Lecture 3
Absorption physics and absorbing materials

Collin Roesler

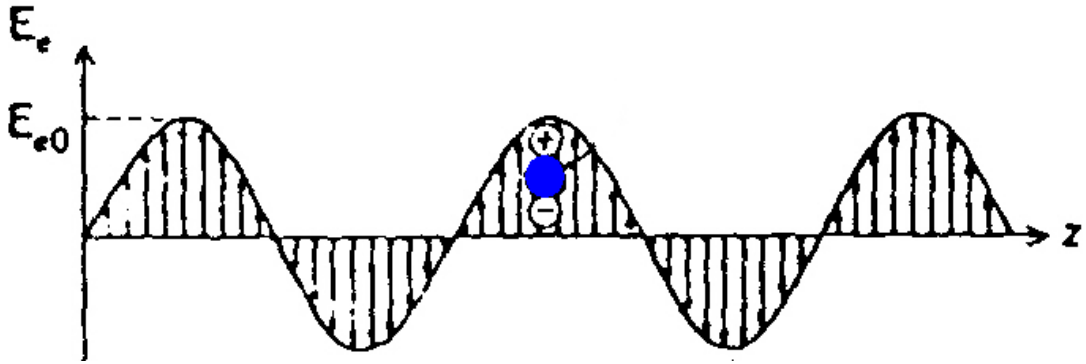
7 July 2015

Lecture Overview

- Overview of the electromagnetic spectrum
- What is absorption?
- What are the major absorbers in the ocean?
- How do we measure absorption in the ocean?

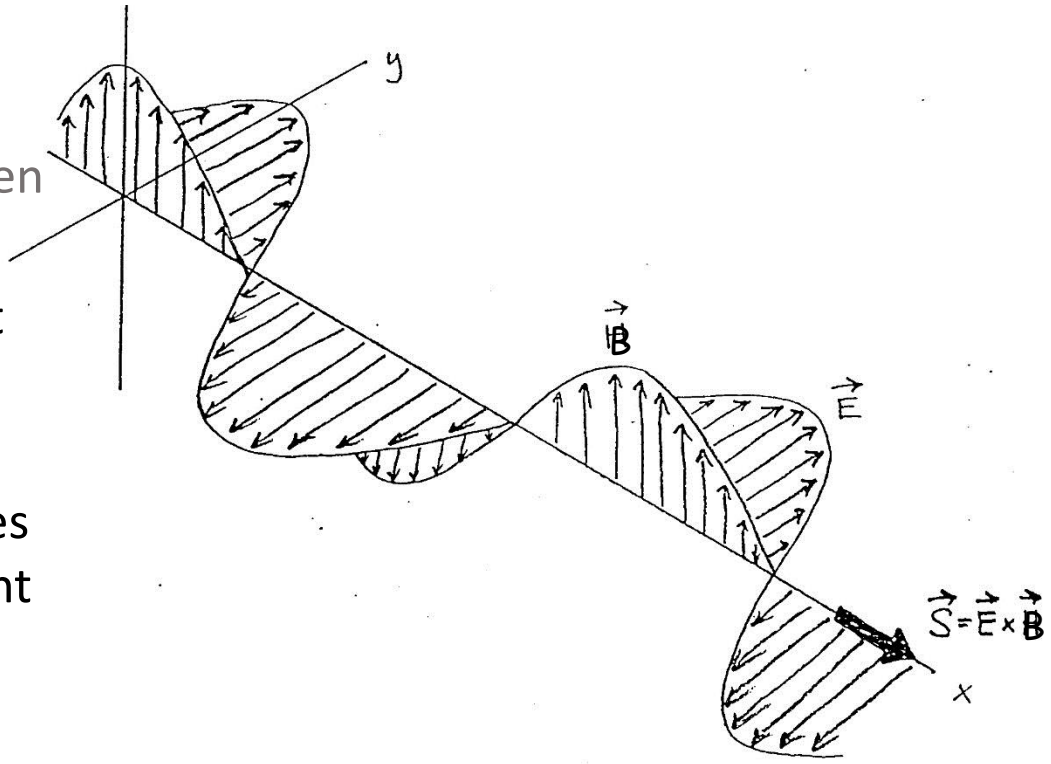
Electromagnetic Radiation

- Charged particles (dipoles) create electric fields **E** (oscillation between +,-)



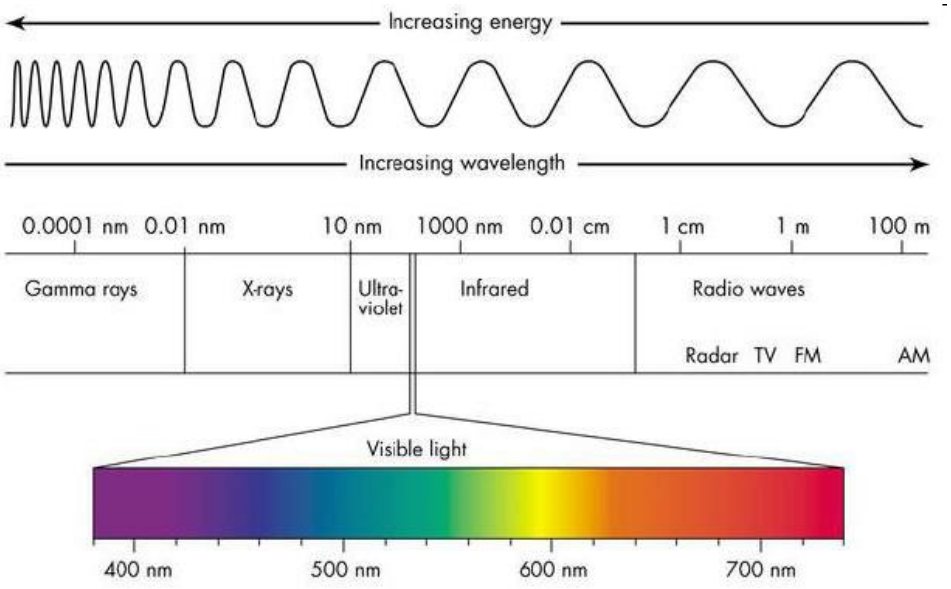
Electromagnetic Radiation

- Charged particles, dipoles, create electric fields **E** (oscillation between +,-)
- When a charged particle moves, it creates a magnetic field, **B** (or H depending on book)
- The electromagnetic field oscillates as the energy propagates **ExB** (right hand rule)



Electromagnetic Radiation

- Charged particles, dipoles, create electric fields E (oscillation between +,-)
- When a charged particle moves, it creates a magnetic field, **B (or H depending on book)**
- The electromagnetic field oscillates as the energy propagates **ExB** (right hand rule)



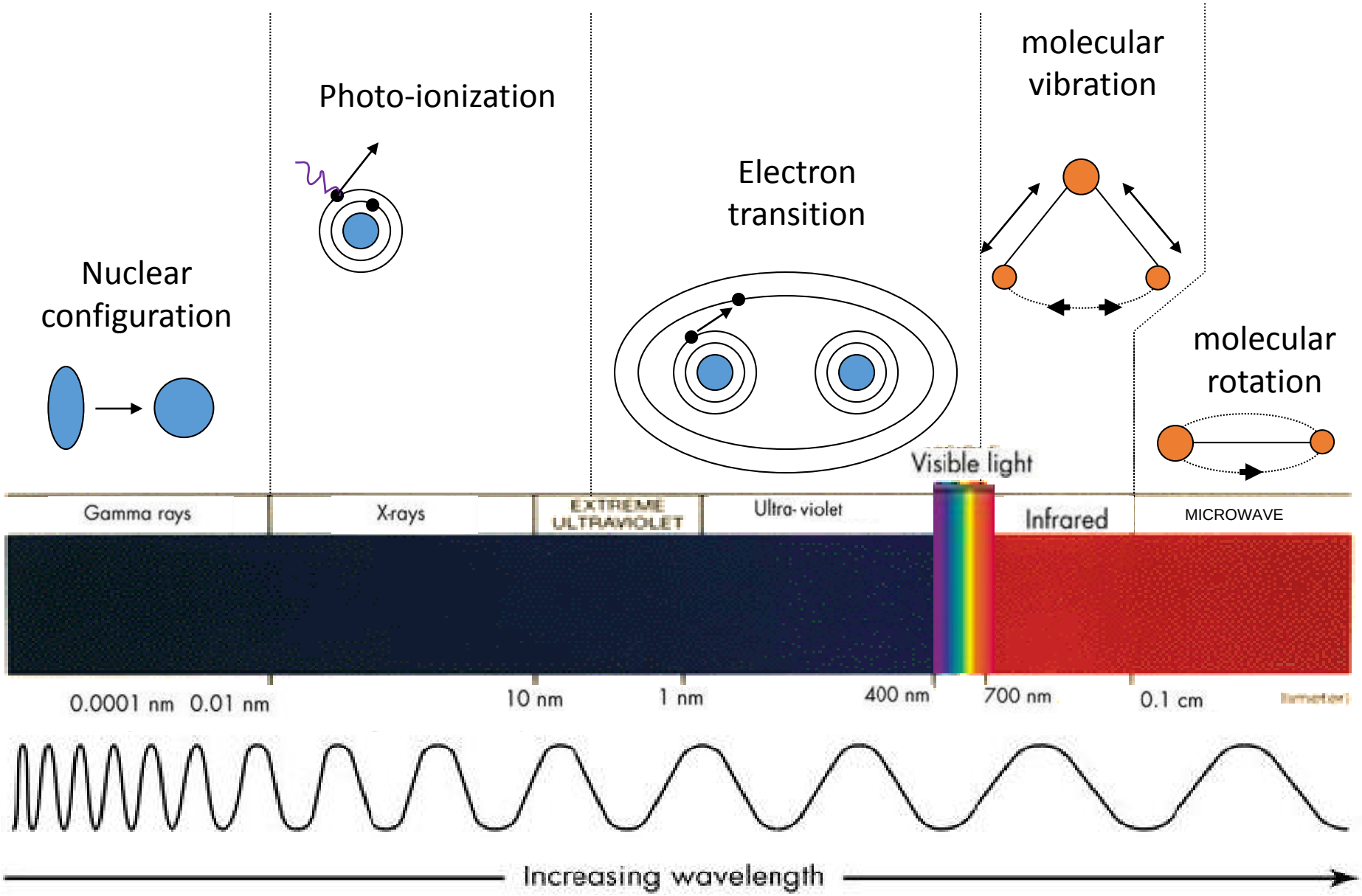
- the range of oscillation frequencies is described by the EM spectrum

http://www.antonine-education.co.uk/physics_gcse

What is absorption?

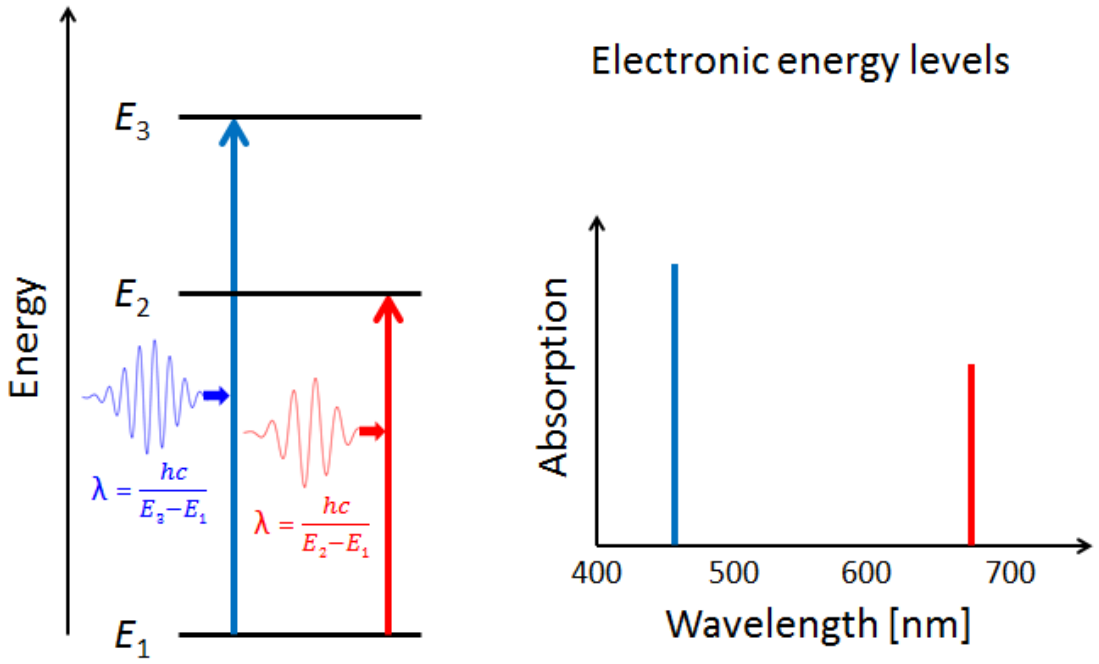
- Since electromagnetic radiation is energy propagation, when materials absorb radiation, they absorb *energy*
- The energy associated with each part of the spectrum is given by $E = hc/\lambda$
- What happens to the molecule depends upon the amount of energy, hence the wavelength

Interactions between energy and matter



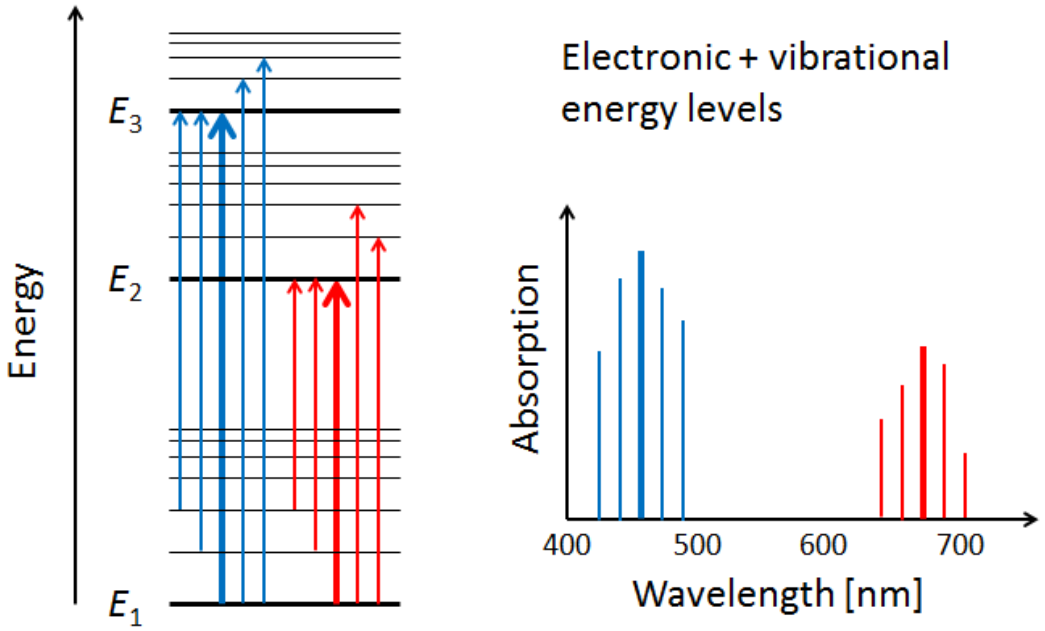
Quantized electronic states

- Amount of energy required to move an electron to another orbital shell (electronic state transition) is quantized
- A molecule can only absorb radiation of this specific quantized energy or wavelength
- This determines the absorption peak



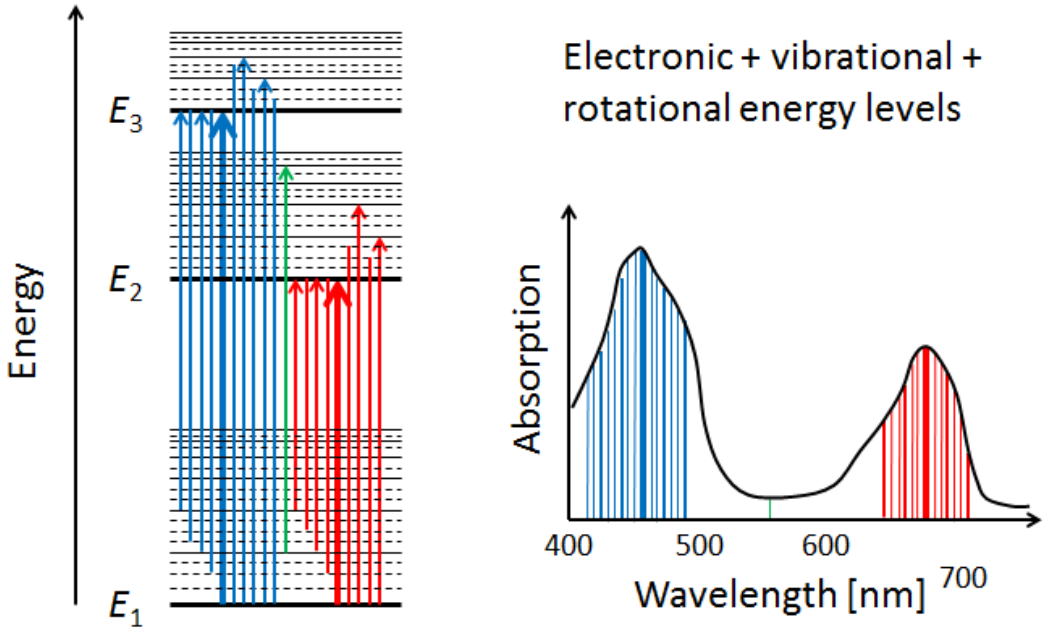
Quantized vibrational states

- Each orbital shell is associated with a series of higher excited states, associated with vibrational energy, which are also quantized
- These determine the wavelengths of the absorption side peaks which are higher (lower) energy but have a lower probability for absorption

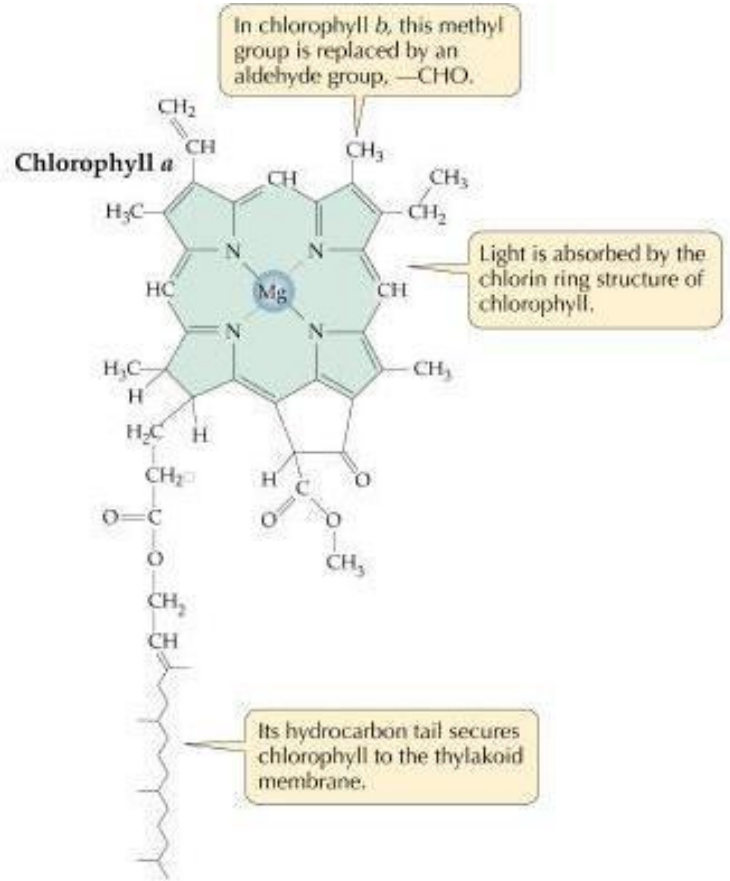


Quantized rotational states

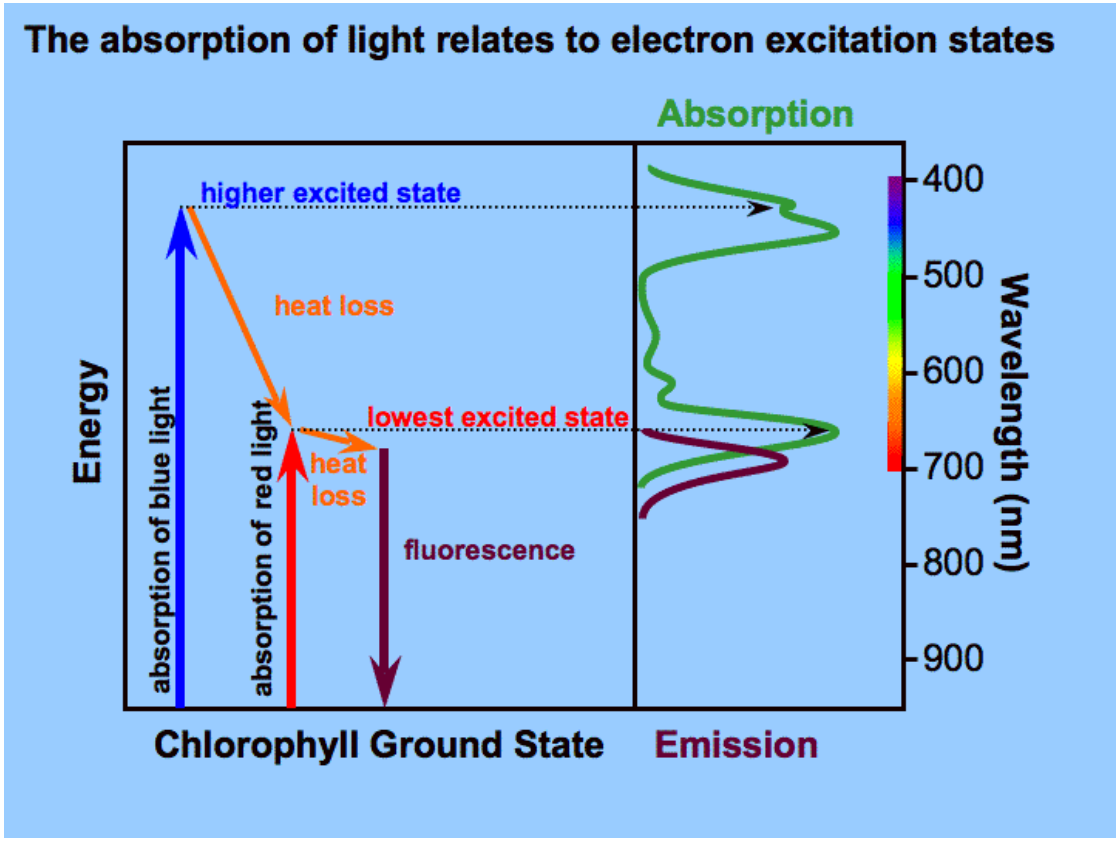
- Each vibrational state is associated with a series of higher rotational states, which are also quantized
- These determine the wavelengths of the absorption that smooth the absorption peaks



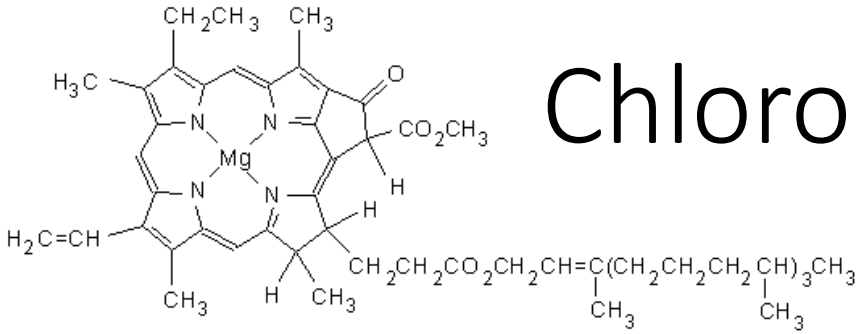
Chlorophyll *a* has two electronic states associated with the energy equivalent of blue(443 nm) and red (676 nm) photons



http://www.mie.utoronto.ca/labs

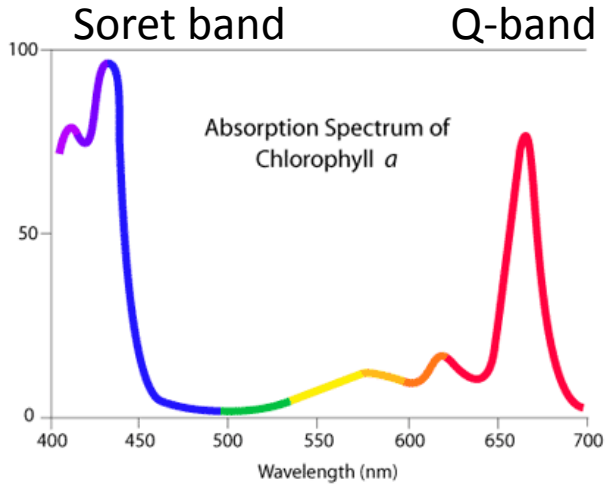


http://plantphys.info/plant_physiology/light.shtml

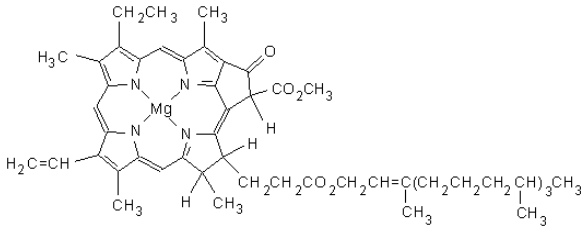


Chlorophyll *a*

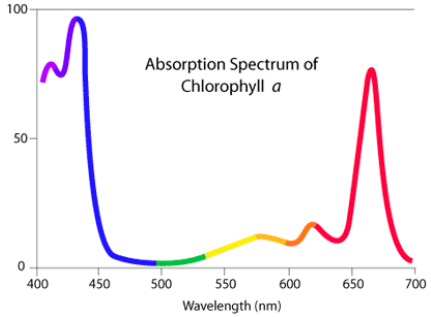
http://scifun.chem.wisc.edu/chemweek/chlrphyl/chlrphyl.gif



http://www.photochembgsu.com/assets/images/graph2.gif



Chlorophyll



Phytol

Enzymatic

Blanching

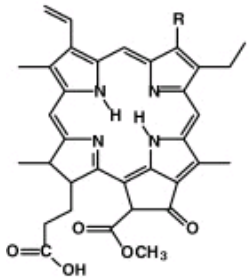
Heat/Acid

Mg^{2+}

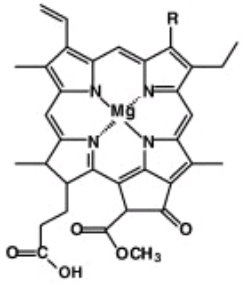
Mg^{2+}

Heat/Acid

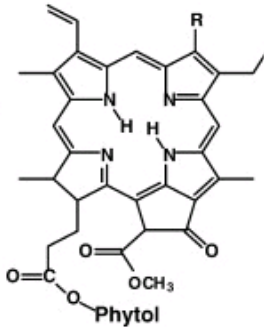
"Pheophyinization"



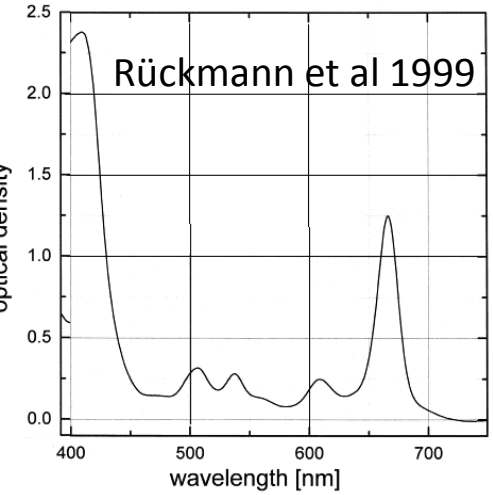
Pheophorbide

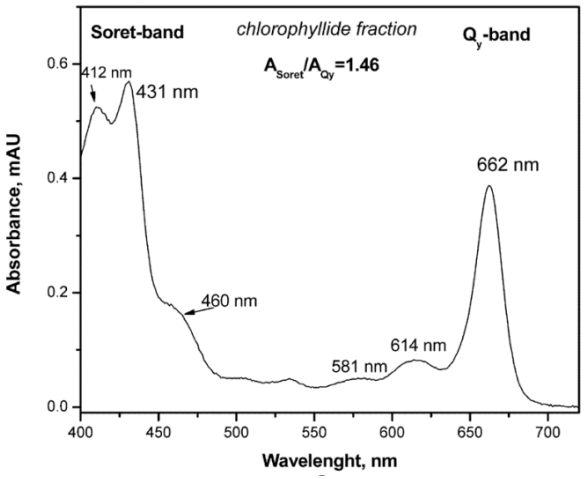


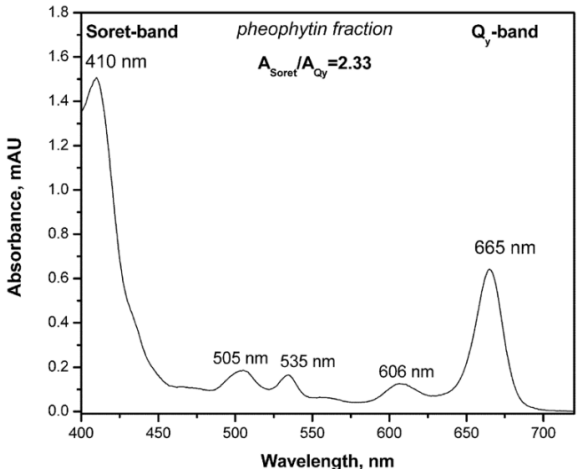
Chlorophyllide



Pheophytin





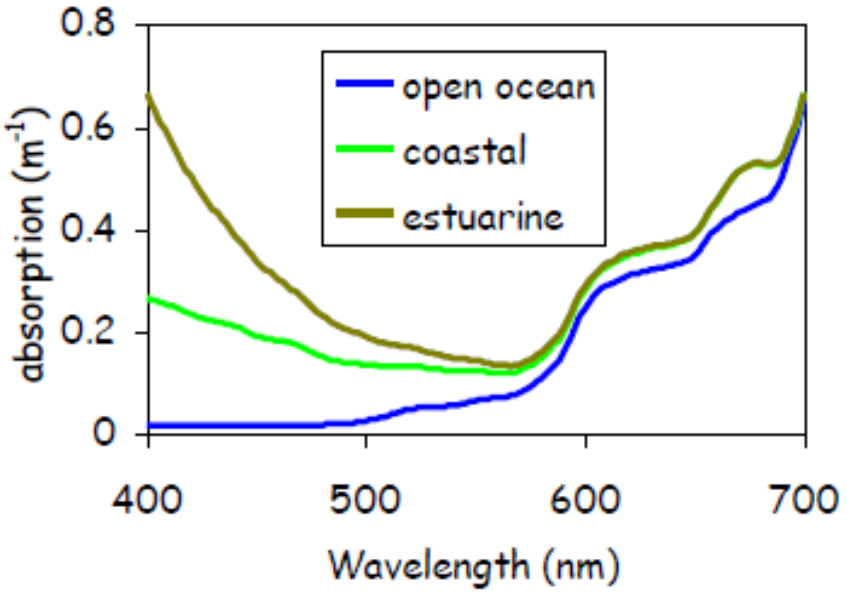


Milenković et al. 2012

What are the major absorbers in the ocean?

Example of absorption spectra for three environments

- What do they have in common?
  - All have strong red absorption
- How do they differ?
  - Variable blue absorption



Absorption is a conservative property

- Total absorption = sum of individual absorbing constituents

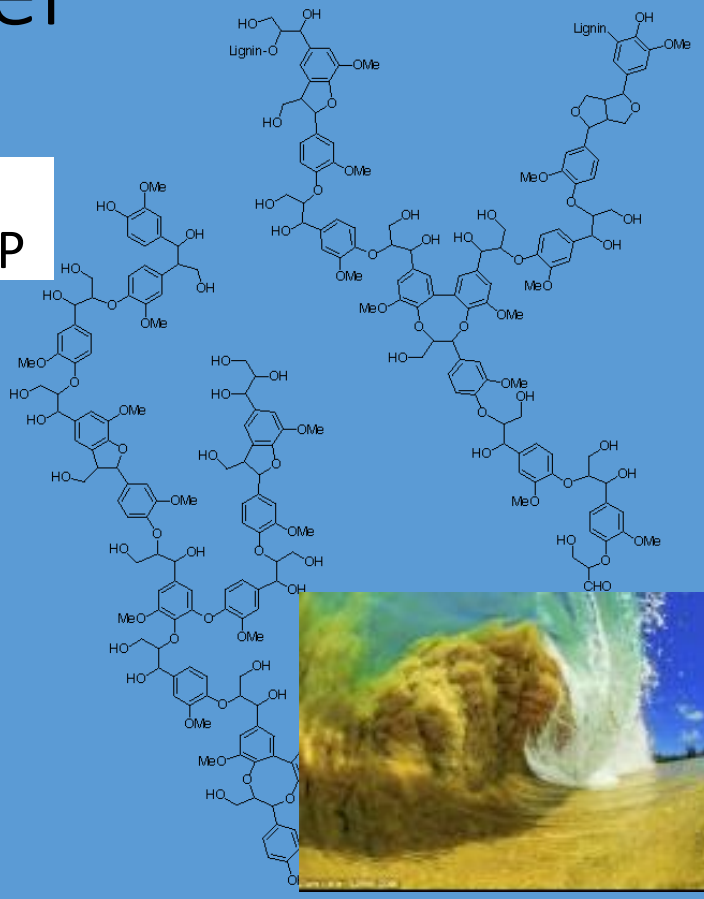
$a_{Total} = a_{water} + \Sigma a_{dissolved\ compounds} + \Sigma\ a_{particles}$

- Absorption is proportional to the concentration (Beer's Law)

$a_{chl}(m^{-1}) = [chl](mg/m^3) * a^*_{chl}\ (m^2/mg)$

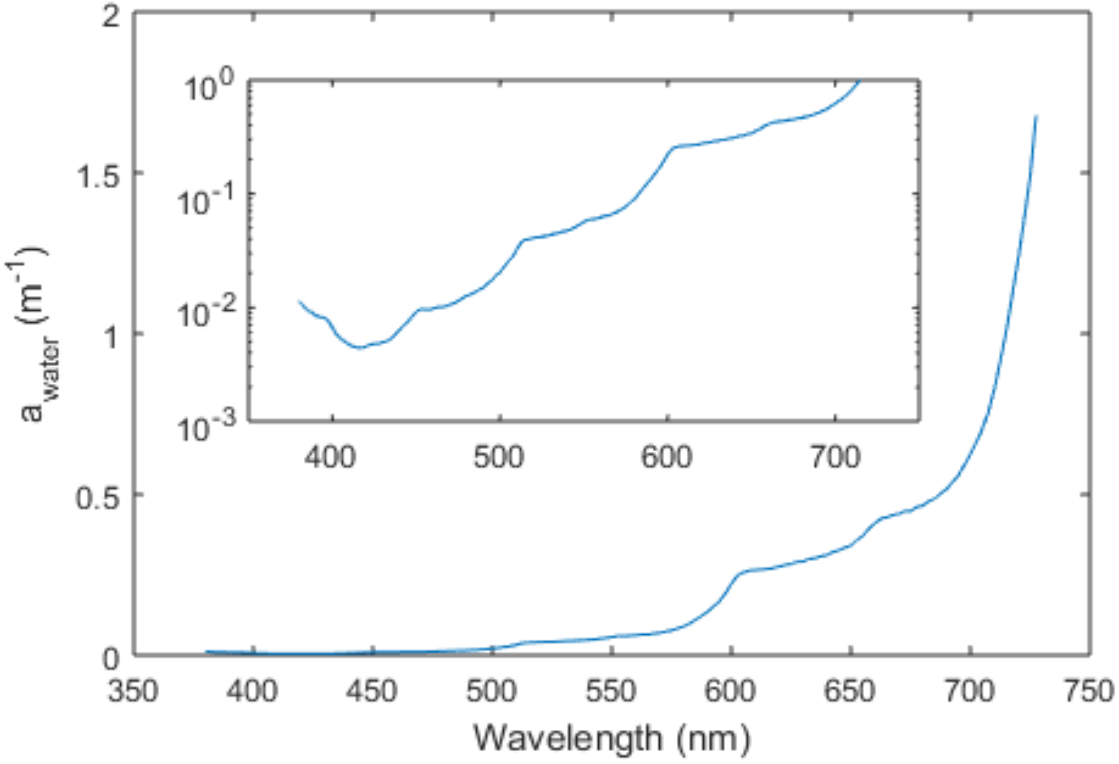
It is impractical to measure absorption spectrum for each absorber

$$a_T = a_w + a_{CDOM} + a_\phi + a_{NAP}$$



Group components by their common absorption properties (an our inability to separate them operationally)

Absorbing Components: Water



R. M. Pope and E. S. Fry 1997
Integrating cavity absorption meter

Nice compendium at
http://omlc.org/spectra/water/abs/index.html

Absorbing Components: Water

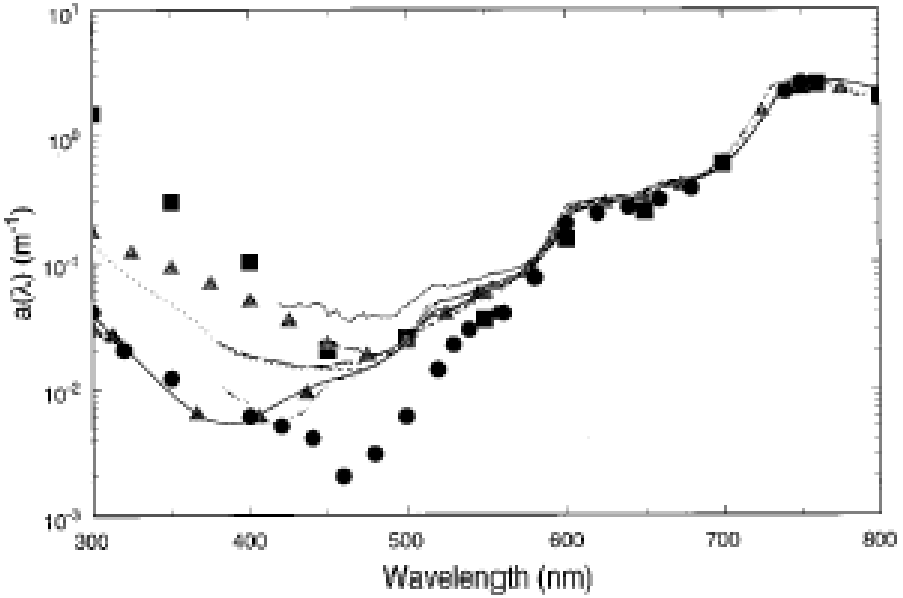


Fig. 1. Absorption coefficient of pure water as measured or compiled by several investigators.[1,2,11,18,19,21,26–33] The discrepancy in the estimated absorption coefficients is largest at short wavelengths where absorption by organic contaminants is significant. At wavelengths longer than 550 nm the standard deviation of the estimates is between 5 and 10% of the mean value.

W. Scott Pegau, Deric Gray, and J. Ronald V. Zaneveld

Absorption and attenuation of visible and near-infrared light in water: dependence on temperature and salinity

20 August 1997 / Vol. 36, No. 24 / APPLIED OPTICS

variations are **methodological**

Absorbing Components: Water

Temperature

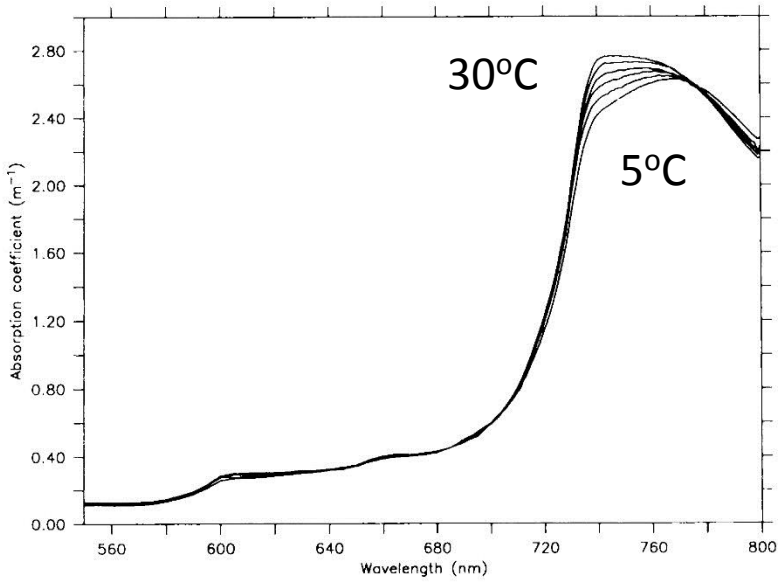
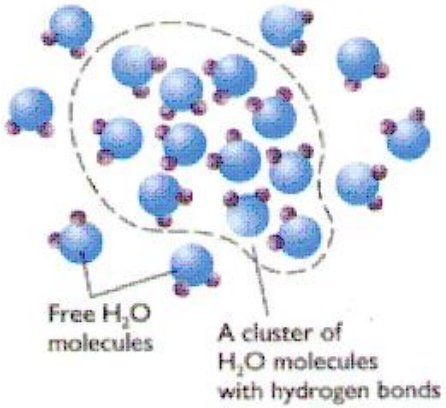
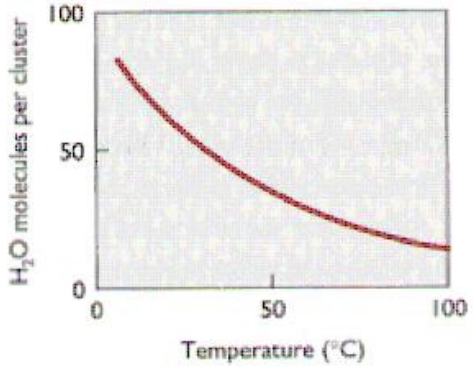


Fig. 3. Absorption coefficient from 550 to 800 nm adjusted at 685 nm to the value of Tam and Patel (1979). The curves represent absorption at temperatures of 5, 10, 15, 21, 25, and 30°C as read from bottom to top at 750 nm.

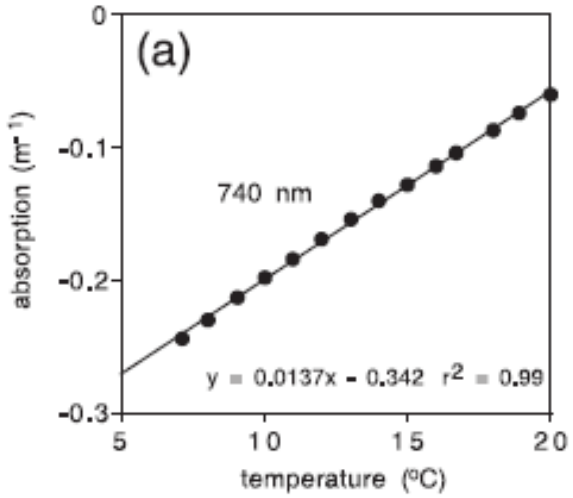
Pegau and Zaneveld 1993 Limnol Oceanogr.



(d) CLUSTERS OF WATER



(e) SIZE OF WATER CLUSTERS



natural variations

Sullivan et al. 2006 Appl Opt

Absorbing Components: Water

Salinity

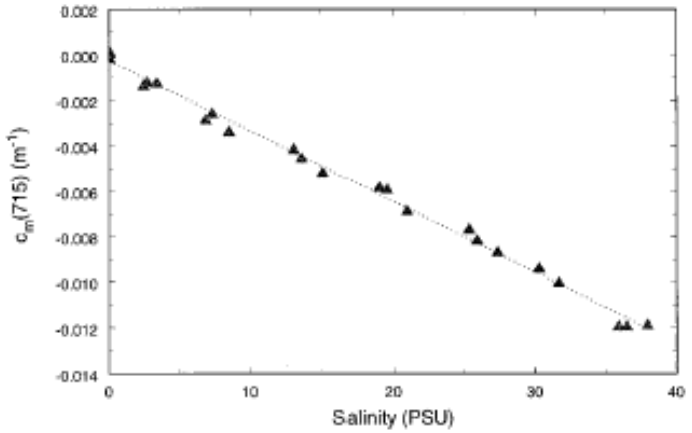
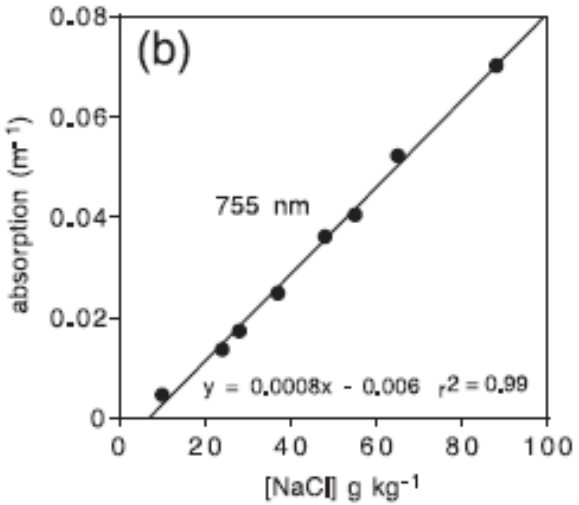
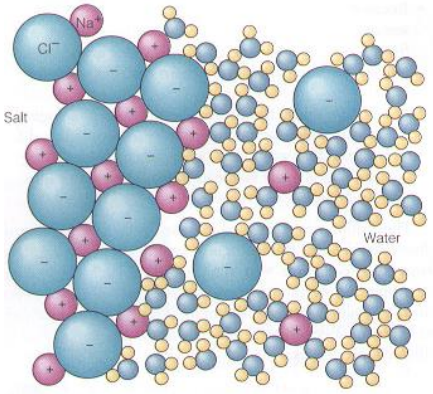


Fig. 6. Attenuation coefficient at 715 nm as a function of salinity. This figure illustrates the linear dependence of the attenuation coefficient on salinity.

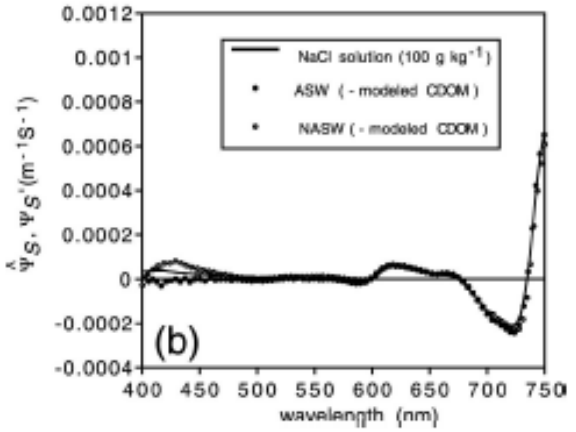
Pegau etal. 1997 Appl.Opt.



Sullivan et al. 2006 Appl Opt



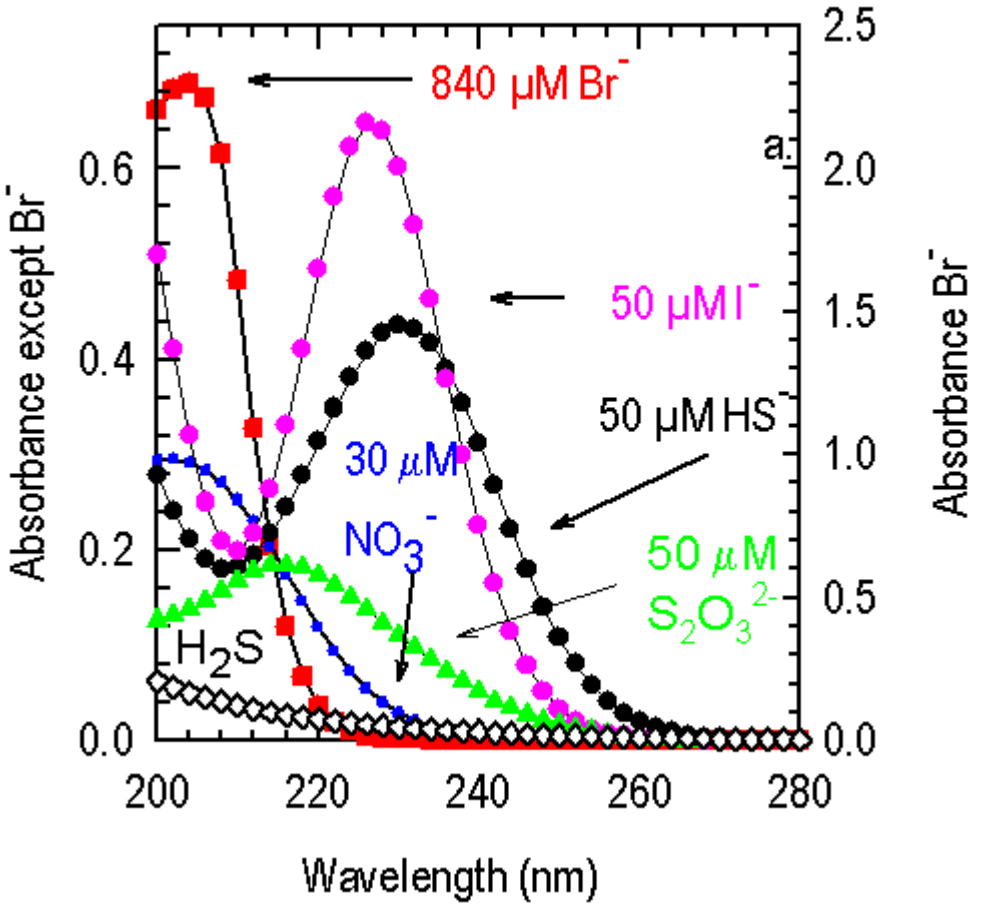
natural variations



Absorbing Components:
Dissolved inorganic matter

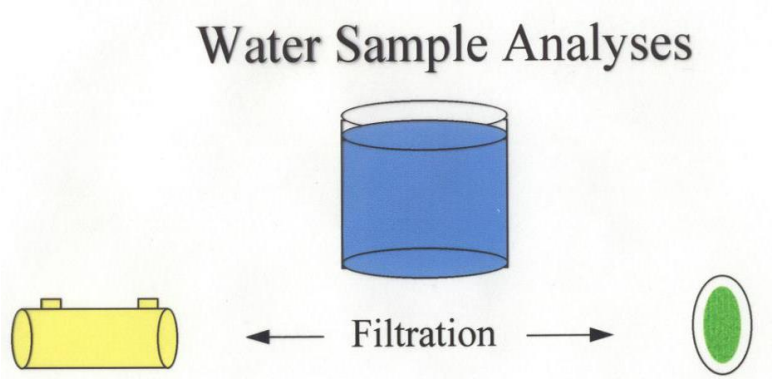
- Basic for UV detection of nitrate and HS, ISUS

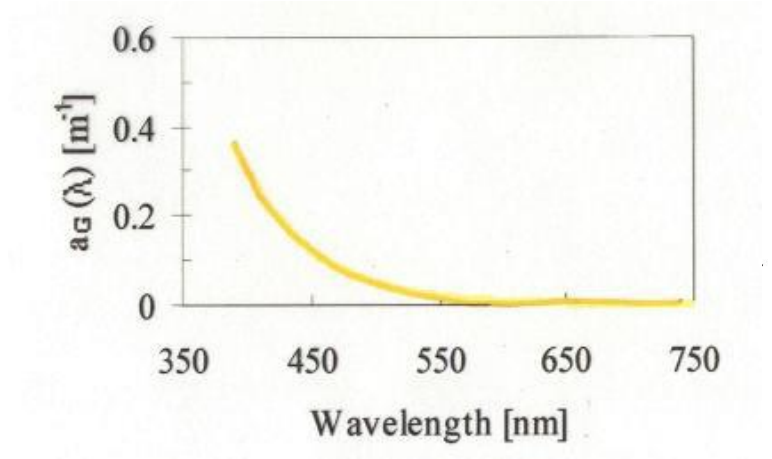
- Johnson, K. S. and L. J. Coletti. 2002

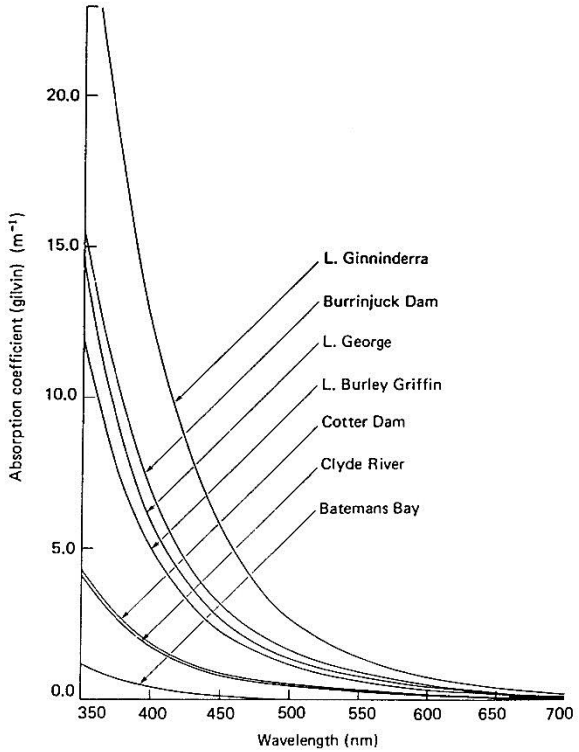


http://www.mbari.org/chemsensor/ISUShome.htm

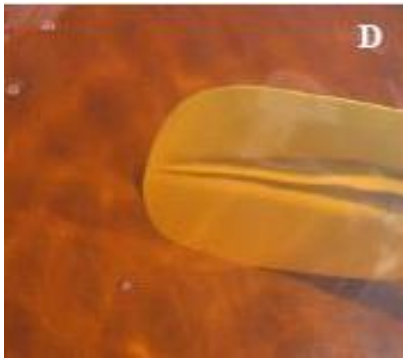
Absorbing Components:
Colored dissolved organic matter (CDOM)







Kirk 1983



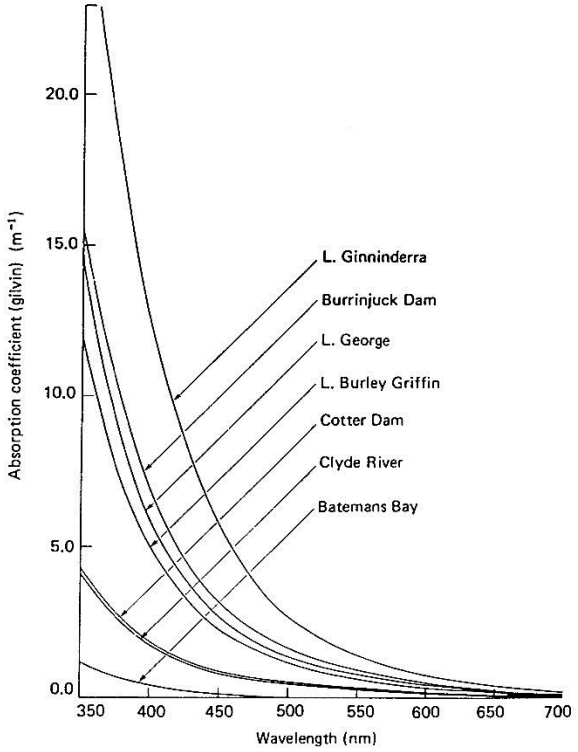
Dierssen et al. 2006

http://clarklittlephotography.com

Absorbing Components:
Colored dissolved organic matter (CDOM)

$$a_{CDOM}(\lambda) = a_{CDOM}(\lambda_o) \exp(-S_{CDOM} (\lambda-\lambda_o))$$

Fig. 3.5. Absorption spectra of soluble yellow material (gilvin) in various Australian natural waters (from Kirk, 1976*b*). The lowest curve (Batemans Bay, NSW) is for coastal sea water near the mouth of a river; the next curve (Clyde River, NSW) is for an estuary; the remainder are for inland water bodies in the southern tablelands of New South Wales/Australian Capital Territory. The ordinate scale corresponds to the true *in situ* absorption coefficient due to gilvin.



Kirk 1983

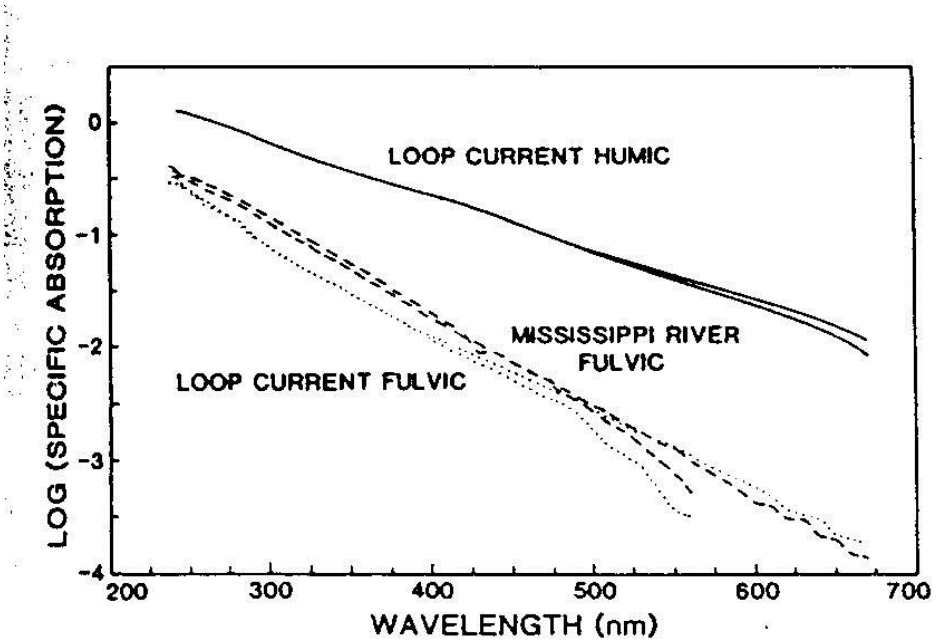


Fig. 1. Specific absorption curves vs. wavelength for marine humic acid and marine fulvic acid.

Carder et al. 1989 L&O

Absorbing Components: Colored dissolved organic matter (CDOM)

$$a_{CDOM}(\lambda) = a_{CDOM}(\lambda_o) \exp(-S_{CDOM} (\lambda-\lambda_o))$$

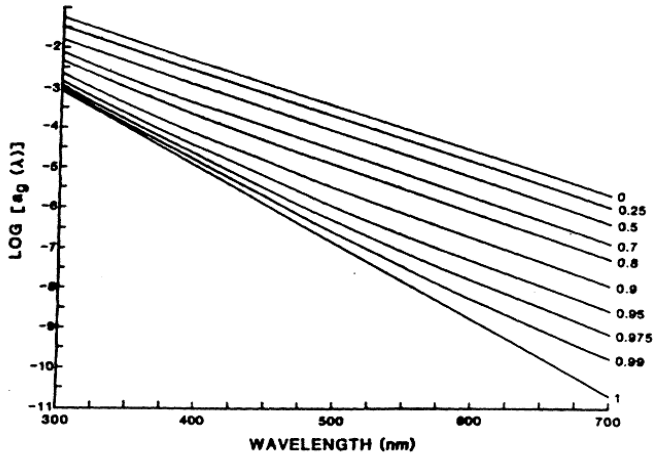


Fig. 3. Spectral variation of the absorption coefficient due to marine humus or Gelbstoff as a function of the fulvic acid fraction of Gelbstoff for $a^*_f = 0.00732$ m² g⁻¹, $a^*_h = 0.131$ m² g⁻¹, $B_f = 0.0186$ nm⁻¹, and $B_h = 0.0110$ nm⁻¹. The fulvic acid fraction is shown beside each curve.

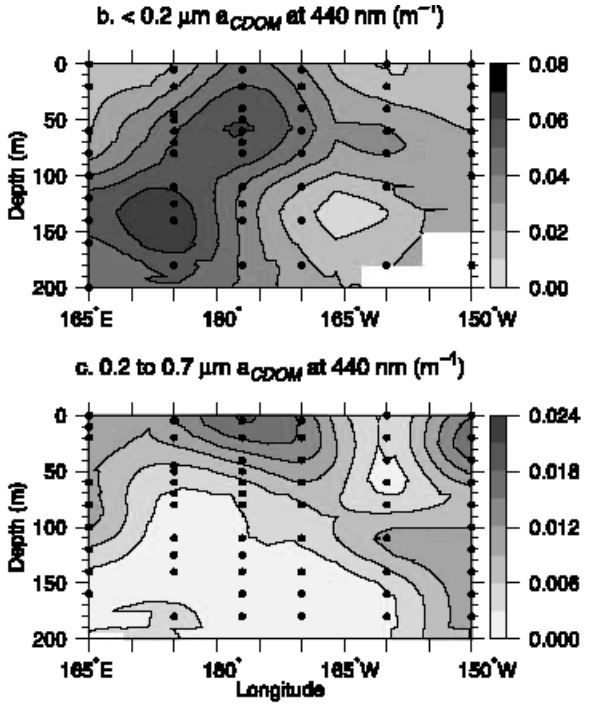
S

0.01

0.02

Carder et al. 1989 L&O

Equatorial Pacific



S=0.014

S=0.011

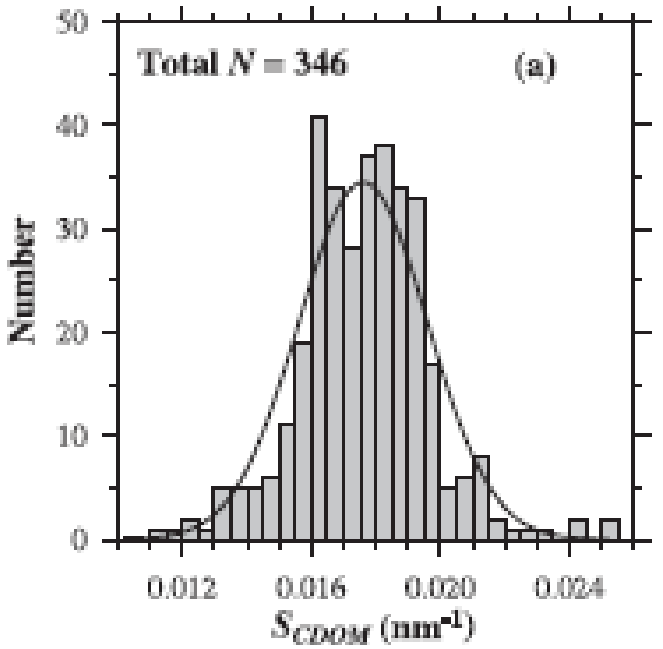
Simeon et al. 2003 JGR

Absorbing Components: Colored dissolved organic matter (CDOM)

Table 1. Ranges for the exponential coefficient, $C2_s$, for gelbstoff and detritus for Eq. 6. Where coefficients were not listed, values were approximated from published spectra using an exponential model.

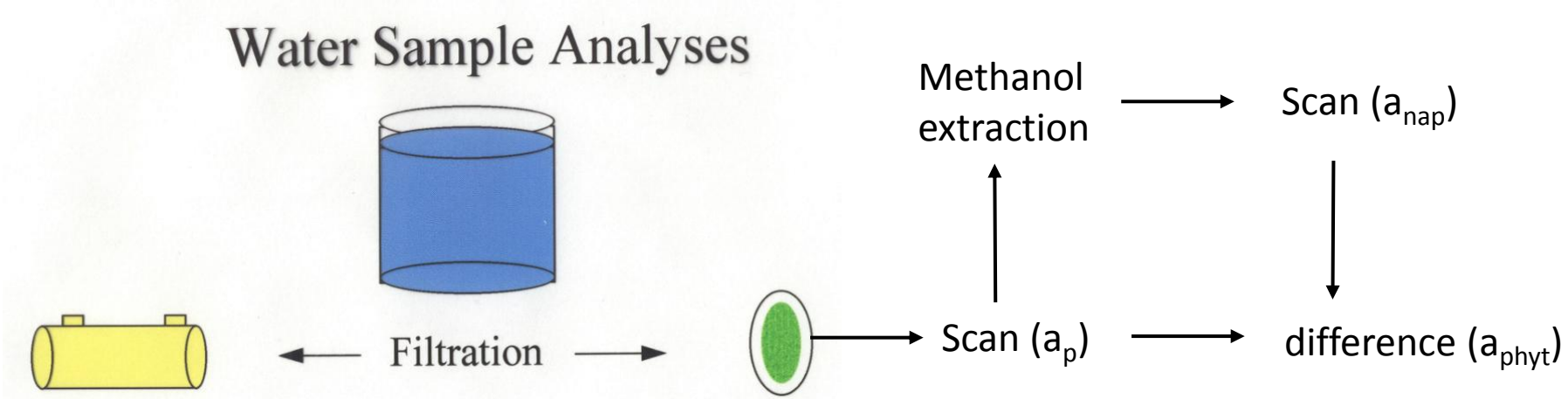
Reference	Site	Avg $C2_s$ (nm^{-1})
Gelbstoff		
Kalle 1966	Baltic, North Sea	0.018
Jerlov 1968		0.015
Kirk 1976	Lakes, coast	0.015
Lundgren 1976	Baltic	0.014
Kopelevich and Burenkov 1977	Indo-Pacific	0.017
Bricaud et al. 1981	Baltic	0.018
	Mauritania	0.015
	Gulf of Guinea	0.014
	Mediterranean	0.014
Okami et al. 1982	East Pacific	0.017
Kishino et al. 1984	Lake Kizaki	0.016
	Nabeta Bay	0.015
	East Pacific	0.014
Carder and Steward 1985	Gulf of Mexico	0.014
Davies-Colley and Vant 1987	Lakes	0.019
Maske and Haardt 1987	Kiel Harbor	0.016
Published mean ± SD		0.016±0.002
This study mean ± SD	San Juan Islands	0.017±0.003
Carder et al. 1989	Marine humic acid	0.011
	Marine fulvic acid	0.018
Detritus		
Kishino et al. 1986	NW Pacific Ocean	0.006
Maske and Haardt 1987	Kiel Harbor	0.014
Iturriaga and Siegel 1988	Sargasso Sea	0.011
Cleveland and Perry in prep.	Sargasso Sea	0.013
Morrow et al. 1989	Sargasso Sea	0.009
Published mean ± SD		0.011±0.002
This study mean ± SD	San Juan Islands	0.011±0.002

Roesler et al. 1989
(global synthesis)

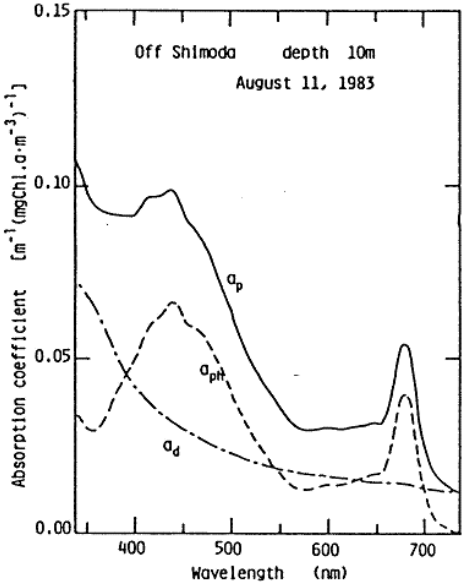


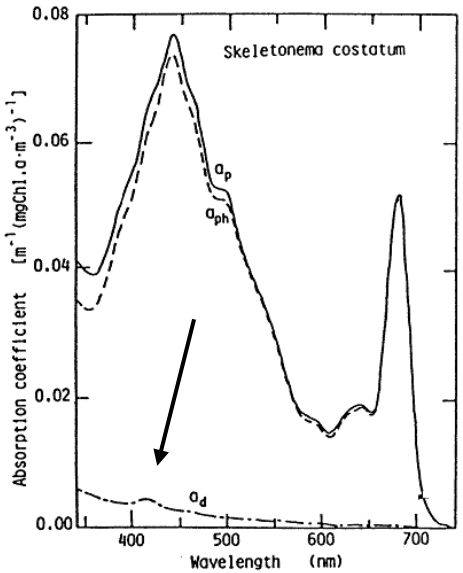
Babin et al. 2003
(European coastal waters)

Absorbing Components: Particles



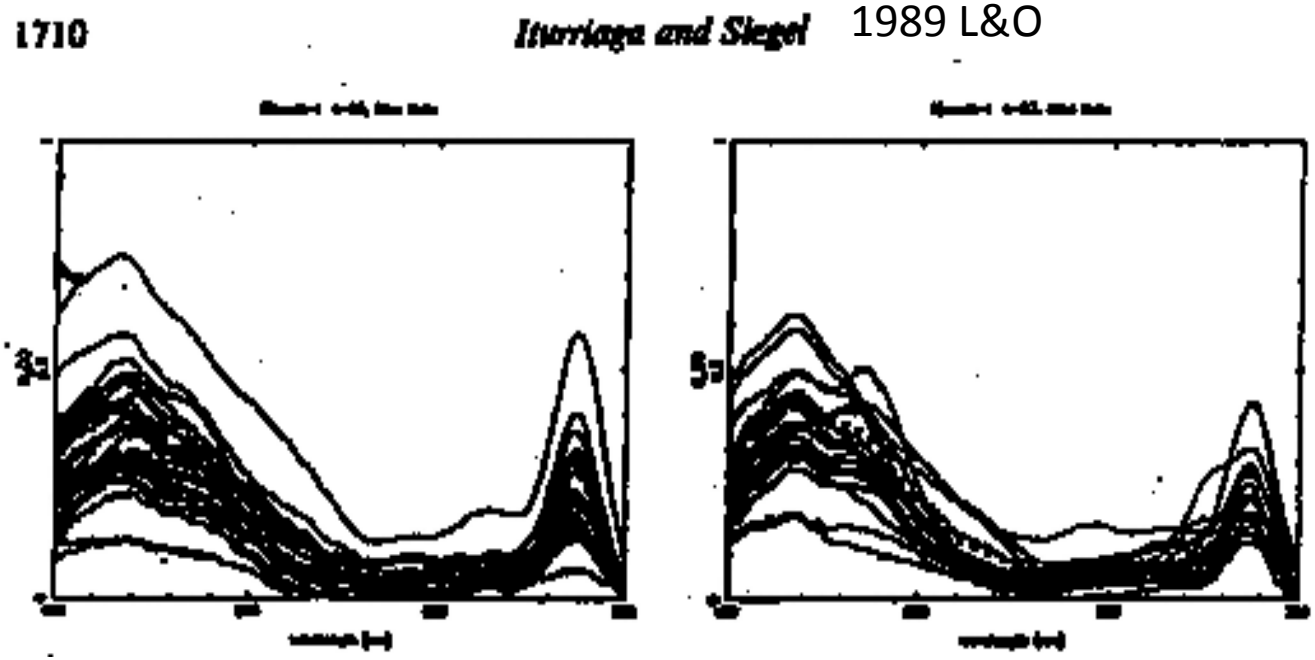
Kishino et al. 19





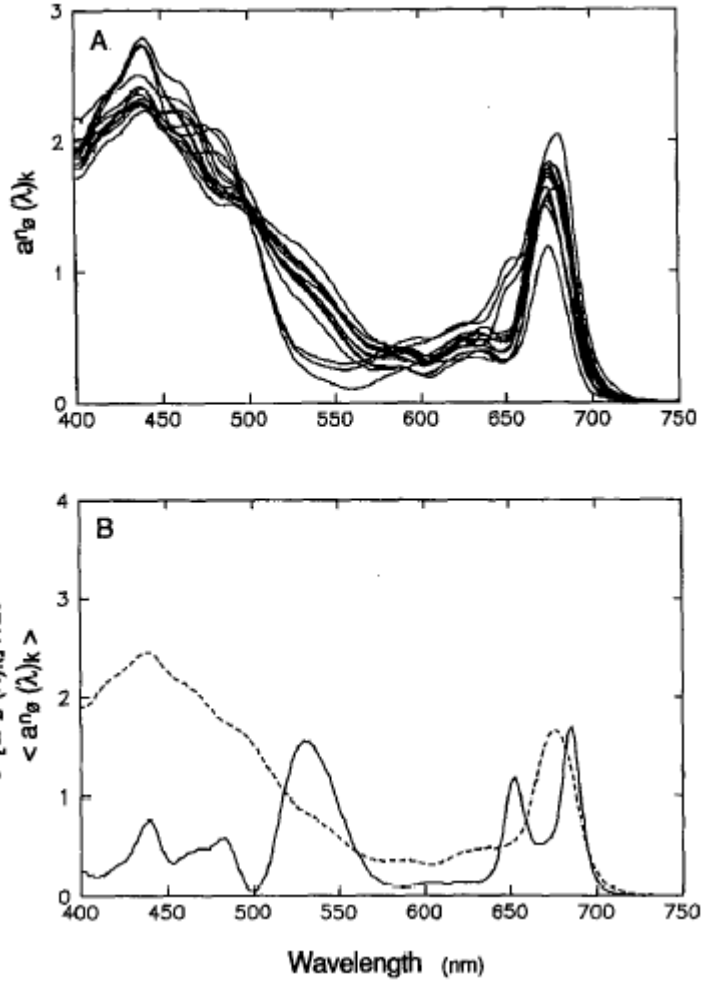
Absorbing Components: Phytoplankton

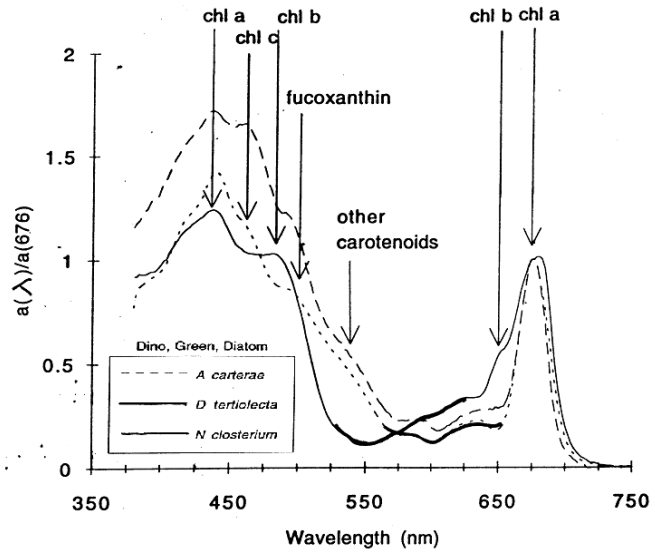
Individual cells, microphotometry

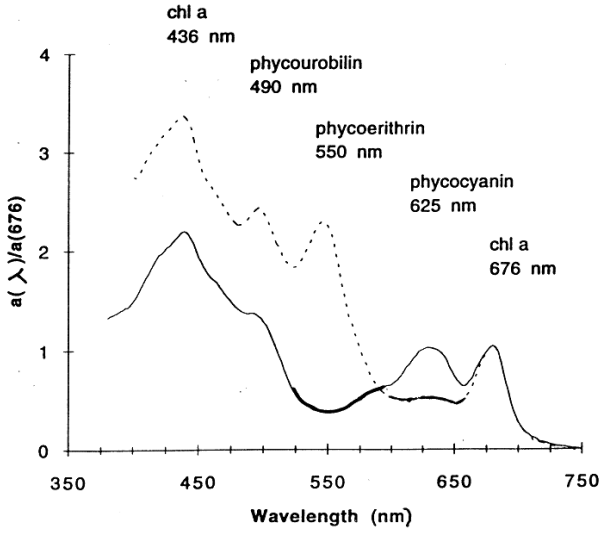


Absorbing Components: Phytoplankton

Species







Roesler et al. 1989 L&O

Absorbing Components: Phytoplankton

Pigment Packaging impact on absorption

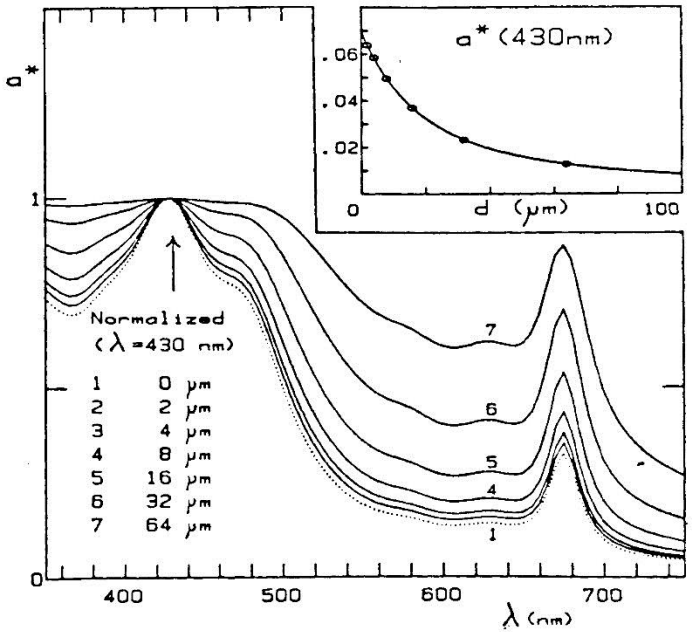


Fig. 2. Change in spectral absorption values with variable cell size (diameter, d, in μm) whereas the cell material forming the cells remains unchanged. The spectral absorption values of this material, somewhat arbitrarily adopted, are shown as the dotted curve. All curves are normalized, at $\lambda = 430$ nm, to evidence the progressive deformation. The variations with size of the specific absolute value at 430 nm (m^2 mg^{-1} Chl a) are shown in inset, under the same assumption of a constant absorption of the cell material ($a_{cm} = 2 \times 10^5$ m^{-1} at 430 nm) and with the additional assumption of a constant intracellular pigment concentration ($c_i = 2.86 \times 10^6$ mg Chl a m^{-3}).

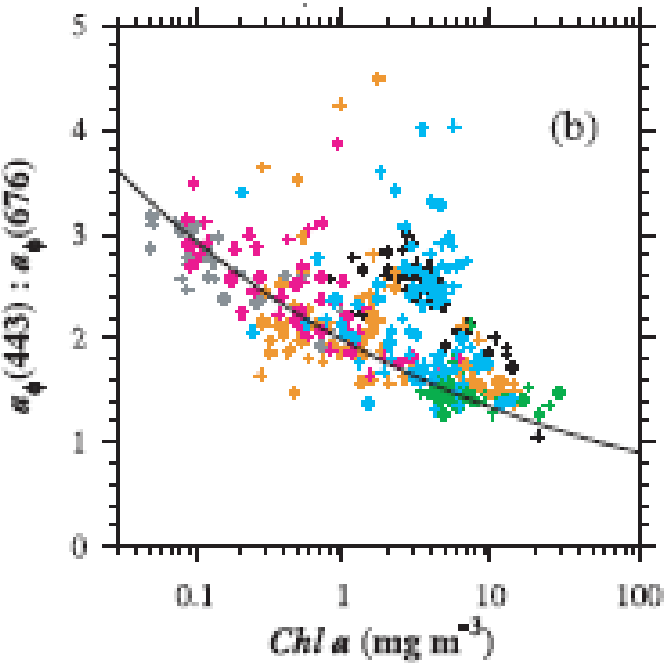
Morel and Bricaud 1981 DSR

(1) vary size, maintain constant intracellular pigment concentration

or

(2) maintain size, vary intracellular pigment concentration

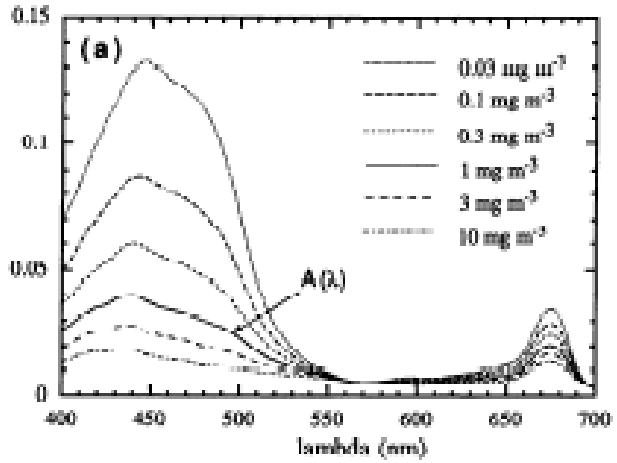
Absorbing Components: Phytoplankton



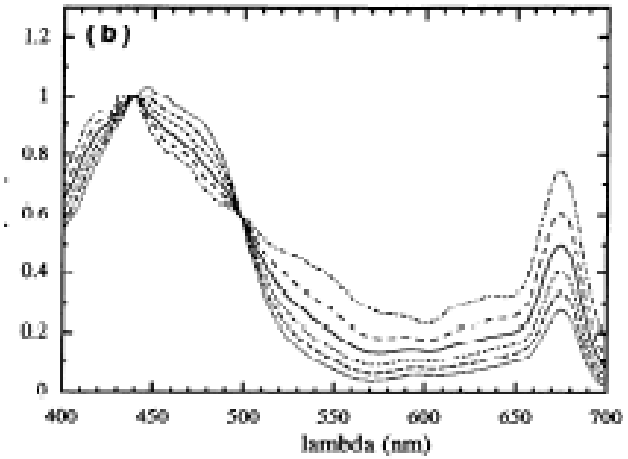
Babin et al. 2003

Bricaud et al. 1995

a^*_{phyt} (m^2/mg chl)



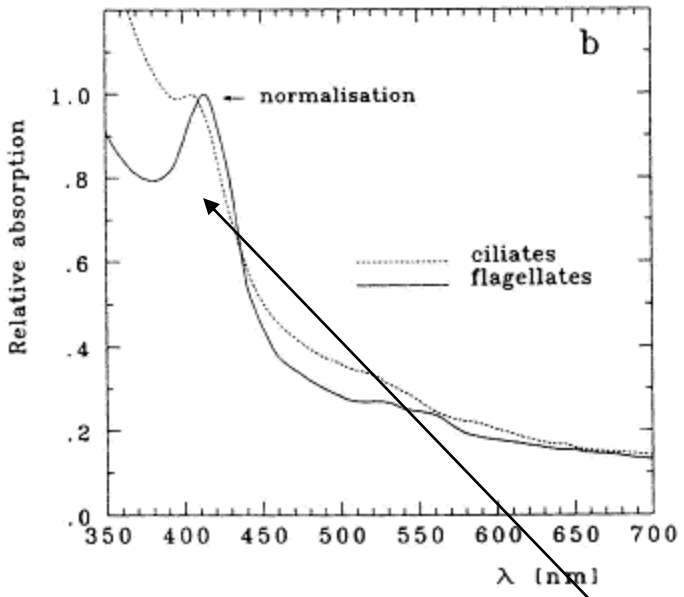
$a_{phyt}(\lambda)$
$a_{phyt}(440)$



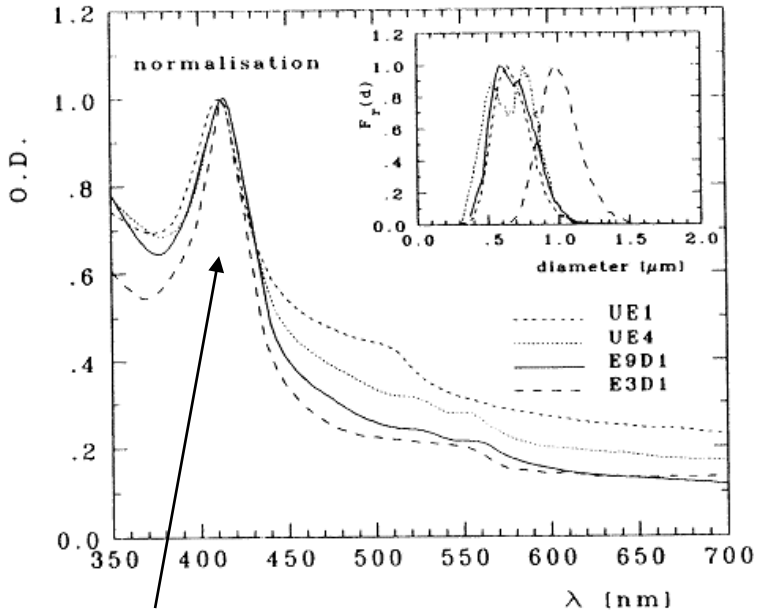
Global Relationships

Absorbing Components: other protists

ciliates and flagellates



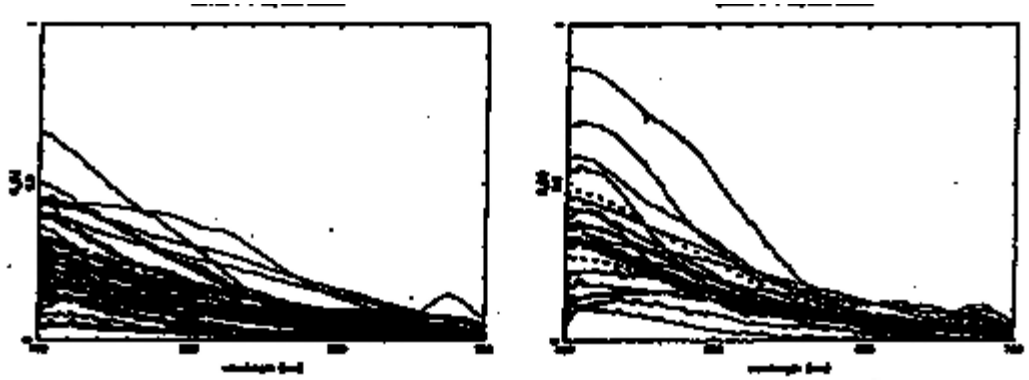
heterotrophic bacteria



cytochrome 412

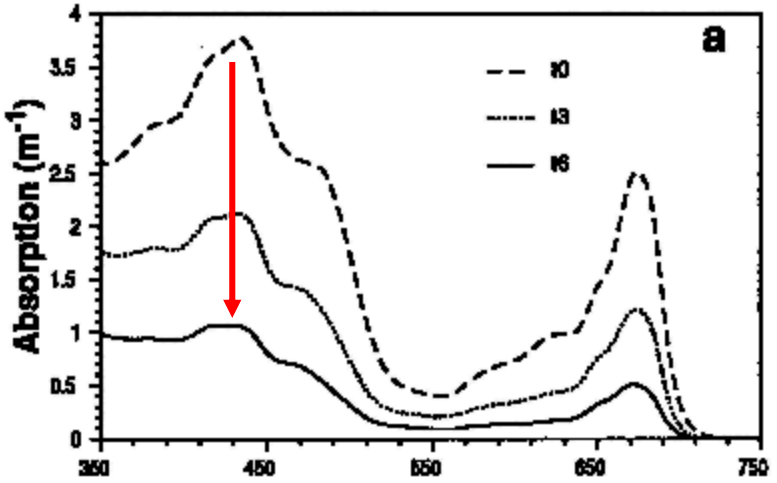
Morel and Ahn 1990 JMR

Absorbing Components:
Non-algal particles →organic detrital particles



Iturriaga and Siegel 1989 L&O

Nelson & Robertson: Detrital spectral absorption 1993] JMR



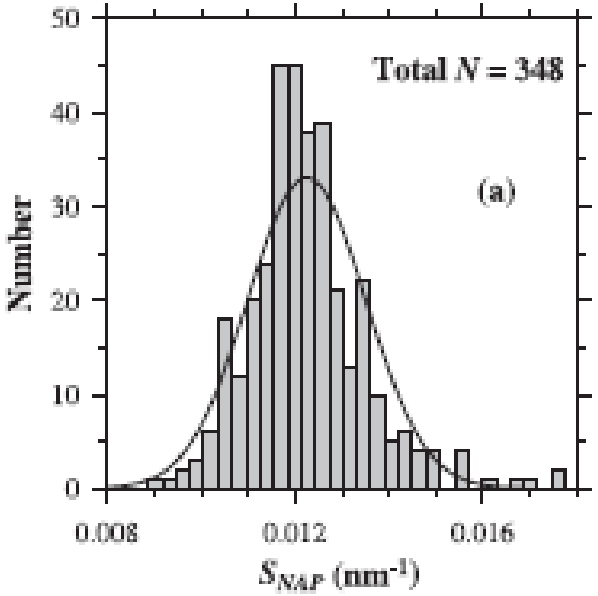
Photobleaching natural light levels

Absorbing Components: Non-algal particles

Table 1. Ranges for the exponential coefficient, $C2_x$, for gelbstoff and detritus for Eq. 6. Where coefficients were not listed, values were approximated from published spectra using an exponential model.

Reference	Site	Avg $C2_x$ (nm^{-1})
Gelbstoff		
Kalle 1966	Baltic, North Sea	0.018
Jerlov 1968		0.015
Kirk 1976	Lakes, coast	0.015
Lundgren 1976	Baltic	0.014
Kopelevich and Burenkov 1977	Indo-Pacific	0.017
Bricaud et al. 1981	Baltic	0.018
	Mauritania	0.015
	Gulf of Guinea	0.014
	Mediterranean	0.014
Okami et al. 1982	East Pacific	0.017
Kishino et al. 1984	Lake Kizaki	0.016
	Nabeta Bay	0.015
	East Pacific	0.014
Carder and Steward 1985	Gulf of Mexico	0.014
Davies-Colley and Vant 1987	Lakes	0.019
Maske and Haardt 1987	Kiel Harbor	0.016
Published mean ± SD		0.016±0.002
This study mean ± SD	San Juan Islands	0.017±0.003
Carder et al. 1989	Marine humic acid	0.011
	Marine fulvic acid	0.018
Detritus		
Kishino et al. 1986	NW Pacific Ocean	0.006
Maske and Haardt 1987	Kiel Harbor	0.014
Iturriaga and Siegel 1988	Sargasso Sea	0.011
Cleveland and Perry in prep.	Sargasso Sea	0.013
Morrow et al. 1989	Sargasso Sea	0.009
Published mean ± SD		0.011±0.002
This study mean ± SD	San Juan Islands	0.011±0.002

Roesler et al. 1989
(global synthesis)



Babin et al. 2003
(European coastal waters)

Absorbing Components: Non-algal or mineral particles

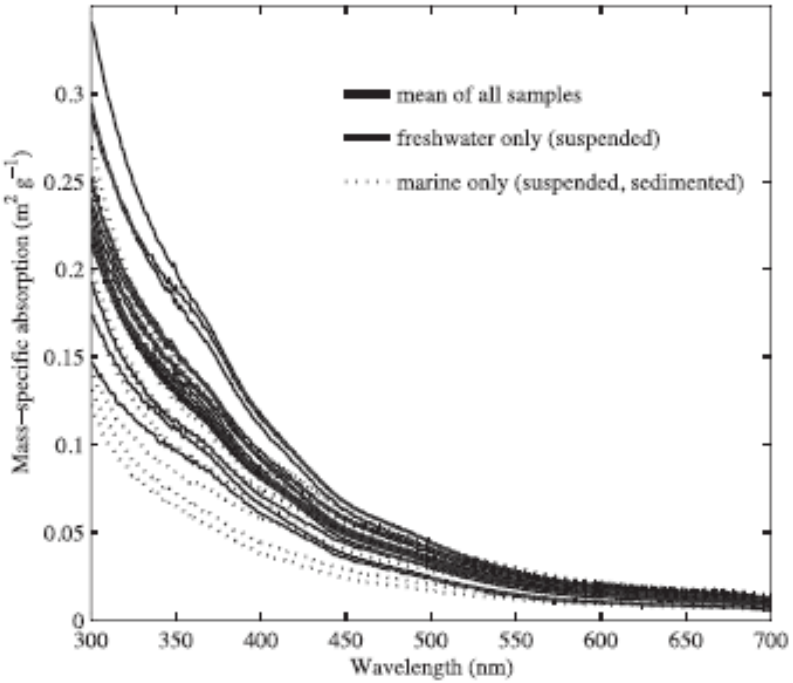


Fig. 3. Mass-specific absorption spectra of all samples analyzed here (n = 25). Heavy black line shows the mean, thin solid lines show samples from freshwater sites on the Atchafalaya and Mississippi Rivers, and dashed lines show samples from marine sites at Freshwater Bayou and the Atchafalaya River delta. River samples are suspended particulates only; marine samples include both sediments and suspended particulates.

Iron oxide minerals

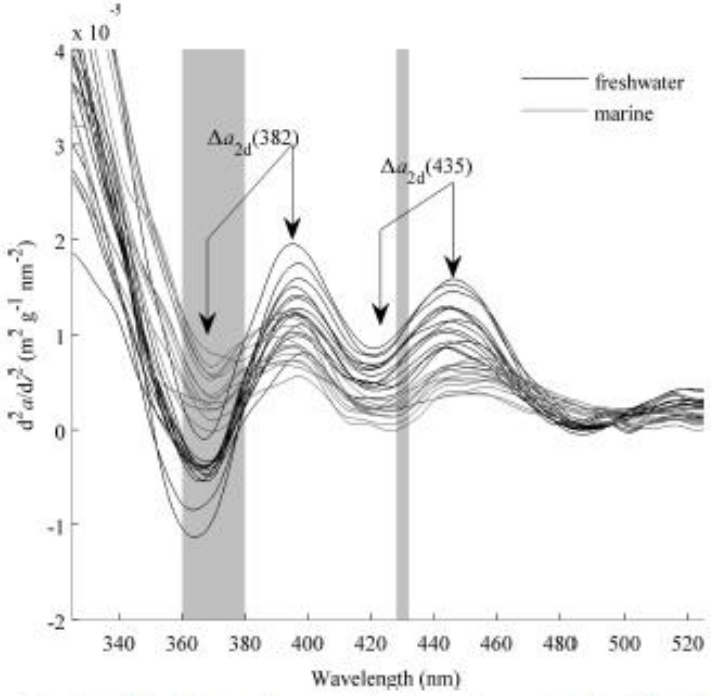


Fig. 10. Second derivatives of mass-specific absorption spectra. Black lines denote freshwater samples, and gray lines denote marine samples. Bracketed arrows labeled $\Delta a_{2d}(382)$ and $\Delta a_{2d}(435)$ show locations of second-derivative maxima and minima used to compute iron absorption peak heights plotted in Fig. 11. Light-gray vertical bars highlight approximate ranges for electronic transition bands of various iron oxide minerals (Sherman and Waite 1985).

Estapa et al. 2012

Absorbing Components: inorganic particles

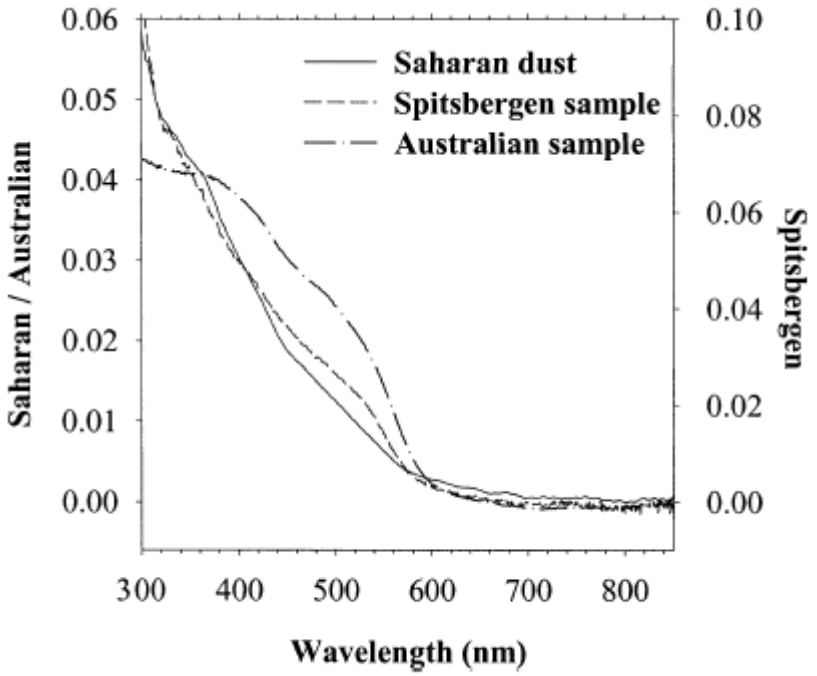


Fig. 5. Absorbance spectra of natural assemblages of mineral particles from three different environments.

Babin and Stramski 2003

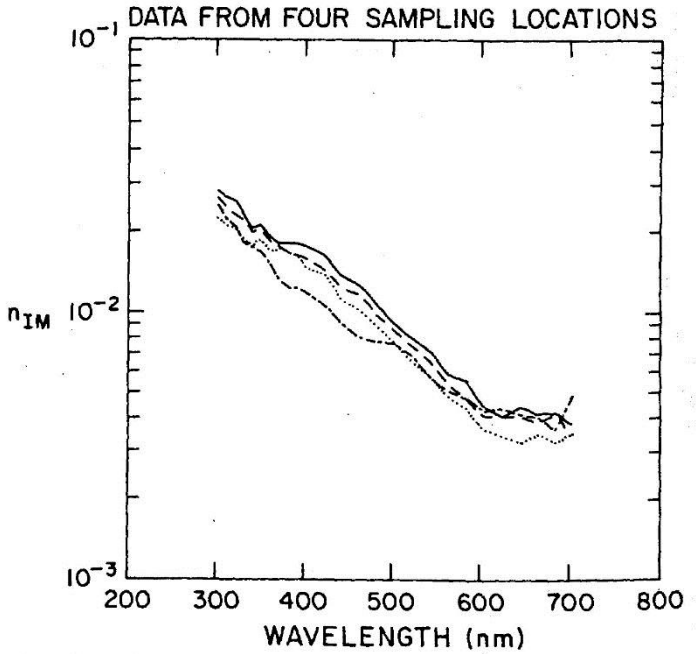
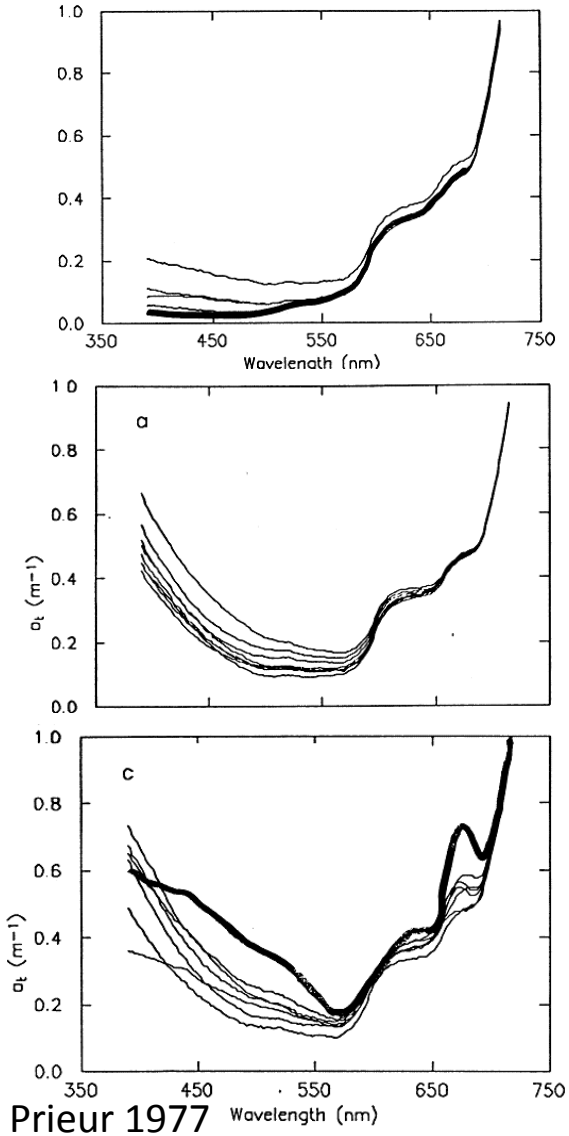


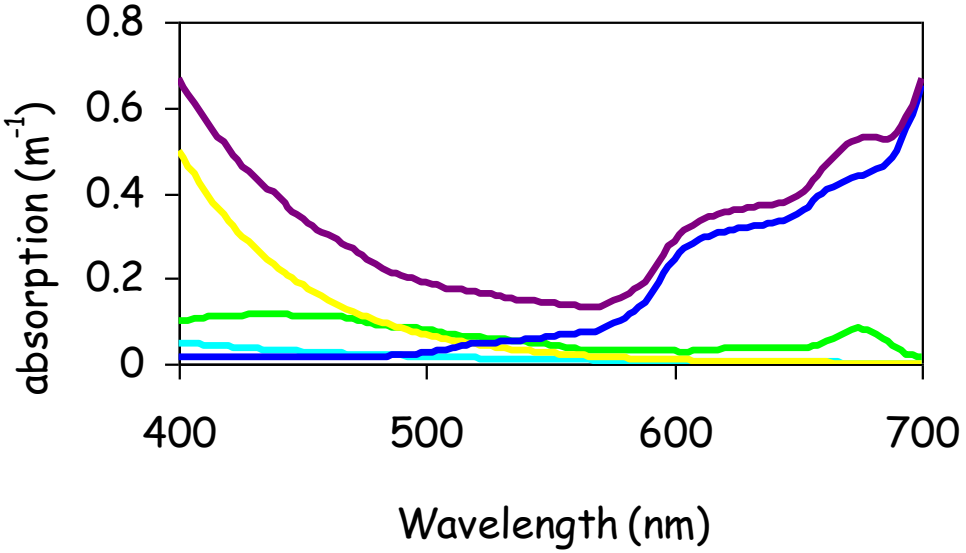
Fig. 8. Imaginary index of refraction for Saharan aerosols from each of the collection locations. The solid line represents the Tenerife sample; the dashed line, the *Meteor* sample; the dotted line, the Barbados sample; and the dashed-dotted line, the Sal Island sample.

Patterson et al. 1977 JGR

To model the impacts of absorbing constituents…add them up



Morel and Prieur 1977



Which component dominates?

- blue waters
- green waters
  - phytoplankton (V-type)
  - inorganic particles (U-type)

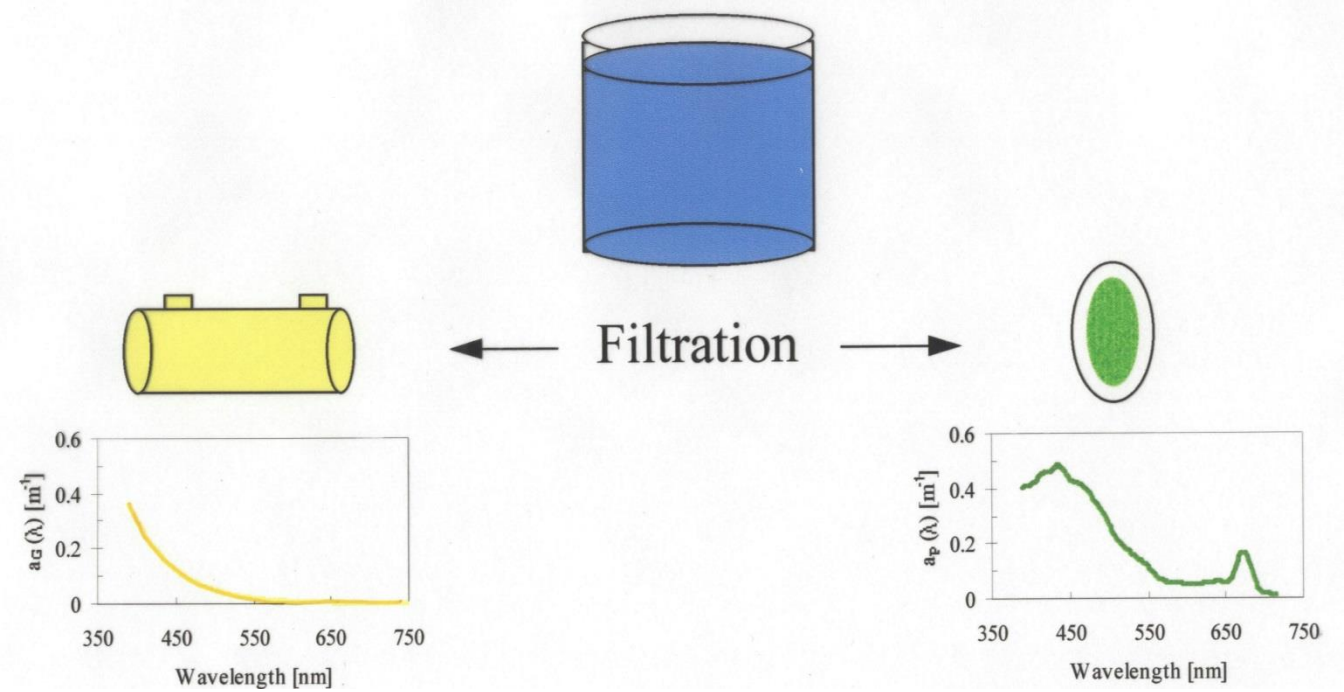
More on absorption

- Phytoplankton absorption
  - Lecture Today
- CDOM absorption methods
  - Lab today
- Particulate absorption methods
  - Lab Wednesday

How do we measure absorption in the ocean?

- In situ meters
  - ac meters
  - ICAM (integrating cavity absorption meters)
- Discrete samples in the lab
  - Quantitative filter technique

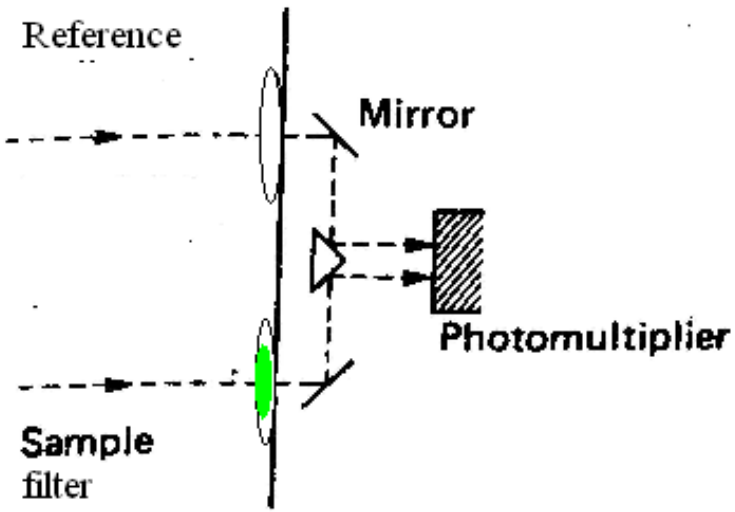
Absorption: Quantitative Filter Technique



- Separates particles from *dissolved*
- Concentrates particles from dilute medium

Measure in Spectrophotometer

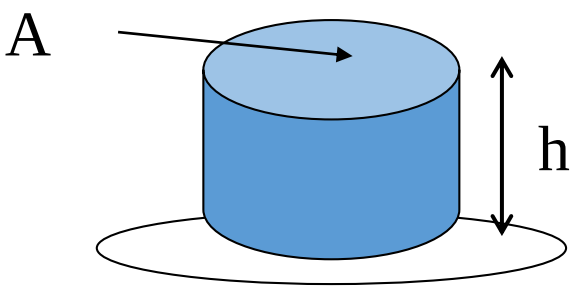
- Reference
  - Match optical density of filter pad
  - No variability
- Baseline
  - Blank filter pad in sample compart (what is $OD_{blankfilter}$:OD_{sample}?)



Compute absorption

$$a\ (m^{-1}) = 2.303\ \frac{OD}{L\ (m)}\ .$$

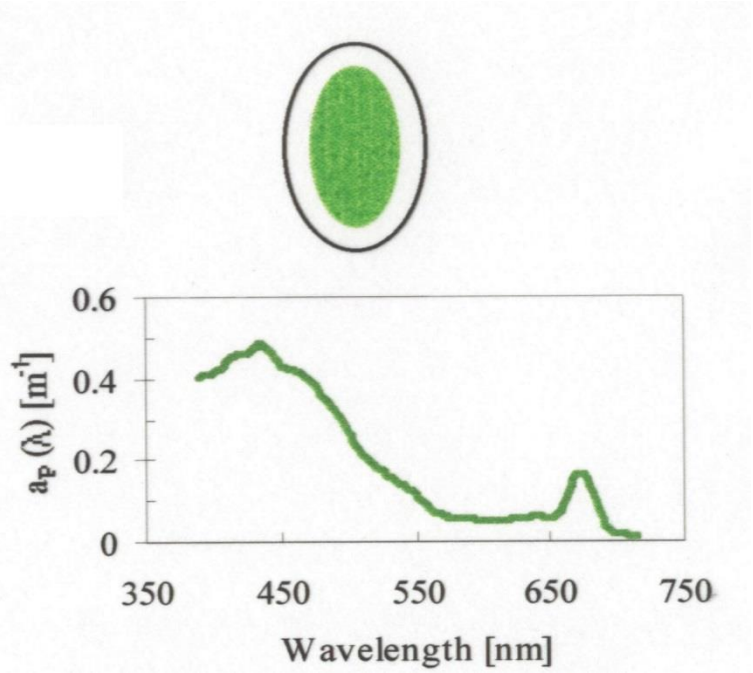
What is L?



$V_{filtered} = A_{eff}\ h$

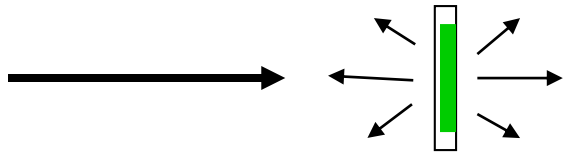
L = h

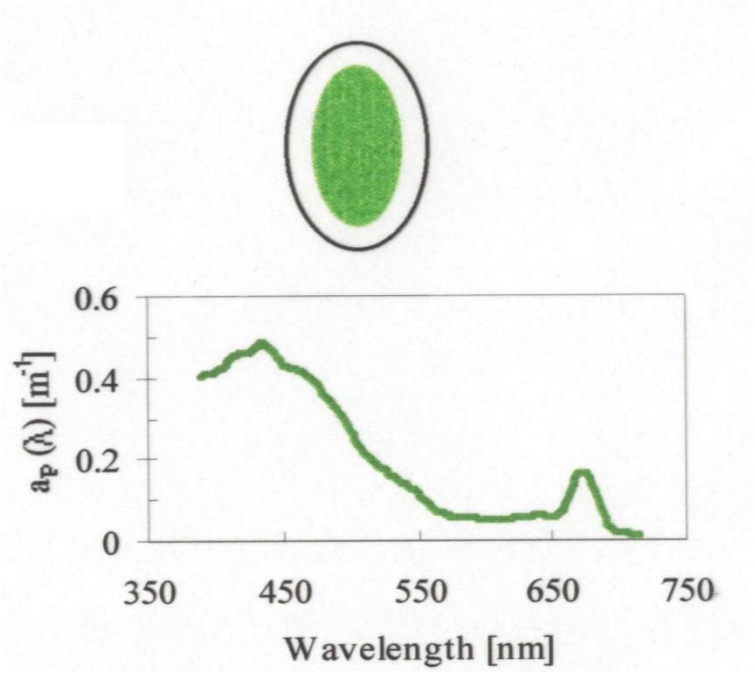
$= \frac{V\ (m^3)}{A\ (m^2)}$



What about the scattering by the filter? Path length amplification

$$a\,(m^{-1}) = 2.303 \frac{OD}{\frac{V(m^3)}{A(m^2)}}$$

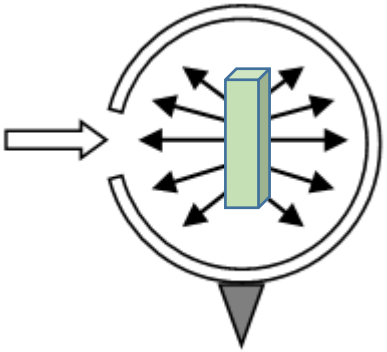


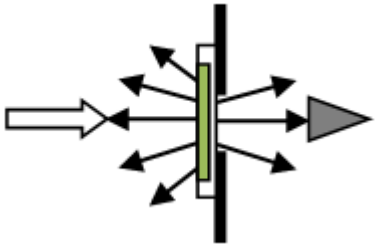


- Filter pad
  - Creates nearly isotropic light field
  - Increases optical path length
  - Increases absorption signal
  - How to correct for it?

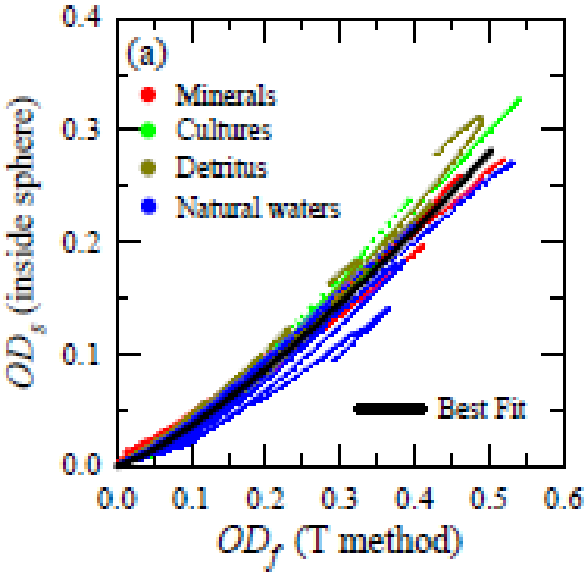
β correction: path length amplification

- Approach
  - Cultures or samples
  - Measure absorption in cuvette (IS-mode)
  - Measure absorption on filter pad (T-mode)
  - Determine ratio, $\beta = \frac{OD_{filt}}{OD_{cuv}} = \frac{\text{optical}}{\text{geometric}}$





$OD_s = 0.679\ OD_f^{\ 1.2804}$



Stramski et al. 2015

What about the scattering by the filter? Path length amplification, *uncertainty calculation*

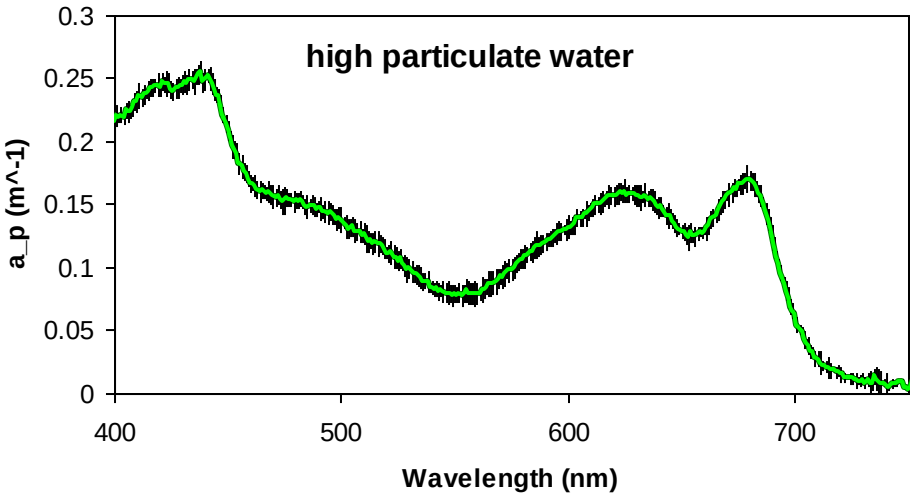
$$a\ (m^{-1}) = 2.303 \frac{OD}{\frac{V(m^3)}{A(m^2)}} .$$

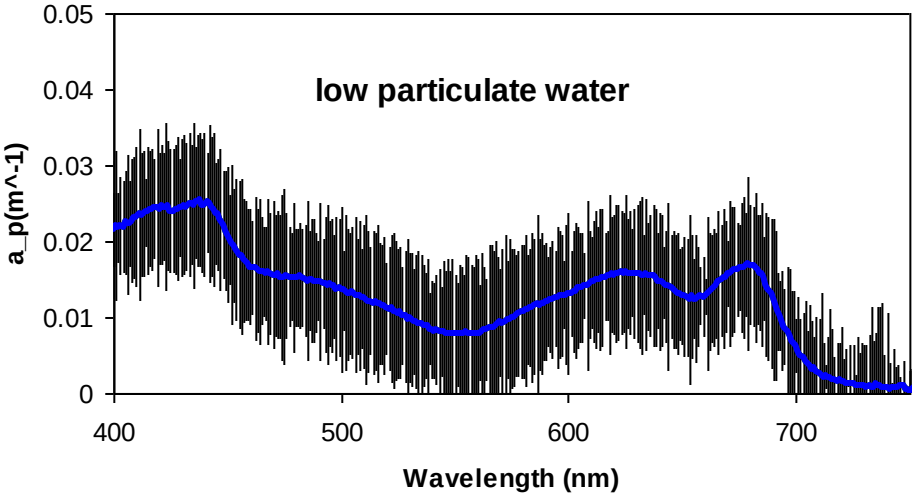
- Run three blank pads relative to your baseline
- Compute the standard deviation of the blank scans, $\sigma_{ODbl}(\lambda)$
- substitute $\sigma_{ODbl}(\lambda)$ for OD in the above equation to compute $\sigma_a(\lambda)$
- note that the uncertainty will be different for each sample:
  - V is different for every sample
  - OD is different sample is different, so the signal:noise will be different

$$\mathbf{\sigma_a\ (m^{-1}) = 2.303 \frac{\sigma_{ODbl}}{\frac{Vsample(m^3)}{A(m^2)}} .}$$

Roesler 1998

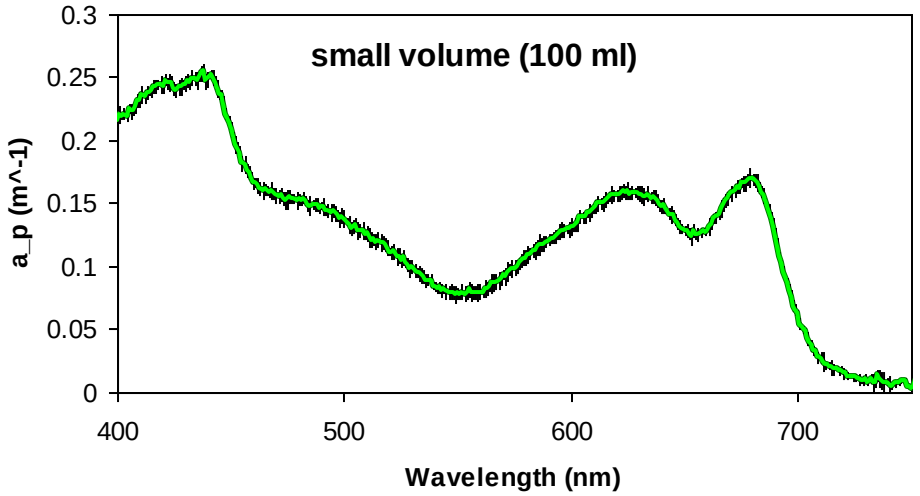
Uncertainty example 1: impact of sample optical density

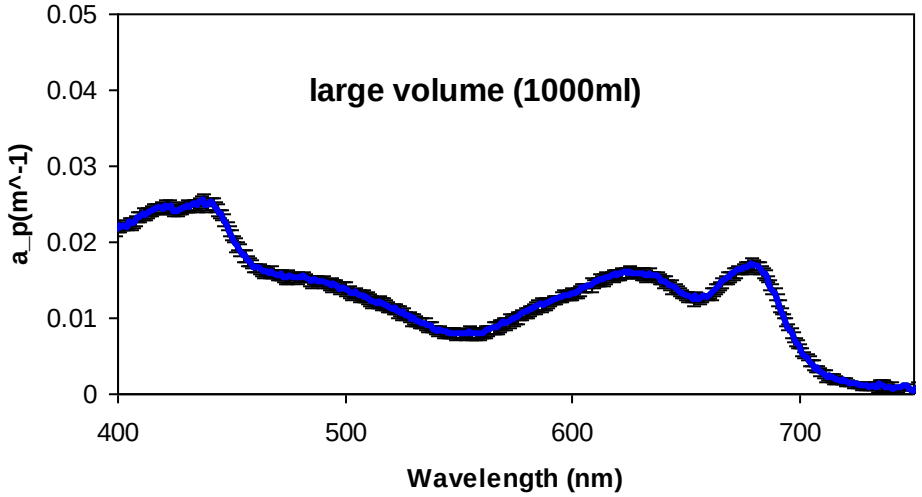




- Same volume filtered for each sample (100ml)
- $OD_{sample1} \sim 10 * OD_{sample2}$ (approx 0.1 vs 0.01)
- $OD_{filter\ blanks} \sim OD_{sample2}$ for low particulate waters

Uncertainty example 2: impact of volume filtered



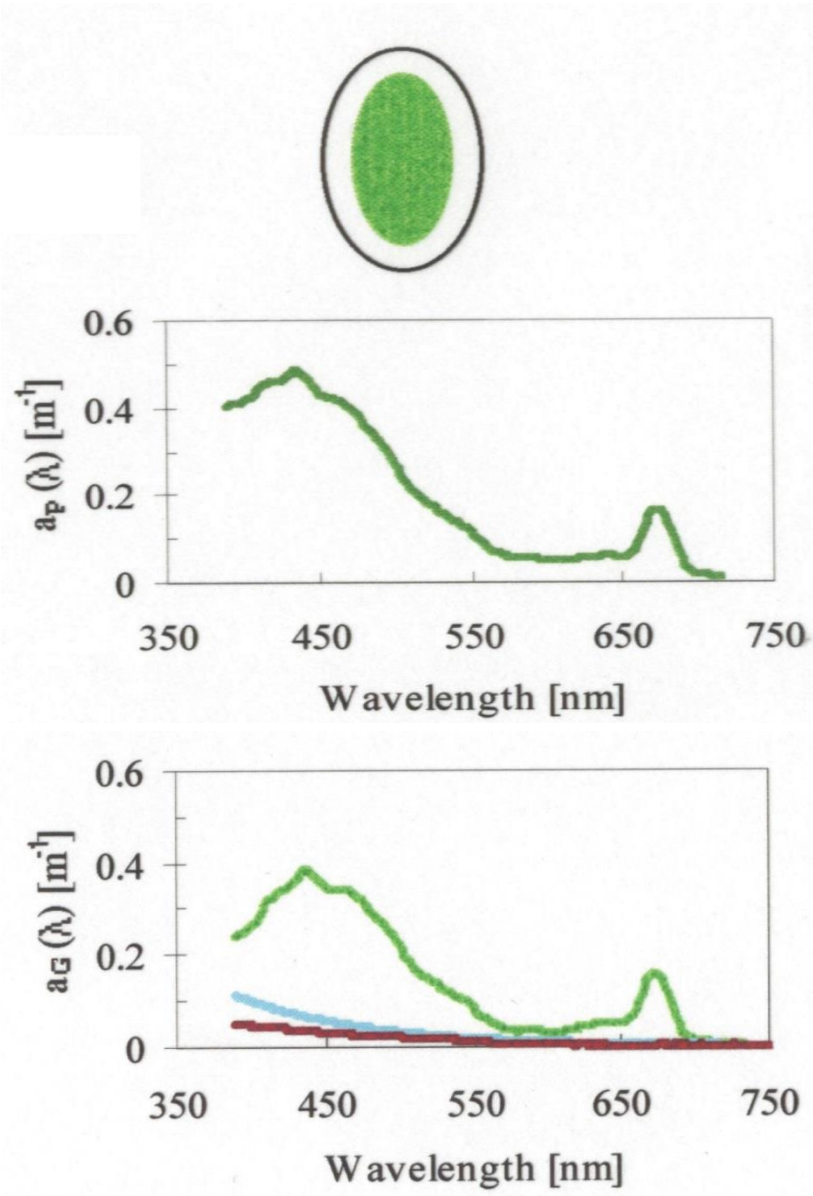


- Different V filtered for each sample (100ml vs 1000ml)
- $OD_{sample1}=OD_{sample2}$ (~0.1)
- $\sigma_{ODfilter\ blank}$~10%OD_{sample}

Better to **filter more volume** and obtain **higher OD_{sample}** relative to blanks

Partitioning of particulate absorption

- First scan is total particles, a_p
- Extract with methanol and scan again, a_{nap}
- $a_{phyt} = a_p - a_{nap}$
- Other issues
  - Phytoplankton “parts”
  - Detrital pigments
  - Phycobilipigments
  - Inorganics



Summary Filter pad technique

- Filter sample, want high loading to overcome the variability in the blank filter pad absorption itself, but not *muddy (0.1 to 0.4 absorbance (OD))*
- Reference?
- Extraction to separate particulates, nap
- Computation
  - Offset correction, Stramski and Babin 2002
  - Beta correction, try all models
  - Absorption calculation, a_p and a_{nap}
  - Phytoplankton calculation, $a_{phyt} = a_p - a_{nap}$

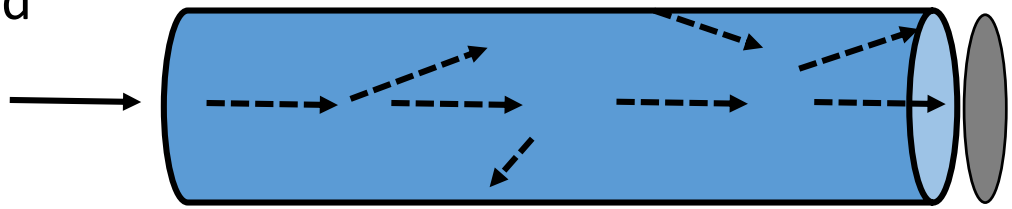
WETLabs ac9/acs sensors

- **Quantitative** measurements of absorption and attenuation
- Calibrated with **pure water**
- Corrections
  - Temperature and salinity of samples relative to pure water calibration
  - Non-ideal configurations for absorption and attenuation
- Strategies for robust measurements

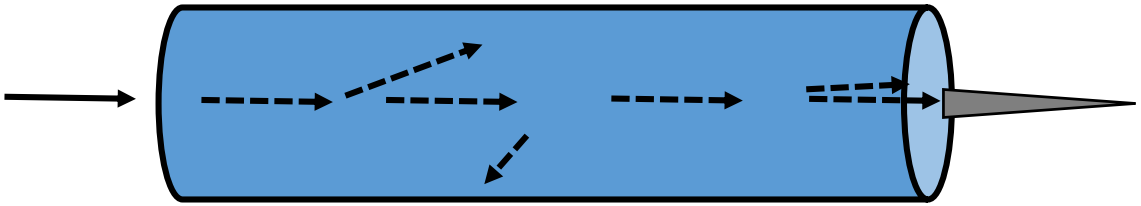
Bio-optical Sensors - Absorption

- Measurement Reality – Sensors
  - Reflecting tube absorption meters

a - Maximize scattered light collection
absorption



c – minimize scattered light collection
beam attenuation



b = c – a **scattering**

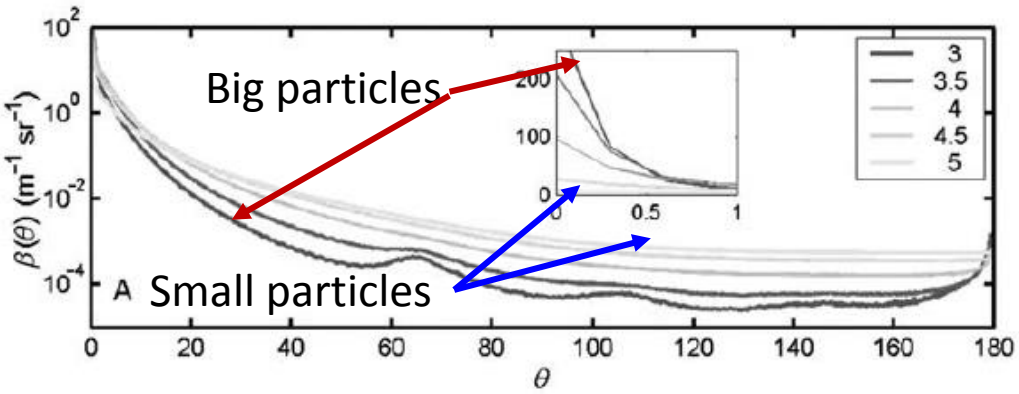
Some scattered light not collected by absorption tube, leads to overestimation of absorption →correction

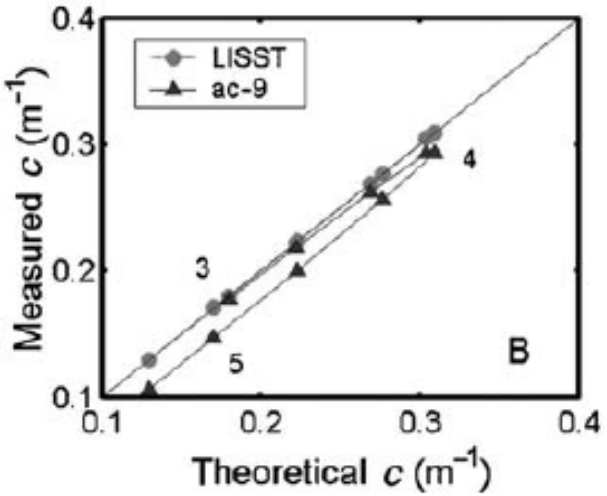
Some scattered light collected by attenuation tube, leads to underestimation of attenuation → report detection angle

An aside on
Beam attenuation acceptance angle

TABLE 5.2 Configuration specifications for commercially available beam attenuation meters

Instrument	Beam source	Beam width (mm)	Acceptance angle (°)	Path length (cm)
AlphaTracka transmissometer	Light emitting diode (LED)	15	0.86	5
SeaTech transmissometer	Collimated incandescent bulb	7	1.5	25
Sequoia LISST	Solid state diode laser	6	0.069(B), 0.006(F)	5, 10
WET Labs ac9, acs	Collimated incandescent bulb	10	0.93	25, 10
WET Labs cstar	LED	10	1.2	25, 10





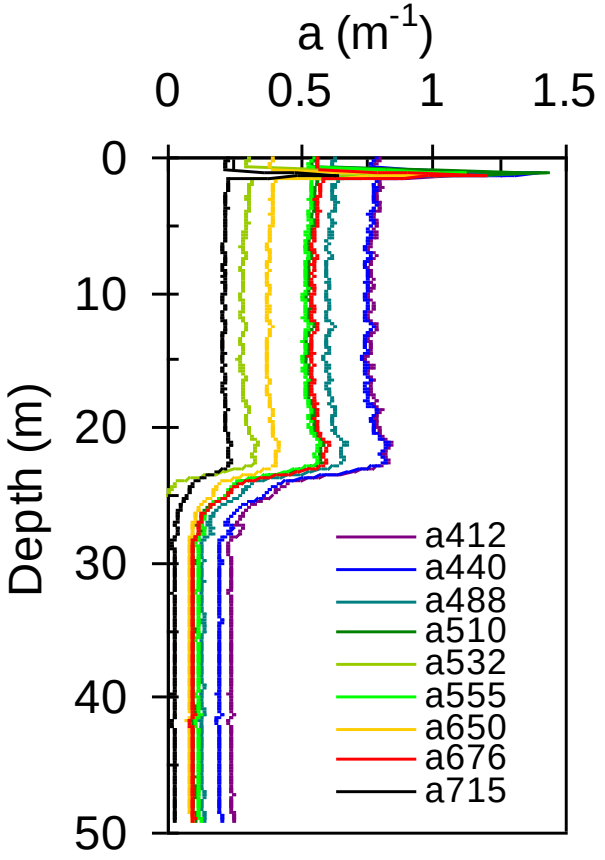
Roesler and Boss 2008

Absorption from ac9/acs

*water calibration for quantitation
air calibration to track instrument drift

- Obtain from factory
- Calibrate* in the lab
- Place in deployment configuration
  - Black tubing
  - Copper tubing
  - Air valve
  - Seat bottom
  - Bracket top
- Calibrate* on the frame
- Deploy
  - Take to depth to purge
  - Remove upcast observations (pump inversion)
- Calibrate* upon recovery

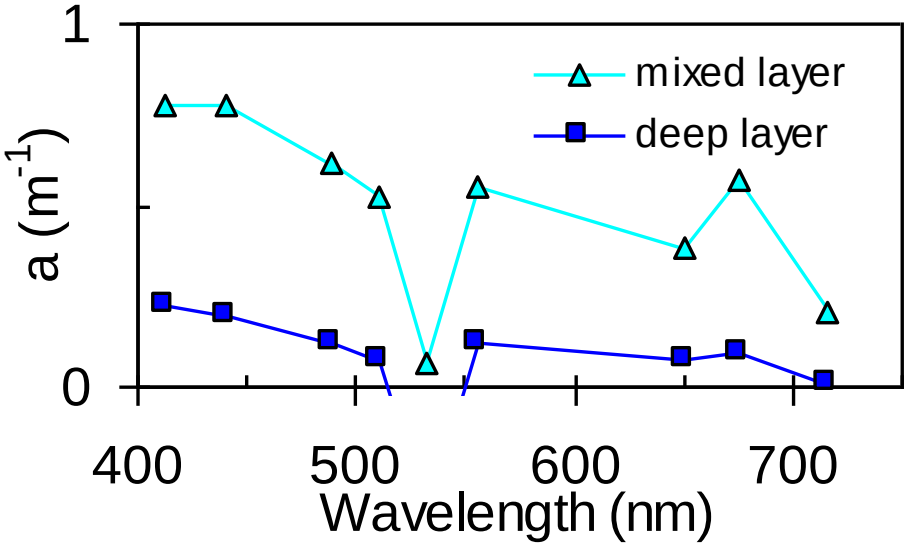
Absorption from ac9 (acs same)



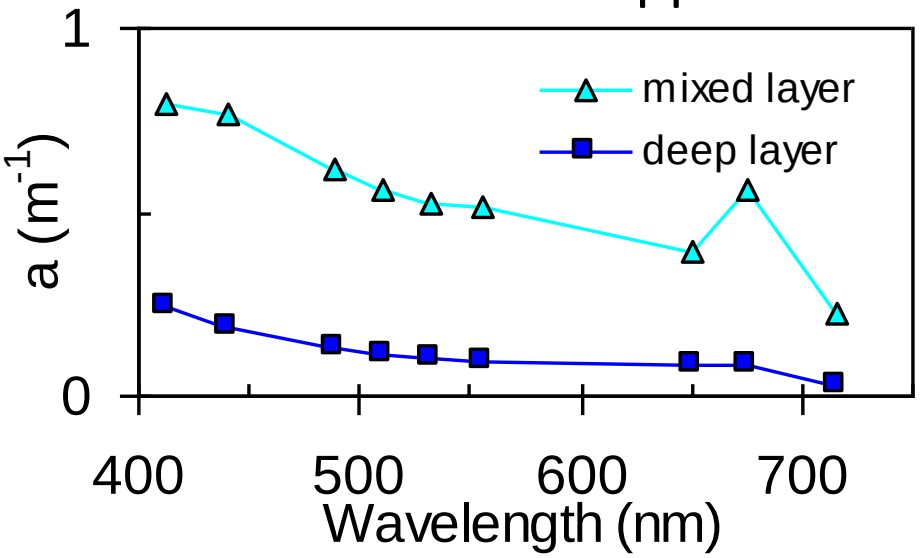
1. Pure water calibration

   $a = a_{meas} - a_{H20}$

But spectra are problematic



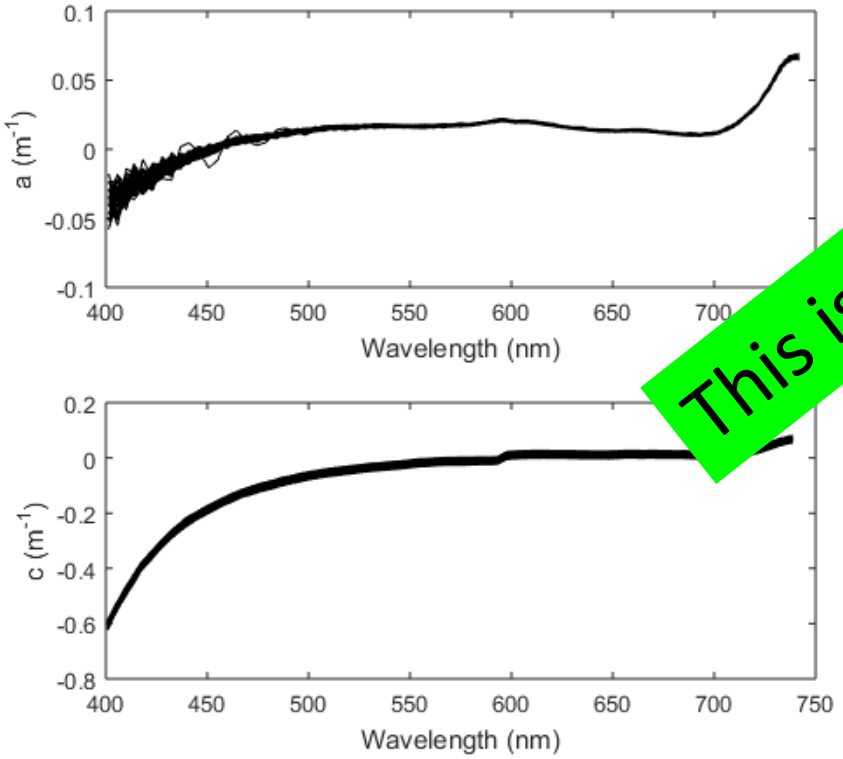
water calibration applied



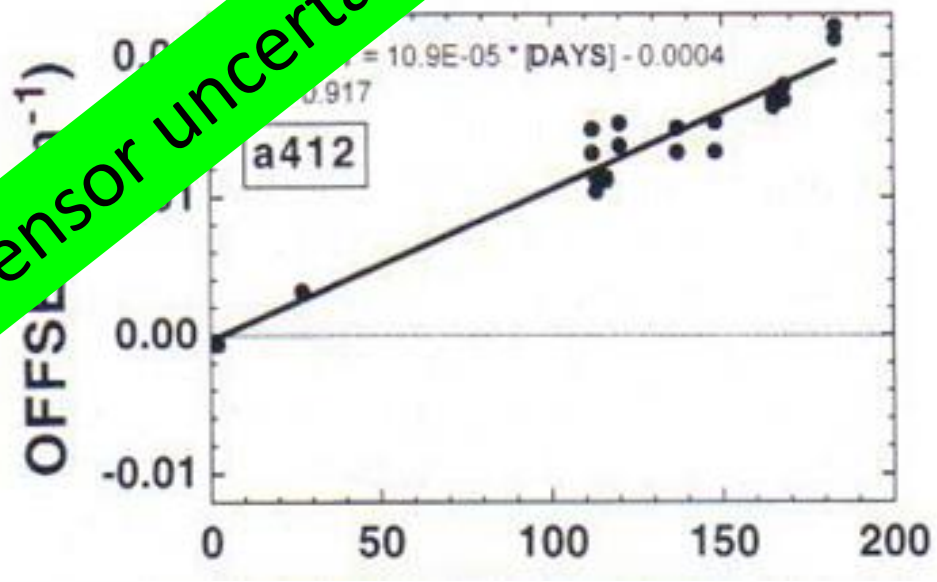
Roesler and Boss 2008

Bio-optical Sensors - Absorption

- Data Analysis and Interpretation – acs example
  1. Measure pure water scans



This is sensor uncertainty



Twardowski et al, 1997
(true for a and c)

The absorption/attenuation by water varies with temperature and salinity

If you calibrate at 25C with fresh water but measure in the ocean at 10C, you have not used a proper **calibration standard**

Temperature

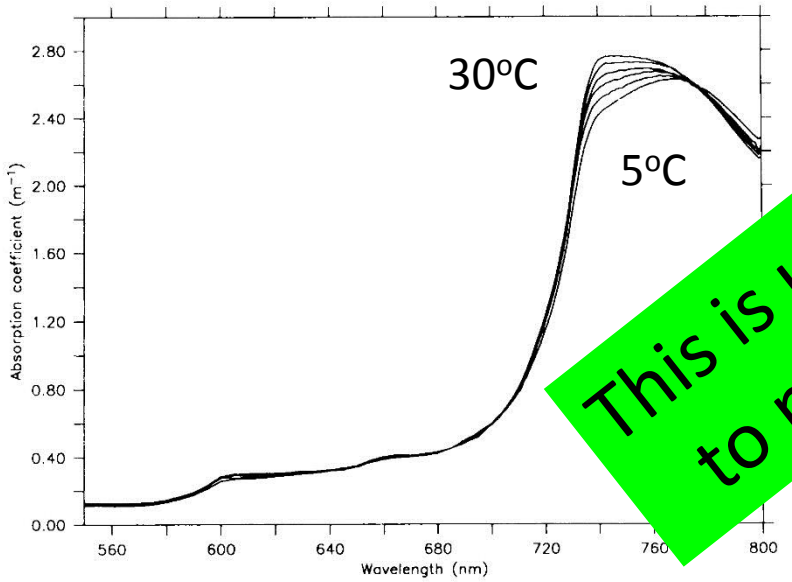


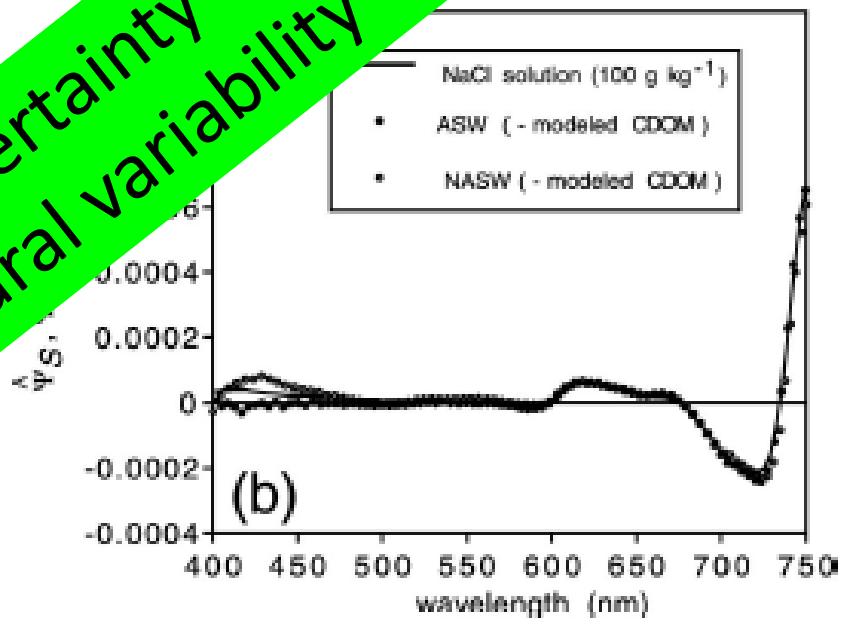
Fig. 3. Absorption coefficient from 550 to 800 nm adjusted at 685 nm to the value of Tam and Patel (1979). The curves represent absorption at temperatures of 5, 10, 15, 21, 25, and 30°C as read from bottom to top at 750 nm.

Pegau and Zaneveld 1993 Limnol Oceanogr.

Pegau et al. 1997 Applied Optics

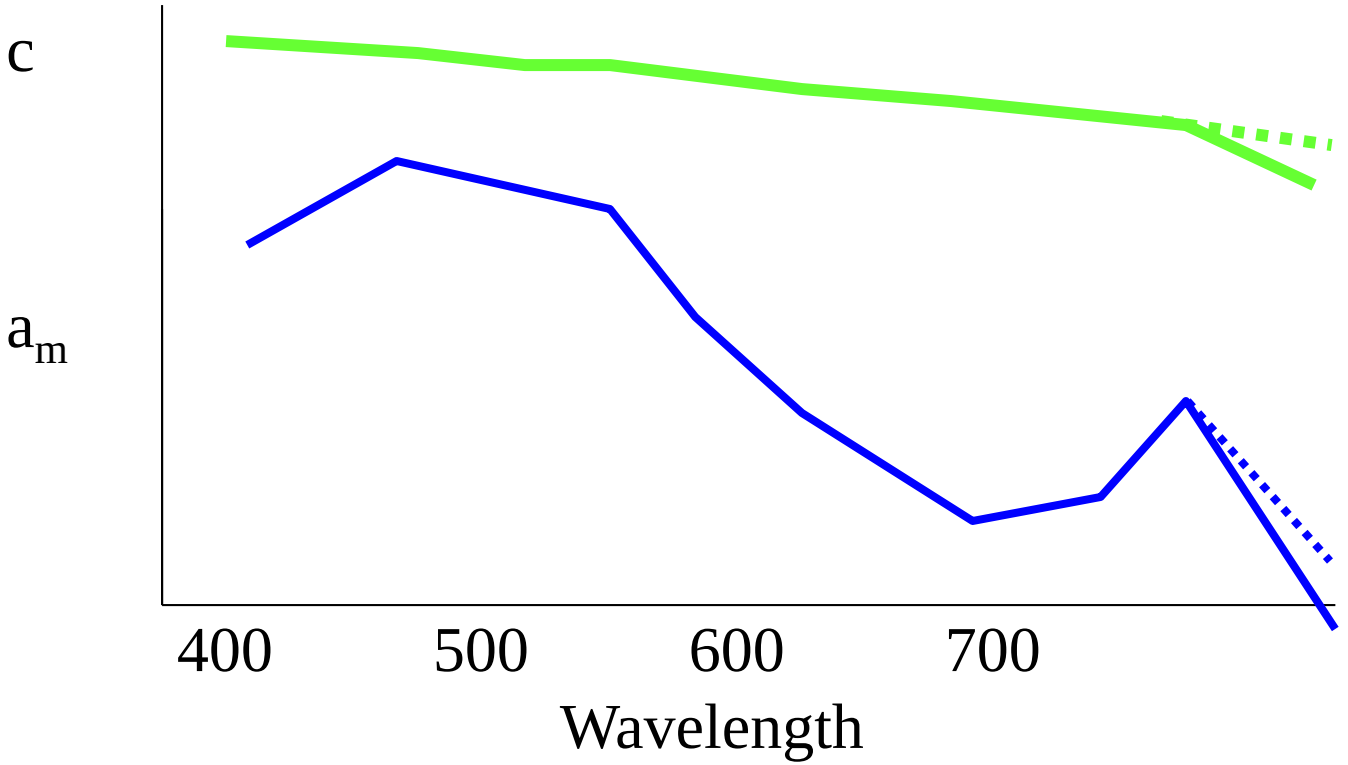
Sa

This is uncertainty due to natural variability



Sullivan et al. 2006 Applied Optics

Absorption from ac9



2. Temperature and salinity correction

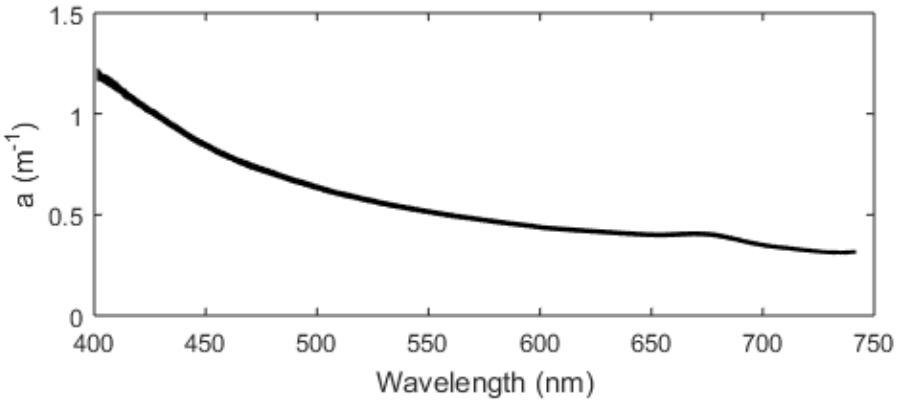
This is due to the fact that the in situ T and S are different than that of the calibration water

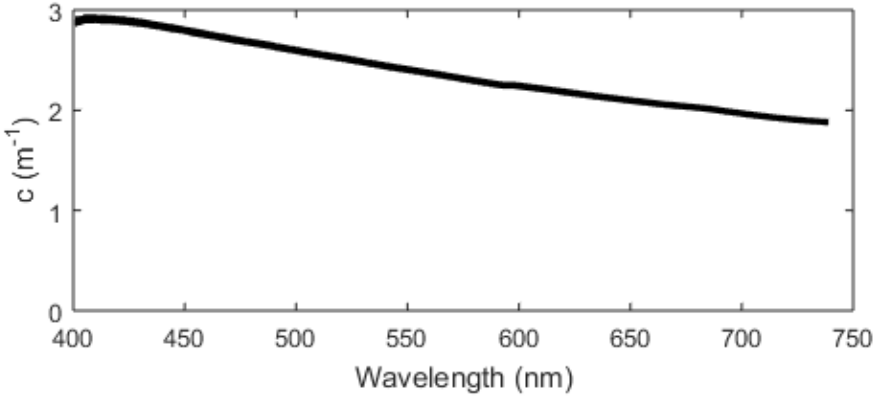
→ Requires measurement of T, S in situ

Bio-optical Sensors - Absorption

- Data Analysis and Interpretation – acs example
  - Collect sample scans

  1. correct for T, S

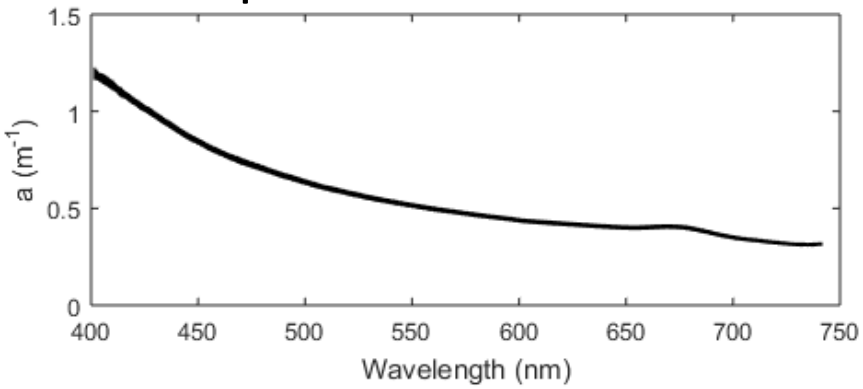


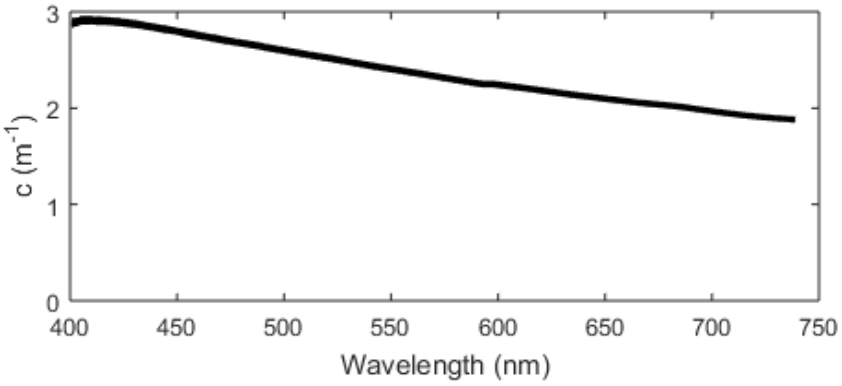


Bio-optical Sensors - Absorption

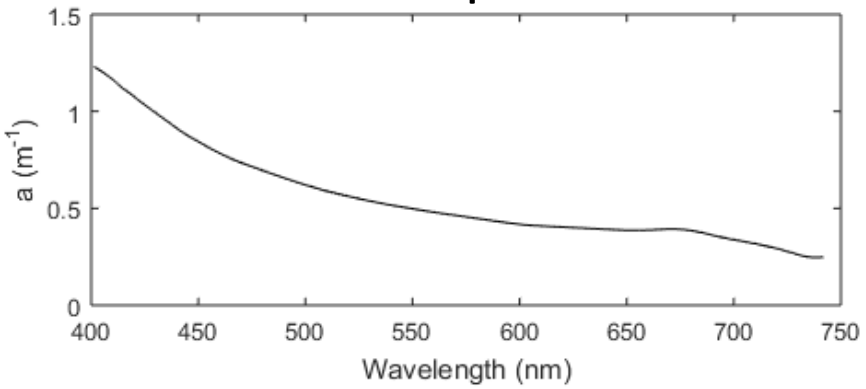
- Data Analysis and Interpretation – acs example
  2. Correct sample scans for pure water values (T, S corr)

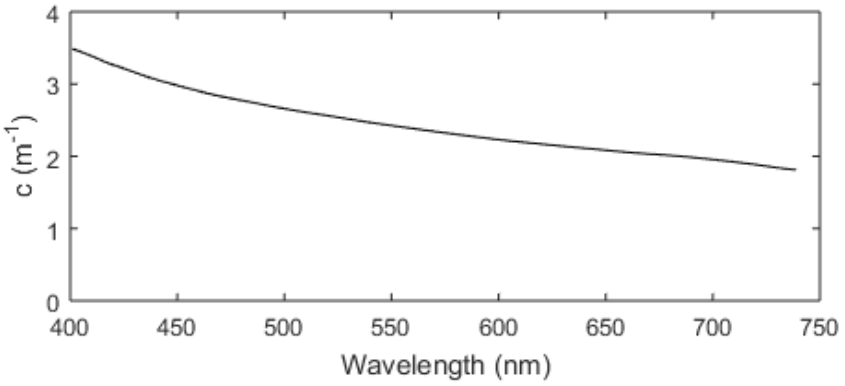
sample scan





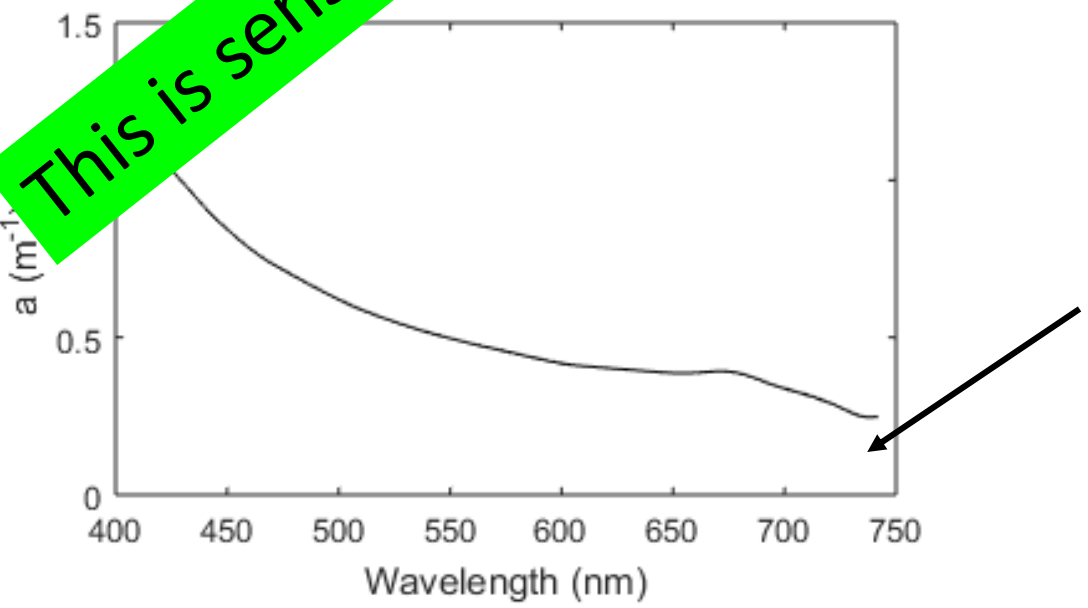
corrected for pure water





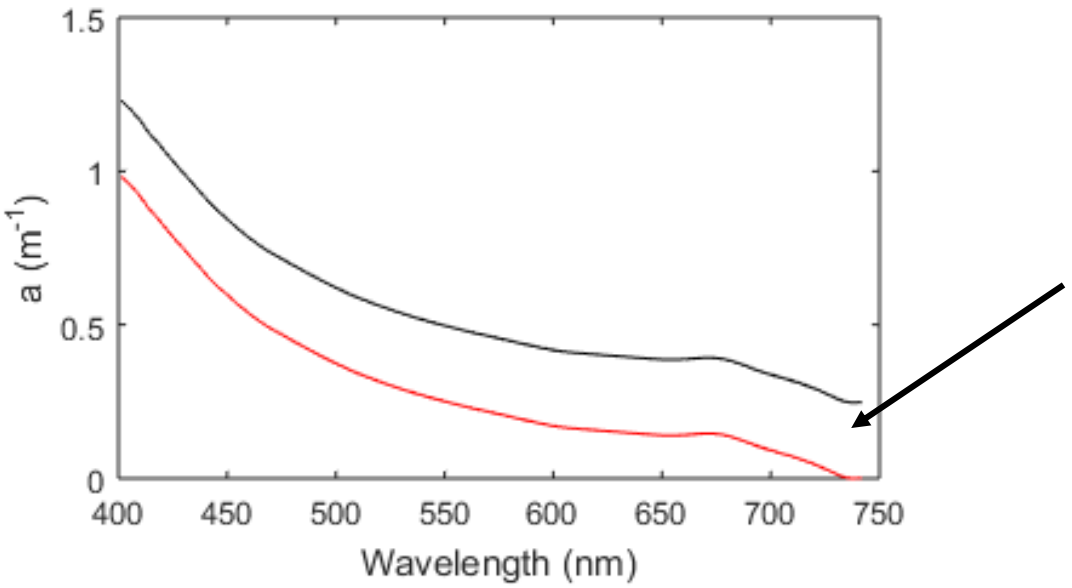
Bio-optical Sensors - Absorption

- Data Analysis and Interpretation – acs example
  3. Scattering correct the absorption spec
     find wavelength where absorption is ne
     → measured *a* is actually **scatterin**
     if T and S have been accurately d for



Bio-optical Sensors - Absorption

- Data Analysis and Interpretation – acs example
  3. Scattering correct the absorption spectra
     a. Subtract a_m(NIR)
        "b not a function of λ"
        spectrophotometric approach



Stramski and Babin 2002

Bio-optical Sensors - Absorption

- Data Analysis and Interpretation – acs example

  3. Scattering correct the absorption spectra

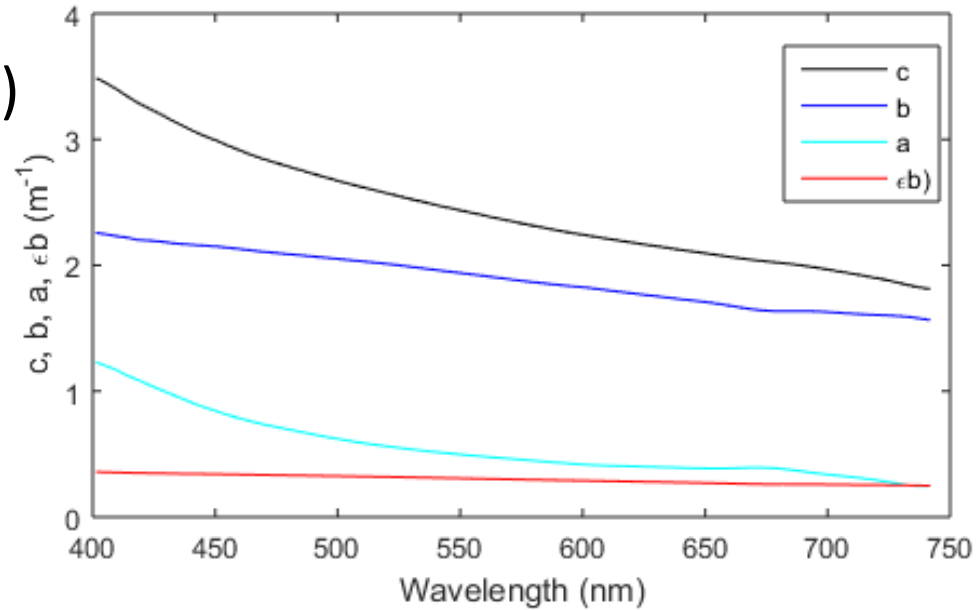
  b. Subtract spectral scattering contribution, fraction of b(λ)

  b(λ) = c(λ) – a(λ)

  if a(NIR) = 0 signal is due to scattering

  fb(λ) = a(NIR)/b(NIR)

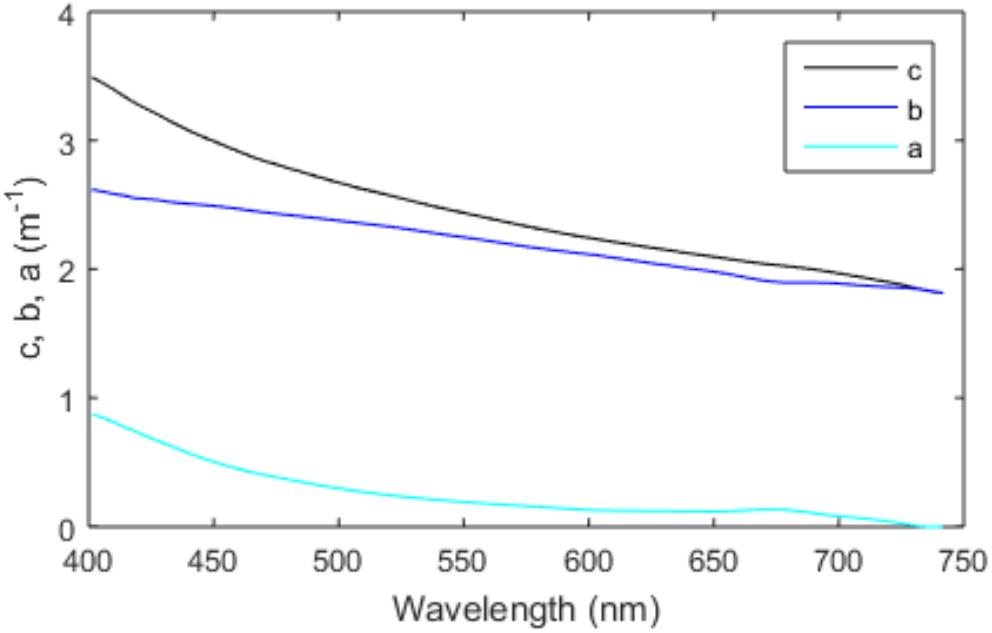
$a_{corr}(\lambda) = a(\lambda) - (f b(\lambda) * b(\lambda))$



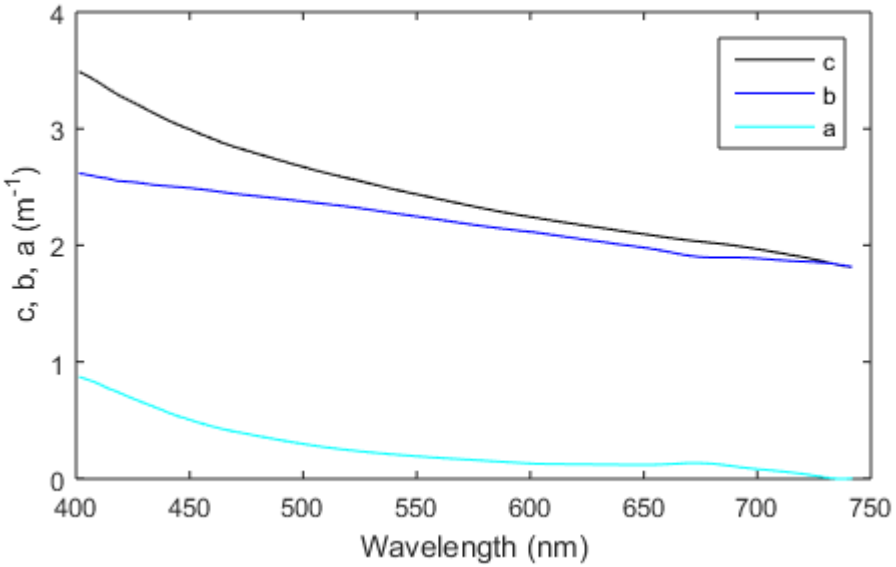
Roesler and Zaneveld 1993

Bio-optical Sensors - Absorption

- Data Analysis and Interpretation – acs example
  4. Compute Scattering spectra
     $b(\lambda) = c(\lambda) - a(\lambda)$



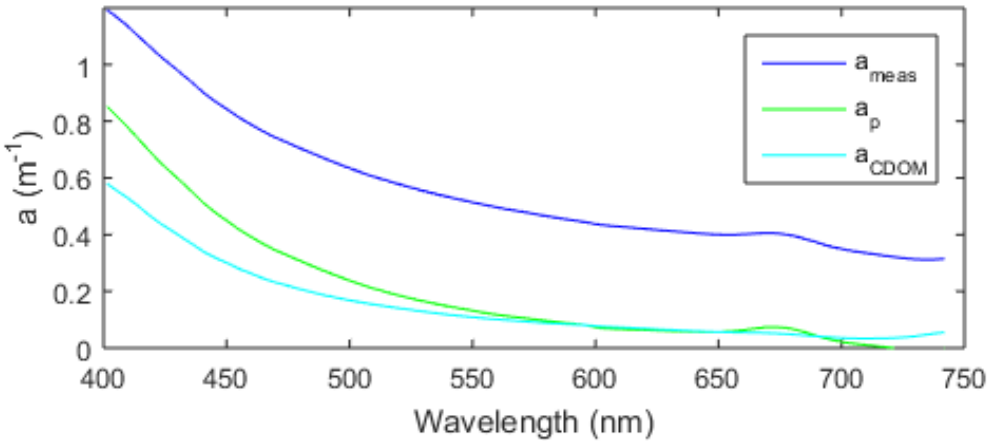
Best practices for obtaining Absorption/Attenuation from acs



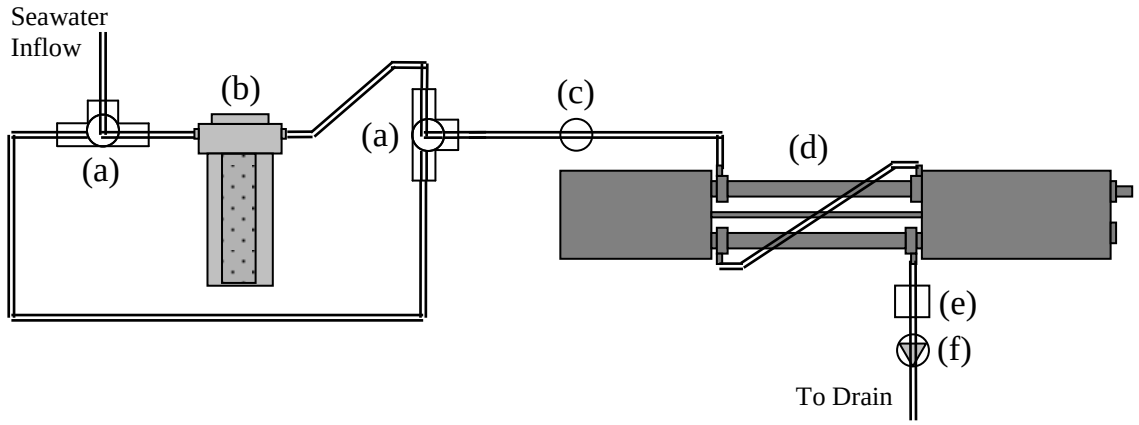
- Review Data processing
  - Temperature/Salinity correct a and c of sample and calibration data
  - Subtract T,S-corrected pure water calibration from sample scans
  - Apply spectral scattering correction to absorption
  - Compute scattering spectrum (b = c – a)

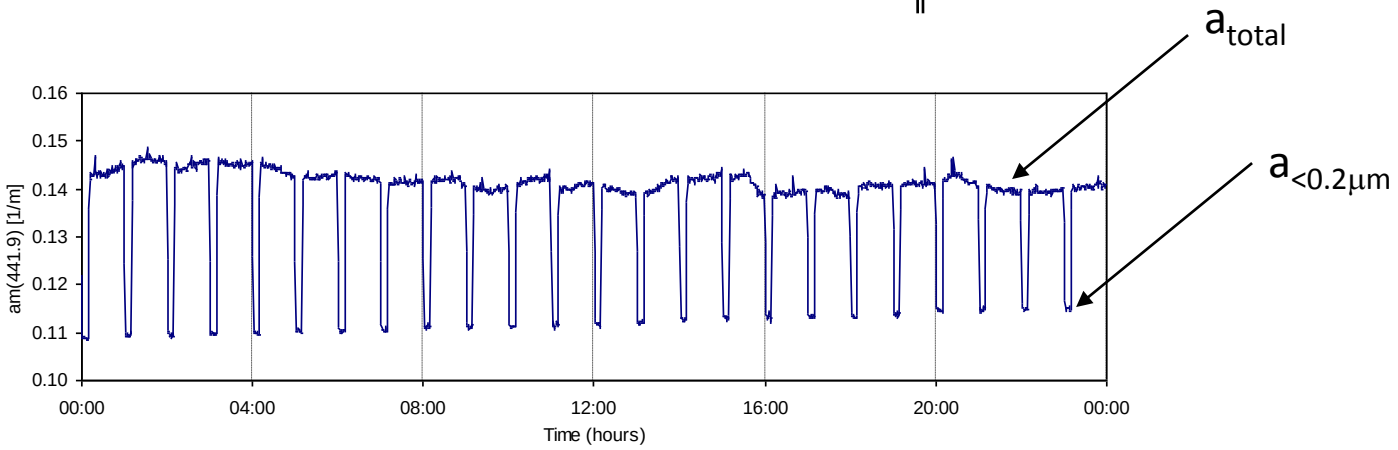
Bio-optical Sensors - Absorption

- Data Analysis and Interpretation – acs example
  - **Calibration independent** method for partitioning
  - (Slade et al. 2010)
    - Measure whole water and filtered water, a_{tot}, a_{filt}
    - Apply Temperature, Salinity correction
    - Apply Scattering correction
    - Subtract filtered water scan from whole water scan, $a_{part}=a_{tot} - a_{filt}$
    - Yields a_{CDOM} and a_{part} ***independent of calibration drift***



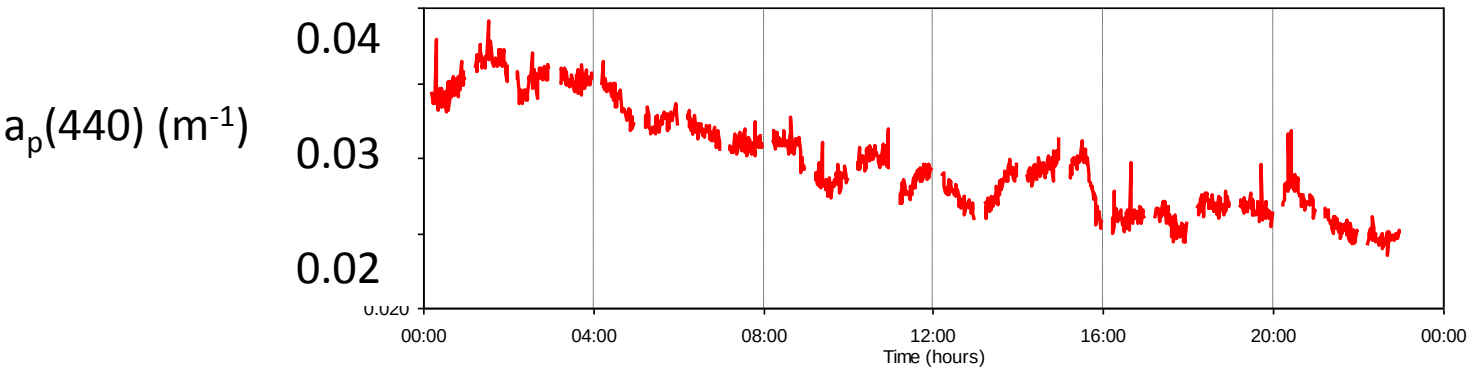
Automated shipboard flow-through method, calibration-independent

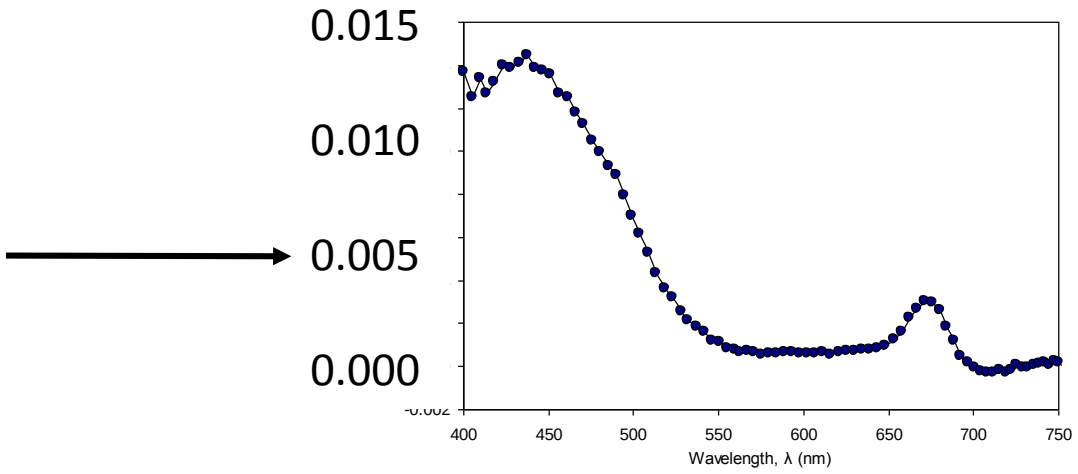




Slade et al., 2010

An example of calibration independent approach on an automated shipboard flow-through configuration





Slade et al., 2010