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Quantum Theory of radiation interactions

Fall 2012 ~ Paola Cappellaro

Why QM?

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- 1 application of QM in (almost) everyday life
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- your favorite QM application
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  - NMR (superconductivity + spins, simple to complex description)

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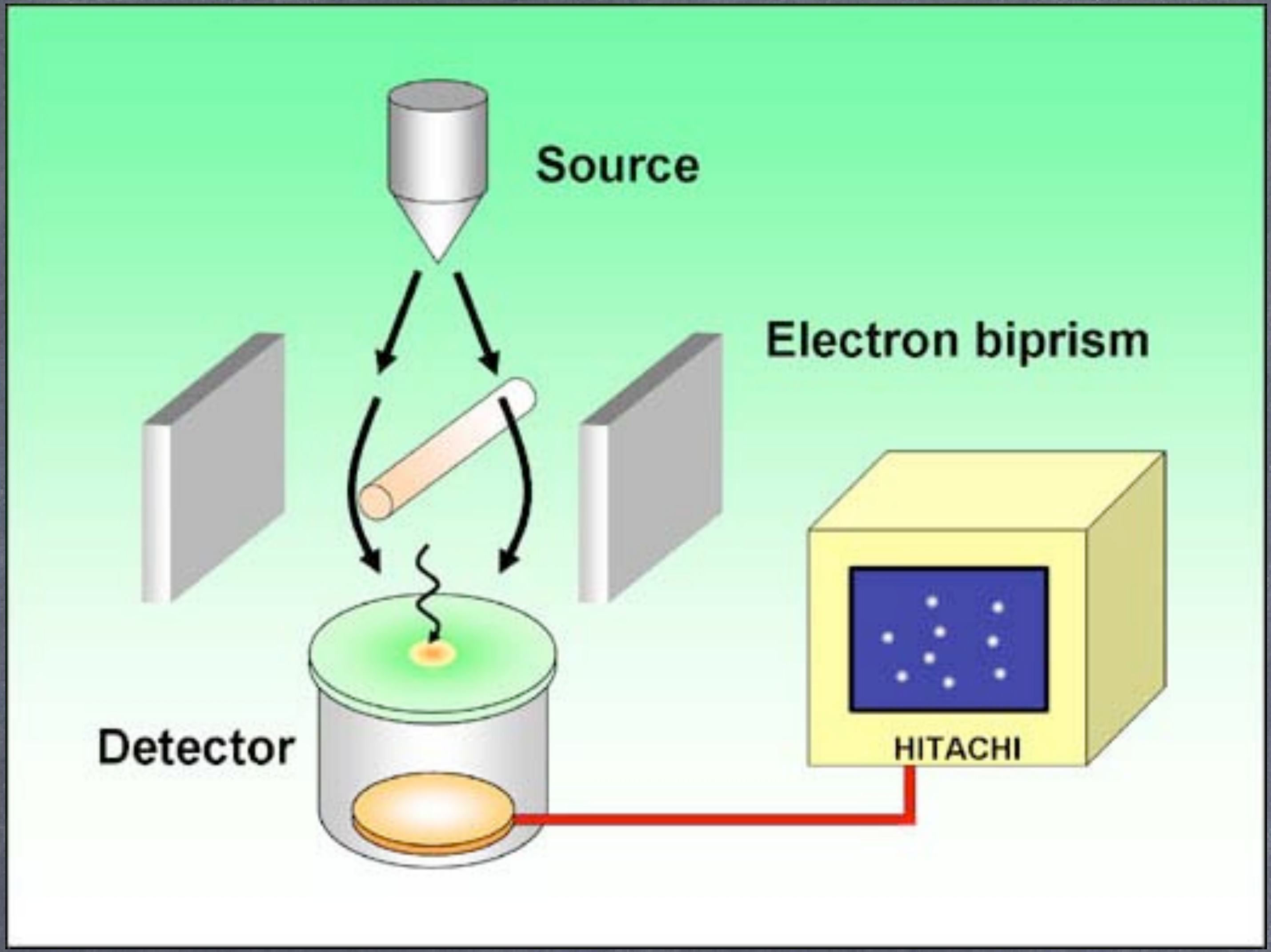
These characteristics are revealed in the interaction between matter and radiation

Young Double Slit experiment

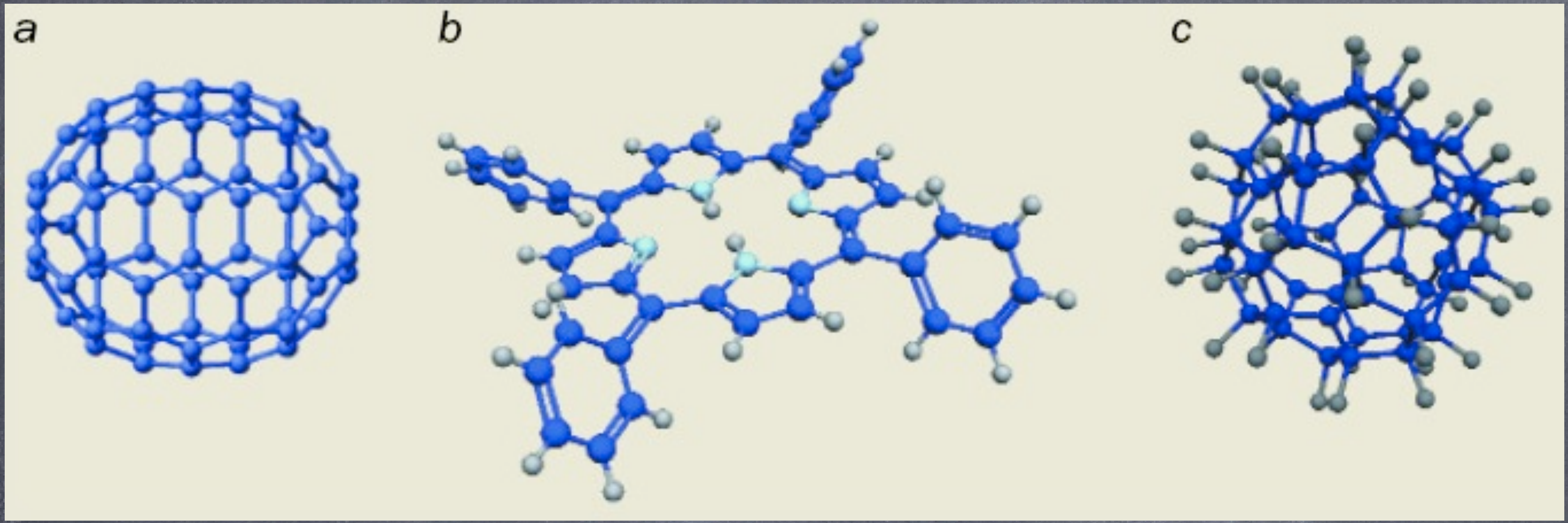


- A. Tonomura, J. Endo, T. Matsuda, T. Kawasaki and H. Ezawa Am. J. of Phys. 57, 117 (1989)

Electrons are emitted 1 by 1 from the source in the electron microscope. They pass through a device called the "electron biprism", which consists of two parallel plates and a fine filament at the center. Electrons are then detected 1 by 1 as particles at the detector. The electrons were accelerated to about 40% of the speed of the light . So they pass through a 1m-long electron microscope in 10^{-8}s. There is no more than one electron in the microscope at one time, since only 10 electrons are emitted per second. The experiment lasts 20 minutes (video 1 min!)

Molecule interferometry

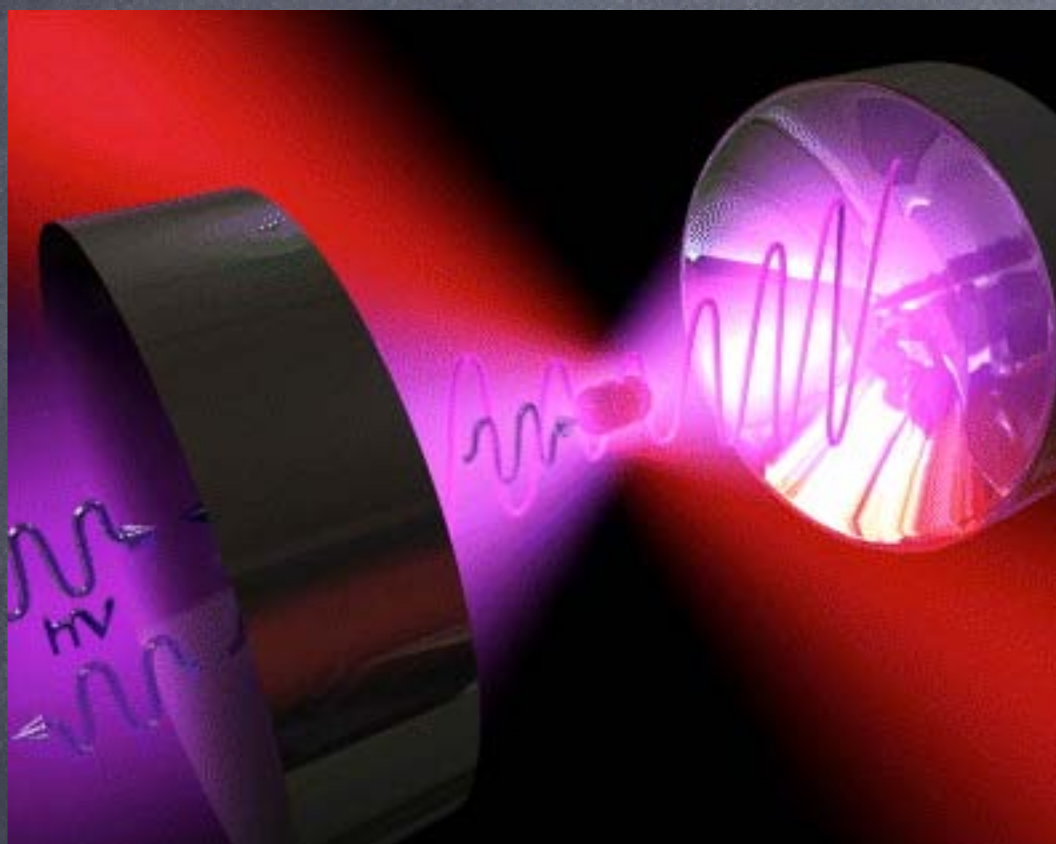
M. Arndt, K. Hornberger, A. Zeilinger



(a) The buckyball carbon-70 (and C-60) (1999)
(b) the pancake-shaped biomolecule tetraphenylporphyrin (TPP) $C_{44}H_{30}N_4$; (2003)
(c) the fluorinated fullerene $C_{60}F_{48}$. (2004)

TPP is the first-ever biomolecule to show its wave nature.
$C_{60}F_{48}$ has an atomic mass of 1632 units and currently holds the world record for the most massive and complex molecule to show interference.

Schrodinger's virus



- Quantum superposition of living organisms. Illustration of the protocol to create quantum superposition states applied to living organisms, such as viruses, trapped in a high-finesse optical cavity by optical tweezers.

- O. Romero-Isart, M. L. Juan, R. Quidant and J. I. Cirac, "Toward quantum superposition of living organisms" New J. Phys. 12 033015 (2010)

Cat State decoherence

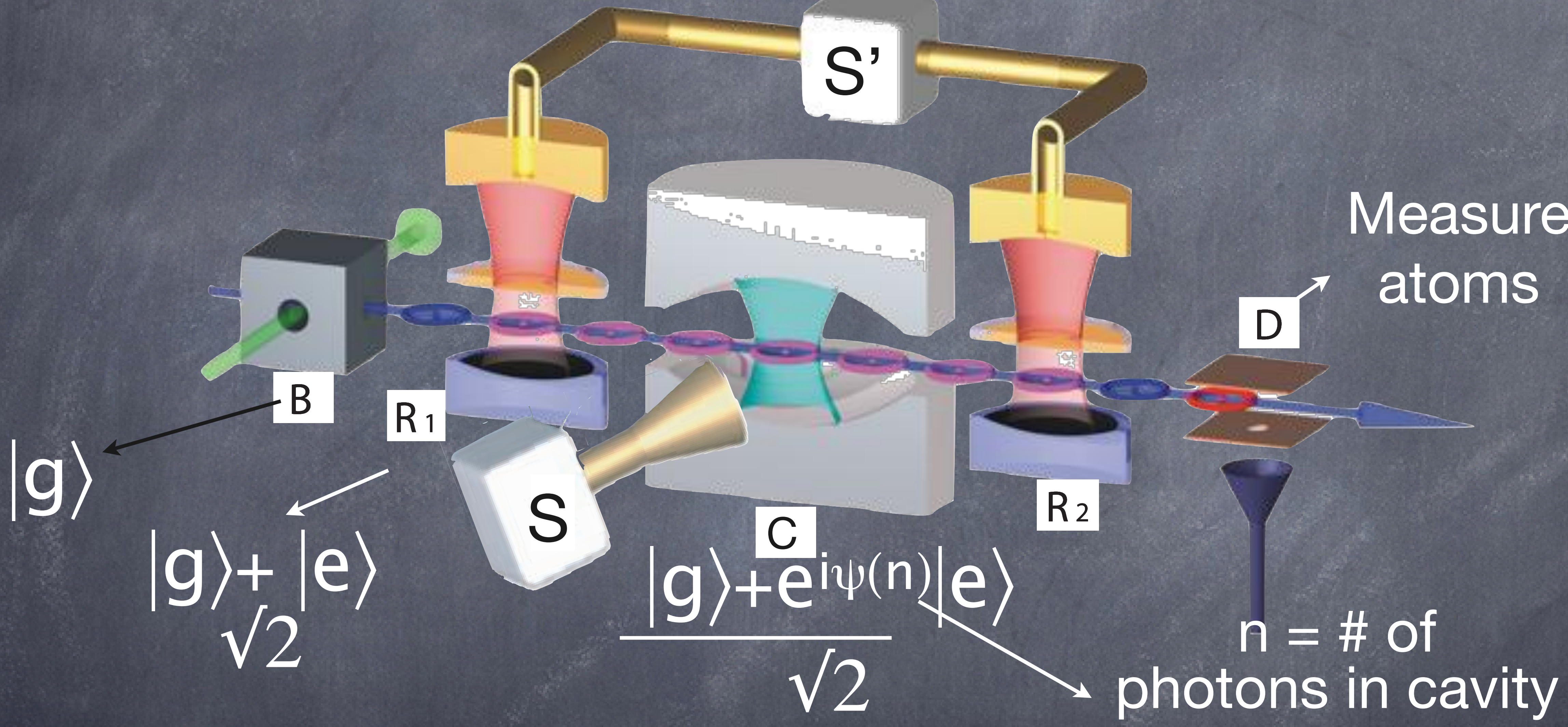
Reconstruction of non-classical cavity field states with snapshots of their decoherence

S. Deléglise,... & Serge Haroche,
Nature 455, 510 (2008)

Quantum e.m. field in a cavity

- Preparation of electromagnetic radiation in Schrödinger cat states
- Atoms crossing the cavity extract information about the field: reconstruction of state
- Cavity damping induces decoherence that quickly washes out interferences

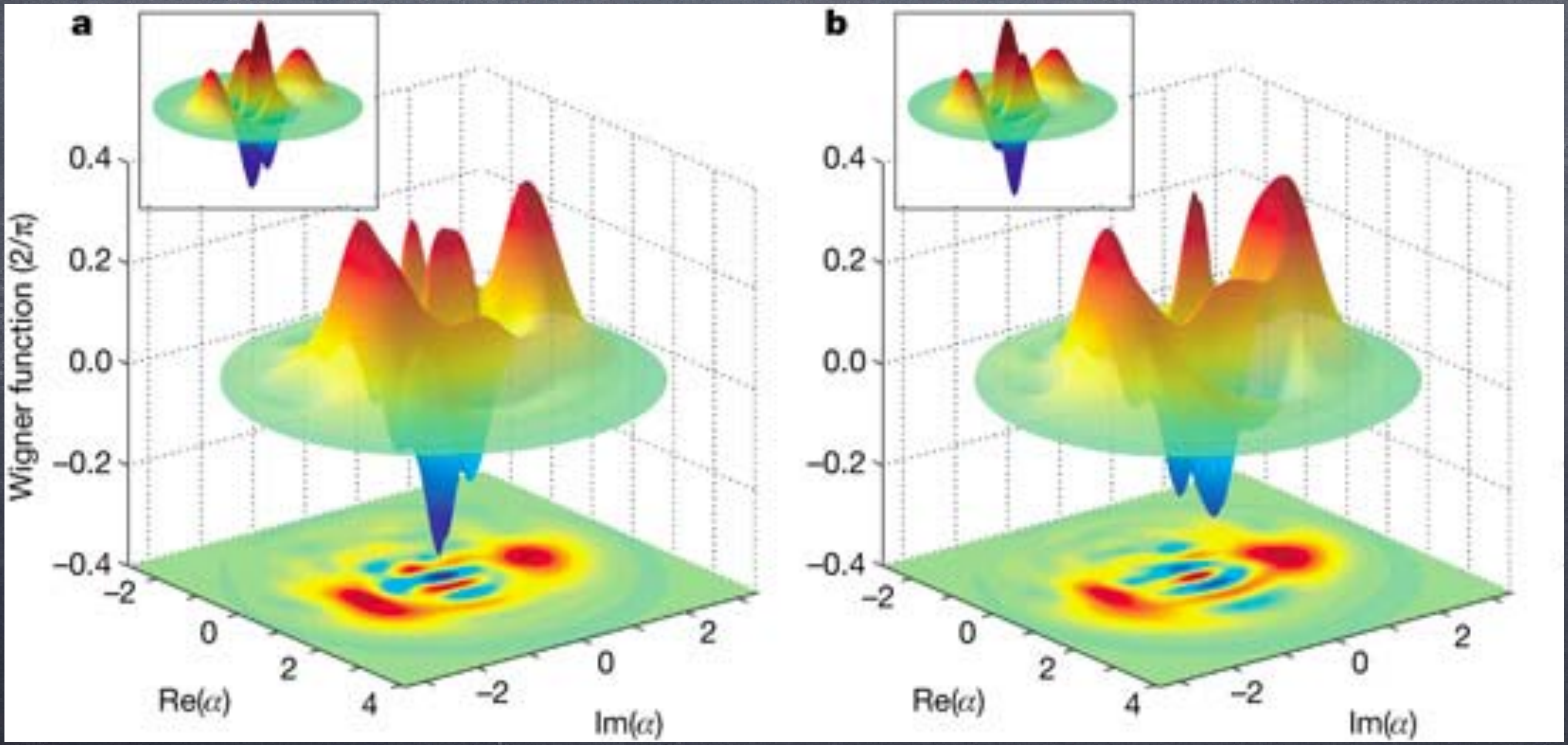
Experimental Setup



Rydberg atoms are prepared in the circular state |g> in box B.
The atoms cross the cavity C sandwiched between the Ramsey cavities R_1 and R_2 fed by the classical microwave source S', before being detected in D.
The source S prepares a coherent field in C in the cat state.

Schrödinger cat

- Wigner Function representation
  - Cat = 12 photons (macroscopic?)
  - Oscillation indicate entanglement (quantumness)



Reprinted by permission from Macmillan Publishers Ltd: Nature. Source: Deleglise, Samuel, et al. "Reconstruction of non-classical cavity field states with snapshots of their decoherence." *Nature* 455 © (2008): 510-4.

50 ms in the life of a Schrödinger cat

VIDEO

http://www.nature.com/nature/journal/v455/n7212/suppinfo/nature07288.html

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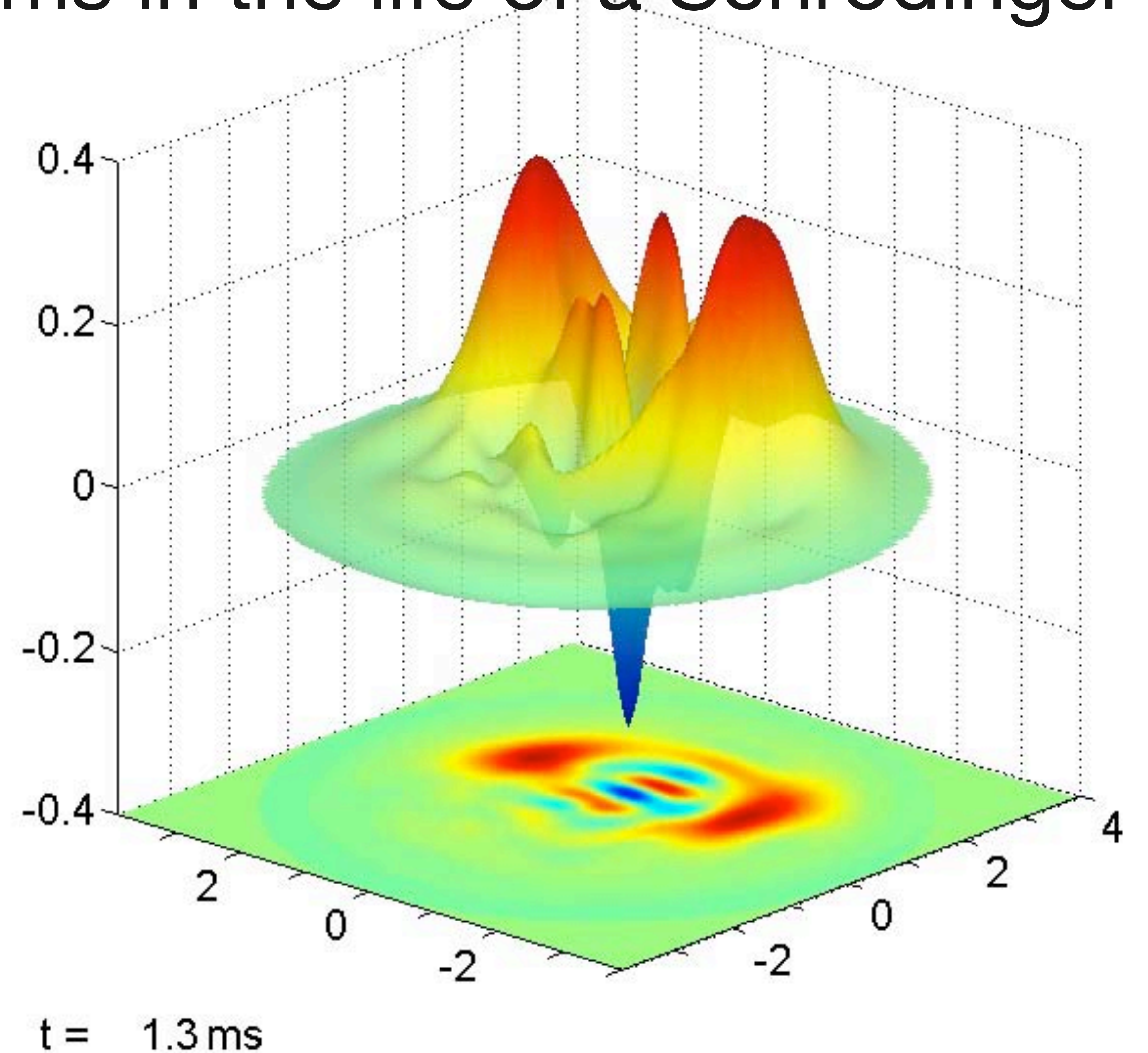

Goals of Course

By the end of the term you should be able to

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- Stop worrying about the qualifying exam!

Textbooks

- **Lecture notes**
  - usually posted before the lecture
- Recommended **books**
  - J.J. Sakurai *Modern Quantum Mechanics*
  - M. Le Bellac *Quantum Physics*
  - Chen, S.H.; Kotlarchyk, M., *Interactions of Photons and Neutrons with Matter*
  - Ballentine, Griffiths, Liboff, Haroche & Raimond, Scully & Zubairy

P-Sets

- The problem sets are an essential part of the course: they are meant for you to learn, not for me to judge you

Grading

- Homeworks will be graded on a 0-1 scale,
  - 0 if no Pset, 1 for a serious effort.
- The final grade will be

$$G = \frac{1}{2}(ME + FE)\left\langle Pset \right\rangle + \delta$$

- Mid-Term: October 29th