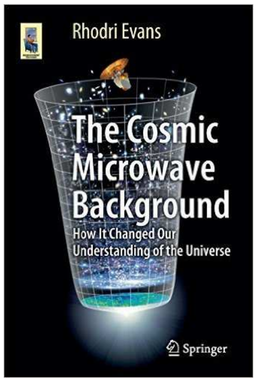

Title: ***The Cosmic Microwave Background: How It Changed Our Understanding of the Universe***
Author: R. Evans
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Reviewer: Whitham D. Reeve

What is the cosmic microwave background radiation, CMBR, and why is it important? The CMBR also is called the cosmic background radiation (CBR) as well as all permutations of the four words *cosmic*, *background*, *radiation* and *microwave*. According to the Hot Big Bang model, the very early universe (after the big bang itself) was an extremely hot, high density mixture of electromagnetic radiation – photons – and fundamental particles (nucleons) – electrons, protons and neutrons. According to this model the energy in the radiation dominated the energy in the mass of matter by a very wide margin. The temperature of this compact ionized gas mixture (plasma) was too high for the electrons to combine with the protons and neutrons. The photons were colliding with the matter and being scattered to such an extent they could not escape this so-called primordial fog.

At some point, as the new universe expanded and cooled after the big bang, the radiation and matter became decoupled; that is, the nucleons could capture the free electrons and form hydrogen, a process of combination for the first time ever, and the radiation could escape and travel in straight lines relatively unimpeded by scattering. This is often called the "epoch of last scattering", or the time that radiation could propagate without undue interference from matter.

As the universe went through additional cooling and expansion – the stretching of space – the radiation's wavelength also stretched out. Thus, the radiation was redshifted to lower and lower frequencies over the Universe's 13.8 billion year life. It is this red-shifted radiation that we detect today. When applying current observations and measurements to the Big Bang model, it can be shown that this decoupling happened about 375 000 years after the big bang at a temperature around 3 000 kelvin. For a 2-minute video of the entire process (but not directly related to the book), see http://www.space.com/20334-oldest-light-in-the-universe-how-it-traveled-to-us-video.html.

It was predicted in 1948 that this so-called *relic* radiation would be thermal (blackbody) radiation at about 5 kelvin. Many, many investigators have attempted to measure the CMBR and the current value is closer to 2.725 K, corresponding to a blackbody spectrum with a peak frequency about 160 GHz and a cosmological redshift z of about 1091. Note that the cosmological redshift is not the same as Doppler shift. Doppler shift results from an emitter's or receiver's motion whereas cosmological redshift is the increase in the emission wavelength from the expansion of space itself.

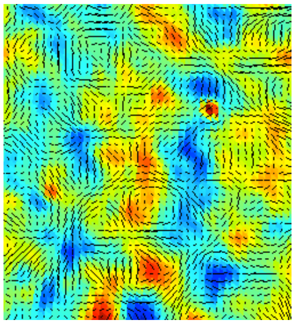
The CMBR was first measured in 1964 at a frequency around 4 GHz, but that was just one point on the spectrum curve. ***The Cosmic Microwave Background*** does not describe these first measurements and apparatus, but they may be found in the Nobel Prize presentation by one of the observers; see [Wilson]. Additional measurements at many frequencies made at terrestrial observatories since then show values that vary a few tenths of a kelvin from the current value noted above. Measurements made from space have better precision because atmospheric effects on the measurements are eliminated. They show the CMBR follows “perfect” blackbody radiation with statistical probabilities reaching 400 standard deviations; thus, the error bars on the spectrum plot are extremely small and the data are indistinguishable from the theoretical blackbody curve.

Early measurements showed the CMBR is isotropic; that is, it radiated equally in all directions. However, the Big Bang model predicts the CMBR did not radiate equally in all directions and, thus, is anisotropic. Variations in the CMBR would indicate events prior to decoupling that could result in the forming of early stars and galaxies. Measurement apparatus in the 1960s was too insensitive to detect these variations. It has since been found that micro-kelvin variations do exist. Furthermore, the variations themselves vary with the angular resolution of the measurements. These tiny temperature variations indicate density fluctuations in the early universe and provide clues as to its origin. In particular, the results of the anisotropy measurements tend to support the Hot Big Bang model as opposed to other models such as the Steady-State model or Cold Big Bang model of the universe. There are many other models but, so far, the Hot Big Bang model provides the best overall (but not perfect) agreement with observations. The importance of the CMBR is in the proof or disproof of these theories and models.

I have long thought about what it would take to detect the cosmic microwave background radiation with my own observatory equipment. From a practical standpoint, my chances of detecting the CMBR probably are pretty slim but, first, I needed to learn what I would be trying to measure. When I saw ***The Cosmic Microwave Background*** in a **Physics Today** magazine book listing, I decided to order it. This is not the first book written about the CMBR but it is the newest (as of this review, which I started writing in August 2015).

When I first received the book and flipped through it, I was initially disappointed at its scope and depth. It seemed to be a simple review of the universe as we have come to understand it over the last couple thousand years. I saw no math or radio equations but there were many pictures and illustrations. However, it cost me 35 bucks and I was determined to read and review the book.

I soon discovered that my initial impressions were wrong. ***The Cosmic Microwave Background*** is, in fact, a good, non-technical review of our understanding of the universe starting from the beginning of serious thought about it by Ptolemy, Copernicus, Brahe and many others, to the prediction of the CMBR in 1948, its first measurement in 1964, onward to the recent measurements by the COBE (Cosmic Background Explorer) spacecraft mission, BICEP2 (Background Imaging of Cosmic Extragalactic Polarization) radio telescope instruments at the South Pole and the Planck spacecraft mission. The book ends with the controversy in fall 2014 over the apparent discovery by scientists using BICEP2 of polarizations and gravitational waves, which have since been debunked by scientists using the Planck mission data; see [Space.com].



The progression of the CMBR’s discovery, like many discoveries of radio astronomy, has been misunderstood, misrepresented and misreported since day one (see [PhysicsToday-1],[PhyscisToday-2]). The author of ***The Cosmic Microwave Background*** appears to have dealt with this adequately. He describes many people involved in the discoveries and theories of the origins of the universe, where they were from and educated and a little about their personalities. Edwin Hubble, who played a very important role in observational astronomy from the 1920s through the early 1950s, is described by one of his contemporaries as a “huge mass of ego”. George Gamow, a Russian physicist who is considered the father of the Hot Big Bang theory, came up with many ideas in his lifetime, “some inspired and some crazy”, and was a practical joker. There were hundreds of others who contributed, some by simply suggesting something to a colleague or student that, when pursued, led to an important discovery and others by a lifetime of highly focused work.

The Cosmic Microwave Background is easy to read and adequately illustrated. It is not mathematical and is accessible to any reader with an interest in cosmology. The syntax and spellings are British English but the writing style is more typical of American authors. The subject is covered in seven chronological chapters and a glossary. It appears to be written as a popular account and not meant to be a reference because it has no index. The missing index might have been from a financial decision by the publisher (saving them a few dollars), but I missed it when I needed to return to a previous discussion for clarification. The book is well cited so readers can pursue additional details if desired. For a much more technical but still readable treatment of the CMBR see [Partridge]. After [Partridge], readers can move onto the more recent and detailed mathematical treatment in [Durrer].

I found ***The Cosmic Microwave Background*** to have three distinct parts. First, there is a history of cosmological discoveries and how our understanding of the universe through the 1930s became more detailed. This is covered in a little more than 50 pages. The CMBR is not mentioned in this part (I was expecting at least a description near the book’s beginning but there was none, accounting in part for my initial disappointment). Next, spanning about another 50 pages, there are the much more detailed descriptions of discoveries over about a 50 year period starting at the end of World War II. These discoveries were enabled by radio and electronic technologies developed during WWII and the Cold War. This middle part is where the CMBR is defined and its prediction and discovery are described. I enjoyed this part the most. Finally, there are descriptions of measurements spanning the last 20 or so years, which correspond to the author’s direct involvement in the science of the universe.

The descriptions and discussions in the third part sometimes are tedious and can get bogged down. I felt a significant portion of the material in the third part is not directly relevant to the discussion of the CMBR but one must read it to get to the good stuff. There are good discussions on the results of the COBE mission, but there could have been more complete explanations on the meaning of the apparent quantum fluctuations in the CMBR measured by COBE and others and the so-called E- and B-mode polarizations supposedly but, as it turned out, not measured by the BICEP2 experiments.

The third part of ***The Cosmic Microwave Background*** is not all bog. I found the author’s discussion of quantum limitations quite interesting. These are described in terms of space and time and, of course, assume that the laws of quantum physics as we presently understand them were the same in the very early universe as now. For example, the *Planck length* is on the order of 10^{-35} m. It is believed the universe is quantized to this level of distance and, therefore, it is impossible to measure a distance less than it. There also is the *Planck time*, which is on the order of 10^{-44} s. Any time period shorter than this is meaningless in the context of quantum physics and impossible to measure. The Planck length and Planck time require only simple calculations but they apparently place a distinct limitation on our ability to say anything about the instant the universe was born – time zero.

I think this is a good book from a learning standpoint, but it helps to confirm my previously stated suspicions that the publisher, Springer, wants to cash in on the radio astronomy book market. As a popular account, ***The Cosmic Microwave Background*** is overpriced but certainly not a waste of money. I was surprised by the number of typographical errors and the predictable results of using an unsupervised word processor spell-check function. If Springer is going to charge 35 bucks for a book, they need to deliver more editing value.

[Durrer] Durrer, R., ***The Cosmic Microwave Background***, Cambridge University Press, 2008

[Partridge] Partridge, R., ***3K: The Cosmic Microwave Background Radiation***, Cambridge Astrophysics Series, Vol. 25, Cambridge University Press, 1995

[PhysicsToday-1] ***Predicting the CMB: The hazards of being first***, Readers Forum, Physics Today, August 2015, pg 10

[PhysicsToday-2] ***Correcting the history of the CMB idea***, Readers Forum, Physics Today, February 2016, pg 13

[Space.com] ***Evidence for Cosmic Inflation Theory Bites the (Space) Dust***: http://www.space.com/28423-cosmic-inflation-signal-space-dust.html

[Wilson] Wilson, R., ***The Cosmic Microwave Background Radiation***, Nobel Lecture, 8 December 1978, http://www.nobelprize.org/nobel_prizes/physics/laureates/1978/wilson-lecture.html

Reviewer - Whitham Reeve presently is a contributing editor for the SARA journal, *Radio Astronomy*. He worked as an engineer and engineering firm owner/operator in the airline and telecommunications industries for more than 40 years and has lived in Anchorage, Alaska his entire life.