CLASS
Collaborators

NASA GSFC
D. Chuss
K. Denis
A. Kogut
N. Miller
H. Moseley
K. Rostem
E. Wollack

JHU
A. Ali
J. Appel
C. Bennett (PI)
J. Eimer
T. Essinger-Hileman
D. Gothe
K. Harrington
J. Karakla
D. Larson
T. Marriage
Z. Xu

Red=Present

NIST
H-M. Cho
K. Irwin
G. Hilton
C. Reintsema

CfA-SAO
L. Zeng

PUC de Chile
R. Dünner

Columbia
D. Araujo
G. Jones
M. Limon
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See Joseph Eimer’s CLASS Poster for more information

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G. Jones
M. Limon
A. Miller

Northwestern
G. Novak

UBC
M. Amiri
M. Halpern
G. Hinshaw
CLASS targets CMB B-modes at large angles.

1) **Recombination bump** packs a lot of signal.

2) **Avoids lensing B-modes.**

Also E-mode **Reionization** Constraints!

\[ \ell(\ell+1)C_{\ell}^{BB}/2\pi \leq 20 \mu K\text{-arcmin over 50\% of total sky} \]
CLASS targets CMB **B-modes** at large angles.

1) **Recombination bump** packs a lot of signal.

2) **Avoids lensing B-modes.**

Also E-mode **Reionization** Constraints!

A unique range of angular scales!
(in a field largely targeting the recombination peak)
Atmospheric Transmission

Antenna Temperature ($\mu$K)

Frequency (GHz)

CLASS is an array of 4 telescopes operating at three frequencies that straddle the foreground minimum.

Additional foreground constraints from PIPER (200 GHz, 270 GHz) and Planck (217, 353 GHz)

CLASS Survey Design Parameters

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Detectors</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 GHz</td>
<td>72</td>
<td>1.5°</td>
</tr>
<tr>
<td>90 GHz</td>
<td>600</td>
<td>40’</td>
</tr>
<tr>
<td>150 GHz</td>
<td>120</td>
<td>24’</td>
</tr>
</tbody>
</table>
To detect **large-angle modes**, CLASS needs a **wide survey**.

The Atacama is the best site for large sky coverage.

Site in Atacama Desert is not far from the equator: **most of sky** is surveyed at zenith angle 45 deg.
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Multiple observing angles through sky and deck rotation in the JHU highbay.

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The CLASS Way

1. Systematics control with front end modulation.

2. Sensitivity with high efficiency optics and TES bolometers cooled to 150 mK.

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Continuous Operation with 50 μW at 100 mK

One of the four CLASS receivers (PT+DR Cooler) undergoing tilt test.
The CLASS Way

1. Systematics control with front end modulation.

2. Sensitivity with high efficiency optics and TES bolometers cooled to 150 mK.


40 GHz Focal Plane Assembly.
M. Hazumi: You want to talk nitty gritty? You are welcome!

Sensitivity Discussion

Photons:

\[ \sigma_P = \frac{h \nu \Delta \nu}{\eta \sqrt{\Delta \nu \tau}} \left[ \eta n_0 (1 + \eta n_0) \right]^{1/2} \]

(Zmuidzinas 2003)

\( \eta = 65\% \) instead of \( \eta = 40\% \): 25\% less shot NET

\( \nu = 90 \ \text{GHz} \) instead of \( 150 \ \text{GHz} \) gives further reduction (generic \( \nu \) dependence and higher atmosphere emissivity)
M. Hazumi: You want to talk nitty gritty? You are welcome!

Phonons:

\[ \sigma_{\text{Phonon}} = \eta^{-1} \sqrt{4(GT)k_bT} \]
\[ \sim \eta^{-1} \sqrt{4(\eta P)k_bT} \]
\[ = \eta^{-1/2} \sqrt{4P k_bT} \]

(P is total power from atm etc)

\[ \eta = 65\% \text{ instead of } \eta = 40\%: 25\% \text{ less Phonon NET} \]
\[ T = 150 \text{ mK instead of } T = 450 \text{ mK: 70\% less Phonon NET} \]

At 90 GHz, total power from atmosphere is lower.

While generally less than 50\% of total power, phonon contribution is not far below that of photons.
M. Hazumi: You want to talk nitty gritty? You are welcome!

Mitigate other practical effects that traditionally have caused problems (more grit):

Able to select best/most uniform detectors to give **better yield** (through fab and biasing)

Able to multiplex readout faster given current electronics options -- **less aliased readout noise**.
M. Hazumi: You want to talk nitty gritty? You are welcome!

Three Designs*

Phonons

NET = 270 μK-√s
150 GHz
modest efficiency
500 mK

Photons

200 μK-√s
150 GHz
high efficiency
150 mK

140 μK-√s
90 GHz
high efficiency
150 mK

*examples for argument; not exact; for instance need to add amplifier noise
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200 μK-√s

150 GHz
high efficiency
150 mK

CLASS goal

Bicep II has nearly achieved this

*examples for argument; not exact; for instance need to add amplifier noise
D. Fixsen: I feel like a ballerina on a football field.
CLASS uses modulation to measure large scales.

A Variable-Delay Polarization Modulator (VPM) is the front-end optical element.

Modulates signal at \(~5\) Hz to separate signal from the I-to-Q leakage of atmosphere and other instrument-related drift.

\[ U' = U \cos \delta + V \sin \delta. \] (1)

Here \(U\) and \(U'\) are the input and output Stokes parameters, and \(V\) is the input circular polarization. Here \(\delta\) is the electrical phase delay between the polarized component transmitted by and that reflected by the grid upon recombination at the output port of the device. This is the phase of interest when using the VPM as a modulator.

In the limit in which the wavelength is much larger than the length scales that characterize the local grid geometry, the VPM phase is proportional to the path difference between the two polarizations, \(\delta_\infty = \frac{4 \pi d}{\lambda} \cos \theta\). (2)
CLASS uses **modulation** to measure **large scales**.

A Variable-Delay Polarization Modulator (VPM) is the front-end optical element. Modulates signal at \( \sim 5 \text{ Hz} \) to separate signal from the I-to-Q leakage of atmosphere and other instrument-related drift.

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*Both the atmosphere and gain time streams have \( 1/f^2 \) power spectra. The atmosphere has an amplitude of 0.05 K at 0.1 Hz and the gain fluctuation has an amplitude of 0.5% at 0.005 Hz.*
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CLASS Detectors

Horns and Planar OMT produce simple single-moded beams.

High-efficiency and design repeatability is achieved through use of monocrystalline silicon dielectric.

Intrinsic OMT design achieves broad 50% fractional bandwidth, which may be divided for multi-frequency operation.

On-chip transmission line filtering, shielding and niobium gap provide well defined bandpass and stringent blue leak control.
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Significant testing infrastructure! Testbeds at GSFC, JHU, and Columbia with dedicated scientist-operators. Crosschecks and high throughput.

Wednesday, June 12, 13
Exploring Constraints with Sky Cuts and Foregrounds

(Pixel-based likelihood as in Katayama & Komatsu 2011)

Note

Non-Gaussian likelihood using large angular scales can yield a detection with tail to high $r$.

$r_{\text{input}} = 0.02$

tensor-to-scalar ratio

Preliminary!!! More work to be done.

Mounts

Cryostats

Atacama Site Preparation

Optics

Focal Planes

VPMs

ACT/ABS

Polarbear

CLASS

1.5 m