LEGACY ARCHIVE FOR MICROWAVE BACKGROUND DATA ANALYSIS (LAMBDA): AN OVERVIEW

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ABSTRACT

This is an overview of the data products and other resources available through NASA's LAMBDA site https://lambda.gsfc.nasa.gov/. An up-to-date version of this document, along with code tools actively maintained and developed by LAMBDA staff, can be found on the LAMBDA GitHub page at https://github.com/nasa-lambda/lambda_overview.

New data products and other updates are announced on LAMBDA's twitter account at https://twitter.com/NASA_LAMBDA.

If you have questions or suggestions relating to LAMBDA, or are interested in joining a LAMBDA advisory group, please contact us using the form here: https://lambda.gsfc.nasa.gov/contact/contact.cfm.

1. INTRODUCTION

The Legacy Archive for Microwave Background Data Analysis (LAMBDA) was set up in 2002 and is part of NASA's High Energy Astrophysics Science Archive Research Center (HEASARC, https://heasarc.gsfc.nasa.gov/). LAMBDA provides a resource for cosmology researchers, hosting data products from cosmic microwave background (CMB) measurements, and other experiments, in addition to a range of software tools, and educational material.

2. DATA PRODUCTS

LAMBDA is the primary data host for NASA's COsmic Background Explorer (*COBE*) and Wilkinson Microwave Anisotropy Probe (*WMAP*) CMB satellite missions. Data products from *COBE* are available here and products from *WMAP* here. Additionally, we host data products from current ground-based and suborbital collaborations, including experiments listed below. We provide imbedded links to each LAMBDA experiment overview page plus a citation to a recent publication; data products can be accessed through tabs on the left of the page.

- Atacama Cosmology Telescope (ACT), including polarization-sensitive ACTPol data [1]

- BICEP1, BICEP2, and Keck Array [2]

- POLARBEAR [3]

- Q/U Imaging ExperimenT (QUIET) [4]

- SPIDER [5]

- South Pole Telescope (SPT), including polarization-sensitive SPTpol data [6]

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These data products include maps of CMB intensity and polarization fluctuations, weight or hit maps and noise simulations, as well as higher-level data products, such as likelihood code for fitting cosmological parameters. We host archival CMB data products from earlier experiments, see list at bottom of this page.

LAMBDA also hosts ancillary data sets of interest to the CMB community, such as measurements of **diffuse Galactic emission** for CMB or intensity mapping foreground studies. These data sets are available here.

A collection of Galactic and extragalactic **compact source catalogs** from radio, microwave, and infrared frequencies is provided here.

Catalogs of clusters detected using the Sunyaev Zel'dovich (SZ) effect from ACT, *Planck*, and SPT, SZ angular power spectrum templates, and SZ simulations, are available here.

Plots of CMB temperature, polarization, and gravitational lensing power spectra from various experiments, designed for use in presentations, are provided on the LAMBDA graphics page. A lensing bandpower plot is provided as an example in Figure 1, updated with the *Planck* 2018 results [7].

3. SOFTWARE TOOLS

Several tools are actively maintained or being developed by LAMBDA staff on GitHub here, including:

- `cmb_footprint`, a tool to visualize footprints of different sky surveys. A sample set of CMB footprints from this tool is shown in Figure 2. An interactive version of the tool can be accessed on the main LAMBDA page here.

- `cmb_analysis`, a set of analysis tools including code for calculating CMB power spectra and mode-mixing matrices from temperature and polarization maps with partial sky coverage

- `cmbpol_plotting`, data files and code for plotting and comparing CMB power spectra measurements from different experiments
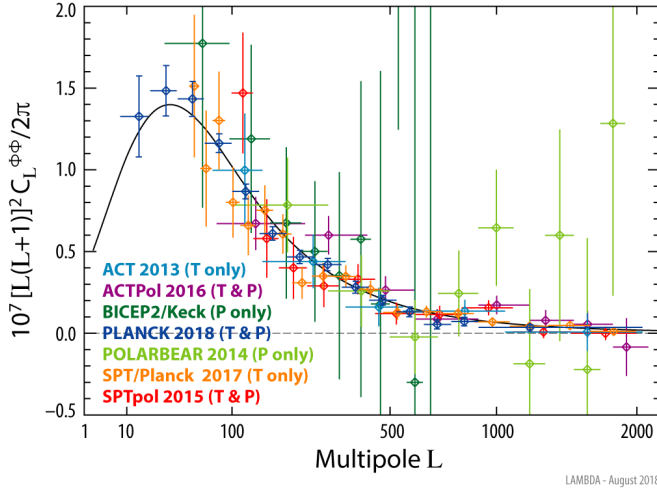
Fig. 1.— Compilation of CMB gravitational lensing potential power spectra from current experiments, estimated using temperature ('T') and polarization ('P') anisotropy data. This figure, and other figures comparing CMB temperature and polarization power spectra, including B-mode measurements, are available here, along with text files containing data points and error bars.

- docker-lambda, a Docker image file providing Python jupyter notebooks with many useful CMB utilities, including ACTPol and BICEP1 likelihood code examples

LAMBDA also hosts an interactive version of the CAMB [8] code for generating CMB power spectra here, and provides links to several unit conversion utilities, and calculator utilities.

An extensive list of external tools for both CMB and broader astrophysical data analysis is provided with links here. Examples include:

- codes for generating CMB and matter power spectra for a given set of cosmological parameters (e.g., CAMB, CLASS [9], PICO [10])

- codes for constraining cosmological parameter constraints from data using various Markov chain Monte Carlo methods (e.g., CosmoMC [11], MontePython [12])

- codes made public by different experimental collaborations (ACT, BICEP2/Keck, SPT, etc.) for using their data in cosmological parameter fitting (e.g., new files to use with CosmoMC)

- codes for simulating aspects of the microwave sky, for example the Python Sky Model (PySM [13]), or the Hammurabi code for simulating polarized Galactic synchrotron emission [14]

- tools relating to pixelization of the sky (HEALPix, HEALPy [15]), and calculating power spectra from pixelized sky maps (e.g., PolSpice [16])

4. EDUCATION

LAMBDA hosts educational material, including several class and lab assignments provided by instructors, here. A graphical history of the ΛCDM model, aimed at students, is provided here. This includes both theoretical material (e.g., description of components of the model and stages in evolution of the universe), and observational results, with graphical comparison of current and historical parameter constraints (e.g., age of the universe, optical depth, density of dark and baryonic matter, and Hubble constant).
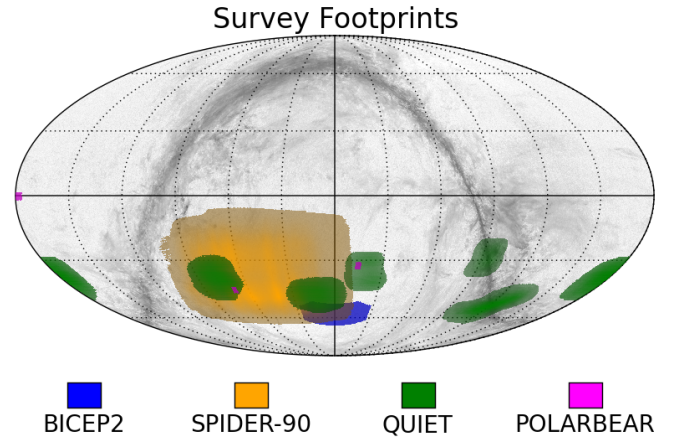
Survey Footprints

Fig. 2.— A comparison of the sky coverage of several CMB polarization surveys in equatorial coordinates, produced by the cmb_footprint code. The grayscale background shows the Galactic polarized dust intensity measured by *Planck*.

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