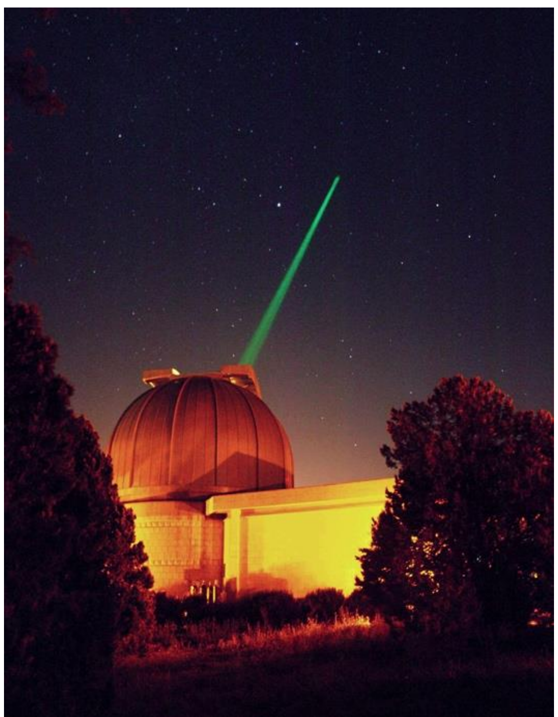

Recent results in experimental satellite quantum communication

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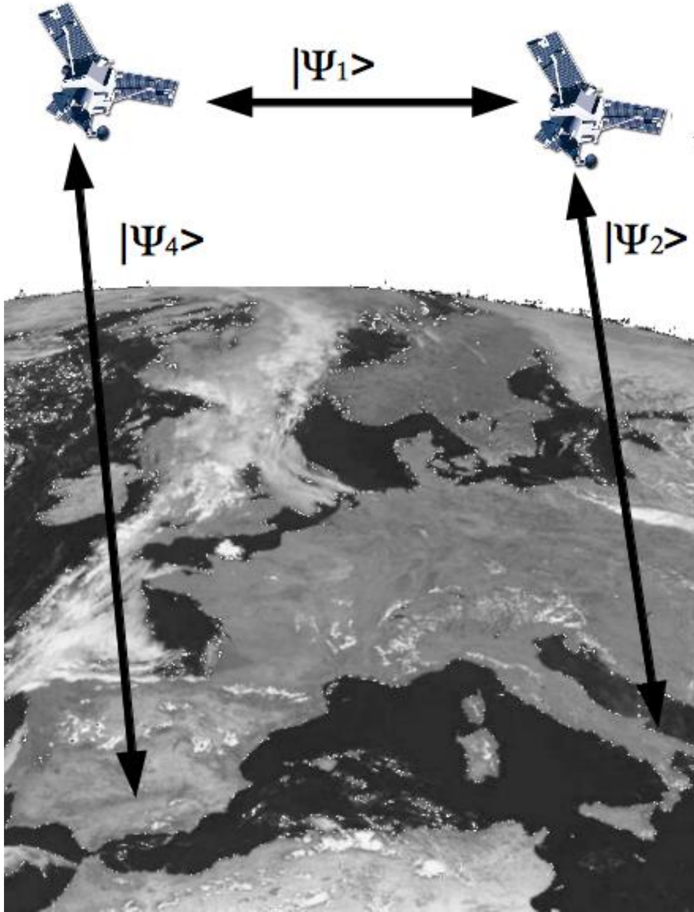
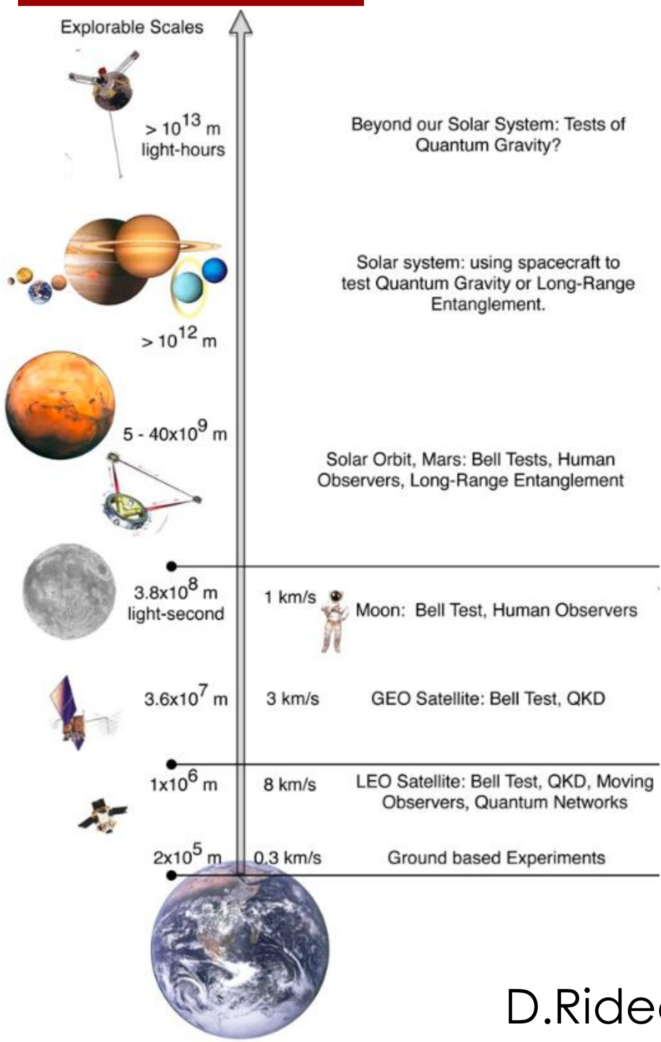
- Why satellites?
- QKD!

- Point-to-point QKD is limited:
  - ***143-km** in free-space (Canaly Islands)*
  - **404 km** *in optical fibre* (DV MDI QKD)
- Global QKD coverage will require hundreds of nodes
- Few orbiting terminal would allow for a **global QKD network**



- Why satellites?
- Fundamental tests!



Satellite Quantum Communication allow testing quantum effects in an unexplored scenario:

- Terminals at **high speed**, testing influences of special relativity on quantum states.
- Terminals at **different gravitational potential**, testing general relativity effects on quantum states.
- Terminals at **long distances**, extending the limits of Bell inequalities violation.

D.Rideout et. al, Class. Quant. Grav. **29**, 224011 (2012)

State of the art

- P. Villoresi et al. (2008), Single photon transmission from LEO satellite (Ajisai satellite **~1400 km**)
- J. Yin et al (2013), Single photon transmission from LEO satellite (Champ satellite **~400 km**)
- Z. Tang et. al (2016), Correlated photon onboard of a cubesat (**~550 km**)
- K. Günthner et. Al (2016), Quantum limited Coherent detection from GEO (**~38600 km**)

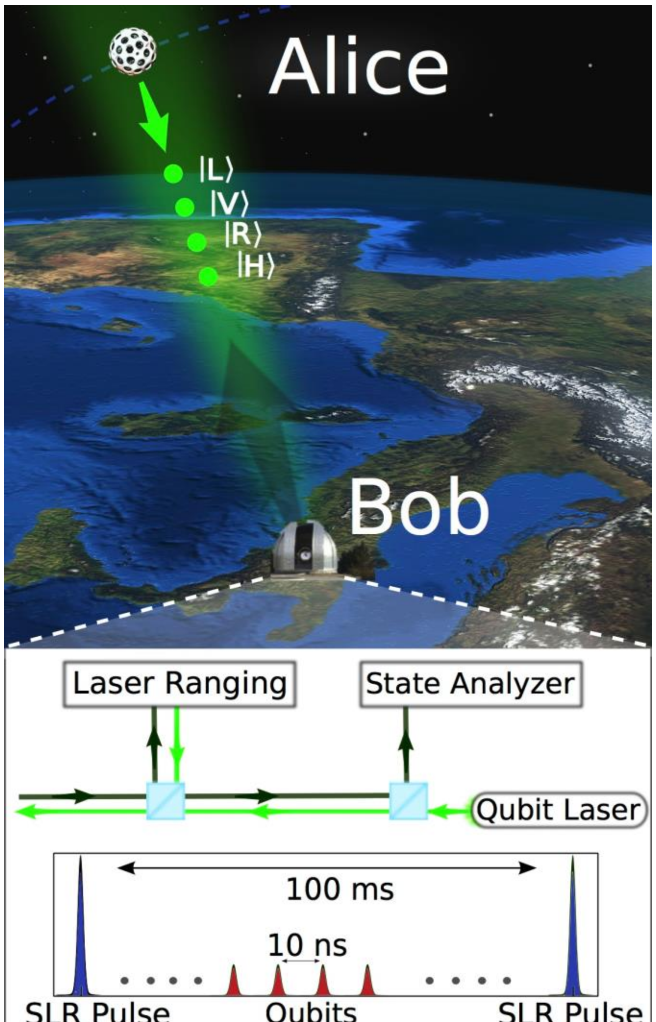
Up to now **no active satellites** have been used for satellite Quantum Communication

Retro-reflectors as weak coherent pulse sources

1. Strong pulsed laser is generated at MLRO and pointed toward the satellite (100 mW @ 100 MHz).
2. The high loss in the uplink reduce the intensity to μ_{sat}~**1 photon per pulse** after reflection.
3. The back reflected beam points precisely to the ground station.

This scheme exploits the retro-reflectors already mounted on satellite for geodesy

Polarization encoded qubit

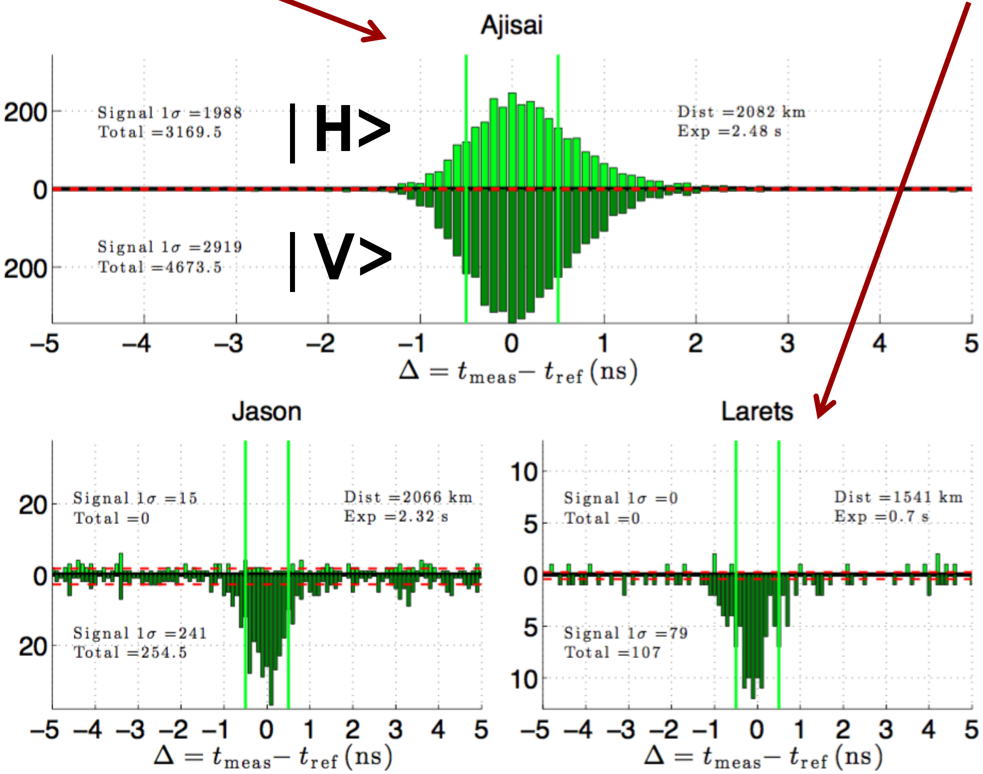


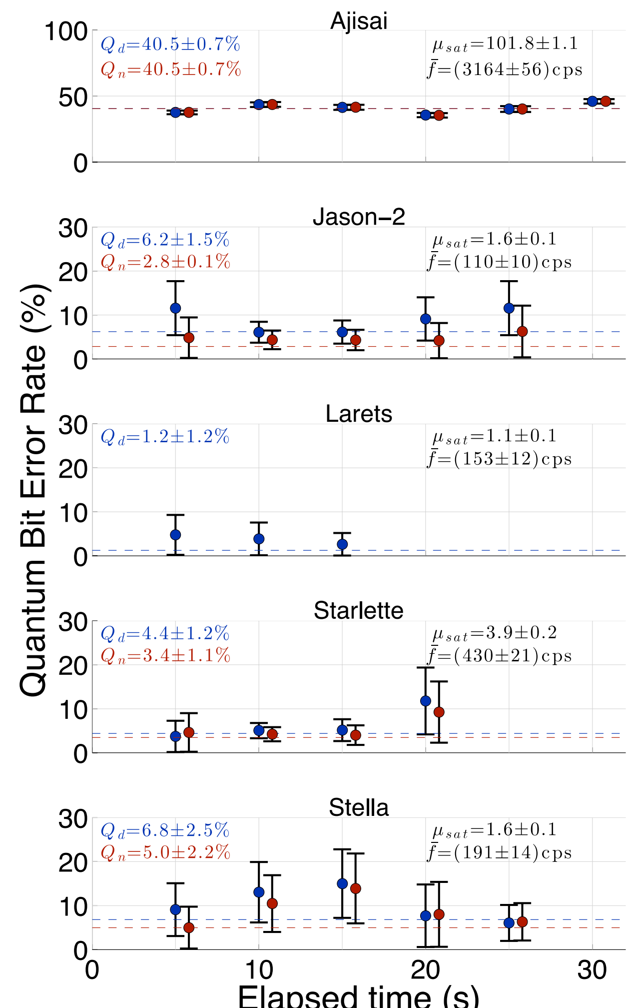
- Sending polarized light pulses toward polarization maintaining satellites.
- CCR emulates weak coherent pulse source of polarized states.
- Measuring the polarization state of the back-reflected photon.

Polarization analysis

Un-coated CCR: polarization is **not** preserved

Metallic coated CCR: polarization preserved

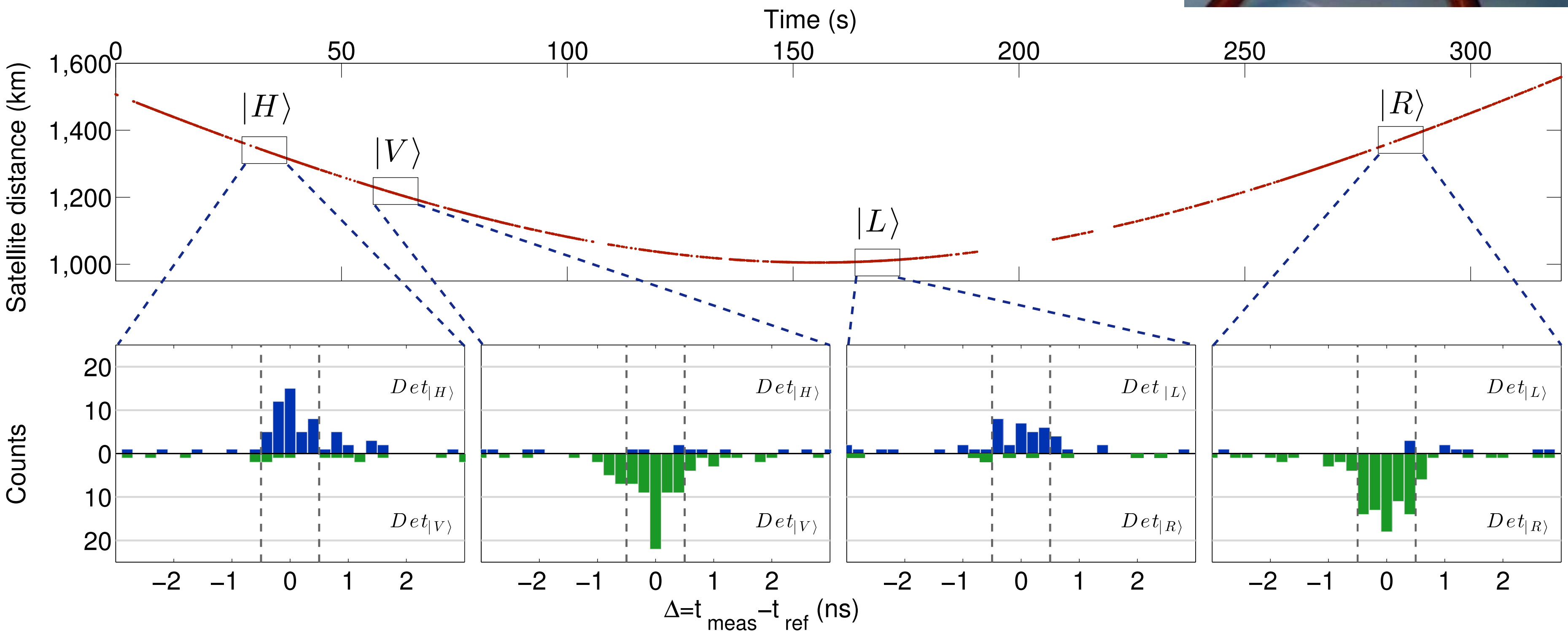




Single passage of LARETS

Orbit height 690 km - spherical brass body
24 cm in diameter, 23 kg mass,
60 cube corner retroreflectors (CCR)
Metallic coating on CCR

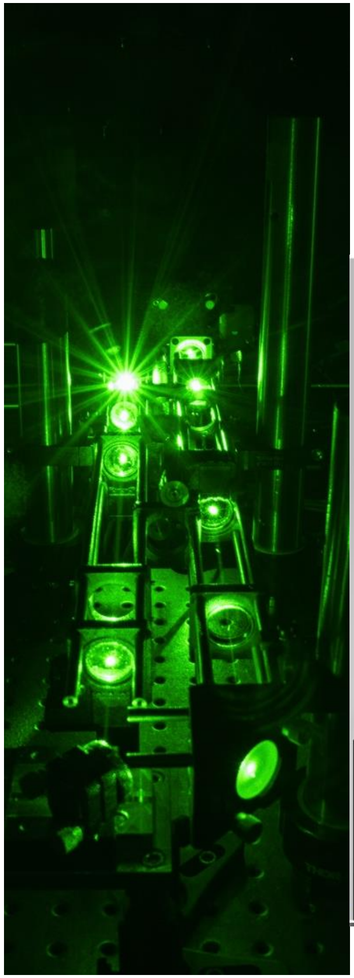
Apr 10th, 2014, start 4:40 am CEST



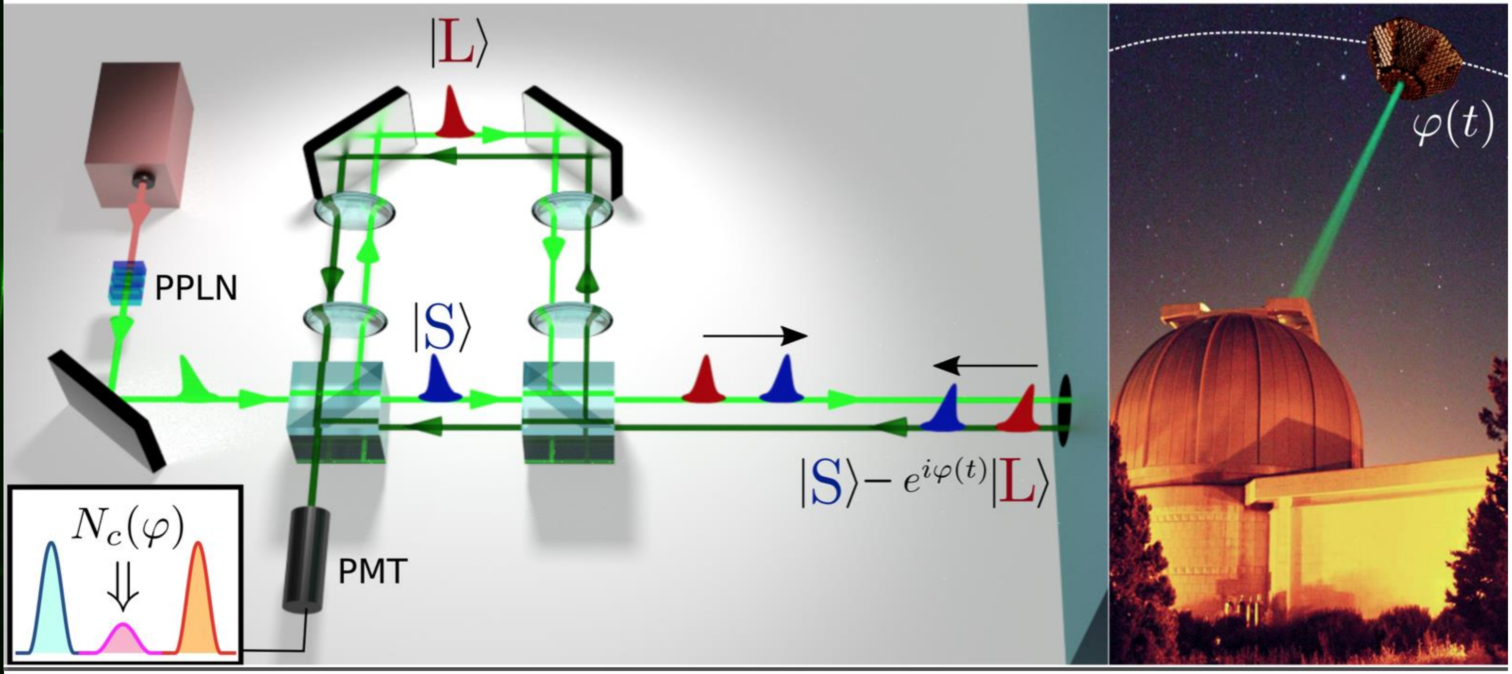
10 s windows **QBER ≃ (6.6±1.7) %** **Return rate 147 cps**

G.Vallone et al., PRL **115**, 040502 (2015)

Phase encoded qubit



A two-modes state is created and detected with the same unbalanced Mach-Zehnder Interferometer with a separation of ~3.3 ns.



LEO satellites move fast!

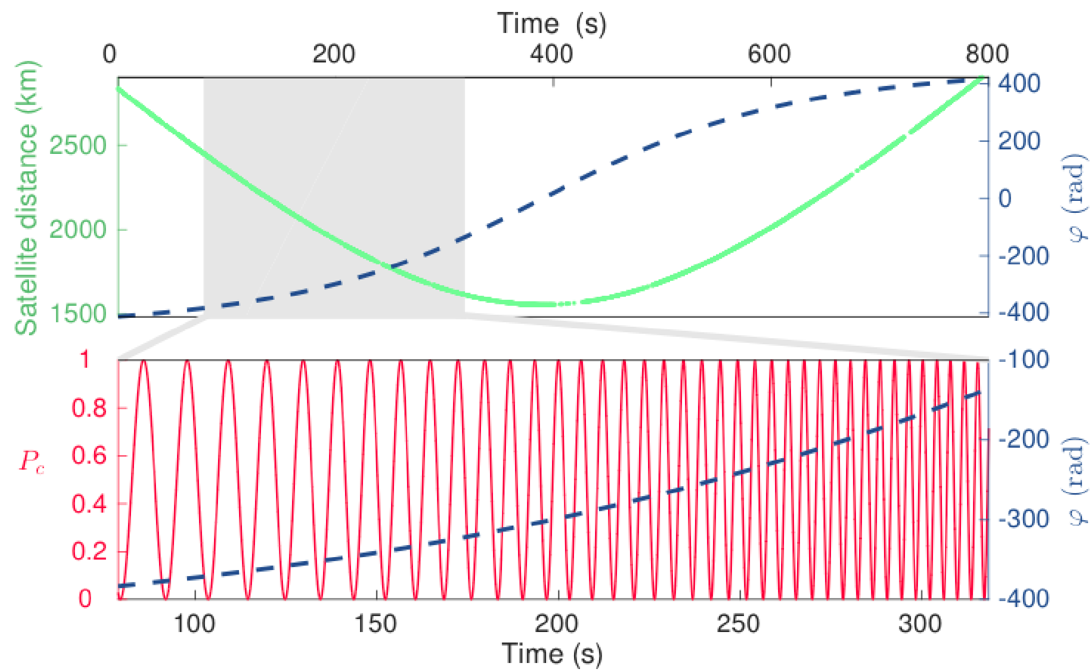
Between two pulses (3.3 ns) the satellite moves :
visibility and phase are modified

$$P_c(t) = \tfrac{1}{2}\left[1 - \mathcal{V}(t)\cos\varphi(t)\right]$$

$$\mathcal{V}(t) = e^{-2\pi\left(\frac{\Delta t}{\tau_c}\frac{\beta(t)}{1+\beta(t)}\right)^2}$$

$$\varphi(t) = \frac{2\beta(t)}{1+\beta(t)}\frac{2\pi c}{\lambda}\Delta t \approx \frac{4\pi}{\lambda}v_r(t)\Delta t$$

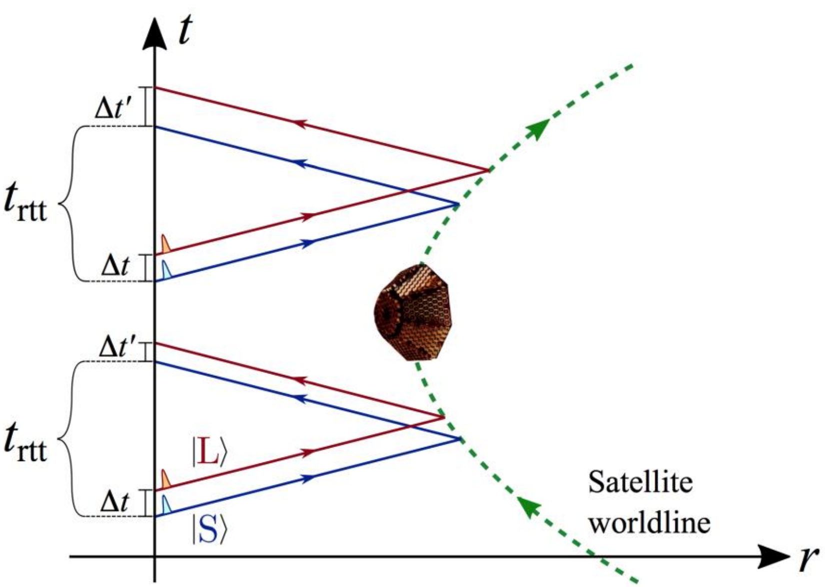
$$\beta(t) \equiv \frac{v_r(t)}{c} \qquad \Delta t \approx 3.4 \text{ ns}$$

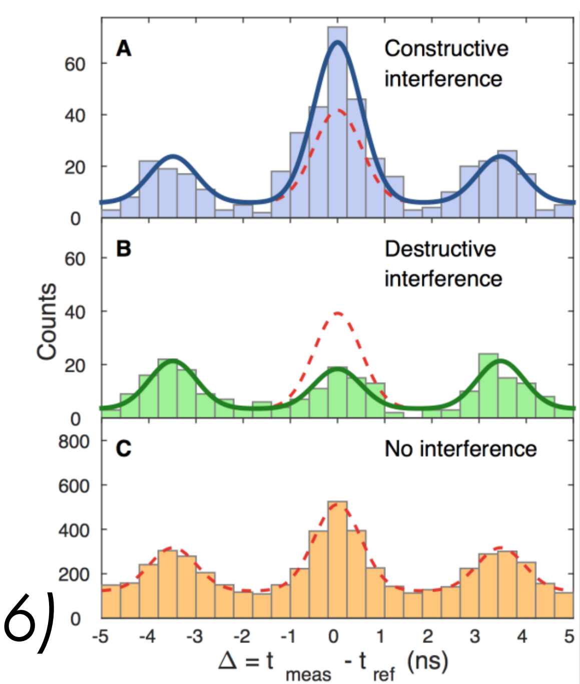


Satellite (radial) velocity changes continuously => continuous modulation effect

Satellite quantum interference

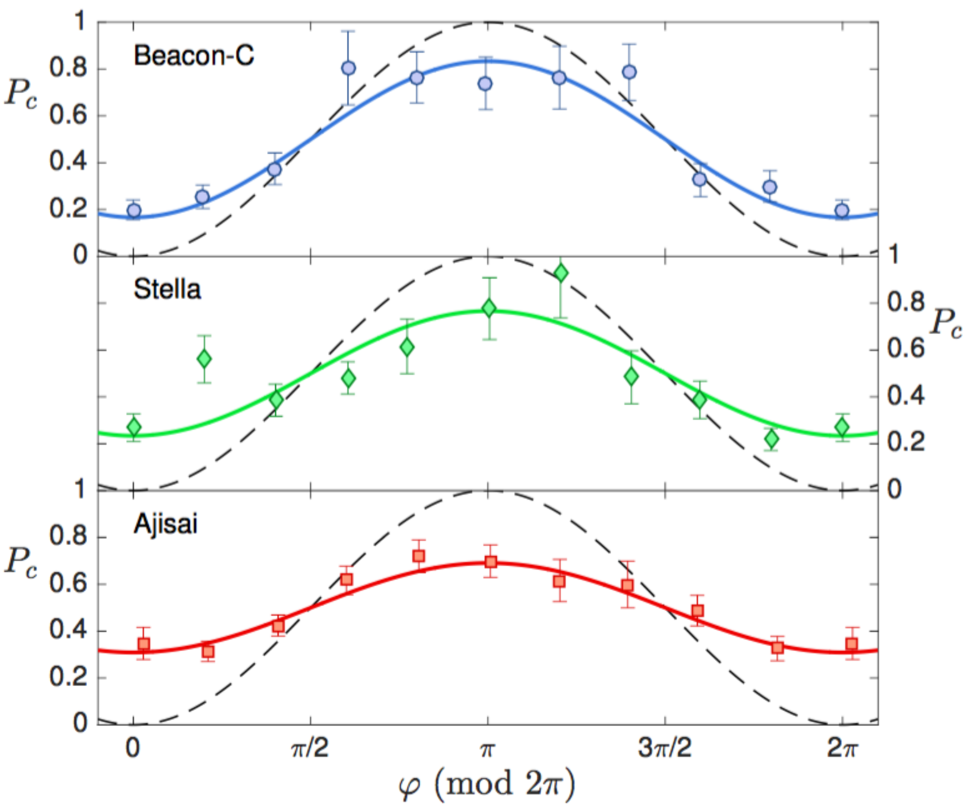
- Satellite motion acts as a phase modulator, depending on radial velocity.
- We measured the interference pattern for different radial velocities.
- Visibility up to 67% has been obtained on a single satellite passage.





G.Vallone et al., PRL, 116, 253601 (2016)

Visibility measurement

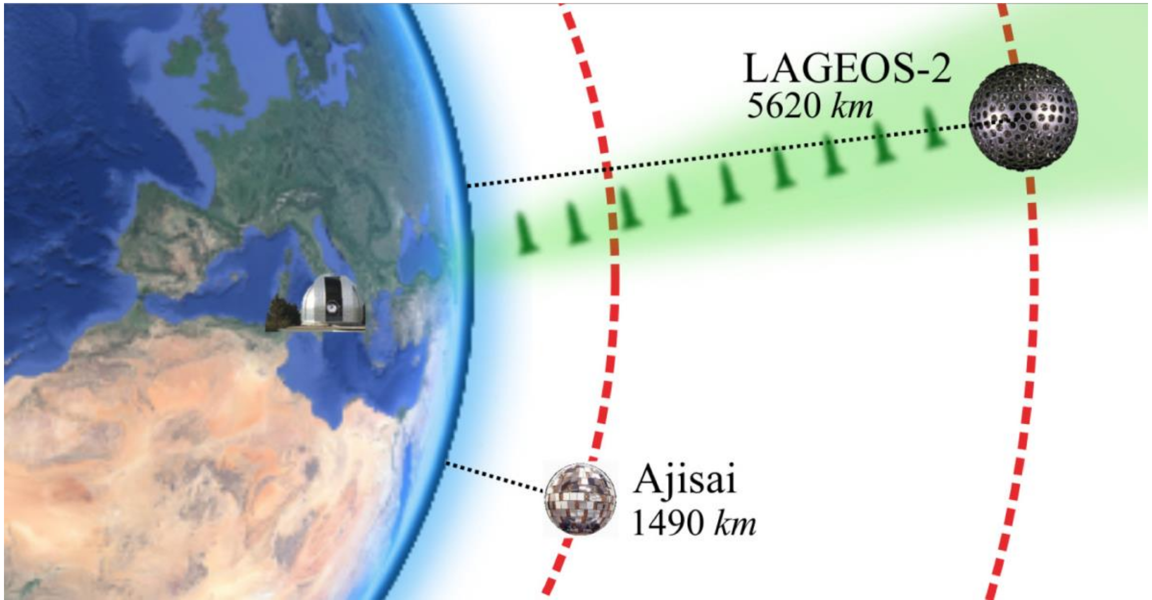


- Photon coherency has been verified at more than 5000 km.
- Visibility is still low (38 to 67%). Probably due to interferometer vibrations.
- Phase is a viable degree of freedom for QC and fundamental test

Probing MEO satellites

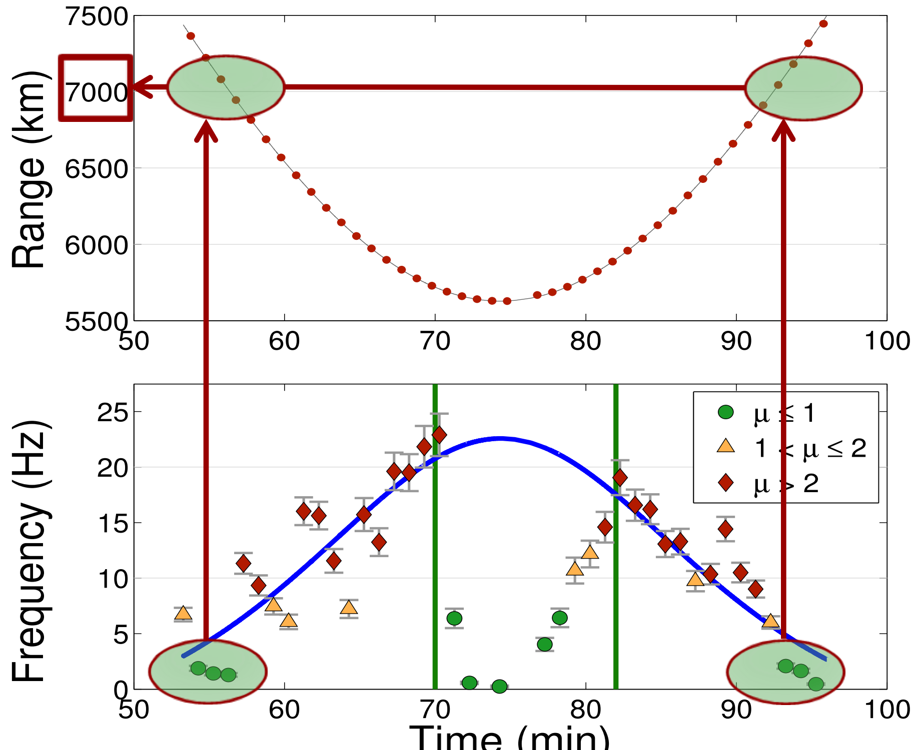
Extending the reach of satellite Quantum Communication to MEO:

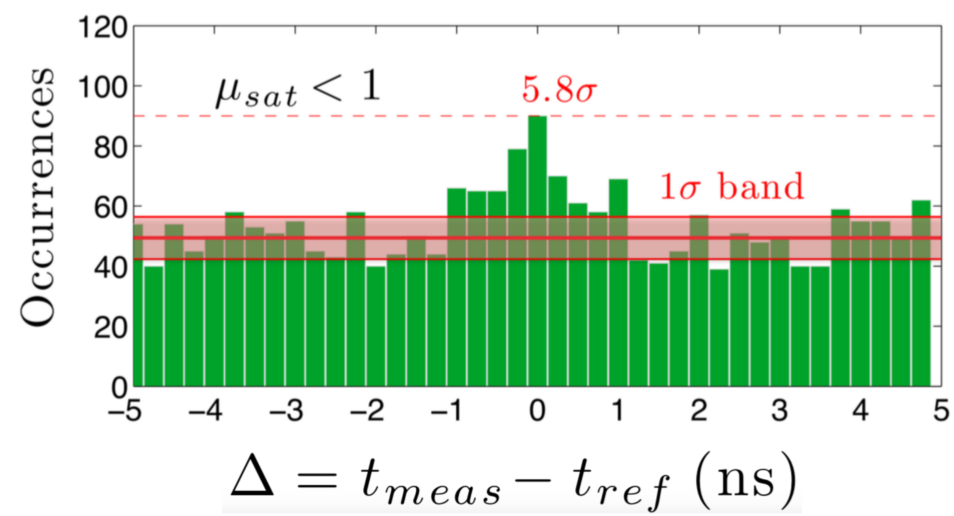
- Longer lasting communication sessions
- Longer distances covered



7000 km: a new record in single photon transmission

- The periods with $\mu_{sat} < 1$ have been analyzed separately.
- Evidence of a peak corresponding to the detection single photons.

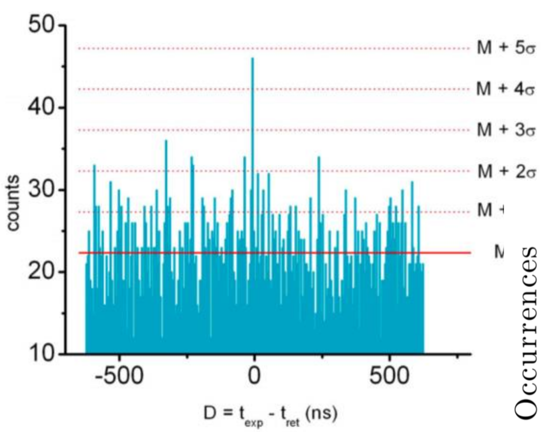




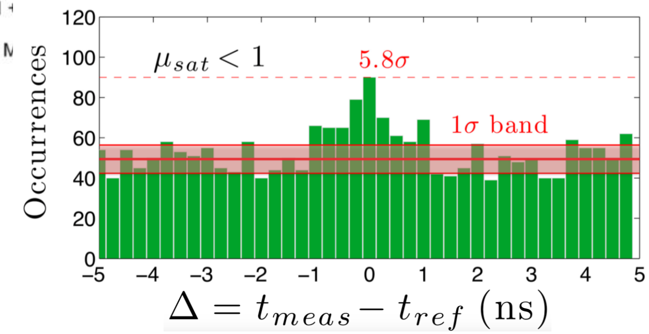
D. Dequal et al., Phys. Rev. A 93, 010301 (2016)

Toward GEO?

2008 Ajisai (1500 km)



2016 Lageos (5600 km)



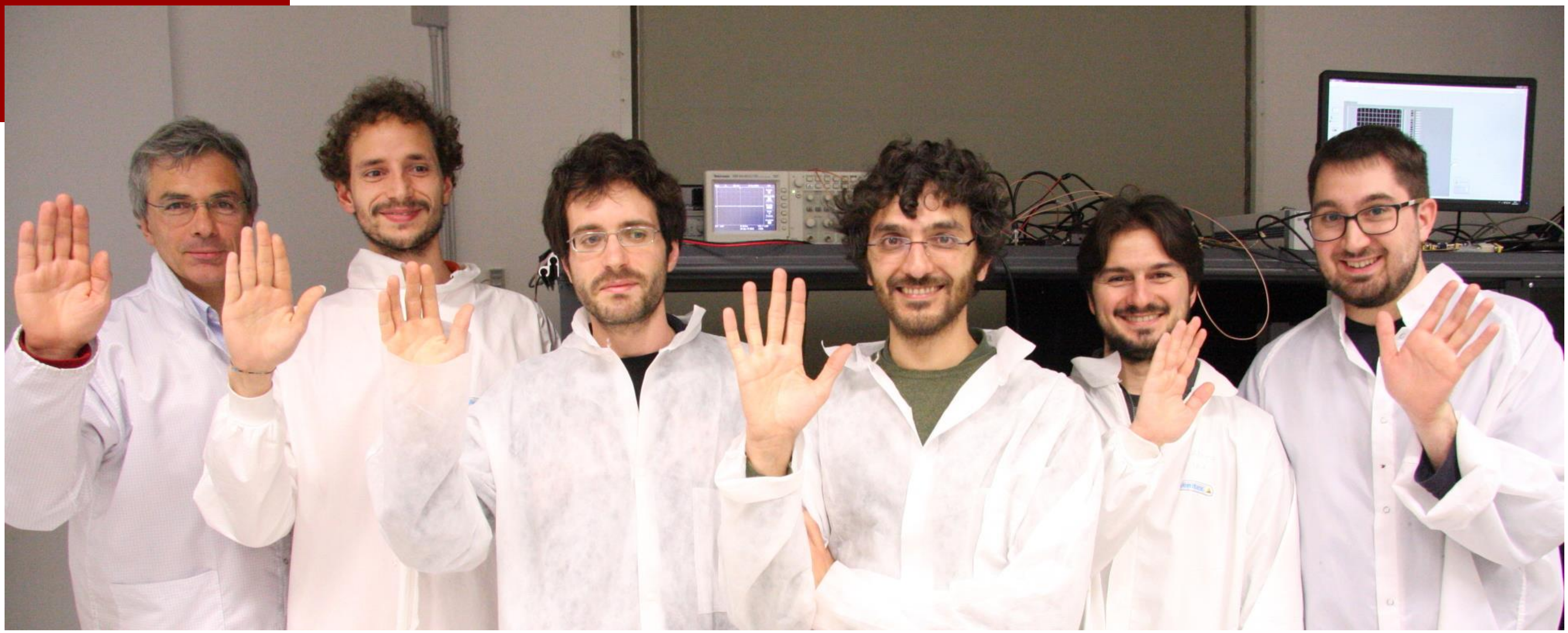
Expected ~20x SNR increase with new detectors and time-taggers

QKD with GNSS (~23000 km) feasible in the near future

Conclusion and perspective

- ✓ Qubit transmission has been successfully demonstrated both for polarization encoding and phase encoding (time bin).
- ✓ Distance up to 7000 km have been covered for single photon transmission, and might be extended up to 23000 km (GNSS) or GEO.
- ✓ MLRO (and eventually any ILRS station) may become a terrestrial node for satellite quantum communication.
- ➢ More work must be done for the realization of an active satellite, interesting news are expected soon!

QF Matera team 2016



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The shift in the communication paradigm

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