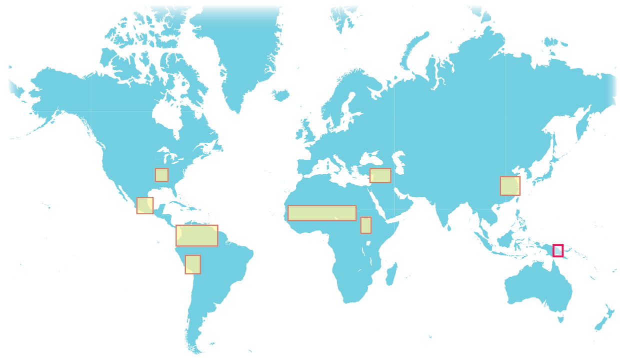


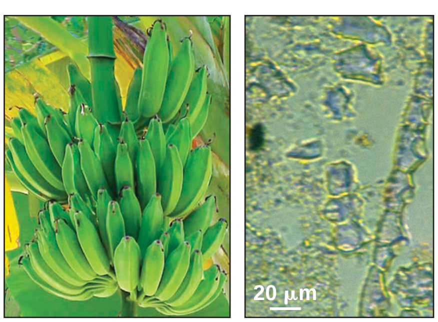
Centers of agricultural origins. New Guinea is marked in red.

that the early inhabitants gradually intensified their cultivation practices in a swampy, resource-poor environment. Early forms of cultivation may have started 10,000 years ago, mounds are attested 7000 to 6400 years ago, and a ditch network was built 4400 to 4000 years ago.

Until recently, the opinion was widespread that remains of root crops (which may have been domesticated before seed crops) are easily destroyed in tropical soils, leaving no traces. The analyses presented by Denham *et al.* contradict this view. The authors found tiny plant remains that help to reconstruct former environmental conditions and plant exploitation (*10*). In addition to wood and seeds, they recovered pollen and phytoliths (plant crystals) from sediments and starch grains from stone tools. The large number of banana phytoliths confirms that this crop was planted 7000 years ago. The presence of taro starch grains indicates cultivation; this species does not grow naturally in the New Guinean highlands and must have been brought there from the lowlands.

In the 1950s, Sauer (*2*) proposed that plant cultivation spread across the world from just two "cradles of agriculture," one each in the Old and the New World. Today, scientists have moved away from this idea, but the question of whether agriculture is indigenous to a region is still vividly discussed. There are only five secure candidates for primary homelands of plant domestication: the Near East, China, Mesoamerica, South America, and the eastern United States. It remains unclear whether African plant domestication was triggered by the arrival of Near Eastern crops (*11*, *12*).

Until recently, the evidence for independent development of agriculture in New Guinea was also equivocal (*9*, *11*). The sweet potato only arrived 300 years ago. But what about taro, yams, bananas, and sugar cane? Were they introduced from Southeast Asia or first cultivated in the New Guinean highlands? Recent biomolecular studies indicate that these crops were domesticated in New Guinea or Melanesia (*13*). The new data from Kuk indicate that New Guinea is more likely, at least for banana (see the second figure) and taro.



New Guinean agricultural heritage: the banana. (Left) Modern banana. **(Right)** Modern banana phytoliths, similar to those that indicate its cultivation in New Guinea 7000 years ago.

Denham *et al.* show that the transition from foraging to farming in Kuk took several thousand years. The evidence attests to cultivation, but not necessarily domestication, of banana and taro. The authors do not solve the question of how significant agriculture was compared to hunting and foraging, but they illustrate impressively how humans have adapted to a specific environment over the past 10,000 years.

Only a few regions were geographically suited to become the homelands of full agricultural systems (*11*). New Guinea seems to have been one of them.

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PHYSICS

Playing Tricks with Slow Light

Marlan O. Scully and M. Suhail Zubairy

Pulses of light travel through a vacuum at the mind-boggling speed of ~100 million miles per hour (mph). In glass and other transparent matter, it moves somewhat slower, at ~50 million mph, but still, for most people, it is infinitely fast. Not anymore. The speed of light pulses has been slowed to the snail's pace of a few meters per second (*1*). The quantum state of such pulses has been stored (stopped light) (*1*) and even reversed in time (*2*).

In this issue of *Science*, two important reports (*3*, *4*) on ultraslow-stopped-reversed light are presented. On page 196, van der Wal *et al.* (*3*) demonstrate experimentally the correlation between the quantum states of two delayed light pulses. This application of "slow light" holds promise for applications in quantum communication and computation. And on page 200, Bigelow *et al.* (*4*) report ultraslow light moving at about 100 m/s in room-temperature solids. This work is of interest for device applications. The researchers have also produced "superluminal" propagation in the same way.

The first demonstration of ultraslow light used ultracold gases (*5*). Shortly thereafter, two groups reported ultraslow light propagation in hot Rb gases (*1*). This work was a milestone on the way to making ultraslow light "on the cheap," that is, without expensive atom traps. However, the density of the Rb atoms in such experiments is modest (about 10^{12} atoms/cm^3). It is therefore of considerable interest to produce ultraslow light in solids, where the density of relevant "atoms" is millions of times larger than in gases. Ultraslow light in solids was recently demonstrated (*6*) in

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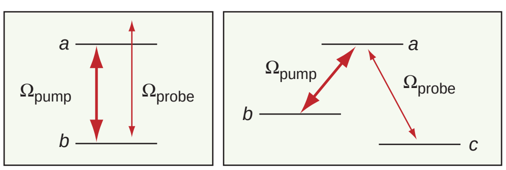
cold (5 K) solids. Bigelow *et al.* have now upped the ante to room temperature.

However, ultraslow and frozen light are just one of many manifestations of atomic coherent effects (*2*). To put things in perspective, we must go back a hundred years. For the first 25 years of quantum physics, the founding fathers of the field were struggling to break away from classical physics (where energy comes in arbitrarily small packages) to the quantum world (where energy is parceled out in quantum lumps and atoms and molecules have discreet energy states).

The next quarter century was devoted largely to applying quantum mechanics to problems such as calculating scattering rates and absorption cross sections. These studies involved quantum probabilities, which require knowledge of the amplitude of the wave function but not of its phase.

In the second half of the 20th century, the phase of the wave function held center stage. For example, the phase of the electron pairs governs much of the physics of superconductivity, and in the gauge field theories of modern particle physics, the phase of a particle (such as an electron or quark) is intimately tied to its gauge quanta (photons and gluons).

More recently, phase-coherent ensembles of atoms have yielded a different state of matter. Often called "phaseonium," this



How to slow down light. Bigelow *et al.* generate ultraslow light via population pulsations (**left**). A pump field with frequency Ω_{pump} causes a spectral hole in the absorption profile when probed by a probe field of frequency Ω_{probe}. Other experiments are based on EIT in three-level systems (**right**).

state has many novel properties, such as the ability to slow or even freeze light. Other examples of novel applications of phase-coherent matter include lasing without inversion (*7–9*), electromagnetically induced transparency (EIT) (*10*), and new sensitive anthrax detectors (*11*).

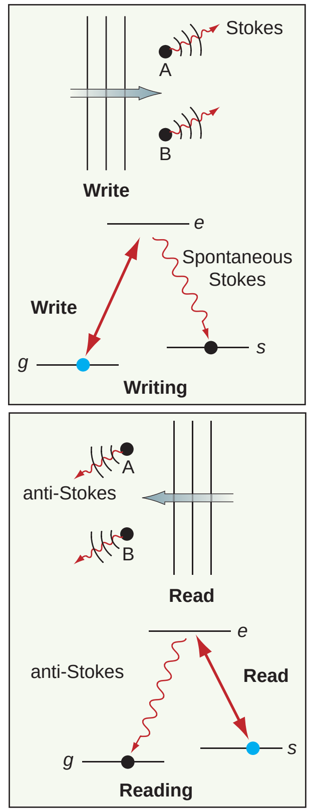
Bigelow *et al.* (*4*) demonstrate a new method for controlling the speed of light pulses propagating through a material medium. They use two-level atoms driven by two lasers, the pump and probe (see the first figure, left panel). The beating between the pump and probe beams leads to a periodic modulation of the ground-state population, creating a narrow, pronounced dip in the probe absorption spectrum. The dip then leads to a rapid variation of the refractive index, thus producing ultraslow light.

These experiments provide a new addition to the quantum optics tool box. The technique should be contrasted with EIT studies of slow (and fast) light. In these experiments, three-level atoms are driven by two lasers (see the first figure, right panel), yielding a coherent superposition of the two ground-state levels.

Van der Wal *et al.* (*3*) apply slow light to a different area of research: quantum information studies. The authors use "slow-light" physics to make correlated photon states (*3*). The work emphasizes the quantum nature of the light pulse. A beautiful experiment at the single photon level has been reported by Kuzmich *et al.* (*12*). These applications (*3*, *12*) of "slow light" and quantum coherence combine both quantum interference and quantum correlation. The quantum interference created with EIT does not allow absorption of the signal photons, resulting in the production of correlated light sources.

The experiments reported by the two groups (*3*, *12*) demonstrate that production of quantum mechanically correlated photons can be combined with atomic memory. Such a technique may become an important new tool for preparing, storing, and manipulating quantum states of light, and has some points in common with the delayed-choice quantum eraser (see the second figure) (*13*).

The experiments can be understood as a two-step process. In the first step, an ensemble of atoms is illuminated by a weak, off-resonant light beam. This results in Raman scattering, which produces pairs of spin-flipped atoms and frequency-shifted photons (called Stokes photons). Energy and momentum conservation ensures that for each Stokes photon emitted in a particular direction, there exists exactly one flipped spin quantum in a well-defined many-particle spin-wave mode. In this sense, the two photons are strongly correlated. But whereas the Stokes photons rapidly leave the medium, the atomic spin coherence stores the correlations for a relatively long time (up to 1 μs). In the second step, the state of the spin wave is retrieved by coherent conversion of the atomic states into a different (anti-Stokes) photon beam. Thanks to EIT, the signal photons are not reabsorbed.



Quantum reading and writing. The elegant experiments by van der Wal *et al.* and Kuzmich *et al.* can be explained in terms of a delayed-choice quantum eraser. (**Top**) The write beam excites atom A or B (but is unlikely to excite both at once) from *g* to *s*, leading to spontaneous emission of a Stokes photon. The Stokes photons from A and B will not interfere because there is "which-way" information left in the atom (either A or B is in state *s*). After some time delay, the read laser (**bottom**) transfers the excited atom back to the ground state, resulting in the emission of an anti-Stokes photon. The Stokes and anti-Stokes photons are strongly correlated (they are "entangled"). Interference between Stokes photons from A (or B) is now restored, because the which-way information is erased. The object of such quantum reading and writing is quantum arithmetic.

Atomic memory elements may some day become important parts of quantum communication networks. The technique demonstrated in (*3*, *12*) represents a basic element of a promising approach recently proposed for long-distance quantum communication (*14*). Someday these ideas may be used—for example, for robust transmission of secret message over distances far beyond those that are possible today.

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