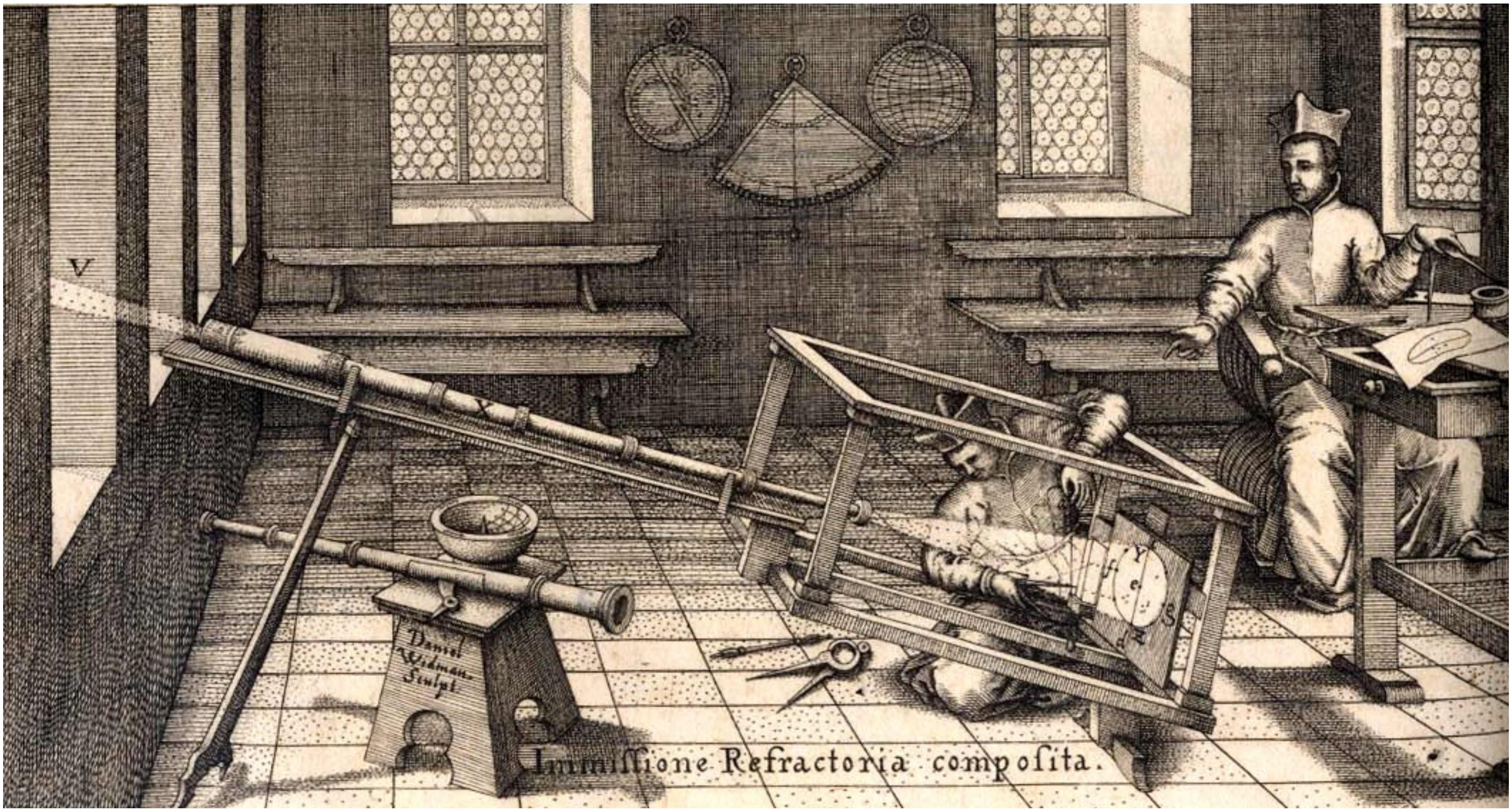
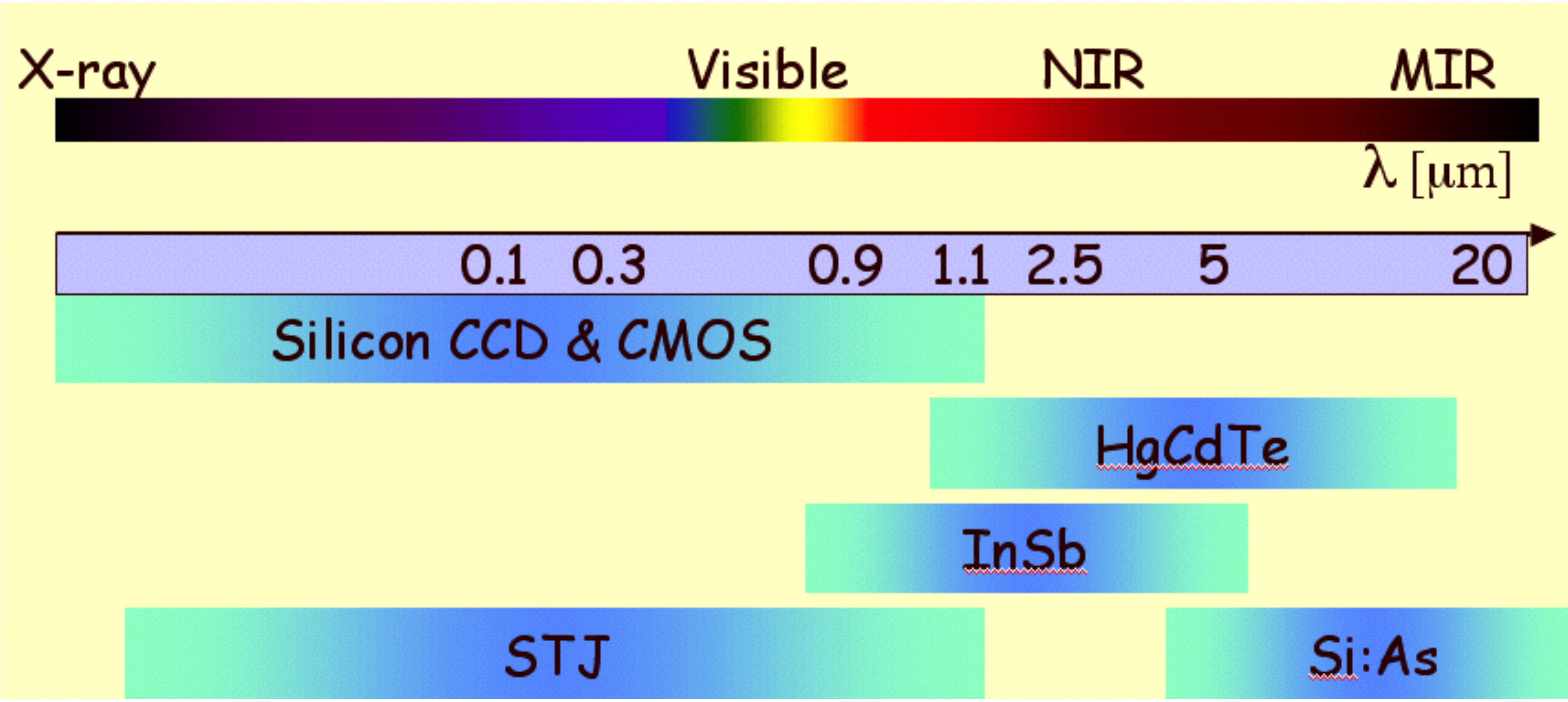
Ay 122a - Fall 2012
Detectors (IR, Energy Resolving)

S. G. Djorgovski



Solid-State Detector Technologies



2-D focal plane arrays :

- Optical – silicon-based (CCD, CMOS)
- Infrared – IR material + silicon CMOS multiplexer

Photovoltaic IR Detectors

- Single pixel infra-red detectors have long used the photovoltaic effect
- Diode is formed at the junction between a p- and n-doped semiconductor
- This pn junction generates an internal electric field to separate the photon generated electron-hole pairs
- Migration of holes and electrons changes the electric field, hence there is a voltage change across the junction which can be measured

IR (Hybrid) Arrays

Not like CCDs!

Each pixel is read out through its own transistor.

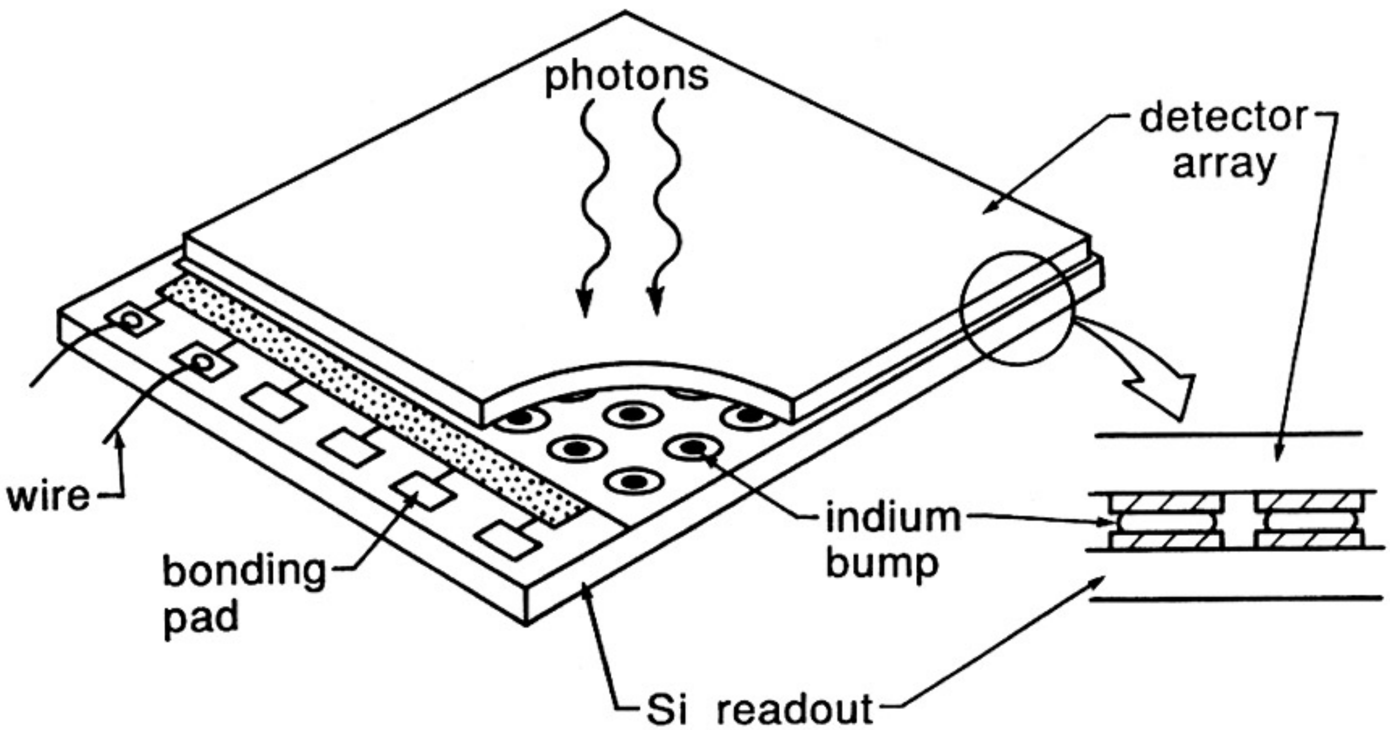


Figure 6.1. Infrared direct hybrid array.

Typical materials:
HgCdTe, InSb, PtSi, InGaAs

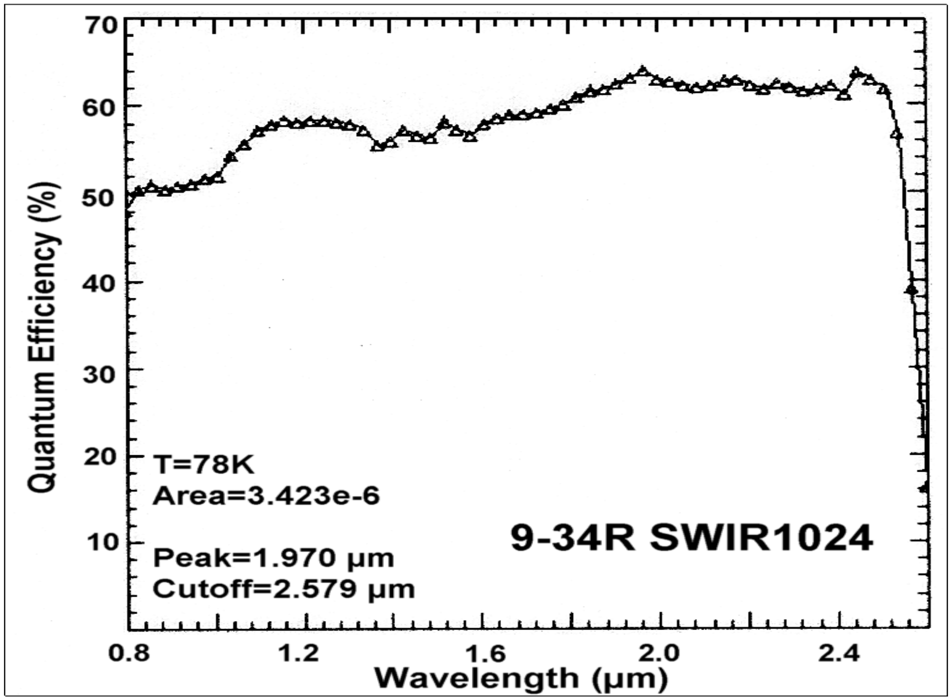
IR Hybrid Arrays

- Modern IR arrays are hybrid arrays, formed of a sandwich of three layers:
- Top layer (assuming radiation is coming down) is a Indium Antimonide or Mercury Cadmiun Telluride, doped to act as a photovoltaic detector
- Bottom layer is a silicon multiplexer, which can be a CCD but if more often an array of tiny MOSFET (Metal Oxide Semiconductor Field effect Transistor) amplifiers
- In between are Indium bump bonds providing an electrical connection between locations on the IR detector and the elements of the silicon multiplexer

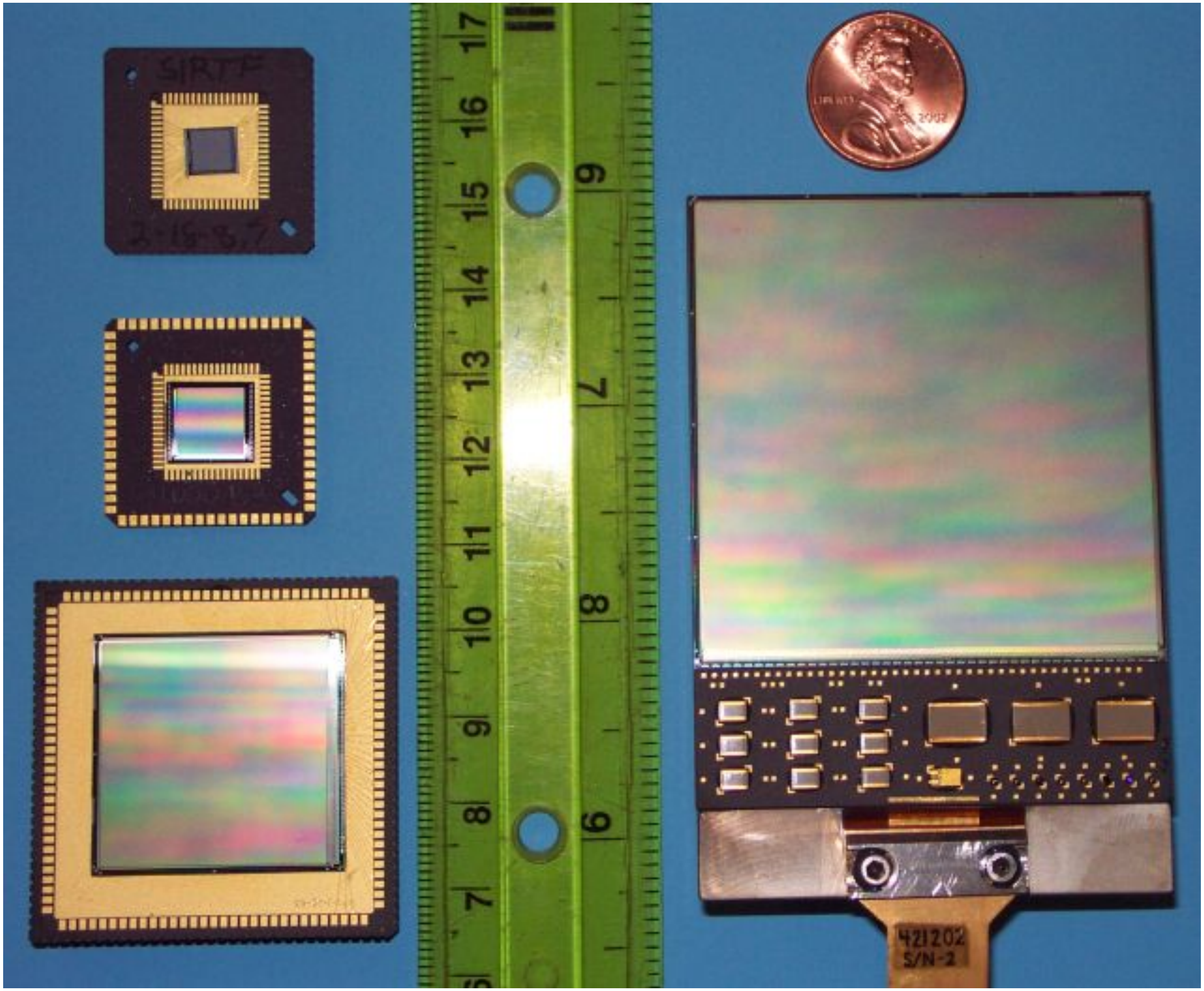
Popular IR Detector Materials

Material	$E_{bandgap}$ (eV)	cut–off (m)	Temperature (K)
Silicon (Si)	1.18	1.05	150 – 300
Indium Gallium Arsenide (InGaAs)	0.7	1.7	77 – 200
Platinum Silicide (PtSi)	0.25	5.0	40–60
Indium Antimonide (InSb)	0.23	5.4	20–40
Mercury Cadmium Telluride (HgCdTe)	0.25 – 0.5	2.4 – 4.8	60–77

State-of-the-art:
2k square arrays
(Rockwell)



IR Arrays



The Future: Energy-Resolving Arrays

Superconducting Tunnel Junctions (STJ),
Transition-Edge Sensors (TES),
Microwave Kinetic Inductance Detectors (MKIDs)

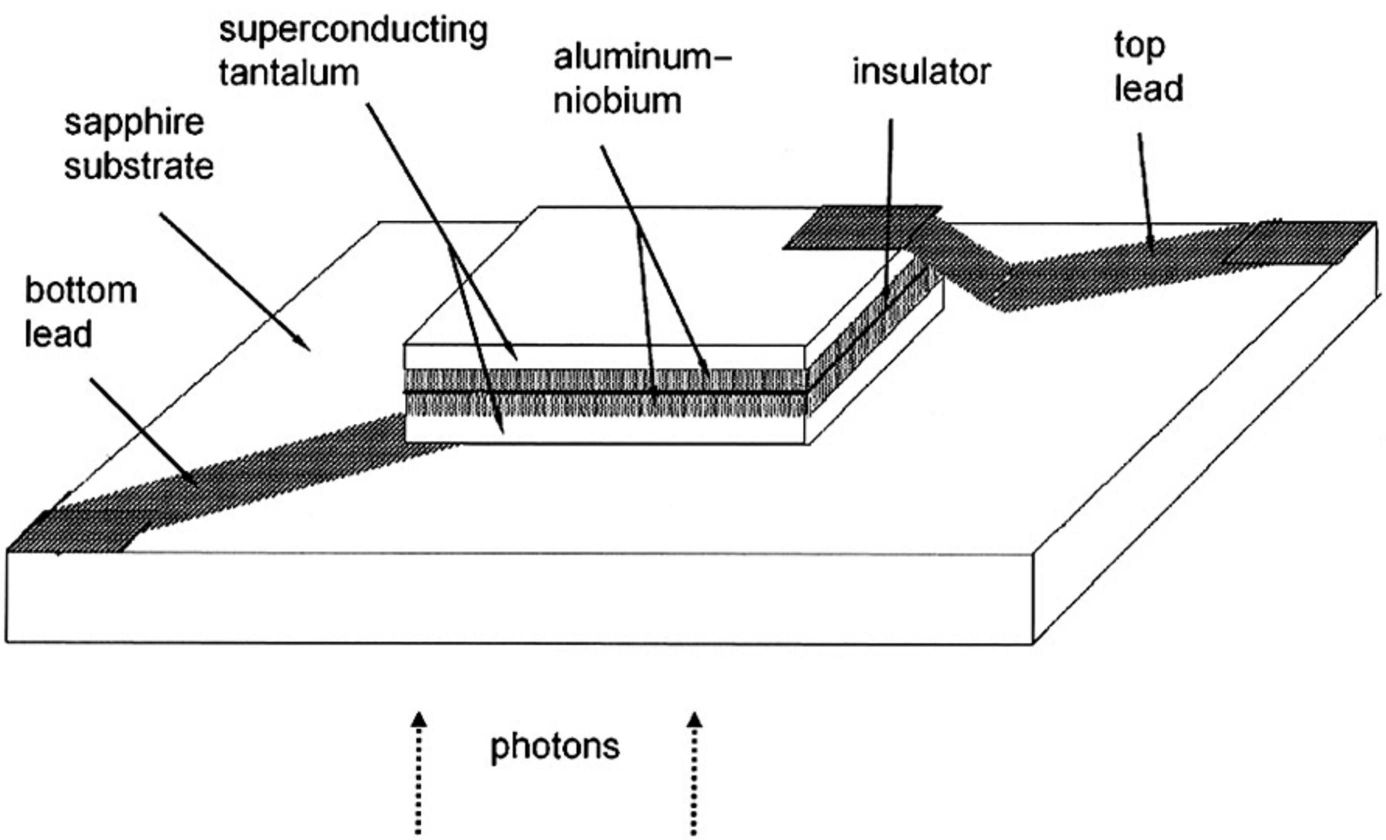
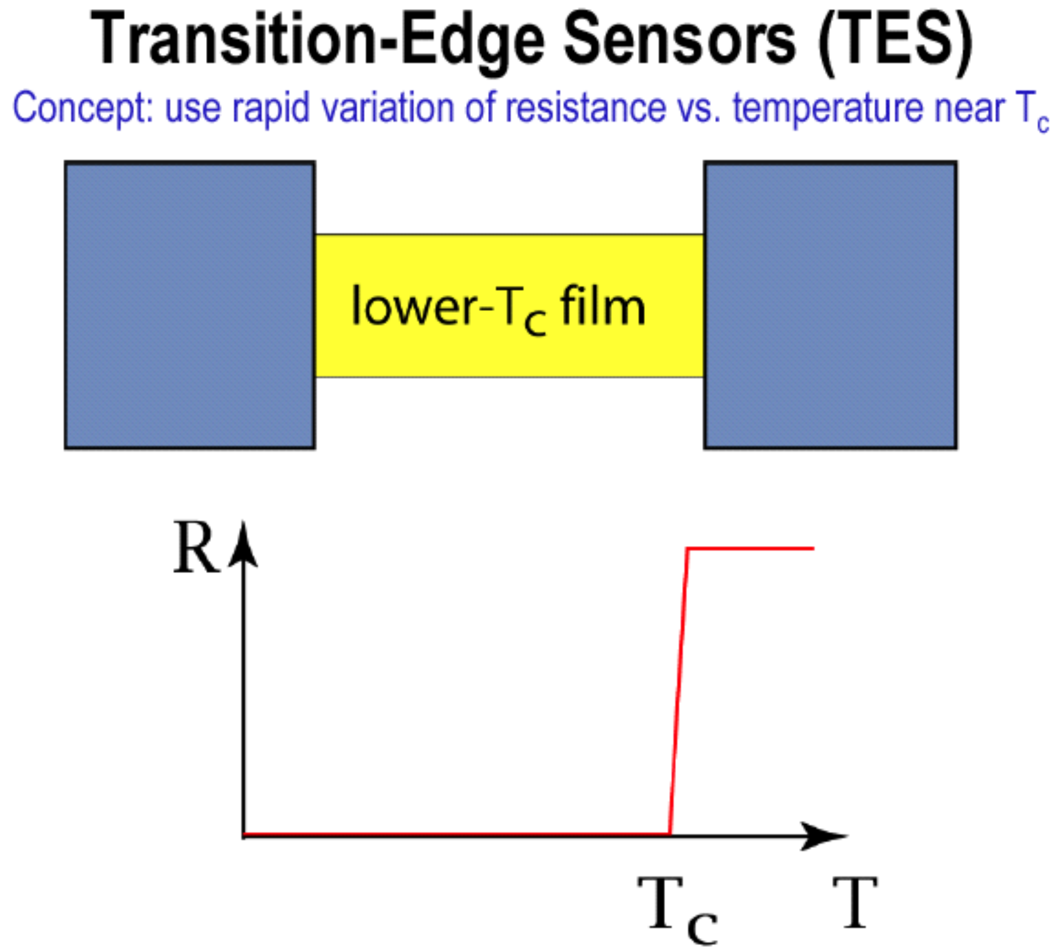


Figure 4.18. Superconducting tunnel junction (STJ) detector.

Siperconducting Detectors: TES

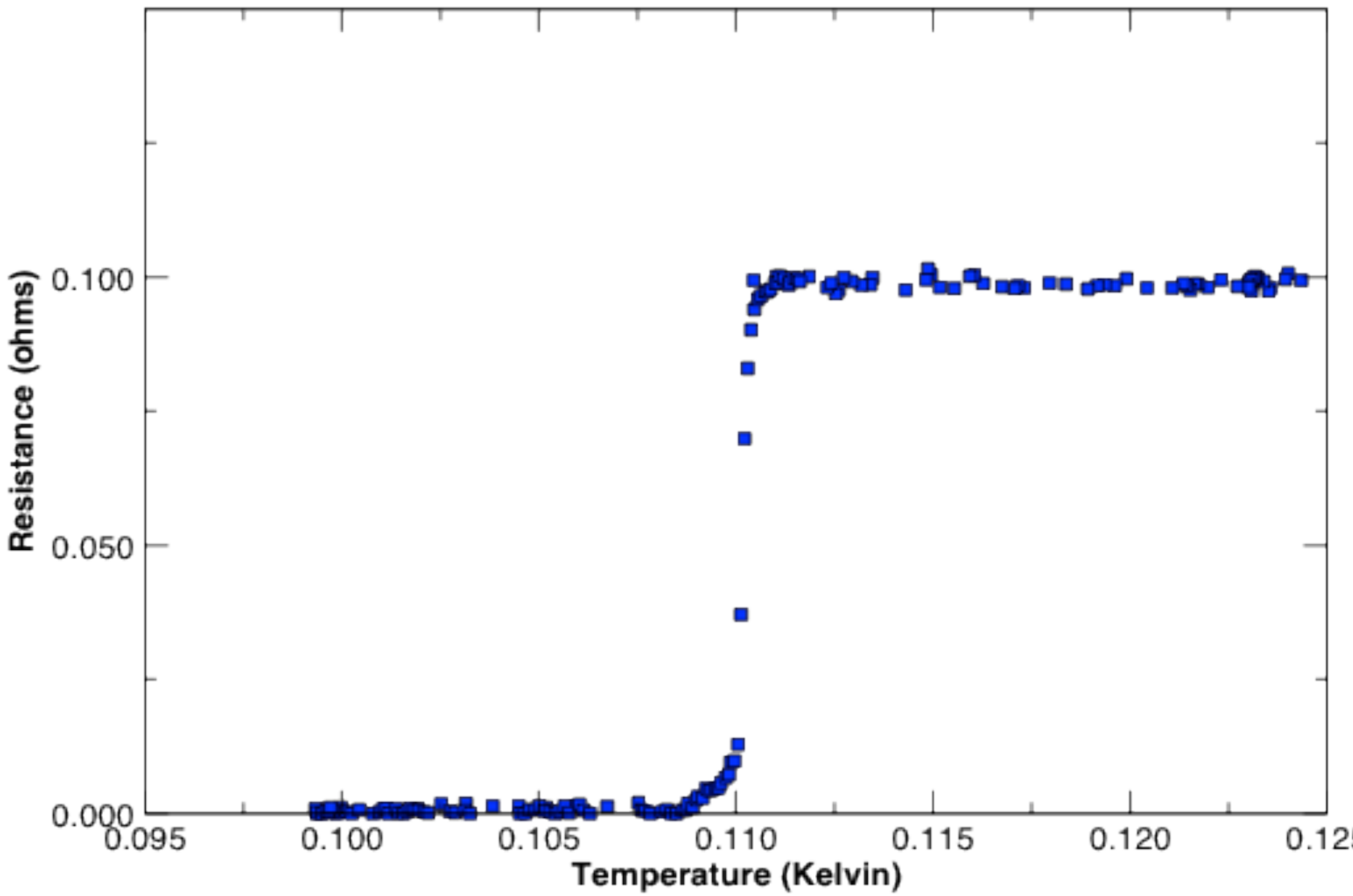


Use SQUID to measure R

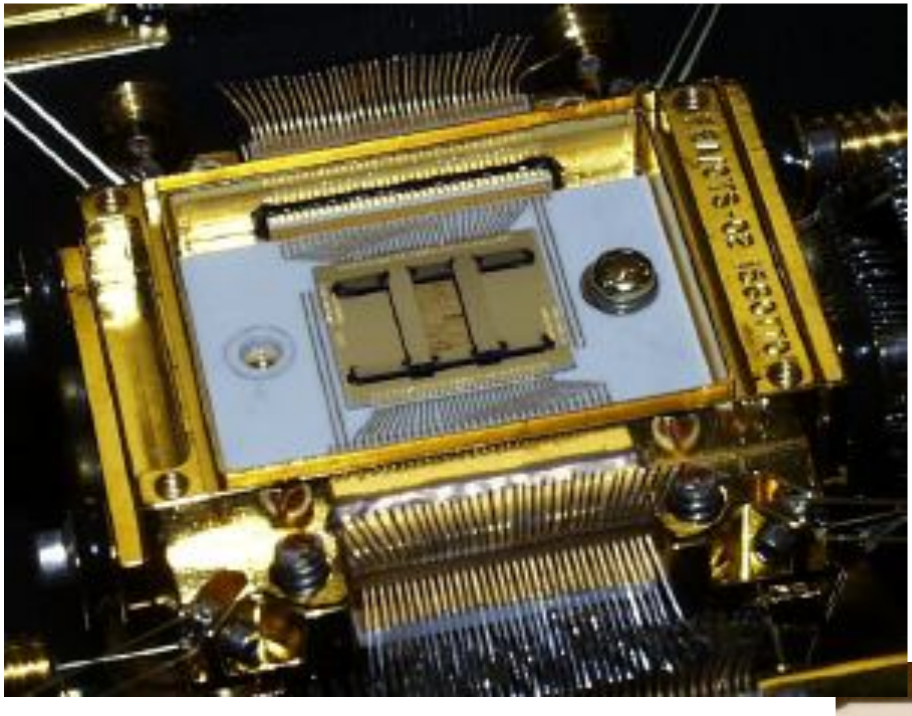
- Very active field at present
- High resolution X-ray detection demonstrated
- UV/optical astronomical observations (Stanford)
- Significant work on mm/submm detectors
- Multiplexing !!!

(From J. Zmuidzinas)

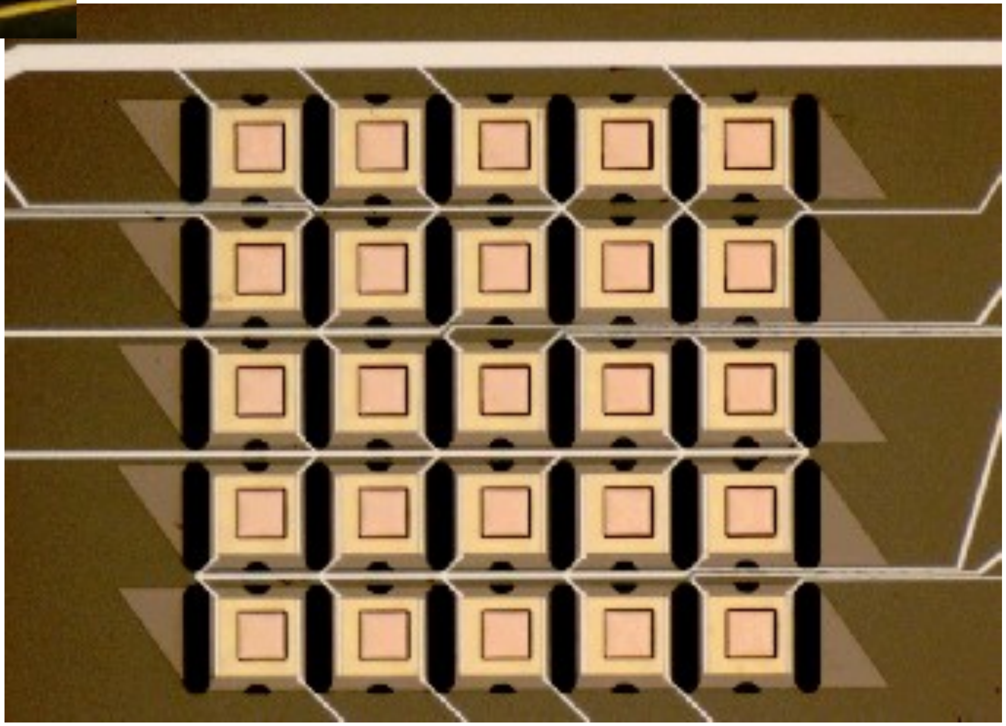
Resistance of a TES



Resistance against Temperature for a Scuba II test pixel

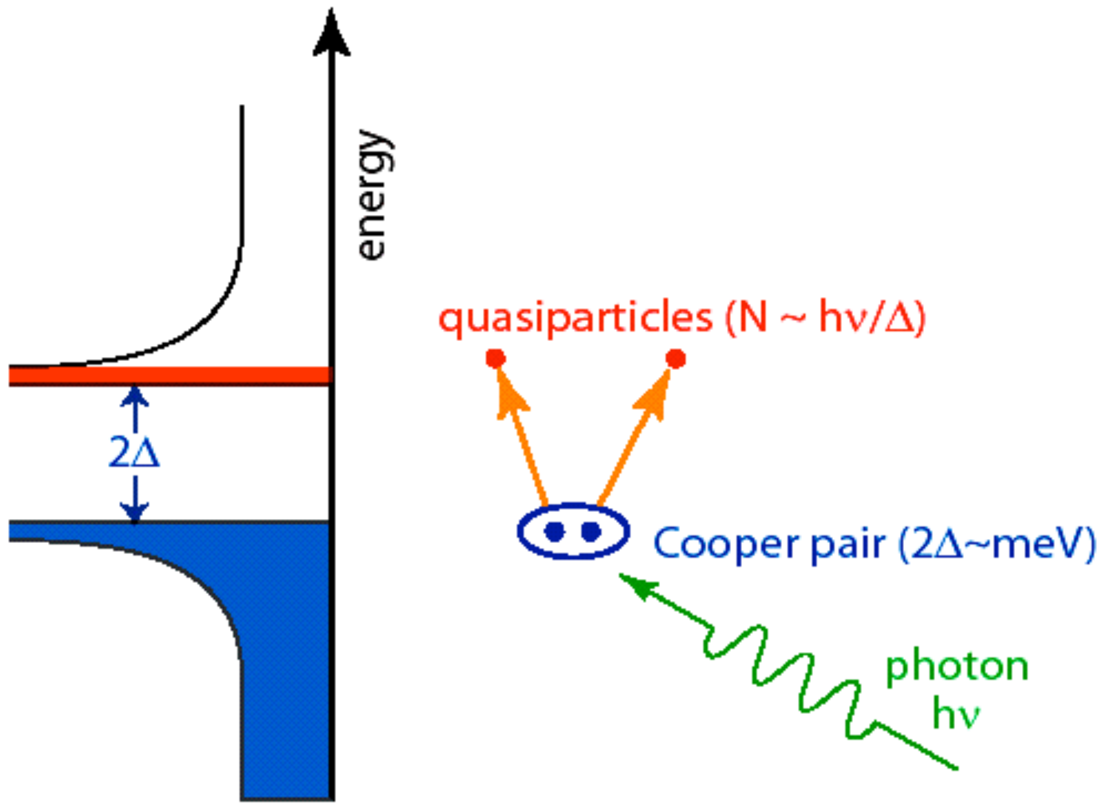


TES Array



Pair-breaking Detectors (e.g. STJ)

- Analogous to photoconductors, with meV gap (tunable)
- Photon-counting with energy resolution in optical/UV/X-ray
- How to measure quasiparticles ?
  - Must separate from Cooper pairs
  - Can use tunnel junction as a "filter" (STJ)
  - Can trap quasiparticles into TES (zero gap energy)

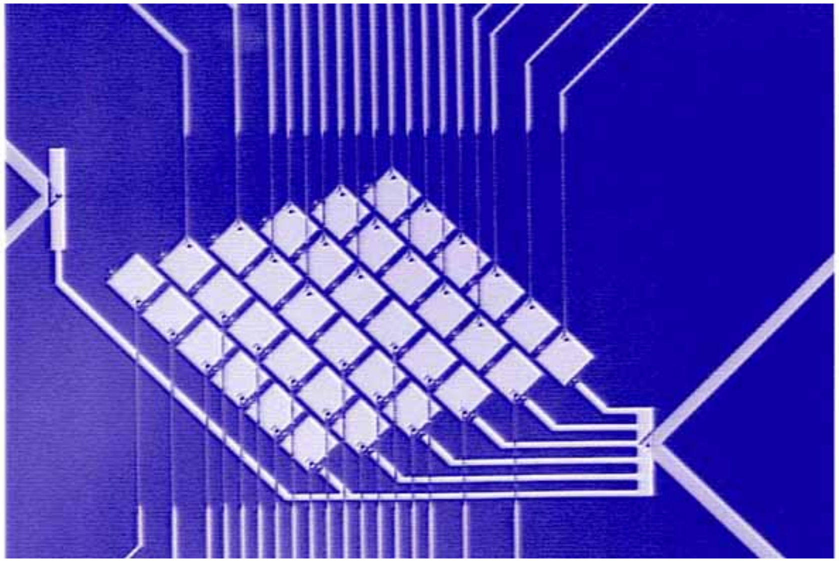


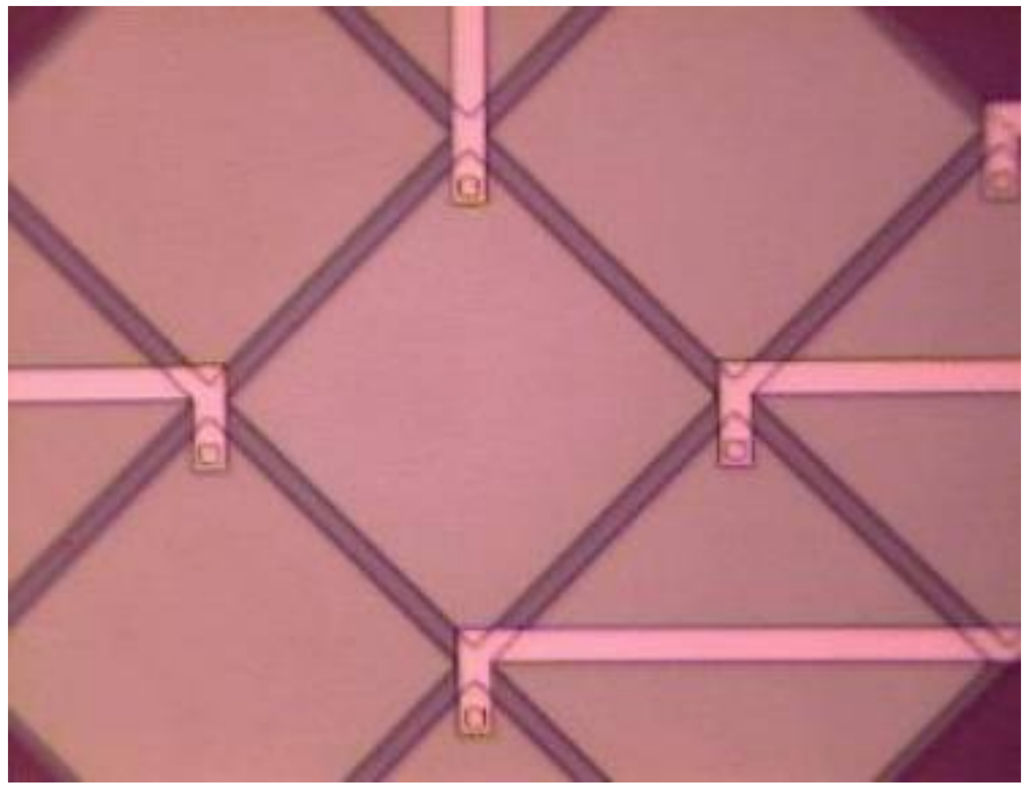
- Operate well below T_c, not at phase transition
  - physics should be simpler (n.b. HEB/TES not fully understood)
- Finite gap energy

Superconducting Tunnel Junctions

- Cryogenic detectors operating in a way similar to the semiconductor detectors we discussed earlier
- Consist of two superconducting electrodes separated by a thin insulator
- There is a small energy gap between the superconducting electronic ground state (which consists of Cooper pairs), and excited single particle states (quasiparticle states)
- Photons break Cooper pairs and excite quasiparticles
- Since the band gap is ~ 1 meV, there are ~1000 times more carriers generated than in Si detectors where the band gap is ~ 1 eV
- Carriers tunnel through the barrier to the other electrode, and produce an increased current which can be measured

STJ Array

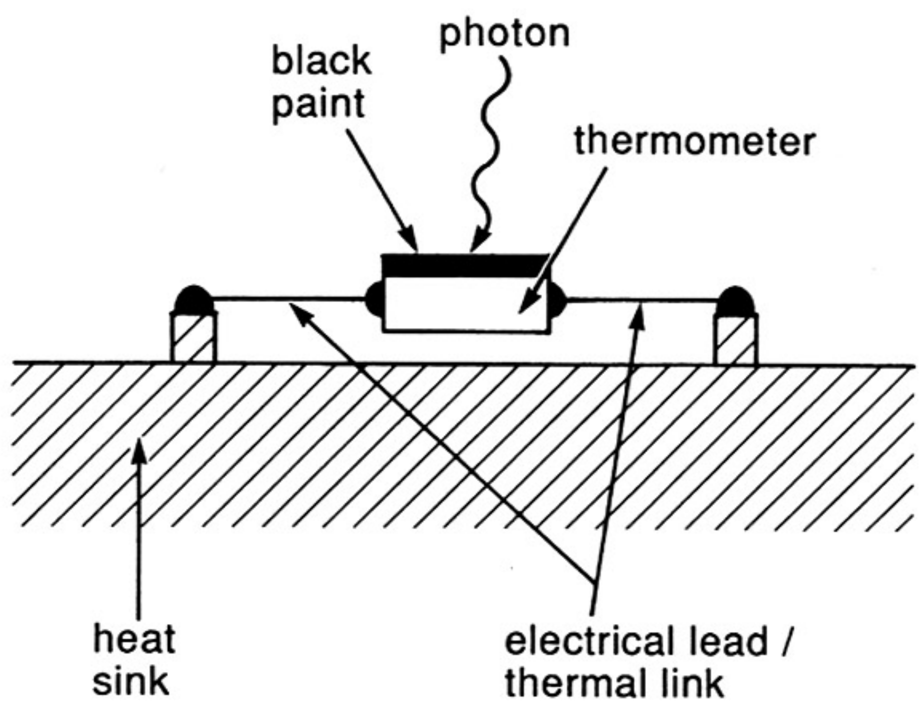




Bolometers

- Measure the energy from a radiation field, usually by measuring a change in resistance of some device as it is heated by the radiation
- Mainly used in FIR/sub-mm/microwave regime
- Sensitivity is measured through the Noise Equivalent Power (NEP): the power absorbed which produces S/N=1 at the output (units W/Hz$^{0.5}$)

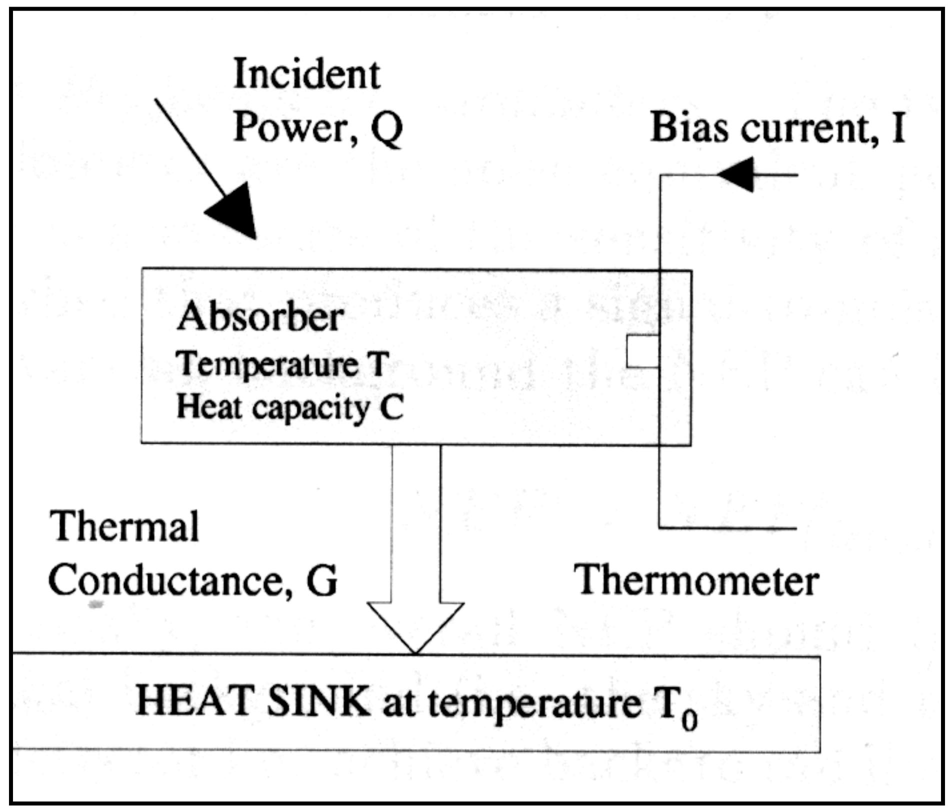
- Typically use a semiconductor resistance thermometer, and a metal coated dielectric as the absorber



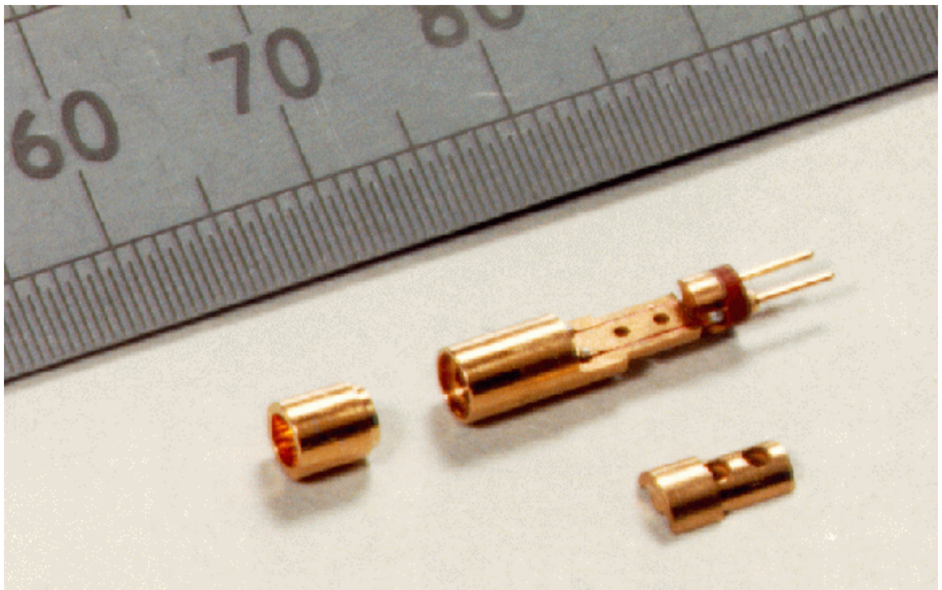
Components of a Bolometer

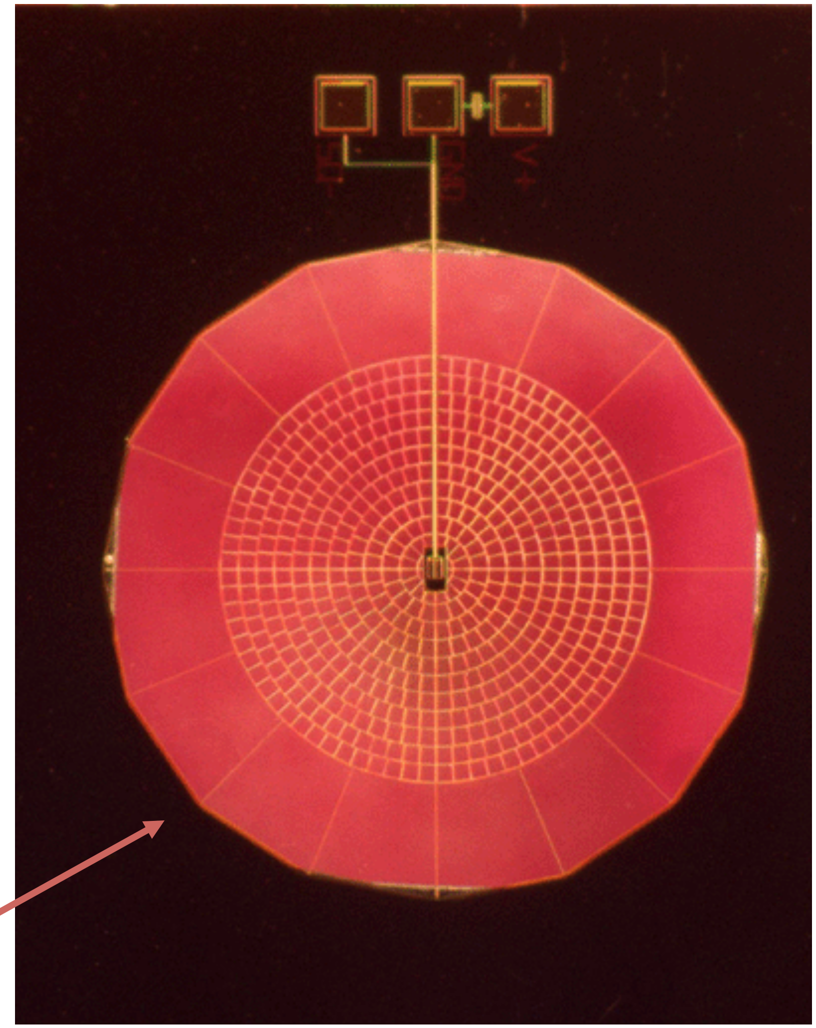
- Absorber with heat capacity C
- Heat sink held at fixed temperature T_0
- Small thermal conductance G between absorber and heat sink
- Load resistor R_L
- Thermometer w. resistance R
- Constant current supply generating bias current I
- Device to measure voltage changes

Schematic of a bolometer



Semiconductor bolometers
from SCUBA





“Spiderweb” bolometer

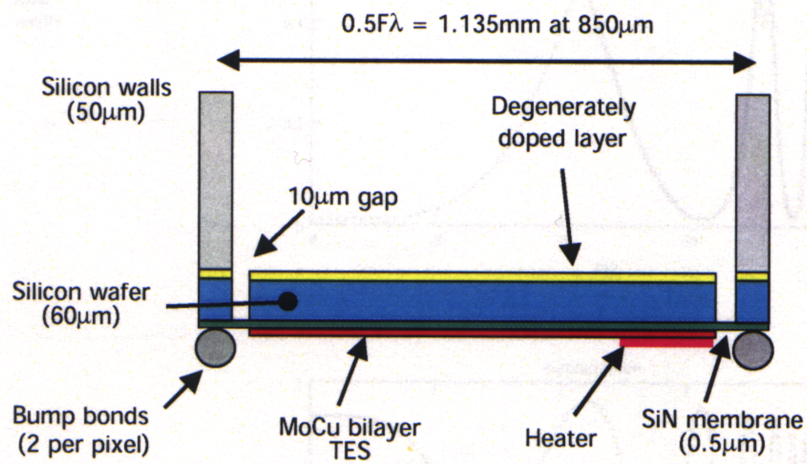
Transition Edge Sensors as Bolometers

- A superconducting material in the region of transition between its superconducting and normal states has a very steep dependence of resistance upon temperature
- Change in resistance results in a change in current through the thin film, which is read out using a Superconducting Quantum Interference device (SQUID) amplifier
- Typically thin film metal bilayers are used, for instance the Scuba II detectors are a Molybdenum-Copper bilayer

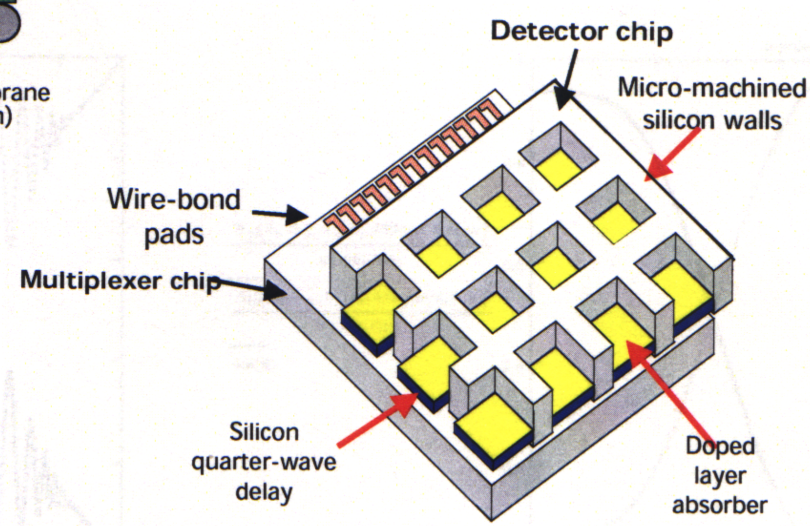
Scuba II Bolometer Array

- Scuba II, being built for the James Clerk Maxwell telescope, is an array of 80 x 80 TES pixels which will be used to map the sky at sub-mm wavelengths

Figure 2 Pixel geometry and array structure.

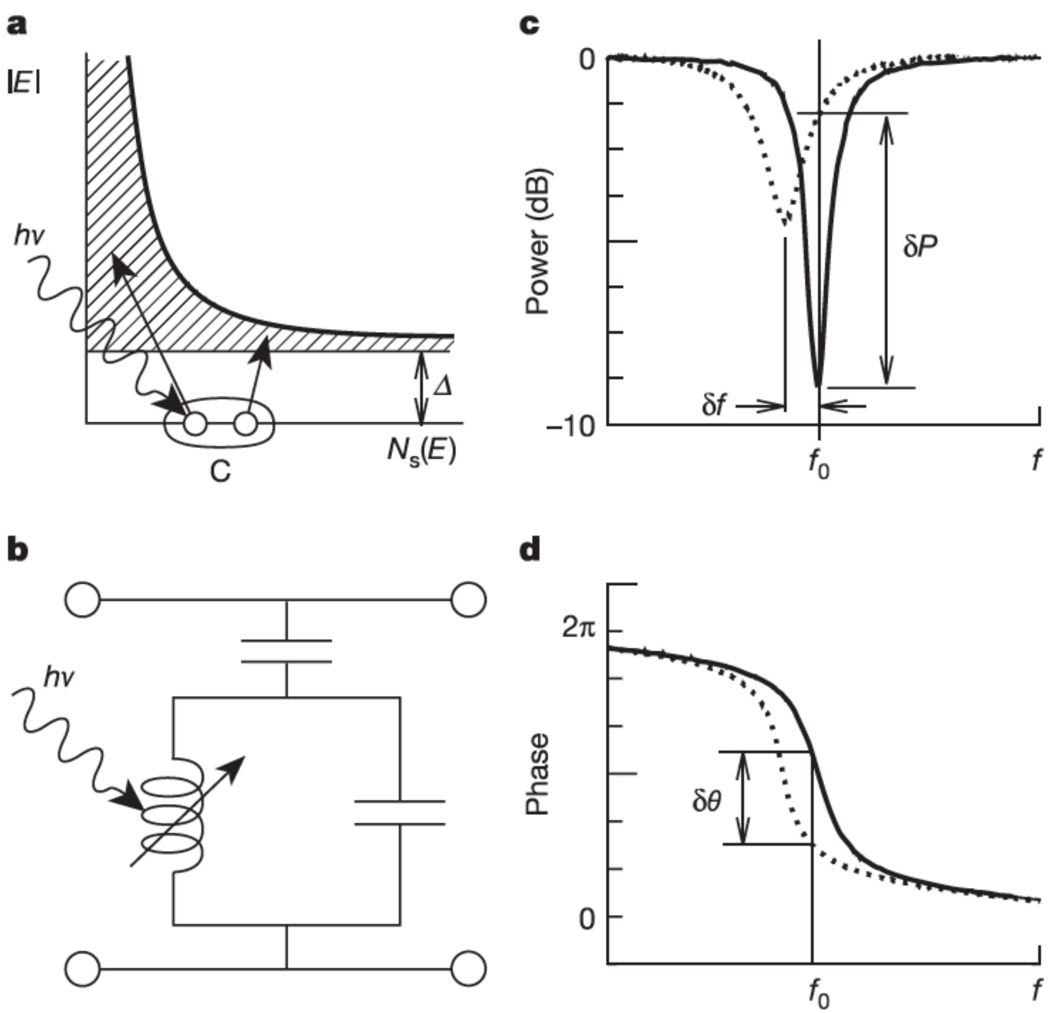


A single pixel design



A concept of the array design

Microwave Kinetic Inductance Detectors (MKIDs)



(from B. Mazin et al.)

The basic operation of an MKID: (a) Photons with energy hν are absorbed in a superconducting film, producing a number of excitations, or quasiparticles. (b) To sensitively measure them, the film is placed in a high frequency planar resonant circuit. The amplitude (c) and phase (d) of a microwave excitation signal sent through the resonator. The change in the surface impedance of the film following a photon absorption event pushes the resonance to lower frequency and changes its amplitude. The energy of the absorbed photon can be determined from the degree of phase and amplitude shift.

Advantages of MKIDs

- Much easier to fabricate and multiplex than TES or STJ det.
  - Megapixel arrays are on the horizon
- Can work from UV (~ 0.1 μm) to MIR (~ 5 μm) to mm wavelengths
- The detector has to be kept on a superconducting temp., but the readout electronics does not