Generation On-Demand of Extreme Pulses in Optically Injected Semiconductor Lasers

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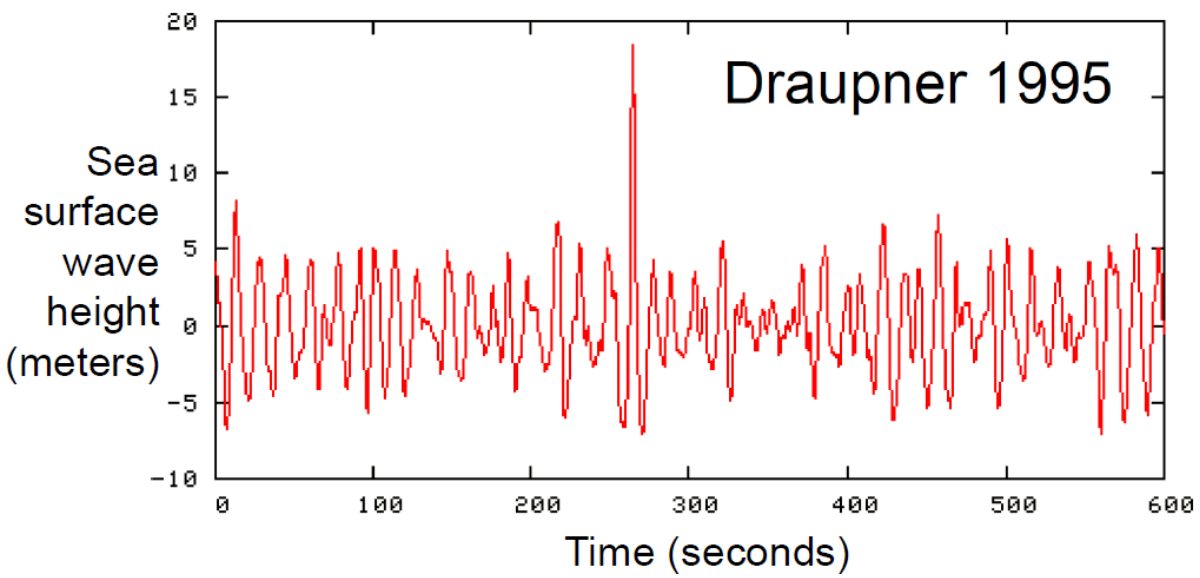
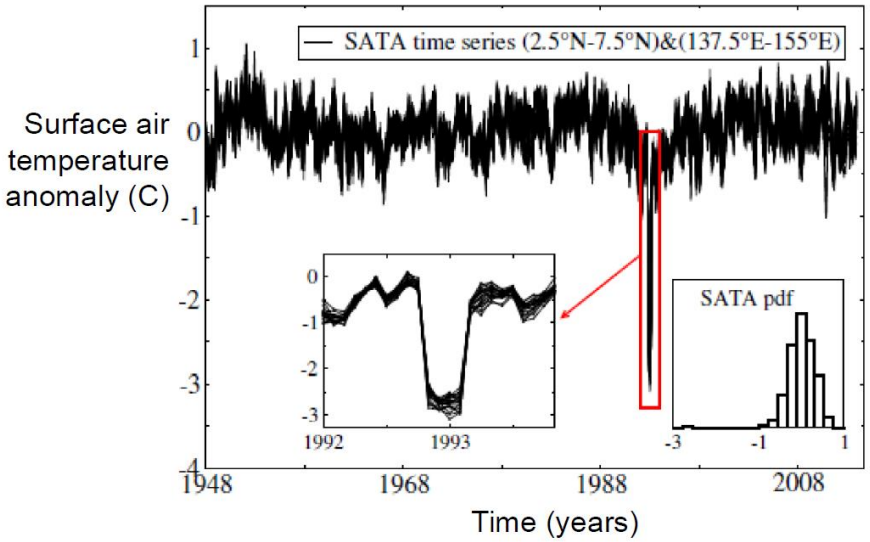
Extreme events in nature





Optical systems generate "big data" and provide an opportunity to understand extreme events & advance their predictability.

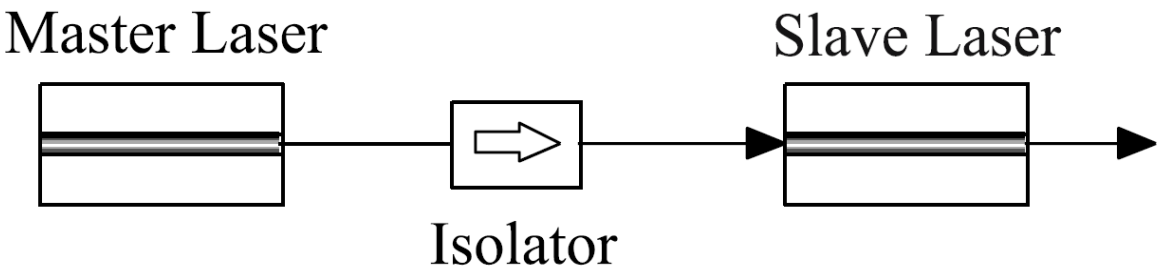
In optics

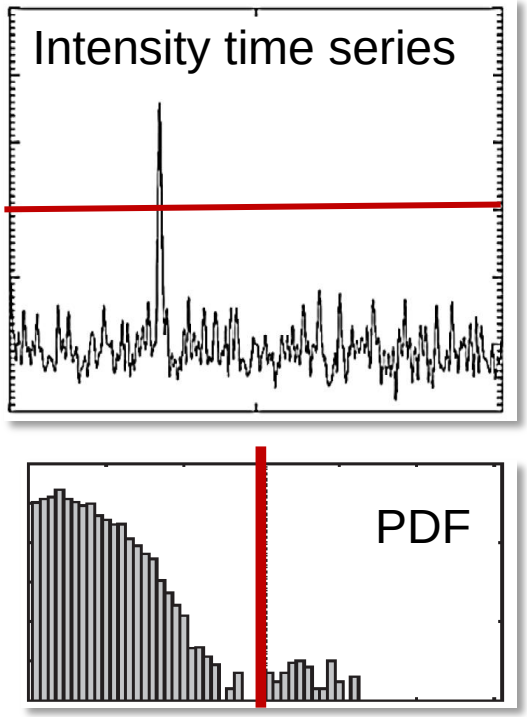
- Extreme intensity pulses (also known as Optical Rogue Waves) have been observed in different laser systems.
- Numerically, they have been studied in 0D, 1D and 2D models, and different mechanisms have been identified.
- In 0D extreme pulses likely occur when the trajectory approaches the saddle point corresponding to the laser "low-intensity" state.
- In 1D or 2D systems, they might be generated by a similar mechanism, but they can also arise due to the presence of one or more spatial degree of freedom (those mechanisms can not be studied with 0D models).

PRL 107, 053901 (2011) PHYSICAL REVIEW LETTERS week ending 29 JULY 2011

Deterministic Optical Rogue Waves

Cristian Bonatto,[1] Michael Feyereisen,[2] Stéphane Barland,[2] Massimo Giudici,[2] Cristina Masoller,[1] José R. Rios Leite,[2,3] and Jorge R. Tredicce[2,3]





- Parameters:
  - Injection ratio
  - Frequency detuning (controlled by varying the pump current of the slave laser)

ORW: pulse above

<A> + **6-8** σ

What did we learn?

In our system, optical rogue waves can be

- **deterministic**, generated by a crisis-like process.
- **controlled** by noise and/or by current modulation.
- **predicted** with a certain anticipation time.

Can they be triggered “on demand”?

Governing equations

- Complex field, **E –Laser intensity ~ $|E|^2$**
- 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
$\Delta\omega = \omega_s - \omega_m$: detuning

spontaneous emission noise

Solitary laser parameters: α τ_p τ_N μ

μ: normalized pump current parameter

Typical parameter values:

$\alpha = 3$, $\tau_p = 1$ ps, $\tau_N = 1$ ns

These simple rate-equations provide good qualitative agreement with the experimentally observed intensity dynamics.

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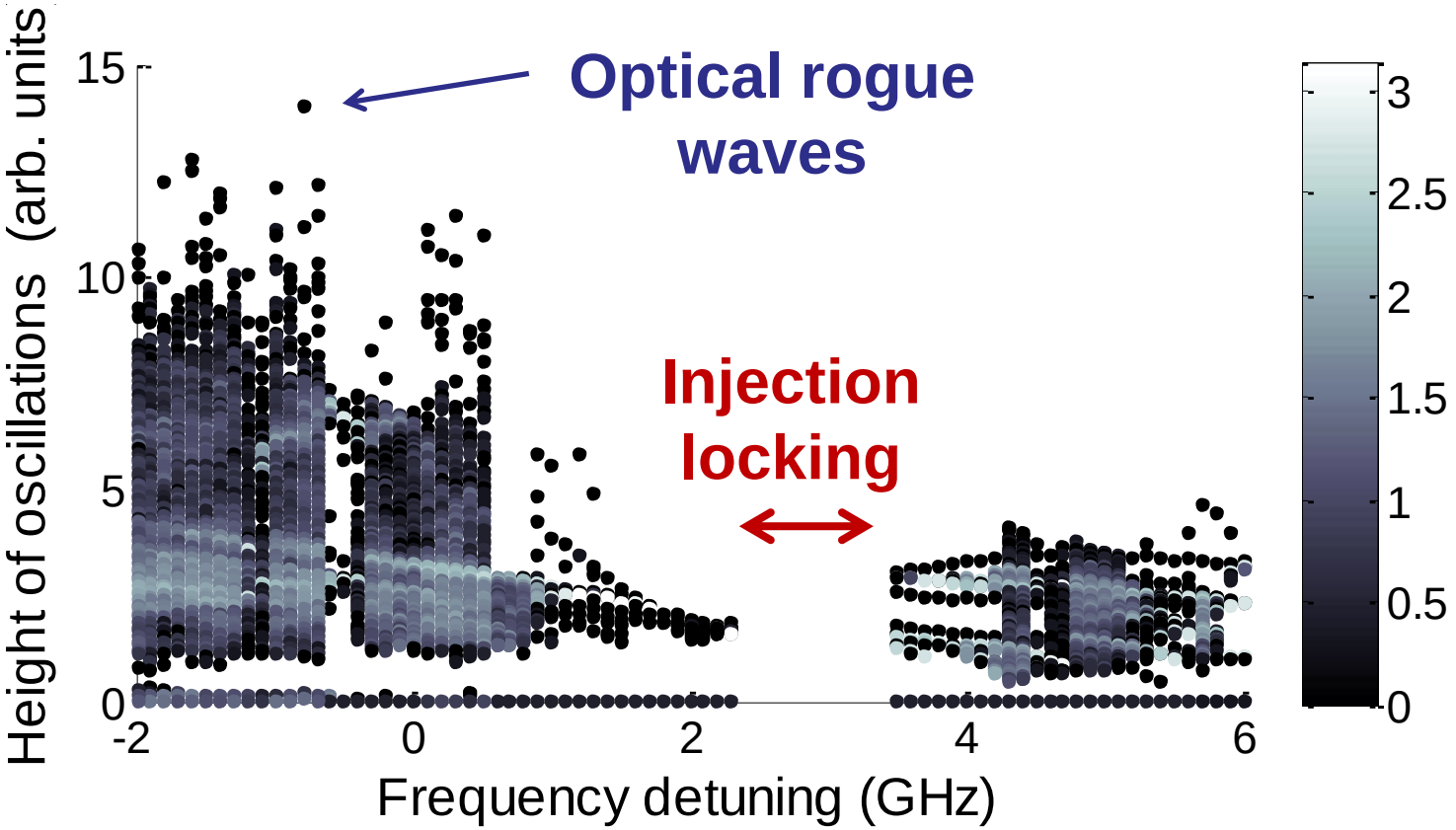
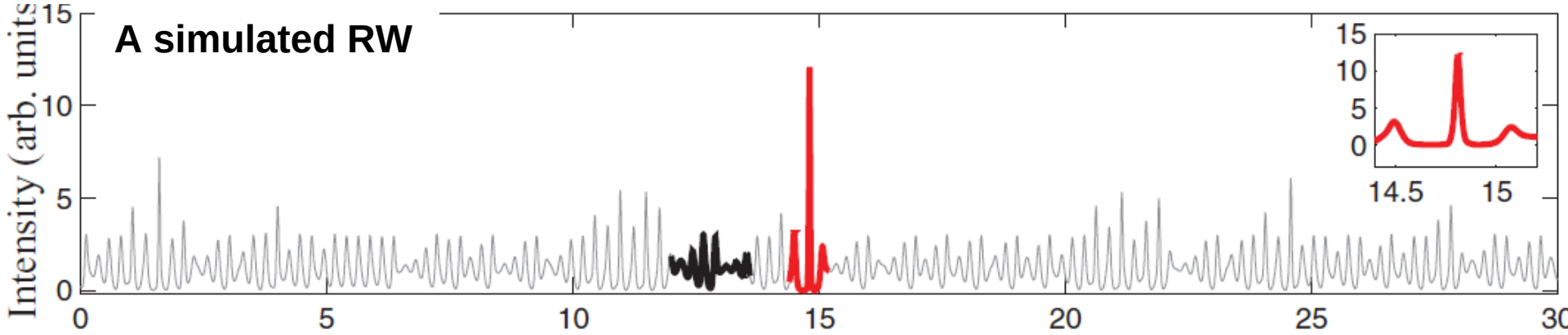
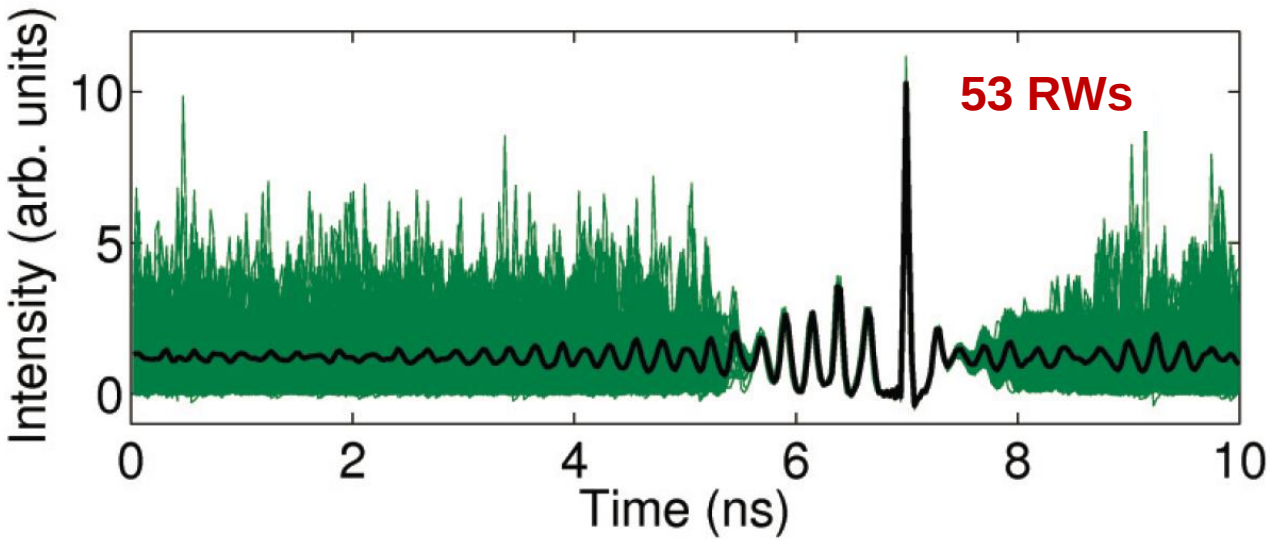
Bifurcation diagram in color code: log(number of pulses)



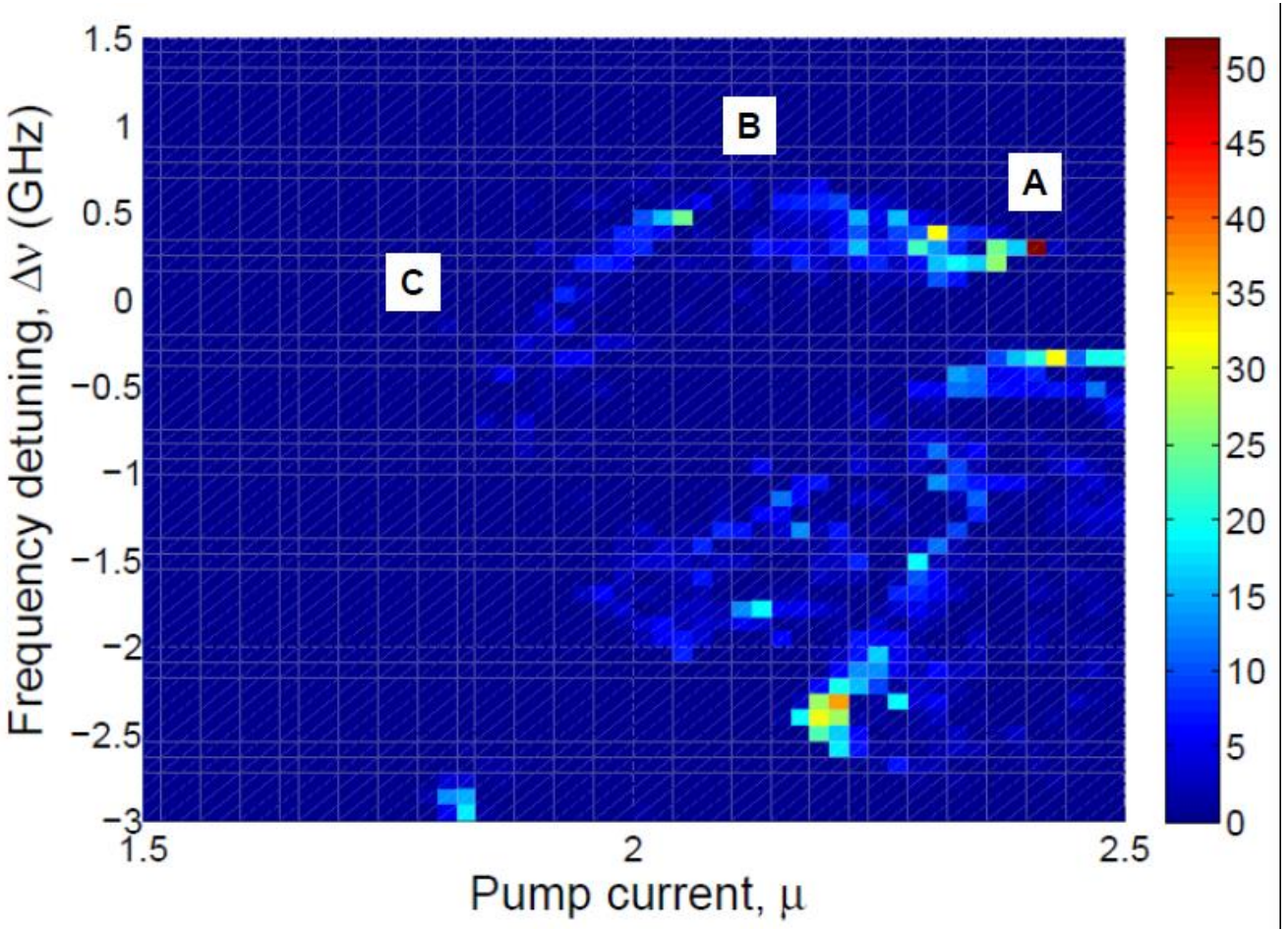
N. Martinez Alvarez, S. Borkar and C. Masoller, Eur. Phys. J. ST 226, 1971 (2017)



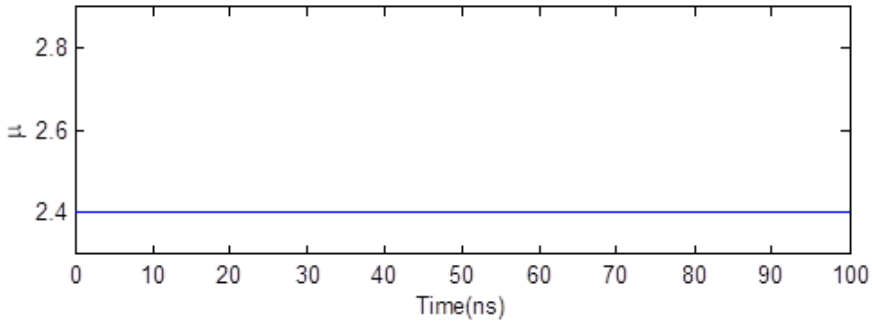


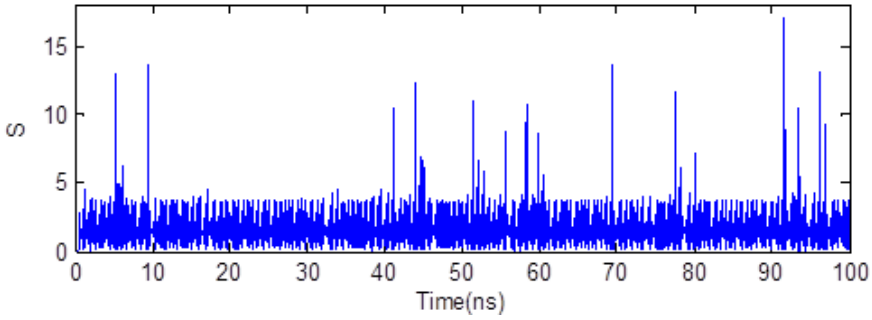
J. Zamora-Munt et al, PRA 87, 035802 (2013)

Number of pulses above $\langle I \rangle + 8\sigma$ in 1μs **deterministic** simulations.

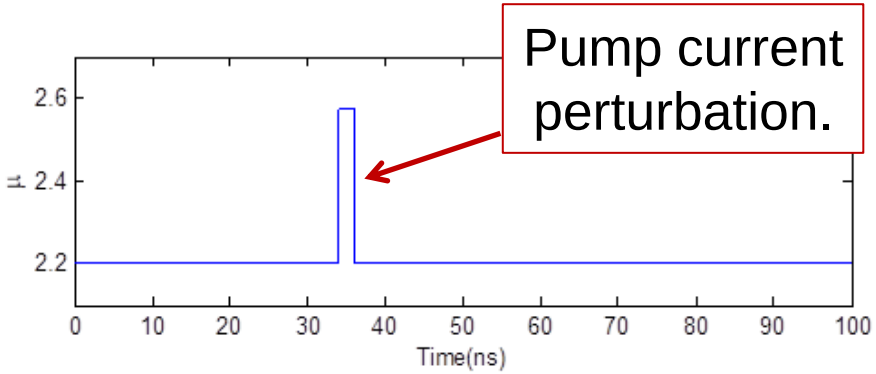


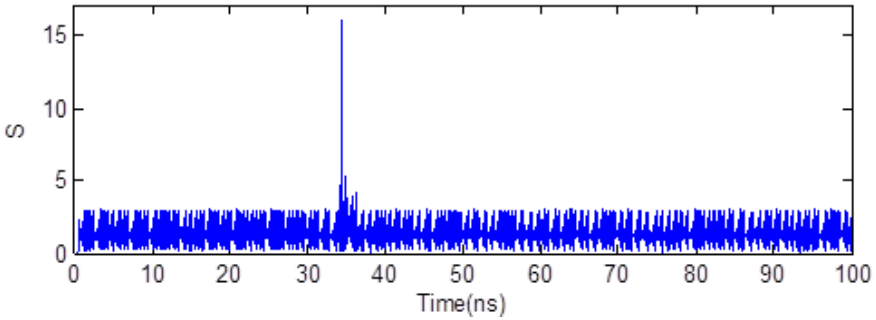
Spontaneous RWs in point "A"





Generated RWs in point "B"

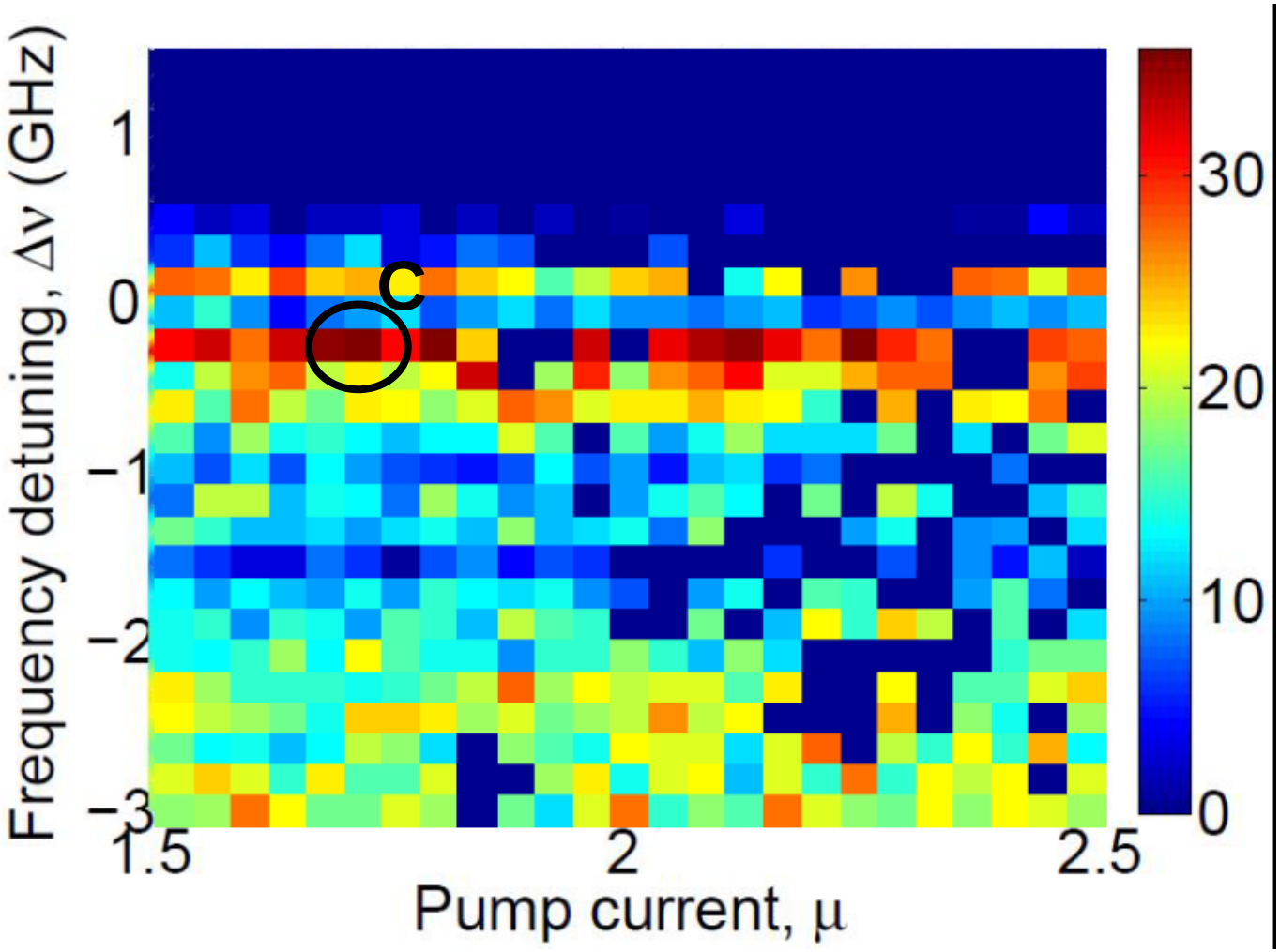




Generated by nonlinear dynamics (deterministic simulations)

Where?

Number of pulses generated by 100 perturbations



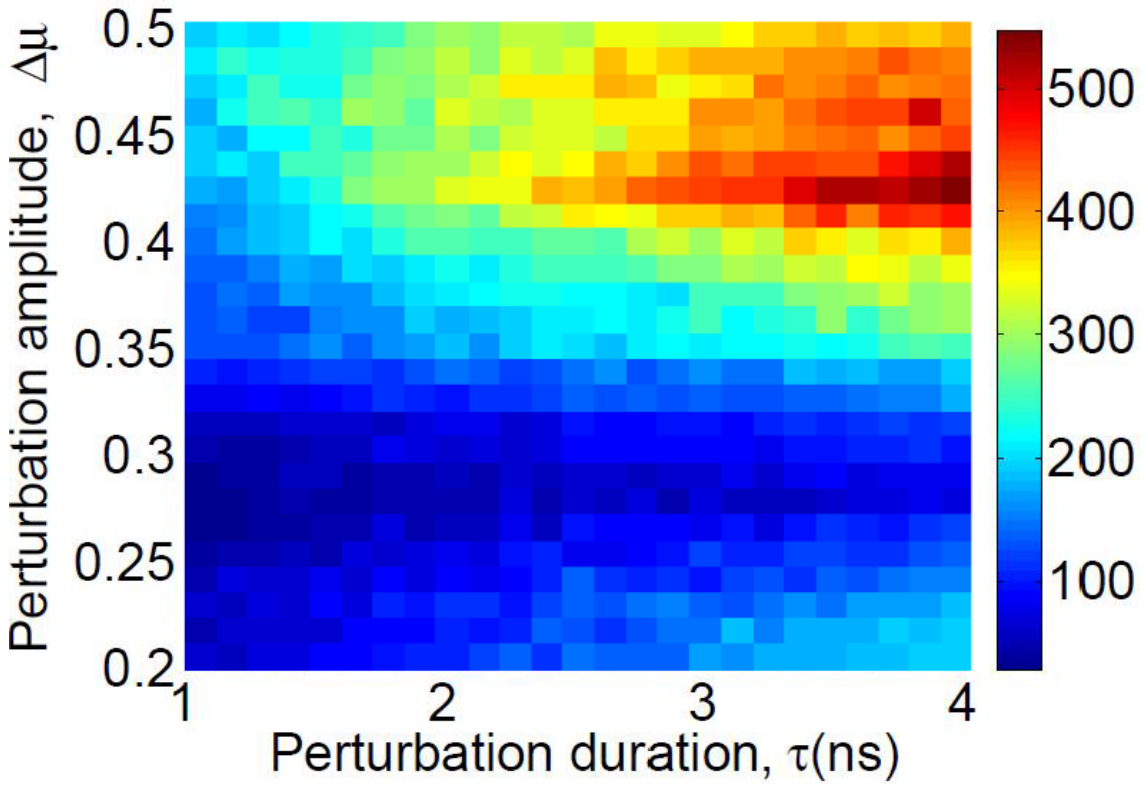
Perturbation amplitude $\Delta\mu=0.35$

Duration $\tau=4$ ns

Dark blue: either spontaneous RWs or no RWs

Optimal perturbation parameters?

Number of pulses generated after 1000 perturbations



Success probability depends on the laser parameters.
In point "C" it can exceed 50%.

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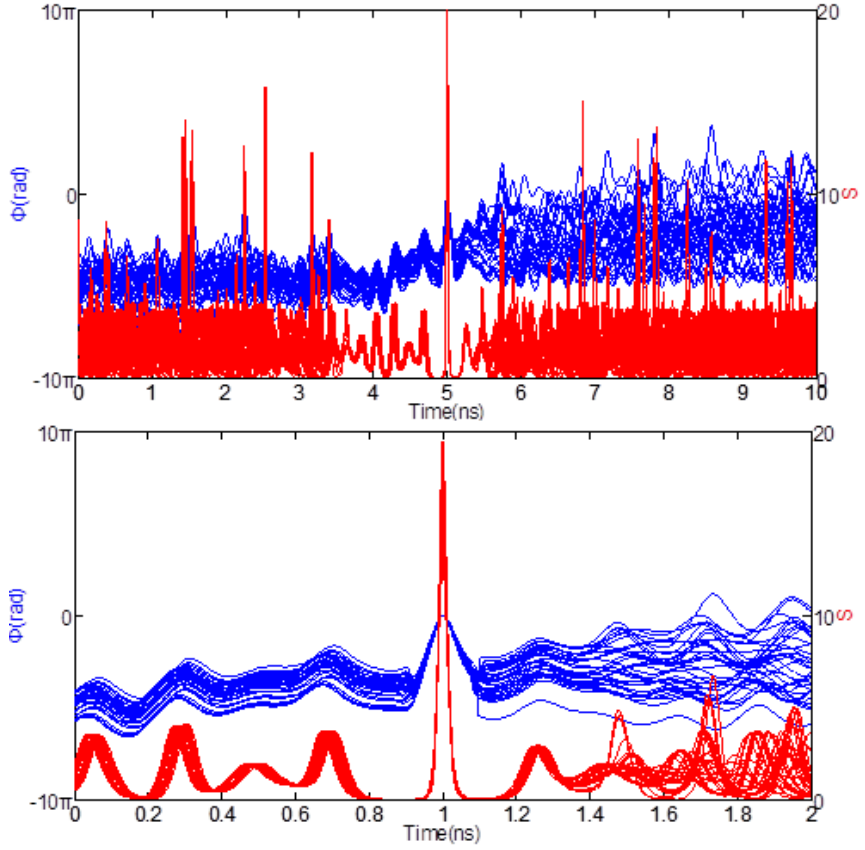
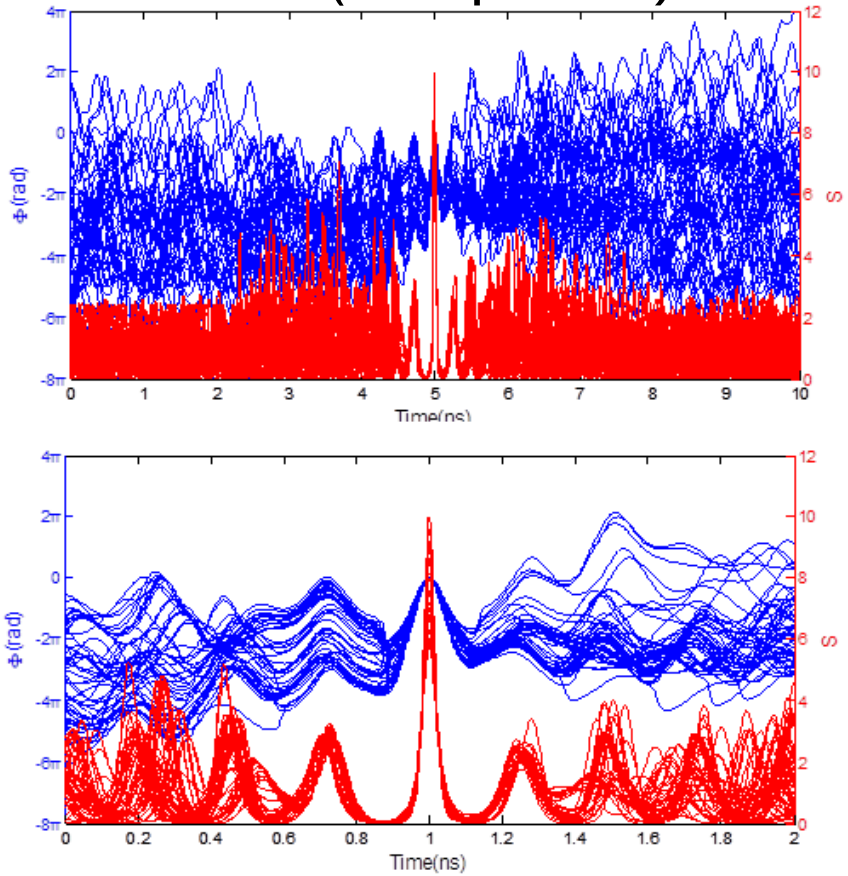
Comparison between "generated" and "spontaneous" extreme pulses

Spontaneous RWs in point "A"



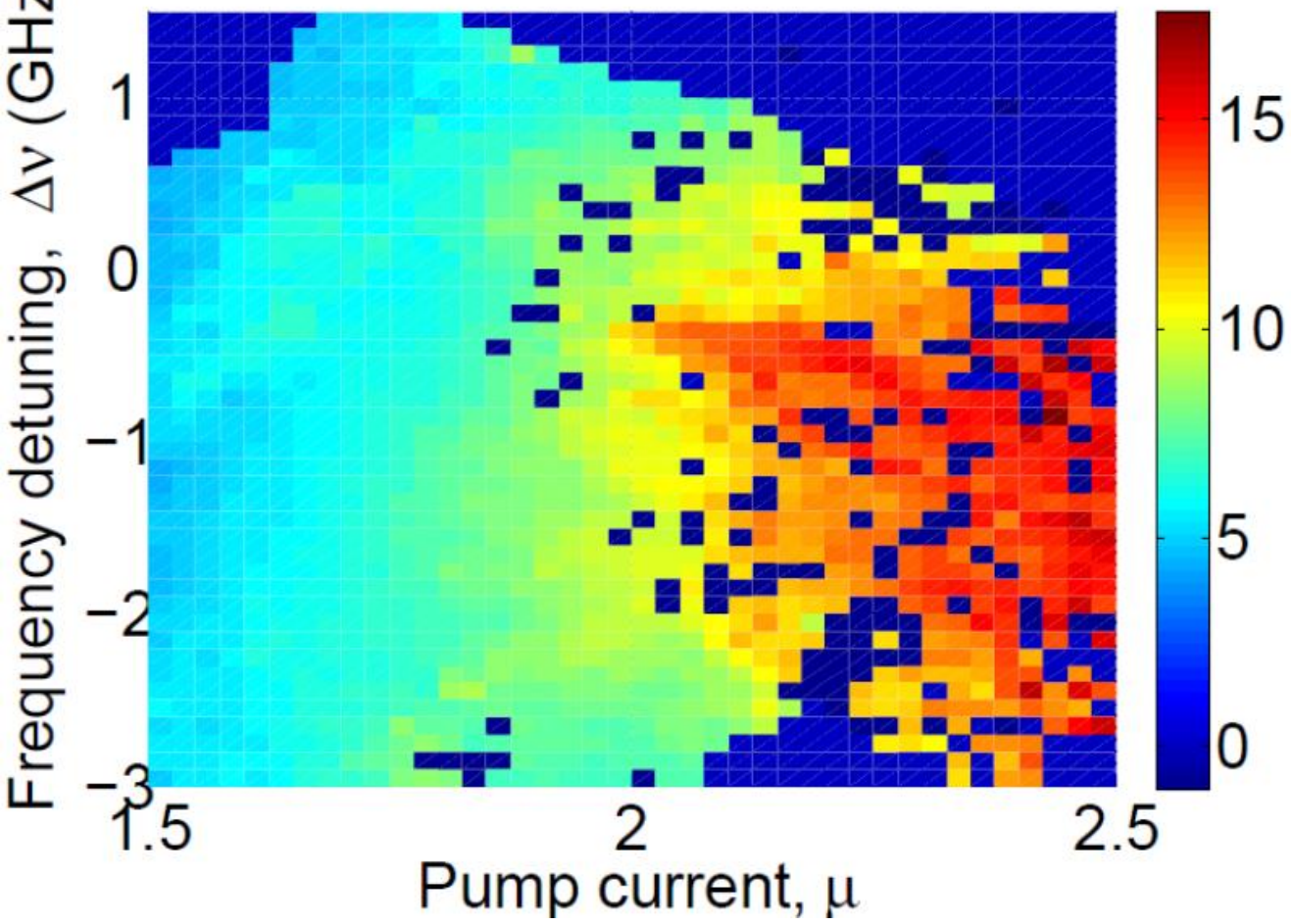
Generated RWs in point "C" (~50 pulses)



⇒ Very similar time-evolution of the intensity and the phase

Statistics of generated pulses

Mean amplitude of the generated pulses



Perturbation amplitude $\Delta\mu=0.35$

Duration $\tau=3$ ns.

Typical delay time < 2 ns

Conclusions

- It is possible to trigger optical rogue waves “on demand" by means of a step-up perturbation of the laser current.
- The success probability strongly depends on the laser parameters and on the perturbation parameters.
- Intensity and phase dynamics during the “generated” rogue wave are the same as during “spontaneous” rogue waves (generated by the intrinsic nonlinear dynamics).
- Practical application?

Thank you for your attention !

Tian Jin, Chen Siyu, and Cristina Masoller, “*Generation of rogue waves by external perturbations and phase dynamics during rogue waves in optically injected semiconductor lasers*”, submitted (2017)
Available at: http://www.fisica.edu.uy/~cris/

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