Agenzia Spaziale Italiana

Community Workshop on Cold Atoms in Space

ASI activities in Quantum Tech

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Italian Space Agency

Introduction

- Quantum technologies are becoming more and more appealing for different space domains: sensing/metrology, computing and simulation, communication, fundamental physics
- Quantum space gravimetry is a crucial technology in improving remote measurements of the mass distribution of Earth and monitor the mass transport processes
- ASI initiatives on quantum gravimetry concepts started in 2016, strong interest expressed from IT Academia and Industry

Introduction

R&D activities in photonics and quantum have an impact on different domains: metrology and sensing, computing, communications, cryptography and they are considered a strategic asset.

Quantum space gravimetry is a crucial technology in improving remote measurements of the mass distribution of Earth and monitor the mass transport processes

ASI initiatives on quantum gravimetry concepts started in 2016, strong interest expressed from IT Academia and Industry

R&D activities

Quantum technologies are an important pillar of ASI technology developments programme:

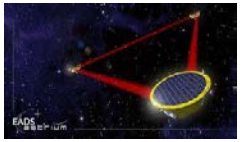
- Development of innovative technologies (entanglement, multiple operative frequencies, miniaturize, ruggedized, modular and flexible components)
- Feasibility studies to develop systems and payloads even for technology evaluation purposes in space;
- Specific agreements with other National research centres (as CNR, INRIM, SSSA, Universities)

Advances in laser science renewed several space applications based on different technology

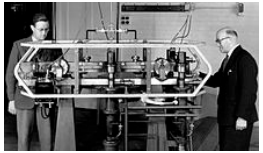
Radio comm

Optical comm

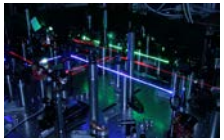
radar



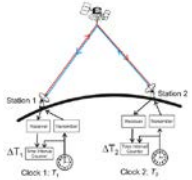
Optical interferometry and velocimetry



Caesium clocks



optical clocks



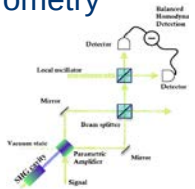
microwave TF transfer

optical link for TF transfer

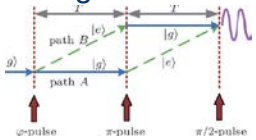
Advent of QT has paved the way to QT for space-based systems

satellite quantum communication

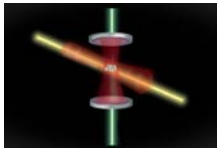
quantum enhanced interferometry



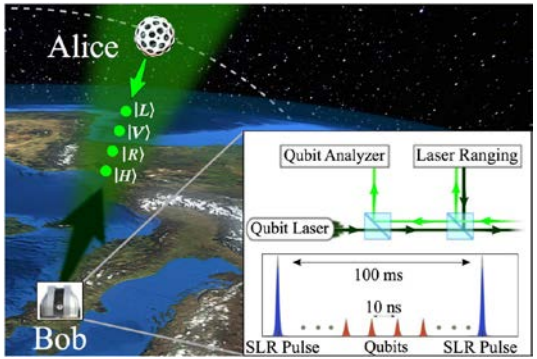
cold atom interferometry based gradiometers

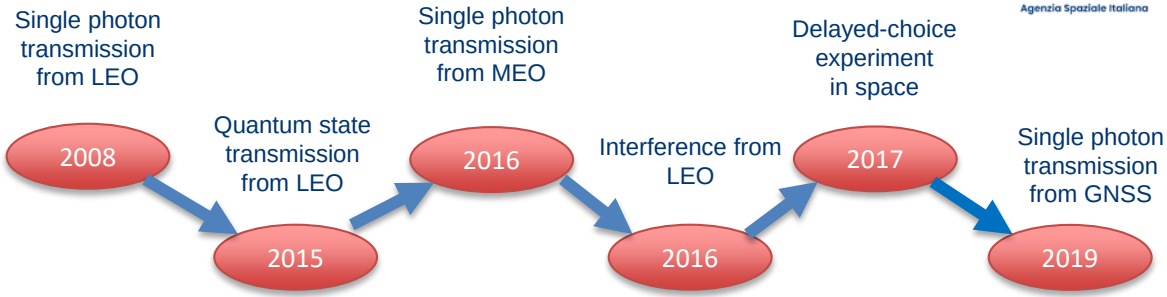


quantum enhanced optical clocks



Quantum communication @MLRO





- The Matera Laser Ranging Observatory (MLRO) is a class 1.5 m telescope, designed for satellite laser ranging.
- Since 2006 MLRO has been used for test toward satellite quantum communication (passive mode: retroreflectors and active mode: first Micius test).

The underlying idea is exploiting reflector on board of satellites to simulate a single photon sources.

Recent activities

- 2020: Upgrade of the MLRO telescope and develop of a fully operative QKD receiver for BB84 QKD

Phys. Rev. Lett. 115, 040502 (2015)
Quantum Sci. Technol. 4 015012 (2019)

Quantum communication payload development

2017, technological developments and ground testing of the receiver and transmitter of a Quantum Key Distribution (QKD) were started, in particular:

- On board Design optimization of QK transmitter
- High performance rugged quantum state transmitter
- Integrated silicon photonic chip for QK transmitter e Quantum Random Number Generator (QRNG)

Fondazione INPHOTEC
Integrated Photonic Technologies Center

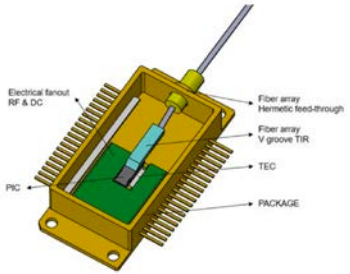
Institute of Communication, Information and Perception Technologies
Scuola Superiore Sant'Anna

ASI Agenzia Spaziale Italiana

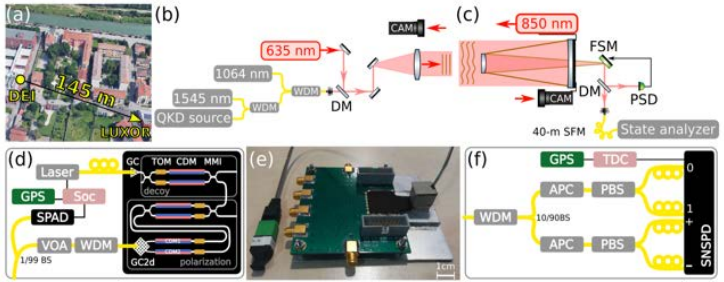
Dipartimento di Fisica e Astronomia Galileo Galilei

Università degli Studi di Padova
Dipartimento di Ingegneria dell'Informazione

PNTLab Photonic Networks&Technologies



Integrated silicon photonics



Experimental demonstration day and night

I-QKD: IOV for satellite QKD system

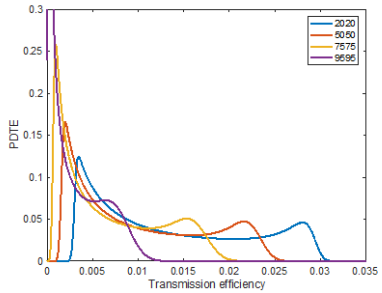
- 2020: a **space qualified** packaged transmitter & QRNG (in a Integrated silicon photonic technology) developments are ongoing and the validation of the technology is planned within 2 years
- 2020: a **space qualified** bulk transmitter development in a classical technology is ongoing

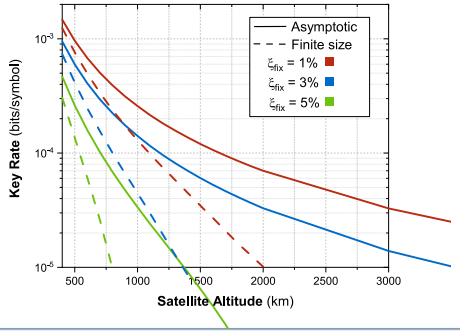
- 2020, a mobile optimized ground station for quantum key exchange is under development (telescope, receiver, protocols etc…)
- 2021 Upgrade of the MLRO telescope to receive quantum communication is ongoing, in particular QK exchange

Exploring other protocols: CV feasibility

Continuous Variable (CV) QKD could increase QKD performances by using standard telecommunication devices (modulator and coherent receivers).

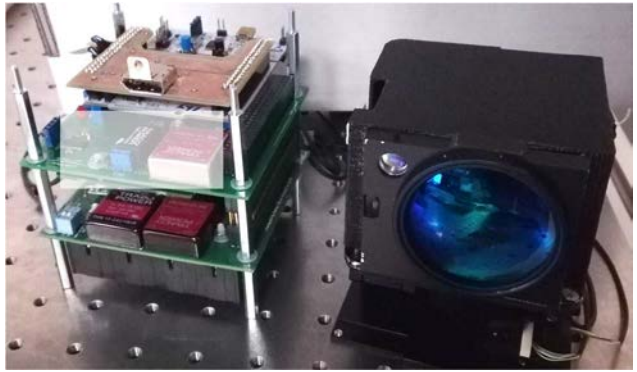
Its feasibility for a satellite channel is still to be verified.





- Simulation of satellite-to-ground communication channel
- Analysis of atmospheric turbulence and adaptive optic implementations
- Estimation of QKD performance for LEO and MEO
- Mitigation techniques for noise reduction

LaserCube: 2U LaserComm terminal



ESA-ARTES Entry contract (2017)
ESA-ARTES C&G (2019)

Key features:

- CubeSat compliant: 2U, 2 kg;
- Precise pointing: <60 µrad coarse, <10 µrad fine;
- 42 mm optical head, optical and quantum comm.

Phase 1: Downlink (2021)

TX channel downlink at 1550 nm
Optional RX for uplink
Data rate 0.5-2 Gbps
Ground stations: Matera and Padova

Phase 2: Inter-satellite link (2022)

Full-duplex ISL at 1550 nm
2-way DL-UL at 1550/808 nm
Data rate 10-100 Mbps

Quantum beside communication

Quantum Cascade Laser (QCL) frequency combs

Universities and Research Institutes:

Coordinator: Consiglio Nazionale delle Ricerche (CNR – Italy)

Eidgenössische Technische Hochschule Zürich (ETH – Switzerland)

Technische Universität München (TUM – Germany)

Centre National de la Recherche Scientifique (CNRS – France)

Agenzia Spaziale Italiana (ASI – Italy)

Companies:

Alpes Lasers (Switzerland)

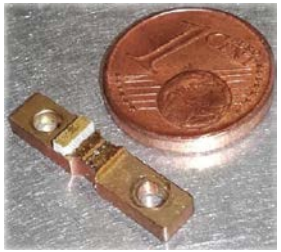
IRsweep (Switzerland)

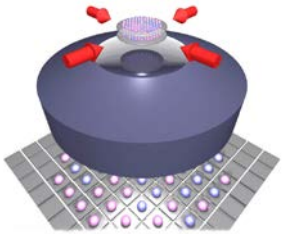
ppqSense (Italy)

Menlo Systems (Germany)

Thales Research & Technology (France)

- Deliver **a new generation of QCLs and QCL-combs** able to emit squeezed light with entanglement among the modes.
- Demonstrate the possibility of quantum simulate the main dynamics proper of **a real device**.





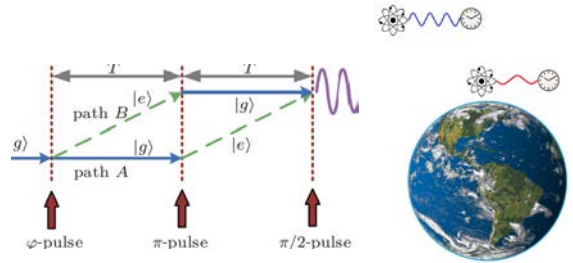
MOnitoring mass variations by Cold Atom Sensors and Time measures MOCASS and MOCAST+

The project MOCASS regarded a new satellite mission proposal for continuously monitoring of the Earth gravity and its changes, based on a satellite-borne interferometer exploiting ultra-cold atom technology

Results:

- **for the static gravity field, MOCASS showed high performance in all the harmonic spectrum of gravity field**
- **for the time-variable gravity field, MOCASS is promising but the accuracy at very low degrees seems to be still insufficient for this type of applications**

MOCAST+: enhanced cold atom interferometer for gravity gradients (atom interferometer) and time measurements (atomic clock)

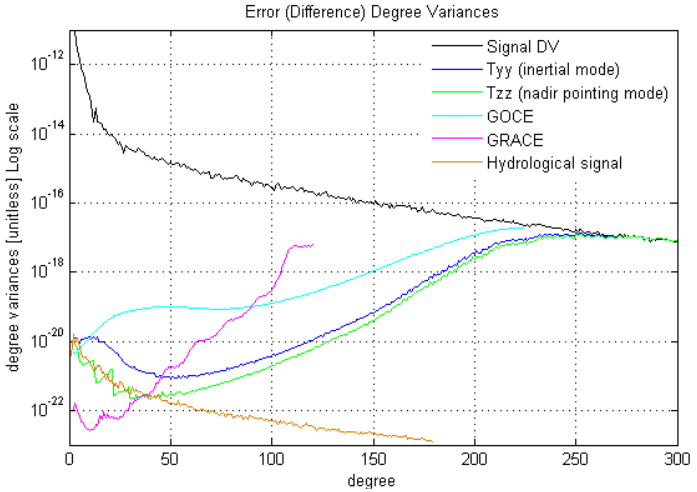


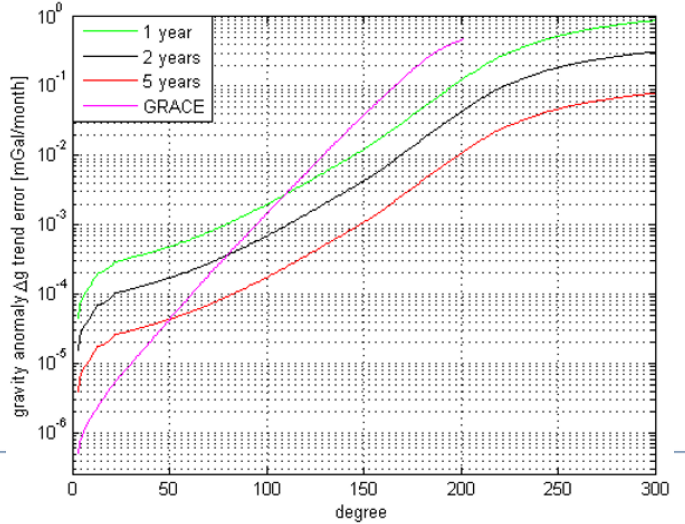
GOAL

improving the estimation of gravity models even at low harmonic degrees, with inherent advantages in the modeling of mass transport.

MOCASS results

- Regarding the recovery of the **static gravity field**, the MOCASS error estimates can improve the performances of GOCE over all the harmonic spectrum, especially at high degrees, with a commission error of about of 1.4 mGal at degree 300, 0.9 mGal at degree 250 and 0.19 mGal at degree 200 for a 5-year mission in nadir pointing mode, using a single-arm gradiometer in radial direction.
- For the **time-variable gravity field**, the MOCASS error estimates are promising (the 2-month solution is better than the GRACE one already above degree 40, while in the case of GOCE this occurs above degree 90). However, the accuracy at very low degrees seems to be still insufficient for this type of applications.





MOCAST+

- MOCAST+ (Monitoring mass variations by Cold Atom Sensors and Time measures) is a new study started in 2020 by POLIMI, Atom Sensors, Thales Alenia Space IT and University of Trieste on behalf of the Italian Space Agency (ASI)
- The idea is to propose an **enhanced payload** which can deliver **gravity gradients** and **time measurements (gravity potential).**
- The study will investigate whether this could give the possibility of **improving the estimation of gravity models even at low harmonic degrees**, with inherent advantages in the modeling of mass transport and its global variations: this would represent fundamental information, e.g. in the study of variations in the hydrological cycle and relative mass exchange between atmosphere, oceans, cryosphere and solid Earth.

FINAL REPORT OF THE MOCAST+ STUDY by Q1 2022

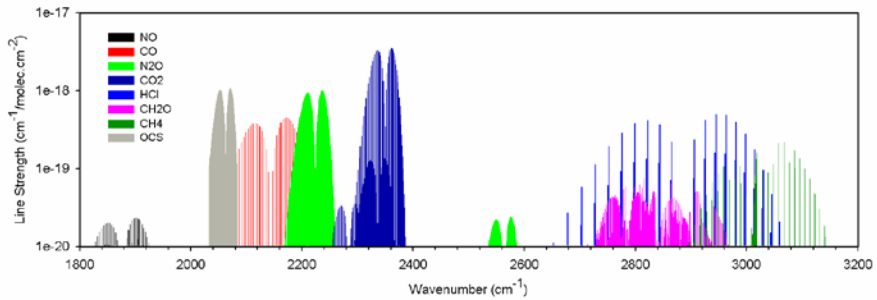
POLITECNICO MILANO 1863

Atom Sensors

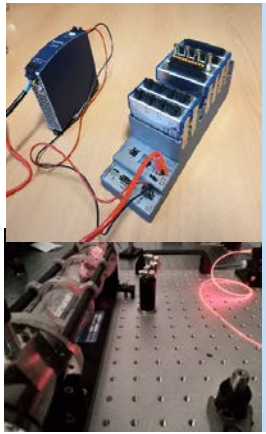
UNIVERSITÀ DEGLI STUDI DI TRIESTE

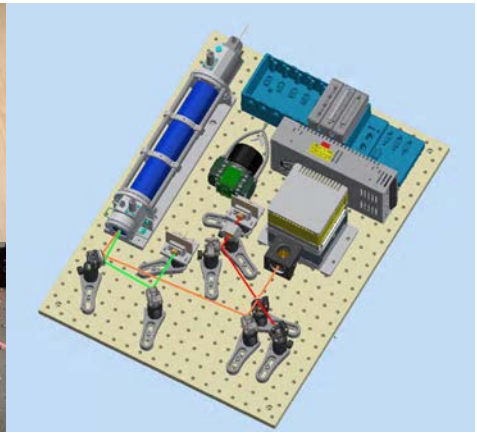
ThalesAlenia Space
a Thales / Leonardo company

PON OT4CLIMA
MIR SENSOR FOR GAS DETECTION



A Laser tuned on a given transition of the target molecule is scanned and, after passing through gas sample, is detected



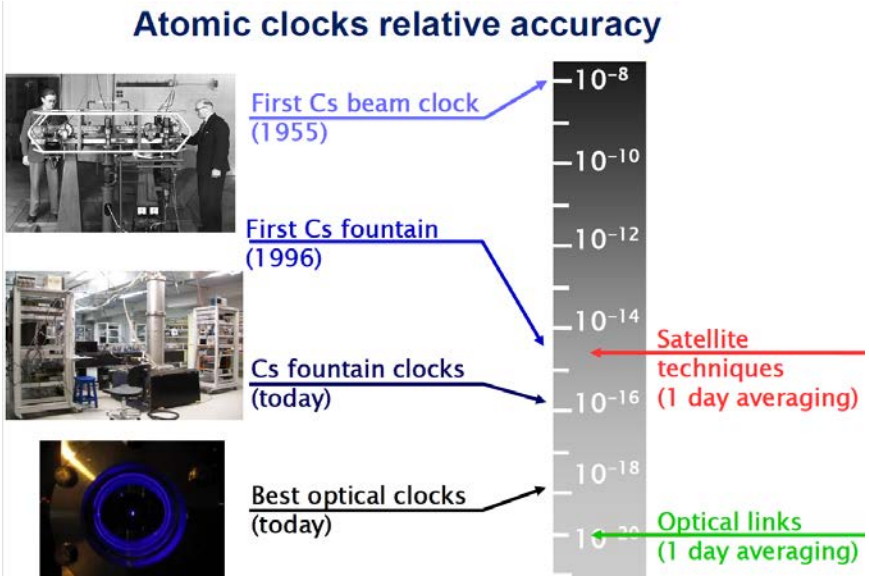


SENSOR COMPONENTS:

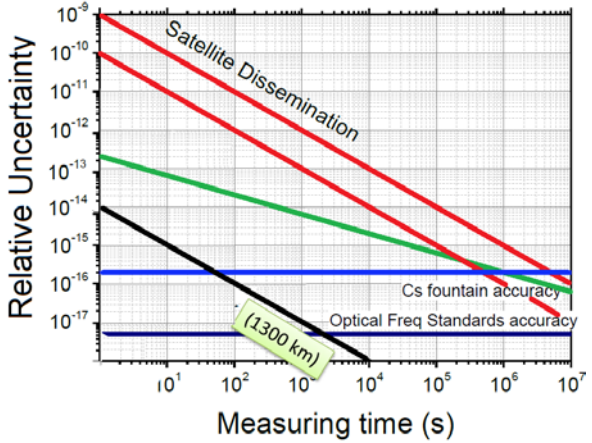
- **QUANTUM CASCADE LASER**
- **MULTIPASS CELL**
- **ETALON**
- **DETECTOR**
- **FPGA CONTROL AND ACQUISITION ELECTRONIC**
- **POWER SUPPLY**

METGESP

Time and frequency fiber optic metrology for geodesy and space



Atomic clock comparison and dissemination



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