Title: ***Radio Astronomy ~ Observing the Invisible Universe***
Author: F. Lockman
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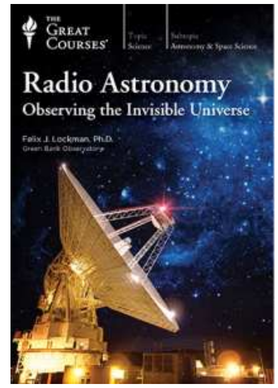
Reviewer: Whitham D. Reeve



Radio Astronomy ~ Observing the Invisible Universe is a series of lectures in electronic format, either DVD or download. The DVD purchase includes a 281 page printed guidebook. Both the DVD and download include a downloadable PDF guidebook and the ability to stream the content from The Great Courses website. The course may be streamed from anywhere with an internet connection and includes mobile devices and electronic readers; however, I did not attempt to use these methods. The DVDs can be watched with closed captioning.

I highly recommend this series of lectures to anyone interested in radio astronomy. The author and lecturer, Dr. Felix Lockman, is principal scientist at the Green Bank Observatory in West Virginia USA. In 24 lectures (listed below) he covers all aspects of contemporary and historical radio astronomy.

1. *Radio Astronomy and the Invisible Universe*
2. *Thermal Radio Emission: The Planets*
3. *The Birth of Radio Astronomy*
4. *The Discovery of Interstellar Hydrogen*
5. *Radio Telescopes and How They Work*
6. *Mapping the Hydrogen Sky*
7. *Tour of the Green Bank Observatory*
8. *Tour of the Green Bank Telescope*
9. *Hydrogen and the Structure of Galaxies*
10. *Pulsars: Clocks in Space*
11. *Pulsars and Gravity*
12. *Pulsars and the 300-Foot Telescope*
13. *The Big Bang: The Oldest Radio Waves*
14. *H II Regions and the Birth of Stars*
15. *Supernovas and the Death of Stars*
16. *Radio Stars and Early Interferometers*
17. *Radio Source Counts*
18. *Active Galactic Nuclei and the VLA*
19. *A Telescope as Big as the Earth*
20. *Galaxies and Their Gas*
21. *Interstellar Molecular Clouds*
22. *Star Formation and ALMA*
23. *Interstellar Chemistry and Life*
24. *The Future of Radio Astronomy*

Both beginning and experienced amateur radio astronomers will benefit from ***Radio Astronomy*** because it covers the fundamentals as well as the types of celestial radio emissions that can be received on amateur radio telescopes. Each lecture is 30 minutes long, giving a total of 12 hours in front of the TV or viewing device. You can watch the lectures on your big-screen TV from the comfort of your recliner. This is far better than watching 24 hour marathons of 7th Heaven. The lectures are not a rehash of past presentations but are purpose-made, uniform in format and consistent in quality. Dr. Lockman is articulate and engaging and English is his native language.

The price for ***Radio Astronomy*** is cheaper than most books and the lectures are up-to-date. One thing that sets these lectures apart from contemporary radio astronomy books is the decent coverage of radio frequencies below 1 GHz, including Jupiter radio emissions in the HF band, something most modern radio astronomy books completely fail to mention. Unfortunately, solar radio astronomy is left out in spite of its importance to understanding space weather.

Most topics include discussions of the radio telescopes associated with discoveries. The lectures are structured so there is continuity from one to the next; each lecture refers to preceding lectures. However, there is no need to go back for a review because that is given when needed, or you can look at the guidebook. People already familiar with the fundamentals covered in the early lectures 1 through 5 can skip to specific lectures of interest later in the series.

Dr. Lockman tries to avoid jargon and makes a point about H I or HI (capital H followed by Roman numeral I) frequently used for neutral atomic hydrogen line radio emissions near 1.4 GHz. He explains that H I refers to emissions from single hydrogen atoms (thus *atomic* hydrogen) and not from hydrogen in molecules or combined with other elements. Jargon in any industry does nothing to improve knowledge and only serves to shut out newcomers. Interestingly, he later discusses H II, which is ionized hydrogen, and calls it just that.

Simple equations are occasionally used to explain concepts but Lockman is careful to walk through and explain why they are important. And, he offers some good advice to students based on his own experience as a graduate student in the 1970s helping to build a radio telescope in Massachusetts: "*Without a stint at manual labor, your education is grossly incomplete.*" Practical advice such as this is important and students of radio astronomy will do well to put those Legos away and get their hands dirty. He also recounts many interesting anecdotes based on his own experiences as well as others, including scientists who made important discoveries.

The lectures include a lot of illustrations. Dr. Lockman explains them with verbal captions and he is careful to actually explain what is being shown – in contrast to many radio astronomy books that do a terrible job with captions. Dr. Lockman frequently shows optical , radio and x-ray images of a celestial object together for easy comparison of the various frequencies (or wavelengths). Of course, the images of non-optical frequencies use colors to indicate frequency or intensity.

The guidebook includes the lecture text almost word-for-word but not quite; for example, personal stories told on screen are left out of the guidebook. These stories make viewing the content even more interesting. Images in the guidebook are black-white whereas they are in color in the videos. Each lecture in the guidebook includes at the end *Suggested Reading* and *Questions to Consider*. Supplementary references in the back of the guidebook list books specific to radio astronomy, books on topics related to radio astronomy and radio astronomy documents available online. Most are non-technical but they cover all aspects of radio astronomy. Now, I will comment on several of the lectures.

The first couple of lectures clearly explain the differences between thermal and non-thermal radio emissions and the mechanisms that produce them. Lecture 3 is an illustrated history and does a good job of crediting the pioneers of radio astronomy Karl Jansky, Grote Reber and Ruby Payne-Scott. Lectures 7 and 8 cover the Green Bank Observatory and its many facilities and then focus on the 100 m Green Bank Telescope (GBT). That Green Bank is singled out is not surprising, given the lecturer's affiliation, but it is a good example of modern facilities. This coverage is quite thorough and interesting even if you have visited and toured the site during a SARA Eastern Conference.

Three lectures – 10, 11 and 12 – are devoted to pulsars, although 12 is more about the 300 ft dish at Green Bank that collapsed in November 1988 and no longer exists. In Lecture 10 Dr. Lockman appeals to "Stockholm" to "do the right thing" and recognize Jocelyn Bell Burnell's contribution to the discovery of pulsars – something the

Nobel Prize committee inexcusably failed to do when instead they awarded Antony Hewish the prize for the discovery. The pulsar lectures do not go into minute detail as to how it is thought pulsars work but they do discuss the difficulties in detecting them and the techniques used to increase the signal-to-noise ratio and extract the extremely weak pulses from the noise.

At this point in the lecture series we are one-half-way through, and the radio astronomy so far discussed is technically feasible for the amateur radio astronomer. However, the methods described in later lectures generally require large antennas or antenna arrays and interferometers with long baselines, something available only to scientists with government funding. This is no reason to stop watching and learning from the remaining lectures. There still is a lot of ground to cover including the quest to improve angular resolution and increase the frequency range. Also, it is necessary to interpret the resulting measurements, determine what they mean and decide where they lead and what to do next.

The cosmic background radiation (CBR) is discussed in detail in lecture 13. The CBR contains “the oldest radio waves” and are left over from the Big Bang. The Big Bang is a concept that explains a lot (but not all) of the beginning of the universe. Included in this lecture are descriptions of the CBR discovery by Penzias and Wilson in 1964 and the CBR measurement results from the COBE spacecraft observations. The latter clearly showed the blackbody nature of the background radiation. Although the CBR also is known by the more familiar acronym CMBR, or cosmic microwave background radiation, Lockman avoids using this because of the potential confusion associated with the word *microwave*. Just ask a group of *experts* what range of frequencies or wavelengths are covered by the word and you will get far too many different answers.

Lecture 19’s main topic is the Very Large Baseline Interferometer, or VLBI. This lecture goes into quite a bit of interesting detail about the need for very high resolution measured in fractions of a milli-arcsecond. Interferometers are used to deliver the needed resolution. Included here are discussions of the very high accuracy in the position and timestamps associated with the individual radio telescopes used in any interferometer, their connections to a correlator or data recorder, and things that can cause errors. The needed resolution has been achieved by using celestial radio sources for calibration and the high-accuracy timing provided by the Global Positioning System.

Lecture 22 discusses star formation. Observations of areas likely to be forming stars are made at extremely high frequencies (EHF) – on the order of 100 GHz corresponding to millimeter wavelengths. Of particular interest to radio astronomers are spectral line emissions from molecules such as carbon monoxide (CO) in so-called dark clouds and giant molecular clouds. Interestingly, these observations do not require large parabolic dish antennas. Instead, a few meters diameter is adequate, but the small antennas do require extremely accurate surfaces. A rule of thumb is that the dish antenna surface accuracy (that is, conformance to a parabolic shape) should be $< \lambda/20$. For observations at 2 mm wavelength the required accuracy is on the order of 0.1 mm, an accuracy that is very hard to achieve with large dish antennas. Radio telescopes that operate in millimeter and submillimeter wavelength ranges normally do not use low noise amplifiers at the antenna because of the difficulty in building amplifiers with adequately low noise figures for the frequencies involved. Instead, the antenna feeds a mixer directly, which down-converts the signals to a lower, more easily amplified frequency. This lecture is not just about the radio telescopes but also the processes that cause stars and planets to form and how these regions are studied.

In conclusion ***Radio Astronomy ~ Observing the Invisible Universe*** is a worthwhile series of lectures that will benefit anyone interested in radio astronomy. The lectures provide newcomers with the big picture while covering aspects of radio astronomy that might not be familiar to specialists. You will need a DVD player and a TV or a PC with an internet connection. The only down-side to your purchase is the great amount of sales spam unleashed by the publisher **The Great Courses** after you sign up and order the course. It is easy to stop all the emails but I was caught off-guard by the volume.

Reviewer - Whitham Reeve is a contributing editor for the SARA journal, Radio Astronomy. He obtained B.S. and M.S. degrees in Electrical Engineering at University of Alaska Fairbanks, USA. He worked as an engineer and engineering firm owner/operator in the airline and telecommunications industries for more than 40 years and now manufactures electronic equipment used in radio astronomy. He has lived in Anchorage, Alaska his entire life. Email contact: whitreeve(at)gmail.com