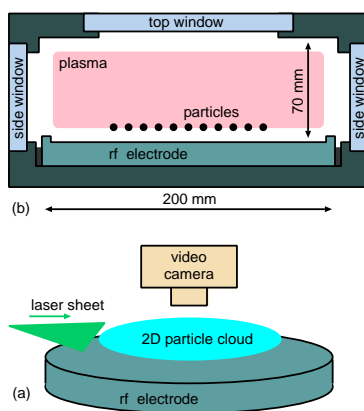


In this work the shape of DMC (dynamic Mach cones) formed by nondispersive linear sound waves in a nonuniform complex plasma is calculated analytically using the method of wave rays. The cases of transversely and longitudinally inhomogeneous media are considered. The theory is compared with experimental observations of Mach cones with curved wings in a two-dimensional complex plasma with a good qualitative agreement. A novel plasma diagnostic method is proposed.

Experimental setup



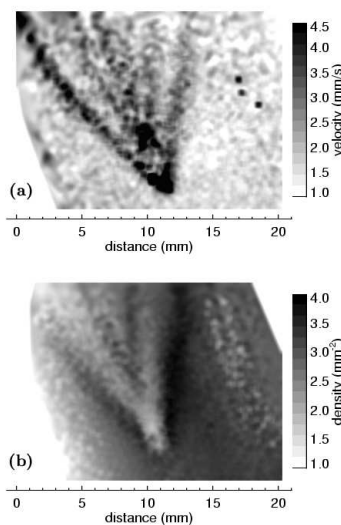
Experimental conditions

- Ar, pressure 1.2 Pa
- argon flow rate 0.5-6 sccm
- 50 W capacitively coupled rf discharge at 13.56 MHz
- 8.9 μm plastic microspheres $\rho = 1.51 \text{ g/cm}^3$
- Optical access: top view, side view

Experimental procedure

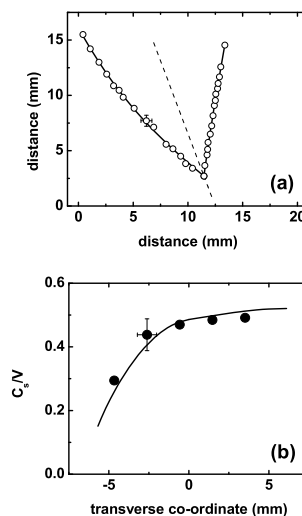
- Particles injected into the plasma, charged negatively ($Q = 17000 e$), and levitated at a height of 9 mm above the lower electrode
- Radial bowl-shaped confinement
- Hexagonal 2D lattice is formed
- Particle separation $a = 590 \mu\text{m}$
- Cluster diameter 7 cm
- Illumination with a laser sheet
- video recording at 25 frames/s
- Particle identification and tracing yields velocities

Max cone images



- V-shaped disturbances travelling through the hexagonal lattice
- Created by fast particles, moving under the layer

Interpretation



Theory of waverays

- Simple basic equations:
 $\dot{\mathbf{r}} = \mathbf{v}_g$, $\dot{\mathbf{k}} = -\partial_{\mathbf{r}}\omega$
 $\omega = kC_s(\mathbf{r}, t)$, $\mathbf{v}_g = \mathbf{k}C_s/k$
- Optimal way to solve analytically direct (find a cone) and inverse problem (restore a medium property)
- Observed bending of Mach cone wing agreed qualitatively with the theoretical predictions
- Comparison to theory allowed to reconstruct the acoustic speed profile across the cone trajectory
- The speed of the perturbing body was determined to be $V = 35 \pm 7 \text{ mm/s}$
- Cone wing curved towards the crystal center, where the lattice was denser ($n_{max} = 3.3 \text{ mm}^{-2}$)

Summary

- The DMC contains information on either the time history of changes in the medium or of gradients in the medium
- Dynamic Mach cones can be used for diagnostics of inhomogeneous or time-dependent complex plasmas
- Different dusty plasma inhomogeneities can affect the Max cone shape in different ways
- Theory based on linear nondispersive waves provides a good approximation even at the kinetic level and for strong gradients