While Hardie's study elucidates many important affinities between Classical and British art and poetry, the subject is too broad to comfortably fit in a single volume (luckily, he did not add literature to his survey). The space he allots to Blackmore's poem (less than 2 pages) is but one casualty. Even so, this ambitious project is a valuable primer of a very rich subject area. Hopefully, it will spark several scholars to plan edited volumes that offer detailed studies of the many astronomical/literary gems that Hardie has embedded in these pages.

References

Burgio, B., 2023. British physico-theological poetry and Newtonian physics: the use of *Principia Mathematica* (1687) in Sir Richard Blackmore's *Creation* (1712). *English Literature*, 9, 5–24.

Cunningham, C., 2020. 'Dark Stars' and a new interpretation of the ancient Greek stellar magnitude system. *Journal of Astronomical History and Heritage*, 23(2), 231–256.

Dr. Clifford Cunningham
University of Southern Queensland,
3915 Cordova Drive,
Austin, TX 78759, USA.
E-mail: Cliff.Cunningham@unisq.edu.au

***Star Noise: Discovering the Radio Universe*, by Kenneth I. Kellermann and Ellen N. Bouton (Cambridge, Cambridge University Press, 2023). Pp. xvii + 396. ISBN 978-1-316-51935-6 (hardback), 180 × 250 mm, US$50.**

It is just on 40 years since the publication of two books that marked the beginning of studies on the history of radio astronomy. Both books were collections of articles by the early pioneers of radio astronomy and both were dedicated to the memory of Karl Jansky who discovered radio waves from space in the early 1930s. One book was edited by Ken Kellermann (1984) and the other by Woody Sullivan (1984). Fast forward 40 years and we have the publication of *Star Noise: Discovering the Radio Universe*, co-authored by Kellermann and Ellen Bouton, with a Foreword by the Australian radio astronomer Ron Ekers, a former President of the International Astronomical Union (IAU).

Star Noise is the first book to present a comprehensive overview of the history of radio astronomy—all 90 years of it. The two authors are well qualified for the task. Kellermann spent almost his entire career at the National Radio Astronomy Observatory (i.e. NRAO) in Charlottesville, Virginia, studying radio galaxies, quasars and cosmology. He is a former President of the IAU Commission on Radio Astronomy, a former Chair of the IAU/URSI Working Group on Historical Radio Astronomy, and a recipient of the prestigious Bruce Gold Medal from the Astronomical Society of the Pacific. Ellen Bouton is the NRAO Senior Archivist, overseeing an extensive collection of historical radio astronomy materials, and is a co-author of a recent history of the NRAO and its impact on US radio astronomy (Kellermann et al., 2020).

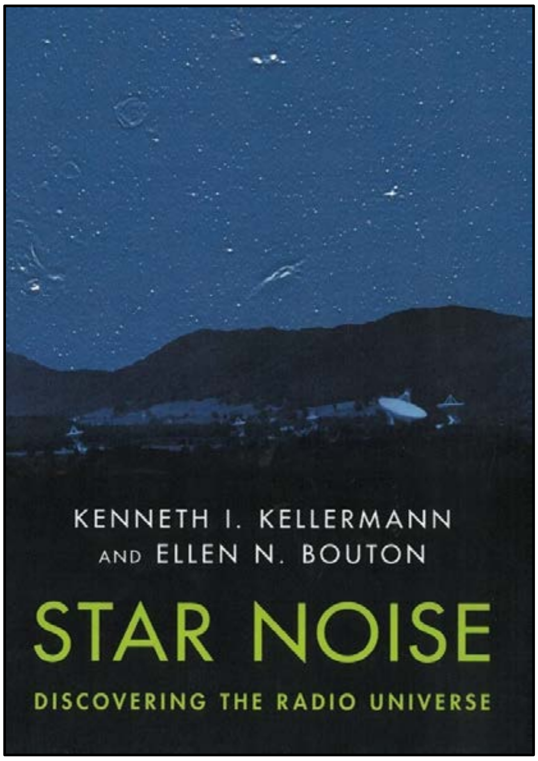
The first of the 12 chapters in *Star Noise* … provides a detailed account of Karl Jansky's discovery of radio waves from space in the early 1930s. The discovery was mostly ignored by astronomers, largely because radio science was outside their area of expertise. The exception was the radio engineer Grote Reber who, at his own expense, built a radio telescope at his home near Chicago and produced the first maps of radio emission across the sky.

Radio astronomy grew rapidly after WWII, thanks largely to wartime advances in radio science. Although the Americans Jansky and Reber had pioneered the field, three main centres emerged elsewhere during the late 1940s. One was at the University of Manchester, another at the University of Cambridge, while the third was at the Radiophysics Laboratory, a Government-funded research centre in Sydney, Australia. Radiophysics was by far the largest and most generously funded of the three. The authors give a detailed and thorough account of the research in Sydney. To this reviewer, this comes as a welcome contrast to some American science writers who seem to think that if the research was not done in the United States then it probably is not worth writing about.

Nine of the 12 chapters are devoted to the discovery by radio astronomy of objects and phenomenon previously unknown to traditional optical astronomy. They include radio studies of the Sun, Moon and planets; interstellar atoms and molecules; pulsars and neutron stars; quasars and radio galaxies; and the cosmic microwave background. An impressive feature of the book are the several hundred illustrations. Most of the line drawings and graphs are taken from the original discovery papers. As far as I can tell, about a half of the numerous photographs were previously unpublished, many of which are reproduced from the NRAO Archives.

A recurring theme throughout the book is that a significant majority of discoveries in radio astronomy have been serendipitous. Only a handful of discoveries have come from theoretical predictions. As noted in the publisher's blurb:

> Theory generally played little or no role – or even pointed in the wrong direction. Some discoveries came as a result of military or industrial activities, some from academic research intended for other purposes, some from simply looking with a new technique. Often it was the right person, in the right place, at the right time, doing the right thing – or sometimes the wrong thing. *Star Noise* tells the story of these discoveries, the men and women who made them, the circumstances that enabled them, and the surprising ways in which real-life scientific research works.



The discovery of pulsars was a classic case of serendipity. In 1967 the Cambridge group built a large array of poles and wires to study a phenomenon known as interplanetary scintillations—the radio equivalent of the twinkling of starlight. Graduate student Jocelyn Bell accidentally discovered several radio sources which emitted a succession of regular pulses, each with an extraordinarily precise timing between individual pulses. Even the announcement of the discovery to a packed Cambridge lecture theatre had an element of serendipity:

> The moniker 'pulsar' was apparently left on a blackboard by a journalist whose name has been lost to history, but the name 'pulsar' was immediately adopted in the scientific as well as the popular literature … (page 169).

Incidentally, the authors reveal that pulsars were independently discovered by Charles Schisler from a US base in Alaska while monitoring Russian radio transmissions, but because of military secrecy the discovery was not made public until 2008.

In Chapter 11 the authors note that

> The history of radio astronomy is largely defined by the continued development of ever more powerful instruments with increasingly greater sensitivity and vastly better angular resolution.

Since radio waves are longer than light by a factor of about 100,000, for many years it was assumed that the resolution of radio telescopes would be very poor when compared to that of optical telescopes. This chapter describes the extraordinary evolution in the size, angular resolution and sensitivity of radio telescopes since the time of Reber's homemade parabolic dish in the 1930s. Following the introduction of very long baseline interferometry (VLBI) in the 1970s, modern radio telescopes can now achieve angular resolutions as low as 20 micro-arcseconds, roughly 10,000 times better than any images from optical telescopes in space or on the ground. Even more remarkable, the sensitivity of radio telescopes since the 1930s has increased by about one hundred billion times!

The final chapter looks at a number of sociological aspects of radio astronomy. The authors list a total of 36 major discoveries in radio astronomy made since Jansky, in 1933, up to the publication of the image of the supermassive black hole at the centre of M87 in 2019. It is interesting to note that 80% of these discoveries were made before 1975, indicating a dramatic fall off in the rate of new discoveries. About two-thirds of the discoveries were made in the US, followed by the UK and Australia, with only a handful from other countries. The most likely age of the radio astronomers at the time of their discoveries was 29 to 34 and only two were aged 50 or older. Perhaps surprising, the number of discoveries made at research organisations, such as Bell Labs in the US and CSIRO in Australia, slightly exceeded the number made at universities.

It is also interesting to note the impact radio astronomy has had on the Nobel Prize for Physics. Originally, from the first Nobel Prizes in 1901, discoveries in astrophysics were considered ineligible for the Physics prize. The Nobel Foundation changed its policy in 1974 when Antony Hewish and Martin Ryle from the Cambridge group received the first astrophysics award. Since then, there have been a further nine Prizes for discoveries in astrophysics, with four of these nine awarded to radio astronomers: 1978, the discovery of the cosmic microwave background (CMB); 1993, a binary pulsar and the detection of gravitational waves; 2006; the spectrum and anisotropy of the CMB; and 2019, the discovery of the first exoplanet.

Finally, under the heading 'Known Unknowns', the authors discuss some of the main issues and challenges facing radio astronomy in the future, including:

(1) The Hubble Constant H_0. There is a relatively small but stubborn disagreement between values of H_0 determined by different methods that might require a change in our understanding of the early Universe.
(2) Dark Matter and Dark Energy. There is strong evidence that dark matter and dark energy make up the great majority of mass–energy in the Universe, but the nature of these phenomena remains a great mystery.
(3) Gravitational Background Radiation. Pulsar timing arrays have so far been unsuccessful in detecting the GBR resulting from the collective inspiraling of supermassive black hole binaries prior to their catastrophic merging.
(4) Epoch of Reionisation. The EoR when the first stars and galaxies began to shine is thought to have occurred about a billion years after the Big Bang, but it is unknown whether it was brief or happened more gradually.
(5) Search for Extraterrestrial Intelligence. Probably no discovery in science would have a more profound impact on society than the detection of radio signals from an intelligent extraterrestrial civilisation.

In conclusion, I do not have any significant criticism of the book, but I do have one concern. The subtitle *Discovering the Radio Universe* is excellent and could have been made the primary title. I'm not so sure about the current title *Star Noise*. Jansky referred to his discovery as 'star noise' and indeed most astronomers assumed that radio emissions came from a new type of 'radio star' within our Milky Way galaxy. However, this perception was challenged after the first few radio sources were identified with extragalactic objects emitting incredible amounts of energy at radio wavelengths. Nevertheless, the terms 'radio star' and 'star noise' continued to be used until the mid-1950s when the extragalactic origin of most of these radio sources became clear. My concern is that the title *Star Noise* might lead some, especially the new generation of radio astronomers, to assume that the book is only about the early years of radio astronomy.

On the contrary, this wonderful book is a sweeping history of the past 90 years, one that points the way to where the future lies for radio astronomy. I can strongly recommend that you add this excellent book to your personal library.

References

Kellermann, K.I., and Sheets, B., (eds.), 1984. *Serendipitous Discoveries in Radio Astronomy*. Green Bank, National Radio Astronomy Observatory.

Kellermann, K.I., Bouton, E.N., and Brandt, S.S., 2020. *Open Skies: The National Radio Astronomy Observatory and Its Impact on US Radio Astronomy*. Cham (Switzerland), Springer.

Sullivan, W.T. III, (ed.), 1984. *The Early Years of Radio Astronomy: Reflections Fifty Years after Jansky's Discovery*. Cambridge, Cambridge University Press.

Dr. Peter Robertson
School of Physics
University of Melbourne
Melbourne, VIC 3010, Australia
E-mail: prob@unimelb.edu.au