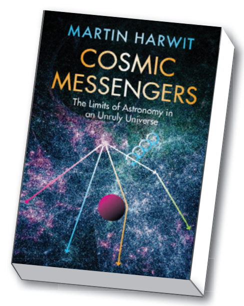
JACQUELINE ORRELL/SLAC/NSF/DOE/RUBIN OBSERVATORY/AURA

The Vera C. Rubin Observatory's focal plane, depicted here, is more than 60 cm wide, contains 189 individual sensors, and will take images at a resolution of 3200 megapixels. Currently under construction in Chile, the observatory is scheduled to see first light in 2023.

Astronomy's upper bounds

Cosmic Messengers
The Limits of Astronomy in an Unruly Universe

Martin Harwit
Cambridge U. Press, 2021. $39.99



Fueled by dramatic technological advances, astronomy has progressed rapidly in recent years. Over the past several decades, astronomers have detected the shadows of supermassive black holes, gravitational waves from merging black holes, fast radio bursts of uncertain extragalactic origin, dark energy, and exoplanets. The *James Webb Space Telescope*, with its 6.5-meter-diameter primary mirror, recently launched; the Vera C. Rubin Observatory in Chile will soon be imaging the entire available sky every few days; and 30-meter ground-based optical telescopes will be operational before 2030. The detection of signs of extraterrestrial life seems within reach. Multimessenger astronomy is thriving.

So it may come as a surprise that Martin Harwit's new book, *Cosmic Messengers: The Limits of Astronomy in an Unruly Universe*, provocatively argues that there may be ultimate bounds to astronomical knowledge. *Cosmic Messengers* is the final book in a trilogy. The first book, *Cosmic Discovery: The Search, Scope, and Heritage of Astronomy* (1981), enumerates the number of distinct breakthroughs in astronomical research and attempts to project the total number of such events (see the article by Harwit, Physics Today, November 1981, page 172). In the second volume, *In Search of the True Universe: The Tools, Shaping, and Cost of Cosmological Thought* (2013), Harwit discusses how new ideas in theoretical physics have led to the discovery of new phenomena in the universe (see Physics Today, October 2014, page 54).

In *Cosmic Messengers*, Harwit synthesizes his earlier efforts. He continues to argue that there may be a finite number of astronomical phenomena to be discovered and that we may someday approach the point of diminishing returns. But not to worry: He projects it will take several more centuries to get there.

Cosmic Messengers is important and thought-provoking because it revisits Harwit's basic idea almost exactly 40 years after the publication of *Cosmic Discovery*. He demonstrates how advances in the field since his first book appeared support his conclusion that there are a total of about 100 distinct phenomena to be discovered. Harwit's historical perspective is fascinating. In *Cosmic Discovery*, for example, he recommends looking into the feasibility and cost of large instruments that would directly detect gravitational waves or neutrinos from cosmic sources. Both types of instruments are now a reality and have proved spectacularly successful.

Harwit is well qualified to take us through such a broad-brush assessment of astronomy. He was a pioneer in the emerging field of IR astronomy in the 1960s and 1970s, a professor of astrophysics at Cornell University for many years, and the author of the 1973 textbook *Astrophysical Concepts*. He also led key review committees for NASA as it built its four highly successful space-based Great Observatories, which were launched in the 1990s and 2000s.

In his new book, Harwit makes a careful distinction between cosmic messengers, such as electromagnetic radiation, cosmic rays, gravitational radiation, and neutrinos, and the fundamentally distinct phenomena discovered by decoding their messages, such as exoplanets, fast radio bursts, and merging black holes. He makes a compelling case for why our knowledge may be ultimately limited by explaining how and why the universe blocks many of its messengers: The electromagnetic spectrum is bounded at longer wavelengths at about 10^6 cm because of the ionized interstellar medium; at shorter wavelengths, the bound is about 10^{-19} cm, below which photons are destroyed by their interaction with microwave photons from the cosmic microwave background.

A more basic problem, however, is that as the universe is examined with ever-finer temporal, spatial, and energy resolutions, the messages become unreliable because of propagation effects. Perhaps the most fundamental example is the way gravitational lensing obscures the arrival time and direction of all conceivable messengers.

The first half of the book is devoted to describing the known cosmic messengers, the instruments used to detect them, and how they have enabled the discovery of fundamental phenomena. It is an impressive tour of the most important advances in astrophysics, one that is enlivened by anecdotes and background material on the discoveries and discoverers. Harwit's coverage is largely fair, although it is possible to quibble with details.

In the second half of the book, Harwit estimates anew the number of astronomical phenomena likely to still be discovered. He argues that astronomers have identified 60 distinct phenomena up to now and, using statistical inference, calculates that his previous estimate of roughly 100 total phenomena was accurate. Harwit suggests that extrasolar asteroids traversing the solar system and as-yet-unknown properties of dark matter and dark energy are possible new messengers that could enable the discovery of some of the 40 phenomena still out there to be uncovered.

In the final chapter, Harwit reflects on how we should move forward in astronomical research given those limitations. Although he has few concrete recommendations, he nevertheless expounds on a wide range of issues: whether large research consortia should be favored over smaller efforts, whether expensive new instruments require international collaboration, how to keep young scientists in the field when they can use their analytic skills to earn far higher salaries elsewhere, and how to move humankind to barren planets.

Cosmic Messengers should be of interest to a wide audience of astronomers, other scientists, historians of science, government agency planners, and anyone who wants to see the fruits of curiosity-driven research. It will also be a valuable resource to students and others aiming to place their research into a much larger context.

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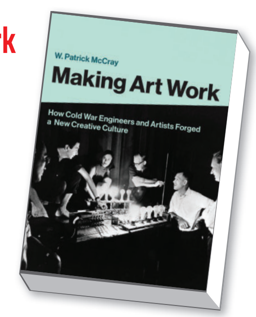
The two cultures, revisited

Making Art Work
How Cold War Engineers and Artists Forged a New Creative Culture
W. Patrick McCray
MIT Press, 2020. $45.00



The 1959 pronouncement of C. P. Snow that the humanities and sciences make up two separate cultures has been a lightning rod for discussion ever since the novelist and physical chemist put forward his famous thesis. In the 1960s, for example, the pages of Physics Today were rife with responses to Snow (see Physics Today, September 1961, page 62; July 1966, page 160; and the article by Jerome Ashmore, November 1963, page 46). But was the divide as extreme as Snow believed it to be?

According to the historian of science W. Patrick McCray, it was not. In his new book, *Making Art Work: How Cold War Engineers and Artists Forged a New Creative Culture*, McCray delves into collaborations in the 1960s between engineers at companies like IBM and Bell Labs and modern artists in the postwar US such as Robert Rauschenberg, Claes Oldenburg, and Deborah Hay. He illustrates how artistic and scientific cultures were not irreconcilable but complementary: During that decade, some of the biggest names in the arts world relied on the technical skills of engineers to bring their artistic ideas to life.

Making Art Work centers on three figures and examines the communities they worked in as both managers and makers. The first is Frank Malina, an aeronautical engineer-cum-artist who founded the arts and technology journal *Leonardo*. The second figure is the artist Gyorgy Kepes, who developed a visual-design program at MIT and founded the university's Center for Advanced Visual Studies. The bulk of *Making Art Work* focuses on the final individual, Billy Klüver, a Bell Labs electrical engineer with close ties to the New York avant-garde art scene who founded Experiments in Art and Technology (E.A.T.), an organization that fostered connections and collaborations between artists and engineers.

McCray adroitly moves between intellectual concepts from a range of disciplines. Historians of science and technology will be able to comfortably orient themselves in McCray's analyses of big science, paradigm shifts, and tacit knowledge. Likewise, historians of modern art will appreciate his careful description of artist–engineer collaborations like the performance series *9 Evenings: Theatre and Engineering* and the E.A.T.-designed Pepsi Pavilion at Expo '70 in Osaka, Japan.

Importantly, McCray observes that engineers often served as "invisible technicians," a category defined by the historian of science Steven Shapin in a 1989 article about skilled craftsmen whose contributions to 17th-century English laboratory experiments were omitted from later histories of science. Like those early-modern craftsmen, the engineers who