新しい時系列解析法
- “Natural time”の地震活動解析への応用 -

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Natural Time Analysis

- P. A. Varotsos and his group
- Natural Time Analysis is effective to predict a critical point in the time-series of critical phenomena.
  - Large earthquakes
    - Varotsos et al., *Phys. Rev. E*, 2002,2003,2006,2007
  - Phase transition on 2D Ising spin systems
    - Varotsos et al., *Phys. Rev. E,* 2003
  - Heart attack
    - Varotsos et al., *Phys. Rev. E*, 2004,2005

This week

Heartbeats warn of sudden death risk

DUNCAN GRAHAM-ROWE

HOW do you tell a healthy heart from one that could stop without warning? By measuring variations in the length of the heartbeat, according to a team of researchers in Greece.

The finding could provide a way to screen for people at risk of sudden cardiac death. Such people's heartbeat often looks perfectly healthy by conventional criteria. Yet a quarter of a million people die each year in the US alone when their heart suddenly stops and, like the soccer player Marc-Vivien Foé who collapsed and died last year while playing for Cameroon, many of them have had no history of heart problems.

Even a person's ECG, or electrocardiogram, can look normal for much of the time. In patients with Brugada syndrome, for example, abnormal electrical signals sporadically stop their hearts from pumping properly. Long QT syndrome is a similar condition, which can strike young, fit adults, and has also been linked to cot death.

Standard approaches to analysing ECGs tend to focus on the peaks and troughs of the trace. Instead, Panayiotis Varotsos of the University of Athens has been studying the variation in the length of time it takes for the heart to complete one beat (see Graphic, below).

The amount of variation in the rate of heartbeats is already used to measure aerobic fitness, with more variation meaning a fitter heart. However, for Varotsos the crucial test is the variation in the length of each beat, and whether this variation is random. He adapted equations he had previously used to describe physical systems such as earthquakes to predict that, in a healthy heart, these variations will have some degree of order. But if there is something wrong with the heart, however subtle, it should disrupt that order, making the variation more random.

To test the theory, Varotsos and his colleagues analysed 95 sample ECGs taken from public databases of people with various heart conditions and 10 from healthy patients. He found that the beats of the diseased hearts did indeed vary more randomly and the results are to be published in a future issue of *Physical Review E*. Varotsos says the method could be used as an initial screen to flag up all types of heart problems. "In principle our method should be applied to all causes of cardiac arrest."

"The method could be particularly useful for screening those who have a family history of sudden cardiac death"

A lot of research has gone into discovering ways to identify cardiac diseases from an ECG. Some have used data mining techniques – screening blind for any effect that comes up, while other studies have looked for chaotic signatures that might distinguish unhealthy hearts from healthy ones (*New Scientist*, 3 January 1998, p 20).

But so far no method has stood up to scrutiny in clinical trials, says Arun Holden, a computational biologist at the University of Leeds, UK. Varotsos believes his discovery has a better chance of turning out to be real because he used a physical model of how the heart works to predict a specific effect.

However, as Tim Bowker of the British Heart Foundation points out, there is no way of knowing more about the patients whose ECGs were used in the database. "Without knowing this, one doesn't know that it applies to any group other than these 105," he says. So the jury will remain out until the method is tested to see if it is able to predict cardiac health.

If it proves reliable, the method could be particularly useful for screening those who have a family history of sudden cardiac death. In the UK, about 3500 people die from this syndrome each year. This may not be enough to give rise to a nationwide screening programme.

Instead, Varotsos suggests that cardiologists could apply his method to Holter monitors – the portable ECG devices that are used to monitor patients thought to be at risk.

Footballer Marc-Vivien Foé died of a cardiac arrest on the pitch last year

HEART ATTACK WARNING?

Varotsos and colleagues studied ECG traces and found that the more random the variation in Q-T interval, the higher the risk of sudden cardiac death

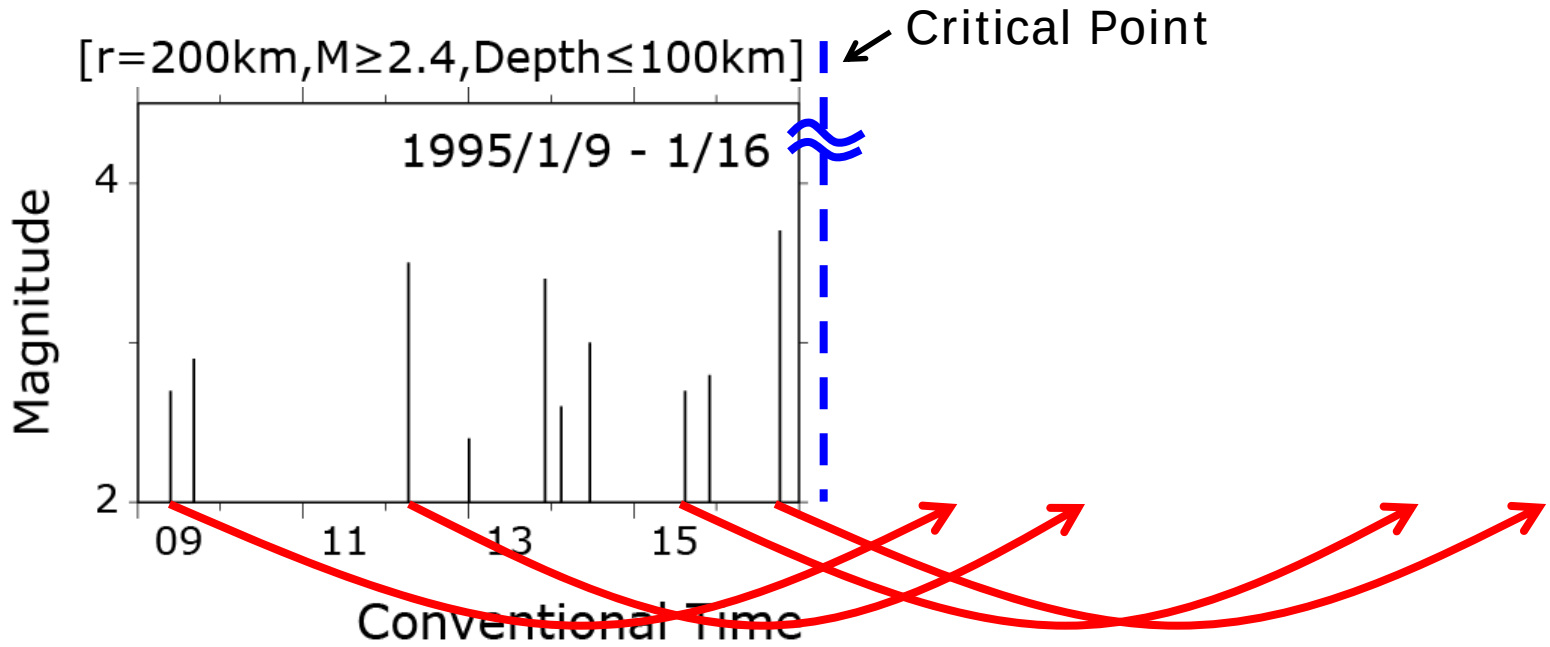
P – Atrial depolarisation: top chambers contract QRS – Ventricular depolarisation: larger, lower chambers contract
ST – Ventricular repolarisation: cells in the lower chambers recharge, in preparation for the next contraction

R P T Q S Q-T interval

10 | NewScientist | 3 April 2004 www.newscientist.com

(New Scientist)

Natural Time



$$\chi_k = \frac{k}{N}$$

k : k th event

N : total number of events

(Varotsos, Is time continuous ?, submitted to *Phys. Rev. Lett.*, 2008)

Power spectrum

$$\Pi(\omega) = \left|\Phi(\omega)\right|^2$$

$$\Phi(\omega) = \frac{\sum_{k=1}^{N} Q_{\chi_k} e^{i\omega\chi_k}}{\sum_{k=1}^{N} Q_{\chi_k}}$$

Q_{χ_k} : *Seismic Moment*

ω : *Natural frequency*

Power spectrum at Critical Stage

Wiener-Khintchin's theorem

$$P(\omega) = \int_{-\infty}^{\infty} G(\tau) e^{-i\omega\tau} d\tau$$

For Natural Time
$(\tau \to \delta)$

$$P(\omega) = \int_{0}^{1} G(\delta) \cos(\omega\delta) d\delta$$

$$\left(\Pi(\omega) = \frac{P(\omega)}{P(0)} \right)$$

Present Model at Critical Stage

$$\left\langle Q_{\chi_k} \right\rangle = Q_{\chi_{k-1}}$$

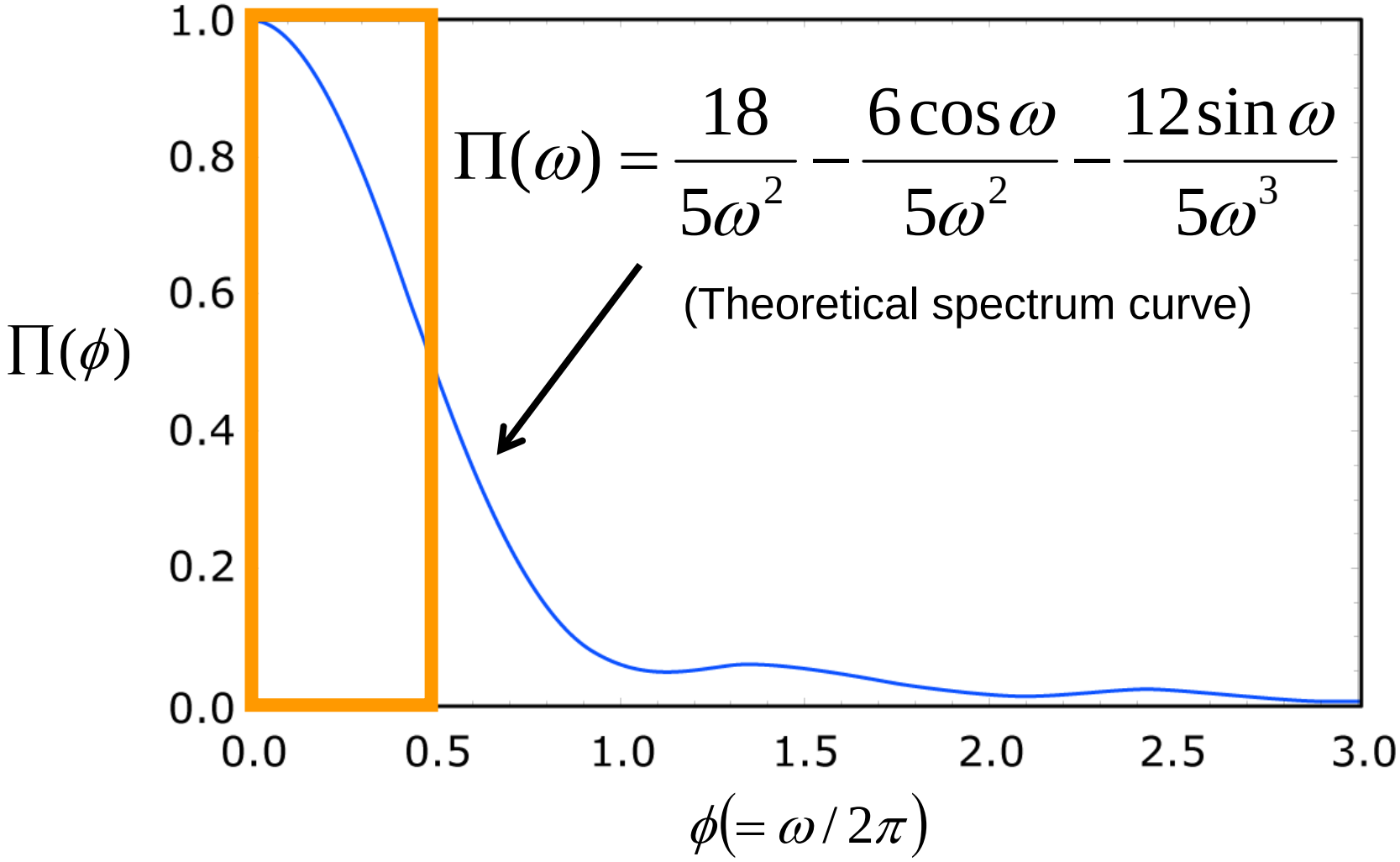
Based on Spin Flip of Ising Model

(Kuntz & Sethna, *Phys. Rev. E.*, 2000)

$$G(\delta) = \iint \int_0^{1-\delta} \left\langle Q_\chi Q_{\chi+\delta} \right\rangle_{n_1,N} d\chi dP_{N,n_1} dP_{n_1}$$

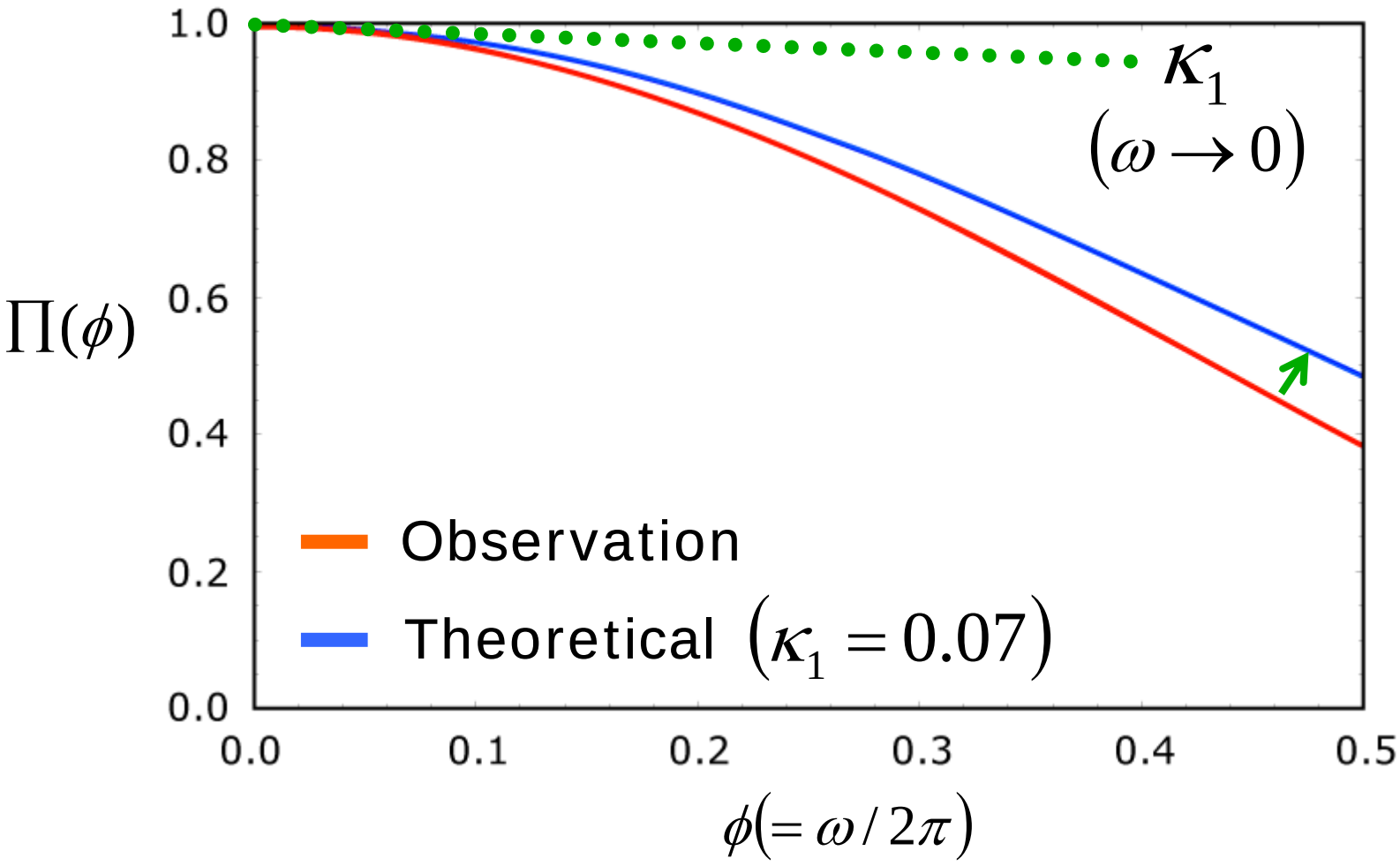
$$\Pi(\omega) = \frac{18}{5\omega^2} - \frac{6\cos\omega}{5\omega^2} - \frac{12\sin\omega}{5\omega^3}$$

Power spectrum at Critical Stage

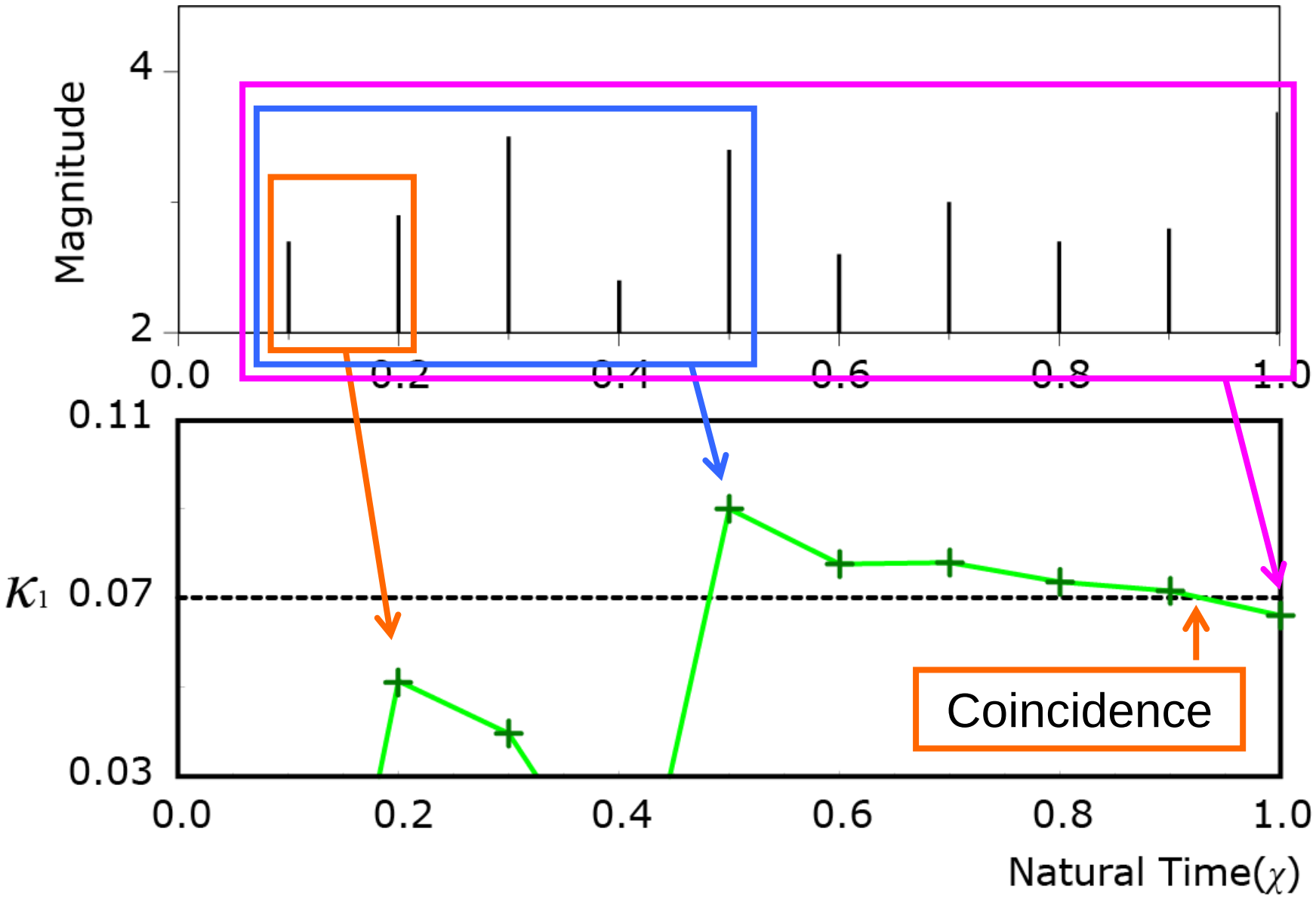


(Varotsos et al., *Phys. Rev. E*, 2003)

$$\Pi(\omega) = 1 - \kappa_1 \omega^2 + \kappa_2 \omega^4 + \kappa_3 \omega^6 + \cdots$$



Time series of κ_1



True Coincidence