UNIVERSITÉ LAVAL

# Optical control of laser induced chaotic dynamics in nematic liquid crystals

E. Brasselet, B. Doyon, and L. J. Dubé

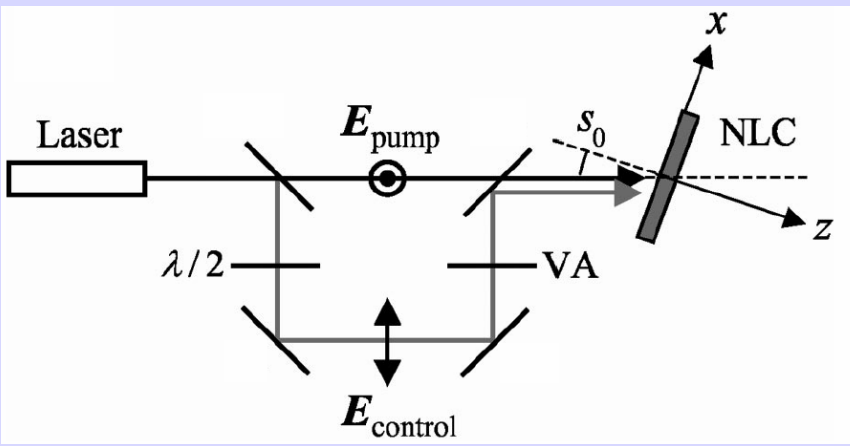
*Département de Physique, de Génie Physique, et d'Optique, Université Laval, Cité Universitaire, Québec G1K7P4, Canada*

**Prepared for the 15th anniversary of COPL, June 7, 2004**

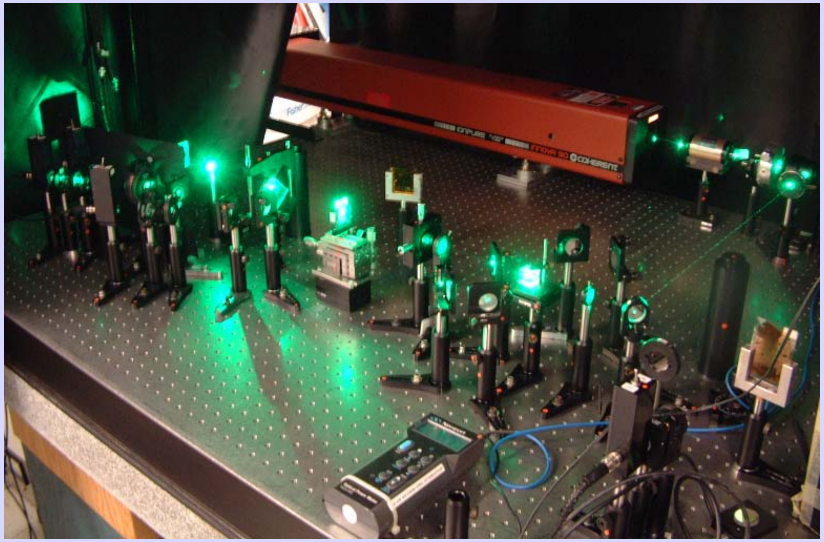
# A nematic liquid crystal film is excited by two light beams :

(1) Ordinary linearly polarized light at oblique incidence (PUMP)

(2) Extraordinary linearly polarized light at oblique incidence (CONTROL)

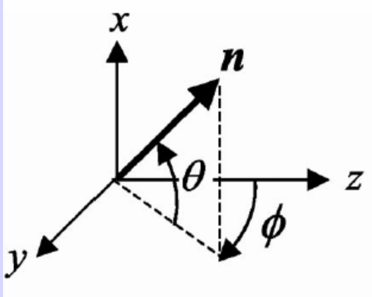



***Experimental set-up***



Light torque induces molecular reorientation

# Rigorous framework for a theoretical description available




- Maxwell's equations
- Hydrodynamic equations of the LC

Boundary conditions

$$\theta(z,t)=\sum_{n=1}^{\infty}\theta_n(t)\sin(n\pi z/L)$$

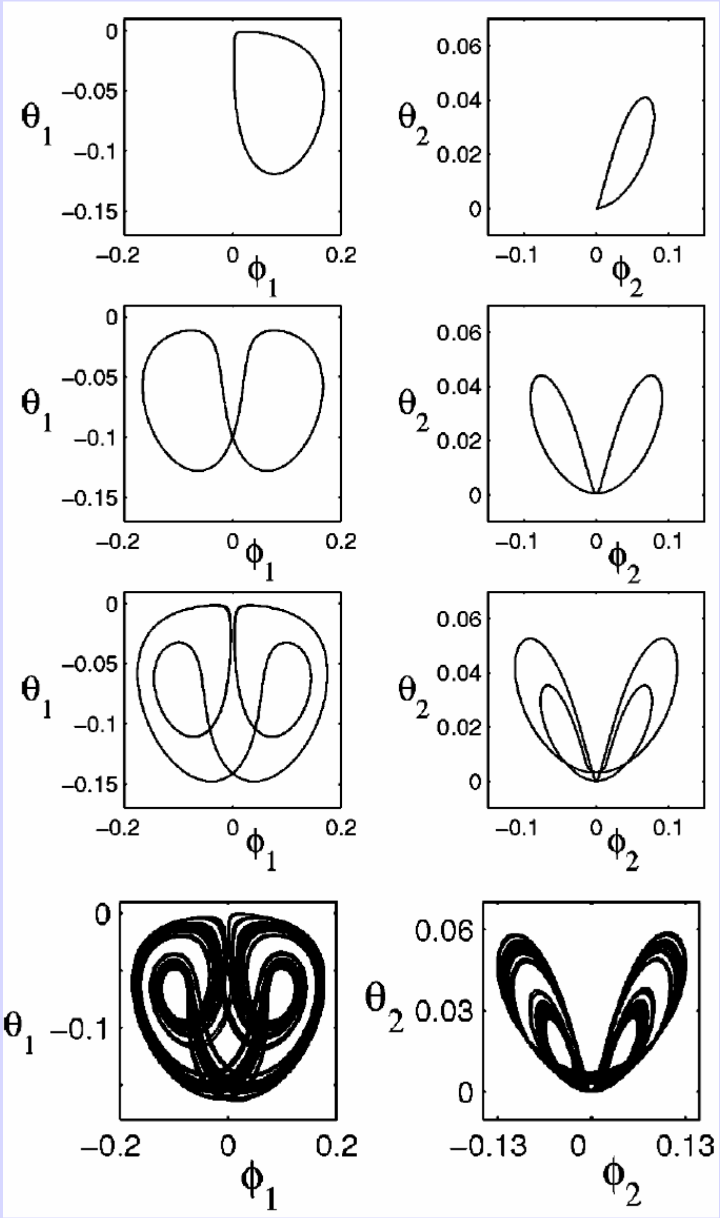
$$\phi(z,t)=\sum_{n=1}^{\infty}\phi_n(t)\sin(n\pi z/L)$$

# Simplest nonlinear model for the director dynamics

$$\tau\frac{\partial}{\partial t}\begin{pmatrix}\phi_1\\ \phi_2\\ \theta_1\\ \theta_2\end{pmatrix}=\sum_{\alpha,\beta,\gamma,\delta}\begin{pmatrix}a_{\alpha\beta\gamma\delta}\\ b_{\alpha\beta\gamma\delta}\\ c_{\alpha\beta\gamma\delta}\\ d_{\alpha\beta\gamma\delta}\end{pmatrix}\phi_1^{\alpha}\phi_2^{\beta}\theta_1^{\gamma}\theta_2^{\delta}$$

$$0\leqslant\alpha+\beta+\gamma+\delta\leqslant 3$$

# Bifurcation scenario with the *pump beam alone*




Well-defined sequence of bifurcations with light intensity as control parameter

(1) Pitchfork (undistorted → distorted)

(2) Supercriticial Hopf (distorted → limit cycle)

(3) Destabilization of symmetric limit cycle

(4) Gluing-1 (double length symmetric limit cycle)

(5) Destabilization

(6) Gluing-2

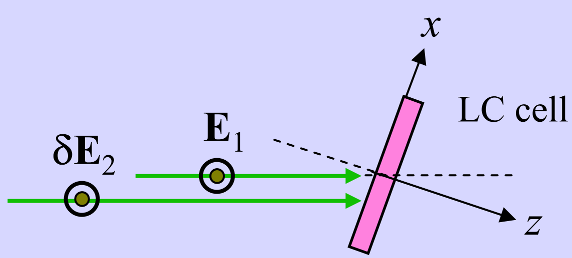
(7) …

(8) Transition to chaos

# Optical intervention on the dynamics

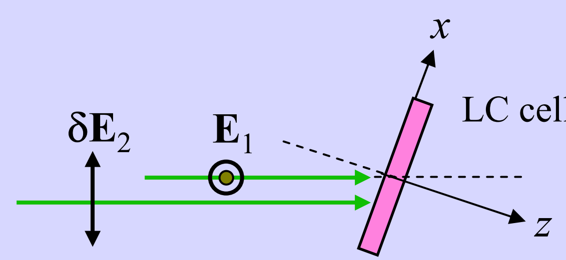
## Variation of the excitation intensity using polarization sensitivity

***Scalar***




$$\{\ \rho_1\ \}$$

***Vectorial***




$$\{\rho_1 , \rho_2\}$$

Control parameters

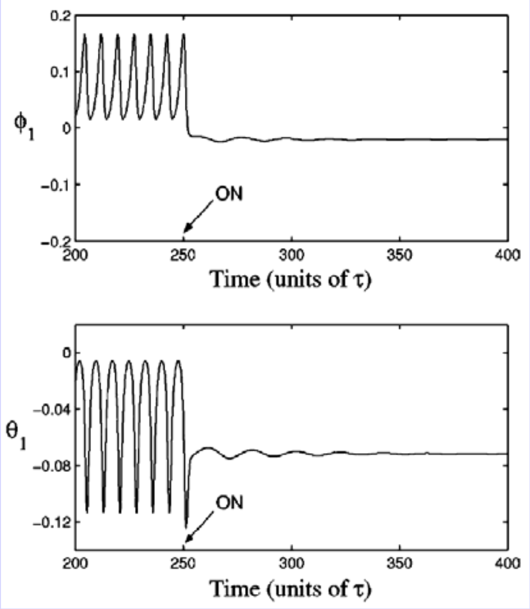
$$\rho_1 = \frac{I_1}{I_F} \quad \text{where} \quad I_1 = |\boldsymbol{E}_{\text{pump}}|^2$$

$$\rho_2 = \frac{I_2}{I_F} \quad \text{where} \quad I_2 = |\boldsymbol{E}_{\text{control}}|^2$$

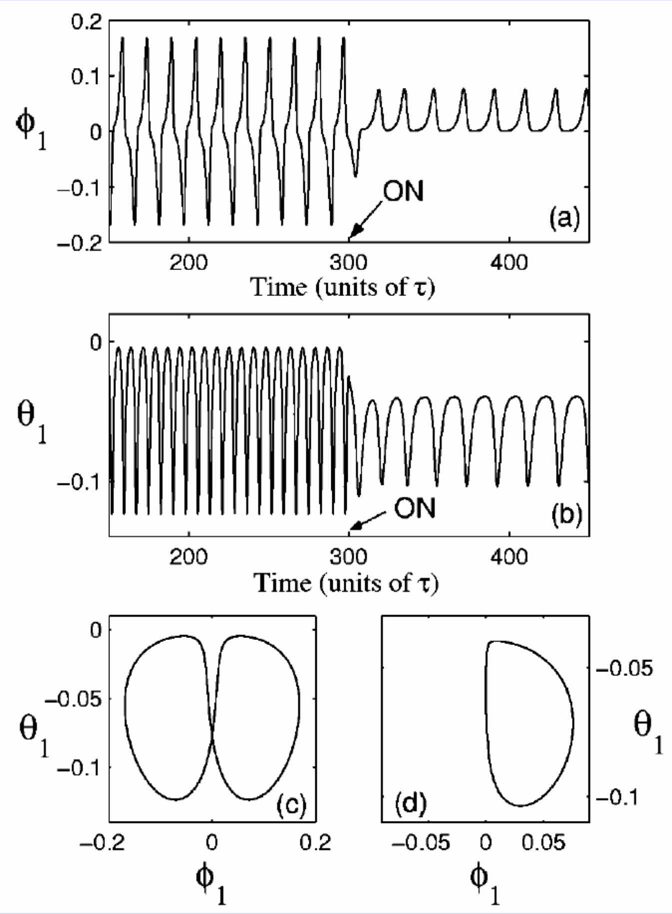
$I_F$ : Fréedericksz transition threshold

# Vectorial optical control of the dynamics

## Between the Hopf and the first gluing bifurcation




## Between the first and the second gluing bifurcation

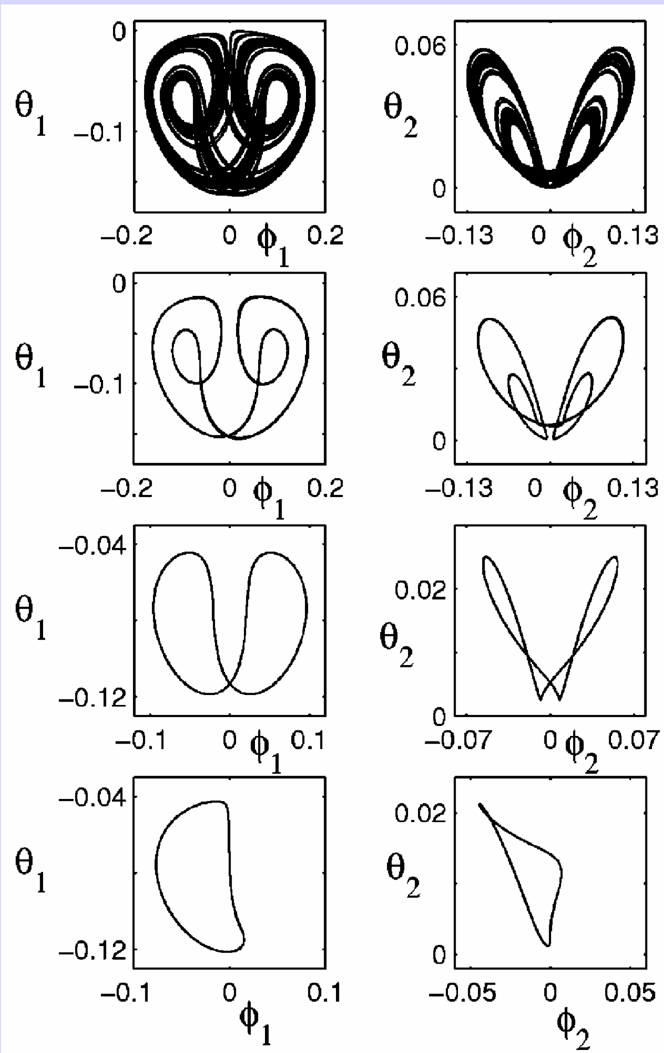



The control beam acts virtually as a reduction of the pump intensity

# Optical tuning of chaotic dynamics

Pump intensity fixed $\rho_1 = 1.98$

Control parameter $R = \rho_2 / \rho_1$



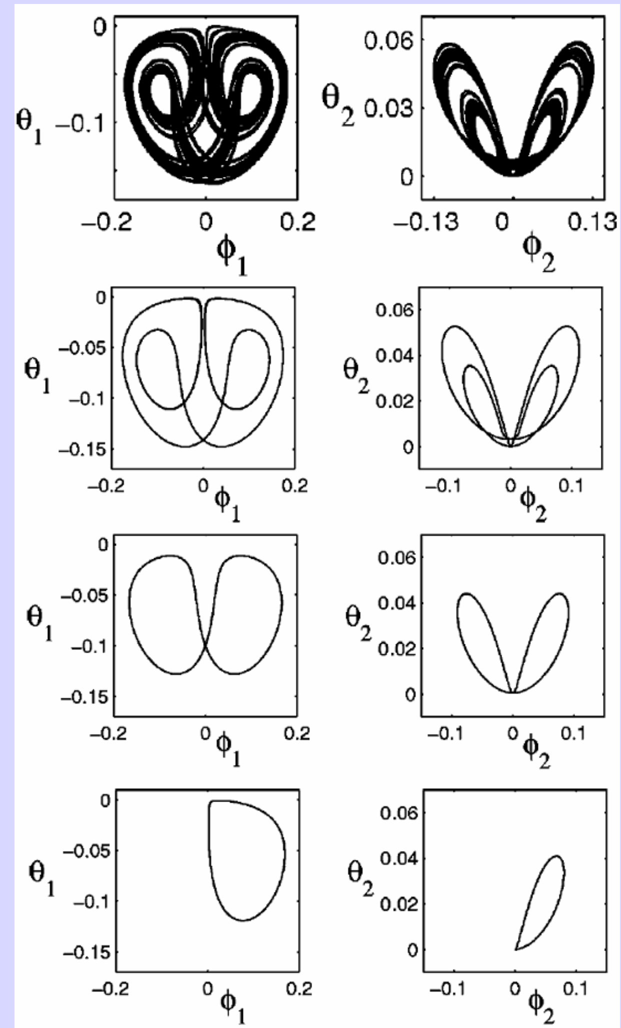

$R = 0$

$R = 0.02$

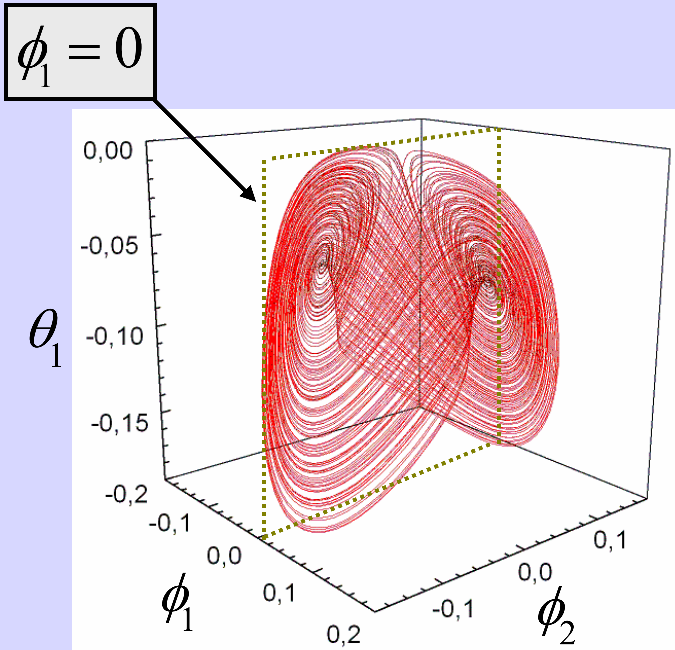
$R = 0.10$

$R = 0.13$

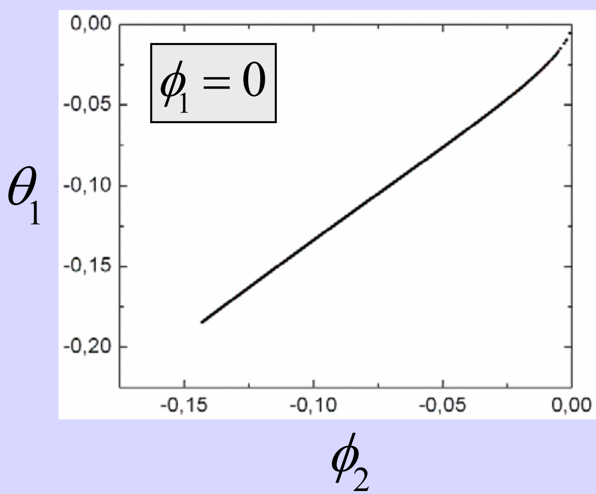
Pump beam *alone*

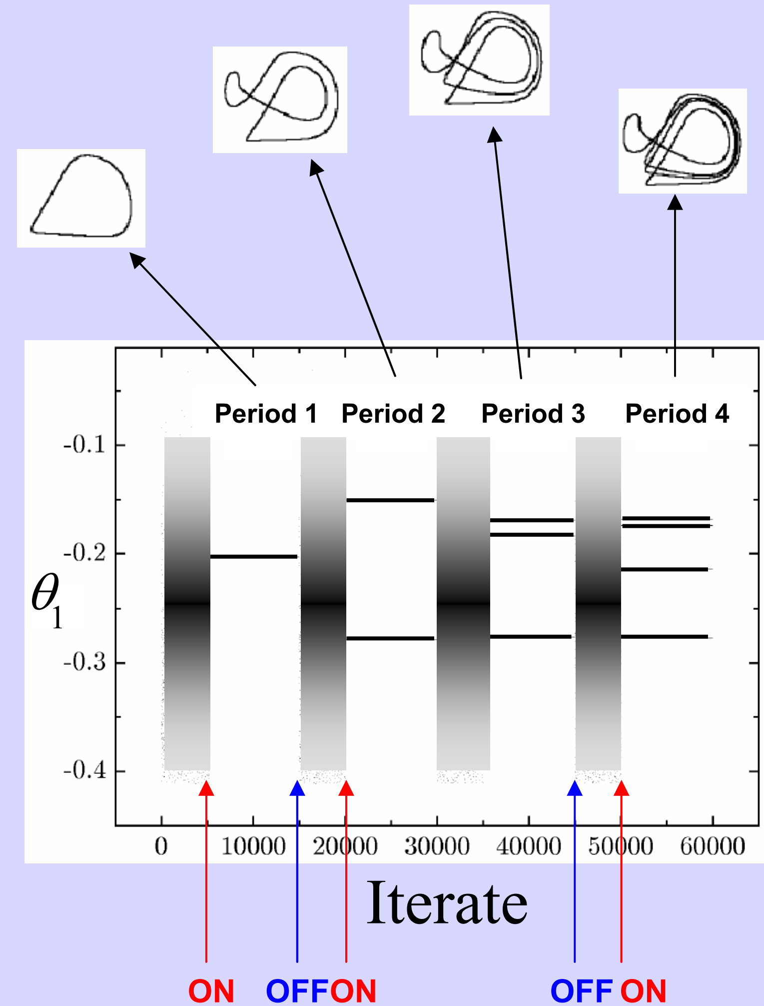


# Scalar optical control of the dynamics



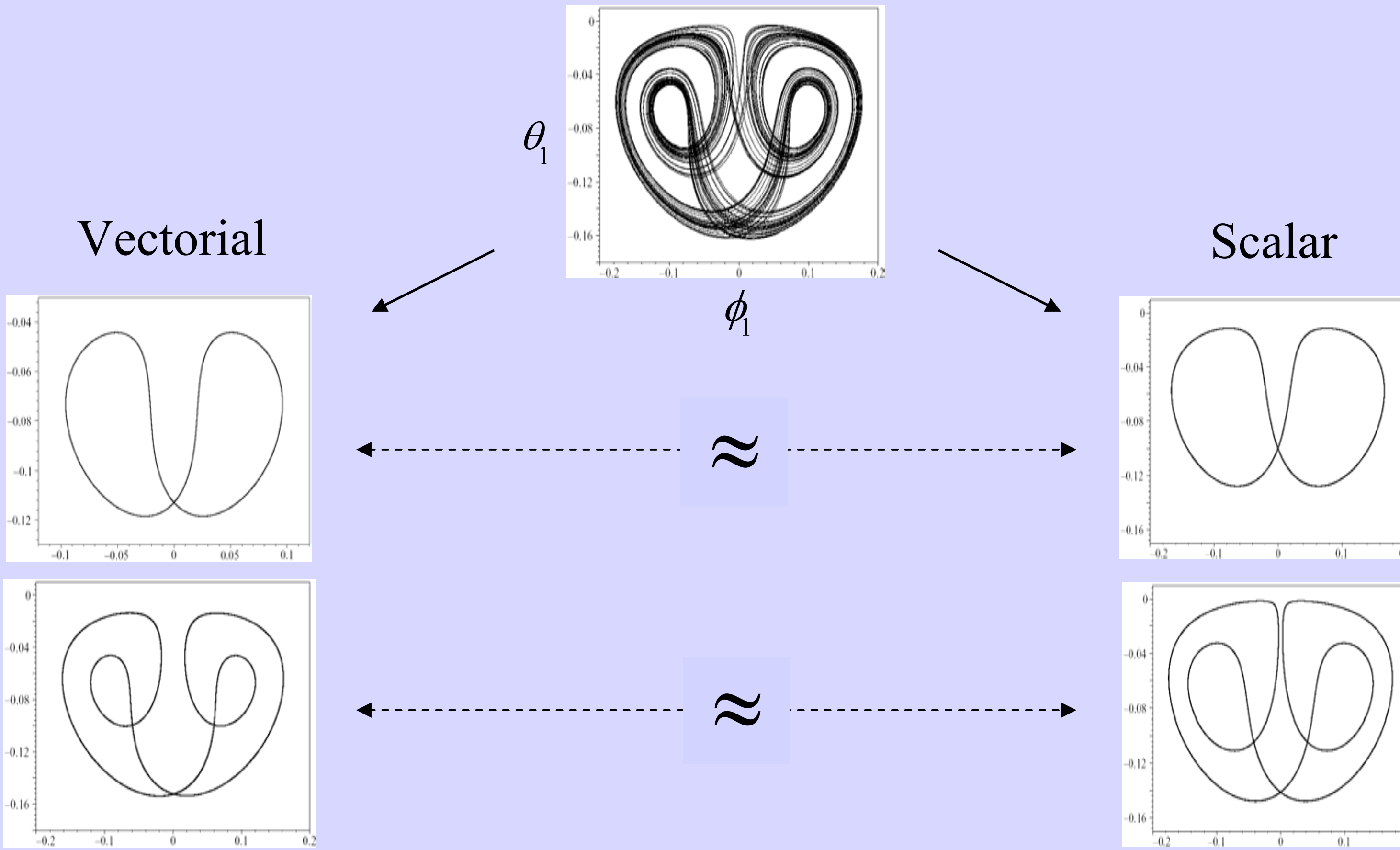

Poincaré surface of section



# *Vectorial* versus *scalar* optical control of the dynamics

Starting from chaotic attractor

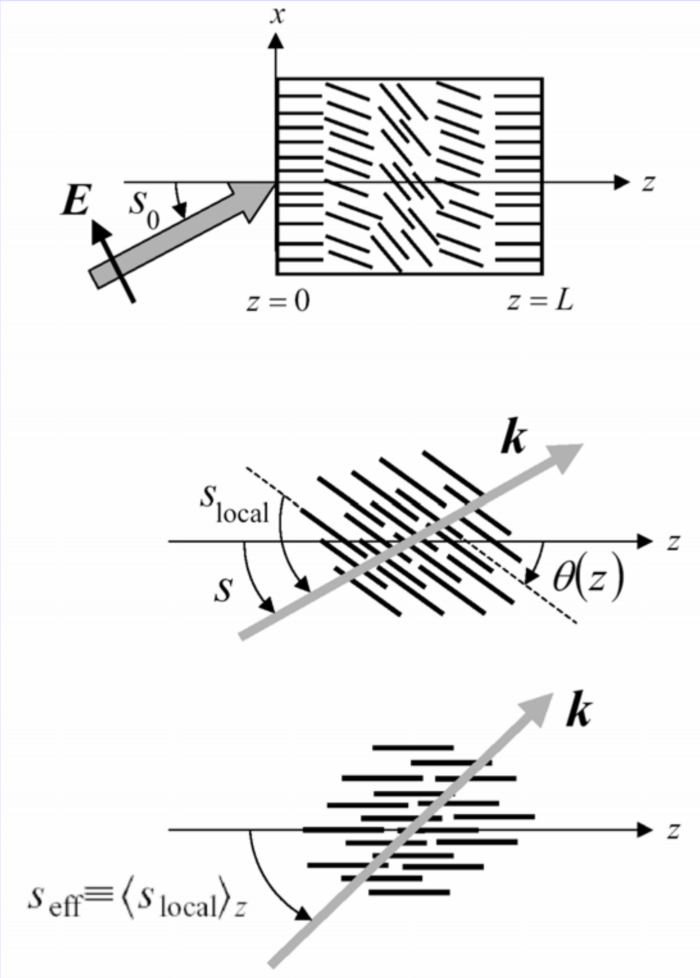



Static perturbations
+
Additional nonlinearities

Small dynamical perturbations

# Qualitative interpretation of the vectorial optical control

## Control beam *alone*

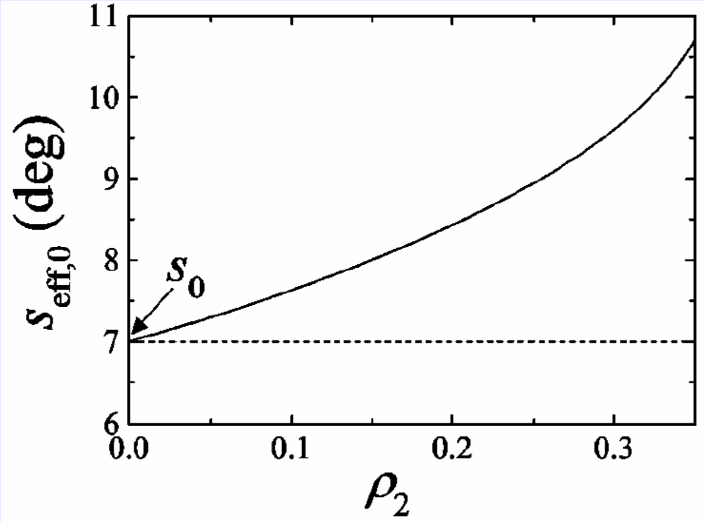



## Effective angle of incidence

$$s_{\text{eff}}(\rho_2, s) = s - \frac{1}{L}\int_0^L \theta(z)_{\rho_1=0}\, dz$$

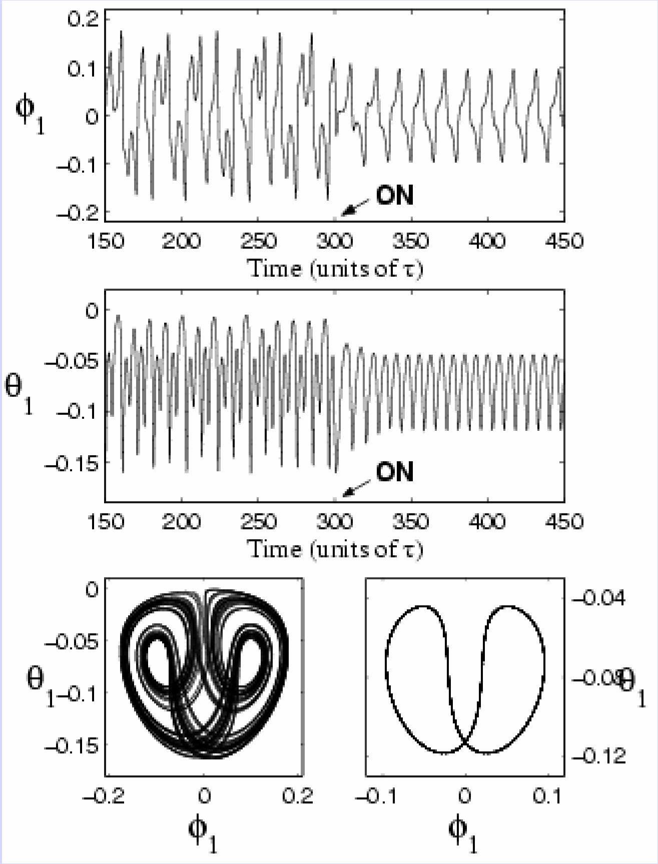
## Effective model

$$[\rho_1, \rho_2, s] \Leftrightarrow [\rho_1, 0, s_{\text{eff}}(\rho_2, s)]$$

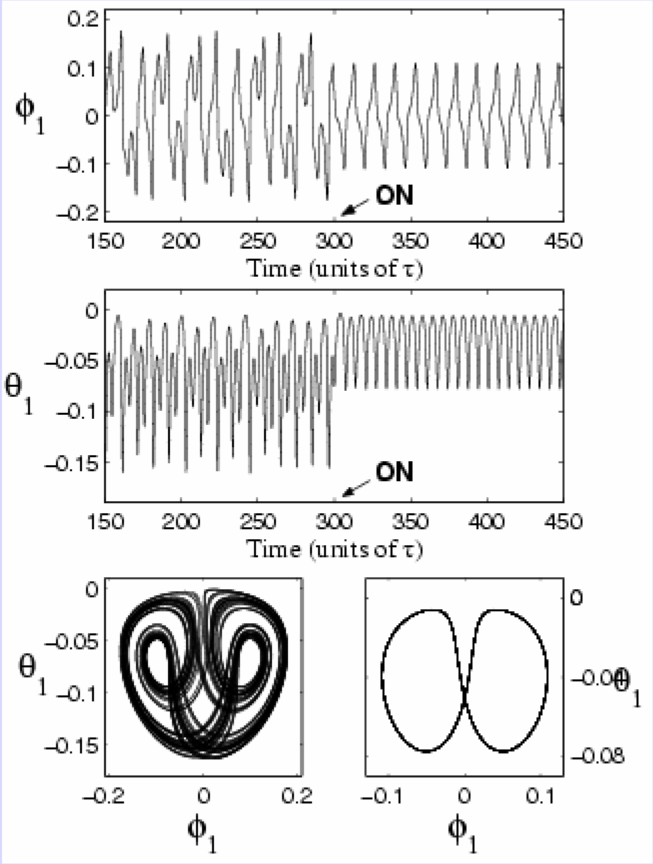


# Effective model simulations for vectorial optical control

## Effective model ($\delta s_0 = 1.4°$)




## Vectorial model ($R = 0.1$)




The stabilized state is qualitatively the same

# Summary

## Optical control of nonlinear dynamics generated by light in nematic liquid crystal films

- Theoretical model and simulations of optical control
- Scalar control : judicious small dynamical perturbations
- Vectorial control : static perturbations (polarization sensitivity)
- Interpretation on the basis of an effective model

*Part of this work has been published in* E. Brasselet, Phys. Rev. E **69**, 021712 (2004)