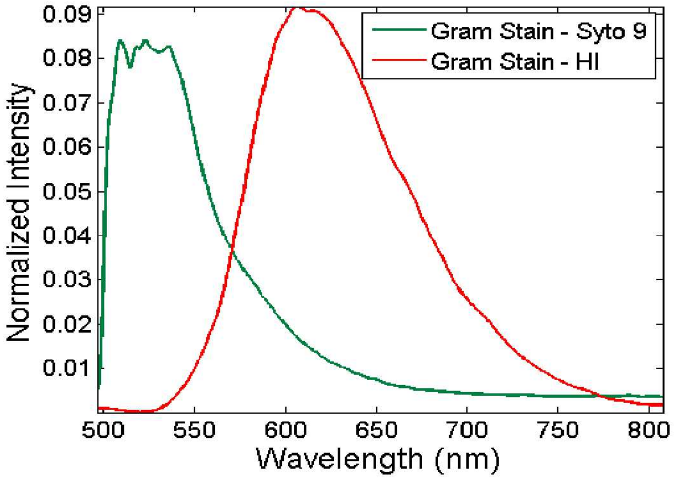
Why? Spectral resolution & cost are more important than spatial resolution for algal monitoring

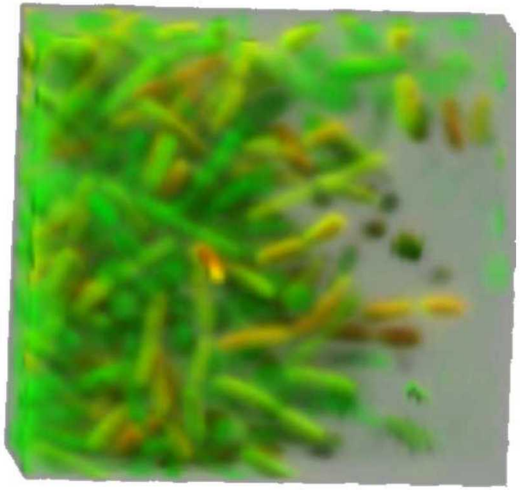
Disadvantage: couples resolution/speed/integration time

Advantage: $$, excellent spectral resolution, can be easily coupled to inexpensive RGB camera and geolocation

Applications of Hyperspectral Imaging at the Cellular Level

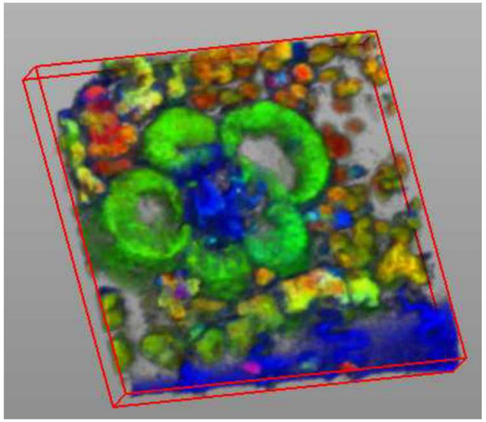
Water Purification Membranes





Gram stained drinking water bio-film (12.5 x 12.5 x 6 μm)

Plant Biology / Crop Analytics



Hyperspectral Imager

Filter Based Imager

Acknowledgements

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