



HAL
open science

Bounded-phase chaotic dynamics in a vectorial laser

Aurélien Thorette, Marco Romanelli, Marc Brunel, Marc Vallet

► **To cite this version:**

Aurélien Thorette, Marco Romanelli, Marc Brunel, Marc Vallet. Bounded-phase chaotic dynamics in a vectorial laser. Conference on Lasers and Electro-Optics Europe and European Quantum Electronics Conference 2017 (CLEO-Europe/EQEC 2017), Jun 2017, Munich, Germany. IEEE Xplore Digital Library, pp.17314439, 2017 Conference on Lasers and Electro-Optics Europe & European Quantum Electronics Conference (CLEO/Europe-EQEC). 10.1109/CLEOE-EQEC.2017.8087570 . hal-01561755

HAL Id: hal-01561755

<https://hal.science/hal-01561755v1>

Submitted on 13 Jul 2017

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Bounded-phase chaotic dynamics in a vectorial laser

Aurélien Thorette, Marco Romanelli, Marc Brunel, Marc Vallet



aurelien.thorette@univ-rennes1.fr

Département Optique et Photonique, Institut de Physique de Rennes (CNRS 6251), now Institut FOTON (CNRS 6082)

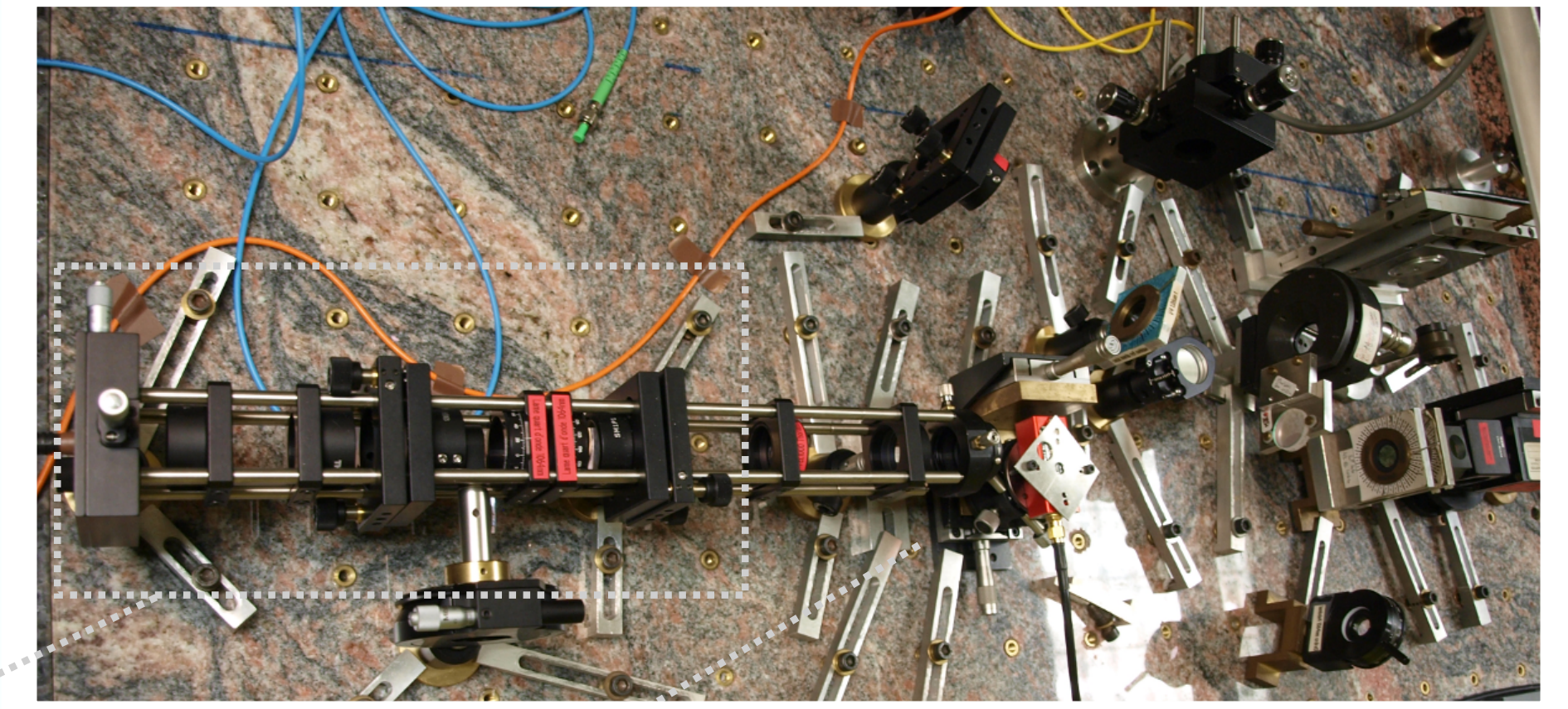
ABSTRACT : We show experimentally that the beat-note signal of the two polarization modes of a dual-frequency laser can be chaotic and at the same time be frequency-locked to a master radio-frequency oscillator.

Dual-frequency laser with frequency-shifted feedback

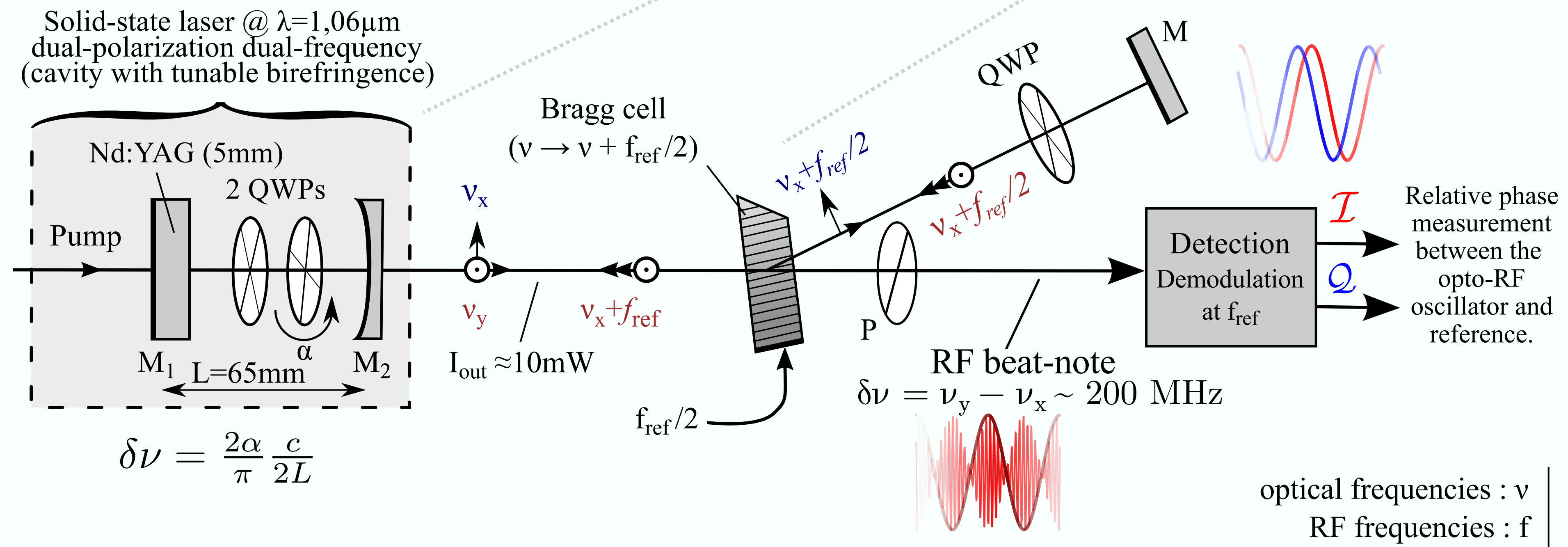
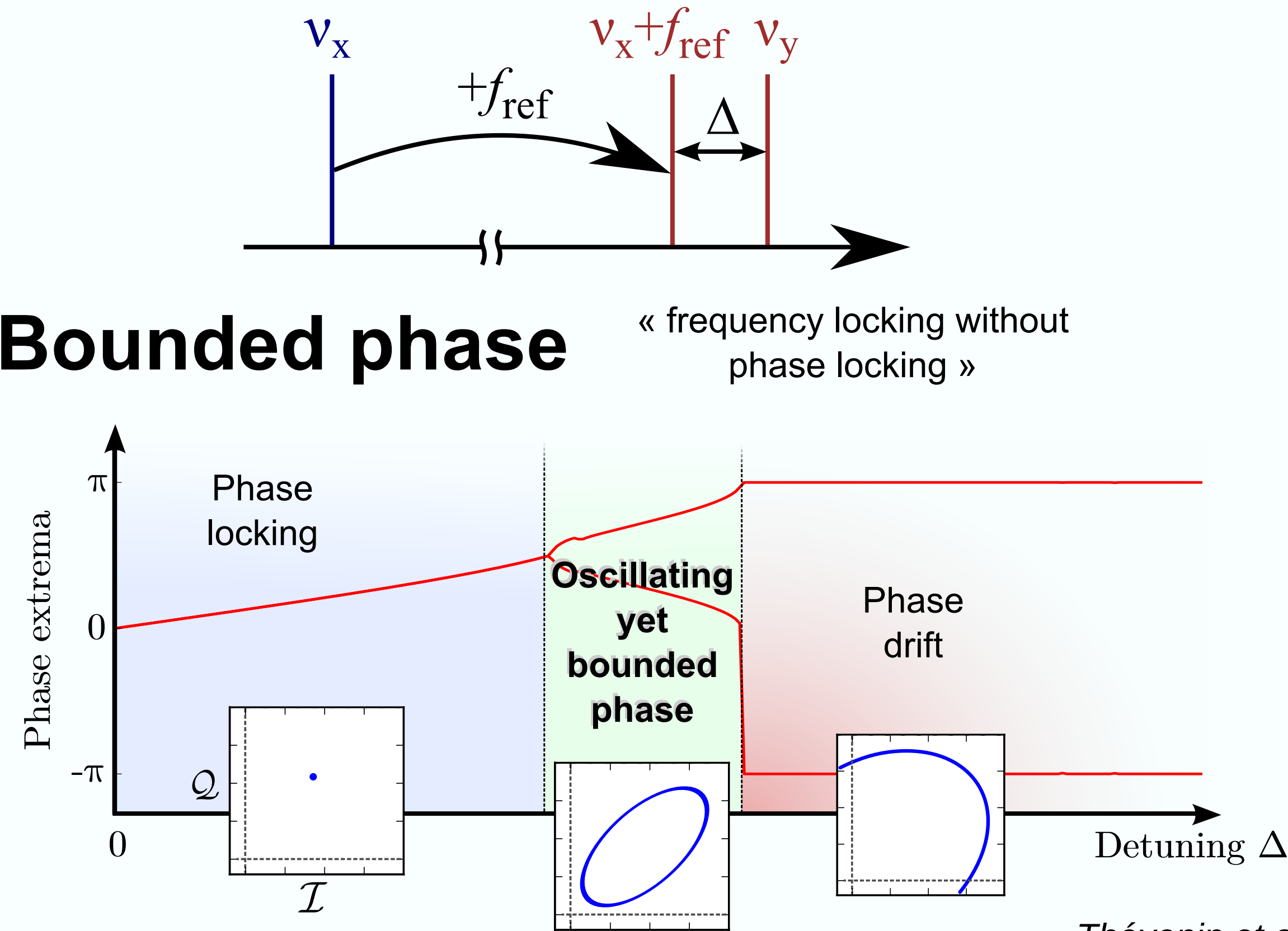
Context : dual-polarisation dual-frequency laser → opto-RF source can be stabilized and/or synchronized on an external reference by an electronic or optical feedback.

Optical frequency-shifted feedback (FSF).

→ coupling between modes through external driving at f_{ref} with intensity Γ and **frequency detuning** $\delta\nu - f_{ref}$.



Bounded phase



Strong injection → supercritical Hopf bifurcation

- Thévenin et al., "Phase and intensity dynamics of a two-frequency laser submitted to resonant frequency-shifted feedback," PRA **86**, 33815 (2012).
- Romanelli et al., "Measuring the universal synchronization properties of driven oscillators across a Hopf instability," Optics Express **22**, 7364 (2014).

Chaotic bounded phase: simulation and observation

Normalized « rate equations » dynamical model for the two polarization modes:

$$\begin{cases} \frac{de_x}{ds} = \frac{m_x + \beta m_y}{1 + \beta} \frac{e_x}{2} \\ \frac{de_y}{ds} = \frac{m_y + \beta m_x}{1 + \beta} \frac{e_y}{2} + i\Delta e_y + \Gamma e_x \end{cases}$$

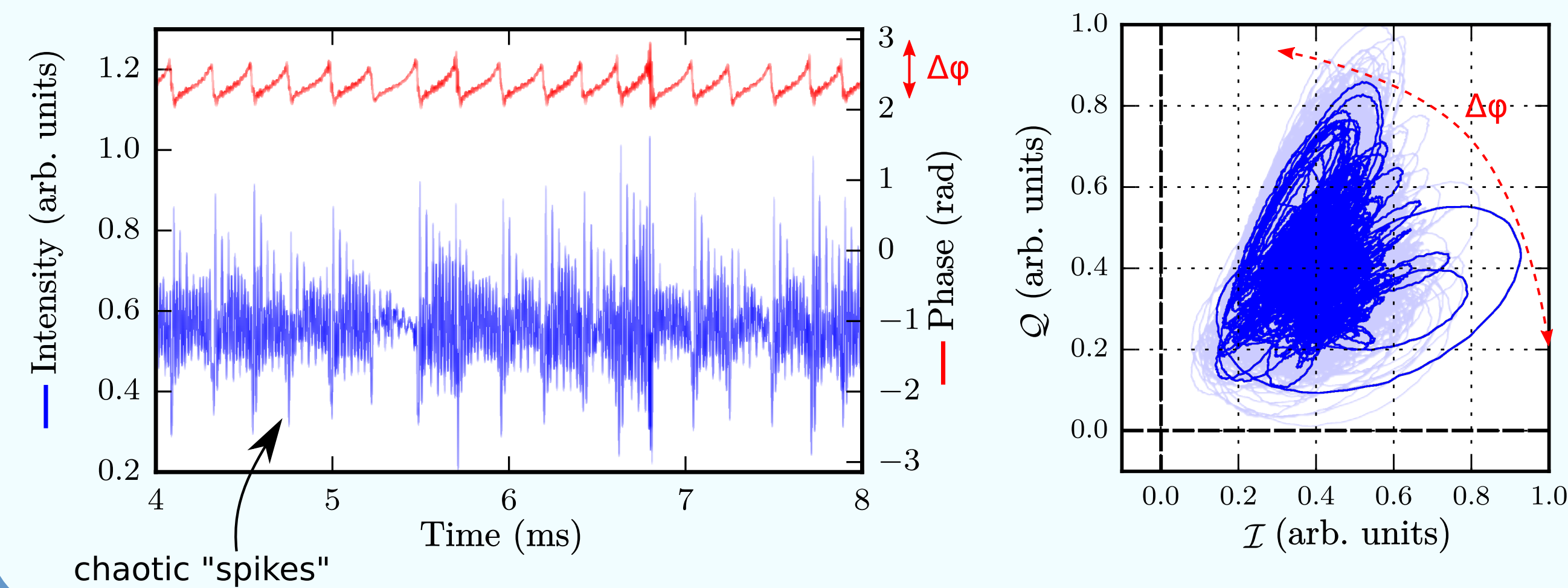
Coupling by reinjection $e_x \rightarrow e_y$

various dynamics are computed in the resonant injection regime

$$\frac{dm_{x,y}}{ds} = 1 - (|e_{x,y}|^2 + \beta|e_{y,x}|^2) - \varepsilon[1 + (\eta - 1)(|e_{x,y}|^2 + \beta|e_{y,x}|^2)]$$

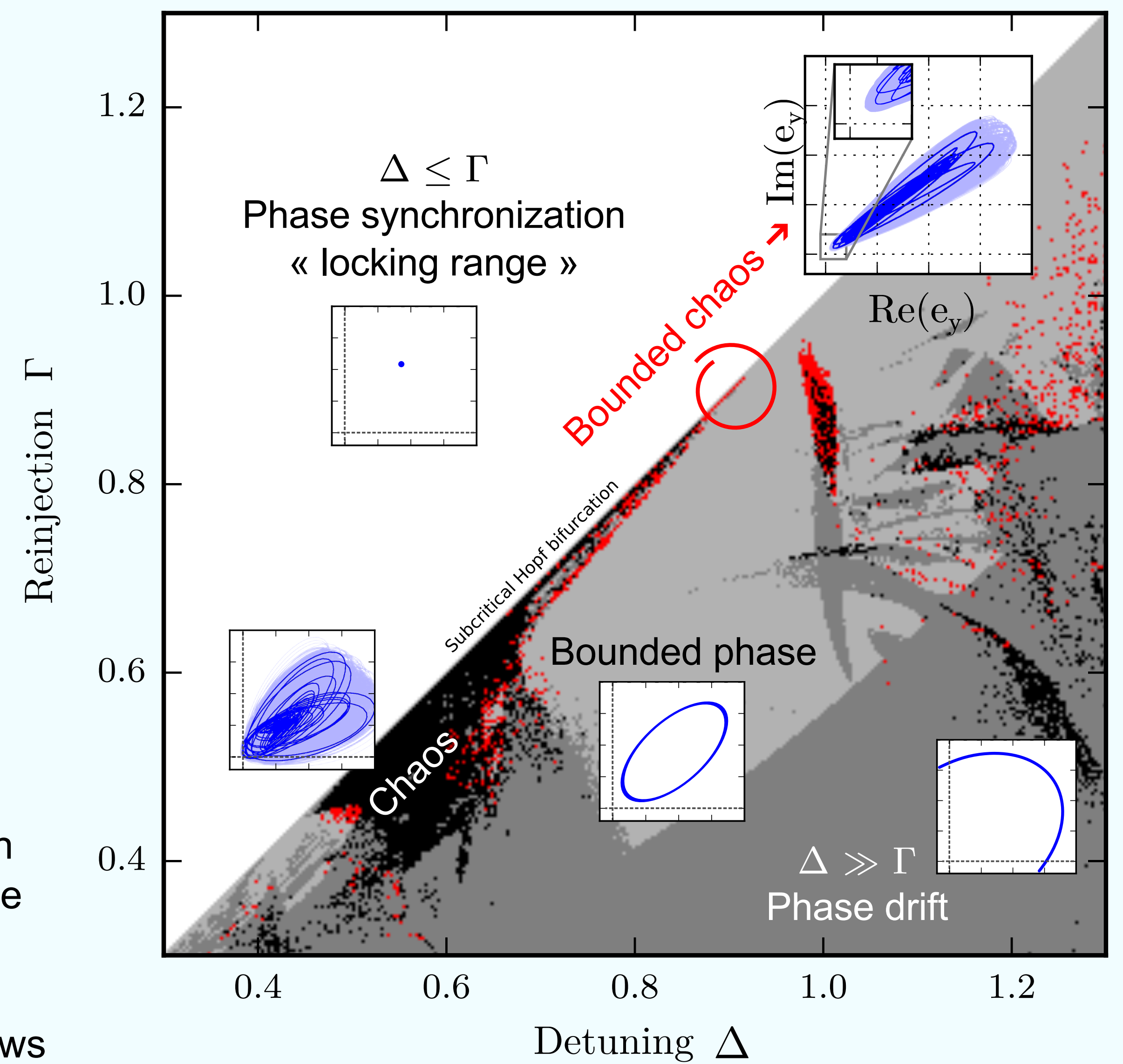
$s = 2\pi f_R t$: characteristic time of the system, based on relaxation oscillations frequency ($f_R=70\text{kHz}$)
 $\Delta = (\delta\nu - f_{ref})/f_R$: frequency detuning.
 Γ : reinjection strength.

$e_x = E_x e^{-2i\pi\nu_x t}$: normalized electric field.
 $e_y = E_y e^{-2i\pi(\nu_x + f_{ref})t}$: demodulated at f_{ref} , contains phase information.
 $\beta = 0,6$: coupling within active medium.
 $\varepsilon = 0,096$: cavity/active medium losses ratio.
 $\eta = 1,2$: pump parameter.



experimental observation of the beat-note amplitude $|e_x + e_y|^2$

IQ demodulation at f_{ref} allows to monitor the phase.

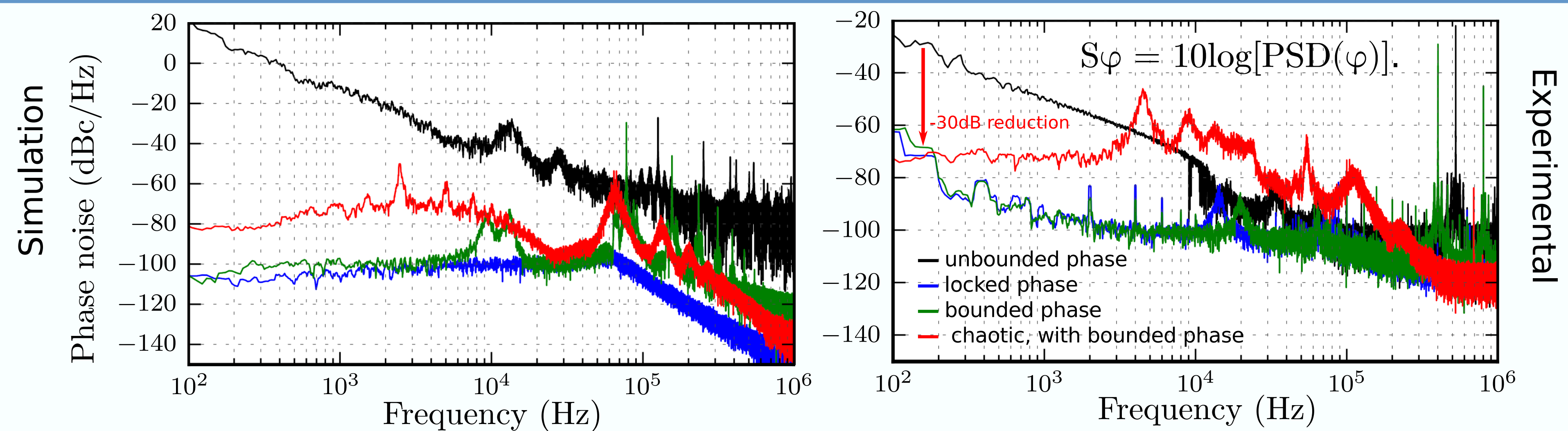


Stability (phase noise spectrum)

Is frequency locking still efficient ?

→ quantifying the quality of the opto-RF oscillator.

In the same way the bounded phase regime preserves the reference spectral purity, the chaotic bounded phase regime still allows to retain the long-time stability of the reference.



Conclusion

- Experimental demonstration of a chaotic bounded-phase regime (frequency locking with chaotic variations of intensity and phase).
- Spectral purity and long-term stability of the reference partially transferred to the opto-RF oscillator.
- Possible applications : chaotic Lidar-Radar proof-of-concept (ongoing, promising results) ; transfer to higher frequencies using semiconductor lasers.

Article : Thorette et al. "Frequency-locked chaotic opto-RF oscillator", Optics Letters **41**, 2839 (2016). Also on <https://arxiv.org/abs/1606.09464>

Partial funding : EDA Hippomos project CLEO-Europe Munich, June 2017

