Optical Lumped Element MKIDs

Ben Mazin, August 2011

The Optical/UV MKID Team:

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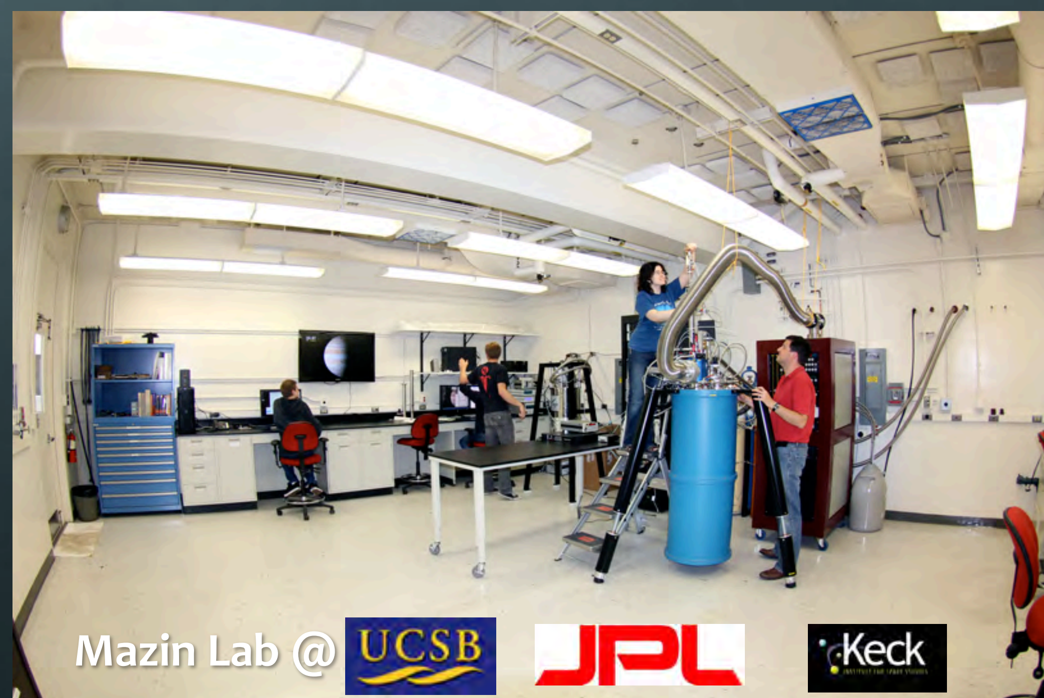
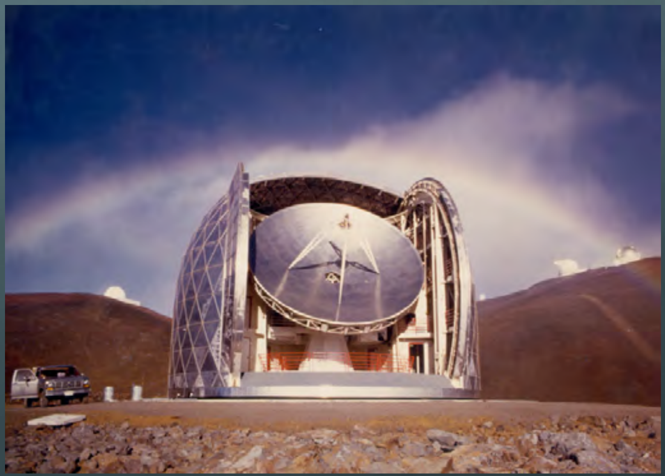
JPL: Bruce Bumble, Rick LeDuc



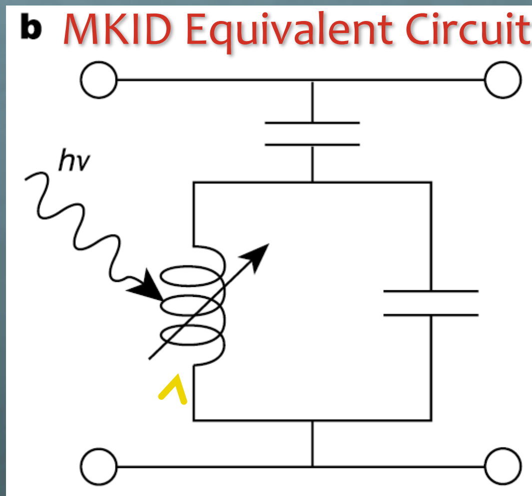
We can’t let the submm guys have all the fun!

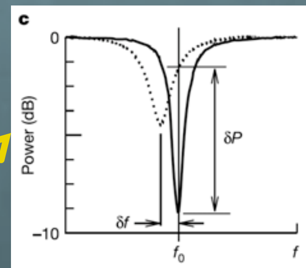
- The “submillimeter” approach to Astronomy:
  - Build your own detectors
  - Don’t be afraid of low temperatures
  - Put them in an instrument
  - Do science

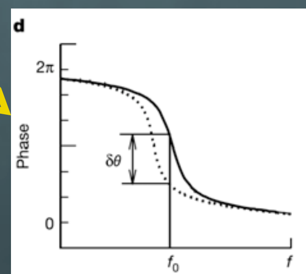


- Can this approach be productive in the UV/optical/near-IR where excellent commercially available detectors exist?
  - Yes! Semiconductor detectors are powerful, but:
    - Usually poor time resolution
    - No intrinsic energy resolution
    - Read Noise, Dark Current, Cosmic Rays

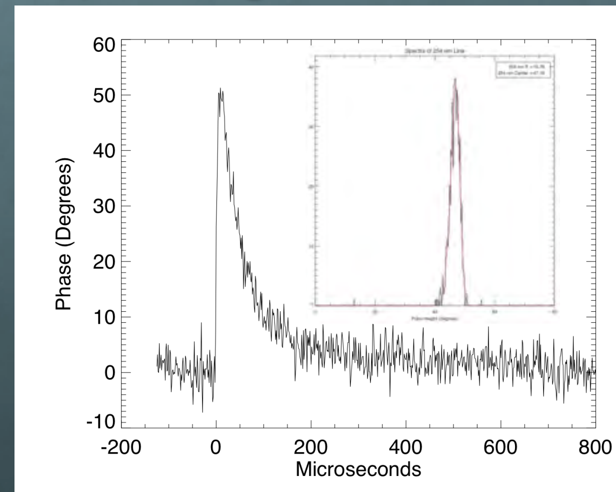
Microwave Kinetic Inductance Detectors



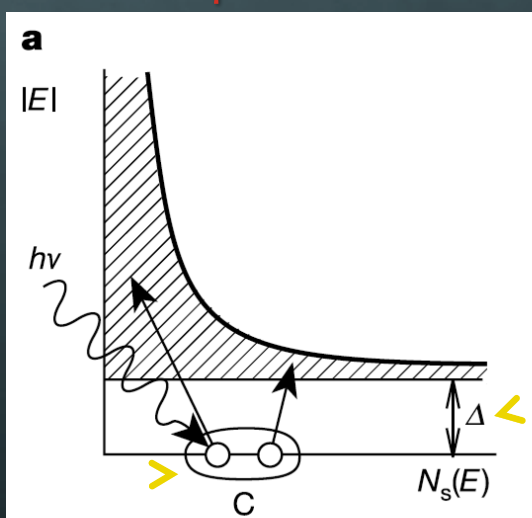




Typical Single Photon Event



Inductor is a Superconductor!



Cooper Pair

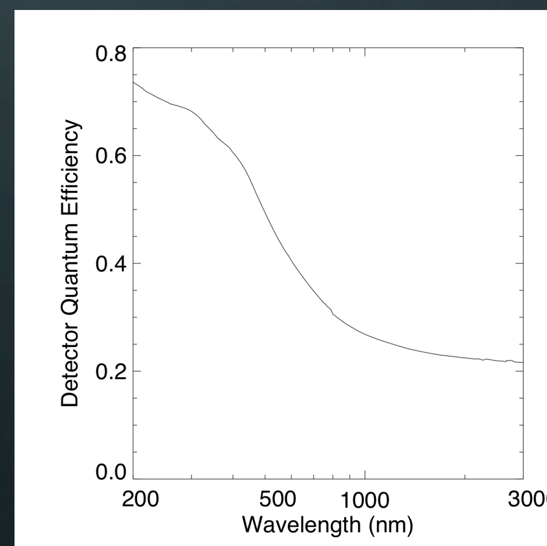
Energy Gap

Silicon – 1.10000 eV

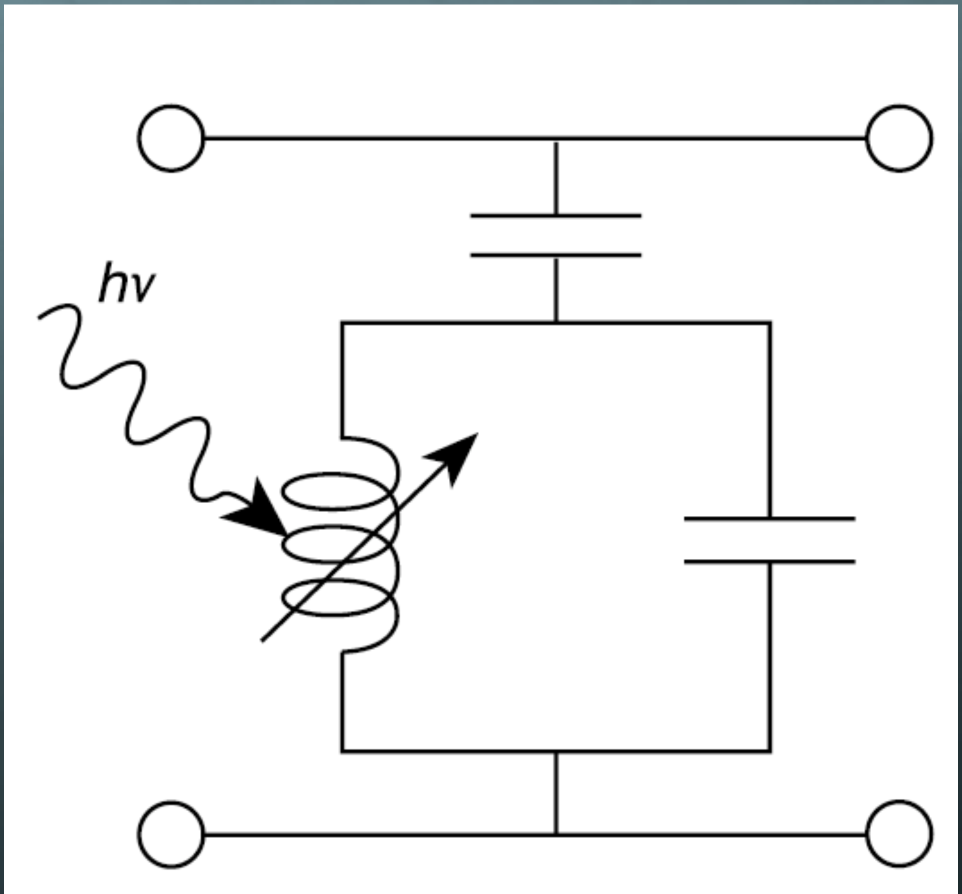
Aluminum – 0.00018 eV

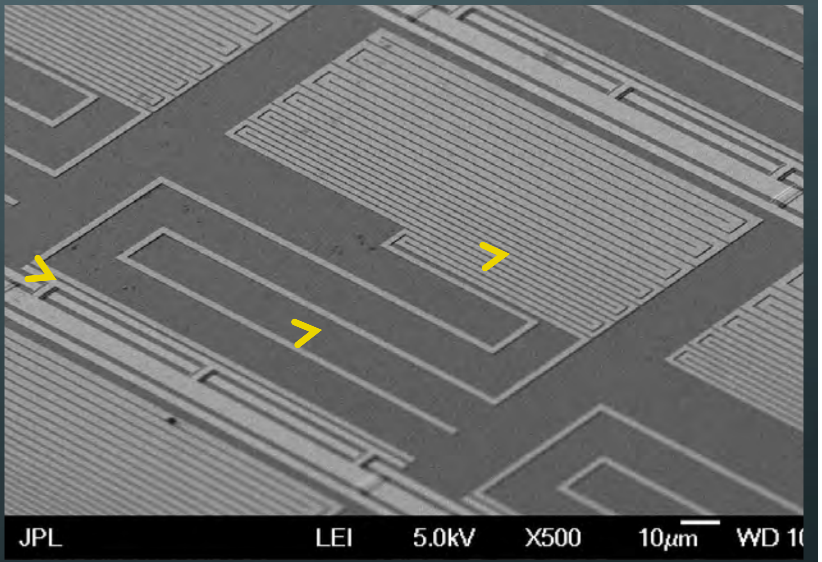
Energy resolution:

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



What is a Kinetic Inductance Detector ?

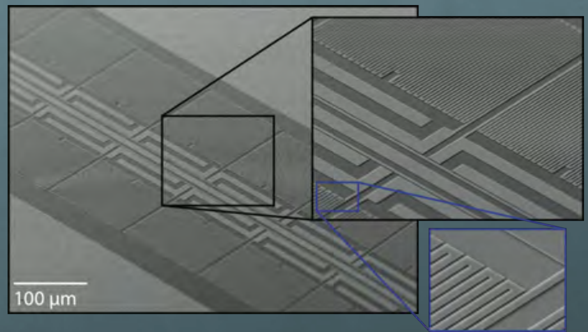




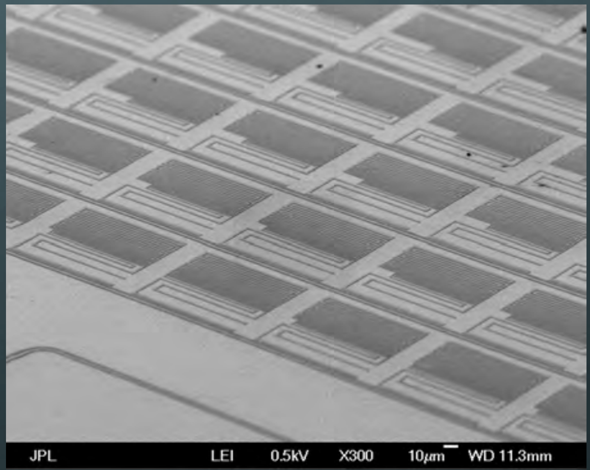
Optical Lumped Element (OLE) Timeline

- Summer 2009 - First TiN Measurements at JPL
- 9/17/09 – OLE1, first TiN lumped element for UV/opt/NIR
  - Functional!
  - good energy resolution, bad feedline reflections and crosstalk
- 1/4/10 – OLE2
  - CPS Feedline, lower reflections
- 4/23/10 – OLE4
  - New meandering eliminates crosstalk
- 8/06/10 – OLE5
  - Strapped FCPW feedline gives more uniform coupling Q and f_0
- 10/27/10 – OLE6
  - High Q_i in a multilayer device!
- 1/18/11– SCI1
  - First 32x32 array
- 5/13/11 – SCI2
  - Revised 32x32 arrays

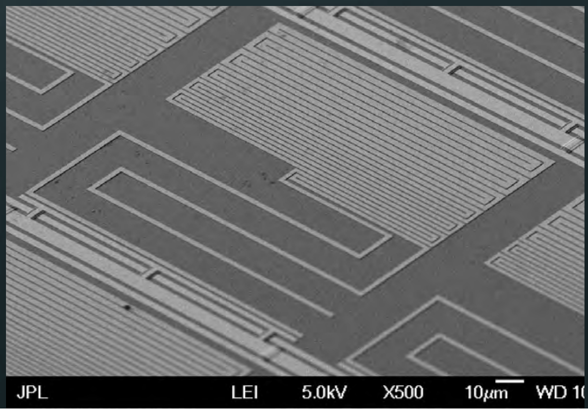
OLE1



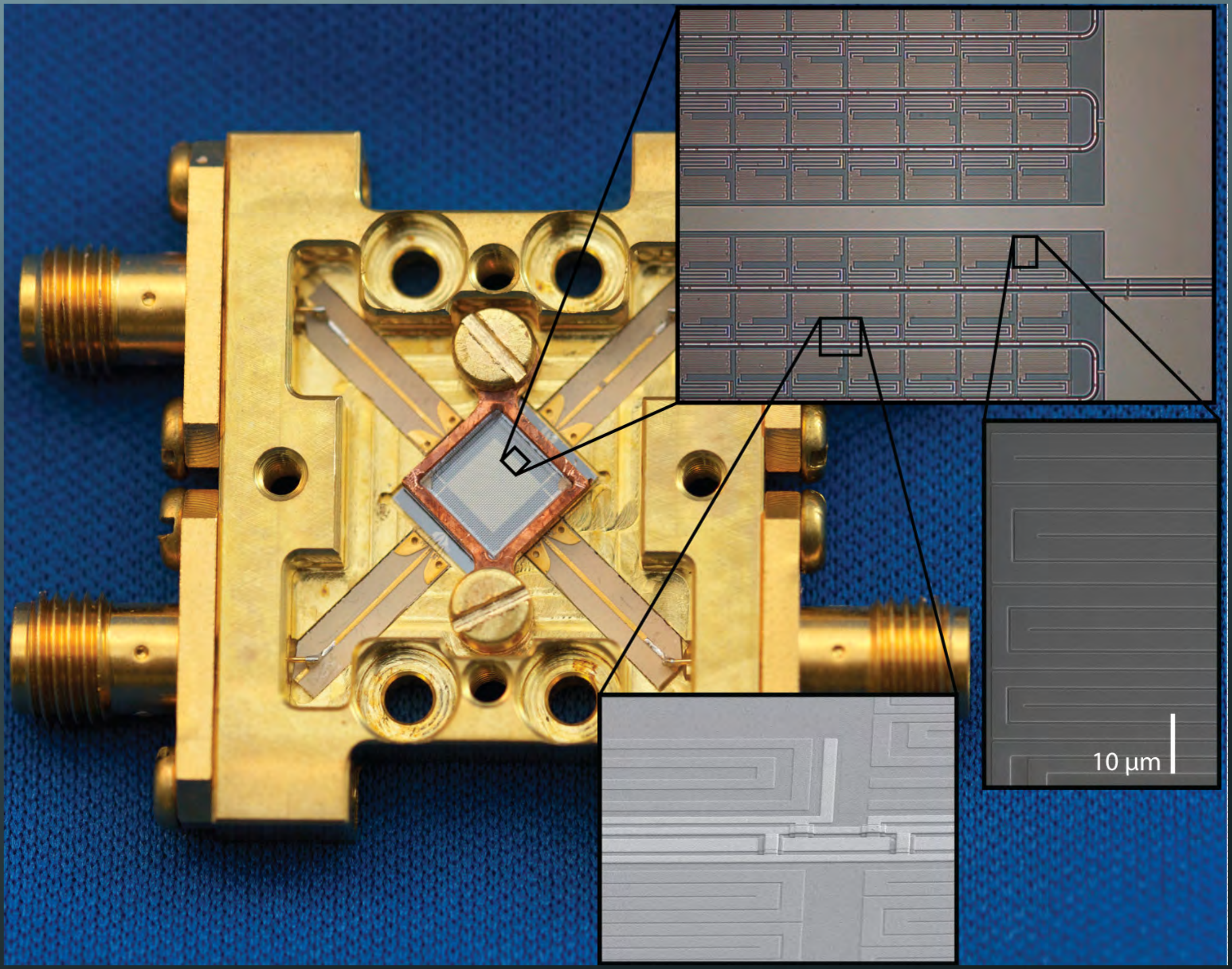
OLE4



OLE5

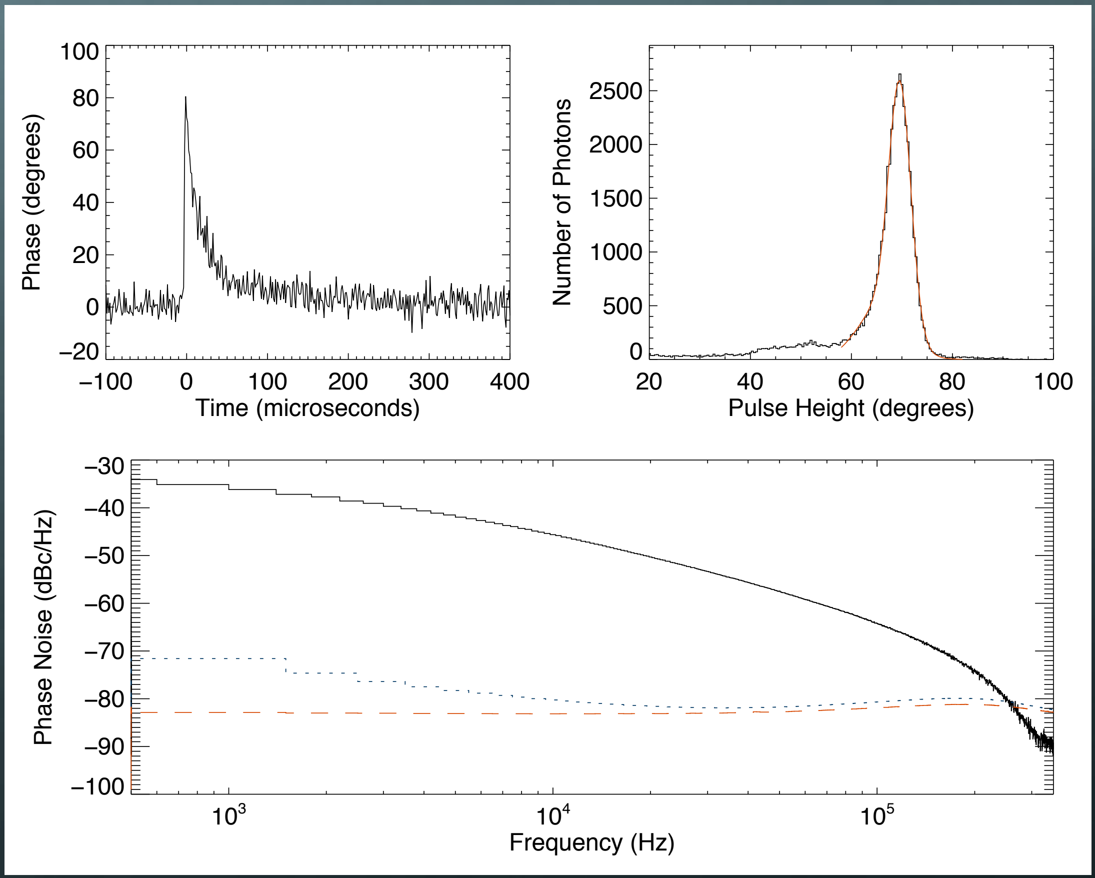


SCI2-B: Demonstrated at Palomar!

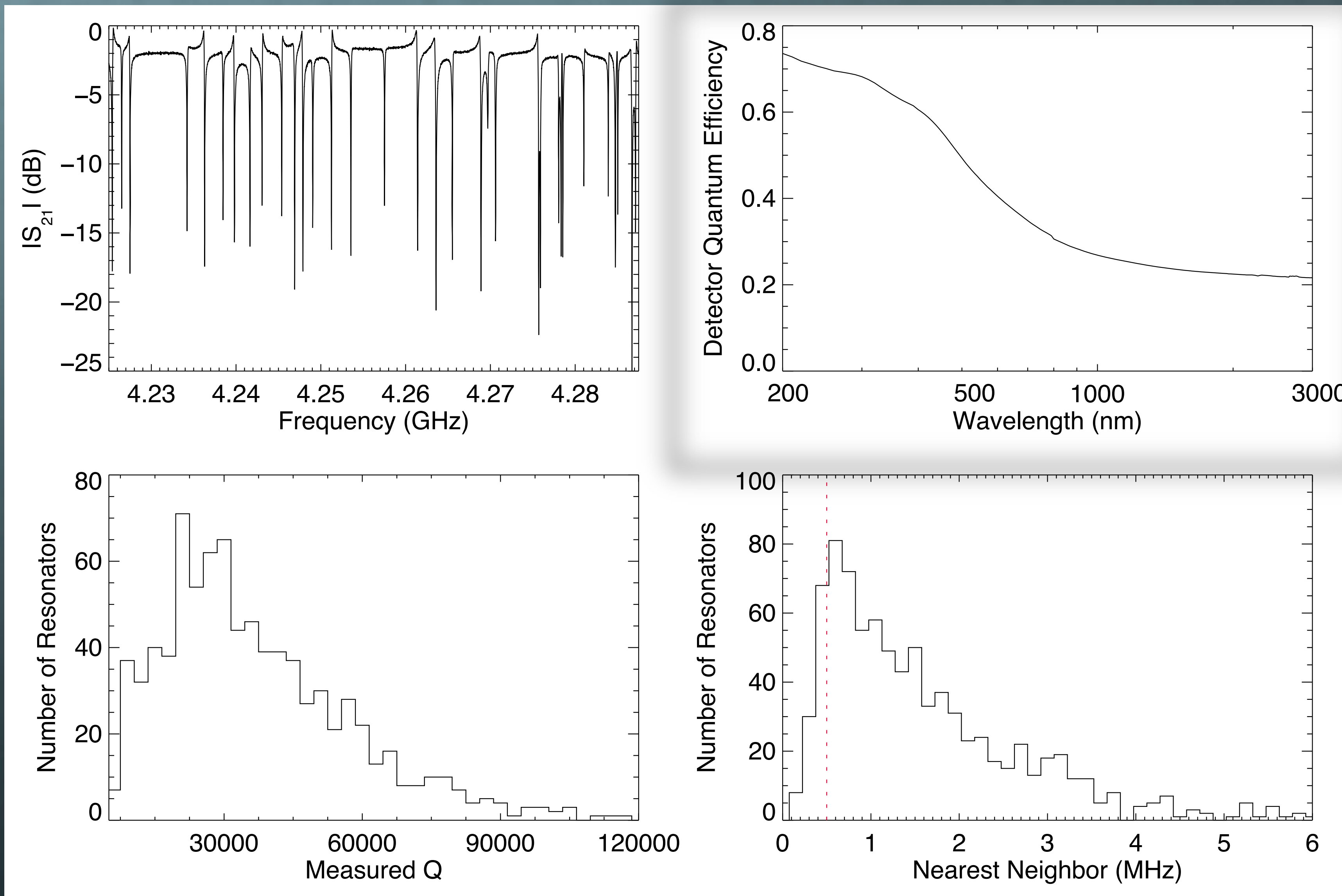


SCI2-B Energy Resolution

- **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**

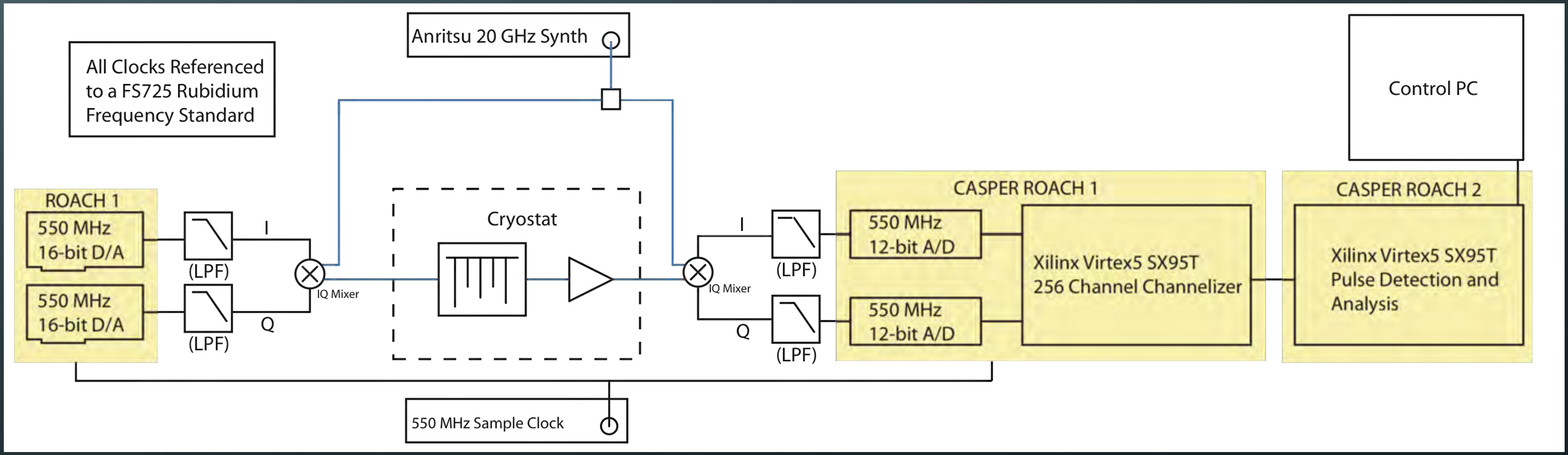


SCI-2B Uniformity



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)**

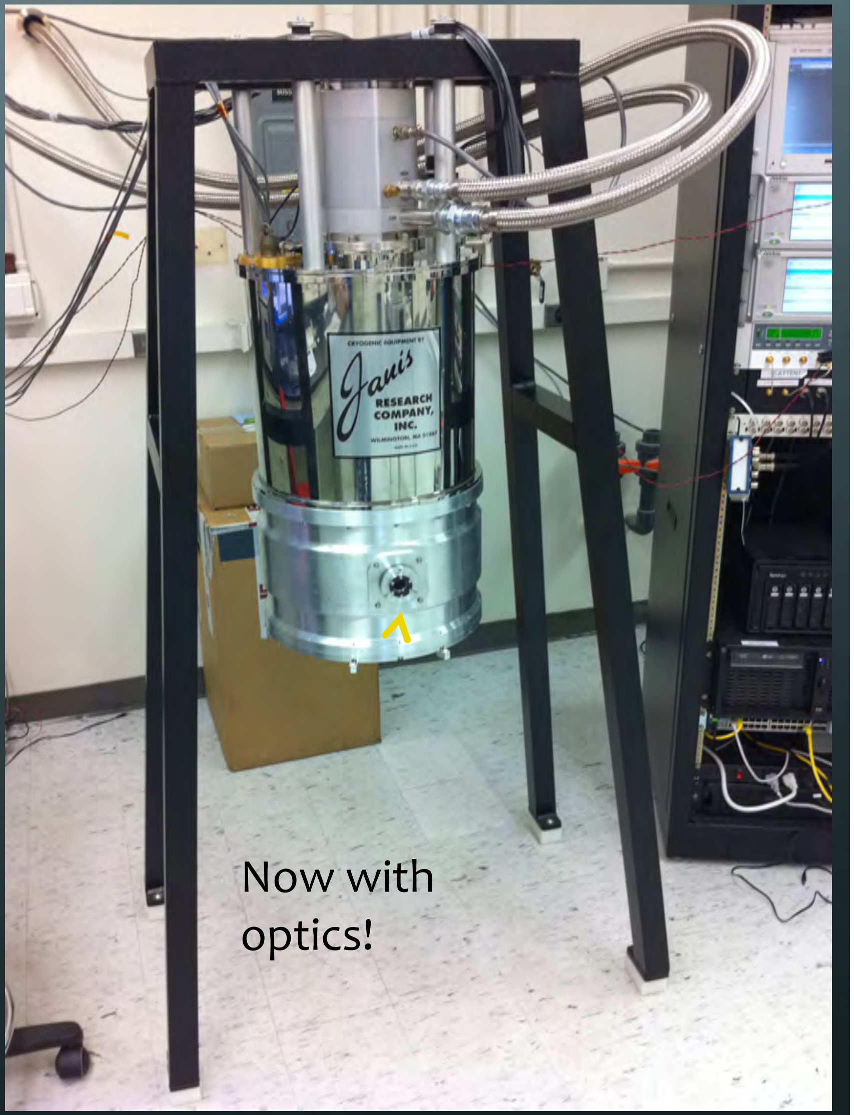


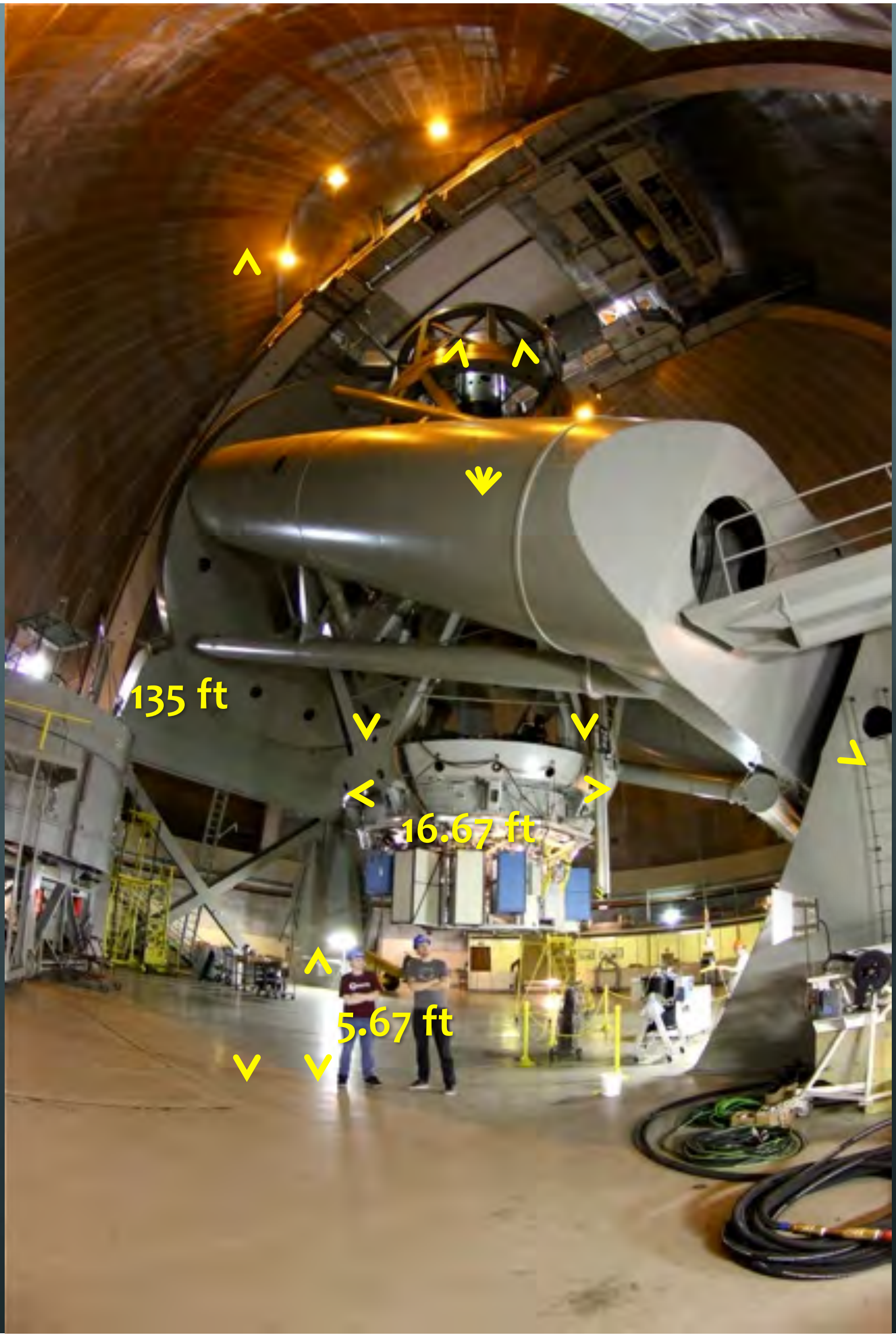
Resonator Readout Consortium

- **Formed a consortium of 7 institutions to develop resonator readout hardware based on the Berkeley CASPER boards**
  - **Dual 1 GSPS 14-bit D/A, 550 MHz 12-bit A/D**
  - **Xilinx Virtex 5 (SX95T) FPGA**
  - **Complete 256 resonator readout in a compact package**
  - **Functional, demonstrated at CSO last April**
  - **UCSB, UCB, Caltech, NIST, Goddard, UK ATC, IRAM**

ARCONS Overview

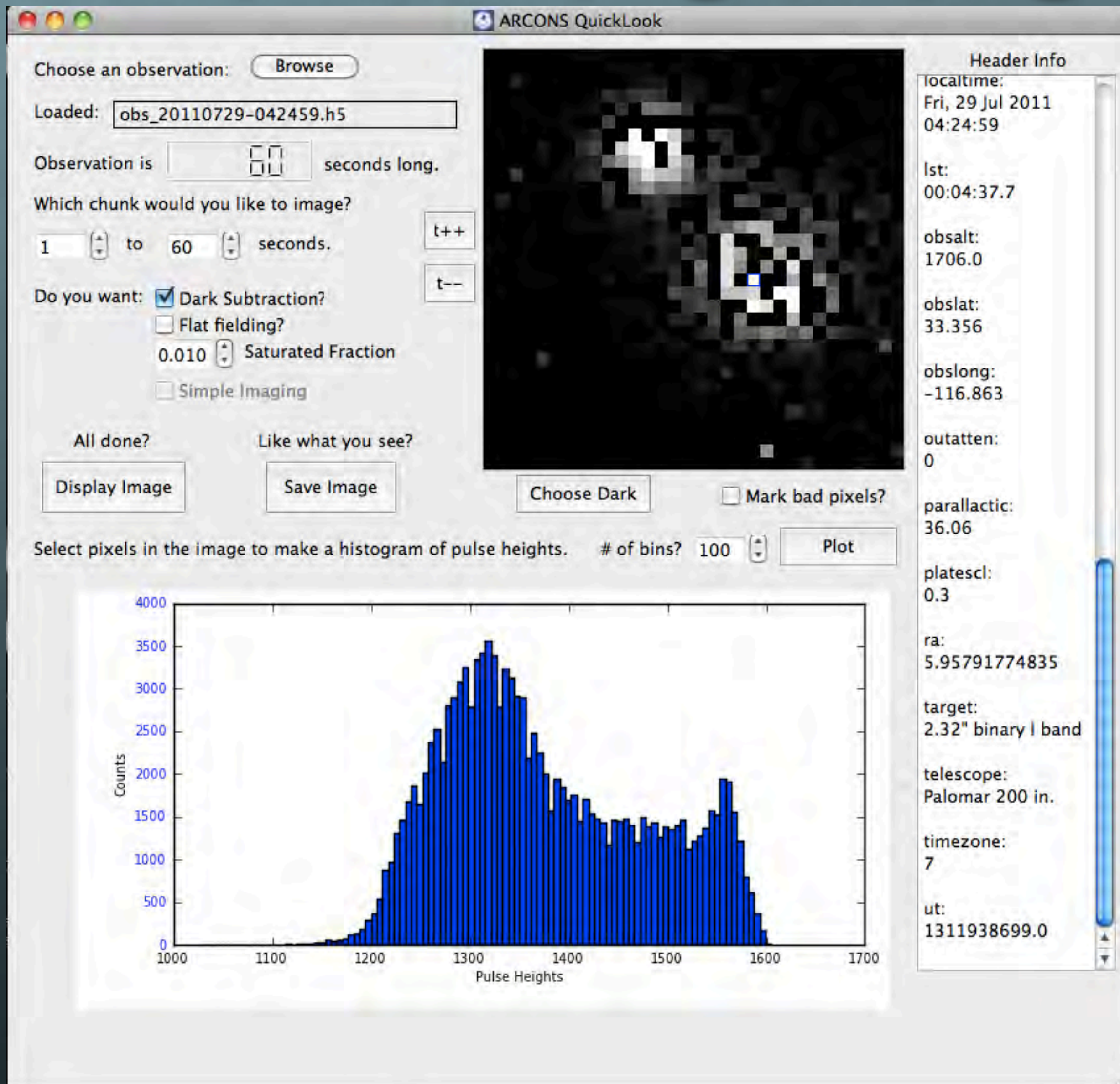
- Array Camera for Optical to Near-IR Spectrophotometery (ARCONS)
- First Light: July 28, 2011, Palomar 200” Coudé
- Lens coupled 1024 (32x32) pixel array in cryogen-free ADR
- 0.2” pixels yields 7”x7” FOV
  - Next run, 45x45 pixels with 0.4” plate scale yields 18”x18” FOV
- 400 nm to 1100 nm simultaneous 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



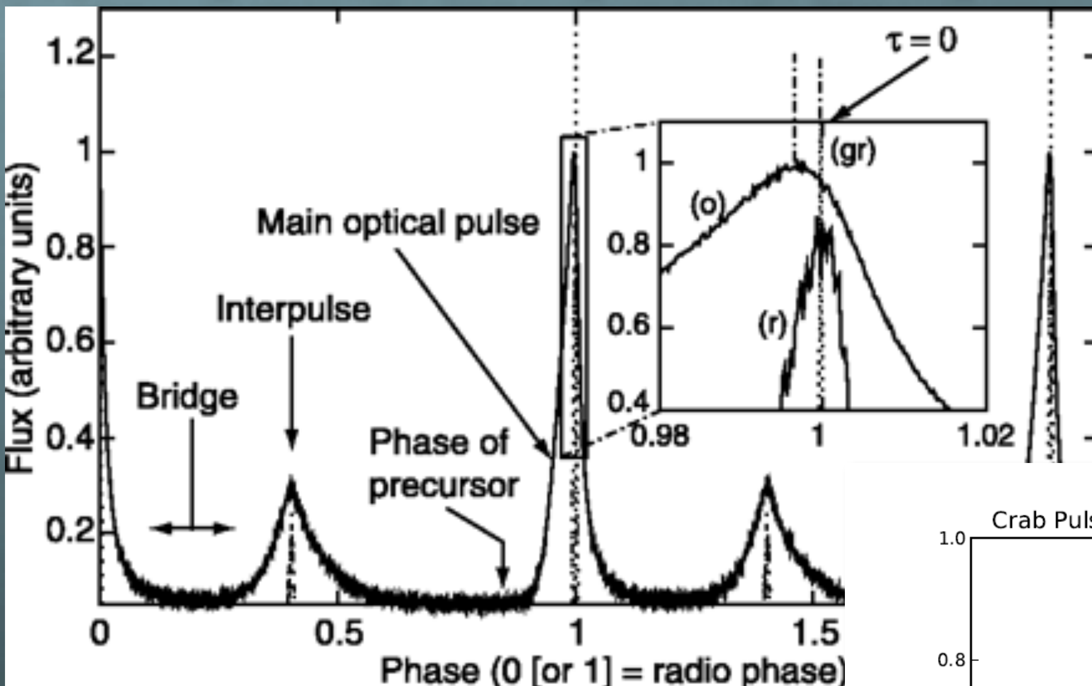


ARCONS

ARCONS First Light Image



Crab Pulsar



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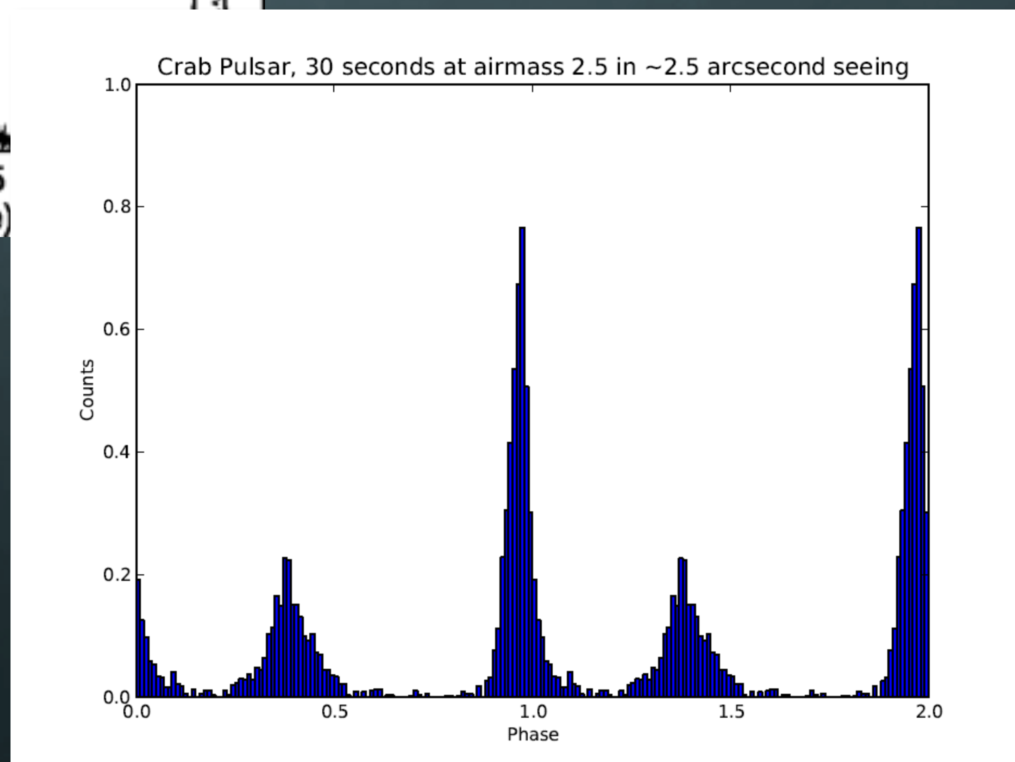
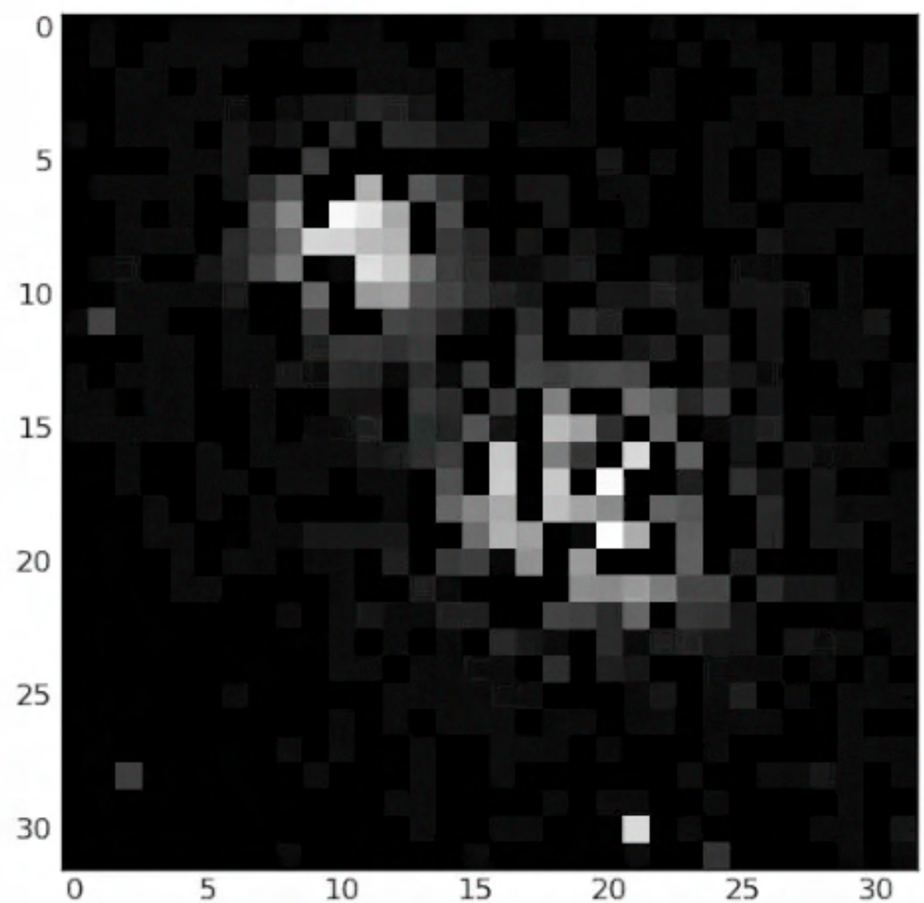
Archival pulse profile for Crab (Shearer 2003)

Pulse profile measured with ARCONS

v



Dancing with the Stars



UV Specific Challenges

- Temperature
  - Far-IR/Submm/X-ray already have flown appropriate cryocoolers (continuous ADR, dilution)
  - $$$
- Contamination
  - Not much worse than a CCD at 100 K? (+N_2, O_2 ice)
  - Mechanical coolers allow unlimited duration (periodic warmups?)
- Thermal IR Blocking
  - This could be hard in the far-UV
- Extremely broad band mirror/AR coatings

Possible UV MKID Instruments

- Emphasize the broad wavelength coverage
- Large (256x256), low resolution (R=100), high QE IFU
  - 0.1 – 3.0 microns simultaneous
  - Behind a coronagraph for planet finding!
    - Spectral and temporal resolution both increase speckle rejection
- High resolution 2 bounce Long Slit Echelle
  - MKID as order sorting detector
- Multi-object spectrograph with microshutter array
  - 0.1 – 3.0 microns, R=100
  - ~100,000 objects at once