SAND2016-7593C

ATP3 Algae Testbed Public-Private Partnership

Spectroradiometric Monitoring for Early Warning Detection of Pond Crash Conditions

T. A. Reichardt[a], T. J. Jensen[a], M. D. Cuevas[b], P. Wensel[b], T. A. Dempster[b], J. A. McGowen[b], and J. A. Timlin[a]

[a]Sandia National Laboratories, USA

[b]Arizona Center for Algae Technology and Innovation, Arizona State Univ., USA

Presented at the 6th International Conf. on Algal Biomass, Biofuels and Bioproducts, San Diego, CA, June 26th-29th, 2016

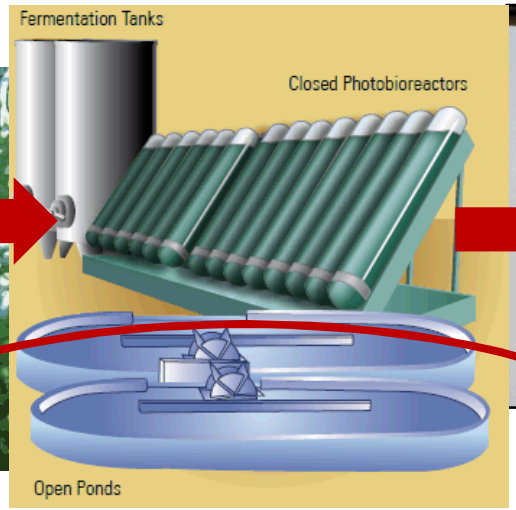
Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Problem Statement

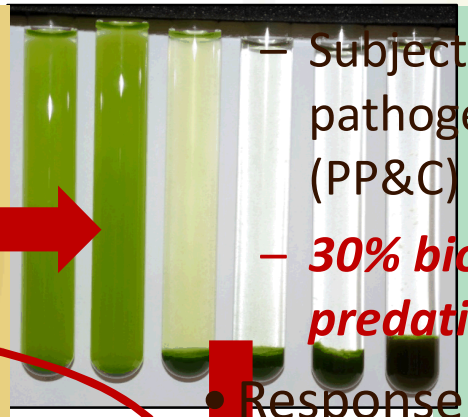
Algae Testbed
Public-Private Partnership

Algae feedstocks

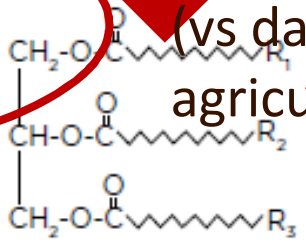
Cultivation



Harvesting/Dewatering



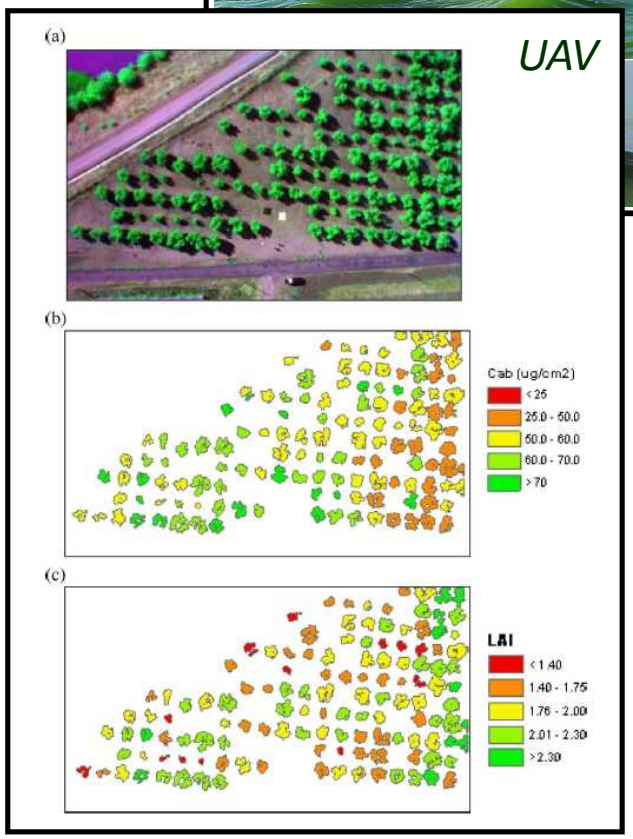
Extraction



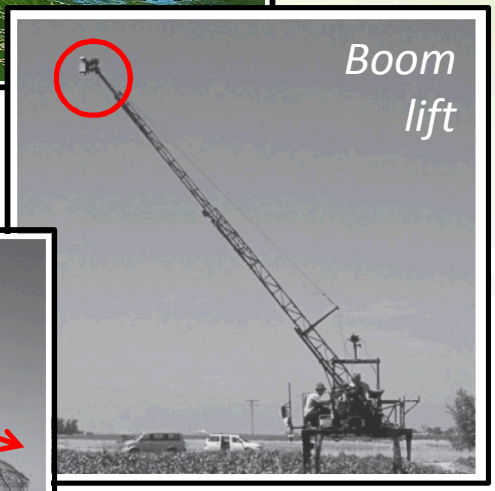
Conversion

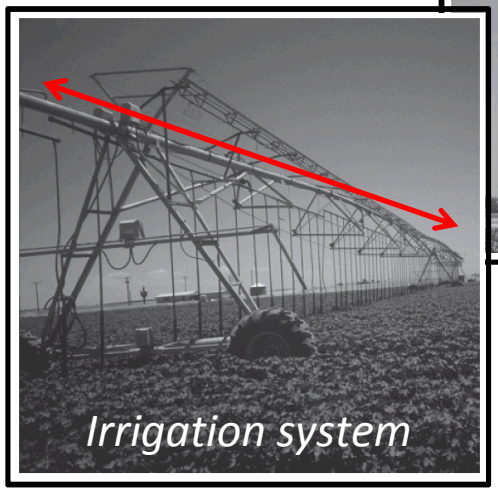
- Typically a raceway design circulated by a paddle-wheel
  - Subject to predators, pathogens, and competitors (PP&C)
  - ***30% biomass lost from predation alone***
- Response desired within hours (vs days for traditional agriculture)

Remote optical sensing could provide rapid, broad area assessment of open systems



*J. A. J. Berni et al, IEEE Trans. Geosci .& Rem. Sens. **47**, 2009.*





S. Moran et al., Photogrammetric Eng. & Rem. Sens., June 2003, 705-718.

ATP³ Algae Testbed Public-Private Partnership

Hyperspectral sensing can now be deployed on small agricultural drones

Hypothesis: (1) Bulk optical biomarkers specific to PP&Cs exist and (2) they can be detected via standoff remote sensing

Photos from R. C. McBride et al., "Contamination management in low cost open algae ponds for biofuels production," Indust. Biotechnol. **10**, 221-227 (2014).

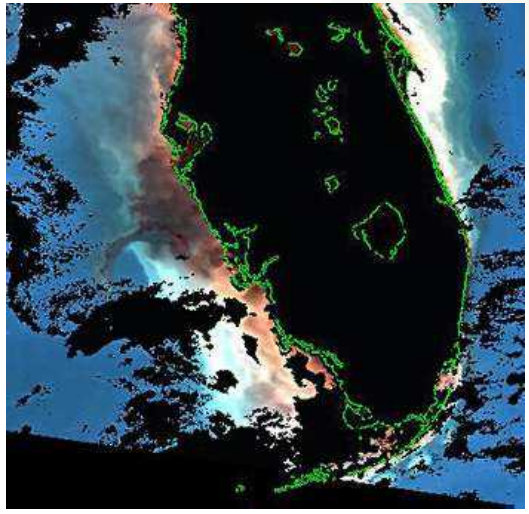
Optical sensing does not require physical sampling, nor does it rely on the transport of aerosols/vapors to the sensor

Only require a line-of-sight

Signatures are fully scalable from the beaker to the satellite

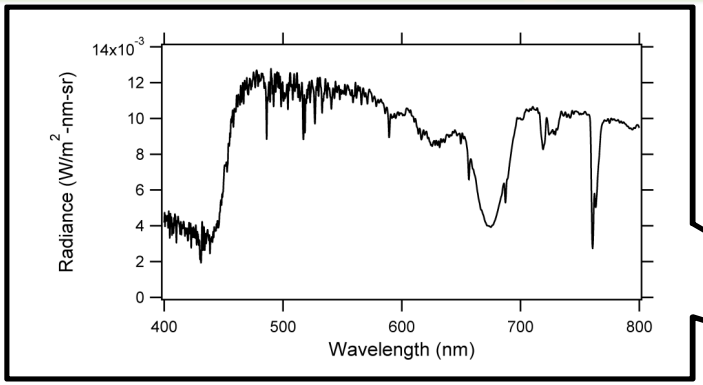
But PP&Cs must first produce optical responses

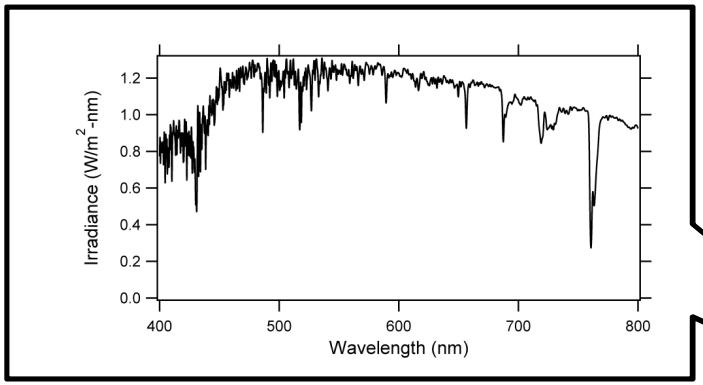
Detect "functional" pest presence for P&P

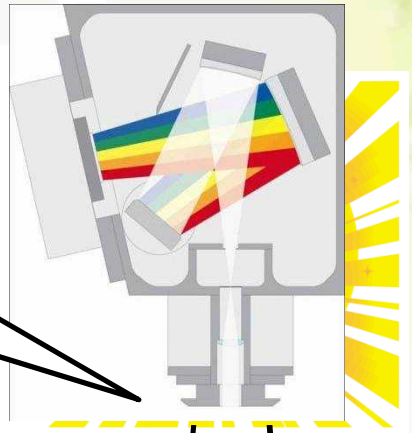


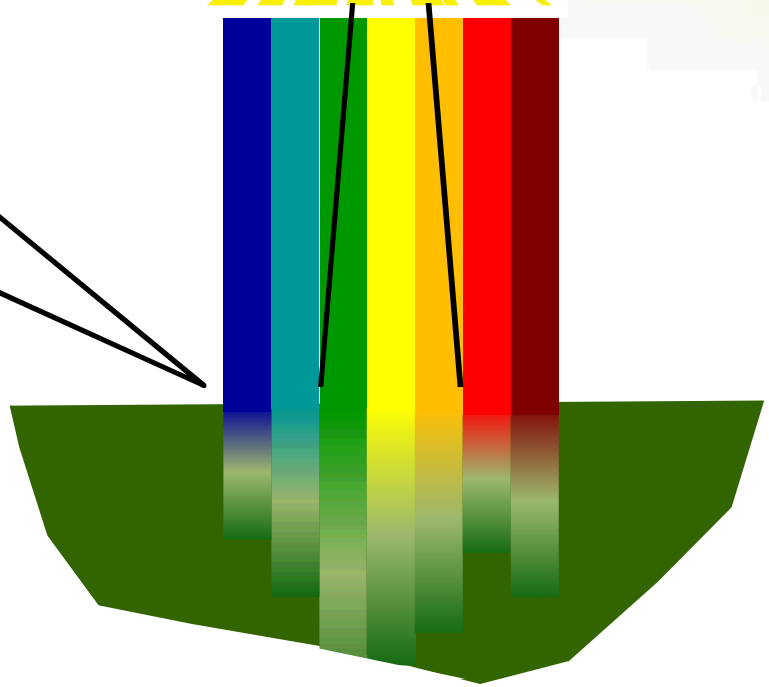
http://earthobservatory.nasa.gov/Features/Redtide/

Hyperspectral Spectroradiometric Monitoring

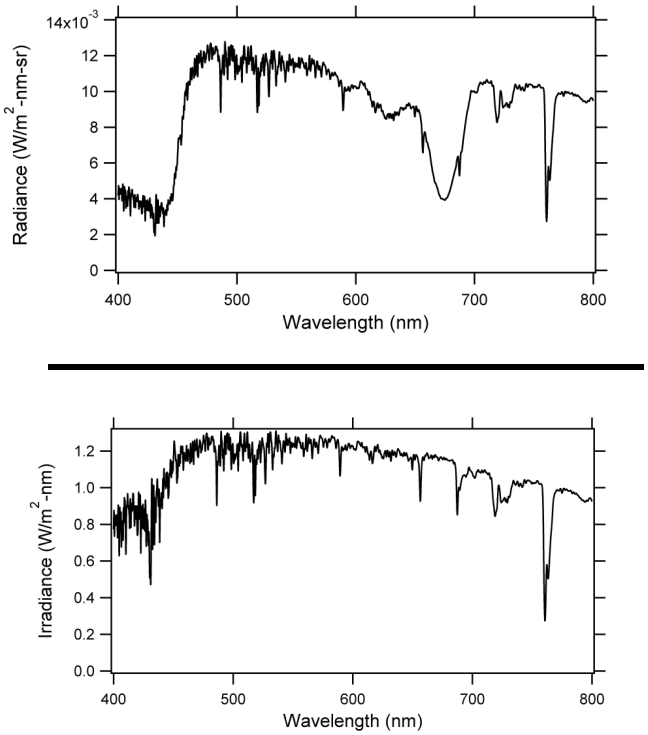




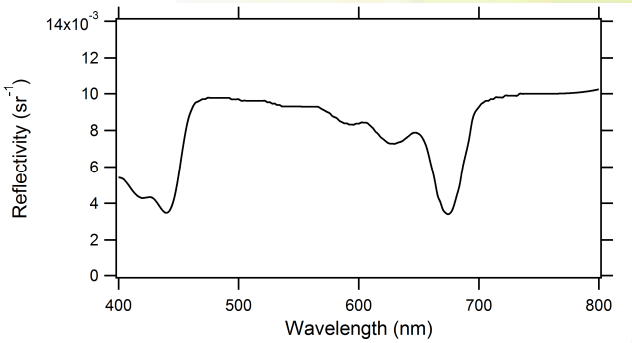




Hyperspectral Spectroradiometric Monitoring

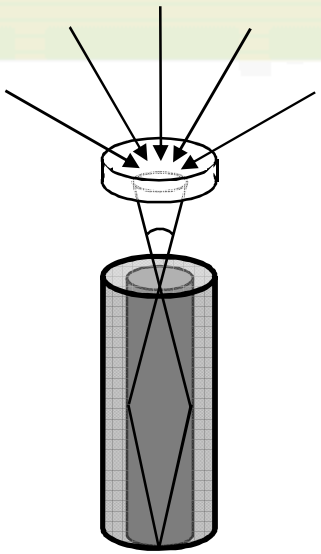


=



Dual-Channel Spectroradiometer

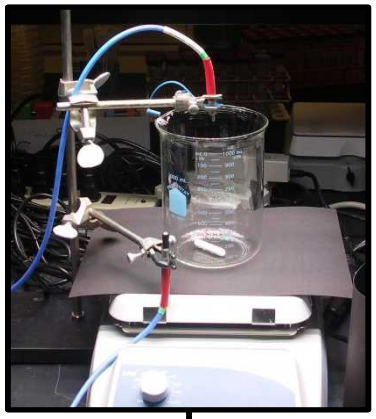
- Diffuser randomizes the direction of incoming light
- Fiber captures light from all downwelling angles
- Refractive indices of core and cladding limit field-of-view to 25^{o} cone of light

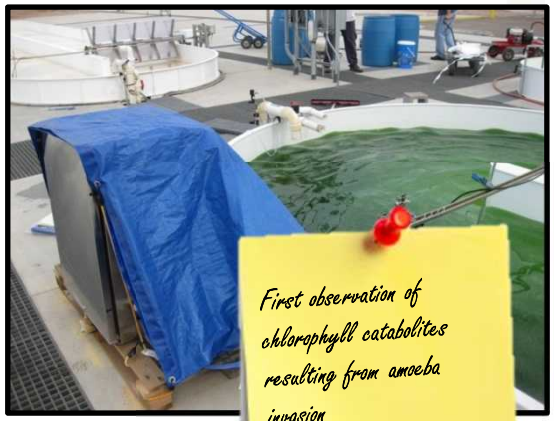


Escapes into cladding

Trapped by core

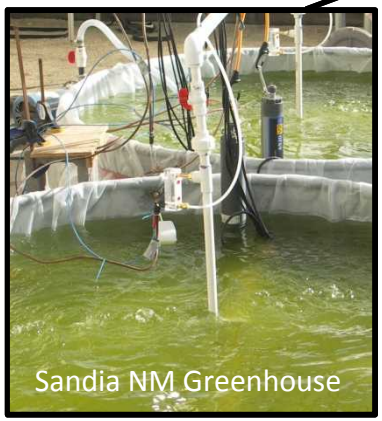
Our Spectroradiometric Monitoring of Algal Biomass

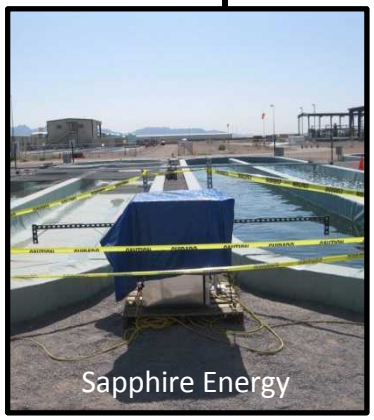


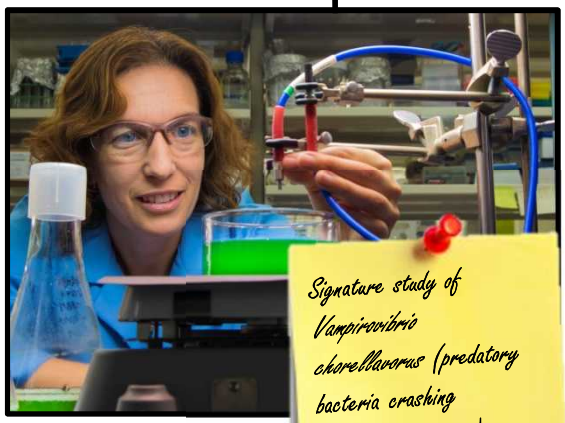


First observation of chlorophyll catabolites resulting from amoeba invasion

2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016







Signature study of Vampirovibrio chlorellavorus (predatory bacteria crashing Chlorella cultures)

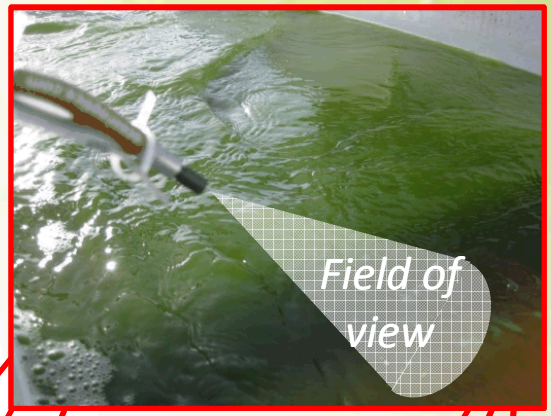
ATP³ Deployment: Monitoring All 6 Mini-Raceway Ponds Simultaneously

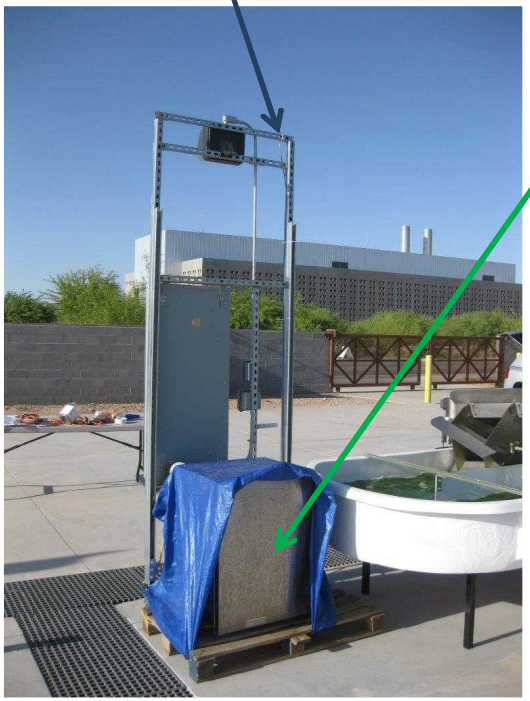
ATP³ Algae Testbed Public-Private Partnership

Monitoring downwelling irradiance

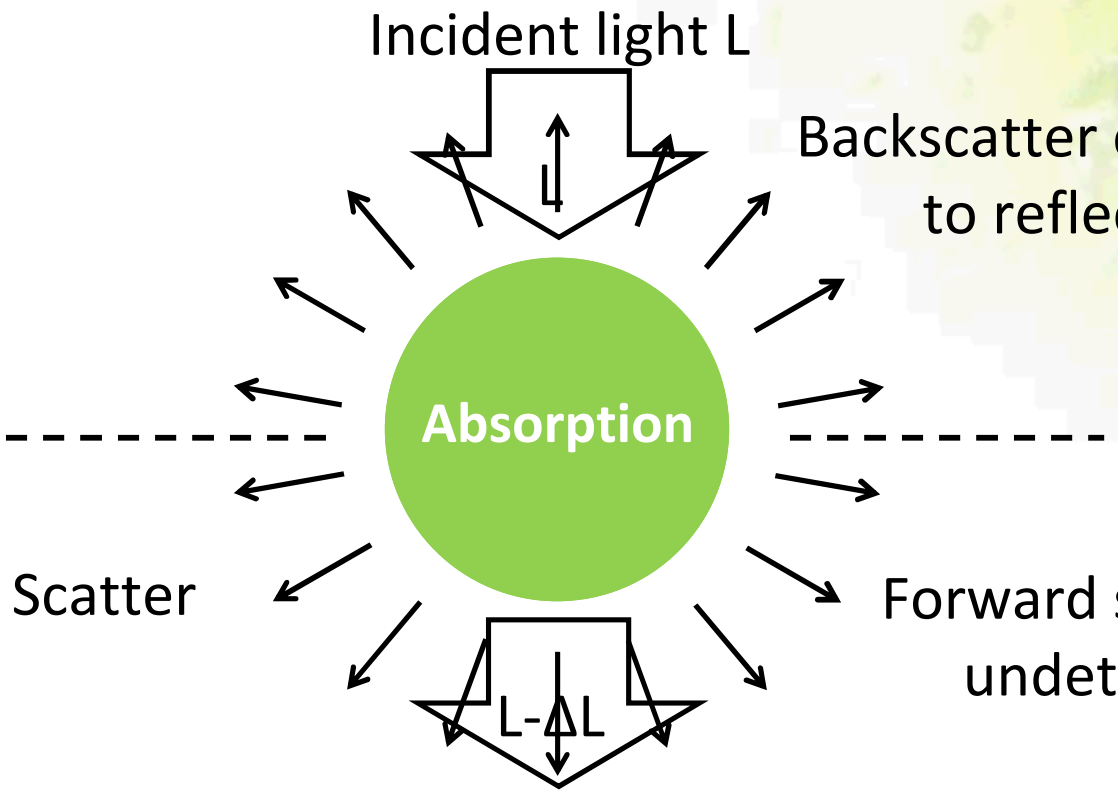
Instrument housed inside temperature-controlled enclosure

Monitoring upwelling radiance from all six mini-raceway ponds





Reflectance depends on single-backscattering albedo $u(\lambda)$

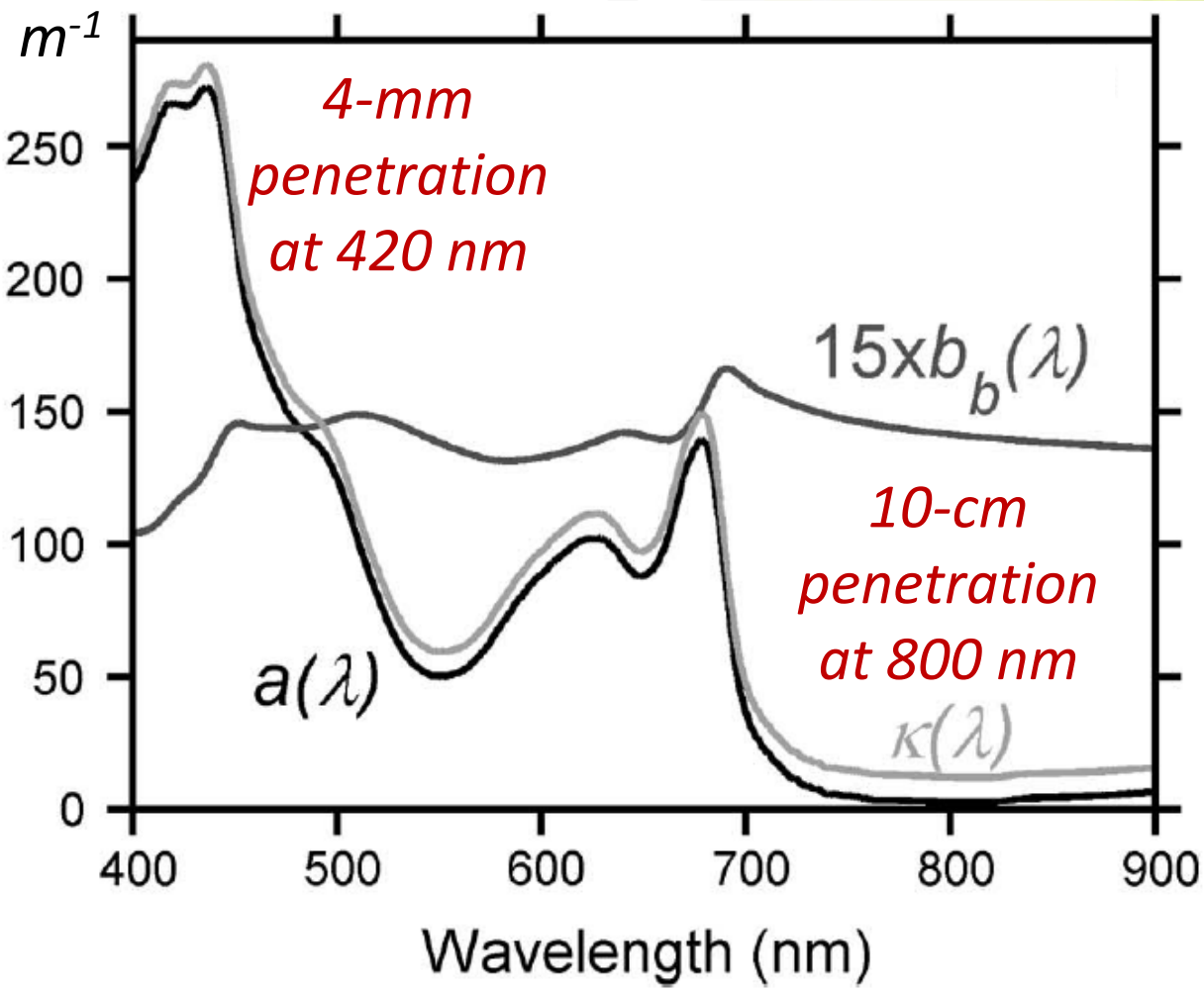


$$u(\lambda) = \frac{\text{Backscatter}(\lambda)}{\text{Backscatter}(\lambda) + \text{Absorption}(\lambda)} = \frac{b_b(\lambda)}{b_b(\lambda) + a(\lambda)}$$

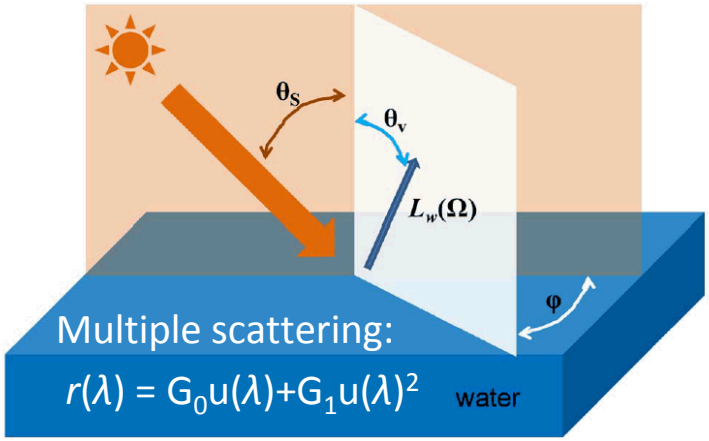
ATP³ Algae Testbed Public-Private Partnership

$\kappa(\lambda) = a(\lambda) + b_b(\lambda)$

1/e light penetration = $1/\kappa(\lambda)$

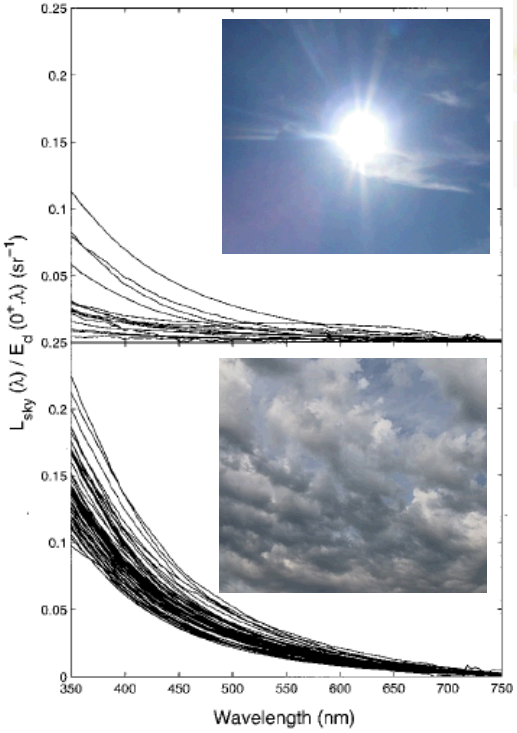


Data are analyzed via a solution of the radiative transfer equation which accounts for the physics of light interacting with the pond, etc.

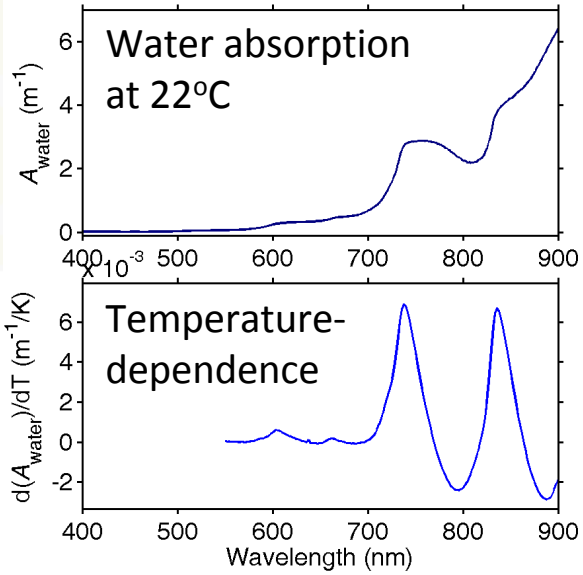


Z. Lee et al., Appl. Opt. ***50****, 3155-3167 (2011).*

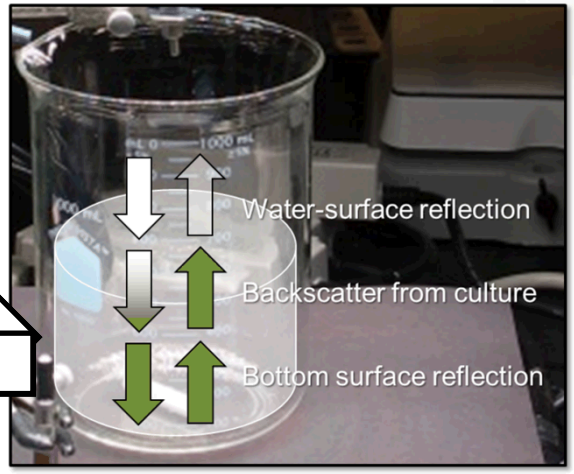
Clear or cloudy conditions



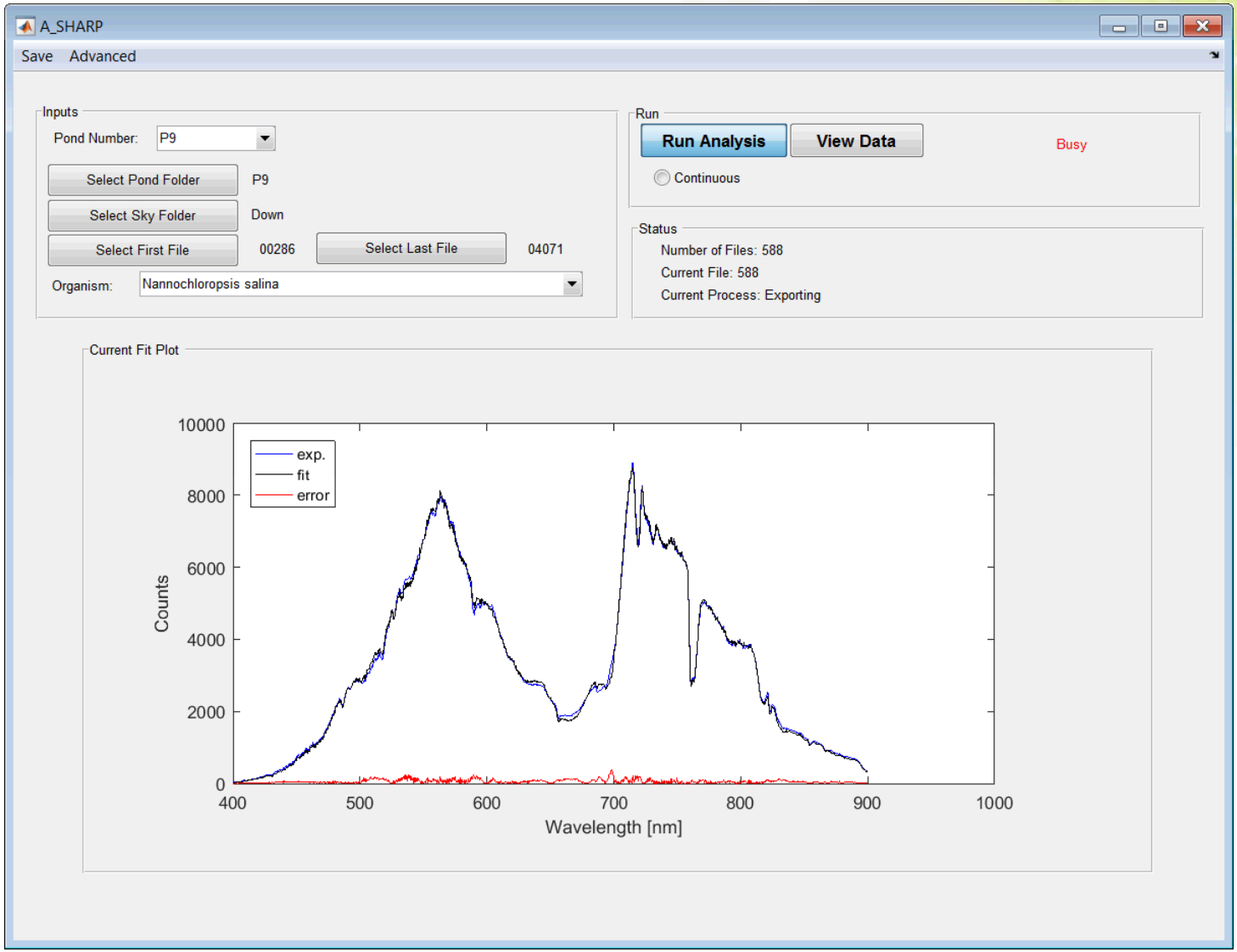
D. A. Toole et al., Appl. Opt. ***39****, 456-469 (2000).*



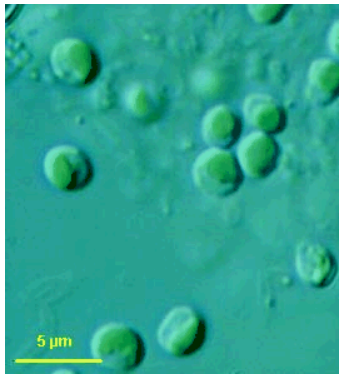
Same $a(\lambda)$ and $b_b(\lambda)$

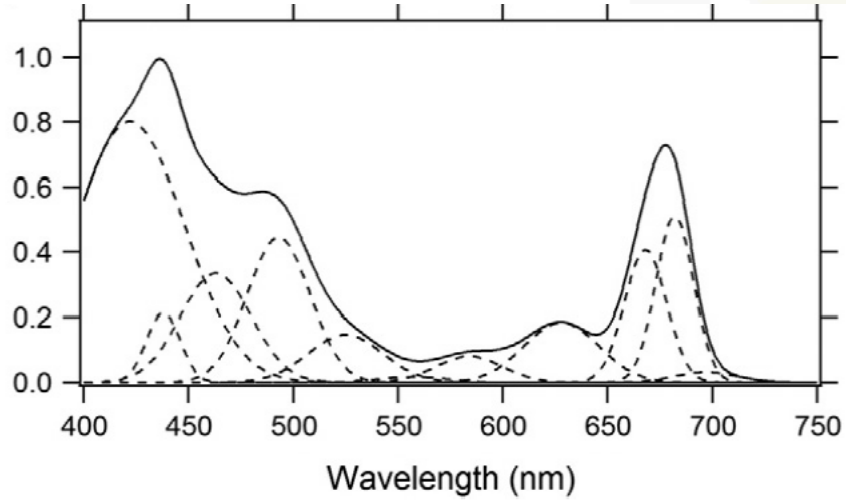


A-SHARP (Analysis-Software for Hyperspectral Algal Reflectance Probes) now provides our partners the capability to perform real-time analysis of reflectance data

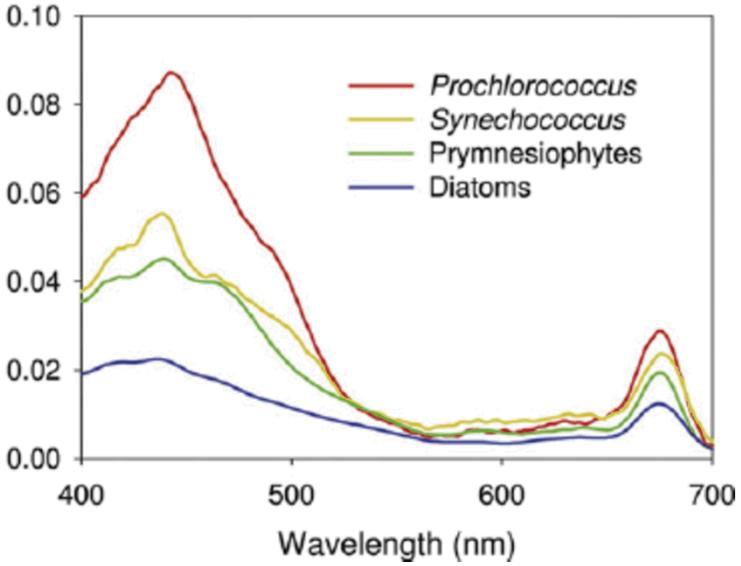


Optical biomarker for competitors: Changes in the absorption spectrum



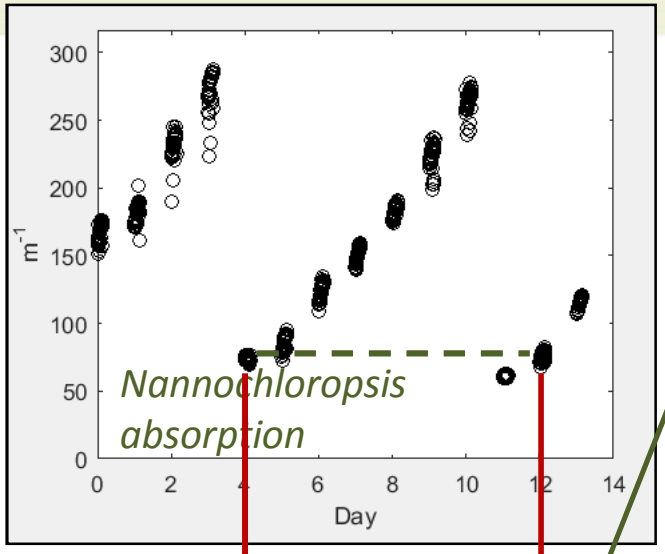


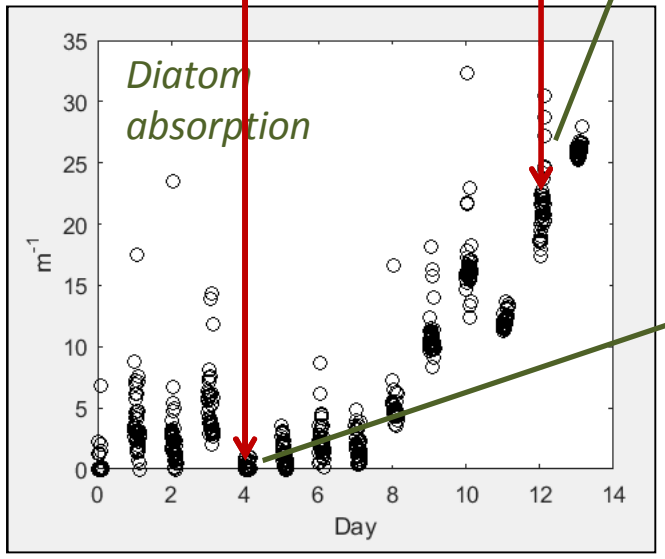
Nannochloropsis exhibits distinct absorption features due to Chl *a* and carotenoids…

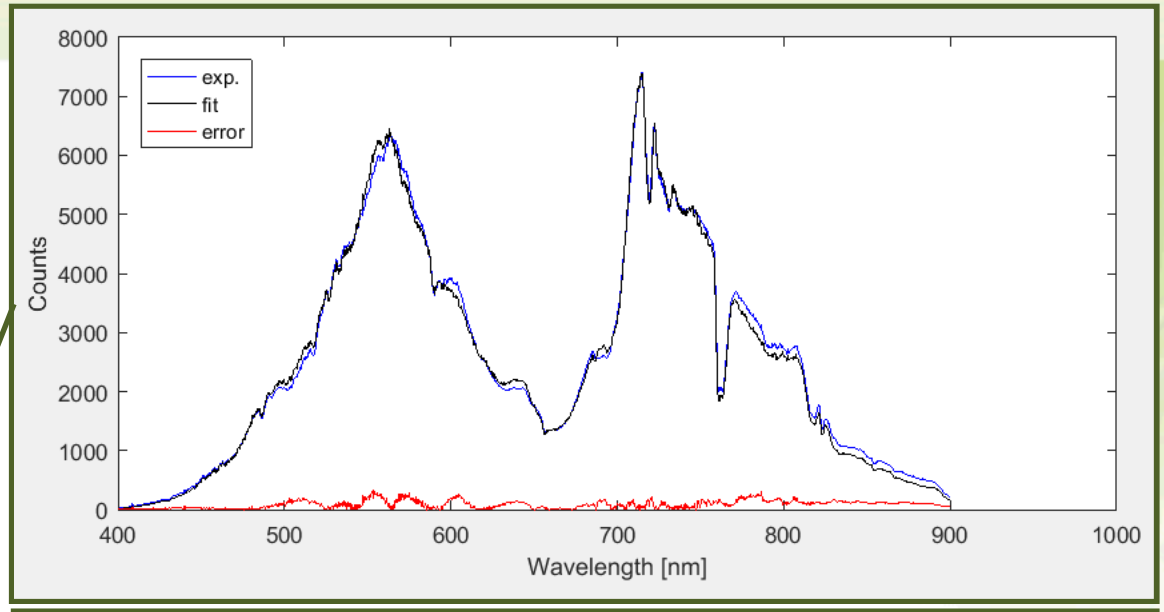


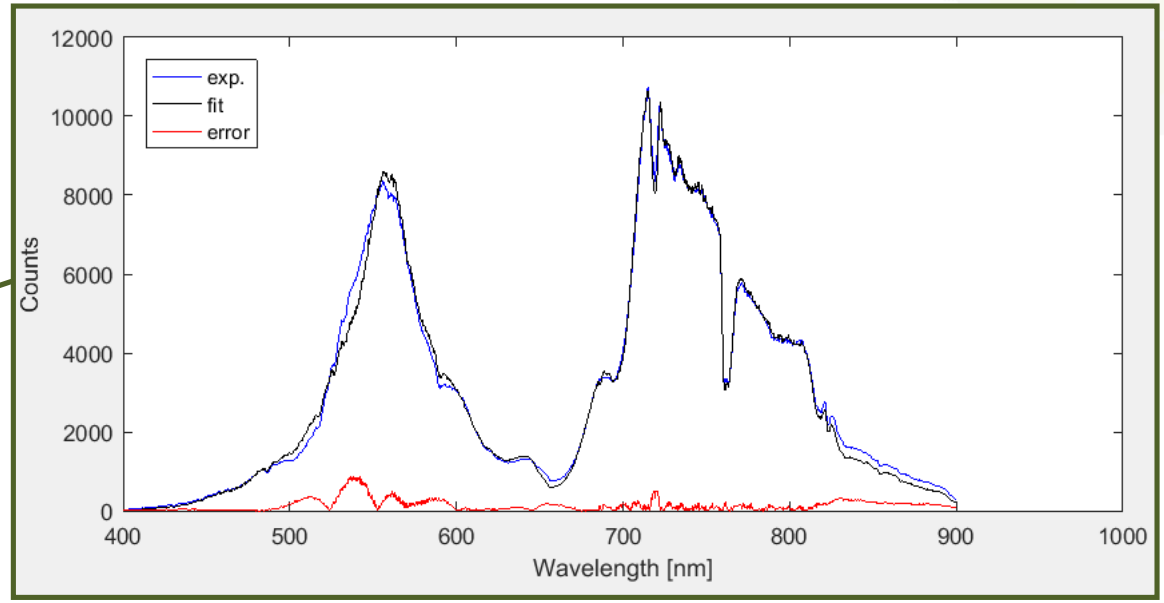
… while diatoms exhibit much less distinct features, probably best described as "green-*ish*"

Detection of Diatom Invasion









Predator Detection

Predators will eventually clear a pond…

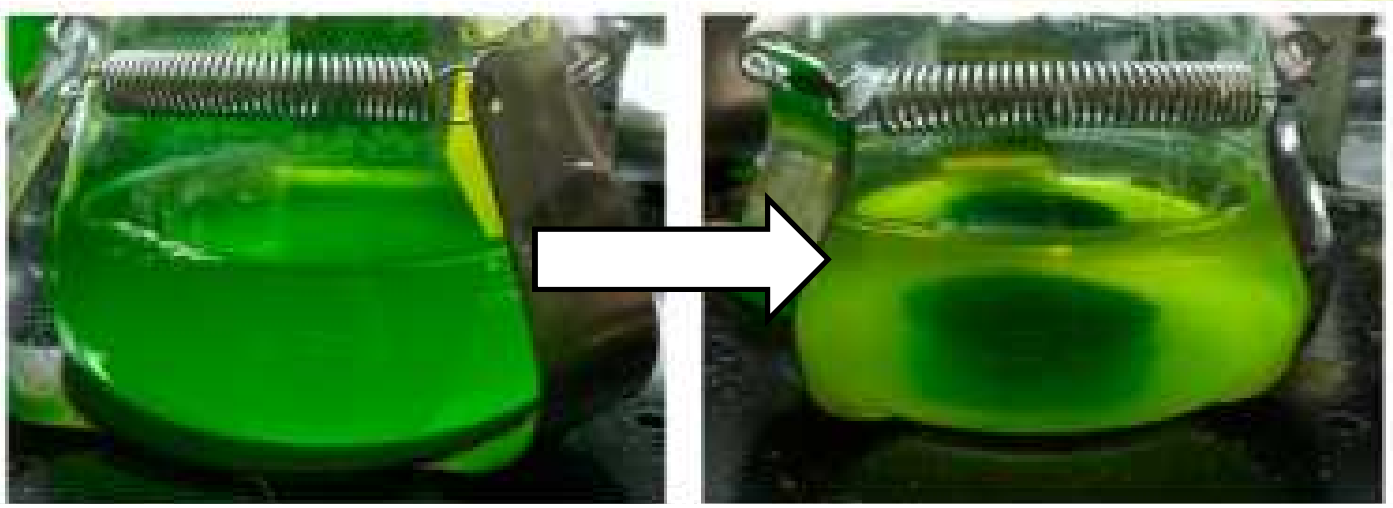
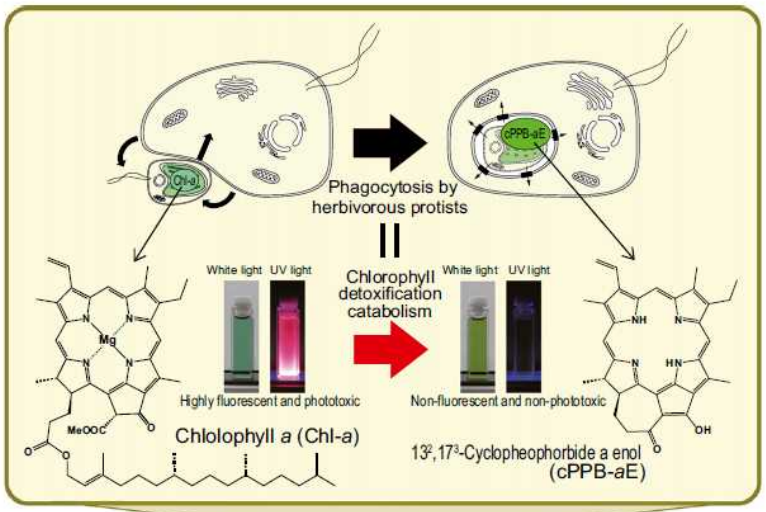


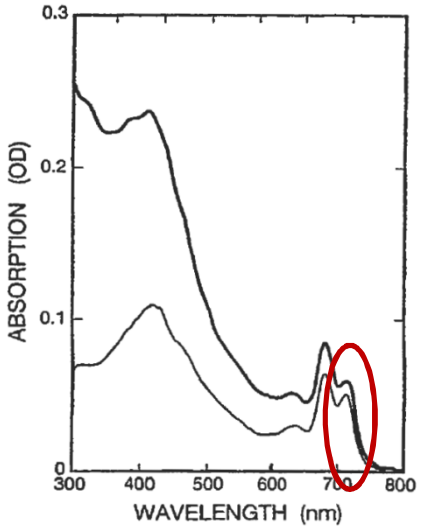
Photo from S. Park et al., "The selective use of hypochlorite to prevent pond crashes for algae-biofuel production," Water Environ. Res. **88**, 70-88 (2016).

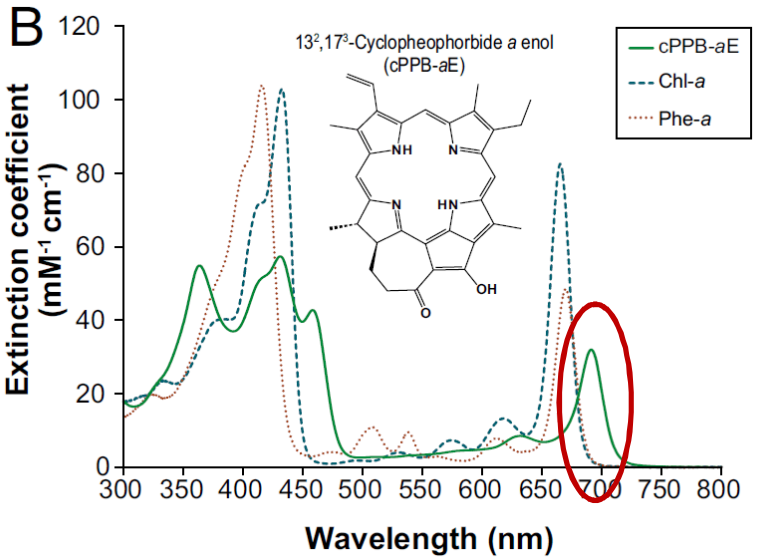
…but another biomarker will appear before that happens.

Optical Biomarker for Predators: 708-nm absorption feature



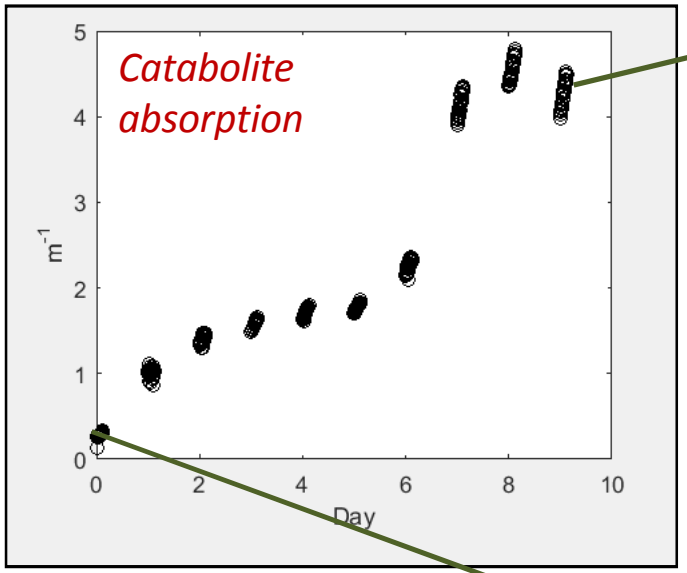
M. Vernet et al. "Evidence for a novel pigment with in vivo absorption maximum at 708 nm associated with *Phaeocystis* cf. *pouchetii* blooms," Mar. Ecol. Prog. Ser. **133**, 253-262 (1996).

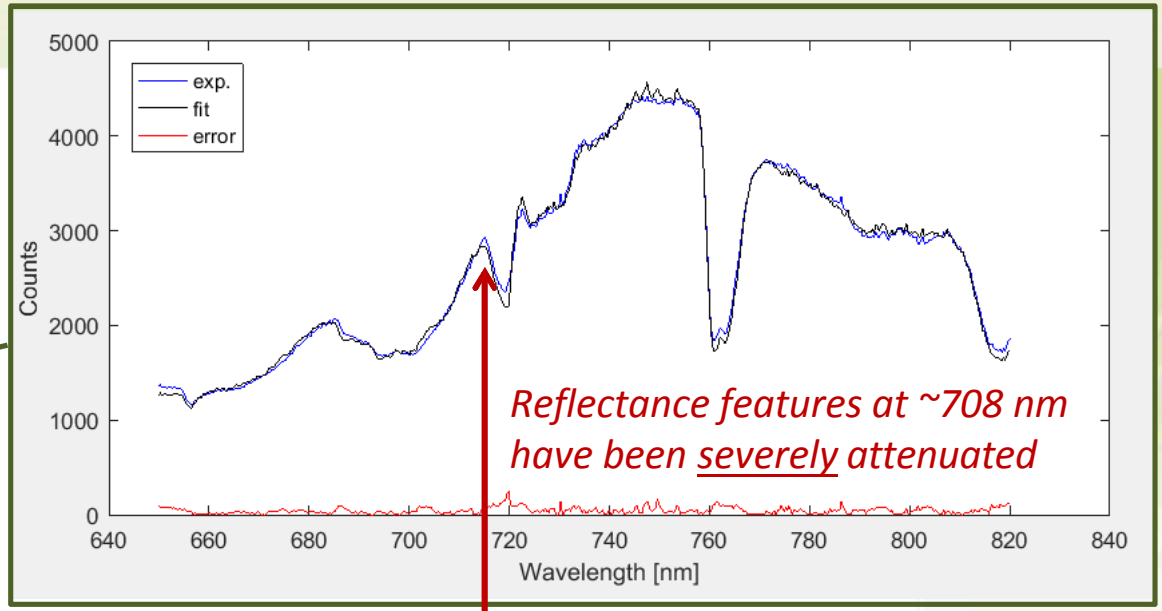


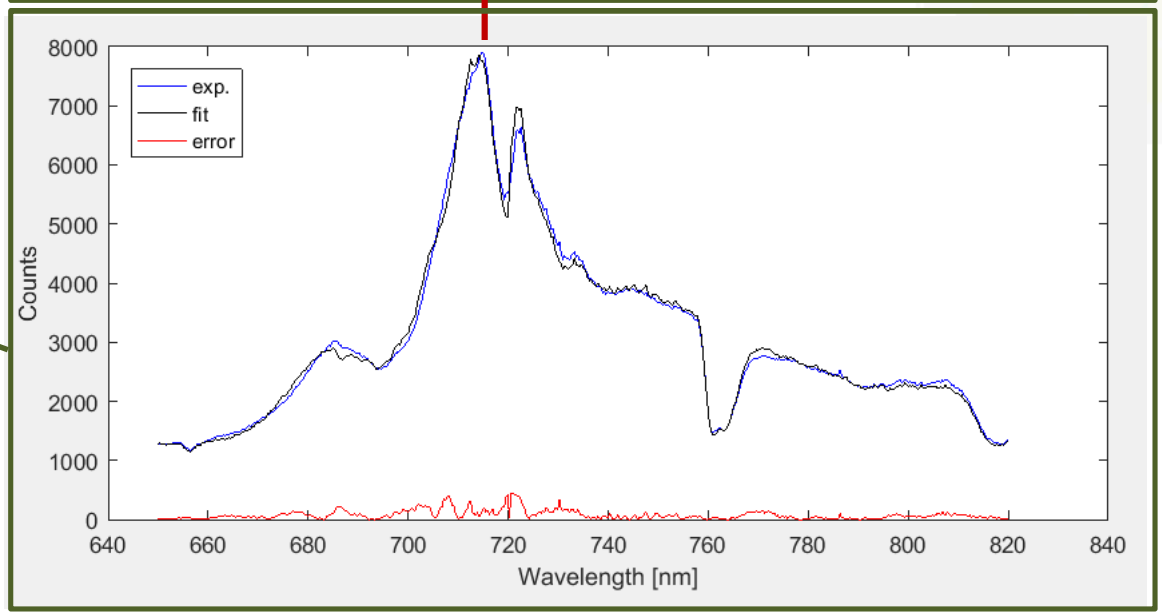


Y. Kashiyama et al. "Ubiquity and quantitative significance of detoxification catabolism of chlorophyll associated with protistan herbivory," PNAS **109**, 17328-17335 (2012).

Detection of Protist Invasion







Summary: Advantages over Current Practices

Having previously demonstrated in-situ measurement of biomass and pigment optical activity, *we have now demonstrated the potential for real-time detection of predators and competitors.* Our method…

… is non-sampling,

no laboratory access required

… integrates physics of light transport into the data analysis,

no extensive pre-calibration required

… is non-contact,

reduces instrument fouling

… allows for fully autonomous operation,

has been deployed for >3 years in the field

… and can be readily extended to other device platforms.

Current pond-side embodiment

Imagers (~$70K)

Single-FOV systems (~$3K)

Handheld smartphone spectrometer, Allied Scientific Pro

Airborne agricultural drones

Acknowledgments

Many thanks to Jackie Murton (Sandia NM) for keeping up with the day-to-day operation of the multichannel spectrometer

Work supported by the U. D. Department of Energy's Office of Energy Efficiency and Renewable Energy (DOE/EERE)

Further reading:

T. A. Reichardt et al., "Spectroradiometric monitoring of *Nannochloropsis salina* growth," Algal Res. **1**, 22-31 (2012).

T. A. Reichardt et al., "Spectroradiometric monitoring for the open outdoor culturing of algae and cyanobacteria," Appl. Opt. **53**, F31-F45 (2014).

ATP³ Algae Testbed Public-Private Partnership

Thanks! …Questions?