An Experimental Investigation of the First Stages of the Formation of Cosmic Structures

Paolo de Bernardis and Andrew Lange†

2006 Balzan Prize for Observational Astronomy and Astrophysics

Balzan GPC Adviser: Per Olof Lindblad
Main Researchers: Martino Calvo, Luca Lamagna, Silvia Masi, Gianluca Polenta, Maria Salatino, Alessandro Schillaci
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Period: 2006-2013

Paolo de Bernardis is Professor of Astrophysics and Observational Cosmology at the Università di Roma "La Sapienza". Andrew Lange† was Marvin L. Goldberger Professor of Physics at the California Institute of Technology.

This project, carried out under Professor Paolo de Bernardis, aimed to measure the effect of the first structures on the background CMB light. This project uses an original approach: performing *spectroscopic* measurements of CMB anisotropy. From the experimental point of view, this strategy requires building a *differential spectrometer* matched to a large aperture telescope to achieve the necessary angular resolution. A long preparation text was needed to qualify the method. Technical publications analyzing possible systematic effects related to these measurements can be cited, and several more are in preparation. The first opportunity to test this idea experimentally will be with the forthcoming flight of the OLIMPO balloon-borne telescope, recently upgraded with an ambient-temperature differential spectrometer, which can be inserted as a plug-in in the optical path between the telescope and the multi-band photometer, transforming the 4-band photometer in a low-resolution spectrometer.

A full phase-A study of an innovative satellite mission, called SAGACE, carried out by the group at "La Sapienza" in the framework of the second project above has

been completed. The full study has been described in a long document (ref. KISAG-RP-010), which has been submitted to the Italian Space Agency for evaluation and possible implementation as a national small mission.

Balzan funds were used to acquire hardware to design and complete the instruments, to support the dedicated work of postdoctoral students already trained on the BOOMERanG project, to support the collaboration with the Cardiff (Ade, Mauskopf) and Pasadena (Lange) groups for the development of subsystems, and the diffusion of cosmology results through the preparation of a book on observational cosmology. Three Balzan postdoctoral fellowships at "La Sapienza" focusing on the data analysis of the BOOMERanG and Planck experiments and on the SAGACE study have been assigned. This work resulted in a large number of papers. Balzan funds also provided support for: the hardware of the large throughput Martin-Puplett interferometer built in the group. This instrument is a prototype for the missions described above, and was the subject of the PhD thesis of Dr. Alessandro Schillaci; the development of innovative mm-wave detectors, the microwave kinetic inductance detectors (paper [16]) and the cold electron bolometers; cooperation with the Caltech group on CMB polarization measurements, with the development of a parallel study carried out in Europe for a space mission devoted to CMB polarization.

Two proposals have been submitted to ESA, with Paolo de Bernardis serving as the PI and the collaboration of the US teams in addition to the European ones. His group is also actively studying the impact of systematic effects on the scientific exploitation of these measurements. An even more ambitious mission, called PRISM, has been studied and proposed to ESA in 2013 in the framework of the call for science with large missions.

Publications

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An Experimental Investigation of CMB Polarization

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2006 Balzan Prize for Observational Astronomy and Astrophysics

Balzan GPC Adviser: Per Olof Lindblad
Project Directors and Main Researchers: Tom Soifer, James Bock (project managers in place of Prof. Andrew Lange); Randol Aikin, James Bock, John Kovac, Roger O'Brient, Tom Soifer
Affiliated Institutions: Università di Roma "La Sapienza"; California Institute of Technology (Caltech)
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The second part of Professor Andrew Lange's investigation was used to support an emerging generation of young experimental cosmologists and an ambitious program of new ground-based and balloon-borne CMB experiments. Funds from the Balzan Prize were thus applied to build upon the results of BOOMERanG, the basis of the 2006 Balzan Prize, to probe the physical process of inflation via CMB polarization measurements. Two experiments were initiated to search for a handed 'B-mode' polarization pattern using new technology millimeter-wave focal plane detector arrays.

The BICEP2 (Background Imaging of Cosmic Extragalactic Polarization) experiment is a degree-scale polarimeter currently carrying out science observations from the South Pole. The receiver is in many ways similar to its predecessor experiment BICEP, but differs in that the focal plane has been greatly enhanced, going from individual detectors, similar to those used in the *Planck* satellite, to entirely micro-fabricated arrays with superconducting sensors and readouts. Balzan funds enabled

them to initiate BICEP2, and a more powerful successor experiment named the Keck Polarimeter Array, with support from the National Science Foundation and the W.M. Keck Foundation.

In parallel, the research group has been developing a powerful balloon experiment named SPIDER that uses 6 new-technology focal plane arrays similar to the focal plane developed for BICEP2, except with even higher sensitivity due to the lower atmospheric emission available on a high-altitude balloon. SPIDER observes CMB polarization in multiple frequency bands, a key to discriminating cosmological polarization from polarized Galactic emission. After a pre-flight integration in Palestine, TX, SPIDER was deployed to Antarctica for its first flight in December 2013. The 2013/14 balloon campaign was cancelled, however, due to the logistical challenges caused by the October government shutdown. Another SPIDER flight was targeted for the 2014/15 season.

The BICEP2 instrument completed its expected three years of scientific observations from the South Pole and was decommissioned in December 2012. BICEP2 successfully led to the implementation of the Keck Polarimeter Array with five receivers of equal sensitivity that have now been fielded at the South Pole station and are currently observing. The collaboration is putting forth a comprehensive effort to analyze the BICEP2/Keck data set. Because BICEP2/Keck comprises the most sensitive probe of inflationary B-mode polarization to date, extreme care must be taken to account for all possible sources of systematic error and foreground contamination. Furthermore, with multiple receivers observing over many years, the data set allows for numerous checks on systematic errors that must be carefully accounted. In the meantime, several intermediate papers have been published describing the instrument performance and the state of the detector technology that enable these measurements.

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