2007 Summer College on Plasma Physics

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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:** $\mu$m - 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

\( \Phi < 0 \)

\( T \gg 0 \)

e\(^{-}\) high energy

hv
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)
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

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>interstellar clouds</th>
<th>zodiacal dust disc</th>
<th>Haley’s comet</th>
</tr>
</thead>
<tbody>
<tr>
<td>$n_e$ (cm$^{-3}$)</td>
<td>$10^{-4} – 10^{-3}$</td>
<td>$1 – 10$</td>
<td>$10^2 – 10^4$</td>
</tr>
<tr>
<td>$T_e$ (K)</td>
<td>$10 – 20$</td>
<td>$10^4 – 10^5$</td>
<td>$10^3 – 10^4$</td>
</tr>
<tr>
<td>$n_d$ (cm$^{-3}$)</td>
<td>$10^{-7} – 10^{-6}$</td>
<td>$10^{-12} – 10^{-11}$</td>
<td>$10^{-8} – 10^{-3}$</td>
</tr>
<tr>
<td>$r_d$ (µm)</td>
<td>$0.1 – 0.5$</td>
<td>$1 – 10$</td>
<td>$0.1 – 10$</td>
</tr>
</tbody>
</table>
Mysterious spokes of Saturn’s B-ring: charged dust: repulsion between dust particles and boulders: trails of dust grains
# Typical parameters of dust-laden plasmas in Saturn’s rings

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>E-ring</th>
<th>F-ring</th>
<th>Spokes</th>
</tr>
</thead>
<tbody>
<tr>
<td>( n_e ) (cm(^{-3}))</td>
<td>10 – 20</td>
<td>10 – 20</td>
<td>0.1 – 10(^2)</td>
</tr>
<tr>
<td>( T_e ) (K)</td>
<td>10(^5) – 10(^6)</td>
<td>10(^5) – 10(^6)</td>
<td>10(^4) – 10(^5)</td>
</tr>
<tr>
<td>( n_d ) (cm(^{-3}))</td>
<td>10(^{-7}) – 10(^{-6})</td>
<td>1 – 10</td>
<td>0.5 – 1.5</td>
</tr>
<tr>
<td>( r_d ) (µm)</td>
<td>0.5 – 1.5</td>
<td>0.5 – 1.5</td>
<td>0.5 – 1.5</td>
</tr>
</tbody>
</table>
## Typical parameters of dust-laden plasmas in NLCs, rocket exhausts and flames

<table>
<thead>
<tr>
<th>characteristics</th>
<th>NLCs</th>
<th>rocket exhausts</th>
<th>flames</th>
</tr>
</thead>
<tbody>
<tr>
<td>$n_e$ (cm$^{-3}$)</td>
<td>$10^3 - 10^4$</td>
<td>$10^{12} - 10^{13}$</td>
<td>$10^{11} - 10^{12}$</td>
</tr>
<tr>
<td>$T_e$ (K)</td>
<td>100 – 200</td>
<td>$10^3 - 10^4$</td>
<td>$10^3 - 10^4$</td>
</tr>
<tr>
<td>$n_d$ (cm$^{-3}$)</td>
<td>$10 - 10^2$</td>
<td>$10^7 - 10^8$</td>
<td>$10^{10} - 10^{11}$</td>
</tr>
<tr>
<td>$r_d$ (µm)</td>
<td>0.1 – 1</td>
<td>0.1 – 1</td>
<td>0.01 – 0.1</td>
</tr>
</tbody>
</table>
Typical parameters of dust-laden plasmas in laboratory devices

<table>
<thead>
<tr>
<th>characteristics</th>
<th>Q-machine (DPD)</th>
<th>dc discharges</th>
<th>rf discharges</th>
</tr>
</thead>
<tbody>
<tr>
<td>( n_e ) (( cm^{-3} ))</td>
<td>( 10^6 – 10^7 )</td>
<td>( 10^9 – 10^{10} )</td>
<td>( 10^9 – 10^{10} )</td>
</tr>
<tr>
<td>( T_e ) (K)</td>
<td>( 10^3 – 10^4 )</td>
<td>( 10^4 – 10^5 )</td>
<td>( 10^4 – 10^5 )</td>
</tr>
<tr>
<td>( n_d ) (( cm^{-3} ))</td>
<td>( 10^3 – 10^4 )</td>
<td>( 10^3 – 10^4 )</td>
<td>( 10^5 – 10^6 )</td>
</tr>
<tr>
<td>( r_d ) (µm)</td>
<td>( 10 – 20 ) (( Al_2O_3 ))</td>
<td>( 1 – 5 ) (Al)</td>
<td>( 5 – 10 ) (( SiO_2 ))</td>
</tr>
<tr>
<td>( Z_d )</td>
<td>( 10^3 – 10^4 )</td>
<td>( 10^5 – 10^6 )</td>
<td>( 10^3 – 10^4 )</td>
</tr>
</tbody>
</table>
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

This 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

MAIN RESEARCH AREAS OF DPP

CHARGING PROCESSES
- PLASMA CURRENTS
- SECONDARY EMISSION
- PHOTOEMISSION
- THERMIONIC EMISSION
- FIELD EMISSION
- RADIO ACTIVITY
- IMPACT IONIZATION

DUST DYNAMICS
- ES FORCE
- EM FORCE
- GRAV. FORCE
- THER. PRESSURE
- DRAG FORCE
- RAD. PRESSURE
- THERMOP. FORCE
- SHAD. FORCE

WAVES/INSTABILITIES
- ES WAVES
- EM WAVES
- DIA
- DA
- DL
- DLH
- DC
- SV
- DSA
- DMW

LINEAR
- NONLINEAR
- SOLITON
- SHOCK
- VORTEX
- TURBULENCE
- CHAOS
remarkable experimental discoveries

1. **DUST CRYSTAL**
   - 1994: Thomas et al, Chu & Lin, Hayashi & Tachibana
   - 1986: IKezi

2. **DA WAVES**
   - 1995: Barkan et al
   - 1990: Rao, Yu & Shukla

3. **DIA WAVES**
   - 1996: Barkan et al
   - 1992: Shukla & Silin

4. **DL WAVES**
   - 1997: Morfill et al, Homann et al
   - 1996: Melandsø

5. **MACH CONES**
   - 1999: Samsonov et al
   - 1996: Havnes et al

6. **DUST VOIDS**
   - 2001: Thomas et al
   - 1999: Morfill et al
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):

$$N = N_0 e^{\left(\frac{T}{3.9}\right)}$$

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