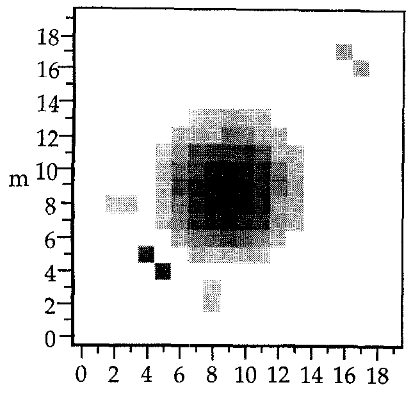
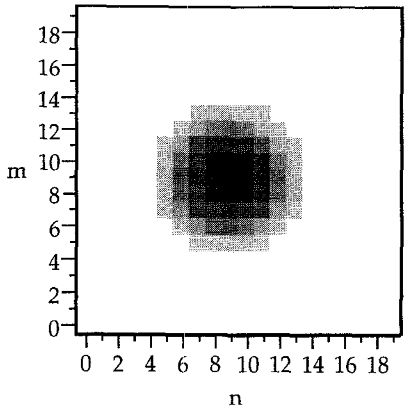


QWD9 Fig. 1 Reconstruction of the density matrix in the number state representation for a single molecular wave packet.



QWD9 Fig. 2 Actual density matrix in the number state representation for a single molecular wave packet.

wave packet in sodium dimer. These results were obtained by taking five different 10-ps (~30 vibrational periods) time series, $S(T, \Omega)$, each corresponding to a different value of Ω.

In addition to being able to reconstruct the density matrix of single wave packets, we believe this method is also capable of fully characterizing more complicated states such as the mesoscopic Schroedinger cat state.

**Fachbereich Physik, Universitat Rostock, Germany*

1. T. J. Dunn, I. A. Walmsley, S. Mukamel, Phys. Rev. Lett. **74**, 884 (1995).

QWD10

Optical pulse propagation at superluminal group velocities

Jason Bowie, Raymond Chiao, *Department of Physics, University of California, Berkeley, California 94720*

An optical pulse propagating through a linear medium is known from the Kramers–Kronig relations to have a group velocity that is superluminal when the pulse's carrier frequency is close to but outside of a gain line. Group velocities that are greater than c, negative or infinite, are found in a transparent window on either side of the gain line. The bandwidth of this window where superluminal group velocities occur is determined by an effective plasma frequency that can be defined as

$$\omega = \sqrt{g_0 \gamma c},$$

where g_0 is the peak gain at line center and γ is the bandwidth of the gain line. The observable effect that a superluminal group velocity has is that the peak of a pulse traveling through the gain medium arrives at a detector that is placed at the exit face of the medium before it would have arrived if it was propagating only through vacuum.

We are making measurements that demonstrate this effect using stimulated Raman gain in an optically pumped rubidium vapor cell. The Raman transition that is being used is between the two hyperfine levels in the ground state. An optical pumping beam tuned to the D_1 line is used to put all of the atomic population in the upper hyperfine level creating a population inversion, while another laser that is tuned just off resonance is used to generate the Raman gain. A pulsed probe laser beam that propagates collinear with the Raman pump laser is tuned such that its carrier frequency is just outside of the Raman gain line. Pulse propagation times are being measured for pulses that travel through the gain medium and are compared with pulses that travel through vacuum.

The goal of this work is to clarify the meaning of Einstein's dictum that no information can be communicated faster than c. In particular, we are demonstrating that among Sommerfeld and Brillouin's five wave velocities, the first four, the phase, group, energy, and "signal" (i.e., the half-maximum wave amplitude) velocities can in fact all be faster than c for wave packets propagating in a transparent spectral region near a gain line, but that only the fifth, the front velocity, does not exceed c. Thus the information velocity of special relativity, which must strictly be less than or equal to c, is the front velocity, but not the phase, group, energy, or "signal" velocities.

QWD11

Source of variable bunched light from a modulated diode laser

G. T. Foster, J. Gripp, S. L. Mielke, L. A. Orozco, *Department of Physics, State University of New York at Stony Brook, Stony Brook, New York 11794-3800*

The development of tunable sources of bunched light with variable correlation time is of great use in the study of quantum optical systems. It can open the possibility of the realization of non-Markovian systems of the kind theoretically pioneered by Carmichael[1] and Gardiner[2] in their studies of open quantum systems.

Diode lasers provide a tunable source of coherent light that can be directly frequency and amplitude modulated through the supply current. A commercial diode laser operating with strong grating feedback has a linewidth of less than 1 MHz at 780 nm. The frequency of the laser is tunable to the appropriate atomic transition of Rb for experiments in quantum optics. To realize the bunched source of light, we lower the intensity to close to threshold and then introduce a modulation from a broadband noise source.

We measure the correlation time of the light through the probability density of the time interval between successive photons. Two avalanche photodiodes (APD) send the start and stop signals to a time to digital converter. The intervals accumulate in memory. From the resulting histogram it is possible to extract the correlation function.

As we change the amplitude of the modulating noise source, we monitor the spectrum with a Fabry–Perot interferometer, while simultaneously measuring the correlation time. With no modulation our measurements show a flat distribution. The 1/e extent of the correlation function depends on the noise amplitude and permits the optimization of the bunched source for the cascaded experiments. This source can match the typical coherence times of alkali atoms in optical cavities used in present day cavity QED experiments.

This work is supported in part by NSF.

1. H. J. Carmichael, Phys. Rev. Lett. **70**, 2273 (1993).
2. C. W. Gardiner, Phys. Rev. Lett. **70**, 2269 (1993).

QWD12

Quantum chaos in mixed phase space: Beyond the delta kicked rotor

B. G. Klappauf, D. A. Steck, M. G. Raizen, *Department of Physics, The University of Texas at Austin, Austin, Texas 78712*

The experimental study of quantum chaos in atom optics has previously centered on quantum effects in a regime of classical phase space that is globally chaotic.[1,2] For these studies it was sufficient to use initial conditions consisting of a band in phase space, localized in momentum but uniformly distributed in position. The situation is more complicated for the generic case of a mixed phase space, characterized by islands of regular motion surrounded by regions of chaos. This direction of research presents important theoretical and experimental challenges. In this case, a band for the initial conditions will cause the dynamics of many different regions of phase space to be represented in the final distribution, making analysis and detailed study of the phase space structure difficult. Therefore, a mixed phase space requires initial localization in both momentum and position.

We report a new method for state preparation in phase space, relying on coherent interaction with far-detuned lasers. A selection process will prepare a subset of atoms from a magneto-optic trap into the lowest band of a periodic optical potential, resulting in localization of the initial momentum and position distribution. Additional spatial localization is possible by adiabatically deepening the wells. This initial condition is ideal for the study of quantum transport in mixed phase space. Our research plans include the study of tunneling from islands of stability in mixed phase space, and the effects of unstable fixed points on transport. We have analyzed the appropriate conditions for conducting these experiments with cesium. Experimental progress will be reported.

1. F. L. Moore, J. C. Robinson, C. F. Bharucha, Bala Sundaram, M. G. Raizen, Phys. Rev. Lett. 75, 4598 (1995).
2. Graham P. Collins, *Physics Today*, June 1995, p. 18.

QWD13

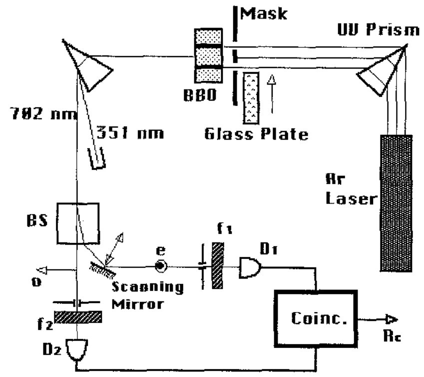
Three-phase biphoton interference

D. V. Strekalov, D. N. Klyshko,* S. P. Kulik,*
Y. H. Shih, *University of Maryland, Baltimore County, 5401 Wilkens Avenue, Baltimore, Maryland 21228*

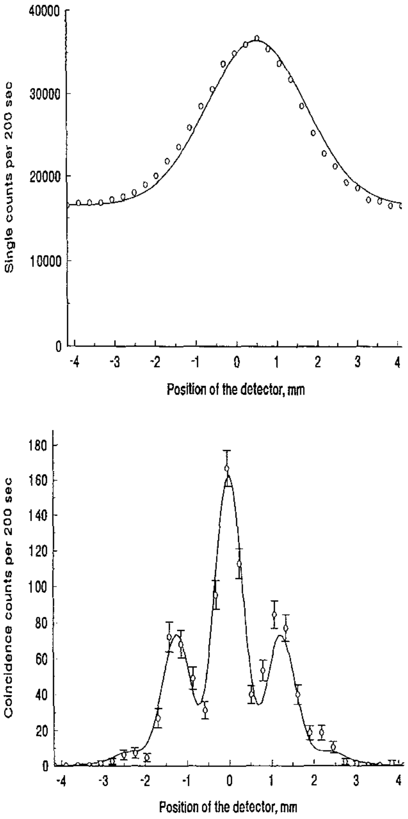
Parametric downconversion is a nonlinear optical process in which three fields are involved: pump, signal, and idler. The signal and idler separately may have fairly large uncertainty of frequencies and momenta, but if one frequency or momentum is measured, the other one is known with certainty because of the phase matching conditions whose physical meanings are momentum and energy conservations. In addition, the signal and idler pair was also shown to "remember" the phase of the pump photon.

We demonstrate experimentally that it is the two-photon wave packet, or a biphoton, that "remembers" the phase of the pump, and the interference fringes depend on the manipulations of three phases: the pump phase and two phases of the biphoton. (The biphoton wave packet has two dimensions in time and thus has two phases.) It is interesting that interference is to be expected even though all three interacting waves are in general of different colors.

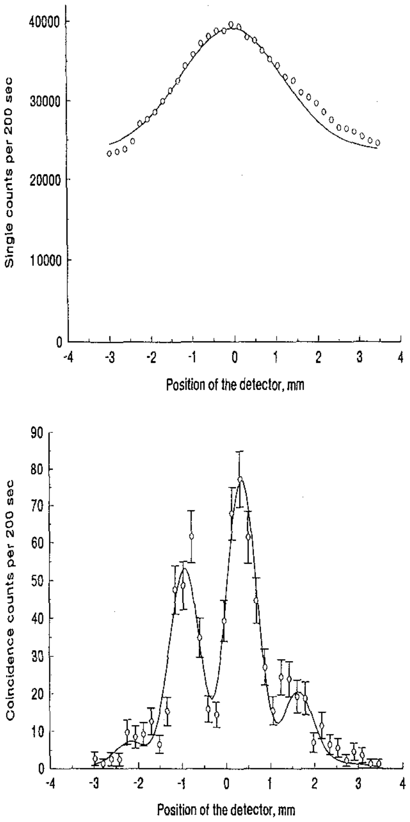
We observed this type of interference using the setup shown in Fig. 1. The signal and idler collinearly emitted from a downconverting crystal pumped through a two-slits mask are sent into two detectors. Scanning one of them across the beam, a typical Young's interference pattern is observed in coincidences (single counting rates display no interference), which is a *sinc* envelope filled with sinusoidal modulations (Fig. 2). If a glass plate is placed in front of one slit of the mask, such that it shifts the pump phase by approximately π, the envelope remains the same but the filling sine shifts by also approximately π.



QWD13 Fig. 1 Experimental setup. The type-II downconverting crystal BBO is illuminated by the pump through two slits of a mask. One of the slits can be covered with a glass plate. The orthogonally polarized signal and idler are emitted collinearly, and have the same wavelength. They are split by a polarizing beamsplitter BS and sent to detectors D_1 and D_2. Instead of moving detector D_1, we scan a mirror by an encoder driver.



QWD13 Fig. 2 Experimental result. Left: number of counts by D_1 per 200 s as function of its transverse position. Right: number of coincident counts per the same time normalized to the counting rate of D_1.



QWD13 Fig. 3 Same as Fig. 2, but the glass plate covers one slit of the mask.

A simple qualitative explanation of what is going on is that the two photon can be created in either one of the illuminated regions of the crystal, so there are two biphoton amplitudes of getting a coincidence. Their relative phase is proportional to the path difference from one detector to the other through two slits. Interference pattern is observed in coincidences as we vary the path difference by scanning position of D_1.

The "pump phase memory" is observed when we change the pump phase on one slit with respect to the other by inserting a glass plate. Then the biphoton amplitude corresponding to that slit "remembers" the pump phase shift, as can be clearly seen comparing Figs. 2 and 3. Hence, the observed interference fringes reveal coherence properties of the pump without ever sending it to interferometer. It is important to understand that it is the biphoton wave packet that carries information about the pump, not the signal and idler individually. This supports our point that a consistent description of such type of phenomena is given in terms of two-photon amplitudes as opposed to two single-photon amplitudes.

Physics Department, Moscow State University, Moscow, Russia

1. Z. Y. Ou, L. J. Wang, X. Y. Zou, L. Mandel, Phys. Rev. A 41, 566 (1990).

QWD14

Laser guiding of atoms in a dark hollow beam

J. P. Yin,* H. R. Noh, K. I. Lee, J. A. Kim,
W. H. Jhe, Y. Z. Wang,** *Department of Physics, Seoul National University, Seoul 151-742, Korea*

In recent years, two kinds of atomic waveguiding schemes that use hollow optical fibers have been proposed and studied, both theoretically[1–3] and experimentally.[4–6] One is a laser waveguide of atoms in a large hollow optical fiber by use of a Gaussian beam with the red detuning[1,4]; Another is evanescent-wave guiding of atoms in a small hollow fiber by means of a evanescent-wave field with the blue detuning.[2,3,5,6] In 1996 Russian scientists Balykin *et al.*[7] proposed a third scheme to waveguide ultracold atoms from a MOT by use of an evanescent-wave field with the blue detuning in a curved hollow convergent optical waveguide. Theoretical analysis shows that this method can further cool atoms and increase the phase density of atoms.

Recently we generated a dark hollow beam (DHB) with a small dark spot by using