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Optical/UV Microwave Kinetic Inductance Detectors (MKIDs)

Ben Mazin, January, 2010

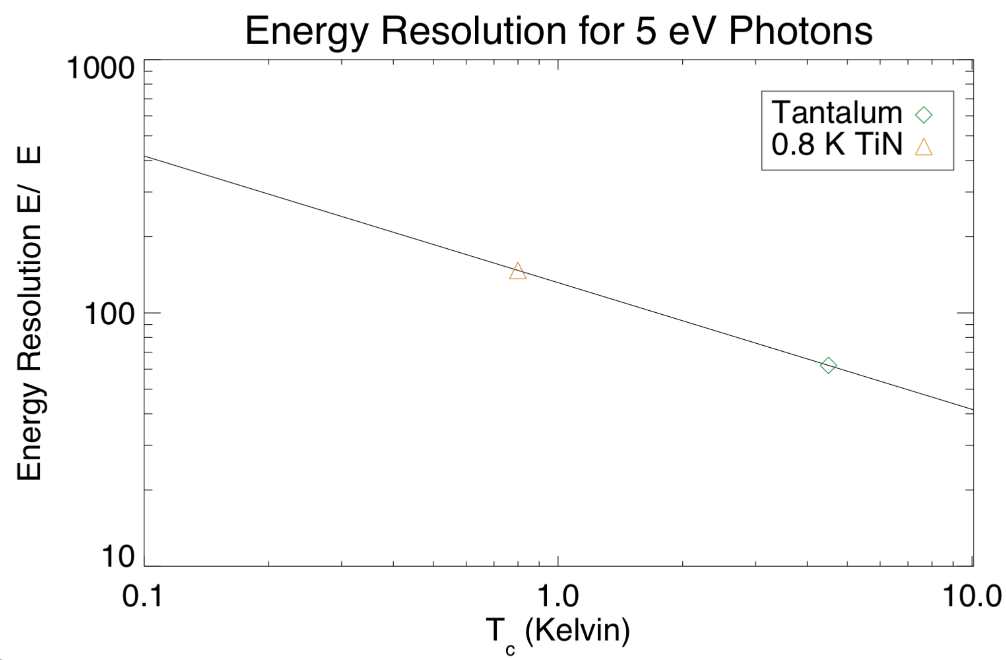
The Optical/UV MKID Team:

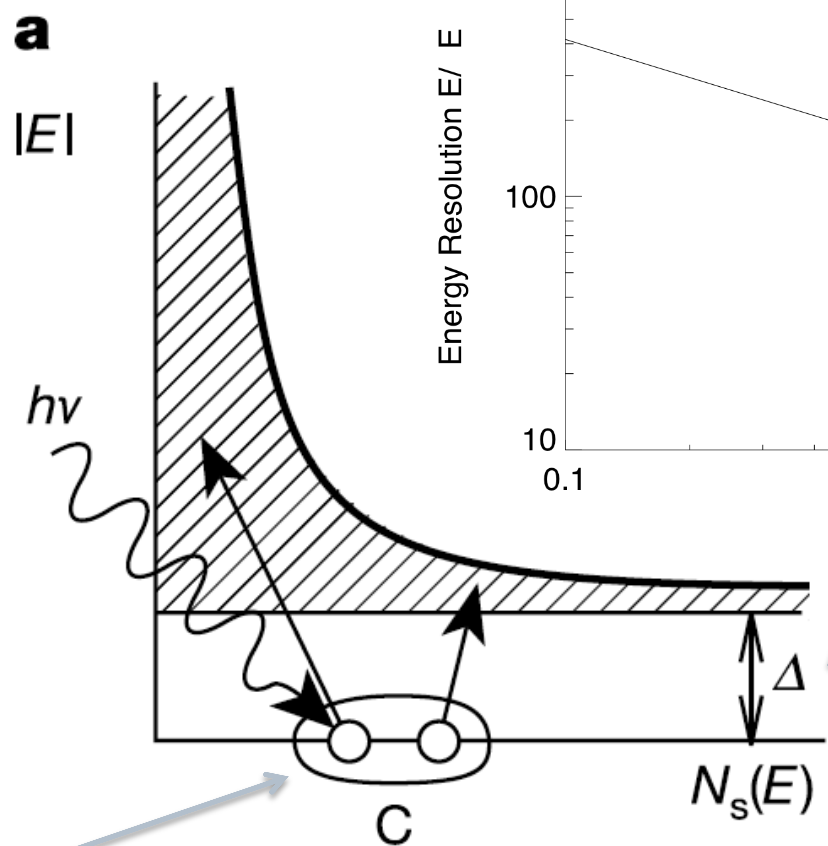
UCSB: Ben Mazin, Sean McHugh, Andrew Merrill, Kieran O'Brien

Caltech: Jonas Zmuidzinas, Sunil Golwala, David Moore

JPL: Bruce Bumble, Rick LeDuc

Why use Low Temperature Superconductors?





Cooper Pair

Energy Gap

Silicon – 1.10000 eV
Aluminum – 0.00018 eV

Energy resolution:

$$R = \frac{1}{2.355}\sqrt{\frac{\eta h\nu}{F\Delta}}$$

Kinetic Inductance Effect

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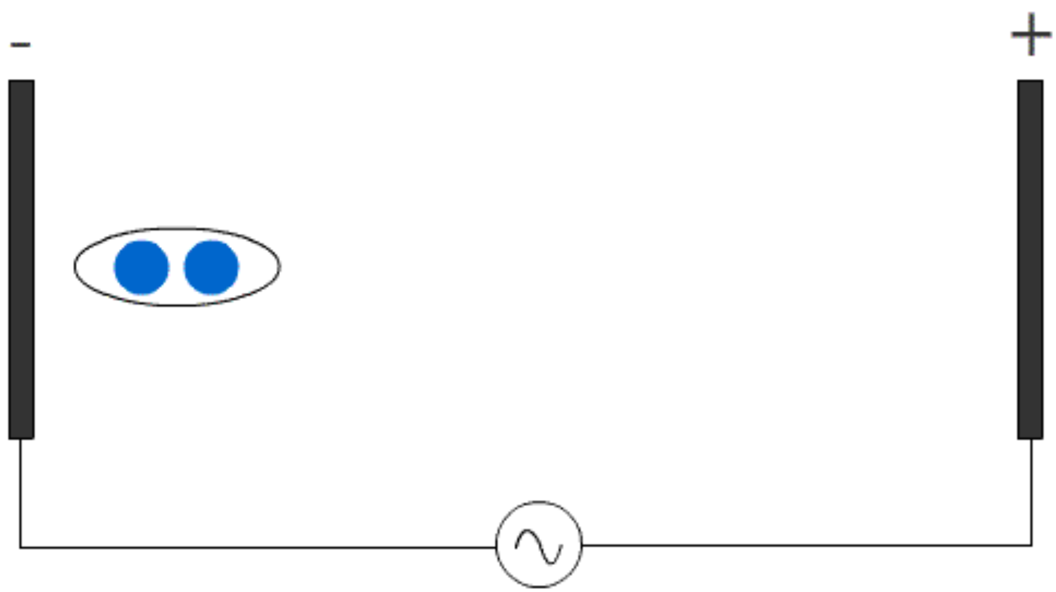
Kinetic Inductance = extra inductance from stored kinetic energy in Cooper Pairs



What is a Kinetic Inductance Detector ?

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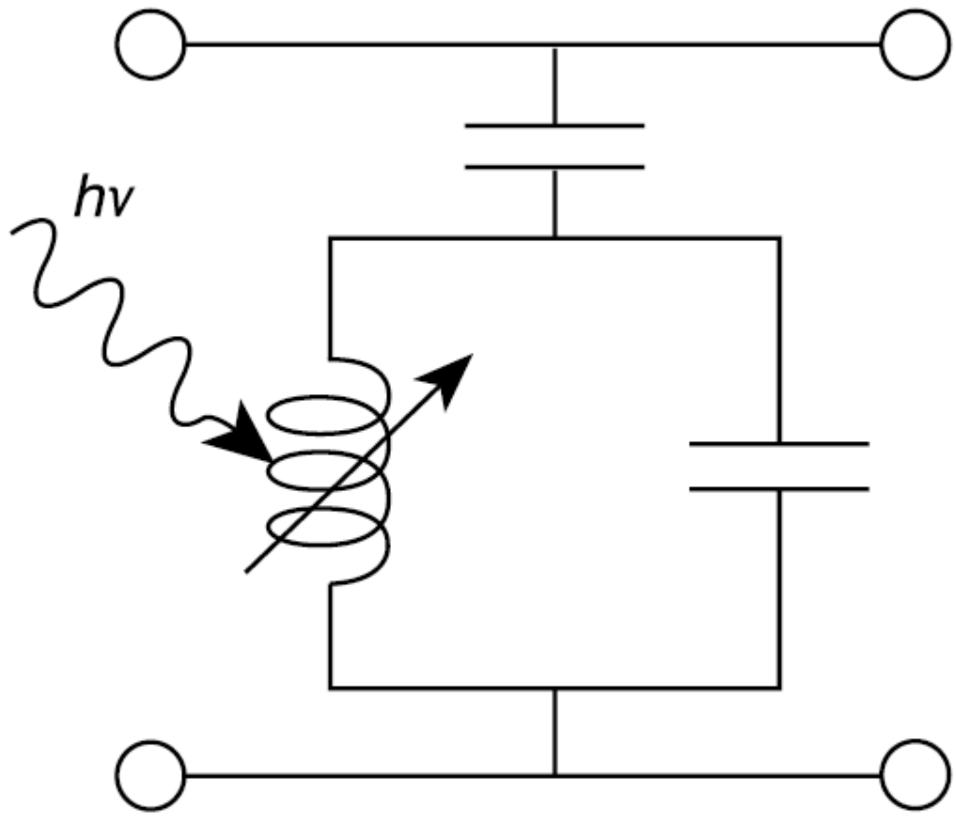

Microwave Kinetic Inductance Detectors (MKIDs)

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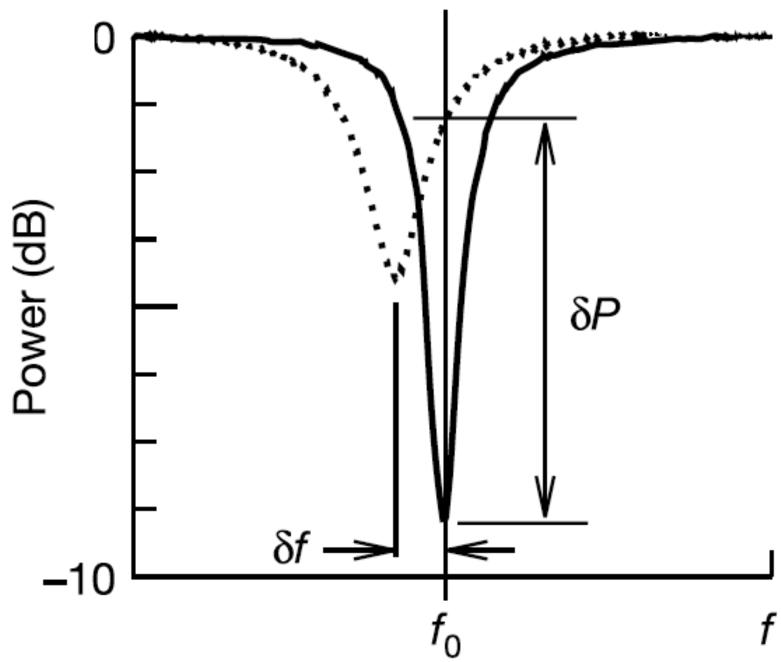
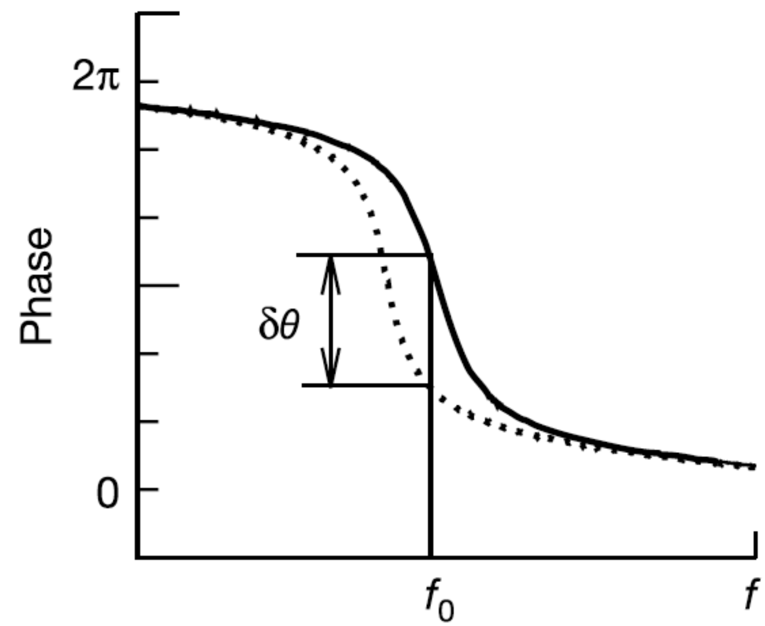
'Microwave' refers to the readout frequency!





- For more details, see:

  Nature, vol. 425, pp. 817-821, 2003
  Mazin's PhD Thesis, Caltech, 2004
  Gao's PhD Thesis, Caltech, 2008

Why is a Kinetic Inductance Detector Interesting?

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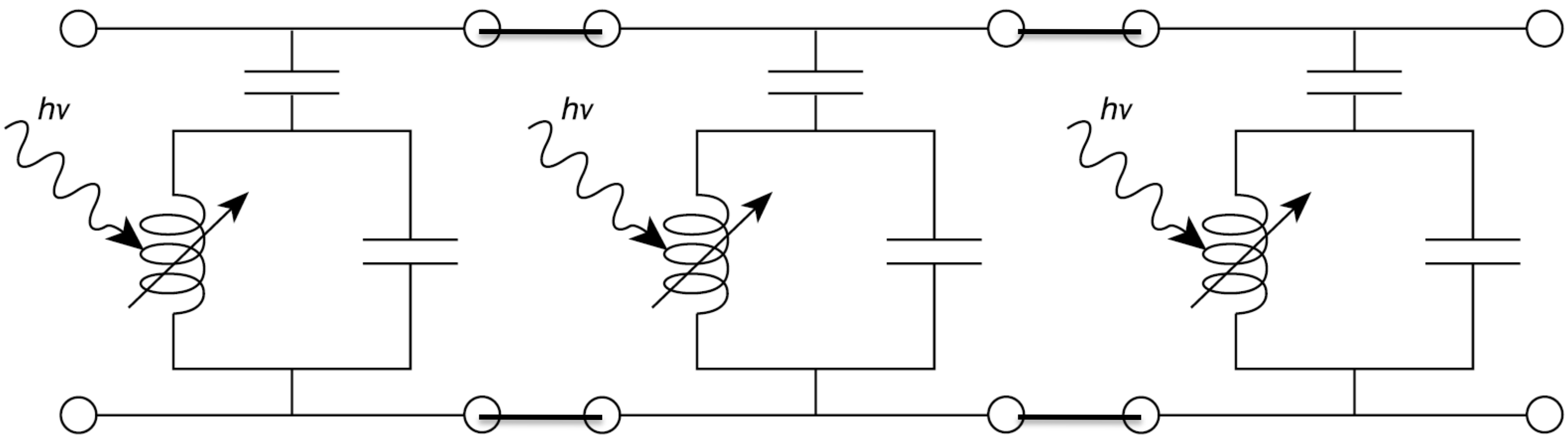

Built in Frequency Domain Multiplexing (FDM)!

Ta/Al Optical/UV Strip Detector

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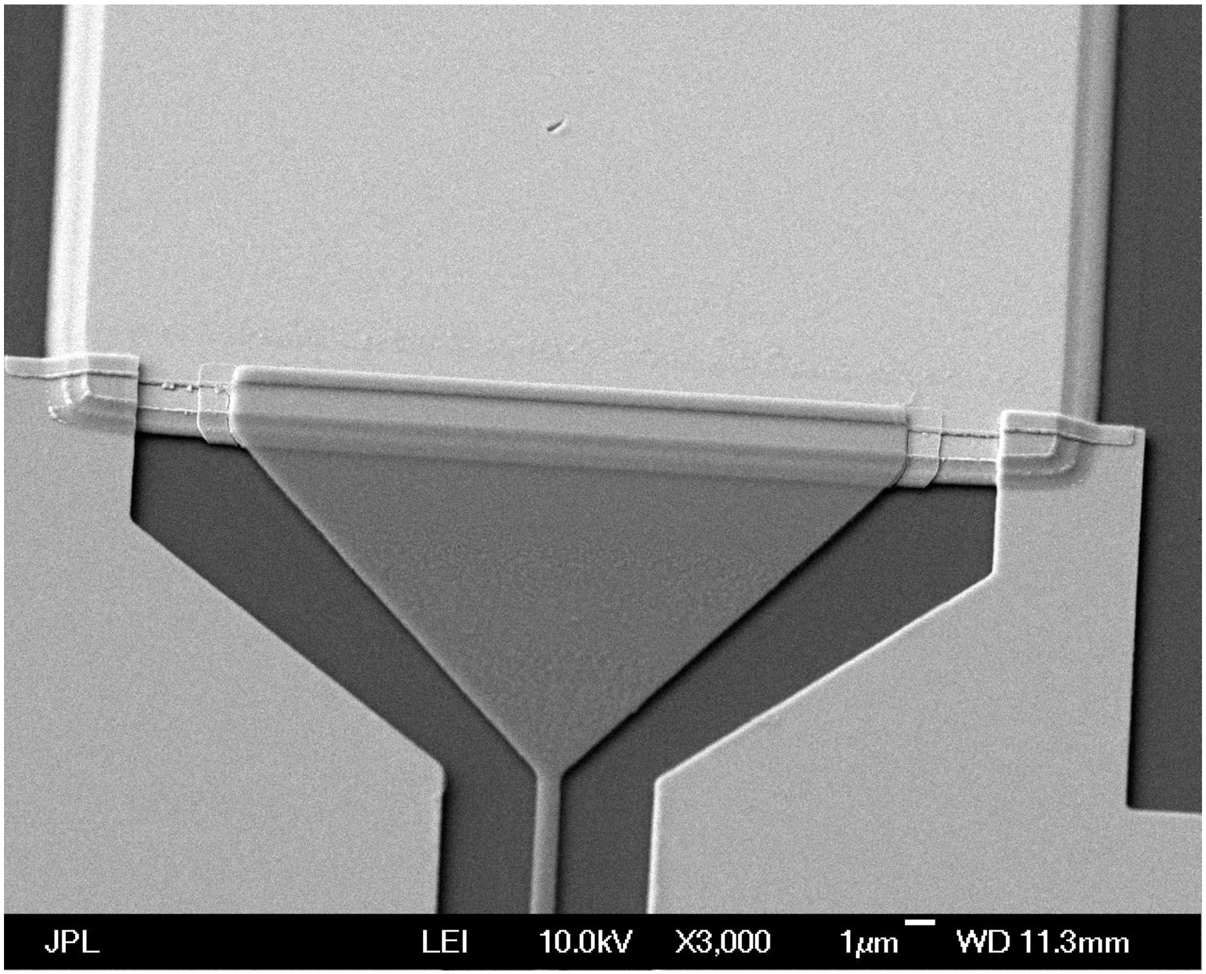

4 Layer Device on Sapphire

180 nm epi-Ta
140 nm SiO2 Ta protect
20 nm Al resonator
100 nm Nb resonator body

1 micron wide center strip

Optical Strip Detector Results

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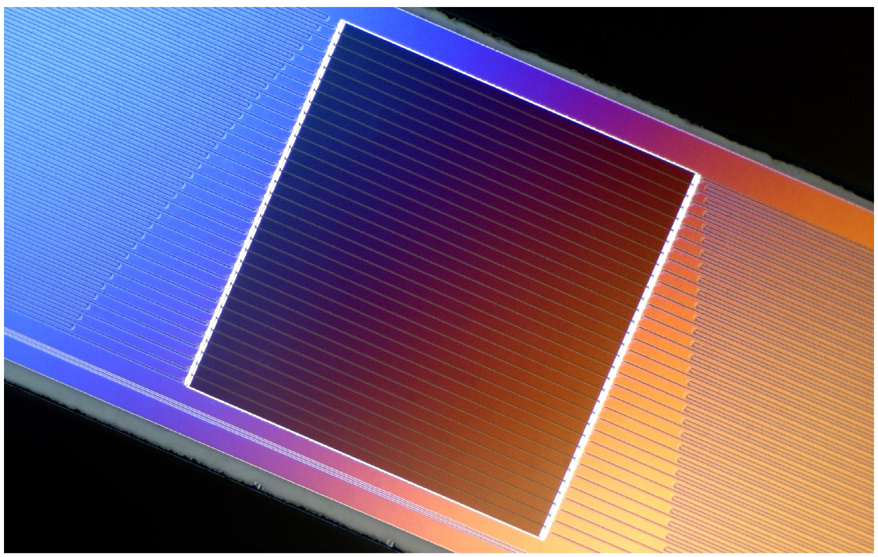
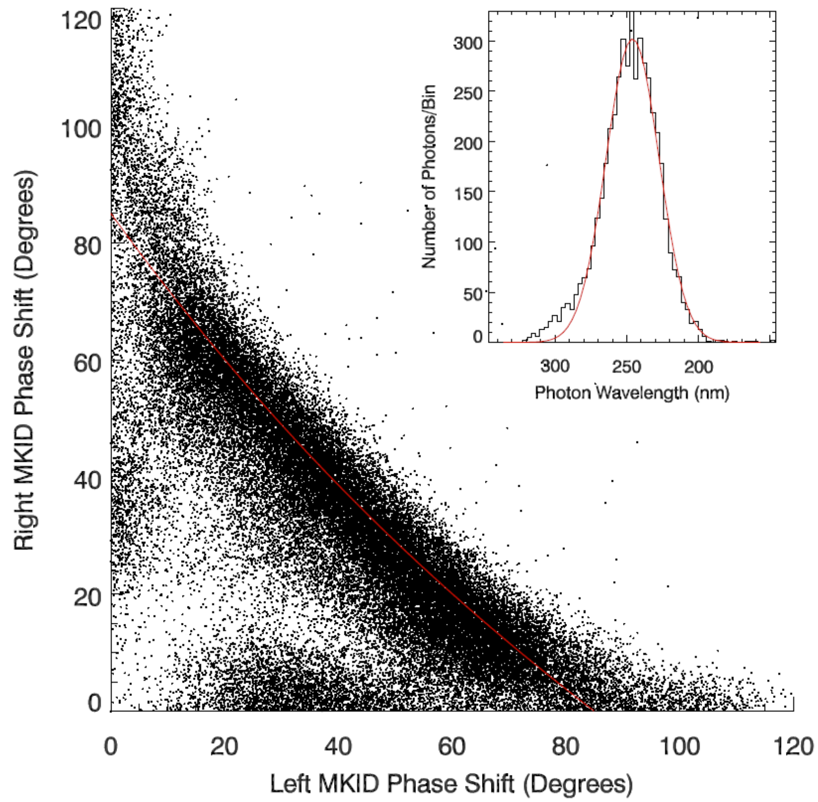
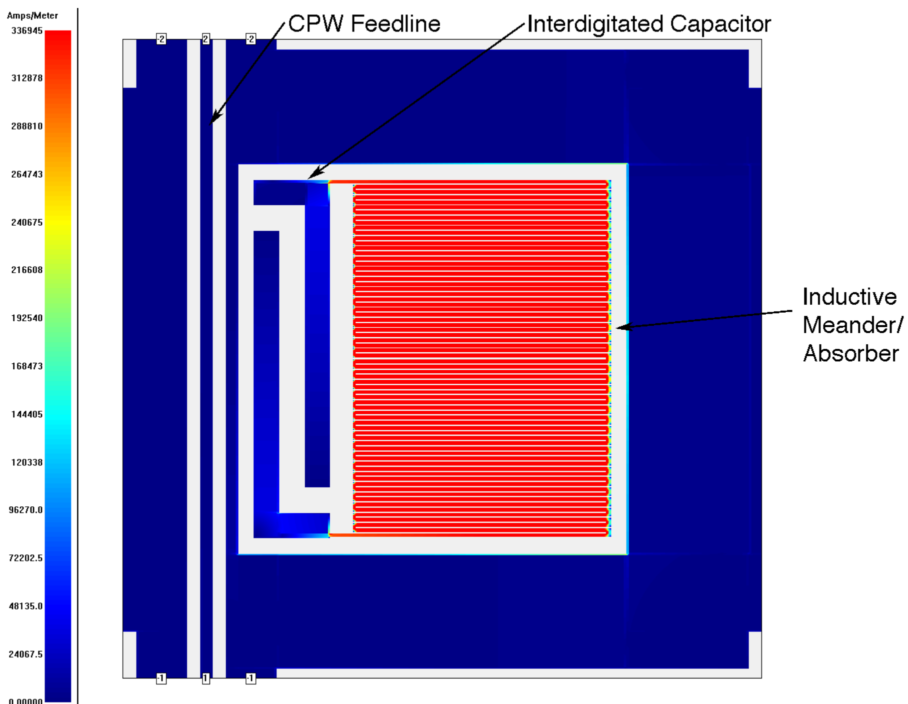
- Optical strip detector demonstrated in late 2007
- ΔE = 40 nm at 250 nm (R=6)
- Problems remain in trapping quasiparticles into thin Al films

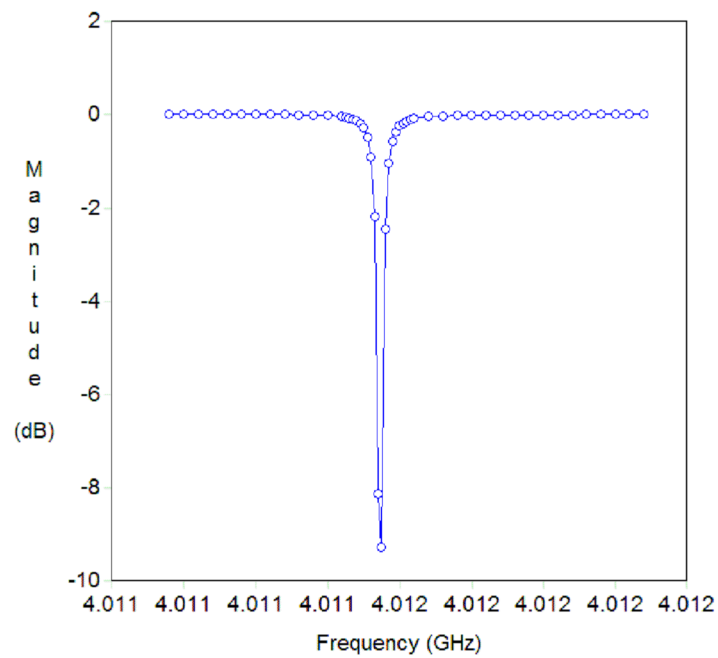




A New Material Leads to a New Approach

- TiN makes lumped element MKIDs attractive
- No quasiparticle trapping = better R (in theory)
- SONNET simulations indicate we can make a good resonator
- Make capacitor large since TLS noise comes from capacitor!





Lumped Element: See Doyle et al., 2009

New Concept: Optical Lumped Element MKIDs

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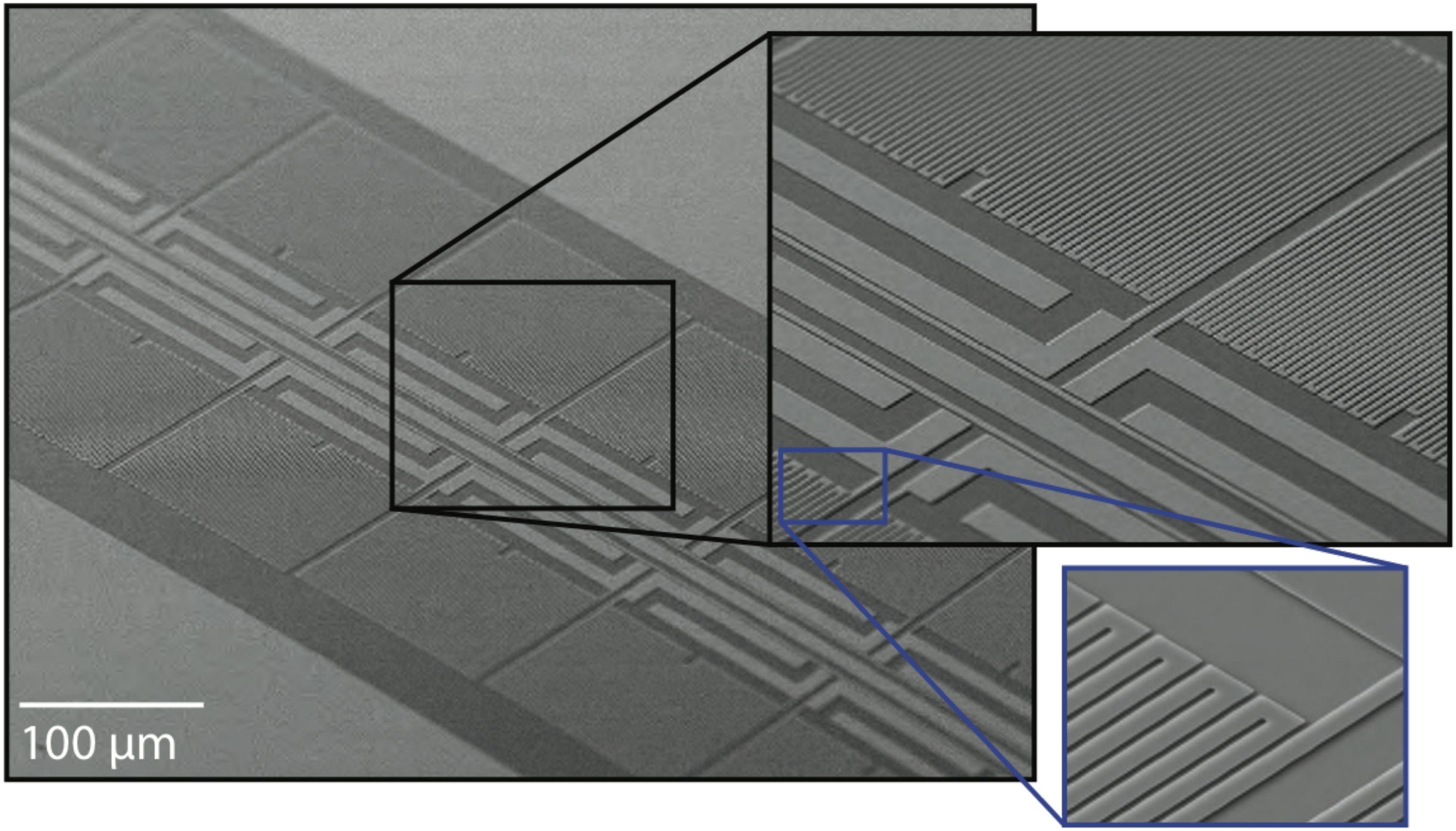
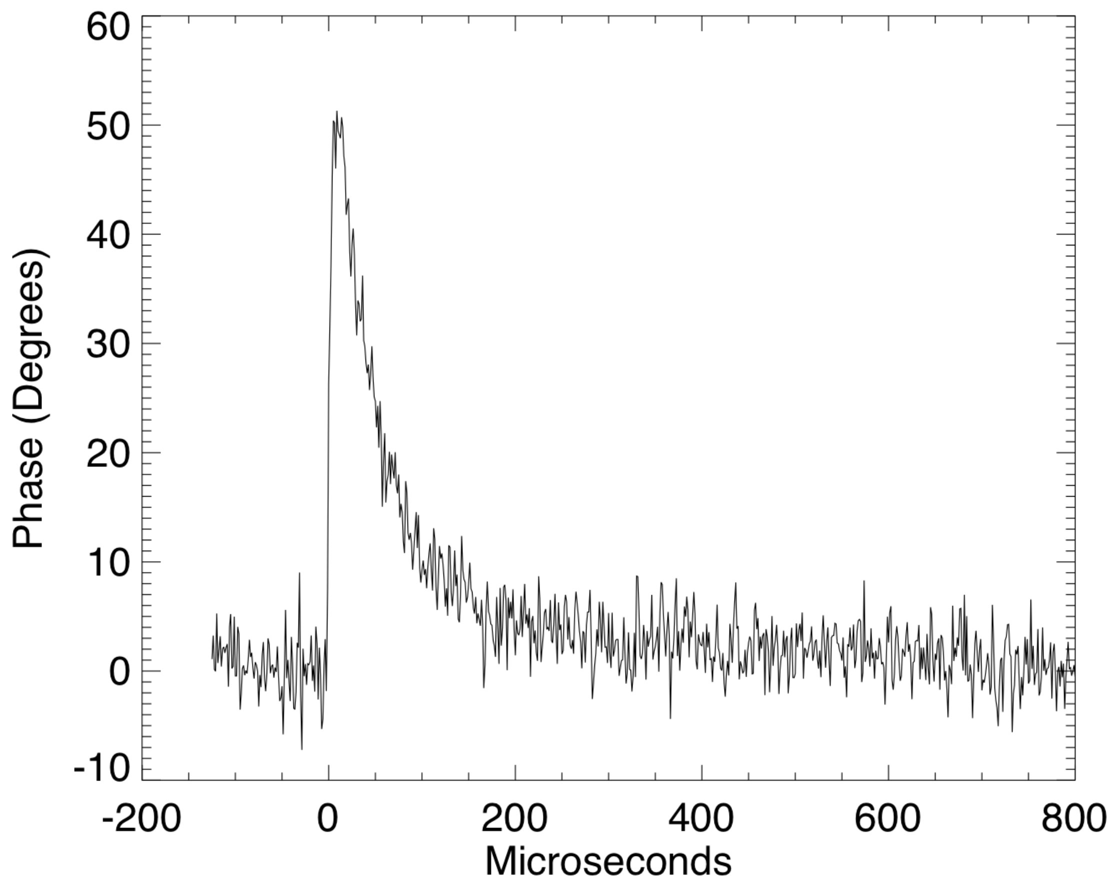


OLE

- Optical Lumped Element (OLE) MKID
- 45 nm TiN on Silicon
  - Tc = 0.8 K
  - QP lifetime ~ 100 μs
  - Qi >> 1,000,000



Highest R Ever Observed with an Optical MKID

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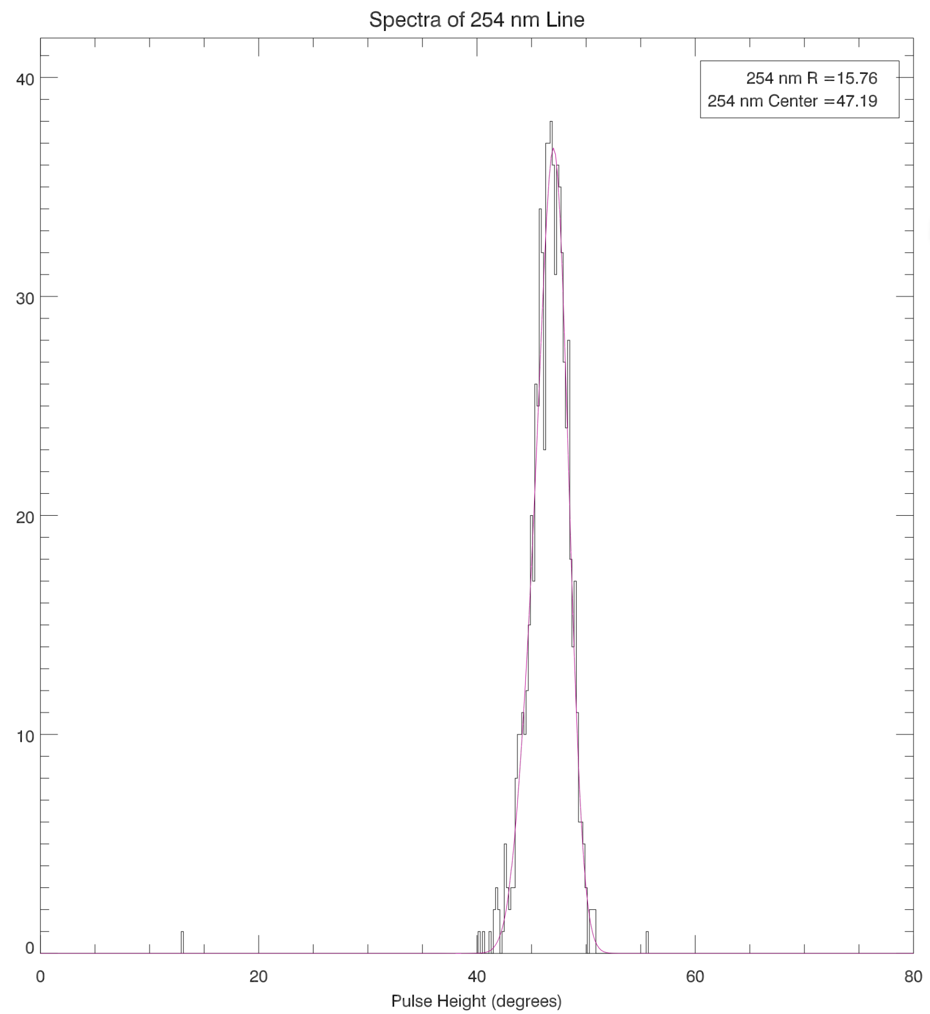
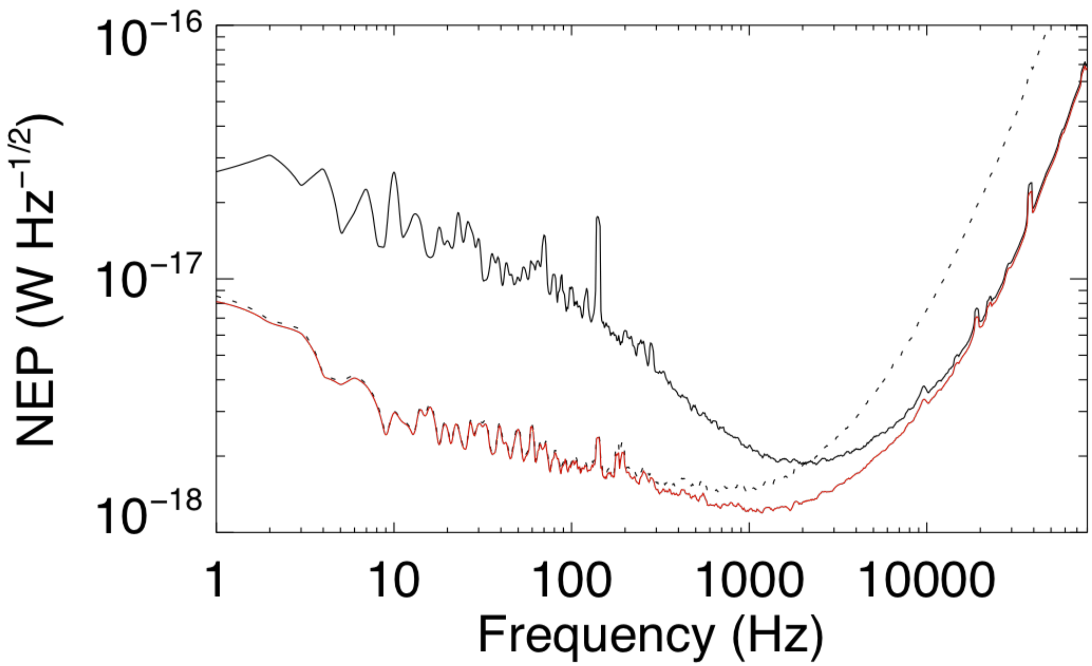


First try good enough to bring to the telescope!!

Noise

- Measured noise and pulse shape: R~30 now!
- Theoretical maximum (Fano) R=150, so a lot of room to grow
  - Increase R by making capacitor larger or reducing TLS



- Rise in dissipation NEP (dashed line) at low frequency is an artifact due to incomplete dissipation/phase separation

Coplanar Stripline

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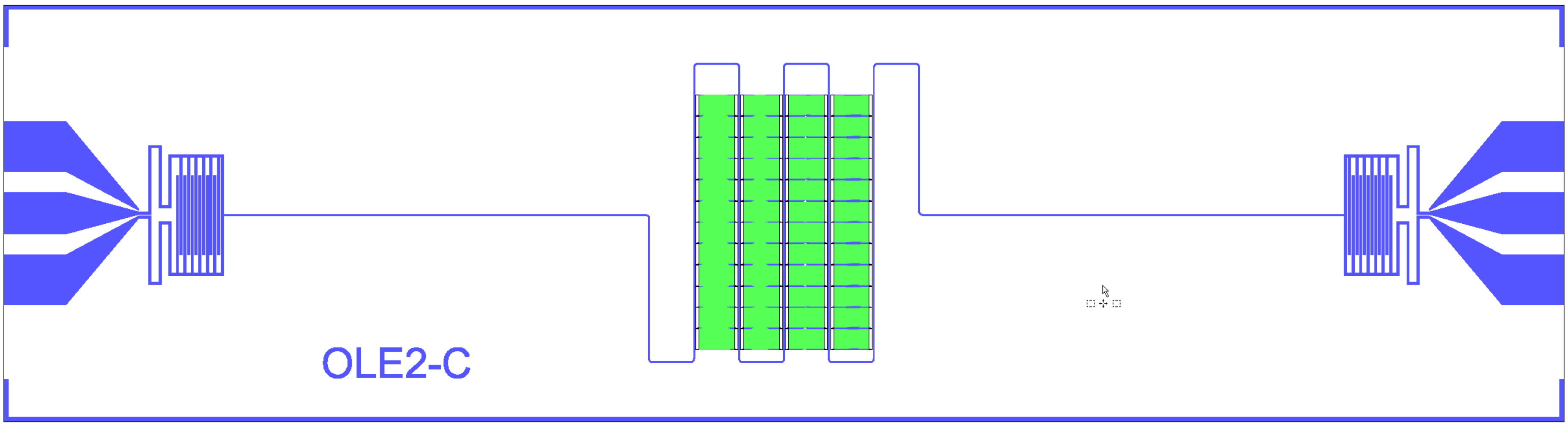
- CPS feedline supports only one mode
- CPS may lead to more uniform coupling Q without straps
- CPW to CPW transformer limits bandwidth
- Small wires, frequency coding to minimize cross talk



- 96 pixel OLE array fabricated and being tested
- Much larger arrays require no major changes
  - 1 Megapixel array with ~200 wires/100 Amps

Digital MKID Readout

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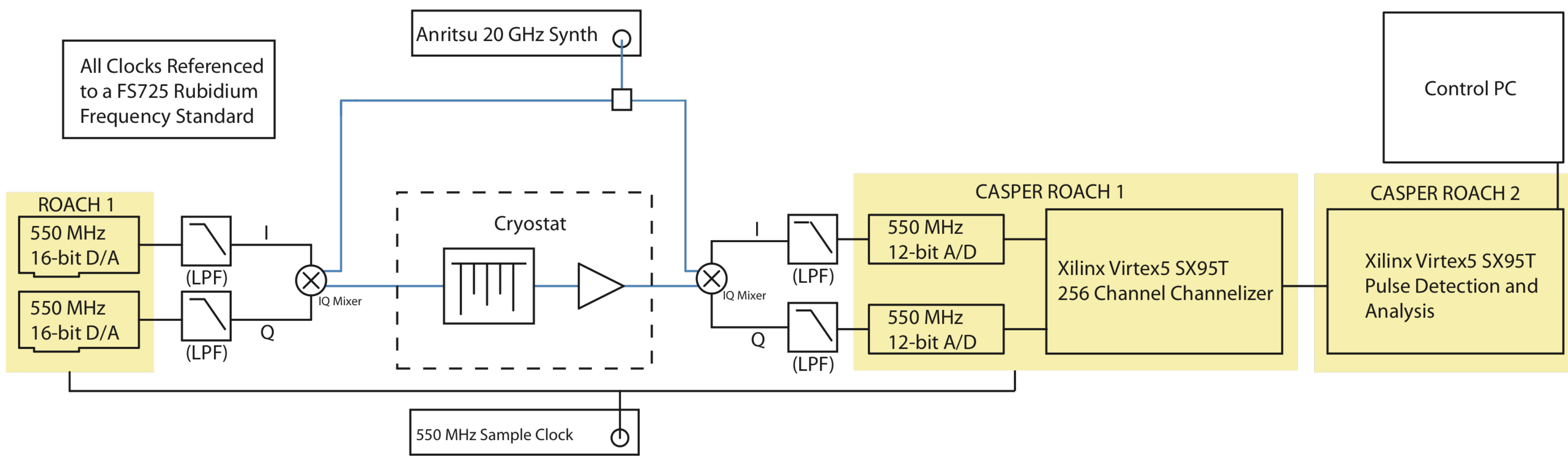
- Software Defined Radio (SDR) Overview
  - Generate frequency comb and upconvert to frequency of interest
  - Pass through MKID and amplify
  - Downconvert and Digitize
  - “Channelize” signals in a powerful FPGA
  - Process pulses (optical/UV/X-ray) or just output time stream (submm)



Open Source Readout

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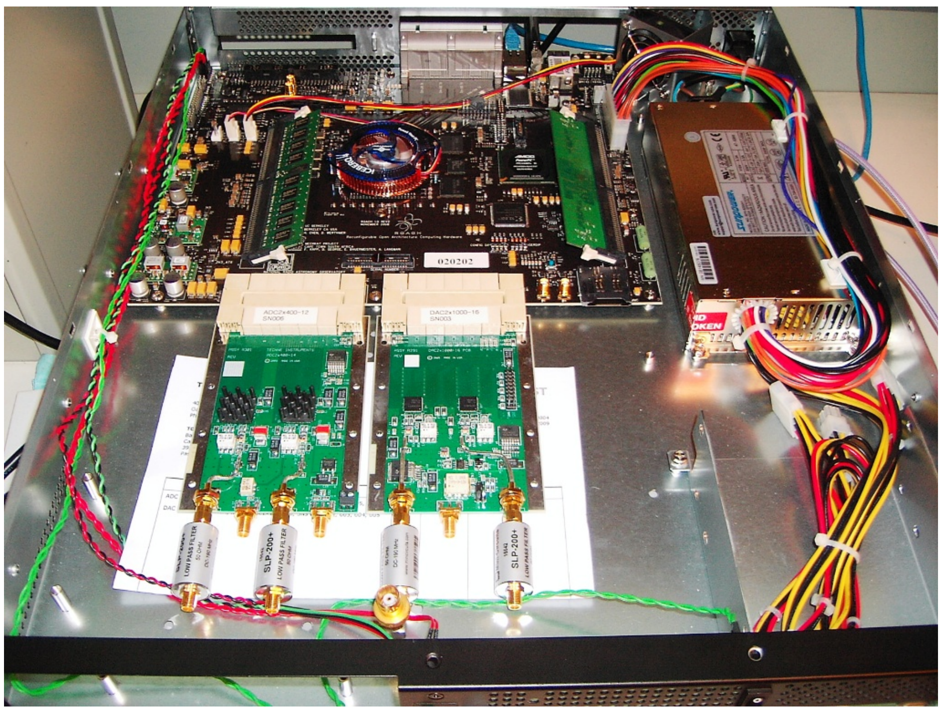
- Consortium of 7 institutions, designed and built in six months
- Functioning in lab now, some firmware development remains
- 256 resonators, 550 MHz of bandwidth in 1U rack mount case
- Cost: ~$30/resonator, going down with Moore's Law
  - *Megapixel arrays in 10-15 years! (20 GSPS ADCs on the horizon)*



Design is Open Source and freely available– if interested, contact me or Dan Werthimer at Berkeley's CASPER group

ARCHONS

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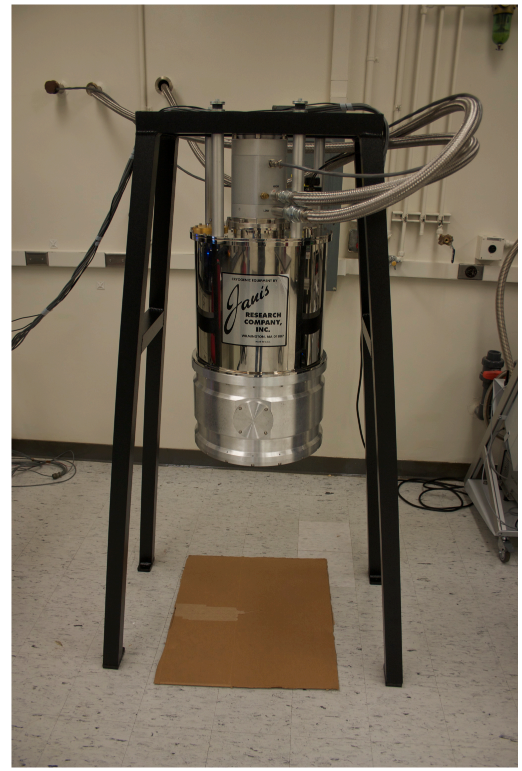
- Array Camera for High-resolution Optical to Near-IR Spectrophotometery (ARCHONS)
- Planned First Light: Fall 2010, Palomar 200”
- Lens coupled 1000 pixel array in cryogen-free ADR
- 0.33” pixels
- 350 nm to 1350 nm simultaneous bandwidth (UV through J Band!) with maximum count rate/pixel of ~2000 cts/sec
- Energy resolution of ~25 at 400 nm
- High on the sky QE (detectors ~50%)
- All digital room temperature readout
- Preliminary design is for Palomar Coudé focus
- Enables unique Compact Object and Extragalactic Science



Once proven, propose for Keck Visiting Instrument Port!

ARCHONS Science

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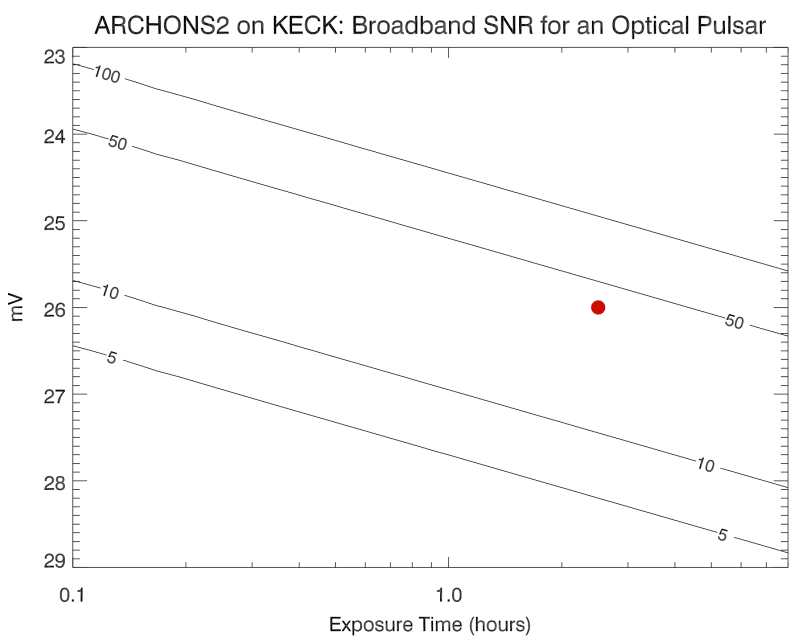
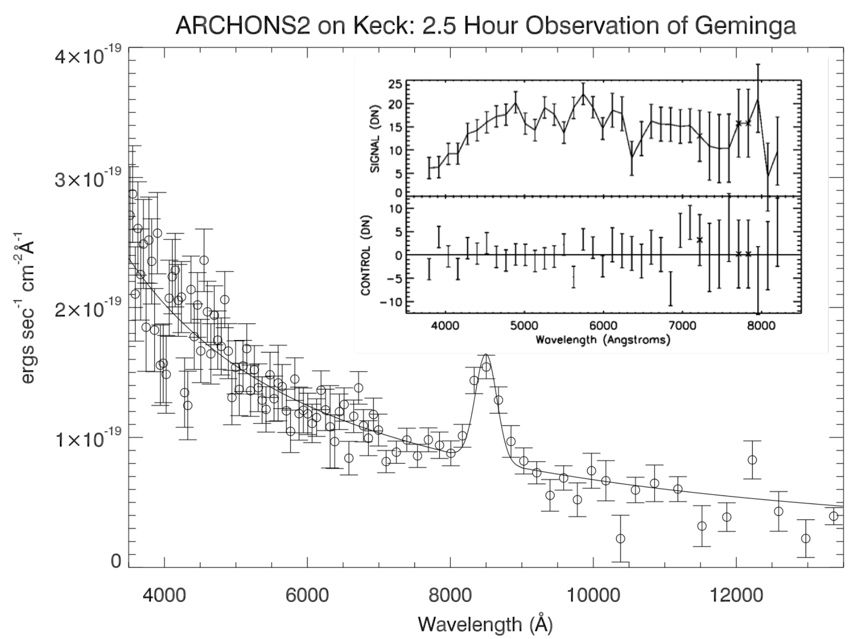
- Optical Pulsars
  - Exciting opportunities based on new Fermi results!
- High Redshift Galaxies
- Planet Finding (coronagraphy)





The Future

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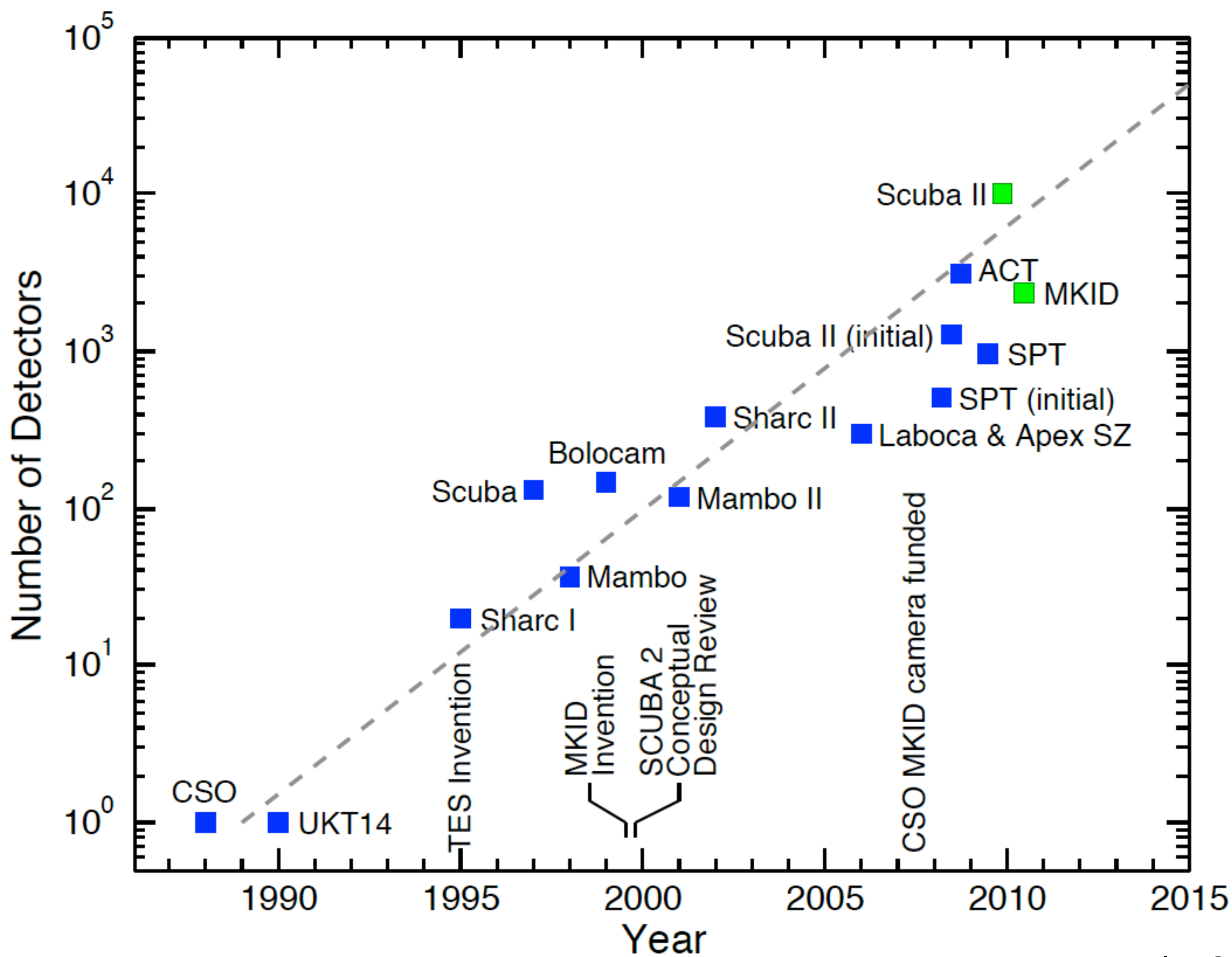

Plot from J. Zmuidzinas