Remembering Riccardo Giacconi: The Father of X-ray Astronomy

Nobel prize-winner, and one of the most influential fig-ures of modern astrophysics, Riccardo Giacconi died on 9 December 2018, at the age of 87. On the occasion of his passing, we present a brief retrospective on the father of X-ray astronomy, the originator of *Chandra*, a mentor, and a friend.

Over his unparalleled career, Riccardo opened up a new window for observing the universe, and as director or guiding force for major observatories spanning ten decades in wavelength, he revolutionized the way "big astronomy" is done.

From 1959 through 1981, first at American Science & Engineering and later at the Harvard-Smithsonian Center for Astrophysics (CfA), Riccardo created and led the group that discovered the first X-ray sources outside our solar system, found the first convincing evidence for the existence of black holes, developed the first focusing X-ray telescope and laid the foundation for the *Chandra* X-ray Observatory. In 1981, he became the first director of the Space Telescope Science Institute (STScI) and played a leading role in repairing the flawed optics for the *Hubble* Space Telescope. From 1993 to 1999, as director of the European Southern Observatory (ESO), he guided the development of the Very Large Telescope (*VLT*). After leaving ESO in 1999, Riccardo became President of Associated Universities, Inc. (AUI), the managing organization of the National Radio Astronomy Observatory (NRAO), and the North American Executive for the construction and operation of the Atacama Large Millimeter/Submillimeter Array (*ALMA*). In 2002, Riccardo was awarded half of the Nobel Prize in physics for "pioneering contributions to astrophysics, which have led to the discovery of cosmic X-ray sources."

In this remembrance, we focus primarily on the arc of Riccardo's career as it relates to X-ray astronomy and *Chandra*.

Riccardo was well-versed in the classics, and often spoke of being driven, like Odysseus, to pursue virtue and knowledge. We three were privileged to accompany him in one way or another on much of his epic journey as friends and colleagues beginning in the late 1960's when, still in our 20's, we came together at AS&E in Cambridge, Massachusetts.

In the theatre, there is a point in the drama called the "insighting moment," when the main character suddenly understands what he or she must do. Riccardo's insighting moment came in 1959 at a party at the home of Bruno Rossi, a professor at MIT and a member of the Space Science Board of the National Academy of Sciences. The Space Science Board had been created in 1957 in response to the launch of Sputnik by the Soviet Union. Bruno was also chairman of the board of American Science & Engineering, a startup high-tech company formed in Cambridge a year earlier by Martin Annis, one of his former students. Annis introduced Bruno to Riccardo, and explained that Riccardo had recently been hired to be the new head of the Space Science Division at AS&E. Bruno took Riccardo aside and suggested that he should consider starting a program in X-ray astronomy, a field that would require space-borne instruments. Suddenly, Riccardo, who had been frustrated by the lack of progress in his cosmic ray physics research, saw an opportunity. He began an intensive study of X-ray optics and the state of the field of X-ray astronomy.

He learned that a group led by Herbert Friedman of the Naval Research Laboratory (NRL) had previously observed X-rays from the Sun, and had set an upper limit of 2×10^{-8} erg cm^{-2} sec^{-1} for 6 keV photons for extrasolar X-rays. Based on the strength of the solar X-rays, the expected fluxes from nearby stars would be orders of magnitude less than that. Riccardo quickly hit upon a solution: build a telescope that could focus X-rays through grazing incidence reflection. He wrote a paper with Rossi on the concept, which was submitted to the Journal of Geophysical Research in December of 1959, only two months after the conversation with Rossi. About 9 months later, he also submitted a proposal to NASA to "design, construct, and test a prototype X-ray telescope".

Concurrently, Riccardo and George Clark of MIT explored the possibility that sources such as the Crab Nebula might be much more powerful sources of X-rays than stars, a possibility also suggested by Friedman. Realizing that the development of an X-ray telescope might take a while, Riccardo began designing rocket-borne experiments with a grant from the Air Force Cambridge Research Laboratory. Although the ostensible goal was to detect fluorescent X-rays from of the Moon, Riccardo's earlier work shows that he was on the hunt for bigger game.

The rocket flights used traditional Geiger counters as detectors. His approach was to build a detector with a much larger field of view and detection area than those used by NRL and to use the anti-coincidence techniques he had learned as a cosmic ray physicist to reduce the background. As a result, his detector was about 50 times more sensitive that the NRL ones.

"And so my point is that X-ray astronomy is especially interesting because of these new mechanisms and you cannot simply extrapolate from ordinary temperature considerations."

Riccardo Giacconi [1]

On June 18, 1962, after two previous launches had ended in failure, Riccardo and his group achieved success. The rocket spent five minutes above the atmosphere. In that time, it detected a strong source in the direction of the constellation Scorpius, which they named Scorpius X-1, as well as an all-pervasive X-ray background radiation. The field of X-ray astronomy had been born!

Giacconi moved quickly to use this new window for the exploration of the universe. In 1963, he and Herb Gursky laid out a bold program for the future of X-ray astronomy that included more rocket flights, an X-ray satellite to survey the entire sky, and within 5 years, an X-ray telescope. This time they received funding from NASA, and by 1967 the development of *Uhuru*, as the X-ray satellite would come to be named, was underway.

For this project Riccardo had engineers and scientists working side-by-side to establish requirements, develop a design, construct and test the hardware, and plan the operations for the satellite. Riccardo himself was familiar with all of the sub-systems –knowing which were critical, which could provide back-up capabilities for others, how the science operations would be carried out, and the like. He successfully applied this approach, which he called science systems engineering, for the rest of his career, refining and extending it from the *Uhuru* and *Einstein* X-ray missions, to the *Hubble* operations at the Space Telescope Science Institute, the building of the *VLT* at ESO, and the *ALMA* development at AUI.

On a personal level, although junior scientists by university standards and relatively new to the project, we and several colleagues received assignments on the project which challenged us to our limits while providing opportunities to develop technical, management, scientific, and communications skills from the very beginning. As Paul Gorenstein, another MIT graduate who had migrated to AS&E a few years earlier, put it, "Riccardo motivated people, got them to do things. Whether he did it by inspiration or by example, he got a lot of people to deliver their best."

For previous NASA science missions, data tapes were delivered by mail several weeks after acquisition. In another departure from business as usual, Riccardo pressed NASA to transmit 20% of the data back to AS&E within 24 hours of acquisition and directed the team to develop a software system to analyze the data as soon we received it. The quick turn-around on the data enabled Riccardo and the team to make important discoveries almost immediately and to rearrange the observing schedule and satellite configuration to follow-up and exploit those discoveries.

Even though Riccardo had multiple responsibilities as a senior executive at AS&E, he set aside part of each day to work with the other scientists to analyze the latest *Uhuru* data. He set up a desk in one of our offices in a building around the corner from the AS&E headquarters, and he gave us explicit directions to reply that we had not seen him if his office called to inquire about his whereabouts.

Within a few months, the team had discovered erratic, sub-second variability in the source known as Cygnus X-1 and a regular periodicity of 4.84 seconds in Centaurus X-3. With intensive follow-ups of Cen X-3, we determined that it orbits in a binary system with a period of 2.087 days. Further observations confirmed that Cen X-3 is powered by the gravitational energy released by matter falling from the companion star towards and onto a neutron star. Subsequently, Giacconi and the *Uhuru* team, along with a number of other observers and theorists, determined that Cygnus X-1 is most probably a black hole (with a mass later established as ~15 times the mass of our Sun) orbiting in a binary system and powered by matter from a companion star matter falling towards the black hole. This finding constitutes the first observational evidence of the existence of black holes.

Figure 1: Ethan Schreier, Herbert Gursky, Riccardo Giacconi, and Harvey Tananbaum at the Nobel ceremonies in Stockholm in December 2002

> *"It was the scientific highlight of my career. It was the most mystical moment, when we suddenly understood."*
> *Riccardo Giacconi [2]*

During the *Uhuru* period, Riccardo met weekly with the *Uhuru* science group. In these often-stormy sessions, there was wide-open give and take regarding what we were seeing, what we thought we understood, what we were clueless about, and what we wanted to do next. Ideas, however wild, were floated with abandon and shot down remorselessly. There was respect for one and all, but no claims were sacrosanct and everyone had to defend their ideas based on logic and scientific merit. *Uhuru* meetings left most of the participants drained but also built confidence—in our results, in our plans for moving ahead, and in one another.

> *"Looking back on that time, I recognize that those intense interactions were a rather unorthodox way of doing science and certainly not to everybody's taste. But we were young, enthusiastic, intoxicated by our daily glimpses into a mysterious new universe, and more than a little giddy with success. It was a unique period, brought about by a singular combination of circumstances, people, events, and instruments that occurs rarely in science."*
> *Riccardo Giacconi [3]*

In 1973, Giacconi's core group moved a mile and a half away to the newly organized Harvard-Smithsonian Center for Astrophysics (CfA), where it formed the High Energy Astrophysics Division. It was there that one of Riccardo's earliest visions was fulfilled, with the development and launch, in 1978, of the *Einstein* X-ray Observatory, the first imaging X-ray telescope for extra-solar sources. *Einstein* demonstrated beyond doubt the importance of X-ray imaging, finding that essentially all types of astronomical objects and systems, from nearby stars to distant quasars, emitted X-rays. Innovations on this mission included the solicitation of proposals from the general community and the development of systematic procedures and techniques to plan, schedule and archive the *Einstein* observations, thereby opening access to the observatory for the broader astronomical community. This model, new at the time, has now been adopted by essentially all NASA astrophysics missions and most ground-based observatories.

In 1976, cognizant of the limited lifetime projected for *Einstein* and confident of the prospects it would engender, Riccardo and Harvey Tananbaum proposed *Einstein*'s successor which would become the *Chandra* X-ray Observatory. Even though the *Einstein* launch was still 2.5 years in the future, the proposal was well-received and technology work on the optics and mission studies led by Marshall Space Flight Center and SAO began in 1977. By the time of the 1980 Decadal Study by the National Academy of Sciences, the successes of *Einstein* made a compelling case for an even more powerful and long-lived X-ray telescope mission.

In 1981, Riccardo left CfA to become the first director of the STScI. The scientific community insisted that the scientific operations of a large, unique, and expensive new facility—the first major, international optical observatory in space, later to be christened *Hubble*—be managed by the community itself, and not by a NASA center. Riccardo insisted on leaving the CfA group intact, but recognizing the need to transfer the scientific operations philosophy from the X-ray group to the optical community, brought Ethan Schreier to Baltimore to oversee the *Hubble* operations and data system.

At STScI Riccardo used many of the same system engineering and scientific principles that had been so successful with his path-breaking X-ray astronomy satellites to create from scratch an entirely new institution. Other innovations, now standard for large astronomy projects, were introduced by Riccardo and his staff for *Hubble*. These included a formal data archive, the distribution and archiving of calibrated data, a formal archival data analysis program, an AI-based planning and scheduling system, reserved time for large and "key" programs, and freely distributed portable data analysis software. The first internet-based networking between astronomy facilities was also developed under the auspices of *Hubble*, as were other programs which became models for other observatories, such as the first community-operated grants program to support *Hubble* users.

When the error in *Hubble*'s optics was discovered, Riccardo set up working groups comprised of both STScI staff and experts recruited from around the world, from many disciplines. What had started as an embarrassment became a major success with *Hubble* becoming a household word.

In 1993, Giacconi moved to Garching, Germany, where he became the first American citizen to serve as director general of the European Southern Observatory (ESO). There he guided the development of the *Very Large Telescope* (*VLT*) which was to be 30 times larger than the previous ESO-built *New Technology Telescope*. Riccardo applied his, by then, practiced science system engineering process, fully reorganizing ESO and introducing modern management techniques. By the end of his tenure at ESO, he had implemented the systems and procedures that had been proven on *Hubble*, applying them for the first time to ground-based optical astronomy.

Even as he successfully guided the *VLT* development, Riccardo came to believe that millimeter wave astronomy should be the next major direction for European research. The United States, via the National Radio Astronomy Observatory, had also been advocating a major facility in this wavelength. Under Riccardo, ESO developed a collaboration with NRAO to build what would become *ALMA*, the world's largest ground-based astronomy facility.

After leaving ESO in 1999, Riccardo became President of Associated Universities, Inc. (AUI), the managing organization of NRAO, and the North American Executive for the construction and operation of *ALMA*. Riccardo instituted many of the same concepts at NRAO that he had developed in his early X-ray career, then refined at STScI and at ESO. NRAO simultaneously expanded the *Very Large Array*, already the forefront radio observatory in the world, while building *ALMA* with several international partners. In addition, Riccardo played a leading role in setting up *ALMA*'s governance structure, a truly worldwide collaboration of North America, Europe, and East Asia, in coordination with Chile, with no single country or region in charge. While Riccardo formally represented North American interests in *ALMA* for the US National Science Foundation, his vision for science permeated the entire project, and *ALMA*'s success is on a par with that of *Hubble*, *Chandra*, and the *VLT*.

Figure 2: Harvey Tananbaum, Riccardo Giacconi, Martin Weisskopf, and Claude Canizares at the Chandra 4-year Symposium in Huntsville, AL

Meanwhile *Chandra* was launched in 1999. Although Riccardo had moved on to new challenges, he had remained involved "in spirit" as many of the people he had recruited and trained played key roles in making *Chandra* a reality, including, but not limited to, Leon Van Speybroeck as Telescope Scientist, Stephen Murray as Principal Investigator for the High-Resolution Camera, and Harvey Tananbaum as first Director of the *Chandra* X-ray Center. Scientifically, Riccardo was involved as team lead for the first few years of *Chandra* observations on the *Chandra* Deep Field South.

Piero Rosati of the University of Ferrara, Italy, who did his Ph.D. thesis with Riccardo and Colin Norman at Johns Hopkins University, was a co-investigator with Riccardo on the *Chandra* Deep Field South project. Here is his recollection of this work:

"The *Chandra* Deep Field Survey (CDFS), a very long exposure in a single field, unimpeded by confusion, which Riccardo had dreamed about for decades, was planned in his ESO director office in 1998. There was some pressure on us to carry out the survey in the *Hubble* Deep Field South; on the other hand, we clearly wanted to select a field in a region in the southern sky with the lowest HI column density, as indicated by the Leiden/Dwingeloo Survey. At that point Riccardo said: "Why should we pick the HDFS? just for the glamour? We will make glamour in another field!" And so it was: the CDFS soon became the center of a coordinated multi-wavelength campaign, which included public imaging and spectroscopic observations with the *VLT*, the GOODS-South survey with *HST*/ACS, as well as deep IR, millimeter and radio observations. The CDFS has since then stimulated a staggering variety of studies, with hundreds of refereed publications, which have reached well beyond the original goal of understanding the nature of the sources making up the X-ray background, Riccardo's lifelong scientific quest."

> *"In 40 years we had improved X-ray astronomy observations between one and ten billion times with respect to the first observation of Sco X-1. I wonder sometimes how Tycho Brahe would have felt if he could have contributed to the development of* Hubble *and could have used it himself."*
>
> *Riccardo Giacconi [4]*

Riccardo retired from AUI in 2003, but stayed active at Johns Hopkins University for another decade He followed the science results from his various projects while remaining engaged in the politics of astro-science until his final days.

In summing up his extraordinary career, Riccardo said: "I am grateful to live in this heroic era of astronomy and to have been able to participate and contribute to its evolution. [5]"

We are grateful that he did, too.

Riccardo is survived by his wife, Mirella, daughters Anna and Guia, and grandchildren Alexandra and Colburn. He was predeceased by his son Marc.

ACKNOWLEDGMENT:

Portions of this article have appeared in Scientific American [6], Physics Today [7] and Proceedings of the National Academy of Science [8].

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