Arab Academy
for Science, Technology & Maritime Transport

EGY Plasma

Dusty Plasma

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Outline

- Types of plasma
- Occurance of dusty plasma
- Properties of dusty plasma
- Dusty plasma terminology

Types of plasma

- **(I) Classical plasma (electron-ion plasma)**

  +ve ions / electrons / -ve ions / positrons

- **(II) Dusty (complex) plasma**

  +ve dust / -ve dust / +ve ions / electrons / -ve ions

- **(III) Quantum (Dense) plasma**

  Electrons / positrons / holes / +ve ions

Occurance of dusty plasma

Natural

- Solar nebula
- Planetary rings
- Interstellar medium
- Comet tails
- Noctilucent clouds
- Lightning

Man-made

- Microelectronic processing
- Rocket exhaust
- Fusion devices

Occurance of dusty plasma

Rosette Nebula

Our solar system accumulated out of a dense cloud of gas and dust, forming everything that is now part of our world.

Occurance of dusty plasma

Hyakutake

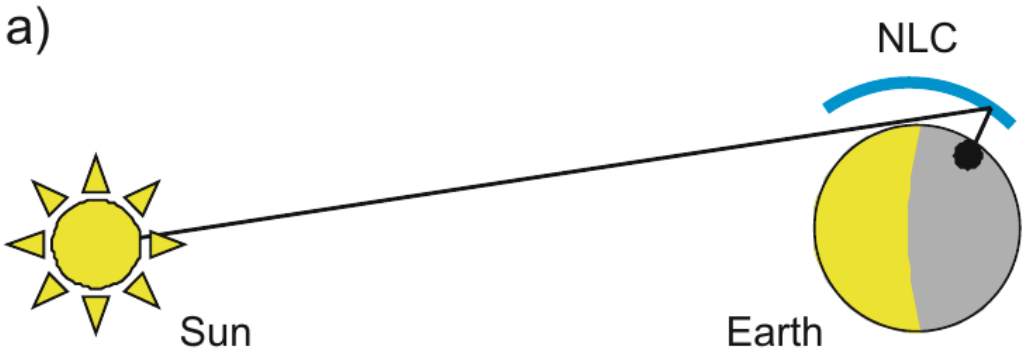
Hale-Bopp

Occurance of dusty plasma

Eagle Nebula

Saturn Rings

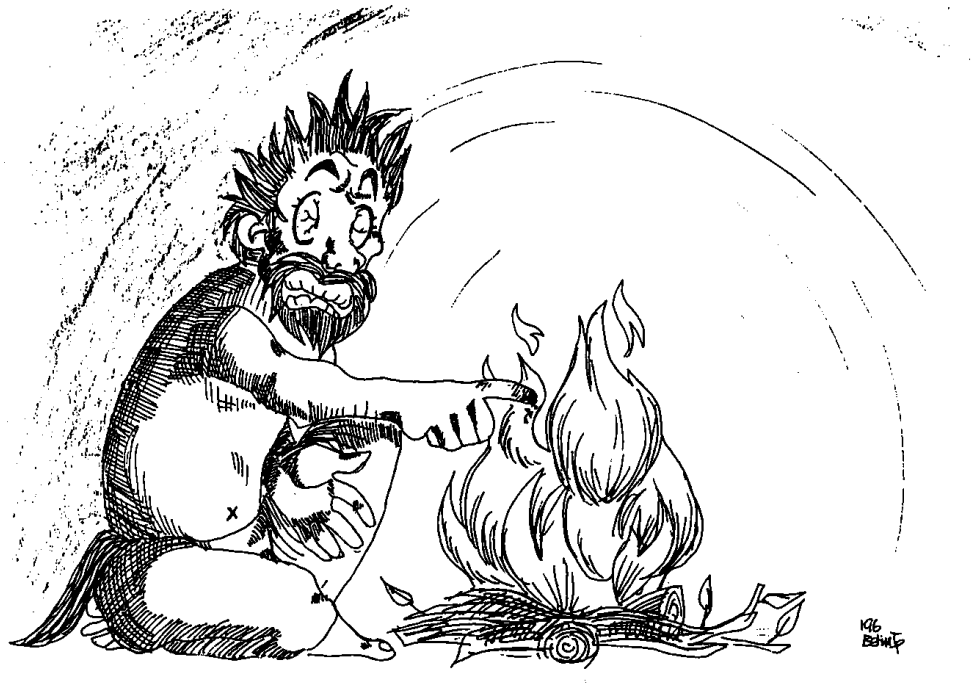
Occurance of dusty plasma



Noctilucent clouds formed in the summer mesosphere at 75-80 km altitude range;
100 nm water ice, charged

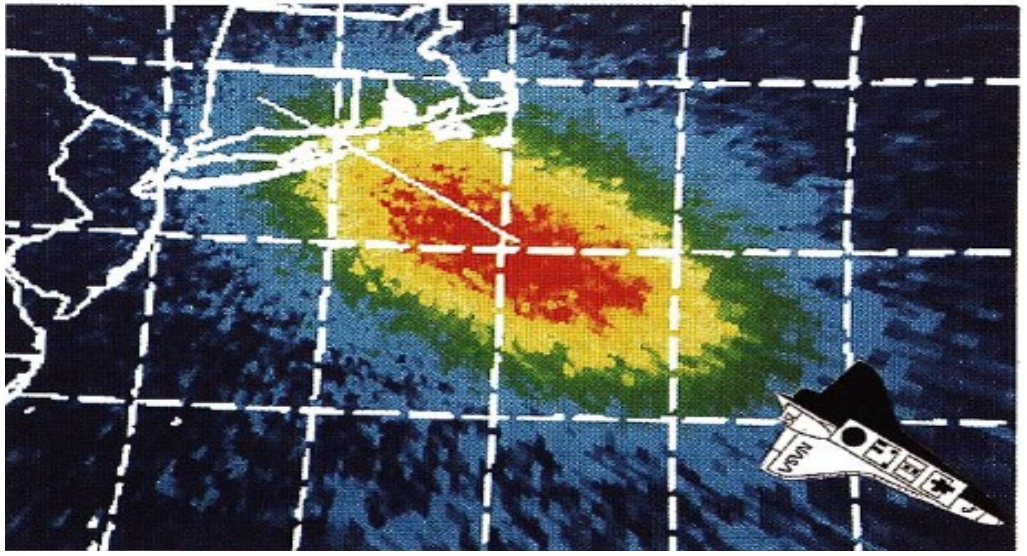
Occurance of dusty plasma

A flame is a very weakly ionized plasma that contains soot particles



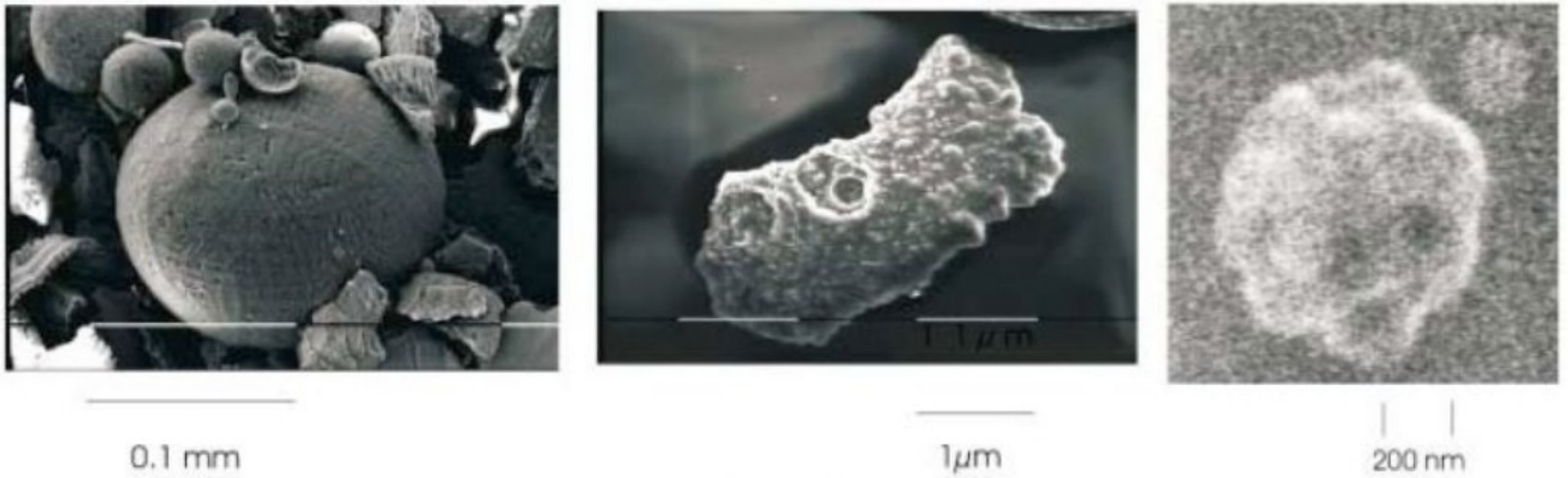
An early temperature measurement in a dusty plasma

Occurance of dusty plasma

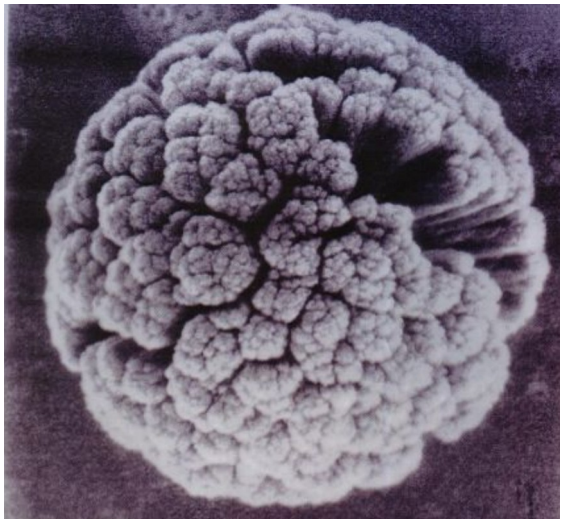


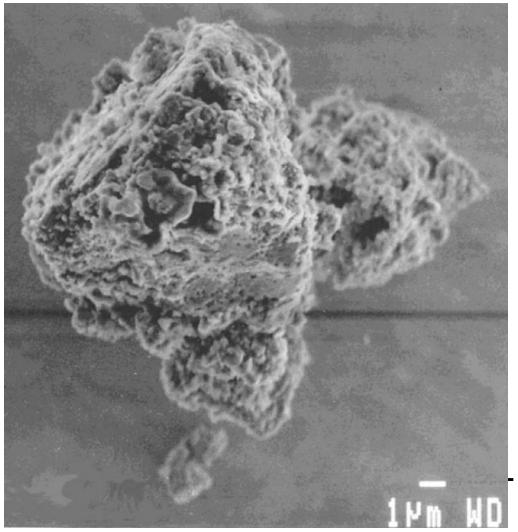
Dusty plasma of charged ice caused by the Space Shuttle engine exhaust

Occurance of dusty plasma



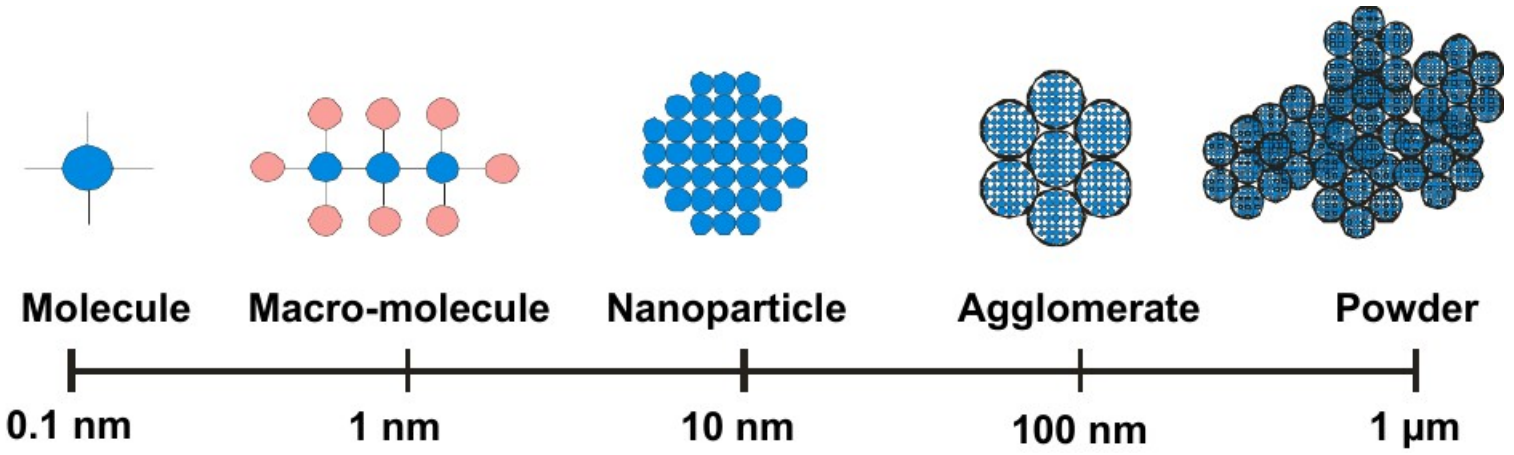
Significant amount of dust particles is observed in the chambers of fusion devices





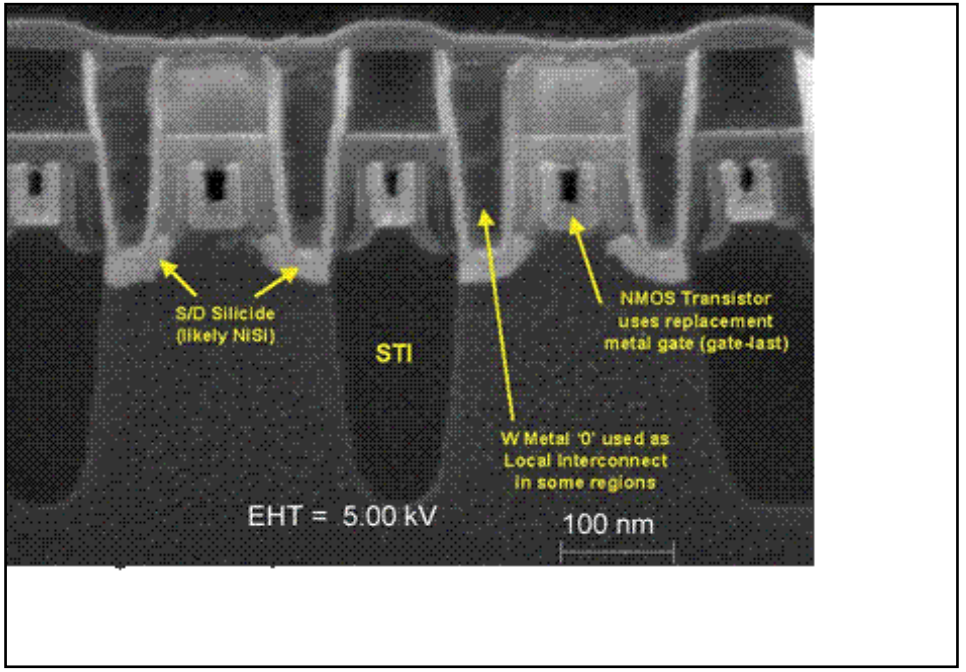
Occurance of dusty plasma

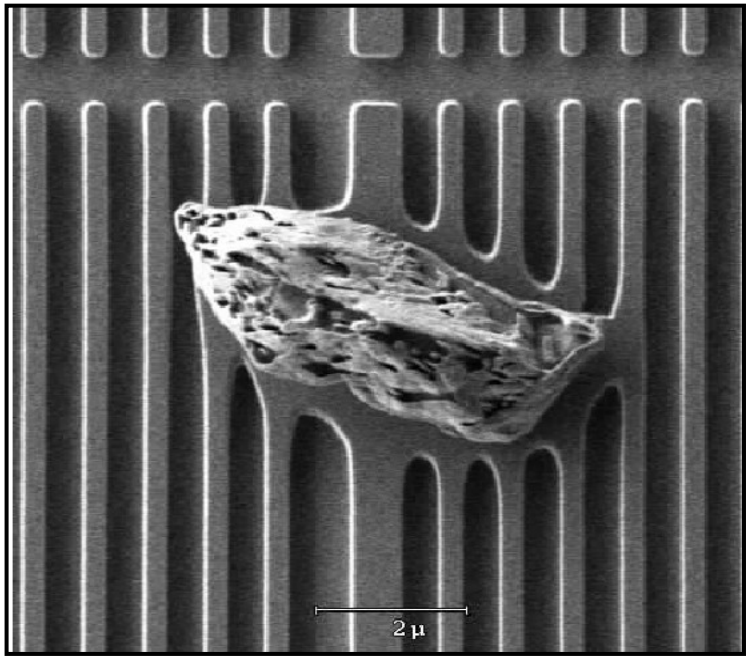
- The “dust” is a result of the strong interaction between the material walls and energetic plasma.
- Studies indicate that dust can be transported deep into the plasma, causing a serious contamination problem.
- Movies



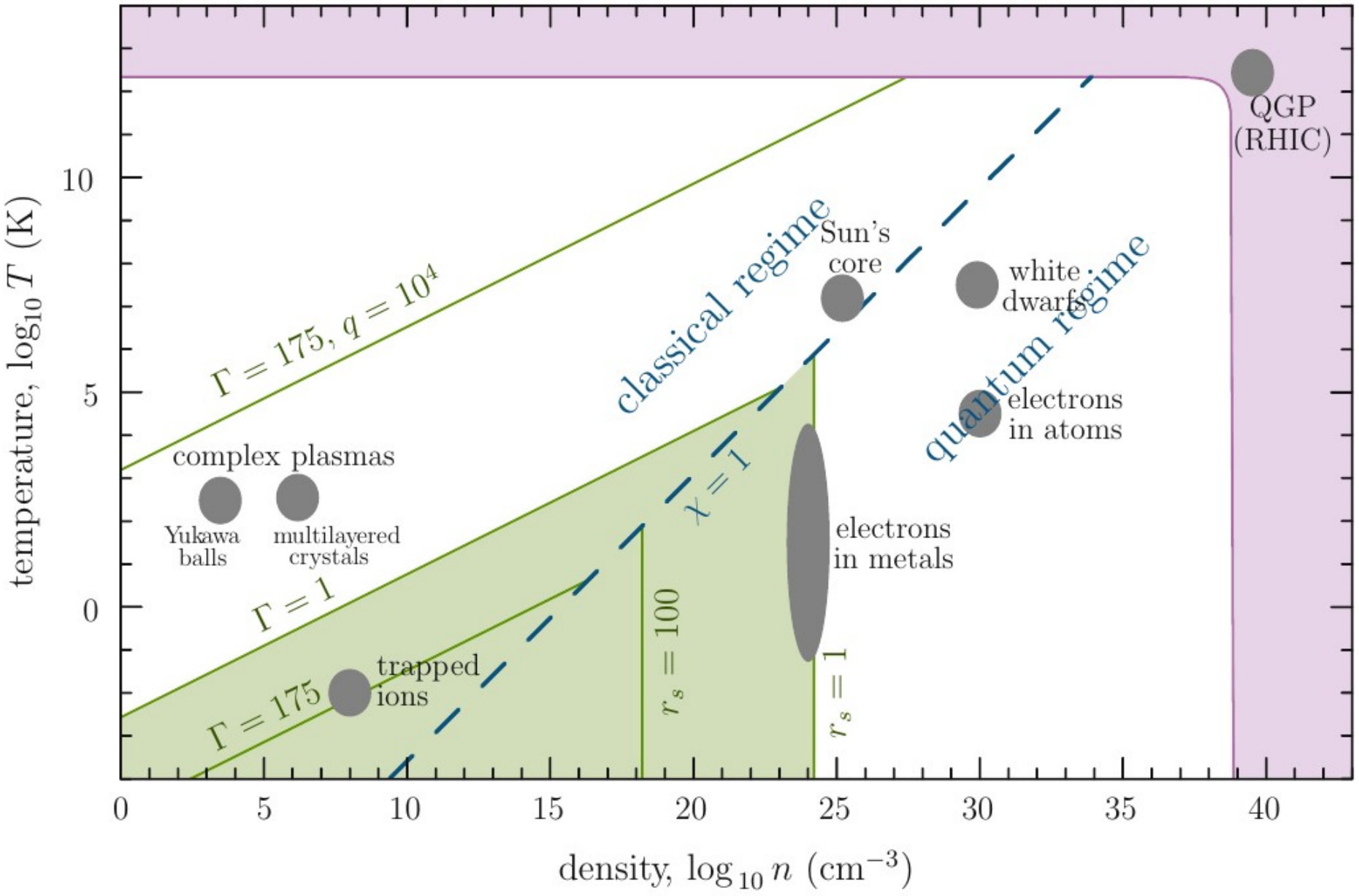
Occurance of dusty plasma

- Microelectronic processing
- Plasma chemistry and nanotechnology → coagulation of macroparticles



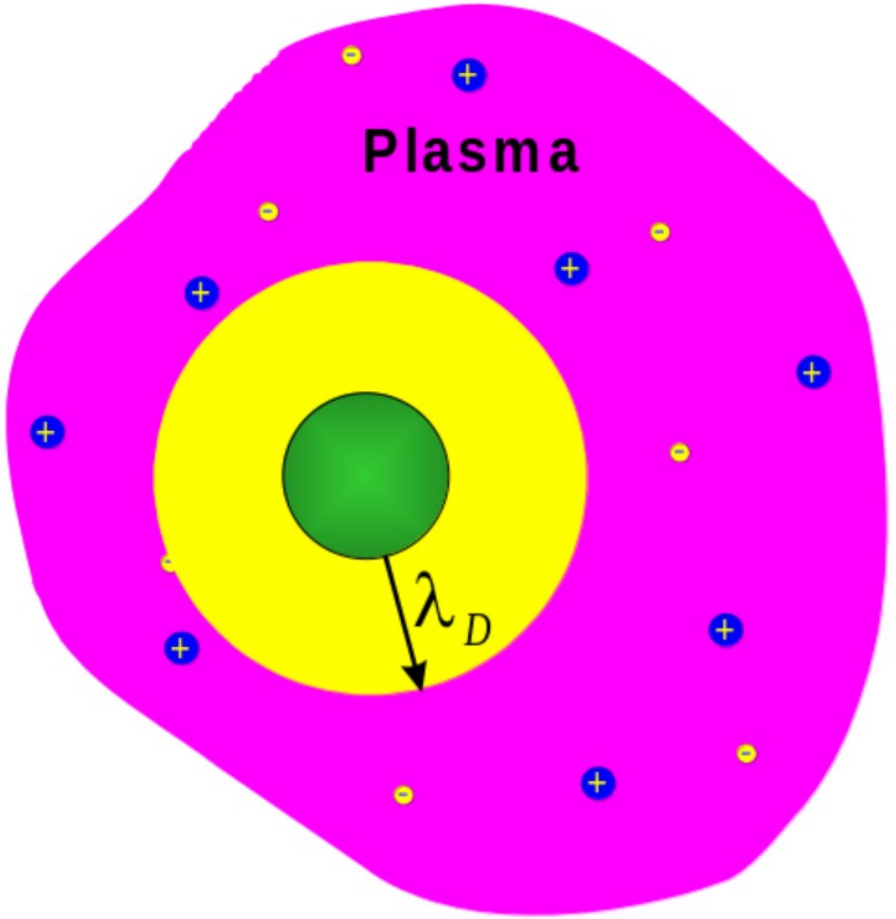


Occurance of dusty plasma



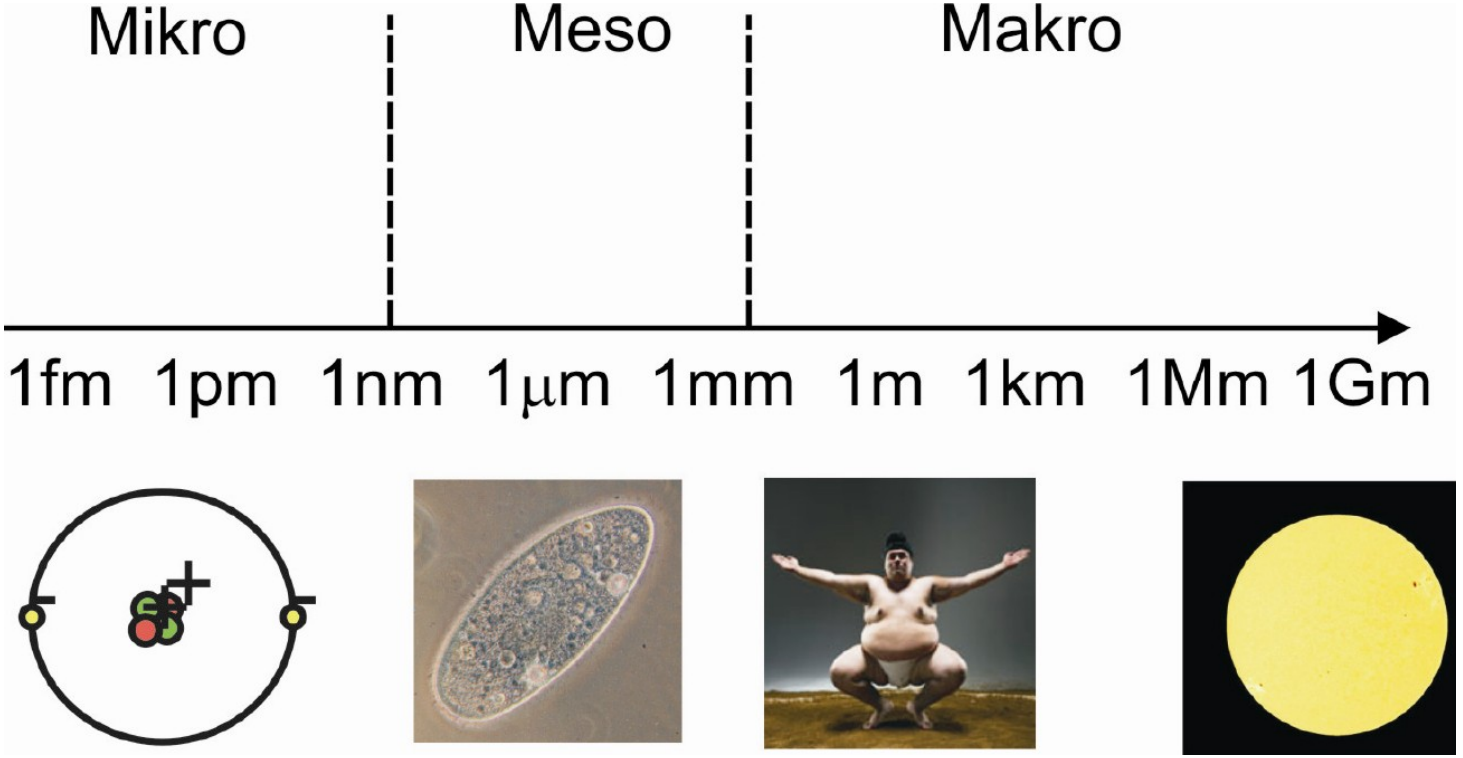
Properties of dusty plasma

- Dusty plasma is a multi-component plasma
- It contains electrons, ions, neutral atoms/molecules, and micro-particles/charged dust grains



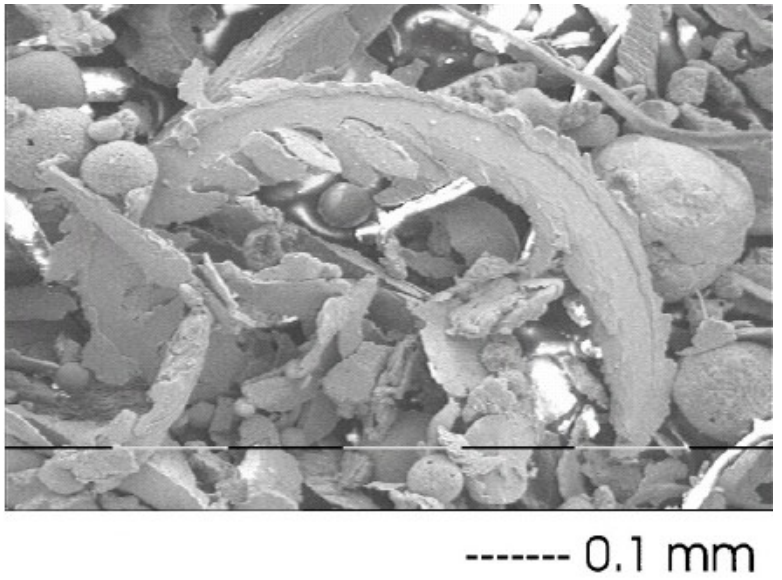
Properties of dusty plasma

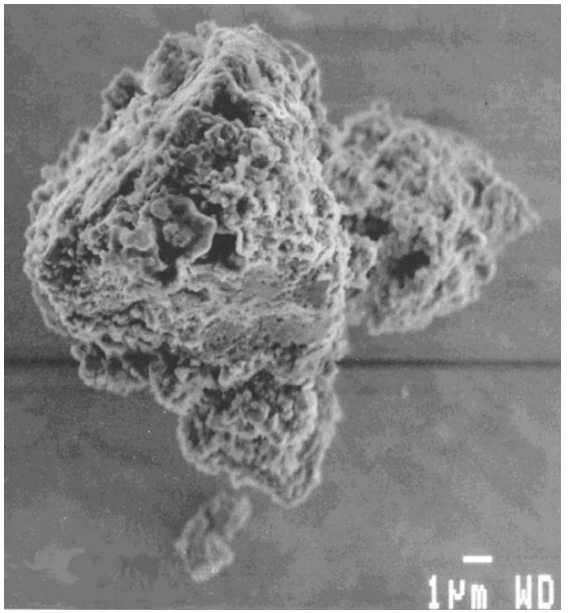
- Range size



Properties of dusty plasma

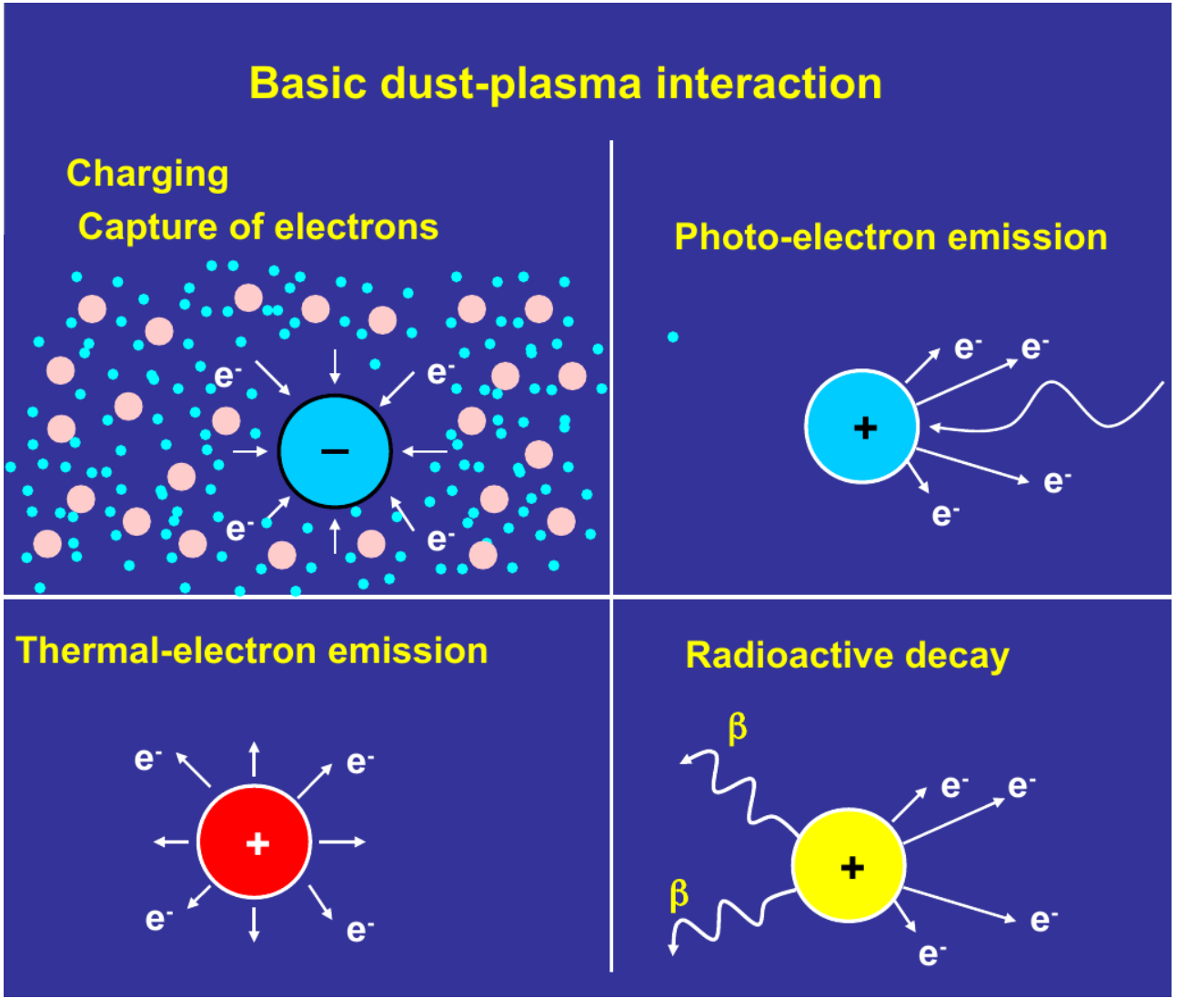
- Dust size distributions





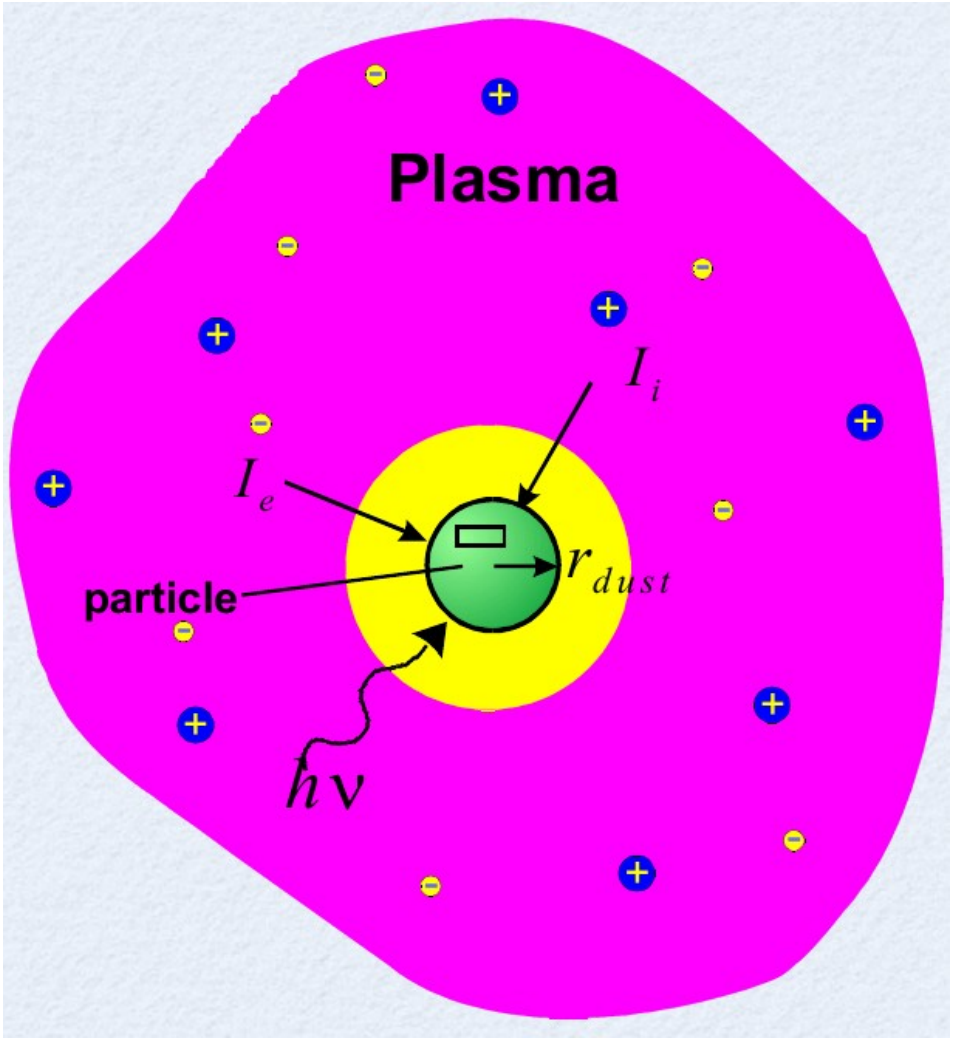
Properties of dusty plasma

- Dynamic dust charging



Properties of dusty plasma

- Dynamic dust charging



Dusty plasma terminology

- Debye shielding $$\lambda_D = \frac{\lambda_{De}\lambda_{Di}}{\sqrt{\lambda_{De}^2 + \lambda_{Di}^2}}$$

$$\lambda_{De} = (k_B T_e / 4\pi n_{e0} e^2)^{1/2} \text{ and } \lambda_{Di} = (k_B T_i / 4\pi n_{i0} e^2)^{1/2}$$

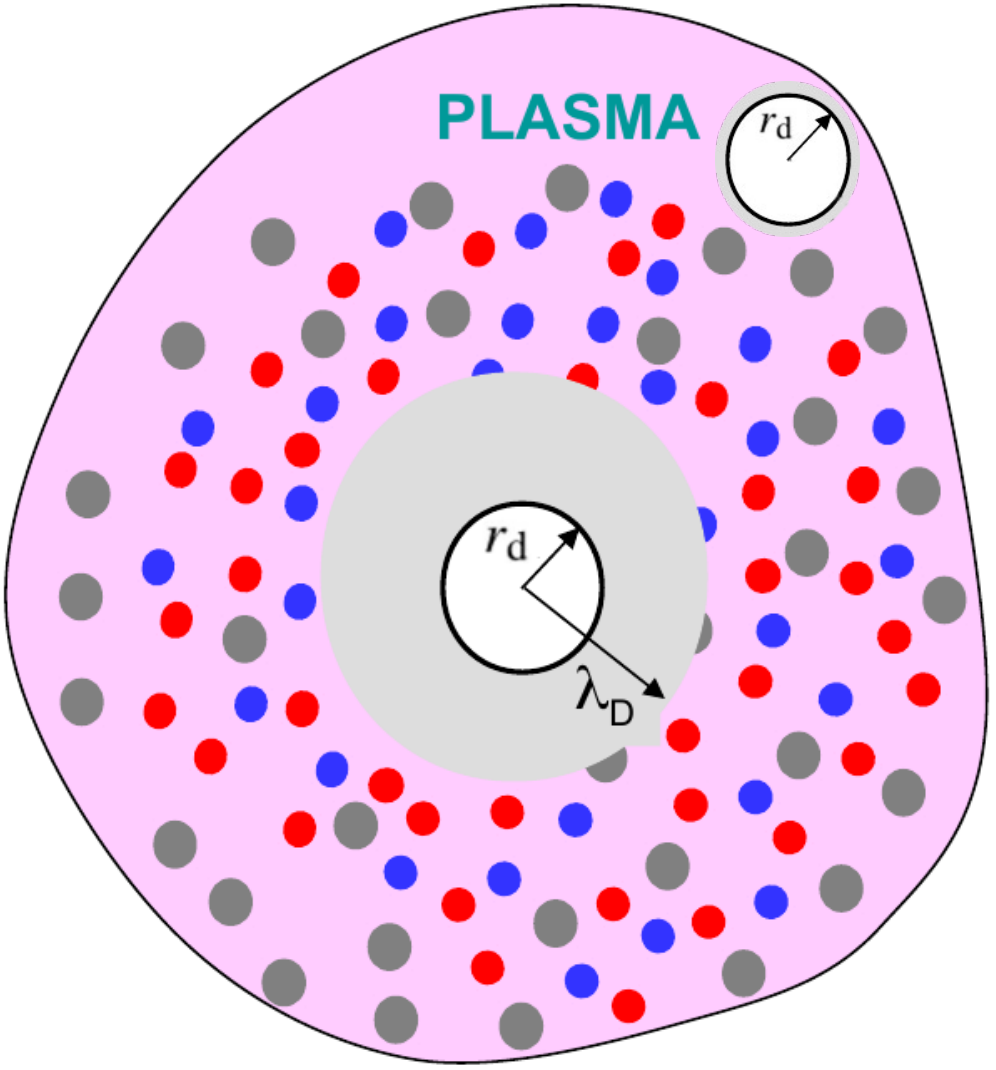
- -ve dust → what happen?
- +ve dust → what happen?

- Dusty plasma frequency

$$\omega_{pd} = (4\pi n_{d0} Z_d^2 e^2 / m_d)^{1/2}$$

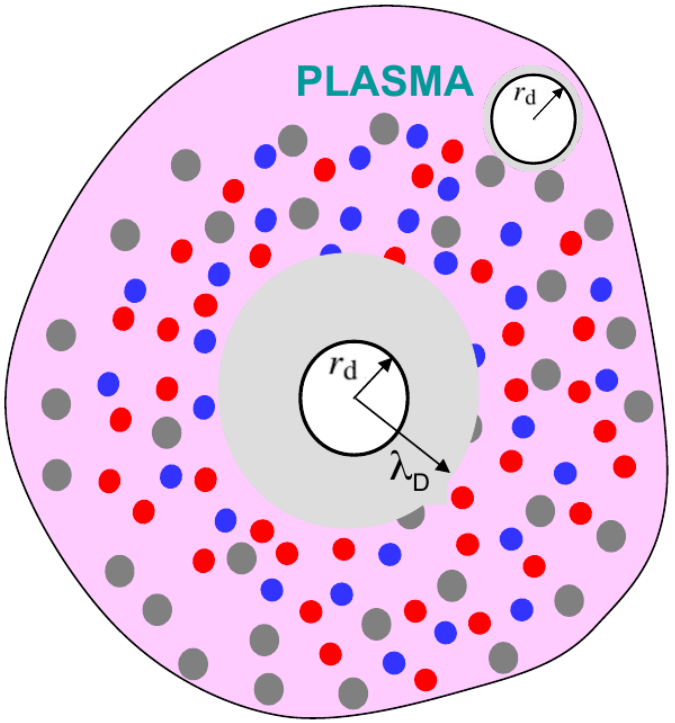
Dusty plasma terminology

Dust radius & Intergrain distance & Debye length (shielding)



Dusty plasma terminology

- **Intergrain distance > Debye length**
- **Intergrain distance < Debye length**



Dusty plasma terminology

- **Intergrain distance > Debye length → Dust-in-a plasma**

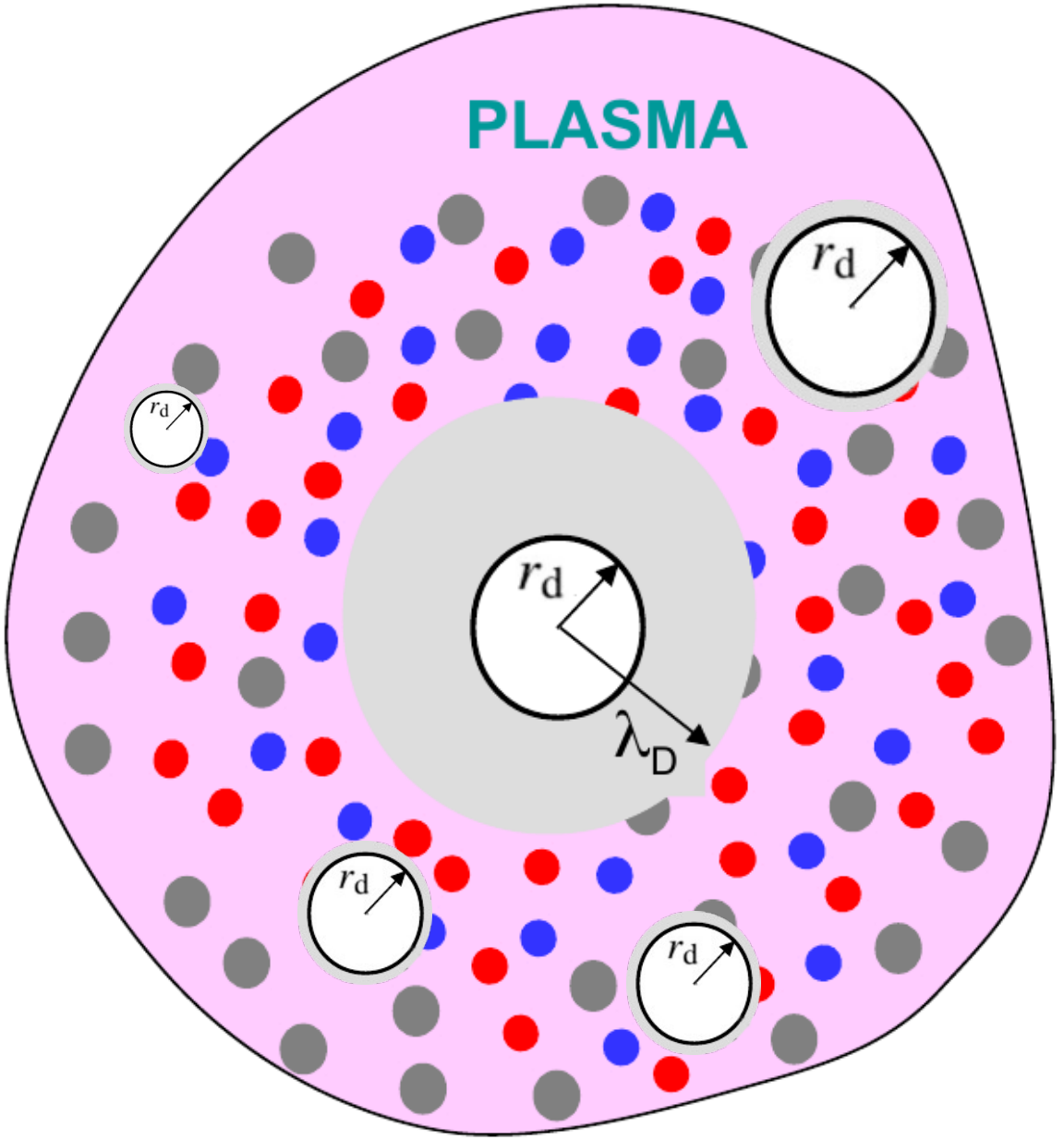
$$r_d \ll \lambda_D < a$$

- **Intergrain distance < Debye length → Dusty plasma**

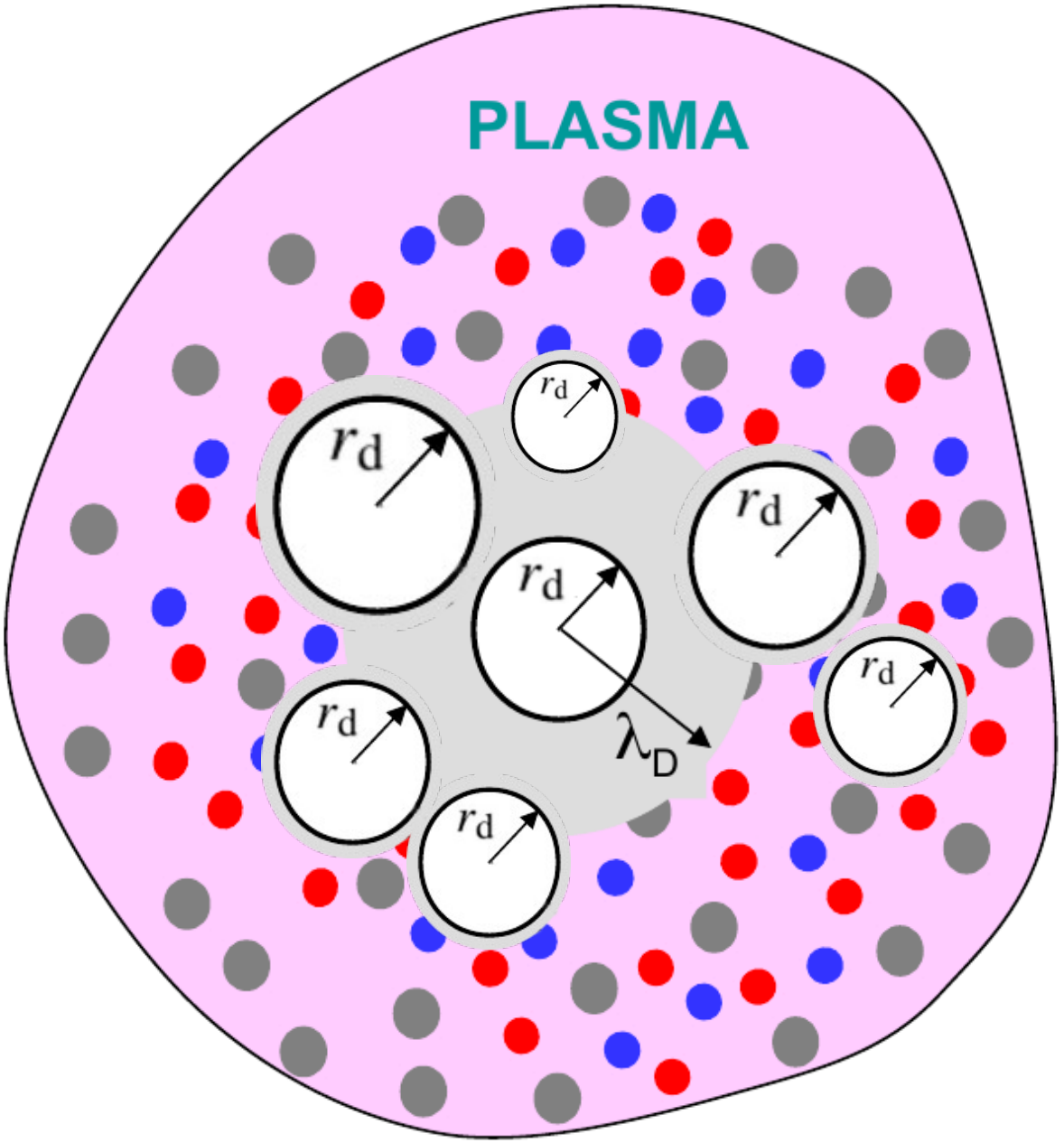
$$r_d \ll a < \lambda_D$$

(collective behavior)

Dusty plasma terminology



Dusty plasma terminology



Dusty plasma terminology

- Coupling (correlation) parameter $\Gamma \ll 1$ ideal gas-like behavior (waves)

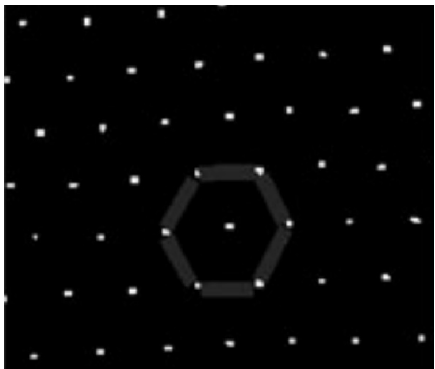
$$\Gamma = \frac{|E_{\text{int}}|}{E_{\text{therm}}}$$

$\Gamma \gtrsim 1$ Strongly coupled (liquid-like) systems

E_{int} is the interaction energy potential energy

E_{therm} is the average thermal energy

$\Gamma \geq \Gamma_{\text{cr}} \approx 100$ crystalline long-range order,



Summary

Electron–ion plasma	Dusty plasma
$n_{e0} = \sum_i Z_i n_{i0}$	$Q_d n_{d0} + e n_{e0} = e \sum_i Z_i n_{i0}$
$Q_i = Z_i e$	$Q_d = Z_d e \gg Q_i$
Z_i =const.	$dQ_d/dt = I_e + I_i + I_s + \ldots$
m_i	$m_d \sim 10^{12} m_i$
λ_{De}	$\lambda_D \sim \lambda_{Di}$
Uniform particle sizes	Size distributions
IAW, EIC, f ~1 kHz	DAW, DLW, f ~10 Hz,

Summary

Terminology

- Dusty plasma (collective behavior)
- Dust-in-a plasma
- Dust size distribution
- Multicomponent plasma
- Dynamic dust charging
- +ve & -ve dust
- Dusty plasma frequency
- Dust radius & Intergrain distance
- Coupling (correlation) parameter

Concept

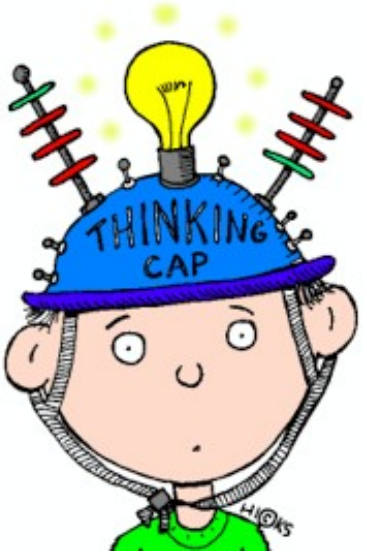
- ????
- ????
- ????
- ????
- ????
- ????
- ????
- ????
- ????

Properties of dusty plasma

$$Z_d \approx 10^3,\ m_d \approx 2 \times 10^{-12}\ \mathrm{g},\ n_{d0} \approx 10^{-9}\mathrm{cm}^{-3}$$

$$T_e \approx 5 - 22\ \mathrm{eV},\ T_i \approx 60 - 120\ \mathrm{eV},\ n_{e0} \approx 1 - 23 \times 10^3\mathrm{cm}^{-3}$$

Calculate



- Debye length (shielding)
- Dust frequency
- Intergrain distance
- Type of plasma (dust-in- a plasma or dusty plasma)