

# Internal Waves Focusing Above a Three-Dimensional Topography

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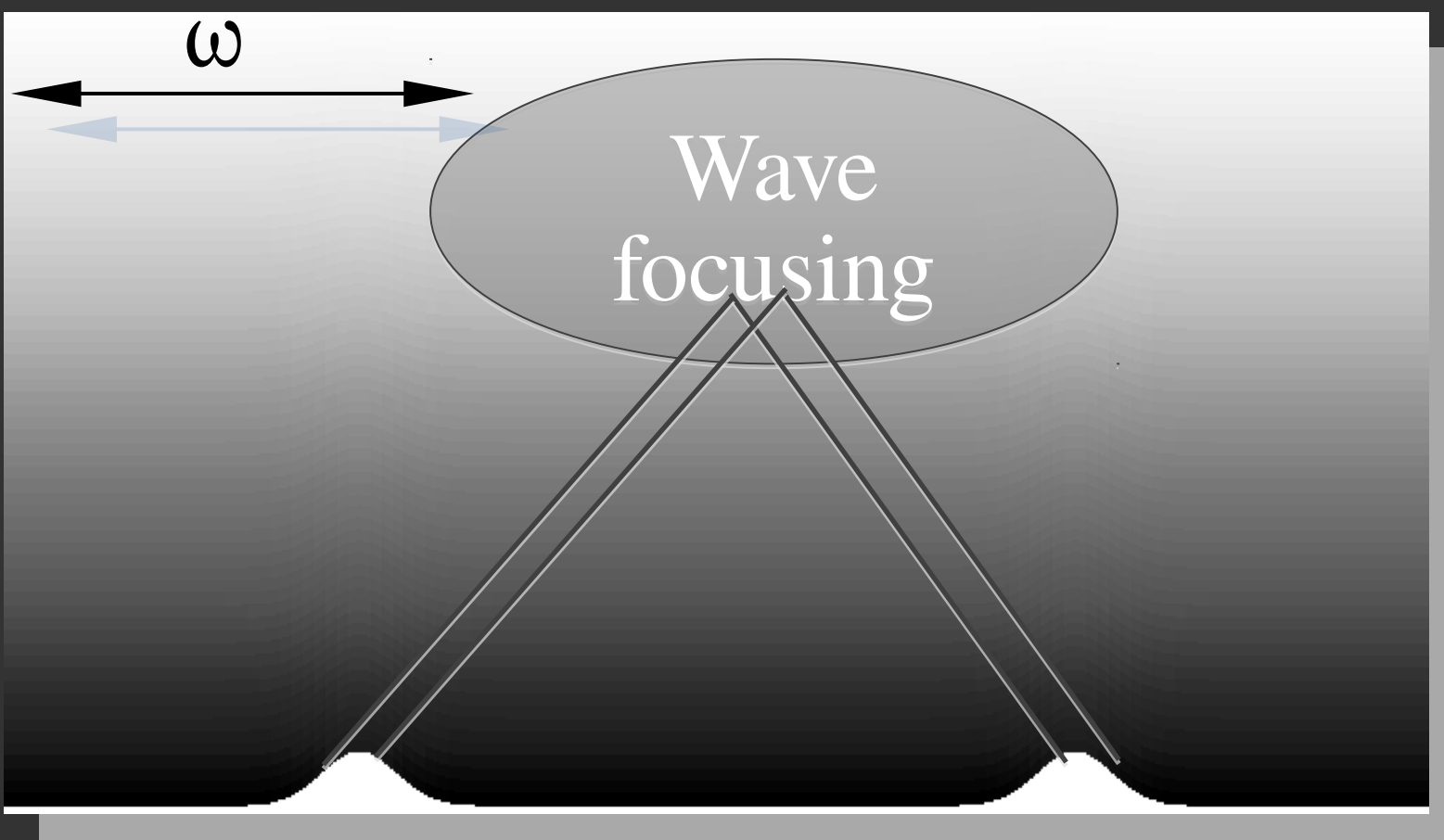
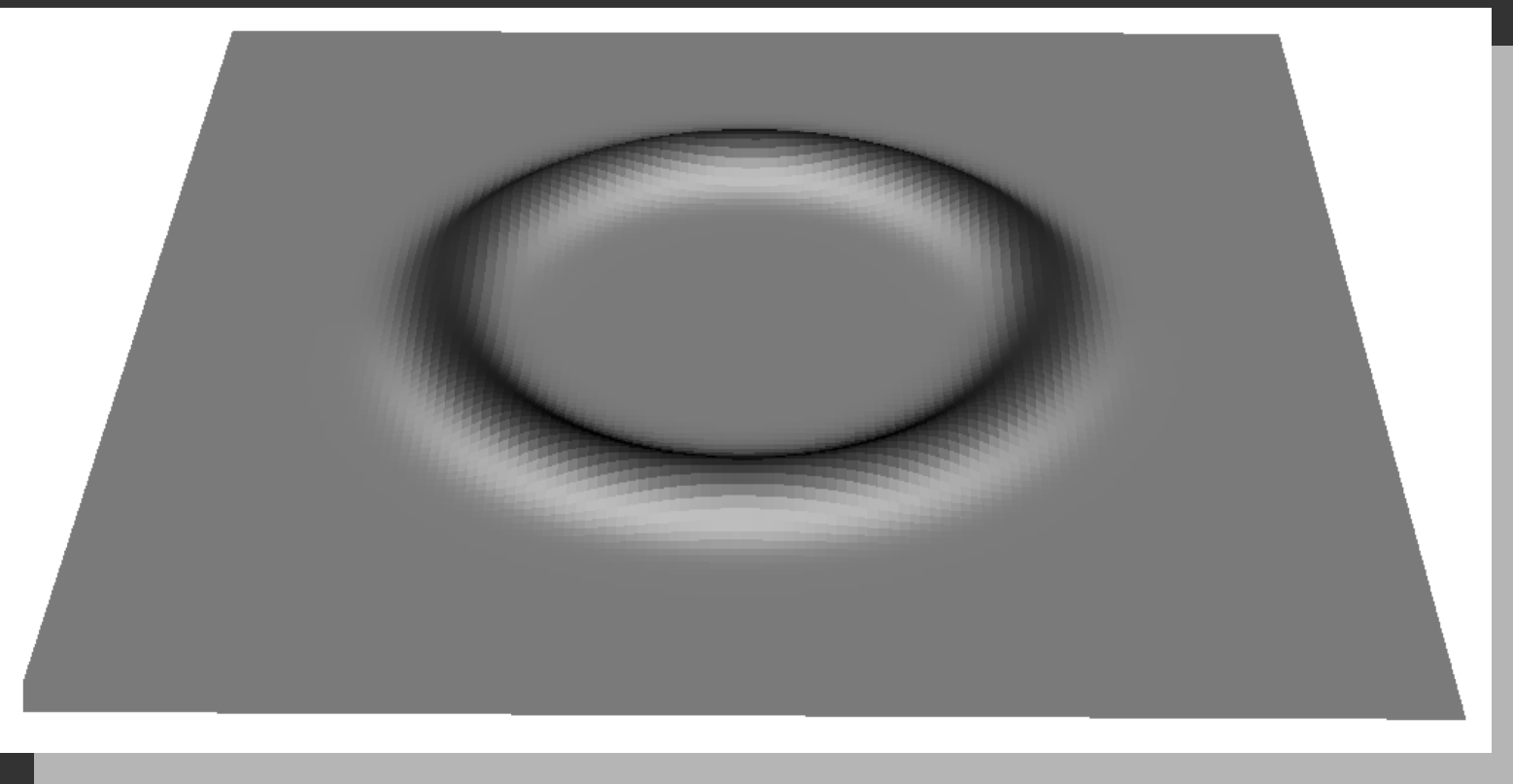
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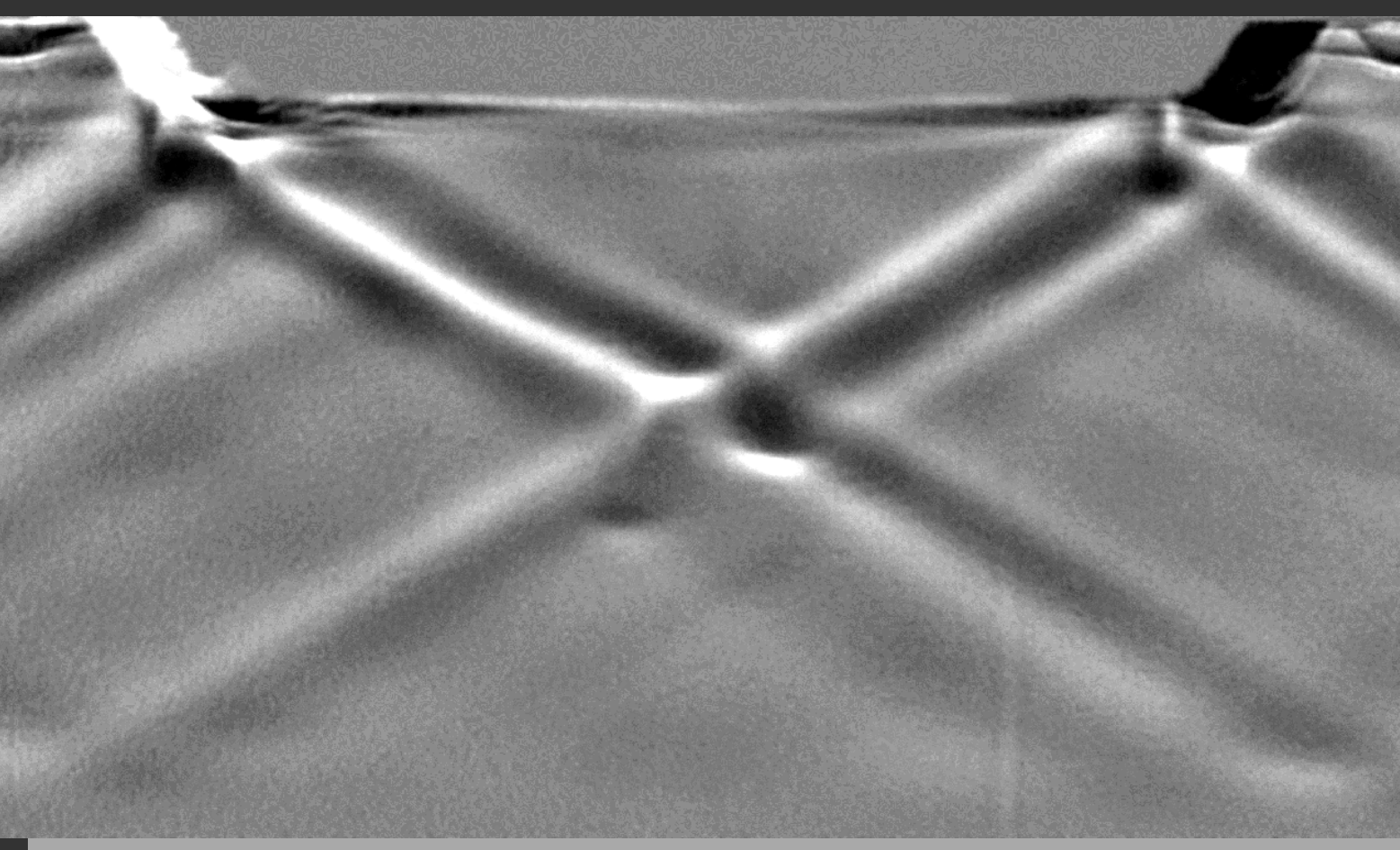
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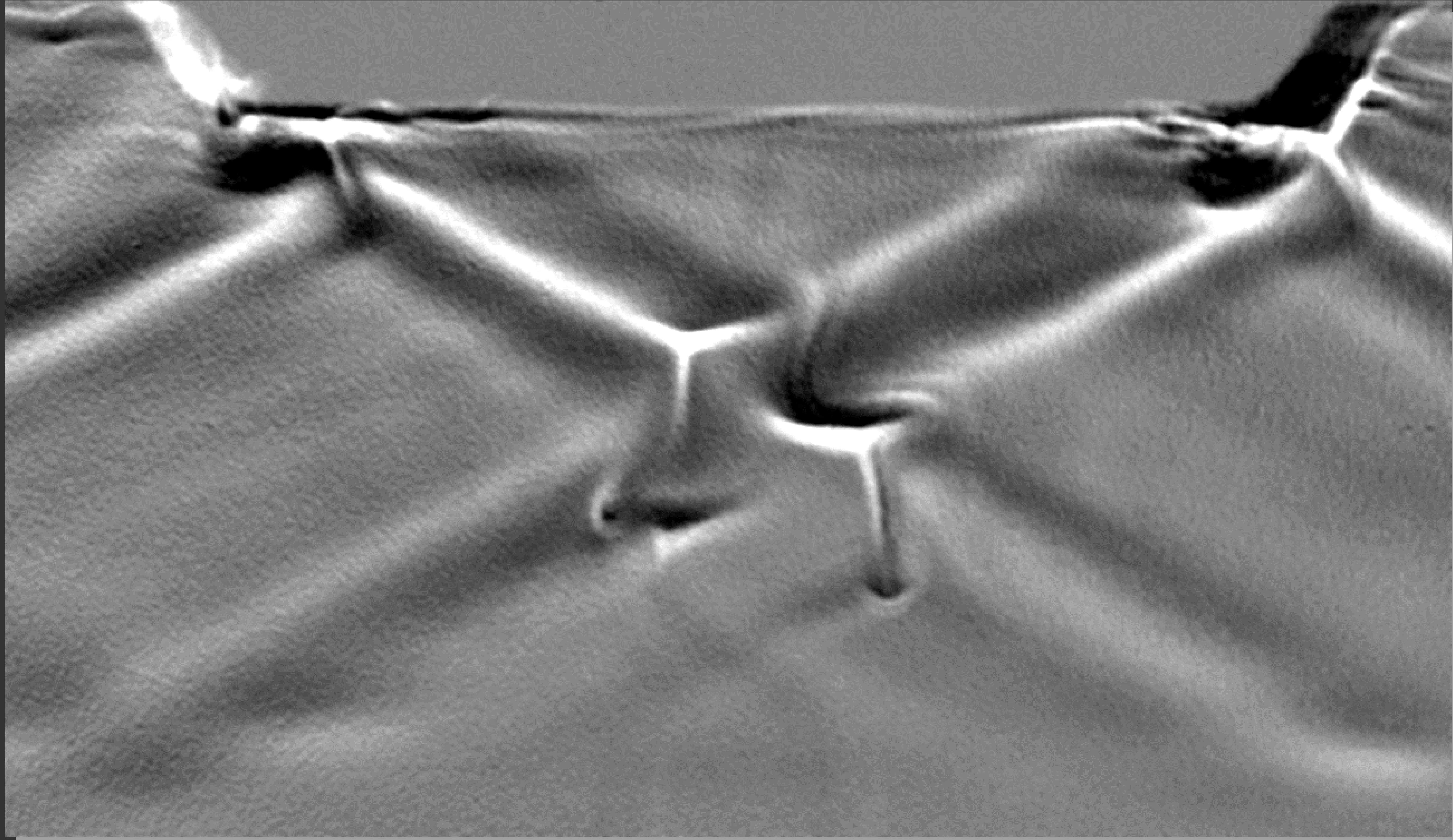
## LABORATORY EXPERIMENTS



We consider a three-dimensional Gaussian ring topography submerged in a stratified fluid and subject to a tidal forcing with an oscillation frequency  $\omega$ . The motion of this stratified flow induces internal waves that focus above the center of the topography, leading to a wave-wave interaction visualized using a shadowgraph.

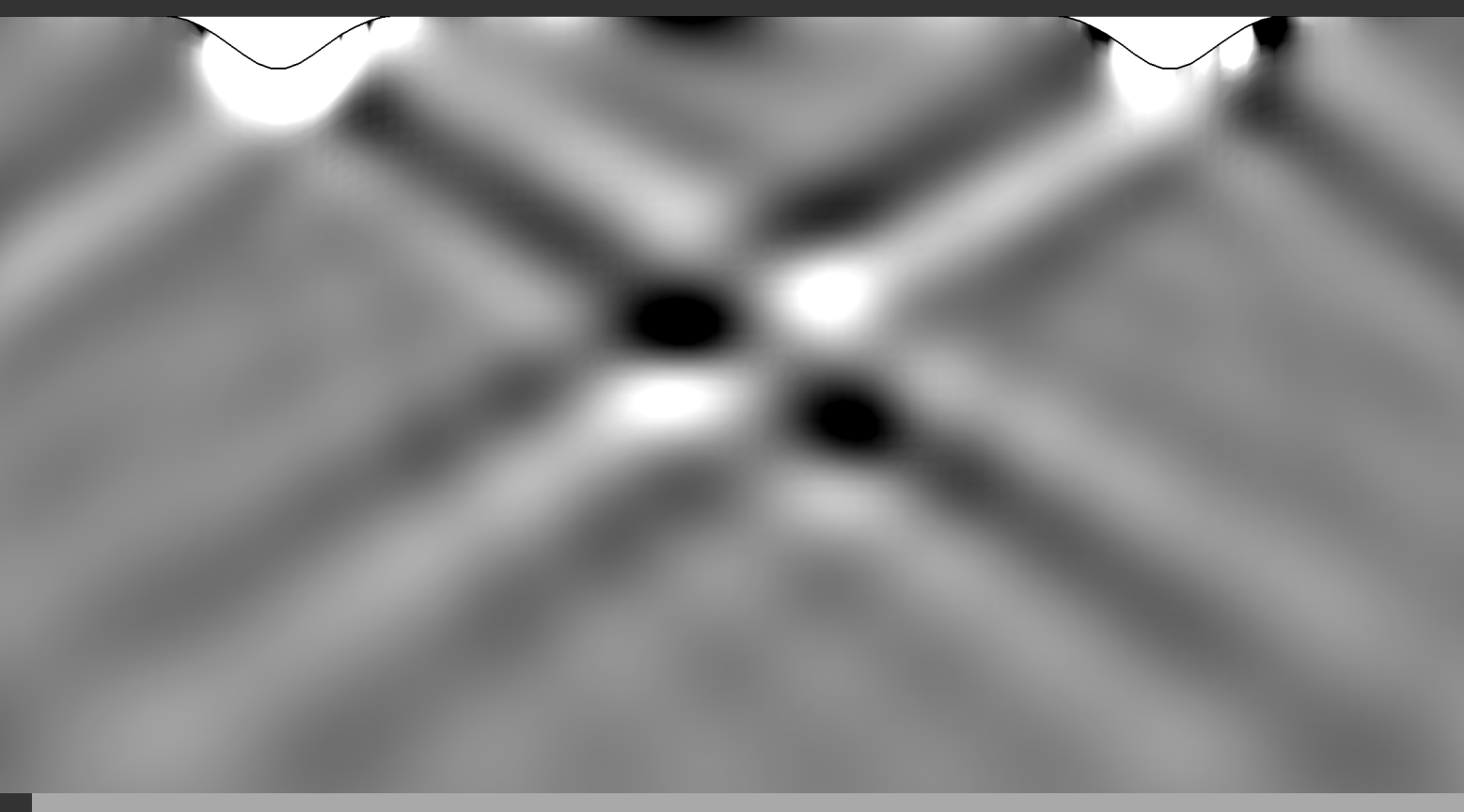


Shadowgraph – small tidal amplitude 8 mm/s

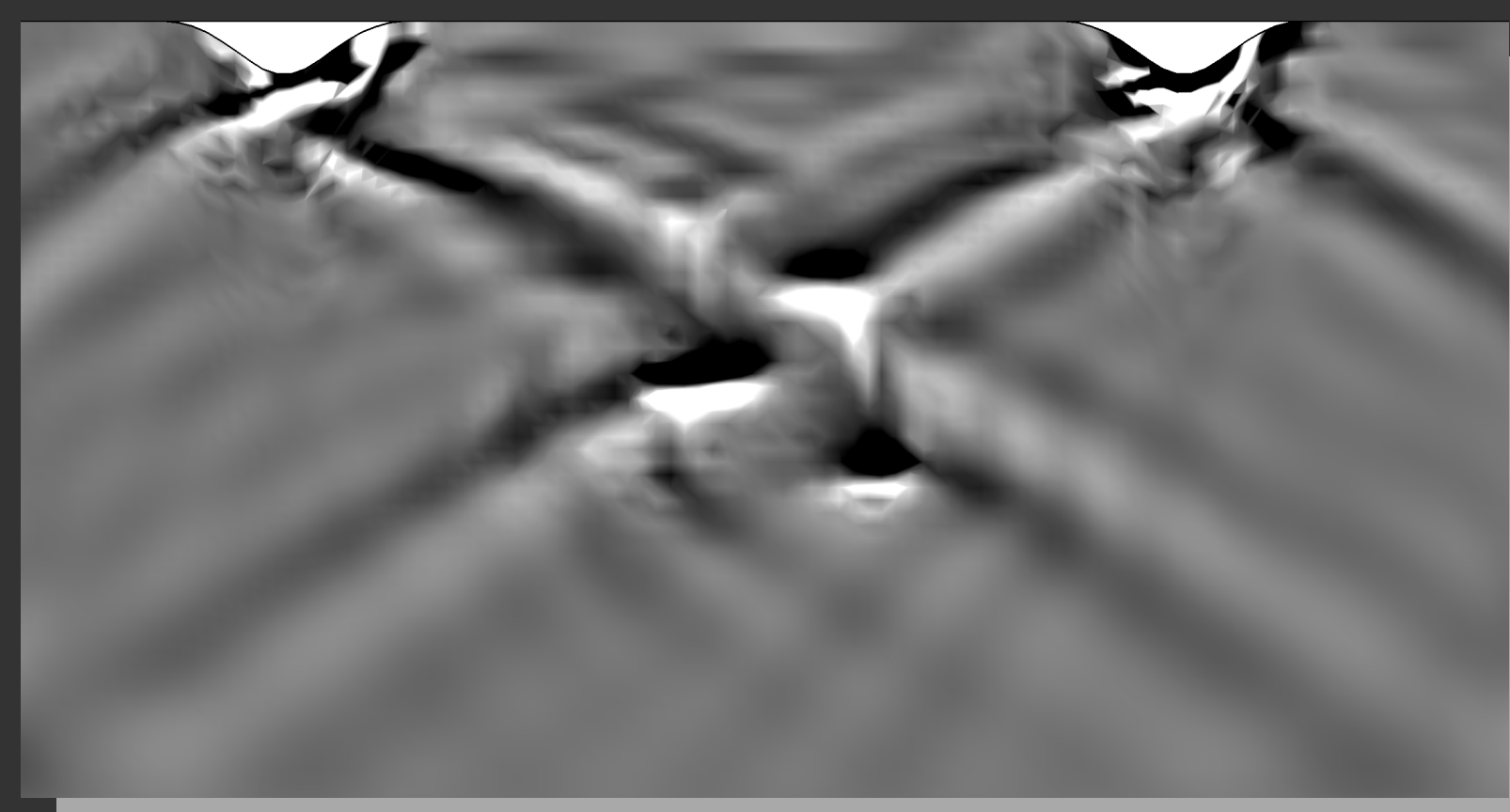


Shadowgraph – Side view – Large tidal amplitude 16 mm/s

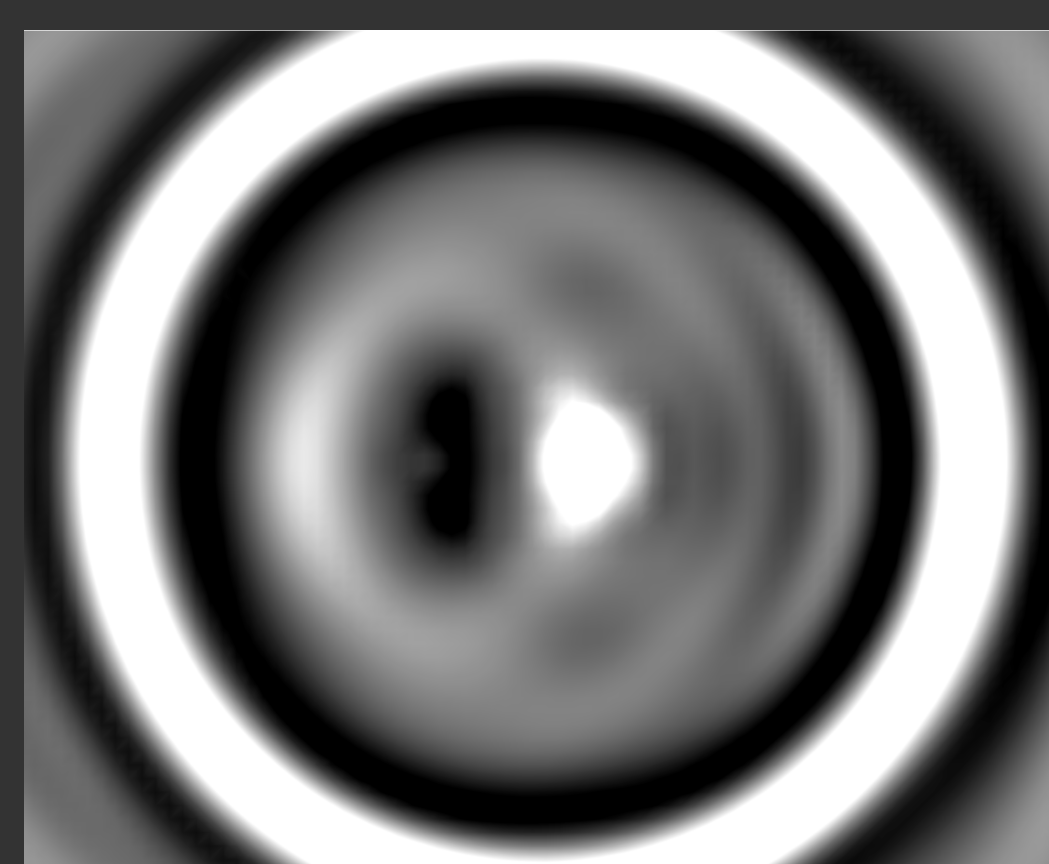
## NUMERICAL SIMULATIONS



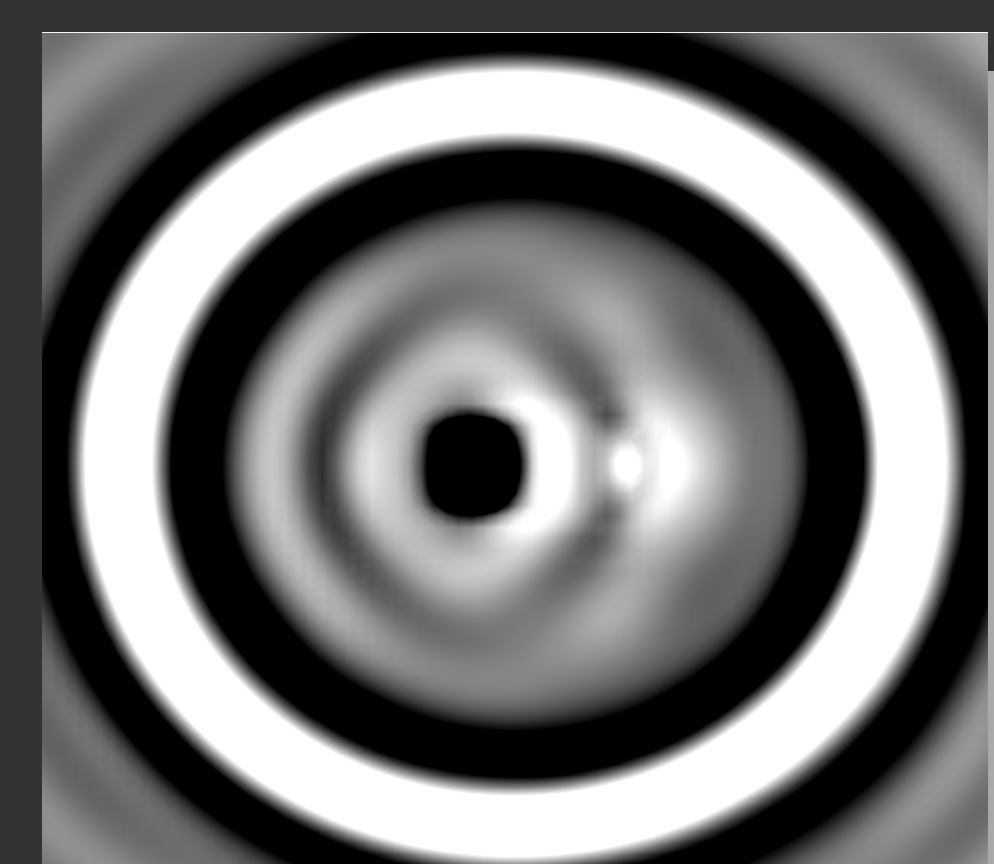
Shadowgraph – small tidal amplitude 8 mm/s



Shadowgraph – large tidal amplitude 16 mm/s



Shadowgraph – Top view



Same as left +  $\frac{1}{4}$  period oscillation



Density perturbation – Top View



Vertical velocity–Top view

## REFERENCES

[1]Ermanyuk, E., Shmakova, N., Flor, J. B., & Barraud, P. A. (2012). Focusing and breaking of internal waves. In 2nd International Conference on Violent Flows. *Editions Publibook*. 29-34, 2012

[2]O. Buhler & C. J. Muller(2007), Instability and focusing of internal tides in the deep ocean, *J. Fluid Mech.*, 588, 1-28, 2007.

[3]E. Santilli & A. Scotti (2015), The Stratified Ocean Model with Adaptive Refinement (SOMAR), *J. Comp. Physics*, 291, 60-81, 2015.

The interaction of an oscillating barotropic tidal flow with three-dimensional topographies such as submarine volcanos or meteorite craters are known to produce vigorous turbulent flow localized above their center [1]. Internal waves generated by tidal flow over the topography propagate away and focus at a point above it [2]. When the internal wave amplitude is strong enough, wave focusing leads to wave breaking and turbulence. Shadowgraph images are computed from simulation data and compared with experimental data. Laboratory experiments are performed in a rectangular tank of dimensions 60 cm x 30 cm x 40 cm. The bottom of the tank is filled with a layer of saturated salty water 23 cm thick. The top 15 cm is filled with linearly stratified fluid. A Shadowgraph is used to capture images during the experiment. Three-dimensional numerical simulations are performed with SOMAR (Stratified Ocean Model with Adaptive Refinement [3]). Dynamic grid refinement is performed based on the velocity gradient, leading to a finer grid in the generation and focusing regions. Numerical simulations are performed at a Prandtl number of 700, reproducing the experimental conditions. The coarse grid resolution: (dx=3mm, dy=3mm, dz=3mm), Fine grid resolution: (dx=0.75mm, dy=0.75 mm, dz=0.75 mm). When the tidal amplitude is 8 mm/s, the internal waves are linear throughout the domain. Increasing the tidal amplitude to 16 mm/s results in nonlinear features become start to appear. Experiments and simulations show qualitatively similar results with density overturns at the focusing region, showing the onset of a wave-wave overturning process. *Acknowledgements:* The authors acknowledge the support by the National Science Foundation under grant OCE-1155558.