2024 Henri Poincare’ Prize Laudatio Kitaev by Bruno Nachtergaele

I am pleased and honored to give the laudatio for Alexei Kitaev today. I have learned so much from his work. It is hard to overstate the influence he has had in my research and I know this holds true for countless others.

Alexei Kitaev was educated at the Moscow Institute of Physics and Technology, from which he received his Masters degree in 1986, and the famed Landau Institute for Theoretical Physics where he obtained his PhD under Valery Pokrovsky in 1989.

Since then he has been affiliated with Caltech where he became a full professor in 2002.

In the mid-nineteen-nineties Quantum Computation emerged as a multidisciplinary research area that quickly attracted some of the brightest and most creative minds in Physics, Mathematics, and Computer Science. Alexei Kitaev was one of them but not just `one-of-them’. It soon became clear he is one-of-a-kind. It is hard to think of anyone who has made as many fundamental contributions that are having such a broad and lasting impact as have Kitaev’s. He has been a trail blazer for this new field time and again.

Let me briefly review some highlights.

The first result of Kitaev’s I became aware of was the Solovay-Kitaev Theorem of 1997 which provides a controlled approximation of an arbitrary unitary by the product of a not-to-long sequence of unitaries (gates in quantum computation language), taken from a generating set. As a consequence, arbitrary quantum algorithms can be executed on a quantum computer using only a small set of unitary gates.

Kitaev is widely regarded as the founder of quantum complexity theory. The quantum complexity class QMA (Quantum Merlin-Arthur) he introduced, is described in his book with Shen and Vyalyi. It is the quantum analogue of the classical complexity class NP and describes problems for which a solution represented as a quantum state can be verified on a quantum computer in polynomial time. In analogy with the classical NP-completeness of satisfiability problems, Kitaev proved that k-local Hamiltonian problems are QMA complete.

Physical quantum computers are not perfect and will never be. Hence the need for quantum error correction. Kitaev did pioneering work on quantum error correction and quantum coding theory, stabilizer codes in particular. With co-authors Dennis, Landahl, & Preskill and Aharonov & Preskill, he proved so-called threshold theorems, which determine maximal allowable error rates for given error correction schemes and noise models.

Kitaev's quantum phase estimation algorithm is an important component at the core of many quantum algorithms that promise a `quantum advantage'.

Perhaps his most widely influential ideas relate to fault tolerant quantum computation and robust quantum memory based on topological states of matter. His most cited papers are on this topic and their influence is wide and deep. At the top of the list is Fault-tolerant quantum computation by anyons , Annals of Physics 2003, which has been cited almost 8000 times.

Topological Quantum Computation, invented by Kitaev's along with Freedman, Larsen, and Wang, gave rise to the very active area studying Topological States of Matter in Mathematical Phyisics.

For his accomplishments, Kitaev has received major honors and awards:

- In 2008 he received a MacArthur Fellowship;
- In 2012 he received a Breakthrough Prize in Fundamental Physics;
- He was awarded the 2015 Dirac medal by the Abdus Salam International Center for Theoretical Physics;
- He received the 2017 Oliver E. Buckley Condensed Matter Physics Prize from the American Physical Society;
- In 2021 Kitaev was elected to the National Academy of Sciences.

The Henri Poincare' Prize he is being awarded today serves to recognize the particular impact of Kitaev's work in Mathematical Physics. That impact has indeed been extraordinary, with two modes of influence: one is at the programmatic and conceptual level, the other stems from his constructing quantum many-body Hamiltonians that illustrate the novel properties of quantum matter in concrete systems. These two modes reinforce each other and together have created new research communities not only in mathematical physics but, I would say uniquely so.

Kitaev's solvable toy models are many-body Hamiltonians that greatly accelerated building our intuition about topological states of matter, anyons, braiding, and related notions.

Here is a list of models that bear Kitaev's name:

- The Kitaev chain with its unpaired Mayorana states;
- The Toric Code model, and its generalizations called Kitaev's quantum double models. The quantum double models elucidated the role of locality in

determining and classifying the nature of elementary excitations in quantum many-body systems. This motivated a range of mathematical work, including algebraic approaches aimed at obtaining general classification results about topological phases and relations between them. It also reinvigorated interest in ideas from axiomatic quantum field theory and the theory of superselection sectors leading to analytic results on families of quantum many-body Hamiltonians with gapped ground states.

- Kitaev's honeycomb model, is another exactly solvable model that solidified the notion of non-abelian anyons and their possible use for quantum computation. His 2006 Annals of Physics paper about this model has been cited close to 5000 times.

- The Sachdev-Ye-Kitaev model, which has its origins in the study of anomalous metals but has since served as a model system to study information scrambling in quantum dynamics.

Kitaev has been no less influential in formulating more abstract notions that are essential elements in the classification program. For example, the periodic table of topological phases of quasi-free fermi systems attracted the attention of K theorists. More recently, Kitaev's Conjecture, as it is widely known, predicts the topological structure of the space of lattice Hamiltonians in d dimensions, for all d.

Many authors have acknowledged Kitaev for illuminating. With the Henri Poincare Prize mathematical physicists do so collectively.

The prize citation sums it up well:

Alexei Kitaev is honored for his pioneering contributions to quantum many-body systems, quantum information, and quantum computation, including the development and application of the notion of topological order and a wealth of inspiring exactly solvable quantum lattice models.

Congratulations, Alexei!