Three-dimensional energy transfer of single particles in dust-density waves

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Abstract

Dust-density waves occur in a wide parameter regime and have been subject to research for many years. However, experimental access to the three-dimensional single particle motion was only gained recently. There, the particles that constitute the “dust-density wave” or “dust-acoustic wave” can be tracked in 3D on the kinetic level of individual particles.
In this contribution we present measurements and simulations of the energy transfer between the different motion components of single particles participating in dust-density waves. Additionally, molecular-dynamics (MD) simulations describing particles in dust-density waves in a given force field have been performed. The energy transfer behavior in the experiment is compared to that from the simulations
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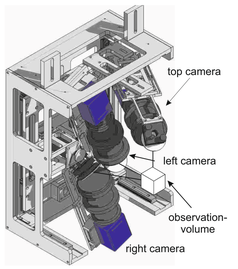
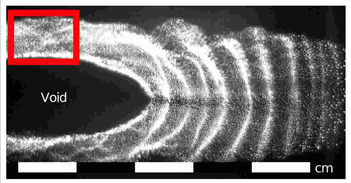
Microgravity stereoscopy setup[1]



Non-orthogonal camera setup, moveable by stepper motors

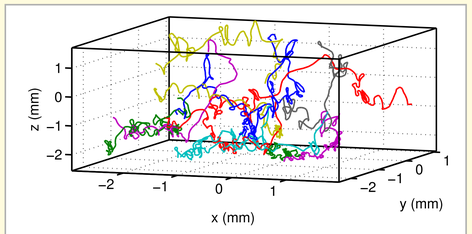


Vertical cut featuring the dust-density waves. The field-of-view is highlighted by the red square.

- 3x Prosilica GE680 cameras @ 640x360 @ 260 Hz
- moveable camera rig allows adjustment of FoV
- calibration by imaging of a defined target-grid
- triangulation from two or three cameras reconstructs particle positions

Microgravity measurements[2,3]

- Singl particle tracking is done by using fluorescent tracer particles
- even particles participating in DDWs can be individually tracked
- approx. 2000 trajectories are reconstructed in each measurement (~10s)



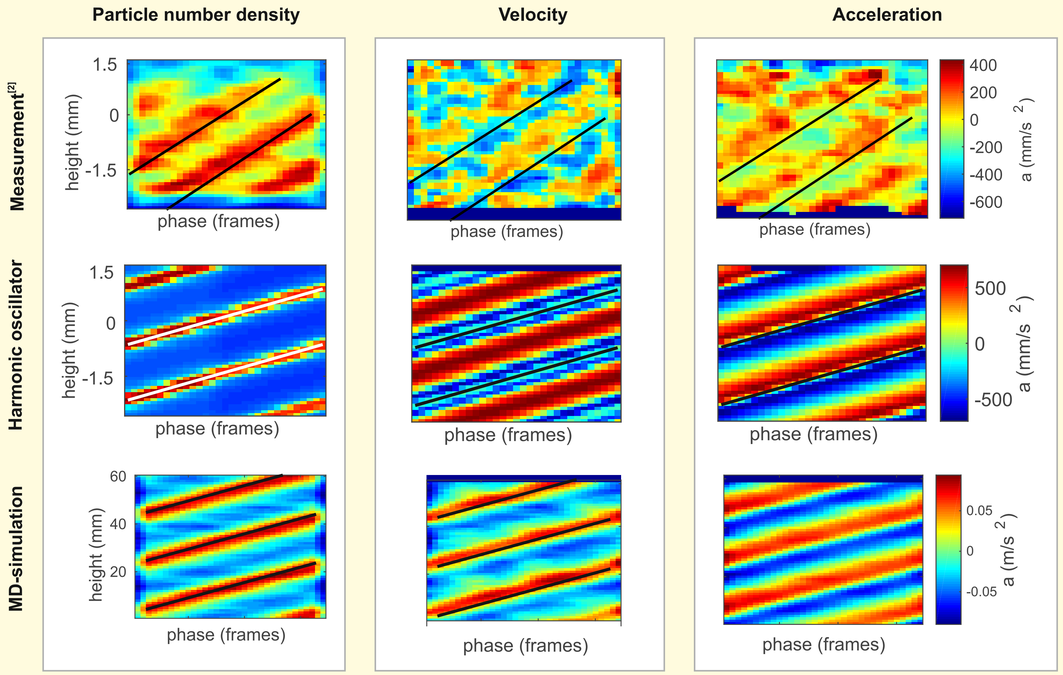
Reconstructed three-dimensional particle trajectories. The full phase space information allows detailed investigations regarding the particle motion.

References

[1] M. Himpel, C. Killer, B. Buttenschön, A. Melzer; Phys. Plasmas **19**, 123704 (2012)
[2] M. Himpel, B. Buttenschön, A. Melzer; Rev. Sci. Instrum. **82**, 053706 (2011)
[3].M. Himpel et al., Phys. Plasmas **21**, 033703 (2014)
[4] J. Williams and E. Thomas, Phys. Plasmas **14**, 063702 (2007)

Simulated DDWs vs. measured DDWs

Wave appearance

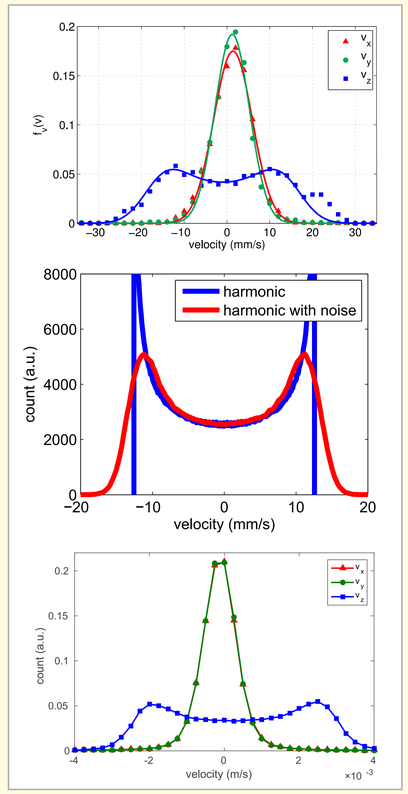


- harmonic oscillator model results in too narrow peaks
- MD-simulation gives appropriate peak broadening due to the particle-particle repulsion

- harmonic oscillator peak is situated in the wave trough
- MD-velocity peak is closer to the wave crest, which better represents the measurement data

- harmonic oscillator features a drop of a_z located at the wavecrest position
- MD-simulation features a smoother drop of the particle acceleration

Velocity distribution functions



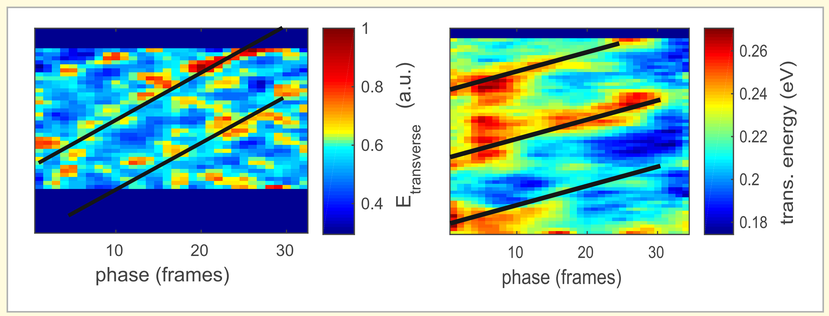
Measured data:
- bimodal z-distribution
- shoulder hints to trapped particles

Harmonic oscillator:
- two-peak distribution (without noise)
- bimodal distribution with Gaussian noise added

MD-results:
- bimodal distribution with positive offset
- collisions transfer momentum to the v_x and v_y components

Phase-resolved energy transfer

The kinetic particle energy in a DDW is found to be higher than the neutral gas temperature. The origin of high temperatures is probably the ion stream that heats the particles and the instabilities that lead to self-excited DDWs [4]. The question is, how much kinetic energy of the particles is transferred from the oscillatory to the transverse velocity components. Additionally, phase resolved investigations allow to find the location in the phase-space where the majority of the energy is transferred.



How much of the total energy is deposed in the transverse motion?
- MD: the transverse energy as a fraction of the total energy is dominant in the wave troughs
- Measurements: no significant signature present

- the measurements as well as the MD data show that the main energy is transfered to the transverse motion in the wave crest