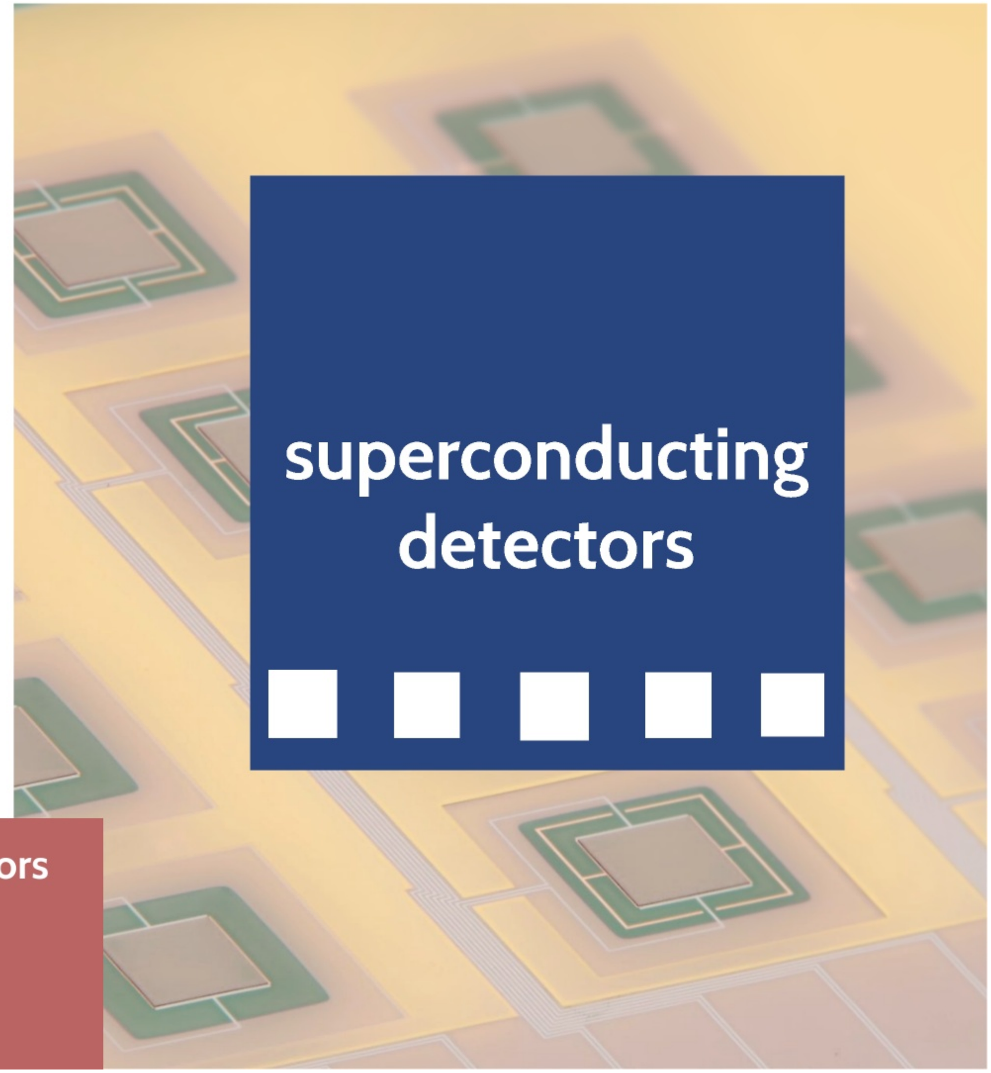
IEEE CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), No. 49, March 2021.
Young Scientist Vision plenary presentation Wk2P3-4 given at the virtual ASC 2020, November 5, 2020.

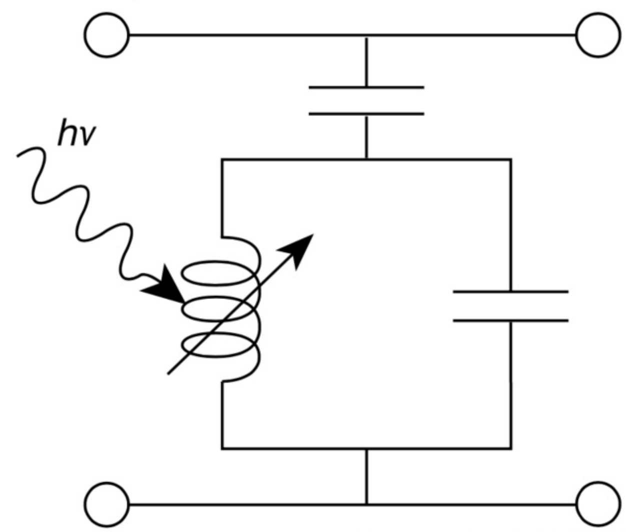


Science in seconds

the bigger, faster future of superconducting detectors

Kelsey Morgan
University of Colorado, Boulder
National Institute of Standards and Technology

microwave kinetic inductance detectors (mkids)

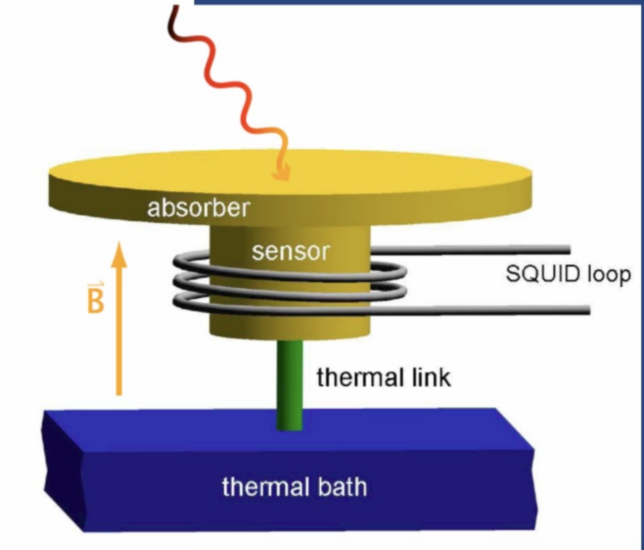


P. Day et al., Nature 425.6960 (2003)

Photon absorption breaks cooper pairs, varies the kinetic inductance of a microwave resonant circuit

- Natural frequency-domain multiplexing
- Difficult to make high resolution X-ray, gamma ray detectors

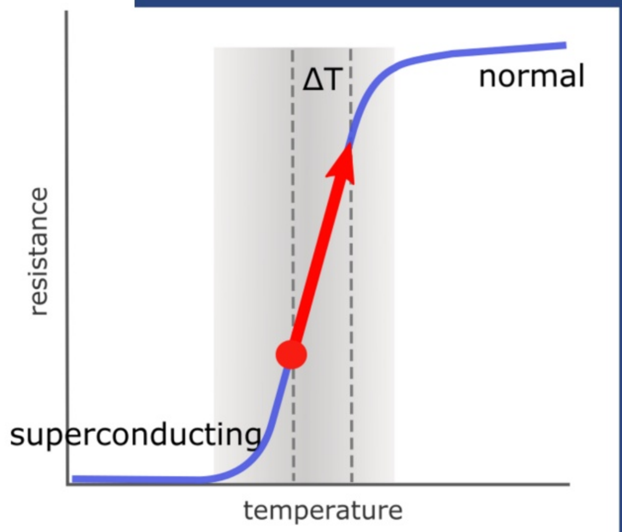
metallic magnetic microcalorimeters (mmcs)



Magnetization of paramagnetic material in weak B-field used to measure temperature change due to photon absorption

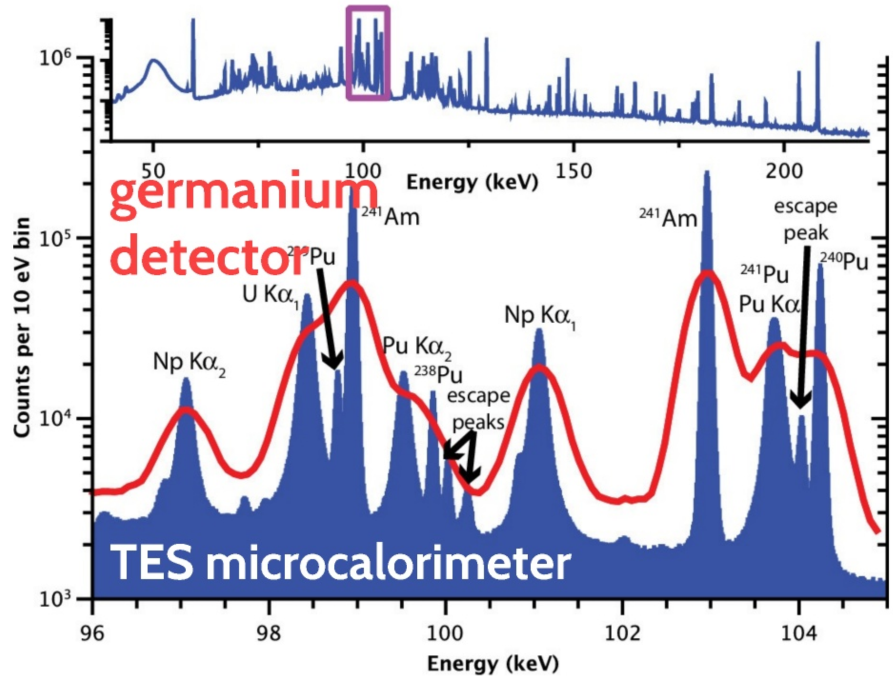
- Demonstrated excellent energy resolution, good linearity with energy
- Difficult to multiplex

transition-edge sensors (tes)



Superconducting resistive transition used to measure temperature change caused by photon absorption

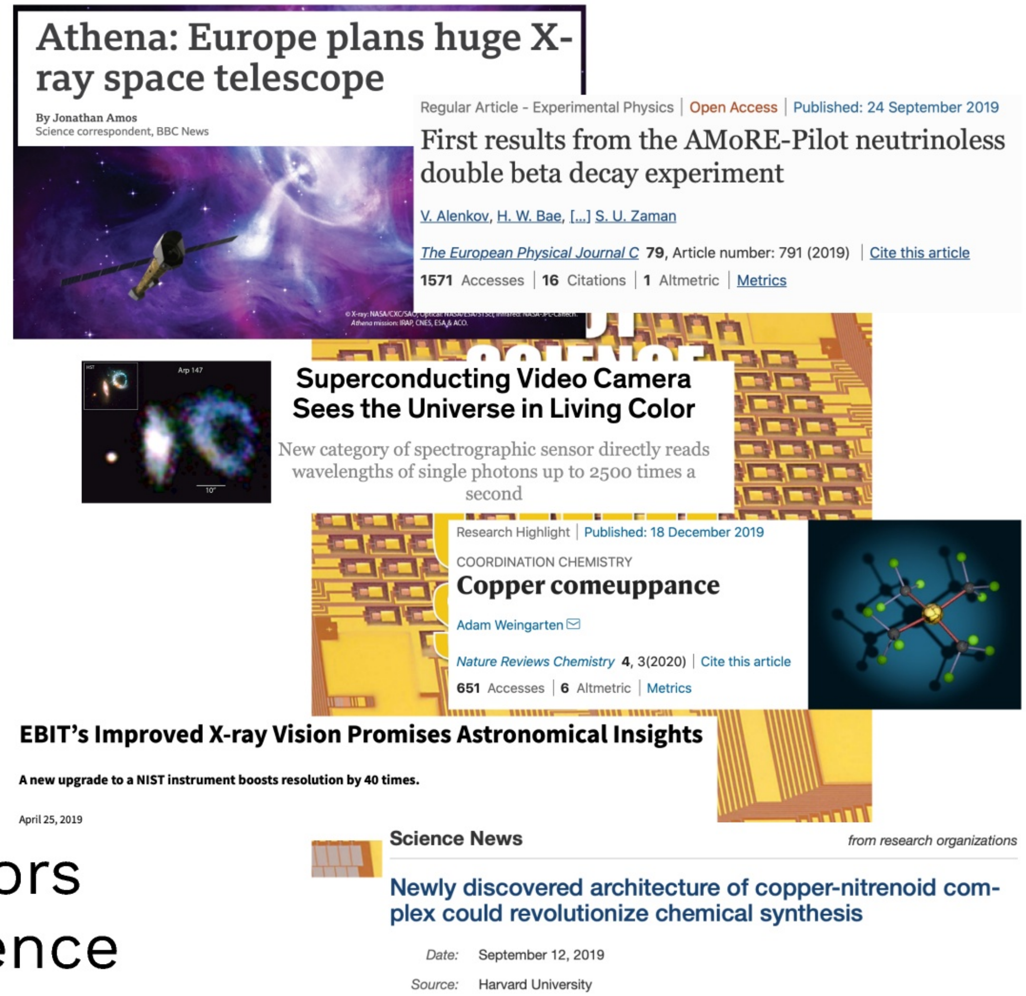
- Many techniques for multiplexing
- Good energy resolution over a wide range of energies (x-ray to gamma ray)



emission spectrum of Pu

Bennett et al., RSI 83, 093113 (2012)

Superconducting detectors are already enabling science



Superconducting detectors are already enabling science

We need to do

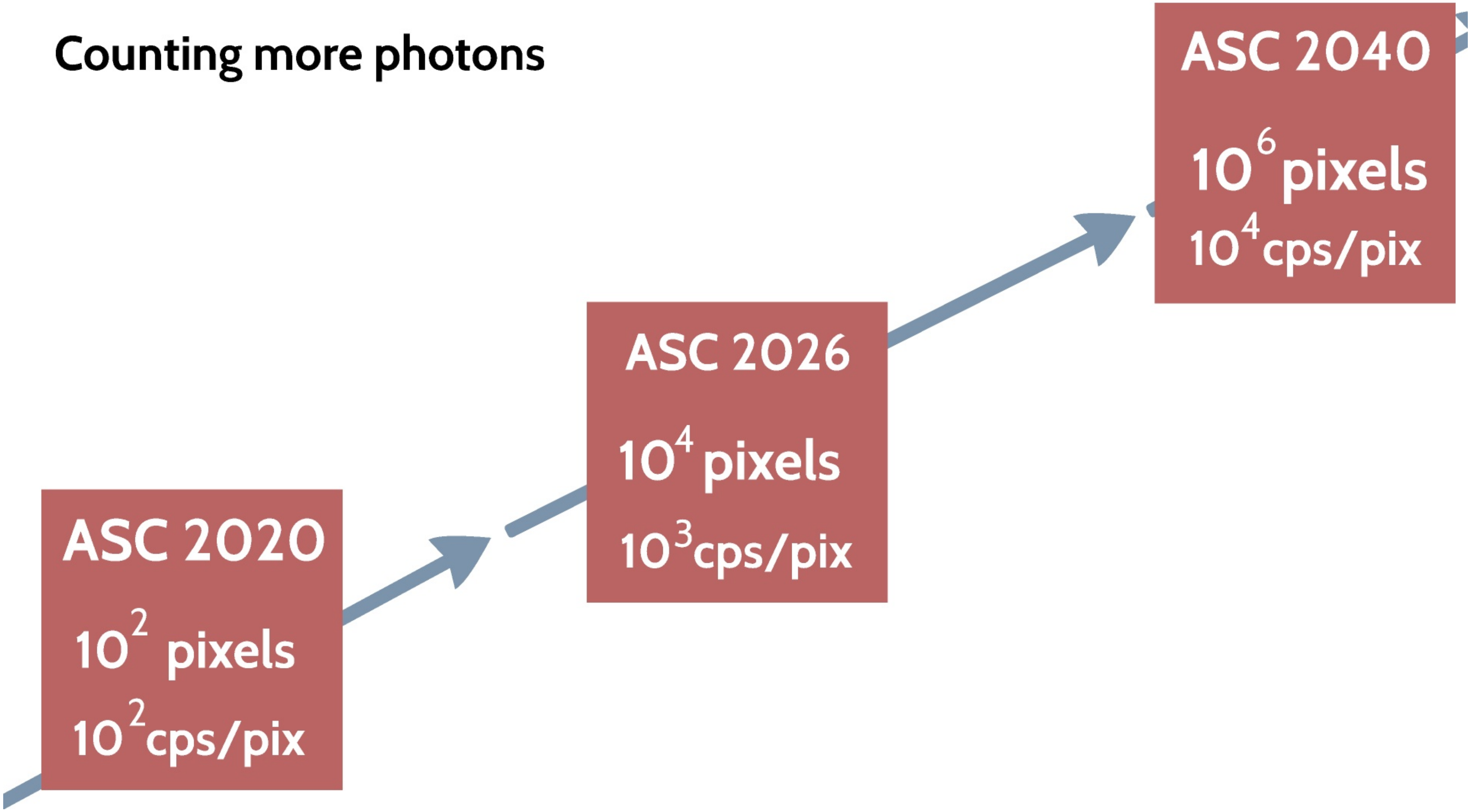
Science*

* collect and analyze a useful energy spectrum

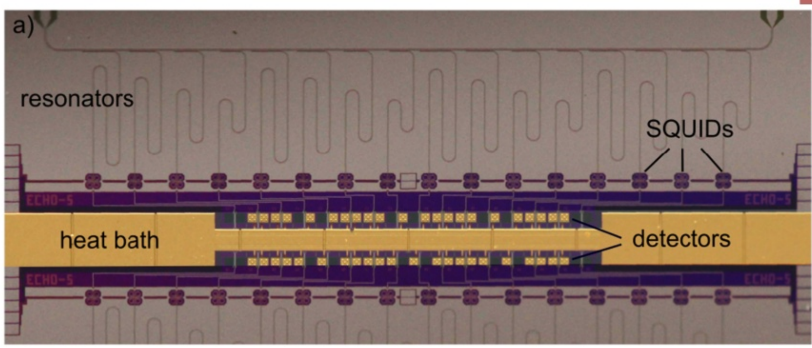
We need to do

Science in seconds

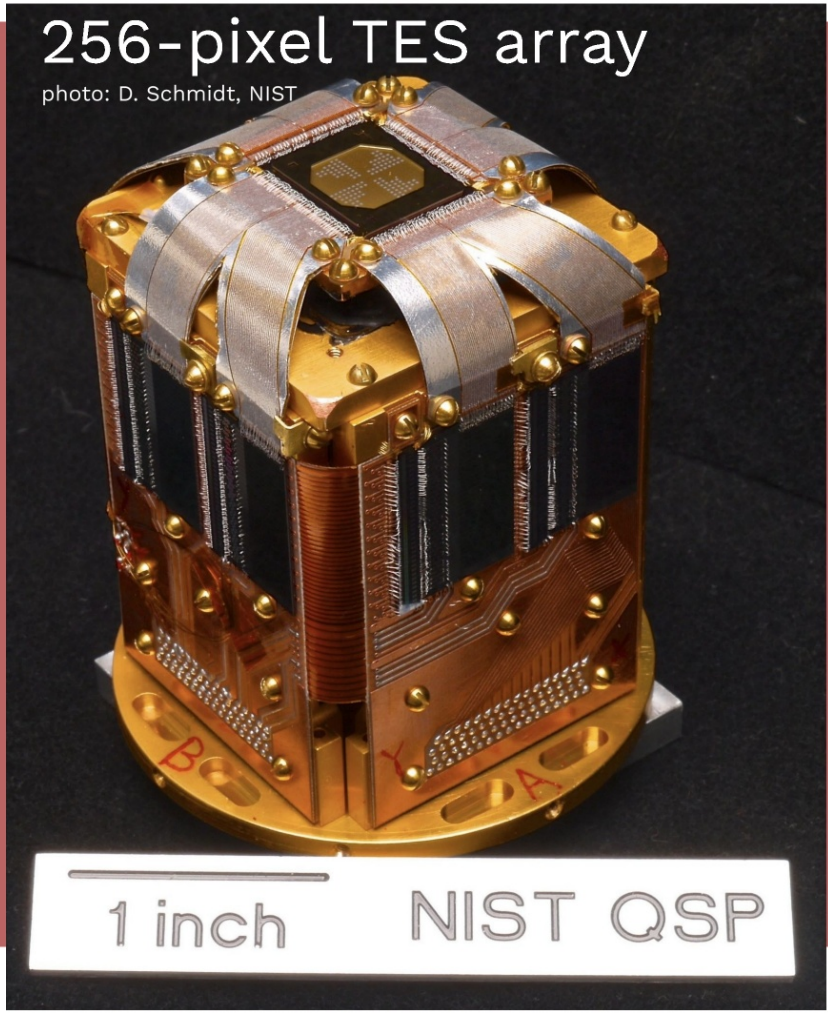
Counting more photons



64-pixel MMC array



S. Kempf et al., AIP Advances **7**, 015007 (2017)



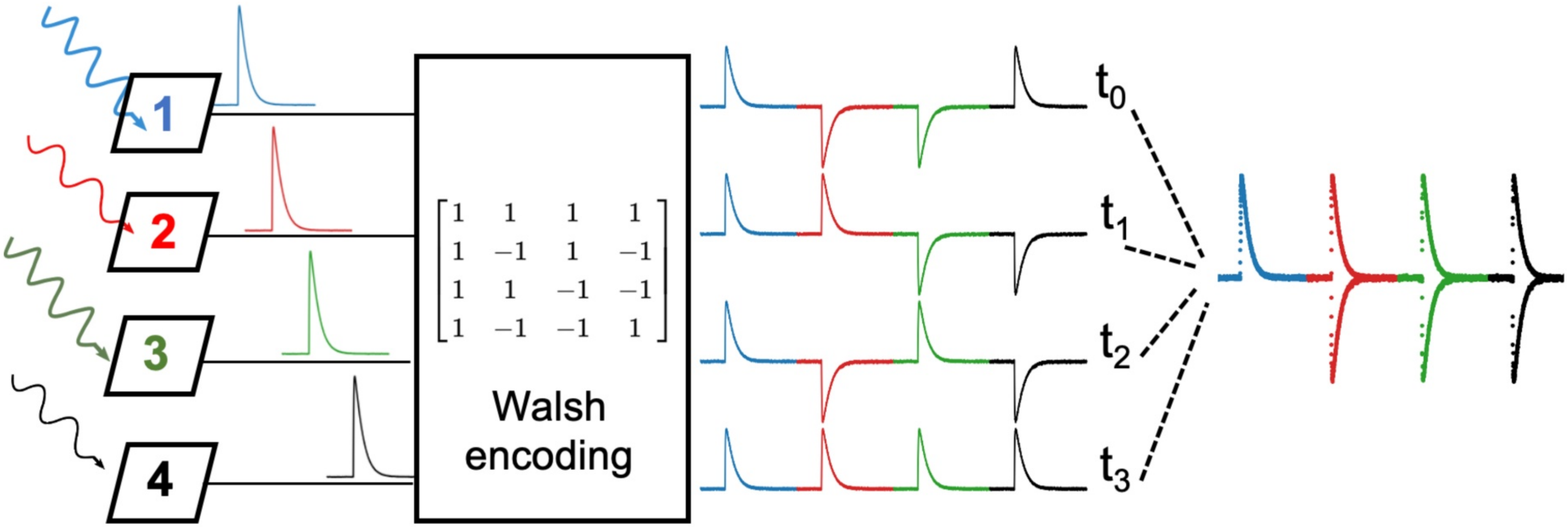
megapixel arrays

Challenges:

- Limit number of readout channels at room temperature
- Make better use of microwave readout bandwidth
- Compact, efficient packaging

larger multiplexing factors

hybrid multiplexing:
stage 1: code-division multiplexing (CDM)



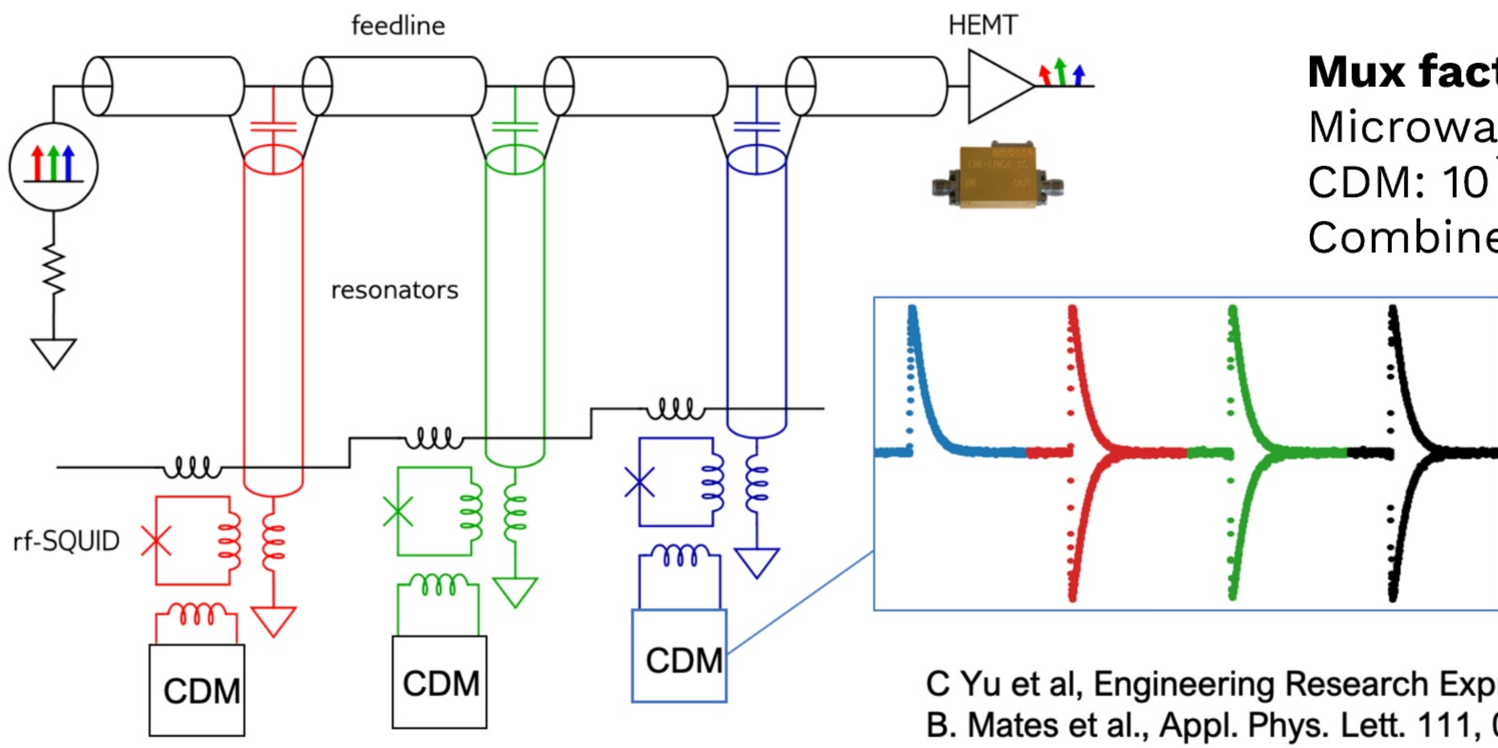
$$\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 \end{bmatrix}$$

K.D. Irwin et al., Supercond. Sci. Tech., 23, 3, (2010)
K.M. Morgan et al., Appl. Phys. Lett. 109, 112604 (2016)

larger multiplexing factors

hybrid multiplexing:

stage 2: high-bandwidth microwave SQUID mux



Mux factors

Microwave: 10^3

CDM: 10^1 – 10^2

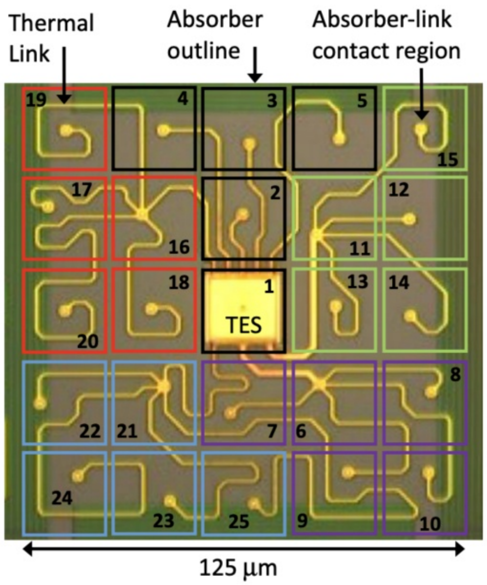
Combined: 10^4+

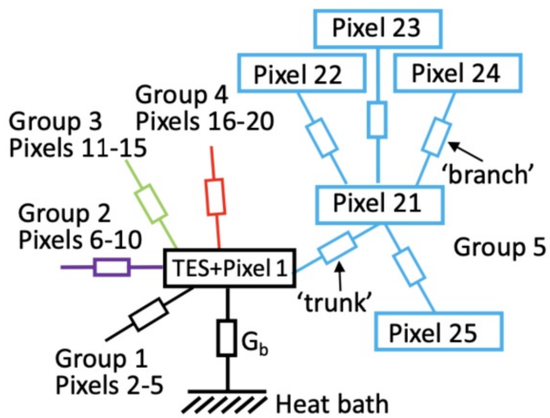
C Yu et al, Engineering Research Express, 2-1 (2020)

B. Mates et al., Appl. Phys. Lett. 111, 062601 (2017)

larger multiplexing factors

"hydra": one thermometer connected to multiple pixels



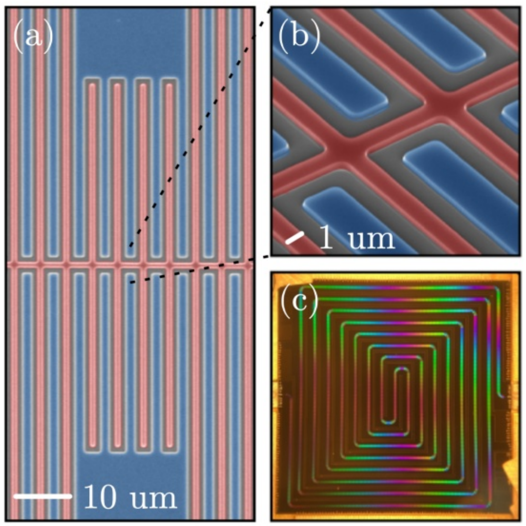


- "mux" factor: ~10^1
- Increases spatial resolution for imaging

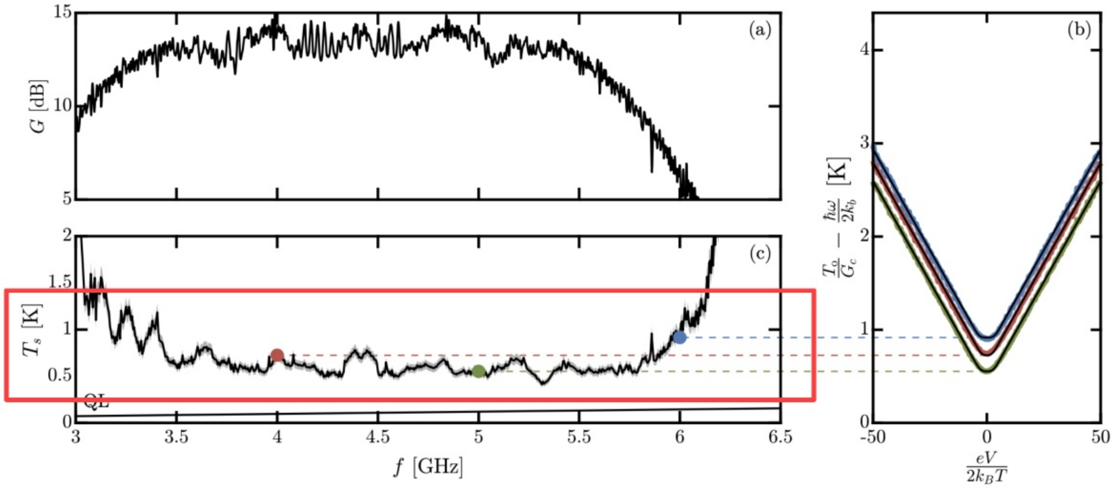
S.J. Smith, et al., JLTP 199:300-338 (2020)

more efficient use of microwave bandwidth

kinetic inductance traveling-wave amplifier



M. Malnou et al., arxiv:2007.00638v1 (2020)
see also: talk by M. Malnou, ASC 2020

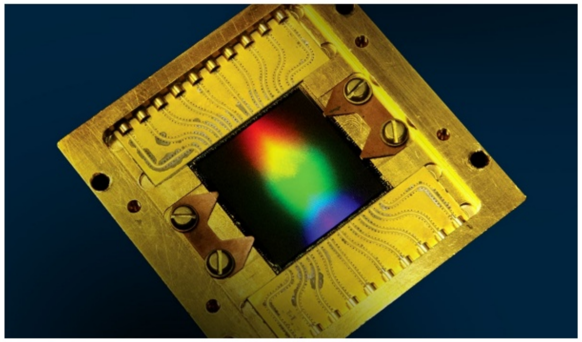


Lower amplifier noise temperature

Decreased resonator coupling

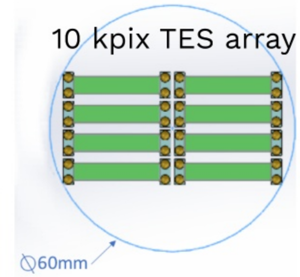
More resonator channels / bandwidth

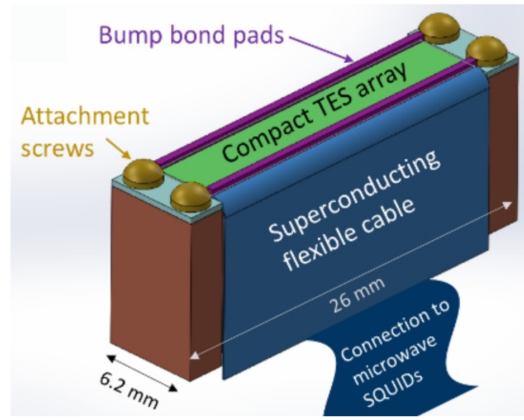
compact, efficient array packaging

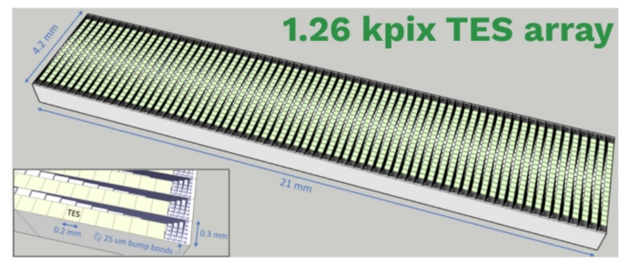


20,000-pixel near-IR mkid array for MEC
https://microdevices.jpl.nasa.gov/capabilities/superconducting-devices/ole-mkids/

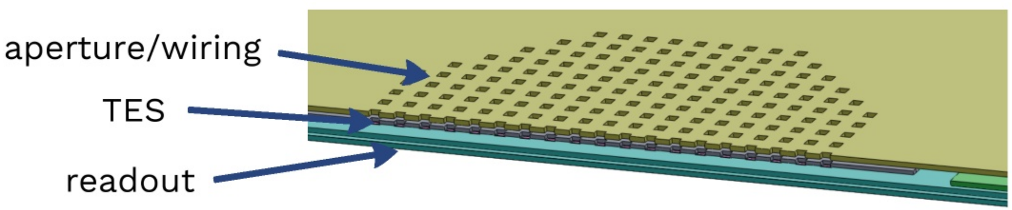
more compact arrays

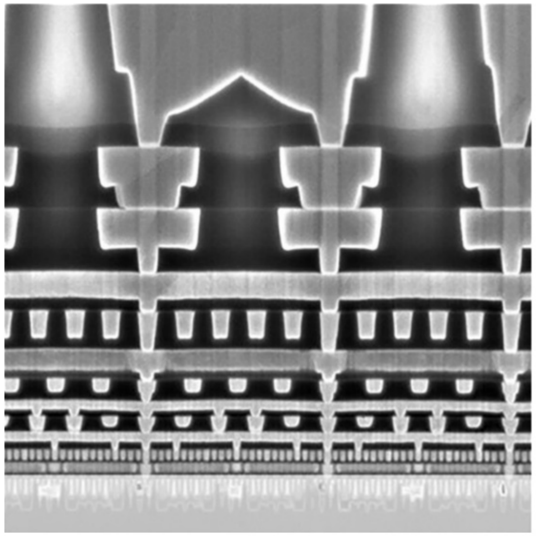






multi-wafer integration



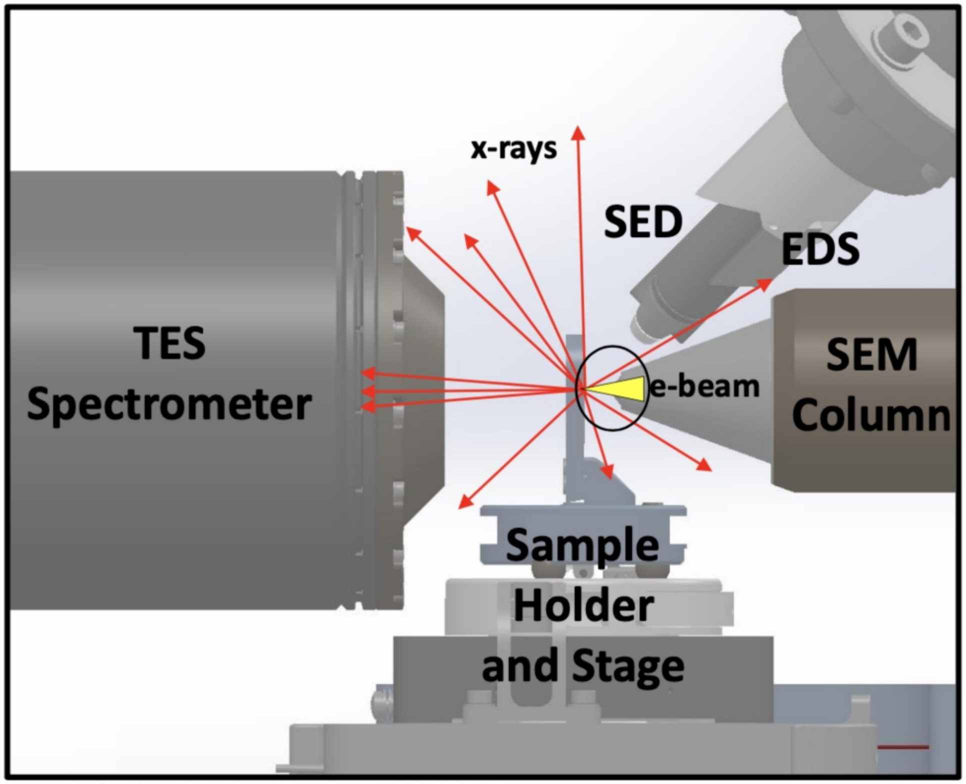


https://en.wikichip.org/wiki/File:intel_interconnect_10_nm.jpg

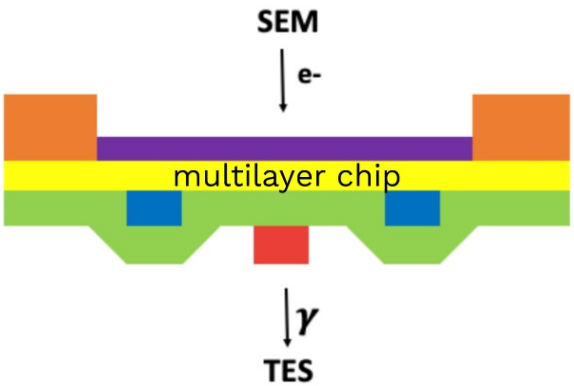
Nanoscale IC screening for defect analysis, process development

- IC manufacturers are already making features on ~10 nm scales
- Difficult to 3D image multi-layer chips: contributes to expense of chip development

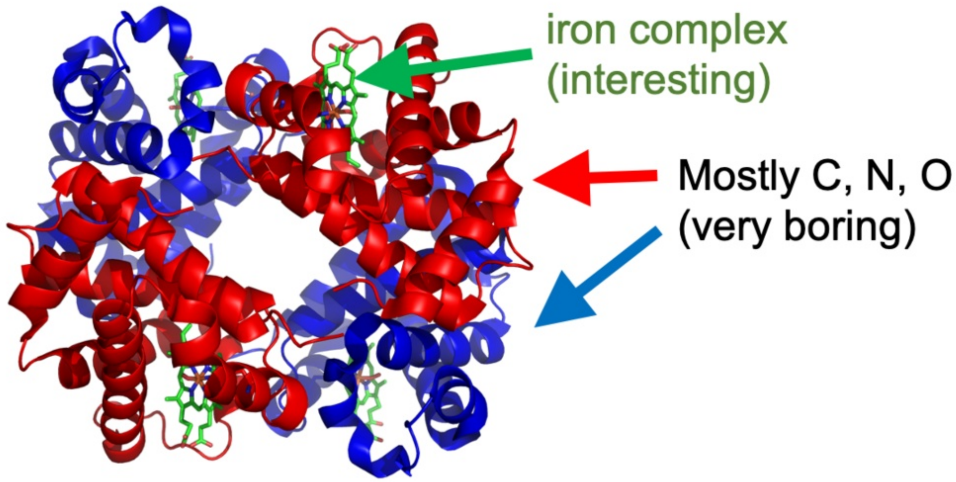
X-ray tomography for nanoscale IC screening



see talk by P. Szypryt, ASC2020



- All-in-one tool for finding, imaging defects in chips at nm scales
- Replaces multi-step, typically destructive techniques currently in use
- Entire chips could be imaged to look for unwanted structures



human hemoglobin

Realistic chemistry, biology at X-ray light sources

- Many interesting metalloproteins create a weak X-ray signal of interest among a huge background
- Powerful X-ray sources (synchrotrons, XFELs) are used to create enough signal to measure

Realistic chemistry, biology at X-ray light sources

Large arrays of superconducting detectors can make measurements of important biological and chemical systems under real-world conditions possible

Astronomy
Materials science
Dilute biological systems
Laboratory-based light sources
Nuclear safeguards
Neutrino mass measurements
Tomographic imaging
Industrial process monitoring
Neutrinoless double-beta decay
Time-resolved chemistry
Radiation-sensitive materials
Catalytic chemistry
Nuclear fuel processing
Decay-energy spectroscopy

Science in seconds

let's take superconducting detectors from "enabling" to "transformative"