Computational light scattering (PAP315)

Lecture 11

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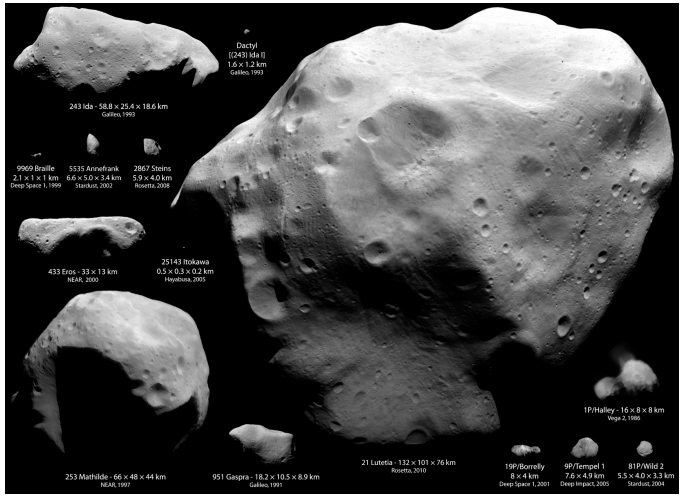

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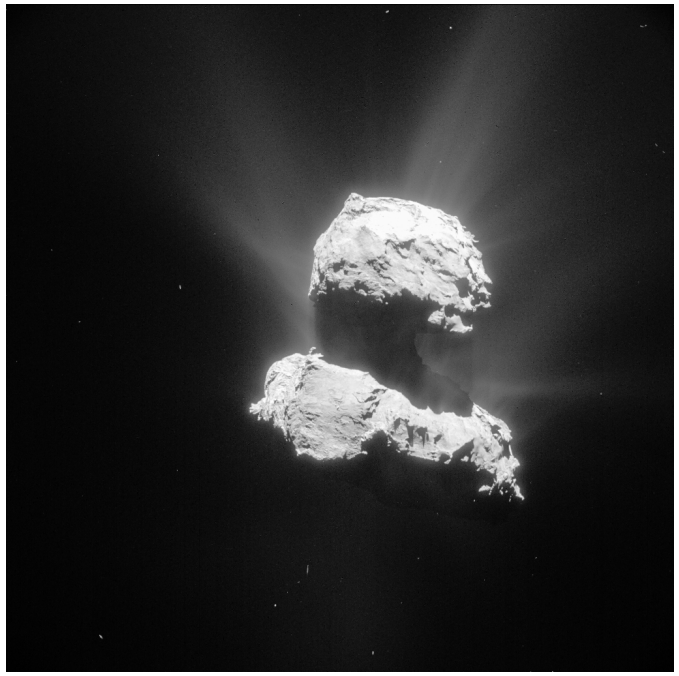
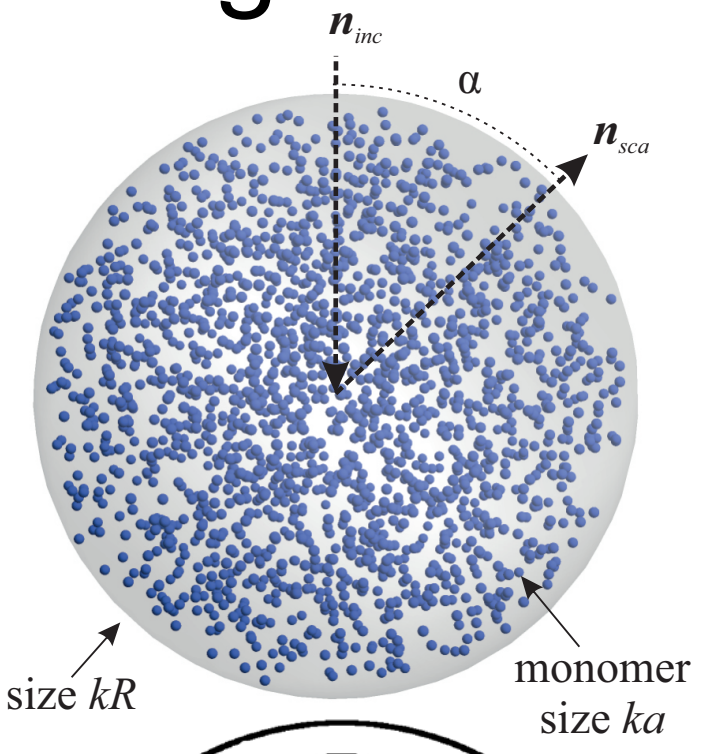


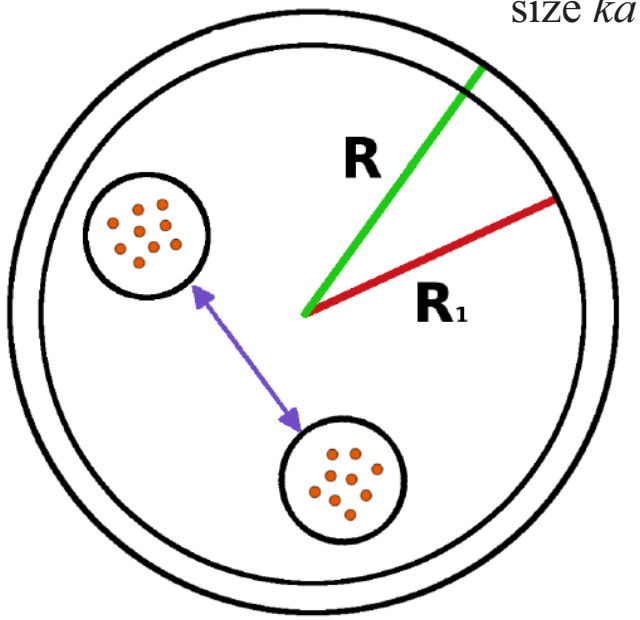
Introduction

- Physical characterization of the surfaces of airless planetary objects
- Direct problem of light scattering by discrete random media of particles with varying particle size, shape, refractive index, and volume density
- Inverse problem based on astronomical observations and/or experimental measurements
- Plane of scattering, scattering angle, solar phase angle, degree of linear polarization

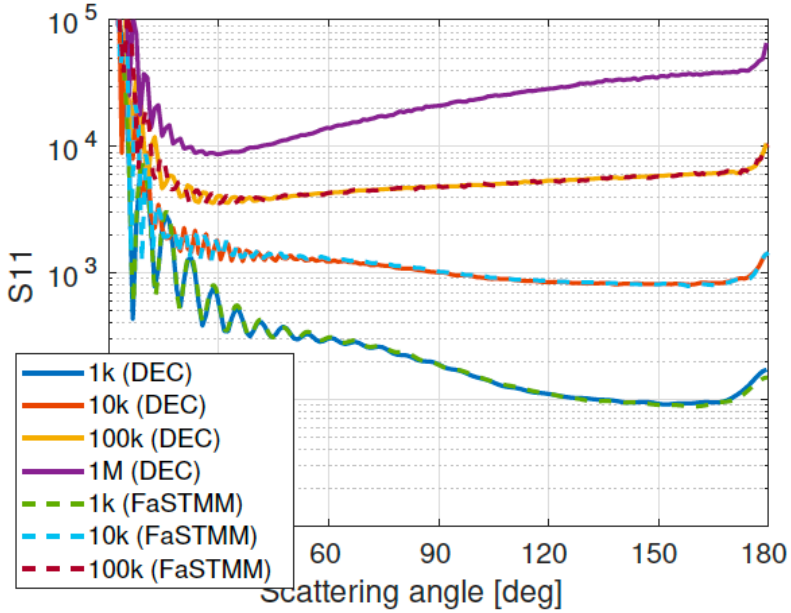
Multiple scattering

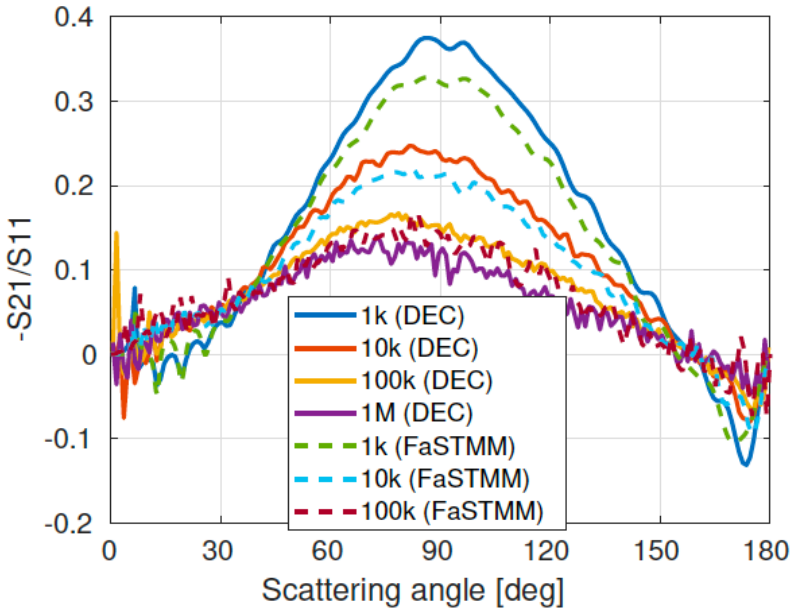
- Radiative transfer and coherent backscattering (RT-CB; Muinonen et al., ApJ 2012; Muinonen, WRM 2004 and URSI EMTS 1989)
- Superposition *T*-Matrix Method (STMM or MSTM; Mackowski & Mishchenko, JQSRT 2011; FaSTMM, Markkanen & Yuffa JQSRT 2017)
- Electric Current Volume Integral Equation Method (JVIE; 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)





Different methods e.g., IEM, DEC, FEM, STMM, ...





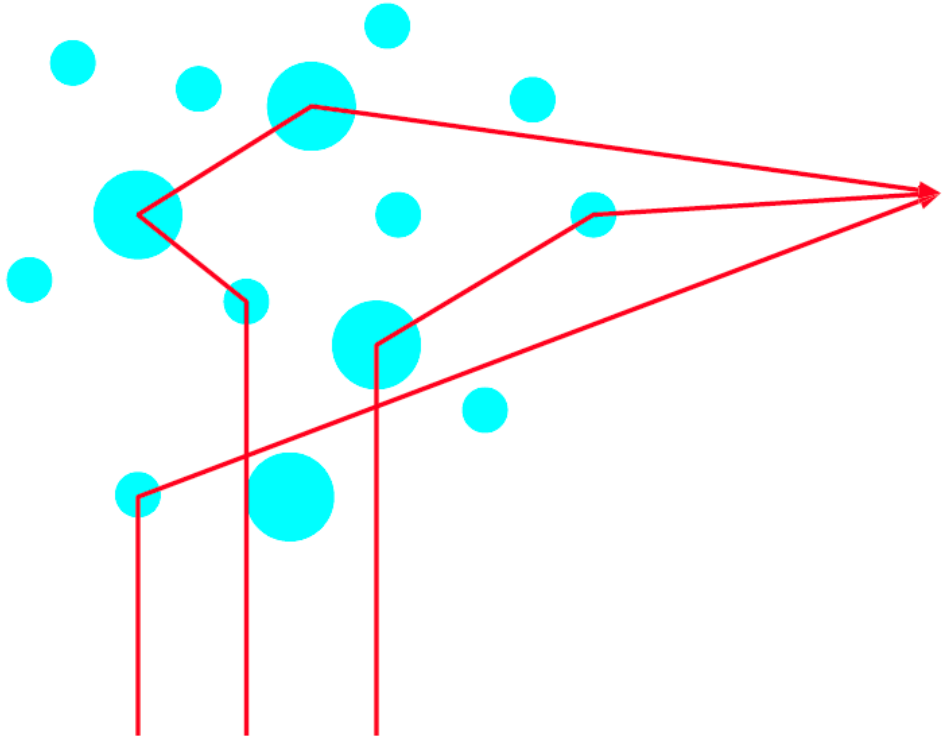
Spherical medium of randomly positioned spheres: $r = 0.18\,\mu\text{m}$, $\epsilon_r = 2.25 + 0.0003i$, $\rho = 0.2$, $\lambda = 0.649\,\mu\text{m}$

size	#particles	unknowns	cores	wall time	total cpu time
$R = 3.1\,\mu\text{m}$	1k	9.6M	192	11 s	0.6 h
$R = 6.7\,\mu\text{m}$	10k	66M	576	30 s	4.9 h
$R = 14.4\,\mu\text{m}$	100k	550M	576	800 s	130 h
$R = 31.1\,\mu\text{m}$	1000k	5000M	4096	2000 s	2400 h

CPU time $\sim R^4$

Order-of-scattering expansion

$$\mathbf{E}^{sca} = \sum_i \mathbf{G}\hat{\mathbf{T}}_i\mathbf{E}^{inc} + \sum_{i,j\neq i} \mathbf{G}\hat{\mathbf{T}}_i\mathbf{G}\hat{\mathbf{T}}_j\mathbf{E}^{inc} + \sum_{i,j\neq i,k\neq j} \mathbf{G}\hat{\mathbf{T}}_i\mathbf{G}\hat{\mathbf{T}}_j\mathbf{G}\hat{\mathbf{T}}_k\mathbf{E}^{inc} + .$$

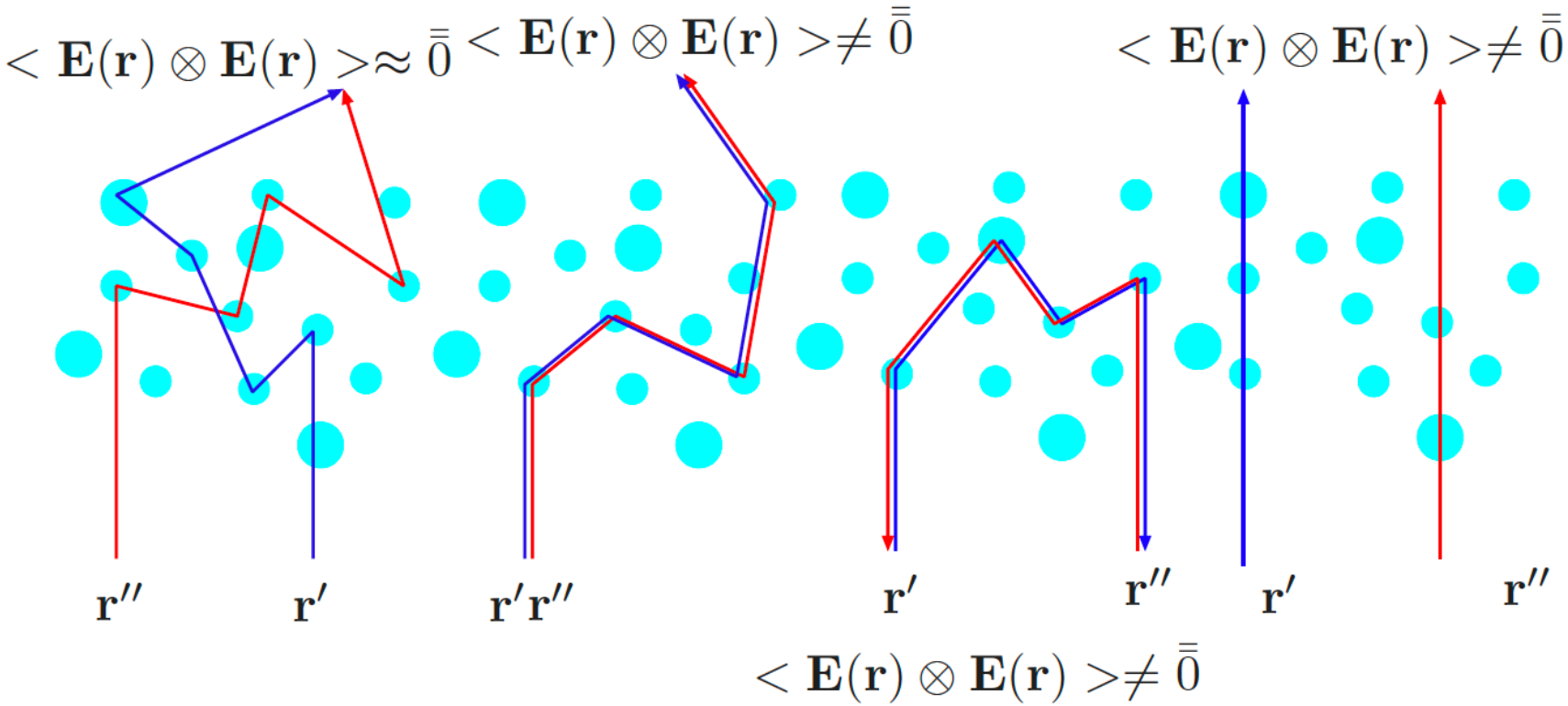


$\hat{\mathbf{T}}$ transition dyadic: $\mathbf{E}^{inc} \rightarrow \mathbf{J}$

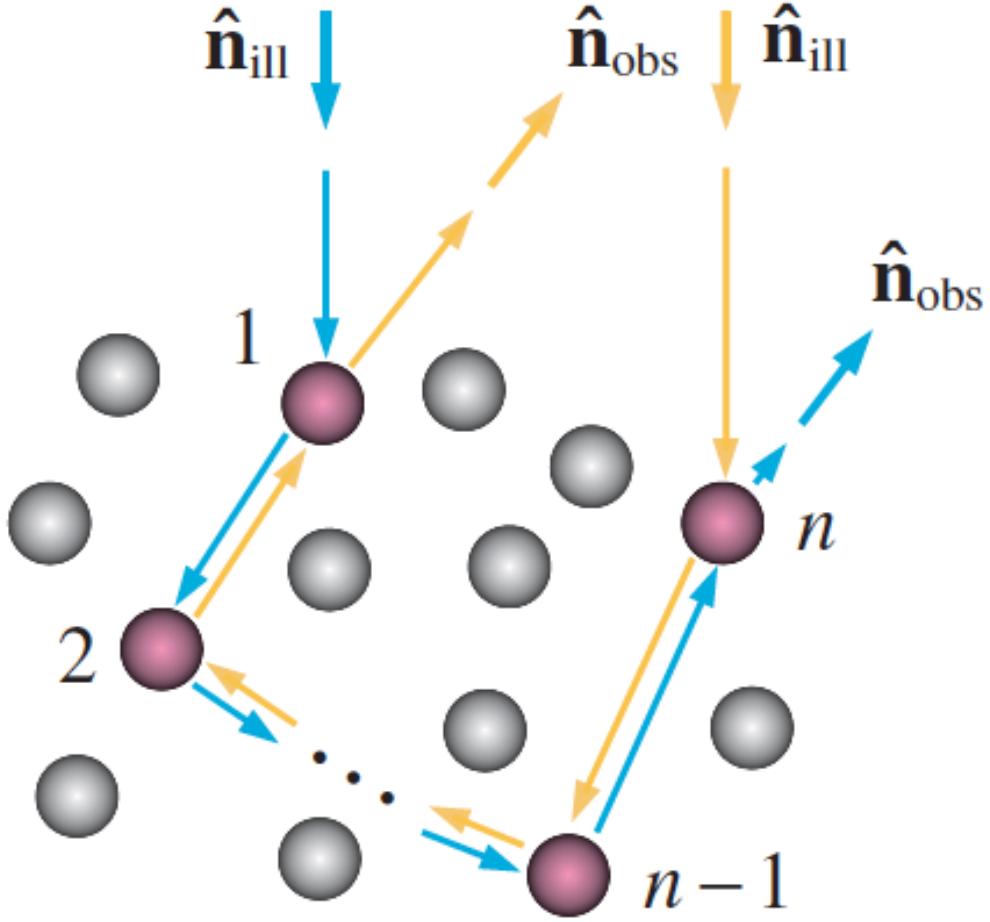
$\mathbf{G}$ Green's dyadic operator: $\mathbf{J} \rightarrow \mathbf{E}^{sca}$

Discrete random media: Ensemple averaged coherency dyadic

$$< \mathbf{E}(\mathbf{r}) \otimes \mathbf{E}(\mathbf{r}) >=< \sum_i \mathbf{G}\hat{\mathbf{T}}_i \mathbf{E}^{inc}(\mathbf{r}') + \sum_{i,j\neq i} \mathbf{G}\hat{\mathbf{T}}_i \mathbf{G}\hat{\mathbf{T}}_j \mathbf{E}^{inc}(\mathbf{r}') + \ldots$$
$$\otimes \sum_k \mathbf{G}\hat{\mathbf{T}}_k \mathbf{E}^{inc}(\mathbf{r}'') + \sum_{k,l\neq k} \mathbf{G}\hat{\mathbf{T}}_k \mathbf{G}\hat{\mathbf{T}}_k \mathbf{E}^{inc}(\mathbf{r}'') + \ldots >$$

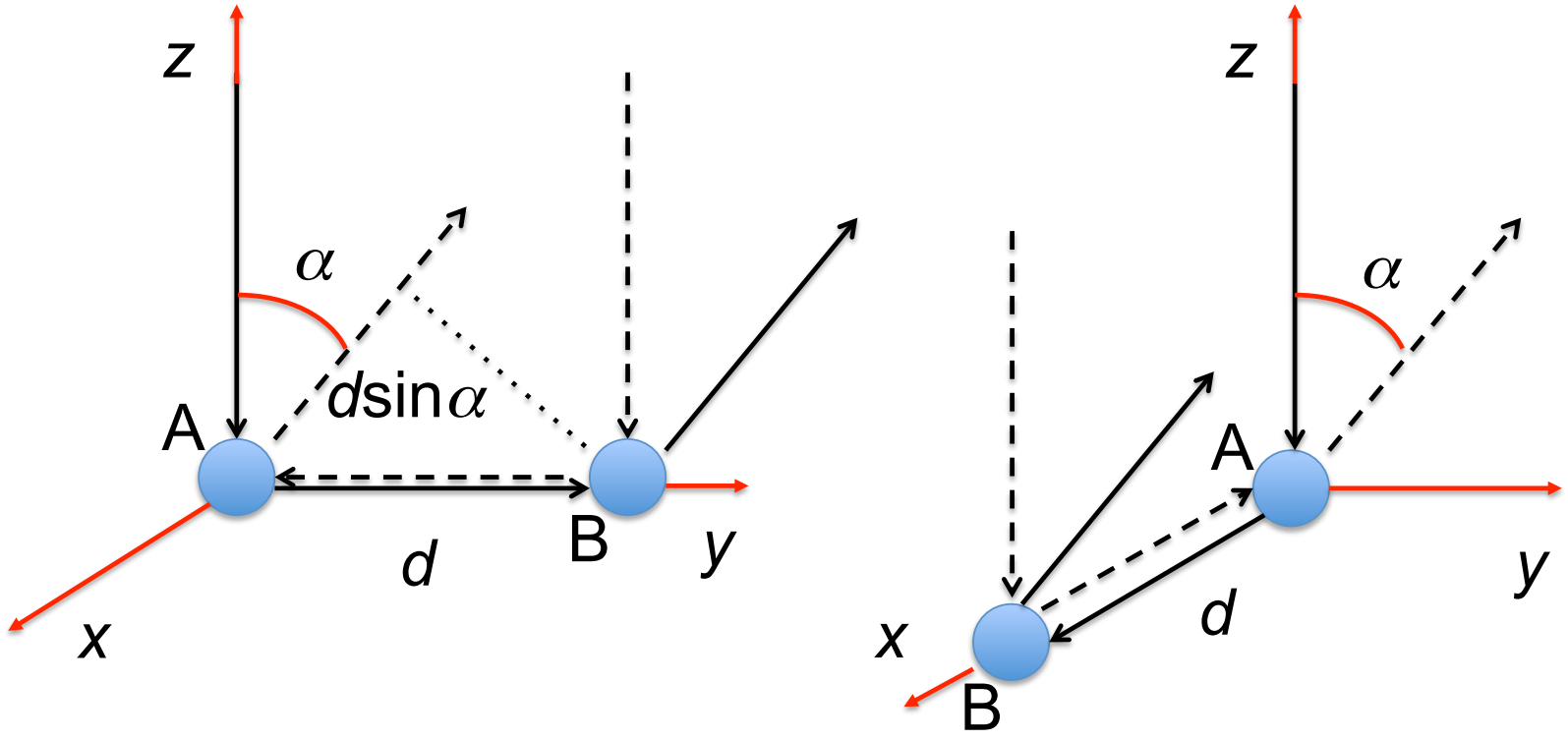


Coherent backscattering mechanism: intensity



e.g., Muinonen 1989, 1990; Shkuratov 1985, 1988, 1989

Coherent backscattering mechanism: polarization



Muinonen 1989, 1990; Shkuratov 1985, 1988, 1989