In Search of the True Universe

Astrophysicist and scholar Martin Harwit examines how our understanding of the Cosmos advanced rapidly during the twentieth century and identifies the factors contributing to this progress. Astronomy, whose tools were largely imported from physics and engineering, benefited mid-century from the U.S. policy of coupling basic research with practical national priorities. This strategy, initially developed for military and industrial purposes, provided astronomy with powerful tools yielding access – at virtually no cost – to radio, infrared, X-ray, and gamma-ray observations. Today, astronomers are investigating the new frontiers of dark matter and dark energy, critical to understanding the Cosmos but of indeterminate socio-economic promise. Harwit addresses these current challenges in view of competing national priorities and proposes alternative new approaches in search of the true Universe. This is an engaging read for astrophysicists, policy makers, historians, and sociologists of science looking to learn and apply lessons from the past in gaining deeper cosmological insight.

MARTIN HARWIT is an astrophysicist at the Center for Radiophysics and Space Research and Professor Emeritus of Astronomy at Cornell University. For many years he also served as Director of the National Air and Space Museum in Washington, D.C. For much of his astrophysical career he built instruments and made pioneering observations in infrared astronomy. His advanced textbook, *Astrophysical Concepts*, has taught several generations of astronomers through its four editions. Harwit has had an abiding interest in how science advances or is constrained by factors beyond the control of scientists. His book *Cosmic Discovery* first raised these questions. The present volume explores how philosophical outlook, historical precedents, industrial progress, economic factors, and national priorities have affected our understanding of the Cosmos. Harwit is a recipient of the Astronomical Society of the Pacific's highest honor, the Bruce Medal, which commends "his original ideas, scholarship, and thoughtful advocacy."

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The Tools, Shaping, and Cost of Cosmological Thought

Martin Harwit

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Preface

When I was a student in college, Albert Einstein was still alive. My friends and I grew up with the myth of this great man who, the story went, while a clerk, third class, at the Swiss Patent Office in Bern, had emerged from nowhere at age 26 to set down the laws of relativity in a paper so fresh, so novel that not a single other scholar needed to be cited as a source of at least partial inspiration for this monumental paper. Einstein's paper contained no list of references; none had existed or could even be found!

We all aspired to emulate Einstein and write a paper as great as his. To this end it seemed we would need only to foster self-reliance, reject outside influences, and rely solely on an inner intellect.

Of course, this could not happen.

Indeed, it had not happened!

But in the first half of the twentieth century, the myth could not be dispelled. Historians of science active at the time preferred to write about a distant past. And, as a young man, Einstein himself may have quietly enjoyed the mystique that surrounded his work. Only three times, as far as I am aware – twice late in life – did he describe the road he had traveled, the difficulties with which he had wrestled, and the inspiration the work of others had provided.

The first occasion came on December 14, 1922, possibly one of the headiest days of his life. Four days earlier, he might have been in Sweden to receive the Nobel prize in physics from the King of Sweden. Instead he was now in Kyoto.

Einstein had not been at home in Berlin when the telegram from Stockholm arrived on November 10.[1] By then, he and his wife had already embarked on the long voyage to the other side of the globe to accept an invitation from Japan.

Einstein didn't seem worried, this December day, that he had missed the trip to Stockholm.[a] Responding to an impromptu request, he talked spontaneously without written notes to students and faculty at Kyoto University. He spoke in German, the language in which he best expressed himself. The professor of physics at Tohoku University, Dr. Jun Ishiwara, who had studied in Munich under the

[a] On Einstein's return to Berlin, the Swedish ambassador dropped by to hand him the award.

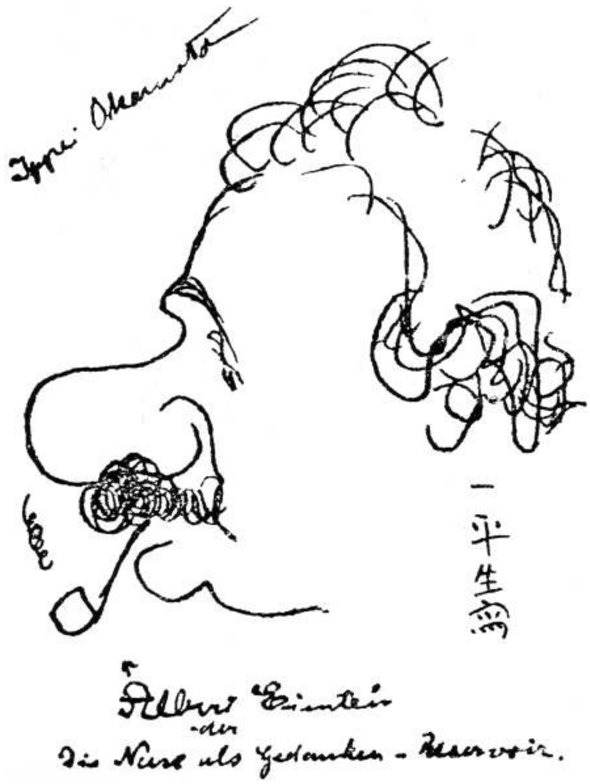

Figure i. ‘The Nose as Reservoir for Ideas.’ A drawing by Ippei Okamoto sketched in December 1922 during Einstein’s visit to Japan. (*From the Japanese newspaper* Asahi Shimbun. *Courtesy AIP Emilio Segre Visual Archives*.)

theoretical physicist Arnold Sommerfeld, took careful notes and gave a running translation to the Japanese audience.

Ishiwara’s notes were published the following year in the Japanese monthly *Kaizo*, but a complete translation did not become available in English until 60 years later, when it appeared in the August 1982 issue of *Physics Today* with the title ‘How I created the theory of relativity.’[2]

In this Kyoto talk, Einstein spoke of the early influences on his thinking that the experiments on the speed of light by the American physicist Albert Michelson and the French physicist Hippolyte Fizeau had played. Einstein had also read the 1895 monograph on electrodynamics by Hendrik Lorentz[3] in the Netherlands and was fully familiar with the *electromagnetic theory* that James Clerk Maxwell had produced a generation earlier in Scotland. He recalled the “enormous influence” on his thoughts by the Austrian philosopher and physicist Ernst Mach.

Einstein may not have referred to the work of others in his ground-breaking paper on relativity, but he had certainly been thoroughly familiar with their efforts.

I wish I had known as a student that the young Albert Einstein had spent most of his undergraduate years reading the great works of Boltzmann, Helmholtz, Hertz, Lorentz, Maxwell, and others. Often he preferred this way of learning to attending lectures at the Eidgenössisches Polytechnikum in Zürich, today's Eidgenössische Technische Hochschule (ETH).[4] It might have disabused me of concentrating on my own strivings instead of more carefully consulting the work of others to learn how they had gone about their contributions to science. For, science is a craft, and craftsmanship can best be acquired by learning from great masters. Their work is fascinating not only in what it tells us about the *Universe*. It is intriguing also in what it teaches us about the roles we humans play in discovering truths.

The scientific method asserts that its use inexorably leads to a faithful portrayal of Nature. A closer look, however, reveals a picture fashioned by individual talents and preferences; by the availability of new tools; by common mistakes and misapprehensions; by an inability to wrest ourselves free from established beliefs adopted and defended over millennia; and by the continual clash of political, military, and economic realities.

My aim in writing the present book has been to show how strongly these factors have shaped and continue to shape our understanding of the Universe. To keep the investigation in bounds, I have largely restricted it to advances made just in the twentieth century and on just one set of intertwined fundamentals – the origin and evolution of matter, of *stars*, and of the Universe, from earliest cosmic times down to the present. These three topics were actively pursued throughout the twentieth century. Their developments were so tightly interwoven that they cannot well be separated.

The book's early chapters show how varying personal choices helped different astrophysicists to arrive at new insights. During the first half of the twentieth century most of these researchers pursued their investigations alone or sometimes with a single student or colleague. Many of these efforts involved importing new theoretical tools from physics or mathematics to enable a novel approach and a convincing advance in our understanding.

* * *

World War II dramatically changed all this. The war had shown that strength in science and technology can determine a nation's future. In the United States, this realization led to a visionary report, 'Science – The Endless Frontier,' commissioned by President Franklin Delano Roosevelt at the suggestion of Vannevar Bush, throughout the war Director of the Office of Scientific Research and Development (OSRD).[5] Widely praised for its persuasive promotion of increased governmental support of science, the report issued in July 1945 advocated a seamlessly integrated program of basic and applied research, dedicated to the nation's health, welfare, and security.

The resulting close cooperation between basic research and practical efforts geared to national priorities soon provided U.S. astronomers powerful new *radio*, *infrared*, *X-ray*, and *gamma-ray* instrumentation. Balloons, aircraft, rockets, and *satellites* for transporting these exceptional tools to high altitudes or into space provided the clearest view of the Universe ever attained. With these technologies, often developed for national security at enormous cost but made available to astronomers free of charge, success followed success in astronomical discoveries and theoretical advances.

* * *

Starting in the early 1980s and gaining speed ever since, the field largely reorganized itself into big science projects shouldered by hundreds if not thousands of scientists, engineers, and managers.

Publications might then be co-authored by scientists working at dozens of separate institutions. In the United States, major research directions no longer were defined by individual investigators or by their observatory directors, but rather through a community-wide consensus established at 10-year intervals, through a Decadal Survey conducted under the auspices of the U.S. National Academy of Sciences. Communal agreement had become necessary because the support of astronomy had become costly, often bordering on the extremes the nation could afford.

Observatories under construction today, whether designed to operate on the ground or in space, have become so expensive that only intercontinental consortia can raise the required means. Europe and the United States already are collaborating on many space missions. Ground-based observatories similarly require the collaboration of nations on separate continents.

Future facilities may soon reach construction costs requiring even larger international consortia and outlays affordable only if budgeted across many decades or longer, though we do not yet have experience in designing scientific enterprises spread over such long periods.

* * *

These are some of the problems our quest to understand the Universe are beginning to encounter as the really hard cosmological problems we are about to face may become unaffordable unless we find new ways for astronomy to advance.

Why unaffordable?

Over the past decade, our investigations have revealed that atomic matter in the Universe – *galaxies*, stars, interstellar gases, *planets*, and life – constitutes a mere 4% of all the mass in the Universe. The far larger 96% is due to a mysterious *dark matter* in galaxies and an equally mysterious *dark energy* pervading the entire Universe. Apart from the gravitational forces these components exert, we know little about either.

This lack of insight is largely due to our current dependence on tools and capabilities originally developed for industrial or defense purposes before their adaption for astronomical *observations*. They enable investigations mainly limited to observations of atomic matter – a constraint that biases our perception of the Universe. We know this because a similar bias misled us once before.

In the years leading up to World War II, astronomy was driven by just one set of tools, those of optical astronomy: The Universe perceived then was quite different from the Cosmos we survey today. Astronomers of the first half of the century described the Universe in serene majestic terms. Today we view with awe the violence of galaxies crashing into each other, forming massive new stars that soon explode to tear apart much of the colliding matter. Yet, our current understanding still comes from piecing together impressions delivered by a limited toolkit. It may be far more versatile than the capabilities available early in the twentieth century, but it still restricts us to dealing primarily with observations of just the 4% of the mass attributed to atoms.

We will require a new set of tools to study the other 96% of the cosmic inventory. These are unlikely to have practical applications and will no longer be conveniently available through simple adoption and adaption of industrial or defense-related technologies. Their development may require support beyond reasonable governmental means unless stretched out over many decades or longer.

More than six decades since first adopting the economic model for astronomy that 'Science – The Endless Frontier' bequeathed, we may accordingly need to review our options for successfully completing our cosmological quest.

I am concerned because, with limited instrumental means, we may reveal only those aspects of the Cosmos the instruments are able to unveil. We might then arrive, just as astronomers working before World War II did, at a false sense of the Cosmos. This is why I place such importance on realistically planning the acquisition of the potentially costly tools we may require to reliably shape our cosmological views and help us succeed in our search for the true Universe.

Contributions from Publishers and Archives

I am indebted to the many publishers and archives that permitted me to include material to which they own copyrights. These figures and quotes have vividly enriched the book. Although the contributions are also acknowledged elsewhere in figure captions and bibliographic citations, I wish to explicitly thank the copyright holders here as well:

I thank the American Astronomical Society (AAS) and its publishers, the Institute of Optics, for permission to quote and include a figure from the *Astrophysical Journal* and to cite a passage from 'The American Astronomical Society's First Century,' published jointly by the AAS and the AIP; The American Institute of Physics (AIP) for the use of nine images from the Emilio Segre Visual Archives; The American Physical Society for figures from four of its journals and quotes from several of these journals as well as others; *The Annual Reviews of Astronomy and Astrophysics* for permission to cite the recollections of Hans Bethe in 'My Life in Astrophysics' and Edwin E. Salpeter in 'A Generalist Looks Back'; Basic Books, a

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Acknowledgments

I thank the many academic institutions and people who made ‘In Search of the True Universe’ possible.

I started work on the book in the spring of 1983 as a visiting Fellow at the Smithsonian Institution’s National Air and Space Museum. I meant the book to be a companion volume to ‘Cosmic Discovery,’ published two years earlier and dealing largely with the way astronomical discoveries have come about; but I did not get very far on my newer efforts before other priorities intervened.[6] In the summer of 2002, the Kapteyn Institute at the University of Groningen invited me to spend three months in Groningen as its Adrian Blaauw Professor. Again, I started writing, but again I did not get as far as I had hoped. Finally, in the fall term of 2007, the Institute of Advanced Study at Durham University in Britain extended its hospitality. There, two other visiting Fellows introduced me to work of which I had been unaware. The sociologist David Stark of Columbia University introduced me to recent studies of social networks, and the Australian theoretical anthropologist Roland Fletcher, an expert on the growth of human settlements, familiarized me with his work. Finally, these tools, which I had been looking for without knowing whether they existed, were at hand to complete the present book satisfactorily. I particularly thank the directors of the Institute of Advanced Study at Durham University for their hospitality.

For nearly half a century the U.S. National Aeronautics and Space Administration has supported my astronomical research, most recently on joint efforts on which NASA partnered with the European Space Agency, initially on its Infrared Space Observatory and later on the Herschel Space Observatory. These efforts have colored many of the approaches pursued in the book’s later chapters.

The theoretical astrophysicist Ira Wasserman, my long-term colleague and friend at Cornell, was the first person I asked to read and critique an early version of the completed book. His insight and recommendations were of immense value. A number of colleagues and family members then read and commented on successive drafts of the book: I thank our sons Alex and Eric Harwit and our daughter Emily and her husband Stephen A. Harwit-Whewell. The astronomer Peter Shaver and the historian of astronomy Robert W. Smith both read the entire book draft as well. Two other historians, Karl Hufbauer and David DeVorkin, kindly read and critiqued specific chapters in which I had heavily drawn on their informed scholarship. Karl also provided me with a number of informative unpublished articles.

The MIT astrophysicist and writer Alan Lightman gave me permission to quote sections of interviews he had conducted with leading astrophysicists. David DeVorkin similarly permitted my quoting some of his insights in his biography of Henry Norris Russell. The theoretical physicist Mark E. J. Newman of the University of Michigan gave me permission to include and adapt figures and tables from several of his publications. A number of colleagues, among them David Clark,

Bruce Margon, Vera Rubin, and Alexander Wolszczan generously answered questions about their personal contributions to astronomy, when I was unsure about how their discoveries had come about. Others, including Bernhard Brandl, Harold Reitsema, Jill Tarter, and Kip Thorne, provided information on issues I had not been able to resolve. Members of the staff at the Cornell University Library, in Ithaca, NY, none of whom I ever had the opportunity to meet and thank as I now live and work in Washington, DC, over the years found and e-mailed me copies of innumerable early scientific articles from many countries. I would not have had access to these on my own. And Peter Hirtle, also at Cornell, provided invaluable expert advice on the complex restrictions of the copyright law.

Working with Vince Higgs, Editor for Astronomy and Physics, and Joshua Penney, Production Editor, at Cambridge University Press, has been a pleasure. I also thank Abidha Sulaiman, Project Manager at Newgen Knowledge Works in Chennai, India, who coordinated the production of the book, and Theresa Kornak whose good judgment as a copy editor helped to improve the book. The book's cover design was produced by James F. Brisson.[b] I thank Brien O'Brien, with whom I first worked nearly thirty years ago, for his design of Figure 11.1 reproduced in gray tone from a 1985 NASA brochure, as well as for the fragment from the figure reproduced in its original colors on the book's back cover.

I owe a debt to my wife Marianne. She consistently encouraged me as I spent innumerable days writing and rewriting. It is clear to me that the book would not have been written without her support.

Notes

1. *Subtle Is the Lord – The Science and the Life of Albert Einstein*, Abraham Pais, Oxford, 1982, pp. 503–504.
2. How I created the theory of relativity, Albert Einstein, Translated from the German into Japanese by the physicist J. Ishiwara, and published in the Japanese periodical *Kaizo* in 1923; then translated from the Japanese into English by Yoshimasa A. Ono and published in *Physics Today*, *35*, 45–47, 1982.
3. Versuch Einer Theorie der Elektrischen und Optischen Erscheinungen in Bewegten Körpern, H. A. Lorentz, Leiden, The Netherlands: E. J. Brill, 1895; reprinted unaltered by B. G. Teubner, Leipzig, 1906.
4. Erinnerungen eines Kommilitonen, Louis Kollros, in *Helle Zeit – Dunkle Zeit*. Zürich, (Carl Seelig, editor), Europa Verlag, 1956, p. 22.
5. *Science – The Endless Frontier, A Report to the President on a Program for Postwar Scientific Research*, Vannevar Bush. Reprinted on the 40th Anniversary of the National Science Foundation, 1990.
6. *Cosmic Discovery – The Search, Scope and Heritage of Astronomy*, Martin Harwit. New York: Basic Books, 1981.

[b] The book's cover by James F. Brisson shows an hourglass displaying, at top, the early Universe crisscrossed by myriad colliding subatomic particles. Over time, today's Universe emerges, below, as an intricate web of galaxies pervading all space.

Notes on Usage

Chapter 1 begins by portraying where the physical sciences stood at the end of the nineteenth century. The chapters that follow deal almost entirely with advances in our understanding of the Universe during the twentieth century and at the turn of the millennium.

Astronomy is an observational science. It differs from the experimental sciences in its inability to manipulate the objects it studies. These difficulties are endemic, and so several of the book's chapters, notably Chapters 3 to 6, 8, and 10, aim at depicting the principal problems twentieth-century scientists faced in delving ever more deeply into the nature of the Universe. Chapters 2, 7, 9, and 11 to 16, in contrast, describe how interactions among the scientists themselves, and their increasing exposure to changing societal forces, affected the ways astrophysics came to be conducted as the century progressed. The scientific questions and the societal factors, although presented in these largely separate chapters, are part and parcel of a more integrated set of processes that the book's final chapters aim to depict.

Because the book is aimed, at least in part, at young researchers as well as scholars from the humanities and social sciences, I hope that unfamiliarity with the few astrophysical formulae and equations I have inserted will not dissuade newcomers from reading on. The text usually seeks to augment the meanings of mathematical expressions with explanations in everyday English. Where I insert symbolic statements, they are there primarily for the benefit of astrophysicists for whom they provide a familiar short-hand way of quickly perceiving the thrust I seek to convey. Wherever possible mathematical expressions are placed in footnotes, so as not to intrude on readers happier to read on without them.

The main impediment to reading a book that may involve a large number of unfamiliar concepts can be a lack of adequate explanation. I approach this difficulty by including a comprehensive glossary. On the first occasion at which I use a term that many readers might not immediately recognize, I *italicize* it. This is meant to indicate that if I do not explain its meaning on the spot, its definition can usually be found in the glossary following the book's epilogue.

* * *

Since the beginning of the twentieth century, scientific notation has steadily evolved. In the 1920s the oxygen isotope weighing 16 *atomic mass units* was written as O^{16}, where as today we write ^{16}O. In the 1930s, expressions representing nuclear transformations were written as though they were equations, with an equality sign (=) inserted between initial and final constituents. Today, the direction of the transformation, from its initial to its final state is indicated by an arrow (→).

Highly energetic helium nuclei, electrons, and X-rays, respectively are named α-particles, β-particles and γ-rays, using the Greek letters, alpha, beta, and gamma.

Temperatures measured in degrees Kelvin that earlier were written as °K now are contracted to K. In astrophysics centimeter-gram-second (cgs) units remain in common use, even though officially the meter-kilogram-second (mks) units are supposed to have been universally adopted. The unit of time, the second, used to be abbreviated as *sec*. Today, physicists and astrophysicists instead write *s*.

In citing the literature written in different years I have opted to uniformly employ current usage, based largely on the cgs set of units, even where I quote earlier scientific texts verbatim. The one exception is that I have kept the abbreviation *sec* for seconds, because *s* in isolation might sometimes be ambiguous. I hope that adoption of this uniform notation throughout will reduce demands on the reader.

Aside from such changes in scientific notation, quoted material always appears in its original form. If a quotation contains words in *italics*, it is because the original text included them that way. Parenthetic remarks of my own that I may insert in direct quotes always appear in [square brackets].

I expect that at least some readers will wish to know how conclusions that astrophysicists reached at various epochs in the twentieth century might be viewed today. In order not to interrupt the flow of the text, but still satisfy curiosity, I occasionally insert such comparisons in footnotes. Bibliographic information appears in endnotes appended to each chapter.

Where the precise expression used by a scientist is worth citing and originally appeared in German, the language in common scientific use in continental Europe up to World War II, I have provided my own translation. Often this is not a verbatim translation which, a century later, might no longer convey its original sense, but rather expresses the intent of the statement as closely as possible in current English. The original text then also appears as a footnote for interested readers.

I should clarify five words I use throughout the book:

I use *Universe* and *Cosmos* interchangeably to encompass all of Nature.

In speaking about *astronomers* and *astrophysicists*, I distinguish colleagues who, respectively, concentrate on *observing*, as distinct from *explaining* the Universe. But the two functions are seldom separable; many colleagues think of themselves as both astronomers and astrophysicists. Accordingly, I use the two designations almost interchangeably.

In using the word *we*, which consistently appears throughout the text, I try to convey the sense of what *we* – the community of astronomers and astrophysicists – would say. In writing this way, I may occasionally misrepresent my colleagues; but astronomy is a rapidly changing field, and *we* may not always fully agree.

The appendix included at the end of the book defines scientific expressions, lists the meanings of symbols, and elucidates the relations between different units that may be unfamiliar to a reader.

A final index locates topics cross-referenced in the text.