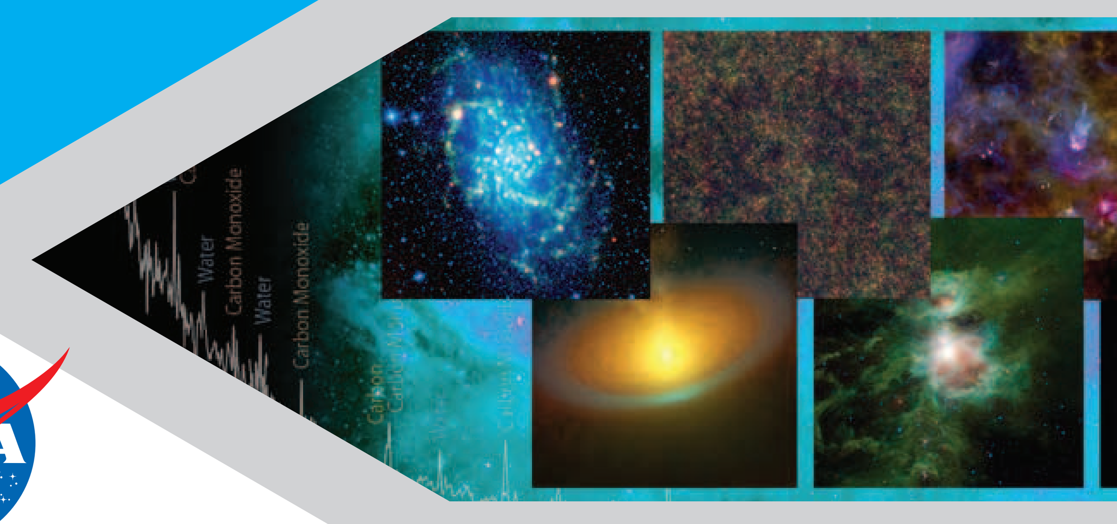
# On the Application of MKIDs and TES Bolometers to FIR Space Astrophysics

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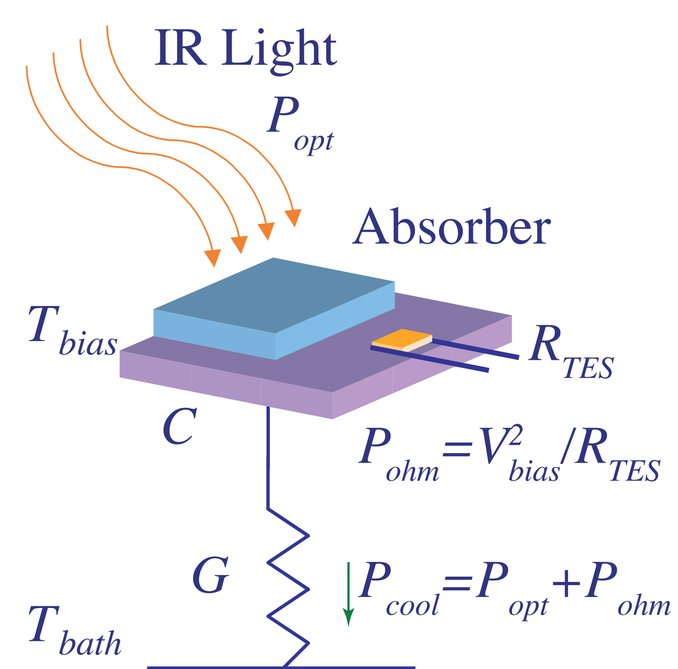
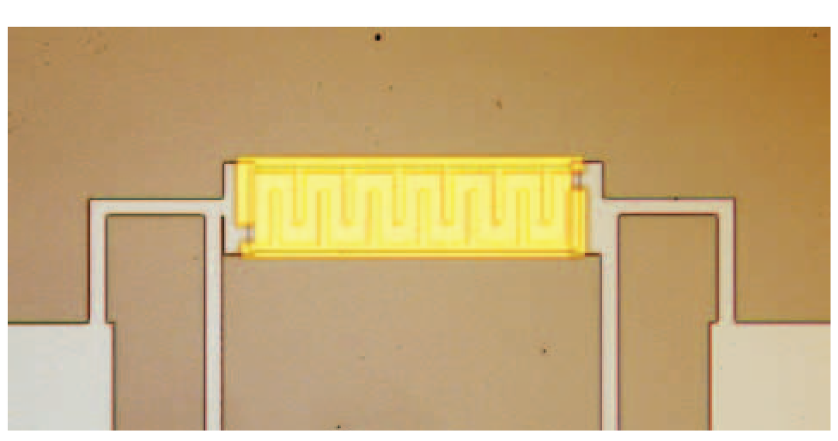
Two competing technologies, Microwave Kinetic Inductance Detectors (MKIDs) and Superconducting Transition Edge Sensor (TES) Bolometers, are currently both providing sensitive, large-format detector arrays for far-infrared through millimeter-wave instruments.

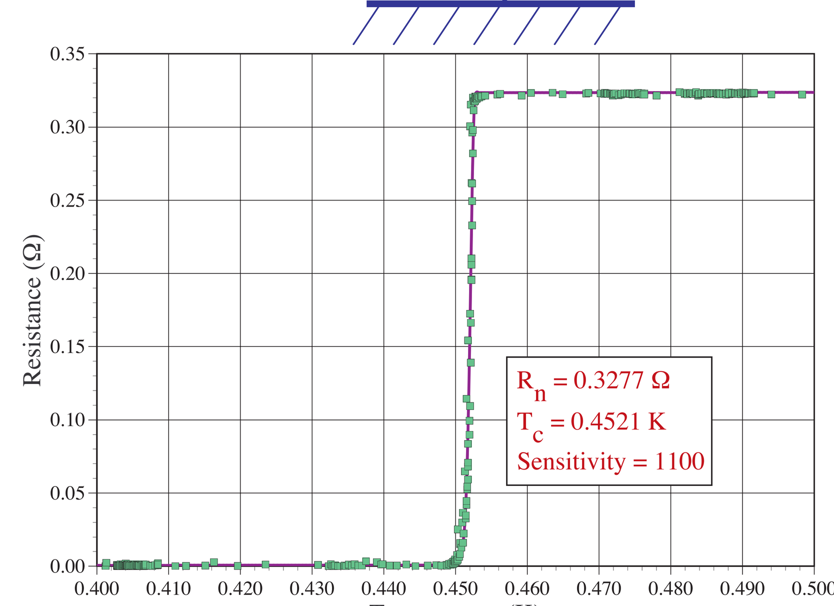
Each has strengths and weaknesses as applied to future far-infrared space astrophysics experiments. In this highly qualitative presentation, I attempt to compare and contrast the two approaches.

*Et nunc reges, intelligite: qui judicatis terram, erudimini.*

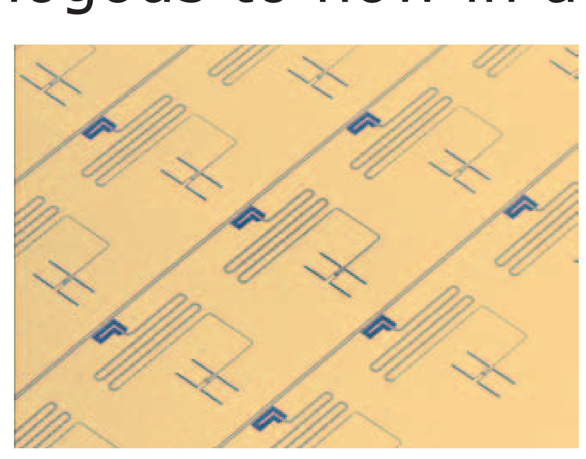
A TES Bolometer is a device that warms up when light shines on it, and the temperature rise is transduced to a change in current through the device as its resistance moves up and down the steep transition between the normal and superconducting states. Bolometers have weak thermal coupling through mechanical or electron-phonon isolation.



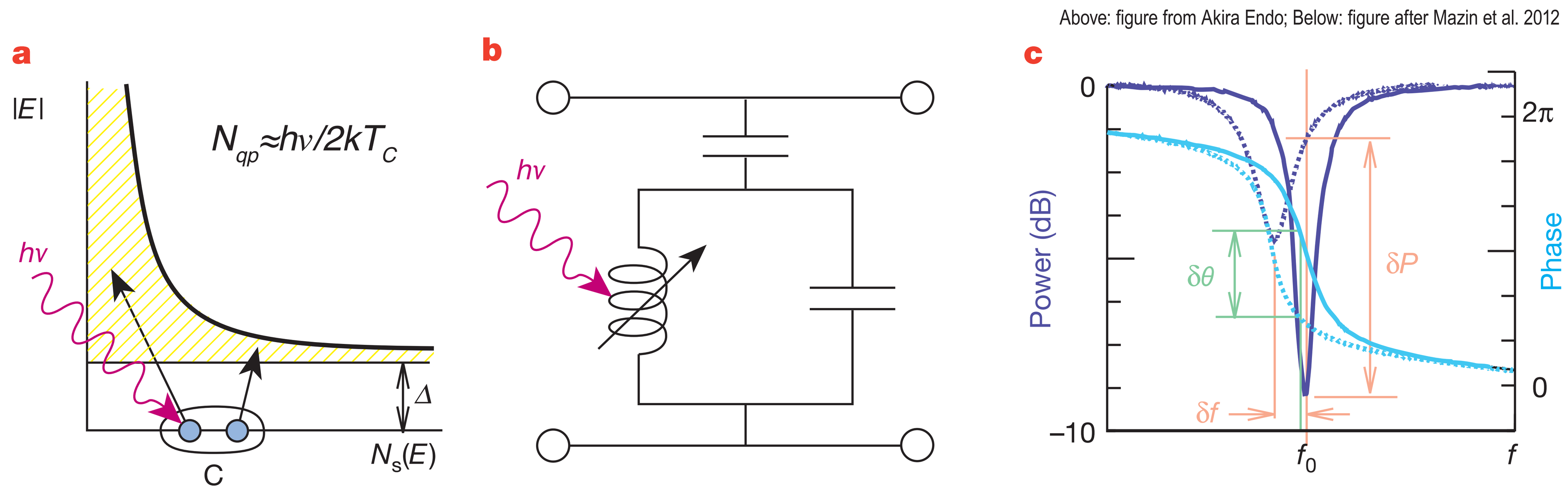



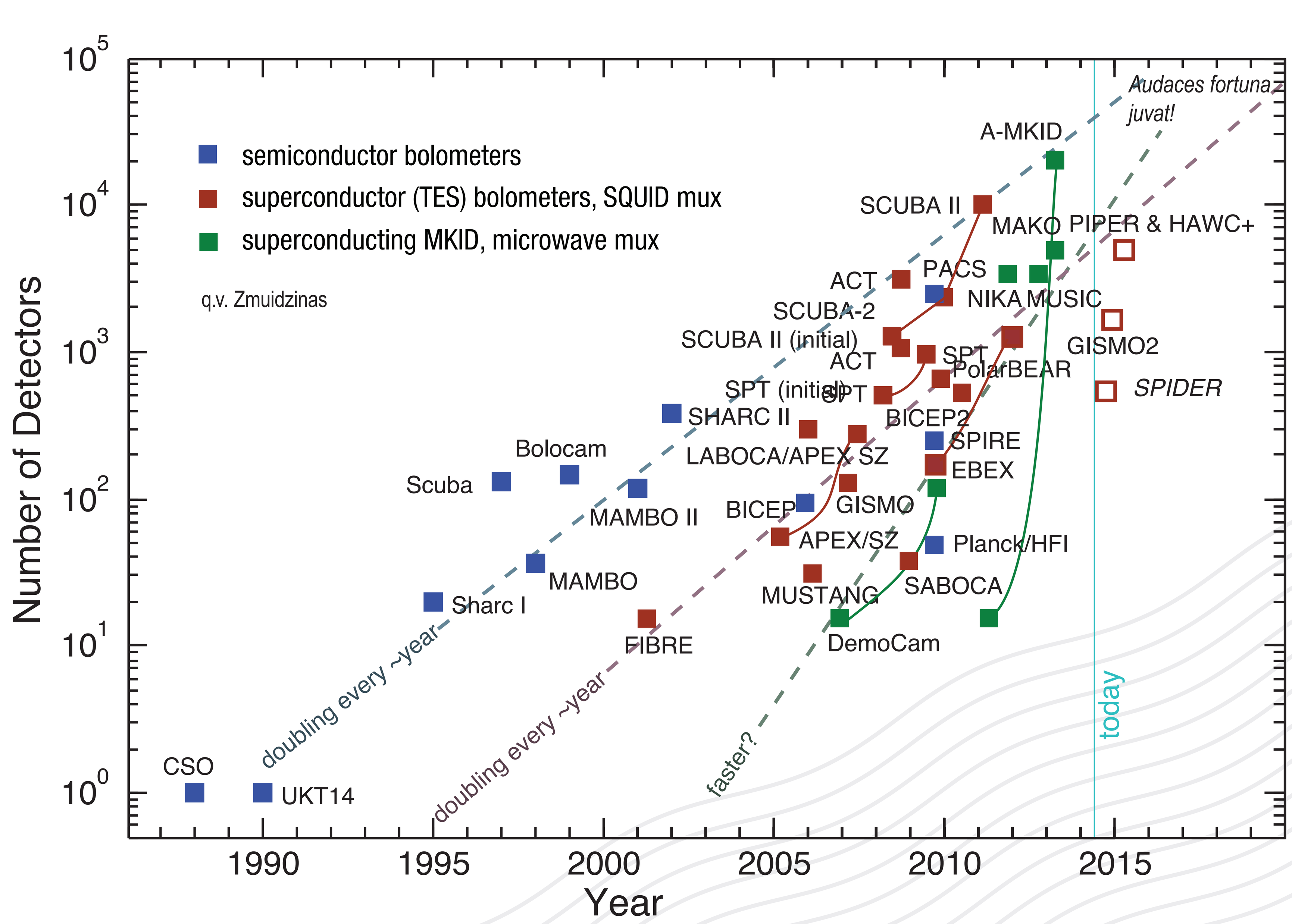



With an MKID, the light becomes one or more quasiparticles in a superconductor (**a**), analogous to how in a semiconductor a photon produces an electron/hole. However, rather than counting quasiparticles, in an MKID the quasiparticle density is sensed by the shift in a microwave resonator's (**b**) phase and amplitude (**c**).



Above: figure from Akira Endo; Below: figure after Mazin et al. 2012




## Heuristics: *...nil nisi bonum*

- The sensitivity of TES and MKID devices is usually photon-noise-limited, so neither technology has a universal per-pixel advantage.
- Both TES and MKID detectors can be made with high optical efficiency and good out-of-band rejection.
- Bolometers are easy to calibrate in physical units such as Watts. For MKIDs, this is more challenging. They measure shifts in phase and amplitude of a resonant signal.
- TES bolometers have a somewhat more limited dynamic range than MKIDs, degrading ungracefully to zero response when saturated.
- For both, at wavelengths long enough that good superconducting transmission lines can be built (a few hundred microns), antenna-coupling enables the energy at the RF frequency to be carried as a signal on a wire. Sophisticated circuit elements for, e.g., spectroscopy are then possible. This allows for highly integrated instruments fabricated in a single wafer.
- Highly integrated instruments (e.g., a sensitive spectrometer) are beneficial for stray light. If good energy can't get out, bad energy can't get in. However, it makes close packing more challenging.
- Antenna coupling is tough at shorter wavelengths (≲300μm).
- MKID readout electronics are improving rapidly with Moore's law. Bolometer readout electronics are also improving, although perhaps not so quickly. However, there are multiple varieties of electronics. Microwave SQUID readouts for bolometers are the same.
- MKIDs are fabricated with a small number of layers and masks. Modern bolometers can take many tens of masks, with their readout many tens more. In practice, this means that fabrication time is a bit faster for MKIDs (although design time may be slower), so it is likely that the rate of improvement in MKID capability is faster than for bolometers. Eventually MKIDs may dominate.
- Both require cooling to around 100mK in order to operate. Both leverage on major NASA or other government resources, but have virtually no commercial, military, or industrial support.
- Bolometer amplifiers, a form of SQUID multiplexer, operate at the same very low temperature, so have simple thermal interfaces. Unfortunately, they are not inherently linear and hence require feedback. MKIDs often use HEMT amplifiers, which feature a linear response, are straightforward for multiplexing and can easily be placed at a different, higher, temperature. Future developments in microwave SQUID multiplexers and parametric amplifiers have the promise of improving the readouts.
- TES/SQUIDs are more sensitive to magnetic fields than MKIDs, although the SQUID multiplexers used are now much improved.
- Photon counting is not unique to either technology. It would present, if successful, a major step forward. When you count photons, you are no longer need to spend time measuring where zero is. In practice, this is a factor of two in observing efficiency.
- Both are substantially immature from a space flight perspective, with a TRL of no more than four. This implies significant resources being required for flight. Unless you have an Explorer!
- Future instruments that contrast the approaches include cameras: GISMO-2 vs. NIKA-2; spectrometers: μSpec; SuperSpec, BLISS.

*Thanks to Jonas Zmuidzinas & Harvey Moseley for useful discussions.*

*Nunc est bibendum.*