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Microwave Pioneers: John C. Mather "A Singular Purpose"

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ABSTRACT This article is the first in a continuing series of biographical pieces on individuals who have made significant and continuous contributions to microwave science, technology, and applications over the course of their careers. It is intended to bring to the reader, especially those new to the field, a portrait of an individual who serves as a role model for the community and a detailed description of their accomplishments. At the same time, it tries to bridge with commonality, the experiences of the subject with those of the scientists, engineers, and technologists who are following in their footsteps or hope to establish a similar record of success. The articles are composed only after an extensive face-to-face interview with the subject and are helped immensely by additional input and editing by the subjects themselves. The focus of this article is Dr. John C. Mather, recipient of the 2006 Nobel Prize in Physics, for the first complete measurement of the cosmic microwave background (CMB) blackbody spectrum, and the first confirmed findings of CMB anisotropy. For astronomers and cosmologists at least, these were arguably two of the most important and influential experimental discoveries of the 20th century. For microwave engineers, the satellite mission that Dr. Mather conceived and worked on for more than fifteen years is a crowning achievement in a very large suite of successful microwave science instruments that NASA has developed, built, and delivered to space.

INDEX TERMS Cosmic microwave background (CMB), COBE, cosmology, John C. Mather, microwave applications, microwave science.

John Cromwell Mather[1] grew up wondering about who we are and how we got here. Born in Roanoke, Virginia, USA in 1946, he was the first of two children of a scientist and a school teacher. His father, Dr. Robert E. Mather, was the son of a missionary and spent part of his childhood in rural Africa. This led him into a career in animal husbandry, which he practiced as a professor of Rutgers University while posted to the Rutgers Agricultural Experiment Station in a fairly isolated part of Sussex County, New Jersey. John's mother, Martha

Cromwell Mather, taught at the local school. This rural setting is where John grew up, which he described as "having as many cows as people." It had a major influence on how he spent his time and more importantly, how he learned. Being one of the only children in his elementary school with an interest in science meant that he had the attention of some of his more enlightened teachers, but also that he had to learn a lot on his own. Fortunately, he was both an avid reader and a bit of an experimentalist. Encouraged by his father's interests in statistics and an early fascination with the night sky, he relied heavily on the bi-weekly visits of a Bookmobile (a traveling library that helped connect

[1]This article was compiled after a series of two interviews with Dr. Mather on August 20 and 21st, 2020, Normally, the interviews would have been face-to-face, but Covid 19 restrictions forced their conversion into video conference sessions. The author has known Dr. Mather personally since having had the fortune to overlap with him at the NASA Goddard Institute for Space Studies in NYC, NY between 1975 and 1976. Dr. Mather participated in the interview from his home in Maryland and graciously consented to look over and edit the final text, as well as the relevant text of the companion article on the CMB that accompanies this article in the Inaugural issue of this new *IEEE Journal of Microwaves*.

US rural areas in the 1950's and 60's) to study math and astronomy. He also practiced some electronics, working on assembling a Heathkit radio, and he put together several small telescopes using Edmund Scientific lenses and mirrors. One of John's early self-study "Bibles" was *Scientific American's* three volume *Amateur Telescope Making* series [1], and he also remembers devouring Lancelot Hogben's very popular, *Mathematics for the Million* [2]. Since it was not formally offered, John also managed to teach himself calculus in high school, by borrowing a textbook from one of his father's recent university classes.

Making use of his book-guided extracurricular studies, he entered science fairs, competed and won several academic competitions, and realized that he was pretty good at science and math. Despite being warned by his parents that the wider world might harbor more significant rivalry, John ended up doing very well in highly competitive summer courses at Assumption College in Worcester, Massachusetts and Cornell University in Ithaca, NY, which he attended in 10^{th} and 11^{th} grades. By this time his general interest in origins had moved from biology to physics, as he found he was much happier deriving than memorizing. He chose to attend Swarthmore College in Pennsylvania, because of its excellent undergraduate physics faculty, its small scale, and its student-focused teaching style. John worked hard, and did very well at Swarthmore. Coincidentally, he had Princeton University's, David Wilkinson (of cosmic microwave background, CMB, origins fame), as an examiner for his graduation with highest honors, in 1968.

John had intended to enroll at Princeton for graduate school, but at the last minute was turned off by the experiences of some of his friends there, who were unhappy with the "male only" student body (Princeton became co-ed in 1969). Instead he decided to try something very different, and very distant from his rural east coast upbringing. A picture of one of his friends posing in shorts and a T-shirt on the University of California Berkeley *Fountain at the Circle* in mid-January, had a strong influence, and John entered the physics department there in the fall of 1968. It was the height of US student protests over the Vietnam War, and UC Berkeley was one of the more active hot beds.

In his first two years at Berkeley, John managed to stay out of politics and focus on science, and in his own way, help the world through the use of books, rather than guns. In looking at research groups in which to pursue his dissertation, he settled upon Paul Richards (a past subject of the precursor to this series [3]), who was working on trying to make measurements of the recently discovered CMB signature (see companion article in this journal issue [4]) along with post-doc Mike Werner, and Nobel Laureate, Charles Townes. The project involved building a submillimeter-wave (in this case, 220-420 GHz) rapid-scanning Fabry-Perot spectrometer with a resolution of approximately 1.5 GHz. The spectrometer used an 8 cm Teflon lens to generate a 6 degree beam on the sky and the detectors consisted of helium-cooled InSb bolometers on the backend of a germanium cone preceded by a 450 GHz low-pass filter. In order to reduce atmospheric water vapor absorption in the passband, the observations were carried out at Berkeley's Barcroft Observatory located at White Mountain Research Center in Bishop, CA at 12,500 feet. The team was looking for discrete spectral lines that might explain the greater than expected 2.7 K blackbody power flux that had been recorded by earlier rocket and balloon measurements, especially near 450 GHz. Following their observations, they saw no extra-terrestrial line signatures within their resolution limits, and were able to set a lower bound to any spectral line contribution to the CMB flux [5].

At this point things were looking promising for John, as his first experience with a complex instrument and difficult observations, had proven successful, if not physically demanding – spending significant time at 3,800 meters is both cold and dizzying! When Paul Richards returned from a sabbatical in UK in 1972, touting the virtues of the newly invented Martin-Puplett interferometer (Derek Martin is also a past subject of the precursor to this series [6]), and suggesting a balloon-borne spectrometer instrument to get much more sensitive CMB measurements, John and groupmate, Dave Woody, began working on the payload. Anyone who has had experience with high altitude balloon programs or instruments, will tell you how stressful and failure prone these ventures can be, from the harsh and wildly varying environmental conditions through launch, ascension and recovery, to the requirement for complete remote operation and data collection operations, to simply transporting and assembling a complex scientific instrument at a remote launch site – all typically, on a resource starved budget. John and Dave's balloon CMB spectrometer was no exception, and, according to John's description, pretty much everything that could go wrong on their first flight (out of the National Science Foundation balloon facility in Palestine, Texas in October 1973) did – including having the telemetry antenna fall off the receiver package while (fortunately) the payload was still on the balloon launchpad, and could be reinstated! Unfortunately, the spectrometer mirror motor froze up during flight and no data could be collected. Needless to say, this "trial by fire" introduction to remote astrophysics experiments did not work out well for John, although it would become a very important lesson for guiding all his later projects.

John finished and turned in his thesis in January 1974, which contained the mountain top experiment results and the design efforts that went into the balloon experiment [7]. Eight months later, in July 1974, after John had already departed Berkeley to start a post-doc in NYC, Dave Woody improved the instrument package and led a successful balloon flight out of Palestine [8], producing sufficiently exciting results (a CMB temperature profile from 120–500 GHz) [9] to complete his own thesis soon after.

Following his sobering experience with the unsuccessful balloon flight, John thought a changeover to a somewhat less challenging area of experimental astrophysics might serve him well, and he accepted a post-doctoral appointment at the NASA Goddard Institute for Space Studies (GISS) in

NYC working in a small research group led by astronomer, Pat Thaddeus. This was the beginning of a golden age for millimeter and submillimeter-wave astrophysics, as pioneers like Thaddeus were taking advantage of new high frequency heterodyne receiver technology and customized radio telescopes to find and map hundreds of very narrowband atomic and molecular spectral line signatures in gas and dust clouds, star forming regions, and galaxies. NASA GISS was a satellite branch of NASA Goddard in Greenbelt, Maryland, but was located a few blocks away from Columbia University – where Thaddeus was a professor – and situated in the building on 112th street and Broadway, which happened to be used as the backdrop for Monk's Cafe (in reality Tom's Restaurant) in the television sitcom *Seinfeld*!

John's task at GISS was to put together and field a Schottky-diode-based heterodyne receiver to measure the J = 1-to-0 rotational line transition of SiO at 43.1 GHz, which was believed to indicate maser action in stellar atmospheres [10]. Using observations at the MacDonald Observatory in Texas and the Naval Research Observatory in Maryland, the team obtained the first confirmed evidence of a fundamental maser line transition in a star [11]. Although John was happy with this accomplishment, his realization that radio observatories operated day and night – no rest for the weary, and that searching for spectral lines was not quite as exciting as the quest to understand the origins of the universe, made him ready to make a major change in his career path when it was offered as a possibility.

The opportunity came as soon as the summer of 1974, when NASA announced an Explorer program proposal call for mid-sized science-based astronomical satellite missions. Thaddeus was of course well connected within NASA, and asked his group for ideas. John was still thinking about his CMB mountain top and balloon experiments and how much better they might have been if the measurements could be performed in space. Despite his inexperience with space instruments, he suggested a satellite CMB measurement as a response to the NASA proposal call. Thaddeus was already well acquainted with both the measurement techniques and the importance of CMB [12], having been a student of Charles Townes when he was at Columbia, and a close colleague and friend of Arno Penzias and Bob Wilson (yet a third subject of the precursor to this series [13]) at nearby Bell Laboratories. He told John to go ahead with the proposal and brought in Rainer (Ray) Weiss at MIT (2017 Nobel Laureate in Physics for his work on gravitational waves), Dave Wilkinson at Princeton, and Michael Hauser and colleagues at NASA Goddard.

The four groups – MIT, Princeton, Goddard and GISS – submitted their joint proposal [14] which included four instruments: an interferometer to measure the CMB spectrum, a broadband IR sensor to look for very young galaxies, and two differential spectrometers to look for CMB anisotropy. There were over 150 other proposals submitted to the NASA call, including two directly competitive CMB instruments, one from a group at Berkeley with George Smoot and recent Nobel Laureate Luis Alvarez, and the other from the NASA Jet Propulsion Laboratory, led by well-known planetary and spectral line astronomers, Sam Gulkis and Mike Janssen. John remembers the competing CMB proposals to have included only anisotropy experiments. As it turned out, none of the CMB proposals were successful for the then current Explorer call, but NASA was definitely interested in a future CMB mission. They even asked John to see if he could fit his spectrometer, at least a scaled down version, as a piggyback instrument on the approved Infrared Astronomy Satellite (IRAS) platform. Although that plan proved not to be viable, NASA infrared program scientist, Nancy Boggess, brought together the three CMB teams in 1976 to form an instrument definition study group that was charged with developing and submitting a CMB satellite proposal concept to NASA. Mather, Hauser, Smoot, Weiss, Wilkinson, and Gulkis formed the heart of the mission definition and science team, and John took on the additional role of study scientist, who would work with the engineering team to define the instrument and satellite system details, and assure the practicality of the mission. Since the study scientist role involved interfacing directly with Goddard Space Flight Center engineers, Mike Hauser offered John a full time position at Goddard, and he relocated from NYC to Greenbelt, Maryland in 1976.

NASA liked the CMB proposal concept, and assigned an experienced engineering team finishing up the International Ultraviolet Explorer (a NASA/ESA/UK mission – Explorer 57, launched in 1978) to work on the detailed design. Soon afterwards, the study team, with Ray Weiss as the science team Chair, submitted its final report to NASA. They had agreed on three instruments: a far infrared absolute spectrophotometer to record the full CMB temperature spectrum (FIRAS), to be led by Mather, a differential microwave radiometer (DMR), for measuring potential CMB anisotropy, led by Smoot, and a diffuse infrared background experiment (DIRBE) imager to map the emission from dust in the Milky Way, extragalactic sources of IR background emission, and search for young IR emitting galaxies, led by Hauser. The team was very thorough and made certain that the instruments were complementary, had overlapping capabilities to help with calibration and backup measurements, and covered as much of the CMB science as they could reasonably accomplish at the time. The mission was to be called COBE – cosmic background explorer [15], [16].

Unfortunately, NASA had just made a decision to dismantle its expendable launch vehicle program and move all science instruments onto the Space Shuttle. The COBE study team's concept for a Delta rocket launch (mandated by the Explorer program) had to be completely rethought. One major hindrance to the shuttle was a Cape Canaveral launch, which could not achieve a polar orbit for its payload without additional hydrazine fueled boosters on the satellite, and the accompanying weight, volume, cost and risk penalties. COBE required a polar orbit to keep its helium cryostat shielded from the radiance of the Sun and the Earth at all times. The redesign was a daunting task. At this point John considered himself to be functioning as a "theoretical instrument designer." He would come to the engineers with a concept of how the instrument had to function and what it had to consist of, and they would work with him to solve the engineering and production problems.

By 1979, NASA decided to bring the complete COBE instrument build into Goddard, rather than contracting it out to industry and/or university partners. This was very convenient for John and Mike Hauser, and John credits this decision for much of the science/engineering teaming that took place, not to mention the excellent training opportunity it provided for him personally. From 1980 through the next six years, John was completely immersed in the COBE instrument design and implementation. He worked on component details, including feed horns [17], [18] and cooled IR bolometers [19]–[22], and as an aside, their spin-off use as sensitive X-Ray detectors with Goddard's Harvey Moseley [23], as well as other instrument functional elements [24]–[26].

The Challenger accident in January 1986 changed everything for the COBE team. All shuttle missions were put on hold, and COBE became a well-developed instrument, nearly ready to fly, but without a pending launch vehicle. COBE deputy project manager at Goddard, Dennis McCarthy, was asked whether he could come up with an alternative launch vehicle, and he began calling everyone he knew with rockets or rocket parts, including folks in Europe, Asia and Russia. Worried that COBE might end up on a non-US launch vehicle – after all the in-house effort, NASA made a more serious attempt to locate a suitable rocket. With help from future NASA director, Mike Griffin, who was working with the US Department of Defense at the time, and McDonnell Douglas, enough spare parts and subassemblies from the dismantled Delta program were brought back together to enable a new set of Delta launches. As fate would have it, the first Delta to launch after the Challenger incident, in May 1986 from Cape Canaveral, was destroyed just over a minute after lift-off, when its main engine unexpectedly shut down! Fortunately, according to John, an analysis revealed exactly what had gone wrong: a design upgrade that added one extra wire to an already overstuffed conduit, causing a short in one of the signal lines. The problem was fixed, and in the interim up to the time COBE was ready to launch, there were no more catastrophic failures. On November 18, 1989 at 14:34 UTC (6:34 AM local time) COBE was successfully launched into its polar Sun-synchronous orbit from Vandenberg Air Force Base in southern California.

The delay between 1986 and the launch in 1989 turned out to be very helpful for COBE, as John described how the lower than desired funding and staffing priority that had been going into the instrument before the Challenger accident, suddenly reversed when COBE became the first major NASA science mission to follow the Challenger accident. Early funding shortfalls had resulted in decisions to cut back on some of the usual flight instrument prototyping, and there were several unanticipated late-in-the-mission component failures, especially in the cryogenics and detector systems. The delay, coupled with the higher visibility of COBE after Challenger, gave the team a chance to correct all of these problems. There were only two instrument glitches after launch. One was a failed gyro, which had multiple back-ups, the other was an unanticipated problem with the fiber optic signaling cables that fed back to the spectrometer motor and kept track of the mirror position on FIRAS. Random cosmic ray hits on the fiber would produce an optical flash that resulted in loss of position information, and the motor would then automatically run the mirror into its stop position. By a stroke of luck, this only occurred when the satellite crossed through the South Atlantic anomaly – where the Van Allen radiation belt comes closest to the Earth's surface, and sometimes near the poles. The fix was to turn the instrument off whenever it crossed these "at-risk" orbital positions (tens of minutes out of the 100+ minute orbital period) to avoid any data stream losses. This worked throughout the course of the mission!

The launch and deployment of a science satellite usually represents the defining moment for the principal investigators involved, and is the start of an all-encompassing immersion into the world of instrument monitoring, data collection, analysis and reporting. In John's case, the FIRAS instrument, for which he was responsible, produced its most important results in very short order. Thanks largely to John's particular focus on calibration and the differential design of the instrument, he was able to present his CMB results within two months of launch. The January 9–13th 175th American Astronomical Society meeting in Washington DC was to be his first technical presentation of the FIRAS data. Much to his early disappointment, he was scheduled for a Saturday talk on the 13th, the last day of the conference, in a special session on "First Results of COBE" (as an interesting side note, US vice-President Dan Quayle gave a major science policy address at this same conference, but earlier in the week [27, pp. 991–992]). When John arrived on stage, following presentations from Nancy Boggess on the overall mission, and Mike Hauser on early DIRBE results, he looked out upon a packed audience of well over 1000 people – standing room only. After showing a slide in which the FIRAS measurement data from 60–640 GHz was overlaid with a 2.735 K blackbody curve that fit so perfectly the superimposed error bars were smaller than the data points displayed, John received a standing ovation. His immediate reaction was simply, "Why are they so excited by this, it is no surprise. The CMB curve is exactly as we expected," and so it was!

The next several years were a whirlwind of data analysis, presentations, reports and papers. The five most prized (by John himself) are listed in the references as: [28], *First publication of the CMB spectrum from COBE*; [29], *Major improvement in CMB spectrum from COBE*; [30], *How the CMB spectrum was calibrated*; [31], *What it meant*; and [32], *How it turned out*. Some selected additional publications with high citation counts are included in [33]–[55]. John was involved in all of the COBE instruments, each of which had its own set of calibration and verification challenges. He brought his strong collaborative and teaming skills, along with his well-balanced physics/engineering approach, to all the issues the team encountered. This included significant contributions to calibrating and removing residuals from the DMR measurements, especially along with Princeton teammate and instrument calibration expert extraordinaire, Dale Fixsen, that resulted in the first full sky CMB anisotropy maps, later honed and presented to wide spread acclaim by George Smoot [56]. With Fixsen's help it was even possible to make detailed spectral line maps of the Milky Way galaxy using the FIRAS interferograms, by pulling out narrowband signatures of ionized carbon, C^+, at 158 microns and a never-before-measured line of ionized nitrogen, N^+, at 205 microns [48].

COBE was decommissioned in December 1993, long after the helium had run out on the DIRBE and FIRAS cryogenic instruments, although DIRBE was able to operate with passive cooling on some of the shorter wavelength channels throughout the mission. The overall success of COBE as well as its contributions to cosmology would reverberate for years to come and of course, would lead to the 2006 Nobel Prize in Physics for John, and for George Smoot, and partially to the 2019 Nobel Prize in Physics recently given to Princeton's Phillip James Edwin Peebles, whose early work on the CMB, was a very strong driver for COBE. The complete story of COBE from John's particular viewpoint can be found in the book that he wrote in 1996 with noted science writer John Boslough [57]. Having fulfilled his "*singular purpose*" of so many years, it was time for John to start thinking about what he might focus on next.

It has to be very hard to follow such a spectacular success with something equally challenging and important. John turned his attention to a problem that had been holding back space telescope missions for many years: how to produce a large aperture to increase signal gathering and resolution, but maintain the required surface accuracy and stability to guarantee diffraction limited image quality, all while fitting inside a tight launch vehicle volume. Serious design efforts had been in NASA's mission study queue since at least the early 1980's when the Large Deployable Reflector – an early precursor to the Herschel Space Telescope, was proposed [58]. John initially tried to convince local colleagues to consider an unfolding panel design that could be squeezed into a small launch vehicle, but no one believed a mechanical deployment of multiple telescope segments could hold the required tolerances for a reasonable budget. There was also a serious ongoing effort to develop much larger deployable-type telescopes – mainly for the infrared region of the spectrum, which required passive cooling as well as meter-scale diameter, in both Europe and the US [59]. Excitement for the idea was already growing as NASA Administrator, Dan Goldin, took charge of the agency in 1992.

In addition to ongoing applications and implications for the COBE data, John had started working on various concepts for future astronomy missions and instruments [60], when, as a new NASA Goddard Fellow, he received an unexpected phone message from NASA Science Mission Director, Ed Weiler. It was the fall of 1995, and Weiler was asking for a proposal – to be handed in the next day, for conducting a study on a "Next Generation Space Telescope," as a follow-on observatory to Hubble. There was already a committee led by the Carnegie Institution for Science's Alan Dressler, that was championing (among other things) both an infrared telescope and a planet finding optical interferometer as NASA's next challenge for astronomy [61]. John submitted his proposal, and officially joined the lobbying and engineering design effort, becoming a Project Scientist along with Peter Stockman (Association of Universities for Research in Astronomy Space Telescope Science Institute, Baltimore, Maryland) and NASA Hubble Space Telescope Project Manager, John Campbell.

When Dressler briefed Dan Goldin in late 1995, Goldin not only liked the concept, but upped the stakes by asking for an even larger telescope than the team had proposed – a goal of 8 meters diameter. Goldin then gave a memorable speech at the 187th American Astronomical Society meeting in January 1996 [62] which included this challenge, and outlined his other ambitious visions for the future of NASA missions and NASA science with a new mantra of "faster-better-cheaper."

Next Generation Space Telescope (NGST) was now a priority, and John took on the role of Senior Project Scientist. The team immediately set out to do a competitive mission feasibility study that included NASA Goddard, TRW (now Northrup Grumman Space Technology), Ball Aerospace and Lockheed. All produced what appeared to be reasonable designs that could achieve an 8 meter deployable aperture for the then $500M price tag. The resulting report [63] became the roadmap for what would be a 25 year, $10 billion dollar plus, international effort to bring NGST to fruition. A science working group was formed in 1997 and two international partners, the European Space Agency and the Canadian Space Agency, were brought in. Project team leaders began significant industry, government and university-based development programs to flush out technical hurdles and achieve major technology milestones in the mirror designs, mirror actuator systems and controls, mirror deployment, cryogenics, detector systems, sunshields, and the launch vehicle and orbital requirements. By 2001, NGST was ranked as the highest priority US astronomy mission by the very influential National Research Council's Decadal Survey on US Science [64].

In September of 2002, the NGST was renamed the James Webb Space Telescope (JWST), in honor of NASA's second administrator, who had led the agency through the Apollo era from 1961-1968 [65]. By 2006, JWST had undergone several redesigns and fielded a slightly smaller mirror (18 segments reaching 6.5 m diameter), but was still basically the same concept as envisioned in the 1997 Stockman report [66], [67]. Major contracts had been let to Ball and Northrop Grumman, and nine of the ten major technology driven elements had passed a non-advocacy review. There were now four major science instruments and 20 participating countries. The launch date was scheduled for 2013, but it would later slip substantially. Meanwhile, 2006 brought the first Nobel Prize to a full-time NASA scientist, and John's "*singular purpose*" was to be intruded upon yet again, this time with even more fame and popularity. He was additionally appointed NASA's

Mission Directorate Chief Scientist in 2007, as he continued to work on JWST and juggle the ubiquitous and unending requests for presentations, papers and talks resulting from his prize. He also supported other astronomy mission proposals [68]–[72], and continued to publish papers on far infrared science and cosmology [73]–[77].

JWST is certain to be the Hubble Telescope for the 21st century, and one of NASA's most ambitious science programs to date. The 2013 launch date has now slipped to October 2021, but John continues to work full time as Senior Project Scientist and to give presentations about the mission [78]. He also has a philosophical side, and has written short articles and given interviews on several general science, or at least astronomy related, topics [79]–[82]. Most recently, with JWST's launch getting closer, John is beginning to think about a new satellite application for astronomers, fielding an orbiting artificial guide star that can be used to correct for atmospheric fluctuations in real time and allow ground-based telescopes to gain the "seeing" advantage enjoyed only by orbiting observatories [83]. This could greatly improve the performance of very large aperture ground-based telescopes and revolutionize planet finding capabilities [84].

At age 74, John Mather is as "*singular purposed*" and productive as the time during which I overlapped with him in the Thaddeus group at NASA GISS in 1975-76. His publication queue has surpassed the 430 mark and will likely climb exponentially after JWST. John is a role model not just for his science accomplishments, but for his emphasis on, and appreciation of teaming, and for a willingness, *nay*, a strong desire, to stride back and forth across the boundaries of science and engineering, working equally well with both, and demonstrating to all of us the benefits of such behavior.

SUBJECT BIO

JOHN C. MATHER is currently a Senior Astrophysicist in the Observational Cosmology Laboratory, NASA's Goddard Space Flight Center. As an NRC Postdoctoral Fellow with the Goddard Institute for Space Studies, New York City, he led the proposal efforts for the Cosmic Background Explorer (1974–1976), and came to GSFC to be the Study Scientist (1976–1988), Project Scientist (1988–1998), and also the Principal Investigator for the Far IR Absolute Spectrophotometer (FIRAS) on COBE. He showed that the cosmic microwave background radiation has a blackbody spectrum within 50 ppm. As Senior Project Scientist (1995–present) for the James Webb Space Telescope, he leads the science team, and represents scientific interests within the project management. His research centers on infrared astronomy and cosmology. He was on the advisory and working groups for the National Academy of Sciences, NASA, and the NSF (for the ALMA, the Atacama Large Millimeter Array, and for the CARA, the Center for Astrophysical Research in the Antarctic). He was the recipient of many awards including the Nobel Prize in Physics 2006, for his precise measurements of the cosmic microwave background radiation using the COBE satellite.

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