The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

**1856-45**

**2007 Summer College on Plasma Physics**

***30 July - 24 August, 2007***

# Dusty Plasma Physics: an overview

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# DUSTY PLASMA PHYSICS: AN OVERVIEW

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# OUTLINE

- What is dusty plasma?
- How are dust charged?
- Why is DPP so important?
- What are our CR on DPP?

# ❑ What is a dusty plasma?

▪ **dusty plasma:**

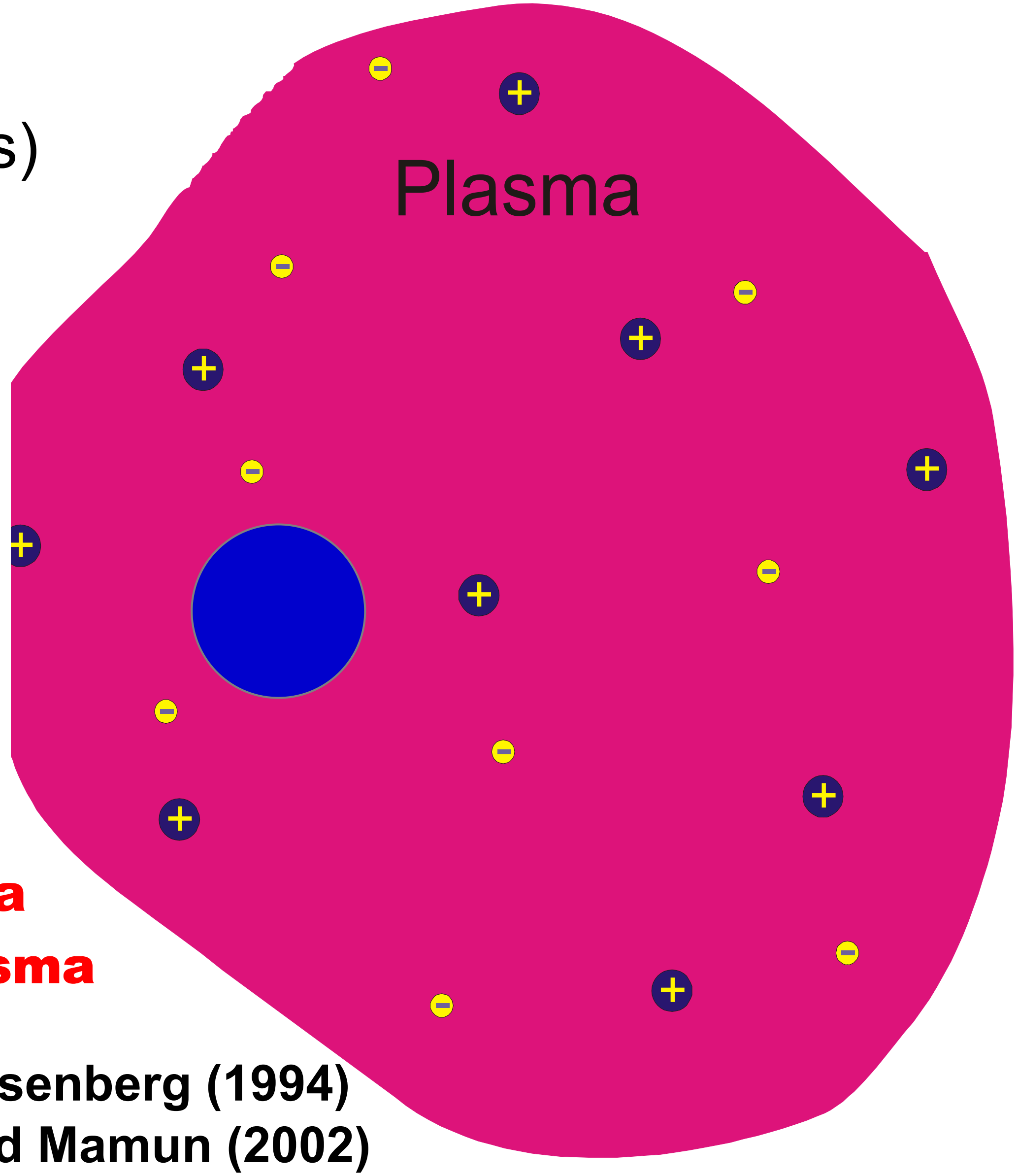
**plasma** (electrons + ions)

and **dust** having

- **size:** μm - mm: not constant
- **mass: billions times heavier than ions: not constant**
- **charge: not neutral: + or − depending on charging processes: not constant**

▪ **dusty plasma: dirty plasma**

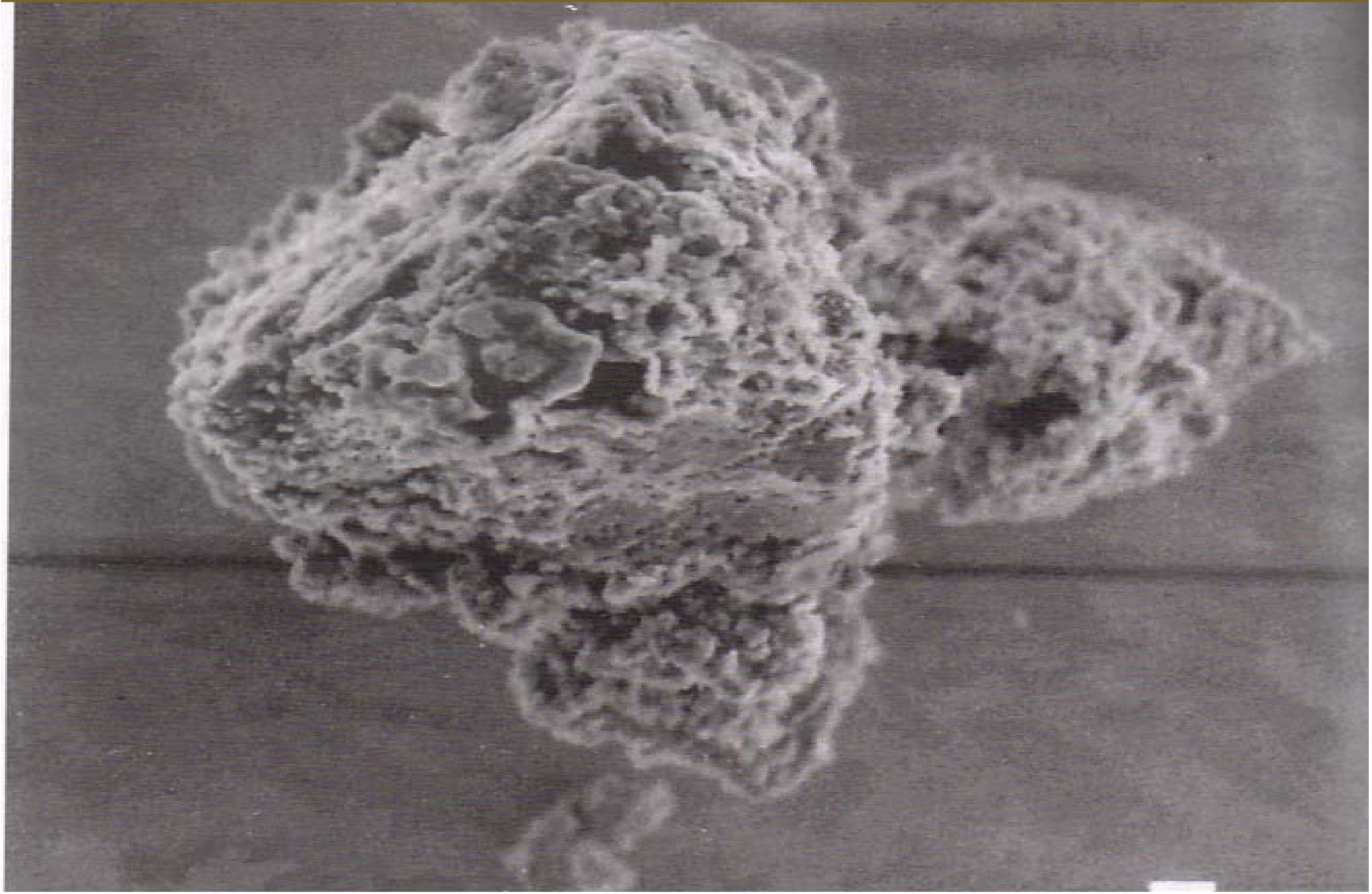
▪ **dusty plasma: complex plasma**



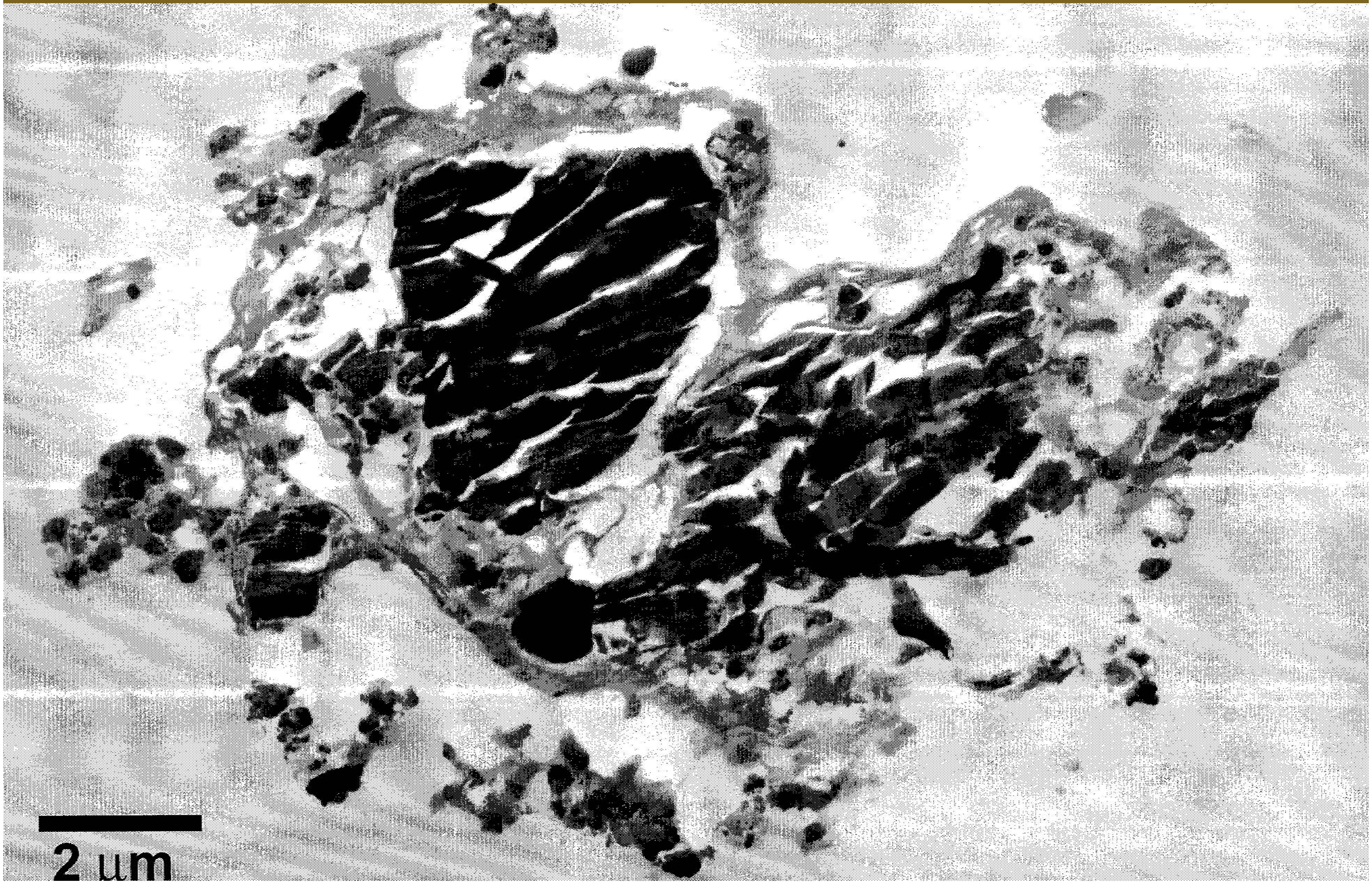

**Ref: Geortz (1989); Mendis & Rosenberg (1994) Verheest (2000); Shukla and Mamun (2002)**

- **The outside of the interplanetary dust**

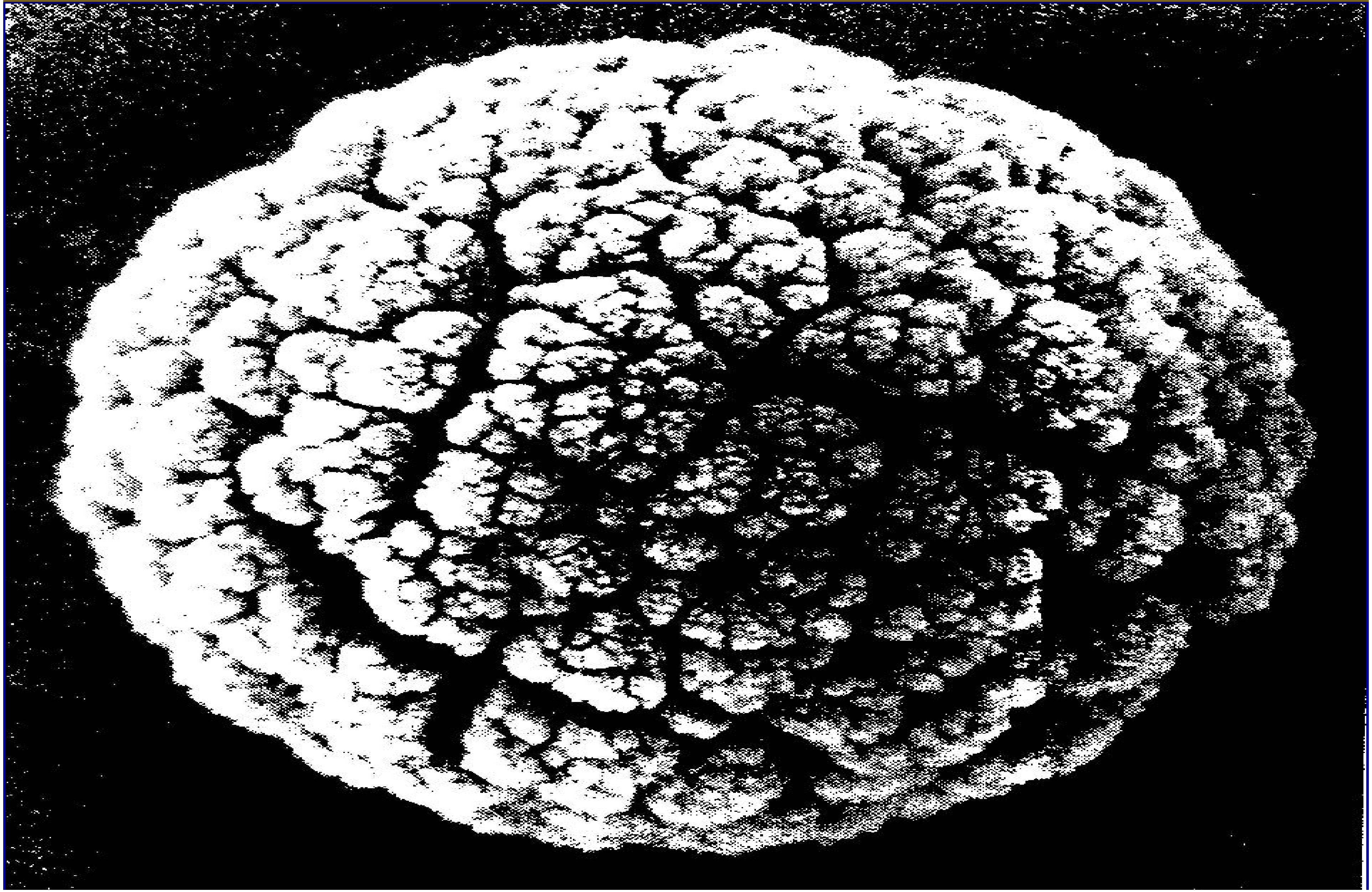
  **(courtesy of Dr. Scott Messenger, WU)**



- **The inside of interplanetary dust [observed by TEM** (courtesy of Dr. Lindsay Keller, JSC)**]**



- **Typical dust particle (650 nm size) grown in a plasma processing reactor** (SEM image: Garscadden et al. 1994)

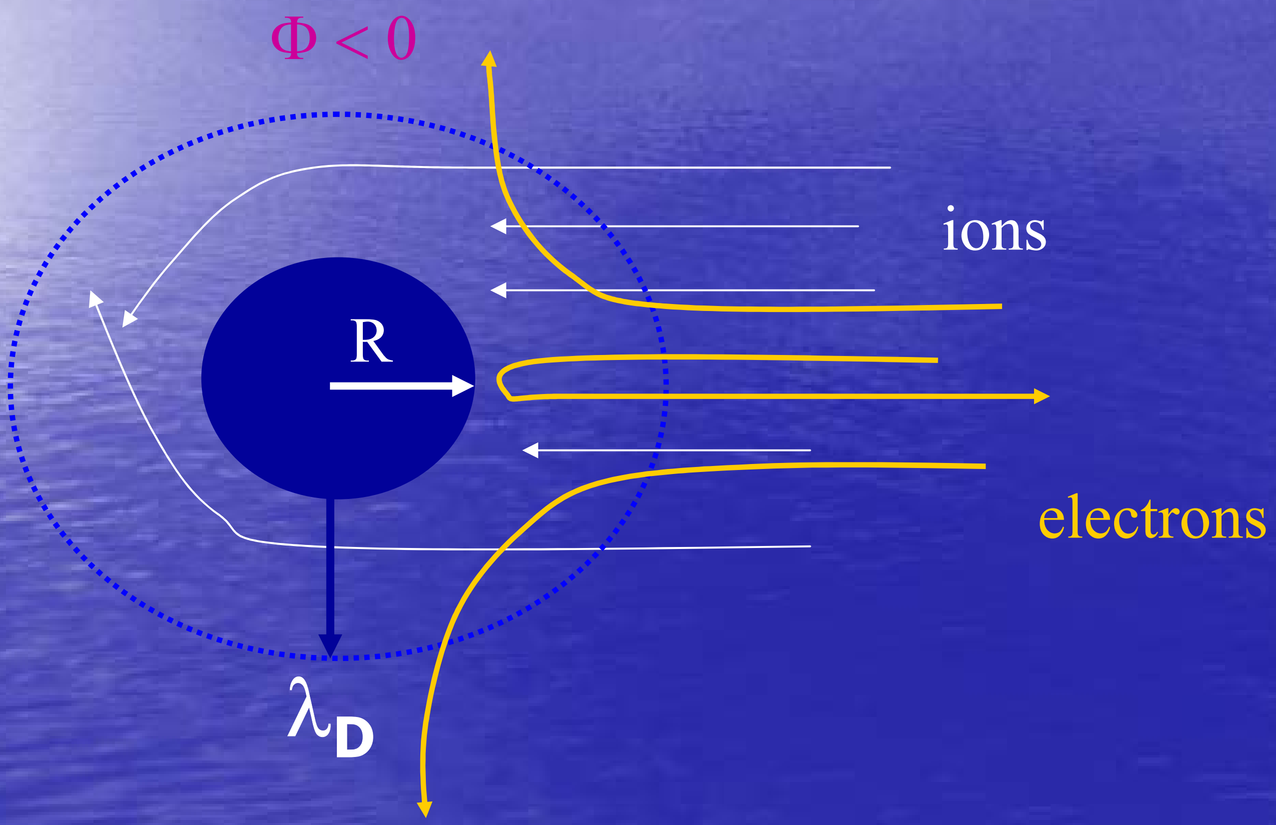


- **Dust particles collected from fusion devices**

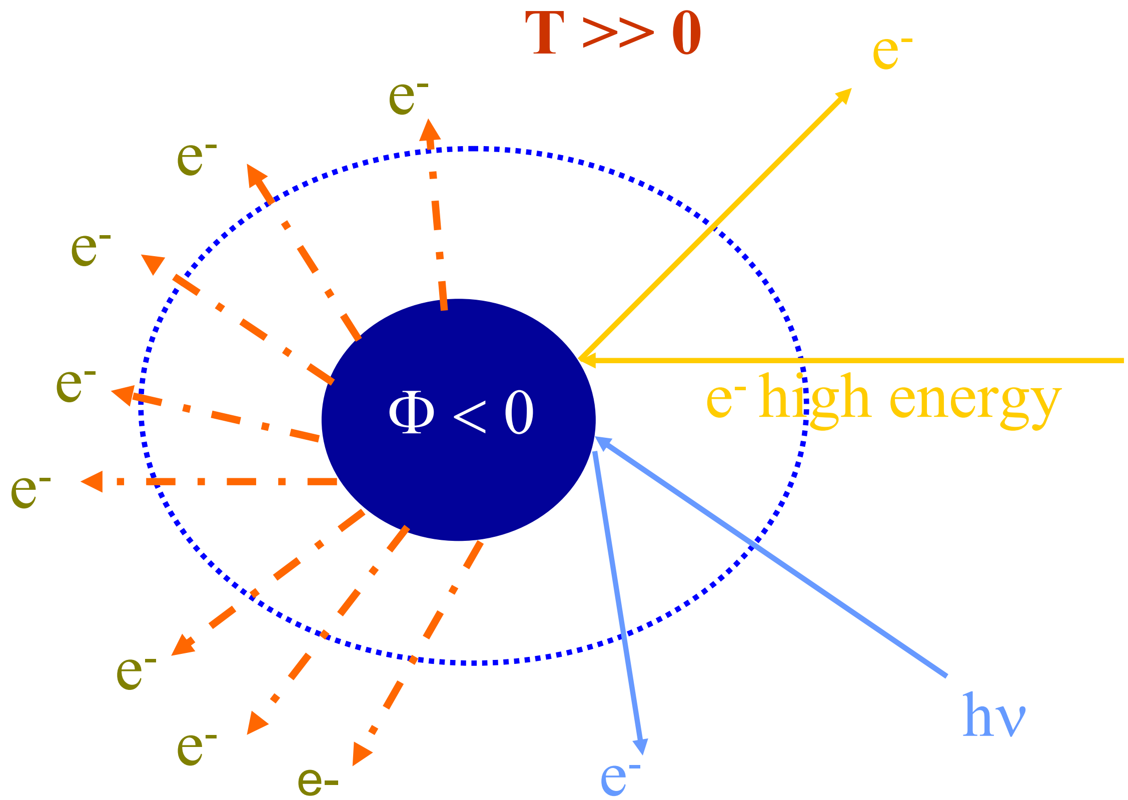
(SEM image: Winter 1998)

# ❑ How are dust charged?

➢ **electron and ion collection currents:**



- **photoelectric emission**
- **secondary emission**
- **thermionic emission**



# ❑ Why is DPP so important?

- ubiquity of dust in plasmas
- versatile applications
- unsolvable complexities
- infinitely large domain
- remark. exp. discoveries
- open issues in DPP

# ▪ ubiquity of dust in plasmas

- Dust is everywhere: all most all plasmas (99.9% matter of our universe) are dusty plasma.
- Dust is an omni-present ingredient of our universe.
- Dusty plasmas are most common in interplanetary space, interstellar medium, interstellar clouds, comets, planetary rings, earth atmospheres, etc.
- Dusty plasma are also observed in laboratory devices, viz. Q-machine, dc discharges, rf discharges, etc.

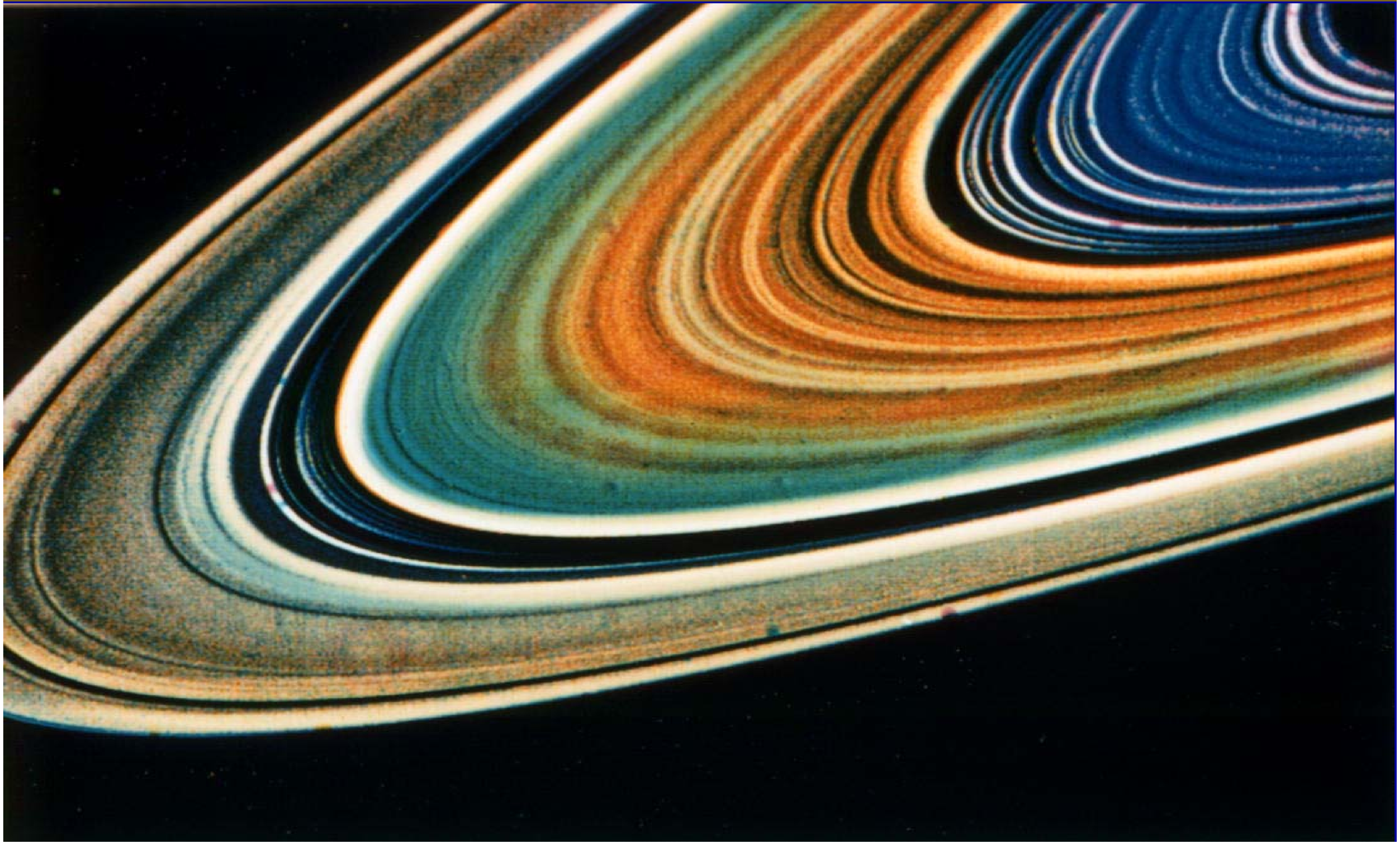
Ref: review articles: Geortz (1989), Mendis & Rosenberg (1994)
books: Verheest (2000), Shukla & Mamun (2002).

- Dust in interplanetary space and in comet: thin blue plasma tail and broad white dust tail (Wurden et al. 1999)

## ❖ Typical parameters of dust-laden plasmas in interstellar clouds, zodiacal dust disc and Haley's comet

| Characteristics | interstellar clouds | zodiacal dust disc | Haley's comet |
| --- | --- | --- | --- |
| $n_e$ ($cm^{-3}$) | $10^{-4}$ – $10^{-3}$ | 1 – 10 | $10^{2}$ – $10^{4}$ |
| $T_e$ (K) | 10 – 20 | $10^{4}$ – $10^{5}$ | $10^{3}$ – $10^{4}$ |
| $n_d$ ($cm^{-3}$) | $10^{-7}$ – $10^{-6}$ | $10^{-12}$ – $10^{-11}$ | $10^{-8}$ – $10^{-3}$ |
| $r_d$ (μm) | 0.1 – 0.5 | 1 – 10 | 0.1 – 10 |

❖ Mysterious spokes of Sarurn’s B-ring: charged dust: es repulsion between dust particles and boulders: trails of dust grains



# ❖ Typical parameters of dust-laden plasmas in Saturn's rings

| Characteristics | E-ring | F-ring | Spokes |
|---|---|---|---|
| $n_e$ ($cm^{-3}$) | 10 – 20 | 10 – 20 | 0.1 – $10^2$ |
| $T_e$ (K) | $10^5 – 10^6$ | $10^5 – 10^6$ | $10^4 – 10^5$ |
| $n_d$ ($cm^{-3}$) | $10^{-7} – 10^{-6}$ | 1 – 10 | 0.5 –1.5 |
| $r_d$ (μm) | 0.5 – 1.5 | 0.5 –1. 5 | 0.5 –1. 5 |

## ❖ Typical parameters of dust-laden plasmas in NLCs, rocket exhausts and flames

| characteristics | NLCs | rocket exhausts | flames |
|---|---|---|---|
| $n_e$ (cm$^{-3}$) | $10^3 – 10^4$ | $10^{12} – 10^{13}$ | $10^{11} – 10^{12}$ |
| $T_e$ (K) | 100 – 200 | $10^3 – 10^4$ | $10^3 – 10^4$ |
| $n_d$ (cm$^{-3}$) | $10 – 10^2$ | $10^7 – 10^8$ | $10^{10} – 10^{11}$ |
| $r_d$ (μm) | 0.1 – 1 | 0.1 –1 | 0.01 –0.1 |

## ❖ Typical parameters of dust-laden plasmas in laboratory devices

| characteristics | Q-machine (DPD) | dc discharges | rf discharges |
|---|---|---|---|
| $n_e$ ($cm^{-3}$) | $10^6 – 10^7$ | $10^9 – 10^{10}$ | $10^9 – 10^{10}$ |
| $T_e$ (K) | $10^3 – 10^4$ | $10^4 – 10^5$ | $10^4 – 10^5$ |
| $n_d$ ($cm^{-3}$) | $10^3 – 10^4$ | $10^3 – 10^4$ | $10^5 – 10^6$ |
| $r_d$ (μm) | 10 – 20 ($Al_2 0_3$) | 1 – 5 (Al) 60–65 (glass) | 5 – 10 ($Si0_2$) |
| $Z_d$ | $10^3 – 10^4$ | $10^5 – 10^6$ | $10^3 – 10^4$ |

# ▪ versatile applications

- The physics of our universe which is full of dust.
- Space & Astrophysics: mysterious dark spokes of saturn's B-rings, collapse of interstellar clouds: star formation, etc.
- Crystal Physics: dust crystals, phase transition.
- Semicond. Technology: low-temperature devices.
- Nanotechnology: agglomeration and coagulation.
- Fusion Research: problem of dust in tokamaks.
- Micro-biology: electrostatic disruption of bacteria.

# ▪ unsolvable complexities

- The addition of dust having

❖ variable size

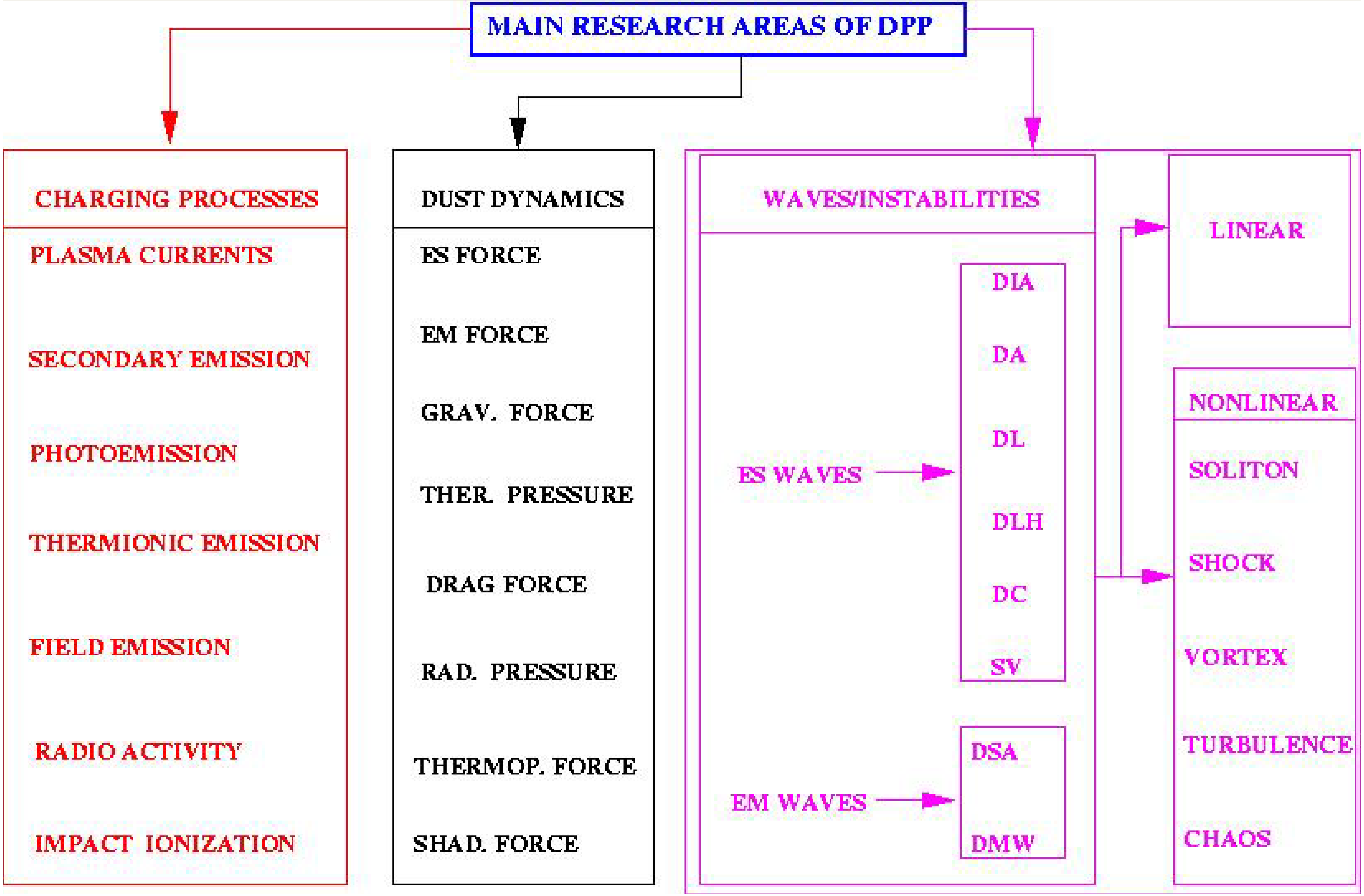
❖ variable mass

❖ variable charge

makes a plasma system very complex & arises an **unsolvable complexity**. This is why, a dusty plasma is also termed as a **Complex Plasma**.

- These unsolvable complexities of dusty plasma physics have introduced a lot of **open issues** which are, the challenges for the young genius brains of present and future generations.

# ▪ infinitely large domain



## ▪ remarkable experimental discoveries

| | | | |
|---|---|---|---|
| DUST CRYSTAL | 1994 | Thomas et al<br>Chu & Lin I<br>Hayashi & Tachibana | $\Gamma>172$ ← IKezi 1986 |
| DA WAVES | 1995 | Barkan et al | Rao, Yu & Shukla 1990 |
| DIA WAVES | 1996 | Barkan et al | Shukla & Silin 1992 |
| DL WAVES | 1997 | Morfill et al<br>Homann et al | Melandsø 1996 |
| MACH CONES | 1999 | Samsonov et al | Havnes et al 1996 |
| DUST VOIDS | 2001 | Thomas et al | Morfill et al 1999 |

## ▪ open issues in DPP

- **The physics of collective processes in a dusty plasma with non-isolated dust of variable size, mass and charge,** particularly when more charging processes must be taken into account.

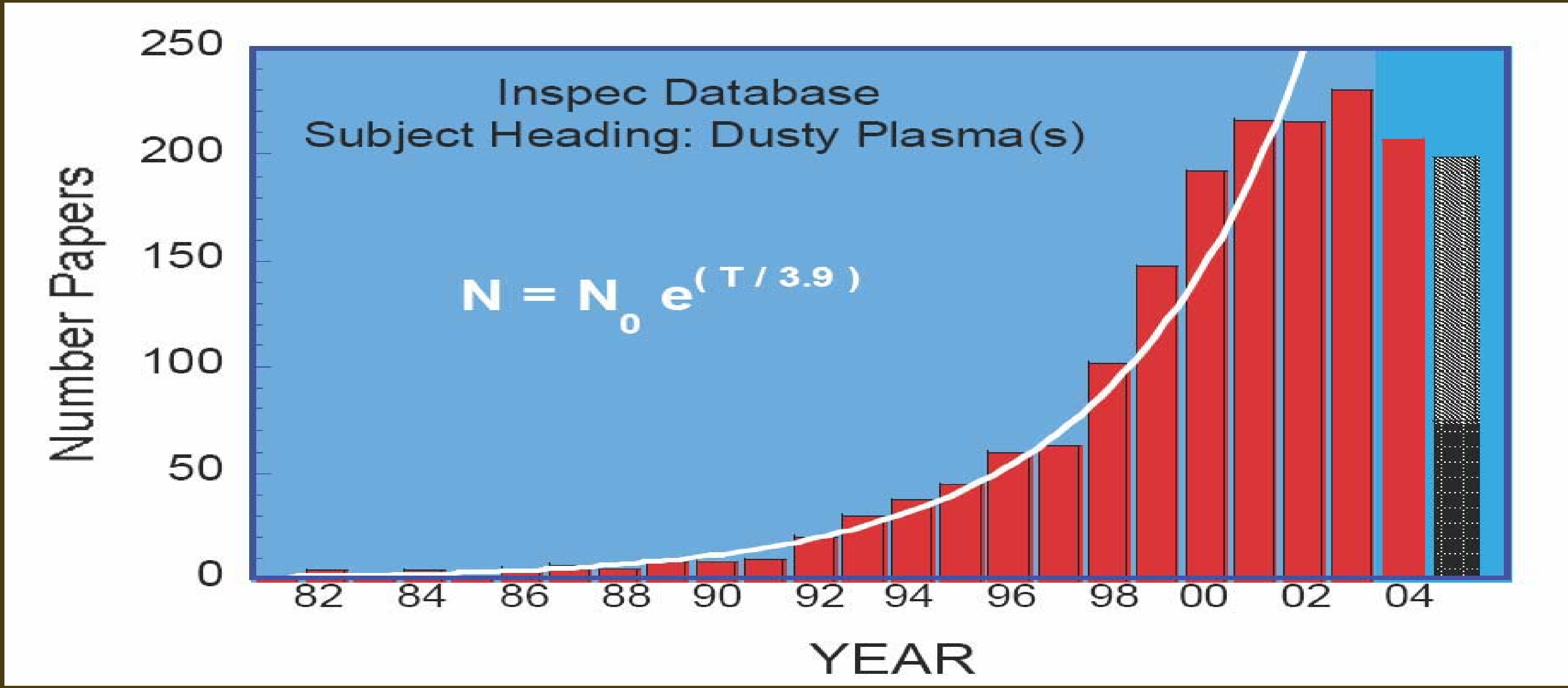
- **The physics of charging processes in a magnetized dusty plasma:** Particularly, to derive the exact expressions for electron and ion currents in a magneto-dusty plasma.

- **The physics of magnetized strongly coupled dusty plasma:** Particularly, to determine the transport coefficients (shear and bulk viscosity coefficients, viscoelastic relaxation time, compressibility, etc.) in a magnetized dusty plasma.

# ❑ What are our CR on DPP?

- Almost dust is everywhere, and there is no branch of science where the physics of dust is not involved.
- The physics of mobile/immobile dust of variable size, charge and mass arises unsolvable complexities, and makes the field of DPP infinitely large.
- These unsolvable complexities of dusty plasma physics have introduced a lot of open issues which are, the challenges for the young genius brains of present and future generations.
- We cannot explain the physics of our universe without the role of charged dust.
- The charged dust modify the existing plasma waves, as well as introduce new waves, e.g. DIA, DA, DL, etc. The physics of these waves must play a significant role in understanding the properties of localized ES/EM structures in space/laboratory dusty plasmas.

- **Dusty plasma physics is a very rapidly (exponentially) growing research field. This is obvious from the figure below (R. L. Merlino 2005):**




- **To conclude: for its infinitely large domain, versatile applications and unsolvable complexities, the field of DPP has become a challenging approach not only for near future, but also for a long --- long --- period of time to come.**

# Thank you all

A SIDE VIEW OF MY HOME UNIVERSITY