Effect of deviations from power law PSDs on backscattering signals.

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Power law PSDs and backscattering

Effect of the particle-size distribution on the backscattering ratio in seawater

Osvaldo Ulloa, Shubha Sathyendranath, and Trevor Platt

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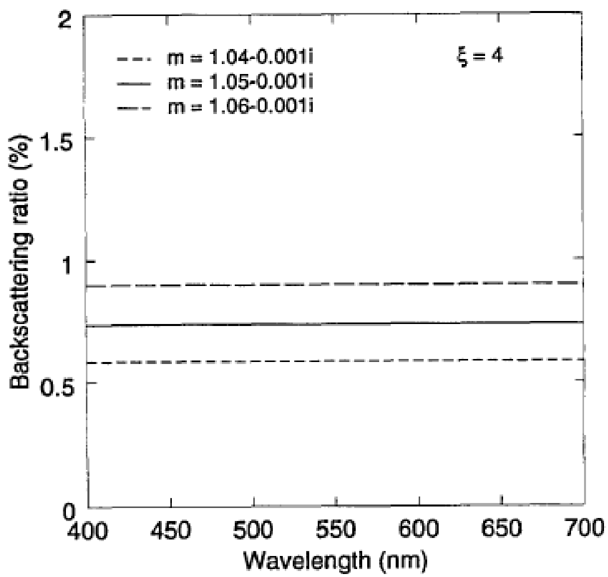

Fig. 4. The backscattering ratio $\tilde{b}_{bp}$ as a function of wavelength for particles with a Junge-type size distribution and a diameter range $0.01 \leq D \leq 200$ μm.

Using a power law PSD

$$f(D) = KD^{-\xi}$$

Mie theory,
uniform spheres,
single refractive index…

Power law PSDs and backscattering

Role of measurement uncertainties in observed variability in the spectral backscattering ratio: a case study in mineral-rich coastal waters

David McKee,[1,*] Malik Chami,[2] Ian Brown,[1] Violeta Sanjuan Calzado,[3] David Doxaran,[2] and Alex Cunningham[1]

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AC-9 / BB9 Data from mineral-rich Bristol Channel

Tried to model using hyperbolic slope of particulate attenuation spectrum (Power 3.1).

$$c_p(\lambda) = A_c\lambda^{-\gamma} \qquad \gamma \approx \xi - 3$$

Tried other power slopes.

Tried adding additional small particles.

Observed spectral dependency in b_{bp}/b_p associated with deviation from power law PSD…

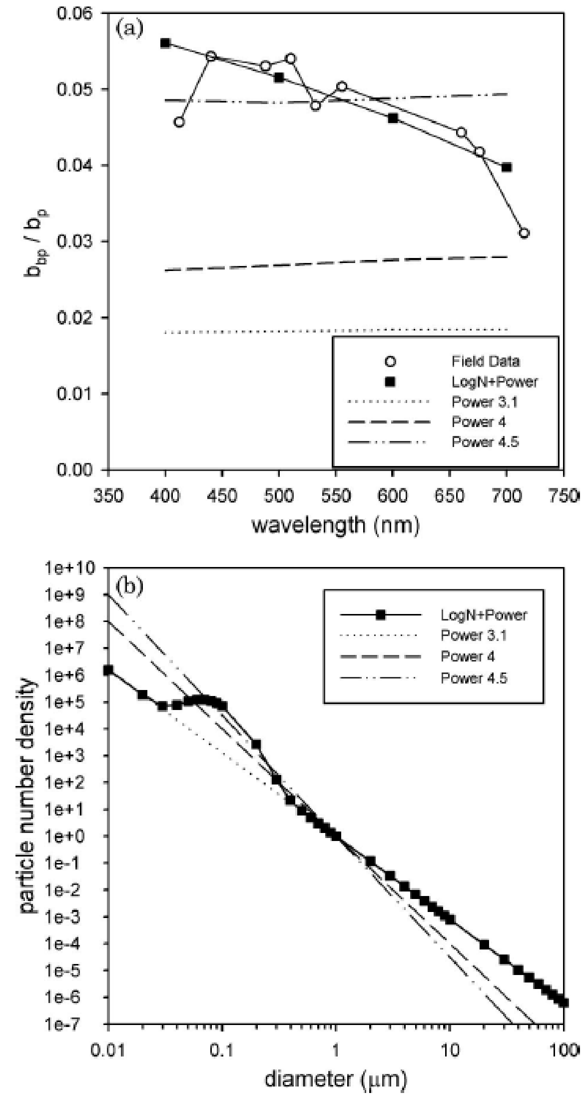


Fig. 9. Particulate backscattering spectra modeled by Mie theory for power-law size distributions with constant values of real and imaginary refractive index (dashed and dotted curves) exhibit no significant spectral variability. Introducing a separate mode (lognormal in this case) of particles is enough to introduce significant wavelength dependence in the b_{bp}/b_p spectrum (squares). b_{bp}/b_p from regression analysis of field data (circles) is shown for an order of magnitude comparison, but there are insufficient data available to perform a full theoretical validation of the field values of b_{bp}/b_p.

Power law PSDs and backscattering

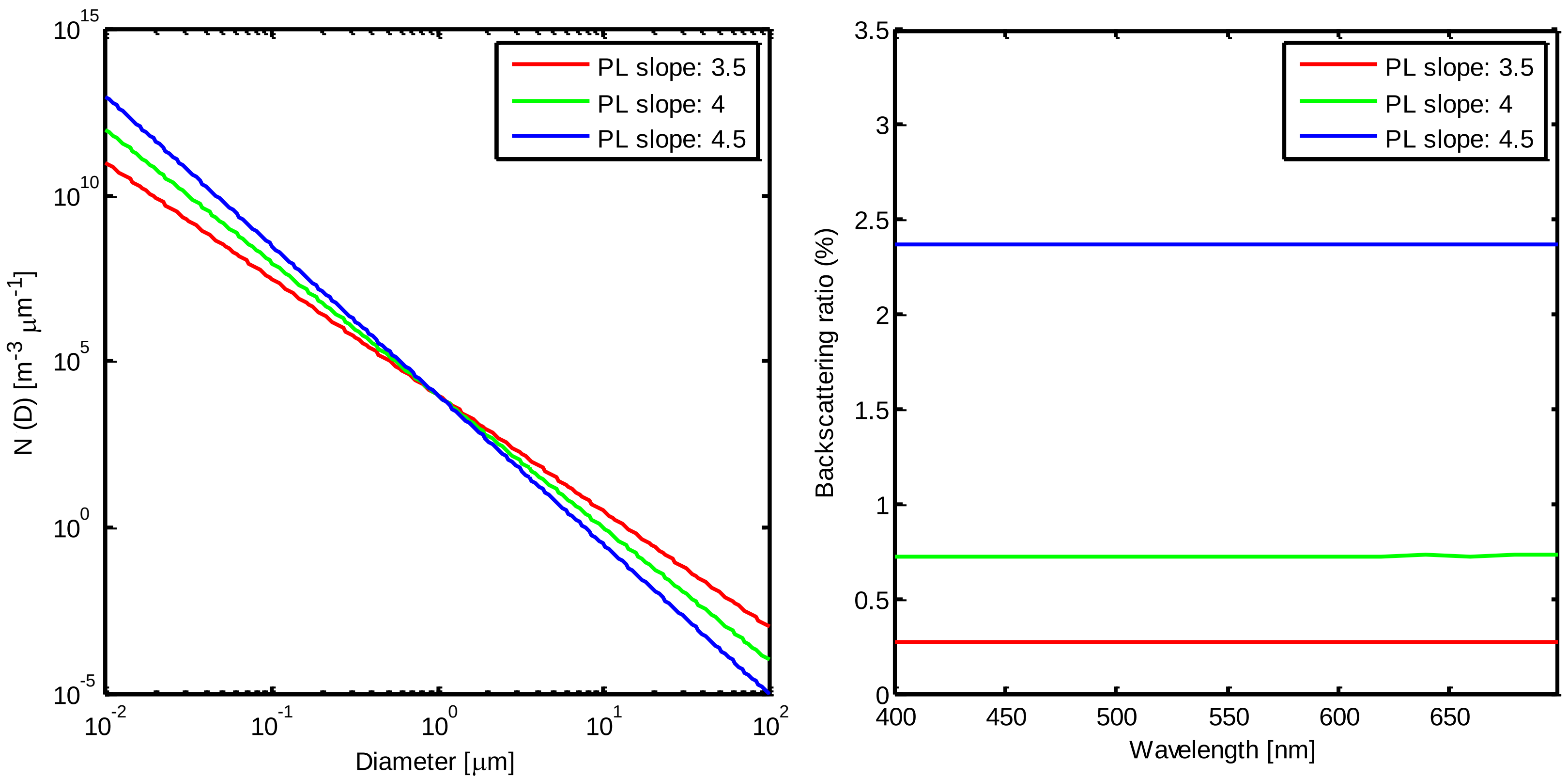
Some questions…

Why does a power law PSD, uniform refractive index and Mie theory give spectrally flat b_{bp}/b_p?

How sensitive is this (very useful) result to deviations in the assumptions?

Are there circumstances where we might predict anomalous scattering properties?

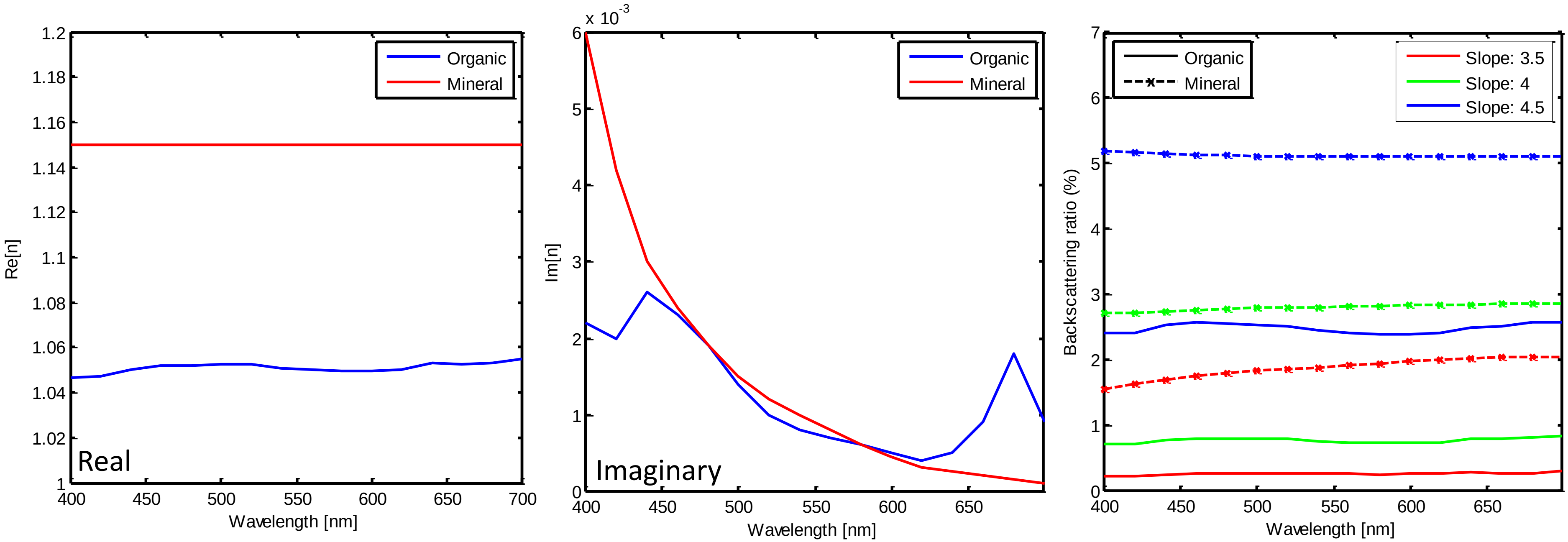
Mie model validation



Using “Fastmie.m” (Slade et al. 2005) implementation of BHMIE code for engine.

Can reproduce Ulloa et al. results…

Mie model inputs - refractive indices



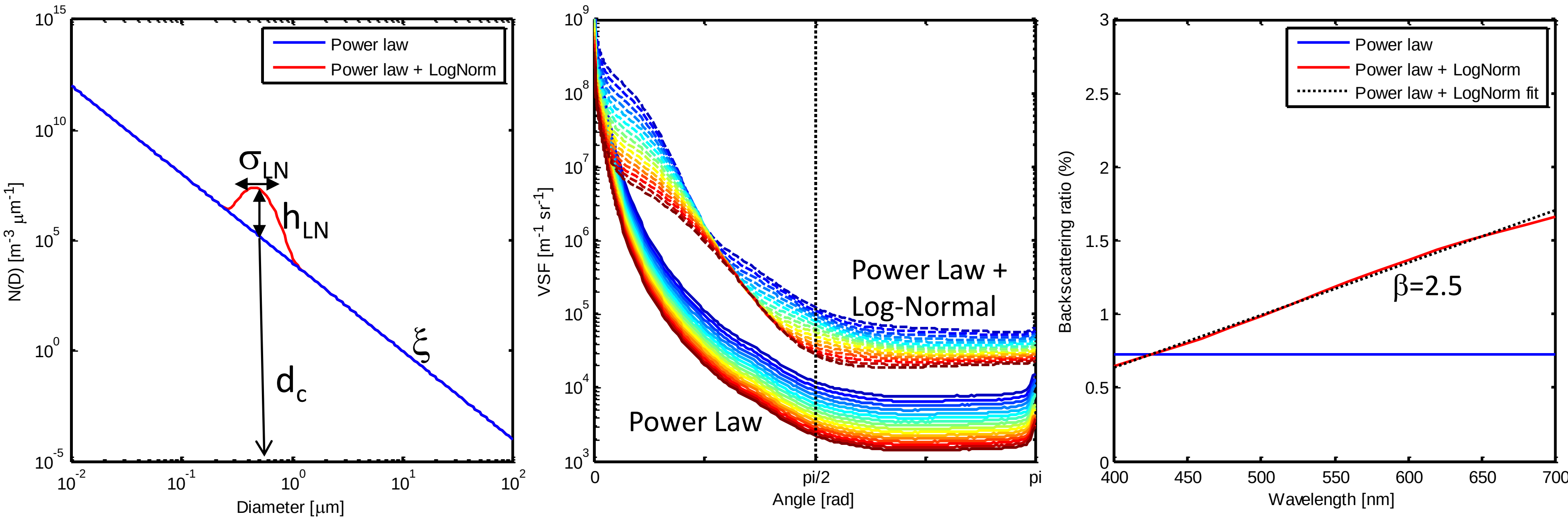
Real and imaginary refractive indices for organic and inorganic materials from literature[1,2].

Complex refractive index introduces small element of wavelength dependence in spectral b_{bp}/b_p.

Not enough to explain significant spectral b_{bp}/b_p found in previous study[3].

1. Stramski et al. Appl. Opt. 27, 3954-3956 (1988) .
2. Babin et al. Limnol. Oceangr. 48 (2), 843-859 (2003).
3. McKee et al. Appl. Opt. 48(24), 4663-4675 (2009).

Mie model inputs - power law + log-normal



Power Law PSD represents summation of approx. log-normal sub-populations.

Deviation from Power Law background potentially due to e.g. algal bloom or local mineral resuspension.

Additional Log-Normal added to Power Law gives fairly crude environmental representation.

Power Law PSD characterized by slope parameter, ξ.

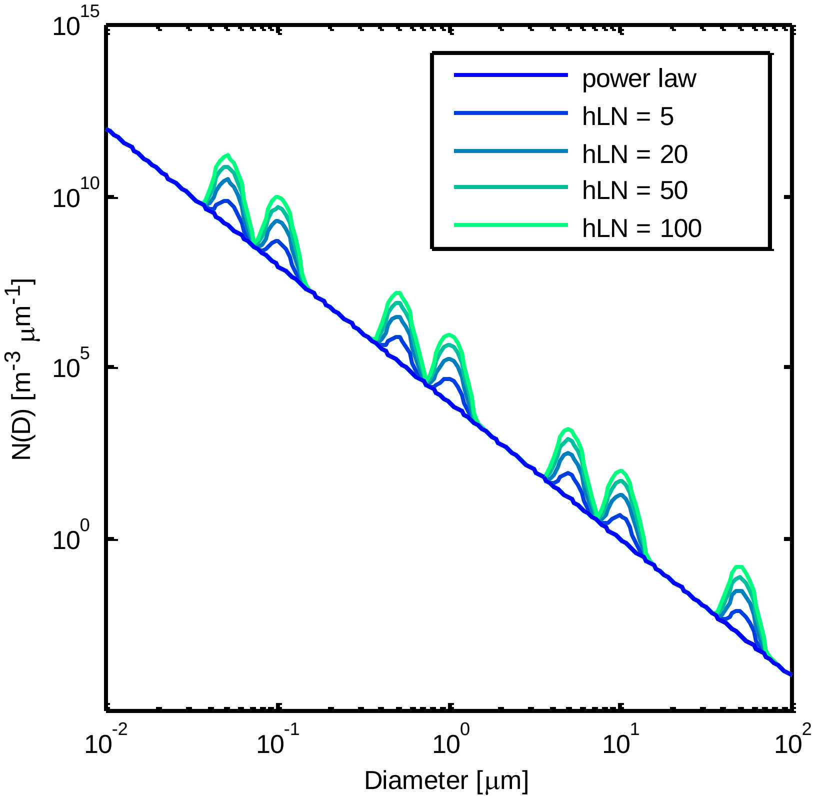
Log-Normal PSD characterized by: central diameter, d_c, peak height, h_{LN}, and peak width, σ_{LN}.

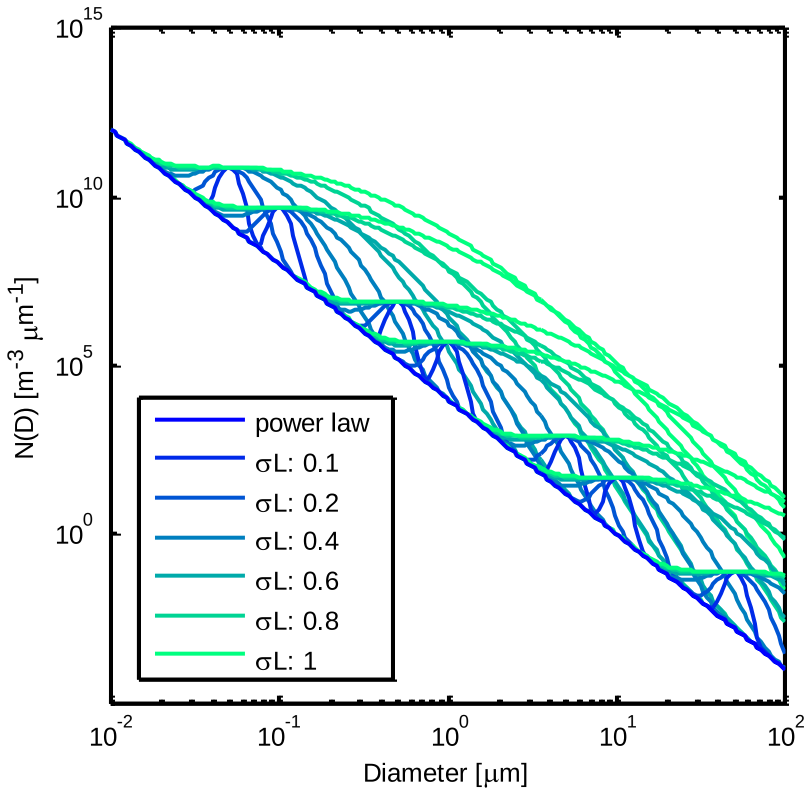
Peak height is expressed as a factor of the Power Law PSD value at the equivalent d_c.

Power Law PSD gives spectrally varying VSF, but spectrally flat backscattering ratio.

Additional Log-Normal induces spectral dependence in backscattering ratio - characterized by a best-fit gradient, β.

Mie model inputs - varying log-normal contributions

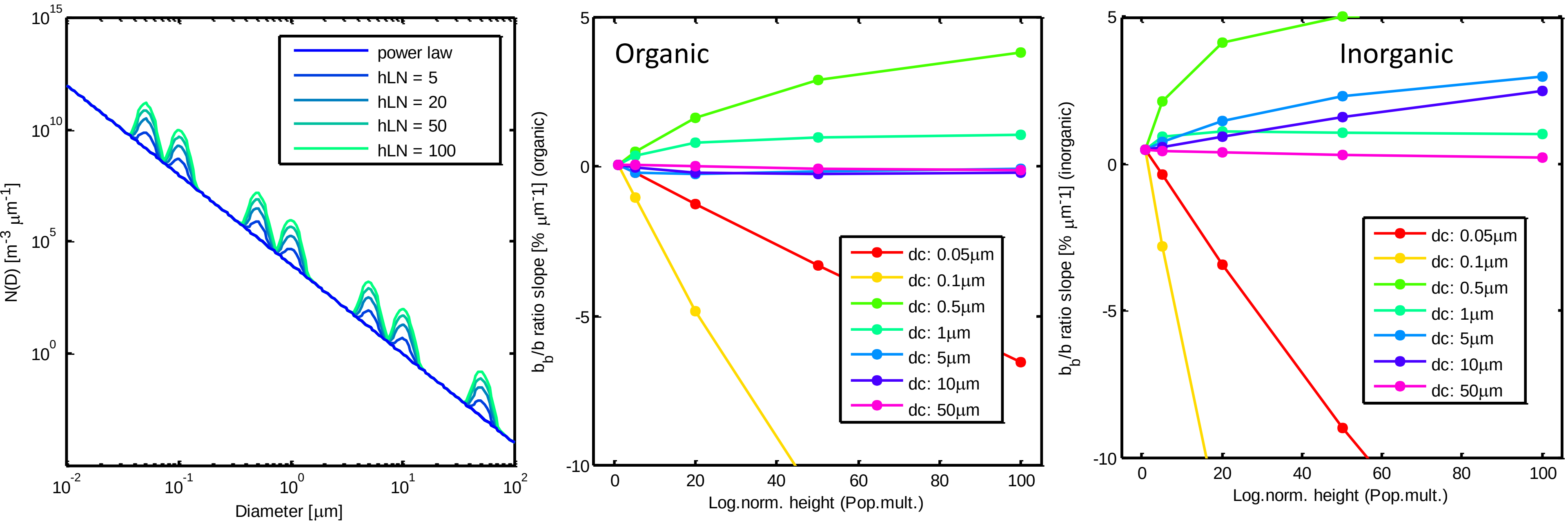




For any given d_c, we can systematically vary the height (h_{LN}) or the width (s_{LN})

Want to observe *trends* more than simulate specific environments…

Effect of log-normal height on spectral b_{bp}/b_p



550nm

Strong sensitivity to introduction of small (submicron) particles.

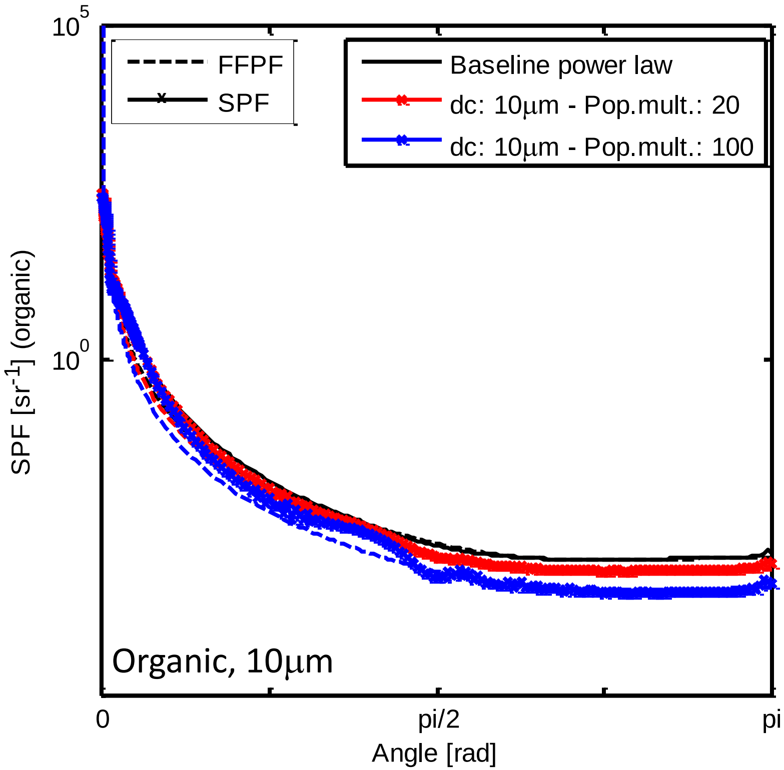
Low sensitivity to large organic particles (> 5 μm).

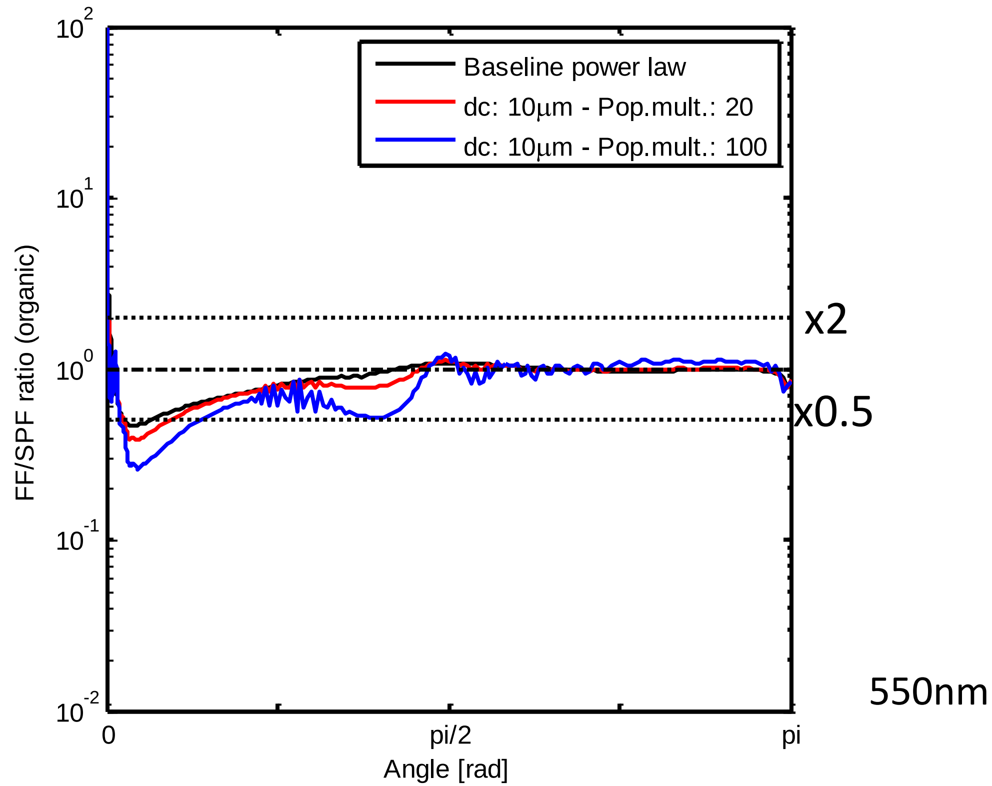
Generally slightly more sensitive to inorganic particles.

Backscattering ratio spectral slope in both positive and negative directions.

(Not shown here) – β decreases with increasing σ_{LN}.

Effect of log-normal height on VSF shape



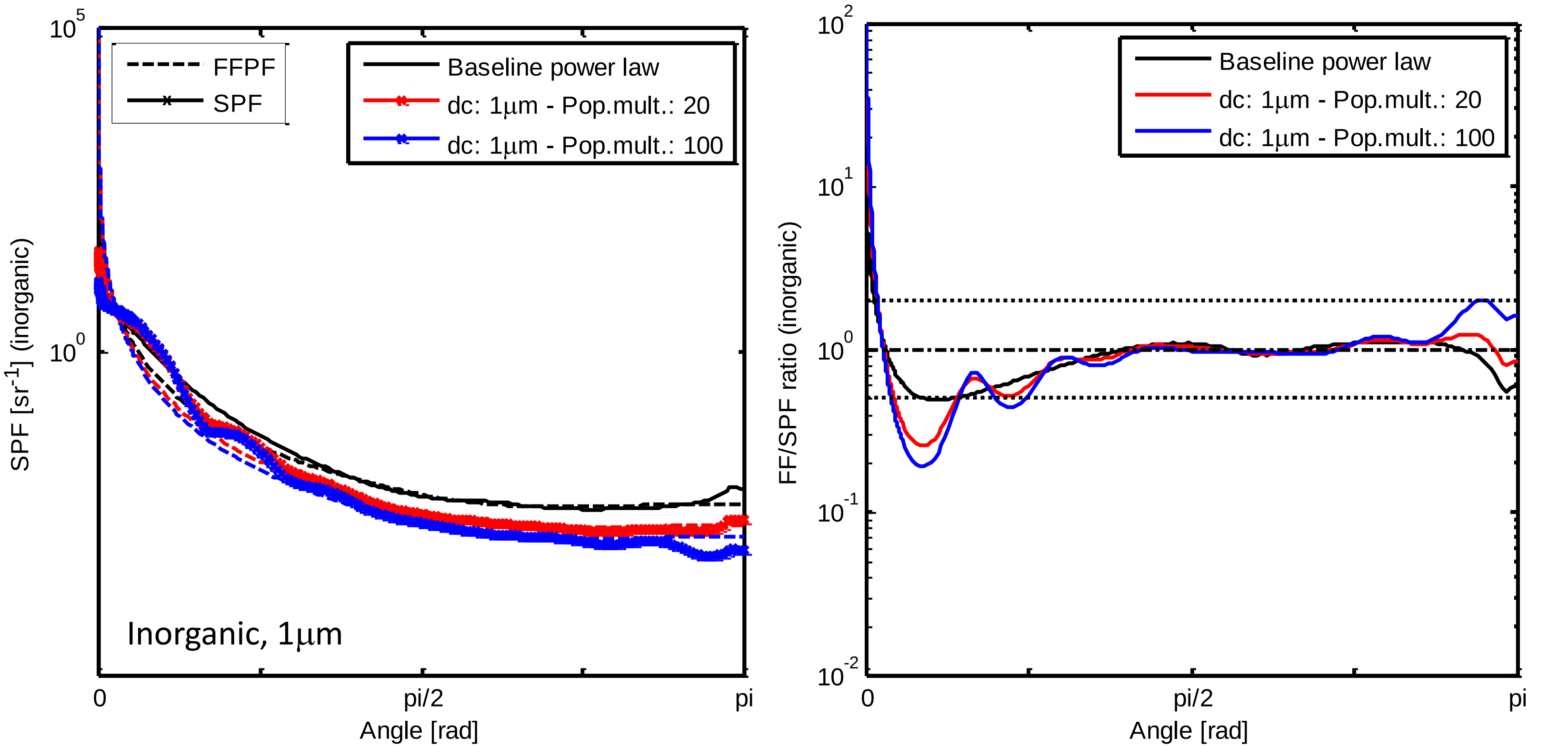


Comparing Mie model outputs with Fournier-Forand phase functions with equivalent b_{bp}/b_p.

Power law PSD does not give exact match with FF, even with same slope and refractive index.

Increasing log-normal height with 10μm organic particles mainly affects forward scattering.

Effect of log-normal height on VSF shape

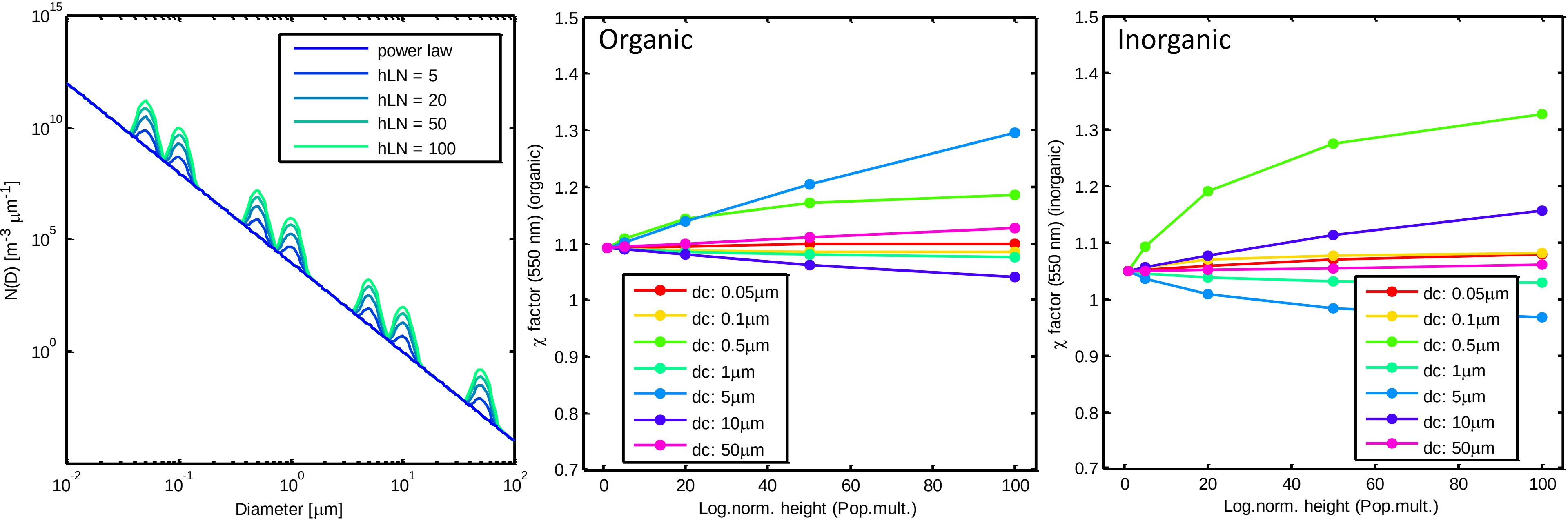


550nm

Increasing log-normal height with 1μm inorganic particles affects both forward and backward scattering.

Are there implications for χ factor for backscattering measurements?

Effect of log-normal height on χ



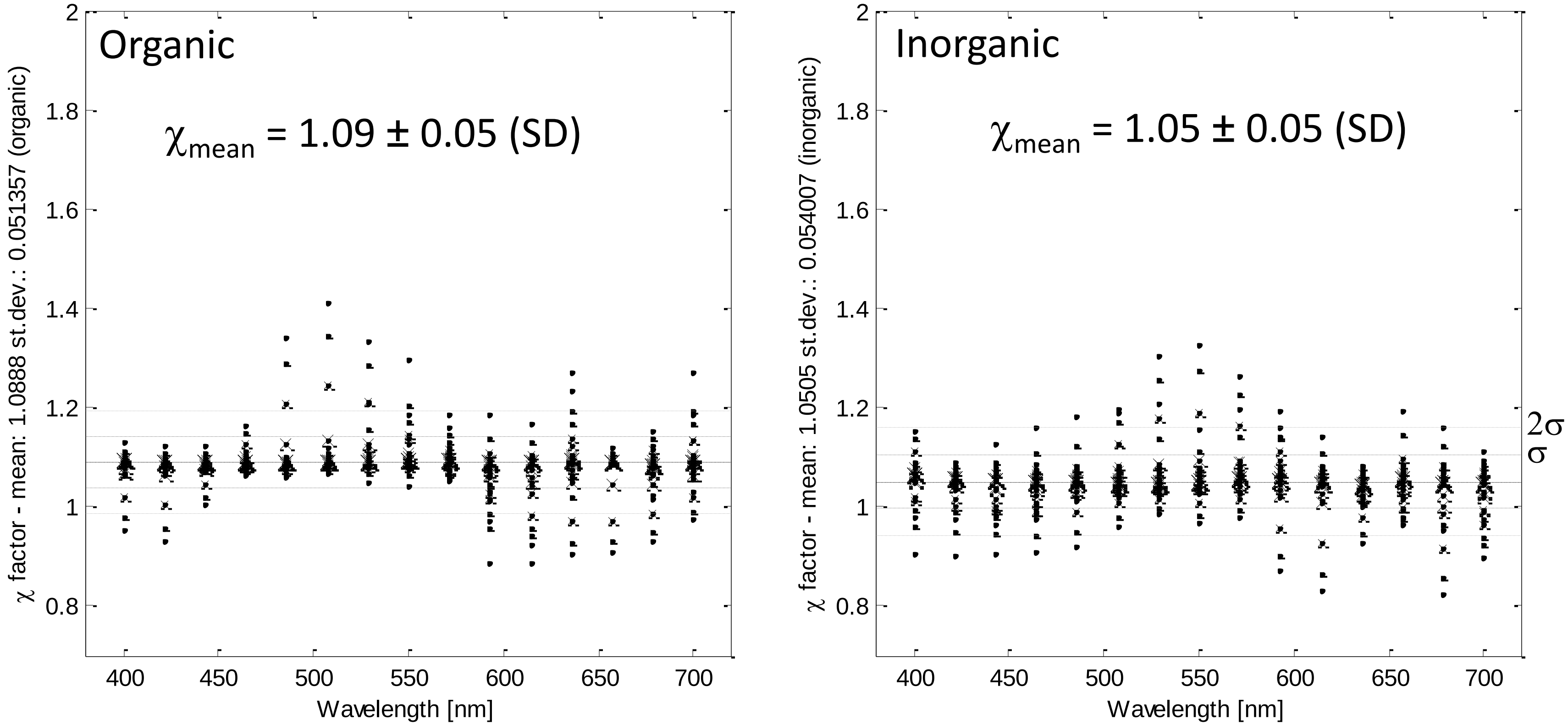
550nm

Power law PSD and organic particles: χ = 1.09

Power law PSD and inorganic particles: χ = 1.05

χ appears to be particularly sensitive to ~0.5µm and 5-10 µm log-normal populations for both organic and inorganic particles.

Effect of log-normal height on spectral χ



Symbol size inversely proportional to h_{LN} i.e. large symbols more probable.

Increasing h_{LN} induces spectral variability in χ, but low for most probable cases.

χ generally lower for inorganic particles than organic.

Deviation from power law PSDs: effect on backscattering

Observations:

Deviations from power law PSD can induce significant effects on: spectral variability of b_{bp}/b_p, angular shape of VSF, and χ.

FF phase functions do not exactly match Mie theory with power law PSD and equivalent refractive indices.

Is this significant for this analysis?
Is one more appropriate than the other?

The χ factor appears to vary with refractive index, even for power law PSDs (1.09 – 1.05).

Limited potential for wavelength dependence in χ.

Other Considerations:

χ calculated for 117° only: need to consider angular weighting for specific sensors?

Are there better approaches to model more realistic PSDs e.g. Riscovic?

Strong blooms (also algal cultures) and mineral resuspension events could pose problems for standard processing approaches.