Compressibility of dusty plasma from observation of compression wave propagation.

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Types of Dust Waves

General equation

$$\rho\left(\frac{\partial \mathbf{v}}{\partial \mathbf{t}} + (\mathbf{v}\nabla)\mathbf{v}\right) = \nabla p - \tau_{dn}^{-1}\rho\mathbf{v} + \mathbf{F}$$

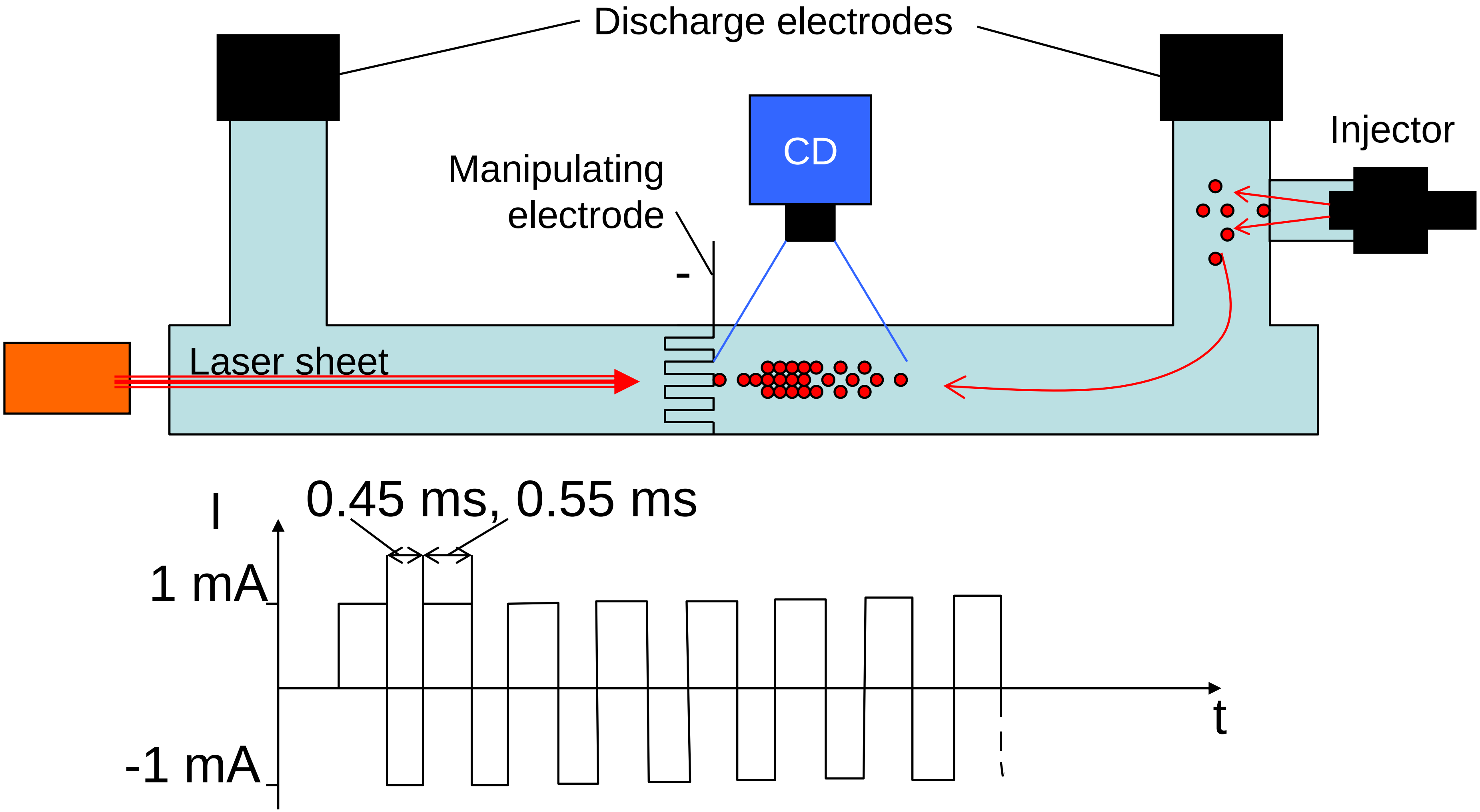
Elastic waves:

$$\rho\left(\frac{\partial \mathbf{v}}{\partial \mathbf{t}} + (\mathbf{v}\nabla)\mathbf{v}\right) \approx \nabla p$$

Drift waves:

$$\tau_{dn}^{-1}\rho\mathbf{v} \approx \nabla p + \mathbf{F}$$

PK-4 Setup Configuration for Dusty Shock Wave Observation

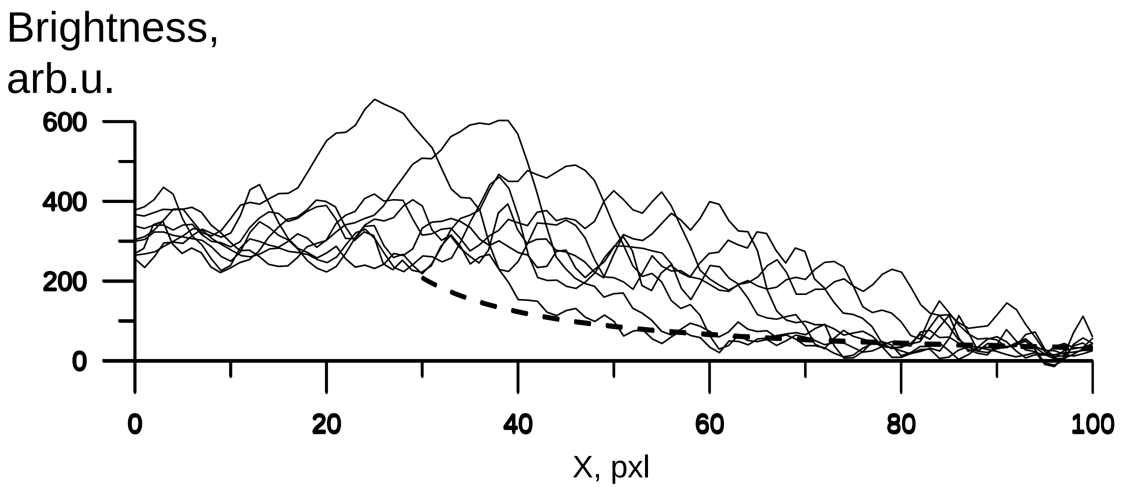


Plasma Parameters

Neon 15 Pa,
Electron number density (in absence of dusty cloud) 10^8 cm^{-3},
Effective electron temperature 7 eV,
Grain diameter 3.4 mcm,
Mass of grain 3.1x10-14 kg.

Frame rate 60 s^{-1}, field of view 3x4 cm, laser sheet width 100 mcm

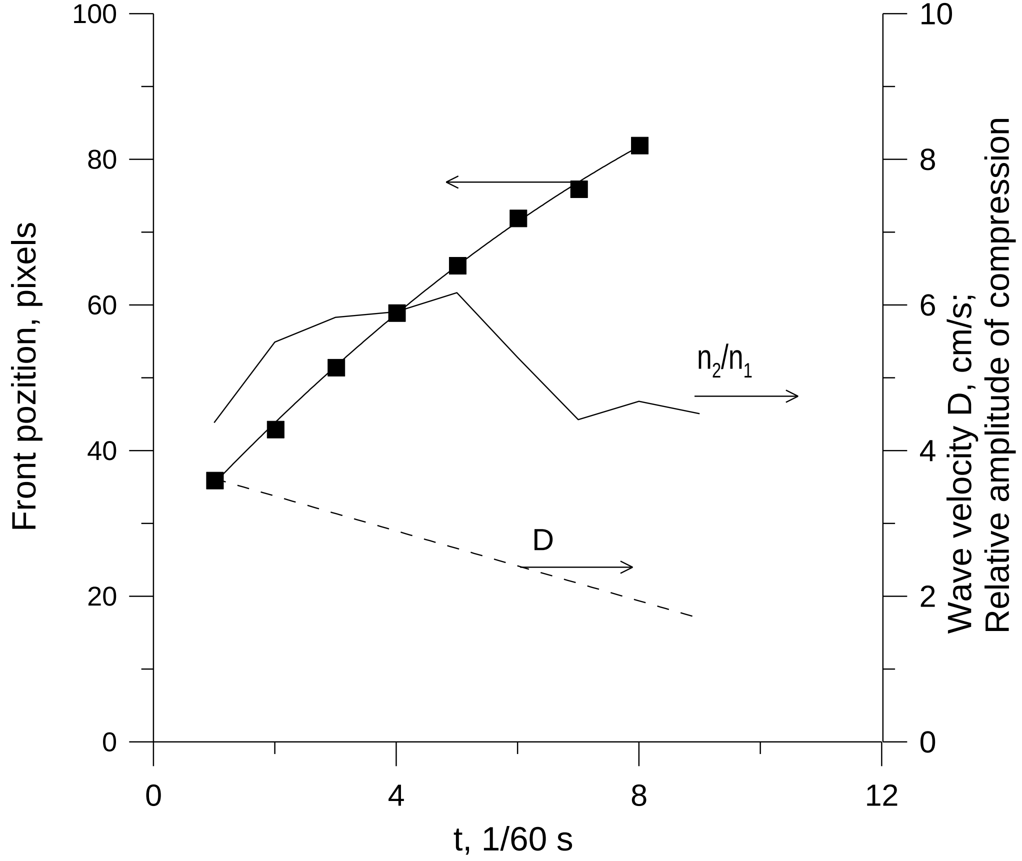
Compressional Wave Propagation



Brightness of 100 arb.u. corresponds to dusty number density of $1.3x10^5$ cm^{-3}

Parameters of the wave:
Length of the front h=300-500 mcm,
Distance between grains: before front 150-200 mcm,
after front 100-150 mcm
Duration of the front of 10-20 ms,
Dust-neutral friction time constant 26 ms.

Velocity and relative amplitude of the wave



Equations for front of compression

Matter conservation

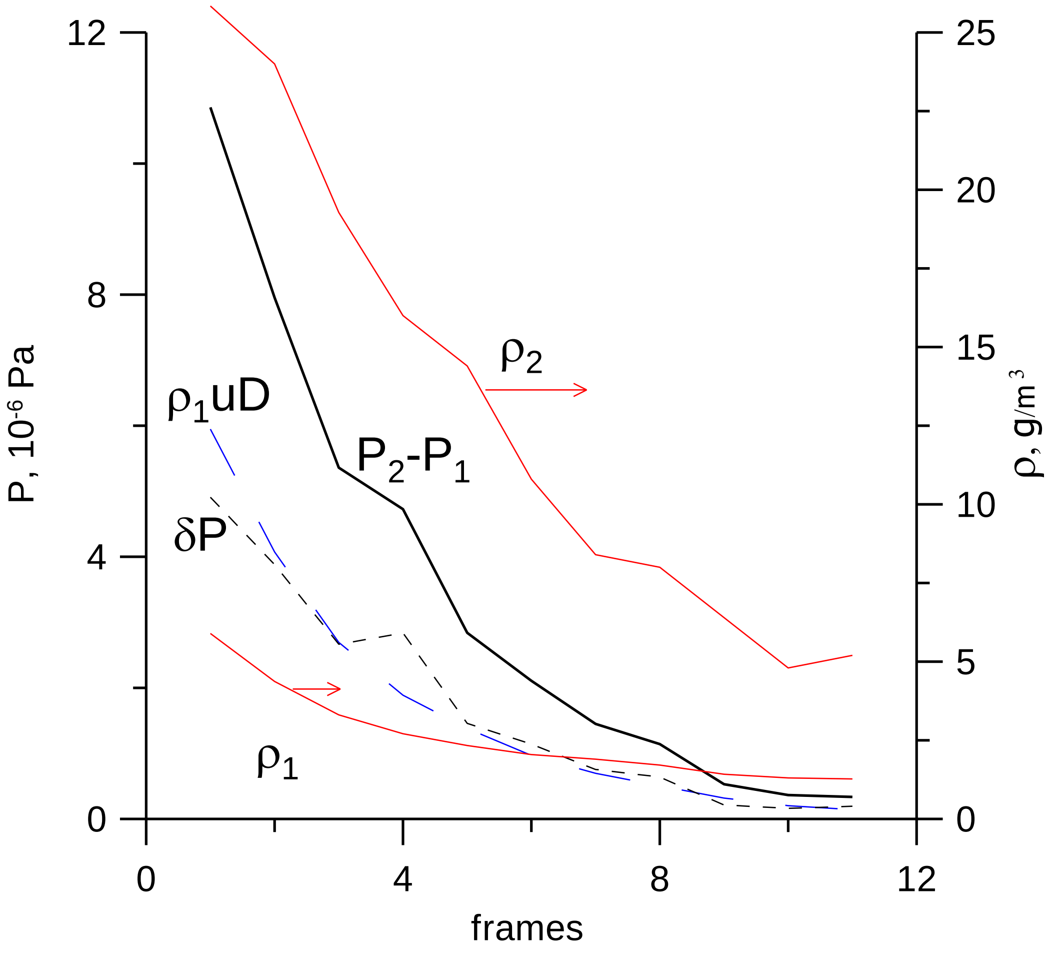
$$u = D\left(1 - \frac{n_1}{n_2}\right)$$

Momentum conservation

$$p_2 - p_1 \approx \rho_1 u D + \frac{\rho_2}{3}\tau_{dn}^{-1} h u$$

h – front width, u – grain velocity after the front

Давление за фронтом волны



Simple Model of the Dusty Plasma

Debye-Huckel pothential

$$\Phi(r) = Q \frac{\exp(-(r-a)/\lambda)}{r}$$

Repulsive force between particles

$$F = Q^2 \frac{\exp(-(r-a)/\lambda)}{r}\left(\frac{1}{r}+\frac{1}{\lambda}\right)$$

Estimation for cool pressure

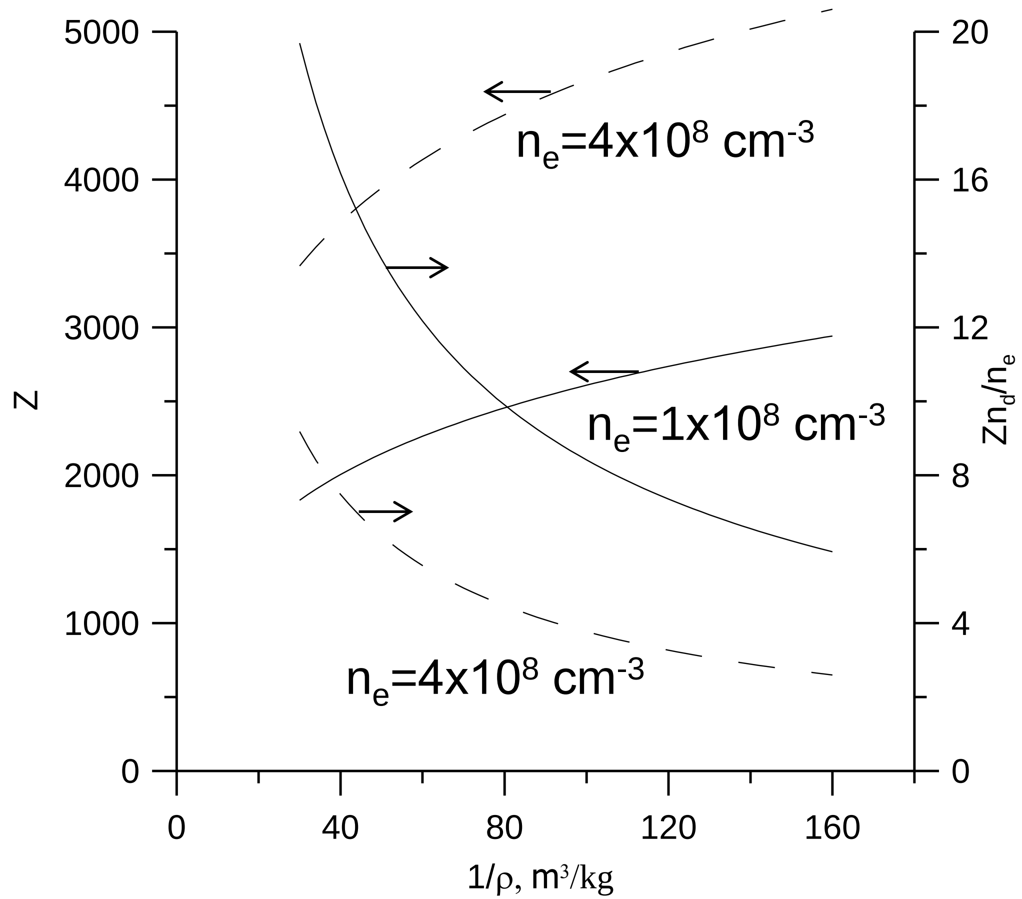
$$P = Q^2 \frac{\exp(-(d-a)/\lambda)}{d^3}\left(\frac{1}{d}+\frac{1}{\lambda}\right)$$

$$d = 2\left(\frac{3}{4\pi n_d}\right)^{1/3}$$

Charges of grains

$I_e = \pi n_e a^2 v_{te} \exp(\varphi/T_e)$

$I_i = \pi(n_e + Z n_d)\, a^2 v_{ti} (1 - e\varphi/T_i)(1 + \delta(\ell_i, a, \varphi))$



Two approaches to definition of effective screening length λ in dense cloud

Model I

Screening length is near to ion Debye length for average ion density

$$\lambda = \left(\frac{kT_i}{4\pi e^2 (n_d Z + n_e)} \right)^{1/2}$$

Model II

Screening length is near to ion Debye length for unperturbed ion density

$$\lambda = \left(\frac{kT_i}{4\pi e^2 n_e} \right)^{1/2}$$

Hugoniot for Dusty Plasma

$$P = \frac{p_c - \frac{\Gamma}{V}\int p_c \, dV}{1 + 0.5\Gamma\left(1 - V / V_0\right)}$$

Gruneisen factor

$$\Gamma = \frac{\partial \ln(\nu)}{\partial \ln(n_d)} \qquad \nu \propto Z\sqrt{\frac{\exp(-d/\lambda)}{m_d}\left(\frac{2}{d^3} + \frac{2}{d^2\lambda} + \frac{1}{d\lambda^2}\right)}$$

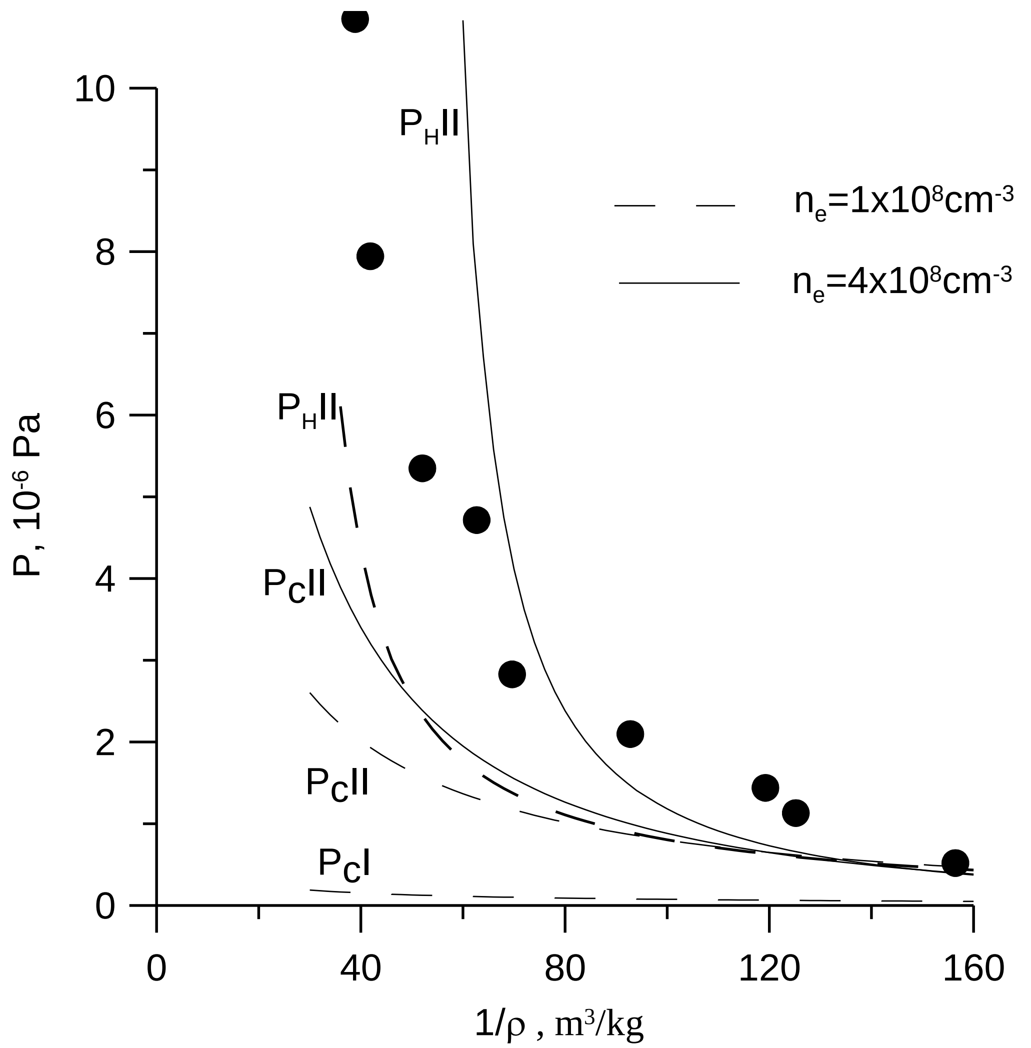
Model I

$$\Gamma = \frac{1}{2} + \frac{d^3}{12\lambda^3\left(2 + 2\frac{d}{\lambda} + \frac{d^2}{\lambda^2}\right)} \frac{\left(2 - \frac{Zn_d}{n_e}\right)}{\left(1 + \frac{Zn_d}{n_e}\right)} + \frac{n_d}{Z}\frac{\partial Z}{\partial n_d}$$

Model II

$$\Gamma = \frac{1}{2} + \frac{d^3}{12\lambda^3\left(2 + 2\frac{d}{\lambda} + \frac{d^2}{\lambda^2}\right)} + \frac{n_d}{Z}\frac{\partial Z}{\partial n_d}$$

Compressibility of Dusty plasma
Modeling calculations and experimental data



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Thank You for attention