Review of Solid State Photon Counters for Laser Ranging to Orbital Space Debris

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OUTLINE

- Requirements on detectors
- Detectors available - review
- Si SPAD detectors (VIS)
- Ge and InGaAs SPAD detectors (NIR)
- Superconducting detectors (NIR)
- Conclusion

Requirements put on detectors
for space debris laser ranging

- EXPERIMENT ENERGY BUDGET
  = > single photon response
  high Photon Detection Efficiency (PDE)

- LASER SOURCES AVAILABLE & SAFETY
  = > sensitive @ 532 or 1064 or 1550 nm

- OPTICAL TRACKING TELESCOPE FoV
  = > detector aperture >= (50) 100 um

- FIELD OPERATION
  = > robust, reliable

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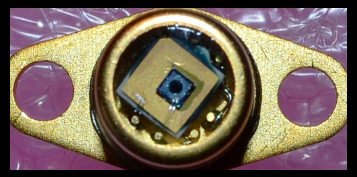
Photon counting detectors
key parameters for laser ranging

- VACUUM / PHOTOCATHODE based
  Apertures 1 mm .. 1 meter
  Wavelength range UV ….. 1550 nm
  Photon Detect.Eff. 30 % ….0.1 %

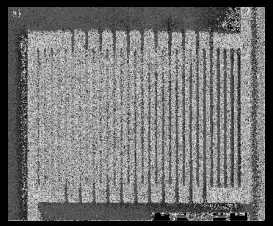
Hamamatsu photomultipliers

- SEMICONDUCTING detectors
  Apertures 0.1 … 0.5 mm
  Wavelength 532 ... 1064 nm Si
  532 ... 1550 nm Ge / 77K
  1064 . 1550 nm InGaAs
  PDE 70 % @ 532 nm Si



Si SPAD 500um, TE cooled

- SUPERCONDUCTING detectors (kryo-cooled)
  Apertures max. 10 um (50 um ?)
  Wavelength UV …. 1550 nm
  PDE > 70 % @ 1550 nm



Superconducting detector 10 x 10 um

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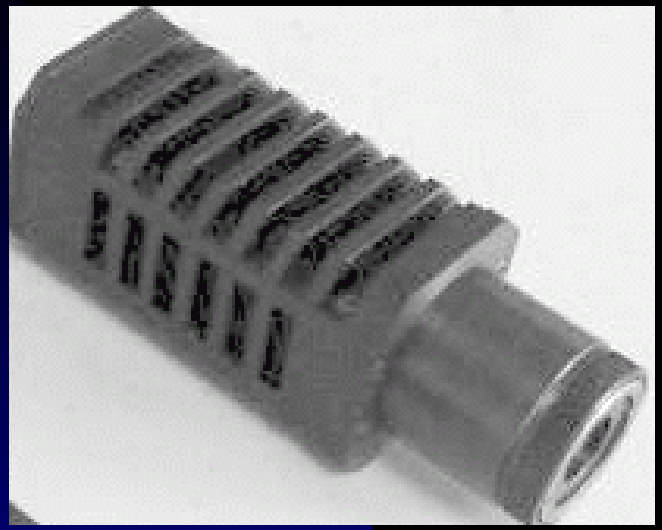
Si SPAD Detector Package for SLR
jointly Czech Tech. Univ. in Prague and IWF Graz



- Self-consistent compact package
- SPAD TE cooled in vacuum
- collecting optics f/D = 1.0
- time walk compensation
- 50 x 50 x 130 mm, 300 g

- Detector aperture 200 um , f/D=1, => acceptable FoV
- Photon Det. Efficiency ~ 40 % @ 532 nm (P.Guilemont, CNES, 2006)
- Used by > 15 SLR stations worldwide
- Applied for the first space debris laser tracking demonstration

I.Prochazka et al, ***Rev. Sci. Instrum****. 84, 046107 (2013)*

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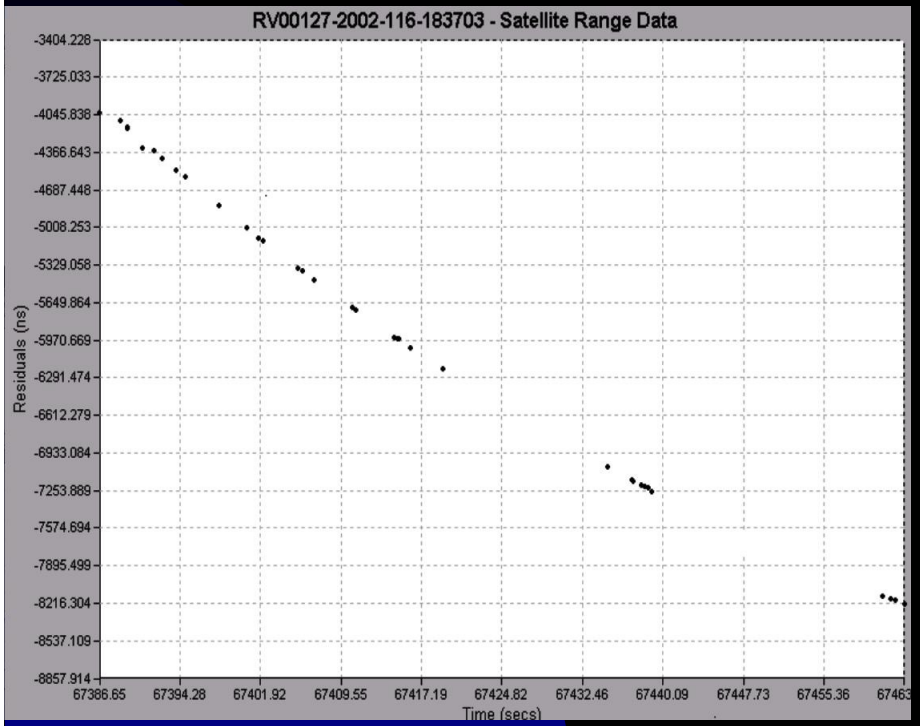
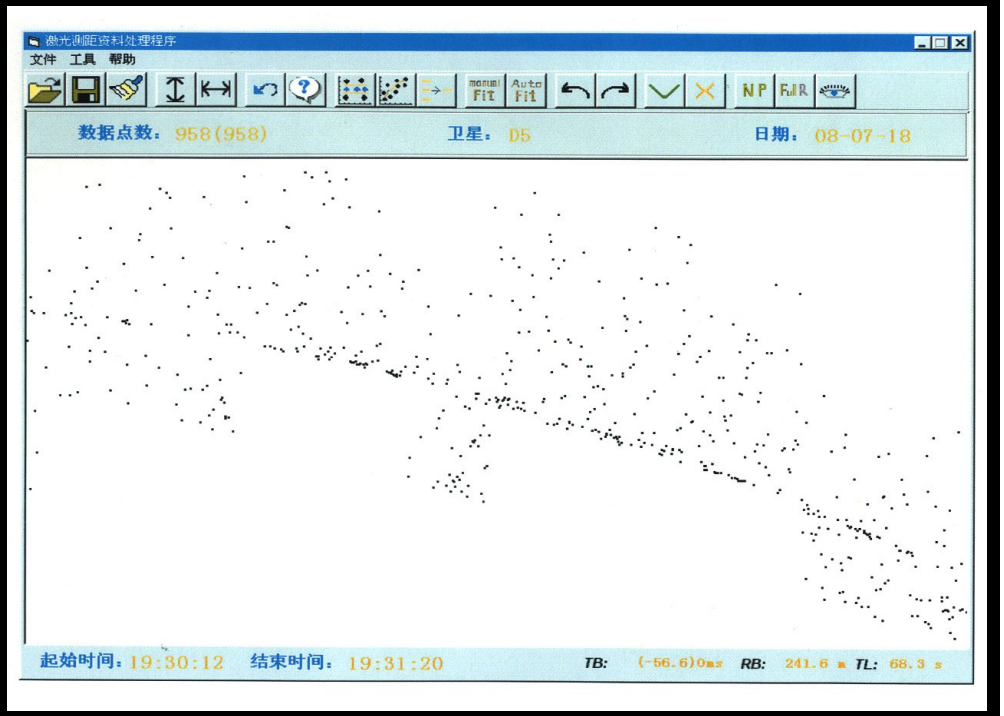
SPAD detector package for SLR
applied for space debris laser tracking



Mt. Stromlo, Australia, 2002
www.eos-aus.com/space/education/..



Shanghai, China, July 17, 2008
discarded US rocket (ID 2007-006G)

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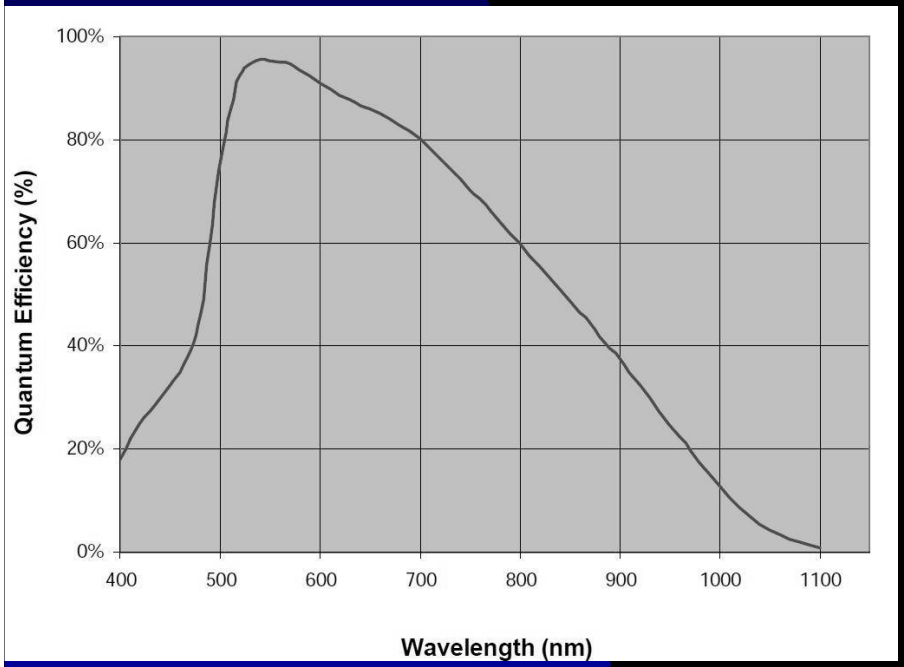
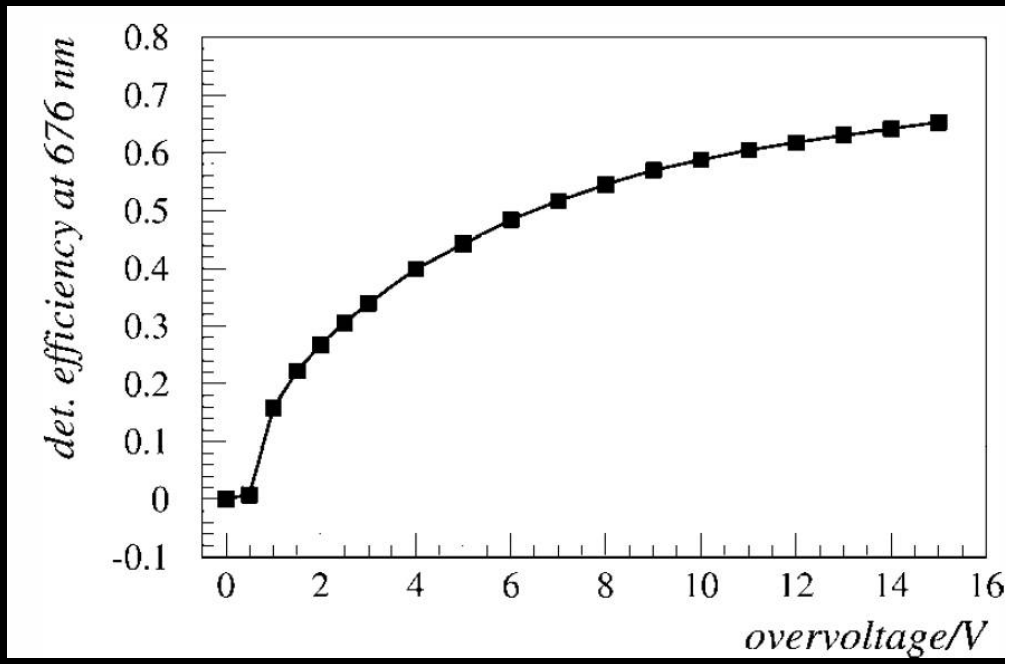
SPAD detector package with high PDE
for space debris tracking

- High Photon Detection Efficiency PDE
- SAP500 detector by Laser Components
- APD on Si, 0.5 mm diameter, ~ 100 V break.
- PDE typically 70 % @ 532 nm
  (M.Stipcevic, 2011)





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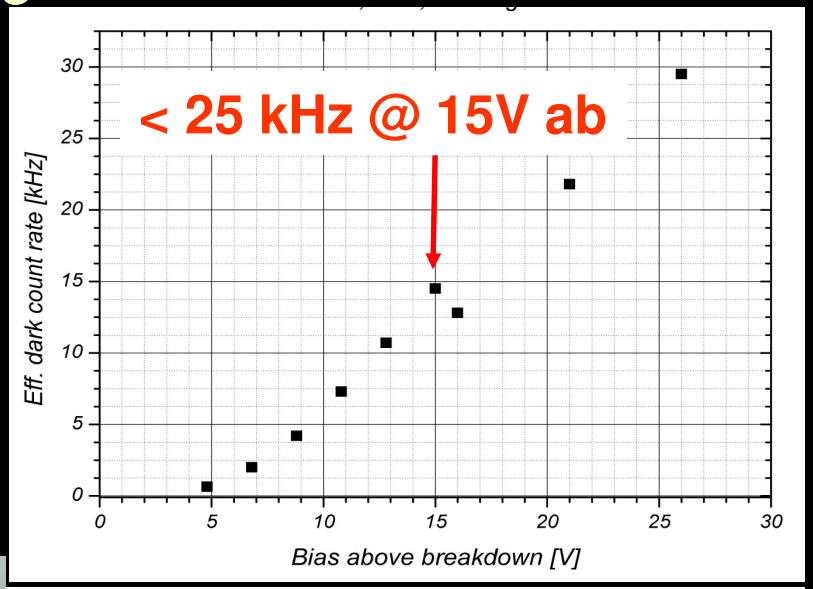
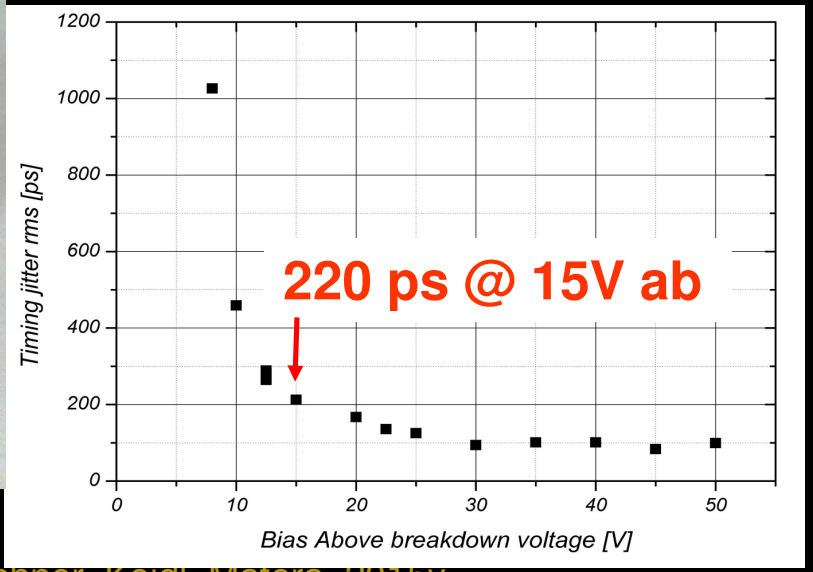
SPAD detector package with high PDE #2
for space debris tracking, version 2015

- HQE Detector package developed
- Single TE cooling to -8°C
- 1 : 1 replaceable to other SPAD detectors
- Operational Graz, Wettzell, Shanghai,…





Prochazka I, et al, ***Journal Advances in Space Research****, JASR11779*

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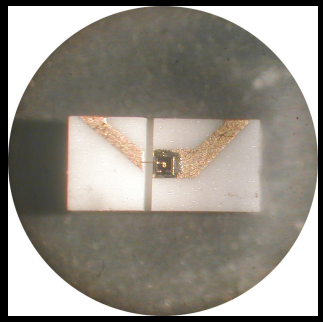
InGaAs/InP Photon Detectors 1064 nm

- candidate for 1064 nm operation in a near future

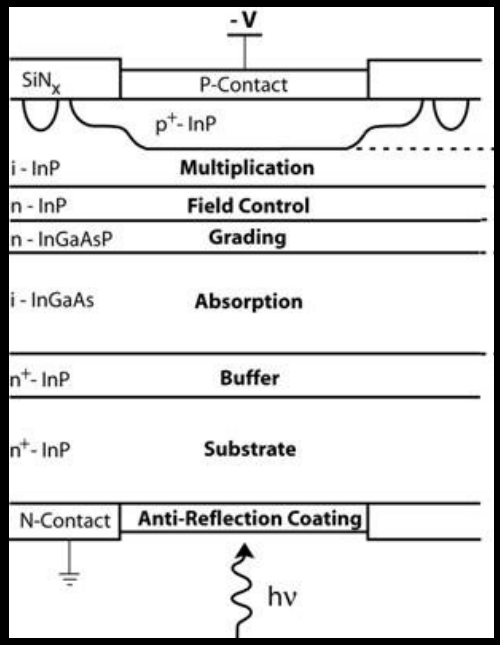
- "never ending story 1064 <-> 532 nm "
- gain of 1064 nm

1 photon	2	x
SHG generation	2	x
atmo. atten.	1.5	x ?
Target reflect.	…	?
Total gain	4..6	x

- Detection efficiency >~ 15 % @ 1064 nm
- Active area 60 um diameter max.
- Dark count rate < 25 kHz / - 60 C
- InGaAs technology still in progress



Fujitsu, ø 30 µm
FPD5W1KS



Separate absorption multiplication APD
S.Cova, NIST 2004 ,

*I.Procházka, **Applied Optics**, Vol 40, No 33, p.1-6, 2001*

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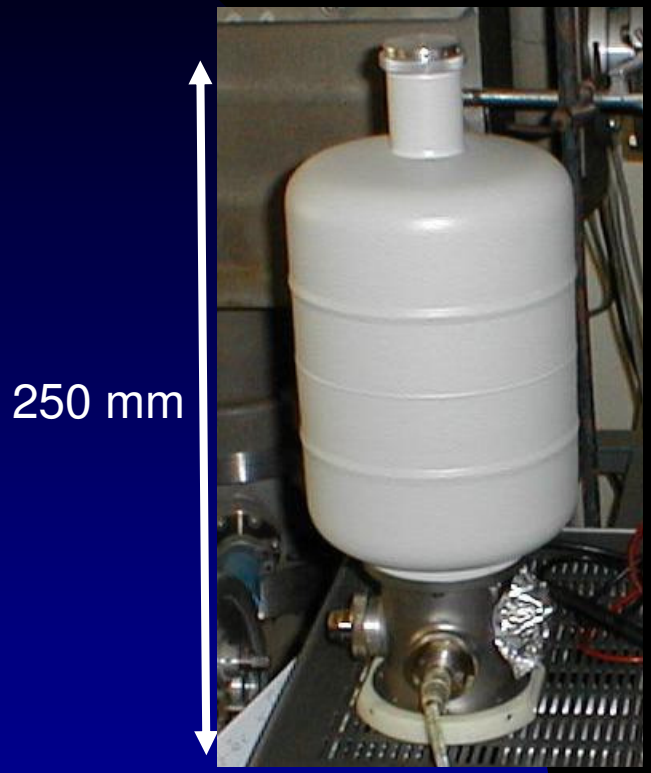
Germanium SPAD Detector Package for VIS - 1550 nm



- Ge SPAD, 100 um / 77 K
- PDE >~ 20%@ 400..1064 nm
  2 - 5% @ 1540 nm
- dark count >= 1 MHz
- SLR and space debris LR @ 1540 nm demonstrated: CRL Tokyo, EOS Australia

I.Procházka et al, ***Optics Letters,*** *Vol.21 (17), September 1, (1996), p 1375-1377*

H.Kunimori et al, ***Journal of Optics****, Pure and Applied Optics, No.2 (2000), p1-4*

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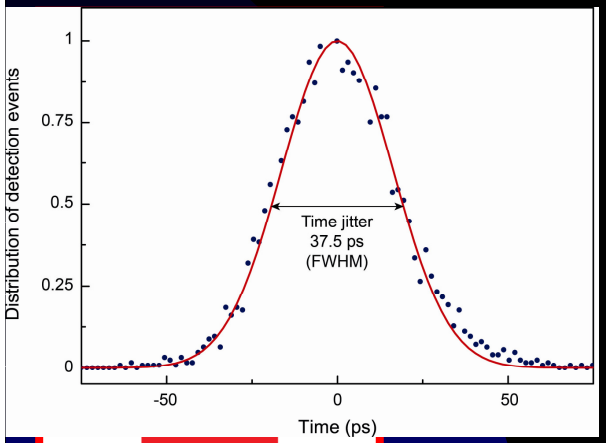
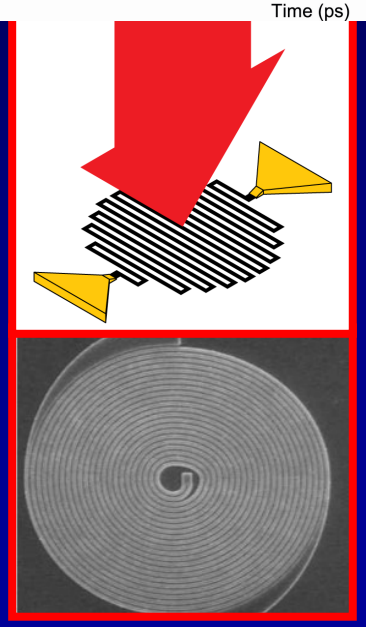
Superconducting Nanowire
Single Photon Detectors

Single Quantum





- **High PDE** >70% 1550nm
- **Jitter** < 16 ps
- **Dark count rate** < 100 Hz

- **Temperature** < 4 K
- **Size** “large” 25 um
  promissed 50 um (?)

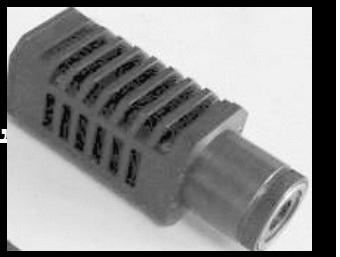
- Proposal for a joint experiments by manufacturer
- Application possibility depends on size and optical coupling improvements

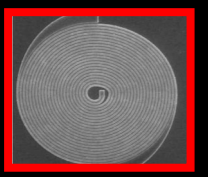
G. Bulgarini, Val Zviler, Single Quantum BV, Lorentzweg 1, 2628CJ Delft, Netherlands

SINGLE QUANTUM

Conclusion

- Photon counting is the only receiver option for laser ranging to orbiting space debris.
- SPADs on Si provide good detection efficiency at 532 nm, existing, available, heritage
- SPADs on InGaAs are promising candidates for 1064 nm range, energy budget **if available**
- Supeconducting detectors are a dream for future systems operating at 1540 nm, energy budget, eye safety **IF AVAILABLE**
- Good News - Europe is a leader in developing these detectors
  We have good contacts to detector labs
- We should not miss this chance !
- Thanks for your attention





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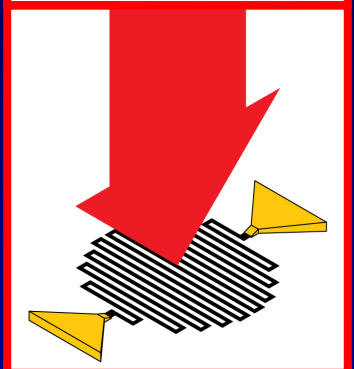
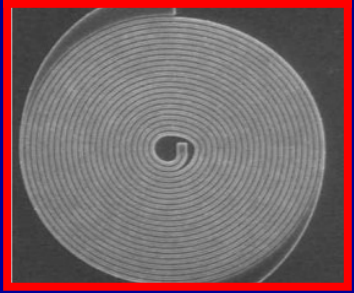
Single Quantum

superconducting nanowire single photon detectors

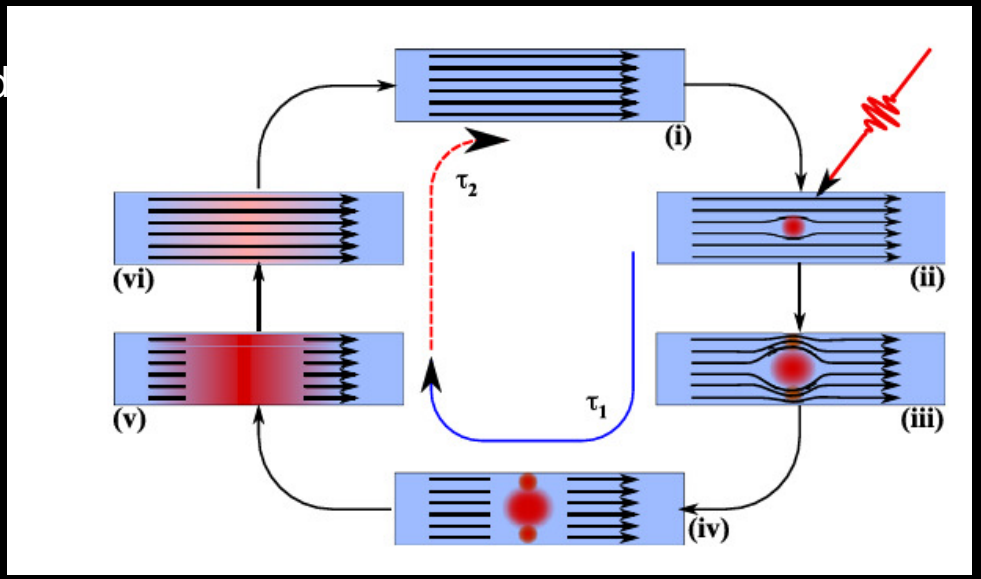




Bias current $I < I_c$

Supercond
recovered

Resistive
barrier



Photon
absorption

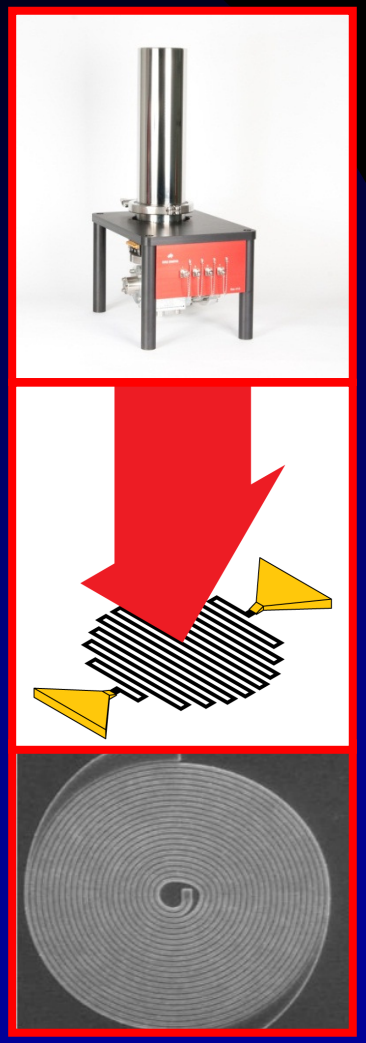
Hotspot:
High current
density

Enlarged hotspot

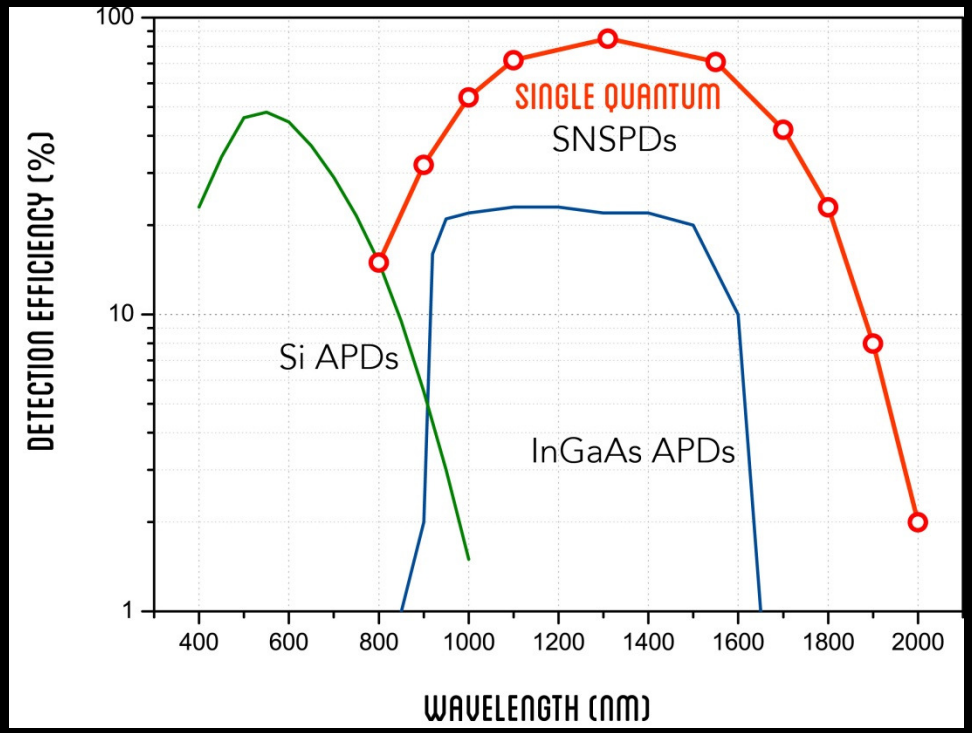
Just a single photon can create a large enough hot spot in a 100 nm wide nanowire to stop the current flowing in the device. The meander geometry enables to cover a large surface area with a single nanowire.

Single Quantum

superconducting nanowire single photon detectors

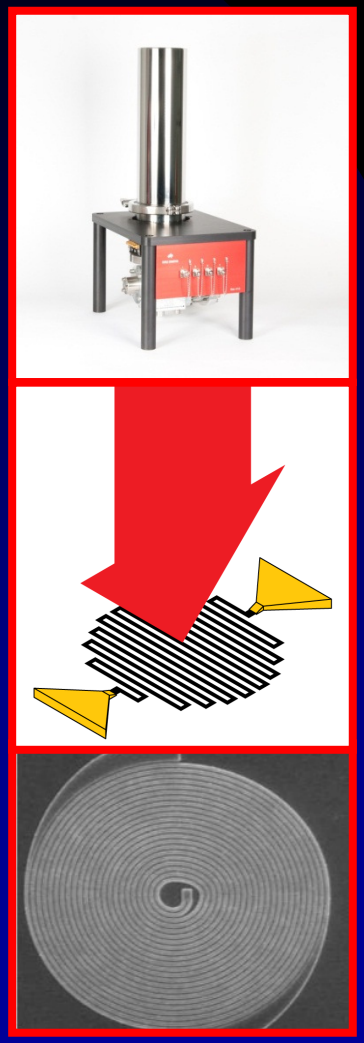


- **Sensitive from UV to MIR**
- **Q.E. can be tailored for desired wavelength:**
  - **e.g. 80% Q.E. for 532 nm possible**

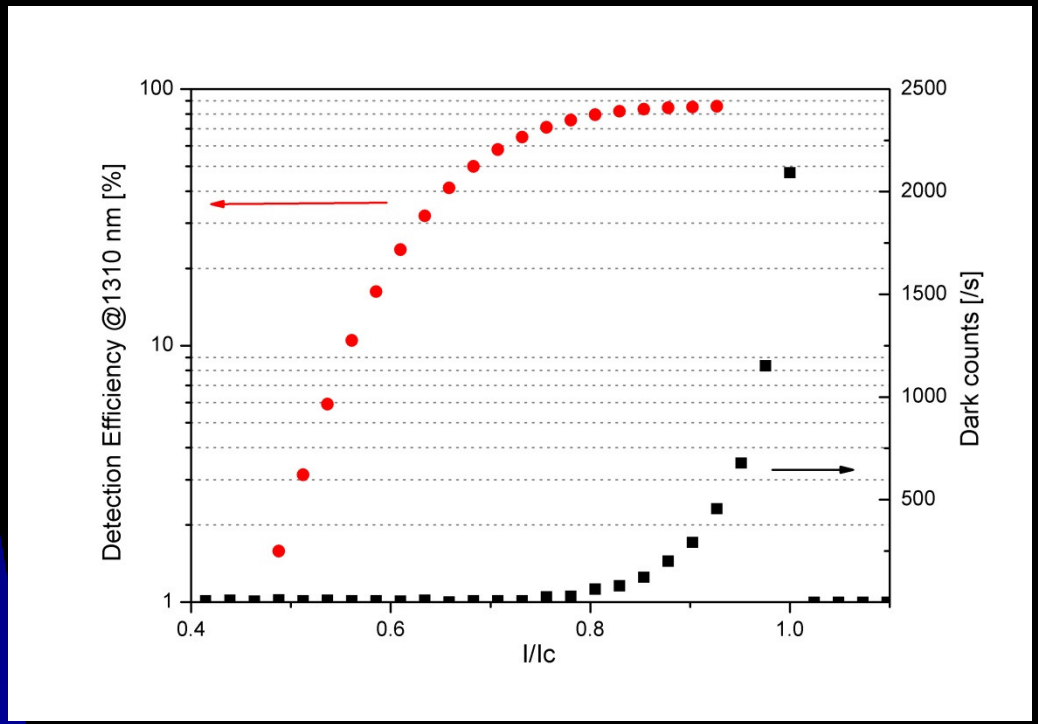


Single Quantum

superconducting nanowire single photon detectors

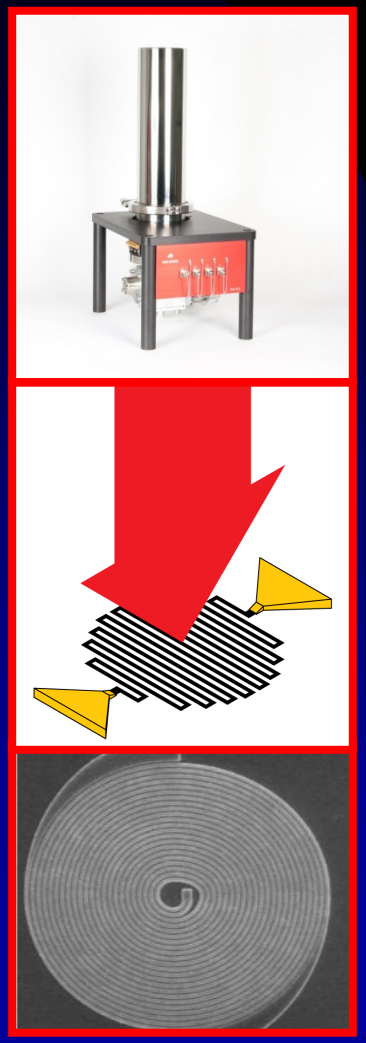


- **High efficiency for NIR**: >75% for 1310nm, >70% 1550nm

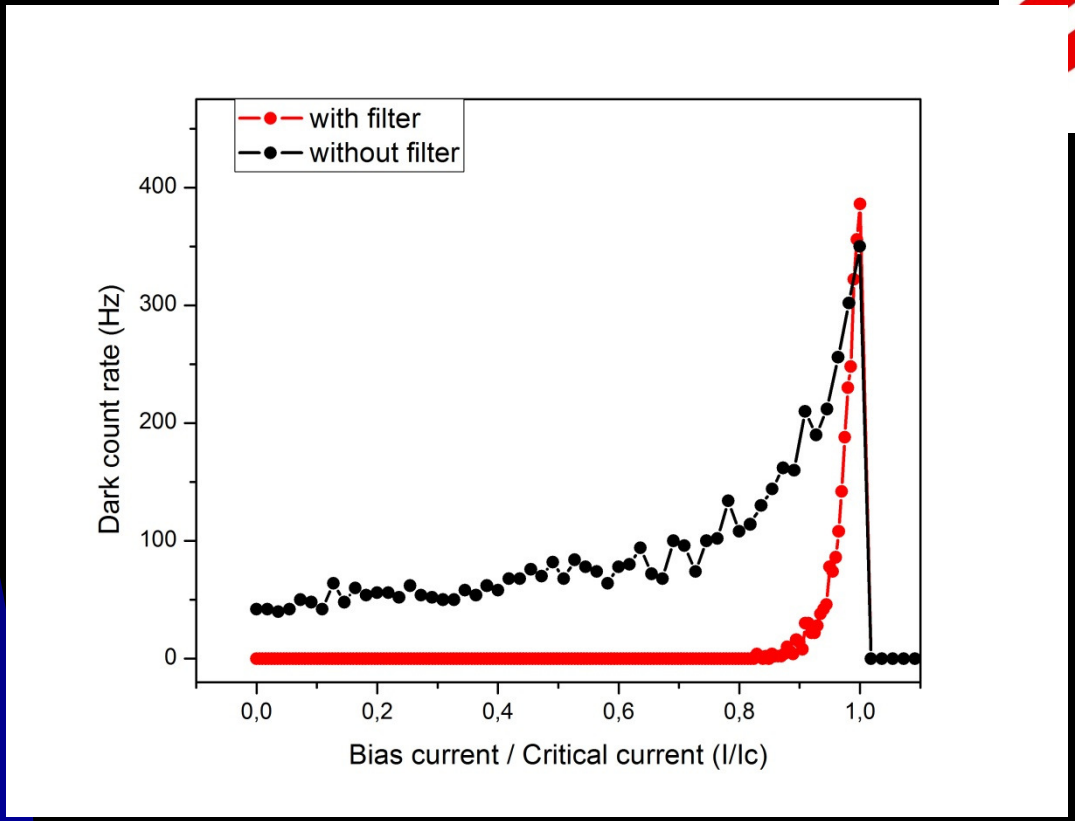


Single Quantum

superconducting nanowire single photon detectors

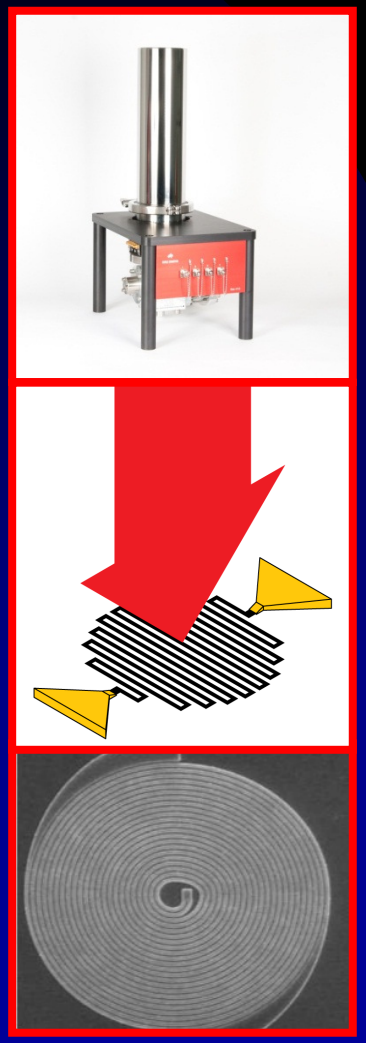


- **Low noise**: dark counts can be reduced to <10 H

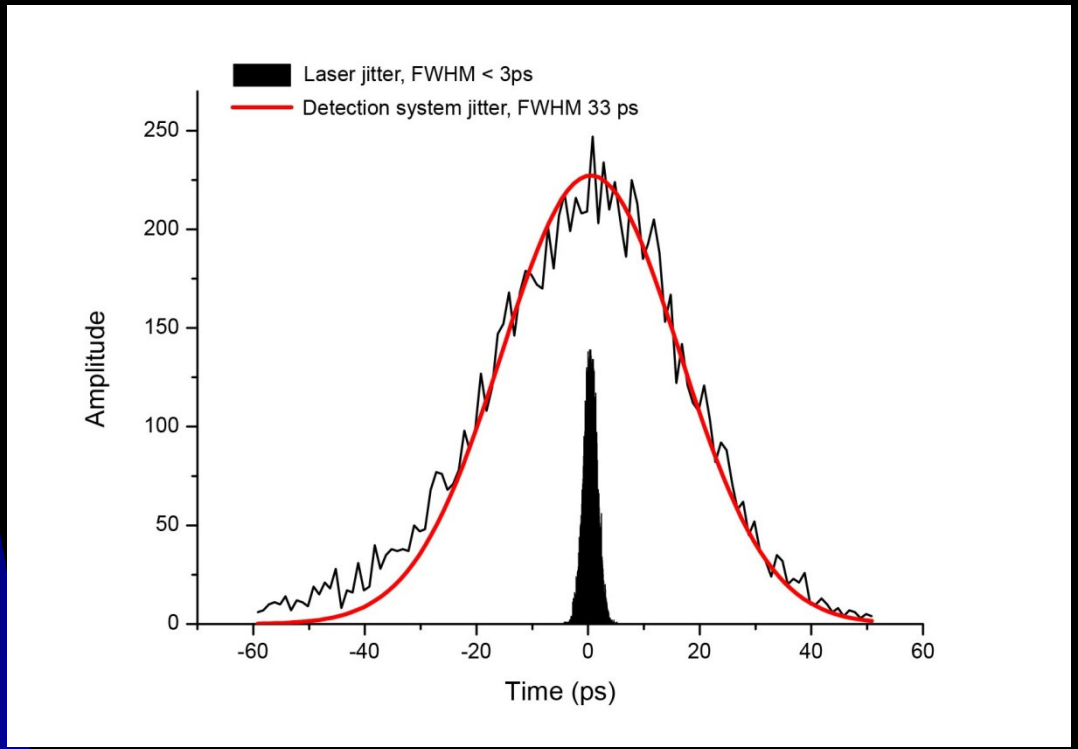


Single Quantum

superconducting nanowire single photon detectors

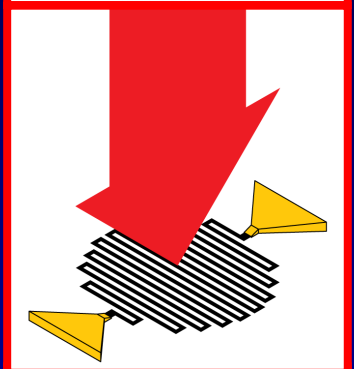


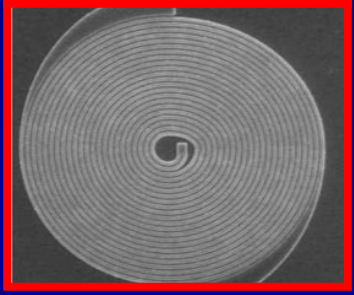
- **High time resolution**: < 40 ps time jitter



Single Quantum

superconducting nanowire single photon detectors





- This Dutch company is developing and producing these detectors
- It operates with a closed-loop cryostat – no refilling etc.
- Graz is checking possibilities to test it in Graz;
- Maybe a station with non-moving detector package would be a more suitable test-bed ?