How particles move in nonlinear acoustic waves?

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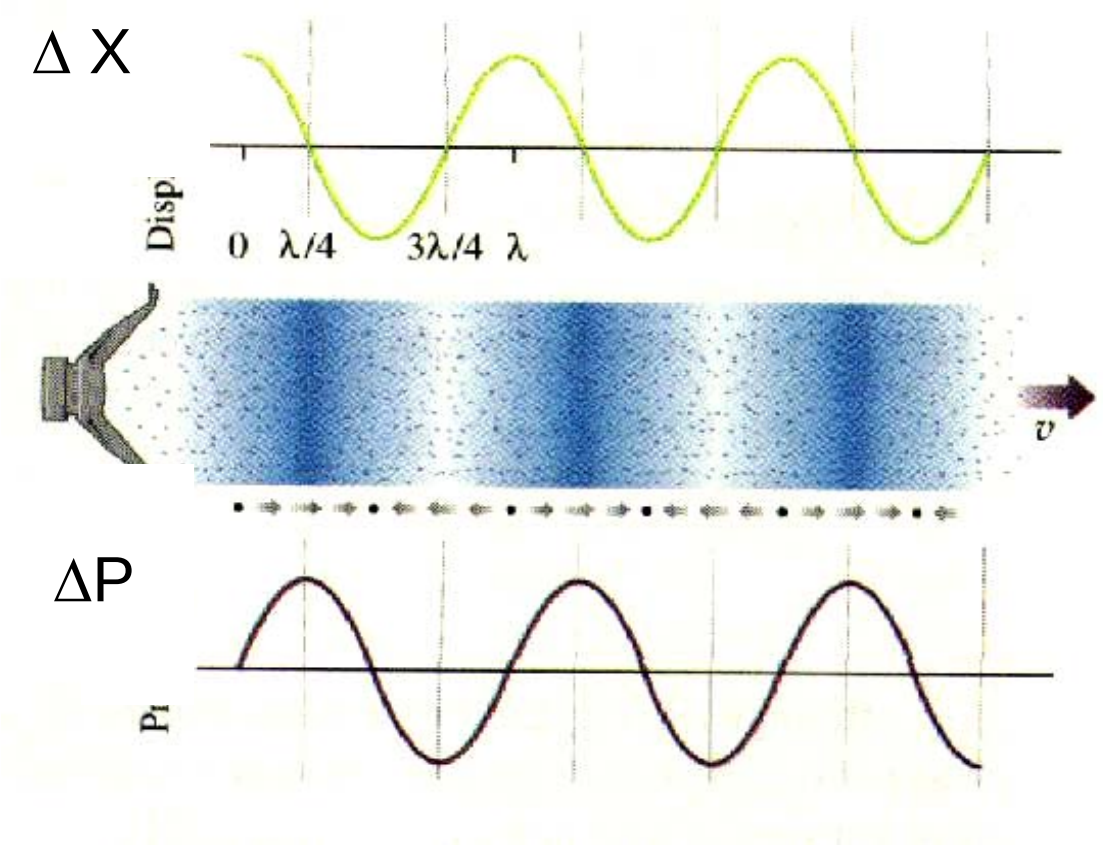
Acoustic wave in gas

A linear perturbation fluid picture



Lagrangian picture at the kinetic level ?

Longitudinal density waves:

- Acoustic waves in solid, liquid, and gas
- Electrostatic waves in plasmas
- Dust density wave in dusty gas
- Dust density wave in dusty plasma

Micro-motion of particles in longitudinal density waves?

Wave-particle micro-dynamics ?

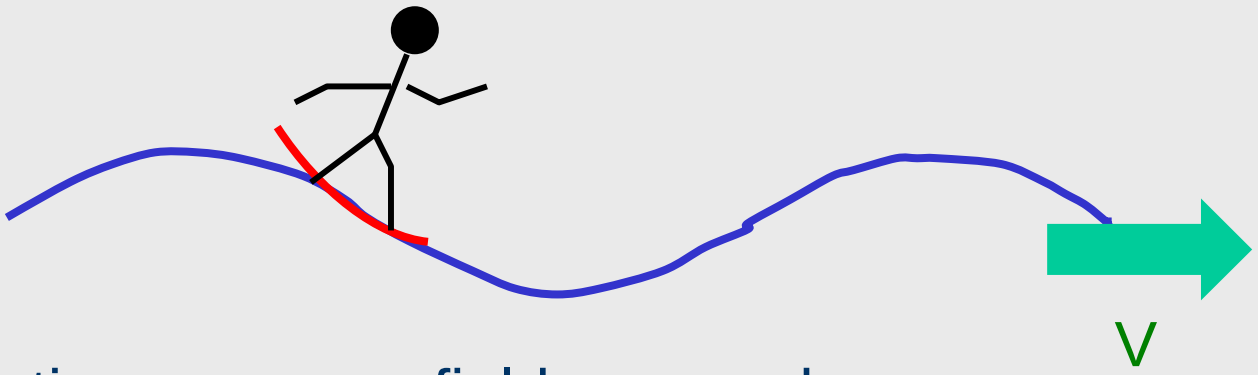
Coherent wave field
& particle-particle
interaction

Particle
motion

Particles interact with and constitute the wave

Nonlinear motion in electrostatic plasma waves

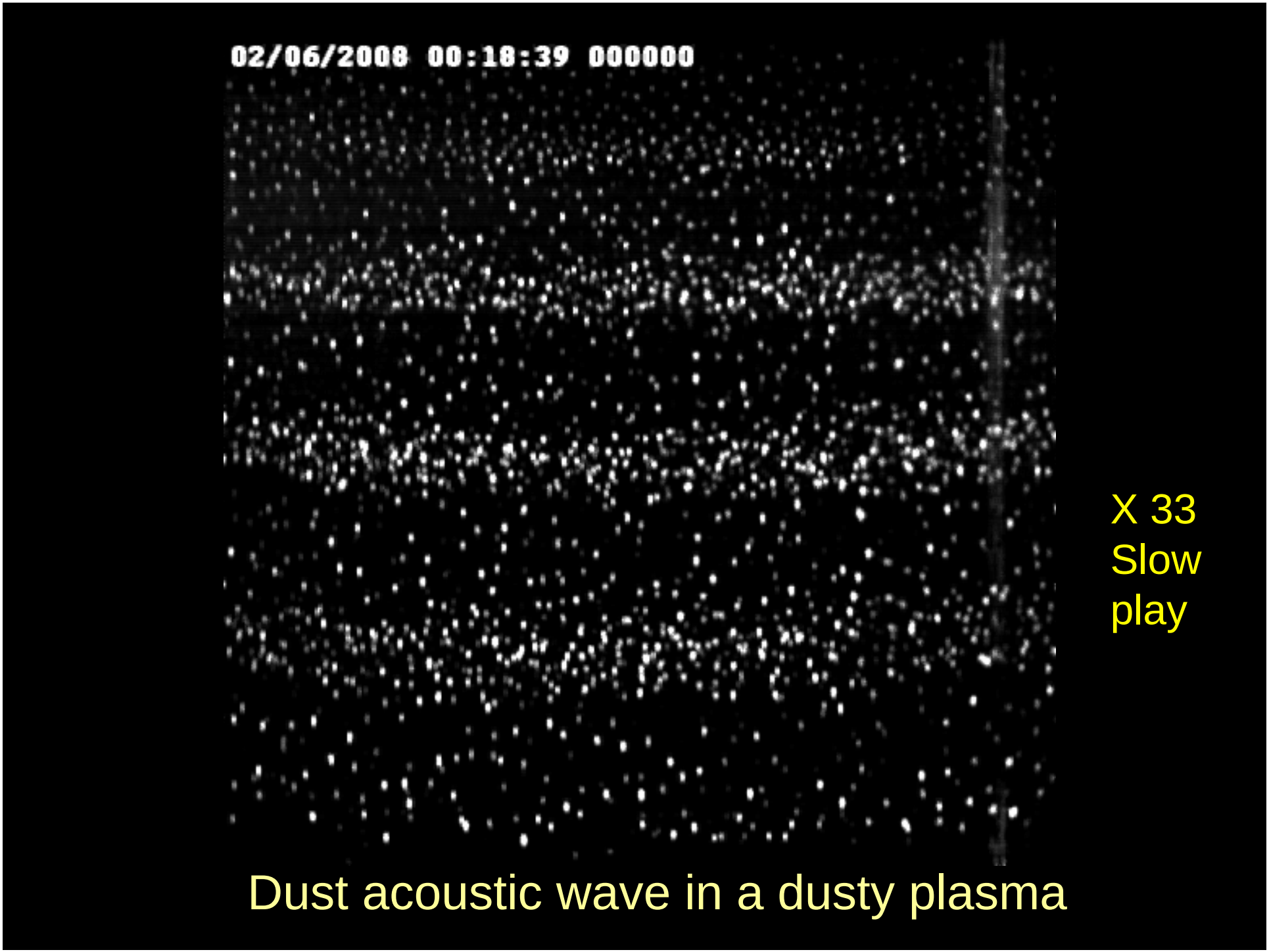
Trapping and surfing in a traveling wash-board field



A continuous mean field approach

Effect of spatio-temporal heterogeneity at the discrete level ?

How particles constitute and sustain the propagating wave ?



Dust acoustic wave in a dusty plasma

Wave-particle micro-dynamics in self excited dust acoustic waves

Our studies

Lagrangian picture through direct particle tracking using high speed CCD

- Nonlinear particle oscillation in waves
- Wave-particle interaction
- How particles sustaining the propagation of waves
- Anisotropic Non-Gaussian wave-particle heating

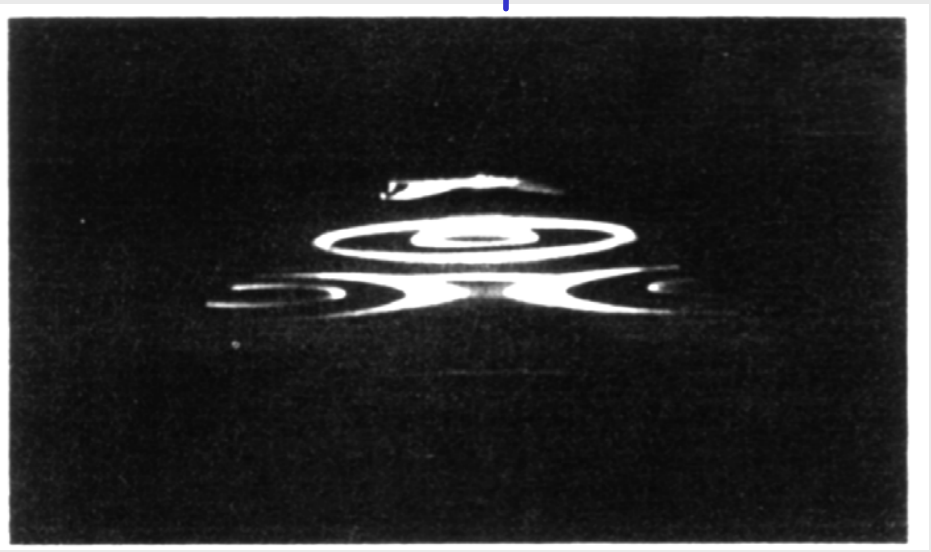
From regular to turbulent wave

Dusty plasma

Charged fine particles suspended in low pressure gaseous plasma

- Interstellar plasma
- Space plasma
- Laboratory discharge

Dust cloud in a plasma etcher

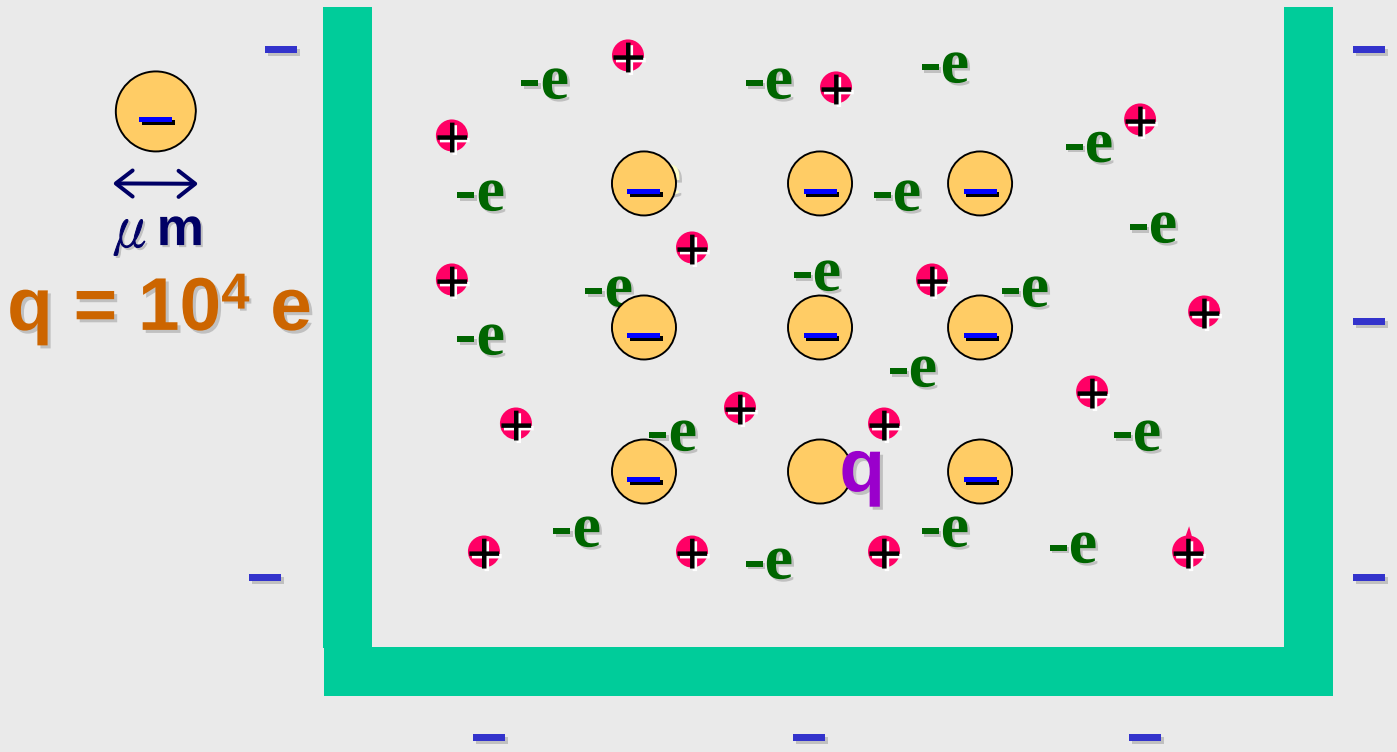


G.S. Selwyn, *et al.*, APL 57, 1876 (1990)

Spokes in Saturn rings

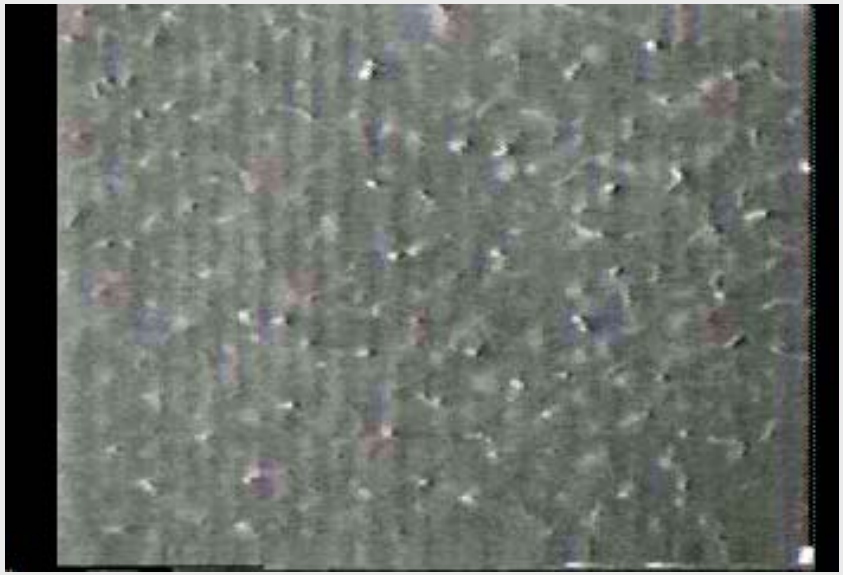
C.K. Goertz, Rev. Geophys. 27, 271 (1989)

Charging and suspension of dust particles in a laboratory discharge

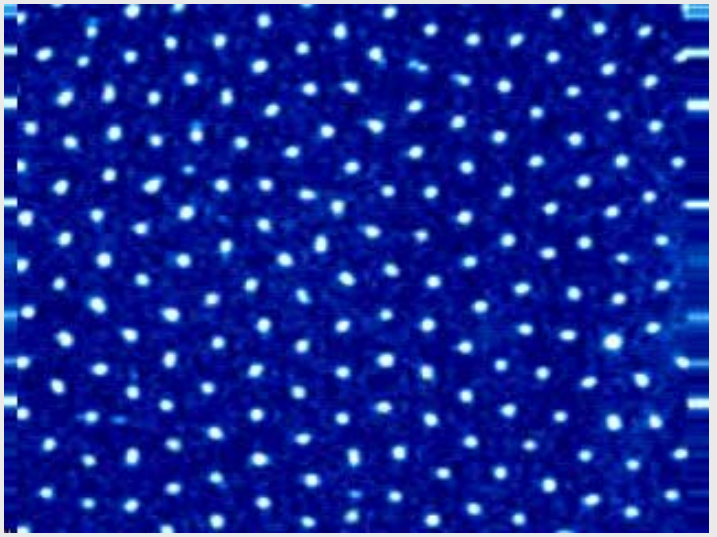


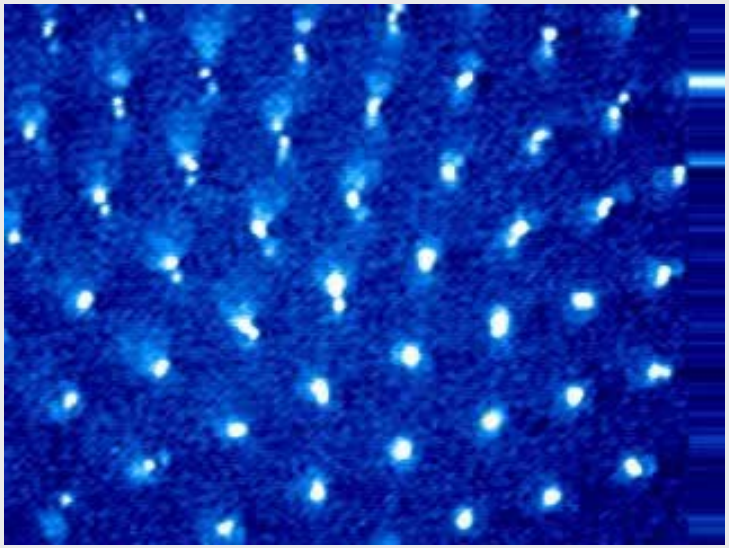
From the gas state to the crystal state

A bridge from plasma to condensed matter

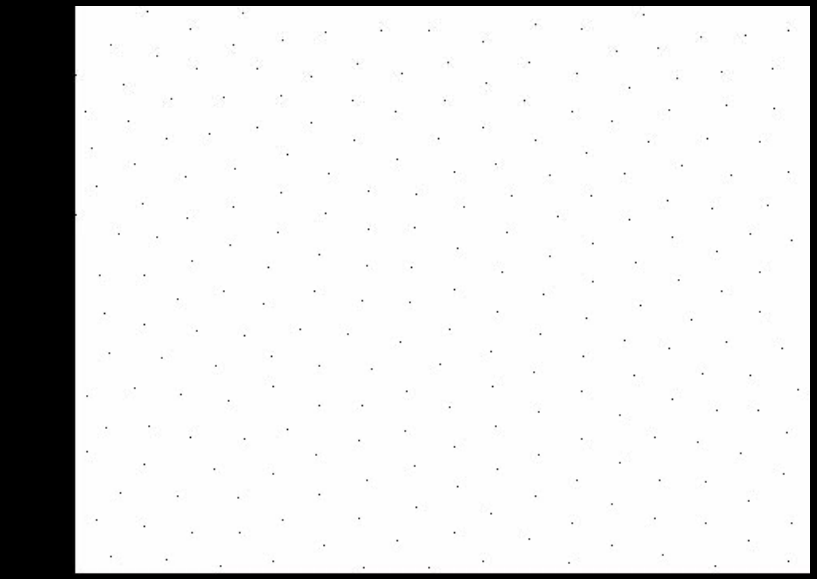


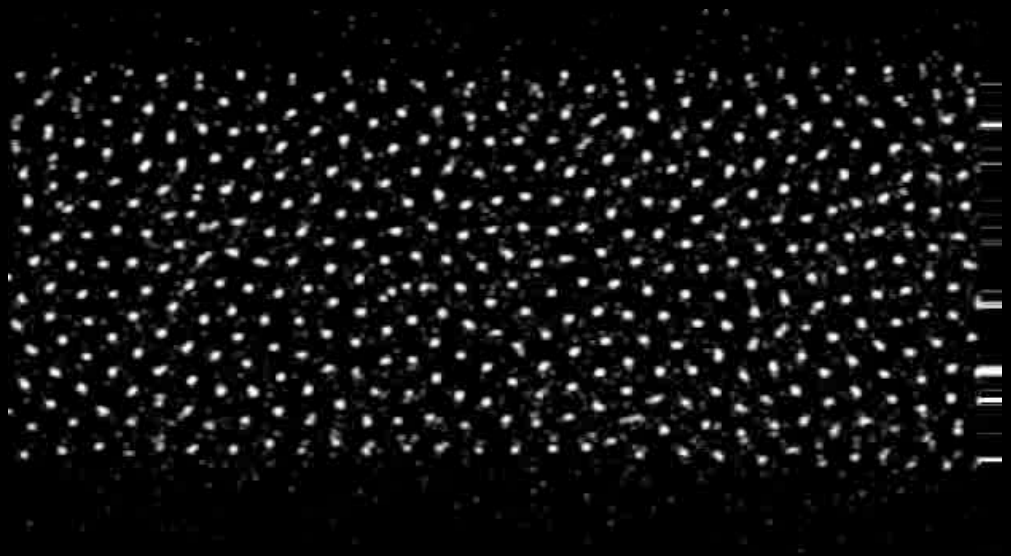
0.5 mm





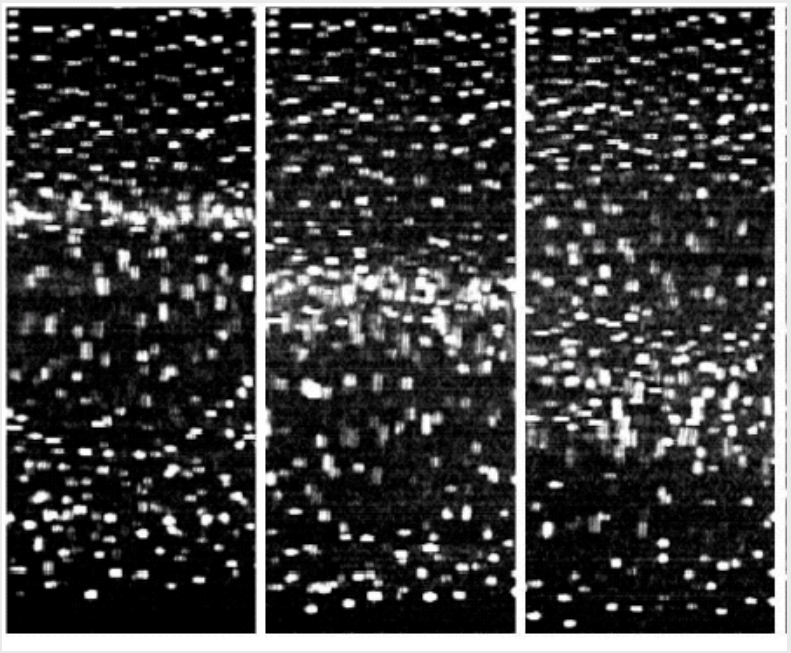
J.H.Chu and Lin I, PRL(1994)
Lin I et al, Science (1996)





- Micro-transport
- Defect dynamics
- Confinement induced layering and slow dynamics
- Visco-elastic response
- Shear induced heating
- Few body cluster
- Chain bundle liquids

Dust acoustic waves (DAW) in dusty plasmas



DAW

- Longitudinal wave with dust density and dust particle oscillations
- Interplay of inertia, Coulomb interaction, ion streaming, dust charging and unfrozen ionization

Previous studies

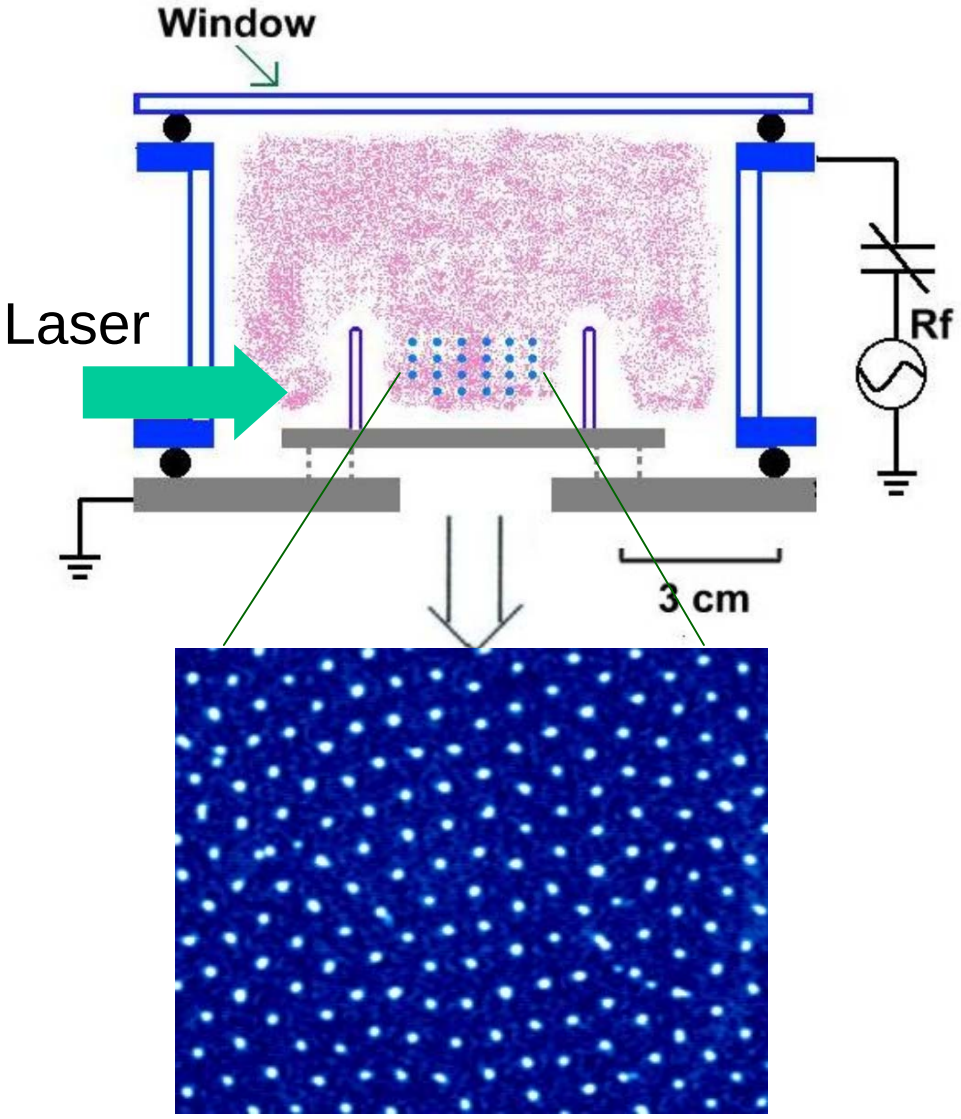
Dispersion relation and various mechanisms using continuous macroscopic approaches

Our system

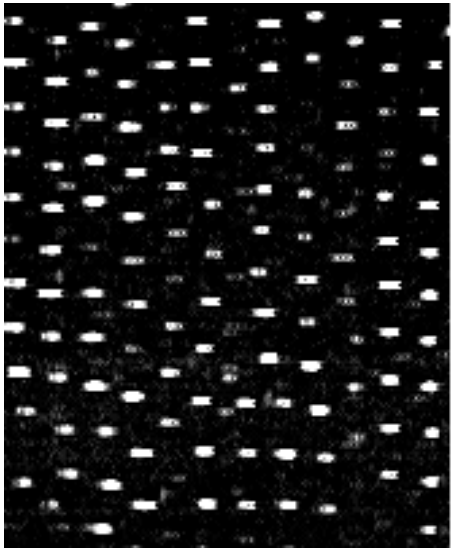
P ~ 200 mTorr Ar

particle diameter : 5 μm

Q/particle ~ 10^4 e

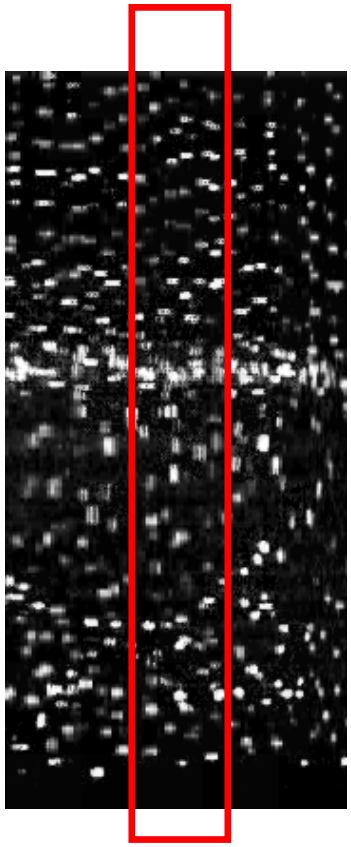


Top view



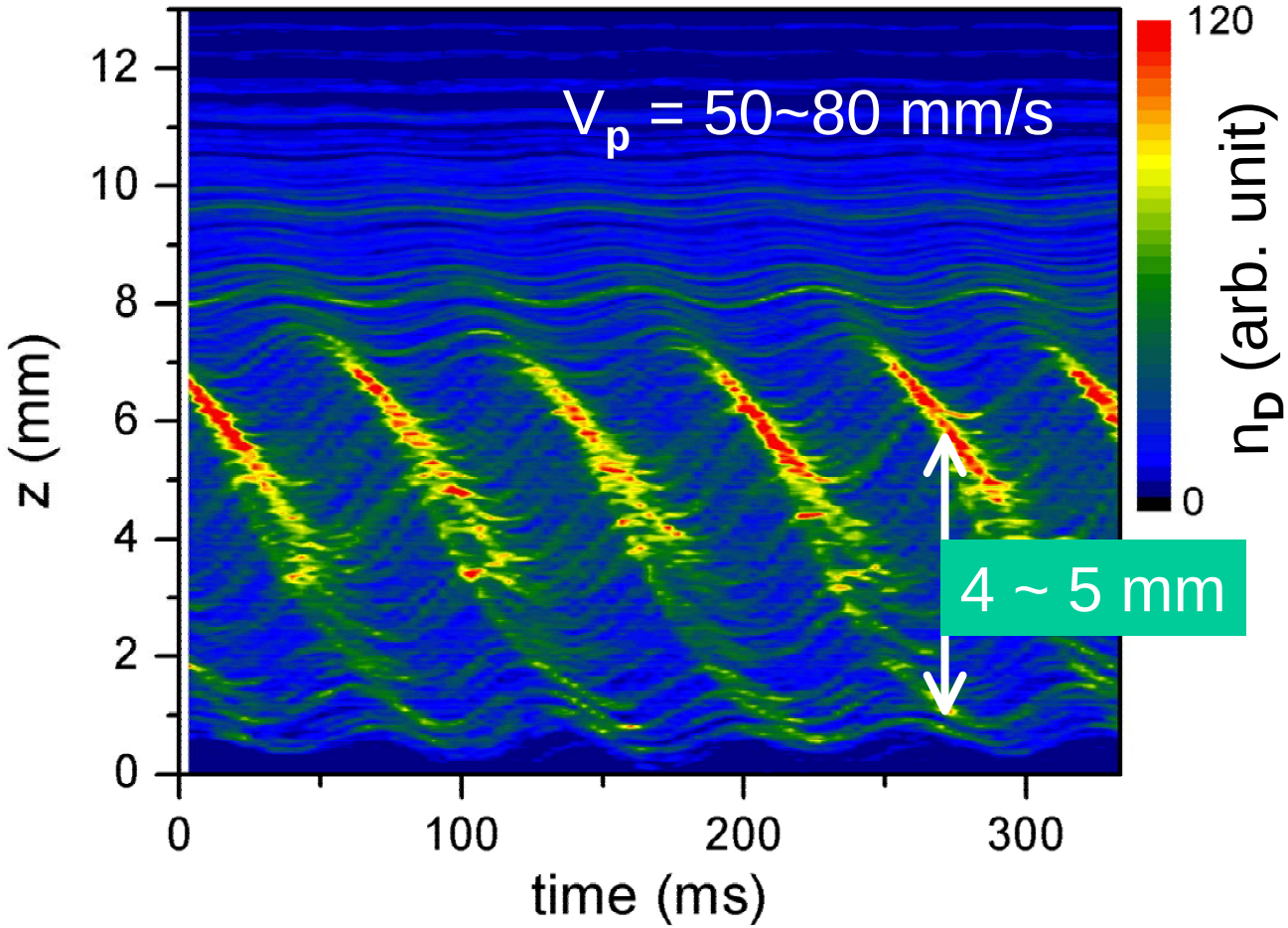
Side view

Turning on self-excited DAW by increasing rf power or decreasing pressure

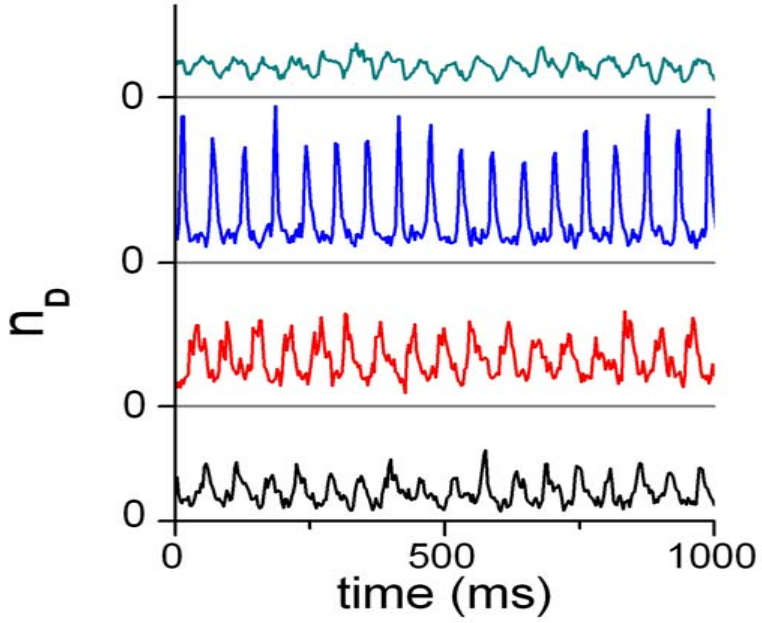


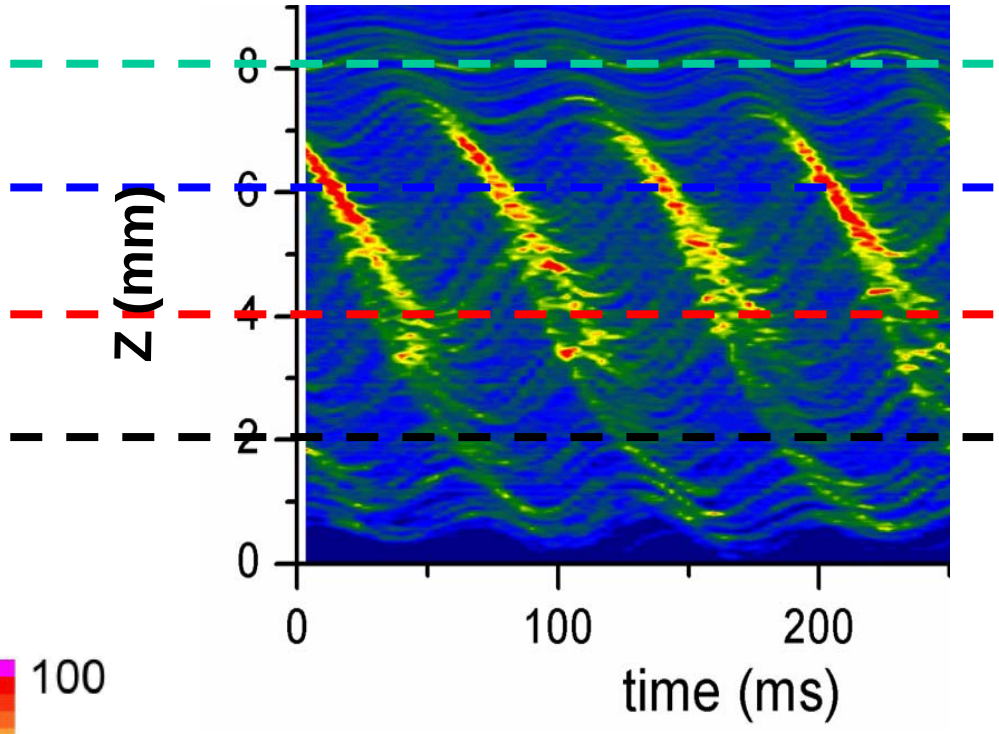
X 20 slow play

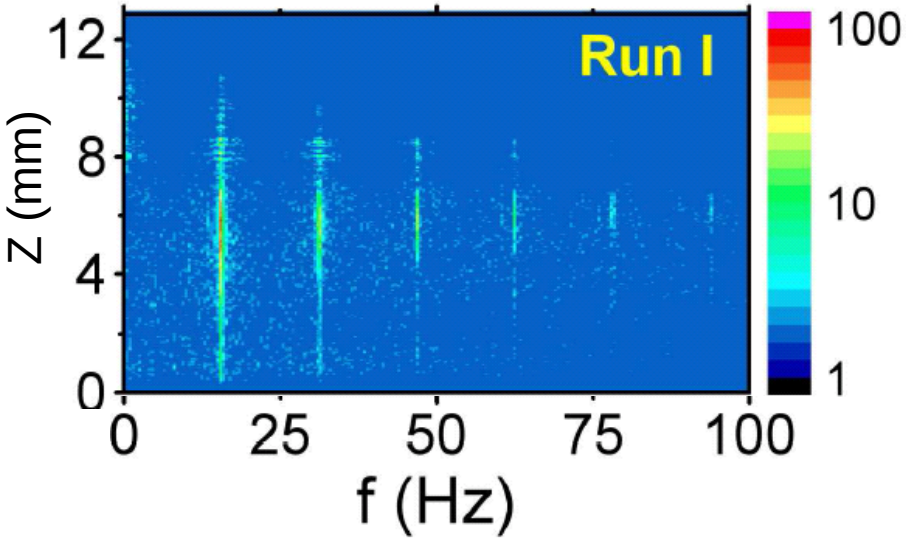
Contour plot of $n_D(z,t)$ - dust density evolution



Dust density evolution at different heights







f_0 = 16 Hz

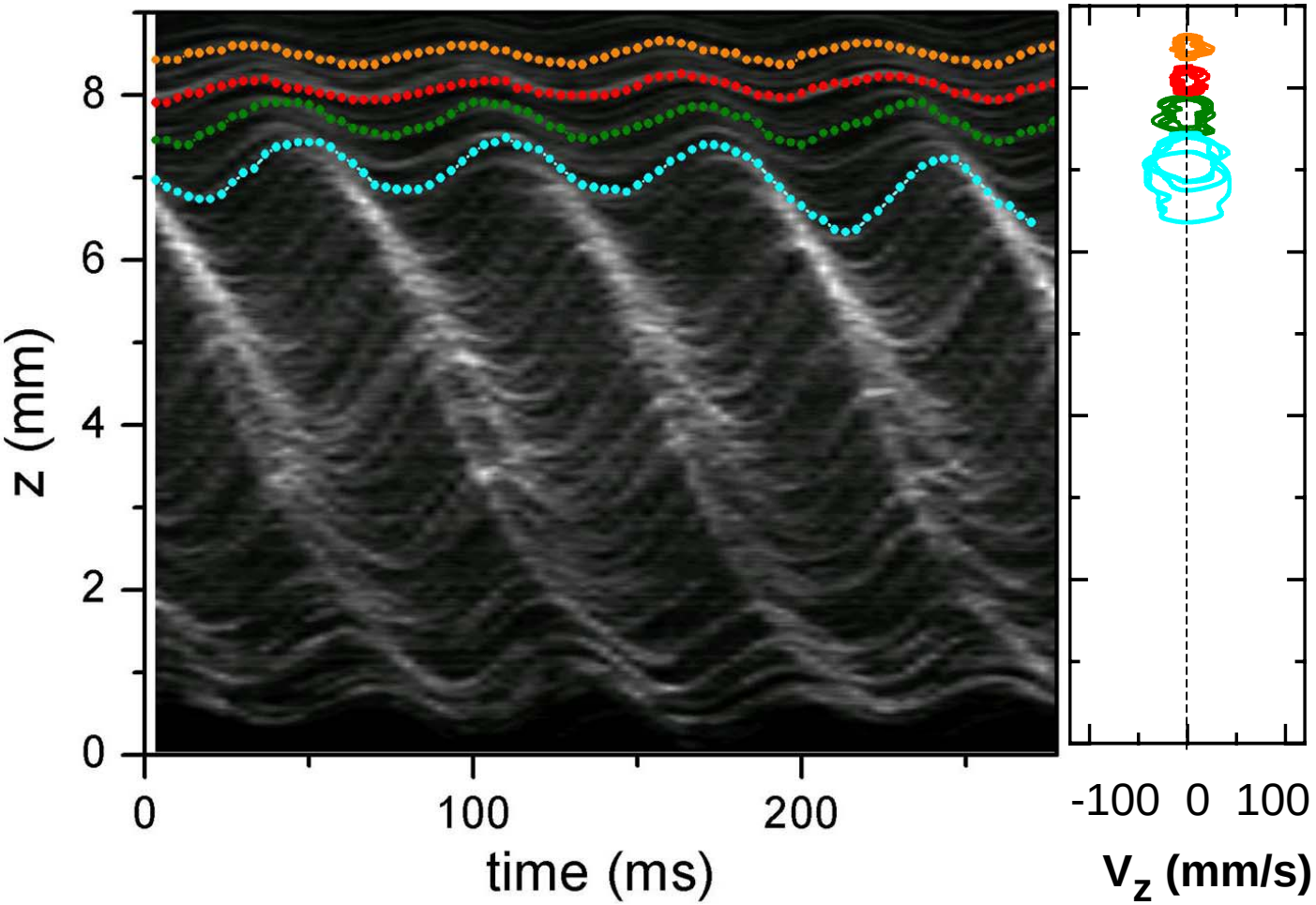
V_p = 50 - 80 mm/s

Particle motions in a DAW

- **Upper region**:

Small amplitude limit cycle oscillation

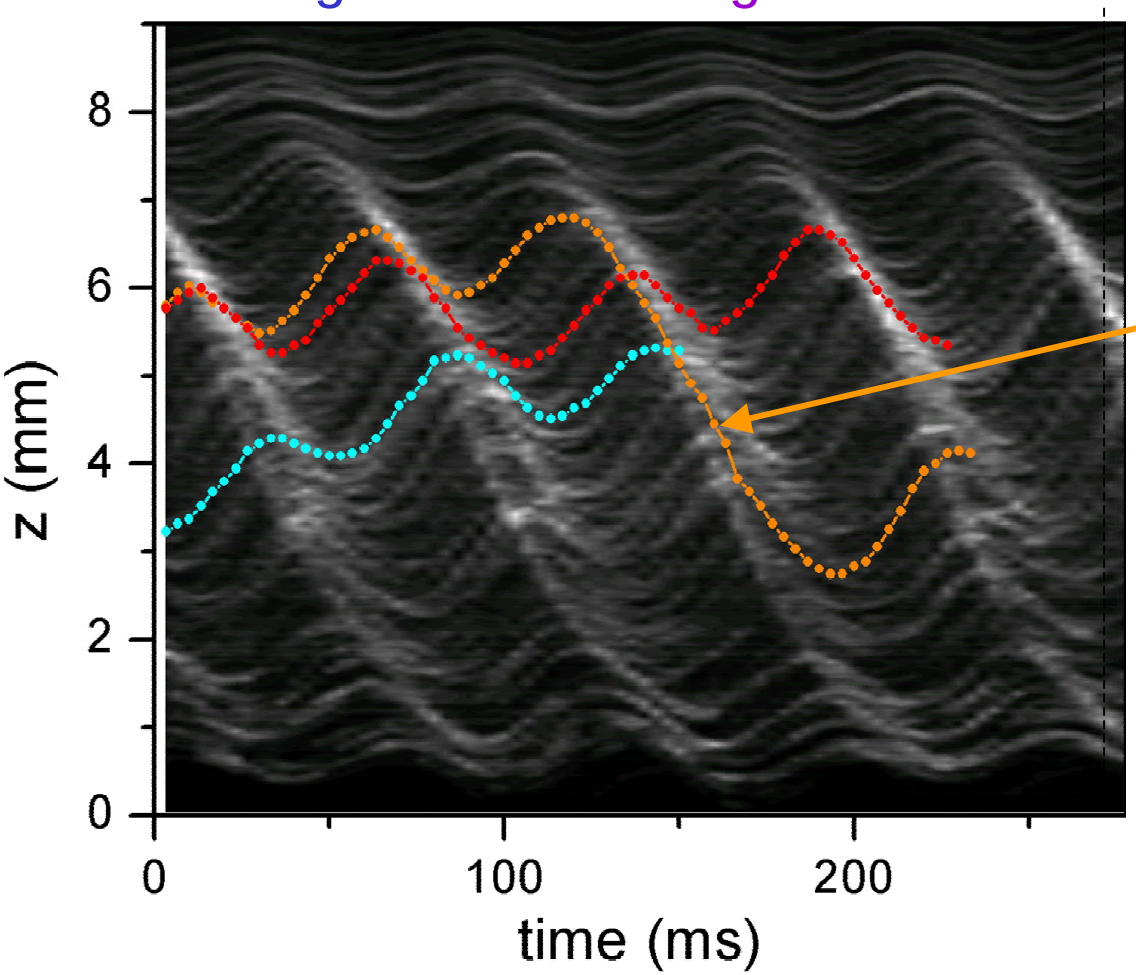
Keeping dusts in the liquid state



Particle motions in a DAW

- **Middle region:**

Large amplitude chaotic oscillation
Turning dusts into the gas state

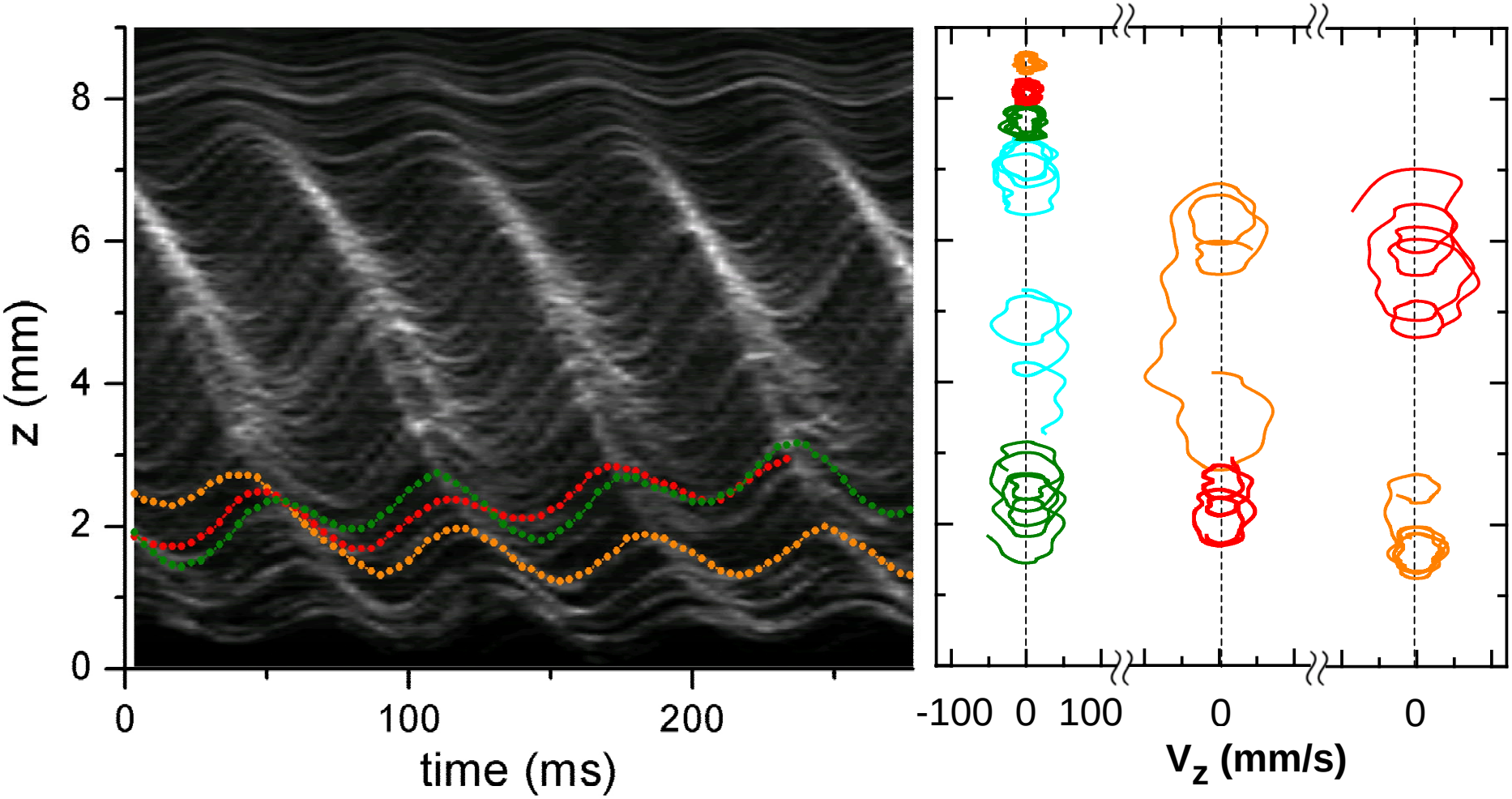


Escalating oscillation followed by long distance downward crest accelation

Particle motions in a DAW

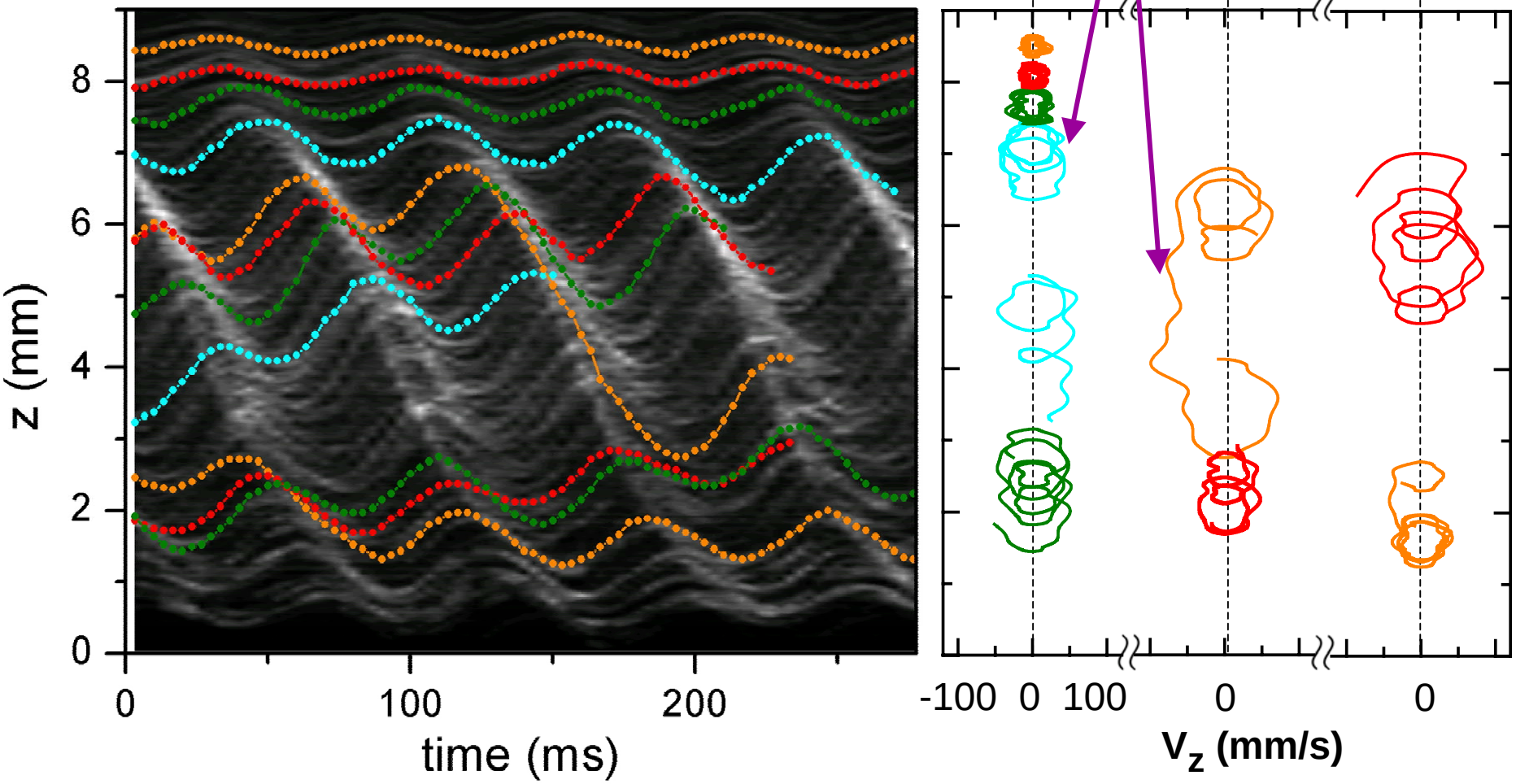
- **Lower region:**

Middle amplitude chaotic oscillation



Particle motions in a DAW

Wiggling induced by local dust interaction



Why chaotic oscillation?

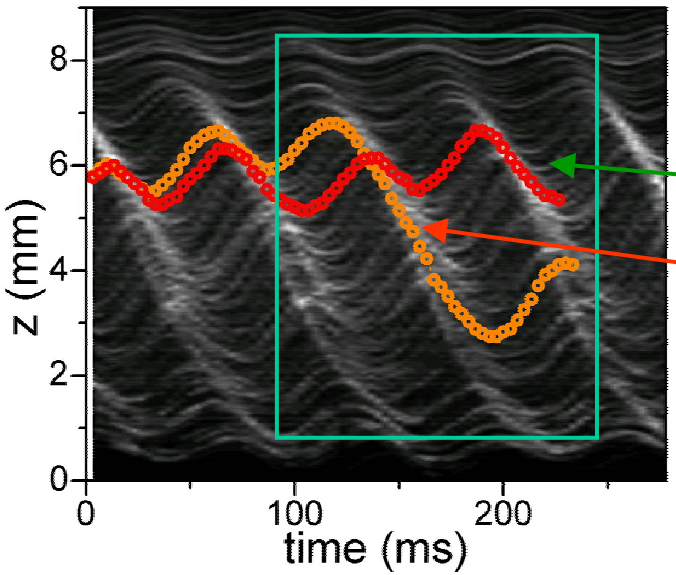
Why long distance downward acceleration?

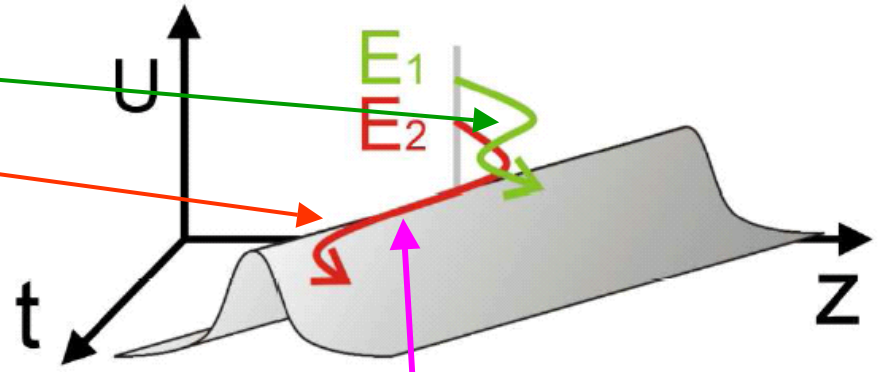
Wave resonance acceleration?

Trough trapping?

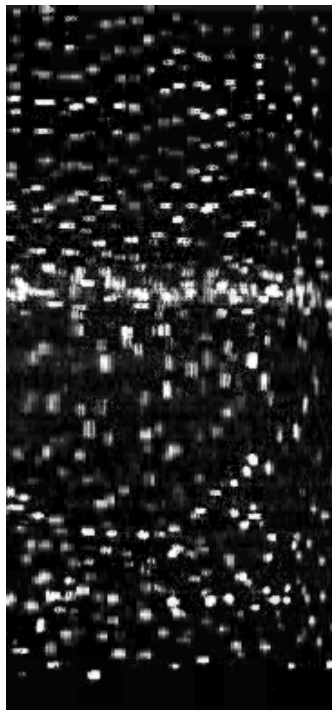
How particles constituting and sustaining the propagating wave?

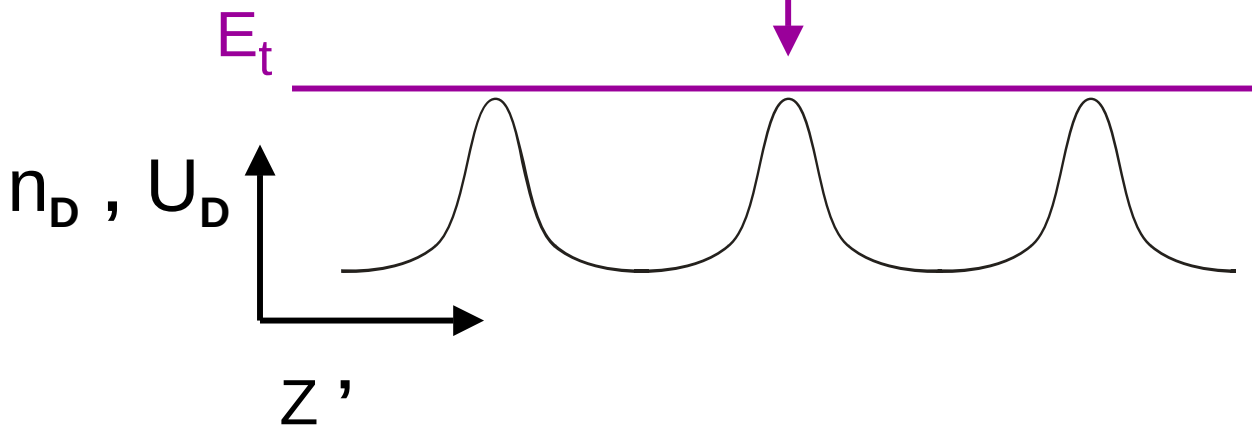
Why waveform steepening?



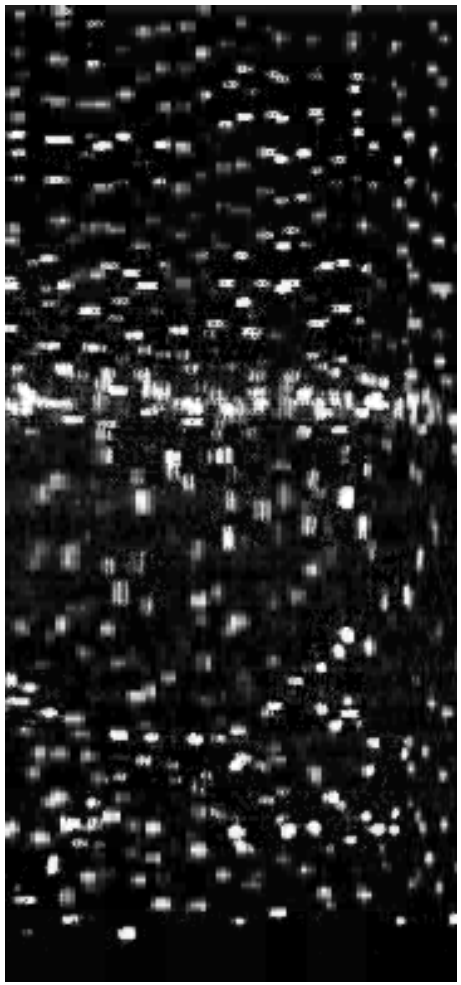


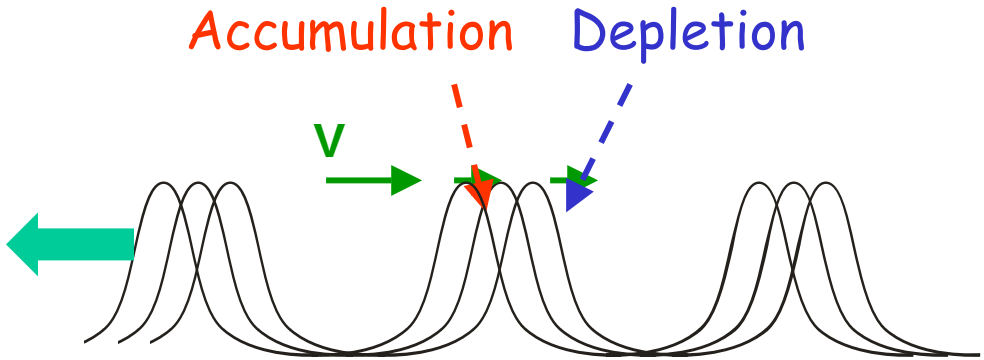
Crest trapping: moving with the crest





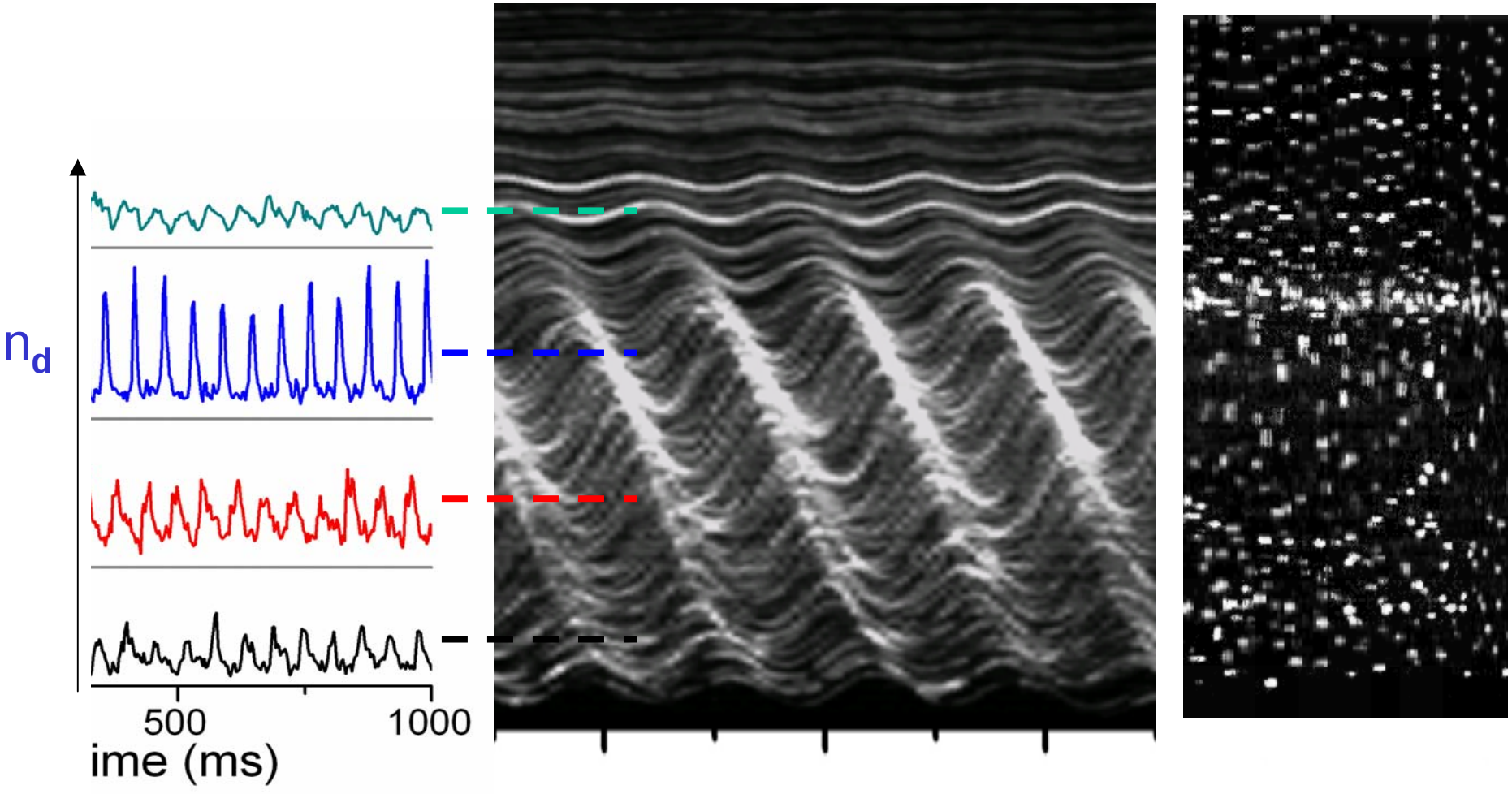
How does the wave propagate ?



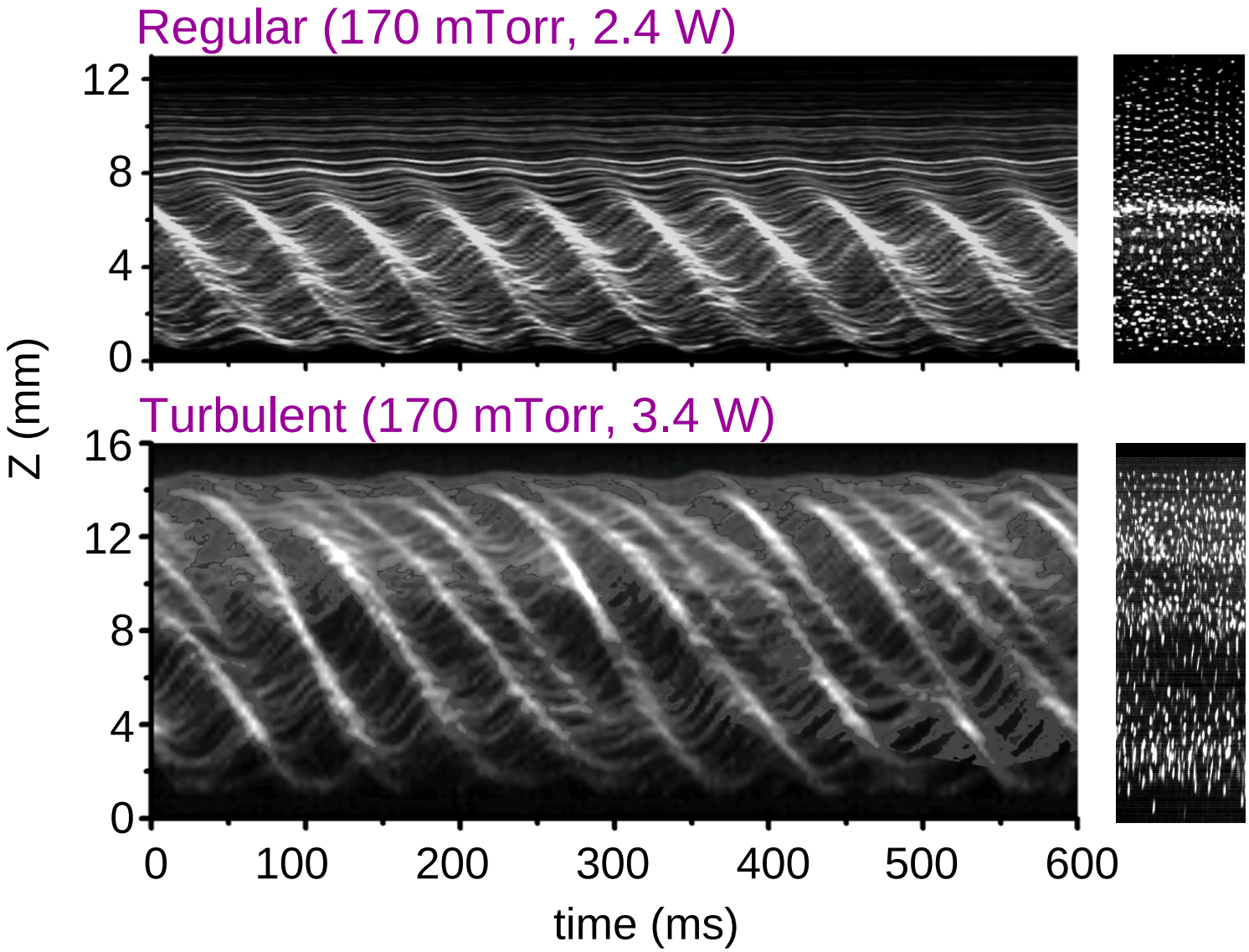


Trough trapping has not been observed !

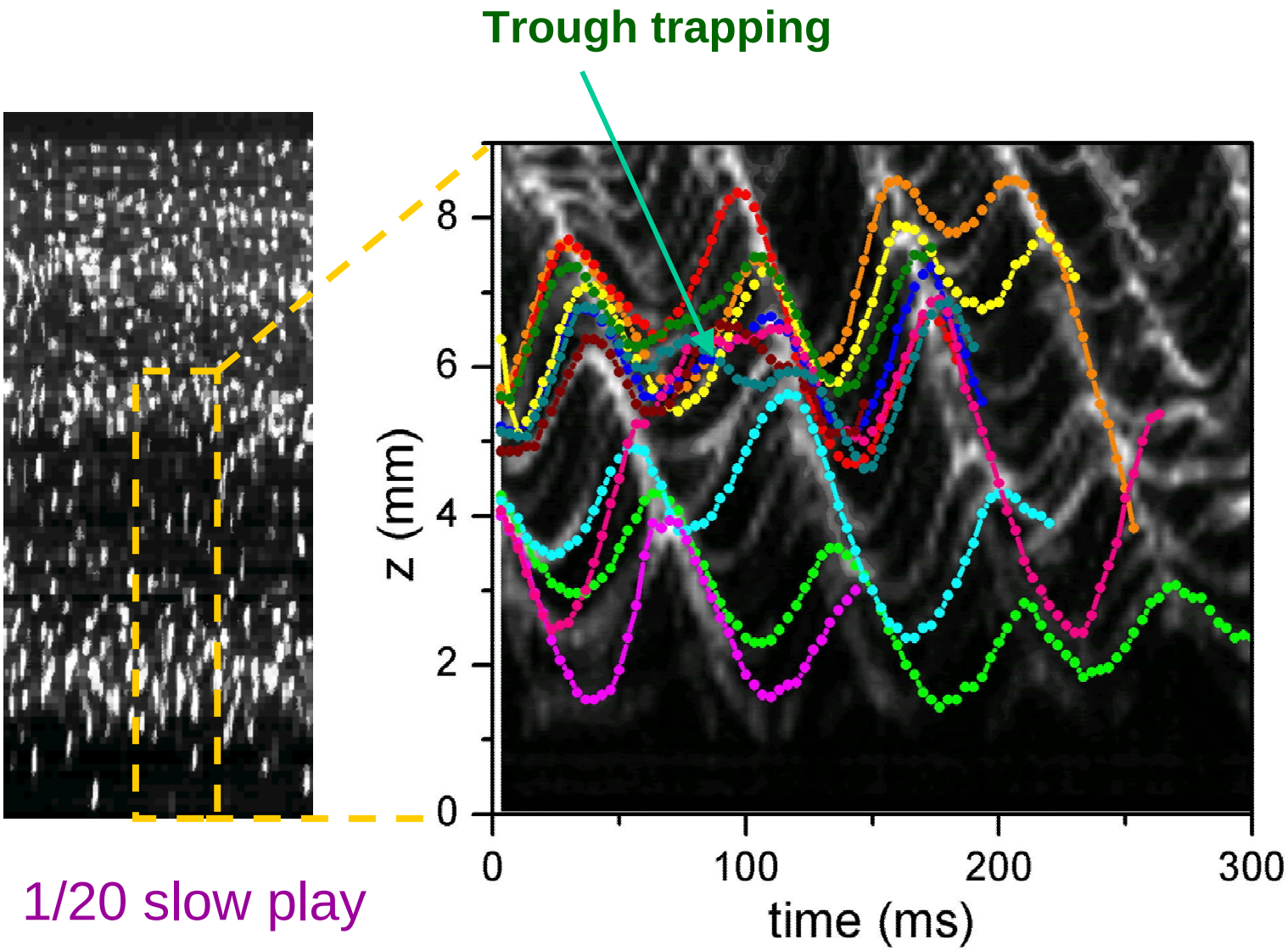
Waveform steepening



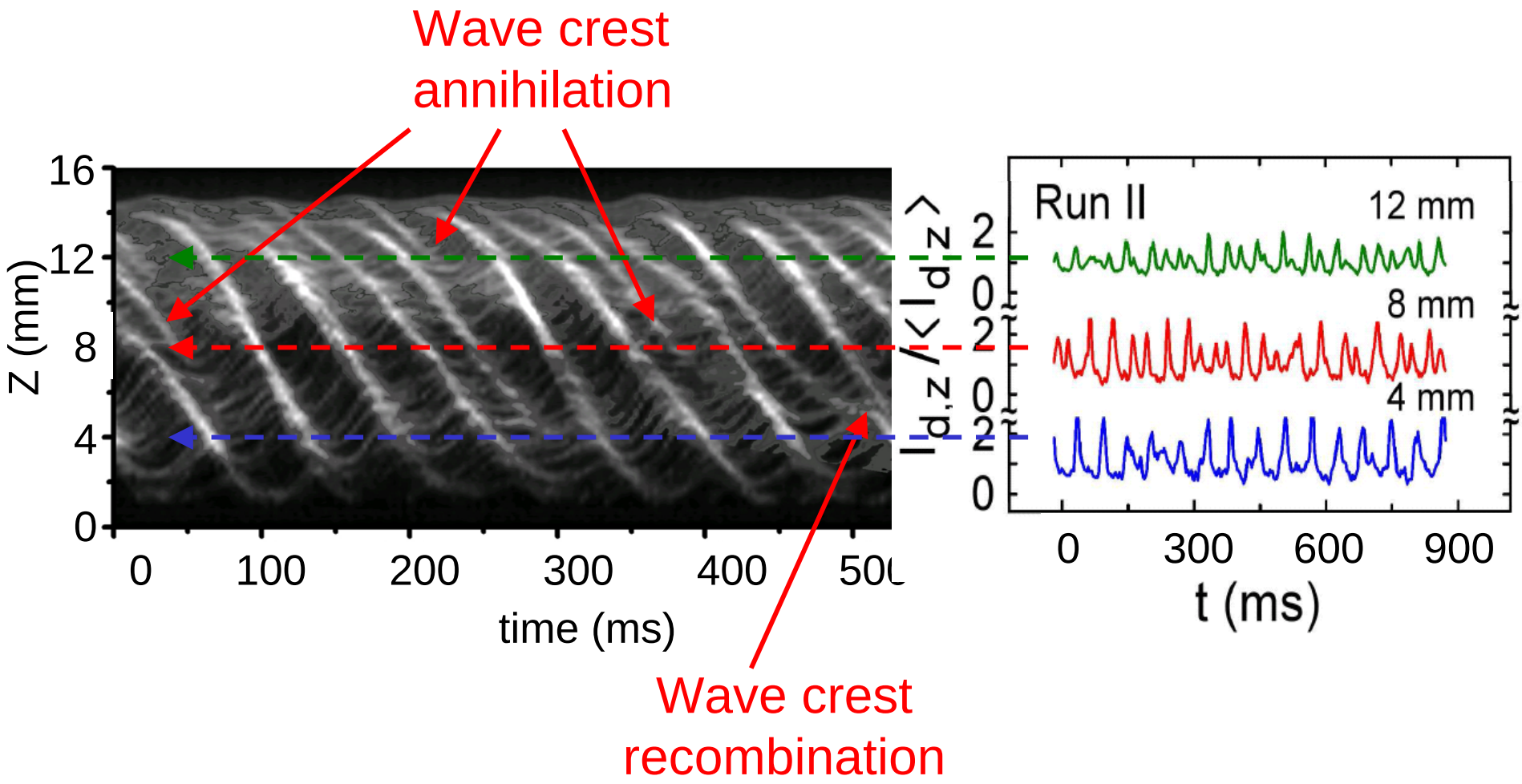
From regular to turbulent DAW



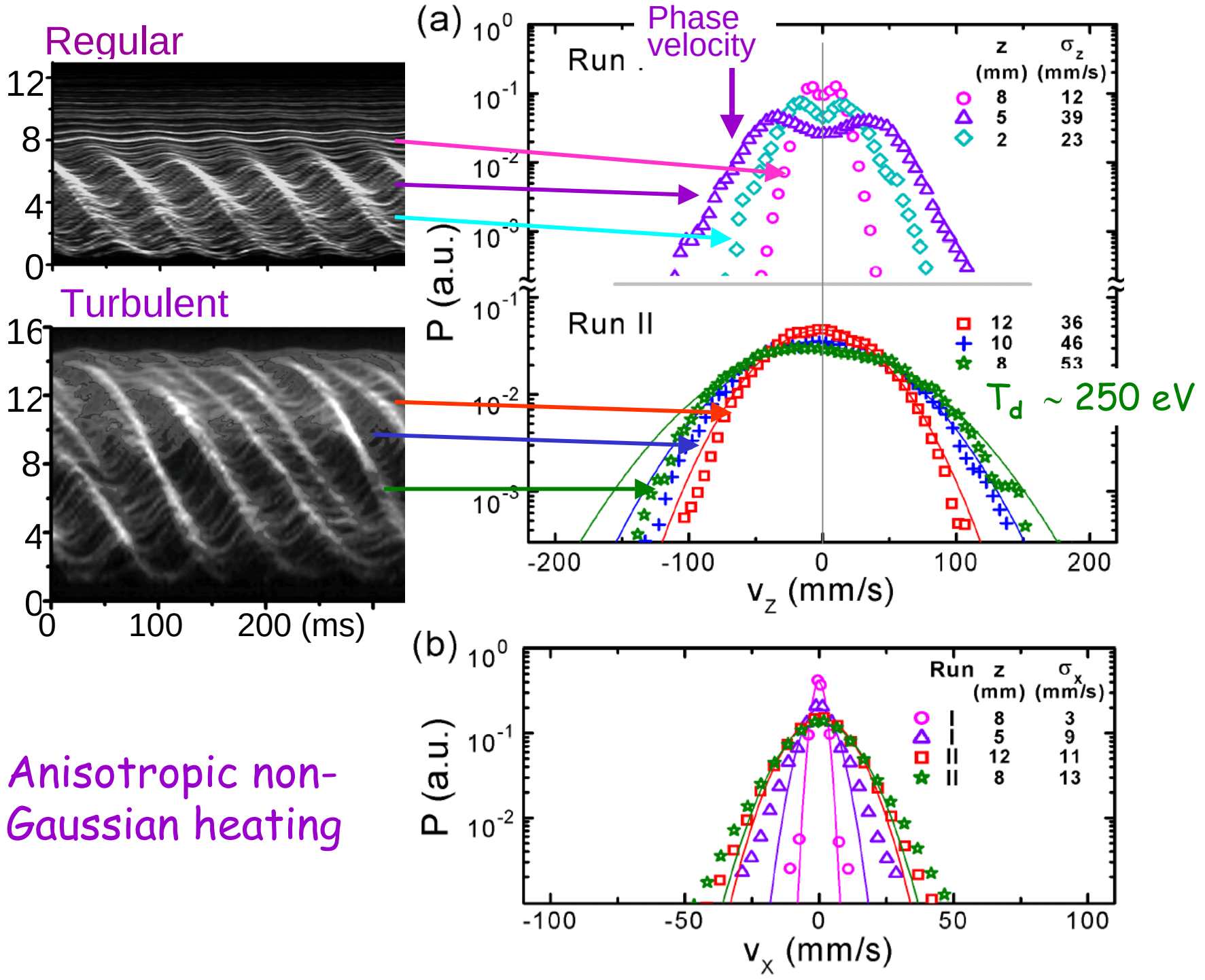
More chaotic trajectories in turbulent DAW



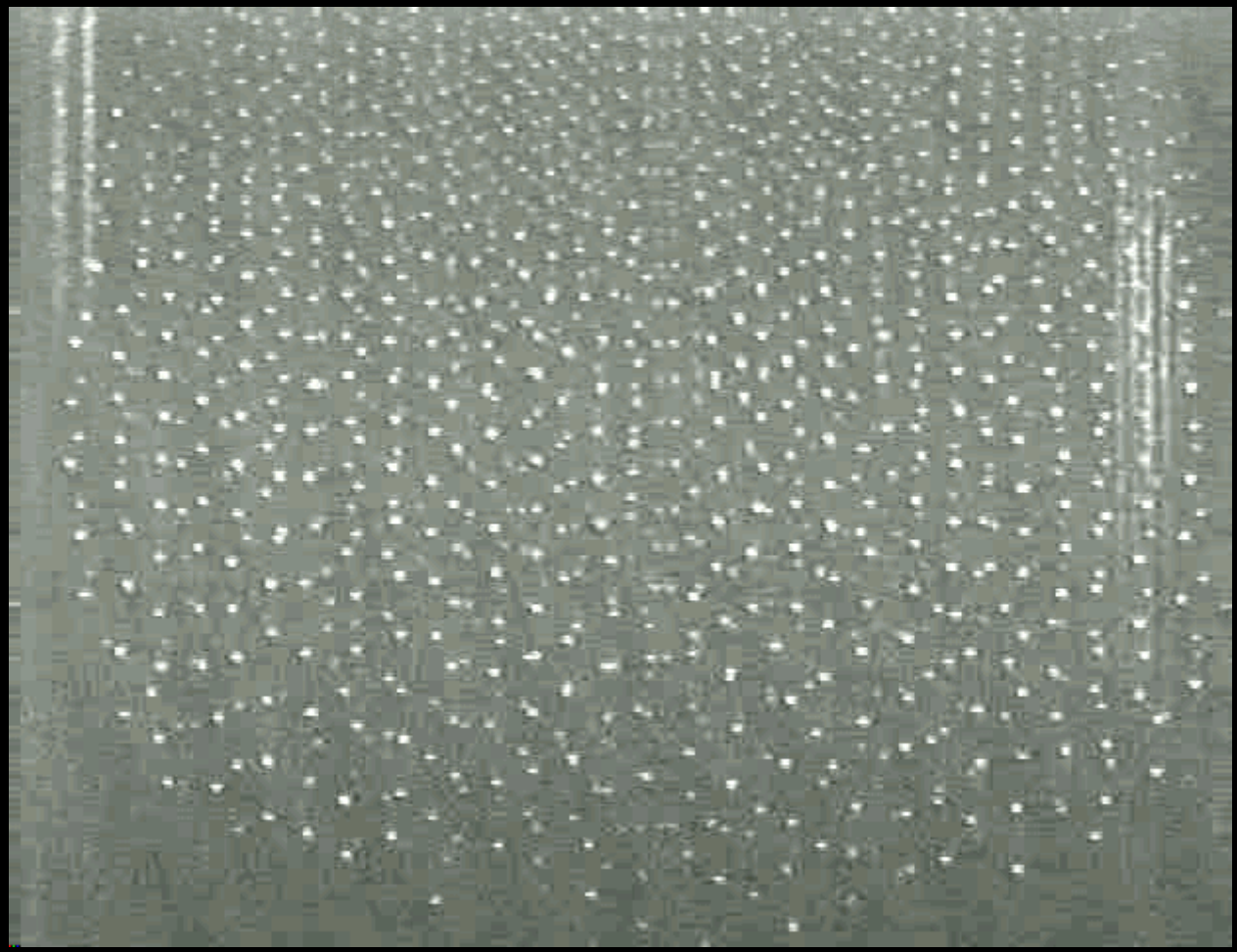
Crest annihilation and recombination in turbulent DAW



DAW induced non-Gaussian heating

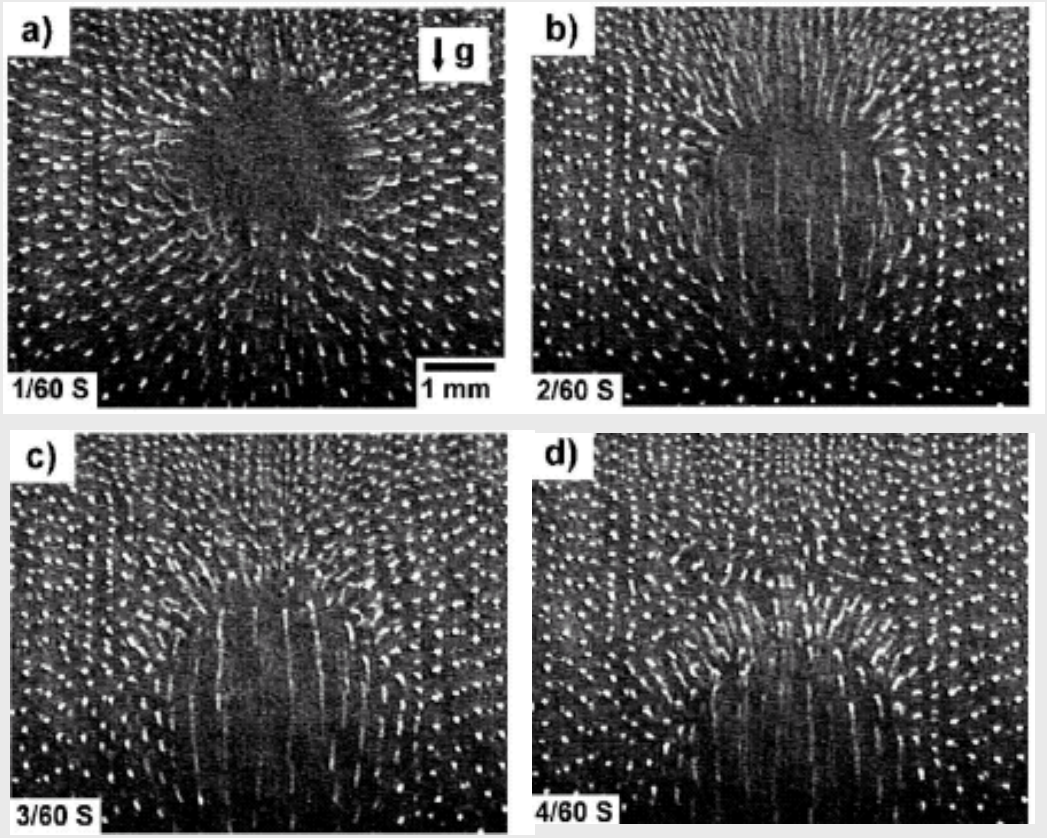

Regular
Turbulent
0
4
8
12
16
0
100
200 (ms)
(a)
Run .
Phase velocity
z (mm)
σz (mm/s)
8 12
5 39
2 23
Run II
12 36
10 46
8 53
Td ~ 250 eV
P (a.u.)
vz (mm/s)
(b)
Run z (mm) σx (mm/s)
I 8 3
I 5 9
II 12 11
II 8 13
vx (mm/s)
Anisotropic non-Gaussian heating

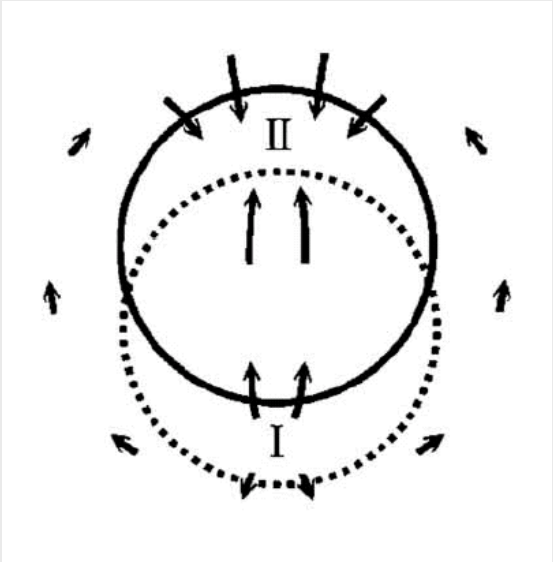
Pulsed laser induced dusty plasma bubble and solitary wake field



Supersonic bubble in dusty plasmas

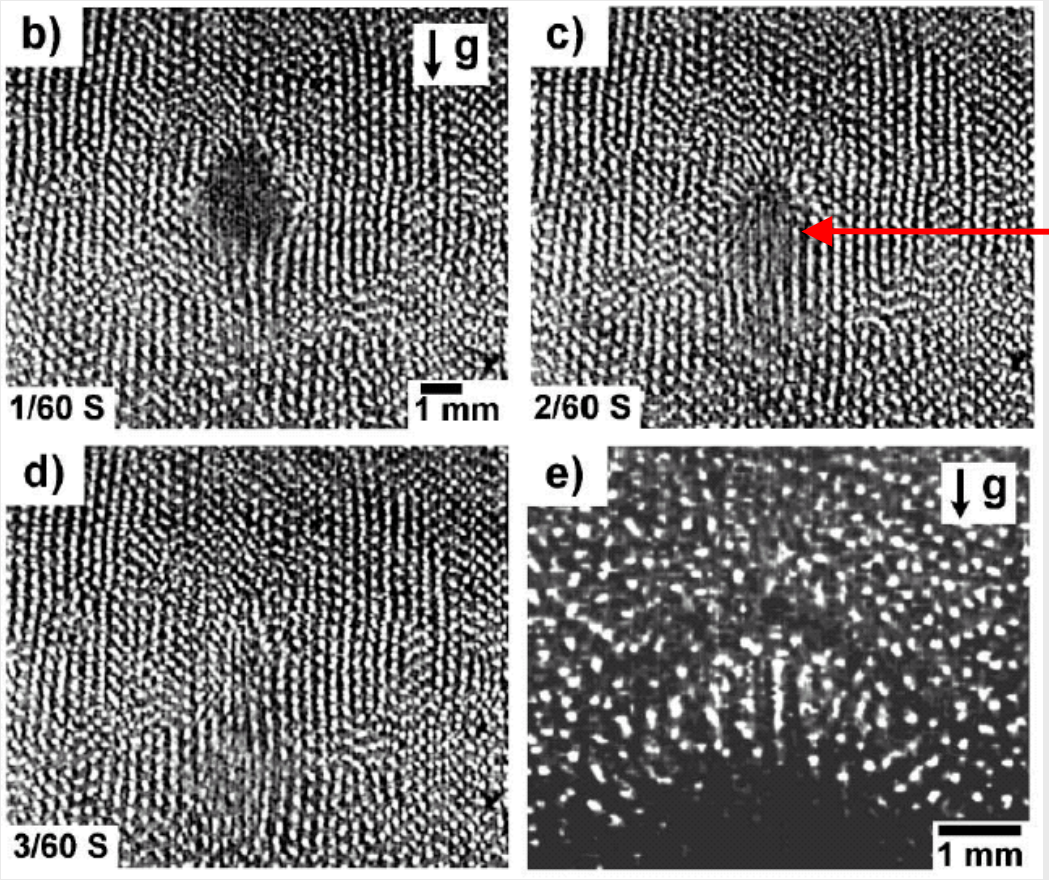
Strong localized density perturbation



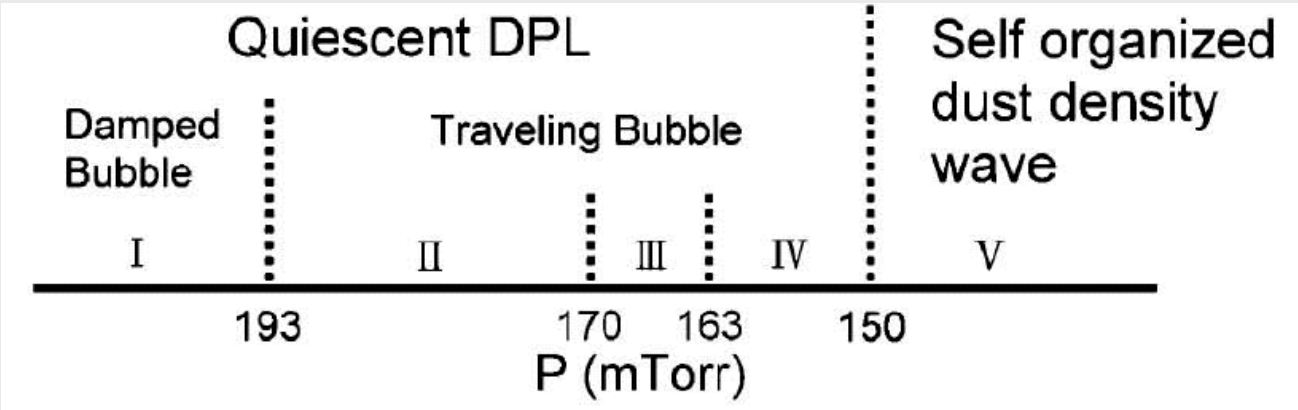


60 Hz sampling rate

Hong Yu Chu and Lin I
PRL 90, 075004 (2003)



Collapsing bubble at high pressure



Summary

- Micro-motion in self-excited DAW and laser induced bubbles
- Melting from the liquid to the gas state with cyclic to chaotic particle oscillation as wave amplitude increases
- Wave crest trapping inducing chaotic motion
- Further trough trapping for the turbulent wave
- Anisotropic non-Gaussian heating by waves
- Supersonic bubble with dust depletion

Thank You