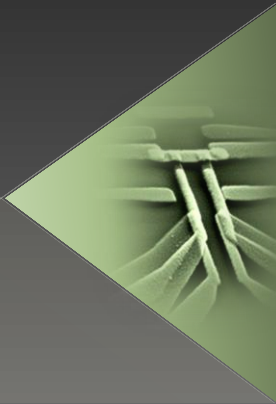
# *Mesoscopic Superconductivity & Quantum Transport* *@ NEST CNR-SNS*

F. Giazotto



*New Ideas for Detecting Dark Matter*

Scuola Normale Superiore, 24 February 2016, Pisa

# *Outline*

- MSQT team @ NEST
- Nanofabrication & measurement facilities @NEST
- MSQT research @ NEST
  - Quantum charge transport at the nanoscale
  - Quantum thermal transport at the nanoscale
- Towards detection of DM: STAX

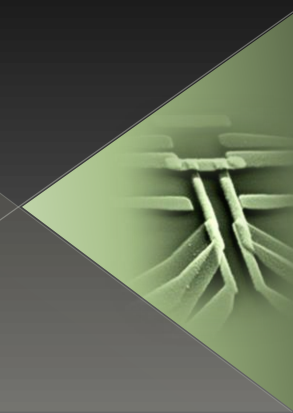
# *MSQT team @ NEST*

- PI – FG (CNR)
- 1 Junior scientist - E. Strambini (CNR)
- 1 Visiting scientist – E. Enrico (INRiM)
- 7 Postdoc researchers - S. D'Ambrosio (CNR), G. De Simoni (CNR), C. Guarcello (CNR), N. Ligato (CNR), N. Poccia (CNR), F. Paolucci (CNR), P. Virtanen (CNR)
- 4 PhD students – A. Fornieri (SNS), G. Marchegiani (UNIPI), A. Ronzani (SNS), G. Timossi (SNS)
- 6 Undergraduate students – O. Durante (UNI Salerno), J. Mastomaki (UNI Jyvaskyla-FI), I. Mendez (CNRS-FR), M. Meissner (UNI Aachen-GE), Y. Venturini (UNIPI), F. Vischi (UNIPI)

# *Nanofabrication facilities @ NEST*

Class ISO 7 Clean Room Facility equipped with:

- N. 2 UV optical lithography mask aligners: MJb3 and MJB4 by SUSS
- N. 3 e-beam pattern generators (EBL)
- FEG-SEM, Ultra Plus from ZEISS, 30 kV 1.2 nm resolution
- FEG-SEM, Merlin from ZEISS, 30 kV 0.8 nm resolution
- Nanoimprint lithographic system (2.5” wafer) from Obducat
- Scanning Probe Microscope (AFM, LFM, KPFM, CFM, Scan-Asyst, Peak Force Tapping): Dimension ICON-PT from Bruker
- Rapid Thermal Annealer (RTA)
- Oxygen Plasma Cleaner
- N.2 Spin Coaters
- Contact Angle Measuring system
- Hot plates and oven for thermal resist treatment
- Nomarsky Optical Microscope
- N.3 high-vacuum Thermal Evaporators
- N. 1 UHV e-beam Evaporator with tiltable sample holder
- 3D Stylus Profilometer DEKTAK XT from Bruker
- Wet bench station
- Wafer Bonding system from SUSS Microtech GmBH
- 4 minirobots "Imina Technology" for SEM and Optical microscopy nanomanipulation



# *Facilities* @ NEST

CBE, Plasma Etching and Deposition:

- Chemical Beam Epitaxy for semiconductor nanowire growth
- Reactive Ion Etching (RIE) system based on $CH_4/H_2$ chemistry
- PECVD system for $SiO_2$ growth
- RIE-ICP system based on Cl, $BCl_3$ chemistry
- DC & RF - Sputtering system for Nb and NbN film deposition, Ar sputtering, Sm desorption
- Atomic Layer Deposition (ALD): "Opal", thermal and plasma system by Oxford Instruments

MSQT lab measurement & cryogenic facilities:

- N.1 Cryo-free dilution fridge (Oxford), 200 $\mu$W, T < 10 mK, 5 windows, 24 filtered DC lines, 12 RF coax lines (<500 MHz), single-axis magnetic field (<0.4 Tesla)
- N.1 Cryo-free TL dilution fridge (LC), 1600 $\mu$W, T < 8 mK, 48 filtered DC lines, 6 RF coax lines (20 GHz), vectorial magnetic field (5-1-1Tesla)
- N.1 Cryo-free TL dilution fridge (LC), 1760 $\mu$W, T < 8 mK, 48 filtered DC lines, 6 RF coax lines (20 GHz), single-axis magnetic field (3 Tesla)
- N.1 Cryo-free dilution fridge (LC), 600$\mu$W, T < 10 mK, 48 filtered DC lines, 6 RF coax lines (20 GHz), 5 windows (to be purchased at beginning 2017)
- Setups for DC electrical and thermal characterization of hybrid nanostructures

# *MSQT research @ NEST*

- Quantum charge transport

(fully metallic, 2DEG- & NW-based hybrid structures)

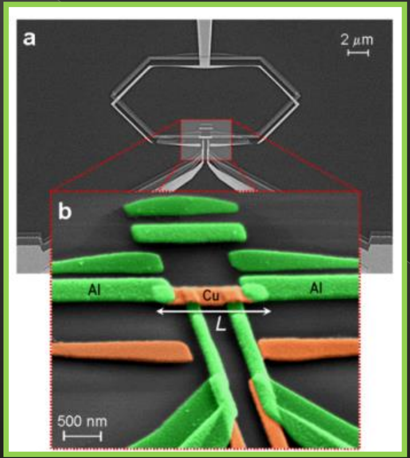
- Quantum thermal transport and dynamics

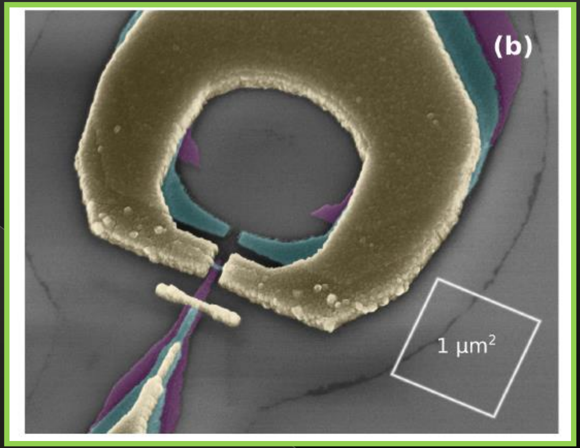
(fully metallic, 2DEG- & NW-based structures)

# *Quantum charge transport at the nanoscale i)*

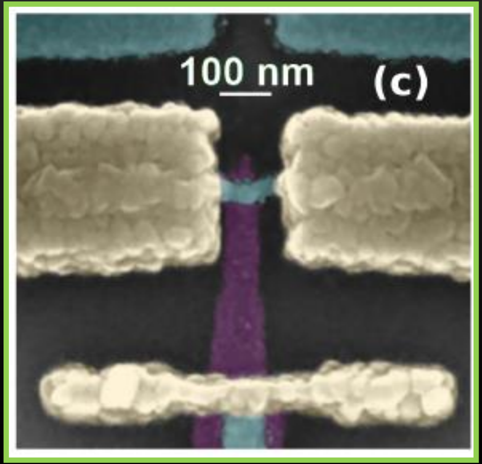
- Fully-metallic hybrids (THz radiation detection, magnetometry)

*SQUIPTs*

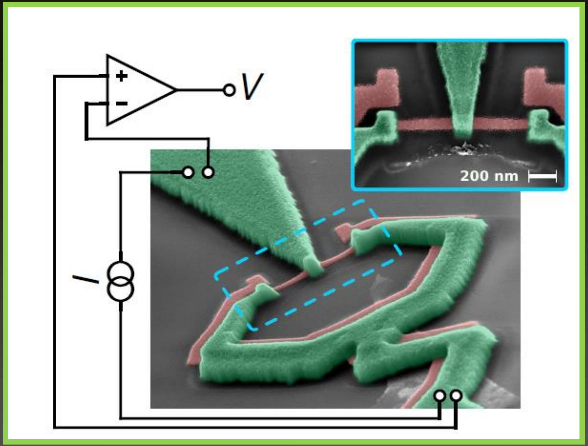


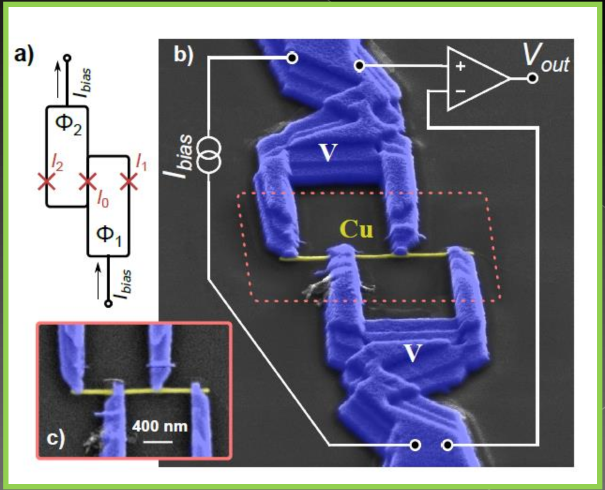




Nature Phys. (2010)
PRB (2011)
PRB (2011)
PRAppl (2014)
APL (2015)




*SNS SQUIDs*



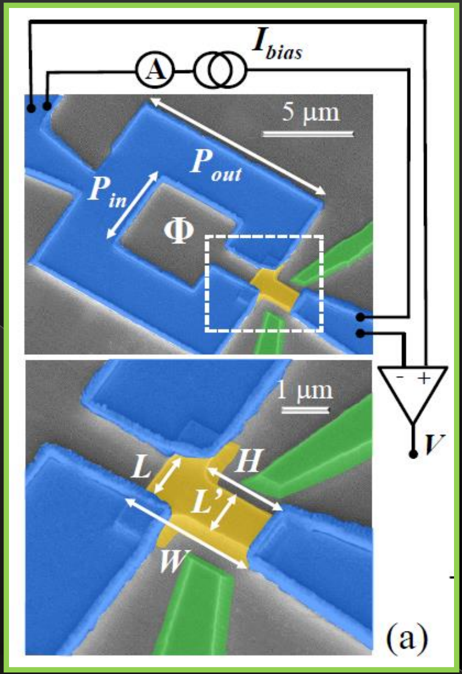




APL (2013)
APL (2014)

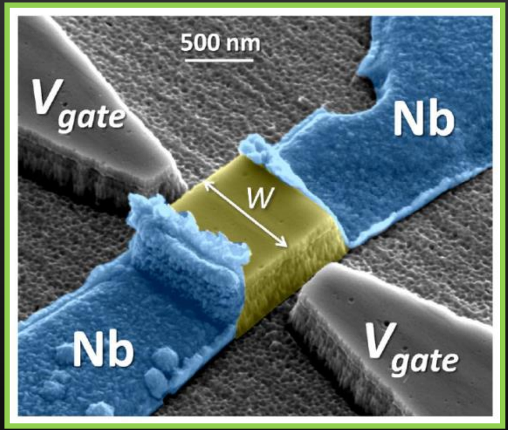
# *Quantum charge transport at the nanoscale ii)*

- 2DEGs-based hybrids (ballistic structures, novel JJs, Majoranas)

*AB JJs*

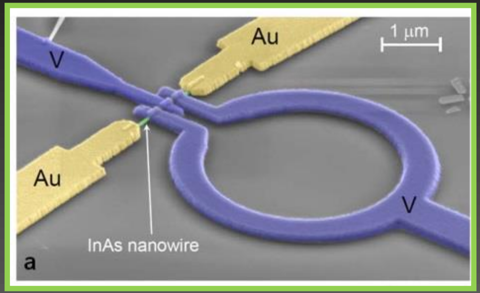

*QPC JJs*



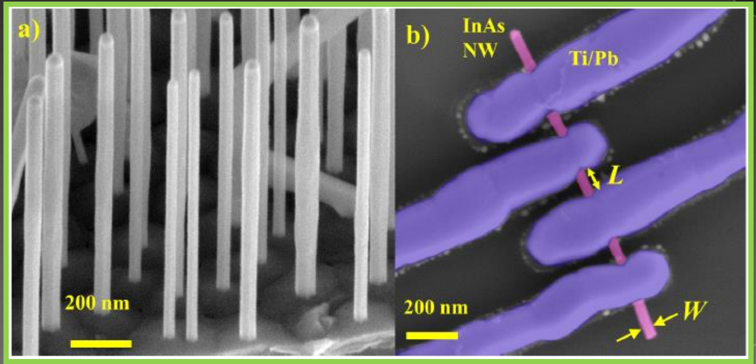

*Andreev Is*

APL (2014)
PRB (2013)
PRB (2011)
APL (2011)
APL (2010)

- InAs NW-based hybrids (SQUIDs, quantum effects & nonequilibrium)




*J QEPs*

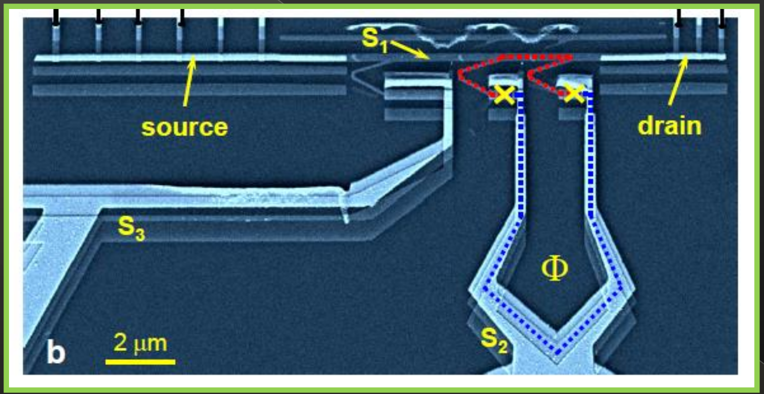



*JJs*

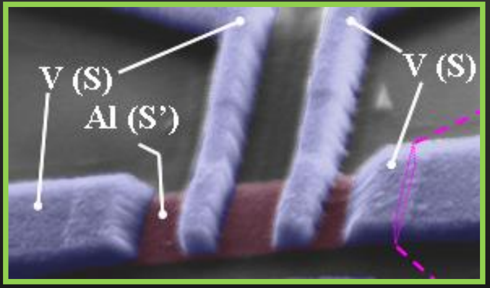
Nano Lett. (2015)
Nature Phys. (2011)
Nanotechnology (2011)
Nano Res. (2011)

# Quantum *thermal* transport at the nanoscale i)

- Fully-metallic hybrids (coherence in JJs, superconducting cooling, thermometry)

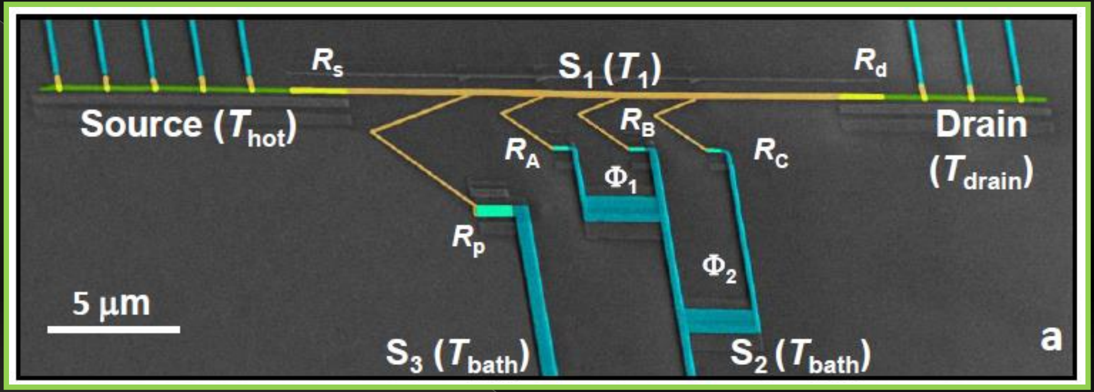



*J heat interferometers*

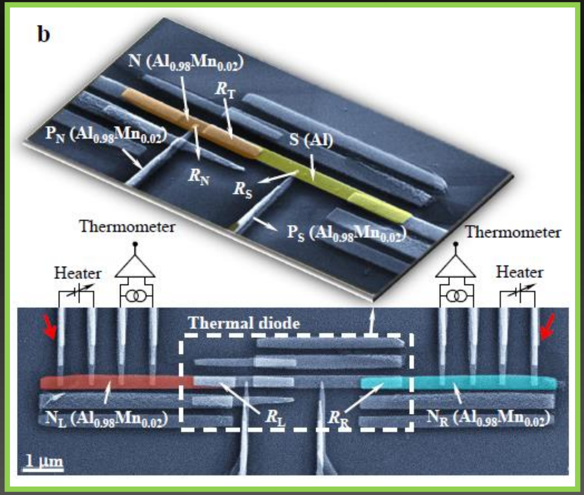



*V/Al electron coolers*

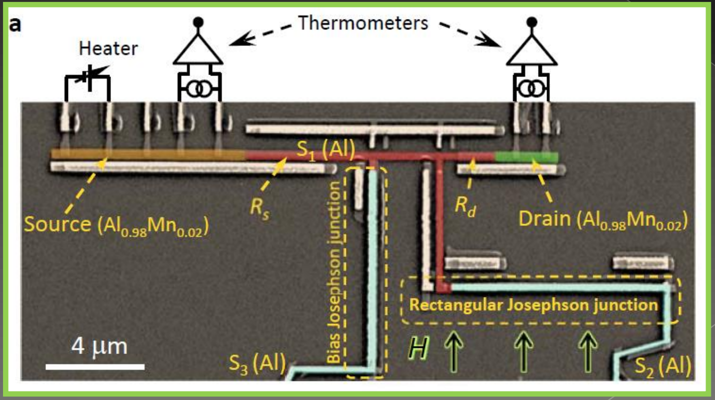
Nature Nanotech. (2015)
Nature Nanotech. (2015)
Nature Commun. (2014)
Nature (2012)
APL (2012)
APL (2011)




*J heat modulators*




*Thermal diodes*

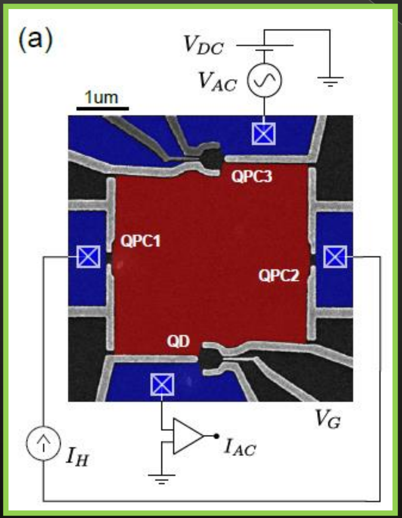


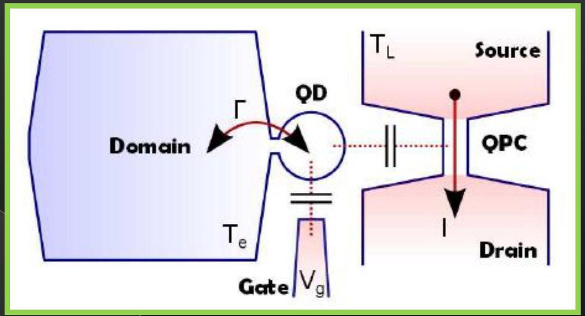

*J heat diffractors*

# Quantum thermal transport at the nanoscale ii)

- 2DEGs-based hybrids (QD refrigeration, QPC contactless thermometry)

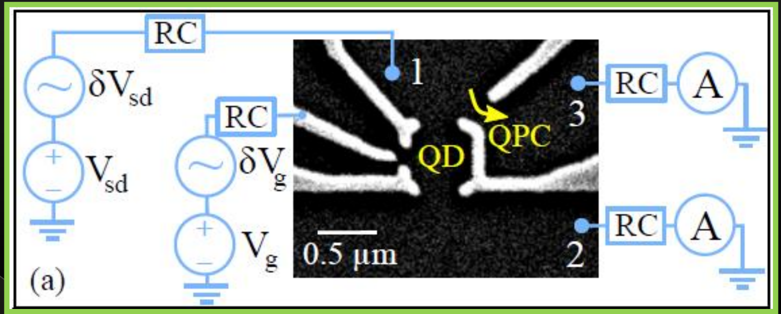
*QD coolers*



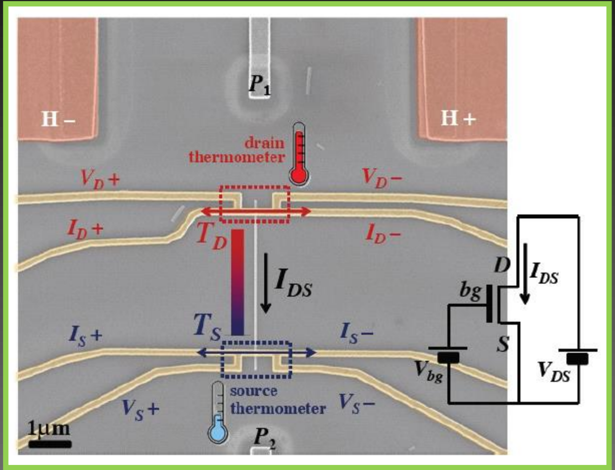

PRB (2013)
APL (2012)
PRB (2011)

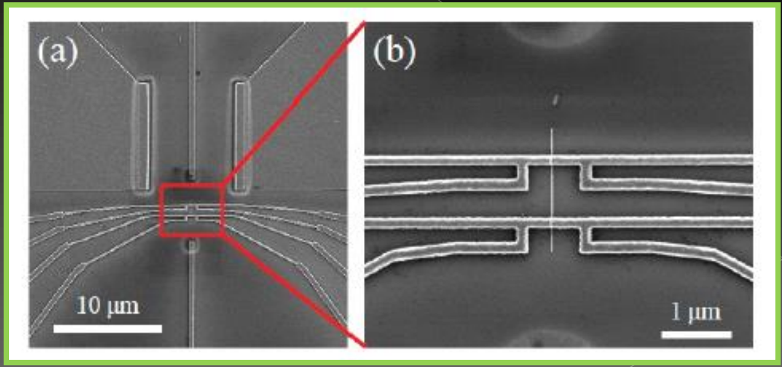
*QPC thermometers*




- NW-based thermoelectricity

Nano Lett. (2013)
Nano Res. (2013)




*Giant thermopower*

# *Towards detection of DM: STAX*

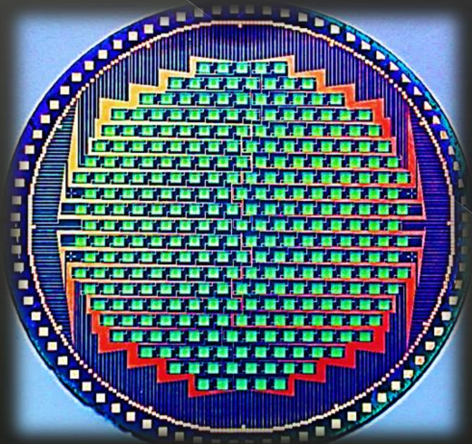
- Quantum technology: when quantum mechanics & nanotechnology merge to boost future devices with enhanced capabilities

- Quantum radiation detectors: accessing ultra-high sensitivity in bolometric & calorimetric operation

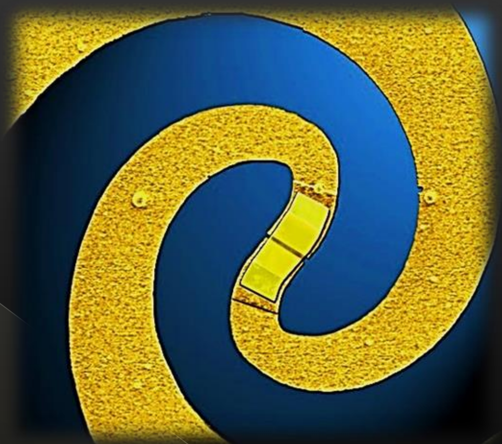
- Paving the avenue to fundamental physics research: quantum computing, quantum criptography, quantum entanglement, particle & astroparticle physics, dark matter, cosmology

# Towards detection of DM: STAX

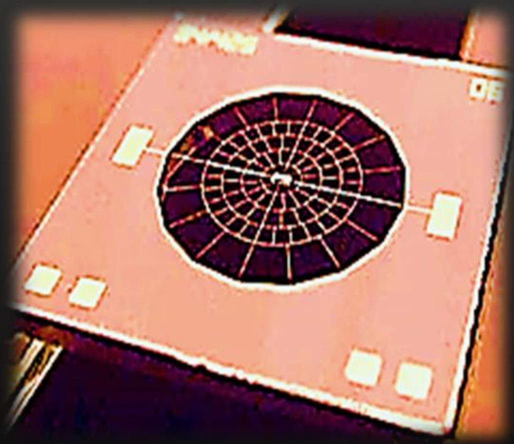
THz Bolometer technology



APEX Camera LABOCA



Advanced HEB TU Delft



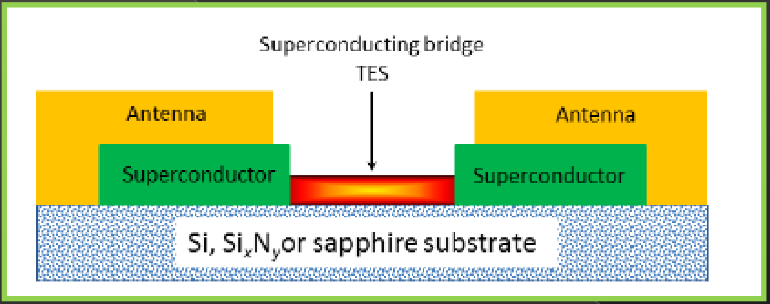
NASA/JPL-Caltech

## Applications:

Safety
- National security
- Chemical safety
- Natural disasters prevention
- Natural disasters rescue
- Air, water & earth pollution monitoring

Human science
- Archeology
- Architectural heritage preservation
- Pattern recognition

# Sub-THz & mw single-photon detection in STAX




STAX: TES operating in the 30 GHz-150 GHz range

TES energy resolution $$\sigma_E \approx 0.3\sqrt{k_B T_c^2 C_e}$$ $\propto T^{3/2}\text{Volume}^{1/2}$

Requirements:

i) Choice of a superconductor with a sufficiently low critical temperature ($T_c < 20$ mK);

ii) Tailoring of the TES active volume in order to achieve a reduced thermal capacitance;

iii) Design of an integrated highly-efficient planar antenna;

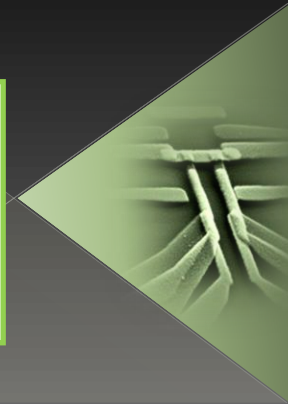
iv) Optimization of low-noise SQUID readout electronics.

# Sub-THz & mw single-photon detection in STAX

- i) Choice of a superconducing bridge with low Tc (≤ 20mK) ($\alpha$-W, $TiN_X$, Ti/Cu, Ti/Au, or Al/Cu bilayers)
- ii) Reduced TES active volume (down to $10^{-3}$-$10^{-4}\mu m^3$)
- iii) EBL to downsize TES lateral dimensions to a few tens of nm
- iv) Highly-efficient log-period spiral antennas (NbTi, Nb, or V)
- v) ultra-low noise dc SQUID amplifiers ($n_I$~10 $fAHz^{-1/2}$ @100mK)

STAX TES calorimeters expected performance:

| Operation frequency $\nu$ (GHz) | Operative temperature (K) | Energy resolution $\sigma_E/h$ (MHz) | DCR (1/year) | Efficiency $\eta$ (%) | Absorber volume ($\mu m^3$) | Speed $\tau_{eff}$ (s) |
|---|---|---|---|---|---|---|
| **30 -100** | **≤ 0.01** | **500 - 1000** | **$10^{-5}$** | **≥ 99** | **$10^{-3}$ – $10^{-4}$** | **$10^{-3}$ – $10^{-1}$** |



# *Acknowledgements*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