

now deal with fiendishly difficult multidisciplinary and technological demands. They are plagued with more and more bureaucracy, suffer constant interruptions by all kinds of urgencies, and must keep ever-longer schedules that increasingly lead to less efficient work. Those stressors affect everyone in the sciences,

from the group leader to the newcomer.

I recommend Tantra's book to all readers of *PHYSICS TODAY*. Group leaders will gain perspective on the difficulties novice researchers face and will perhaps also gain some empathy toward their junior colleagues. Graduate students will benefit from tips that could help them avoid

painful learning from experience. I also hope the administrators responsible for so many aspects of research management and the well-being of young researchers will view *A Survival Guide for Research Scientists* as required reading.

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A late-19th-century Edison phonograph.

Re-creating the physical experience of sound

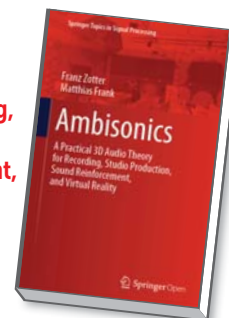
The recording and reproduction of sound has long been a source of fascination for scientists and engineers. The phonograph, invented by Thomas Edison in 1877, was arguably the first device that could both record and reproduce an acoustic signal. Although it was one of the most remarkable inventions of its time, the phonograph did not attempt to convey any spatial characteristics of the recorded sound field; it simply recorded sound and replicated the signal through a single acoustic source. The

monophonic sound field the phonograph generated could not reproduce the original sound's spatial variability.

Over the next several decades, researchers made various attempts to replicate the spatial characteristics of a recorded sound field, without much practical progress. In the 1930s, however, Alan Blumlein invented stereo sound. One technique involved recording a sound field with two microphones, one with sensitivity to sound waves from all directions and one with a figure-eight di-

Ambisonics A Practical 3D Audio Theory for Recording, Studio Production, Sound Reinforcement, and Virtual Reality

**Franz Zotter and
Matthias Frank**
Springer, 2019. \$59.99



rectivity pattern. When the signals from the two microphones are played back over a pair of loudspeakers spaced carefully apart, a centrally located listener experiences, at least to some extent, the illusion of directional sound.

The invention of ambisonics in the 1970s by Michael Gerzon, Peter Fellgett, and Peter Craven extended Blumlein's technique. As Franz Zotter and Matthias Frank explain in the opening pages of *Ambisonics: A Practical 3D Audio Theory for Recording, Studio Production, Sound Reinforcement, and Virtual Reality*, first-order ambisonics allows a recording studio to use four coincident microphones. One microphone is uniformly sensitive and three use figure-eight directivity patterns aligned to the x -, y -, and z -axes of a Cartesian coordinate system. Appropriate processing of those four microphone signals, along with a six-loudspeaker playback system, yields an approximate reconstruction of the directions of arrival of the recorded sound.

The book's first chapter concisely describes those microphone techniques and related approaches and provides the reader with a solid framework for understanding the basic concepts behind ambisonics. Chapter 2 covers numerous experiments that capture how well listeners perceive a change in the direction of arrival of sound as the amplitudes of the inputs to the loudspeakers are varied, or "panned" in the terminology of acoustics. Ville Pulkki's vector-base amplitude panning (VBAP) technique is the subject of

chapter 3. It is a straightforward and successful approach to determining the amplitudes of the inputs to arbitrarily arranged loudspeakers in order to generate the illusion of sound coming from a location between the loudspeakers.

The meatiest material, higher order ambisonics, is covered in chapter 4. Zotter and Frank introduce the reader to the spherical harmonic decomposition of the sound field in order to determine the loudspeaker inputs. They also explore the relationship of VBAP to higher-order ambisonics and describe various refinements that can improve the listener's experience of a sound recording. Subsequent chapters deal with signal flow

effects, ambisonic microphone arrays, and compact loudspeaker arrays.

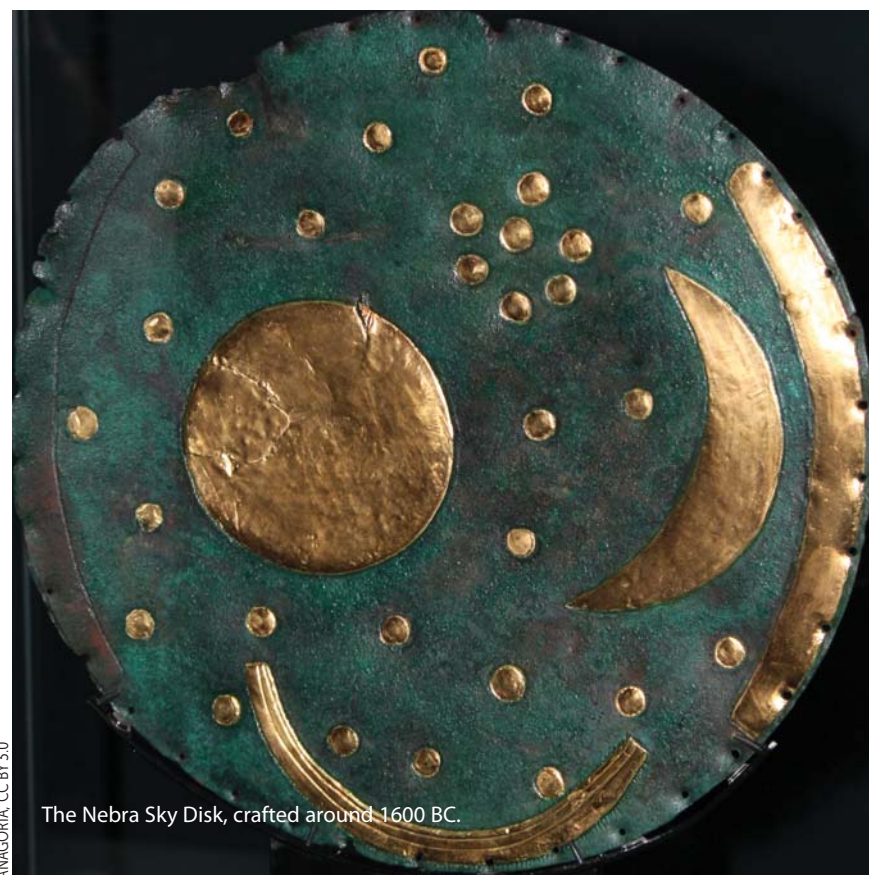
Zotter and Frank include an extremely useful bibliography of research in the field and provide many practical and free software options. The authors also helpfully describe several experiments of what listeners perceive as the source of a sound generated by the various recording techniques and their associated panning functions. However, they barely discuss the extent to which various recording strategies are able to replicate the physical properties of the recorded sound field, particularly in the earlier chapters. Chapter 6, on higher-order ambisonic microphones, comes closest to providing some physical

insight; it presents the classical problem of a rigid sphere scattering sound waves, shows the steps necessary to reproduce a sampled version of the sound field, and offers some helpful simulations of the resulting pressure distributions.

Ambisonics makes some useful contributions, but the picture is far from complete. There is still room to provide an even deeper understanding of those approaches to sound recording and reproduction. The subject will doubtless continue to fascinate scientists and engineers for some years to come.

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The Nebra Sky Disk, crafted around 1600 BC.

From Cave Art to Hubble A History of Astronomical Record Keeping

Jonathan Powell
Springer, 2019.
\$29.99 (paper)



tronomer and author Jonathan Powell daringly navigates those obstacles for us in his *From Cave Art to Hubble: A History of Astronomical Record Keeping*.

Powell opens *From Cave Art to Hubble* with the black hole in the Messier 87 galaxy, a staple of black hole research for more than two decades. The author then turns his attention to archaeology and tells us about a collaboration between historian of religion Alistair Coombs and chemical engineer Martin Sweatman. The two argue that images of animals and a human-bird hybrid at the French Lascaux cave from around 15 000 BC and engravings on T-shaped monoliths at Göbekli Tepe in Turkey from roughly 9000 BC memorialize comets and terrestrial impacts. Although the paintings and monuments contain no obvious images of comets and no evidence exists of terrestrial impacts during the time of the Lascaux cave paintings, new geological evidence supports the idea that a comet impact may have occurred around the time of the Göbekli Tepe site's construction.

The geological evidence is intriguing, but we will never be able to recapture the thoughts of Paleolithic artists to learn if some of their greatest works were inspired by astronomical catastrophes or by

The rich past of astronomical discovery

Exploring the history of astronomy is a more challenging journey than one might expect. To understand how humans have viewed the stars, readers must

be ready to grapple not only with astronomical concepts but with archaeological discoveries, ancient mythology, and the human imagination. South Wales as-