# Different void regimes and the heartbeat instability in complex plasmas

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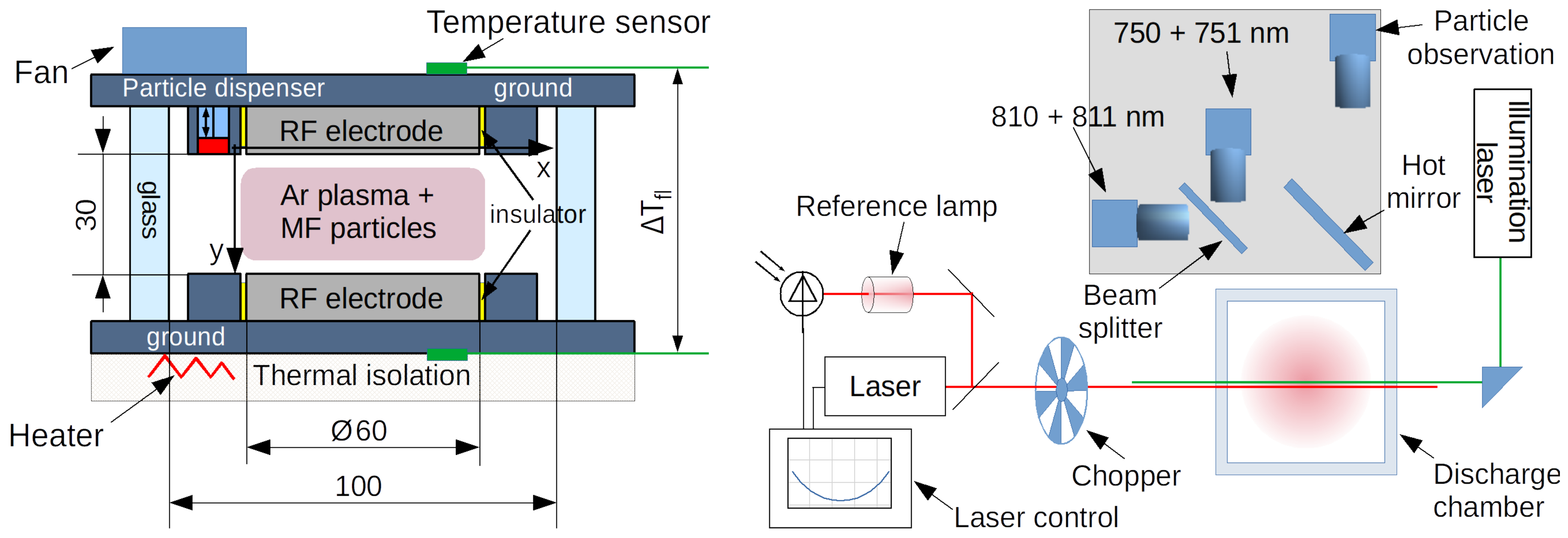
## Introduction

Dusty or complex plasma contains electrons, ions, neutral gas, radiation and micrometer-sized solid particles. The particles are negatively charged and form strongly coupled suspensions. A void, i. e. a microparticle-free area, disturbs the homogeneity of the suspension. The void formation and growth also determine the nanoparticle generation cycle in plasma reactors. Under certain conditions, the void can periodically contract. This phenomenon is called “heartbeat instability”. Despite two decades of investigation, the instability mechanism is still unclear.

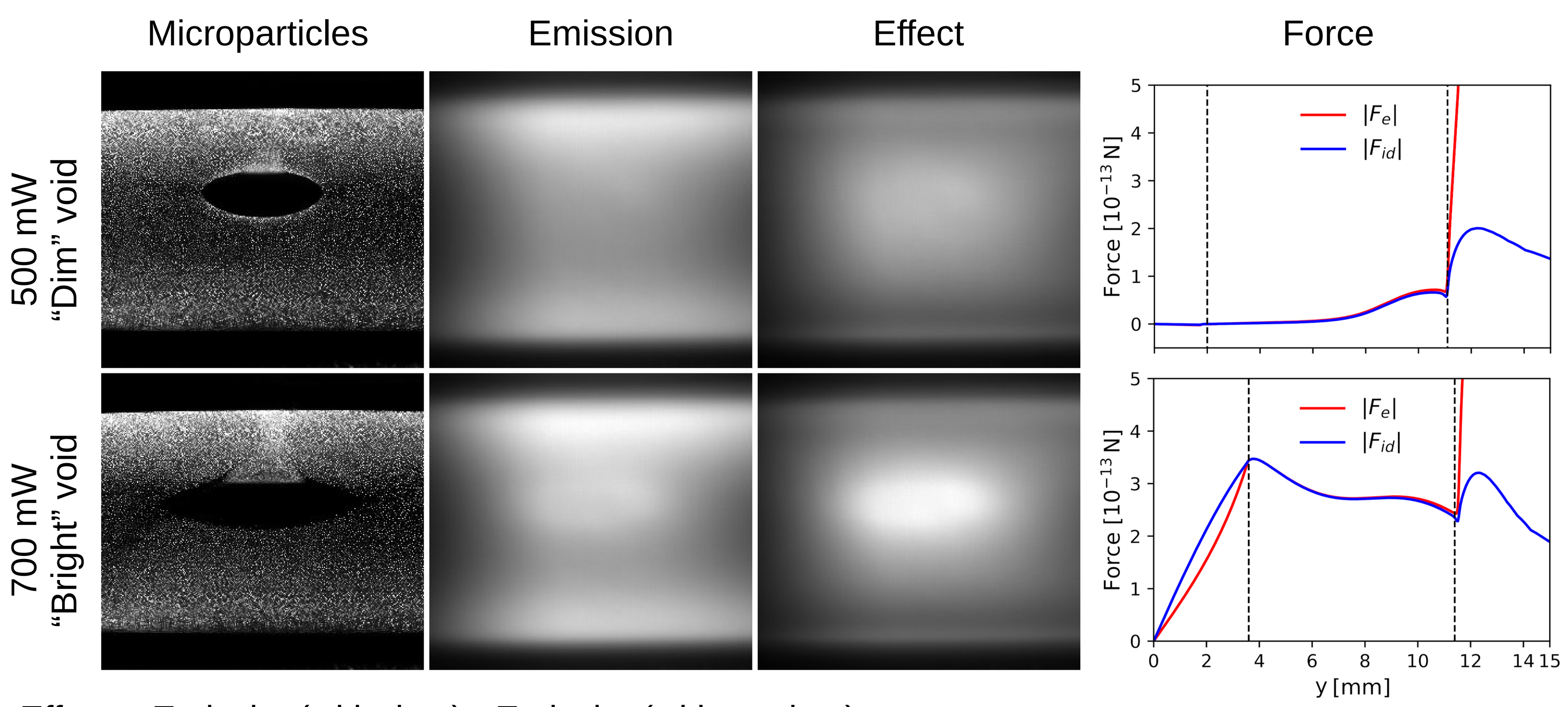
We have found out that the void can exist in two qualitatively different regimes: “dim” and “bright” [1]. Observations of the heartbeat instability and its optogalvanic control let us suggest that the instability occurs due to an abrupt transition between the dim and bright void regimes [2].

## The PK-3 Plus Setup




The gravity is compensated by the thermophoresis. The three cameras on the one side observe the microparticle motion and period-averaged plasma emission. The microparticle diameter is either 1.95 or 2.15 µm. The diode laser is tuned in resonance with 772.38 nm Ar spectral line causing fluorescence in 810.37 nm spectral line.

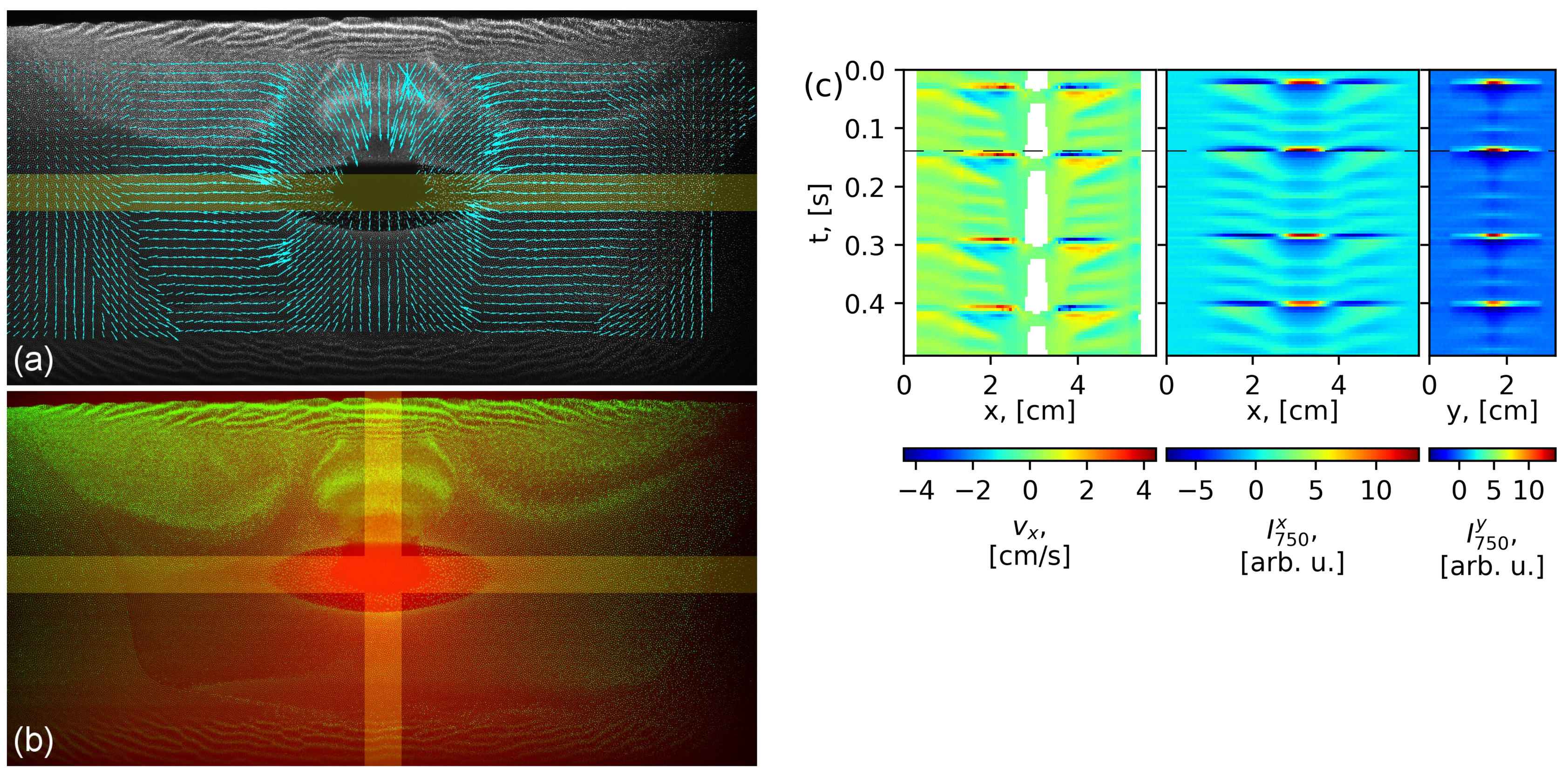
## Dim and bright voids




Effect = Emission(with dust) - Emission(without dust).
Pressure: 37 Pa

Electrostatic and ion-drag forces acting on a microparticle are calculated by a simplified time-averaged 1D fluid model [1]. The bright emission in the void is caused by the strong time-averaged electric field at the void boundary and elevated electron density in the void. This model could reproduce the dim void only when the radial ion losses were artificially introduced in the microparticle-free region of the plasma.

## Self-exited heartbeat instability

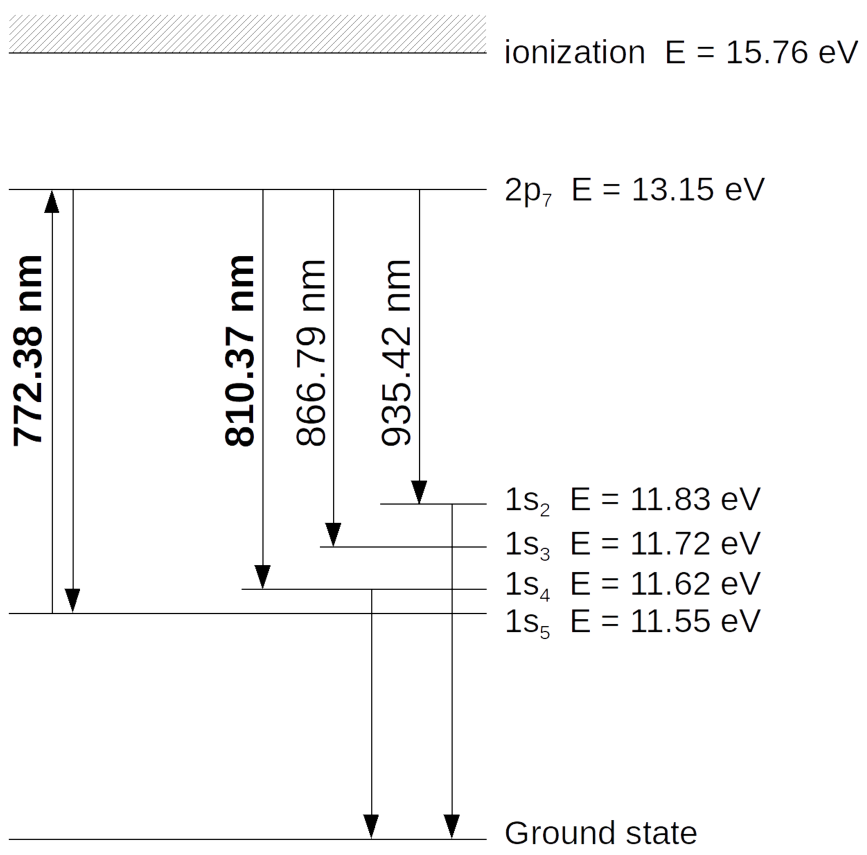



(a) One of the frames with the velocity field reconstructed using the OpenPIV software.

(b) The same frame with superimposed images of (green) the microparticle suspension and (red) the plasma emission captured through the filter with the central wavelength of 750 nm. The yellow stripes in plates (a) and (b) depict the areas used for the calculation of the spatiotemporal distributions.

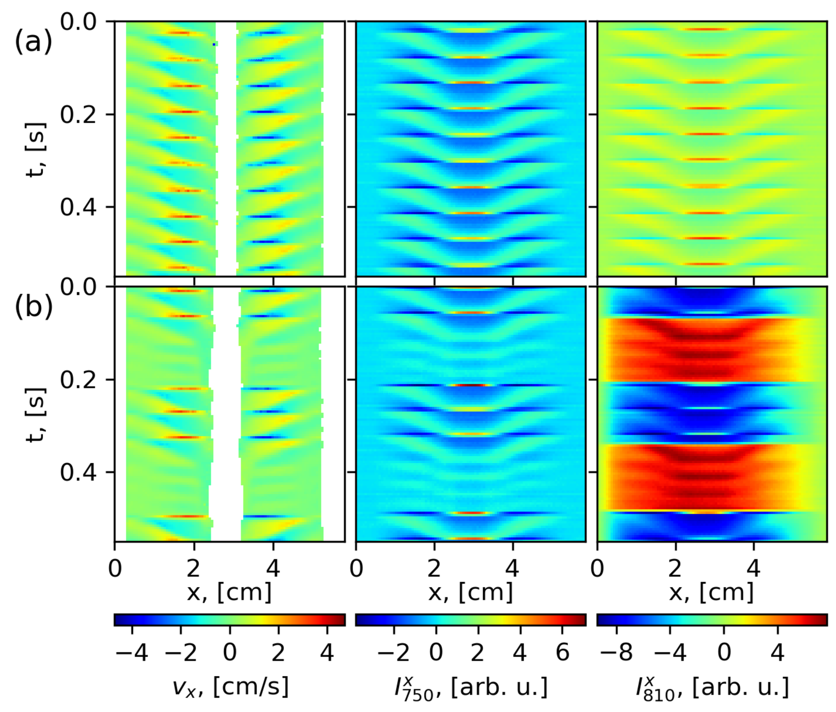
(c) Spatiotemporal distributions of the velocity $v_x$ and the plasma emission variations. White color in the $v_x$ plot depicts the areas in which no microparticles are present. The black dashed lines depict the temporal position of the frames shown in plates (a) and (b). Small breathing oscillations are visible between the contractions. The discharge power is 400 mW.

## Optogalvanic control of the instability




The laser excites the metastable atoms to higher excited state, and they can spontaneously stepwise relax to the ground state. The decrease of the metastable density leads to a decrease of the ionization rate.

The heartbeat instability occurs with the discharge powers near the transition between the dim and bright void regimes. Passing through the void, the laser shifts the void to the dim regime, similar to the decrease of the discharge power

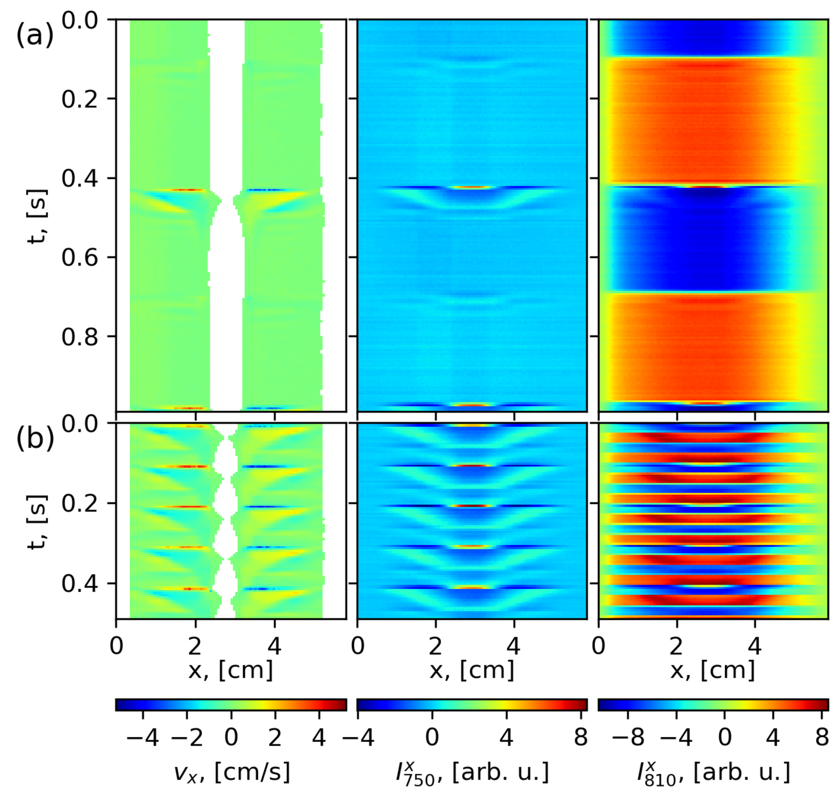



**Stabilization effect of the continuous laser.**

(a) without the laser, self-excited heartbeat instability occurs

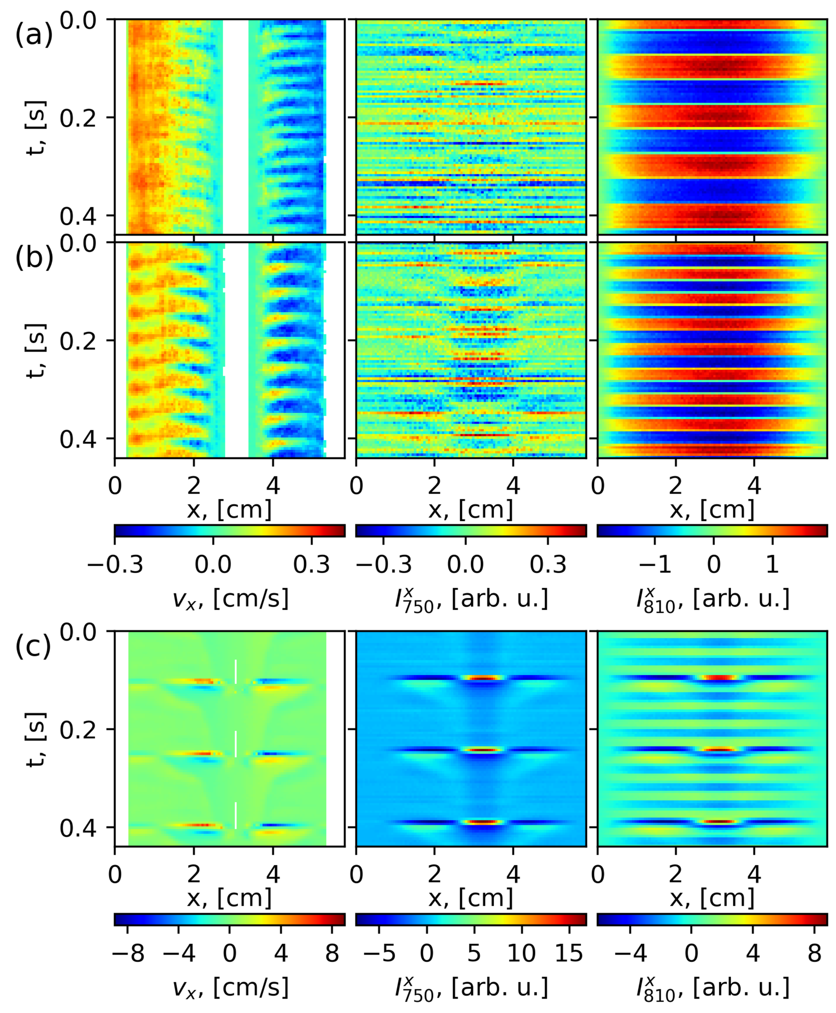
(b) with the modulated laser.

No oscillations are visible with the continuous laser. The discharge power is 500 mW.




**Transient optogalvanic heartbeat excitation** with the chopper frequency of (a) 1.7 Hz, (b) 19.6 Hz. The discharge power is 500 mW. The laser beam passes through the void center.

If the laser beam is shifted horizontally by 1 cm, the void collapses just after the beam opening.

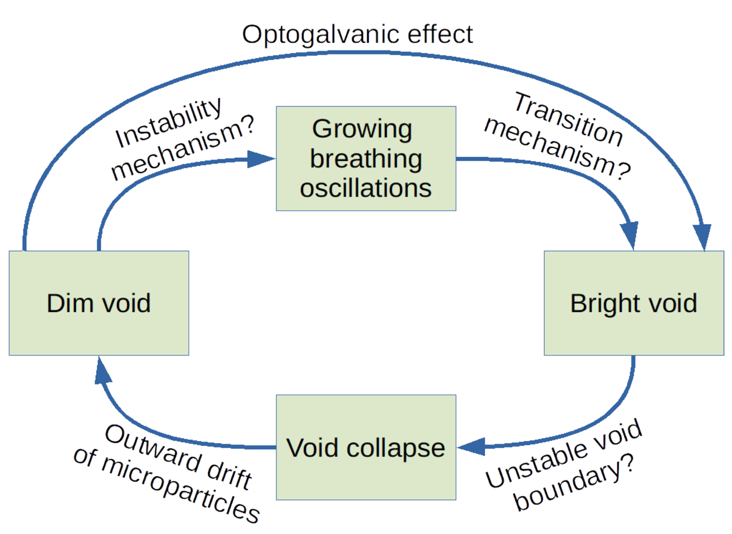



**Resonant heartbeat excitation.**

The laser beam is attenuated down to 0.7 mW. The discharge power is 350 mW. The laser modulation frequency is (a) 9.8 Hz, (b) 19.5 Hz, and (c) 27.3 Hz.

The resonance width is several Hz.

## Conclusion




The heartbeat cycle starts from a microparticle suspension with a dim void. The dim void undergoes a transition to the bright regime due to the breathing oscillations or the laser-induced transient process in the plasma.

In the bright regime, the void boundary becomes mechanically unstable and the void collapses due to large electrostatic forces on its boundaries. After that, the microparticles move back and restore the dim-void configuration.

**References**

1. Pikalev et al., Plasma Src. Sci. Technol., **30**, 035014, 2021
2. Pikalev et al., arXiv:2103.06795 [physics.plasm-ph]