Types of Plasma and the Related Forces

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Aim of the lecture

- **Types of plasma → Different forces in plasma**
- **How to select a sutaible model for your study**
- **Advantage & disadvantage of each model**

Taking notes → discuss with me after the lecture OR by email wmmoslem@hotmail.com

Outline

PART (I)

- Types of plasmas
- How many forces exist in plasma...!!

PART (II)

- Single particle model
- Kinetic model
- Multi-fluid model
- MHD model

Outline

PART (I)

- **Types of plasmas**
- **How many forces exist in plasma...!!**

PART (II)

- **Single particle model**
- **Kinetic model**
- **Multi-fluid model**
- **MHD model**

Types of plasmas

- **(I) Classical plasma**

  +ve ions / electrons / -ve ions / positrons

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

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

- **(III) Quantum plasma**

  Electrons / positrons / holes / +ve ions

Types of plasmas, cont.

Irving Langmuir
1927

Padma Kant Shukla
1990

Giovanni Manfredi
2000

Outline

PART (I)

- Types of plasmas
- How many forces exist in plasma...!!

PART (II)

- Single particle model
- Kinetic model
- Multi-fluid model
- MHD model

Forces in plasma

- Inertial force
- Electric force
- Magnetic force
- Pressure gradient force
- Collisional force
- Drag force
- Corilis force
- Ponderomotive force
- Viscosity
- Tunnling force
- Exchange-correlation force
- Gravitational force
- Thermophoretic force
- Radiation pressure force
- Diffusion force
- **15 Forces**

Types & Forces

- Classical
- Dusty
- Quantum

Experiment

OR

Application

OR

Observation

- Inertial force
- Electric force
- Magnetic force
- Pressure gradient force
- Collisional force
- Drag force
- Corilis force
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Types & Forces, cont.

What are the criteria to decide the leading force?

- ✔ **Understanding each force → 15 forces**
- ✔ **Knowing the physics of the Exp. / App. / Obs.**

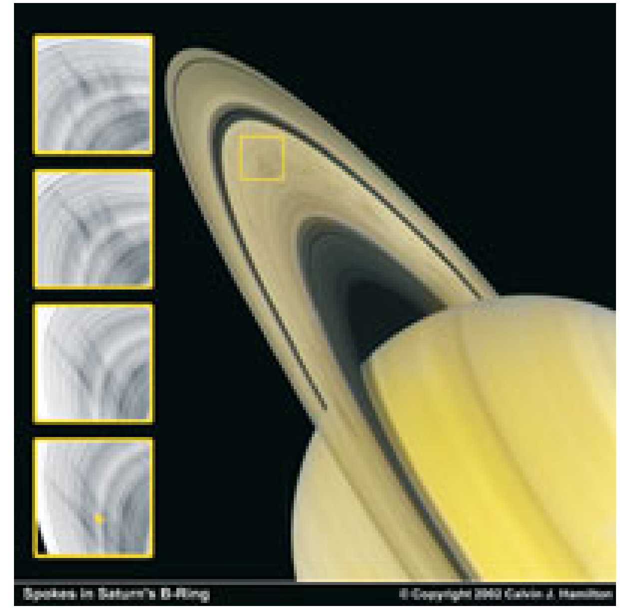
- ✔ **Select a suitable plasma type → 3 types**

Classical Plasma

- Mainly $\rightarrow$ +ve ions & electrons
- Sometimes $\rightarrow$ -ve ions & positrons
- 1927 $\rightarrow$ now
- Applications / observations / Experiment $\rightarrow$ laboratory, space plasma, astrophyical plasma

Dusty Plasma

- Dust particles in plasmas → particles have different sizes → a few nanometers to tens of micrometers
- First observations → interstellar space, planetary atmospheres, ring structures, cometary tails, ...etc
- 1960's, → 1980's
- It is a time for theoreticians → ????



Dusty Plasma, cont.

- Padma K. Shukla and his collaborators predicted the existence of dust acoustic waves, dust ion acoustic waves and shocks….etc.
- His interest:

(1)Physics of low- and high-temperature plasma
(2)Nonlinear quantum plasma physics
(3)Nonlinear space and astroplasmas
(4)Nonlinear processes in geophysical flows
(5)Collective interactions in dusty plasmas
(6)Intense laser-plasma interactions
(7)Plasma high-energy charged particle accel.
(8)Nonlinear photonics/optics

Padma Kant Shukla
1950 – 2013 (India-Germany)
Member of The Royal Swedish Academy of Science

Dusty Plasma, cont.

Planet. Space Sci., Vol. 38, No. 4, pp. 543–546, 1990
Printed in Great Britain.

DUST-ACOUSTIC WAVES IN DUSTY PLASMAS

N. N. RAO,* P. K. SHUKLA and M. Y. YU

Physica Scripta. Vol. 45, 508, 1992.

Dust Ion-Acoustic Wave

P. K. Shukla* and V. P. Silin†

Dusty Plasma, cont.

- Xu et al 1992 → modifay the Q-machine to allow the dispersal of dust grains over a portion of the cylindrical plasma column

- Chu and I 1994 → for the first time a dusty plasma has been confined in a cylindrical symmetric rf plasma system

Dusty Plasma, cont.

Phys. Plasmas **2** (10), October 1995

Laboratory observation of the dust-acoustic wave mode

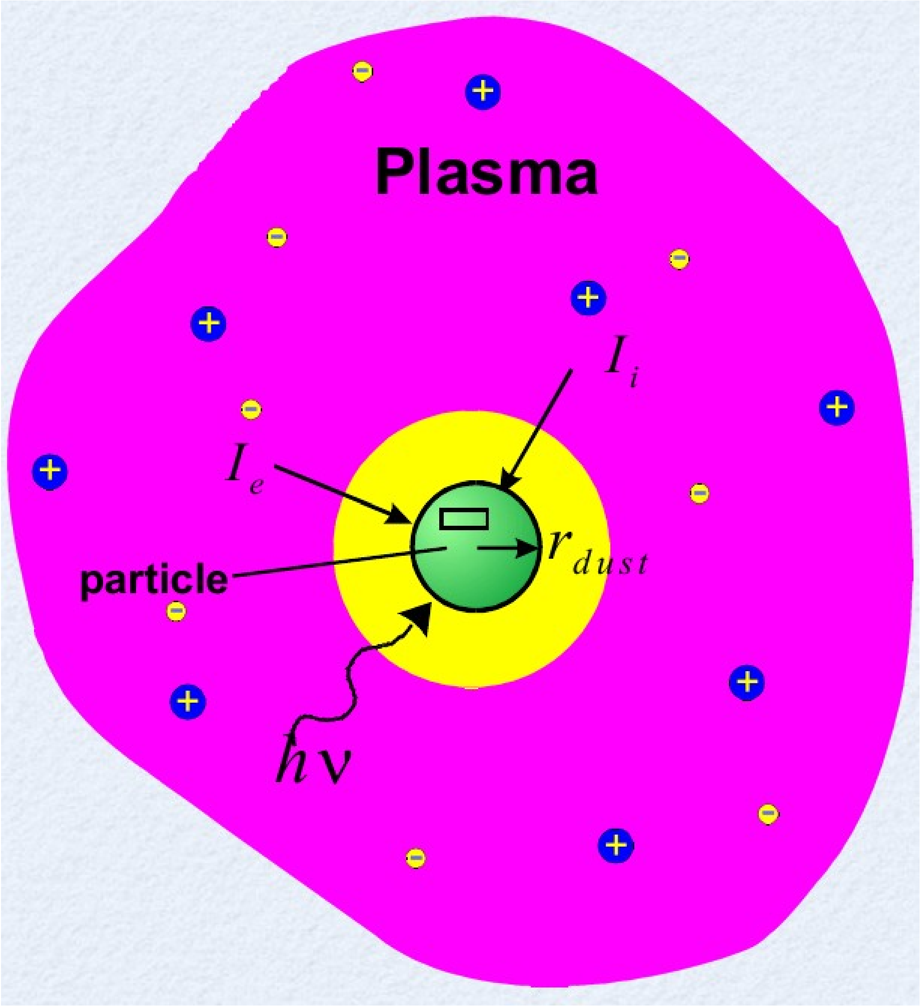
A. Barkan, R. L. Merlino, and N. D'Angelo

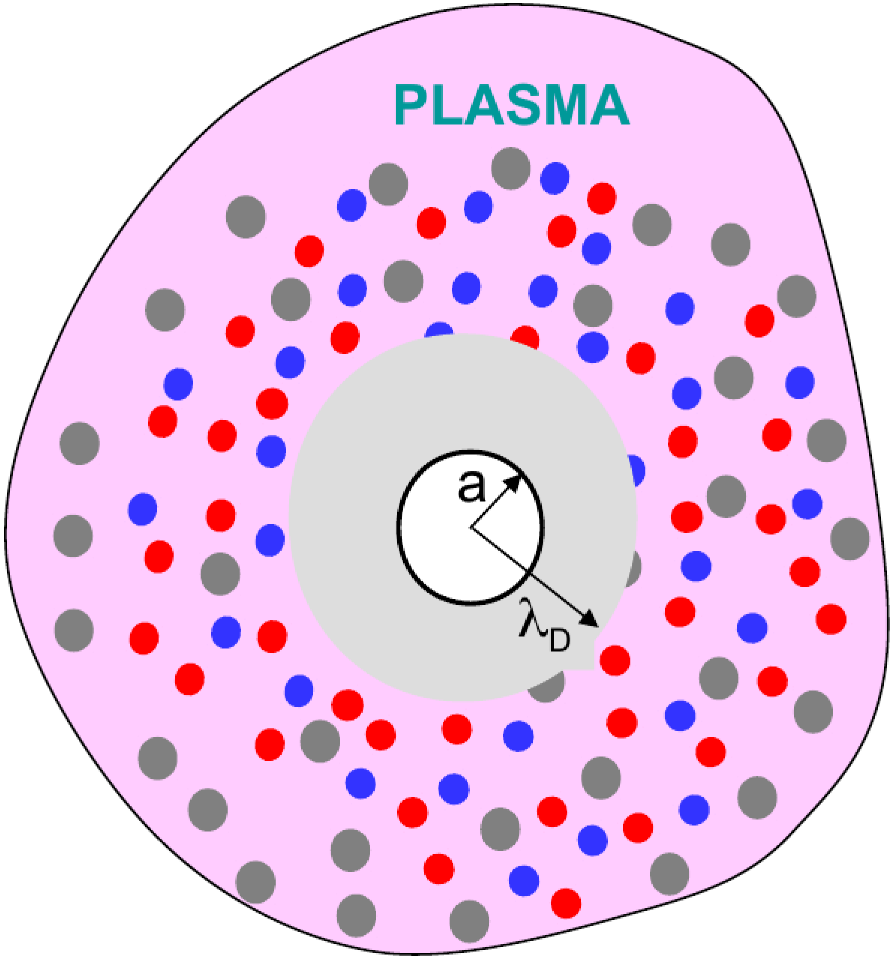
Planet. Space Sci., Vol. 44, No. 3, pp. 239–242, 1996

Experiments on ion-acoustic waves in dusty plasmas

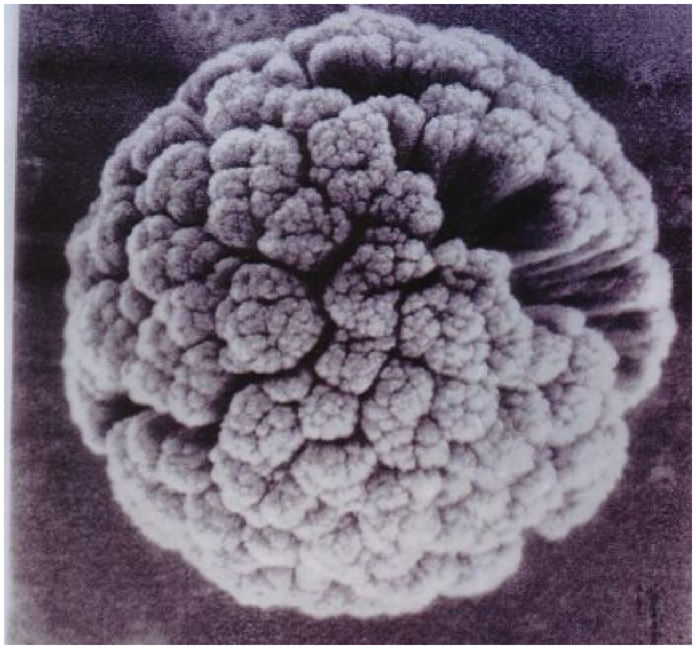
A. Barkan, N. D'Angelo and R. L. Merlino

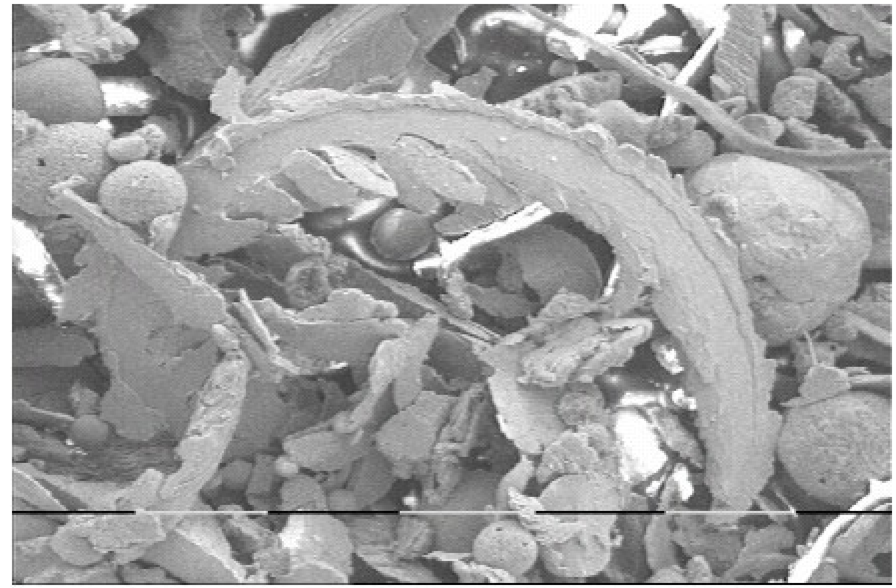
Dusty Plasma, cont.





Dusty Plasma, cont.





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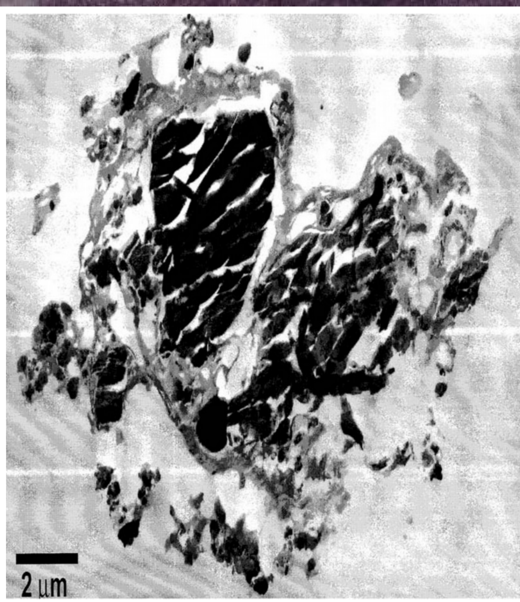
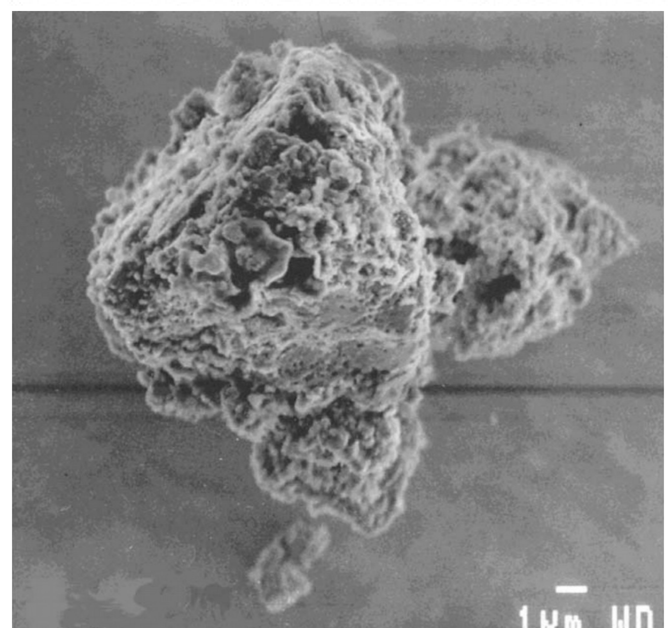
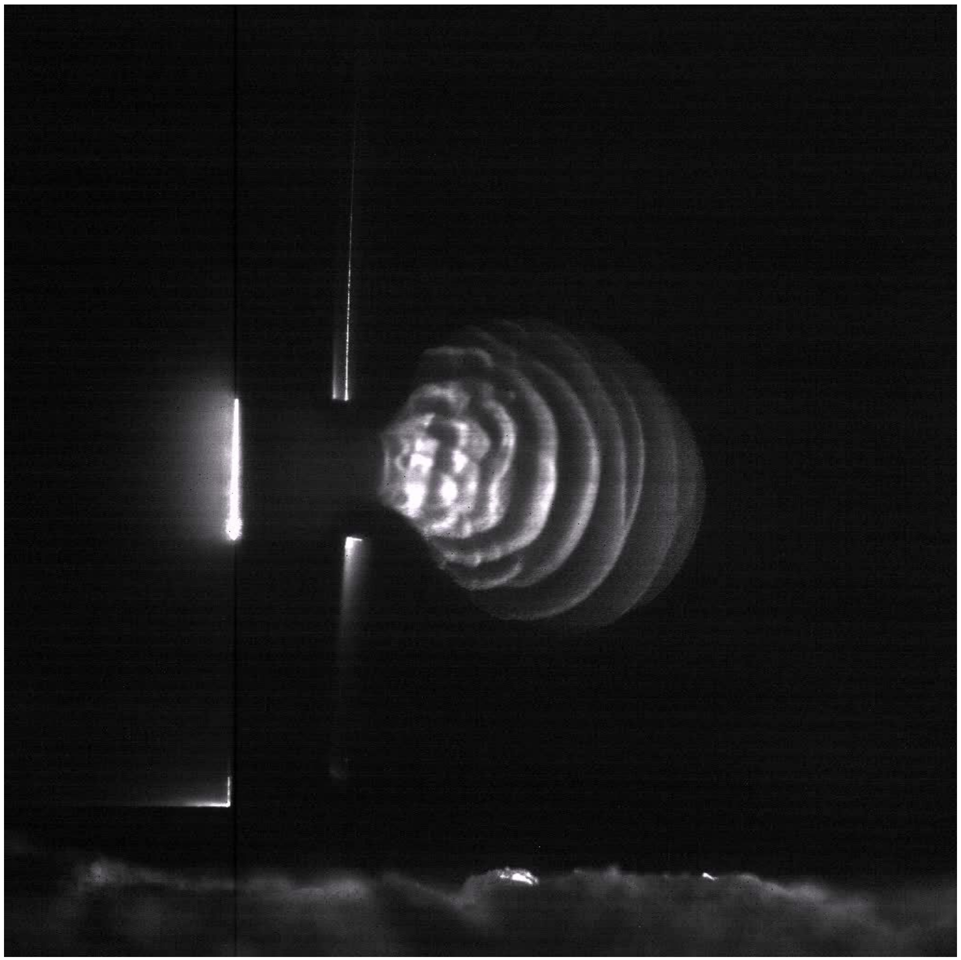
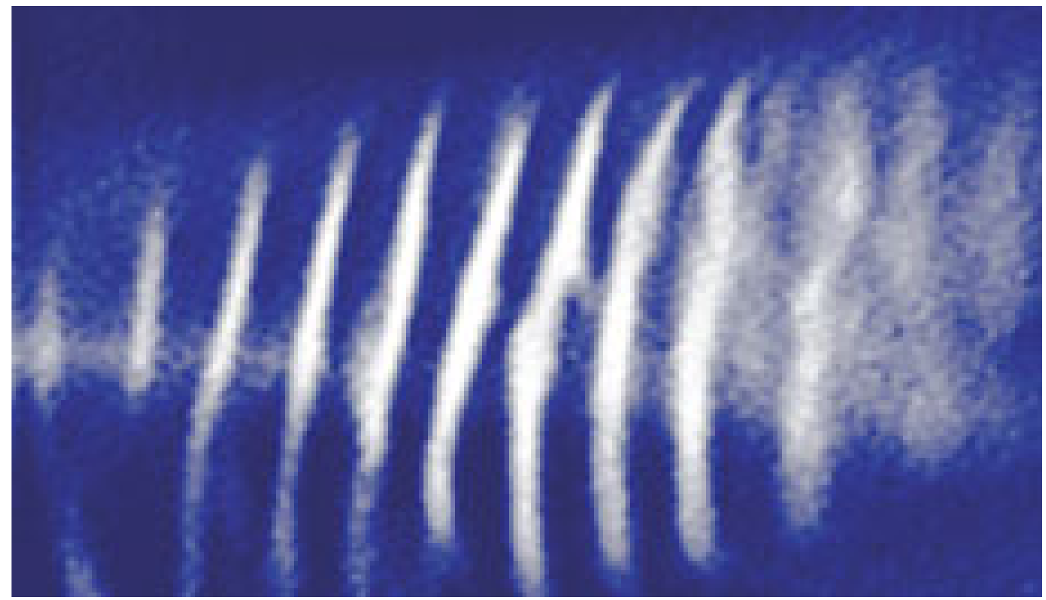




Dusty Plasma, cont.

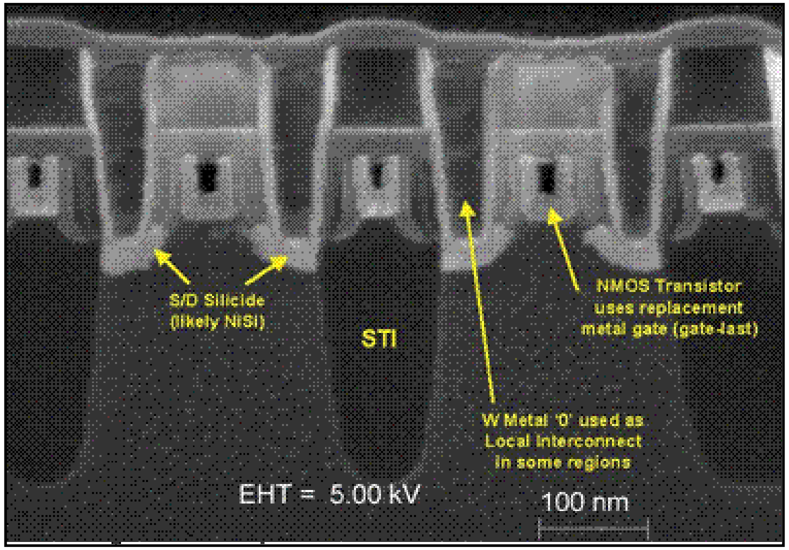




Movie

Dusty Plasma, cont.

- Moving dust in fusion devices → Movie
- Semiconductor industry
- Plasma chemistry and nanotechnology → coagulation of macroparticles
- Crystal physics



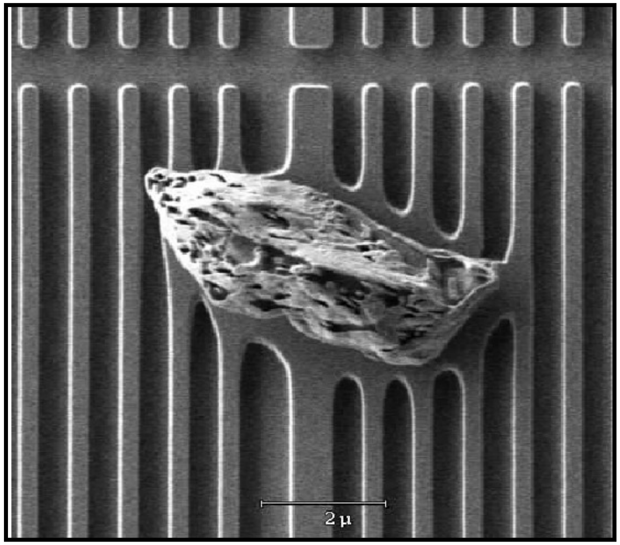


Table 1.8. The basic differences between the solid and dusty plasma crystals.

Characteristics	Solid-state crystal	Dusty plasma crystal
Crystal type	atomic crystals	dust crystals
Interaction energy	a few eV	~900 eV
Lattice spacing	~0.1 nm	~1 mm

Dusty Plasma, cont.

Table 1.1. The basic differences between electron–ion and dusty plasmas.

Characteristics	Electron–ion plasma	Dusty plasma
Quasi-neutrality condition	$n_{e0} = Z_i n_{i0}$	$Z_d n_{d0} + n_{e0} = Z_i n_{i0}$
Massive particle charge	$q_i = Z_i e$	$\lvert q_d \rvert = Z_d e \gg q_i$
Charge dynamics	$q_i =$ constant	$\partial q_d / \partial t =$ net current
Massive particle mass	m_i	$m_d \gg m_i$
Plasma frequency	ω_{pi}	$\omega_{pd} \ll \omega_{pi}$
Debye radius	λ_{De}	$\lambda_{Di} \ll \lambda_{De}$
Particle size	uniform	dust size distribution
$\boldsymbol{E} \times \boldsymbol{B}_0$ particle drift	ion drift at low B_0	dust drift at high B_0
Linear waves	IAW, LHW, etc	DIAW, DAW, etc
Nonlinear effects	IA solitons/shocks	DA/DIA solitons/shocks
Interaction	repulsive only	attractive between grains
Crystallization	no crystallization	dust crystallization
Phase transition	no phase transition	phase transition

Dusty Plasma, cont.

- Debye shielding

$$\lambda_{\mathrm{D}} = \frac{\lambda_{\mathrm{De}}\lambda_{\mathrm{Di}}}{\sqrt{\lambda_{\mathrm{De}}^2 + \lambda_{\mathrm{Di}}^2}}$$

$$\lambda_{\mathrm{De}} = (k_{\mathrm{B}}T_{\mathrm{e}}/4\pi n_{\mathrm{e0}}e^2)^{1/2} \text{ and } \lambda_{\mathrm{Di}} = (k_{\mathrm{B}}T_{\mathrm{i}}/4\pi n_{\mathrm{i0}}e^2)^{1/2}$$

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

- Dust plasma frequency

$$\omega_{\mathrm{pd}} = (4\pi n_{\mathrm{d0}}Z_{\mathrm{d}}^2e^2/m_{\mathrm{d}})^{1/2}$$

Dusty Plasma, cont.

- Dust-in-plasma & Dusty plasma $\rightarrow$ G.W.
- Intergrain distance & Debye length
- Intergrain distance $>$ Debye length $\rightarrow$??
- Intergrain distance $<$ Debye length $\rightarrow$??

Dusty Plasma, cont.

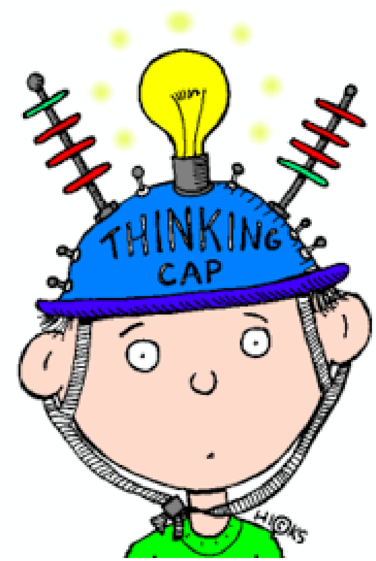
- Dust-in-plasma & Dusty plasma $\rightarrow$ G.W.
- Intergrain distance & Debye length
- Intergrain distance > Debye length $\rightarrow$ Dust-in-plasma
- Intergrain distance < Debye length $\rightarrow$ Dusty plasma

Example

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

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

Calculate



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

Leading Forces

- Inertial force
- Electric force
- Magnetic force
- Pressure gradient force
- Collisional force
- Drag force
- Corilis force
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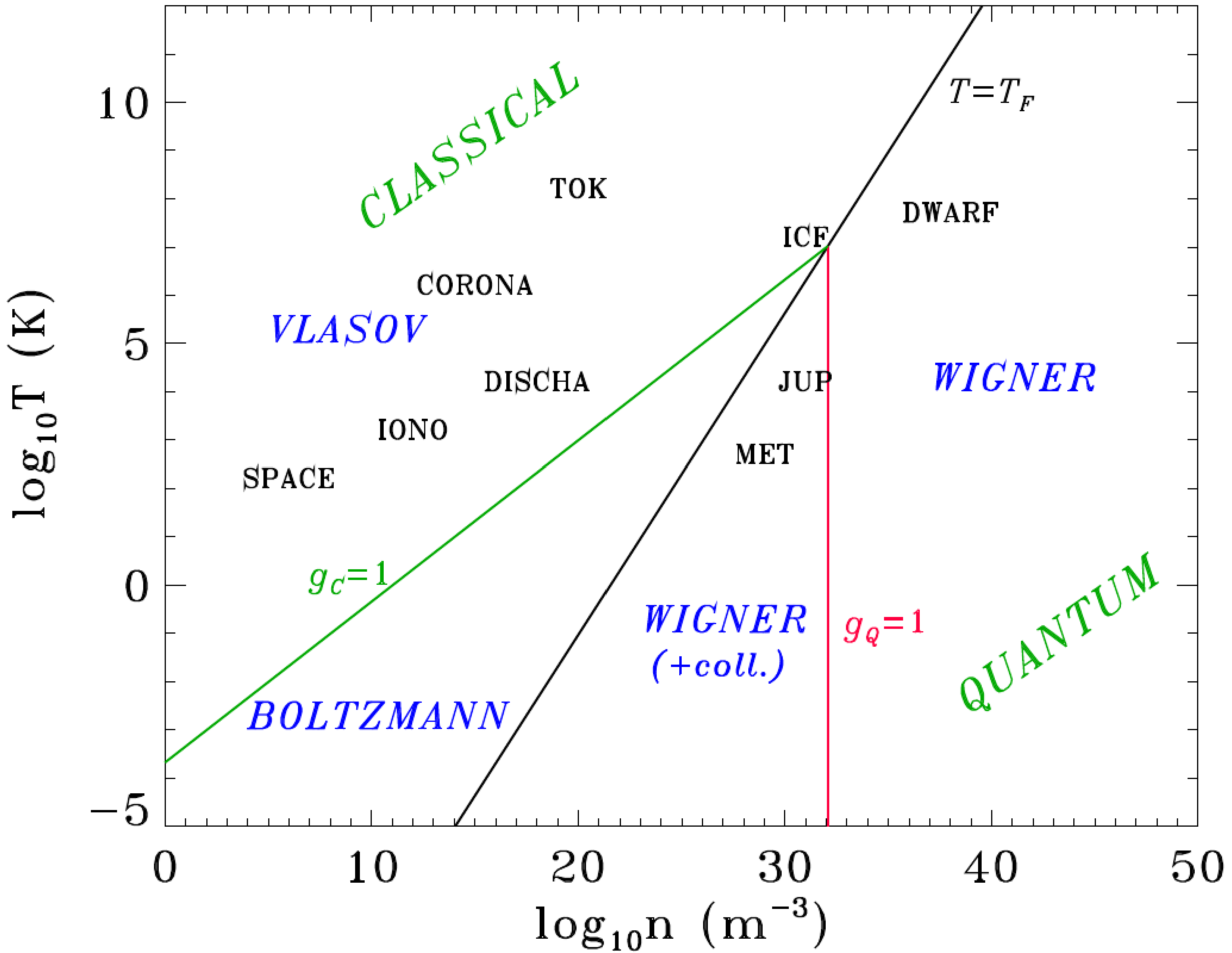
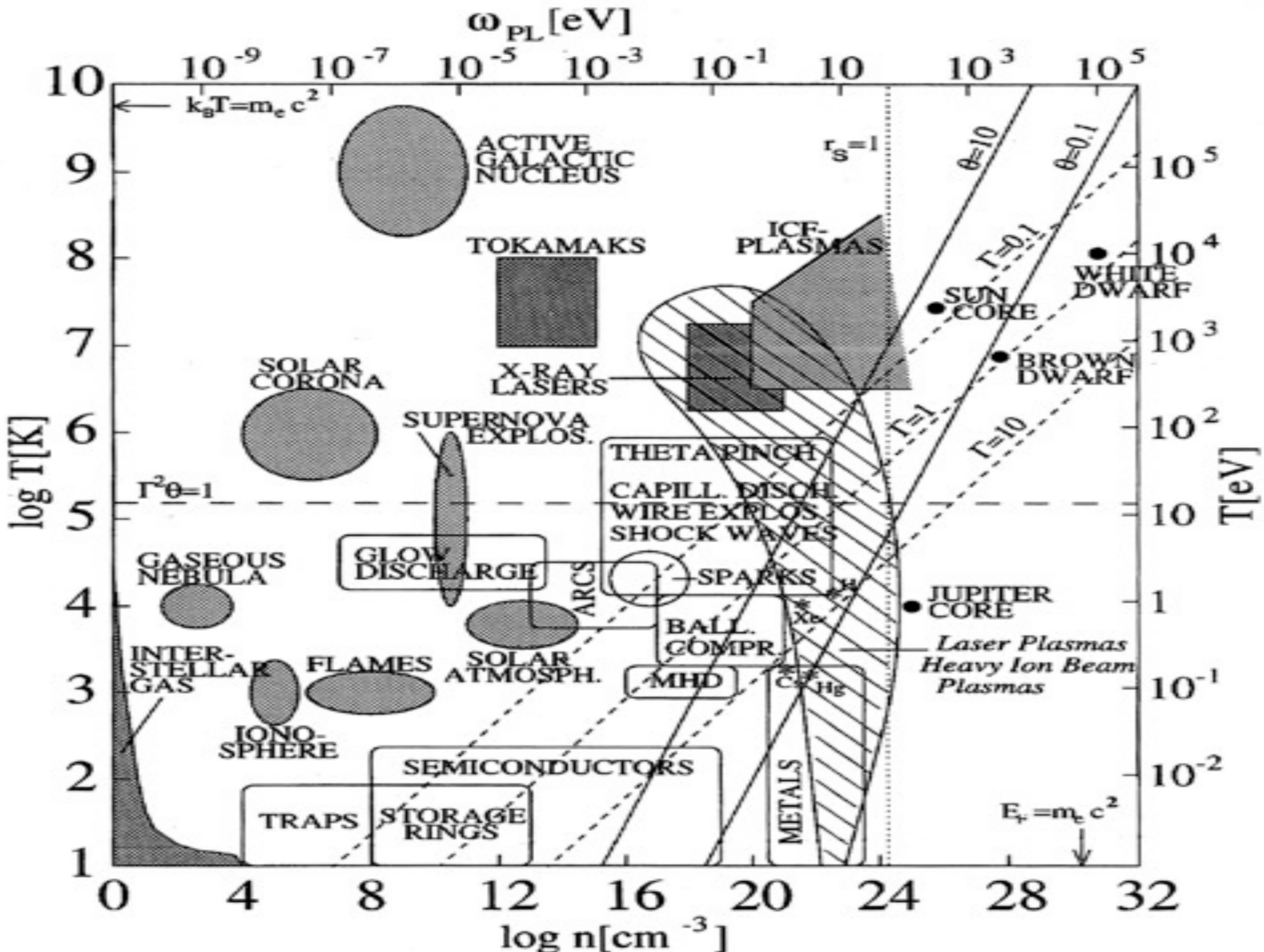
Plasma applications & observations



Plasma applications & observations, cont.



Finally ....!!!!!!

End of Part I

Thanks