as the atom moved outside the cavity. Thus, as the atom changed position, it altered the resonant frequency of the atom–photon interaction, which in turn affected the transmission rate of photons through the cavity. In that way, the transmission intensity could neatly track the radial position of the atom.

The Caltech–Auckland experimenters monitored the intensity of the photons coming out of the cavity by a heterodyne detection scheme, whereas the Garching researchers detected the individual photons. Both experiments began with the photon field in the cavity well below an average occupancy number of one, just enough to sense the arrival of a single atom. That signal triggered an increase in the laser intensity in the cavity, trapping the atoms with the higher fields for average times on the order of a few hundred microseconds.

Working backward

Because the photon transmission rate depends on the atom's radial position, the Caltech–Auckland team developed an algorithm for working backward from the measured transmission to determine the actual atomic orbit, which was predominantly in the transverse plane. Reconstruction was possible only because of the strong coupling provided by the single photon field. The dipole coupling force, which conserves the atom's orbital angular momentum, exceeds more diffusive forces, which change the angular momentum. By extensive measurements and simulations, Kimble and company have carefully verified that the angular momentum does indeed vary slowly along the orbits.

The bottom figure on page 20 shows one such reconstruction, which has a spatial resolution of about 2 μm over a 10-μs time period. Of course, the real atom orbits can't be viewed by any existing technique, so the Caltech–Auckland group checked its calculations by thorough comparison with the simulated motion of atoms. With each simulated trajectory, the team calculated the transmission intensities one might expect for such trajectories. Finally they applied their inversion algorithm to the simulated transmission data to infer the original orbits. The procedure fails to work well when the atom has little or no angular momentum, but the experimenters know ahead of time which cases those are. In about 90% of the reconstructions they tried, the inferred trajectories came close to the simulated ones. Feedback schemes should put their reconstructions to the most stringent test yet.

The Caltech collaborators have recently done extensive modeling of the atomic trajectories both in their experiment and that of the Garching group, in part studying the extent to which the light-induced forces in the strong coupling regime are distinct from their free-space counterparts.[6]

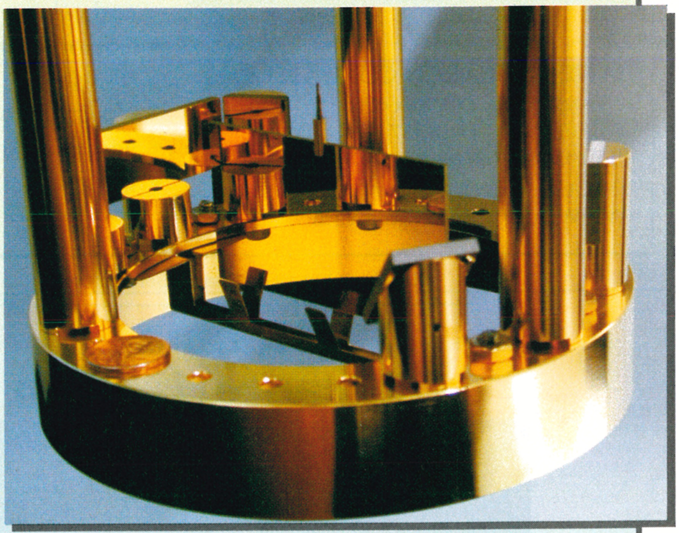
Right now, Kimble and company can treat the atom essentially as a classical particle, but as the resolution of their measurements increases, the quantum nature of the atomic motion will become increasingly important. That challenges theorists

Our Knowledge of *G* Gets Worse, Then Better

The precision with which we know a fundamental constant usually gets better with the passing years. Just the opposite, however, was happening recently to *G*, Newton's gravitational constant. In 1987, CODATA, the international arbiter of metrology, was quoting an uncertainty of ± 128 parts per million for *G*, the most poorly known of the fundamental constants. But then things got even worse. Several recent measurements have given values many standard deviations outside these limits, forcing CODATA to *increase* its assigned uncertainty to ± 1500 ppm for the latest compilation.

What was needed, obviously, was a new way of beating down the systematic uncertainties that have long plagued the torsion-pendulum experiments descended from Henry Cavendish's pioneering measurements in the1790s. Jens Gundlach and Stephen Merkowitz at the University of Washington have taken up this challenge. At the spring APS meeting in Long Beach, California, they reported a preliminary new value of *G* with an uncertainty of only 14 ppm. They find that $G = 6.674215 \pm 0.000092 \times 10^{-11}\ \mathrm{m^3/kg\ s^2}$.

Their torsion pendulum, shown below, is a mirrorlike gold-coated Pyrex rectangle hanging from an almost invisible torsion fiber and surrounded by other mirrors for a laser system that monitors any twisting. Slowly rotating on a turntable past a surrounding array of 8-kg steel balls (not shown here), the pendulum feels a periodic gravitational torque. Traditionally one measures the twisting of the pendulum as its turntable rotates uniformly past the stationary attracting balls. The most innovative feature of the new experiment is intended to eliminate uncertainties due to the torsion fiber's nonlinear response: The optical monitoring system controls a feedback mechanism that accelerates the rotation of the pendulum turntable in response to the periodic torques, thus minimizing the actual twisting of the fiber. The requisite acceleration of the turntable becomes the principal signal.



Furthermore, the array of steel balls is uniformly rotated in the opposite direction on a faster, collarlike turntable of its own, to average out the effects of any unintended environmental anisotropies and also to reduce $1/f$ noise by increasing the signal frequency. Another innovation is the pendulum's simple rectangular geometry, designed to minimize the system's sensitivity to unknown higher multipoles of the pendulum's mass distribution.

Others who measure gravity in the laboratory are certainly seeking confirmation of this claimed tenfold reduction in the uncertainty of *G*. At the same time, the experimenters are also gearing up to look for the departures from $1/R^2$ Newtonian falloff at millimeter distances predicted by string theorists trying to explain why gravity is so much weaker than any other force.

Bertram Schwarzschild