# MICROWAVE KINETIC INDUCTANCE DETECTORS

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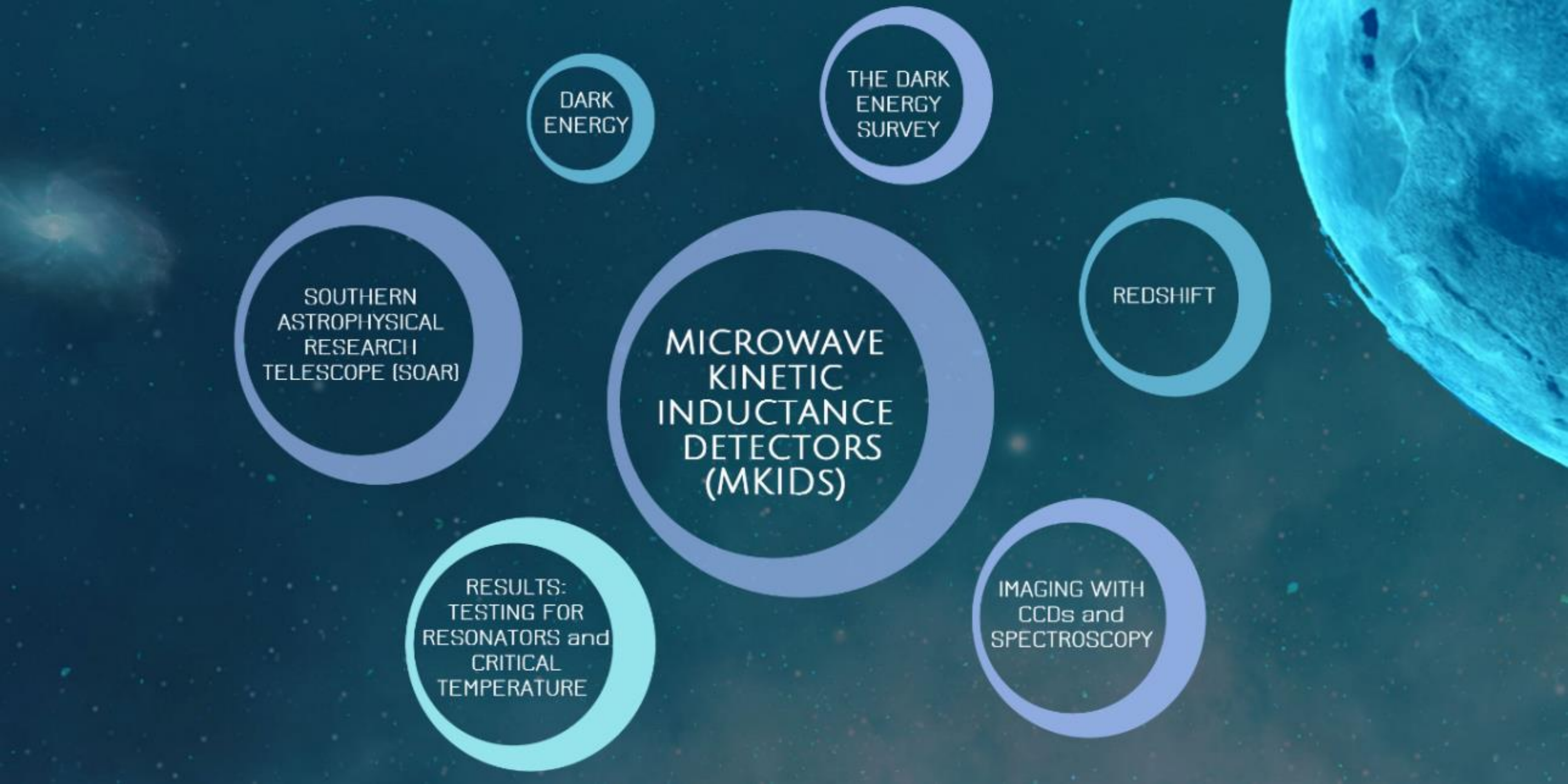
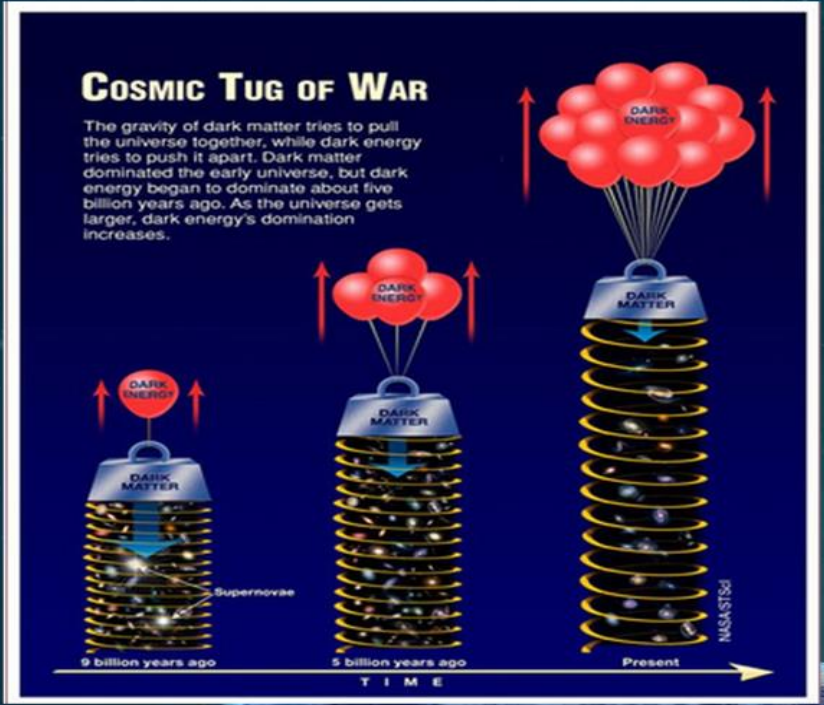
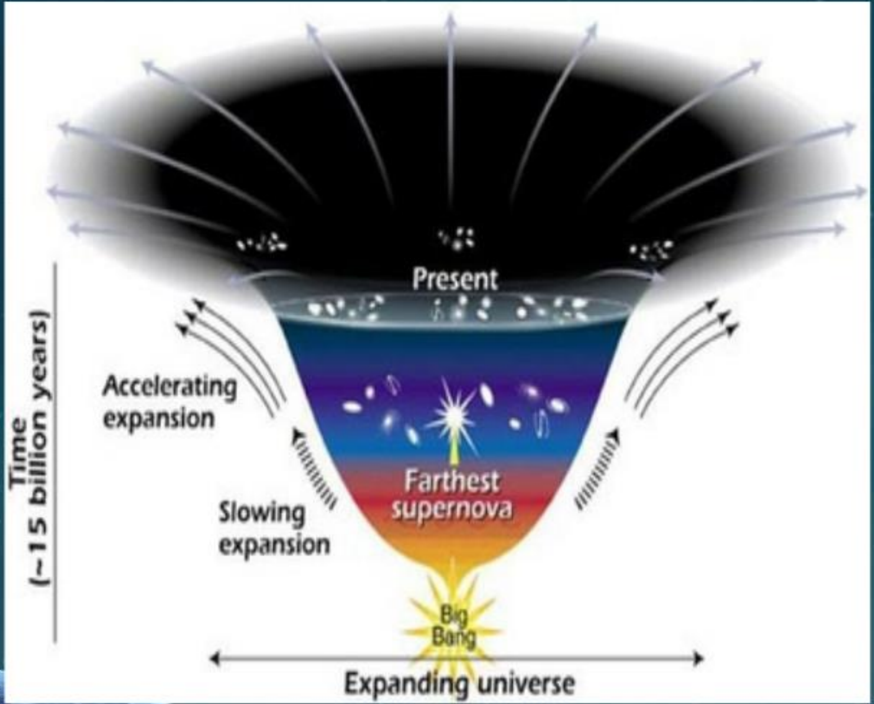
U.S. DEPARTMENT OF ENERGY


DARK ENERGY
THE DARK ENERGY SURVEY
SOUTHERN ASTROPHYSICAL RESEARCH TELESCOPE (SOAR)
MICROWAVE KINETIC INDUCTANCE DETECTORS (MKIDS)
REDSHIFT
RESULTS: TESTING FOR RESONATORS and CRITICAL TEMPERATURE
IMAGING WITH CCDs and SPECTROSCOPY

# DARK ENERGY

Dark energy is a theoretical repulsive force that counteracts gravity and accelerates the expansion of the universe. Scientists Saul Perlmutter, Brian Schmidt, and Adam Reiss uncovered the phenomenon of dark energy. Working for their respective projects (the Supernova Cosmology Project or the High-Z Supernova Search team), these men explored supernovae in distant galaxies. By studying distant supernovae, they found that large stars that were further away appeared dimmer than they should have been. The scientists concluded that there must be a different force at work, counteracting the force of gravity. This force was dubbed "Dark Energy."


COSMIC TUG OF WAR
The gravity of dark matter tries to pull the universe together, while dark energy tries to push it apart. Dark matter dominated the early universe, but dark energy began to dominate about five billion years ago. As the universe gets larger, dark energy's domination increases.
DARK ENERGY
DARK MATTER
Supernovae
NASA-STScI
9 billion years ago
5 billion years ago
Present
TIME

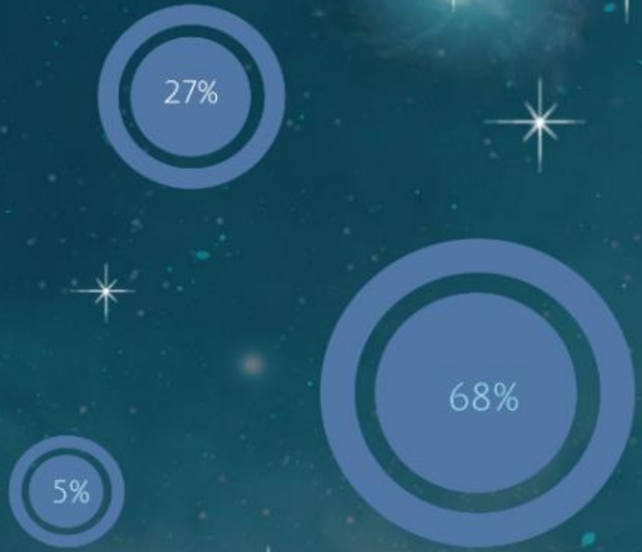

Present
Accelerating expansion
Slowing expansion
Farthest supernova
Big Bang
Time (~15 billion years)
Expanding universe

# DARK ENERGY AND MATTER

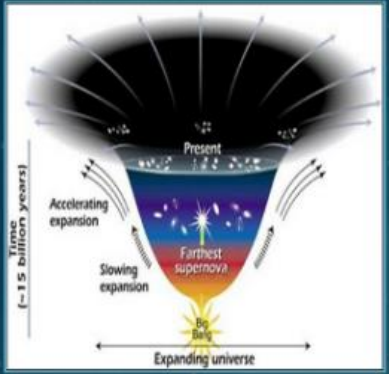
Roughly 68% of the Universe is made of dark energy.

Dark matter makes up 27% of the Universe.

All normal matter adds up to 5% of the Universe.



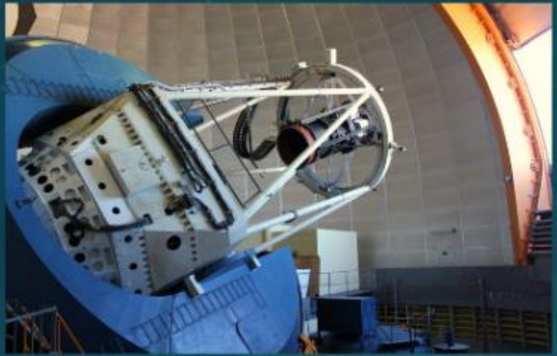
# THE DARK ENERGY SURVEY

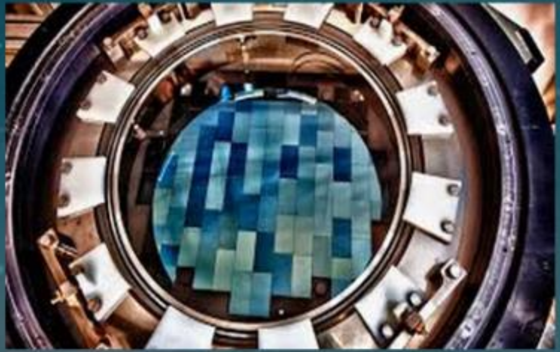




The Dark Energy Survey is an effort to measure the expansion of the universe with high precision. Over one hundred and twenty scientists from twenty-three different institutions are collaborating on this project. The Dark Energy Survey uses a powerful telescope equipped with the Dark Energy Camera (DECam) to survey the skies and create a better understanding of dark energy.

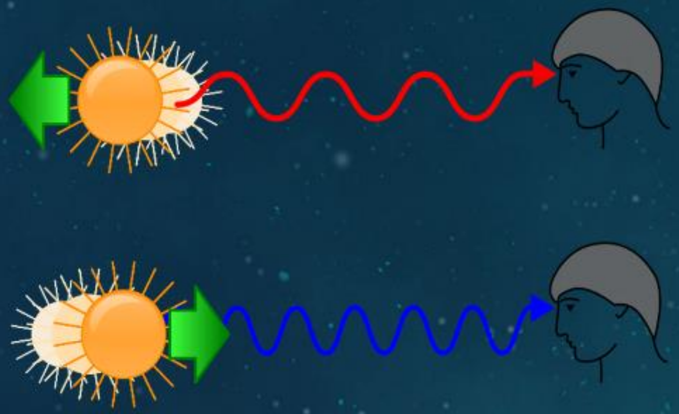
# THE DARK ENERGY CAMERA (DECAM)

The DECam is mounted on the Blanco telescope in Chile.  The DECam is a wide-field charge-coupled device (CCD) imager that includes seventy-four CCDs.  CCDs work by counting the number of photons incident on their pixels while the shutter is open.





# REDSHIFT



- The wavelength of light increases as it traverses the expanding universe between its point of emission and its point of detection by the same amount that space has expanded during the crossing time.
- Scientists use redshift to determine the position of galaxies. Dark energy affects the way galaxies are distributed in the universe.
- Redshift measurements of many galaxies are needed to characterize dark energy with more precision.
- Redshift can be determined using two different methods: Imaging with Charge Coupled Devices and Spectroscopy.
- Microwave kinetic inductance detectors have the ability to accomplish both of these methods on the same device.

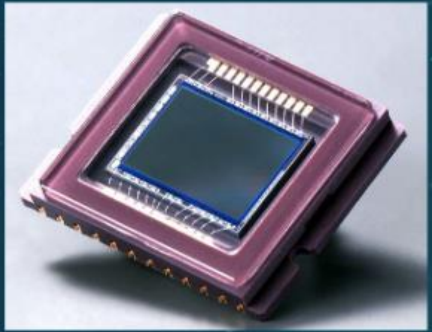
# REDSHIFT: MEASUREMENTS

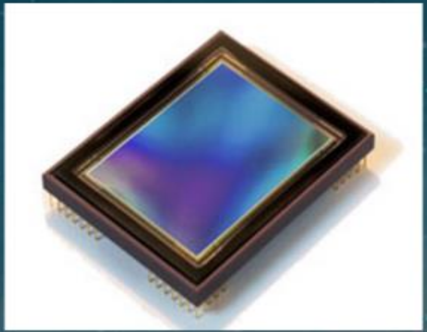
## IMAGING WITH CCDs

The CCD is an integrated circuit that contains many different pixels.

A CCD is able to count the number of photons that hit one of its pixels during a certain length of time. Using color filters, an image of photon intensity is created.

CCDs are limited by their inability to track the time at which a photon hits its pixels.



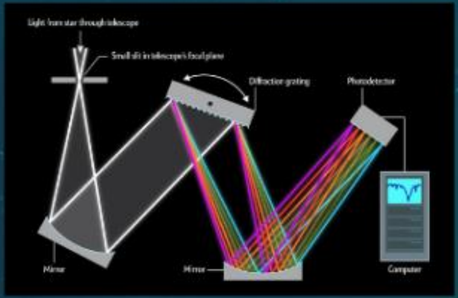


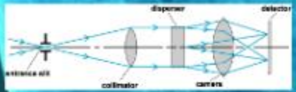
# REDSHIFT: MEASUREMENTS

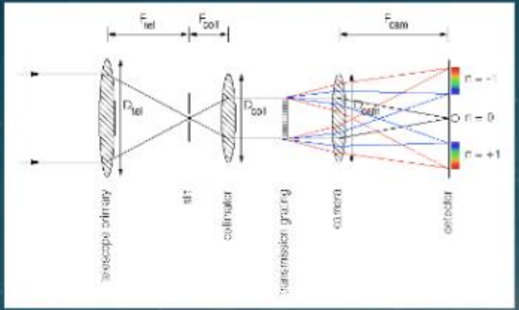
## SPECTROSCOPY

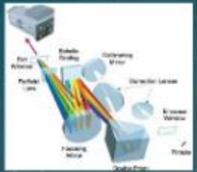
Spectrographs are able to accurately split the light into different wavelengths and shine it onto CCDs to create high-resolution spectra.

Because they can only track individual objects in the sky, this method is slow and time consuming and therefore inefficient.



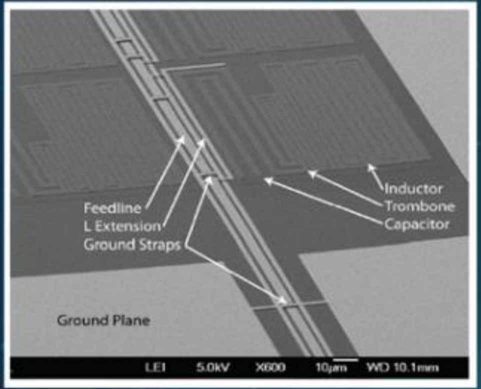



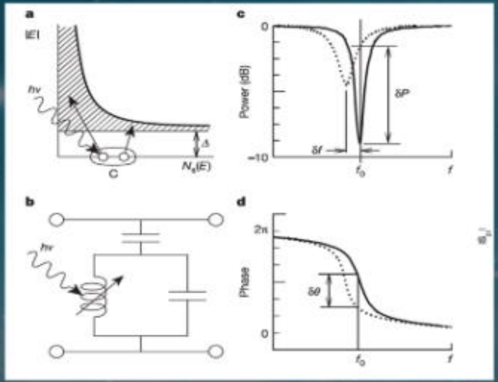



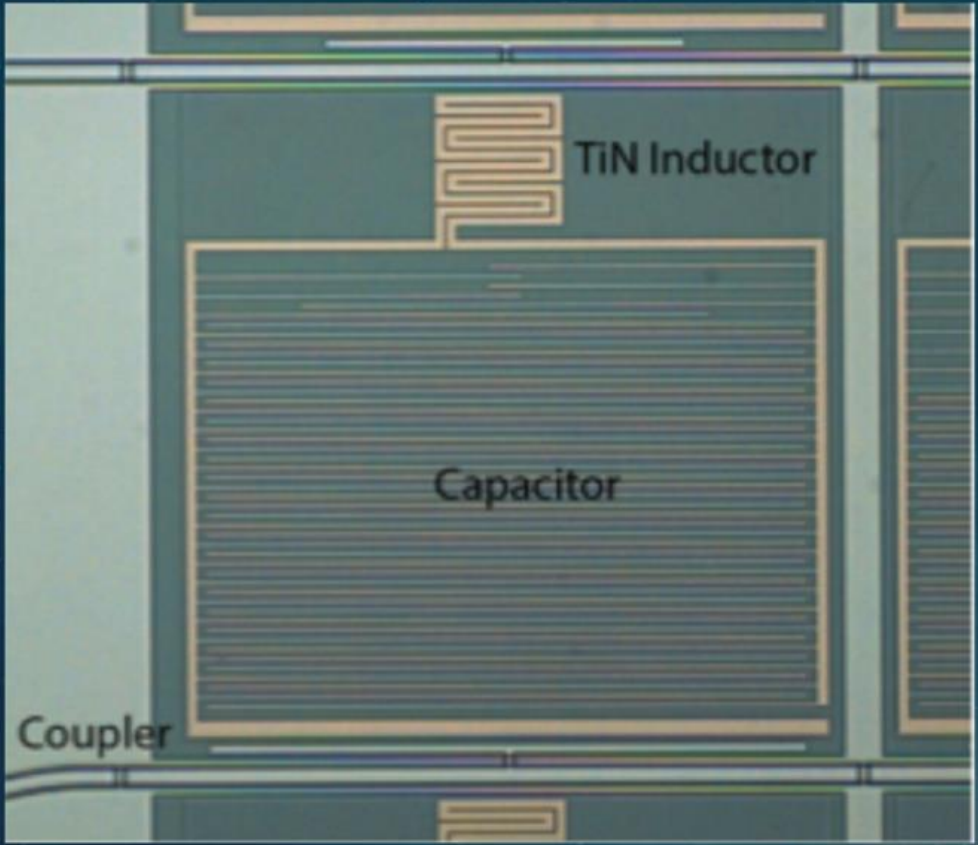



# MKIDS

Microwave kinetic inductance detectors are superconducting detectors developed at the California Institute of Technology. MKIDs consist of thousands of pixels. Each pixel resonates at its own frequency.






# MKIDS: A SINGLE PIXEL

- Each pixel is 100 microns.
- Each pixel includes an inductor, capacitor, and a coupler.
- Light is collected at the inductor.

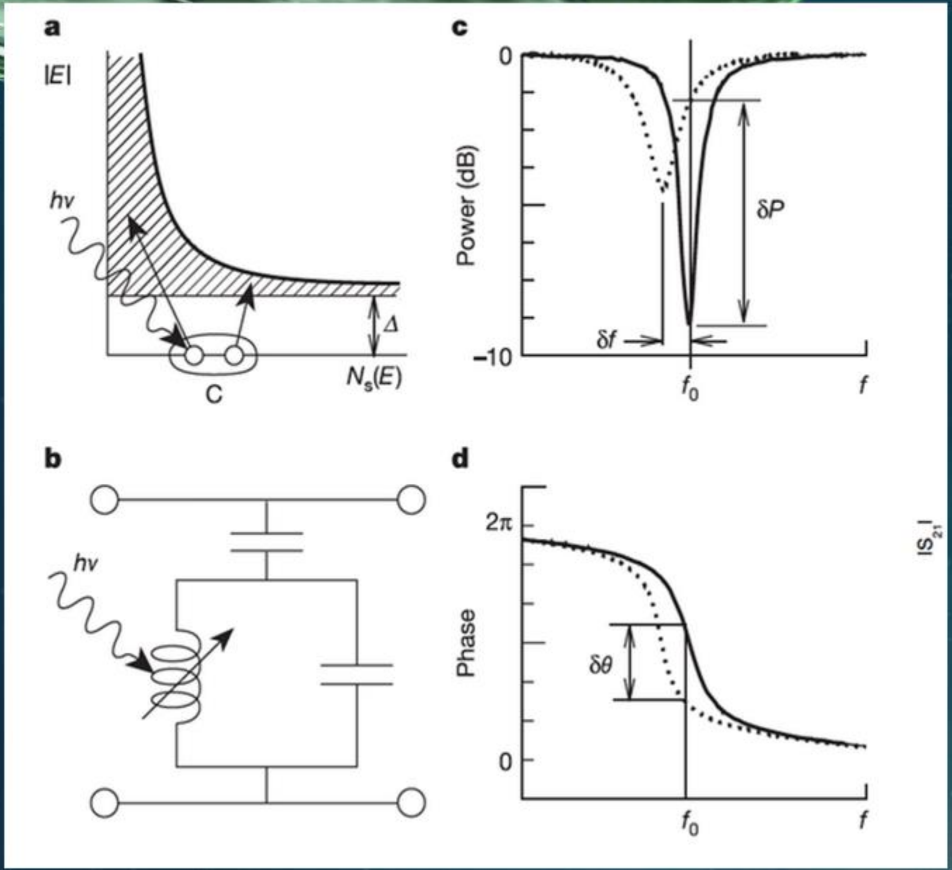



figure (a) shows a photon of light hitting a Cooper Pair and creating quasi-particles.

Figure (b) shows a single pixel. A photon of light hits its inductor, breaking Cooper Pairs, changing the inductance, and shifting the resonant frequency of the pixel.

When a photon hits the inductor on the pixel and changes the resonant frequency, a shift in phase occurs. This is shown in figures (c) and (d).

This phase shift is what we use to measure the energy and time resolution of individual photons of light.

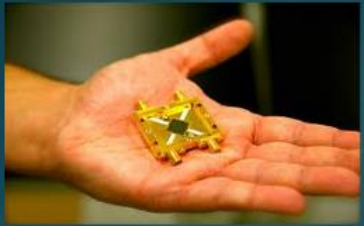
# MKIDS: ADVANTAGES

MKIDs have the ability to execute astronomical studies with a high efficiency.

- Because MKIDs consist of thousands of pixels, they have the ability to create images of multiple objects in the sky.

- Each pixel on a MKID acts as its own spectrograph. Therefore, MKIDs have the ability to track the energy of each individual photon as it hits a pixel.

- MKIDs also have time resolution capabilities. By tracking the change of inductance of the MKID, scientists are able to tell at what time the photon hit the pixel.



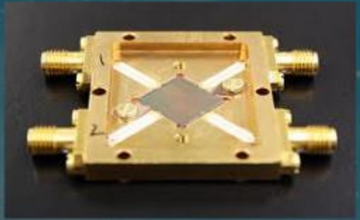
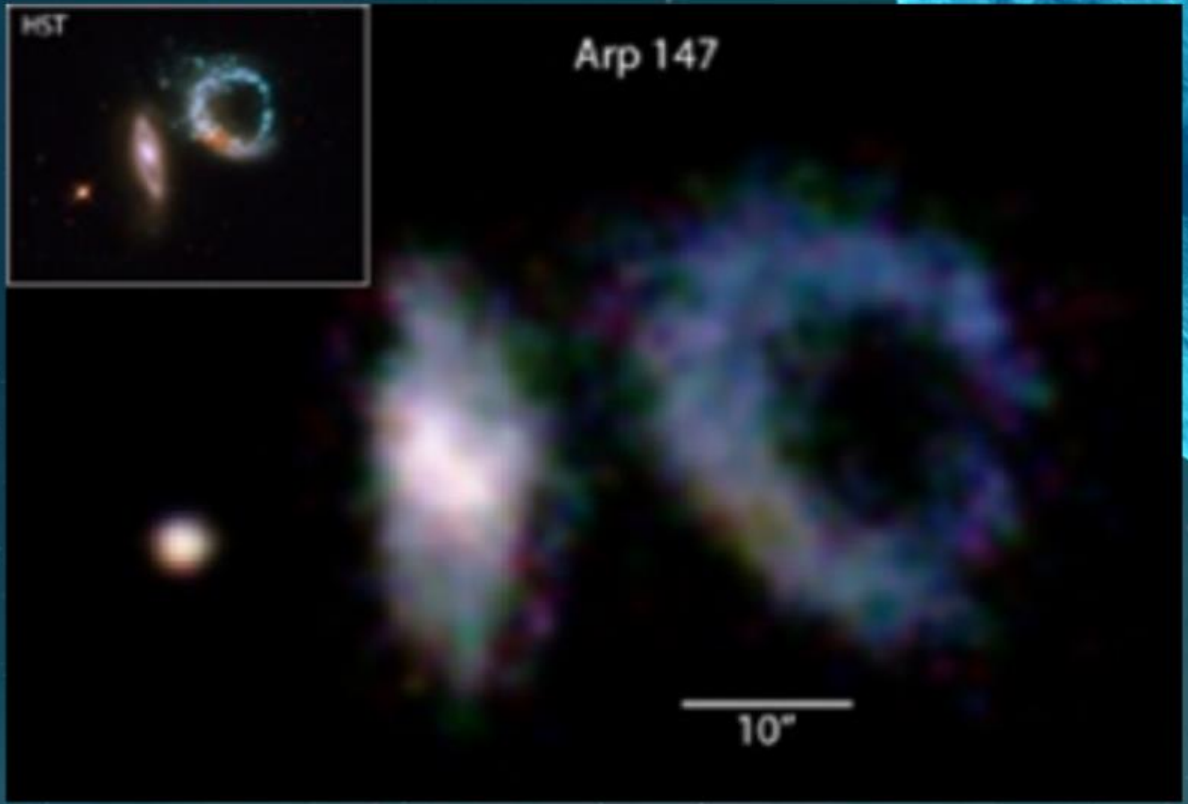


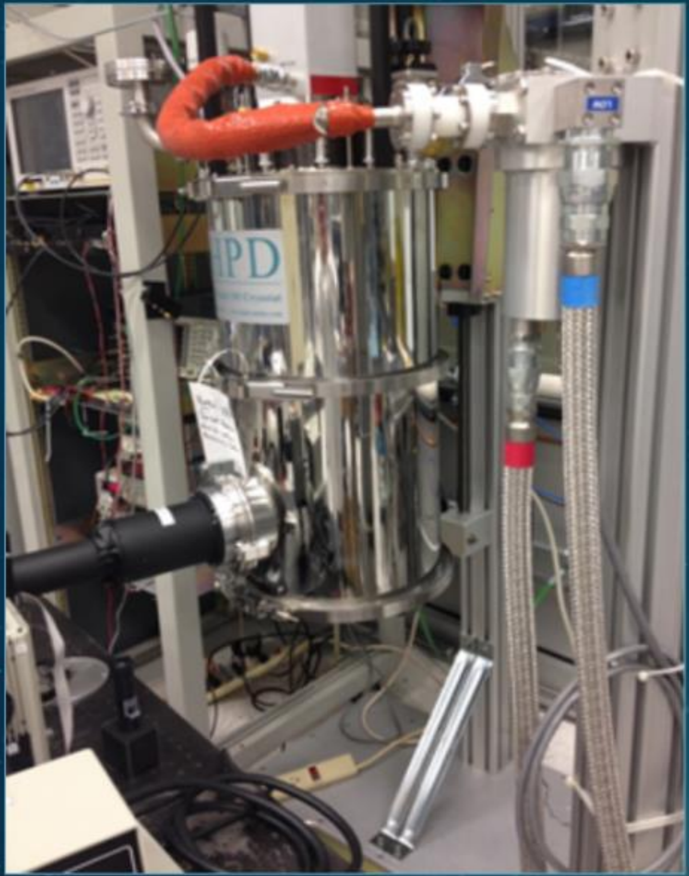
Image taken with the Hubble Telescope

Image taken with camera with MKID



# ADIABATIC DEMAGNETIZATION REFRIGERATOR

## MKID SETUP



# Adiabatic Demagnetization Refrigerator

- Cryogenic refrigerator – gets down to millikelvin temperatures.
- Cool down the refrigerator to 100 mK day-to-day.
- The ADR has the ability to run at temperatures as low as 30 mK.

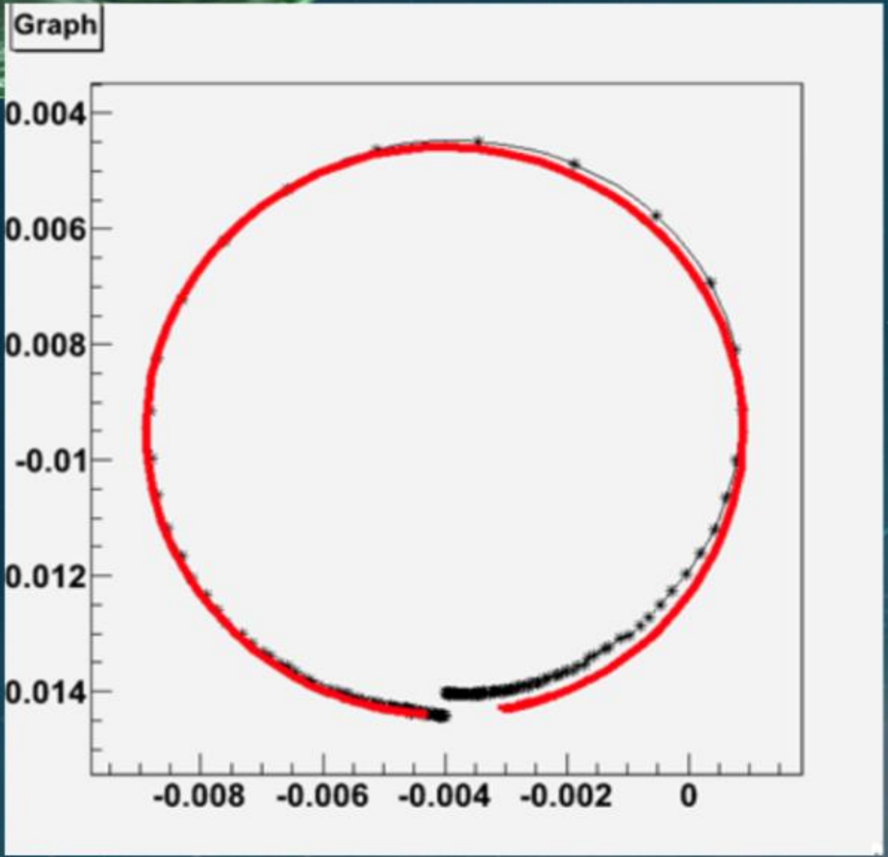
# NETWORK ANALYZER AND ROACH BOARD

- The Network Analyzer is used to perform wide-sweeps of the pixels to find resonators.
- A range of frequencies is sent through the DAC (ex: 4.01-4.60 gHz) to find pixels that resonate and those frequencies.
- The ROACH board is a programmable board that includes software and hardware attenuators.

# ADR Open – MKID

# TEMPLAR: A SINGLE RESONATOR (Q AND I)

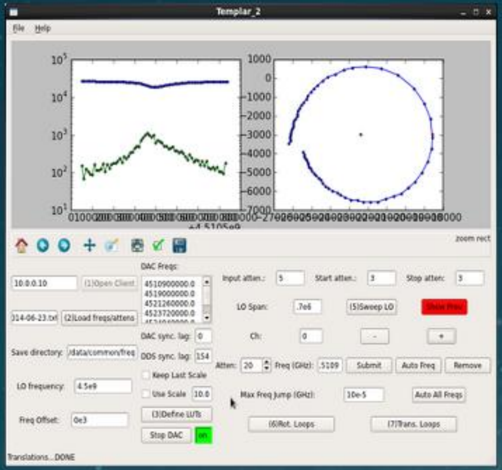

S21 is the sum in quadrature of Q & I.


Graph
0.004
0.006
0.008
-0.01
0.012
0.014
-0.008
-0.006
-0.004
-0.002
0

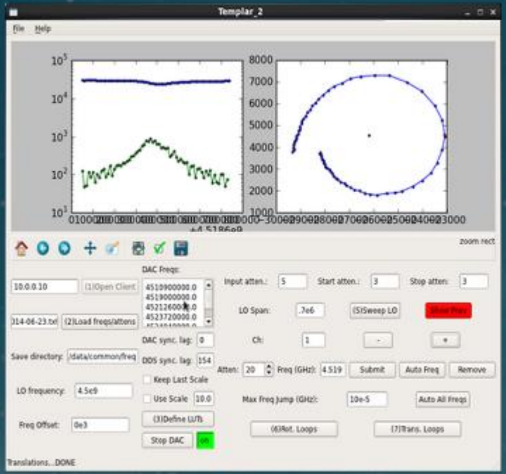
# RESULTS

## TESTING FOR RESONATORS

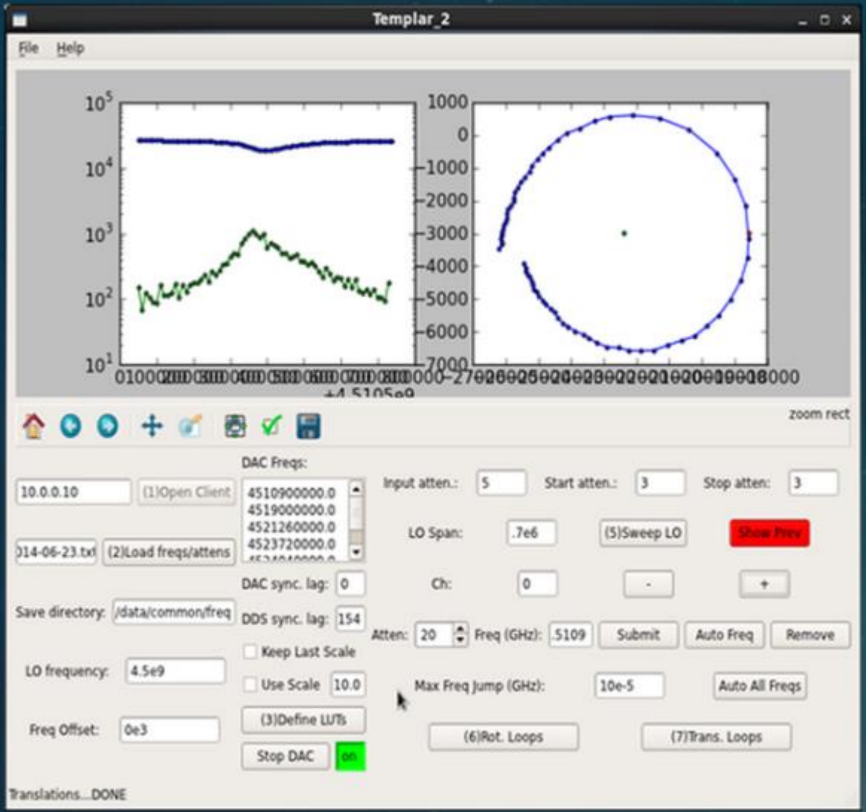
- To test for resonators, we use the Network Analyzer and the ROACH to complete a "wide sweep" of the pixels at chosen frequencies.
- Using the Templar GUI, each resonator is shown as a separate channel.
- Templar shows each resonator plotted in the complex plane.



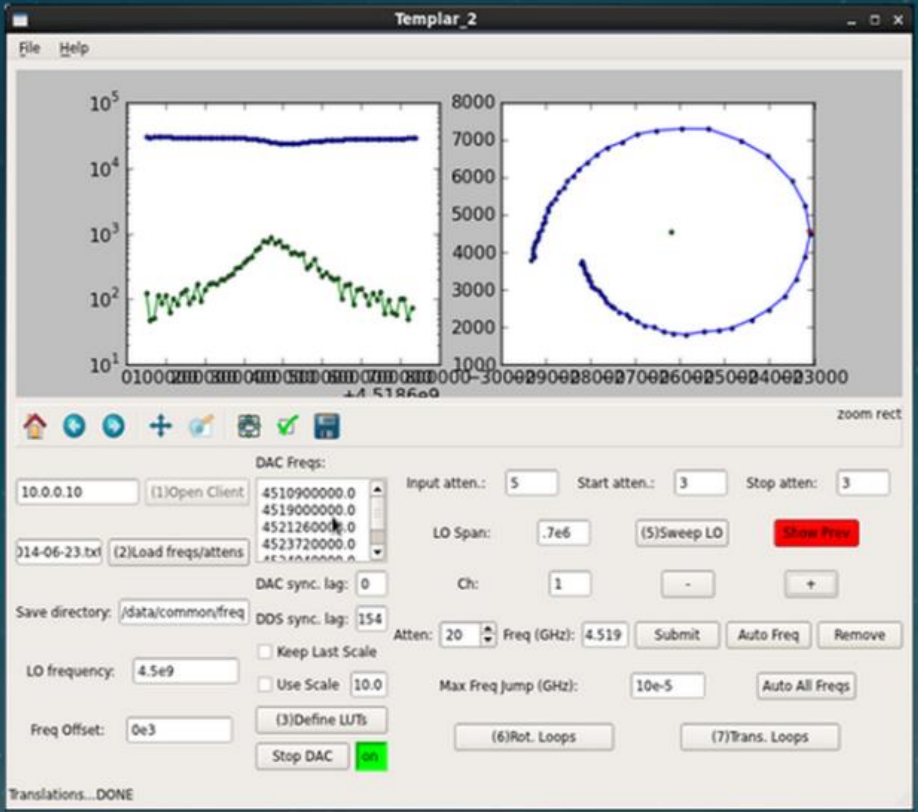

Templar – Channel Zero




Templar – Channel One




Templar – Channel Zero

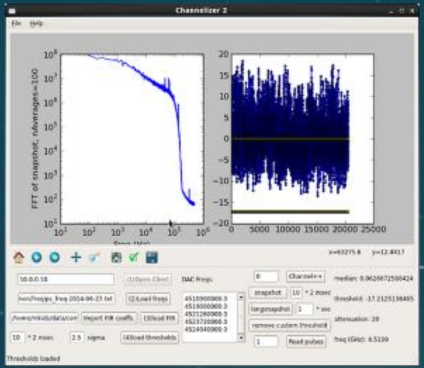



Templar – Channel One

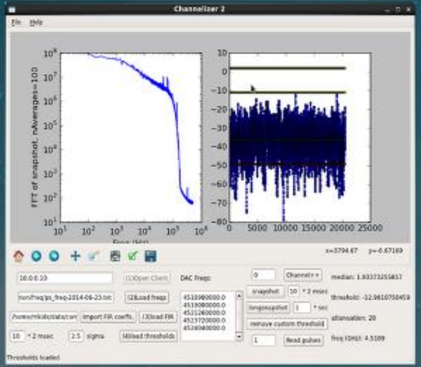
# RESULTS

## TESTING FOR RESONATORS

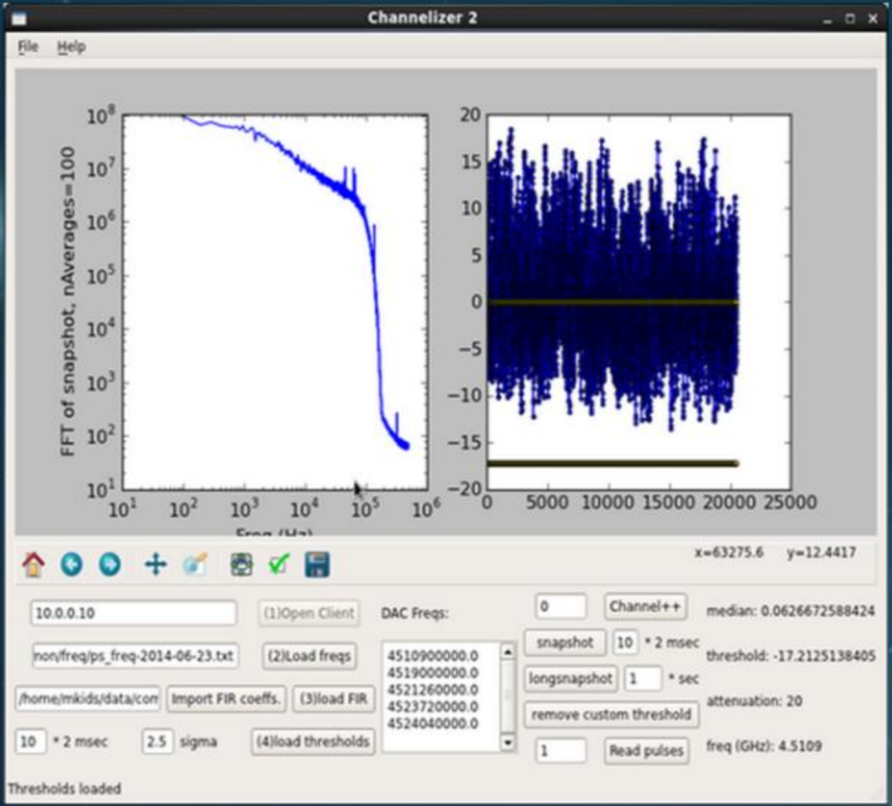
- After finding resonators, the Channelizer GUI is used to observe photons making contact with the detector.
- Long and short snapshots can be taken to view the noise and light coming through the shutter and monochromator.



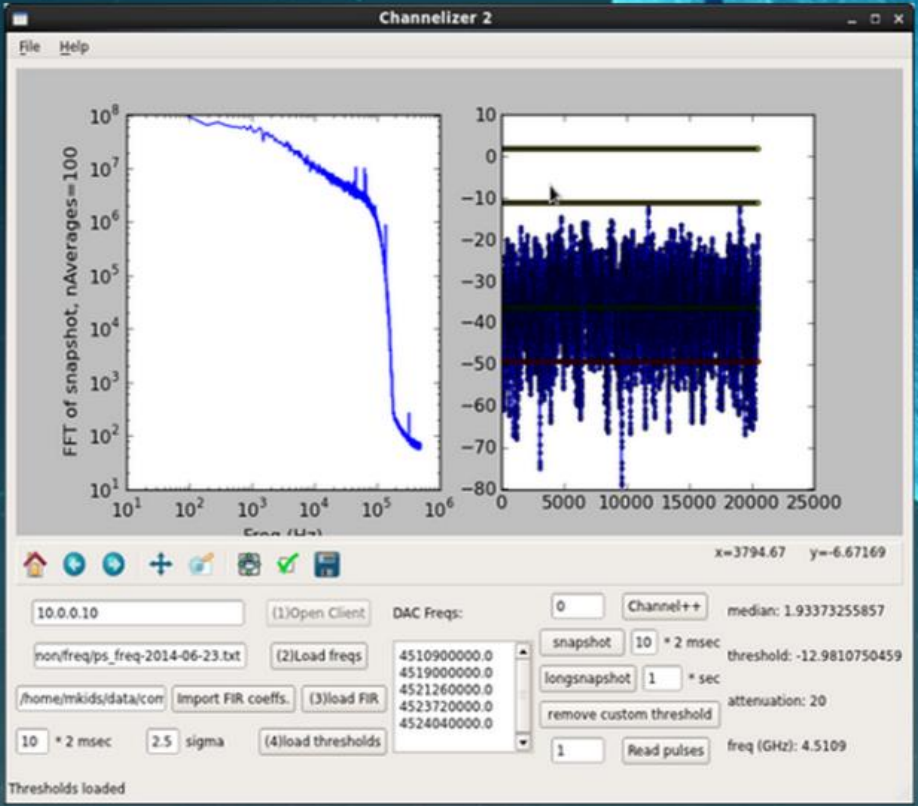

Channelizer – No Light




Channelizer – Light



Channelizer – No Light

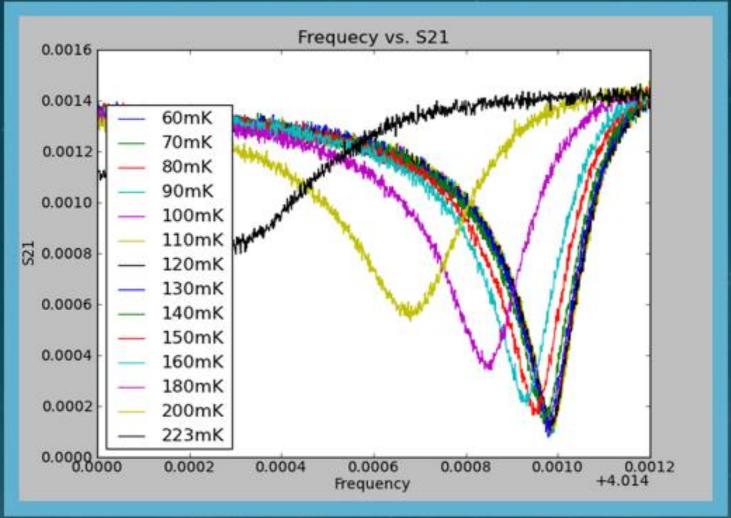


Channelizer – Light

# RESULTS

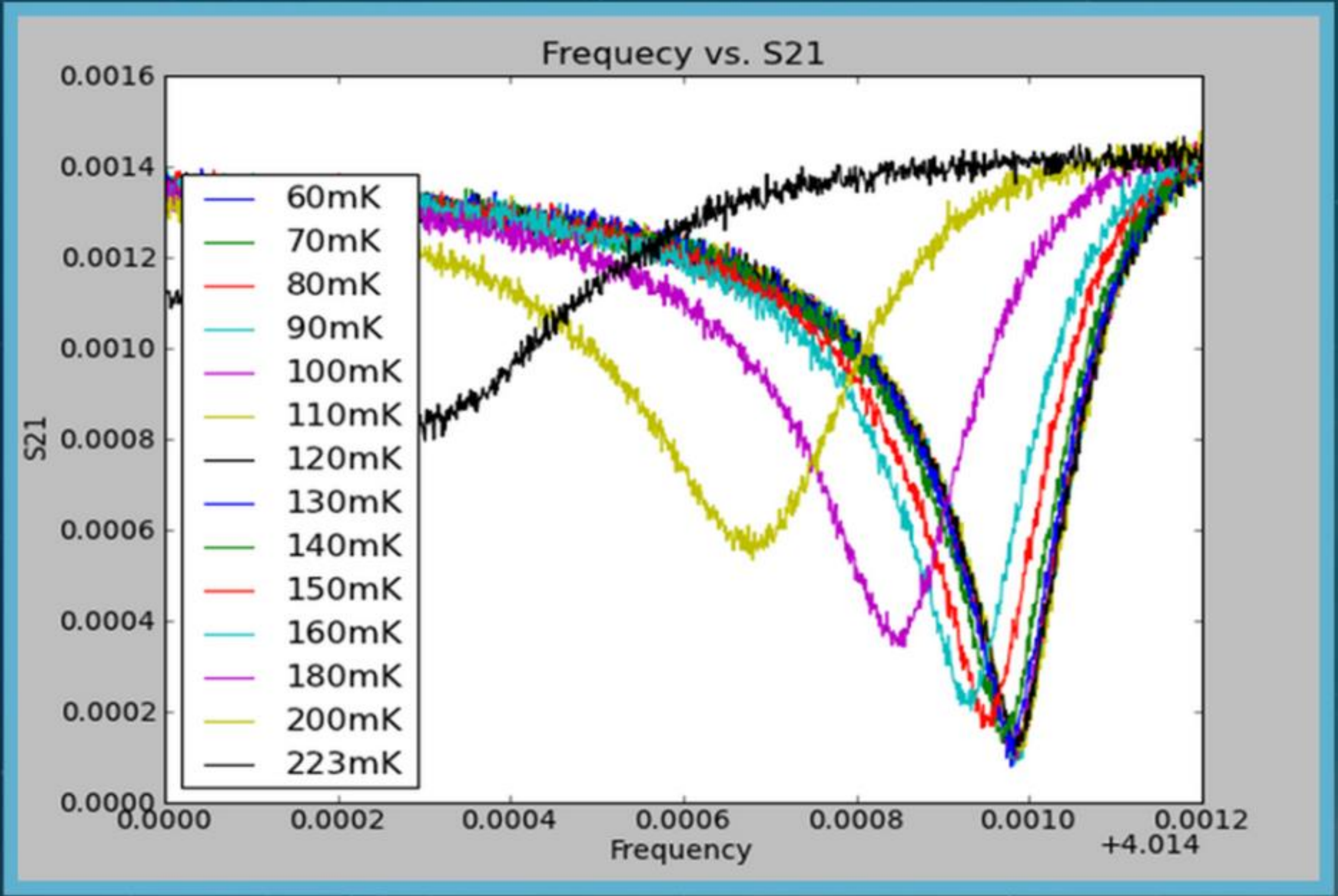
## CHANGING TEMPERATURE

- To test the effects of temperature on the performance of the device, tests were run ranging from 60 mK through 223 mK




Frequency vs. S21

S21

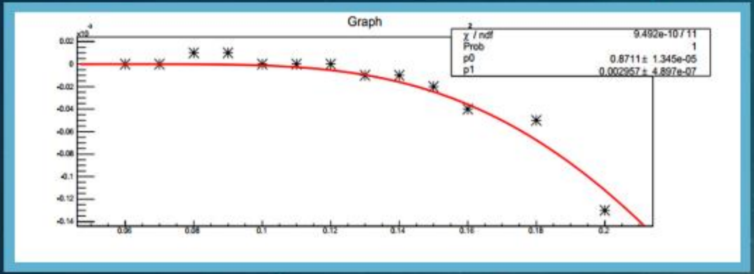

Frequecy vs. S21
S21
Frequency
+4.014
0.0016
0.0014
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
0.0000
0.0002
0.0004
0.0006
0.0008
0.0010
0.0012
60mK
70mK
80mK
90mK
100mK
110mK
120mK
130mK
140mK
150mK
160mK
180mK
200mK
223mK

Freq.

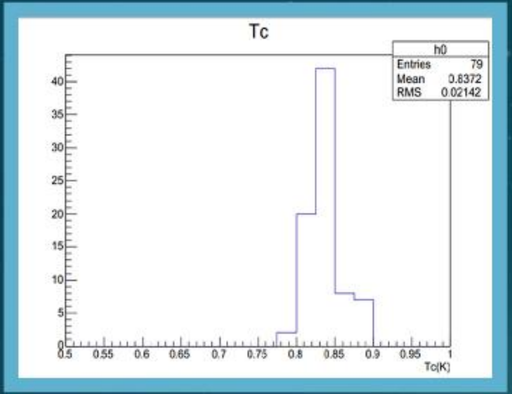
# RESULTS

## FITTING FOR CRITICAL TEMPERATURE

- Using the data from the S21 versus frequency graph, each pixel was fit for its critical temperature.
- By finding the critical temperature of each pixel, the temperature at which the pixel becomes superconducting can be found.
- In the figure below, pixel twenty-four was fitted and found to have a critical temperature of .87 Kelvin.



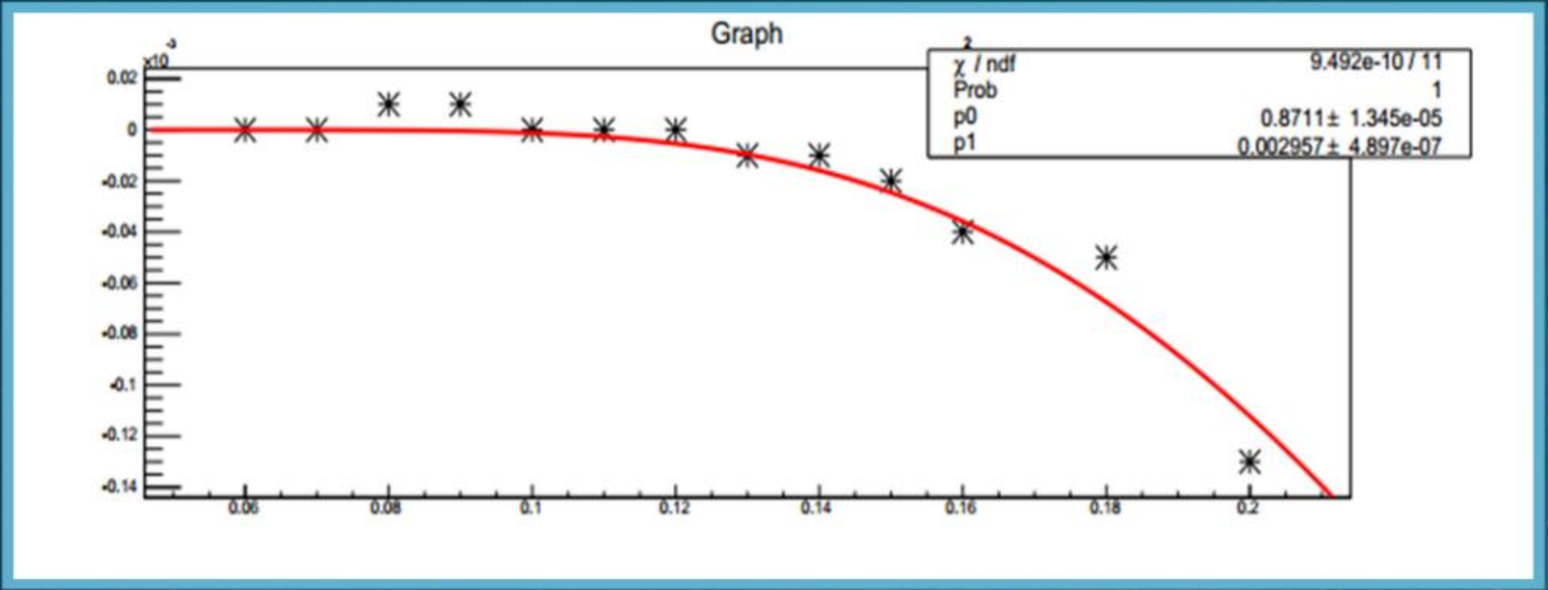

Pixel Twenty-Four – Fit for Critical Temperature



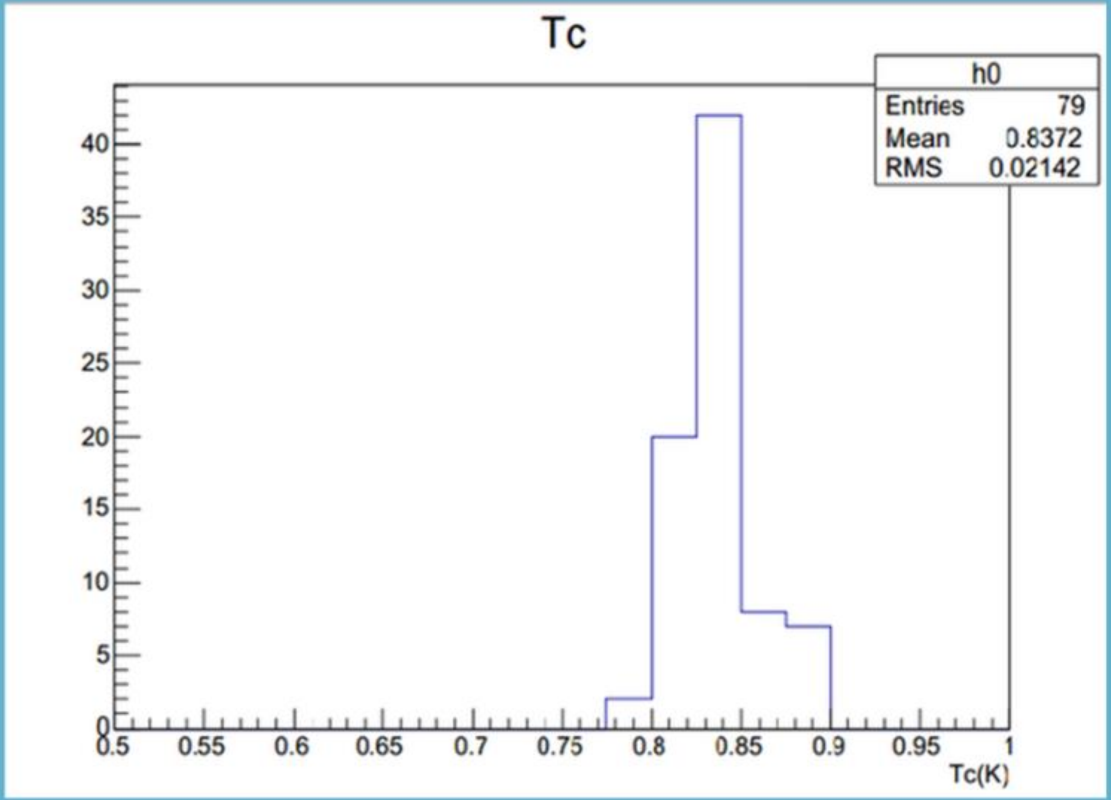

Distribution of Critical Temperature

- This plot shows the distribution of the critical temperature of the ninety resonators that were observed.
- Out of ninety, seventy-nine had good critical temperature fits. RMS of the temperature = .02 K or 20 mK

Delta F/F0




Critical Temperature (K)



Tc
h0
Entries 79
Mean 0.8372
RMS 0.02142
0
5
10
15
20
25
30
35
40
0.5
0.55
0.6
0.65
0.7
0.75
0.8
0.85
0.9
0.95
1
Tc(K)

# MOVING FORWARD…

## THE SOAR TELESCOPE

At Fermilab the goal of the MKIDs project is to mount it onto a camera which will in turn be used in a telescope to take images of the sky.

The Detector Development and Operations Department at Fermi is currently working on a proposal to test the MKID at the Southern Astrophysical Research telescope (SOAR) in Chile.

This proposal includes several projects the department would like to execute using the MKID devices.

An example of one of these projects is MegaZ, which is the MKID Extra-Galactic Redshift Survey.