Quantum State Reconstruction of Squeezed Light

These five images are probability distributions for quantum states of light, as measured by a group at the University of Konstanz in Germany.[1] The top distribution is a coherent state and the other four are a variety of squeezed states.

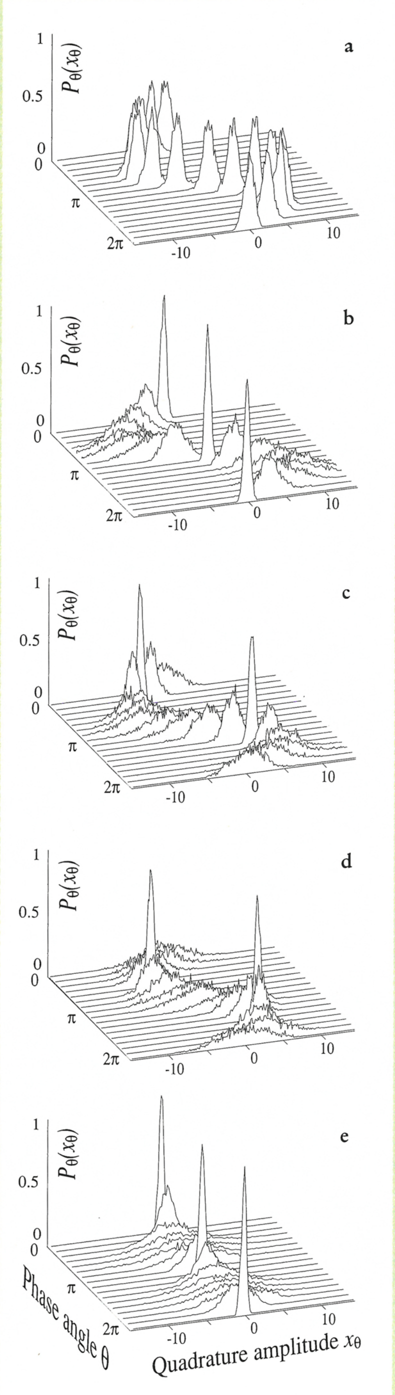
"Squeezed" refers to the reduction of some of the innate uncertainty required by quantum mechanics. In particular, a state ψ is squeezed in an observable x if the uncertainty Δx is less for ψ than it is for the vacuum state. The Heisenberg uncertainty relation is still satisfied because squeezing in x must always entail a corresponding increase in uncertainty of the complementary observable p.

For about a decade now, squeezed states have been produced using lasers and nonlinear optical media, but detailed mapping of such states has been achieved only in the past few years. The Konstanz researchers, Gerd Breitenbach, Stephan Schiller and Jürgen Mlynek, apply a technique called optical homodyne tomography. This uses an electro-optic modulator, piezoelectrically controlled phase delays and a homodyne detector in such a way that the detector's output is essentially a measurement of the instantaneous electric field of the light at a certain phase θ of the light's oscillation. The statistics of these measurements are plotted in the five images.

The quadrature amplitude x_θ is proportional to the electric field measured at the phase θ. The vertical axis of each plot shows the probability of measuring the specified value of x_θ at phase θ. The variation with phase from 0 to 2π can be interpreted as time evolution through one oscillation period of the light.

Part (a) shows a coherent state and can be interpreted as time evolution of the wavepacket of this pure state. (See Daniel Kleppner's Reference Frame on page 11 for more about coherent states.) The other states are mixtures and therefore cannot be described by a single wavepacket. State (b) is phase squeezed and state (d) is squeezed in the complementary quadrature: amplitude. The uncertainty of the amplitude of the light in state (d) is smaller than the fluctuations of electric field of a vacuum state! State (c) demonstrates the group's ability to squeeze a state in an arbitrary quadrature: It is squeezed in the 48° quadrature (where 0° corresponds to phase squeezed and 90° corresponds to amplitude squeezed). The final part, (e), shows a squeezed vacuum state.

For each state, the Konstanz group uses the quadrature probability distribution to reconstruct the state's Wigner function and density matrix. Either of these fully characterizes the quantum state of the light in much the same way that a wavefunction fully characterizes a pure quantum state.



Reference

1. G. Breitenbach, S. Schiller, J. Mlynek, Nature **387**, 471 (1997).

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South America. A similar line of high-speed anomalies, at least as long, stretches between Europe and Indonesia, across southern Asia. In both cases, the stuctures persist at many depths. The figure on page 19 shows the P-wave velocity anomalies in vertical cross sections centered on Central America and Japan, respectively. The cold regions appear to be continuous as a function of depth, suggesting the descent of slabs of oceanic lithosphere at the edge of tectonic plates: Indeed, the features both in the Americas and South Asia coincide with regions that have a long history of subduction (the descent of a continental plate). Unfortunately, the data coverage is not uniform, so the resolution is not as good in other regions of the globe as it is in the Americas and Eurasia.

The data used in these studies are not new. For the S-wave study, Grand has analyzed thousands of individual seismograms from the World Wide Standardized Seismograph Network and the Global Digital Seismograph Network, ending up with high-quality data. The data used in the P-wave study come from the database published by the International Seismological Center and, for recent years, the USGS's National Earthquake Information Center, but Engdahl, Van der Hilst and Ray Buland (USGS in Denver) have carefully reprocessed it, narrowing the constraints on the focal depth of the earthquakes and placing stricter selection criteria on the events.

Geochemical data

Earth may be the ultimate black box, whose internal workings can be deduced only by measuring what goes in and what comes out. Whereas geophysicists record the vibrations sent forth from rumblings within the mantle, geochemists look at the materials—primarily the radioisotopes and trace elements—that Earth spews from erupting volcanoes or squeezes out at mid-ocean ridges.[4] Many geochemists assume that when Earth formed, its composition was largely homogeneous, with the relative proportion of heavy elements similar to that found today in the Sun or in meteorites. As Earth has evolved over the past 4.5 million years, its composition has become more heterogeneous, although the geochemists assume that the lower mantle has remained fairly pristine. (A contrasting theory is that the material melted and degassed soon after the planet was accreted and while it was still hot, so that little primordial material is left.)

One class of elements that seems to have been significantly redistributed are the "incompatible" elements—those that do not fit easily into the