# Andrew E. Lange

1957–2010

BIOGRAPHICAL *Memoirs*

*A Biographical Memoir by*
*Marc Kamionkowski*



NATIONAL ACADEMY OF SCIENCES

# ANDREW E. **LANGE**

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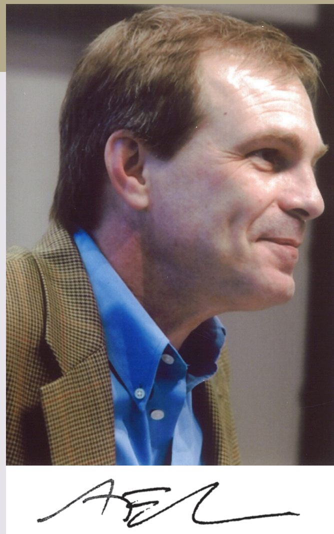
Elected to the NAS, 2004



*By Marc Kamionkowski*

Andrew Lange was an experimental cosmologist, a key figure in the transformation of cosmology from an order-of-magnitude game to a precise science. He had a penchant for instrumentation, which was combined with the highest scientific ambitions and an unusual gift for leadership and group building. He will perhaps be best known for his co-leadership of Boomerang, the balloon-borne experiment that provided the first high-angular-resolution map of the cosmic microwave background, from which cosmologists inferred that of the three possible cosmological geometries—open, closed, or flat—ours is a flat Universe. Lange then led and/or played a significant role in many of the most important cosmic microwave background (CMB) experiments in the decade that followed, including the Planck satellite, and in so doing mentored an impressive number of outstanding young scientists who now make up a good fraction of the current leadership of the field.

Lange did his undergraduate work at Princeton, graduating with a B.A. in physics in 1980. He then earned his Ph.D. from UC-Berkeley in 1987, whereupon he was named an assistant professor at Berkeley. In 1994 he moved to Caltech as a full professor and in 2008 became the chairman of its Division of Physics, Mathematics, and Astronomy.

Andrew E. Lange was born in Urbana, Illinois, on July 23, 1957, the son of an architect and a librarian, and raised primarily in Easton, Connecticut, in a small-town environment. Andrew was into everything: he played Little League baseball, was an Eagle Scout, had a photographic darkroom, ran cross-country track, skied, and canoed. He was student council president during his senior year in high school. The reminiscences of family and early friends, who recall a smart, good-humored, friendly, responsible young man, resonate with those who knew him later in life.

> "...He asked to take on the most complicated and difficult project I had with the idea that this way he could learn the most."

Andrew's lifelong interest in cosmology was nurtured as an undergraduate at Princeton University by pioneering cosmologist David Wilkinson, and he often recalled fondly a summer spent working with future Nobel Laureate John Mather and John Arens on an infrared camera at Goddard Space Flight Center. Andrew stayed during that summer in a basement room at Mather's house, and Mather recalls that after a long day working at the center, the young man would disappear into his room to systematically work his way through all 1215 pages of Misner, Thorne, and Wheeler's classic *Gravitation*.

Given Andrew's undergraduate work with several members of the team developing NASA's Cosmic Background Explorer (COBE) satellite, it was no surprise that he wound up in graduate school at Berkeley (where he was sent with a recommendation, "best senior thesis I've seen in 15 years," from Wilkinson) working with Paul Richards. According to Richards, "The Andy Lange who walked into my office in the fall exhibited great enthusiasm, great confidence and remarkable people skills. It would obviously be fun to work with him. He asked to take on the most complicated and difficult project I had with the idea that this way he could learn the most."

Andrew's thesis project was a rocket experiment to measure the frequency spectrum of the cosmic microwave background. On the initial flight the cover of the rocket failed to open, so he had to settle for an instrument thesis. Nevertheless, the Physics Department recognized his talents and appointed him assistant professor in 1987 upon completion of his Ph.D. and promoted him to associate professor with tenure in 1993. A subsequent flight of the Berkeley-Nagoya rocket experiment showed an anomalous sub-millimeter excess in the cosmic microwave background (CMB) frequency spectrum, an exciting result that received considerable attention. However, it was shown shortly thereafter by COBE-FIRAS (Far Infrared Absolute Spectrophotometer), as well as a later flight of the same rocket, to be incorrect. According to Richards, "It was a difficult experiment, but somehow, no matter how tough things got, he had people smiling."

The main focus of Andrew's subsequent work was to seek angular fluctuations in the CMB, the thermal bath of radiation, discovered in 1965 by Penzias and Wilson, left over from the Big Bang. A dipole temperature anisotropy of roughly one part in a thousand had been discovered in the early 1970s and was attributed to our 300 km/sec motion with respect to the CMB rest frame. As far as could be determined, the CMB intensity was otherwise perfectly isotropic. Still, theorists surmised that galaxies, clusters of galaxies, and even larger-scale cosmic structures grew via gravitational amplification of primordial fluctuations in the density of matter, and virtually any theory for these cosmic structures predicted there should be intensity fluctuations in the CMB, although quite tiny (one part in 10,000 or smaller). The purpose of a Differential Microwave Radiometer (DMR) experiment aboard COBE was to seek these fluctuations, but in competition with COBE were a number of other groups seeking these fluctuations from ground or balloon experiments.

While Andrew was a student, the National Science Foundation funded the creation of the Berkeley Center for Particle Astrophysics, which then supported measurements from a balloon of degree-scale CMB fluctuations. Support for such experiments was limited from NASA, which was focused on COBE, whose DMR experiment was seeking fluctuations at larger angular scales. Richards' group (including Lange, as he was promoted from student to faculty) and some collaborators began the MAX project, which had five balloon flights. The MAX measurements showed that dust emission would not be a problem for degree-scale CMB measurements and enabled the team to develop bolometric techniques—including the first 100 mK bolometers—and produce the first report of degree-scale anisotropy, following by a few years COBE-DMR's discovery of CMB fluctuations at large angular scales.

Also during this time, while an assistant professor, Andrew obtained early detections of the Sunyaev-Zeldovich effect via the SuZIE ([eponymous] Infrared Experiment), and flew, with the Nagoya group, a successful rocket measurement of infrared emission from singly ionized carbon at high Galactic latitude. With a broader Japanese collaboration, he built a bolometric instrument for the Japanese Infrared Telescope in Space (IRTS). According to Lange's student Jamie Bock, who arrived at Berkeley as Andrew was joining the faculty (six months post-Ph.D.), "The early projects had some uneven scientific results but showed a lot of moxie and pioneered new techniques that paid off later," both in CMB science and in infrared/sub-mm astronomy.

About the time that Andrew was promoted to the tenured faculty, a group from Rome, led by Francisco Melchiorri, approached Richards with the idea for Boomerang (Balloon Observations of Millimetric Extragalactic Radiation and Geophysics)—hereafter referred to, simply, as Boomerang—a CMB experiment to be carried out via a long-duration balloon flight in Antarctica. Richards suggested that Andrew lead the Berkeley portion of the effort, and Andrew then partnered with Melchiorri's young protégé, Paolo de Bernardis. The Italians were responsible for the telescopes, cryogenics, and gondola, while Berkeley would provide the detectors and the electronics. This was also around the time that MAX evolved into the much more powerful Millimeter Anisotropy Experiment Imaging Array (MAXIMA) experiment, and there was considerable overlap and close coordination between the MAXIMA team, led by Richards, and the Boomerang team, led by Andrew. MAXIMA was to have higher sensitivity and better cryogenics but was designed to operate on a relatively short flight from NASA's North American balloon facility, while Boomerang was to compensate for its lesser sensitivity with a much longer balloon flight, launched from NASA's McMurdo Station in Antarctica.

The Antarctic sensing operation posed a challenge, given the higher flux of cosmic rays, which provide a spurious signal, on a balloon flown near the South Pole. To remedy the situation, Andrew and Bock developed a bolometer with wires arranged in a spider-web pattern to provide a large cross-section for microwave radiation but minimal cross-section for cosmic rays. These spider-web bolometers were to not only prove valuable for Boomerang and MAXIMA, but also to dominate CMB science and sub-mm/IR astronomy for a decade and to enable the remarkable results, twenty years later, from the Planck and Herschel satellites.

According to Paolo de Bernardis, Andrew said of Boomerang that "a new experiment of this kind is like falling in love: there's no way anybody can stop it." In the same vein, about this time, Andrew met, at a 1992 meeting of Packard Fellows (he was awarded the Fellowship in 1989), Frances Arnold, an assistant professor in chemical engineering at Caltech. Oddly, they had never met during all the years they had overlapped as Princeton undergraduates and Berkeley graduate students, but eventually they married. Andrew then raised James, Frances's son from a previous marriage, as his own, and Frances and Andrew had two sons, William and Joseph, together. Frances and Andrew separated in 2007. After a few years of weekly flights that Andrew made between Burbank and Oakland airports, people at Caltech and the Jet Propulsion Laboratory (JPL) realized the extraordinary talent they might lure away from Berkeley. Andrew then moved to Caltech as a full professor in 1994, while JPL hired Bock.

Upon his arrival at Caltech Andrew led a team that proposed a space CMB mission to be called FIRE, one of several proposals growing out of the exciting results flowing from COBE. While FIRE lost out to the Wilkinson Microwave Anisotropy Probe (WMAP) team, Andrew and his collaborators, though disappointed, were free to focus on Boomerang, which, although of more limited scope than the satellite mission, could be launched far more quickly for far less money. After Andrew and Bock moved to Caltech, the MAXIMA and Boomerang groups also began to drift apart, communication between them slowed, and they began to work more as competitors than collaborators.

With Boomerang.

Andrew's efforts on Boomerang paid off with a long-duration Antarctic balloon flight in 1998 and the dramatic announcement, on April 26, 2000 ("the day cosmology changed," according to University of Chicago theoretical cosmologist Michael Turner), of the remarkable science results from this flight, which were reported the next day on the front page of the New York Times. Boomerang provided the first high-resolution high-signal-to-noise-ratio map of the CMB, from which was obtained a crystal-clear measurement of the first acoustic peak in the CMB power spectrum and thus a robust determination of the geometry of the Universe.

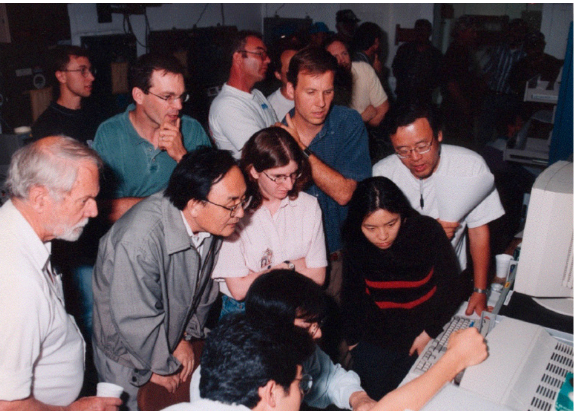
When Andrew heard from Richards that MAXIMA would publish results a few days after the Boomerang announcement, he initially thought that MAXIMA was simply trying to cash in on Boomerang's carefully orchestrated publicity. However, when he saw the MAXIMA data, he was astonished to see that it had almost as much cosmological information as the initial Boomerang release. While Boomerang had better sky coverage and signal-to-noise numbers, MAXIMA was better calibrated and went to slightly smaller angular scales—in other words, the two sets of results beautifully complemented each other. The agreement between the two experiments assuaged concerns from other competitors about systematic uncertainties and convinced the community that a new era of cosmology had begun, one in which the discipline would be promoted from an order-of-magnitude game to a paragon of precision science.

Results announced roughly one year later, which used the complete Boomerang data set (the May 2000 announcement used just a small fraction), showed the advantages of longer flight times and produced results that MAXIMA could not rival. This second release was coordinated with that of another competitor, the Degree Angular Scale Interferometer (DASI) collaboration, led by John Carlstrom of the University of Chicago, using a ground-based interferometer, a completely different technique. Carlstrom and Andrew had agreed to exchange their results just days before the press release. Andrew called me into his office after Carlstrom's fax arrived. Andrew overlaid the DASI power spectrum on top of Boomerang's, and the two agreed perfectly. Andrew was thrilled to see the two results—obtained with completely different techniques by two completely independent groups—agree. He drew the most satisfaction from seeing that this extremely complicated measurement had succeeded and got the right answer.

As CMB science transformed from a series of increasingly constraining upper limits to precise measurement, however, Andrew was also awed by the agreement of the results with theory and the implications for our understanding of the detailed evolution of the Universe a tiny fraction of a second after the Big Bang. And he was energized by the prospects for rapid further developments. This second release was also reported on the front page of the New York Times and, according to Michael Turner (perhaps with tongue in cheek), "was a first for science—the first time that a spherical harmonic power spectrum has ever appeared above the fold."

These measurements also implied something else new in cosmology: the need to incorporate a different kind of data analyst into the field to fully capitalize upon the data. For decades CMB experimentalists outdid each other with null results—upper limits to the fluctuation amplitude. With Boomerang/MAXIMA/DASI, they suddenly found themselves submerged in large data sets to be weighed against the complicated statistical predictions of theoretical models. Andrew recognized that the experiments would require the expertise of an analyst with a strong background in theory and a broad arsenal of tools in statistics and computation. He thus grew the collaboration to include such specialists, and in this way expanded his role as a scientific leader even further.

In subsequent years, Andrew continued to improve the precision of CMB cosmological-parameter measurements, leading and/or participating in a string of subsequent CMB experiments, including several outgrowths of Boomerang, as well as the Arcminute Cosmology Bolometer Array Receiver (ACBAR) experiment, which pushed to smaller angular scales, and the ARCHEOPS (named after a mythical giant bird conceived for the Pokemon game) experiment, which dealt in larger angular scales. The Boomerang/MAXIMA/DASI years were followed by the extraordinary improvement in sensitivity afforded by the decade of measurements by NASA's Wilkinson Microwave Anisotropy Probe.



Andrew in the turquoise shirt, during a rocket experiment circa 1996 looking for low-mass stellar halo around edge-on galaxies and near-infrared background fluctuations as part of Herschel/SPIRE.

The amazing results from WMAP have now been improved even further by the European Space Agency's Planck satellite. The collaboration Andrew had assembled for the unsuccessful FIRE proposal later evolved into U.S. participation in the Planck satellite project. In particular, the heart of Planck ("the most fun, sexy parts", as Andrew described them) are the spider-web bolometers provided by JPL, and so Andrew's impact on precision CMB science continues, even though he did not live to see the spectacular science that has emerged from it. He was also a collaborator in several IR-astronomy projects—for example, Herschel-SPIRE (Spectral and Photometric Imaging Receiver)—though he participated primarily in the development of instrumentation; his interests in these more astronomical subjects waned relative to his interest in cosmology. He was, however, very excited in his group's Cosmic Infrared Background ExpeRiment (CIBER) to seek fluctuations in the cosmic far-infrared background, although some wondered whether this excitement had more to do with his eagerness to see the rocket launch (which he took his son to see) than in the science.

In the years after Boomerang, Andrew's primary research interest turned increasingly to the search for the signature of inflationary gravitational waves in the CMB polarization. In 2001, Brian Keating, a new postdoc in Andrew's group, explained to Jamie Bock during a tennis game this intriguing "curl" pattern in the CMB polarization that would be induced by gravitational waves. Although nobody knew whether it was there, this pattern, if observed, would have revolutionary implications for our understanding of the early Universe. The signal was expected to be very faint, even in the best-case scenario, but an initial search could be carried out with a relatively small telescope. Bock enjoyed the challenge of designing telescopes and thus followed through with a novel refracting design that he and Keating then took to Andrew. According to Keating, Andrew responded, "What you're proposing will cost 10 million dollars ...but that's okay...that's


Lange would often show this cartoon during talks on the search for B-modes.

okay!" Andrew was always drawn to the most difficult and most important measurements—and thought that that was what Caltech was supposed to do—and so he quickly threw himself into this endeavor, even though he initially thought it crazy. From these initial discussions emerged the Background Imaging of Cosmic Extragalactic Polarization (BICEP) experiment, co-led by Andrew and Bock, followed by the subsequent generations,BICEP2 and the Keck Array. The BICEP2 detectors were being deployed at the South Pole at the time of Andrew's death. Andrew also led SPIDER, a balloon-borne experiment to measure the polarization.

Andrew often described these polarization efforts as a "wild goose chase," as theorists could not be sure that these gravitational waves existed, even if inflation occurred. Over the past 5 to 10 years, and in particular with the advent of results from Planck, the parameter space for inflation models has been greatly narrowed, and cosmologists now expect that if inflation proceeded as most theorists surmise, this polarization signal is within striking distance of detection by experiments within the next decade, if not sooner. If it transpires that the result is null, it will have serious consequences for how theorists view inflation.

While Andrew was very effective as a scientific leader and took pride in his accomplishments, he was happiest working in the laboratory, something that occurred with decreasing frequency with time. The spider-web bolometers that he and Jamie Bock developed dominated sub-orbital CMB science (and beyond) for nearly 15 years. The new generation of transition-edge sensors that he and colleagues at Berkeley, Caltech, and JPL began to develop in the years after Boomerang are now providing science results in experiments like BICEP, the Keck Array and elsewhere.

Relaxing on a Lange Group ski trip.

As a mentor, too, Andrew amassed an extraordinary track record. He had a unique ability to identify and attract the most talented young scientists, to motivate them, and to provide them with what they needed to succeed. He routinely relinquished to younger colleagues leadership of projects that he had initiated. The number of his former students, postdocs, and other younger collaborators who now occupy faculty positions in top departments is remarkable. Collectively, his former students and postdocs are, as Andrew did, “making measurable what is not so,” a Galileo quotation that Andrew was drawn to.

In the year before his death, Andrew served as chairman of the Division of Physics, Mathematics, and Astronomy at Caltech. He had originally agreed only to lead the committee to search for a new chair. He was, however, frustrated with his colleagues when several obvious candidates did not step up. Although reluctant to do the job himself, he felt that he owed it to Caltech, which had provided such a strong platform for his research, to take the job. It was no surprise, given the high regard his colleagues had for him and for his excellent scientific judgment, charisma, and managerial skills, that his colleagues were very happy with the job he did. He did not like being chairman, but he did find things within the job that he enjoyed and took pride in.

Andrew's work was recognized through a number of honors, including the California Scientist of the Year Award (2003, which he shared with Saul Perlmutter), election to the National Academy of Sciences (2004); the Balzan Prize (2006, shared with de Bernardis), and the Dan David Prize (2009, shared with Richards and de Bernardis). It is likely that but for his untimely death he would have been honored with many other prizes.

Andrew was a devoted father to his three sons with Frances, constantly seeking out new experiences to share with them. He and Frances took the entire 2003-'04 academic year off to travel around the world with the boys, with stops in Australia, Africa, and Europe. While Andrew and Frances did find host academic institutions en route to maintain their research programs, the primary purpose of the voyage was to show the boys the world, with extended wilderness adventures on multiple continents that only the most ambitious parents would ever attempt.

Andrew's death was sudden, shocking, and tragic. On Thursday, January 15, 2010, he stepped down from his position as division chairman, speaking enthusiastically about getting back to full-time research, and that's what he seemed to be doing the next week. That Thursday evening—when data was flowing from Planck, which had been launched 10 months earlier, and with promising results on the initial deployment of BICEP2 being reported by his colleagues at the South Pole—he took his own life. Andrew was arguably the most admired man on a campus that was densely packed with extraordinary talents. It wasn't just his good looks, easy charm, amazing accomplishments, outstanding leadership, and the continuing excitement of his ever-growing research endeavors. Andrew seemed to have an absolutely solid personality, someone with great patience, always focused on the issues at hand, an excellent listener, with extraordinary empathy for others. But unbeknownst to almost everyone, even his closest friends and colleagues, Andrew had long struggled with mental illness, of a severity no one imagined, which he for years fought but to which he finally succumbed. This posthumous knowledge colors the recollections of many of those whose lives were so deeply affected by him.

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