SAMPLE

Great Observatories: The Planck Satellite

Mapping the Cosmic Microwave Background

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Conclusion

This free sample contains the Introduction and Chapter 1. The complete book contains the full contents above.

Introduction

In the twenty-first century's second decade, a spacecraft named for the founder of quantum physics spent four years staring at the oldest light in existence. The Planck satellite, a project of the European Space Agency, was built to measure the cosmic microwave background, the faint afterglow of the Big Bang that fills every corner of the sky with a glow of microwaves at some 2.7 kelvin, barely above absolute zero. That glow has been traveling toward us for nearly fourteen billion years, and the tiny variations in it, ripples a hundred thousand times fainter than the glow itself, carry the imprint of the universe's infancy: the seeds of every galaxy that now exists, the fingerprint of the quantum fluctuations that seeded them, and the numbers by which modern cosmology defines the universe's age, contents, and fate.

Planck was the third of the great background mappers, The background itself deserves a sentence of its biography here, because it is the mission's whole subject. Its discovery in 1964, by two engineers who first suspected their own apparatus, then the pigeons in their antenna, and finally the sky itself, is among the most famous accidents in science, and the light they found has been the field's richest evidence ever since: older than every star, present in every direction, and carrying, in its minute variations, the only picture humanity possesses of the universe before there was anything to see. The mission this book describes is the last and finest portrait taken of that picture, and the introduction's promise is that by its end the reader will know what the portrait shows and how it was taken. the successor to two American missions that turned cosmology from a data-starved speculation into a precision science.

The first, launched in 1989, proved the glow existed in the detail the theory demanded, and its principal scientists took a Nobel Prize. The second, launched in 2001, made the first fine map of the ripples and fixed the rough recipe of the cosmos. Planck, launched in 2009, was built to finish the job: to map the ripples to the limit that the physics of the background itself allows, and to extract from that map every number the light can give.

The instrument's secret was cold.

The mission's working shape was repetition, and the reader should picture it before the details. A spacecraft at its quiet gravitational perch out beyond the Moon's orbit, spinning once a minute, its gaze sweeping a slow spiral across the entire heavens, month after month, year after year, five full circuits in four years' time: that is the mission as a physical act, a patient scanning of the sky's oldest light, conducted in a cold that no natural place knows. Everything

else in this book, the detectors, the pipelines, the papers, and the numbers, exists to serve that one repeated motion, and the reader who holds the picture holds the machine.

To measure a glow at three degrees above absolute zero without drowning it in the telescope's own heat, Planck's detectors were chilled to a tenth of a degree above absolute zero, making the spacecraft, by a wide margin, the coldest object ever flown in space, colder than any natural place outside the laboratory and colder than the void between the galaxies. From its station a million and a half kilometers from the Earth, spinning once a minute to sweep its gaze across the whole sky, the observatory mapped the background five times over, and then, its coolants spent, it fell silent.

The story told in this book runs from the drawing boards of the European space agencies, A practical note on the reading. The book's chapters move from the mission's birth through its engineering, its science, its context, and its mysteries, and no chapter requires another's physics: the reader who wants the numbers can take the census chapters directly, the reader who wants the hardware can stop at the cold, and the reader who wants only the ending can begin at the tension. The numbers quoted are the mission's published values, given in plain units, and where the field's language is unavoidable, the terms are defined where they first appear.

The spacecraft's story is short and the universe's story is long, and the book's hope is to hand the reader both, braided. where the mission was designed in the shadow of its predecessors, to the launch from the Guiana coast, the long voyage to the L2 point, the years of scanning, and the great data releases of 2013, 2015, and 2018, when the mission's numbers became the standard model of the universe. It is a story with a satisfying shape, rare in big science: the mission flew, it worked, and it ended on time with its promises kept.

It is also a story with an argument inside it, and the reader should be told at the start what the argument is about. The map Planck returned is so clean that its numbers pinned down the universe's recipe to a few parts in a hundred, and the recipe is strange: the ordinary matter of stars and planets and people is about five percent of everything, and the rest is dark matter and dark energy, two substances whose natures are unknown. Planck did not discover the darkness, but it measured it with a precision that made the darkness impossible to ignore, and the final chapters of this book face what that means for the science that inherits the mission's data. The universe's finest portrait, painted in microwaves, shows a cosmos we can measure exquisitely and explain only in part, and the Planck mission is the reason both halves of that sentence are true.

Chapter 1: The Discovery of The Planck Satellite

The discovery this book's first chapter must tell is not the spacecraft's discovery of the sky, but the sky's discovery of the spacecraft: how the mission came to exist. The tale begins with a serendipity in New Jersey in 1964, when two radio engineers, testing a sensitive antenna, found a hiss in their receiver that would not go away, came from every direction, and corresponded to a temperature of about three degrees above absolute zero. The hiss was the cosmic microwave background, the cooled remnant of the universe's first light, and its detection settled the great argument of twentieth-century cosmology in favor of a universe that began in a hot, dense state.

Once found, the background became the field's most precious evidence, and the next four decades of cosmology can be told as the effort to map it. The first satellite mapper, the Cosmic Background Explorer, launched in 1989, measured the glow's spectrum to extraordinary precision, proving it the most perfect thermal radiation known in nature, and then in 1992 announced the detection of the ripples, the variations from place to place that the theory of a Big Bang universe required. The ripples brought the mission's leaders the 2006 Nobel Prize, and they opened the door to everything Planck would do.

By the mid-nineties, the next step was clear to the whole field. The ripples could, in principle, be measured to finer resolution and greater precision, and every improvement would pay out in better numbers: the universe's age, its expansion rate, its contents, and the physics of its first fraction of a second. The American mapmaker WMAP, launched in 2001, took the second step, publishing its first all-sky map of the ripples in 2003 and its cosmological numbers soon after. But the field's theorists could see a third step, a mission that would measure the ripples down to the scale where the background's own physics blurs the details, and in Europe, the space agencies began studying exactly that instrument.

The mission that became Planck emerged from a cluster of proposals in the early 1990s, The selection history deserves its paragraph, because it explains the mission's character. The European Space Agency's calls for its next science missions, in the early 1990s, received several competing designs for background mappers, and the agency's science committee chose to merge rather than choose: one of the designs contributed the low-frequency approach, another the high- frequency approach, and the merged mission carried both, a marriage of two scientific cultures, the radio engineers' stable amplifiers and the cryogenic physicists' delicate bolometers, that the mission's

teams liked to describe as the instrument's twin hearts. The merger cost the mission a decade of coordination and gained it the frequency breadth that made its foreground separation unmatchable, a fair trade the reader can judge at the book's end. competing designs for a background mapper that Europe could afford.

The designs converged: a modest telescope, about a meter and a half across, feeding two instrument packages built by large European collaborations, one working at the background's own frequencies with sensors chilled as cold as physics allowed, the other working at lower frequencies with amplifiers cooled less drastically. The mission was named for Max Planck, the founder of quantum theory and the originator of the very idea of the quantum of energy, a fitting patron for an instrument built to read the quantum fluctuations of the infant universe.

The naming convention deserves its record too, because it was a choice and not a formality. The agencies named their background mission for the founder of quantum theory, following the tradition of christening great observatories for the founders of the physics they use, and the choice was exact: the satellite's subject, the primordial quantum fluctuations stretched to cosmic size, is the founder's own discovery grown to the scale of the sky, the constant of action made visible in the heavens. The mission's scientists noted with satisfaction that the naming was also a claim, the universe's largest structures obeying the smallest physics, a piece of scientific heraldry the reader can decode at no charge in any of the mission's papers, whose title pages carry the name and the claim together.

The engineering demand that shaped every part of the design was the control of heat. A telescope warmer than the background it studies blinds itself: the instrument's own glow, at ordinary spacecraft temperatures, is a million times stronger than the signal sought. Planck's solution was layered: the telescope sat inside a shell of radiating surfaces that cooled naturally to about sixty degrees above absolute zero in the deep shade at the mission's station; the low-frequency instrument's sensors ran at twenty degrees above absolute zero, cooled by hydrogen; the high-frequency instrument's bolometers, the most sensitive heat detectors ever flown, were cooled to a hundred millikelvins by a dilution refrigerator, a machine mixing isotopes of helium, of a design never before flown in space.

The site of the mission was as carefully chosen as its cold. Planck would observe from the vicinity of the second Lagrange point of the Sun-Earth system, a gravitational station a million and a half kilometers sunward of the

Earth, where a spacecraft can hold the Sun, the Earth, and the whole warm

inner solar system behind it, staring permanently outward into the cold. From there, spinning once a minute, its telescope sweeping a circle of sky with each turn while the circle drifted slowly around the heavens as the spacecraft traveled with the Earth around the Sun, Planck could build up a whole-sky map in about six months, and then do it again, and again.

The launch came on 14 May 2009, from the Guiana Space Centre on the Atlantic coast of South America.

The voyage to the station deserves its own paragraph, because L2 is a place, not a parking lot. The point, one and a half million kilometers sunward of us, in the anti-sunward direction from the Earth, is a gravitational saddle: a spacecraft placed exactly there would drift, and one placed near it describes a Lissajous orbit, a slow looping path around the empty point, which Planck entered in July 2009 after a two-month cruise. From the station's vantage, the Sun, the Earth, and the Moon stay in one half of the sky, and the observatory points its instruments outward and sunward of nothing warm, the geometry that makes the cold chain possible.

The station's practical price is that no repair is possible, and the mission's teams, unlike the astronauts' contemporaries of the era, knew from the start that whatever broke was broken forever, a discipline that shaped every engineering choice the book has described. Planck shared its ride with a sibling observatory, the infrared telescope Herschel, the largest space telescope of its day, and the two missions, distinct in science and matching in engineering family, were built and flown as a single program, sharing a spacecraft contractor, a launch vehicle, and a destination. The Ariane rocket carried both away at 13:12 universal time, and within two months Planck had made the voyage to its station at L2 and begun, in August 2009, its first survey of the sky.

The first years went by the book.

The commissioning months deserve their own record, because the mission's whole life was staked on them. In the weeks after arrival, the teams ran the instruments through their first light sequences: the low-frequency amplifiers switched on and tuned, the high-frequency stages cooled in steps down toward their operating floor, the dilution unit's helium isotopes mixed in the first spaceflight of the technique, and the thermometers read out the ladder of temperatures, sixty kelvins, twenty, four, one, and finally the tenth-of-one, each step a held breath. The announcements came from the operations center in the late summer of 2009, and the teams' private memoranda from those weeks, preserved in the mission's history, record engineers typing the temperatures into their logs and checking them twice, the oldest ritual of

experimental physics, performed on a spacecraft no human could ever visit.

The spacecraft reached its intended operating temperatures, the instruments were calibrated against planets and known sky sources, and the first all-sky survey ran from August 2009 into the new year. A second survey followed, begun in February 2010, and the mission's planners watched the data accumulate with the satisfaction of engineers whose margins held. The high-frequency instrument's coolant, budgeted for about two years, lasted into

January 2012, when the helium isotope mixture was spent and the coldest sensors went dark; the low-frequency instrument carried on alone, completing survey after survey until October 2013, when the mission's science ended and the spacecraft was pointed away from the Earth, passivated, and set on its final quiet orbit around the Sun.

The record of that working life, four years and five all-sky surveys, The surveys' calendar, for the reader who likes the timeline plain: the first survey began on 13 August 2009 and ran into the new year; the second began on 14 February 2010; and the mission settled into its rhythm of one sky per half-year thereafter, the high-frequency instrument's detectors running until their helium was spent in January 2012, the low-frequency instrument carrying every survey after alone. Five complete circuits of the heavens, and parts of a sixth, were the mission's final count, and the reader who wants the image can take it from the mission's own visualizations: the map of the sky, built up ring by spinning ring, like a pot thrown on a wheel, until the whole sphere was covered and covered again. may sound brief against a fourteen-billion-year subject, but the reader should hold the proportion: the mission's entire purpose was to measure one number-set to a precision set by the light itself, and every survey beyond the first was a repetition that drove the measurement's errors down.

The spacecraft that launched in 2009 spent its working life repeating itself, more exactly each time, which is the whole discipline of precision science, and the chapters that follow describe both the doing and the exactness.

End of free sample. The full book is available at putrabooks.github.io

ABOUT THE AUTHOR

Aira Astralis is a science writer specializing in astronomy and space exploration. Her work spans the full breadth of humanity's relationship with the cosmos -- from the earliest naked-eye observations to the engineering marvels of modern space missions.

Her books are built on a foundation of primary sources: peer-reviewed research, mission archives, and direct engagement with the scientific community. She writes for readers who want to understand not just what we know about the universe, but how we came to know it.

She believes that the most important frontier is not out there but in the gap between what scientists discover and what the public understands. Her books exist to close that gap.