Focusing of internal waves

Experimental study

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Réunion du GdR Turbulence

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Contents

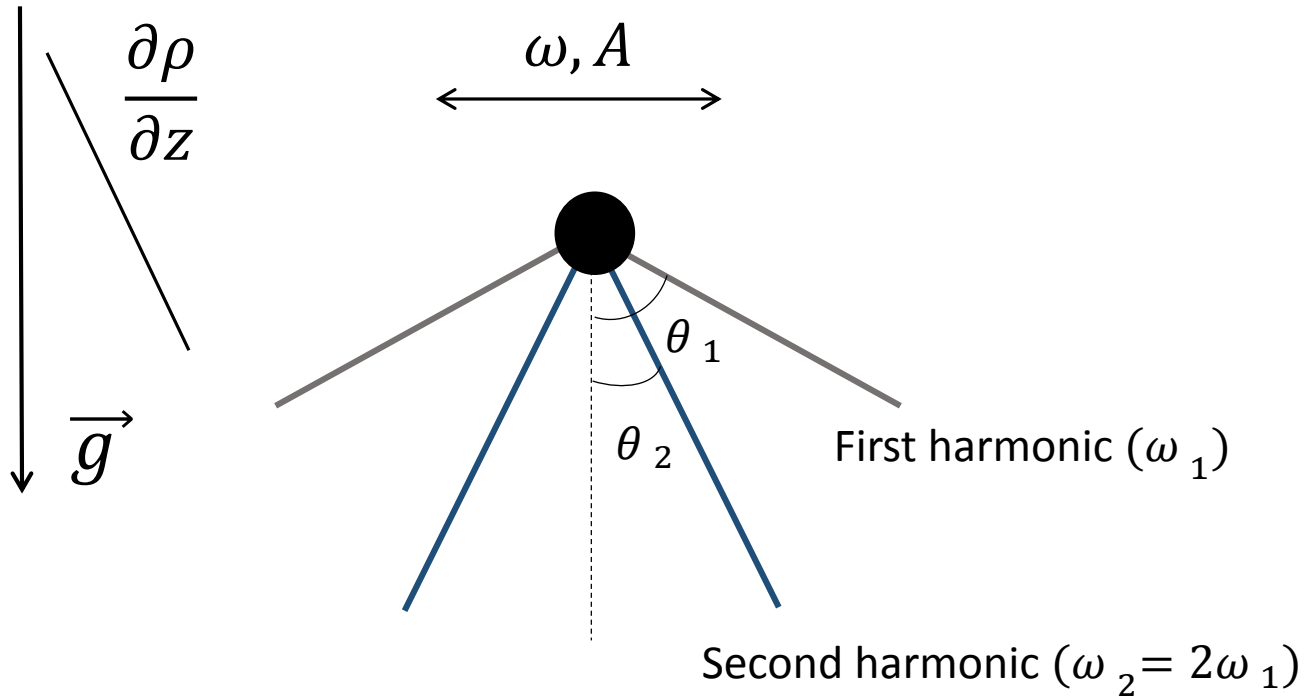
- Comparison of experimental results with linear theory (first order waves)
- Secondary waves (higher harmonics)
- Increase of oscillation amplitude → nonlinear regime

Internal gravity waves

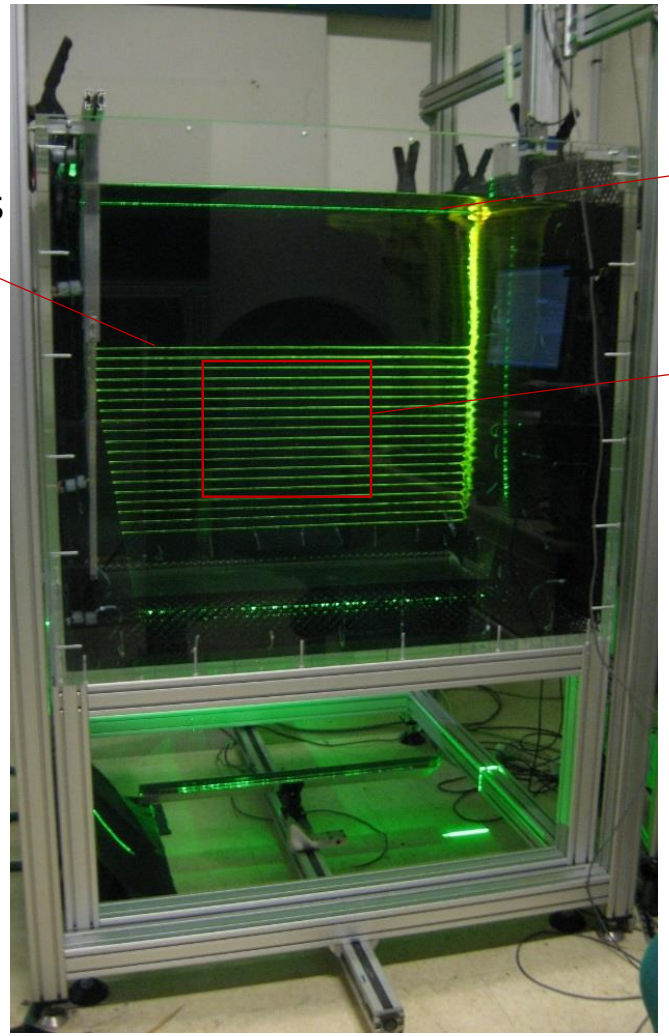
Buoyancy frequency: $N = \left[\left(-\frac{g}{\rho}\right)\left(\frac{\partial \rho}{\partial z}\right)\right]^{1/2}$

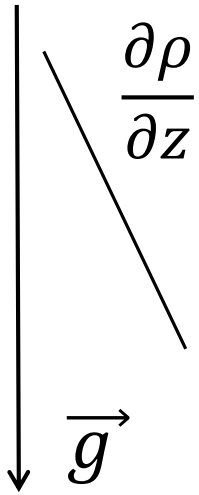
Dispersion relation : $\frac{\omega}{N} = cos\theta$

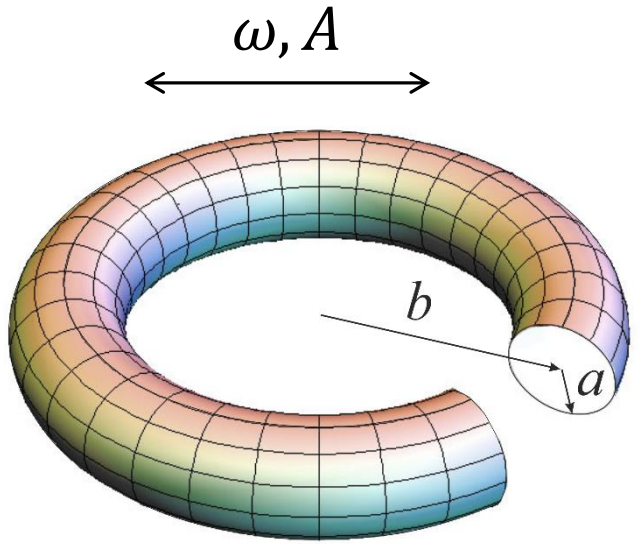
First harmonic	$0.5 < \frac{\omega}{N} < 1$
First and Second harmonic	$0.33 < \frac{\omega}{N} < 0.5$



Experimental setup & parameters







$$N = \left[\left(-\frac{g}{\rho}\right)\left(\frac{\partial \rho}{\partial z}\right)\right]^{1/2}$$

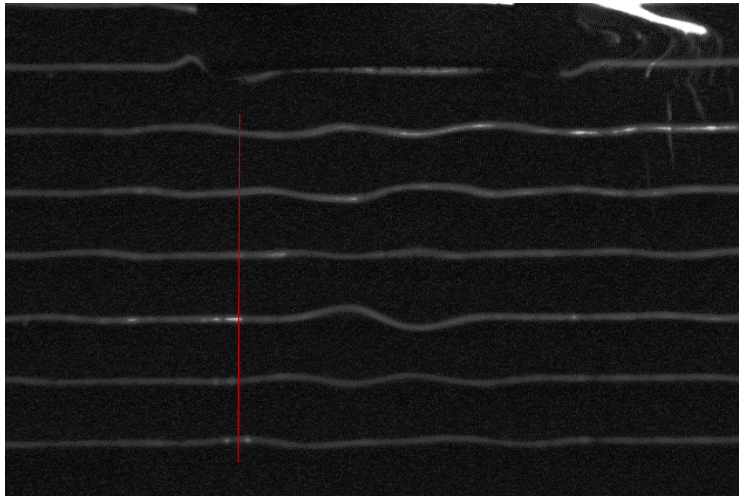
$$\varepsilon = \frac{b}{a} = 5$$

$$\frac{\omega}{N} = 0.8, 0.45$$

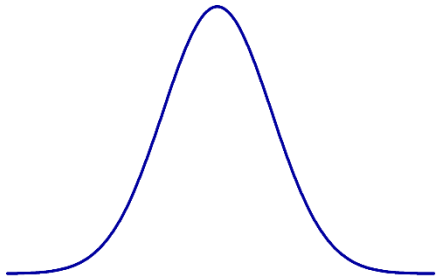
$$Ke = \frac{A}{a} \qquad St = \frac{\omega a^2}{\nu} \qquad Re = \frac{2a \cdot \omega A}{\nu}$$

Data processing

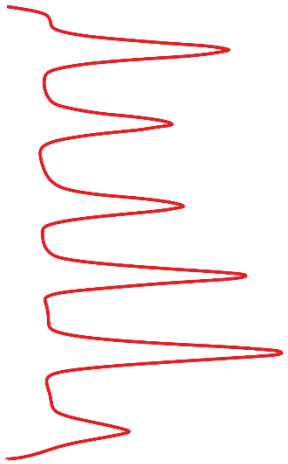
$$G(z, z', s_0) = e^{-\frac{(z-z')^2}{2s_0}} \Big/ \sqrt{2ps_0}$$ Gaussian



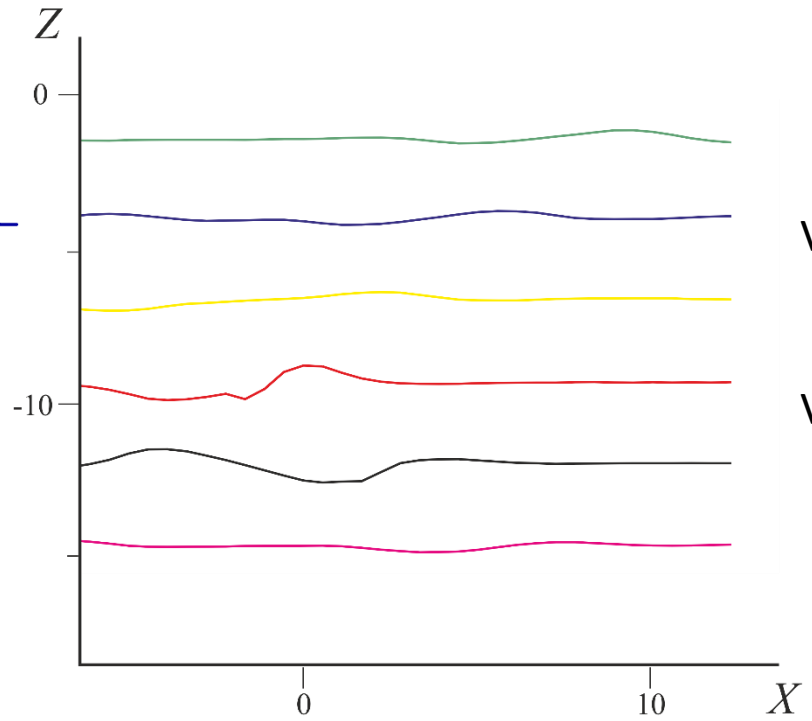
Typical image



$I(z)$ light intensity



$$C_k = \sum_{n=0}^{N-1} G_n I_{n+k}$$



$\zeta(t)$ result

Vertical displacement

$\Delta\zeta(t) = \zeta(t + \delta t) - \zeta(t)$

Vertical velocity

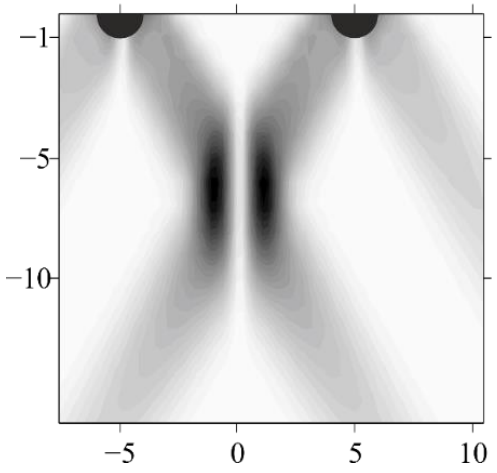
$w(t) = \Delta\zeta(t)/\Delta t$

LIF results: Vertical Velocity

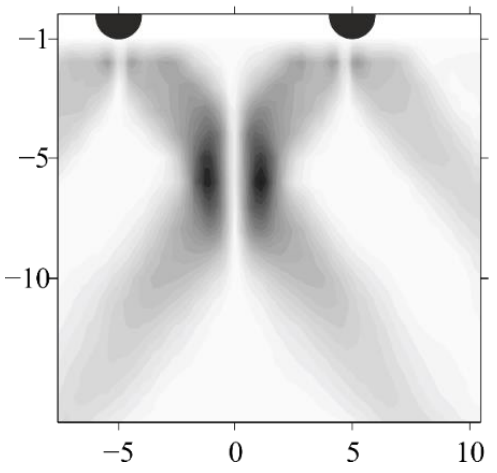
$\omega/N = 0.85$

$St = 222$

Vertical velocity

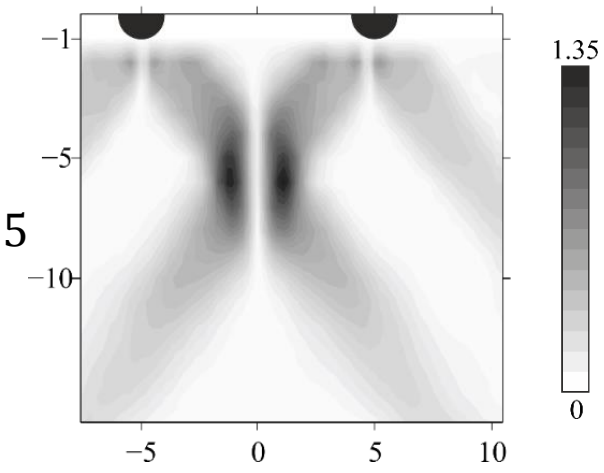


Theory



Total

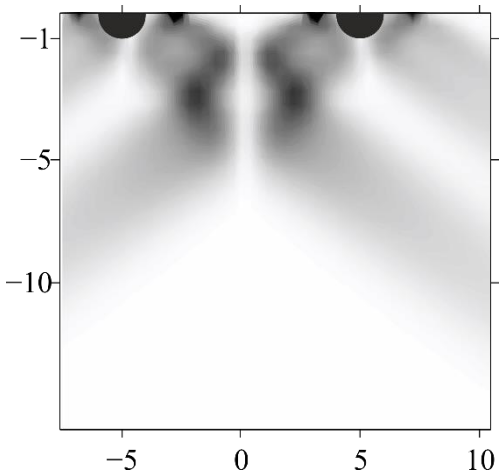
$Ke = 0.15$

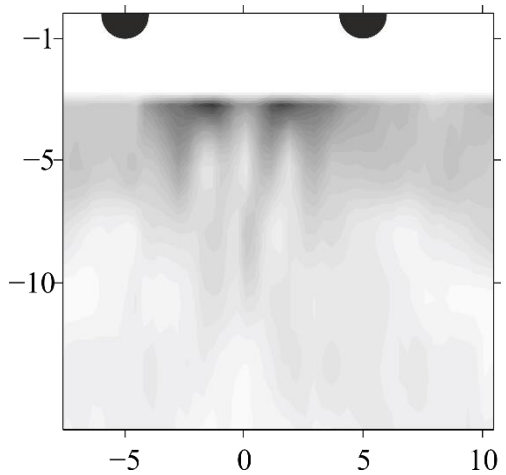


1st Harmonic

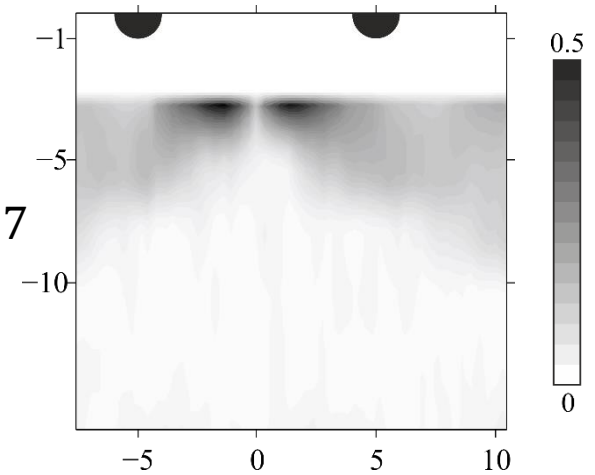
$\omega/N = 0.45$

$St = 117$





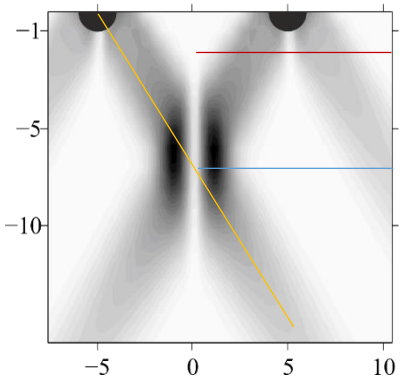
$Ke = 0.17$



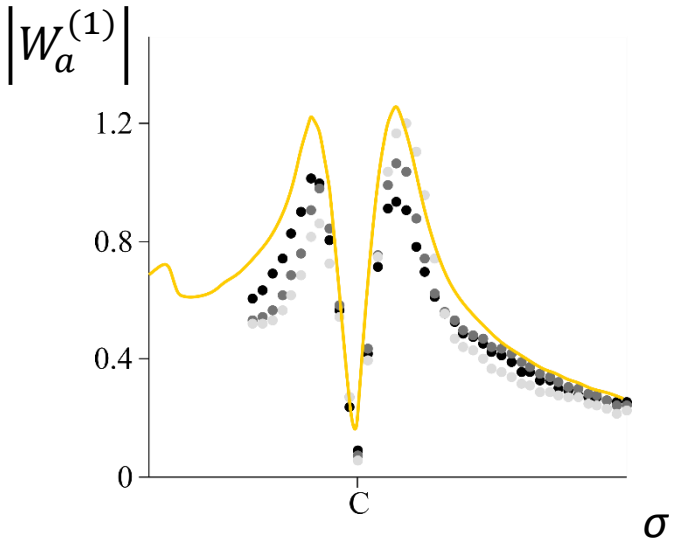
LIF results: Vertical Velocity, comparison with linear theory

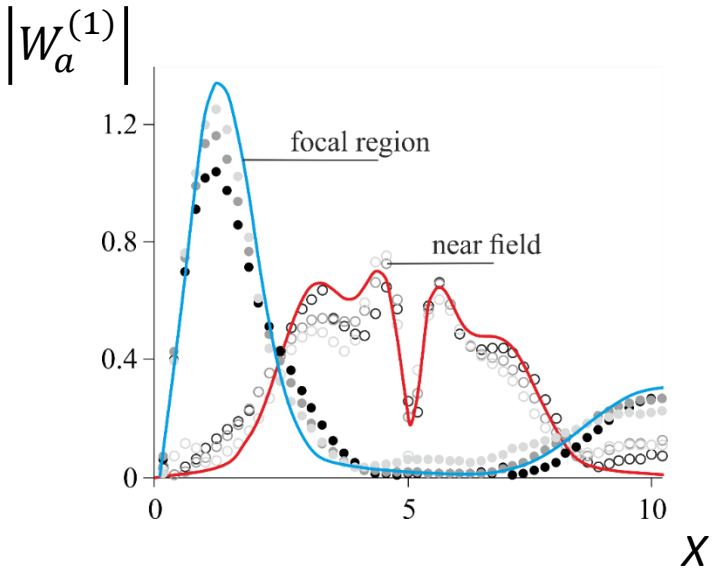
$\omega/N = 0.85$
$St = 222$

$Ke = 0.15, 0.3, 0.52$



Vertical velocity



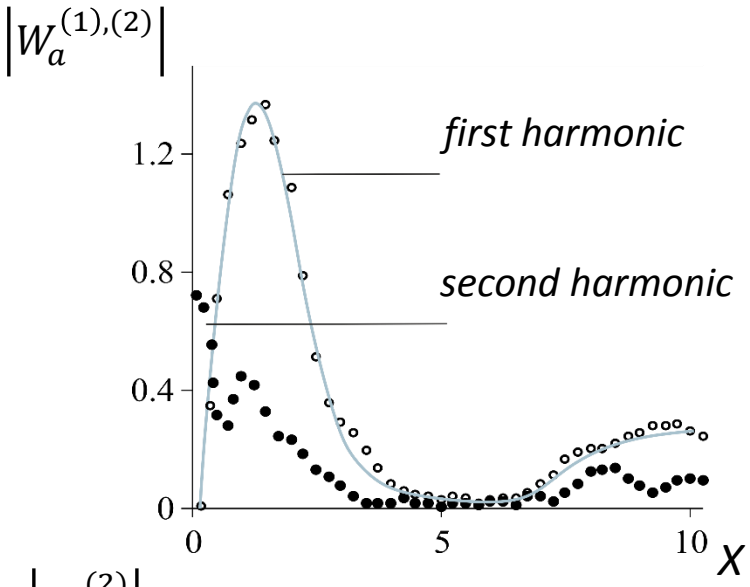


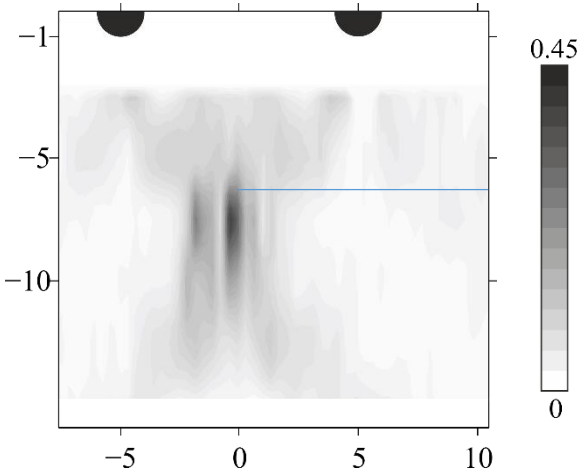
- Amplification of amplitude in focal zone
- Good comparison with linear theory

LIF results: Second harmonics

Evanescent second harmonic

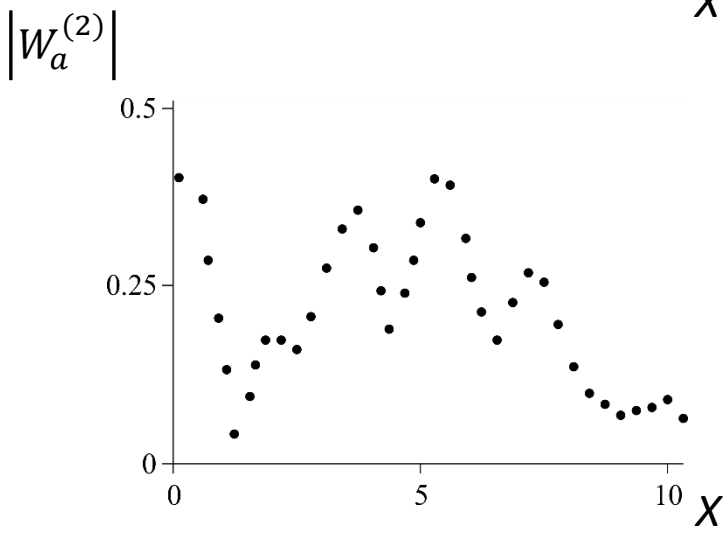
$\omega/N = 0.85$

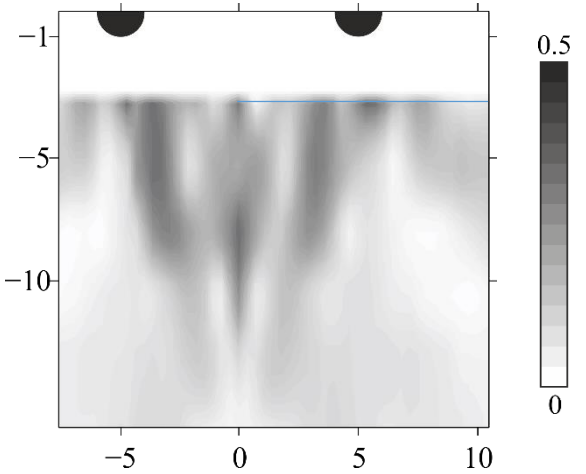




Propagative second harmonic

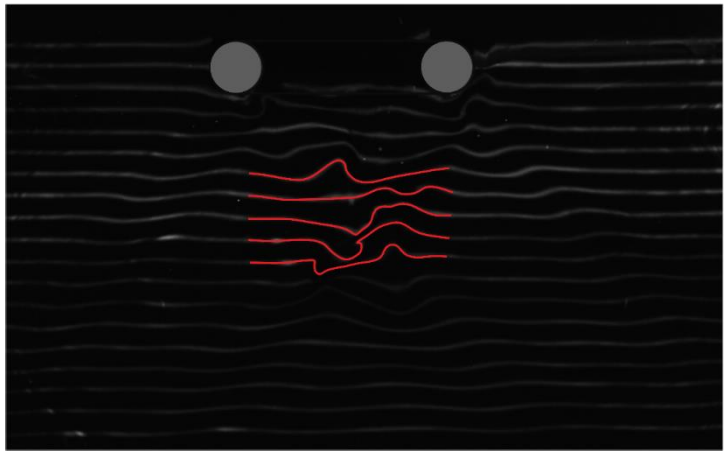
$\omega/N = 0.45$





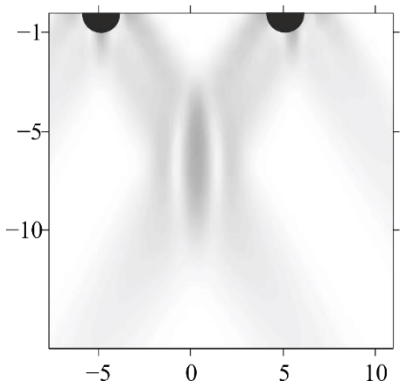
LIF results: slopes, nonlinear effects

$Ke = 0.7$

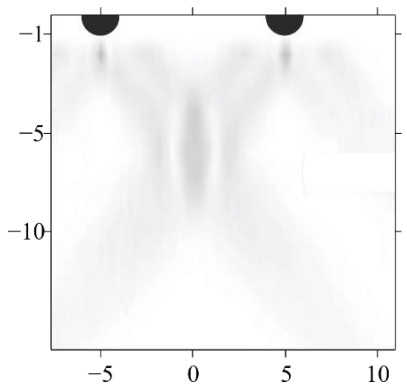


Slope

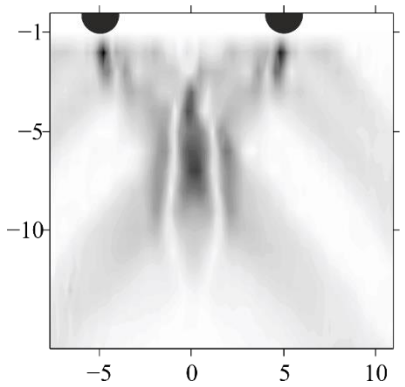
$$S_a = \left|\arctan\left(Ke\frac{\partial W_a}{\partial X}\right)\right|$$



Theory



$Ke = 0.15$



$Ke = 0.52$

- Steep slopes at moderate Ke
- Breaking of waves in the focal region

PIV: Linear approach

Side view

Theory

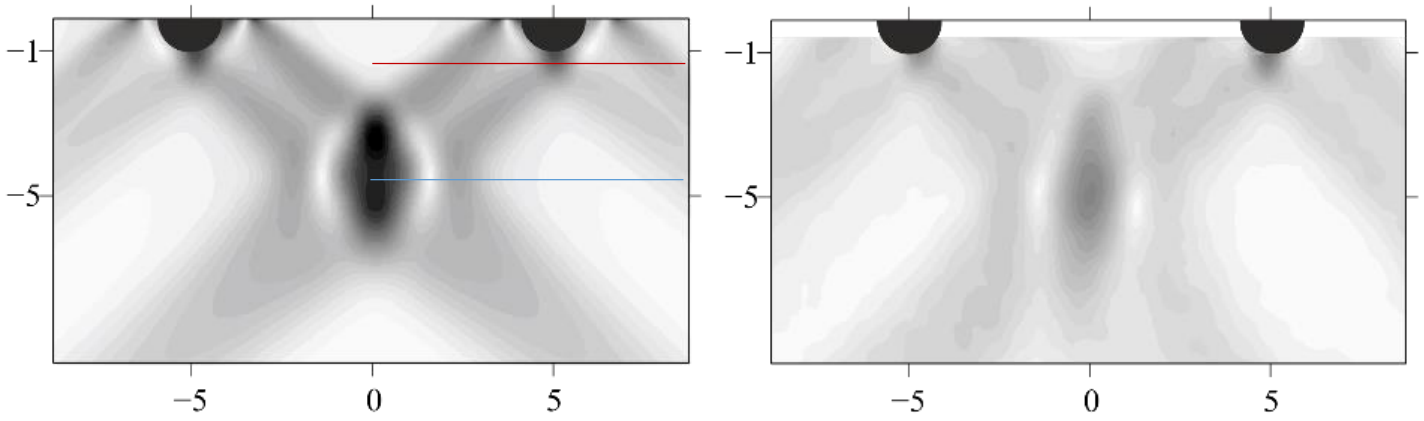
Experiment, $Ke = 0.19$

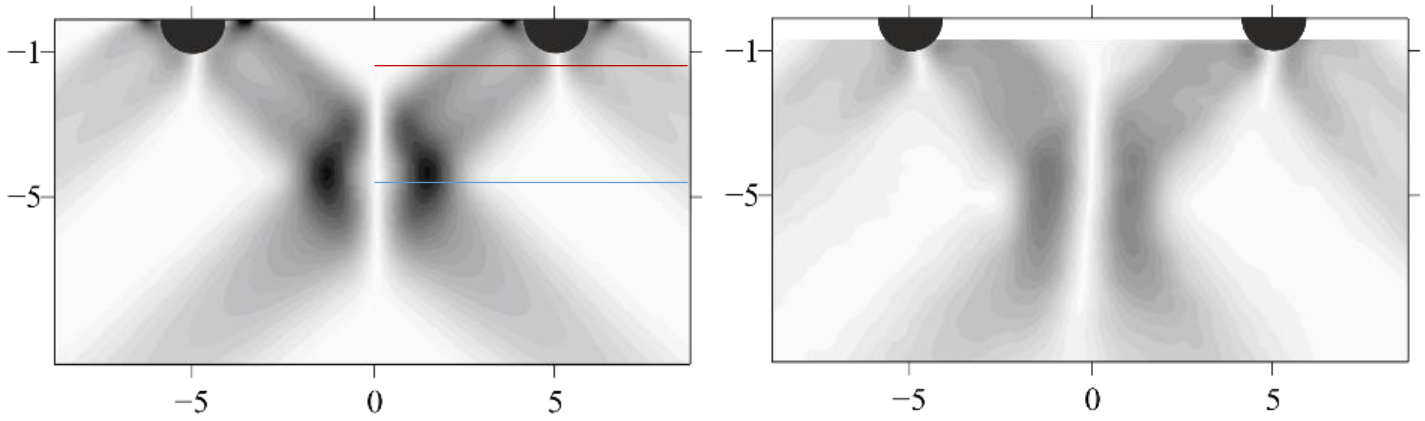
Horizontal velocity

$\omega/N = 0.8$

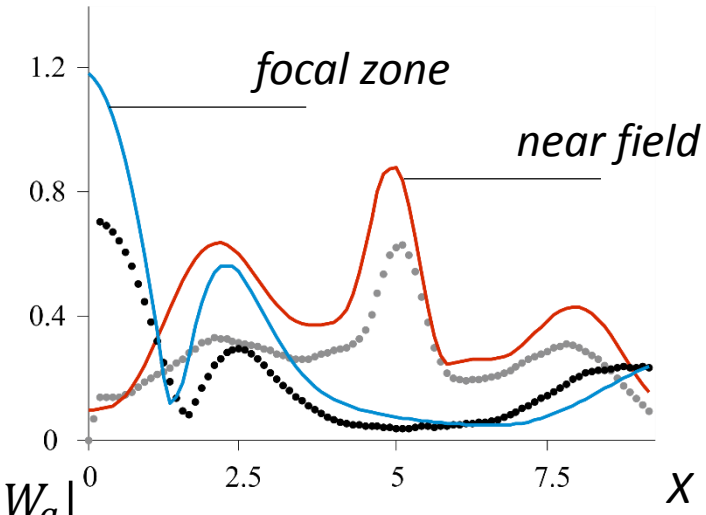
$St = 250$

Vertical velocity

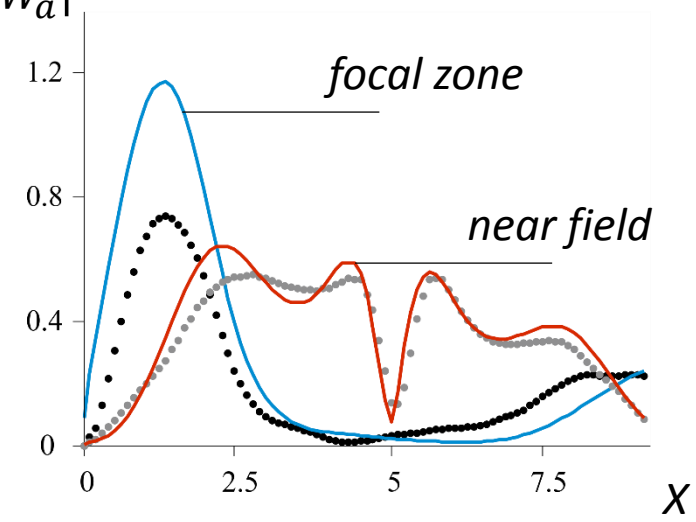




$|U_a|$



$|W_a|$



From linear to weakly nonlinear

Side view

Theory

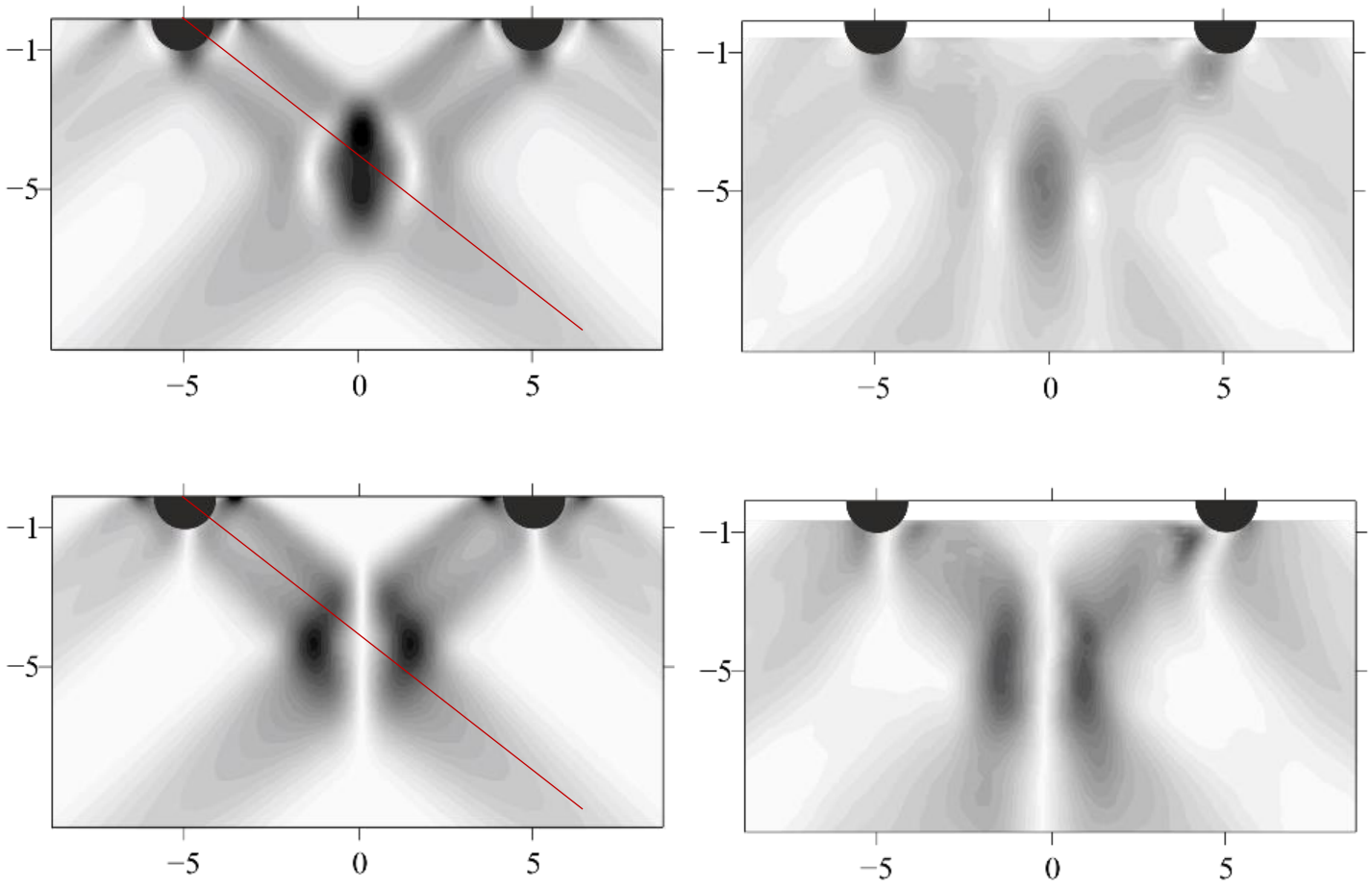
Experiment, $Ke = 0.6$

Horizontal velocity

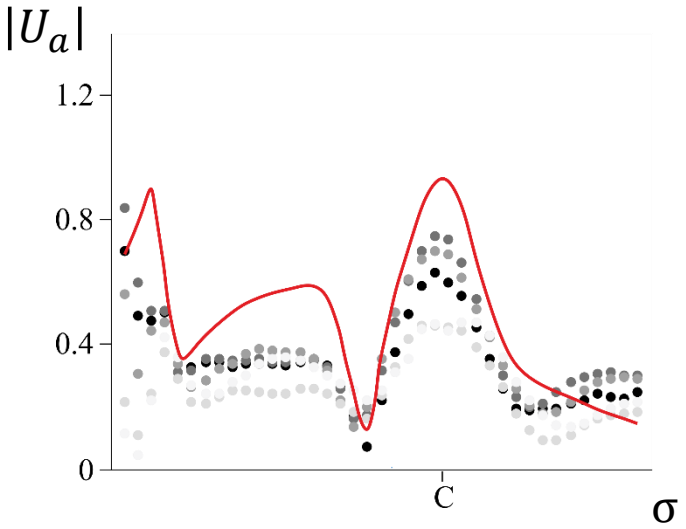
$\omega/N = 0.8$

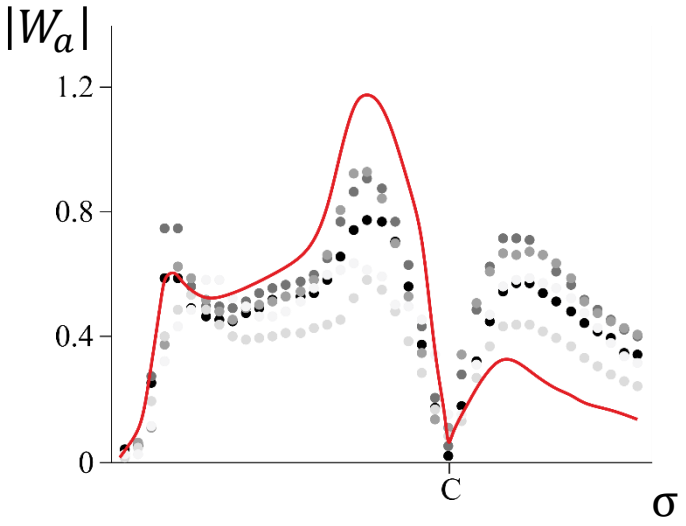
$St = 250$

Vertical velocity

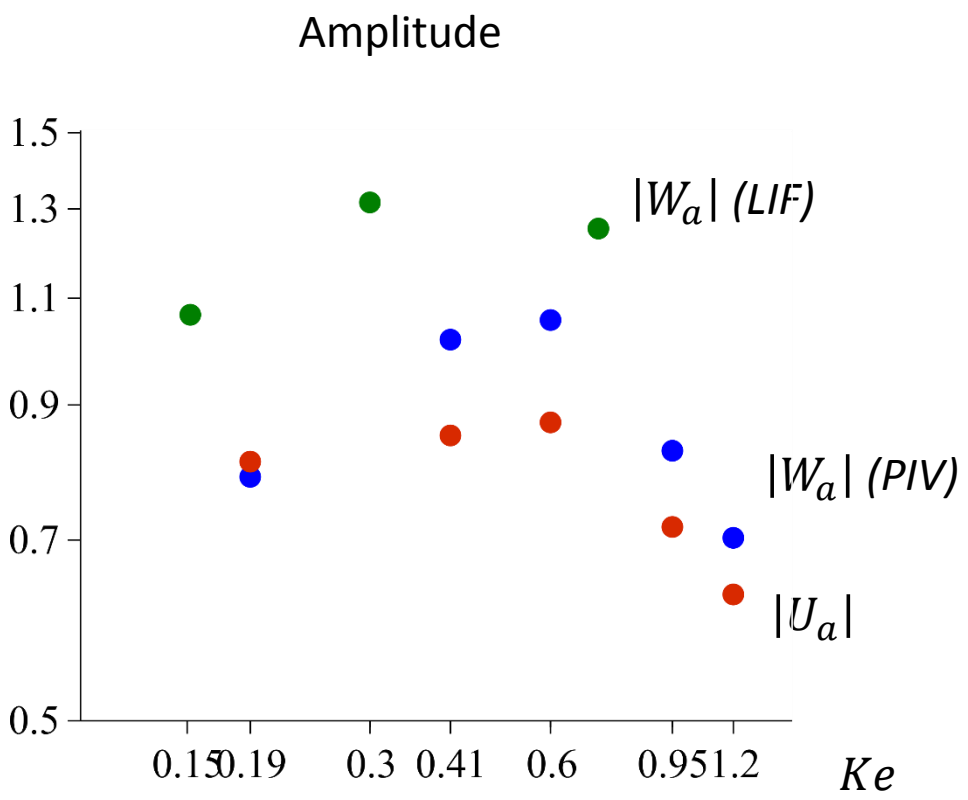


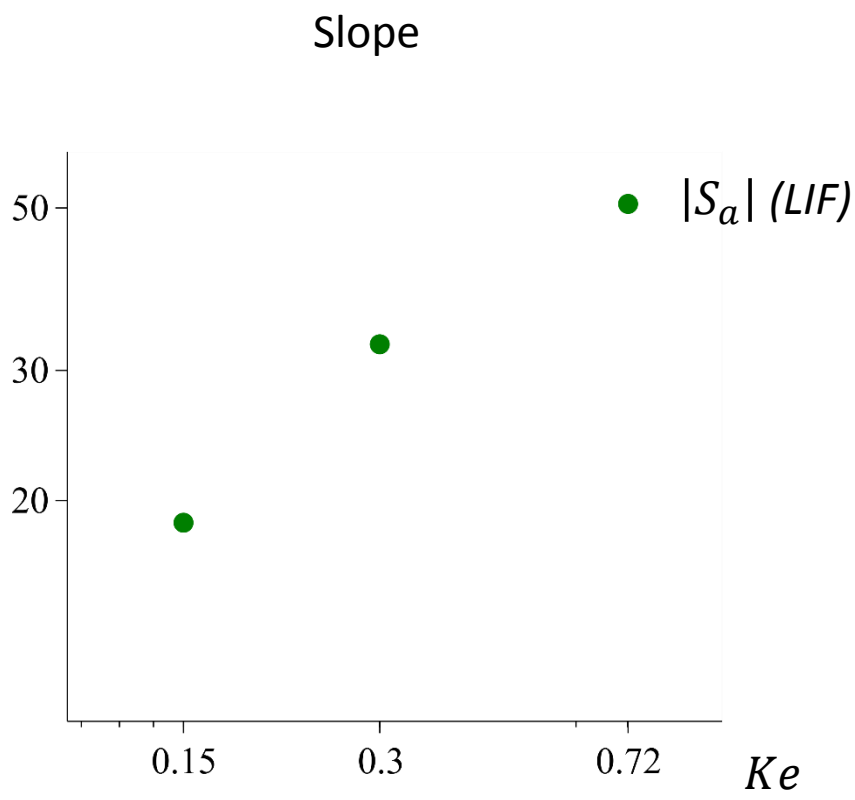
$Ke = 0.19, 0.41, 0.6, 0.95$





Weakly nonlinear effects





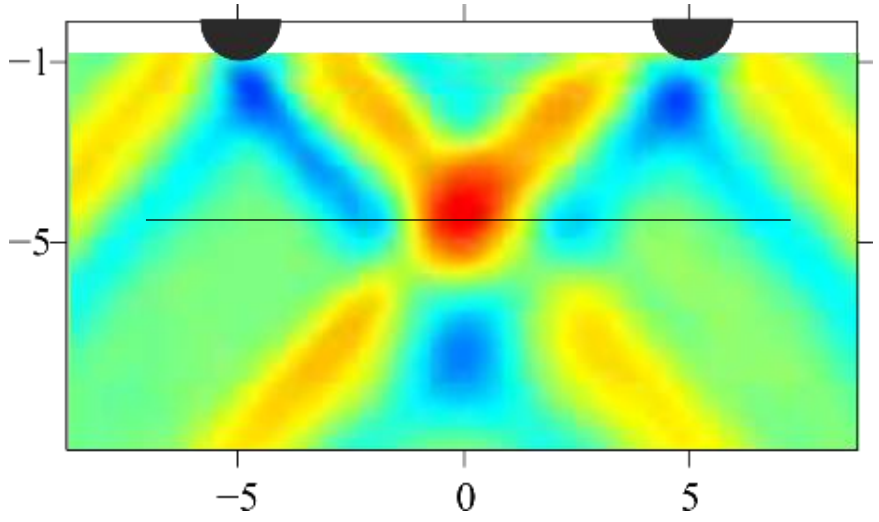
- Moderate *Ke:*
  breaking before reaching the maximum amplitude;
  $Ke_{critical} = 0.65$

Weakly nonlinear effects

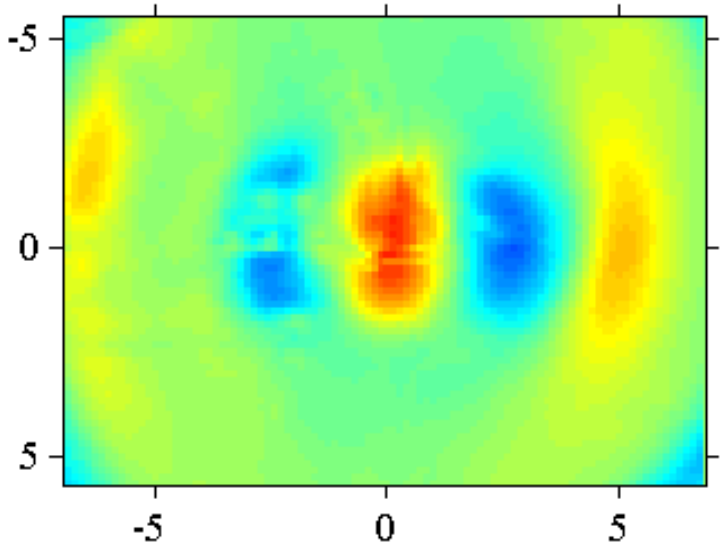
Instantaneous velocity at $\varphi = \pi/2$

$Ke = 0.95$

U, front view



U, top view



$Ke = 1$

- Internal waves propagation from the focal region

Conclusions

Linear case

- Amplification of the amplitude in focal zone
- Good comparison with linear theory

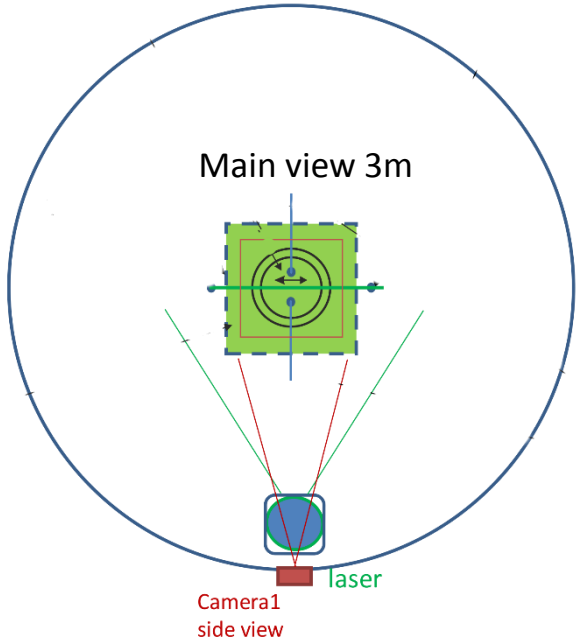
Weakly nonlinear effects

- Presence of higher harmonics in the focal zone
- Horizontal radiation of waves from the focal zone
- Steep slopes at moderate *Ke*

Next step: strongly nonlinear effects and turbulence

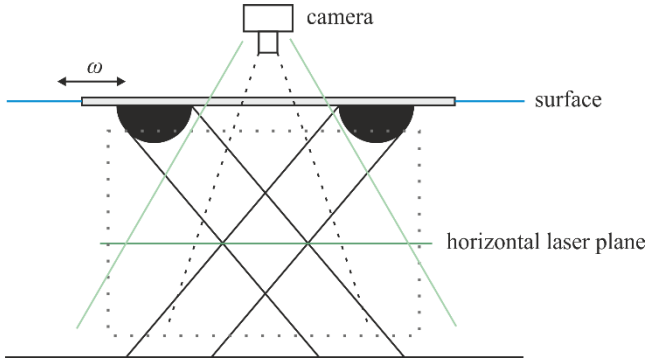
Need higher *St*, *Re* → larger radius of generatrix *a*

Experimental study of wave induced turbulence on the Coriolis platform

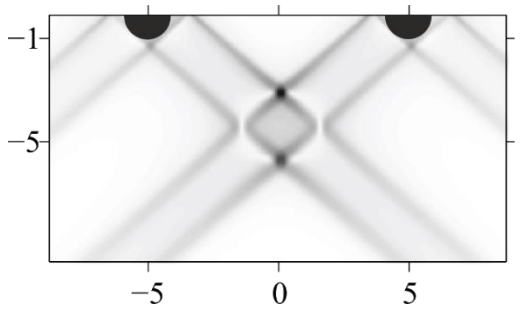


	Small Tank	Coriolis platform
a	2 cm	15 cm
b	10 cm	75 cm
St	250	9900
Re_{focal}	150	3000

1. Internal gravity waves and higher harmonics; breaking and generation of momentum
2. Turbulence generated by
   - Internal gravity waves
   - Inertia-gravity waves
   - Inertial waves



Horizontal velocity



Vertical velocity