

# *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

**Researchers:** Martino Calvo, Luca Lamagna, Silvia Masi, Gianluca Polenta, Maria Salatino, Alessandro Schillaci

**Affiliated Institutions:** Università di Roma “La Sapienza”; California Institute of Technology (Caltech)

**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, using an original approach, performing *spectroscopic* measurements of CMB anisotropy. From the experimental point of view, this strategy required building a *differential spectrometer* matched to a large aperture telescope to achieve the necessary angular resolution. Several publications resulted from the preparatory phases. The idea was tested experimentally with the flight of the OLIMPO balloon-borne telescope, which had been upgraded with an ambient-temperature differential spectrometer, 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, was carried out by the group at “La Sapienza” in the framework of the second project above, and is 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 were 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 (a prototype for the missions described above, and the subject of Alessandro Schillaci’s PhD thesis); the development of innovative mm-wave detectors, the microwave kinetic inductance detectors (paper submitted for publication) 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 European Space Agency (ESA), with Paolo de Bernardis serving as the PI and with 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, PRISM, was studied and proposed to the 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*

**Paolo de Bernardis and Andrew Lange †**

**2006 Balzan Prize for Observational Astronomy and Astrophysics**

**Balzan GPC Adviser:** Per Olof Lindblad

**Project Directors and Researchers:** Tom Soifer, James Bock (project managers in lieu of Andrew Lange); Randol Aikin, John Kovac, Roger O’Brient

**Affiliated Institutions:** Università di Roma “La Sapienza”; California Institute of Technology (Caltech)

**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.

Funding for Professor Andrew Lange’s prize 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 that carried 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.

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.

In parallel, the research group has been developing SPIDER, a powerful balloon experiment that uses 6 new-technology focal plane arrays similar to the focal plane developed for BICEP2, but 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. SPIDER was deployed to Antarctica for its first flight in December 2013, and was launched in 2015.

## **Publications**

*For publications prior to 2012, see the Balzan Foundation website at <http://www.balzan.org/en/prizewinners/paolo-de-bernardis-e-andrew-lange/research-project-bernardis-lange>.*

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