Multi Spectral Volume Scattering Meter (MVSM) a.k.a. The BEAST

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Plus the spirits of:

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What was desired (Goal) versus "sort of" delivered

Multi-spectral (8 wavelengths minimum close to SeaWiFs bands, spectral requirement to a) examine angular scattering that may play role in some remote sensing validation, b) particle type spectral information, and c) LIDAR applications)

- 8 bands (443, 490, 510, 532, 555, 565, 590, 620 nm)

Deployable in-situ (to 200 meters)or laboratory setting

- Users told "don't submerge to more than 5 meters below the surface"

Spanned measurements over angular range of 0.5 - 179^{o} with 0.25 resolution

Dynamic range to handle clean ocean waters to 'c' values greater than 20 m^{-1} (acceptance "coffee" test with 18.5 beam attenuation at 443 and absorption of 3.5 m^{-1})

- Calibration issues in cleanest water due to "embedded" coefficients
- Operationally 'c' values < 0.3 and > 4 m^{-1} are inherently difficult

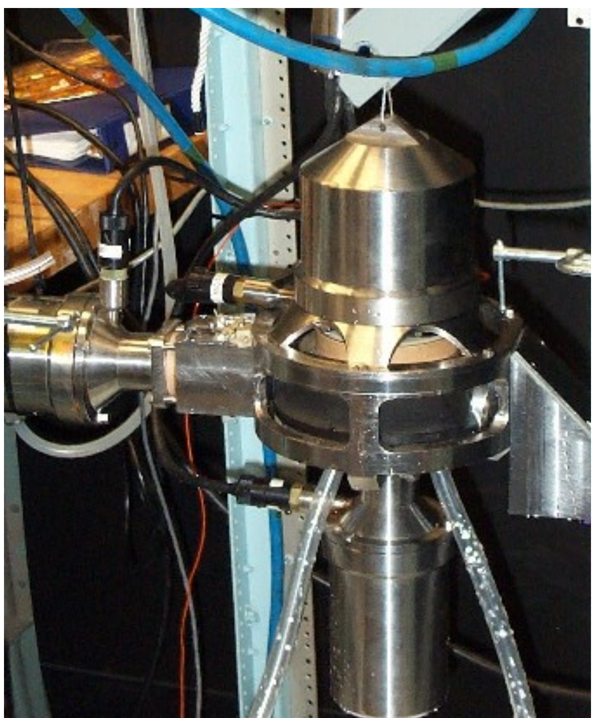
General History

2000-2002- Work by Lee et al., on system design and used in measurements of bubble scattering function (Zhang and Lewis)
2002- Start of NRL project on Particle Optics in Littoral Environment 2002-2006 (points to VSF as desired information so Capital Procurement requested but not MVSM specific)
2002- Scattering workshop where Ukrainian VSF meter showed some differences with phytoplankton in initial analysis; Dr. Pegau with "prototype" in Gulf of Mexico
2003- Contract initiated to have a MVSM for project by 2004 [after negociations with various parties a bust]
2004- Prototype taken by Lee et al to Tyrrhenienne Basin, Mediterranean Sea
2005- Final delivery with MVSM with testing in New York Finger lakes; Dr. Deric Gray PUSHED into pit of the MVSM and the natural name of "The BEAST" arises with Serial number 666 applied
2006- Gulf of Mexico (Ukrainians present) & Monterey CA; Original PROJECT OVER; Monterey data seemed best to date.
2006- Everett, WA [Electro-magnetic field discovered capable of taking out T.V. one floor away in hotel]
2007- Hudson River Plume
2008 – Ligurian Sea
2012 & 13 – East Sound, WA (coincident with LIDAR measurements in 2013)
2014- Atlantic (SABOR)………….MASCOT on vessel….Some leakage in seals

MVSM progressed from single wavelength and range extending from 1.25 to 165 degrees and benchtop only

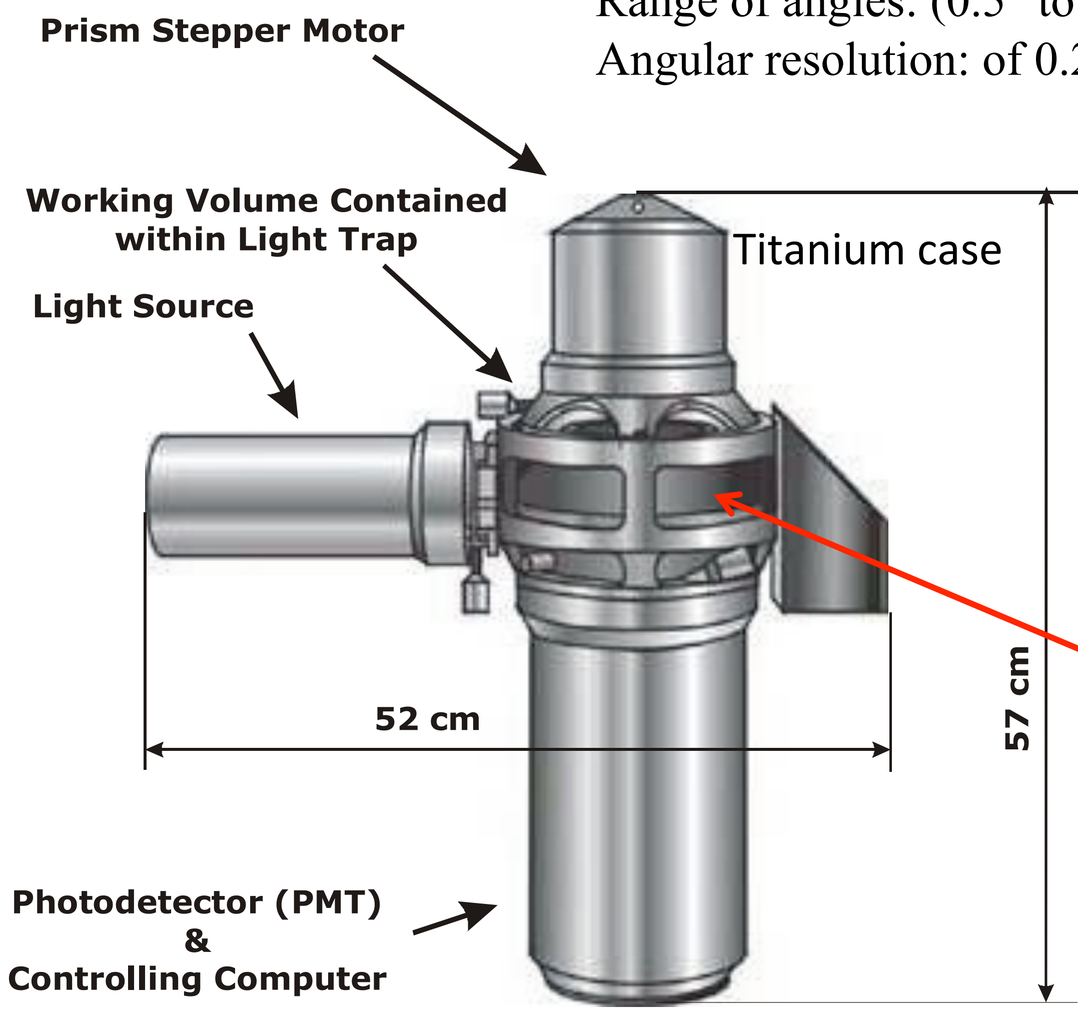
"Semi-submersible" with multiple wavelengths and 0.5 to 177.8 degrees
Combined with LISST for VSF measurements

Baby Beast
2002- 2004

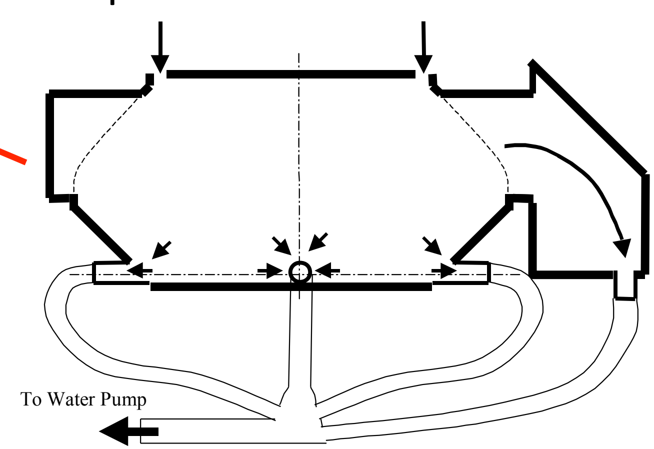


MVSM (BEAST) characteristics

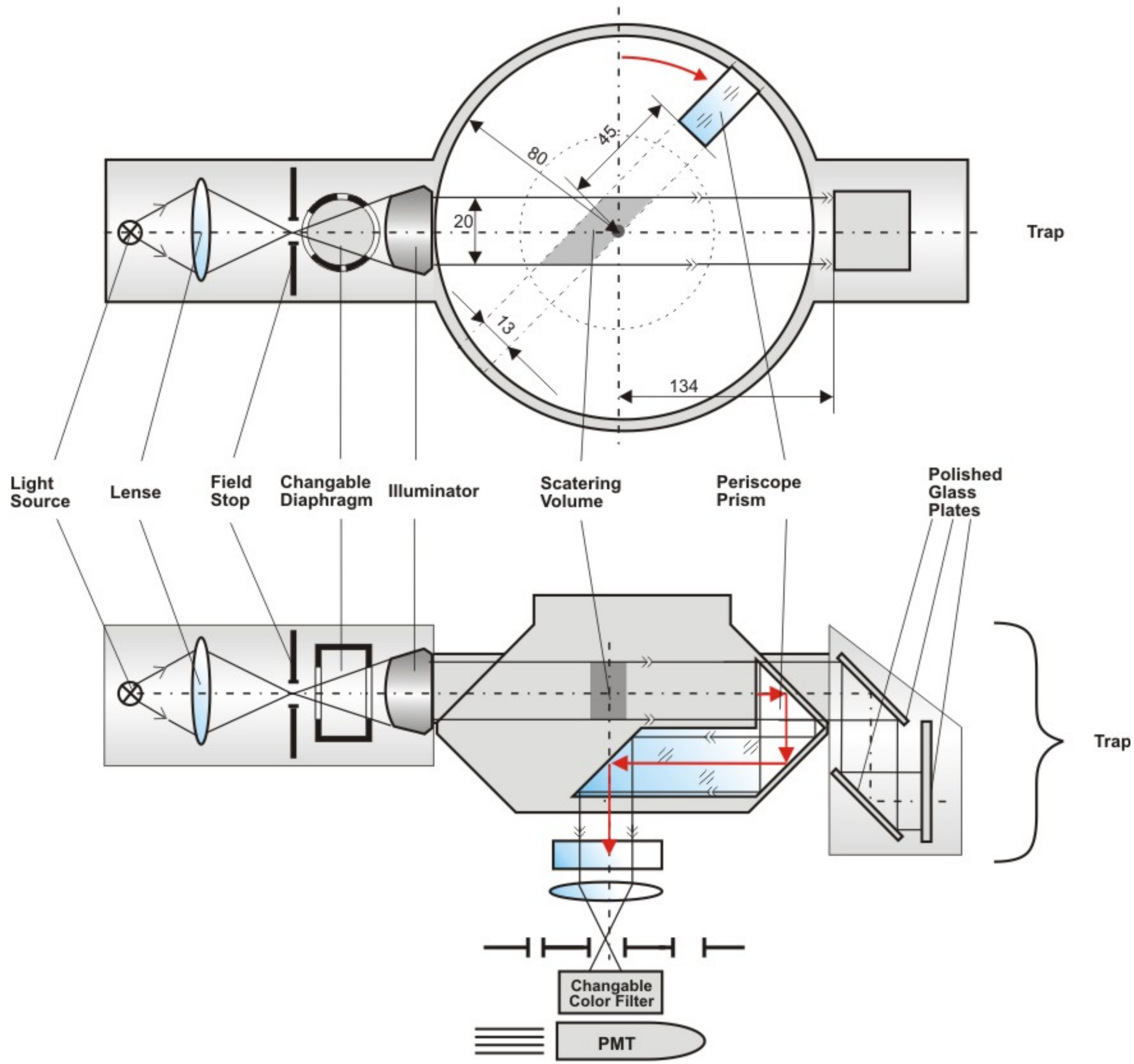
Spectral: 8 channels (443, 490, 510, 532, 555, 565, 590, 620 nm)
Bandwidth: 9 nm FWHM (channel dependent)
Pathlength: 13.3 cm
Beam cross section: 2x2 cm, regulated
Light source divergence: 0.08°
Acceptance angle of photodetector: 0.1-1°
Range of angles: (0.5° to 177.6°)
Angular resolution: of 0.25°



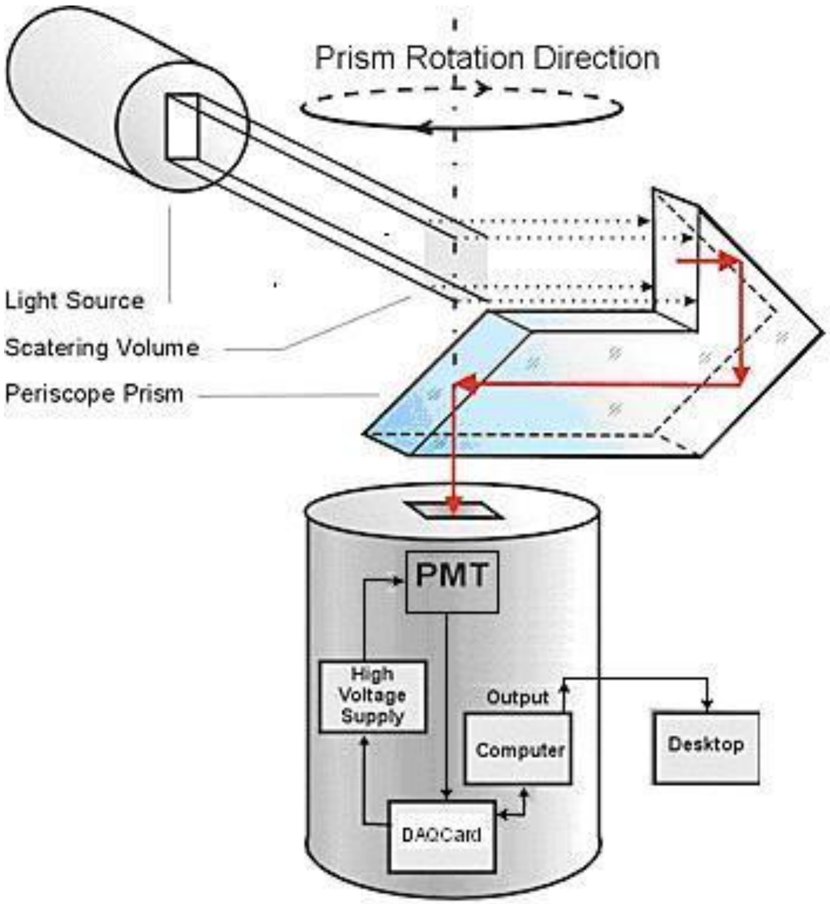
Water pulled into MVSM from gap between body of sample chamber and top



General Optical Design



General BEAST configuration

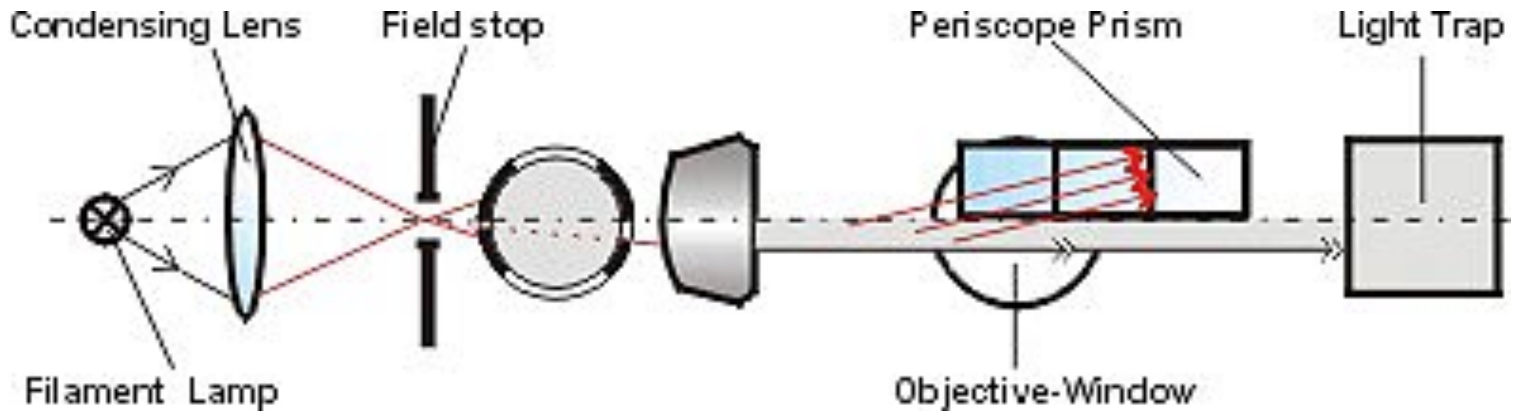


Unique Design Features:

- Light source is in fixed position
- Rotating prism is used to provide angular scattering measurement
- Angular range extended to in near forward to about 0.5°, and to 178° in the near backward direction using shadow method
- Multiple gains
- Multi-spectral

Critical points:

- Volume for each angle changes and knowing this is critical
- Scanning is slow and continuous sample moved through chamber (not open configuration)
- Calibration difficult and attenuation effects at high ‘c’ difficult to adjust for
- Spectral filters at detector level so fluorescence issue possible (white halogen light source)



Shadow method for small angle scattering measurements and exploitation of periscope prism

Near forward:

- Periscope prism has a parallel shift so prism boundary aligns precisely along the boundary edge of the optical axis.
- Direct beam not able to move into the receiving objective; light scattered ~0.5° will reach photomultiplier without interference.
- Near zero angles the beam edge slides along the prism boundary, but no direct light is received. The amount of light interference from the direct beam is decreased by several orders of magnitude.
- Varying aperture to narrow beam width to minimize imperfect collimated beam with spatial side-lobes that could pass light to the receiving objective.

Near backward:

- Normally the dimensions of the light source and the photodetector unit restrict measurements in the near-backward Accurate determination of the scattering volume and specular reflection required.
- Contains two polished absorbing glass plates fixed at an angle of 45° to the primary optical axis so light in the collimated beam that is not scattered moves toward the polished plates and is fully absorbed [due to small difference between the refractive index of glass and the refractive index of seawater.
- Only a small fraction of the incident light is reflected. [Reflections reduce the amount of encumber background light significantly (10^9 fold)].

Operational Sequence

- Scan begins at 90^o and proceeds to 180^o
- Prism continues to rotate through its 360^o range (on the GUI operating screen the plotting line is drawn in backward direction from 180^o to 0^o)
- Gain changes due to beam width and field of view occur at about 22 and 8 degrees
- When the scan reaches 0.5^o, the instrument checks its zero position setting and gives indication of its “goodness” or “how close to zero are you likely to be”
- System rotates to 90^o and proceeds with next scan

Software GUI allows for monitoring the progress of measurement

Ability to
- run all wavelengths or subset such as one
-control number of cycles
-Monitor “zero” location via angle error
-Visual progress of scan
- Input “comments” during scan

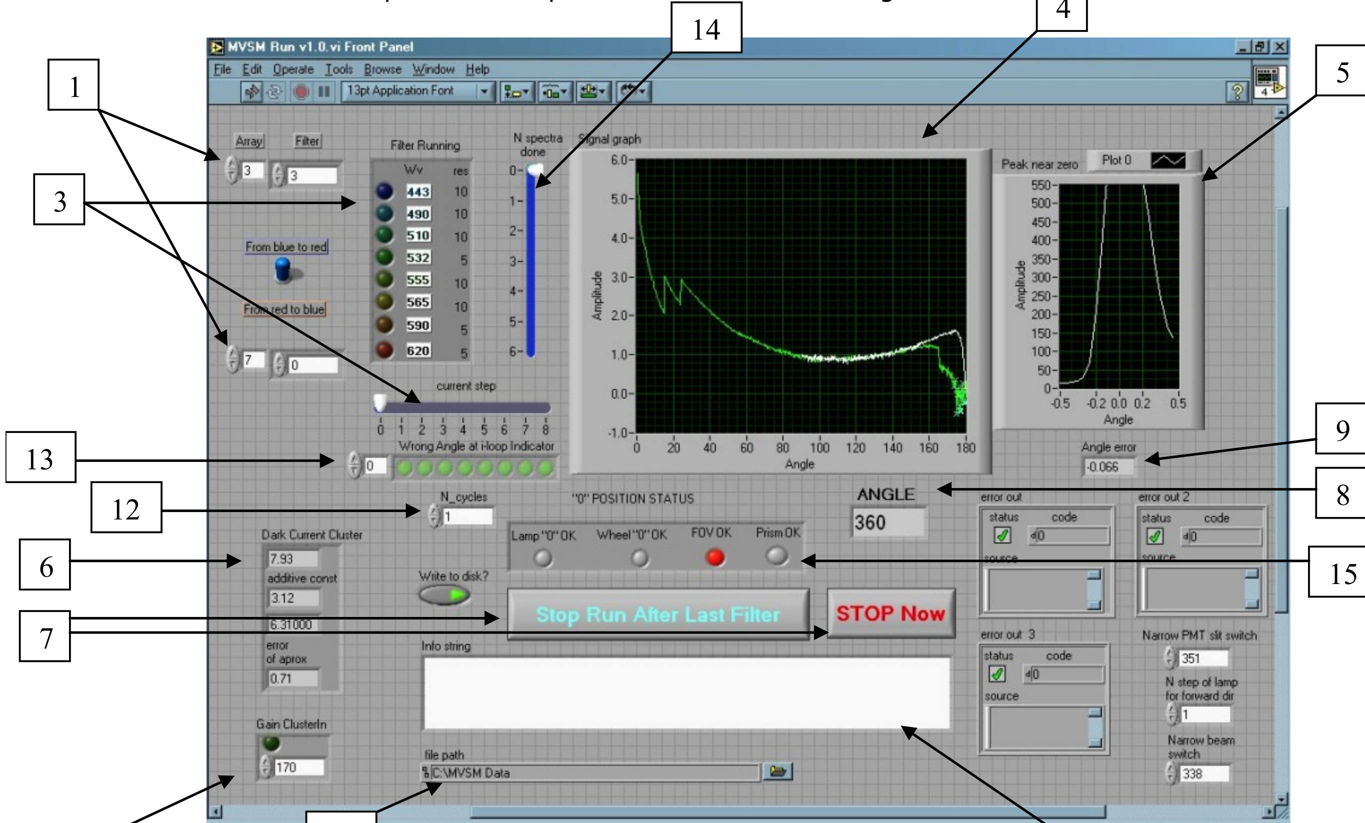


Fig.1.6 Program SnapShot

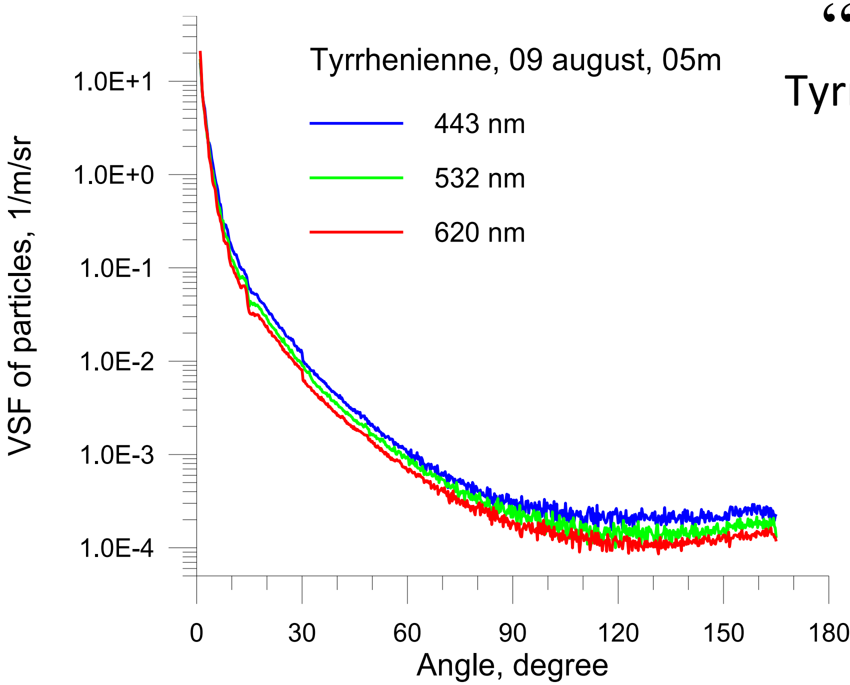
1. Array for defining of color filters sequence
2. PMT gain for transparency measurement (measurement of direct beam intensity)
3. Cluster of color filters description, identifying current color filter
4. Raw Data Graph: Log base 10 of amplitude vs. Angle
5. Light beam intensity in small angles, peak power at prism “0” position
6. Dark Current Cluster: parameters of approximation curve (up to down: value in quanta corresponding to max voltage, constant of addiction component of signal, exponent, error of approximation)
7. Measurement STOP Buttons
8. Current angle of prism position (measurement angle)
9. Error adjustment of prism in zero direction
10. An Information String bar where the user can enter descriptive information (Lat. Long., Cast #, ect…) about the collected data that will be stored along with the file. Note that a time stamp is automatically saved with each data file collected.
11. 21 Clusters of errors (are defined in LabView help)
12. Array for entering the number of iterations to conduct of a wavelength sequence
13. Angle Position Indicator
14. Current Iteration Indicator
15. “0” Position Indicator
16. Default File Path

Calibration

"What to you want it to look like?"

“Baby Beast” First Cruise------

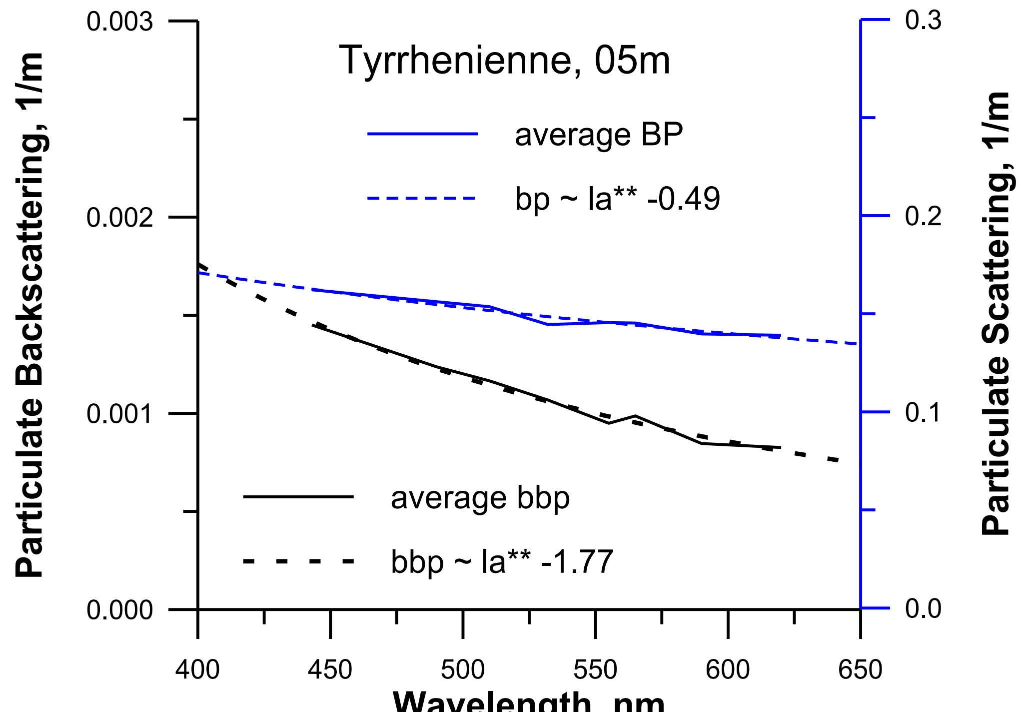
Tyrrhenienne Basin, Mediterranean Sea
August 9, 2004



Wavelengths and resolution

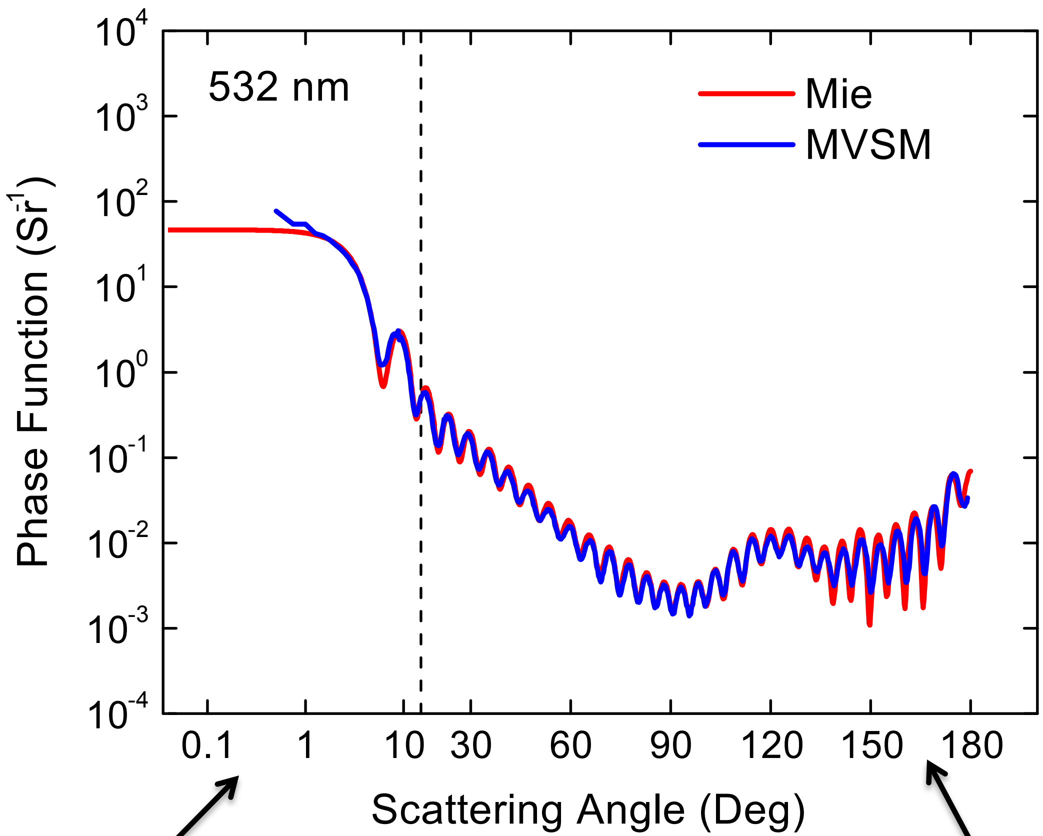
443 nm	20 nm
490 nm	20 nm
510 nm	20 nm
532 nm	9 nm
555 nm	20 nm
565 nm	20 nm
590 nm	9 nm
620 nm	9 nm

Angular Range **1.25 – 165** Degrees



Comparison with Mie theory

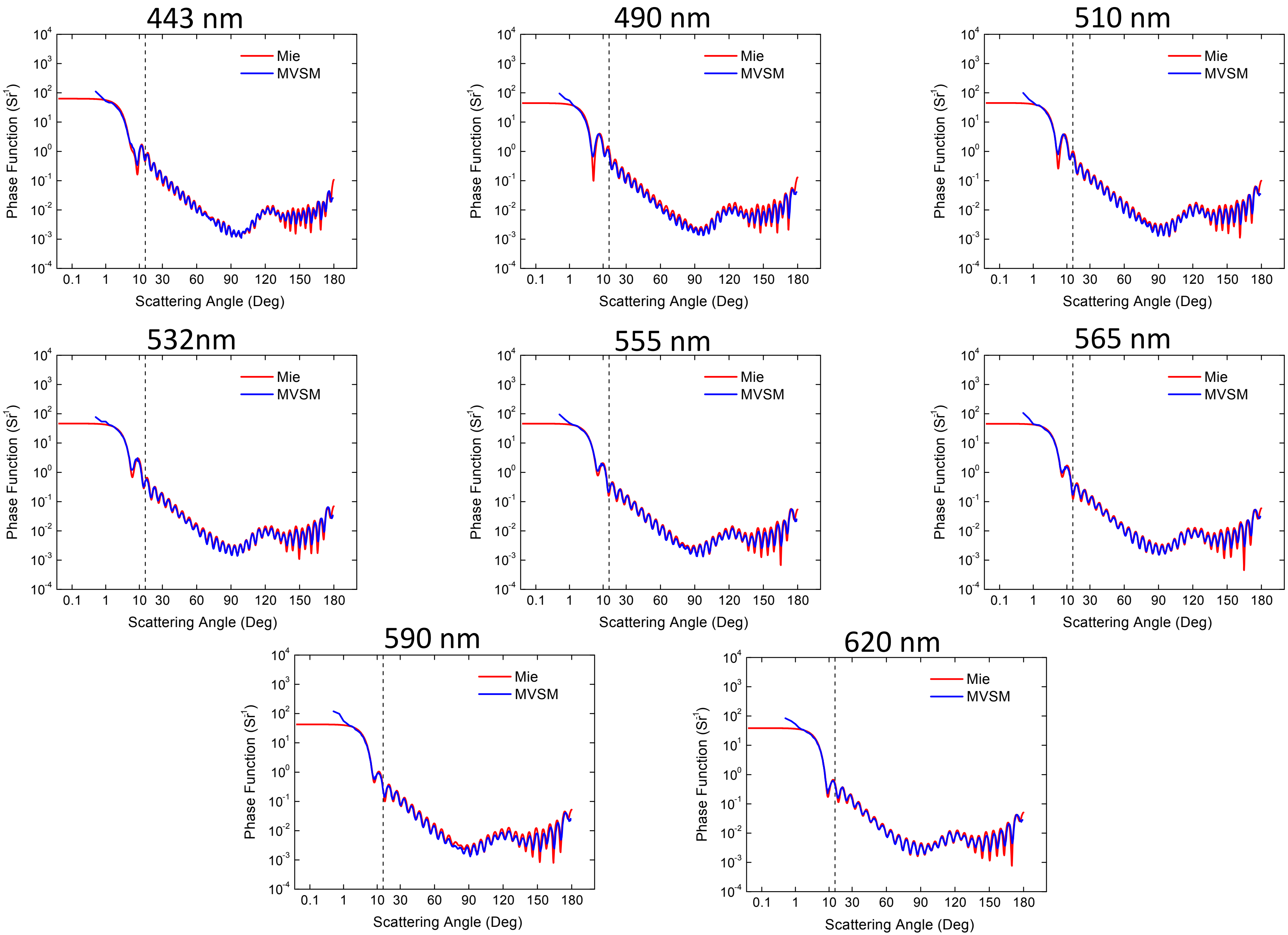
4 μm spheres



log-log scale to 15°

semi-log scale

Comparison with Mie theory

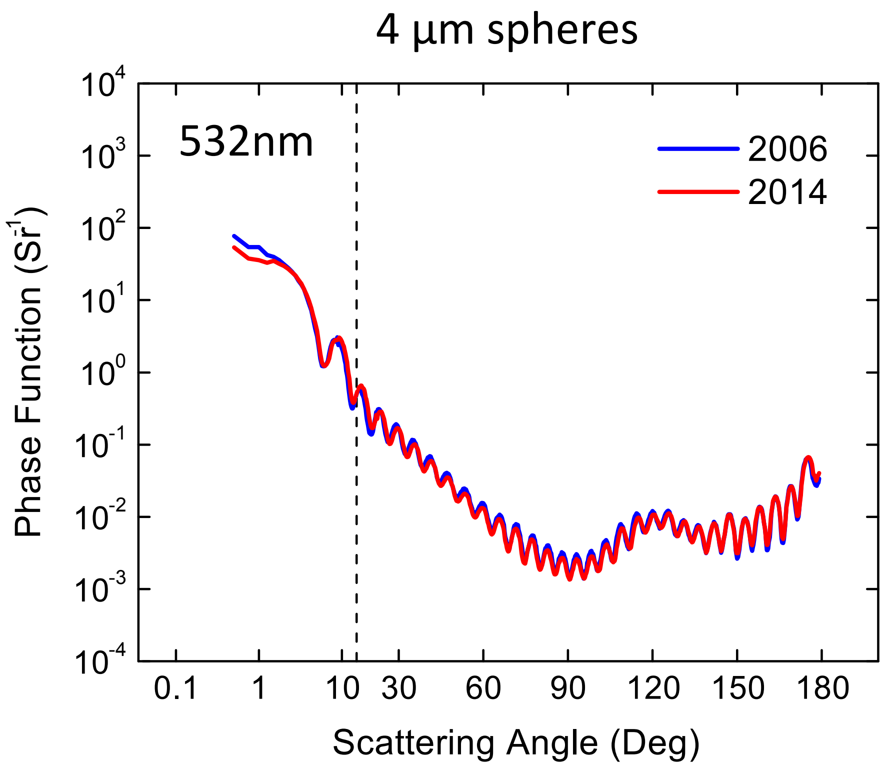


Instrument Stability Over Time

MVSM has been surprisingly stable

Only lamp(s) and a neutral density filter have been replaced

Variation over time about the same as the variation from run to run



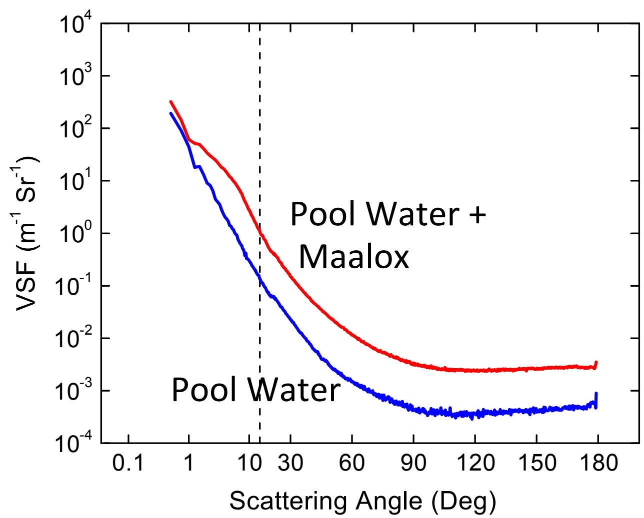
Early NRL Pool Tests

IOP package with CTD, ac-9, LISST (532nm), MVSM, Hydroscat

All OSHA regulations carefully followed

Important Issues identified:

- backscattering coefficients compare well with other instruments
- scattering coefficients larger than ac-9



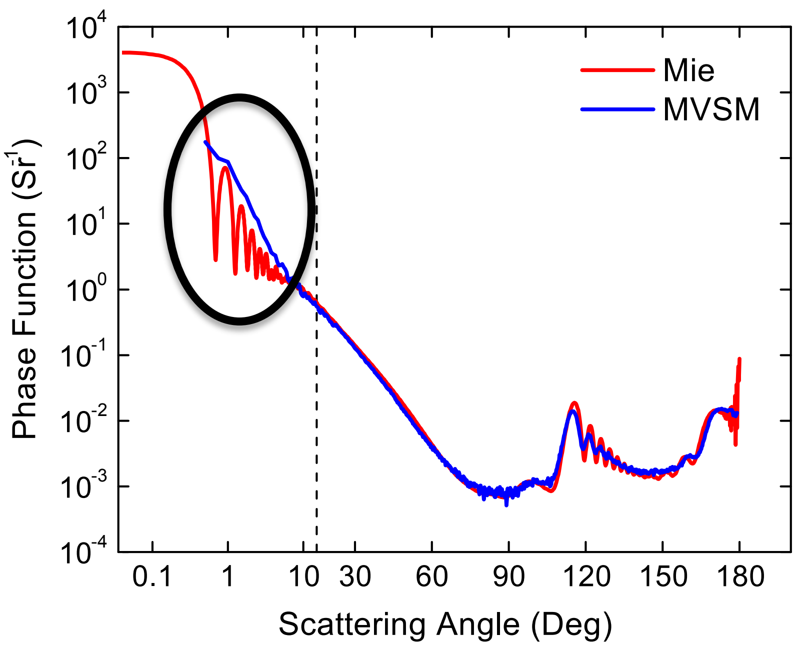
	Pool Water		Pool Water + Maalox	
	b (m^{-1})	b_b (m^{-1})	b (m^{-1})	b_b (m^{-1})
ac-9/ Hydroscat	0.15	0.0024	1.24	0.014
MVSM	0.30	0.0027	1.61	0.017

Overestimation of the near-forward scattering

Just having larger scattering coefficient than ac-9 doesn't the the MVSM is wrong (difference in acceptance angle)

But the MVSM scattering coefficients also larger than the LISST attenuation coefficient

Comparisons with larger spheres shows MVSM overestimates the near-forward VSF at angles < 10^{o}



Combined LISST-MVSM VSF

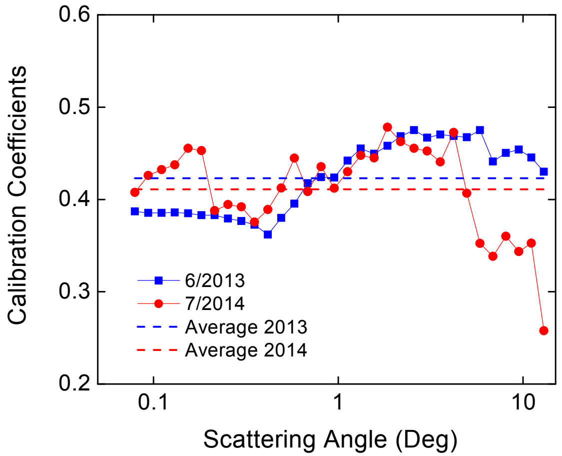
Can we use the LISST to get a better measurement of the near-forward VSF and combine it with the MVSM (532 nm only)?

LISST Calibration Procedure:

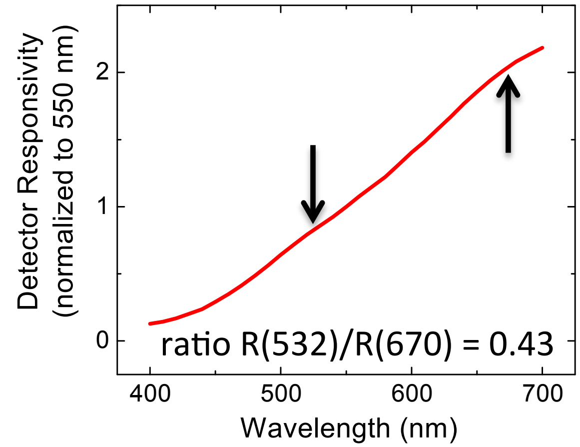
- Start with the procedure outlined in the Sequoia application notes (Yogi's method)
  - constant coefficient across the ring detector based on physical parameters of instrument
  - only applicable to 670 nm
- Make measurements with sequence of spheres of different sizes
- Calculate coefficients for each detector ring (similar to Slade and Boss)
- Test with solutions of Maalox and/or Arizona Road Dust
- Choose calibration coefficients from different methods based on results from test solutions

Combined LISST-MVSM VSF

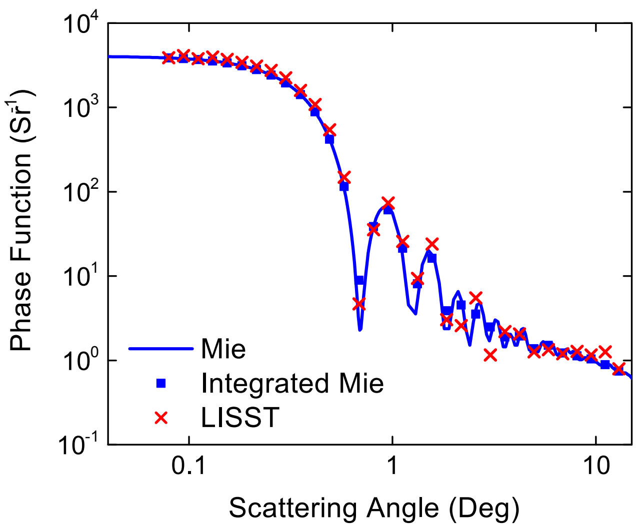
Coefficients from last two calibrations



Average value over all rings is consistent with the ratio of the responsivity of silicon between 670 and 532 nm



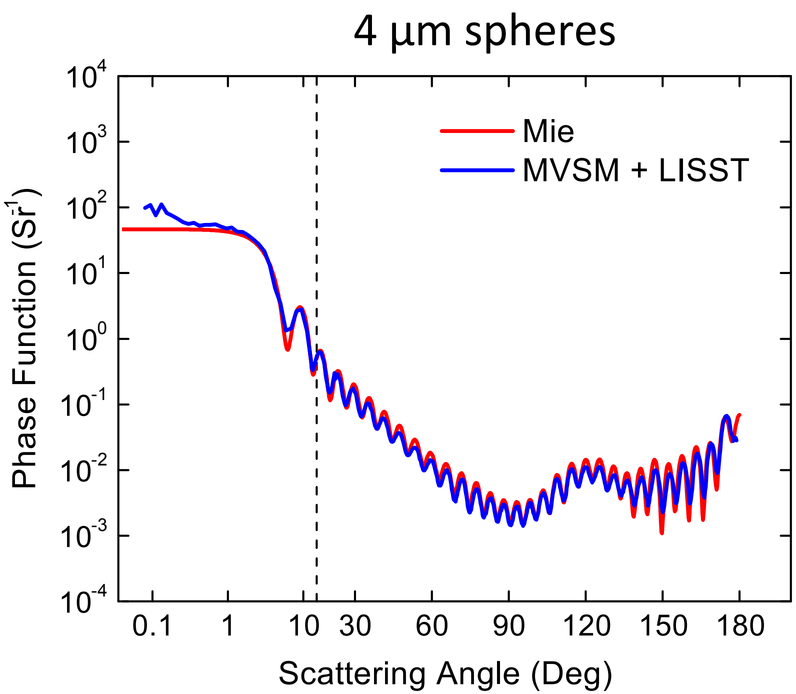
Calibrated near-forward VSF for 40 µm spheres

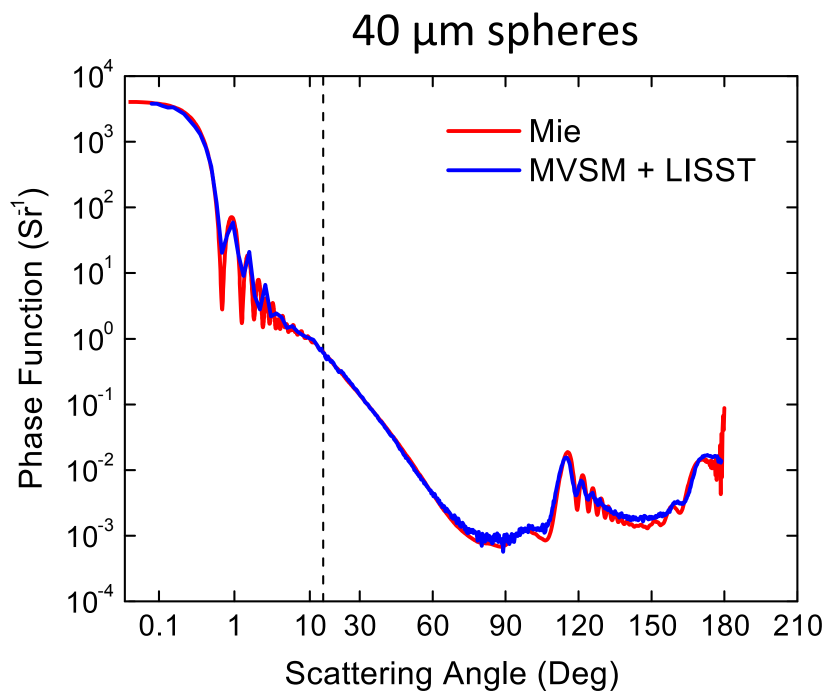


Combined LISST-MVSM VSF

Merging the LISST and MVSM VSFs

- Remove the MVSM VSF at angles < 13°
- Replace with LISST VSF



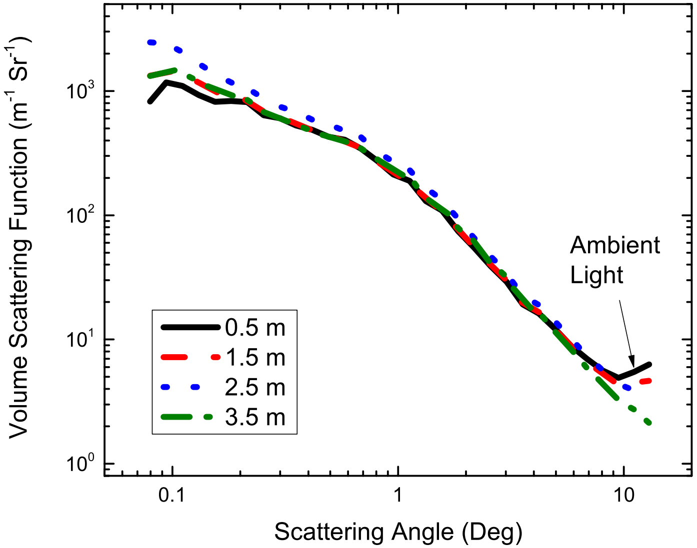


Combined LISST-MVSM VSF with Field Data

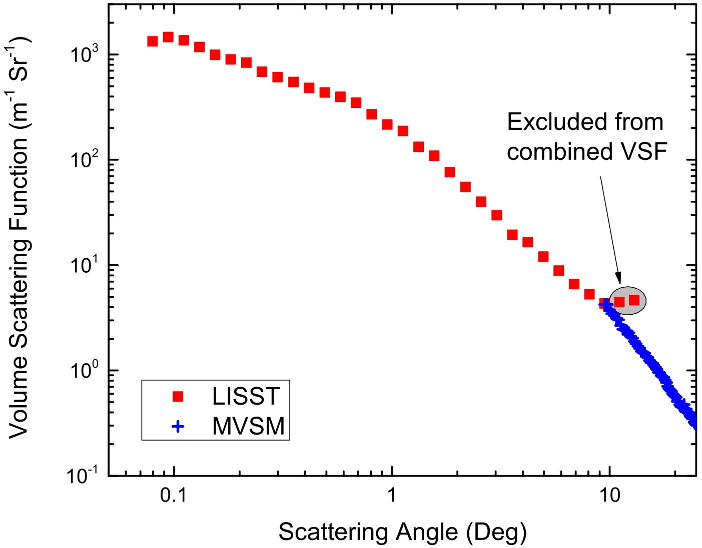
In the field:

- MVSM is typically deployed near the surface: 1-2 meters
- LISST is either co-deployed with the MVSM or profiled separately
- LISST VSF data from the same depth merged with MVSM
  - Typically drop last two angles from LISST due to ambient light contamination

LISST profiles near the surface

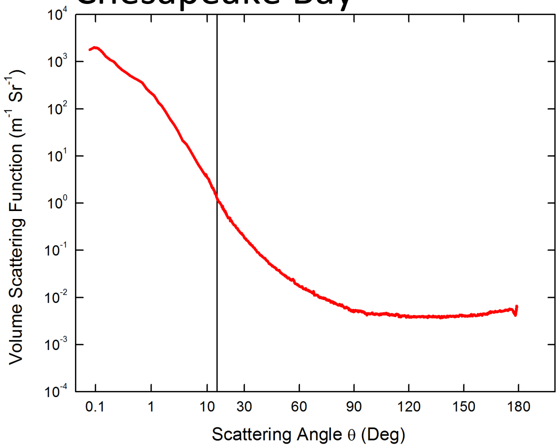


LISST + MVSM at 1.5 m

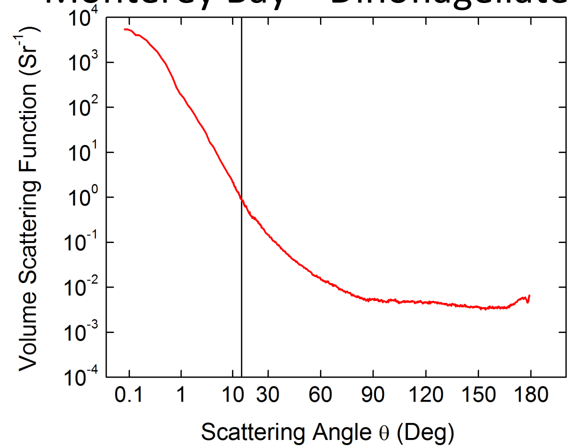


Examples of Combined LISST-MVSM VSF with Field Data

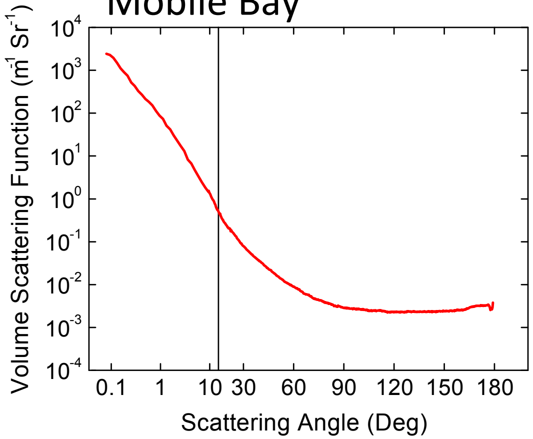
Chesapeake Bay



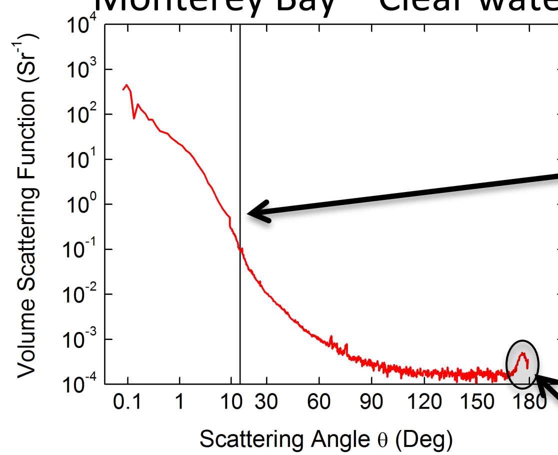
Monterey Bay – Dinoflagellate bloom



Mobile Bay



Monterey Bay – Clear water

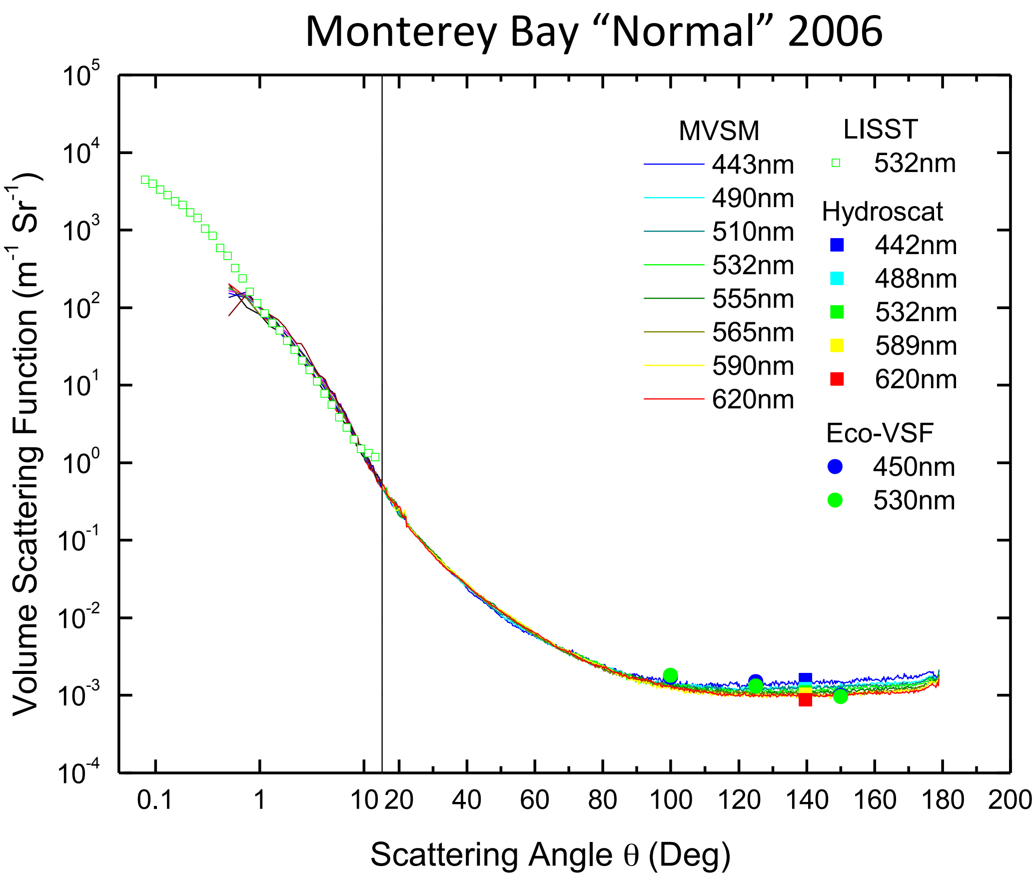


Match not great in clear water – typical behavior

bubbles in light trap

Individual VSFs compared to other backscattering instruments

Individual VSFs from different instruments compare well….



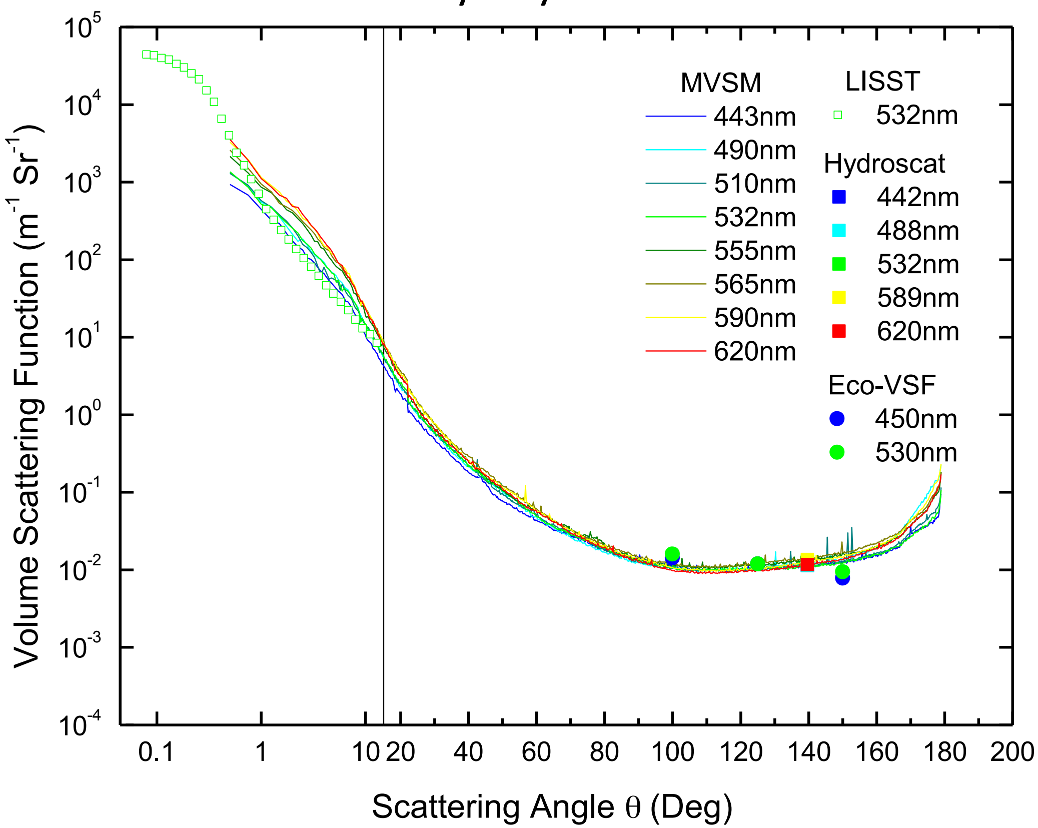
Individual VSFs compared to other backscattering instruments

Individual VSFs from different instruments compare well….

…even in ridiculously high concentrations

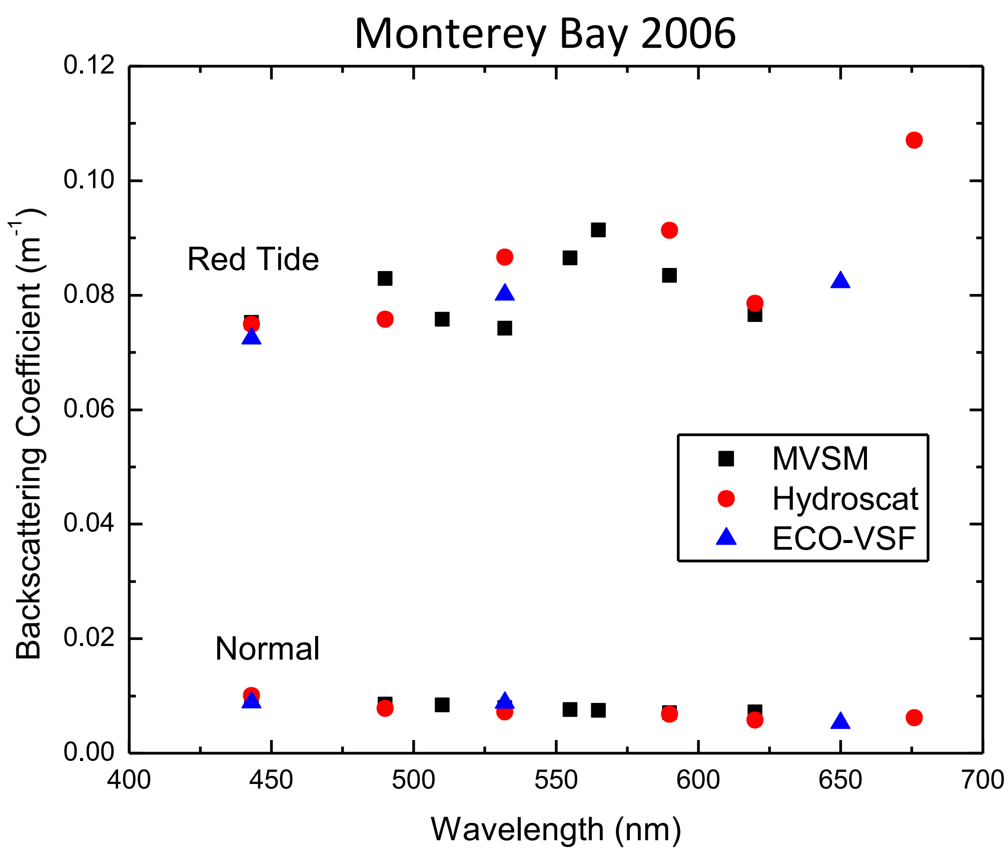
$c_p(532nm) \sim 30\ m^{-1}$

Monterey Bay "Red Tide" 2006



Individual VSFs compared to other backscattering instruments

The backscattering coefficients again compare reasonably well between instruments

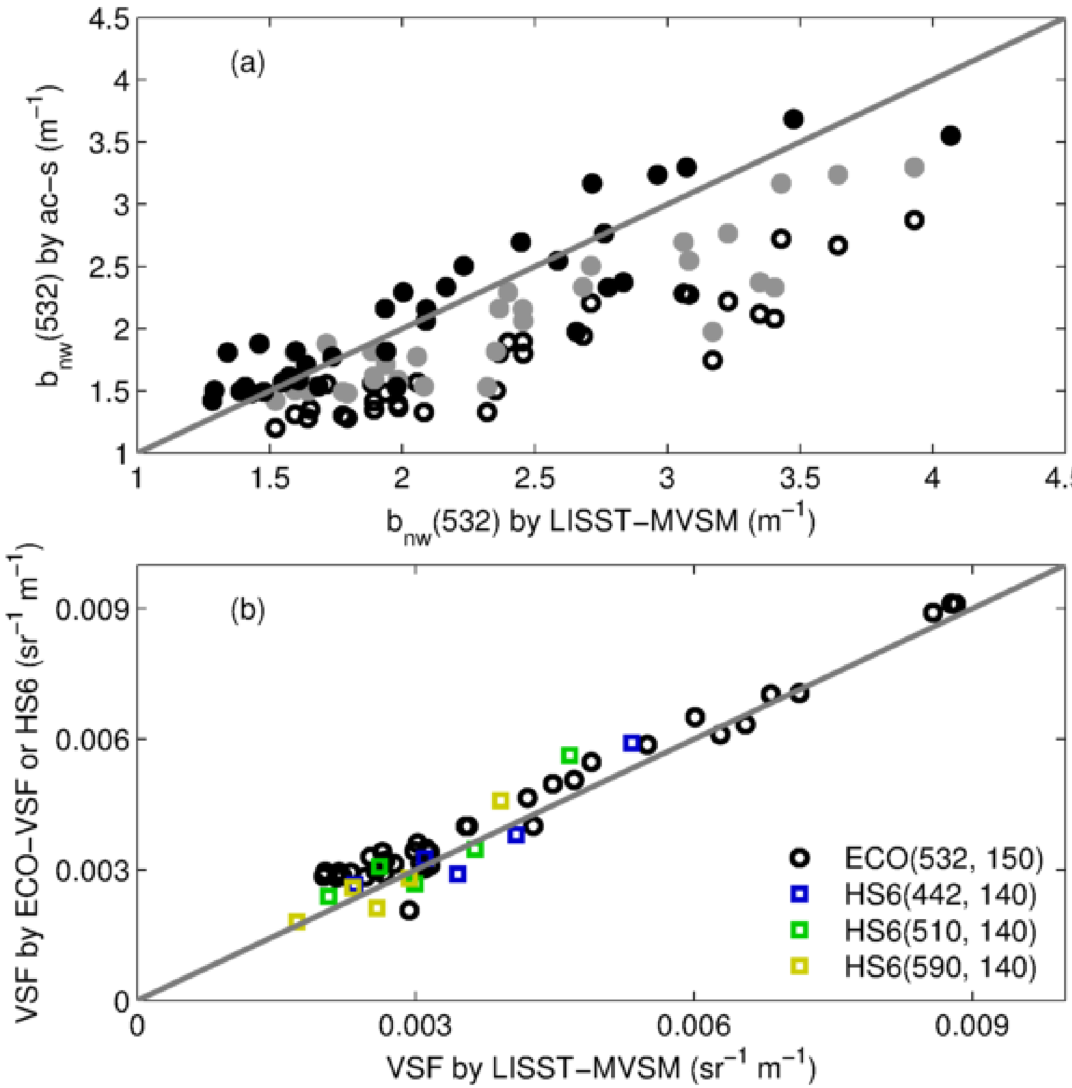


Statistical Comparison of Scattering and Backscattering Coefficients

The integrated scattering coefficient from the combined LISST+MVSM VSF is lower than the attenuation coefficient

Scattering coefficients are larger than the ac-meter values, but comparable when corrected for acceptance angle

Backscattering coefficients compare very well with other instruments



Variability of the Phase Function

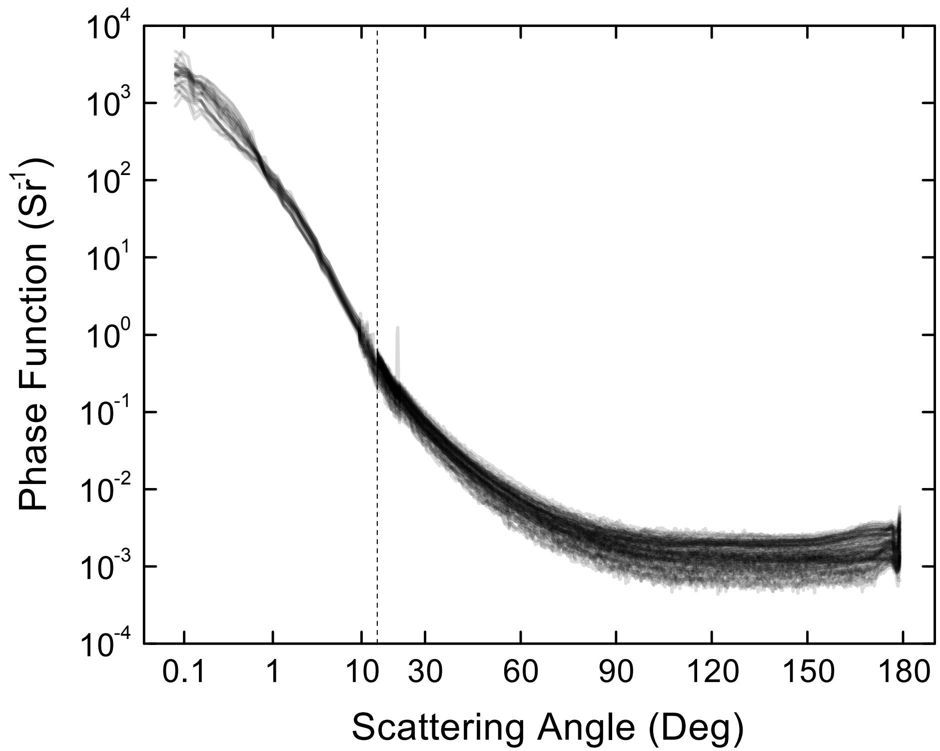
Phase functions from coastal waters

- Monterey Bay
- Chesapeake Bay
- Mobile Bay

Wide variety of particle types:

- terrigenous
- diatoms
- dinoflagellates

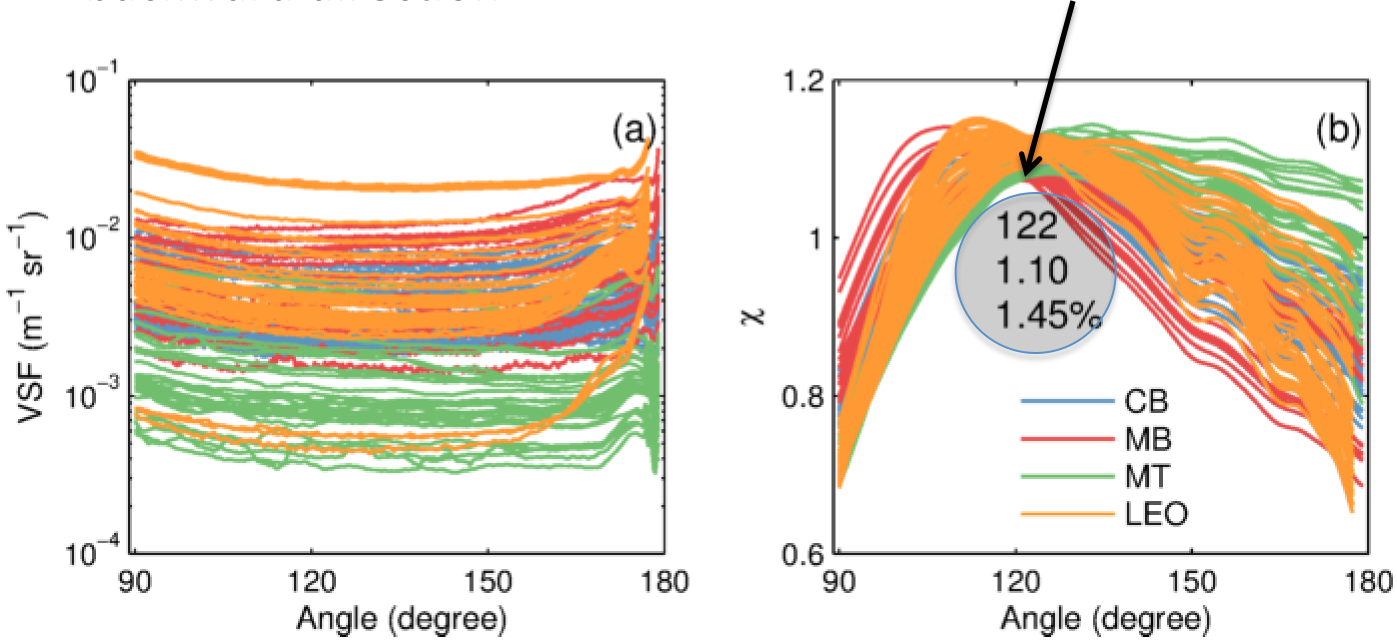
Remarkably consistent across different water types



Backscattering VSF and Chi factors

Angular shape is relatively flat and "feature-less" in backward direction

1. Angle of minimum variation
2. Chi factor
3. Coefficient of variation

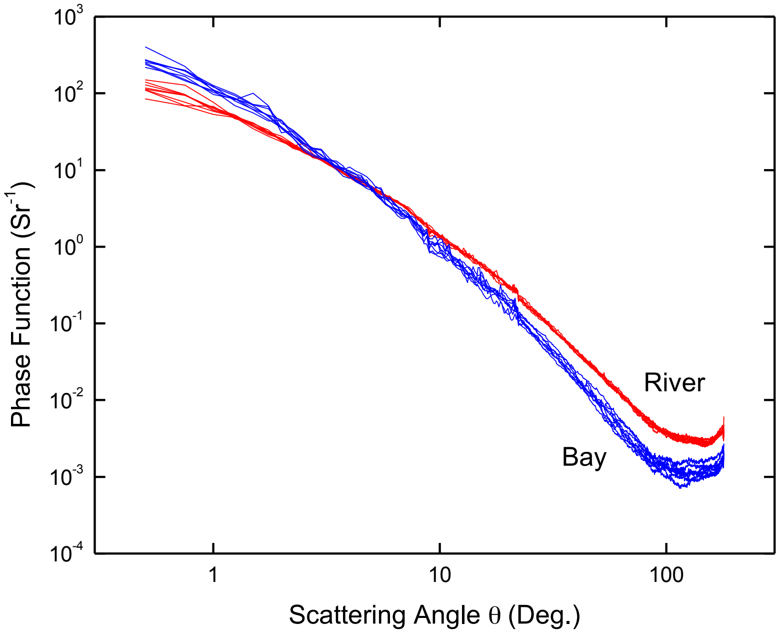


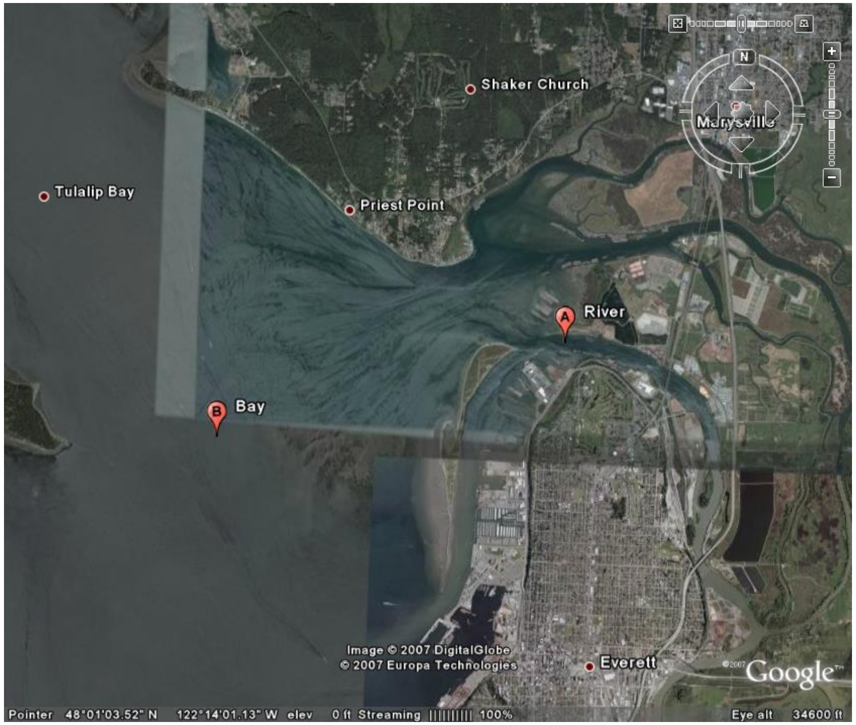
Spectral Variability of the Phase Function

none

Spectral Variability of the Phase Function

There has been some evidence of spectral variation in different water types





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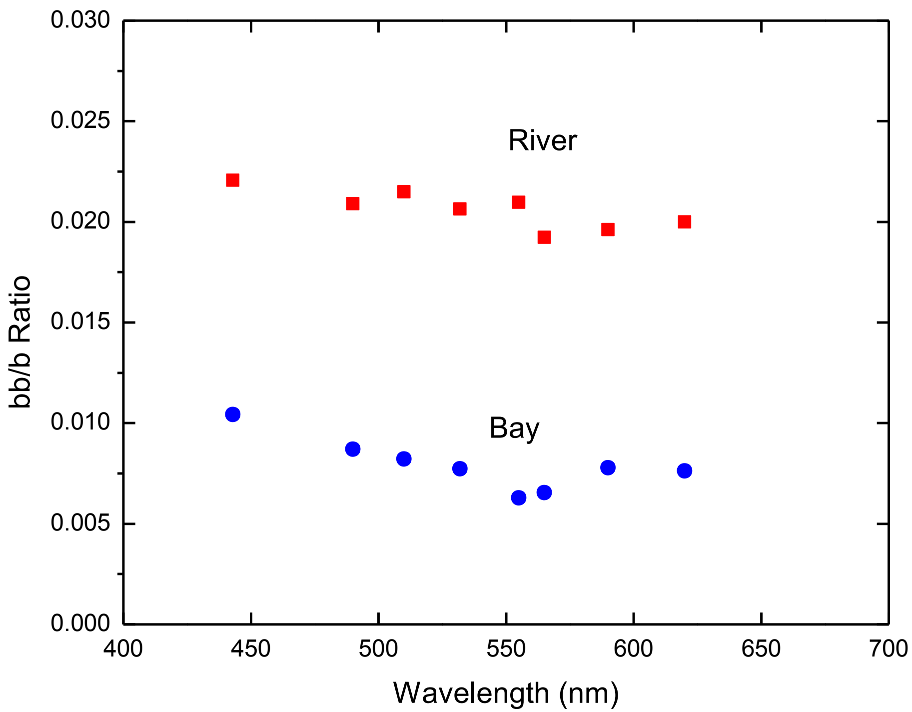
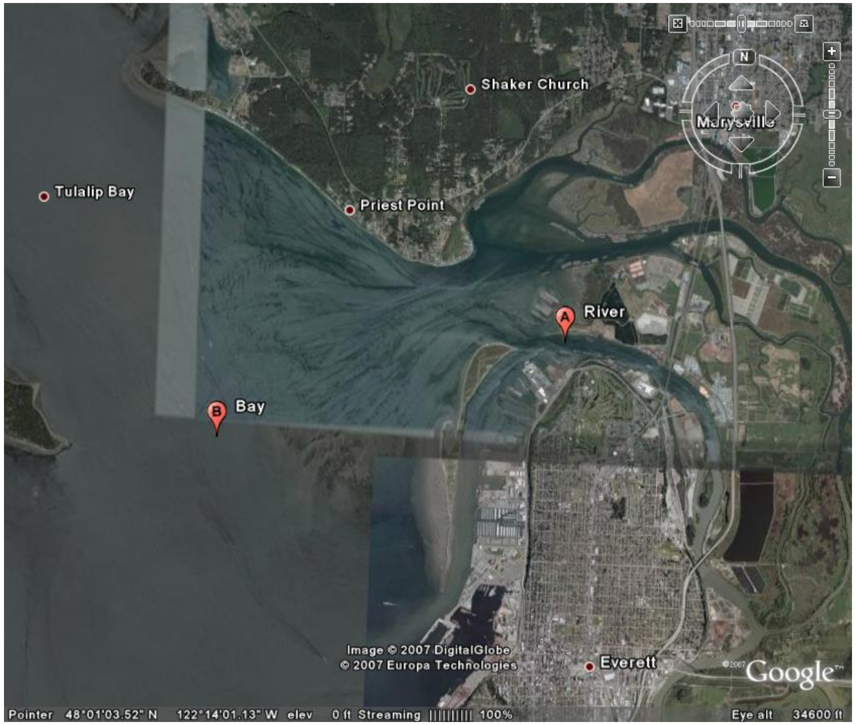




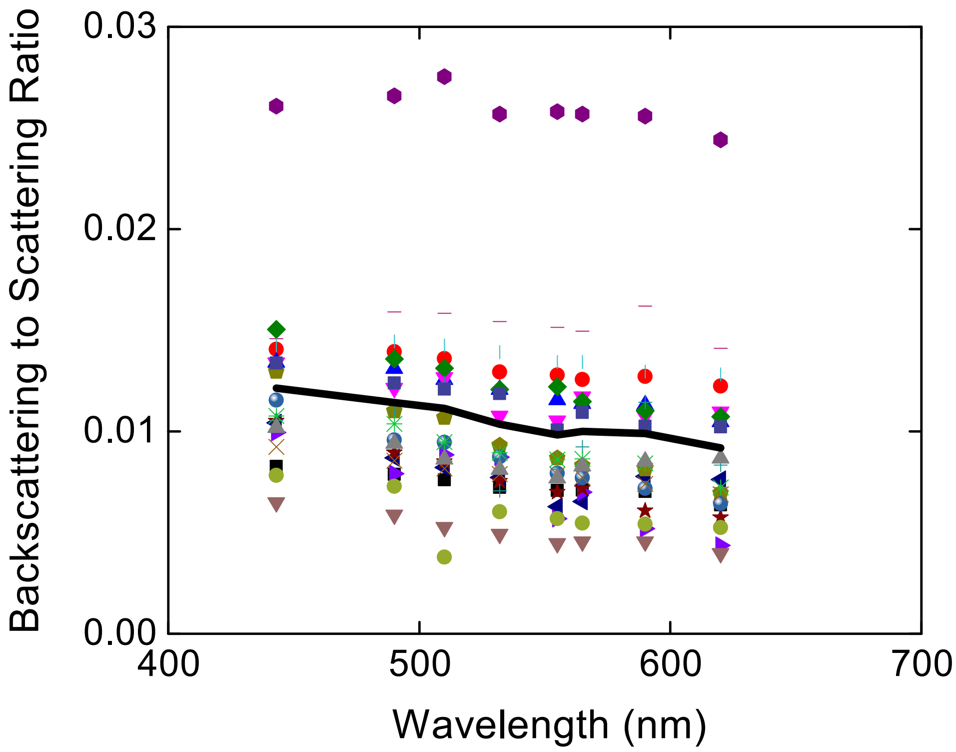
Spectral Variability of the Phase Function

The MVSM does show a slight decrease in b_b/b ratio with increasing wavelength

It is very consistent across different water types

BUT the uncertainty of the scattering coefficient does cast a long shadow over the results

Subset of bb/b ratios for coastal waters



BEAST vs. Killer Daphnia is not something to mess around with