Linear Optical Rogue Waves in Disordered Photonic Networks

Marios Mattheakis

University of Crete

Collaborators: I.J.Pitsios, G.P. Tsironis, S. Tzortzakis

European Union
European Social Fund

OPERATIONAL PROGRAMME
EDUCATION AND LIFELONG LEARNING
investing in knowledge society
MINISTRY OF EDUCATION & RELIGIOUS AFFAIRS, CULTURE & SPORTS
MANAGING AUTHORITY

NSRF 2007-2013
programme for development
EUROPEAN SOCIAL FUND

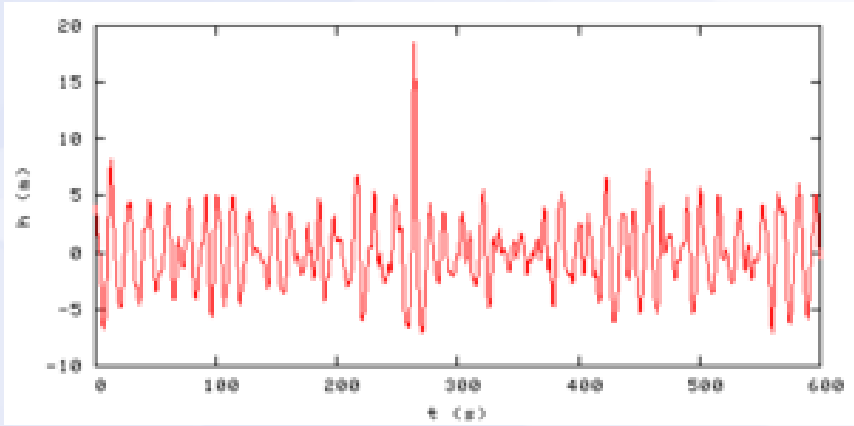
Co-financed by Greece and the European Union

Outline

- Rogue (or Freak) waves
- Luneburg and inverted Luneburg lens
- Simulation and Experiment setup
- Linear optical rogue wave
- Rogue wave as strong scattering effect
- Nonlinearity in linear rogue wave
- Conclusion

Rogue Waves

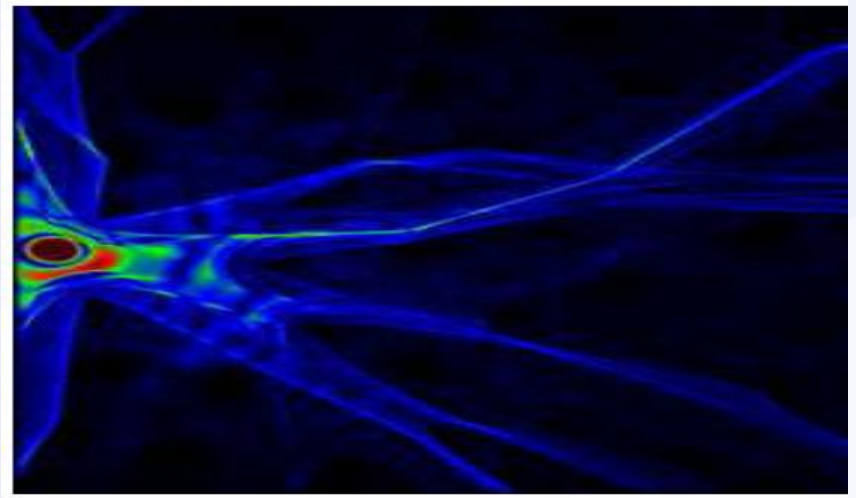
- Rogue waves are spontaneous events which are defined as waves whose height is more than twice the significant wave height (SWH)
- SWH is defined as the mean of the largest third of waves in a wave record
- Firstly observed in 1995 in oceanic surface waves



Artistic illustrator of oceanic rogue waves

Rogue Waves in Optics

- R.Hohmann et al. have observed experimentally optical rogue waves in microwave regime.
- They study the microwave transport through a scattering system composed of randomly placed metallic cones

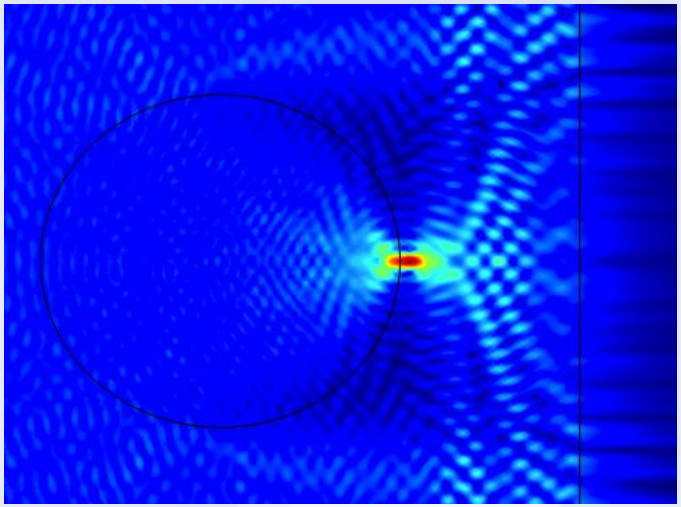


R. Hohmann et al. Phys. Rev. Lett. 104, 093901 (2010)

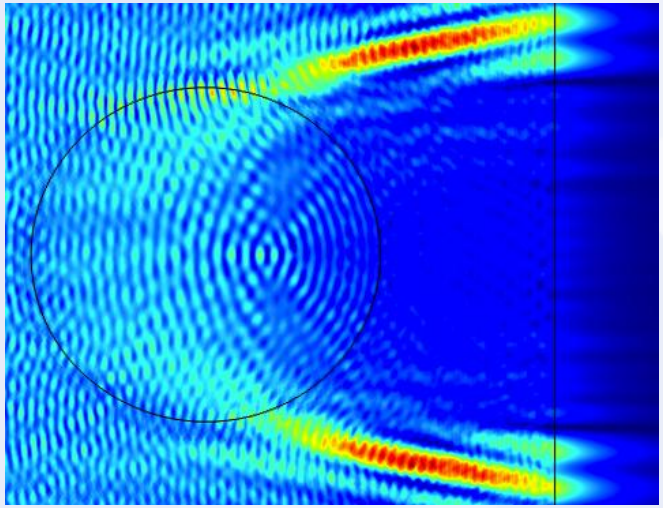
Luneburg and inverted Luneburg lens

- A Luneburg lens is a spherical structure with a specific functional dependence on the lens radius (Eq. 1)
- Its basic property is that it focuses parallel rays on the spherical surface on the opposite side of the lens
- An inverted Luneburg lens has the opposite characteristics (Eq. 2)

$$n(r)=\sqrt{2-\left(\frac{r}{R}\right)^2} \quad (1)$$



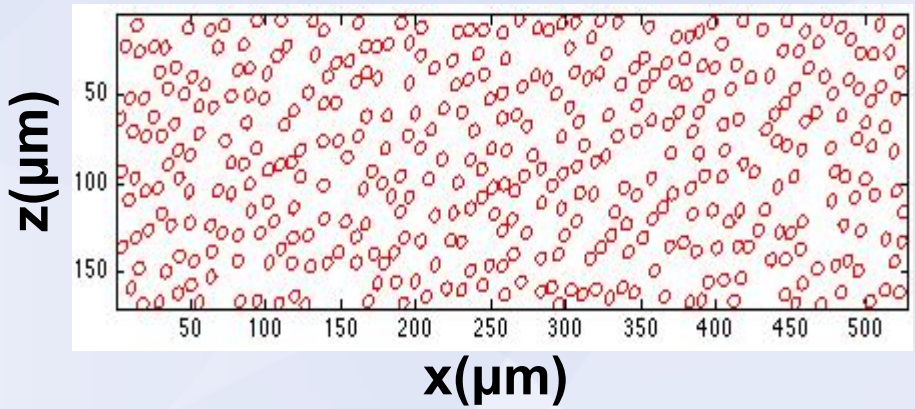
$$n(r)=\sqrt{1+\left(\frac{r}{R}\right)^2} \quad (2)$$



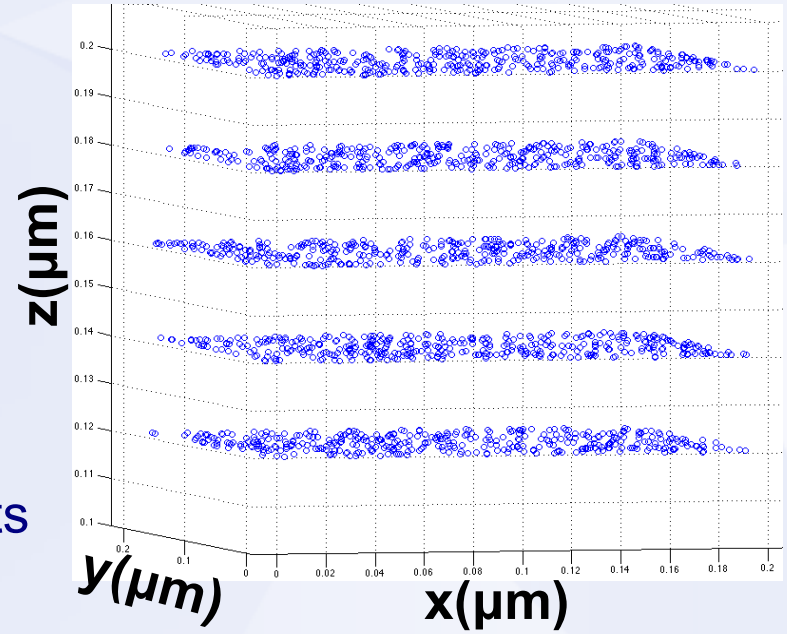
Simulation and Experiment setup

- A number of inverted Luneburg lens network, where constructed in the bulk of glass plates forming a lattice. By allowing a laser beam to propagate through these lattices we could monitor the occasion of freak wave.

- Simulations have been performed in 2D lattices

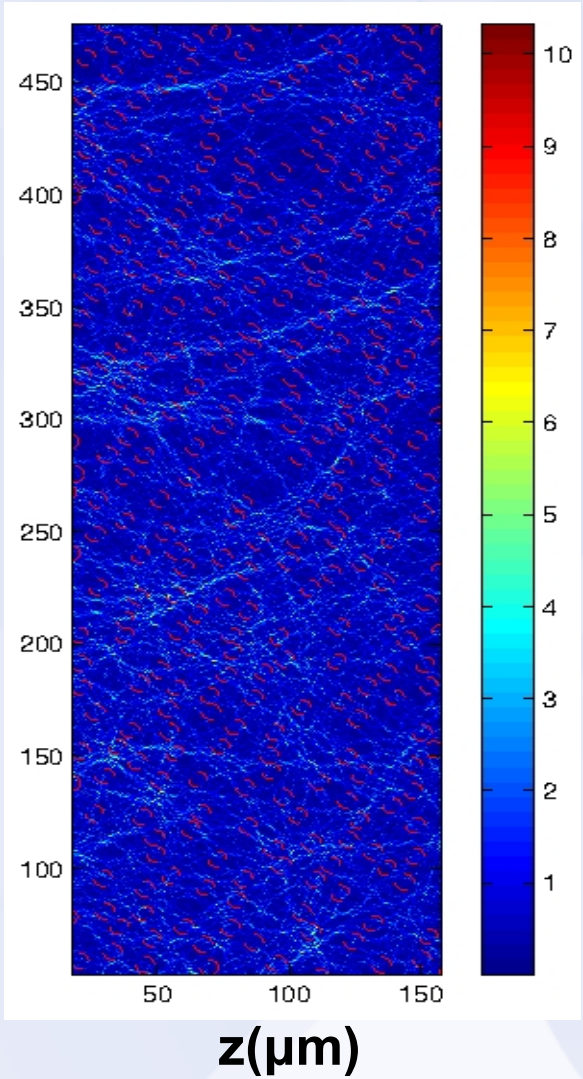


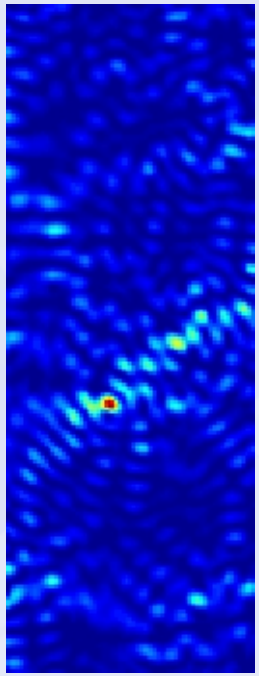
- Experiments have been performed in 3D lattices

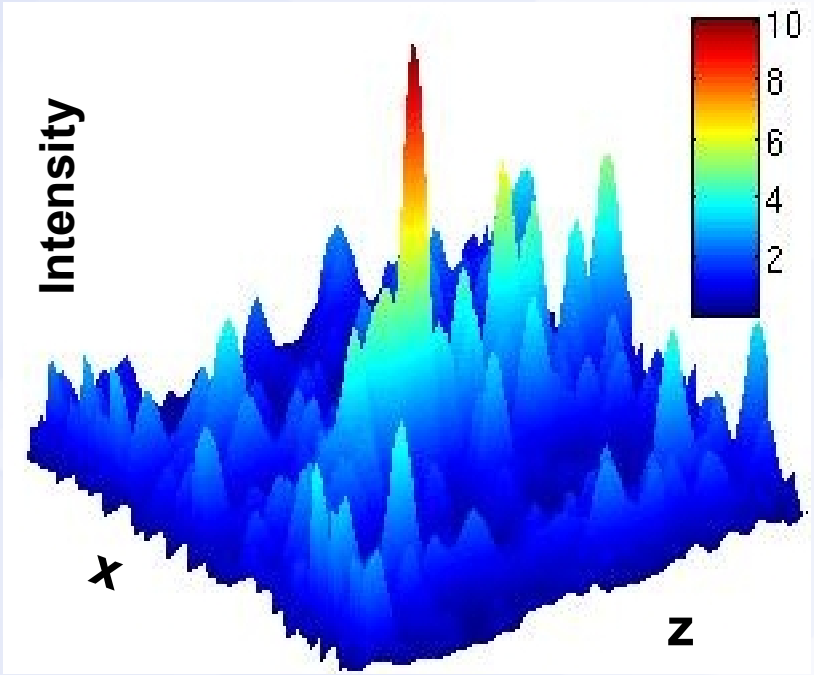


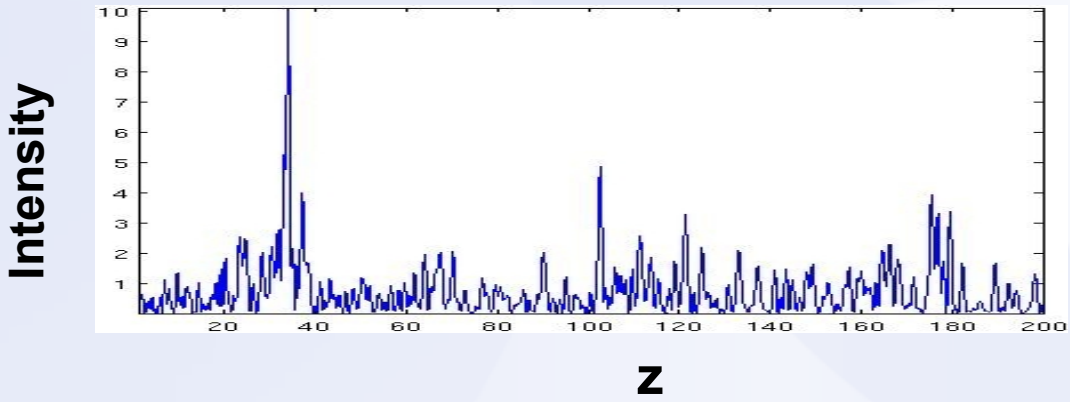
Both in simulations and in experiments the beam propagates in z axis

Linear Rogue Wave (simulation)









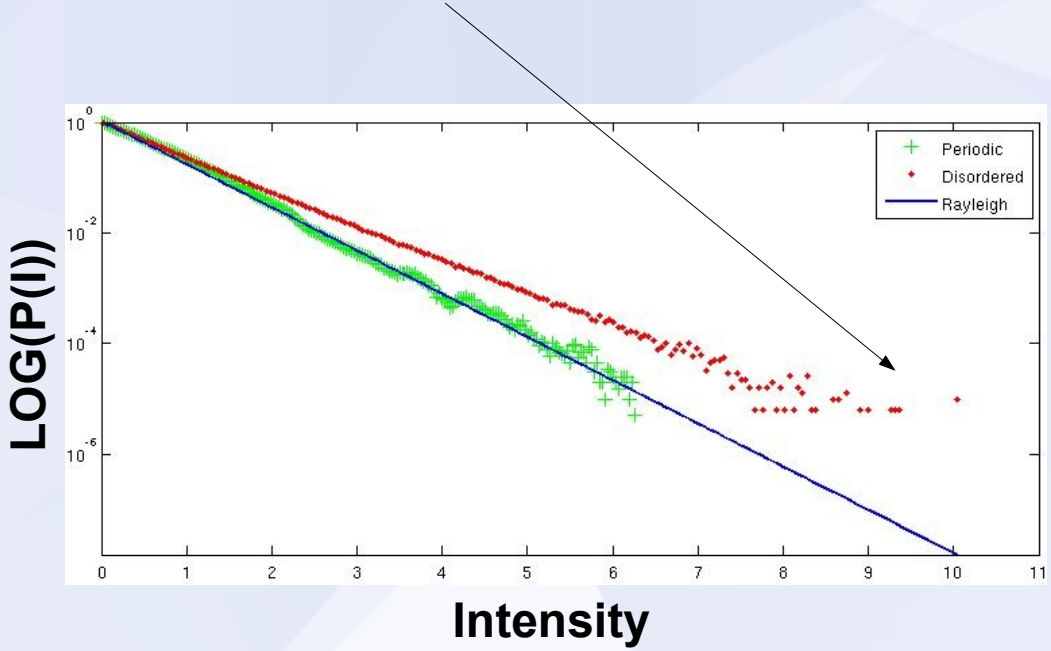
Distribution of Intensities

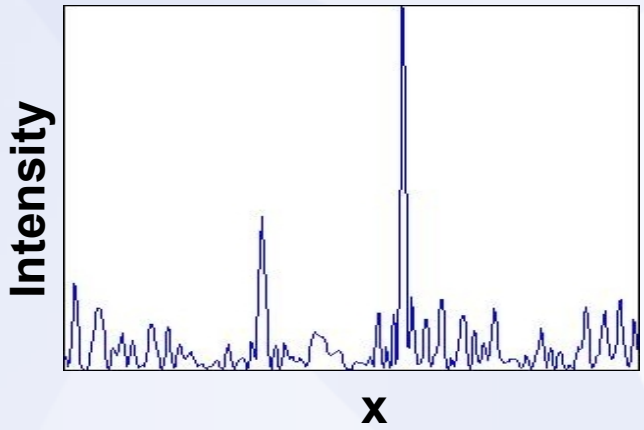
- Rayleigh distribution for the propagation through a random media

$$P(I) = e^{-I}$$

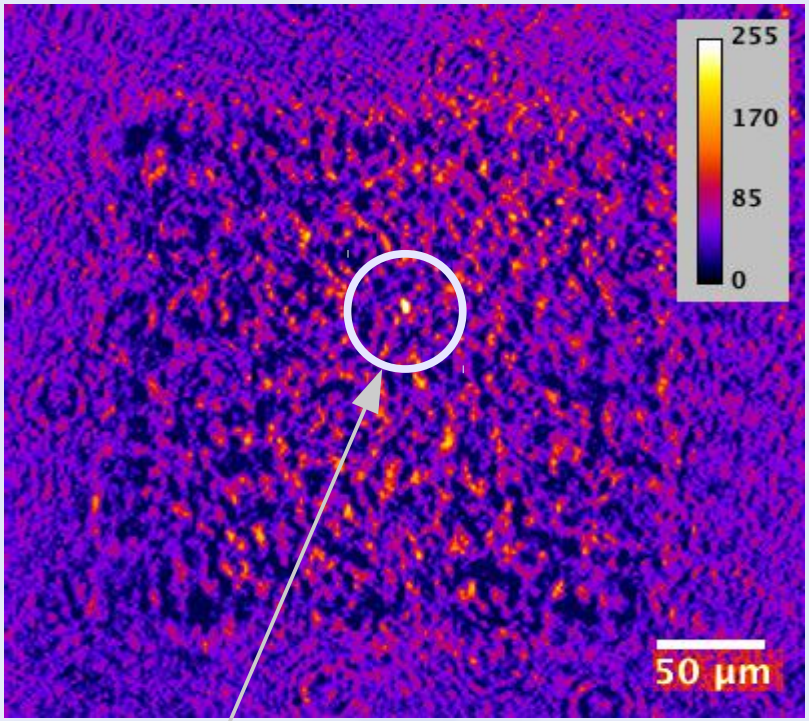
  - *I* is the intensity normalized to one

- Long tails implies rogue waves

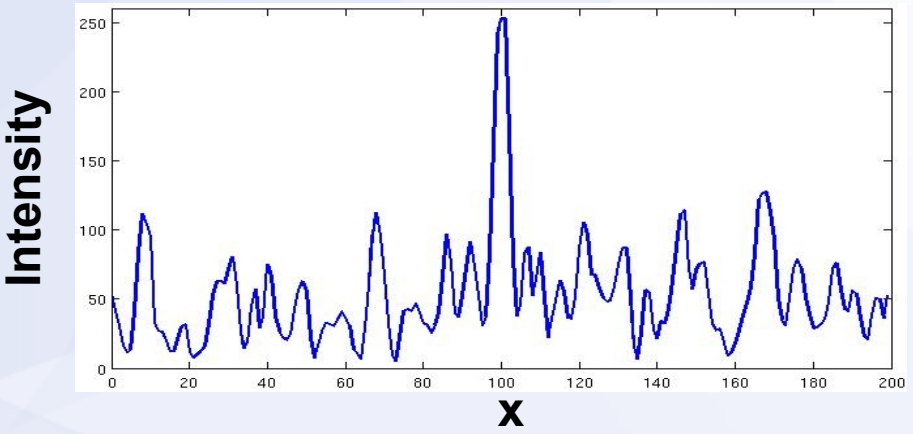


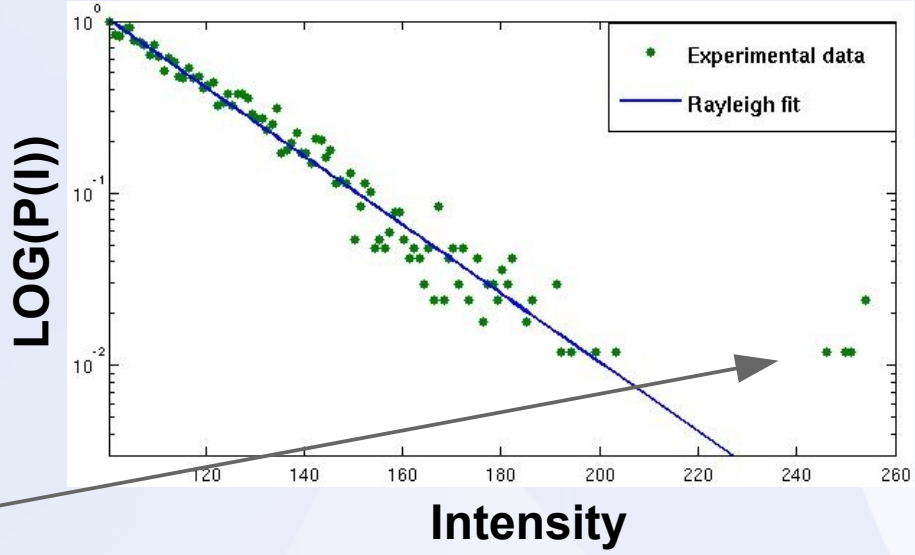


Linear Rogue Wave (experiment)



Rogue Wave



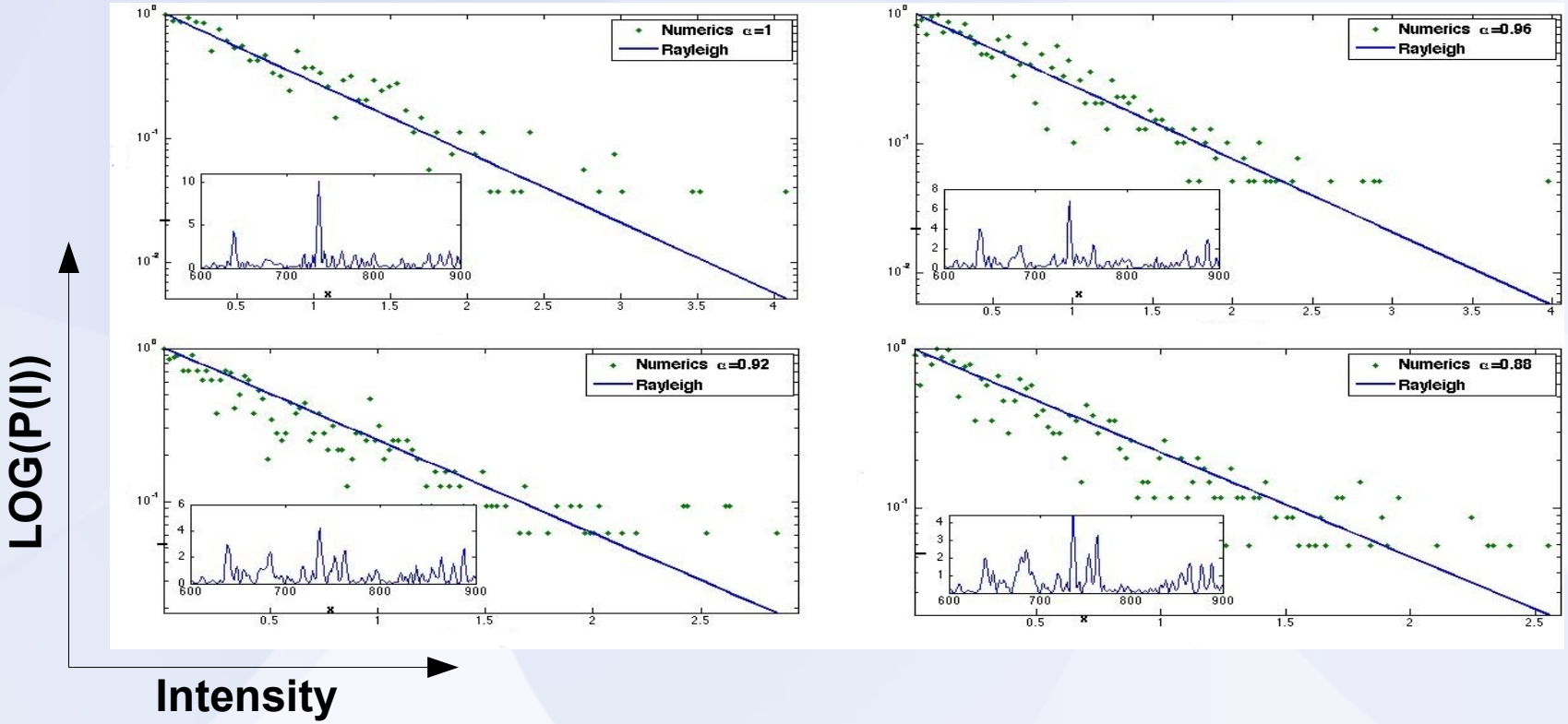


Long Tail

Refractive index variation (simulations)

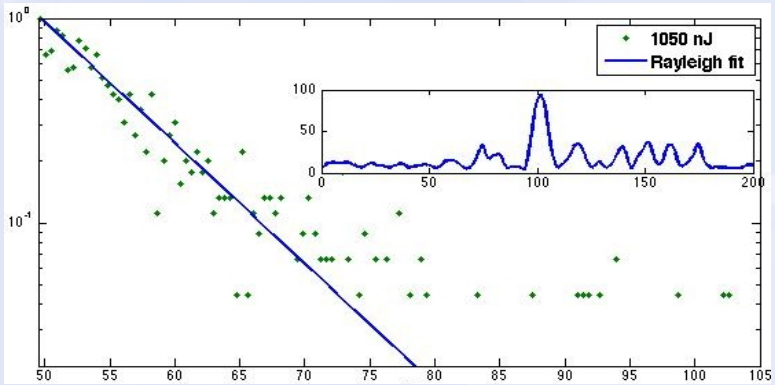
- Generalizing the refractive index by introducing a “strength” factor α, which is proportional to refractive index variation

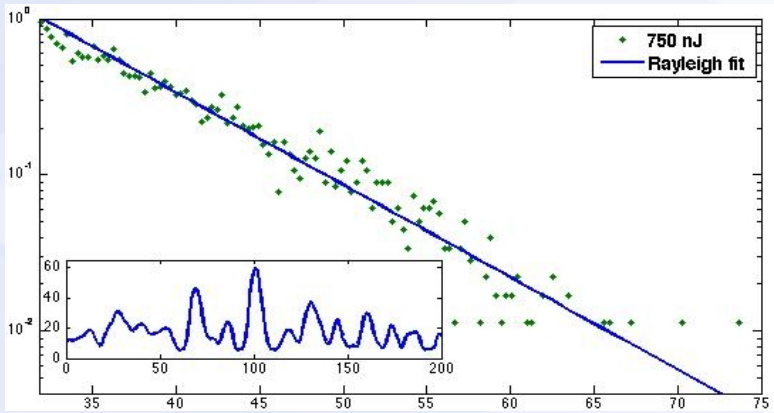
$$n(r;\alpha)=\sqrt{2+\alpha\left(\left(\frac{r}{R}\right)^{2}-1\right)}$$

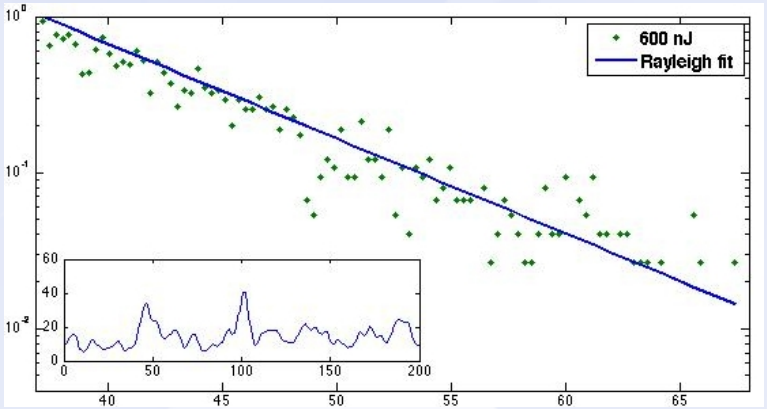


Refractive index variation (experiment)

- Changing lens refractive index the variation by controlling the irradiation energy that we construct the lenses.
- The irradiation energy is proportional to the refractive index variation







LOG(P(I))

Intensity

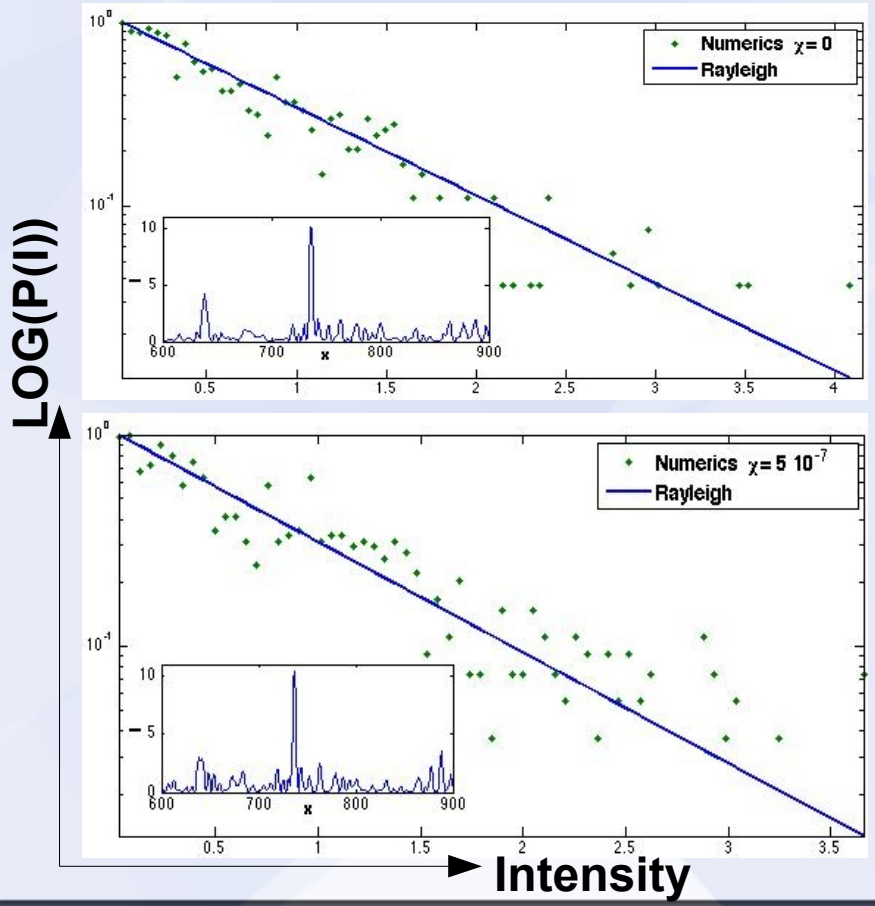
- No Rogue waves for low refractive index variation, resulting that Rogue wave is a strong scattering effect.

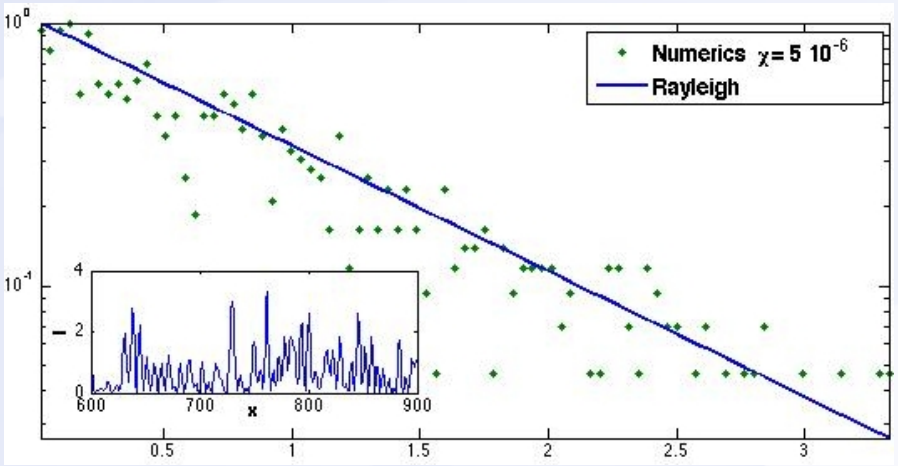
Rogue waves in the non-linear regime (simulations)

- Introducing nonlinearity in the refractive index (Kerr effect)

$$n(r)^2 = n_L^2 + \chi |E|^2$$

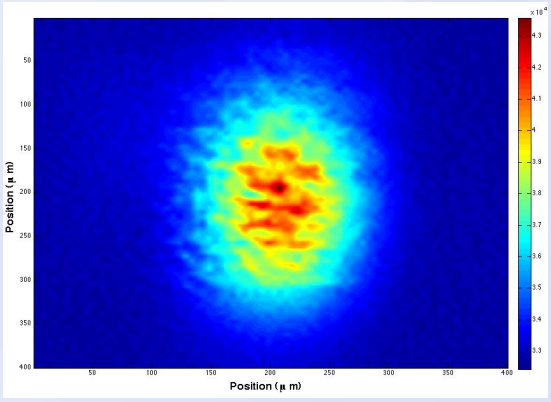
- n_L is the linear part of refr. index
- E is the electric field

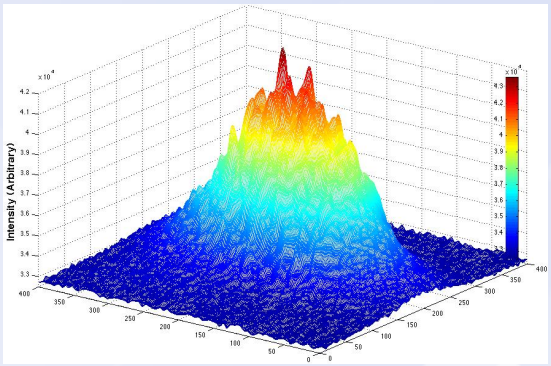




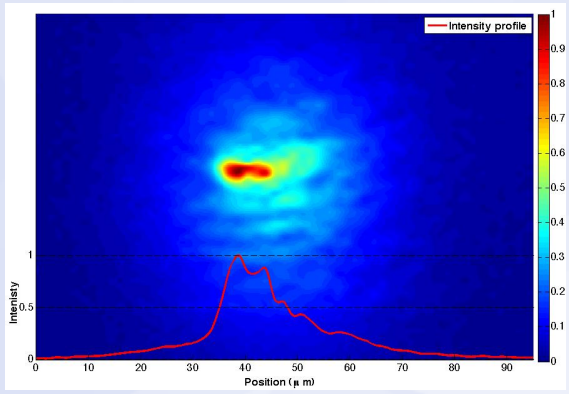
- ✔ Low nonlinearity does not affect the linear rogue wave
- ✔ In very high nonlinearity the rogue wave disappears

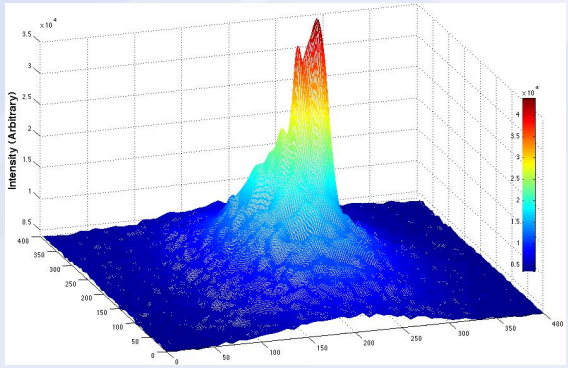
Rogue waves in the non-linear regime (experiment)



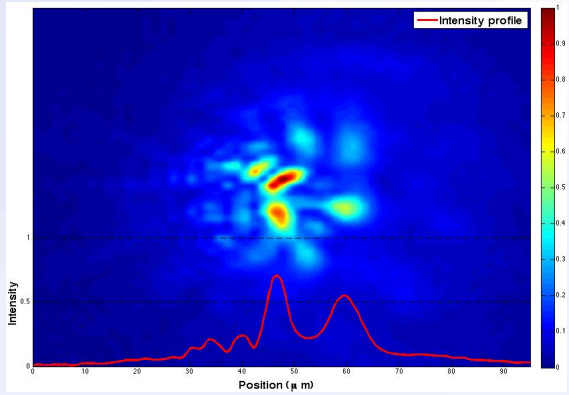


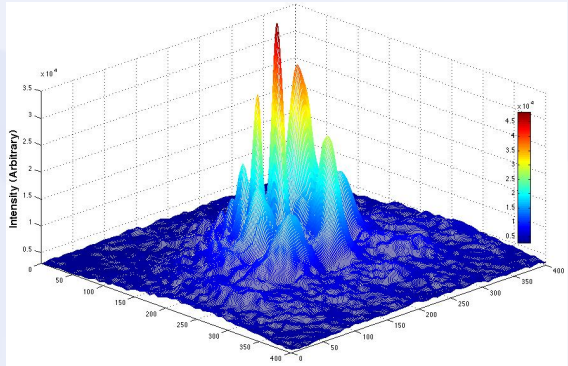
Rogue wave lattice below non-linear threshold





Rogue wave lattice above non-linear threshold





Non rogue wave lattice above non-linear threshold

Conclusion

- The experimental results, although in 3D lattices, are in perfect agreement with the numerics which are performed in 2D, further proving the advisability of this work.
- Rogue wave seems to be a purely LINEAR event
- We propose that Rogue wave is a strong scattering phenomenon

M.Mattheakis et al, *Linear Optical Rogue Waves,* (in preparation)

Thanks for attention

Email: mariosmat@physics.uoc.gr

website: http://nls.physics.uoc.gr

This research has been co-financed by the European Union (European Social Fund ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) - Research Funding Program: THALES. Investing in knowledge society through the European Social Fund.

Co-financed by Greece and the European Union