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Poster B28

INSTABILITIES IN COMPLEX DC PLASMAS

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Abstract. Complex plasmas are ideal tools to investigate self-organization effects in multi-particle systems. E.g., with varying parameters they can be put in nearly any state from crystalline ('Plasma Crystal', see fig.1) to super-critical. The microparticles can be visualised individually by cameras and this allows us to study the dynamical phenomena on the 'atomistic' (kinetic) level of individual particles which is hardly possible in ordinary matter.

To compensate for gravity (being most of the time the dominating force) complex plasma experiments (RF and DC generated) were performed onboard the International Space Station (ISS) and on parabolic flights.

There, several experiments exhibit effects of self-organization/instabilities, such as 'lane formation' [4]: The particles in interpenetrating clouds form lanes to minimize the energy needed to pass through each other. These effects are also known from two-component fluids, granular media, and even people moving in a crowd (fig. 7) [5]. These cases are discussed here.

Keywords: Complex plasma, instability, self-organisation, lane formation, crowd dynamics, microgravity.

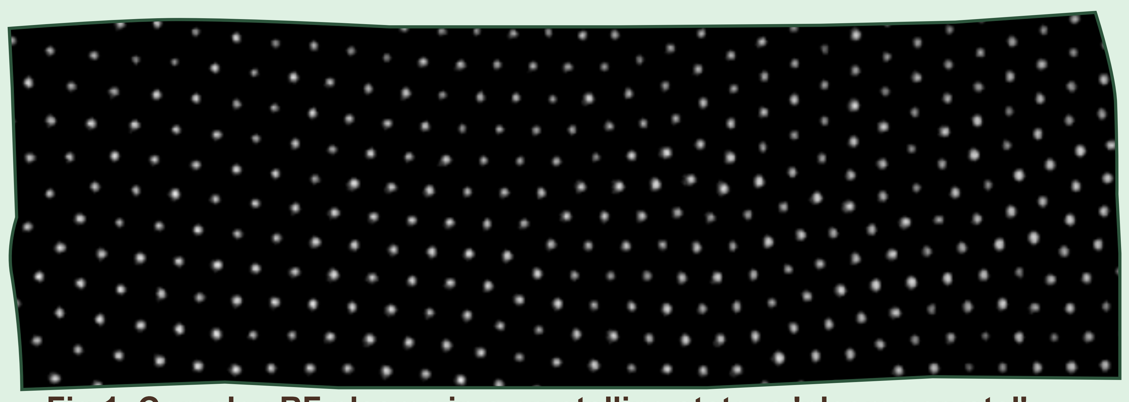
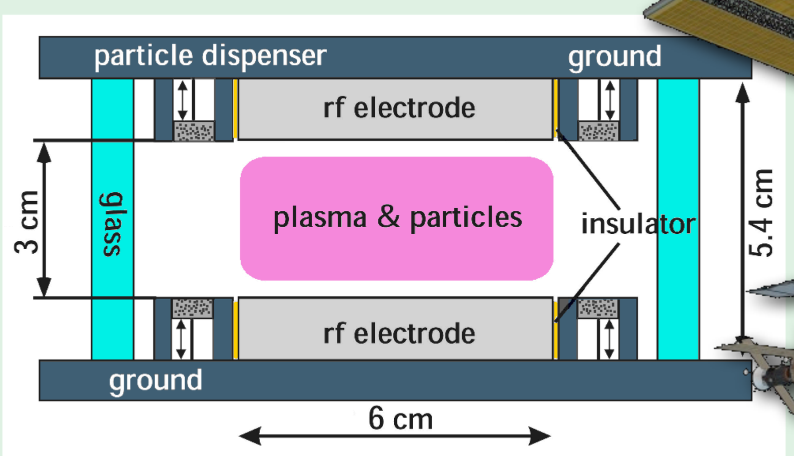


Fig.1. Complex RF plasma in a crystalline state, a 'plasma crystal'.

PK-3 Plus Experiment description (see fig. 2)

- RF plasma (13.56 MHz, few W), circular electrodes with 6 cm diameter and 3 cm distance inside glass/aluminum chamber
- Optimal to study phases (crystalline, fluid, gaseous) & trans.
- Gases: Argon, Neon @ 0.1 - 2.50 mbar (10 - 250 Pa)
- Micro-particles: 1.55 (SiO_2), 2.55 - 3.4 - 6.8 - 9.2 - 15 µm (MF)
- Particles are injected from the guard rings
- Illuminated by laser sheets (2x 40 mW, red)
- 4 CCD cameras (PAL): Overview, Quadrant, HiRes, Glow
- Means for particle manipulation: Gas flow, electrode heating for thermophoresis, electric field (function generator)
- Arrival at ISS: December 2005, 21 missions in total
- Final mission: June 2013.



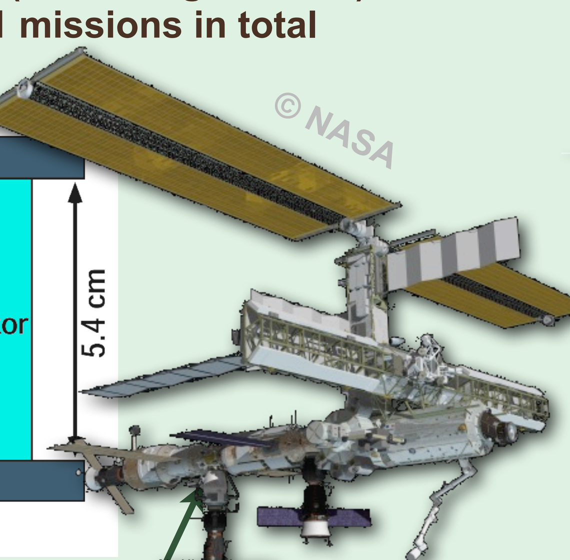


Fig.2. Scheme of the PK-3 Plus RF plasma chamber.

Fig.3. German cosmo/astronaut Thomas Reiter with the PK-3 Plus plasma facility onboard the ISS (Russian segment) in 2008.

Results:

- Particles collect ~10^4 electrons inside plasma and interact
- Microgravity allows to see small forces and particle mixtures
- In many experiments self-organization showed all kind of structures, e.g. plasma crystals (fig.1)
- Lane formation was observed after injecting 3.4 µm particles into stationary 9.2 µm particles (fig. 4) [4]. Particles flow to the center of the discharge converging to a droplet
- PK-3 Plus geometry difficult for lane formation (→simulation)

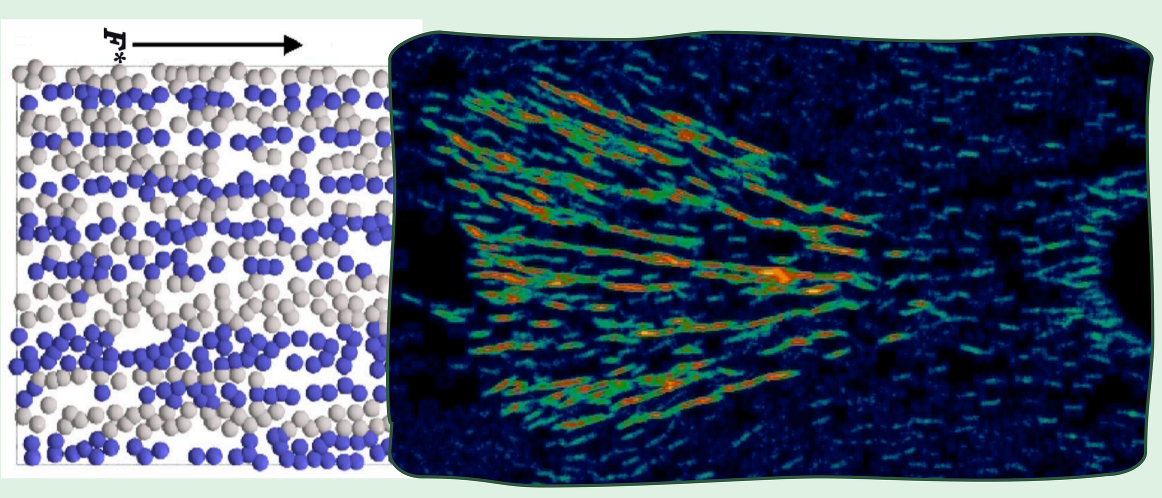
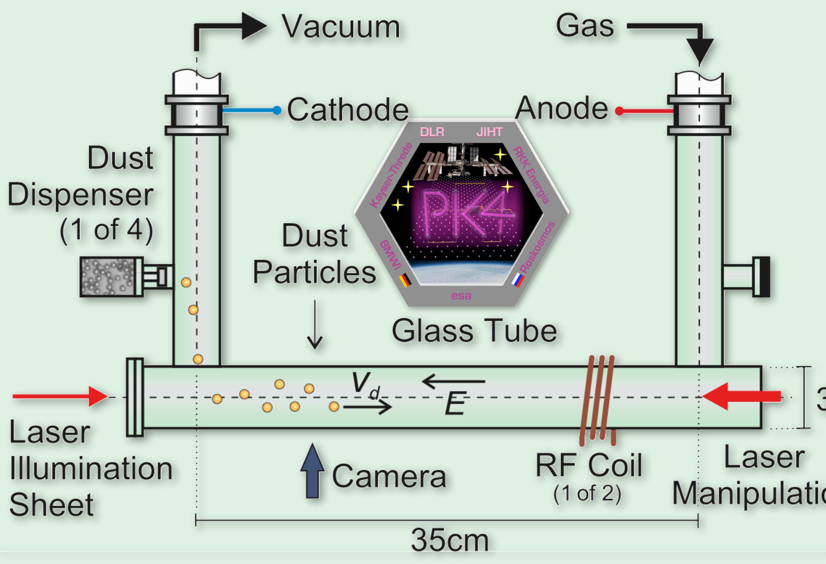


Fig.4. Simulation (left) [7] and experiment (right): Penetrating particle clouds (3.4 µm particles injected into stationary 9.2 µm) forming lanes. [4]

PK-4 Experiment description

(as used for parabolic flights, see fig. 5)

- DC plasma (~900 V, 1 mA) in a L=35cm, d=3cm glass tube
- Optimal to study particle flows (fluid phase)
- Gases: Argon, Neon @ 0.1 - 2.50 mbar (10 - 250 Pa)
- Micro-particles sizes used: 1.2 - 3.4 - 6.8 - 11.0 µm (MF)
- Particles injected on cathode side, E ~ 2 V/cm
- Illuminated by laser sheet (max. 150 mW, 532 nm - green)
- CCD Camera resolution: 10 µm/pixel @ 120 fps
- Means for particle manipulation: Gas flow, RF coil, EM electrode, 20 W laser, heating wire for thermal manipulation.
- Effects of particle manipulation: Constrict/stop/reverse flow, shear flows, cloud collisions, etc.
- Parabolic flight rack: 1.55 x 0.85 x 1.1 m³, 350 kg
- ESA project: FM launched to ISS Oct. 28 2014 (Progress M-25)



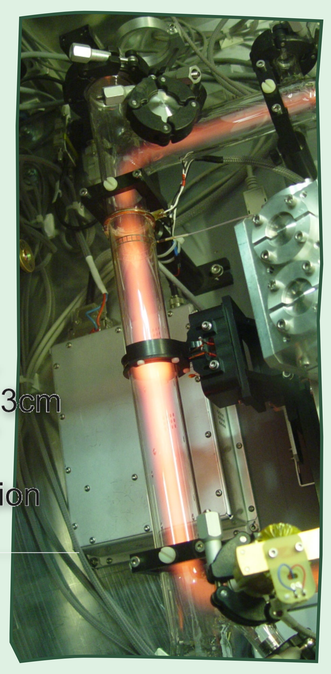
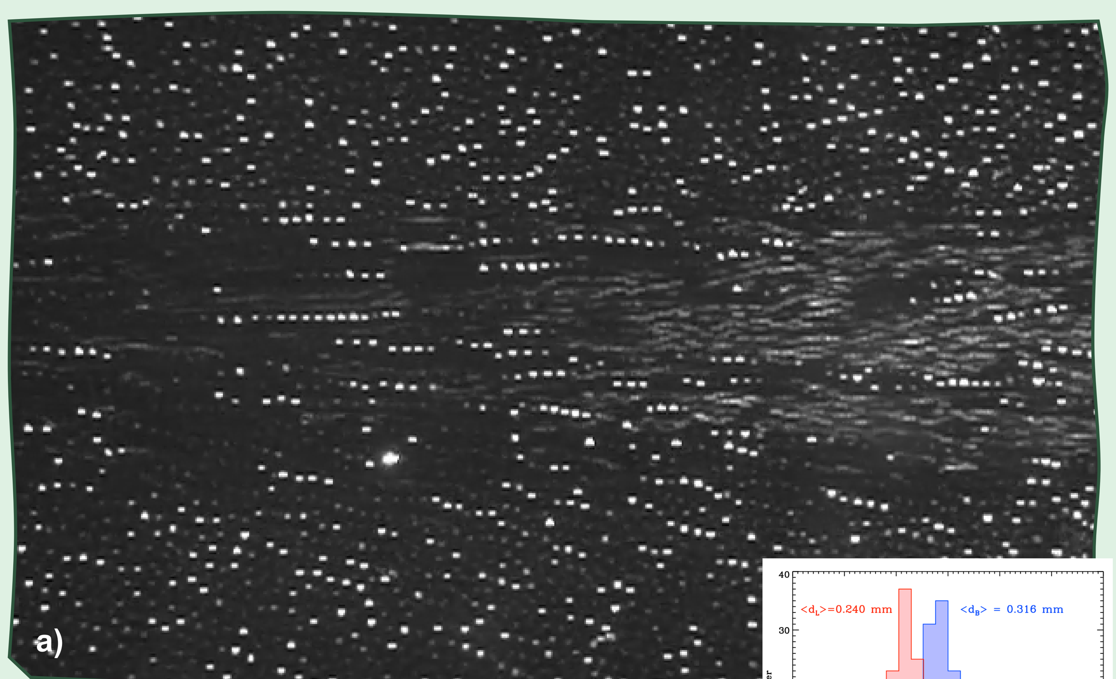


Fig.5. Scheme (left) and image (right) of the PK-4 setup inside the parabolic flight setup.

Observations in streaming complex plasmas

- Laminar flows, waves [6], chains & lanes, 'surfers', 'bullets', etc. Most phenomena only visible in microgravity
- Lane formation appears mostly in particle cloud collisions, especially with different particle sizes (fig. 6a)
- This is also known as 'two stream instability' from two-component liquids, granular media [7], or people! [5]
- The lanes are easily distinguished from the bulk particles, e.g. by the typical particle distance (fig. 6b)



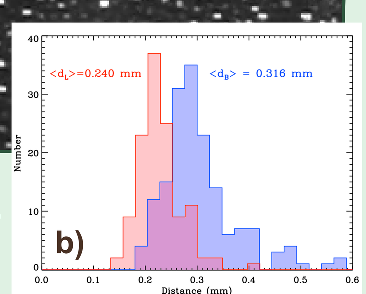


Fig.6a. Lane formation of 3.4 µm particles caused by fast-streaming 1.3 µm particles, b. Particle distances in the bulk (blue) and in the lanes (red). Inside lanes the mean distance is ~30% shorter.

Fig.7. View of a pedestrian zone with people moving in lanes.

Observation of RT instability: (in PK-4 lab)

- Particle mixtures (see fig. 8): Region A: 3.4 µm, B: 1.28 µm, C: ≤ 1.28 µm (sputtered). D: Grown, very small particles.
- Particles are stopped at (floating) electrode ring E.
- Parameters: Neon, p=1mbar; I=1mA, polarity switching: 50%.
- Density waves occur in region C from within E with v_L = 6.1 mm/s to the left and with v_R = 0.59 mm/s to the right side. Both waves interfere in region Z. CL: central line of the tube.
- This drives an instability in region B and on B-C interface.

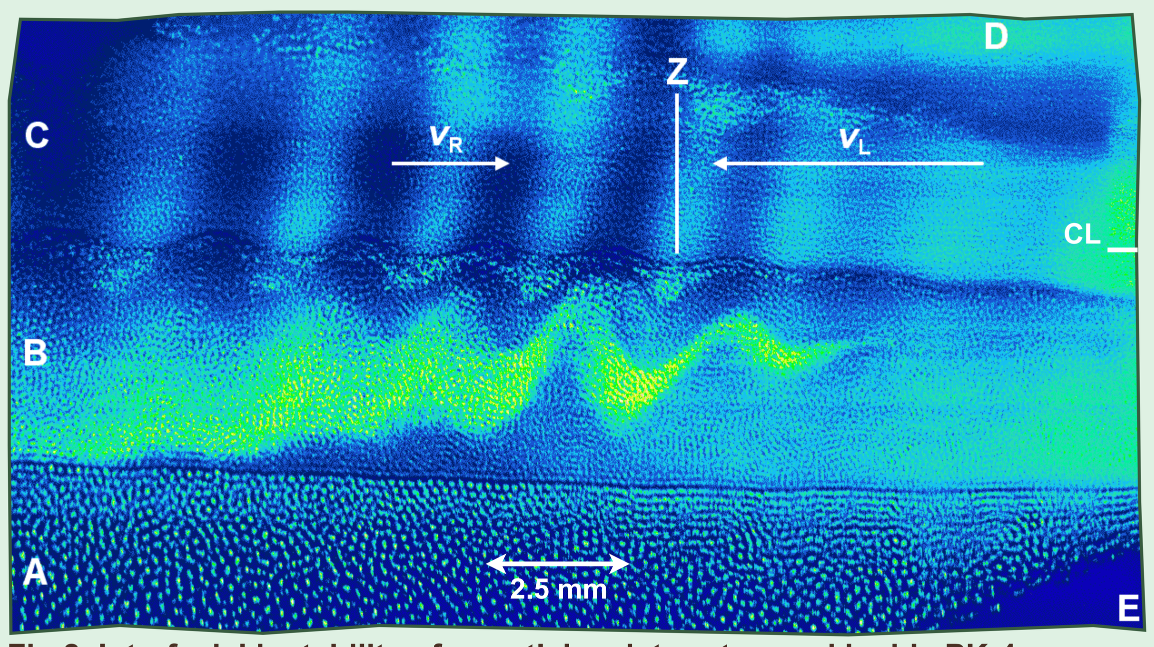


Fig.8. Interfacial instability of a particle mixture trapped inside PK-4.

Discussion:

- Wavelengths of both waves are nearly identical (2.5-2.6 mm).
- The observed instability in region B looks like Kelvin-Helmholtz (KH) or Rayleigh-Taylor (RT) type.
- Epstein drag in B ≈ 490s⁻¹. Way too much for KH! (See [9].)
- → Instability may be "deep water" RT.
- Spatial increment [exp(x/L)], estimated from first 3 maxima: L^{-1} = 3-5 cm⁻¹. Good agreement with [9] (4cm⁻¹).
- Open questions: Why are the 'swinging' particles brighter? What causes the waves in C? A velocity gradient of the Ions?
- Further analysis of particle positions needed.

CONCLUSIONS

- Complex plasmas with µ-sized particles show various kinds of self-organization effects in spatial and temporal easily accessible ranges.
- Many particle systems with uniform or different particles properties can easily be constructed.
- In many cases microgravity experiments are needed to overcome gravity-driven sedimentation.
- Particle flows in PK-4 on parabolic flights exhibit several phenomena, such as lane formation in two-stream instabilities, stop-and-go waves, etc.
- Particles inside a complex plasma are not only suitable for modeling the states of matter but also for the collective behavior in crowds, e.g. a large number of humans.
- Also classical instabilities can be observed and modeled in complex plasmas.

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