Title: ***Fundamentals of Radio Astronomy: Observational Methods***
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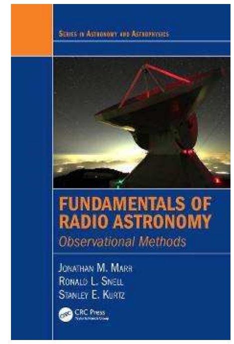

This review is the second of three covering contemporary radio astronomy books. ***Fundamentals of Radio Astronomy: Observational Methods*** is a modestly priced book that is well worth the money for the technical reader. It is a volume in the CRC Press Series in Astronomy and Astrophysics, which includes textbooks and handbooks to more advanced books covering current research.

I started reading the current book soon after reading and writing a review of ***Radio Astronomy: An Introduction*** by [Joardar]. I immediately noticed a contrast between the two. The book reviewed here is quite easy to read, partly because it has numerous detailed and worked examples and partly because it follows what I feel is a more logical progression of topics. It seems to not have as many illustrations as [Joardar] but the illustrations are easier to read and the captions are detailed and helpful. There are some color plates in the middle of the book mostly of, you guessed it, parabolic dish antennas but not all are big ones. This book took me about six weeks to read at my leisure.

Review problems are placed at the end of each chapter. A solutions manual for these problems is available but readers can forget about obtaining a copy. The publisher, CRC Press, has terrible customer service, and a solutions manual is available only from them. Contacting CRC Press is similar to what you experience when you call most government agencies – your call rolls into someone's voicemail and nobody ever calls you back and nobody ever replies to your email inquiries. If you are like me, a serious student of radio astronomy but not enrolled in a university course that uses this book, your learning is hindered by not having access to a solutions manual. However, in spite of CRC Press's hindrance, I did get a look at the solutions manual. Unlike traditional solutions manuals that are scanned images or paper copies of hand-written notes, the solutions manual for ***Fundamentals of Radio Astronomy: Observational Methods*** is professionally formatted and immensely helpful in answering the complex review problems or simply verifying the easier ones. It is obvious the authors spent a lot of time on this.

The *Preface* indicates that the book is intended for undergraduate radio astronomy courses and also as a reference for graduate students of radio astronomy. As with [Joardar] my review is from the standpoint of a long-time radio engineer who also is a radio astronomy student. Unlike [Joardar], the emphasis is not on the mathematics of radio astronomy, but differential and integral calculus are used where appropriate. However, it is not necessary to solve or even understand calculus to benefit from this book. Supplemental material available for download from the publisher's website includes hands-on lab exercises for the Small Radio Telescope (SRT) and Very Small Radio Telescope (VSRT) developed by MIT's Haystack observatory. I discuss these in more detail near the end of this review.

As the title indicates, the emphasis is on understanding how observations can be made. There are six chapters in ***Fundamentals of Radio Astronomy: Observational Methods***, each with many sections and subsections, and seven appendices. As one would expect, a lot is revealed by examining the table of contents. The chapters are:

Chapter 1	*Introductory Material*	29 pages
Chapter 2	*Introduction of Radiation Physics*	44 pages
Chapter 3	*Radio Telescopes*	52 pages
Chapter 4	*Single-Dish Radio Telescope Observations*	54 pages
Chapter 5	*Aperture Synthesis Basics: Two Element Interferometer*	40 pages
Chapter 6	*Aperture Synthesis: Advanced Discussion*	60 pages

The appendices cover constants and conversions, derivation of beam pattern, cross-correlations, complex-exponential form of wave functions, primer on Fourier Transforms with focus on use in aperture synthesis, convolution theorem and interferometer simulation lab exercises and activities.

Most readers of this review probably use single antenna radio telescopes so they will be most interested in the first four chapters, in particular chapter 4, *Single-Dish Radio Telescope Observations*. The emphasis is on parabolic dish antennas but the concepts apply to any type. Practical single-antenna radio telescopes have relatively low resolution, but that can be improved in one-dimension by setting up two radio telescopes as an interferometer. Aperture synthesis is used to further improve resolution.

With aperture synthesis many relatively small individual radio telescopes are setup in an array. Each pair in the array forms an interferometer. Any one antenna can be paired with any of the others to attain different baselines (distances between antennas). The outputs from each pair are combined mathematically to synthesize a much larger radio telescope. These are described in chapters 5 and 6, first in terms of the basics and then in terms of more advanced topics. To support the aperture synthesis discussions, one of the appendices (VII) provides details for interferometer simulations that can be run on any PC using free software developed by the authors and available on the publisher's website.

One immediately notices that the material in ***Fundamentals of Radio Astronomy: Observational Methods*** is explained by example, and the examples are practical. This method is of immense value to practitioners who wish to understand the subject rather than merely slog through the math. The authors are very careful about using units of measure in all equations and examples. In many cases both SI and CGS units are given, as are units of measure unique to radio astronomy such as the jansky (Jy).

Many technical books can be quite tedious at times but this one is not, at least in the first five chapters. I believe the many practical examples help in this regard – using real numbers to get real results. A nice feature of this book is that when discussions reference a topic covered previously, the specific section or equation number is called out, making it easy to go back for a quick review. I encountered a few minor typographical errors and occasional distracting editing problems in which the authors mix optical and radio terminology to discuss some aspects of a radio telescope. For example, in chapter 3 the authors state that the resolution of an individual radio telescope "depends only on the optics of the telescope and the wavelength being observed". I assume the term "optics" used here means the dimensional characteristics of a parabolic dish antenna. The book does not cover array design – the layout of the array antennas to achieve particular performance objectives – but it does mention a Mathematica program for this purpose. Unfortunately, the stated internet link to this program did not work for me.

Chapter 1, *Introductory Material*, covers a lot of ground but does so nicely and efficiently. It includes the obligatory brief history of radio astronomy and then goes into “Some fundamentals of Radio Waves”. Here, radio waves are compared to visible light for the benefit of those readers who do not know of light’s electromagnetic nature (given the technical level of this book, I was surprised to see this). The basic types of celestial spectra are explained, including: Continuous spectra or continuum; Bright line or emission line spectra and Dark line or absorption line spectra. The section in chapter 1 called “Finding Our Way in the Sky” includes a lucid discussion of apparent size of celestial objects in terms of their sold angle in units of steradians.

Also included in chapter 1 are definitions associated with observer-centered coordinate systems, which include local sidereal time, hour angle, right ascension and declination, among others. While chapter 1 includes a brief discussion of radio maps and how to read them, missing are actual radio maps of the entire sky at various frequencies, which are helpful to visualize the extent of celestial radio sources. Also missing is a table of the more powerful celestial radio sources, many of which are potentially accessible to amateur radio astronomers, their location in the sky, types of emission and spectral content and radio flux densities. I think these would be helpful to readers already familiar with optical astronomy who are trying to visualize what is up there at radio frequencies. It probably would have been appropriate to discuss radio frequency interference in this or maybe the next chapter, but it is completely missing from the book – a significant oversight given that RFI impairs any method used to observe weak celestial emissions.

Introduction to Radiation physics is covered in chapter 2. Here the important concepts of luminosity, flux, flux density and intensity are defined, each with an example of its application and use. Chapter 3, *Radio Telescopes*, is a good chapter especially for readers who want to learn about radio telescopes based on parabolic dish antennas. Missing from chapter 3 is any significant discussion of different types of feed systems for reflector-type antennas. A feed system is the hardware that actually couples the reflected radio waves into a coaxial cable or waveguide to the receiver. Feed horns are discussed, probably because they are the most common type on professional radio telescopes, but many other types are useful including dipoles and Yagis (both are narrowband) and log periodic dipole arrays (wideband). Unfortunately, this chapter ignores the fact that not all radio telescopes are based on parabolic dish antennas. For example, many arrays based on crossed-dipole antennas currently are being used to investigate the relatively low frequency (highly red-shifted) radiation from the early universe (for example, see [ReeveLF] and [ReeveLW]).

Chapter 4, *Single-Dish Radio Telescope Observations*, is a comprehensive look. Much of this chapter is based on examples. In fact, the application and use of each equation is demonstrated by example and many build on previous examples. Readers will be able to easily insert data for their own radio telescope to calculate system noise temperature, sensitivity, aperture efficiency and resolution, among many other characteristics.

Chapter 5, *Aperture Synthesis Basics: Two Element Interferometer*, and chapter 6, *Aperture Synthesis: Advanced Discussion*, are meant to be read in order. However, Appendix VII, *Interferometer Simulation Activities*, should be read and the software and lab materials available on the publisher’s website {CRCPress} should be used beforehand. I found that running and playing with the simulations before reading chapter 5 were quite helpful.

Aperture synthesis is mainly used to increase angular resolution. The authors state that ground-based optical astronomy observations can achieve a resolution on the order of one acrsecond. To match this they say the diameter of a single dish radio telescope would have to be on the order of 5 km, which is far beyond economic practicality. To synthesize the equivalent of a large radio telescope, the same celestial radio source is simultaneously observed by many smaller antennas, and the outputs from each interferometer pair are combined to synthesize a narrow beam pattern.

The longer the baseline distances between each antenna pair, the higher the resolution of the combination. Using many antennas also increases the sensitivity but not as much as the resolution. An example is provided of the Jansky VLA in New Mexico, which has 27 individual radio telescopes each with 25 m diameter. The maximum distance between a pair of antennas is 36 km. When these are used together, the resolution is increased more than a 1000 times that of one antenna but the sensitivity is increased only 27 times. The 27 antennas provide 351 different baselines that are simultaneously used to produce a large aperture. The Jansky VLA is used as an example radio telescope array many times in this book.

The simplest way to combine the outputs from each interferometer pair is to add them in what is called an *additive interferometer*. A more complicated method is to multiply the outputs, called a *multiplicative interferometer* or more often a *cross-correlation interferometer*. Although the cross-correlation type is much more complex, it has the advantage of lower noise, making it more sensitive. Amateur radio astronomers who build radio interferometers generally use the additive type because it is comparatively simple and low cost whereas all modern professional systems are cross-correlation types. As one would expect, there is considerable geometry and calculus involved in aperture synthesis and cross-correlation interferometers. Being that modern professional systems use these types, one immediately knows that big bucks are involved. It is clear that saying "synthesize" or "cross-correlation" is much easier than actually doing it.

Chapter 5 is focused on 2-element interferometers in which the two antennas are on an east-west baseline and the antennas and radio source being observed all are in the equatorial plane. In this situation, Earth's rotation moves the radio source through the interferometer beam. Chapter 5 includes discussion of the effects of source size, integration time and bandwidth on observations. The interferometer setup of chapter 5 is extended to more generalized situations in chapter 6, *Aperture Synthesis: Advanced Discussion*; however, the "advanced discussion" is still considered by the authors to be "basic". Only cross-correlation interferometers are discussed. For readers who desire truly advanced study of aperture synthesis, the authors provide at the beginning of chapter 6 the titles and authors of two reference books, one of which may be obtained for free via internet download.

Chapter 6 introduces the use of 2-dimensional Fourier Transforms to produce images of radio sources. Since the book assumes no prior knowledge of Fourier Transforms, a primer is provided in Appendix V and references are made to exercises using the software Tool for Interactive Fourier Transforms (TIFT) available by download. Because radio astronomers use computers to perform Fourier Transforms and do not do it by hand, the TIFT is a very useful learning tool to help visualize the processes used to build images of radio sources.

I mentioned above the Small Radio Telescope (SRT) and Very Small Radio Telescope (VSRT). At one time the SRT could be purchased from MIT but it is no longer available. Motivated users still can construct their own SRT because complete construction details are available at {Haystack}. There are two versions of the SRT, one using a conventional superheterodyne receiver and another using an RTL-dongle software define radio (SDR) receiver, the latter being much cheaper. The VSRT is somewhat similar to the Itty-Bitty Telescope {IBT}) in that it uses repurposed Ku-band satellite feeds, off-the-shelf video amplifiers and a simple diode detector. The VSRT can be used along with one or two compact fluorescent lamps (CFL) to demonstrate interferometer operation with one or two radio sources.

One strong advantage of these self-built systems is that the simulation software associated with the book is completely compatible with them. However, readers do not have to own or have access to these particular radio telescopes, because the exercises and software can work with other setups or they can be used only for simulations. The programs are written in Java (*.jar files) and have built-in instructions that are read in a browser (*.html files). I ran the programs on a Windows 7 laptop and found them very easy to use. They are nice for experimenting with different scenarios such as single and double and resolved and unresolved sources. The authors have assumed that users of these programs are not already familiar with interferometers and Fourier Transforms. Kids! Yes, you *CAN* try this at home!

In summary, ***Fundamentals of Radio Astronomy: Observational Methods*** is the first contemporary professional radio astronomy book I have seen that is actually quite useful from start to finish and that attempts to help the reader learn rather than simply demonstrating how much the authors know. Any reader with technical inclination and a serious desire to learn radio astronomy, and not just the big budget stuff, will benefit from this book. Its value goes far beyond its printed pages when one considers the ready-made lab exercises, free software and inexpensive experimental apparatus that can be used with it.

Citations:

[Joardar] S. Joardar and J. Claycomb, ***Radio Astronomy: An Introduction***, Mercury Learning and Information LLC, 2016. See review of this book in *Radio Astronomy*, September-October 2016

[ReeveLF] Reeve, W., Report of Science at Low Frequencies II Conference, December 2~4, 2015, *Radio Astronomy*, January-February 2016

[ReeveLW] Reeve, W., Review of ***Radio Astronomy at Long Wavelengths***, *Radio Astronomy*, May-June 2014

Weblinks:

{CRCPress} https://www.crcpress.com/Fundamentals-of-Radio-Astronomy-Observational-Methods/Marr-Snell-Kurtz/p/book/9781420076769

{Haystack} http://www.haystack.mit.edu/edu/undergrad/srt/index.html

{IBT} http://www.radio-astronomy.org/pdf/Ibt.pdf

Reviewer - Whitham Reeve is a contributing editor for the SARA journal, *Radio Astronomy*. He worked as an engineer and engineering firm owner/operator in the airline and telecommunications industries for more than 40 years and has lived in Anchorage, Alaska his entire life.