

Focusing of internal waves generated by an oscillating torus

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Internal waves generated by the tidal motion over the topography of the abyssal sea play an important role in ocean dynamics, and are relevant to climate prediction in view of the potential mixing and consequent change of the ocean heat distribution (Ferrari, 2014). In continuation of former studies on the generation of internal waves by oscillating objects (see e.g. Voisin, 2003; Voisin *et al.*, 2011; Voisin, 2020) we consider the waves generated by a horizontally oscillating torus. Circular ring topography produces convergent waves that increase in amplitude towards the focal point, and are therefore especially conducive to nonlinear effects and mixing (Bühler and Muller, 2007; Ermanyuk *et al.*, 2017; Shmakova and Flór, 2019; Shmakova *et al.*, 2021).

The structure of the waves is set by the Stokes number St and ranges from unimodal waves at moderate St (moderate viscosity) with thick wave beams of the width of the torus section, to bimodal waves at high St (low viscosity) with thin wave beams, having the shape of shear layers tangential to the section. Other parameters are the aspect ratio ε of the torus, and the Keulegan–Carpenter number Ke (see e.g. Voisin *et al.*, 2011).

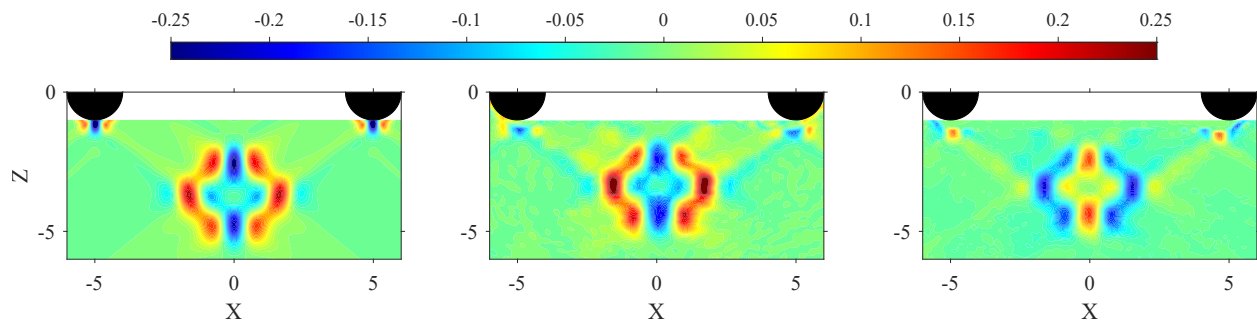


Figure 1: Theoretical Stokes drift (left), experimental Stokes drift (middle) and experimental mean flow (right) for the oscillations of a torus of aspect ratio $\varepsilon = 5$, with cross sections shown in black, at Stokes number $St = 400$ and Keulegan–Carpenter number $Ke = 0.13$.

For a very large range of Stokes numbers, set by tori of diameters ranging from 24 to 180 cm, we compare experimental results obtained from PIV measurements to a 3D theoretical model of focusing waves that includes viscous effects. We discuss nonlinear effects such as the generation of sub- and higher harmonics, triadic resonance, wave breaking as a function of Stokes number, and the generation of a mean flow. In particular, the Stokes drift is calculated from the linear theory (see figure 1 left), and separately calculated from the experimental data (see figure 1 middle), and exactly opposes the measured mean flow (see figure 1 right).

References

- Bühler O., Muller C. J. (2007). Instability and focusing of internal tides in the deep ocean. *J. Fluid Mech.* 588, 1–28.
- Ermanyuk E. V., Shmakova N. D., Flór J.-B. (2017). Internal wave focusing by a horizontally oscillating torus. *J. Fluid Mech.* 813, 695–715.
- Ferrari R. (2014). What goes down must come up. *Nature* 513, 179–180.
- Shmakova N., Voisin B., Sommeria J., Flór J.-B. (2021). Internal and inertia–gravity wave focusing at large Stokes numbers. *Phys. Rev. Fluids* 6, 114804.
- Shmakova N. D., Flór J.-B. (2019). Nonlinear aspects of focusing internal waves. *J. Fluid Mech.* 862, R4.
- Voisin B. (2003). Limit states of internal wave beams. *J. Fluid Mech.* 496, 243–293.
- Voisin B. (2020). Near-field internal wave beams in two dimensions. *J. Fluid Mech.* 900, A3.
- Voisin B., Ermanyuk E. V., Flór J.-B. (2011). Internal wave generation by oscillation of a sphere, with application to internal tides. *J. Fluid Mech.* 666, 308–357.