RADIO ASTRONOMY

Journal of the Society of Amateur Radio Astronomers

September-October 2026



Brian Chad O'Rourke
SARA Journal Editor

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It is the mission of the Society of Amateur Radio Astronomers (SARA) to: Facilitate the flow of information pertinent to the field of Radio Astronomy among our members; Promote members to mentor newcomers to our hobby and share the excitement of radio astronomy with other interested persons and organizations; Promote individual and multi station observing programs; Encourage programs that enhance the technical abilities of our members to monitor cosmic radio signals, as well as to share and analyze such signals; Encourage educational programs within SARA and educational outreach initiatives. Founded in 1981, the Society of Amateur Radio Astronomers, Inc. is a membership supported, non-profit [501(c) (3)], educational and scientific corporation.

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Cover Photo:
Andrew Thornett

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President's Page



Hello everyone. As always, there are many exciting and innovative projects happening in our midst. I look forward to reading about the many interesting experiments and explorations our members have been pursuing over the past couple of months.

The board has created a new committee specifically for the purpose of pursuing the establishment of HF beacons across North America for amateur Meteor Detection. This will include partnering with another amateur organization known as HamSci. For further information contact Jay Wilson W0AIR (jay.wilson@vodec.net) who will be leading this effort along with Chip Sufitchi N2YO. Stay tuned for updates on this exciting project!

Keep tinkering!

Cheers!

Jason L. Burnfield

Editor's Notes

We are always looking for basic radio astronomy articles, radio astronomy tutorials, theoretical articles, application and construction articles, news pertinent to radio astronomy, profiles and interviews with amateur and professional radio astronomers, book reviews, puzzles (including word challenges, riddles, and crossword puzzles), anecdotes, expository on "bad astronomy," articles on radio astronomy observations, suggestions for reprint of articles from past journals and other publications, and announcements of radio astronomy star parties, meetings, and outreach activities.

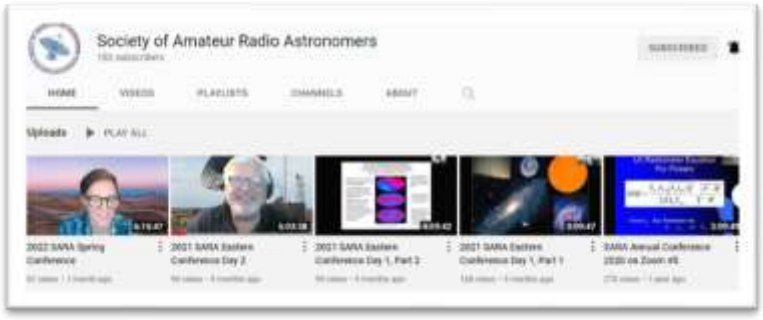
Subscribe to the SARA YouTube Channel

SARA has a YouTube channel at: https://www.youtube.com/@radio-astronomy



Don't forget to LIKE the videos! It helps with the YouTube distribution algorithm.

We are also looking to add content to the site. Anyone who wants to help produce a series of 5 - minute videos relating to radio astronomy technology or observations please contact me. (drrichrussel@netscape.net)



SARA NOTES

SARA Student & Teacher Grant Program

All, SARA has a grant program that is, sad to say, very underutilized. We will provide kits or money for students and teachers, including college students, to help them with a radio telescope project. SARA can supply any of the following kits:

1. SuperSID
2. Scope in a Box
3. Radio Jove kit
4. Inspire
5. Sky Scan

We can also provide up to five hundred dollars ($500.00 USD) for an approved radio telescope project.

We have on occasion provided more money based on the merits of the project and SARA Grant Committee approval.

More information on the grant program can be found at the URL below.
SARA Student and Teacher Project Grants | Society of Amateur Radio Astronomers (radio-astronomy.org)

All that is required is the SARA grant request form to be filled out and sent in. If it needs more work for approval, we will work with the students to help ensure their success.

Please pass the word that SARA will fund any legitimate radio telescope project anywhere in the world.

If you have a question, contact me at crowleytj@hotmail.com .
Tom Crowley - SARA Grant Program Administrator

Monthly Zoom Meetings

Radio Telescope Observation Party (RTOP)

RTOP is designed to demonstrate how to take observations using various radio telescopes. It will also cover how to record and analyze data.

RTOP is every month on the 1st Sunday at 2 pm Eastern time (1800 UTC). ZOOM email notifications will be sent to all members.

Drake's Lounge

Join the SARA community as we discuss the latest astronomy and radio astronomy news. The lounge also provides a forum to share and get advice on your radio astronomy projects from very experienced amateur radio astronomers. Drake's Lounge is every month on the 3rd Sunday at 2 pm Eastern time (1800 UTC). ZOOM email notifications will be sent to all members.

Drake's Lounge Australia

This new zoom forum is geared to the Melbourne, Australia time zone (UTC+10) in order to improve coordination with our Australia, New Zealand, and Japanese members. The meetings are scheduled for the 4th Friday of every month, 9 AM Melbourne time. A zoom announcement will be sent out to all SARA members before the meeting.

British Astronomical Association
Supporting amateur astronomers since 1890
Radio Astronomy Section



Director: Paul Hearn

The Radio Astronomy Section aspires to encourage and support the construction of radio telescopes by amateurs, their use for observing programmes, and the development of a deeper understanding of the science underlying what is being observed. Programmes can be aimed at any radio astronomical phenomenon, at any radio frequency. This encouragement will be through the operation of continuing group programmes, and through building communication and information exchange between individuals and groups pursuing their own projects. The main purpose of the Group is to act as a reservoir and clearing house for information on radio telescope design, construction and debugging, and how to use these instruments effectively. This will include the discussion of observing techniques and data analysis. Members should be able to exchange ideas, give advice and help each other. Establishing a pool of design information and software suitable for use in observing and data processing is a priority.

BAA Radio Astronomy Section Seminar programme.
These seminars are on Zoom, if you are not on the BAA RA Section email list please contact Paul Hearn – Section Director – [*paul@hearn.org.uk*](mailto:paul@hearn.org.uk)

Friday Nov. 6th. 19:30 GMT (19:30 UTC)
TBC: What radio observation of core collapse supernovae tells us about the life and death of the star or A home-built receiver and results.

Friday December 4th 19:30 GMT (19:30 UTC)
Dr Peter Higgins
Project Manager NASA (Retired)
NASA's Solar Particle Alert Network
NASA’s Solar Particle Alert Network (SPAN) was developed to protect astronauts from potentially lethal solar radiation events during lunar missions. Experience from the solar cycle preceding the Apollo Moon landings showed that major solar-particle events could incapacitate or kill astronauts on the lunar surface, while the Lunar Module could not carry enough shielding without an unacceptable weight penalty. The solution will be presented.
Biography:
Peter served in several key space-program roles: leading the Solar Particle Alert Network, a worldwide system of seven optical and three radio telescopes designed to warn of dangerous solar activity during Apollo lunar missions; heading the Radiation Analysis Section, which calculated astronaut radiation

exposure from solar storms and passage through the Van Allen belts; working as Console Coordinator in the Gemini Mission Control Centre; and planning experiments involving solar-constant measurement and microwave radiometry for Earth resources research.

Wednesday January 13th 19:30 GMT (19:30 UTC)
Professor Clive - Dyer Surrey Space Centre
Space Weather: Past, Present & Future; Is It Safe to Fly Today?
Space Weather refers to the effects of solar activity on Earth, including disruptions to satellites, communications, GPS, power grids and aircraft, as well as increased radiation exposure. Now recognised as one of the UK's highest national risks, research at the Surrey Space Centre is helping to improve the monitoring and forecasting of these events. Although recent solar storms have been moderate, much larger events have occurred in the past, underlining the need to understand and prepare for their potentially serious impacts.

There are four additional on-line meetings - Practical Radio Astronomy host: Andy Thornett. H-Line instruments and observation, GNU Radio, muon instruments and observation, VLF observing Sudden Ionospheric Disturbance

If you are interested, please contact Andy (andrew@thornett.net].

Join the RA conversation
Join the muon conversation
Join the UK Beacon conversation
Society of American Radio Astronomers
UK Radio Astronomy Association
(UKRAA) BAA RA YouTube channel

Paul Hearn
BAA Radio Astronomy Section Director
UKRAA Trustee

¦¦ British Astronomical Association ¦¦
https://britastro.org/section_front/24

paul@hearn.org.uk a RG6 1BU UK t +44 (0)7967 388 578

SuperSID

SuperSID

Collaboration of Society of Amateur Radio Astronomers and Stanford Solar Center

- Stanford provides data hosting, database programming, and maintains the SuperSID website
- Society of Amateur Radio Astronomers (SARA) sells the SuperSID monitors for 48 USD to amateur radio astronomers, and the funds are then used to support free distribution to students all over the world (image below as of Fall 2017)
- Robert Canillas (formerly Jonathan Pettingale) at SARA is responsible for building and shipping the SuperSID monitor kits: SuperSID@radio-astronomy.org
- SuperSID kits may be ordered through the SARA SuperSID webpage: http://radio-astronomy.org/node/210
- Questions about the SuperSID project may be directed to Steve Berl at Stanford: steveberl@gmail.com
- Jaap Akkerhuis at Stanford is responsible for the SuperSID software and SARA has provided financial support for his efforts
- SuperSID website hosted by Stanford: http://solar-center.stanford.edu/SID/sidmonitor/
- SuperSID database: http://sid.stanford.edu/database-browser/
- The data is searchable by time, station, date, and multiple plots may be placed on the same graph for comparison.



-
-

SuperSID Space Weather Monitor
Request Form

For official use only

Monitor assigned: _____

Site name: _____

Country: _____

	Your information here
Name of site/school *(if an institution)*:	
Choose a site name: *(3-6 characters) No Spaces*	
Primary contact person:	
Email:	
Phone(s):	

Primary Address:	Name School or Business Street Street		
	City Country	State/Province Postal Code	
Shipping address, if different:	Name School or Business Street Street City Country	State/Province Postal Code	
Shipping phone number:			
Latitude & longitude of site:	Latitude: _____ Longitude: _____		

I understand that neither Stanford nor the Society of Amateur Radio Astronomers is responsible for accidents or injuries related to monitoring use. I will ensure that a surge protector and other lightning protection devices are installed if necessary.

Signature: _____ **Date:** _____

I will need:

What	*Cost*	*How many?*
SuperSID distribution USB Power (no options)	$48 (assembled)	

USB Sound card 96 kHz sample rate *(or provide this yourself)*	$40 *(optional)*	
Antenna wire (120 meters) *(or you can provide this yourself)*	$23 *(optional) with connectors attached and tested*	
RG 58 Coax Cable (9 meters) *(or provide this yourself)*	$14 *(optional) with connectors attached and tested*	
Shipping	US $12 Canada & Mexico $40 all other $60	
	TOTAL	$

____ **I have included a $ _____ check (payable to SARA)**

____ I will make payment thru www.paypal.com to treas@radio-astronomy.org

or

____ If you are a Minority-serving institution, in a Developing or economically deprived nation, and/or you are using the monitor with students for educational purposes, you may qualify for obtaining a monitor at reduced or no cost. Check here if you wish to apply for this designation. Then tell us how you want to use the SuperSID monitor. Include type of site, number of students involved, whether public or private school, grade levels, etc. and describe your program. The goal of the SuperSID project is to provide as many students with systems as possible. If you are able to pay for a system, even if you qualify for a free one, please do so and help support our goal. For more details on the Space Weather Monitor project, see: **http://sid.stanford.edu**

To set up a SuperSID monitor you will need:

1. Access to power and an antenna location that is relatively free of electric interference (could be indoors or out)
2. A **PC**** with the following minimal specifications:
   a. A sound card that can record (sample) up to 96 kHz, or a USB port to connect such a sound card
      (for North and South America)
      i. All other countries can use AC97 sound card with 48 kHz record (sample) rate. Most computers made after 1997 will have AC97.
   b. Windows 2000 or more recent operating system
   c. 1 GHz Processer with 128 mb RAM
   d. Ethernet connection & internet browser (desirable, but not required)
   e. Standard keyboard, mouse, monitor, etc.

[3] An inexpensive antenna that you build yourself. You'll need about 120 meters (400 feet) of **insulated** wire.

Solid wire is easier to wind than stranded. Magnet wire will work but be more fragile. You can use anything from #18 to #26 size wire. The antenna frame can be made of wood, PVC pipe, or similar materials. We'll provide instructions. You can purchase the wire from us or obtain your own.

[4] RG58 coax cable with a BNC connector at one end to run from the antenna to the SuperSID receiver. 9 meters is recommended, but the length will depend on where you place the antenna. You can purchase the coax from us or obtain your own.

[5] Surge protector and other protection against a lightning strike

---

Return this form to: SuperSID@radio-astronomy.org

Announcing Radio JOVE 2.1

The Radio JOVE Team



Radio JOVE students and amateur scientists from around the world observe and analyze natural radio emissions of Jupiter, the Sun, and our galaxy using their own easy to construct radio telescopes.

Our Project announces Radio JOVE 2.1, where participants assemble a 16-24 MHz radio spectrograph to observe solar, Jupiter, Galactic, and Earth-based natural radio emissions and share their observations with fellow

participants.

In the Beginning

Radio JOVE started as a NASA sponsored educational outreach project in 1999. We developed a radio telescope kit suitable for receiving signals from Jupiter, the Sun, the Galaxy, and Earth-based radio emissions. The original kit comprised a radio receiver (RJ1.1) and a dual dipole antenna for 20.1 MHz. An important goal was to teach electronic principles including how to build, solder, and assemble the radio receiver and antenna.



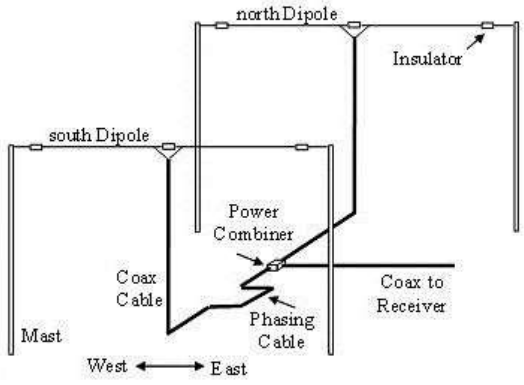


Figure 1. A Radio JOVE RJ1.1 receiver and a schematic of the dual-dipole antenna.

In addition to the hardware, three software packages were developed. These were Radio Jupiter Pro (Jupiter emission prediction program), Radio-SkyPipe (strip chart program) and Radio Sky Spectrograph (control and display of radio spectrograph data).

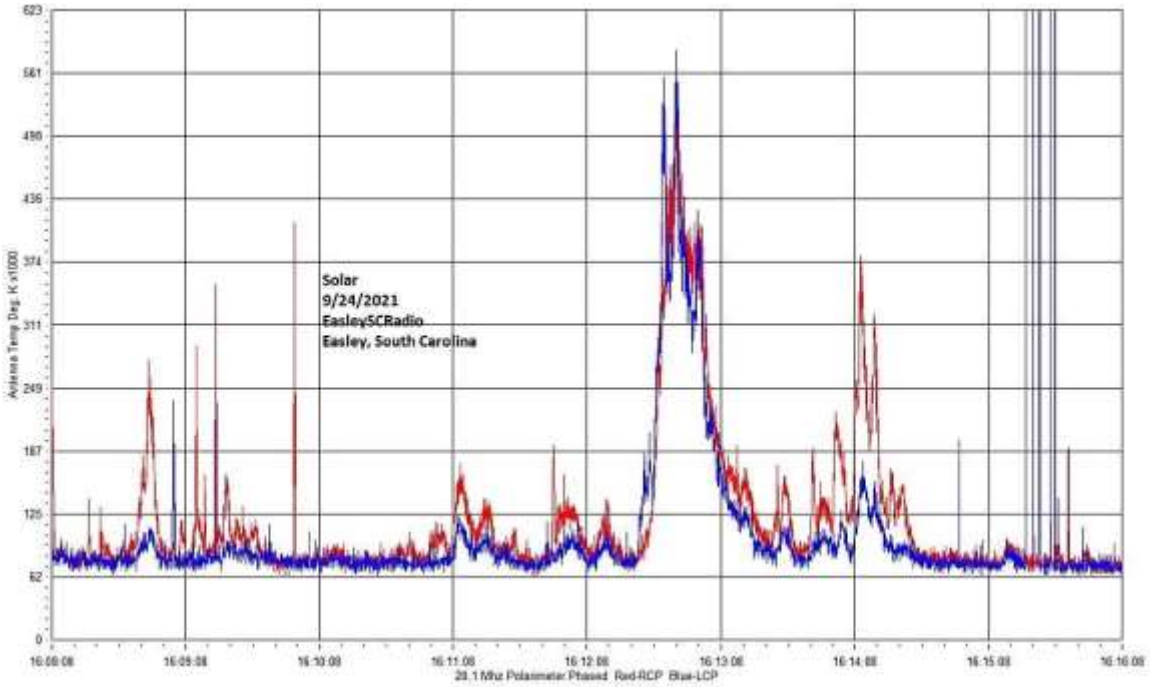


Figure 2. A SkyPipe strip chart showing multiple solar bursts using a JOVE receiver. John Cox, SC.

The Growth of Radio JOVE

As of Autumn 2021, over 2,500 kits have been sold at cost to schools and individuals around the world. Thousands of data submissions from observers have been made to the Radio JOVE data archive.

The Radio JOVE web site has always provided a wealth of information describing observation methods and various educational materials intended to teach radio astronomy techniques and scientific methods. Biannual newsletters are produced and several telephone help sessions are held each year.

A sub-group of experienced observers known as the Spectrograph Users Group (SUG) evolved from the core JOVE group. These observers developed data collection and analysis techniques using more advanced equipment and techniques. SUG members have contributed to articles published in peer-reviewed scientific journals. This group remains active under the Radio JOVE listserv at https://groups.io/g/radio-jove/.

Moving Forward with New Technology

In the past, Radio JOVE provided the hands-on experience of building a radio kit. We have many RJ1.1 receivers in operation successfully contributing scientifically valuable data. It has, however, become increasingly difficult to obtain parts for the RJ1.1 receiver kits and we therefore decided to replace the RJ1.1 receiver with a new SDRbased design for the receiver portion of our radio telescope kits. While we continue to support the hardware and software for the original RJ1.1 receivers, the only kits now available for purchase from Radio JOVE contain this newly designed system.

In recent years, new technologies have made software defined radios (SDRs) ever more afforable. These radios can operate on a single frequency like the original JOVE receiver but can also generate spectrograms which depict radio activity as a function of both time and frequency. Such displays offer new insights into our studies of the Sun, Jupiter, the Galaxy, and both natural and artificial Earth-based radio emissions.

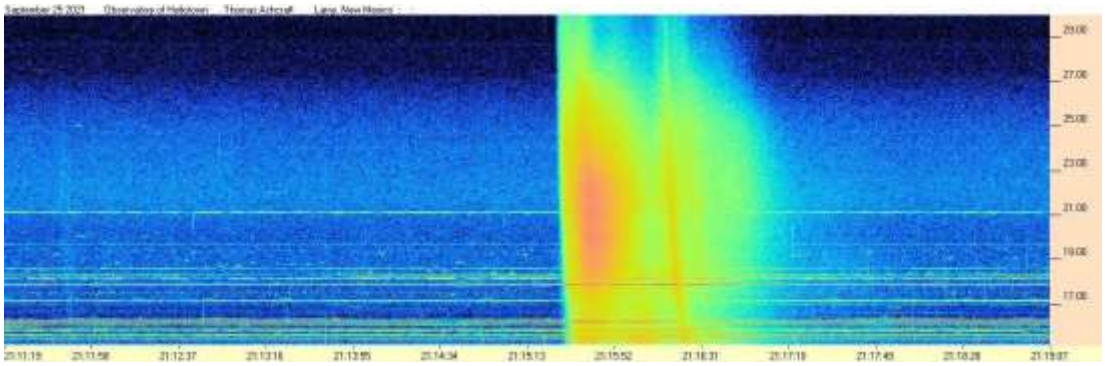


Figure 3. Radio spectrogram showing multiple solar bursts received by Tom Ashcraft in New Mexico. Horizontal scale is time and the vertical scale is frequency. Amplitude is displayed using different colors corresponding to the strength of signals.

Radio JOVE continues to sell radio telescope packages including an antenna, receiver, and software; however, the receiver is now a commercially built SDR.



Figure 4. As of 2025, Radio JOVE has moved from the SDRPlay RSP1A SDR to the RSP1B. The JOVE team will continue to provide support both instruments as used in our radio astronomy program. Not all SDR types can be supported, but it is our intent to provide support for some other SDRs as they become available during this period of rapid SDR development.

It continues to be our goal to introduce new observers to the scientific method and help them experience the thrill of receiving cosmic radio signals. Through a series of educational training modules and observing and analysis projects we aim to guide new observers to levels where they can contribute to Citizen Science projects.

We continue to support our large user base that uses JOVE RJ1.1 receivers – both in terms of technical support for the receivers but also with new and exciting observing projects for both RJ1.1 and SDR users.

We welcome both new and experienced observers to the JOVE 2.1 program as we share the excitement of receiving, studying, and understanding radio signals from our corner of the galaxy.

Please see the Radio JOVE web site at https://radiojove.gsfc.nasa.gov for more information.



RADIO JOVE 2.1 RADIO TELESCOPE KIT ORDER FORM

Order Online using PayPal™

* * * Please allow 2 to 3 weeks for delivery. * * *

IMPORTANT: Before you order the Jove receiver kit and/or the antenna kit, we suggest that you read the on-line manuals. You will need to provide additional materials and tools to complete the antenna. The cost of additional materials for the antenna support structure (masts, etc.) may be in the range of US$75 to US$100. Also note that the optimal antenna height can be up to 20ft, depending upon your latitude.

Item # RJK2u – Complete 2.1 Kit: Receiver + Unbuilt Antenna Kit + Software This kit includes an SDRplay RSP1B, USB Cable, SMA/F adapter cable, unbuilt Antenna Kit (RJA), printed assembly manuals, and Radio-Sky Spectrograph (RSS) software. Note: Kit does not include antenna support structure. **Price: $306 + Shipping (See below for shipping)**	**Item # RJK2p** – Complete 2.1 Kit: Receiver + Professionally Built Antenna Kit + Software This kit includes an SDRplay RSP1A, USB Cable, SMA/F adapter cable, Professionally Built Antenna Kit (RJA2), printed assembly manuals, and RadioSky Spectrograph (RSS) software. Note: Kit does not include antenna support structure. **Price: $472 + Shipping (See below for shipping)**

Item # RJA – Unbuilt Antenna Kit The RJA Radio JOVE Antenna Kit includes a printed construction manual, stranded copper easy-to-solder antenna wire, ceramic insulators, RG-59 easy-to-solder coax cable, screw-on Fconnectors, and a power combiner. Note: Kit does not include antenna support structure. Assembly requires a soldering gun and other tools. **Price: $133 + Shipping (See reverse for shipping)**	**Item # RJA2** – Professionally Built Antenna Kit The RJA2 Radio JOVE Antenna Kit includes a printed installation manual, two professionally assembled dipole antennas constructed of #14 Copperweld wire with Budwig center insulators and center support rope attachment points, high quality RG-6 coax with pre-installed commercial grade connectors, and a power combiner. Note: Kit does not include antenna support structure. **Price: $299 + Shipping (See below for shipping)**
Item # LTJ2 – Listening to Jupiter, 2nd Ed. by R. S. Flagg PDF download of Richard Flagg's book "Listening to Jupiter, 2nd Ed., 2005". The file is downloaded from a secure website. **Price: $10 + $0 shipping (PDF file download)**	

Order Online at https://radiojove.net/kit/order_form.html OR

Complete this form and mail with payment

Payment may be made by Credit Card via PayPal™, U.S. Check, U.S. Money Order, International Money Order in U.S. funds drawn on a U.S. bank, or Western Union Money Transfer made payable to **The Radio JOVE Project**. No bank-to-bank wire transfers are accepted. Purchase Orders are accepted from U.S. Institutions.

Send to: The Radio JOVE Project
1301 East Main St. MTSU
Box 412 Murfreesboro, TN
37132, USA email:
chiggins@mtsu.edu
FEIN: 20-5239863

Item	Description	Quantity	Item Price	Shipping (see below)	Subtotal
RJK2u	Complete Radio JOVE 2.0 Kit Receiver + unbuilt Antenna		$306		
RJK2p	Complete Radio JOVE 2.0 Kit Receiver + Professionally Built Antenna		$472		
RJA2	Professionally Built Antenna-Only Kit		$299		
RJA	Unbuilt Antenna-Only Kit		$133		
LTJ2	Listening to Jupiter, 2nd Ed., by R.S. Flagg (PDF download)		$10	$0	
				Total:	

Shipping Fees for Radio JOVE: We ship all packages using USPS Priority Mail flat rate boxes.

U.S.A.: $25.00

Canada: $70.00

All Other International Shipping: $110.00

Ship to: (Please print clearly)

Name: _____

Address: _____

City, State, Postal Code: _____

Province, Country: _____

Email: _____

Visit the Radio JOVE web site and fill out the team application form at https://radiojove.net/sign_up_form.php even if you are just an interested individual so that you can receive important information about kit updates, online services, and activities within the project as they occur!

Rev 10/25

Your British Accent – Isn’t It Cute! A British Visitor at the 2026 SARA Eastern Conference.

Andrew Thornett, M6THO
Lichfield Radio Observatory, England
andrew@thornett.net

Abstract

The 2026 Society of Amateur Radio Astronomers (SARA) Eastern Conference was held at Green Bank Observatory, West Virginia, from 1–5 August 2026. For a radio astronomer travelling from Britain for my first ever visit to the USA, the conference offered me a rare opportunity to combine amateur observing, practical experimentation and personal contact with other SARA members with a visit to one of the most important sites in the history of radio astronomy.

This article is a personal account of the conference and the journey surrounding it. Particular highlights included seeing the reconstruction of Karl Jansky's pioneering antenna, the historic 140-foot telescope, the 20-m telescope available for SARA observing projects, the Ewen horn associated with the first detection of the 21-cm neutral hydrogen line, and, dominating the site, the 100-m Robert C. Byrd Green Bank Telescope. Practical activities demonstrated the continuing experimental nature of amateur radio astronomy. The journey itself also became an astronomical experiment through the operation of a portable cosmic-ray detector aboard a transatlantic flight.

The conference illustrated how modern low-cost receivers, digital signal processing and home-built antennas are allowing amateurs to undertake increasingly sophisticated projects while remaining part of a tradition that stretches back to the earliest days of radio astronomy.

From England to Green Bank

Some astronomical sites are familiar long before we ever visit them. Green Bank Observatory is one of these places.

For decades I had seen photographs of the great telescopes at Green Bank and read about the discoveries made there. When the opportunity arose to attend the SARA Eastern Conference from 1–5 August 2026, it was therefore difficult to resist.

Travelling from England also meant that the conference became the centrepiece of a much larger American adventure.

The title of this article comes from one of my favourite comments made to me during the trip:

"Your British accent – isn't it cute!"

The Atlantic may separate Britain and the United States, but it became apparent remarkably quickly that an English accent remains a surprisingly effective conversation starter.

My introduction to the landscape of the eastern United States came partly through the generosity of fellow SARA member Jack Ganssle, who drove with me through Shenandoah National Park and along Skyline Drive on the way towards Green Bank.

West Virginia is spectacularly beautiful. The wooded ridges extend one behind another towards the horizon, and the journey through the mountains provides excellent preparation for arriving at an observatory deliberately situated away from large concentrations of human-generated radio interference.



The mountainous scenery encountered enroute to Green Bank, travelling through Shenandoah National Park and along Skyline Drive.

There were cultural discoveries too.

Green Bank lies in Pocahontas County. I have to confess that seeing copies of The Pocahontas Times produced the rather embarrassing realisation that, somewhere in my mind, Pocahontas was still principally associated with Disney.

There were also linguistic hazards associated with American food. A West Virginian breakfast of biscuits and gravy with eggs "over easy" sounds quite different to British ears from what eventually arrives on the plate.

Fortunately, radio astronomy uses a rather more internationally standard vocabulary.



Rich Russel models Biscuits and Gravy with Eggs Over Easy.

Arriving at Green Bank



Seeing the Green Bank Observatory sign for the first time was one of those moments when a place previously known from photographs suddenly becomes real.

The site contains an extraordinary mixture of radio-astronomical history and modern observational capability. It is possible to walk from instruments representing the earliest days of radio astronomy to one of the world's largest fully steerable radio telescopes. That makes Green Bank particularly appropriate for a SARA conference.

Amateur radio astronomers occupy an interesting position in modern astronomy. Our collecting areas may be small and our equipment inexpensive compared with professional observatories, but the experimental philosophy remains very similar to that which characterised the earliest days of the subject. We construct antennas. We experimented with feeds. We compare amplifiers. We search for sources of interference. We modify software. We make mistakes. Occasionally we detect something that

convinces us the entire exercise was worthwhile. Green Bank provides a wonderful reminder that radio astronomy itself began with precisely this sort of experimental approach.

Jansky and the birth of radio astronomy

One of the first historic instruments that demanded attention was the reconstruction of Karl Jansky's famous directional antenna. During the early 1930s Jansky was working at Bell Telephone Laboratories investigating sources of radio interference. His antenna could be rotated, allowing him to determine the direction from which unwanted signals were arriving. Among the signals was a persistent component that repeated, not according to the solar day but approximately according to the sidereal day. Jansky eventually associated this signal with the direction of the centre of the Milky Way (Jansky, 1933).

Radio astronomy had effectively been born.

The story remains particularly relevant to amateurs because Jansky's discovery came not from an elaborate astronomical observatory but through engineering, careful observation and curiosity about an unexplained signal.



The reconstruction of Karl Jansky's rotating radio antenna at Green Bank. Jansky's investigation of radio interference led to the discovery of radio emission from the Milky Way. Standing beside the reconstructed antenna is an unexpectedly moving experience for anyone interested in radio astronomy.

It is easy to look at the enormous modern telescopes elsewhere on the Green Bank site and imagine that meaningful radio astronomy requires enormous engineering resources. Jansky's antenna provides a useful corrective. The important component was not simply the size or complexity of the instrument. It was the observer asking why a signal behaved as it did. That remains something every amateur can and should do, regardless of how large or small their experiment is.

The 21-cm hydrogen line

Another exhibit of particular significance to amateur observers is the horn antenna associated with Harold Ewen and Edward Purcell and with which they made first detection of the 21-cm neutral hydrogen line. The possibility of detecting this hyperfine transition had been predicted before its experimental observation. In 1951 Ewen and Purcell reported detection of radiation from Galactic neutral hydrogen close to 1420 MHz (Ewen and Purcell, 1951). Today, the hydrogen line is perhaps the ideal introduction to serious amateur radio spectroscopy. The rest frequency of the line is approximately 1420.4058 MHz, conveniently within a frequency range for which inexpensive modern software-defined radios, low-noise amplifiers, filters and antenna components are readily available.

For an amateur who has already spent considerable time observing the hydrogen line, seeing the historic horn was very exciting. I have built one of the SETI League's versions of this same horn antenna – and standing next door to Ewan and Purcell's instrument helped me to feel like I was standing in their footsteps in my own work.



The historic horn antenna associated with Ewen and Purcell's first detection of the 21-cm neutral hydrogen line. For modern amateur radio astronomers, the hydrogen line has become one of the most accessible forms of astronomical spectroscopy.

The attraction of hydrogen-line observing is that detection is only the beginning. By examining the frequency of the line, Doppler velocities can be obtained. Measurements made at different Galactic longitudes reveal components associated with variously moving clouds of hydrogen. With sufficiently systematic observations, amateurs can investigate Galactic rotation and begin constructing maps of hydrogen distribution within the Milky Way, weigh our galaxy and demonstrate the findings that suggest the presence of dark matter to many scientists.

The equipment required would have seemed extraordinary to an amateur only a few decades ago. Today an SDR costing comparatively little can perform much of the function once requiring specialised laboratory receivers and spectrum analyzers. This democratization of instrumentation is one of the reasons why, to me and many others, amateur radio astronomy currently feels particularly exciting.

The 20-m telescope – a resource for SARA members

One telescope at Green Bank that deserves particular attention from SARA members is the 20-m Skynet telescope. It is easy to concentrate on the largest dishes and walk past smaller professional instruments, yet from the point of view of an amateur astronomer the 20-m may be one of the most interesting telescopes on the site. This is because SARA members are able to use this telescope remotely as part of their membership of the society. I find it extraordinary that in my talks to amateur astronomy societies in the UK I can talk about my remote telescope – a 20-m instrument located in a radio-quiet zone in West Virginia. I have been able to take spectra from and map the area around galaxies and nebulae outside our own Milky Way using this instrument in the last couple of years and present papers at SARA meetings and write articles for the SARA Journal on my findings.



The Green Bank 20-m telescope. One of the significant benefits of SARA membership is the opportunity for members to make use of this instrument for suitable observing projects.

A home radio telescope teaches a great deal, but access to a 20-m aperture changes the types of observations that become possible, extending the range of objects to include masers and pulsars, and also offers an opportunity to learn some of the practical issues that confront professional observers: selecting targets, planning observing time, understanding beamwidth, acquiring calibration data and deciding how observations should be reduced afterwards. This is an area where I suspect SARA could encourage even greater participation. Many members may simply not realise that this capability is available to them. Certainly, only a very small proportion of the organisation's membership ever conduct an observation with this telescope.

The 140-foot telescope

Another of the great instruments at Green Bank is the historic 140-foot telescope, one of the influential radio telescopes of all time.

There is an appealing solidity to the telescope. Modern electronics can shrink from one generation to the next, but a large steerable radio telescope remains unmistakably large. The 140-foot telescope contributed to an enormous range of radio-astronomical research during its operational life. Seeing it close up also emphasises just how substantial the mechanical engineering of large dish radio astronomy must be. Pointing a huge reflector accurately at an astronomical source while compensating for gravity, wind and structural deformation is quite different from placing an optical telescope on a tripod.



The historic 140-foot telescope at Green Bank. Its scale is difficult to convey in photographs and provides a reminder of the mechanical engineering required for precision radio astronomy.

For someone accustomed to metre-sized amateur dishes, walking around structures of this size altered my sense of scale dramatically. It also encouraged dangerous thoughts along the lines of: "I wonder how large a dish I could fit into the garden?"

The conference star: the 100-m GBT

And then there is the Green Bank Telescope.

The 100-m Robert C. Byrd Green Bank Telescope dominates the site both physically and psychologically. Even after seeing many photographs, its scale is difficult to appreciate until standing nearby. The telescope represents a remarkable combination of structural, mechanical, electronic and computational engineering. The GBT uses an unusual offset design that avoids the conventional support structures crossing the aperture of a centre-fed dish. This reduces aperture blockage and associated sidelobe responses. An active surface is used to maintain the required reflector shape as the enormous structure changes orientation (Prestage et al., 2009). This is achieved by actuators constantly changing the shape of the surface as it points in different directions.

During the conference the GBT became, inevitably, the favourite background for photographs.



The 100-m Robert C. Byrd Green Bank Telescope. Its unblocked aperture and enormous collecting area make the GBT the visual and scientific centrepiece of the observatory.

SARA – where the practical work continues after the talks

The formal presentations are obviously an important part of any conference, but one of the strengths of SARA is what happens between and after them. Radio astronomy remains a hobby in which people build things. Receivers and antennas appeared outside. Equipment was demonstrated. Systems were connected to laptops. Discussions moved rapidly from astronomy to impedance matching, filtering, SDR software and the inevitable question of why a particular signal was appearing where it should not. This

mixture of astronomy, physics, radio engineering and computing is one of the attractions of the subject. The amateur radio astronomer may have to be an antenna designer in the morning, a radio-frequency engineer after lunch, a programmer in the afternoon and an astronomer at night. There is also considerable educational value in seeing other people's equipment.



Practical amateur radio astronomy at the conference. Demonstrations and home-built equipment provided opportunities for exchanging construction ideas and observing techniques away from the formal lecture programme.

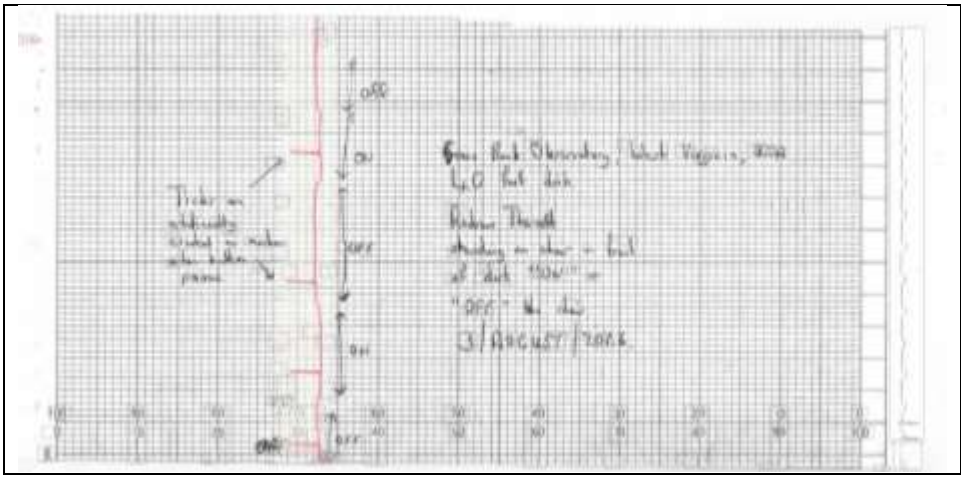


Tom Crowley demonstrates radio astronomy equipment and programs.



Measuring an astronomer with a radio telescope

One of the more entertaining demonstrations involved the 40-foot radio telescope. Instead of pointing it at a conventional astronomical source, I became the source. The human body radiates thermal energy at microwave wavelengths. A person at approximately 300 K can therefore be detected by a sufficiently sensitive microwave radiometer against a cooler background. The experiment involved allowing the telescope to detect the increase in received power associated with my body.



Measuring the author's body temperature using the 40-foot radio telescope. The experiment provides a simple demonstration that a radio telescope is fundamentally a sensitive radiometer.

It is tempting to dismiss such experiments as demonstrations rather than astronomy, but they teach an important lesson: A radio telescope does not inherently know that it is looking at the sky. It measures electromagnetic power within a defined frequency range and beam. Whether that power originates from the Milky Way, the Sun, the ground or a radio astronomer standing inconveniently in front of the antenna is a question for the observer to determine and the answers to these questions affect how we interpret the results coming out of our telescopes. That is precisely why calibration is so important.

The Drake Lounge and a sense of history

Green Bank's historical associations extend beyond conventional radio astronomy into the search for extraterrestrial intelligence. Frank Drake carried out Project Ozma at Green Bank in 1960, using a radio telescope to search for signals from the nearby stars Tau Ceti and Epsilon Eridani. The experiment is generally regarded as the first modern targeted radio search for extraterrestrial intelligence (Drake, 1961). During the conference, I had a chance, with other attendees, to visit the 85-foot radio telescope used by Drake for this project and sit in front of the equipment he used.

Once a month, SARA holds an online meeting called “Drake’s Lounge”. This is named after a social area in the accommodation block at Green Bank Observatory with the same name. We all met each evening after our meal in this original Drake Lounge. Perhaps appropriately, some of the best conference discussions took place in these informal surroundings. E-mail, mailing lists and videoconferencing allow international collaboration on a scale previous generations could scarcely imagine, and SARA has adopted these methods very successfully. However, none of these completely replaces the enjoyment and encouragement of meeting fellow amateurs and friends face-to-face.



SARA members relaxing in the one and only original Drake Lounge at Green Bank. Informal conversations are one of the most valuable aspects of an international amateur scientific meeting.

Turning the flight into an experiment.

My astronomical activities on this journey were not confined to Green Bank. For the transatlantic flight I carried a small PicoMuon cosmic-ray detector. The detector records events produced by energetic particles passing through its scintillators and can operate autonomously while storing data. This allowed the aircraft journey itself to become an experiment.



PicoMuon cosmic-ray detector operating during the transatlantic flight. A small autonomous detector turns a routine airline journey into an opportunity to investigate the altitude dependence of secondary cosmic radiation.

Cosmic rays interacting with the upper atmosphere generate showers of secondary particles, including muons. Many of these particles reach the Earth's surface, but the detected flux changes substantially with altitude. Muon and cosmic-ray physics therefore provides an intriguing area in which relatively inexpensive detectors can make genuine quantitative measurements (Gaisser, Engel and Resconi, 2016). During the aircraft observations the coincidence event rate increased dramatically compared with the rate measured on the ground, reaching approximately 35 times the ground-level value at cruising altitude. That is an enormous effect to observe with a device small enough to travel in hand luggage. There is something satisfying about performing an experiment while travelling to a scientific conference. It demonstrates one of the advantages amateur scientists possess: we can turn almost anything into an excuse to collect data.

The wider American adventure

Travelling from Britain for a conference at Green Bank also created an opportunity to visit some places that had long been on my personal bucket list. New York inevitably included the Statue of Liberty. Washington provided an even greater concentration of science and history.

At the Steven F. Udvar-Hazy Center I finally saw Space Shuttle Discovery, an object that had been high on my list for many years.



Space Shuttle Discovery at the Steven F. Udvar-Hazy Center. The visit formed part of the wider scientific and historical journey surrounding the SARA conference.

The National Archives provided another long-awaited visit, to see the Declaration of Independence and the original American Constitution, while the Smithsonian museums offered enough scientific material to occupy considerably more time than I had available.

At the National Air and Space Museum I saw the Freedom 7 Mercury capsule and Neil Armstrong's spacesuit – objects with an immediacy that is difficult to obtain from photographs. The National Museum of Natural History provided a chance to observe their phenomenal collection of meteorites.

I even had a chance to observe the partial solar eclipse with Jack and his astronomy group in Maryland before I returned to the UK, completing what had been one of the most amazing holidays of my life. I have made many good friends and had a great number of unforgettable experiences.

Why meetings like SARA matter

The technical possibilities available to amateurs have changed dramatically. Software-defined radio has placed capable receivers within reach of almost anyone. Digital signal processing that once required dedicated hardware can be performed on an ordinary computer. Low-noise amplifiers and microwave components can be purchased relatively inexpensively.

At 1420 MHz, an amateur can detect the hydrogen line with an antenna small enough to fit comfortably in a garden. Other projects include solar radio astronomy, Jupiter observations, meteor scatter, VLF monitoring, interferometry, maser and pulsar observations, extragalactic spectroscopy and cosmic-ray detection.

The limiting factor is increasingly not access to technology but deciding what experiment to attempt next. This is where organisations such as SARA are particularly valuable.

1. A conference exposes observers to experiments they might never otherwise have considered.
2. Somebody demonstrates an antenna and another observer thinks, "I could build that."
3. A result shown during a presentation leads someone else to repeat the experiment with different equipment.
4. A conversation over breakfast becomes a new observing project.
5. Science advances through published results, but ideas often begin through conversations.

Acknowledgements

I would like to thank the Society of Amateur Radio Astronomers for organising the 2026 Eastern Conference and the staff of Green Bank Observatory for making their remarkable facilities available to visiting amateur radio astronomers.

Particular thanks are due to Jack and Marybeth Ganssle for their hospitality, friendship, transport and enthusiasm throughout my American visit, and to the many SARA members who generously shared their equipment, knowledge and ideas.

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Commissioning and Characterisation of an FE-5650A Rubidium Frequency Standard

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Abstract

An FE-5650A rubidium frequency standard was obtained for use as a high-stability frequency reference at Lichfield Radio Observatory (LRO). The unit had been removed from service in Chinese telecommunications equipment.

Initial investigation established that this particular unit requires both +15 V and +5 V supplies. The DB-9 connector was wired accordingly, with a 4.7 kOhm pull-up resistor connected between +5 V and the Pin 3 status output.

A series of power-up experiments was performed to investigate warm-up behaviour, power consumption, the Pin 3 status output and the 10 MHz reference output. During a controlled 30-minute test, power consumption from the 15 V supply initially measured 24.88 W and progressively declined. The Pin 3 status voltage remained exceptionally stable at approximately 3.196 V during the first 2.5 minutes, before abruptly changing to approximately 1.01 V between 2.5 and 3 minutes. Approximately one minute later, the heater power underwent a major reduction, falling from 14.86 W at 3 min 30 s to 7.90 W at 4 min. Following a brief recovery to approximately 9.8 W, power consumption gradually declined to 7.253 W after 30 minutes.

The 10 MHz output was examined using a Rigol DS1102Z-E oscilloscope. A stable approximately sinusoidal waveform was observed with a measured frequency of 10.0 MHz, period of 100.0 ns, amplitude of approximately 2.22 V peak-to-peak and RMS voltage of approximately 0.762 V.
These experiments indicate that the unit is functioning and undergoing a reproducible warm-up and status-transition sequence. However, without definitive documentation for the exact FE-5650A variant tested, the precise logical meaning of the Pin 3 states should not yet be regarded as established.

---

1. Introduction

Rubidium frequency standards provide a highly stable frequency reference by disciplining a quartz oscillator against an atomic transition in rubidium.

The FE-5650A examined in this investigation was obtained for use at Lichfield Radio Observatory. Potential applications include frequency calibration of radio astronomy receivers, local oscillators, software-defined radio systems and laboratory test equipment, and the possibility of taking part in long distance interferometry experiments with partners in Europe.

The objectives of the initial commissioning were to:

1. establish the required electrical connections;

2. power the unit safely;
3. determine its warm-up behaviour;
4. investigate the Pin 3 status output;
5. confirm the presence of the nominal 10 MHz output;
6. measure the approximate amplitude and waveform of that output; and
7. establish a baseline against which subsequent measurements can be compared.

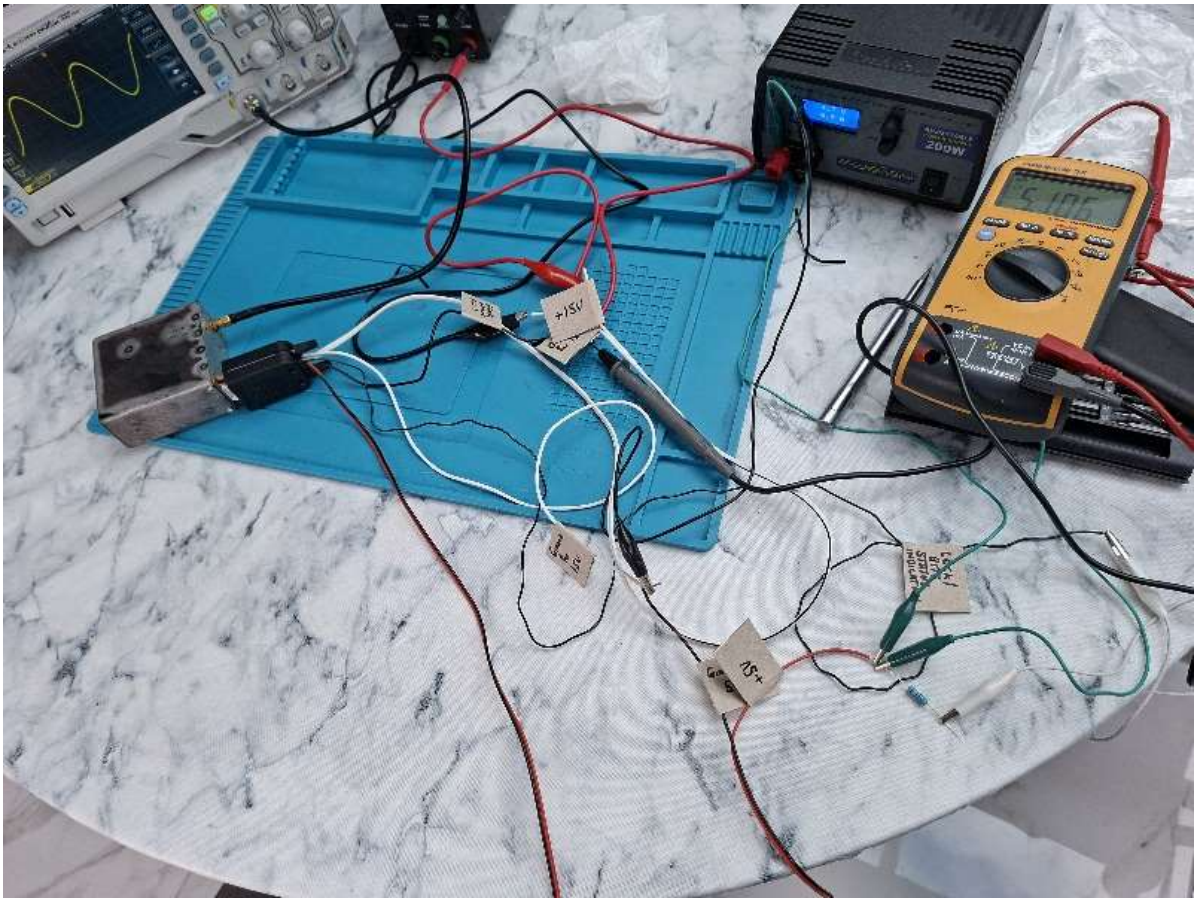


Figure: Test arrangement used in this exercise:

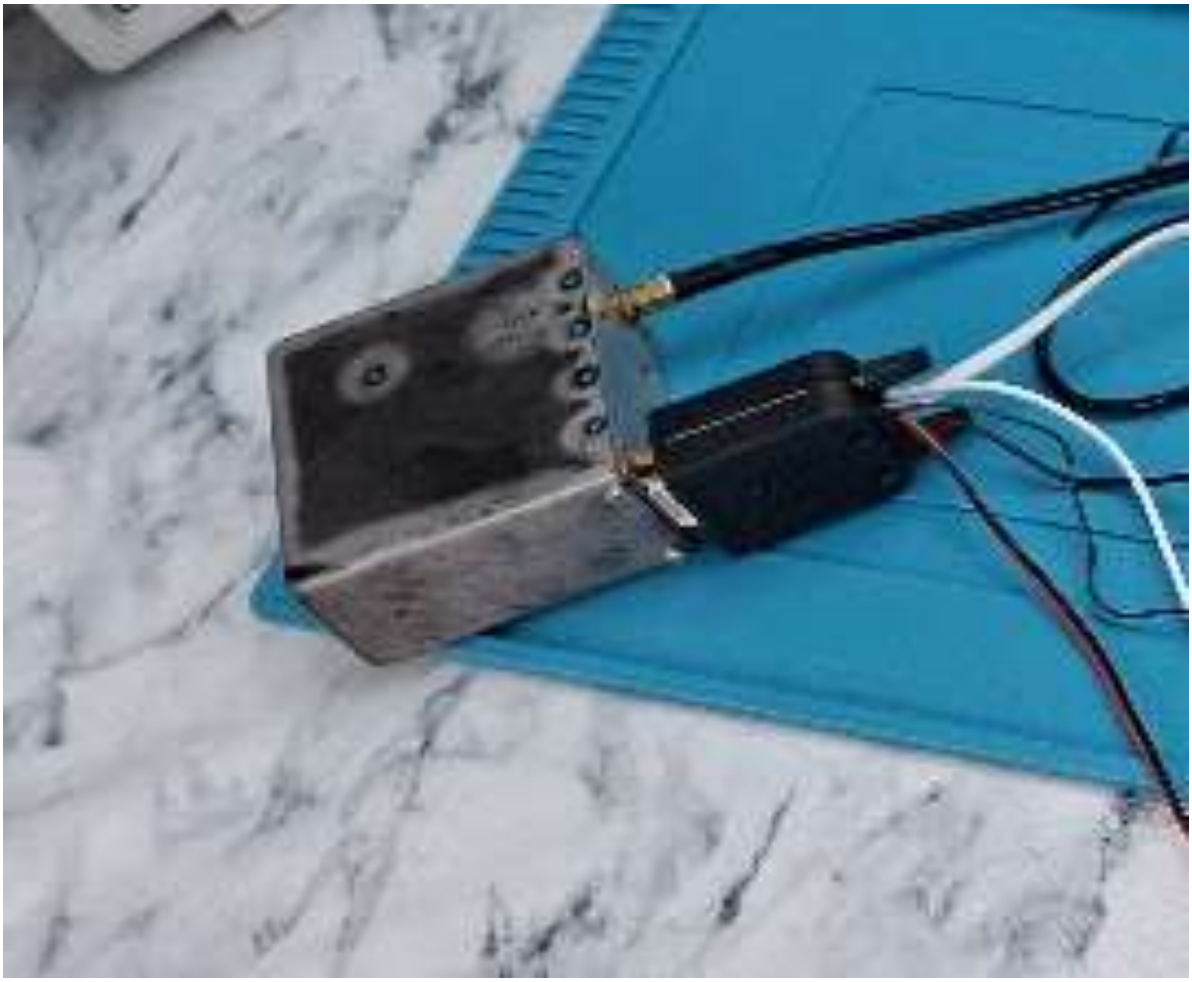


Figure: FE-5650A rubidium time source at LRO:

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2. DB-9 CONNECTIONS USED

The FE-5650A rubidium time source has an SMA RF connector and a DB-9 connector, the latter including all power and lock signal connections.

Wiring and pin assignments were checked against the 1998 Frequency Electronics FE-5650A technical manual, but a dedicated manual specifically for this particular unit/sub-variety of the 5650A was not available – a common problem when purchasing such items on the used market. It is also worth noting that alternative documentation found online gives different uses for pins 6, 8 and 9.

On the table below, I have stated whether I was able to confirm that the functions of each pin listed above in the experiments on the unit under test at LRO ➔ I do not have any confidence in the functions stated above for the non-confirmed pins.

Pin	Function used	Initial connection
1	+15 V	+15 V supply – FUNCTION CONFIRMED
2	15 V ground	15 V supply negative/0 V – FUNCTION CONFIRMED
3	LOCK/BITE status	4.7 kOhm pull-up to +5 V; measure to signal ground – FUNCTION CONFIRMED
4	+5 V	+5 V supply – FUNCTION CONFIRMED
5	5 V ground	5 V supply negative/0 V – FUNCTION CONFIRMED
6	EFC	Leave disconnected initially – THIS HAS NOT BEEN CONFIRMED
7	Signal ground	Measurement reference; common ground used in tests – FUNCTION CONFIRMED
8	TTL serial IN	Leave disconnected initially – THIS HAS NOT BEEN CONFIRMED
9	TTL serial OUT	Leave disconnected initially – THIS HAS NOT BEEN CONFIRMED

Table: Confirmation status of pins on the DB-9 connector following the tests described in this paper

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3. Wiring arrangement & Power Connection

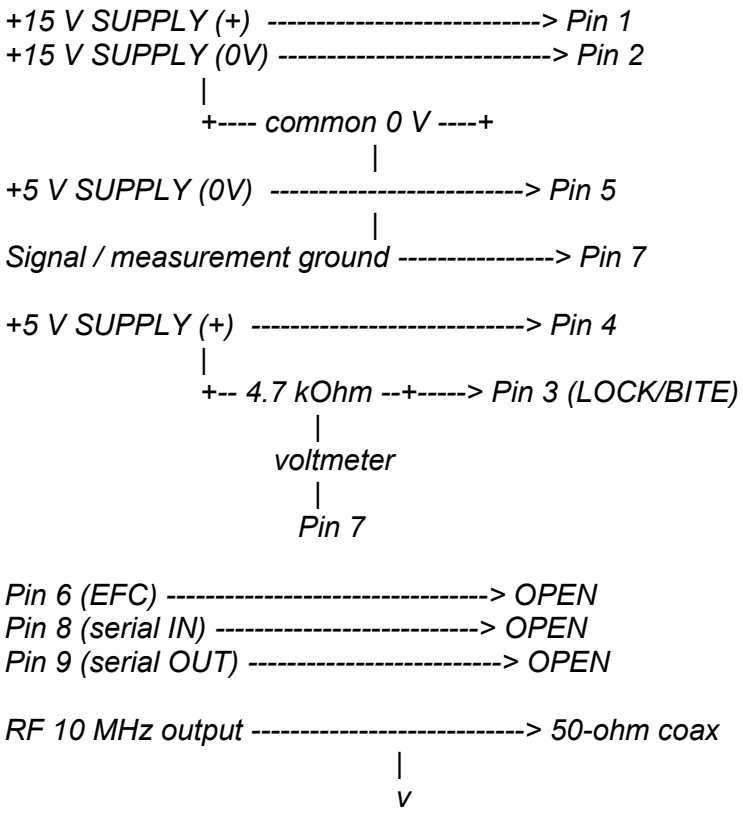
Both regulated 15V (supplying 3A) and 5V (>0.5A) supplies are required for the particular unit tested.

Supply	Connect to	Polarity	Recommended rating
+15 V	Pin 1	+	≥ 3 A (≥ 30 W)
15 V Ground	Pin 2	–	
+5 V	Pin 4	+	≥ 0.5 A
5 V Ground	Pin 5	–	
Signal Ground	Pin 7	–	(common with measurement)

Figure: Summary of Power Connections on the FE-5650A.

An important finding during the commissioning process was that supplying only +15 V could cause the unit to heat and draw substantial current without necessarily establishing the complete intended operating condition.

Power wiring used:



Oscilloscope CH1

During the successful tests, the grounds of the 15 V and 5 V supplies were made common. Pin 7 was used as the signal reference for status measurements. Before applying power, polarity and DB-9 pin numbering should be checked carefully with the connector orientation physically in hand.

---

4. STATUS OUTPUT CONNECTION

Pin 3 was not connected directly to a voltage supply.
Instead, it was connected to +5 V through a 4.7 kOhm pull-up resistor:

```
   +5 V
    |
    |
  4.7 kOhm
    |
    +---------- Multimeter +
    |
  PIN 3
 LOCK/BITE
 FE-5650A
```

PIN 7 ---------- Multimeter -
Signal ground.

Thus, the multimeter measured:

V(Pin 3) - V(Pin 7)

This distinction is important because the measured voltage is therefore dependent upon both the internal circuitry connected to Pin 3 and the external pull-up resistor. Consequently, the measured values should not automatically be interpreted as conventional 0 V and +5 V logic levels.

---

5. POWER-UP PROCEDURE

The procedure adopted for subsequent testing was:

1. Check all wiring with power OFF.

2. Confirm that Pin 1 is connected to +15 V.

3. Confirm that Pin 4 is connected to +5 V.

4. Confirm the ground connections.

5. Confirm that lock status Pin 3 is connected to +5 V ONLY through the 4.7 kOhm pull-up resistor (and not directly to the +5V supply).

6. Switch ON the +15 V supply first.

7. Switch ON the +5 V supply second.

8. Observe:
   15 V power consumption
   Pin 3 status voltage
   10 MHz output

8. Allow the unit to warm up and stabilise.

The sequence used experimentally was therefore +15 V first followed by +5 V.

---

6. POWER-DOWN PROCEDURE

For experimental shutdown:

1. Stop measurements/recording.

2. Switch OFF the +5 V supply.

3. Switch OFF the +15 V supply.

4. Allow the unit to cool before altering wiring.

5. Do not change DB-9 connections while powered.

---

7. INITIAL OBSERVATIONS

Earlier tests showed that the FE-5650A drew substantial power immediately after startup.
Typical observations included an initial power consumption in the region of 20-30 W, followed by a progressive reduction as the unit warmed.

The Pin 3 voltage was also observed to change during the warm-up process.
This prompted a more systematic experiment in which both quantities were recorded against elapsed time.

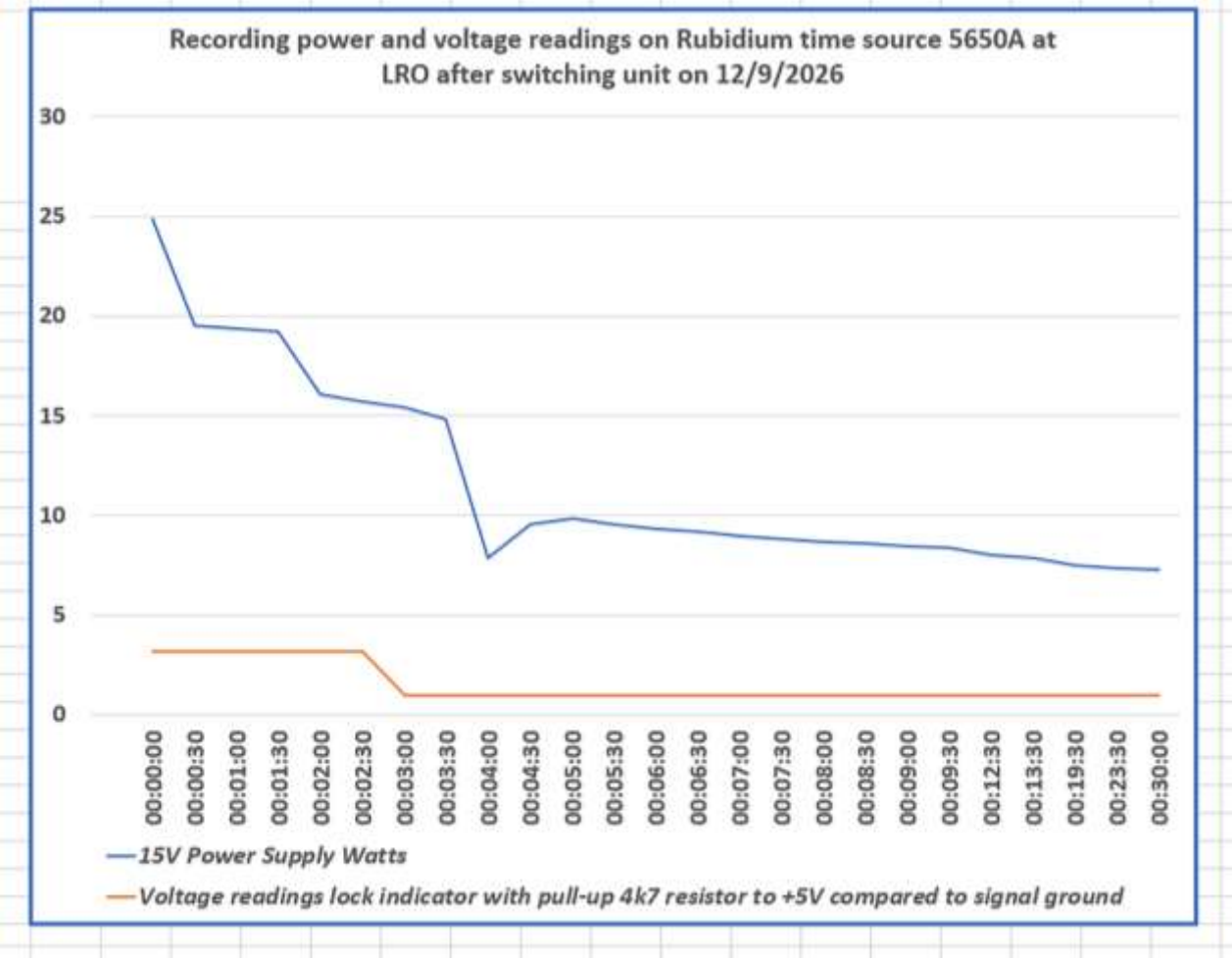
8. CONTROLLED 30-MINUTE WARM-UP EXPERIMENT

On 12 September 2026, the unit was switched on and the following measurements were obtained.

Figure: Table of power and voltage measurements after the FE-5650A was switched on.

Time Mins:Secs	*15V Power Supply Watts*	*Voltage readings lock indicator with pull-up 4k7 resistor to +5V compared to signal ground*
00:00:00	24.88	3.196
00:00:30	19.5	3.196
00:01:00	19.37	3.197
00:01:30	19.2	3.197
00:02:00	16.1	3.196
00:02:30	15.67	3.196
00:03:00	15.38	1.013
00:03:30	14.86	1.012
00:04:00	7.9	1.008
00:04:30	9.53	1.01
00:05:00	9.837	1.009
00:05:30	9.549	1.009
00:06:00	9.309	1.009
00:06:30	9.204	1.009
00:07:00	8.964	1.009
00:07:30	8.799	1.01
00:08:00	8.694	1.012
00:08:30	8.574	1.009
00:09:00	8.469	1.009
00:09:30	8.379	1.009
00:12:30	7.99	1.009
00:13:30	7.867	1.009
00:19:30	7.495	1.009
00:23:30	7.375	1.009
00:30:00	7.253	1.009

Figure: Plot of power and voltage measurements after the FE-5650A was switched on.



---

9. ANALYSIS OF WARM-UP BEHAVIOUR

The experiment reveals several distinct phases.

9.1 Initial high-power phase
Immediately after switch-on, the 15 V supply delivered:
24.88 W
This rapidly decreased to:
19.50 W after 30 seconds
and subsequently decreased more slowly.
This is consistent with substantial initial heating demand during warm-up.

9.2 Initial Pin 3 stability & abrupt transition

Pin 3 remained at about 3 volts during the first 2.5 minutes after power up despite signification changes in heater power. At 2 min 30s pin 3 dropped to about 1 volt, suggesting that this signal represents successful rubidium lock, though this is not confirmed."

9.3 Heater transition occurs later

At 3 min:
Power = 15.38 W
Pin 3 = 1.013 V
At 3 min 30 s:
Power = 14.86 W
Pin 3 = 1.012 V
At 4 min:
Power = 7.90 W
Pin 3 = 1.008 V
Thus, the Pin 3 transition occurs approximately one minute before the dramatic reduction in heater demand.
This is an important observation.
The sequence appears to be:

START
|
V
HIGH HEATER POWER
~25 W
|
V
Progressive warm-up
|
| Pin 3 ~3.196 V
|
V
2.5-3 minutes
|
+----> PIN 3 STATUS TRANSITION
| ~3.196 V -> ~1.01 V
|
V
Further heating
|
V
~4 minutes
|
+----> MAJOR HEATER-POWER REDUCTION
| ~14.9 W -> ~7.9 W
|
V

Temperature-control settling
|
V
~9.8 W
|
V
Gradual decline
|
V
30 minutes
|
+----> 7.253 W
Pin 3 = 1.009 V

---

10. LONG-TERM PIN 3 STABILITY

Following the transition, Pin 3 remained between approximately:
1.008 and 1.013 V
for the remainder of the 30-minute experiment.
At exactly 30 minutes the measured voltage remained:
1.009 V
This is remarkably reproducible.
The existence of two stable states,
PRE-TRANSITION ~3.196 V

POST-TRANSITION ~1.009 V
provides strong experimental evidence that Pin 3 represents an intentional status output.
However, this experiment alone does not establish the exact manufacturer's definition of the two states.
It would therefore be premature to state unequivocally:
1.0 V = LOCKED
3.2 V = UNLOCKED
until this has been verified for this exact FE-5650A configuration.
The safer conclusion is that the transition to approximately 1.01 V is reproducibly associated with completion of an important stage in the FE-5650A warm-up/operating sequence.

---

11. HEATER CONTROL

Following the large reduction to 7.90 W at four minutes, the power subsequently increased:
4:00 7.900 W
4:30 9.530 W
5:00 9.837 W
It then progressively decreased:
10 min approximately 8.4 W

12:30 7.99 W
19:30 7.495 W
23:30 7.375 W
30:00 7.253 W
This behaviour is compatible with an actively regulated thermal system approaching equilibrium rather than a simple heater being switched permanently from high to low power.

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12. TEN MHz OUTPUT

The nominal 10 MHz output was connected by coaxial cable to Channel 1 of a Rigol DS1102Z-E digital oscilloscope.

A clear and stable approximately sinusoidal waveform was observed.

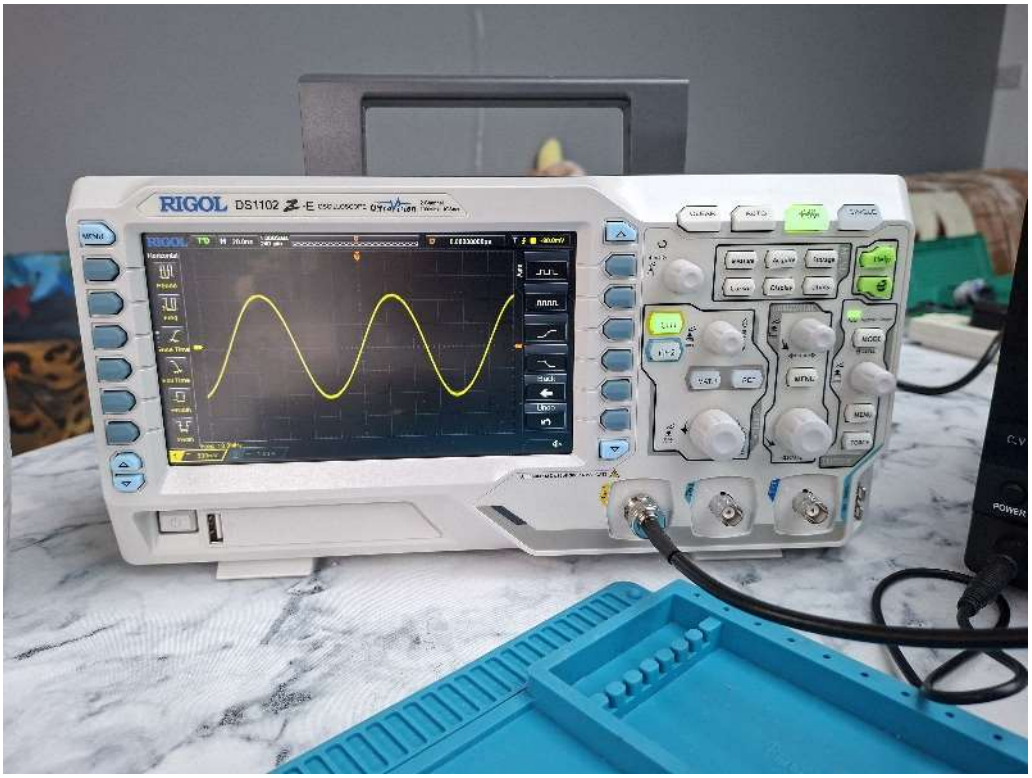


Figure: Stable 10MHz waveform on oscilloscope.

The oscilloscope measurements visible during testing included:
Frequency 10.0 MHz
Period 100.0 ns

Maximum +1.10 V
Minimum -1.12 V

Peak-to-peak 2.22 V
Amplitude 2.17 V
RMS 762 mV

Average -10.5 mV

Positive duty cycle 50.40 %
Negative duty cycle 49.60 %

Positive width 50.40 ns
Negative width 49.60 ns
These measurements are internally consistent with a nominal 10 MHz signal:
f = 1/T

T = 100 ns

f = 1 / (100 x 10^-9)

f = 10,000,000 Hz

f = 10 MHz
The waveform was also centred close to zero volts:
Maximum = +1.10 V
Minimum = -1.12 V
Average = -10.5 mV
This provides useful evidence that the observed signal is a genuine AC reference output rather than a DC-biased logic signal.

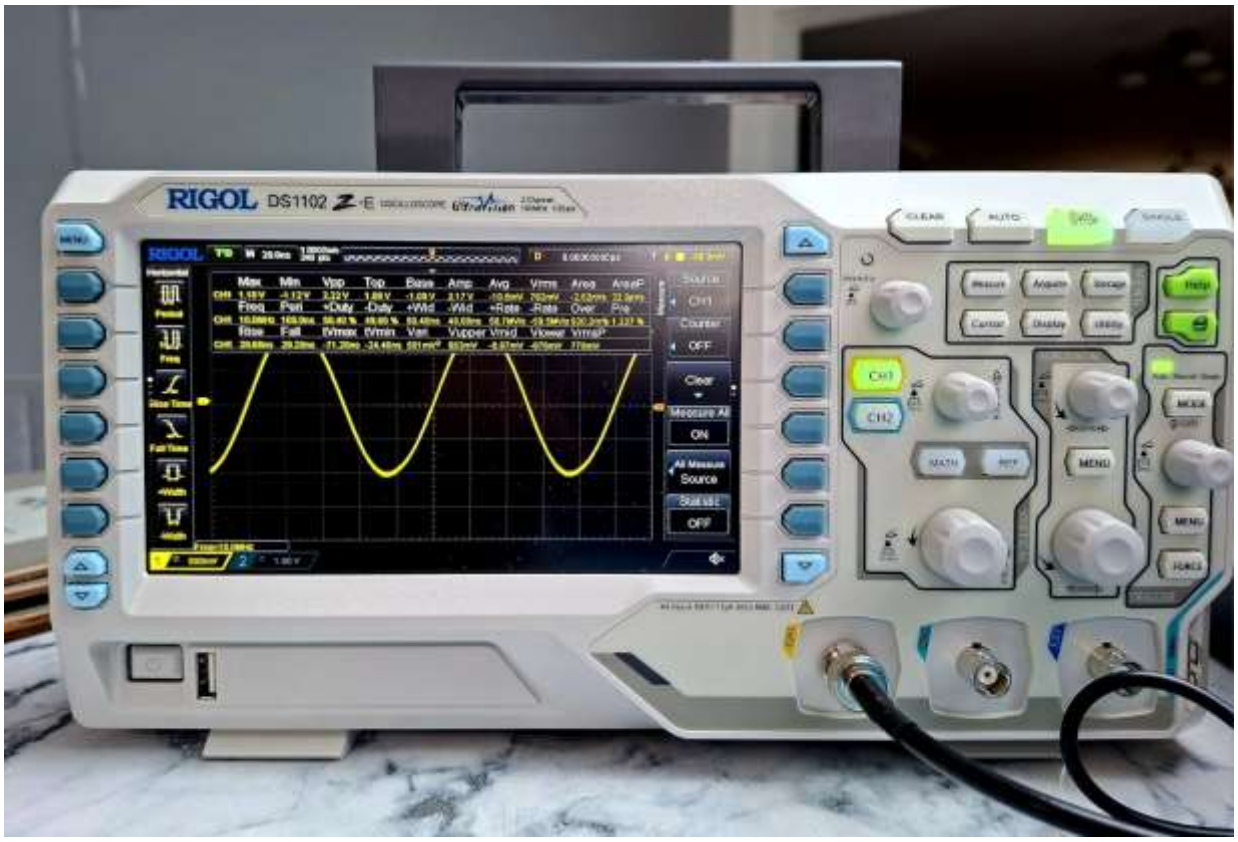


Figure: Rigol DS1102Z-E connected to the FE-5650A frequency output during testing.

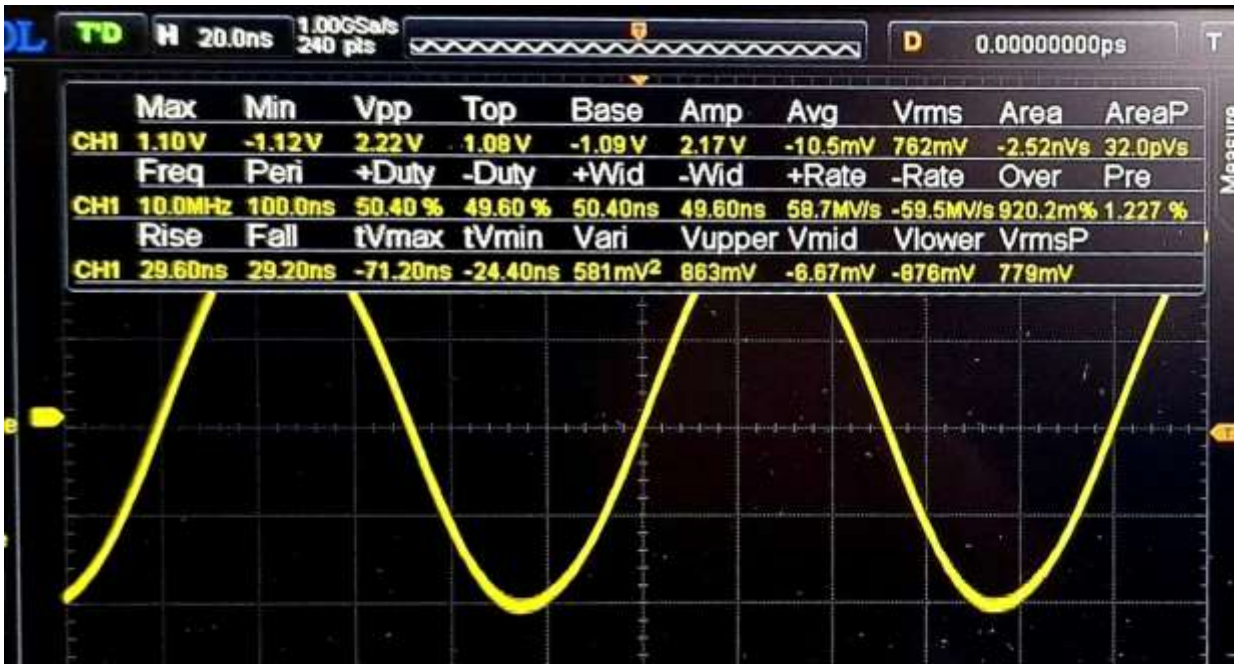


Figure: Oscilloscope measurement of the FE-5650A output. The display shows approximately 10.0 MHz, 100.0 ns period, 2.22 Vpp and 762 mVrms

13. EFFECT OF CHANGING PULL-UP 4.7KOHM RESISTOR TO 20KOHM

I changed the pull-up resistor from 4.7k to 20k linking the lock status pin to 5V power supply and this led to changes in the recorded voltages:

New measurements:

Initially = 2.8V
Later = 0.260V (at similar point to previous change to 1.008V occurred when 4.7k resistor was in place)

---

14. LIMITATION OF OSCILLOSCOPE FREQUENCY MEASUREMENT

Although the oscilloscope display of 10.0 MHz confirms that the FE-5650A is producing the expected nominal output, it does **not** demonstrate rubidium-level frequency accuracy.
For example, the distinction between

10,000,000.000 Hz

and

10,000,000.100 Hz

is extremely important when characterising a frequency standard but cannot be established from a display reading simply "10.0 MHz."

The oscilloscope result should therefore be interpreted as confirmation of:

correct nominal frequency
+
correct waveform generation
+
appropriate output amplitude
+
stable visual waveform

rather than a precision measurement of absolute frequency accuracy.

A future experiment should compare the FE-5650A against an independent frequency reference or high-resolution counter.

---

15. RELATIONSHIP BETWEEN OUTPUT AND WARM-UP

An interesting qualitative observation was that a stable-looking 10 MHz waveform was present very early after power-up, including before completion of the thermal warm-up process. This finding is not contradictory. The presence of a 10 MHz output means that the oscillator is operating. It does not necessarily demonstrate that the oscillator has reached its final rubidium-disciplined accuracy.

The likely conceptual sequence is therefore:

POWER APPLIED
|
V
Quartz oscillator operates
|
+------> 10 MHz output already present
|
V
Rubidium system warms
|
V
Atomic/servo operating conditions develop
|
V
Pin 3 changes state
|
V
Thermal system continues settling
|
V
Long-term stable operating condition

---

16. POWER-OFF EXPERIMENT

A separate experiment provided additional information concerning Pin 3.
After the device had stabilised and rubidium lock was achieved, the +15V supply was switched off whilst leaving the +5V switched on. When the +15 V supply was removed while the other experimental connections remained present, the Pin 3 voltage did not simply reproduce its normal warm-up behaviour.

In one experiment the voltage measured on the lock status pin did not change for 3 or 4 seconds, and then changed slowly over approximately 10-20 seconds before stabilising at approximately 1.241 V.

When +15 V was restored, Pin 3 immediately changed to approximately 3.191 V and the +15 V power consumption increased to approximately 17.9 W.

The power consumption subsequently decreased towards approximately 9 W, and as it dropped Pin 3 returned to approximately 1.007 V.

This further supports the conclusion that Pin 3 responds to the internal operating condition of the FE-5650A.

It also demonstrates why Pin 3 should not be interpreted simply as a conventional TTL output on the basis of its measured voltage alone.

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17. OVERALL EXPERIMENTAL INTERPRETATION

The combined evidence now demonstrates four important facts.

1. The FE-5650A produces a nominal 10 MHz output.

2. The output amplitude is approximately 2.22 Vpp.

3. The unit exhibits a reproducible thermal warm-up cycle.

4. Pin 3 exhibits a reproducible discrete electrical transition during that warm-up cycle.

The most interesting new observation from this last experiment was the timing relationship:

0:00
|
| 24.88 W
| Pin 3 = 3.196 V
|
2:30
|
| 15.67 W
| Pin 3 = 3.196 V
|
2:30-3:00
|
+---- PIN 3 TRANSITION
| 3.196 -> 1.013 V
|
3:30
|
| Power still 14.86 W

|
4:00
|
+---- MAJOR HEATER TRANSITION
14.86 -> 7.90 W
|
|
30:00
|
+---- 7.253 W
Pin 3 = 1.009 V
10 MHz output present

The approximately one-minute separation between the Pin 3 transition and the major heater-power transition argues against Pin 3 merely being a direct indication of heater current.

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18. CAUTIONS

Several points remain important.

First, the pinout described here applies to the particular FE-5650A configuration tested. FE-5650A variants and options should not automatically be assumed to have identical connections. The 1998 Frequency Electronics manual lists more than 40 option numbers, covering output frequency, power arrangements, temperature range, tuning, stability, phase noise, lock indication, mechanical configuration, etc.

Second, Pin 3 should never be connected directly to +5 V. The experiments described here use a 4.7 kOhm pull-up resistor.

Third, the observed approximately 1.01 V state should not yet be labelled definitively "LOCKED" without suitable documentation or further experimental confirmation.

Fourth, the presence of a visually stable 10 MHz waveform immediately after startup does not prove that the oscillator has achieved rubidium-referenced frequency accuracy.

Fifth, frequency measurements made with the Rigol oscilloscope are sufficient to establish a nominal 10 MHz output but are not sufficient for precision characterisation of a rubidium frequency standard.

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19. CONCLUSIONS

The FE-5650A tested at Lichfield Radio Observatory appears to be operating successfully.

- When correctly supplied with both +15 V and +5 V, the unit initially draws substantial heater power. During a controlled test this measured 24.88 W at startup.
- During the first 2.5 minutes Pin 3 remained extraordinarily stable at approximately 3.196 V despite a considerable reduction in heater power.
- Between 2 min 30 s and 3 min, Pin 3 underwent a distinct transition to approximately 1.01 V.
- Approximately one minute later the heater power dropped dramatically, reaching 7.90 W at four minutes. Following a short recovery to approximately 9.8 W, power gradually declined to 7.253 W after 30 minutes.
- Pin 3 remained at approximately 1.009 V throughout this subsequent period.
- A stable nominal 10 MHz output was demonstrated using a Rigol DS1102Z-E oscilloscope. The measured output was approximately 2.22 V peak-to-peak and 762 mV RMS, with a period of 100.0 ns.

The results provide strong evidence that the FE-5650A is functioning and that Pin 3 represents a meaningful internal status indication.

The present evidence does **not**, however, establish with certainty that the approximately 1.01 V Pin 3 state specifically means "rubidium locked." Establishing this should be a priority for subsequent investigation. However, it is unlikely that documentation specific to this particular variant will be available, so a pragmatic decision may need to be made when the device is used in practical applications.

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20. REFERENCES.

1. Frequency Electronics, Inc. FE-5650A Series Rubidium Frequency Standard, Technical Manual TM0107, February 1998. Key items used here: Table 2A connector functions; Table 3 reference data; Turn-On Procedure 2-2.

2. Seller-supplied interface information for the user's telecom-derived FE-5650A CPOM/Option-58 unit, September 2026. This information was used to identify the need for both +15 V and +5 V on this particular unit; auxiliary pin assignments remain treated as unit-specific because they differ from the generic FEI manual.

Visualization of a 21cm hydrogen line and continuum survey of the northern sky

Eduard Mol

Introduction

Back in April of this year, I started with a 21 cm hydrogen line survey of the entire northern sky with my 3- metre radio telescope. At the time of writing, I am working on a video series covering different aspects of this project, and the first two parts have already been uploaded to YouTube (see [1] and [2]). This article serves as a reference document to the video series, with a focus on different methods used to visualize the data from the hydrogen line survey.

The 3 metre dish

For this project a homemade 3 metre f/0.5 dish was used. The telescope has been described in earlier articles in the SARA journal and in a video on my YouTube channel (see references [3] and [4]), but a short description is included below.

The dish has a plywood construction with an aluminium mesh reflector. It is not permanently set up in the backyard but consists of four segments which can be assembled around a central hub and stored in a shed when not in use. The system temperature is approximately 110- 120 K.



Figure 1: the modular 3 metre dish.

In summary, the electronics chain of the 3 metre dish setup consists of the following components:

- 1420 MHz W2IMU type feed

- G8FEK L-band LNA (noise figure 0.5 dB)
- 1420 MHz interdigital filter (built after the design of T. Saje and M. Vidmar)[5]
- 16 dB amplifier (to overcome cable losses)
- Airspy mini SDR receiver

The SDR is attached to an aluminium block with thermal paste and cooled using an old PC fan to reduce gain drift due to temperature changes.

For integrating and recording spectra, SDR# with the IFaverage plugin was used. Spectra were saved every 147 seconds. The resolution was set to 512 FFT bins, with a total bandwidth of 6 MHz this translates to a spectral resolution of 11.718 kHz/bin.

Data collection and processing

Because the mount of the dish is not motorized, the dish is pointed manually and operated in driftscan mode. Every day, a driftscan is recorded. After at least one full sidereal day (23 hours and 56 minutes) the dish is pointed half a beam width higher in declination (2.5 degrees). Because my view towards the south below 0 degrees declination is partially blocked by buildings and trees, the survey was started at 0 degrees declination. The pointing of the dish was calibrated by performing a driftscan on the Sun and timing when the amount of Sun noise relative to cold sky reached its maximum.

In Figure 2, the data processing pipeline for the individual driftscans is summarized. In short, there are two signals of interest in the spectra that must be treated separately: the hydrogen line and the continuum background. The continuum signal is extracted from the driftscans by averaging all spectral channels outside the range of the hydrogen line (<1419.6 and >1420.9 MHz). The hydrogen line requires a bit more work: first the bandpass response of the SDR and receiver chain needs to be removed. This “background correction” procedure was done by fitting a 3rd order polynomial through the background of each spectrum, excluding the hydrogen line and the roll- off at the edges of the spectrum (see Figure 3). The spectrum is then divided by this polynomial. The vertical scale of the spectrum is converted to brightness temperature, using observations of the hydrogen line towards Cygnus X and the Galactic anticentre (both ~100K according to LAB survey simulations) as calibration points. In the following step, the frequency axis is converted to velocity relative to the Local Standard of Rest (LSR), following the same method that is used in the Python script made by T. J. Dijkema [6]. Plotting the results of all driftscans in a sky map is handled in a separate script using the Matplotlib contourf function.

After processing all driftscans, there are multiple ways to create a sky map from the hydrogen line data. First of all, one could choose to represent the peak intensity of each spectrum. Another method is to sum up all FFT bins in the spectrum to get an integrated brightness temperature over the entire hydrogen line profile. In order to avoid adding in residual bandpass artifacts, noise and RFI, only the FFT bins with a brightness temperature greater than 1.5 K were included in the sum.

Finally, it is also possible to create maps at different LSR velocities, which is described later in this article.

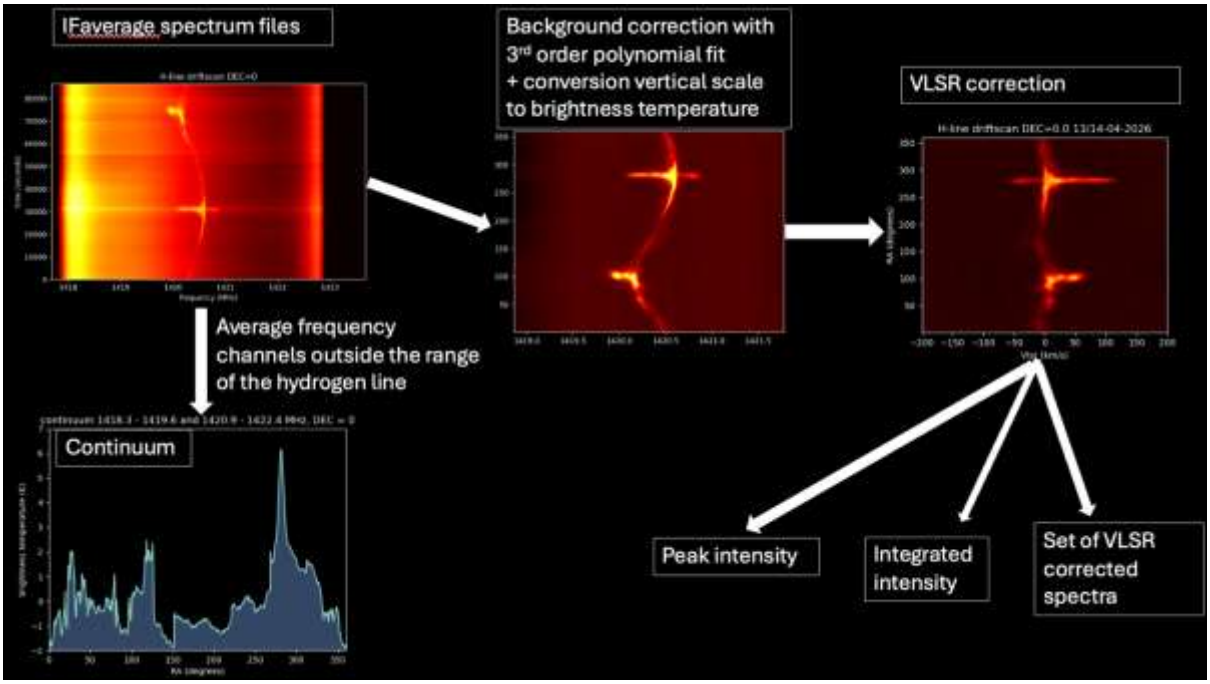


Figure 2: diagram summarizing the different steps in the processing of the driftscans.

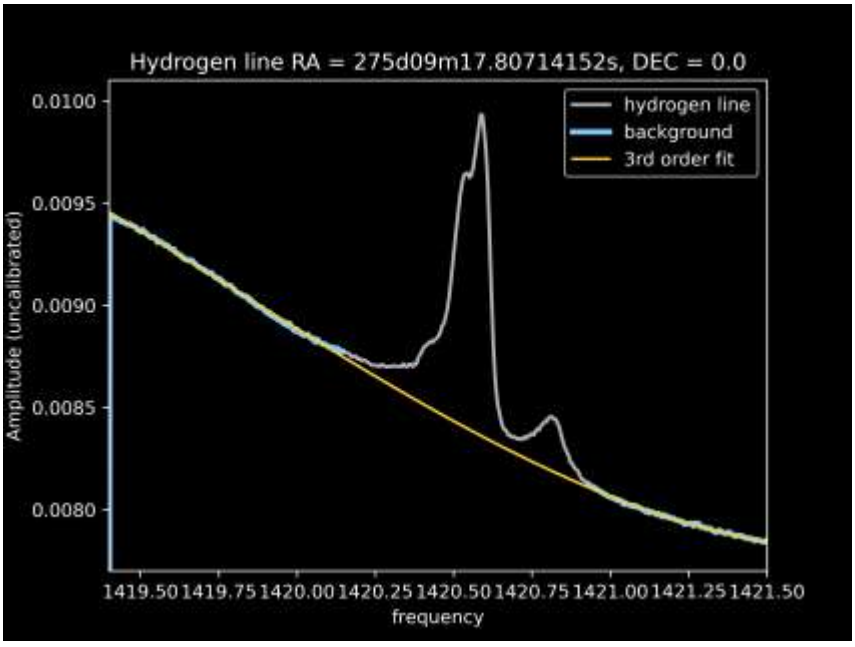


Figure 3: removal of the SDR bandpass response by fitting a 3rd order polynomial through the parts of the spectrum outside the hydrogen line.

Continuum map

The continuum map does not show much interest at first glance. It is completely dominated by a single bright source: the Sun.

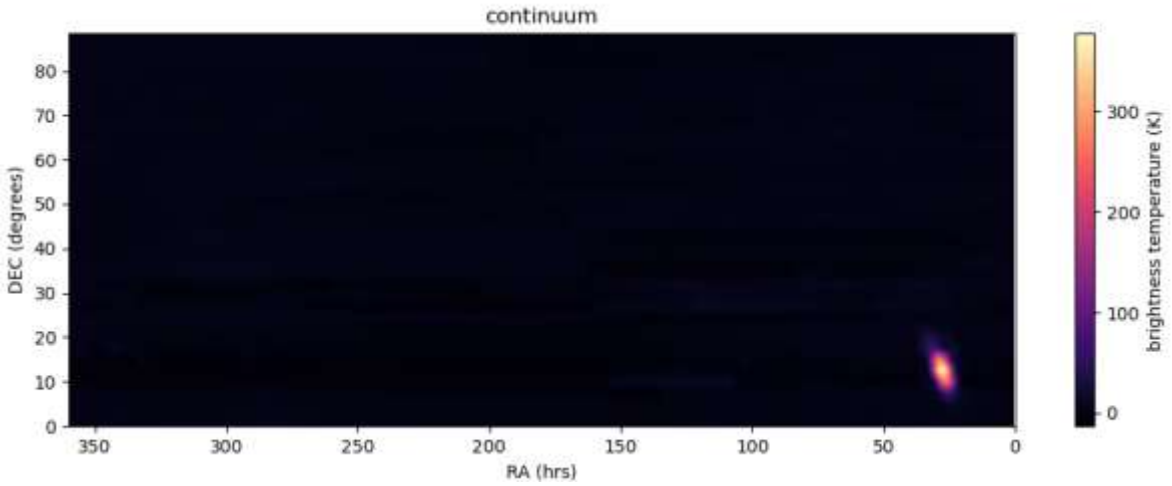


Figure 4: sky map showing the continuum emission at 21cm outside the frequency range of the hydrogen line. The bright spot in the lower right, near 25 degrees right ascension and 12.5 degrees declination is the strong continuum emission from the Sun.

However, if we zoom in on the part between 0 and 55 degrees declination and between 270 and 330 degrees right ascension, there is a subtle but persistent hump in the continuum data which appears to follow the galactic plane. Unfortunately, there is also RFI and background drift due to temperature changes. Therefore, a line was fitted through each continuum trace between 270 and 330 degrees declination to at least remove the overall slope and normalise the continuum scans to the same level.

In the map below the continuum emission of the Galactic plane is visible as a diagonal bright band. A bright area at 300 – 310 degrees right ascention and ~40 degrees declination stands out in particular. This region corresponds to the radio sources Cygnus A and Cygnus X, which were covered in more detail in an earlier article in the SARA journal [4]. Cygnus X is a star forming region located in the Milky Way, while Cygnus A is a distant radio galaxy located at a distance of ~750 million light years. Because these two bright radio sources are only a few degrees apart, they can not be separated with the 5 degree beamwidth of the 3 metre dish [7].
Other continuum sources were not detected due to RFI and/or variations in the background.

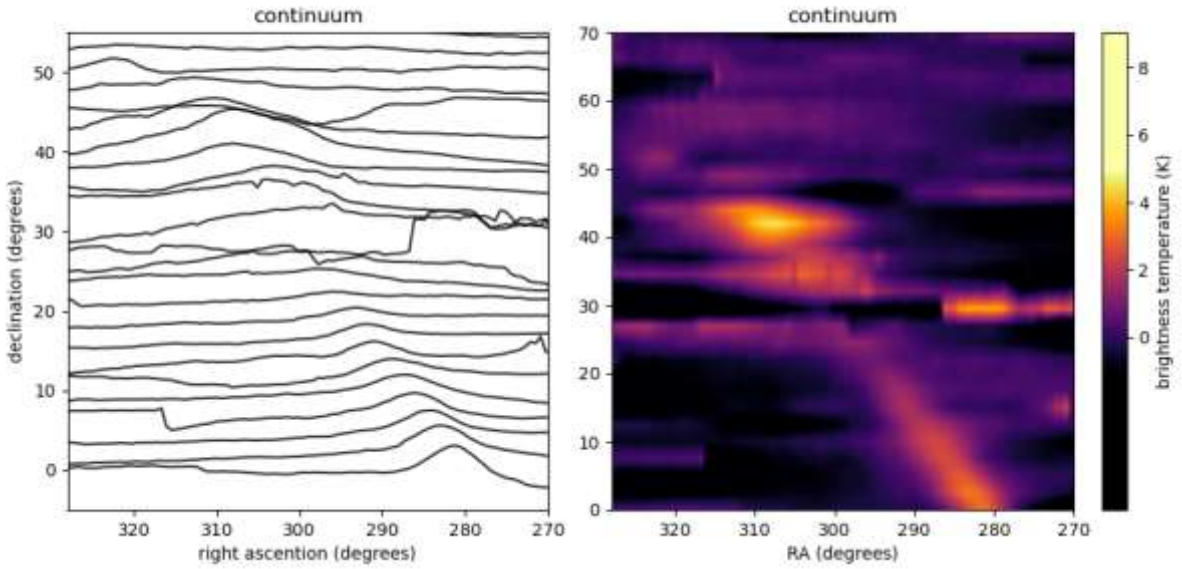


Figure 5: continuum emission from the Milky Way between Scutum and Cygnus.

Peak and integrated brightness temperature maps

The following maps show the brightness temperature of the highest peak in each spectrum and the integrated brightness temperature from each spectrum. The peak brightness temperature map in particular shows a lot of fine structure. The dark spot centered at 25 degrees right ascension and +12 degrees declination is where the Sun was during the observations. In the integrated brightness temperature map, the hydrogen line emission appears more confined to the galactic plane.

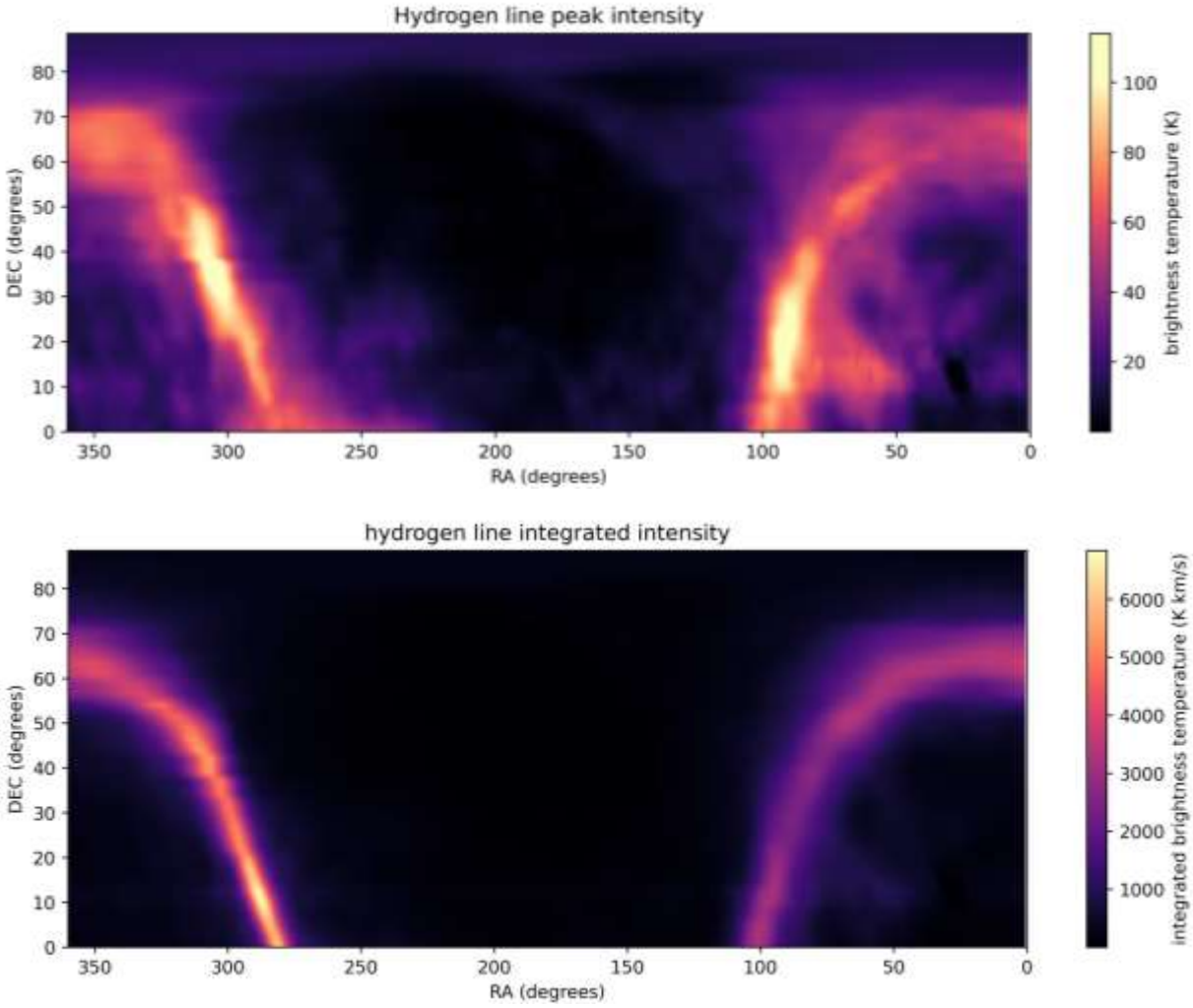


Figure 6: sky maps showing the peak and integrated brightness temperature of the hydrogen line.

One problem that is particularly noticeable in these maps is that the northernmost part appears very stretched out. This could be solved at least to some extent by choosing a different projection, although every projection of one half of a sphere on a flat surface will inevitably have some distortion. For this project I chose a simple polar projection, where the center north celestial pole is located at the center of the map and edge represents the celestial equator. The transformation to polar coordinates was done in using the free image editing software GIMP (the polar coordinates tool in GIMP can be found under filters → distorts → polar coordinates).

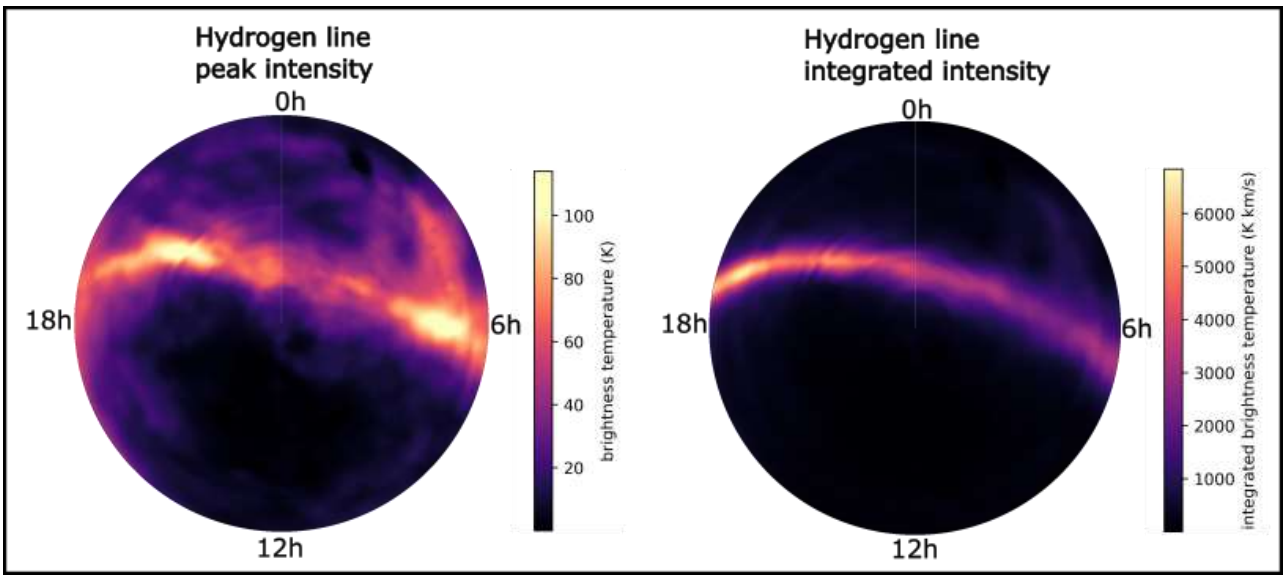


Figure 7: same as Figure 6 but showing the same maps in polar projection.

Doppler velocity map

The maps shown above only show a fraction of the information in the hydrogen line survey. At each point in the sky, an entire spectrum was measured. The full data set is therefore not a single image, but rather a "data cube" with three dimensions: right ascention, declination, and Doppler (radial) velocity relative to the Local Standard of Rest (LSR). In principle it should be possible to create a map at every Doppler velocity, color these maps by velocity from red (receding) to blue (approaching) and stack them. This would result in a single map showing the dominant Doppler velocity at every point in the sky as a color. This method was also used by the CAMRAS team to create a Doppler colour image of the Leiden/ Argentine/ Bonn (LAB) HI survey [8]. However, creating a Doppler colour image from my own data set involved some trial and error.

First of all, because of the VLSR correction the velocity axes of the spectra are not exactly the same. This problem was solved by interpolating all spectra on the same velocity axis (from -200 to 200 km/s in steps of 1 km/s). The channels at Doppler velocities greater than ± 100 km/s contained barely any hydrogen emission and would mostly add noise, therefore only the channels between -100 and +100 km/s were used for the final Doppler colour map. In total 20 maps at 10 km/s intervals were loaded in GIMP as layers (it would of course be possible to make a map for every 1 km/s channel; however, 200 layers is a bit much to handle in GIMP…). Then, each layer was colored from red (-100 km/s) via green (0 km/s) to blue (-100 km/s) using the channel mixer feature (Colors → components → channel mixer). The layer mode was set to "lighten only", so that the dark areas in each layer (where there is little to no hydrogen) are essentially transparent, and the underlying structure is preserved.

The resulting map from this first attempt (Figure 8) was not a great success: it was very oversaturated and dominated by green. The more red- and blue shifted gas clouds were barely visible. This is because the nearby hydrogen gas, which is located relatively close to our solar system, is both very widespread

and very bright at the hydrogen line. The more red- and blue shifted gas clouds are generally located at a greater distance, and as a result they are more confined to the Galactic plane and appear weaker.

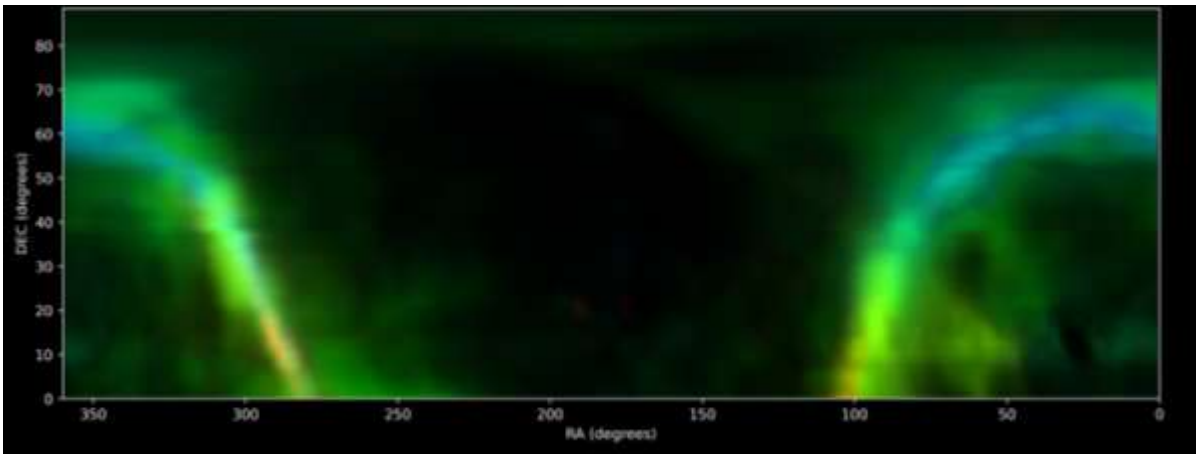


Figure 8: First attempt at a Doppler velocity map where the Doppler shift of the hydrogen line is shown as a colour. Red corresponds to redshift (hydrogen gas moving away from us) and blue corresponds to blueshift (hydrogen gas moving towards us). Note that the map is almost completely dominated by green, which represents hydrogen gas which has relatively low Doppler velocities relative to the Local Standard of Rest (LSR). This gas is predominantly located at relatively small distance from our solar system (on galactic scales at least) and therefore appears brighter and more widespread than the more strongly red and blue shifted hydrogen line emission from more distant regions of our galaxy.

In order to make the “green” low- velocity layers less dominant, the opacity of the layers was decreased linearly with velocity, from 100% at ±100 km/s to only 25% at 0 km/s. The color scale was also changed: by using a square root relationship between the Doppler velocity in km/s (v) and the RGB values of each channel (equation 1), the changes at lower Doppler velocity are expressed more clearly in the final map.

$$-100 - 0\ km\ s^{-1}: R = 0, \qquad G = 1 - \sqrt{v/100}, \qquad B = \sqrt{v/100}$$

$$0 - 100\ km\ s^{-1}: R = \sqrt{v/100},\ G = 1 - \sqrt{v/100},\ B = 0 \quad \text{(eq. 1)}$$

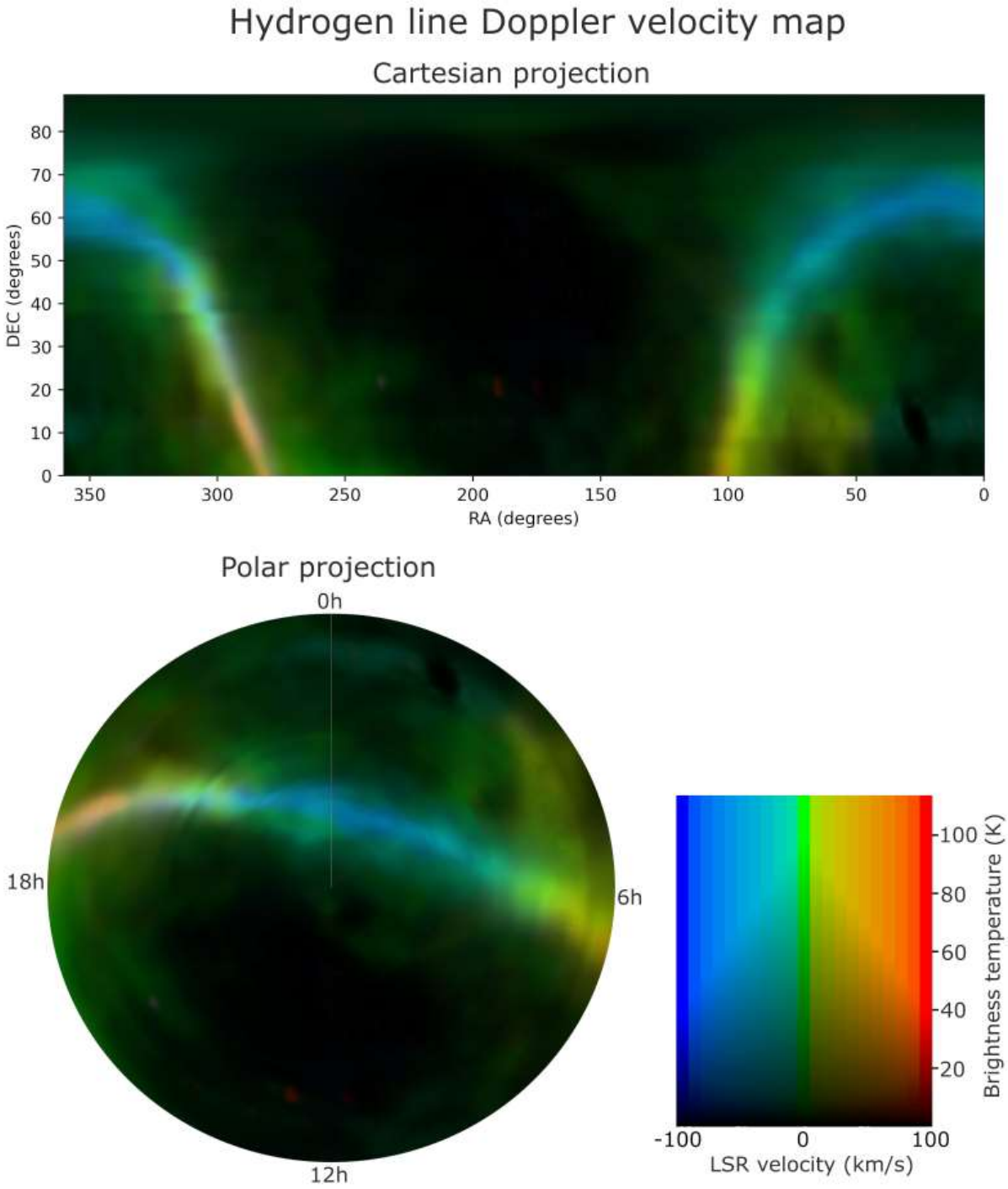


Figure 9: final Doppler velocity map in Cartesian (above) and polar (below) projection.

The final Doppler velocity map clearly shows the differences in the overall Doppler shift in the Milky Way Galaxy: the region on the left-hand side of the map between 18h and 19h right ascension corresponds to quadrant 4 in the inner part of our galaxy. This region has an overall redshift. In quadrant 3, blue shifted

hydrogen line emission from the Perseus arm Outer arm in the outer regions of our galaxy dominate. A small portion of quadrant 2, where redshift once again dominates, can be seen on the right-hand side near 6h right ascension.

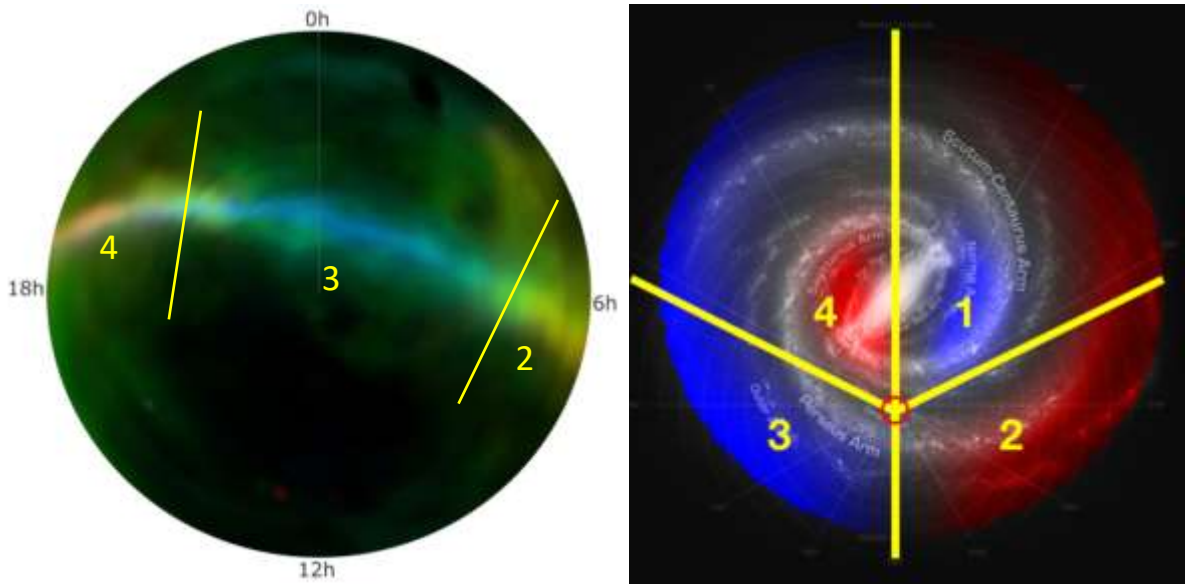


Figure 10: explanation of the four Doppler velocity regions in our galaxy as seen from the Solar System (red circle in the diagram on the right). Hydrogen gas in quadrants 1 and 3 is mostly moving towards us due to galactic rotation, therefore we observe an overall blueshift in the hydrogen line from these parts of our galaxy. In quadrants 2 and 4, the hydrogen gas is mostly moving away from us, leading to an overall redshift. In my own map (left), only quadrant 3 and parts of quadrants 2 and 4 are visible. (Right: diagram by M. Meiborg (2025); https://www.camras.nl/blog/2025/de-melkweg-bewegingen-in-kleur/

References

1) Hydrogen line driftscans explained! https://youtu.be/TbilqlDiDpQ?si=WQ9kCxL_0P62_l1b
2) What would the sky look like if you could see the 21cm hydrogen line? https://youtu.be/rJ0sJwMcr5Y?si=UDMxGraXhBbT6801
3) 3-metre backyard radio telescope tour and demo: https://youtu.be/2HZcwk9hkGQ?si=wzfHclMHhrNhdI6Y
4) "Observation of the H167α radio recombination line towards Cygnus X with a 3 metre dish", Eduard Mol, SARA journal July – August 2025 p.42 –
5) T. Saje and M. Vidmar, "A compact radio telescope for the 21 cm neutral hydrogen line" https://lso.fe.uni-lj.si/literatura/Razno/Diplome/Radioteleskop/clanek/review/radioteleskop.r.pdf
6) VLSR.py: Astropy- based script for VLSR correction by T. J. Dijkema: https://gitlab.camras.nl/dijkema/HPIB/blob/185d241ad9bd7507ed90c9fa91fe0a63009d3eee/vlsr.py
7) "The 3 metre dish at the "Astropeiler Stockert", part 2: characterization and observations", Wolfgang Herrmann. (https://astropeiler.de/wp-content/uploads/2017/12/Part2_The_3-Meter_Dish_Astropeiler_Stockert_Characterisation_and_Observations.pdf)
8) "The Milky Way motion in color", M. Meiborg, 2025 (https://www.camras.nl/en/blog/2025/the-milky-way-motion-in-color/)

"Awakening" of evolved star IRAS 17004-4119 in OH "main" lines

by Dimitry Fedorov UA3AVR

This report presents results of 1-year observations of the star IRAS 17004-4119 in OH molecular lines 1612, 1665, 1667 MHz. A part of observations is presented in [1], but here fresh September 2026 results are included. These results confirm the star's recent activity ("awakening") in 1665, 1667 MHz lines, which often referred to as the "main" lines.

IRAS 17004-4119 is an oxygen-rich OH/IR star in the AGB phase [2], with progenitor mass >4 $M_\odot$ and ≈2000 days of variability period [3]. Hydroxyl (OH) emission from such stars often undergoes maser amplification. Observations were made using the 20-meter Green Bank telescope [4].

Activity in "main" lines is connected with efficiency of collisional processes in OH excitations and de-excitations [5], and, therefore, with density of gas in the circumstellar envelope (CSE) [1,6], which can vary during the star's pulsation cycle.

The emission line at 1612 MHz from OH/IR stars usually dominates and is typically characterized by distinctive double-peaked spectral profile [7-9]. This radiation originates from outer layers of CSE rather far from the star; hydroxyl (OH) molecules are pumped mainly by infrared radiation from dusty inner CSE layers. The "main" 1665/1667 MHz lines may also demonstarte two peak in spectra, which coincides with the peak velocities observed at 1612 MHz. In this case, as supposed, the "main" line is pumped at the same locations as the 1612 MHz line, and the CSE gas density there is rather high for collisional processes. Other cases of the appearance of "main" lines can be associated with OH population closer to the star, where the gas density **ρ** is higher (**ρ** ~ 1/**r**^{2} with distance from the star **r**), and OH molecules still concentrate and well pumped there [1,6].

The star IRAS 17004-4119 is one of the most interesting objects for observations in OH lines including 1665/1667 MHz [6]. Its activity and appearance (or significant strengthening) of 1665/1667 MHz lines should be not considered as explained in details; only a part of this variability mechanism is understood now.

Instrumentation



Figure 1. Green Bank 20 m telescope.

All presented observations were conducted using 20 m Green Bank single dish telescope under Skynet Network control [4], see photo on Figure 1. The telescope is located in the radio quiet zone.

Parameters of the telescope and observations are presented in Table 1 (for April-September 2026), or in [10], Table 1 (for October 2025). The Minimal Detectable Peak Flux density was calculated by the Radiometer Equation derived for spectral lines [11]

$$F_{peak} = \frac{K\ SEFD}{\sqrt{\Delta t\ RBW}}, \quad (1)$$

where **K** ≈ 3 – the peak factor of the background noise, **Δt** – the integration (source tracking) time, RBW – the Resolution Bandwidth of the receiver. Averaging the data of two polarizations reduces $\mathbf{F_{peak}}$ by correcting factor $1/\sqrt{2}$.

Table 1. Parameters of the telescope and parameters of observations (April-September 2026).

Dish diameter	**D**	20 m
Beamwidth (HPBW)	deg	0.63°
Aperture Efficiency	η_A	0.6
System Temperature	$\mathbf{T_{sys}}$	60 K (X pol), 62 K (Y pol)*
Forward Gain (dish sensitivity)	Γ	0.068 K/Jy
System Equivalent Flux Density (=$\mathbf{T_{sys}}$ /Γ)	SEFD	880 Jy (Xpol), 910 Jy (Y pol)
Resolution Bandwidth	RBW	3.8 kHz
Resolution in velocities		< 0.7 km/s
Integration (tracking) Time	**Δt**	30 s (1612 MHz), 200 s (1665, 1667 MHz)
Minimal Detectable Peak Flux Density (max level of background noise peaks)	$\mathbf{F_{peak}}$	≈5.5 Jy (1612 MHz), ≈2 Jy (1665, 1667 MHz), after averaging data of two linear polarizations

** System temperatures for both polarizations were determined using the calibration procedure described in [12].*

Historical observations and 2026 "main" lines activity

Historical spectra of 1990s [3] are shown on Figure 2. Double-peaked profiles are observed in 1612 MHz line, as well as in 1667 MHz line with anomalous behavior of the spectrum between the peaks. Velocities of the peaks at 1667 MHz coincide with the velocities of the peaks at 1612 MHz. The peaks at 1667 MHz are expectedly weaker than the line at 1612 MHz. No detection of the 1665 MHz line was reported.

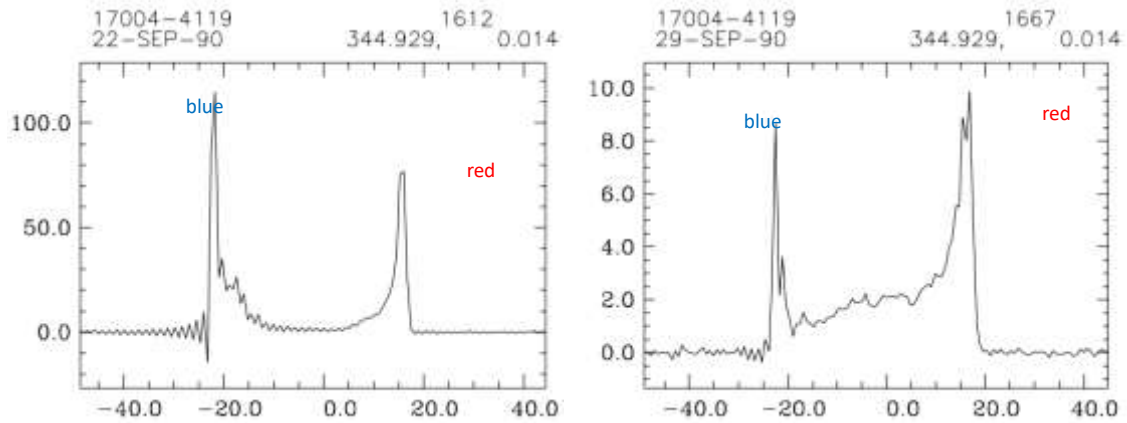


Figure 2. IRAS 17004-4119 historical 1990s spectra of at 1612 MHz and 1667 MHz [3]. The 1665 MHz line was not observed.

1612 MHz spectra obtained in October 2025 – September 2026 are shown in Figure 3.

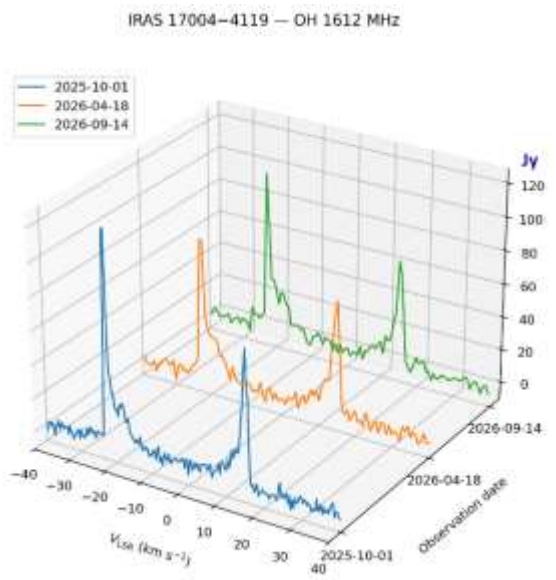


Figure 3. IRAS 17004-4119 1612 MHz spectra observed in October 2025–September 2026. The peak levels are close to 1990s levels in historical spectra (Figure 2).

Some variability in 1612 MHz peaks is observed, but no unusual behavior of the line is noted. The spectra in the "main" lines are much more interesting, see Figure 4.

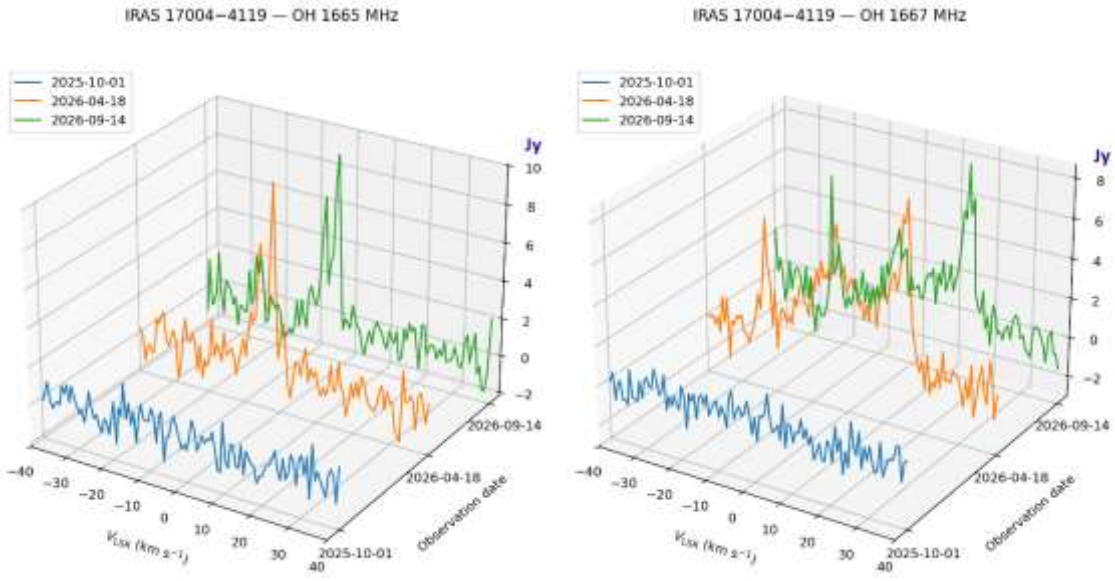


Figure 4. Observed spectra of IRAS 17004-4119 in "main" lines: left – 1665 MHz line, right – 1667 MHz line.

No activity in 1665, 1667 MHz lines has been detected in October 2025; however, in 2026 these lines are "awakening".

Details of 1665 and 1667 MHz spectra are seen better on 2D overlay plots in Figures 5 and 6. The 1667 MHz line has a double-peak profile with an anomalous part between the red- and blue-shifted peaks.

The velocities of the 1667 MHz red- and blue-shifted peaks at 1667 MHz coincide with the velocities of corresponding peaks in the spectrum at 1612 MHz. As supposed the double-peak profile radiation originates from the same CSE layers as the 1612 MHz radiation.

The line is 1665 MHz mainly located around -4.5 km/s with two narrow spikes confirmed in two 2026 observations. The 1667 MHz anomalous peak is also located approximately at the same velocities. As supposed the 1665 MHz radiation and the 1667 MHz anomalous part radiation the peak -4.5 km/s 1667 MHz are originated from closer to the star CSE layers where OH molecules still concentrate, and their clouds are efficiently pumped. All 1667 MHz anomalous parts are "breathing" in observations during 2026.

All results for the spectra (for 2025 and 2026) are presented as averaged over two linear polarizations.

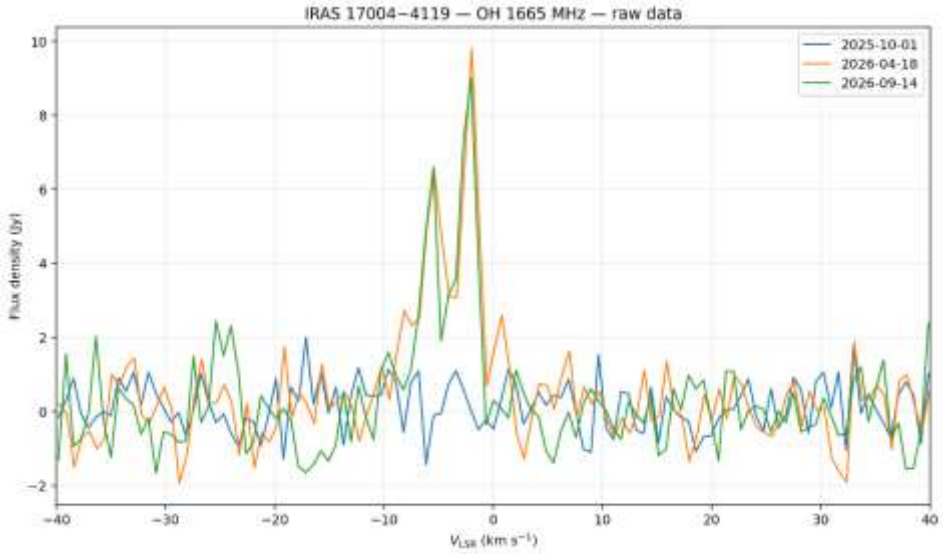


Figure 5. 2D overlay 1665 MHz spectra October 2025–September 2026.

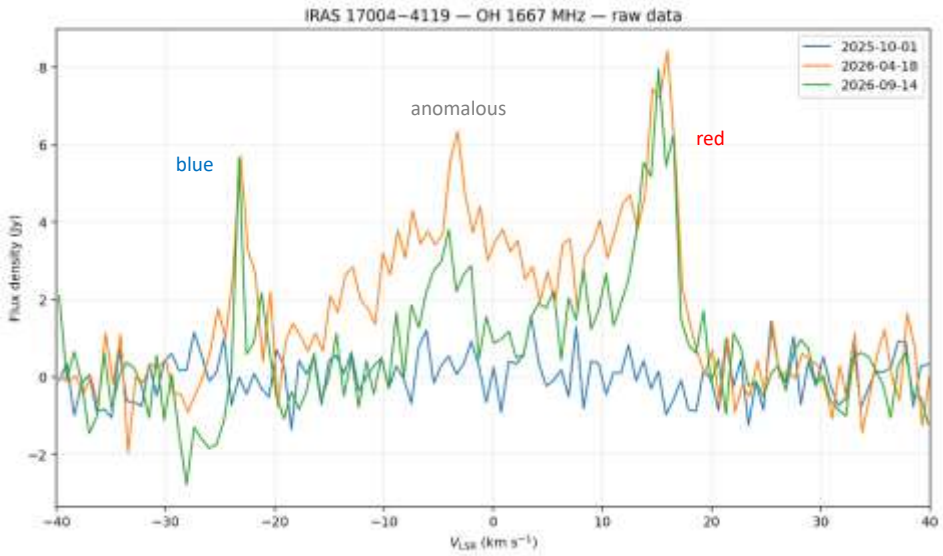


Figure 6. 2D overlay 1667 MHz spectra October 2025–September 2026.

Concluding notes

The star IRAS 17004-4119 is active now (Autumn 2026) in "main" lines; its "awakening" in comparison to 2025 is confirmed in at least two observations this year. A series of systematic observations of evolved stars in "main" lines was conducted by me since 2025 [1,6,10,12]. In [6], an intermediate summary has been made; the star IRAS 17004-4119 was noted as one of the most interesting for monitoring, and observations in 2006 lived up to expectations.

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About the author



Dimitry Fedorov, UA3AVR was first licensed as a radio amateur in 1982. In 1990 Dimitry graduated with MS in electronics from Moscow Power Engineering University. Now he works as research and development engineer in the wireless industry and SAT communications. He also has previous scientific experience in nuclear and particle physics, while working at Moscow State University, Institute of Nuclear Physics and Universität Tübingen, Institut für Theoretische Physik, see his profile blog at https://www.researchgate.net/profile/Dimitry-Fedorov-2. Radio Astronomy has been a hobby since 2012, mainly in applications for weak signals reception. You can contact Dimitry at ua3avr.feddk@gmail.com, ua3avr@yandex.ru.

A Low-Cost Broadband ENR Meter Using FFT-Based Power Measurement

Reference Implementation Using a HackRF Pro SDR

Christian Monstein

Abstract

This report describes a simple method for measuring the Excess Noise Ratio (ENR) of broadband noise sources using a Software Defined Radio (SDR). The received RF signal is digitized and processed entirely in software. Power is estimated from the FFT spectra, averaged in the linear domain and converted into decibels only after averaging. After calibration with a reference noise source of known ENR, the instrument can determine the ENR of unknown broadband noise sources over a wide frequency range. The illustrations were prepared with assistance from ChatGPT (OpenAI).

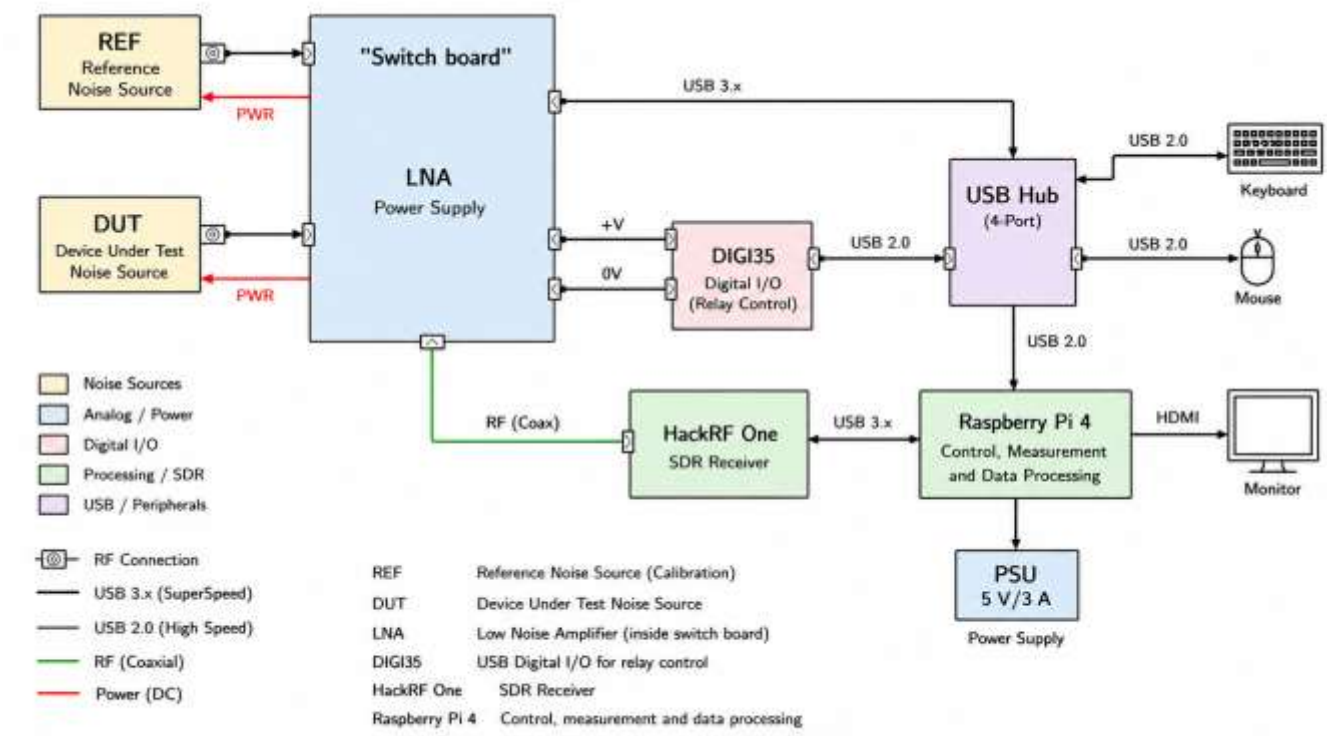
1. Introduction

Commercial ENR meters are accurate but expensive. The objective of this project was to investigate whether a low-cost SDR receiver could be transformed into a practical ENR meter using digital signal processing and a calibrated reference noise source. The prototype described here uses a HackRF Pro SDR, although the measurement principle is independent of the receiver hardware.

2. Instrument Overview

The instrument consists of an RF front-end and a digital Power-Meter. The RF-front end, denoted as ‘Switch board’ in figure 1 below, consists of a relay that switches the supply voltage between a reference noise source (REF) and device under test (DUT) as well as a microwave relay to switch the noise output of the two sources into a cascade of two low noise amplifiers (LNA). The LNAs are series-connected by the switch to obtain up to 40 dB of gain. The RF gain is adjusted so that the signal utilizes the full dynamic range of the SDR analog-digital converter (ADC) without clipping. The ‘Switch board also contains power supplies to power the LNAs and microwave relay. The two relays are controlled by a low-cost USB-relay board (purchased through AliExpress) and connected via the USB-Hub to the Raspberry Pi 4.

The SDR converts the RF noise signal into complex IQ samples. All power estimation, calibration and ENR calculations are performed in software. As there are many noise sources with different supply voltages, typically +28 V or +15 V but also –28 volts, there is a programmable laboratory power supply denoted as DIGI35, which can be controlled via an RS-232 serial interface. An RS-232 – USB adapter supports connection to the USB-Hub (not shown in figure 1). The main reason for the USB-Hub is to protect against power surges from the ‘Switch board as well as from the DIGI35 programmable power supply, which during development destroyed a Raspberry Pi 4. Thus, the USB-Hub is only connected after power is applied to all sub-units and after the Raspberry Pi 4 has been booted. Also, the USB-Hub must be disconnected from the Raspberry Pi 4 before switching off all the sub-units.


REF
Reference
Noise Source
PWR
DUT
Device Under Test
Noise Source
PWR
"Switch board"
LNA
Power Supply
+V
0V
USB 3.x
DIGI35
Digital I/O
(Relay Control)
USB 2.0
USB Hub
(4-Port)
USB 2.0
Keyboard
USB 2.0
Mouse
USB 2.0
RF (Coax)
HackRF One
SDR Receiver
USB 3.x
Raspberry Pi 4
Control, Measurement
and Data Processing
HDMI
Monitor
PSU
5 V/3 A
Power Supply
Noise Sources
Analog / Power
Digital I/O
Processing / SDR
USB / Peripherals
RF Connection
USB 3.x (SuperSpeed)
USB 2.0 (High Speed)
RF (Coaxial)
Power (DC)
REF Reference Noise Source (Calibration)
DUT Device Under Test Noise Source
LNA Low Noise Amplifier (inside switch board)
DIGI35 USB Digital I/O for relay control
HackRF One SDR Receiver
Raspberry Pi 4 Control, measurement and data processing


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HackRF Pro
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Figure 1: Complete measurement system. Upper: Block diagram prepared with assistance from ChatGPT (OpenAI). Lower: Test setup with the following numbered components:
1: Programmable USB- laboratory power supply 0V ... 30V
2: Reference noise source AILTECH 7618E 0.01-18 GHz (+28Vdc)
3: 'Switchboard' containing low voltage relays and microwave relay, both controlled via USB
4: Software defined radio (SDR) HackRF Pro and for testing HackRF One which is compatible
5: Raspberry Pi 4, shown here without enclosure or ventilator, both of which will be mounted later
6. DUT, a self-manufactured low-cost noise source 10 MHz ... 870 MHz (+15Vdc)
7: USB-Hub to connect keyboard, mouse, USB-relays and laboratory power supply
8: Monitor shown running python3 script (left) and ENR-plot (right)
9: Mouse
10: keyboard

3. Measurement Principle

A frequency table is used to specify each measurement frequency. Two measurements are performed for each frequency in the table. During the Cold measurement the reference noise source is switched OFF. During the Hot measurement the reference noise source is switched ON. The ratio between the two measurements is the Y-factor of the reference source and forms the basis of calibration and ENR determination. Immediately after measuring the reference source the same procedure is applied to the noise source under test (DUT), which provides the Y-factor of the DUT. Since the ENR of the reference source is well documented, the ENR of the DUT can be calculated, saved on disc and a plot can be generated.

4. FFT-Based Power Measurement

The SDR continuously acquires IQ samples. An FFT is calculated for each data block. The power spectrum is obtained from the squared magnitude of the FFT coefficients. Multiple spectra are averaged in the linear domain before the final result is converted into decibels. The FFT is therefore used as a digital RF power detector rather than as a spectrum display.

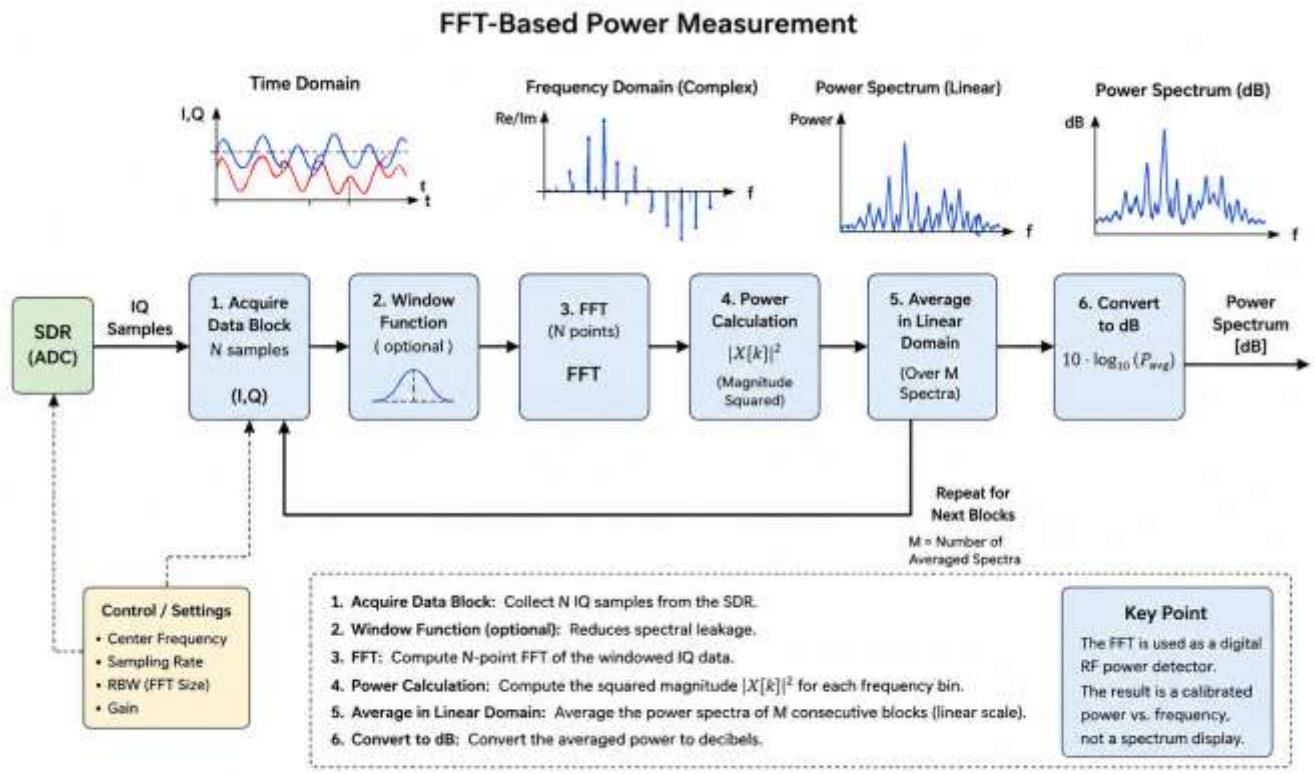


Figure 2: FFT processing chain as Python script on Raspberry Pi 4. Diagram prepared with assistance from ChatGPT (OpenAI).

5. Linear Averaging

Noise is a random process, and a series of individual measurements fluctuates continuously. Stable results are obtained by averaging linear power values. Averaging logarithmic values produces an incorrect Y-factor and must be avoided. Approximately four hundred FFT spectra were found to provide a good compromise between speed and repeatability.

6. Calibration

The complete measurement chain is calibrated using a reference noise source with known ENR. For every frequency, a Cold and a Hot measurement is performed. The resulting calibration data include the frequency response of the complete system, including cables, bias-tee, filters, SDR receiver and software. The calibration only has to be repeated when the hardware configuration changes. The measurement should be performed in a temperature-controlled environment. To get stable results the system should go through a warm-up sequence of at least 5 minutes as amplifiers of an SDR can show some temperature gradients in gain. Every measurement generates beside the graph also an ASCII-file with numerical values as well as measured temperature. For verification of the calibration process, see Appendix: Measurement of the reference source.

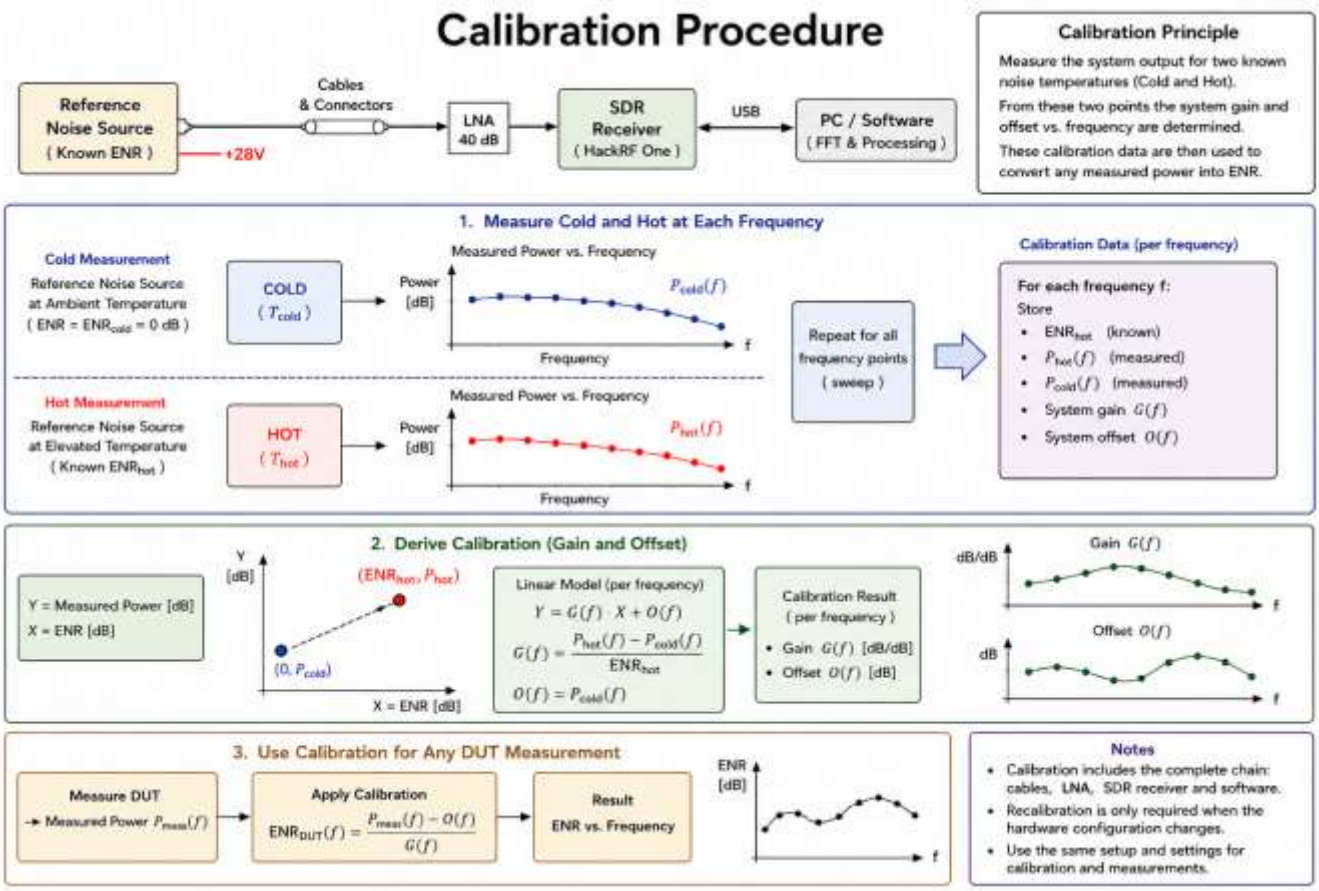


Figure 3: Calibration procedure, simplified. Diagram prepared with assistance from ChatGPT (OpenAI).

7. Measurement of Unknown Noise Sources

After calibration as described above, the reference source is replaced by the Device Under Test (DUT). The same Hot/Cold measurement sequence is repeated. Using the stored calibration data, the ENR of the unknown noise source is calculated automatically.

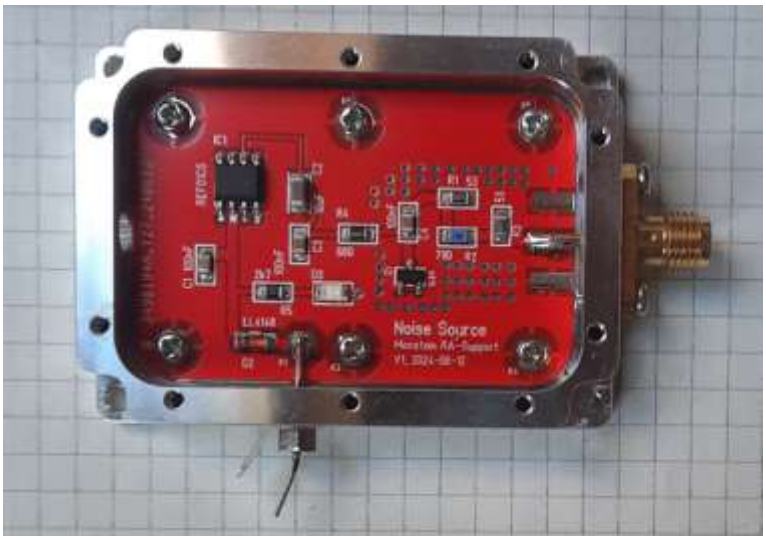


Fig. 4: Typical self-manufactured low-cost noise source, based on a Zener diode. The unit is shown without the metal-cover. The supply voltage is +15 volts and current is less than 10 mA. The frequency range is 10 MHz up to about 900 MHz and is meant for Callisto related applications such as calibration or noise measurement or just functional testing.

8. Experimental Results

The prototype was calibrated using a commercial AILTECH 7618E 0.01-18 GHz broadband noise source with a nominal ENR of +15 dB ± 1.0 dB. Measurements were performed from 10 MHz to 900 MHz, which is the typical frequency range for applications used in e-CALLISTO. Stable and repeatable Y-factor measurements were obtained after averaging approximately four hundred FFT spectra. For each manufactured noise source, a plot and a table are supplied to the customer; see figure 5 and table 1.

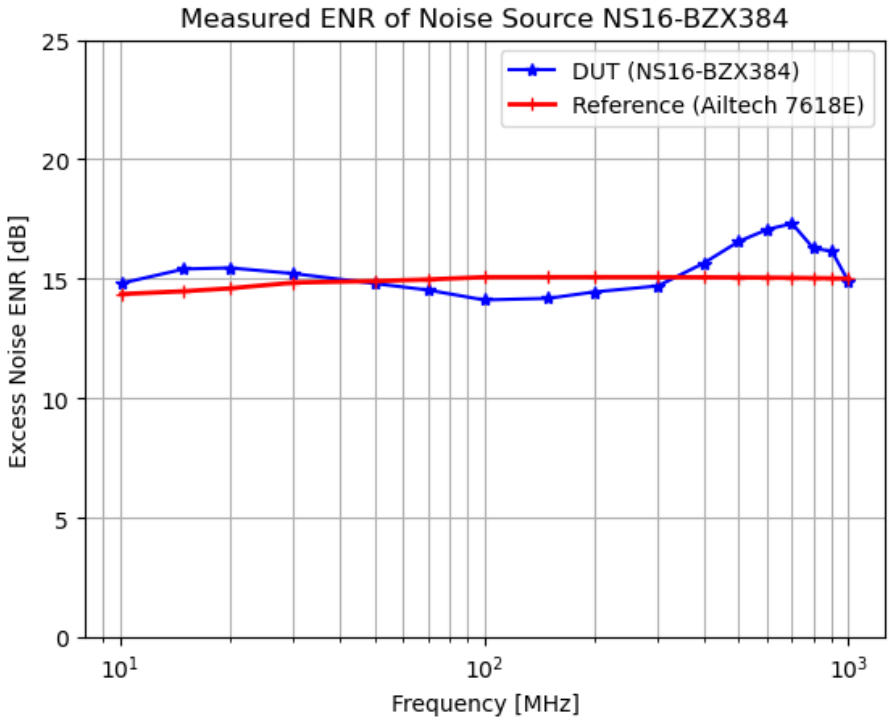


Figure 5: Measured ENR of DUT noise source Snr15, based on Zener diode BZX384.

Frequency [MHz]	ENR [dB]
10.100	14.82
15.000	15.03
20.000	15.32
30.000	15.30
50.000	14.82
70.000	14.56
100.000	14.10
150.000	14.10
200.000	14.27
300.000	14.68
400.000	15.26
500.000	16.66
600.000	16.81
700.000	17.13
800.000	14.92
900.000	15.90
999.900	14.67

Table 1: Protocol for noise source #16 which will be provided to the customer with the plot.

9. Conclusions

The proposed instrument demonstrates that practical ENR measurements are possible using inexpensive SDR hardware combined with FFT-based power estimation, linear averaging and calibration. Although the prototype uses a HackRF Pro receiver, the measurement principle can easily be implemented on other SDR platforms. Whoever is interested in the Python script, it can be downloaded from here: https://e-callisto.org/Software/AutoCalJoy.py but, no guarantee for anything, use it as it is.

Key Equations

- $P = k \cdot T \cdot B$
- $Y = P_{hot} / P_{cold}$
- $Y(dB) = 10 \cdot \log10(Y)$
- $Fsys = ENR_{cal,lin} / (Y_{cal,lin} – 1)$
- $ENR(linear) = Fsys \cdot (Y(linear) - 1)$
- $ENR(dB) = 10 \cdot \log10(ENR(linear))$

References

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- Keysight Technologies, Fundamentals of RF and Microwave Noise Figure Measurements.
- HackRF Pro Documentation.

- SoapySDR Documentation.
- CALLISTO spectrometer, https://e-callisto.org/index.html

Appendix: Measurement of the reference source

To verify the calibration process, the reference source was swapped during measurement from REF-port to the DUT-port. This demonstrates the stability of the measurements.

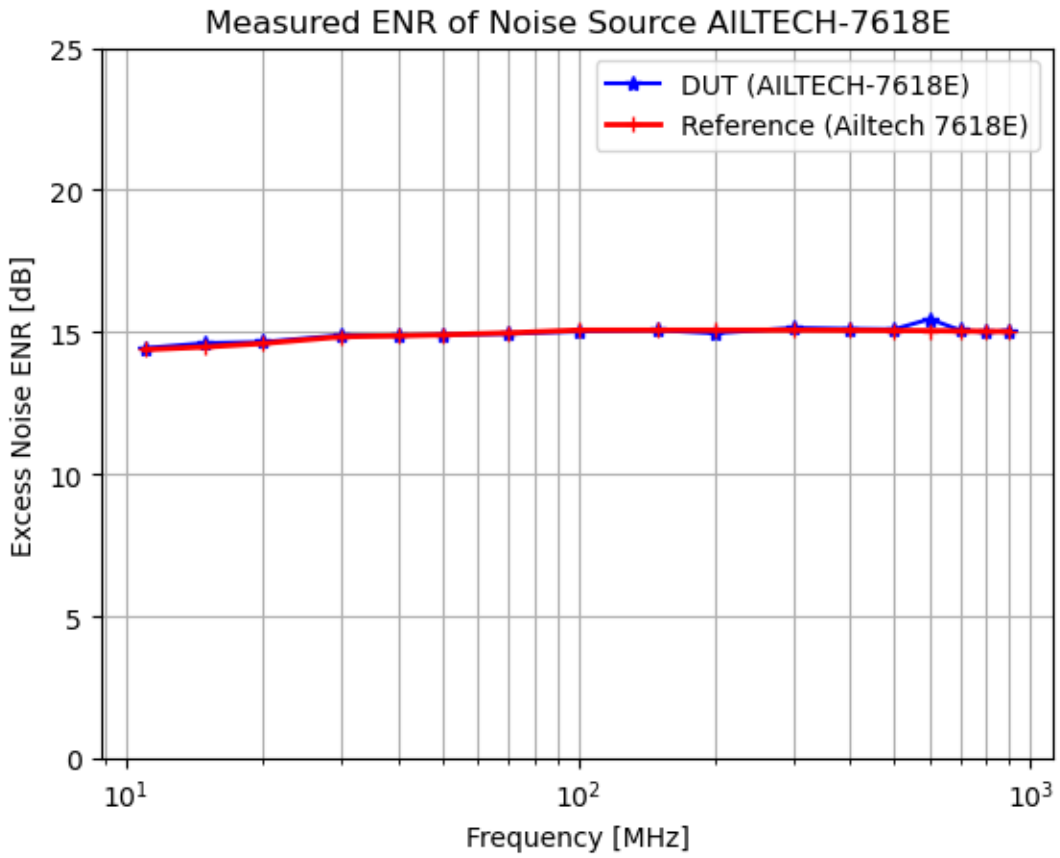
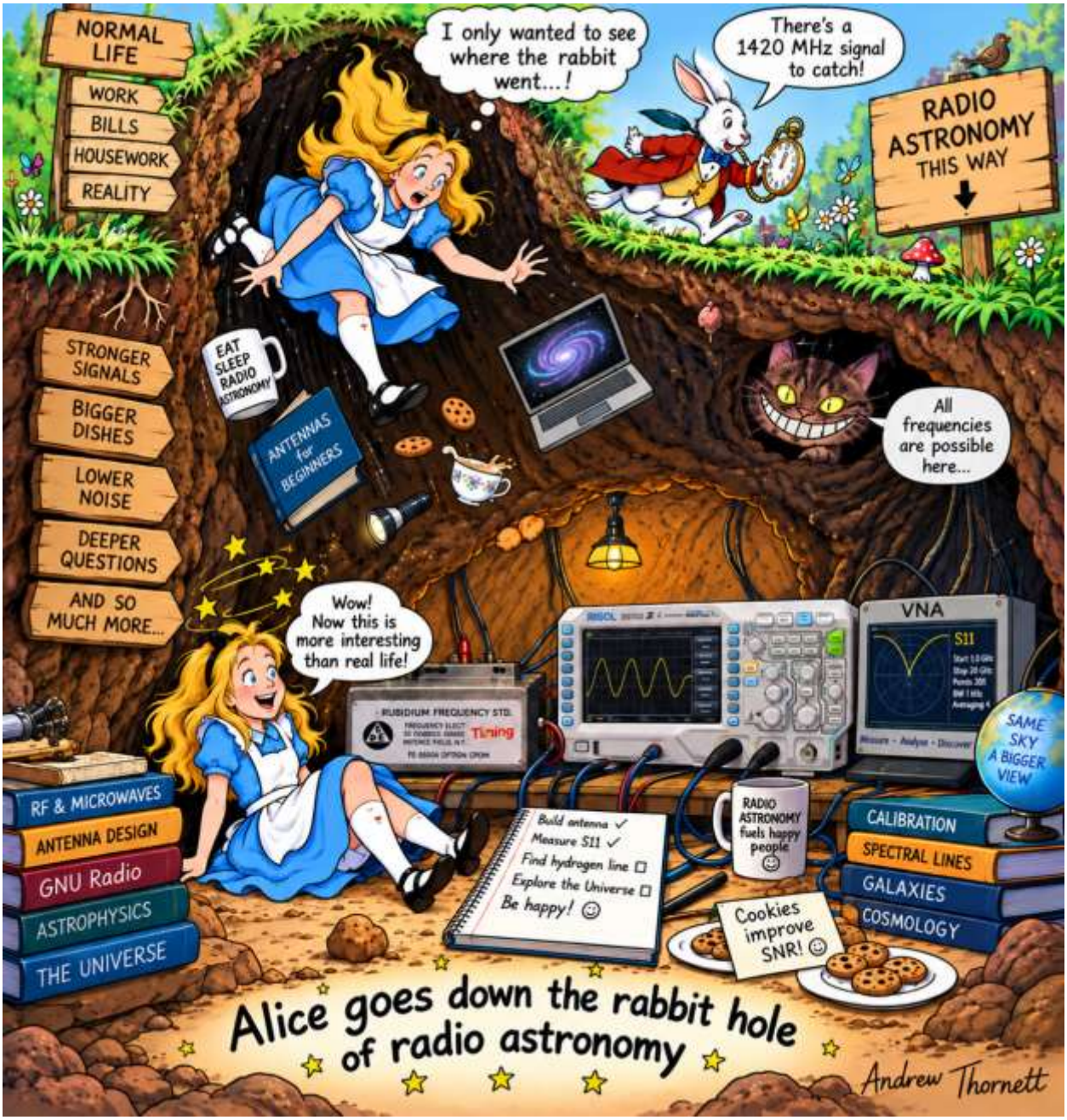


Figure 5: Measured reference source by swapping the source from REF-port to the DUT-port. Maximum error in this case was found at 600 MHz with +0.41 dB error while all other frequencies were measured with less than ± 0.1 dB error which also corresponds with the statistical noise of the measurements.

Radio Astronomy Cartoons



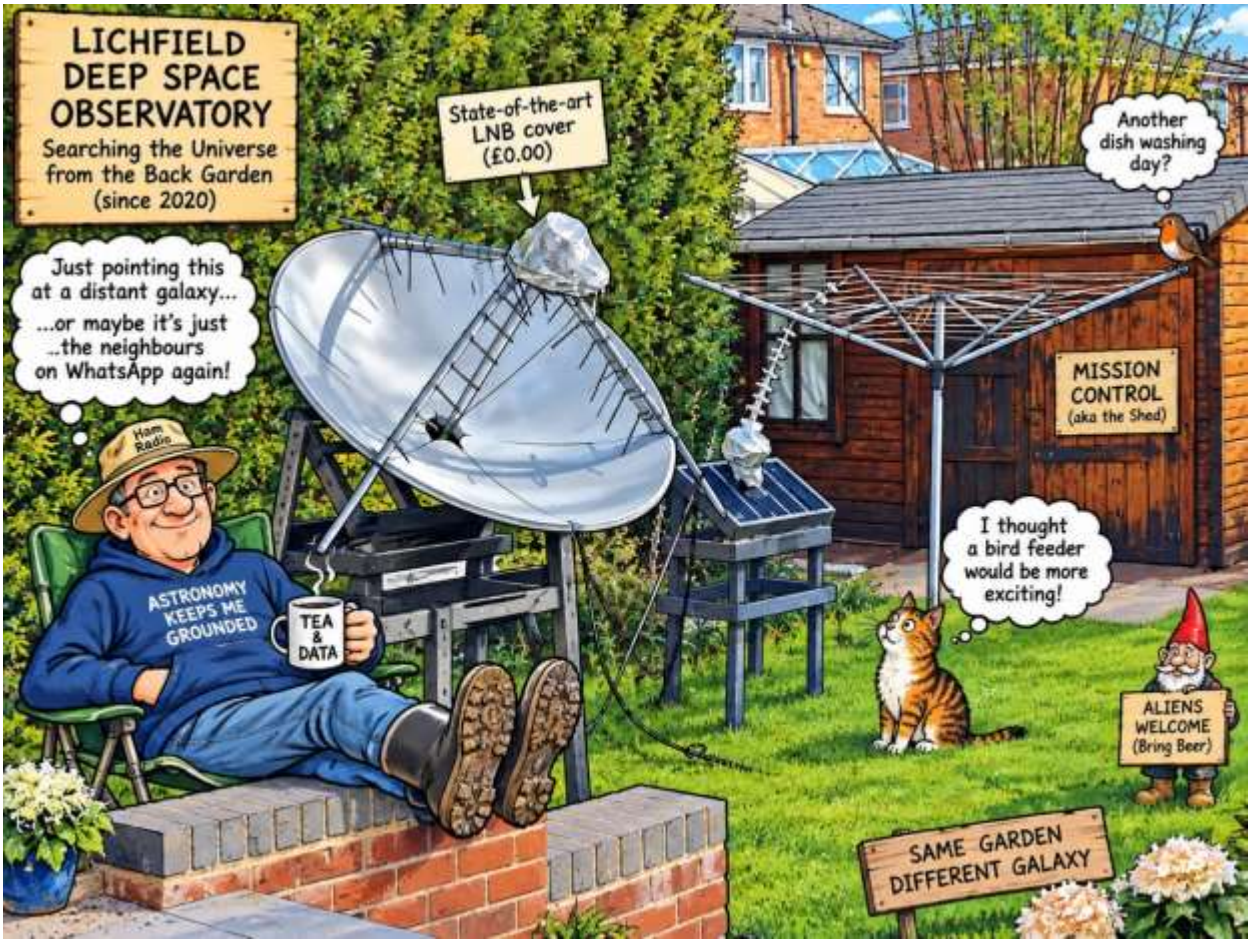
Cartoon. Alice goes down the rabbit hole of radio astronomy. Andrew Thornett.



Cartoon. Off to America for the SARA Conference at Green Bank Observation. Andrew Thornett.



Cartoon. The day I tried to build a radio telescope in my garden. Andrew Thornett.



Cartoon. Astronomy keeps me grounded. Andrew Thornett.

Journal Archives and Other Promotions

The rich and diverse legacy of member contributed content is available in the SARA Journal Archives. Table of contents for journals is available online at: SARA-Journal-Master-Index.xlsx (live.com)

The entire set of The Journal of The Society of Amateur Radio Astronomers is available by online download. It goes from the beginning of 1981 to the present (over 6000 pages of SARA history!)

All SARA journals and conference proceedings are available through the previous calendar year.

SARA Store (radio-astronomy.org/store.)

SARA Online Discussion Group

SARA members participate in the online forum at http://groups.google.com/group/sara-list. This is an invaluable resource for any amateur radio astronomer.

SARA Conferences

SARA organizes multiple conferences each year. Participants give talks, share ideas, attend seminars, and get hands-on experience. For more information, visit http://www.radio-astronomy.org/meetings.

What is Radio Astronomy?

Radio Astronomy is just what the name implies…. Astronomy observed at radio wavelengths instead of optical. But why do radio astronomy? Radio astronomy has expanded the knowledge of the universe about as much since its discovery in 1932 as optical has since humans first looked up at the sky. (The sky in the different frequencies or colors of radio are as different and varied as all of the flowers on Earth. Each frequency has its own information about what is happening in the universe.) This knowledge has been gained by both professional astronomers as well as amateurs, with amateurs contributing to this day.

Do I need a big dish and expensive equipment?

No. Complete beginner projects are available at the SARA store at very reasonable prices. You can monitor the Sun's effects upon our planet with SuperSID. This information is gathered for Stanford for research into our ionosphere and radio signal propagation. Another project is the detection of the hydrogen line just like Dr. Ewen had done in 1951 for a fraction of the cost using the Scope in a Box kit.

That said, radio astronomy is like optical astronomy in that you can spend as much as you want to. Many amateurs push the lower boundaries of cost by using very low-cost receivers and low-noise low-cost amplifiers that were not available even a few years ago. (See the Scope in a Box kit in the store for examples of both.)

Is everything 'plug and play' and boring?

The kits mentioned above are a starting point which are mostly plug-and-play… that gets you started. After you have mastered the basics, where you go from there depends upon your interests. Monitoring pulsars is done by amateurs. (One even noticed a pulsar glitch before the professionals!) These amateurs are pushing the boundaries of what can be done. Papers are being published and discussions are being held about pulsar detection as well detection of a MASER with a 50-inch dish. Techniques on new detection methods are posted in the SARA forum and elsewhere. You are free to build your own equipment to receive the signals as well as software to collect and analyze the data.

What is SETI?

SETI is the Search for Extra-Terrestrial Intelligence. Some amateurs scan the sky and search for signals that might be from aliens. To date no one has received a definitive alien signal (professional or amateur), but the search continues. The search has resulted not just in better receiving equipment but also wide and lively discussions about how aliens might communicate and how they might be trying to contact us. Some of these techniques have interesting ideas for our own communication techniques here on Earth!

What should I do to get started?

You should start with reading our Introduction to Radio Astronomy and joining our online SARA Forum. Look at the SARA store to get a project to get your feet wet without much expense and minimal risk. We will work with you so you can succeed.

Administrative

Officers, directors, and additional SARA contacts

The Society of Amateur Radio Astronomers is an all-volunteer organization. The best way to reach people on this page is by email with SARA in the subject line SARA Officers.

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Secretary: Dr. Andrew Thornett , https://www.radio-astronomy.org/contact/Secretary

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Past President: Dr. Richard Russel

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Resources

Great Projects to Get Started in Radio Astronomy

Radio Observing Program

The Astronomical League (AL) is starting a radio astronomy observing program. If you observe one category, you get a Bronze certificate. Silver pin is two categories with one being personally built. Gold pin level is at least four categories. (Silver and Gold level require AL membership which many clubs have membership. For the bronze level, you need not be a member of AL.)

Categories include.

1) SID

2) Sun (aka IBT)

3) Jupiter (aka Radio Jove)

4) Meteor back-scatter

5) Galactic radio sources

This program is a collaboration between NRAO and AL. Steve Boerner is the Lead Coordinator and a SARA member.

For more information:

Steve Boerner
2017 Lake Clay Drive
Chesterfield, MO 63017
Email: sboerner@charter.net
Phone: 636-537-2495 http://www.astroleague.org/programs/radio-astronomy-observing-program

Radio Jove



The Radio Jove Project monitors the storms of Jupiter, solar activity and the galactic background. The radio telescope can be purchased as a kit, or you can order it assembled. They have a terrific user group you can join. http://radiojove.gsfc.nasa.gov/

INSPIRE Program



The INSPIRE program uses build-it-yourself radio telescope kits to measure and record VLF emissions such as tweeks, whistlers, sferics, and chorus along with man-made emissions. This is a very portable unit that can be easily transported to remote sites for observations. http://theinspireproject.org/default.asp?contentID=27

SARA/Stanford SuperSID



Stanford Solar Center and the Society of Amateur Radio Astronomers have teamed up to produce and distribute the SuperSID (Sudden Ionospheric Disturbance) monitor. The monitor utilizes a simple pre-amp to magnify the VLF radio signals which are then fed into a high-definition sound card. This design allows the user to monitor and record multiple frequencies simultaneously. The unit uses a compact 1-meter loop antenna that can be used indoors or outside. This is an ideal project for the radio astronomer that has limited space. To request a unit, send an e-mail to supersid@radio-astronomy.org

Radio Astronomy Online Resources

SARA YouTube Videos: https://www.youtube.com/@radio-astronomy	Pisgah Astronomical Research Institute: www.pari.edu
AJ4CO Observatory – Radio Astronomy Website: http://www.aj4co.org/	A New Radio Telescope for Mexico - ORION 2021 01 20. Dr. Stan Kurtz https://www.youtube.com/watch?v=Q9aBWr1aBVc
Radio Astronomy calculators https://www.aj4co.org/Calculators/Calculators.html	National Radio Astronomy Observatory http://www.nrao.edu
Introduction to Amateur Radio Astronomy (presentation) http://www.aj4co.org/Publications/Intro%20to%20Amateur%20Radio%20Astronomy,%20Typinski%20(AAC,%202016)%20v2.pdf	Exotic Ions and Molecules in Interstellar Space -- ORION 2020 10 21. Dr. Bob Compton https://www.youtube.com/watch?v=r6cKhp23SUo&t=5s
RF Associates Richard Flagg, rf@hawaii.rr.com 1721-1 Young Street, Honolulu, HI 96826	The Radio JOVE Project & NASA Citizen Science – ORION 2020.6.17. Dr. Chuck Higgins https://www.youtube.com/watch?v=s6eWAxJywp8&t=5s
RFSpace, Inc. http://www.rfspace.com	UK Radio Astronomy Association: UK Radio Astronomy Association (UKRAA) - Home
CALLISTO Receiver & e-CALLISTO http://www.reeve.com/Solar/e-CALLISTO/ecallisto.htm	CALLISTO software and data archive: www.e-callisto.org
Deep Space Exploration Society http://DSES.science	Radio Jove Spectrograph Users Group http://www.radiojove.net/SUG/
Deep Space Object Astrophotography Part 1 -- ORION 2021 02 17. George Sradnov https://www.youtube.com/watch?v=Pm_Rs17KIyQ	Radio Sky Publishing http://radiosky.com
European Radio Astronomy Club http://www.eracnet.org	The Arecibo Radio Telescope; It's History, Collapse, and Future - ORION 2020.12.16. Dr. Stan Kurtz, Dr. David Fields https://www.youtube.com/watch?v=rBZlPOLNX9E
British Astronomical Association – Radio Astronomy Group http://www.britastro.org/baa/	Shirleys Bay Radio Astronomy Consortium marcus@propulsionpolymers.com
Forum and Discussion Group http://groups.google.com/group/sara-list	SARA Twitter feed https://twitter.com/RadioAstronomy1
GNU Radio https://www.gnuradio.org/	SARA Web Site http://radio-astronomy.org

SETI League http://www.setileague.org	Simple Aurora Monitor: Magnetometer http://www.reeve.com/SAMDescription.htm
NRAO Essential Radio Astronomy Course http://www.cv.nrao.edu/course/astr534/ERA.shtml	Stanford Solar Center http://solarcenter.stanford.edu/SID/
NASA Radio JOVE Project http://radiojove.gsfc.nasa.gov Archive: http://radiojove.net/archive.html https://groups.io/g/radio-jove	https://www.csiro.au/ There's a wealth of info on this site of the Australian National Science Agency. It's much more than just radio astronomy. Looking under "Research" opens a real family tree of interesting pages of things they are involved with.
Green Bank Observatory https://greenbankobservatory.org/ .	

Found an interesting Grote Reber link: https://www.utas.edu.au/community-and-partners/community-programs/mt-pleasant-observatory-grote-reber-museum?_gl=1*3p3fzv*_gcl_au*ODg0NTUxLjE3OTI0MzE1MjEuLS4tLjE3OTI0MzE1ODQuMTM0NzAwODk1LjE3OTI0MzE1ODQuMTc5MjQzMTU4NA..*FPAU*ODg0NTUxLjE3OTI0MzE1MjE

Their gallery is interesting but sure wish they had some captions to indicate who and what some of it is about. I can guess, knowing some of Grote's stories, but others might need more info. Several pictures show the University of Tasmania 26m dish that was once one of the NASA worldwide Satellite Tracking and Data Network (STDN) dishes like the ones at the Pisgah Astronomical Research Institute (www.pari.edu). PARI's dishes were the first qualification units for that network.

For Sale, Trade and Wanted

At the SARA online store: radio-astronomy.org/store.

New on-demand store for SARA SWAG! https://saragifts.org/

Scope in a Box radio-astronomy.org/store.

Kit of parts and software to build a working Radio Telescope to detect Hydrogen Line emissions. Available to USA addresses only at this time.

SuperSID Complete Kit radio-astronomy.org/store.



SARA Publication, Journals and Conference Proceedings (various prices) radio-astronomy.org/store. **SARA Journal Online Download** radio-astronomy.org/store.

The Journal archive covers the society journal "Radio Astronomy" from the founding of the organization in 1981 through the present. Articles cover a wide range of topics including cosmic radiation, pulsars, quasars, meteor detection, solar observing, Jupiter, Radio Jove, gamma ray bursts, the Itty Bitty Telescope (IBT), dark matter, black holes, the Jansky antenna, methanol masers, mapping at 408 MHz and more.

New! **SARA On-Demand Store: https://saragifts.org**

These are the current items – more to come in the future!

(Note: No returns or refunds possible because of the on-demand production approach)










I
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Astronomy













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Membership Information

Annual SARA dues Individual $20, Classroom $20, Student $5 (US funds) anywhere in the world. Membership includes a subscription to Radio Astronomy, the bimonthly Journal of The Society of Amateur Radio Astronomers, delivered electronically (via a secure web link, emailed to you as each new issue is posted). We regret that printing and postage costs prevent SARA from providing hardcopy subscriptions to our Journal.

We would appreciate the following information included with your check or money order, made payable to SARA:

Name: .....

Email Address : .....
(required for electronic Journal delivery)

Ham call sign: ..... (if applicable)

Address: .....

City: .....

State: .....

Zip: .....

Country: .....

Phone: .....

Please include a note of your interests. Send your application for membership, along with your remittance, to our Treasurer.

For further information, see our website at:

http://radio-astronomy.org/membership

How to get started?

SARA has a made a kit of software and parts to detect the Hydrogen line signal from space. This is an excellent method to get started in radio astronomy. It teaches the principles of antenna design, signal detection, and signal processing. Read more about this and other projects on our web site.



Society of Amateur Radio Astronomers, Inc.
Founded 1981

Membership supported, nonprofit [501(c) (3)] Educational and Radio Astronomy Organization

Knowledge through Common Research, Education and Mentoring





SARA members have been privileged to use this forty foot diameter drift-scan hydrogen line radio telescope every year at their annual meeting in Green Bank.

http://radio-astronomy.org

Why Radio Astronomy?

Because about sixty five percent of our current knowledge of the universe has stemmed from radio astronomy alone. The discovery of quasars, pulsars, black holes, the 3K background from the "Big Bang" and the discovery of biochemical hydrogen/carbon molecules are all the result of professional radio astronomy.

The Society of Amateur Radio Astronomers

SARA was founded in 1981, with the purpose of educating those interested in pursuing amateur radio astronomy.

The society is open to all, wishing to participate with others, worldwide.

SARA members have many interests, some are as follows:

SARA Areas of Study and Research:

- Solar Radio Astronomy
- Galactic Radio Astronomy
- Meteor Detection
- Jupiter
- SETI
- Gamma Ray/High Energy Pulse
- Detection
- Antennas
- Design of Hardware / Software

The members of the society offer a friendly mentor atmosphere. All questions and inquiries are answered in a constructive manner. No question is silly!

SARA offers its members an electronic bi-monthly journal entitled Radio Astronomy. Within the journal, members report on their research and observations. In addition, members receive updates on the professional radio astronomy community and, society news.

Once a year SARA meets for a three-day conference at the Green Bank Observatory in Green Bank West Va.

There is also a spring conference held at various cities in the Western USA. Previous meeting have been at the VLA in Socorro, NM and at Stanford University.



How do I get started?

Just as a long journey begins with the first step, the project you elect must start with a clear idea of your objectives. Do you wish to study the sun? Jupiter? Make meteor counts? Do you wish to engage in imaging radio astronomy? What you decide will not only determine the type of equipment you will need, but also the local radio spectrum.

How do amateurs do radio astronomy?

Radio astronomy by amateurs is conducted using antennas of various shapes and sizes, from smaller parabolic dishes to simple wire antennas. These antennas are connected to receivers and most of these receivers are software defined radios these days. Data from the receivers are collected by computers, and the received signals will be displayed as charts, graphs or maybe even sky maps. As diverse as the observed objects, so is are the instruments and tools used. SARA members will always be supportive to find good solutions for what one wishes to observe.

Is amateur radio astronomy instrumentation expensive?

Technical information freely circulated in our monthly journal helps amateurs to obtain good low noise equipment from off the shelf assemblies, or to build their own units. The actual cash investment in radio astronomy equipment need not exceed that of any other hobby.

What are amateurs actually looking for in the received data?

The aim of the radio amateur is to find something new and unusual. Just as an amateur optical observer hopes to notice a supernova or a new comet, so does an amateur radio observer hope to notice a new radio source, or one whose radiation has changed appreciably.



The Reber Telescope at NRAO. Constructed by Grote Reber in 1937 in his back yard in Wheaton, Illinois



SARA Members discussing the IBT (Itty Bitty Telescope)

