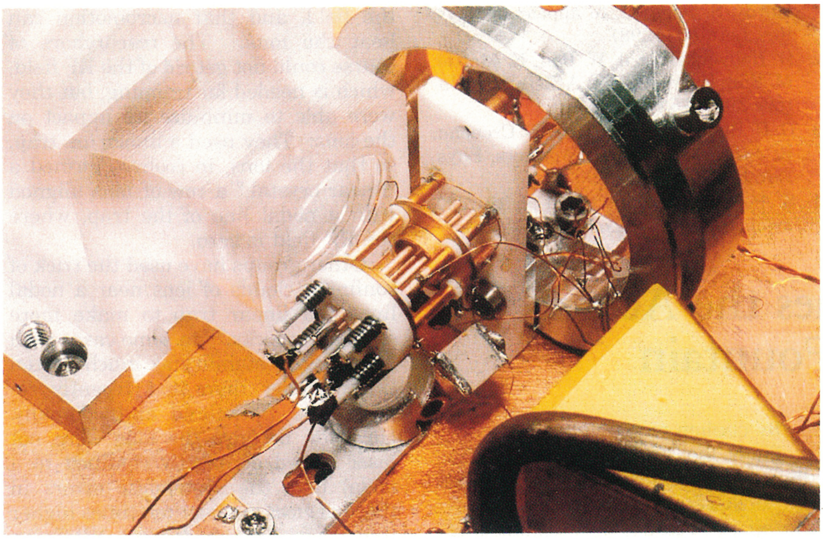

COOLED-ION CLOCK with its cover removed. Mercury ions are trapped and laser cooled to lie along a nodal line of the RF field generated by four electrodes—the innermost set of rods protruding from the far side of the alumina support disk. (The disk is about 1 cm in diameter.) A lens (upper left) views the trap, and radiation pulses from the microwave horn (lower right) drive the hyperfine transition. All the components are enclosed in an evacuated pillbox container and cooled by contact with a liquid helium reservoir. (Photo courtesy of the National Institute of Standards and Technology, Boulder, Colorado.)

more accurate the clock.

In the atomic-beam device, the time between pulse measurements can be no longer than the transit time of the atom through the device, which is on the order of 10 to 20 milliseconds; there is no practical way to lengthen this transit time. The real advantage of the atomic fountain over the atomic beam is its longer sampling time of about one second. In an atomic fountain, first built at Stanford in 1989 (see PHYSICS TODAY, December 1997, page 17; see also page 15 in this issue), operators cool a cloud of cesium atoms and then project them upward. The first Ramsey pulse occurs when the atoms cross a microwave cavity on the way up and the second when they pass through the same cavity on the way down.

Salomon told us that he and his colleagues in Paris feel that the accuracy of their atomic fountain can be improved by a factor of ten over its present value of 2×10^{-15}, and that it is realistic to expect this much improvement in the coming year. They are building another atomic fountain that, they hope, will incorporate these improvements. They will compare the new clock to their existing fountain as a benchmark. A number of other standards groups around the globe are also building atomic fountain clocks.

The measurement time in a cryogenic ion trap is limited in practice only by the length of time the ions can remain in the trap and be stable against heating. In their recent experiment, the NIST researchers saw no heating during their 100-second measurement periods.

As with the atomic fountain, several groups are working on an improved cooled ion timekeeper. But, as we were told by Robert Drullinger, who operates the atomic beam clock at NIST's Boulder facility, lots of real-world gremlins stand in the way of improved accuracy in any of these clocks.

Toward the optical

Researchers eventually expect to develop clocks based on atomic transitions in the visible range. Many atoms have narrow linewidths in this higher frequency region, and a clock based on one of these transitions should be more stable than one with a microwave transition because the stability is inversely proportional to the frequency. But two factors inhibit the move in this direction. One is the lack of lasers stable enough to realize the narrow linewidths that some atoms have in the optical region of the spectrum. The other is the lack of a way to convert from a measurement of frequency to an interval of time. The basic unit of time is currently defined as the duration of a certain number of oscillations of the cesium atom. With a visible light source, there would be orders of magnitude more cycles per second, and there are currently no electronic devices that allow us to count that fast.

Progress was made recently in low-

Space Clock to Fly on the International Space Station

A major role of the national standards labs is to keep the world's clocks running on the proper time. That means making a continual comparison of the primary clocks that are used as the standards. But some of the accuracy achieved in a given lab's measurement of time is lost as that information is communicated to another location on Earth's surface. As good as it is, the Global Positioning System (GPS) system (which at its best enables comparison of clocks with accuracies of 10^{-14}), is becoming a weak link in this relay of information.

Thus, both a French group and a US group hope to build a space clock that will fly on the international space station. Scientists at the various national standard labs could compare their clocks to this standard as it flew overhead. The clock would be similar to a beam clock, with cooled atoms being given a small kick to start them traveling down the measurement path.

The institutions involved in the French space clock include the Ecole Normale Supérieure (ENS), the Laboratoire Primaire de Temps et Frequences, the Laboratoire de l'Horloge Atomique and the Centre National d'Etudes Spatiales. Christophe Salomon of ENS told us that researchers in this collaboration have tested a prototype in a microgravity environment: The clock was flown on an aircraft that was executing a free-fall parabolic trajectory at an altitude of 8–10 km. The European Space Agency has approved the flight of this instrument on the international space station, sometime around 2002.

A US group based at the National Institute for Standards and Technology's facility in Boulder, Colorado, is also launching a space clock development program, thanks to recent funding from NASA.

A space clock is intended to make the most accurate primary standard available to all the world, according to Don Sullivan of NIST, the principal investigator for the NASA project. He also told us that it could be used for gravitational measurements such as an improved determination of the gravitational red shift, and that it might also provide for more accurate determinations of the orbits of GPS satellites. Salomon mentioned the possibility of searching for a drift in the value of the fine structure constant, which is conjectured by some recent theories.

BARBARA GOSS LEVI