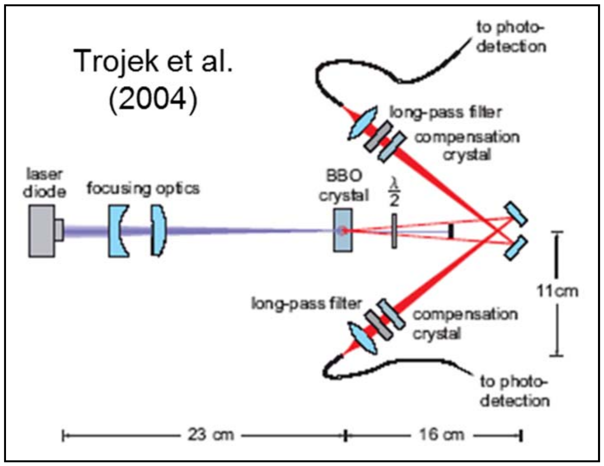
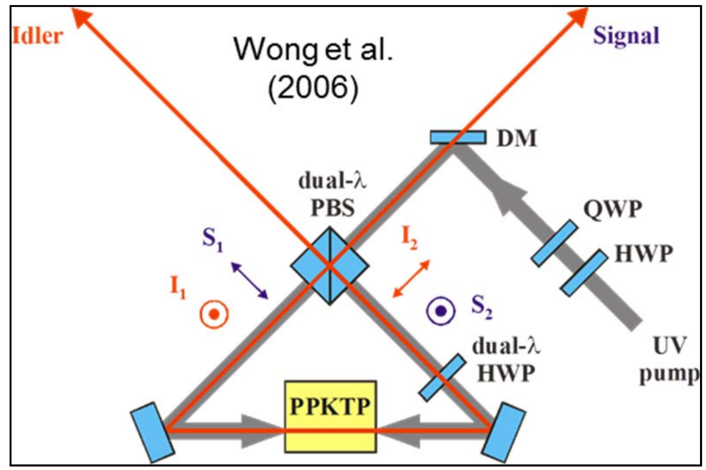
Entanglement distribution in space

Richard Hughes, LANL

SPDC two-photon light sources have become brighter, smaller, more stable …





- **attributes: coincidence counting; two-photon interference; entanglement**

discussion topics:

- **what experiments can <u>only</u> be performed in space with SPDC sources ?**
- **what is the status and heritage ?**
- **what are the challenges/risks/mitigations ?**

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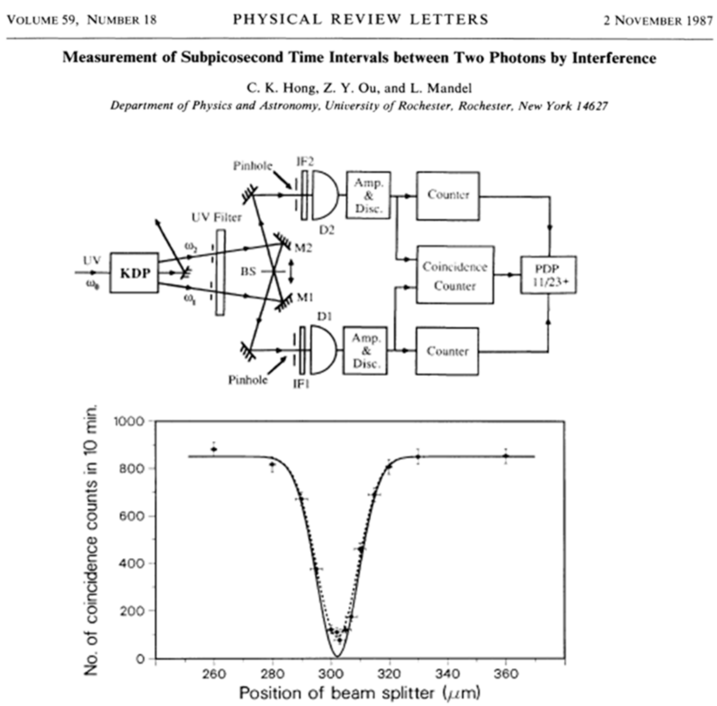
Experiments accessible with SPDC sources in space

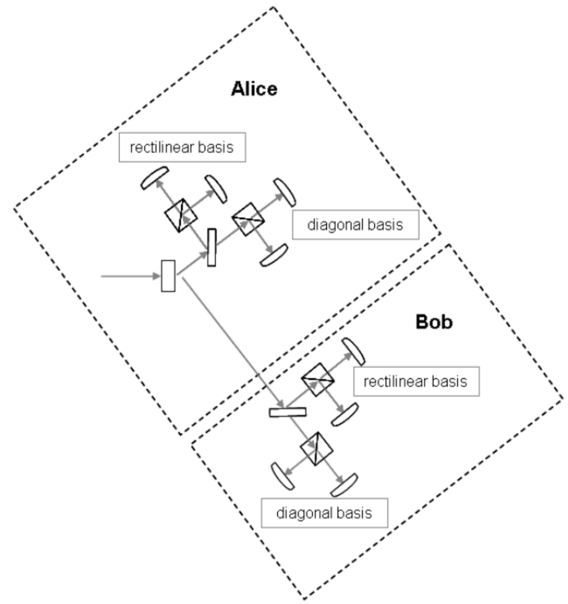
Two-photon interference (HOM):



Quantum Metrology

- **ranging**
- **clock synchronization/time transfer**
- **+ entanglement enhancement ?**

Two-photon entanglement:



Quantum Mechanics

- **non-locality tests**
  - moving frame; long distances; special and general relativistic considerations
- **teleportation; entanglement swapping**

Quantum Cryptography

- **satellite re-key; global key distribution**

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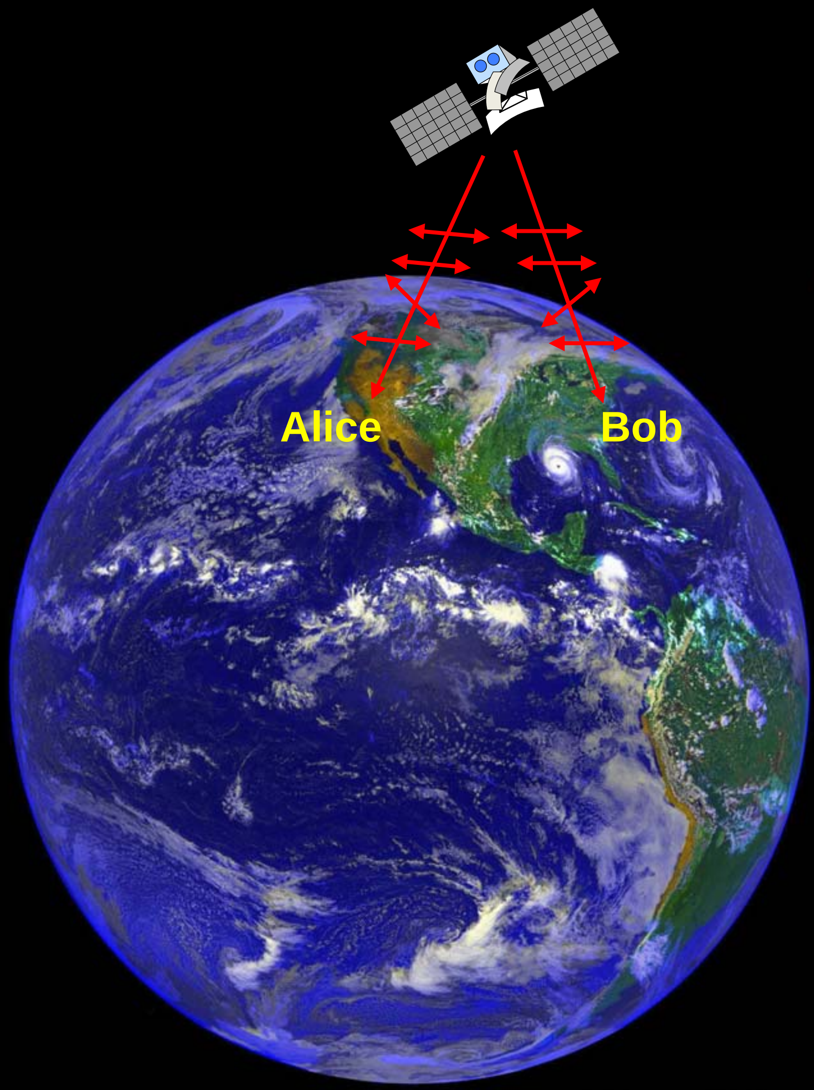
Satellite-based quantum communications

RJH + JEN (1994); US patent 5,966,224 (1999); J. Mod Opt 47, 549 (2000)



on-orbit re-key

- secure satellite command & control
- secure data up/downlink

a "trusted QKD node in the sky"

- populate key stores of ground-based trusted QKD nodes
- establish secure connectivity between geographically diverse domains
- extend the reach of QKD to continental, global scale

international projects/proposals

- Japan: M. Toyoshima et al. (2013)
- China: J. –W. Pan et al. (2016)
- Europe-Canada "Space-QUEST": A. Zeilinger et al.
- Canada: T. Jennewein et al.

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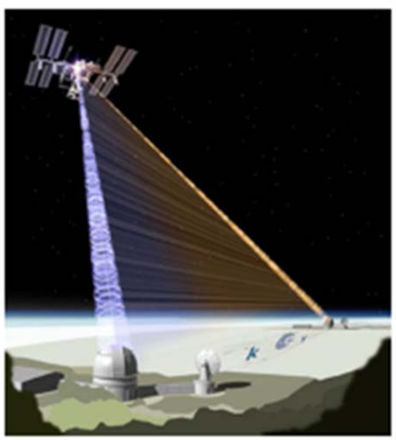
Multiple experimental configurations possible

Complete experiment on satellite

- **e.g. Ling et al. (NUS): "**Small Photon Entangling Quantum System" (SPEQS)
  - fundamental QM focus
- **feasible on a cubesat ?**

Satellite-to-two-ground (common view)

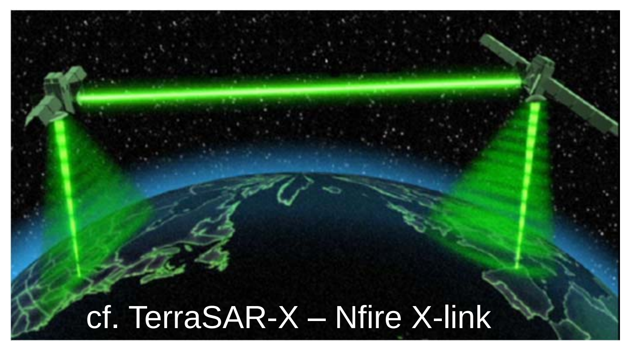
- **Pan et al.; Ursin et al.**
  - teleportation, entanglement swapping



Satellite-to-ground

- **Toyoshima et al. (NiCT): SOCRATES**
  - comm focus + QKD
- **Pan et al. (USTC): quantum satellite**
  - QKD + teleportation
- **Ursin et al. (U Vienna): Space-QUEST**
  - teleportation, QKD
- **(Jennewein et al., U. Waterloo: ground-to-satellite)**

Satellite-to-satellite



cf. TerraSAR-X – Nfire X-link

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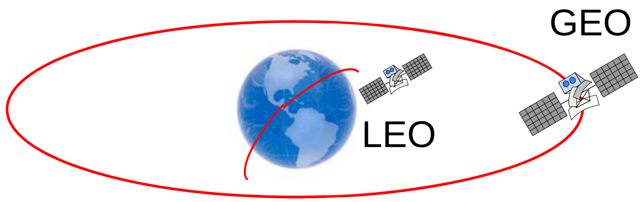
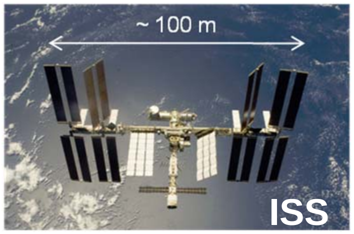
Orbits, platforms and potential opportunities for quantum science



geostationary orbit (GEO): 36,000 km altitude
(~ 5.6 $R_{\oplus}$)

medium-earth orbit (MEO): 2,000 – 36,000 km alt
- **e.g. GPS**



<u>low-earth orbit</u> (LEO): 200 – 2,000km alt.
- **possibilities for on-orbit experiments:**

A) <u>ISS</u>
- ~ 350-km altitude

B) secondary experiment on an <u>imager</u>

C) agile, 3-axis stabilized <u>small-sat</u>
- standalone, or secondary to optical comm

D) cubesat
- challenging SWaP allocation

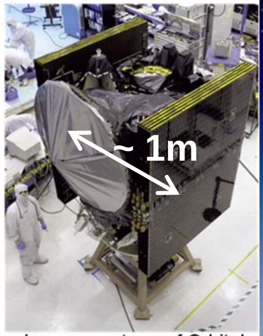
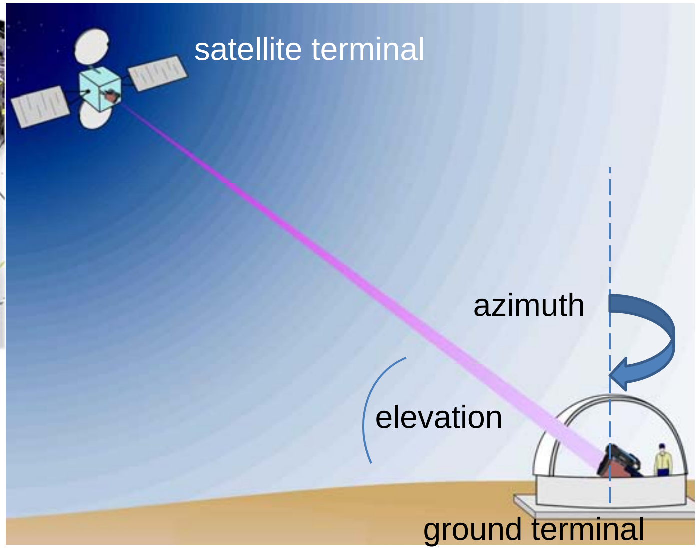


Image courtesy of Orbital Sciences: "LEOStar" bus



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SPDC experiments have not been demonstrated on-orbit

Considerable heritage at the component, sub-system levels:

- satellite laser communications
- satellite laser ranging
- satellite laser altimetry
- ground experiments

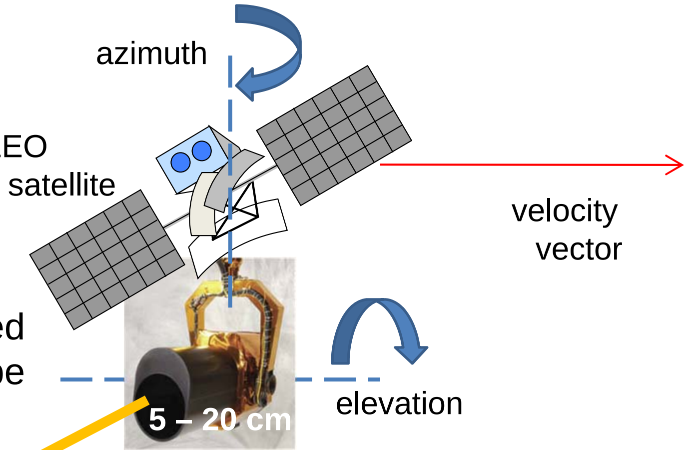


Image courtesy of Ball Aerospace

~ 10^6-m range

acquisition, tracking and pointing

azimuth-elevation gimballed telescopes

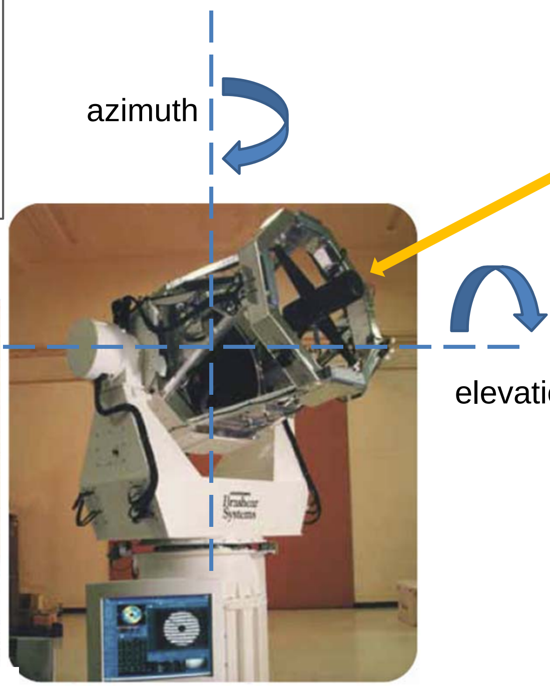


image courtesy of L3-Brashears

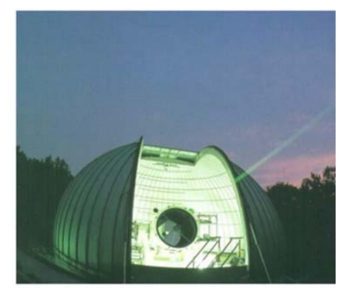
< 50-cm telescopes: <u>transportable</u>

1-m class telescopes: <u>fixed installations</u>

Satellite optical communications ground terminals

ESA Tenerife

NASA-JPL OCTL



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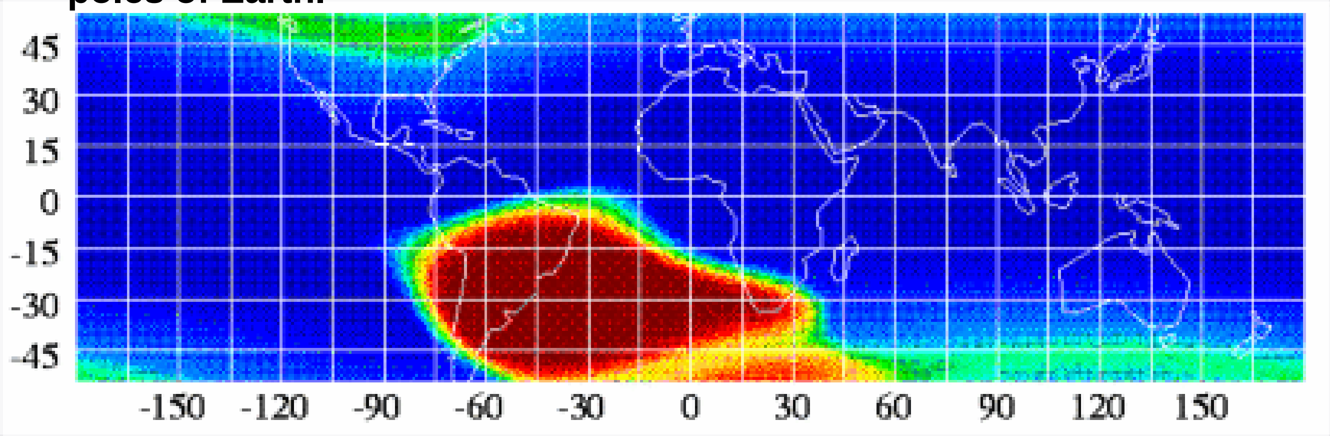
Low Earth Orbit Radiation Exposure

SAA is the primary contributor to the doses received in low earth orbits.

Given 500Km, 60º inclination orbit, surrounded by Al shielding the daily dose from trapped protons is less than 1 Rad/day.

SAA is a result of the eccentric displacement of the center of the magnetic field from the geographical center of the Earth (by 280 miles) as well as the displacement between the magnetic and geographic poles of Earth.



South Atlantic Anomaly Detector (SAAD) aboard the ROSAT spacecraft.

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Space Radiation Effects on SPDC Photonics

- **Displacement Damage Dose** (principal mechanism)

  Cumulative long term ***non-ionizing*** damage mainly due to protons

- **Effects**

  Production of defects that results in performance degradation

  Shielding has some effect
  Can eliminate electron damage, reduce some proton damage

- **SPDC Devices -** radiation tolerance

  Pump Laser - good ?

  Optical Fiber – good

  Down-conversion crystal/PPLN - ?

  Single-photon detectors - ?

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Single-photon detectors in space

space-qualified PMTs and SPADs exist

- **PMTs flown on NASA CALIPSO**
- **photon-counting APDs on GLAS**
- **Czech Technical University:**
  - **Si SPAD @ 532 nm:**

- Active area: 25 micron diameter
- Quantum Efficiency: 10%
- Timing Resolution: 75 psec
- Dark Count Rate: < 8 kHz @ 20°C
- Operating Temperature Range: -30°C to 80°C (no cooling)
- Power Consumption: <400 mW
- Mass: 4 g
- Resistant to solar and ionizing radiation (100 krad) damage
- Expected lifetime of greater than 10 years in space

- **<u>good enough for quantum science in space</u> ?**

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Risk reduction experiments with SPDC sources

ground-based …

Entanglement-based quantum communication over 144 km

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balloons …

aircraft ?

Viewing
Through
Side window

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Discussion topics

- what experiments can <u>only</u> be performed in space with SPDC sources ?
- what are the flight opportunities ?
- what are the challenges/risks/mitigations ?

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