Computational light scattering (PAP315)

Lecture 12

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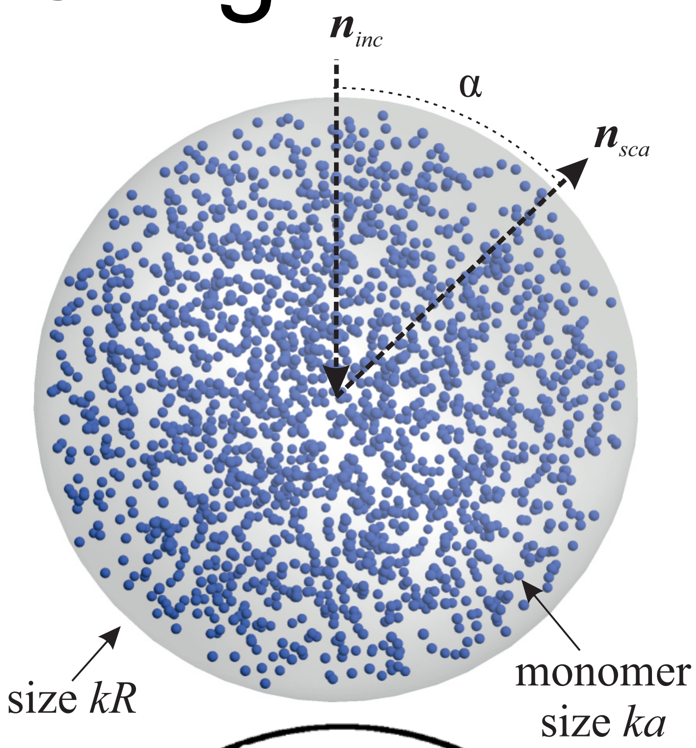
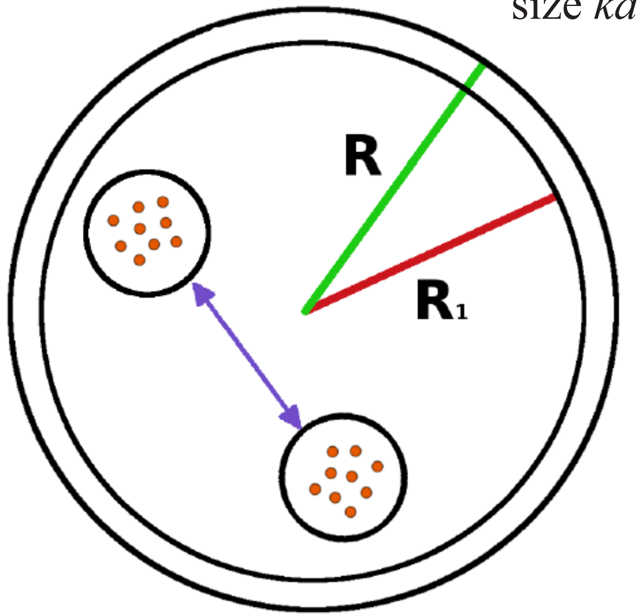
Multiple scattering

- Radiative transfer and coherent backscattering (RT-CB; Muinonen et al., ApJ 2012; Muinonen, WRM 2004 and URSI EMTS 1989)
- Superposition *T*-Matrix Method (STMM or MSTM; Mackowski & Mishchenko, JQSRT 2011; FaSTMM, Markkanen & Yuffa JQSRT 2017)
- Electric Current Volume Integral Equation Method (JVIE; Markkanen & Yuffa, JQSRT 2017, Markkanen et al., IEEE-TAP 2012)
- Radiative transfer with reciprocal transactions (R^2T^2; Muinonen et al., URSI EMTS 2016ab, RS 2017, OL 2018, JoVE 2019; Markkanen et al., OL 2018, ApJL 2018; Väisänen et al., PLoS ONE 2019)



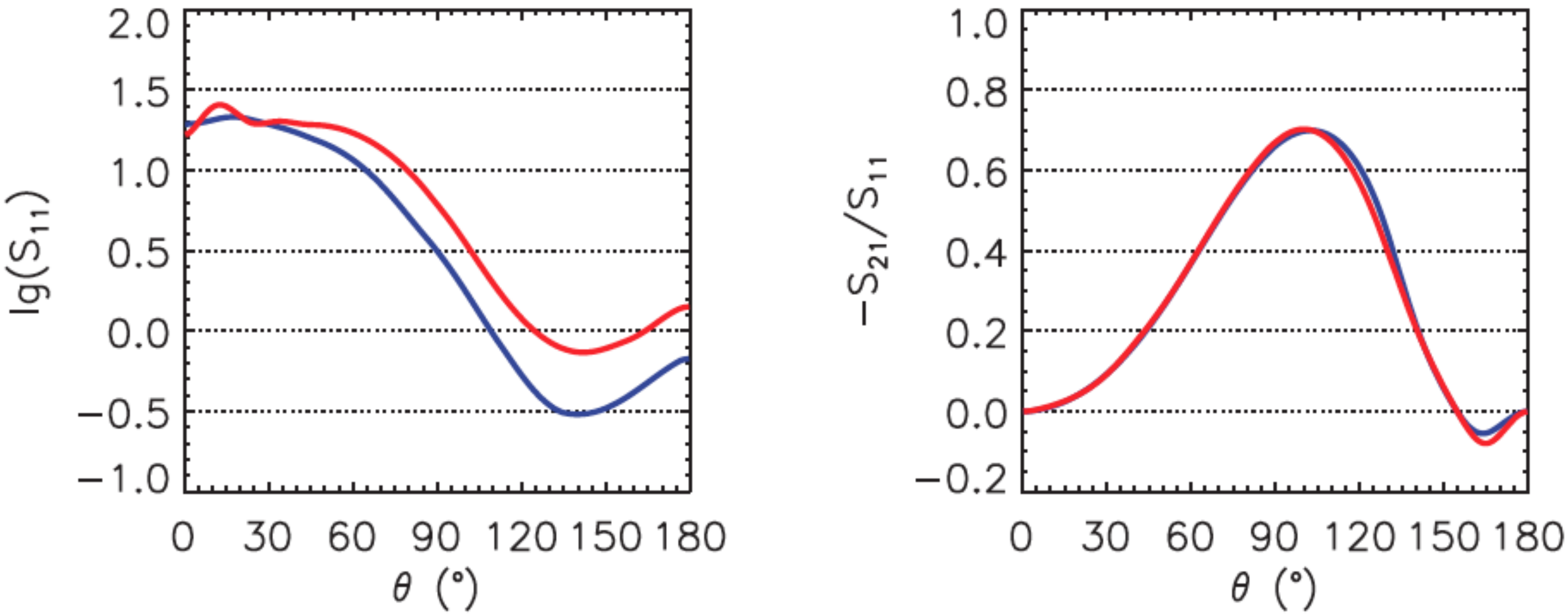


Coherent and incoherent electromagnetic fields

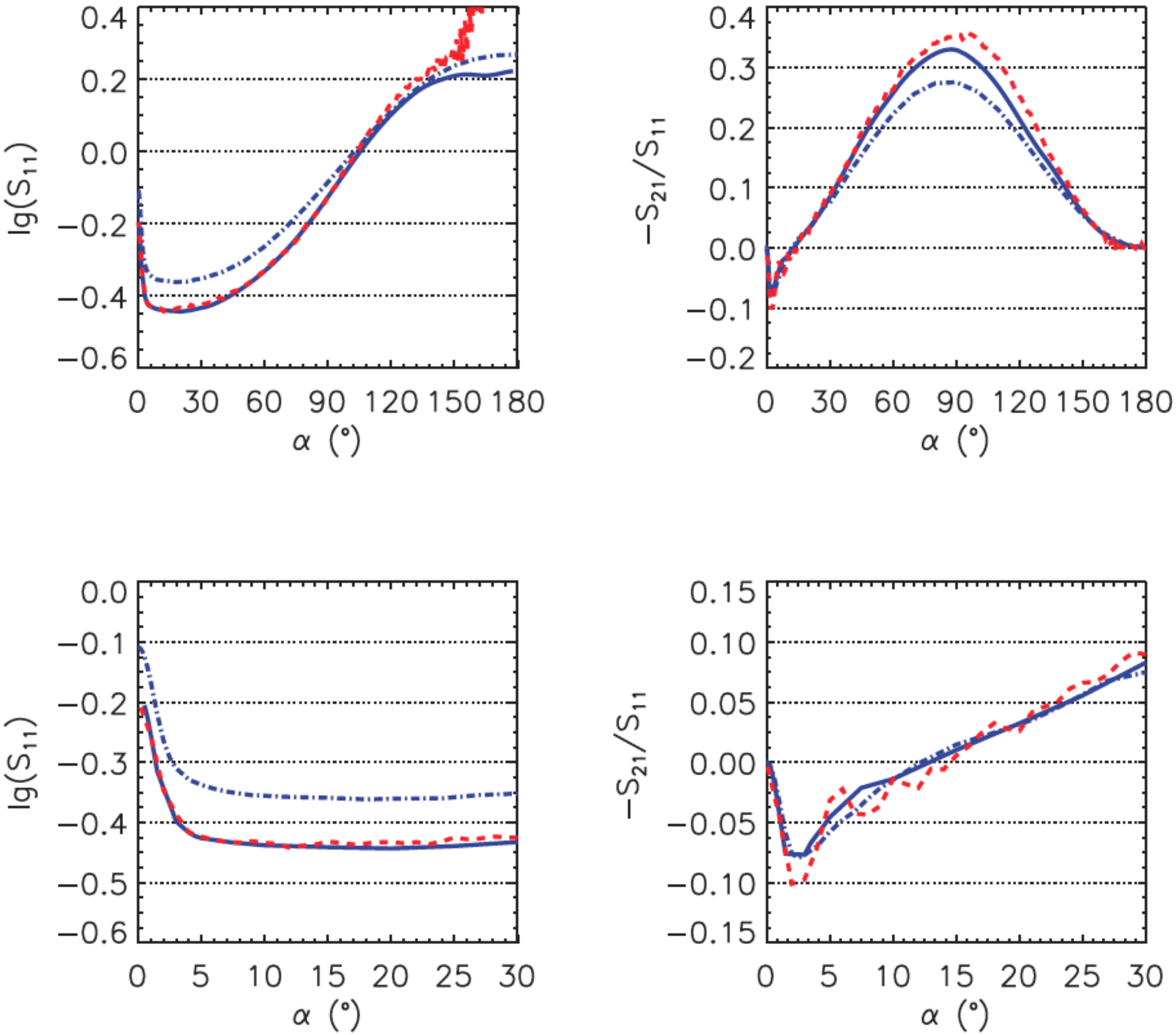
- Coherent field equals the mean field from separate realizations (not measurable)
- Incoherent field equals the free-space field with subtraction of the mean field
- Incoherent field specifies the elementary scattering in an infinite medium
- Scattering by an infinite medium invariant: independence of elementary scattering
- Recipe: revise RT-CB for incoherent elementary scattering by a wavelength-scale volume element and rigorous interactions among the elements
- Expanding the work by Zurk et al. (1995, 1996)

Validation of numerical methods Comparison with STMM

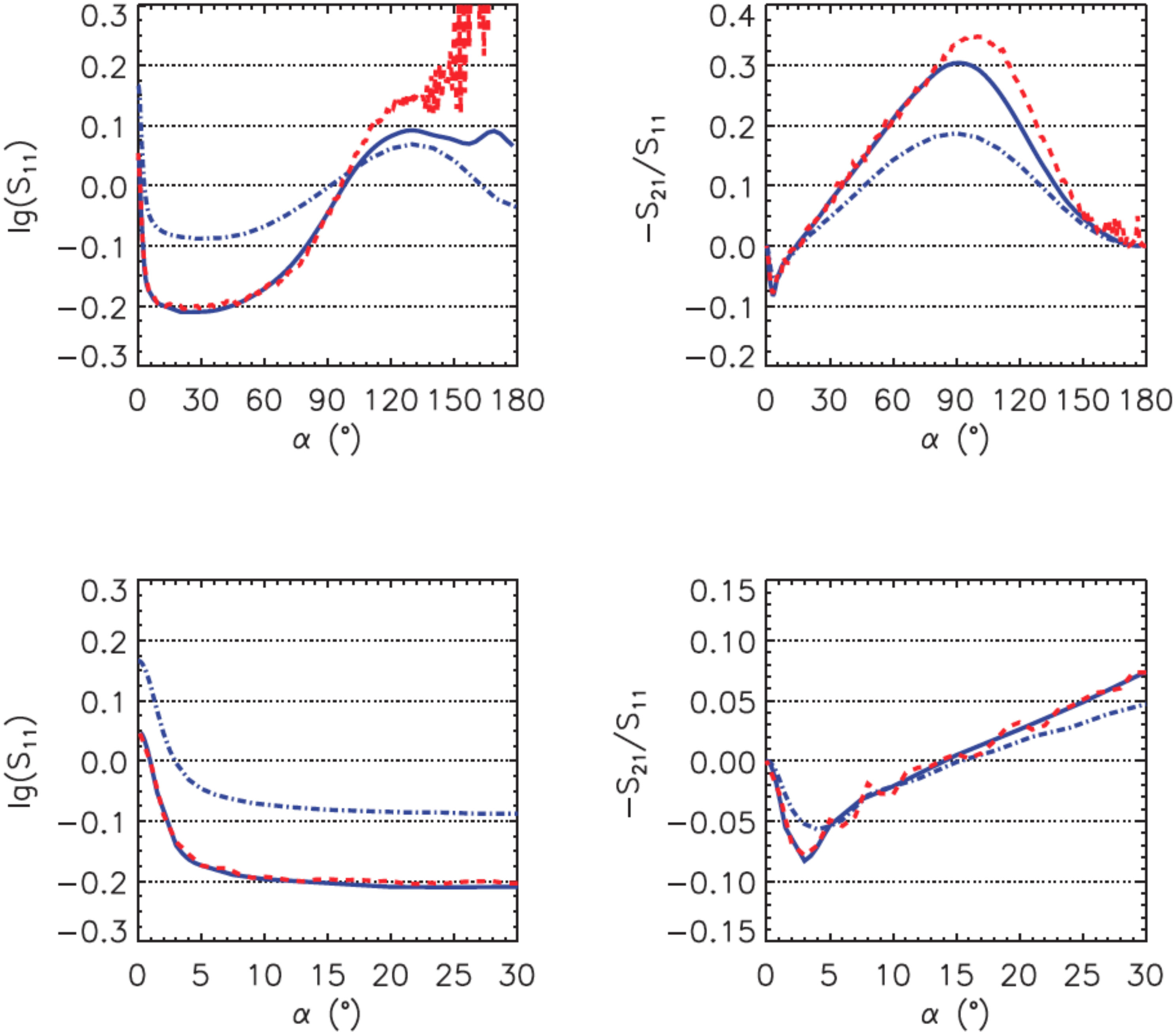
- R^2T^2, exact incoherent interactions using *T*-matrices from FaSTMM (Muinonen et al., Optics Letters 2018)
- Spherical media, radius $kR = 100$:
  - Number of spheres $N = 15625, 31250$
  - Case, Ice:
    - radius $kr = 2.0$, refractive index $m = 1.31$
    - single-scattering albedo $\omega = 1.0$
    - volume densities $v = 0.125, 0.25$



lg(S11)
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
0
30
60
90
120
150
180
θ (°)
−S21/S11
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
0
30
60
90
120
150
180
θ (°)

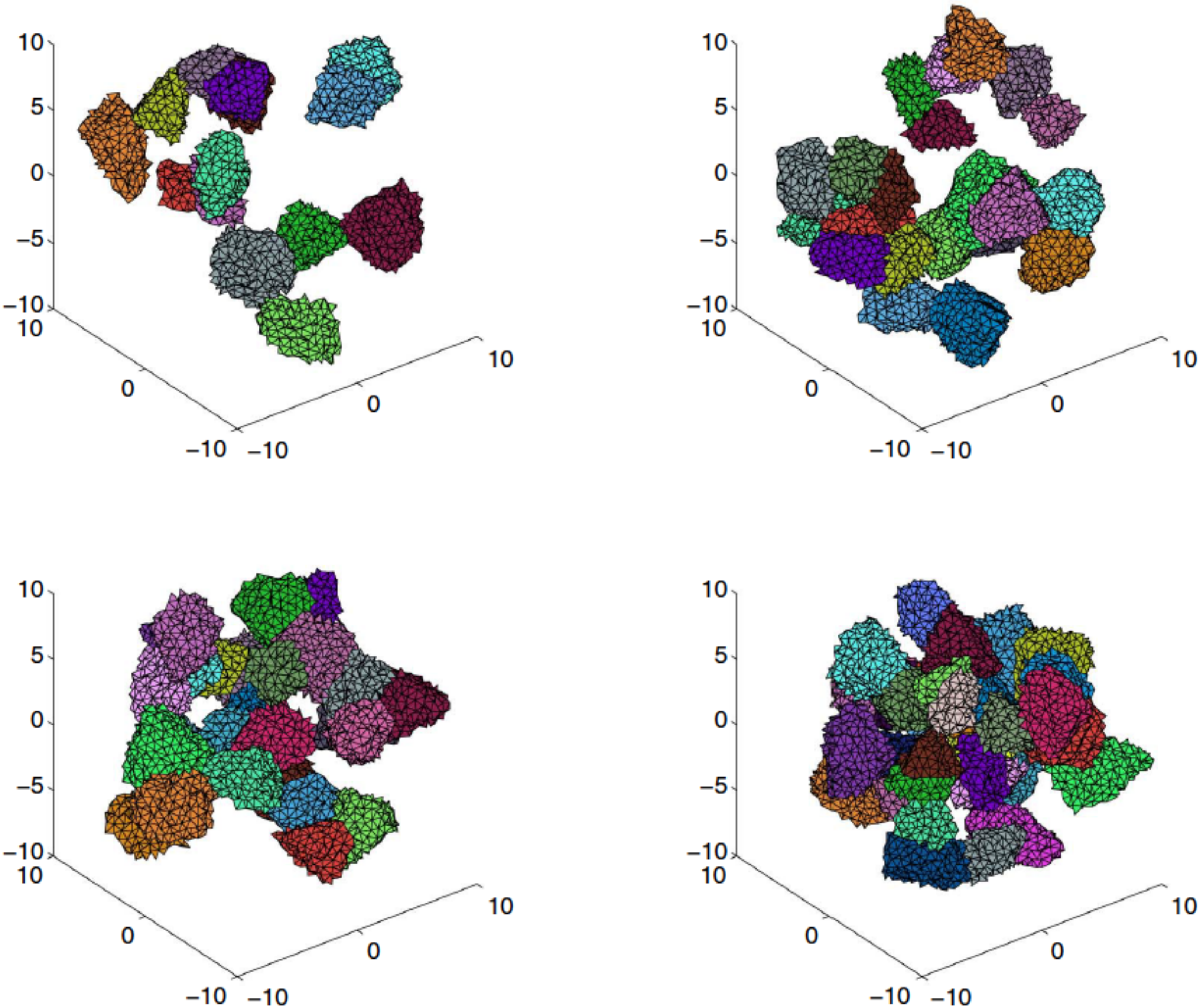


lg(S11)
−S21/S11
α (°)
0.4
0.2
0.0
−0.2
−0.4
−0.6
0.3
0.1
−0.1
0 30 60 90 120 150 180
0.15
0.10
0.05
0.00
−0.05
−0.10
−0.15
−0.3
−0.5
0 5 10 15 20 25 30


lg(S11)
−S21/S11
α (°)
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
0.4
0.15
0.10
0.05
0.00
−0.05
−0.10
−0.15
0 30 60 90 120 150 180
0 5 10 15 20 25 30

Comparison with JVIE

- R^2T^2, exact incoherent interactions using *T*-matrices from JVIE (Markkanen et al., Optics Letters 2018)
- Spherical media, radius $kR = 60$, Voronoi media:
  - Case I, Ice:
    - radius $kr = 2.0$, refractive index $m = 1.31$
    - volume densities $v = 0.125, 0.25$
- Spherical media, radius $kR = 1.2 \times 10^{13}$ (!):
  - Case II, Silicate:
    - radius $kr = 1.5$, refractive index $m = 1.8 + i0.000188$
    - volume densities $v = 0.15, 0.30$


10
5
0
−5
−10
10
0
−10
−10
0
10
10
5
0
−5
−10
10
0
−10
−10
0
10
10
5
0
−5
−10
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10
10
5
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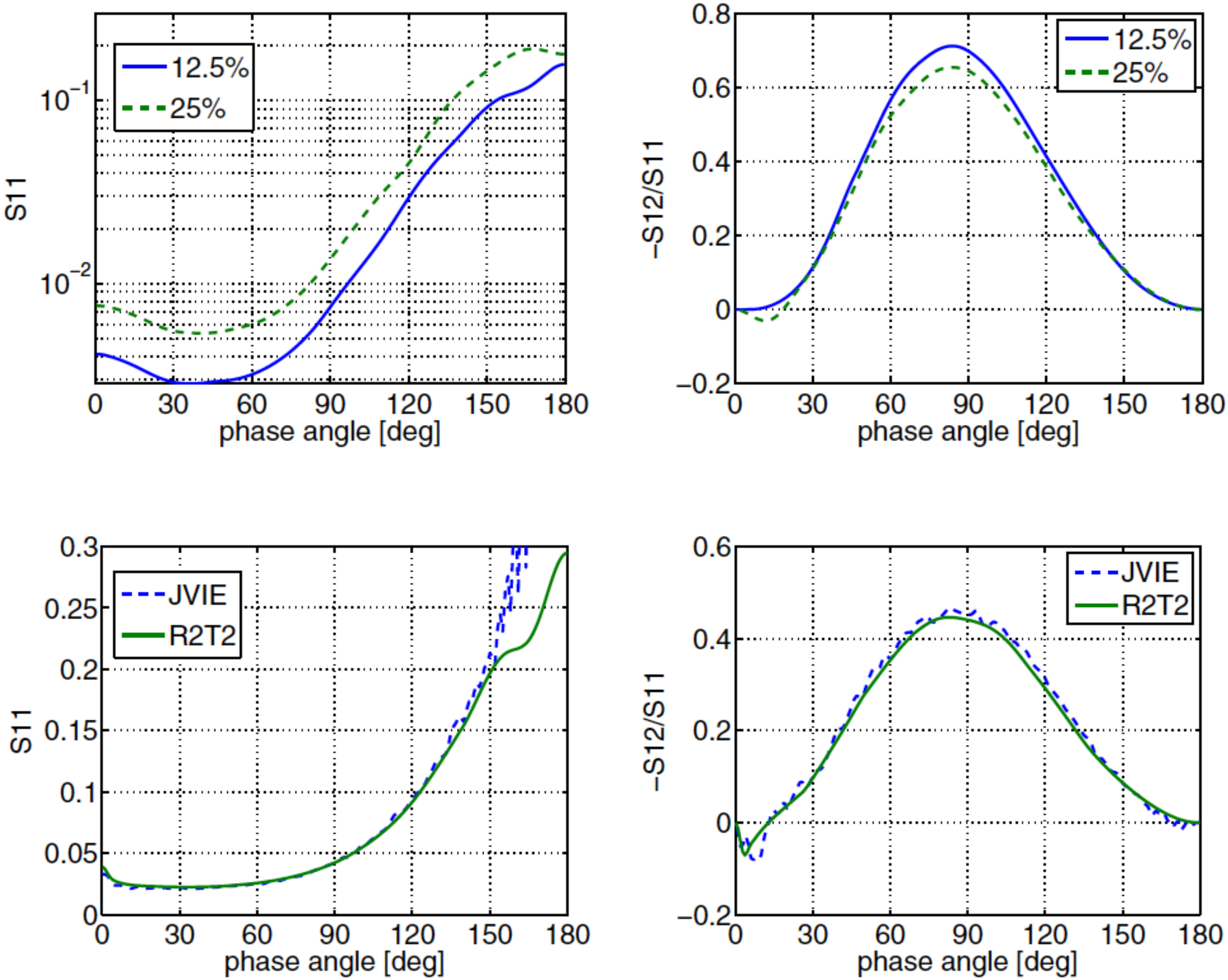
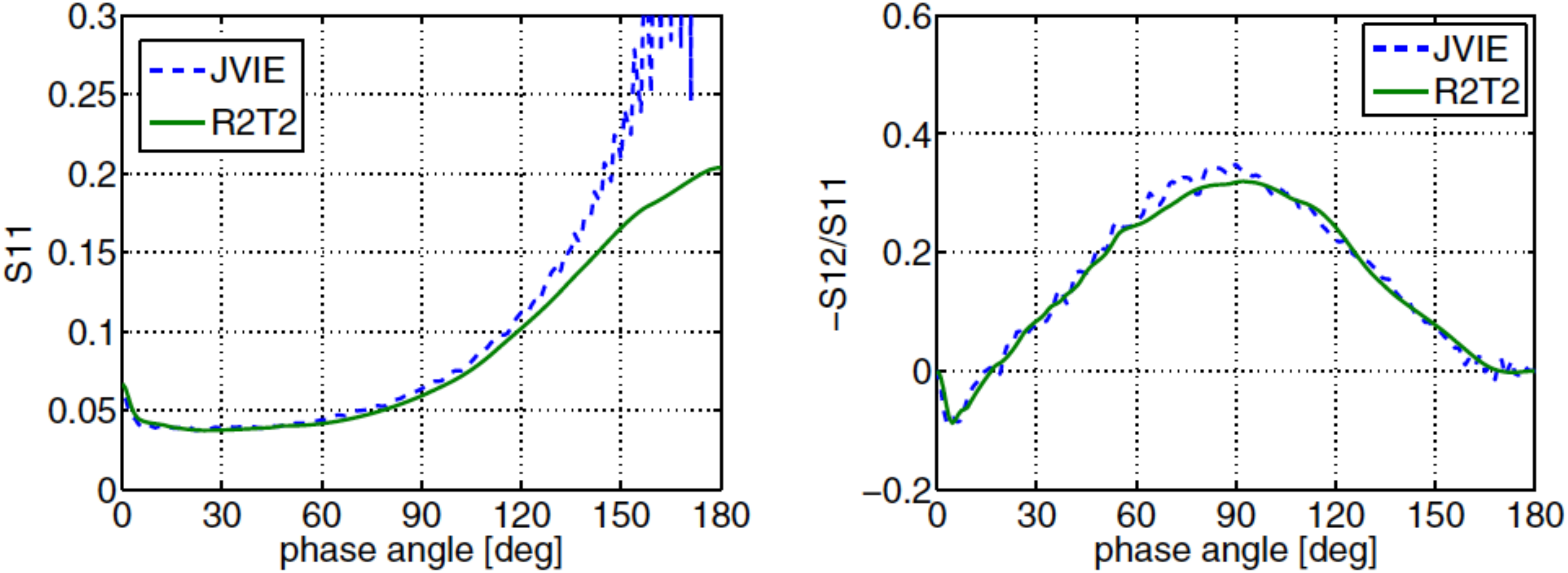
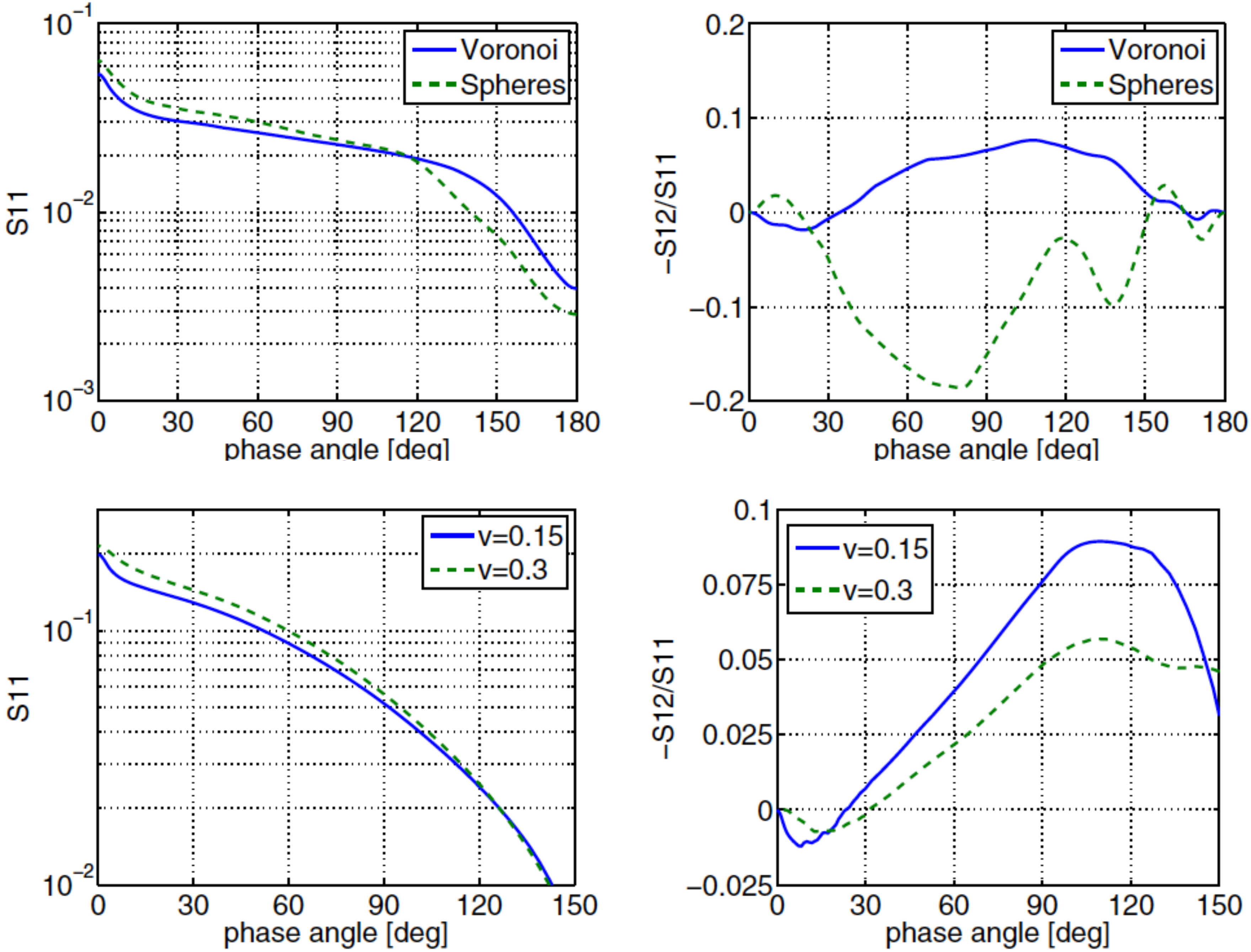
10
0
−10
−10
0
10



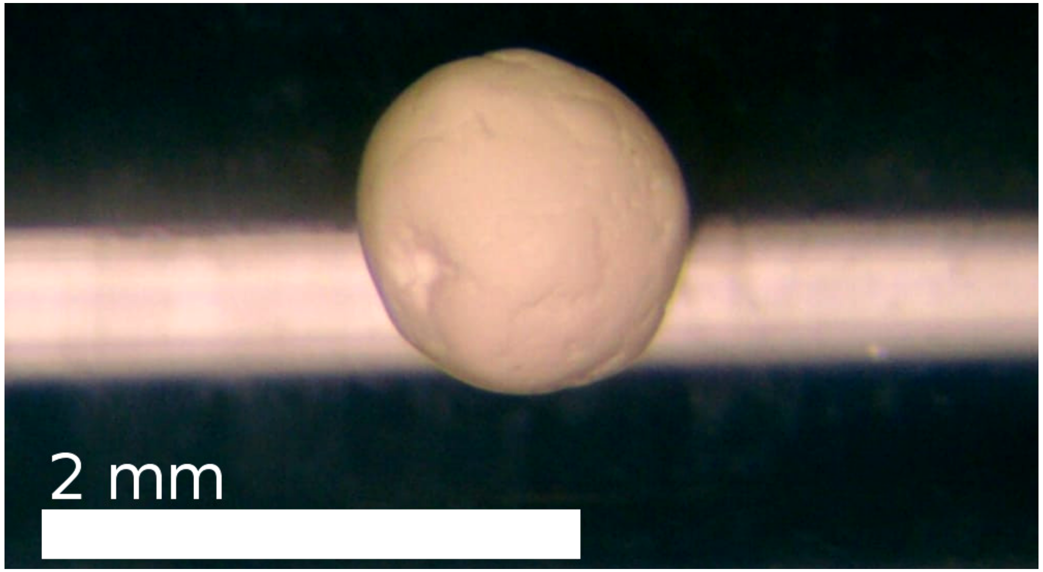
12.5%
25%
S11
phase angle [deg]
−S12/S11
JVIE
R2T2



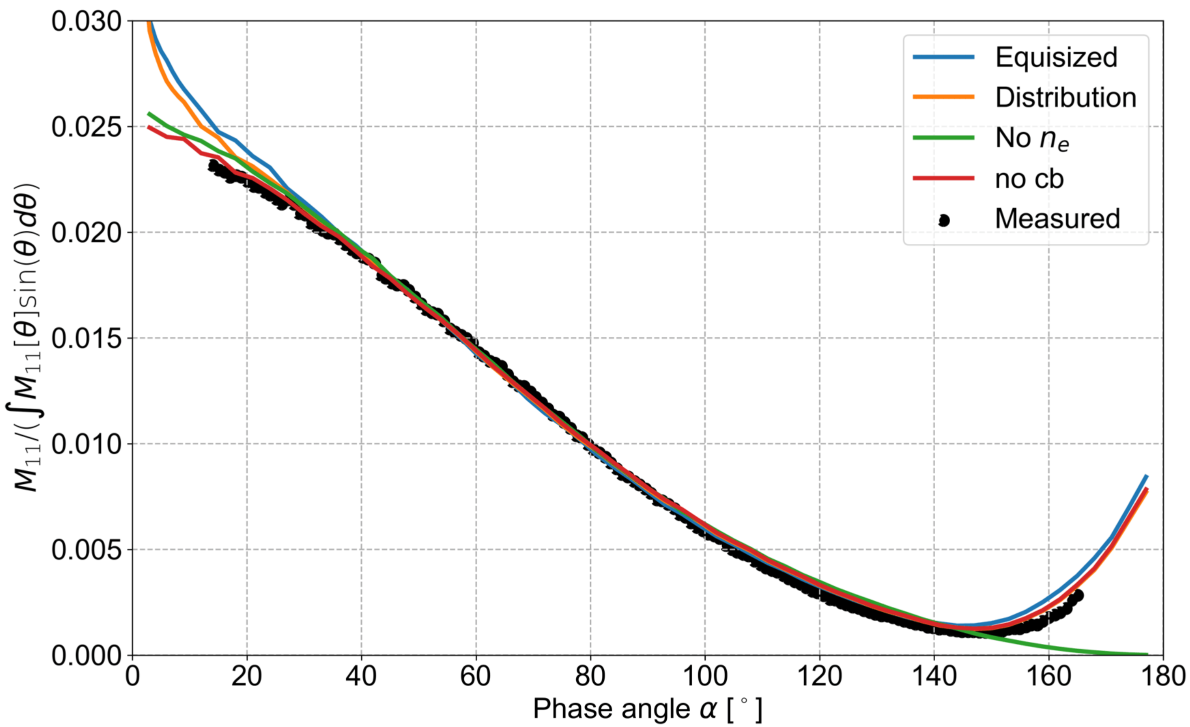
0.3
0.25
0.2
0.15
0.1
0.05
0
S11
JVIE
R2T2
0
30
60
90
120
150
180
phase angle [deg]
0.6
0.4
0.2
0
−0.2
−S12/S11
JVIE
R2T2
0
30
60
90
120
150
180
phase angle [deg]

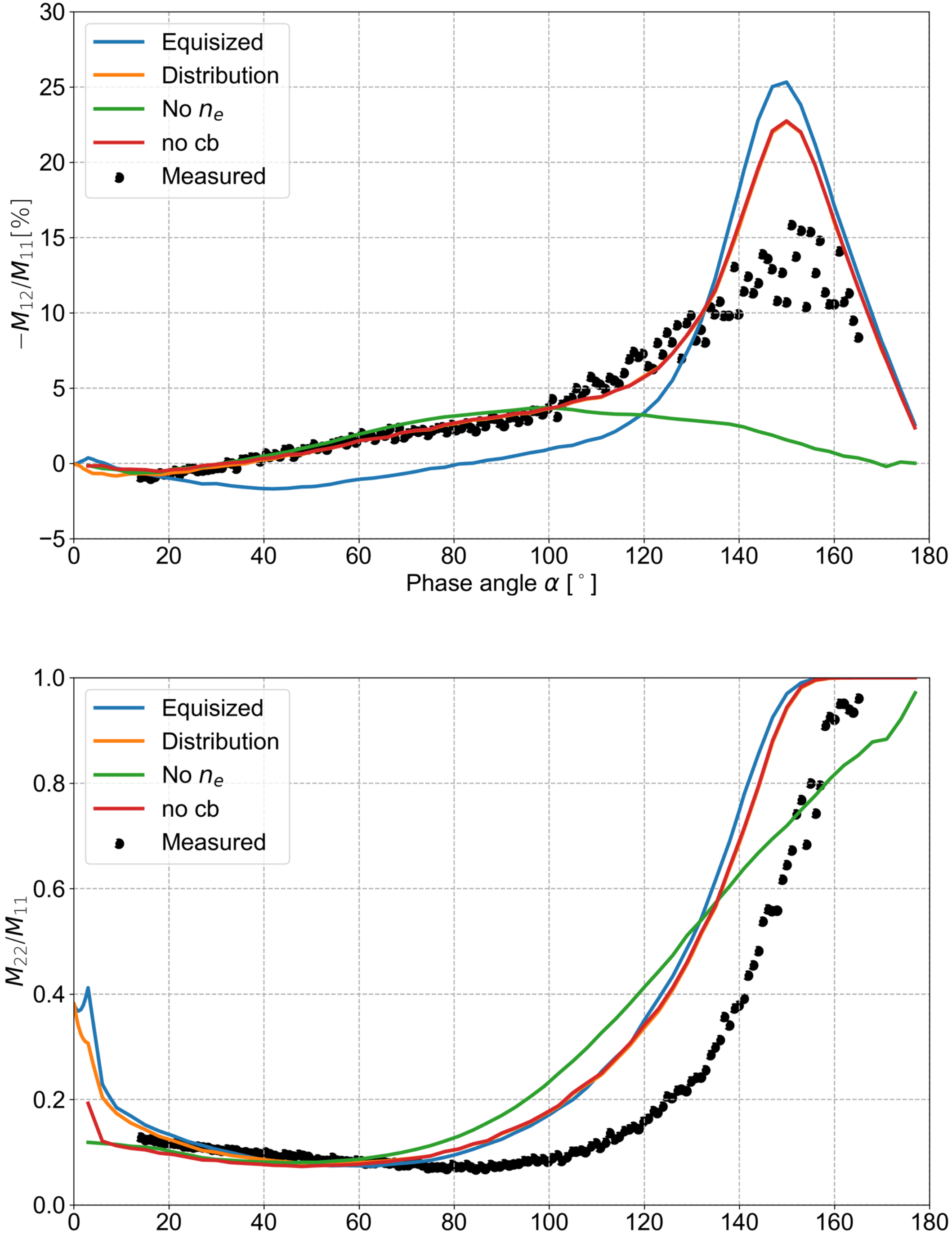


Voronoi
Spheres
S11
phase angle [deg]
-S12/S11
v=0.15
v=0.3



Muinonen et al., JoVE 2019

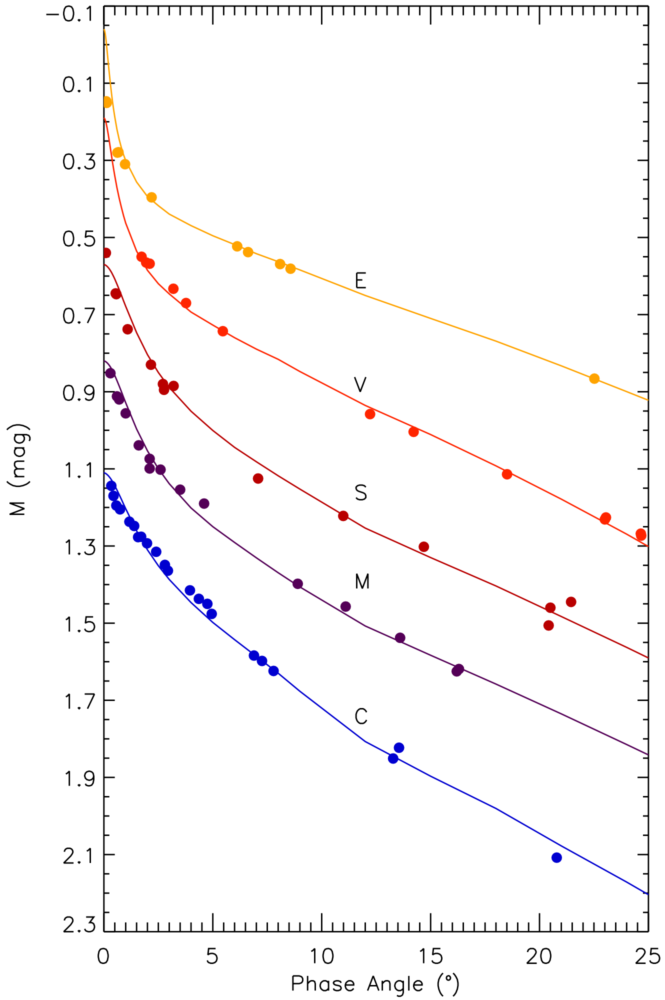




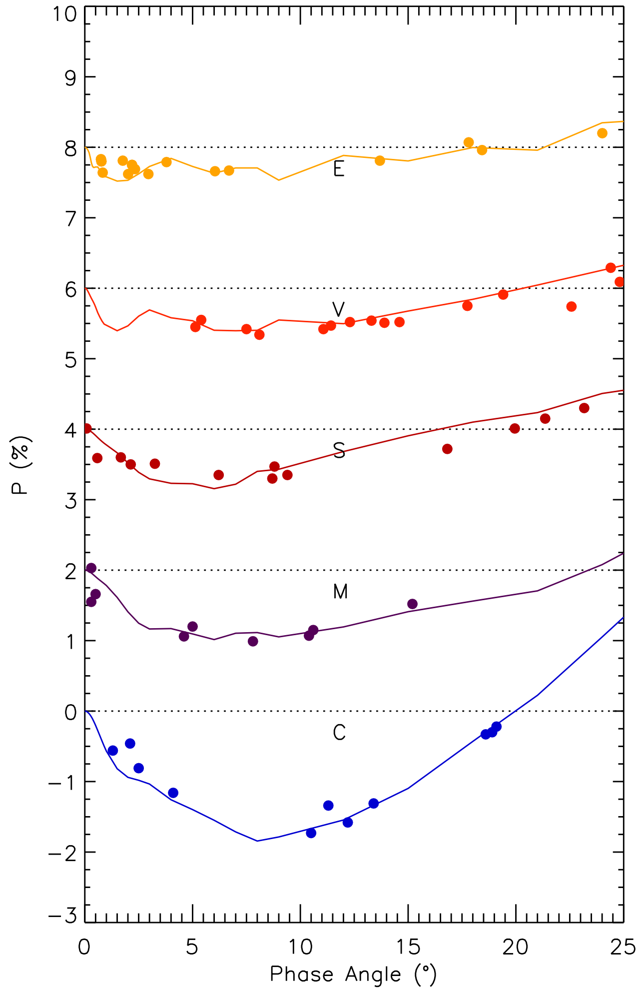
Equisized
Distribution
No n_e
no cb
Measured
$-M_{12}/M_{11}$ [%]
Phase angle α [$^\circ$]
Equisized
Distribution
No n_e
no cb
Measured
M_{22}/M_{11}

Application: asteroids

Photometry



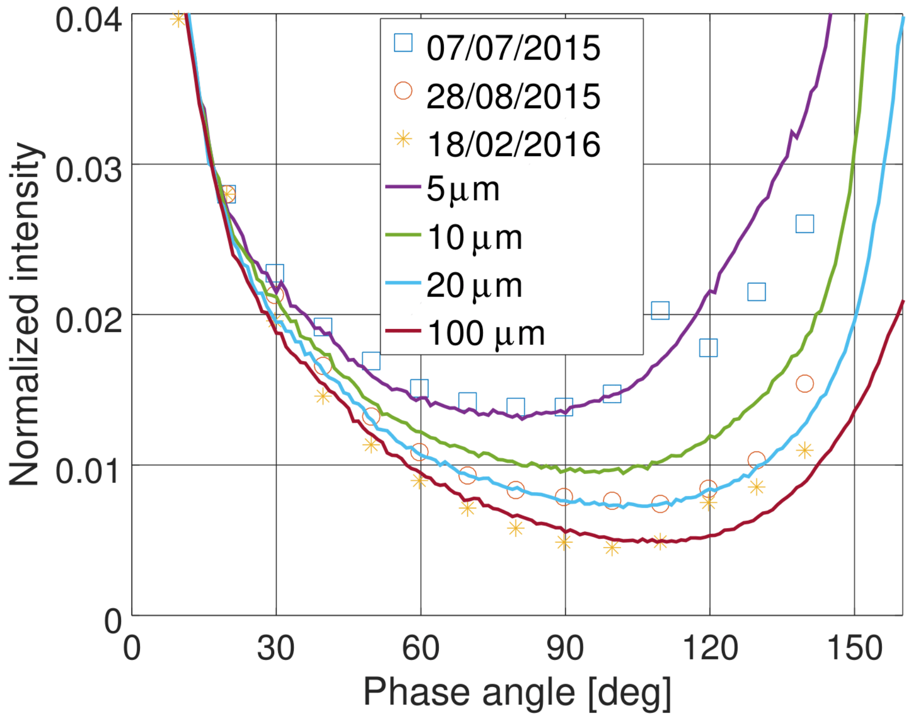
Polarimetry



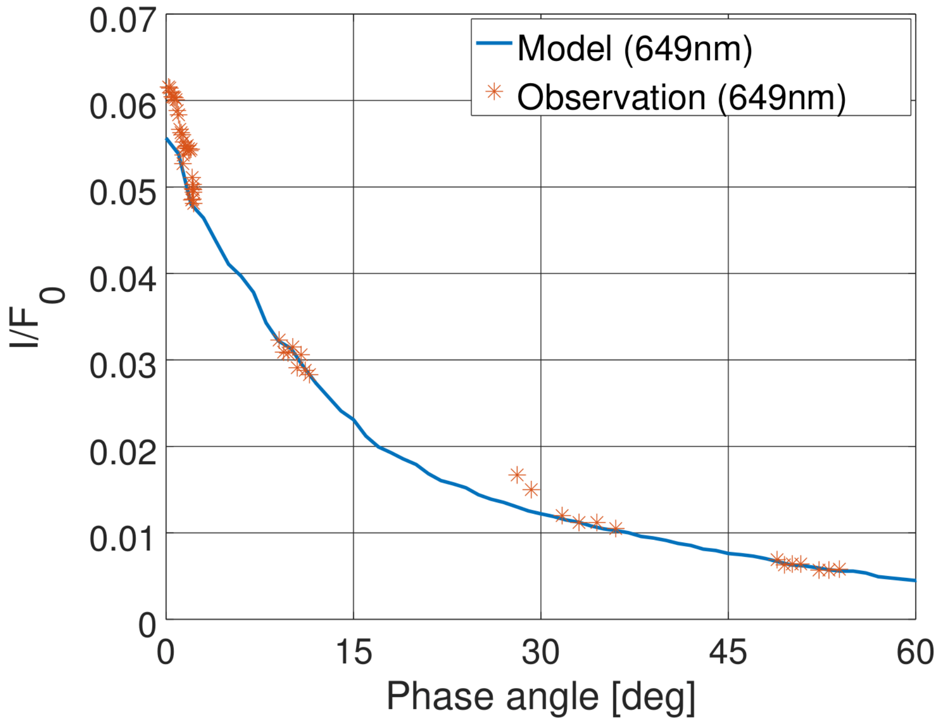
Muinonen et al. 2019, in press (obs. ref. therein)

Application: comet 67P/Churyumov-Gerasimenko

Coma photometric phase functions



Nucleus photometric phase function



Markkanen et al., ApJL 2018