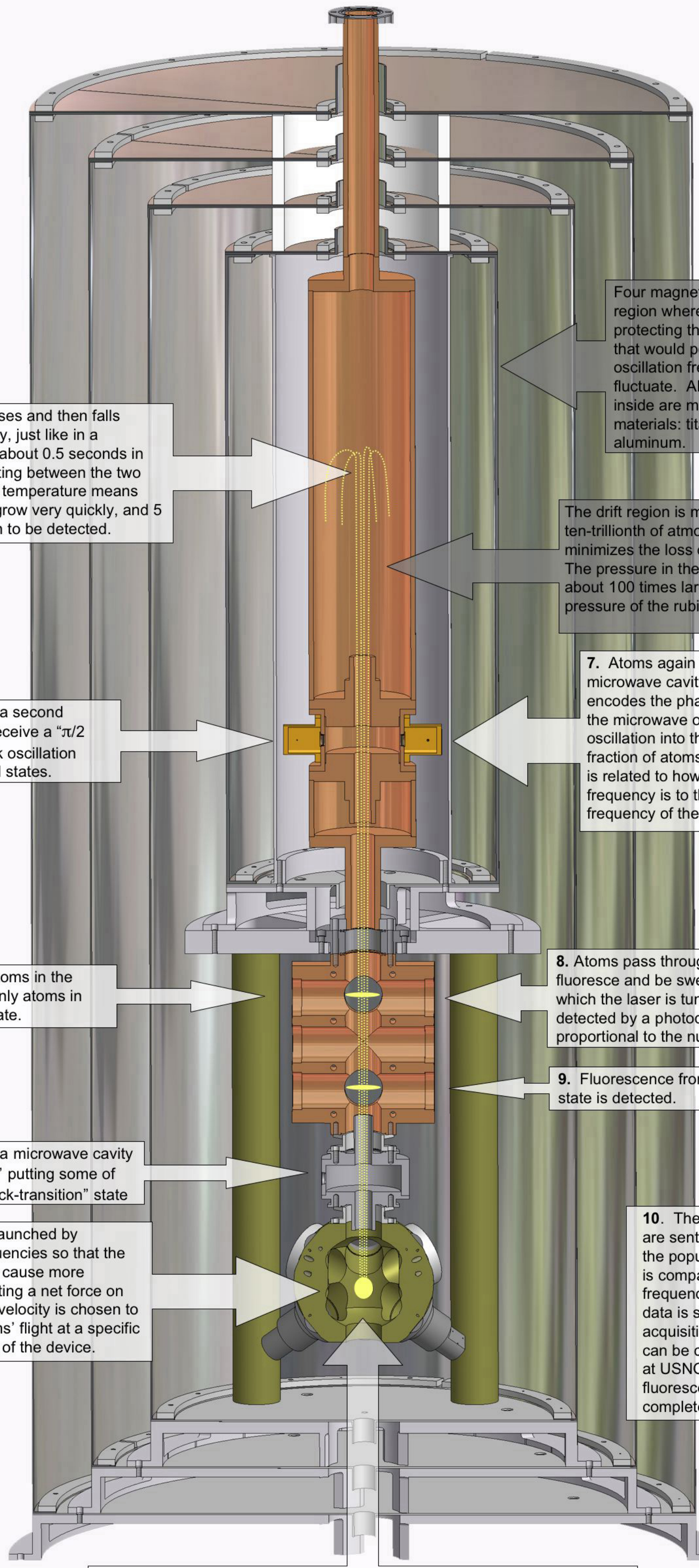
USNO Rubidium Atomic Fountain

Atomic fountains are improvements of the "physics package" of an atomic-beam clock. By measuring the atoms' oscillations for a longer period of time a more precise measurement can be made. This is difficult to do in the horizontal geometry of a beam clock.

Below is a cutaway view of the fountain and a step-by-step description of the operation of the fountain, and some other important features of the device. Not shown are the supporting electronics and laser systems, which are housed in two equipment racks.



Four magnetic shields surround the region where the atoms oscillate, protecting them from any external field that would perturb them and cause the oscillation frequency to change or fluctuate. All of the metal components inside are made of nonmagnetic materials: titanium, copper, brass or aluminum.

6. The cloud of atoms rises and then falls under the force of gravity, just like in a fountain. Atoms spend about 0.5 seconds in the "drift region," oscillating between the two ground states. The low temperature means the atom cloud will not grow very quickly, and 5 - 10% of them will return to be detected.

The drift region is maintained at about one ten-trillionth of atmospheric pressure. This minimizes the loss of atoms due to collisions. The pressure in the trapping chamber is about 100 times larger, due to background pressure of the rubidium.

7. Atoms again pass through the microwave cavity. The interaction encodes the phase difference between the microwave oscillation and the atoms' oscillation into the atomic states. The fraction of atoms in each of the two states is related to how close the microwave frequency is to the actual transition frequency of the atoms.

5. Atoms pass through a second microwave cavity and receive a "$\pi/2$ pulse," starting the clock oscillation between the two ground states.

8. Atoms pass through a laser, and will fluoresce and be swept out if in the state to which the laser is tuned. This fluorescence is detected by a photodetector, and is proportional to the number of atoms.

4. Lasers sweep out atoms in the wrong states, leaving only atoms in the "clock-transition" state.

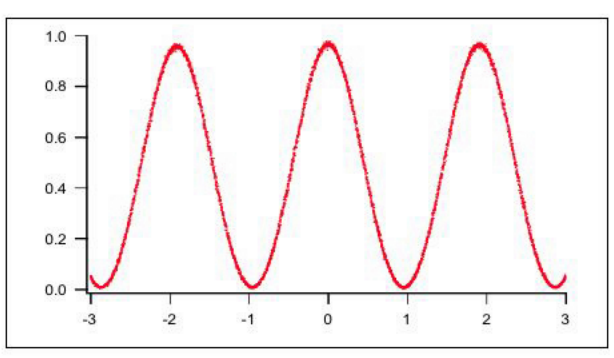
9. Fluorescence from the atoms in the other state is detected.

3. Atoms pass through a microwave cavity and receive a "π pulse," putting some of them in the desired "clock-transition" state

10. The fluorescence signals are sent to a computer, where the population of the two states is compared and the microwave frequency is calculated. This data is sent to a central data acquisition system, so the clock can be compared to other clocks at USNO. Immediately after the fluorescence detection is complete, the next cycle begins

2. The atoms are then launched by changing the laser frequencies so that the upward-directed beams cause more photons to scatter, exerting a net force on the atoms. The launch velocity is chosen to put the apex of the atoms' flight at a specific height in the drift region of the device.

1. Rubidium atoms are slowed and trapped by six counter-propagating lasers (two fiber collimator assemblies are shown in black) which cool the atoms to a few millionths of a degree above absolute zero.



"Ramsey Fringe" data from an atomic fountain. The vertical axis represents the fraction of atoms in one of the two ground states, and the horizontal axis is the frequency difference from resonance. As the microwave frequency is changed (**5,7**) the fraction of atoms in each state changes, changing the fluorescence signal (**8,9**) and allows the relative frequency of the microwaves to be calculated (**10**). This set of fringes is measured by scanning the microwave frequency; normally this is fixed at some value.

The spacing between resonances (peaks) is approximately 2 Hz, which is a direct result of the atoms spending about 0.5 seconds in the drift region (**6**). This means that by knowing the ratio of the two state populations, in a single measurement the frequency can be determined to about a thousandth of 1 Hz out of an oscillation frequency of 6.8 GHz (billions of cycles per second), or a few parts in 10^{13} (ten trillion). By continuing to make and average these measurements, the precision can be improved to several parts in 10^{16} (ten quadrillion).