Giancarlo Ghirardi

The physicist Giancarlo Ghirardi passed away on 1 June 2018, after a life devoted to the foundations of quantum mechanics.

Giancarlo Ghirardi (pictured), a leading expert in the study of quantum foundations, passed away in June. In 1986, together with his colleagues and friends Alberto Rimini and Tullio Weber, he published a model for the spontaneous collapse of the wavefunction, which is now referred to as the Ghirardi–Rimini–Weber (GRW) model. One of the most significant results in the field since Bell’s inequalities, it opened a new line of research that is now in rapid expansion.

Remembering Giancarlo Ghirardi means celebrating quantum foundations, his great scientific passion. His career as theoretical physicist started in nuclear physics, a mainstream line of research in Italy back in the 1960s and 1970s, in the wake of the Fermi school. In 1965 Ghirardi and Rimini established a limit on the number of states in a binding potential — referred to as the Ghirardi–Rimini bound — which can now be found in the legendary Reed–Simon volumes of mathematical physics. In 1973 he, together with Luciano Fonda, Alberto Rimini and Tullio Weber, solved the open problem of the exponential decay law of unstable particles.

Then, in the late 1970s, once installed at the University of Trieste and fascinated by Bernard d’Espagnat’s book *Conceptual Foundations of Quantum Mechanics*, Ghirardi convinced Rimini and Weber to switch to quantum foundations — a bold decision in those times, when the quantum paradigm was unquestionable. There were (and still are) two major open problems in the field: the measurement problem and the relation between quantum non-locality and relativity. Ghirardi’s contributions to both proved to be influential.

The history of quantum non-locality goes back to the Einstein–Podolsky–Rosen (EPR) paper from 1935. While it discussed the completeness of quantum theory, it turned out that the paper was actually about (non)-locality. Then, in the 1960s, John Stuart Bell, fascinated by Bohmian mechanics but worried by its manifest non-local behaviour, uncovered the deepest insight one could have imagined: the non-local character of quantum phenomena, mathematically encoded in terms of inequalities. Now, EPR states and Bell inequalities form the basis of quantum communication.

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Quantum non-locality means that the world is not local. But then where does relativity fit in? The problem was not irrelevant at those times, as several papers claimed that quantum theory would permit superluminal signalling. In refuting one of them in 1981, before the paper of William Wootters and Wojciech H. Zurek, Ghirardi proved what is now known as the no-cloning theorem, a cornerstone of quantum information processing. Before that, in 1980, Ghirardi, Rimini and Weber gave the general proof that quantum non-locality cannot be used to send information faster than light.

But it is with the GRW solution to the measurement problem that Ghirardi made his most profound contribution. Quantum mechanics is inconsistent in its formulation: it assumes that physical systems evolve according to the Schrödinger equation until a measurement is performed, at which point the wavefunction collapses. What is so special about measurements? Shouldn’t it be possible to describe them in quantum terms? But if this was possible, there should be no collapse and quantum effects should be all around us.

Back in the 1980s, Bohmian mechanics and the many-world interpretation had been around for a long time. Both theories, although they represented alternatives to a traditional view on the wavefunction collapse, still assumed the universal validity of the Schrödinger dynamics, which people did not

dare change — until the GRW model came, showing that an alternative was possible. This was not obvious at all because, as we now know from the works of Nicolas Gisin, Joseph Polchinski and others, almost all modifications to the linear structure of quantum dynamics lead to inconsistencies such as faster-than-light signalling. Only the careful mixing of nonlinear terms with stochastic ones makes a sensible dynamics possible.

Research on collapse models dates back to the 1970s and early 1980s, with key contributions from Philip Pearle, Lajos Diosi, Nicolas Gisin and others. The GRW model succeeded in putting all pieces of the puzzle together by proposing a ‘unified dynamics of microscopic and macroscopic system’, as the title of the original paper states. In a nutshell, the GRW model predicates that microscopic systems are supposed to evolve quantum mechanically except at random times, when their wavefunction collapses in space according to a well-defined law. These collapses are rare for microscopic systems. However, an in-built amplification mechanism makes this effect stronger and stronger as the size of the system increases, to the point that macroscopic objects are always so well-localized in space as to behave for all practical purposes like particles moving along well-defined trajectories. The wave nature of quantum systems and the particle nature of classical objects can thus be described within a single mathematical framework. This model came as a revelation to the community, and Bell celebrated it during Schrödinger’s centennial conference in London.

After more than 30 years from its formulation, the GRW model is still studied and an increasing number of people is facing the challenge of testing it at increasing levels of precision. This, in turn, is pushing the development of refined tabletop experiments to control the dynamics of massive quantum systems that can probe the quantum-to-classical transition and potentially serve as new quantum sensors. What better way to honour the scientific legacy of Giancarlo Ghirardi? □

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