Entangled Photon Systems for Small Satellites

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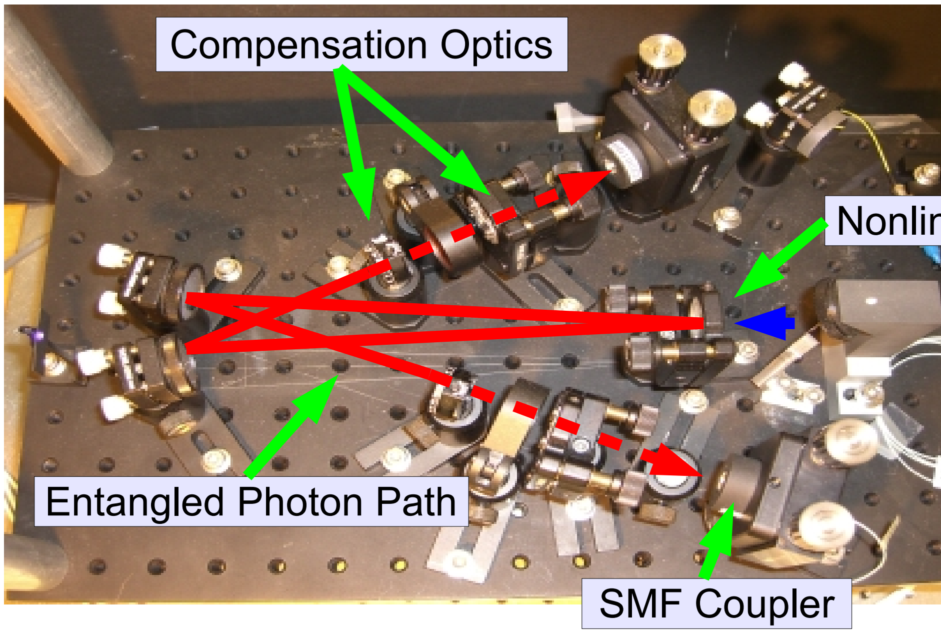
NASA QFT 1.0, Moffett Field, CA

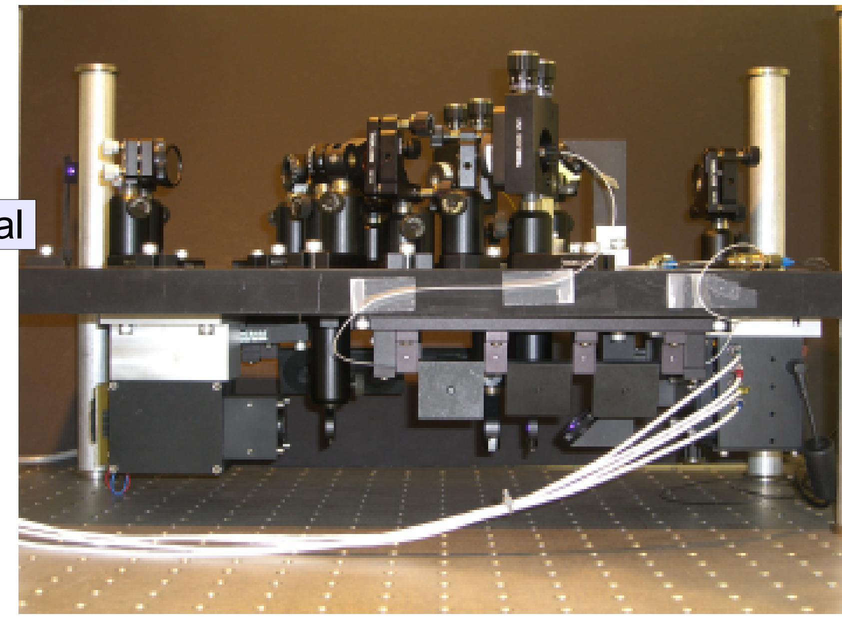
Centre for Quantum Technologies

Agenda

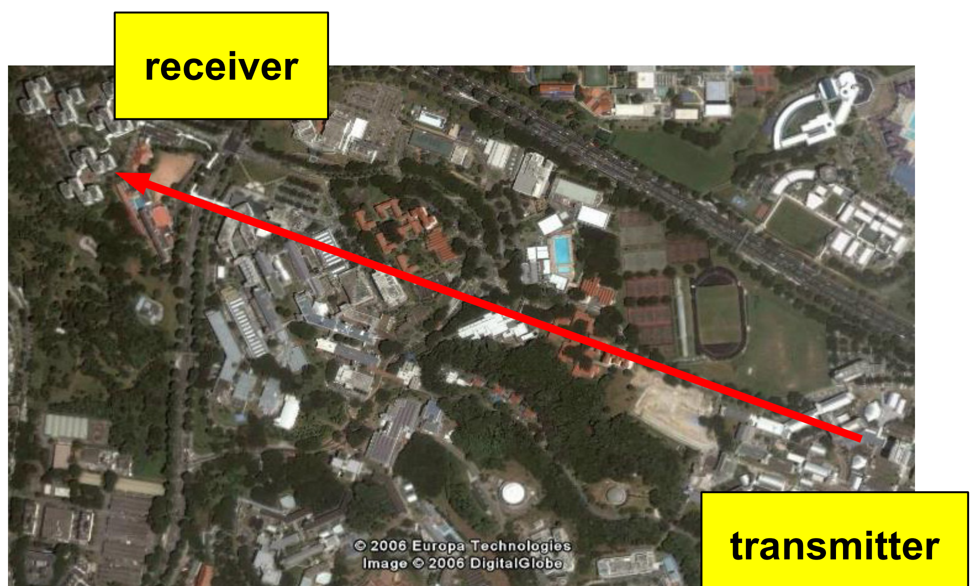
- Portable Entanglement Systems, Long Distance QKD?
- Economy Satellites?
- LEO Challenges
- What we are building

“Portable” Photon Pair System





NUS Test Range
1.5 km



Entanglement Distribution

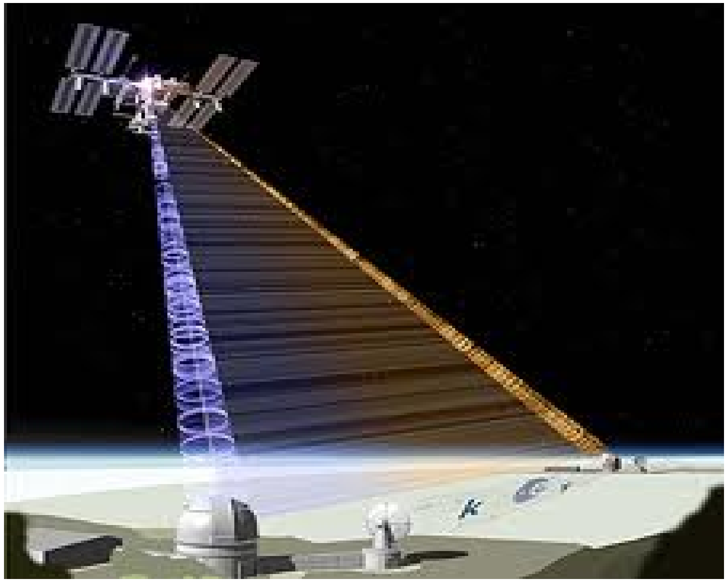
- Optical Fibre Networks:
  - Mature Technology, Widespread
  - 250 km with special fibres **[Geneva, NJP 11, 075003 (2009)]**

- Ground Based Optical Links:
  - Ad Hoc Links, Flexible
  - Atmospheric Distortion
  - 144 km with mountain-tops

[Canary Islands, Nature 3, 481 (2007)]

SPACE QUEST

- International Space Station
- 270 km to 460 km



Small Satellites

Wet Mass

Hubble Space Telescope – 11,100 kg

Gravity Probe B – 3,100 kg

1000kg

MiniSat (Singapore X-Sat)

100kg

MicroSat (Sputnik 1)

10kg

NanoSat (CuteSat/PhoneSat)

1kg

PicoSat

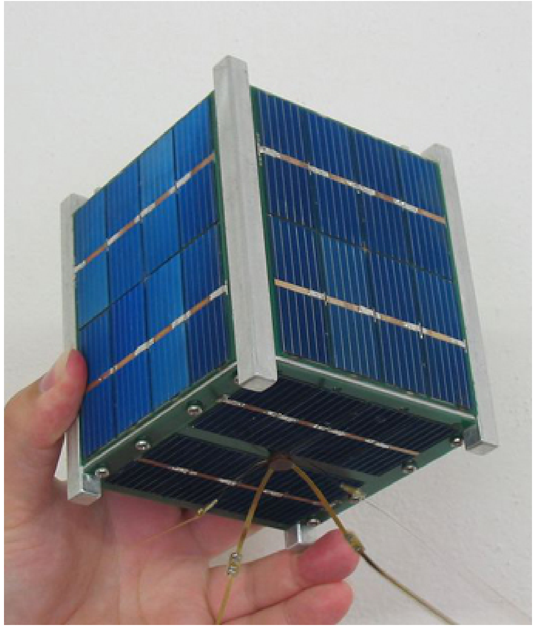
0.1kg

Launch costs:
S50,000 per kg ?

CUBESATS

The 1-U Cubesat:

- 1 kg
- 10 cm cube
- Stack more cubes to 2-U and 3-U



ClydeSpace LLC

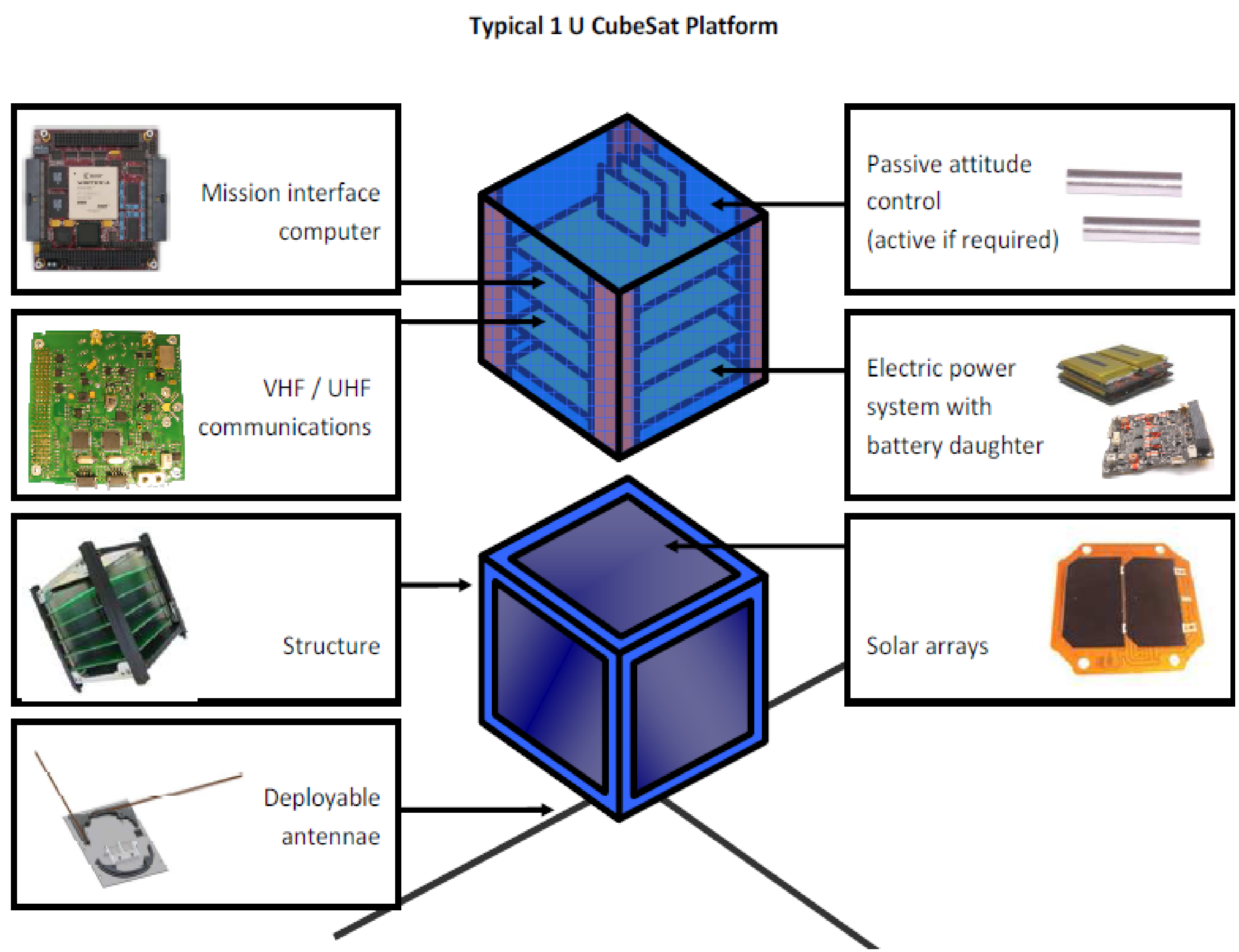
Established Standard

CUBESATS

Typical Cubesat Operation

- Altitude: 300 – 1000 km
- Orbital Cycle: 100 min
- Polar Orbit (seen twice a day)
- Lifetime: 2-3 years

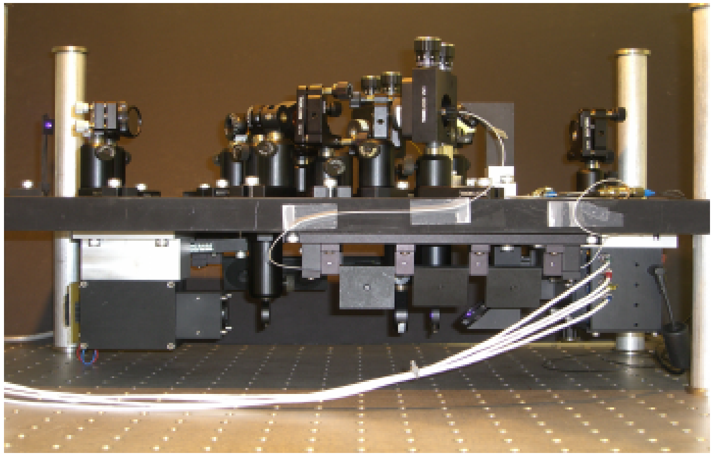
The 1-U Cubesat

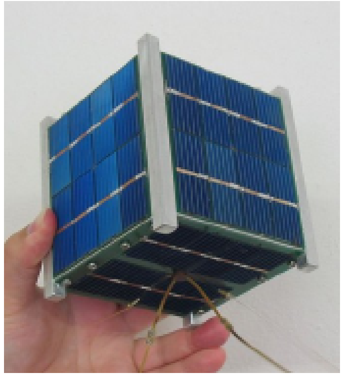


Radio: 1200 bps (tx)

ClydeSpace LLC

Can we use CubeSats?





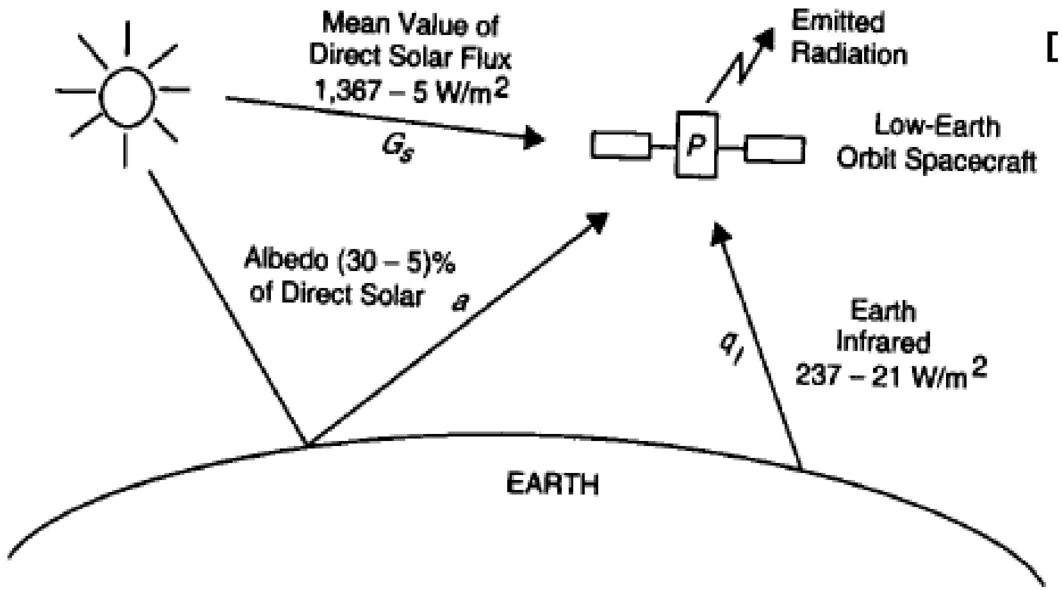
Physics Package is only 30% of CubeSat!

- 10 cm x 10 cm x 3 cm
- 1.5 W
- 300 gm
- 6.5 g acceleration (20 Hz $\leftrightarrow$ 20 kHz)
- And what about Space Weather?

Space Weather

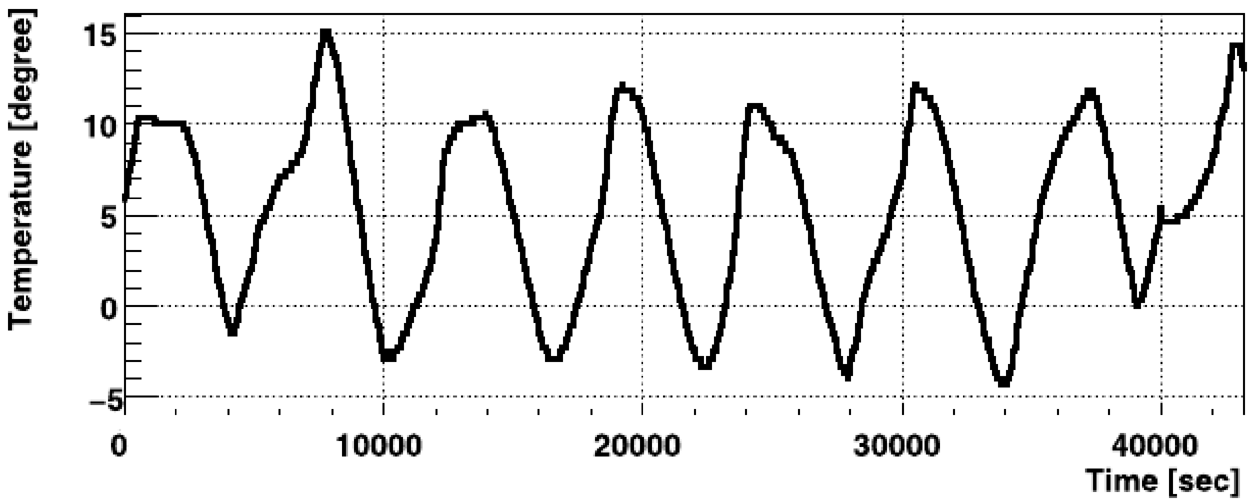
- Vacuum – 0.1 uBar
- Temperature Fluctuations
  - Altitude, Attitude & Orbit
- Radiation
  - Radiation Belts
  - Sunspot Cycle

Thermal Environment



[F. Hansen, DSRI, Denmark]

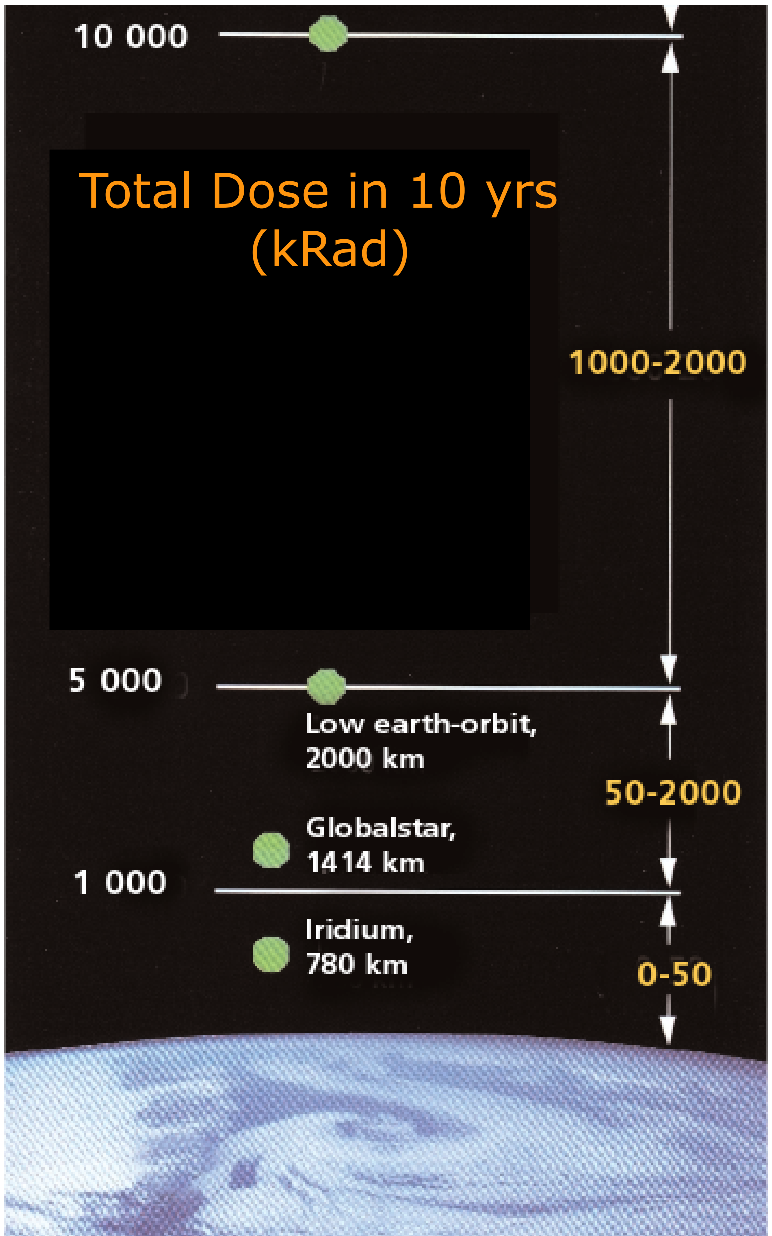
CuteSat



[Kataoka, J. GeoPhys. Res., 115, A05204, 2011]

Total Ionizing Dose

[Benedetto, IEEE Spectrum 35, 1998]



[Johnston, 4th IWRE, Tsukuba, Japan, 2000]

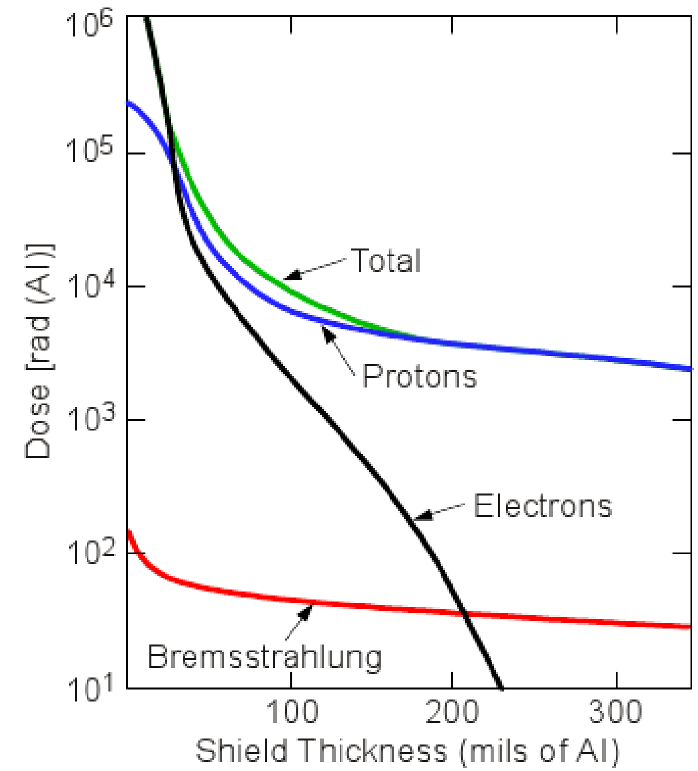
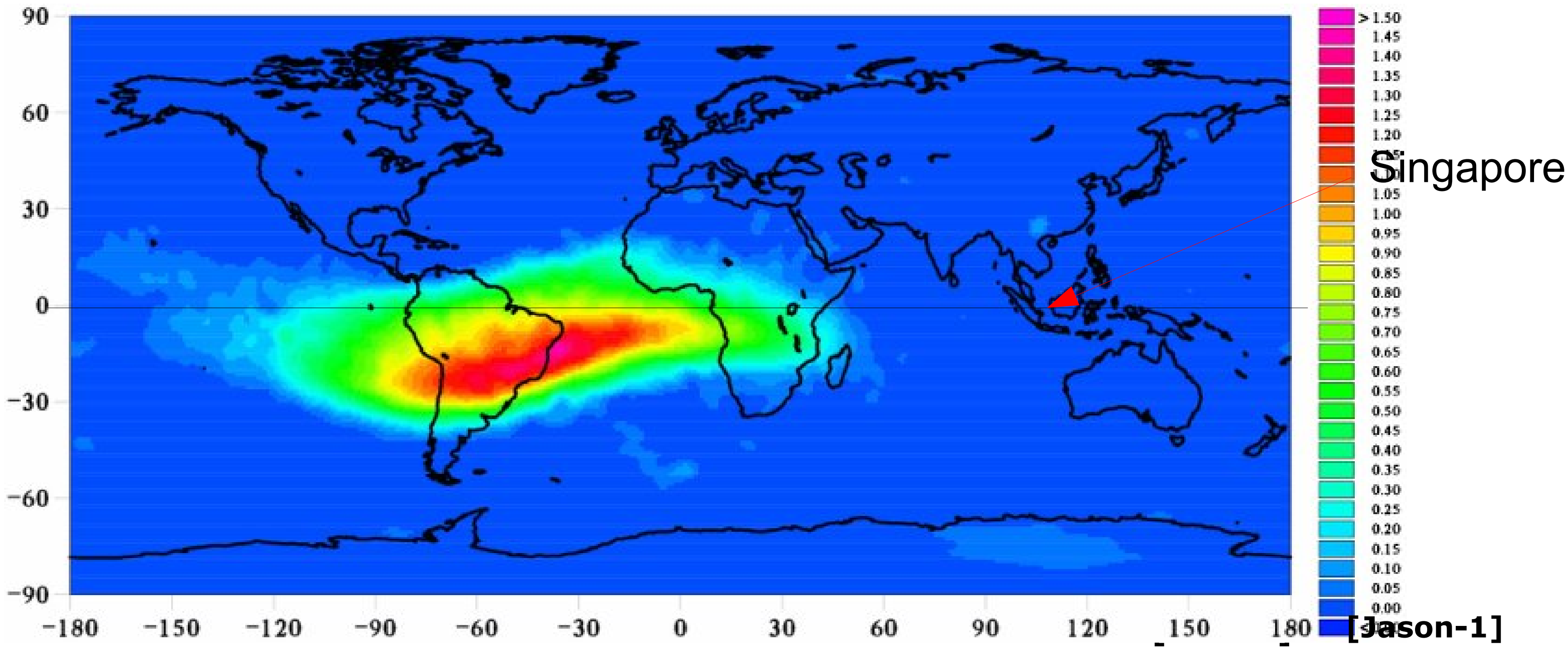


Figure 1. Effect of shielding on total dose for a five-year mission at 705 km, 98 degrees.

Commercial TID: 10 kRad

The South Atlantic Anomaly



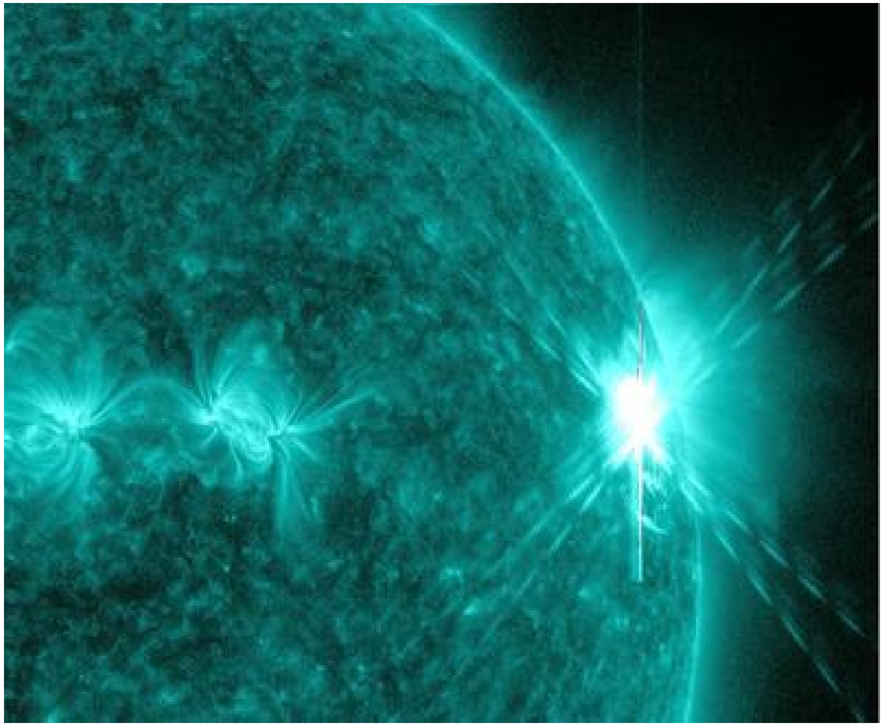
Higher rate of:

- Single Event Upsets (Memory Bits Flipping)
- Single Event Latchups (Short Circuits), protective circuits?

No active operation in the SAA

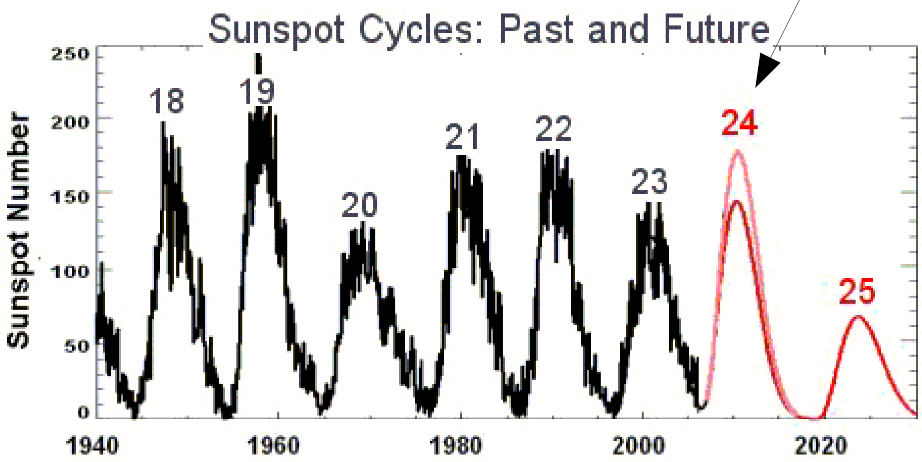
Sunspot Cycle

Solar Flare on Aug 9th
False Color (13 nm)
Biggest in last 5 years



[NASA]

2013



[M. Dikpata, NCAR, 2007]

Need to monitor space weather

Coping with Space

- Vacuum (not issue)
- Temperature Fluctuations
  - Temperature tolerant light source
  - Temperature tolerant electronics
- Radiation
  - TID – lifetime is short (not issue)
  - SAA – redundancy, stand-by mode
  - Solar Flares – monitor space weather

Project Targets

What to build?

- Compact source of photon pairs
- Compact Electronics

How to quantify success?

- Demonstrate entanglement under orbital conditions
- Space qualification is sufficient, launch is a bonus!

Launch ready by Q4 2012?

Choosing a source geometry

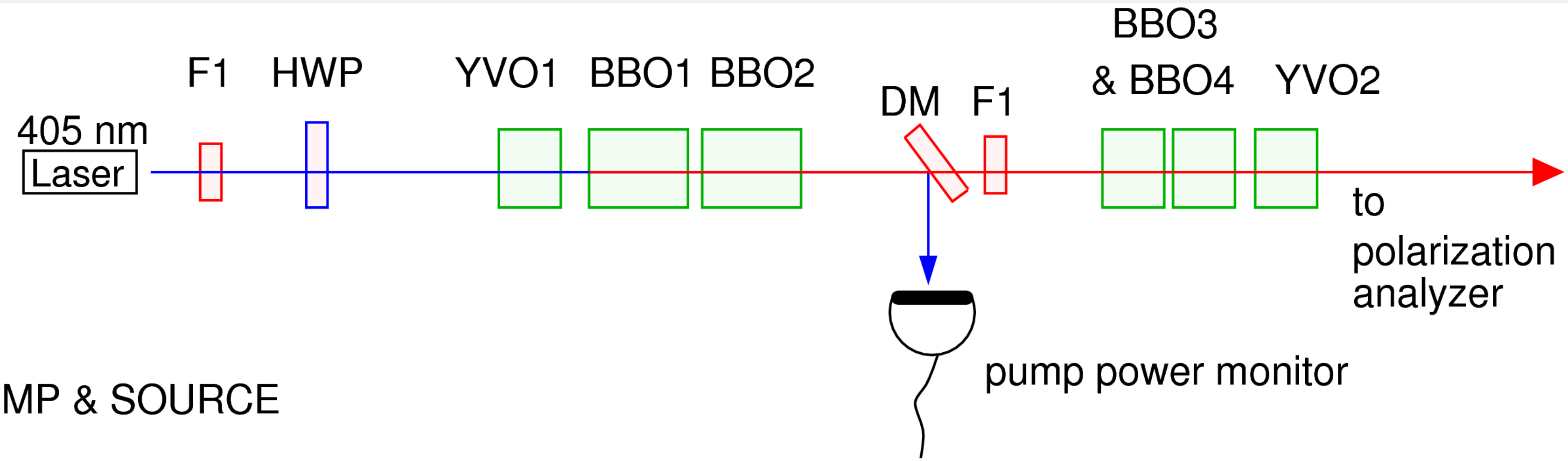
Compactness

- SPDC Collinear $\frac{1}{\sqrt{2}}(|H\,H\rangle + |V\,V\rangle)$
- Type-I with BBO

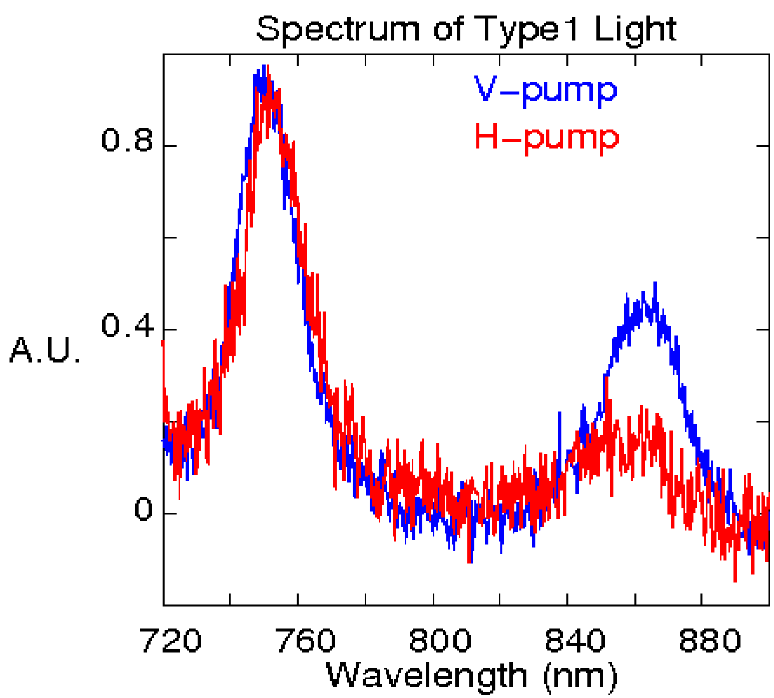
Temperature Stability

- BBO nonlinearity $\frac{\partial n_o}{\partial T} = -9.3\times10^{-6} /^{\rangle} C\,,\ \frac{\partial n_e}{\partial T} = -16.6\times10^{-6} /^{\rangle} C$
- Pump Wavelength $0.1\,\mathrm{nm}/^{\circ}\mathrm{C}$
- Wavelength Dependence $\frac{\Delta\lambda_s}{\Delta\lambda_p} \simeq 20$

The Source

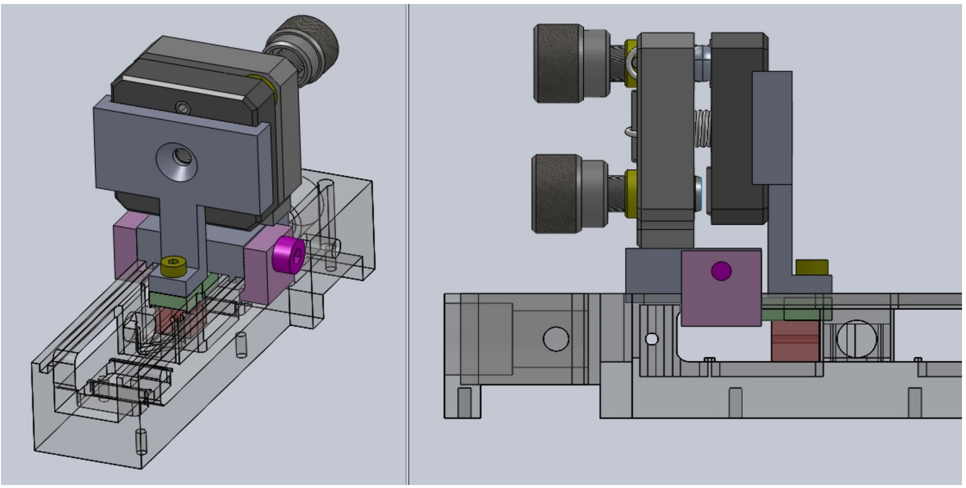


PUMP & SOURCE



(Trojek & Weinfurter, APL 92, 211103 (2008))

Mechanical Stability/Tolerance

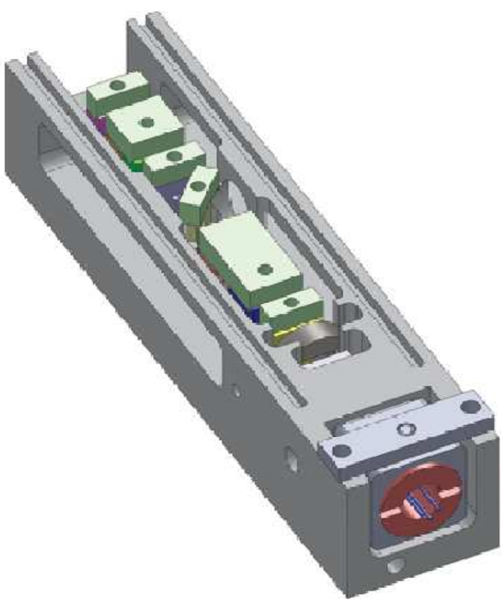


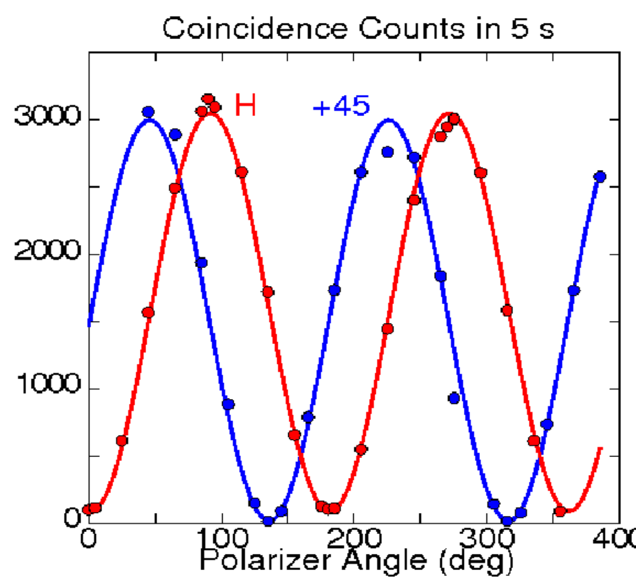
Manufacturing tolerances

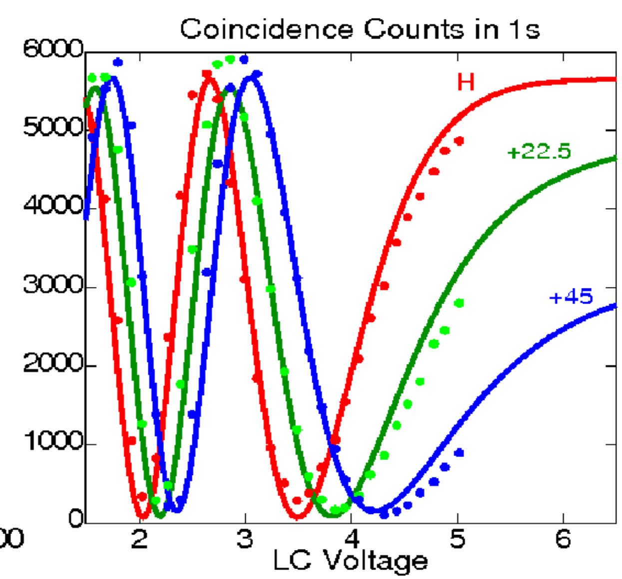
- Optical Axis & Perpendicularity

  ± 10 Arc Minutes

- SPDC wavelength: 7 nm/Arc Min







Average: 94% visibility -

Electronics

Target Power: 1.5 W

Power Budget

- Laser Diode 400 mW
- Logic Circuit 200 mW
- 2 Detectors 900 mW
- 2 Detectors 1900 mW (with cooling)

THERMOELECTRIC COOLER SPECIFICATIONS

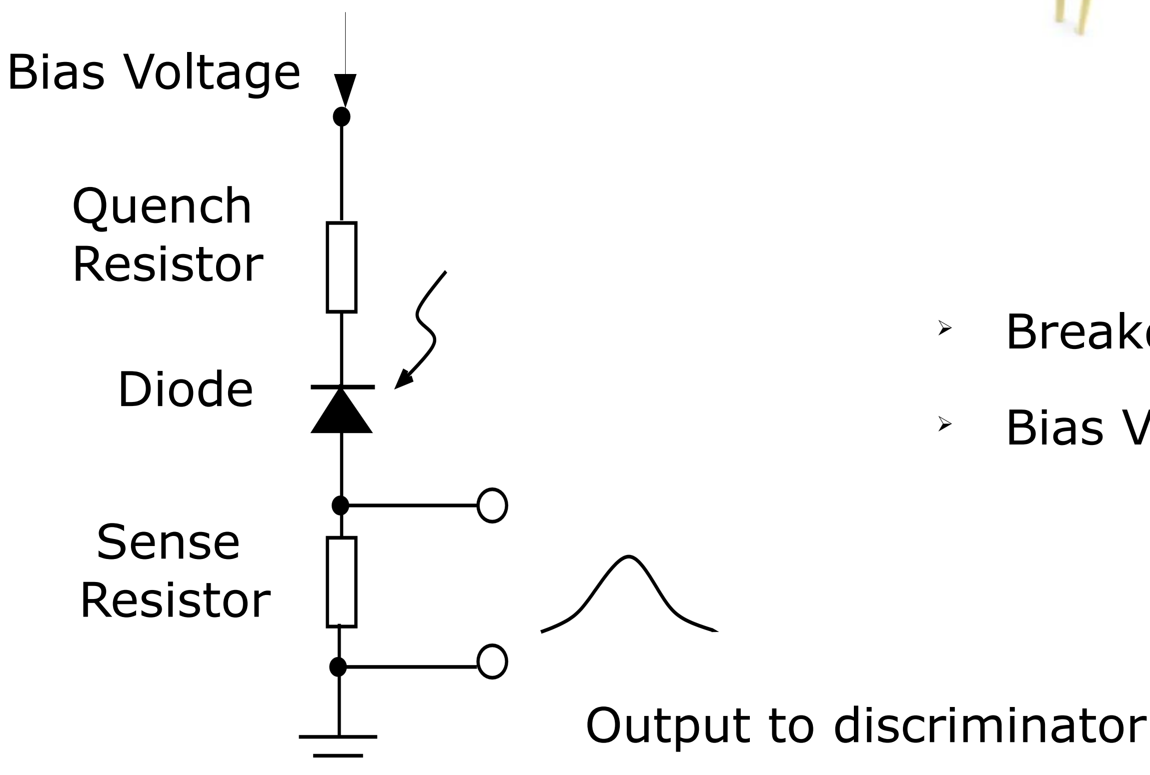
Parameter	Unit	Value (conditions)
Resistance ACR	Ω	3.56 +/- 0.16 (at T_r=300K)
Maximum Current I_{max}	A	0.4 +/- 0.02 (at ΔT_{max})
Maximum Voltage Drop U_{max}	V	1.35 +/- 0.07 (at ΔT_{max})

Courtesy – id101 Si APD datasheet from IDQuantique

P = V x I = 540mW

Detectors & Temperature

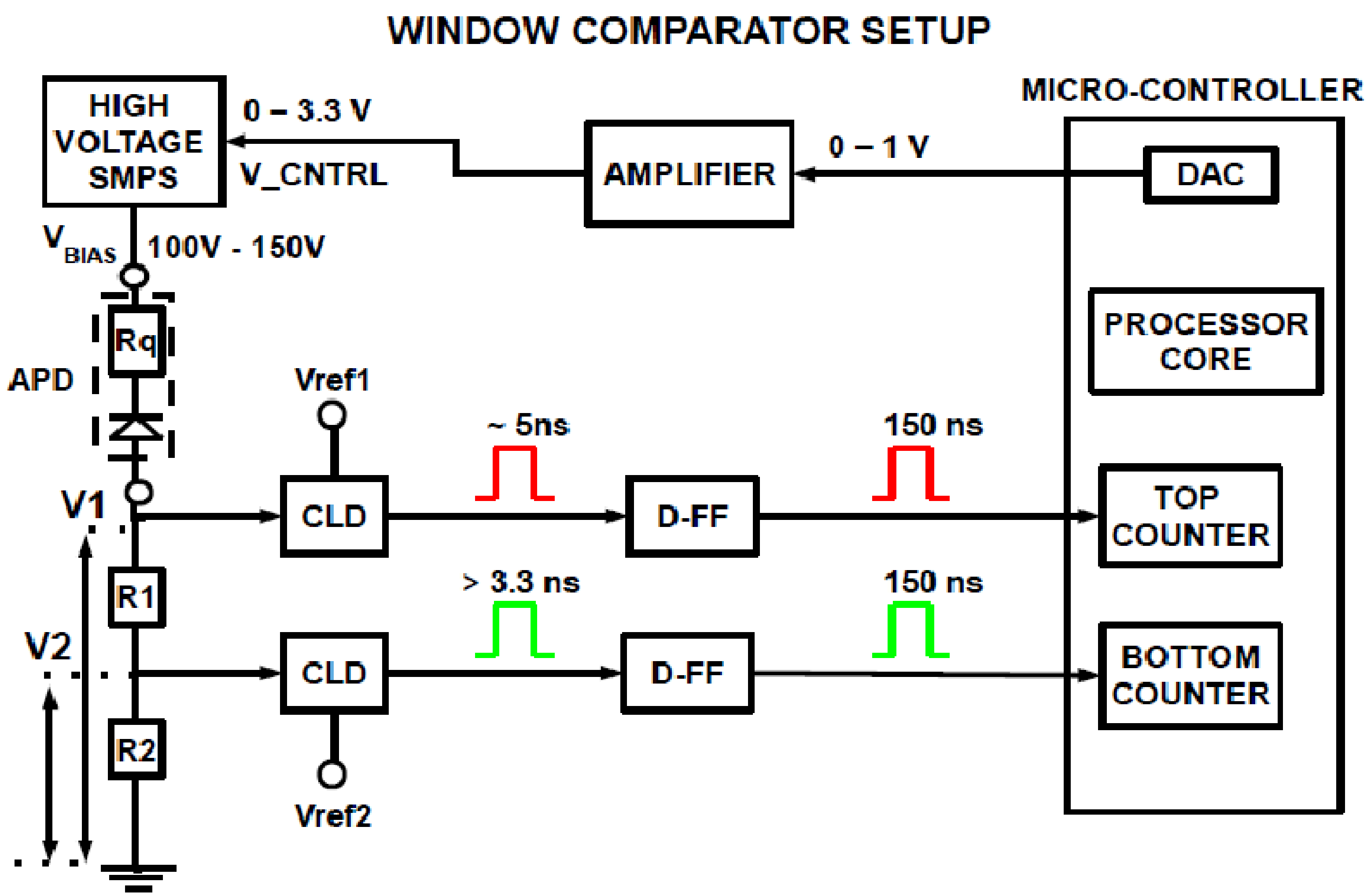
- Avalanche Photo Diodes
- Geiger Mode
- Passively Quenched



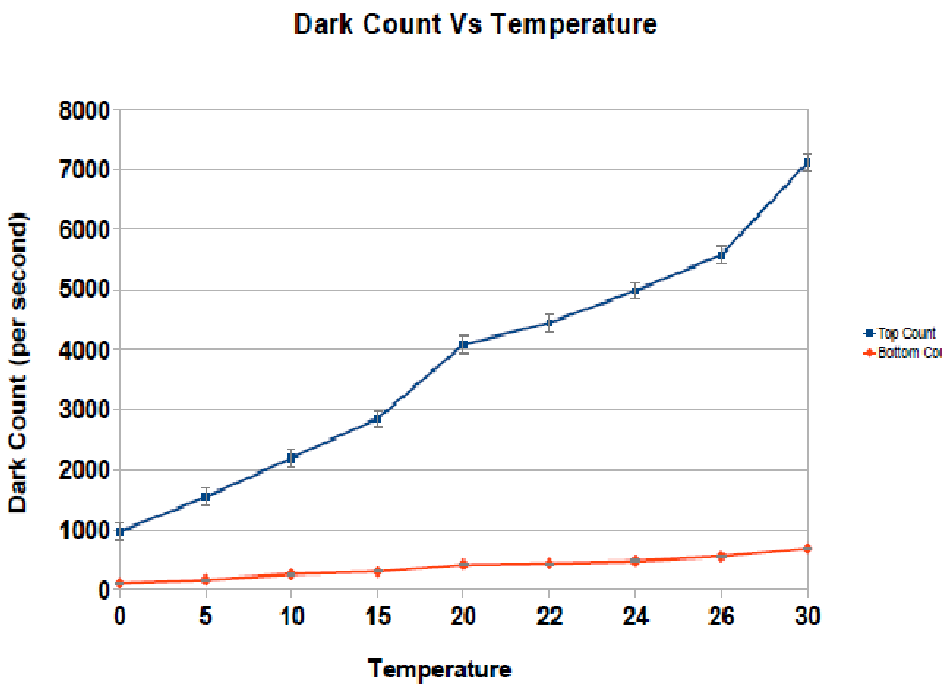
- Breakdown Voltage, $\mathbf{V_{br}}$
- Bias Voltage = $\mathbf{V_{br}} + \Delta$

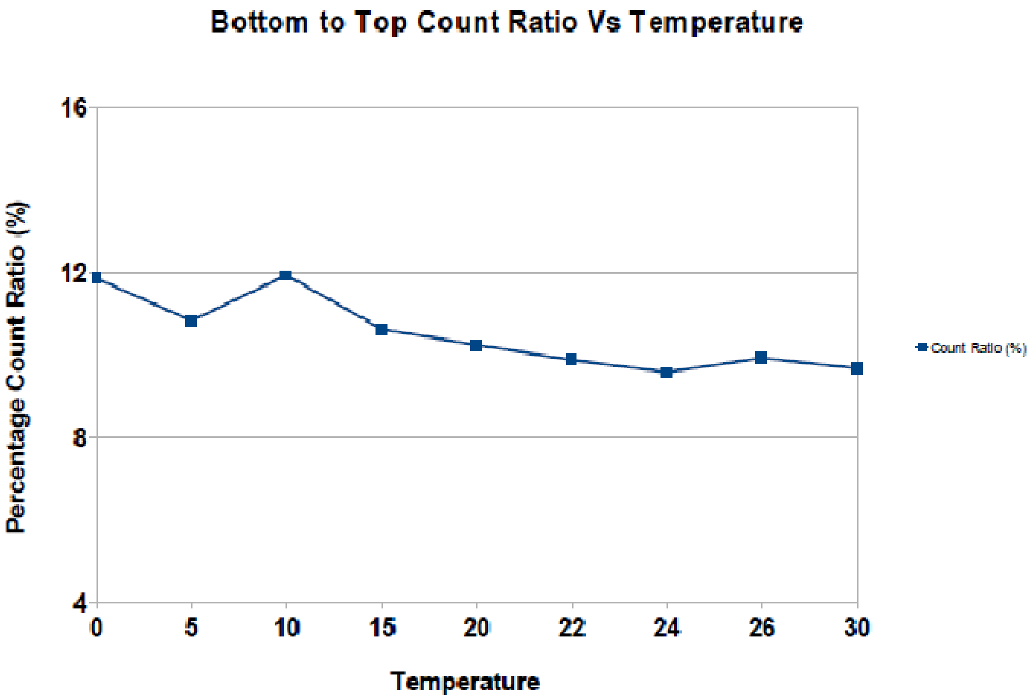
Depends on temperature

Detectors & Temperature

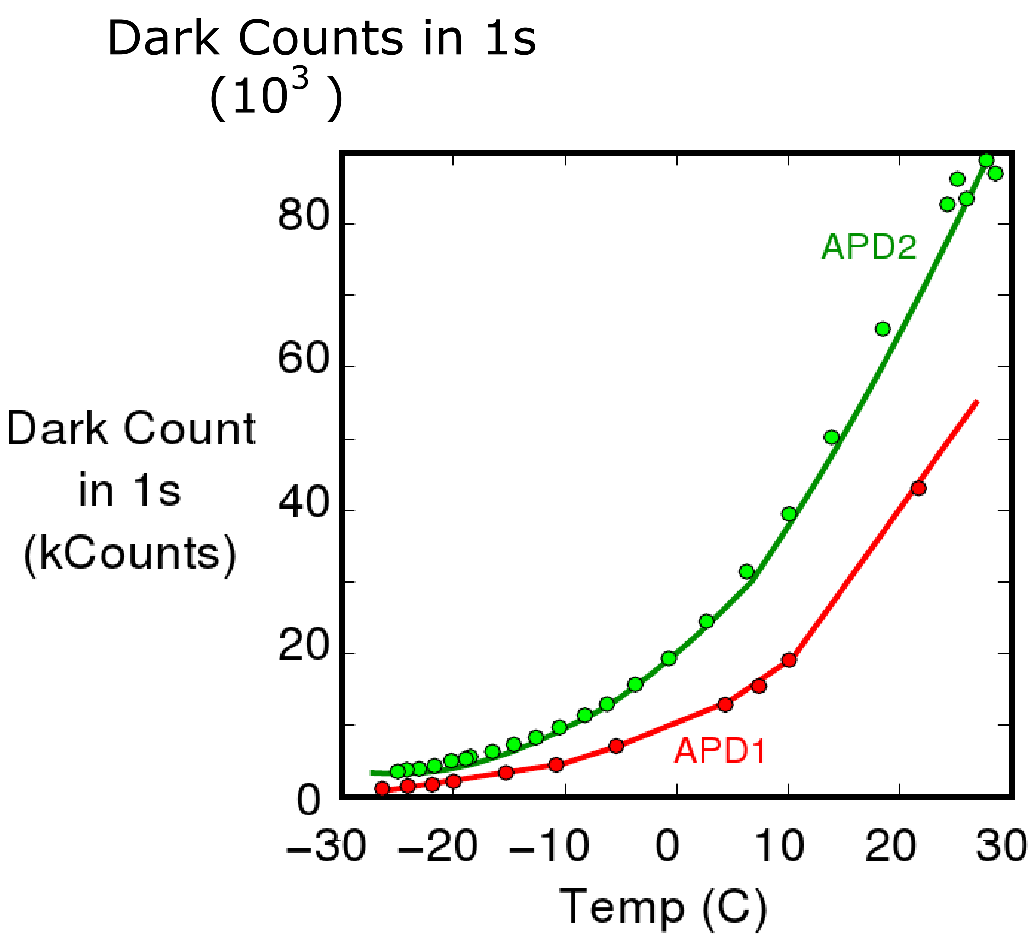


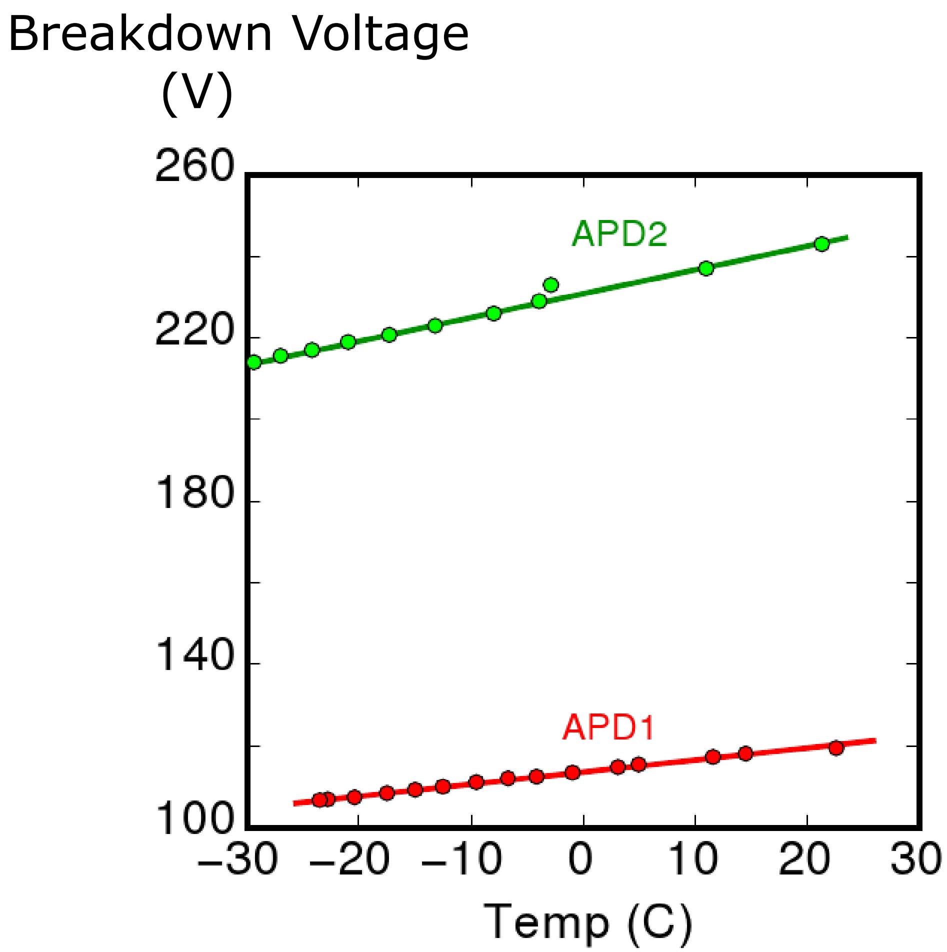
Window Comparator Results



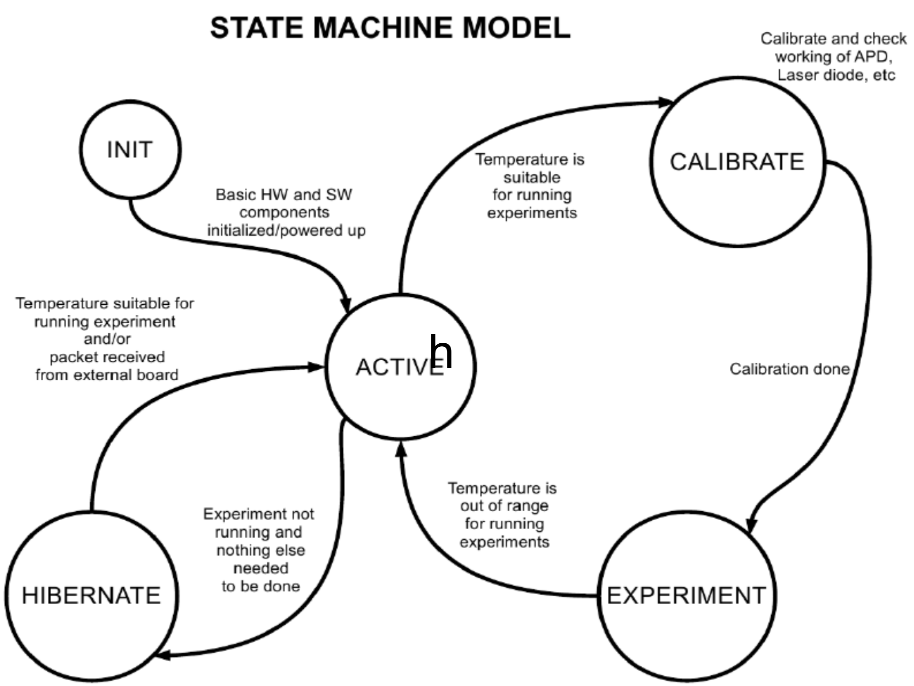


A better detector?





Putting it together...



Roadmap...

- Q4 2012 – Flight Model
- Q3 2012 – Qualification Model (Electronics & Optics)
- Q3 2011 – Engineering Model (Electronics) ✓
- Intermediate Tests
  - Vibration Tests (passed) ✓
  - Vacuum Tests (passed) ✓

People

- William Morong (RA)
- Tan Yue Chuan (RA)
- Rakhitha Chandrasekhara (PhD)
- Yau Yong Sean (Support)
- Gan Eng Swee (Support)
- Christian Kurtsiefer

External Folks

- Daniel Oi (U. Of Strathclyde)
- Nanyang Technological University

Velox-1

- 700 km
- 3U-CubeSat
- Multi-expt
- Link: 146 MHz
- Link: 1200 bps