AIAA SPACE 2007 Conference & Exposition
18 - 20 September 2007, Long Beach, California

AIAA 2007-6071

An Astrosocial Observation: The Nobel Connection to the Space Program

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The 2006 Nobel Prize in Physics was heralded by some in the press as the "First Nobel Prize for Space Exploration." Indeed the Nobel Foundation's announcement specifically cited the Cosmic Background Explorer (COBE) satellite launched by NASA in 1989 as the prime-enabling instrument It elaborated further, "The COBE results provided increased support for the Big Bang scenario for the origin of the Universe… These measurements also marked the inception of cosmology as a precise science." NASA also seized this unique moment of fame to honor its favorite son, the first Nobel scientist of the agency, John Mather, of the Goddard Space Flight Center, who shared the honor with Professor G. Smoot of the University of California, the Principal Investigator of the COBE measurement. It is without any dispute that the Nobel Prize is the highest scientific honor and best-known award of admiration and inspiration to the public and educational sectors. Unfortunately in the American culture, youths are mostly exposed to success icons in the sports, entertainment, and business domains. Science icons (of either gender) are largely unknown to them. We sincerely hope that success stories of Nobel scientists will become part of the learning curriculum in the K-16 educational experience. In this paper, we examine the pedigree of a number of Nobel Prizes over the years, and discuss their interactions with, and connections to, the space program. It is advantageous for the context of educational and public outreach to see such connections, because in a number of public surveys, one important customer expectation for the space program is the search for new knowledge, to which the Nobel Prize is a prominent benchmark.

We have organized this paper into nine, fairly independent sections for ease of reading:

I. Introduction

THE scene was surreal. "Who's a better athlete, Michael Jordan or Mia Hamm? Their first commercial together didn't settle the question, so they're back to compete in sports neither one has ever played before. See what happens in Michael vs. Mia II." This Gatorade commercial has been considered extremely successful, pitching two well-known athletes, appealing to young people as prominent success icons. The commercial world consistently

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uses such icons for brand equity. The educational world, however, does not always take advantage of its favorite sons and daughters. The following *Los Angeles Times* article (Ref. 1) is telltale:

Margaret Wertheim, Director of the Institute for Figuring, a Los Angeles-based organization that promotes public engagement with science and mathematics, visited the revamped $93M Griffith Observatory. She was impressed with the high-tech simulated tour through the Milky Way, the Universe and through the passage of time. While expecting a Carl Sagan type of scientific star, she was befuddled that the impressive show was narrated by a snappily suited thespian. Earlier that month, when she attended a conference on science education, she heard from speaker after speaker that "science is not just a compilation of facts, but a set of methods and approaches practiced by living, breathing, idiosyncratic human beings."

In Europe and Asia, Nobel scientists are given rock-star prominence, in part, because they have fewer such luminaries than we do in the US. For example, when Abdus Salam was announced as the first Nobel winner in Pakistan, he made a very public pilgrimage to pray in the mosque, and had headline coverage. Shortly after the Nixon-Mao détente in China, a top Chinese university dedicated two houses to Lee and Yang, two Chinese-American Nobel scientists, with the standing invitation to visit for any amount of time. For several decades in France, the Curies, with three wins for four prizes in one family, enjoyed royal status.

So? What do these anecdotes have to do with space exploration? First, let's revisit what taxpayers expect from space ventures. Various studies over a 10-year period (1995 to 2005, Refs. 2 to 4) show the following top five objectives expected by the public, including a sub-population of students:

1. Advance knowledge;
2. Benefit general aviation;
3. Aid national security; (this item only became prominent after September 11^{th}, 2001);
4. Increase our understanding of the Earth;
5. Increase our understanding of the Universe.

When it comes to advancing knowledge and understanding our environs, the Nobel Prize is without a doubt the best-known benchmark for success, and moreover, for the youth of today, Nobel scientists are the best success icons for them to look up to. For a short while, the movie *A Beautiful Mind* did bring John Nash toward folk hero status. But we need more stories to be planted in the public's consciousness, so that no planetarium feels the need to hire movie stars to narrate space tours.

II. "Connecting the Dots between the Heavens and Earth" – From Newton to Bethe

During the past century, Nobel Prizes in physics and chemistry have mostly recognized contributions to the sub-atomic world. To the best of our knowledge, the very first time that the Nobel Foundation recognized contributions in cosmic exploration was when the 1967 Prize for Physics was bestowed for the discovery of nuclear reactions in stars. The citation, recognizing Hans Bethe read, "For his contributions to the theory of nuclear reactions, especially his discoveries concerning the energy production in stars." Note that his theory was applicable for both celestial and terrestrial phenomena. (For the materials in this section, see Ref. 5).

It is interesting to note that almost three centuries earlier, Sir Isaac Newton with his theory of gravitation, connected the dots between celestial and terrestrial mechanics. Today, we still largely rely on Newtonian mechanics for space travel and navigation, when all artificial satellites are way below relativistic speed.

Bethe was a German scientist who escaped Hitler's regime to join Cornell University in 1935. After the Pearl Harbor attack, he actually became eager to contribute to fighting against Nazism and Japanese Imperialism. Not yet a US Citizen, he was not able to participate in any classified work. After being naturalized in 1941, he was a natural candidate for the Manhattan Project. Recognizing his talents, Director Oppenheimer appointed him to be Director of the Theoretical Division. Thus, he directly contributed to the very first atomic bombs. Several years after World War II, he became a reluctant participant on another atomic race, this time for the H-Bomb against the potential Soviet threat. In fact, he thought his contribution would be to prove that such a bomb could not be built. Instead, he solved some theoretical hurdles that led to the Ulam-Teller success.

Throughout his work on the microcosmic world, Bethe also pondered the role of nuclear reactivity and energy in the cosmic realm. Starting with the investigation of solar energy production, he formulated a general theory of nucleosynthesis for the Sun. Thanks to his contributions in both earthly and cosmic phenomena, the Nobel Foundation – for the first time – turned their attention toward the heavens. In fact, we suppose that had it not been for his studies in the sub-atomic worlds, his work on stellar energy might not have won the attention of the Nobel Foundation. This conjecture is founded on the observation that earlier great astrophysicists, such as Hubble, Eddington and Jeans, did not get any Nobel recognition.

III. "From Cosmic Noise to the Big Bang – The First Recognition about Space Exploration

The 2006 Nobel Prize in Physics was heralded by some of the press as the "First Nobel Prize for Space Exploration." Indeed the Nobel Foundation's announcement specifically cited the Cosmic Background Explorer (COBE) satellite launched by NASA in 1989 as the prime enabling instrument. (Ref. 6). It further mentioned, "The COBE results provided increased support for the Big Bang scenario for the origin of the Universe… These measurements also marked the inception of cosmology as a precise science."

Naturally, NASA seized this unique moment of fame to honor its favorite son, the first Nobel scientist of the agency, Dr. John Mather, of the Goddard Space Flight Center, who shared the honor with Professor G. Smoot of the University of California, the Principal Investigator of the COBE measurement.

But the pedigree of this Prize can be traced back to the 1978 Physics Prize to A. Penzias and R. Wilson "for their discovery of cosmic microwave background radiation." Some NASA technologists argued that this was the first Nobel Prize in space science, though the discovery was a serendipitous one in some calibration tests of ground-based antennas. Whether we argue for the first in 1978 or the first in 2006, both Prizes led to a new era in exciting cosmic research. One condensed way to summarize the significance of the two Prizes would be to say that they stumbled onto cosmic background noise – a discovery recognized in the 1978 Prize, which then led to proposed space exploration that confirmed the "Big Bang," a final confirmation and detailed measurement that was recognized with the 2006 Prize.

The Nobel lecture by John Mather was entitled, "From the Big Bang to the Nobel Prize: The Cosmic Background Explorer (COBE) and Beyond." He went back to the 1929 Hubble discovery of the expanding Universe, and recognized the foundational work of Einstein and Lemaitre. From there he jumped to the thermal history of the Universe as postulated by Dicke et al in 1965, and in the same year, the serendipitous discovery of the cosmic microwave background (CMB) by Penzias and Wilson. This theory and observational discovery stimulated a number of investigations in the 1970's, including Mather's doctoral dissertation and his post-doctoral research at the Goddard Institute for Space Studies. In 1976, NASA issued an Announcement of Opportunities for Explorer Satellites. Out of 150 proposals, three teams were selected: The GSFC/MIT/Princeton team that included Mather; a Berkeley team that included Smoot; and a JPL team of Gulkis and Janssen. In the next year, NASA selected the PI's and formed the Mission Science Definition Team, which included all these names aforementioned.

Smoot's Nobel lecture highlighted the three C's in the title, "CMB, COBE and Cosmology." He started with a more personal journey during his pre-doctoral years when he heard lectures on the excitement of the Penzias-Wilson discoveries. Trained in experimental particle physics, he also heard reactions from his theoretical senior colleagues that the field of cosmology was in its infancy in terms of rigorous formulation, and thus offered many opportunities. Toward the completion of his doctorate, he went for interviews and was attracted by Nobel scientist Alvarez' interests in anti-matter and anisotropy, which might be measurable in young galaxies or a young Universe. He then joined the Berkeley team and later submitted the anisotropy proposal to the COBE exploration team with Alvarez.

The Nobel Foundation, in a press release to a lay audience, explained the significance of the 2006 Prize as follows: "COBE was launched using its own rocket on 18 November 1989. The first results were received after nine minutes of observations: COBE had registered a perfect blackbody spectrum. When the curve was later shown at an astronomy conference the results received a standing ovation." COBE also had the task of seeking small variations of temperature in different directions (which is what the term "anisotropy" refers to). Extremely small differences of this kind in the temperature of the cosmic background radiation – in the range of a hundred-thousandth of a degree – offer an important clue to how the galaxies came into being. The variations in temperature show us how the matter in the Universe began to "aggregate." This was necessary if the galaxies, stars, and ultimately life-forms like us, were to be able to develop. Without this mechanism, matter would have taken a completely different form, spread evenly throughout the Universe.

The success of COBE was the outcome of prodigious teamwork involving more than 1,000 researchers, engineers and other participants. **John Mather** coordinated the entire process and also had primary responsibility for the experiment that revealed the blackbody form of the microwave background radiation measured by COBE. **George Smoot** holds the main responsibility for measuring the small variations in the temperature of the radiation."
Note: For all Prize-related information, see Ref. 7.

IV. "Gone with the Wind" – Ozone Depletion Galore

While we may argue over which was the first Nobel Prize for space science, the first one for earth remote sensing science was the Chemistry Prize in 1995. It was awarded for the discovery of the series of measurements captured from high-altitude aircrafts and the space satellite Nimbus-7 carrying the Total Ozone Mapping Spectrometer (TOMS). P. Crutzen, M. Molina, and F. Rowland were awarded the Prize "for their work in atmospheric chemistry, in particular, ozone depletion." For years, Mario Molina was employed at NASA/JPL before joining the Massachusetts Institute of Technology where he received the Prize. This was an interesting social footnote for the Mexican American community, which was wildly enthusiastic to recognize their first Nobel scientist. It was a welcome breath of fresh air against the backdrop of famous names from entertainment and sports.

The significance of this Prize was announced by the Nobel Foundation with an arousing headline, "The ozone layer - the Achilles heel of the biosphere," followed by these explanations: "The atmosphere surrounding the earth contains small quantities of ozone - a gas with molecules consisting of three oxygen atoms (O_3). If all the ozone in the atmosphere were compressed to a pressure corresponding to that at the earth's surface, the layer would be only three mm thick. But even though ozone occurs in such small quantities, it plays an exceptionally fundamental part in life on earth. This is because ozone, together with ordinary molecular oxygen (O_2), is able to absorb the major part of the sun's ultraviolet radiation and therefore prevent this dangerous radiation from reaching the surface. Without a protective ozone layer in the atmosphere, animals and plants could not exist, at least upon land. It is therefore of the greatest importance to understand the processes that regulate the atmosphere's ozone content."

"Paul Crutzen, **Mario Molina** and **Sherwood Rowland** have all made pioneering contributions to explaining how ozone is formed and decomposes through chemical processes in the atmosphere. Most importantly, they have in this way showed how sensitive the ozone layer is to the influence of anthropogenic emissions of certain compounds. The thin ozone layer has proved to be an Achilles heel that may be seriously injured by apparently moderate changes in the composition of the atmosphere. By explaining the chemical mechanisms that affect the thickness of the ozone layer, the three researchers have contributed to our salvation from a global environmental problem that could have catastrophic consequences."

Crutzen was actually the trailblazer who took the next fundamental step towards a deeper understanding of the chemistry of the ozone layer. In 1970 he showed that the nitrogen oxides NO and NO_2 react catalytically (without themselves being consumed) with ozone, thus accelerating the rate of reduction of the ozone content. The next leap in our knowledge of ozone chemistry was in 1974, when Molina and Rowland published their widely noted *Nature* article on the threat to the ozone layer from chlorofluorocarbon (CFC) gases - *freons* - used in spray bottles, as the cooling medium in refrigerators and elsewhere and plastic foams.

The following table on the EPA Ozone home page dramatically shows the destructive potential of CFC, and the improvement from replacement products, HCFC and HFC:

Common Ozone-Depleting Substances and Some Alternatives‡

Substance	Uses	Ozone-Depleting Potential*	Global Warming Potential**
Chlorofluorocarbons (CFCs)	Refrigerants, cleaning solvents, aerosol propellants, and blowing agents for plastic foam manufacture.	0.6 – 1.0	4,680 – 10,720
Halons	Fire extinguishers/fire suppression systems, explosion protection.	3 – 10	1,620 – 7,030
Carbon tetrachloride (CCl_4)	Production of CFCs (feedstock), solvent/diluents, fire extinguishers.	1.1	1,380
Methyl chloroform ($CHCl_3$)	Industrial solvent for cleaning, inks, correction fluid.	0.1	144
Methyl bromide (CH_3Br)	Fumigant used to control soil-borne pests and diseases in crops prior to planting and in commodities such as stored grains. Fumigants are substances that give off fumes; they are often used as disinfectants or to kill pests.	0.6	5
Hydrochlorofluorocarbons (HCFCs)	Transitional CFC replacements used as refrigerants, solvents, blowing agents for plastic foam manufacture, and fire extinguishers. HCFCs deplete stratospheric ozone, but to a much lesser extent than CFCs; however, they are greenhouse gases.	0.01 – 0.5	76 – 2,270
Hydrofluorocarbons (HFCs)	CFC replacements used as refrigerants, aerosol propellants, solvents, and fire extinguishers. HFCs do not deplete stratospheric ozone, but they are greenhouse gases.	0	122 – 14,130

‡ This is a limited list and does not represent all of the alternatives approved by EPAs Significant New Alternatives Policy (SNAP) program. For a complete list, see: www.epa.gov/ozone/snap/lists/index.html.

* Ozone depleting potential (ODP) is the ratio of the impact on ozone caused by a chemical compared to the impact of a similar mass of CFC-11. The ODP of CFC-11 is 1.0.

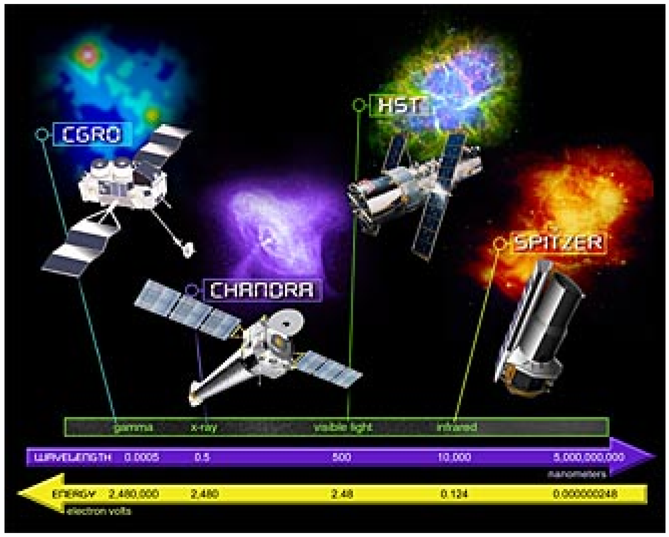
** Global warming potential (GWP) is the ratio of the warming caused by a substance compared to the warming caused by a similar mass of carbon dioxide. The GWP of carbon dioxide is 1.0.

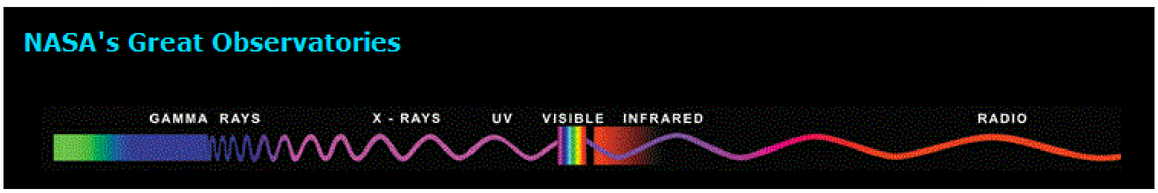
Space exploration has very directly contributed and interacted with this area of environmental research, as summarized on the "NASA Facts Online" (Ref. 9): "Two decades ago, stratospheric ozone depletion was mainly of interest to atmospheric scientists. Today, it is a worldwide environmental concern that has been addressed by several international accords. Ozone depletion epitomizes the environmental problems humans face today: it is global and the direct but unintended result of human industry. Remedying it will have direct and indirect economic consequences. Since the mid-1970s, NASA has been in the forefront of research with space-based, airborne and ground-based observing programs." Under the umbrella of the Mission to Planet Earth (MTPE) enterprise, continued explorations contribute to this important area: Upper Atmosphere Research Satellite (UARS); the Atmospheric Laboratory for Applications and Science (ATLAS), a series of Space Shuttle-Spacelab missions; NASA high altitude airborne campaigns, a continuous series of TOMS instruments on various satellites; the latest on a Japanese Advanced Earth Observations Satellite; the Shuttle Solar Backscatter Ultraviolet Experiment (SSBUV); the Stratospheric Aerosol and Gas Experiment (SAGE); and the Earth Observing System (EOS) which will continue the chemical, dynamical and solar measurements important to understanding ozone processes. In particular, the EOS-Aero series (first launched in 2000) and EOS-Chem series (first launched in 2002) will provide data on atmospheric chemistry and solar radiation important to ozone studies. We look forward to honoring more Earth scientists at future Nobel ceremonies.

V. "The Great Observatories" – From Einstein to Spitzer

The following headline announced a new program endorsed by the prestigious National Academy of Sciences for the New Millennium Astronomy and Astrophysics. It has a catchy title, "Beyond Einstein."

The banner starts with "Beyond Einstein," which carries multiple meanings. First, it has a chronological meaning, beyond the 20th Century, which saw the dominant influence of Einstein in physics. Second, it will be a quest beyond his unfulfilled dream of the unified field theory. Third, and closer to space exploration, these are new space-borne observatories beyond the last series started by the High Energy Astronomical Observatories later named after Einstein. For the context of this paper, Einstein was the first Nobel scientist for whom a space-borne observatory was named, followed by Compton and Chandrasekhar. Shortly after the Einstein Observatory, the new series of "Great Observatories" was born, described by NASA as follows: (Ref 10). "To grasp the wonders of the cosmos, and understand its infinite variety and splendor, we must collect and analyze radiation emitted by phenomena throughout the entire electromagnetic (EM) spectrum. Towards that end, NASA proposed the concept of Great Observatories, a series of four space-borne observatories designed to conduct astronomical studies over many different wavelengths (visible, gamma rays, X-rays, and infrared). An important aspect of the Great Observatory program was to overlap the operations phases of the missions to enable astronomers to make contemporaneous observations of an object at different spectral wavelengths."





NASA’s Great Observatories covered four parts of the EM wave spectrum (Ref. 11): Compton for Gamma rays, Chandra for X-ray, Hubble for visible lights, and Spitzer for infrared.

The "Great Observatories" series have a major significance for the theme of this paper. It raised the awareness of the public and educational sectors to some success icons. It did it by promoting a competition for the naming, and by using the names in press releases. Of the five names associated with the observatories, only Einstein is sufficiently well known to the public. The others, Compton, Hubble, Chandra and Spitzer, may not even pass the first round of the "Jeopardy" show. But it's a good start. As we'll see in the following section, "Chandra" is gaining prominence.

VI. “And the Winner is… Chandra” – How an Unpronounceable Name Won Over the Household name “Mother X-ray"

The evolution of the name Chandra X-ray Observatory (CXO) from AXAF (Advanced X-ray Astrophysical Facility) is a good case study for astrosociology. First, let's get to know this scholarly gentleman, whose full name is hardly pronounceable in America -- Subrahmanyan Chandrasekhar. We are sure most readers will wonder who this man was and why NASA named a whole space-borne Observatory after him. He was born and raised in India, and went to Cambridge for his doctoral education. Shortly after he obtained his PhD, he came to the University of Chicago where he was a professor until his retirement into emeritus. His primary fame was in stellar structure, relativistic astrophysics, and the mathematical theory of black holes. For several decades he was the Chief Editor of the Astrophysical Journal, the premier publication in that field. He was awarded the Nobel Prize in 1983 with this citation: "For his theoretical studies of the physical processes of importance to the structure and evolution of the stars."

Chandra's work certainly opened the windows onto many fronts in x-ray astrophysics, such as stellar evolution, black holes, and high-energy cosmic interactions. Ever since the launch and operations of CXO in 1999, we have seen many headlines like this one on May 7, 2007 (Ref. 12):

However, for the social theme in this paper, it is educational to revisit how Chandra's name won over a household name, Madame Curie, who was hailed as the mother of X-ray (Ref. 13), and is in a very exclusive club of only three persons who have ever won two Nobel Prizes.. In fact, she was the first, predating two other legends, Linus Pauling and John Bardeen (Ref. 7).

NASA announced the winning name in this news release (Ref. 14): “NASA Selects New Name and Sets New Launch Date for Advanced Space X-Ray Telescope.” NASA set a new launch date for the Advanced X-ray Astrophysics Facility (AXAF), and announced its new name, the "Chandra X-ray Observatory" in honor of the late Indian-American Nobel Laureate, Subrahmanyan Chandrasekhar. “Chandra,” a shortened version of Chandrasekhar’s name, which he preferred among friends and colleagues, was the name chosen in a contest to rename the X-ray telescope. “Chandra” also means “moon” or “luminous” in Sanskrit. The winners were a high school student in Laclede, Idaho, and a teacher in Camarillo, California.
The Chandra X-ray Observatory shipped to NASA’s Kennedy Space Center, Florida, and launched aboard STS-93 on July 23, 1999.

Chandrasekhar made fundamental contributions to the theory of black holes and other phenomena that the Chandra X-ray Observatory will study. His life and work exemplify the excellence that we can hope to achieve with this great observatory,” said NASA Administrator Daniel Goldin. “Chandra probably thought longer and deeper about our Universe than anyone since Einstein,” said Martin Rees, Great Britain’s Astronomer Royal.

Other luminary names submitted included Curie, Feynman, Asimov, Cannon, and even Da Vinci! Currie was the runner-up, and was passionately promoted by a number of young women, possibly to break the NASA glass ceiling on all famous names so honored. In the end, astrophysics trumped X-ray. To be fair, this was a contest between the themes of “exploring the heavens” versus “enhancing the Earth.” Curie’s passion and contributions were far too Earth-bound to fare well in such a competition.

VII. “From the Mother of X-ray to the Father of X-ray Astronomy"

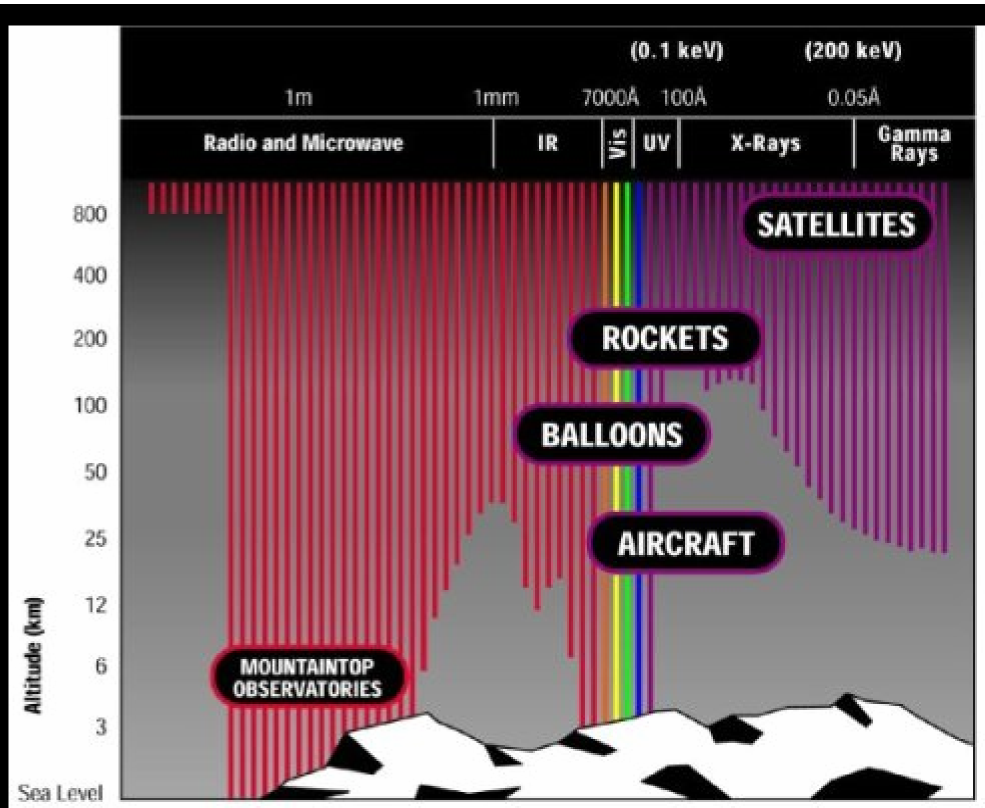
On October 10th, the headlines from Cambridge, MA read, “Riccardo Giacconi, one of the founding fathers of X-ray astronomy, is a co-recipient of the 2002 Nobel Prize in Physics. Dr. Giacconi received this award in honor of his work in the field of X-ray astronomy. Much of that work was carried out by him and his colleagues at the Smithsonian Astrophysical Observatory (SAO) during the 1970’s. Giacconi was also at that time a professor in the Department of Astronomy at Harvard University and an Associate Director at the Harvard-Smithsonian Center for Astrophysics (CFA).” (Ref. 15)

The Nobel Foundation honored Giacconi with a very succinct citation, “For pioneering contributions to astrophysics, which have led to the discovery of cosmic X-ray sources.”

As the colorful life of the Mother of X-ray was portrayed in such biographies as *Madame Curie* (Ref. 16), an equally colorful portrayal can be written of this Father of X-ray Astronomy. Giacconi was born in Genoa, Italy, a city made famous by Columbus. His childhood years were scarred by the hardship under Mussolini fascism. His father suffered greatly for a courageous anti-Fascist stance. His mother was a teacher of mathematics and physics, who pronounced that God invented geometry. At the start of World War II, Giacconi was eight years old, and had to move to Milan to live with his aunts (which later became his adopted hometown where he received all his education and launched his career as an Assistant Professor). In the 1950's, Fulbright Scholarships attracted many European talents to the US. It was this lucky arrangement that brought this one star to space exploration and NASA. In 1954, he landed at the University of Indiana as a Fulbright research fellow. In the ensuing five years, he literally drifted into an intellectual wilderness to find a permanent field (as admitted in his autobiography, Ref. 17). In his Nobel lecture, he gave a tear-inspiring recount of how his wife of five decades gave him the necessary inspiration and encouragement during his down years. "The influence of Mirella on my life has been greater than that of any other person. She brought love, calm, and stability where none had existed before. She created a home for us full of beauty and tenderness. She is brighter than I am, translated many books for the MIT press, and has an uncompromising view of reality. Through thick and thin we are still together today." (Ref. 7) As mentioned in Section 1 regarding science education, much more than a set of facts and equations, students, and youth, are inspired by the flesh-and-blood humanity of successful icons.

In September 1959, he joined a small private research firm, American Science and Engineering, and was given a bold assignment to define and promote a new programmatic initiative in space research. He finally found his vocational calling! It was to be "rocket science," and more, as the Nobel Press Release declared, "A new window on the Universe." The first few of his years were in classified research: 19 rocket payloads, six satellite payloads, one entire satellite and an aircraft payload, as well as four rocket payloads for geophysical research. The following years witnessed the blossoming of his career. In the 1970's, he led the development of the Einstein X-ray Observatory, launched in 1978. The Einstein Observatory was the first fully imaging non-solar X-ray telescope put into space. This "first" led to another first. In 1976, Giacconi and Harvey Tananbaum of SAO submitted a proposal letter to NASA to initiate the study and design of a large X-ray telescope. This proposal led to the construction and launch of the very successful AXAF, the renamed Chandra described above.

For all his conspicuous contributions to the space program and formulations in space exploration, he was awarded three NASA medals: 1) Medal for Exceptional Scientific Achievement, 1971, 2) Distinguished Public Service Award, 1972, and 3) Exceptional Scientific Achievement Medal, 1980. It is significant and instructive to note that NASA and the Nobel Foundation are recognizing the same pioneering contributions by Giacconi, that is, without the initiatives of the space-borne design and instrumentation, there would not have been this new window on the Universe. The following diagram, with the gray area depicting opaqueness in that area of the EM spectrum, show that X-ray sources can mainly be observed in space. This is also a reminder of our fortune of being protected from cosmic x-rays by atmospheric moisture:



The depth of penetration of different frequencies of light into the Earths atmosphere. This shows why we need satellites for X-ray astronomy. (Image courtesy NASA)

VIII. "To Catch a Ghost" – Hunting for That Elusive Cosmic Messenger

The 2002 Nobel Prize in Physics was awarded to three persons. One half of the Prize recognized Giaconni for opening a new window on the Universe. The other half recognized another new window – neutrino astronomy. Unlike the previous example where space exploration played a central role that led to the advances, this case is a reverse, that is, ground-based efforts leading to new research opportunities in space exploration. This new window will add to research and interpretation of data from the Great Observatories.

The Nobel Foundation gave a press release (Ref. 7) with this explanation: "The mysterious particle called a neutrino was predicted as early as 1930 by Wolfgang Pauli (Nobel Prize in 1945), but it would take 25 years to prove its existence by Frederick Reines (Nobel Prize in 1995). This is because neutrinos, which are formed in the fusion processes in the Sun and other stars when hydrogen is converted into helium, hardly interact at all with matter and are therefore very difficult to detect. For example, thousands of billions of neutrinos pass through us every second without our noticing them. **Raymond Davis Jr.** constructed a completely new detector, a gigantic tank filled with 600 tons of fluid, which was placed in a mine. Over a period of 30 years he succeeded in capturing a total of 2,000 neutrinos from the Sun and was thus able to prove that fusion provided the energy from the Sun. With another gigantic detector, called Kamiokande, a group of researchers led by **Masatoshi Koshiba** were able to confirm Davis's results. They were also able, on 23 February 1987, to detect neutrinos from a distant supernova explosion. They captured 12 of the total 10^{16} neutrinos (10,000,000,000,000,000) that passed through the detector. The work of Davis and Koshiba has led to unexpected discoveries and a new, intensive field of research, *neutrino-astronomy."*
Actually, Neutrino astronomy as a new window already had NASA's attention four decades earlier. A document record of 1962, by HY Chiu of NASA Goddard, describes an earlier investigation, and a bold projection of a new field of space studies. (Ref. 29)

But the theoretical underpinnings of the work that finally led to this Nobel Prize should be traced back to John Bacall, who with Davis has for 35 years preached a gospel of that ghost particle. During the 1960's and 1970's, astronomy and astrophysics seemed to suffer a kind of competing dichotomy, with NASA leading the space-borne observations and investigations, while NSF (National Science Foundation) leading the ground-based research. As we saw in the previous examples, major breakthroughs could be achieved if the two paradigms became complimentary, such as in the studies of Cosmic Microwave Background and the Ozone depletion. Bacall was a visionary theoretician who saw the need for a complimentary paradigm. His vision was finally appreciated and won distinctive recognitions from both NASA and NSF. In fact, he was very instrumental in the progress and success of the Hubble Space Telescope program (Ref. 18).

A Nova program, *The Ghost Particle*, produced by the Public Broadcasting Service (Ref. 19), gave a very vivid and moving account of these two men's quest for the impossible dream. Bacall first produced a theoretical model that predicted the neutrino flux from the Sun, and Davis was determined to measure this flux, building his gigantic underground tank. But for about three decades, there were big discrepancy between theory and experiment. Bacall reminisced that every year both had to recalculate or recalibrate their results to justify that they were both correct. It was more than two decades into their impasse when help came from a totally unexpected land and unrelated search. In Japan, for the study of radioactive decay, entirely unrelated to the neutrino hunt, Koshiba led a team to build an underground detecting device analogous to Davis', in fact, to protect them from neutrino disturbance or intrusion. For their investigation in radioactive decay, the Koshiba team had to subtract out the effects of the terrestrial neutrinos from the atmosphere. But their calculation showed exactly the same kind of discrepancy observed by Davis and Bacall. After many iterative confirmation and revisions between theory and experiments, the so-called discrepancy actually led to a happy ending, revealing the richness of neutrinos, which come in three flavors and can oscillate among the flavors, thereby giving an earlier misinterpreted result.

There are many morals to this exciting and interesting saga. But let's confine these to the context of space exploration. First, space-borne research must go hand-in-hand with ground-based efforts. Bacall deserved the many awards he had won for such holistic vision. Second, serendipity abounds in science, even between heaven and Earth. In this case, the Japanese experiment was the most unexpected stroke of luck that anyone expected on this side of the Pacific. Third, a very small seed idea – almost an afterthought in 1930, then audaciously projected in 1962 as a field of study at NASA, which finally led to international consensus and recognition in 2002 – was proudly declared as a new window into the Universe. What a heart-warming and awe-inspiring epic of 70 years – a hunt for that elusive cosmic messenger!

IX. "The Stars Spell Your Name" – Christa's 73 Seconds in Space

The space enterprise is comprised of numerous unsung heroes and heroines. Students see the most visible ones, astronauts, lauded in the movies *The Right Stuff* and *Apollo 13*. Even that hero identification took a significant discount when an astronaut was caught committing acts of criminal intent. Somehow we may have forgotten that the space domain is a large workforce made up of flesh-and-blood humanity. When we are reminded of the Nobel laureates and some of their co-workers, who have had interactions and relations with space exploration, we are impressed with the intellectual, national and cultural diversity, which we can celebrate. There was the German who escaped Nazism (Bethe); and the Italian who survived childhood hardship under Fascism (Giaconni). There was the Indian immigrant who came to the US by way of a UK education at Cambridge (Chandrasekhar). There was the chemical engineer who grew up and was educated in Mexico City (Molina), and then sought post-graduate education in Europe. After doctoral and post-doctoral education at Berkeley, CA, he joined JPL of the NASA family, where he had the opportunity to collaborate with a professor at the University of California (Rowland), who did the breakthrough research. The fortune of this duo was complemented by a cosmopolitan Dutch scientist (Crutzen), who taught and researched in the Netherlands, Sweden, Germany and the United States. Together, they shared the pinnacle of honor in Sweden. But more importantly, they opened a new vista in meteorological science and world consensus on climate change. Of course, there were the first-rate American scientists whom NASA chose to honor with its most visible space-borne observatories: Einstein, Compton, Hubble, Chandra and Spitzer. And last but not least, there was NASA's favorite son Mather, and his humble beginning at Swarthmore College.

While we celebrate the intellectual and cultural diversity of these fellow humans with super-human accomplishments to advance the space enterprise, we cannot help but notice, with a sense of sad incompleteness that all names honored happened to be of one gender. We salute the gallant efforts of several young students who tried very hard to put Marie Curie's name in space. We are also reminded of the tender words of singer Elton John at the funeral of a princess, "Goodbye England's rose …and the stars spell out your name." We still wait for the day when a prominent spacecraft with a woman's name, flies among the stars, like Einstein, Compton, and Chandra.

Unfortunately, during much of the 20th century, gender bias was blatant in both space and Nobel politics. Shortly after the space race began in 1960, both the US and USSR started training women astronauts. But the Soviets put their first woman in space in 1963, while we were still arguing about women in the US Space Program. 13 women were selected to train at NASA in the FLAT program (First Lady Astronaut Trainees). They later proved to be every bit as qualified as the Mercury 7 men, some of whom loudly testified to Congress against women in space. Political and cultural hurdles delayed American women in space until 20 years later, when Sally Ride first flew on the Shuttle as a Mission Specialist. We waited another 12 years, when Eileen Collins first piloted a spacecraft in 1995. “We cannot help but notice the great irony that we were so determined to beat the Soviets in space, but yet were quite content to settle for a 20-year laggard in gender participation” (Ref. 22). Several books with telltale titles documented this less-than-proud history of the American space program: *The Mercury 13: The True Story of Thirteen Women and the Dream of Space Flight* (Ref. 20); *Women in Space: Following Valentina* (Ref. 21); *Right Stuff, Wrong Sex: America's First Women in Space Program (Gender Relations in the American Experience*) (Ref. 22) .

Given the Nobel experience, gender bias was not any better than the space initiatives mentioned above. The books *Lady Laureates* (Ref. 13) and *Nobel Prize Women in Science* (Ref. 30) documented many extraordinary efforts to overcome prevailing hurdles at the time. There was the story of Marie Curie’s first Nobel Award when she had to sit in the audience to see her husband accepting the Prize for both. There was the story of Maria Gephard-Mayer, the Mother of Nuclear Shell Theory, who during her teenage years was told that she was too pretty to waste her life in science. There was her story of having to work in a famous university as a voluntary professor because of nepotism rule in favor of men. Then there were the mysterious cases of Jocelyn Bell and C.S. Wu who saw their male co-discoverers off to the Swedish honor ceremonies. While we enumerated many heart-warming stories in this paper, we also sincerely hope that some of these heart-breaking anecdotes will not be repeated in the 21st Century.

Conclusion

To close this paper on a higher note, we honor a woman whose name is certainly spelled out among the stars, even though she spent only 73 seconds in space. Christa McAuliffe was never destined for a Nobel Prize, nor ever dreamed to be a space scientist. She was so ordinary that she was considered a best candidate to relate to ordinary folks. When she entered the competition to be the first teacher in space, she did not have any high hopes of winning. After all, there were 11,500 applicants, including scholars, professors, authors, and doctors. She was only a high school social studies teacher. Her teaching career was even punctuated by the birth and rearing of two children. But her popularity among teachers and students, and her long record of involvement in community services – church, hospital, playhouse, girl scouts, and YMCA, was impressive to the selection committee. Finally, she was selected to be the one, but a new worry came over her. “Was she only chosen for the ride – a symbolic passive passenger?” To overcome her concern, she worked extra hard, and in no time blended into the astronaut team. Often called the "Field Trip Teacher," Christa believed it was the hands-on experience that was the most valuable teaching tool. In fact, she called her impending trip on the *Challenger* the "Ultimate Field Trip" (Ref. 23). During this ultimate field trip, she was to have taught two lessons from space, one explaining the Shuttle structure and the astronaut’s living conditions, while the other explaining the rationale and technological benefits of space exploration. She was to keep a journal like that of many pioneering women in search of new frontiers. This was to be her ultimate frontier.

After her 73 seconds in space, the Challenger tragedy ended her field trip. However, her legacy lives on. Today there are inspiring books, the Christa McAuliffe Planetarium, the Challenger Centers, and numerous teaching materials in honor of Christa (Refs. 24 to 28). Students all over the US can take a field trip to witness that Ultimate Field Trip. When we study the lives of the extraordinary scientists, we see how they were influenced by ordinary teachers. For every Nobel scientist, there was at least one Christa McAuliffe who took him/her to field trips.

We end this paper with the hopeful confidence that someone will look back and write about the space scientists, astronauts, and Nobel scientists, who will testify that a Christa brought inspiration to their lives.

Postscript: Shortly after we completed our manuscript for this paper, we witnessed on headline news the lift-off of the Space Shuttle Endeavor, on Aug. 8, 2007, carrying into outer space Barbara Morgan. Fondly addressed as Barb in the NASA community, she was Christa’s understudy and back-up. After 21 years, Barb has become a full-fledge astronaut, but still represents the Teacher in Space ventures. She will carry out Christa’s dream on that ultimate field trip.

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