Quantum Sensors in Weighlessness

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Abstract—Gravity is considered as a fundamental limit to a large panel of experiments with ultra cold quantum gases and space missions [1], [2] are considered to reach extremely low temperature and long interrogation time inaccessible to terrestrial laboratories. This is particularly relevant for quantum technology based cold-atom interferometers that hold great promise for inertial sensing applications in geophysics or fundamental tests of general relativity. We present our Earth-based microgravity operated quantum sensors using a new simulator that can produce all optical BEC of $10^4$ at 15 nK every 12 s with an observation time of 500 ms in micro-gravity.

I. THE EXPERIMENT

Our experiment is designed specifically for mobile applications and inertial sensing in microgravity [3]. The vacuum system is a hollowed Rhombicuboctahedron. All the 780 nm light (colling and Atom interferometry beams) is produced by a single 1550 nm diode in a all fibered master-slave architecture. We use an Electro-Optic Modulator to produce sidebands at 1550 nm for the repumping light and the interferometry beams. After amplification the laser is frequency doubled through a PPLN and split in three different paths for the MOT beams, Raman Beams and imaging beam. When operated on the microgravity simulator, the apparatus is set on a platform supported by two chariot on air bearings sliding on two marble stages. The plate can then be set in motion using two linear motor fixed on the pillars. Pistons attached to each side of the plate create the gravity compensation during the motion, which is controlled to follow a well-defined acceleration profile: the acceleration increases from 1 g to 2 g in 250 ms, then goes down to 0 g in 150 ms before the parabola begins. The deceleration of the apparatus is done in a symmetrical way. The simulator then needs to cool down before launching a new sequence in about 12 seconds (Fig. 1).

II. ULTRACOLD ATOMS AND INETERFEROMETRY IN MICROGRAVITY

For our atom interferometer, we create a sample of ultracold atoms by first loading $10^8$ 87Rb atoms in a Magneto-Optical Trap (MOT). The atoms are then sub-Doppler cooled in two steps: first a short stage of red detuned optical molasses followed by grey molasses on the D2 line [4]. Atoms are then transferred in an optical dipole trap (Fig. 1) using 23 Watts of 1550 nm light. An Acousto-Optic Modulator (AOM) is modulating the amplitude and the position of the 35 µm waist. About $10^7$ atoms are loaded in the dipole trap thanks to the position modulation of the waist, leading to an effective capture volume of radius 200 µm. The atomic cloud is then adiabatically compressed by ramping the spatial modulation down to zero while increasing the laser power from 5 Watts to 20 W in 50 ms. We then start the evaporation by reducing the power by 1:400 in three steps during 2.9 seconds to reach BEC with $10^4$ atoms at 15 nK. We optimized the cooling sequence so that most of the evaporation happens during the acceleration and deceleration before the parabola to optimally use the full microgravity time.

Atom interferometry is achieved by using double diffraction [5] since in weightlessness and with ultracold atoms, when the resonance conditions for Raman diffraction is satisfied, the two pairs of contra-propagating Raman beams couple the initial state $|1,0\rangle$ to the two states $|2,±2\hbar k\rangle$. Preliminary experiments allowed us to test atom interferometry in 0-g with this technique (Fig. 2).

REFERENCES