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Experimental Investigations of Dusty Plasmas

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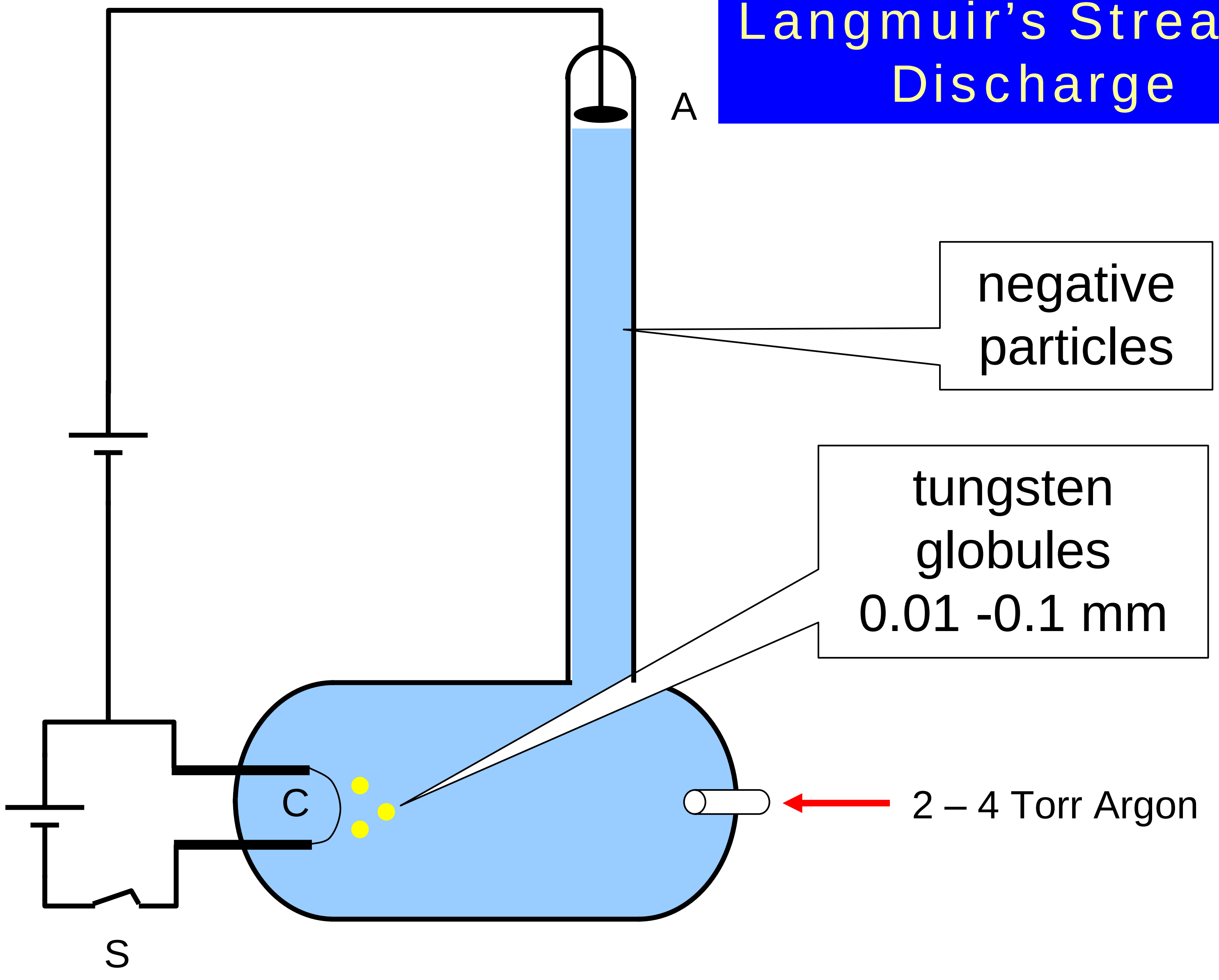
Purpose

- Highlight some of the experimental work on dusty plasmas (1980-present)
- theorists had about a 10 year head start on the experiments
- Provide some “historical perspective”

I. Early History

- The first observations of a dusty plasma in the laboratory were made by Langmuir.
- He reported these observations on September 18, 1924 at an address at the Centenary of the Franklin Institute in Philadelphia.
- *“. . . we have observed some phenomena of remarkable beauty which may prove to be of theoretical interest.”*
- Langmuir, Found and Dittmer, Science, vol. 60, No. 1557, p 392 (1924)

Langmuir's Streamer Discharge



Langmuir’s Observations

- small tungsten ‘globules’ were sputtered into the discharge from the filament
- these globules could be made to move upward and their motions could easily be followed visually
- by concentrating a beam of sunlight into the tube, he could see a ‘very intense scattering’ from the particles

Langmuir's conclusions

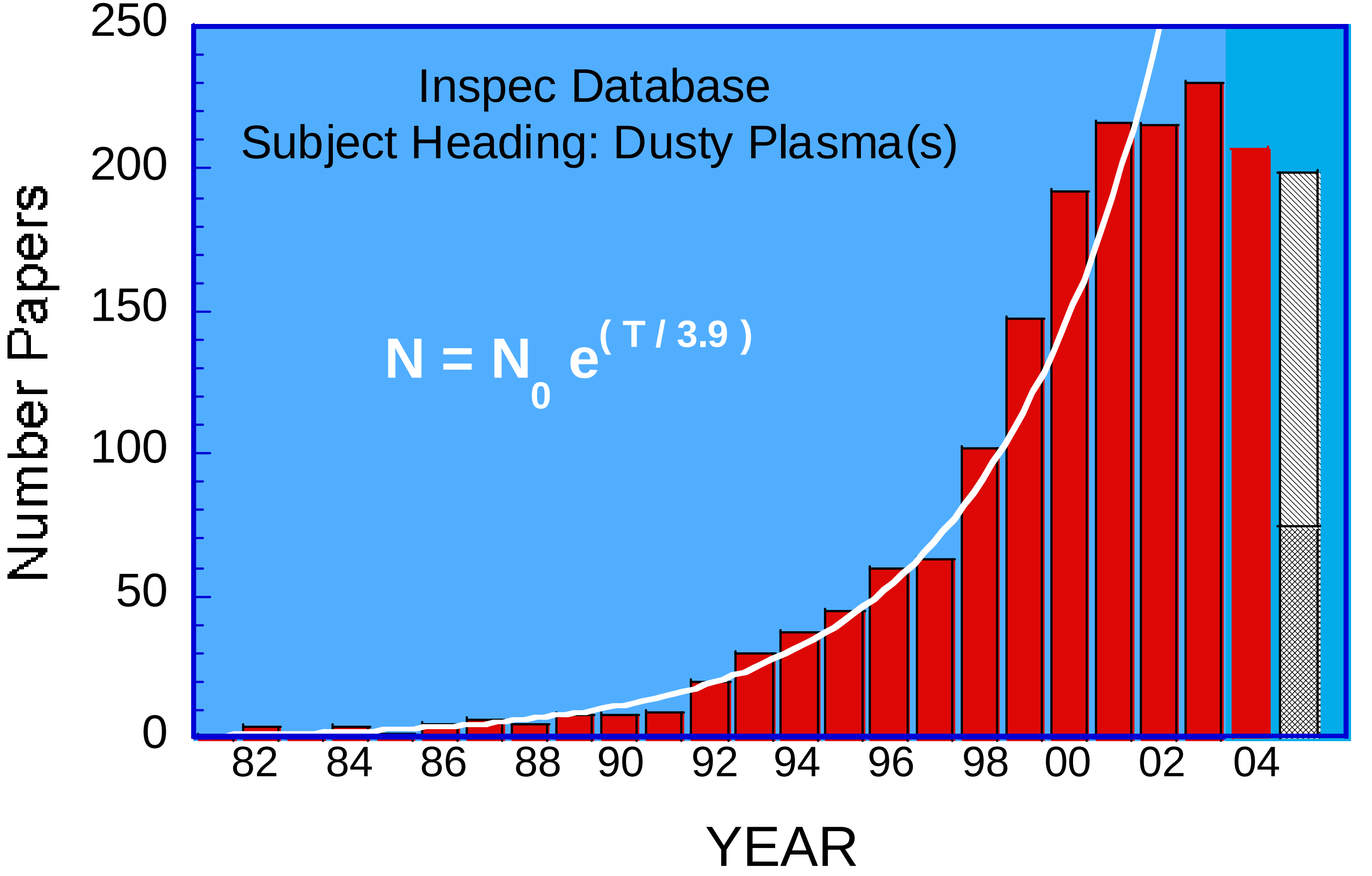
- Langmuir concluded that since the walls of the tube are negatively charged, the *particles must also be negatively charged* because they do not deposit on the walls
- the negatively charged particles is surrounded by a positive ion shielding cloud
- the negative particles can lose their charge when moving through an ion sheath, and the resulting neutral particles can condense into larger solid particles

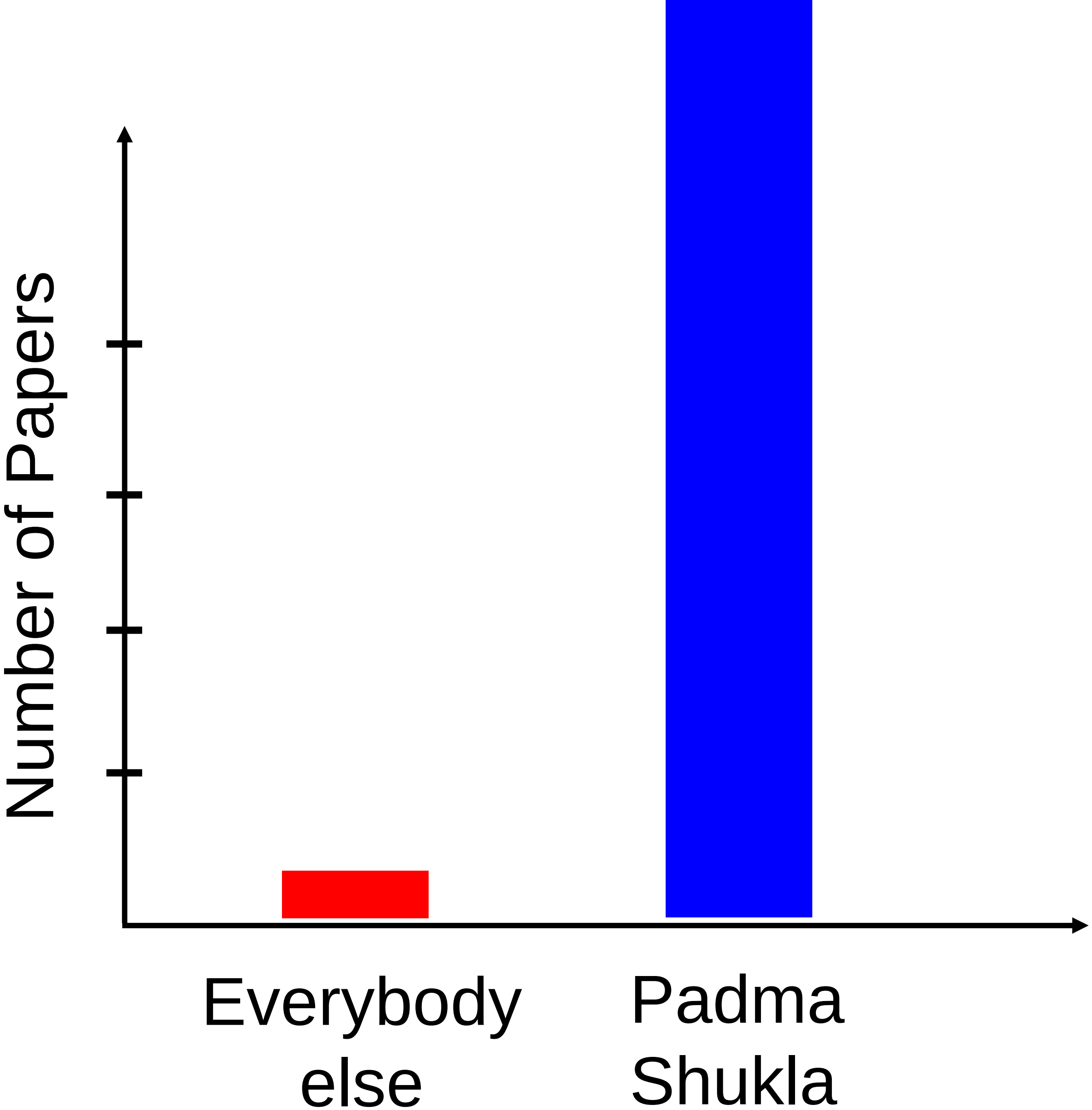
Langmuir's other contributions

- The concept of the *floating potential –*

  "Any electrode to which no current flows is negatively charged with respect to the surrounding plasma."
- a probe placed in a plasma does not measure the space potential
- He derived the form of the OML current to a probe
- However, Spitzer (1941) was the first to write down the equation $1-\varphi_f-(m_i/m_e)^{1/2}\ e^{\varphi_f}=0$

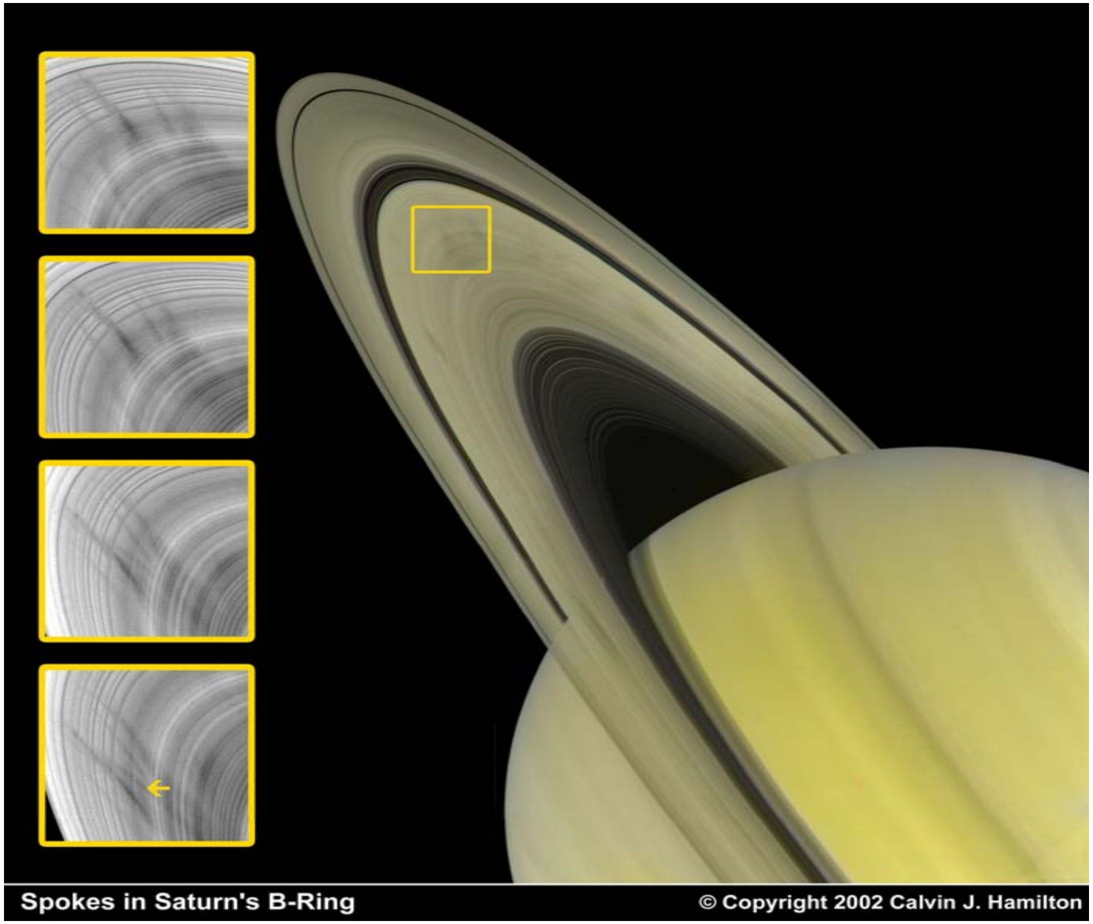
II. Dusty Plasma Research



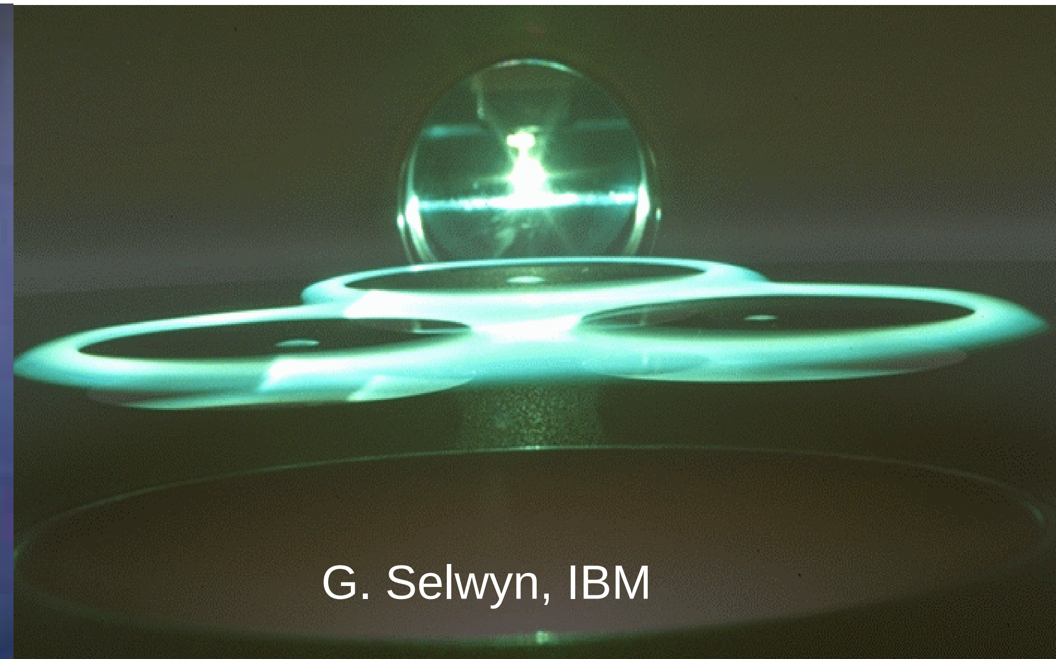

Number of Papers
Everybody else
Padma Shukla

III. Experimental work on dusty plasmas

1. discovery of the spokes in Saturn's B ring by the Voyager 2 imaging team in 1981.—



2. Dust contamination in plasma processing tools.—

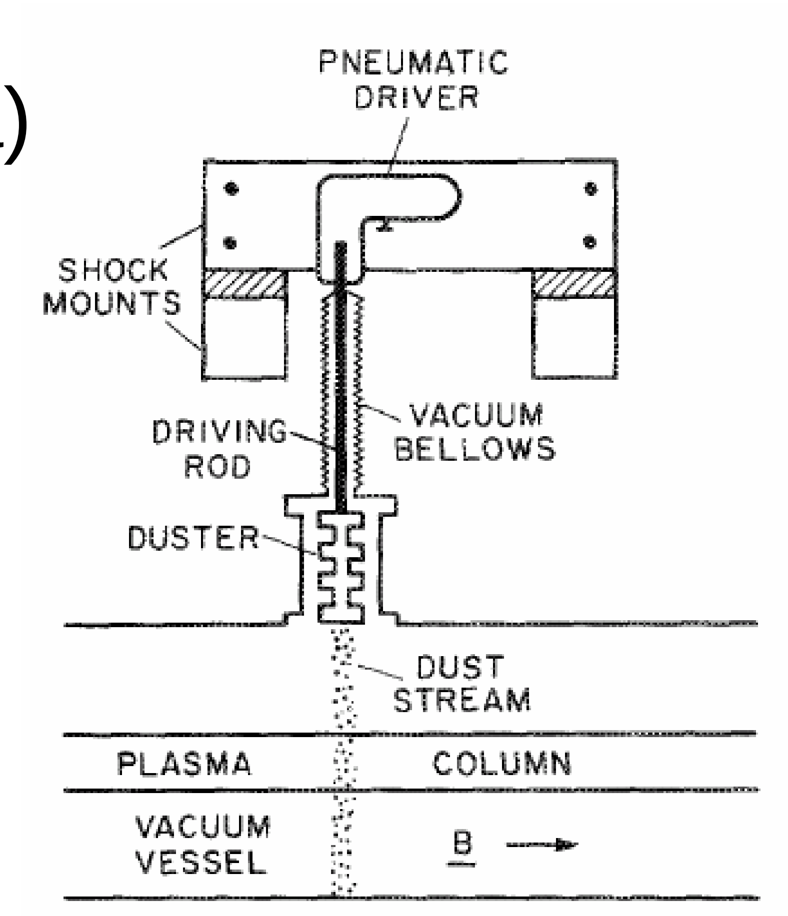


Time (s)

L. Boufendi and A. Bouchoule,
Plasma Sources Sci. & Technol. 3, 262, 1994.

3. Devices specifically introduced to make a dusty plasma.—

a)



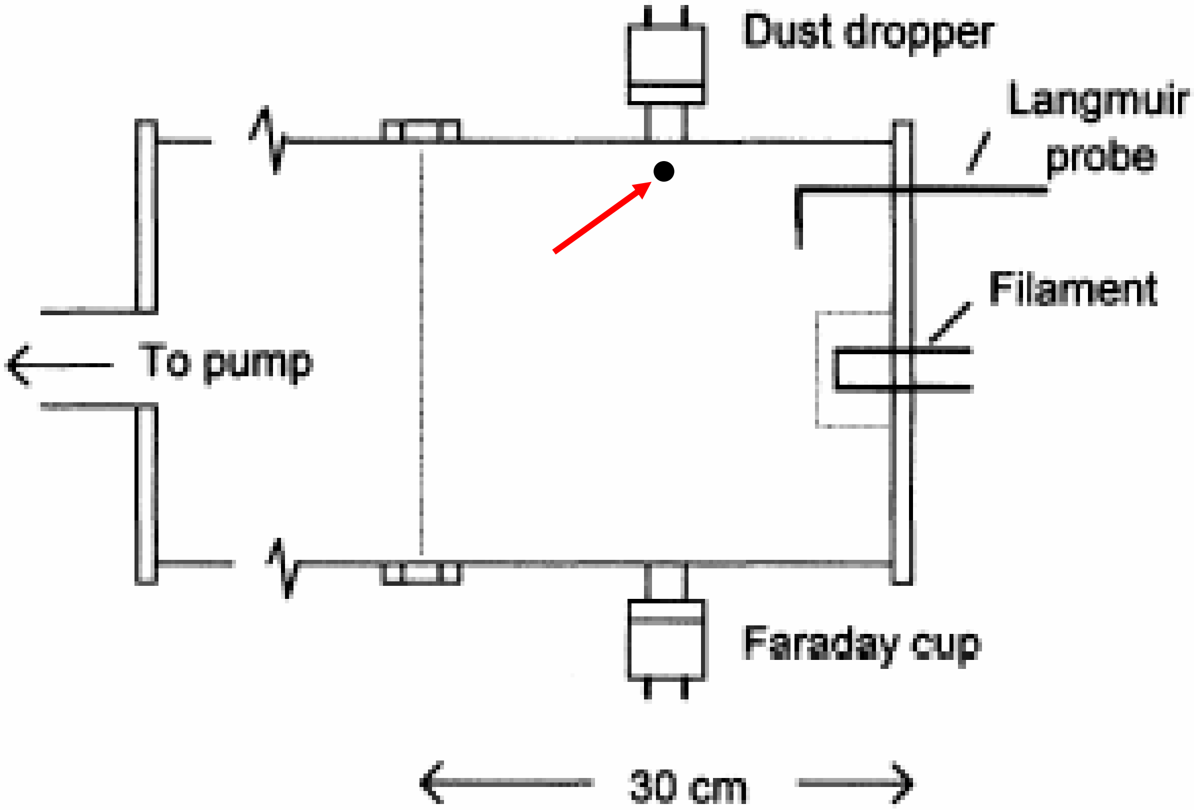
University of California at Irvine-

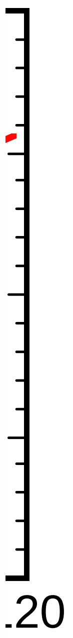
Sheehan, Carillo and Heidbrink

RSI 61, 3871 (1990)

b) Device used for basic charge measurement

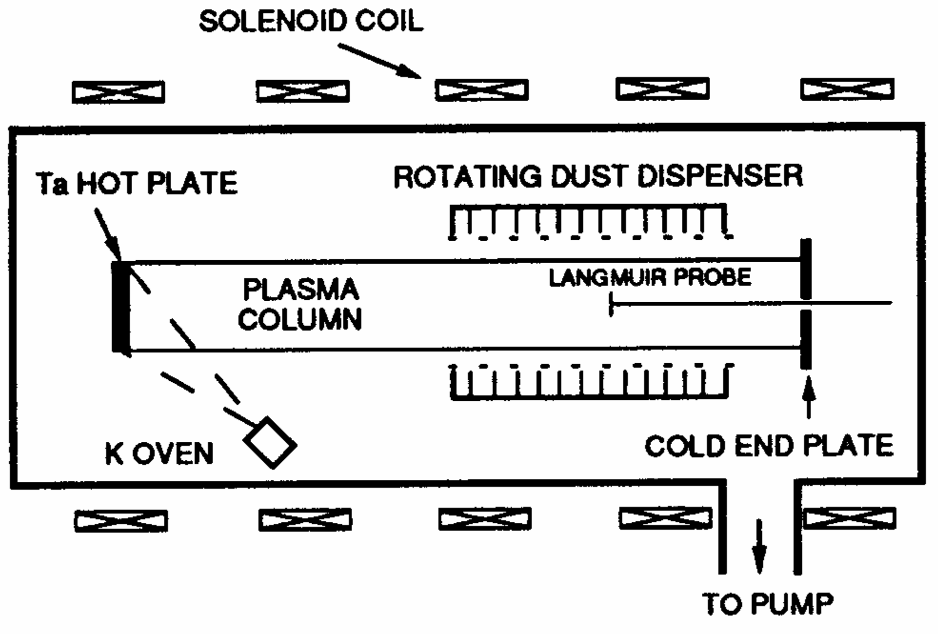
Walch, Horanyi, & Robertson,
Phys. Rev. Lett. 75, 838 (1995)

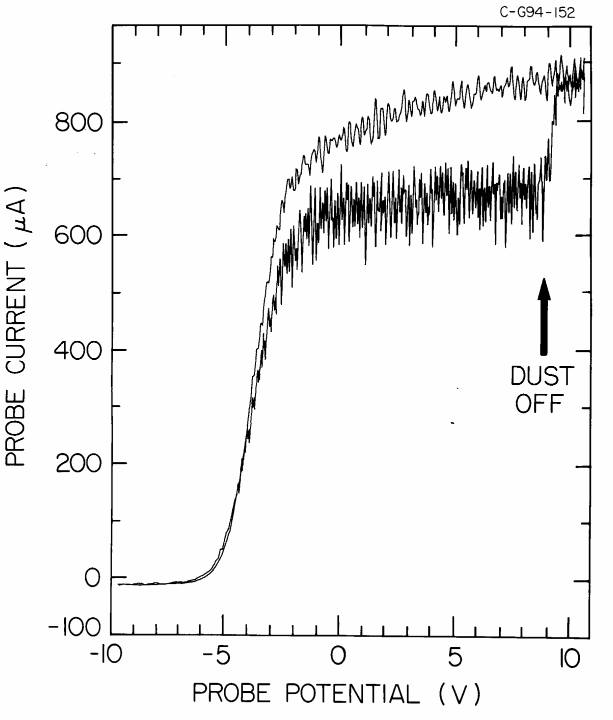




c) The Iowa rotating dust dispersal device

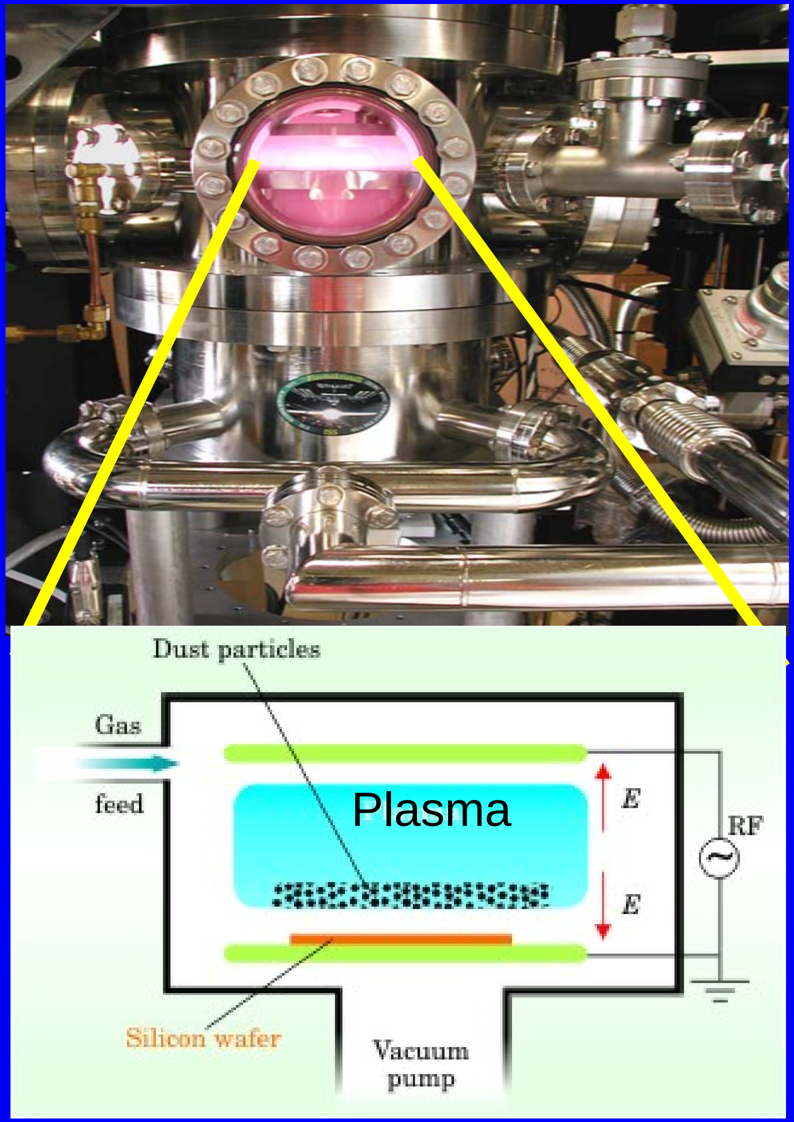
(Xu, Song, Merlino, D'Angelo, RSI 63, 5266 ,1992)





This device produced a relatively large volume of dusty plasma, suitable for wave experiments

d) The GEC radio frequency reference cell



- introduced in 1988 for experimental studies of plasma-processing discharges
- adopted by many labs as the standard platform for dusty plasma studies
- provided an almost ideal environment (not intended) for the study of strongly coupled dusty plasmas

RF parallel plate devices and the discovery of Coulomb Crystals

- Operate at relatively high gas pressures (*40 Pa, 200 mTorr, 2 mbar*) which helps calm down the dust particles
- Have strongly inhomo-geneous vertical and horizontal electric fields that provide a "trap" for negatively charged dust particles

- Hayashi & Tachibana, Jpn. *J. Appl. Phys. 33, 804, 1994*.
- Chu & I, *Phys. Rev. Lett. 72, 4009, 1994*.
- Thomas, Morfill, Demmel, Goree, Feuerbacher & Mohlmann, *Phys. Rev. Lett. 73, 652, 1994.*

IV. Waves in dusty plasmas

- experiments on dusty plasmas lagged seriously behind theory
- e.g., the theoretical discovery of the dust acoustic wave (*Rao, Shukla, and Yu, Planet. Space Sci. 38, 543, 1990*) preceded experimental observations by 5 years (*Barkan, Merlino, and D'Angelo, Physics of Plasmas 2, 3563, 1995.)*

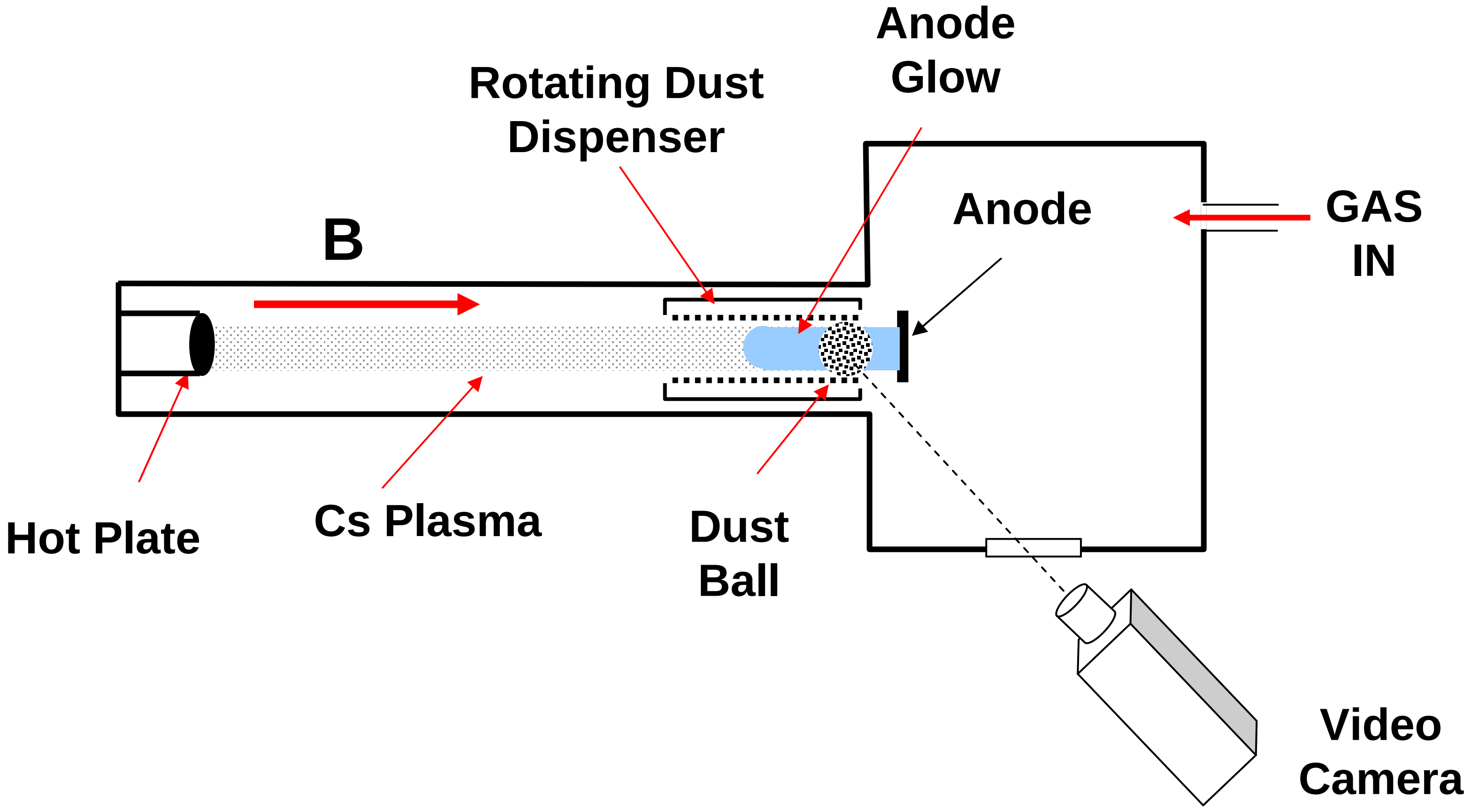
Unexpected findings: the role of serendipity

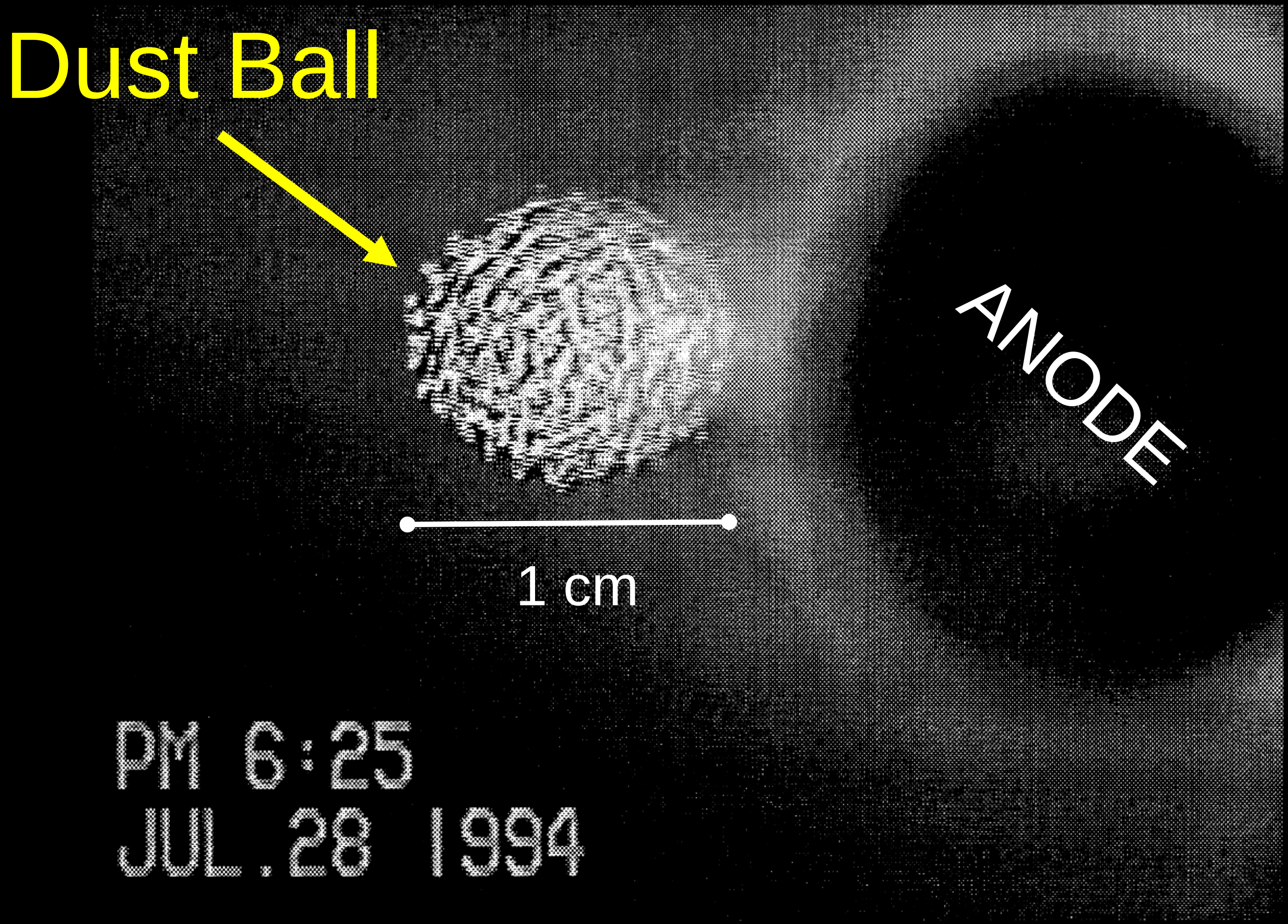
- Dust acoustic waves and Coulomb crystals
- Chu, Du and I (*J. Phys. D 27, 296, 1994*) reported that in order to see Coulomb solids, low frequency fluctuations (12 Hz with wavelengths of 0.5 cm, v_φ= 6 cm/s) had to be suppressed.
- D'Angelo (*J. Phys. D 28, 1009, 1995*) interpreted these fluctuations as DAWs.

Dust Acoustic Waves

- Adrian Barkan and I were studying the confinement and structure of “dust balls” in an anode double layer
- In an attempt to improve the viewing geometry, the anode was pulled back into the weaker magnetic field region
- the spherical dust structure expanded into a dust cloud (fluid) and 15 Hz fluctuations appeared, which we later identified as dust acoustic waves (*Barkan, Merlino and D’Angelo, PoP 2, 3563, 1995*).

Observation of the Dust Balls




Dust Ball
ANODE
1 cm
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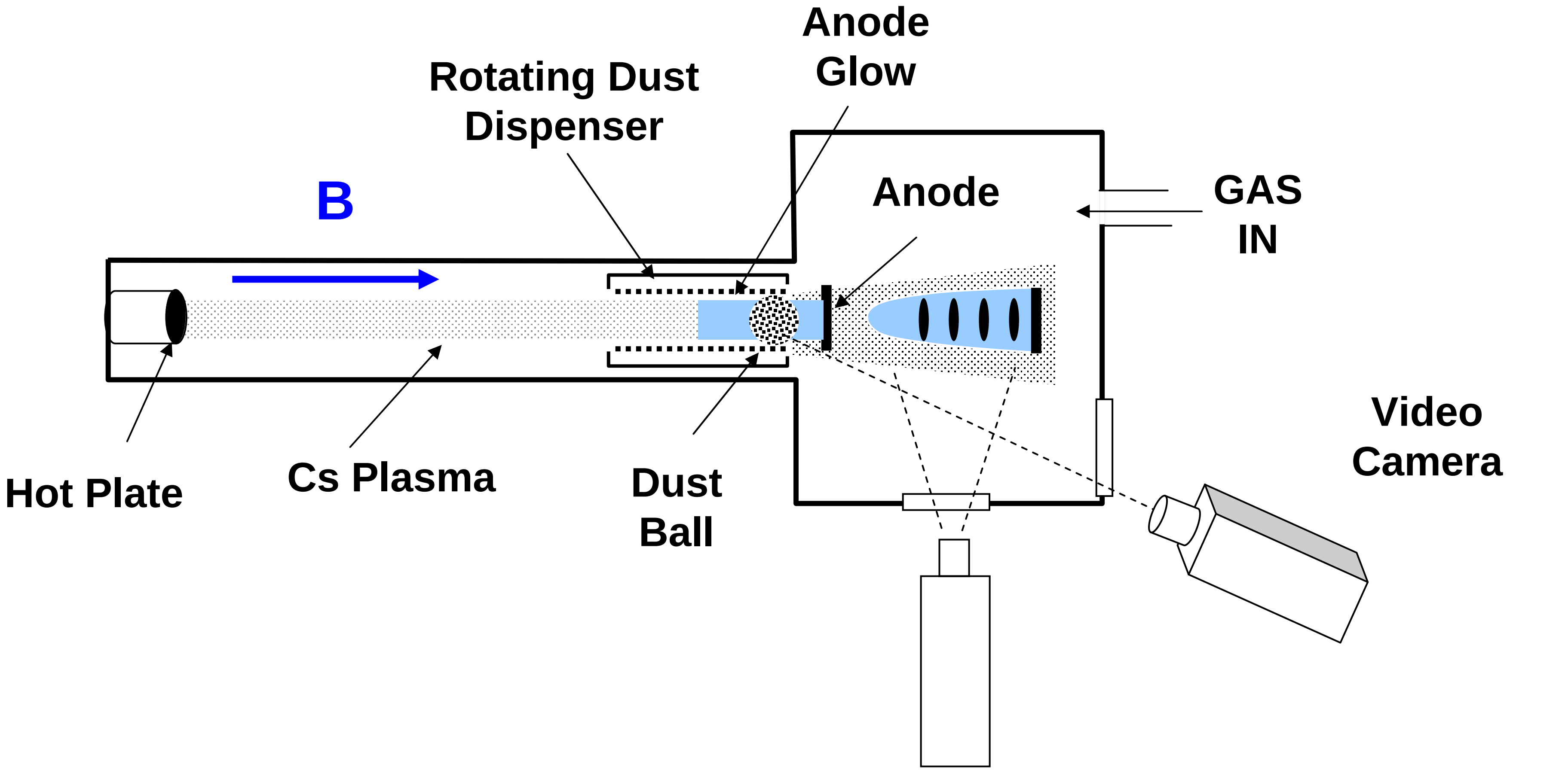
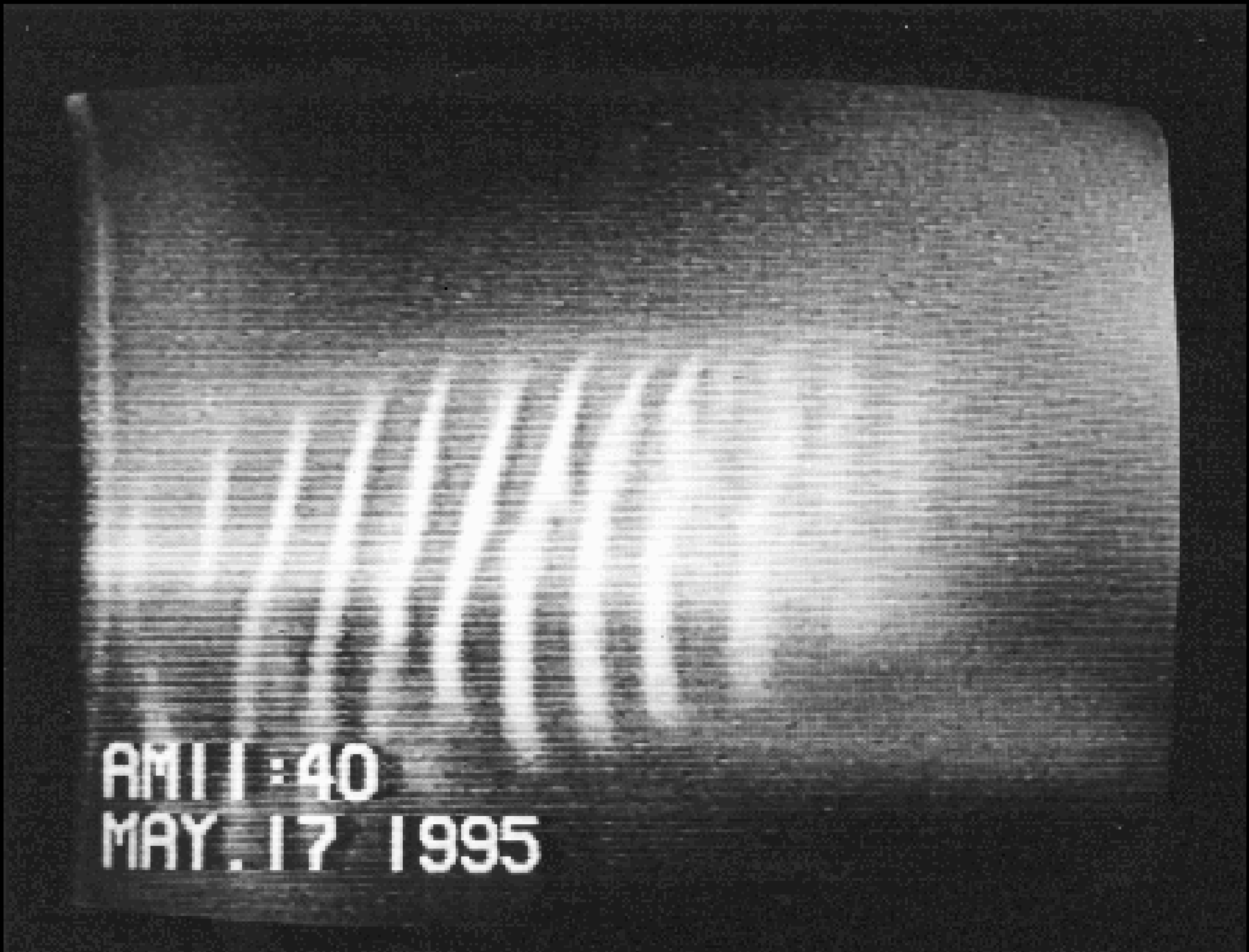
JUL.28 1994

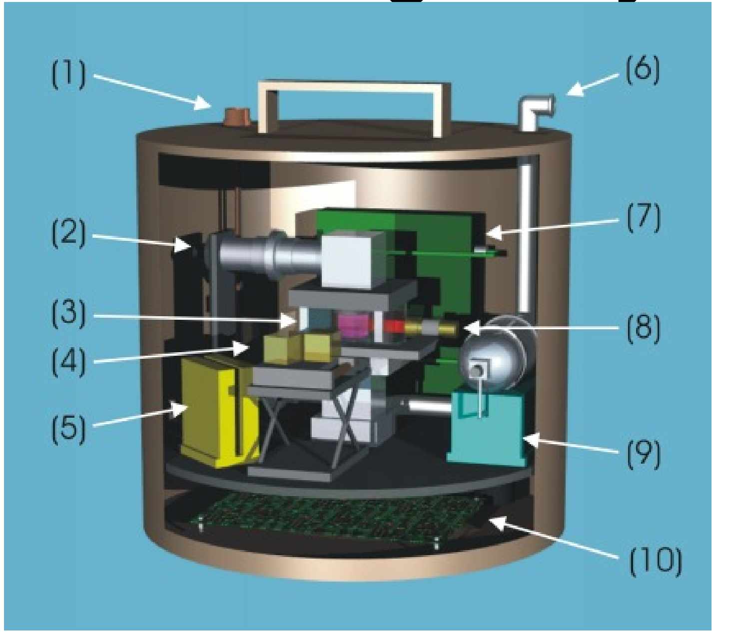
Observation of Dust Acoustic Waves

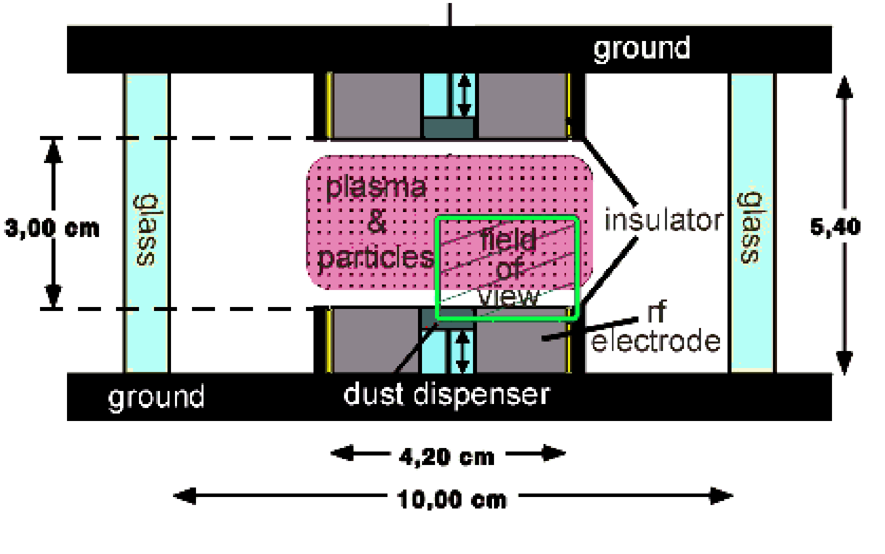



AM11:40
MAY.17 1995

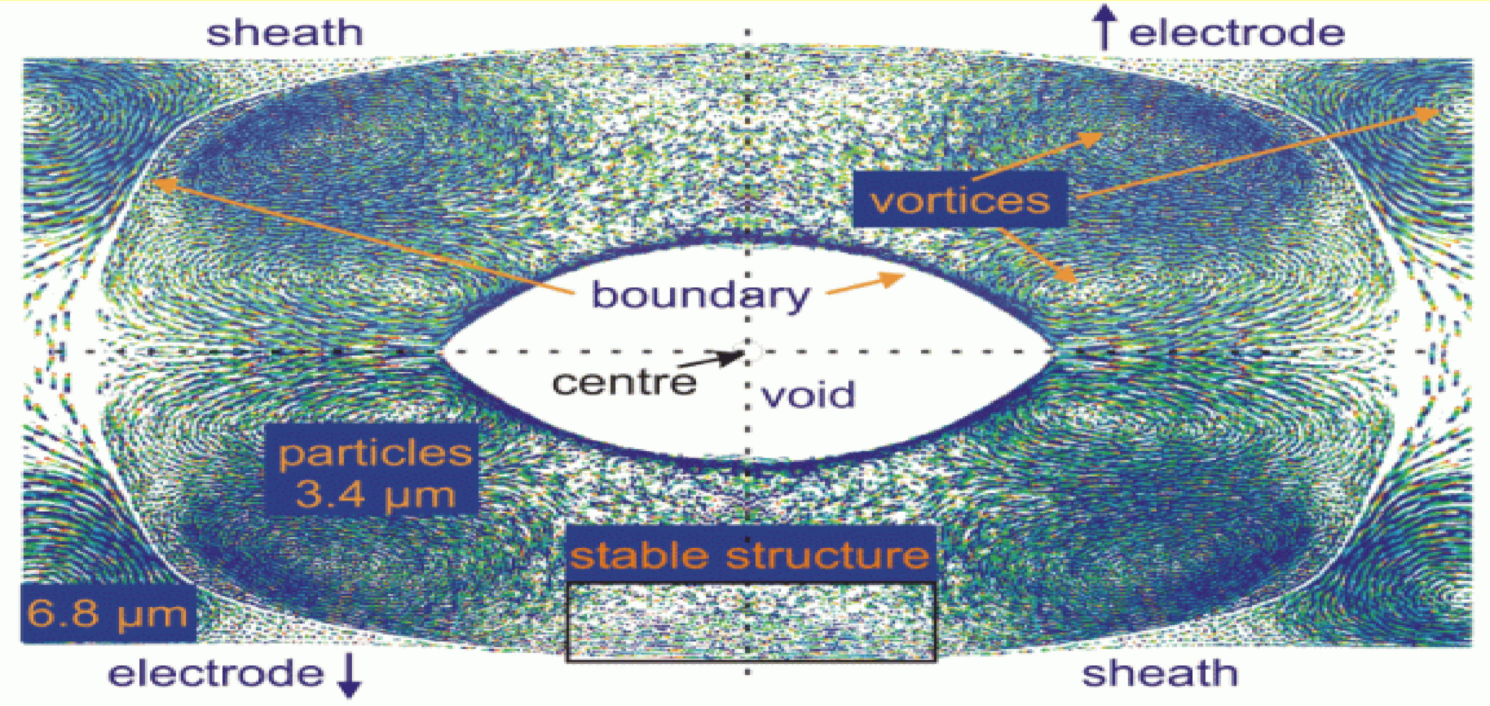
V. Dusty Plasmas under Microgravity

- Often dusty plasmas on earth tend to be dominated by gravity
- Gravity causes dust crystals to consist of a few layers of two dimensional structures
- Led to the development of the PKE- Nefedov device onboard the ISS





More Surprises and New Physics!



- **Elimination of gravity reveals the ion drag force**
- **Ions shuffled out the center of the positive discharge region, carry dust particles along, creating a void.**

A look back ➔ 1990 - 2000

- 4th Workshop on dusty plasmas (1990, Iowa City)
  - 2 ½ days, 23 presentations
  - dominated by discussions on planetary rings and comets
  - 3 preliminary laboratory experiments
  - only one talk on plasma processing
  - no dust crystals or strongly coupled plasmas

- 8th Workshop on dusty plasmas (2000, Sante Fe)
  - 3 days, 76 presentations
  - 16 oral and 18 poster experimental presentations
  - 4 from plasma processing community
  - topics included plasma crystals, Mach cones, waves in strongly coupled plasmas, microgravity

A look forward ➔ ICPDD4

- effects of strong magnetic fields
- dust in fusion devices
- dust phenomena in the earth's atmosphere
- nonlinear dusty plasma physics
- nanoparticle growth
- to a greater and greater extent, the experiments are motivating theory