

RADIO ASTRONOMY

Journal of the Society of Amateur Radio Astronomers

July-August 2026



SARA 2026 Eastern Conference



Dr. Richard A. Russel

SARA President and 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:

Dr. Gary Memory

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Introduction

I am humbled to be taking on the role of SARA president. Having been an active member since 2024, SARA has been a significant positive part of my life. I have gotten to know and collaborated with many wonderful people over the past couple of years. I look forward to what is to come as we all continue to push the boundaries of this hobby and tread where the pros have tread before us! For me, the most gratifying part of Amateur Radio Astronomy is the sense of tangible connection to the universe out there as well as to the pioneering astronomers who have gone before us. I look forward to what's ahead! Let's make this next year for SARA one for the history books!

Cheers!

Jason L. Burnfield

Successful Eastern Conference

The Eastern Conference was a huge success this year with members travelling to Green Bank from as far as Great Britain and many all over the world joining us online. As always, the presentations were top-notch and the opportunity to meet many of our members face to face in such an iconic setting was unforgettable!

Election Results

Incoming SARA Officers are as follows:

President – Jason Burnfield

Vice President – Ken Redcap

Treasurer – Brian O'Rourke

Secretary – Andrew Thornett

Incoming Members on the Board of Directors:

John Colt Sr.

Dimitry Fedorov

Martin Knoblauch

Stephen Tzikas

Editor's Notes

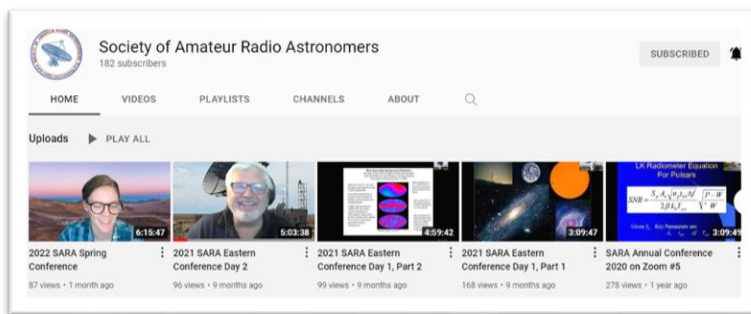
We are always looking for basic radio astronomy articles, radio astronomy tutorials, theoretical articles, application and construction articles, news pertinent to radio astronomy, profiles and interviews with amateur and professional radio astronomers, book reviews, puzzles (including word challenges, 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)



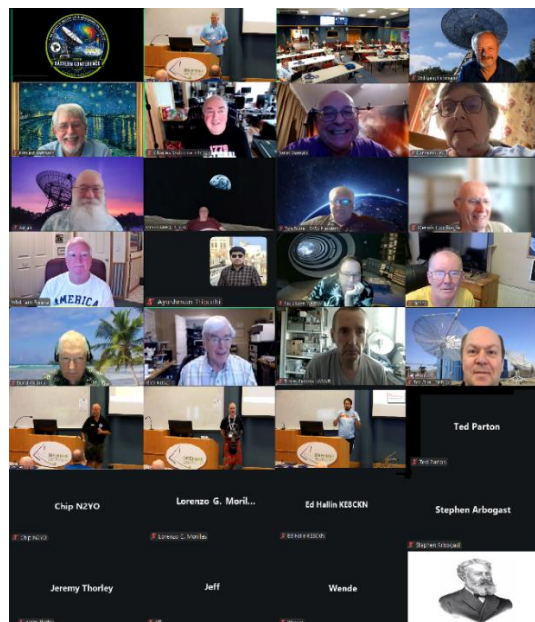
SARA NOTES

Society of Amateur Radio Astronomers (SARA)

2026 SARA & Radio Jove Eastern Conference
August 2 (Sun) – August 5 (Wed) 2026
Green Bank Observatory (GBO) West Virginia (WV)



“Wheels Stop” – Wrapping Up the 2026 SARA and Radio JOVE Eastern Conference





"Wheels stop" signals the official conclusion of a space shuttle mission and so I borrow that phrase to mark the successful end of our 2026 Eastern Conference. Maybe a more relative term might be "telescope parked, observing complete".

The 2026 SARA and Radio Jove Eastern Conference held August 2–5 at the Green Bank Observatory (GBO) in West Virginia, focused on practical radio astronomy, observing techniques, and instrumentation. This year's sessions covered hydrogen-line observing, including mapping hydrogen emission across the Milky Way with a simple horn antenna and detecting nearby galaxies with a small dish. Attendees also explored solar radio phenomena, such as eclipses, flares, and occultations along with introductory radio astronomy concepts and the use of portable observing systems.



Evenings at Drake's Lounge became an important informal part of the conference experience. Attendees gathered for chess matches and wide-ranging technical conversations that extended the day's sessions, strengthened connections among participants, and generated ideas for future observations and experiments.

Participants also expressed appreciation for a generous literature donation from SARA member Alfred Aburto. SARA installed a bookcase in Drake's Lounge to house the collection, creating a lasting resource that will support learning and benefit attendees at future conferences.



A major theme this year was the design, operation, and application of radio-astronomy equipment. Presentations addressed millimeter-wave radio astronomy, raster-scan mapping with the Green Bank 20-meter telescope, radio interferometry, very-long-baseline interferometry, portable dish construction, and methods for measuring low-frequency noise. Our agenda also included discussions of electromagnetic and radio-frequency interference, emphasizing the importance of protecting radio-astronomy observations from unwanted signals. Additional technical topics included pulsar-observing workflows, narrow-bandwidth pulse-pair measurements, and cosmic-ray and muon detection.

The conference was strongly hands-on and collaborative. Attendees received training and tours of the telescopes and Green Bank facilities. Outreach, amateur-radio-astronomy workshops, technical discussions, and informal social sessions complemented the formal presentations, giving our members opportunities to share methods, learn from one another, and build practical observing skills.



As this marks my final conference as chair, I am especially grateful to SARA and its members for the encouragement, support, and shared commitment they have provided throughout the past two years. It has been a privilege to help bring these gatherings together and to work alongside a community so dedicated to learning, observing, and advancing amateur radio astronomy.

Special appreciation goes to Ted Cline for managing the online portion of the conference with exceptional care and professionalism. I also extend my sincere thanks to the entire conference committee and the Green Bank Observatory staff. Their time, expertise, and dedication made this event possible and helped create a meaningful experience for everyone who attended.

Start thinking about topics to discuss in 2027!



Comments and suggestions please send to vicepresident@radio-astronomy.org

Marcus Fisher

Former Vice President, Society of Amateur Radio Astronomers (SARA)

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 the 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

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.

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.



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

Booking is now open for our day conference at the Sherwood observatory NG17 5LF (Oct. 3rd. 09:30 - 17:30)

£20 with 50% discount for BAA members.

Booking: <https://britastro.org/event/radio-astronomy-section-day-meeting>

Friday September 11th BST (18:30 UTC) Dr William McGenn

Research Associate, Manchester University

Low noise amplifiers at the cutting edge

There are four additional on-line meetings - Practical Radio Astronomy host: Andy Thornett.

H-Line instruments and observation,

1GNU 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

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SuperSID

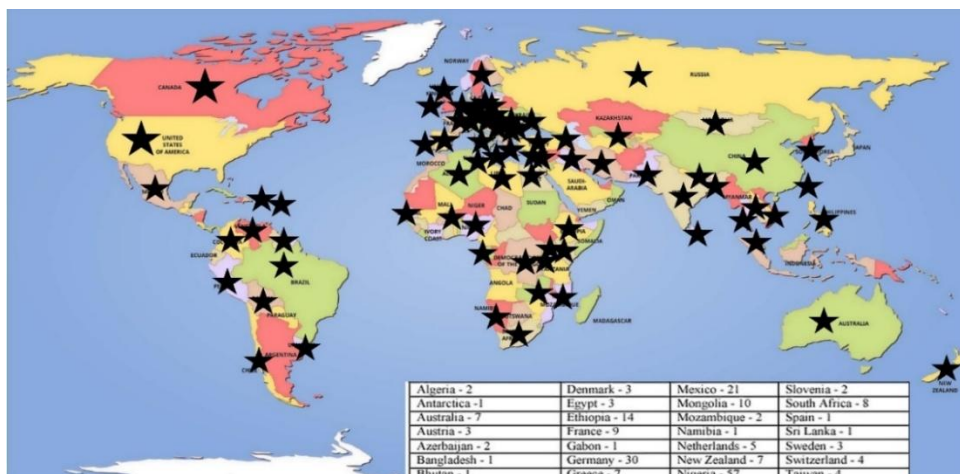


SuperSID

*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)
- 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.



★
SID Monitor
Distribution
 1078 instruments
 82 countries
 7 continents

Algeria - 2	Denmark - 3	Mexico - 21	Slovenia - 2
Antarctica - 1	Egypt - 3	Mongolia - 10	South Africa - 8
Australia - 7	Ethiopia - 14	Mozambique - 2	Spain - 1
Austria - 3	France - 9	Namibia - 1	Sri Lanka - 1
Azerbaijan - 2	Gabon - 1	Netherlands - 5	Sweden - 3
Bangladesh - 1	Germany - 30	New Zealand - 7	Switzerland - 4
Bhutan - 1	Greece - 7	Nigeria - 37	Taiwan - 4
Bolivia - 1	Guyana - 1	Pakistan - 4	Thailand - 5
Bosnia-Herzegovina - 2	Hungary - 1	Peru - 10	Tunisia - 9
Brazil - 11	India - 33	Philippines - 3	Turkey - 2
British Virgin Islands - 1	Indonesia - 2	Poland - 2	Uganda - 5
Bulgaria - 2	Iran - 4	Portugal - 3	UK - 32
Burkina Faso - 1	Iraq - 1	Rep of Congo - 3	Uruguay - 9
Canada - 33	Ireland - 9	Romania - 4	US Virgin Islands - 2
Chile - 1	Italy - 42	Russia - 3	USA - 491
China - 38	Kenya - 23	Rwanda - 1	Uzbekistan - 2
Columbia - 9	Korea (South) - 2	S Africa - 4	Venezuela - 2
Croatia - 7	Lebanon - 11	Senegal - 1	Vietnam - 1
Cyprus - 1	Libya - 1	Serbia - 1	Zambia - 2
Czech Republic - 1	Malaysia - 19	Singapore - 3	
D Rep of Congo - 4	Malta - 1	Slovak Repub - 2	

For official use only

Monitor assigned:

Site name:

Country:

SuperSID Space Weather Monitor

Request Form

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	State/Province	
	Country	Postal Code	
Shipping address, if different:	Name		
	School or Business		
	Street		
	Street		
	City	State/Province	
	Country	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:

<i>What</i>	<i>Cost</i>	<i>How many?</i>
SuperSID distribution USB Power (no options)	\$48 (assembled)	
USB Sound card 96 kHz sample rate (<i>or provide this yourself</i>)	\$40 (<i>optional</i>)	
Antenna wire (120 meters) (<i>or you can provide this yourself</i>)	\$23 (<i>optional</i>) <i>with connectors attached and tested</i>	
RG 58 Coax Cable (9 meters) (<i>or provide this yourself</i>)	\$14 (<i>optional</i>) <i>with connectors attached and tested</i>	
<i>Shipping</i>	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.

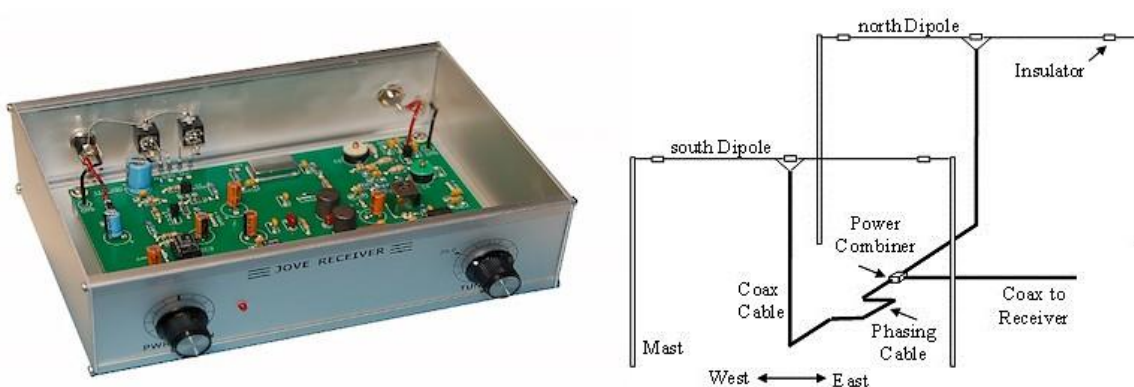


Figure 1. A Radio JOVE RJ1.1 receiver and a schematic of the dual-dipole antenna.

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).

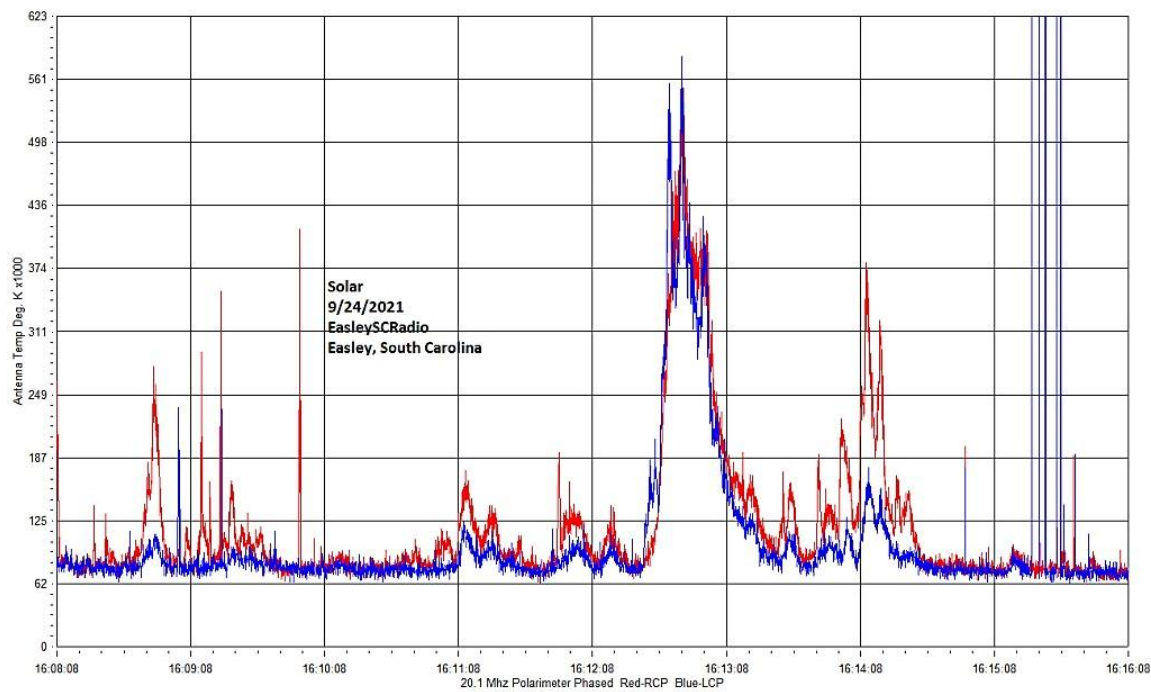


Figure 2. A SkyPipe strip chart showing multiple solar bursts using a JOVE receiver. John Cox, SC.

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 SDR-based 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 affordable. 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.

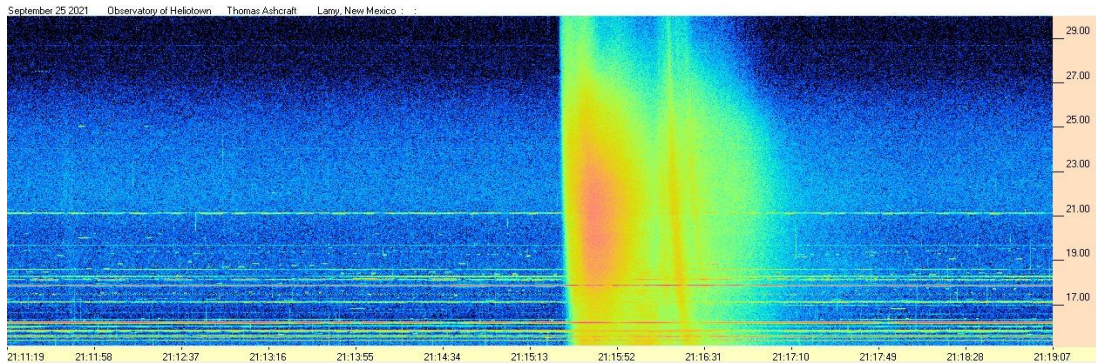


Figure 3. Radio spectrogram showing multiple solar bursts received by Tom Ashcraft in New Mexico. Horizontal scale is time and the vertical scale is frequency. Amplitude is displayed using different colors corresponding to the strength of signals.

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)	
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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, 2 nd 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

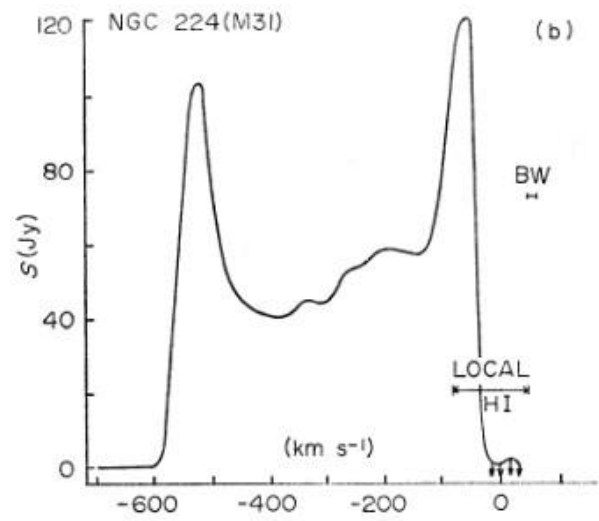
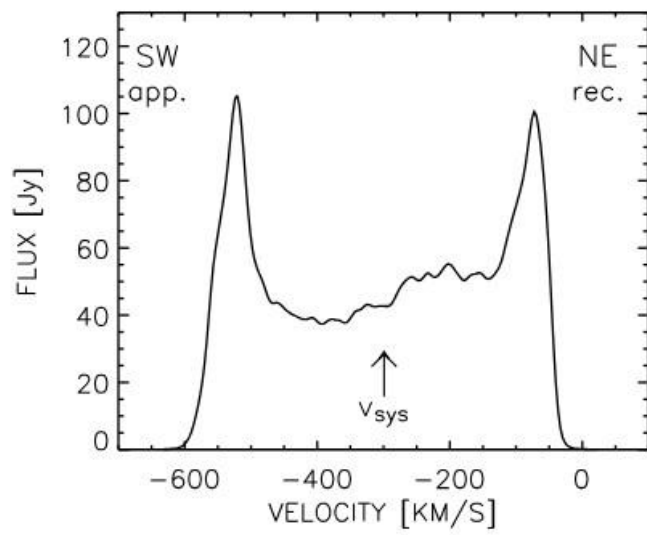
A Brief Guide to the Nearest Bright HI Galaxies

Jason Burnfield 21 July 2026

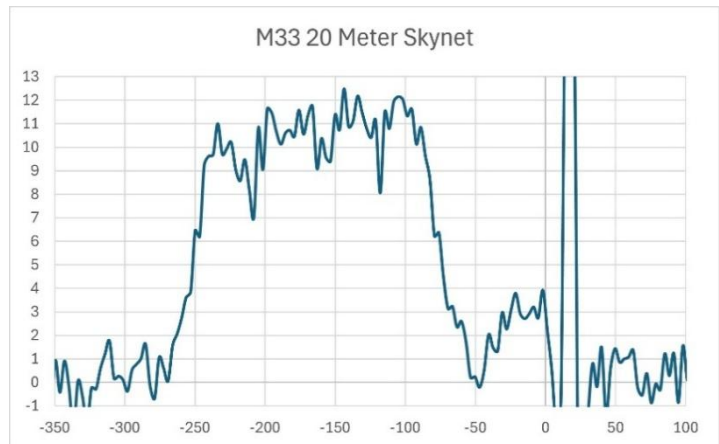
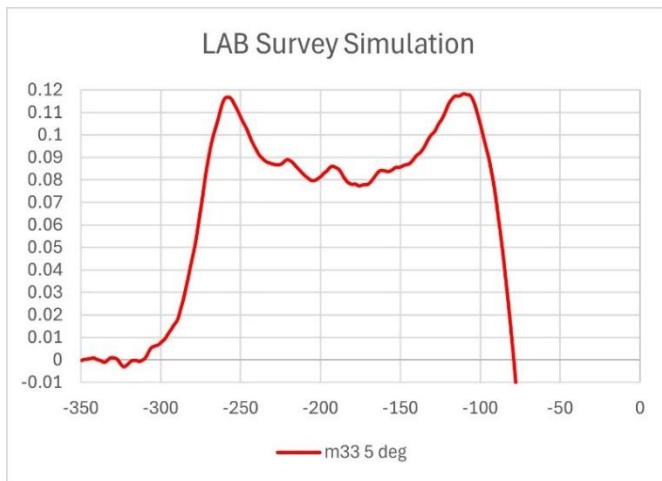
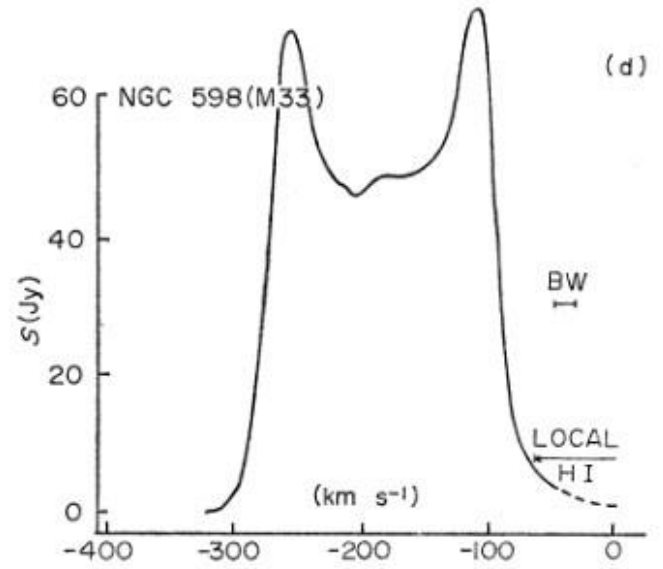
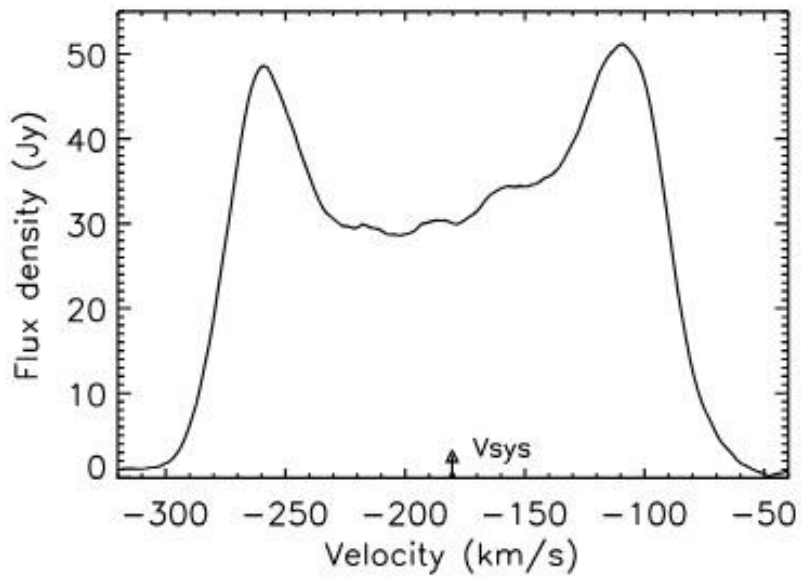
After doing Hydrogen Line drift scan observations of nearby galaxies with small aperture amateur setups over the past few years, I wanted to put together a quick guide for others who may want to try detecting them as well. I have pulled together hydrogen spectra of the brightest nearby galaxies from several professional surveys as well as my own observations using the 20 Meter Skynet Dish at Green Bank Observatory. I have averaged together the relative peak amplitudes from all the available sources for each galaxy to come up with a ranking from brightest to dimmest. I have also given the relative brightness of each as compared with Messier 31.

Nearby Hydrogen Line Galaxy Observation List											
Galaxy Name	Alternate Name	RA	Dec	Center Velocity (km/s)	Chemin, Carignan, & Foster/Kam, Carignan, Chemin, Foster, Elson, & Jarrett Jy	Dean & Davies Jy	A. H. Rots Jy	THINGS Jy	LAB Survey (5 deg HPBW) K	20 Meter Skynet K	Compared to M31
Messier 31	Andromeda Galaxy	00 43	41 16	-301	105	120					100%
Messier 33	Triangulum Galaxy	01 34	30 40	-179	51	72			0.118	12	54%
IC342	Hidden Galaxy/ Caldwell 5	03 47	68 06	31			36		0.066	7	39%
Messier 101	Pinwheel Galaxy/ NGC5457	14 03	54 21	241		16	15	8	0.032	2	15%
Messier 81	Bode's Galaxy/ NGC3031	09 56	69 04	-39			13	5.9	0.022	1.2	12%
IC10		00 20	59 18	-350		10			0.014	1.6	7%
Messier 74	NGC628/ Phantom Galaxy	01 37	15 47	657		9	7.9	5.4		1.3	9%
NGC2403	Caldwell 7	07 37	65 36	133			7.5	5.8	0.012	1	8%
Holmberg ii	AO814	08 19	70 43	142		5.9	5.9	3.8		0.9	7%

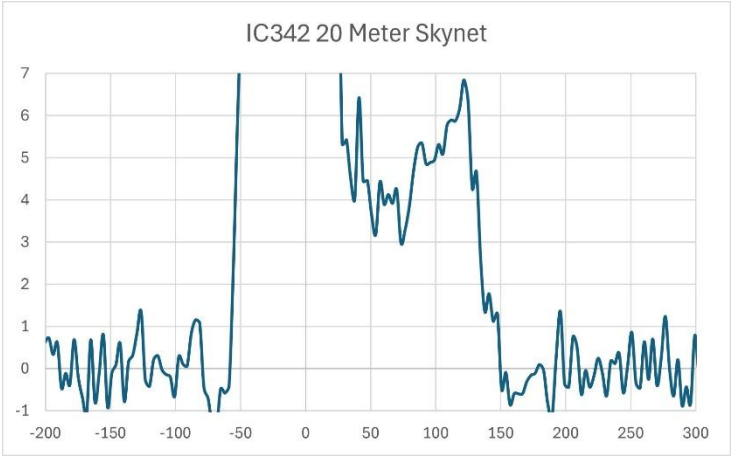
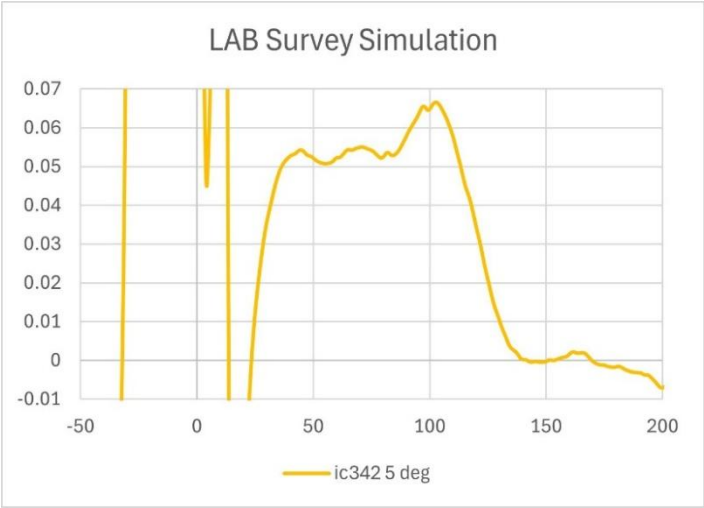
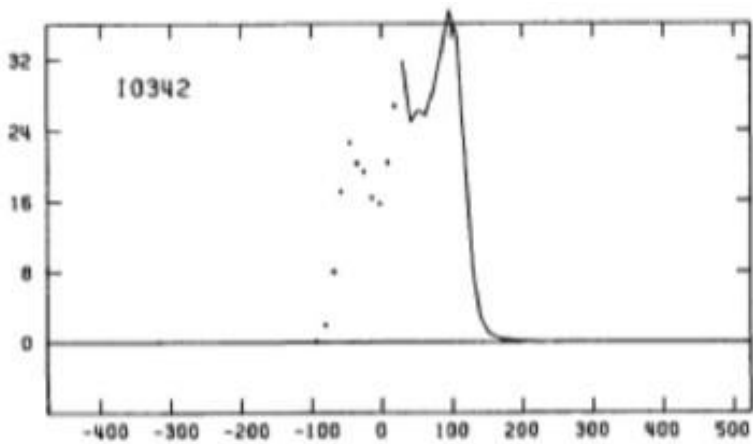
M31 – The Andromeda Galaxy (NGC224)



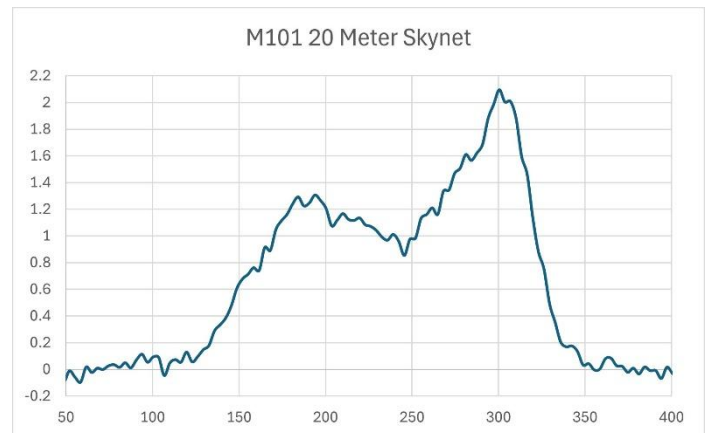
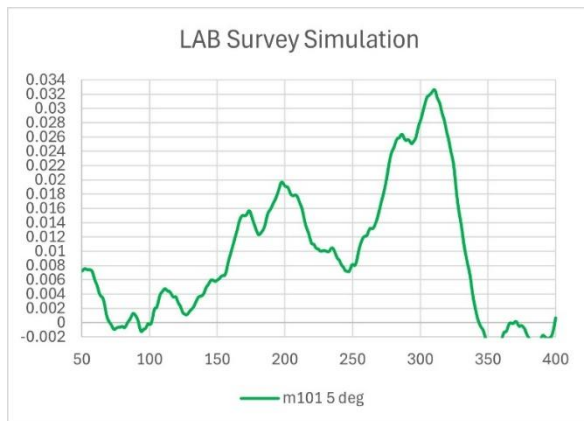
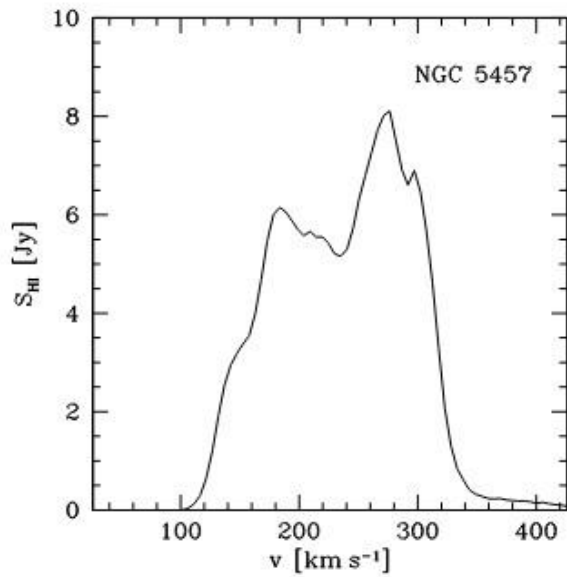
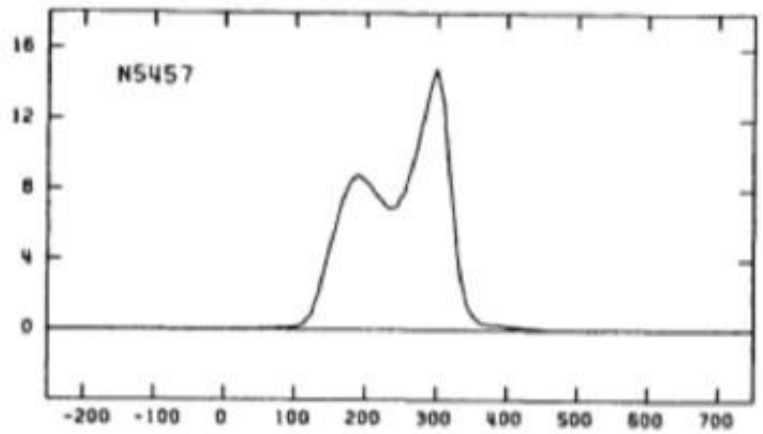
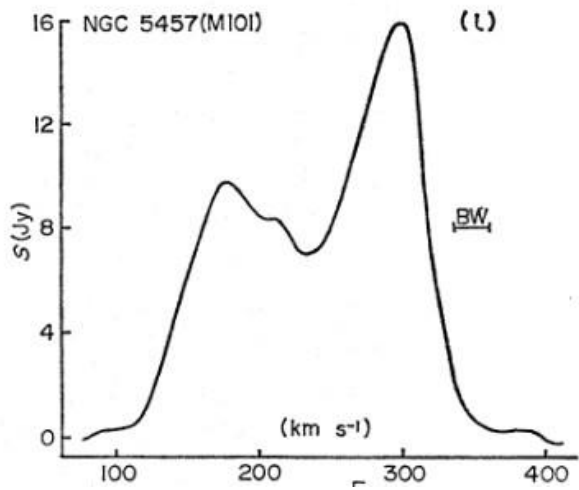
M33 – The Triangulum Galaxy (NGC598)



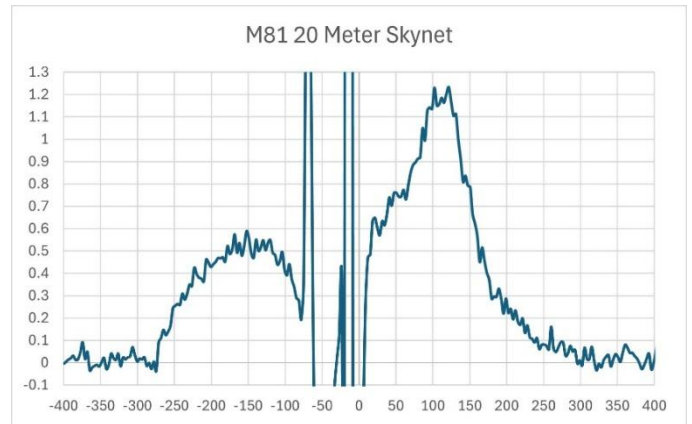
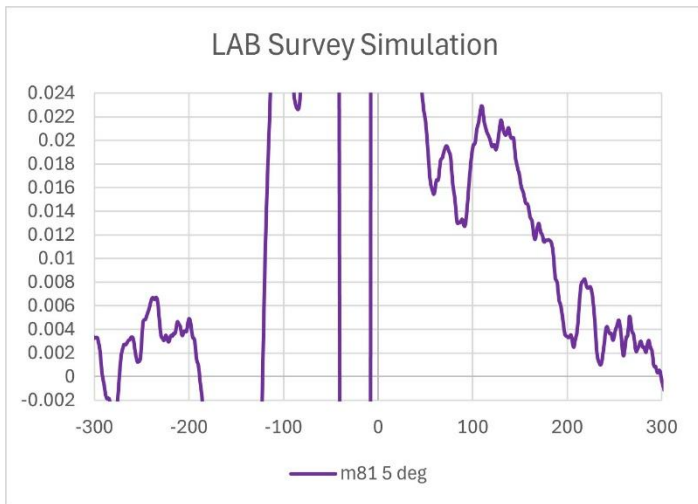
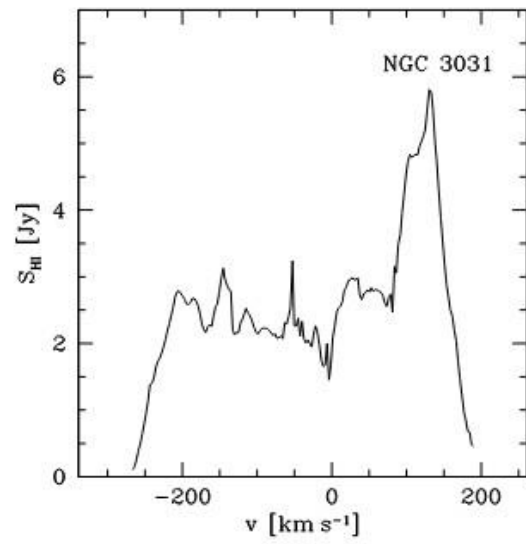
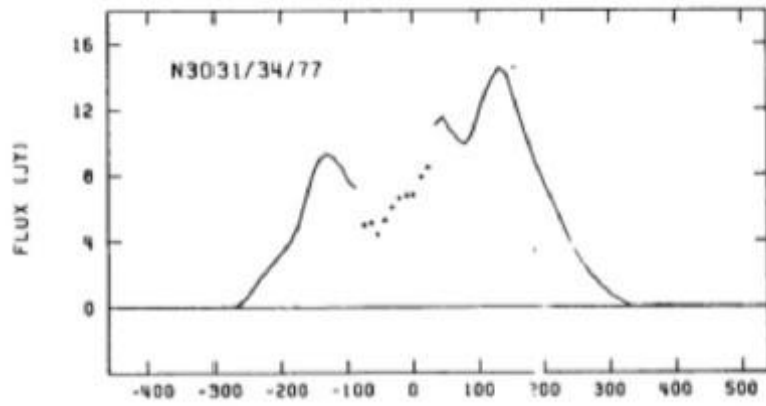
IC342 – The Hidden Galaxy (Caldwell 5)



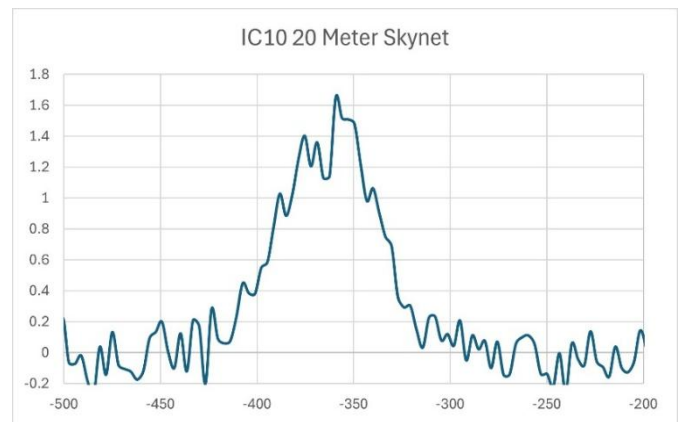
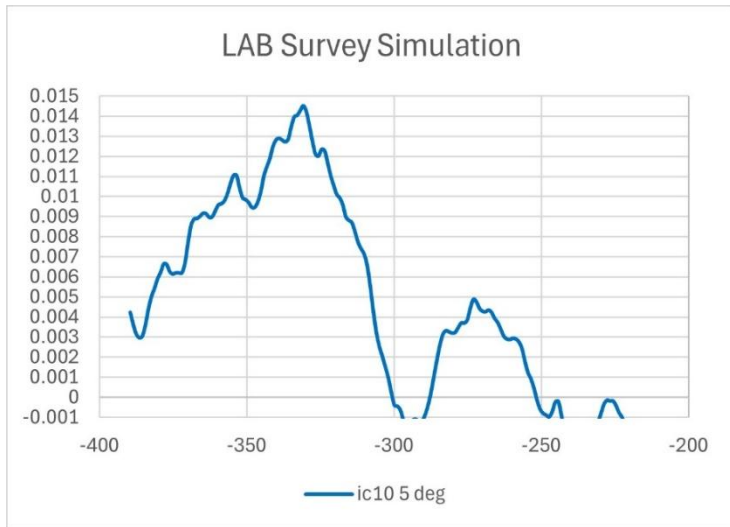
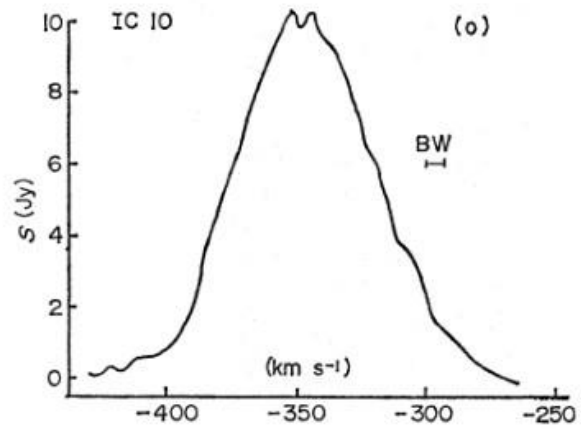
M101 – The Pinwheel Galaxy (NGC5457)



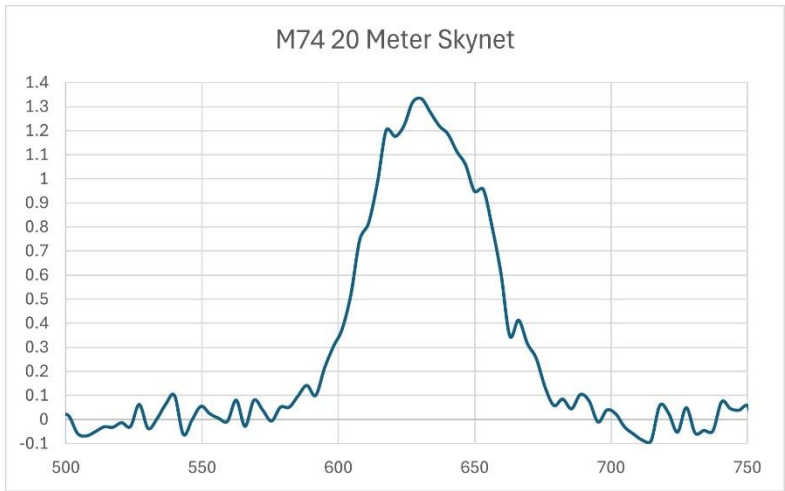
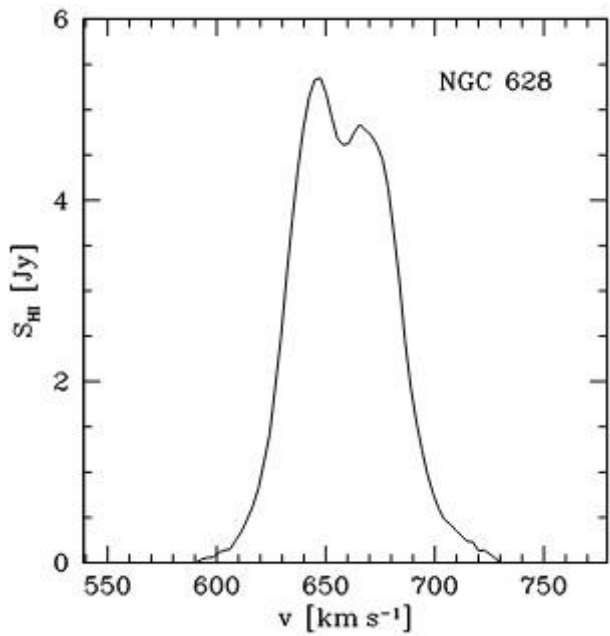
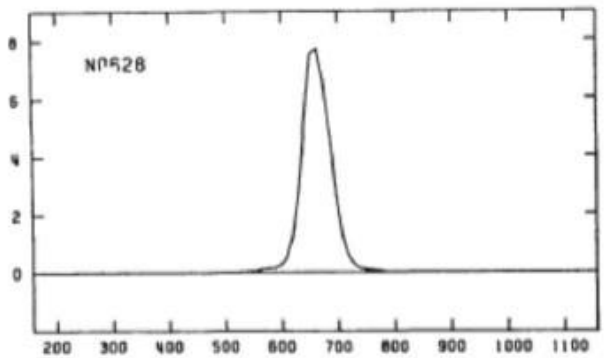
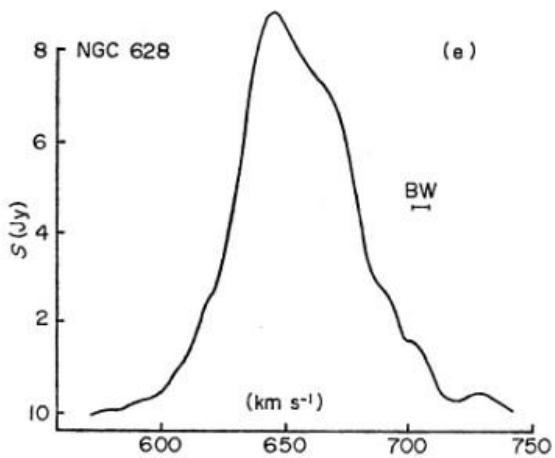
M81 (NGC3031)



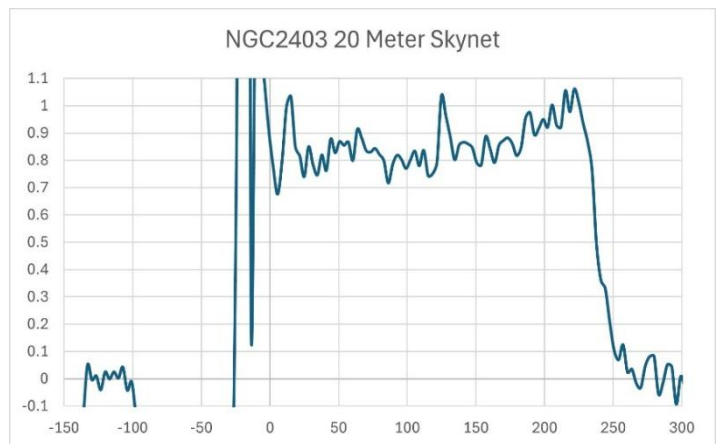
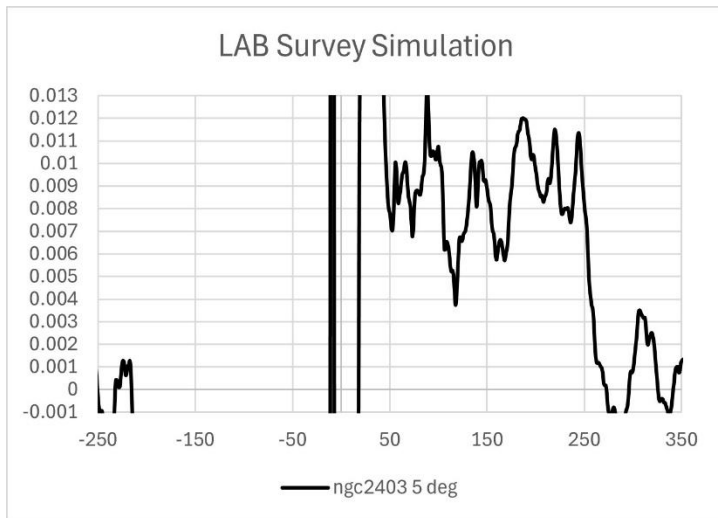
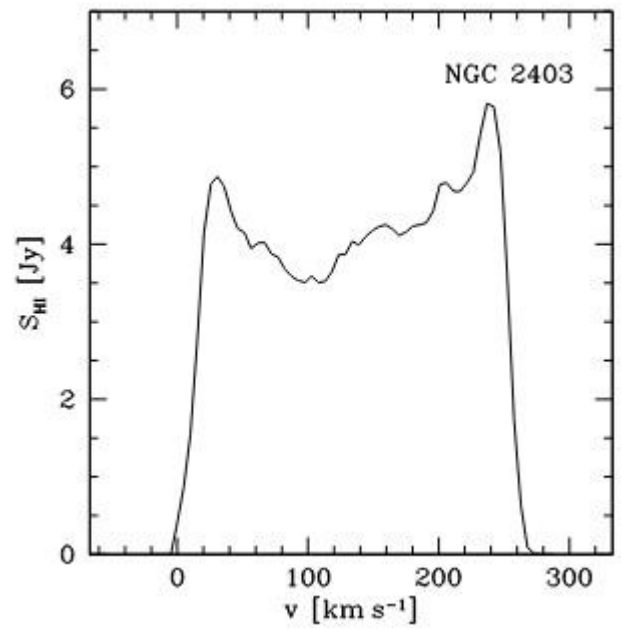
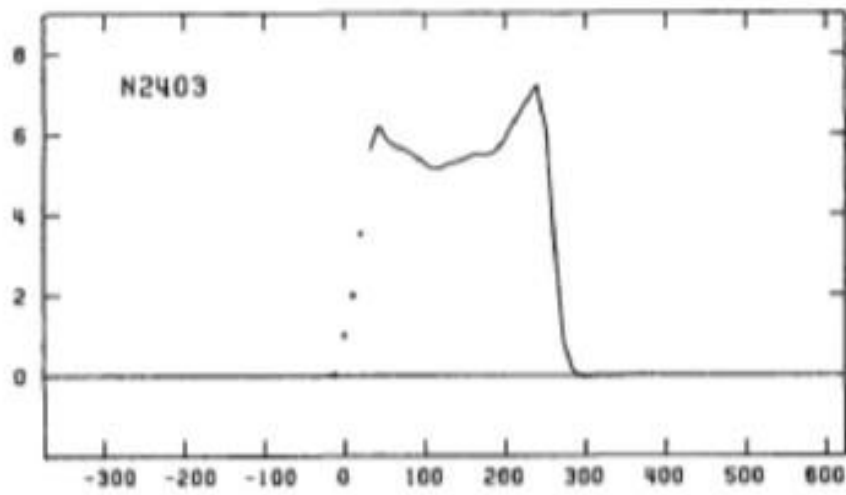
IC10



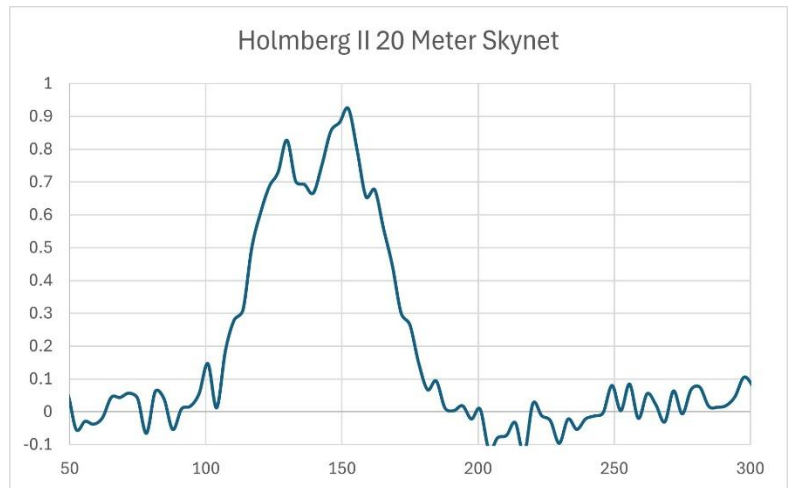
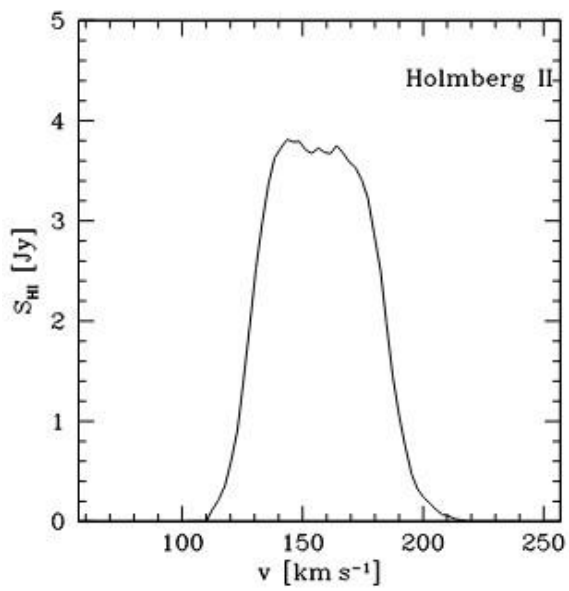
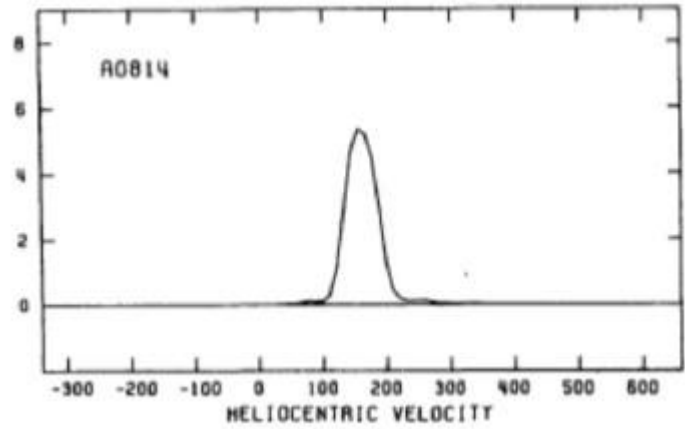
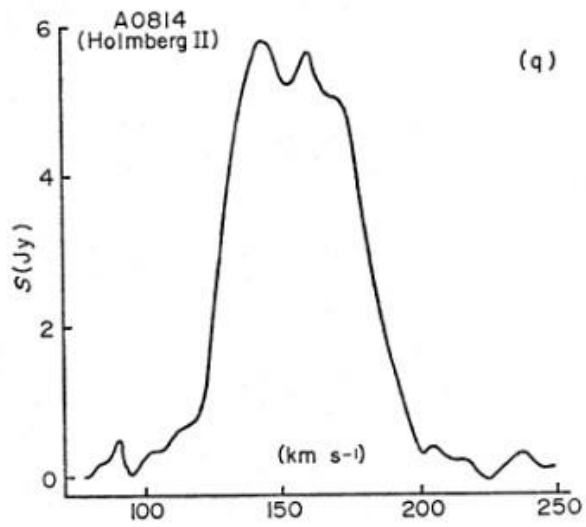
M74 – Phantom Galaxy (NGC628)



NGC2403 (Caldwell 7)



Holmberg II (A0814)



References

1. Laurent Chemin, Claude Carignan and Tyler Foster – H I Kinematics and Dynamics of Messier 31
<https://arxiv.org/pdf/0909.3846v1.pdf>
2. S. Z. Kam, C. Carignan, L. Chemin, T. Foster, E. Elson, T. H. Jarrett – H I Kinematics and Mass Distribution of Messier 33 <https://arxiv.org/pdf/1706.04248.pdf>
3. J.F. Dean and R.D. Davies - The Integrated Neutral Hydrogen Properties of Nearby Galaxies
<https://academic.oup.com/mnras/article/170/3/503/961865>
4. A. H. Rots - A Neutral Hydrogen Mapping Survey of Large Galaxies
https://www.researchgate.net/publication/234361514_A_neutral_hydrogen_mapping_survey_of_large_galaxies_I_-_Observations
5. Fabian Walter, Elias Brinks, W.J.G. De Bolk, Frank Bigel, Robert C. Kennicutt, Jr., Michele D. Thornley, Adam K. Leroy – THINGS: The HI Nearby Galaxy Survey <https://arxiv.org/abs/0810.2125>
6. J. Burnfield - H1 Galaxy Observations Using the Green Bank 20 Meter Skynet Dish
7. https://www.astro.uni-bonn.de/hisurvey/AllSky_profiles/

Noise Figure Measurements Below 10 MHz

Whitham D. Reeve

1. Introduction



Common commercial noise sources used in everyday lab work are specified and calibrated at intervals from a low frequency limit of 10 MHz to the source's upper frequency limit. I previously investigated extending the lower frequency limit of certain noise sources down to 2 MHz {[Reeve26](#)}.

The present article provides examples of some amplifier noise figure measurements at lower frequencies using two of those noise sources and a spectrum analyzer with a noise figure measurement option.

A benefit of the noise figure measurements is that the amplifier gain is measured and displayed at the same time, so both noise figure and gain measurements are provided. Of importance to these measurements and also discussed are the somewhat specialized analyzer settings below 10 MHz.

2. Amplifier Descriptions

The amplifiers listed in table 1 and shown in figure 1 make up the measurement regimen. Most of these devices are of interest to me because they have frequency ranges that are compatible with the Callisto instruments used in the e-CALLISTO Solar Radio Spectrometer Network {[eCALLISTO](#)}.

Table 1 ~ Amplifiers used for noise figure measurements

Model	Datasheet Frequency range	Measured frequency range	Remarks
LWA FEE V2	20 to 85 MHz	2 to 200 MHz	Routinely used down to 5 MHz or lower
nenuFAR LNA	10 to 85 MHz	2 to 200 MHz	Not presently used in the USA
LNA-1 LNA	25 to 3000 MHz	2 to 3000 MHz	S/N 101, also 2 to 200 MHz
LNA-2 LNA	25 to 1000 MHz	2 to 1000 MHz	S/N 201, also 2 to 200 MHz
HP 8447A Modified	9 kHz to 3000 MHz	2 to 3000 MHz	S/N 9600, Wenteq ABL0300-00-3030 amplifier

The Callisto has a native frequency range of 45 to 870 MHz, but that is easily extended with an up-converter or down-converter whose intermediate frequency (IF) output is within the native frequency range. With an up-converter, the Callisto is an ideal instrument for use with the Long Wavelength Array (LWA) Antenna over a frequency range of 5 to 85 MHz. The noise figure measurements purposely extend below the amplifiers' datasheet frequency ranges shown in the table to see if they might be usable at the lower frequencies.

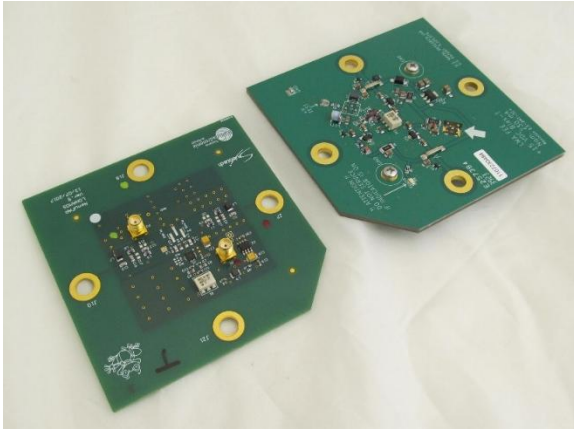


Figure 1.a ~ NenuFAR LNA (left) and LWA FEE V2 (right). Both amplifiers have the same dimensions but are different designs. The NenuFAR LNA is shown with the two SMA connectors pointed up and the LWA-FEE V2 is shown with the connectors pointed down. Both amplifiers have one amplifier on the top and other on the bottom to provide a dual polarization device. The dipole elements connect to the larger holes along the sides. A polarizing notch in one corner of the PCBs ensures the proper orientation when mounted in the hub of a crossed-dipole LWA Antenna.



Figure 1.b ~ LNA-2 (left) and LNA-1 (right). Both LNAs have an antenna connector and receiver connector. The 12 Vdc powering voltage is fed through the receiver connector from a bias-tee near the receiver. The weatherproof cover is plastic while the mounting base/bracket is aluminum. A mast clamp is used with the amplifiers to attach to a mast immediately below the antenna.



Figure 1.c ~ HP 8447A Modified. This is a lab amplifier and not intended for dedicated use with a receiver. This particular unit has been internally modified with a Wenteq ABL0300-00-3030 amplifier that replaces the original HP amplifier. The modification included replacing the original BNC-F connectors on the front panel with type N-F connectors as well as modifying the internal power supply for the lower voltage required by the Wenteq amplifier.

The Long Wavelength Array (LWA) Front End Electronics (LWA FEE) is used in the LWA and its many derivatives, all of which use the well-known tied-fork, crossed-dipole *LWA Antenna*. The nenuFAR LNA is another front end alternative for the LWA Antenna. It is electrically and mechanically compatible with this antenna, but its design is far different from the LWA FEE V2 and its frequency range extends to approximately 300 MHz. The nenuFAR uses an ASIC instead of the MMICs used in the LWA FEE V2. The noise figures of both front ends are measured under identical conditions while installed in the LWA FEE Test Fixture V2, which powers the amplifiers through the test fixture's built-in bias-tee. The LWA FEE V2 design documents and PCB EDA files are located at [{LWAFEE}](#). No design documents are available for the nenuFAR amplifier but overall information is here {nenuFAR}.

The LNA-1 and LNA-2 are commercial products intended for use with broadband antennas such as Log Periodic Dipole Array antennas, Discone antennas or, at higher frequencies, parabolic dish antennas. The amplifiers are powered through a lab bias-tee (Mini-Circuits ZBT-4R2GW+). Two sets of measurements are provided, one that covers the amplifier's entire frequency range and another that covers from 2 to 200 MHz as a compatibility test for use with the LWA Antenna.

The HP 8447A Modified amplifier is a repurposed single-channel laboratory amplifier originally manufactured by Hewlett-Packard for many years starting in the 1970s. The original internal amplifier was not very reliable, and I replaced it with a modern low noise amplifier manufactured by Wenteq. The Wenteq amplifier has the same or better operating specifications compared to the old HP internal amplifier. The two main enhancements are noise figure and frequency range. This amplifier normally is not used for operational observations, but it could be.

3. Noise Source Selection

There are no rigid rules for selecting the noise source used in noise figure measurements. Guidelines published by Rohde & Schwarz, immediately below, are the most rigorous of the methods described here; two simpler methods are described later.

$$\text{Guideline 1. } NF_{DUT} + G_{DUT} - NF_{SA} > 1 \text{ dB} \quad (\text{Alternative form: } NF_{DUT} + G_{DUT} > NF_{SA} + 1 \text{ dB}) \quad (1)$$

$$\text{Guideline 2. } ENR_{NS} - NF_{DUT} > 5 \text{ dB} \quad (\text{Alternative form: } ENR_{NS} > NF_{DUT} + 5 \text{ dB}) \quad (2)$$

$$\text{Guideline 3. } ENR_{NS} - NF_{SA} > 3 \text{ dB} \quad (\text{Alternative form: } ENR_{NS} > NF_{SA} + 3 \text{ dB}) \quad (3)$$

To use the guidelines, some basic knowledge of the amplifier, or Device Under Test (DUT) as it sometimes is called here, and spectrum analyzer is needed. First, estimates of the DUT noise figure and gain are needed for Guidelines 1 and 2. These may be estimated or obtained from the amplifier datasheet if available. If necessary, an initial estimate can be made and then updated after measurements, but this is necessary only if the guidelines produce

a far different ENR afterwards. This potentially could be an iterative process, but more than an initial estimate usually is unnecessary. Commercial noise sources are available with only a few ENR values, typically 5 or 6, 15 and 21 dB, so some judgement almost always is needed. Table 2 summarizes the values obtained from the alternative form of Guidelines 1 and 2 for each amplifier.

Next, the analyzer noise figure is needed in Guidelines 1 and 3. The analyzer noise figure, NF_{SA} , is the composite of the internal preamplifier, which always is enabled for noise figure measurements, and the spectrum analyzer noise figures. The FPL analyzer noise figure with the preamplifier enabled was not explicitly determined in {Reeve26} but it can be found from the DANL specification in the datasheet or from the DANL measurements. The noise markers used to measure the FPL analyzer DANL take into account all corrections, in which case the analyzer noise figure is simply

$$NF_{SA} = DANL + 174 \quad (4)$$

where NF_{SA} is the spectrum analyzer noise figure with preamplifier enabled (dB), DANL is the Display Average Noise Level (dBm Hz⁻¹) and the constant 174 is the noise power spectral density at the reference temperature 290 K (dBm Hz⁻¹). It was determined in {Reeve26}, figure D2.a (see appendix of this article for a duplicate copy), the FPL DANL is not constant below 10 MHz, so the analyzer noise figure is separately calculated for several frequencies below 10 MHz (table 3). For frequencies between measurement points, the noise figure can be interpolated but this is not normally necessary.

Table 2 ~ Amplifier nominal noise figures and gains (assumed to be flat across the frequency range) and Guidelines 1 and 2.

Model	DUT Noise figure (dB)	DUT Gain (dB)	Guideline 1 $NF_{DUT} + G_{DUT}$ (dB)	Guideline 2 $NF_{DUT} + 5$ dB
LWA FEE V2	3	34	37	8
nenuFAR Front End	2	26	28	7
LNA-1 LNA	1	25	26	6
LNA-2 LNA	1	25	26	6
HP 8447A Modified	3	30	33	8

Table 3 ~ FPL analyzer noise figure measurements (NF_{SA}) calculated from DANL in {Reeve26} and Guidelines 1 and 3.

Frequency (MHz)	DANL (dBm Hz ⁻¹)	NF _{SA} (dB)	Guideline 1 NF _{SA} + 1 dB	Guideline 3 NF _{SA} + 3 dB
2	-162.53	11.5	12.5	14.5
3	-164.36	9.6	10.6	12.6
5	-166.13	7.9	8.9	10.9
7	-166.75	7.3	8.3	10.3
≥ 10	-167.09	6.9	7.9	9.9

Results of the above analysis:

Guideline 1. $NF_{DUT} + G_{DUT} > NF_{SA} + 1 \text{ dB}$: 20 to 37 dB > 12.5 dB (2 MHz) to 7.9 dB (≥ 10 MHz) (Table 2 & 3) ✓

Guideline 2. $ENR_{NS} > NF_{DUT} + 5 \text{ dB}$: If $ENR_{NS} = 15 \text{ dB} > 6 \text{ to } 8 \text{ dB}$ depending on amplifier (Table 2) ✓

Guideline 3. $ENR_{NS} > NF_{SA} + 3 \text{ dB}$ If $ENR_{NS} = 15 \text{ dB} > 14.5 \text{ dB}$ (2 MHz) to 9.9 dB (≥ 10 MHz) (Table 3) ✓

The above guidelines favor a 15 dB ENR especially at the lower frequencies. Above 2 or 3 MHz, a 5 or 6 dB ENR may be appropriate.

A simpler noise source selection can be made by using a rule of thumb (Reeve14), which I will call a *Rule of Thumb*. I do not remember the source, but it probably was published years ago in technical literature:

The noise source ENR should be within about 10 dB of the device's noise figure. For example, a 5 dB ENR noise source may be used to measure noise factors up to about 15 dB, and a 15 dB ENR noise source should not be used to measure noise factors below approximately 5 dB or above approximately 25 dB.

This rule of thumb assumes the analyzer has an internal low noise preamplifier, or an external low noise amplifier is used in the measurement setup. This method favors a 5 dB ENR noise source for the amplifiers to be measured here.

Keysight recommends using a 15 dB ENR noise source to measure noise figure up to 30 dB, and a 6 dB ENR noise source when the DUT has a very low noise figure or does not exceed 15 dB [Keysight18]. Keysight does not define a *very low noise figure* in their recommendations. This method favors a 5 dB ENR noise source for the amplifiers to be measured.

Based on the three above selection methods, either the HP 346B: s/n 2614A06872, with ENR = 15 dB or the HP 346A: s/n 2614A01751 with ENR = 5 dB may be used. For comparison, two sets of measurements are described later, one set for each noise source.

4. Instrumentation

The Rohde & Schwarz FPL1003 spectrum analyzer is used for the noise figure measurements. Its frequency range is 5 kHz to 3 GHz. This is the same analyzer used to measure the noise sources described in {[Reeve26](#)}. The FPL is equipped with the *Noise Figure* option (FPL1-K30) and *Additional Interfaces* option (FPL1-B5). It also is equipped with the *Preamplifier* option (FPL1-B22) that simplifies most noise figure measurements (an external low noise preamplifier usually is required if this option is not equipped).

The Noise Figure option provides signal processing and measurement displays that are tailored to noise figure measurements. The Additional Interfaces option includes a connector on the instrument's rear panel and an internal 28 Vdc source for controlling the hot and cold states of an external noise source.

As mentioned in the previous section, the HP 346A noise source with a nominal ENR of 5 dB and HP 346B noise source with a nominal ENR of 15 dB are used for all measurements. Both sources were calibrated within a couple months of their use here. The 28 Vdc noise source control cable from the analyzer rear panel was equipped with multiple ferrite beads to reduce common mode noise that might be conducted into the noise sources.

The noise source calibration certificate and sticker on the noise source itself show the calibration frequencies and corresponding ENRs but only down to 10 MHz. The ENRs at frequencies below 10 MHz are set to the value at 10 MHz as discussed in {[Reeve26](#)}. The ENRs were Saved in the FPL as an ENR Table from 0 Hz to the noise source upper frequency limit, which is 18 GHz for both the HP 346A and HP 346B (figure 2). ENR tables for any number of noise sources can be entered this way. The analyzer interpolates the ENR values at frequencies not listed in the tables.

Prior to noise figure measurements, the FPL was calibrated using the *2nd Stage Correction* calibration procedure, which takes into account the inherent noise of the analyzer when calculating the measurement results. The procedure requires a noise source to be connected directly to the analyzer RF Input and controlled by the voltage source on the rear panel. This correction was done for each frequency range and measurement points combination. Each Calibration set was Exported to an XML file stored on a USB drive and then Imported as needed for measuring each amplifier frequency range. This avoids repetitive setup and calibration when making a series of measurements over different frequency ranges.

A variable linear power supply, Siglent SPD3303X, was used to provide the operating voltages necessary for the amplifiers. The nenuFAR operates from 5.5 to 16 Vdc and was measured at 12 Vdc input. The LNA-1 and LNA-2 use 12 Vdc supplied through the LPC-3 power coupler. The TSS-23ULN+ is setup on its evaluation board to use either 3 or 5 Vdc but it was measured with 5 Vdc input. The GALI-74+ may be operated from 7.0 to 15.0 Vdc depending on the bias resistance installed on the evaluation board; I used the bias resistor for 12.0 Vdc input that was supplied with the board.

Frequency	Value
0 Hz	5.06 dB
1.00000000 MHz	5.06 dB
10.00000000 MHz	5.06 dB
100.00000000 MHz	5.11 dB
1.000000000 GHz	5.00 dB
2.000000000 GHz	4.95 dB
3.000000000 GHz	4.74 dB

Figure 2 ~ Partial ENR table for the HP 346A noise source. ENR values below 10 MHz are according to {Reeve26} and for 10 MHz and above are from the calibration sticker on the noise source or the associated calibration certificate. A value is included for 0 Hz but any measurements with the FPL1003 spectrum analyzer under the conditions described in this article are valid only down to 2 MHz. The table is stored in the XML format and can be imported or exported. A similar ENR Table was populated for the HP 346B noise source.

4. Instrument settings

The following discussion applies to the FPL1003 analyzer described in the previous section, but the concepts can be applied to other spectrum analyzers. There are some important parameters that must be considered when making noise figure measurements – frequency, resolution bandwidth (RBW) and sweep time.

Dedicated noise figure analyzers (NFA) typically have a 3 or 4 MHz resolution bandwidth filter, which is suitable for measurements at 10 MHz and above. The analyzer sweep rates are optimized for those bandwidths. When measuring noise figures below 10 MHz, lower RBW settings and longer sweep times are necessary to maintain measurement accuracy.

The FPL allows specific RBW and sweep times to be listed in a Frequency Table, which is then used for the noise figure measurements. The Frequency Table itself is manually or automatically populated based on the user specified frequency span and number of measurement points.

For frequencies ≥ 10 MHz, the default Sweep Time per frequency and RBW are 30 ms and 3 MHz, respectively. For frequencies < 10 MHz, the same product of Sweep Time per frequency and RBW is used, as in

$$\text{Sweep Time}_{\text{Freq}} \cdot \text{RBW} = 30\text{ms} \cdot 3\text{MHz} = 90 \cdot 10^3 \tag{5}$$

It is intuitive that the RBW must be lower than the frequency being measured. For example, a 3 MHz RBW setting is not suitable for a measurement at 1 MHz because it would attempt measurements outside the filter frequency range. In this example, 250 kHz RBW would be suitable. The RBW depends on the filter characteristics including type or shape and number of poles. Specific filter details are seldom available for commercial spectrum analyzers, but it is generally understood that the measurement frequency should be at least 3 times higher than the RBW. Factors higher than 3 may be used at the expense of longer sweep times, although most analyzers have only discrete sweep time and RBW settings and a compromise is almost always necessary.

With that in mind, the following may be used for noise figure measurements below 10 MHz:

$$RBW = f_{Meas} / (k) \quad (6)$$

$$Sweep\ Time = 90 \cdot 10^3 / RBW \quad (7)$$

where f_{Meas} is the measurement frequency in Hz, k is a constant between 3 and 6, and sweep time is in s. The k values of 3 and 6 provide practical boundaries on the RBW. The RBW may be found by dividing the measurement frequency f_{Meas} by 3 and again by 6 and then selecting the nearest available RBW setting between the two results. RBW settings are available in the FPL analyzer in a 1-2-3-5 sequence. For example, if $f_{meas} = 3.5$ MHz, $RBW_3 = 1.167$ MHz and $RBW_6 = 583$ kHz. The nearest available RBW setting between the two is 1 MHz.

The Sweep Time in equation (7) applies to each individual frequency in the FPL Frequency Table. The available sweep time settings in the FPL are 1 ms to 8000 s, but the settings for noise figure measurements cover a much smaller range. For the noise figure measurements of interest here, the sweep time settings vary from 300 ms to 30 ms. The RBW and sweep time settings given in table 4 are based on equations (6) and (7). Note that either smaller RBW settings or longer sweep times may be used than those listed.

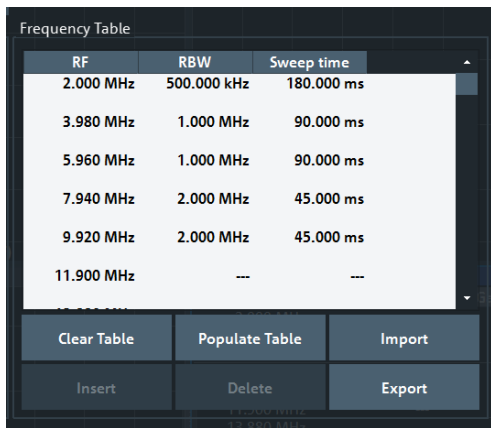
Table 4 ~ Resolution bandwidth and sweep time

Frequency f (MHz)	RBW	Sweep time	Remarks
$1.0 \leq f < 1.5$	300 kHz	300 ms	Frequencies not useable with FPL unless an external preamplifier is used that covers them
$1.5 \leq f < 3.0$	500 kHz	180 ms	2 MHz is lowest usable frequency with FPL internal preamplifier
$3.0 \leq f < 6.0$	1 MHz	90 ms	
$6.0 \leq f < 10.0$	2 MHz	45 ms	
$10.0 \leq f$	3 MHz	30 ms	

For a frequency span f_{span} and number of measurement points n_{Points} , the frequency spacing f is found from

$$f = f_{\text{span}} / (n_{\text{Points}} - 1) \quad (8)$$

For example, if the measurement start and stop frequencies are 2 and 200 MHz, respectively, the frequency span is 198 MHz. If 101 points are to be measured, the frequency spacing or interval $f = 1.98$ MHz. The first measured frequency is 2.0 MHz, and the next one is 3.98 MHz, and so on (figure 3). The frequency Table does not have to be incremental or evenly spaced. It could be manually filled with arbitrary frequencies if they are in the proper range and order, low to high, top to bottom, and the number of frequencies corresponds to the number of measurement points. After the measurement point frequencies are selected, the RBW and Sweep Times are determined as described above and entered in the table for each frequency.



RF	RBW	Sweep time
2.000 MHz	500.000 kHz	180.000 ms
3.980 MHz	1.000 MHz	90.000 ms
5.960 MHz	1.000 MHz	90.000 ms
7.940 MHz	2.000 MHz	45.000 ms
9.920 MHz	2.000 MHz	45.000 ms
11.900 MHz	---	---

Figure 3 ~ Partial frequency table showing frequencies from 2.0 to 11.9 MHz. The RBW and Sweep times may be entered manually with the Insert/Delete buttons or automatically with the Populate Table button based on the frequency span (198 MHz) and number of measurement points (101) specified in another window. The automatic method ensures optimum settings predetermined by the instrument manufacturer. Note that the 11.900 MHz frequency point in this example shows a blank RBW and Sweep time with the — symbol. This is because I used the Populate Table button and this frequency point is set to default values of 3 MHz and 30 ms, respectively. All frequencies above 11.900 MHz (not shown in this image but in the Frequency Table) also are blank and use default values.

Four Frequency Tables were setup with the following ranges (see section 2): 2 to 200 MHz, 2 to 1000 MHz, 2 to 2000 MHz and 2 to 3000 MHz. The number of measurement points was set to provide approximately the same frequency spacing f in each table (table 5). The tables were Exported to an external USB Drive on the analyzer and then recalled as needed (they could just as easily have been stored on the analyzer's internal SSD).

Table 5 ~ Measurement points and frequency spacings

Frequency range & span f_{span} (MHz)	Measurement points	Frequency spacing f (MHz)	Remarks
2 – 200 (198)	101	1.98	
2 – 1000 (998)	506	1.98	
2 – 2000 (1998)	1013	1.97	
2 – 3000 (2998)	1520	1.97	

Improved accuracy at higher frequencies is achieved by compensating for the losses in the coaxial cables or other devices used to connect the DUT to the noise source and analyzer. These are called Input Loss and Output Loss, respectively. However, the noise sources were connected directly to the DUT inputs and no cables were used. Also, since this article is concerned mostly with measurements below 10 MHz, in which the cable losses are negligible, no Output Loss setting was needed. No effort was made to determine cable loss effects on the measurements at the higher frequencies.

5. Measurements

The 2nd Stage Correction (Calibration) was performed for each frequency span and each of the two noise sources discussed in the previous section. These were Saved as Calibration Result files and then Imported as appropriate for each amplifier. The saved Calibration Results were given unique filenames for easy identification such as

CalibrationResults_346A_2-200MHz_YYYY_MM_DD_HH_MM.

Autoscale was used for the vertical scale in all plots, so some measurements appear magnified or compressed. The thicker trace in the noise figure plots is the actual measured value, and the thinner traces above and below it indicate the estimated uncertainties. Uncertainty was automatically calculated for each measurement by the FPL. No Averaging was used except on the HP 8447A Modified amplifier measurements.

The FPL supports only four markers in the Noise Figure mode. For several of the amplifier measurements, two markers were set at 45 and 870 MHz to mark the Callisto lower and upper native frequency limits. Another marker was set at a low frequency and one at a midspan frequency.

The calibration and measurement setups are shown in figure 4, and pictures taken during the lab measurements are shown in figure 5. The measurement results are shown in plot images with the noise figure in the upper frame and gain in the frame immediately below. The Marker Table is in the bottom frame. Two plots labeled a. (5 dB ENR) and b. (15 dB ENR) are shown for each amplifier (figures 6.a and 6.b through figure 11.a and 11.b). The Discussion section provides detailed comments about each measurement set.

Figure 4 ~ Setup schematic. Left: 2nd Stage Correction (Calibration); Right: Measurement

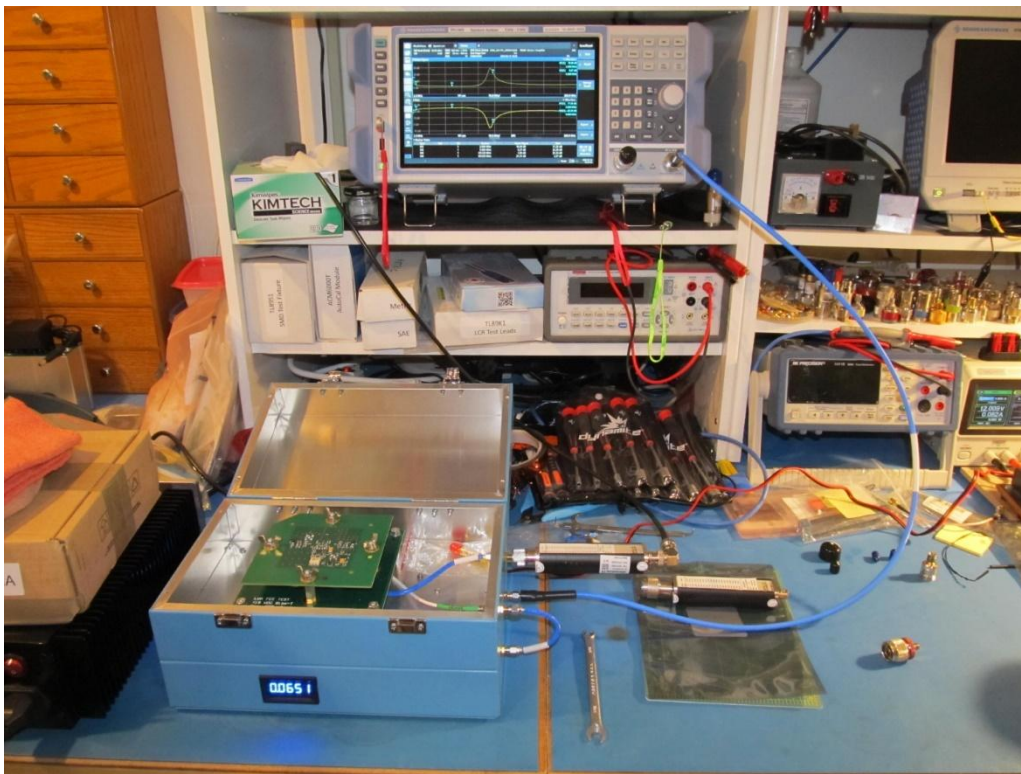
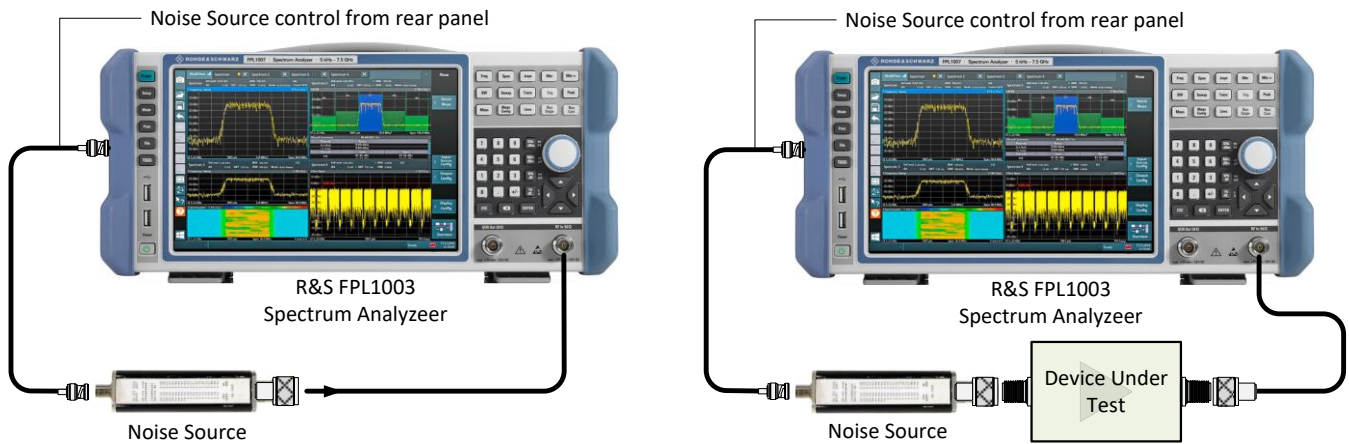


Figure 5.a ~
Foreground: NenuFAR LNA in test fixture before lid is closed and latched. The HP 346A noise source is connected with the HP 346B stands by.
Background: FPL1003 analyzer.

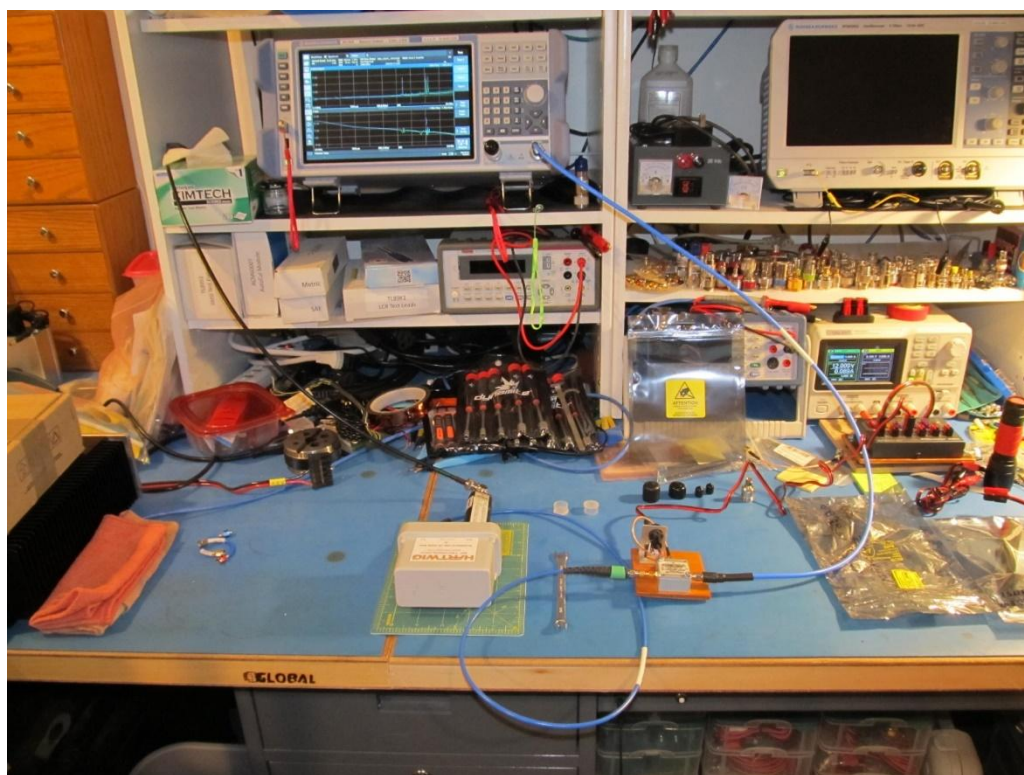


Figure 5.b ~ LNA-1
with lab bias-tee to
right.

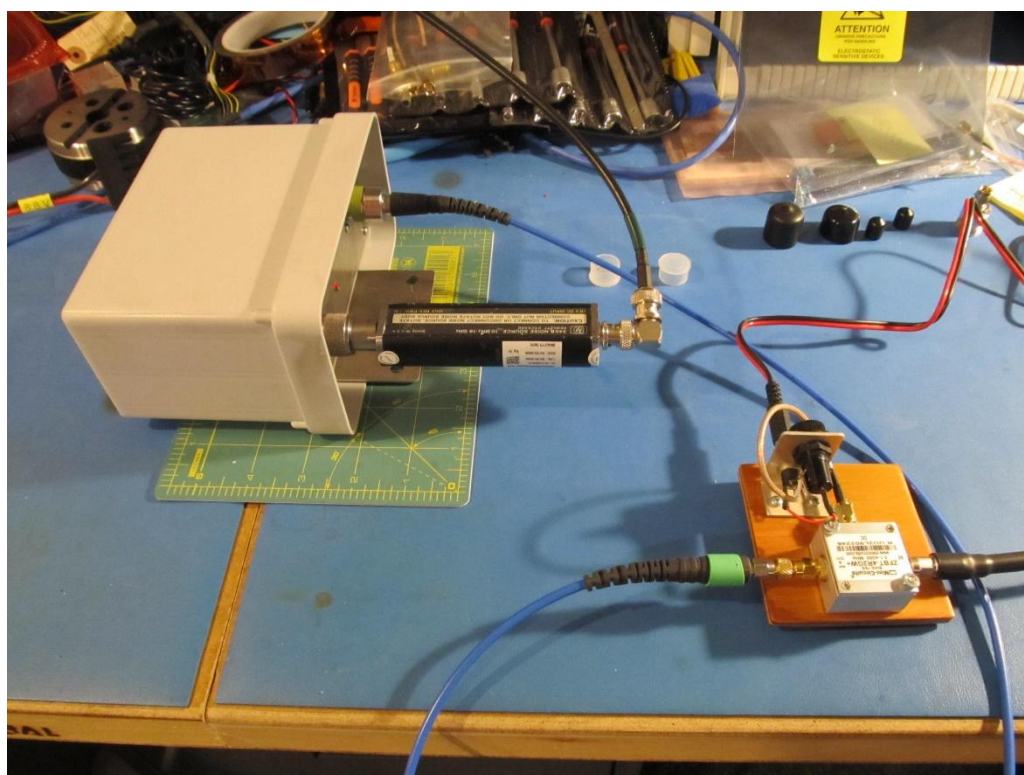


Figure 5.c ~ LNA-2
with HP 346B Noise
Source and Bias-Tee.



Figure 5.d ~ HP 8447A Modified showing HP 346A in use and HP 346B below.

Figure 6.a ~ LWA-FEE V2 (5 dB ENR)

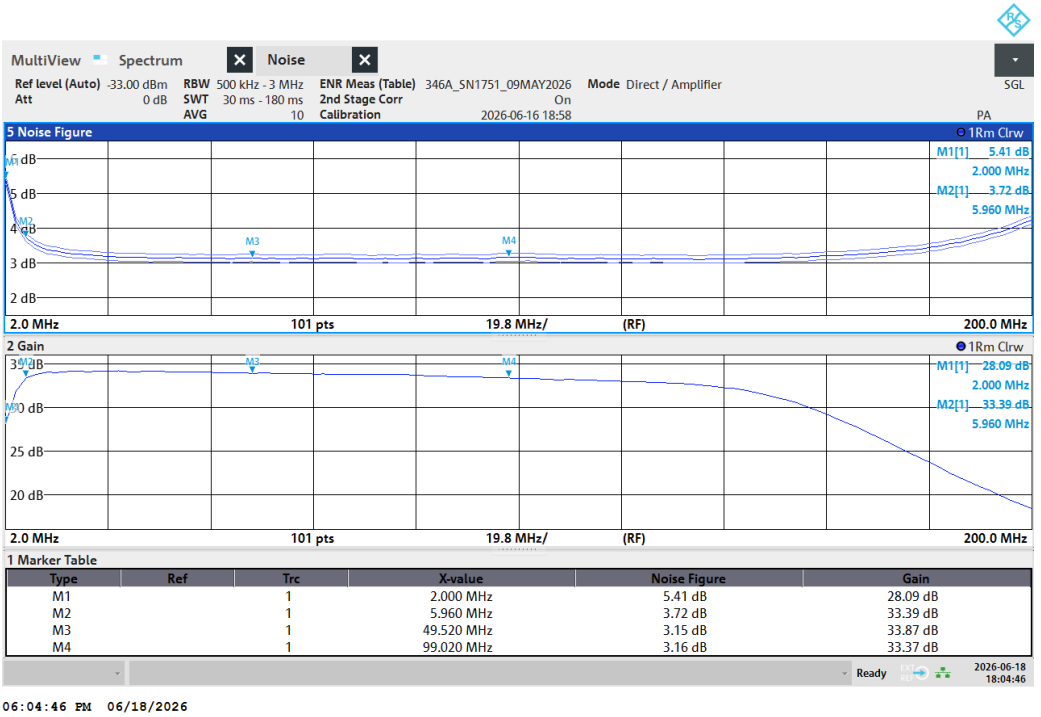


Figure 6.b ~ LWA-FEE V2 (15 dB ENR)

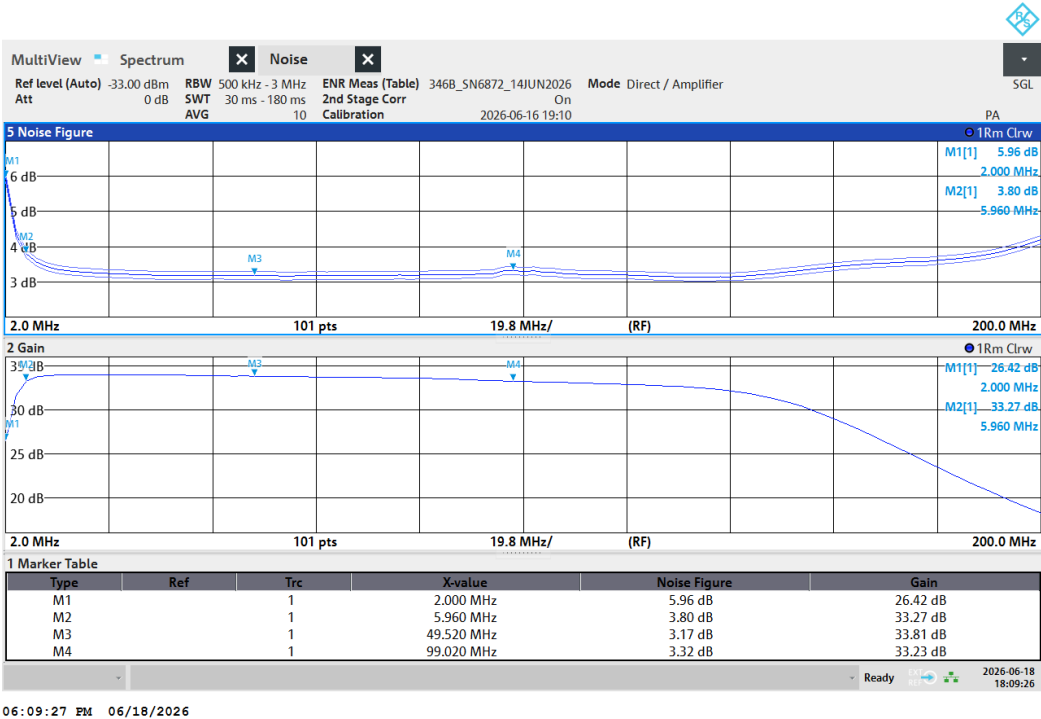


Figure 7.a ~ NenuFAR LNA (5 dB ENR)

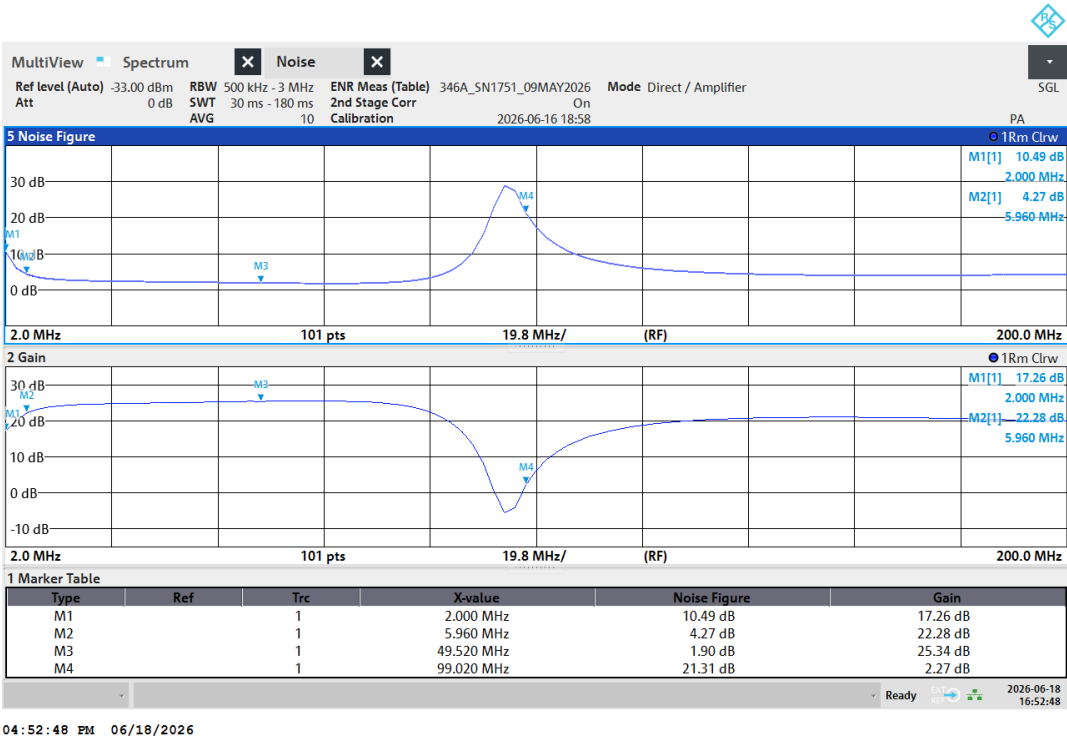


Figure 7.b ~ NenuFAR LNA (15 dB ENR). Note noise figure and gain difference with 346A above

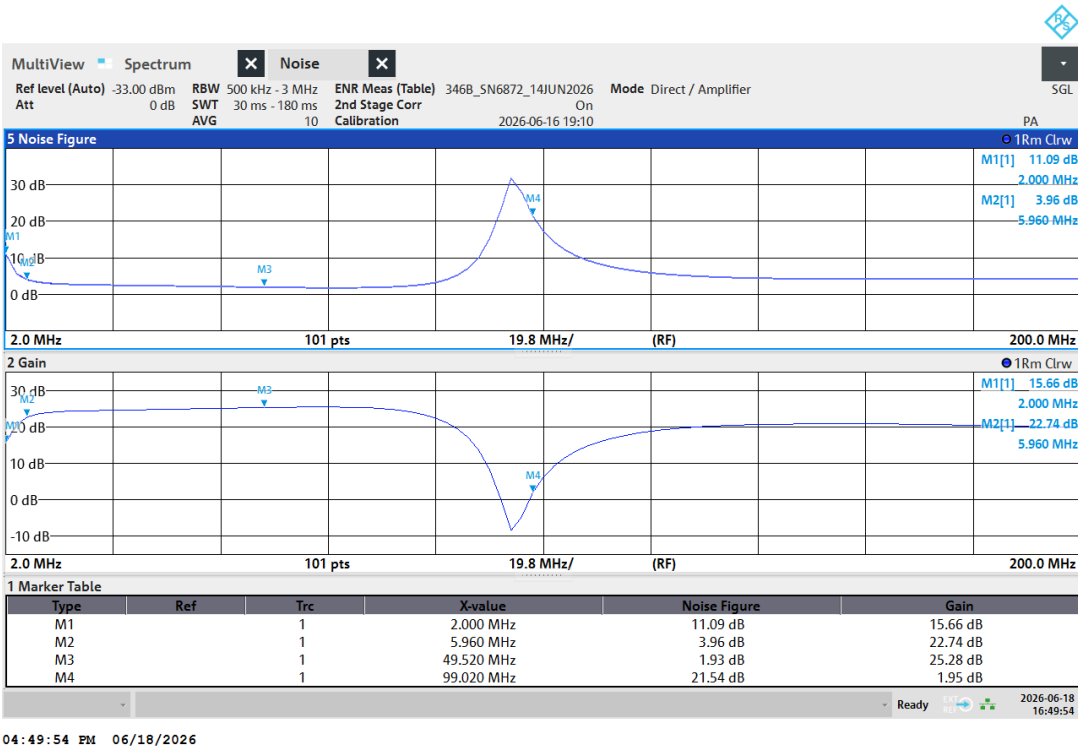


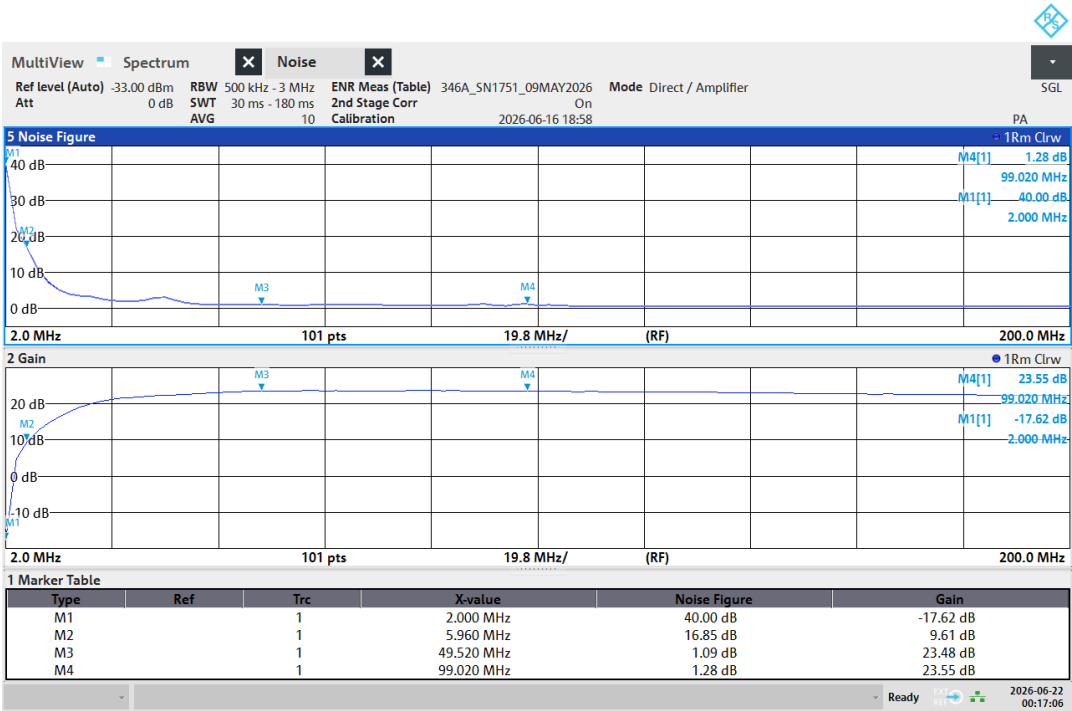
Figure 8.a ~ LNA-1 LNA (5 dB ENR): 2 – 3000 MHz



Figure 8.b ~ LNA-1 LNA (15 dB ENR): 2 – 3000 MHz

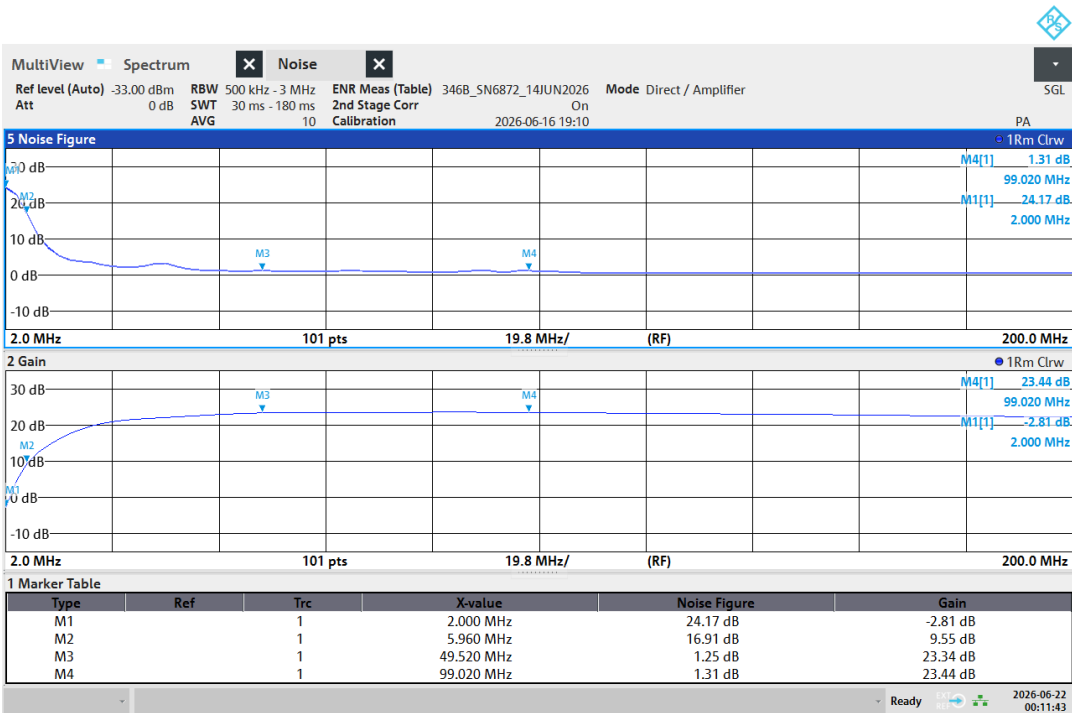


Figure 9.c ~ LNA-1 LNA (5 dB ENR): 2 – 200 MHz



12:17:07 AM 06/22/2026

Figure 9.d ~ LNA-1 LNA (15 dB ENR): 2 – 200 MHz



12:11:44 AM 06/22/2026

Figure 10.a ~ LNA-2 LNA (5 dB ENR): 2 – 1000 MHz

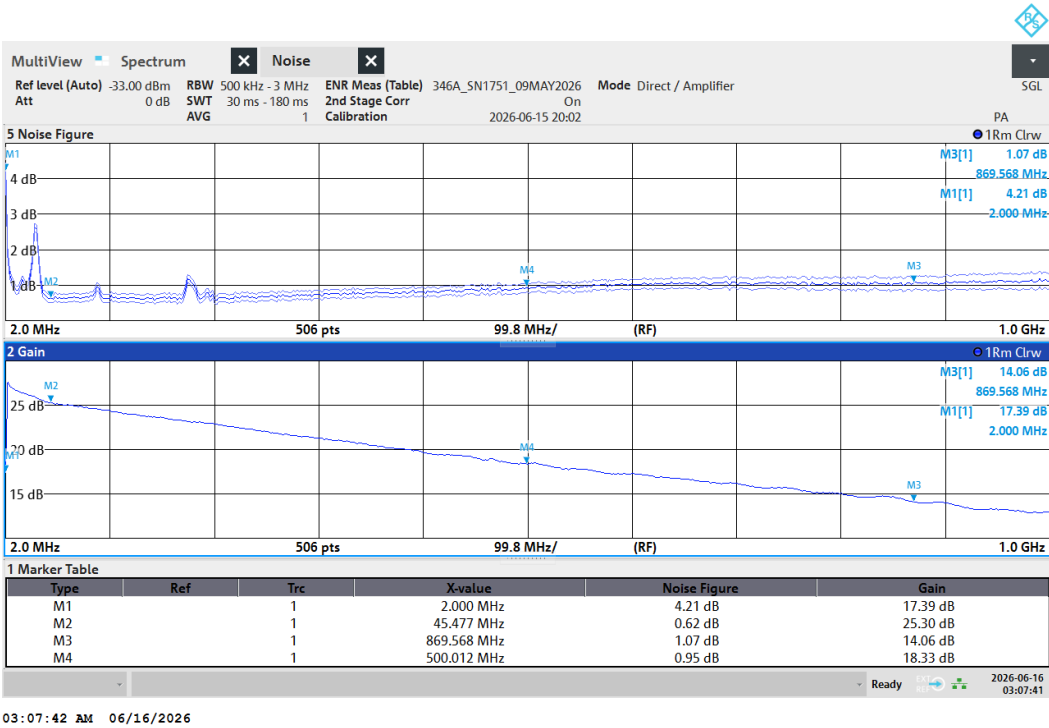


Figure 10.b ~ LNA-2 LNA (15 dB): 2 – 3000 MHz

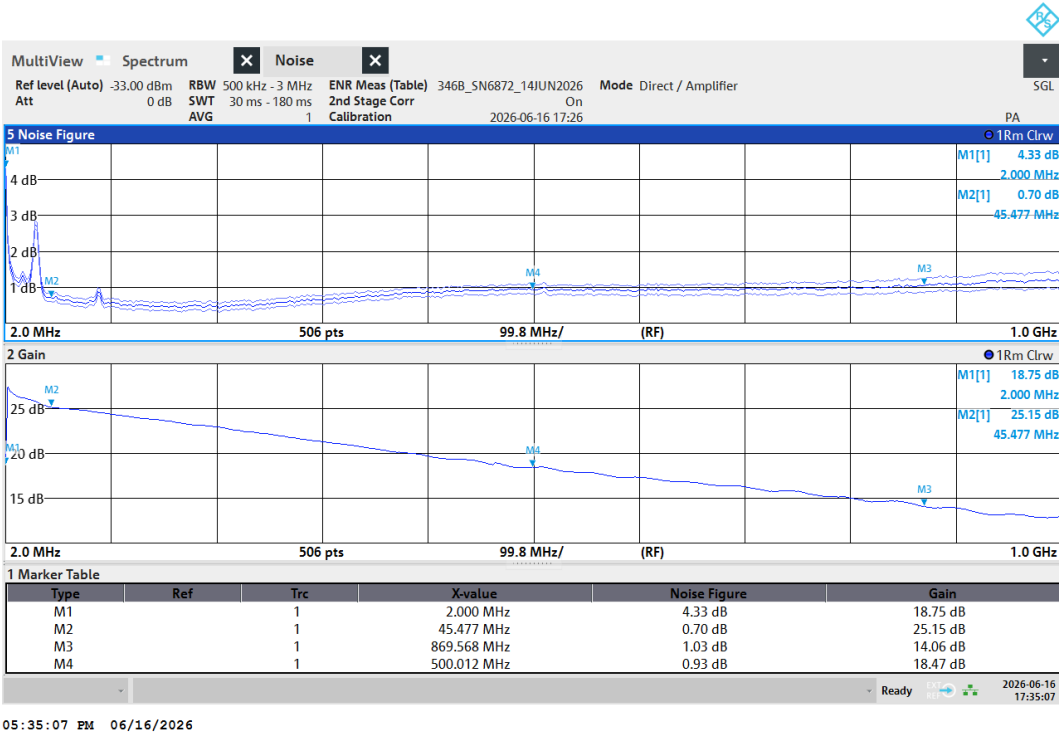


Figure 10.c ~ LNA-2 LNA (5 dB ENR): 2 – 200 MHz

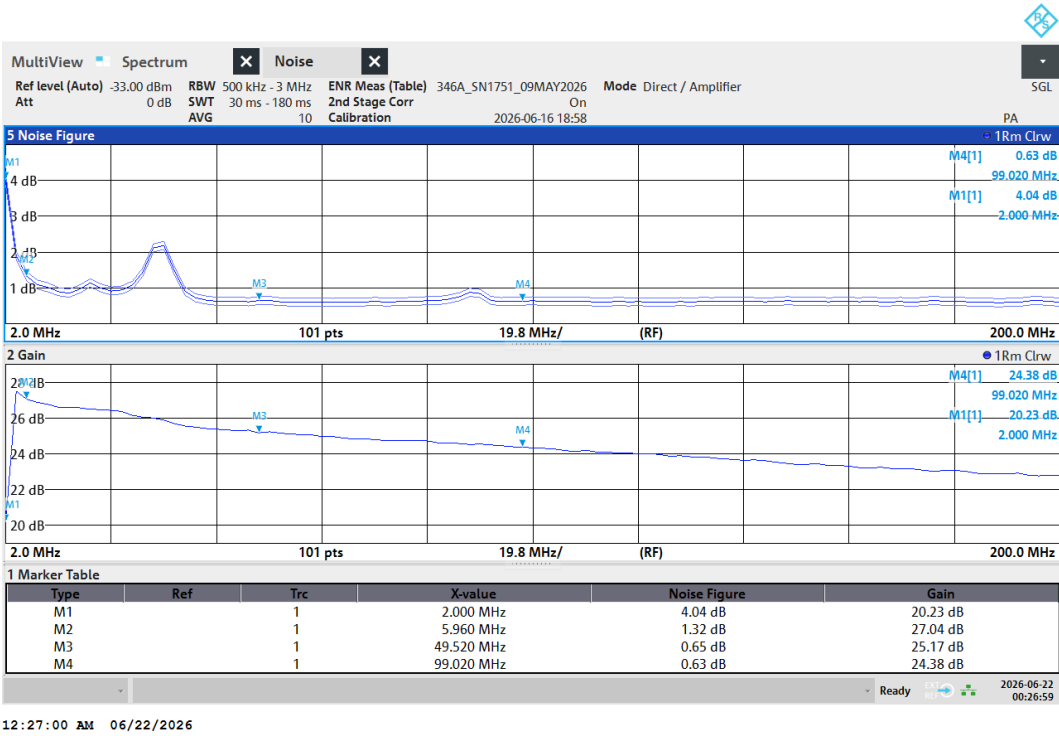


Figure 10.d ~ LNA-2 LNA (15 dB ENR): 2 – 200 MHz

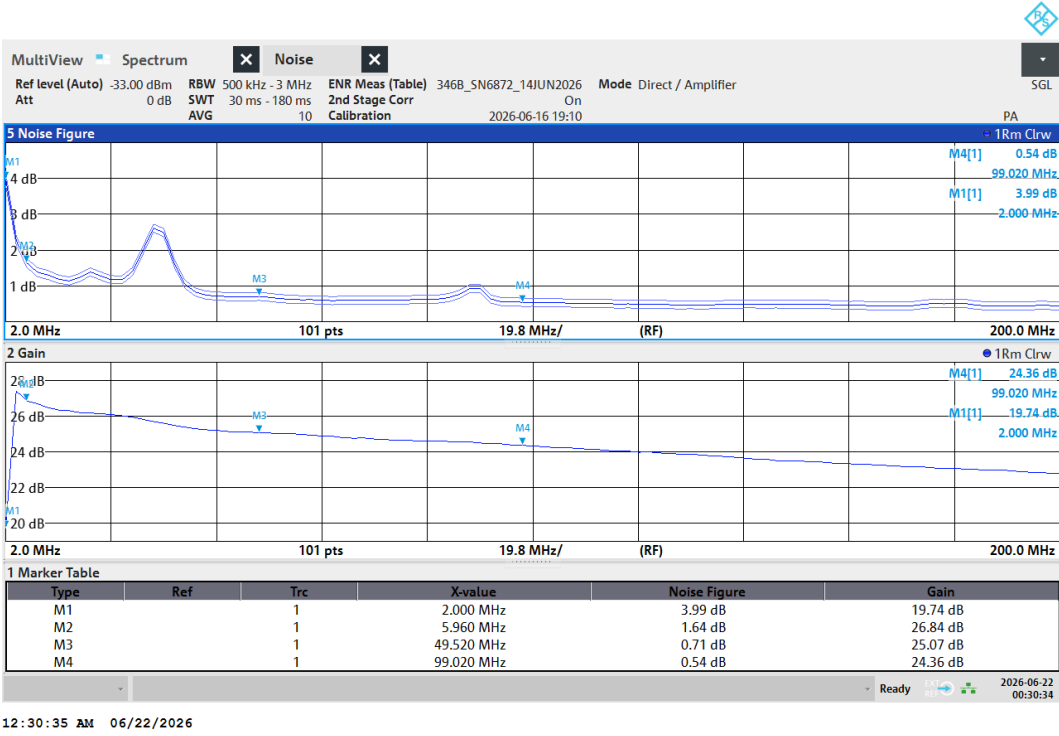


Figure 11.a ~ HP 8447A Modified (5 dB ENR)

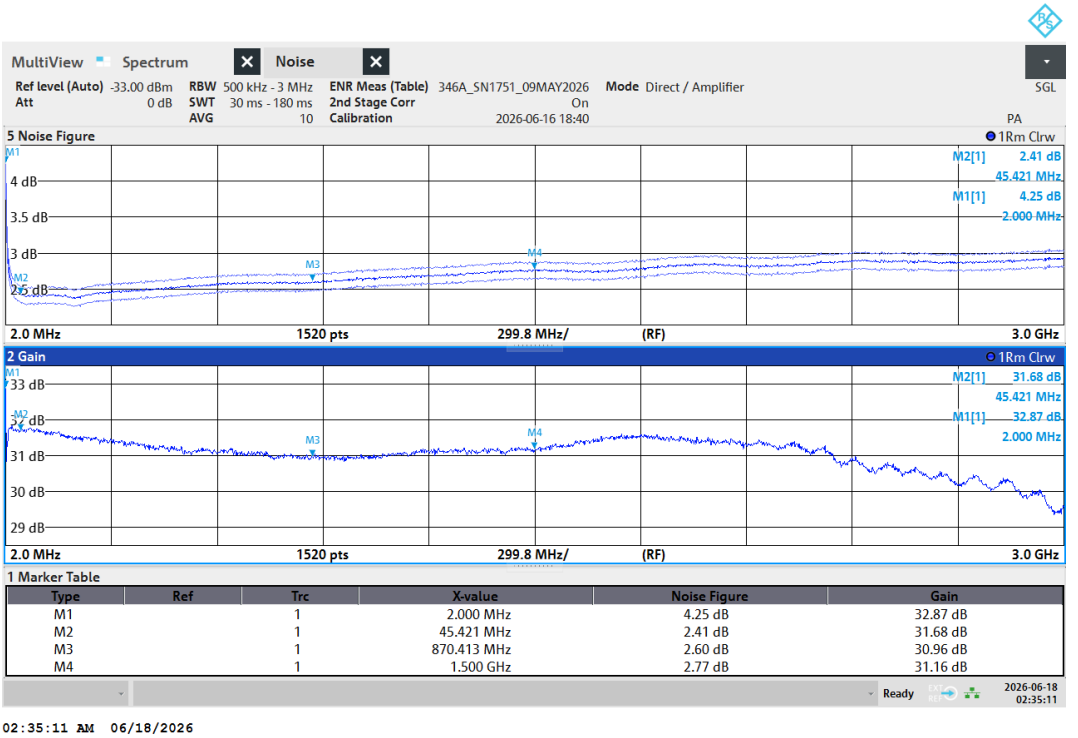


Figure 11.b ~ HP 8447A Modified (15 dB ENR)



6. Discussion

1. LWA-FEE V2: The noise figure and gain measurements are within a couple tenths dB at the marker frequencies with the two noise sources except at 2 MHz where the difference was 0.4 dB. However, the gain measurements at 2 MHz varied by a couple dB indicating measurement difficulties at that frequency. The gain measurements at higher frequencies were approximately 1 dB lower than gain measurements made with both a spectrum analyzer/tracking generator and vector network analyzer. Also, the noise figure measurements at 10 MHz and above were about 1 dB higher than measurements made with a different instrument, a Keysight N9917A Microwave Analyzer with Noise Figure option. This may have been due to the more involved calibration and measurements with the Keysight analyzer in which the test fixture losses were compensated.

The noise figure measurement with the 15 dB ENR noise source showed a very small bump near 100 MHz, which was not seen with the 5 dB ENR noise source, and it did not appear in the gain measurement. The probable source of the bump is FM broadcast band interference. The LWA-FEE V2 was measured while mounted in the LWA FEE Test Fixture with the lid closed and latched. If the lid was left open, FM broadcast and TV band interference was far more obvious in the noise figure measurements.

2. NenuFAR LNA: The NenuFAR LNA measurements were undertaken with the test fixture lid closed and latched; otherwise, interference was observed similar to the LWA-FEE V2. The noise figure and gain measurements at 2 MHz showed about the same variations as the LWA-FEE V2 with the two noise sources. The differences in the noise figure measurements with the two noise sources at the 6, 49 and 99 MHz marker frequencies were 0.3 dB or less.

3. LNA-1 LNA: The LNA-1 contains an unshielded amplifier in a plastic dome-like outdoor enclosure. This configuration was susceptible to radio frequency interference when undergoing the highly sensitive noise figure measurements. Several interfering frequencies were observed. The most prominent one was 30 MHz, which is the 3rd harmonic of the lab 10 MHz reference frequency. Interestingly, the reference frequency is a sinewave but it apparently has some distortion that produced the 3rd harmonic. The other interference in the LNA-1 measurements corresponded to TV station frequencies, 1900 MHz cellular band and 2.4 GHz in-house WiFi. Surprisingly, the interference from FM broadcast transmitters was almost undetectable.

A few attempt were made to reduce the interference by wrapping the LNA-1 in a cocoon of aluminum foil and anti-static bags but this effort had no effect. This might indicate that the interference is entering the amplifier some other way, but I was not able to mitigate it. Two sets of measurements were made on this amplifier, one set from 2 to 200 MHz and another from 2 to 3000 MHz. The lower frequency noise figure measurements showed a small (2 dB) interference bump at 30 MHz, and the measured noise figure at 2 MHz was unreliable due to the low gain at that frequency. From 6 MHz to 99 MHz, the markers read within a tenth dB for both noise sources. The higher frequency measurement set with the two noise sources showed a 1 dB difference at 870 MHz but only 0.05 difference at 1.5 GHz.

4. LNA-2 LNA: The LNA-2 amplifier is mounted in an enclosure similar to LNA-1 but the amplifier itself is enclosed in a machined aluminum enclosure. Even so, there was interference in the noise figure measurements from the 10 MHz lab reference (3rd harmonic) and TV station frequencies; FM broadcast band interference was small. These

were approximately the same as in the LNA-1. Noise figure measurements with the two noise sources indicate very close agreement, less than 0.3 dB difference, in the 2 to 200 MHz measurement set and about 0.1 dB or less difference up to 500 MHz. It is interesting that interference from the 10 MHz lab reference frequency only appeared in the LNA-1 and LNA-2 and not any of the other amplifiers.

5. HP 8447A Modified: Although the 8447A Modified has relatively high gain (nominal 30 dB) and low noise figure (nominal 2.5 dB), the traces for both the gain and noise figure measurements were a little noisy when the 5 dB ENR noise source was used. The traces were less noisy with the 15 dB ENR noise source. Both measurement sets shown here used averaging (10) to reduce trace noise and this helped considerably. The noise figure measurements were within 0.1 dB at all four markers for both noise sources. The amplifier gain plots show a few tenths dB ripple from impedance mismatch above 2.1 GHz

7. Conclusions

The noise figure and gain measurements appear to be reliable down to at least 3 MHz. Some variations were noted at 2 MHz, which indicates either an error in the ENRs used at that frequency or a misapplication of the FPL internal preamplifier below its datasheet specification of 3 MHz. If it is necessary to make additional measurements below 3 MHz, an external preamplifier with the appropriate frequency response should be used.

The 5 and 15 dB ENR noise sources produced very similar results and the differences can be explained by the measurement uncertainties.

Ability to specify RBW and Sweep Time at each measurement frequency is essential.

Noise figure measurements involve very small power spectral densities and can be subject to interference from the ever-present FM broadcast band, television bands, cellular bands and local WiFi systems. Even the local reference frequency can cause interference. However, these generally are easily recognized and could be avoided by using specially designed Frequency Tables in the analyzer. It also is necessary to use high-quality cables to connect to the DUT. Ferrite beads on the cables can be used to reduce their antenna effects.

It is well known that noise figure measurements are difficult to make accurately.

Based on noise figure and gain measurements described above:

- ✍ LWA-FEE usable to at least 3 MHz
- ✍ NenuFAR LNA usable to at least 3 MHz
- ✍ LNA-1 amplifier may be usable to about 5 MHz
- ✍ LNA-2 amplifier usable to at least 3 MHz
- ✍ HP 8447A Modified usable to below 2 MHz

8. References

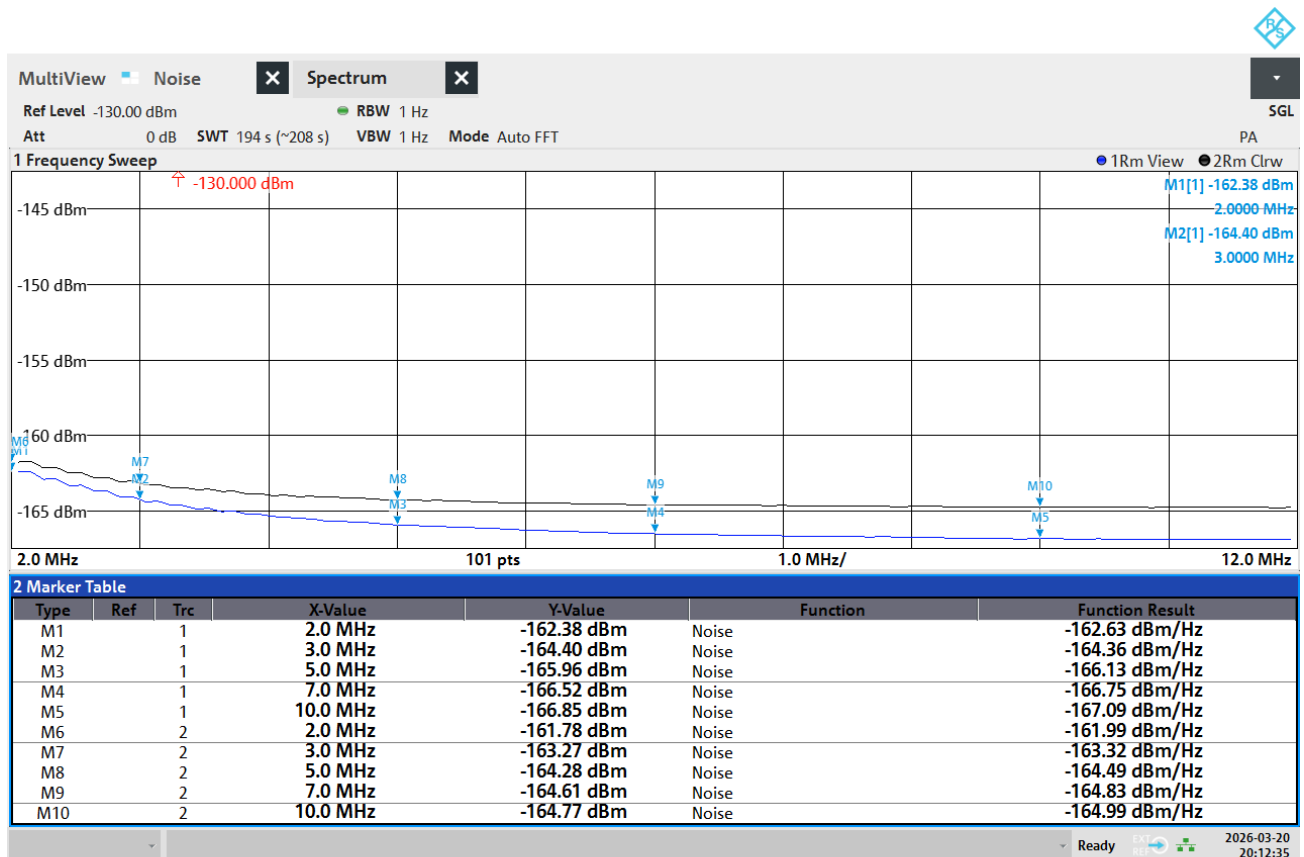
- [Keysight18] Keysight 10 Hints for Making Successful Noise Figure Measurements – Application Note, 5980-0288E, 2018
- {LWAFEE} LWA Front End Electronics (FEE) v2, https://github.com/lwa-project/Front_End
- {Reeve14} Reeve, W., Noise Tutorial: Part V ~ Noise Factor Measurements, 2014, available at: https://www.reeve.com/Documents/Noise/Reeve_Noise_5_NFMeas.pdf
- {Reeve26} Reeve, W., Noise Sources at Lower Frequencies, 2026, available at: https://www.reeve.com/Documents/Articles%20Papers/Reeve_NoiseSrcLFMeas.pdf

Appendix ~ FPL DANL Measurements

Reference: {Reeve26}:

Figure D2.a ~ HP 346A, s/n 2614A01751, ENR 5 dB (nominal), APC 3.5-M adapted to N-M, 2 – 12 MHz

Note: Markers M1 through M5 show the analyzer DANLs (noise source in the cold state, equivalent to 50 ohm termination) in dBm Hz⁻¹ in the Marker Table far-right column.



08:12:36 PM 03/20/2026

A 4.5-Meter Amateur Radio Telescope for Long-Term Radio Astronomy Observations

Author: Tim Cherrone (WK9P)

Affiliation: Deep Space 1420 MHz Radio Telescope

Location: Mishawaka, Indiana, USA

Date: August 6, 2026

Abstract

This paper describes the design, construction, instrumentation, and initial observational results of a custom-built 4.5-meter amateur radio telescope developed for long-term continuum and spectral observations of Galactic neutral hydrogen at the 21-centimeter wavelength. The observatory combines a precision prime-focus reflector, hydrogen-optimized receiving system, software-defined radio technology, and automated data reduction software to produce highly repeatable drift-scan observations.

Over several months of operation, the observatory has completed numerous daily continuum drift scans together with multiple full sidereal-day continuum and spectral surveys. Independent observations demonstrate excellent repeatability of the principal Galactic continuum crossing and demonstrate consistent repeatability during a six-day continuum survey. The results demonstrate that carefully designed amateur instrumentation can produce repeatable continuum observations suitable for long-term comparative studies.

1. Introduction

Neutral atomic hydrogen (HI) is the most abundant element within the Milky Way and naturally emits radio energy through the 21-centimeter hyperfine transition (1420.4057 MHz). Observations at this wavelength have long been used to investigate Galactic structure, spiral arms, and the large-scale distribution of interstellar hydrogen.

Advances in low-noise electronics, software-defined radio receivers, digital signal processing, and precision telescope control have enabled experienced amateur radio astronomers to perform observations that complement established radio astronomy surveys.

The observations presented in this paper represent one component of a broader amateur radio astronomy program. The work documents the long-term repeatability of continuum drift observations obtained with a 4.5-meter radio telescope. The observatory and associated software continue to support additional continuum and spectral-line investigations beyond the scope of this paper.

2. Instrumentation

Antenna System

- **Reflector:** 4.5-meter prime-focus mesh parabolic reflector
- **Feed Horn:** Resonant VE4MA feed tuned for 1420 MHz
- **Beamwidth (-3dB):** Approximately 3.3°
- **Gain:** Approximately 34 dBi
- **System Temperature (T_{sys}):** Estimated approximately 155 K
-

Receiver Chain

- **Front-End LNA:** DEMI low-noise amplifier, custom-tuned for 1420 MHz with an internally installed 1420 MHz bandpass filter
- **Transmission Line:** Low-loss LMR-400 coaxial transmission line
- **Post-Amplification:** DEMI 10 dB gain block
- **SDR Receiver:** SDRplay RSP1A 12-bit software-defined radio receiver

Mount and Control System

- **Mount Type:** Dual-axis elevation-azimuth mount
- **Encoders:** High-resolution optical encoders on both axes
- **Hardware Interface:** Custom-built RS-232 encoder interface driver boards utilizing SIPEX232 integrated circuits
- **Controller & Interface:** F1EHN antenna controller paired with EME System interface
- **Pointing Repeatability:** Better than 0.5° with a fixed calibration reference point

Data Acquisition and Software Pipeline

- **Acquisition Software:** HDSDR, SpectraVue, Spectrum Lab, and OBS Studio
- **Processing Pipeline:** Custom Python software leveraging NumPy, Pandas, Matplotlib, and AstroPy for automated data reduction, UTC to Right Ascension conversion, baseline normalization, 3D coordinate interpolation, and FITS cube visualization

The Deep Space 1420 MHz Radio Telescope has operated continuously throughout the duration of this study, allowing repeated observations under varying sidereal and seasonal conditions while maintaining a consistent observing and processing methodology.



Figure 1. (a) Physical 4.5-meter mesh dish assembly and feed setup. (b) Control instrumentation station and processing suite.

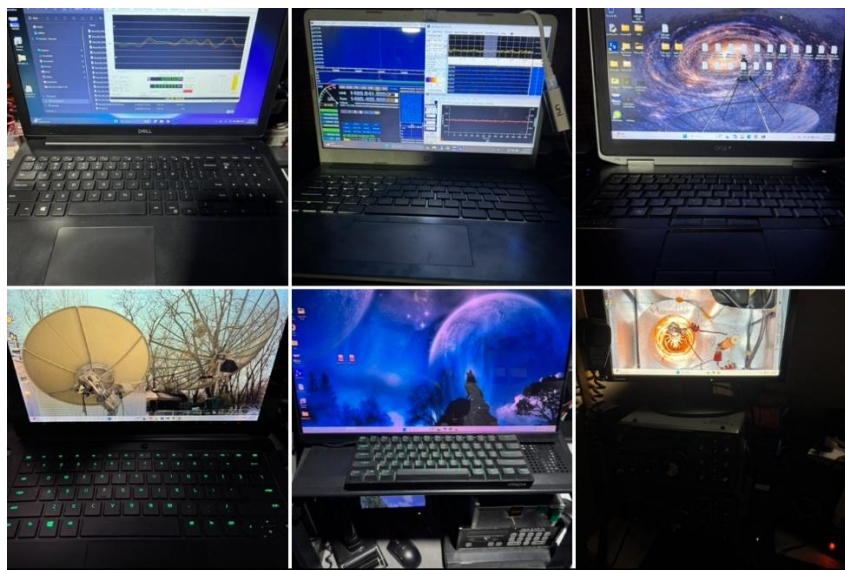


Figure 1. (b)

3. Observational Method

The Deep Space 1420 MHz Radio Telescope supports multiple complementary observing programs designed to investigate Galactic neutral hydrogen through both continuum and spectral observations. Each observing mode addresses a different aspect of the overall research program while utilizing a common instrumentation platform and standardized data reduction pipeline.

Daily Continuum Drift Surveys

Daily observations consist of approximately three-hour continuum drift scans performed with the telescope fixed at predetermined azimuth and elevation coordinates. As the Earth rotates, the sky naturally drifts through the antenna beam, producing repeatable continuum profiles suitable for long-term monitoring and comparison.

Each observation is processed using custom Python software that performs baseline normalization, removes transient radio-frequency interference (RFI), converts observation time to Right Ascension, and generates publication-quality plots, three-dimensional visualizations, and celestial location maps. These products provide both qualitative and quantitative evaluation of the observatory's long-term repeatability.

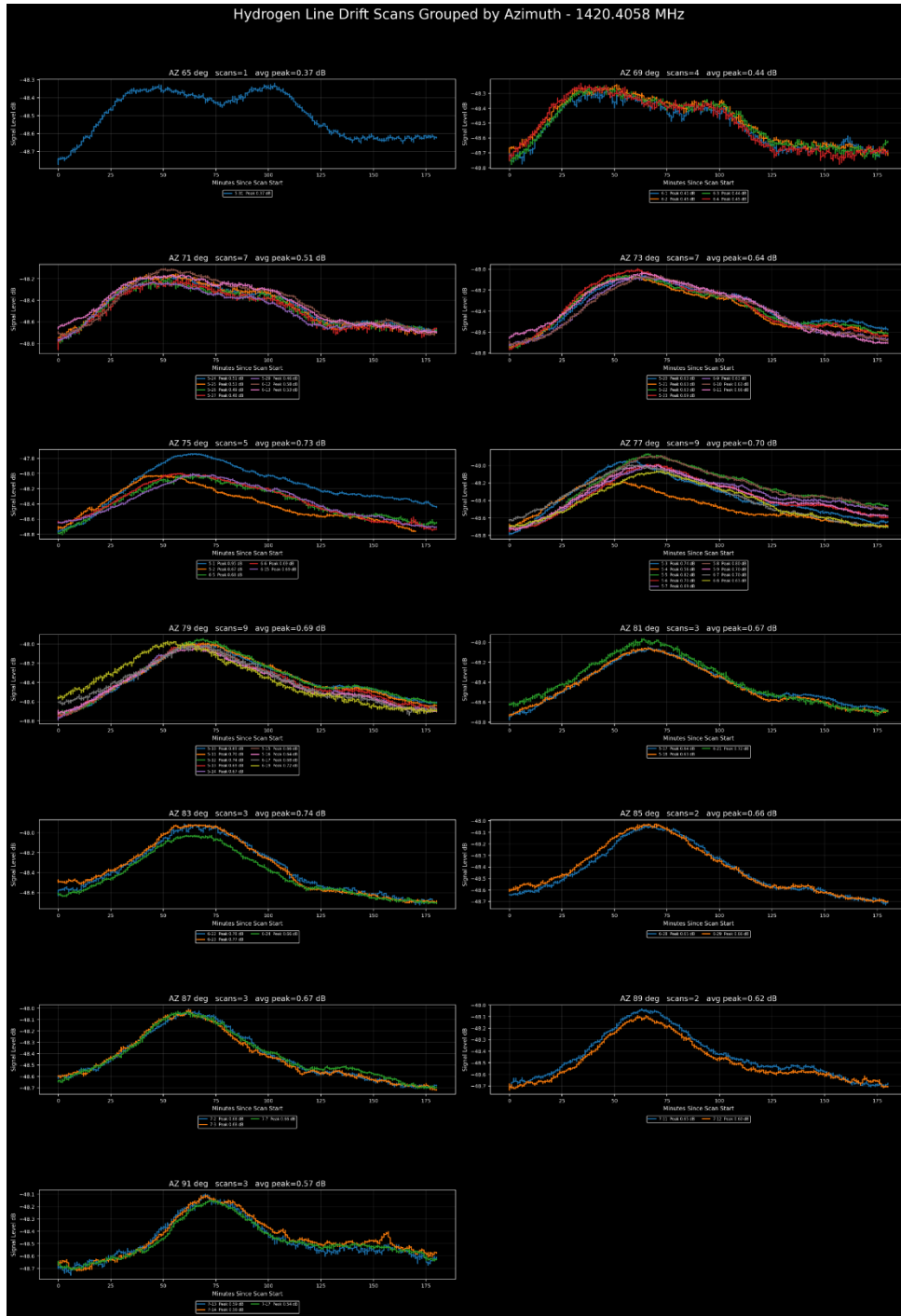


Figure 2. (a) Representative daily continuum drift observation following baseline normalization and conversion from UTC to Right Ascension. (b) Joined into a 3D surface rendering.

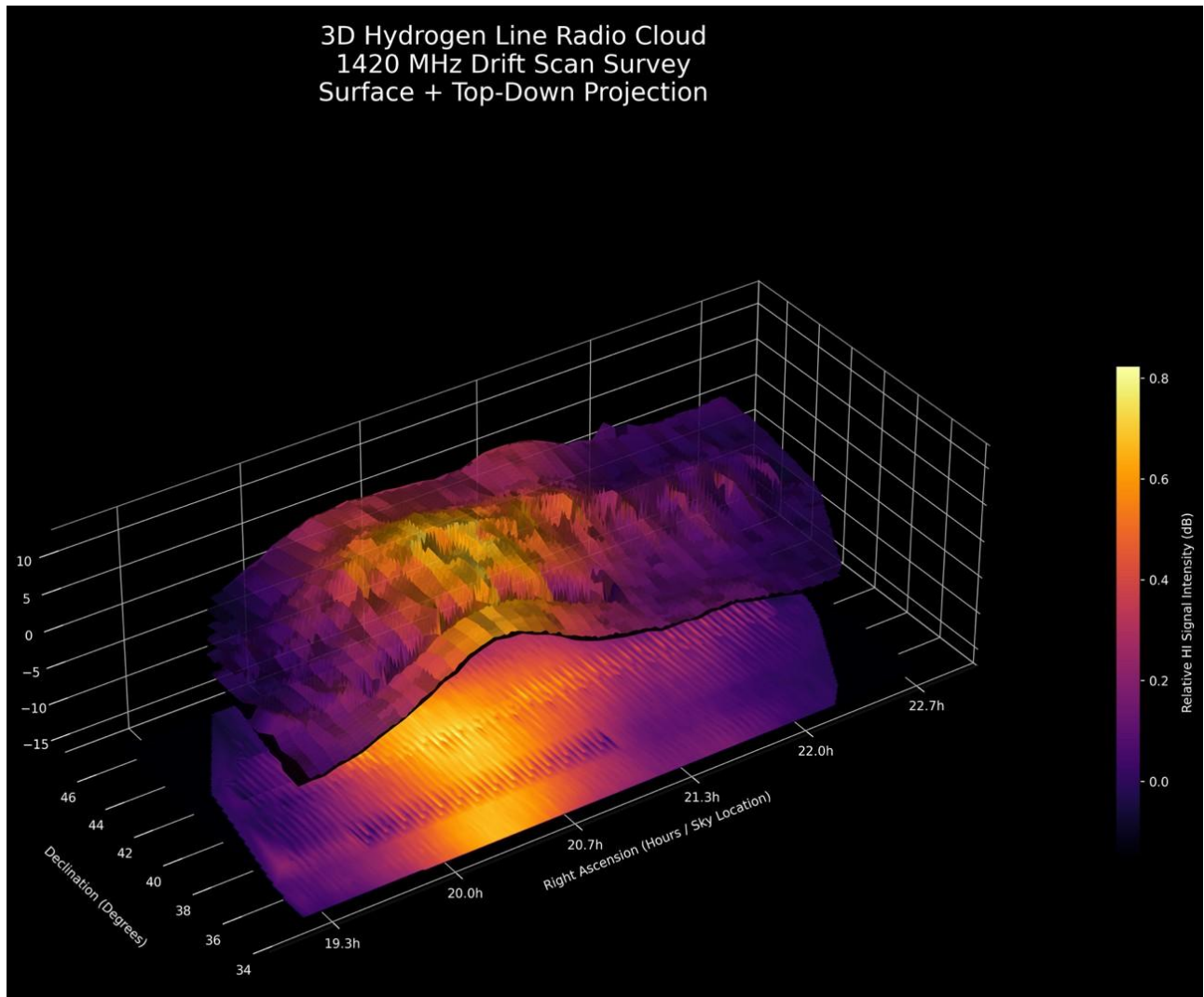


Figure 2. (b)

Twenty-Four-Hour Continuum Surveys

Full sidereal-day continuum observations are conducted to provide continuous Right Ascension coverage at a fixed declination. These observations were initiated to compare results obtained with the Deep Space 1420 MHz Radio Telescope over a course of several days.

The resulting datasets are processed using the same software pipeline employed for the daily observations, producing Right Ascension intensity plots, three-dimensional renderings, and celestial location maps that facilitate direct comparison between observing sessions and historical survey data.

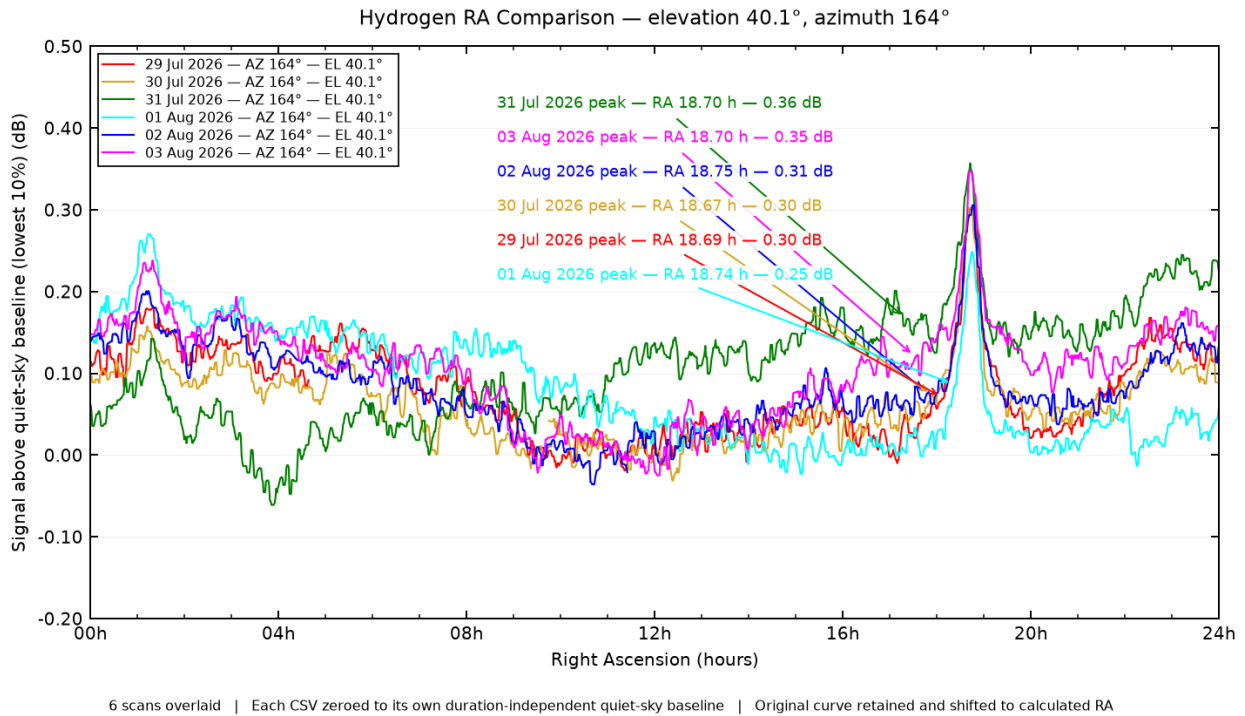


Figure 3. Alignment and comparison of the Deep Space 1420 MHz Radio Telescope continuum observations over 6 days during a continuum survey, demonstrating high baseline stability and profile repeatability.

Twenty-Four-Hour FFT Spectral Surveys

In addition to continuum observations, full 24-hour FFT-based spectral surveys are routinely conducted. Successive surveys are acquired at azimuth positions separated by approximately two degrees (advancing northeast towards lower azimuth steps), allowing adjacent regions of the sky to be sampled while maintaining identical processing techniques.

Custom Python software converts these observations into spectral displays, velocity plots, three-dimensional renderings, and celestial location maps. These visualization products provide an intuitive representation of the spatial distribution of Galactic neutral hydrogen and assist in identifying repeatable structures across adjacent observing positions.

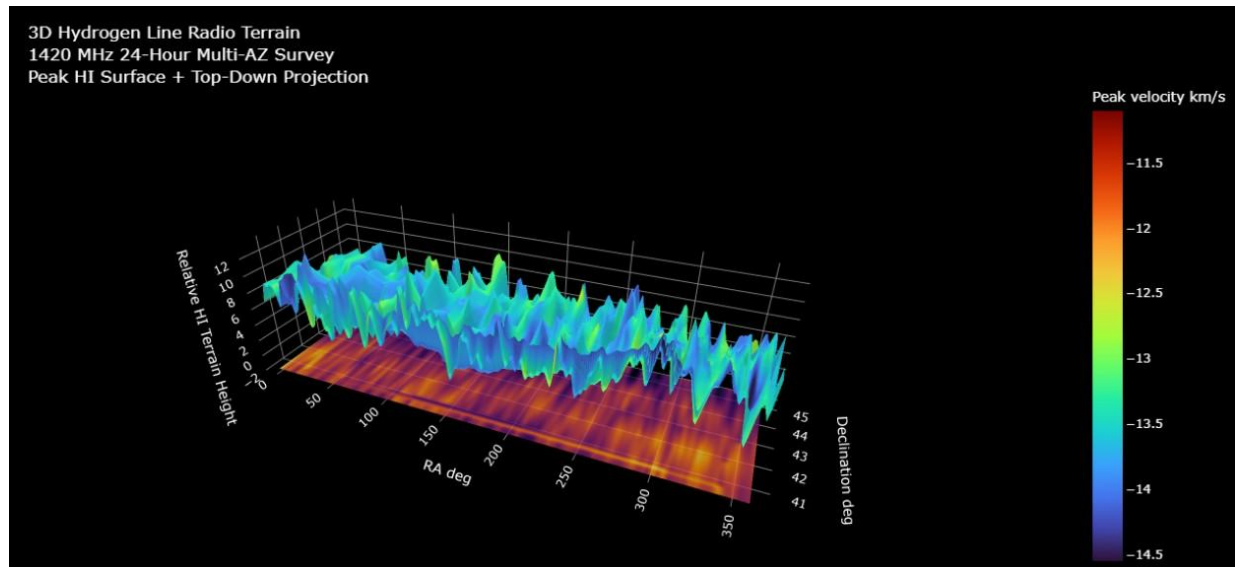


Figure 4. Three-dimensional rendering generated from a 24-hour spectral survey illustrating Galactic neutral hydrogen structure as a function of Right Ascension and spectra intensity.

Data Reduction

Raw receiver output is converted into comma-separated value (CSV) format and processed using custom Python software developed specifically for this observatory. The automated reduction pipeline includes:

- Baseline normalization
- Automated removal of transient radio-frequency interference
- Reconstruction of removed interference using surrounding baseline interpolation
- Conversion of observation time to Right Ascension
- Multi-session alignment and comparison
- Automated generation of publication-quality plots
- Three-dimensional renderings
- Celestial location mapping

The objective of the reduction process is to preserve persistent astronomical structure while removing transient terrestrial interference that could influence repeatability. The processing software has evolved throughout the observing program as additional visualization techniques and quality-control methods have been developed. Maintaining a consistent reduction workflow has been essential for ensuring meaningful comparison between observations acquired over extended periods.

Data Availability

This investigation is conducted as an open and ongoing observing program. Observatory operation, telescope control, and many observing sessions have been documented through a continuous public YouTube livestream. Processed observational products, including CSV datasets, PNG plots, three-dimensional renderings, and derived analysis products, are routinely shared through a public Google Drive repository to encourage independent review, comparison, and collaboration within the amateur radio astronomy community.

The open availability of observational data and processed results provides transparency, allows independent verification of the processing methodology, and enables future comparison with observations obtained by other amateur and professional observatories.

https://www.youtube.com/@Backyard_4.5m_Radio_Telescope

<https://drive.google.com/drive/folders/17JhGsPBFxXecTJqHEjSD96UQDZtLI1b->

Results

Repeated observations demonstrate a high degree of consistency between independent observing sessions.

Independent daily drift surveys exhibit similar profile morphology (Figure 2), providing confidence in both the stability of the instrumentation and the repeatability of the observing methodology.

The 24-hour spectral surveys further demonstrate the observatory's capability to generate repeatable three-dimensional representations of Galactic neutral hydrogen structure from adjacent observing positions separated by approximately two degrees in azimuth (Figure 4). These visualization products provide an additional means of examining spatial continuity while complementing conventional continuum plots.

The 6-day continuum survey (Figure 3) shows encouraging agreement in the position and overall morphology of the principal continuum across consecutive 24-hour observing runs.

The continued acquisition of observations under varying sidereal conditions has further strengthened confidence in the long-term stability of both the instrumentation and the data reduction pipeline.

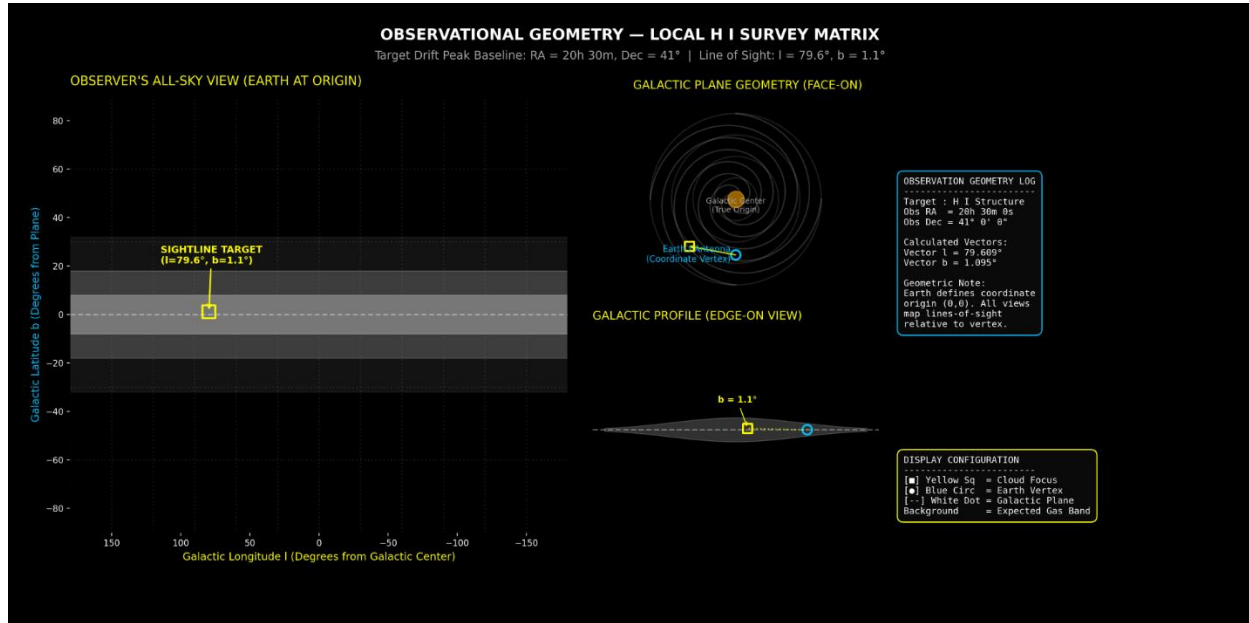


Figure 5. Observational Geometry — Local HI Survey Matrix showing sightline target, Galactic plane geometry, and edge-on profile.

Discussion

The observations presented here demonstrate that a modest-aperture amateur radio telescope can produce stable and repeatable continuum and spectral measurements when combined with optimized instrumentation, precise telescope positioning, and standardized digital data reduction techniques.

One objective of this work has been to determine the practical capability of modern amateur instrumentation for long-term radio astronomy observations. The consistency observed throughout multiple months of operation indicates that reliable measurements can be obtained using commercially available components integrated with custom-designed receiving, control, and analysis systems.

Equally important has been the development of an automated processing pipeline capable of transforming raw observational data into calibrated plots, Right Ascension displays, three-dimensional renderings, and celestial location maps. Automating these processes has improved repeatability while reducing the possibility of operator-induced processing differences between observing sessions.

Although the observations presented here represent only a portion of a larger observing program, they establish a foundation for continued continuum and spectral investigations, expanded sky coverage, and future comparisons with additional historical and contemporary astronomy surveys.

4. Conclusions & Future Work

The operational results from the Deep Space 1420 MHz Radio Telescope demonstrate that a carefully calibrated 4.5-meter amateur radio telescope can execute high-repeatability continuum and spectral line surveys of Galactic neutral hydrogen. Long-term continuum drift scans confirm excellent stability across multi-day observation windows.

Future work will focus on, but is not limited to, expanding both observational capability and scientific analysis, the spectral survey sky coverage, refining multi-track 3D coordinate interpolation for full galactic plane slice modeling, performing further continuum surveys, solar observations, strong radio galaxy surveys and seasonal sky comparisons.

5. References

1. Kalberla, P. M. W., et al. "The Leiden/Argentine/Bonn (LAB) Survey of Galactic HI." *Astronomy & Astrophysics*, 440(2), 775–782, 2005.
2. Ward, A. (VE4MA). "Parabolic Reflector Antennas and Feeds." ARRL UHF/Microwave Experimenter's Manual, American Radio Relay League, 1990.
3. Down East Microwave Inc. "1420 MHz Low Noise Amplifier Technical Specifications." DEMI Technical Documentation, Down East Microwave Inc., Live Oak, FL.
4. SDRplay Ltd. "RSP1A 12-bit SDR Technical Specification & Performance Data Sheet." SDRplay Limited, UK, 2017.
5. The Astropy Collaboration. "Astropy: A Community Python Package for Astronomy." *Astronomy & Astrophysics*, 558, A33, 2013.
6. Harris, C. R., et al. "Array programming with NumPy." *Nature*, 585(7825), 357–362, 2020.
- 7.

Author Biography

Tim Cherrone (WK9P) is an Extra Class amateur radio operator with over 32 years of experience in amateur radio operations, radio frequency systems, and Earth-Moon-Earth (EME) communications. Professionally, he works as an industrial process engineer specializing in process development and systems engineering. His current radio astronomy research focuses on long-term 21-cm continuum and spectral drift surveys, signal processing automation, and custom observatory hardware integration at the Deep Space 1420 MHz Radio Telescope in Mishawaka, Indiana.

Practical Hydrogen Line Observing at Lichfield Radio Observatory: Lessons from Five Years of Development

Andrew Thornett

Lichfield Radio Observatory

andrew@thornett.net

Introduction

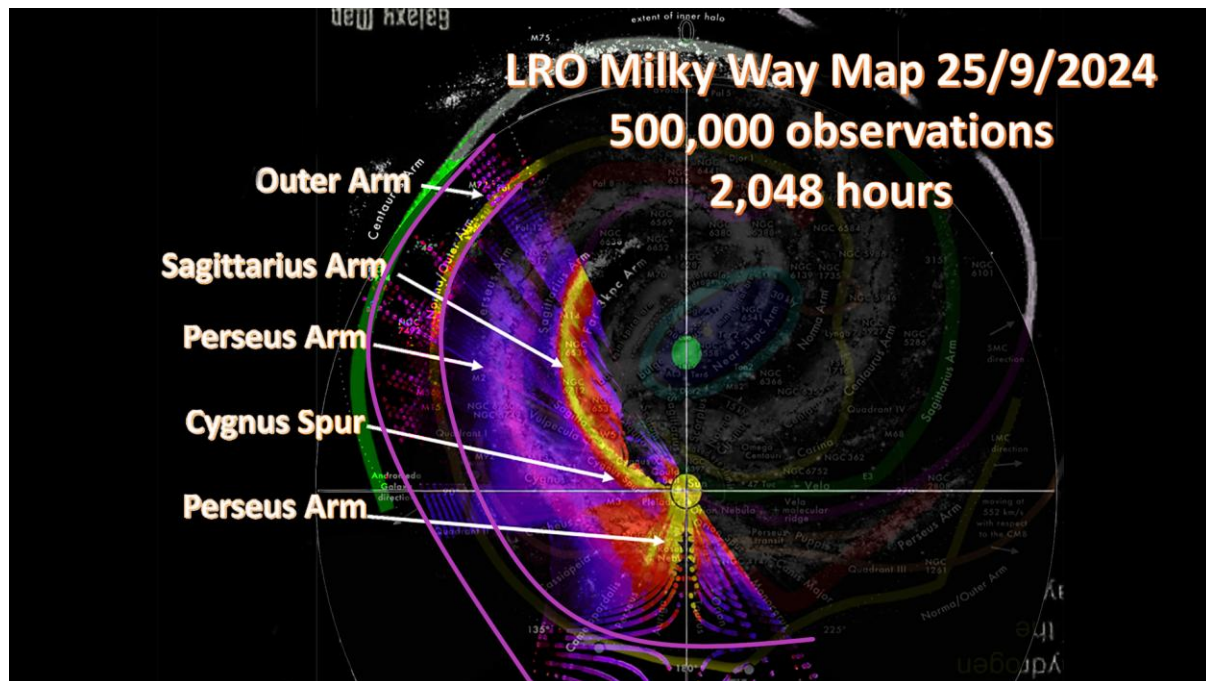
Hydrogen line radio astronomy has become one of the most accessible areas of amateur radio astronomy. Affordable software defined radios (SDRs), low-noise amplifiers and open-source processing software now allow amateurs to detect the 1420.405 MHz neutral hydrogen emission and produce scientifically useful observations using relatively modest equipment.

Over the past five years, Lichfield Radio Observatory (LRO) has developed a range of hydrogen line radio telescopes, each exploring different antenna designs and observing techniques. Rather than searching for a single "perfect" instrument, the project has concentrated on understanding the strengths and weaknesses of several practical approaches and identifying systems that can be reproduced successfully by other amateurs.

Lichfield is located in the United Kingdom at latitude 52.683498° N and longitude -1.826530° W (52°40'53.5" N 1°49'31.8" W). The observatory is 70m above sea level, close to the centre of a small town. Time zone is UTC in Winter (Greenwich Mean Time, GMT), and GMT/UTC+1 between March and October (British Summer Time).

This article summarises the evolution of the LRO hydrogen line programme and highlights the practical lessons learned during that journey.

Mapping the arms of the Milky Way at 1420.405 MHz at Lichfield Radio Observatory using the LRO-H1 radio telescope:



Building a Family of Hydrogen Line Telescopes

The LRO hydrogen line programme has steadily expanded from a single antenna into five separate observing systems.

The observatory has experimented with:

- a compact ex-military Ptarmigan Triffid dipole array;
- a 1.5 m pressed-steel "solar cooker" dish;
- a dedicated hydrogen line Yagi, designed by Alex Pettit – the LRO example is one of the original 17-element Yagi antennas with continuous electrical connection between its elements. Since the development of this antenna, Alex has produced a range of alternative designs.
- a SETI League Horn of Plenty; and
- a 1.4 m deep communications dish fitted with a Discovery hydrogen line feed.

Although each telescope shares broadly similar electronics—including RTL-SDR receivers, Nooelec SAWBird H1 low-noise amplifiers and drift-scan observing on simple wooden mounts build from offcuts obtained from a local hardware store—the different antenna geometries provide an excellent opportunity to compare real-world performance under identical observing conditions with quite a significant level of RFI present.

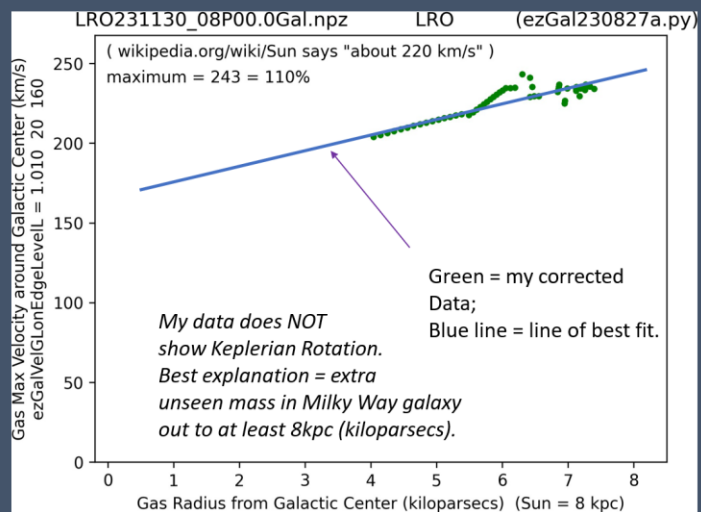
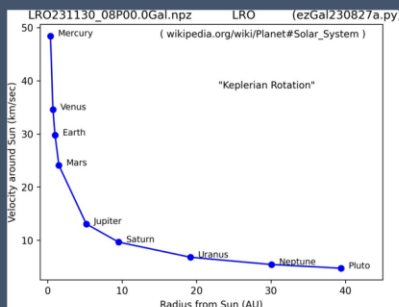
The Value of the Small Dipole Array

One of the most surprising results has been the performance of the small Ptarmigan Triffid array. Despite its modest physical size, it has consistently produced reliable Milky Way drift scans and has been capable of generating rotation curve measurements that agree with the now well-established evidence for non-Keplerian galactic rotation. The resulting observations are consistent with the presence of significant unseen mass within the Milky Way, demonstrating that even relatively simple amateur equipment can contribute to understanding large-scale galactic structure.

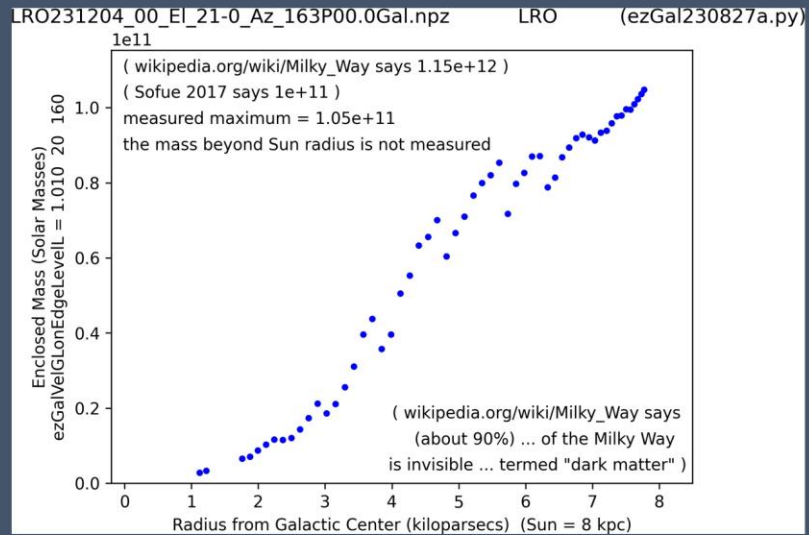
Repeated drift scans have also enabled construction of two- and three-dimensional maps of hydrogen within our Galaxy, illustrating the educational value of long-term observing programmes using uncomplicated equipment.

Dark Matter – galactic rotation curve from my data

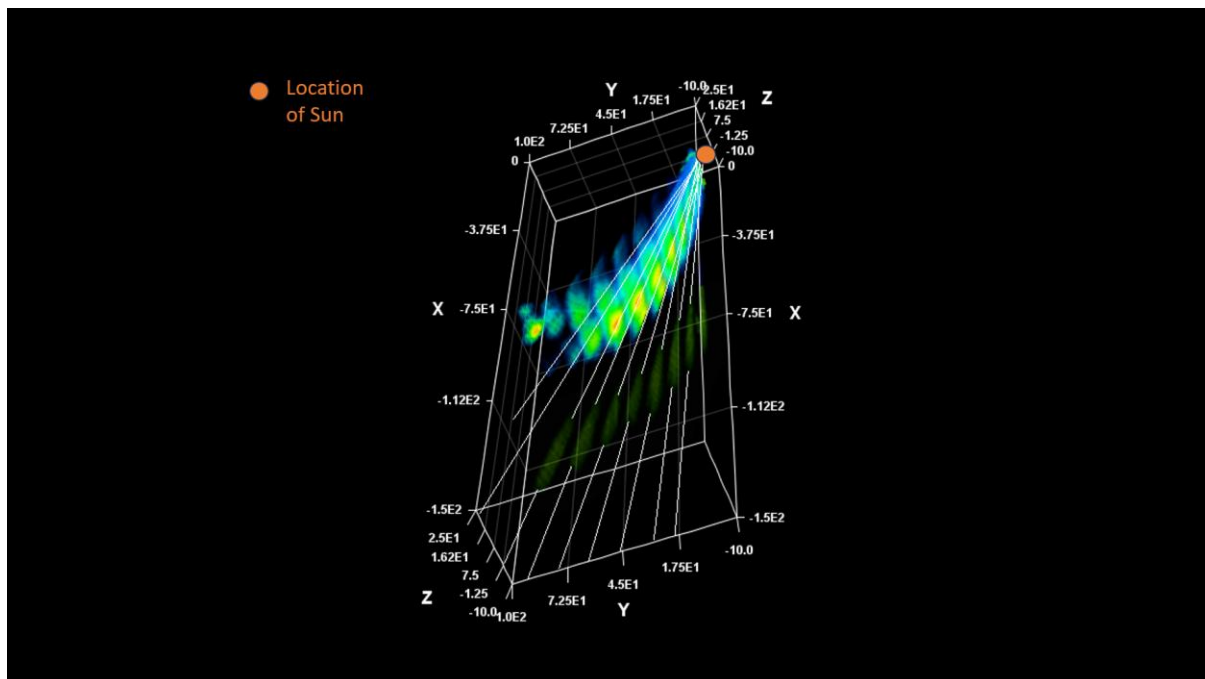
Below is typical Keplerian Rotation Curve which would be expected without dark matter, on right my data (ezRA suite/Pharmigan array)

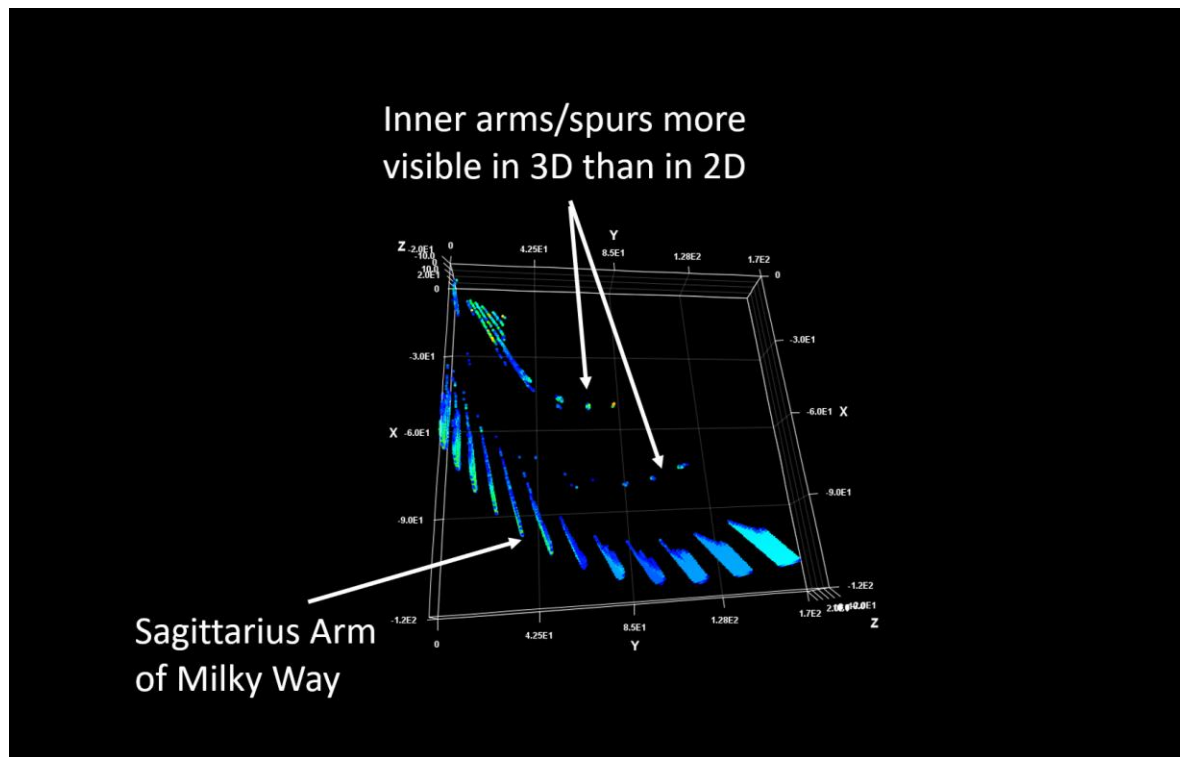


Enclosed Milky Way galactic mass



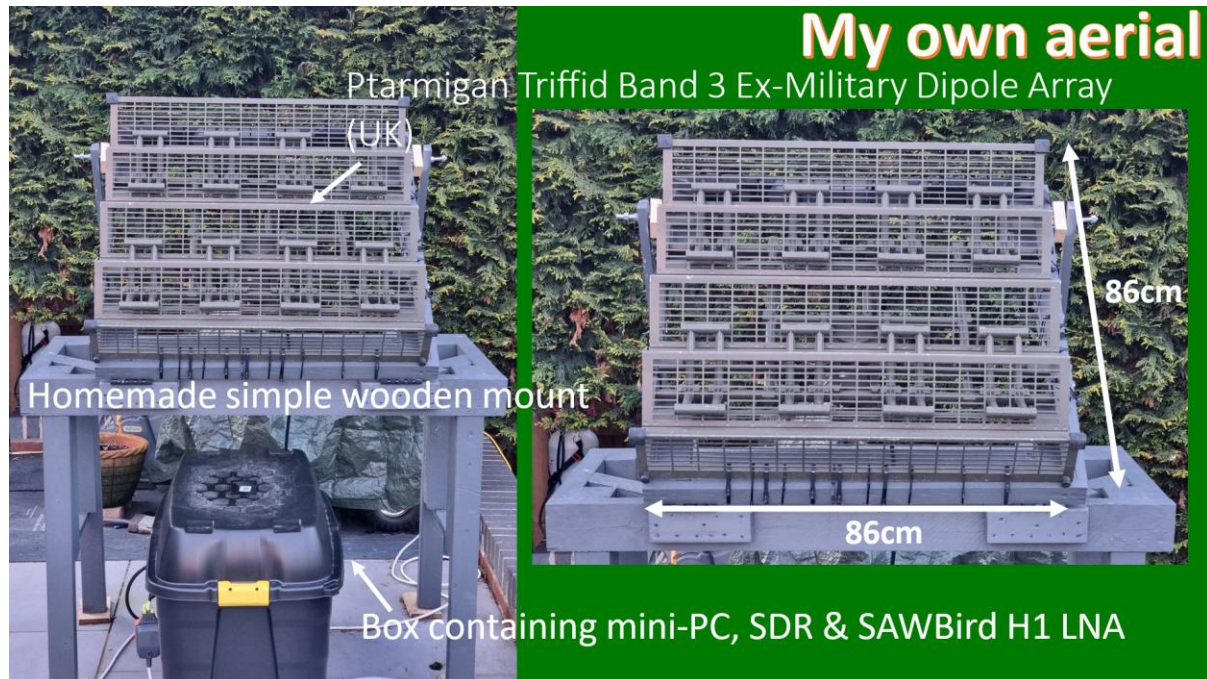
3D Mapping of the Milky Way using LRO-H1:





Of particular benefit with this antenna is its robustness – consistent with its military origin – it works, regardless of weather, RFI, or other detrimental environmental element. It continuously actively observes at LRO to provide a baseline against which other hydrogen line experiments can be compared, and is currently on its fourth Milky Way mapping exercise.

LRO-H1, ex-military Ptarmigan Triffid 4x4 dipole array at Lichfield Radio Observatory used for 1420 MHz observations:



Learning from the Solar Cooker Dish

The second-generation telescope employed a commercially available 1.5 m steel dish originally sold as a solar cooker. Initial expectations were high, but practical experience showed that antenna performance depends on far more than dish diameter.

Signal levels were consistently lower than anticipated when compared with published survey data. Investigation suggested several possible causes, including ground noise, structural flexure introduced by support modifications, feed geometry and mechanical alignment. Even relatively small distortions of the reflector appeared capable of degrading performance at 1420 MHz. In addition, it suffered major problems with RF ground spillover. Attempts to reduce this with a surrounding mesh extension to the antenna proved ineffective.

This experience reinforced an important lesson for amateur constructors: mechanical rigidity is every bit as important as receiver sensitivity. Increasing antenna size alone does not guarantee improved results.

LRO-H2, 150cm Solar Cooker Petal Dish with bespoke Brian Coleman hydrogen line feed, and the start of the construction of surrounding mesh extension in an attempt to reduce ground spillover:



Rediscovering the Horn Antenna

The construction of a SETI League Horn of Plenty represented a return to one of the classic antenna designs in hydrogen line radio astronomy. Inspired by Harold Ewen's original hydrogen horn, the SETI design sacrifices a few decibels of gain in exchange for excellent impedance matching, very low sidelobes and minimal ground spill-over.

LRO-H4, The LRO example of the SETI League Horn of Plenty:



Building the horn proved relatively straightforward, although practical challenges emerged during operation. Rainwater accumulated inside the WR-650 waveguide, eventually covering the feed monopole.

Careful drilling of drainage holes restored normal operation without apparent degradation in performance.

Despite experiencing considerable radio frequency interference (RFI), the horn demonstrated how effectively hydrogen line observing can recover astronomical signals even in difficult RF environments. Early mapping showed the Milky Way beginning to emerge directly from unprocessed drift scan data, illustrating the inherent robustness of the design.

A Deep Communications Dish Changes the Picture

The most recent telescope combined a 1.4 m communications dish with a commercially available Discovery hydrogen line feed. This configuration rapidly proved to be the strongest performer within the LRO programme.

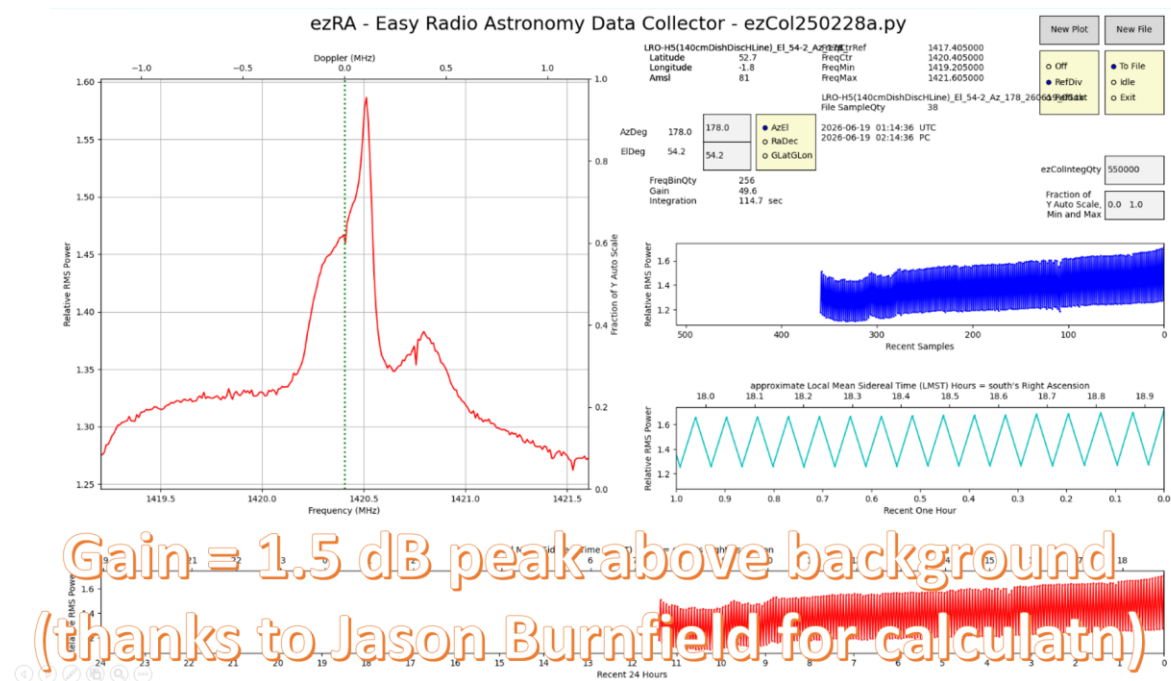
LRO-H5 (left, below), constructed from 140cm ex-communications antenna (deeper than the petal dish used in LRO-H2), plus a Discovery Dish Hydrogen Line Feed and 3D-printed feed support, sits alongside LRO-H4 (right, below), the LRO SETI League Horn of Plenty:



Initial testing revealed that earlier disappointing observations were partly attributable to a computer fault rather than antenna performance. Once corrected, hydrogen line detections immediately became apparent. The Discovery feed also simplified focusing considerably, allowing optimum feed position to be established while observing the signal in real time.

Subsequent observations produced stronger hydrogen detections, noticeably reduced RFI and encouraging early Milky Way maps. The combination of a deep dish and an optimised feed appears to minimise ground spill while providing consistently high sensitivity.

Measuring gain on LRO-H5 during first light:



Practical Recommendations

Perhaps the most valuable outcome of the LRO project is not identifying a single "best" telescope, but understanding which designs are most forgiving for amateur construction.

Experience suggests two approaches deserve particular attention.

The SETI League Horn of Plenty is mechanically robust, relatively tolerant of construction inaccuracies and naturally suppresses unwanted ground radiation through its low sidelobe characteristics.

Alternatively, a deep communications dish fitted with a Discovery hydrogen line feed combines mechanical stability with straightforward focusing and excellent observing performance. Unlike lightweight pressed-metal dishes, communications antennas are rigid, weather resistant and comparatively easy to mount accurately.

For newcomers wishing to construct their first hydrogen line telescope, either design offers a realistic path to successful observations without the need for highly specialised fabrication techniques.

Looking Ahead

Development at Lichfield Radio Observatory continues. Planned work includes formal comparison of antenna system temperatures, evaluation of improved low-noise amplifiers, completion of Milky Way mapping with each telescope and investigation of hydrogen spectra from selected extragalactic sources in collaboration with Jason Burnfield.

Conclusions

Five years of experimentation have demonstrated that successful hydrogen line radio astronomy depends upon careful optimisation of the complete observing system rather than maximising antenna size alone. Mechanical stability, feed design, receiver performance and resistance to local interference all contribute significantly to the final result.

Perhaps the most encouraging conclusion is that scientifically meaningful hydrogen line observations are now well within the reach of amateur astronomers. With affordable SDR technology, open-source software and thoughtfully designed antennas, amateurs can not only detect the Milky Way but also explore its structure and dynamics from their own gardens.

The experience at Lichfield Radio Observatory suggests that the barriers to entry are lower than ever—and that there remains considerable scope for experimentation, collaboration and discovery within the amateur radio astronomy community.

References:

SETI League Horn of Plenty. Theoretical and Construction Notes. SETI Article: SETI Horn of Plenty.
<https://setileague.org/articles/horn.htm>

Hydrogen Line radio Observing. British Astronomical Association.
https://britastro.org/section_information_/radio-astronomy-section-overview/h-line

To add your details to the mailing list for the monthly British Astronomical Association Practical Radio Astronomy Monday Workshops contact andrew@thornett.net

ASV 8.5m Dish Radio Telescope - Horizon Thermal Noise Calibration

Written by: Stephen Bentley

Date: 15th May 2026

1.0 Introduction

When the radio telescope dish is aimed closer to the horizon, the effect of the Earth's thermal noise degrades the sensitivity of the telescope receiver due to the background radio noise increase, particularly at the current primary operating frequency of the receiver at 1420 MHz. The additional effect of local trees also degrades the ability of the telescope to observe objects that are visually blocked by trees. The impact of trees will be the subject of a future report. This report provides information of the horizon impact based on the telescope orientation and elevation above the horizon.

2.0 Measurement Method

To obtain the required thermal noise measurements, the 8.5m dish telescope was aimed at 8 azimuth orientations as listed below.

	Orientation	Angle – degrees (true north)
1	North	0
2	North-East	45
3	East	90
4	South-East	135
5	South	180
6	South-West	225
7	West	270
8	North-West	315

For each orientation the dish was moved above the horizon from 0 degrees up to an elevation of 29 degrees in 1 degree step and a measurement sample recorded at each step. The measurement integration time of 10 seconds was used. Shown in Figure 1 is a screen capture of the radio telescope program which provides an example for the North azimuth scan.

The timing of each scan was planned to avoid the impact of the Milky Way strong radio emissions at 1420 MHz. This was possible to achieve during daylight hours for many of the scans however a couple required a delayed scan at night which was possible with a recent feature addition to the radio telescope program.

Some orientations are still impacted by the Milky Way however this did not affect the overall analysis.

As shown in Figure 1, the single line scan grid (path) is not precisely set. This is because the dish position was manually set. However, precision was not critical and errors or ± 1 degree are acceptable for this study.

Figure 2 provides an example of the radio temperature observed, again for the northern scan and in this example for an elevation of about 20 degrees. Note the thermal noise temperature is about 80 degrees Kelvin.

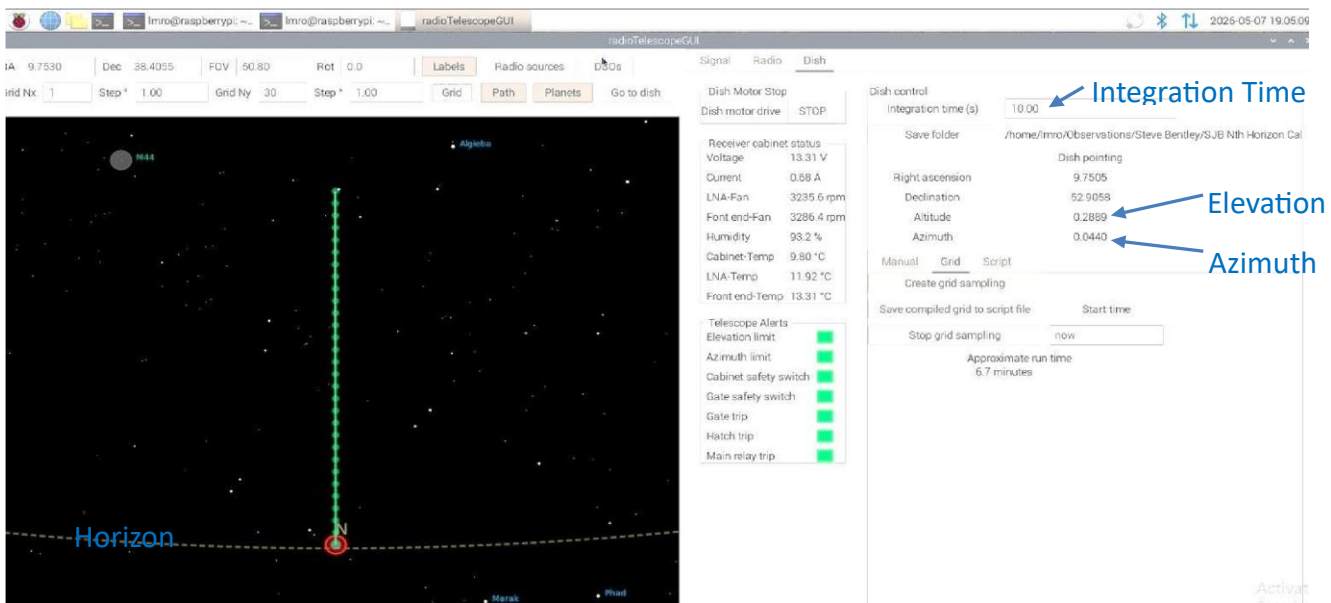


Figure 1 North Horizon Example

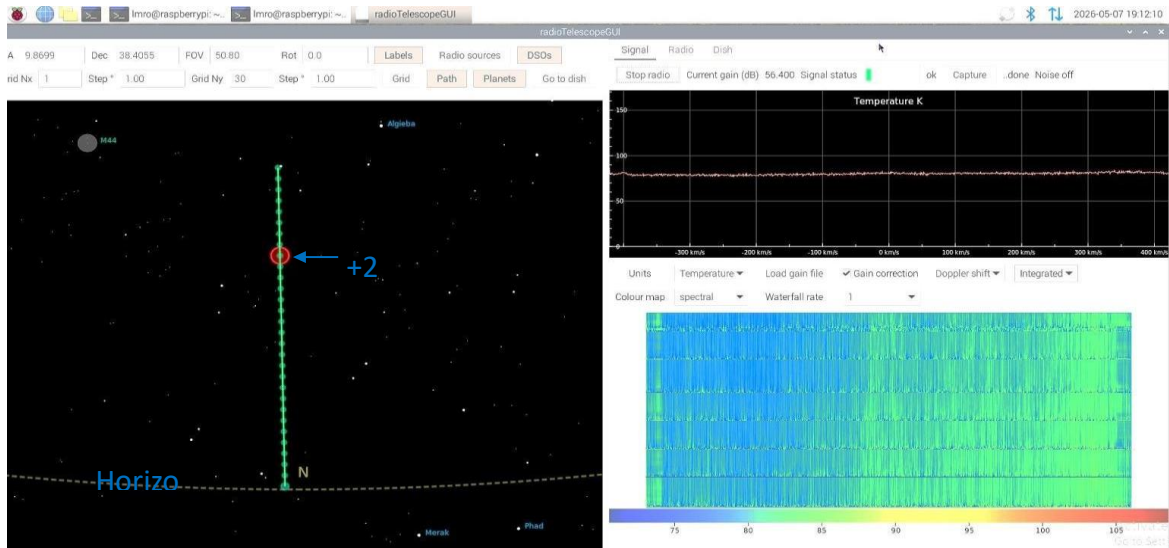


Figure 2 North Horizon Scan Example at 20 degree Elevation

3.0 Result

The recorded results were studied manually in detail to obtain a single figure for each azimuth and elevation. Figure 3 provides how the single figure was obtained. The radio analysis program was used to replay each scan. At each sample step relating to a given elevation angle, a unique spectrum is produced. A visual estimate of the temperature at the 0 Km/s Doppler shift in the centre of the spectrum display was recorded into a spreadsheet. Figure 4 provides a detailed view of the spectrum display.

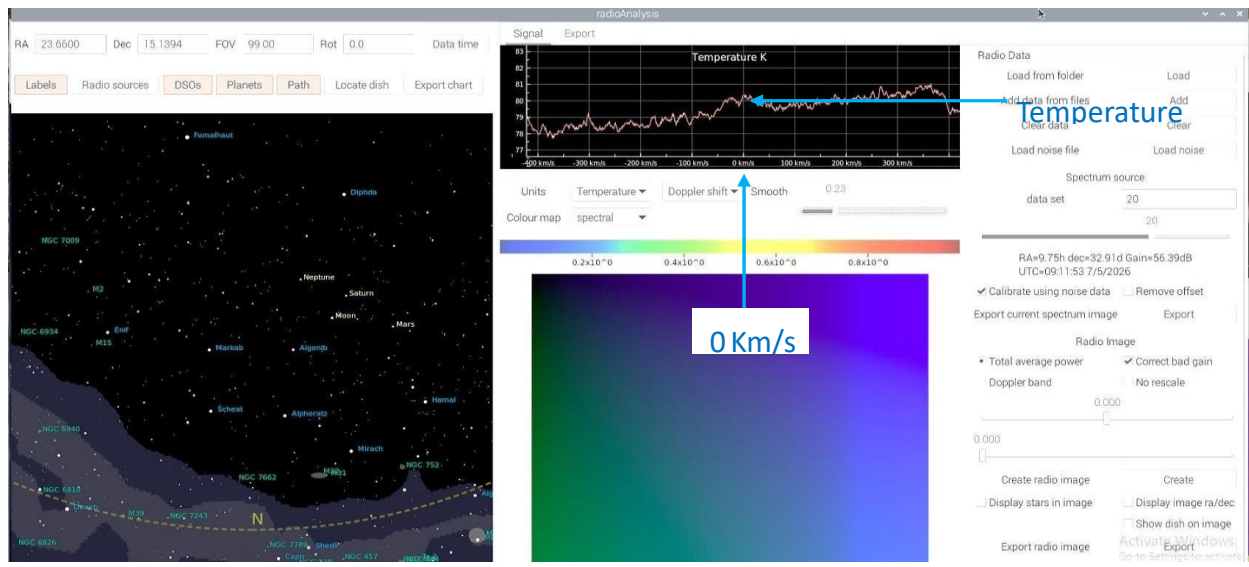


Figure 3 North Horizon Temperature Recording at 20 degree Elevation 0 Km/s Doppler

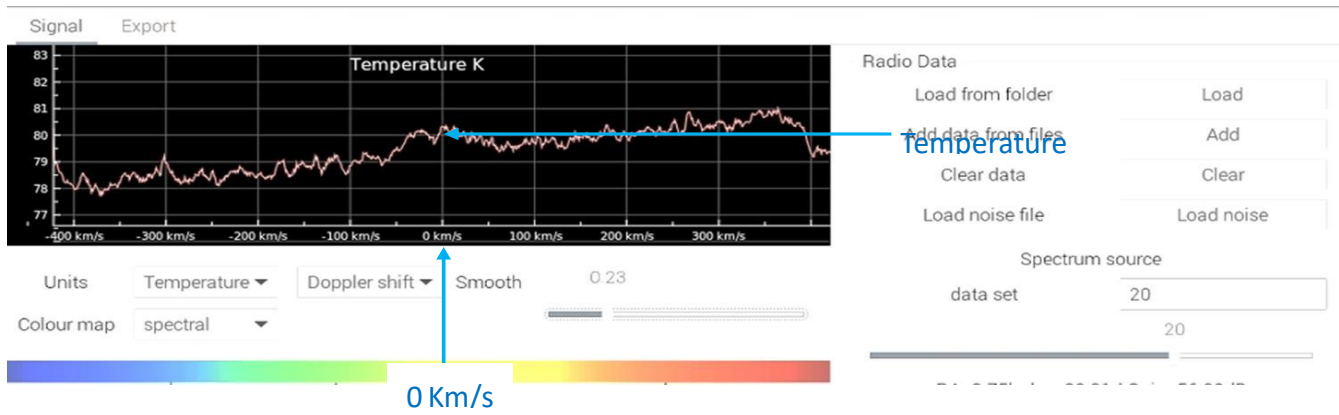


Figure 4 North Horizon Detail of Temperature Recording

The accumulation of the results is presented in table 1. In some instances, a measurement sample was faulty for yet unknown reasons. A faulty recording typically presents the result with an abnormally low value. Where this occurred, the previous measurement sample was placed into the table to permit completion of a chart in the Excel application. There was also 1 measurement at west 20 degrees elevation which appeared anomalous, so this value was replaced by the average of the result using the adjacent measurements. It is not sure if the anomalous measurement was real or not.

The measurements in Table 1 can be presented graphically. A graphical chart for the temperature measurements is shown in Figure 5. In the chart, the horizon axis shows the elevation angle from 0 to +35 degrees above the horizon. The vertical axis shows the radio temperature over the range 70 to 230 degrees Kelvin. The family of curves represent the 8 azimuth angles measured in degrees relative to true north.

Highlight	Due to bad sample previous value used							
Odd value, adjacent mean used instead	Original value = 113							
	1	2	3	4	5	6	7	8
Elevation degrees	North	North- East	East	South-East	South	South-West	West	North-West
	0	45	90	135	180	225	270	315
0	215	200	215	182	210	198	198	197
1	220	198	214	188	207	197	195	197
2	225	192	202	190	205	197	195	197
3	217	183	168	187	206	195	196	196
4	217	170	127	175	204	193	195	193
5	212	135	108	166	200	191	195	193
6	205	96	100	153	190	188	195	191
7	200	87	97	126	195	186	193	184
8	195	84	92	100	190	180	190	169
9	187	83	91	86	182	170	185	153
10	177	81	85	81	170	163	180	137
11	157	81	84	79	149	155	177	130
12	130	80	82	78	125	150	174	120
13	105	78	83	78	106	145	170	113
14	97	79	80	77	94	138	168	105
15	87	78	80	77	88	133	164	100
16	83	78	81	77	85	128	160	97
17	82	77	80	76	82	123	159	96
18	81	77	79	76	80	119	154	94
19	80	77	78	77	78	116	150	92
20	80	76	79	77	78	112	147	92
21	80	76	79	76	78	108	143	88
22	79	77	78	76	78	105	138	85
23	79	76	78	77	78	102	132	83
24	79	76	77	76	78	98	126	81
25	79	76	78	75	78	94	121	80
26	79	76	78	76	77	91	115	79
27	79	76	77	76	77	88	111	78
28	79	77	77	76	77	85	107	77
29	79	77	77	76	77	83	102	76

Table 1 Summary of Horizon Temperature Measurements

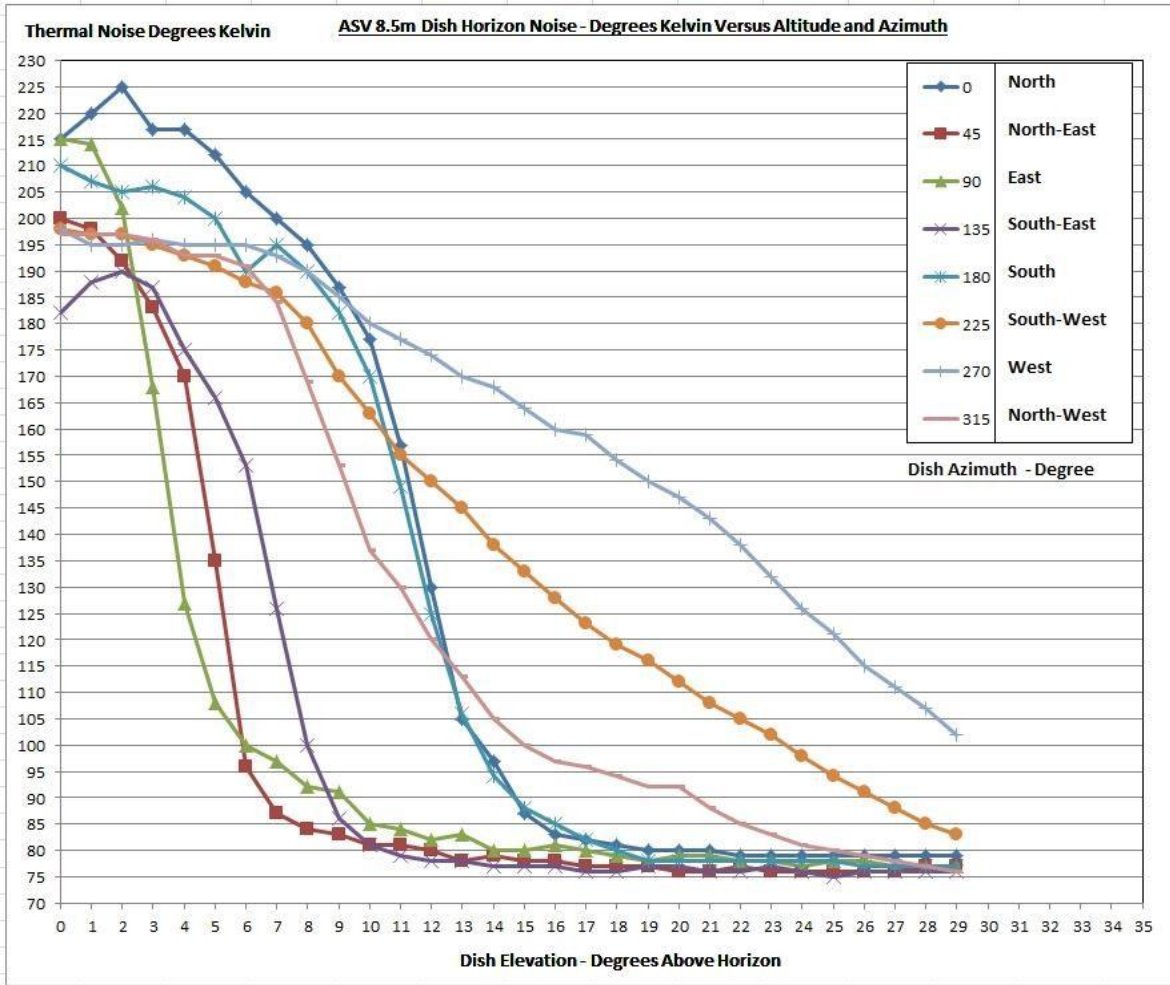


Figure 5 Horizon Temperature Profile Chart Versus Dish Elevation

The results may also be presented in an alternative format where the horizontal axis is the dish orientation relative to true north, the vertical axis is the thermal noise temperature, and the family of curves represent the dish elevation above the horizon. This chart format is shown in Figure 6.

The details in Figure 6 may appear confusing therefore a simplified chart is shown in Figure 7. This chart has reduced the family of elevation curves to just 7 with the elevation angles of 0, 5, 10, 15, 20, 25 and 29 degrees above the horizon.

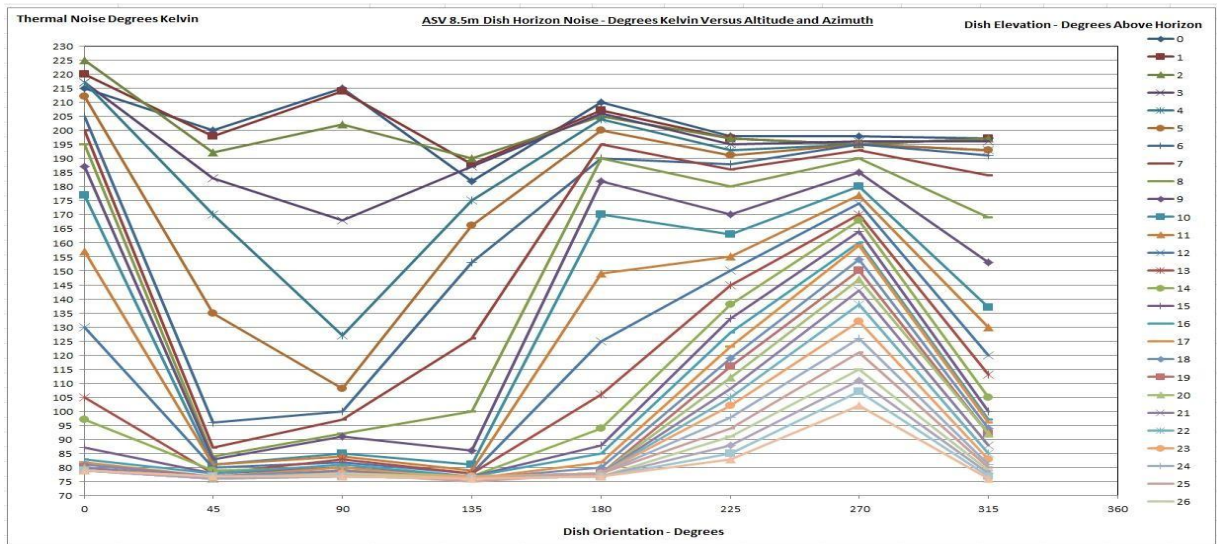


Figure 6 Horizon Temperature Profile Chart Versus Dish Orientation

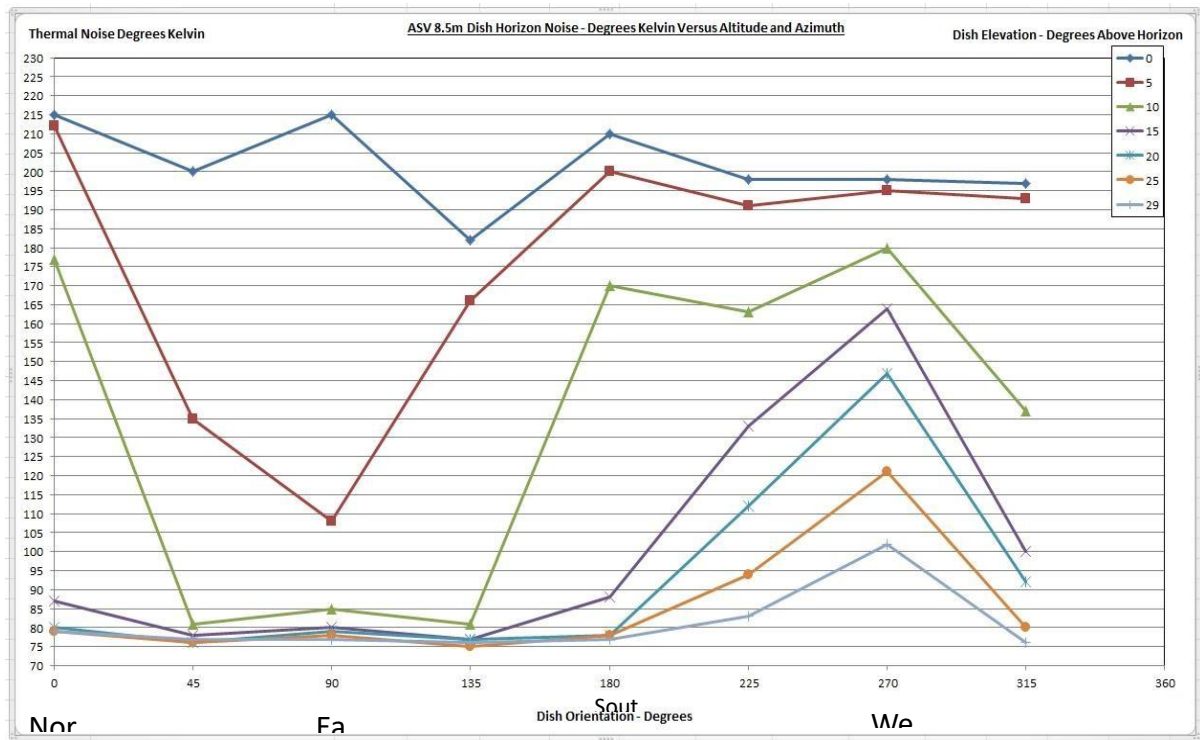


Figure 7 Horizon Temperature Profile Chart Versus Dish Orientation (reduced family of elevation angles)

4.0 Discussion of Results

The thermal noise floor of the dish and receiver combination appears to be at a temperature of 75 degrees Kelvin. This noise floor is achievable for only a limited range of telescope orientations and elevations above the horizon. Based on the results shown in Figure 7, the range of optimum performance is typically for the orientation range from 45 to 180 degrees and elevations of greater than 20 degrees above the horizon.

The noticeable “bump” in the family of elevation curves around 270 degrees orientation indicate a problematic area for the telescope operation where the lowest noise floor is never realised even with dish elevations above 29 degrees.

5.0 Conclusion

The radio telescope may be unusable for weak signal observations unless the horizon noise effects are taken into careful consideration. The results presented in the charts shown in Figures 6 and 7 will provide an ongoing guide for the optimum use of the telescope.

There is evidence that the observed noise is not just related to Earth’s thermal noise emissions but the local trees near the telescope. The effect of the local trees has already been observed when attempting to study objects low on the northern horizon such as M31, M33 and Cygnus. The nearest trees to the radio telescope are to the west. This is also evident in the noise measurement charts.

To add to this radio measurement reference, the author plans to obtain a panoramic photograph which presents the local view as seen from the height of the dish receiver feed point. Once obtained, this addendum will be issued.

Observations of the radio recombination line H166 α and the HI line in the Sagittarius A region

by Dimitry Fedorov UA3AVR

This report presents the results of observations of the H166 α radio recombination line and the neutral hydrogen (HI) line at 1420 MHz in the Sagittarius A (Sgr A) region, conducted in June 2026 using the 20-meter antenna at Green Bank. [1]. Their rest frequencies are close: 1424.734 MHz for H166 α and 1420.405752 MHz for the HI spin-flip line. The Sgr A region is also bright in the continuum. The HI line observations can be used as auxiliary for checking the telescope calibration. HI data for comparison can be retrieved from the LAB survey [2].

More info about the object

The object is located at the center of the Galaxy. Sgr A is formed around a supermassive black hole, Sgr A*; its mass is about $4.4 \times 10^6 M_{\odot}$ [3]. As supposed, Sgr A* was active recently like Active Galactic Nuclei (AGN) with much higher than today X-ray luminosity about 1.5×10^{39} erg/s ($\approx 4 \times 10^5 L_{\odot}$) [4]. Now its accretion is rather low, but, nevertheless, the accretion disk is seen in mm-wave EHT image, see Figure 1, left. Fermi Bubbles up and down from the Galaxy plane (Figure 1, right) are assumingly considered as traces of previous Sgr A* activity. They are also radiate in HI 1420 MHz line [5].

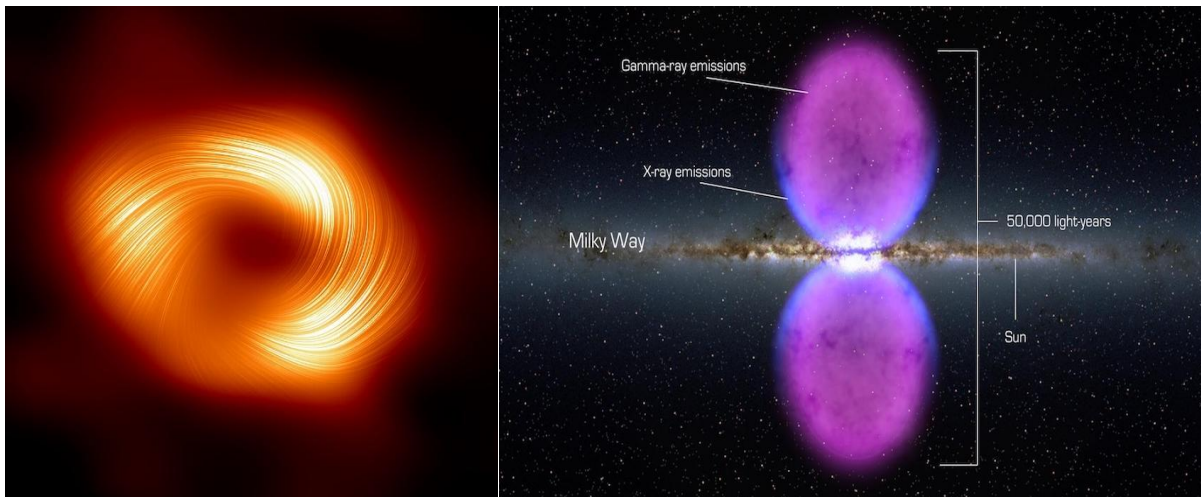


Figure 1. Sgr A* mm-wave image 2017 by Event Horizon Telescope (released 2022, left); Fermi bubbles up and down of the Galaxy disk (right), <https://www.space.com/fermi-bubbles-milky-way-radiation-mystery.html>.

Sgr A region is bright in HI line; the HI radiation is expected to be unpolarized. Part of the hydrogen gas in the region is ionized by UV radiation from O- and B-type stars, forming HII zones that can be observed in radio recombination lines (RRL) [6]. Recombination lines are expected of moderate widths 20-30 km/s [7]. Expected size of the HII spot is about 1° , see Figure 2.

Strong intrinsic polarization is not generally expected for ordinary thermal RRL emission from the Sgr A region. Near-LTE, predominantly spontaneous RRL emission is supported for the ionized gas of Sgr A

West, a part of the Sgr A complex, at millimeter wavelengths, with electron temperatures of order 6000–7000 K [8]. However, this should not be generalized to the entire Sgr A complex, and for centimeter-wave transitions such as H166 α , non-LTE and stimulated-emission effects may occur. RRLs at centimeter wavelengths may contain a stimulated emission component and be affected by pressure broadening [9]. For centimeter-wave transitions such as H166 α , stimulated amplification of polarized synchrotron background radiation could, in principle, produce polarization-dependent content of RRLs.

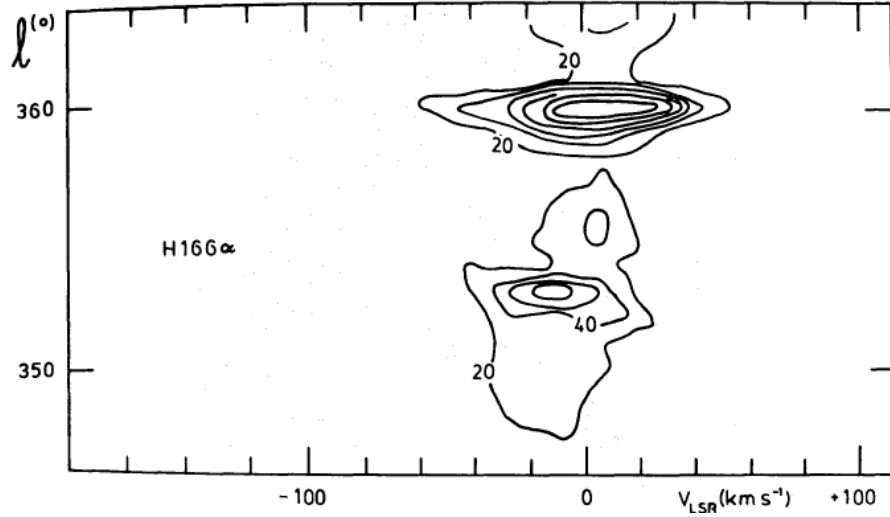


Figure 2. HII spot of Sgr A in the H166 α line [6]. Adopted size of the region is about 1°.

Instrumentation

Observations were made using 20 m Green Bank single dish telescope under Skynet Network control, see photo on Figure 3. The telescope is located in the radio quiet zone.

The beamwidth for frequencies about 1420-1425 MHz is 0.73°. With the spot angular size $\theta_s=1^\circ$ we get for the Beam Filling Factor (see 8.2.3 in [10]),

$$f_{beam} = \frac{\theta_s^2}{\theta_s^2 + \theta_{beam}^2} = 0.65. \quad (1)$$

The system temperature T_{sys} was obtained in calculations using the ambient temperature for

the observation date $T_{amb} = 300$ K and estimated values of the receiver temperature T_{rcvr} and the temperature T_{bgr} of the continuum background at the Galactic center. The antenna spillover is also taken into account.

$$\begin{aligned} T_{sys} &= T_{rcvr} + T_{spill} + T_{bgr} = 93 \text{ K}, \\ T_{rcvr} &= 15 \text{ K}, \quad T_{spill} = T_{amb} (1 - \eta_B) k = 30 \text{ K}, \quad k \approx 0.5, \quad T_{bgr} = 48 \text{ K}. \end{aligned} \quad (2)$$

The system temperature T_{sys} is obtained by estimations and taken the same for both linear polarizations. T_{sys} was *a posteriori* corrected for the best match of observed HI peak and LAB survey HI [2] peak (see HI plots in the next section) slightly adjusting the T_{bgr} value; T_{bgr} value is known only approximately, and its



Figure 3. Green Bank 20 m telescope.

uncertainty can reach 10-20 K. It should be noted that the continuous background radiation from the galactic center may be polarized; instrumental polarization effects are also possible.

Parameters of the telescope and observations are collected in Table 1.

Table 1. Parameters of the telescope and parameters of present observations

Dish diameter	D	20 m
Half Power Beam Width (HPBW)	θ_{beam}	0.73°
Beam Filling Factor	f_{beam}	0.65
Aperture Efficiency	η_A	0.6
Main Beam Efficiency, $\approx \eta_A/0.75$	η_B	0.8
System Temperature	T_{sys}	93 K (for both polarizations)
Resolution Bandwidth	RBW	15.26 kHz
Resolution in velocities		≈ 3 km/s
Integration Time (tracking duration)	Δt	200 s

Observations at 1420 and 1425 MHz and HI spectra

The observation was made on 2026-06-07, and the raw data from the observation over a wide frequency range including 1420 MHz and 1425 MHz are available [here](#). The observation was performed in the on-off mode, which helps to identify RFI spikes effectively. Observed HI spectrum averaged over two polarization is shown on Figure 4, left. The right spectrum Figure 4 shows LAB survey data [2] for comparison.

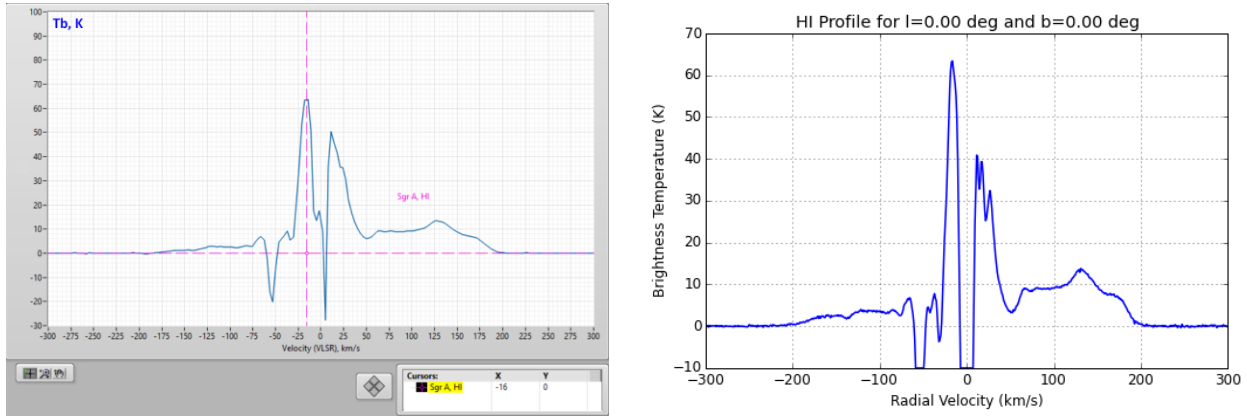


Figure 4. Observed HI spectrum of Sgr A averaged over two linear polarizations (left); LAB survey spectrum of the Galaxy center [2] for the same beamwidth 0.73° .

Brightness temperatures T_b was obtained from the antenna temperatures T_A by

$$T_b = \frac{T_A}{\eta_B f_{beam}}. \quad (3)$$

Calculations were based on temperatures T_A extracted from the observation data. The angular size of the HI spot was taken to be the same as for the H166 α line, i.e. 1° .

The spectra in Figure 4 are similar; moreover, the T_{sys} parameter of the telescope was slightly corrected for the best fit of observed HI peak ≈ 64 Jy to LAB survey HI [2] peak (see **Instrumentation** section for comments).

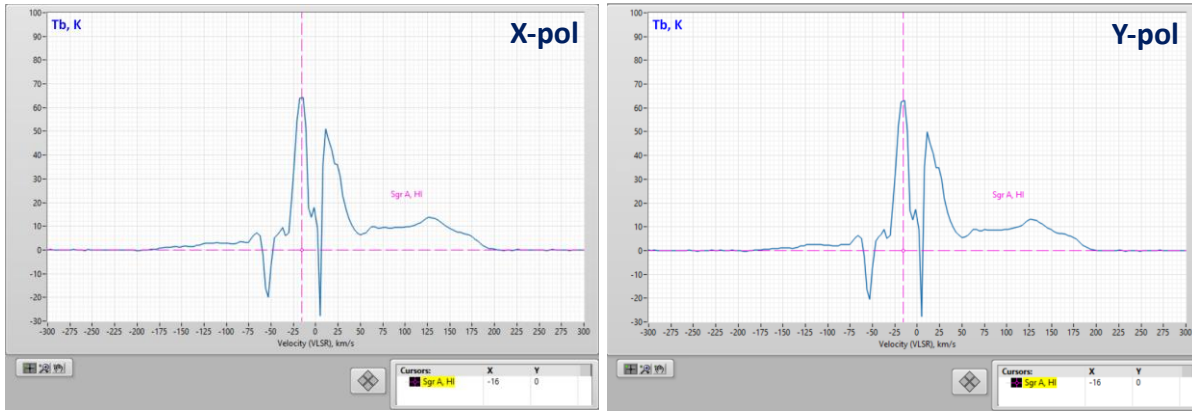


Figure 5. Observed HI line in two linear polarizations.

Figure 5 shows the HI spectra in the two linear polarizations. The X/Y polarization asymmetry parameter

$$p = \frac{T_X - T_Y}{T_X + T_Y} \quad (4)$$

calculated from these spectra is <1%. Here T_X, T_Y – the peaks of the brightness temperature T_b for two linear polarizations. The HI spin-flip radio emission from Sgr A is supposed to be unpolarized, and possible difference can be related to instrumental effects and baseline errors in the post-processing.

H166 α observed spectra

Figure 6 shows the spectrum of Sgr A averaged over two polarizations. Observed lines are of moderate width 20-30 km/s as expected. Recalculation of the data from [6] for this line yields a peak value of $T_b = 0.6$ K, which is in good agreement with the levels observed in the present work.

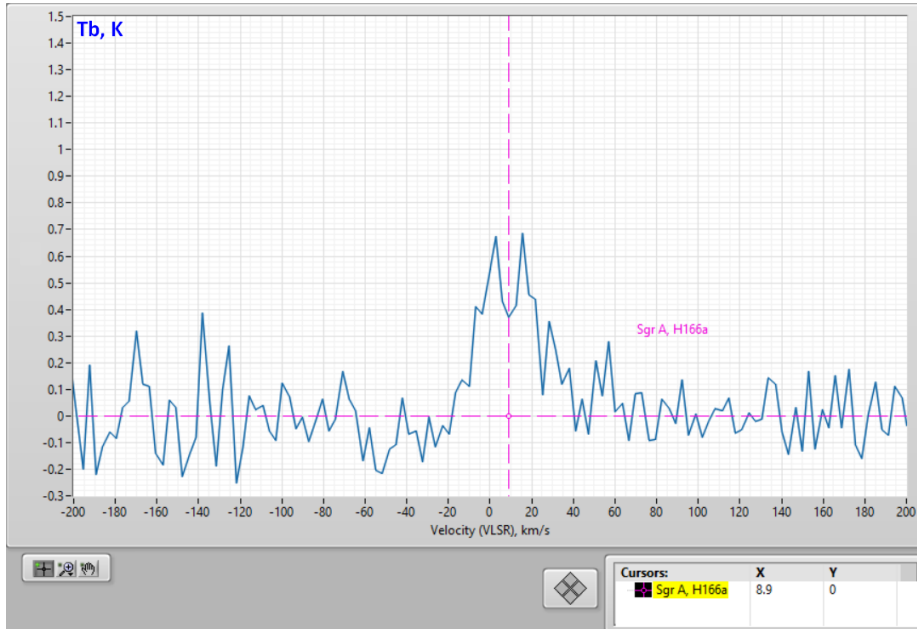


Figure 6. H166 α line spectrum averaged over polarizations.

Figure 7 shows H166 α line spectra in two linear polarizations. For the spectra in Figure 7, the polarization asymmetry parameter $p \approx 19\%$ according to Eq. (4).

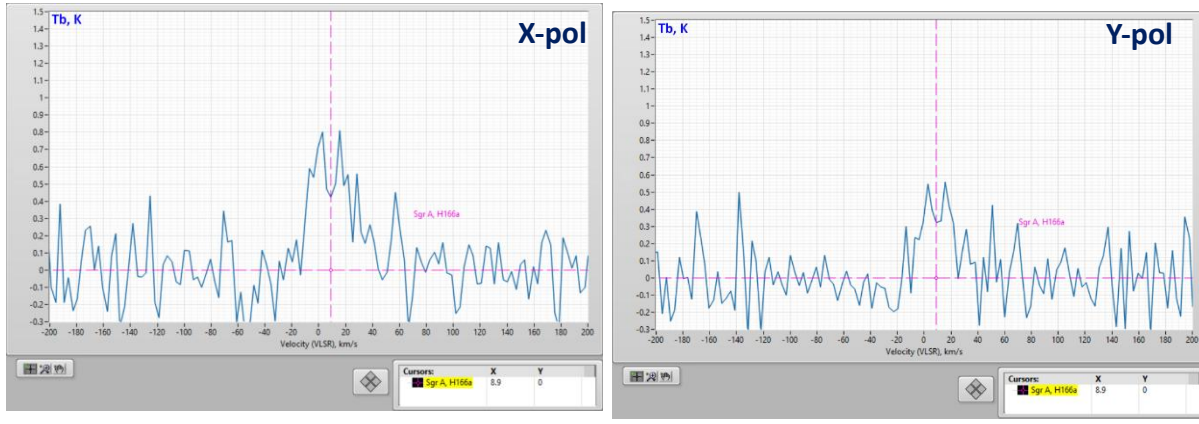


Figure 7. Observed H166α line spectrum in two linear polarizations.

Remarks on H166α detection, polarization issues and concluding notes

The H166α spectra are quite noisy; however, this radio recombination line has been detected. The line velocity at the center ≈ 9 km/s and the brightness temperature are about expected according to the data [6]. The line width 20-30 km/s also is about expected for HII regions in Sgr A [7]; it can be estimated also using the formula for the Doppler broadening (see Eq. (14.20) in [10] and comments therein)

$$\Delta V(\text{km/s}) = 0.21\sqrt{T_e(\text{K})}, \quad (5)$$

according to which the minimal expected line width is 21 km/s for the electron gas with a temperature T_e up to 10^4 K.

The following remarks should be made regarding the observed polarization asymmetry:

1. Radio frequency interference (RFI) may affect the results, but is expected to be reduced in the 1420-1425 MHz range in the telescope's radio quiet zone. Nevertheless, a RFI spike was identified in both polarization close to 1425 MHz, but it is located away from the detected H166α line. The observation presented here was not a first attempt of detection; previous attempts in the tracking mode give the same RFI birdie at 1425 MHz.
2. Instrumental polarization effects and background noise contribute to the observed asymmetry of $p \approx 19\%$. They distort possible polarization features of the emitted H166α line; therefore, polarization calibration and noise reduction are needed to be quite assured in secure detection of the H166α polarization.

At centimeter wavelengths, RRL emission may include a stimulated component that amplifies the nonthermal synchrotron background. Because synchrotron radiation can be linearly polarized, this process could, in principle, produce a polarization-dependent RRL signal. However, such a signal would reflect amplification of polarized background emission rather than necessarily intrinsic polarization of the recombining gas, and it should be distinguished from instrumental X/Y effects and the background noise.

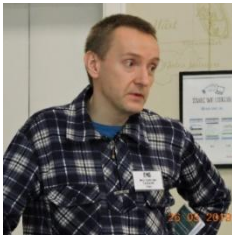
The observations performed do not include the polarization calibration; also, longer on-off observations of the Sagittarius A region are needed to reduce the background noise and identify RFI more accurately.

The result presented for the H166 α line should be regarded as tentative and requiring confirmation by follow-up observations and analysis.

References

- [1] Skynet Network resource, <https://skynet.unc.edu/>; *Observing Advice for the NRAO Skynet 20-meter telescope*, <https://www.gb.nrao.edu/20m/obsadvice.html>, Stephen Tzikas, [Maser observation program \(pptx file\)](#), Analytical Section Meeting: Demo, Masers, & W3 Radio Mapping, SARA Eastern Conference 2021.
- [2] HI Profile Search, Leiden/Argentine/Bonn (LAB) survey, <https://www.astro.uni-bonn.de/hisurvey/euhou/LABprofile/>.
- [3] Reinhard Genzel, Frank Eisenhauer, and Stefan Gillessen, *The Galactic Center massive black hole and nuclear star cluster*, Rev. Mod. Phys. 82, p 3121 (2010).
- [4] M.G. Revnivtsev et al., *Hard X-ray view of the past activity of Sgr A* in a natural Compton mirror*, A&A 425, L49-L52 (2004), [arXiv:astro-ph/0408190v1](https://arxiv.org/abs/astro-ph/0408190v1).
- [5] Felix J. Lockman and N.M. McClure-Griffiths, *Tracing the Milky Way nuclear wind with 21 cm atomic hydrogen emission*, ApJ 826, p 215 (2016), [arXiv:1605.01140v1](https://arxiv.org/abs/1605.01140v1); <https://www.youtube.com/watch?v=UMzTTJrzLP0>.
- [6] J.C. Cersosimo, I.N. Azcarate, L. Hart, F.R. Colomb, *H166 alpha emission from the southern galactic plane*, A&A 208, pp 239-246 (1989).
- [7] A.D. Anderson et al., *The Galactic Center Lobe as an HII Region*, ApJ 949, p 43 (2024); [arXiv:2405.11054v1](https://arxiv.org/abs/2405.11054v1).
- [8] Hemant Shukla, Min S. Yun, and N. Z. Scoville, *Dense, Ionized, and Neutral Gas Surrounding Sagittarius A**, ApJ 616, p 231 (2004), [arXiv:astro-ph/0408136v1](https://arxiv.org/abs/astro-ph/0408136v1).
- [9] K. Ferrière, *Interstellar gas within ~10 pc of Sagittarius A**, A&A 540, A50 (2012), [arXiv:1201.6031v1](https://arxiv.org/abs/1201.6031v1).
- [10] T.L. Wilson, K. Rohlfs, S. Hüttemeister, *Tools of Radio Astronomy*, 6th ed, Springer, 2013.

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

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The Crab Nebula Radio Astronomy Study

Written by: Stephen Bentley, Phil Costigan

Date: 21st April 2026

1.0 Introduction

On the 27th of February 2026, Phil Costigan performed a study of the Crab Nebula an object also known as M1 (Messier 1).

This report provides a summary of the method used to obtain the radio astronomy survey of M1 using the ASV 8.5m radio telescope at Heathcote and an analysis of the results obtained by Phil Costigan

2.0 M1 The Object

Shown in Figure 1 is an all sky chart of the neutral Hydrogen radio emissions with an overlay showing the constellations. The neutral Hydrogen plot was obtained using 2 large radio telescopes, one in Germany and the other in Argentina.

The Crab Nebula, M1 is within the red circle shown on the lower left side of the chart. M1 resides within the constellation of Taurus, the Bull. M1 appears above the northern horizon from our Australian southern skies.

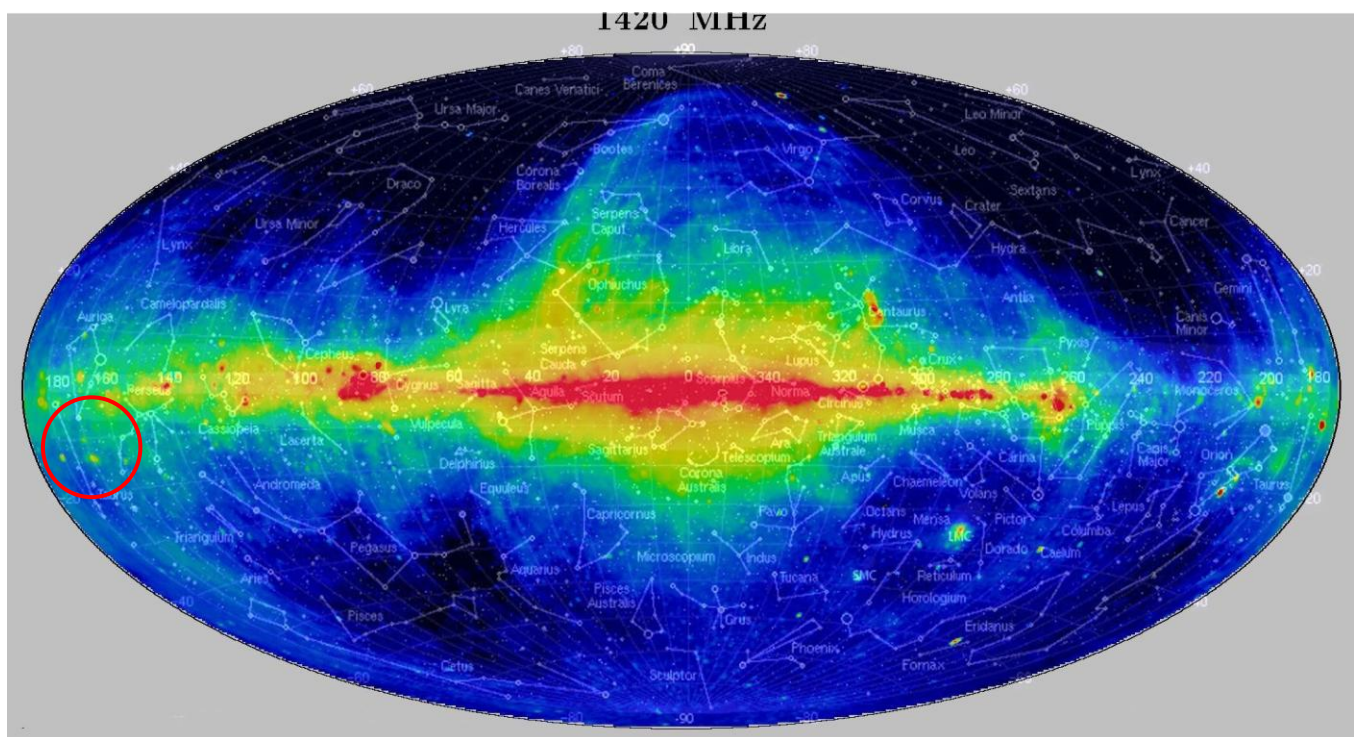


Figure 1 All Sky Neutral Hydrogen Chart with Constellation Overlay

In Figure 2, a Hubble Space Telescope image of the Crab Nebula is shown. M1 is the glowing remnant of a supernova which was observed by the Chinese in 1054 CE. M1 is approximately 6,500 light years away from Earth.

At the heart of the still expanding remnant, is a rapidly spinning neutron star also known as a pulsar. The pulsar is spinning at a rate of 30 times per second.

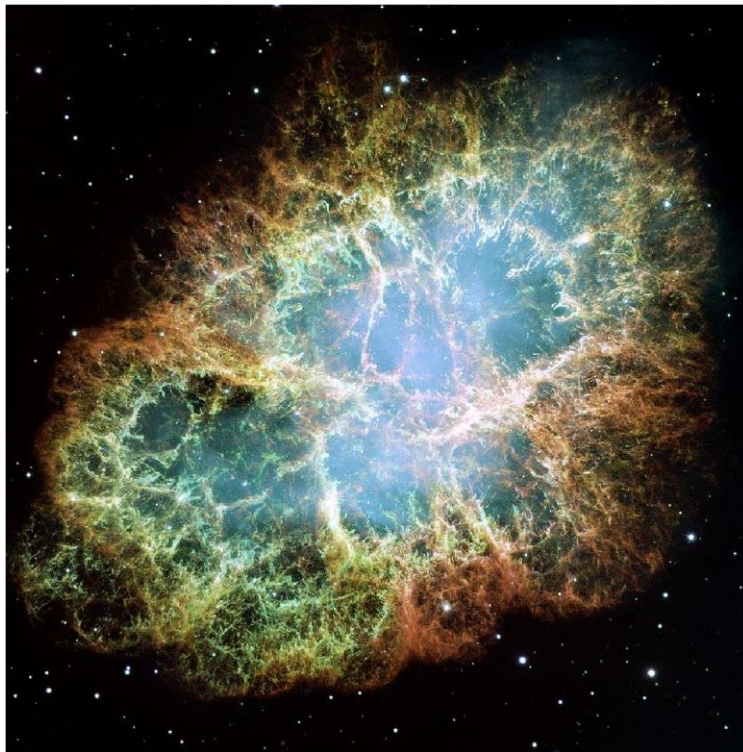


Figure 2 Optical Image of the Crab Nebula Captured by Hubble Space Telescope. Source Wiki Media Commons

3.0 Locating M1

Shown in Figure 3 is a screen capture of the radio analysis program for the study of the radio survey. On the left side of the screen is a sky chart. Part of the Taurus and Auriga constellation outlines have been shown with construction lines added to the image. The location of M1 is also shown with the yellow circle. The red circle is the aiming location of the telescope for the specific measurement sample which in this case is the start of the survey at sample “0”.

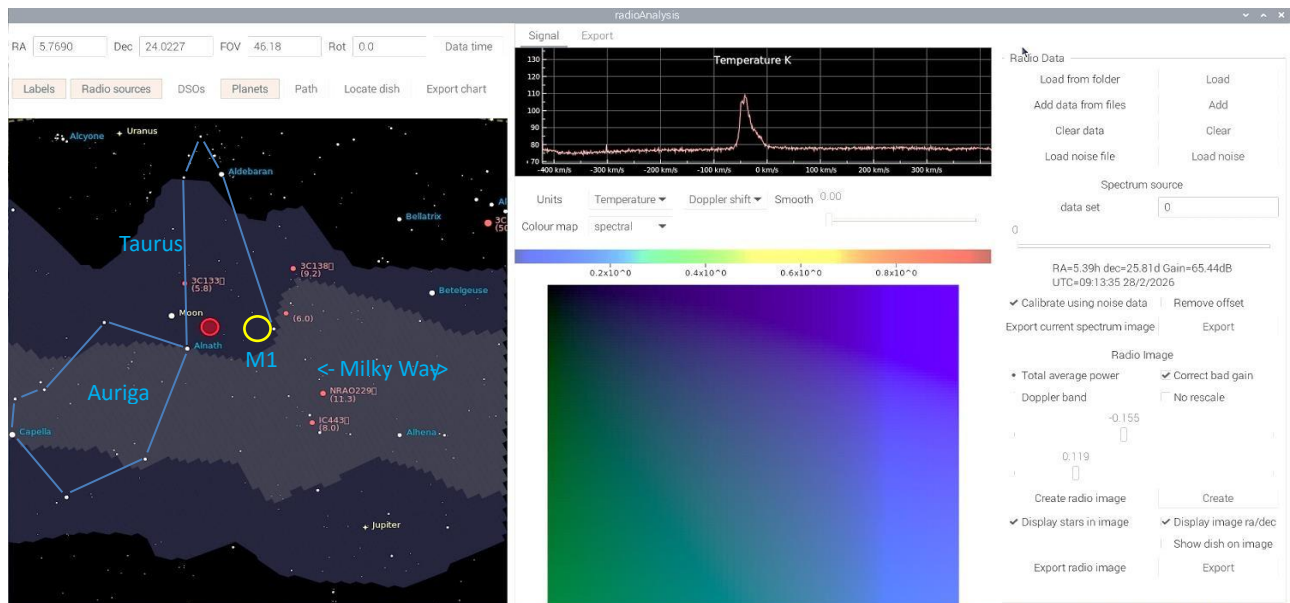


Figure 3 Radio Telescope Survey of M1 - Location

In figure 4 the scan grid for the survey of M1 is shown. A grid of 7 x 7 points was captured with a grid spacing of 1 degree.

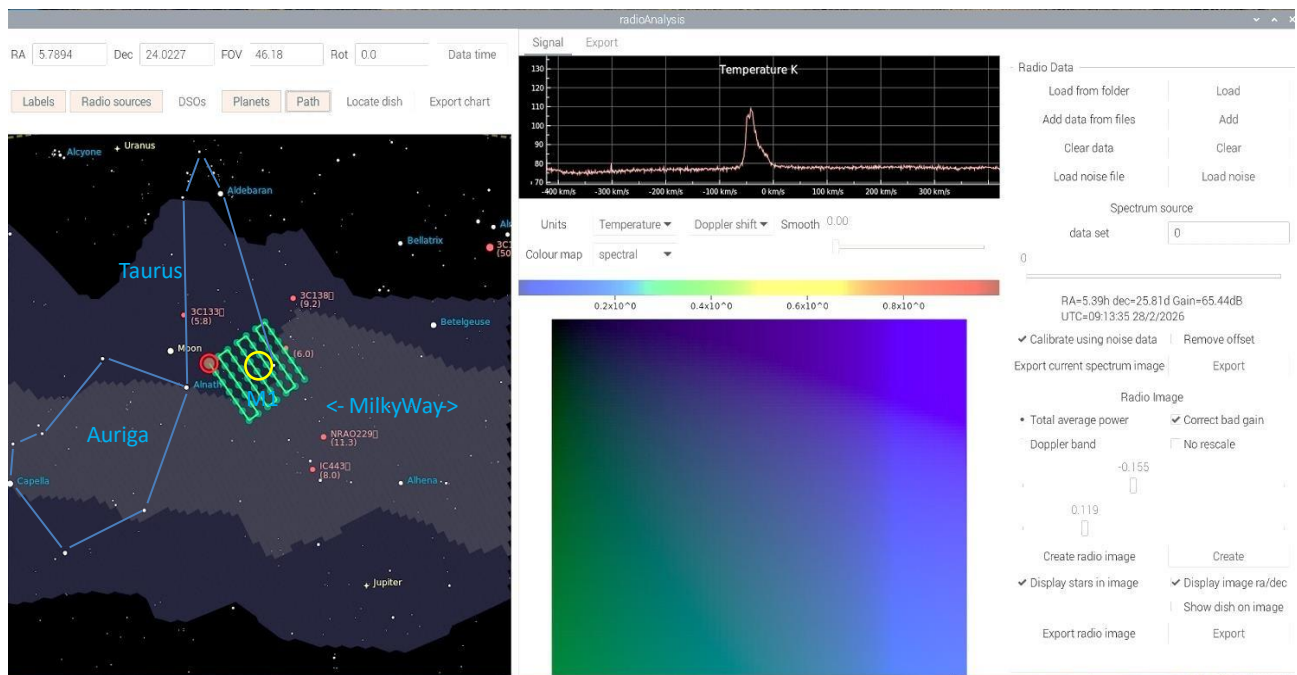


Figure 4 Radio Telescope Survey of M1 - Scan Grid

4.0 Survey Results

Shown in Figure 5 a radio temperature plot has been presented using the filter settings to only include the measurements within the small Doppler range between -100Km/s and 0Km/s. This is the area highlighted in the spectrum plot on the top right. The 2D intensity plot on the bottom right has rotated the image relative to that shown in the sky chart. This is to conform to the RA and Dec scales on the X and Y axis. A construction line has been added to the plot showing the horn of Taurus. Note the well-defined high intensity radio signal to the right of centre in the plot.

This radio source is centred over where the M1 Crab Nebula is located.

To enhance the radio object, the plot scale was manually altered slightly from its default settings.

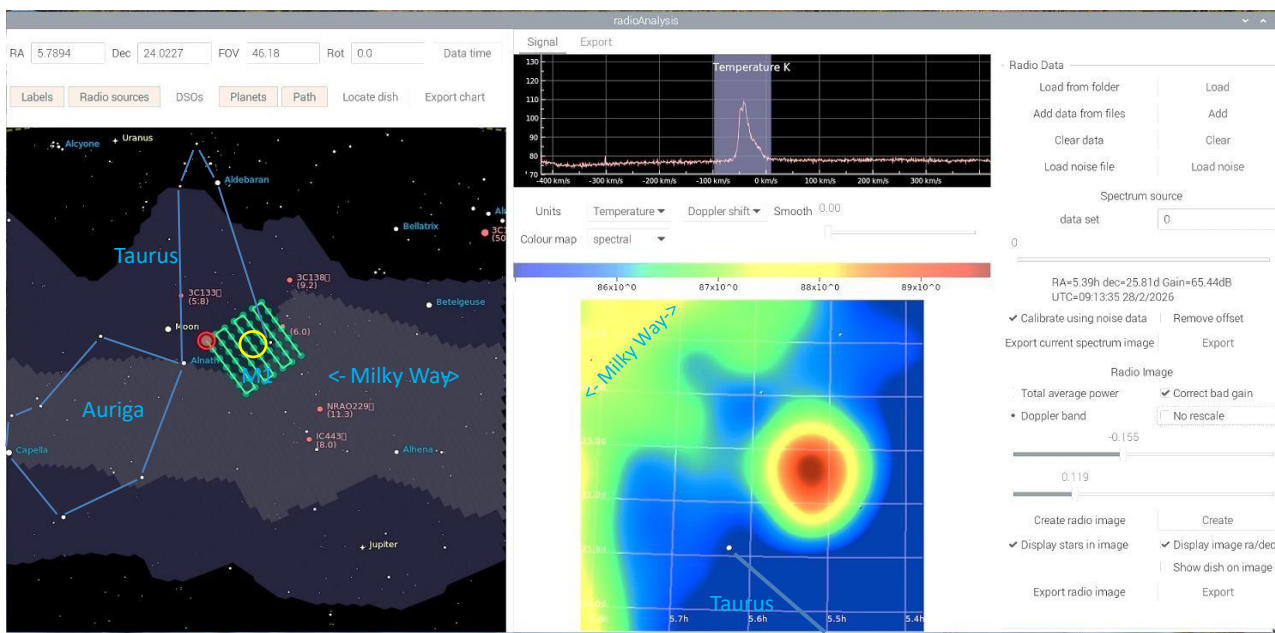


Figure 5 M1 – Neutral Hydrogen only Temperature Plot

A second analysis of the same measurement was then performed this time using an area on the spectrum display well separated from the dominant neutral Hydrogen peak around the centre of the spectrum. As shown in the spectrum display in Figure 6 the Doppler area is from about +100 and +240Km/s.

The intensity plot created no longer has the temperature intensity of the Milky Way neutral Hydrogen which was evident in Figure 5 however the strong pattern of radio temperature on the right of centre remains. The conclusion is that this radio source is not specifically related to neutral Hydrogen but is a broad band radio source.

A detailed plot of the Crab Nebula radio source is shown in Figure 7. The plot has been rotated to better match the sky charts.

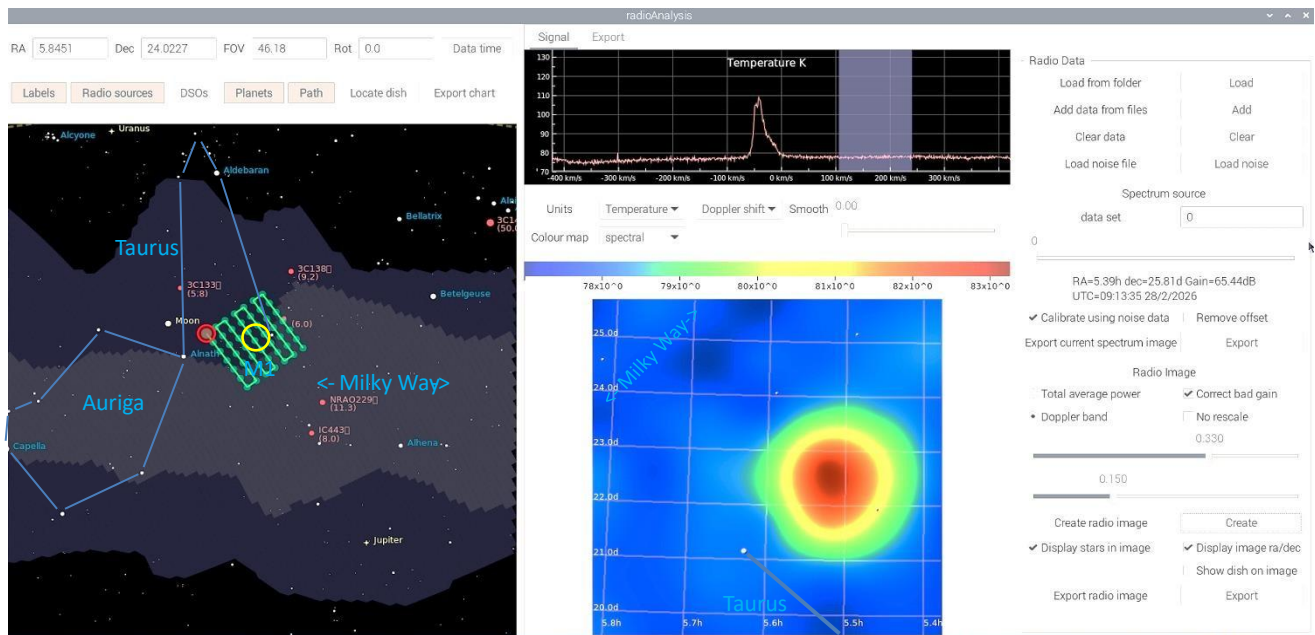


Figure 6 M1 Background Only Temperature

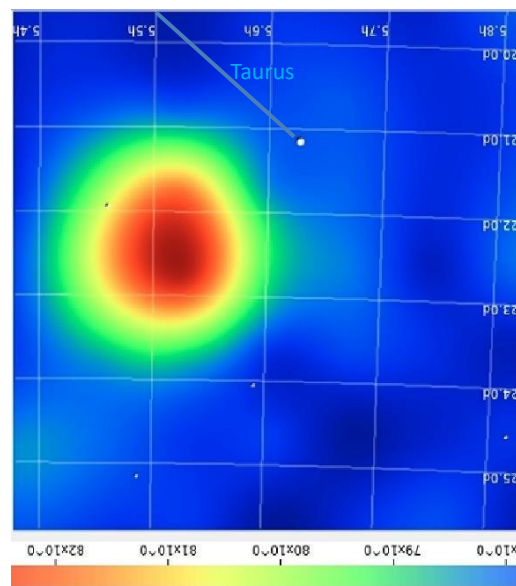


Figure 7 M1 Temperature Plot Detail

5.0 Conclusion

The object studied is undoubtedly M1 the Crab Nebula. In terms of radio astronomy, the source is also referred to as Taurus A. The radio emissions are due to the spinning neutron star which generates synchrotron radiation which occurs when fast moving electrons encounter the magnetic field of the nebula.

The brightness temperature varies with frequency diminishing with higher frequency.

The temperature is about 120K +/- 20K at 8.5mm.

The flux density is also about 875 Jansky at 1420 MHz.

The bright centre of the object shown in the temperature plots appearing as a brown colour is at least greater than 90 Kelvin at 1420 MHz. Therefore the 8.5m dish is measuring the object close to its actual temperature.

The British Astronomical Association's Monday Practical Radio Astronomy Workshops:

Building an International Community of Practical Amateur Radio Astronomers.

Dr Andrew Thornett Lichfield Radio Observatory

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Abstract

The rapid growth of software-defined radio, affordable low-noise electronics and powerful open-source software has transformed amateur radio astronomy over the past decade. While these developments have made radio astronomy more accessible than ever before, they have also created a need for practical guidance to help newcomers design, construct and operate successful observing systems.

To address this need, the British Astronomical Association (BAA) Radio Astronomy Section launched a series of online Monday evening Practical Radio Astronomy Workshops during late 2024. Initially centred on hydrogen line observing, the programme has since expanded to include GNU Radio, Very Low Frequency (VLF) radio astronomy, muon detection and radio meteor scatter. Although organised by the BAA, participation has been international from the outset and has included members of the Society of Amateur Radio Astronomers (SARA) together with many independent observers.

This article reviews the first two years of the programme, examining its educational philosophy, development, achievements and future direction. It also considers how regular practical workshops can complement traditional conferences and lectures by providing a collaborative environment in which observers learn through shared experience, discussion and experimentation.

Keywords: Amateur Radio Astronomy, Hydrogen Line, GNU Radio, VLF, Muon Detection, Meteor Scatter, Education, Outreach, Software Defined Radio

Introduction

There has never been a better time to become involved in amateur radio astronomy.

Only a few years ago, many observing projects required equipment that was either prohibitively expensive or beyond the technical capabilities of most amateurs. Today, inexpensive software-defined radios, highly sensitive low-noise amplifiers, surplus satellite components and powerful open-source software have transformed the landscape. A dedicated observer can now detect the neutral hydrogen line, monitor solar radio bursts, record meteor scatter, investigate solar flares through Sudden Ionospheric Disturbances (SIDs) or even detect cosmic-ray originated muons using equipment that would once have been available only to professional laboratories.

Ironically, this technological revolution has created a new challenge.

While information about radio astronomy is abundant, it is often scattered across websites, discussion forums, scientific papers and videos. Beginners frequently know **what** they would like to observe but have little idea **how** to assemble a working receiving system, choose appropriate components, configure software or interpret the results they obtain. Even experienced observers can find themselves faced with unfamiliar technologies such as GNU Radio, digital signal processing or advanced spectrum analysis.

Recognising this need, the British Astronomical Association (BAA) Radio Astronomy Section established a series of practical online workshops on Monday evenings (UK time) designed specifically to bridge the gap between theory and successful observation. Rather than presenting theoretical lectures, these meetings concentrate on the practical aspects of amateur radio astronomy: selecting equipment, constructing receivers, solving technical problems, processing data and sharing observing results.

From modest beginnings as a single Hydrogen Line workshop, the programme has expanded into a family of specialist groups covering several areas of practical radio astronomy and related sciences. Throughout this development, one principle has remained constant: every meeting should help participants become more capable observers.

Although organised under the auspices of the BAA, the workshops have always welcomed participants from all backgrounds. Members of the Society of Amateur Radio Astronomers (SARA), independent experimenters and observers from many countries regularly contribute to discussions, creating an international community united by a shared enthusiasm for practical radio astronomy. Recordings of every meeting are freely available through the BAA YouTube channel, extending their educational value far beyond the live audience and creating a permanent library of practical instruction.

Why Practical Workshops?

Most astronomy meetings concentrate, quite understandably, on scientific discoveries and observing results. Such presentations inspire audiences and demonstrate what is possible, but they often leave newcomers wondering how those results were actually achieved.

Practical radio astronomy presents a different set of educational challenges. Success depends not only upon understanding astrophysics but also upon acquiring skills in electronics, antenna design, software-defined radio, signal processing, computing and statistical analysis. Few beginners possess experience in all of these disciplines, and many are discouraged by the complexity of bringing them together into a functioning observing system.

The Monday workshops were created specifically to address this problem.

Instead of asking, *"What have we discovered?"*, they ask, *"How do we make these observations ourselves?"*

This simple change of emphasis has proved remarkably effective. Meetings typically combine short presentations with live demonstrations, practical problem solving and discussion of members' own equipment and results. Participants are encouraged to ask questions, share difficulties and present work in progress. Unsuccessful experiments are regarded as every bit as valuable as successful ones, since they often lead to discussions that benefit the entire group.

Over time, the workshops have developed into far more than a series of online meetings. They have become an ongoing collaborative learning community in which participants not only acquire new skills but also contribute their own experience for the benefit of others. This atmosphere of mutual support reflects the long-standing traditions of both the British Astronomical Association and the Society of Amateur Radio Astronomers (particularly the monthly SARA Radio Telescope Observation Parties), demonstrating that amateur science flourishes most effectively when knowledge is shared freely.

The Birth of the Monday Practical Radio Astronomy Workshops.

The idea for the Monday Practical Radio Astronomy Workshops emerged during 2024 from a simple observation. Although there was no shortage of enthusiasm for amateur radio astronomy, many newcomers found the first steps unexpectedly difficult. Information existed in abundance, but it was widely scattered across websites, books, conference presentations and online discussion groups. Finding reliable guidance on building a working radio telescope often proved far more challenging than understanding the underlying science.

Experienced observers were frequently asked similar questions, including the following:

- "Which SDR should I buy?"
- "Why can't I detect the hydrogen line?"
- "Is my antenna working properly?"
- "Which software should I use?"
- "How do I know whether my results are genuine?"

These are not questions that can easily be answered in a single lecture or by referring someone to a textbook. They require discussion, demonstration and often several conversations as an observer's project develops. It became clear that many amateurs would benefit from regular meetings devoted specifically to the practical aspects of building and operating radio telescopes. Some SARA members had already been offering 1:1 support by dedicated and experienced colleagues, but the numbers of individuals requiring support was beginning to make this difficult to facilitate for everyone. The SARA monthly meetings also provided opportunity, but these cover all aspects of radio astronomy in each meeting and there was evidence that many observers would like to also participate in meetings dedicated to their area of investigation.

Towards the end of 2024, the British Astronomical Association Radio Astronomy Section therefore established a new series of online workshops dedicated entirely to practical radio astronomy. The concept was deliberately different from that of a conventional lecture programme. Instead of inviting speakers simply to describe completed projects, the meetings would encourage members to demonstrate equipment, explain observing techniques, discuss software and, perhaps most importantly, solve problems together.

The workshops were inspired in part by the friendly and informal atmosphere of SARA's highly successful Drake's Lounge and Radio Telescope Observation Party meetings. From the outset, SARA members were actively invited to participate alongside members of the British Astronomical Association, and attendance was opened to anyone with an interest in amateur radio astronomy, regardless of nationality or organisational membership, ethnicity or political views. There was no charge to attend, reflecting the organisers' desire to make practical radio astronomy as accessible as possible.

One further decision proved particularly important. Every workshop would be recorded and made freely available through the BAA's YouTube channel. This transformed each meeting from a single evening's discussion into a permanent educational resource that could be revisited by participants or discovered by newcomers months or even years later. As the archive has grown, it has become one of the most comprehensive collections of practical amateur radio astronomy material available online. Again, this decision copied the successful approach adopted by SARA.

Initially, the programme consisted of a single workshop devoted to hydrogen line radio astronomy. The enthusiastic response from participants soon demonstrated that the format had wider potential. As attendance increased, additional specialist groups were introduced to address other areas of practical radio astronomy and related scientific instrumentation, including GNU Radio, Very Low Frequency (VLF) radio astronomy, muon detection and radio meteor scatter. By July 2026, the programme had grown to include fourteen hydrogen line meetings, nine GNU Radio workshops, four VLF meetings, three muon detection workshops and the first dedicated meteor scatter session.

This steady expansion reflected not only the success of the original hydrogen line group but also the breadth of interests within the amateur radio astronomy community. Participants were no longer seeking information on a single observing technique; they were developing a broad range of scientific skills that extended from antenna construction and software-defined radio to particle detection and space weather monitoring. Many of the participants were attending multiple groups – with active projects in one or two, and exploring the possibility of starting others.

An Educational Philosophy Based on Practical Experience.

From the outset, the Monday Practical Radio Astronomy Workshops were designed to be more than a series of technical presentations. Their purpose was to provide an environment in which participants could develop the practical skills needed to become successful radio astronomers.

Many astronomy lectures naturally focus on the scientific discoveries made using sophisticated instruments. While these talks are both informative and inspiring, they rarely have sufficient time to explain the practical steps required to reproduce similar observations with amateur equipment. As a result, newcomers can easily understand the science yet remain uncertain how to begin building an observing system of their own.

These BAA workshops were established to bridge this gap.

Every meeting follows a similar educational pattern. Sessions begin by introducing the scientific background to the topic under discussion before progressing to the equipment required, the software used for data acquisition and processing, and finally the practical aspects of construction and operation. Wherever possible, these discussions are illustrated by real observing systems rather than theoretical examples, allowing participants to see complete working installations and the results they produce.

As the workshops have developed, a characteristic format has emerged. Theory provides the foundation, but equal emphasis is placed on practical construction, software configuration and the interpretation of real observational data. Participants are encouraged to present their own projects; describe the difficulties they have encountered and seek advice from others who may have solved similar problems. The result is a learning environment that is highly interactive and collaborative rather than simply instructional.

One of the strengths of this approach is that observers at every level can contribute. Beginners ask questions that often stimulate valuable discussion, while experienced members share techniques that may have taken years to develop through trial and error. In many meetings, participants demonstrate equipment live, compare different hardware solutions or explain why one particular approach proved more successful than another. Such discussions provide insights that are difficult to capture in books or formal presentations.

An equally important feature of the workshops is their willingness to examine unsuccessful experiments. Amateur scientists are sometimes reluctant to discuss projects that have not worked as intended, yet these experiences often contain the most valuable lessons. Within the Monday workshops, problems are viewed as opportunities for collective learning. A receiver that fails to detect the hydrogen line, an unstable GNU Radio flowgraph or an unexpectedly noisy VLF antenna can all become starting points for discussions in which several members contribute possible explanations and practical solutions. The problems experienced by one group attendee are often the same ones experienced by others – and their discussion helps all.

This emphasis on shared problem solving has created a supportive atmosphere in which participants feel comfortable asking questions regardless of their previous experience. As confidence grows, many members who initially joined simply to listen gradually begin presenting their own work, demonstrating new equipment or helping newcomers overcome similar difficulties. In this way, the workshops create a continuous cycle of learning in which today's beginner becomes tomorrow's mentor.

The philosophy underpinning the programme closely reflects the objectives of both the British Astronomical Association and the Society of Amateur Radio Astronomers. Both organisations seek to encourage education, collaboration, technical development and the sharing of observational experience. The Monday workshops complement these aims by providing regular opportunities for practical interaction between observers with a wide range of backgrounds and experience.

Perhaps the greatest measure of success is that the workshops have evolved from a programme delivered to participants into a community created by its participants. While each meeting has a planned topic, the discussions frequently develop in unexpected directions as members contribute ideas, ask questions and demonstrate their own projects. The workshops have therefore become not simply a means of teaching practical radio astronomy, but a forum in which new ideas are generated.

The Hydrogen Line Workshops – From First Detection to Scientific Investigation

The Hydrogen Line workshop was the first of the Monday Practical Radio Astronomy groups and remains the cornerstone of the entire programme. It was established because hydrogen line observing represents one of the most rewarding areas of amateur radio astronomy. Detecting the 1420.4058 MHz emission from neutral hydrogen allows amateurs to observe the structure of our own Galaxy, measure Doppler velocities and investigate Galactic rotation using equipment that is increasingly within the reach of dedicated observers.

Despite this accessibility, hydrogen line observing presents a formidable challenge for beginners. Success depends upon understanding not only the underlying astrophysics but also antenna design, feed construction, low-noise amplification, receiver configuration, software-defined radio, calibration

techniques and digital signal processing. A problem in any one of these areas can prevent successful observations, even when the remainder of the system performs perfectly.

The Hydrogen Line workshops were created specifically to overcome these barriers.

Unlike a conventional lecture course, the workshops begin with practical questions rather than theoretical ones. Participants discuss which antennas are suitable, how to illuminate a dish correctly, how to minimise system noise, which software-defined radios provide the best performance and how observations should be calibrated. Real observing systems are demonstrated wherever possible, allowing newcomers to understand not simply what equipment is required but why individual design choices have been made.

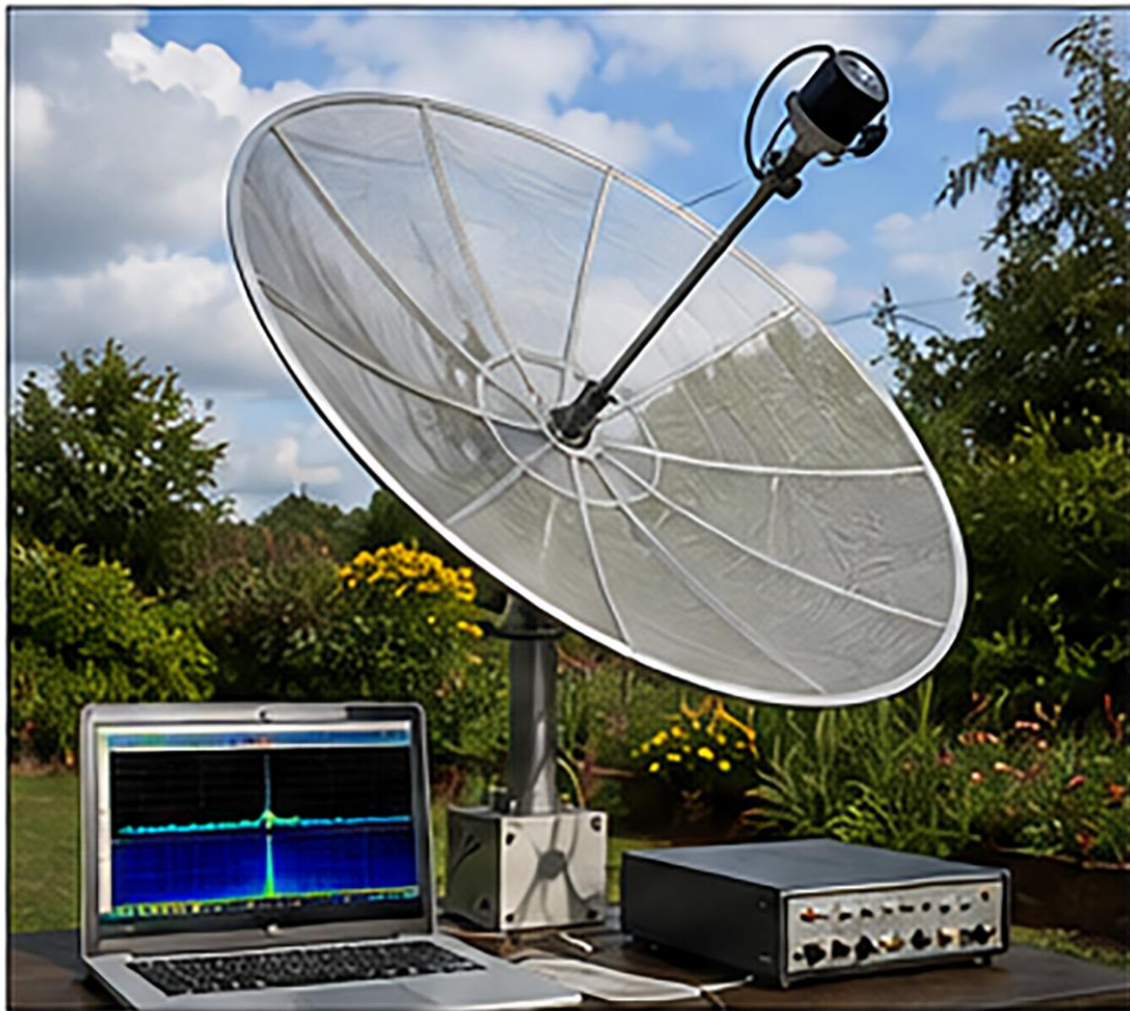


Figure 1. A typical Hydrogen Line observing station using an SDR receiver and parabolic dish antenna.

One of the earliest objectives was to help members achieve their first successful hydrogen line detection. Few moments in amateur radio astronomy equal the excitement of seeing the characteristic spectral peak emerge from the background noise for the first time. Many participants have described this experience as the point at which radio astronomy became real for them. The workshops therefore place considerable emphasis on careful receiver setup, correct observing techniques and methods of improving signal-to-noise ratio, enabling members to progress from unsuccessful attempts to reliable detections.

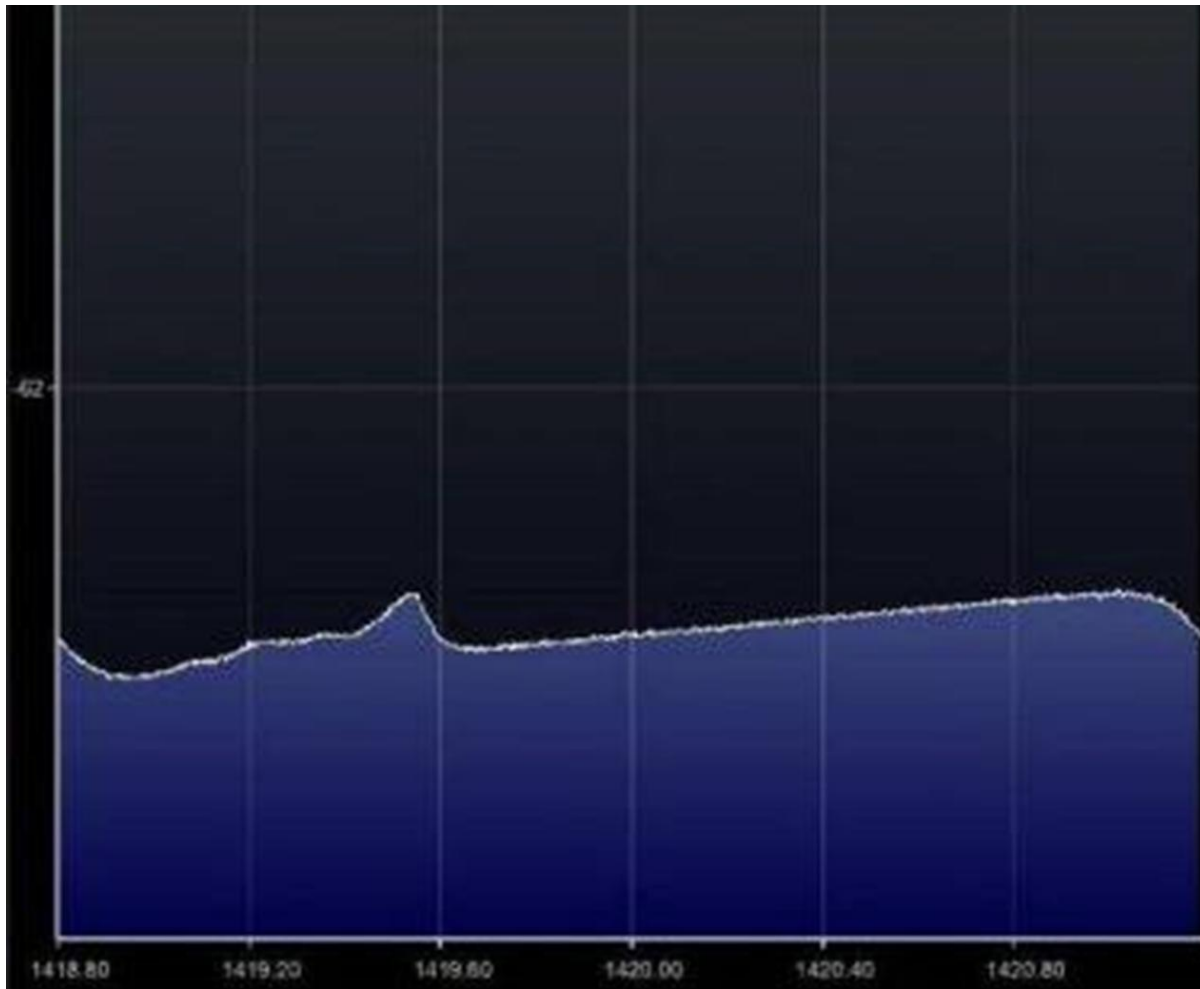


Figure 2. Example of a hydrogen line spectrum of the Milky Way obtained by a workshop participant.

As confidence has grown, the scope of the workshops has expanded considerably. Discussions have moved beyond simply detecting the hydrogen line to exploring how increasingly sophisticated observations can be made using amateur equipment. Topics now include Doppler velocity measurements, Galactic rotation, frequency calibration, baseline correction, spectral averaging and methods of improving sensitivity through longer integrations and careful signal processing. Participants compare different observing strategies, discuss sources of systematic error and examine techniques for extracting weak astronomical signals from noisy data.

An important feature of the Hydrogen Line group has been its willingness to compare different hardware solutions. Members have demonstrated observations using a wide variety of antennas, from relatively modest dishes to larger installations, together with a diverse range of feeds, low-noise amplifiers and software-defined radios. Rather than promoting a single "correct" design, the workshops encourage observers to understand the strengths and limitations of different approaches. This diversity has proved particularly valuable for newcomers working within varying budgets and observing environments.

Software has become an increasingly important theme throughout the series. Modern radio astronomy depends as much upon digital signal processing as upon receiver hardware, and considerable time has been devoted to demonstrating methods of recording, averaging and analysing spectra. Participants have explored different approaches to data processing, discussed techniques for improving spectral quality and demonstrated innovative ways of presenting Galactic hydrogen observations. These developments reflect a broader trend within amateur radio astronomy, where advances in computing now allow sophisticated analysis to be carried out on relatively modest personal computers.

The collaborative nature of the workshops has also accelerated technical progress. It is common for participants to present observations that raise unexpected questions or reveal apparent anomalies. Rather than treating these as failures, the group examines them collectively. Discussions frequently identify subtle issues such as receiver instability, calibration errors, radio-frequency interference or software configuration problems that might otherwise have remained unresolved. In many cases, improvements suggested during one meeting are demonstrated successfully at the next, creating an ongoing cycle of experimentation and refinement.

As the programme has matured, the Hydrogen Line workshops have increasingly resembled collaborative research meetings rather than introductory classes. While newcomers continue to receive practical guidance, experienced observers now contribute sophisticated analyses, innovative hardware developments and advanced processing techniques. This natural progression demonstrates one of the central strengths of the workshop model: participants do not simply acquire knowledge—they become contributors to the continuing development of amateur radio astronomy.

Perhaps the clearest evidence of the group's success lies in the continued popularity of the recorded meetings. Hydrogen Line workshops consistently account for the one of the largest audiences on the BAA Radio Astronomy Group's YouTube channel, with seven of the ten most-viewed Monday Practical Radio Astronomy recordings devoted to this subject. This sustained interest suggests that there is a widespread appetite for practical instruction in hydrogen line observing and confirms its position as one of the most accessible and scientifically rewarding branches of amateur radio astronomy.

GNU Radio – Bringing Modern Digital Signal Processing to the Amateur Community.

The rapid development of software-defined radio has fundamentally changed amateur radio astronomy. Tasks that once required specialised hardware can now be performed within software, allowing receivers to become increasingly flexible and powerful. At the centre of this revolution lies GNU Radio, an open-source software framework that enables users to construct sophisticated digital signal-processing systems by linking together individual processing blocks into graphical "flowgraphs".

Despite its capabilities, GNU Radio can appear intimidating to newcomers and experienced radio astronomers alike! Many amateur radio astronomers are highly experienced in antenna construction and

receiver design but have limited programming experience. Others are familiar with conventional SDR software such as SDR#, SDRUno or HDSDR but have never ventured into designing their own signal-processing chains. Recognising this challenge, the Monday workshops established a dedicated GNU Radio group to provide a practical introduction to this increasingly important technology.

Rather than beginning with complex radio astronomy examples, the first meetings concentrated on building confidence. Participants learned the principles of flowgraph design by constructing simple AM and FM receivers, exploring how individual processing blocks combined to form complete receiving systems. This gradual approach allowed members to understand the logic of GNU Radio before applying the same techniques to astronomical observations.

As participants became more familiar with the software, the workshops are now increasingly focused on radio astronomy applications. Standard communication examples are giving way to spectrometers, signal averaging, filtering techniques and automated observing systems specifically designed for astronomical use. By working with genuine observing problems rather than abstract programming exercises, it is hoped that members will quickly appreciate how GNU Radio can simplify many aspects of radio astronomy data acquisition and processing.

One of the strengths of the GNU Radio group has been its emphasis on understanding rather than simply copying existing flowgraphs. While complete working examples were demonstrated, participants were encouraged to examine how individual blocks functioned and how they could be modified to meet their own requirements. This approach has helped many observers move beyond using software created by others to designing customised processing systems tailored to their own observing programmes.

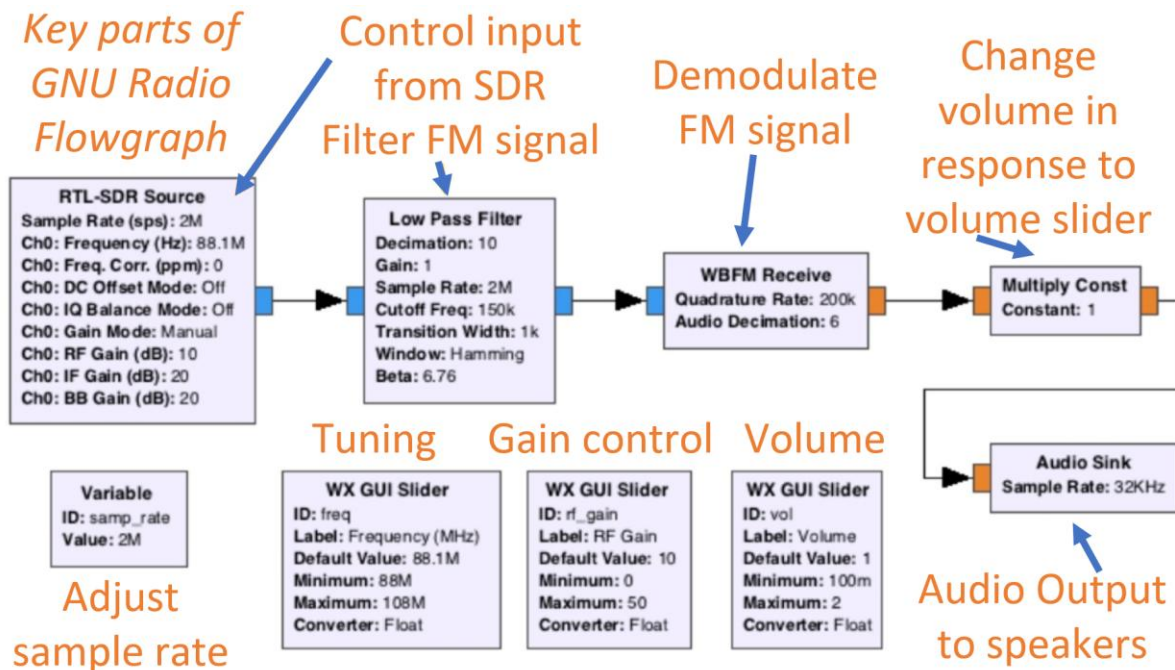
As confidence increases, the workshops are starting to introduce progressively more advanced topics. Members are exploring the development of embedded Python and C++ blocks, allowing specialised signal-processing algorithms to be incorporated directly into GNU Radio flowgraphs. Although these techniques are considerably more sophisticated than those encountered in introductory sessions, they illustrate the remarkable flexibility of the software and the opportunities it offers amateur observers wishing to automate complex processing tasks. Examples presented during the workshops demonstrate how custom blocks can control observing systems, manipulate large datasets and implement algorithms specifically designed for radio astronomy.

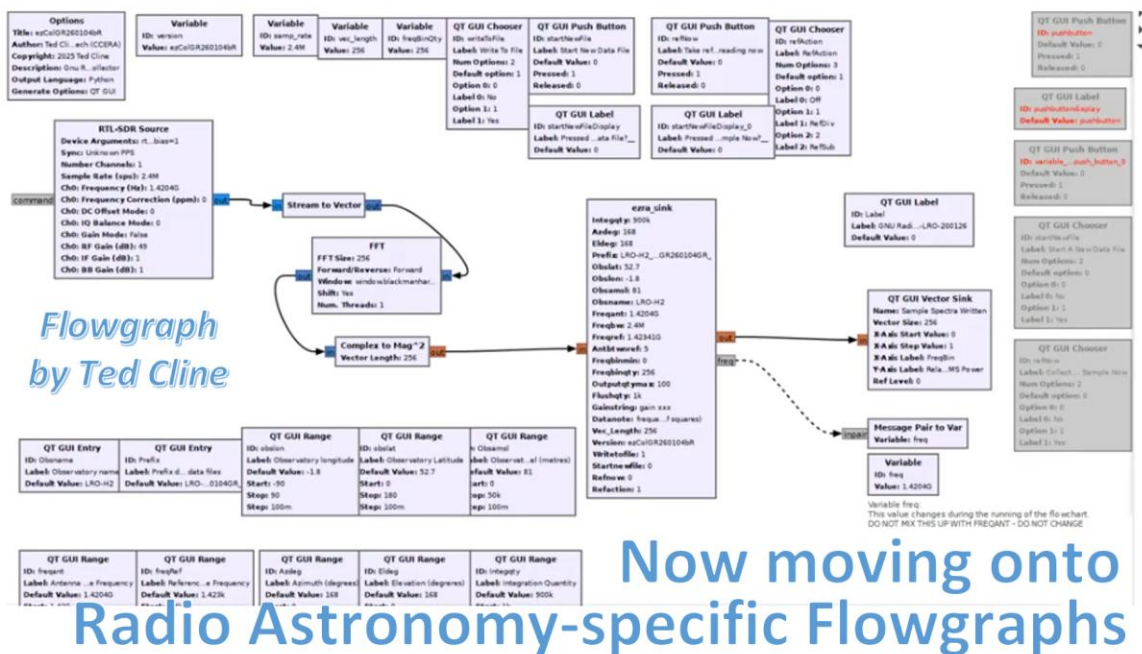
Equally important has been the willingness of experienced members to share their own work and help others to understand the software, blocks and flowgraph construction. Several participants have presented complete radio astronomy flowgraphs developed for their personal observing systems, illustrating how GNU Radio can be used to automate data collection, calibration and spectral analysis. These presentations not only demonstrate what is possible but also encourage others to experiment with their own designs, fostering a culture of innovation within the amateur community.

The GNU Radio workshops have also highlighted an important trend within amateur radio astronomy. Increasingly, the performance of an observing system depends as much upon software as upon hardware. A well-designed processing chain can improve sensitivity, reduce noise, automate repetitive tasks and present data in forms that reveal subtle astronomical signals. By helping observers understand these techniques, the workshops have enabled participants to make more effective use of the receivers they already own while opening the door to increasingly ambitious observing projects.

Perhaps the most significant achievement of the GNU Radio group has been to remove much of the perceived complexity surrounding digital signal processing. What initially appeared to many participants as an inaccessible programming environment has become a practical tool that can be applied directly to solving real observational problems. In doing so, the workshops have equipped amateur radio astronomers with skills that will become increasingly important as software-defined instrumentation continues to evolve.

Figure 3. As the course developed, participants explored increasingly sophisticated radio astronomy flowgraphs, including custom Python blocks and automated signal-processing systems developed by members of the group.





Expanding Horizons – The Muon Detection Workshops.

One of the strengths of the Monday Practical Radio Astronomy Workshops has been their willingness to explore scientific disciplines closely related to radio astronomy. Although the programme began with observations of cosmic radio emissions, it soon became apparent that many participants shared a wider interest in experimental astrophysics and the construction of scientific instruments.

This naturally led to the introduction of a workshop devoted to cosmic-ray muon detection.

Muons are elementary particles produced high in the Earth's atmosphere when energetic cosmic rays collide with atmospheric nuclei. Travelling close to the speed of light, many survive long enough to reach the Earth's surface, where they can be detected using relatively compact electronic instruments. Although the physics differs from radio astronomy, the practical challenges are remarkably similar. Both disciplines require sensitive detectors, careful calibration, reliable electronics and thoughtful interpretation of statistical data.

For many participants, muon detection represented an opportunity to broaden their scientific interests while making use of skills already developed through radio astronomy. Knowledge of electronics, data logging, computer software and signal analysis transferred naturally from one field to the other, demonstrating how practical scientific techniques often transcend traditional subject boundaries.

The workshops introduced the physical principles underlying cosmic-ray showers before examining the operation of modern amateur muon detectors. Discussions covered scintillation detectors, coincidence techniques, photodetectors, electronic processing and methods of recording and analysing count rates. Rather than presenting the physics in isolation, each topic was linked directly to practical observing,

enabling participants to understand how theoretical concepts influence detector performance and experimental design.

As with every specialist group, the emphasis remained firmly on practical experience. Members demonstrated complete detector systems, explained their construction and shared examples of real observational data. Particular attention was given to understanding natural variations in count rates, recognising instrumental effects and interpreting long-term measurements. These discussions helped participants appreciate that successful experiments depend as much upon careful analysis as upon the performance of the detector itself.

The workshops also encouraged members to compare different detector designs and discuss their respective strengths and limitations. Such comparisons illustrated an important principle that runs throughout the Monday programme: there is rarely a single "correct" solution. Different instruments may be better suited to different experimental objectives, budgets or levels of technical experience. By examining a range of approaches, participants were able to make informed decisions when developing their own projects.

Perhaps most importantly, the muon workshops demonstrated the flexibility of the educational model established by the Hydrogen Line group. The same combination of theory, practical construction, data analysis and collaborative problem solving proved equally effective when applied to particle astrophysics. This success suggests that the workshop format could readily be adapted to many other branches of amateur scientific research.

For several participants, muon detection also provided a valuable introduction to statistical thinking. Unlike many radio astronomy observations, where a signal may be visible immediately, muon experiments often rely upon analysing long-term variations in count rates and distinguishing genuine physical effects from random statistical fluctuations. Learning to interpret these datasets strengthened skills that are equally valuable in radio astronomy, where weak signals frequently emerge only after careful averaging and detailed analysis.

This discussion provided an important theoretical underpinning for one member's attempts to record variations in muon count with altitude during a transatlantic flight and led to the development of bespoke software by two other members written to complement this experiment.

The inclusion of muon detection therefore broadened the scope of the Monday Workshops while remaining entirely consistent with their original philosophy: enabling amateur scientists to build instruments, collect reliable data and understand the science behind their observations.

The Muon Detection workshops introduced participants to detector technology, data acquisition and interpretation of cosmic-ray measurements, illustrating how practical scientific skills developed in radio astronomy can be applied to other areas of astrophysics.

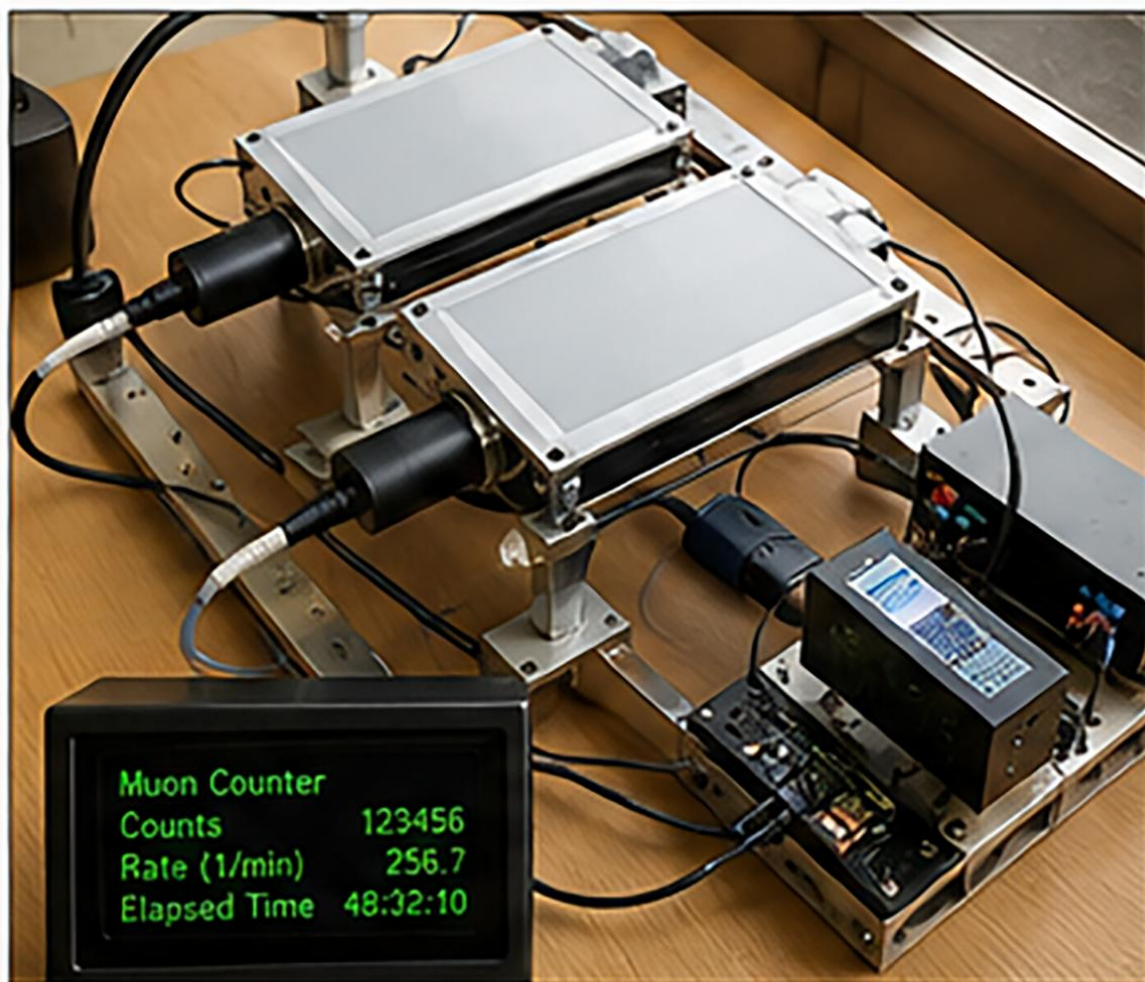
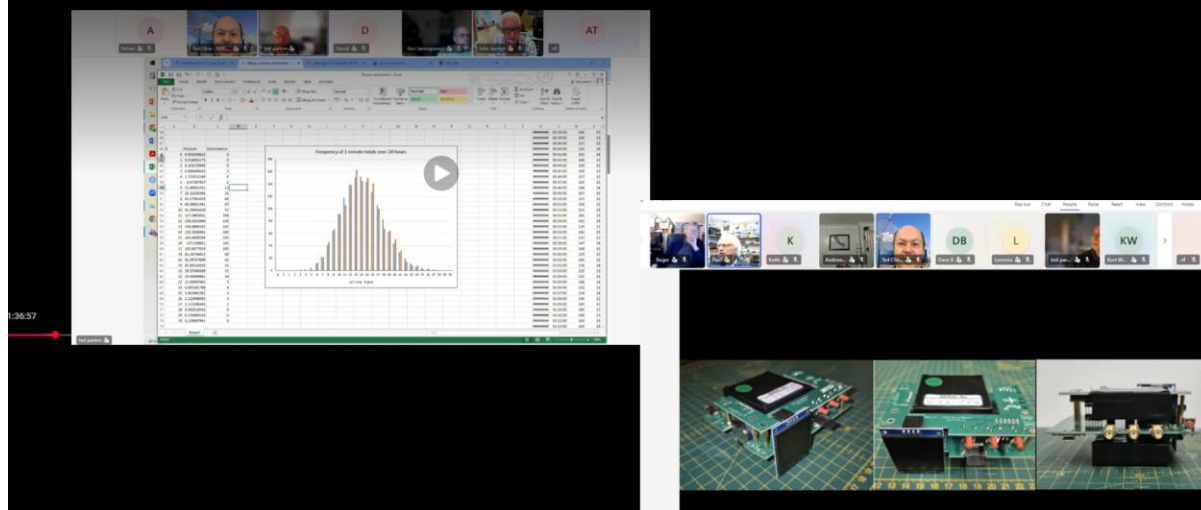


Figure 4. A typical cosmic-ray muon detector using two scintillator paddles in coincidence with a digital counter.

Exploring the technology involved in detecting muons and interpreting muon data



Radio Meteor Scatter – Exploring the Dynamic Radio Sky.

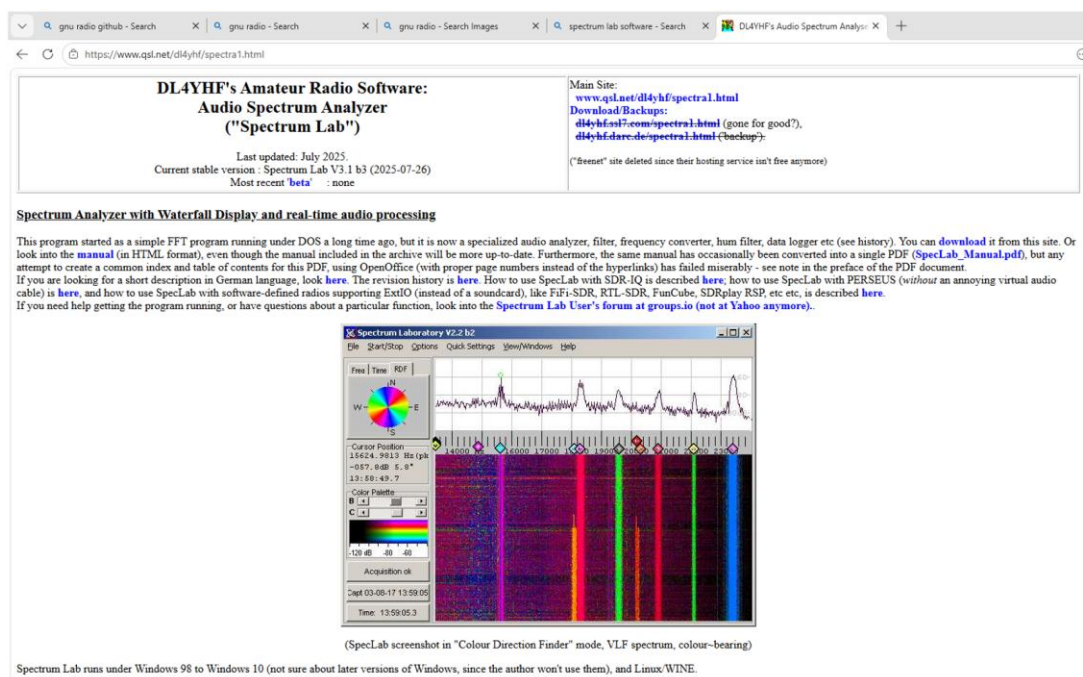
While hydrogen line observations investigate the structure of our Galaxy, radio meteor scatter focuses attention much closer to home. Every day, countless tiny particles enter the Earth's atmosphere at high velocity, producing brief trails of ionised gas as they burn up. These ionised trails can reflect radio signals, allowing meteors to be detected regardless of cloud cover or daylight and making radio meteor scatter one of the most accessible branches of amateur radio astronomy.

Recognising the growing interest in this field, the Monday Practical Radio Astronomy Workshops introduced a specialist session devoted to meteor scatter observing. Although only one dedicated workshop has so far been held (by July 2026), it attracted considerable interest and demonstrated how the practical workshop format could be applied successfully to yet another area of observational science.

The workshop began by introducing the physical principles behind meteor scatter before examining the practical requirements for establishing an observing station. Participants discussed suitable receiving systems, antenna configurations and the choice of transmitters used as radio beacons. Particular emphasis was placed on creating systems capable of operating continuously, allowing observations to be accumulated over many days or even throughout the year.

One of the central themes of the meeting was the use of Spectrum Lab, the highly versatile software developed by Wolfgang Böscher (DL4YHF). Although originally created as a general-purpose audio spectrum analyser, Spectrum Lab has become one of the most widely used software packages in amateur radio astronomy because of its remarkable flexibility. The workshop demonstrated how it can be configured to produce waterfall displays, three-dimensional visualisations and automated detection of transient events such as meteor echoes. These capabilities allow observers to monitor radio signals continuously and record meteor activity without constant supervision. Alternative software will be

explored in future meetings, together with hardware options and attendees' own observations showing meteor counts and unusual and more expected meteor traces.



In this first meeting, participants also examined different methods of displaying and analysing observational data. Waterfall plots provide an immediate visual record of meteor activity, while three-dimensional displays and statistical summaries help reveal longer-term trends associated with annual meteor showers. Automated event detection enables large datasets to be collected efficiently, transforming what would otherwise be an impractical observing task into a routine monitoring programme.

As with all of the Monday workshops, practical considerations remained central throughout the discussions. Attention was given not only to software but also to antenna installation, receiver stability and the interpretation of different types of meteor echoes. By examining real observational examples, participants gained confidence in distinguishing genuine meteor reflections from radio-frequency interference and other transient signals.

Meteor scatter provides an excellent introduction to long-term observational science. Individual meteor echoes are fascinating in themselves, but their greatest scientific value emerges when observations are accumulated over extended periods. Continuous monitoring allows annual meteor showers to be identified, activity profiles to be compared between years and unusual outbursts to be recognised. In this respect, meteor scatter shares much with hydrogen line radio astronomy: both disciplines reward patience, careful instrumentation and systematic data collection.

The workshop also illustrated an important characteristic of the Monday programme. Rather than treating each subject as an isolated discipline, participants were encouraged to recognise the common skills that unite them. Techniques developed for hydrogen line observing—such as receiver optimisation, digital signal processing and automated data recording—could readily be adapted for meteor scatter work. This transfer of knowledge between different branches of amateur radio astronomy has become one of the defining strengths of the workshop series.

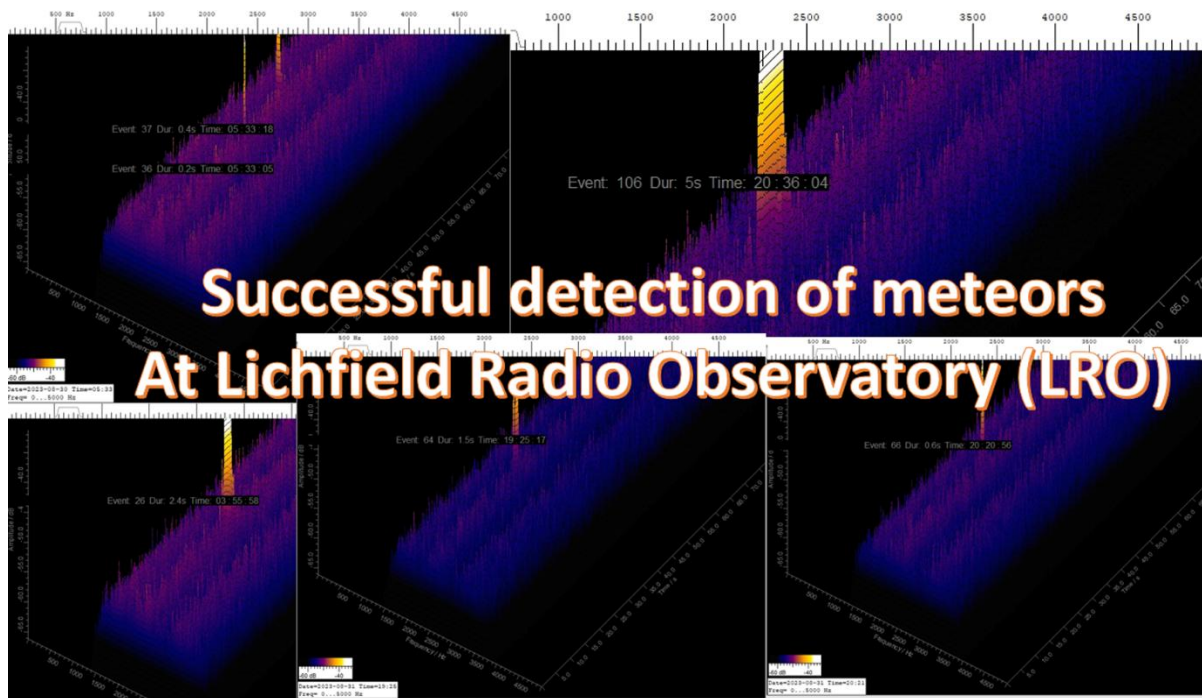


Figure 5. Radio meteor scatter display in Spectrum Lab showing several meteor echoes

Very Low Frequency Radio Astronomy and Space Weather.

The final specialist group to be established during the period covered by this review focused on Very Low Frequency (VLF) radio astronomy and the monitoring of Sudden Ionospheric Disturbances (SIDs). While operating at frequencies far removed from the hydrogen line, VLF observing provides another accessible way in which amateurs can investigate the interaction between the Sun and the Earth's atmosphere.

Unlike many astronomical observations, VLF monitoring can be carried out using comparatively simple receiving systems, making it particularly attractive to newcomers and educational groups. Nevertheless, successful observations require an understanding of antenna design, receiver characteristics, software configuration and the interpretation of changing ionospheric conditions. These practical aspects formed the basis of the VLF workshop programme.

Although radio astronomers often think first of observing distant astronomical objects, our nearest star provides a wealth of opportunities for practical scientific investigation. Solar flares, coronal mass ejections and other energetic events can disturb the Earth's ionosphere, producing measurable changes in the propagation of Very Low Frequency (VLF) radio signals. Monitoring these disturbances provides amateurs with an accessible way of studying space weather using relatively simple equipment.

Recognising the educational potential of this field, the Monday Practical Radio Astronomy Workshops established a dedicated VLF group. By July 2026, four meetings had been held, covering the scientific principles of VLF propagation together with the practical aspects of constructing receiving systems and interpreting observations.

Unlike hydrogen line astronomy, where each observer is detecting natural radio emissions from the Galaxy, VLF monitoring normally relies on receiving powerful terrestrial transmitters whose signals are reflected within the Earth–ionosphere waveguide. Sudden changes in the ionosphere, particularly those produced by solar flares, alter the strength and phase of these transmissions. By recording these variations continuously, observers can detect Sudden Ionospheric Disturbances (SIDs) and monitor the effects of solar activity on the Earth's upper atmosphere.

The workshops therefore began by introducing the underlying science before moving quickly to practical matters. Participants examined different methods of constructing VLF antennas, discussed tuning techniques and compared the performance of several receiver systems. By presenting complete observing systems rather than isolated components, the meetings helped newcomers understand how antennas, receivers, software and data analysis combine to produce reliable observations.

One of the strengths of the VLF group has been its balanced comparison of available equipment. Rather than recommending a single solution, the workshops examined several different approaches, including the Stanford SuperSID system, the UKRAA VLF receiver and a variety of home-constructed receivers. Each offers different advantages in terms of sensitivity, complexity and cost, allowing participants to choose equipment appropriate to their own interests and experience.

Particular attention was given to practical construction. Demonstrations showed how simple loop antennas could be assembled and tuned, while discussions covered the importance of careful installation, noise reduction and receiver optimisation. Such practical guidance is often difficult to convey through written manuals alone and proved especially valuable for participants attempting their first VLF receiving systems.

Software forms an equally important part of modern VLF observing. The workshops demonstrated the latest versions of SuperSID software together with alternative approaches that make use of a computer sound card as the receiving interface. These developments have significantly reduced the cost of establishing a monitoring station while introducing new capabilities, including the simultaneous observation of multiple transmitters. Participants discussed both the advantages and the limitations of these systems, enabling informed decisions when selecting equipment for their own projects.

As with the Hydrogen Line and GNU Radio groups, real observational data formed an important part of every meeting. Members presented recordings of Sudden Ionospheric Disturbances associated with solar flares, demonstrating how changes in received signal strength could be related directly to events occurring on the Sun. These examples illustrated the remarkable fact that relatively inexpensive amateur equipment can contribute meaningfully to the study of space weather while providing an engaging introduction to solar–terrestrial physics.

The workshops also emphasised the value of coordinated observations. Since ionospheric disturbances may be observed differently at different geographical locations, collaboration between multiple observing stations can provide a more complete picture of space weather events. This theme of cooperation runs

throughout the Monday programme and reinforces the idea that amateur radio astronomy is at its strongest when observations are shared and compared.

Perhaps more than any other specialist group, the VLF workshops demonstrate how practical radio astronomy extends beyond the traditional boundaries of astronomy itself. By linking observations of the Sun with changes in the Earth's atmosphere, they provide participants with a direct appreciation of the dynamic relationship between our planet and its nearest star. In doing so, they also illustrate the broader educational philosophy that underpins the entire workshop programme: science is most effectively learned by building instruments, making observations and interpreting real data.

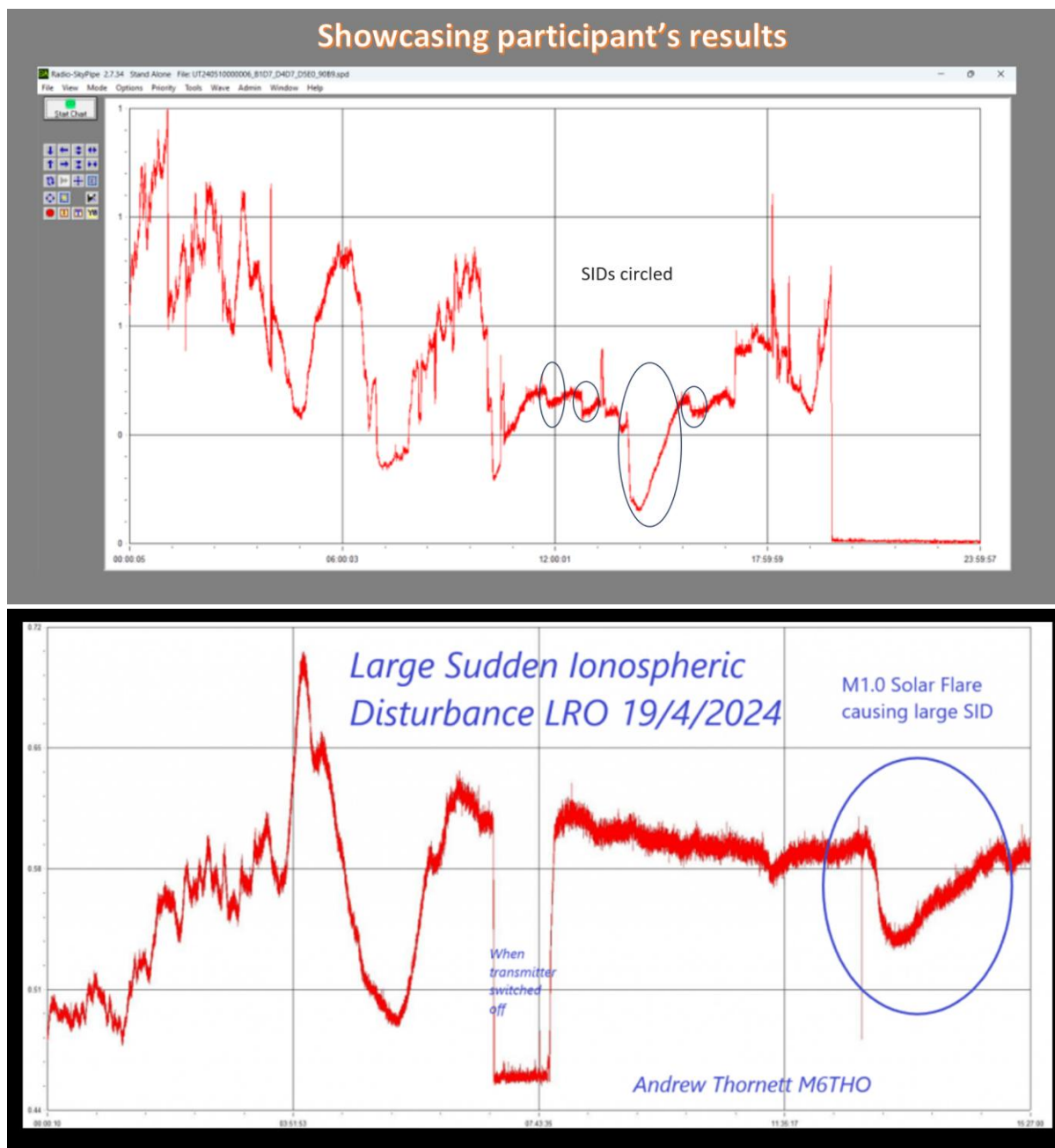


Figure 6. VLF observation of a Sudden Ionospheric Disturbance

Building a Community of Practical Radio Astronomers.

Although each specialist group has developed its own identity, together they represent something greater than the sum of their individual subjects, with many attendees attending more than one group. The Monday Practical Radio Astronomy Workshops have evolved into a collaborative international community in which ideas, designs and observing techniques are shared freely across organisational and geographical boundaries.

Participants no longer attend simply to listen; they attend to contribute. A newcomer struggling to detect the hydrogen line may receive advice from an experienced observer on another continent. Someone experimenting with GNU Radio may demonstrate a new processing technique that is later adapted for meteor scatter or VLF observations. A discussion that begins with a simple technical question often develops into an exchange of ideas involving many participants, each bringing different experience to the problem.

This willingness to share both successes and setbacks has become one of the defining characteristics of the workshops. Rather than presenting only polished results, members routinely discuss projects that remain under development, encouraging collaborative problem solving and accelerating progress throughout the community. In many respects, this atmosphere of openness has proved to be one of the programme's greatest achievements.

Measuring Success – Beyond the Live Meetings.

Educational initiatives are often difficult to evaluate. Enthusiastic feedback from participants is encouraging, but it provides only a partial picture of their wider impact. One of the advantages of the Monday Practical Radio Astronomy Workshops is that every meeting is recorded and made freely available through the British Astronomical Association's YouTube channel. These recordings provide an objective measure of continuing interest long after the live meeting has ended.

The viewing statistics presented at the 2026 SARA Eastern Conference reveal several interesting trends. Perhaps the most striking is the sustained popularity of the Hydrogen Line workshops. Of the ten most-viewed Monday Practical Radio Astronomy recordings available at the time of the conference, seven were devoted to hydrogen line observing. This reflects both the enduring appeal of the subject and the demand for practical guidance in one of amateur radio astronomy's most accessible scientific disciplines.

Figure 7. YouTube viewing statistics presented at the 2026 SARA Eastern Conference demonstrate the continuing popularity of the Monday Practical Radio Astronomy Workshops, with Hydrogen Line meetings accounting for seven of the ten most-viewed recordings.

Viewing figures from YouTube – all Monday Practical RA Meetings up to 18/6/2026

Video title	Video publish time	Duration	Views	Watch time (hours)	Subscribers	Impressions	Impressions click-through rate (%)	YouTube Video ID
Introductory workshop on hydrogen line radio observing of the Milky Way #1 - 22 Jan 2026	Jan 22, 2026	8626	533	109.8752	7	4232	4.87	IDOL_8v_YCM
Introduction to Hydrogen Line Radio Astronomy Part II Workshop	Feb 19, 2026	4456	375	44.5733	7	3395	5.42	Lg-7RGWv3QI
BAA RA Section H-Line group meeting #11 hosted by Dr Andrew Thornett- 02 March 2026	Mar 3, 2026	9206	185	36.4343	1	1898	3.16	E4GHXWvTt8
BAA RA Section GNU Radio meeting #1 - 7th Oct. 2025	Oct 13, 2025	5302	185	20.4888	3	1543	3.05	hw297wq5-lw
BAA RA Section H-Line group meeting #5 hosted by Dr Andrew Thornett.	Aug 6, 2025	6063	178	21.9418	1	3105	1.9	rbUOE6s4jDA
BAA RA Section H-Line group meeting #8 hosted by Dr Andrew Thornett.	Nov 7, 2025	8362	154	29.8198	1	1929	2.9	hjdxdPdGCaQ0
BAA RA Section Muon Detection #2 - 18th May 2026	May 19, 2026	8227	152	29.8534	0	1915	3.29	ZX3IKgnZ0oQ
BAA RA Section H-Line group meeting #9 hosted by Dr Andrew Thornett- 05 Jan 2026	Jan 6, 2026	8246	144	20.8474	0	2639	2.58	Q753Qz4u3Yg
BAA RA Section H-Line group meeting #14 hosted by Dr Andrew Thornett- 01 June 2026	Jun 2, 2026	14235	141	44.6044	1	1692	3.66	vHMsCcpdX3Y
BAA RA Section GNU Radio meeting #6 - 9th March 2026	Mar 10, 2026	7716	140	21.0964	3	1416	2.33	VH1UsvYOfss
BAA RA Section GNU Radio meeting #5 - 31st Jan 2026	Feb 2, 2026	5416	138	18.7249	0	2072	1.74	2Cyr-OvJMwM
BAA RA Section VLF meeting #1 - 16th March 2026	Mar 17, 2026	6835	133	28.7591	0	1653	4.23	FDO5g_E2Dbw
BAA RA Section H-Line group meeting #6 hosted by Dr Andrew Thornett.	Sep 21, 2025	4670	132	13.6749	1	1611	2.42	ckb5s4OuFNA
BAA RA Section VLF meeting #2 - 22nd April 2026	Apr 23, 2026	7009	131	36.1188	0	1206	3.48	zE8dc0IEQ2A
BAA RA Section H-Line group meeting #7 hosted by Dr Andrew Thornett.	Jul 9, 2025	7637	127	15.8792	0	2164	3.05	3dDVH_JVHms
BAA RA Section H-Line group meeting #12 hosted by Dr Andrew Thornett- 06 April 2026	Apr 7, 2026	8422	125	34.7283	0	1578	2.09	G6_dltLFU7E
BAA RA Section VLF meeting #3 - 25th May 2026	May 26, 2026	4379	109	24.6987	1	1372	3.43	tAUa64LzFo
BAA RA Section Muon Detection #1 - 20th April 2026	Apr 21, 2026	5857	106	23.7217	0	1629	3.13	suZofa6kBR8
BAA RA Section H-Line group meeting #10 hosted by Dr Andrew Thornett- 02 Feb 2026	Feb 3, 2026	9728	102	19.3324	2	1543	3.37	nnN2IGsKNWY
BAA RA Section GNU Radio meeting #7 - 13th April 2026	Apr 14, 2026	5645	101	9.8791	0	1540	3.25	RgRay69W7YH
BAA RA Section H-Line group meeting #13 hosted by Dr Andrew Thornett- 05 May 2026	May 5, 2026	7505	94	14.976	0	1263	2.53	ZKc2-xzdHc8
BAA RA Section GNU Radio meeting #8 - 11th May 2026	May 15, 2026	8045	91	16.842	0	1332	2.93	TzhvgdxYD8k
BAA RA Section H-Line group meeting #7 hosted by Dr Andrew Thornett.	Sep 30, 2025	6152	89	12.8995	0	1308	3.06	EthcJ49iwnw
BAA RA Section GNU Radio meeting #4 - 20th Dec. 2025	Dec 23, 2025	4466	79	9.8903	0	1693	1.77	w_nhUkuU140
BAA RA Section GNU Radio meeting #3 - 29th Nov. 2025	Dec 1, 2025	3370	78	9.286	1	1518	2.77	ub6qLxHTSc
BAA RA Section GNU Radio meeting #2 - 27th Oct. 2025	Oct 28, 2025	6850	73	7.9424	0	1584	2.34	8lBo5agdFyg
BAA RA Section H-Line group meeting #3 hosted by Dr Andrew Thornett.	Jun 4, 2025	6163	56	2.3255	0	983	1.02	CF8sBOR9RIQ
BAA RA Section GNU Radio meeting #9 - 08th June 2026	Jun 9, 2026	4116	46	4.5392	0	729	2.74	185j05vqb8Y
Inaugural meeting of BAA RAG H Line Group	Mar 19, 2025	5827	37	3.8727	0	487	3.08	2jGZW8Lszp0
BAA RA Section H-Line group meeting #2 hosted by Dr Andrew Thornett	Apr 15, 2025	7040	33	3.2867	0	850	2	w4lqy8TtONG
BAA RA Section Muon Detection #3 - 15th June 2026	Jun 16, 2026	5817	24	6.9751	0	514	1.75	5DOghroXdVA

Top ten viewed meetings online

Notably Hydrogen Line RA consistently tops the bill, with 7 out of 10 in the top ten being hydrogen line meetings

Video title	Video publish time	Duration	Views	time (hours)
Introductory workshop on hydrogen line radio observing of the Milky Way #1 - 22 Jan 2026	Jan 22, 2026	8626	533	109.8752
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BAA RA Section H-Line group meeting #14 hosted by Dr Andrew Thornett- 01 June 2026	Jun 2, 2026	14235	141	44.6044
BAA RA Section GNU Radio meeting #6 - 9th March 2026	Mar 10, 2026	7716	140	21.0964

The figures also demonstrate that there is a significant audience for detailed technical material. Conventional wisdom often suggests that online audiences prefer only brief introductory presentations. The continuing popularity of the workshop recordings indicates otherwise. Many participants are clearly willing to invest considerable time in understanding instrumentation, software and observing techniques when those subjects are presented in a practical and engaging manner.

Another important feature of the statistics is that the educational value of each meeting extends far beyond the evening on which it was delivered. A live audience may number only a few dozen participants, yet recordings continue to attract new viewers months or even years after publication. As a result, every workshop becomes a long-term educational resource rather than a single event.

This archive has grown steadily into a substantial library covering a remarkably broad range of amateur radio astronomy topics. Newcomers beginning a hydrogen line project can watch the introductory sessions before progressing to more advanced discussions of calibration and Doppler measurements. Those interested in software-defined radio can follow the GNU Radio workshops in sequence, while others can explore VLF observing, muon detection or meteor scatter according to their own interests. The cumulative value of this archive increases with every additional meeting that is added.

The workshops have therefore demonstrated an important principle for scientific outreach in the digital age. Online meetings need not replace traditional conferences or society meetings; instead, they can complement them by providing a permanent educational resource that remains available whenever participants need it. This combination of live interaction and recorded material has proved particularly effective for practical subjects where observers may need to revisit demonstrations several times while constructing or commissioning their own equipment.

The success of the recordings also reflects another characteristic of the programme: authenticity. The workshops are not highly polished studio productions. They are genuine working meetings in which presenters discuss both successes and difficulties, demonstrate equipment live and answer questions from participants. This informal style creates an atmosphere in which viewers feel they are joining a collaborative workshop rather than watching a formal lecture. For many newcomers, this makes practical radio astronomy appear both more approachable and more achievable.

Perhaps the most encouraging conclusion that can be drawn from the viewing statistics is that there remains a strong and growing appetite for practical amateur radio astronomy. In an era when inexpensive software-defined radios, open-source software and affordable computing have transformed the capabilities available to amateurs, observers are eager not only to learn the science but also to acquire the practical skills necessary to make meaningful observations themselves. The Monday Practical Radio Astronomy Workshops have helped meet that demand by providing a welcoming environment in which knowledge is shared freely and enthusiasm is encouraged.

Lessons Learned.

Looking back over the first two years of the programme, several important lessons have emerged.

The first is that practical mentoring remains essential. Books, websites and videos provide valuable information, but many technical challenges can only be overcome through discussion with others who have faced similar problems. Regular interactive workshops allow these conversations to take place in a way that static resources cannot.

Secondly, the workshops have demonstrated the remarkable generosity of the amateur radio astronomy community. Participants willingly share designs, software, observing techniques and hard-earned experience without hesitation. This culture of openness has accelerated learning for everyone involved and has undoubtedly contributed to the rapid development of many individual projects.

A third lesson concerns the increasingly interdisciplinary nature of amateur radio astronomy. Modern observers require knowledge not only of astronomy but also of electronics, computing, digital signal processing, programming and statistical analysis. By bringing together specialists from these different

areas, the workshops have created an environment in which participants can develop a much broader range of scientific and technical skills than would be possible within a single traditional discipline.

Finally, the workshops have shown that enthusiasm is contagious. Participants who initially joined simply to learn have gradually become presenters, mentors and innovators in their own right. This progression from student to teacher may prove to be one of the programme's most enduring achievements, ensuring that knowledge continues to be passed on to future generations of amateur radio astronomers.

Looking to the Future.

The first two years of the Monday Practical Radio Astronomy Workshops have demonstrated that there is a substantial international appetite for practical education in amateur radio astronomy. What began as an experiment in online mentoring has developed into an established programme covering multiple scientific disciplines, supported by a growing archive of educational material and an enthusiastic community of observers. Nevertheless, the programme remains very much a work in progress, and there are many opportunities for further development.

One of the most immediate priorities is to make the accumulated knowledge within the workshop archive even more accessible. While the full-length recordings provide a valuable record of each meeting, many participants have suggested that shorter instructional videos focusing on individual topics would make it easier for newcomers to find the information they require. Extracting concise tutorials on subjects such as feed construction, receiver calibration, GNU Radio flowgraphs or VLF antenna tuning would complement the existing recordings and provide a useful introduction before viewers explore the more detailed workshop discussions. Experience elsewhere within both the BAA and SARA suggests that shorter videos often attract significantly larger audiences while acting as gateways to more comprehensive material.

The programme also has considerable scope for expansion into new areas of practical radio astronomy and space science. One obvious possibility is a dedicated Radio JOVE group, introducing participants to observations of Jupiter's decametric radio emissions. Such a group would provide a natural progression for those wishing to explore planetary radio astronomy while making use of relatively inexpensive receiving equipment.

Earth science represents another promising direction. Many of the techniques developed within amateur radio astronomy—continuous monitoring, automated data logging and long-term statistical analysis—can equally be applied to atmospheric and geophysical investigations. Workshops exploring these applications would broaden the educational scope of the programme while remaining firmly rooted in practical observational science.

One of the most imaginative ideas discussed during the workshops has been the development of CubeSat analogue projects. Rather than attempting to construct spacecraft, participants would design compact scientific payloads based on CubeSat technology and test them in terrestrial environments. Instruments could be carried aboard commercial aircraft, taken to mountain summits, lowered into caves or mines, or exposed to controlled changes in pressure and temperature. Such projects would provide valuable experience in systems engineering, environmental testing and scientific data collection while illustrating many of the challenges faced by modern space missions. Although experimental in nature,

this concept has considerable educational potential and could appeal particularly to younger participants and schools.

Looking further ahead, the workshops may also play an increasingly important role in coordinating collaborative observing programmes. As the number of experienced participants grows, opportunities arise for multiple observing stations to work together on common projects, combining observations from different geographical locations to investigate astronomical and geophysical phenomena. Such collaboration has long been one of the strengths of professional astronomy, and modern communication technologies now make similar approaches practical for amateur observers.

The continued development of affordable software-defined radios, low-noise receivers and open-source software is likely to expand these opportunities still further. Capabilities that were once confined to professional observatories are becoming increasingly accessible to dedicated amateurs, opening the possibility of more ambitious observing programmes in areas such as spectral line astronomy, pulsar detection, space weather monitoring and radio transient studies. The workshops are well placed to help observers make effective use of these rapidly evolving technologies.

Whatever new directions the programme may take, its guiding philosophy is unlikely to change. Practical experience, collaborative learning and the free exchange of knowledge have proved to be the foundations upon which its success has been built. Preserving these values while embracing new scientific opportunities will be essential if the workshops are to continue serving the amateur radio astronomy community in the years ahead.

References.

Getting Started in Radio Astronomy. Society of Amateur Radio Astronomers. <https://www.radio-astronomy.org/getting-started>

Projects for Amateur Radio Astronomers. Society of Amateur Radio Astronomers. <https://www.radio-astronomy.org/projects>

Review of British Astronomical Association's Weekly Monday Practical Amateur Radio Astronomy Online Workshops. Thornett, A. M. (2026). Presentation at the Society of Amateur Radio Astronomers Eastern Conference, Green Bank, WV.

Radio Astronomy Section – Monday Practical Radio Astronomy Workshops. British Astronomical Association YouTube Channel. <https://www.youtube.com/@britishastronomical>

Radio Astronomy Section. British Astronomical Association. <https://britastro.org/sections/radio-astronomy>

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A Discriminator based Four Element Imaging Interferometer

K. Shoemaker, Shoemaker Labs, Inc.

Abstract:

A low cost, scaleable four element low frequency imaging interferometer is described based on phase/amplitude discriminators with digital backend electronics. This approach allows for the design of a sky noise limited radio telescope capable of imaging multiple radio sources for the purposes of propagation studies and radio source dynamics measurements. Software consists of a FX style correlator followed by CLEAN and Delay/Delay Rate routines for source location and flux measurements.

Background:

As a fundamental example, the DLITE (Helmholtz, J. F. et al., 2021) was used. It consists of a four element interferometer using direct digitization of the RF signal and Python based software for imaging. Additional systems, like PAPER (Bradley, R. F. et al., 2018) and (Parsons, A. R. et al., 2008), Long Wavelength Array (LWA, Taylor, G., et al.), Murchison Widefield Array (MWA, Tingay et al), Low-Frequency Array (LOFAR, Bower, G., et al.) and are also based on similar approaches and have been successful in imaging as well as accurate measurements of radio astronomical source phenomena.

System Description:

The array consists of four inverted “V” dipole antennas cut at 38 MHz (for the present system). These are placed over ground plane consisting of a metal mesh grid 5m x 5m and configured in a diamond pattern with N-E-S-W orientation. The N-S and E-W baselines are approximately 200 meters apart. Low Noise Amplifiers (LNAs) are placed at the center of the dipole with +15 vdc supplied through the center conductor of the feed coax. See figures 1, 2.



Figure 1, 38 MHz inverted “V” dipole with LNA enclosure over ground plane

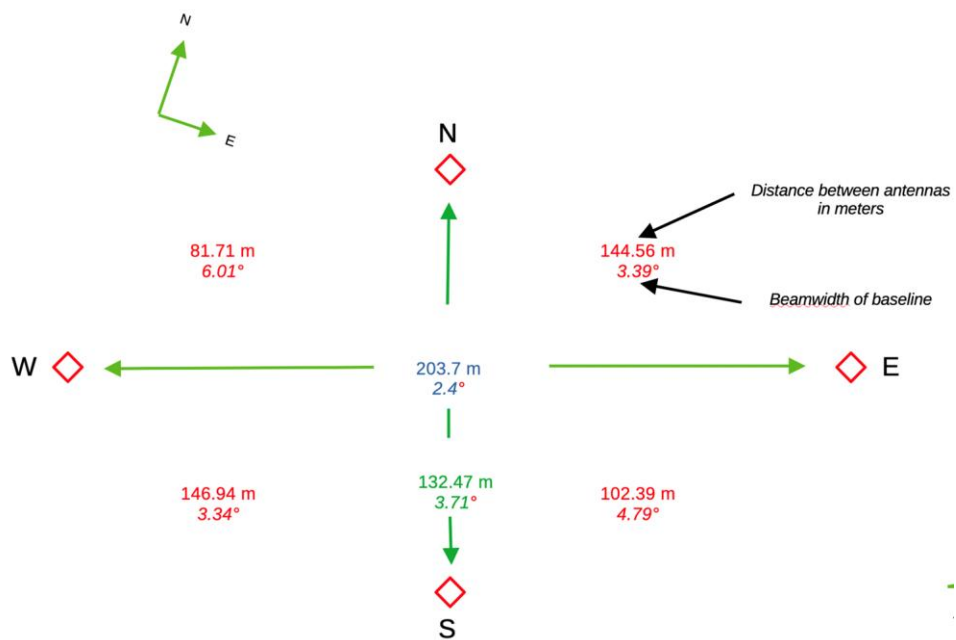


Figure 2, Array orientation, element position and associated beamwidths

Note: Beamwidths calculated with standard $(\text{Wavelength}/\text{Distance}) * 57.3$ for each baseline

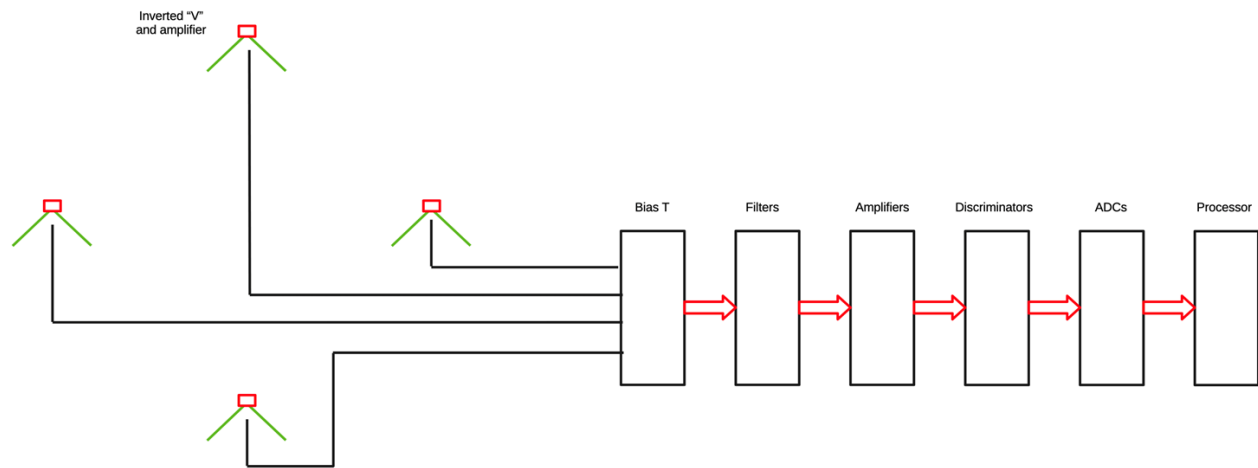


Figure 3, System Layout and signal flow

RG-6 is used for feed cable and for each element, a 300 meter length is used. One end is connected to the LNA located at the vertex of the antenna element and the other end is fed to the bias-T board which provides voltage to operate the LNA and transfers the received electromagnetic energy to the rest of the receiver hardware.

The receiver hardware consists of several elements in series for each of the four elements. After the bias-T board a bandpass filter is placed. Typically, this is an inexpensive 10 MHz bandwidth filter that removes local RFI out of band. For this paper, 38 MHz is used within the bandpass of a 30-40 MHz filter, however reception with alternate filters can span 20-90 MHz.

The filter then sends the filter's output to a 20 dB amplifier and then to a tunable bandpass filter. This filter is controlled by a USB port and can be set to any 10% portion of the band between 20-90 MHz. This further removes local RFI and can relocate operational frequencies within the initial filters bandpass.

Following the tunable filter is a three way splitter which feeds each of three phase/amplitude discriminators. There are a total of six such discriminators which sample each available baseline for a four element array. The six phases and six amplitudes are then sampled by a low frequency ADC like the LabJack U3-HV. The sample rate is 30 Hz and the Input bandwidth of the ADCs is DC to 300 KHz. The LabJack then sends the sampled signals via USB to a host computer. See figure 4.

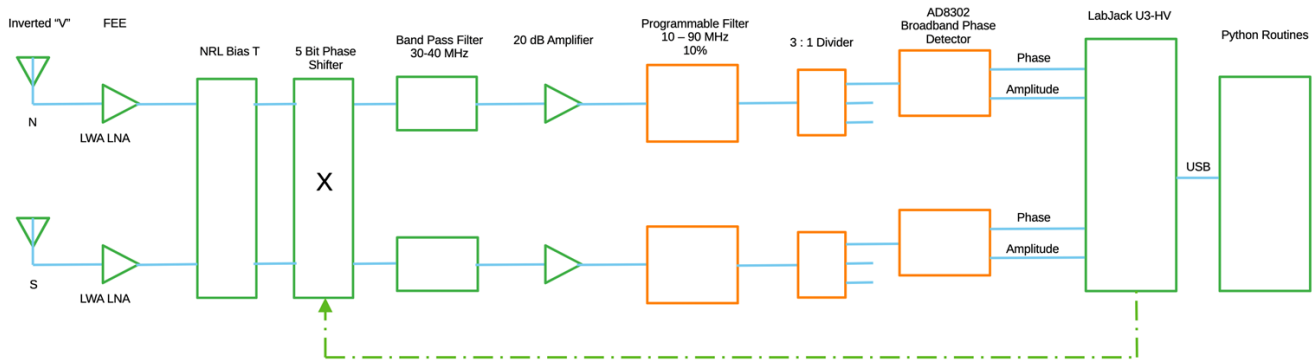


Figure 4, N/S beam steered portion of array

The AD8302 broadband phase/amplitude detector forms a central part of the receiver architecture. Manufactured by Analog Devices, it has two inputs for two sinusoidal signals followed by two separate 60 dB amplifier chains. These then are fed into a separate phase and amplitude discriminator whose outputs are fed into the LabJack ADC. Each individual baseline is measured with a separate device. Data are sent into a laptop running Python routines via a USB connection. Figure 5 shows the details of this device.

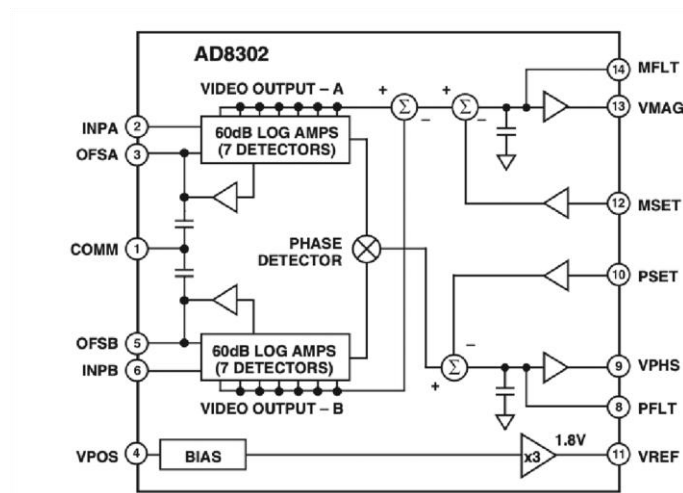


Figure 5, Details of the phase/amplitude discriminator

This device can measure gain/loss and phase up to 2.7 GHz with an amplitude input range of -60 dBm to 0 dBm using a 50 ohm system.

The data from the receiver are sampled at 10 KHz rates and averaged over one second. The integrated values are placed in arrays representing each phase and amplitude for each baseline. Each phase and amplitude can be plotted over a designated period, typically one hour. Other calculations can be made for plotting purposes including variation, summations and other diagnostic measurements. The last stage is to determine visibilities over the UV plane. These values are determined from all baselines and are placed in another array. The visibilities are derived by a "FX" correlation technique described in *Interferometry and Synthesis in Radio Astronomy* (Thompson, A. R., et al., 1991).

After visibilities are determined for each right ascension and declination in the field of view, The CLEAN algorithm is applied (Hogbom, J., A, 1972) and plotted. Following this algorithm, a Delay/Delay-Rate algorithm is applied (Parsons, A. R., 1990) and plotted, see Figures 7 and 8. From these data sets, the final 24 hour LMST plot is produced. In addition, a .csv file is assembled with the highest four visibilities that can be used for later analysis.

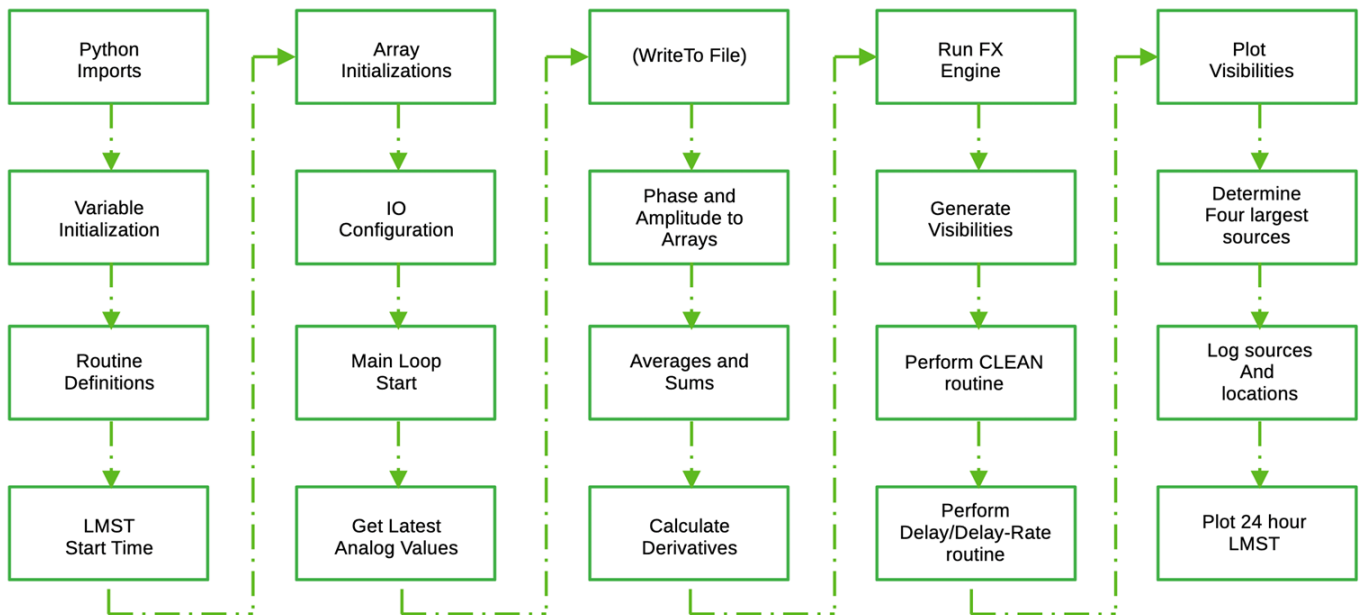


Figure 6, Data flow using Python routines

Figures 7 and 8 show several of the available plotting routines employed for data quality determination as well as source selection for the final all sky plot. The components of the CLEAN algorithm and Delay/Delay-Rate algorithm can be views. Other plots (not shown) depict individual phase and amplitude measurements on each baseline.

Hogbom CLEAN -- 200 m N-S/E-W diamond, nu0 = 38 MHz, dec +82 -> -12

Local time	: 2026-06-10 17:05:12
MaxV dirty	: 2.1
MaxV CLEAN	: 3.1
Brightest Dec	: +23.8 deg
Brightest LMST	: 09:00:21

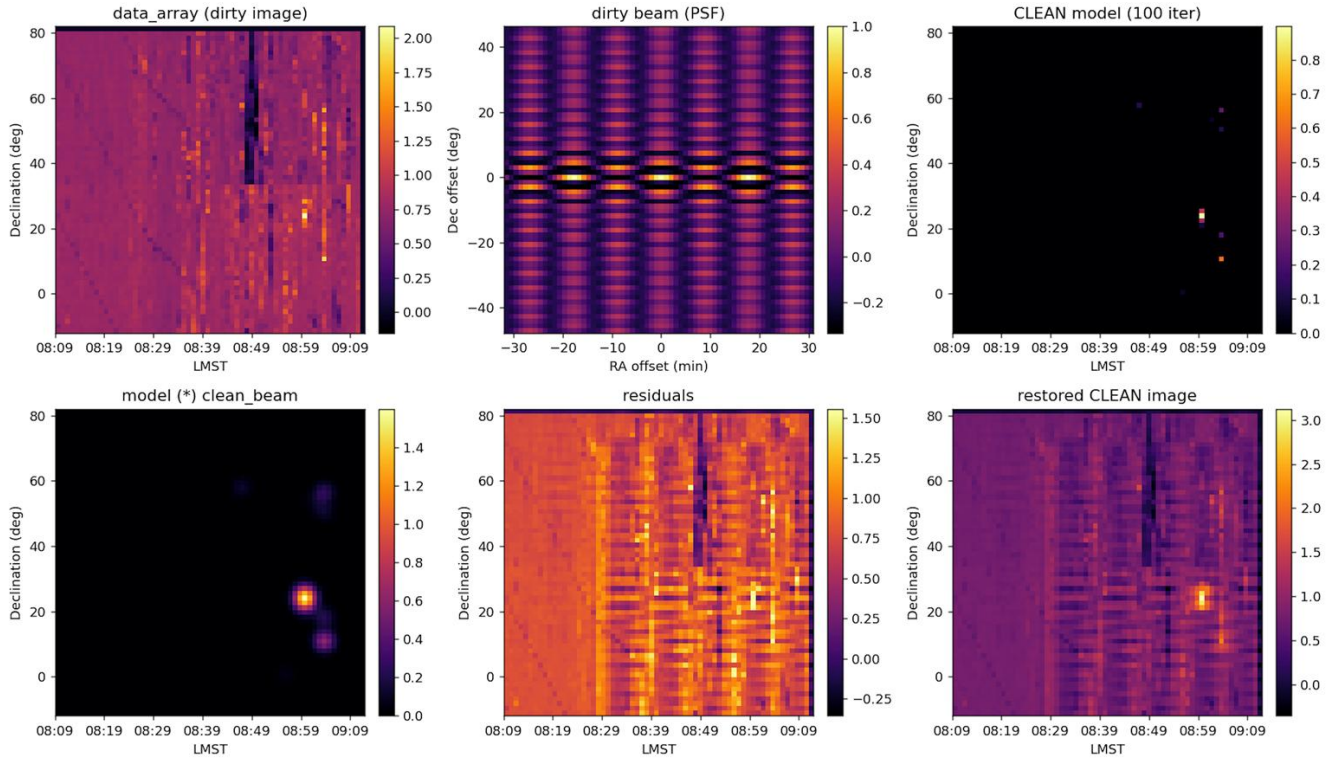
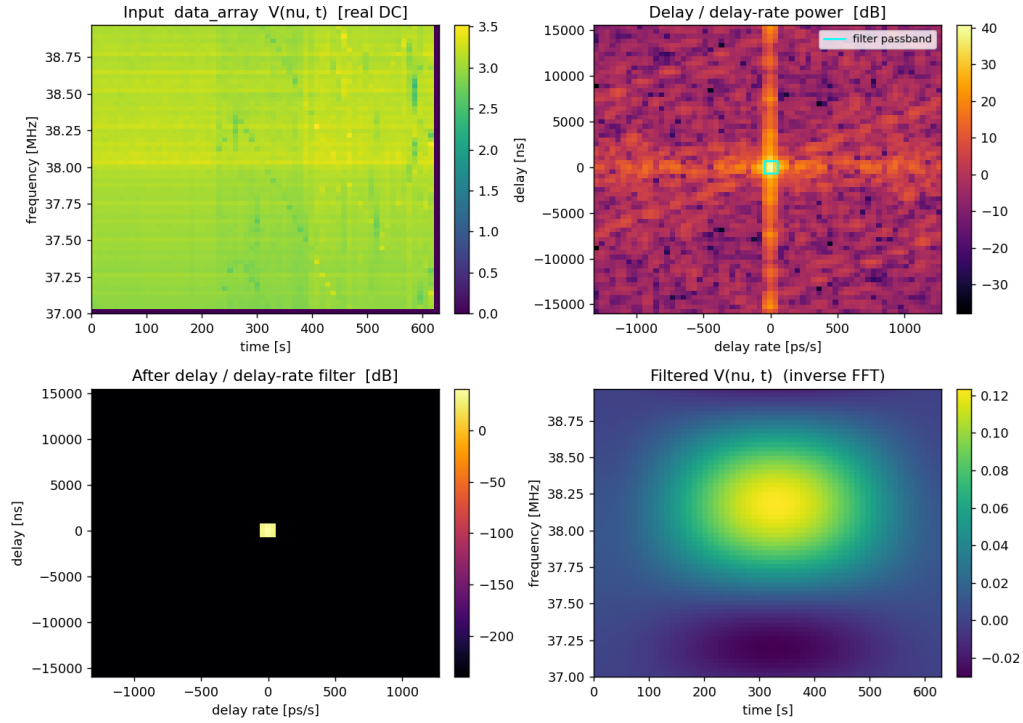


Figure 7, Plots of CLEAN algorithm output

Delay / delay-rate filter — 200 m N-S / E-W diamond, nu0 = 38 MHz



Peak intensity low → high Known radio source Galactic plane View limit

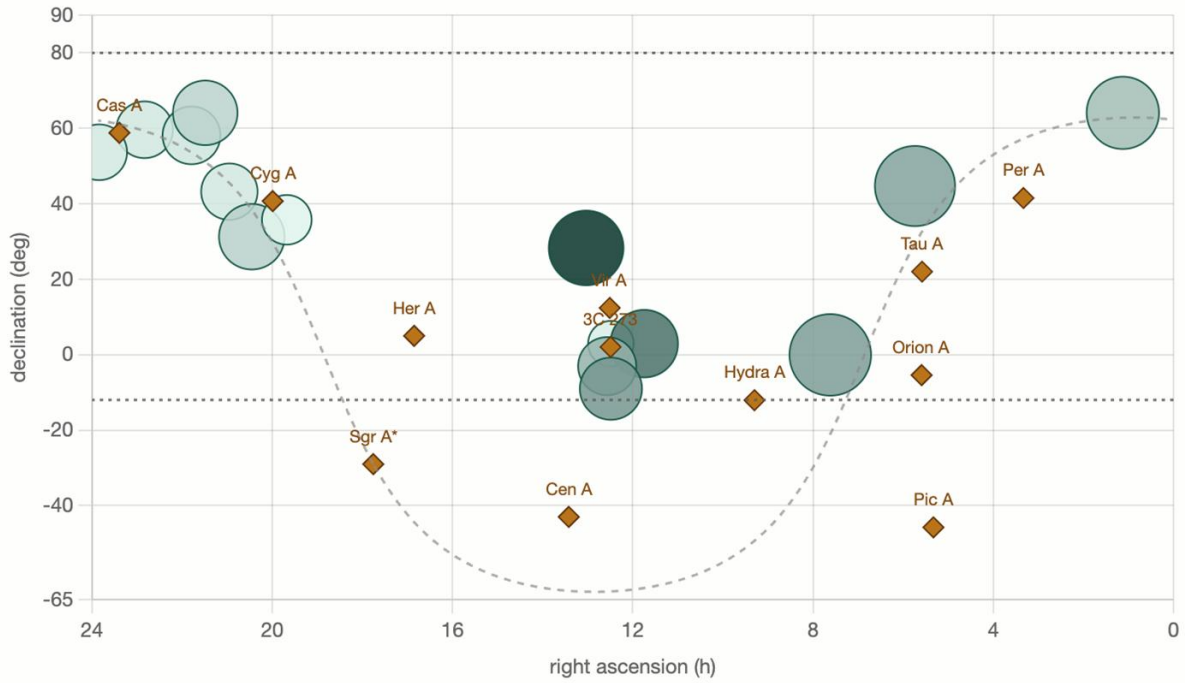


Figure 8, Delay/Delay-Rate output plots on single source

Figure 9, Plots of radio sources over a several day period

Science:

This array and associated software are usable for observing major radio astronomy sources, ionospheric reflections and dynamics as well as solar and Jovian emissions. The array is sky noise limited and capable of measuring total electron count as well as scintillation behavior using the four or five brightest radio sources. These are valuable measurements for communications and long term astronomical interest.

Ionospheric Density Gradiometer

Other researchers have used low-frequency radio telescopes as ionospheric density gradiometers, (e.g., Cohen & Röttgering, 2009; Helmboldt & Hurley-Walker, 2020; Helmboldt, Lazio, et al., 2012; Jacobson & Erickson, 1992a; Loi et al., 2015). The apparent position of the source can be determined by observing Total Electron Count (TEC) by the following formula:

?

$$\vec{\nabla} TEC = 1.20 \times 10^{-4} (f / 100 \text{ MHz})^2 (\partial \theta / 1 \text{ inch}) TEC U km^{-1} \quad (1)$$

where:

TEC = Total Electron Count Gradient

f = Frequency of Operation

θ = Apparent position of the source

Therefore using this approach while observing bright sources can yield positional changes and thus show gradients in the TEC over short periods of time.

Imaging Scintillometer

Modifying this array by introducing high speed Analog to Digital Converters (ADCs), one can determine the Time Domain of Arrival (TDOA) as well as the Frequency Difference of Arrival (FDOA) using the following set of equations:

$$TDOA = c^{-1}(\Delta x l + \Delta y m + \Delta z n) + TDOA_{inst} \quad (2)$$

$$FDOA = \lambda^{-1}(\Delta x \dot{l} + \Delta y \dot{m} + \Delta z \dot{n}) \quad (3)$$

$$l = \cos e \cdot \sin a = -\sinh \cdot \cos \delta \quad (4)$$

$$m = \cos e \cdot \cos a = -\cosh \cdot \cos \delta \cdot \sin \phi + \sin \delta \cdot \cos \phi \quad (5)$$

$$n = \sin e = \cosh \cdot \cos \delta \cdot \cos \phi + \sin \delta \cdot \sin \phi \quad (6)$$

$$\dot{l} = -\omega_e \cdot \cosh \cdot \cos \delta \quad (7)$$

$$\dot{m} = \omega_e \cdot \sinh \cdot \cos \delta \cdot \sin \phi \quad (8)$$

$$\dot{n} = -\omega_e \cdot \sinh \cdot \cos \delta \cdot \cos \phi \quad (9)$$

where:

h = hour angle

a = right ascension

e = elevation

δ = declination

ϕ = reference latitude for the array

ω_e = angular rotation rate of the Earth

Greater detail on this technique can be found in Helmboldt et al., 2021.

Time Domain Astronomy

With longer baselines TDOA imaging is possible using the above equations. These are particularly useful for examining transient and variable cosmic radio sources.

Conclusion:

A unique radio telescope design is described that can provide good imaging and several science based measurements. The main advantage is the lowering of cost by use of discriminators early in the receiver chain. This removes the need for high speed, costly, analog to digital converters. The type of discriminator used here is a Analog Devices AD8302. The inputs from each baseline are sent to this device and phase and amplitudes are then measured, digitized and used for the FX, CLEAN and Delay/Delay-Rate algorithms. Variation of cable lengths over temperature are observed and calibrated against know radio source positions.

The system is scaleable, still retaining its cost advantage and providing better science measurements as more elements are added. Estimates on the cost ratios are around 5:1. Like the LWA and PAPER arrays, this system can produce higher quality imaging with the use of many more elements.

The array is frequency agile by way of the programmable filters within the receiver. The center frequencies can be adjusted quickly using USB 2.0 level commands.

Early science from this pilot array show the presence of radio source scintillation, ionospheric refraction, ionospheric reflection of radio sources some distance from the array, solar activity and Jovian activity.

Future enhancements will include higher speed image formation, wider spectral coverage and reduction of the components to a single, easily transportable box.

References:

Aaron R., Parsons, Donald C. Backer, Richard F. Bradley, James E. Aguirre, Erin E. Benoit, et al. (2024). The Precision Array for Probing the Epoch of Reionization: 8 Station Results. ArXiv:0904.2334v2

Helmboldt, J. F., Clarke, T. E., Craig, J., Dowell, J. D., Ellingson, S. W., Hartman, J. M., et al. (2013). Passive all-sky imaging radar in the HF regime with WWV and the first station of the Long Wavelength Array. *Radio Science*, 48, 491–512. <https://doi.org/10.1002/rds.20056>

Helmboldt, J. F., & Hurley-Walker, N. (2020). Ionospheric irregularities observed during the gleam survey. *Radio Science*, 55(10), e2020RS007106. <https://doi.org/10.1029/2020RS007106>

Helmboldt, J. F., Kooi, J., Ray, P., Clarke, T., Intema, H., Kassim, N., & Mroczkowski, T. (2019). The VLA low-band ionosphere and transient experiment (VLITE): Ionospheric signal processing and analysis. *Radio Science*, 54(11). <https://doi.org/10.1029/2019rs006887>

Helmboldt, J. F., Lane, W. M., & Cotton, W. D. (2012). Climatology of midlatitude ionospheric disturbances from the Very Large Array Low-frequency Sky Survey. *Radio Science*, 47, 5008. <https://doi.org/10.1029/2012RS005025>

Helmboldt, J. F., Lazio, T. J. W., Intema, H. T., & Dymond, K. F. (2012). High-precision measurements of ionospheric TEC gradients with the Very Large Array VHF system. *Radio Science*, 47. <https://doi.org/10.1029/2011RS004883>

Hogbom, J.A.. Aperture Synthesis with a Non-Regular Distribution of Interferometer Baselines, *Astronomy and Astrophysics Supplement* 15, 417-426, 1974

Parsons, A. R., et al. 2008, PASP, 120, 1207

Parsons, A. R. & Backer, D. C. 2009, Sub. to AJ. ArXiv:0901.2575

Thompson, A. R., Moran, J. M., & Swenson, G. W. (1991). *Interferometry and synthesis in radio astronomy*. 2nd Edition (New York, Wiley-Interscience, 2001. 692 p.)

Note:

Author can be contacted at Shoemakerlabs@gmail.com

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Sun Starts Independence Day Celebration Early and Stays Late

Whitham D. Reeve

The Sun started celebrating early with lots of fireworks on July 3rd, continuing through the United States Independence Day holiday on July 4th, and into July 5th. The fireworks included x-ray flares and coronal mass ejections with associated radio events, noise storms, and slow and fast radio sweeps. Some of the flares caused HF radio blackouts on Earth. There was too much activity for me to cover in one article, but I will describe a few of the events in terms of their spectra as received at the Coho and HAARP Radio Observatories in Alaska using Callisto instruments and LWA Antennas. Both stations are part of the e-CALLISTO Solar Radio Spectrometer Network (<https://e-callisto.org/>).

Solar Radio Burst ~ General Spectral Classifications (<https://www.reeve.com/Solar/Solar.htm>)

Type	Characteristics	Duration	Frequency Range (MHz)	Associated Phenomena
I	Short, narrow-bandwidth bursts. Usually occur in large numbers with underlying continuum	Single: ~1 second Storm: hours – days	80 – 200	Active regions, flares, eruptive prominences
II	Slow frequency drift bursts. Usually accompanied by a second harmonic	3 – 30 minutes	Fundamental: 20 – 150	Flares, proton emission, magneto-hydrodynamic shockwaves
III	Fast frequency drift bursts. Can occur singularly, in groups, or storms often with underlying continuum. Can be accompanied by a second harmonic	Single: 1 – 3 seconds Group: 1 – 5 minutes Storm: minutes – hours	0.01 – 1000	Active regions, flares

Solar Radio Bursts ~ Summary of Major Characteristics (source: Table 1, Radio emission from the sun and stars, Dulk, 1985, <http://adsabs.harvard.edu/abs/1985ARA&A..23..169D>)

Burst type	Duration at 100 MHz or 10 GHz	Temperature (K)	Polarization (circular)	Frequency range/ bandwidth	Height range/ magnetic topology	Association	Emission mechanism
I	≤ 1 s	$\geq 10^{10}$	50 – 100%	50-300 MHz/ ~1 MHz burst)	0.1 – 0.6 R_0 / closed	large sunspots	fundamental plasma
I storm	days to weeks	$\geq 10^{10}$	o-mode	~100 MHz (storm)			
III storm	days to weeks	$\geq 10^{10}$	o-mode	50 MHz – 30 kHz/	0.6 R_0 – 1 AU/ open	Type I storms	fundamental and/or harmonic plasma
II	≥ 10 min	$10^8 - 10^{11}$	usually unpolarized	200 $\rightarrow$ 1 MHz/ 10 MHz	0.2 – 200 R_0 / open	flare shockwave	fundamental and harmonic plasma
III	few seconds	$10^8 - 10^{12}$ (to 10^{13} at ~ 1 MHz)	fundamental: 30% harmonic: 10% o-mode	200 $\rightarrow$ 1 MHz/ 10 MHz 2 harmonics	0.2 – 200 R_0 / open (closed for U or J burst)	c/3 electron stream	fundamental and harmonic plasma

Acknowledgements:

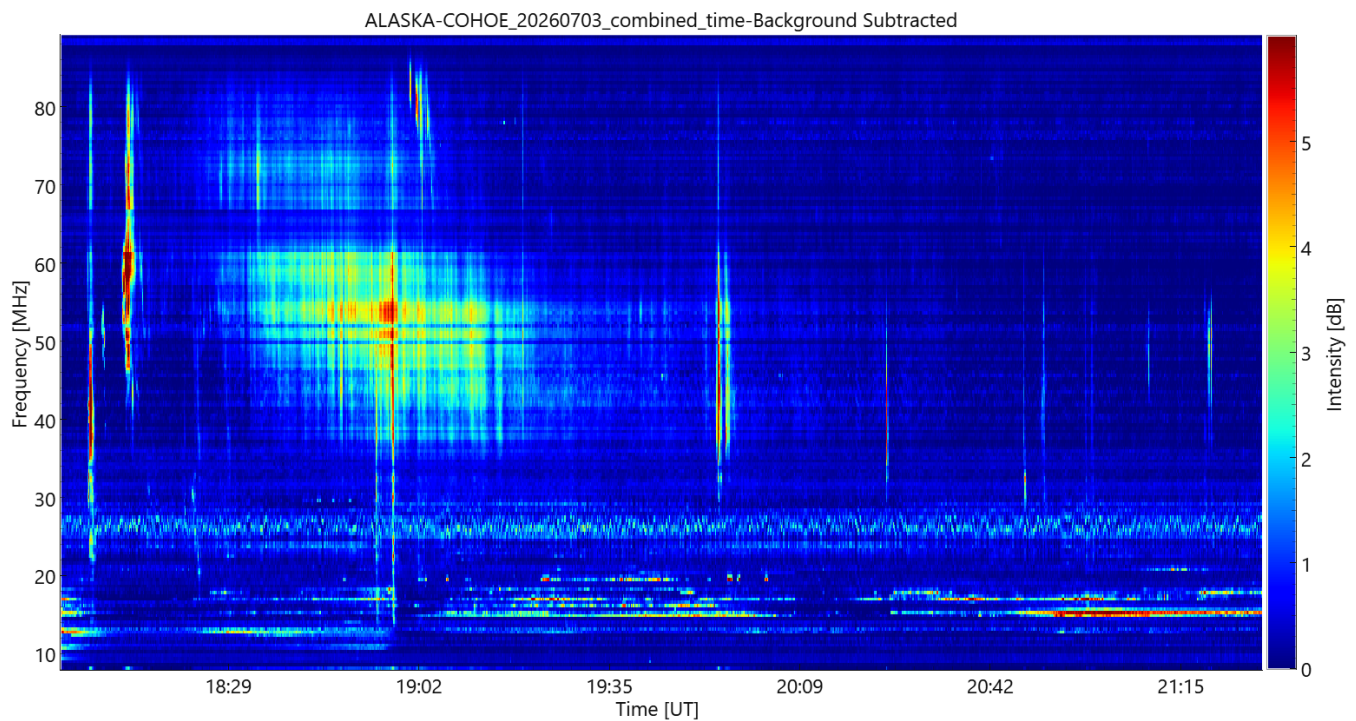
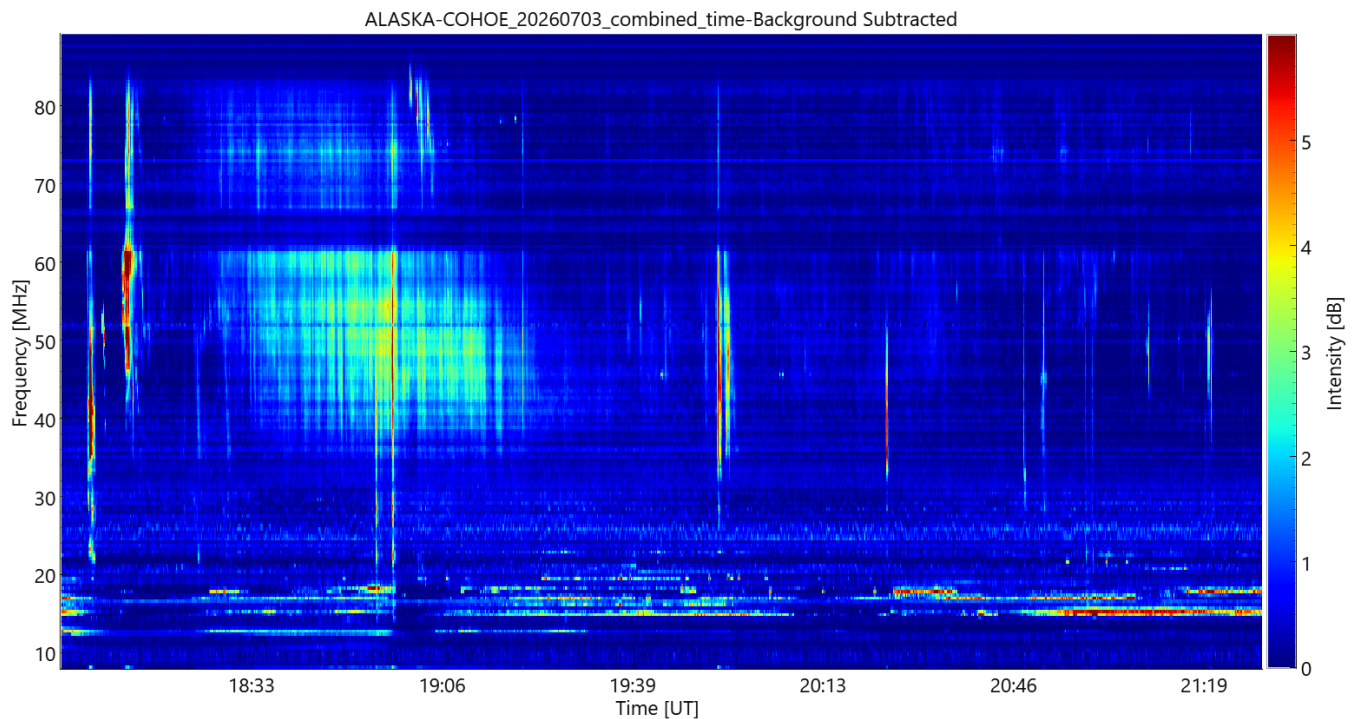
e-CALLISTO data host: Institute for Data Science FHNW Brugg/Windisch, Switzerland:

<https://soleil.i4ds.ch/solarradio/callistoQuicklooks/>

Post processing software: Sahan S. Liyanage, University of Colombo, Sri Lanka

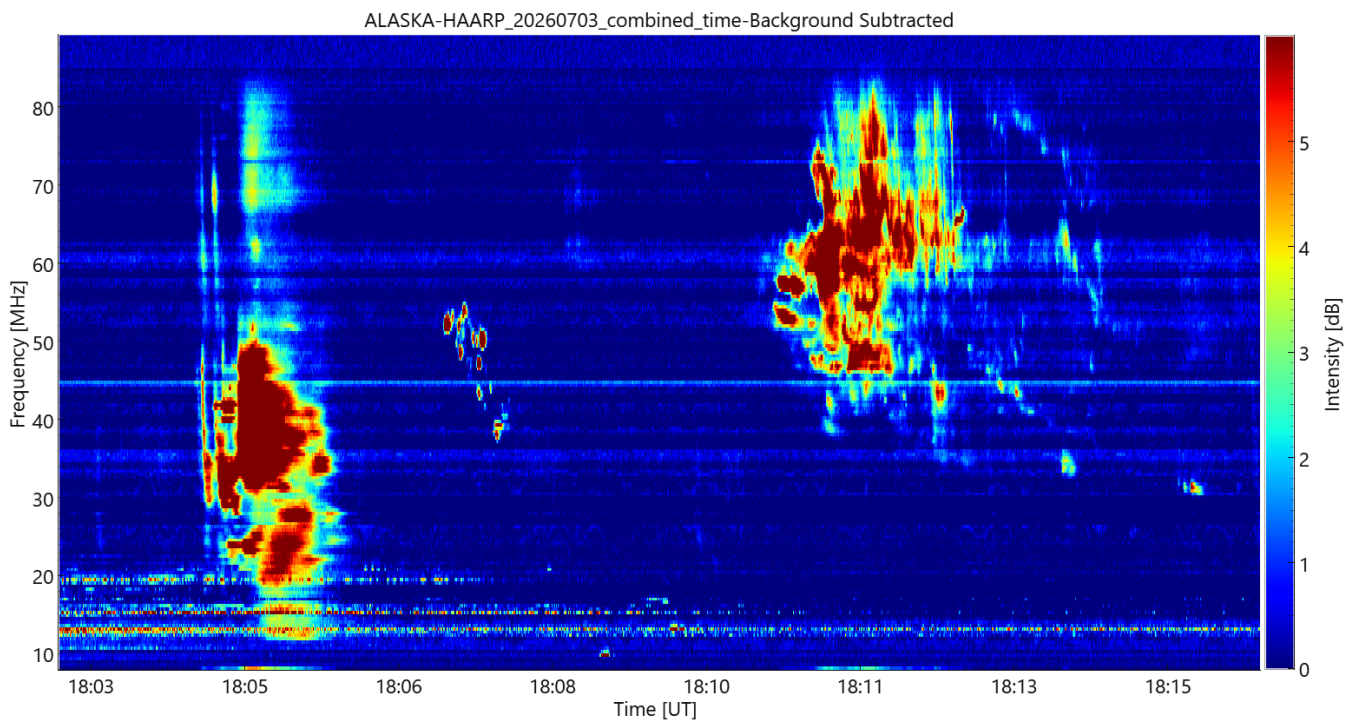
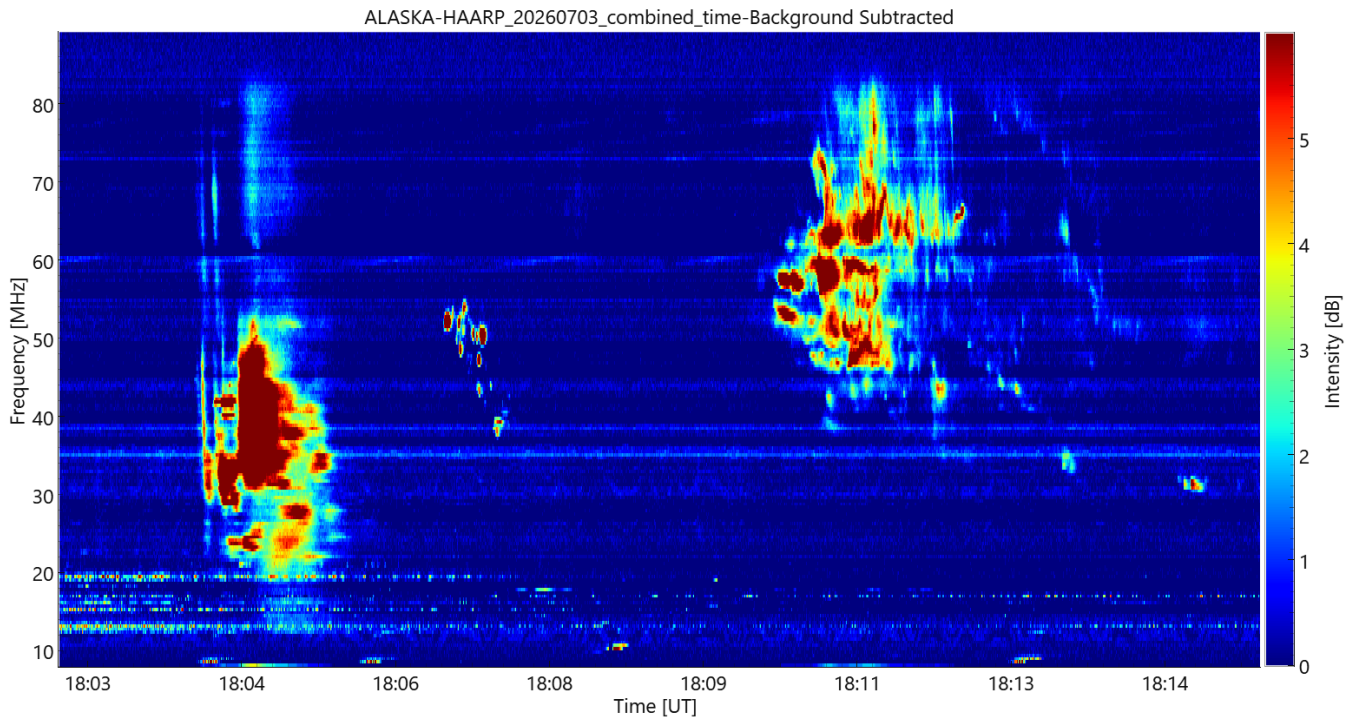
Cohoe RHCP (FC62) upper and LHCP (FC63) lower: 1800 ~ 2130 UTC, 3 July 2026, Color scale 0 → 6 dB

Type I continuum (CTM) interspersed with Type III fast radio sweeps; three HF radio blackouts. There is an indication of higher intensity in the CTM LHCP than RHCP. At the time of these events, the Sun elevation at Cohoe was approximately 45° and the true azimuth was 130° . The emissions observed at HAARP, about 400 km northeast, were almost identical to Cohoe.



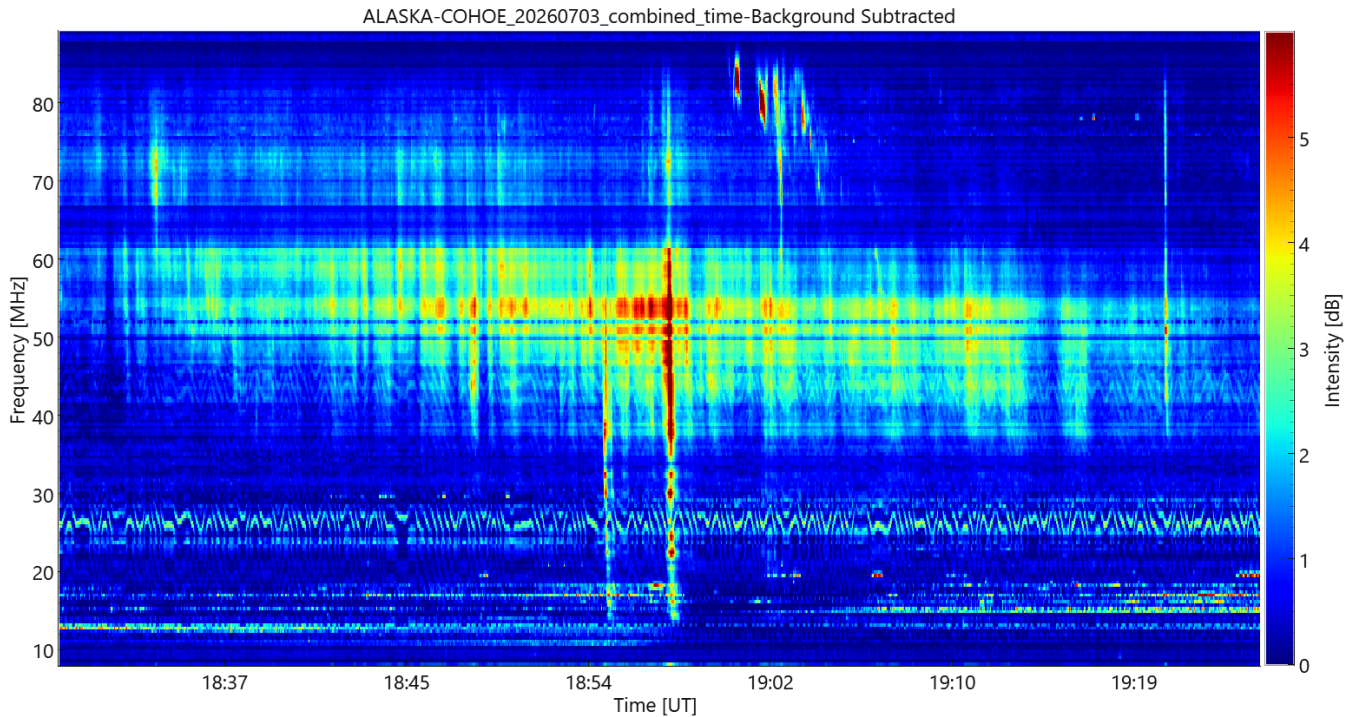
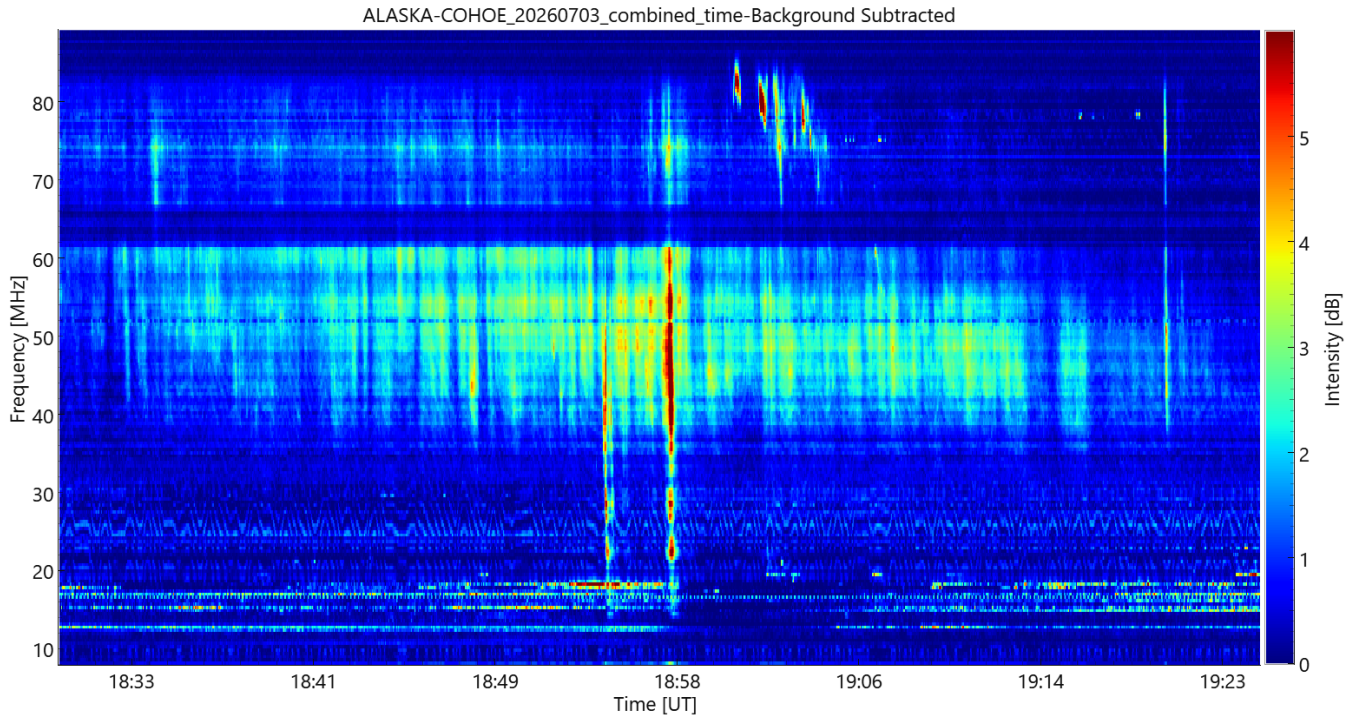
HAARP RHCP (FC62) upper and LHCP (FC63) lower: 1803 ~ 1816 UTC, 3 July 2026, Color scale 0 → 6 dB

Type V (Type III with continuum) followed by Type II slow radio sweep; terrestrial HF signals fade about 1805. At the time of these events, the Sun elevation at HAARP was approximately 47° and the true azimuth was 112° . The emissions received at Coho, about 400 km southwest, were almost identical.



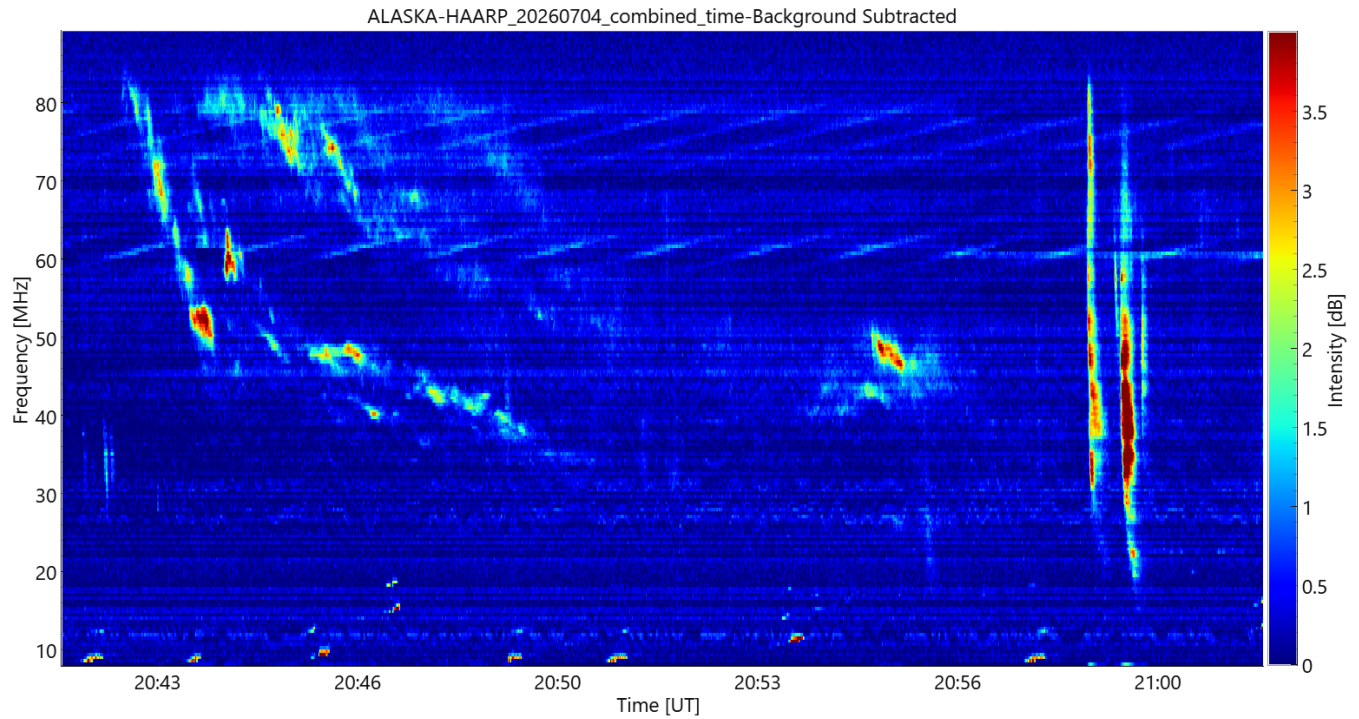
Cohoe RHCP (FC62) upper and LHCP (FC63) lower: 1830 ~ 1925 UTC, 3 July 2026, Color scale 0 → 6 dB

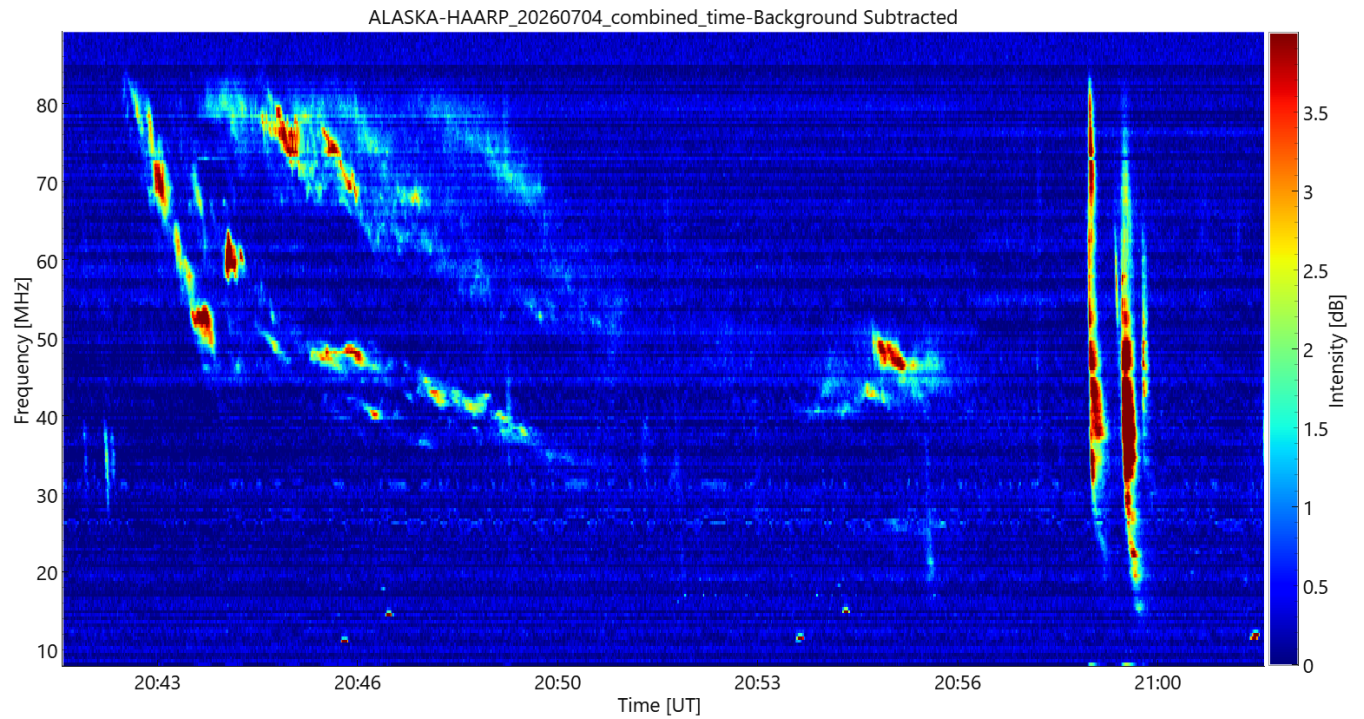
Type I continuum (CTM) interspersed with Type III fast radio sweeps and brief Type II slow radio sweep; HF radio blackout 1858 to about 1906. There is an indication of higher intensity in the CTM LHCP than RHCP. At the time of these events, the Sun elevation at Cohoe was approximately 40° and the true azimuth was 117°. The emissions received at HAARP were slightly weaker but had the same structure.



HAARP RHCP (FC62) upper and LHCP (FC63) lower: 2042 ~ 2102 UTC, 4 July 2026, Color scale 0 → 4 dB

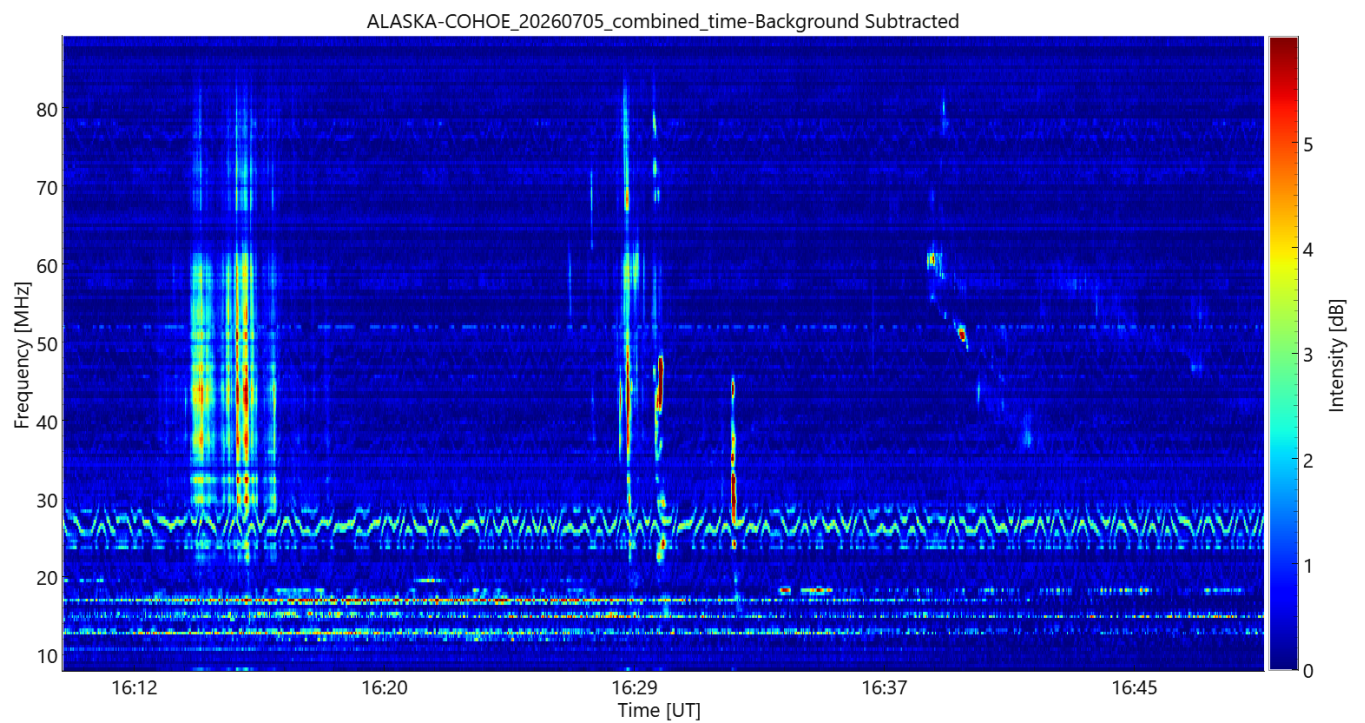
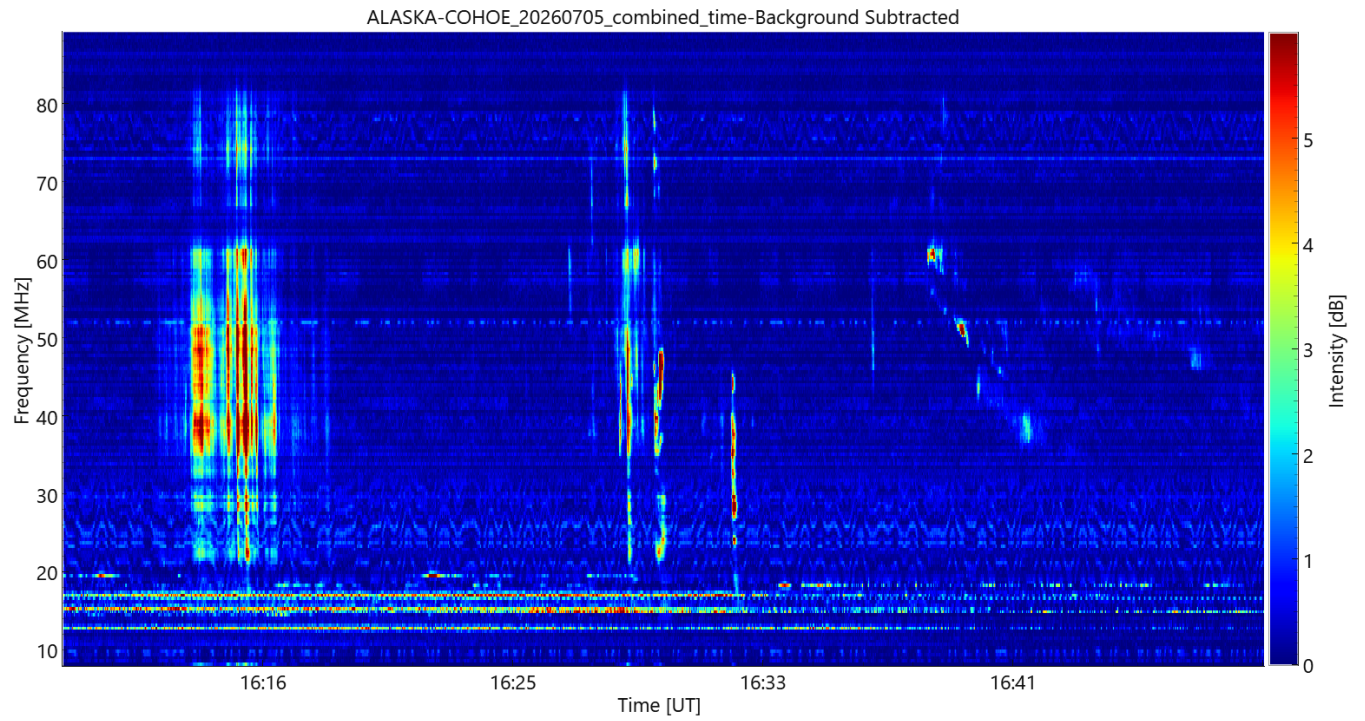
Type II slow radio sweep with split band and harmonic followed by Type III fast radio sweep. At the time of these events, the Sun elevation at HAARP was approximately 49° and the true azimuth was 160° . The emissions received at Cohoe were almost identical.





Cohoe RHCP (FC62) and LHCP (FC63) lower: 1610 ~ 1650 UTC, 5 July 2026, Color scale 0 → 6 dB

Type III fast radio sweeps with faint Type II slow radio sweep; HF radio blackout commences about 1633. At the time of these events, the Sun elevation at Cohoe was approximately 22° and the true azimuth was 88° . The emissions received at HAARP were substantially the same but possibly a little stronger (the Sun elevation was 3° higher than Cohoe).



INTERNATIONAL EARTH ROTATION AND REFERENCE SYSTEMS SERVICE (IERS)

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SERVICE DE LA ROTATION TERRESTRE DE L'IERS

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<http://hpiers.obspm.fr/eop-pc>

Paris, 06 July 2026

Bulletin C 72

To authorities responsible for the measurement and distribution of time

INFORMATION ON UTC - TAI

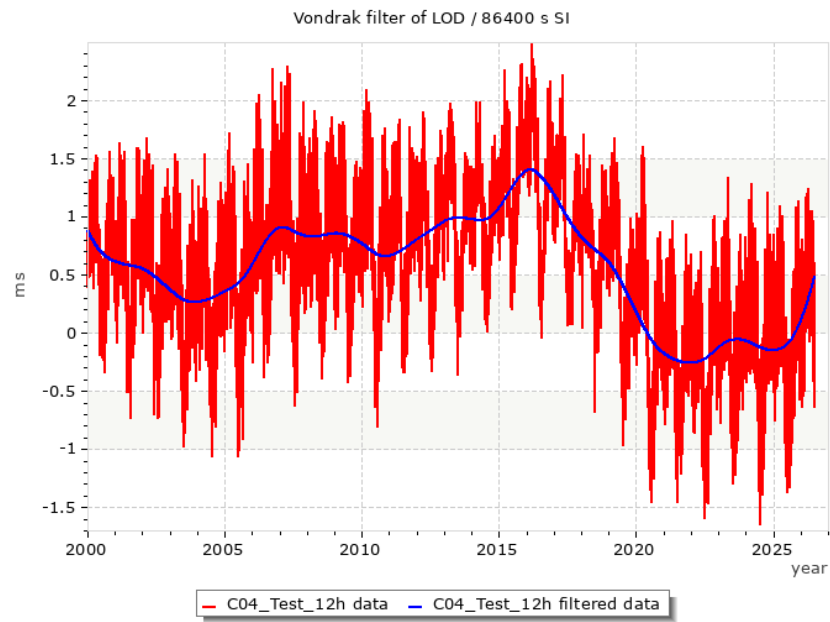
NO leap second will be introduced at the end of December 2026. The difference between Coordinated Universal Time UTC and the International Atomic Time TAI is :

from 2017 January 1, 0h UTC, until further notice : $UTC-TAI = -37 \text{ s}$

Leap seconds can be introduced in UTC at the end of the months of December or June, depending on the evolution of UT1-TAI. Bulletin C is mailed every six months, either to announce a time step in UTC, or to confirm that there will be no time step at the next possible date.

Christian BIZOUARD

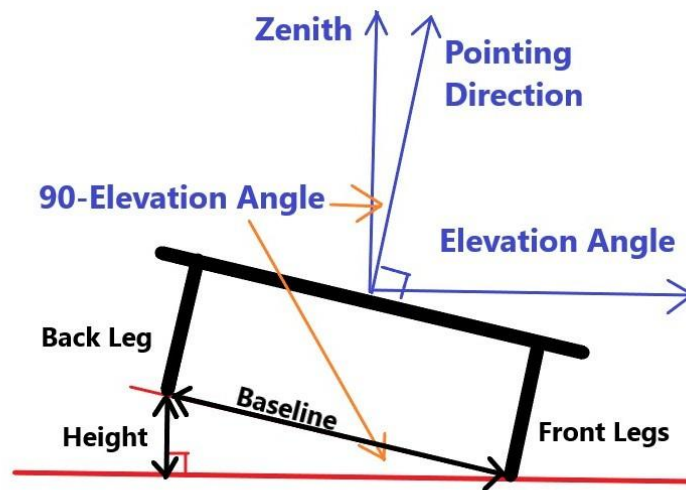
Director, Earth Orientation Center of IERS, Observatoire de Paris, France



Useful Formulas for Extragalactic Hydrogen Observing and Drift Scanning

Jason Burnfield - 21 July 2026

1. Calculating how high to raise the back leg of a tripod to achieve a specific elevation setting:



h: height of back leg

b: Baseline (distance between front and back legs)

EL: Elevation Angle

$$h = b\sin(90-EL)$$

2. Calculating the frequency setting for a particular VLSR corrected doppler velocity:

F_o: Observation Frequency (MHz)

V_o: Doppler Velocity of Observation (km/s)

VLSR: Local Standard of Rest Velocity

$$F_o = 1420.406 \left[\frac{1}{\frac{(V_o + VLSR)}{300,000} - 1} \right]$$

Note – VLSR can be determined by entering the date (don't worry about the time, it doesn't matter especially if you are pointing due North or South) and coordinates of your target galaxy into the Green Bank Observatory radial velocity calculation web page:

<https://www.gb.nrao.edu/~fghigo/gbt/setups/radvelcalc.html>

3. Converting observed frequency to VLSR corrected doppler velocity

F_o: Observed Frequency (MHz)

V_o: Doppler Velocity of Observation (km/s)

VLSR: Local Standard of Rest Velocity

$$V_o = 300,000(1420.406/F_o - 1) - VLSR$$

4. Converting raw amplitude values to dB:

$$dB = 20\text{Log}(\text{Amplitude})$$

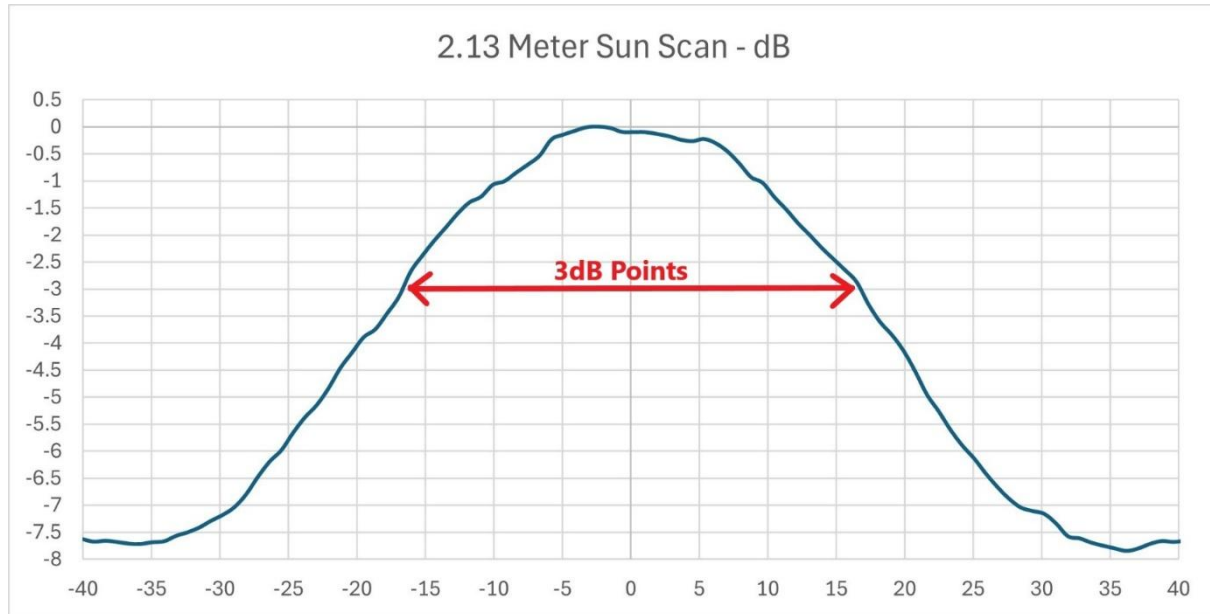
$$dB \text{ (compared to background)} = 20\text{Log}(\text{Peak/Background})$$

5. Calculating the Half-Power Beamwidth (HPBW) of your antenna using a sun scan:

t: Time between 3dB points (minutes)

Dec: Declination of the sun (degrees)

$$\text{HPBW} = t(15/60)\text{Cos(Dec)}$$



6. Calculating the duration of the main transit:

T: Duration of the main transit (minutes)

Dec: Declination of the target galaxy

HPBW: Half-Power Beam Width of your dish

$$T = \text{HPBW} \left[\frac{60}{15\text{Cos(Dec)}} \right]$$

7. Helpful tips for correcting the background of a spectral plot:

The background can be corrected by subtracting a fitting function to the portion of the plot that only contains the background (not the actual spectrum of the galaxy).

It is helpful to try and select as narrow of a horizontal scale as possible with just enough background included to fit an accurate curve.

Use the lowest order function possible that will flatten and normalize the background. I usually can get away with a second order or lower polynomial.

The polynomial coefficients behave as follows:

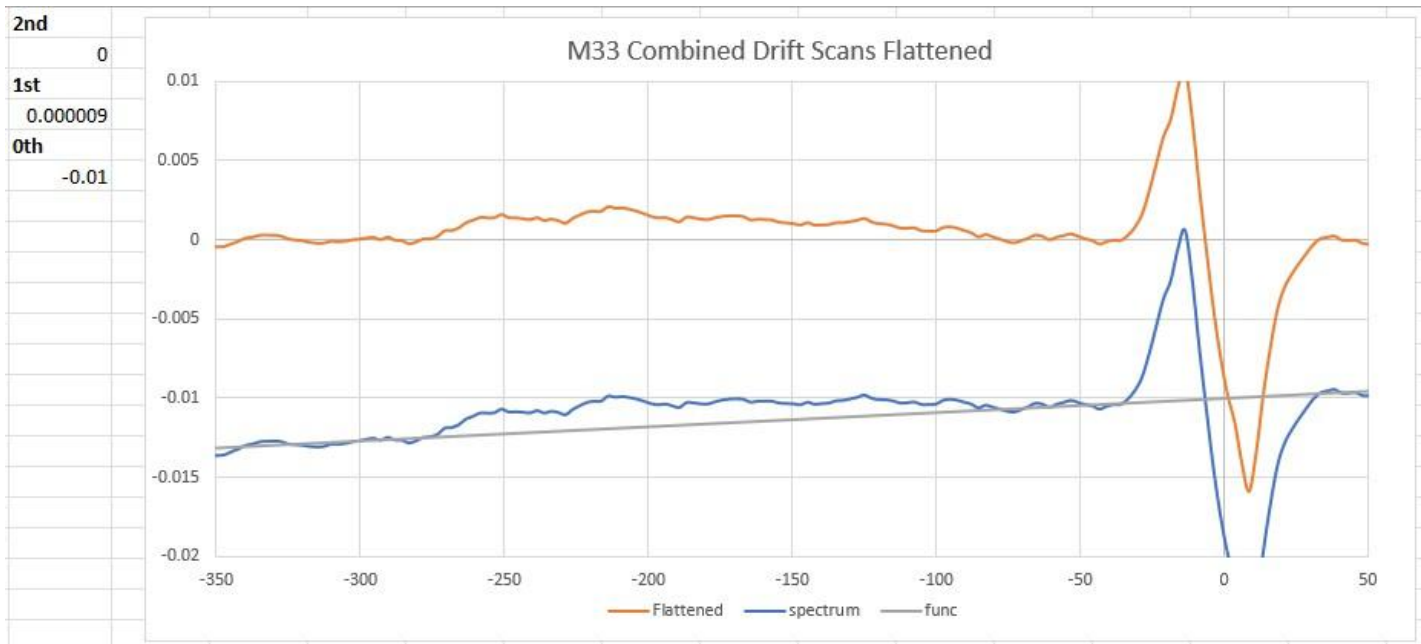
0th order coefficient: vertical offset (positive goes up, negative goes down)

1st order coefficient: slope (positive goes up to the right, negative goes down to the right)

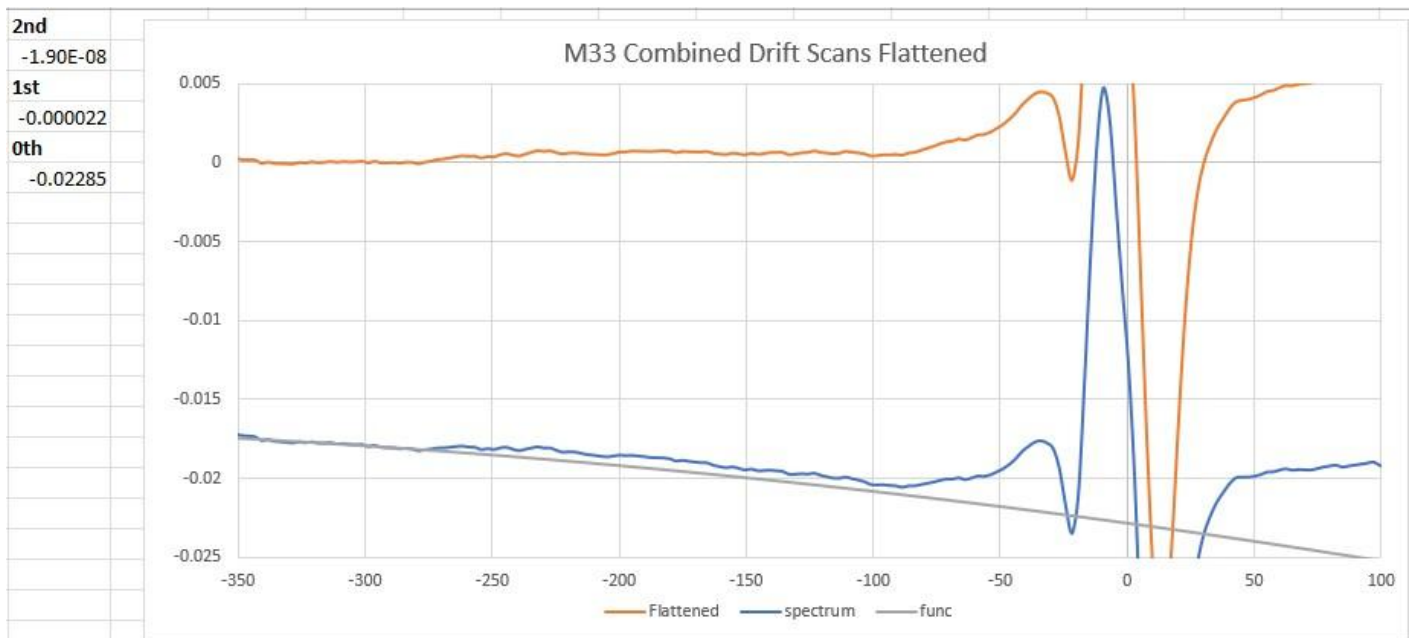
2nd order coefficient: curvature (positive is a “u” shape, negative is a “hump”)

See examples on the following pages:

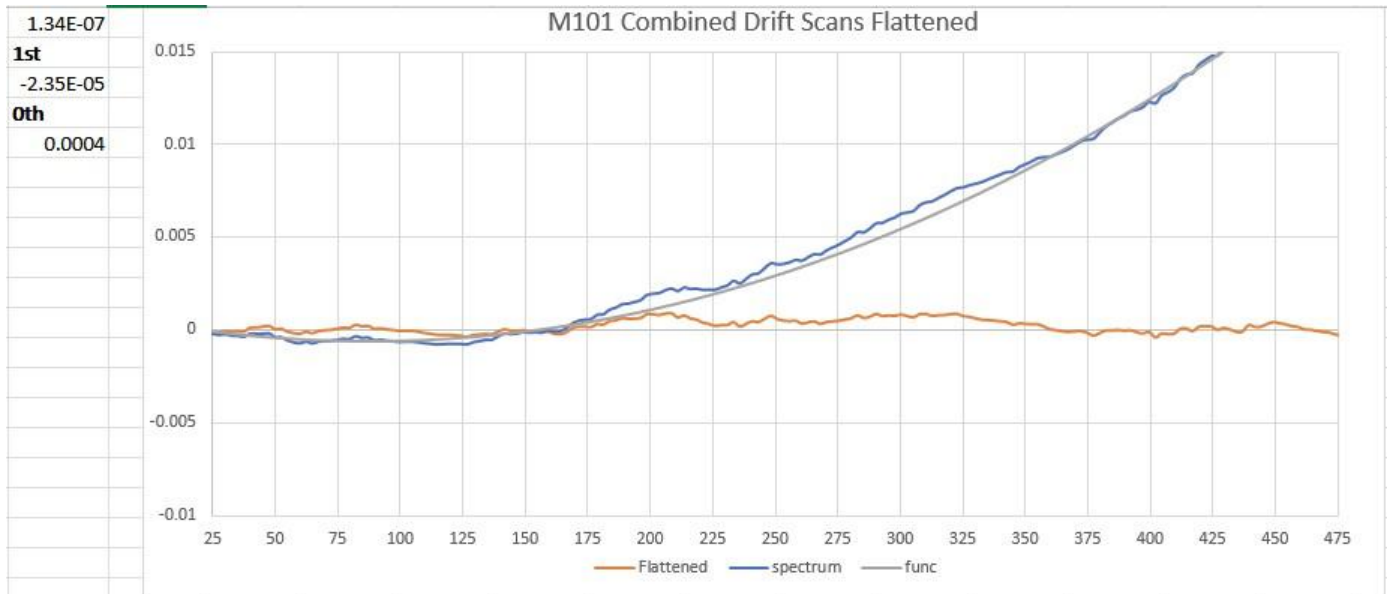
This one was corrected with a linear fit (slope and vertical offset only).



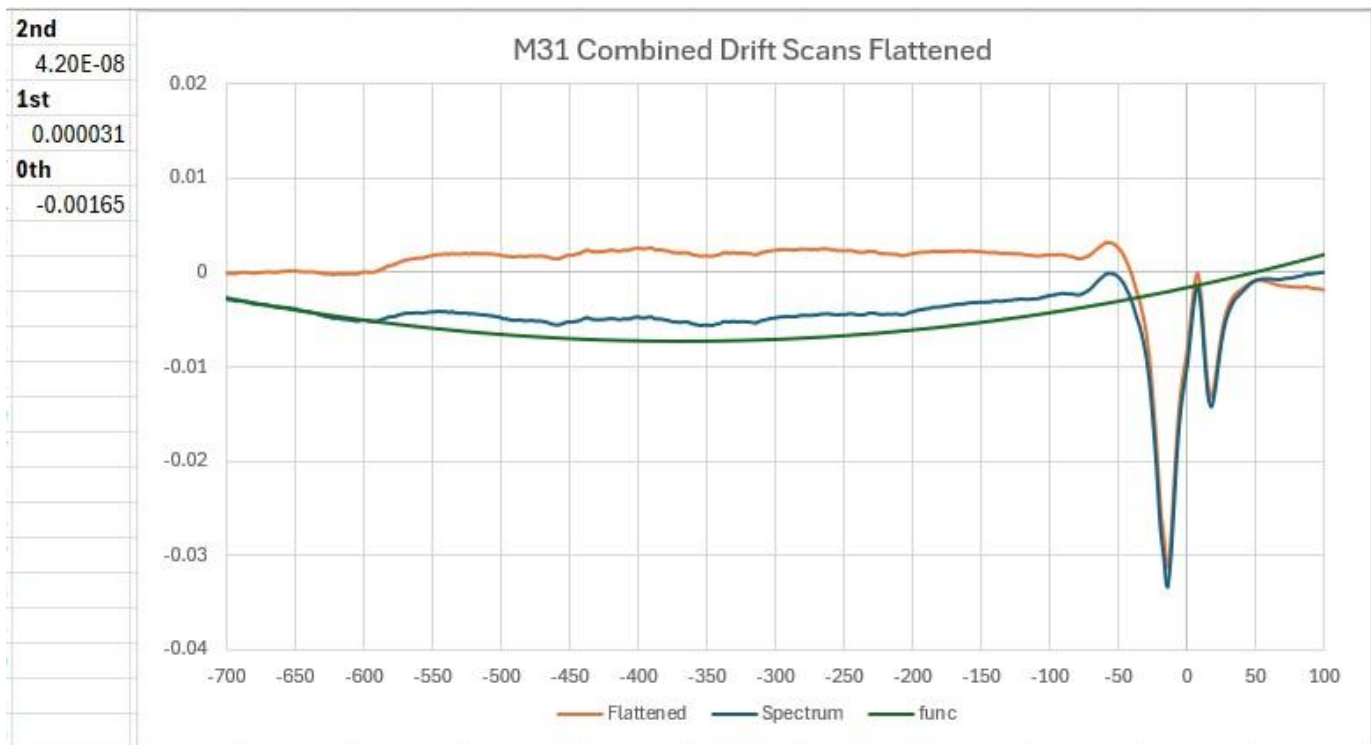
This one needed a negative curvature with a negative slope and vertical offset.



This one has positive curvature with a negative slope and positive vertical offset.



This one has positive curvature, positive slope, and negative vertical offset



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 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 had 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. Anthony Thornett , <https://www.radio-astronomy.org/contact/Secretary>

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Eastern Conference Coordinator	http://www.radio-astronomy.org/contact/Annual-Meeting	
All Radio Astronomy Editors	http://www.radio-astronomy.org/contact/Newsletter-Editor	
Radio Astronomy Editor and YouTube Producer	Dr. Richard A. Russel	drrichrussel@radio-astronomy.org
Educational Co-Chairs	Ken Redcap, Tom Hagen: http://www.radio-astronomy.org/contact/Educational-Outreach	
Grant Committee	Tom Crowley	grants@radio-astronomy.org
Membership Chair	http://www.radio-astronomy.org/contact/Membership-Chair	
Webmaster	Ciprian (Chip) Sufitchi, N2YO	webmaster@radio-astronomy.org

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/e-callisto.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=rBZIPOLNX9E
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://solar-center.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/groterebermuseum> 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.

Now! 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)







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: _____

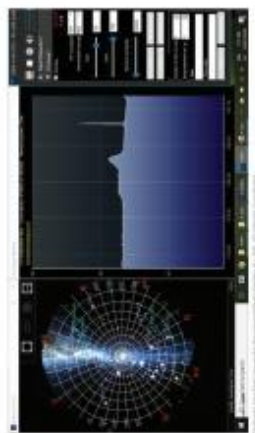
Please include a note of your interests. Send your application for membership, along with your remittance, to our Treasurer.

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.



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.

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.



<http://radio-astronomy.org>

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 meetings 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 the 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)

