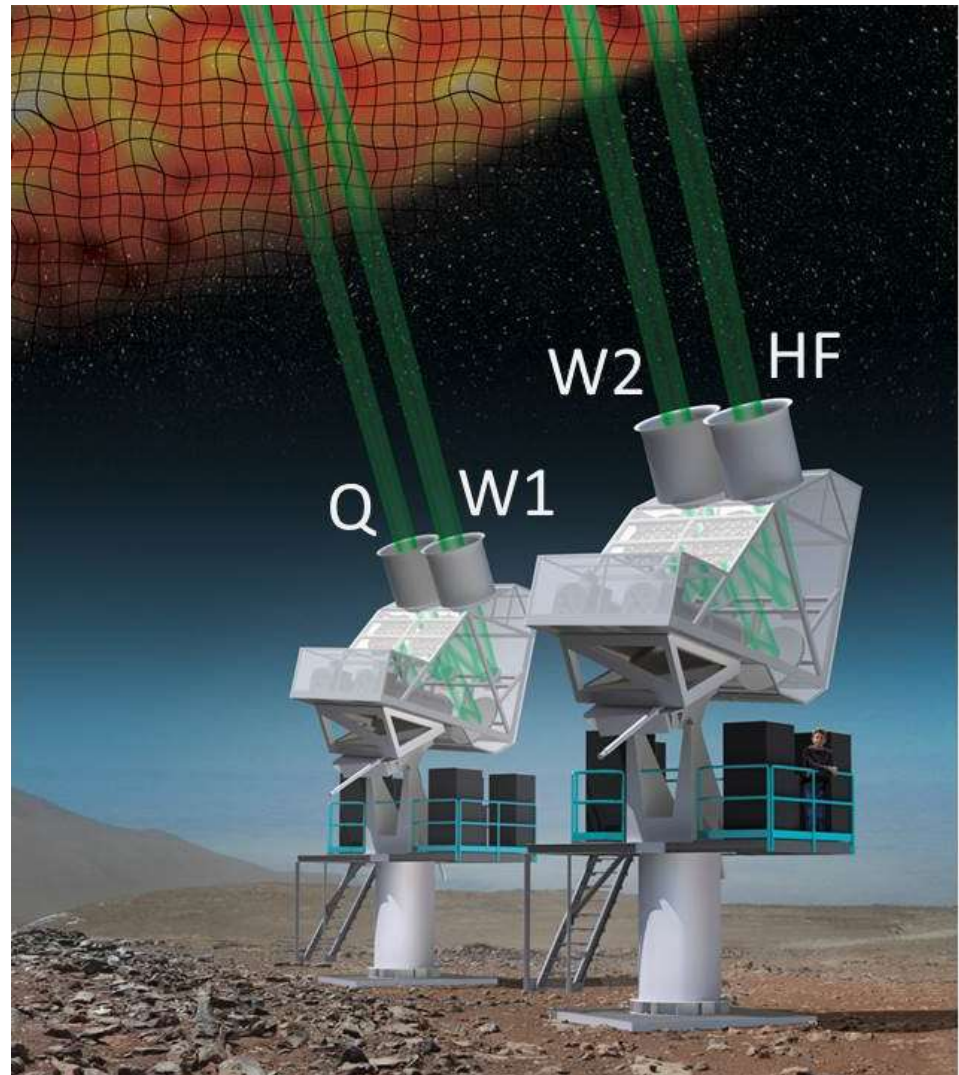
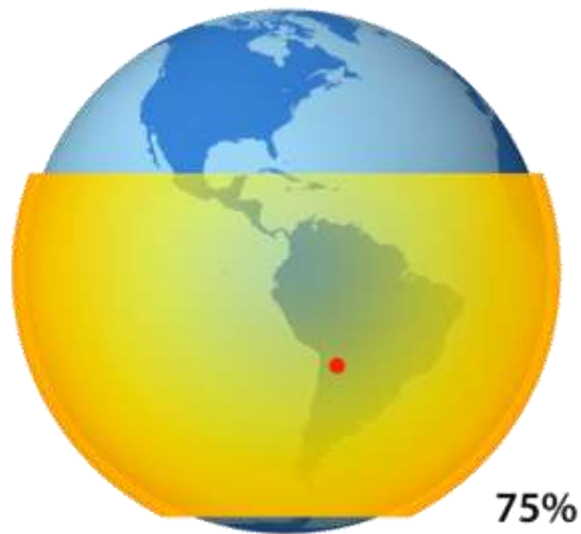


The Cosmology Large Angular Scale Surveyor (CLASS)

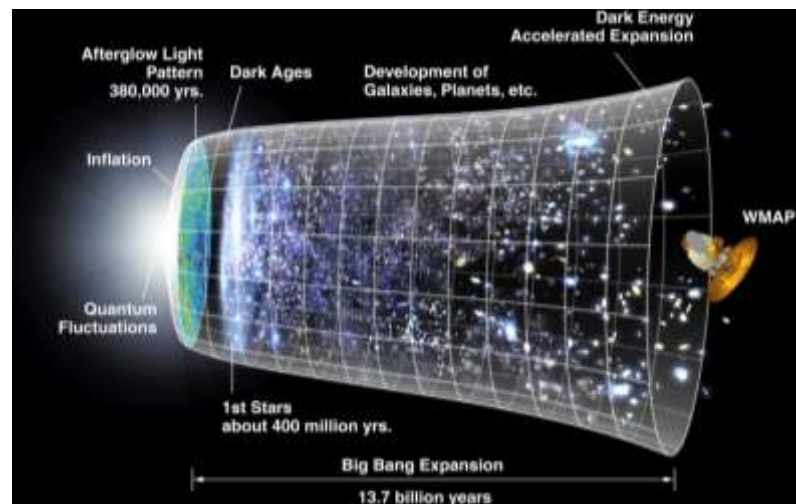
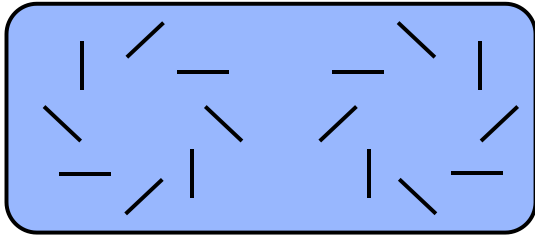
Tom Essinger-Hileman

Quarknet 2014

Johns Hopkins University



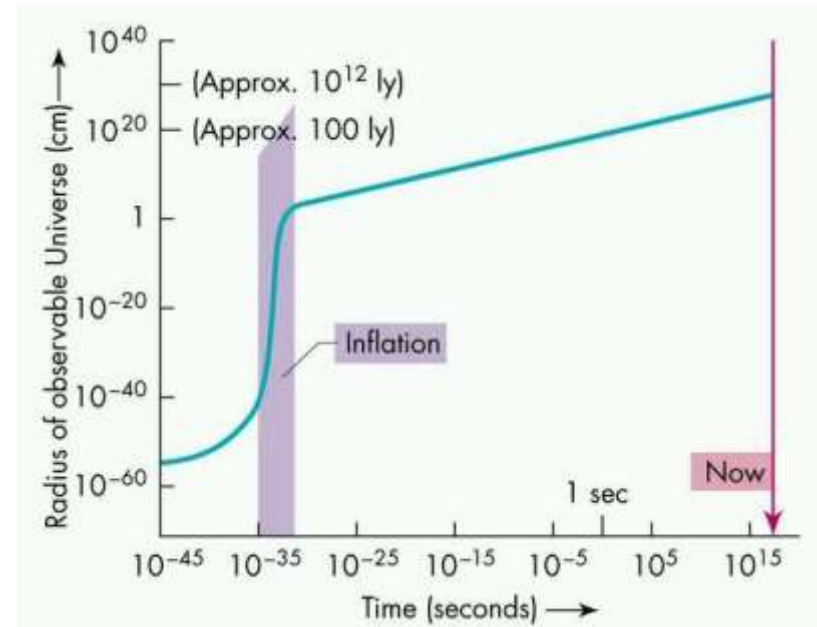
The Search for B-Modes

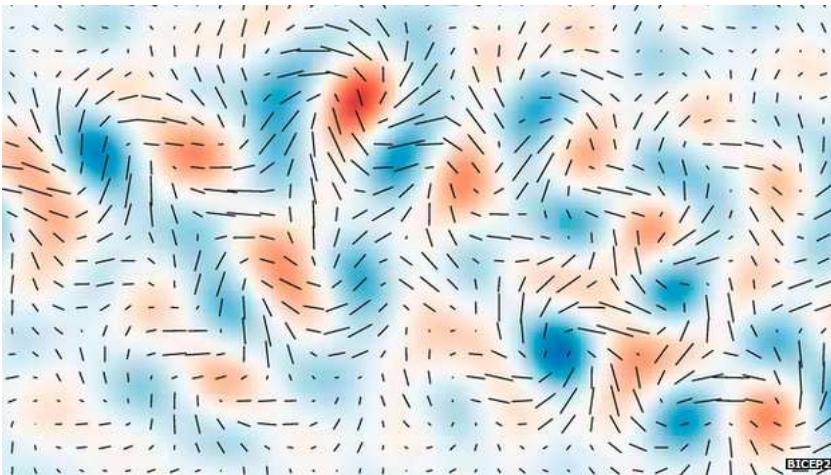


Measurement of primordial B-modes would be:

- Confirmation of Inflation.
- Measurement of energy scale of inflation.
- Evidence of quantum-gravitational effects.

Probing physics at energies around 10^{16} GeV, 13 orders of magnitude above those achievable by the Large Hadron Collider (LHC).





PUTIN RECOGNIZES CRIMEA SECESSION, DEFYING THE WEST

Decree Increases Fears of Annexation by Russia, Despite More Sanctions

By STEVEN LEVY MYERS and PETER BAKER
 Moscow — President Vladimir V. Putin of Russia signed a decree on Monday formally recognizing Crimea as a "sovereign and independent state," laying the groundwork for annexation and defying the United States and Europe just hours after they imposed their first financial sanctions against Moscow since the crisis in Ukraine began.



Chinese relatives of those on the missing Malaysian plane watched news from Malaysia in Beijing. Page A8.

Lost Jet's Path Seen as Altered Via Computer

By MATTHEW L. WALK and MICHAEL S. SCHMIDT

WASHINGTON — The first hint to the west that diverted the missing Malaysia Airlines plane from its planned flight path from Kuala Lumpur to Beijing was carried out through a computer system that was most likely programmed by someone in the plane's cockpit, who was knowledgeable about airplane systems, according to senior American officials.

Instead of manually operating the plane's controls, whoever diverted Flight 370's path typed seven or eight keystrokes into a computer on a low-high pedestal between the captain and the first officer, according to officials. The Flight Management System, as the computer is known, directs the plane from point to point specified in the flight plan with various letters a flight. It is not clear whether the plane's path was reprogrammed before or after it took off.

The fact that the turn away

Space Ripples Reveal Big Bang's Smoking Gun

By DENNIS OVERBYE

CAMBRIDGE, Mass. — One night late in 1970, an observatory pointed toward the Big Bang, and that his hypothesis, known informally as inflation, looked right.

Reaching back across 13.8 billion years to the first glimmer of cosmic time with telescopes at the South Pole, a team of astronomers led by John M. Kovay of the Harvard-Smithsonian Center for Astrophysics detected ripples in the fabric of space-time — so-called gravitational waves — the signature of a universe being stretched rapidly apart when it was roughly a trillionth of a second of a trillionth of a second

old. They are the long-sought smoking-gun evidence of inflation, said Dr. Kovay and his colleagues, that Dr. Guth was correct.

Inflation has been the workhorse of cosmology for 25 years, though many, including Dr. Guth, wondered whether it could ever be proved.

It corroborated, Dr. Kovay's work was cited as a landmark in science responsible to the recent discovery of dark energy, probing the universe's expansion, or of the Big Bang itself. It would open new realms of time and space and bring to screens and spectators.

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Continued on Page A12

A Campaign Inquiry in Utah



3 Years of Strife And Cruelty Put Syria in Free Fall

By UNE BARNARD

BEIRUT — Day after day, the Syrian civil war has ground down a cultural and political center of the Middle East, turning it into a stage for disaster and cruelty on a nearly incomprehensible scale. Nowhere are brutalized by their government and by jihadists claiming to be their saviors as nearly half of Syrians — more than 5 million children — have been dis-

BICEP2 Announcement

Made headlines with measurement of celestial B-modes.

Open question whether they are seeing B-modes in the CMB or from our galaxy.

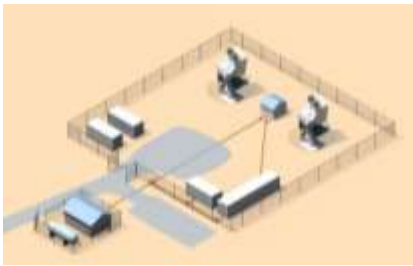
CLASS (among other experiments) is critical in verifying result.



The Cosmology Large Angular Scale Surveyor (CLASS) experiment

- Searching for gravitational-wave background from the birth of the universe, during a period of inflationary expansion.
- Observing at millimeter wavelengths in four observing bands.
 - Allows separation of Milky-Way signal from CMB.
- High-altitude site (17,000 ft above sea level!) in the Atacama Desert of Chile to reduce loading from the atmosphere.

CLASS
coming soon!

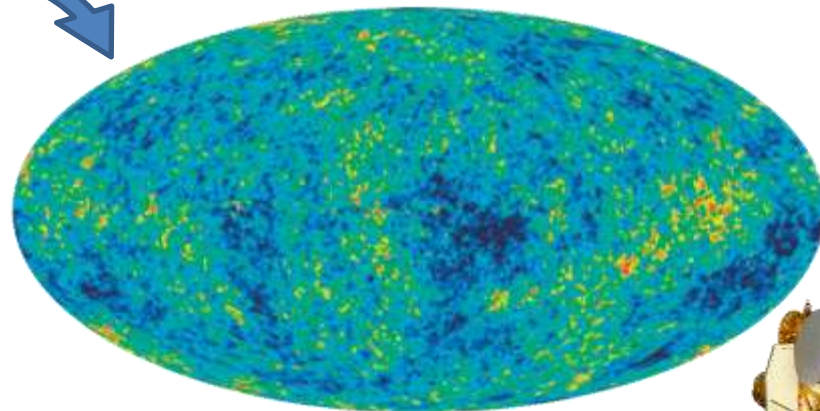


The Atacama Desert is one of the premier sites for microwave astronomy.



**2.725 K
CMB**

Temperature fluctuations 50,000 smaller



WMAP

$\pm 50 \mu\text{K}$

E-mode polarization 50 smaller still!

$\pm 1 \mu\text{K}$



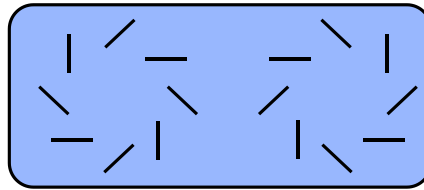
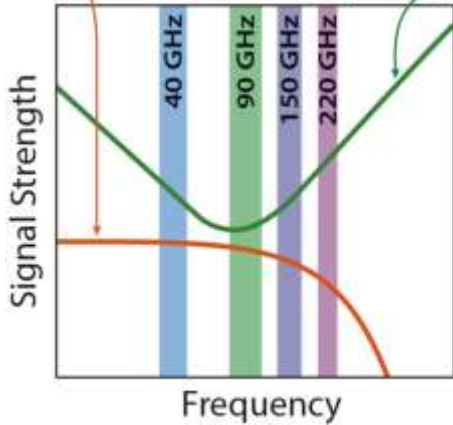
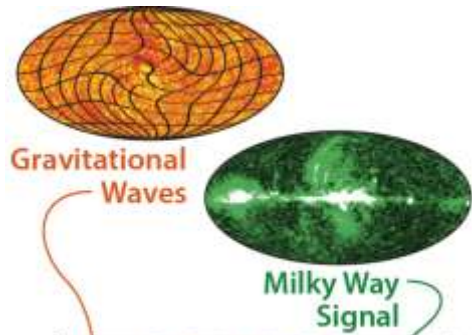
B-mode polarization at
least 100 times smaller



$< 100 \text{ nK}$

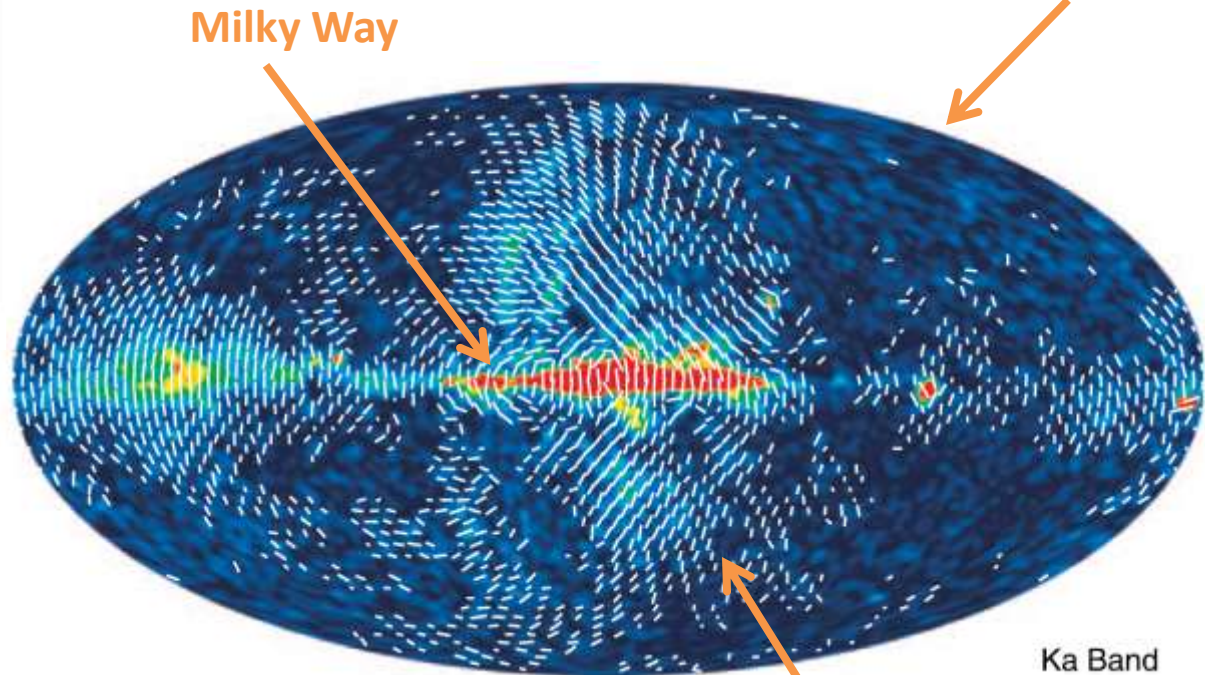
Our detectors typically measure **pico-watts** (10^{-12} W) of optical power with ability to distinguish changes in power on the order of tens of **atto-watts** (10^{-18} W)

The microwave sky

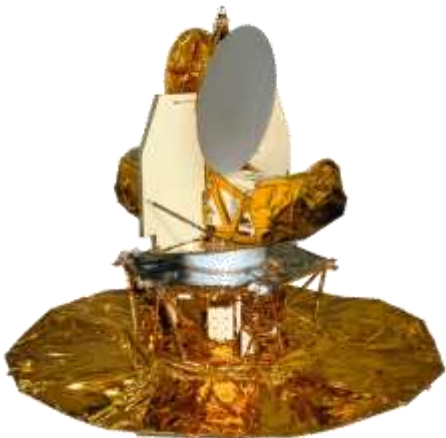


B-modes are a tiny signal under all of this.

CMB
Temperature
Anisotropy



Polarization (largely from Milky Way)

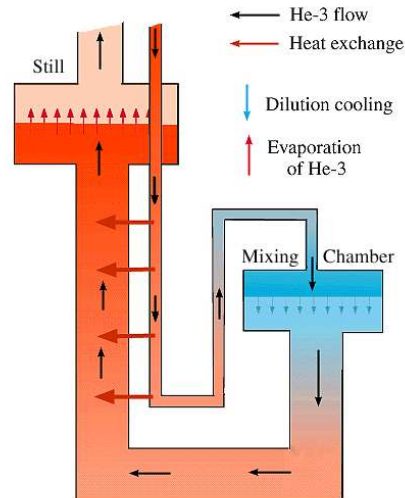
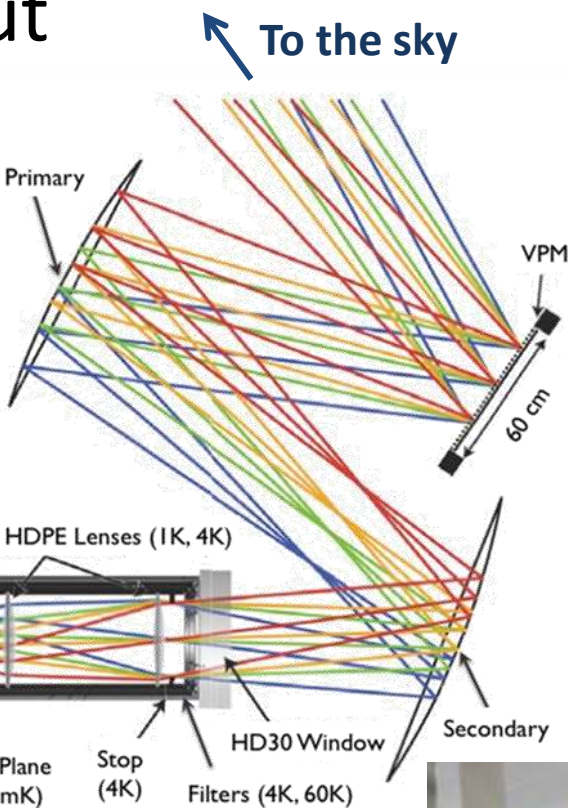
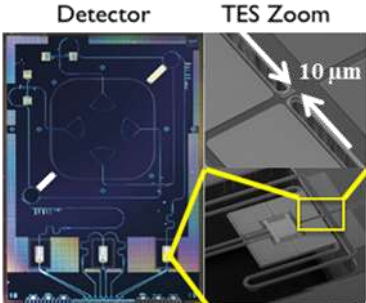


As measured by the Wilkinson Microwave Anisotropy Probe (WMAP)

CLASS Telescope Layout

Transition-edge sensor (TES) bolometers allow measurement of tiny signals

when cooled to a tenth of a degree above absolute zero by dilution refrigerators

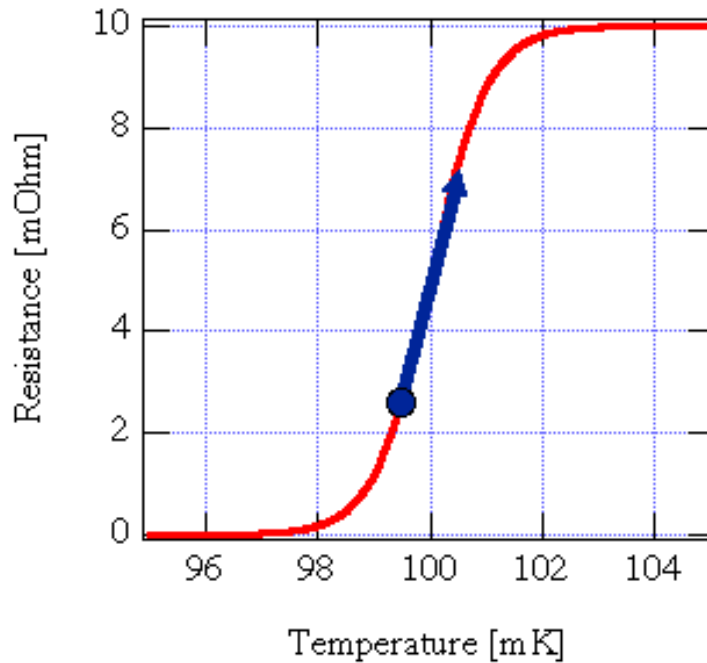
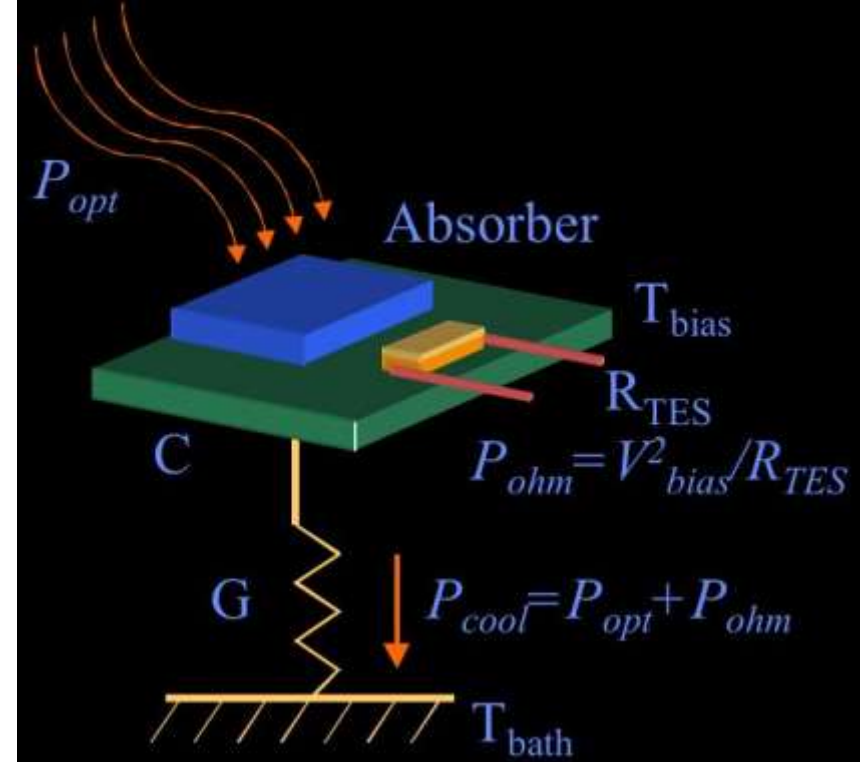


Transition-edge sensor (TES) bolometers

Cooled to below 100 mK to reduce thermal noise in the detector.

Allows detectors to be “background-noise limited” – the dominant noise seen by the detectors is from *quantum fluctuations of the incoming light*.

This arises from different numbers of photons arriving at different times.



A TES is a superconducting film operated at its transition between superconducting and normal-metal states.

Negative electrothermal feedback keeps detectors at a stable point on the transition.

The TES acts a thermometer. Optical power changes the temperature of an absorber, and we measure this change in temperature.

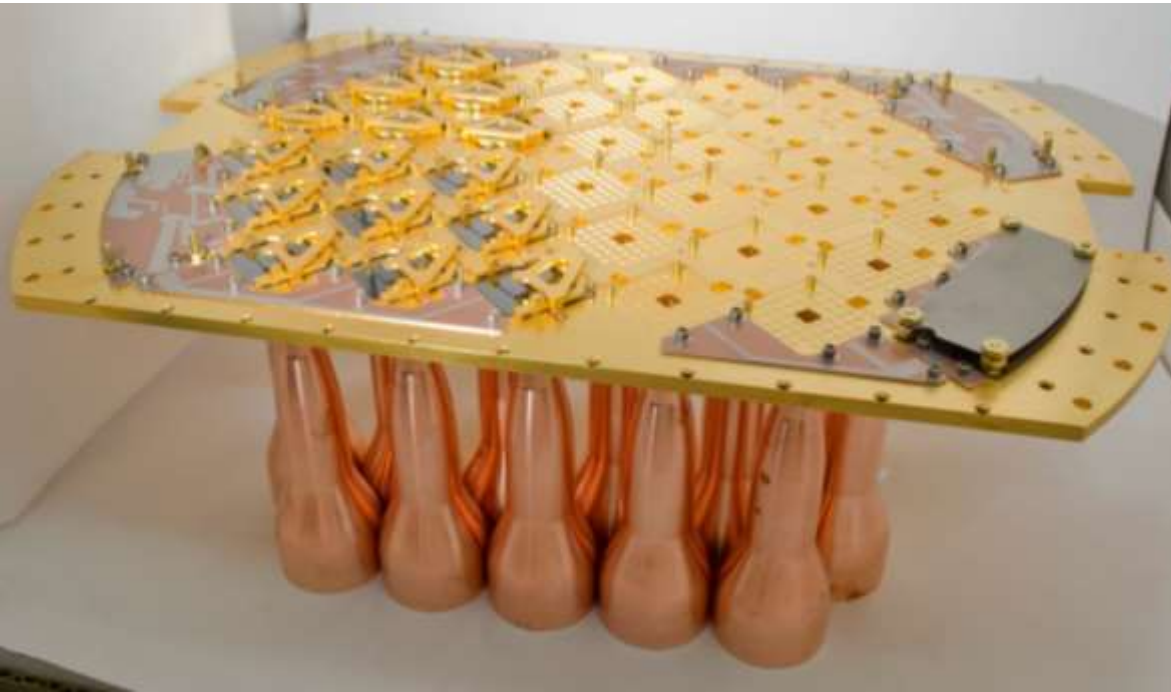
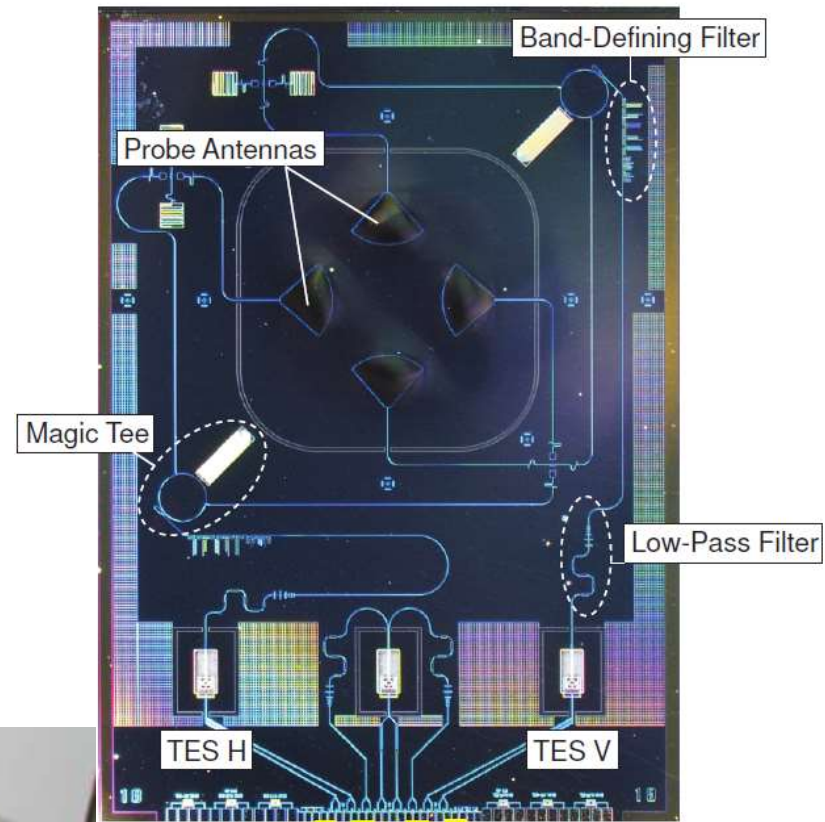
CLASS detectors

Two perpendicular linear (horizontal H and vertical V) polarizations are separated by metal probe antennas.

Microwave circuitry on a silicon detector chip carries signals from H and V probes to separate TES bolometers.

Example shown is for lowest frequency (40 GHz) channel of CLASS.

Detectors are made at NASA Goddard Space Flight Center



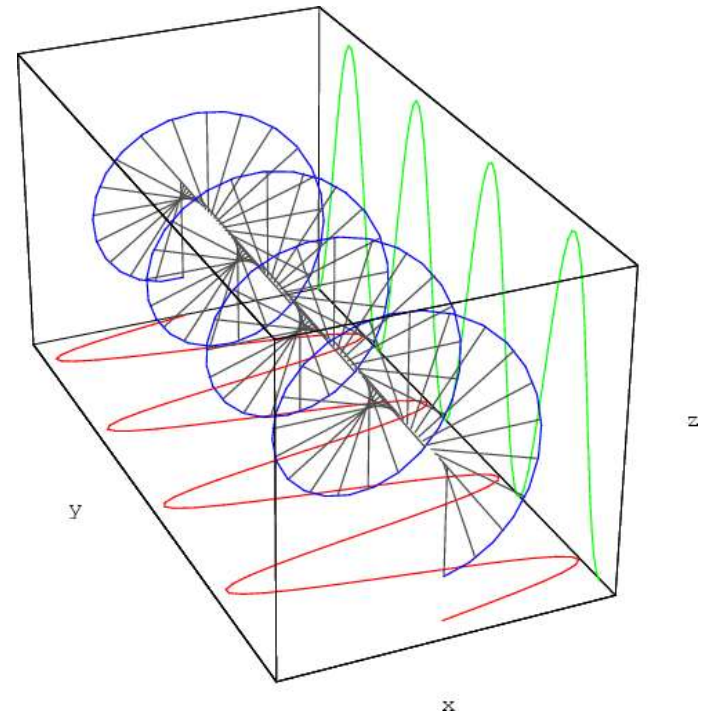
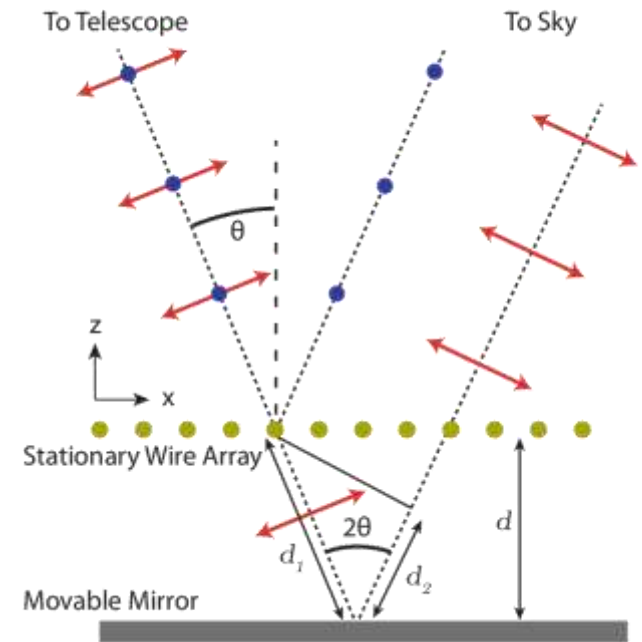
Variable-delay polarization modulators (a.k.a. VPMs)

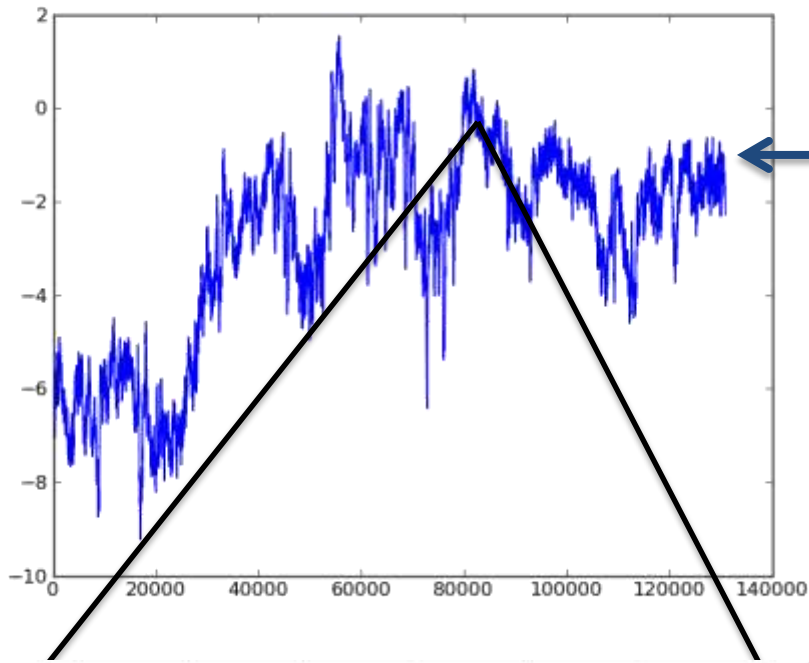
The VPMs consist of a polarizing wire grid in front of a movable mirror.

As the mirror moves, horizontal and vertical polarizations are phase-shifted relative to each other and recombined.

This changes linear to circular polarization, and vice versa. CLASS detectors are only sensitive to vertical polarization.

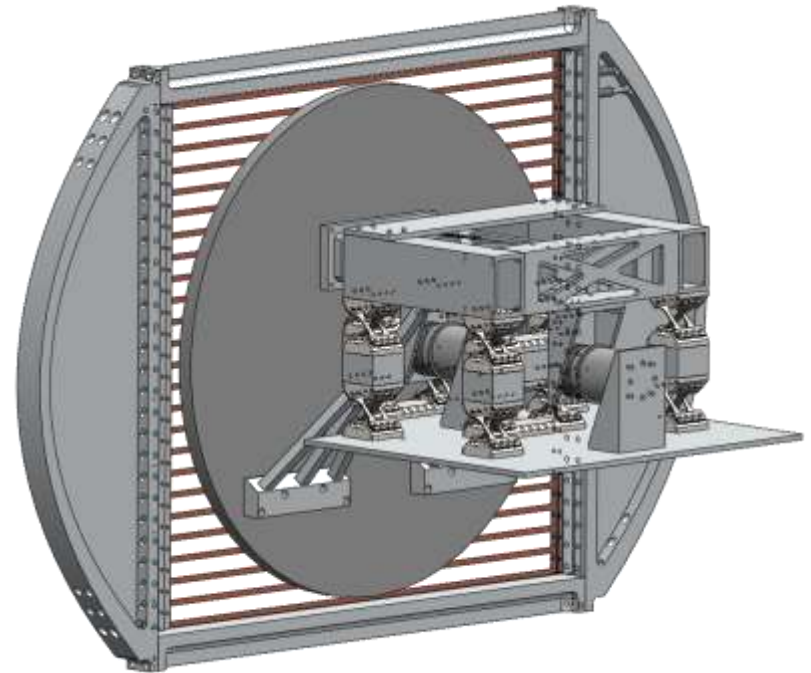
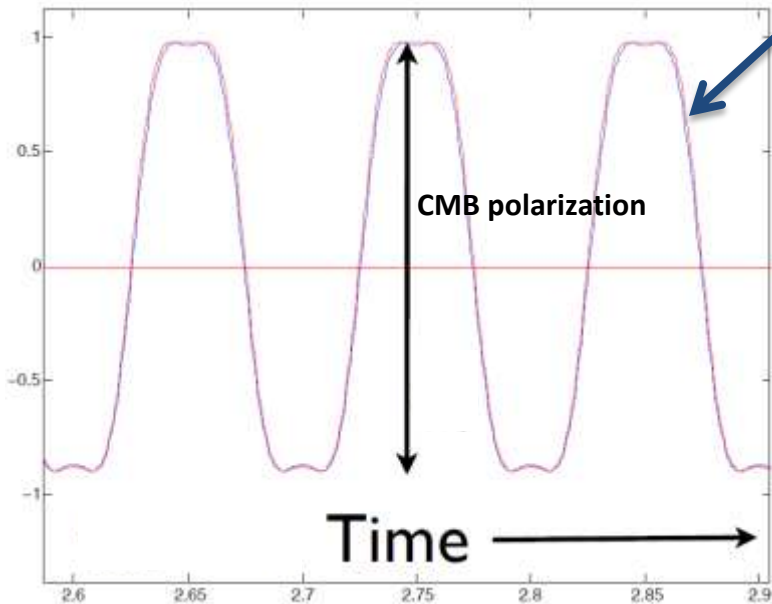
The CMB is linearly polarized (no circular polarization), so as the VPM mirror moves the CMB polarization signal is turned on and off.



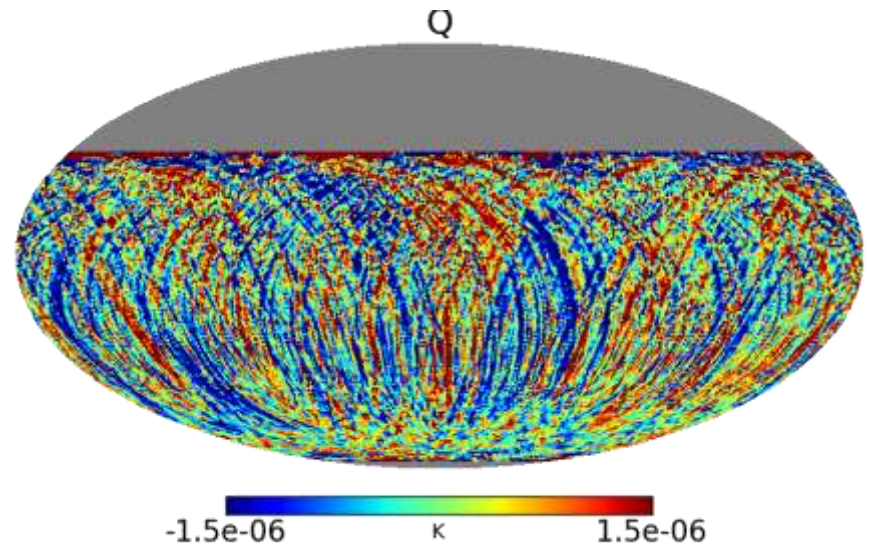
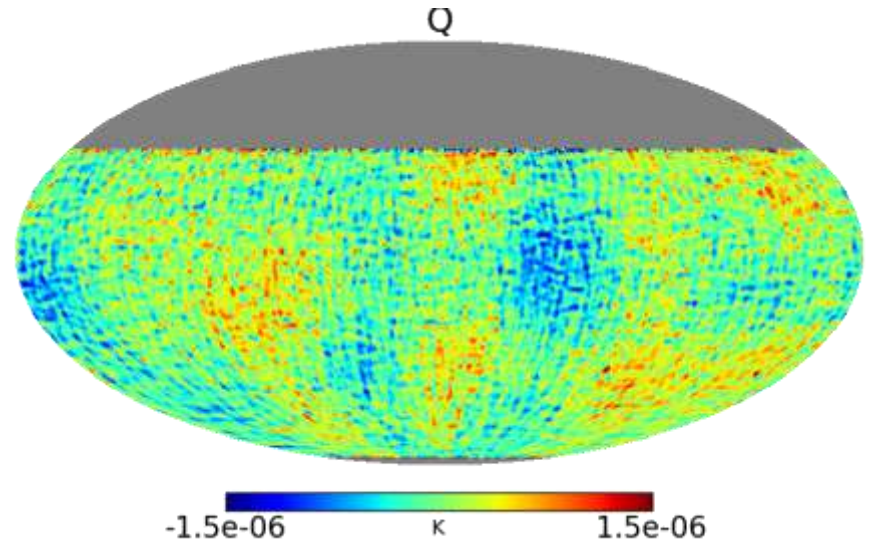
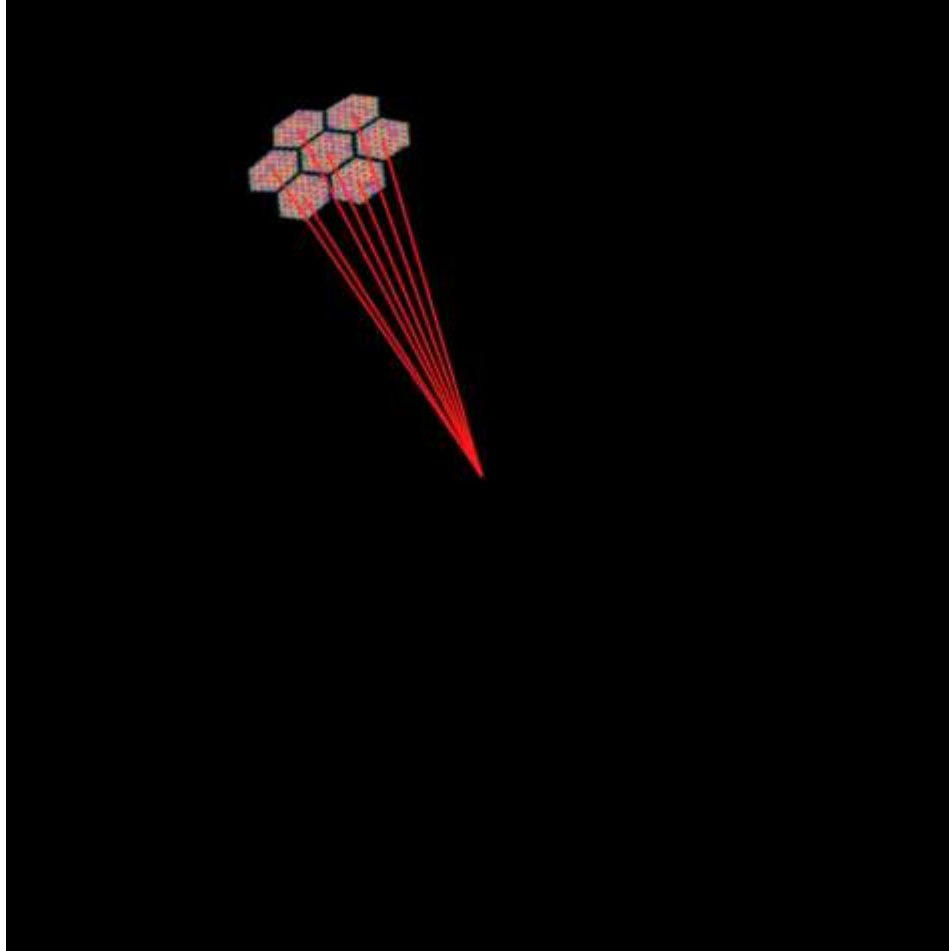


The atmosphere introduces a slowly drifting signal in the detectors that is much larger than the CMB signal.

The VPM allows CLASS to “lock in” to the CMB polarization. We look for the quickly-varying, modulated signal.

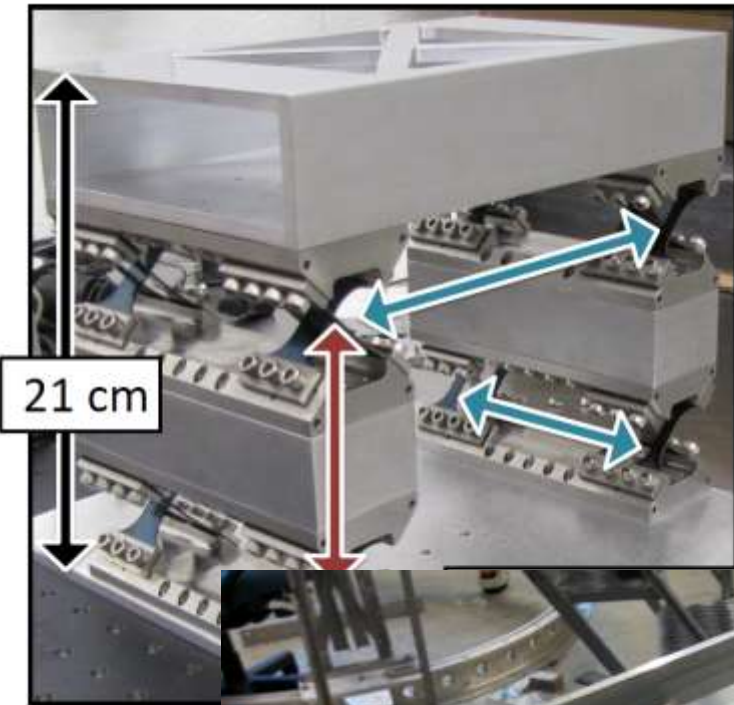


The advantages of modulation



VPM development at JHU

- 1.5 miles of copper-coated tungsten wire.
- Wire grid under 1 ton of tension.
- Wires are wrapped on a cylindrical mandrel in a computer-controlled milling machine.



Questions?

