Time's arrow as a signature of fuzzy spacetime

In thermodynamics and cosmology or for that matter in everyday life we encounter the arrow of time – it goes relentlessly from past to future. However, the most fundamental laws of the universe, starting from Newton's laws of motion, are time-symmetric. To put it graphically, if the most fundamental processes are filmed, and the film is shown backwards, one would still not encounter a contradiction.

A puzzling exception has been the kaon decay first observed by Cronin *et al.*[1]. This was a Nobel Prize-winning discovery which contradicted time reversal symmetry. We would like to point out that this violation of time reversal could be a signature of fuzzy spacetime[2].

Though a smooth point spacetime has been taken for granted in physics, it is well known that the Heisenberg uncertainty principle forbids this, unless we allow for infinite energies and momenta. However, as has been pointed out by the present author[3], and indeed originally by Dirac[4], our measurements of time intervals are averages over the Compton time. Within the Compton time, we encounter the Zitterbewegung effects. Salecker and Wigner[5] argued that a finer estimation of time, than the Compton interval is not possible. In other words, spacetime is in some sense fuzzy rather than being point-like[6,7]. Indeed to date, the smallest interval that we have been able to measure[8] has been 10^{-16} sec. This is well above the typical Compton time. A good way to approximate the time we encounter is to consider a minimum interval τ, a typical Compton time. It can be argued that as $\tau \to 0$, we recover usual physics.

With this background and keeping in mind the kaon puzzle and another recent observation of the *B*-meson, we consider a two-state system:

$$\psi_1 = \psi(t),$$

$$\psi_2 = \psi(t + \tau). \tag{1}$$

We have, as for any two-state system[9],

$$\imath\hbar \frac{\mathrm{d}\psi_\imath}{\mathrm{d}t} \approx \imath\hbar \left[\frac{\psi_\imath(t+\tau)-\psi_\imath(t)}{\tau}\right]$$

$$= \sum_{\imath=1}^{2} H_{\imath j}\psi_j, \;\; \psi_\imath = \mathrm{e}^{(\imath/\hbar)Et}\phi_\imath, \tag{2}$$

where $H_{11} = H_{22}$ (which we set = 0 as only relative energies of the two levels are being considered) and $H_{12} = H_{21} = E$, by symmetry. So the second term of eq. (2) reduces to

$$\left[E + \imath\frac{E^2\tau}{\hbar}\right]\psi_\imath = [E(1+\imath)]\psi_\imath,$$

$$\text{as } \tau = \hbar/E. \tag{3}$$

Interestingly, in the above analysis, in eq. (3), the fact that the real and imaginary parts are of the same order is in fact borne out by experiment.

From eq. (2) we see that the Hamiltonian is not Hermitian, that is, it admits complex eigen values indicative of decay, if the lifetimes of the states are $\gtrsim \tau$.

In general this would imply the exotic fact that if a state starts out as ψ_1 and decays, then there would be a non-zero probability of seeing in addition the decay products of the state ψ_2. In the process it is possible that some symmetries, which are preserved in the decay of ψ_1 or ψ_2 separately, are violated.

In this context we will now consider first the kaon puzzle. As is well known from the original work of Gellmann and Pais, the two-state analysis above is applicable here[10,11]. In the words of Penrose, 'the tiny fact of an almost completely hidden time-asymmetry seems genuinely to be present in the K^0-decay. It is hard to believe that nature is not, so to speak, trying to tell something through the results of this delicate and beautiful experiment[12]'. On the other hand, as Feynman[13] put it, 'if there is any place where we have a chance to test the main principles of quantum mechanics in the purest way ... this is it'.

What happens in this well-known problem is that, given CP invariance, a beam of K^0 mesons can be considered to be in a two-state system as above, one being the short-lived component K^S which decays into two pions and the other being the long-lived state K^L which decays into three pions. In this case $E \sim 10^{10}\,\hbar$ (ref. 10), so that $\tau \sim 10^{-10}$ sec. After a lapse of time greater than the typical decay period, no two pion decays should be seen in a beam consisting initially of the K^0 particle. Otherwise, there would be violation of CP invariance and therefore also *T* invariance. However, exactly this violation was observed[1] as early as 1964. This violation of time reversal has also been confirmed directly by experiments at Fermilab and CERN[14]. I would like to point out that the kaon puzzle has a natural explanation in the quantized or fuzzy time scenario discussed above.

This effect has now been observed again and reported by Bernabeu *et al.*[15] at the Stanford Linear Accelerator with *B* mesons. This is the first time that time-reversal violation has been observed directly without reference to CP invariance as in the kaon case.

Lees *et al.*[16] have recently observed time-reversal violation in the decay of *B* mesons. The Stanford Linear Accelerator Center (SLAC) experiment takes advantage of B^0 and $\bar{B}^0$ mesons in the Y(4s) resonance produced in electron–positron (e^+e^-) collisions. This allows measurement of an asymmetry that can only come about through a *T* inversion and not by a CP transformation.

Each of these mesons can decay into either a CP eigenstate (e.g. $J^0/\psi K_L$, called B_+ for CP even and $J/\psi K_S$, called B_- for CP odd), or a state that identifies the flavour of the meson. To study *T* inversion, the experimenters selected events where one meson decayed into a flavour state and the other decayed into a CP eigenstate. The time between these two decays was measured and the rate of decay of the second with respect to the first was determined.

To sum up, after detecting and identifying the mesons, the experimenters determined the time difference between the decay of the two *B* states via the energy of each meson. With time reversal they found discrepancies in the decay rates. The asymmetry which could only be due to a *T* transformation and not a CP violation, was significant, being 1400 sigmas away from time invariance. That means there is a confirmation of time reversal asymmetry without invoking any other symmetry (cf. Zeller[17]).

All this, it can be argued is a signature of a fuzzy time described earlier.

1. Cronin, J. W. *et al.*, *Phys. Rev. Lett.*, 1964, **13**, 138.

2. Sidharth, B. G., *Chaos, Solitons Fractals*, 2000, **11**, 1045–1046.
3. Sidharth, B. G., *Chaotic Universe: From the Planck to the Hubble Scale* (Nova Science, New York), Science Publishing, New York, 2001.
4. Dirac, P. A. M., *The Principles of Quantum Mechanics*, Clarendon Press, Oxford, 1958, pp. 4ff; 253ff.
5. Salecker, H. and Wigner, E. P., *Phys. Rev.*, 1958, **109**, 571–577.
6. Sidharth, B. G., In Proceedings of Fourth International Symposium on 'Frontiers of Fundamental Physics', Kluwer Academic/Plenum Publishers, New York, 2001, pp. 97–108.
7. Madore, J., *An Introduction to Non-Commutative Differential Geometry*, Cambridge University Press, Cambridge, 1995.
8. Burderi, L. and Di Salvo, T., arXiv: 1207.0207VI, grqc 2012.
9. Sidharth, B. G., *Indian J. Pure Appl. Phys.*, 1997, **35**, 456ff.
10. Lee, T. D., *Particle Physics and Introduction to Field Theory*, Harwood Academic, 1981, pp. 391ff.
11. Tassie, L. J., *The Physics of Elementary Particles*, Longman, New York, 1973.
12. Hawking, S. and Israel, W., *General Relativity: An Einstein Centenary Survey*, Cambridge University Press, Cambridge, 1979.
13. Feynman, R. P., *Lectures on Physics Vol. 3*, Addison-Wesley, Reading, MA, USA, 1965.
14. Angelopoulos, A. *et al.*, *Phys. Lett. B*, 1998, **444**, 43.
15. Bernabeu, J., Martinez-Vidal, F. and Villanueva-Perez, P., *J. High Energy Phys.*, 2012, **064**, 1208.
16. Lees, J. P. *et al.*, *Phys. Rev. Lett.*, 2012, **109**, 211801.
17. Zeller, M., *Physics*, 2012, **5**, 129.

Received 30 November 2012; accepted 28 January 2013

B. G. SIDHARTH

G. P. Birla Observatory & Astronomical Research Centre,
B. M. Birla Science Centre,
Adarsh Nagar,
Hyderabad 500 063, India
e-mail: birlasc@gmail.com

Implications of temperature change on spring arrival dates of chiffchaff (*Pylloscopus collibyta* Vieillot) in a site in Croatia

Recent changes in climate have impacted plant and animal ecology worldwide[1]. In the past two decades, numerous papers have been published to describe long-term changes in phenology, demography, distributions and other important parameters in many species over the globe[2]. Significant changes in biological systems have already been reported from all the continents[3]. For instance, many plant species have extended their growing season[4] and warmer temperatures are associated with earlier spawning in some amphibians[5]. Likewise, climate change influences birds in different ways. In the United Kingdom, bird species have extended their breeding ranges northwards by a mean of 18.9 km, a shift which is potentially linked to increasing average temperatures[6]. Dolenec *et al*.[7] found that breeding dates for the tree sparrow *Passer montanus* have advanced between 1979 and 2009 in Croatia, in response to warming springs. Studies have demonstrated increased clutch sizes[8], brood sizes[9] and changes in population size[10] in relation to climate change. Furthermore, for many bird species in the Northern Hemisphere arrival dates have advanced in response to increase in spring temperature[11–13]. In general, studies have shown that short- and medium-distance migrant birds have earlier first arrival dates than long-distance migrant birds[14,15]. Studies on the timing of migration of birds have been an important model for characterizing the impacts of climate change. Warming affects the phenology of different species in different ways, which can have a negative effect on events such as migration and breeding, which were previously synchronized with the phenology of resources[16,17].

The main purpose of this note is to reveal long-term (1982–2010) trends in the arrival dates of chiffchaff *Phylloscopus collibyta* (Vieillot, 1817) to the Mokrice area, northwestern Croatia (46°00′N, 15°55′E; 140 m amsl) and to examine the relation with mean monthly temperatures. This area is mostly mixed landscape with deciduous woods (dominated by pedunculate oak *Quercus robur* and hornebeam *Carpinus betulus*; other tree species that occur in low proportion include common maple *Acer campestre*, ash *Fraxinus angustifolia* and common elm *Ulmus minor*). According to Cramp[18],

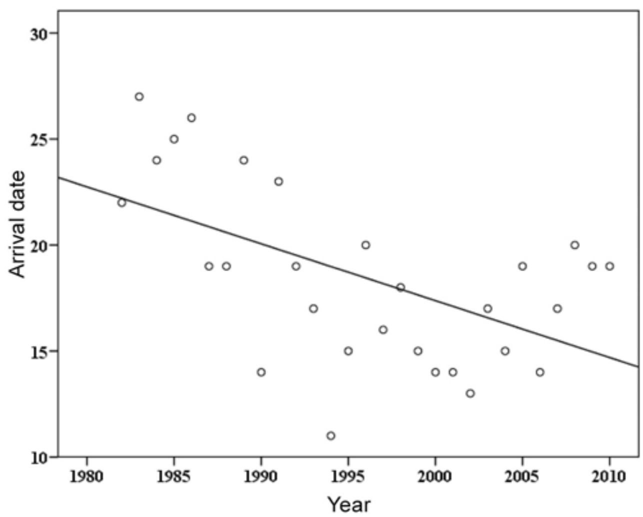

Figure 1. Temporal trend (1982–2010) in arrival date (1 indicates 1 March) of the chiffchaff in northwestern Croatia. Arrival date for each year was calculated as the mean of the first five bird arrivals recorded for that year.