# Lectures 3-5

The AC-S meter overview

AC-S Processing Steps

Derived Parameters from AC-S data

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# 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

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# ac-s

## SPECTRAL ABSORPTION & ATTENUATION SENSOR WITH LED LIGHT SOURCE

ac-s ac-s 5000

### Overview

The ac-spectra (ac-s) is a top tier optical instrument with no equal in the market. Based on the highly successful ac-9, the ac-s offers almost an order of magnitude increase in spectral resolution of in-situ absorption and beam attenuation coefficients. The ac-s features a proven flow-through system, compact size, and excellent stability.

The updated LED light source provides a longer lifetime at 10,000 hours coupled with a 55% power reduction at 12 VDC. Field deployments demonstrate signal-to-noise ratio improvements for a(λ) and c(λ) for λ < 550 nm, improving data quality in the blue region.

The simpler, faster service and calibration on a 2-year cycle means more time collecting data that matters.

The ac-s 5000 retains the same performance as the ac-s in a titanium housing deployable to 5000 meters.

### Features

- Dual path, flow-through measurement, beam attenuation acceptance angle = 0.93°
- 80 ± 5 wavelengths of absorption (a) and attenuation (c) from 400 -730 nm
- Linear variable filter monochromator
- 4 nm resolution, 15 nm bandpass
- 10 or 25 cm path lengths
- LED light source
- 4 Hz sampling rate
- 500 m / 5000 m rating

| **Optical** | |
|---|---|
| Spectral Range | 400 - 730 nm |
| Bandpass | 15 nm/channel |
| Pathlength | 10 (ac-s) or 25 cm |
| Beam Cross-Section | 8 mm dia. (nominal) |
| Linearity | ≥ 99% $R^2$ |
| Output Wavelengths | 80 ± 5 (nominal) |
| Resolution | 4 nm |
| Precision | |
| (400–449 nm) | ±0.005 $m^{-1}$ typ., 0.012 $m^{-1}$ max @ 4 Hz<br>±0.000 $m^{-1}$ typ., 0.006 $m^{-1}$ max @ 1 Hz |
| (450–730 nm) | ±0.001 $m^{-1}$ typ., 0.003 $m^{-1}$ max @ 4 Hz<br>±0.005 $m^{-1}$ typ., 0.0015 $m^{-1}$ max @ 1 Hz |
| Accuracy | ±0.01 $m^{-1}$ |
| Dynamic Range | 0.001-10 $m^{-1}$ |
| Light Source | LED |
| **Electrical** | |
| Input | 10 - 35 VDC |
| Current Draw | 0.37 A @ 12 VDC |
| Serial Output | RS-232, -422, or -485 |
| Connector | MCBH6M |
| Sample Rate | 4 scans/sec., nominal |
| **Mechanical** | |
| Diameter | 10.4 cm<br>9.9 cm (5000) |
| Length | 77 cm<br>75.8 cm (5000) |
| Weight in Air | 5.9 kg<br>0.3 (5000) |
| Weight in Water | 0.8 kg<br>5.3 kg (5000) |
| **Environmental** | |
| Temperature Range | 0 - 30 °C |
| Depth Rating | 500 m \| 5000 m |

# Reflecting-tube absorption & attenuation meters

*b* = scattering
*c* = beam attenuation
$b = c - a$

But!

Absorption is overestimated because not all the scattered light is detected in a-tube

Attenuation is underestimated because a little bit of scattered light *is* detected in c-tube

$a_m(\lambda)$, $b_m(\lambda)$, $c_m(\lambda)$ = measured spectra


Photo: ac-s datasheet, https://www.seabird.com/asset-get.download.jsa?id=54627862140

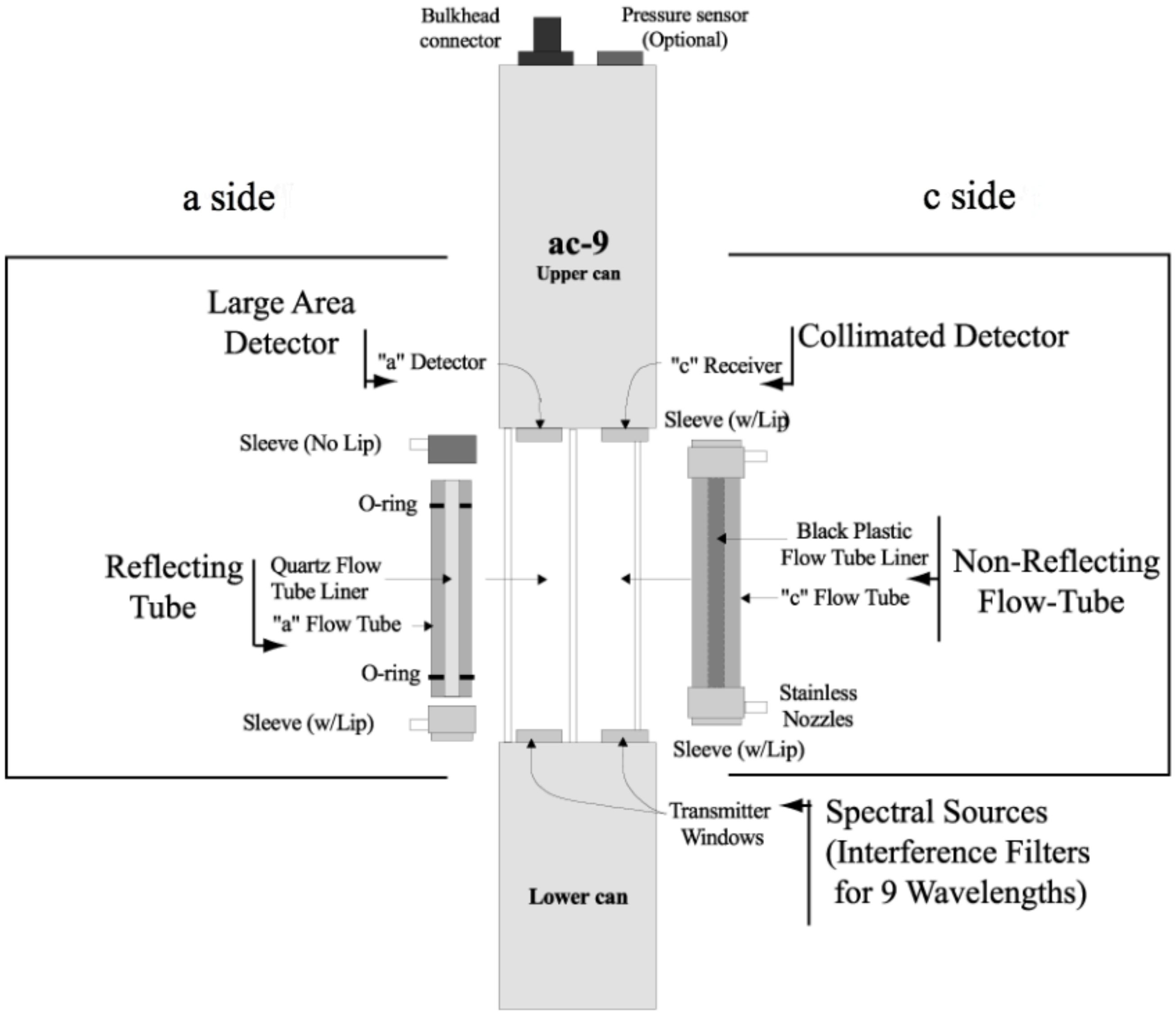


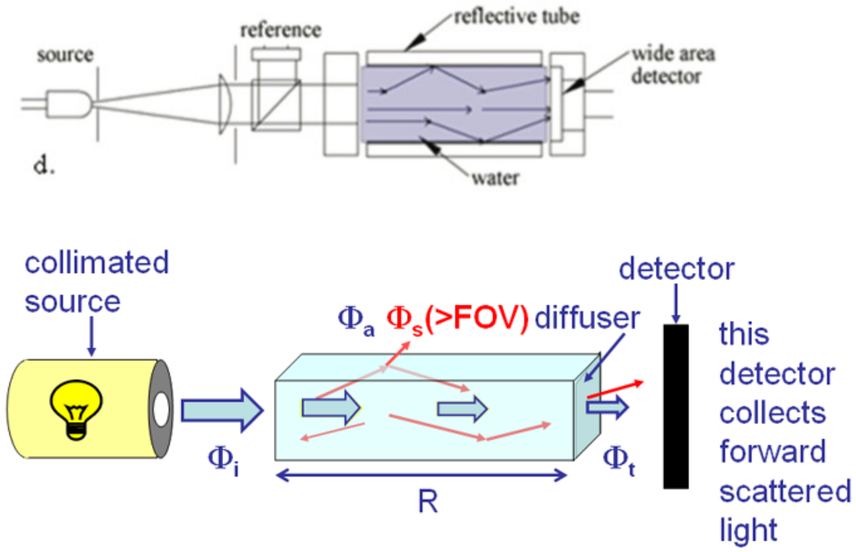

Figure 2.3. Schematic illustration of the ac-9 beam attenuation and absorption meter (courtesy of Sea-Bird Scientific).

Figure: Neeley et al., 2018. doi:10.25607/OBP-119

# Reflecting-tube absorption & attenuation meters

- Measure absorption and beam attenuation simultaneously. Use the beam attenuation measurement to correct for undetected scattered light in the absorption measurement. Compute scattering by difference.
- Absorption measured in a cylinder with reflective interior and a diffuser in front of the detector. Only light scattered through angles > ~42° is lost.
- Attenuation measured in a cylinder with black, non-reflective walls and a detector with a narrow field of view

a




Moore et al 2009

## Absorption tube schematic

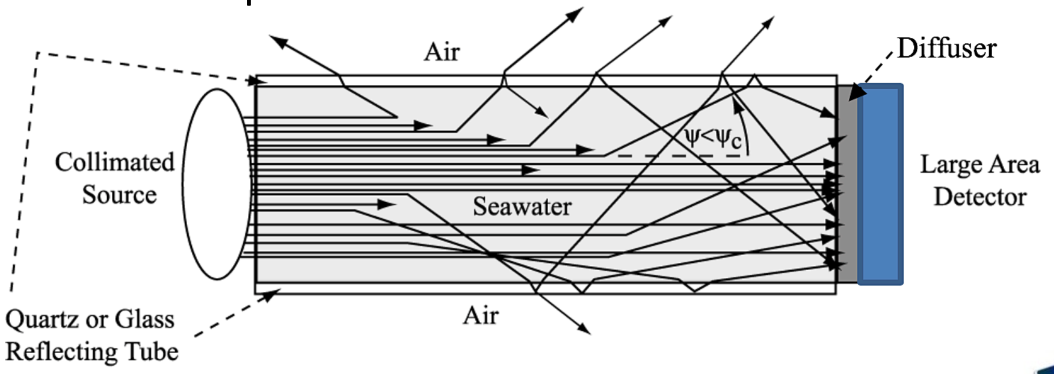
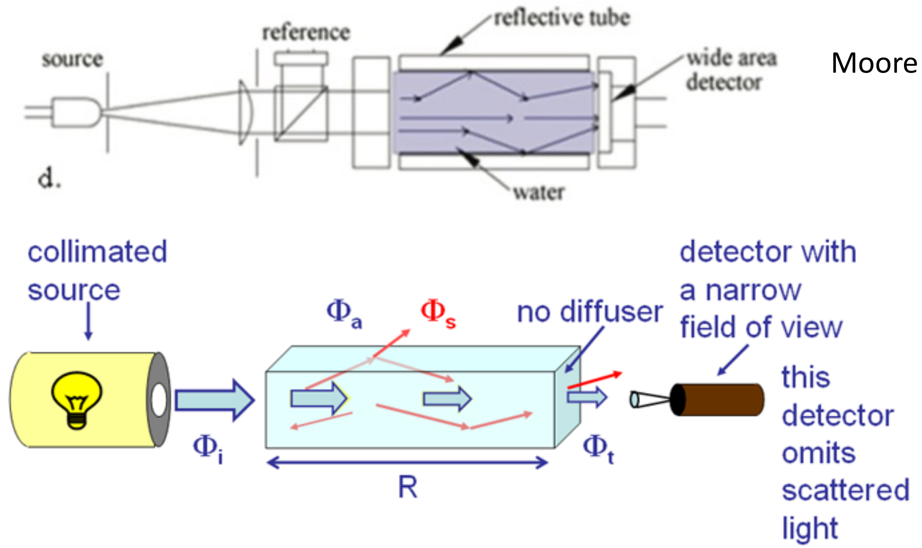
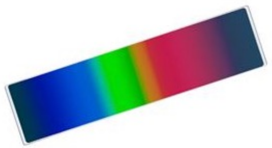



Figure: Neeley et al., 2018. doi:10.25607/OBP-119

c




Moore et al 2009



LVF: For spectral discretization

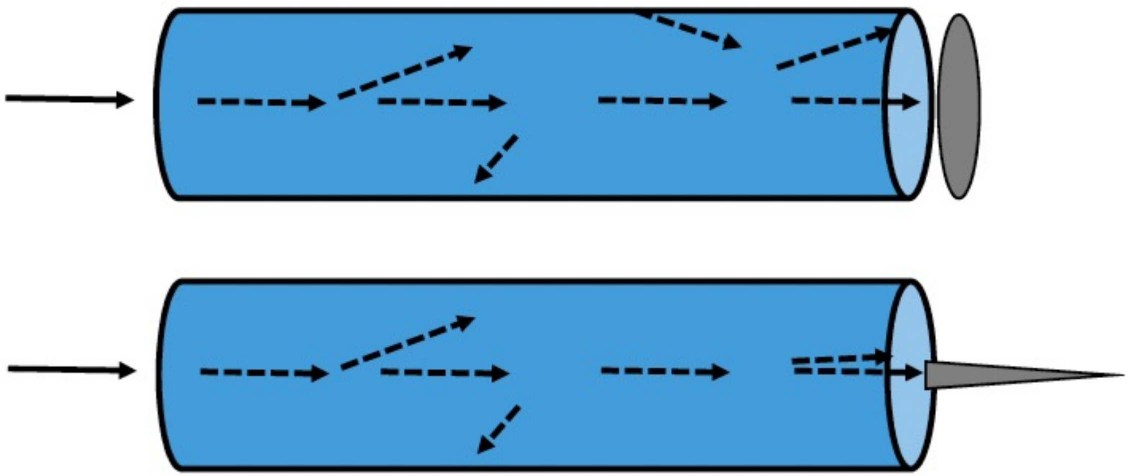
Figures 3.8-3.9, Mobley et al. 2022, *The Oceanic Optics Book*

# 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

Credit: Meg Estapa

# Absorption from ac9/acs

- 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

*water calibration for quantitation
air calibration to track instrument drift

# Recent Improvement to the AC-S


# ac-s Spectral Absorption and Attenuation Sensor

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## The same ac-s...but with a 10,000-hour LED light source

### New, improved LED light source

- Longer life: 10,000 hours
- Demonstrated signal-to-noise ratio improvement for $a(\lambda)$ and $c(\lambda)$ for $\lambda < 550$ nm
- 55% power reduction: 0.83 A → 0.37 A @ 12 VDC
- Simpler, faster service and calibration on a 2-year cycle.

### Standard ac-s features

- Dual path, flow-through measurement, beam attenuation acceptance angle = 0.93°
- 80 ± 5 wavelengths of absorption ($a$) and attenuation ($c$) from 400 -730 nm
- Linear variable filter monochromator
- 4 nm resolution, 15 nm bandpass
- 10 or 25 cm pathlengths
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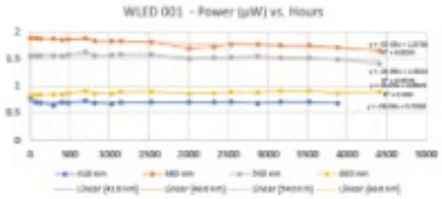
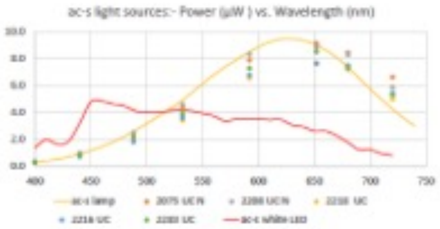
### In-house LED lifetime testing

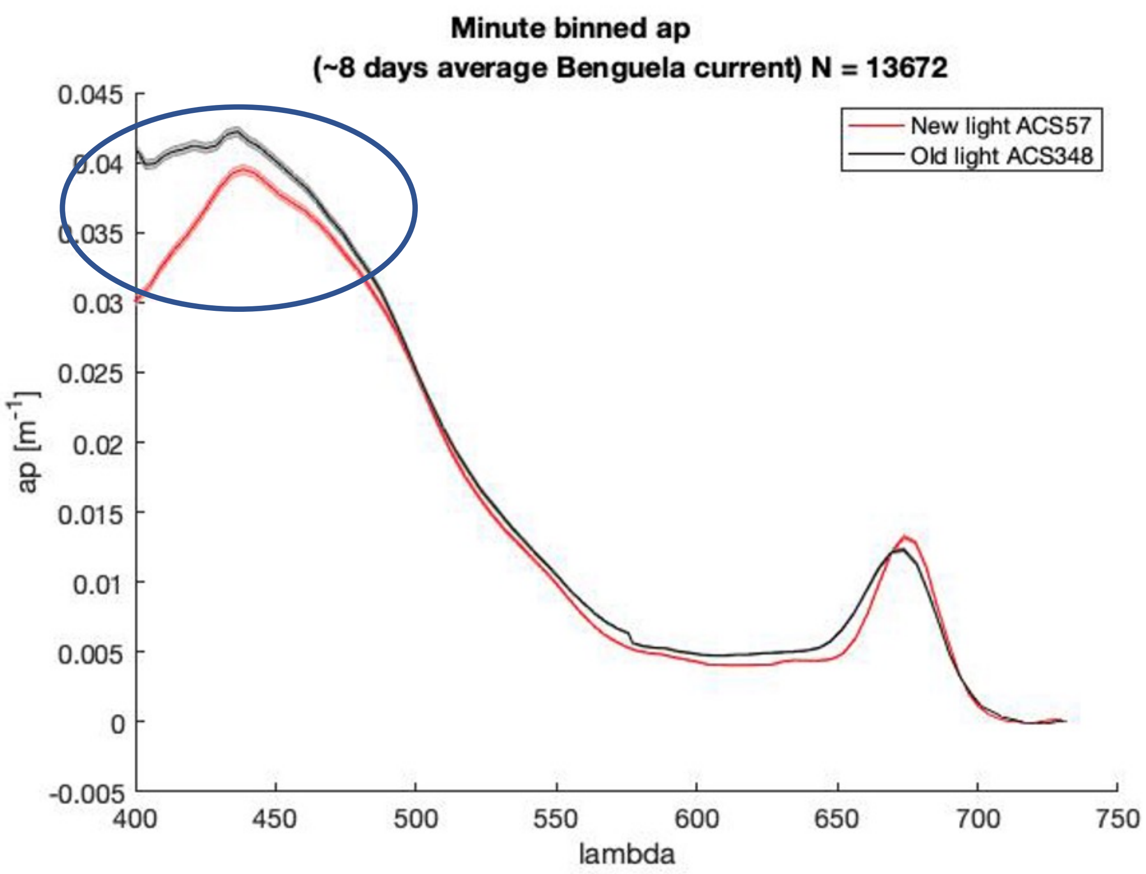


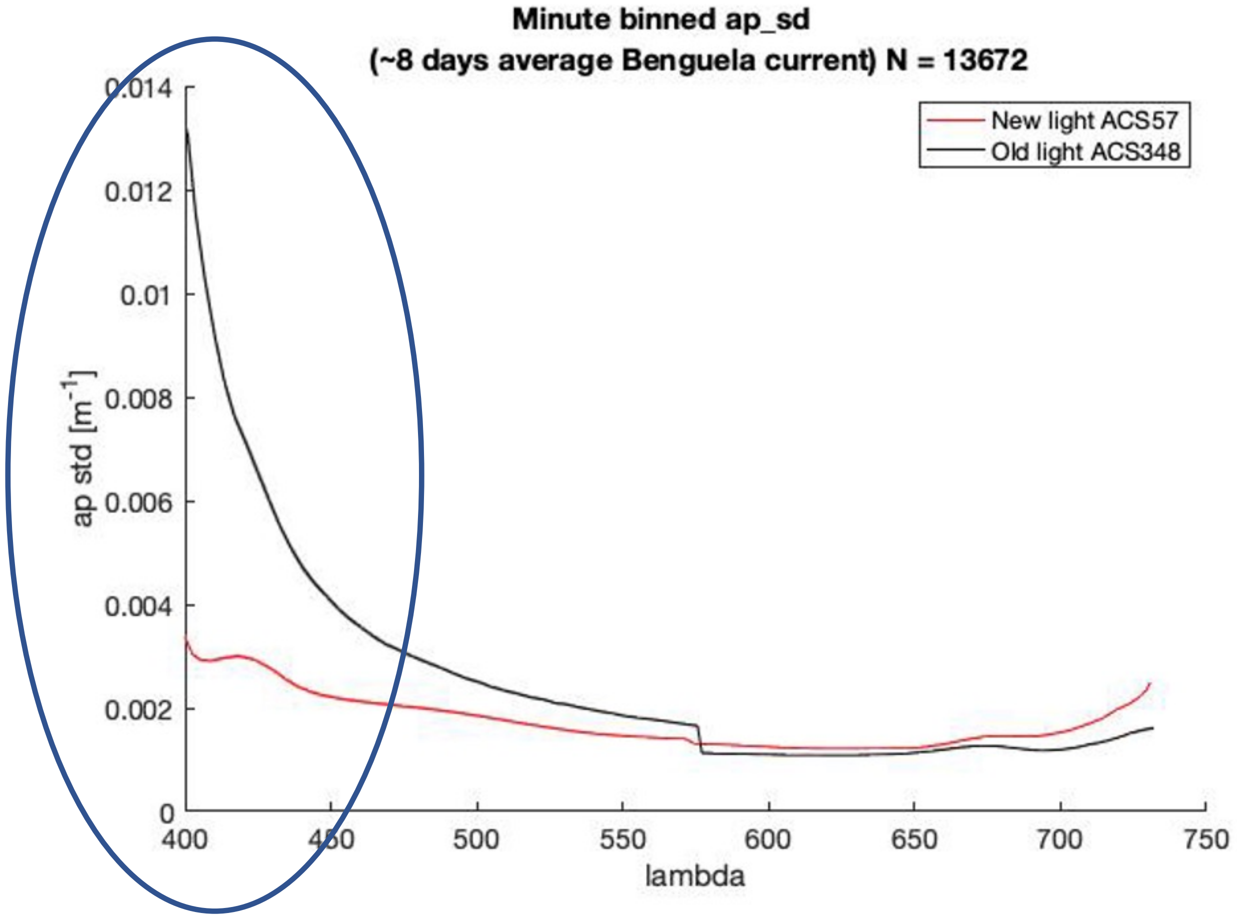




### Extensive field testing

- In-line deployment 4500 h (187 d) on SV Tara using switched 0.2 µm filter
- Bourdin & Boss, 2022, personal comm.

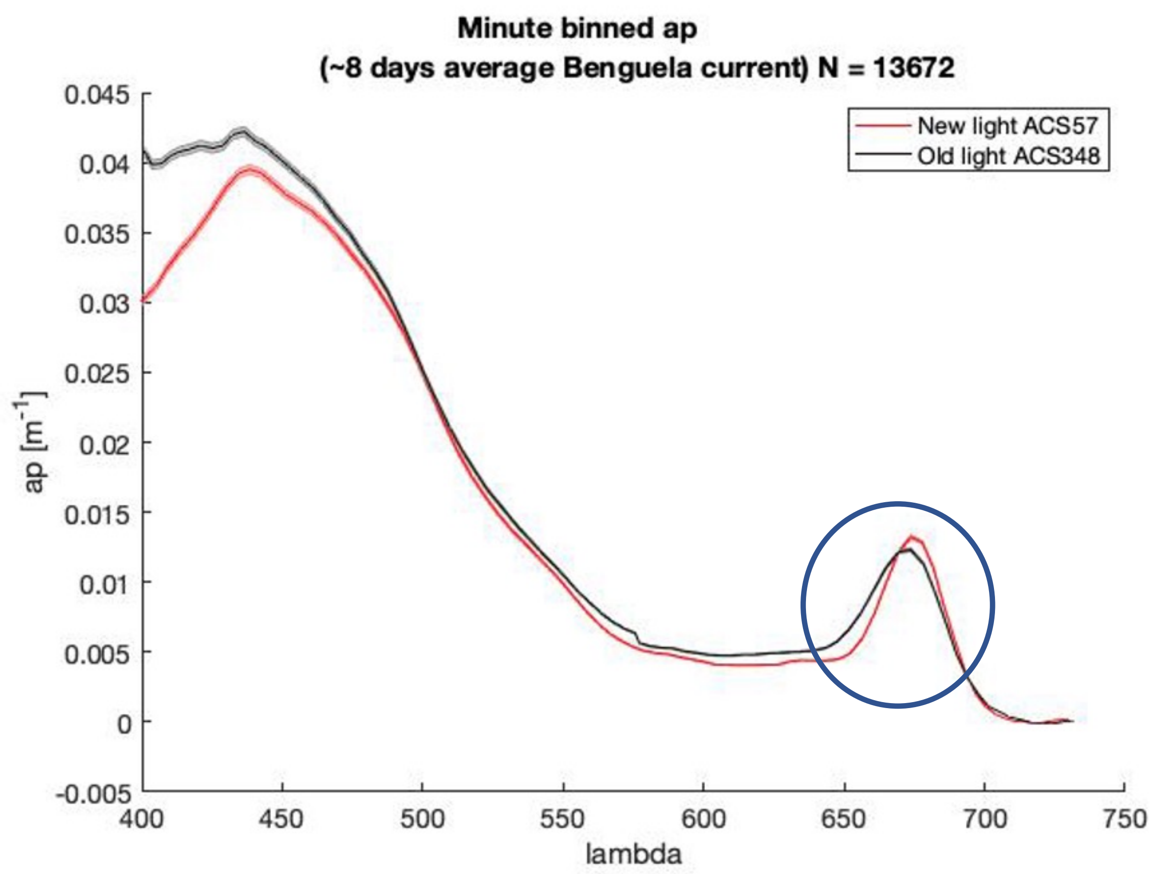
# Comparison of white LED source and traditional ac-s

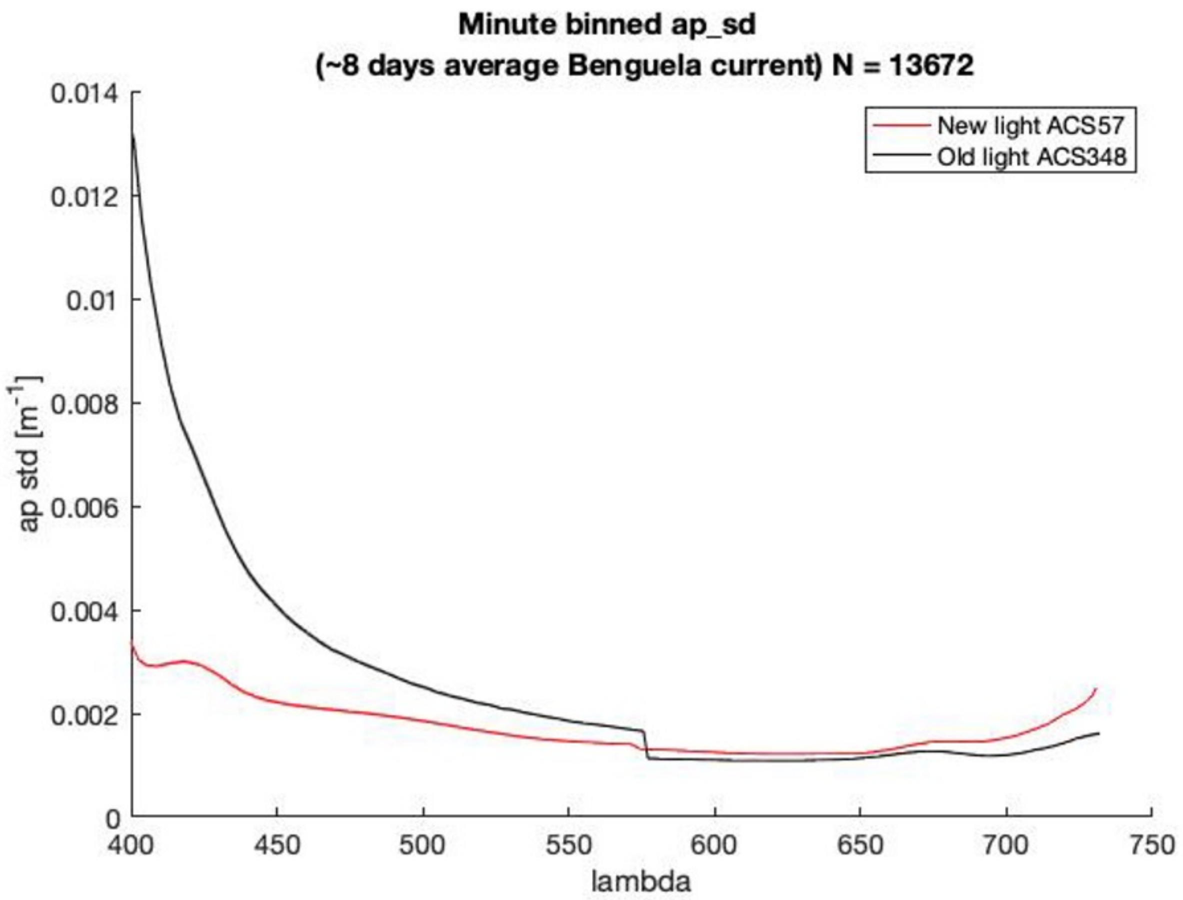



Credit: Emmanuel Boss, University of Maine

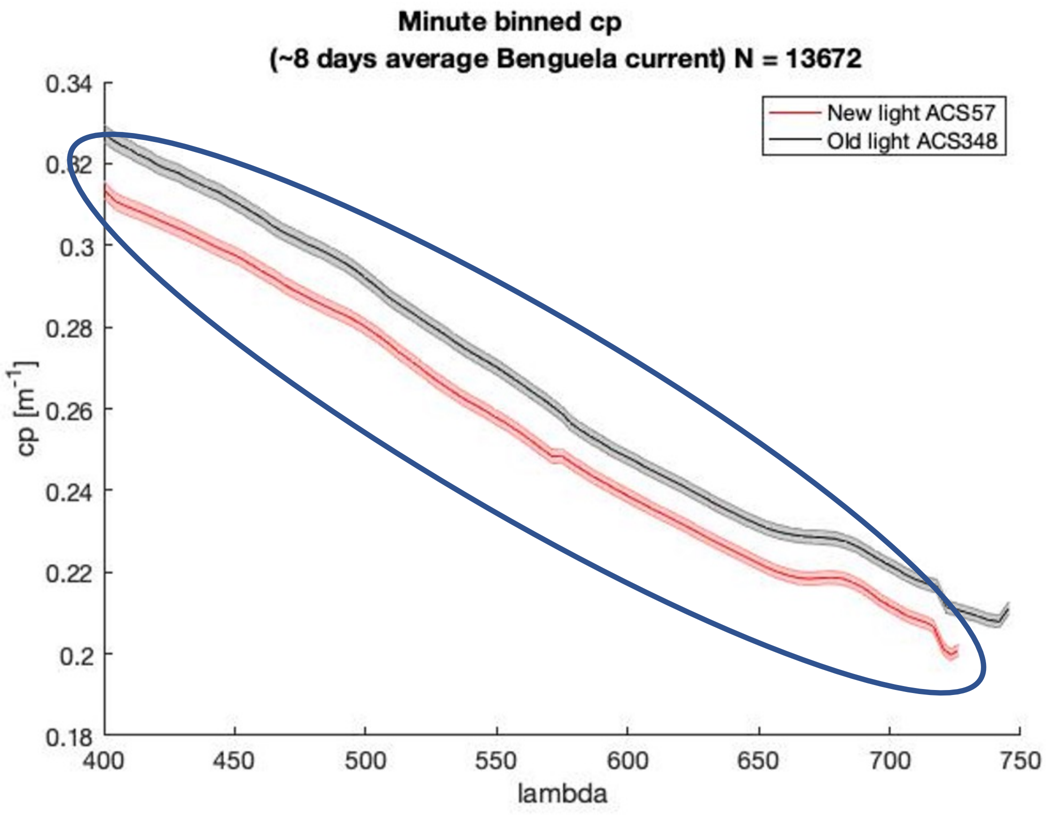
# Comparison of white LED source and traditional ac-s

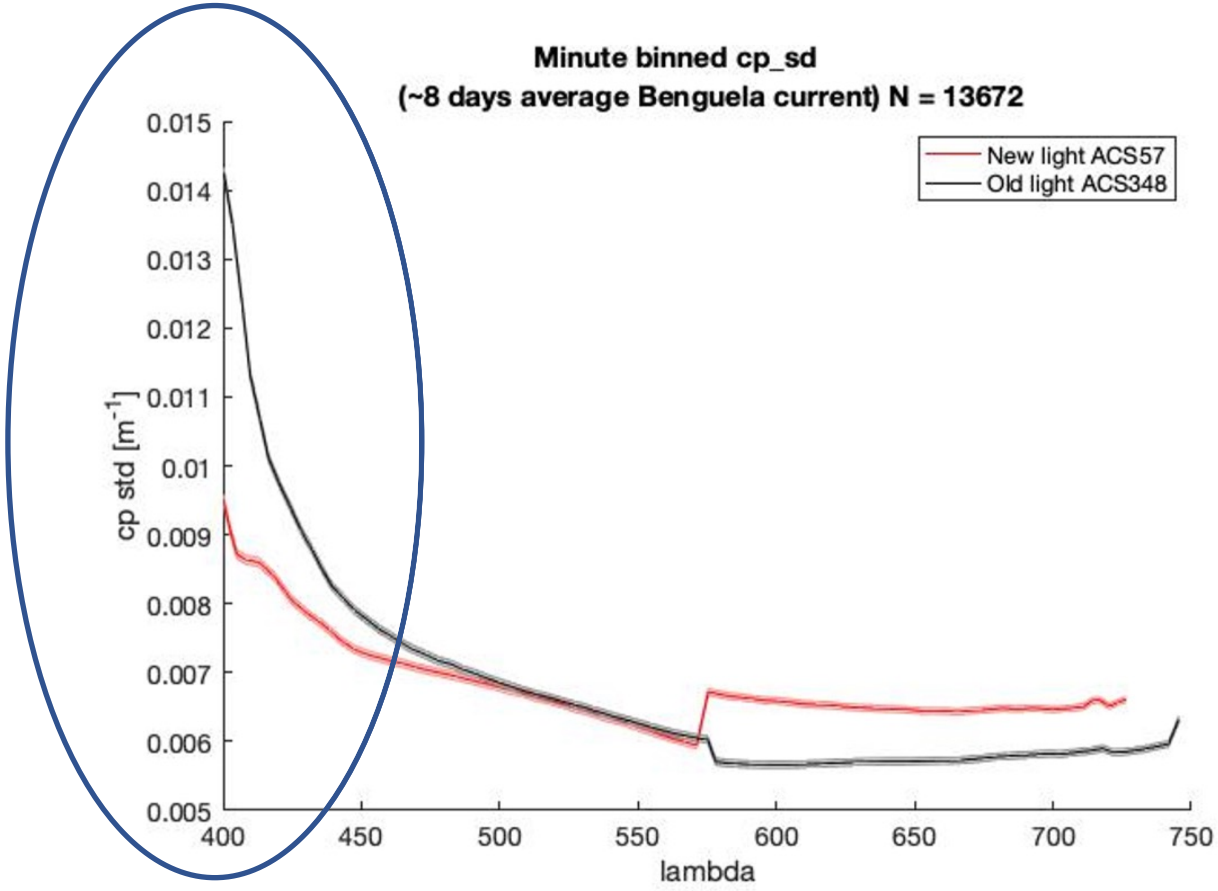



Credit: Emmanuel Boss, University of Maine

# Comparison of white LED source and traditional ac-s



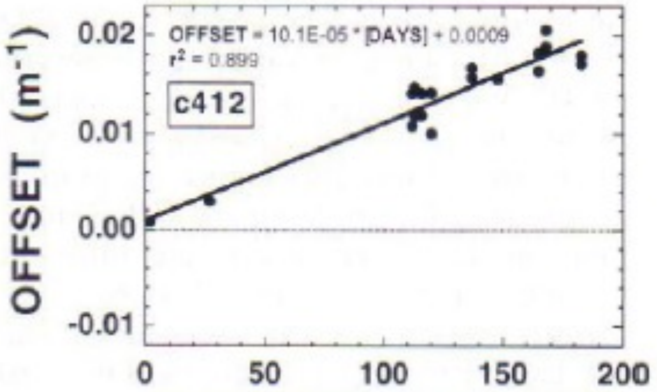

Acceptance angle?

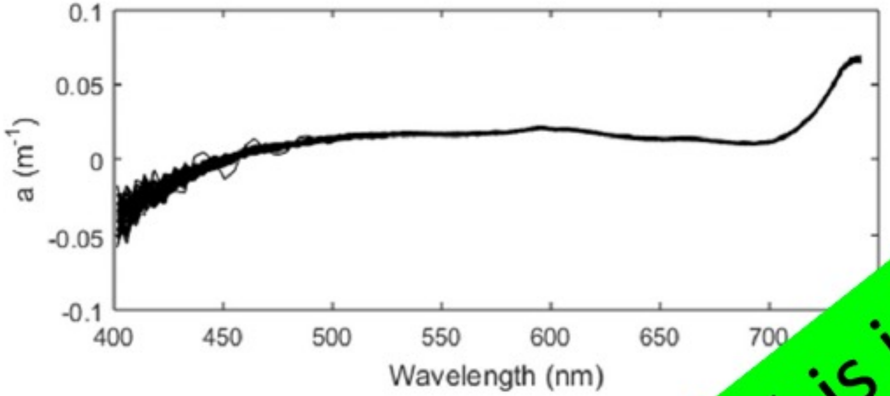
Credit: Emmanuel Boss, University of Maine

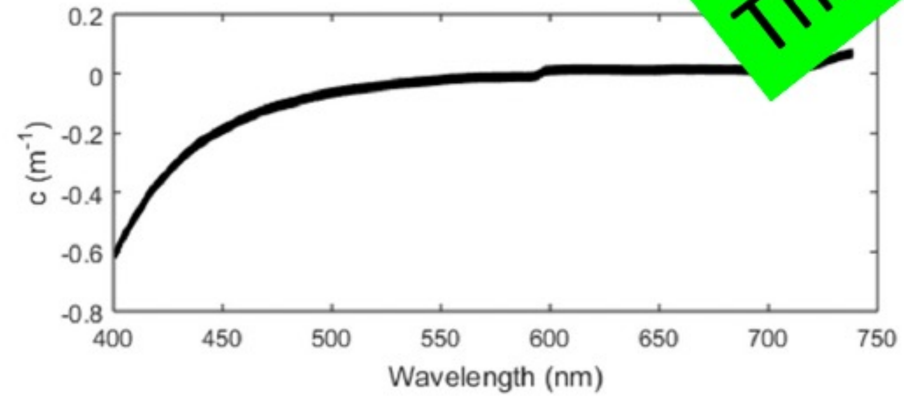
# Bio-optical Sensors - Absorption

- Data Analysis and Interpretation – acs example

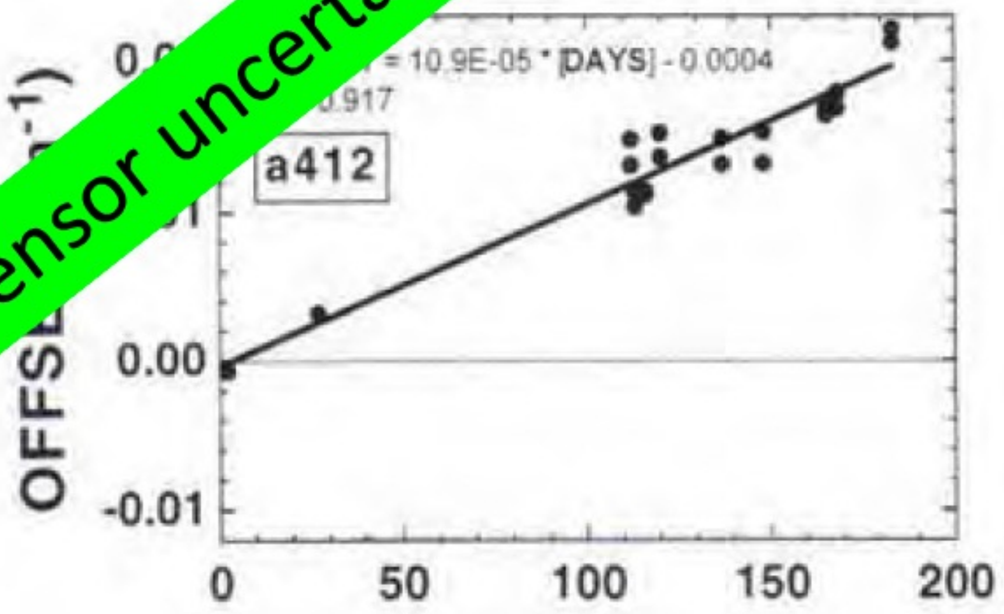
    Measure pure water scans




This is sensor uncertainty

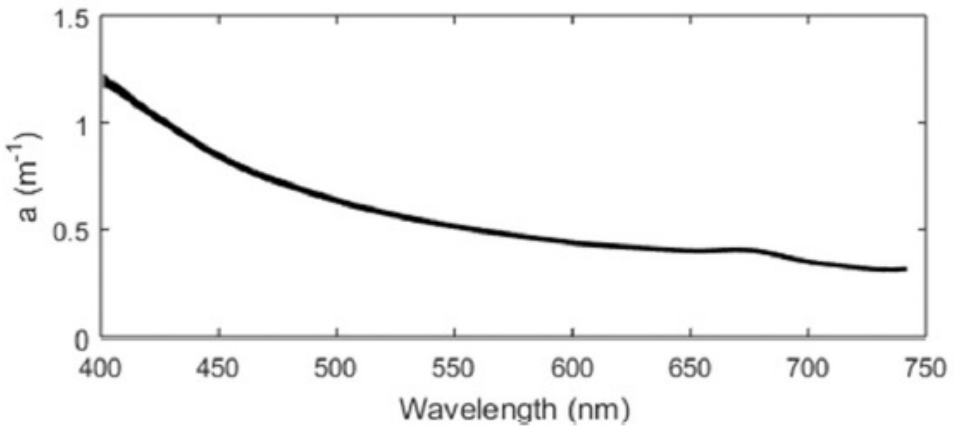


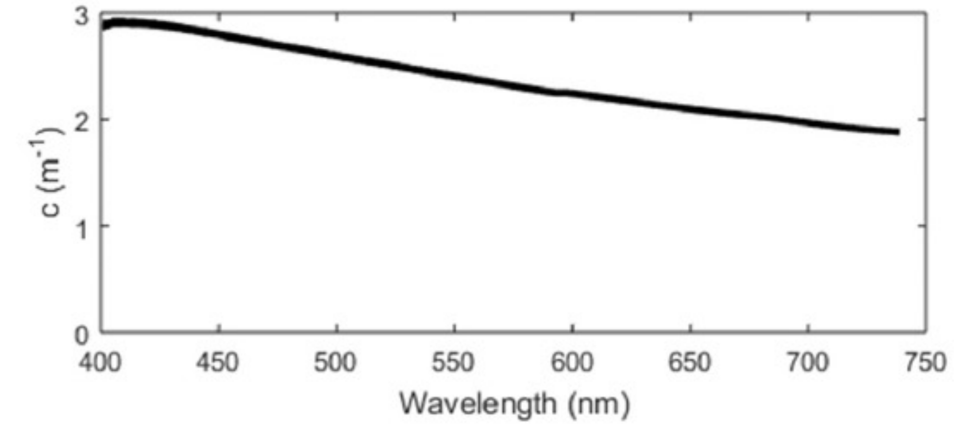

Twardowski et al, 1997
(true for a and c)

# Bio-optical Sensors - Absorption

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

  1. correct for T, S




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

$$a_{mts} = a_m - [\ \Psi_t * (t - t_r) + \Psi_{sa} * S]$$
$$c_{mts} = c_m - [\ \Psi_t * (t - t_r) + \Psi_{sc} * S]$$

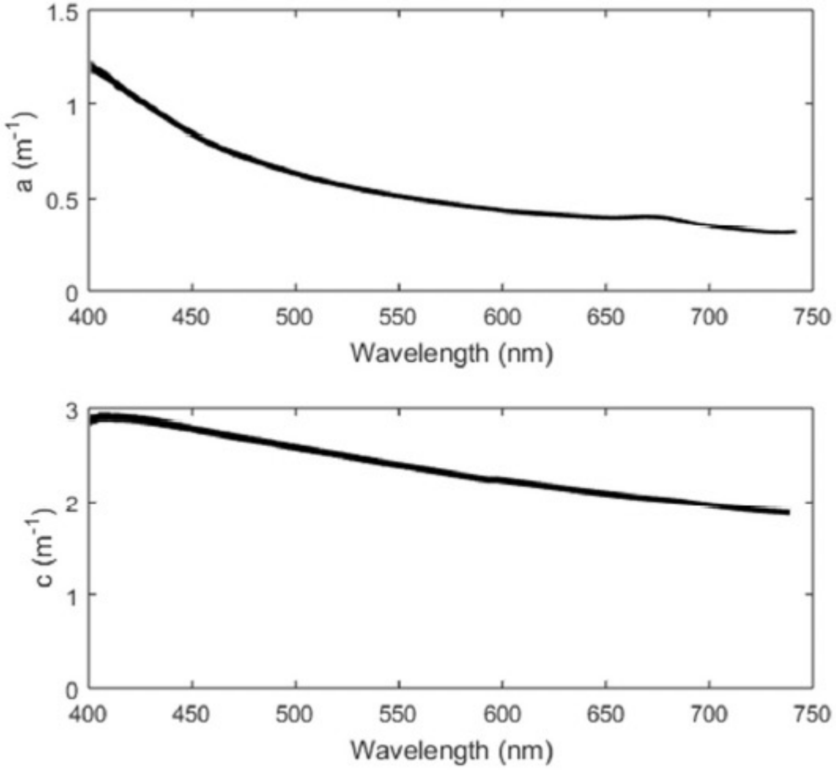
https://www.seabird.com/ac-s-spectral-absorption-and-attenuation-sensor/product-downloads?id=60762467715

Tables of T,S psi parameter as a function of wavelength available from OOI and in the AC Protocol Document on the seabird.com web site

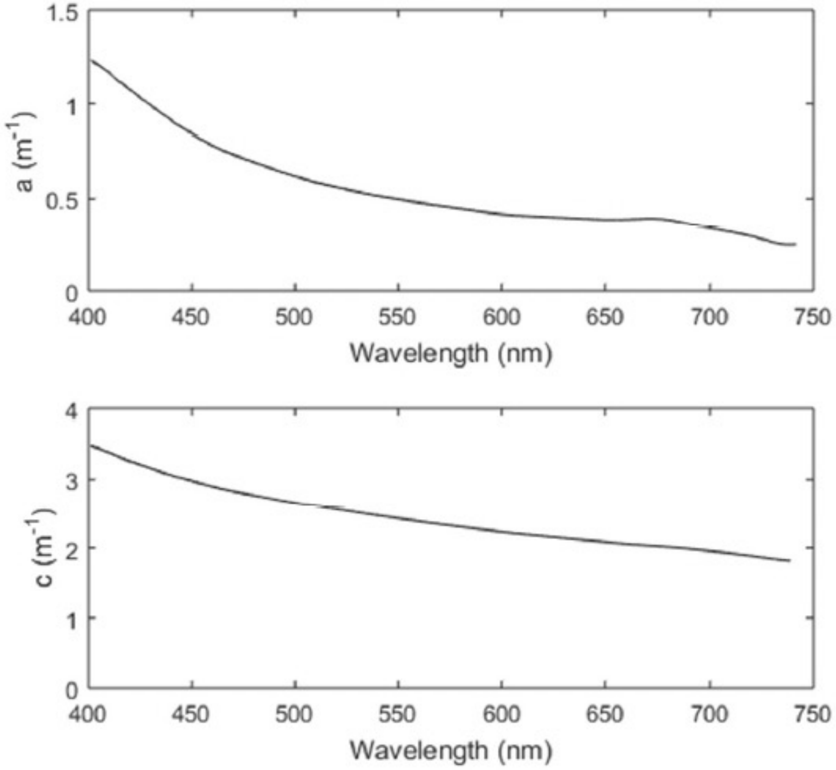
# Bio-optical Sensors - Absorption

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

## sample scan

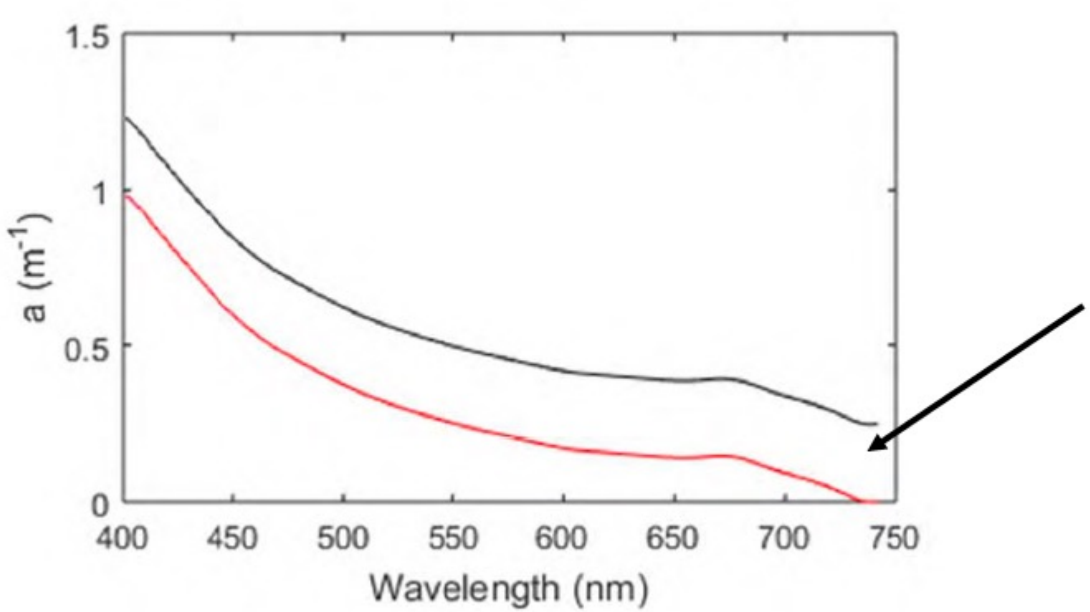



## corrected for pure water



# Bio-optical Sensors - Absorption

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




Stramski and Babin 2002

# Bio-optical Sensors - Absorption

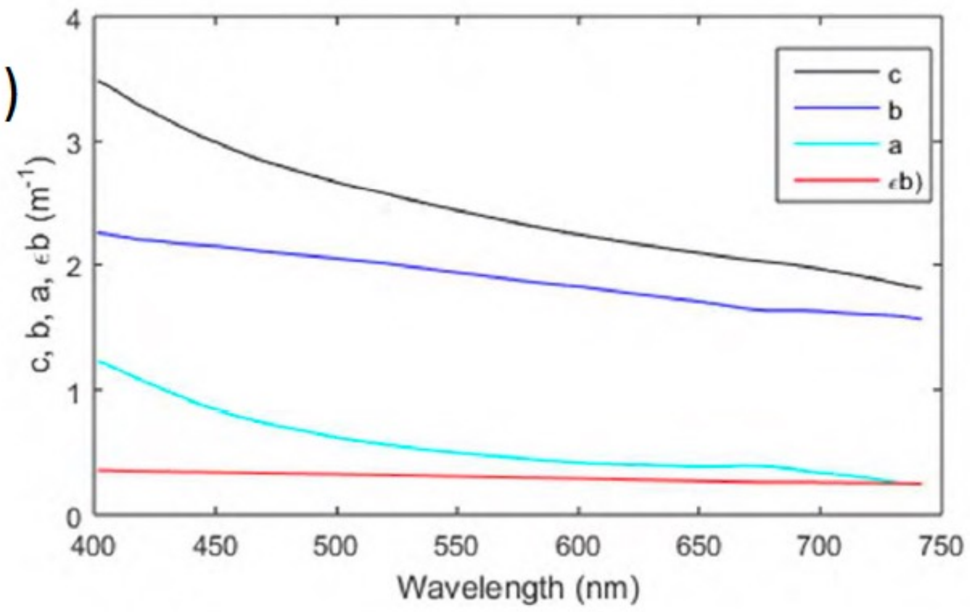
- Data Analysis and Interpretation – acs example
  3. Scattering correct the absorption spectra
     b. Subtract spectral scattering contribution, fraction of $b(\lambda)$

$b(\lambda) = c(\lambda) - a(\lambda)$

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

$fb(\lambda) = a(NIR)/b(NIR)$

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




Roesler and Zaneveld 1993

# Reflecting-tube absorption & attenuation meters

- $a(\lambda)$ = true absorption spectrum (measured in suspension in an integrating sphere)
- For measured $a_m(\lambda)$, $c_m(\lambda)$:
  - temperature-salinity corrections performed
  - pure water absorption already removed

Use the calculated scattering $b_m(\lambda)$ to estimate the scattering *correction* $\varepsilon$ (Zaneveld, 1994). Assume $a_m(\lambda_r)$ in the near infrared (NIR) is zero...

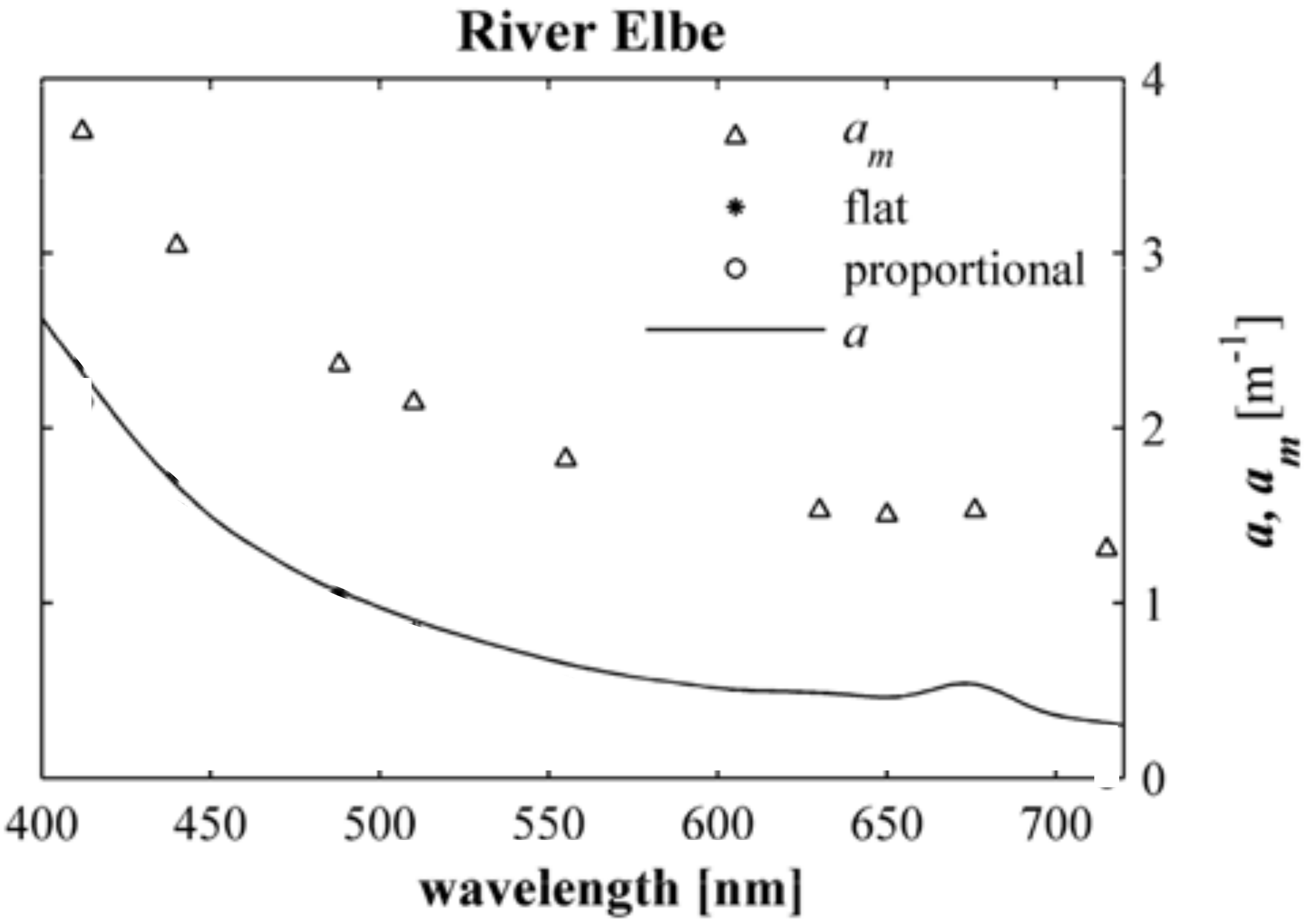



Figure: Röttgers et al., 2013. 10.1016/j.mio.2013.11.001

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*Option 1 "Flat": ...*and that $\varepsilon$ is the same at all wavelengths.

*Option 2 "Proportional":* ... or that $\varepsilon$ is equal to a constant *proportion* of the measured scattering

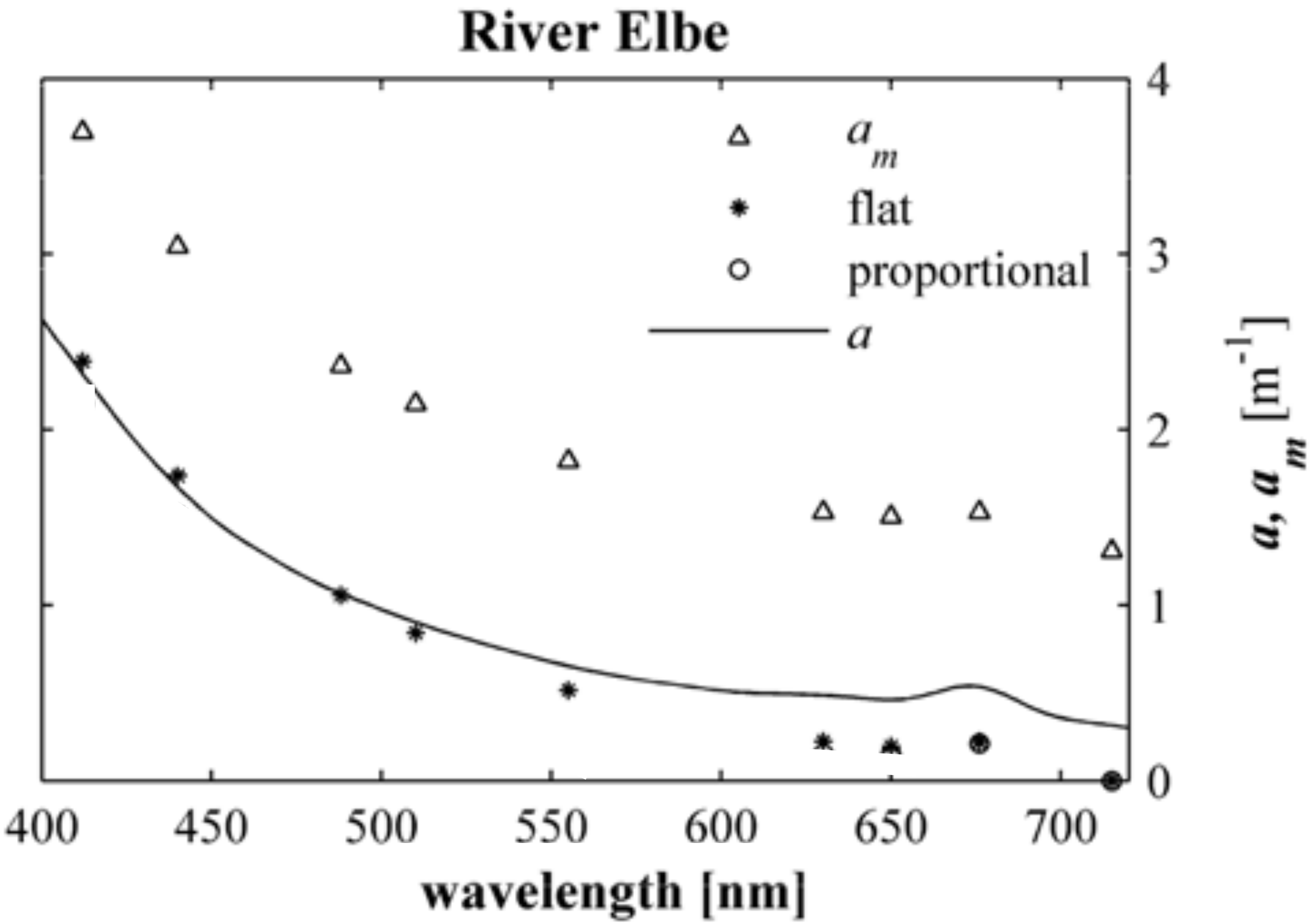
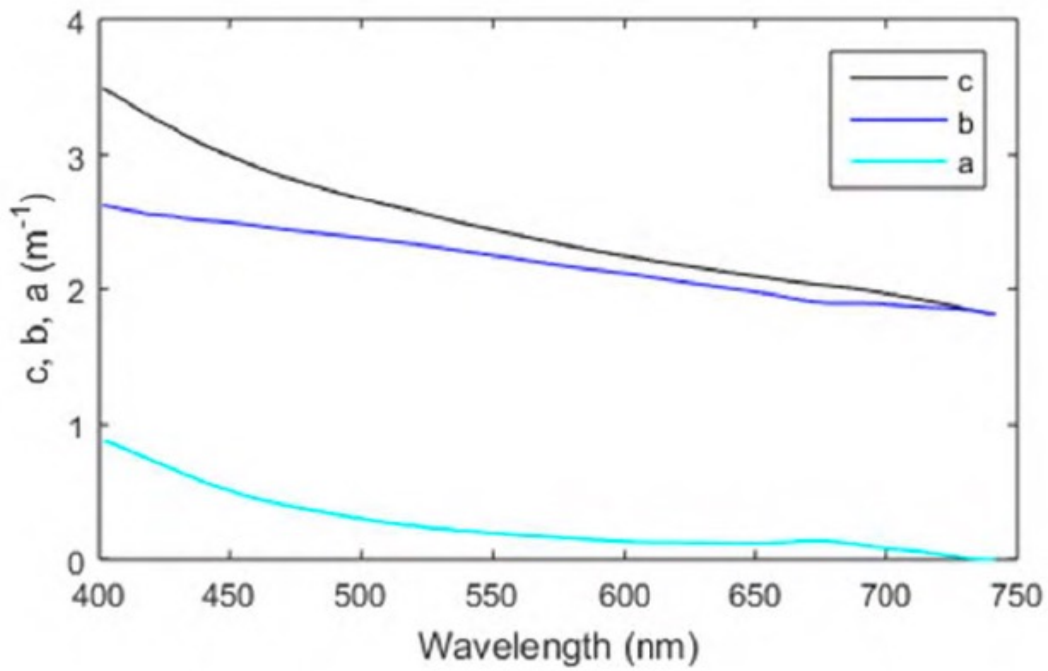



Figure: Röttgers et al., 2013. 10.1016/j.mio.2013.11.001

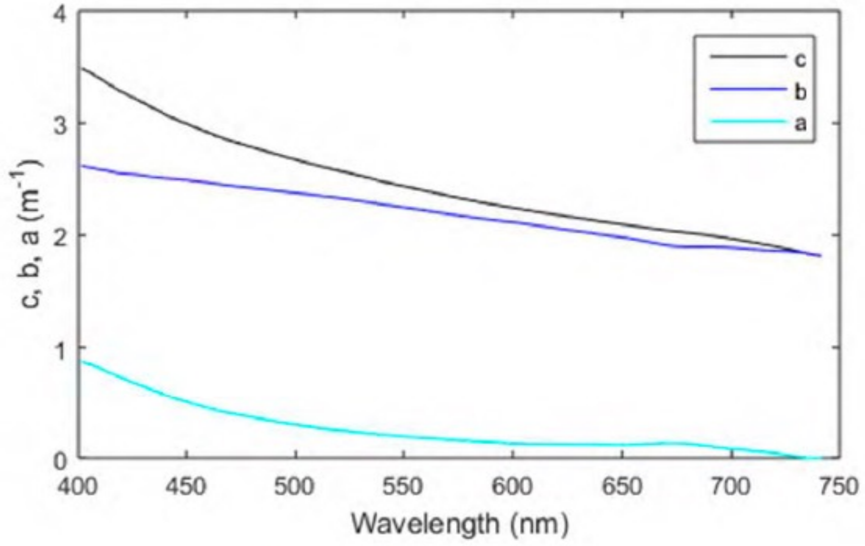
# Bio-optical Sensors - Absorption

- 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)

# Questions?