

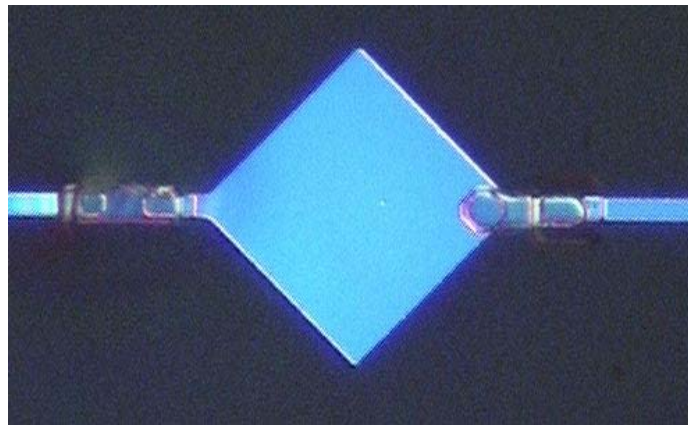
# Optical photon detection in Al Superconducting Tunnel Junctions

**Guy Brammertz, A. Peacock, P. Verhoeve, D. Martin**

*Science Payload and Advanced Concepts Office, Estec/ESA, Noordwijk, Netherland*

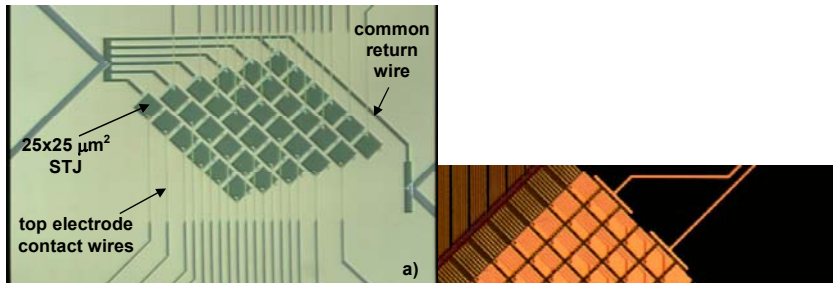
**and R. Venn**

*Cambridge MicroFab Ltd, Cambridge, UK*

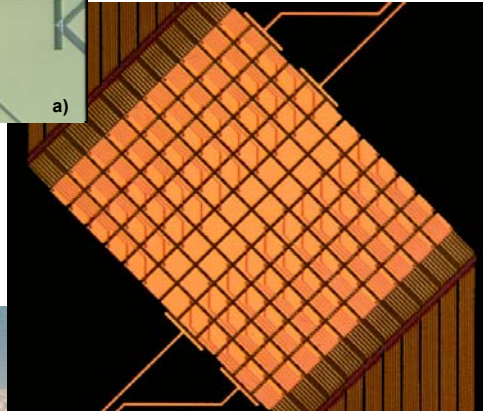


# Introduction

## Development of Ta-based STJs for ground based optical astronomy at Estec/ESA



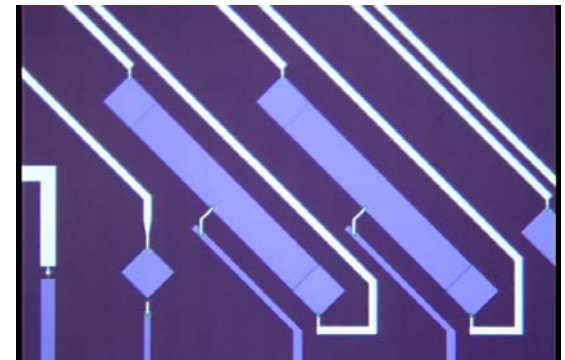
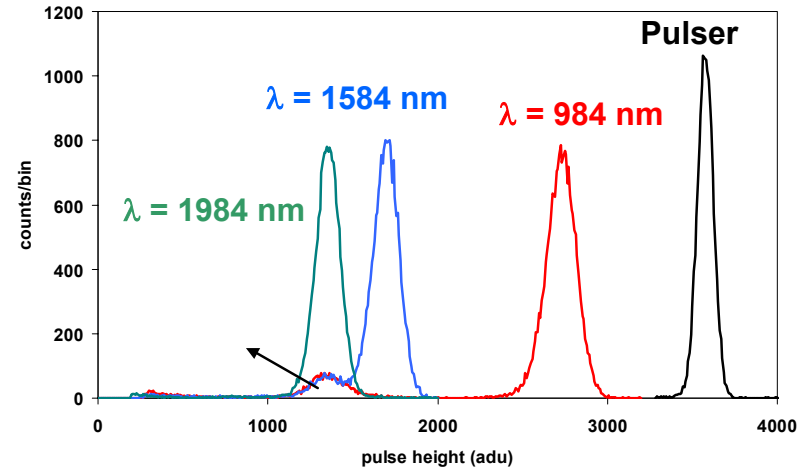
**S-Cam 1-2  
6x6**



**S-Cam 3  
12x10**



**4.2m WHT (La Palma)**



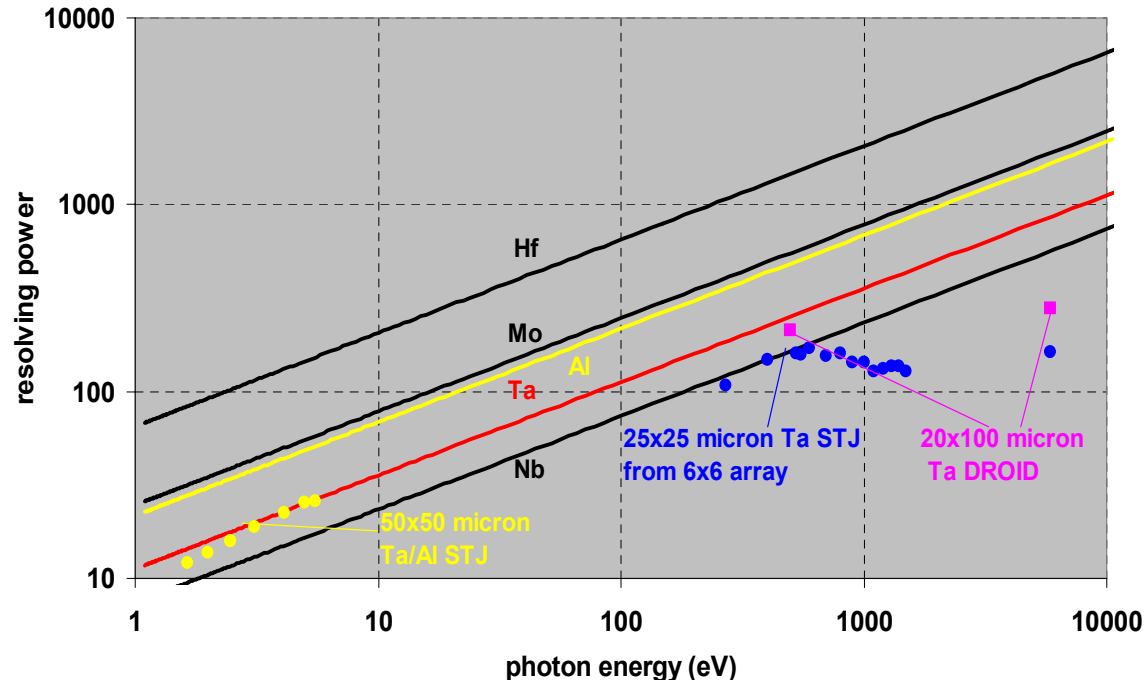
# Objective: Improved Energy Resolution

The tunnel limited energy resolution of an STJ is given by:

$$\Delta E = 2.355 \sqrt{1.75 \Delta_g E (F + G + H)}$$




- $\Delta_g$  energy gap
- E photon energy.
- F = 0.22 Fano factor.
- G  $\sim$  1 tunnel noise
- H cancellation noise.

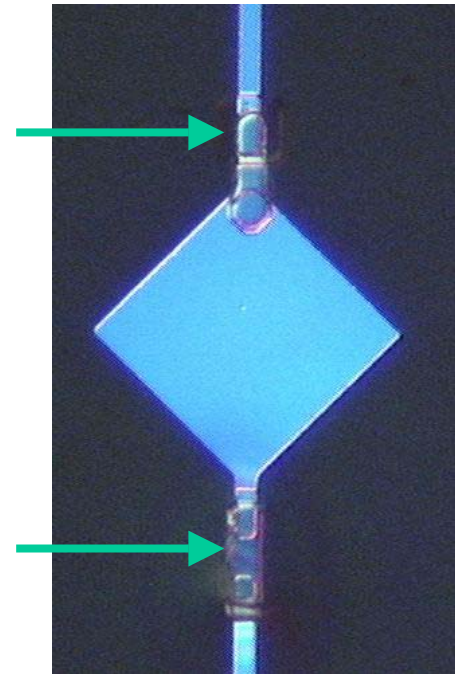
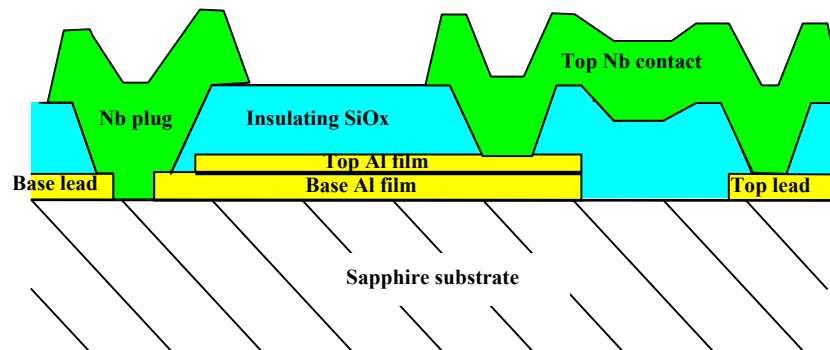
Material	$\Delta_g$ ( $\mu\text{eV}$ )	$T_C$ (K)
Nb	1550	9.4
<b>Ta</b>	<b>700</b>	<b>4.5</b>
<b>Al</b>	<b>180</b>	<b>1.2</b>
Mo	140	0.92
Hf	19.4	0.13



# Fabricated junctions

- square Al STJs in diamond orientation
- 4 different device sizes:  
10, 30, 50 and 70  $\mu\text{m}$ .
- Nb plugs in leads to prevent outdiffusion
- 20  $\mu\text{m}$  junctions with 5  $\mu\text{m}$  wide leads for energy gap and normal resistance measurements.

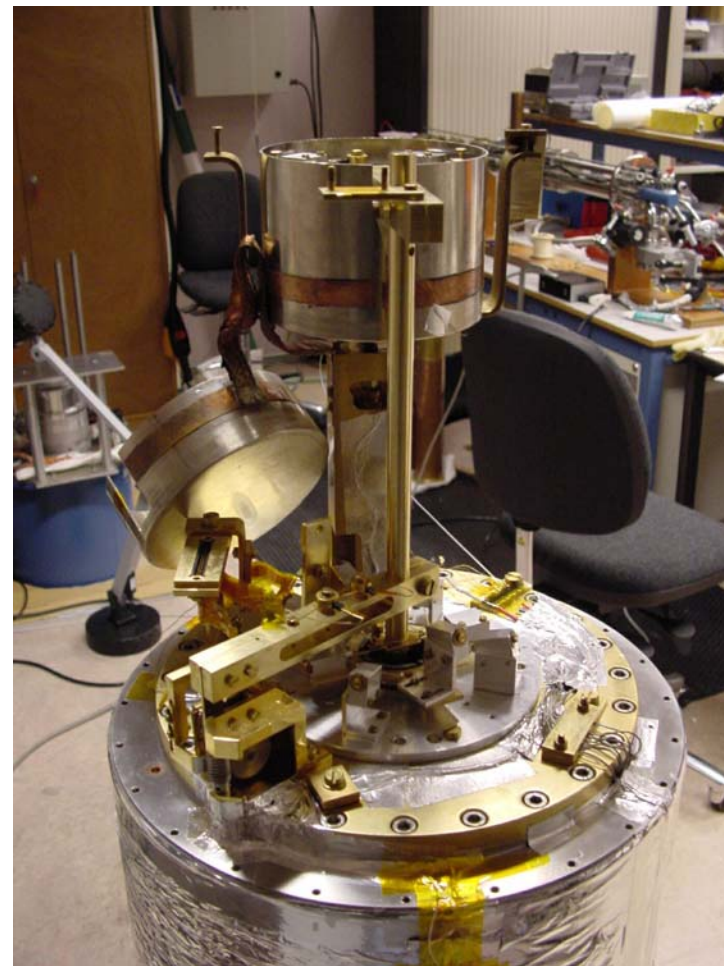
 Nb: 400 nm  
 Al: 100 nm base; 50 nm top  
 SiOx: 350 nm



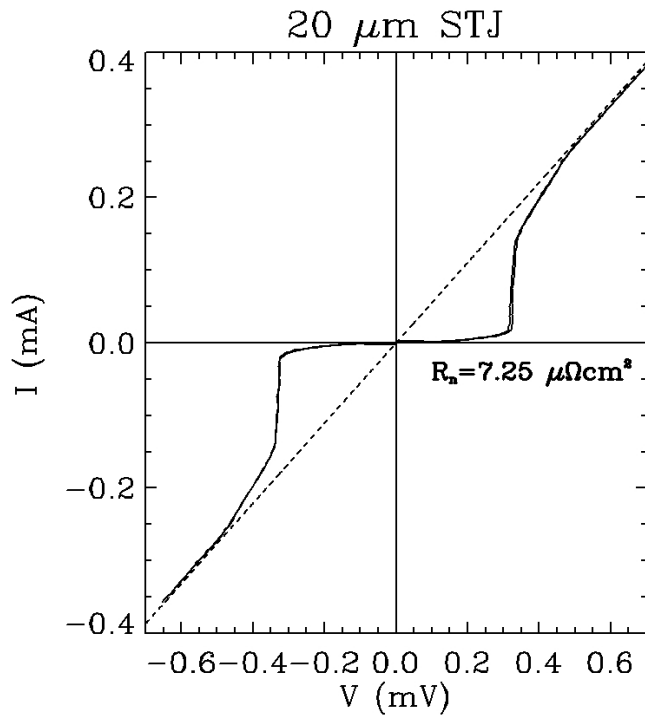
fabricated by **Cambridge MicroFab Ltd** (Cambridge, UK).

# Cryogenic Set-up: ADR

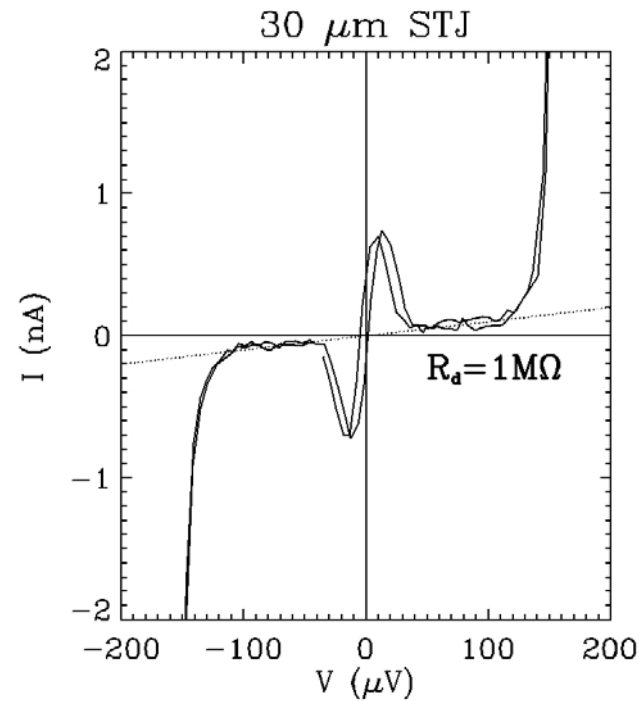
- STJs have to be operated at temperatures lower than  $\sim T_c/10$  in order to freeze out all thermal quasiparticles.
- $\rightarrow$  Al STJs  $< 120$  mK.
- adiabatic demagnetisation refrigerator (ADR):
  - base temperature  $\sim 35$  mK
  - hold time below 100 mK  $> 10$  hrs.



# IV-characteristics



**Barrier resistivity  $\sim 7.25 \mu\Omega \text{cm}^2$**



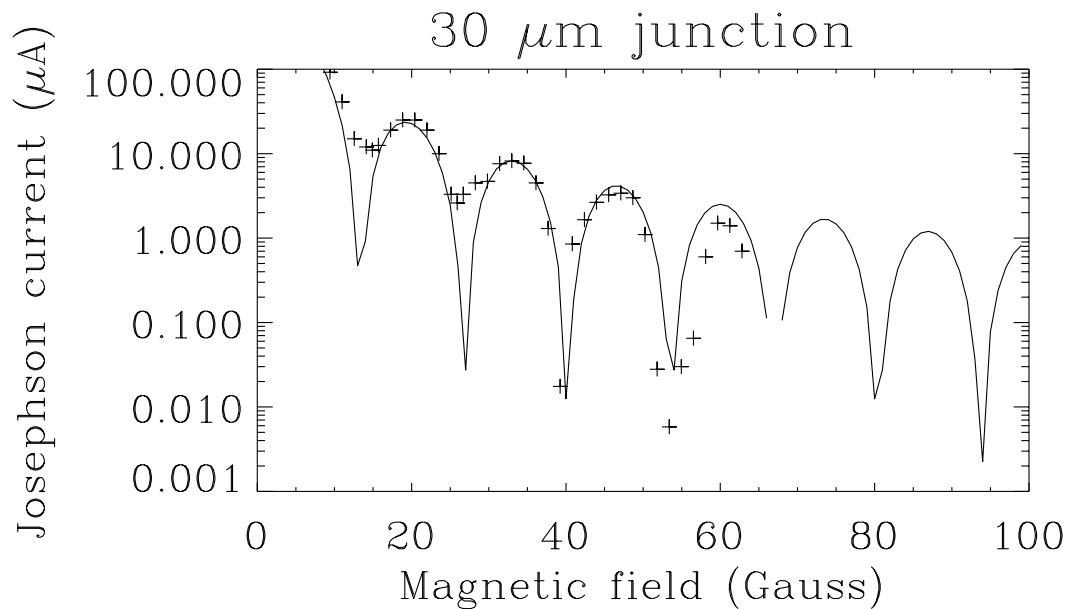
**Leakage current  $\sim 100 \text{pA}$**

**Dynamical resistance  $\sim 1 \text{M}\Omega$**

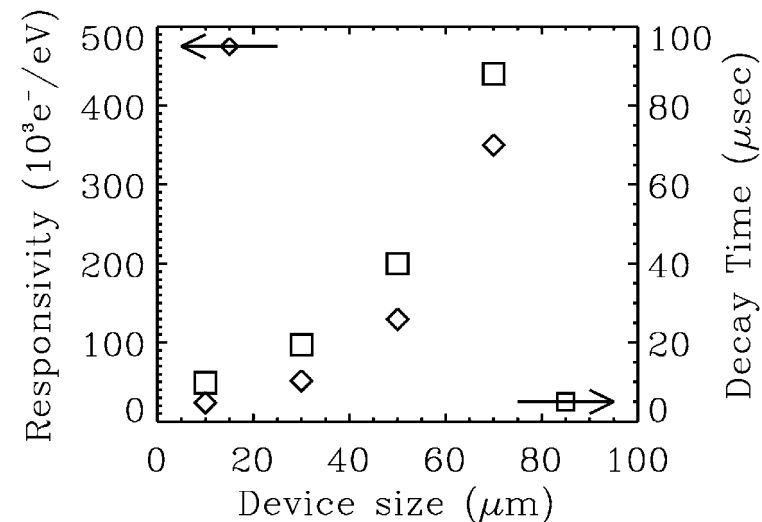
**quality factor:  $Q = R_d/R_n \sim 10^6$ .**

# Josephson current suppression

- A magnetic field has to be applied parallel to the junction in order to suppress the Josephson currents.
- required field strength for optimum suppression  $\sim 40\text{-}55\text{ G}$



# Optical photon response: Responsivity + Decay Time



- The responsivity (Charge output per eV of photon energy) and the decay time of the junctions **depend strongly on the size** of the devices => losses are at the edges or into the leads of the detector.

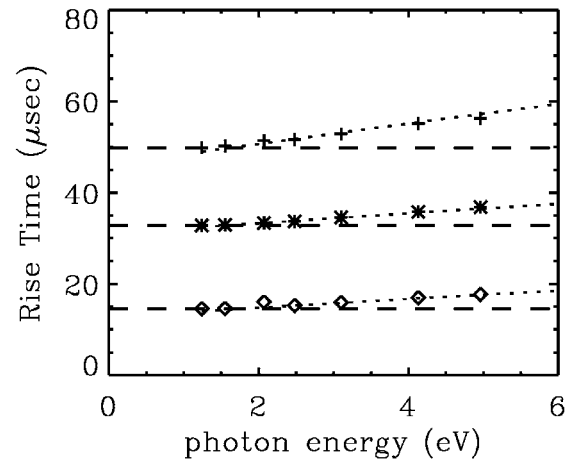
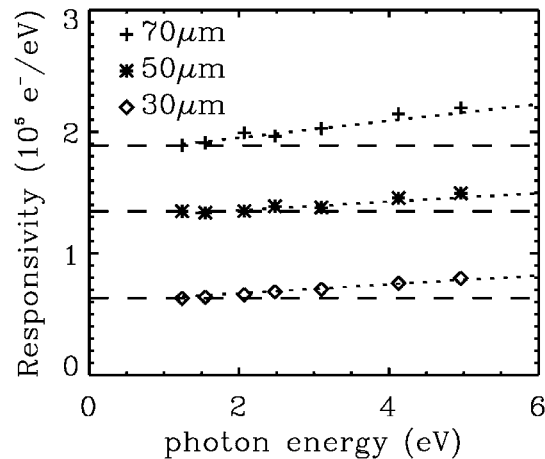
- 3300 electrons are initially created in the absorbing electrode for every eV of photon energy but many more electrons are detected at the output of the detector. The **charge amplification (backtunneling) varies between 7 and 105** depending on device size.

- In these junctions tunnelling is fast, whereas quasiparticle scattering to the gap energy is slow (dependence on  $\Delta_g^3$ ). As a consequence the quasiparticles are not at the gap energy, but have an energy distribution with a lot of quasiparticles above  $\Delta_g + eV_b$ . Those can tunnel against the bias (**cancellation**) => **a considerable fraction of signal is lost** because of this effect.

- **Simulations** with an **energy dependent kinetic equation model** (to be published) **show:**  
=> 60% of signal is lost.



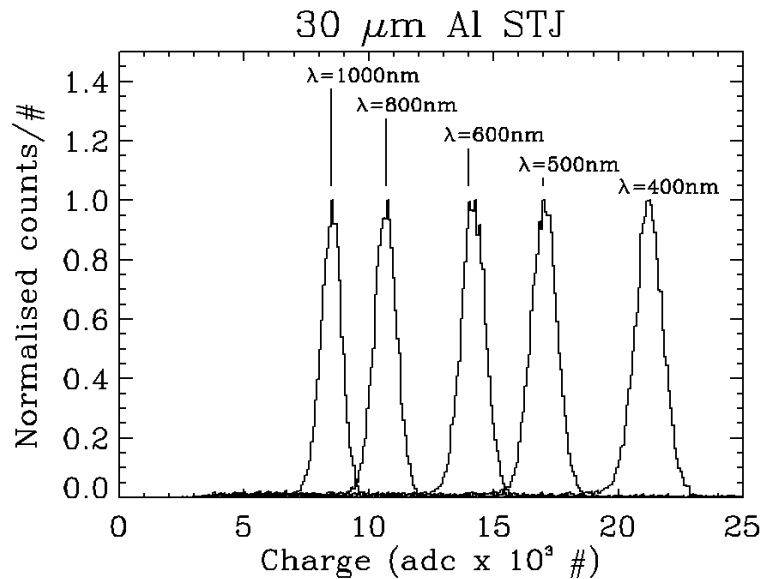
# Optical photon response: Energy non-linearity



- considerable **energy non-linearity in the visible** indicates a finite but low number of traps.
- As the quasiparticle traps get filled up (6000 available traps versus 3300 quasiparticles per eV of photon energy) the fraction of quasiparticles that is available for tunnelling increases with increasing photon energy.

Simulations with an <b>energy dependent kinetic equations model</b> (to be published) show typically:	Unit	Materials		
		Al	Ta-Al	Nb-Al
Number of traps per electrode	/	6 000	20 000	185 000
Trapping probability	/	0.02	0.07	0.22
Trap depth	$\mu eV$	82	160	240

# Energy resolution



- A fit to:

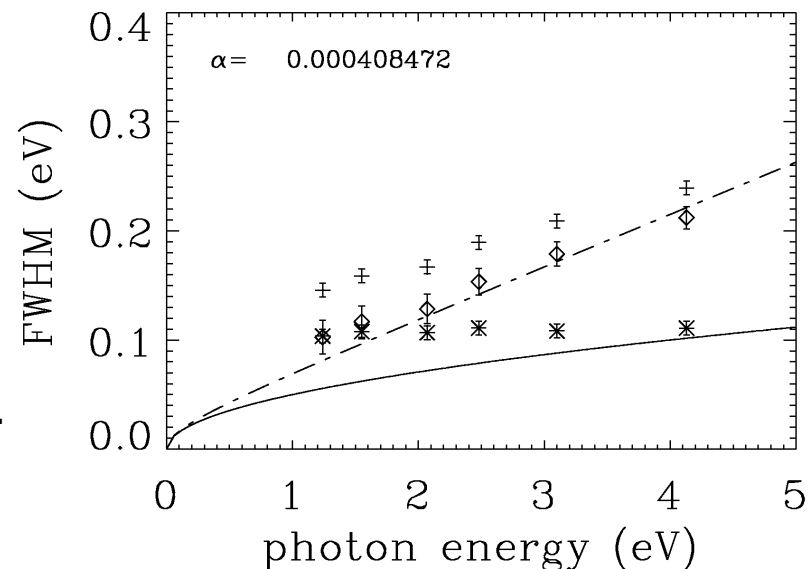
$$\Delta E = 2.355 \sqrt{1.75 \Delta_g (F + G + H) E + \alpha E^2}$$

where  $\alpha$ , representing the spatial non-homogeneities, was used as free fitting parameter, yields  $\alpha = 4 \cdot 10^{-4}$ .

Cf. Ta-Al STJs:  $\alpha = 2 \cdot 10^{-6}$

- The intrinsic energy resolution in the optical is still considerably worse than the expected tunnel limited resolution for an Al junction.  
At  $\lambda=500\text{nm}$ :  $E/\Delta E = \mathbf{16.5}$  (tunnel limit  $\sim 33$ ).

- $\rightarrow$  **spatial non-uniformities in the response of the STJ**, possibly due to losses into the Nb contacts and plugs or edge losses.



# Conclusions

---

- We have fabricated **high quality Al STJs** and operated them in a 35 mK environment.
- The **leakage currents** are of the order of 100 fA per  $\mu\text{m}^2$  of junction area and the normal resistivity is equal to  $7 \mu\Omega \text{ cm}^2$ .
- high responsivity due to back-tunnelling ( $\langle n \rangle \sim 7-10^5$ , depending on device size). The strong dependence on device size indicates dominating perimeter-related losses.
- We observe an **energy non-linearity in the optical domain** reflecting a low number of quasiparticle traps (6000 trapping states compared to 3300 quasiparticles created per eV of photon energy).
- The measured **resolving power at  $\lambda=500\text{nm}$  is equal to 13**, limited by spatial non-homogeneities in the response of the detector.