TES Detectors (and SQUID Muxes) at NIST

Gene Hilton
Kent Irwin
William Duncan

National Institute of Standards and Technology
Boulder, Colorado

December 13, 2006

Quantum Sensors Project

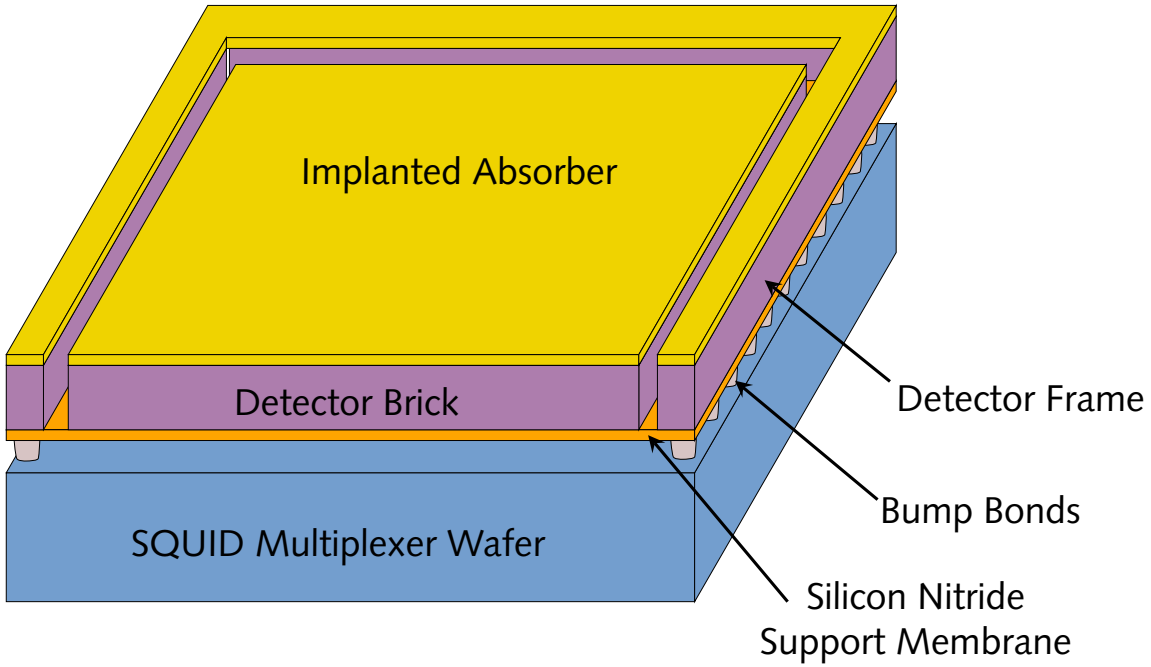
Jim Beall
Randy Doriese
William Duncan
Lisa Ferreira
Gene Hilton
Rob Horansky
Kent Irwin
Ben Mates
Nathan Miller
Galen O'Neil
Carl Reintsema
Dan Schmidt
Joel Ullom
Leila Vale
Yizi Xu
Barry Zink

Some of us . . .

Outline

- SCUBA-2
  - Overview
  - Multiplexers
  - Detectors
  - Array Integration
  - Readout Electronics
  - Results
  - Yield
- NIST sub-mm Imagers for CCAT
  - Overview
  - Multiplexer improvement
  - Detector simplification
  - Array Integration
  - Testing
  - Costs

SCUBA-2 Overview



- SCUBA Imagers are fabricated using two separate wafer-scale chips - Detector and Multiplexer
- Each wafer sub-arrays consists of 32 $\times$ 40 array pixels (1280 total) on a 1.135 mm pitch
- Four sub-arrays are tiled to make a focal plane
- Two focal planes, 450 μm and 850μm

SCUBA-2 Multiplexer

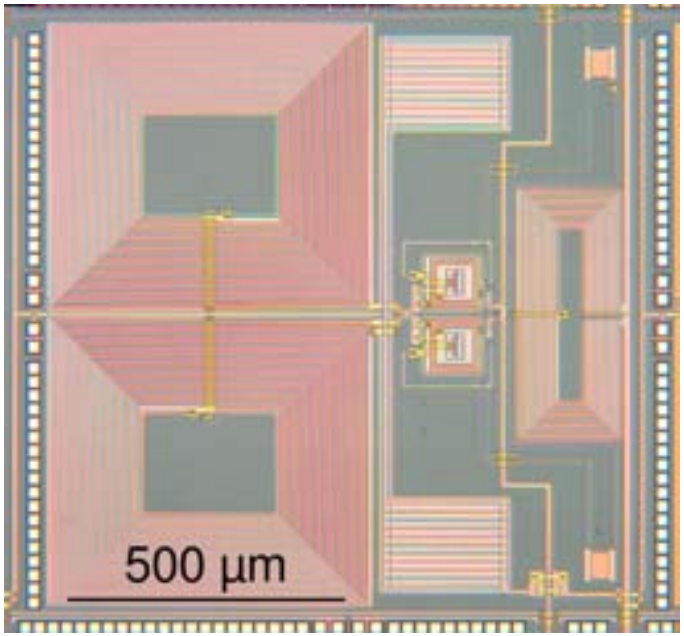
Standard NIST SQUID process

- Nb/AlO_x/Nb junction
- ECR-PECVD low-temperature SiO_2
- 3 wiring levels, 10 lithography levels
- 0.8 μm minimum feature size

SCUBA-2 Multiplexer

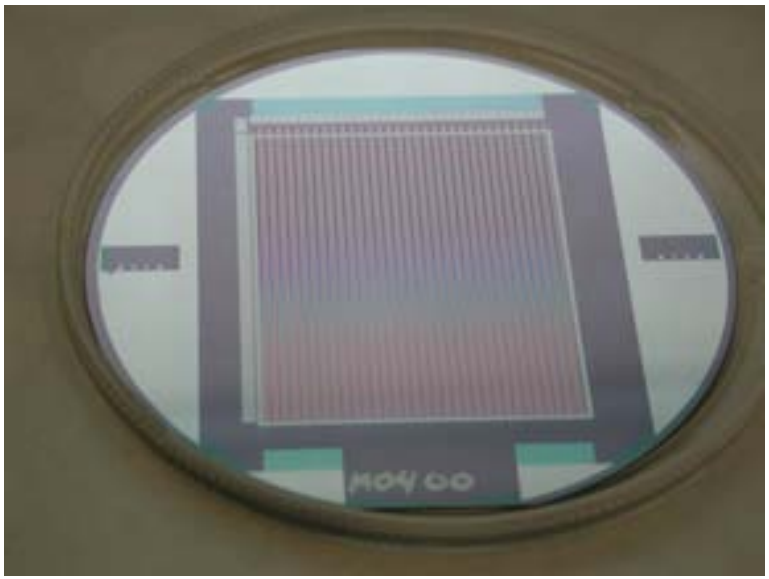
Standard NIST SQUID process

- Nb/AlO_x/Nb junction
- ECR-PECVD low-temperature SiO_2
- 3 wiring levels, 10 lithography levels
- 0.8 μm minimum feature size

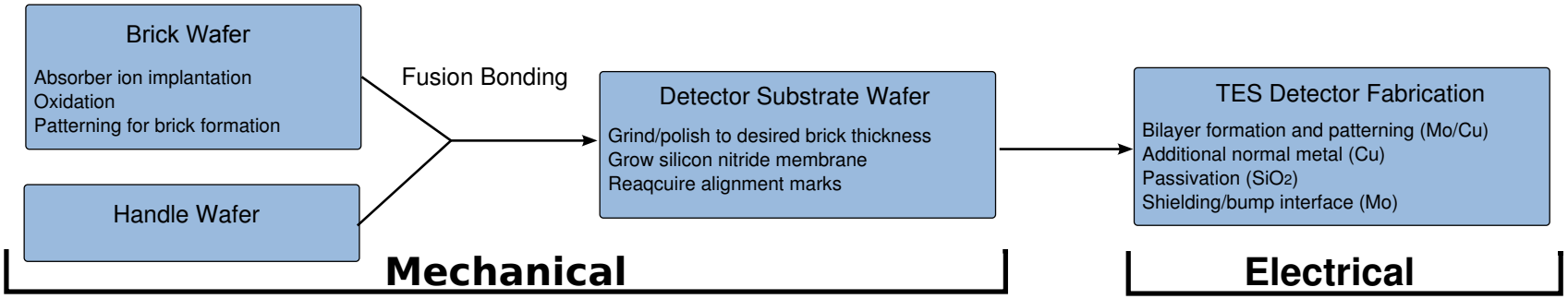


. . . with some differences

- Wafer-scale pattern (made on a stepper) - 60 reticles!
- Two additional layers (SiO_2 and Mo) for bump-bond compatibility
- In-process testing

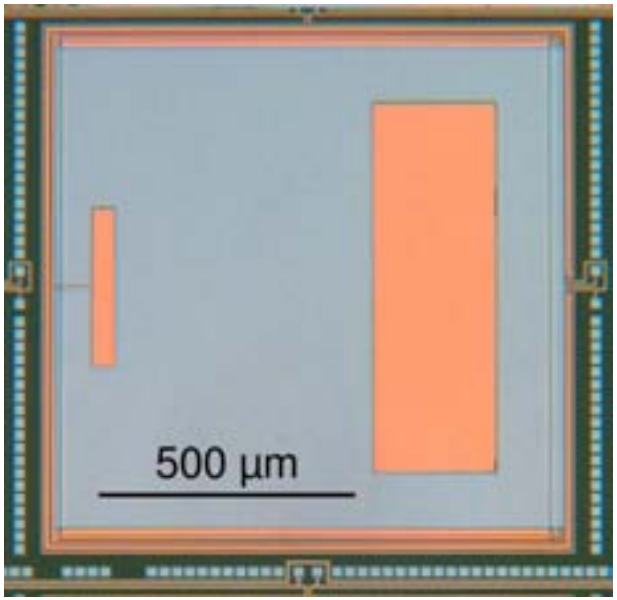


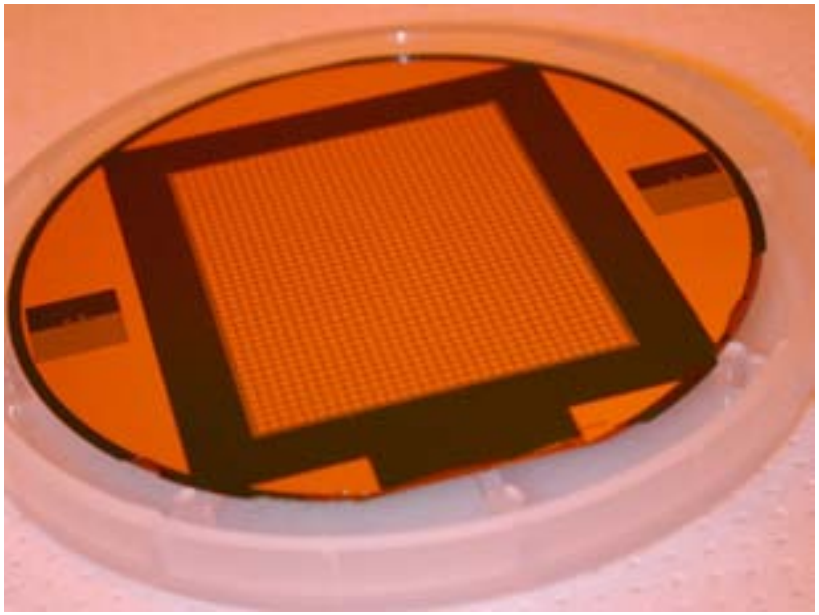
SCUBA-2 Detectors



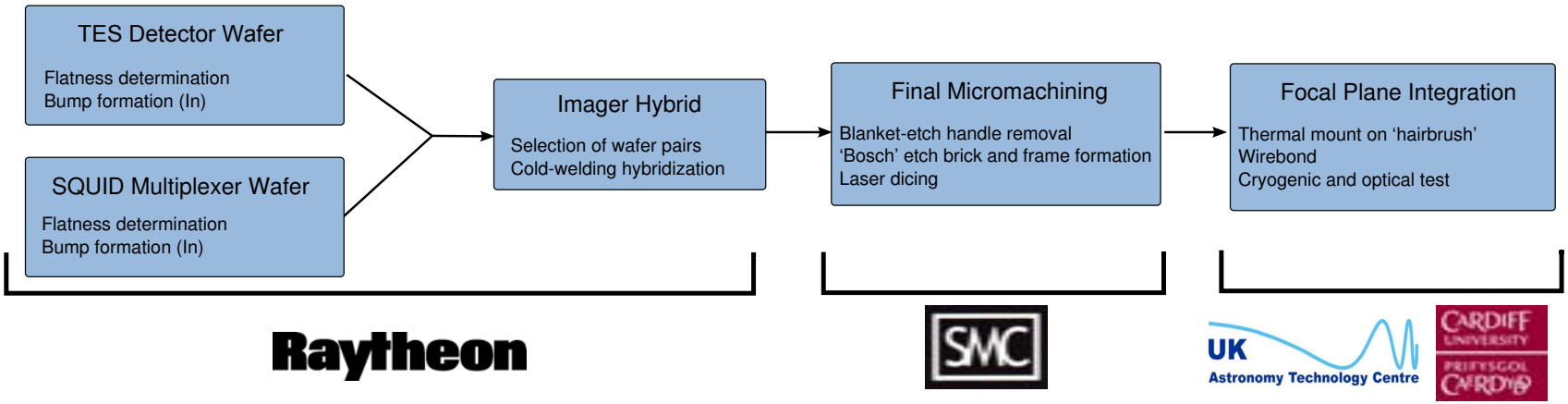
SMC Scottish Microelectronics Centre

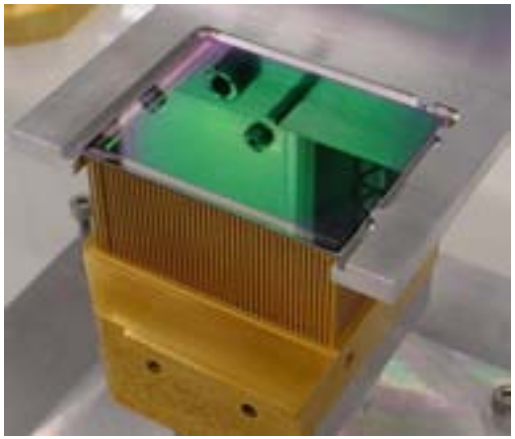
NIST

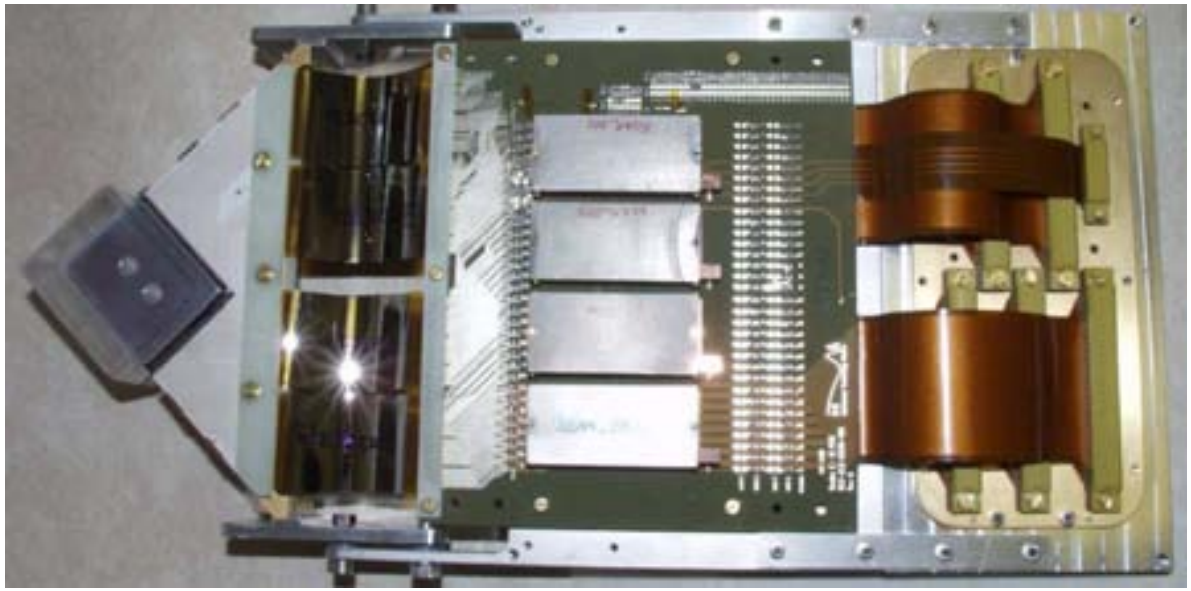




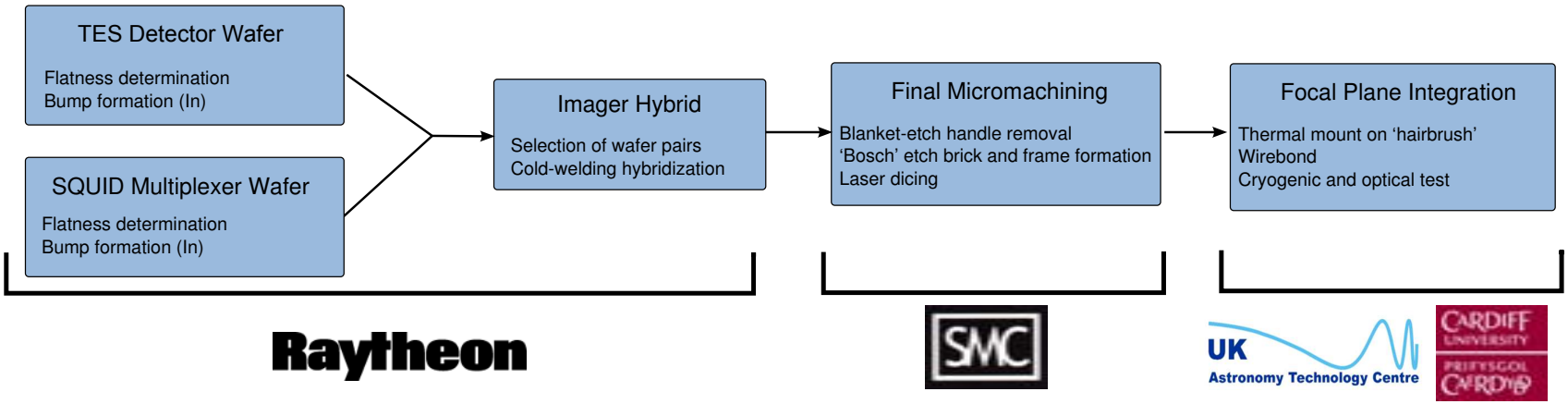
SCUBA-2 Array Integration

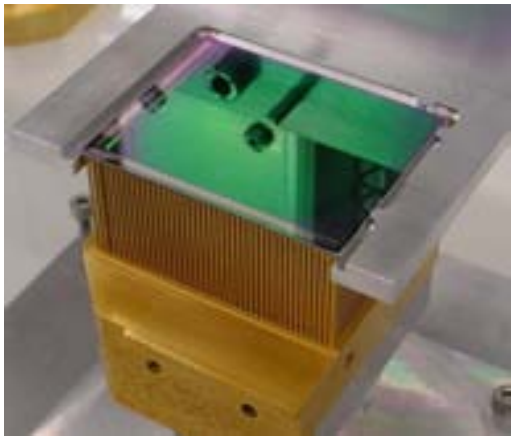


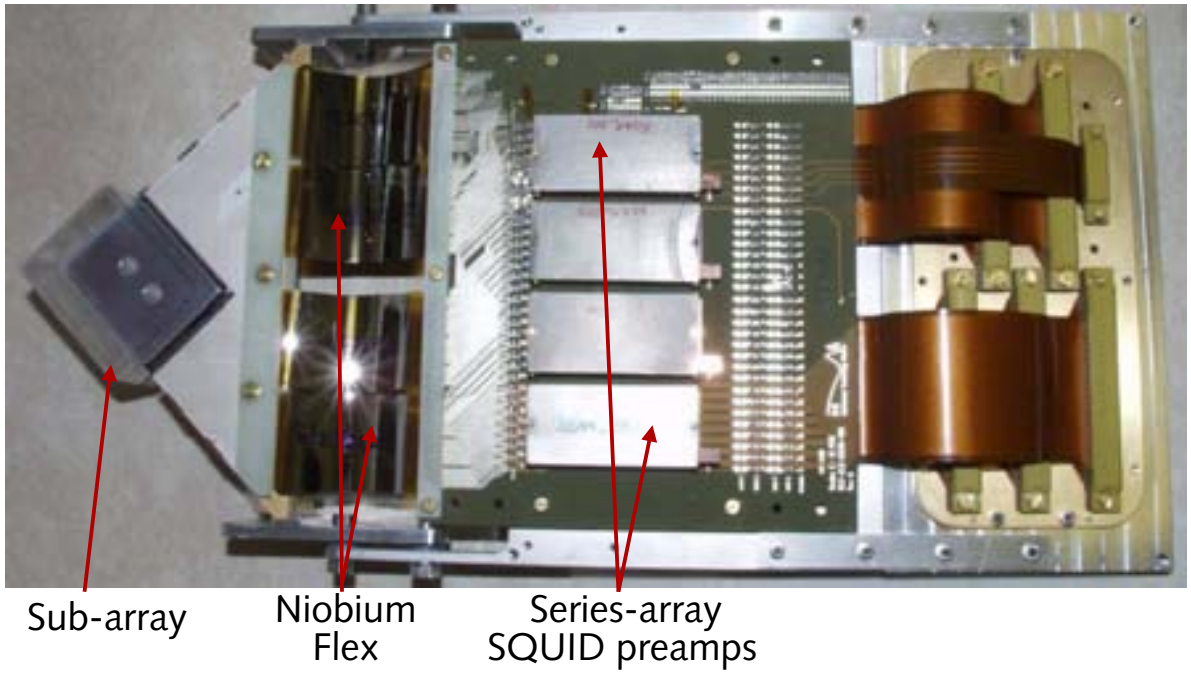




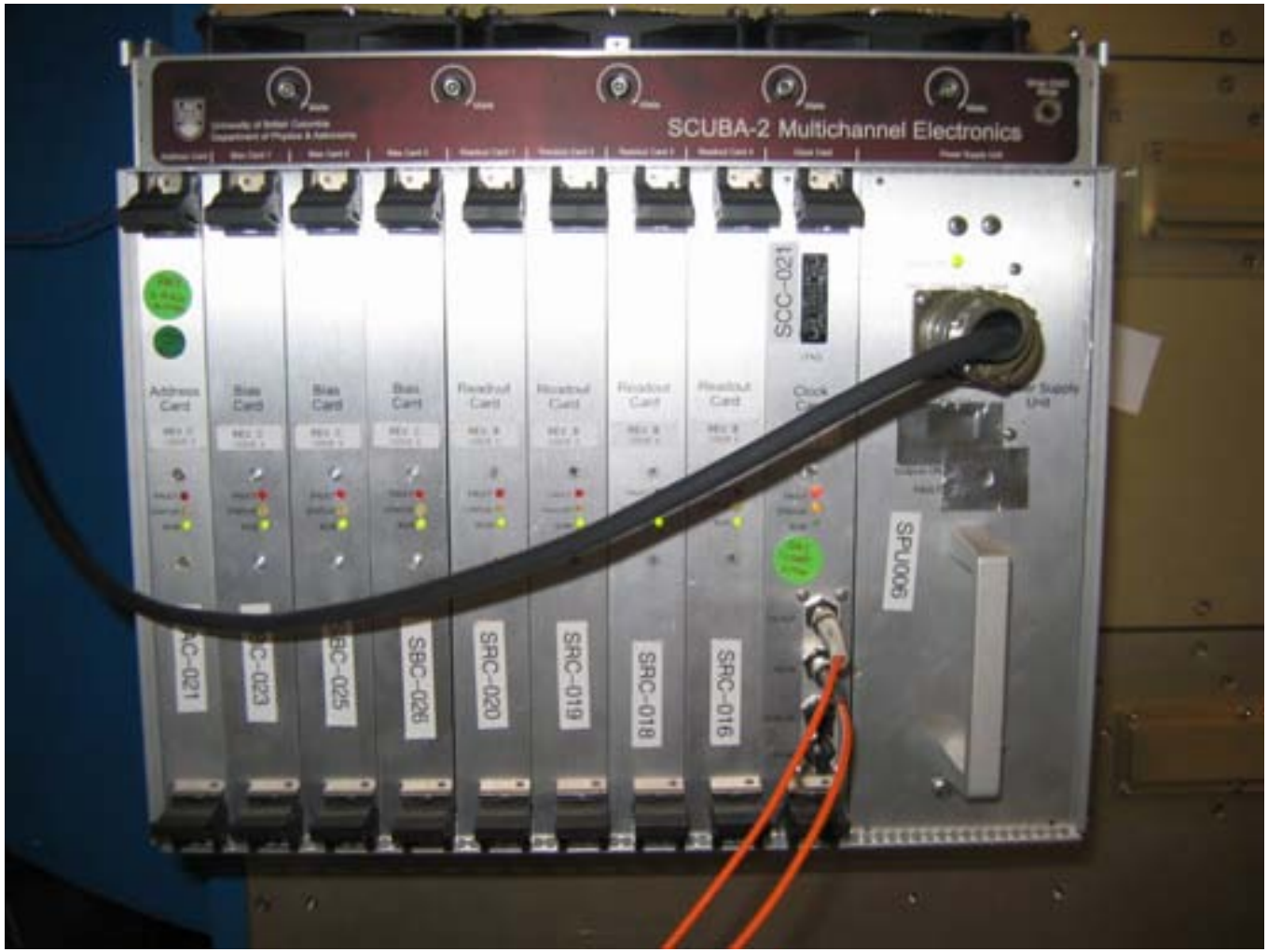
SCUBA-2 Array Integration







Readout Electronics



UBC readout electronics - next talk

Two Detector Subarrays Are Now Cold

Carl and Kent in Edinburgh November 30, 2006

Key Results

Prototype Arrays

- Basic mux and detector functionality
- Measured detector/mux interactions - detector design changed and tested
- Measured mux crosstalk issues - multiplexer design changed and tested
- Measured NEP and optical response - well within requirements

Key Results

Prototype Arrays

- Basic mux and detector functionality
- Measured detector/mux interactions - detector design changed and tested
- Measured mux crosstalk issues - multiplexer design changed and tested
- Measured NEP and optical response - well within requirements

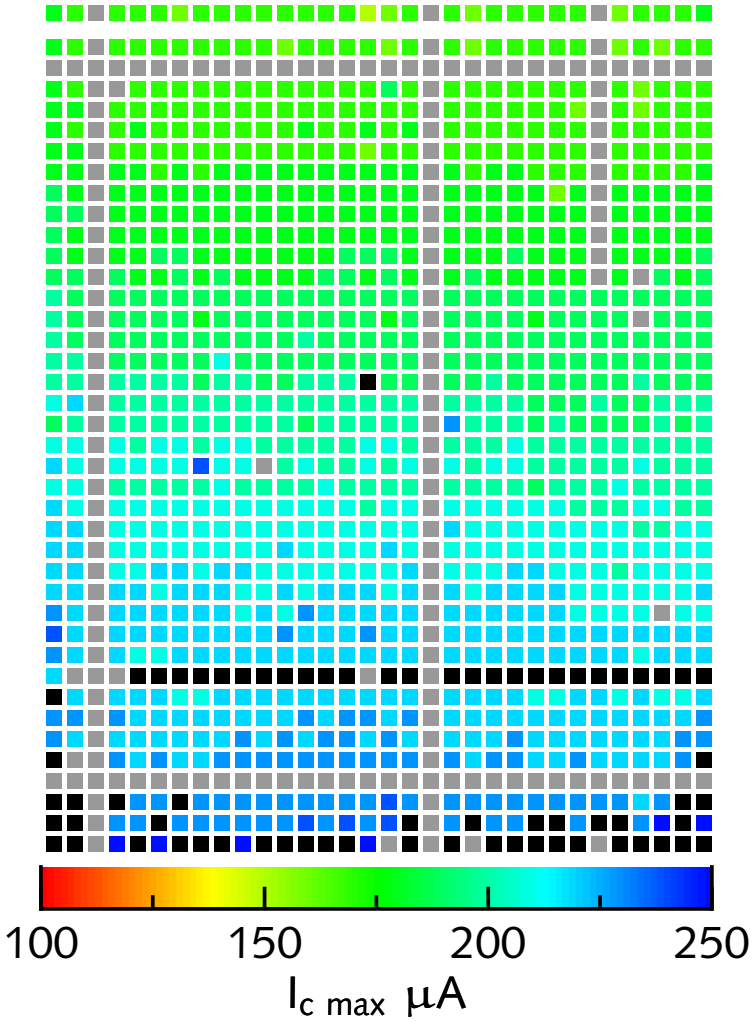
Science-Grade Arrays

- Two currently cold at the ATC in Edinburgh
- Working TESs and heaters on both arrays
- Optical response
- Further software development is key next step

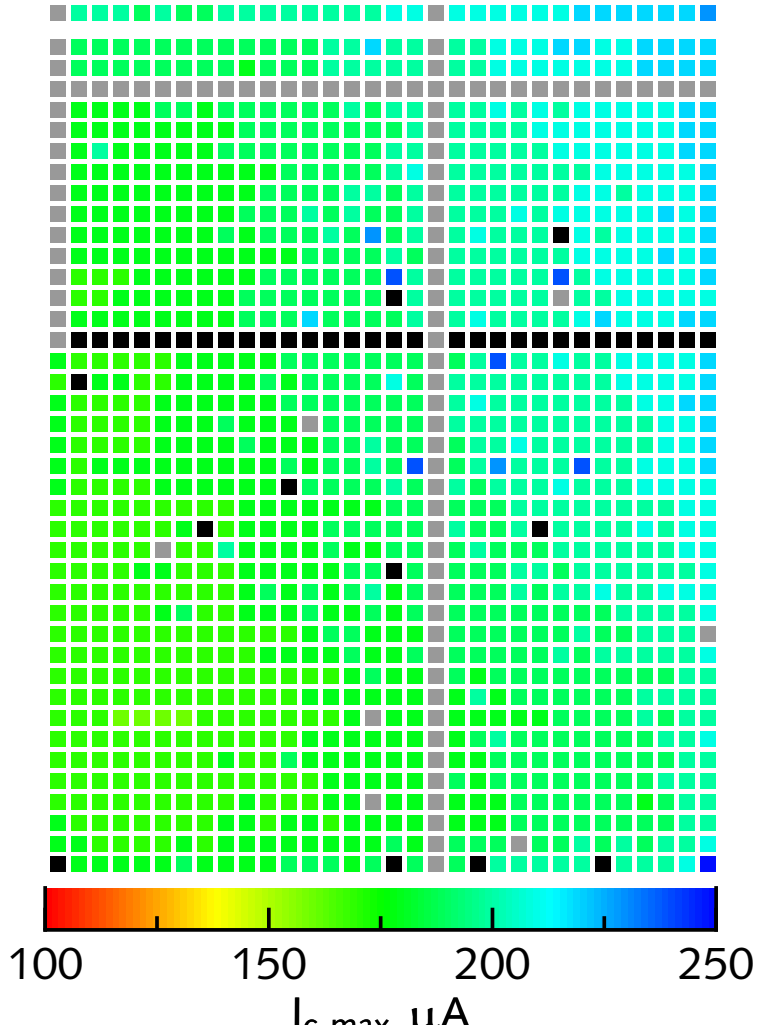
Yield

- Multiplexer wafers - obtain ∼50% usable parts after cryogenic testing. First cryogenic testing ∼ 1 year ago.
- Detectors wafers - obtain ∼40% for starting stock (mechanical wafer bonding)
- Detector wafers - TESs and deep etch high but unknown
- Hybridization - 100% so far

M.07.0X

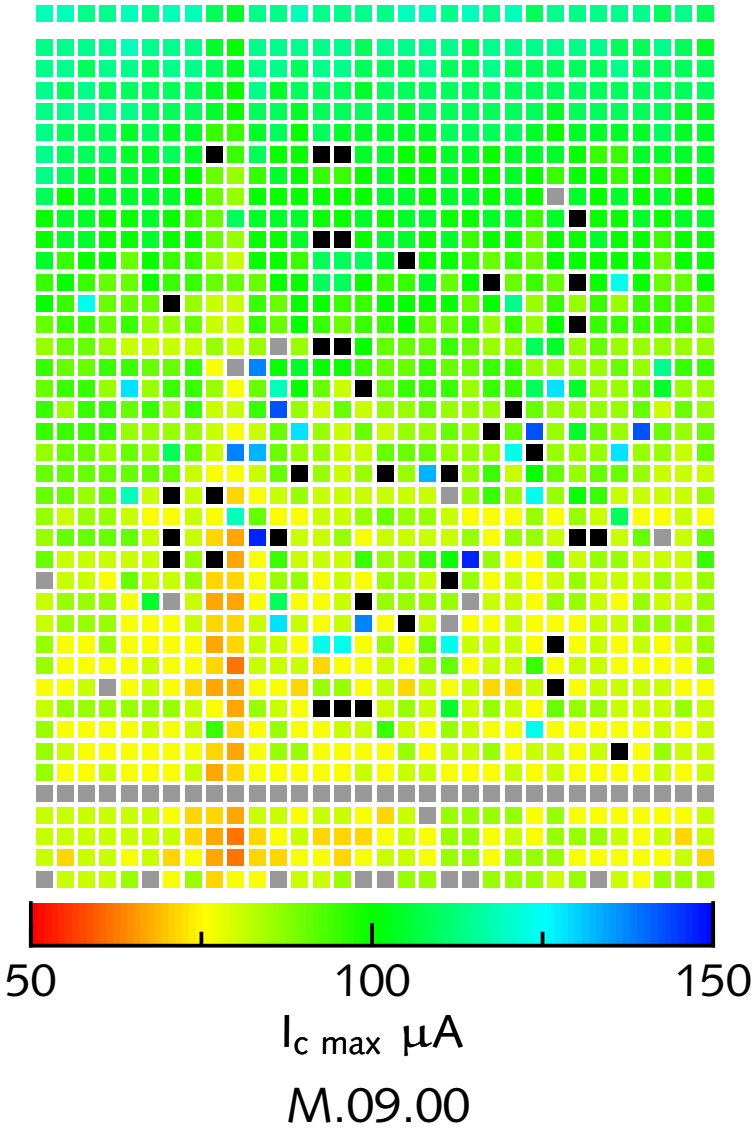


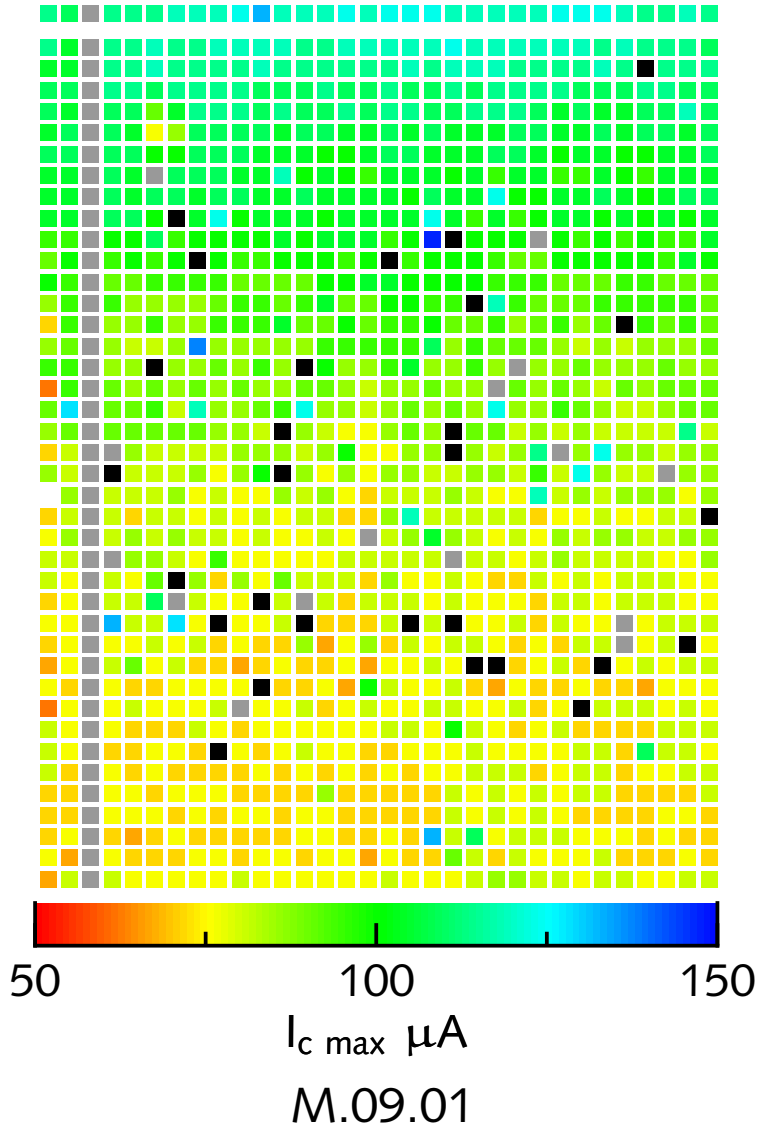
M.07.01



M.07.02

M.09.0X





New sub-mm Imagers

More SCUBA-2 Like

Less SCUBA-2 Like

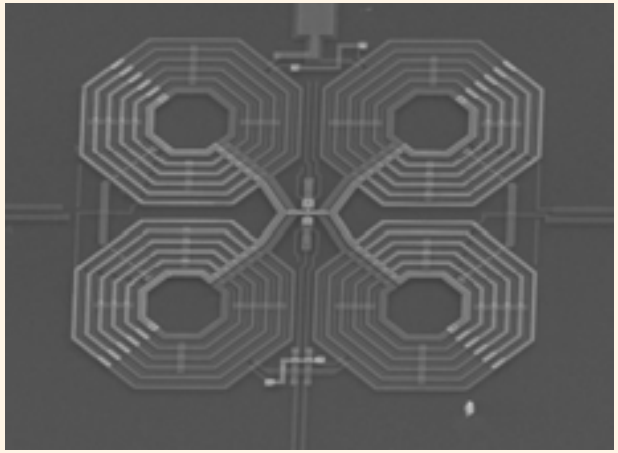
- Less risk, less flexibility
  - ~1K pixel/subarray
  - 1.135 mm pixel pitch
  - 130 mK
- Less setup cost
- Earlier initial production
- Other wavelengths possible with minimal development

- More flexibility, more risk
  - ~4K pixel/subarray
  - 0.5 mm pixel pitch
  - More pixels per output channel
  - Simpler magnetic shielding
  - Other operating temperatures?
- Less production cost (per pixel, per sub-array?)

Multiplexer improvement

Second-order gradiometric SQUIDS

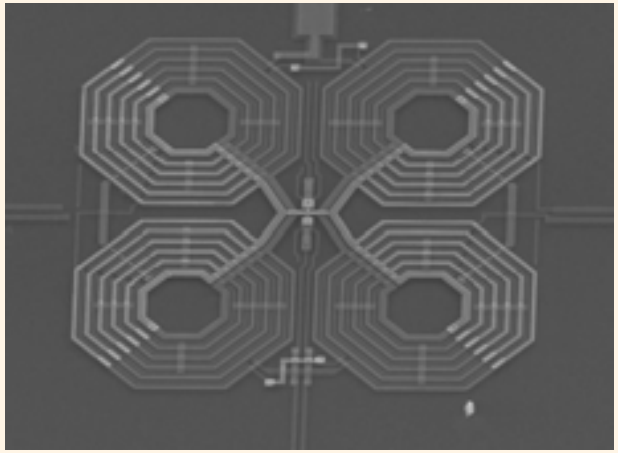
- Much less magnetic shielding required ($\sim$100$\times$ reduction in effective area)
- Improved SQUID noise (2$\times$ - helps muxing or reduces unit cell)
- Improved dynamic range (4$\times$)



Multiplexer improvement

Second-order gradiometric SQUIDS

- Much less magnetic shielding required (∼100× reduction in effective area)
- Improved SQUID noise (2× - helps muxing or reduces unit cell)
- Improved dynamic range (4×)



The new designs will allow us to shrink the multiplexer unit cell to ∼ **0.5 mm** and allow pixel 4× increase in pixel count.

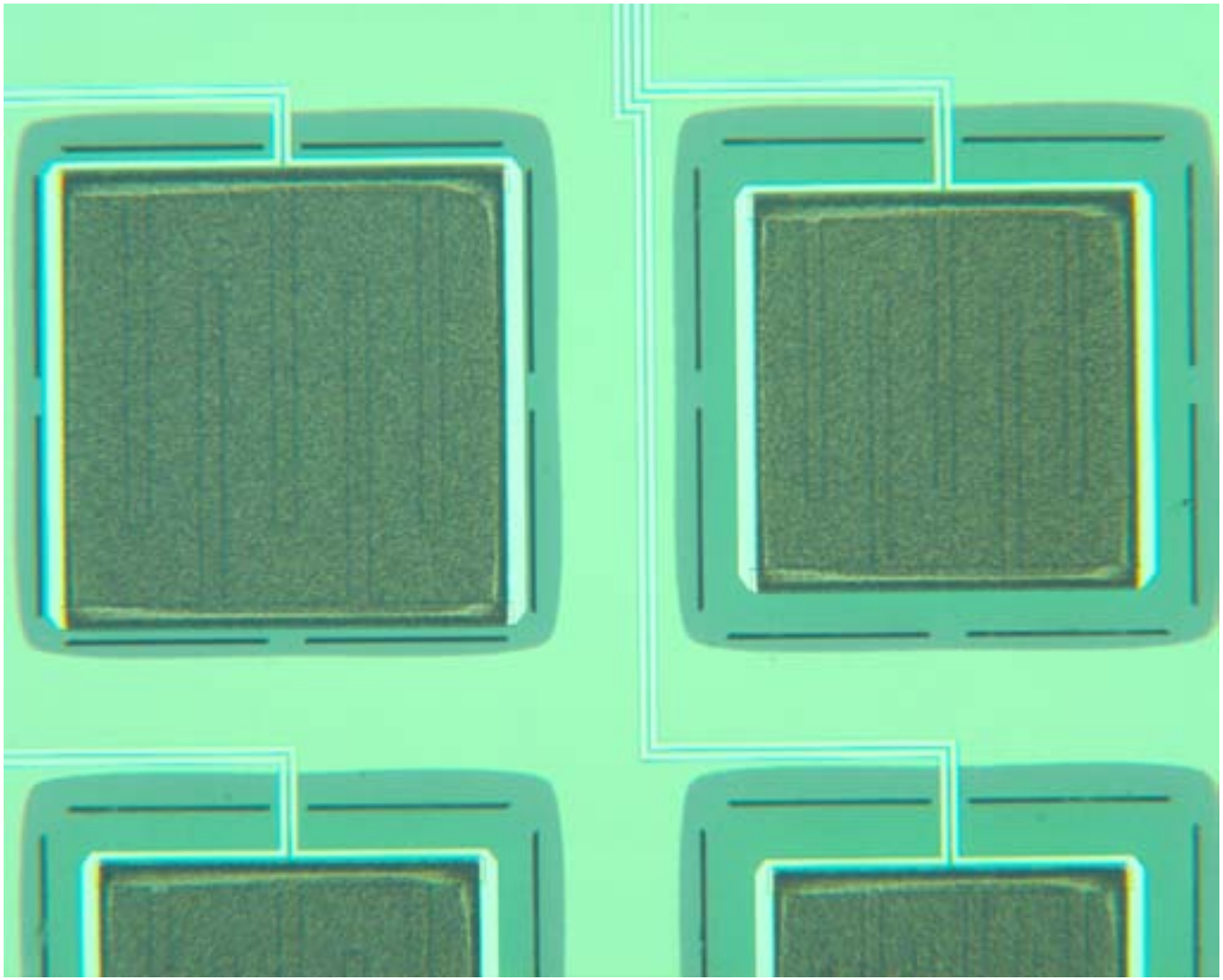
We believe new designs can achieve significant yield enhancement over older SCUBA-2 designs.

Detector Improvements

Since original SCUBA-2 start, NIST now has all tools necessary to replicate SCUBA-2 detector mechanical wafers (STS Deep Etch, Wafer Bonder)

- Simplification
  - Can fabricate on thin flat wafers ($\gtrsim 100\ \mu m$)
  - Use temporary carrier wafers (wax mounted) as necessary.
  - Some implications for passband at shorter wavelengths
  - Other methods (SOI, polymer bonding, . . .) under study
- Bump Bonding
  - Now have potential two sources for Indium bump bonding, Raytheon and NASA GSFC
  - Goddard has experience bonding fragile parts - microshutters for NGST
- Higher Operating temperature -lower G with membrane perforation
- Other possibilities
  - Different geometries (HCP, match to spectrometer, . . .)
  - Multi-color sensitivity

Relieved (Low G) X-ray Pixels



Testing

SCUBA-2 has taught us the importance of fast turn-around on testing.

We have invested in a very large dilution refrigerator to enable large-scale testing of imager components.

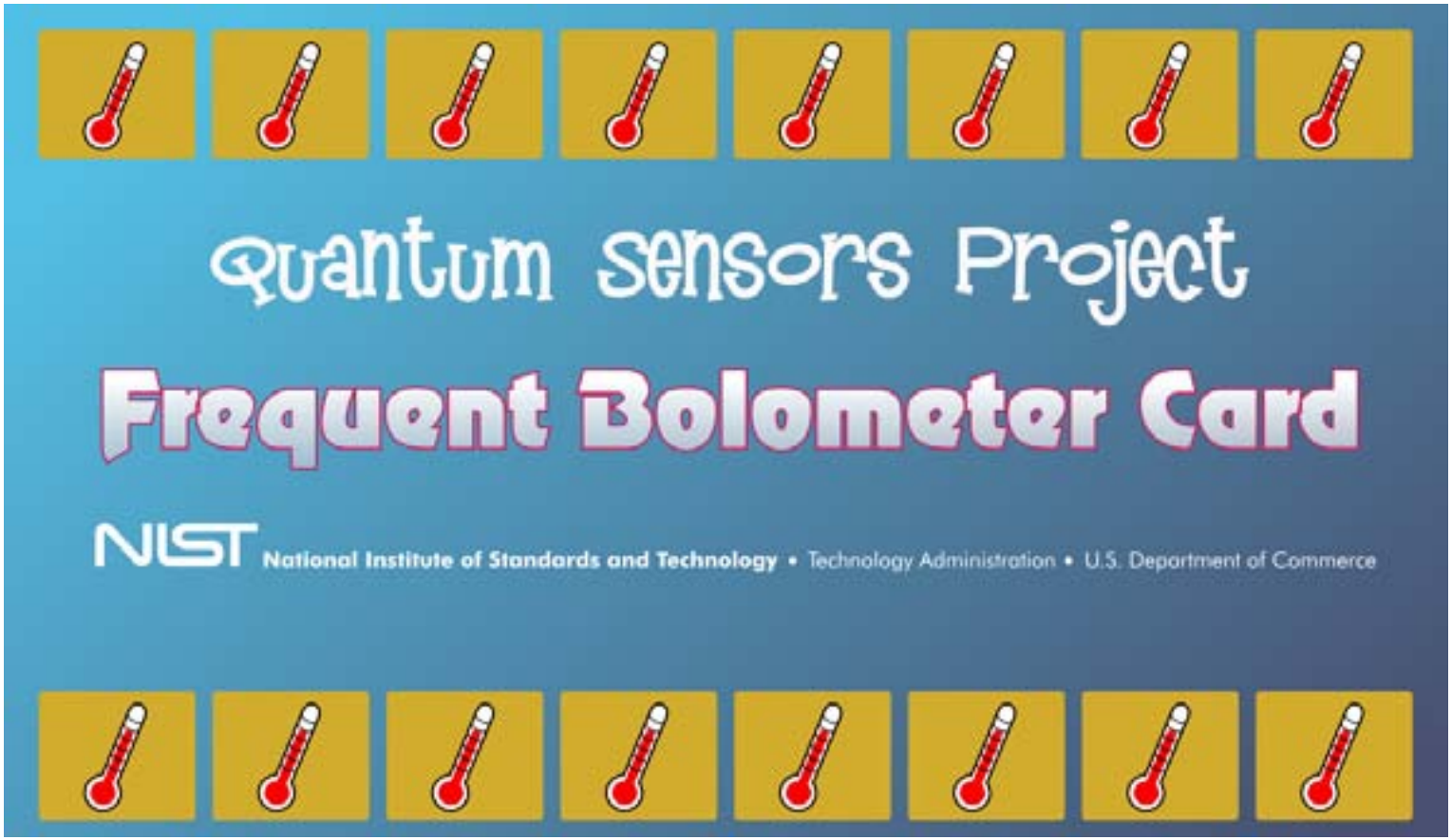
Testing

SCUBA-2 has taught us the importance of fast turn-around on testing.

We have invested in a very large dilution refrigerator to enable large-scale testing of imager components.

Cost

Cost


Quantum Sensors Project
Frequent Bolometer Card
NIST National Institute of Standards and Technology • Technology Administration • U.S. Department of Commerce

Outline