Aerossóis, aula 3

Fisica Atmosférica, 2019

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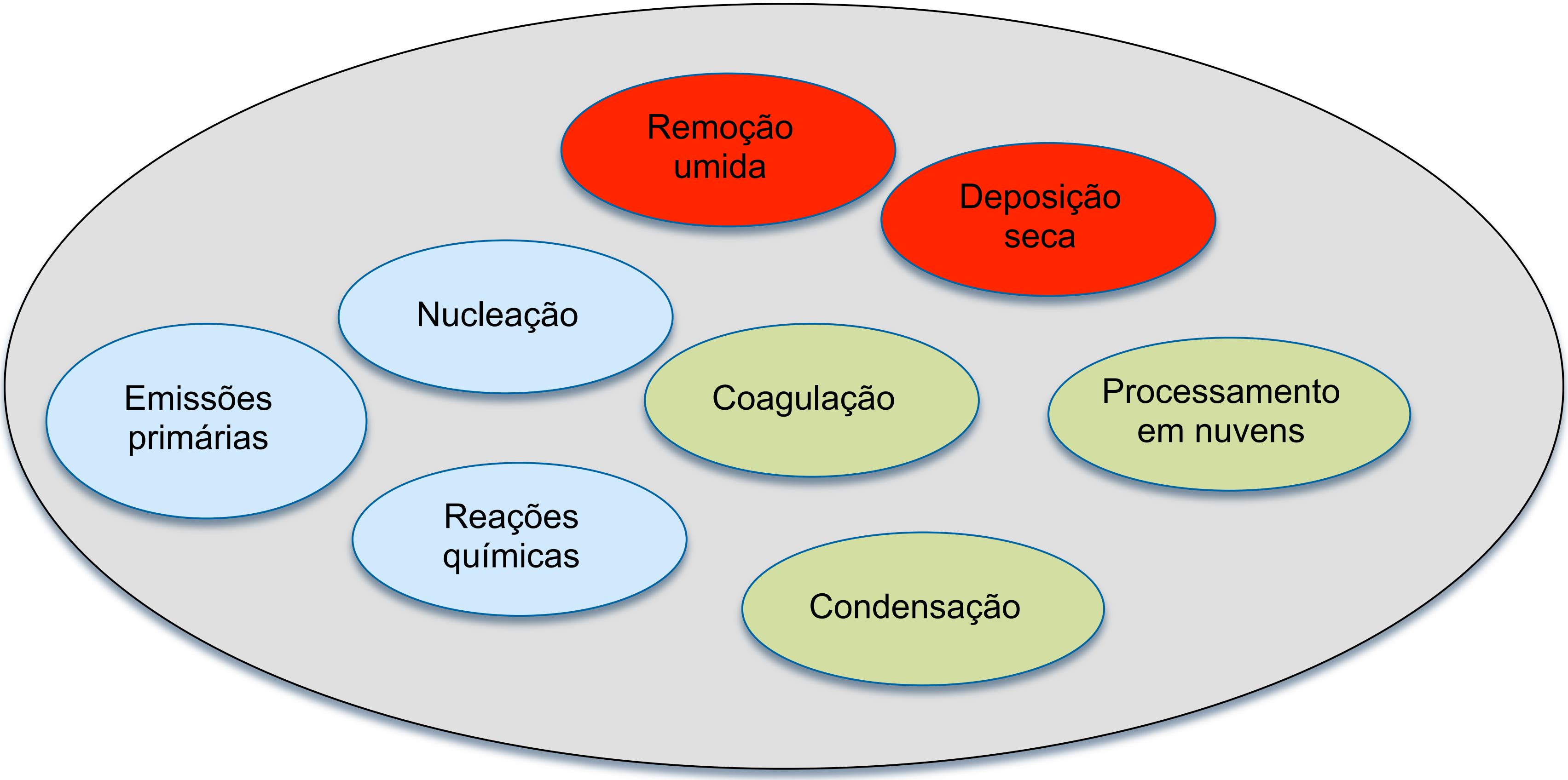
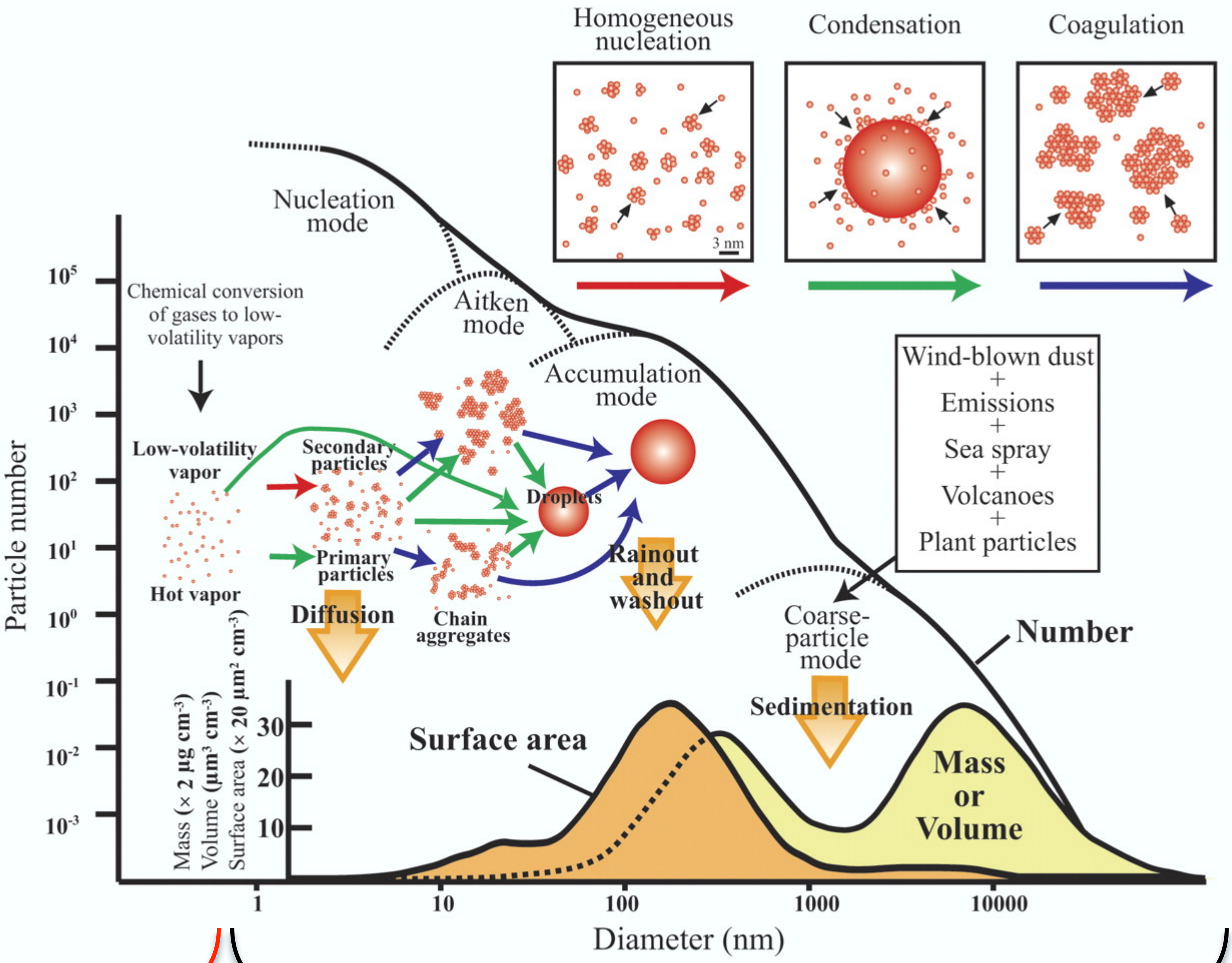
Com slides de HC Hanssen, Peter Tunved, Andre Burger, Marco Franco, etc.

- Sea salt
- Dust
- Biomass burning
- Biogenic
- Volcanic
- Urban

Processos envolvendo aerossóis





gases

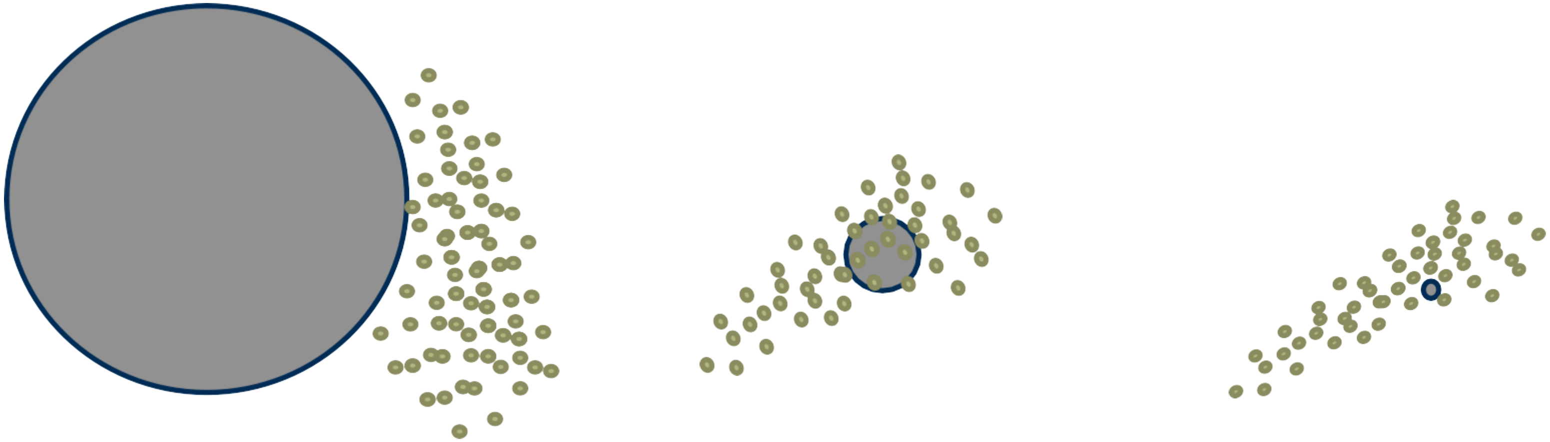
aerosols

Basic processes acting on single aerosol particles

- Gravitational settling
- Drag force
- Brownian motion

Single particle dynamics and Knudsen number

Continuum regime transition regime Free molecular regime



$Kn \rightarrow 0$ $Kn \approx 1$ $Kn \rightarrow \infty$

$$K_n = \frac{2\lambda}{D_p}$$

Knudsen number
Where λ is mean free path of air
D_p is diameter of particle

Single particle dynamics and Knudsen number

$$\lambda_a = \frac{2\nu_a}{\bar{\upsilon}_a}$$

$$= 65nm$$

ν_a Kinematic viscosity of air (m²/s)

$\bar{\upsilon}_a$ Average speed of an air molecule (m/s)

$$T = 288K$$

$$P_a = 1013hPa$$

$$\bar{\upsilon}_a = \sqrt{\frac{2N_a k_B T}{\pi m_a}}$$

T is temperature

m_a is molar mass

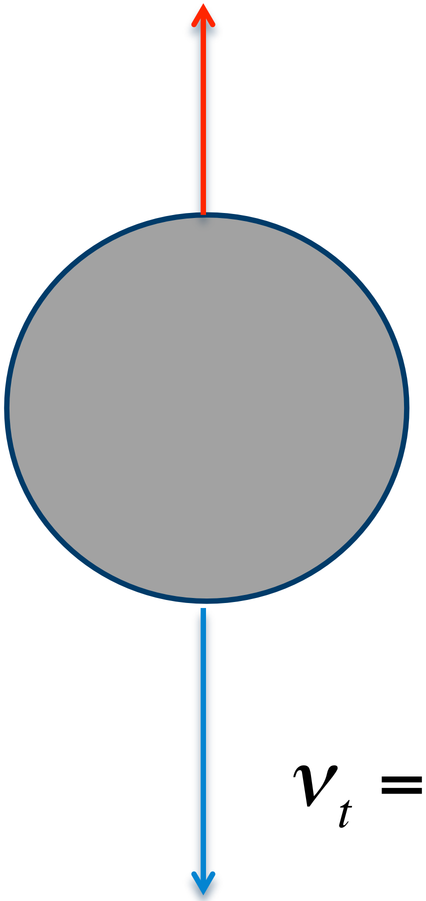
D_P (μm)	Kn
0.01	12.9
0.1	1.29
1	0.129
10	0.0129

$$\nu_a = \frac{\eta_a}{\rho_a}$$

$$\eta_a = \frac{5}{16Ad_a^2}\sqrt{\frac{m_a R^* T}{\pi}}$$

d_a is diameter of air molecule

Gravitational settling



$$F_{drag} = F_{grav}$$

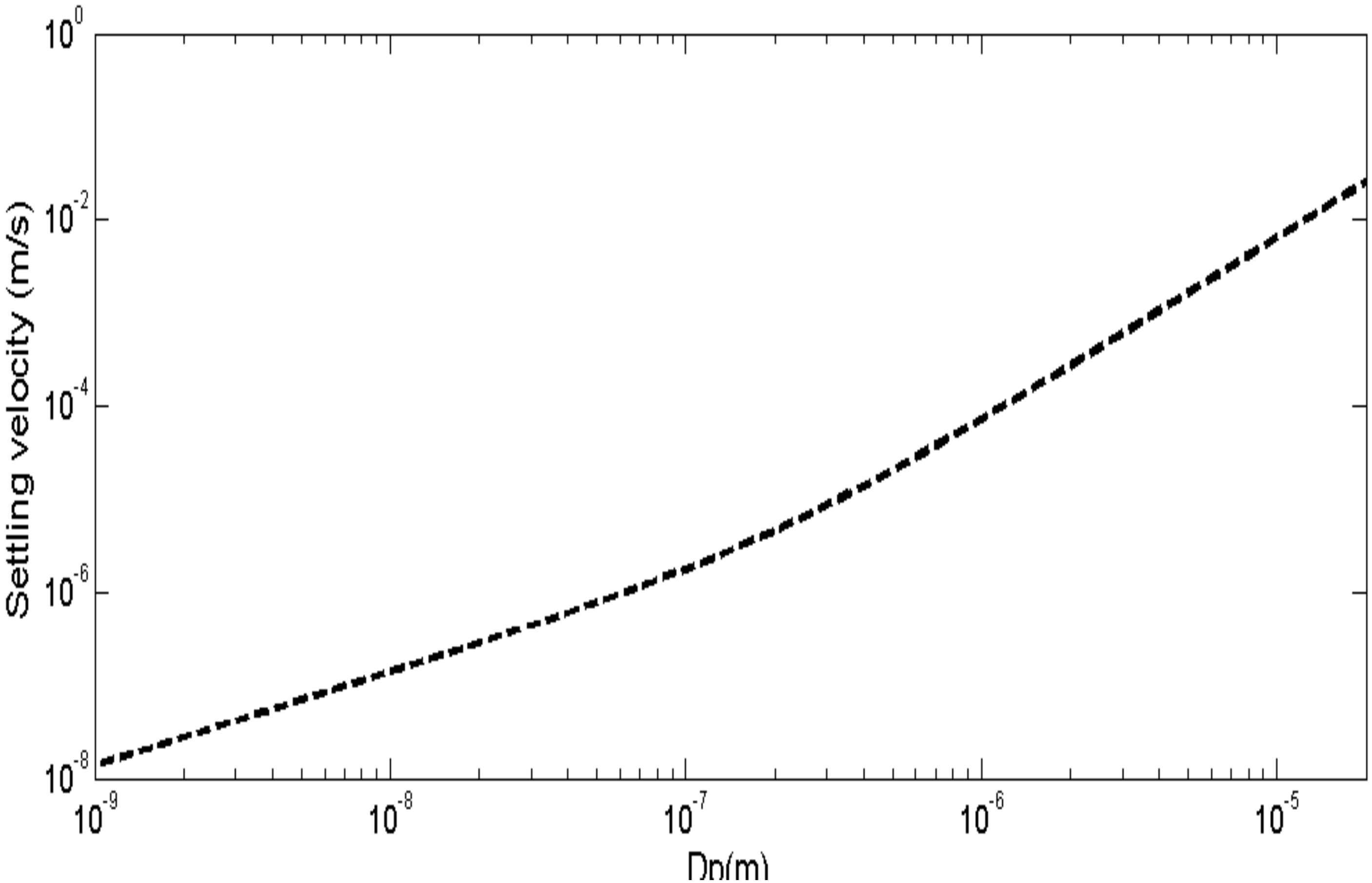
$$F_{grav} = mg = \frac{\pi}{6}\rho_P D_P^3 g$$

$$F_{drag} = \frac{3\pi D_P \eta_a v_t}{C_c}, C_c = 1 + K_n$$

$$v_t = \frac{m_P C_c g}{3\pi \eta_a D_P}$$

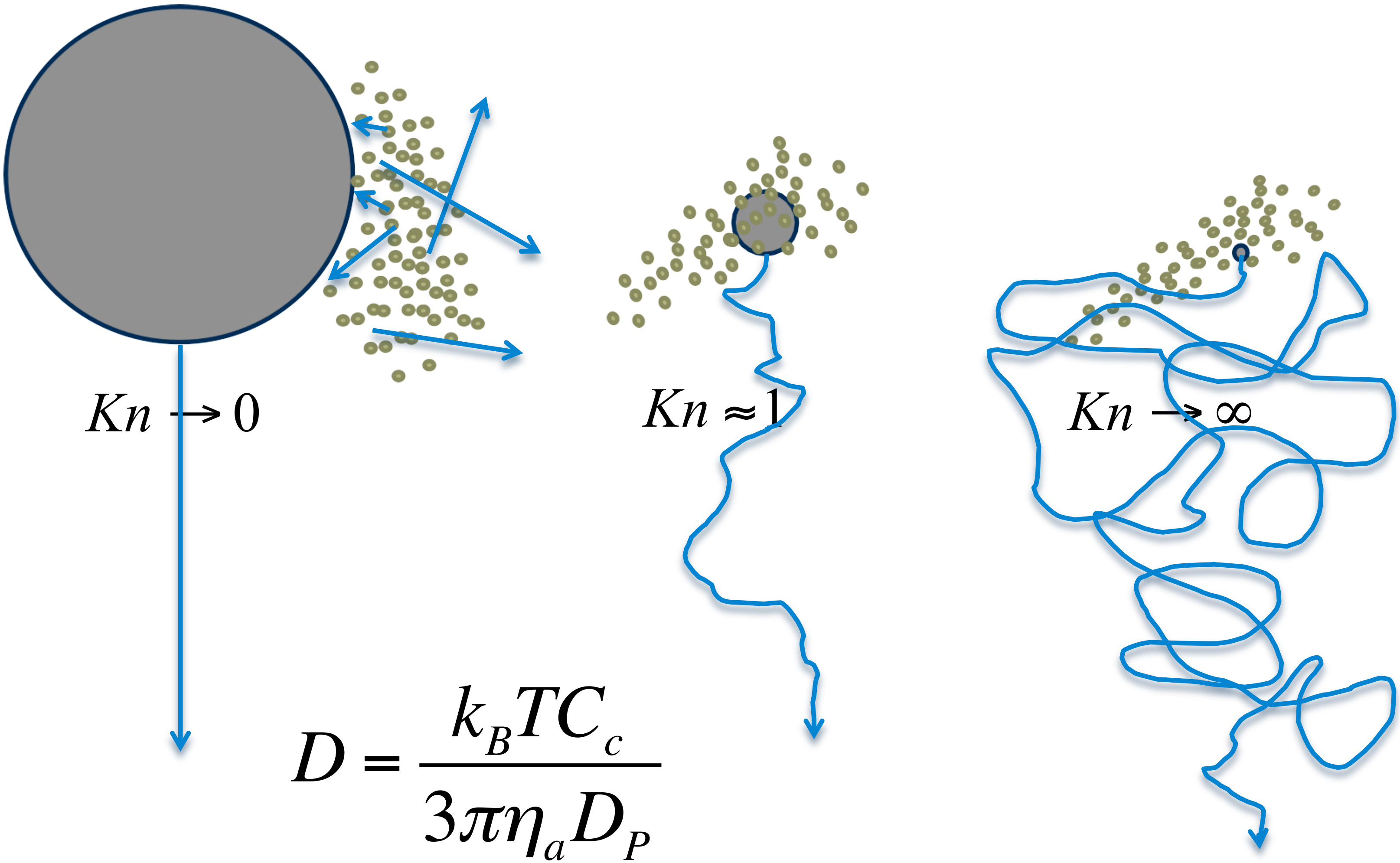
D_P (μm)	Vt (μm/s)
0.01	0.062
0.1	1
1	51
10	4576

Terminal velocity



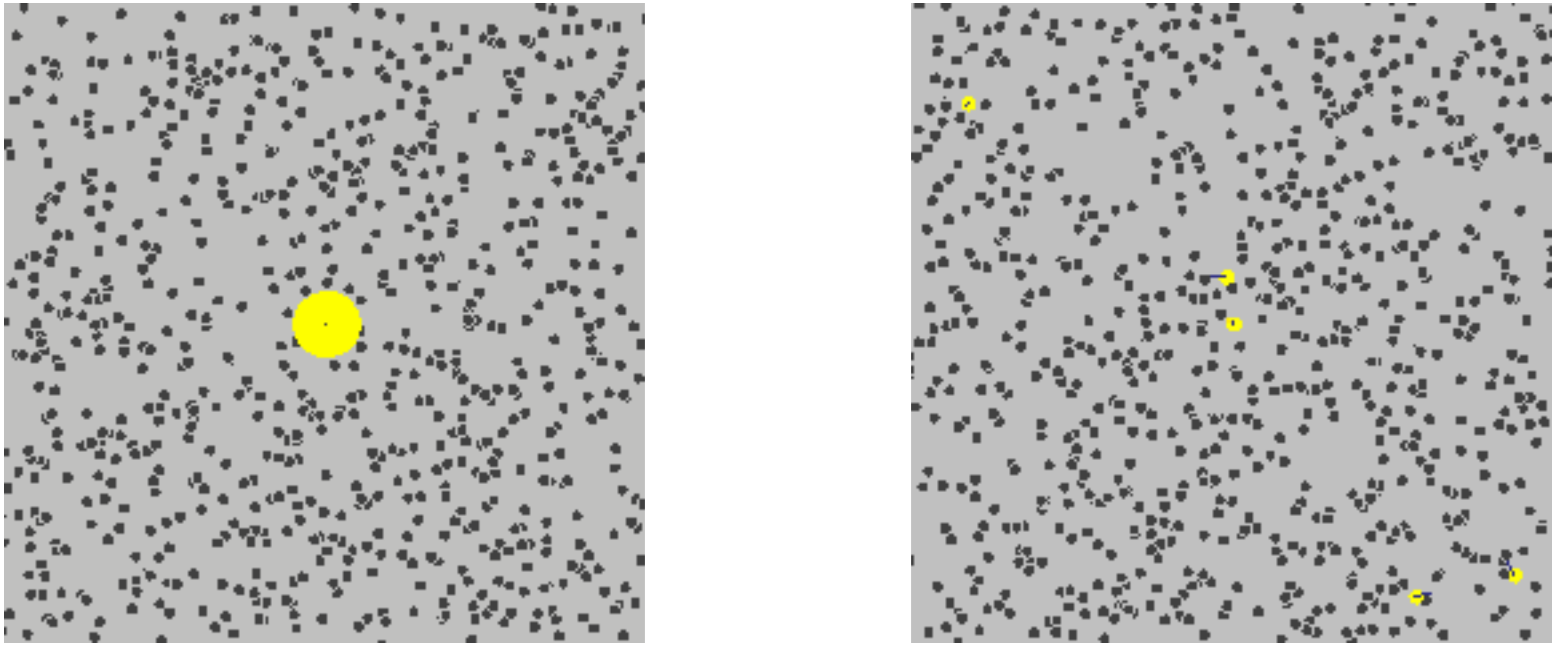
Brownian diffusion

Continuum regime   transition regime   Free molecular regime



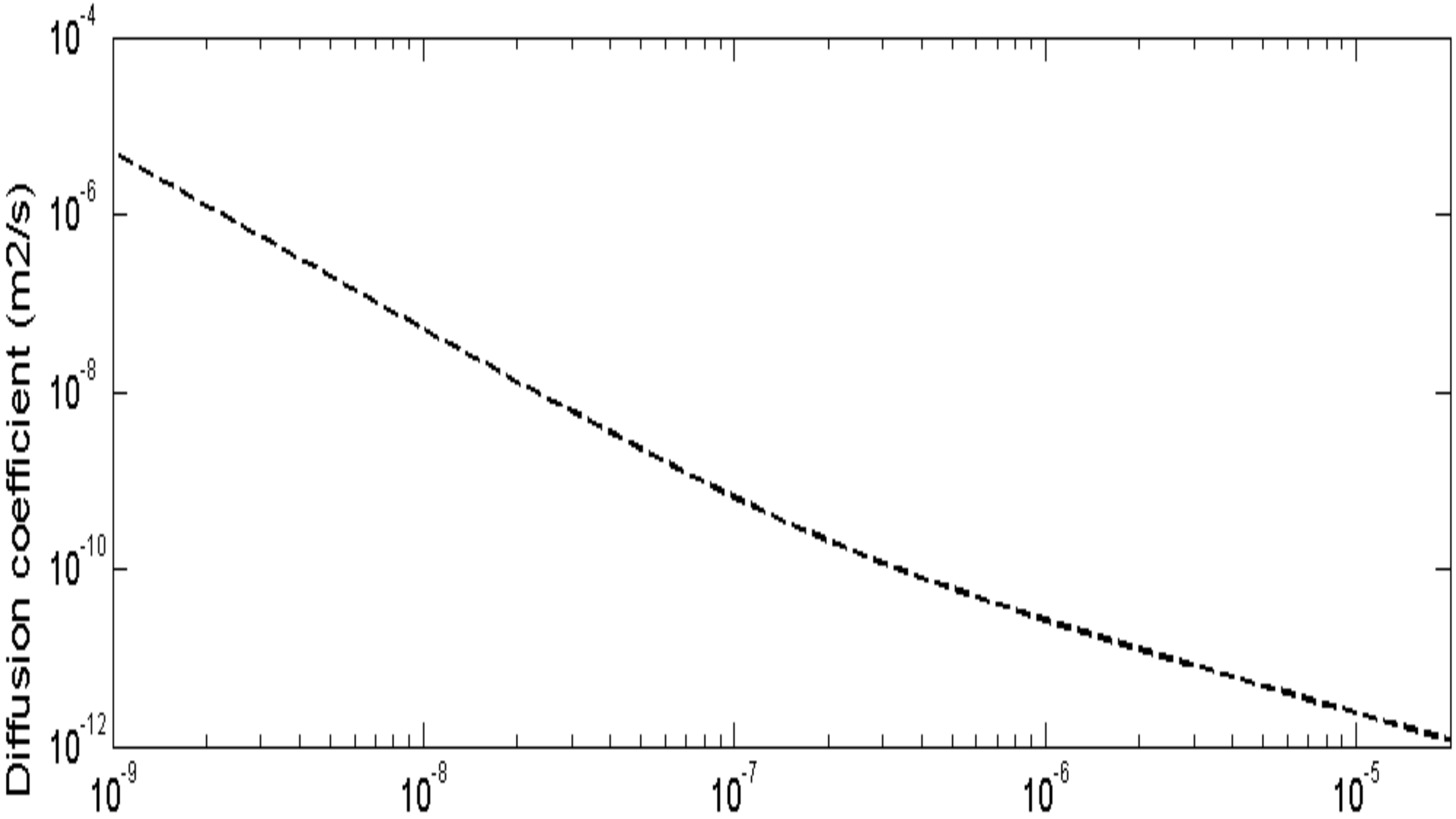
$$D = \frac{k_B T C_c}{3\pi \eta_a D_P}$$

Brownian diffusion

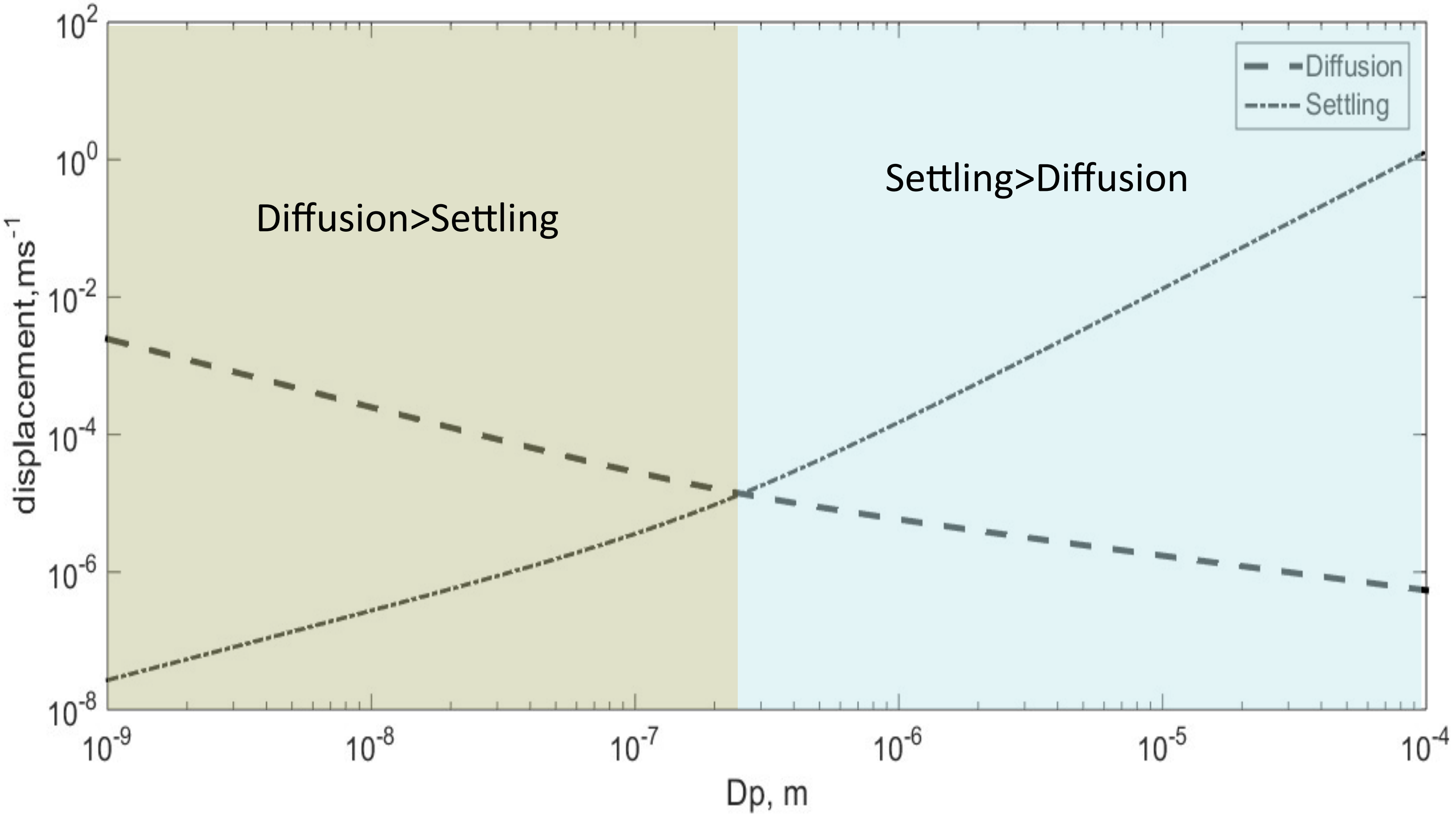


By Lookang Author of computer model: Francisco Esquembre, Fu-Kwun and lookang - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=19140345

Diffusion coefficient



Estimating displacement as function of size; Brownian diffusion vs gravitational settling



Coagulação

- Resultado, principalmente, de movimento Browniano, mas outras forças também tem um papel (elétrica, gravitacional, etc)
- Duas partículas colidem, agregam e formam uma nova partícula
- Coagulação não afeta a massa, mas reduz o número
- É mais eficiente para partículas pequenas

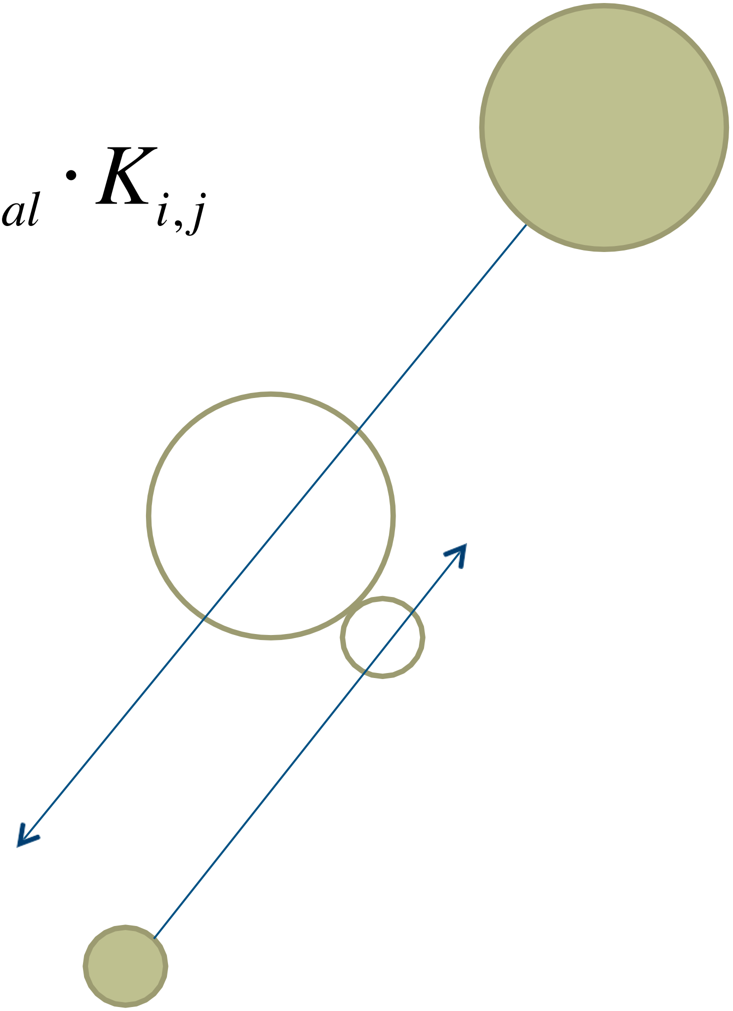
Coagulation

Free molecular regime

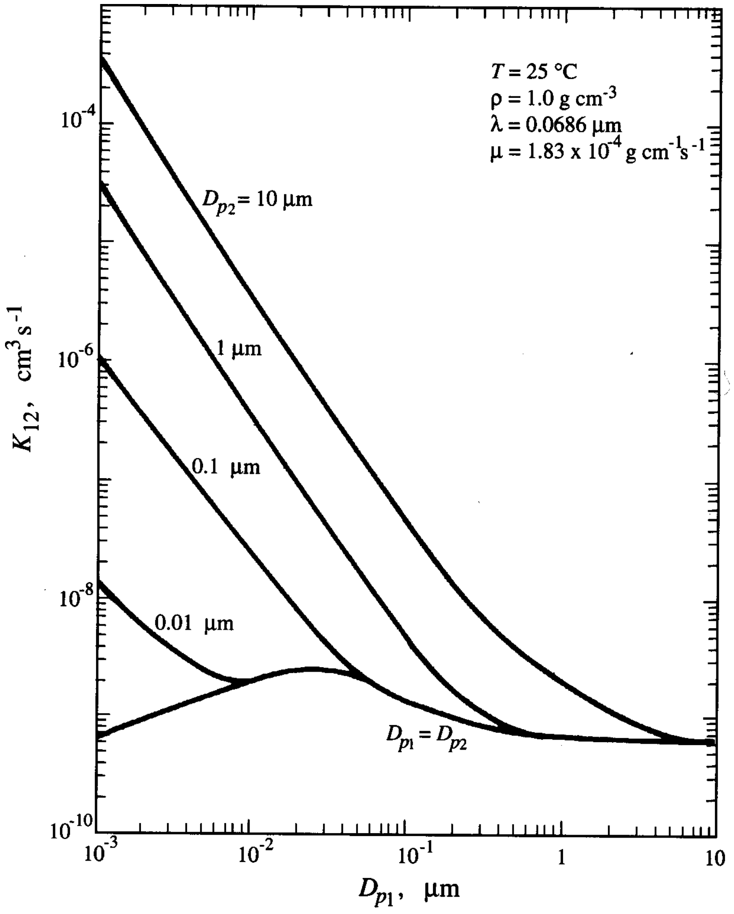
Coagulation rate coefficient = $E_{coal} \cdot K_{i,j}$

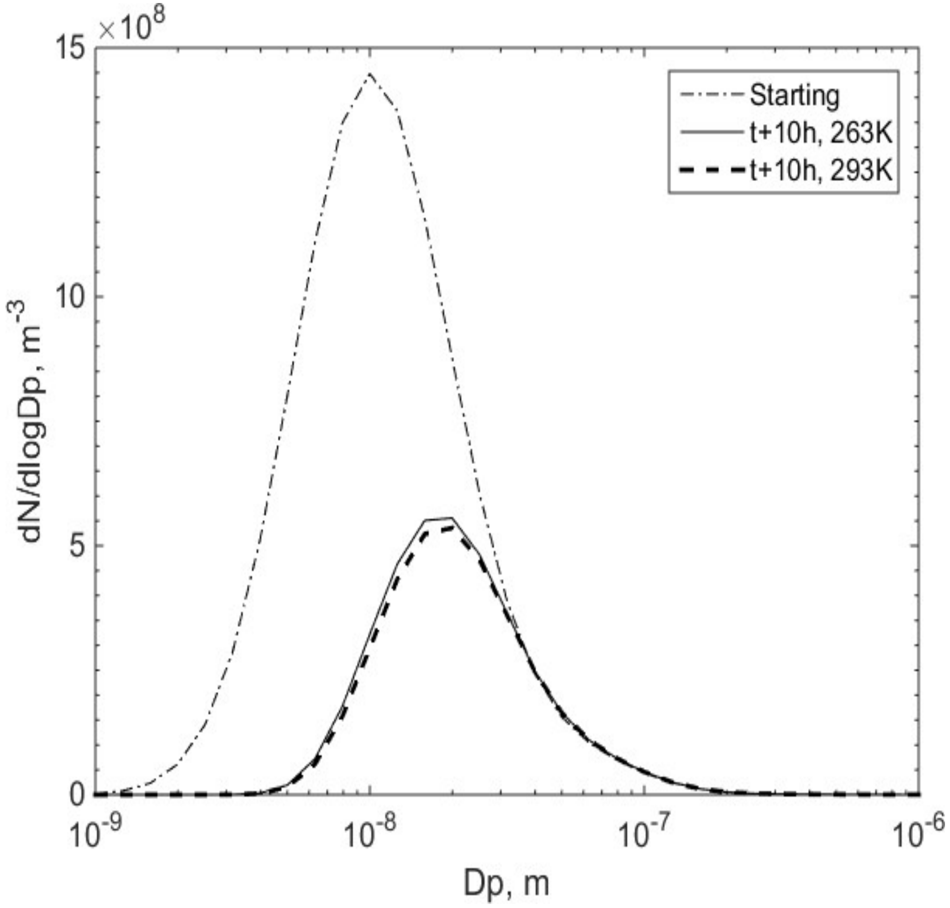
When two aerosol particles collide, they may or may not stick together, depending on the efficiency of coalescence. The efficiency of coalescence depends on particle shape, composition, ambient relative humidity, and other factors.

$$K_{i,j}^{B} = 4\pi(r_i + r_j)^2 \sqrt{v_i^2 + v_j^2}$$

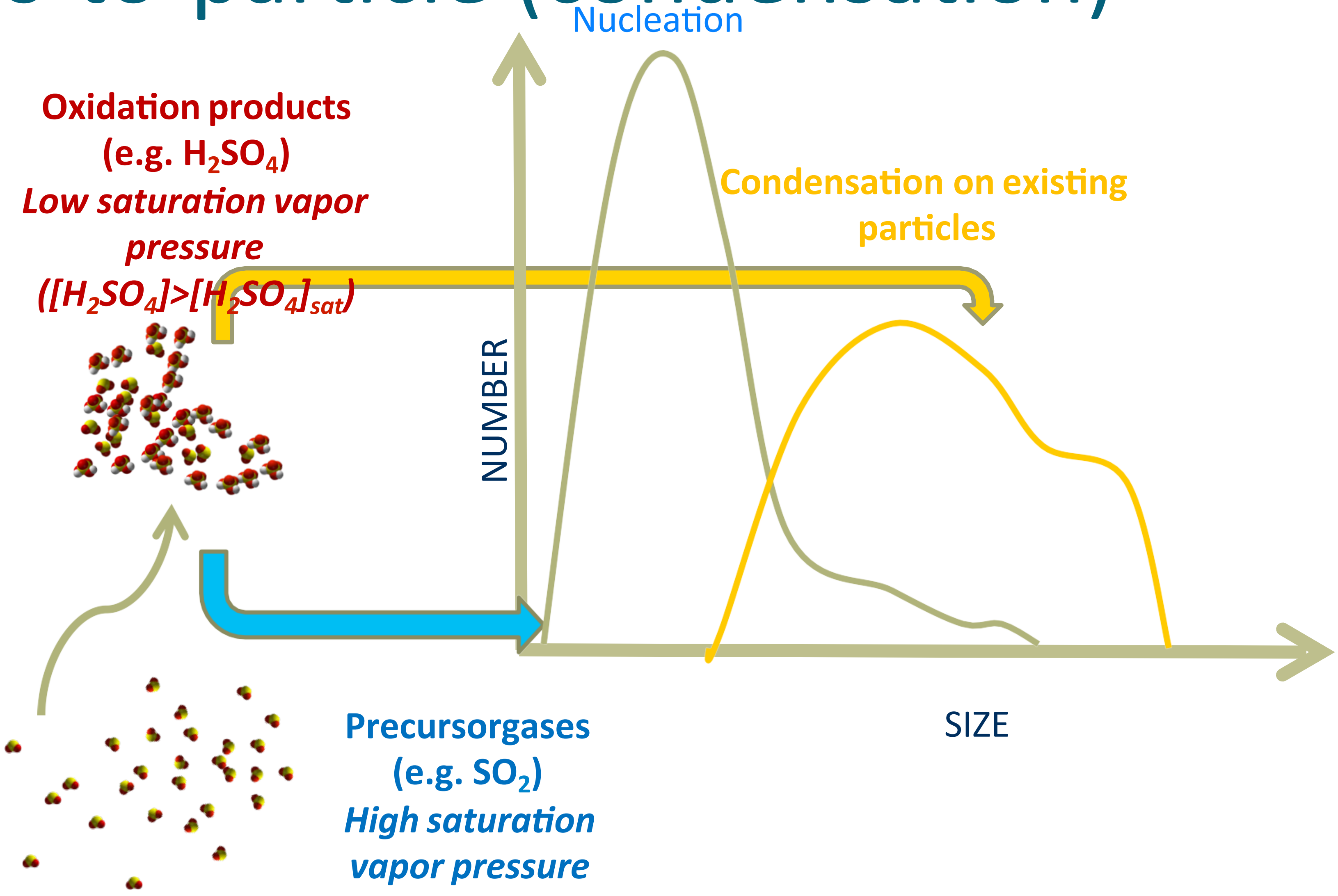


Coagulation





Gas-to-particle (condensation)



Nucleation

Oxidation products
(e.g. H_2SO_4)
Low saturation vapor pressure
$([H_2SO_4]>[H_2SO_4]_{sat})$

Condensation on existing particles

Precursorgases
(e.g. SO_2)
High saturation vapor pressure

Condensation

$$S = \frac{p_a}{p^s{}_a(T)}$$

$$S < 1, Subsaturation$$

$$S > 1, Supersaturation$$

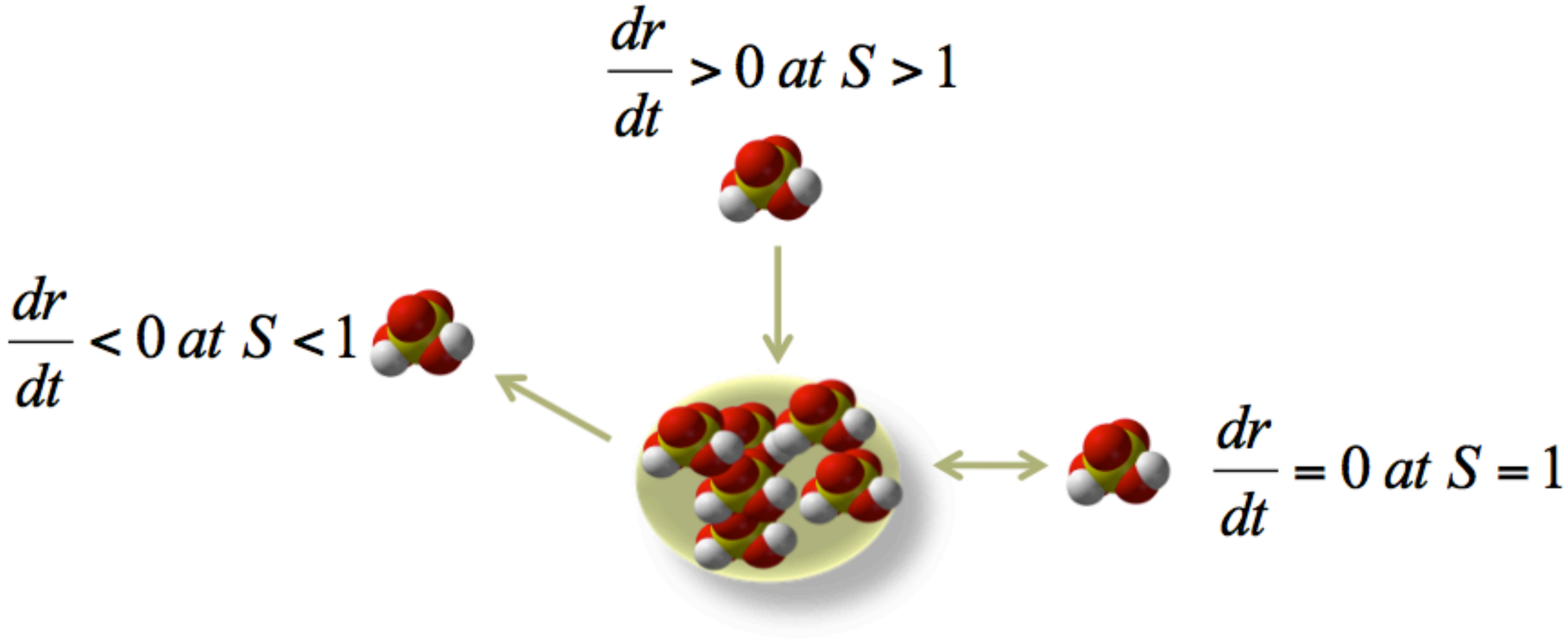
$$S = 1, Saturation$$

S=saturation ratio
$p_{a=}$partial pressure of a
$p_a{}^s$=saturation vapor pressure of a at temperature T

$$\ln\left(\frac{p^s{}_{a,1}}{p^s{}_{a,2}}\right) = \frac{\Delta H_{vap}}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$

Clausius-Clapeyron relation

Condensation

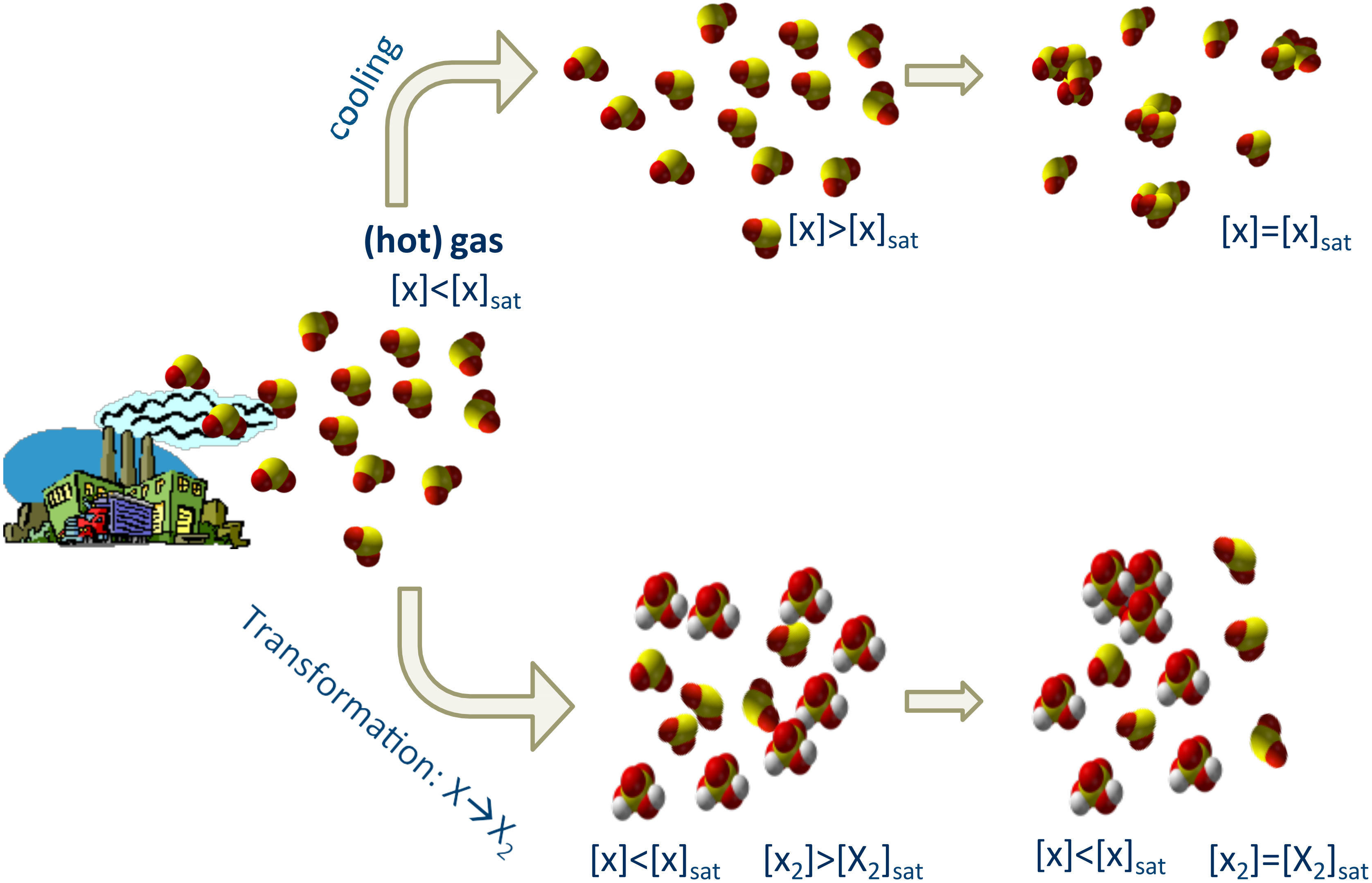


$$\frac{dr}{dt} > 0 \; at \; S > 1$$

$$\frac{dr}{dt} < 0 \; at \; S < 1$$

$$\frac{dr}{dt} = 0 \; at \; S = 1$$

How is supersaturation reached?



cooling

(hot) gas

$[x]<[x]_{sat}$

$[x]>[x]_{sat}$

$[x]=[x]_{sat}$

Transformation: $X \rightarrow X_2$

$[x]<[x]_{sat}$ $[x_2]>[X_2]_{sat}$

$[x]<[x]_{sat}$ $[x_2]=[X_2]_{sat}$

Nucleation x Condensation

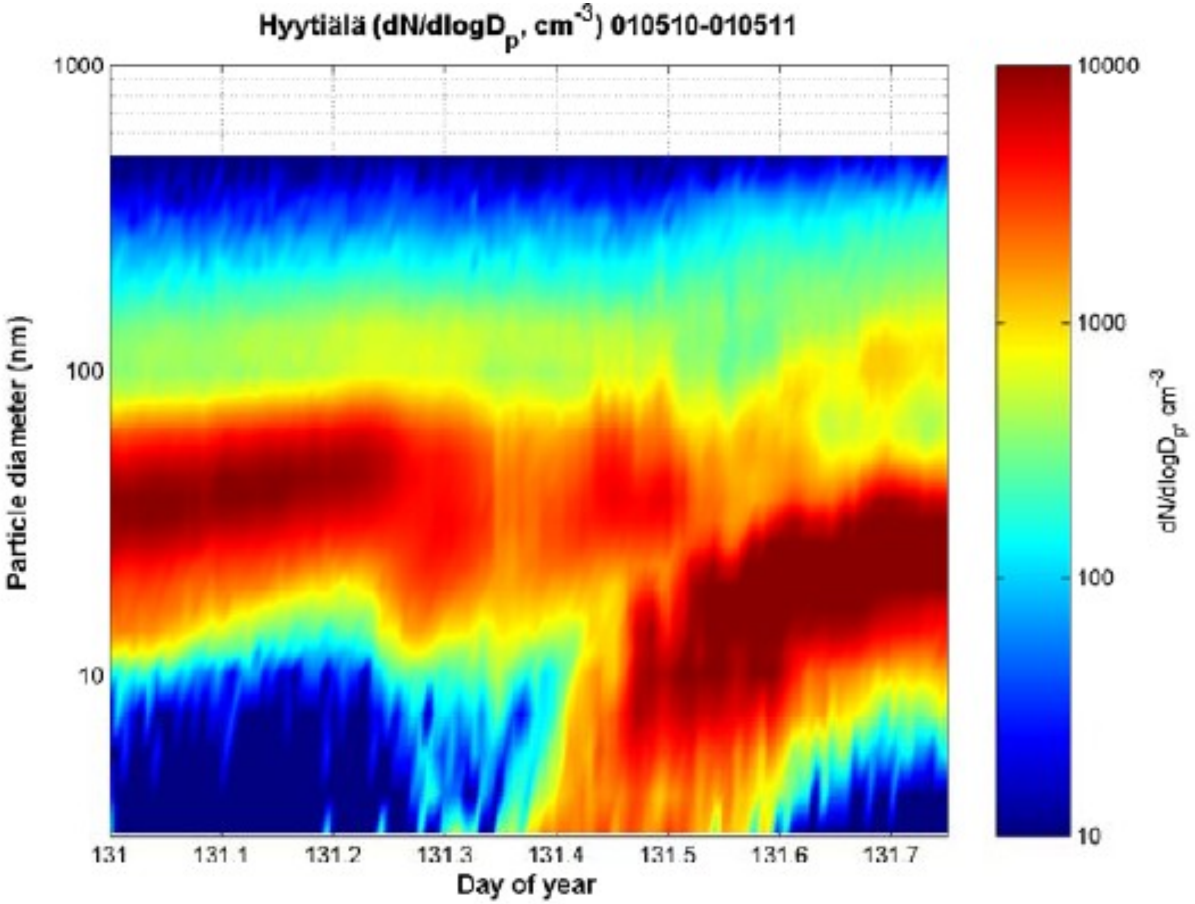
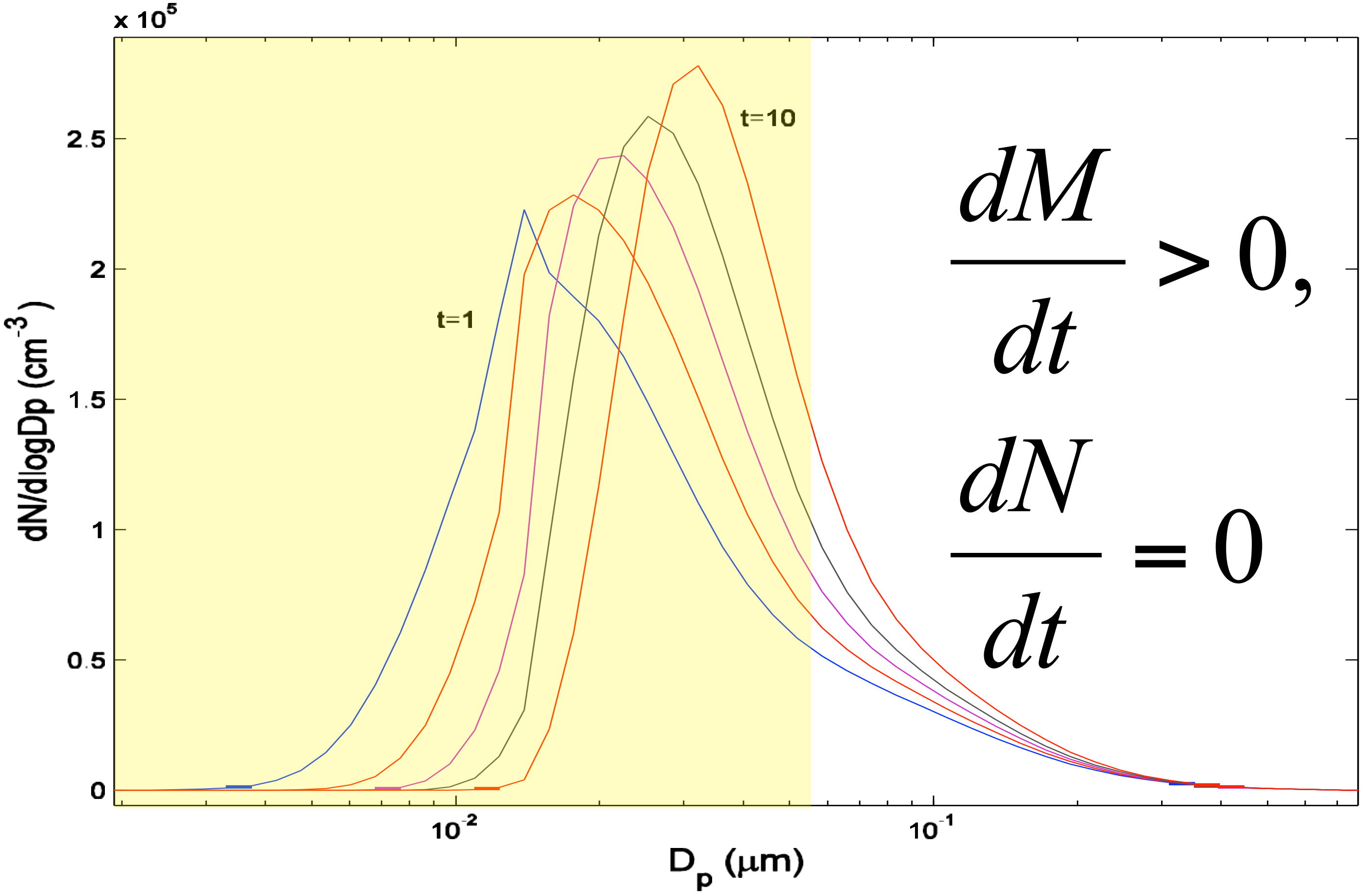


Figure 2: Example of nucleation event observed on 11th May 2001, Hyytiälä (61.51ºN, 24.17ºE).

Number or Mass?

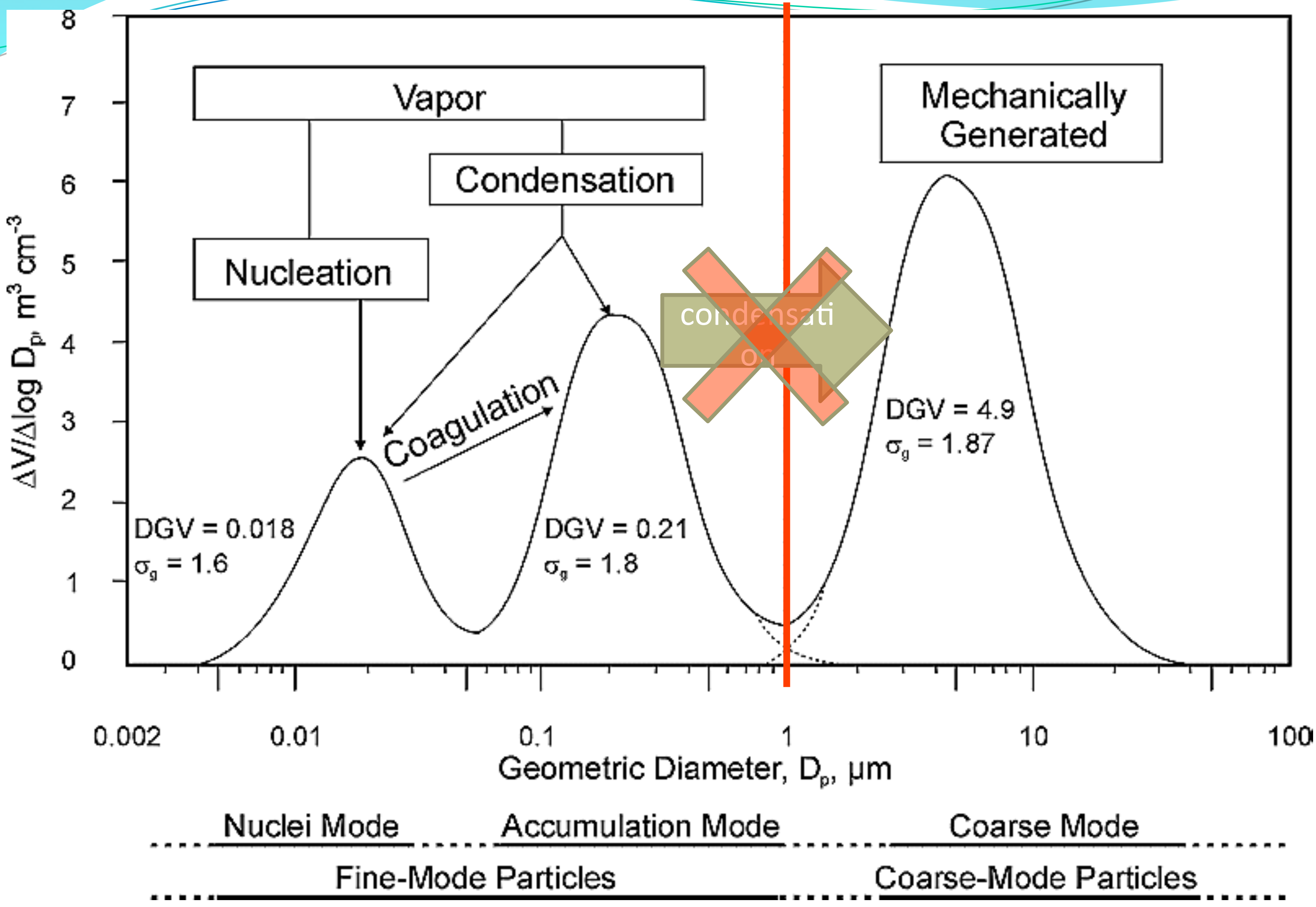
- Amount of pre-existing aerosol surface crucial
  - Generation of supersaturated conditions + low surface area of pre-existing particles favours formation of particle number via nucleation
  - Generation of supersaturated conditions + High concentration of pre-existing particles favours formation of particle mass via condensation

Condensation



$$\frac{dM}{dt} > 0,$$

$$\frac{dN}{dt} = 0$$


Vapor
Condensation
Nucleation
Coagulation
Mechanically Generated
~~condensation~~
DGV = 0.018
σ_g = 1.6
DGV = 0.21
σ_g = 1.8
DGV = 4.9
σ_g = 1.87
$\Delta V/\Delta \log D_p$, $m^3\ cm^{-3}$
0
1
2
3
4
5
6
7
8
0.002
0.01
0.1
1
10
100
Geometric Diameter, D_p, µm
Nuclei Mode
Accumulation Mode
Coarse Mode
Fine-Mode Particles
Coarse-Mode Particles

Dry deposition

- **Dry deposition** occurs when a gas or particle is removed at an air–surface interface, such as on the surface of a tree, a building, a window, grass, soil, snow, or water.
- Dry-deposition speeds are generally parameterized as the inverse sum of a series of resistances

$$V_{d,part} = \frac{1}{r_t} + v_t$$

$$F = -V_d C$$

F=flux to surface $m^{-2}s^{-1}$
v_d=deposition velocity (m/s)
C=concentration of particles

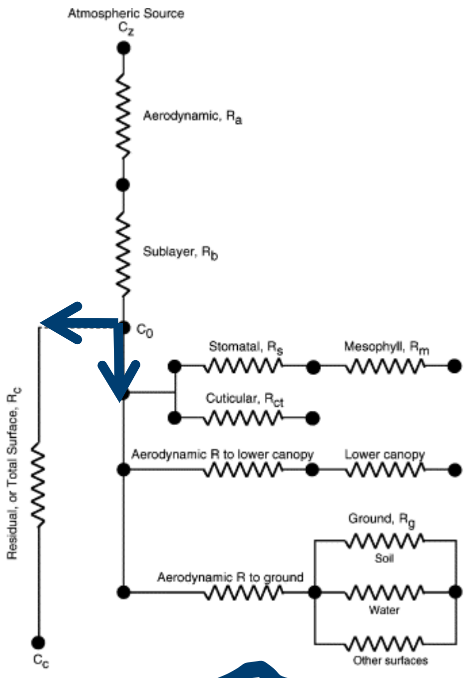
Dry deposition

Only removal path in the dry atmosphere

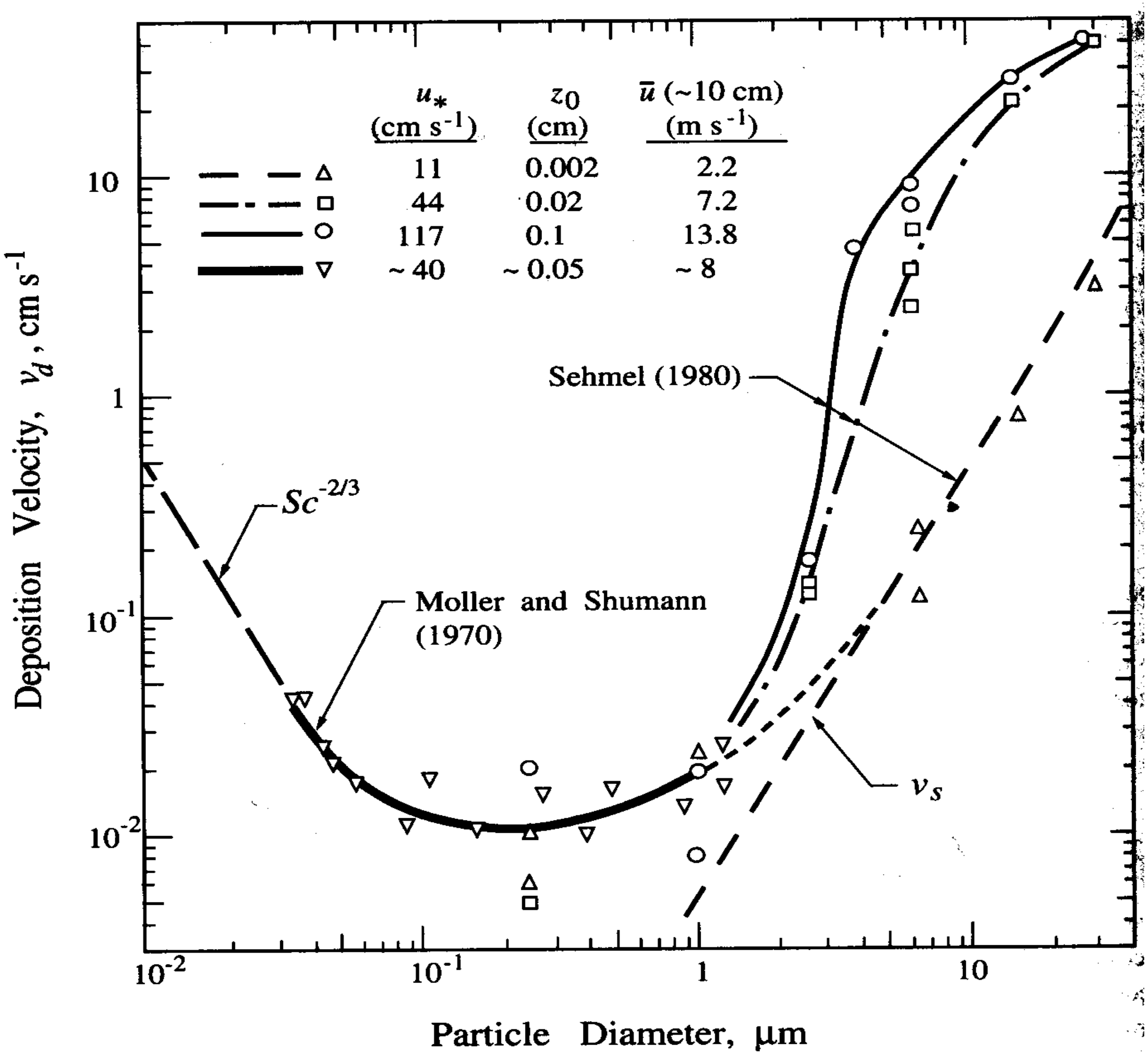
Depends on:

- Atmospheric turbulence
- Phase of species (gas or particle)
- Physio-chemical properties of depositing species
  - Particles: size, density
  - Gases: water solubility, reactivity
- Surface properties: Reactive? Sticky? Irregular? (eg vegetation)

Resistance analogy cont’d



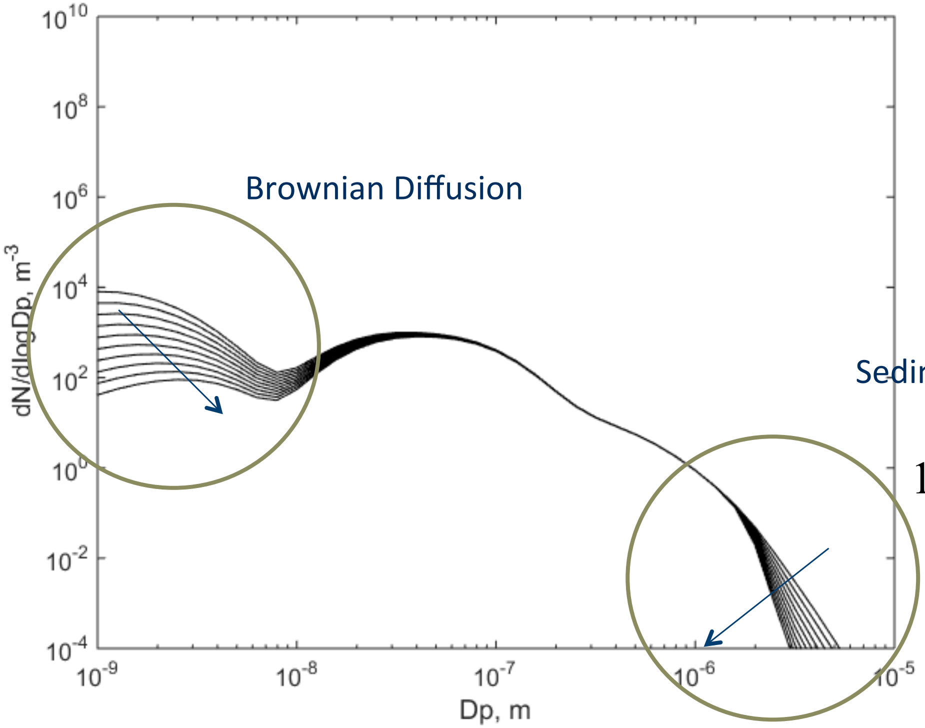
Dry deposition-strongly dependent on size



Ageing due to dry deposition

$$Sc^{-2/3}$$

$$Sc = \mu_{air} / Diff_p$$



Brownian Diffusion

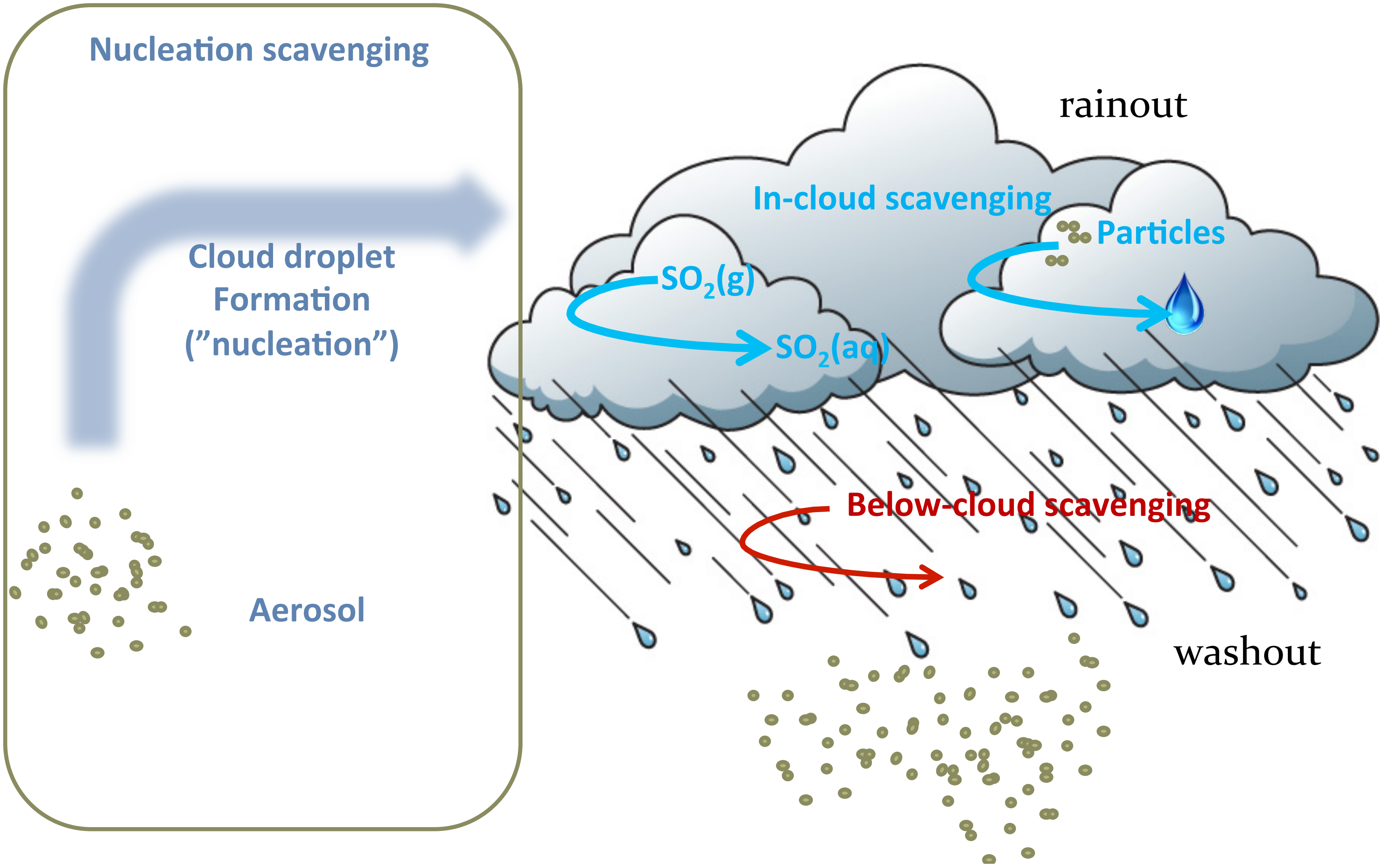
Sedimentation, impaction

$$\frac{dM}{dt} < 0,$$

$$\frac{dN}{dt} < 0$$

$$10^{-3/St}, St = \frac{u*^2 V_s}{g\mu} \text{ and } V_s$$

Wet depositon



Nucleation scavenging

Cloud droplet
Formation
(”nucleation”)

Aerosol

rainout

In-cloud scavenging

$SO_2(g)$

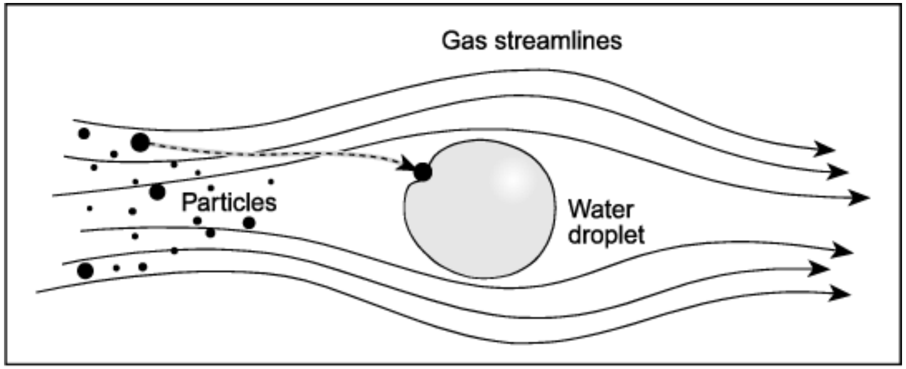
$SO_2(aq)$

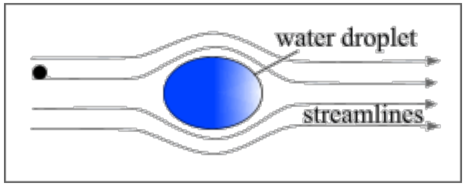
Particles

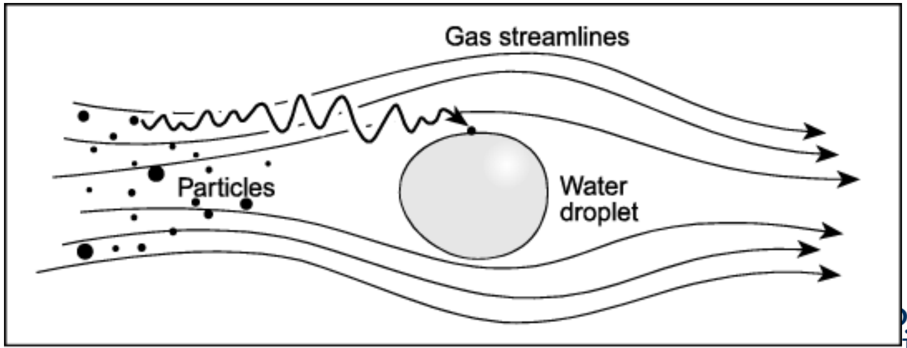
Below-cloud scavenging

washout

Scavenging of aerosols: Impaction, diffusion and interception







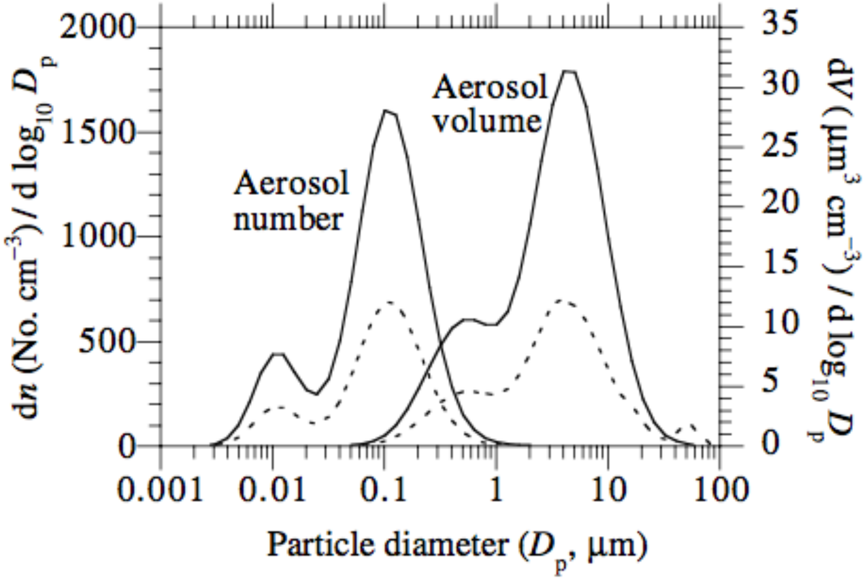
Scavenging

Within a cloud

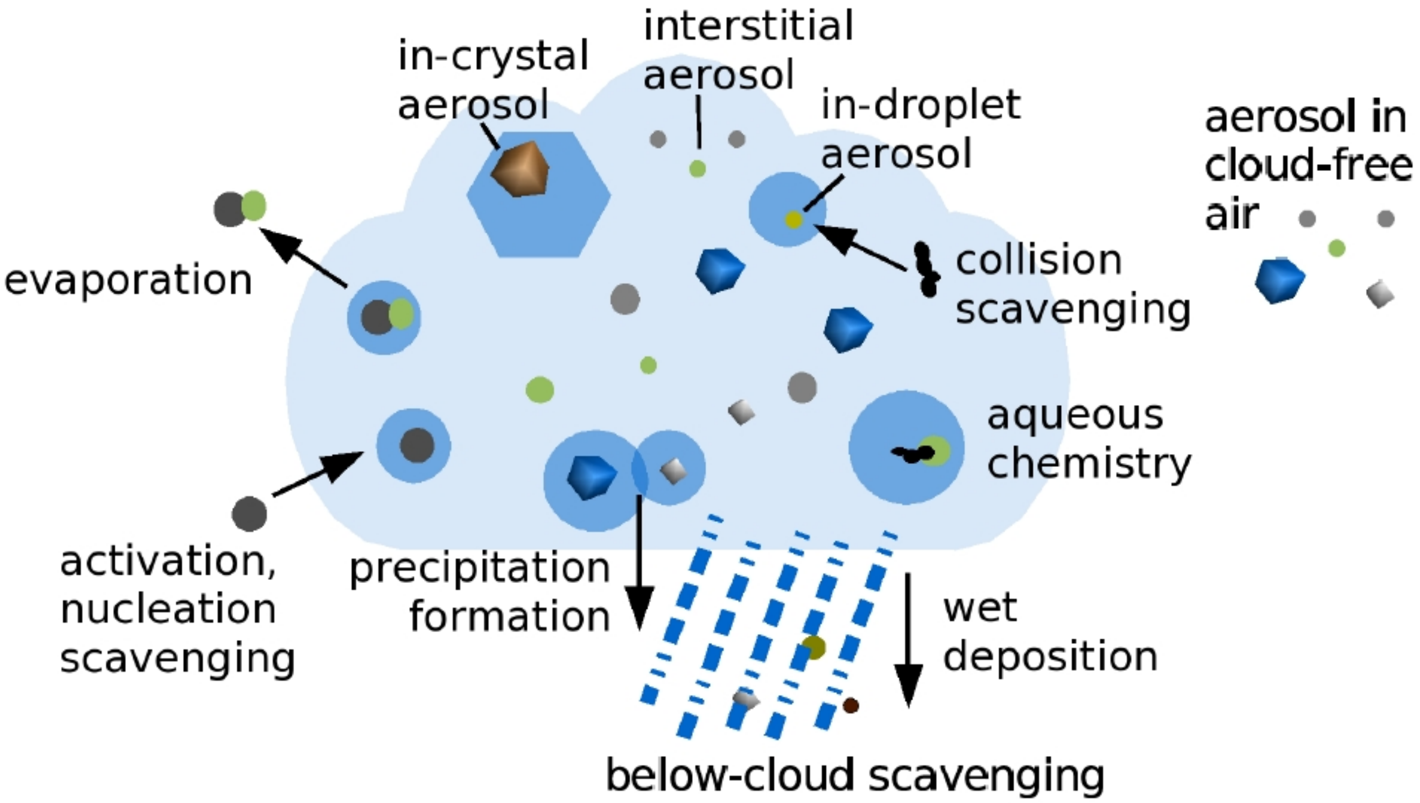
- Rainout scavenges all large and most midsize particles, which have large mass, before washout has a chance to remove particles within a cloud.

Below a cloud (no rainout)

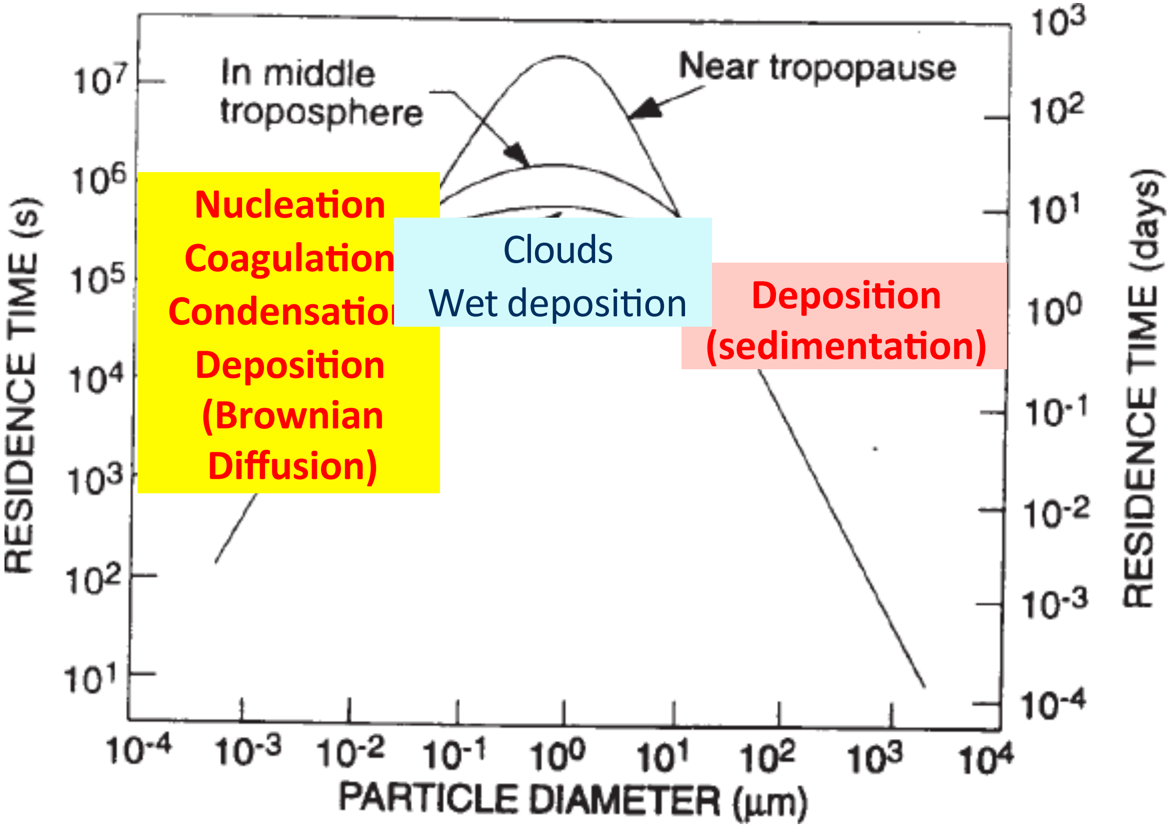
- Washout generally removes more particles by number than does rainout.



Cloud processing



Explaining the residence time

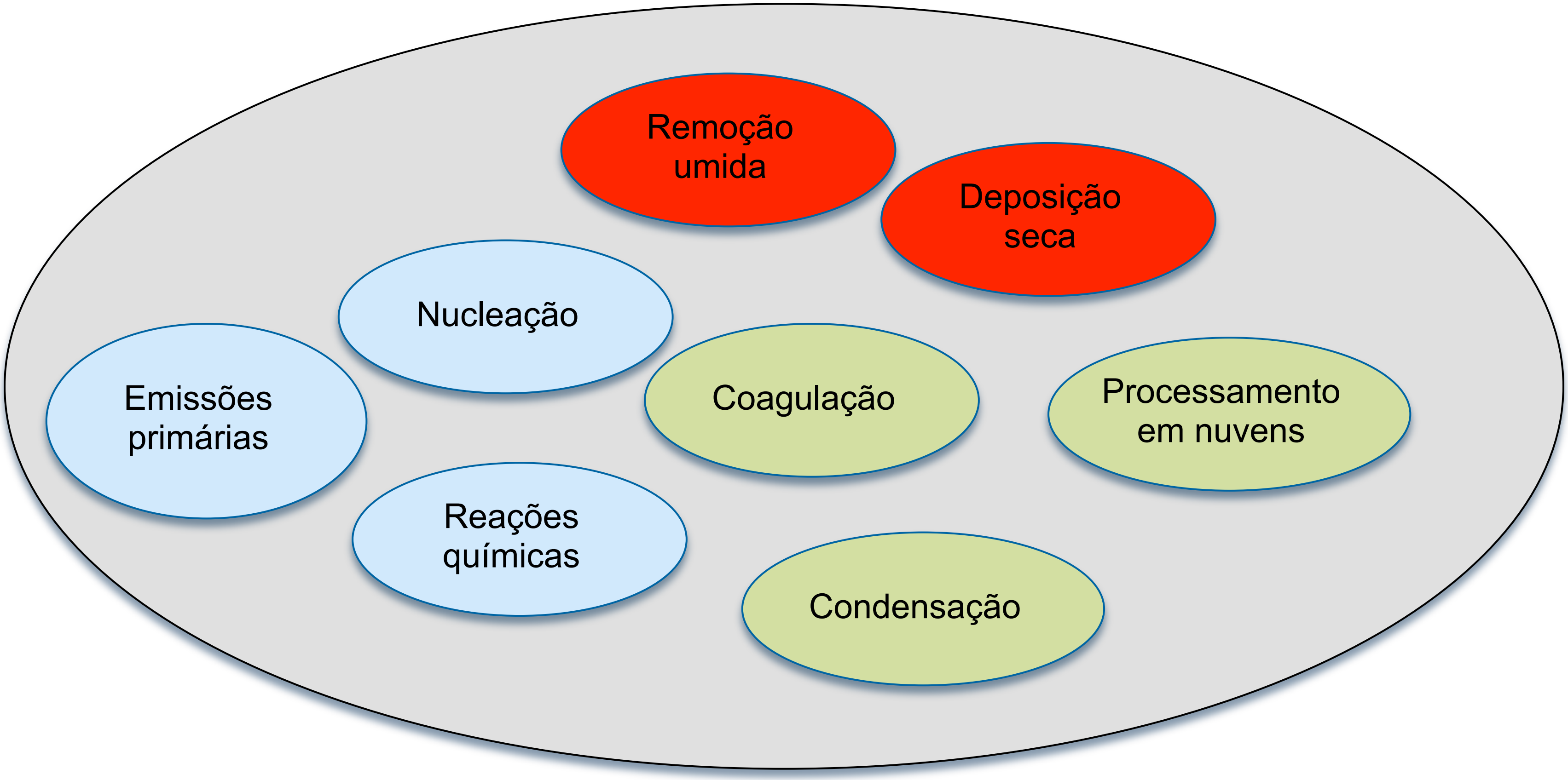


Nucleation
Coagulation
Condensatio
Deposition
(Brownian
Diffusion)

Clouds
Wet deposition

Deposition
(sedimentation)

Processos envolvendo aerossóis



Remoção umida

Deposição seca

Nucleação

Emissões primárias

Coagulação

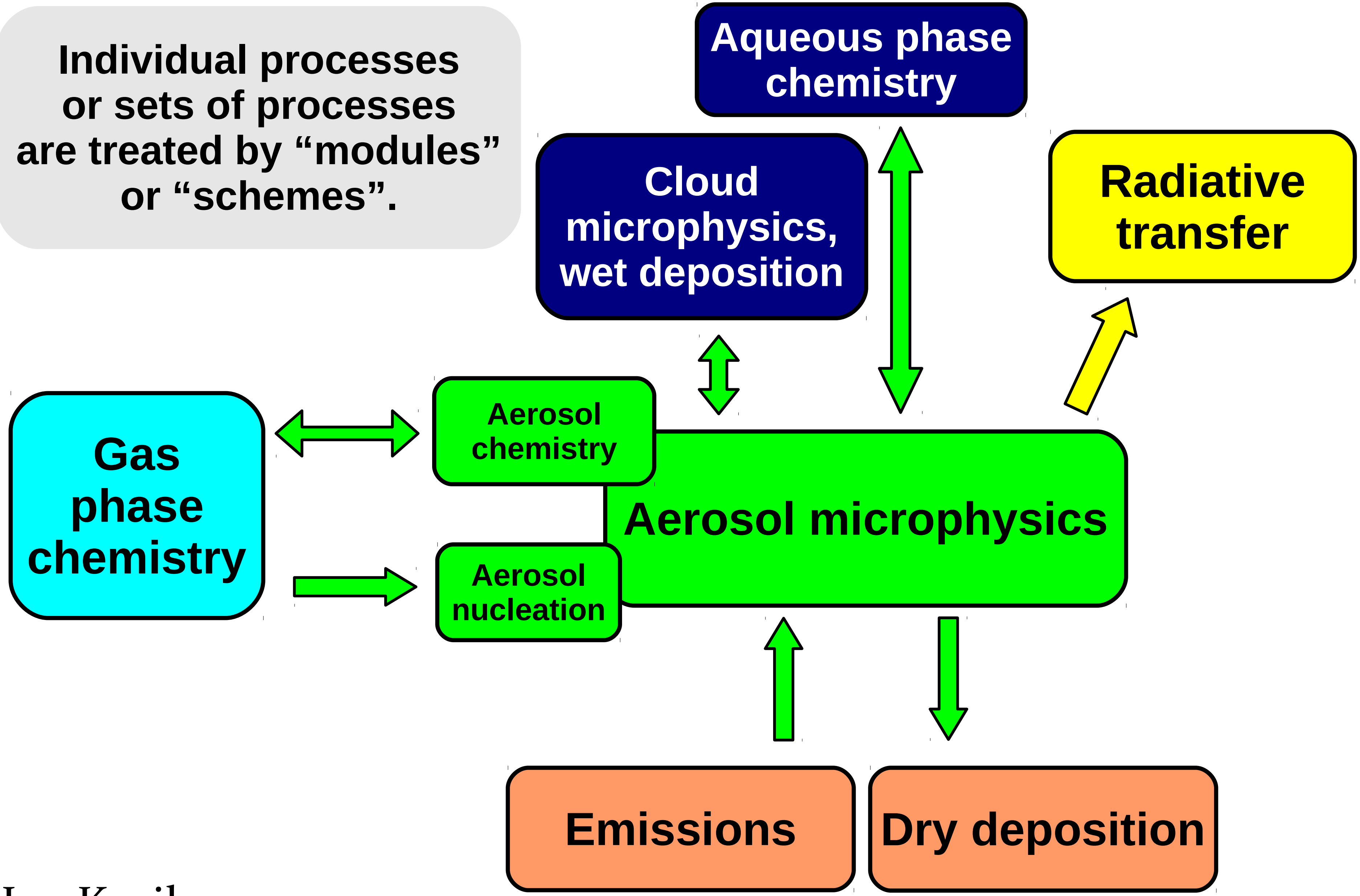
Processamento em nuvens

Reações químicas

Condensação

Model treatment of aerosol

Individual processes
or sets of processes
are treated by “modules”
or “schemes”.



Aqueous phase chemistry

Cloud microphysics, wet deposition

Radiative transfer

Gas phase chemistry

Aerosol chemistry

Aerosol nucleation

Aerosol microphysics

Emissions

Dry deposition

Jan Kazil