An Iodine-Based Ultra-Stable Optical Frequency Reference and its Application in Fundamental Physics Space Missions

Thilo Schuldt[1], Johannes Stühler[2], Klaus Döringshoff[3], Julia Pahl[3], Evgeny V. Kovalchuk[3], Matthias Franz[2], Ulrich Johann[4], Achim Peters[3], Claus Braxmaier[1,5]

[1]German Aerospace Center (DLR), Institute for Space Systems, Bremen, Germany
[2]University of Applied Sciences Konstanz (HTWG), Konstanz, Germany
[3]Institute for Physics, Humboldt-University Berlin, Germany
[4]Astrium GmbH – Satellites, Immenstaad, Germany
[5]Center for Applied Space Technology and Microgravity (ZARM), University Bremen, Germany

Email: thilo.schuldt@dlr.de

Over the last years, an iodine-based frequency reference for future potential applications in space was developed. Based on a state-of-the-art laboratory setup using modulation transfer spectroscopy, design criteria for space compatibility were taken into account, yielding to setups on elegant breadboard (EBB) and engineering model (EM) level. Both setups use a baseplate made of glass material in combination with a dedicated easy-to-handle assembly-integration technology (adhesive bonding). These setups ensure high pointing stability of the two counter-propagating laser beams in the iodine cell and therefore high long-term stability. Compactness and robustness were main design drivers. While the EBB setup uses a commercial off-the-shelf 30 cm long iodine cell in triple-pass configuration, the EM setup utilizes a specifically designed and manufactured compact iodine cell made of fused silica in a nine-pass configuration with a specific robust cold finger design (cf. Fig. 1). Both setups achieve similar frequency stabilities of about $1\cdot10^{-14}$ at an integration time of 1 s and below $5\cdot10^{-15}$ at integration times between 10 s and 100 s. These values are comparable to the currently best laboratory setups.

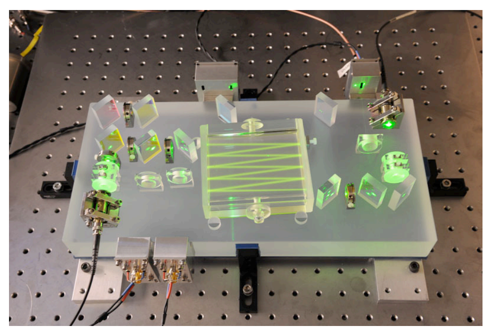

Fig. 1: Photograph of the spectroscopy unit realized on Engineering Model level. The baseplate made of fused silica has dimensions of 380x180x40 mm^3.

Space applications of such an optical frequency reference can be found in fundamental physics, geoscience, Earth observation, navigation and ranging. One example is the proposed mSTAR (mini SpaceTime Asymmetry Research) mission, dedicated to perform a Kennedy-Thorndike experiment on a satellite in a low-Earth orbit. By comparing an iodine standard to a cavity-based frequency reference and integration over 2 year mission lifetime, the Kennedy-Thorndike coefficient will be determined with up to two orders of magnitude higher accuracy than the current best ground experiment.

Financial support by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant numbers 50 QT 1102 and 50 QT 1201 is highly appreciated. The authors thank Jan Hrabina and Josef Lazar from the Institute of Scientific Instruments of the Academy of Sciences of the Czech Republic, Brno, for fruitful discussions on the realization of the multipass iodine cell.