Extreme Events in a periodically forced laser system

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from the movie Poseidon

Real Examples of Extreme Events

- Ocean rogue waves, also referred to as “freak waves”, are several times the average height of surrounding waves and have steep, fast rising and fast falling sides, like “a wall of water”.
- They can develop suddenly even in calm and apparently safe seas.
- They have been responsible of several boat accidents.

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Oceanic Rogue Waves

Devastating effects on a petrolic platform.

Rogue Waves in financial market.

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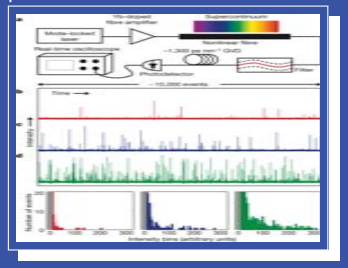

Optical Rogue waves.

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- Second
  Their appearance (and disappearance) is random and unpredictable.

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- First
  They have a peak amplitude exceeding the significant wave height.
- Second
  Their appearance (and disappearance) is random and unpredictable.
- Third
  They occur more frequently than gaussian statistic predicts.

Previous work in this field

Some articles about Rogue Waves in optics:

- D. R. Solli et al, Optical rogue waves, Nature 450, 1054 (2007)
- Pisarchik et al., Rogue Waves in a Multistable System, PRL 107, 274101 (2011)
- S. Randoux and P. Suret, Experimental evidence of extreme value statistics in Raman fiber lasers, Opt. Lett 37, 500 (2012)
- A. Zaviyalov et al, Rogue waves in mode-locked fiber lasers, PRA 85, 013828 (2012)
- F. T. Arecchi et al, Granularity and in homogeneity are the joint generators of optical rogue waves, Phys. Rev. Lett. 106, 153901 (2011). 044102 (2012)
- F. Baronio et al, Solutions of the vector nonlinear Schrdinger equations: evidence for deterministic rogue waves, Phys. Rev. Lett. 109,
- M. Kovalsky et al, Extreme events in the Ti:sapphire laser, Opt. Lett 36, 4449 (2011)
- J. M. Dudley et al, Harnessing and control of optical rogue waves in supercontinuum generation, Opt. Express 16, 3644 (2008).
- A. Mussot et al, Observation of extreme temporal events in CW-pumped supercontinuum, Opt.Express 17, 17010 (2009).

Goals of this research

- We investigate the possibility to induce or suppress extreme events into a nonlinear system by means an external periodic current modulation.

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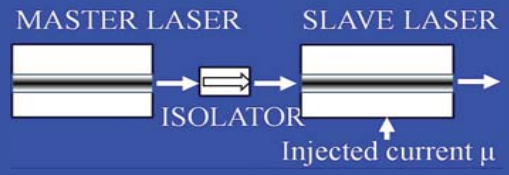
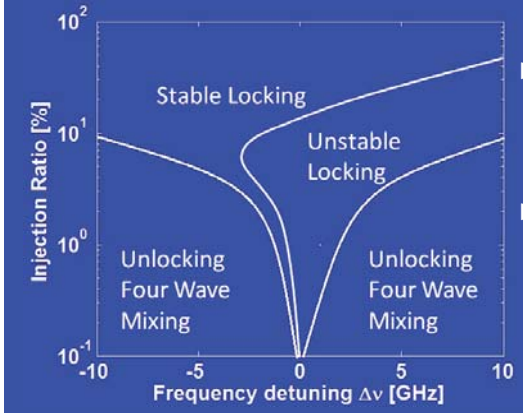
- We investigate the possibility to induce or suppress extreme events into a nonlinear system by means an external periodic current modulation.
- We investigate the effects to the RWs occurrence due to either noise and external modulation strength or frequency

Semiconductor Laser (SCLs) with optical injection



Detection system
(photo detector,
oscilloscope,
spectrum analyzer)



- Parameters
  1) Injection ratio
  2) Frequency detuning
     $\Delta\nu = \nu_s - \nu_0$
- Dynamic regions
  1) Injection locking (cw output)
  2) Period-one oscillation
  3) Period-two oscillation
  4) **Chaos**

Equation Model for the slave laser

$$\frac{dE}{dt} = k(1+i\alpha)(N-1)E + \underbrace{i\Delta\omega E}_{frequency\ \ detuning\ \ master-slave} + \underbrace{\sqrt{P_{inj}}}_{Injected\ \ power} + \underbrace{\sqrt{D}\xi(t)}_{Spontaneous\ \ emission\ \ noise} \quad (1)$$

$$\frac{dN}{dt} = \gamma_N(\underbrace{\mu(t)}_{Injected\ \ current} - N - |E|^2) \quad (2)$$

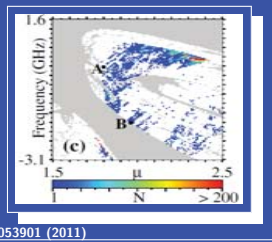
$$\mu(t) = \mu_0 + \mu_{mod} sin(\omega_0 t) \quad (3)$$

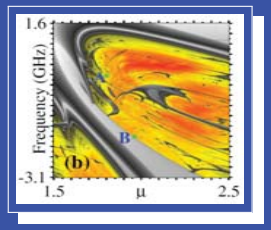
E: Complex electric field $|E^2|$: photon number
N: Carrier density

Parameters values used:
We are into the Chaos region

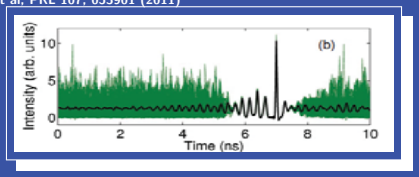
$\alpha = 3$
$\gamma_n\ (ns^{-1}) = 1$
$k = 300$
P_{inj} =60
D $(ns^{-1}) = 10^{-2}; 10^{-3}; 10^{-4}; 0$
$\Delta\omega$ (GHz)= from -3 to 1,5
μ_0 (a.u.)= from 1,5 to 2,5
μ_{mod} (% of μ_0) = from 1 to 20%
ω_0 (GHz) = from 0 to 5 GHz

Previously in this direction...

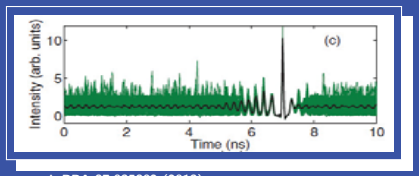




C. Bonatto et al, PRL 107, 053901 (2011)



D=0

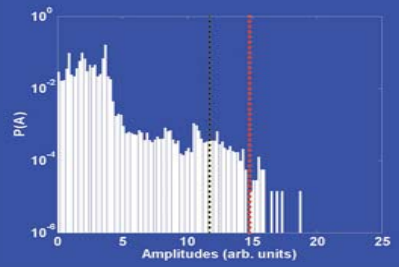


D=10^{-2}

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

Output intensity with Rogue Waves @ A

Play



Threshold: $< I > + k_{var}\sigma(I)$

$k_{var} = 8 \Rightarrow$ 26 RWs

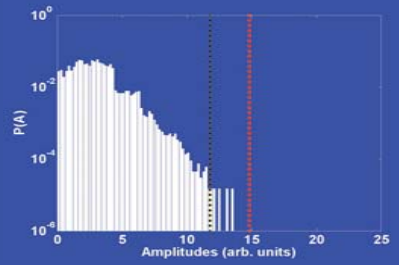
k_{var}=6 $\Rightarrow$ 289 RWs

Parameters:

- $\Delta\omega$=0,22 GHz
- μ=2,4
- Noise=10^{-4}
- modulation=0

Output intensity with an external forcing @ A (**RWs suppression**)

Play



Threshold: $< I > + k_{var}\sigma(I)$

k_{var}=8 ⇒ 0 RWs

k_{var}=6 ⇒ 5 RWs

Parameters:

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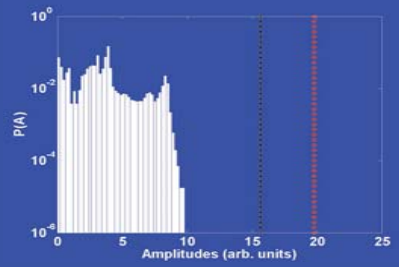
- μ=2,4
- Noise=10^{-4}
- modulation=10% bias current; f=1 GHz

Output intensity without Rogue Waves @ B

Play



Threshold: $< I > + k_{var}\sigma(I)$

k_{var}=8 $\Rightarrow$ 0 RWs

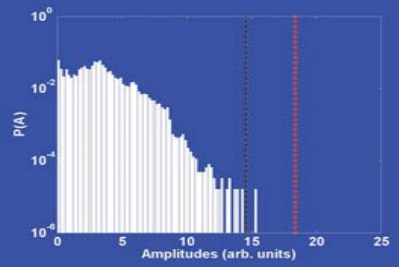
k_{var}=6 $\Rightarrow$ 0 RWs

Parameters:

- $\Delta\omega$=-0,24 GHz
- μ=2,4
- Noise=10^{-4}
- modulation=0

Output intensity with an external forcing @ B

Play



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$k = 6_{var}$ $\Rightarrow$ 1 RWs

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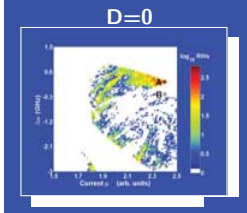
Rogue Waves: influence of noise without modulation



D=10^{-4} ?

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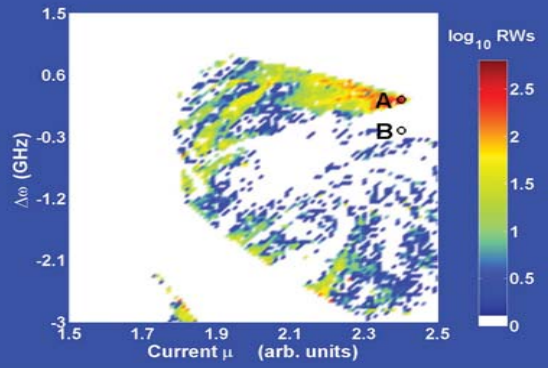

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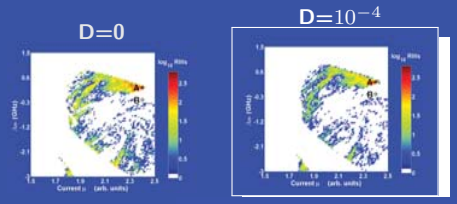

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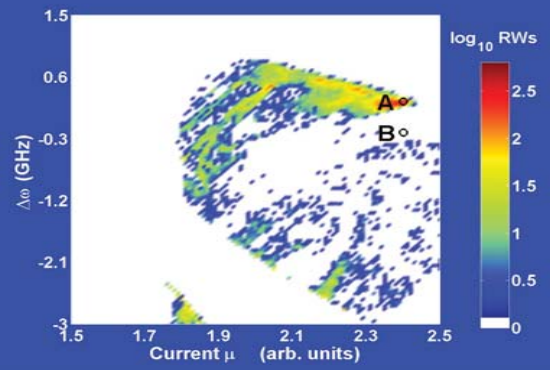

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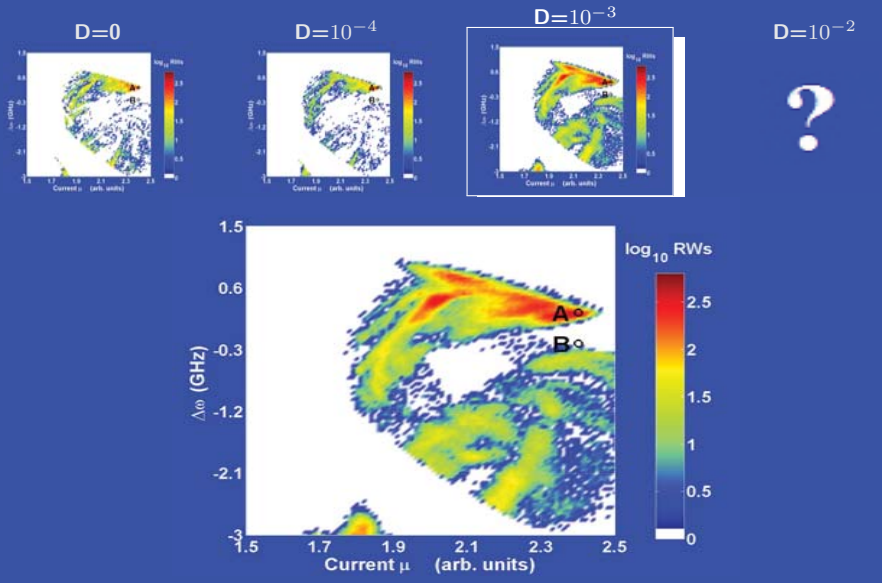

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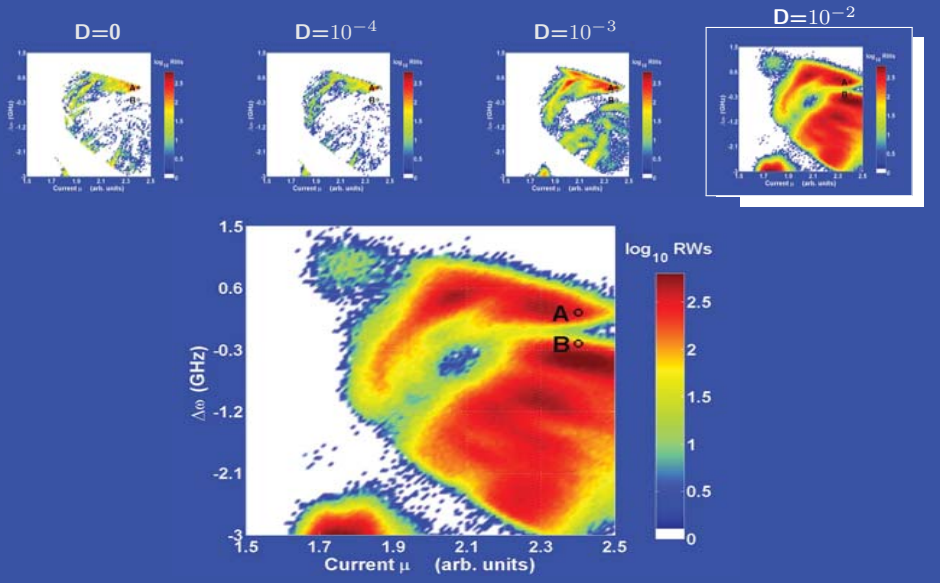
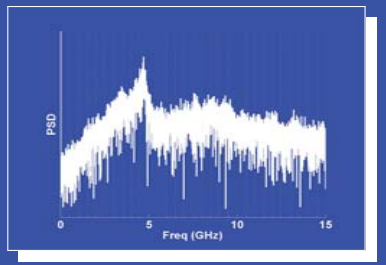
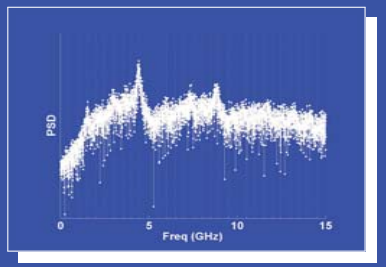


$|(FFT)|^2$ of the output intensity @ A and B



Point A:
$\Delta\omega$=0,22 GHz; noise=10^{-4}



Point B:
$\Delta\omega$=-0,24 GHz; noise=10^{-4}

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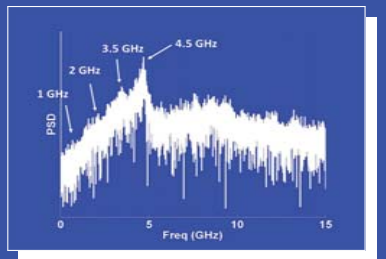

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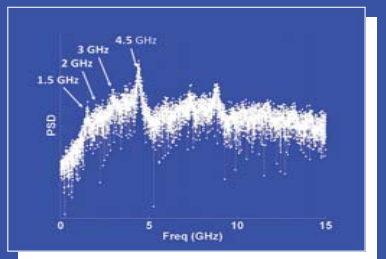

Point B:
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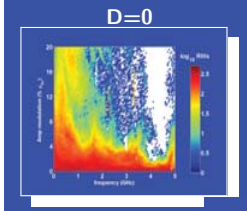
RWs maps *Frequency* vs *Amplitude* @ A



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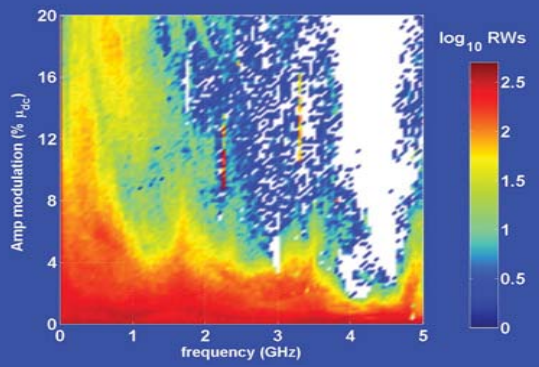

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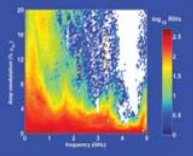

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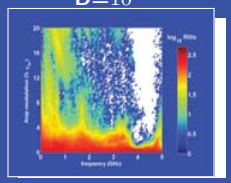

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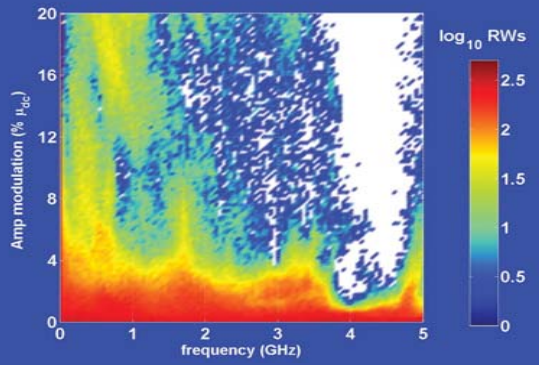

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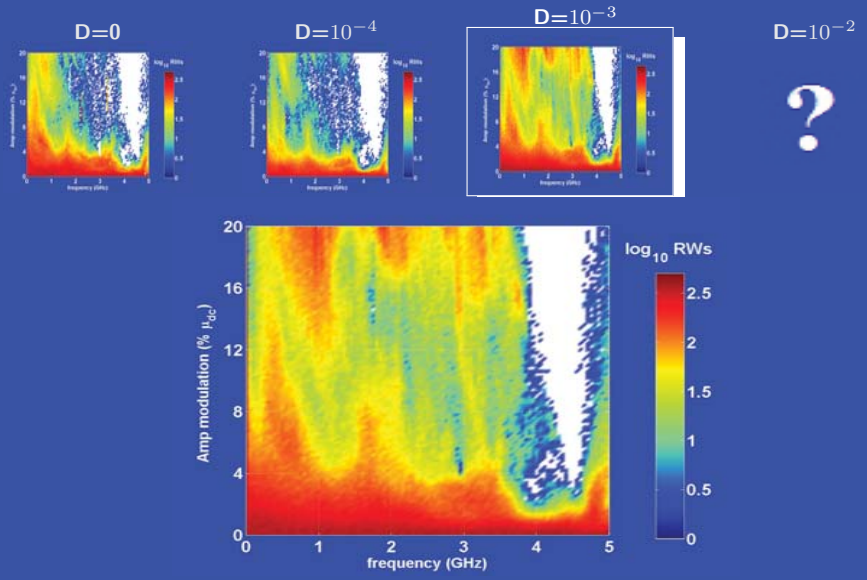

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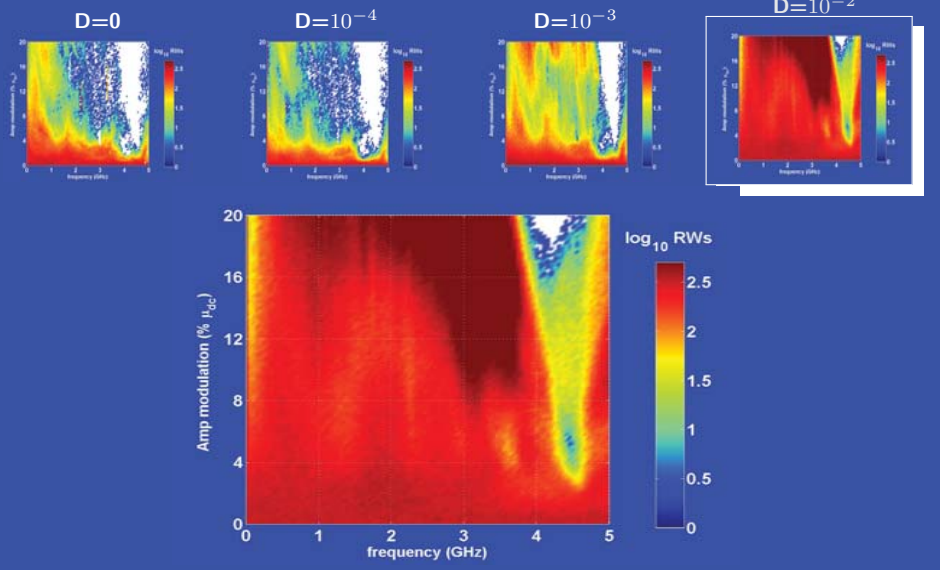

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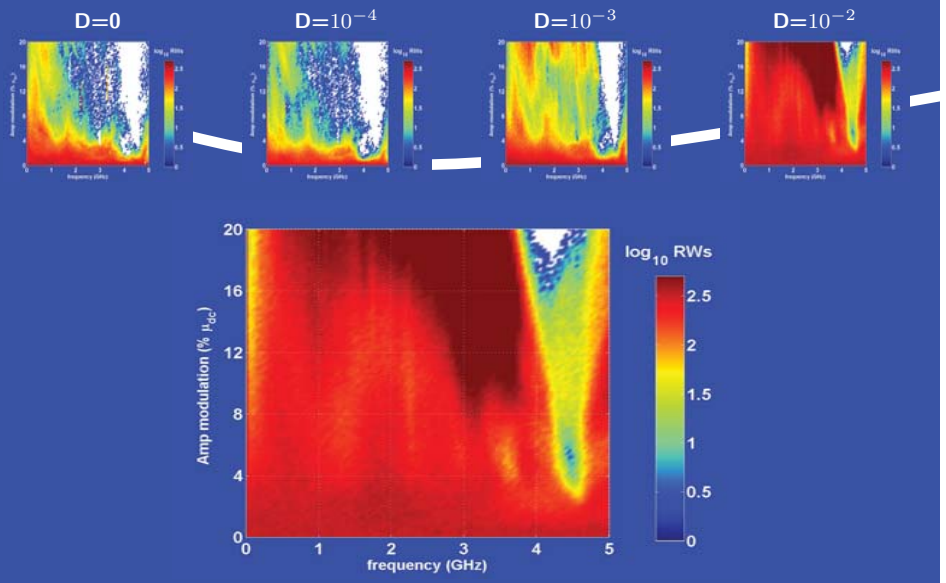

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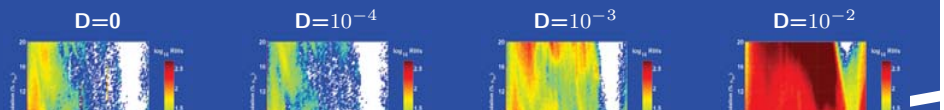
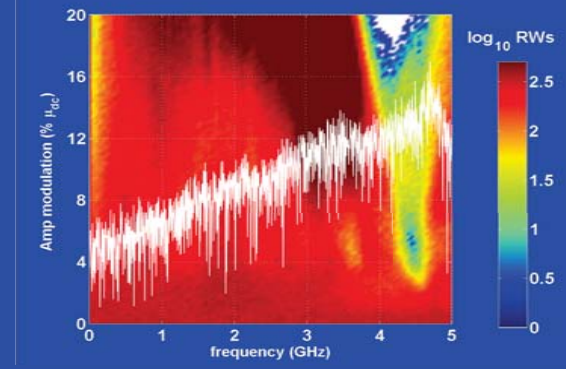
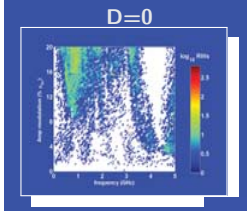




RWs maps *Frequency* vs *Amplitude* @ B



D=10^{-4} ?

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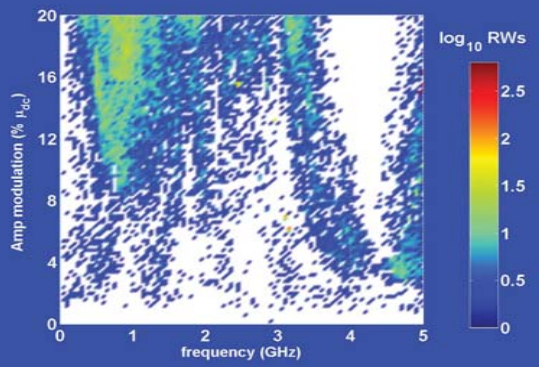

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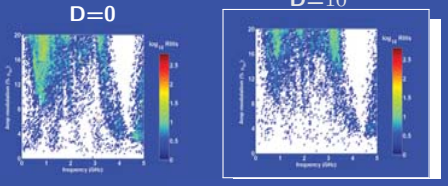

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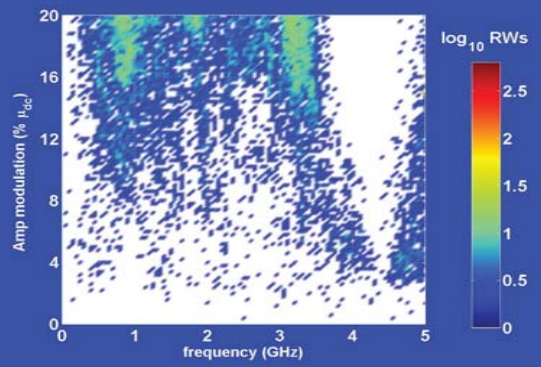

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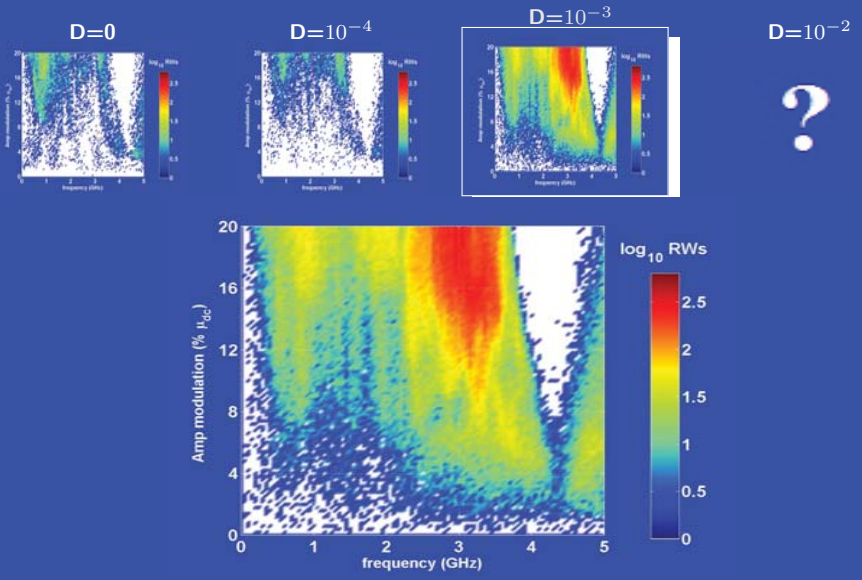

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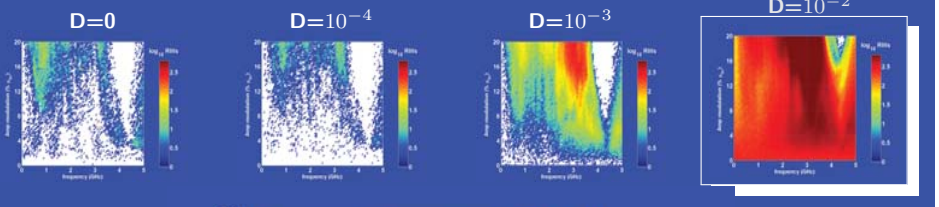

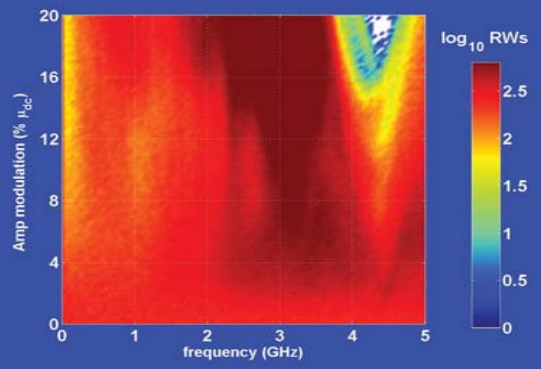

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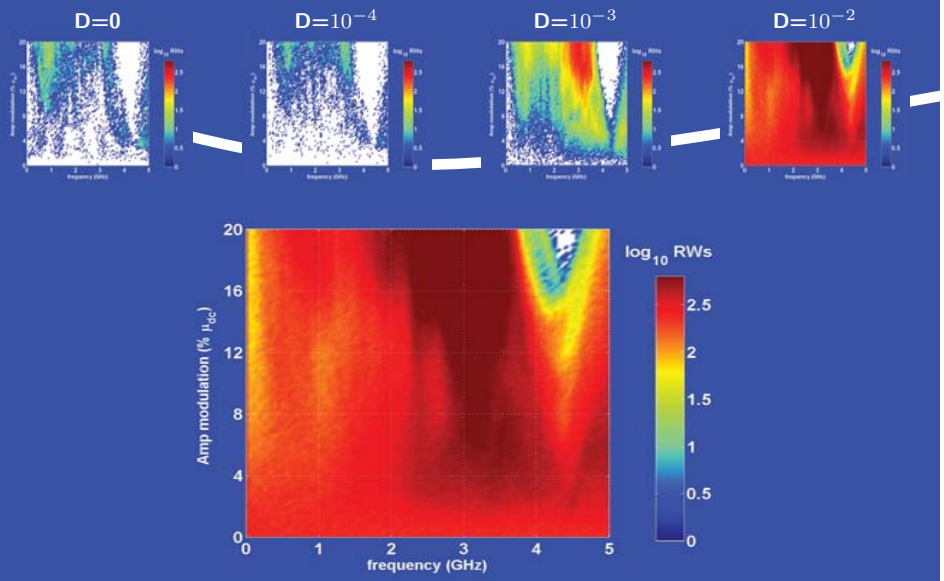

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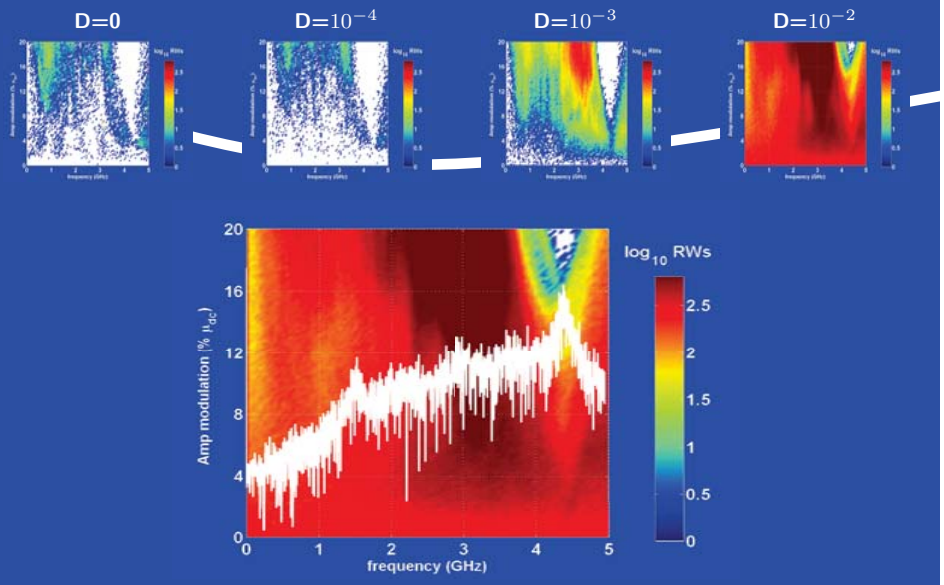

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- We obtained new insigth into the dynamics of a nonlinear external periodically driven system which can suppress or induce extreme events, for realistic noise of order 10^{-4}
- For high noise level, order of 10^{-2}, the dynamics is dominated from the noise therefore the modulation doesn't afford any change into the dynamics
- Modulating at proper system frequencies, it can control the system into excitable states where extreme events became more or less likely

Future Work

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- Observe the dynamics at low frequencies modulation regime.
- RWs time-appearances dependence with the external forcing.

People involved in this project

Post doc Researcher Jordi Zamora-Munt

Professor Ramon Vilaseca

Professor Cristina Masoller

The End
Thanks for your attention