EPIC Online Technology Meeting on Atomic Clocks and Quantum Sensors

E. Murphy ESA, ESTEC
Eamonn.murphy@esa.int

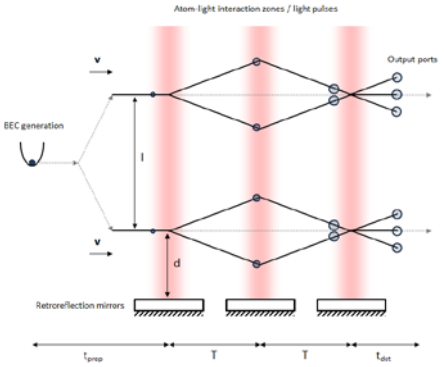
O. Carraz ESA, ESTEC

April 3, 2020

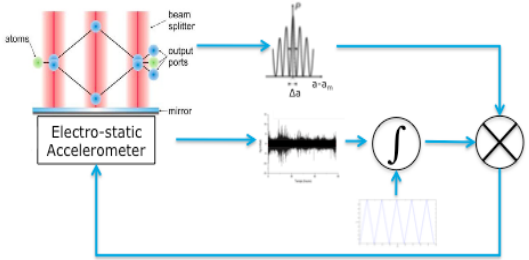
Matter-Wave Interferometer for EOP

Concepts for Earth Geodesy

1. MWI interleaved gravity gradiometer

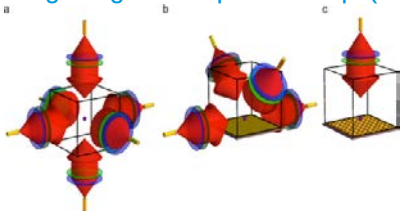


2. Hybridization classical accelerometers/MWI

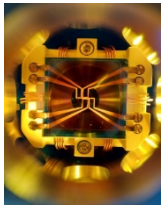


Hardware development

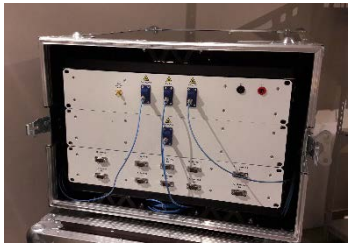
1. Grating Magneto Optical Trap (MOT)



2. Atom Chip for fast BEC

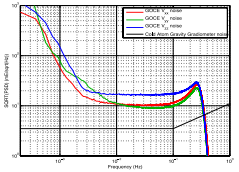


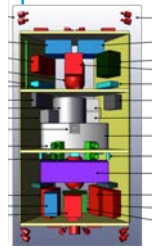
3. Agile and compact laser system for MWI

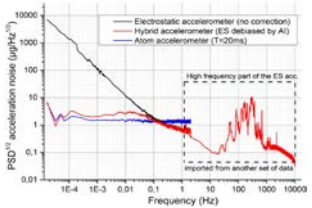


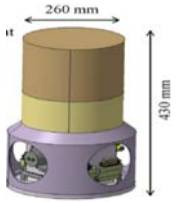
Results

1. Mission and instrument concepts validated

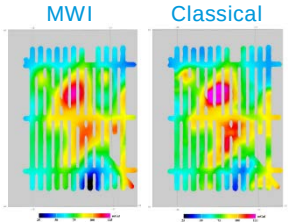




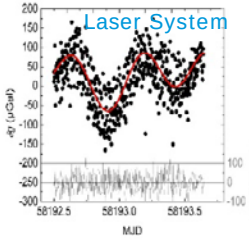




2. On-ground validation



Airborne campaign



Eamonn Mur

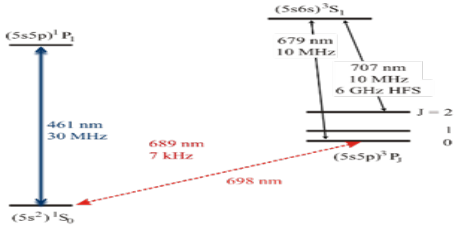
Optical Atomic Frequency Standard for TEC

Optical Atomic Clocks

^{133}Cs, ^{87}Rb, ^{1}H — Al^{+}, Hg, Sr, $Sr^{+/2+}$, ...

Microwave frequencies → x 10^5 → **Optical frequencies**

1 - 10 GHz ~ 500 THz



Relevant energy levels and transitions Sr

Optical clocks 4.8 x 10^{-17} stability in 1s
(Oelker *et al.*, Nature Photonics, 2019)

Hardware development

1. Optical Stabilising Reference Cavity
- 30Hz/Hz-1/2
- Passed Environmental tests (TRL6)
  - Thermal-Vacuum
  - Shock
  - Vibration (sine and random)
  - Radiation

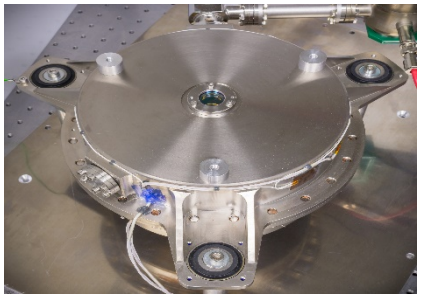
2. Cooling & trapping lasers
- 461nm Solid State laser 150mW
- 689nm DPSSL

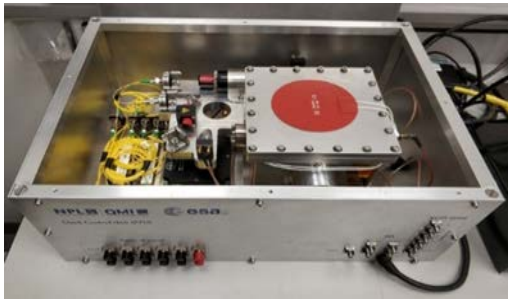
DPSSL to cover all red wavelengths
- 813nm Lattice laser

Ti3+:Sapphire VBG

3. Clock Control Unit CCU
- *Wavemeter-mode 7 wavelengths*
- *Adjustable duty cycle (chopper mode)*
- *Drift correction mode*

Results





Ongoing & Future plans

Ongoing Developments

Refinement of Laser Systems into a fully integrated system [TRL 6]
- Provide all required laser wavelengths
- Achieve short-term bandwidth needs
- Thermo-Mechanical system modelling to manage variable heat loads
- Explore alternative wavelengths

Environmental validation of CCU [TRL6]
- FEA refinement of design
- Full Digital control of functions

Cavity development for Sr [TRL6]
- Implement vacuum improvements
- Novel thermal shielding concept

Compact laser system for MWI
- Space qualification of Rb laser optics
- Laser electronics for space

Technology Roadmap

G-MOT for Strontium
- Implement for blue & red MOT's

Demonstrate Optical / Hybrid G-MOT Rb BEC
- Achieve rapid BEC cycle
- Phase control on beam (EPIC)

Novel Atomic Reference Units (ARU)
- To reduce complexity on sub-systems
- "Active" Optical Clocks

Kerr frequency combs
- SiN and crystalline platforms

Explore Fully Integrated Photonic solutions
- Exploit SiN platform

(NIST demonstrated on Rb transition)

Frequency dissemination infrastructure
- Enhance performance
- Align with QCI?

Road to Space

Development of subsystem components to high TRL [6/7] (2021-2024) (ALL)

Phase 0 study for instrument concept, mission concept and techno demonstrator concept (2015-2020) (MWI)

Flight Opportunity as SmallSat payload to verify scientific goal (Engineering) as demonstrator mission
- SpaceRider on Vega-C
- AN Other

QT inertial sensor demonstrator opportunity: 2023+
Enabling long term mission for a MWI gravity mission: 2030+

Implement initiative for both Sr and Rb to establish foundation for successful Flight development program.