The Cosmology Large Angular Scale Surveyor (CLASS) 93 GHz Receiver Design

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Cosmology

- What happened immediately after the Big Bang?
- How did the universe begin to expand?
- What's responsible for making our universe homogeneous, isotropic, and spatially flat?

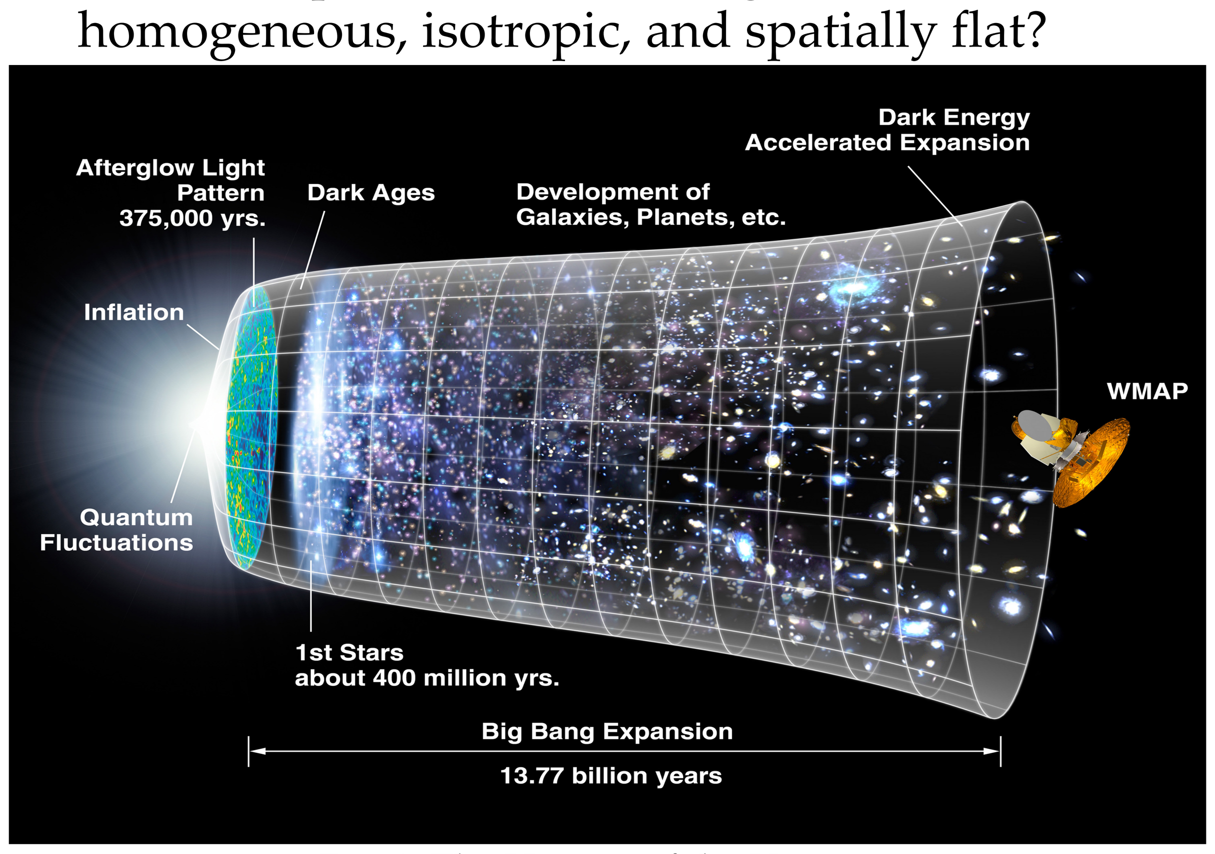

Fig. 1: The History of the Universe.

During the late 20th century, theoretical physicist Alan Guth hypothesized an explanation he coined "Inflation". Inflation is the theory of exponential cosmic expansion believed to have happened 10^{-36} to 10^{-32} seconds after the beginning of time. This expansion roughly evenly distributed the young, hot and dense universe into a much less dense one where it could begin to cool. At about 375 kYr, the universe had cooled enough so as to allow photons to finally freely travel without continuous scattering.

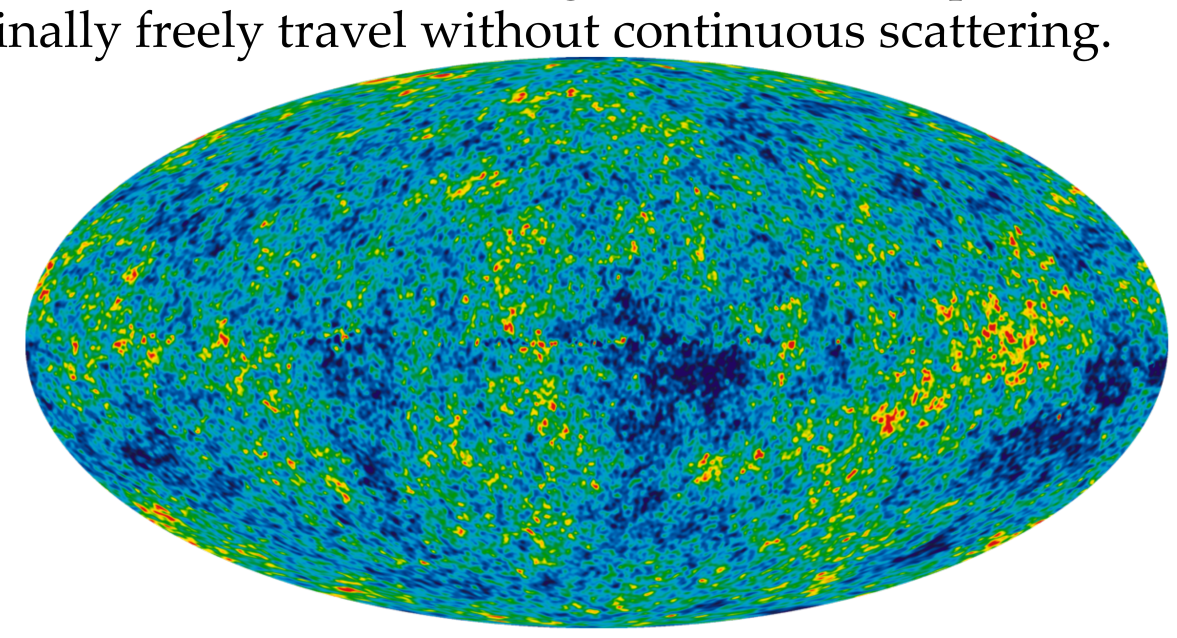

Fig. 2: A full sky map of the cosmic microwave background (CMB) created from 9 years of WMAP data.

These photons today are known as the cosmic microwave background (CMB) and are the oldest radiation in the universe. The inflationary epoch would have produced quantum gravitational waves which would have polarized the CMB, as would have density perturbations. This polarization would still be visible to us in the CMB today.

Many widely agreed upon ideas in physics accept Inflation as a proper explanation for otherwise difficult problems. Its confirmation, or denial, would have tremendous implications for our understanding of the universe.

References

[1] Harrington, K., et. al., arXiv.1608.08234
[2] Iuliano, J., et. al., arXiv.1807.04167
[3] Essinger-Hileman, T., et. al., arXiv.1408.4788

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CLASS Overview

CLASS is a four telescope array designed to measure the polarization of the cosmic microwave background (CMB) in order to characterize relic primordial gravitational waves corresponding to cosmic inflation and the optical depth to reionization.[1]

Located at 5200m in the Atacama desert of Northern Chile, CLASS will map 70% of the sky everyday. The frequency bands, one at 38GHz, two at 93GHz, and one dichroic receiver at 145/217GHz, are chosen to minimize interference by avoiding regions of high galactic and high atmospheric noise (see Fig. 4).

CLASS has an operational lifetime of around 5 years, with that timeline beginning back in the spring of 2016 when the first receiver was installed. The telescope will continue to be fully integrated over the next year and a half with structural completion planned for 2019. The 38GHz data analysis has already begun.

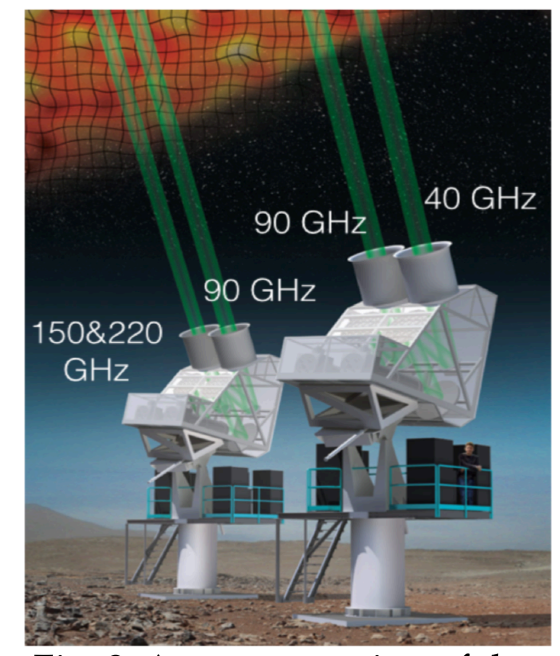
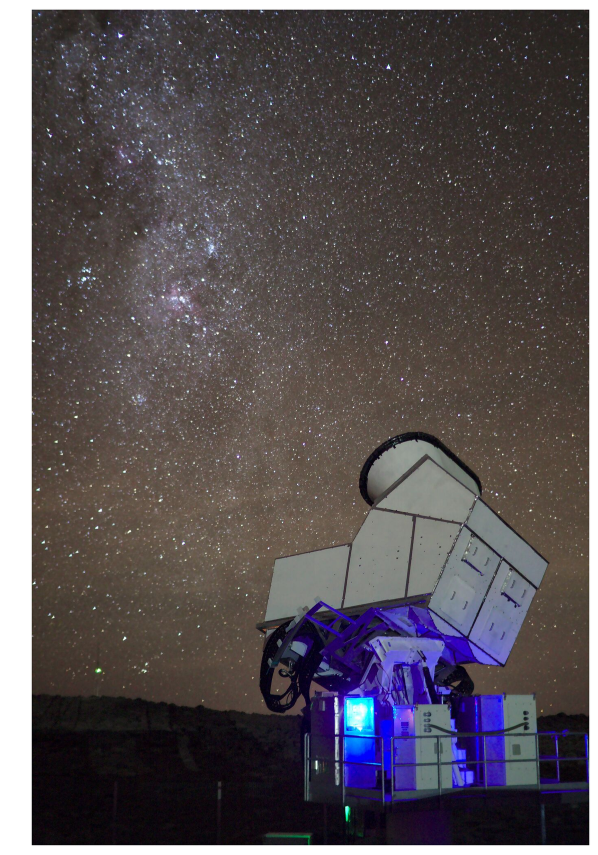


Fig. 3: A representation of the two mount, four array system.



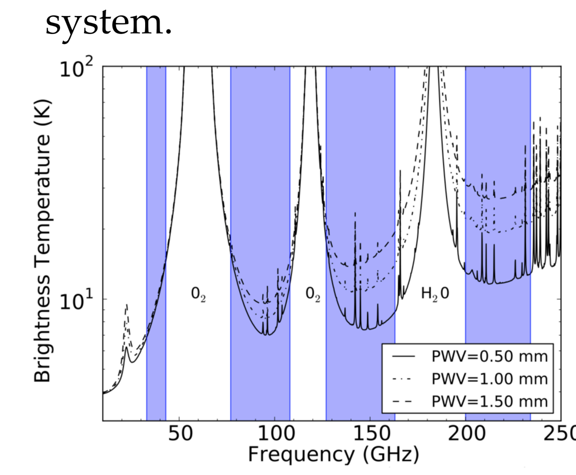


Fig. 4 (left): A plot showing atmospheric temperature versus frequency for a few perceptible water vapor levels. CLASS bands are in blue near the local minima.

Fig. 5 (above): Mount 1, which houses the 38GHz and first 93GHz receivers, observes the sky on a beautiful night.

93 GHz Receiver

Optical Design [2]

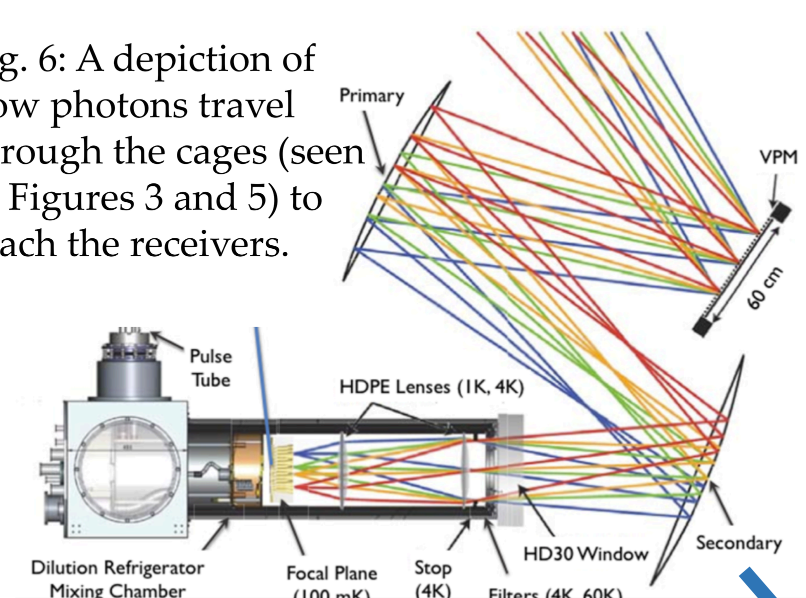


Fig. 6: A depiction of how photons travel through the cages (seen in Figures 3 and 5) to reach the receivers.

The filters and lenses at each stage are:

300K

The outer vacuum window is anti-reflective (AR) coated UHMWPE.

60K

Two reflective MMF and two absorptive PTFE filters.

4K

The 4K stage has an absorptive PTFE filter and a lens machined with holes much smaller in diameter than the wavelength of the CMB.

1K

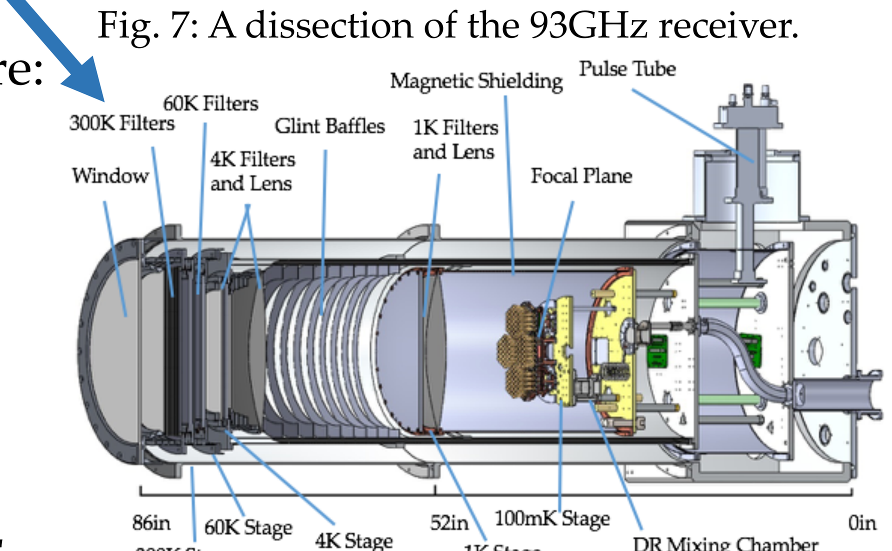
Here there is an absorptive nylon filter, coated with a simulated dielectric layer and another lens like in the previous stage.

The net result is an incredibly effective filtration system. With a loss of less than 30% of in-band power, the 93GHz receiver reaches, on average, 38mK in skyward operation. This corresponds to only 50μW of the original 70W power reaching the 100mK cold stage from the receiver window.

Receiver Overview

Each CLASS receiver is a cryostat placed at the base of the mirror path inside the cages (see Fig. 6). A system of many filters and lenses guide the photons to the detectors. The detectors require sub-100mK temperatures in order to drown out all undesired noise. The cryostat is a dilution refrigerator (DR) continuously cycling liquid helium-3.

Fig. 7: A dissection of the 93GHz receiver.



In the DR mixing chamber, the final stage, cycled helium-3 mixes with helium-4 before being recycled, leading to temperatures close to 25mK in factory configuration. All four receivers are nearly identical with the only differences being the filters, lenses, magnetic shielding, and the detectors.

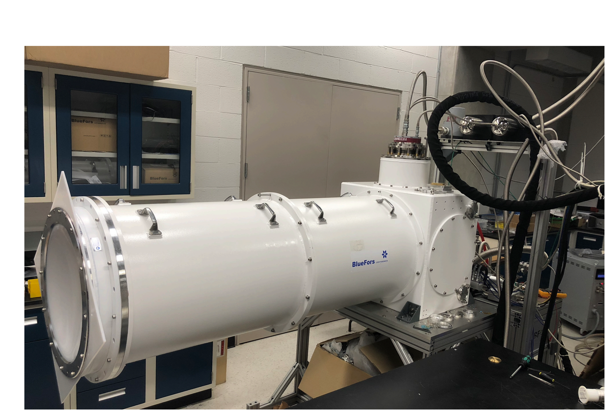


Fig. 8: The second 93GHz receiver under testing. The first is already in the field.

Detector Design [3]

All four of the detectors were built at the Goddard Space Flight Center (GSFC) and are each housed inside nearly identical cryostats built by BlueFors Cryogenics, a Finnish cryogenics company. Feedhorns attach to the focal plane and funnel the CMB photons onto the transition-edge-sensor (TES) detectors, the bolometers which encode the radiation into data. The diameter of each feedhorn is machined to the proper size for each frequency band's corresponding wavelength. Each receiver's focal plane is covered with these different sized feedhorns. The 38GHz receiver has only 36, while both 93GHz receivers each have 259. As the last stage, the focal plane reaches sub-50mK temperatures, with the exact temperature depending on the band.

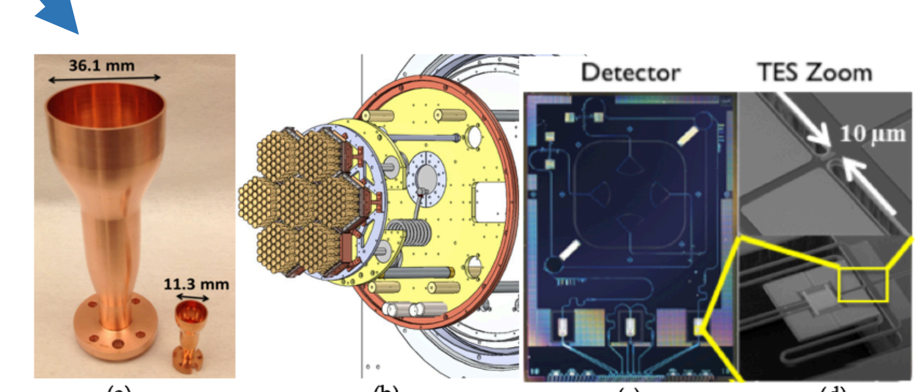


Fig. 9: (a) The feedhorns of the 38GHz receiver (38.1mm) and the 93GHz receiver (11.3mm). (b) A software model showing the 93GHz detector and its 259 oxygen-free high-conductivity copper feedhorns connecting to the focal plane. (c) A TES-based detector, found at the base of a feedhorn. (d) A picture from a scanning-electron-microscope of a TES for the 38GHz detector.