

Lineas de investigacion y temas de interes

Cristina Masoller

Departamento de Física
Universitat Politecnica de Catalunya
Cristina.masoller@upc.edu

www.fisica.edu.uy/~cris



UNIVERSITAT POLITÈCNICA
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Campus d'Excel·lència Internacional

Seminario online en el Instituto de Fisica
Facultad de Ciencias, Uruguay
Mayo 21, 2020



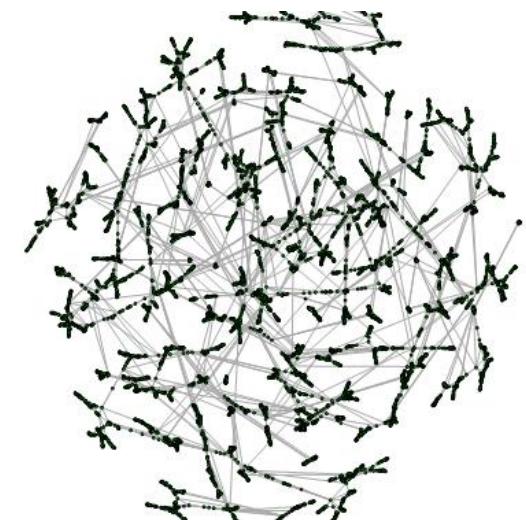
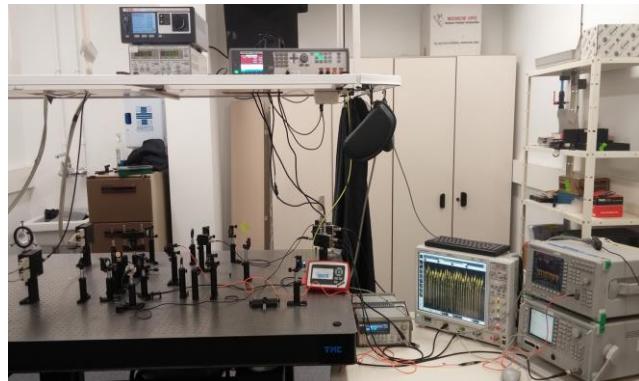
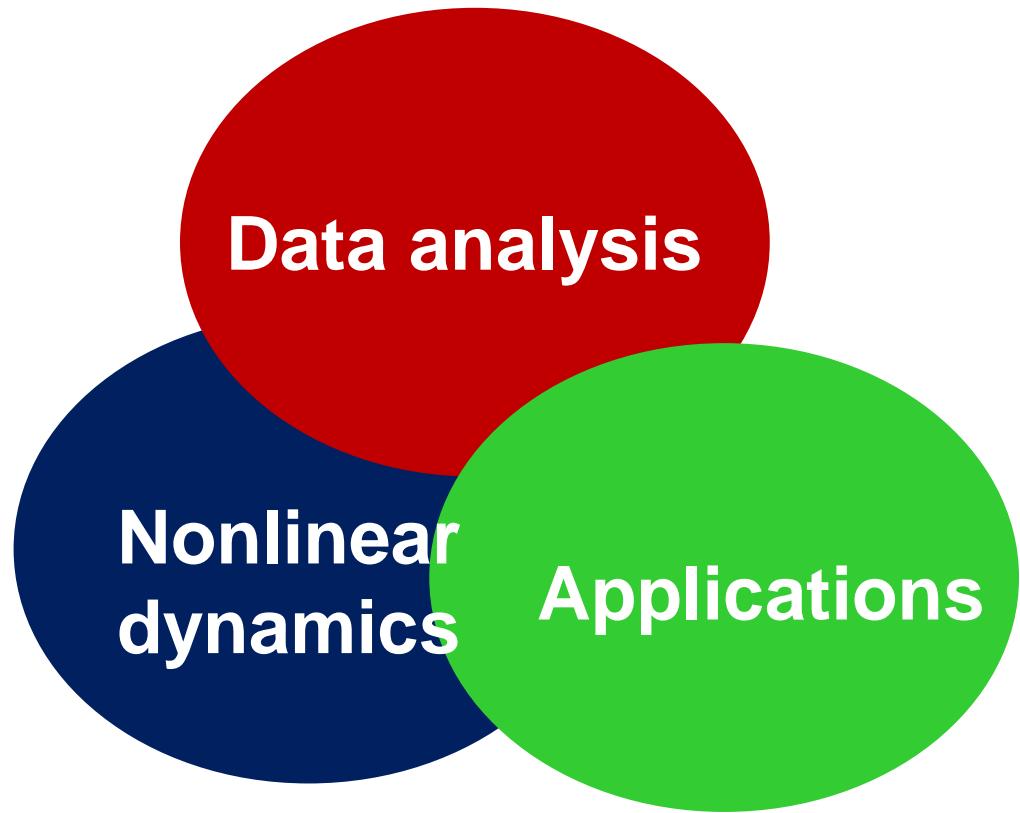
Introducing our research group Dynamics, Nonlinear Optics and Lasers

Web page: donll.upc.edu



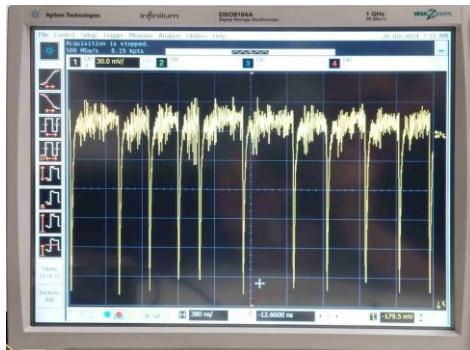
Research lines

- Nonlinear and stochastic phenomena
 - laser dynamics
 - neuronal dynamics
 - complex networks
 - data analysis (climate, biomedical signals)

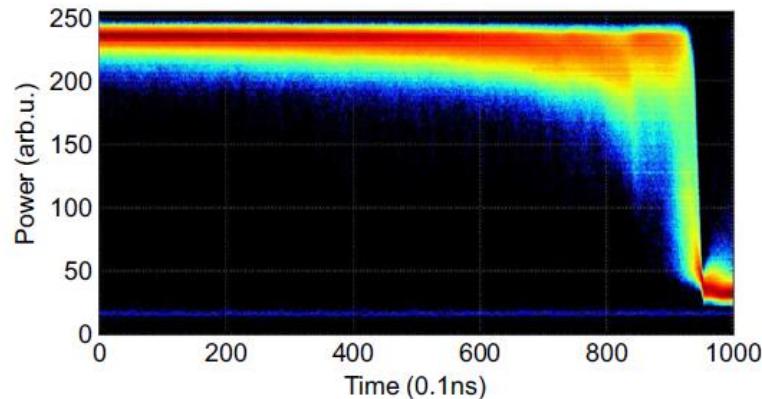


Lasers, neurons, climate, complex systems?

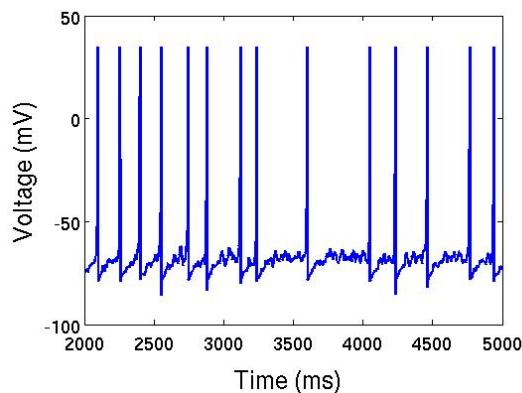
- Lasers allow us to study in a controlled way phenomena that occur in diverse complex systems.
- Laser experiments allow to generate sufficient data to test new methods of data analysis for prediction, classification, etc.



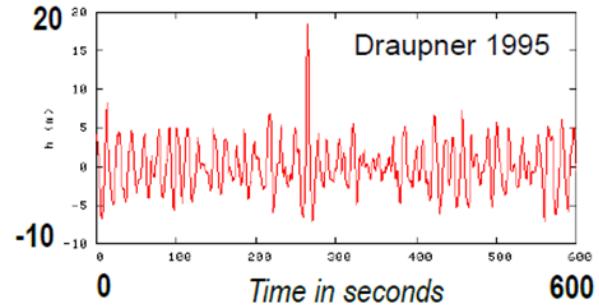
Abrupt switching



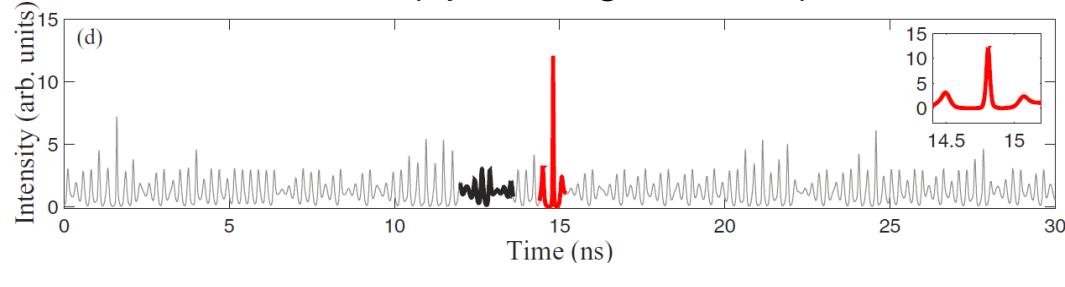
Laser & neuronal spikes



Ocean rogue wave (sea surface elevation in meters)



Extreme events (optical rogue waves)



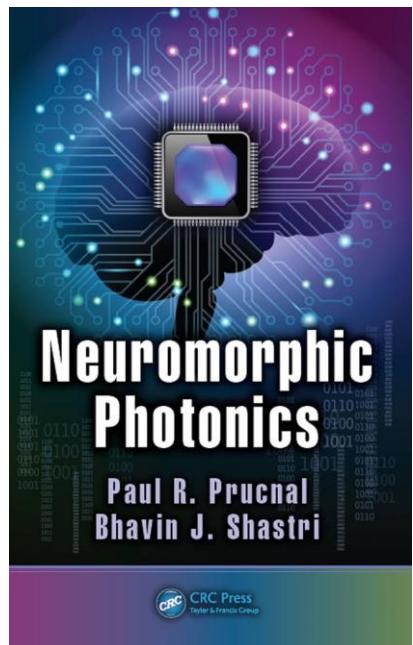
Outline

- Photonic neurons
- How neurons encode information?
- Methods of time series analysis able to identify patterns in data
- Applications to climate data
- Biomedical applications

Photonic neurons

Spiking lasers can be the building blocks of optical information processing systems

- neuro-inspired (spike-based),
- ultra-fast (ns vs ms),
- energy-efficient



Can lasers mimic real neurons?

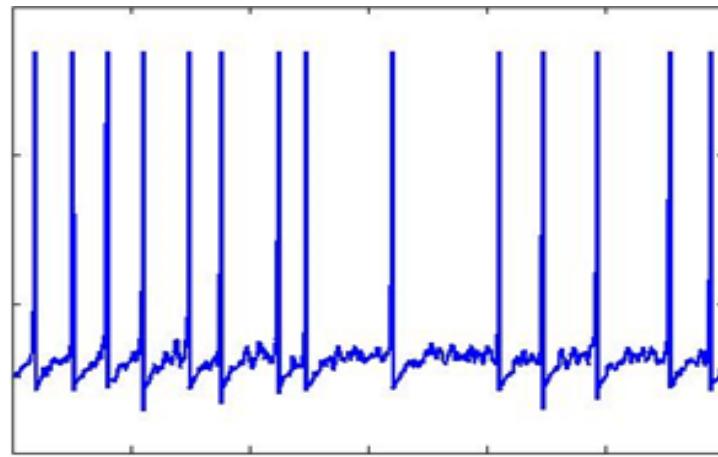
Laser spikes



Time (μ s)



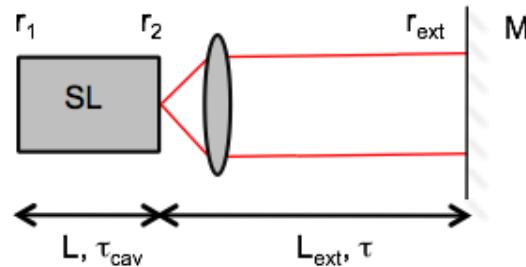
Neuronal spikes



Time (ms)



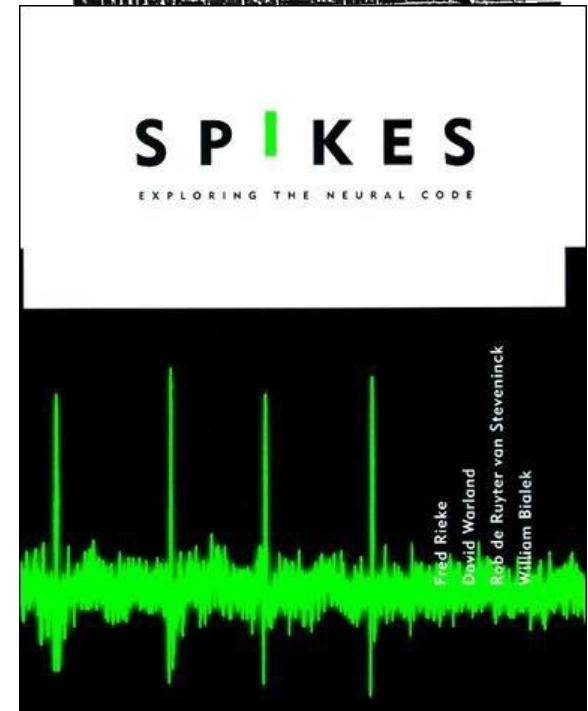
- Inexpensive laser diodes (perturbed by optical feedback).



How neurons encode and process information?



Cracking (deciphering) the neural code: important for neuroscience, and also, for building photonic neurons.



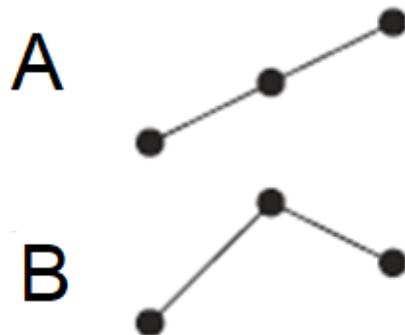
**We need methods of time
series analysis that are able
to identify “patterns” in data**

Método de análisis de datos: análisis ordinal

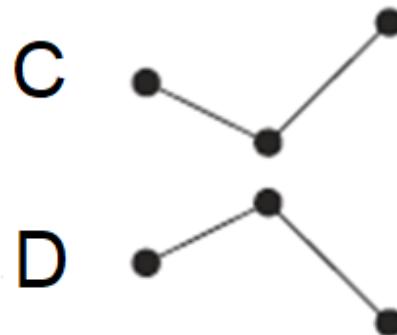
$$\{\dots x_i, x_{i+1}, x_{i+2}, \dots\}$$

¿Como pueden estar “ordenados” tres números, digamos 2, 5, 7?

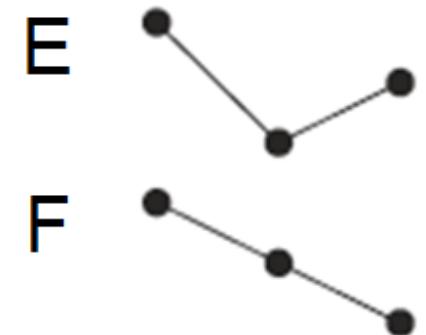
$$\{\dots 2, 5, 7\dots\}$$



$$\{\dots 5, 2, 7\dots\}$$



$$\{\dots 7, 2, 5\dots\}$$



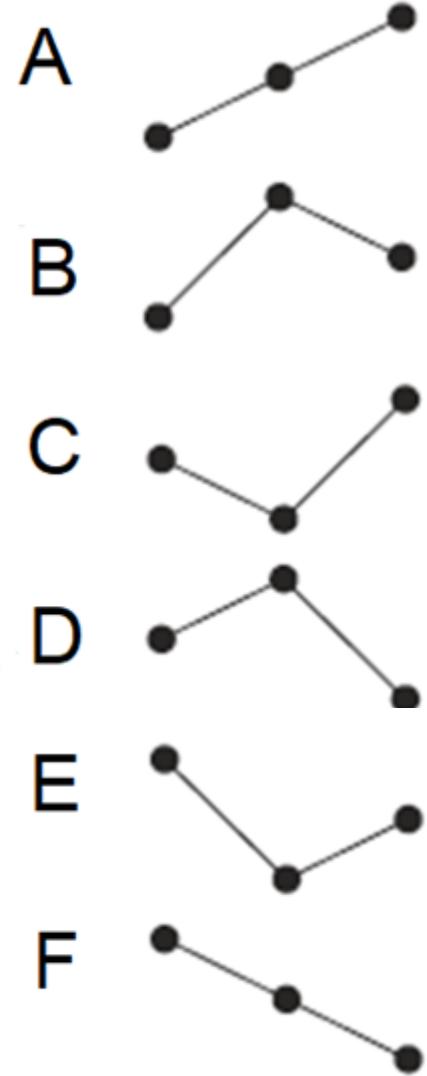
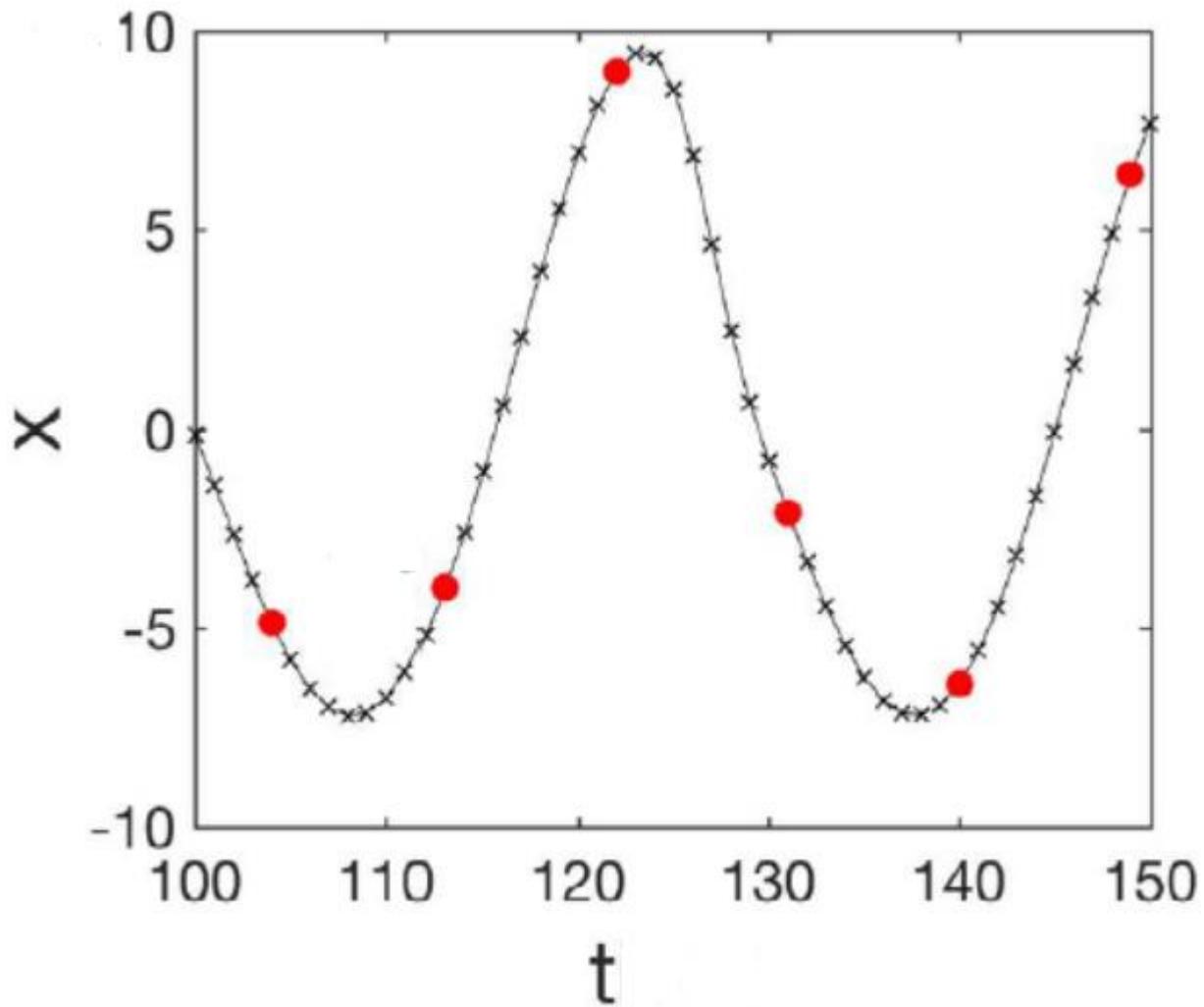
$$\{\dots 2, 7, 5\dots\}$$

$$\{\dots 5, 7, 2\dots\}$$

$$\{\dots 7, 5, 2\dots\}$$

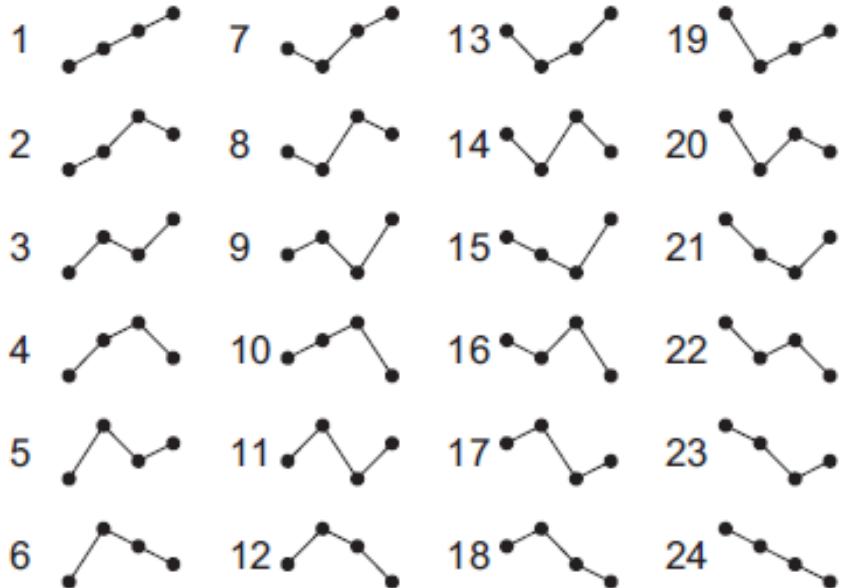
Usando “patrones ordinales”: ¿cuál es el “mensaje”?

Mensaje: A B F C

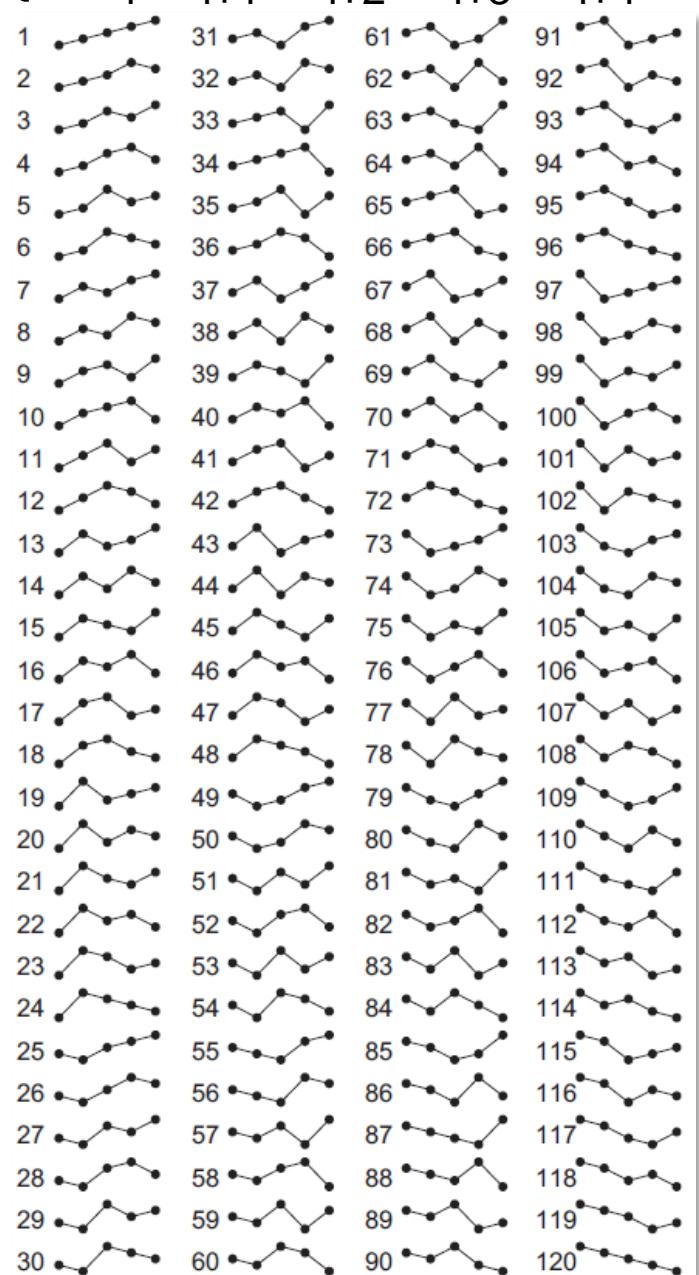


El número de posibles patrones aumenta con el número de datos

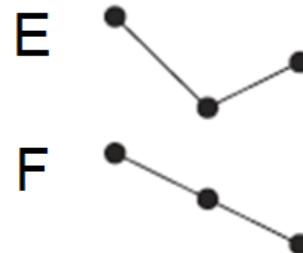
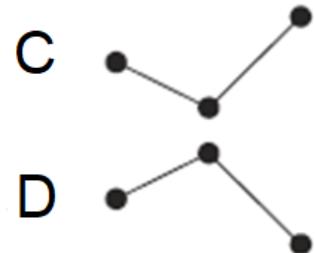
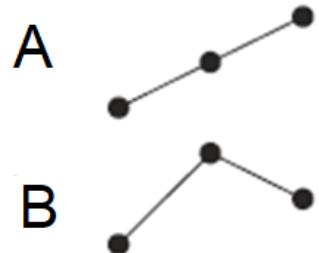
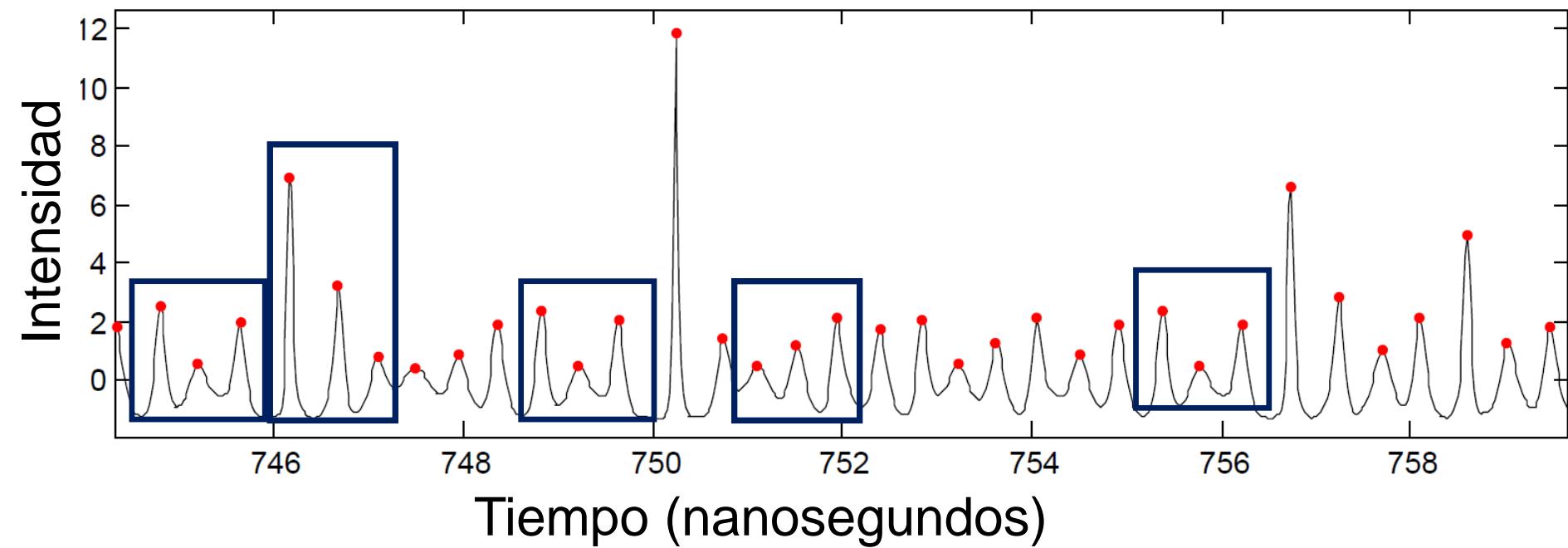
$$\{ \dots x_i, x_{i+1}, x_{i+2}, x_{i+3} \dots \}$$



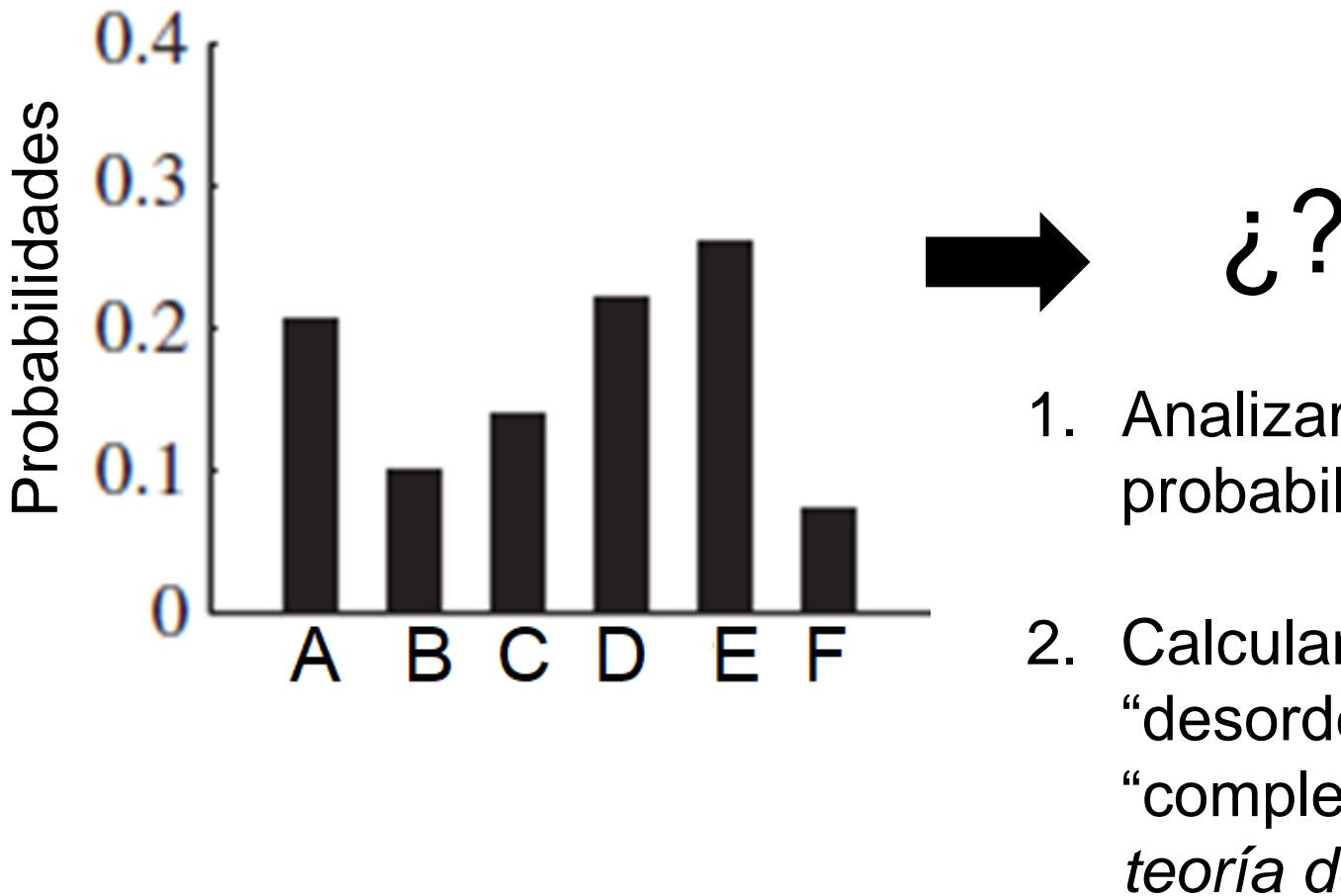
$$\{ \dots x_i, x_{i+1}, x_{i+2}, x_{i+3}, x_{i+4} \dots \}$$



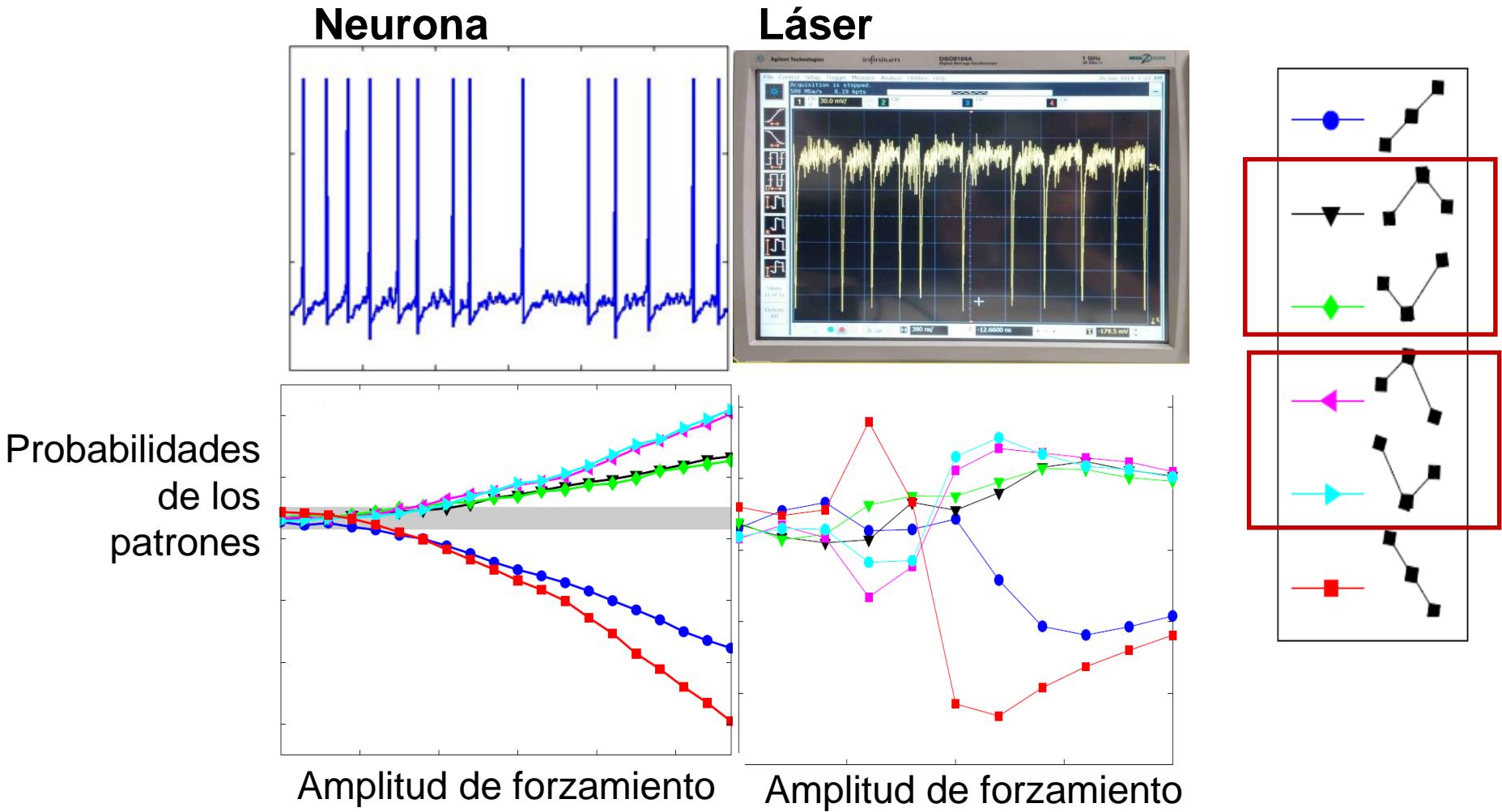
Análisis de pulsos ópticos ¿cuál es el patrón ordinal?



Para cada serie temporal calculamos la frecuencia de aparición de los distintos “patrones”



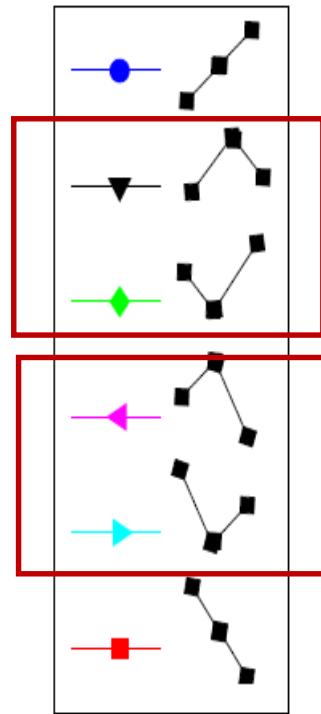
Analizando probabilidades podemos encontrar similaridades estadísticas entre sistemas muy distintos



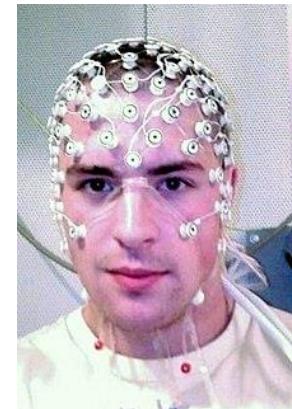
Probabilidades
de los
patrones

Amplitud de forzamiento

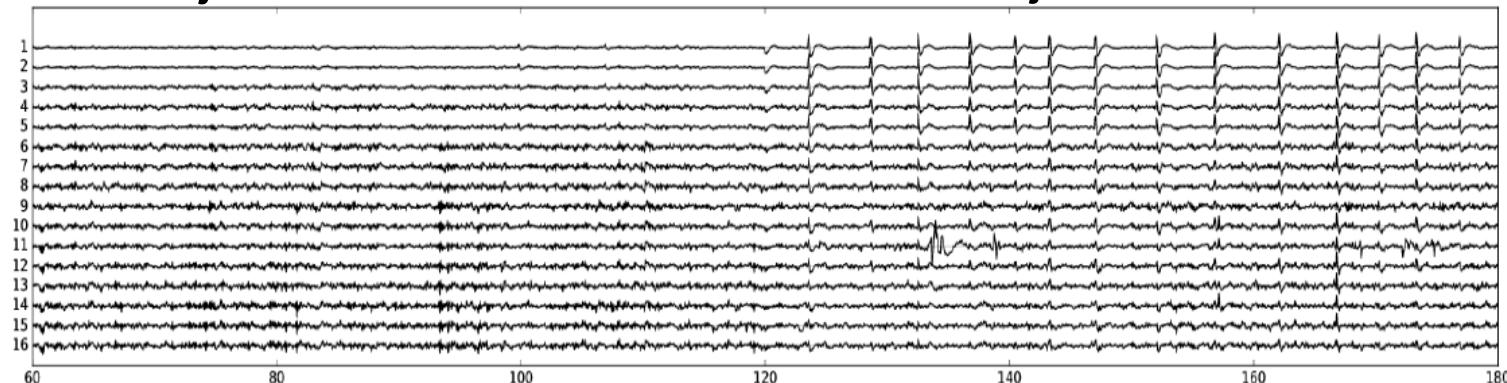
Amplitud de forzamiento



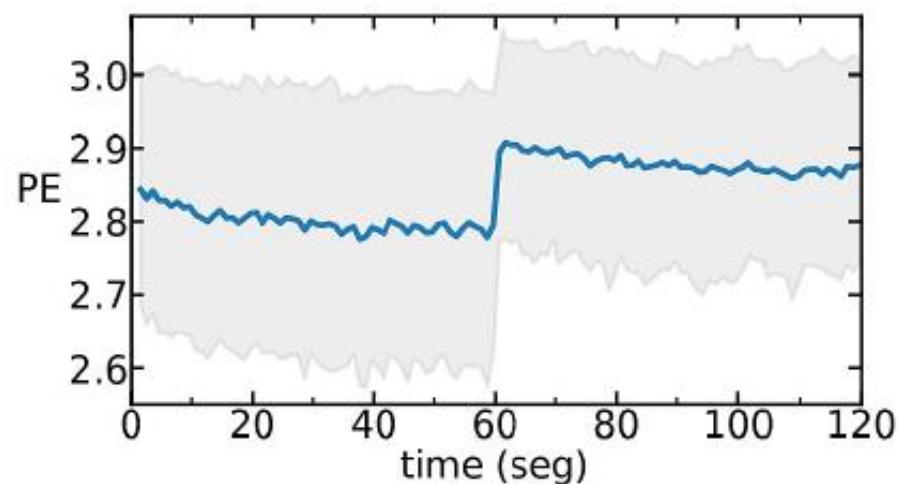
Analizando la estadística de los patrones ordinales podemos diferenciar los dos estados



Ojos cerrados

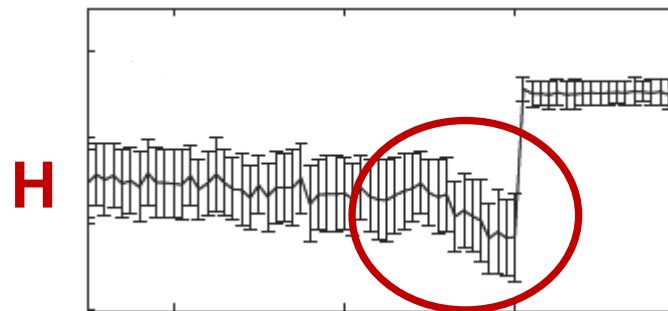
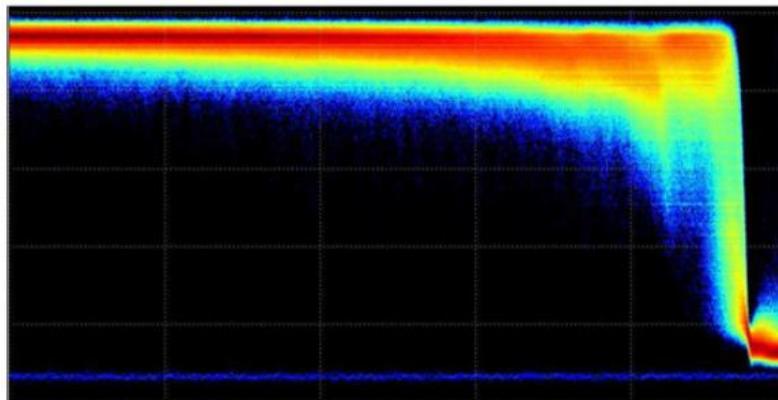


Ojos abiertos



C. Quintero-Quiroz et al, “*Differentiating resting brain states using ordinal symbolic analysis*”, Chaos 28, 106307 (2018).

Analizando la estadística de los patrones ordinales podemos anticipar transiciones abruptas



Parámetro de control

C. Masoller et al, *Quantifying sudden changes in dynamical systems using symbolic networks*, New J. of Phys. 17, 023068 (2015)

El metodo tambien permite caracterizar transiciones graduales

Video: [how complex optical signals emerge from noise](#)

Quantitative identification of dynamical transitions in a semiconductor laser with optical feedback

Carlos Quintero, Jordi Tiana-Alsina, Jordi Roma,
M. Carme Torrent, and Cristina Masoller.



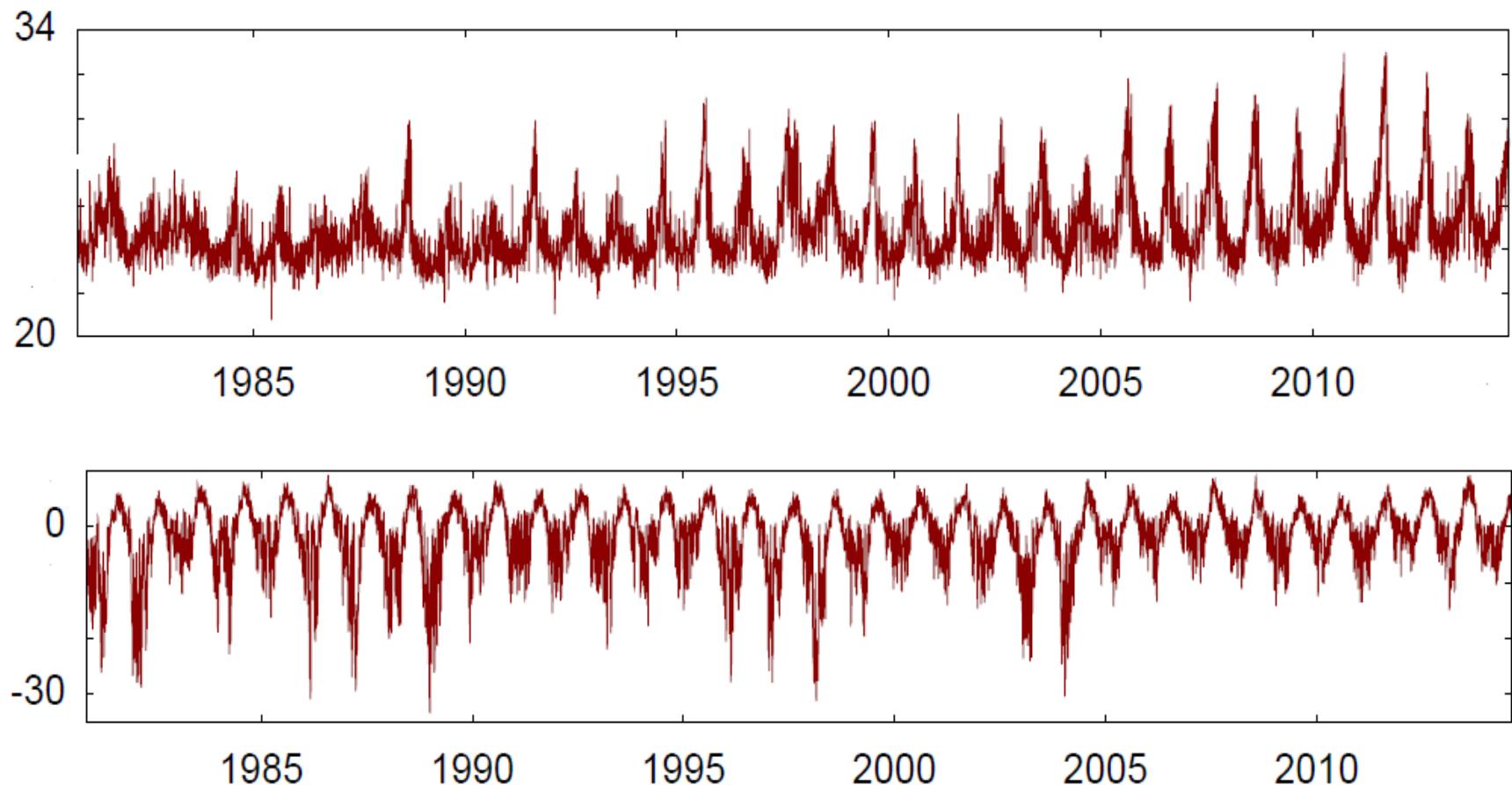
Grup de Recerca en Dinàmica No Lineal, Òptica No Lineal i Làsers
UNIVERSITAT POLITÈCNICA DE CATALUNYA

Dinàmica i Òptica No Lineal i Làsers (DONLL)
Dept. Física, Terrassa, Barcelona, Spain

Podemos usar estas tecnicas en series climatologicas, para identificar regiones afectadas por cambios climaticos graduales?

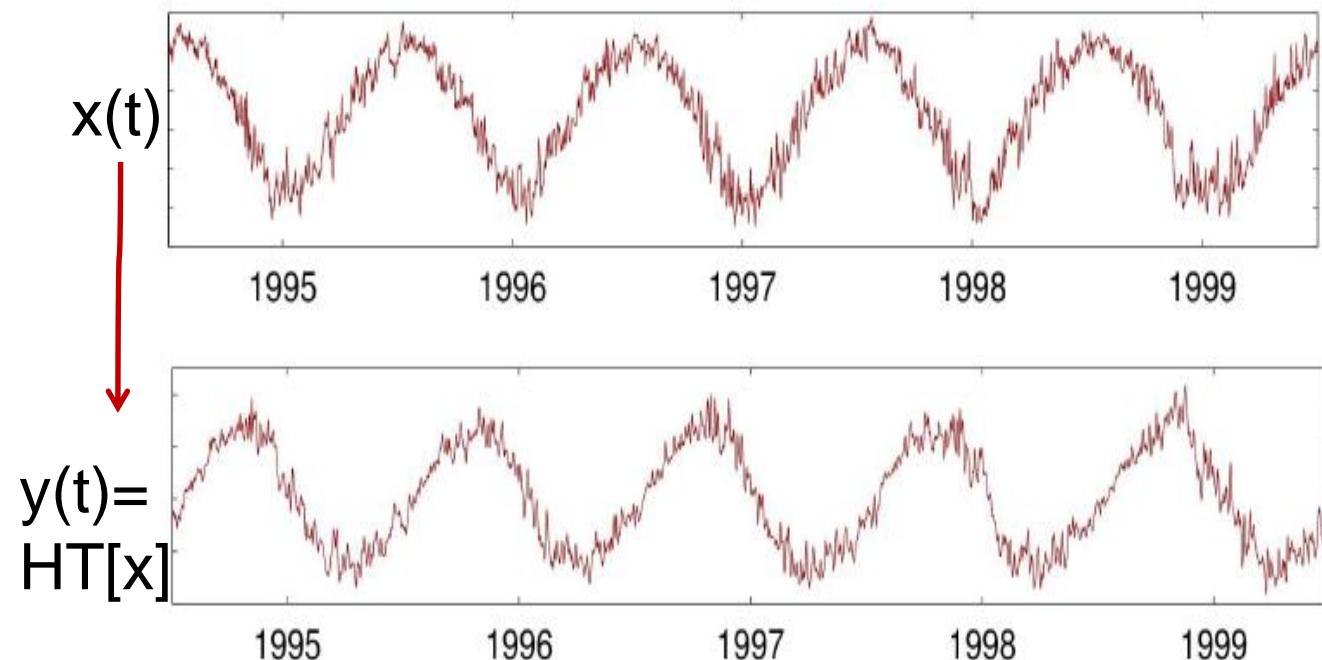


Surface air temperature in two different regions



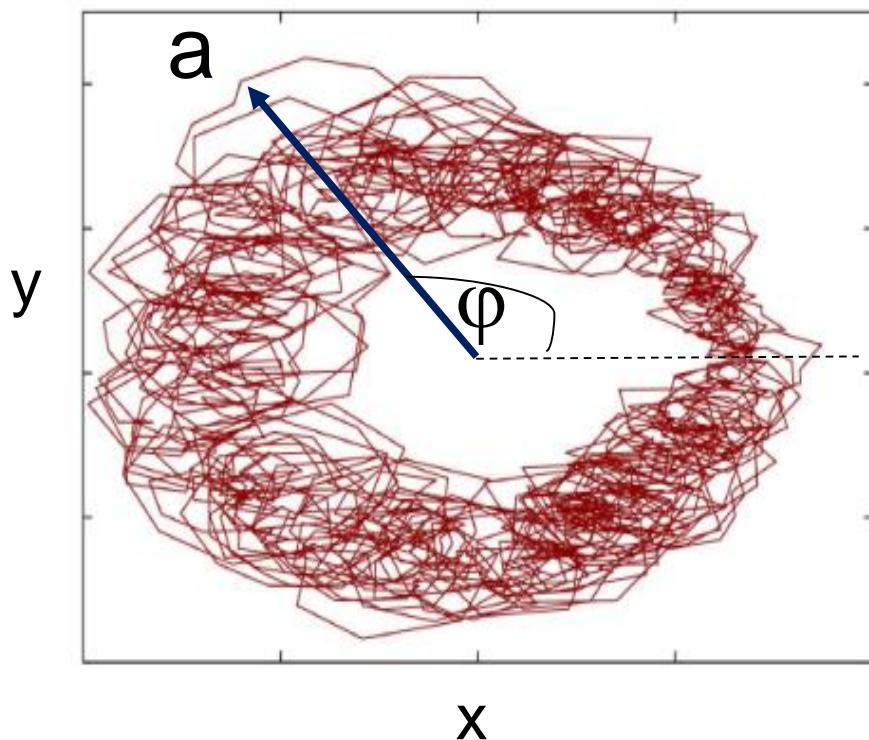
Can changes be quantified? With what reliability?

Transformada de Hilbert

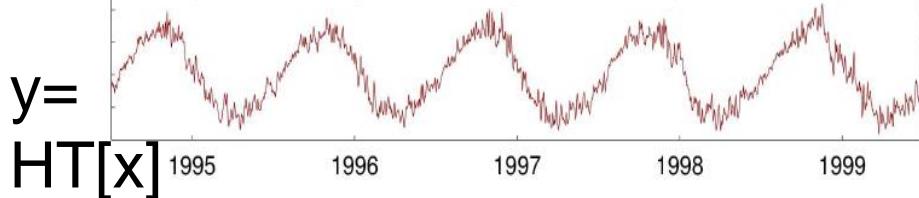
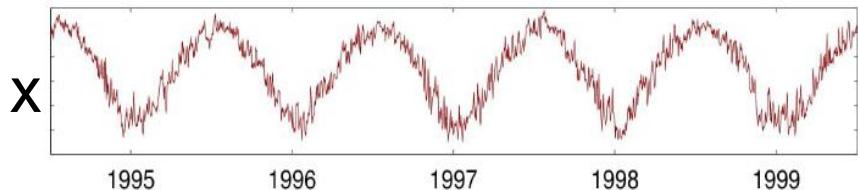


Temperatura de
superficie del aire
en una región del
Hemisferio Norte

Graficando “y” versus “x” obtenemos una “trayectoria”

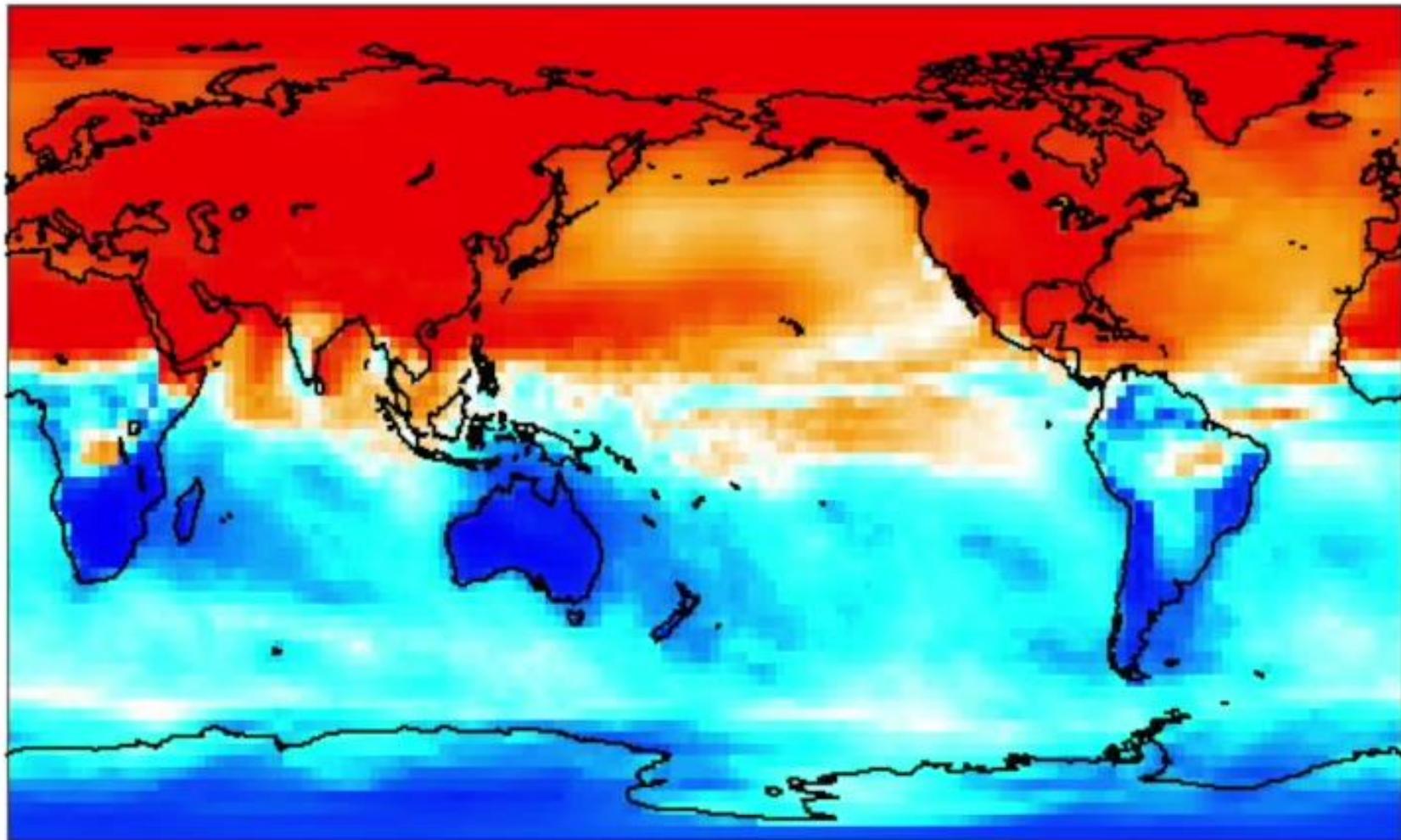


Para cada punto calculamos la amplitud y la fase.

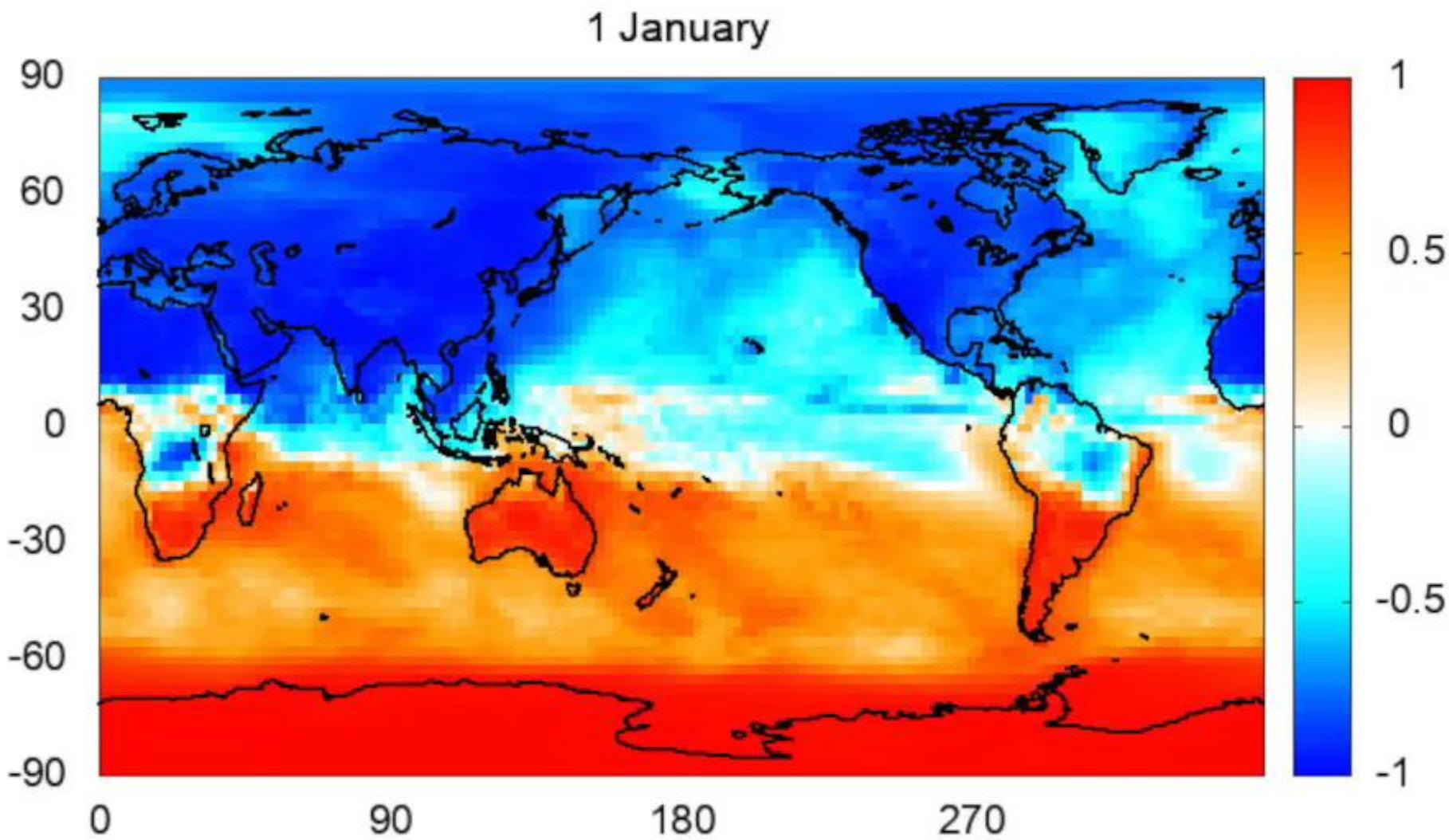


Coseno de la fase de Hilbert

1 July



¿Como pasan las estaciones? Evolución típica del coseno de la fase



¿Cómo detector cambios significativos ocurridos en los últimos 30 años?

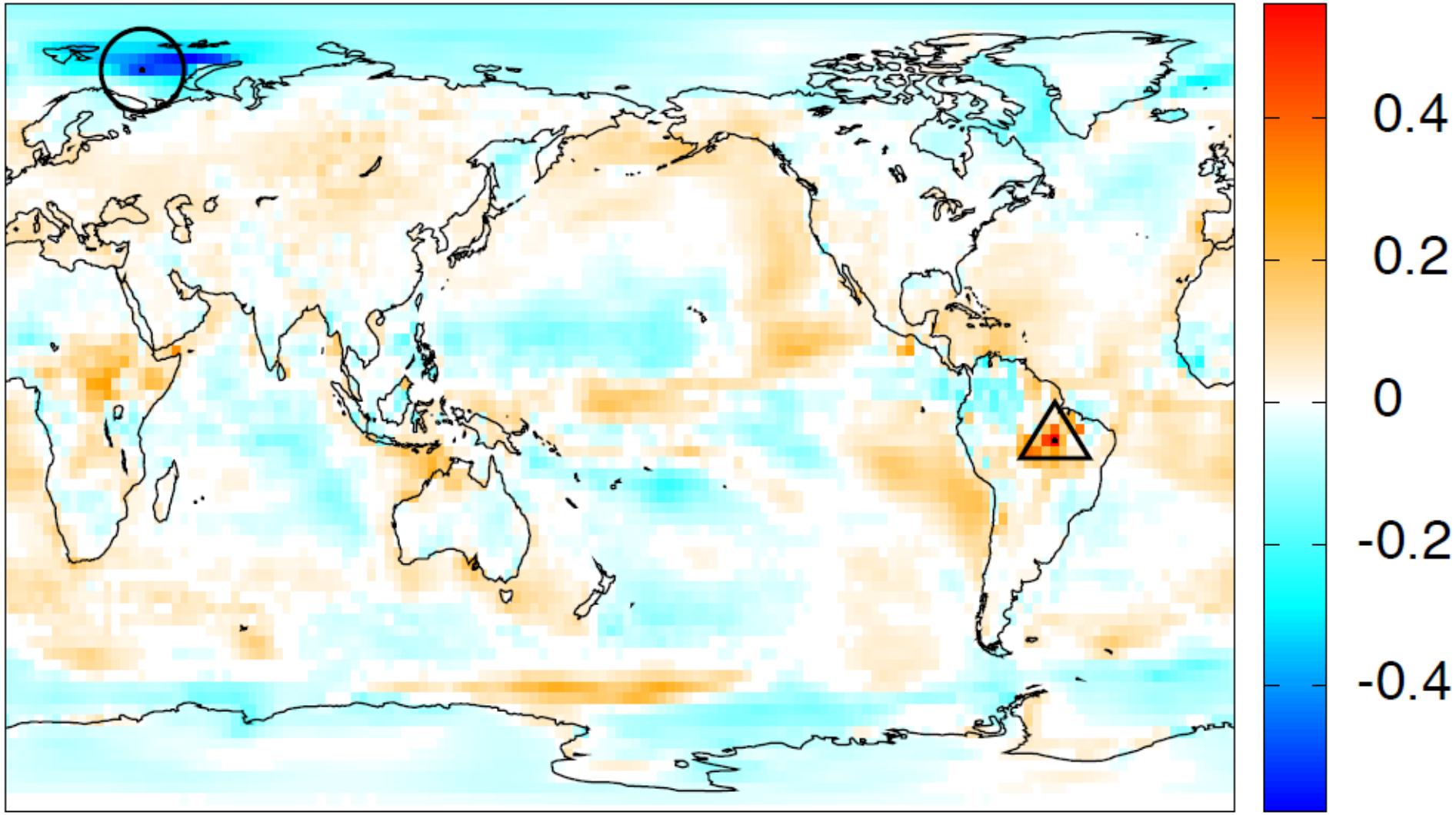
$$\Delta a = \langle a \rangle_{2016-2007} - \langle a \rangle_{1988-1979}$$

$$\frac{\Delta a}{\langle a \rangle_{2016-1979}}$$

Son significativos si $\frac{\Delta a}{\langle a \rangle} \geq \langle \cdot \rangle_s + 2\sigma_s$ o $\frac{\Delta a}{\langle a \rangle} \leq \langle \cdot \rangle_s - 2\sigma_s$

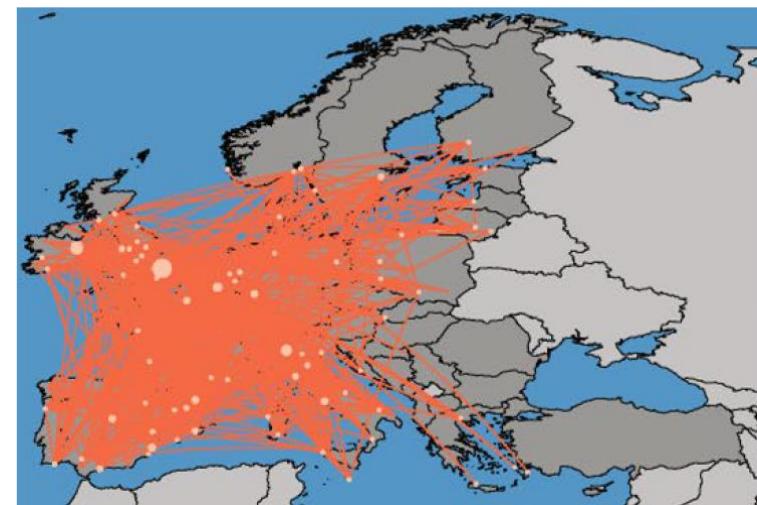
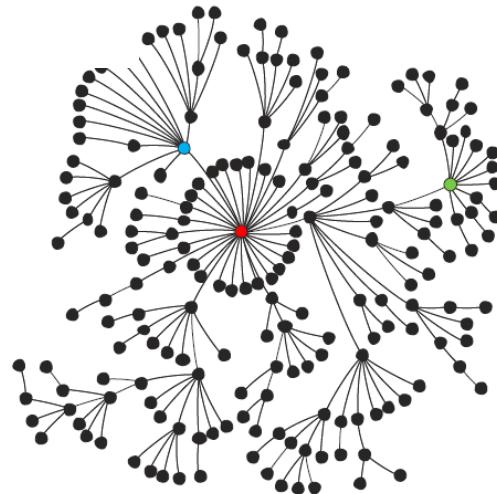
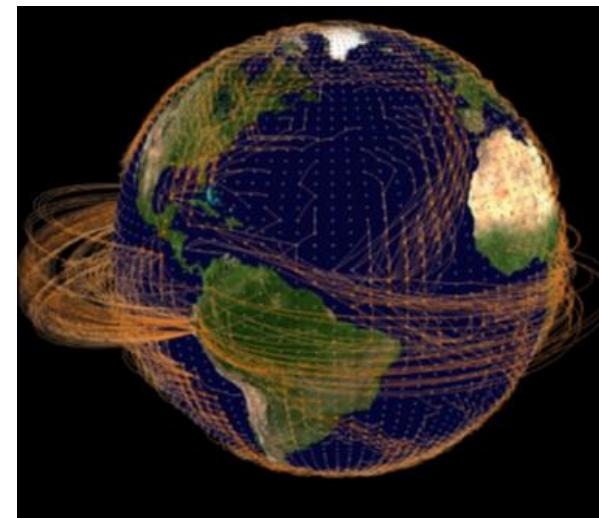
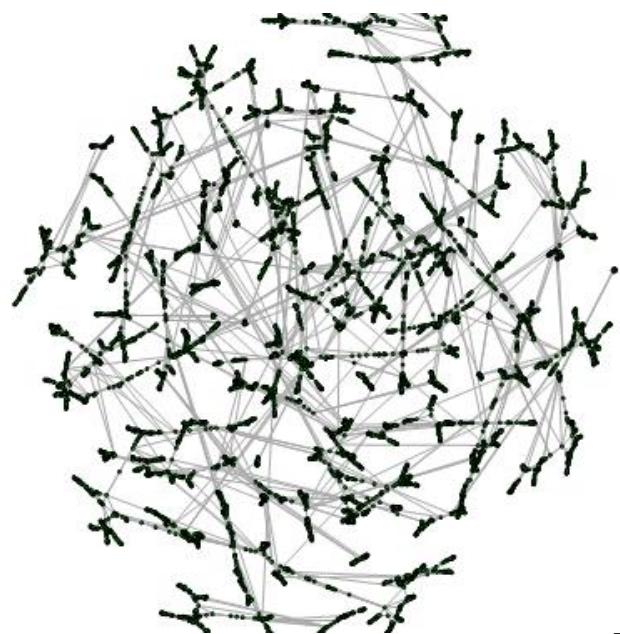
100 “surrogados”



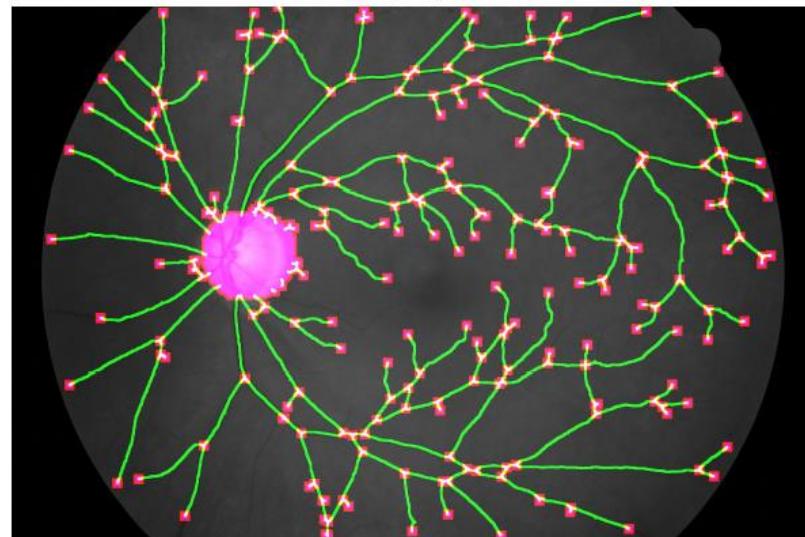
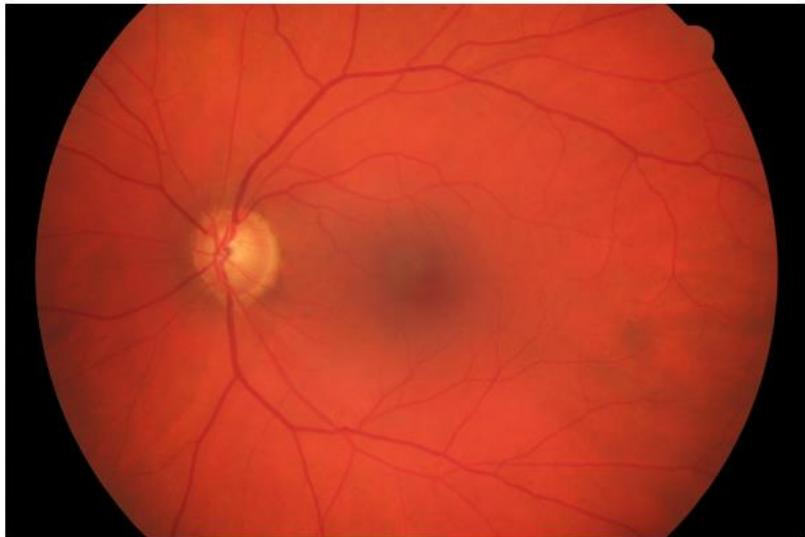


D. A. Zappala, M. Barreiro, and C. Masoller, “*Quantifying changes in spatial patterns of surface air temperature dynamics over several decades*”, Earth Syst. Dynam. **9**, 383–391 (2018).

¿Que son los sistemas complejos?

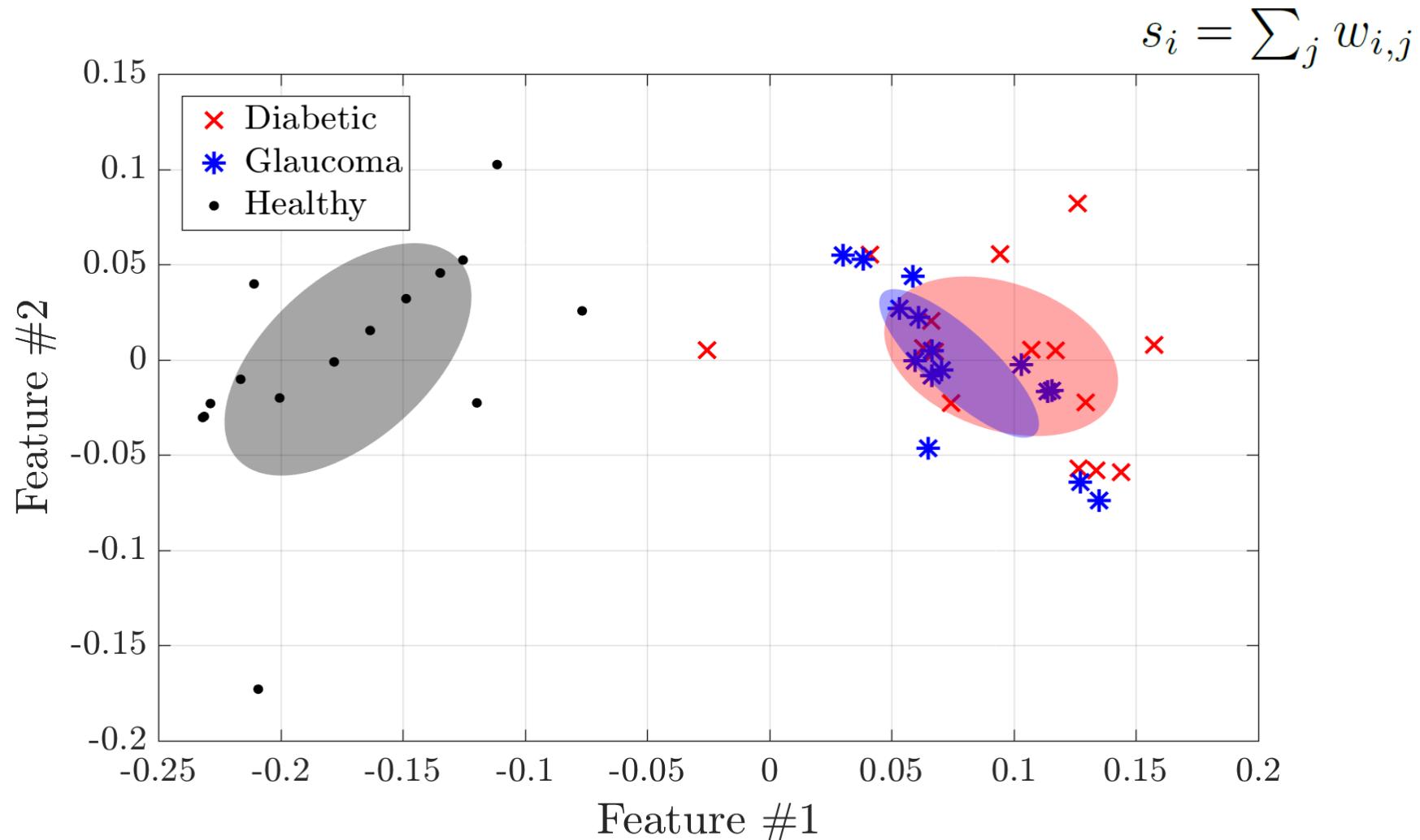


Aplicacion de analisis de redes a imagenes de retina



the fractal dimension of the blood vessels in the normal human retina is ~ 1.7 while it tends to increase with the level of diabetic retinopathy.

Manual segmentation: distribution of weighted degrees



¿como sincronizan los sistemas complejos?

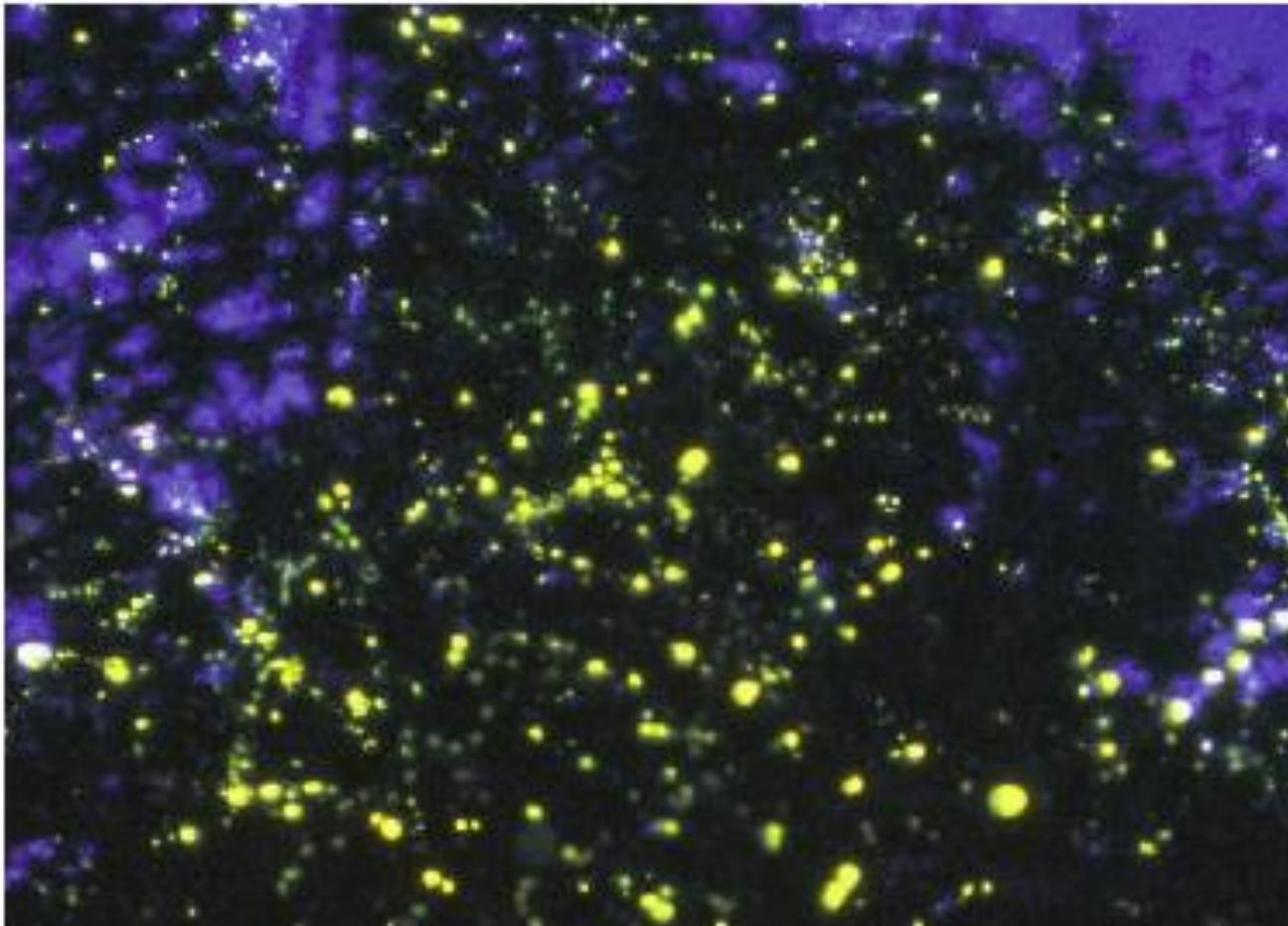


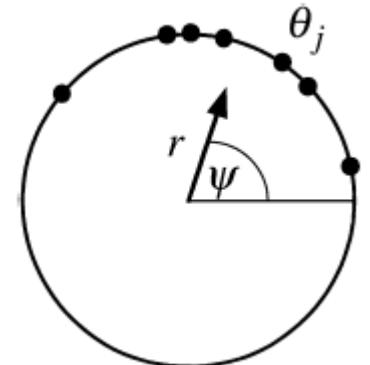
Figure 1 | Fireflies, fireflies burning bright. In the forests of the night, certain species of firefly flash in perfect synchrony — here *Pteroptyx malaccae* in a mangrove apple tree in Malaysia. Kaka *et al.*² and Mancoff *et al.*³ show that the same principle can be applied to oscillators at the nanoscale.

Kuramoto model

(Japanese physicist, 1975)

Model of **all-to-all** coupled **phase oscillators**.

$$\frac{d\theta_i}{dt} = \omega_i + \frac{K}{N} \sum_{j=1}^N \sin(\theta_j - \theta_i) + \xi_i, \quad i = 1 \dots N$$



K = coupling strength, ξ_i = stochastic term (noise)

Describes the emergence of collective behavior

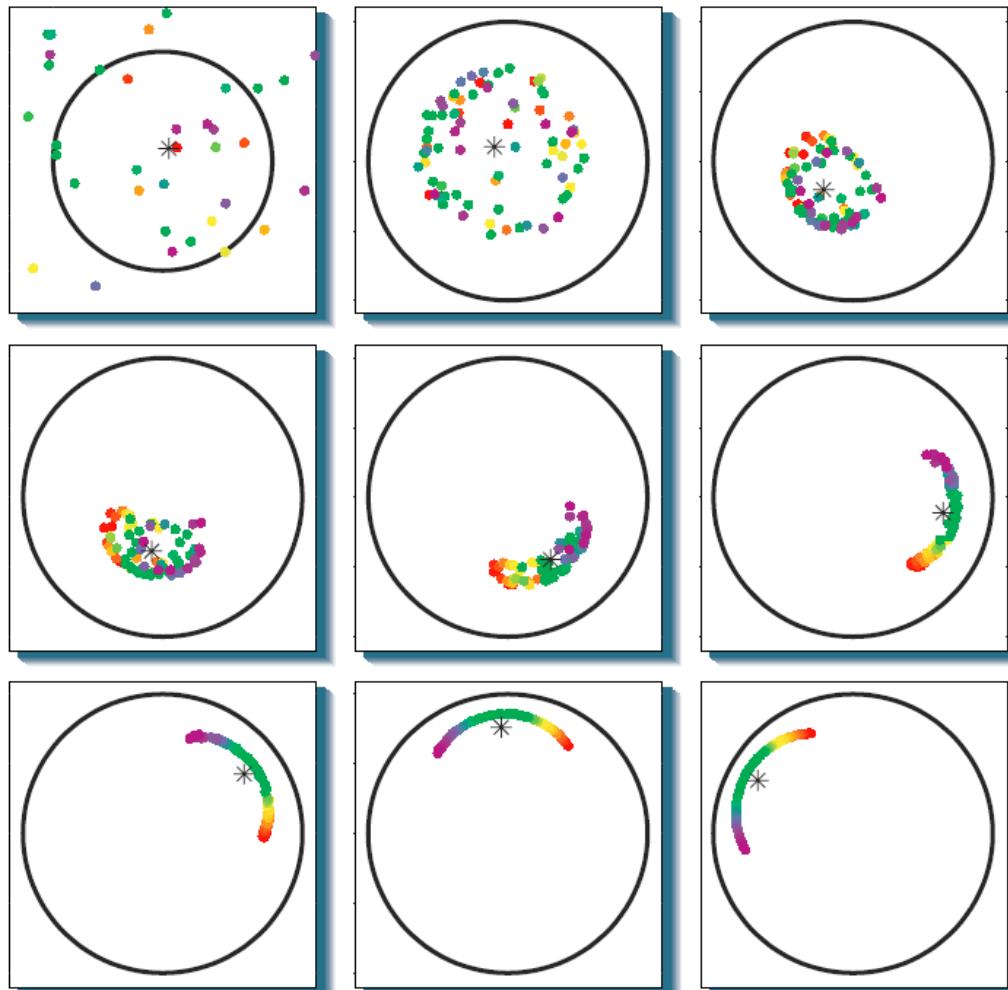
How to quantify?

With the **order parameter**: $re^{i\psi} = \frac{1}{N} \sum_{j=1}^N e^{i\theta_j}$

$r = 0$ incoherent state (oscillators scattered in the unit circle)

$r = 1$ all oscillators are in phase ($\theta_i = \theta_j \forall i, j$)

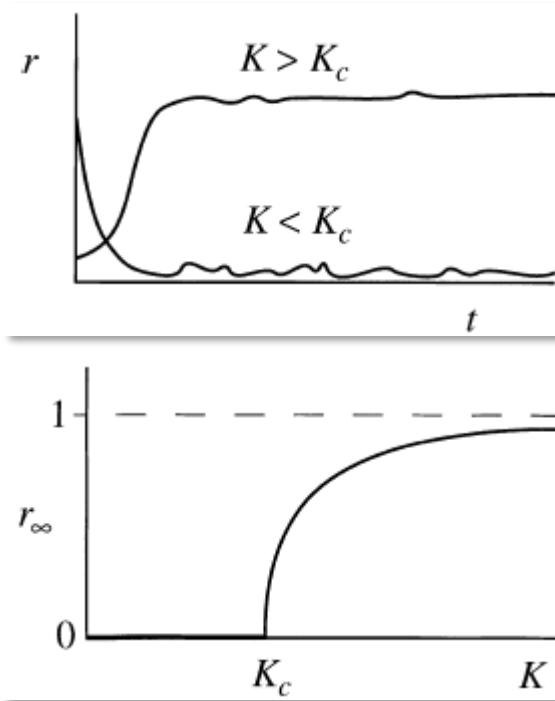
Synchronization transition as the coupling strength increases



Strogatz, Nature 2001

Video: https://www.ted.com/talks/steven_strogatz_on_sync

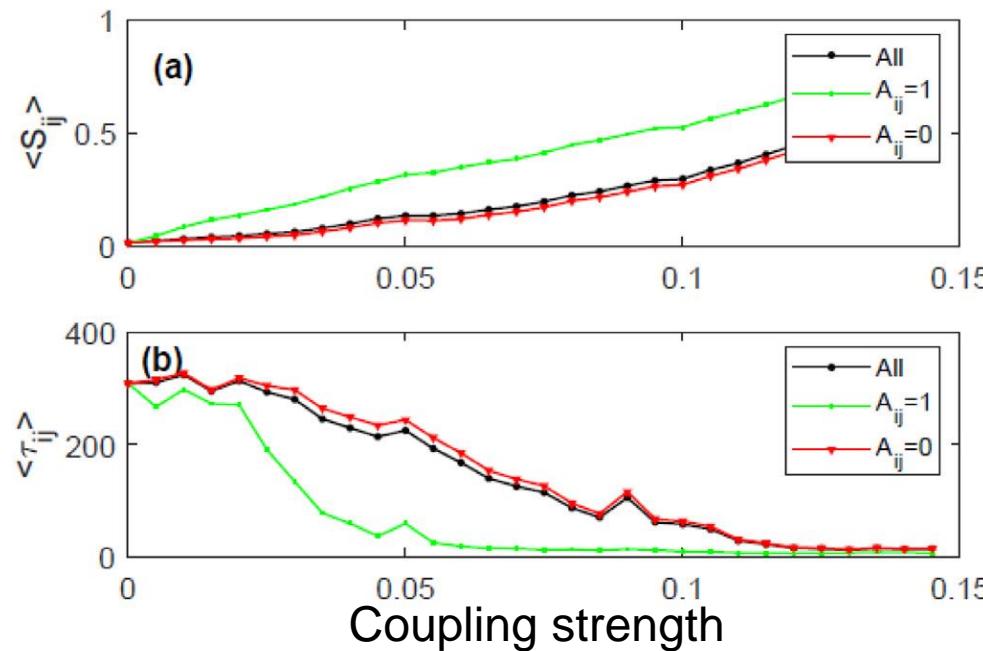
Strogatz and others, late 90'



The synchronization transition can be second order or “explosive”.

Analizando la estadistica de los “lags” entre pares de osciladores podemos *tratar* de

- Inferir la existencia de “direct links”
- Anticipar la transicion a la sincronizacion.



I. Leyva and C. Masoller, “*Inferring the connectivity of coupled oscillators and anticipating their transition to synchrony through lag-time analysis*”, Chaos, Solitons and Fractals 133 109604 (2020).

Resumiendo

- Estamos utilizando diversos métodos de análisis de datos para investigar sistemas complejos
 - Datos empíricos (laseres, EEGs, clima, imágenes)
 - Datos sintéticos (modelos de neuronas, modelos de osciladores acoplados)
- Nos interesa
 - Identificar patrones de comportamiento similares en sistemas distintos
 - Caracterizar cambios de comportamiento (graduales o abruptos).

Agradecimientos: D. Zappala, D. Halpaap, P. Amil, M. Masoliver, C. Quintero, J. Tiana