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BOOK REVIEW

The cosmic toolkit for all possible observations

Martin Harwit: Cosmic messengers: The limits of astronomy in an unruly universe. Cambridge: Cambridge University Press, 2021, 380 pp, $39.99 HB

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Divided thematically into four parts, this book's nine chapters of varying lengths and levels of technical detail aim to provide an overview of all possible sources of information about the cosmos and our prospects for developing a "complete cosmic toolkit" (26) able to actually detect every potentially detectable signal arriving near the Earth.

Although Harwit refers to this as the third book in a trilogy, the others being *Cosmic Discovery* (1984) and *In Search of the True Universe* (2013), they can be read independently. *Cosmic Messengers* is a somewhat odd mix of introductory-level textbook, detailed scientific analysis, and speculative planning document. The level of technical sophistication varies widely in different parts. It is therefore unclear who the audience is, though astronomers and physical scientists are clearly meant to be the main part of it. Historians and philosophers of physics, astrophysics, and cosmology might also be interested.

The goal of the book is to determine how to find all the messengers that reach us from the cosmos, to figure out how they are affected by interfering causes on their long journeys to us, and to create a catalog of the instruments we would need to observe them all.

> Assembling the full toolkit for satisfying all these observational capabilities, for electromagnetic radiation, or for the detection of any and all other astronomical messengers including gravitational waves, neutrinos, high-energy cosmic rays, and other carriers of information, can thus be seen to be an essential long-term aim of astronomy. (23)

A *messenger* is an entity—photon, fundamental particle, chemical (element, molecule, or compound, usually radioactive or ionized), or gravitational wave—that can be detected by human devices, and for which there is some plausible

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causal story that allows us to turn the properties of the messenger into information about its source. The better our causal theory and our knowledge of background conditions—for example, of particle physics and of the interstellar medium—the greater, and more reliable, the information about the source we can learn from its messengers. In earlier work, Harwit discusses Dudley Shapere's account of observation and it seems to remain in the background here.

One of Harwit's key points is that

> based on the apparently finite energy ranges, and the finite ranges of useful resolving powers required to identify distinct messengers, the number of dedicated instruments and observatories we will require to detect the entire cache of information the Universe transmits should also be finite, enabling us to estimate how soon a complete set of observational tools may ultimately be assembled. (127–128)

This leads to an "end of science" claim: we will eventually realize that no meaningful new information could be attained by increasingly sophisticated detectors (211).

An idea that comes up repeatedly is the ultimate cost of acquiring such a complete cosmic toolkit. Harwit guesses it will take a couple of hundred years at most, at astronomy's current funding levels. But almost no attention is paid to whether doing this would be a good investment. What are the epistemic and practical benefits of this huge investment? Given we are talking about public money, this is a crucial issue that deserves far more attention.

Building the cosmic toolkit is an interesting goal, but clearly not one that needs to be finished before doing astronomy. However, the surveys and planning Harwit outlines might identify new observing tools or techniques likely to yield results quickly and relatively cheaply. Difficult to account for, and left out of this account, are the serendipitous combinations of technologies which might lead to still other excellent observing tools. Think of photography plus spectroscopy.

After stage-setting in Chapter 1, Chapter 2 gives the history of the early cosmos via a history of early scientific cosmology. Key moments, even some missteps, are included, though this is nothing like a complete account or a historian's approach. That said, I am not aware of a better 36-page introduction to cosmology. The point of the exercise is to explain what messengers are available from which cosmic epochs. Turn to the final two pages of the chapter to see the list if you are not interested in the narrative.

Chapter 3 tells the story of cosmic rays and their ultimate interpretation as products of distant supernovae, the story of neutrinos and gamma rays from Gamma Ray Bursts, and the story of neutrinos and antineutrinos from supernovae. It also mentions studying deep sea sediments to find radioactive remnants of supernovae, the debris clouds of which Earth has passed through. The interplay between particle physics, astrophysics, and observational astronomy is nicely illustrated. It is easy, however, to lose the thread in all this detail.

Chapter 4 discusses gravitational waves. The success of the LIGO-Virgo interferometry experiments proves the existence of gravitational waves, thus confirming General Relativity, and also enabling theorists to use gravitational wave signatures to acquire information about astrophysical events such as black hole and neutron star mergers. The advent of gravitational wave detectors has also made possible “multi-messenger astronomy,” where several messengers (gravitational waves, neutrinos, and various wavelengths of EM radiation) are received by different observatories from the same direction at roughly the same time. This is an important development in the epistemology of science, worthy of further attention from philosophers, since it enables scientists to build and test more detailed models and theories of these distant, rare, and extreme events. Again, the point is to illustrate what it might be possible to observe regarding or with gravitational waves; current technology has barely begun to explore the possibilities, though the physical and technological limitations are significant.

Chapter 5 covers micro, macro, and weak gravitational lensing. General Relativity allows us to study the distribution of masses between us and a source, even if the intervening masses are too small or dim to be directly visible. The path of light is bent by gravity as it passes near these masses. This is both good and bad news. It means we can detect the existence of these intervening masses and even learn something about them. But it also means that, since the mass distribution is not fully known, there are limitations on what we can infer about the accuracy of our observations of distant objects, since their signals are spatially and temporally distorted in unknown ways.

Chapter 6 starts by noting three methods for detecting exoplanets from changes in the signal from their parent star: changes of angular position, changes of signal timing for pulsars, and the Doppler redshift of the star’s light along the line of sight. It goes on to make the interesting point that the information carried by any messenger can be described in terms of just five characteristics: energy (usually wavelength), angular resolution, time resolution, spectral resolution, and polarization. These characteristics are thus design parameters for instruments and observing programs (203–204). Together, they allow us to construct a phase space of possible observations, which we can compare against our current instrumental capabilities; empty regions of the phase space are opportunities for exploration (208). There is no guarantee of finding something informative in every region of the phase space. There might be no physical phenomena producing messengers with those parameters, as the phenomena might have temporal or spatial resolution beyond our ability to detect, the messengers might have too-short lives, or there might be no instrument we can construct that would reliably detect them. The hardest problem seems to be that we cannot know enough about the causal factors that scramble signals during transmission to be able to unscramble them. This would be a fruitful topic for philosophical engagement.

Chapter 7 goes through a series of quick snippets of the history of astronomy. This culminates in a list of 22 recent major astronomical discoveries. Chapter 8 then discusses these as a statistical base for calculating the total number of distinct major phenomena to be discovered in the universe. In 1981, Harwit had estimated this number at 130 from the 43 major phenomena he then listed; here, he revises his estimate to 90, based on 60 phenomena (22 discovered since 1980). The application of the statistical methodology, which Harwit claims derives from Fisher, seems problematic, the concepts vague, and the conclusion not terribly important, so it is unclear to me why Harwit is so interested in this. Philosophers could engage this material by analyzing the methodology, the concept of "major phenomenon," and showing where the inferential gaps are.

Chapter 9 discusses the policy and practical elements of building the cosmic toolkit, under the heading "The Human Aspect of the Cosmic Search." Rather than a sociological or psychological approach, however, this chapter provides an insider's institutional analysis of funding mechanisms of astronomical science in America. It ends with speculation about humans colonizing other worlds. The book lacks a concluding chapter to tie everything together and say what it all means.

Overall, the book is interesting and informative, if idiosyncratic in its approach and focus.

There are tables, graphs, and illustrations in each chapter; most are interesting and useful. There is no bibliography for the book as a whole; instead, endnotes after each chapter provide citations. There is a fifteen-page glossary, though I doubt many people who need the glossary would be able to follow the technical details in the text. There is also an index.