IMEDEA

Polarization Encoding through Vectorial Chaos Synchronization in VCSELs

Alessandro Scirè [1], Josep Mulet [1], Claudio R. Mirasso [2], Jan Danckaert [1,3] & Maxi San Miguel [1]

Universitat de les Illes Balears. E-07071 Palma de Mallorca, Spain

1 Instituto Mediterráneo de Estudios Avanzados (CSIC- UIB)

2 Departament de Física

3 Vrije Universiteit Brussel, Brussels, Belgium.
Dept. of Applied Physics and Photonics (TW-TONA)

Scire et al. Phys. Rev. Lett. 90, 113901 (2003)

Motivation

A VCSEL with the active region surrounded by a saturable absorber can display *vectorial chaos*

The study of vectorial chaos and its synchronisation properties is useful to

- **widen the dynamical systems knowledge**
- **study new cryptographic and encoding schemes**
- **enhance the transmission capacity in view of cryptographic applications**

OUTLINE

- **Vectorial chaos: characterisation**

- **Synchronisation**

A continuous control synchronisation (CCS) required to achieve high quality synchronisation

- **Encoding:**

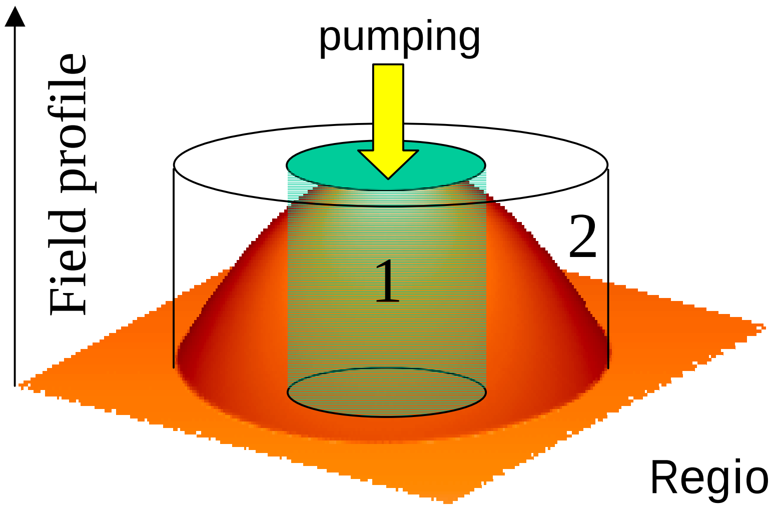
a) **CSK**: Double-contact VCSEL simple modulation technique and lower P(E) at the receiver

–> talk Alessandro last year

b) **polarisation message encoding**: bit rate not limited by relaxation oscillation freq.

- **Conclusions**

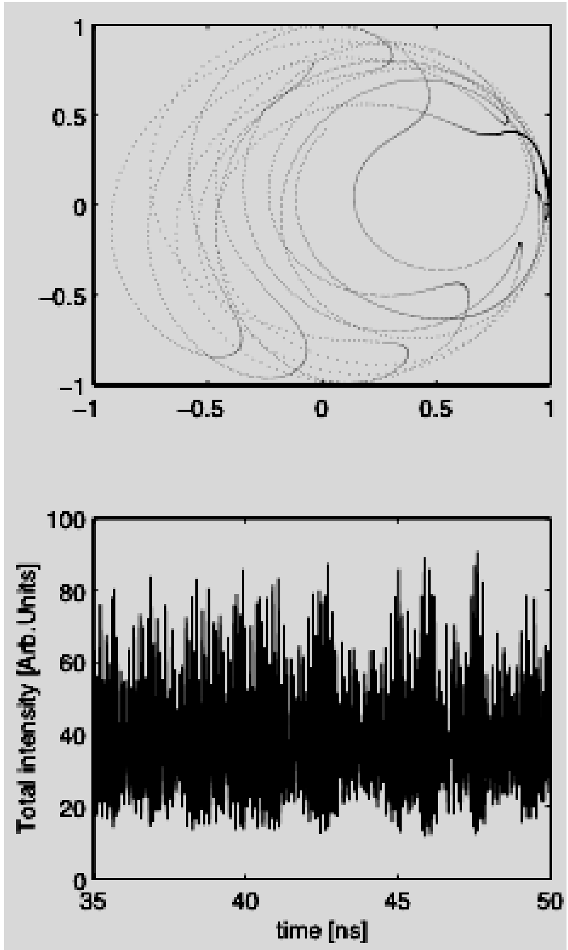
Characterising Vectorial Chaos

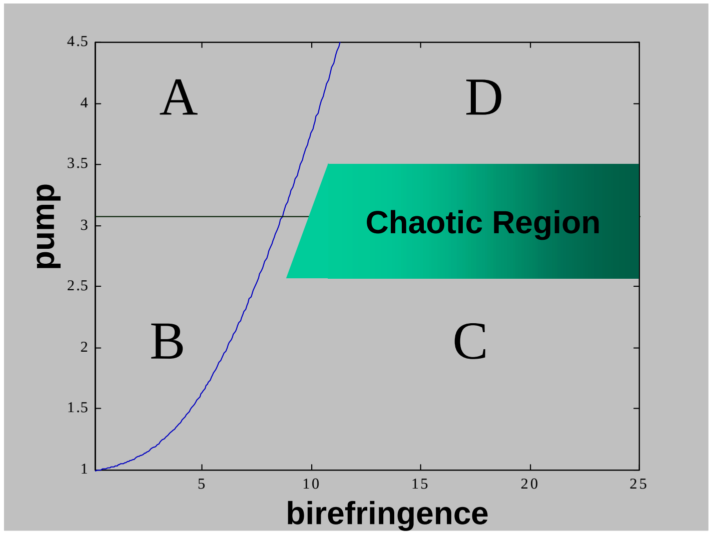


VCSEL with saturable absorber,
described by theSFM+ Yamada appropach

A. Scirè et al., *Opt.Lett*. **27**, 391 (2002).

Region of the phase space:
chaos.





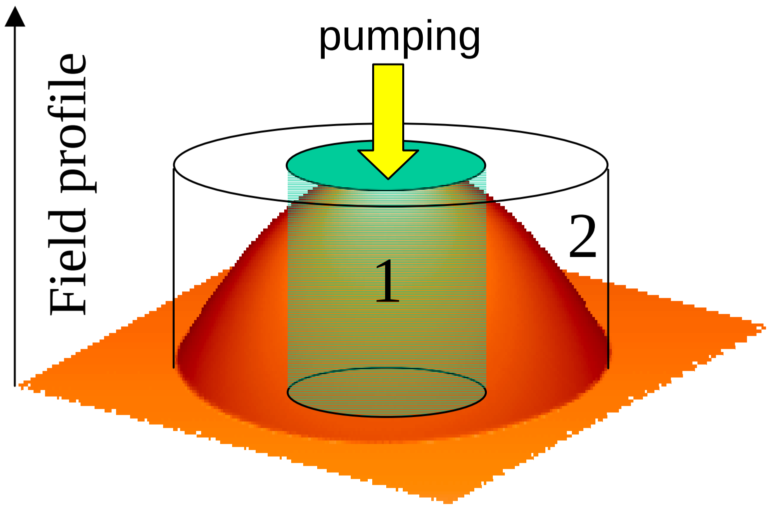
A: stable y-LP

B: pulsations in one polarization

C: coupled pulsations

D: polarization pulsations

Characterising Vectorial Chaos



VCSEL with saturable absorber, described by theSFM+ Yamada appropach

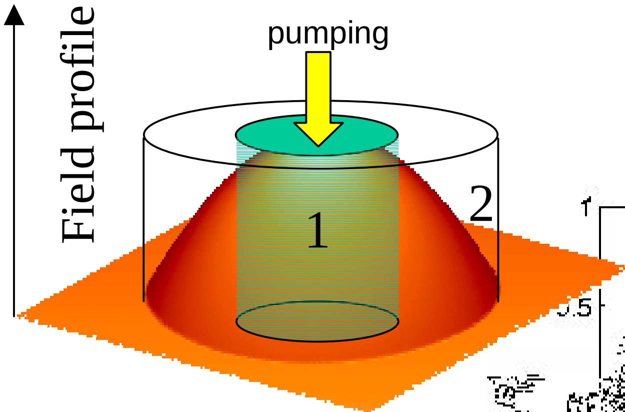
A. Scirè et al., *Opt.Lett*. **27**, 391 (2002).

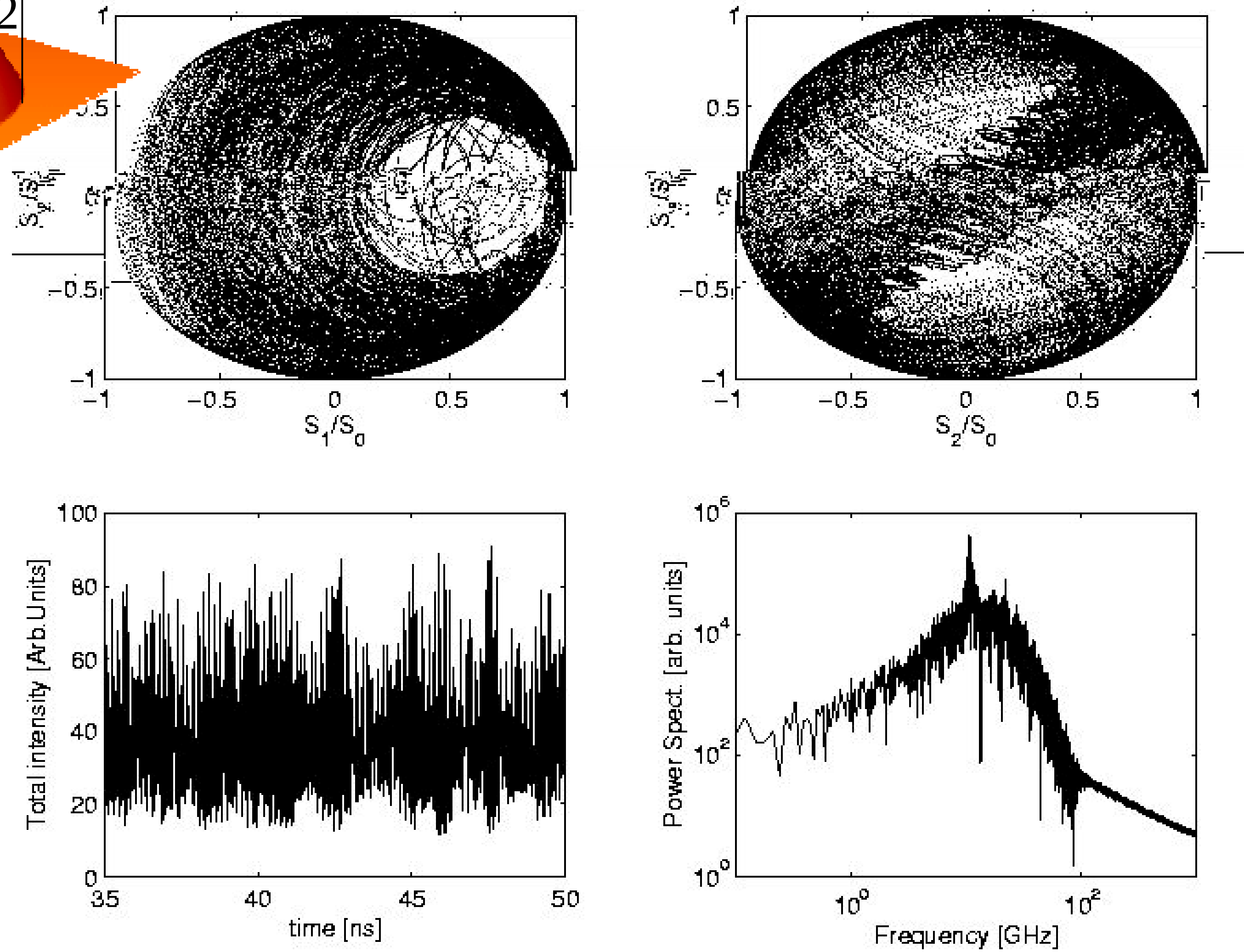
$$\dot{F}_{\pm} = \frac{1}{2}(1+i\alpha)\left[D_1 + D_2 \pm d_1 \pm d_2 - 1\right]F_{\pm} - (\varepsilon_a + i\varepsilon_p)F_{\mp}\,,$$

[illegible]

$d_{2,1}]$, $\dot{d}_{1,2} = -\gamma_{s1,2}d_{1,2} - \gamma_{1,2}\left[(D_{1,2}+d_{1,2})|F_+|^2 - (D_{1,2}-d_{1,2})|F_-|^2 - c_{21,12}\right.$

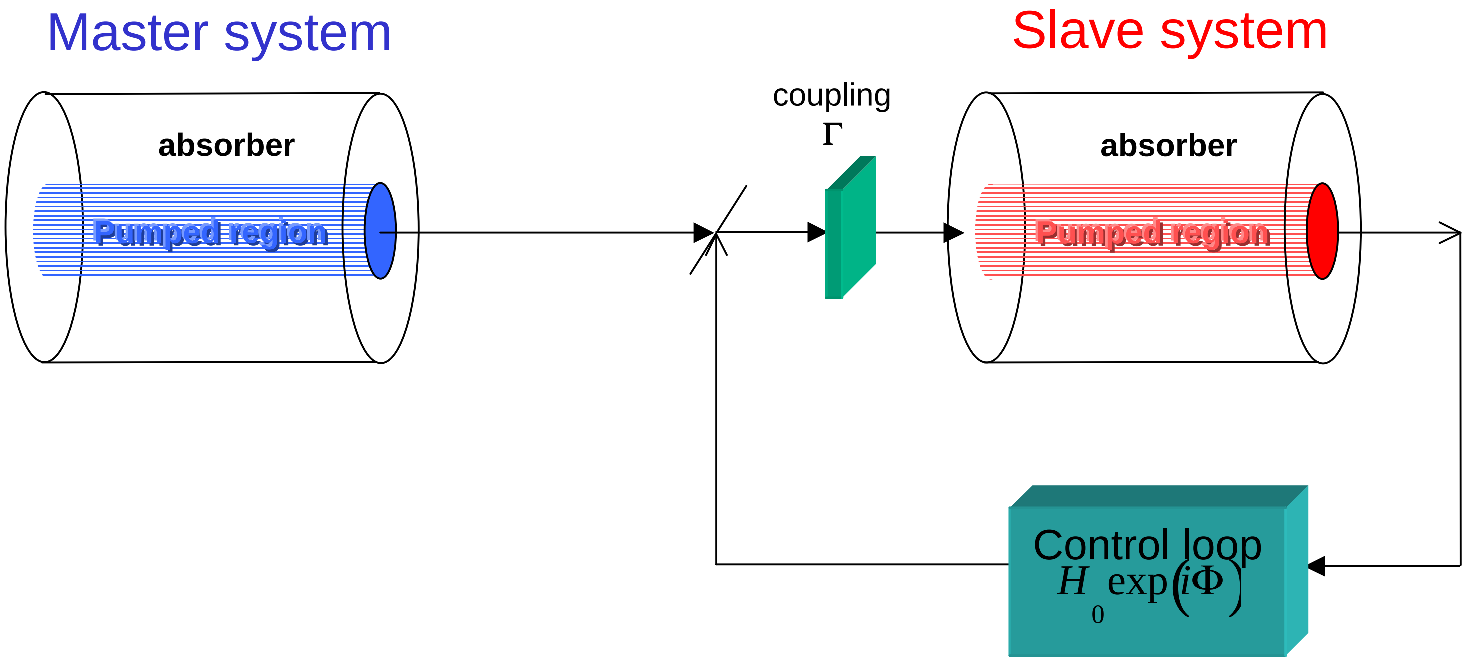
Characterising Vectorial Chaos





2 positive Lyapounov exponents: total intensity & pol. instab.)

Coupled system



$$\dot{F}_{\pm}^{M} = f_{\pm}\left(D_{1,2}^{M}, d_{1,2}^{M}\right)F_{\pm}^{M} + \left(\gamma_a + i\gamma_p\right)F_{\mp}^{M} + \xi_{\pm}^{M}(t)$$

$$\dot{F}_{\pm}^{S} = f_{\pm}\left(D_{1,2}^{S}, d_{1,2}^{S}\right)F_{\pm}^{S} + \left(\gamma_a + i\gamma_p\right)F_{\mp}^{S} + \xi_{\pm}^{S}(t) + \Gamma\left(F_{\pm}^{M} \qquad \right)$$

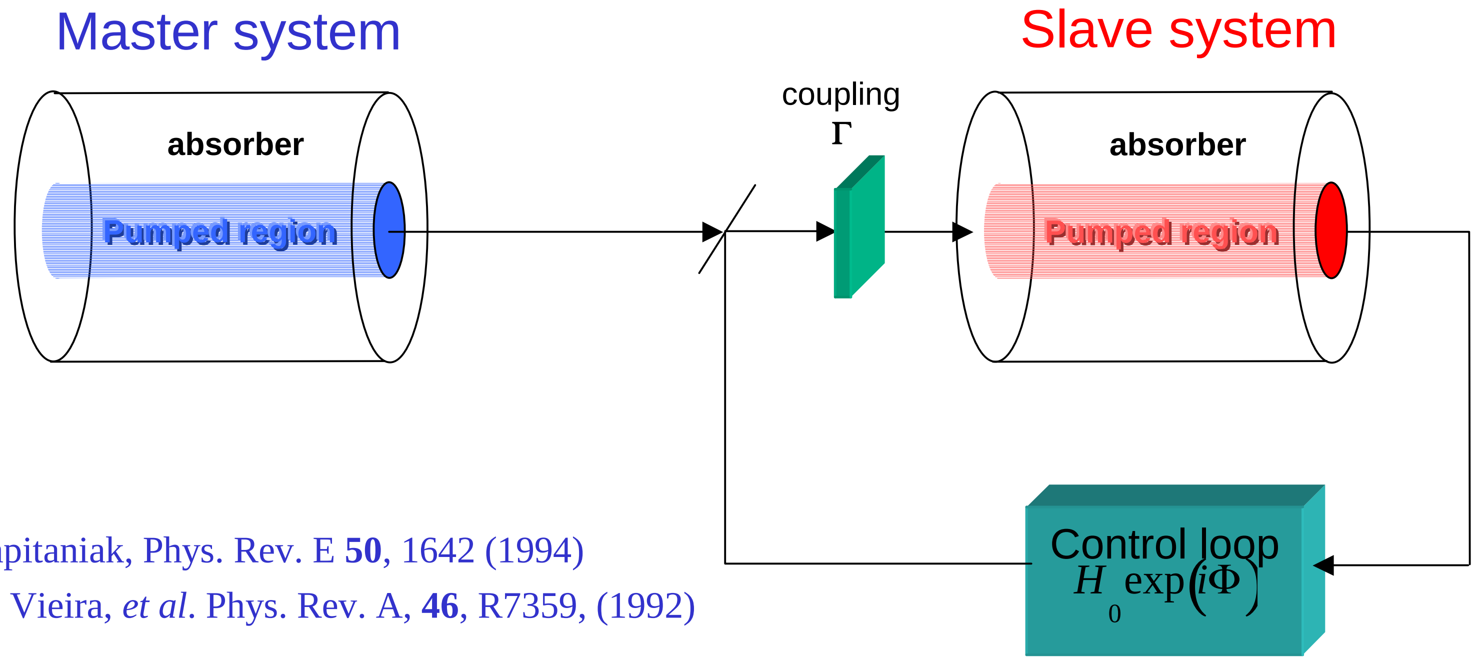
direct coupling: no robust synchronisation

Continuous Control Synchronisation Scheme

=> A Continuous Control of the Synchronisation is required.

The optimum phase condition is $\phi=\pi$ and $H_0 = 1$ [1]

- Phase condition introduces a dissipative term in the Slave system [2]
- The coupling Γ governs the transition from unsynchr. to synchronised behaviour.

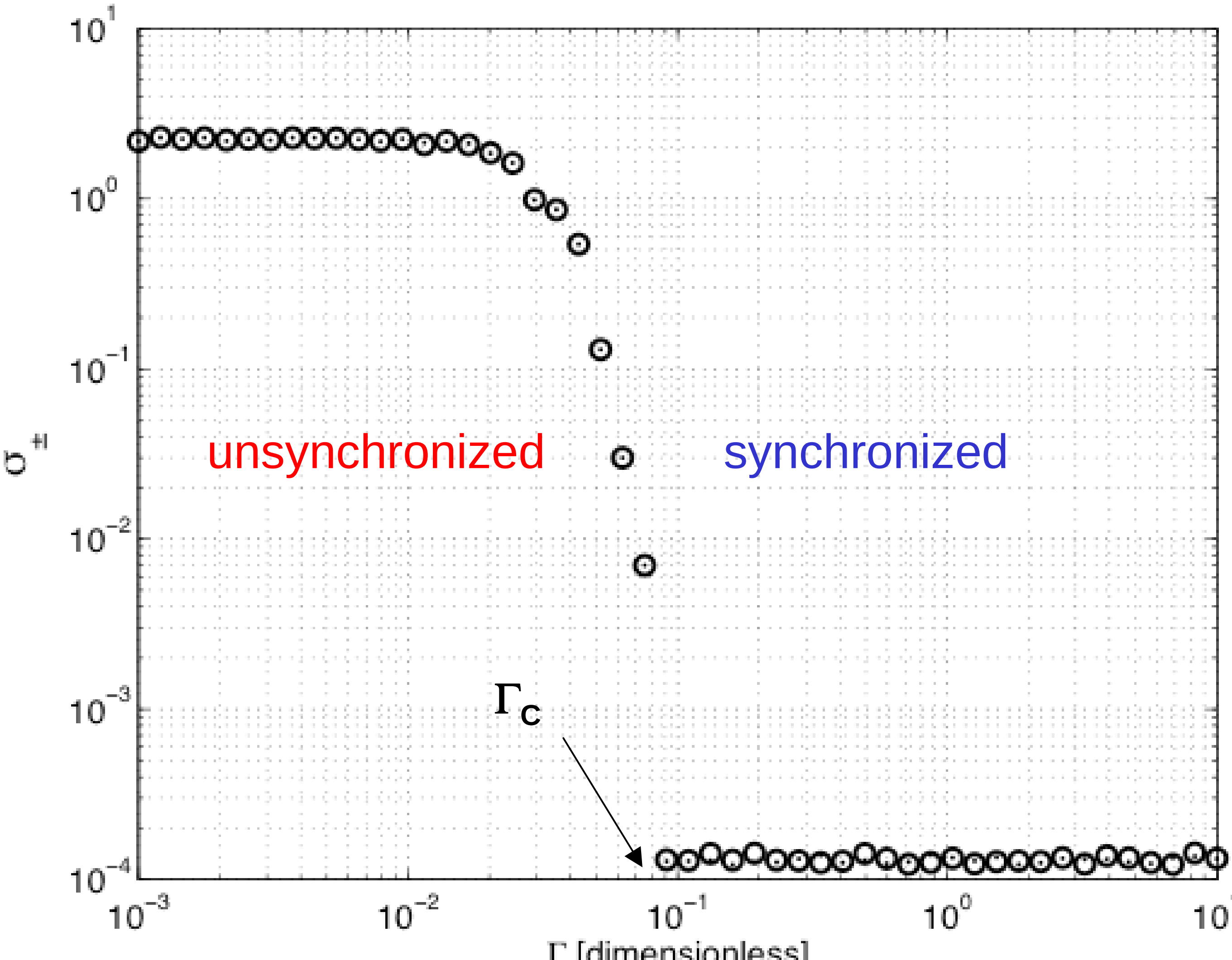


[1] T. Kapitaniak, Phys. Rev. E **50**, 1642 (1994)

[2] M. S. Vieira, *et al*. Phys. Rev. A, **46**, R7359, (1992)

Synchronisation properties

Increasing the coupling Γ, a transition to a synchronized state in both circular components takes place at $\Gamma = \Gamma_c$



Circular components of the *mean vectorial synchro. error*

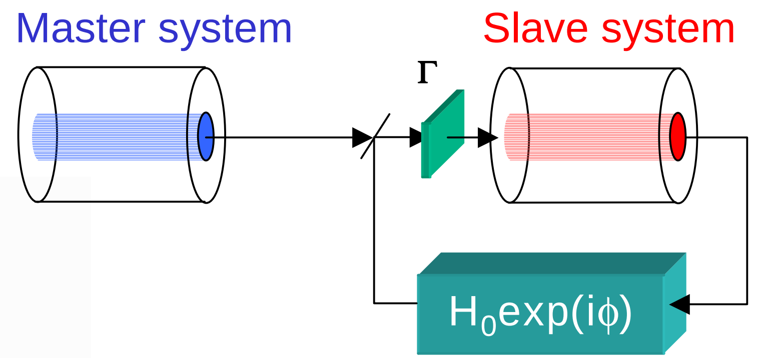
$$\sigma_{\pm} = \frac{\left\langle \left| F_{M,\pm} - F_{S,\pm} \right| \right\rangle}{\left\langle \left| F_{M,\pm} \right| \right\rangle}$$

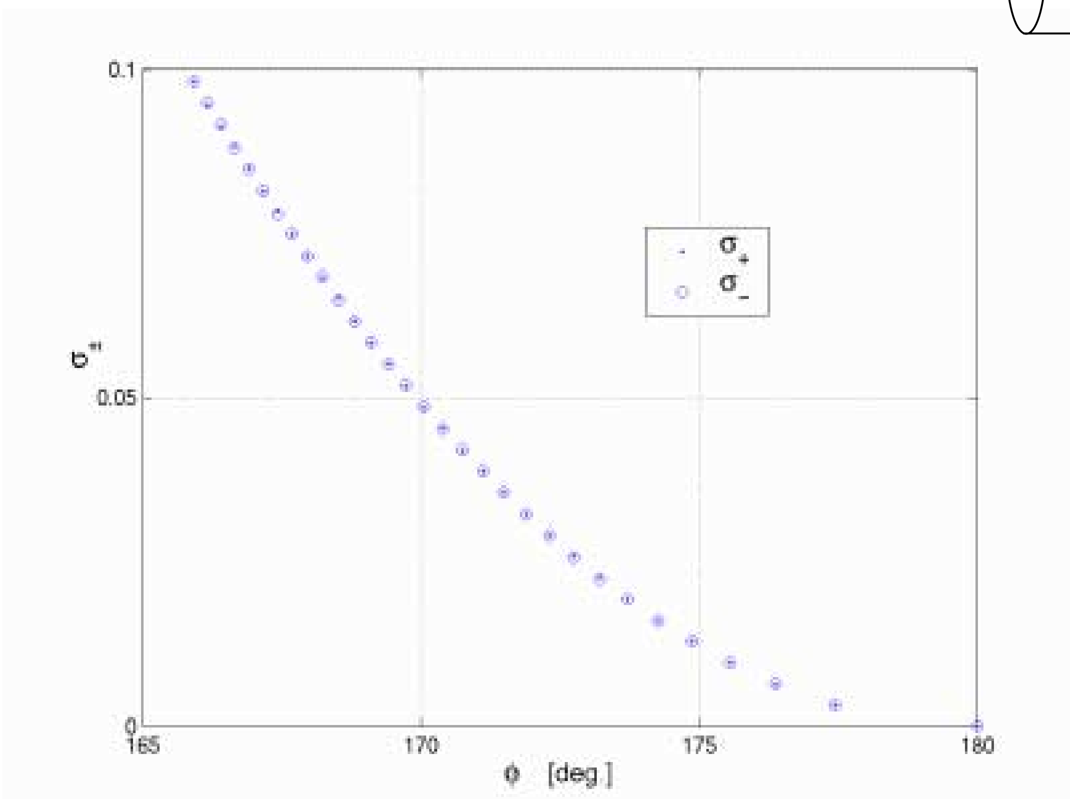
Noise floor

http://www.imedea.uib.es/PhysDept/

Control Loop Phase Mismatch

A phase mismatch with respect to the optimum condition lowers the synchronization quality.





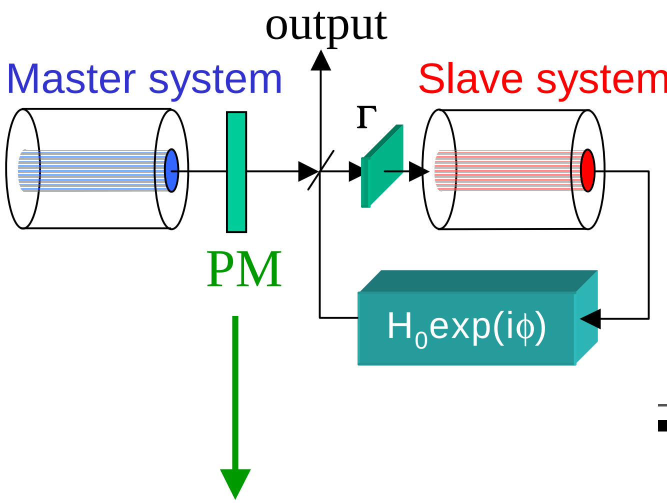
In practice, the accuracy level required to fulfil

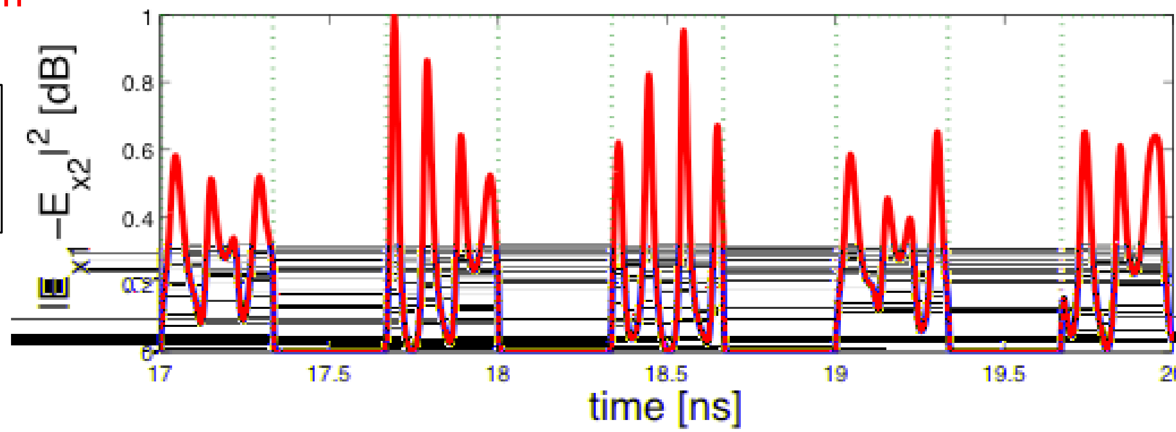
$\phi=\pi$

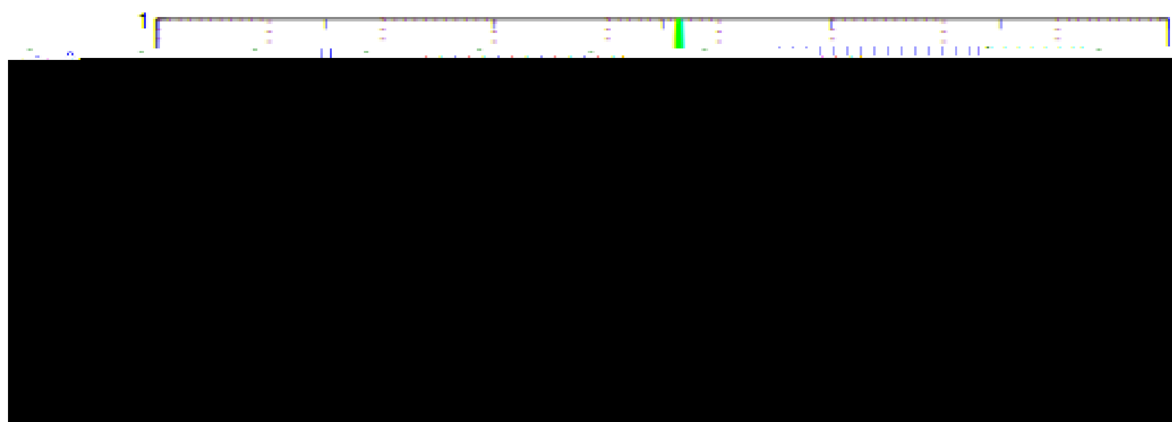
is of the same order of magnitude as in coherent detection or interferometry.

Polarisation message encoding

*Van Wiggeren & Roy, PRL **88**, 097903, 2002*







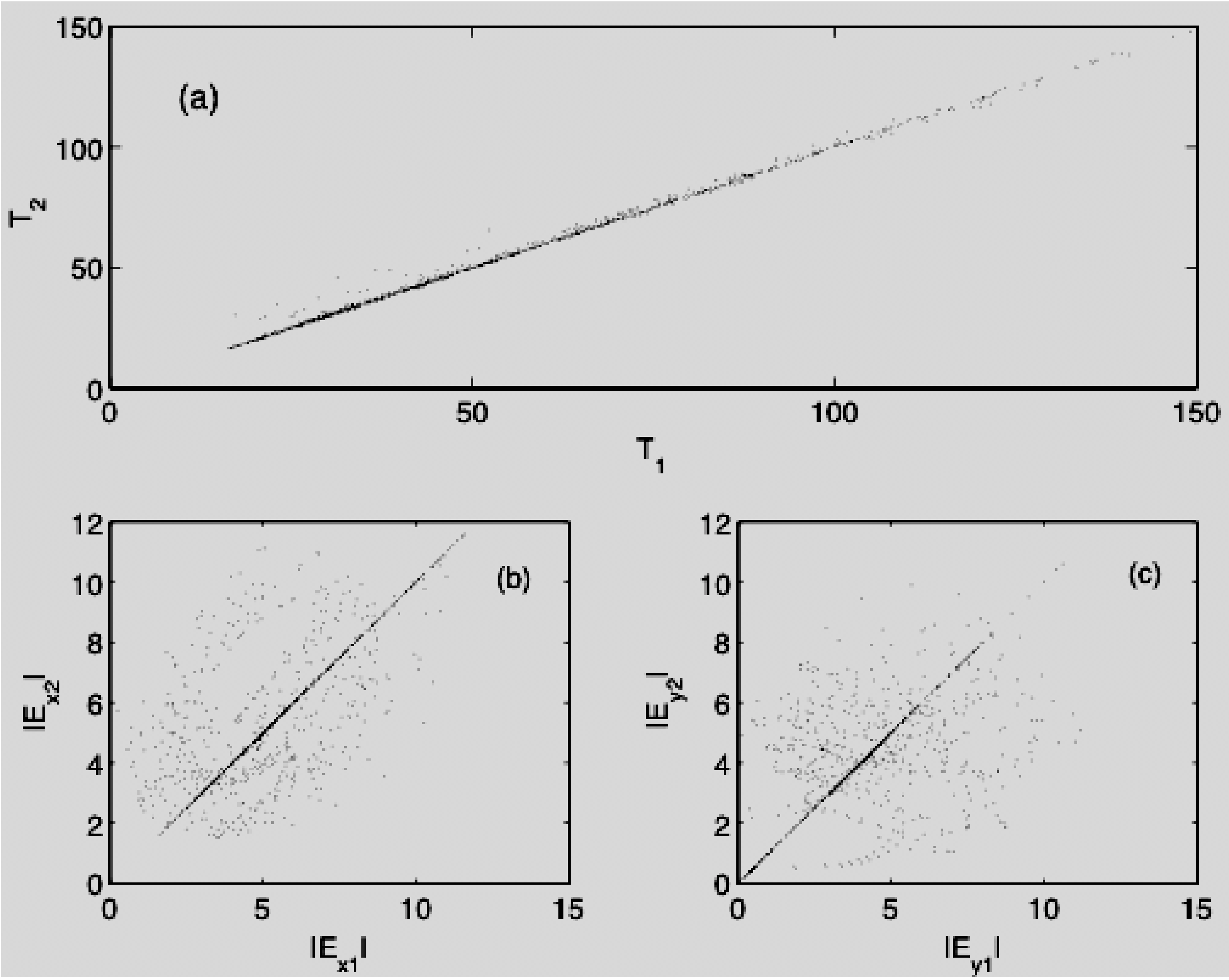
Polarisation message encoding
Off-state (bit 0): no phase shift
On-state (bit 1): phase shift

Demodulation: OOCSK:
bit *"0"* : slave synchronises;
bit *"1"* : slave desynchronises partially: **I_{tot} remains synchronised,**
x,y- pol. comps desynchronise.

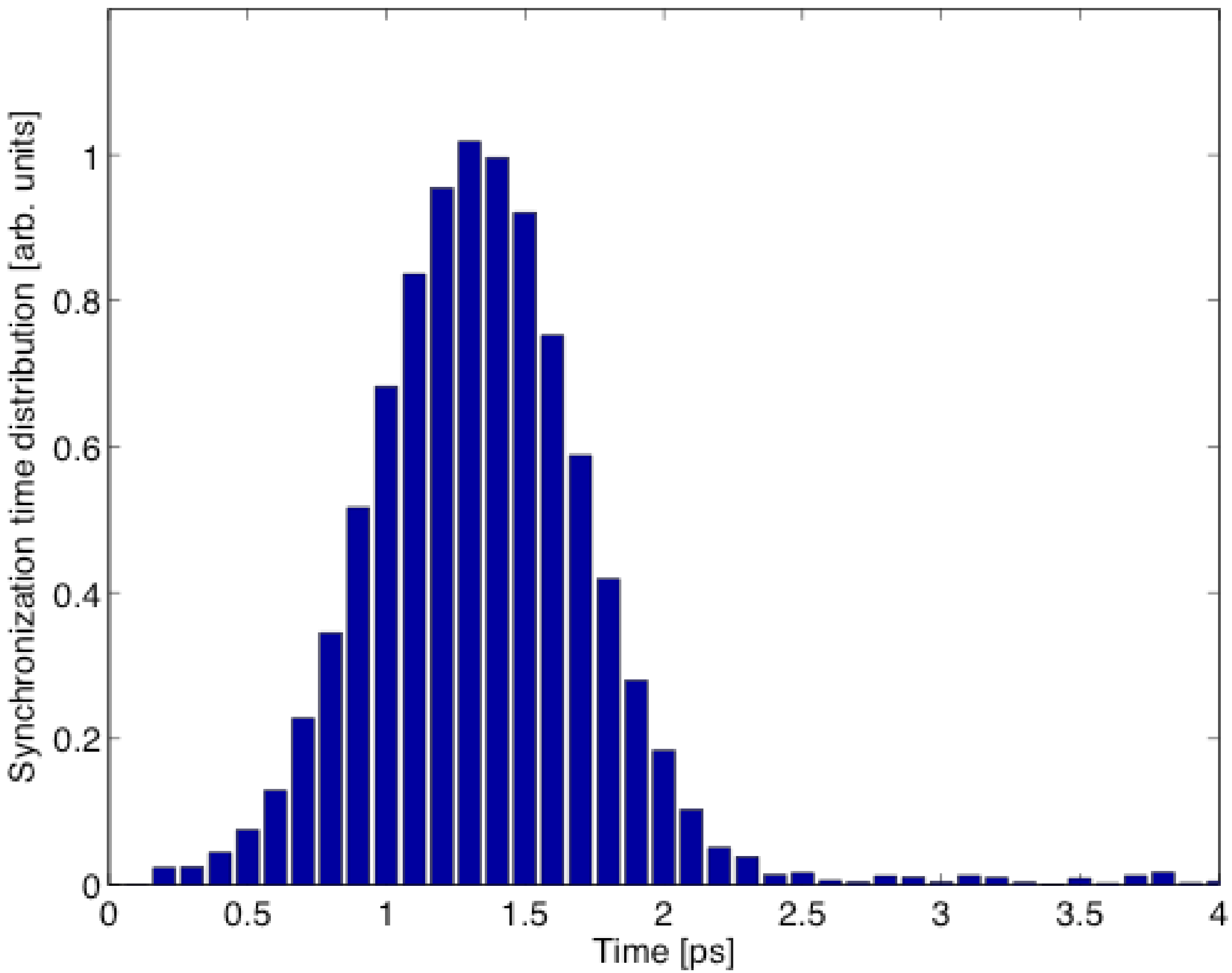
Bit recovery through On-Off Chaos Shift Keying (OOCSK)

Synchronisation diagrams:

total intensity and polarisation comp's



Synchronisation time



Very fast synchronisation: bit rates up to 100 Gbps possible

Conclusions

- **VCSEL where active region is surrounded by saturable absorber can exhibit vectorial chaos: chaos in both intensity & pol. No feedback scheme required!**

- **synchronization properties of two such VCSELs:**
  direct coupling: no robust synchr.
  continuous control scheme required
due to vectorial nature of the chaotic field.

- **Novel encryption scheme, exploiting phase modulation:**
  - **average Itot remains unaffected**
  - **very fast synchr. -> 100 Gbps transmission possible**

- **-> other laser sources with vectorial chaos?**
Cf Van Wiggeren & Roy, PRL 2002.

Scire et al. Phys. Rev. Lett. 90, 113901 (2003)