Lecture 5
Measuring Absorption

Collin Roesler and Emmanuel Boss

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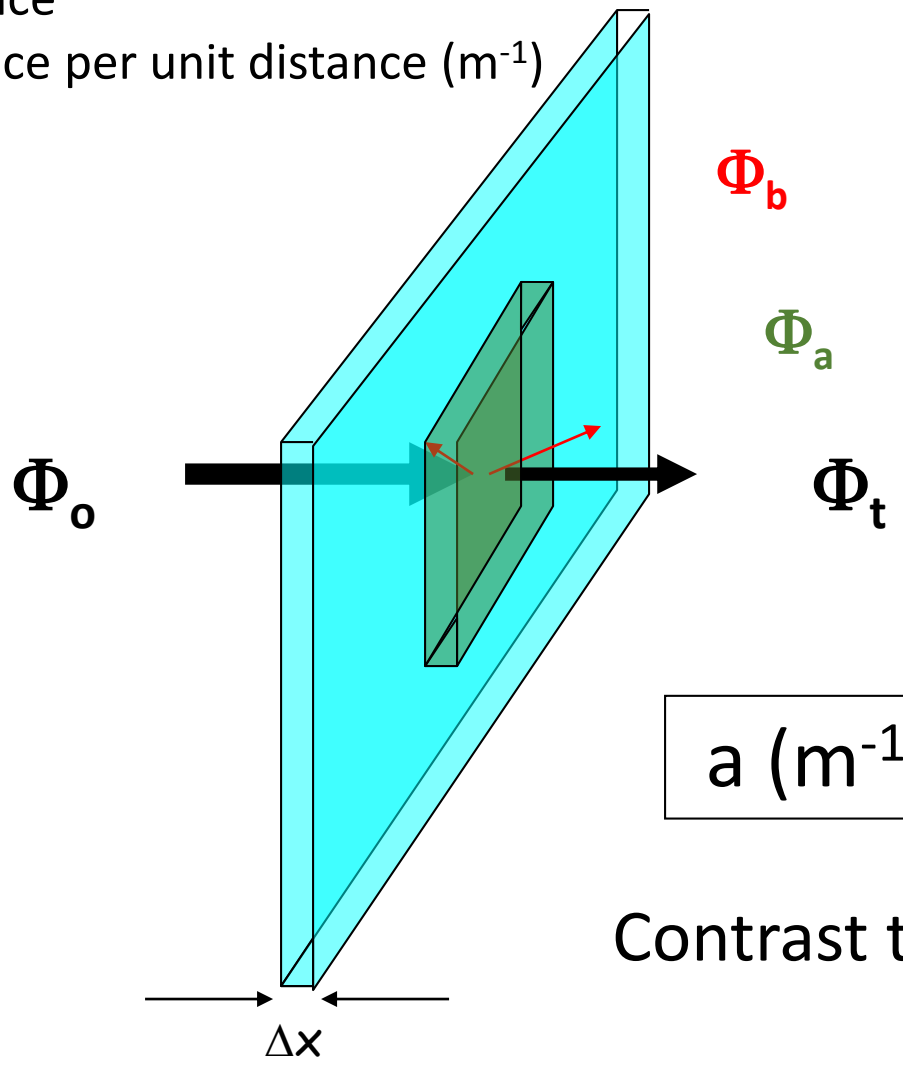
How do we measure absorption in the ocean?

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

Remember Absorption Theory

A = absorbance

a = absorbance per unit distance (m^{-1})



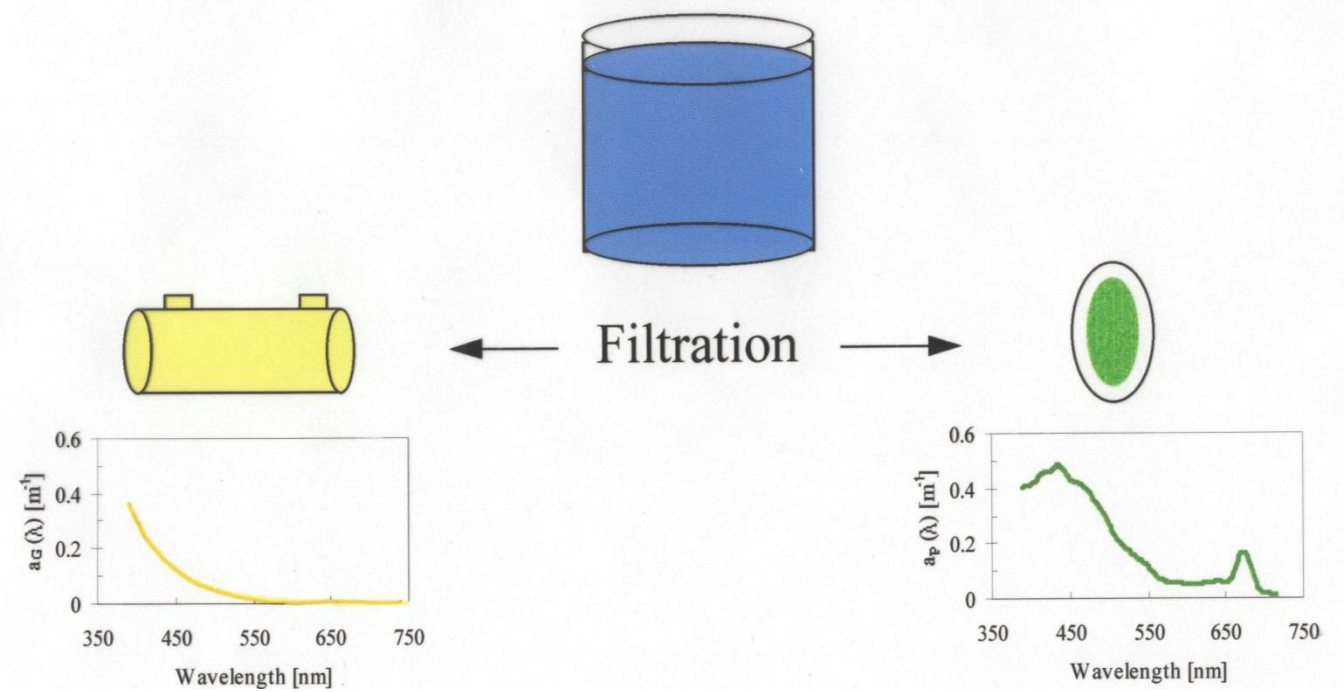
$$A = \Phi_a/\Phi_o$$

$$a = A/\Delta x$$

$$a\ (m^{-1}) = (-1/x)\ \ln(\Phi_t/\Phi_o)$$

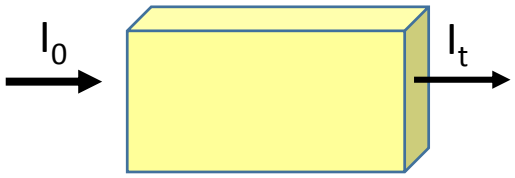
Contrast to measuring beam c

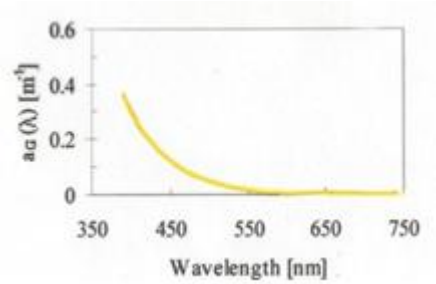
Absorption:
Discrete spectrophotometry



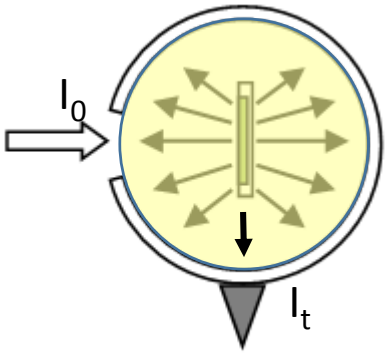
- Separates particles from *dissolved*
- Concentrates particles from dilute medium

Absorption:
"Dissolved" absorption

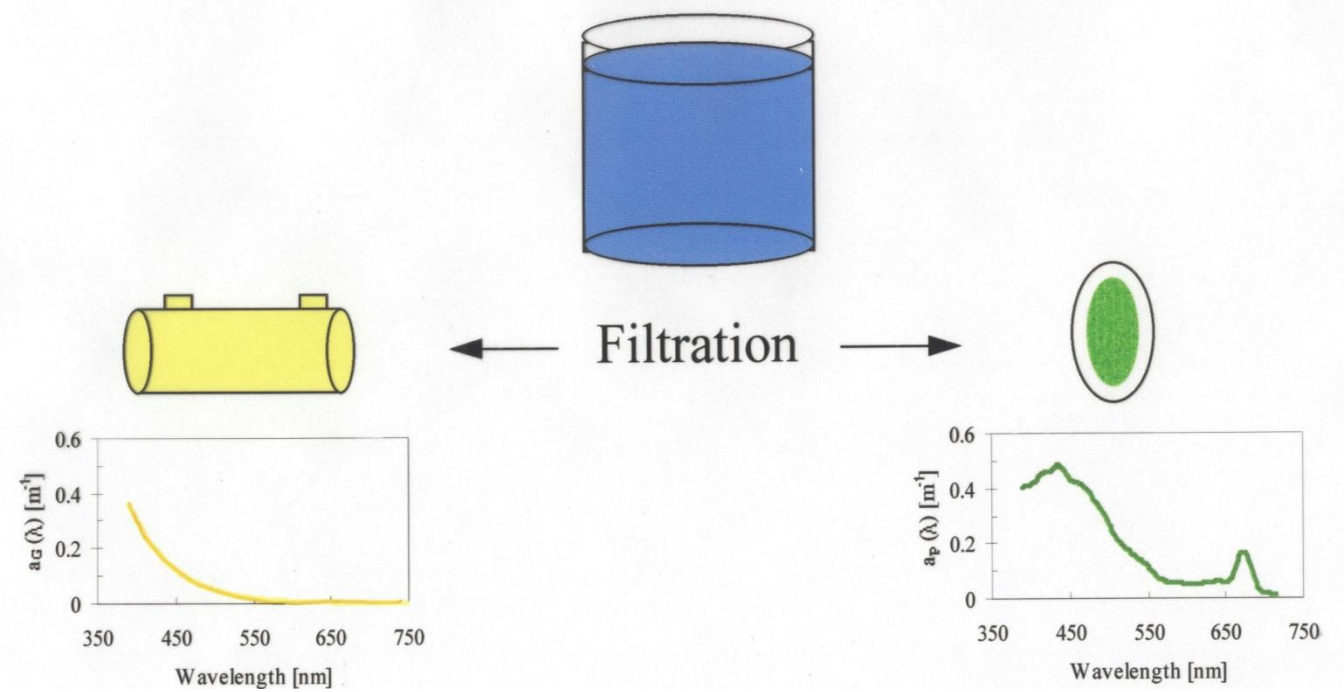




- How does spectrophotometer represent the theory?
- What are the assumptions of this method
- When might this assumption fail?

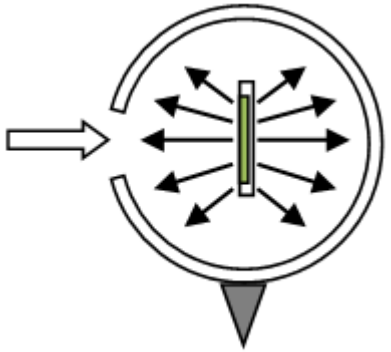


Absorption: Quantitative Filter Technique

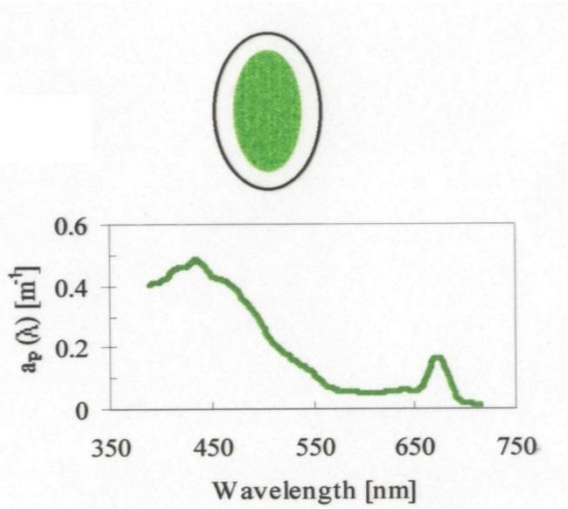


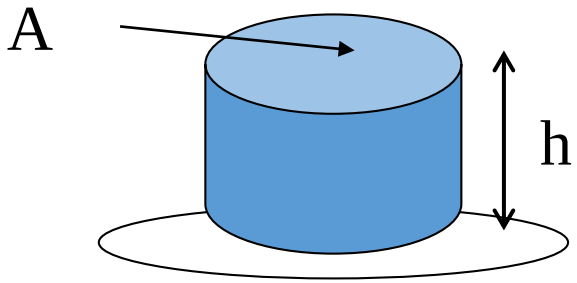
- Separates particles from *dissolved*
- Concentrates particles from dilute medium

Measure in Spectrophotometer Integrating Sphere Mode



- Baseline: mean blank filter pad scans
- Sample scans: mean of filters, rotations
- Compute absorption from absorbance
  - $a\ (m^{-1}) = 2.303 \frac{OD}{L\ (m)}$. What is L?



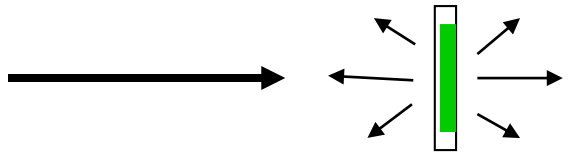


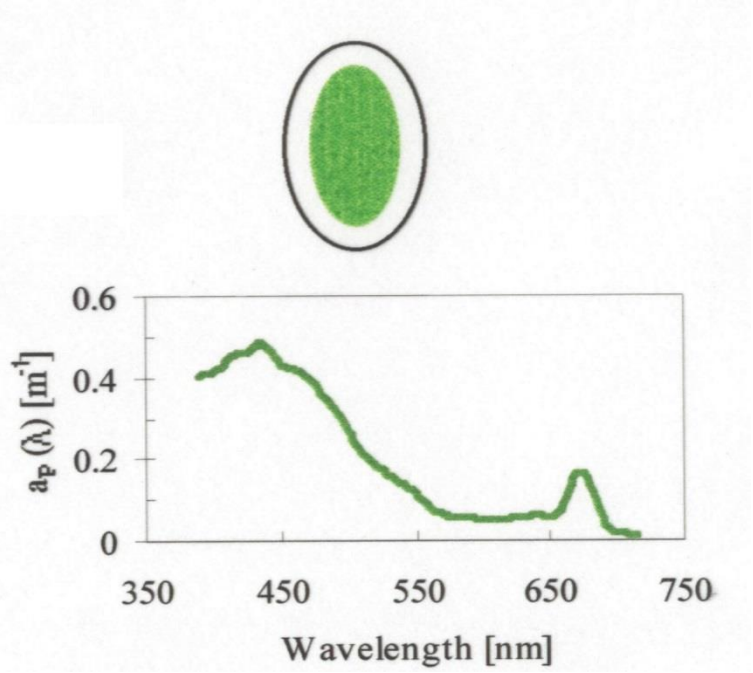
$$V_{filtered} = A_{eff}\ h$$

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

What about the scattering by the filter? Path length amplification

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

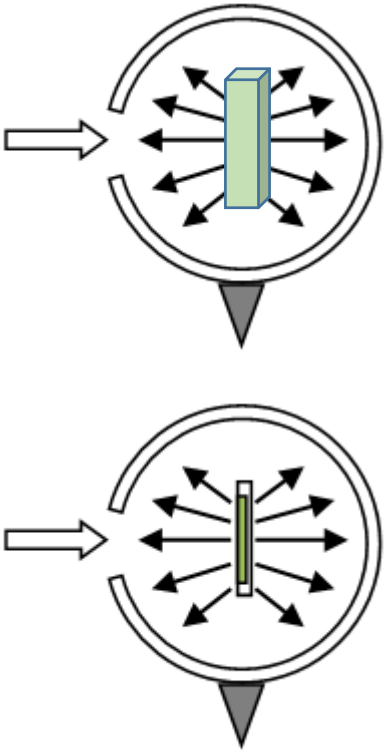


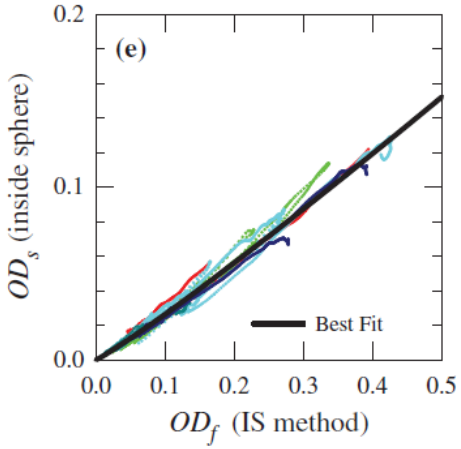


- Filter pad
  - Creates nearly isotropic light field
  - Increases optical path length
  - Increases absorption signal
  - How to correct for it?

β correction: path length amplification

- Approach
  - Cultures or samples
  - Measure absorbance in cuvette (IS-mode)
  - Measure absorbance on filter pad (IS-mode)
  - Determine ratio, $\beta = \frac{OD_f}{OD_s} = \frac{\text{optical}}{\text{geometric}}$
  - Correct OD_f, then compute a



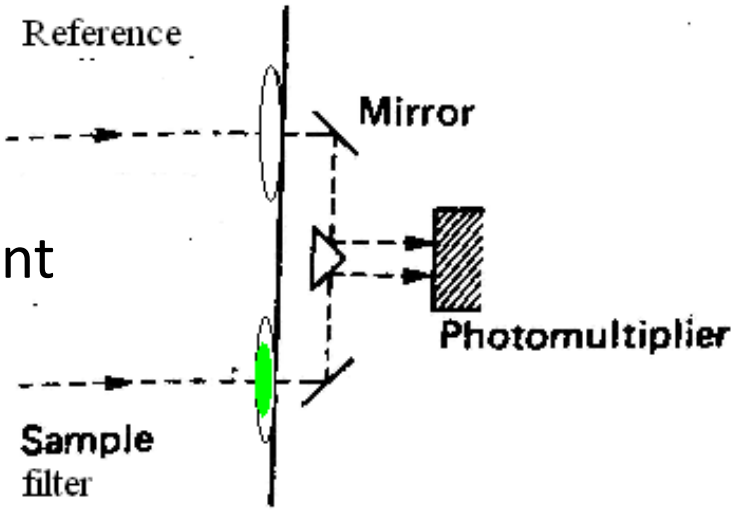


$OD_s = 0.323\ OD_f^{1.0867}$

Stramski et al. 2015

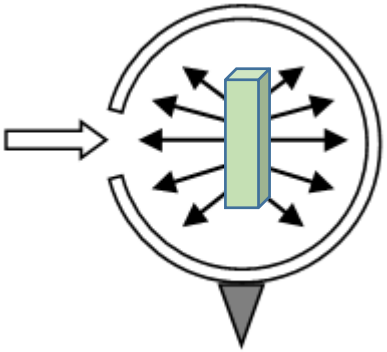
Measure in Spectrophotometer Transmission Mode (if you don't have an integrating sphere)

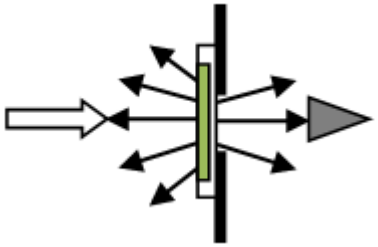
- Reference (neutral density filter)
  - Match optical density of filter pad
  - No variability
- Baseline
  - Blank filter pad in sample compartment
- Samples

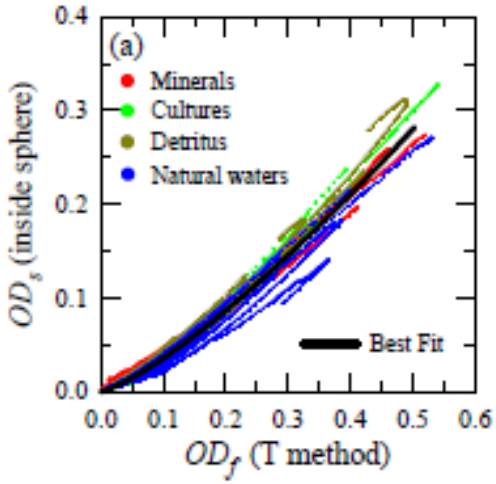


β correction: path length amplification

- Approach
  - Cultures or samples
  - Measure absorption in cuvette (IS-mode)
  - Measure absorption on filter pad (T-mode)
  - Determine ratio, $\beta = \frac{OD_f}{OD_s} = \frac{\text{optical}}{\text{geometric}}$
  - Correct A_f, then compute a







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

Stramski et al. 2015

Uncertainty calculation

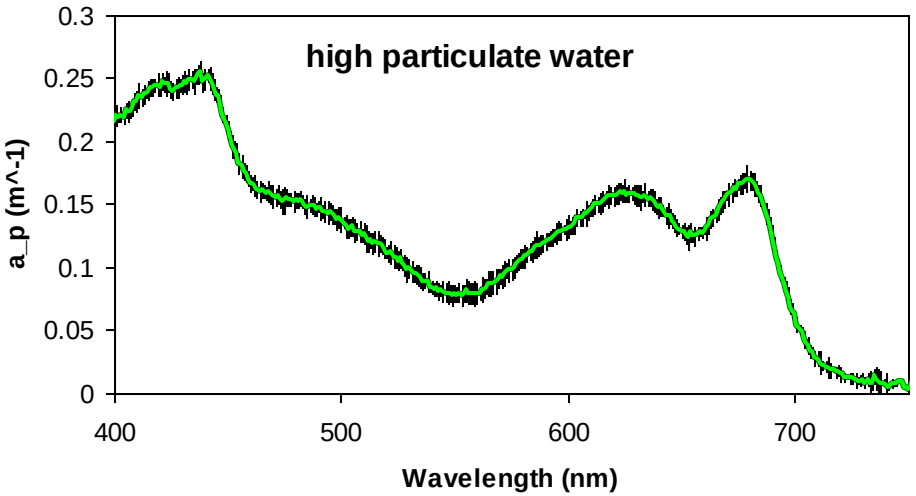
$$a\ (m^{-1}) = 2.303 \frac{OD}{\frac{V(m^3)}{A(m^2)}}.$$

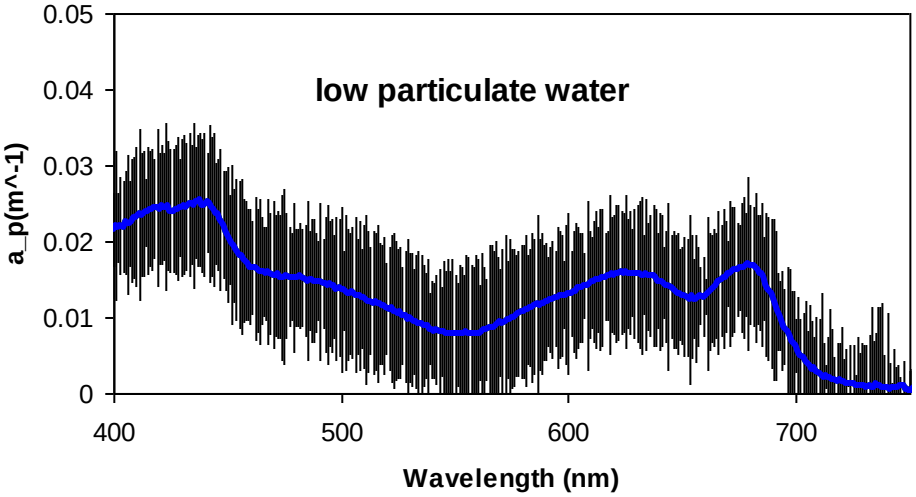
- Run three blank pads relative to your baseline
- Compute the standard deviation of the blank scans, $\sigma_{ODbl}(\lambda)$
- substitute $\sigma_{ODbl}(\lambda)$ for OD in the above equation to compute $\sigma_a(\lambda)$
- note that the uncertainty will be different for each sample:
  - V is different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

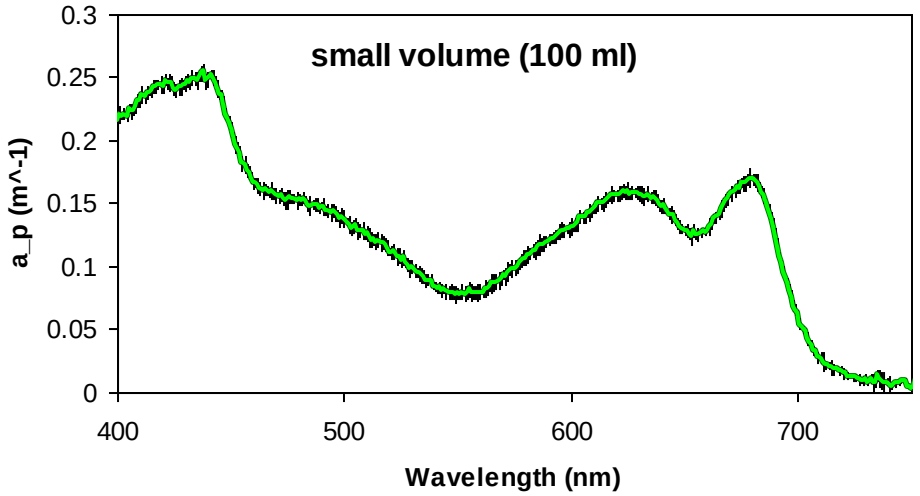
Uncertainty example 1: impact of sample optical density

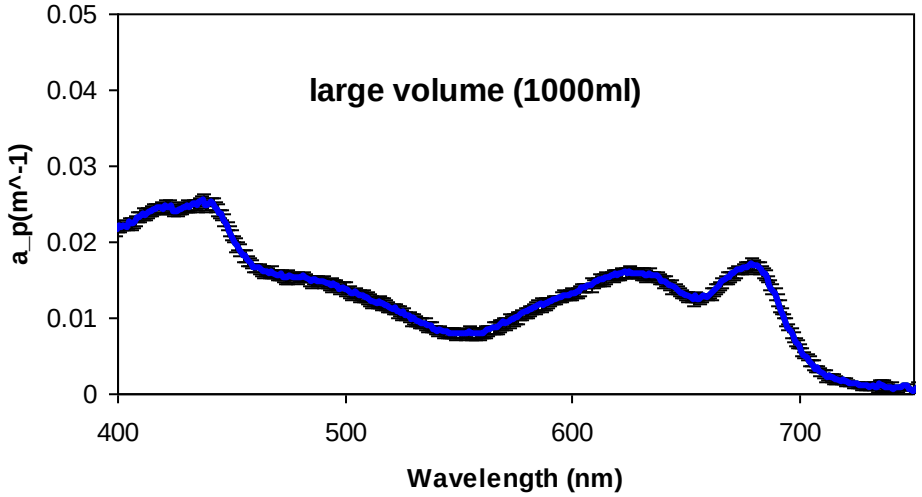




- Same volume filtered for each sample (100ml)
- $OD_{sample1} \sim 10 * OD_{sample2}$ (approx 0.1 vs 0.01)
- $OD_{filter\ blanks} \sim OD_{sample2}$ for low particulate waters

Uncertainty example 2: impact of volume filtered

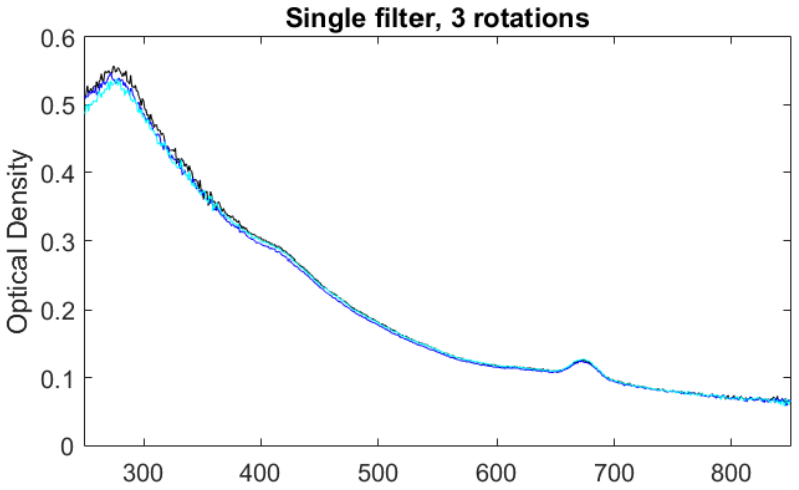


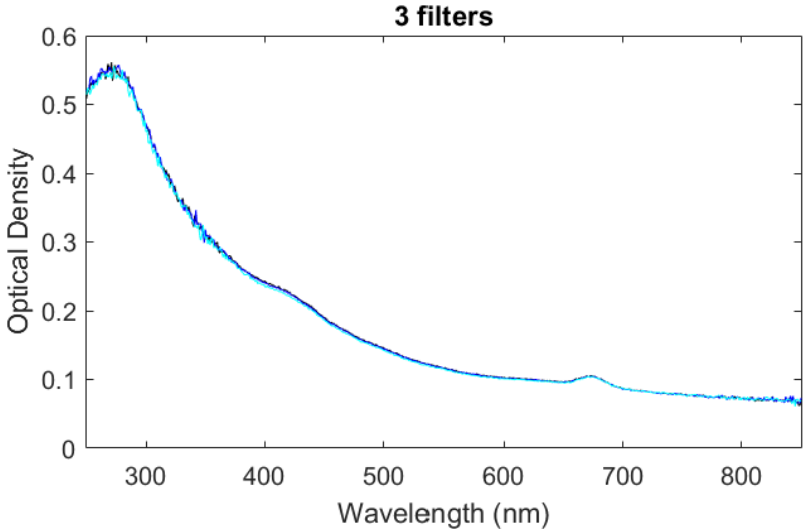


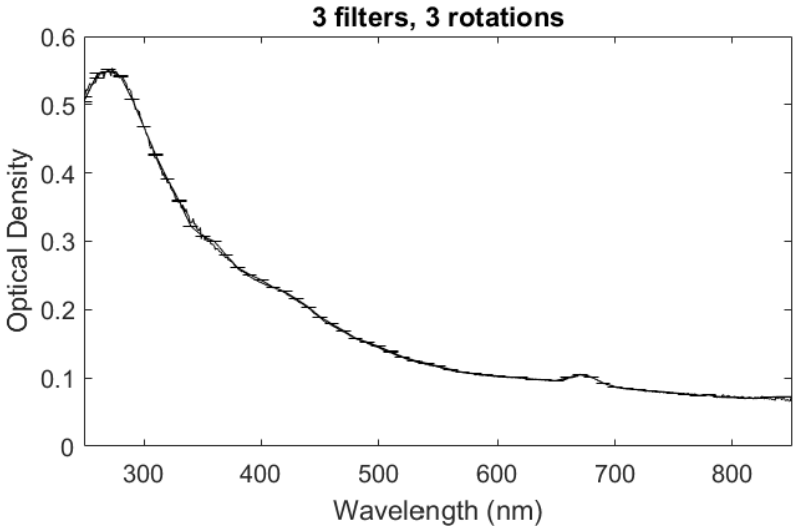
- Different V filtered for each sample (100ml vs 1000ml)
- $OD_{sample1}=OD_{sample2}$ (~0.1)
- $\sigma_{ODfilter\ blank}$~10%OD_{sample}

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

Uncertainty Budget

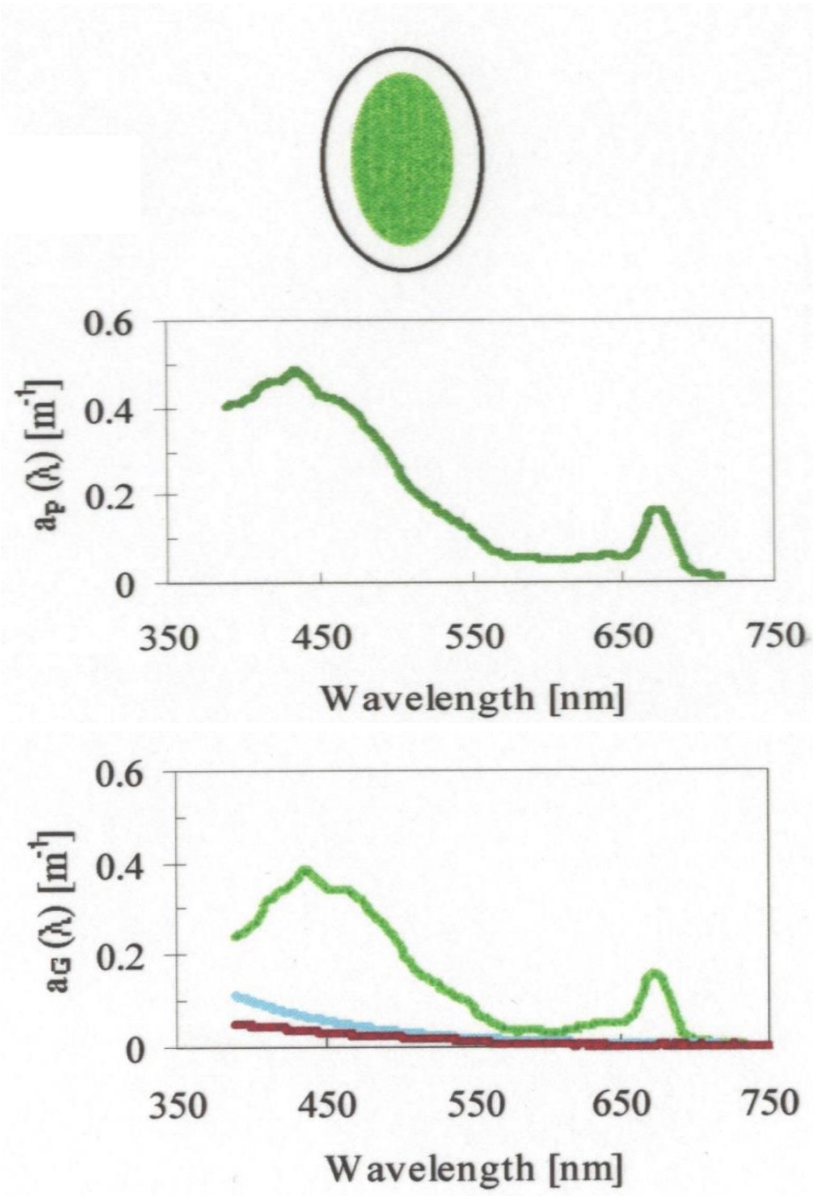






Partitioning particulate absorption

- 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))*
- What is the reference?
- Extraction to separate particulates, nap
- Computation
  - Offset correction or not? (Stramski and Babin 2002)
  - Absorption calculation, a_p and a_{nap}
  - Phytoplankton calculation, $a_{phyt} = a_p - a_{nap}$

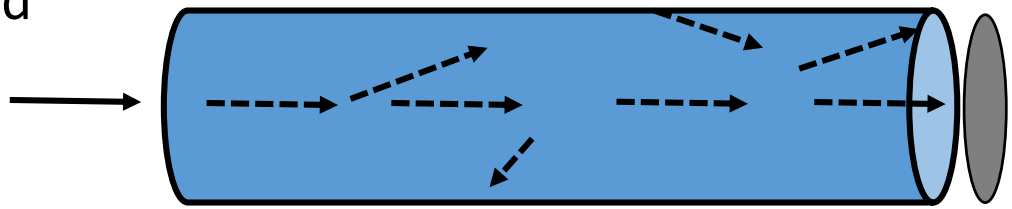
WETLabs ac9/acs sensors

- **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

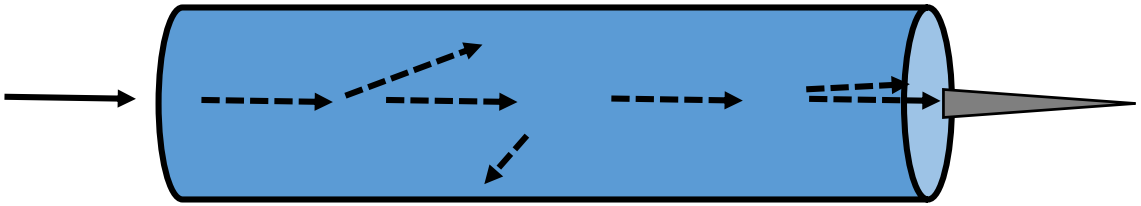
Bio-optical Sensors - Absorption

- 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

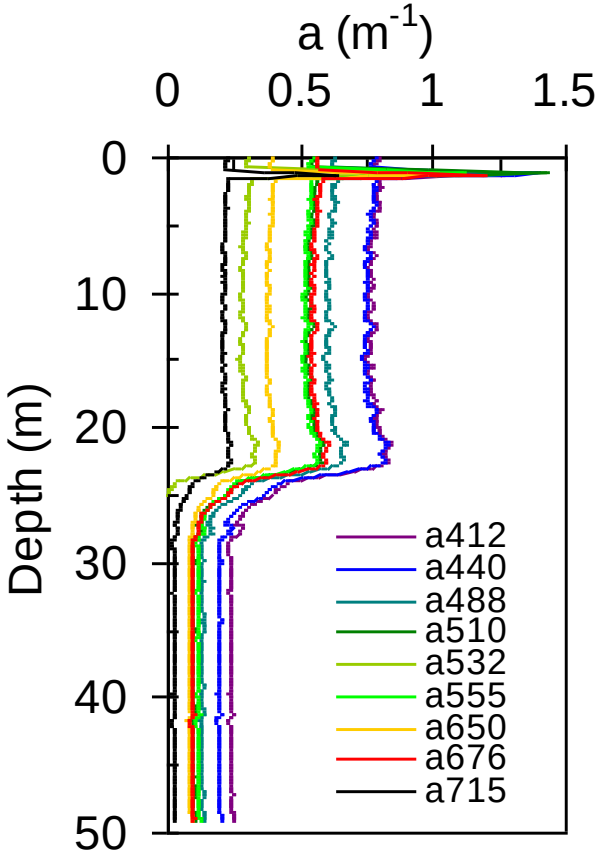
Some scattered light collected by attenuation tube, leads to underestimation of attenuation → report detection angle

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

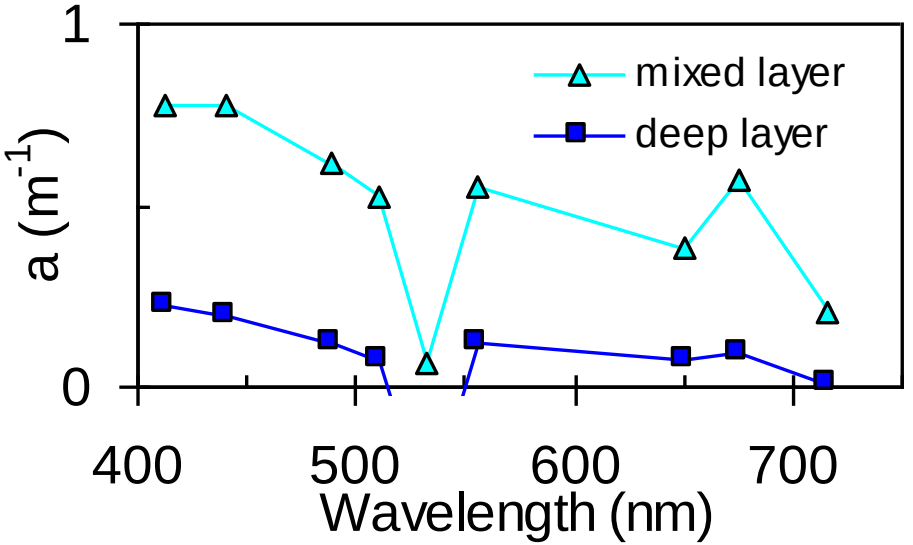
Absorption from ac9 (acs same)



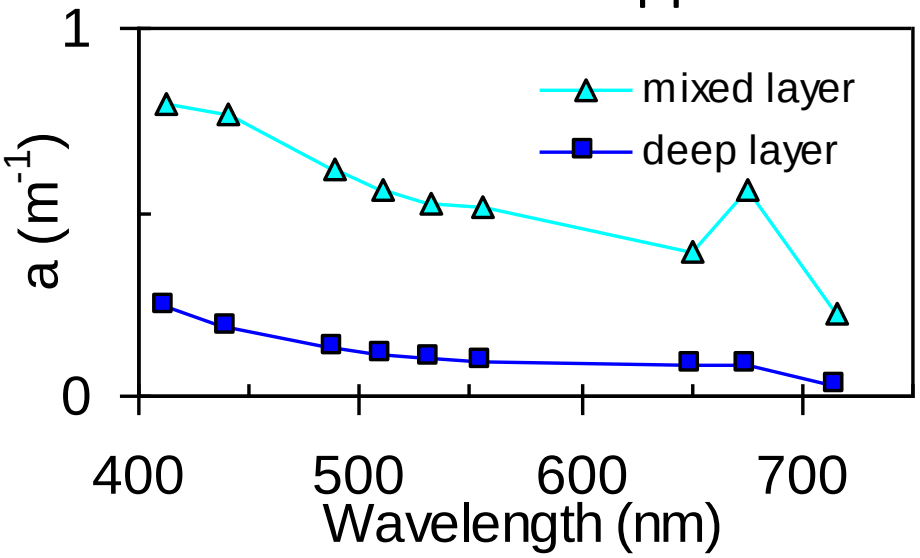
1. Pure water calibration

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

But spectra are problematic



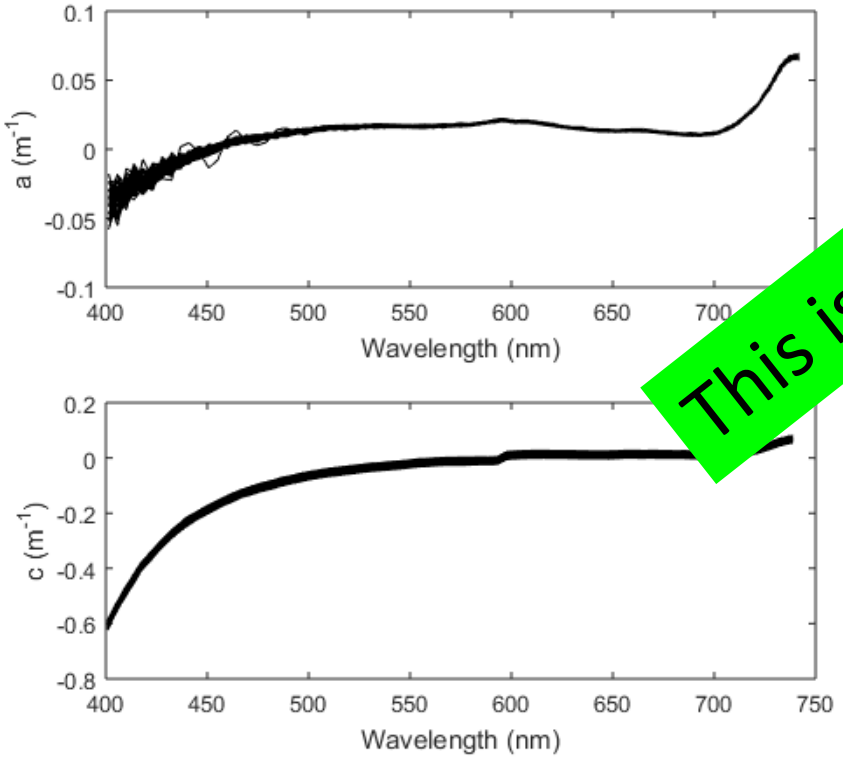
water calibration applied



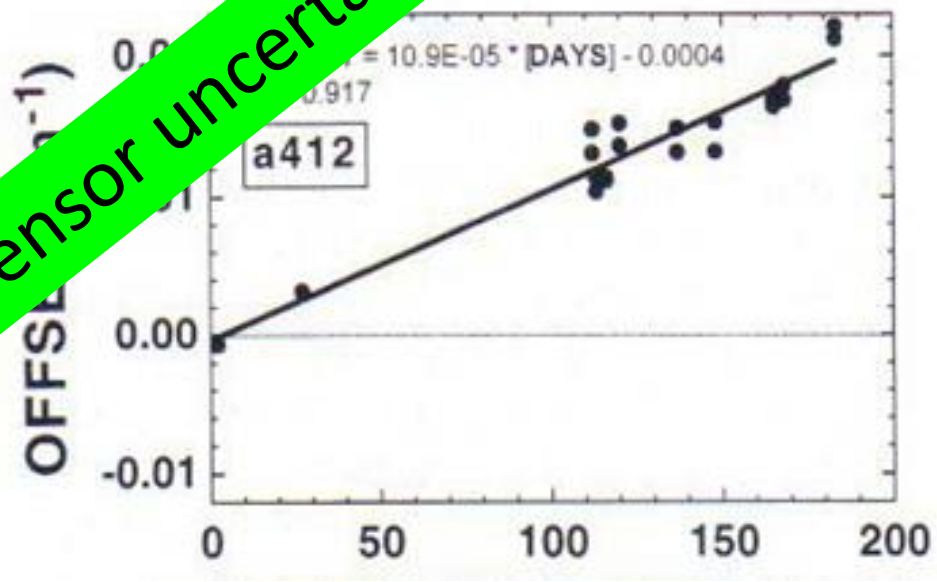
Roesler and Boss 2008

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

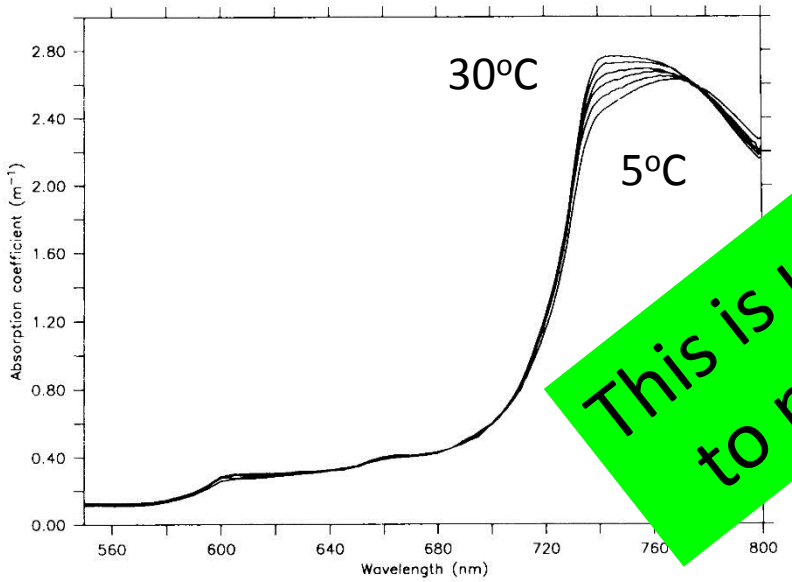


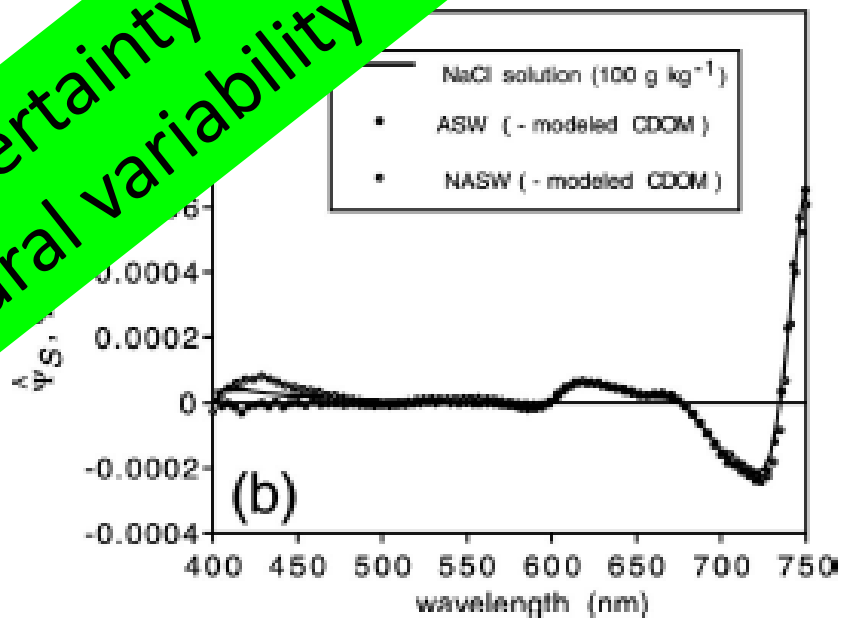
Fig. 3. Absorption coefficient from 550 to 800 nm adjusted at 685 nm to the value of Tam and Patel (1979). The curves represent absorption at temperatures of 5, 10, 15, 21, 25, and 30°C as read from bottom to top at 750 nm.

Pegau and Zaneveld 1993 Limnol Oceanogr.

Pegau et al. 1997 Applied Optics

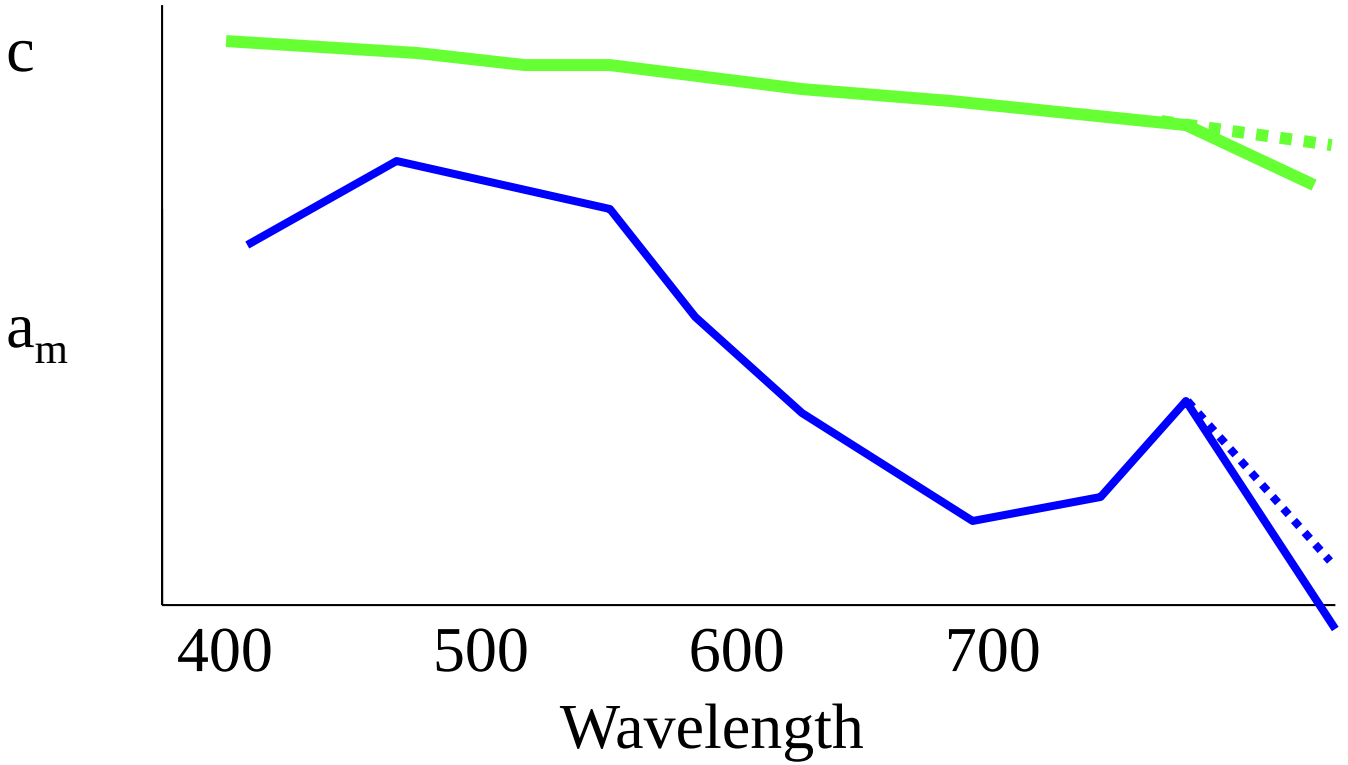
Sa

This is uncertainty due to natural variability



Sullivan et al. 2006 Applied Optics

Absorption from ac9



2. Temperature and salinity correction

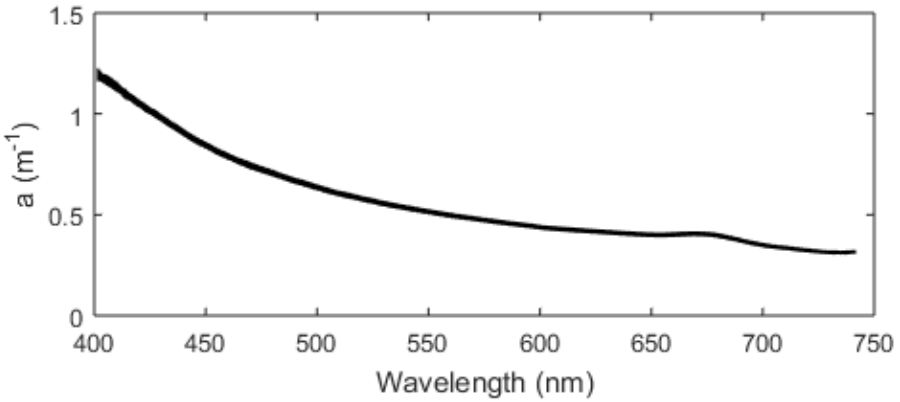
This is due to the fact that the in situ T and S are different than that of the calibration water

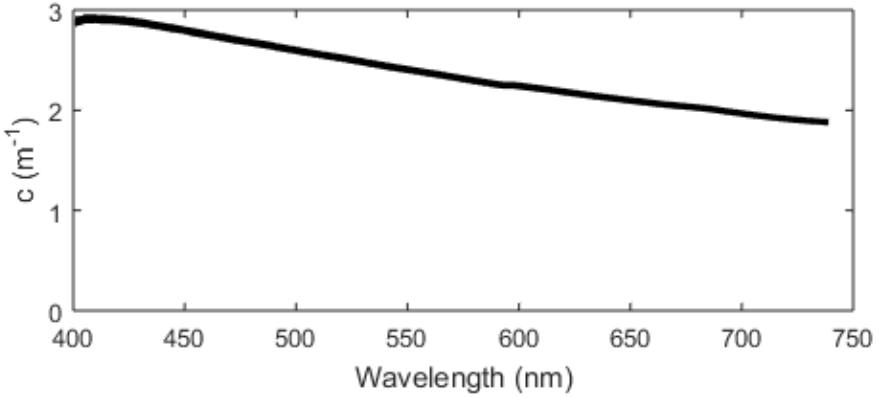
→ Requires measurement of T, S in situ

Bio-optical Sensors - Absorption

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

  1. correct for T, S

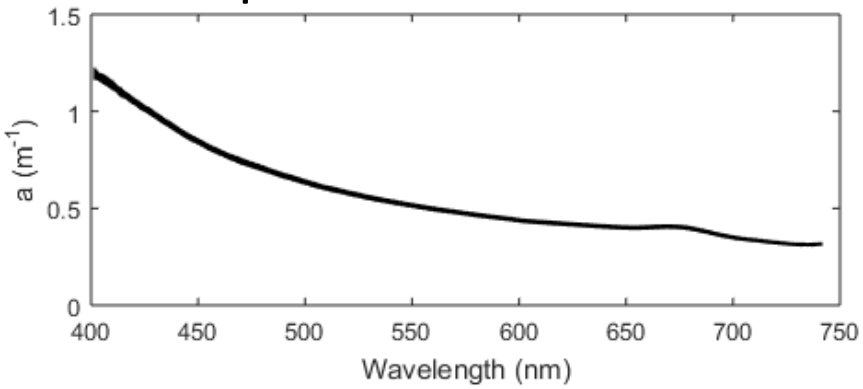


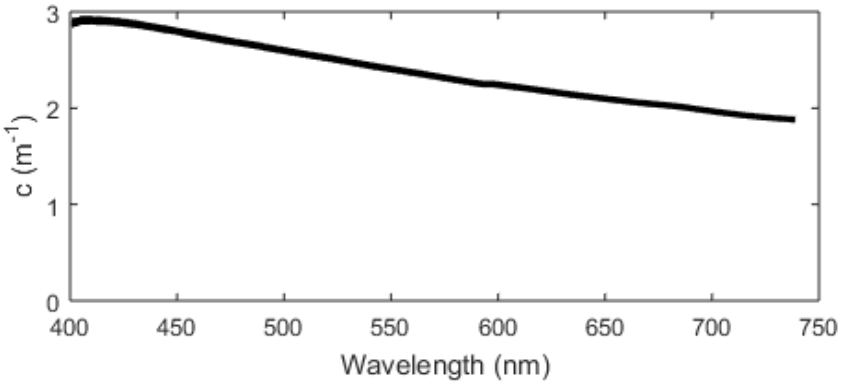


Bio-optical Sensors - Absorption

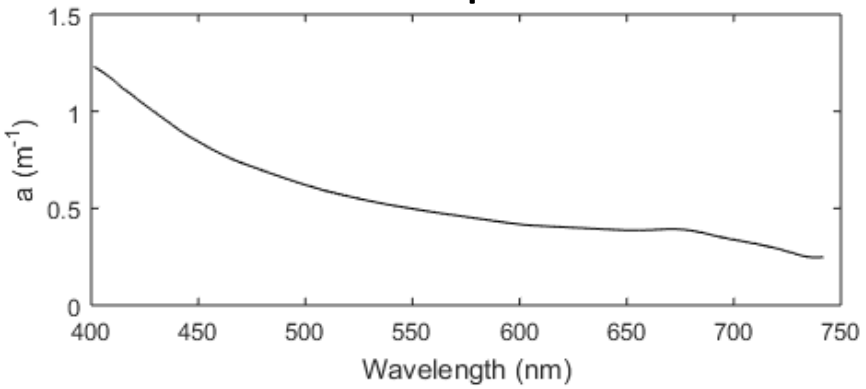
- Data Analysis and Interpretation – acs example
  2. Correct sample scans for pure water values (T, S corr)

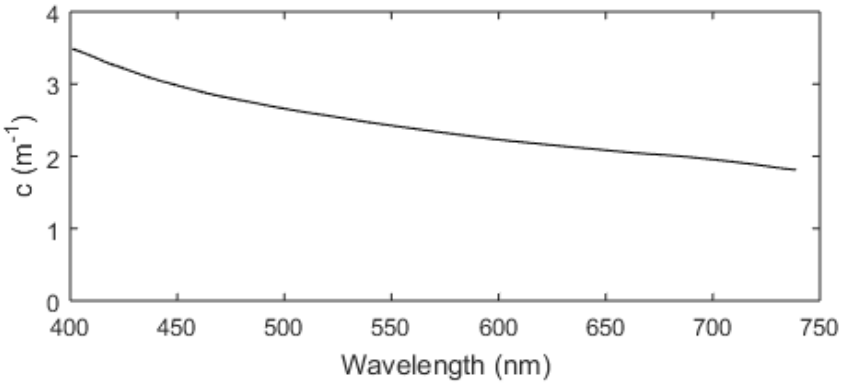
sample scan





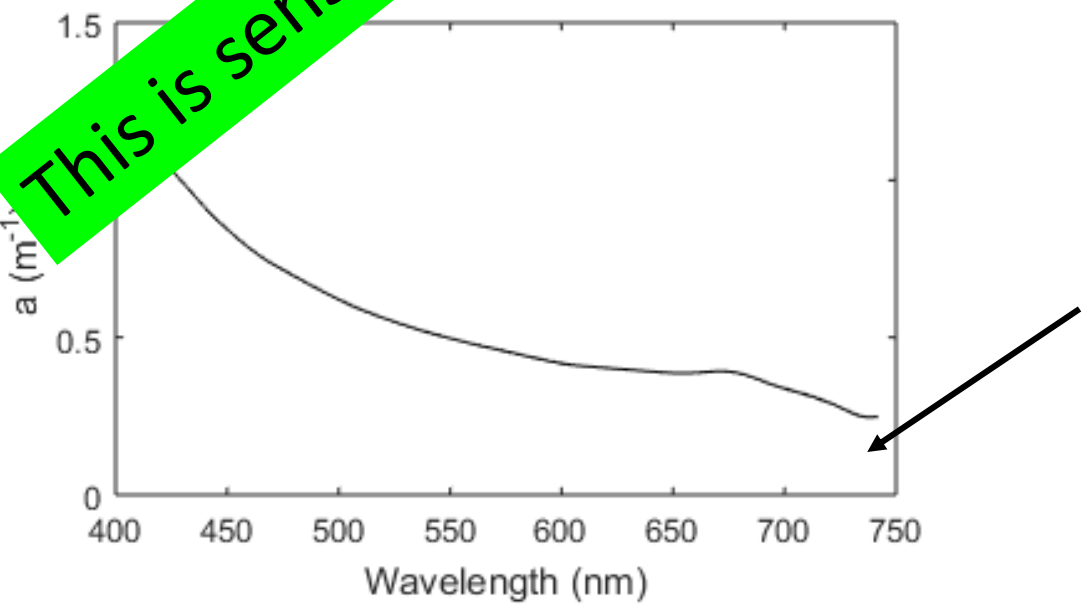
corrected for pure water





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



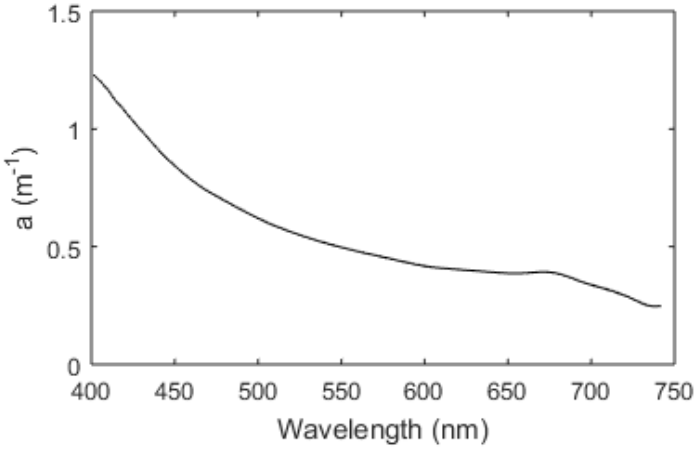
Bio-optical Sensors - Absorption

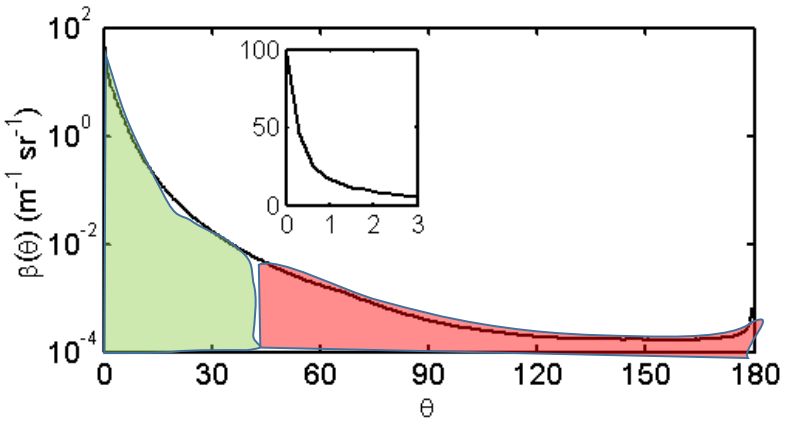
- Data Analysis and Interpretation – acs example
  - 3. Scattering correct the absorption spectra

    we know the ac meters collect scattered light 0 to 40^{o}

    so miss >40^{o} or back and side scattering

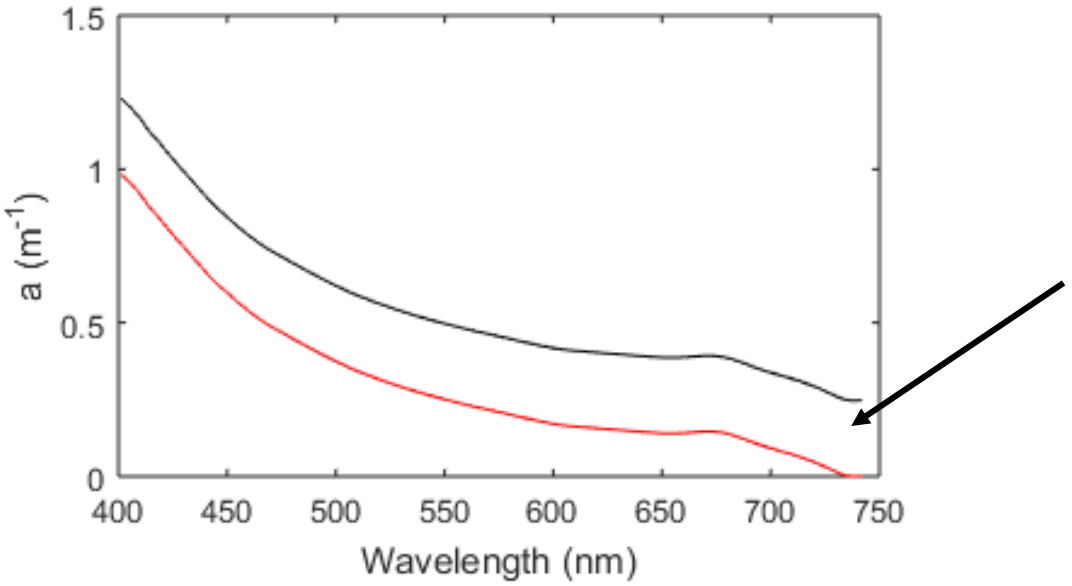
    how do we best correct the a for scattering loss?





Bio-optical Sensors - Absorption

- Data Analysis and Interpretation – acs example
  3. Scattering correct the absorption spectra
     a. Subtract a_m(NIR) → "there is no NIR absorption"
        "b not a function of λ"
        spectrophotometric approach

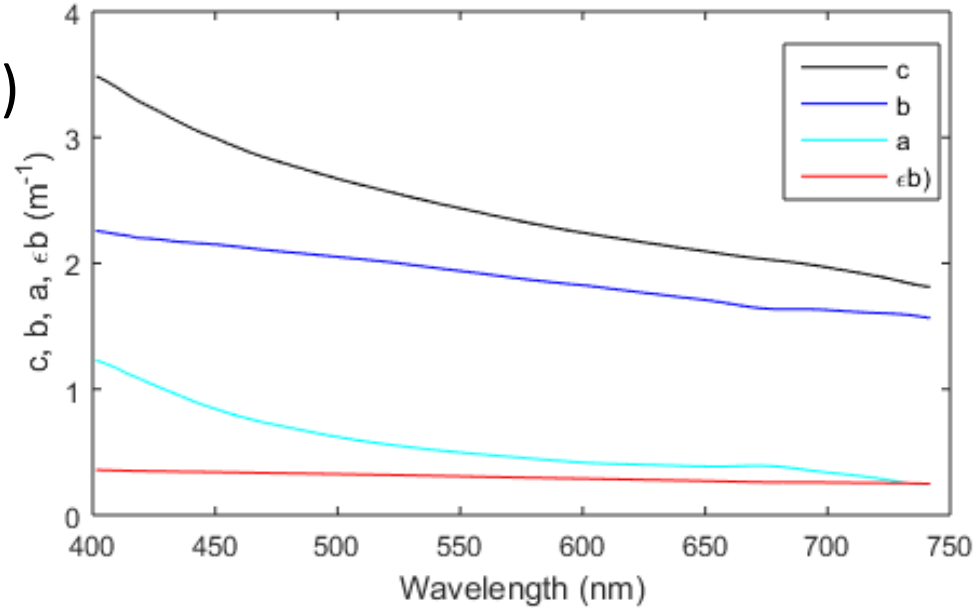


Stramski and Babin 2002

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)
        "there is no NIR absorption"
        b(λ) = c(λ) – a(λ)
        if a(NIR) = 0 signal is due to scattering
        *f*b(λ) = a(NIR)/b(NIR)

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



Roesler and Zaneveld 1993

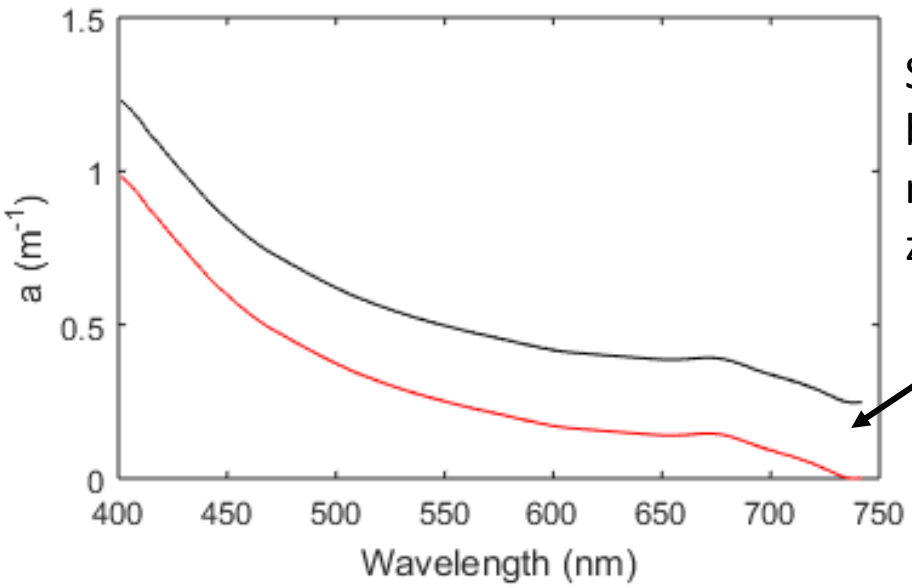
Bio-optical Sensors - Absorption

- Data Analysis and Interpretation – acs example

  3. Scattering correct the absorption spectra

     a. Subtract some fraction of the NIR signal → "there is some NIR absorption"

This is an active area of research!!!

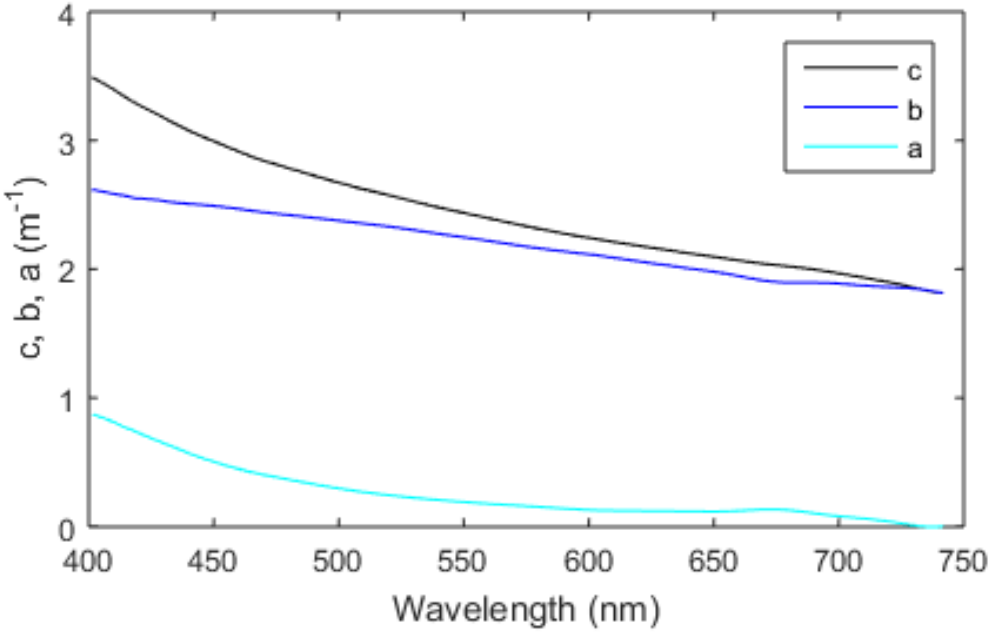


Somewhere between measured and zero

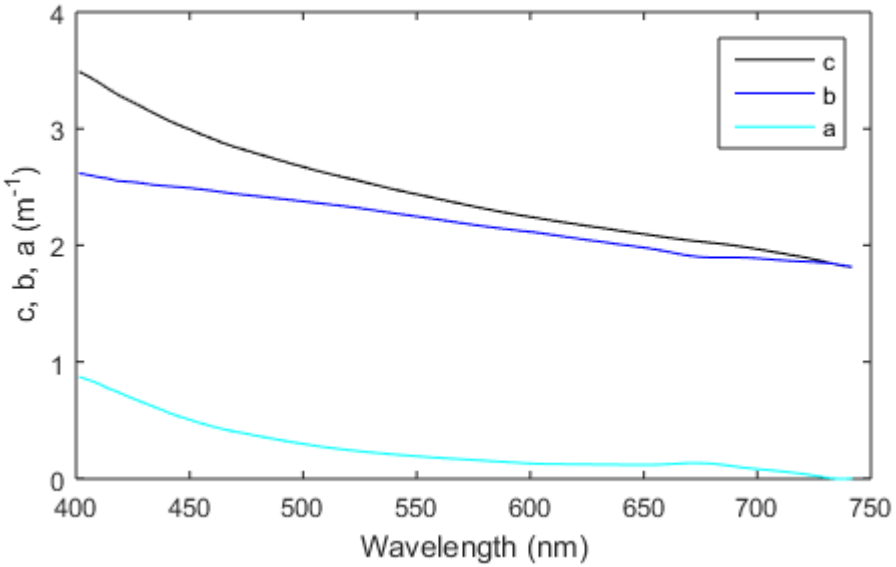
Röttgers et al 2007
Röttgers et al 2013

Bio-optical Sensors - Absorption

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



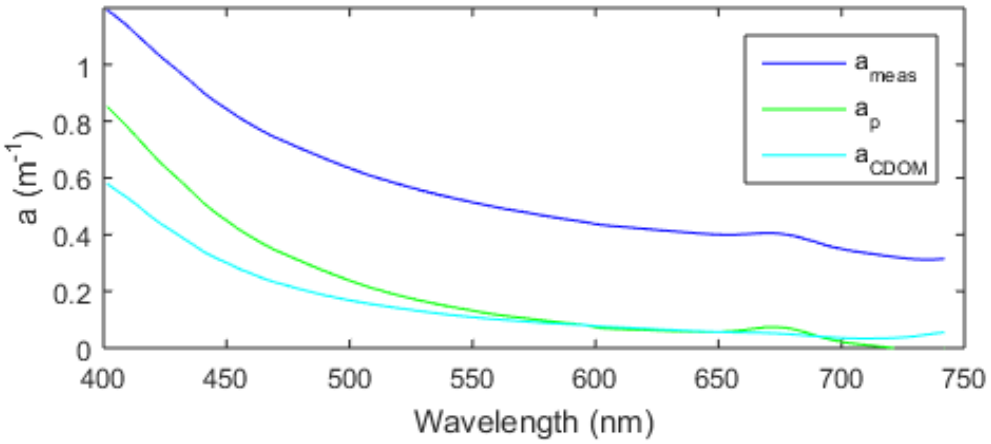
Best practices for obtaining Absorption/Attenuation from acs



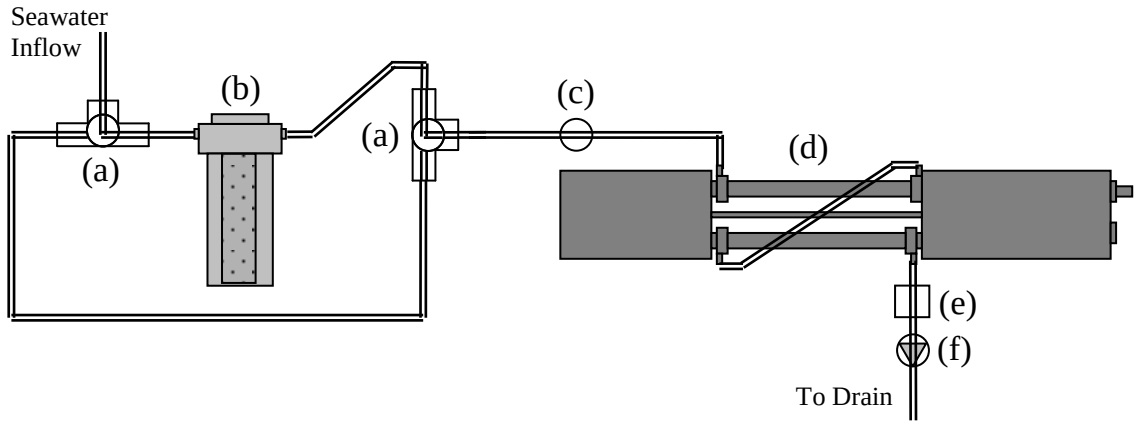
- Review Data processing
  - Temperature/Salinity correct a and c of sample and calibration data
  - Subtract T,S-corrected pure water calibration from sample scans
  - Apply scattering correction to absorption
  - Compute scattering spectrum (b = c – a)

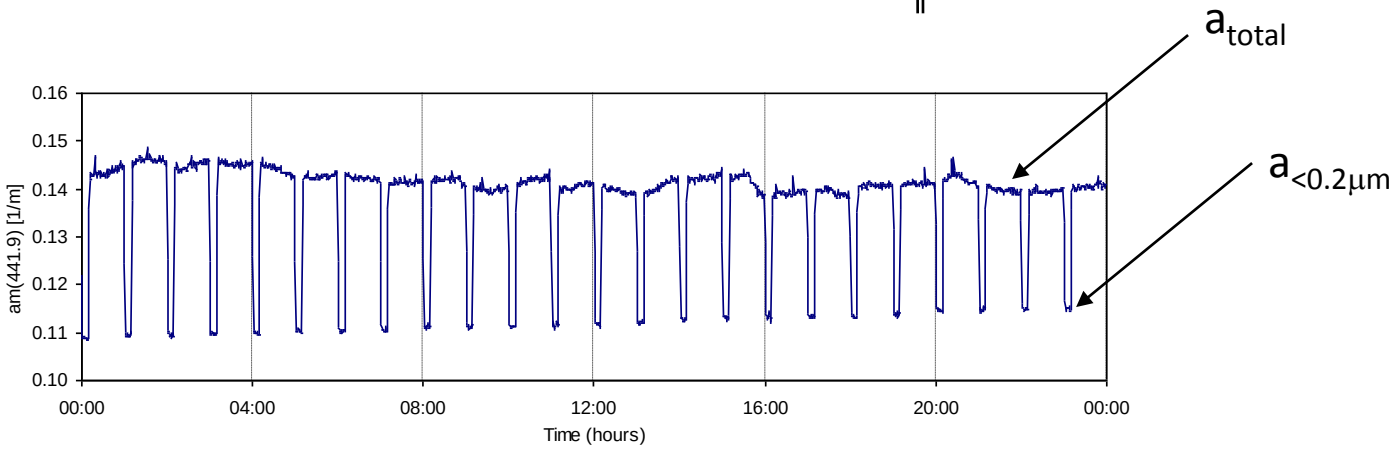
Bio-optical Sensors - Absorption

- 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***



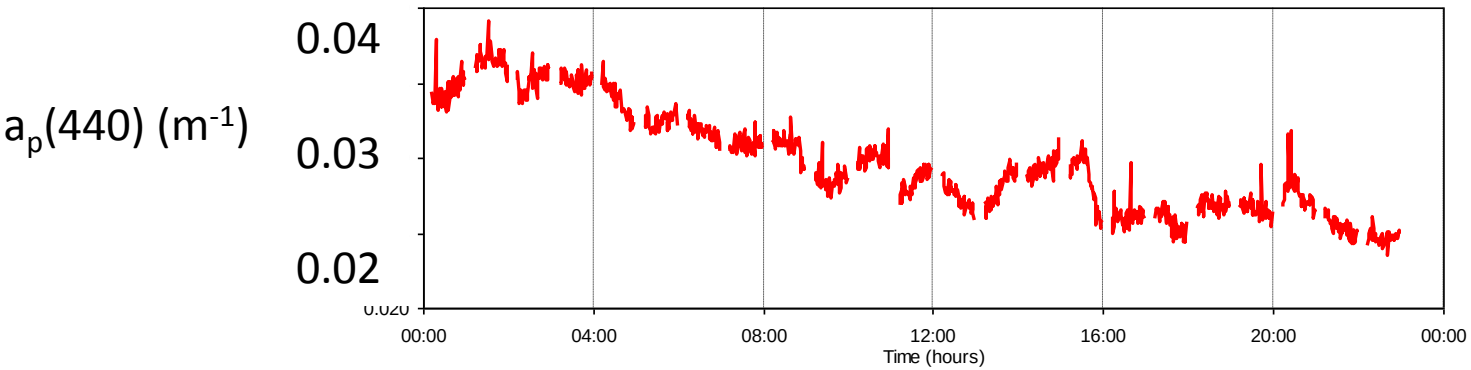
Automated shipboard flow-through method, calibration-independent

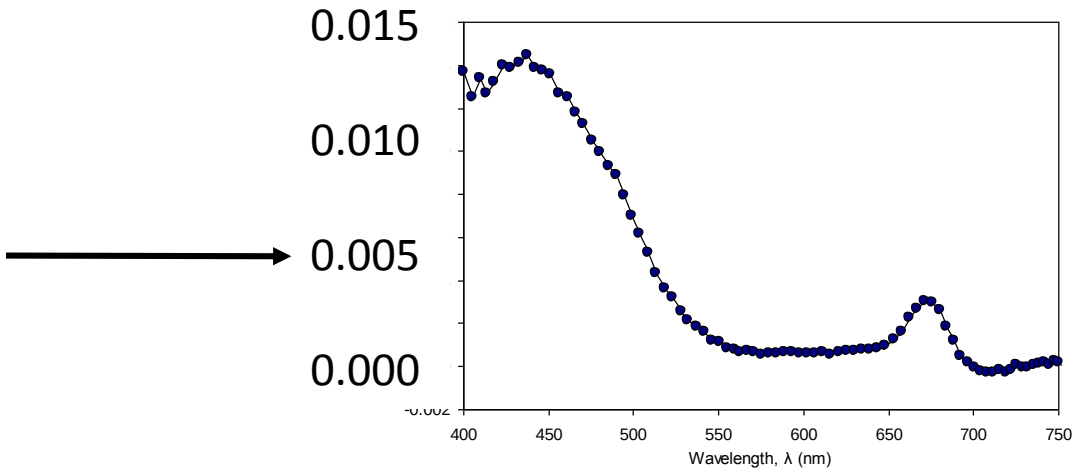




Slade et al., 2010

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





Slade et al., 2010

Today in the lab

- CDOM absorption
- Divide into two groups of 10
  - Station 1 in Lecture Hall – lab spectrophotometry
  - Station 2 in Mitchell Lab – in situ spectrophotometry
- Will take about 2 hours for each station, then we will switch