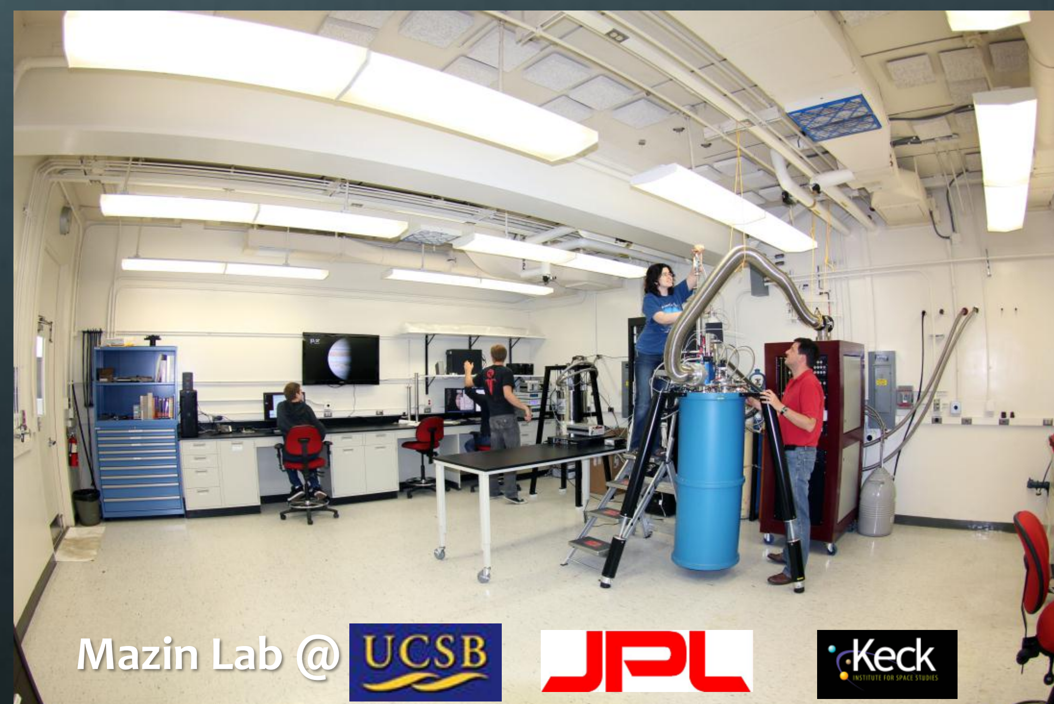
MKIDs for Coronagraphic Direct Detection

Ben Mazin, January 2012



The Optical/UV MKID Team:

UCSB: Ben Mazin, Sean McHugh, Kieran O'Brien, Seth Meeker, Erik Langman, Danica Marsden, Matt Strader

Caltech: Jonas Zmuidzinas, Sunil Golwala, David Moore

JPL: Bruce Bumble, Rick LeDuc

A New IFU Technology

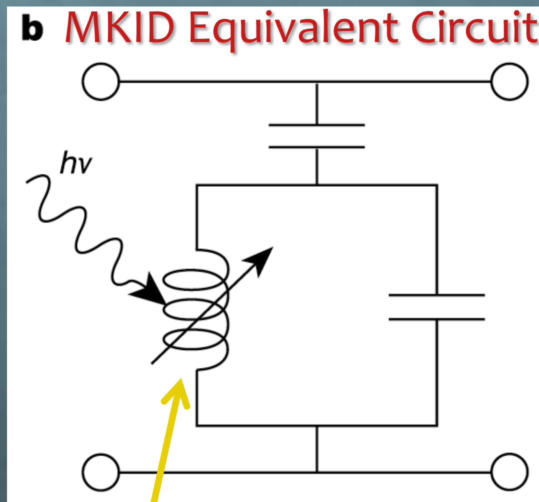
Applicable to Internal Coronagraphs and Occulters

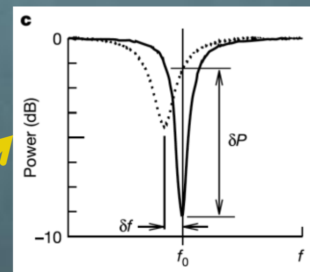
- Promise:
  - R ~ 50 photon counting with microsecond timing
  - 10-100 kpix arrays (larger possible) with pixels at any location
  - System throughput ~70% in optical and near-IR (0.1-3 μm)
  - No read noise or dark current
  - Nearly perfect cosmic ray rejection
- At A Price:
  - 100 mK operating temperature
    - On the ground, no problem – demonstrated.
    - In Space
      - TRL9 100 K cryocooler ~$7M
      - 100 mK cryocooler done by Japan (Astro-E2), ESA (Planck)
        - Costs would be tens of millions of dollars + Power + Weight

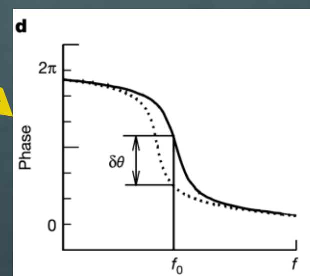
Why?

- On the ground, MKIDs are at TRL6
  - Pursuing funding for IFU for Palomar 200” (1640/VV) now
  - Could be on sky in 3 years
- In space things are much more complex, 2 scenarios:
  - Mission cannot succeed without it
    - Need to do studies to quantify improvement
      - Volunteers?
    - Throughput (2x), read noise (7 e- → 0), cosmic rays all add up
  - Enough time before mission for technology to mature
    - Unfortunately very possible for flagship-class planet finder
    - Requires technology investment by NASA
      - MKIDs funded through APRA, would eventually need SAT or similar
      - Cryocooler development, shared with X-ray/Far-IR/CMB

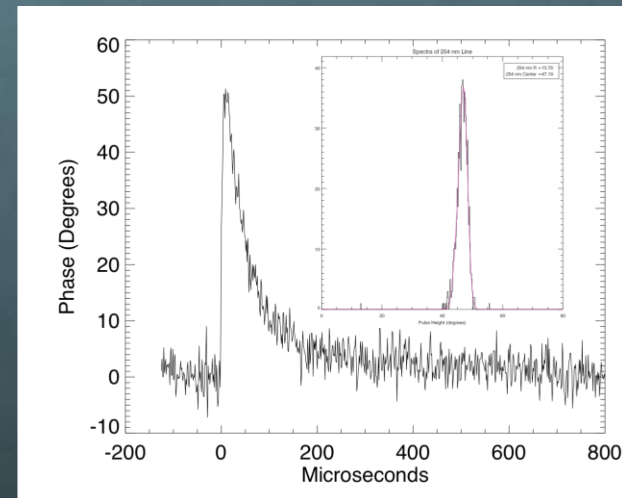
Microwave Kinetic Inductance Detectors



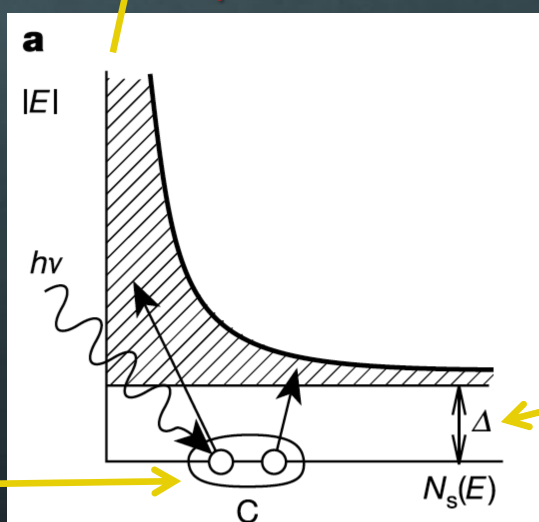




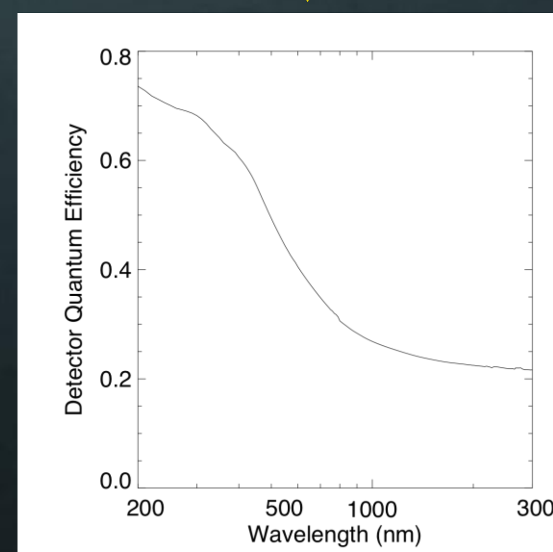
Typical Single Photon Event



Inductor is a Superconductor!



Cooper Pair



Mazin et al., Optics Express 2012

Energy Gap

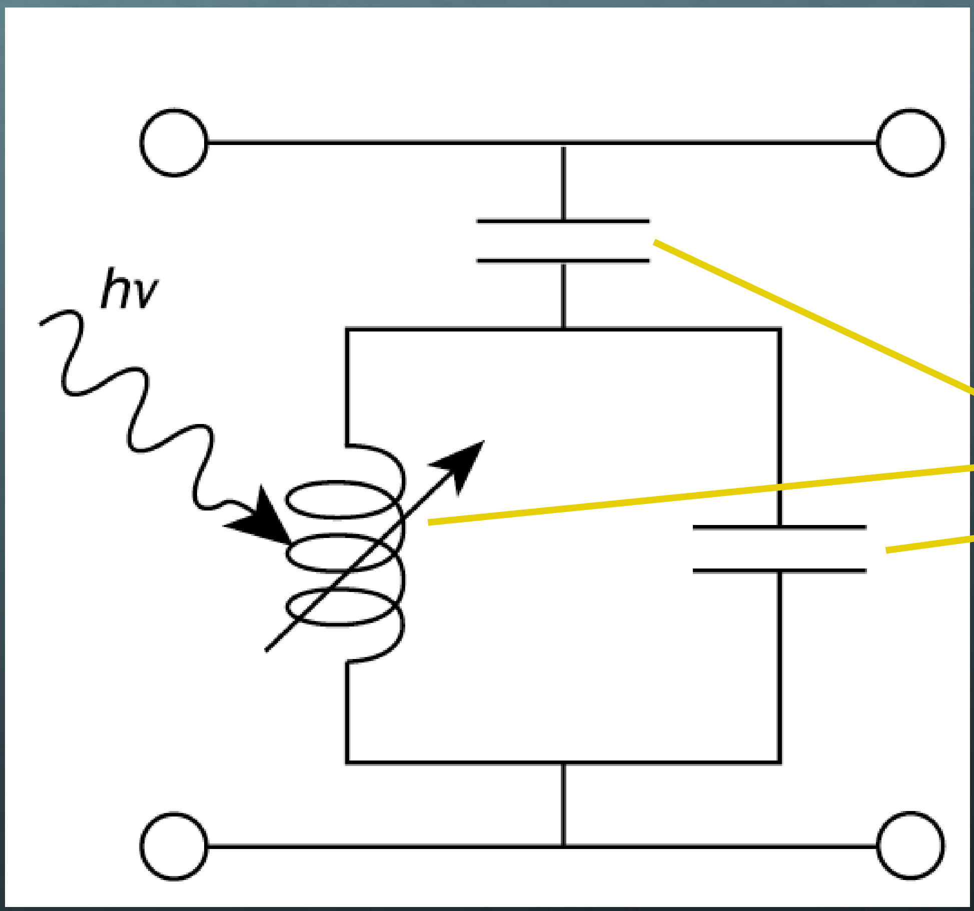
Silicon – 1.10000 eV

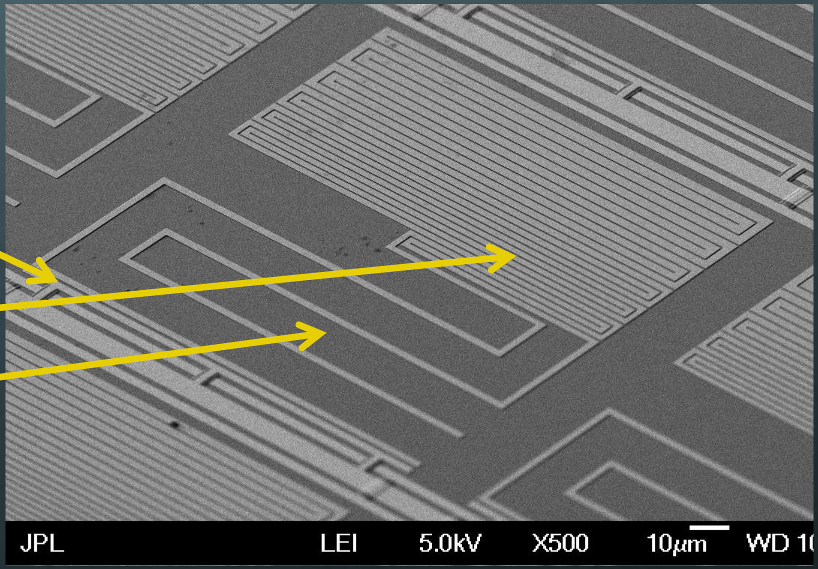
Aluminum – 0.00018 eV

Energy resolution:

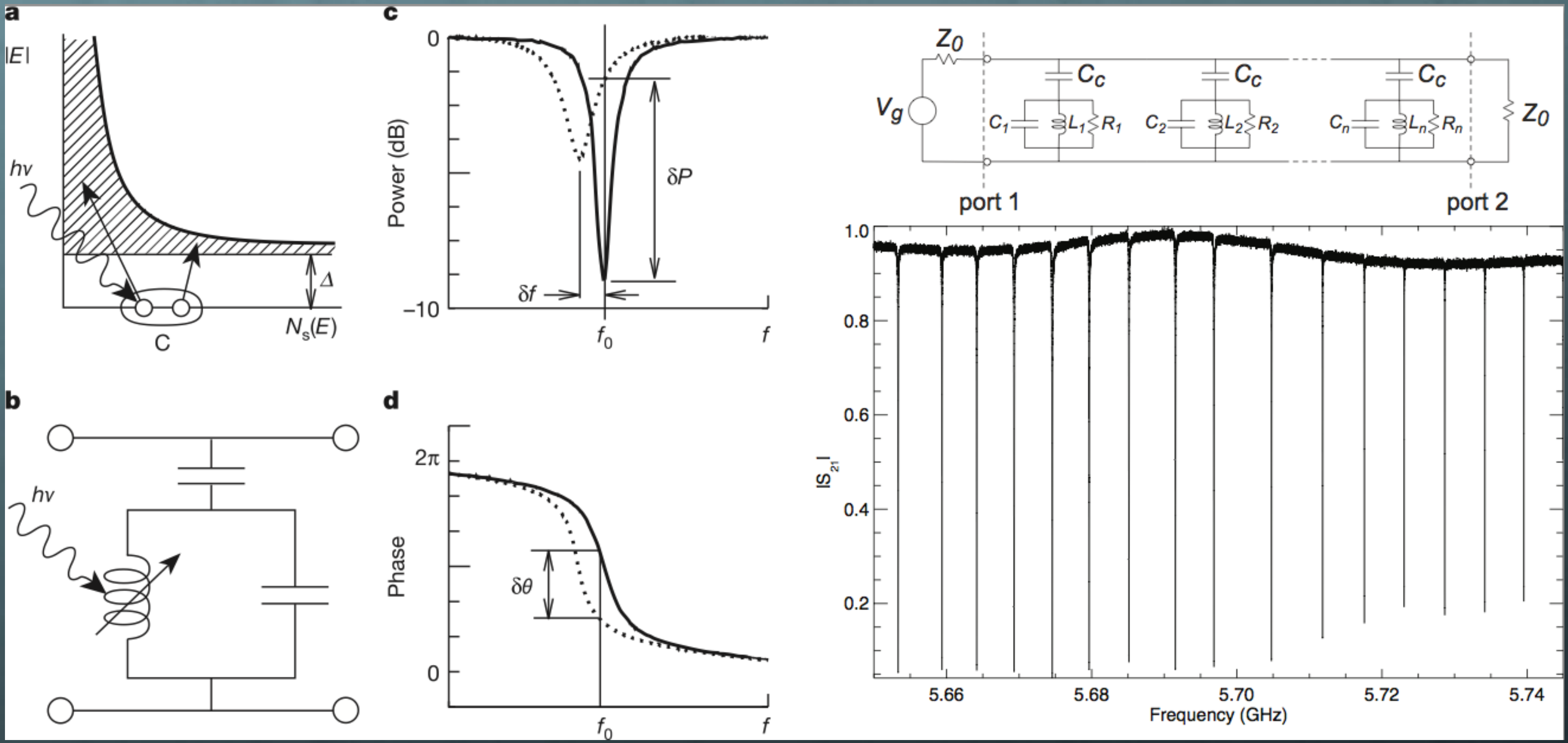
$$R = \frac{1}{2.355}\sqrt{\frac{\eta h\nu}{F\Delta}}$$

What is a Kinetic Inductance Detector ?



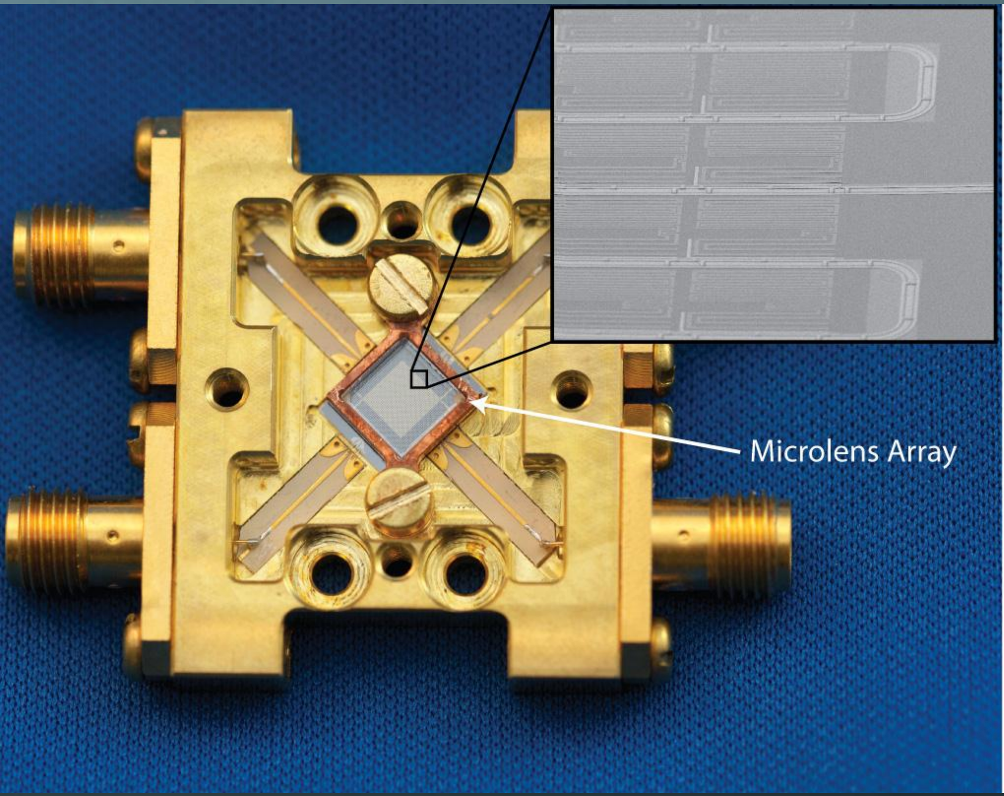


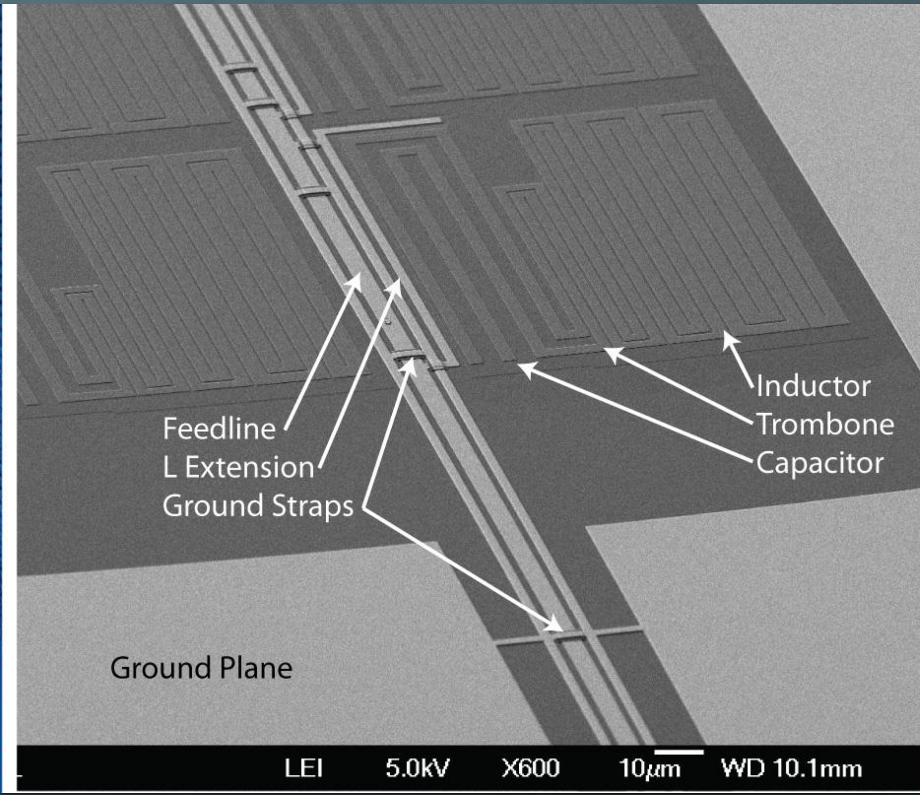
Frequency Domain Multiplexing



- Each resonator(pixel) has a unique resonant frequency in the GHz range
- A comb of sine waves is generated and sent through the device
- Thousands of resonators can be read out on a single microwave transmission line (FDM)

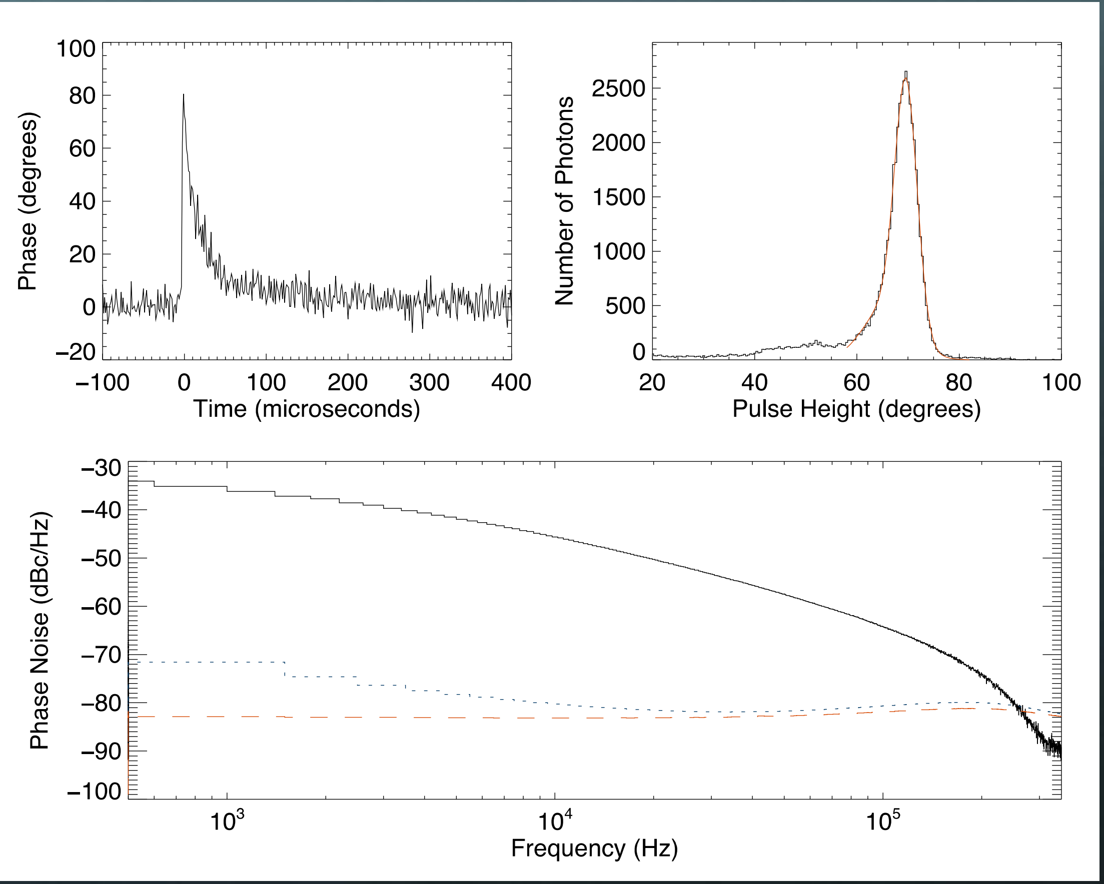
SCI2-B: Demonstrated at Palomar!



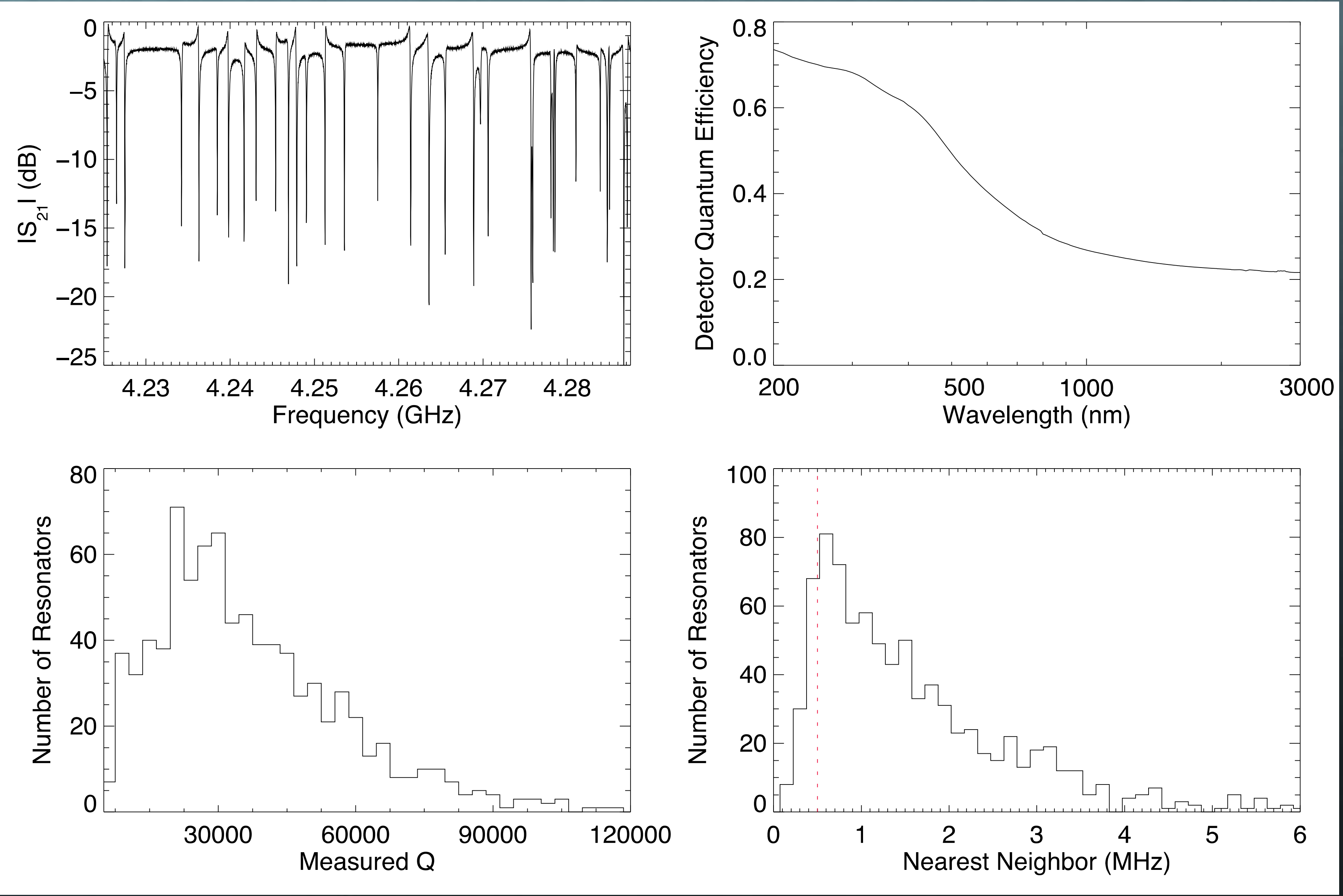


SCI2-B Energy Resolution

- 20 nm TiN on Silicon
- Tc = 0.8 K
- QP lifetime ~ 50 μs
- Q_i ~ 1,000,000
- R=E/ΔE=16 at 254 nm
  - R limited by HEMT/power handling/Q_i
  - R=150 theoretical max for 100 mK operating temp

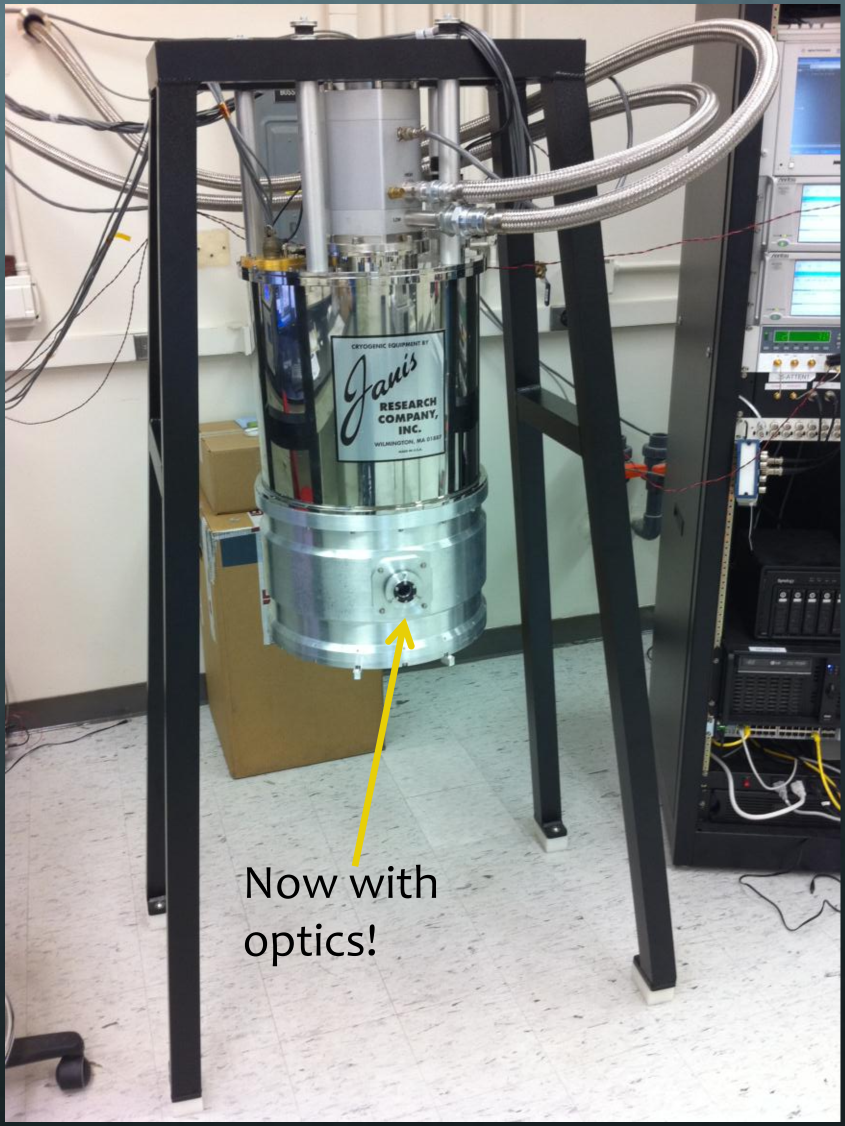


SCI-2B Uniformity

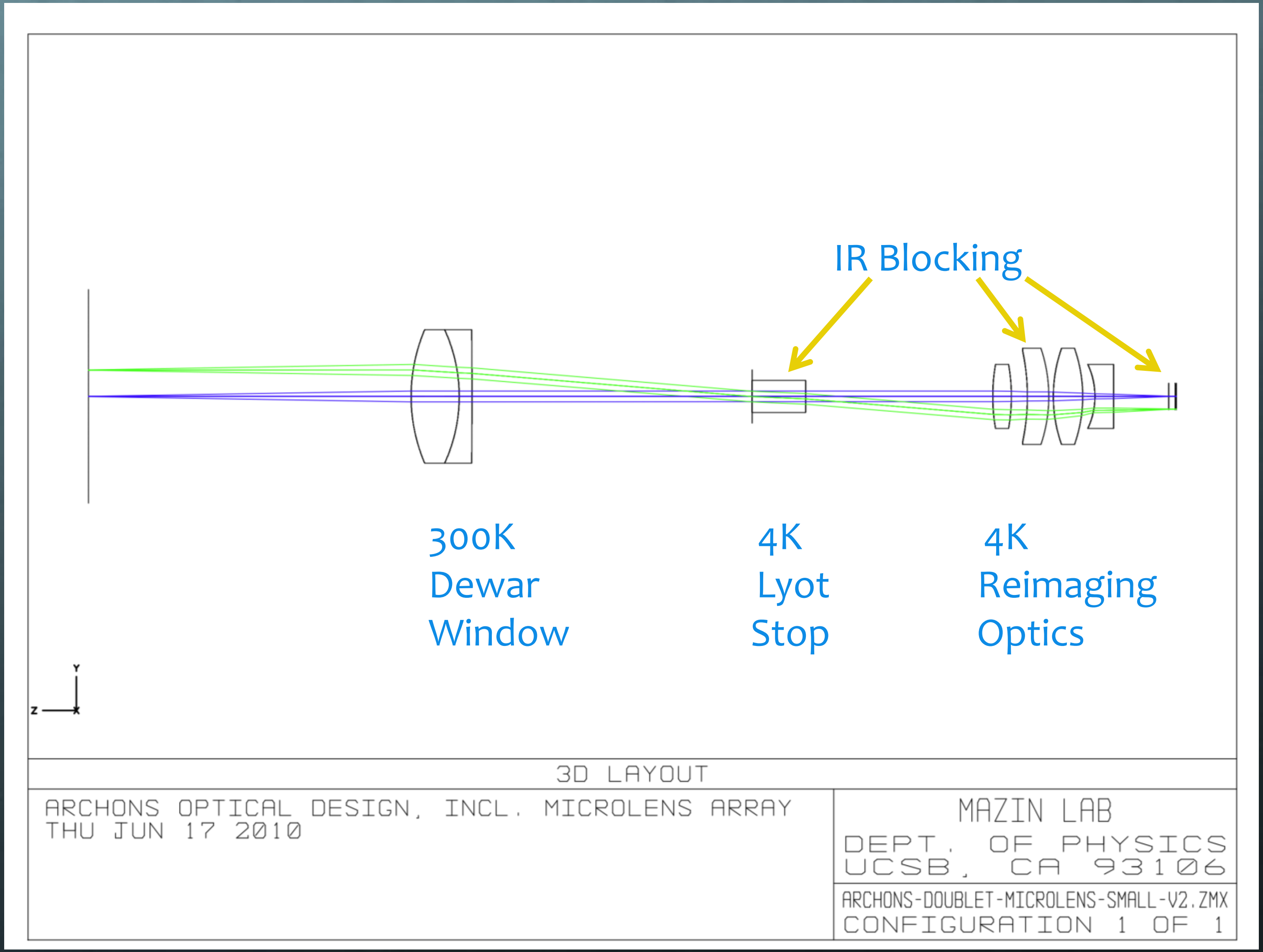


ARCONS Overview

- Array Camera for Optical to Near-IR Spectrophotometery (ARCONS)
- First Light: July 28, 2011, Palomar 200" Coudé
- Lens coupled 1024 (32x32) pixel array in cryogen-free ADR
- 0.2" pixels yields 7"x7" FOV
  - Next run, 45x45 pixels with 0.4" plate scale yields 18"x18" FOV
- 400 nm to 1100 nm simultaneous bandwidth with maximum count rate of ~2000 cts/pixel/sec
  - Next run, 350-1350 nm
- Energy resolution R~10-20 at 400 nm
- 50 Gbit/sec -> FPGA -> 32 Mbit/sec

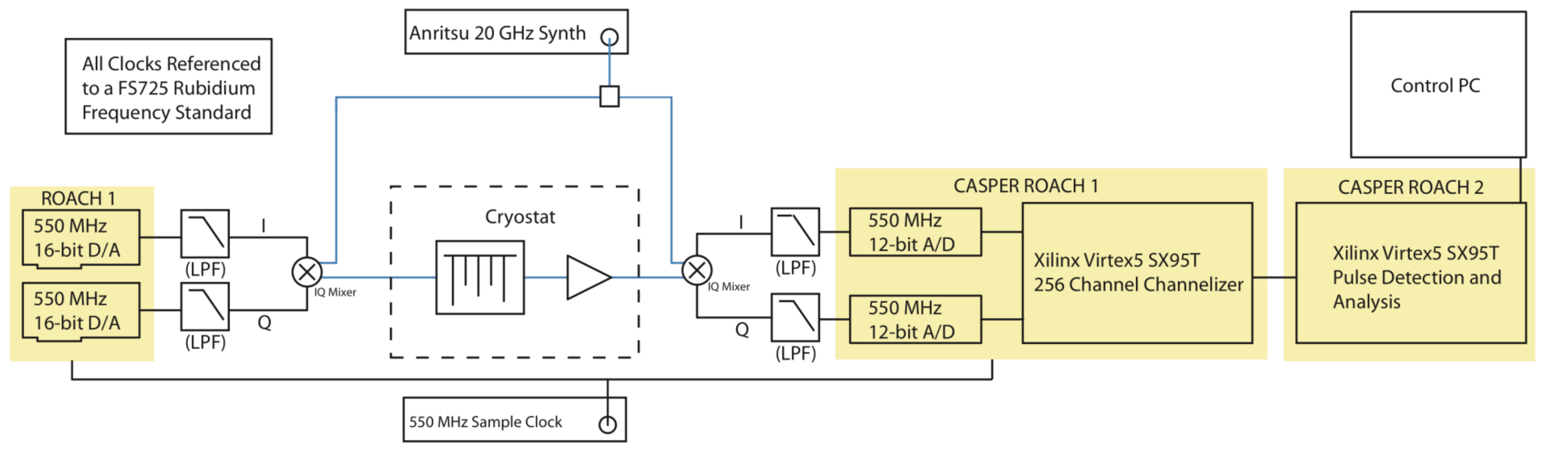


Optics

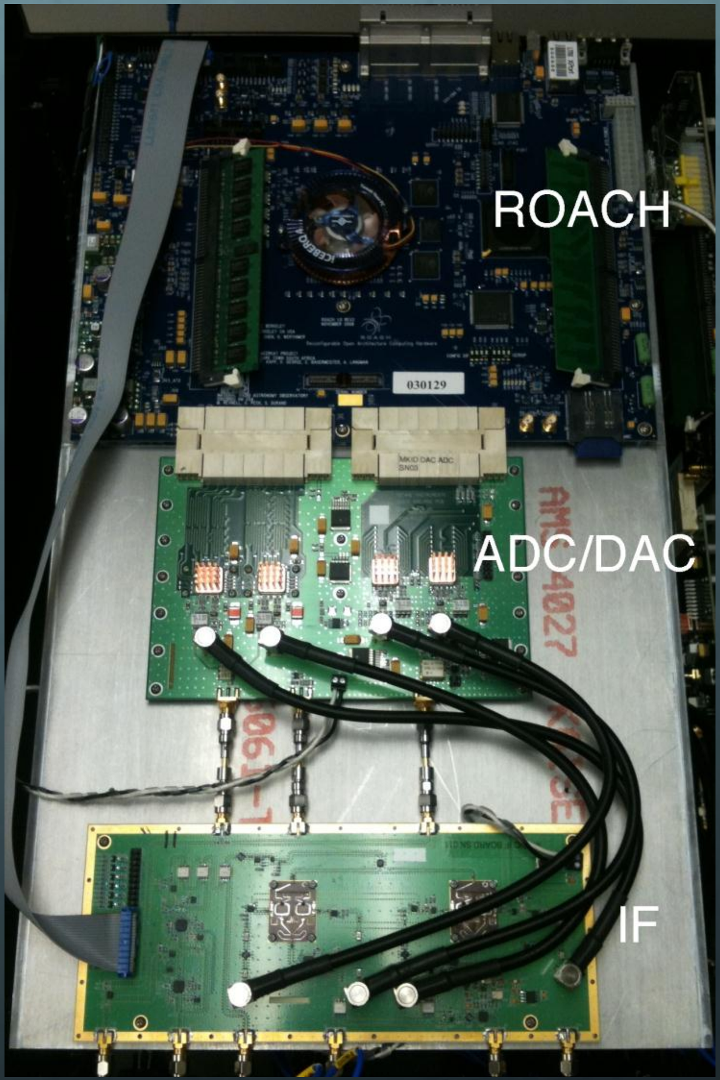

IR Blocking
300K
Dewar
Window
4K
Lyot
Stop
4K
Reimaging
Optics
Y
Z
3D LAYOUT
ARCHONS OPTICAL DESIGN, INCL. MICROLENS ARRAY
THU JUN 17 2010
MAZIN LAB
DEPT. OF PHYSICS
UCSB, CA 93106
ARCHONS-DOUBLET-MICROLENS-SMALL-V2.ZMX
CONFIGURATION 1 OF 1

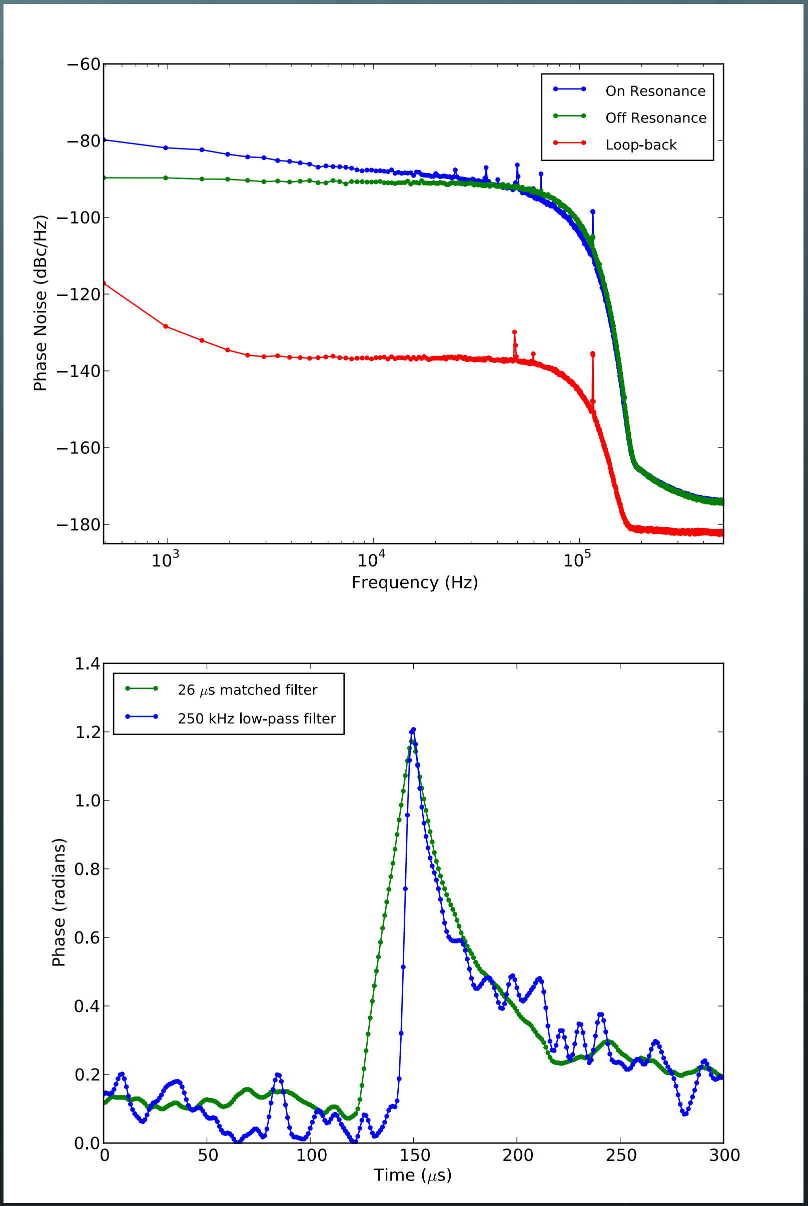
Digital MKID Readout

- Software Defined Radio (SDR) Overview
  - Leverages massive industry investment in ADCs/FPGAs
  - 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)



SDR Readout

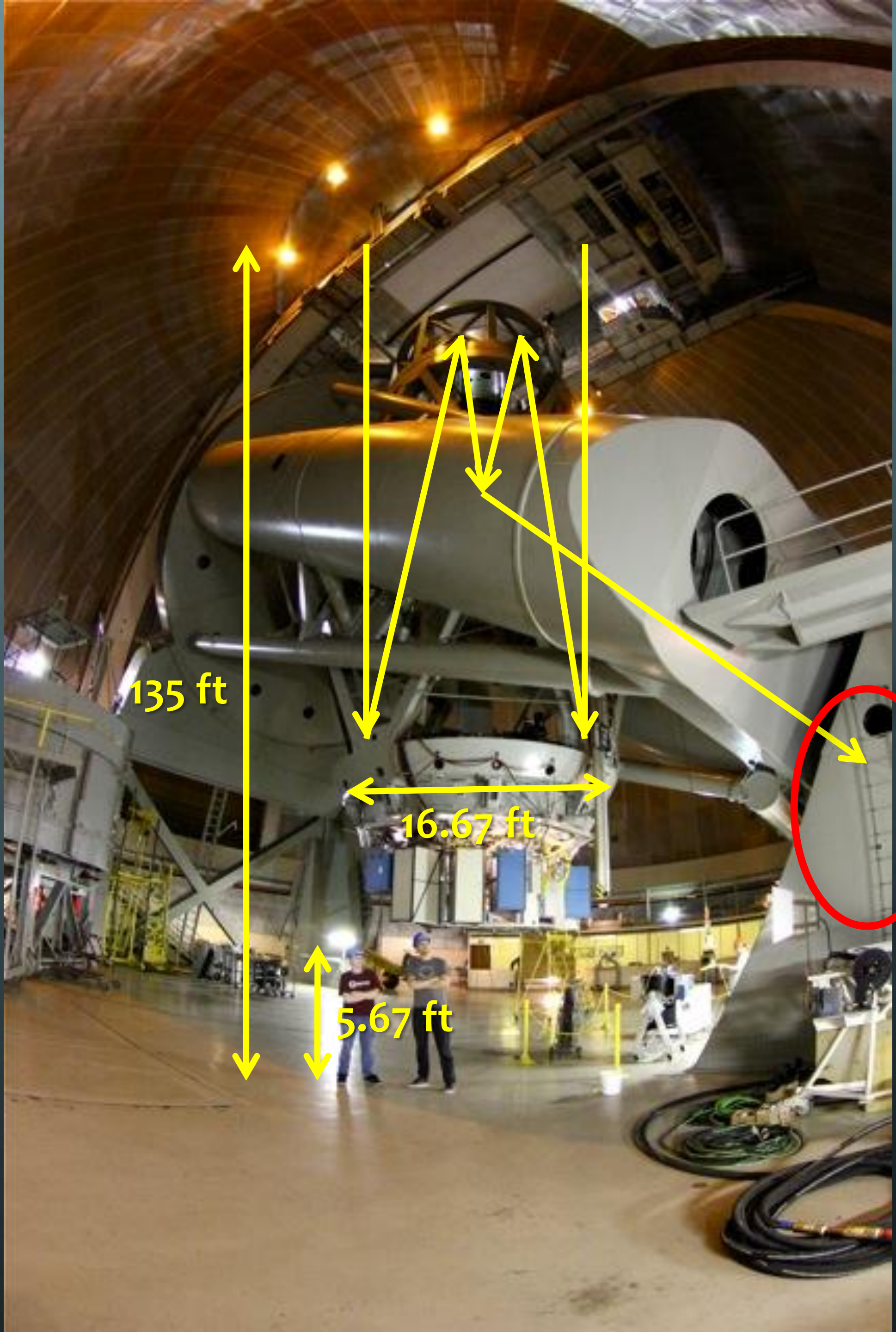




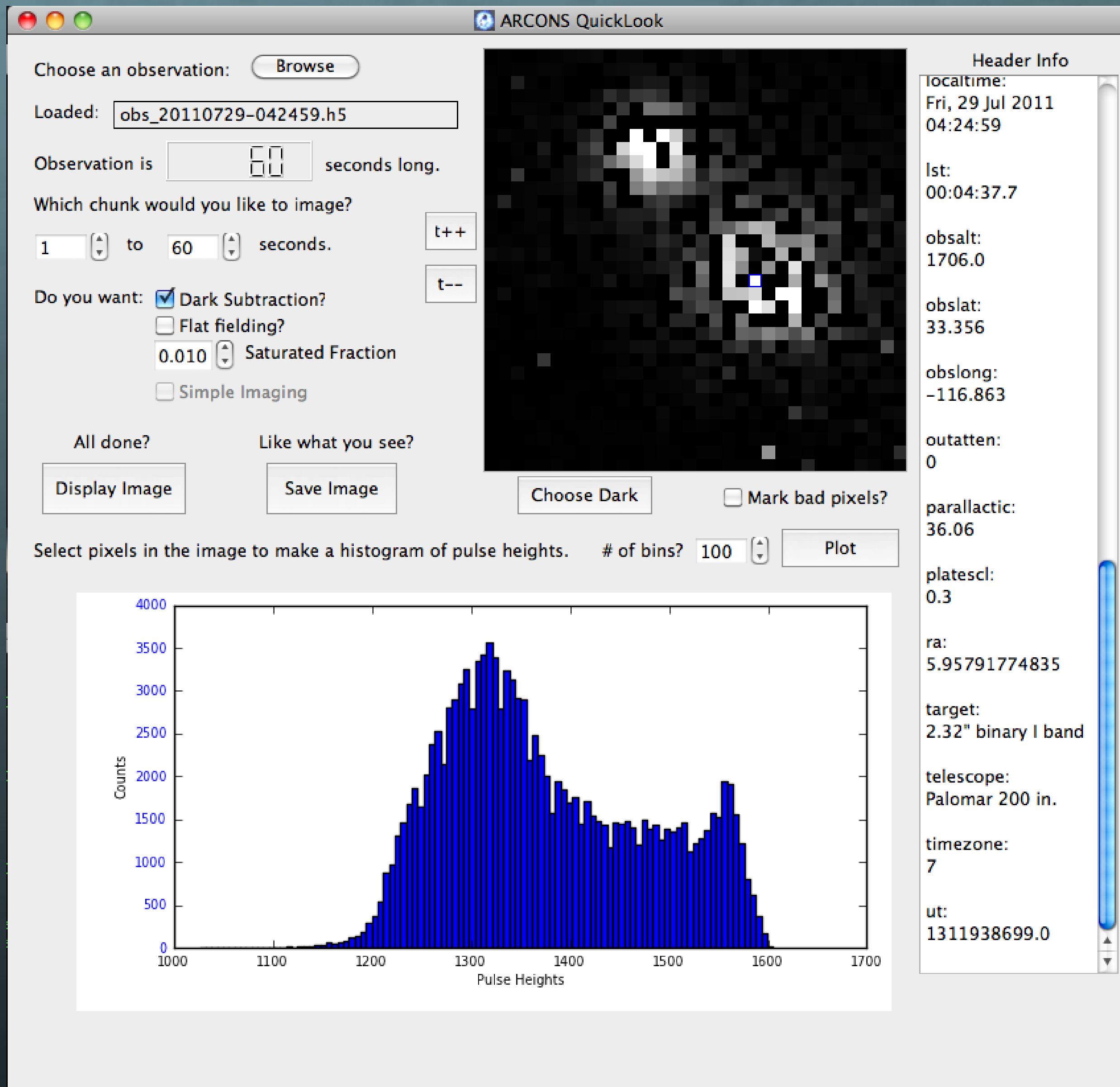
ROACH Based readout cost ~$20/pixel
Readout up to ~10 kpix feasible now

Readout Crate

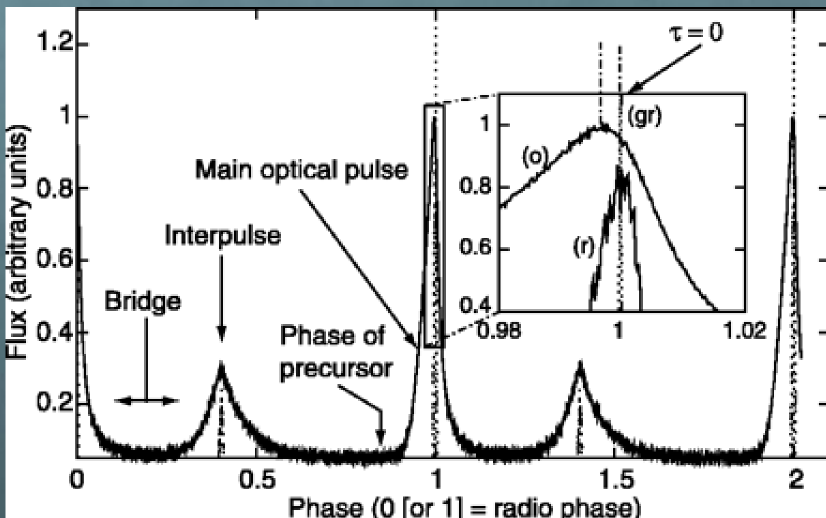
To Palomar!


135 ft
16.67 ft
5.67 ft
ARCONS

ARCONS First Light Image

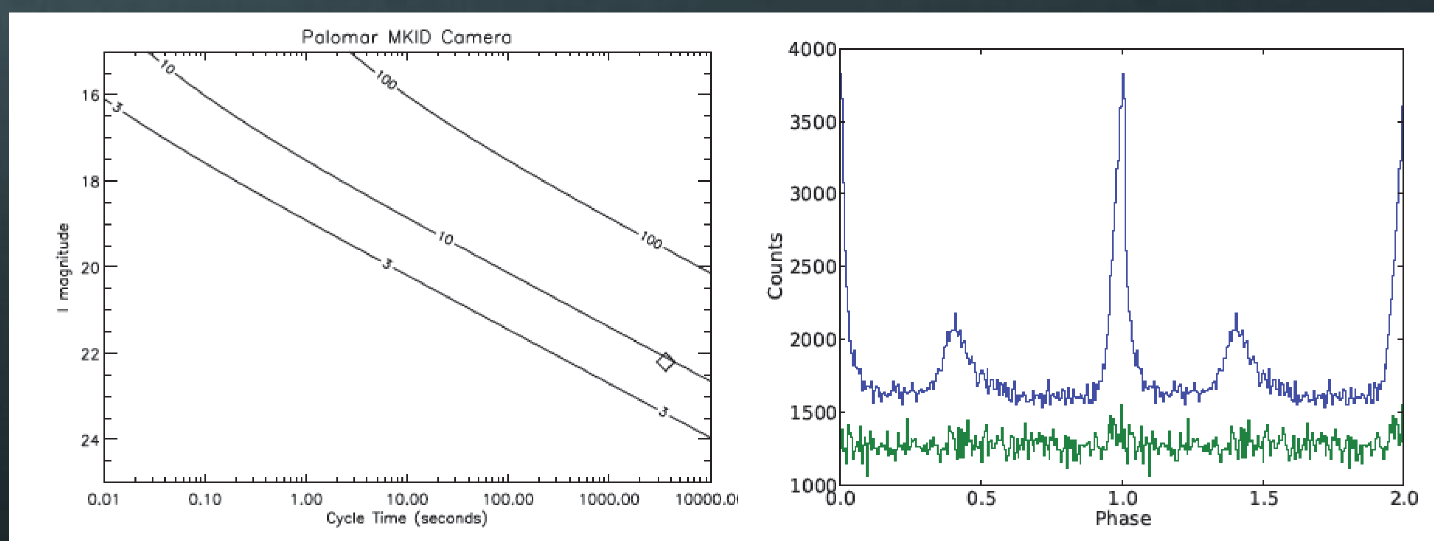


Crab Pulsar



Archival pulse profile for Crab (Shearer 2003)

Pulse profile measured with ARCONS



Strategy

- Quantify advantages of realistic MKID IFU for TPF-C and Occulters
- Demonstrate coronagraphic direct detection with MKIDs on the ground in 2-4 years
- Keep an eye towards SAT and UV/X-ray sounding rockets to drive TRL
- Very tight budgets = Plenty of time to mature the technology!