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Statistical Parametrization of the Backscattering Properties of Snowflakes

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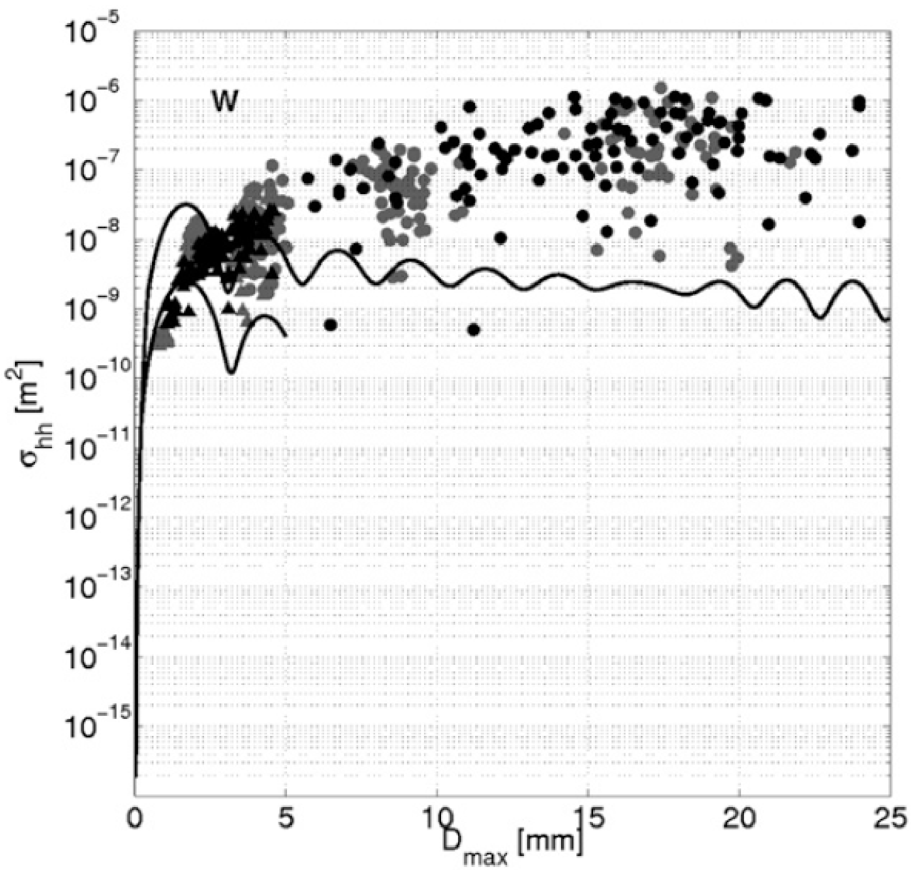
Backscatter from snowflakes

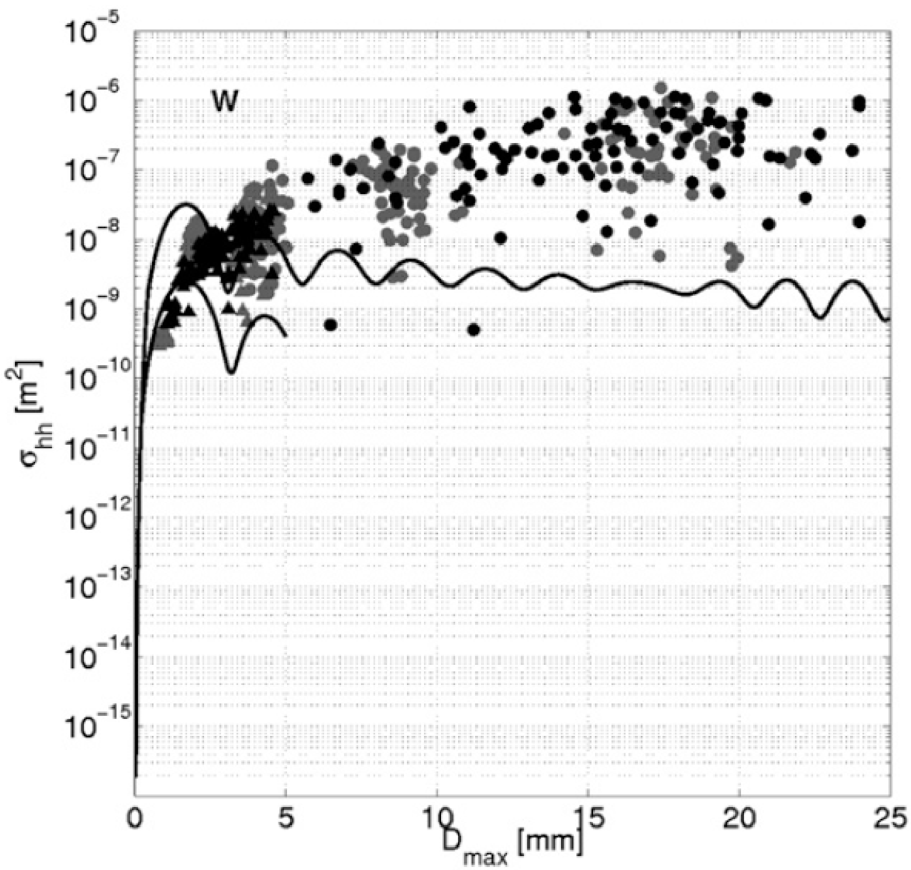
- **Sphere/spheroid models are sometimes incompatible with observations at mm-wavelengths**
- **In many cases, spheroid models still work**



Source: Tyynelä et al. (2012)

Backscatter from snowflakes

- **Sphere/spheroid models are sometimes incompatible with observations at mm-wavelengths**
- **In many cases, spheroid models still work**
- **What causes these differences and how to understand them?**



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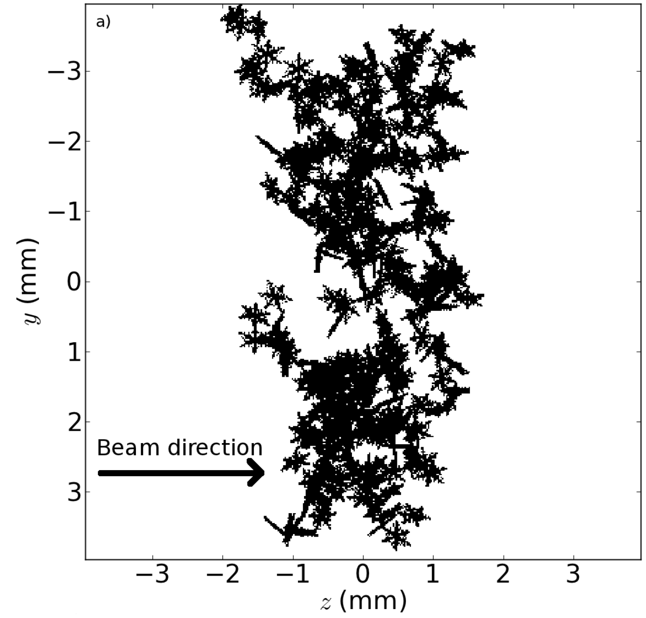
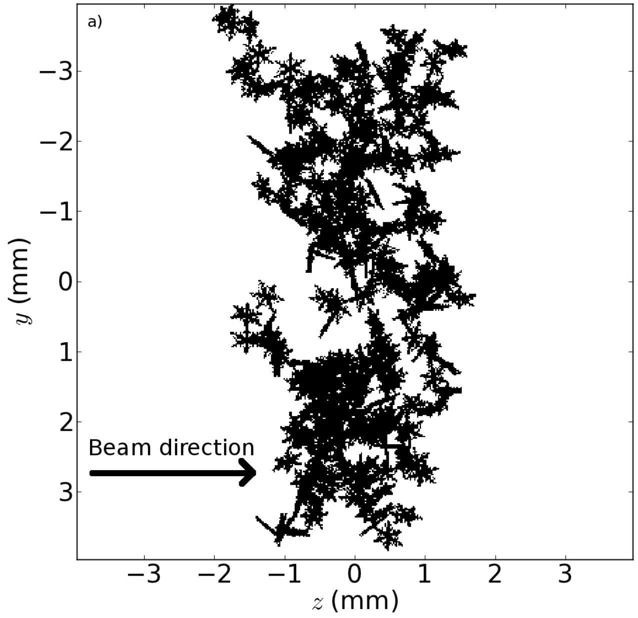
Backscatter from snowflakes

- **Snowflakes are complex shapes, so the scattering from one snowflake is a complicated process**

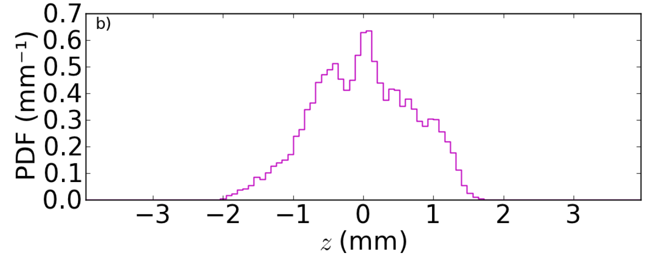


Backscatter from snowflakes

- **Snowflakes are complex shapes, so the scattering from one snowflake is a complicated process**

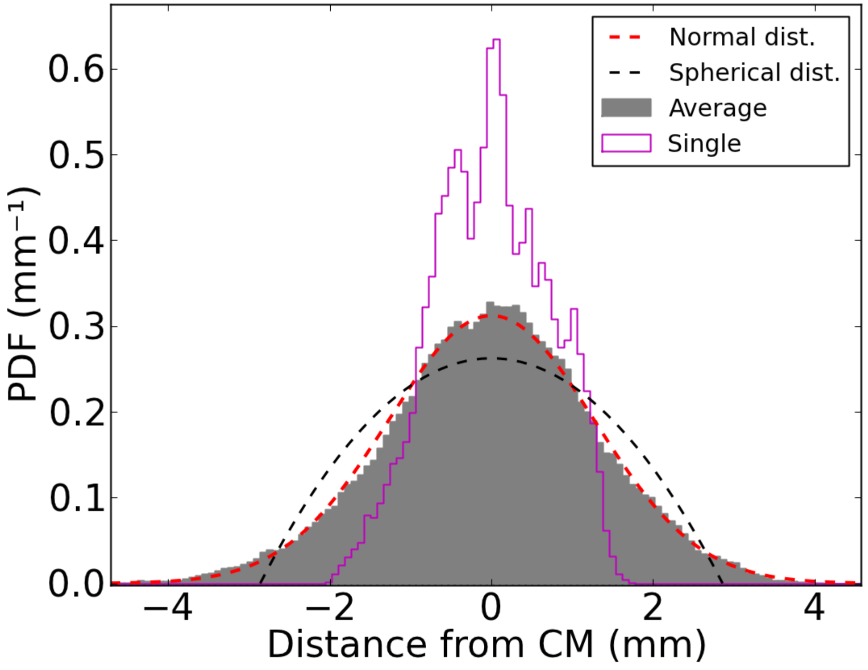


- **The ice density is distributed unevenly**



Averaging

- **For radar studies, we only need to know the average backscattering**
- **On average, the mass is normally distributed**
- **...but what is the correct quantity for averaging the particle shape?**

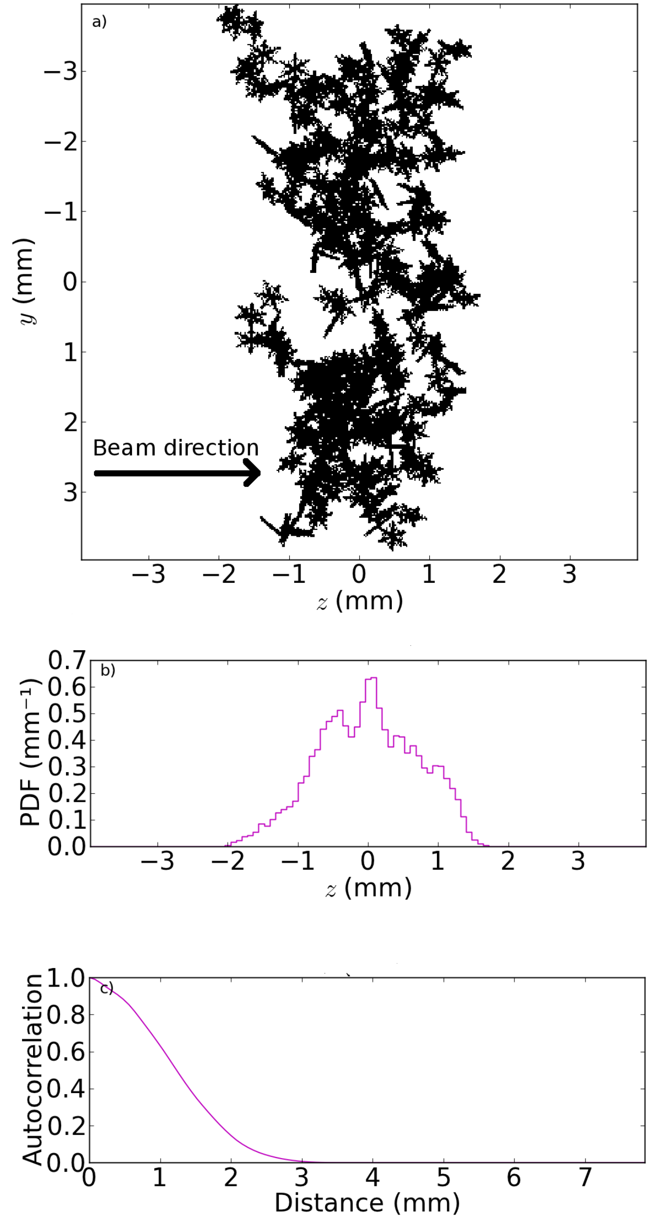


Backscatter from snowflakes

- **Snowflakes are complex shapes, so the scattering from one snowflake is a complicated process**

- **The ice density is distributed unevenly**

- **The density autocorrelation carries information about the structure of the snowflake**



Autocorrelation

- **Use Rayleigh-Gans scattering theory**
- **Result: the density autocorrelation function should be averaged**

Autocorrelation and backscattering

- **Use Rayleigh-Gans scattering theory**
- **Result: the density autocorrelation function should be averaged**
- **Result: the change in radar reflectivity as a function of frequency is given by the Fourier transform of the autocorrelation function**

$$\langle Z(k) \rangle = \int_{-\infty}^{\infty} R(z)\, exp(-2jkz)\, dz$$

- **Analogy: autocorrelation function and power spectral density in signal processing**
- **Understanding the autocorrelation function → understanding the radar backscattering**

Autocorrelation and backscattering

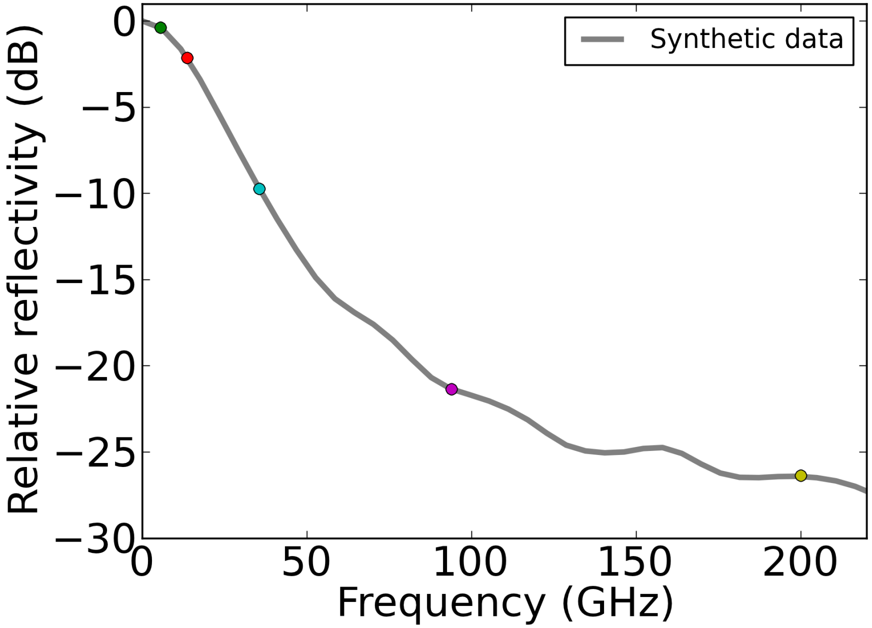
- **Our aggregate model suggests a mixture-of-Gaussians average autocorrelation function**
- **One Gaussian (large weight) for the whole aggregate, another (small weight) for the mass clusters**

$$\langle R(z) \rangle = \frac{N^2 - N}{N^2} \frac{1}{\sqrt{4\pi(\sigma_m^2 + \sigma_a^2)}} \exp\left(-\frac{z^2}{4(\sigma_m^2 + \sigma_a^2)}\right) + \frac{N}{N^2} \frac{1}{\sqrt{4\pi\sigma_m^2}} \exp\left(-\frac{z^2}{4\sigma_m^2}\right)$$

- **Then, the radar reflectivity also follows a mixture-of-Gaussians curve**
- **The individual-crystal term is only significant at large size-wavelength ratios**

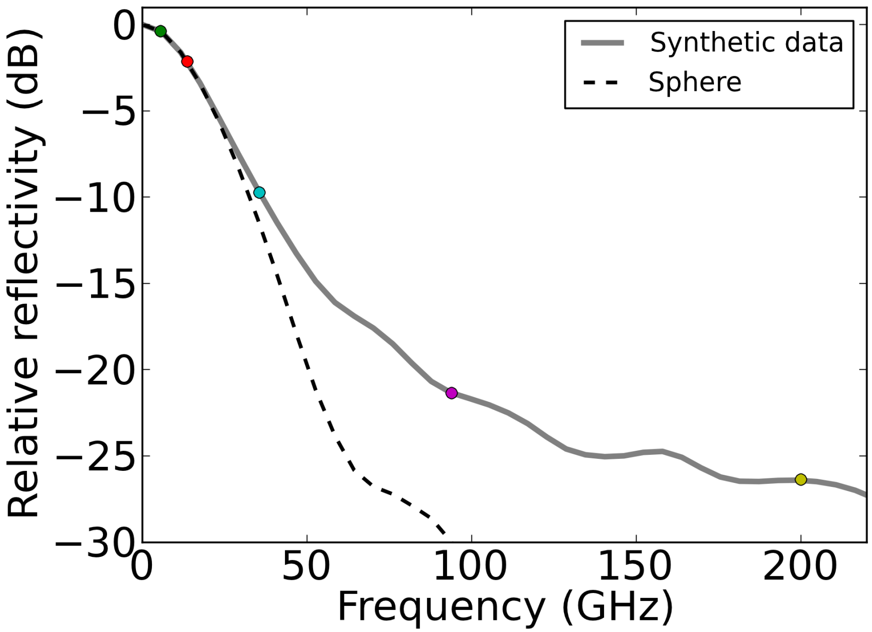
Change of reflectivity with frequency

- **From synthetic data (average of 50)**



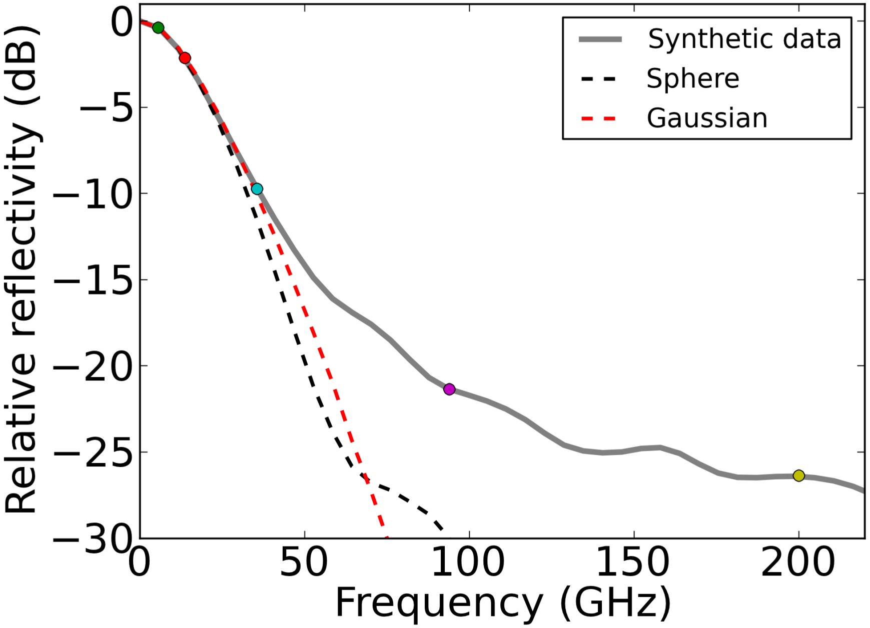
Change of reflectivity with frequency

- From synthetic data (average of 50)
- **Modeled using spheres**



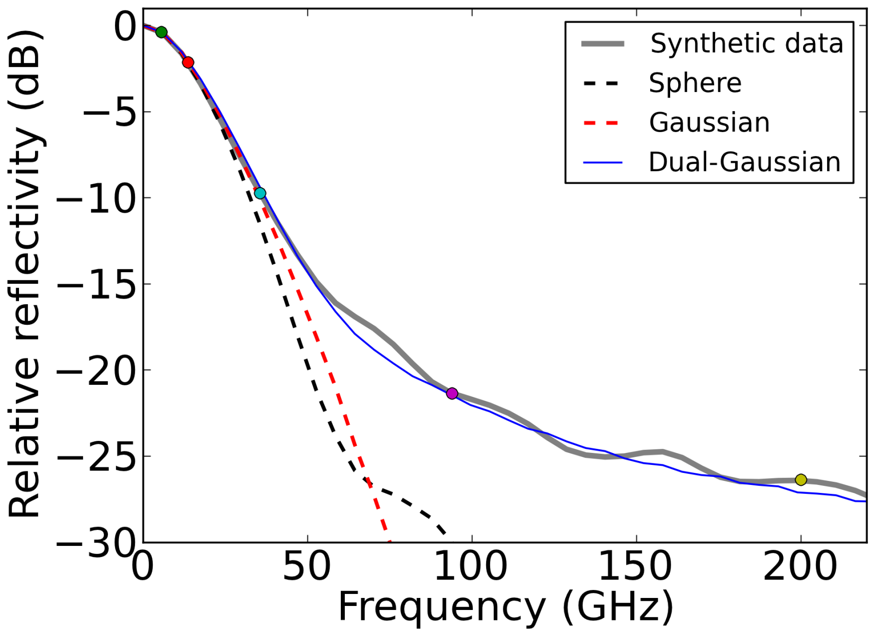
Change of reflectivity with frequency

- From synthetic data (average of 50)
- Modeled with spheres
- **Modeled using the Gaussian function**



Change of reflectivity with frequency

- From synthetic data (average of 50)
- Modeled with spheres
- Modeled using the Gaussian function
- **Modeled with mixture-of-Gaussians parametrization**



Summary

- Sphere/spheroid and Gaussian models of aggregate snowflakes work well at low frequencies
- These models may fail at higher frequencies (W-band, Ka-band for the largest snowflakes)
- This failure can be explained in terms of the effect of individual mass clusters on the autocorrelation function
- Analysis suggests a mixture-of-Gaussians model where one term corresponds to the aggregate structure and another to the individual crystals