Centre for Quantum Technologies

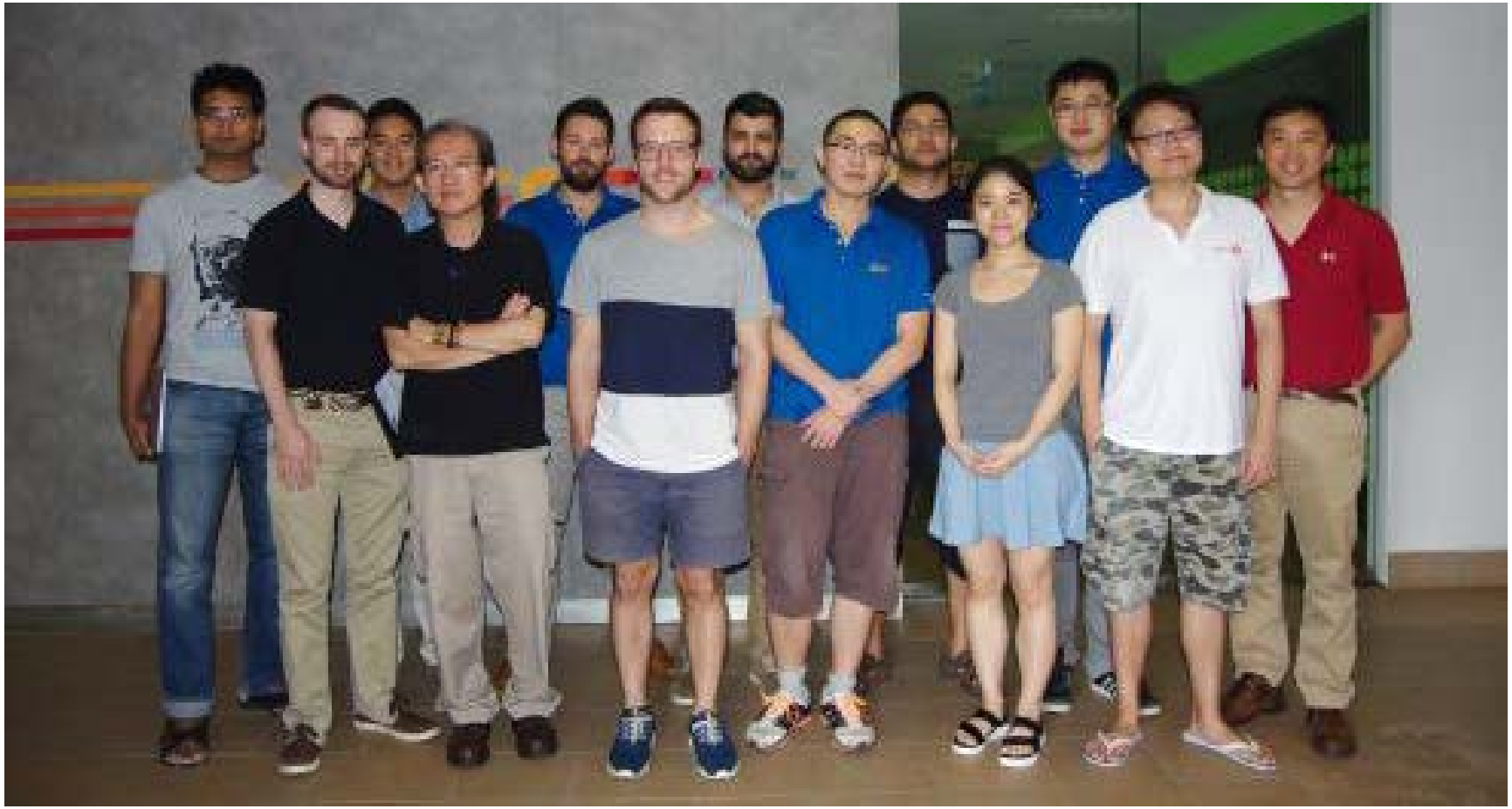
NUS National University of Singapore

# Quantum Tech demos on CubeSat nanosatellites

Robert Bedington – Satellite team leader

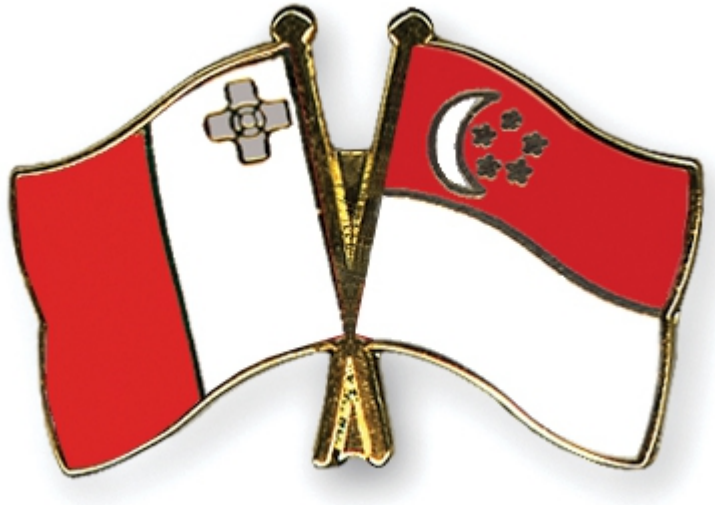
Alex Ling Group

# Alex Ling - SpooQyLabs



# Singapore and Malta

- Densely populated, small island nations
- British colonies until 1960s
- Red and white flags



# Contents

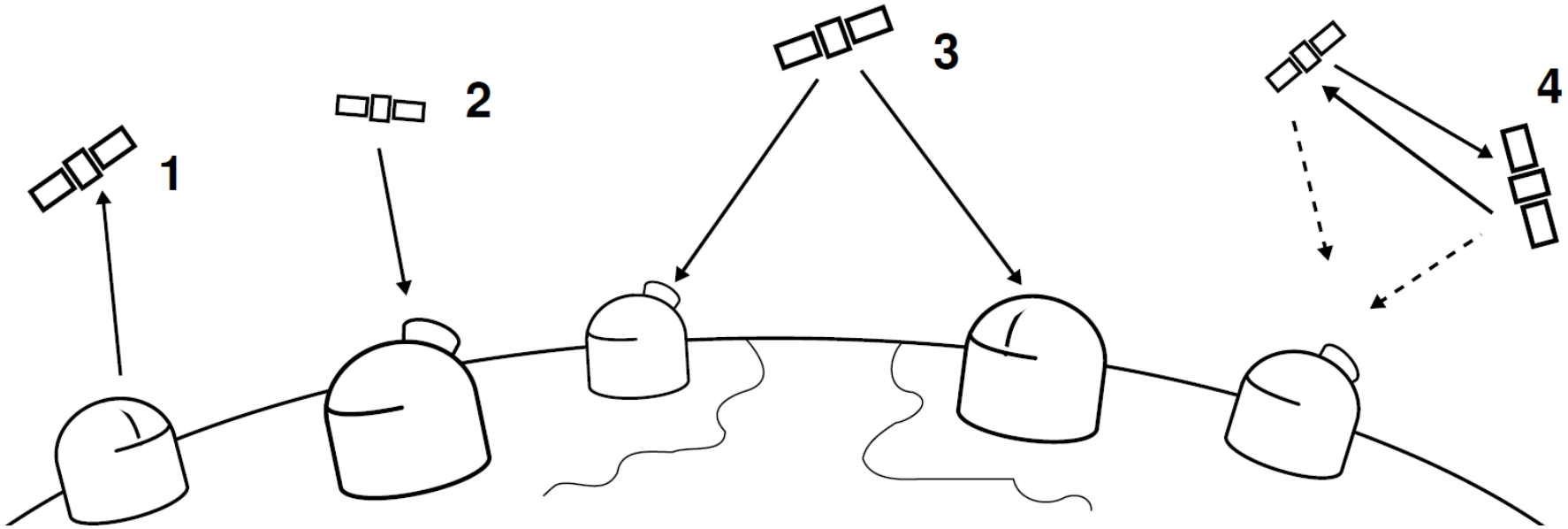
- Miniaturised entangled photon sources for CubeSats
  - Key technologies
- Current and previous missions: SPEQS-CS
  - results
- Upcoming missions: SpooQySats
  - challenges
- Future missions
  - Challenges

# Free-Space Polarisation Entanglement QKD

1.5 km

Marcikic, I. et al. (2006). Free-space quantum key distribution with entangled photons.
Peloso, M. P., et al. (2009). Daylight operation of a free space, entanglement-based quantum key distribution system

# Space based QKD experiments



# CubeSats – Tiny Satellites for a tiny nation.

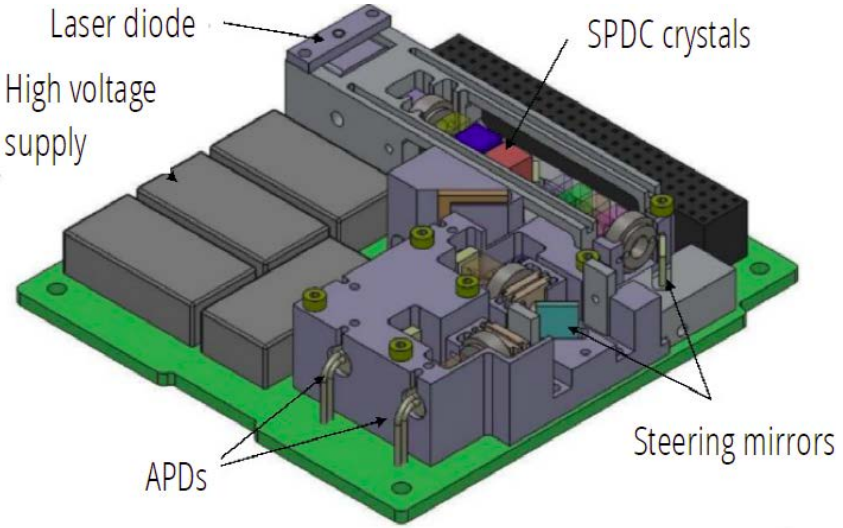
- CQT is not a space research group
- Limited access to Space in Singapore

- Iterative development cycle
- Incremental technology demonstrations

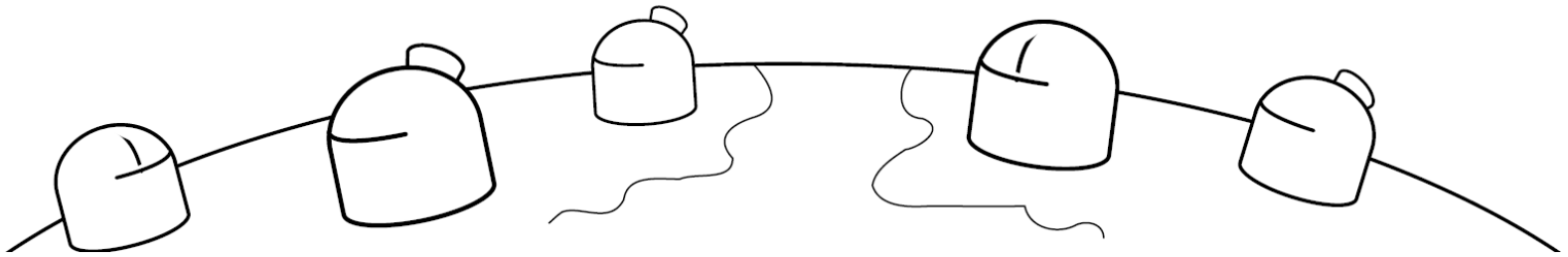
- Semi-standardised interfaces make multiple collaborations easier
- Space-heritage COTS platforms facilitate DIY satellites

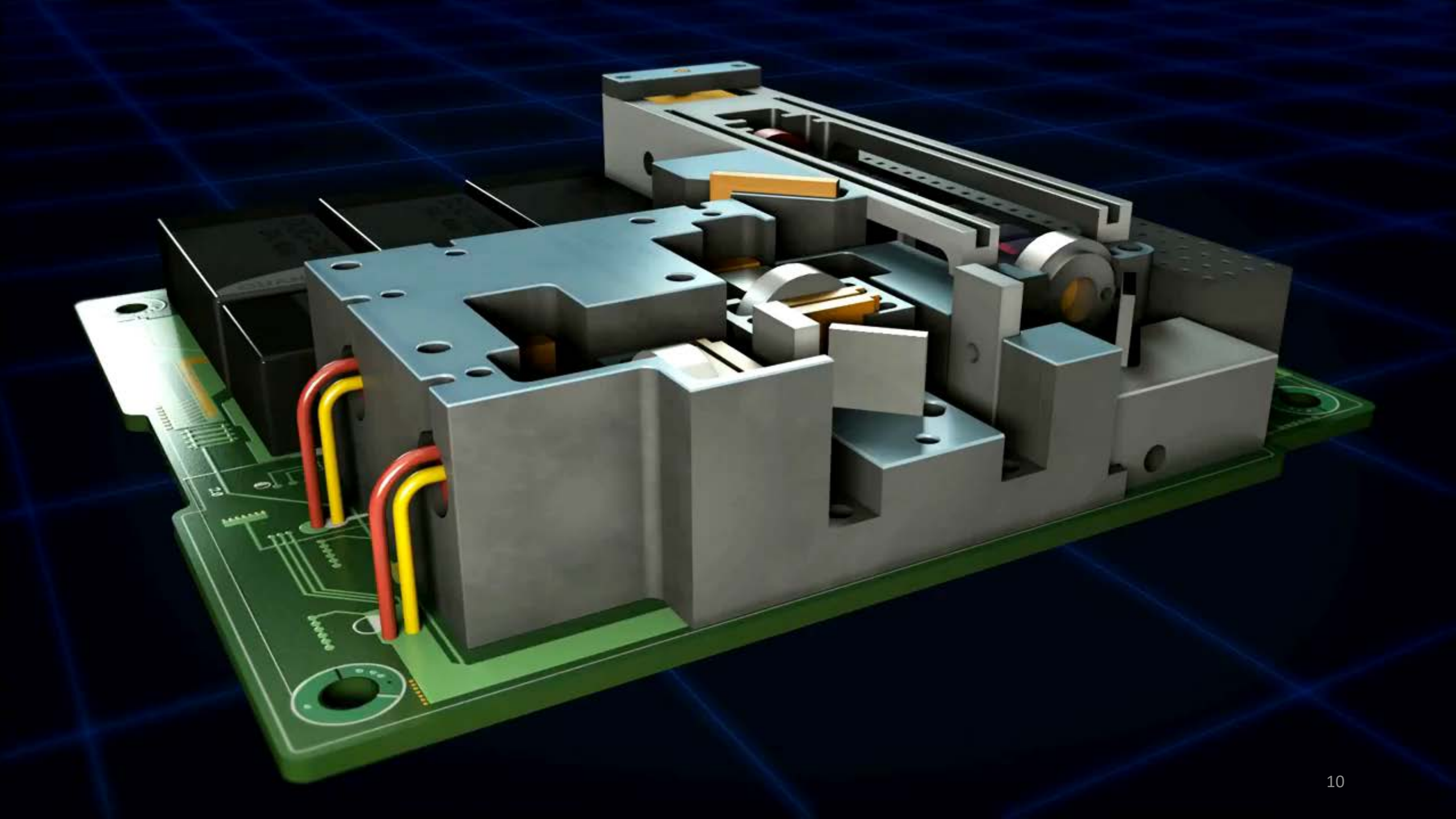
# Proving rugged miniaturised sources in space

**S**mall
**P**hoton
**E**ntangling
**Q**uantum
**S**ystem

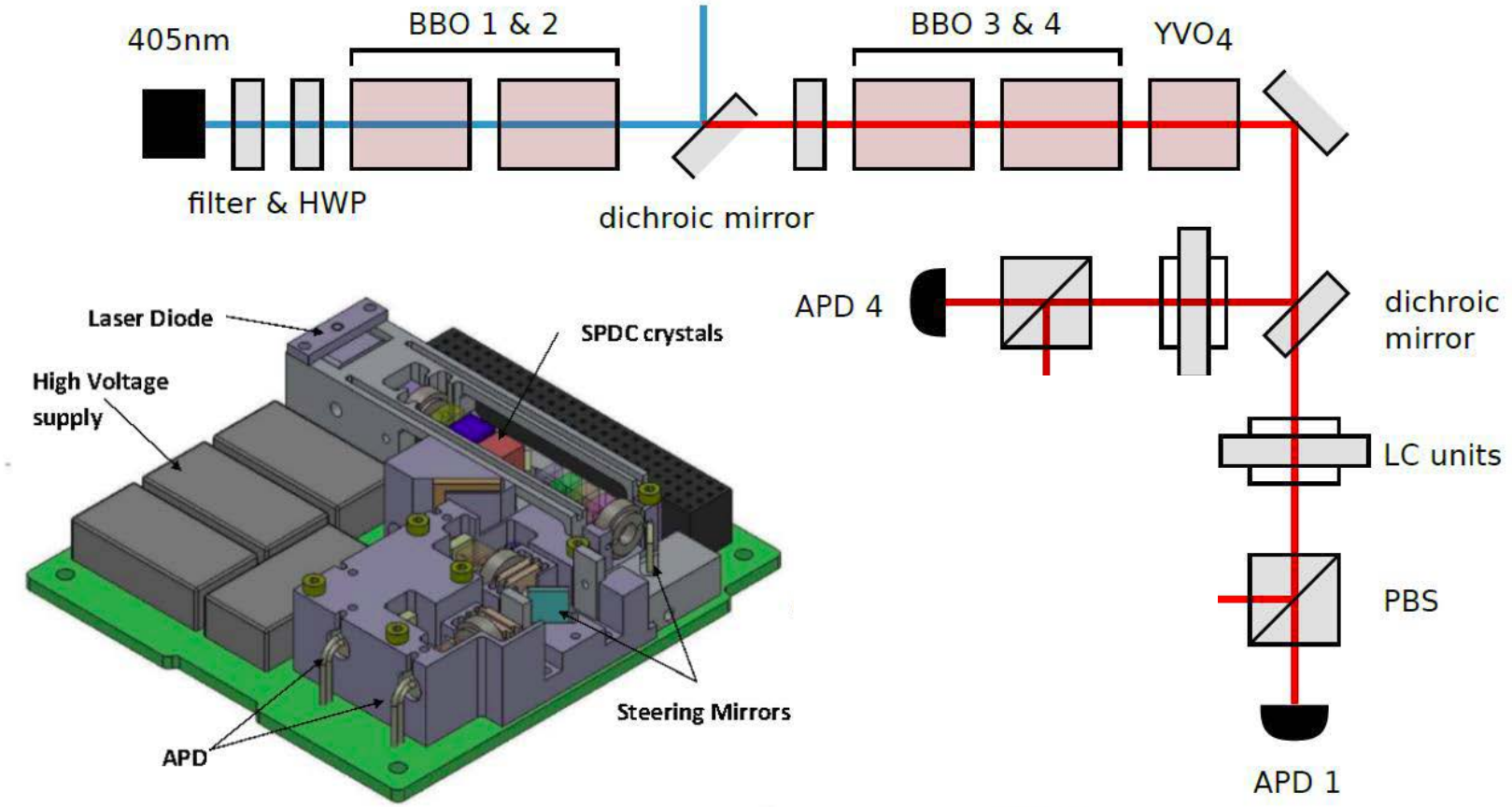



SPEQS

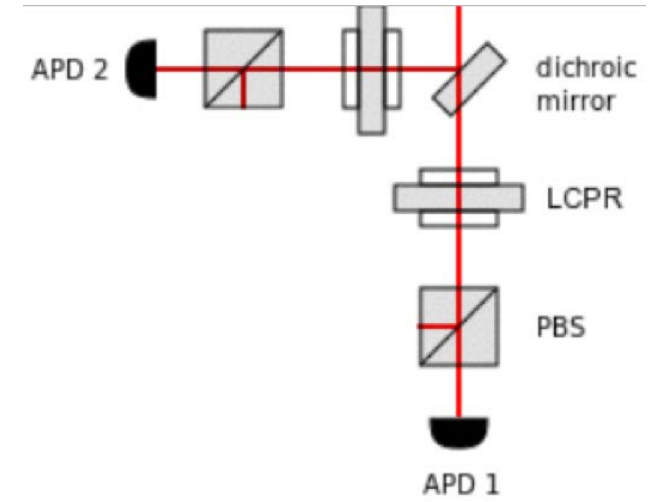


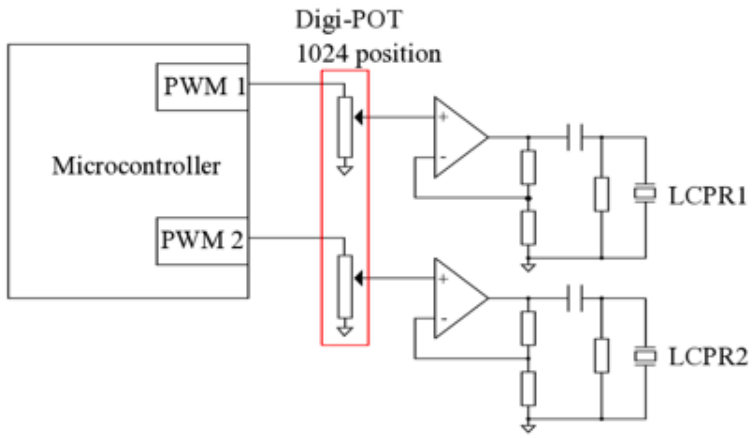


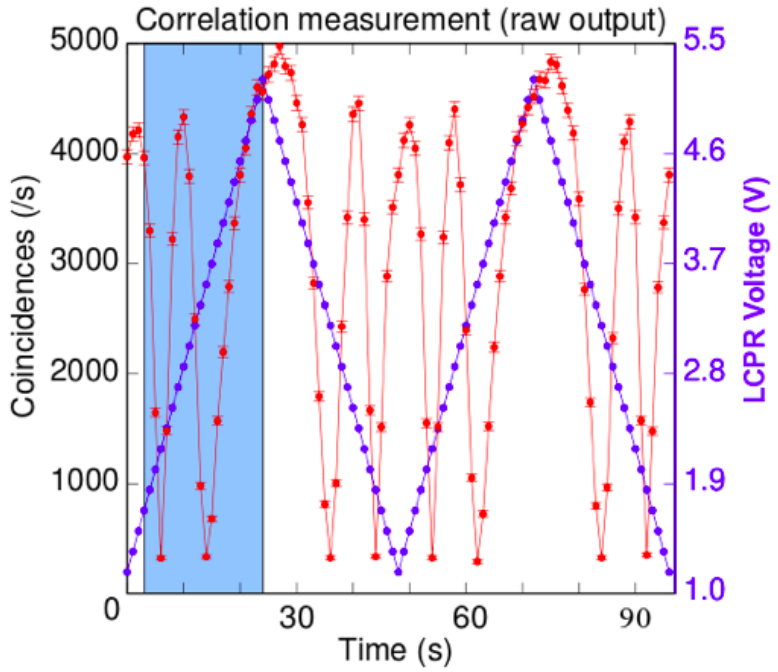
# Type I SPDC with BBO Crystals



# Verifying SPEQS on board



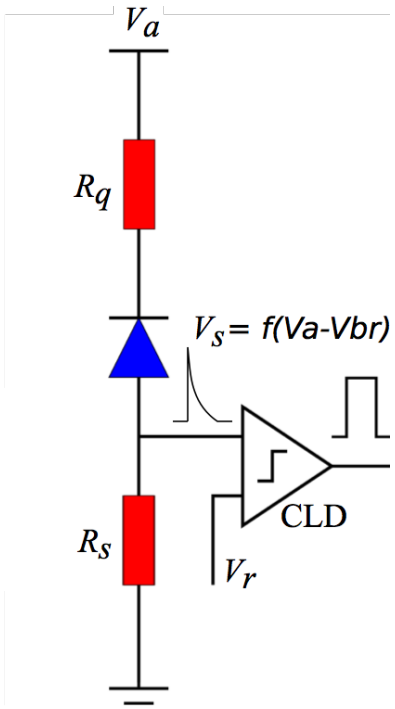



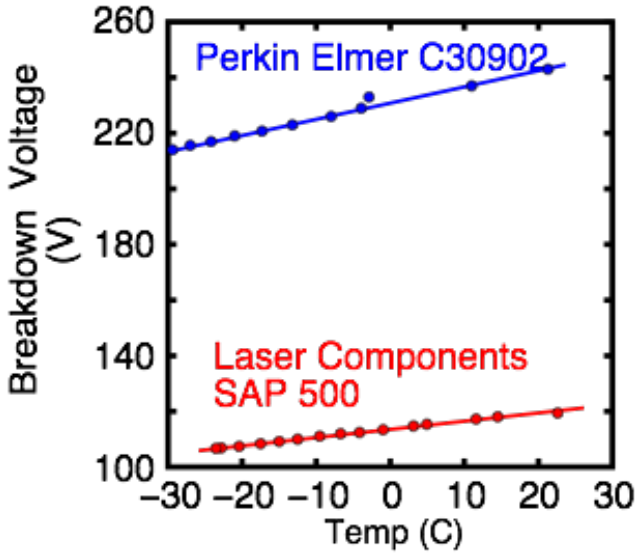

Liquid Crystal polarisation rotators

visibility = ( max - min ) / ( max + min )

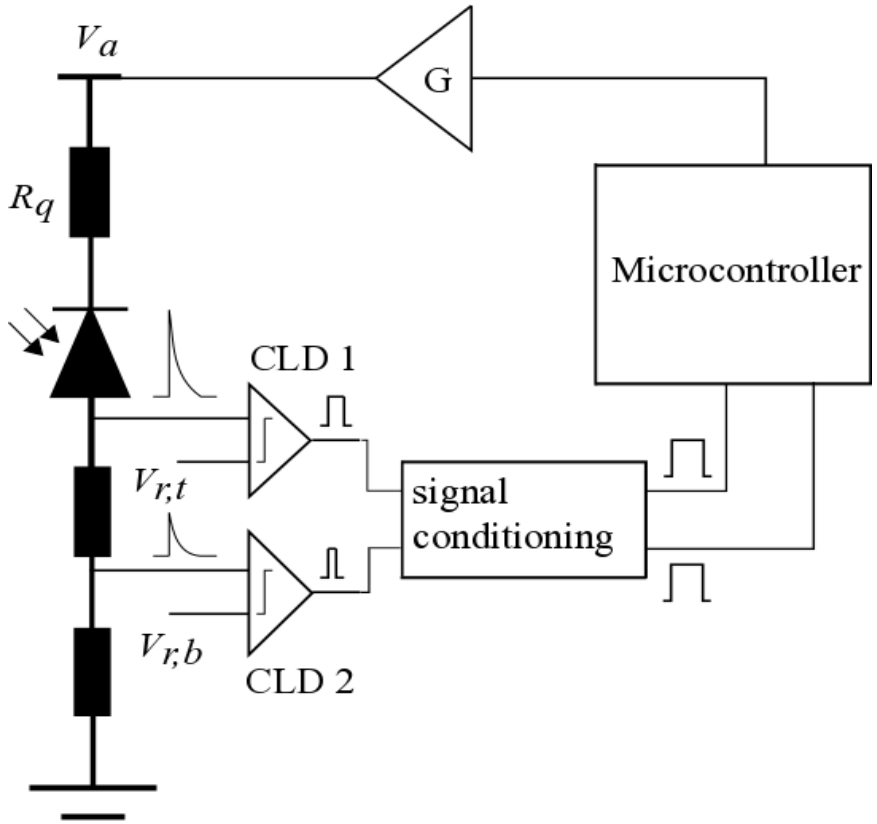
Visibility quantifies the quality of the source

# Uncooled, single photon detectors on board




- Detection efficiency varies with temperature
- Vary bias voltage to compensate




Cheng, C., et al. (2015). Space qualified nanosatellite electronics platform for photon pair experiments, 1–6.

# Iterative QKD source development

**Previous**

- Correlated photon sources
- 10 x 10 cm (1U) - Hosted by third party CubeSats

**Now**

- Entangled photon sources
- 20 x 10 cm (2U) size – Dedicated CubeSats

*Future*

- *Collaborator-built optical links.*
- *CQT-built **QKD** sources*

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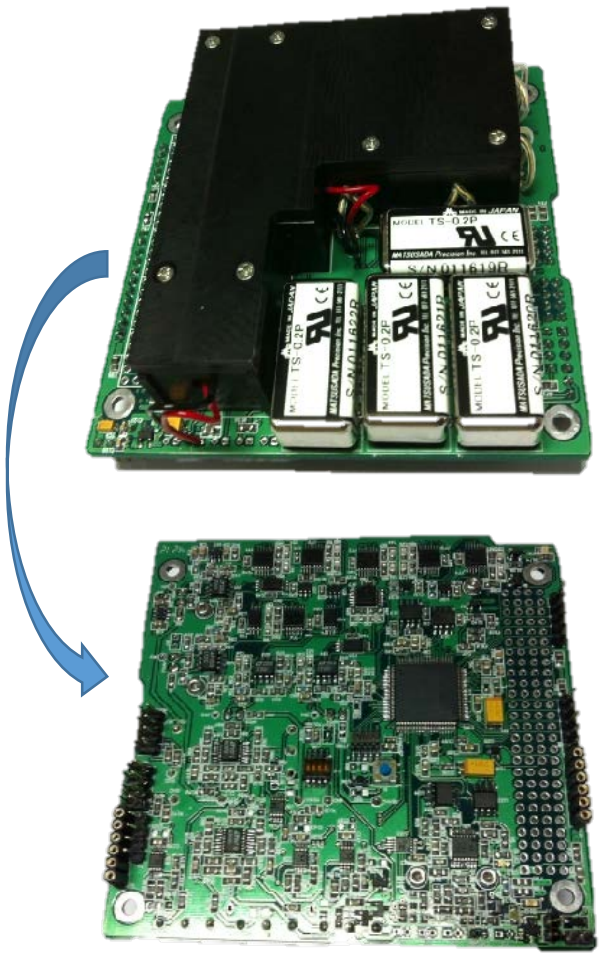
# SPEQS-CS (Correlated source)

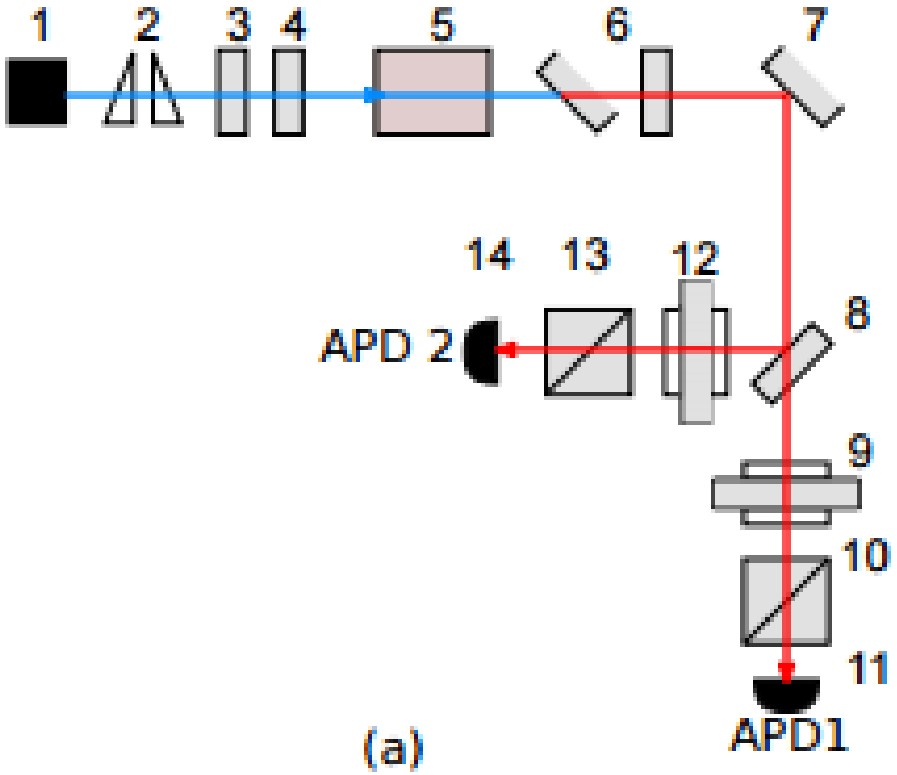


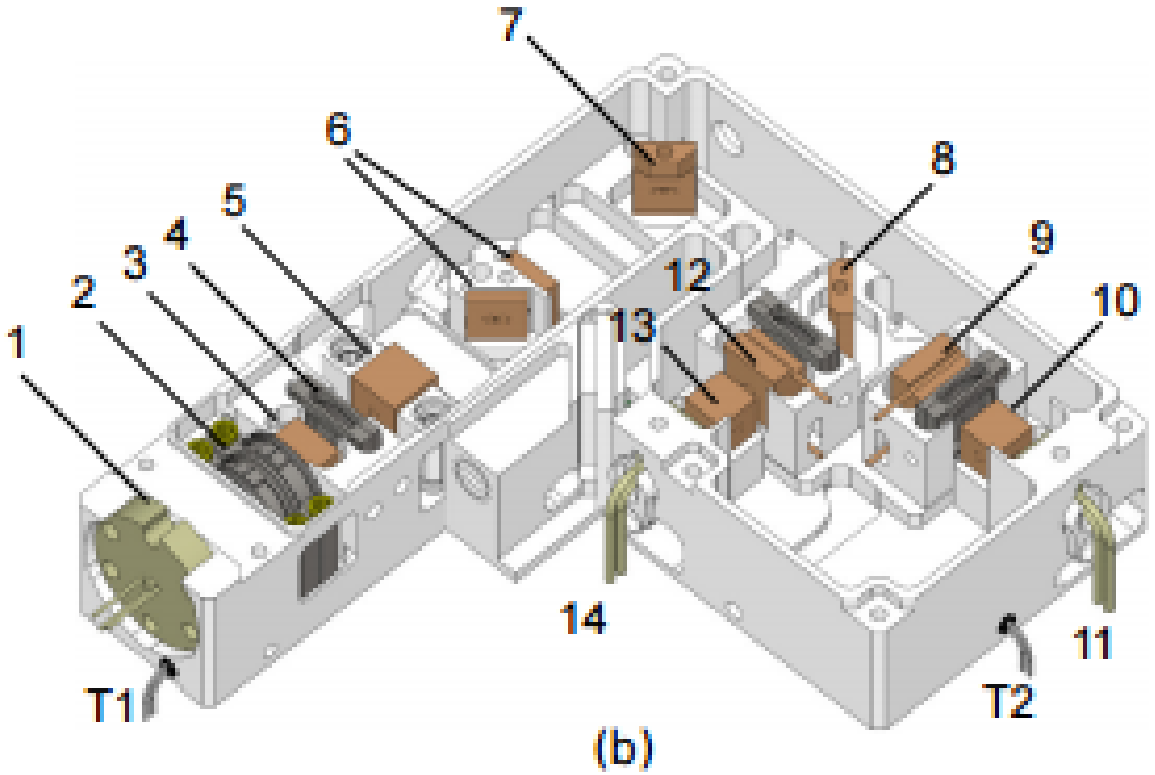
SPEQS – CS specs
- 1/3U
- < 300g
- < 2W

Provided as a black box payload to
- GomSpace
- NUS engineering dept.

Key challenges
- Miniaturisation and robustness
- Optical alignment
- GM-APD
  - Radiation effects
  - Temperature stability

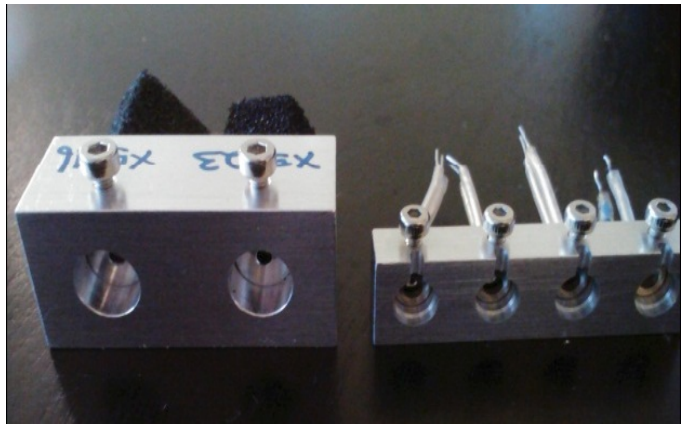
# Correlated source layout

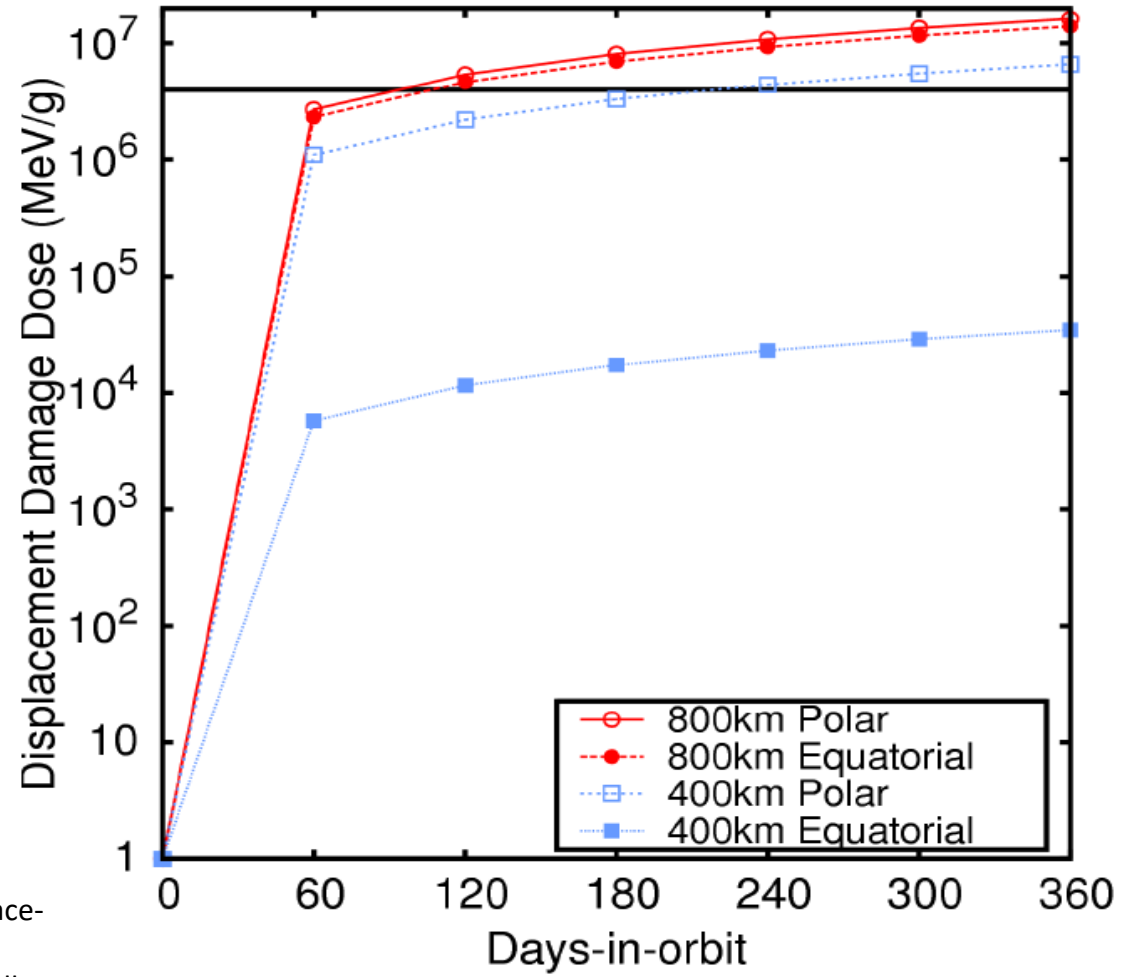



1. ONDAX laser diode
2. Risley prism pair
5. BBO crystal
6. Dichroic
7. Fold mirror
8. Dichroic
9, 12. LCPR
10, 13. PBS
11,14. GM-APDs
T1, T2. Thermistors

# TID – gamma, DD - protons

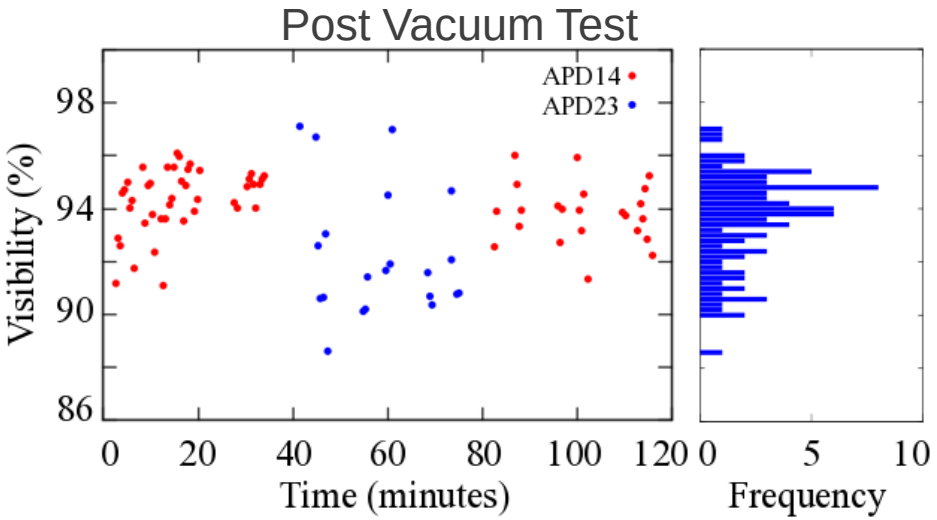


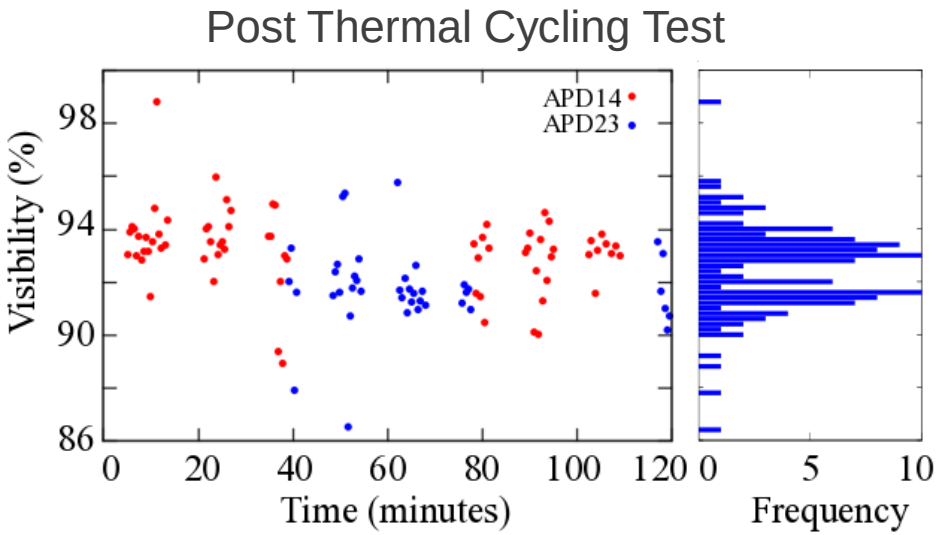


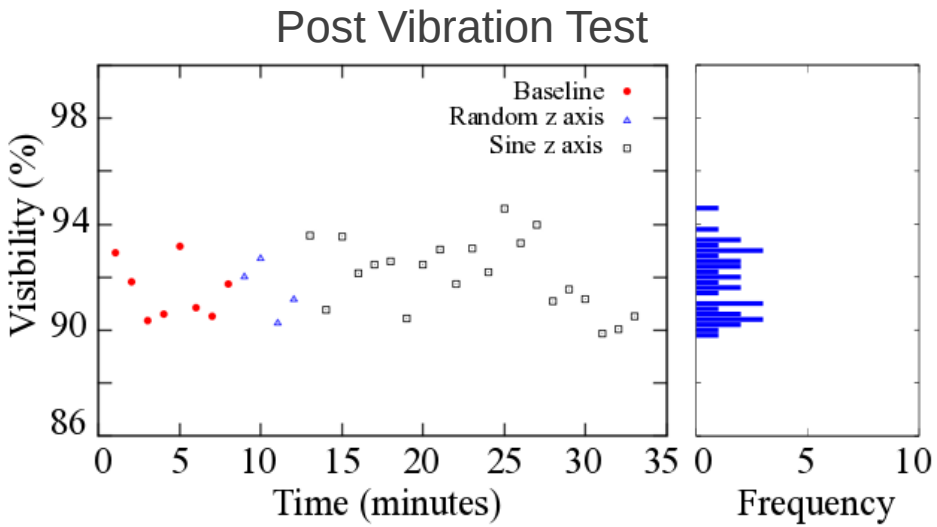

Tan, Y. C., et al. (2015). Radiation tolerance of opto-electronic components proposed for space-based quantum key distribution. *Journal of Modern Optics*, *62*(20), 1709–1712.
Tan, Y. C., et al. (2013). Silicon avalanche photodiode operation and lifetime analysis for small satellites. *Optics Express*, *21*(14), 16946

# Space qualification tests

- Vacuum test - $10^{-6}$ mbar over 24 hours
- -10 C to +40 C ramping up and down 50mins
- sine sweep (5 -100Hz) 2.5g
- random ( 20 - 2000 Hz) 7.4 g rms



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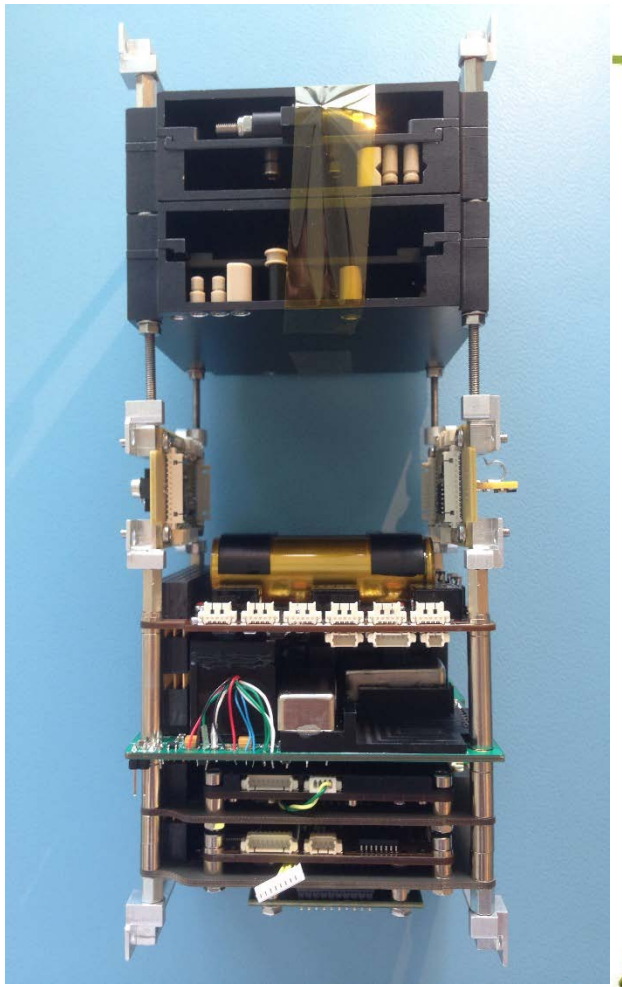
# Correlated source pathfinder missions

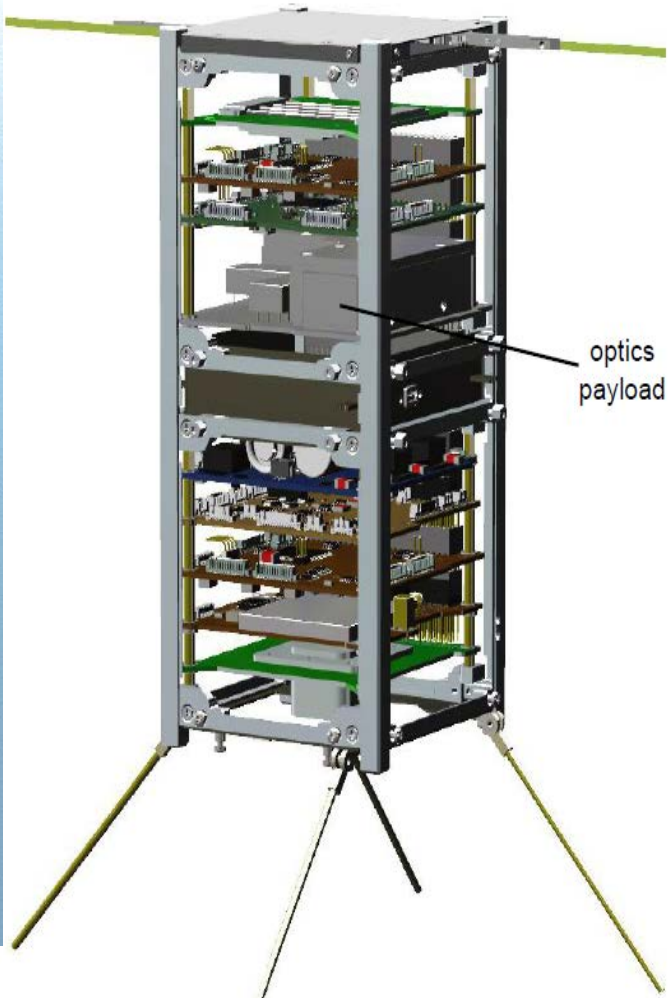
2012/13

37.5km

2014 *GomX-2*



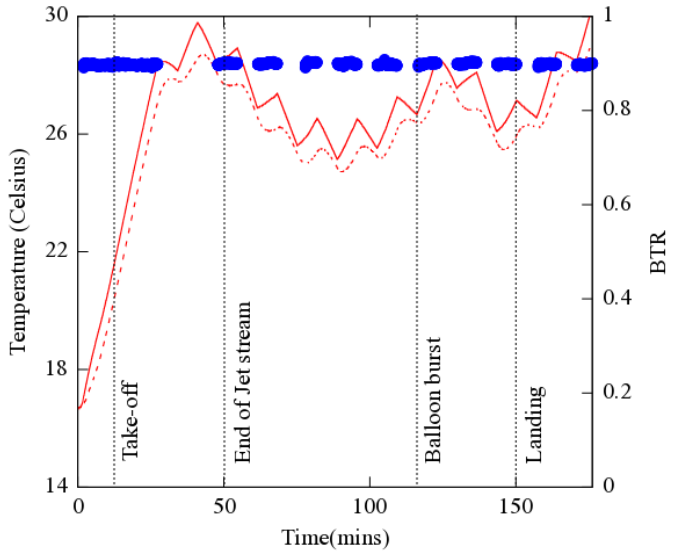
2015 *Galassia*

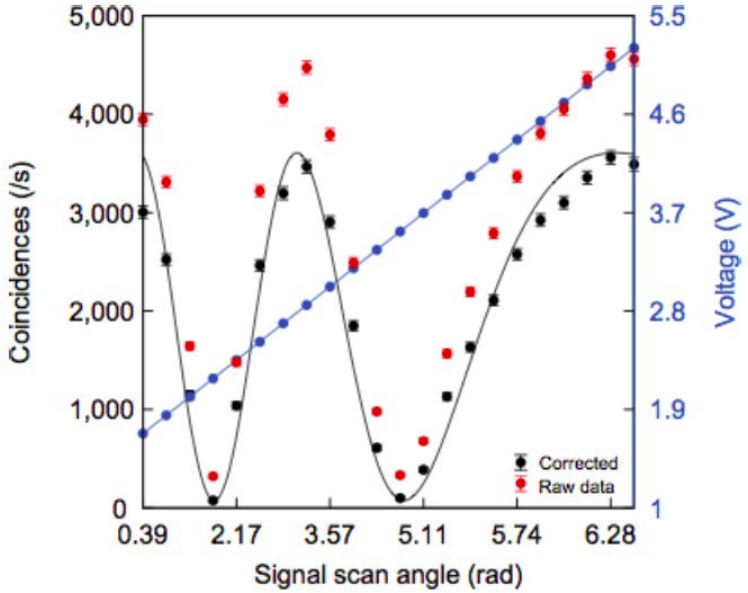


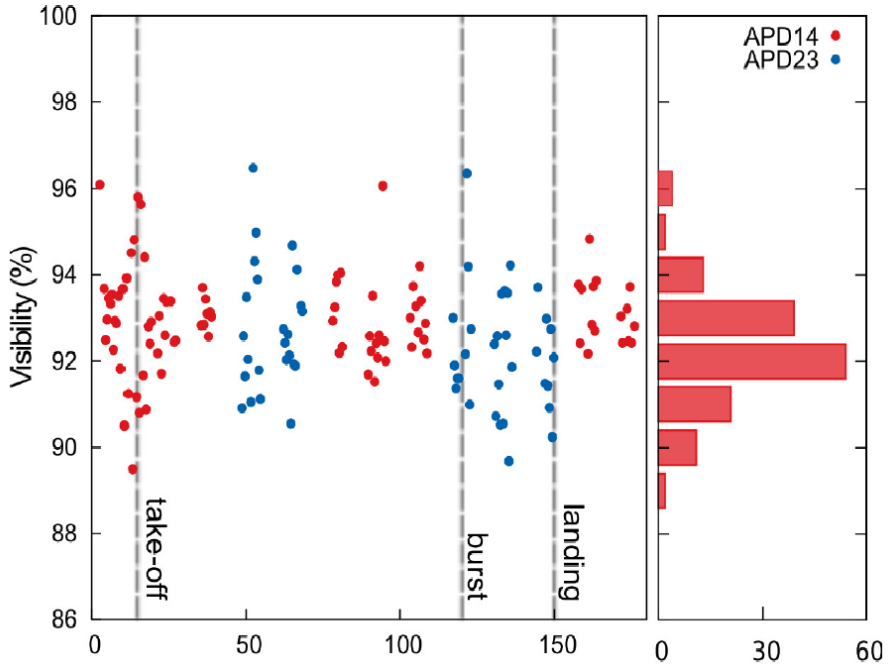
# Near Space Demonstration

- Location - Sursee, Switzerland
- Max altitude - 35.5 km
- Max acceleration – 22g
- Temp 0 to 20 deg Celsius
- In collaboration with Sursee Radio club

# SPEQS-CS performance



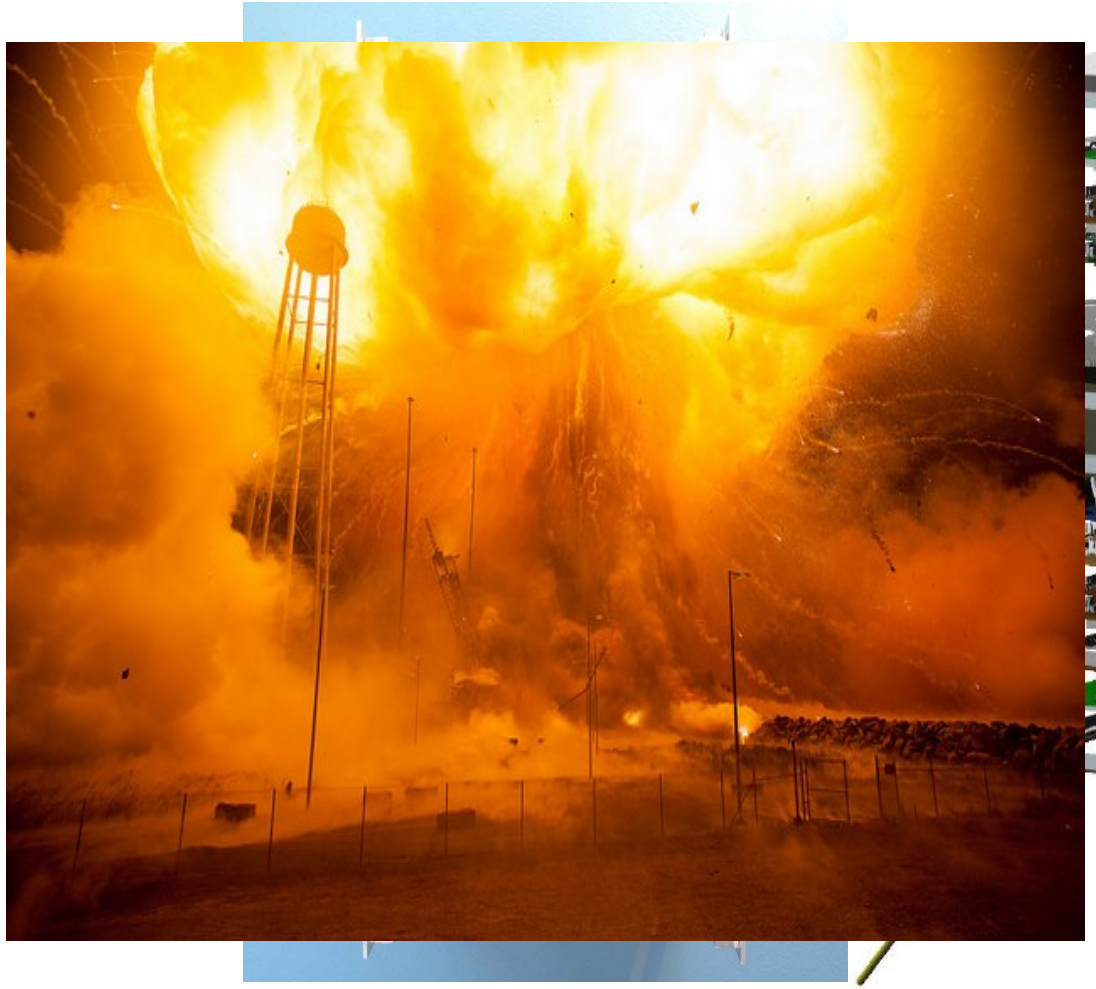





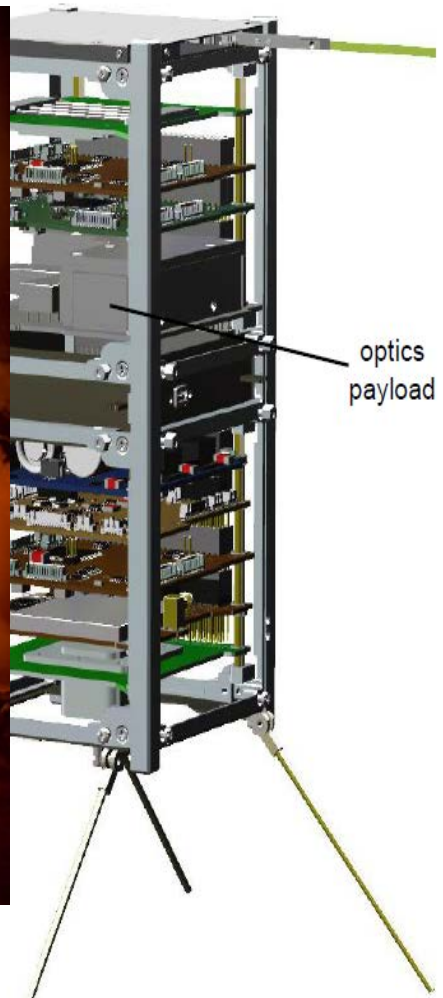
Z. Tang et. al. “Near-space flight of a correlated photon system”, Scientific Reports, vol. 4, no. 6366, 2014

# Correlated source pathfinder missions

2012/13 2014 *GomX-2* 2015 *Galassia*



37.5km



# Post explosion

Cornell University Library

arXiv.org > quant-ph > arXiv:1504.00171

Quantum Physics

## Extreme environmental testing of a rugged correlated photon source

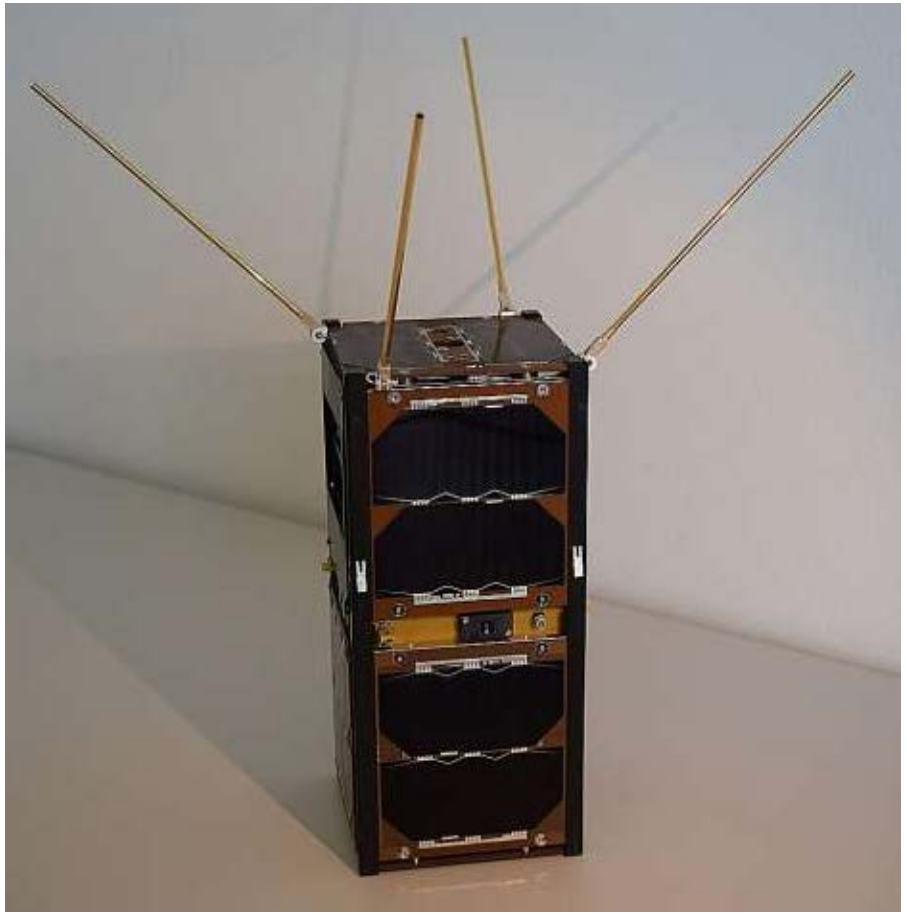
James A. Grieve, Robert Bedington, Alexander Ling

(Submitted on 1 Apr 2015)

Experiments in long distance quantum key distribution have motivated the development of ruggedised single photon sources, ca
from the warm, nurturing environment found in most optics laboratories. As part of an ongoing pro- gramme to place such device
number of rugged single photon sources based on spontaneous parametric downconversion. In order to evalu- ate device reliabi
mechanical and atmospheric stresses. Our results show that while such a device may tolerate launch into orbit, operation in orbi
unable to survive the forcible disassembly of a launch vehicle at the top of a ball of rapidly expanding and oxidising kerosene an

*"Our results show that while such a device may tolerate launch into orbit, operation in orbit and casual mishandling by graduate students,* ***it is probably unable to survive*** *the forcible disassembly of a launch vehicle at the top of a ball of rapidly expanding and oxidising kerosene and liquid oxygen."*

# GomX-2 recovered!



SCIENTIFIC REPORTS

OPEN

## The photon pair source that survived a rocket explosion

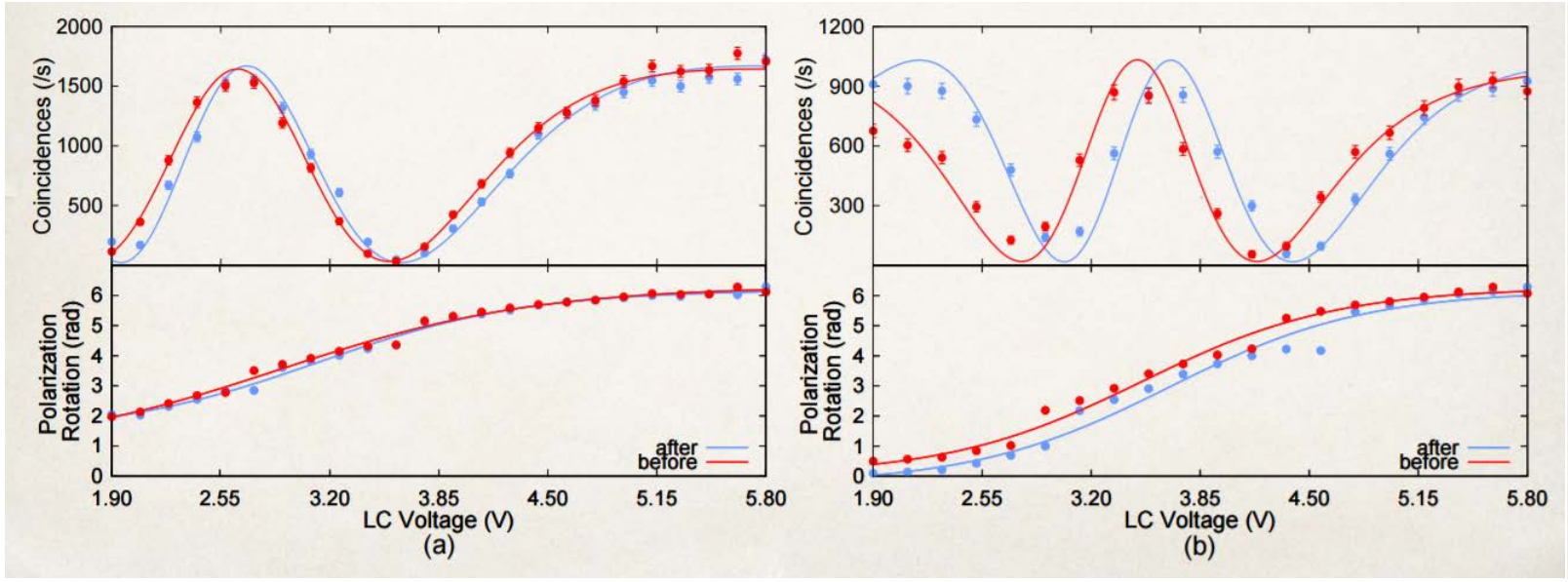
Zhongkan Tang[1], Rakhitha Chandrasekara[1], Yue Chuan Tan[1], Cliff Cheng[1], Kadir Durak[1] & Alexander Ling[1,2]

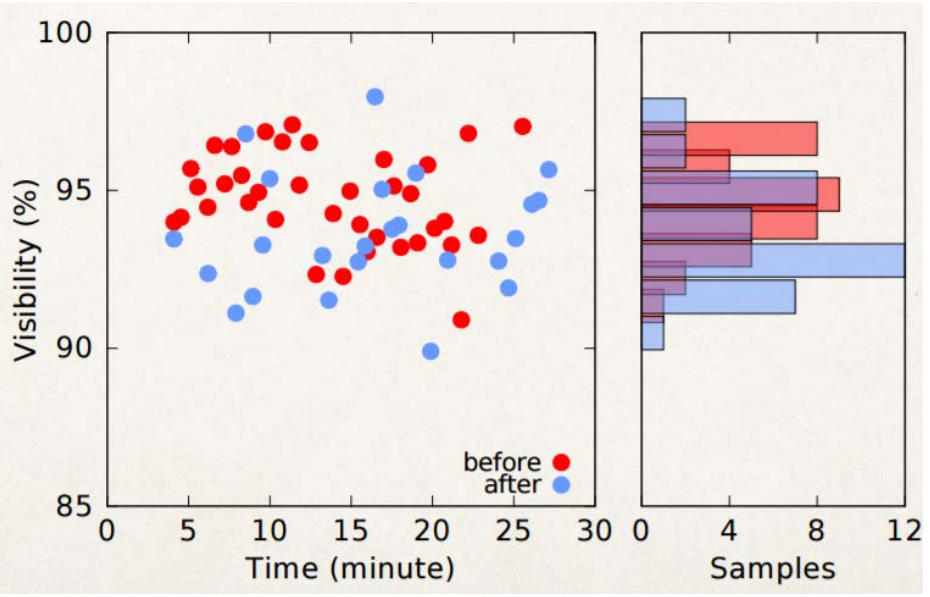
Received: 30 January 2016
Accepted: 18 April 2016
Published: 10 May 2016

We report on the performance of a compact photon pair source that was recovered intact from a failed space launch. The source had been embedded in a nanosatellite and was designed to perform pathfinder experiments leading to global quantum communication networks using spacecraft. Despite the launch vehicle explosion soon after takeoff, the nanosatellite was successfully retrieved from the accident site and the source within it was found to be fully operational. We describe the assembly technique for the rugged source. Post-recovery data is compared to baseline measurements collected before the launch attempt and no degradation in brightness or polarization correlation was observed. The survival of the source through an extreme environment provides strong evidence that it is possible to engineer rugged quantum optical systems.

# Post explosion correlated source performance

| parameter | baseline | post-recovery |
|---|---|---|
| pump threshold | 27.8 mA | 27.8 mA |
| stabilised pump power | 12 mW | 12 mW |
| APD dark count rate | 13000 cps | 14500 cps |



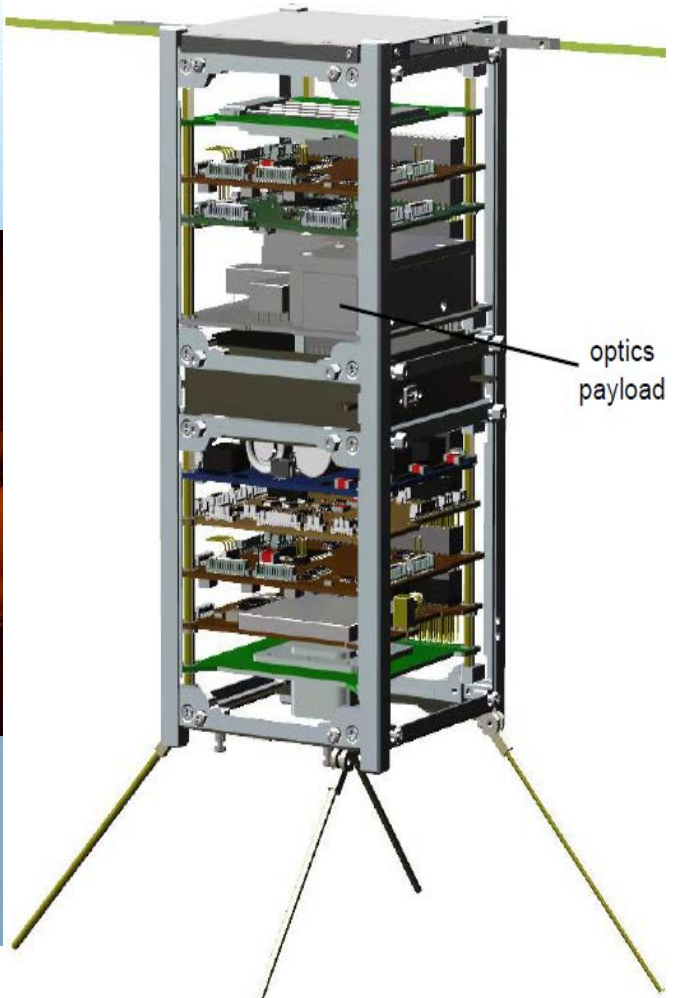

Scientific Reports, 6, 25603, 2016

# Correlated source pathfinder missions

2012/13

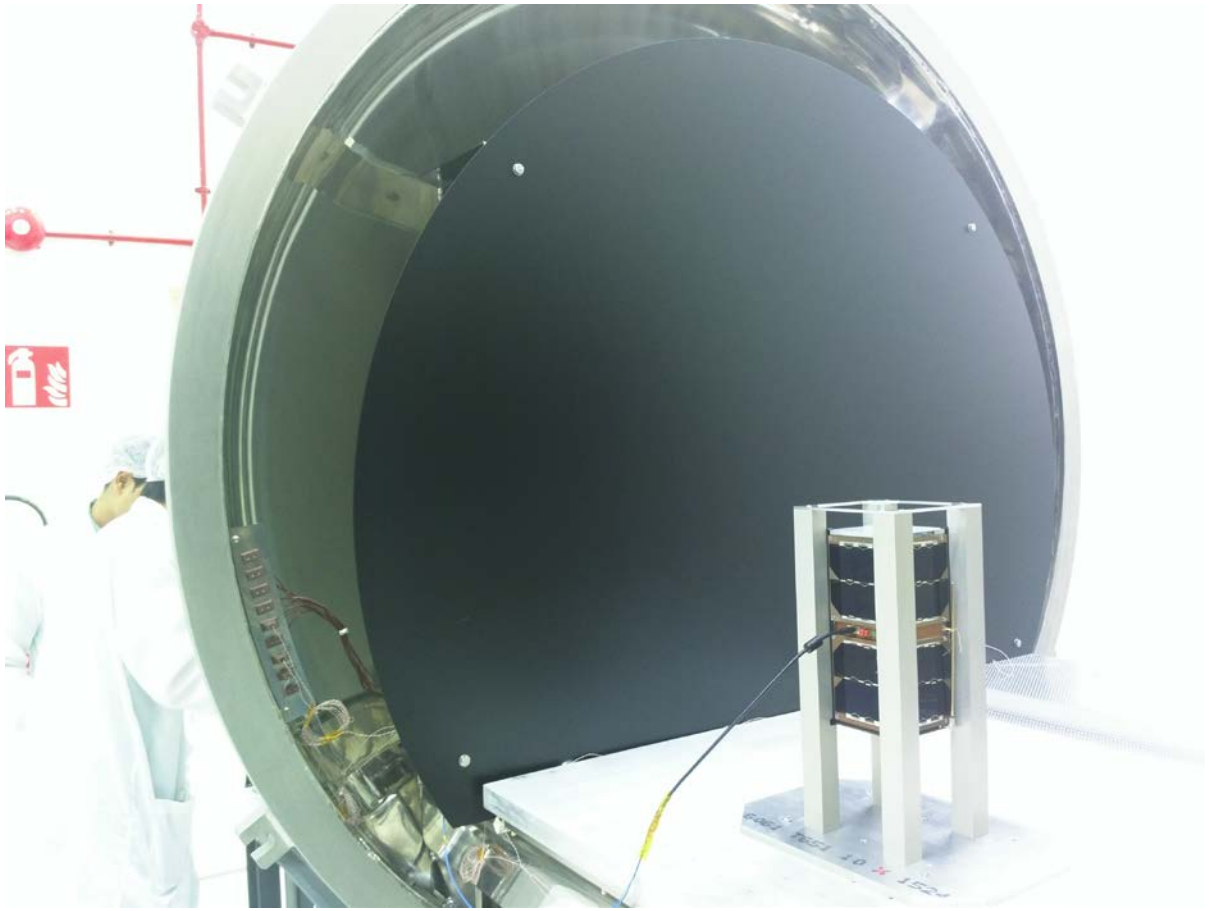
2014 *GomX-2*

2015 *Galassia*

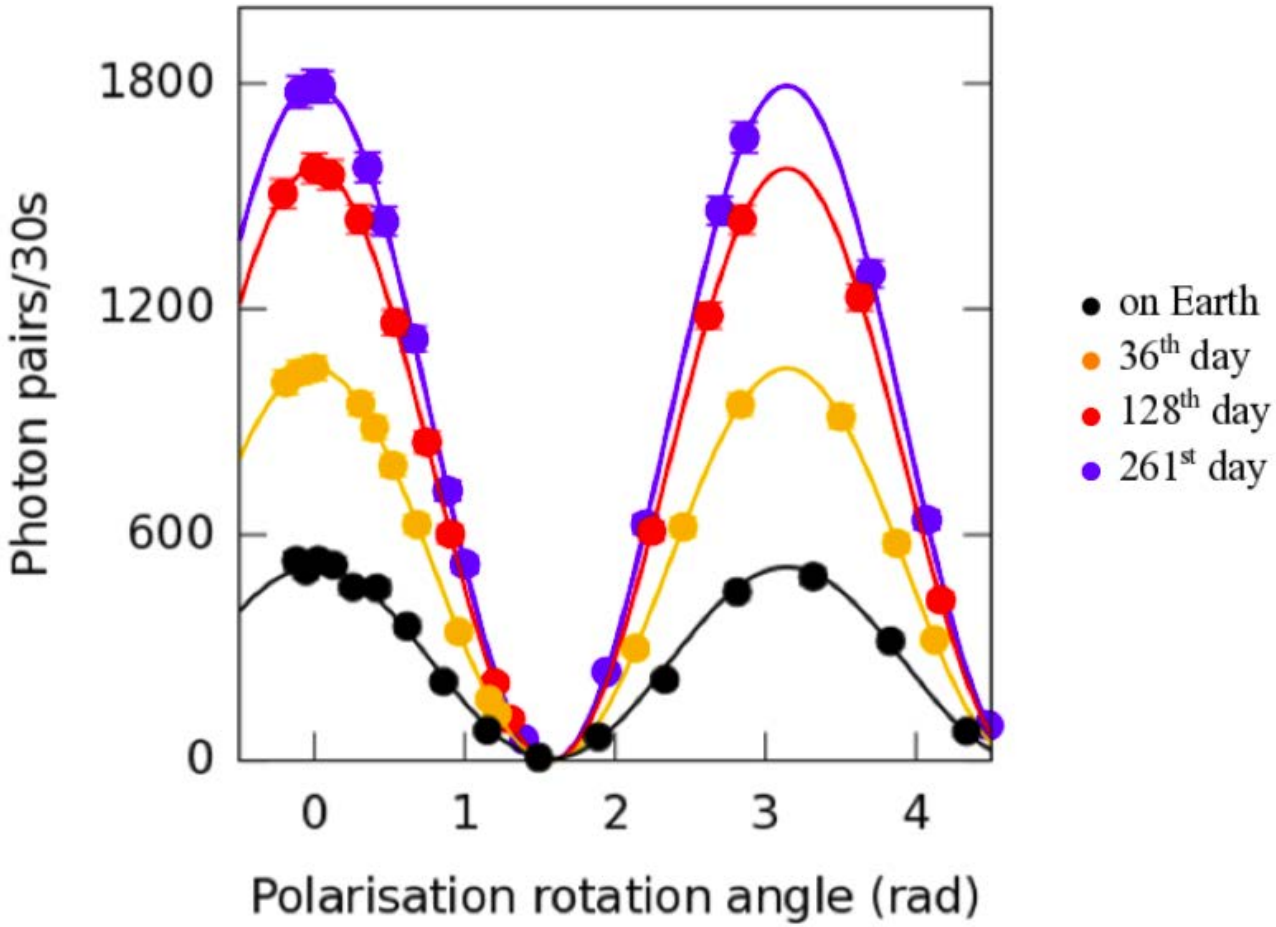


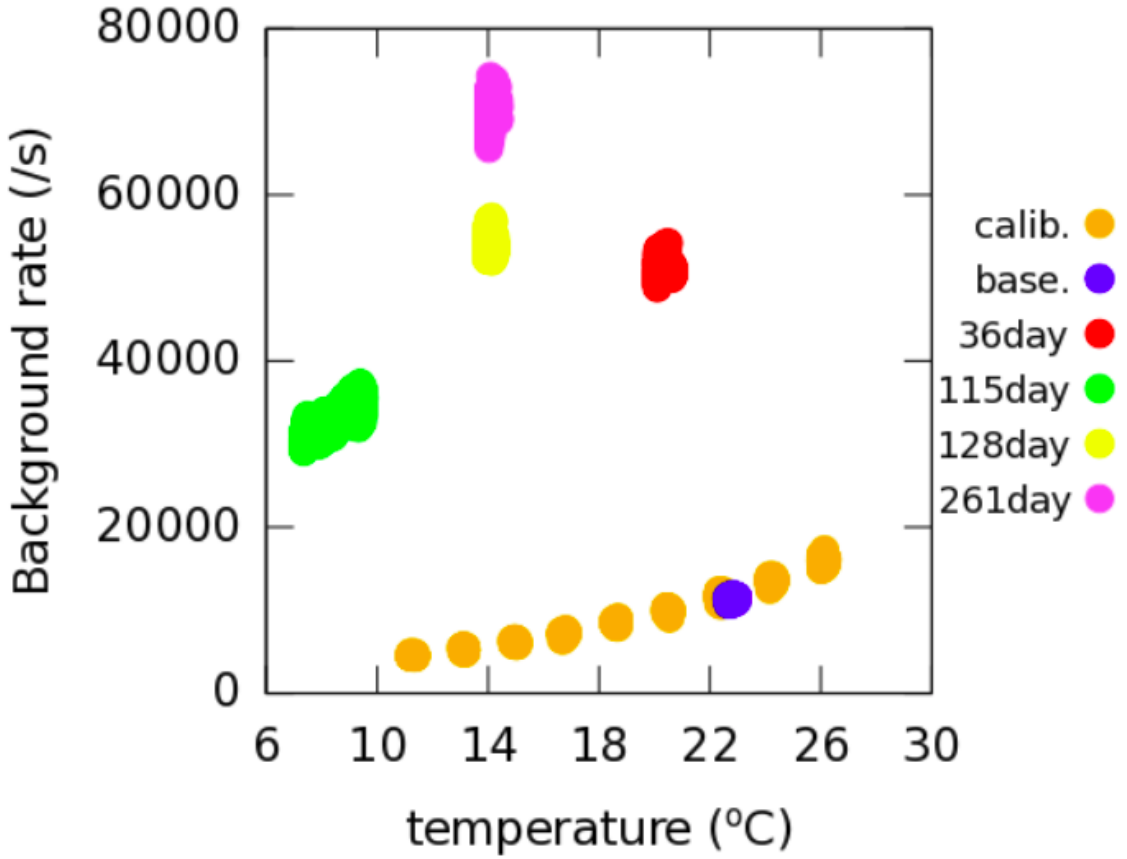

37.5km

# Galassia – 2U student-built CubeSat



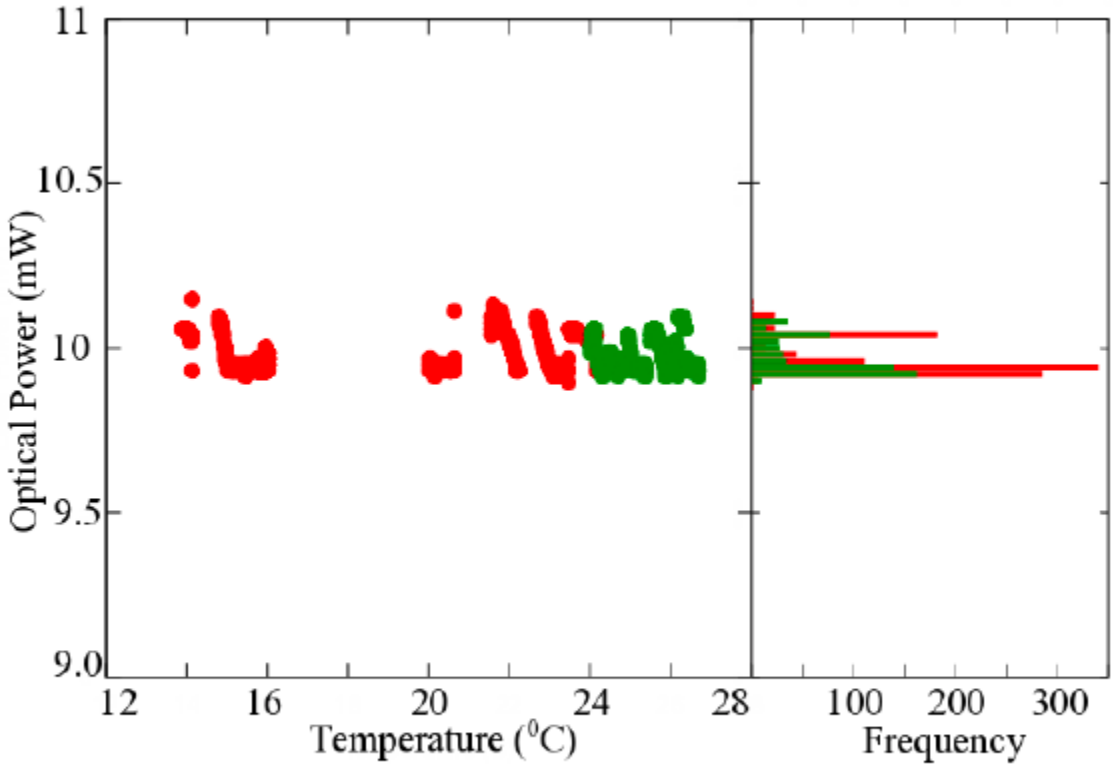
# In-orbit correlated source results



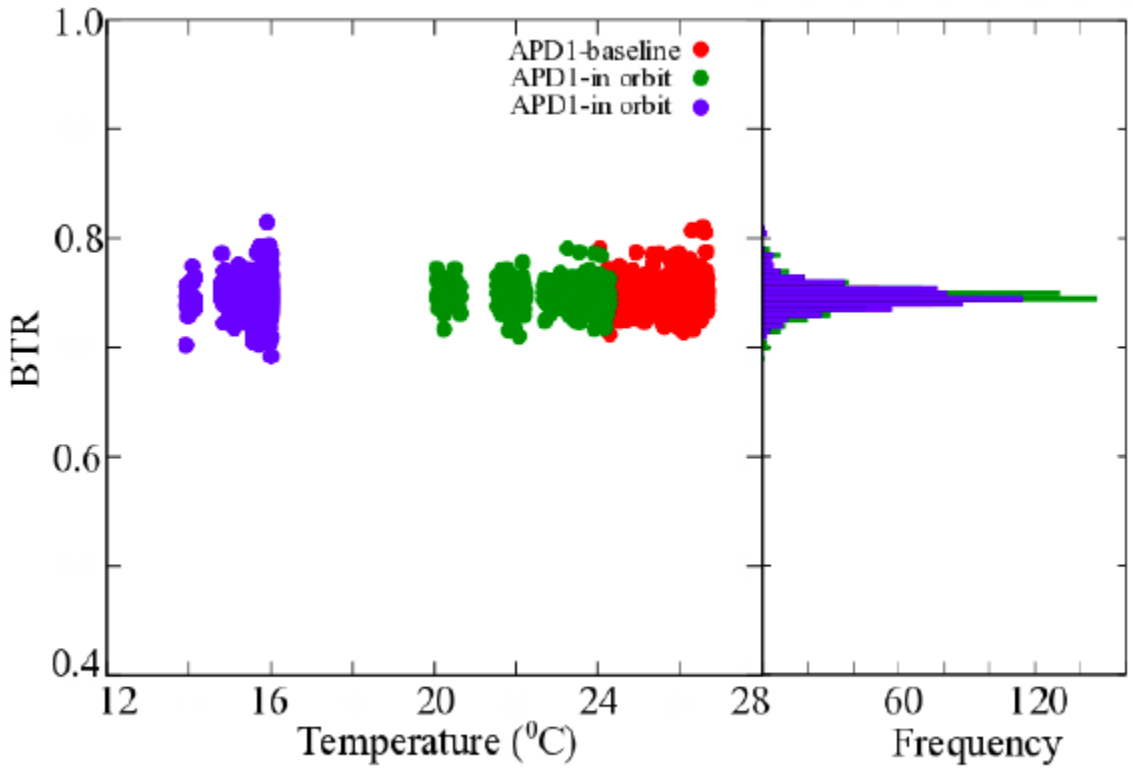




Z. Tang et al. "Generation and analysis of correlated pairs of photons onboard a nanosatellite', Physical Review Applied, vol. 5, 054022, 2016

# In-orbit Subsystem performance




Optical power stabilisation 9.975 +/- 0.051 mW




GM-APD BTR maintenance 0.75 +/- 0.04

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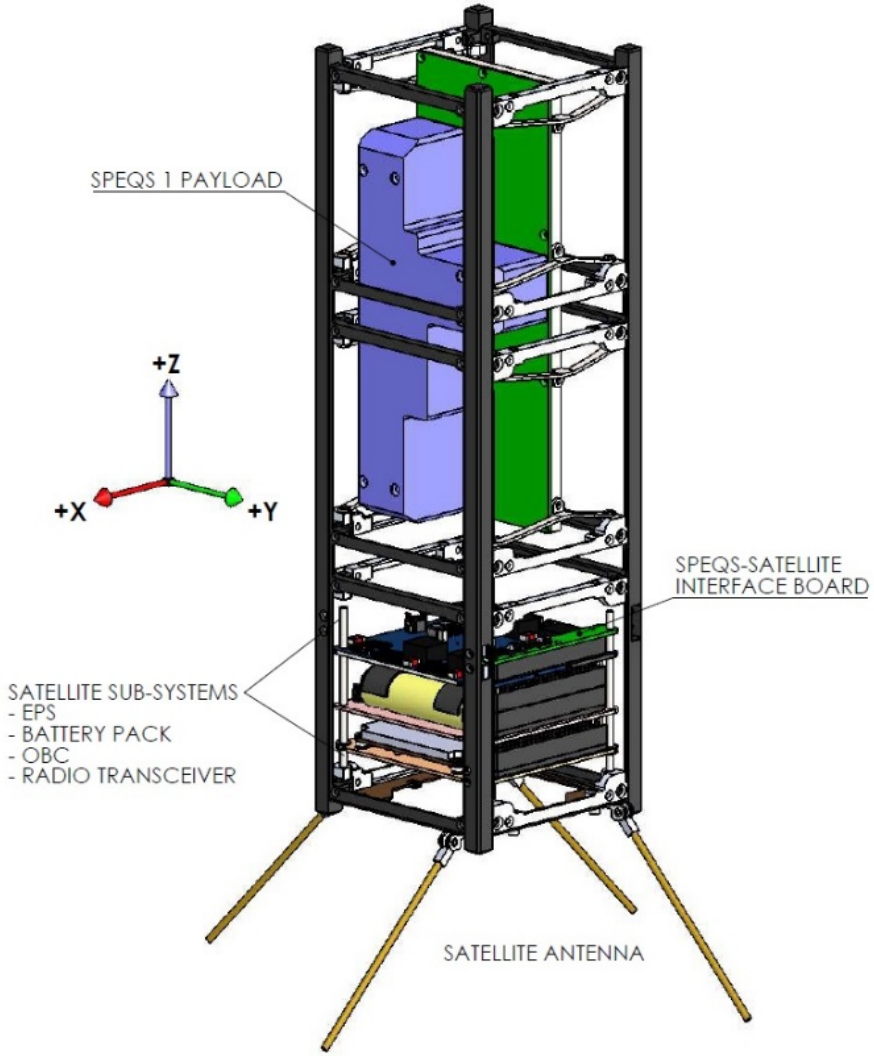
# CQT SpooQySat demonstration programme

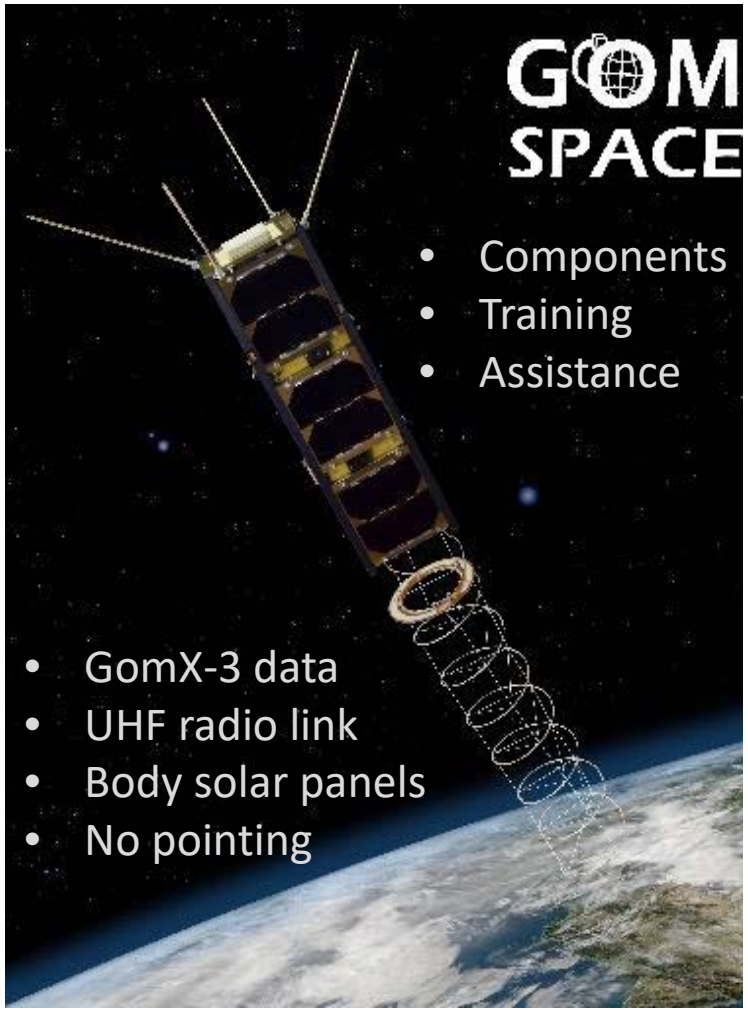
SpooQy

***GomX platform - capability-driven missions***

**SpooQy-1**
First entangled source on a CubeSat.
Launch 2018

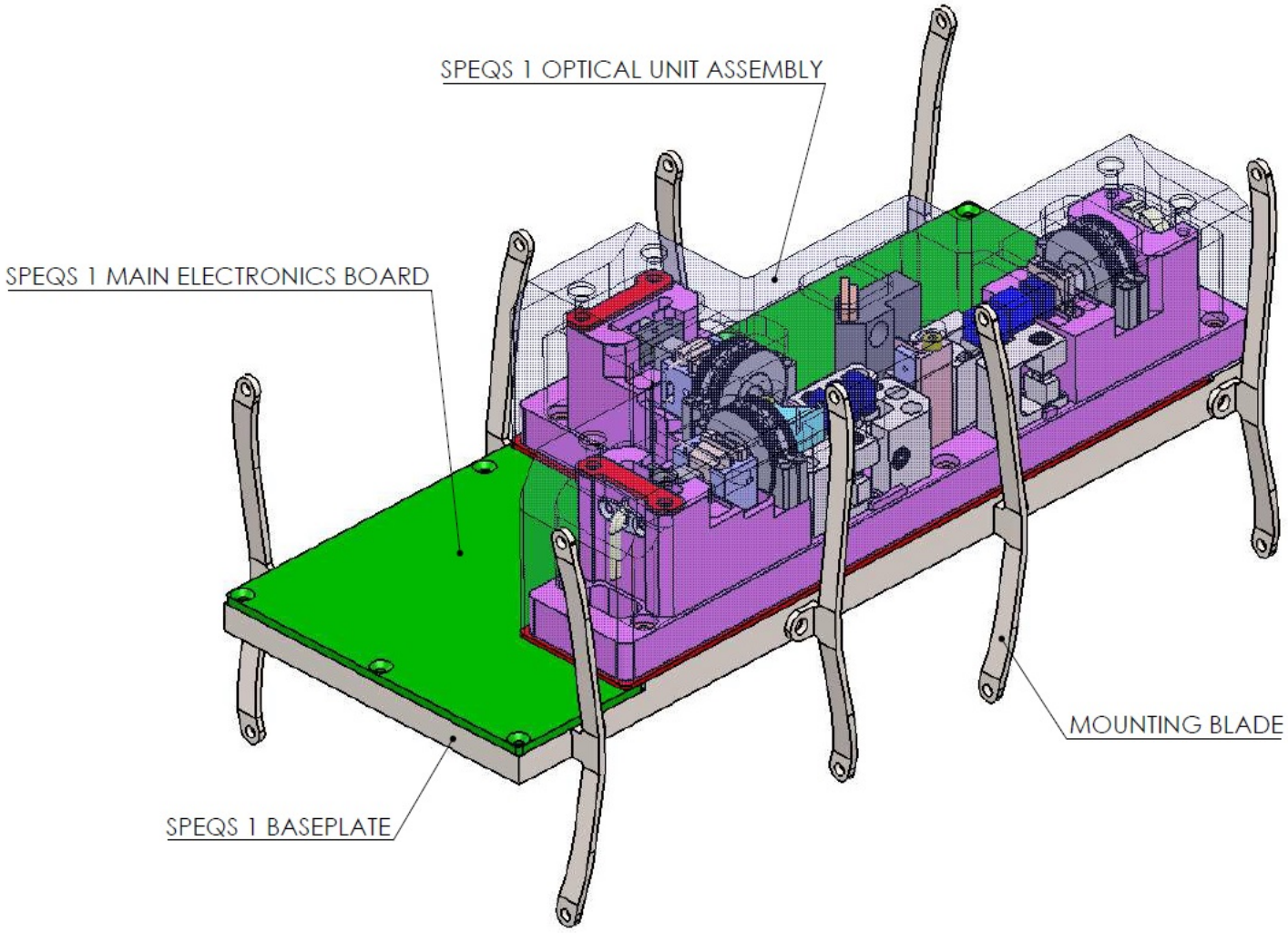
**SpooQy-2**
High brightness entangled photon source.
Launch 2019



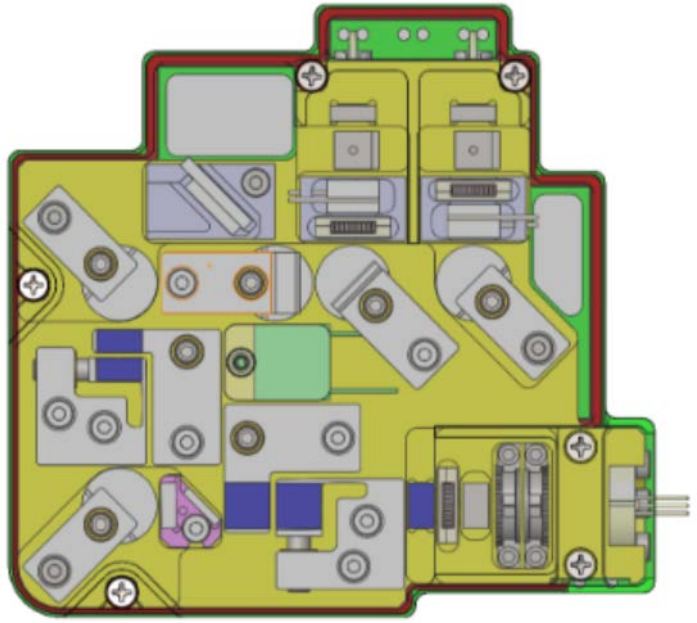
# Technologies demonstating

- Entanglement upgrade
- New form factor
- New flexure stages
- LCPR locking
- Thermal controls

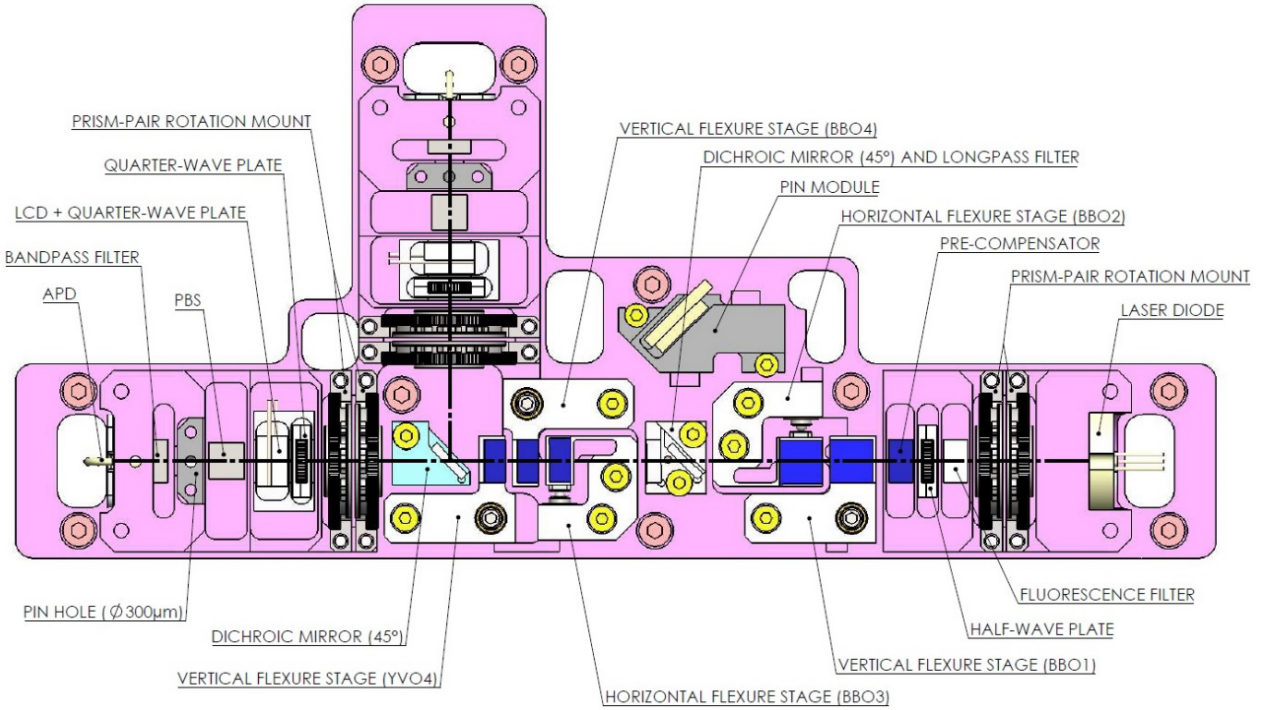


# SPEQS-1 Entangled photon source

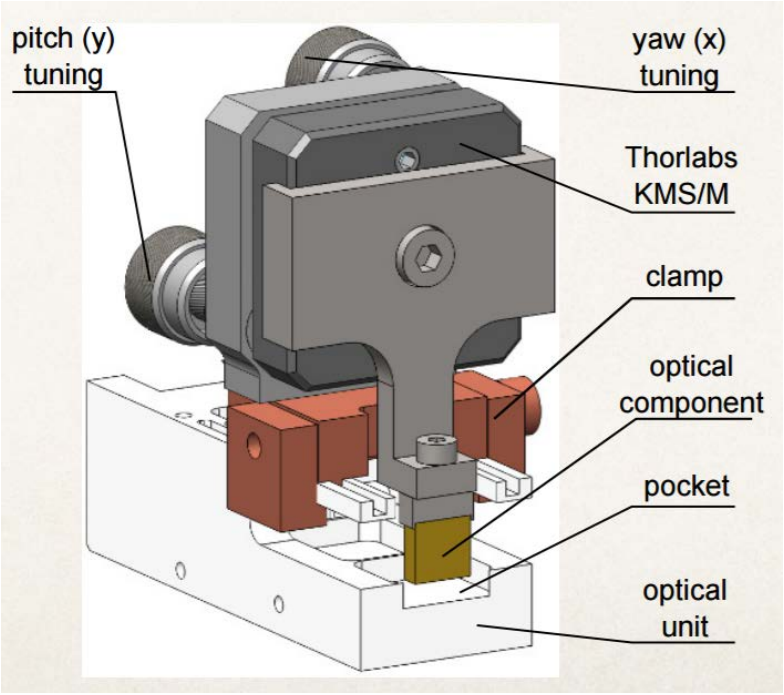
1U Layout



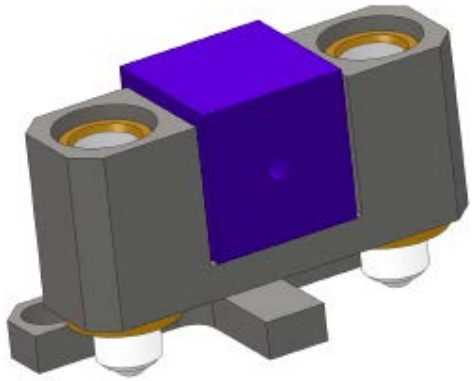
2U Layout



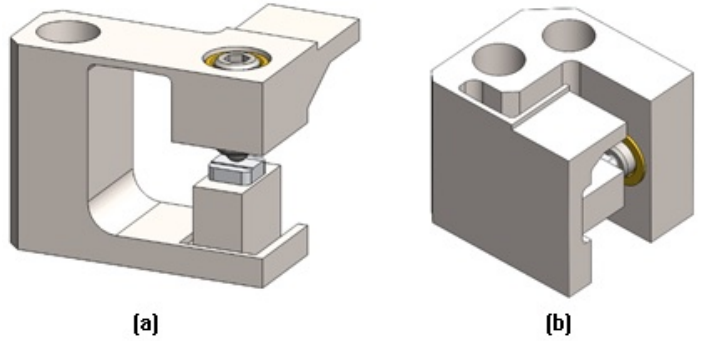
# Optimising and maintaining alignment




Align and glue



Flexure stage




Improved flexure stage

# Performance targets

| | SPEQS-1 CS [26] | *SPEQS-1* | *SPEQS-2* |
|---|---|---|---|
| Brightness | 3,000 | *3,000* | *1,000,000* |
| Visibility | 96% | *96%* | *99%* |
| Efficiency | 1% | *1%* | *20 %* |
| Power (peak) | 2.5W | *2.5W* | *10W* |
| Mass | 0.3kg | *0.5kg* | *1kg* |
| Volume | 0.25U | *0.5U* | *1U* |

Bedington, R., et al. (2016). Nanosatellite experiments to enable future space-based QKD missions. *EPJ Quantum Technology*, *3*(1), 12. https://doi.org/10.1140/epjqt/s40507-016-0051-7

# SPEQS-2 High brightness entangled source

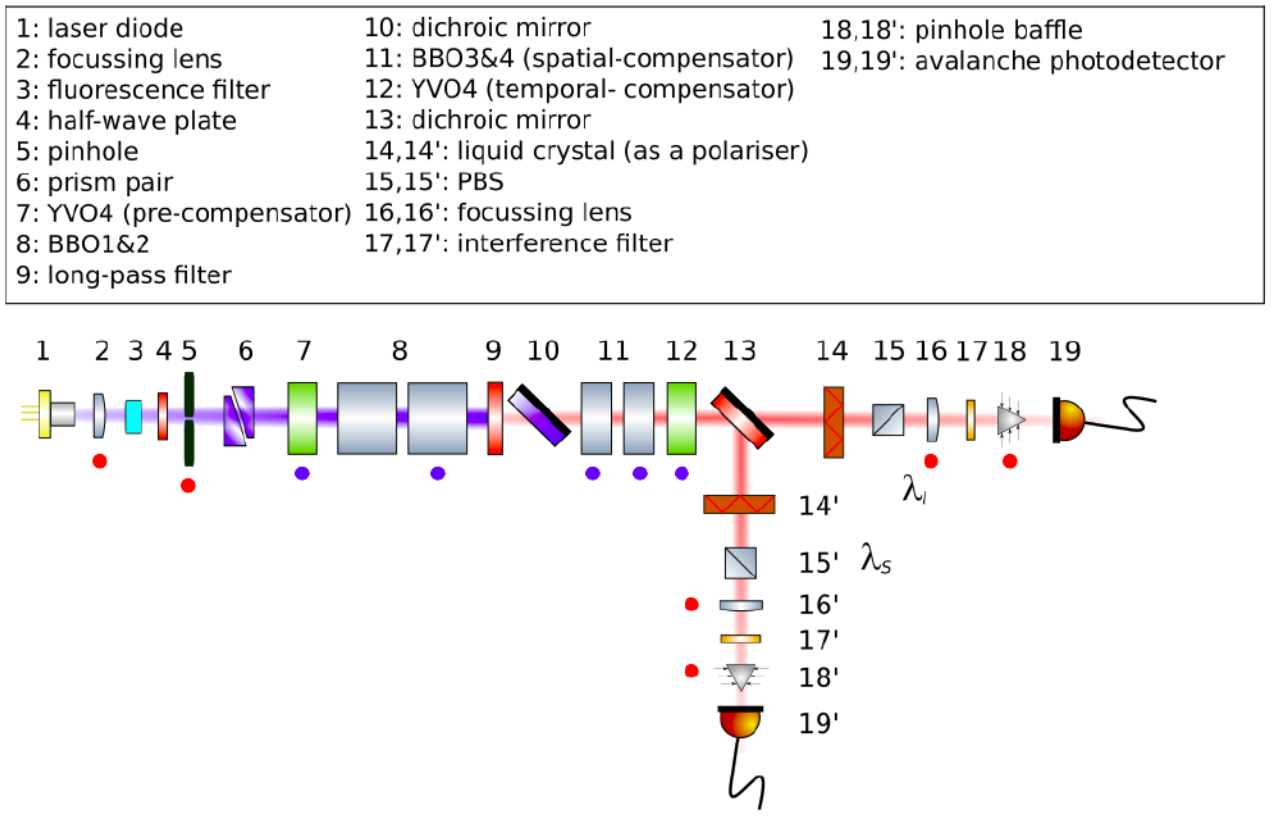


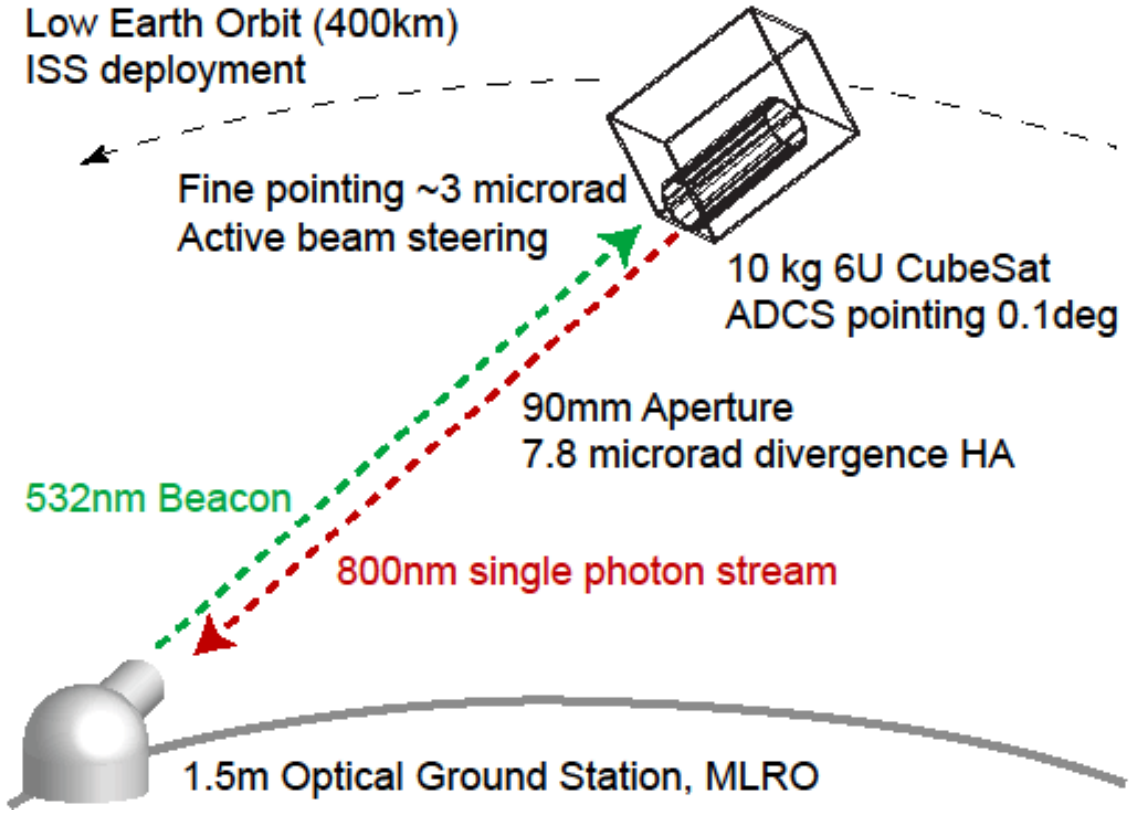

**Figure 4** SPEQS-2 optical layout (SPEQS-1 omits the components with red spots, SPEQS-1-CS additionally omits the components with blue spots).

- In development
- Demonstrates
  - High brightness
  - Collection lenses
  - Pinhole baffles
  - Active quench APDs
  - Alternative geometries?
  - Piezo flexures?
- Challenges
  - Thermal
  - Stray light
  - Count rates

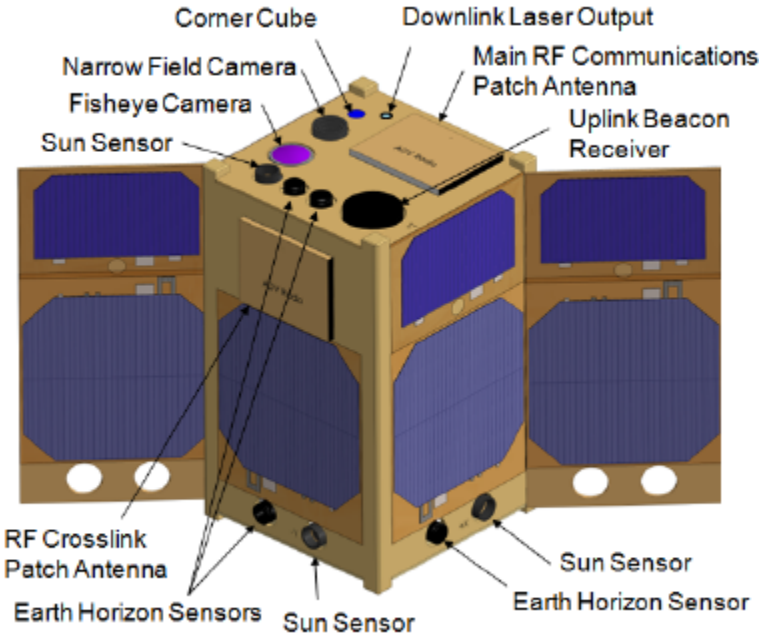
# Contents

- Miniaturised entangled photon sources for CubeSats
  - Key technologies
- Current and previous missions: SPEQS-CS
  - results
- Upcoming missions: SpooQySats
  - challenges
- Future missions
  - Challenges

# QKD demonstrators with CubeSats?



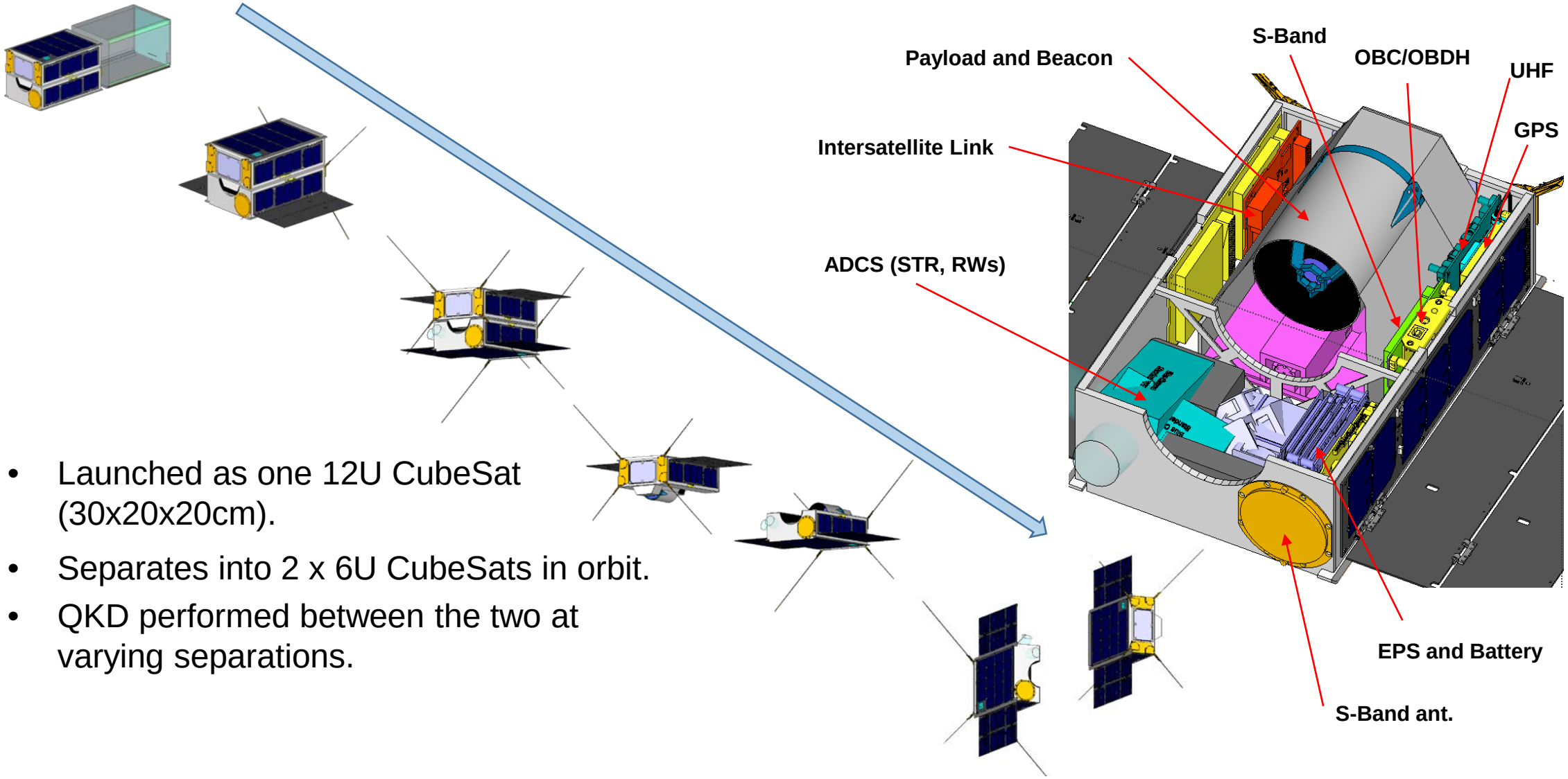

AeroCube-OCSD




Janson & Welle SSC13-II-1

*Oi, D. K. L. et al. (2016). Nanosatellites for quantum science and technology.*

# UNSW:Canberra-led Inter-satellite QKD study




- Launched as one 12U CubeSat (30x20x20cm).
- Separates into 2 x 6U CubeSats in orbit.
- QKD performed between the two at varying separations.

# Seeking collaborators!

CQT can provide and fund the entangled source

We are seeking:

- Space-based, optical transmitters
  - Active beam steering
  - Micro-radian pointing
- Optical ground stations
- Alternative scenarios
  - Drones, inter-satellite, balloons, ships ….

Also seeking students, post-docs, interns, **thermal/mechanical engineers**

More Info: http://www.quantumlah.org/AlexLinggroup