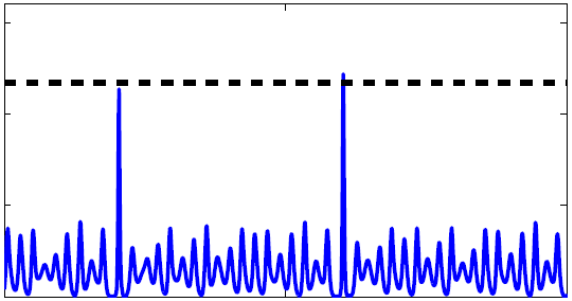

Controlling the likelihood of rogue waves

in an optically injected semiconductor laser via direct current modulation

Cristina Masoller

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Workshop on Abnormal Wave Events (W-AWE 2014)

Nice, France, June 2014

Collaborators

- Sandro Perrone (ex PhD student at UPC, now at the University of Leicester, UK)

- Jordi Zamora Munt (IFISC, Mallorca, Spain)

- Ramon Vilaseca (UPC)

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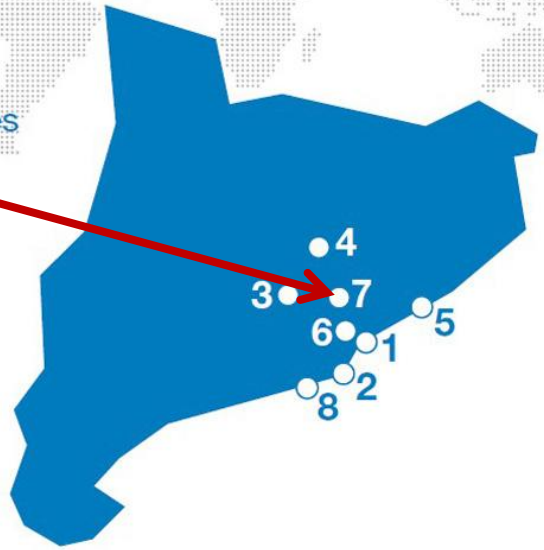
Where are we?

We are at Campus Terrassa

UPC in Catalunya

1. Barcelona
2. Castelldefels
3. Igualada
4. Manresa
5. Mataró
6. Sant Cugat del Vallès
7. Terrassa
8. Vilanova i la Geltrú



Viernes, 25 de septiembre de 2009 Diari de Terrassa

El edificio Gaia centraliza grupos científicos consolidados y emergentes.

Research building (Gaia)
New students' residence (Hipatia)

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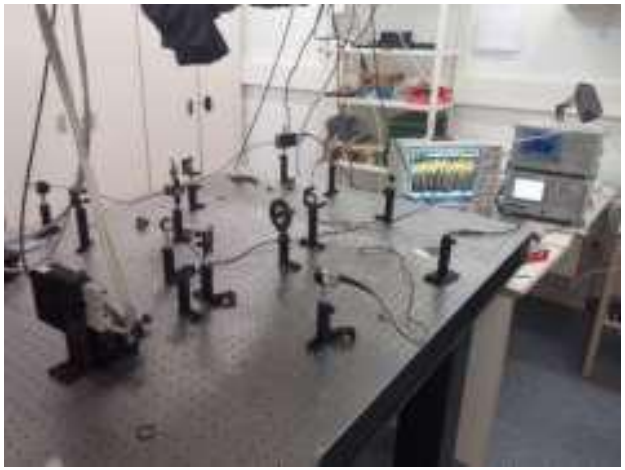
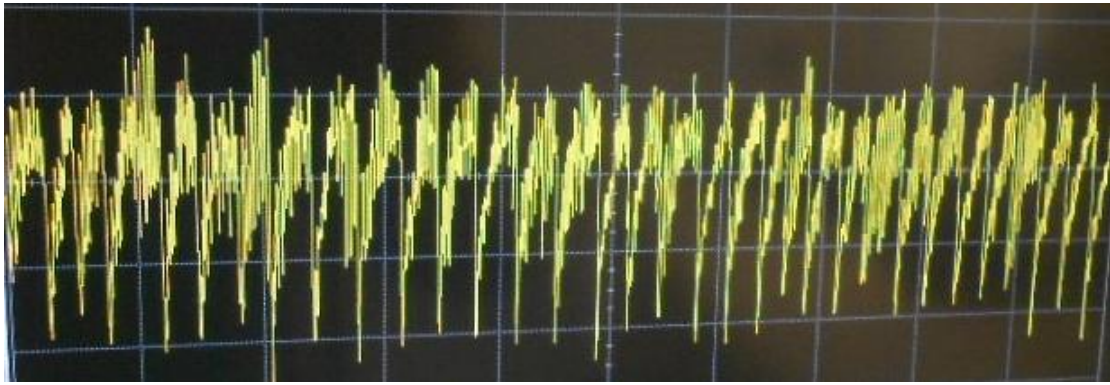
Dynamics, Nonlinear Optics and Lasers research group

www.donll.upc.edu

Semiconductor laser lab





- Time-series analysis of low-frequency fluctuations
- Statistical features similar to neuronal spikes

Outline

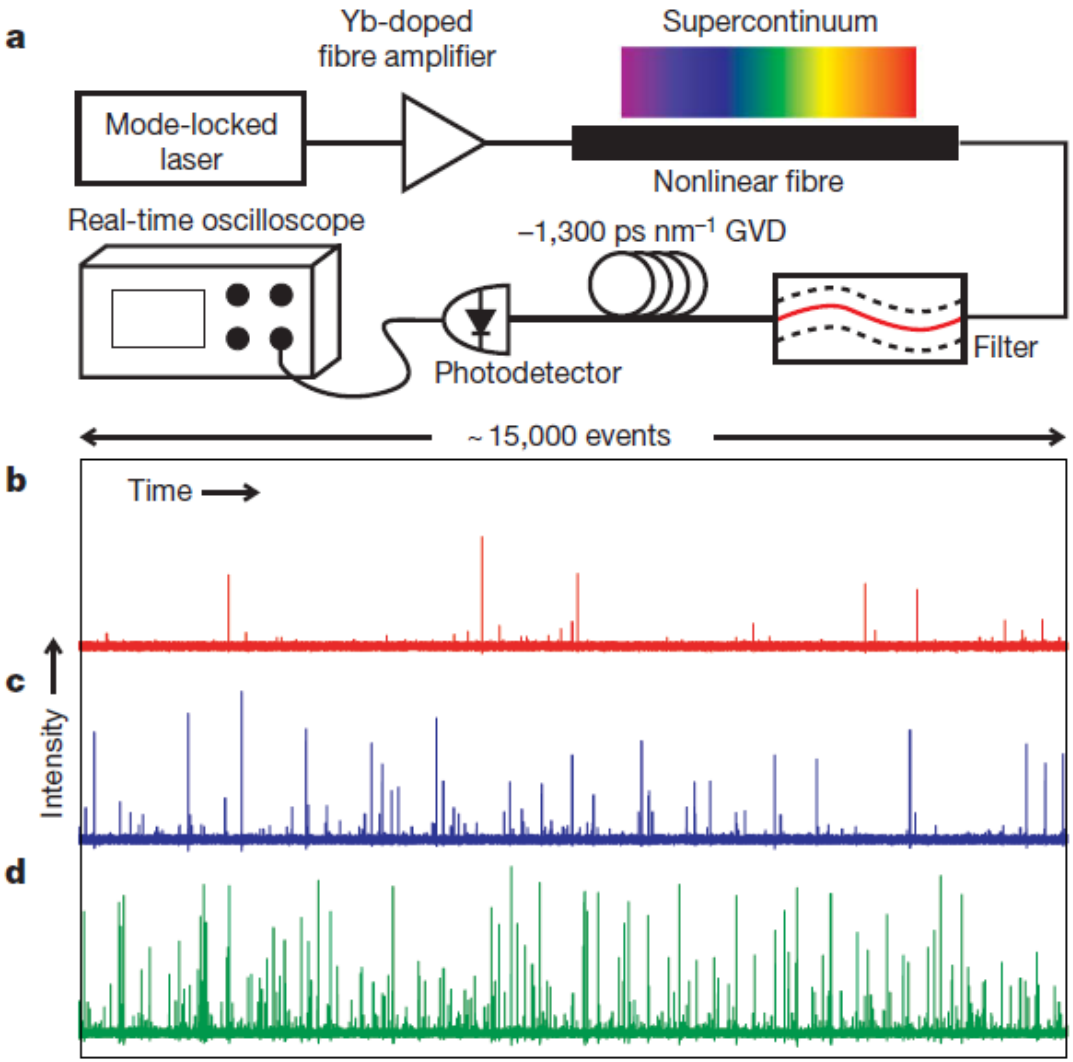
- Introduction (optical rogue waves, semiconductor lasers).
- Semiconductor laser with **optical injection**: experimental observations & numerical results.
- Influence of **current modulation** (numerical results).
- Summary and conclusions.

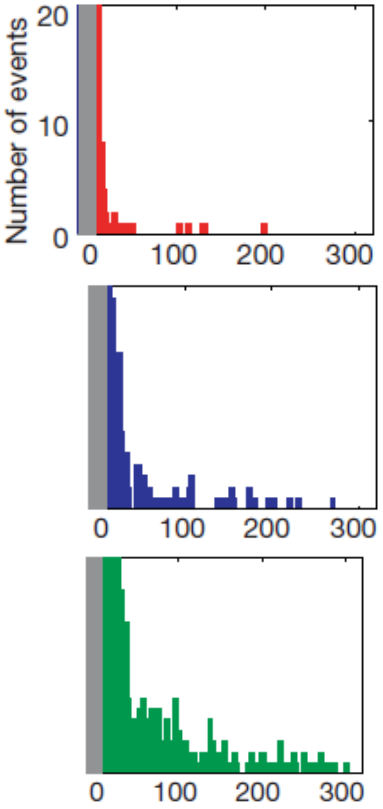
Rogue waves

RWs are rare, ultra-high waves that fall outside (and far from) the main part of long-tailed probability distributions.

The Great Wave of Kanagawa, Katsushika Hokusai. Source: Wikipedia

Optical RWs: first observation





D. R. Solli et al, Nature 450, 1054, 2007

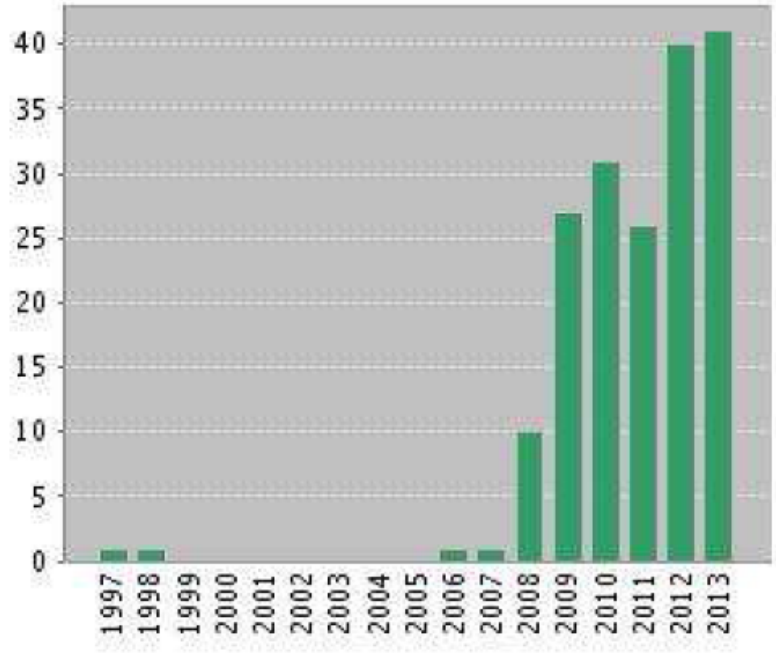
Since 2007: a lot of work

Citation Report Topic=(optical rogue wave)

Timespan=All years. Databases=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH.

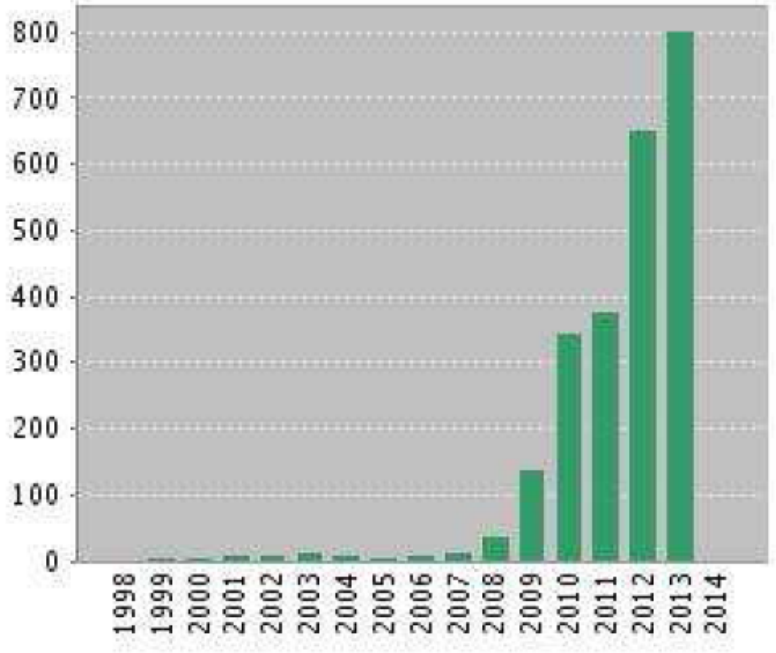
This report reflects citations to source items indexed within Web of Science. Perform a Cited Reference Search to include cita
indexed within Web of Science.

Published Items in Each Year



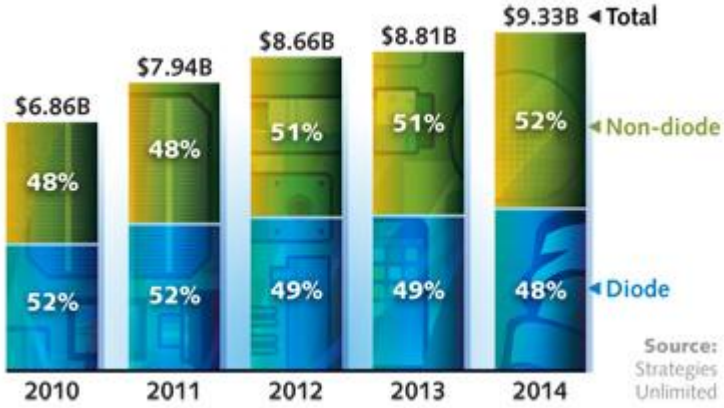
The latest 20 years are displayed.

Citations in Each Year



The latest 20 years are displayed.

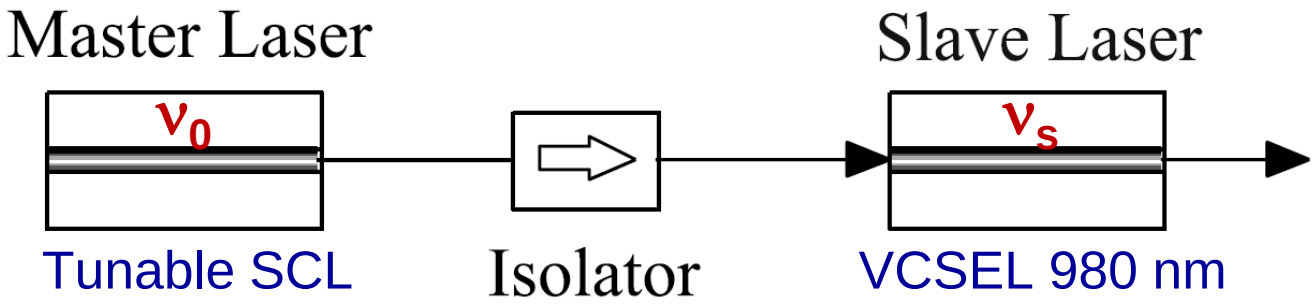
Why semiconductor lasers? (diode lasers)



- Used in
  - Telecommunications
  - Data storage (CDs, DVDs, Blu rays)
  - Barcode scanners, printers, mouse
  - Material processing
  - Biomedical applications (imaging, sensing, etc)

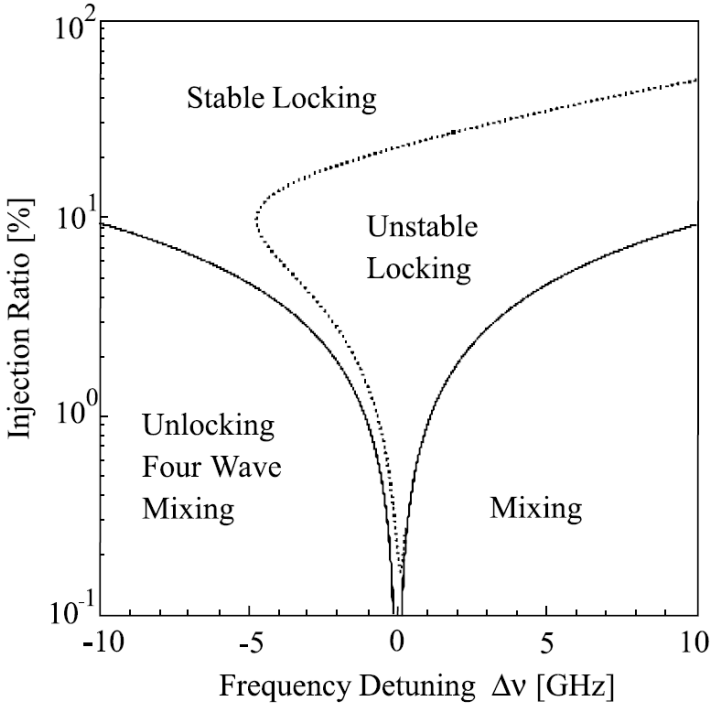
- SLs provide an inexpensive setup for the study of ORWs

Optically injected diode lasers



Detection system (photo detector, oscilloscope, spectrum analyzer)

- Parameters:
  - Injection ratio
  - Frequency detuning $\Delta\nu = \nu_s - \nu_0$
- Dynamical regimes:
  - Injection locking (cw output)
  - Period-one oscillation
  - Period-two oscillation
  - Chaos



Adapted from J. Ohtsubo

Eur. Phys. J. D 58, 181–186 (2010)
DOI: 10.1140/epjd/e2010-00061-4

THE EUROPEAN PHYSICAL JOURNAL D

Regular Article

Labyrinth bifurcations in optically injected diode lasers

V. Kovanis[1], A. Gavrielides[2], and J.A.C. Gallas[3,4,5,a]

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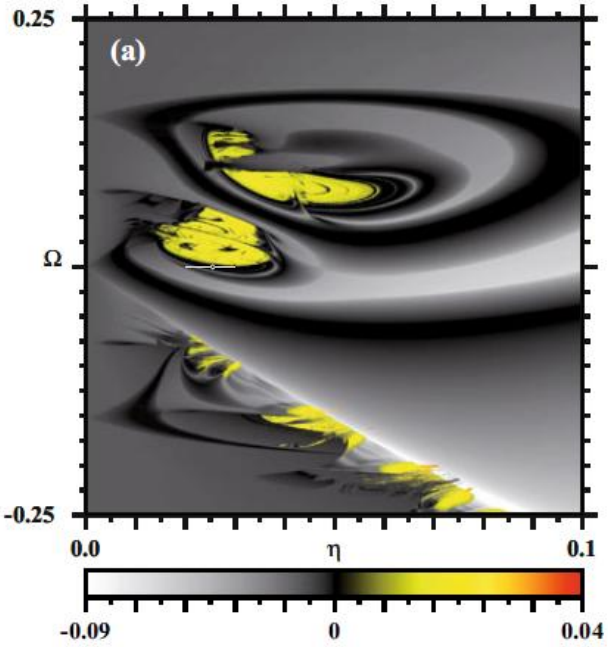
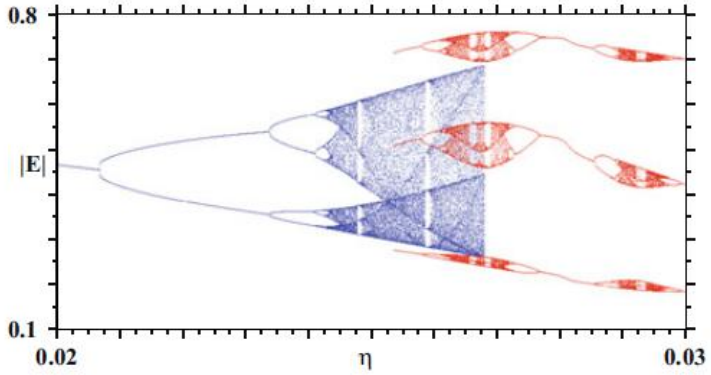
[2] USAF, Research Laboratory, High Power Solid State Lasers Branch, Kirtland AFB, NM 87117, USA
[3] TecEdge, Wright Brothers Institute, 5100 Springfield Street, Dayton OH 45431, USA
[4] Departamento de Física, Universidade Federal da Paraíba, 58051-970 João Pessoa, Brazil
[5] Instituto de Física, Universidade Federal do Rio Grande do Sul, 91501-970 Porto Alegre, Brazil

Lyapunov diagram



Bifurcation diagram

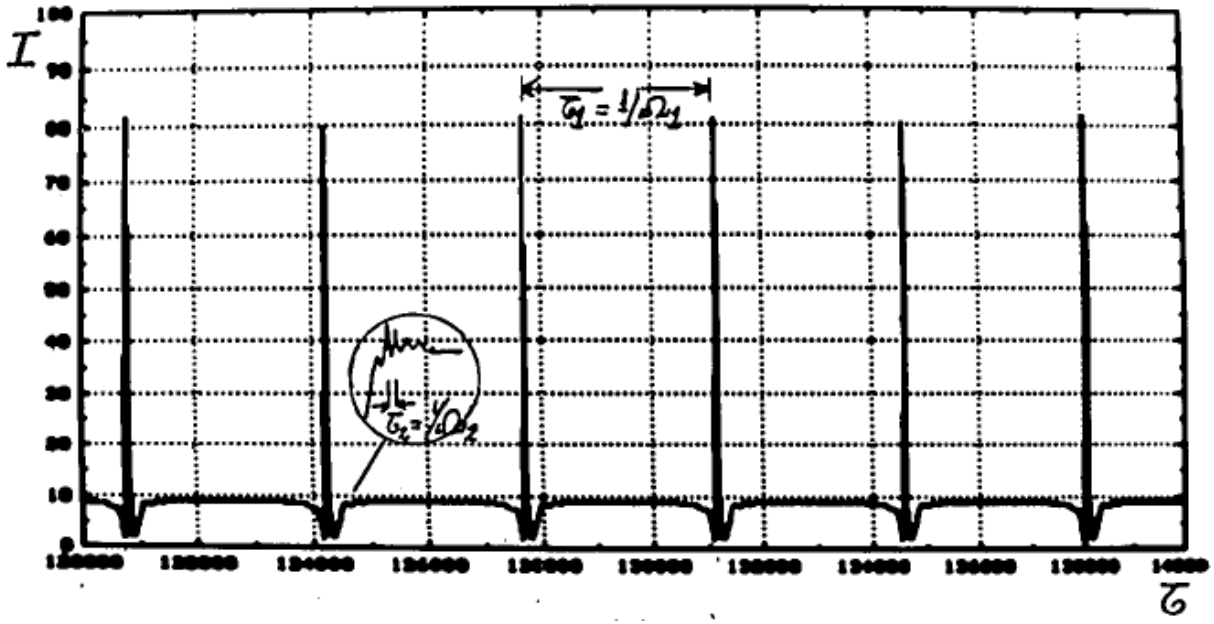


Also RWs?

Instabilities in lasers with an injected signal

J. R. Tredicce, F. T. Arecchi, G. L. Lippi, and G. P. Puccioni

178 J. Opt. Soc. Am. B/Vol. 2, No. 1/January 1985



Our work in optically injected semiconductor lasers

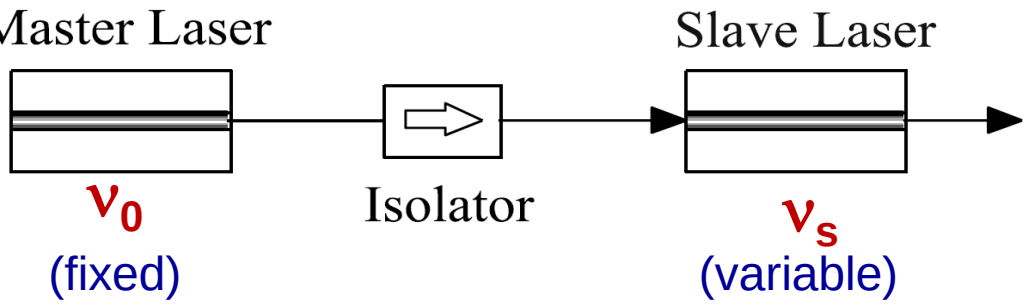
- Experimental and numerical identification of deterministic rogue waves.

C. Bonatto et al, *Deterministic optical rogue waves*, PRL 107, 053901 (2011).

- RWs can be predicted with a certain anticipation time.
- They are generated by an external crisis-like process.
- Noise can either enhance or diminish their probability of occurrence.

J. Zamora-Munt et al, *Rogue waves in optically injected lasers: origin, predictability and suppression,* PRA 87, 035802 (2013).

Control parameters



The **frequency detuning** between the lasers, $\Delta\nu = \nu_s - \nu_0$, is controlled by the slave laser pump current, **I**

When **I** increases:

→ **Joule heating**

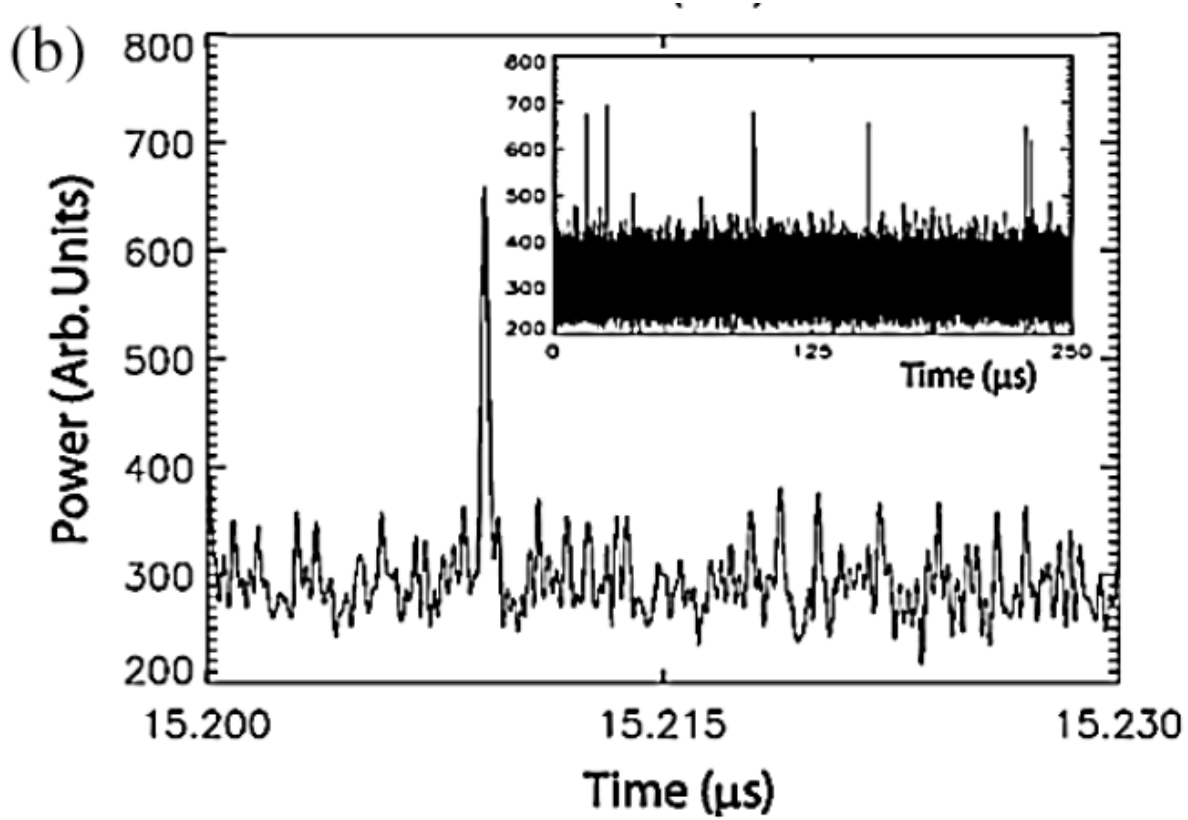
→ **the temperature modifies the cavity refractive index**

→ **decreases the cavity resonance frequency** $\nu_s = g(Temp) = f(I)$

(f approximately linear)

By varying the slave laser pump current we changed the frequency detuning between the lasers

Time series of the laser intensity

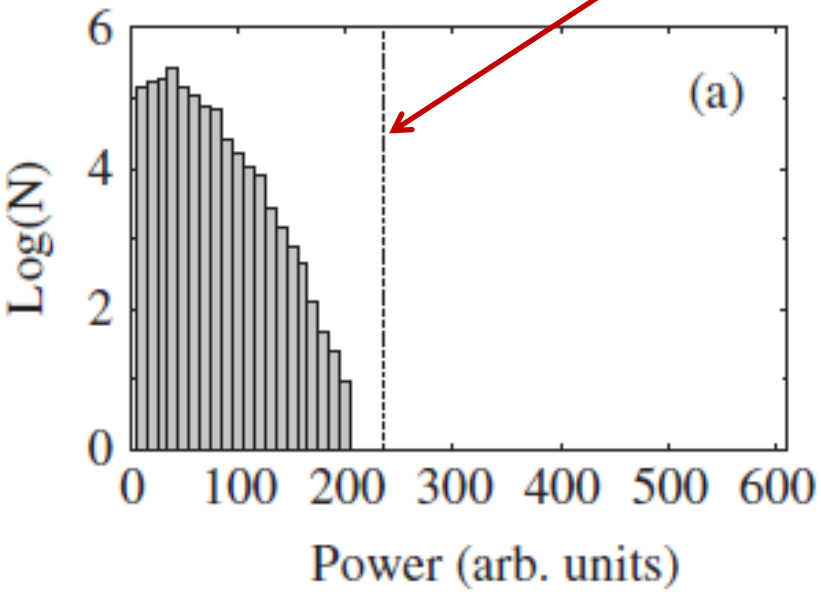


I = 0.976 mA,
$\Delta\nu$ = -1.34 GHz

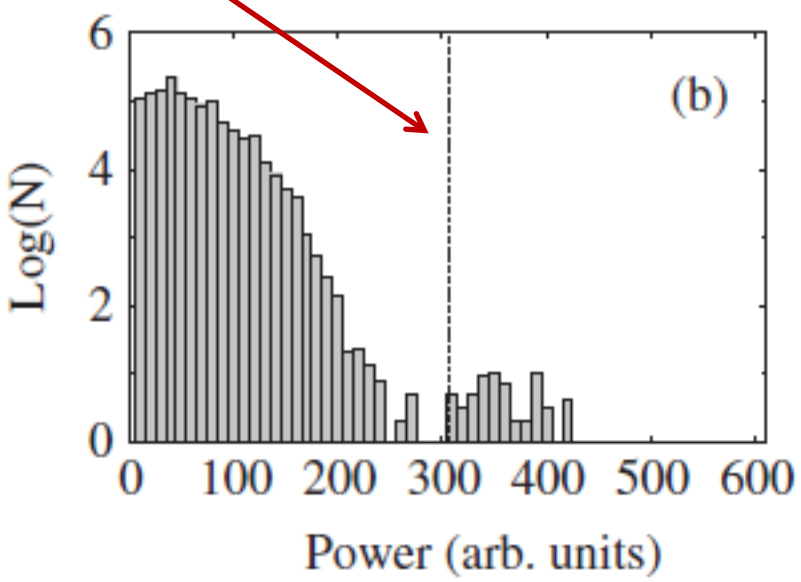
C. Bonatto M. Feyereisen, S. Barland, M. Giudici, C.Masoller, J. R. Rios Leite and J. R. Tredicce, PRL 107, 053901 (2011)

Histograms of pulse amplitude

Border = mean value + 8 σ



I = 0.972 mA



I = 0.976 mA

Governing equations

- The *complex* optical field, **E** (photon number $\propto$ **$|E|^2$**)
- The carrier density, **N**

$$\frac{dE}{dt} = \frac{1}{2\tau_p}(1+i\alpha)(N-1)E + i\Delta\omega + \sqrt{P_{\text{inj}}} + \sqrt{2\beta_{sp}/\tau_N}\,\xi(t)$$

$$\frac{dN}{dt} = \frac{1}{\tau_N}\left(\mu - N - N|E|^2\right)$$

optical injection
η: injection strength
Δω: frequency detuning

spontaneous emission noise

Solitary laser parameters: **α τ_p τ_N μ**

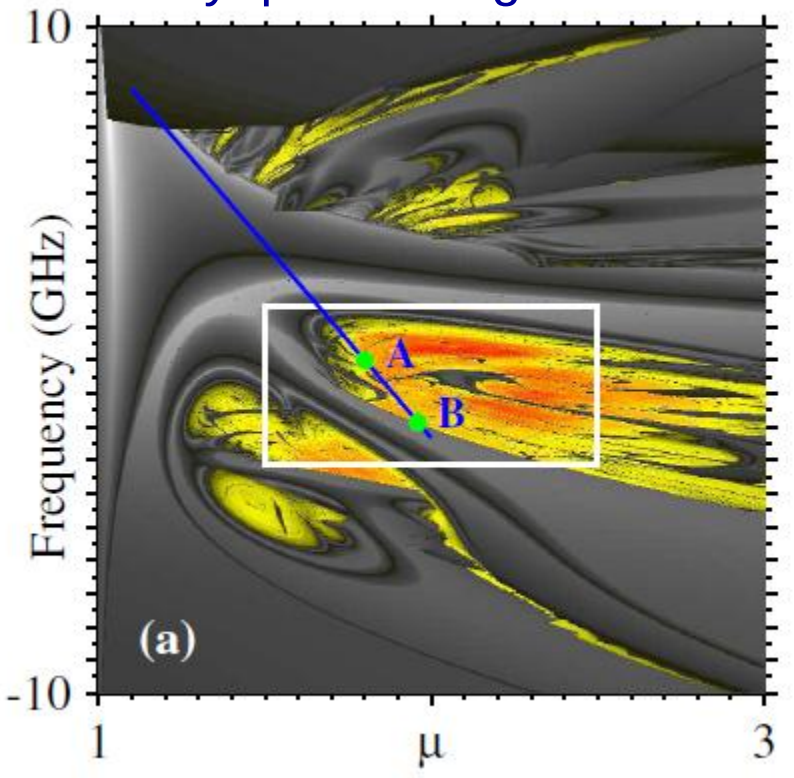
Typical parameters:
$\alpha = 3$, $\tau_p = 1$ ps, $\tau_N = 1$ ns

μ: normalized pump current parameter

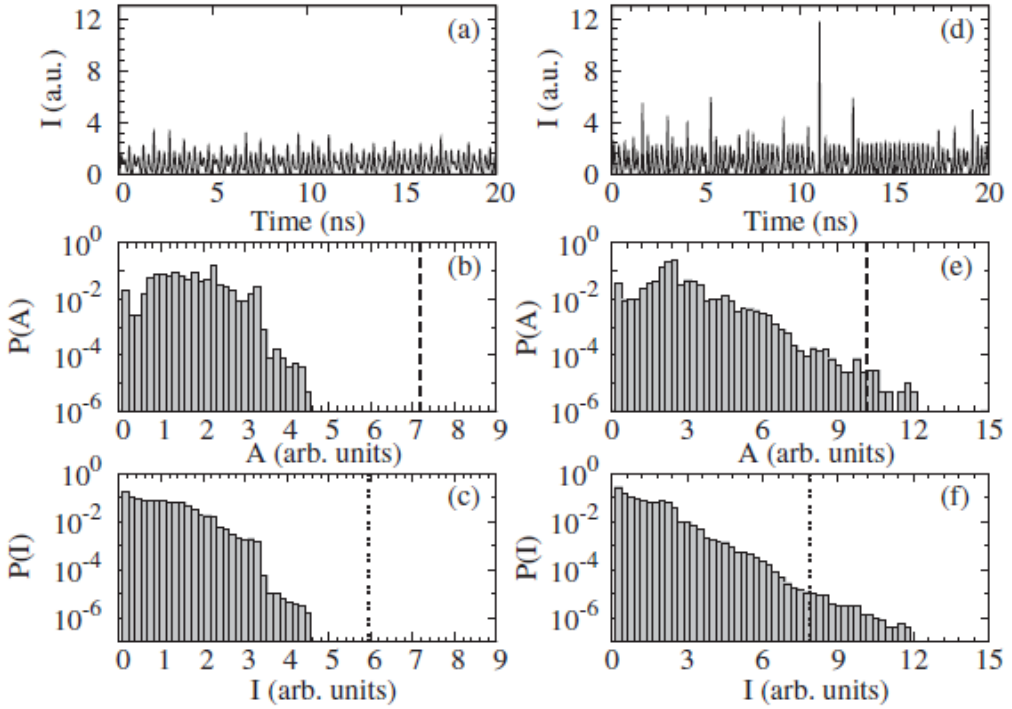
$$\mu = \mu_{dc} + a_{\text{mod}}\sin(\omega_{\text{mod}}\,t)$$

Deterministic simulations (β_{sp}=0)

Lyapunov diagram



Slave laser pump current

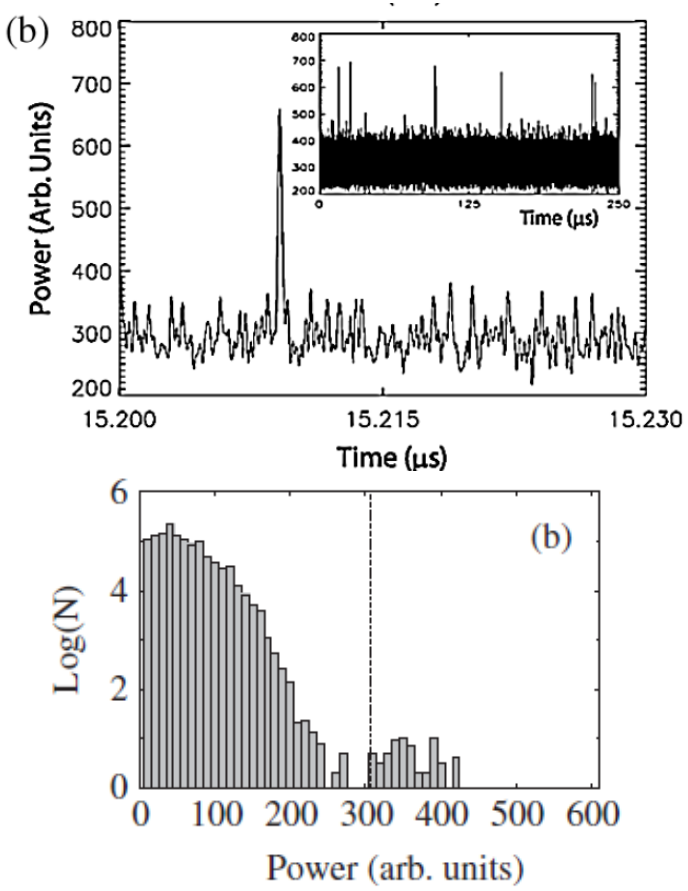


Point A: No RWs

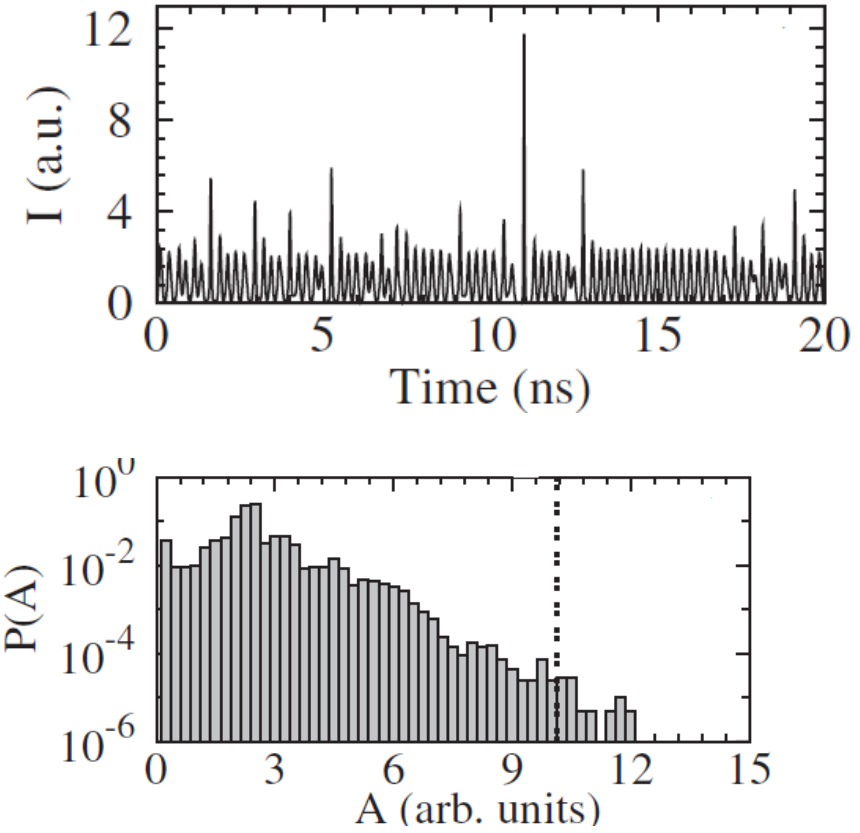
Point B: RWs

Comparison

Experiments

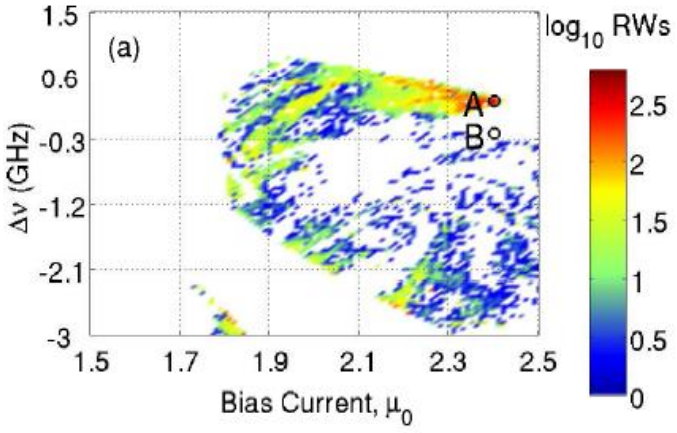


Simulations



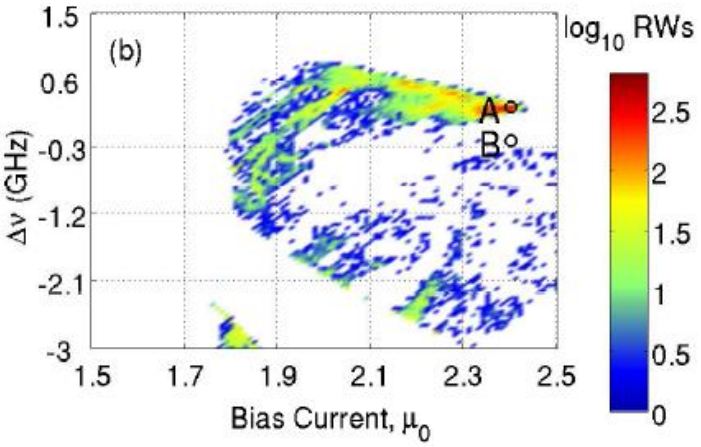
Influence of noise in the Number of RWs

Deterministic RWs (β_{sp}=0)

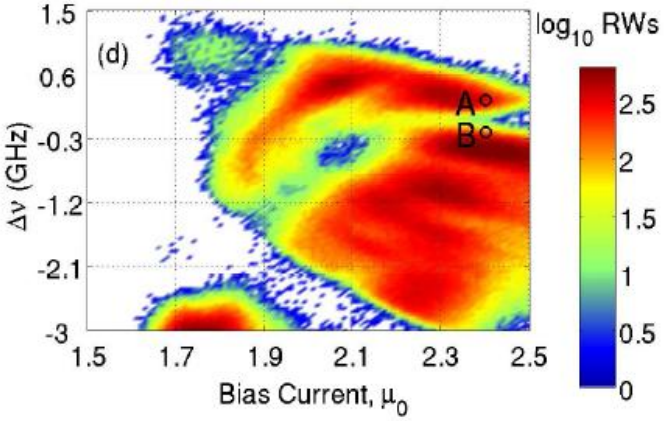


White = No RWs

Weak noise (β_{sp}=0.0001)



But with stronger noise (β_{sp}=0.01)



Weak noise can reduce the number of RWs; strong noise induces RWs

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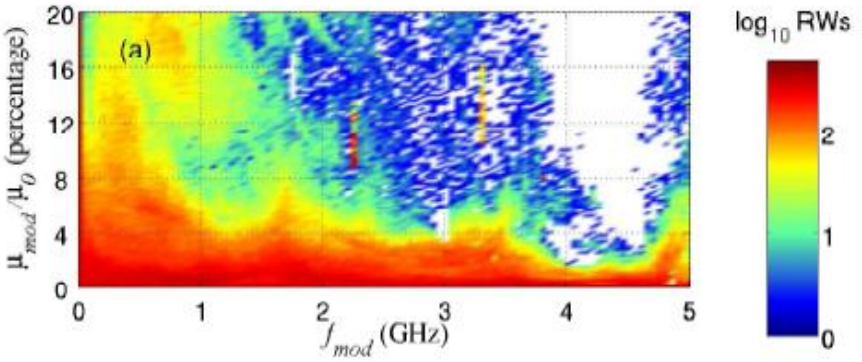
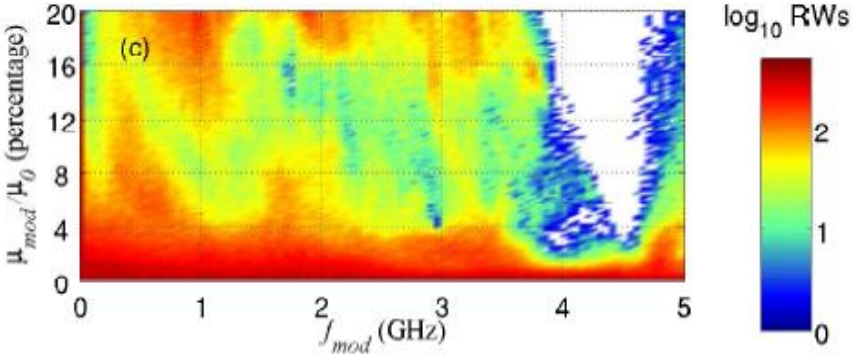
Point A (deterministic RW): Influence of current modulation

β_{sp}=0



β_{sp}=0.01



White = No RWs

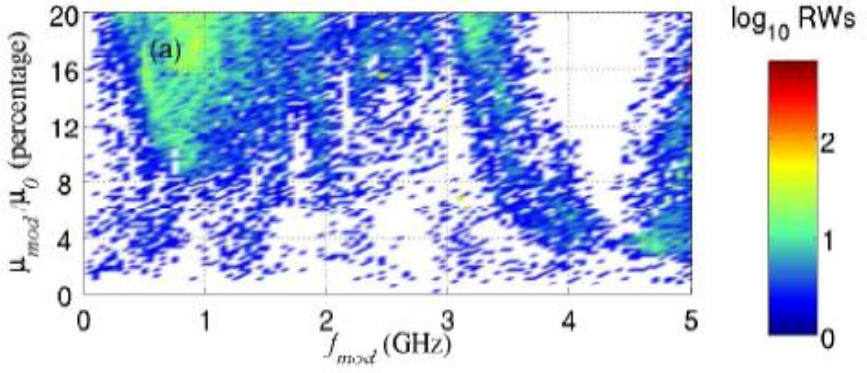
Current modulation with appropriated amplitude and frequency can completely suppress the RWs.

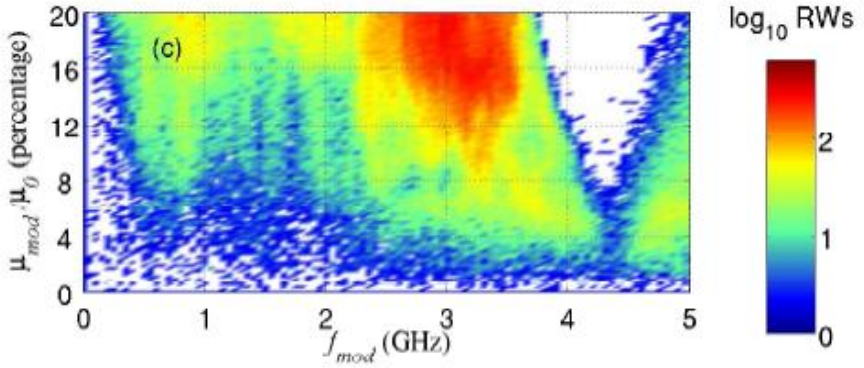
S. Perrone et al, PRA 89, 033804 (2014)

In point B (no deterministic RW)

$\beta_{sp}=0$

$\beta_{sp}=0.01$





White = No RWs

Current modulation induces RWs except in a region of (amplitude, frequency) where no RWs occur.

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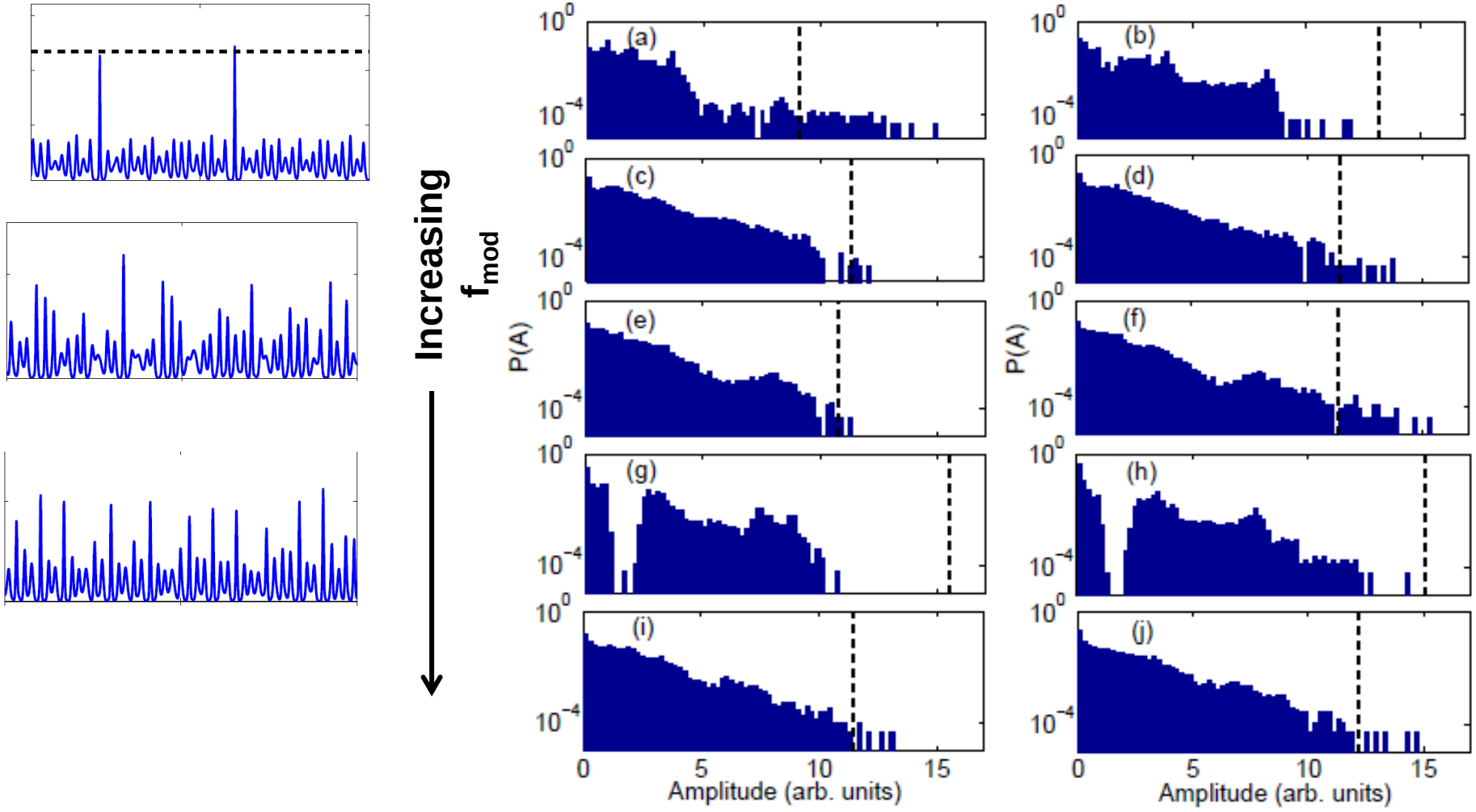
Histograms of pulse amplitudes



RWs are suppressed because high (but not ultra high) pulses are frequent

Summary

- Intensity pulses characterized by long-tailed histograms; giant rare pulses interpreted as Rogue Waves.
- Different types of chaos identified: without and with rogue waves.
- Noise strongly affects the probability of RW occurrence.
- Current modulation (with appropriate amplitude and frequency) can suppress RWs.

THANK YOU FOR YOUR ATTENTION !

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Universitat Politecnica de Catalunya

http://www.fisica.edu.uy/~cris/

Papers:

C. Bonatto et al, PRL 107, 053901 (2011)

J. Zamura-Munt et al, PRA 87, 035802 (2013)

S. Perrone et al, PRA 89, 033804 (2014)