Radar Observable Simulations:

Interpretation in terms of near-surface physical properties of asteroids

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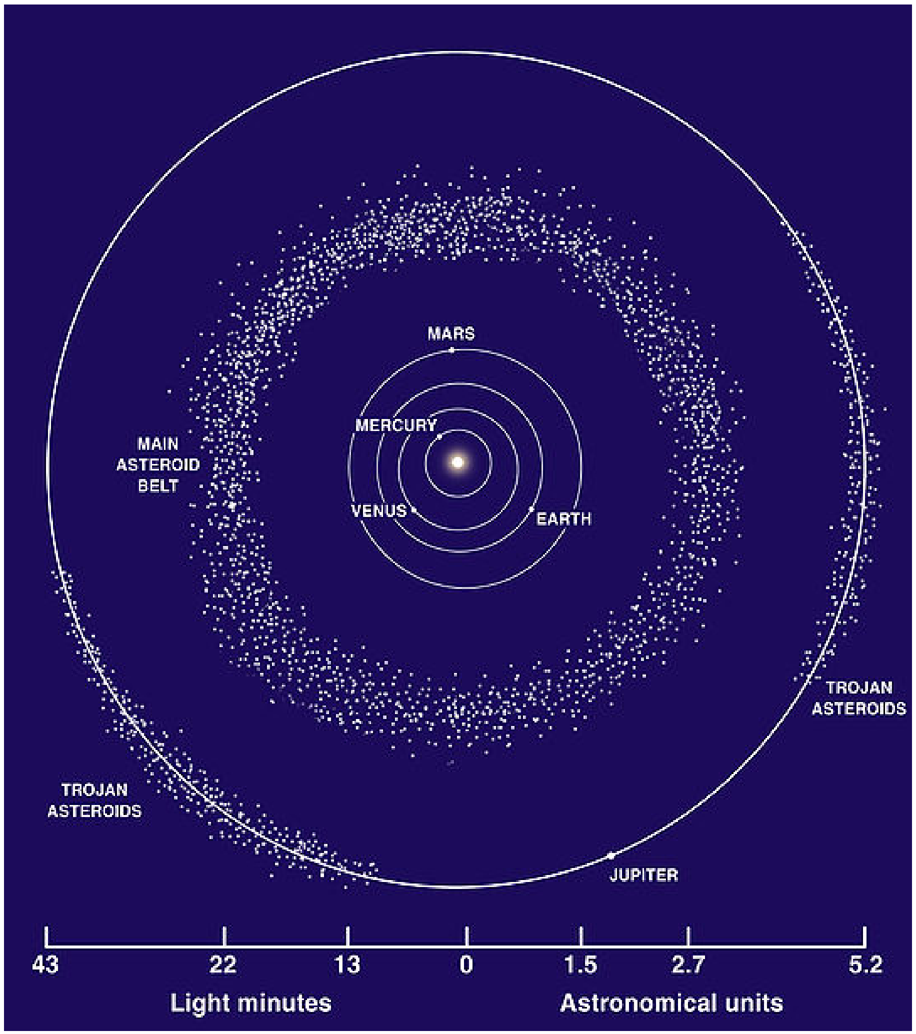
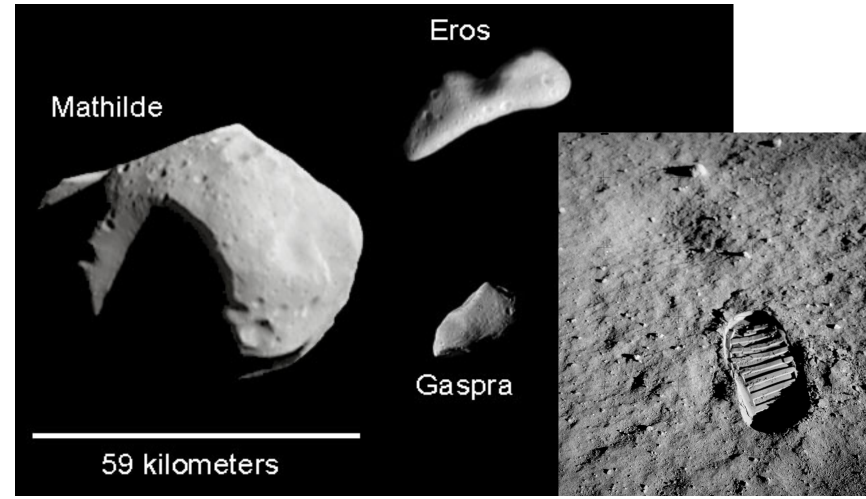
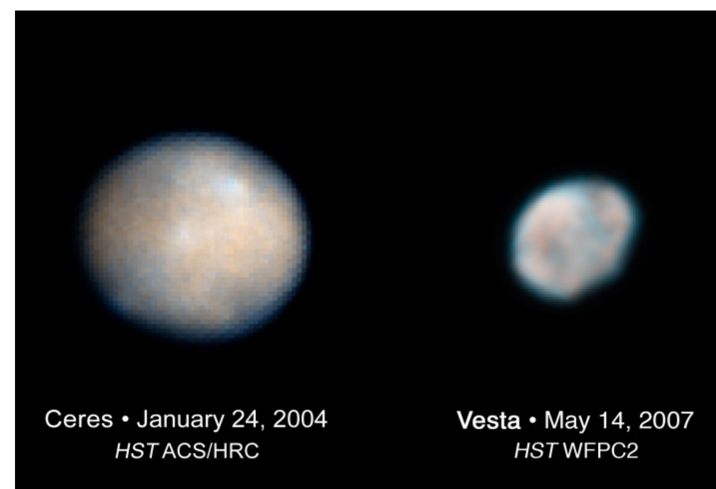
Background


MARS
MERCURY
MAIN ASTEROID BELT
VENUS
EARTH
TROJAN ASTEROIDS
TROJAN ASTEROIDS
JUPITER
43
22
13
0
1.5
2.7
5.2
Light minutes
Astronomical units


Eros
Mathilde
Gaspra
59 kilometers


Ceres • January 24, 2004
HST ACS/HRC
Vesta • May 14, 2007
HST WFPC2

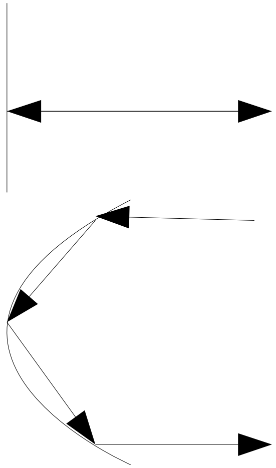
Background

- Radar measures
  - distance (distribution of echo power in time delay)
  - velocity (Doppler frequency)
- Transmits and receives fully circularly polarized waves
- Received waves are polarized in the same sense (SC) or in the opposite sense (OC) to the transmitted wave

$$\mu = \frac{SC}{OC}$$

Background

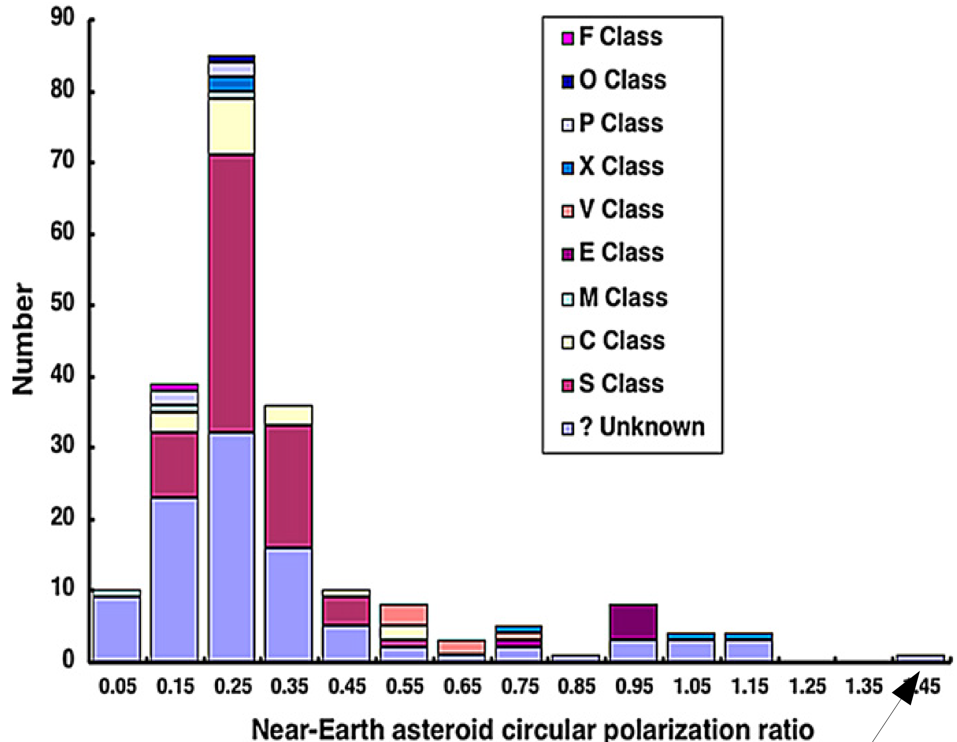
- Wavelength-scale roughness of a surface can be determined using the SC/OC ratio
  - smooth surface causes a complete turn in the handedness
  - rough surfaces do not, due to multiple scattering



- But *how* does the wave interact with the medium?
  - surface roughness not the only contributor? (Mishchenko & Hovenier, 1995)
  - Effect of electric permittivity not fully established

Background

- Typical radar transmitter frequencies are 2.38 GHz (S-band, λ=12.6 cm) and 8.46 GHz (X-band, λ=3.6 cm)
- Limited data available on refractive indices of asteroid material at microwave frequencies
- Different taxonomic classes produce different μ-value → the effect of the refractive index?



The maximum value for asteroids observed using radar is $\mu = 1.48 \pm 0.4$ for the asteroid 2003 TH_2 (Benner et al. 2008)

Stokes parameters and polarization

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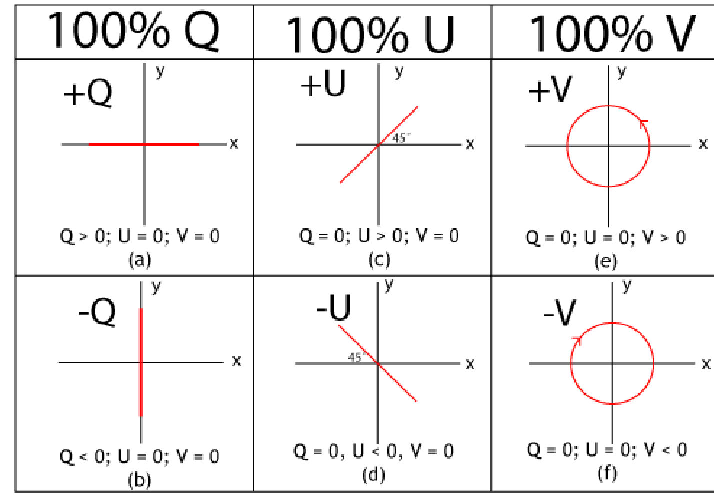
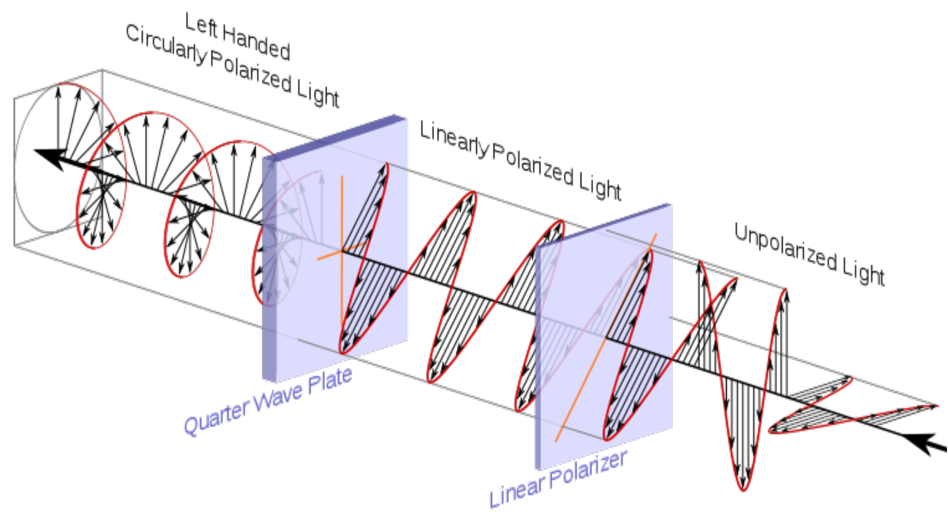
- The intensity and polarization of the electromagnetic wave:

$$I = E_{\parallel} E_{\parallel}^{\dagger} + E_{\perp} E_{\perp}^{\dagger}$$
$$Q = E_{\parallel} E_{\parallel}^{\dagger} - E_{\perp} E_{\perp}^{\dagger}$$
$$U = -E_{\parallel} E_{\perp}^{\dagger} - E_{\perp} E_{\parallel}^{\dagger}$$
$$V = i(E_{\perp} E_{\parallel}^{\dagger} - E_{\parallel} E_{\perp}^{\dagger})$$



- Relation to the scattering (phase) matrix:

$$(I, Q, U, V)^T \propto \boldsymbol{F} \cdot (I_0, Q_0, U_0, V_0)^T$$



Circular polarization ratio

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- Using Stokes vector $(1,0,0,1)^T$ backscattering circular-polarization ratio in terms of the 4x4 phase matrix elements is:

$$\mu\left(180^o\right) \approx \frac{F_{11}+F_{44}}{F_{11}-F_{44}}$$

- Always zero for single spheres

Procedure

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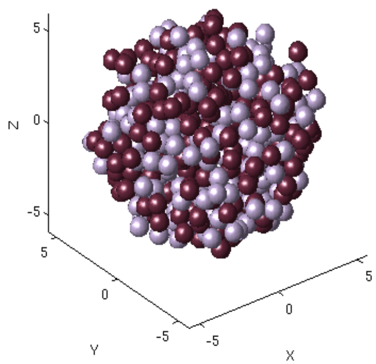
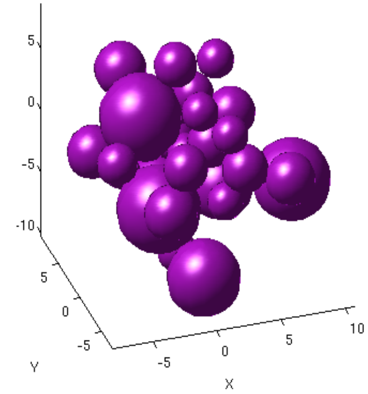
- Computation of the scattering matrix
  - multiple-sphere *T*-matrix method software (Mackowski & Mishchenko, 2011)
  - shape model: iterative ballistic clustering
- Comparison of the effects of
  - size parameters
  - refractive indices: real and complex part
  - size distribution: monodisperse (MS) vs. polydisperse spheres (PS)

MS aggregate



PS aggregate

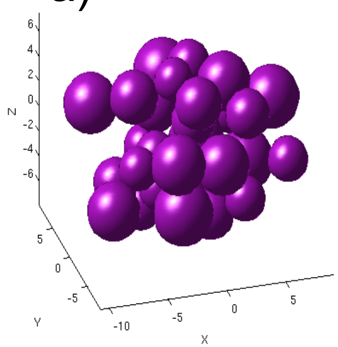


Procedure

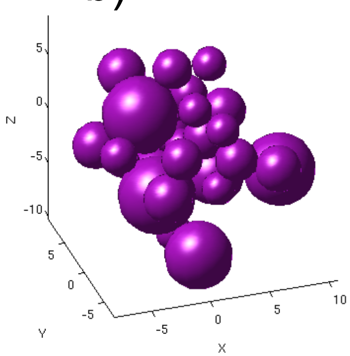
The distribution of the polydisperse sphere aggregates:

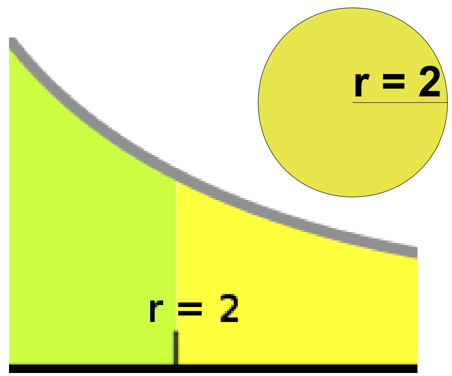
A cut power law distribution ~ r^{-3}

a)



b)





Effective radius

Width of the range of radia is
a) 1 (1.6 → 2.6)
b) 2 (1.3 → 3.3)

$$V = \frac{4}{3}\pi r^3$$

$$x = \frac{2\pi r}{\lambda}$$

The expected value of the ***volume****:*
Sum of the volumes of the polydisperse spheres
≈ sum of the volume of the monodisperse spheres

Simulation results

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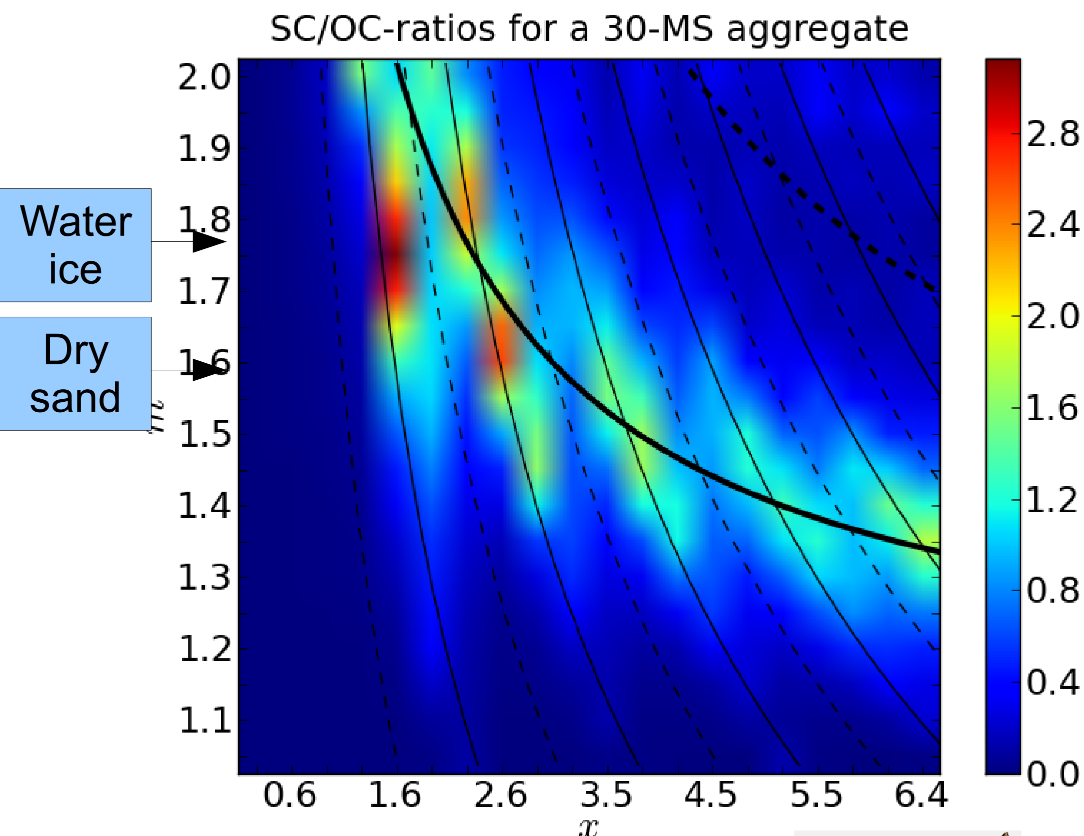



- **The primary band:** $\rho \sim 2x|m - m_e|$, where ρ is about π, for the maximum (thick solid line) and 7.7 for the minimum (thick dashed line)
- **Vertical bands:** approximately $4xm = N\pi$ where $N = 3, 5, 7...$ for the maxima and $N = 2, 4, 6...$ for the minima.

$$\mu \propto J_{n+1/2}(\rho) \quad ?$$

Simulation results

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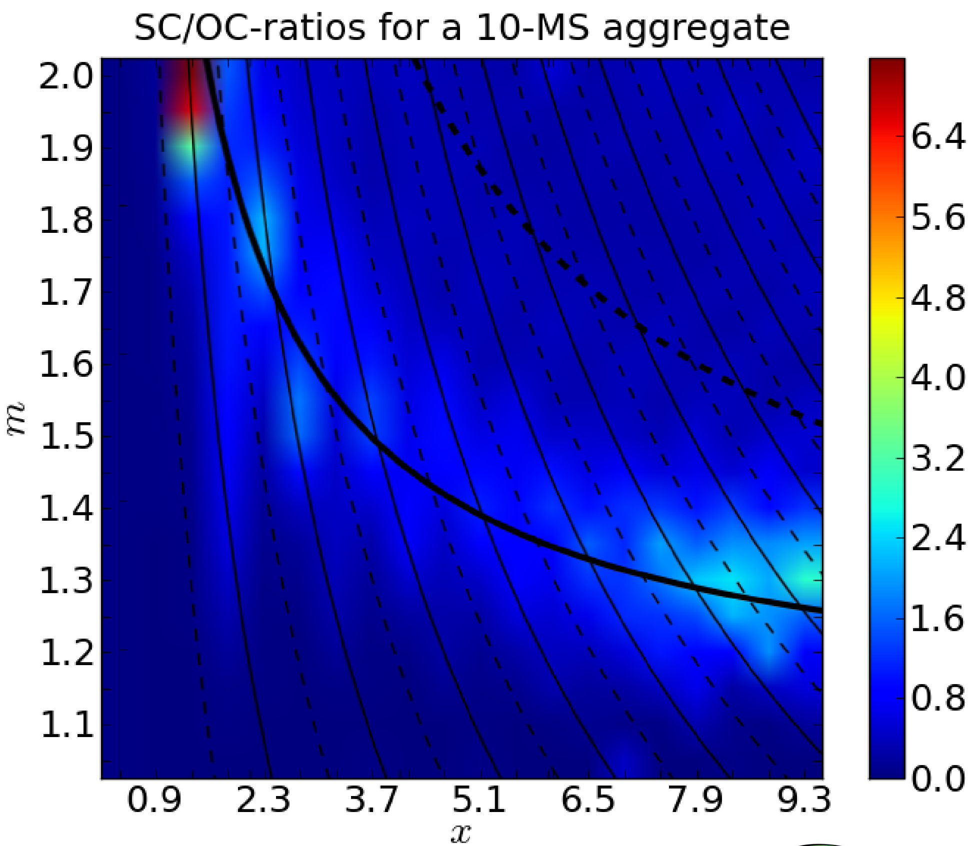
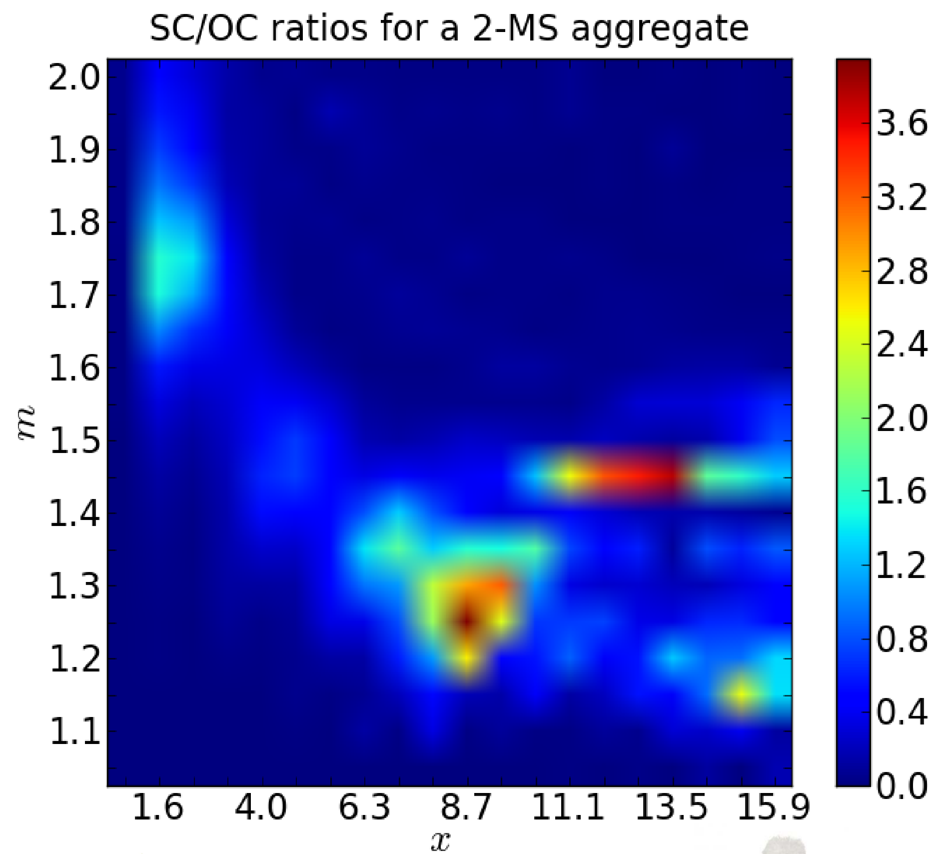
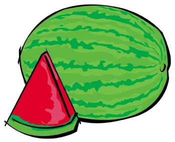
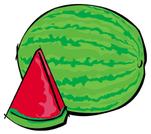
Backscattering circular-polarization ratio by aggregates of 2 and 10 monodisperse spheres



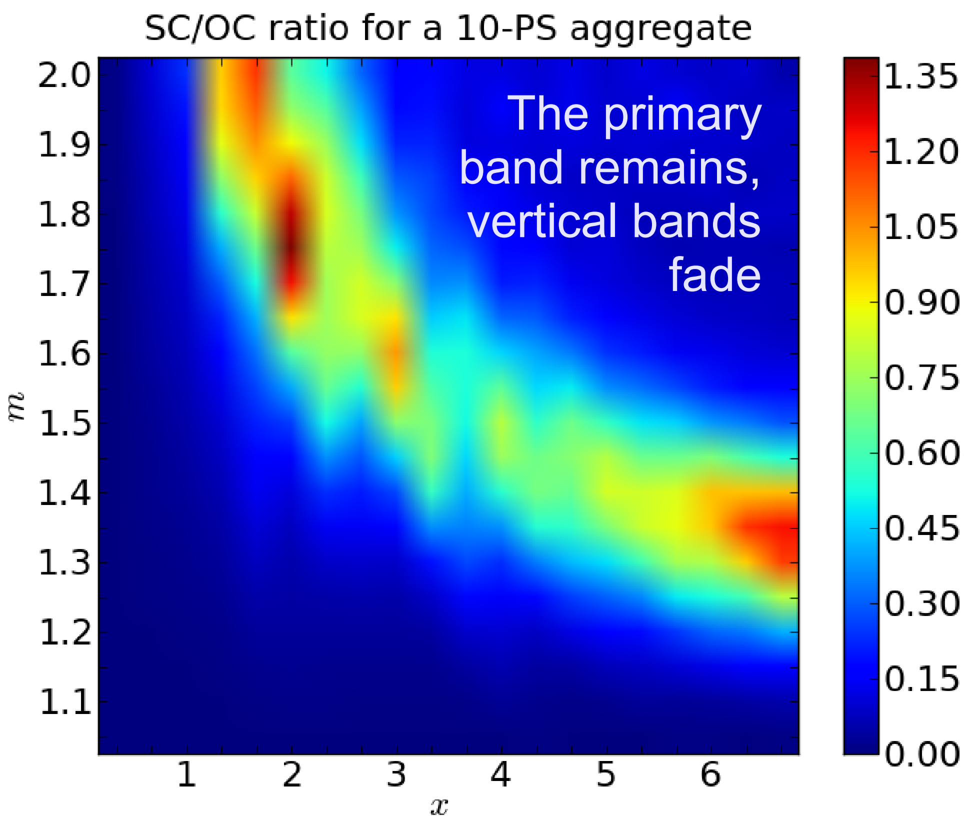


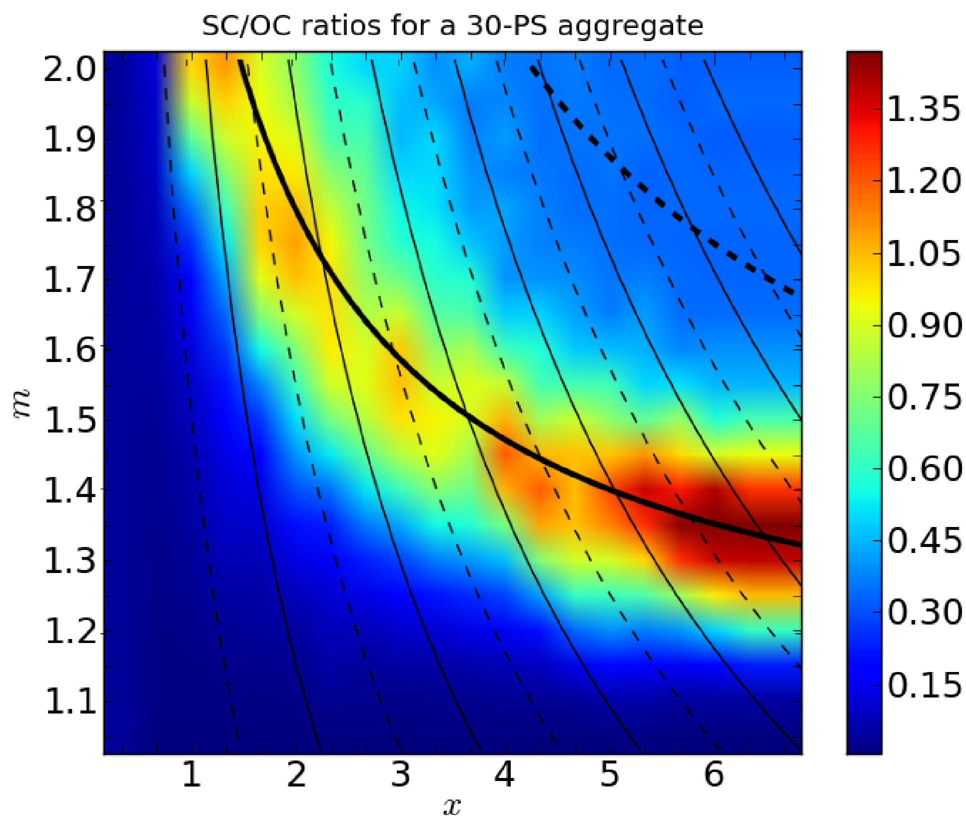




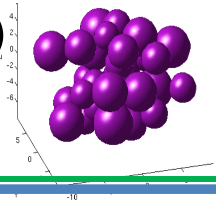
Simulation results

Effect of the size distribution



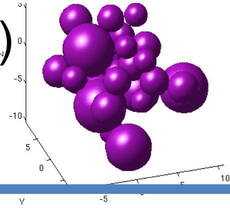


a)



Size distribution width 1

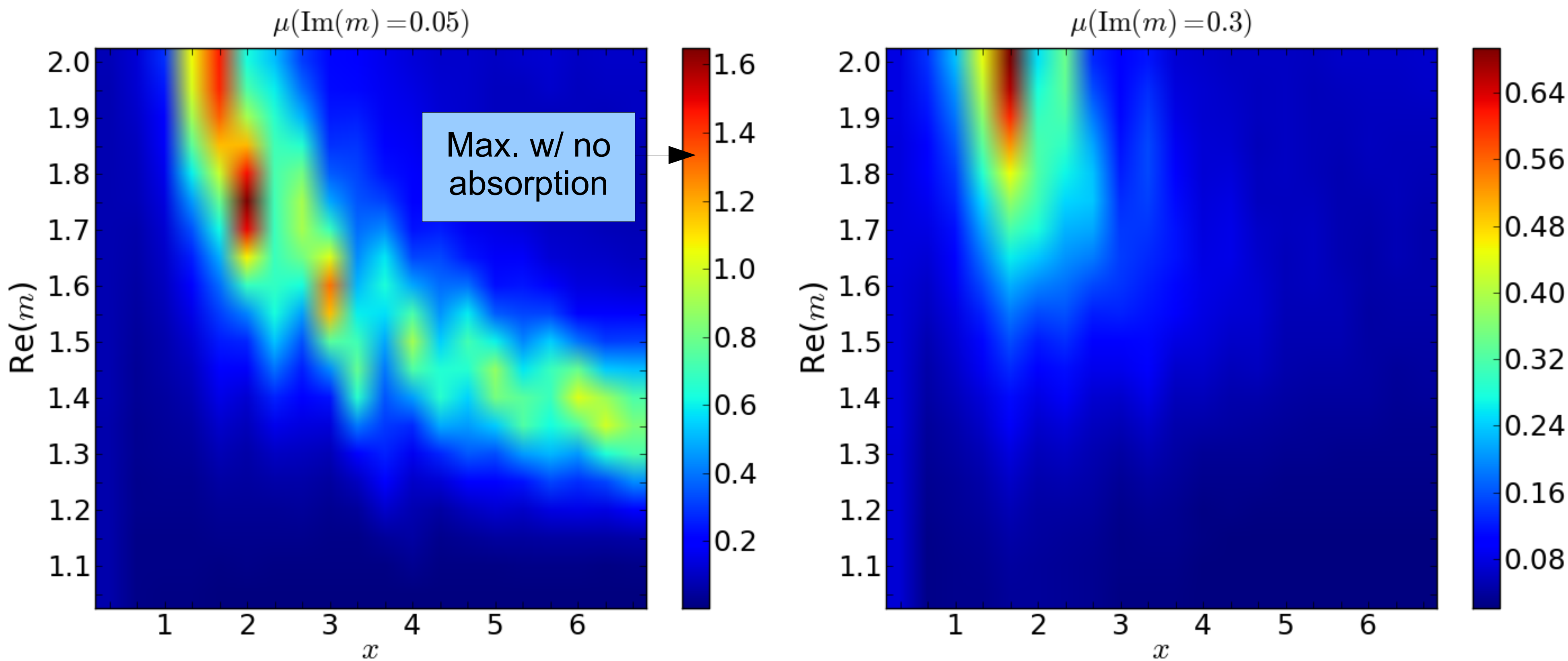
b)



Size distribution width 2

Simulation results

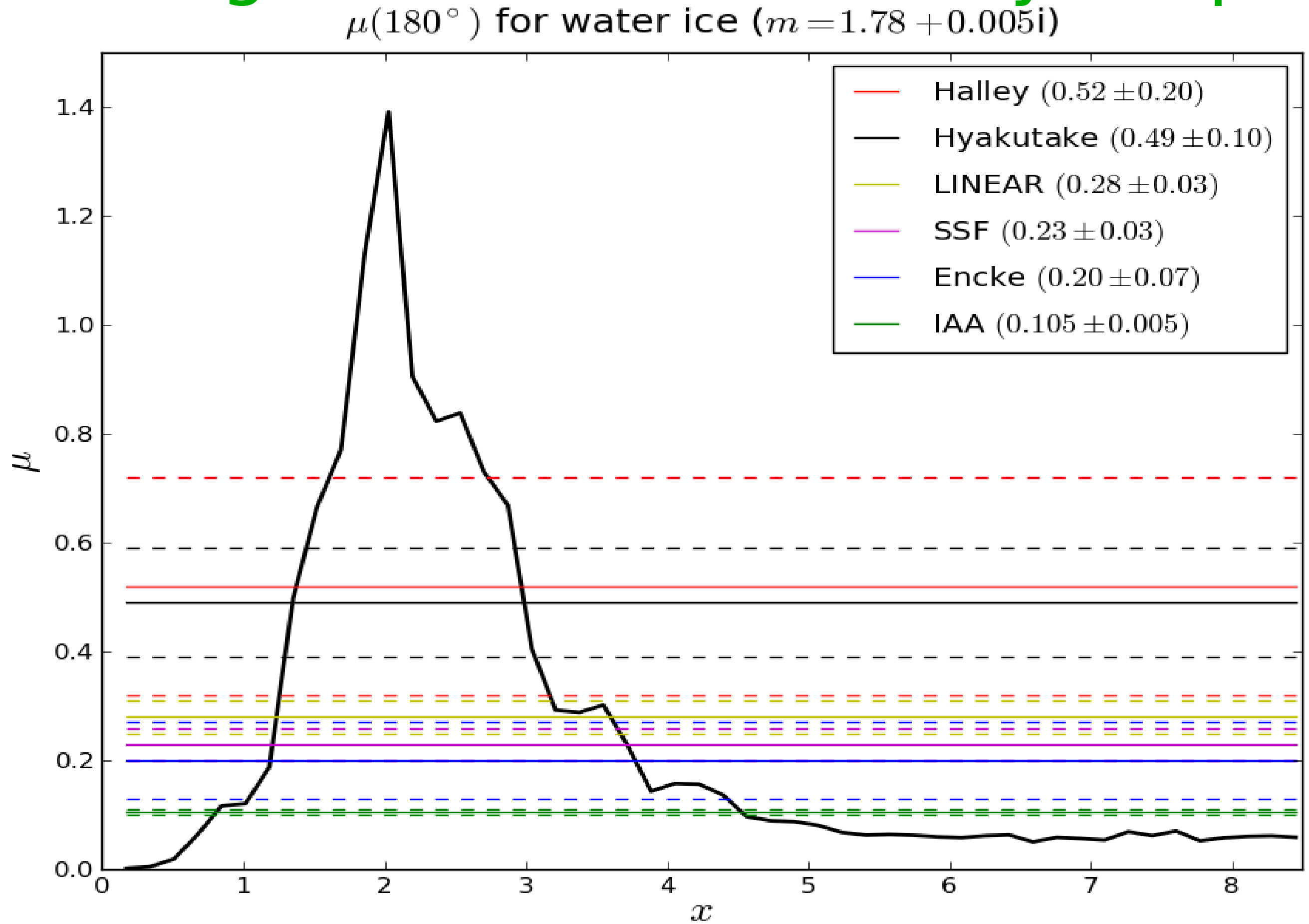
Absorbing monomers



Backscattering circular-polarization ratio by the aggregate of 10 monodisperse spheres

Example of interpretation

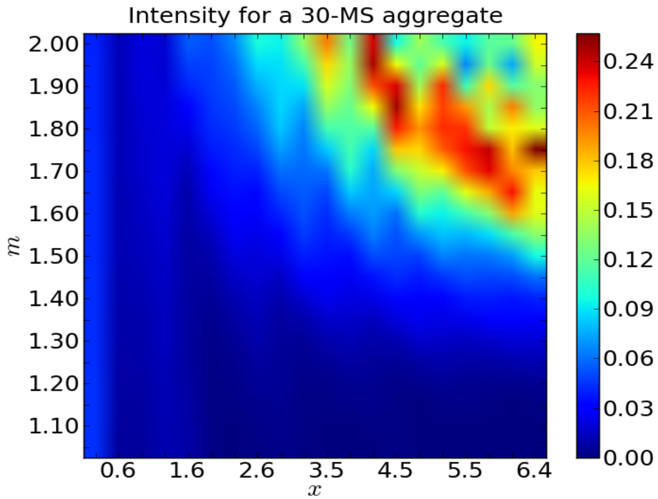
Obtaining the size of cometary ice particles

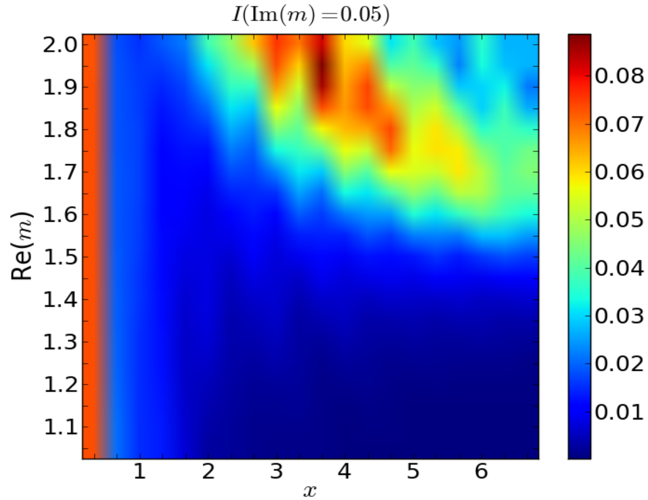


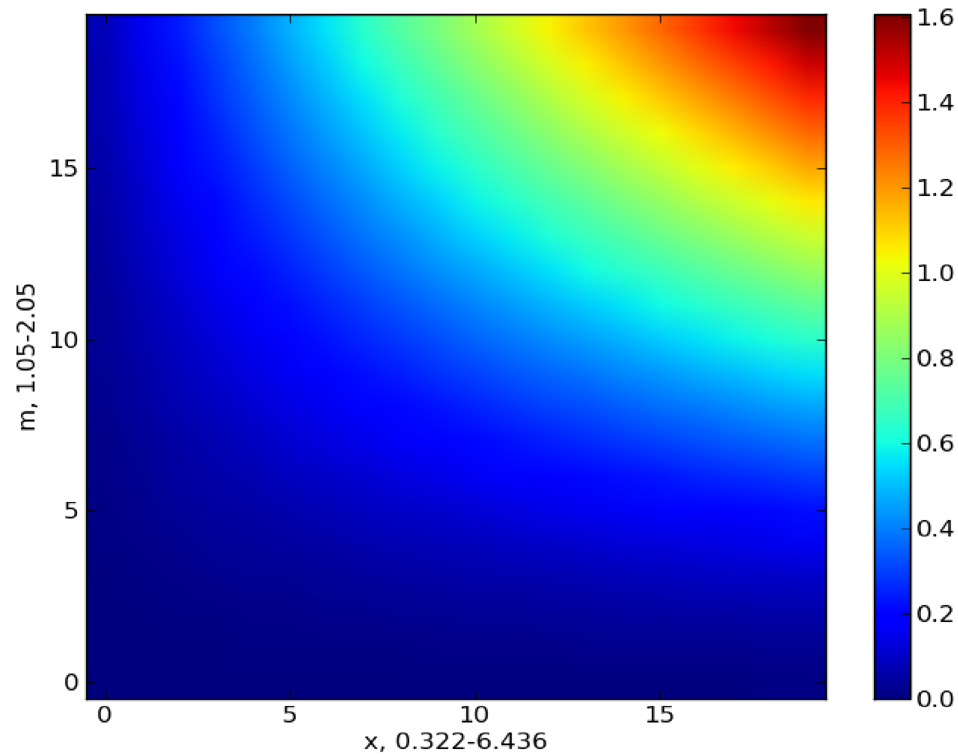
λ = 12.6 cm	0.0	2.0	4.0	6.0	8.0	10.0	12.0	14 .0	16.0	cm
λ = 3.5 cm	0.0	0.557	1.114	1.671	2.228	2.785	3.342	3.899	4.456	cm

Simulation results

Radar albedo (vs. Intensity)







$$\hat{\sigma} \propto \sum \left| \frac{m_i^2 - 1}{m_i^2 + 2} \right|^2 \times \frac{1}{x_i} \times C(m, x)$$

Conclusions & future

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- A non-trivial dependence of the circular polarization ratio on refractive indices and monomer size parameters
  → surface complexity/roughness not the only contributor .
- More realistic asteroid/regolith model to give more realistic indications on the behaviour of the radar signal.
- If refractive index is known, the results may give indications on the size scale of the scattering medium (cf. Cometary ice).

Thank you for your attention!