Mem. S.A.It. Vol. 74, 516

Memorie della

Futuristic applications of quantum EPR states

F. Tamburini[1], C. Barbieri[2], A. Bianchini[2], and S. Ortolani[2]

[1] Institute of Cosmology and Gravitation, University of Portsmouth, Portsmouth, UK
[2] Dipartimento di Astronomia, Università di Padova, Padova, Italy

Abstract. The Physics of Quantum Information is getting mature enough, in the laboratory and in ground based applications, to consider the possibility of future Space extensions. The nonlocal properties of Einstein-Podolsky-Rosen entangled states might define a new frontier both in the field of remote communications and in the astronomical detectors of the new generation. Here we present:
(1) a communication technique based on the use of entangled pairs in polarization states, organized in bunches with precise statistically correlated distributions.
(2) In addition we briefly discuss the conceptual development of gravitational wave (GW) detectors based on Quantum Entangled STate (QUEST) technology.

Key words. relativity – gravitational waves

1. Remote quantum communication

We propose to apply Einstein-Podolsky-Rosen (EPR) correlations and Bell's inequalities to realize an instantaneous non-standard communication (NSC) to transfer fuzzy information over long distances into space without violating causality (Tamburini et al. 2000b; Aspect et al. 1981, 1982a, 1982b, 1999; Weihs et al. 1998).

This thought experiment is realized by a particular sequence of simultaneous local measurements performed by the sender Alice (A) and the receiver Bob (B) on a known, given, set of maximally entangled photon pairs, in agreement with the violation of Bell's inequalities.

For both the experimenters the outcome of each, single, polarization measurement is always random. For this reason it is impossible to transfer classical information within a quantum channel. Alice and Bob choose to fix their polarizers settings following a previously agreed deterministic protocol thus building a random Weierstrass function-like record in time of their outcomes. The detection and non-detection of statistical correlation due to a fractal record in time defines what we call *fuzzy* information. As comparing the potential outcomes under different settings at the same time is equivalent to a sequence of single pairs distributed in time, this implies that the records in time are equivalent to the collection of the outcomes of different (A)s and (B)s who previously agreed on

Send offprint requests to: F. Tamburini
Correspondence to: Institute of Cosmology and Gravitation, University of Portsmouth, Mercantile House, Hamsphire Terrace, PO 21EG Portsmouth, UK

how to fix their polarizers. By iterating the experiment several times, the correlations detected from sets of polarization outcomes can be used as a Morse code by assigning a logical value '1' when enough correlation is detected and '0' in the opposite case.
Many factors like the low photon rate, the noisy environment (Cordes et al. 1997), the relative motions of A and B would conspire against the fidelity of the communication. In a probabilistic analysis of quantum mechanics, like in Nelson's scenario, stochastic processes describe the evolution of quantum states (Nelson 1984, 1985). In this case the Weierstrass random function mimics a fractional Brownian motion, which can be characterized with a wavelet filter from the noisy environment (Hwang 1996).

2. The detection of gravitational waves

EPR states may also allow the detection of gravitational waves (for a review see e.g. Abramovici et al. 1992; Bender et al. 1995) by measuring the rotation of the local reference frames associated to Alice and Bob $\Delta\theta$ induced by the GW obtained comparing the polarization states of the entangled pair as recently proposed by Tamburini et al. (2002a). The keys derived from an ideal experiment are Markovian, pure white noise discrete random strings of '0's and '1's and the presence of a gravitational wave colors the cross-correlation statistics so they are no longer white. In resonance regime we obtain a deviation $\Delta\theta$ proportional to the gravitational wave amplitude $h \sim 10^{-18} - 10^{-21}$ rad.
This 'Quantum Mousetrap' allows detection of gravitational waves with quantum cryptographic techniques, reconciling the nonlocality of entangled quantum states with the intrinsic local aspects of Einstein's theory of gravitation. What is certain is that gravitational waves will act as shadow eavesdroppers, reducing the degree of entanglement between quantum states controlled by Bell's inequalities.

3. Conclusions

We have outlined how quantum technology may be exploited both to realize remote non-standard communication techniques and to construct a detector of gravitational waves.

References

Abramovici, A., et al. 1992, Science, 256, 325
Aspect, A. 1999, Nature, 398, 189
Aspect, A., Grangier, P., & Roger, G. 1981, PhRvL, 47, 460
Aspect, A., Grangier, P., & Roger, G. 1982a, PhRvL, 49, 91
Aspect, A., Dalibard, D., & Roger, G. 1982b, PhRvL, 49, 1804
Bender, P. L., et al. 1995, in Gravitational Wave Experiments, ed. E. Coccia, G. Pizzella, & F. Ronga, (Singapore: World Scientific)
Cordes, J. M., Lazio, T. J. W., & Sagan, C. 1997, ApJ, 487, 782
Hwang, W. L. 1996, EDICS sp2.1.1
Nelson, E. 1984, Quantum Fluctuations - An Introduction, 1984, Phy, 124A, 509
Nelson, E. 1985, Quantum Fluctuations, (Princeton: Princeton University Press)
Tamburini, F., Bassett, B., & Ungarelli, C. 2000a, CQGraL, submitted (gr-qc/0006106)
Tamburini, F., Bianchini, A., & Ortolani, S., 2000b, in Bioastronomy 99: A New Era in the Search for Life, ed. G. A. Lemarchand, & K. J. Meech (San Francisco: ASP), ASP Conf. Ser. 213, 585
Weihs, G., Jennewein, T., Simon, C., Weinfurter, H., & Zeilinger, A. 1998, PhRvL, 81, 5039