Anthony Leggett and Foundations of Quantum Mechanics

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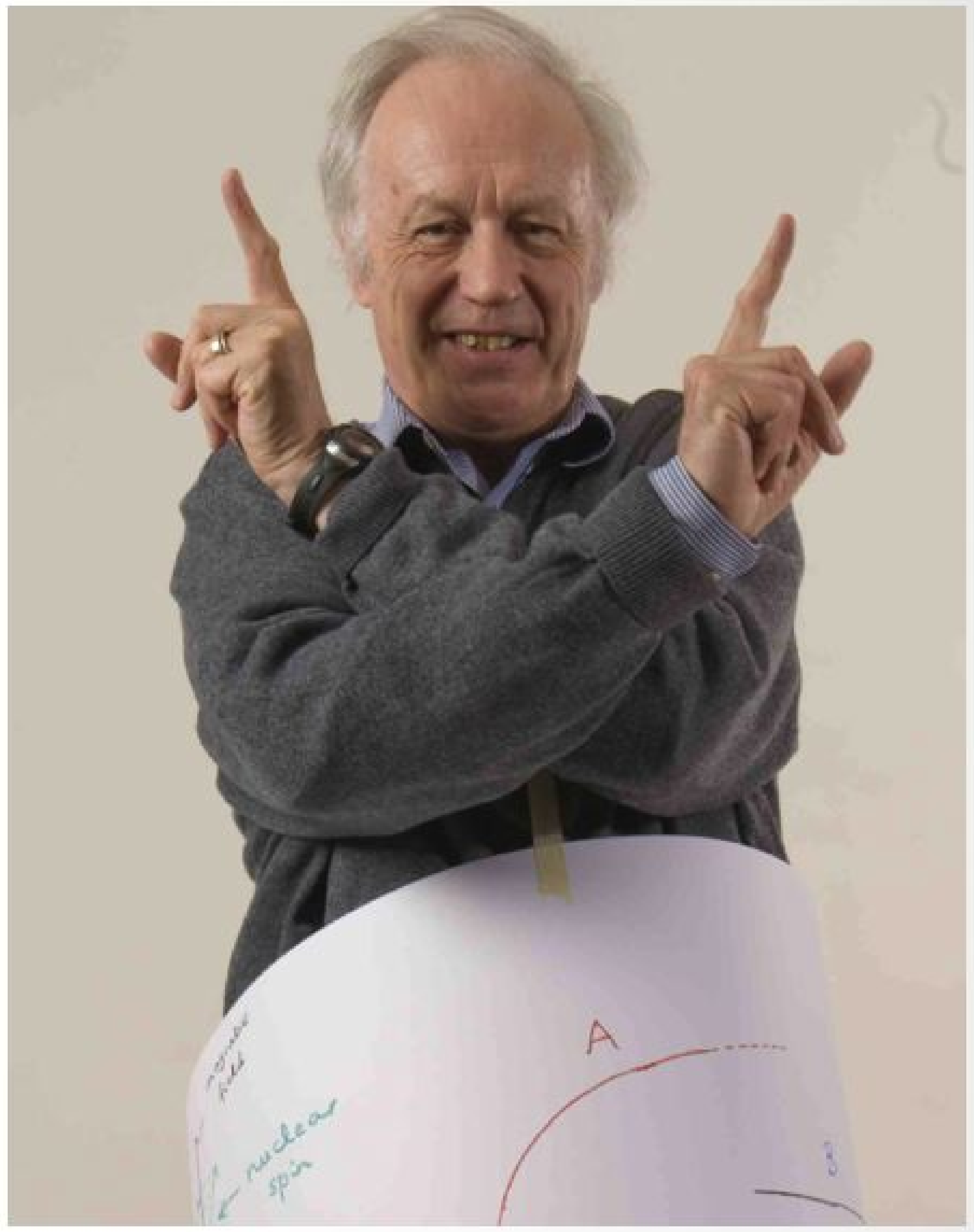
HQ3 – 3rd international conference on the history of quantum physics

Outline

- Who is Tony Leggett?
- What has he done in Physics?
- His work related to Foundations of Quantum Mechanics
- Further Questions

Sir Anthonny Leggett



- Born in 1938, England

- BSc in Classical Studies, 1959
- BSc in Physics, 1961, Oxford University

- Ph.D in Physics, 1964, Oxford University

- Lecturer, 1967, Sussex University
- John MacArthur Professor, 1982, University of Illinois, Urbana-Champaign

Prizes and Awards

- 1975-Maxwell Medal and Prize of the British Institute of Physics
- 1980-Fellow of the Royal Society
- 1981-Ninth Simon Memorial Prize of the British Institute of Physics
- 1985-Fellow of the American Physical Society
- 1991-Paul Dirac Medal and Prize
- 1997-Elected Foreign Associate, National Academy of Sciences
- 1998-Honorary Fellow, Institute of Physics, UK
- 2002/2003 Wolf Foundation Prize
- Knighted, Order of the British Empire (KBE) "for services to physics" by Queen Elizabeth II, 2005
- 2003 Nobel Prize in Physics

Superfluidity of ^3He

A theoretical description of the new phases of liquid ^3He

Anthony J. Leggett

School of Mathematical and Physical Sciences, University of Sussex, Falmer Brighton, England

This paper reviews the theory of anisotropic superfluid phases and its application to the new A and B phases of liquid ^3He. It is tutorial in nature and advanced formal techniques are avoided; even the formalism of second quantization is not required. After an initial discussion of the Fermi-liquid theory of Landau and its application to the normal phase of liquid ^3He, the idea of instability against formation of Cooper pairs is introduced. The effective interaction in liquid ^3He is considered, with emphasis on the spin-dependent interaction arising from virtual spin polarization of the medium ("spin fluctuation exchange"). Next, a self-contained discussion of the "weak-coupling" BCS theory as applied to anisotropic superfluids is given, with special attention to the "Ginzburg–Landau"

Rev Mod Phys, 1975

Foundations of QM in ^3He

Indeed, my initial reaction to these result were that they were so extraordinary that they might be the first evidence for a breakdown of some fundamental principle of quantum mechanics (such as the Pauli exclusion principle) under the very exotic conditions characterizing liquid ^3He in the mK regime.

Nobel Prize Lecture, 2003

And, I had actually, I got so interested in the foundations of quantum mechanics over the last few years that I had actually been intending to go off and do that. (…) But, this result of Bob's quite literally struck me so surprisingly that I seriously began to consider the possibility that it was evident, the first evidence that quantum mechanics was breaking down under these very extreme—because you have to remember, you're dealing with a very dense system at very low temperatures where almost no one had been before. **These were conditions which were really quite anomalous by ordinary terrestrial standards. And so, was it conceivable that quantum mechanics was actually breaking down?**

Interview with Babak Ashrafi, 2005

The new project

- **ASHRAFI:** So, should we think of your work, when you examine the question about, "Is this a violation of quantum mechanics?" (Leggett: Yeah.) Was that something in the back of your mind? Something you considered just for an instant? Or was this really . . .
- **LEGGETT:** No, it was very explicit.
- **ASHRAFI:** This was the project you were setting up to do?
- **LEGGETT:** Yeah. Yeah, that's right. Yes.
- **ASHRAFI:** So, if I could follow your thoughts at the time, these thoughts that you described (Leggett: Yeah.) are attempts to find (Leggett: Yeah.) violations of quantum mechanics?
- **LEGGETT:** Yeah.

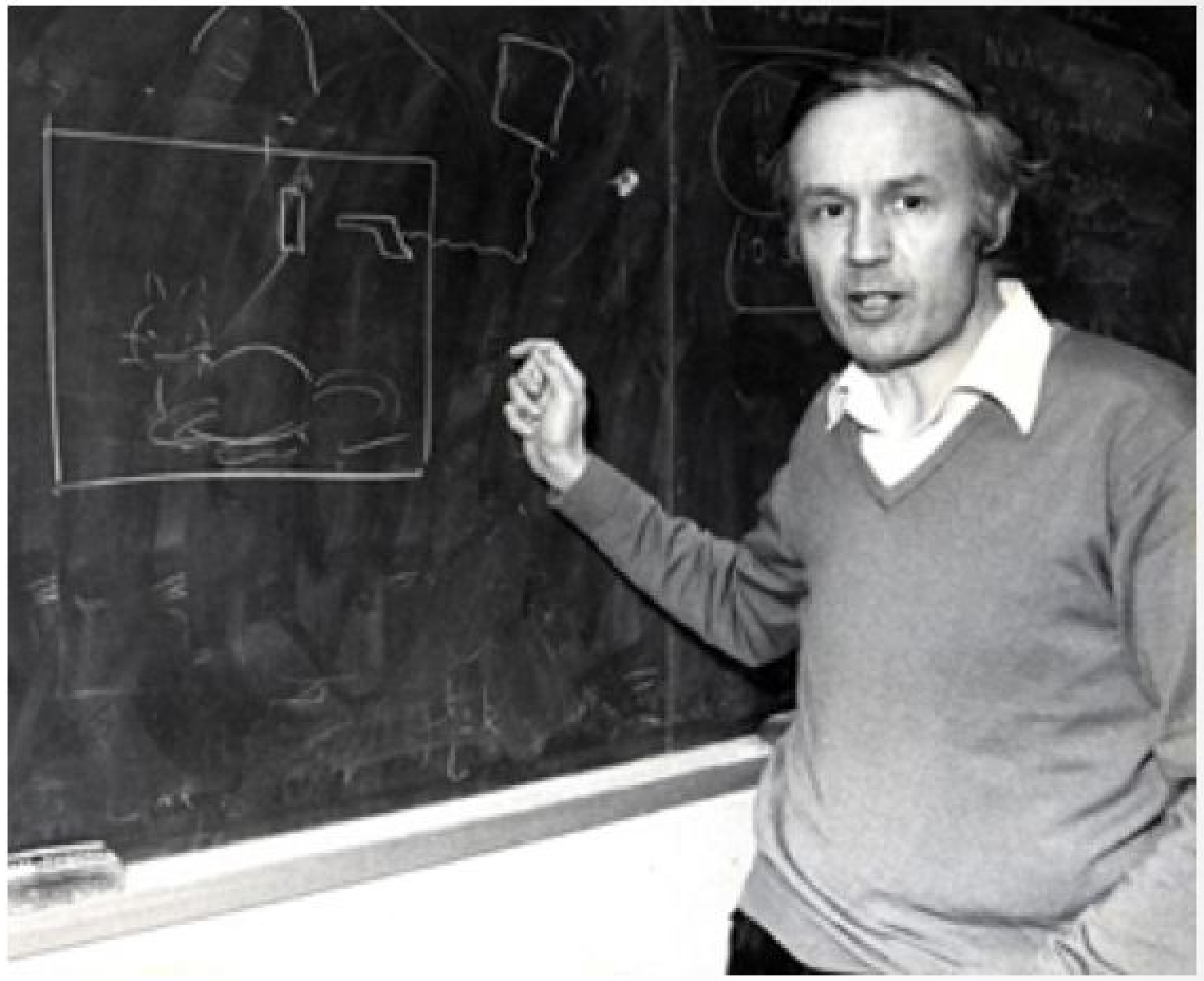
The new project

In the fall of 1967 I took up a lectureship at the University of Sussex, and for the next few years, in the intervals allowed by my teaching duties, I continued to work on various problems in low-temperature physics, including liquid ^3He. However, I found myself becoming increasingly bored with this area of research, and indeed with much of conventional physics; at the same time, thanks in part to a remarkable series of lectures delivered by my colleague Brian Easlea, I got more and more intrigued by the conceptual foundations of quantum mechanics, and by the summer of 1972 had made a firm decision that I would abandon the sort of physics that gets published in Phys. Rev. B and devote myself full-time to foundational studies. (Fortunately, in those days even lectureship positions in British universities carried tenure, so that it was possible to make such a switch without drastically affecting one's career prospects!)

Nobel Prize Lecture, 2003

MQT and Decoherence

- Building Schrödinger's Cat in the laboratory
- Squids and Macroscopic Quantum Tunneling
- Master equations, dissipations and environment
- Modeling systems for experimental tests



Caldeira and Leggett

- Amir Caldeira, PhD in 1980, Sussex University
  - PhD dissertation: Macroscopic Quantum Tunneling and related topics
  - Master degree on dissipation in Bosons, 1976, Catholic University of Rio de Janeiro, Brazil

- The influence of dissipation on quantum tunneling in macroscopic systems, PRL, 1981 (1226 citations)
- Quantum tunneling in a dissipative system, Ann Phys, 1983 (2186 citations)
- Path integral approach to quantum brownian-motion, Physica A (1283 citations)

Leggett's program

- Quantum Mechanics of macroscopic systems
- Degree of disconnectivity
    - Macroscopic Quantum Physics and the Quantum Theory of Measurement, Prog. of Inter. Phys, 1980
- Understanding the effects of dissipation on quantum effects
- To model extreme quantum systems to test them empirically

Further Questions

- Since his work was so important to the theory of decoherence, why his name is seldom mentioned when this topic is faced?

- Conjectures
  - Leggett's criticism of quantum theory
    - 80's context and Bell's experiments
  - Unique style in foundations of quantum mechanics
    - Complicated vs simple systems
  - Disassociation of his criticisms and his physics
  - Lack of concept of information
    - Zurek's 1991 article and the new context of quantum information

- We would like to acknowledge the following supports:

- FAPESB – Bahia, Brazil
- CNPQ – Brazil
- MPIWG – Berlin, Germany
- AIP – Washington, USA

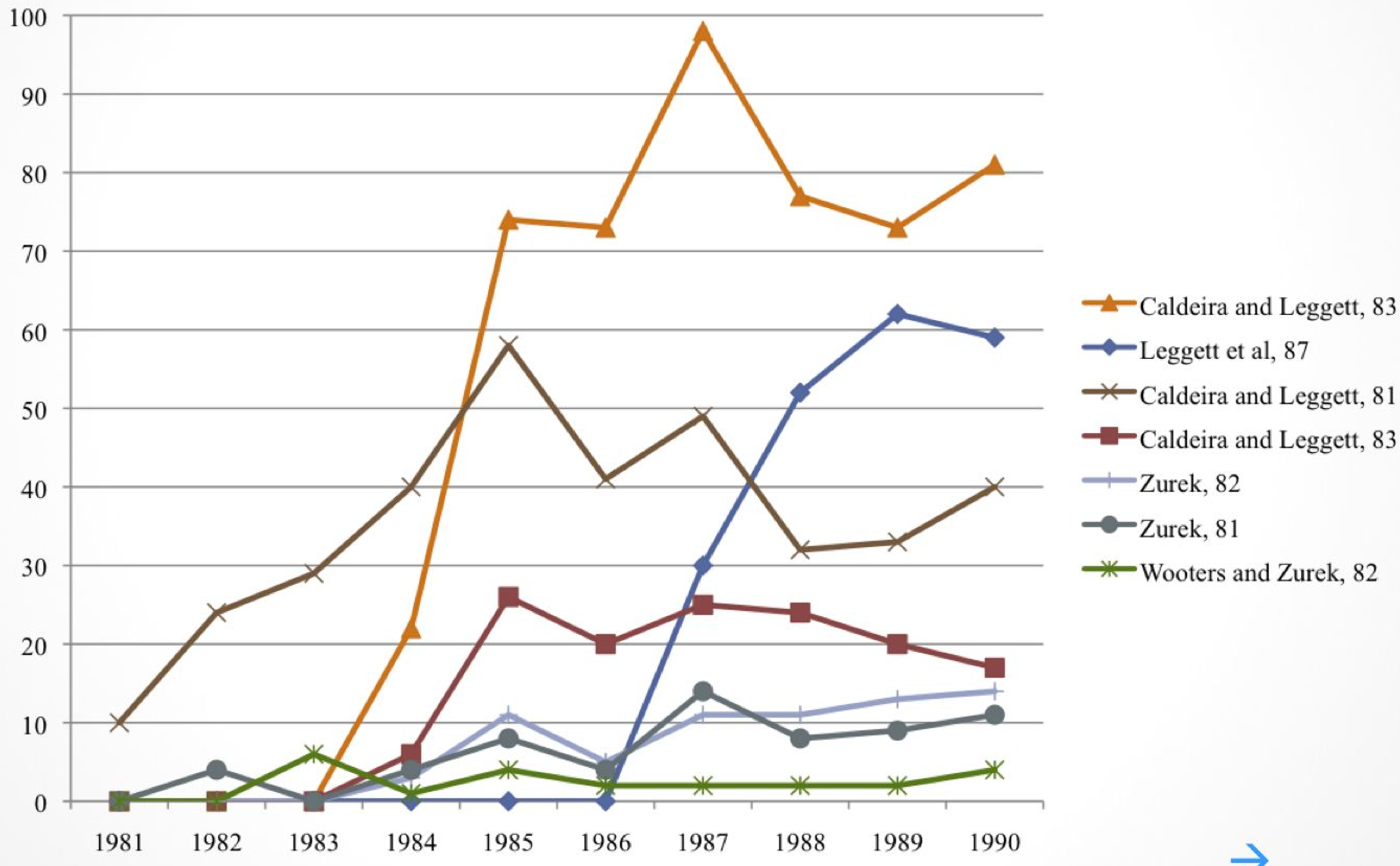
Vinay Ambegaokar

"(…) Since A. J. Leggett's lectures at this institute take very much a phenomenological point of view, mine should complement his rather well.

"One matter I leave entirely to Leggett. That is the general question of whether ordinary quantum mechanics describes transitions between macroscopically distinct quantum states in superconducting devices. (See his lectures, and references therein**). I would be most surprised if it does not, and it would never occur to me to doubt that it does.** What follows is a technical but straightforward application of the quantum mechanical machinery which – basically mysterious though it may be – we have all learned to operate with instructions from Copenhagen. As for Schrödinger's cat, my way out of that conundrum is to remark that, as a reluctant co-owner of one, I know that cats are more devious – for which read complex – than superconductors."

← Percolation, Localization, and Superconductivity, NATO Series in Physics, 1984

Leggett's and Zurek's citations



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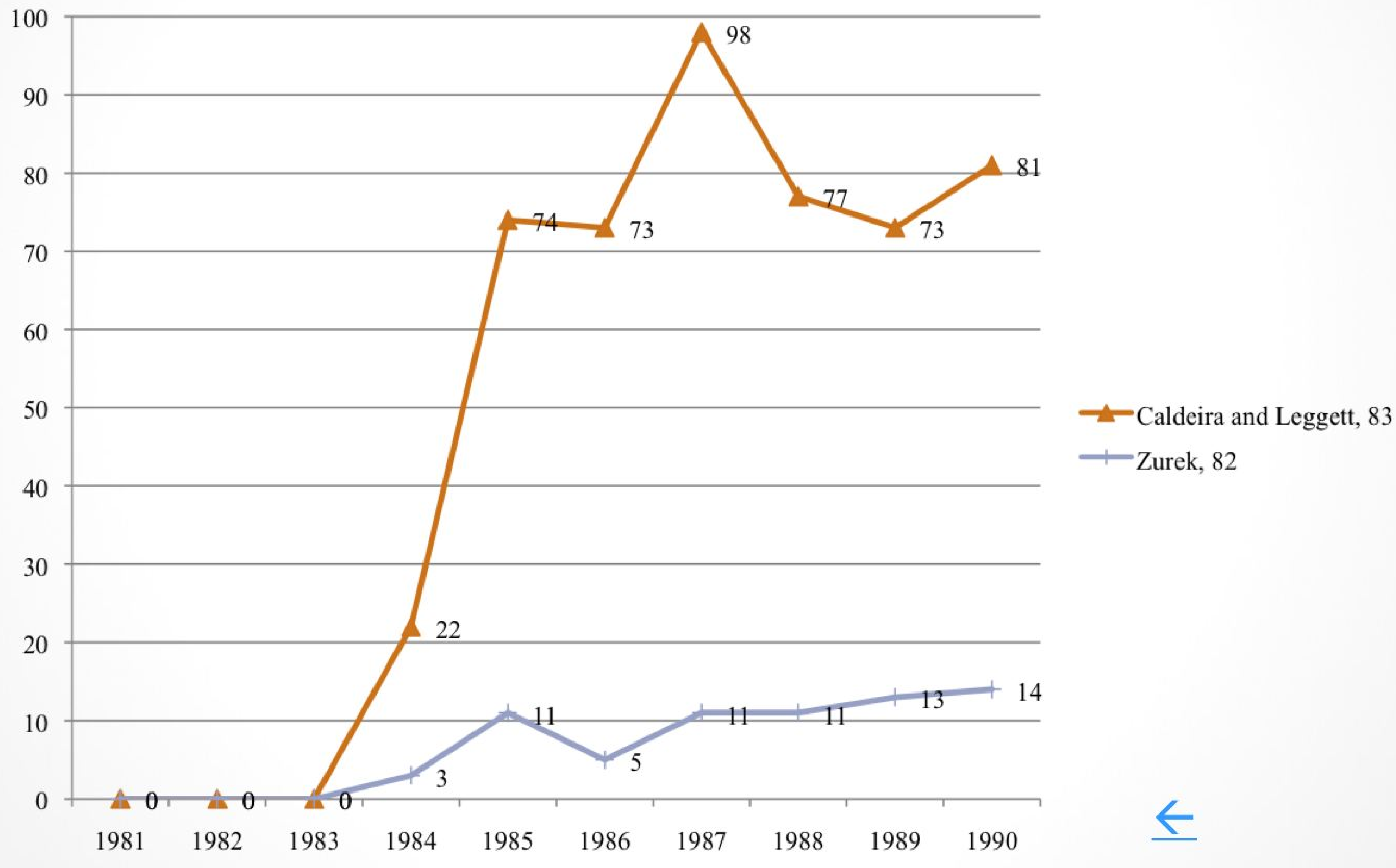
Source: ISI web of science

Leggett '83 and Zurek '82



Source: ISI web of science

Macroscopic Systems

"In discussions of the quantum theory of measurement, **a crucial question is whether the usual laws of quantum mechanics can be applied to macroscopic bodies**, and in particular, whether is legitimate to assume the occurrence in nature of linear superpositions of states with macroscopically different properties. In recent years, with the development of the technology of Josephson devices and of submillidegree cryogenics, **it has become clear that his is not entirely a matter of "quantum theology" but can be tested**, at least indirectly, by experiment."

← Percolation, Localization, and Superconductivity, NATO Series in Physics, 1984

Leggett's approach

"My general approach will be to assume that the linear laws of quantum mechanics do apply without modification to macroscopic bodies and to explore the consequences of this assumption. Naturally, if the experiments were to fail to show the predicted results, the assumption might have to be re-examined."

← Percolation, Localization, and Superconductivity, NATO Series in Physics, 1984

Amir Caldeira

When we began working with that, i was the one which had already worked with relaxation, I had my master in this thing, so I was really saying : no, this is the way, we are going to do like this, and this and this. Of coure I had a feedback of him, obvious, during the discussions... I thought that the model was to naive, and he: “no, no, it’s not, go ahead, it will be great”. So it was really a collaborative work and my part was... I already knew dissipation and brownian motion, trying to develop a quantum theory of brownian motion”

← Interview with Olival Freire and Fabio Freitas, 2009

Skeletons in the cupboard

vigorously by some of my colleagues. It seems to me that the many-worlds interpretation is nothing more than a verbal placebo, which gives the superficial impression of solving the problem at the cost of totally devaluing the concepts central to it, in particular, the concept of 'reality'. When it is said that the 'other worlds'

quite literally meaningless. I believe that our descendants two hundred years from now will have difficulty understanding how a distinguished group of scientists of the late twentieth century, albeit still a minority, could ever for a moment have embraced a solution which is such manifest philosophical nonsense.

← Problems of Physics, 1987

Leggett to Joos, 1985

two reservations, one of them academic and one more practical in nature. The academic point is that we do not really have anyone here who is working full time on the quantum theory of measurement as such (that of course includes me); our approach has on the whole been to try to take account of the considerations which are raised in a general context in that area while doing specific calculations on concrete systems such as superconducting devices. Nevertheless, if you should wish to continue your present line of work, I believe some fruitful interaction should be possible; alternatively, if you wanted to get involved in more specific calculations in the superconducting-device area or elsewhere we should be very happy.

←

"I am often asked whether and how my Greats training has been useful to me in my subsequent career in physics. To that question I have a joking answer, namely that unlike (apparently) some of my physics colleagues I at least know the difference between the Greek letters ϕ and ψ! However, there is a serious answer: I certainly do feel the philosophy component of the degree, at least, has helped to shape the way at which I look at the world and in particular at the problems of physics."

← Nobel Prize autobiography, 2003