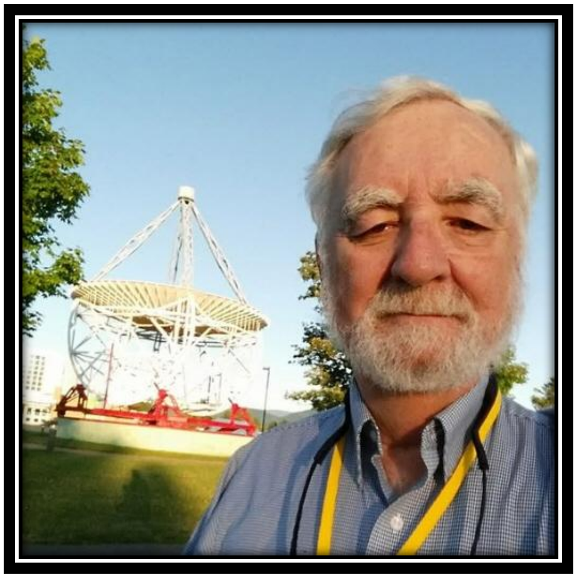
RADIO ASTRONOMY

Journal of the Society of Amateur Radio Astronomers

May - June 2026



Dennis Farr, WB4RJK

SARA President and Treasurer Emeritus

1947 - 2026

Dr. Richard A. Russel

SARA President and Editor

Bogdan Vacaliuc

Contributing 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.

Cover Photo:

Charles Osborne

Contents

President's Page

This Journal is dedicated to Past President and Treasurer Dennis Farr.

Dennis was an enthusiastic radio astronomer who poured his heart and soul into SARA over the years. As late as last month, knowing he had terminal cancer, he kept up the Treasurer work by processing Eastern Conference fees and Memberships. Dennis was the advocate for the Scope-in-the-Box project, which was a key driver for a lot of members getting into this hobby.

Thank You Dennis! It was an HONOR to know you!

Elections:

The draft ballot is in this issue. It includes biographies of the candidates. We are still trying to get nominations for President, VP, and Secretary. The final ballots will be emailed July 26 with the counting completed at the Eastern conference by Monday August 3. Don't forget to vote!

Farewell as President

This is my last President's Page post. The next issue will be from the new SARA President.

I've truly enjoyed the sense of camaraderie that SARA members brought over my 5+ years as president. SARA has truly been an inspirational organization that has brought together worldwide members based on our shared passion for radio astronomy.

Editor's Notes

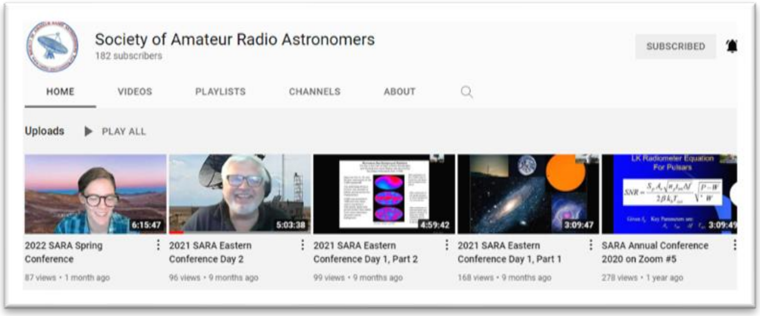
We are always looking for basic radio astronomy articles, radio astronomy tutorials, theoretical articles, application and construction articles, news pertinent to radio astronomy, profiles and interviews with amateur and professional radio astronomers, book reviews, puzzles (including word challenges,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



Observation Reports

We are now accepting 1-2 page observation reports. These reports should include the astronomical object's RA/DEC plus UTC of the observation. Also include the telescope configuration, process used to observe the object and results. Picture of the setup and plots of the observation are a plus to the report.

If you would like to write an article for Radio Astronomy, please follow **the newly updated Author's Guide** on the SARA web site:

http://www.radio-astronomy.org/publicat/RA-JSARA_Author's_ Guide.pdf.

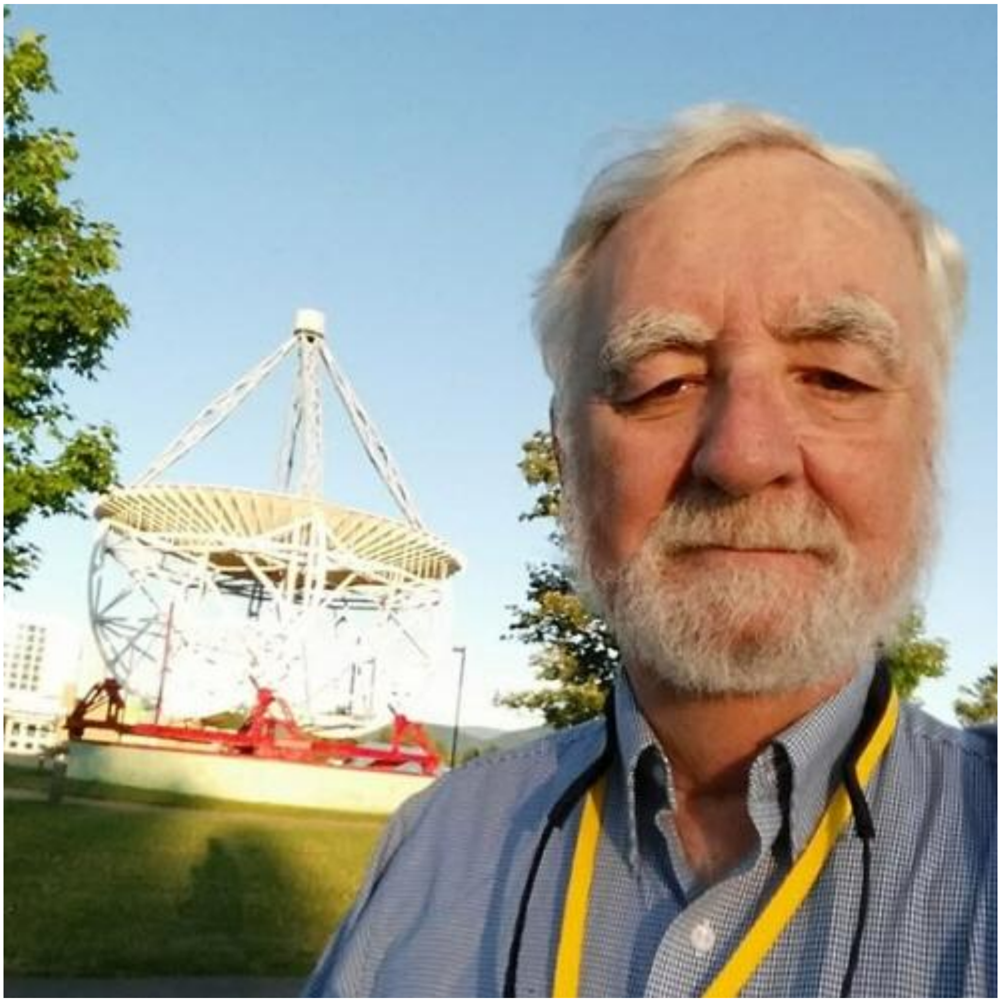
Let us know if you have questions; we are glad to assist authors with their articles and papers and will not hesitate to work with you. You may contact your editors any time via email here: edit@radio-astronomy.org.

The editor(s) will acknowledge that they have received your submission within two days. If they do not reply, assume they did not receive it and please try again.

Please consider submitting your radio astronomy observations for publication: any object, any wavelength. Strip charts, spectrograms, magnetograms, meteor scatter records, space radar records, photographs; examples of radio frequency interference (RFI) are also welcome.

Guidelines for submitting observations may be found here: http://www.radio-astronomy.org/publicat/RA-

Dennis Farr Tribute – Charles Osborne



Dennis Farr , WB4RJK

May 1st 1947 - May 5th 2025

Dennis and Helen moved to Country Place 6 years ago, he was a smart, wonderful person who loved his family, his Country and knowledge. Dennis lost the war with cancer on May 5, 2026, in his home surrounded by his family. There was a memorial service on May 19th to celebrate his life. He recently quoted the following which is a good summary of his life.

“Look at the stars, it won’t fix the economy, it won’t stop wars. It won’t give you flat abs or even help you figure out your relationship and what you want to do with your life. But it’s important. It helps you remember that you and your problems are both infinitesimally small and conversely, that you are a piece of an amazing and vast universe."

Looking for pictures and anecdotes I found that Dennis in a way wrote his own memorial. One merely has to page through his Facebook comments over many years to get a real feel for his love of family, veterans, and our country.

https://www.facebook.com/dennis.farr.180/

You'll find Dennis was a Vietnam Vet (Naval Chief) and was deeply concerned and often mentioned the Veteran's Suicide Help Line encouraging folks to spread the message, so I'll honor Dennis' wish and do that here:

"New Veterans Suicide Help Line is 988 and then option 1, you can then chat online at the VeteransCrisisLine.net or text 838255." 1-800-273-8255

Dennis was a perennial volunteer giving radio astronomy presentations all over central Florida at astronomy clubs and amateur radio clubs. Well known enough that there's even one video in there by the local TV station interviewing Dennis about a meteor that exploded and was seen by many.

Some of the places Dennis gave radio astronomy presentations:

The Villages Amateur Radio Club

Tampa Amateur Radio Club

Spring Hill Amateur Radio Club

St. Petersburg Amateur Radio Club

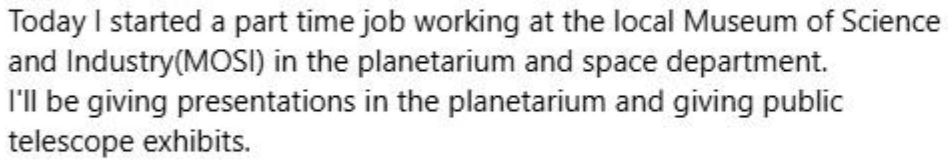
MARS MOSI Astronomy Club

Brandon Amateur Radio Club

Tampa Hackerspace

SARA table at Hamcation with Tom Crowley

I think one of Dennis’ proud moments was working at the Museum of Science and Industry (MOSI) as a docent and planetarium operator.



Today I started a part time job working at the local Museum of Science and Industry(MOSI) in the planetarium and space department. I'll be giving presentations in the planetarium and giving public telescope exhibits.

He was involved in the Center for Planetary Science restoring a 10 meter dish and a NASA mobile tracking trailer to become an astronomy observatory. Some of the before and after pictures are below. I’ve included Dennis’ own words he posted with the picture where possible.

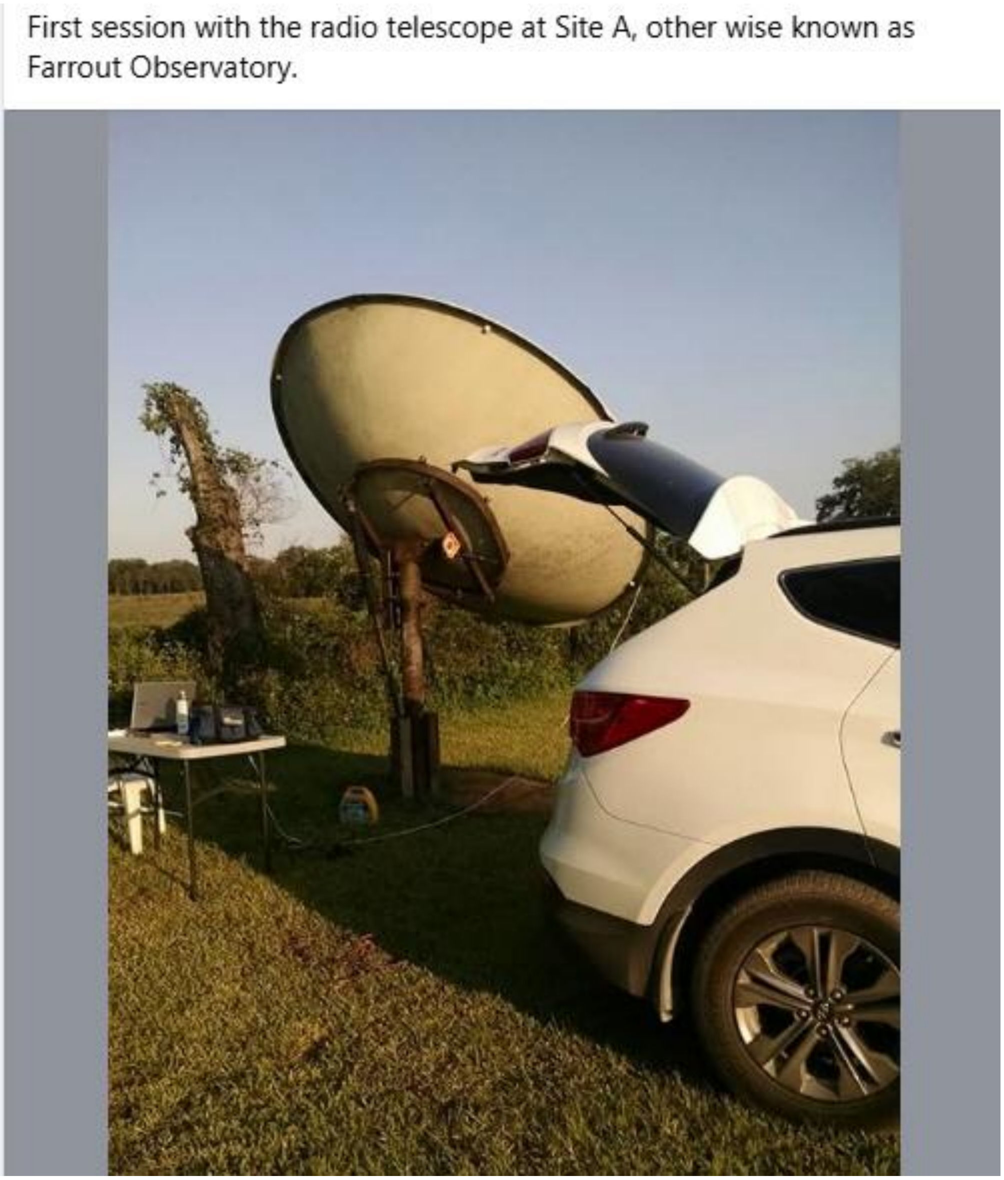
I've been working on this NASA relic dome with The Center for Planetary Science. We are restoring it and hope to have it be a rolling museum piece.

I've been promoted. I wash bigger dishes now

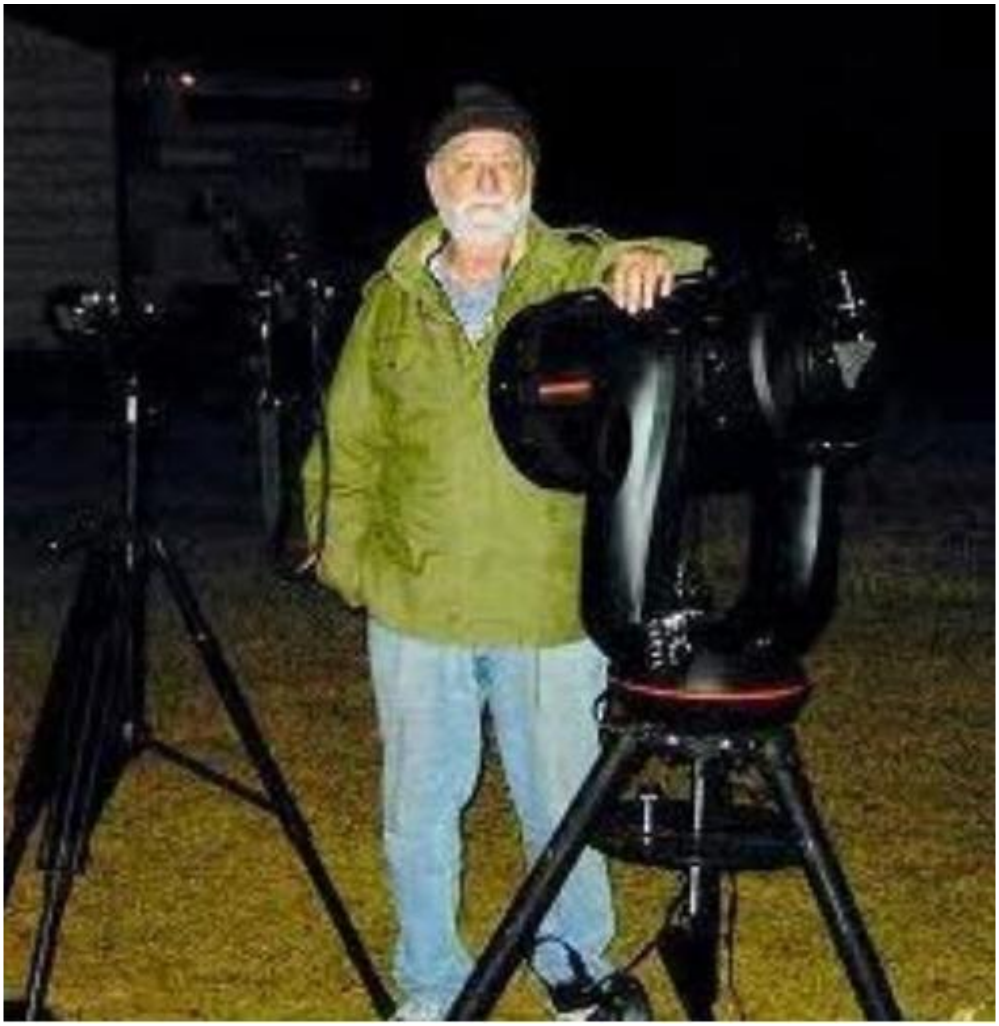
Dennis’ own remote observatory he named the Farrout Observatory (FOO) started with similar dish washing of a 10 foot dish.

My new telescope. 10' aluminum satellite dish to be used for radio telescope.

Old school technician working on state of the art radio astronomy equipment.



First session with the radio telescope at Site A, other wise known as Farrout Observatory.



One of Dennis' big contributions to SARA was the idea of the "Scope-In-A-Box". This proved to be a popular kit that became the beginner's way to get past many of the initial hurdles he saw as slowing or stopping beginners.

In 2024 he proudly posted: "I've just been informed that a radio telescope I helped develop a few years ago is being included in a display at the Smithsonian Institution."

Dennis' car's bumper stickers included SARA and the Drake Equation.

The other "My Other Car is on Mars" indicated Dennis' comments that the cost and risk of getting humans there wasn't justified when one looked at the decades of rovers' accomplishments.

https://www.foxnews.com/.../sending-astronauts-to-mars...

Sombody finally had the nerve to say it.

FOXNEWS.COM

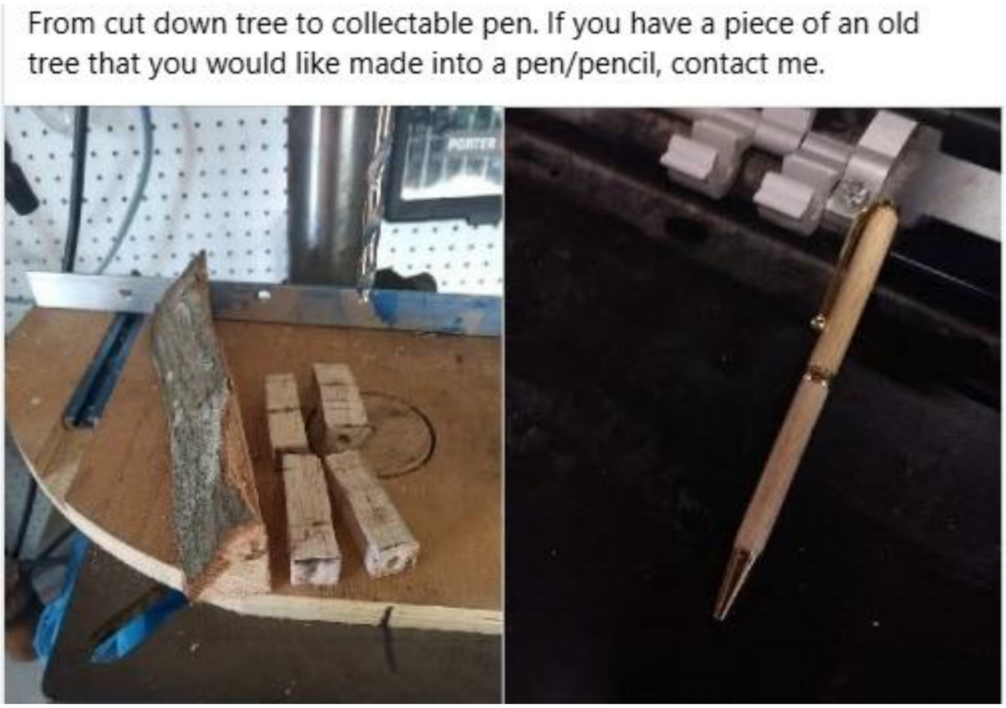
Sending astronauts to Mars would be stupid, says Apollo 8 pilot

Why we had children, to get grandchildren.

Or as Dennis put it “If you’re really good at being parents, you get promoted to Grand parents.”

Dennis was a woodworker too. He recycled live oak from his Farrout Observatory into pens and pencils plus some stunning cutting boards.


QUIET PLEASE
Woodworker
AT WORK



From cut down tree to collectable pen. If you have a piece of an old tree that you would like made into a pen/pencil, contact me.

https://www.youtube.com/watch?v=A9mFurTSJmc

YOUTUBE.COM

Dennis Farr Presents Radio Astronomy to the St Petersburg Astronomy Club March 23 2018

But above all Dennis loved the annual pilgrimage to Green Bank. In his own words:

7/13/18 “Driving home from Green Bank West Virginia. What a rush.”

Dennis Farr

August 8, 2019 ·

Returning from my annual pilgramage to Green Bank WV.
Special year, got to go up in the big scope. 350 feet to the level indicated.

Dennis’ wit and personality is evident throughout his many posts about living in Tampa and dealing with hurricanes and his challenges with cancer . Here’s a few classics:

“..The boys are outside playing. Someday they’ll tell people they played outside in a hurricane.”

“So it turns out digital exam has nothing to do with computers.”

“I find it ironic that the government can’t pay people who are working but must pay people who are not.”

“It’s bucket list day and I didn’t kick mine. It’s a good day.”

Buffalo Springfield – For What It’s Worth 1967 “Just heard this song, one of my favorites. Pretty relevant today.”

“Some of us dealt with physical warfare, most of us dealt with psychological warfare.”

“My GP says I’m healthy as a horse. Now I have to see a Vet.”

“Welcome to retirement where you find out how all the decisions in your life are going to play out.”

Rich mentioned that Dennis was volunteering to help with SARA membership calls even a week before he passed.

Society of Amateur Radio Astronomers (SARA)

2026 SARA & Radio Jove Eastern Conference
August 1 (Sat) – August 5 (Wed) 2026
Green Bank Observatory (GBO) West Virginia (WV)

We are still accepting presentations!

Submit an abstract to vicepresident@radio-astronomy.org to present at the Conference

Block your calendars and start thinking about this year's travels. The 2026 Eastern Conference has been set to occur the first week in August 2026 back in Green Bank WV!

- 2026 SARA and Radio Jove Eastern Conference
- August 1 (Sat) – August 5 (Wed) 2026
- Green Bank Observatory (GBO) West Virginia (WV)

We will be following a similar format as years past. For example:

- Saturday (8/1): Guided tours of public exhibits, Dave Lacko and Jay Wilson discussion on "What is Radio Astronomy Anyhow?", hands on workshop assembling Scope in a Box and eZRA software
- Sunday (8/2): hands on workshop for 40' telescope and 20-meter telescopes, with attendees able to plan and make observations
- Monday – Tuesday: Technical discussions
- Wednesday (8/5): Guest Speaker and technical tours of GBO
- Evenings: Drake lounge discussions, flea market, and observations using Scope in a Box, Radio Jove, Super SID, 40', 20 meter telescopes

Any comments and/or suggestions please reach out to the committee chair Marcus Fisher (vicepresident@radio-astronomy.org)

2026 SARA Officers and Board Members Nominations

As required by Article VII, Section 3 of SARA By-Laws (see below), this is the official call for nominations for SARA officers and board members.

If you are interested in running for office and would like to know more about the positions, please contact a board member, SARA President Rich Russel, or SARA Secretary Brian O'Rourke.

The requirement to be on the board is to attend the board meetings at the annual meeting and to actively participate in board-related activities.

If you are unable to attend the annual meetings, then the director at large position may be for you. This position is a full board position except that attending the annual meeting is not required.

The following positions will be up for election in August 2026: President, Vice President, Treasurer, and four Board of Director members.

If you would like to run for one of the available SARA Officer or Board positions, please send a note to Secretary Brian O'Rourke with a copy to President Rich Russel. Please include a short biography and head shot photo. The biography and photo will be used to inform the membership about who you are.

Contact information:
Brian O'Rourke: brian.chad@gmail.com
Dr. Rich Russel: drrichrussel@netscape.net

Please Note: It is important to get someone's permission before nominating them!

Text from the By-Laws: Article VII, Section 3:
Elections of Directors and Officers will be accomplished by the President placing an initial call for nominations in "The Journal" no less than ninety (90) days prior to the regular scheduled meeting. Two (2) nominations from different members will be required to nominate a member for an office. No less than thirty (30) days prior to this meeting (in a newsletter issued prior to the meeting), the President will
place a notice of the results of the nominations in "The Journal", along with a ballot for the members to use to vote for the nominee of their choice. This ballot will be forwarded to the Secretary for collection and counting at the regular meeting.

Responsibilities of President:

1. Preside over all business of the Society.
2. Appoint committees as needed, and will be an ex-officio member of all committees.
3. Act as the official spokesman for the Society.
4. Perform all other duties normally assigned to the office of a President.

Responsibilities of Vice President:

1. Preside and assume the duties of the President in any case where the President cannot assume his normal duties, or at the request of the President.
2. Promote the Society in the areas of public relations, information, and membership recruiting.
3. Responsible for organizing and conduction the annual meeting.

Responsibilities of Treasurer:

1. Deposit funds into bank account in a timely fashion.
2. Manage PayPal account.
3. Record all financial transaction.
4. Pay all SARA bills on time.
5. Reconcile bank and PayPal statements.
6. File Form 990EZ with IRS by November 15th
7. Maintain membership records.
8. Send renewal notices to members.
9. Email members when a new Journal is available.
10. Send list of new members to be in next Journal.
11. Handle sales of SARA items.

Responsibilities of Directors:

The Director needs to respond to and vote on business brought before the Board of Directors. This includes the SARA annual meeting, email meetings, and teleconference meetings such as Zoom. The requirement to be on the board is to attend the board meetings at the annual meeting and to actively participate in board-related activities. For a more detailed list of responsibilities, See Article VII, Sections 4 through 8.

[If you have any questions or comments, please email the Secretary at brian.chad@gmail.com]

DRAFT BALLOT

Elections 2026

Final Ballot will be sent out the week before the Eastern Conference

President

(NO NOMINEES)

Vice President

(NO NOMINEES)

Treasurer

Brian O'Rourke (USA) _____

Secretary

(NO NOMINEES)

Board of Directors (Vote for 4) (Alphabetical Order)

Jason Burnfield (USA) _____

John Colt (USA) _____

Dimitry Fedorov (Russia) _____

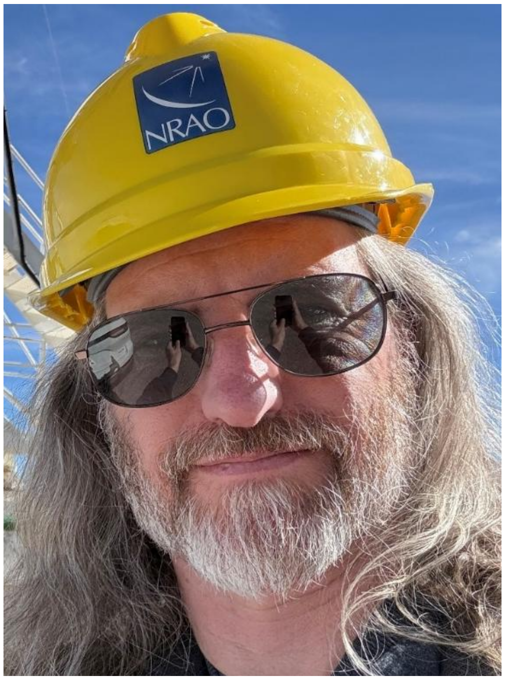
Martin Knoblauch (USA) _____

Andrew Thornett (UK) _____

Stephen Tzikas (USA) (INCUMBENT) _____

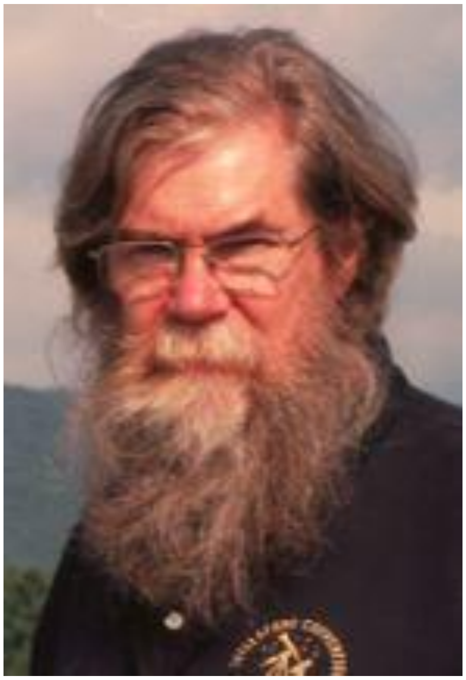
Biographies

Jason Burnfield



Jason Burnfield has been a member of SARA since October of 2022. He got his start just like many amateurs do, with an RTL-SDR, a Nooelec Sawbird +H1 LNA/BPF, and a homemade antenna for detecting the Hydrogen Line signal from the Milky Way. In Spring of 2024, he successfully detected the Hydrogen Spectra from both Messier 31 and Messier 33 using a portable homemade dish. After presenting his results at the 2024 SARA Eastern Conference at Green Bank Observatory, he got his dream job working as an Electronics Engineer for the National Radio Astronomy Observatory in Socorro, New Mexico, supporting the Very Large Array and the Very Long Baseline Array. He has been active in SARA using the 20 Meter Dish at Green Bank Observatory to detect Hydrogen Spectra from nearby galaxies as well as doppler mapping a few of the closest galaxies. He helped coordinate the logistics of the 2025 SARA Western Conference which was held in Soccoro, NM at the NRAO Domenici Science Operations Center (which is also his workplace). In his spare time, he has been designing, building, and testing new and improved versions of his portable umbrella type dish.

John Colt



I'm a retired engineer (defrocked physicist) living in Vermont and spending most of my time as a volunteer emergency communications coordinator for hospitals here in the state.

Way too much of my working life was in corporate America, but I'm recovering pretty well. The best parts of my career were characterizing integrated circuits at microwave frequencies (ham radio at work!), and later, developing multivariate fab yield models (predicting the future!) for IBM.

My wife Karen (WE1E), son John (AC1QY) and I have been members of SARA since 2016.

We've learned a lot, and thoroughly enjoyed our time in SARA, and I'm more than willing to help out as a board member.

Dimitry Federov

Dimitry Fedorov, UA3AVR was first licensed as a radio amateur in 1982. In 1990 Dimitry graduated with MS equivalent degree in electronics from Moscow Power Engineering University. Dimitry currently resides in Moscow and 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.

Radio Astronomy became a hobby in 2012 and began with experiments and observations at mm-waves. Dimitry has realized several projects involving solar and lunar observations at mm-waves and is currently working on a project to observe molecular spectral lines in millimeters. He was active in observing methanol masers (6.7 GHz line) in Galaxy objects using small single dishes 1.8–2.4 m. He is also active using the 20-meter radio telescope at the Green Bank Observatory, observing hydroxyl (OH) maser lines of evolved stars and other objects, such as HII regions via hydrogen recombination lines.

Dimitry is a lifetime member of SARA.

Martin Knoblauch

Martin Knoblauch (N3BEV) has been in Amateur Radio since 1963. He has been a SARA member for 7 years. He is active on the HF bands, He has Bachelors (1972) and Masters (1976) degrees in music from the University of the Arts and a Juris Doctor (1985) degree from Temple University School of Law. He has also studied Gross Anatomy at Jefferson Medical School. For the last 60 years he has worked as a teacher and conductor for orchestras chorus and opera and as a church music director and organist in various positions. He has been a member of the Pennsylvania Bar since 1985 and is in private practice. He has a Celestron C 14 in a back yard observatory, a 3 meter RA dish and various other instruments which he uses for star parties in the NASA Solar System Ambassador Program. He is a member of the Delaware Valley Amateur Astronomers and the Rittenhouse Astronomical Society. In addition to radio and astronomy he is also interested in Medicine and Ancient Languages. He lives in Philadelphia PA. with Dianne, his wife of 54 years

He has attended the SARA Eastern conference for the last 4 years and is humbled that his presence is tolerated among such eminent minds.

Andrew Thornett:

Dr Andrew Thornett was a family doctor in England, UK, until retirement last year. He is passionate about amateur radio astronomy, doing a lot of work with other SARA members on projects, the output of which he uses in the introductory talks he gives to amateur astronomy organisations in the UK. He has spoken on radio astronomy at a number of amateur astronomy conferences in the UK, and at the Radio Society of Great Britain Annual Convention. He is also active in the British Astronomy Association (BAA), running every Monday an online practical amateur radio astronomy meeting on subjects including hydrogen line radio astronomy, GNU Radio for amateur radio astronomy, muon detection, VLF/SID monitoring, and meteor radio scatter. These are recorded and available on YouTube and are helping stimulate interest from people who have never done radio astronomy before. These meetings have an almost equal number of BAA and SARA members attend and are open to people who are not members of either organisation. They are very much organised around the structure of SARA Drakes' Lounge amd RTOP and were always intended to be open to anyone who wanted to find out more about practical aspects of our hobby.

Andrew is a great fan of the open, inclusive philosophy of SARA, the level of support its members give anyone who needs it, both financially and through group and 1:1 personal support from experienced members, and the incredible resource that its meetings and publications are building up for current and future radio astronomers.

He would love to take on the role of foreign board member to contribute further to help SARA achieve its goals.

Steve Tzikas

Steve Tzikas joined SARA in 2013. While pursuing his goals in radio astronomy, he created the SARA Sections to focus the interests of members and help disseminate information. Steve also took an interest in promoting the remotely operated Skynet 20m radio telescope found at GBO. He helped create a SARA account for it and does an annual demonstration of it for the participants at the SARA eastern conference. Each year he explores a new demo topic for posting on the SARA Analytical Section webpage, which has become the collection point of the 20m radio astronomy observing programs. Steve has a MAppSc in Chemical Engineering and Industrial Chemistry from UNSW in Australia, and a BS in Chemical Engineering from Rensselaer Polytechnic Institute in NY. In 2025 he retired from Federal government and has been pursuing his interests in interdisciplinary engineering and science. Steve's goals with SARA are to remain active and continue to explore the full capabilities of the 20m radio telescope for educational purposes.

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 July 10th 19:30 BST (18:30 UTC) Dr Tim Molteno TART
The Transient Array Radio Telescope: An open-source aperture synthesis imaging radio telescope
Dr Tim Molteno is a Senior Lecturer in Physics at the University of Otago, New Zealand, Senior Research Associate, Physics and Electronics, Rhodes University, South Africa, and Director of the Electronics Research Foundation. He is an expert on Nonlinear Dynamics, Bayesian Inference, Measurement, Electronics, Signal Processing and Radio Astronomy Instrumentation. Twelve years ago, he founded the Transient Array Radio Telescope (TART) project. Tim has contributed code to many parts of the TART project, his recent contributions include tart-cargo, disko, tart2ms, spotless, the version 3 hardware for the correlator, motherboard and radio-board as well as the current calibration system.

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].

There are three additional on-line meetings and discussions hosted by Andy Thornett. H-Line instruments and observation, GNU Radio, and muon instruments and observation. 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

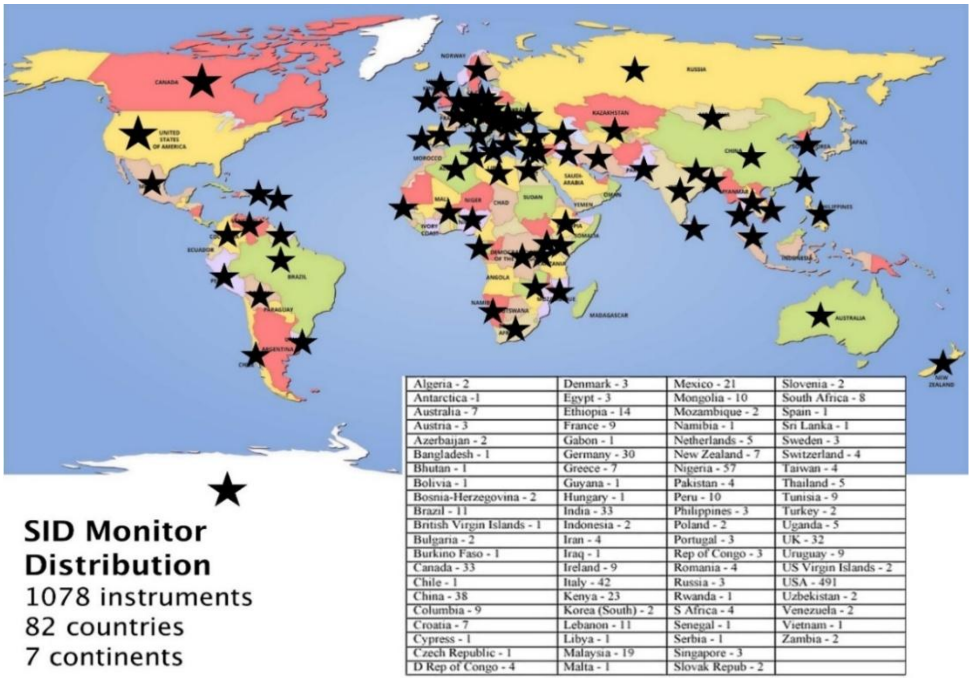
¦¦¦ British Astronomical Association ¦¦
https://britastro.org/section_front/24

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 - 57	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
Burkino 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
Cypress - 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:

What	*Cost*	*How many?*
SuperSID distribution USB Power (no options)	$48 (assembled)	
USB Sound card 96 kHz sample rate *(or provide this yourself)*	$40 *(optional)*	
Antenna wire (120 meters) *(or you can provide this yourself)*	$23 *(optional) with connectors attached and tested*	
RG 58 Coax Cable (9 meters) *(or provide this yourself)*	$14 *(optional) with connectors attached and tested*	
Shipping	US $12 Canada & Mexico $40	

	all other $60	
	TOTAL	$

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

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

or

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

For more details on the Space Weather Monitor project, see: **http://sid.stanford.edu**

To set up a SuperSID monitor you will need:

1 Access to power and an antenna location that is relatively free of electric interference (could be indoors or out)

2 A **PC**** with the following minimal specifications:

- a. A sound card that can record (sample) up to 96 kHz, or a USB port to connect such a sound card (for North and South America)
    - i. All other countries can use AC97 sound card with 48 kHz record (sample) rate. Most computers made after 1997 will have AC97.
- b. Windows 2000 or more recent operating system
- c. 1 GHz Processer with 128 mb RAM
- d. Ethernet connection & internet browser (desirable, but not required)
- e. Standard keyboard, mouse, monitor, etc.

3 An inexpensive antenna that you build yourself. You'll need about 120 meters (400 feet) of **insulated** wire. Solid wire is easier to wind than stranded. Magnet wire will work but be more fragile. You can use anything from #18 to #26 size wire. The antenna frame can be made of wood, PVC pipe, or similar materials. We'll provide instructions. You can purchase the wire from us or obtain your own.

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

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

---

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

Announcing Radio JOVE 2.1

The Radio JOVE Team

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

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

In the Beginning

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

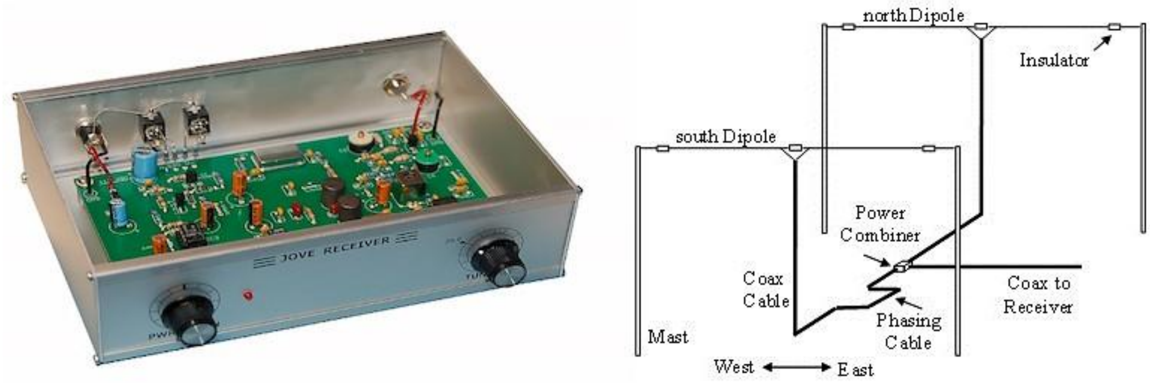
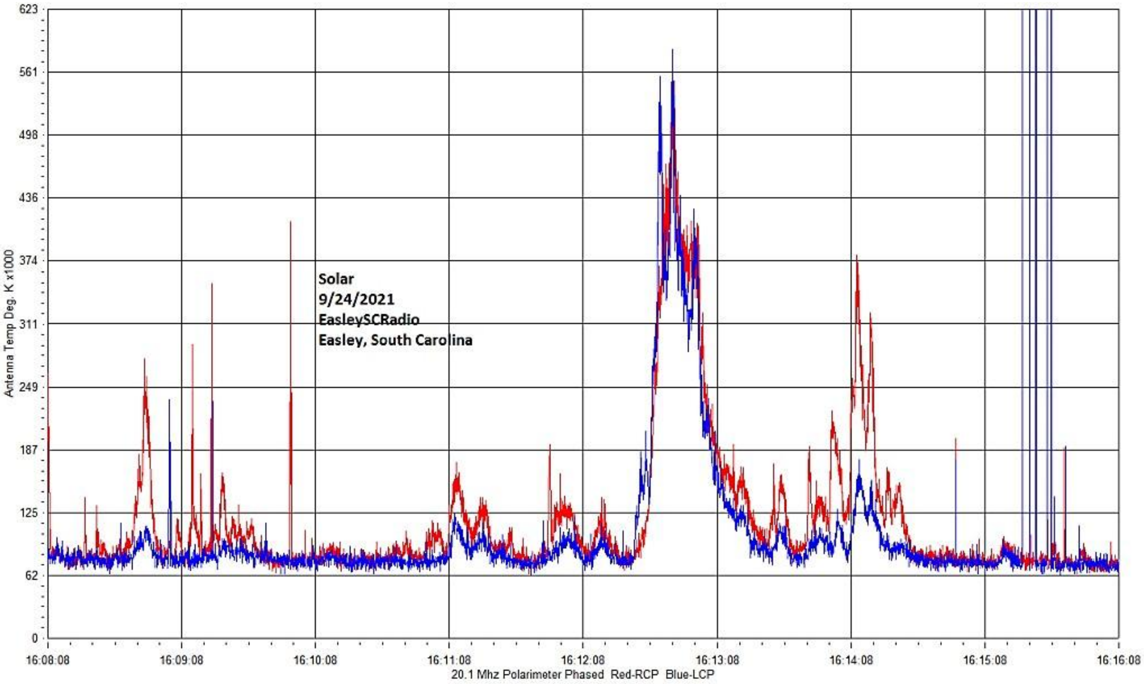


Figure 1. A Radio JOVE RJ1.1 receiver and a schematic of the dual-dipole antenna.

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



Solar
9/24/2021
EasleySCRadio
Easley, South Carolina

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 aforable. These radios can operate on a single frequency like the original JOVE receiver but can also generate spectrograms which depict radio activity as a function of both time and frequency. Such displays offer new insights into our studies of the Sun, Jupiter, the Galaxy, and both natural and artificial Earth-based radio emissions.

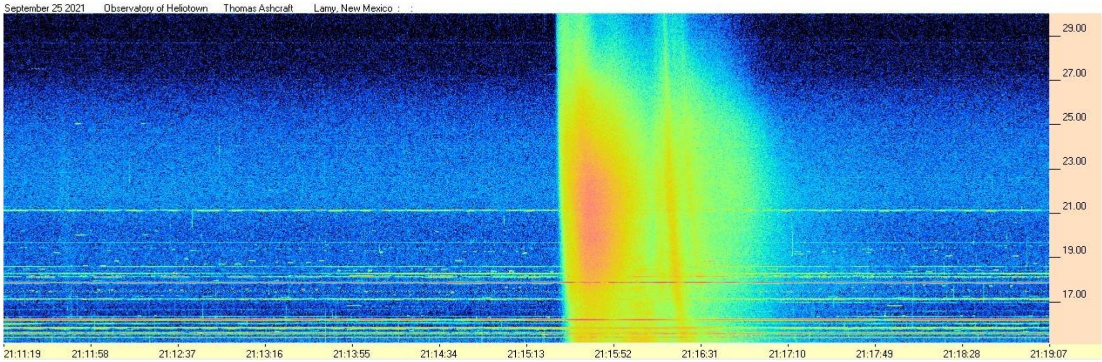


Figure 3. Radio spectrogram showing multiple solar bursts received by Tom Ashcraft in New Mexico. Horizontal scale is time and the vertical scale is frequency. Amplitude is displayed using different colors corresponding to the strength of signals.

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

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

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

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

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

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

RADIO JOVE 2.1 RADIO TELESCOPE KIT ORDER FORM

Order Online using PayPal™

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

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

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

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

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

OR

Complete this form and mail with payment

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

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

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

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

U.S.A.: $25.00
Canada: $70.00
All Other International Shipping: $110.00

Ship to: (Please print clearly)

Name: ____
Address: ____
City, State, Postal Code: ____
Province, Country: ____
Email: ____

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

Rev 10/25

UNC Greensboro Science Everywhere Open House

By Charles Osborne

April 11th 2026 I helped man exhibits at the University of North Carolina at Greensboro in support of a statewide science museum day called Science Everywhere. The topic was Space Weather and solar interactions with Earth.

I brought an Itty Bitty Telescope (IBT) to demo how the Sun produces radio noise. And using the audio vs signal strength tone from a satellite finder I was also able to show that hot buildings, people, and trees make radio noise.

In support of the topic Space Weather Rusty Moore K1FVK also had a ham radio display where students could listen to contacts with other states on HF frequencies. He even managed to catch an International Space Station pass using a handheld radio and arrow antenna for 2m/440 MHz.

Our group also had two solar telescopes for visual and Hydrogen Alpha that students and their parents could look through.


RADIO
ASTRONOMY


WINEGARD


Nursing & Instructional Building
78
UNCG Science Everywhere
Space Weather and its Effects on Radio Communications
RISE NETWORK
labcorp
NASA

Featured Articles

Artemis II Orion Portable Doppler Tracking System Overview

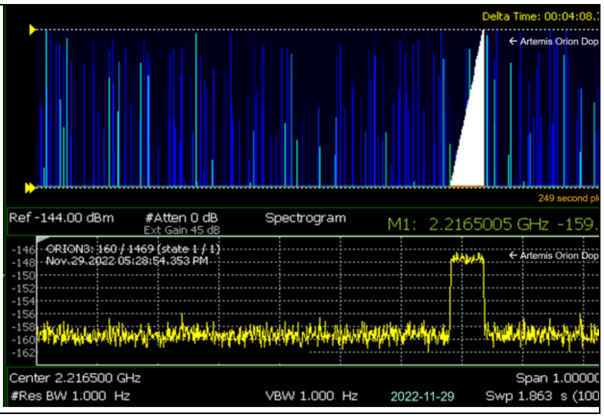
Dan Slater AG6HF 2026-06-08 - dslater@ix.netcom.com

Introduction

On 2025-08-26 NASA announced a Request for Information (RFI) [1]: "NASA Seeks Volunteers to Track Artemis II Mission". As part of this RFI, NASA wrote "For one-way Doppler measurements, Orion's transmission power specifications are anticipated to be in sync with antenna apertures having a diameter of 9-meters or more (or equivalent gain for a non-parabolic dish antenna). Smaller apertures may be suitable depending on their capabilities." Previously I had successfully used a small, sub-meter aperture Wi-Fi dish antenna to receive S-band Doppler signals from the 2022 Artemis 1 Orion spacecraft while it was in a lunar Distant Retrograde Orbit (DRO). For Artemis II Orion a similar small aperture solution was proposed and accepted by NASA [2]. In total NASA selected 34 participants ranging from the Canadian Space Agency, large Earth stations, commercial organizations, universities, amateur radio organizations and down to 4 individual participants. Many of the volunteer observer antennas were larger than the NASA recommended 9-meter aperture although others were significantly smaller. My interest was in the continuing development of a small, field portable S-band receiving system fully capable of meeting the NASA RFI requirements.

Background

The S-band receiver used in this project is part of a larger system supporting optical and radio observations of rockets, spacecraft and other aerospace phenomena. An earlier version was used during the 2022 Artemis 1 Orion lunar orbit mission. That receiving system consisted of a small, sub-meter aperture parabolic antenna on a motorized tracking mount that was coupled through a Low Noise Amplifier (LNA) to a Keysight Field Fox microwave analyzer. Also previously observed were various rocket launches and spacecraft Entry Descent and Landing (EDL) offshore operations near Southern California. There was a possibility of optical and S-band observations of the Artemis II Orion spacecraft during the Earth atmospheric reentry and offshore landing.



Delta Time: 00:04:08.

249 second pl

Ref -144.00 dBm

#Atten 0 dB

Ext Gain 45 dB

Spectrogram

M1: 2.2165005 GHz -159.

ORION3: 160 / 1469 (state 1 / 1)

Nov.29.2022 05:28:54.353 PM

Center 2.216500 GHz

#Res BW 1.000 Hz

VBW 1.000 Hz

2022-11-29

Span 1.00000

Swp 1.863 s (100

The left image shows the small fully self-contained S-band Doppler system receiving NASA Lunar Reconnaissance Orbiter (LRO) one-way Doppler signals on 2017-11-20. The small parabolic Wi-Fi antenna on a lunar tracking mount was connected through a LNA to a Keysight Field Fox microwave analyzer.

This same S-band Doppler receiving system was used in 2022 to observe the Artemis 1 Orion spacecraft while in lunar DRO. The peak amplitude spectrum waterfall display shows a solid Orion 1 spacecraft Doppler signal.

NASA Artemis II Orion S-band Doppler

The NASA SCaN RFI requirements were: 1) Consistently receive Artemis II Orion S-band one-way Doppler signals throughout the entire deep space mission. 2) Deliver the resulting Orion Doppler frequency measurements to NASA as CCSDS Tracking Data Message (TDM) files for further NASA analysis. [1,3]

Several radio science experiments unrelated to the NASA RFI were also simultaneously performed. Earth horizon occultation and Earth reentry phenomena were of interest. Additional technology development included even smaller receive antennas, Doppler extraction algorithms and Time Frequency Reference (TFR) enhancements.

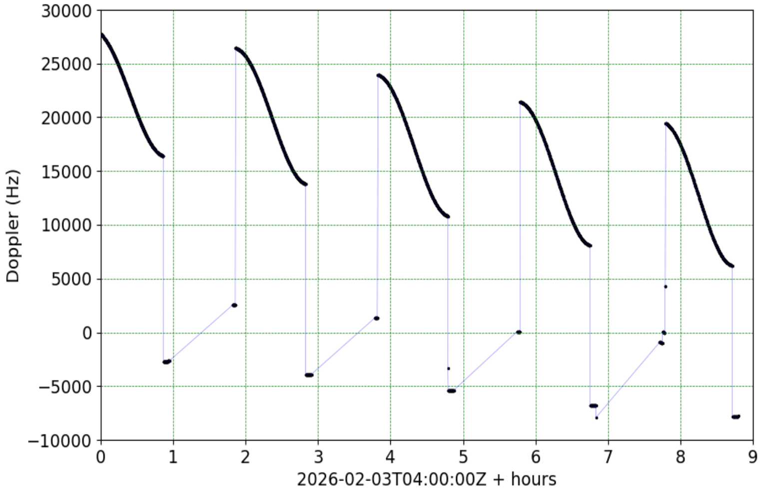
The observing site was a semi-rural hilltop location near Los Angeles. The predicted Orion spacecraft trajectory was provided by the JPL Horizons system. The Orion spacecraft would be above the local horizon roughly between midnight and 9 AM local time on most flight days so around 80 hours of long duration autonomous operation was needed.

Artemis II Orion S-band Doppler receiving system

The original S-band receiving system used during the 2022 Artemis 1 Orion flight was upgraded to fully support the NASA RFI requirements. A computer-controlled antenna positioner provided full mission cislunar spacecraft tracking. A better LNA and GNSS Time Frequency Reference (TFR) improved the Doppler signal measurement accuracy. Custom Python and C++ software was developed for test planning, test automation, Doppler signal extraction and CCSDS TDM file generation. Several radio science experiments unrelated to the NASA RFI were also supported with the addition of a switched 12 dBic RHCP helix antenna, a second microwave analyzer and an SDR. This updated system remained fully field portable and could be setup and operated by a single person.

Operations

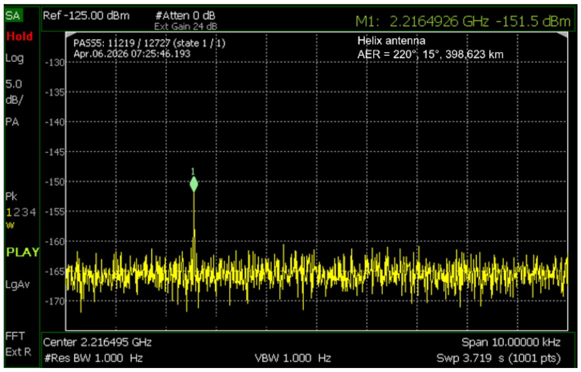
A series of system development and qualification tests were performed prior to the Artemis II Orion mission. Most important were several long duration LRO Doppler signal recordings including TDM file generation confirming the full up system operational readiness.

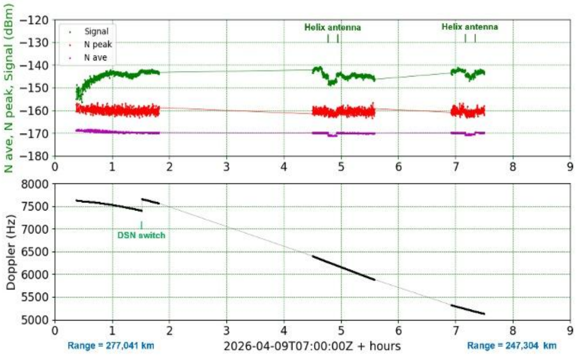


This is an example of an automated 9-hour duration S-band Doppler signal recording of the LRO spacecraft as it orbits the Moon 5 times. This confirmed proper S-band receiving system operation prior to starting the Artemis II Orion mission.

Results

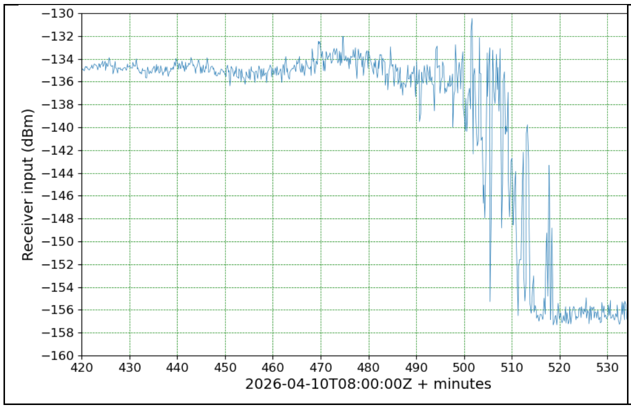
The Artemis II Orion spacecraft launched on 2026-04-01T22:35:12Z for a 9-day lunar flyby mission ending with an ocean landing near Southern California. Continuous Doppler measurements were made while the Orion spacecraft was above the local horizon. The primary focus was on NASA TDM production, but other radio science experiments were also run simultaneously. Several examples follow.

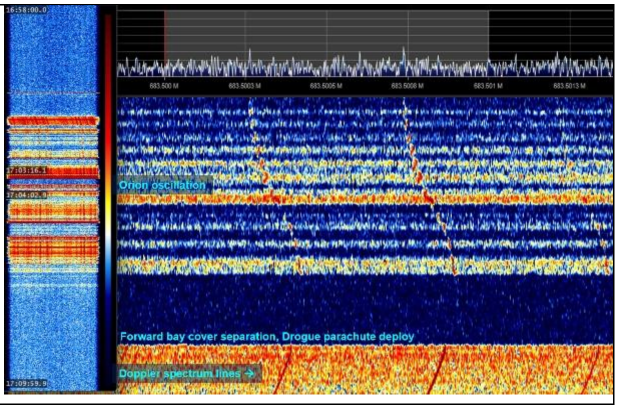




The left spectrum plot clearly shows the Orion 2 spacecraft Doppler signal while using the small helix receiving antenna. At this time, the Orion 2 spacecraft was 400,000 km from Earth, rapidly approaching the Moon.

The right figure shows a representative Orion 2 Doppler acquisition summary plot on 2026-04-09 from midnight to 9 AM local time. The upper green trace between 0:30 and 1:00 AM shows the Orion Doppler signal level increasing as Orion appears from behind a nearby eastward obstruction. At 1:30 AM the Orion spacecraft switches from Madrid to the Goldstone DSN tracking station causing a carrier frequency jump and slight power increase. At 1:50 AM the Doppler signal disappears when the Orion spacecraft downlink changes to suppress carrier modulation. The Orion Doppler signal reappears again around 4:30 AM. Most of this data was acquired using the sub-meter parabolic reflector antenna but two 10-minute segments used the smaller helix antenna. The two corresponding dips in average noise power indicate a decrease in the Orion downlink wideband noise power, demonstrating that the data modulation noise term is separately observable in a narrowband receiver.





The left plot shows the Orion 2 spacecraft S-band received power during a 2-hour duration Earth horizon occultation observation.

The right SDR image shows various EDL events including Orion 2 parachute deployments and capsule oscillations that were observable for about 6 minutes. The wider-angle helix antenna was used during initial acquisition due to trajectory uncertainty and then the parabolic antenna for increased SNR when closer to the known off shore landing location.

Conclusions

A relatively simple, accurate, field portable S-band system capable of passively receiving Artemis II Orion one-way Doppler signals and delivering NASA TDM files during all cislunar flight phases has been briefly described. Several long duration LRO spacecraft Doppler practice test observations prior to the Artemis mission provided a solid path toward successful Orion Doppler measurements starting day one. Doppler reception during all Orion flight phases using both the larger parabolic and smaller helix antennas was successfully demonstrated. Additional radio science objectives including Earth horizon occultation observations, S-band EDL observations and SDR data collection were also met although much of this data is still awaiting further analysis.

Generally, the system worked well providing a nearly full mission NASA TDM data set. A program crash caused about an hour of Doppler data loss and a local RF obstruction toward the East delayed initial Doppler signal acquisition. The most significant problem was a communications issue between the Field Fox microwave analyzer and the Doppler extractor causing a Doppler timing uncertainty sometimes exceeding 10 seconds. Occasional restarts reduced this timing error. A code error in the Doppler extractor limited the frequency accuracy to around 1 Hz (2 Hz during early mission). In spite of these issues, a review of the measured Orion Doppler data along with the prior TFR and full system qualification tests, suggests that the absolute Doppler frequency measurement accuracy was likely within a few Hz and with a 10 second UTC time uncertainty. All of these issues will be resolved and combined with other lessons learned for more capable and accurate future systems.

Large ground station antennas such as DSN are essential for wide band telecommunications between the Orion spacecraft and Earth and for OQPSK or similar suppressed carrier Doppler measurements [4]. The Orion spacecraft dynamically switches between several different downlink data modulation schemes, with some including a carrier signal. The Orion carrier signal, when present, works well with small antenna narrowband receiving systems such as the system described here. Thermal, excess system and mission specific data modulation noise terms limit Doppler sensitivity defined in terms of the Carrier to Noise Ratio (CNR). Larger antennas increase the CNR by reducing the thermal and system noise term contributions but do not reduce the downlink data modulation noise component. For narrowband Doppler systems, increasing the antenna aperture above a certain point does not increase the Doppler CNR. The small parabolic Wi-Fi antenna used during Orion Doppler measurements provided a 25 dB peak CNR near Earth, and around 15 dB peak CNR near the Moon. A 4 to 6 dB reduction in 1-way Doppler CNR was typically observed when switching to the smaller helix antenna.

The Artemis Orion S-band Doppler receiving system can be smaller and simpler than commonly assumed. The S-band Doppler receiving system successfully used during the 2022 Artemis 1 Orion mission consisted of only a small parabolic Wi-Fi antenna, an LNA, a lunar rate tracking mount and a microwave analyzer. The upgraded Artemis II Orion S-band Doppler receiving system demonstrated that both a smaller helix and the original Wi-Fi parabolic reflector antenna coupled through a high quality LNA to a GNSS frequency referenced receiver could provide long duration full mission Doppler recording including CCSDS TDM file generation. Antenna pointing was automated using JPL Horizons trajectory information although a NASA or similar VR app could provide a simpler short duration antenna pointing solution. The current receiving system uses an expensive Keysight Field Fox microwave analyzer with top notch RF performance. Other lower cost spectrum analyzers and Software Defined Radios (SDR) are viable alternatives.

References

[1] NASA Seeks Volunteers to Track Artemis II Mission (link)
[2] NASA Selects Participants to Track Artemis II Mission (link)
[3] CCSDS Tracking Data Message (TDM) standard (link)

[4] SDR IQ to NASA CCSDS TDM v2.0 Converter (link)

Building the LRO-H4 "SETI League Horn of Plenty" Hydrogen-Line Antenna, and further work on the LRO-H2 Solar Cooker Radio Telescope.

A Modern Recreation of the SETI League Classic.

Andrew Thornett

andrew@thornett.net

www.astronomy.me.uk

Introduction

In May 2026, the Lichfield Radio Observatory (LRO) completed construction of a modern version of the famous "Horn of Plenty" hydrogen-line antenna. Based on a design popularised by the SETI League and ultimately derived from the pioneering work of Harold I. "Doc" Ewen, the project aimed to evaluate whether a simple horn antenna could provide an effective and affordable alternative to parabolic dish systems for observations of neutral hydrogen at 1420 MHz.

The project provided an opportunity not only to revisit an important chapter in radio astronomy history, but also to investigate the practical advantages and challenges of horn antennas for amateur hydrogen-line work, and to compare these with the other existing antennas on site – LRO-H1, 86cm x 86cm 4x4 ex-military dipole array, LRO-H2, 150cm Solar Cooker Satellite Dish originally sold as a solar cooker, and LRO-H3, a hydrogen-line radio telescope based on a Yagi antenna designed by Dr Alex Pettit from SARA.

Historical Background & Design of the SETI League Horn of Plenty:

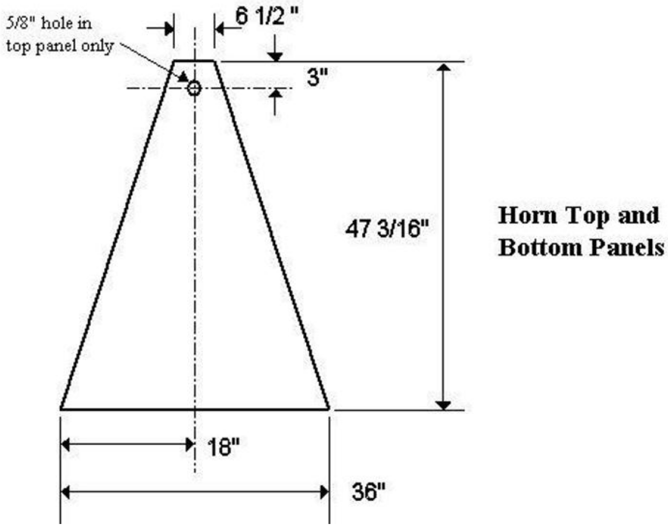
The origin of the hydrogen horn design can be traced to 1951 when Harvard graduate student Harold I. Ewen and Professor Edward Purcell made the first successful detection of the 21-centimetre hyperfine transition line of neutral hydrogen. Their horn antenna, approximately 10 feet long, achieved a gain of just under 24 dBi and produced a nearly symmetrical radiation pattern with beamwidths of around 10 degrees in both principal planes.

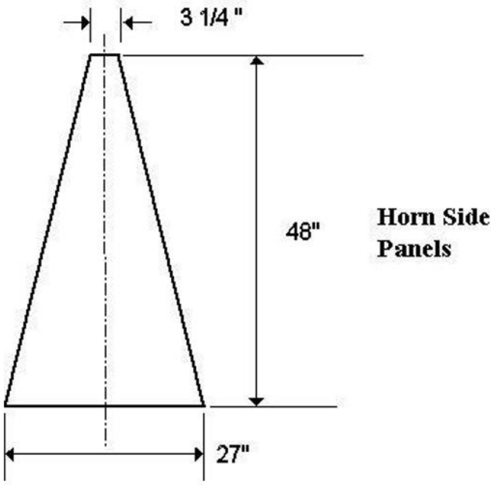
Ewen and Purcell Hydrogen Horn (below):

While highly effective, Ewen's original horn is simply too large for most amateur applications. As a result, several decades later, the SETI League developed a scaled-down version known as the "Horn of Plenty." The design was intended to be inexpensive, easy to construct, and capable of being built from readily available materials. The horn dimensions were reduced to approximately four feet in length and three feet in width, allowing construction from standard 3 ft × 4 ft sheets of galvanised steel, available at the time for around $10 per sheet.

To maintain performance, the designers retained the original L-band waveguide dimensions while scaling the remaining geometry. The result was a horn antenna with approximately 3–4 dB less gain than Ewen's original instrument but with a still respectable performance level and symmetrical beamwidths of approximately 16 degrees.

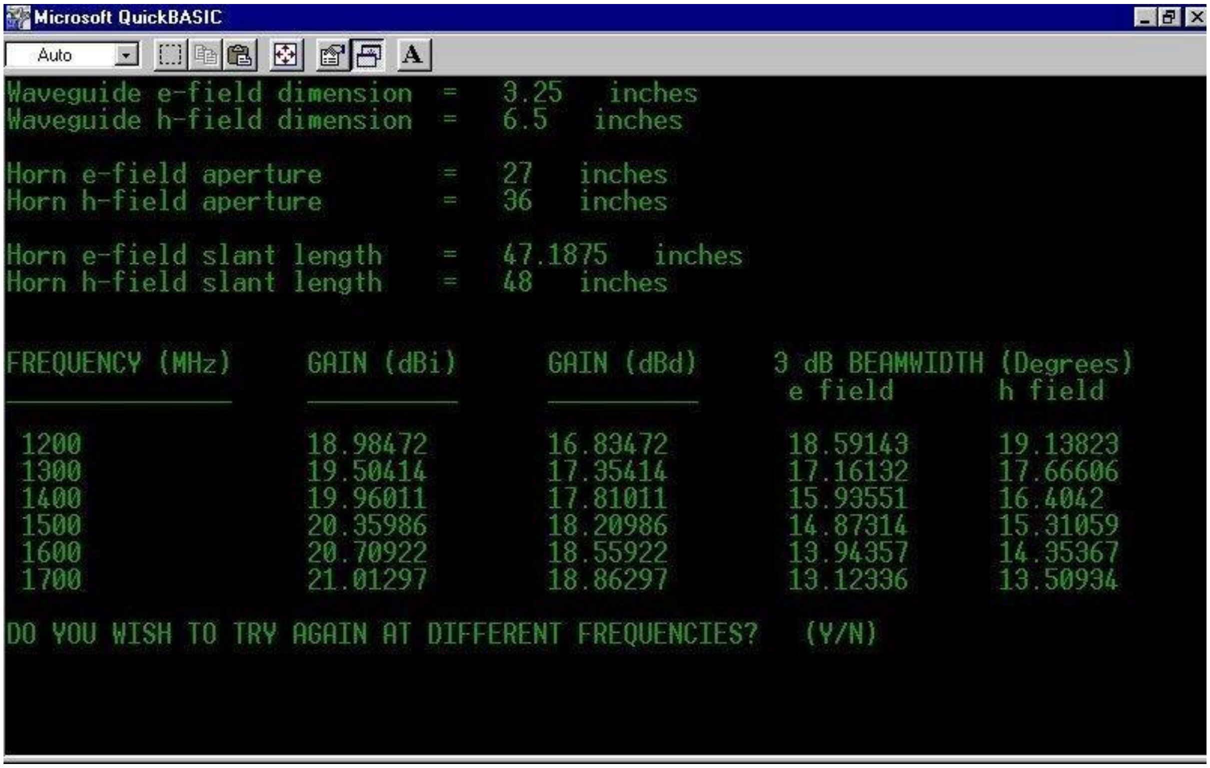
SETI League Horn of Plenty Dimensions:





Prior to construction, the SETI League team used software modelling to analyse expected performance and verify the design dimensions. The simulations confirmed that the scaled horn should retain the desirable radiation characteristics later reported by the SETI League.

SETI League software modelling results:



```
Waveguide e-field dimension  =   3.25   inches
Waveguide h-field dimension  =   6.5   inches

Horn e-field aperture        =   27   inches
Horn h-field aperture        =   36   inches

Horn e-field slant length    =   47.1875   inches
Horn h-field slant length    =   48   inches


FREQUENCY (MHz)     GAIN (dBi)      GAIN (dBd)     3 dB BEAMWIDTH (Degrees)
                                                    e field       h field
_______________     __________      __________

 1200               18.98472        16.83472        18.59143      19.13823
 1300               19.50414        17.35414        17.16132      17.66606
 1400               19.96011        17.81011        15.93551      16.4042
 1500               20.35986        18.20986        14.87314      15.31059
 1600               20.70922        18.55922        13.94357      14.35367
 1700               21.01297        18.86297        13.12336      13.50934

DO YOU WISH TO TRY AGAIN AT DIFFERENT FREQUENCIES?   (Y/N)
```

They then constructed a working prototype which confirmed that the design worked, and since then many observers have made horns aplenty – using a range of materials including insulating boards, cardboard, and wood. Although galvanised steel sheets, as originally used, have gone up in cost, the use of that material in the design still provides a cost-effective method of making an effective and very robust radio telescope in the 1m class, that can safely be left outside 24/7 in order to obtain detailed maps of Milky Way arms, weigh the Milky Way, and detect the smoking gun findings of dark matter.

The SETI League's own prototype of its Horn of Plenty:

Why Consider a Horn Antenna?

At first glance, sacrificing several decibels of gain may appear undesirable. However, the Horn of Plenty offers several advantages that are particularly attractive for radio astronomy.

According to SETI League studies, the gain is roughly equivalent to that of a one-metre dish. More importantly, the horn exhibits:

- Excellent broadband impedance matching.
- Very low sidelobe levels.
- Minimal overspill.
- Reduced pickup of ground noise.

These characteristics can significantly improve signal-to-noise performance compared with some dish systems, where spillover and sidelobes often contribute substantial unwanted noise.

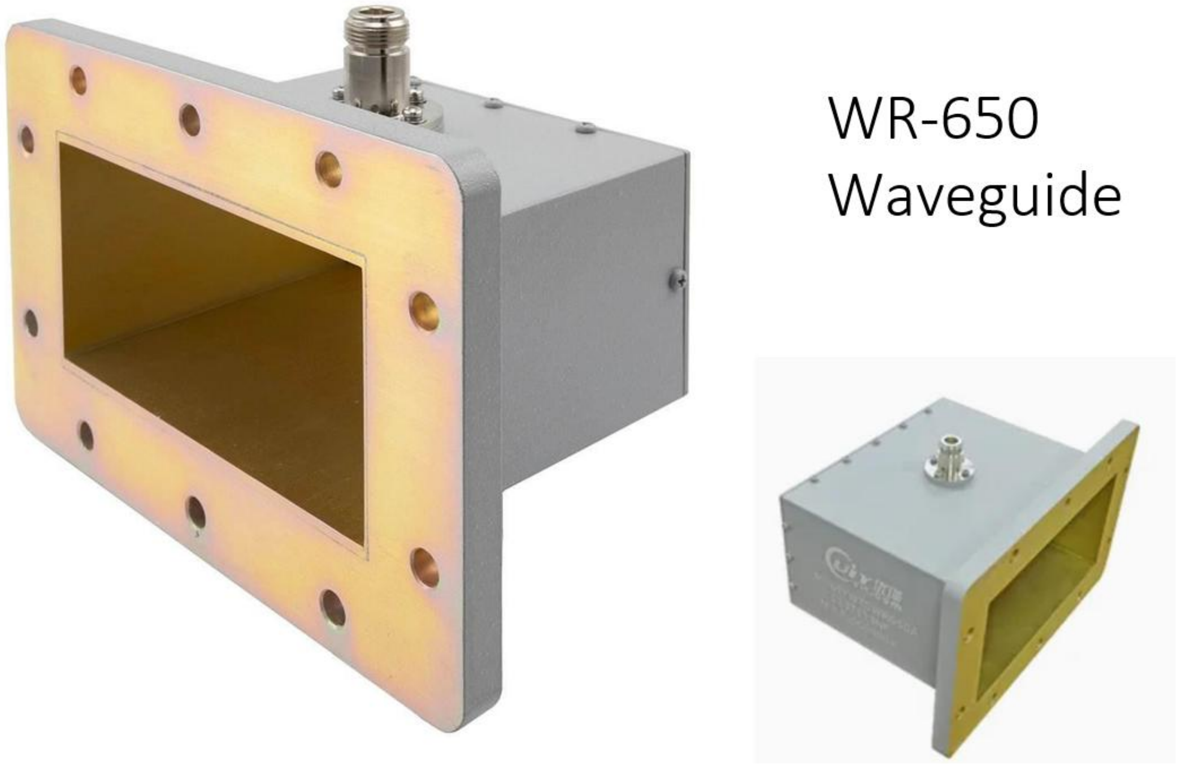
Modern low-noise amplifiers and software-defined radio receivers also compensate for much of the gain deficit compared with historical equipment. Improvements in receiver noise figures exceeding 10 dB mean that today's amateur systems can outperform professional installations from the early days of radio astronomy.

Design and Construction of the LRO Horn of Plenty.

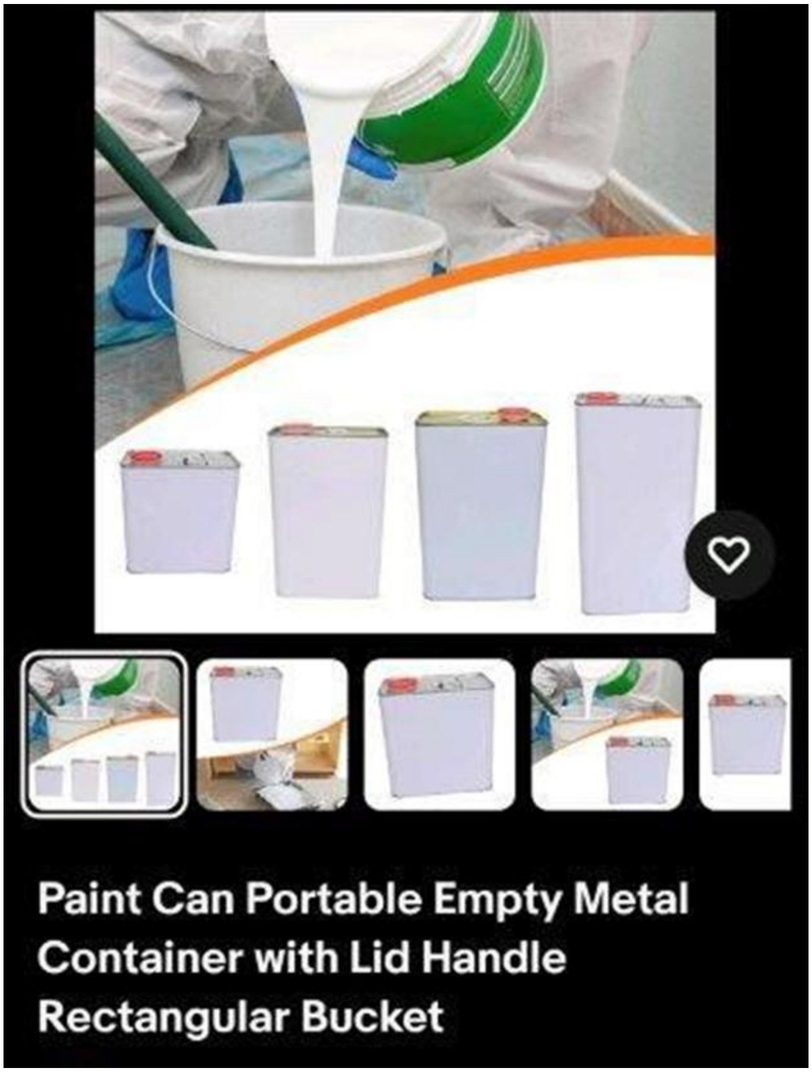
The LRO version closely followed the SETI League dimensions.

A standard WR-650 waveguide was employed as the feed structure. In addition, experiments were undertaken using a rectangular paint tin purchased online as a potential low-cost alternative waveguide structure. Such approaches are particularly attractive to amateur constructors seeking economical solutions for hydrogen-line observing.

WR-650 Waveguide purchased commercially to use on the LRO Horn of Plenty:



A rectangular paint/oil tin, which has very similar dimensions to the WR-650 and provides much cheaper solution for amateur builders:



Paint Can Portable Empty Metal Container with Lid Handle Rectangular Bucket

Assembly was straightforward, requiring basic metalworking techniques and readily available materials.

Construction of the LRO Hydrogen Horn:

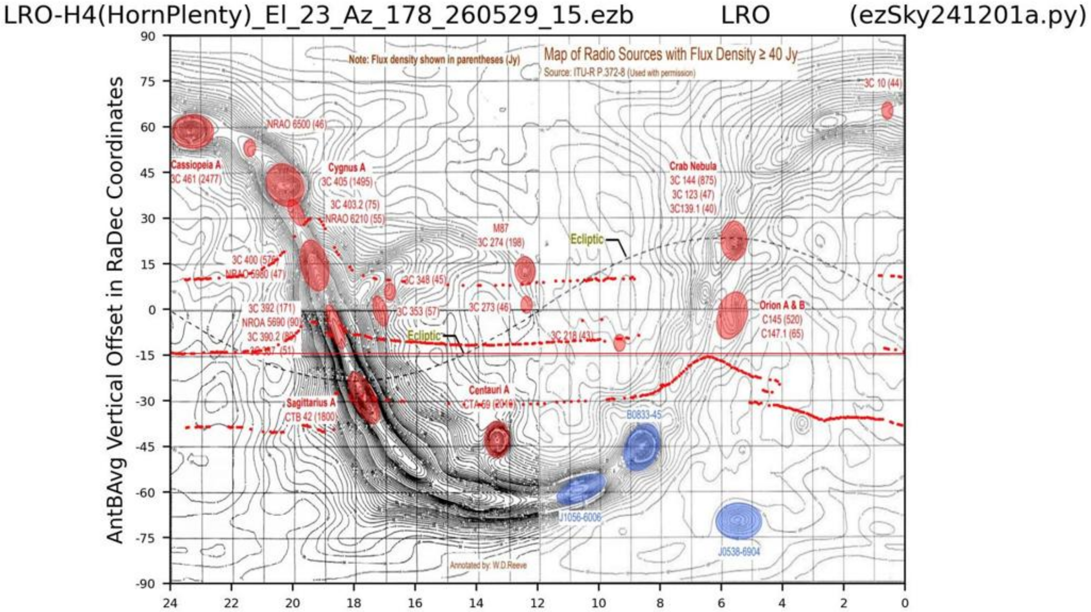
The completed LRO Horn of Plenty in place for observing tests:

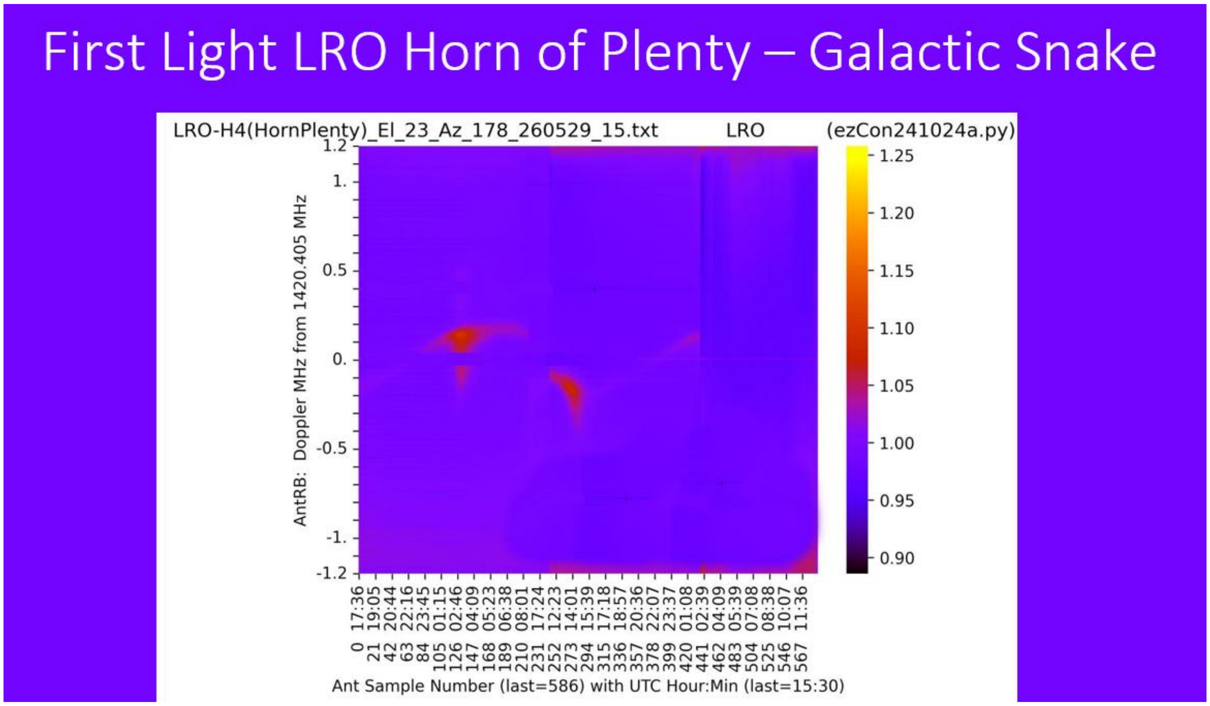
First Light Observations

Following completion, the antenna was connected to a hydrogen-line receiving system and put into operation. The receiving system consisted of a Nooelec SAWBird H1 low noise amplifier and filter placed immediately behind the WR-650 waveguide as close to the waveguide's N-type coaxial connection as possible, 5m of LMR 240 coaxial cable, a Nooelec NESDR SMArTee software-defined radio, and an Intel i5 MiniPC running Easy Radio Astronomy (ezRA, Ted Cline, GitHub).

Initial observations successfully detected variations in galactic hydrogen emission, including observations of features associated with the Milky Way's large-scale hydrogen structure, sometimes referred to as the "Galactic Snake."

First Light LRO Horn of Plenty – Data Collected





First Light LRO Horn of Plenty – Galactic Snake

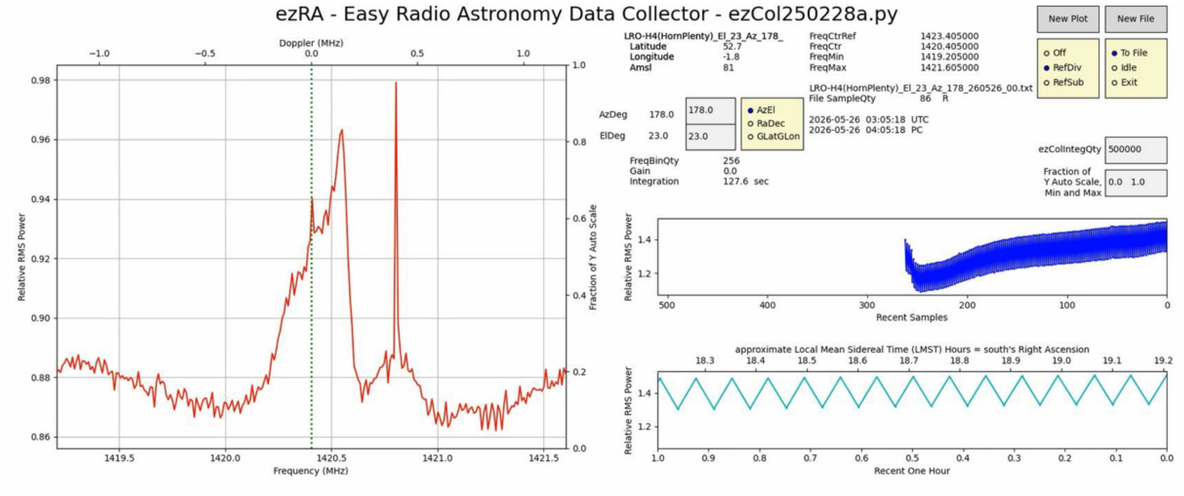
Analysis by Jason Burnfield of data collected using the Nooelec NESDR SmarTee software-defined receiver, indicated a peak hydrogen signal approximately 0.855 dB above the local background level.

Although seemingly small, such signal levels are entirely consistent with amateur hydrogen-line observations and demonstrate successful operation of the antenna.

The results confirmed that the Horn of Plenty is capable of detecting Galactic neutral hydrogen using relatively modest equipment.

Gain calculations of the LRO Horn of Plenty from first light data:

Jason calculated max. gain with LRO SETI Horn of Plenty using Nooelec SmarTee XTR SDR = 0.855 dB above background.



ezRA - Easy Radio Astronomy Data Collector - ezCol250228a.py

LRO-H4(HornPlenty)_El_23_Az_178_
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Longitude -1.8
Amsl 81

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FreqCtr 1420.405000
FreqMin 1419.205000
FreqMax 1421.605000

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File SampleQty 86 R

AzDeg 178.0 178.0
ElDeg 23.0 23.0
● AzEl
○ RaDec
○ GLatGLon

2026-05-26 03:05:18 UTC
2026-05-26 04:05:18 PC

FreqBinQty 256
Gain 0.0
Integration 127.6 sec

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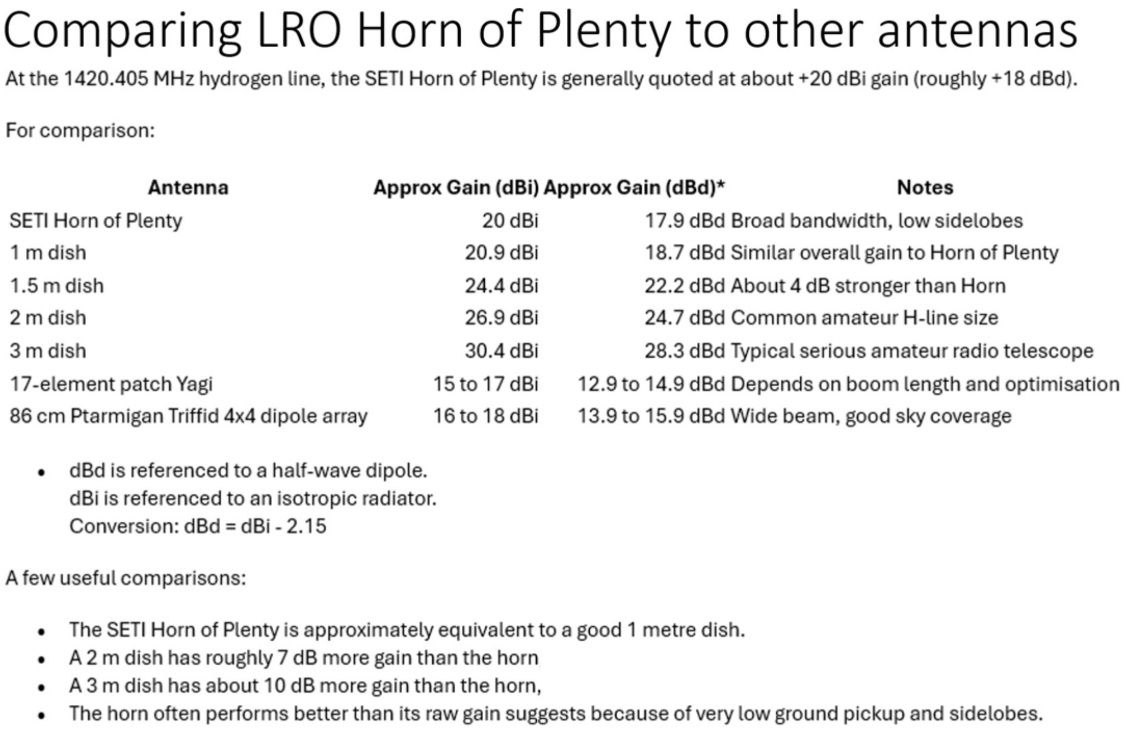
● RefDiv
○ RefSub

● To File
○ Idle
○ Exit

ezColIntegQty 500000

Fraction of Y Auto Scale, Min and Max 0.0 1.0

Theoretical comparisons of the performance of this telescope compared to other options:



Comparing LRO Horn of Plenty to other antennas

At the 1420.405 MHz hydrogen line, the SETI Horn of Plenty is generally quoted at about +20 dBi gain (roughly +18 dBd).

For comparison:

Antenna	Approx Gain (dBi)	Approx Gain (dBd)*	Notes
SETI Horn of Plenty	20 dBi	17.9 dBd	Broad bandwidth, low sidelobes
1 m dish	20.9 dBi	18.7 dBd	Similar overall gain to Horn of Plenty
1.5 m dish	24.4 dBi	22.2 dBd	About 4 dB stronger than Horn
2 m dish	26.9 dBi	24.7 dBd	Common amateur H-line size
3 m dish	30.4 dBi	28.3 dBd	Typical serious amateur radio telescope
17-element patch Yagi	15 to 17 dBi	12.9 to 14.9 dBd	Depends on boom length and optimisation
86 cm Ptarmigan Triffid 4x4 dipole array	16 to 18 dBi	13.9 to 15.9 dBd	Wide beam, good sky coverage

- dBd is referenced to a half-wave dipole.
  dBi is referenced to an isotropic radiator.
  Conversion: dBd = dBi - 2.15

A few useful comparisons:

- The SETI Horn of Plenty is approximately equivalent to a good 1 metre dish.
- A 2 m dish has roughly 7 dB more gain than the horn
- A 3 m dish has about 10 dB more gain than the horn,
- The horn often performs better than its raw gain suggests because of very low ground pickup and sidelobes.

An Unexpected Problem

On 31 May 2026 an operational issue was discovered.

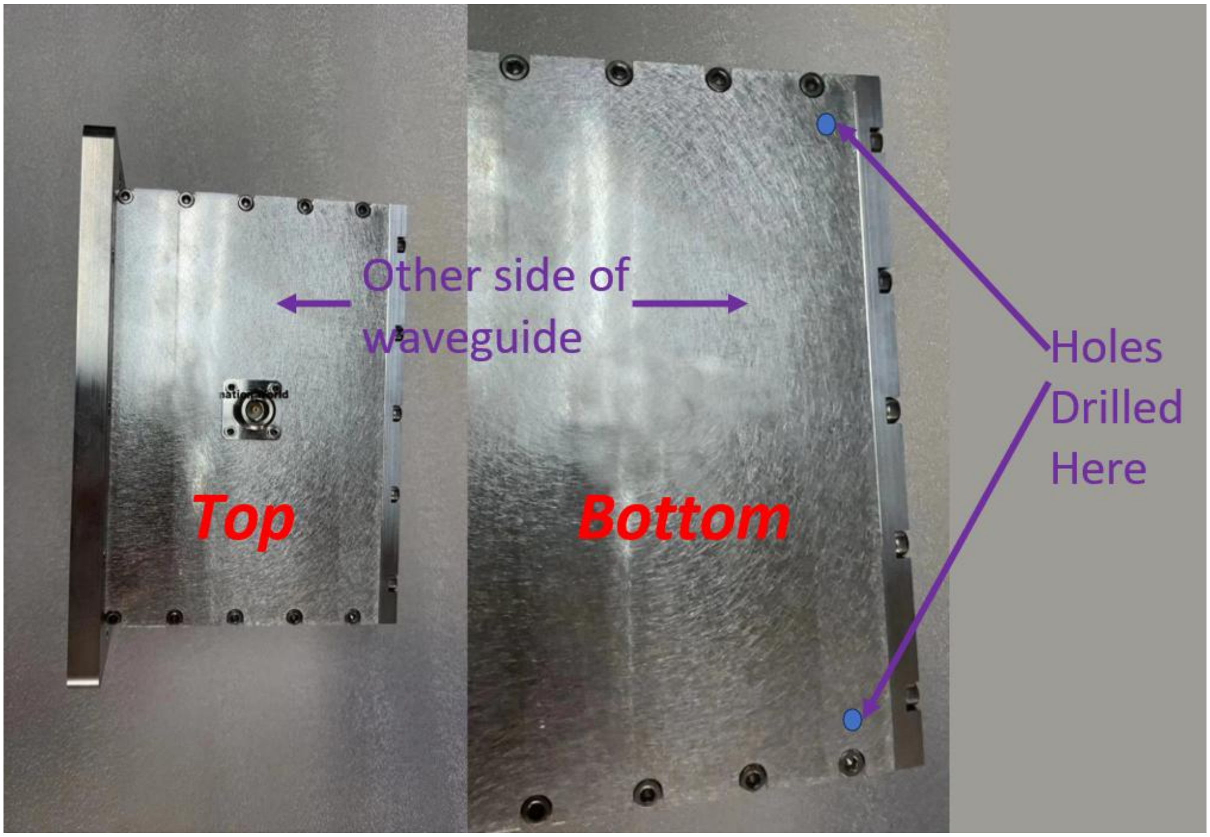
Inspection revealed that rainwater had accumulated inside the waveguide and completely covered the monopole probe mounted at its base. Unsurprisingly, antenna performance deteriorated significantly, so that no hydrogen line signal was visible.

Collection of rainwater inside the back of the WR-650 waveguide:

The immediate question was whether drainage holes could be drilled into the waveguide without compromising its electrical performance.

After consideration, two small drainage holes were drilled near the rear lower section of the waveguide, on the opposite side from the probe, away from the critical probe region and areas of strongest RF current.

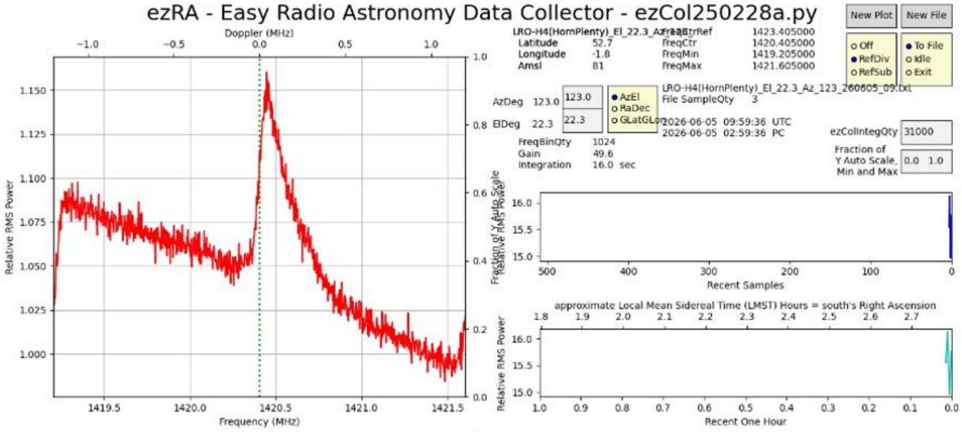
Drilling two small holes in the waveguide:



The modification proved successful. Water was able to drain freely and subsequent testing showed no measurable degradation in performance. The antenna quickly returned to service and hydrogen observations resumed. This time the antenna was rotated so that the probe entered the waveguide from the top surface, in order that any water collection would not cover the probe before it had a chance to fully drain.

Plot showing successfully collection of hydrogen line data in ezCol (ezRA) following drilling two holes in the waveguide. This plot also shows a benefit from increasing the number of FFT bins from 256 to 1024 on the quality of the signal:

Back in action after drilling 2 small holes at back of waveguide – 10 bits (1024 FFT bins)


ezRA - Easy Radio Astronomy Data Collector - ezCol250228a.py

LRO-H4(HornPlenty)_El_22.3_Az_123
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Longitude -1.8
Amsl 81
FreqCtrRef 1423.405000
FreqCtr 1420.405000
FreqMin 1419.205000
FreqMax 1421.605000
AzDeg 123.0 [123.0]
ElDeg 22.3 [22.3]
FreqBinQty 1024
Gain 49.6
Integration 16.0 sec
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2026-06-05 02:59:36 PC
ezColIntegQty 31000
Fraction of Y Auto Scale, Min and Max 0.0 1.0

This experience highlights an often-overlooked aspect of outdoor radio astronomy installations: environmental protection can be just as important as RF design.

Receiver Improvements

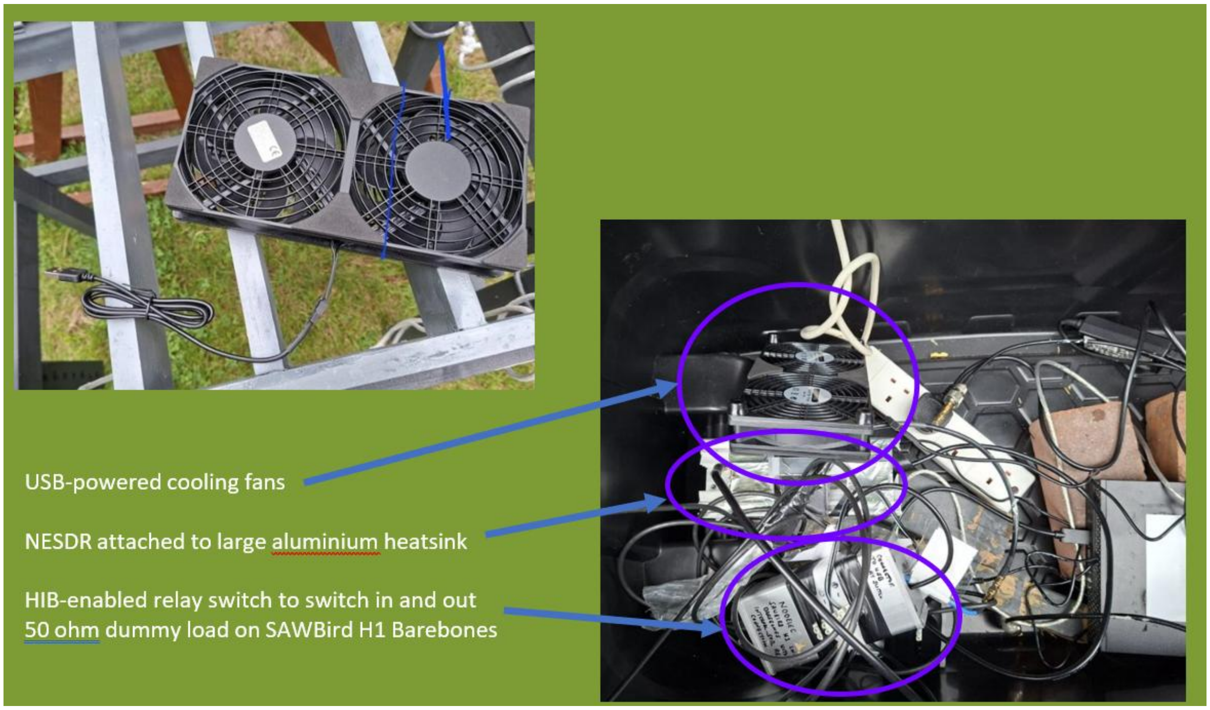
Several additional improvements were implemented to optimise system performance.

A hydrogen-line signal generator was used for testing and calibration purposes. This was based on a small patch antenna tuned to 1420 MHz made by Bob Stricklin of SARA, a variable attenuator, and a Nano VNA, set to CW mode, and tuned to 1.42 GHz.

Attention was also given to receiver thermal management, as the system crashed several times during a particularly hot couple of weeks (high for the UK at around 30 C in direct sunlight near the telescope, unusual for Lichfield). We instituted temperature control methods including mounting the SDR receiver on a large aluminium heatsink and adding active cooling using a pair of USB-powered fans. Maintaining stable receiver temperature helps minimise gain drift and improves long-duration observing consistency, as well as preventing extreme events such as the computer crashes observed.

The system additionally incorporated a relay arrangement enabling optional automatic switching of a 50-ohm reference load connected to a SAWBird H1 Barebones low-noise amplifier. This arrangement provides a convenient means of performing calibration measurements. It is an alternative to using offset frequencies (typically 1423 MHz where hydrogen is not seen), or part of the spectrum outside of the area occupied by the hydrogen peak.

Thermal management of the SDR:



USB-powered cooling fans

NESDR attached to large aluminium heatsink

HIB-enabled relay switch to switch in and out 50 ohm dummy load on SAWBird H1 Barebones

Lessons from the 150cm Solar Cooker Dish (LRO-H2):

During the same period, work continued on LRO-H2, the observatory's larger hydrogen-line dish system, known informally as the "Solar Cooker."

The intention was to add a wooden framework supporting aluminium mesh extensions around the dish perimeter to reduce ground-noise pickup, and the work to add the framework was completed 7 June 2026.

Addition of wooden framework to extend the perimeter of LRO-H2 (at this stage aluminium netting has not been added):

However, an unexpected effect became apparent. As the wooden framework was attached, visible flexure of the dish structure was observed when changing elevation angle. The dish is constructed from six light-weight rolled steel petals, each one held to its neighbour with only 4 bolts and nuts. This finding raises concerns that deformation of the reflector surface might be degrading performance at 1420 MHz.

Until then, underperformance of LRO-H2 below that expected from a dish of its size had largely been attributed to excess ground noise. The newly observed mechanical distortion suggested another possible explanation, and further testing will now be conducted to explore this possibility.

Expert Advice on Dish Performance

Helpful guidance was subsequently received from BAA amateur radio astronomer Brian Coleman.

Brian noted that dish antennas generally become most effective when their usable diameter exceeds approximately ten wavelengths. At 1420 MHz, this corresponds to a diameter of just over two metres.

He also emphasised the importance of matching feed design to dish geometry. The dual-mode feed currently used at LRO was designed for dishes with an F/D ratio of approximately 0.43. For dishes with shorter focal lengths, alternative feed designs such as scalar feeds may provide superior illumination.

Brian further highlighted several important considerations:

- Feed blockage reduces effective aperture.
- Support structures can introduce scattering.
- Under-illumination can be beneficial because it reduces spillover noise.
- System temperature (Tsys) is often more important than raw gain.

Using a dual-mode feed on his own 3.7 m dish together with a low-noise amplifier having a noise figure of approximately 0.26 dB, Brian reported achieving a system temperature below 50 K.

His comments served as a valuable reminder that radio astronomy performance depends on the optimisation of the entire receiving system rather than antenna gain alone.

Conclusions

The LRO Horn of Plenty project demonstrates that a simple horn antenna remains a highly practical tool for amateur hydrogen-line radio astronomy. Despite offering less gain than large dish systems, the horn provides several compensating advantages, including low sidelobes, reduced ground-noise pickup and straightforward construction. Modern SDR receivers and low-noise amplifiers further enhance its usefulness.

The successful detection of Galactic hydrogen during first-light observations confirms that the design remains as relevant today as when the SETI League first introduced it.

For amateurs interested in entering hydrogen-line radio astronomy without the complexity of large reflector systems, the Horn of Plenty continues to offer an attractive and historically significant solution, and is quite capable of collecting data to demonstrate all the major findings usually associated with 1m class drift-scanning hydrogen line radio telescopes.

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

by Dimitry Fedorov UA3AVR

This report presents results of historical and recent observations of the star IRAS 17004-4119 in OH molecular lines 1612, 1665, 1667 MHz. This is an oxygen-rich OH/IR star in the AGB phase [1], with a progenitor mass of >4 $M_\odot$ [2]. Observations were made with the 20-meter Green Bank telescope [3]. The 1665 and 1667 MHz lines are often referred as "main" lines, as they were considered common for the OH emission – particularly in star-forming regions; the 1612 MHz line is called "satellite". In the specific case of evolved stars, the situation is reversed: the 1612 MHz line dominates; however, in some such stars, other lines can be also observed with lower intensities. Maser amplification in the 1612 MHz line is common for oxygen-rich OH/IR stars and makes this line remarkably strong; as expected, 1612 MHz masers of OH/IR star are strongly saturated [2]. Emission in "main" 1665/1667 MHz lines is usually weaker, but sometimes also observed with the maser amplification.

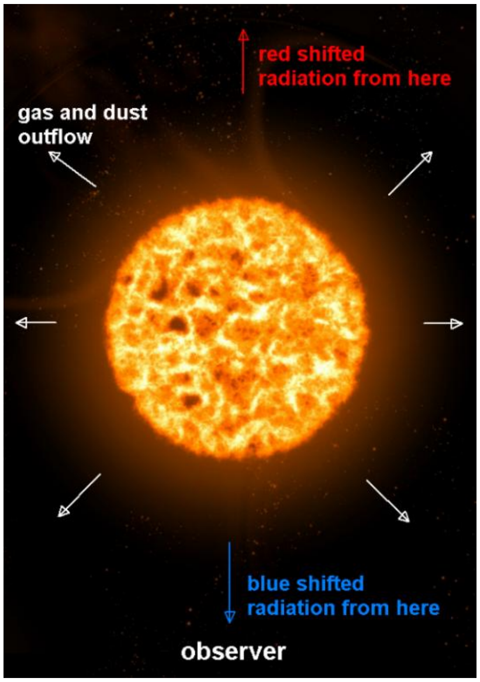

Figure 1. OH radiating CSE layers in front of the evolved star and behind it (not to scale).

Evolved stars lose their mass shedding gas and dust; this process is characterized by the mass-loss rate $\dot{M}>10^{-5}$ $M_\odot$/year; these gas and dust form the circumstellar envelope (CSE). OH molecular clouds are usually concentrated in outer layers of the circumstellar envelope, at distances >10 stellar radii R_* [4,5]. OH molecules are pumped usually by the infrared (IR) radiation from the hot dust, which concentrates close to the star in inner CSE layers, mainly in transitions 34.6 and 53.3 μm [6] with subsequent cascading downward. The collisional processes, which favor the 1665/1667 MHz inversion in star forming regions, play a minor role in OH/IR stars [7], but much depends on specific mass-loss rate $\dot{M}$ and how high the local gas density, where the OH clouds are concentrated.

The emission line at 1612 MHz from OH/IR stars is typically characterized by a distinctive double-peaked spectral profile [8-10]. Two peaks appear because of the radiation comes from different parts of the pumped molecular clouds: in front of the star and behind it, see Figure 1. The radiating cloud behind the star moves from the observer leading to a red shift of the spectral line due to the

Doppler effect; the radiating cloud in front of the star moves toward the observer making a blue shift of the line. The "main" 1665/1667 MHz lines may also exhibit a double-peaked profile, where the peak velocities coinciding with the velocities observed in the spectrum at 1612 MHz. This means that the corresponding line is excited at the same locations as the 1612 MHz line, and the gas density there is sufficient for collisional processes. Other instances of the appearance of "main" lines can be associated with excitations close to the star, where the gas density is higher, but OH molesules still concentrate there [5]. The density **ρ** of the CSE decreases with distance **r** from the star approximately as $\boldsymbol{\rho} \sim 1/\mathbf{r}^2$.

The variability period of such stars is in the range from hundreds to thousands of days. There are monitoring programs for the variability of OH/IR stars in the 1612 MHz line; see, for example, the program at Nançay [8]. Variations in the 1612 MHz emission are associated with variations in the dust temperature and, therefore, in the infrared pumping of OH clouds. These periodic variations find remarkable application in determining the sizes of CSEs and the distances to optically obscured stars using the phase-lag method [11]. Nevertheless, the variability of the "main" 1665/1667 MHz lines is also a subject of interest, as it reflects the efficiency of collisional processes $\mathbf{C}_{\mathbf{col}}$, which depend on the gas density in the outer CSE layers containing the emitting OH clouds, $\mathbf{C}_{\mathbf{col}} \sim \boldsymbol{\rho}$.

The star IRAS 17004-4119 represents one of the most interesting objects for observations of variability in the "main" lines at 1665/1667 MHz [5]; its observational history (1990) and recent results (2025 and 2026) are presented here.

Instrumentation

Figure 2. Green Bank 20 m telescope.

Recent observations were made using 20 m Green Bank single dish telescope under Skynet Network control [3], see photo on Figure 2. The telescope is located in the radio quiet zone.

The beamwidth for OH frequencies is about 0.63°. Parameters of the telescope and observations are collected in Table 1. The Minimal Detectable Peak Flux density was calculated by the Radiometer Equation adapted for spectral lines [12,13]

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

where **K** ≈ 3 – the peak factor of the background noise, $\mathbf{\Delta t}$ – the integration (source tracking) time, RBW – the Resolution Bandwidth of the receiver. If the maser line reaches $\mathbf{F_{peak}}$ from Eq. (1), its level would be about the background noise peaks. Averaging the data of two polarizations reduces $\mathbf{F_{peak}}$ by correcting factor $1/\sqrt{2}$.

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

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

** System temperatures for both polarizations were determined using the calibration procedure described in [14].*

Historical and recent spectra

Historical spectra of 1990s [2] are shown on Figure 3. Double-peaked profiles are observed in 1612 MHz line, as well as in 1667 MHz line. It should be noted that the velocities of the peaks at 1667 MHz coincide with the velocities of the peaks at 1612 MHz. As expected, the line at 1667 MHz is weaker than the line at 1612 MHz. The 1665 MHz line was not detected then. Anomalous behavior of the 1667 MHz spectrum between peaks was also noted [2].

Observations in October 2025 with the 20-meter Green Bank Telescope yield only the 1612 MHz spectrum [15]; the 1667 MHz and 1665 MHz lines were not detected at all.

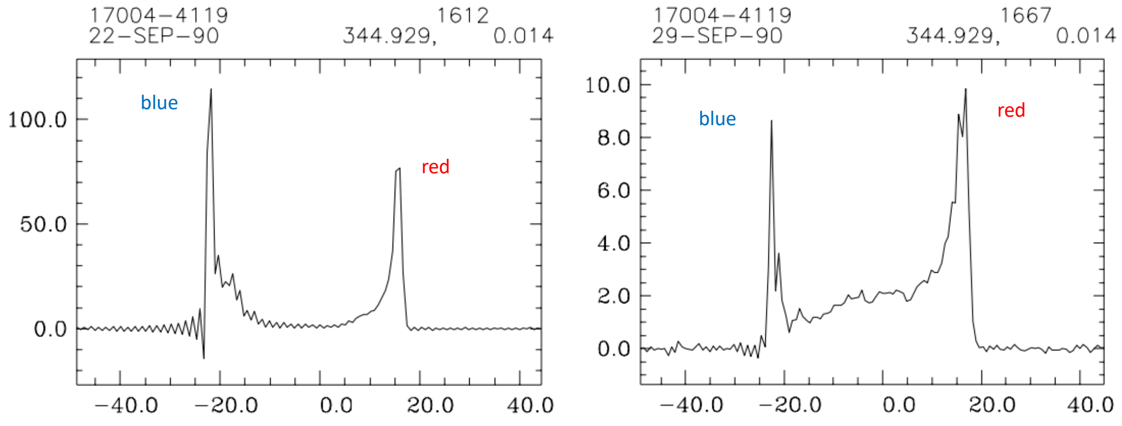

Figure 3. Historical 1990s spectra of IRAS 17004-4119 at 1612 MHz and 1667 MHz [2]. The 1665 MHz line was not observed.

The spectrum 1612 MHz obtained in October 2025 is reproduced in Figure 4. Peak levels and velocities at 1612 MHz are consistent with historical data from the 1990s (Figure 3).

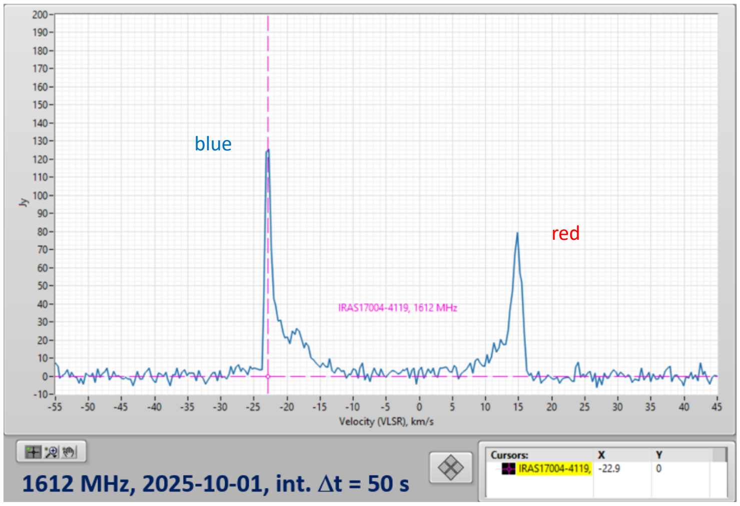

Figure 4. Observed 1612 MHz spectrum from IRAS 17004-4119, October 2025; reproduced according [15]. The peak levels are close to 1990s levels in historical spectra (Figure 3).

The detection of the 1667 MHz line in the 1990s and the non-detection in 2005 can be explained by the variability of the "main" lines, but the most striking pattern of variability is observed in the new spectra from April 2026 (Figure 5, raw data).

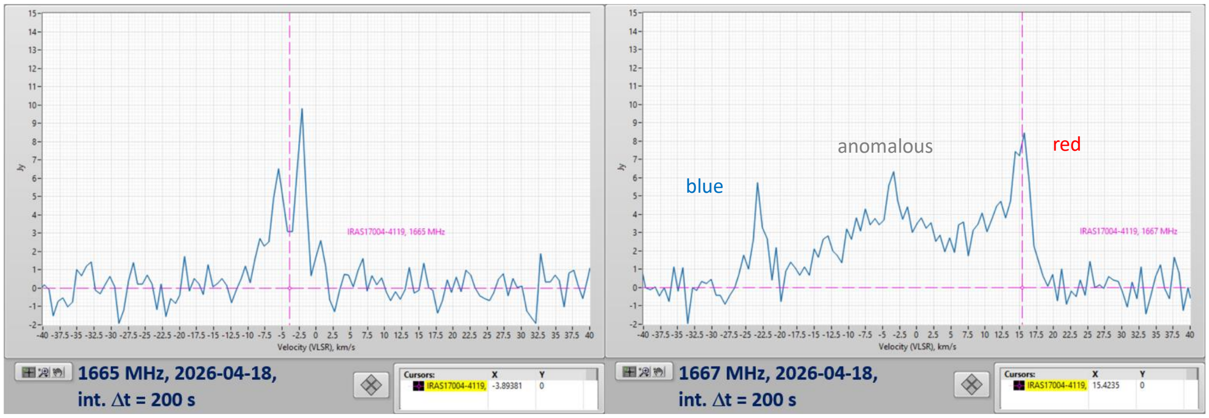

Figure 5. April 2026 spectra of IRAS 17004-4119 in "main" lines: left – 1665 MHz line, right – 1667 MHz line.

As can be seen on Figure 5, the line at 1667 MHz has appeared with a double-peaked profile and with anomalous behavior of the spectrum between the peaks. Moreover, the line at 1665 MHz – which was detected neither in the 1990s nor in 2025 – has been reliably detected now; the velocity of the line median approximately corresponds to the velocity of the anomalous peak (between the regular red- and blue-shifted peaks) of the spectrum at 1667 MHz.

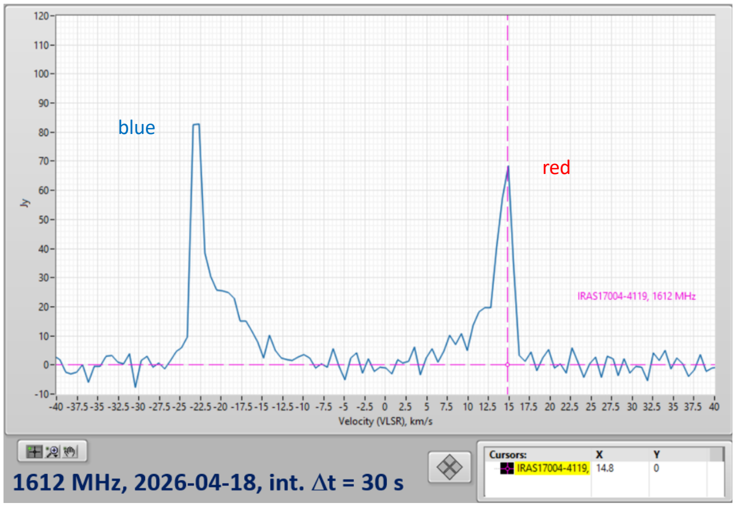

Figure 6. New 1612 MHz spectrum from IRAS 17004-4119 observed in April 2025.

The spectrum at 1612 MHz, obtained in April 2026, is presented in Figure 6 (raw data). The peak levels are somewhat lower than previously; however, the maser remains strong. The velocities of the regular red- and blue-shifted peaks in the spectrum at 1667 MHz coincide with the velocities of analogous peaks in the spectrum at 1612 MHz.

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

Discussion and concluding notes

The star IRAS 17004-4119 was suggested as interesting for variability observations in "main" lines in [5], The line 1667 MHz has disappeared in October 2025, but the line 1612 MHz was still strong like in the 1990s. The reappearance of double peaks of the 1667 MHz line might be expected; however, observations in April 2026 yielded much more. The variability of the star IRAS 17004-4119 in the "main" lines was caught and confirmed, but with a surprise.

In [5, 14] the envelope density indicator [5, 14] $\dot{\mathrm{M}}/\mathrm{R}_*^2$ was introduced. Its value >10^{-10} M⊙/(year R⊙^{2}) signals that appearance of the "main" line emission is possible [5]. For the star IRAS 17004-4119, the estimate of $\dot{\mathrm{M}}/\mathrm{R}_*^2$ > 10^{-10} M⊙/(year R⊙^{2}) was obtained from typical mass-loss rates $\dot{\mathrm{M}}$ and stellar radii R_* for similar OH/IR red giants, not from measurement data. The line at 1667 MHz reappeared in observations in April 2026, exhibiting anomalous behavior of the spectrum between red and blue peaks, and this might be expected keeping in mind this star history; however, the appearance of the line at 1665 MHz came as a genuine surprise.

The regular red and blue peaks in the spectra at frequencies of 1612 and 1667 MHz coincide in velocities; their emission, as supposed, originates from far outer CSE layers, and the gas density there is sufficient for collisional processes associated with 1667 MHz line excitations. The center of the line at 1665 MHz coincides in velocity with the anomalous peak in the spectrum at 1667 MHz. This can be interpreted as evidence that corresponding emission originates from layers of the CSE closer to the star, where the gas density is higher. The anomalous behavior of the spectrum at 1667 MHz noted in [2] and confirmed in April 2026 observations is supposedly attributed to OH emission from closer CSE layers too. The beam of the instrument's single dish antenna is quite wide (0.63°); it receives radiation from the star as a whole, including the far outer layers of the circumstellar envelope.

The search for other stars with a similar "main" lines variability is ongoing. An extensive list of potential candidates can be found in [8]; they are under continuous monitoring for variability in the dominant 1612 MHz line. The star IRAS 17004-4119 was not included in this list among the objects observed at the NRT [8], as it is located in the Southern Hemisphere; however, it remains visible from Green Bank, albeit at low elevation angles.

References

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About the author

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Testing a LMX2820 based 22.6 GHz Synthesizer Board

Wolfgang Herrmann

1. Introduction

The Ka-Band has recently gained attention as the reception of water maser emissions became possible with amateur equipment. Typically, commercial Ka-Band low noise blocks (LNB) are used as receivers. Unless one uses very expensive LNBs for professional use, these LNBs use Dielectric Resonator Oscillators (DRO) to generate the local oscillator signal for the down-conversion of the received signal. The disadvantage of these DROs is that they are not very good with respect to frequency accuracy and stability. Therefore, either the DRO needs to be replaced by a more accurate and stable signal or there needs to be a reference signal injected into the received signal. In order to implement either solution, a good source of such a signal is needed. This is where the “ LMX2820 22.6-GHz wideband RF synthesizer” from Texas Instruments [1] is an option to generate the appropriate signal. This synthesizer covers the frequency range from 45 MHz up to 22.6 GHz. So, the water maser frequency of approx. 22.235 GHz is included.

2. Options for using the device

It would be very cumbersome to just purchase the chip and build everything from the board to the software. Fortunately, there are a number of options to make life easier:

- There is an evaluation board from Texas Instruments (LMX2820EVM) [2]
- There are simple boards from Chines suppliers which allow using the LMX2820 with pushbuttons to set frequency and output power (search on online platforms using LMX2820 as search criterion)
- You will also find with this search a similar product which is in a housing.
- There is a campaign on Crowd Supply for a device called DSG-22.6 GHz [3]. Even though it does not mention the LMX2820 it seems obvious that the equipment advertised is based on this chip. The DSG-22.6 comes with various additions like output filters and other enhancements.

The lowest cost option is the “simple board” which sells in the range of $160 to $200.

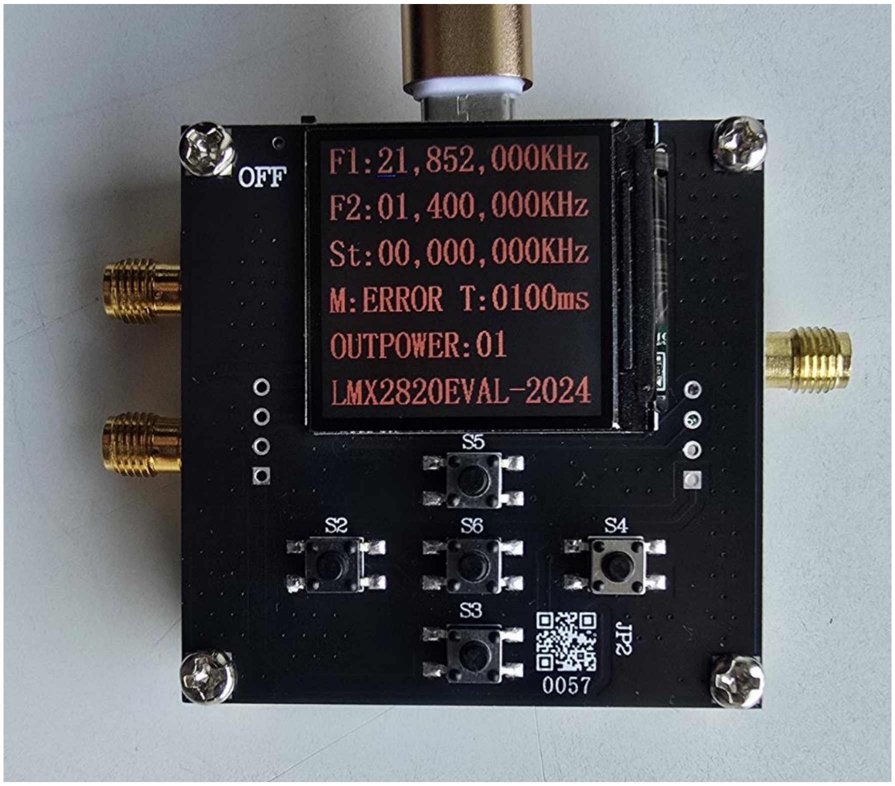
There is also the possibility to purchase just the RF board as shown in Fig. 1. But in this case, you will need to do all the programming yourself.

This article is based on said low-cost option with a controller board.

3. The simple low-cost board

The low-cost board used for this review consist of two circuit boards stacked on top of each other. The upper board contains a display and some buttons to control the device on the upper side. The lower side has a STM32 microcontroller.

The second board contains the actual LMX2820 chip with the ancillary circuitry, including a 10 MHz oscillator. There are two RF outputs with connectors. Two more are available with provisions to add connectors. There is also a clock out connector.



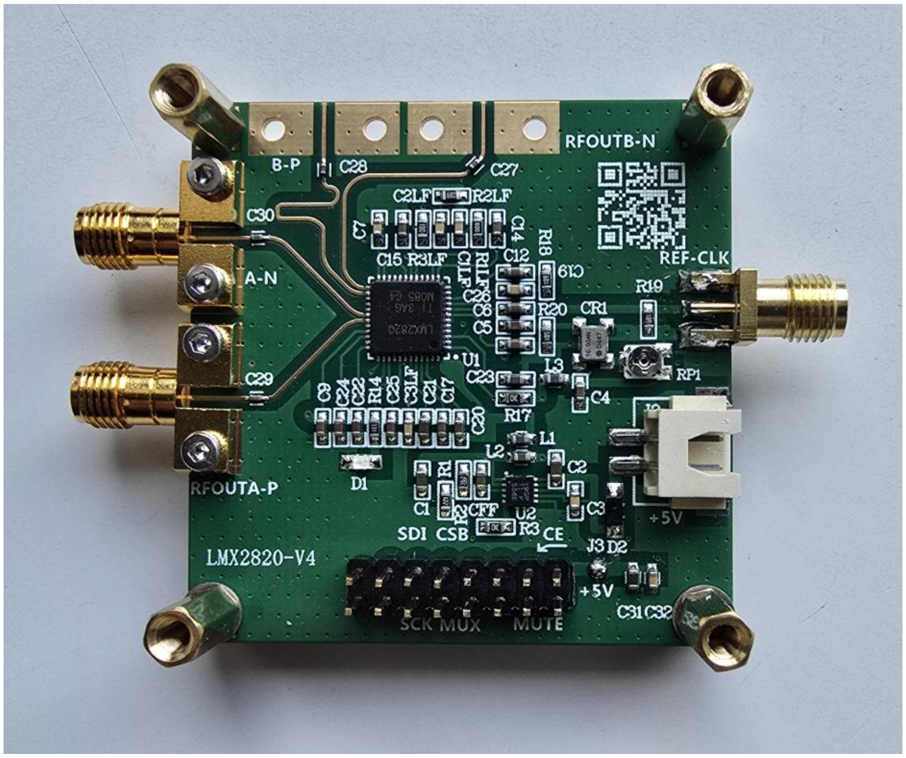


Fig. 1: Controller and RF board of the device

4. Frequency accuracy and stability

The frequency of the RF output was measured at several settings using a HP5351B microwave frequency counter. The counter was referenced to our campus 10 MHz clock which is based on a rubidium oscillator. This rubidium is known to have an offset of about $5*10^{-11}$.

The results were:

Nominal Frequency (MHz)	Measured Frequency (MHz)	Deviation (ppm)
1000	1000.000744	0.744
1420	1420.001059	0.745
2000	2000.001495	0.747
5000	5000.004003	0.800
10000	10000.007540	0.754
15000	15000.010831	0.722
20000	20000.015381	0.769
225000	22500.017547	0.779

Table 1: Frequency deviation

The frequency accuracy is surprisingly good considering the simple design of the reference clock. Measuring the clock itself also showed a deviation of ~0.75 ppm. So, the accuracy is essentially determined by the reference clock.

In order to assess the stability, another measurement was made a couple of days later at a nominal frequency of 22 GHz. The deviation in this case was 0.776 ppm indicating a good stability.

One of the possible applications is to determine the frequency and hence, the velocity of a spectral emission. In this case, a reasonable requirement would be to achieve an accuracy of 1 km/s. This corresponds to 3.3 ppm. This requirement is met by the device, assuming that the reference clock remains stable over a longer time period. This, however, may not be guaranteed. Therefore, using an external more controlled reference clock may be advisable.

5. External clocking option

There is no direct provision for an external clock. The connector labeled “REF-CLK” is an output of the internal oscillator. However, the board can be easily modified either by removing the onboard oscillator altogether or removing a capacitor connecting the oscillator. In the context of this article, this has not been tested.

6. Spectral characteristics: Harmonics

A major limitation of the device is that it creates strong harmonics. This demonstrated below in Fig 2.

It shows the spectrum recorded with a HP 8566B spectrum analyzer over its full range. The base frequency was set to 500 MHz at the LMX2820. Output power was -5.8 dBm.

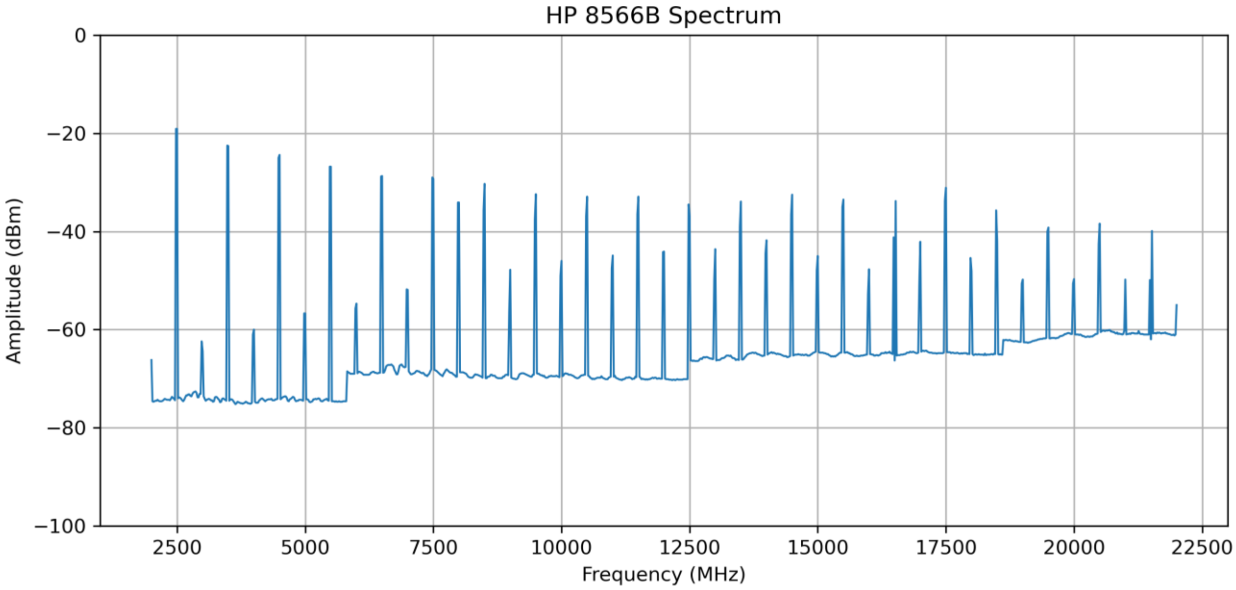


Fig. 2: Harmonics of a 500 MHz signal

The baseline level changes in the different parts of the spectrum are due to the spectrum analyzer. Also, in this wide span mode the HP 8566B starts at > 2GHz. For the sake of completeness here are the levels for the remaining harmonics:

1 GHz: -50.5 dBm

1.5 GHz: -14.3 dBm

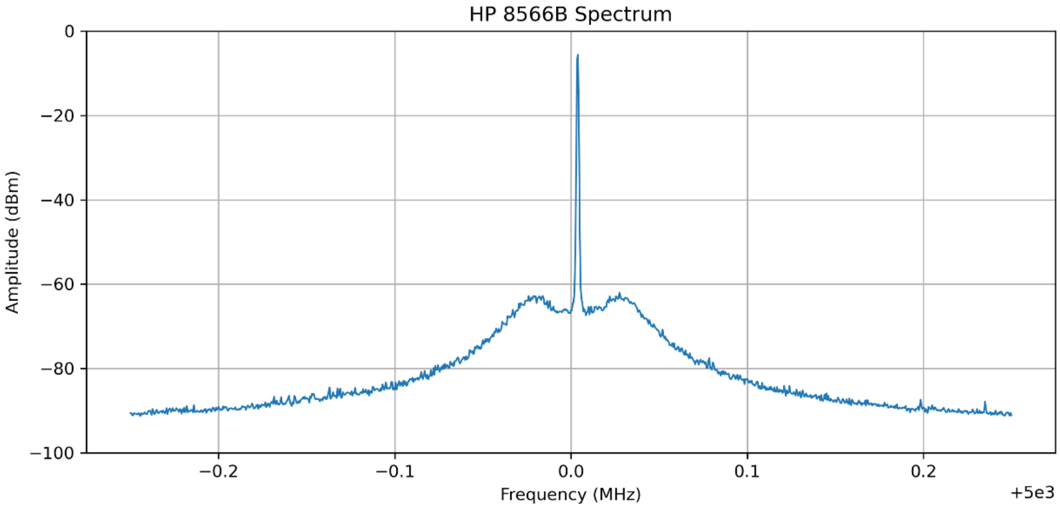
2 GHz: -60.4 dBm

Obviously, the harmonics get less dense if the base frequency is higher. This will make it easier to filter out harmonics.

7. Spectral characteristics: Phase noise

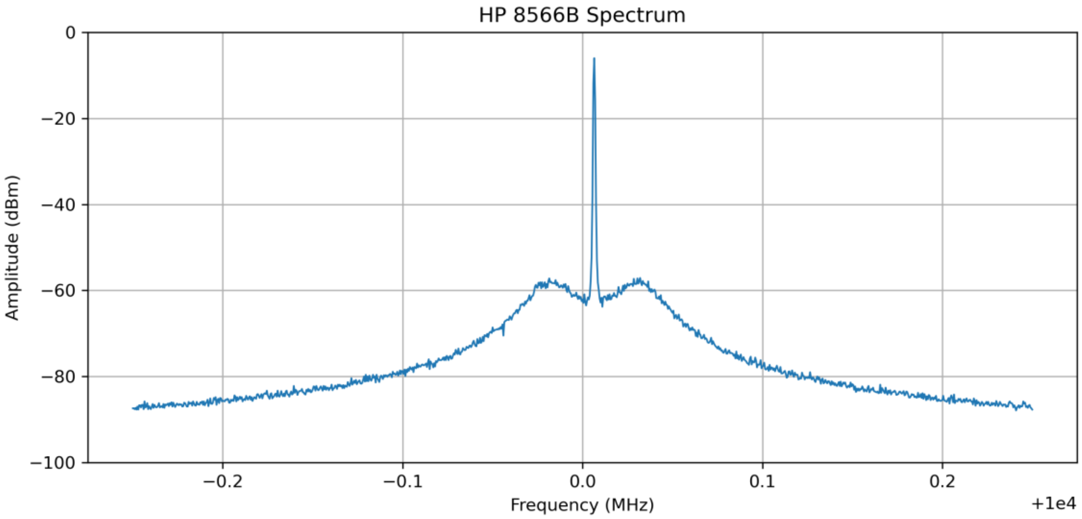
The phase noise has been measured using the HP 8566B spectrum analyzer set to a span of 500 kHz and a resolution bandwidth of 300 Hz.

Fig. 3, 4 and 5 show the phase noise at 5, 10 and 20 GHz respectively. The offset to the center frequency is not “real”, it is an artefact of the instrumentation. The frequencies are fairly accurate as explained above.



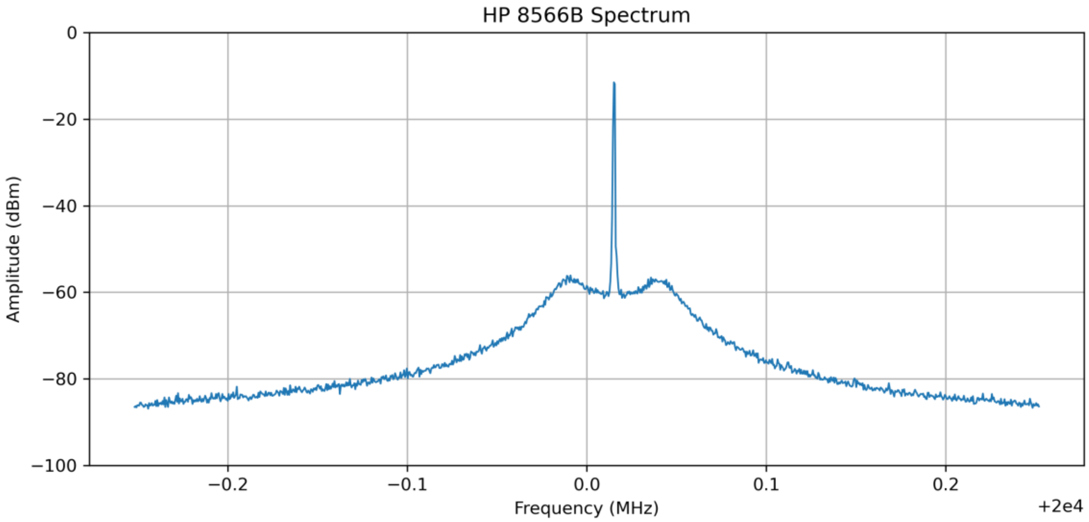
Parameter	**Value**
Start (MHz)	4999.750000
Stop (MHz)	5000.250000
Peak (MHz)	5000.004000
Peak (dBm)	-5.60
RBW	300 Hz
Ref Level (dBm)	0.00
Attenuation (dB)	10.0

Fig. 3: Phase noise at 5 GHz



Parameter	Value
Start (MHz)	9999.750000
Stop (MHz)	10000.250000
Peak (MHz)	10000.006500
Peak (dBm)	-6.00
RBW	300 Hz
Ref Level (dBm)	0.00
Attenuation (dB)	10.0

Fig. 4: Phase noise at 10 GHz



Parameter	**Value**
Start (MHz)	19999.748000
Stop (MHz)	20000.252000
Peak (MHz)	20000.015120
Peak (dBm)	-11.50
RBW	300 Hz
Ref Level (dBm)	0.00
Attenuation (dB)	10.0

Fig. 5: Phase noise at 20 GHz

Overall, the phase noise is not comparable to a good laboratory synthesizer, but it may suffice in various applications. It is worthwhile noting, that spectral lines in astronomy are fairly broad anyway, so such measurements may not be affected if this device is used as a local oscillator.

8. Power

The output power can be set to eight different levels. There are no particular dBm steps, and the output power varies with frequency.

The output power has been measured with a HP 8485A power sensor head connected to a HP 436A power meter. Also, the power has been measured with the spectrum analyzer. Since the power sensor is broadband, it will measure the power including all harmonics. The spectrum analyzer measures only the power at the desired frequency. Due to the high harmonics, there is a noticeable difference. The result is shown in Fig.6.

For clarity, only the two lowest power settings (P=0, P=1) and the two highest power settings (P=6, P=7) are shown.

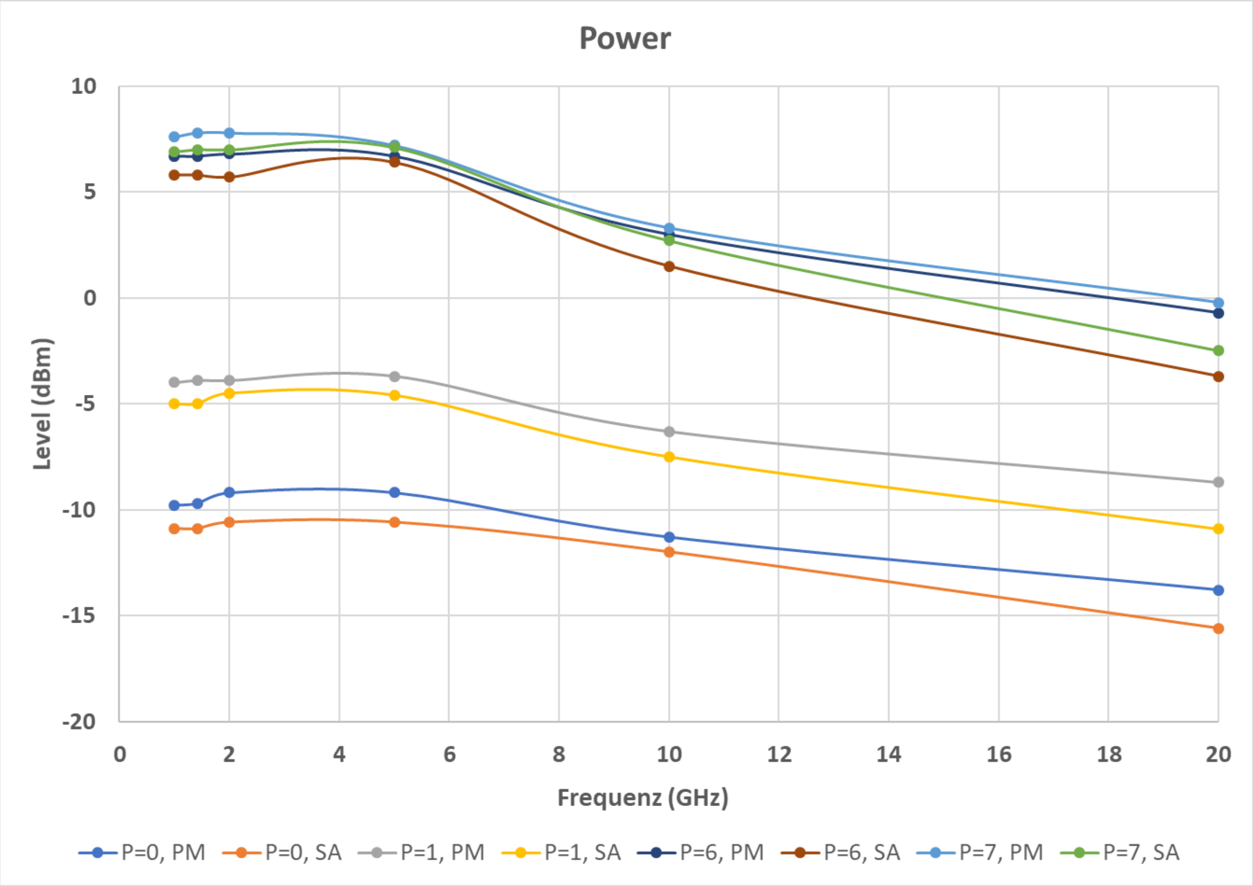


Fig. 6: Power at different settings with power meter (PM) and spectrum analyzer (SA)

8. Remote control

Unfortunately, there seems to be no possibility to control the device through its USB port. When connected to a computer, it shows up as a USB serial device. However, it was not possible to issue any commands. There was no documentation which came with the device. Research in the internet did not reveal any possibility either.

9. Conclusion

Even though the device has its limitations, it seems to be useful if one wants to play around with Ku/Ka-band frequencies. If the high frequency accuracy is not a “lucky item” it can be used as frequency reference for water maser observations. Of course, the long-term stability is not known. So, it is advisable to reference the unit to a more stable 10 MHz reference clock if used for that purpose.

10. Further reading

There is a test report dealing with the device in a housing [4]. This also mentions control via USB which is not available with the device tested here.

Two YouTube videos from a person with the ham call VK5FE also deal with this board highlighting some issues and possible enhancements [5,6].

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He received his PhD in Physics from the University of Bonn. He has spent most of his professional career in the telecommunication industry. At retirement age, he now enjoys learning as much as possible about radio astronomy, doing observations and improving the instruments at Astropeiler.

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Noise Sources at Lower Frequencies

Whitham D. Reeve

1. Introduction

A noise source is an essential component in receiver performance measurements. Noise sources are characterized by their Excess Noise Ratio (ENR), which expresses the amount of output noise power above a reference power based on a temperature of 290 K.

The ENRs of commercial noise sources generally are flat within about 1 dB throughout their specified frequency range. However, the datasheets for all the sources in my lab have a low frequency limit of 10 MHz, and I would like to know if the ENR flatness extends below 10 MHz to, say, 2 or 3 MHz. I could not find any online resources that discuss the low frequency performance of commercial noise sources, such as the ubiquitous Hewlett-Packard 346-series, so I decided to do my own investigation and describe it here.

I am motivated by my work with receiver systems in the HF and lower VHF bands, specifically, the Long Wavelength Array (LWA) and Deployable Low-band Ionosphere and Transient Experiment (DLITE), among others. In order to measure the noise performance of these receivers at the lower frequencies, I need to know the noise source characteristics at those frequencies.

This investigation involves two sets of measurements: Noise power spectral density (PSD, or power per unit bandwidth) measurements using a spectrum analyzer; and Noise source hot and cold reflection coefficient measurements using a vector network analyzer. The PSD measurements are designed to show how the noise source outputs vary across my extended frequency range, and the reflection coefficients show any impedance mismatches that could affect the measurements. Five calibrated noise sources were used in this investigation (table 1, figure 1).

This article is based on many measurements described in later sections. The relevant datapoints are taken from analyzer plot images and are tabulated. However, the plots themselves are in the Data section, which is provided only in the online version of this article.

Table 1 ~ Noise sources listed with relevant specifications from manufacturer's datasheets

Noise source	Nominal ENR (dB)	Maximum SWR	Reflection Coefficient	Remarks
HP 346A: s/n 2614A01751	5	< 1.31, 10 – 30 MHz < 1.15, 30 – 5000 MHz	0.13, 10 – 30 MHz 0.07, 30 – 5000 MHz	
HP 346B: s/n 2614A06872	15	< 1.31, 10 – 30 MHz < 1.15, 30 – 5000 MHz	0.13, 10 – 30 MHz 0.07, 30 – 5000 MHz	
HP 346B: s/n 2614A06967	15	< 1.31, 10 – 30 MHz < 1.15, 30 – 5000 MHz	0.13, 10 – 30 MHz 0.07, 30 – 5000 MHz	
Noise Com 346D: s/n 8026	21	≤ 1.5, 10 – 5000 MHz	Not specified	
RF Design RFD2305: s/n 10025	5	≤ 1.25, 10 – 3400 MHz	Not specified	Δ Γ = 0.01

Figure 1 ~ Noise sources, left-to-right in same order as table 1. Note that the RFD2305 (far-right) has a Mini-Circuits 10 dB attenuator on its output. The attenuator adapts the 15 dB ENR of the base unit to 5 dB ENR and also improves impedance matching. The RFD2305 is calibrated with the dedicated attenuator. The 346A on the far-left and RFD2305 are shown with type N RF adapters for the measurements. The other three sources have a native type N connector.

2. Instrumentation

I used a Rohde & Schwarz FPL1003 spectrum analyzer for the noise power spectral density measurements and a Copper Mountain Technologies (CMT) S5045 vector network analyzer (VNA) for the impedance measurements. A CMT ACM2506-011 AutoCal Module was used for VNA calibration. This module is equipped with N-F connectors so it required an N-M coupler (adapter) for direct connection to the VNA during calibration. The coupler has negligible effect on the calibration at the low frequencies used here (port extension was not needed). The unused AutoCal port was terminated with 50 ohms during calibration, and only one VNA port was calibrated. All noise sources in this investigation require 28 Vdc to turn On (Hot state) and 0 Vdc to turn Off (Cold state). A small 28 Vdc power supply and switch-box was used to control the two states. The analyzer setups are simple (figure 2).

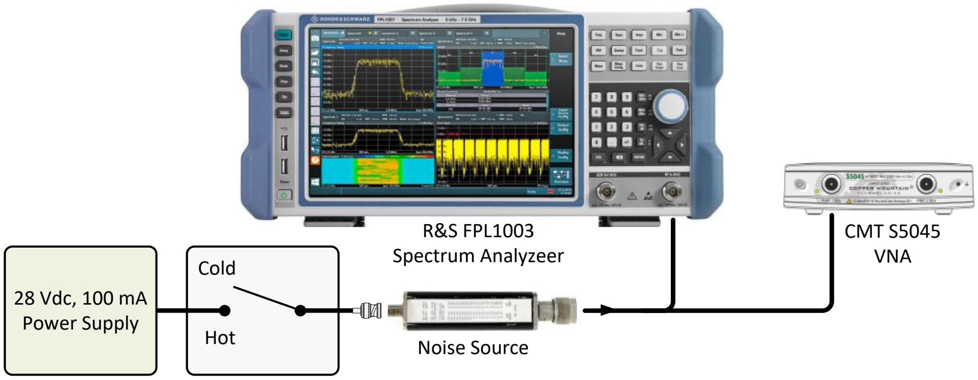

Figure 2 ~ Analyzer setups. The noise source is connected directly to the RF input connectors on the analyzers through an RF adapter if necessary. The spectrum analyzer and vector network analyzer are shown relative scale.

Noise source output power: The following are worst-case calculations to ensure that the input powers to the analyzers do not exceed their specifications. The most powerful noise source is the Noise Com 346D with a nominal 21 dB ENR over its 18 GHz frequency range. The maximum power at the input to the analyzers is when this noise source is On (Hot state). The Hot state noise power is related to the Cold state reference noise power, which is given by (see {Reeve14})

$$P_{Cold} = P_0 = k \cdot T_0 \cdot B_n = 1.38 \cdot 10^{-23} \cdot 290 \cdot 1 = 4.002 \cdot 10^{-21} \text{ W} \quad (1)$$

where k is the Boltzmann constant (W s K^{-1}), T_0 is the reference temperature (290 K) and B_n is the bandwidth (Hz). Since this calculation is for a 1 Hz bandwidth, the power is referred to as W Hz^{-1}, which is a unit for PSD.

A more familiar unit is dBm Hz^{-1} calculated from

$$P_{Cold(dBm)} = 10 \cdot \log(P_{Cold}) + 30 = 10 \cdot \log(4.002 \cdot 10^{-21}) + 30 = -173.98 \text{, rounded to –174 dBm Hz}^{-1} \tag{2}$$

The hot power spectral density when the ENR is in dB may be determined from

$$P_{Hot} = P_0 \cdot \left(10^{\left(\frac{ENR_{dB}}{10}\right)} + 1 \right) \tag{3}$$

For ENR = 21 dB,

$$P_{Hot} = P_0 \cdot \left(10^{\left(\frac{ENR_{dB}}{10}\right)} + 1 \right) = 4.002 \cdot 10^{-21} \cdot \left(10^{\left(\frac{21}{10}\right)} + 1 \right) = 5.08 \cdot 10^{-19} \text{ W Hz}^{-1} \tag{4}$$

Equivalently, the hot power spectral density in dBm Hz^{-1} is

$$P_{Hot(dBm)} = 10 \cdot \log\left(P_{Hot}\right) = 10 \cdot \log\left(5.08 \cdot 10^{-19}\right) + 30 = -152.94 \text{ dBm Hz}^{-1} \tag{5}$$

If it is assumed that all noise power is contained within the 18 GHz bandwidth, the total noise power when turned On (hot) can be found by multiplying equation (4) by $18 \cdot 10^{9}$ Hz. The total power is then $9.14 \cdot 10^{-9}$ W, which is equivalent to –80 dBW or –50 dBm.

Analyzer input protection: The specified maximum input power for the FPL1003 spectrum analyzer is +20 dBm (100 mW) with the internal attenuator set to 0 dB and +30 dBm (1 W) with it set ≥ 10 dB. Both maximums are reduced 7 dB when the FPL's internal preamplifier is enabled. The noise source measurements require the spectrum analyzer to be operated at maximum sensitivity, so its internal preamplifier is enabled and its internal attenuator is set to 0 dB. The maximum allowed power input under these conditions is +13 dBm. If an external preamplifier is used instead of the internal preamplifier, +20 dBm applies if the attenuator is set to 0 dB. The specified maximum power input to the S5045 VNA is +23 dBm (200 mW) under all operating conditions.

The actual bandwidths of the analyzers are much less than 18 GHz (3 GHz for the spectrum analyzer and 4.5 GHz for the VNA), so the actual input power will be lower than calculated above. Therefore, both instruments have plenty of margin and the noise sources may be connected directly to their inputs with no damage risk.

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3. Measurements

Spectrum analyzer setup: I initially set the spectrum analyzer start frequency to 1 MHz to check the analyzer's sensitivity and preamplifier response. Spectrum analyzer sensitivity is specified in terms of its Displayed Average Noise Level (DANL). The FPL datasheet does not specify the DANL below 3 MHz with the internal preamplifier (PA) enabled. With the preamplifier enabled, I found that the DANL made a step-increase of a few dB just under 2 MHz indicating that the preamplifier is switched out at this frequency. However, the DANL was smooth from 2 MHz to at least 1 GHz, which was the highest frequency I used while verifying the setup.

I then moved forward with noise measurements over narrower frequency ranges from 2 to 102 MHz as a cross-check with noise source calibrations points at 10 and 100 MHz and 2 to 12 MHz for the actual measurements. Until I made these measurements, I had no idea if there would be any wild variations in the noise source power output at the lower frequencies. it turned out there were none (spectrum plots are in the Data section).

The spectrum analyzer trace detectors were set to *rms power* (labeled RMS in the FPL analyzer and calculated from $(V_{rms})^2/R$). When the FPL analyzer Resolution Bandwidth (RBW) setting is ≤

50 kHz, as it was here, the analyzer switches to an FFT sweep mode. The RMS detector averages all the rms voltage samples in a given FFT frequency bin. The RMS detector is good for observing signals near noise and provided smooth traces in this investigation. *Noise markers* were used for the actual PSD measurements. The noise markers in the FPL analyzer take into account all corrections for bandwidth and averaging.

The noise sources have a relatively low power spectral density, which requires that the spectrum analyzer be operated at its highest possible sensitivity setting. This was achieved by setting the RBW and video bandwidth filters (VBW) to 1 Hz and enabling the internal preamplifier. Low RBW and VBW settings improve sensitivity but slow the analyzer sweeps. To obtain reasonable sweep times, I setup 101 measurement points for both frequency ranges. The sweep times were about 33 minutes for the 2 to 102 MHz range and 4 minutes for the 2 to 12 MHz range. The frequency resolutions were 1 MHz and 100 kHz, respectively.

The frequency range 2 to 102 MHz covers two noise source calibration points, 10 and 100 MHz, which allows comparison of the measured data to the calibration data provided with the noise source. The narrower frequency range from 2 to 12 MHz allows higher resolution examination of the noise source outputs at the lower frequencies, which was my primary interest.

For the 2 to 102 MHz range, noise markers were set at 5, 10, 50 and 100 MHz and, for the 2 to 12 MHz range, noise markers were set at 2, 3, 5, 7 and 10 MHz. Two sweeps were made for each noise source. The first was with the noise source Off (cold) and, after the sweep finished, that trace was set to View mode. Another trace was activated for a sweep with the noise source On (hot). The cold trace indicates the analyzer noise floor and not the actual cold power of the noise source (this is discussed more below).

I did some preliminary calculations using equations (3) and (5) to determine the expected noise source hot state power spectral densities (table 2). I needed to know if the PSDs would be above the analyzer DANL and, if so, I would then be able to observe any significant variations. It turned out that the measured PSDs were above the DANL for all noise sources.

Table 2 ~ Noise source nominal ENR and calculated hot-state PSD based on the nominal values. See text for the measured PSD and resulting calculated ENR for each noise source.

Noise source	**Nominal ENR (dB)**	**Calculated PSD (dBm Hz^{-1})**
HP 346A: s/n 2614A01751	5	–167.78
HP 346B: s/n 2614A06872	15	–158.84
HP 346B: s/n 2614A06967	15	–158.84
Noise Com 346D: s/n 8026	21	–152.94
RF Design RFD2305: s/n 10025	5	–167.78

Power spectral density measurements and ENRs: The ENRs shown on the noise source calibration stickers are compared to the ENRs calculated from the measured PSD (table 3). The ENRs are found by solving equation (5) for ENR, as in

$$ENR_{dB} = 10 \cdot \log\left(\frac{P_{Hot} - P_0}{P_0}\right) = 10 \cdot \log\left(\frac{10^{\frac{P_{Hot(dB)}}{10}}}{10^{\frac{P_{0(dB)}}{10}}} - 1\right) \qquad (6)$$

Note that P_0 (and P_{Cold}) is the noise source cold power spectral density (–174 dBm Hz^{-1}) that corresponds to a reference temperature of 290 K. 290 K is the standard reference temperature and not necessarily the actual noise source temperature. The spectrum analyzer measurement of the noise source in the cold state is really a measurement of the analyzer noise floor, which has a much higher equivalent noise temperature of about 2000 K for the setup and measurements described here. Plots of all spectrum analyzer measurements are in the Data section, figures D1.x (2 – 102 MHz) and D2.x (2 – 12 MHz).

Table 3 ~ Comparison of calibrated to measured ENR. Calibrated ENR is from the calibration sticker on the noise source and measured ENR is calculated from noise marker PSD values at 10 and 100 MHz. The analyzer DANL for all measurements averaged –166.5 and –167.4 dBm Hz^{-1} at 10 and 100 MHz, respectively, with only a small fraction of a dB variation across the many measurements.

Noise source	Measured PSD (dBm Hz^{-1})	Calculated ENR (dB)	Calibrated ENR (dB)	Δ (dB)
HP 346A: s/n 2614A01751, 10 MHz	–164.67	8.8	5.01	+3.8
HP 346A: s/n 2614A01751, 100 MHz	–165.26	8.1	5.12	+3.0
HP 346B: s/n 2614A06872, 10 MHz	–158.50	15.4	15.07	+0.3
HP 346B: s/n 2614A06872, 100 MHz	–158.61	15.2	15.24	–0.0
HP 346B: s/n 2614A06967, 10 MHz	–158.35	15.5	15.18	+0.3
HP 346B: s/n 2614A06967, 100 MHz	–158.72	15.1	15.06	+0.0
Noise Com 346D: s/n 8026, 10 MHz	–152.31	21.6	21.45	+0.1
Noise Com 346D: s/n 8026, 100 MHz	–152.34	21.6	22.03	+0.6
RF Design RFD2305: s/n 10025, 10 MHz	–164.29	9.2	6.1	+3.1
RF Design RFD2305: s/n 10025, 100 MHz	–164.97	8.4	5.8	+2.6

With the setup described above, measurements of the three noise sources with 15 and 21 dB ENRs were quite close to their calibrated values at 10 and 100 MHz (the differences are seen to have a very small positive bias); however, the measurements of the two noise sources with 5 dB ENR were approximately 3 to 4 dB high. As a check I disabled the internal preamplifier and connected an external preamplifier with 2.5 dB noise figure and 30 dB gain; however, after taking into account the gain, the results were substantially the same as with the internal preamplifier.

I then realized the errors with the 5 dB ENR measurements likely resulted from the low signal-to-noise ratios (the signal in this case being the noise source outputs); that is, the noise source hot powers were just too close to the analyzer DANL for accurate measurements (see [Keysight]). It is seen in table 2 that the expected PSD associated with the 5 dB ENR noise sources is –167.8 dBm Hz^{-1}, which is only 1 dB above the analyzer DANL at 10 and 100 MHz given in the table 3 caption. See Discussion section.

Vector network analyzer setup: The reflection coefficient measurements involved performing a *Full 1-Port* Calibration of the VNA Port 1 with the AutoCal module and RF coupler and then connecting the noise source directly to that VNA port. As above, a relatively large frequency range from 1 to 1000 MHz was measured to check the overall setup, and then the frequency range was reduced to 2 to 102 MHz and finally to 2 to 12 MHz. The number of measurement points was set to 1001 for all measurements. Separate calibrations were made for each frequency range and separate measurements were made with the noise source in the cold and then hot states. The analyzer was set to display VSWR so that the measurements could be easily compared to the noise source datasheets.

Reflection coefficient measurements: Reflection coefficients indicate the level of impedance matching. Impedance matching is especially important for noise sources because their power levels are very low and power transfer must be maximized. Well matched impedances reduce measurement uncertainties.

Reflection coefficients may be displayed in many equivalent forms but noise source datasheets generally use VSWR. VSWR measurements for each noise source are tabulated (table 4). The VNA plots from which the VSWR data were taken are shown in the Data section, figures D3.x (2 – 1000 MHz), D4.x (2 – 102 MHz) and D5 (2 – 12 MHz).

Table 4 ~ Measured VSWRs at 2, 3, 10 and 100 MHz listed as Cold VSWR/Hot VSWR. No attempt was made to reduce the number of displayed decimal points and incur the wrath of rounding errors.

Noise source	**Frequency**			
	2 MHz	**3 MHz**	**10 MHz**	**100 MHz**
HP 346A: s/n 2614A01751	1.0305/1.0290	1.0238/1.0225	1.0083/1.0096	1.0042/1.0050
HP 346B: s/n 2614A06872	1.3922/1.3904	1.2893/1.2896	1.1023/1.1066	1.0469/1.0548
HP 346B: s/n 2614A06967	1.2945/1.2465	1.2115/1.1718	1.0844/1.0518	1.0575/1.0139
Noise Com 346D: s/n 8026	1.8101/1.9970	1.5560/1.7664	1.1672/1.3308	1.0464/1.2185
RF Design RFD2305: s/n 10025	1.0319/1.0260	1.0273/1.0182	1.0220/1.0054	1.0169/1.0057

The measurements at 10 and 100 MHz are well within the respective datasheet limits presented in the Introduction section. On the other hand, if the maximum VSWRs for 10 MHz from the datasheets are also applied to the lower frequencies, one of the HP 346B noise sources (VSWR = 1.39) and the Noise Com 346D noise source (VSWR = 1.8) failed. This does not mean these noise sources are unusable, it means the uncertainty and potential error due to mismatch are higher.

Hand calculations of measurement uncertainties are tedious and error-prone, so Rohde & Schwarz and others produce application notes and Uncertainty Calculator software tools for estimating uncertainty (R&SUnc). Here is an example using the R&S calculator (figure 3) with the following values:

Noise source ENR, uncertainty = 15 dB, ±0.2 dB.

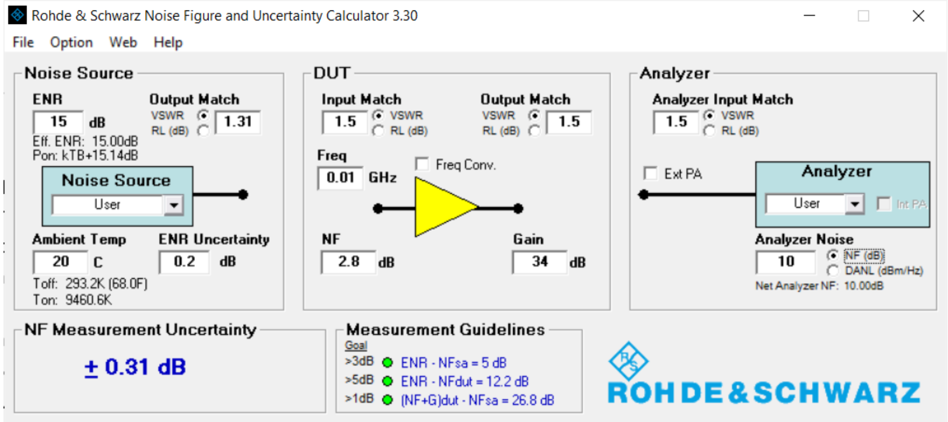
Noise source reflection coefficient = 0.1342 (1.31 VSWR)

DUT input and output reflection coefficients = 0.2 (1.5 VSWR)

DUT gain, noise figure = 34 dB, 2.8 dB

Spectrum analyzer input reflection coefficient = 0.2 (1.5 VSWR)

Spectrum analyzer noise figure = 10 dB



Noise Source

ENR: 15 dB

Output Match: ● VSWR ○ RL (dB): 1.31

Eff. ENR: 15.00dB

Pon: kTB+15.14dB

Noise Source: User

Ambient Temp: 20 C

ENR Uncertainty: 0.2 dB

Toff: 293.2K (68.0F)

Ton: 9460.6K

DUT

Input Match: 1.5 ● VSWR ○ RL (dB)

Output Match: ● VSWR ○ RL (dB): 1.5

Freq: 0.01 GHz

☐ Freq Conv.

NF: 2.8 dB

Gain: 34 dB

Analyzer

Analyzer Input Match: 1.5 ● VSWR ○ RL (dB)

☐ Ext PA

Analyzer: User ☐ Int PA

Analyzer Noise: 10 ● NF (dB) ○ DANL (dBm/Hz)

Net Analyzer NF: 10.00dB

NF Measurement Uncertainty

± 0.31 dB

Measurement Guidelines

Goal

>3dB ● ENR - NFsa = 5 dB

>5dB ● ENR - NFdut = 12.2 dB

>1dB ● (NF+G)dut - NFsa = 26.8 dB

Figure 3 ~ R&S Uncertainty Calculator. The noise figure measurement uncertainty for this example with noise source output VSWR set to 1.31 is ±0.31 dB. See text. The frequency has no effect when the noise source and analyzer characteristics are user specified.

The initial calculation shown above used a noise source VSWR of 1.31. If it was possible to improve the VSWR to 1.2, the uncertainty would decrease from ±0.31 dB to ±0.26 dB, and increasing the VSWR to 1.5 raises the uncertainty to ±0.41 dB.

---

4. Discussion

Power spectral density: The PSD measurements of the 5 dB ENR noise sources did not yield reliable results because their PSDs are too close to the spectrum analyzer noise floor. An attempt was made to improve the measurement setup by using an external preamplifier but this was not successful. Nevertheless, the PSD plots looked normal with no discontinuities or ripple.

VSWR: The VSWR of all devices was smooth across all frequency ranges but rose slightly at frequencies below approximately 10 to 20 MHz. The VSWR of all but one noise source is reasonably low (< 1.5) down to 2 MHz with no discontinuities or ripple. The increased VSWR will have some effect on noise measurements.

Attenuators usually are used in noise sources to improve their impedance matching. The Noise Com 346D (21 dB ENR) VSWR was not as low as the other noise sources, probably because of the relatively low internal attenuation between the noise diode and connector. In contrast, the HP 346A (5 dB ENR) has much higher internal attenuation, which probably resulted in its much better measured VSWR.

Specifications: By assuming that 1) a smooth and nearly flat PSD trace indicates a constant ENR and 2) the specified maximum VSWR at 10 MHz also is a reasonable benchmark at lower frequencies, then the specifications for three of the five noise sources may be extended down to 2 MHz (table 5). If the frequency is raised to 3 MHz, then only the Noise Com 346D are not extended but only marginally so.

Table 5 ~ Noise source usability based on relatively flat ENR and maximum allowable VSWR at 10 MHz.

Noise source	**Frequency (MHz)**		**Remarks**
	2	**3**	
HP 346A: s/n 2614A01751	✓	✓	
HP 346B: s/n 2614A06872	X	✓	
HP 346B: s/n 2614A06967	✓	✓	
Noise Com 346D: s/n 8026	X	X	Marginal fail at 3 MHz
RF Design RFD2305: s/n 10025	✓	✓	

Variations: I found it surprising that the two HP 346B noise sources (5 dB ENR) are only 100 serial numbers separated but the measured VSWRs not only were significantly different in overall magnitude but the difference between the cold and hot measurements varied as well.

Analyzer noise figure: In order to meet the Measurement Guidelines in the R&S Uncertainty Calculator, the analyzer noise figure (with internal or external preamplifier) must be at least 3 dB lower than the noise source ENR. Therefore, to measure a noise source with 5 dB ENR, the analyzer would need a 2 dB noise figure, which is equivalent to –169.9 dBm Hz^{-1} power spectral density. As shown in the Measurements section, the DANL for the analyzer was, at best, –167.4 dBm Hz^{-1}. An external amplifier with a 2 dB or lower noise figure could be used to make additional measurements but that was not done here.

Uncertainty: The uncertainty calculations using the R&S Uncertainty Calculator tool showed a variation of a couple tenths of a dB depending on the noise source VSWR. The uncertainty of a couple tenths of a dB is not a big concern to me.

Other noise sources: The question naturally arises: Do these results apply to all commercial noise sources? I think it is reasonable to assume they apply to all HP 346-series sources whose serial numbers start with 2614A and have been treated well and regularly calibrated. The measured reflection coefficients (displayed as VSWR) at the lower frequencies were much better than the datasheet limits, which likely indicates there could be some wider variations across a larger population of these noise sources. To be on the safe side, individual units should be specifically evaluated if they are to be used below 10 MHz.

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5. Conclusions

Excess Noise Ratio: None of the noise sources showed step-changes or anomalies in their outputs down to 2 MHz. Although it was not possible to reliably measure the ENR of the noise sources that have nominal 5 dB ENR, the spectrum analyzer traces indicate a smooth output as the frequency is decreased. The noise sources with higher ENRs, 15 and 21 dB, were reliably measured.

The sources with the higher ENRs showed a nearly flat output down to 2 MHz while the 5 dB ENR noise sources showed a slow rise at the bottom end. The rise probably is due to spectrum analyzer response. Until proven otherwise, I assume all the noise source ENRs below 10 MHz equal their value at 10 MHz, the lowest commercial calibration point.

Reflection Coefficients: Although all noise sources showed some reduction in impedance matching (increased VSWR) below 10 MHz, the reduction was not serious enough to increase uncertainty beyond a few tenths of a dB according to the Uncertainty Calculator. The slightly increased measurement uncertainty (±0.1 to ±0.2 dB) brought about by the higher VSWR is not important in my applications.

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6. Future Work

A future article will apply the information in the present article to actual noise figure measurements below 10 MHz using a spectrum analyzer and will cover the special considerations needed for resolution bandwidth and sweep time.

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7. References

[Keysight] Spectrum Analyzer Basics, Application Note AN150, https://www.keysight.com/us/en/assets/7018-06714/application-notes/5952-0292.pdf

{Reeve14} Reeve, W., Noise Tutorial, Part 1 to Part 6, 2014, https://www.reeve.com/RadioScience/Radio%20Astronomy%20Publications/Articles_Papers.htm#Noise_and_Noise_Tutorial

{R&SUnc} The Y-Factor Technique for Noise Figure Measurements, Application Note: https://www.rohde-schwarz.com/us/applications/the-y-factor-technique-for-noise-

figure-measurements_56280-15484.html (Note: This link also includes access to the Uncertainty Calculator software tool)

6. Data

Data figures D1 and D2 included only in the online version of this article at:

https://www.reeve.com/Documents/Articles%20Papers/Reeve_NoiseSrcLFMeas.pdf

Precipitation Static Observed in Radio Astronomy Receiving Systems During a Passing Rainstorm

Jim Brown, Hawks Nest Radio Astronomy Observatory May 6, 2026

Introduction

Precipitation static occurs when electrically charged particles such as rain, snow, or windblown dust interact with an antenna system. These particles can become charged through frictional processes in the atmosphere. When they strike antenna wires or nearby structures, they can transfer charge, producing small corona discharges or impulsive currents. The result is increasing broadband radio-frequency noise that raises the baseline noise level at the receiving station..

Instrumentation

In the examples that follow the affected antennas were a 2-element 20.1 MHz Radio JOVE dual-dipole array and a 4-element 16 to 30 MHz terminated folded dipole (TFD) array.

These antennas and the receiving systems used for these observations are normally used as part of a Radio JOVE station for observing Jupiter and solar events. During late night hours, free of radio frequenccy interference (RFI), the antenna temperature normally runs around 50 kilo kelvin (denoted as kK). This so called galactic background noise is generated by electrons spiraling in the galactic magnetic field. When precipitation static occurs it causes an increase in the background noise level.

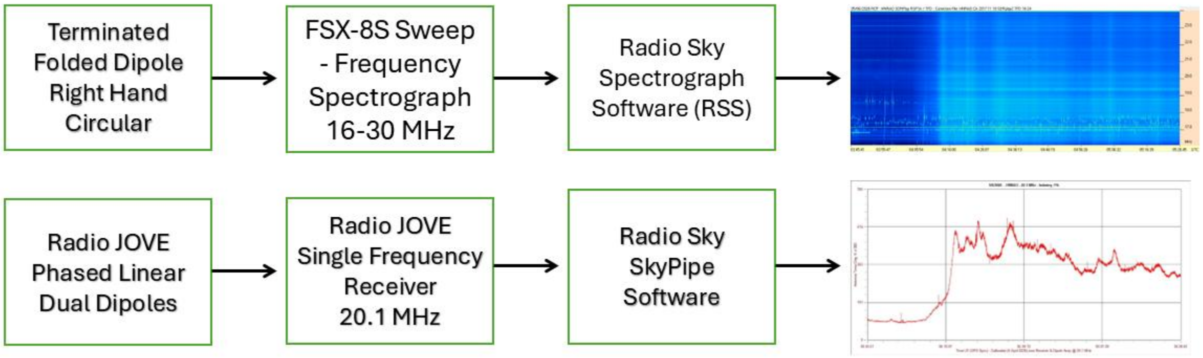

Figure 1

A 20.1 MHz JOVE receiver connected to the linearly polarized dual dipole antenna was used to produce a strip chart record of antenna temperaature. The spectrogram was produced by an FSX-8S spectrograph connected to the right hand circularly polarized TFD.

Observation

A rainstorm passed over the observatory on May 6, 2026, as seen in the radar image in Figure 2. The corresponding Radio SkyPipe strip chart record is seen in Figure 3. The rain lasted approximately 11 hours, from about 0330 UT to about 1430 UT.

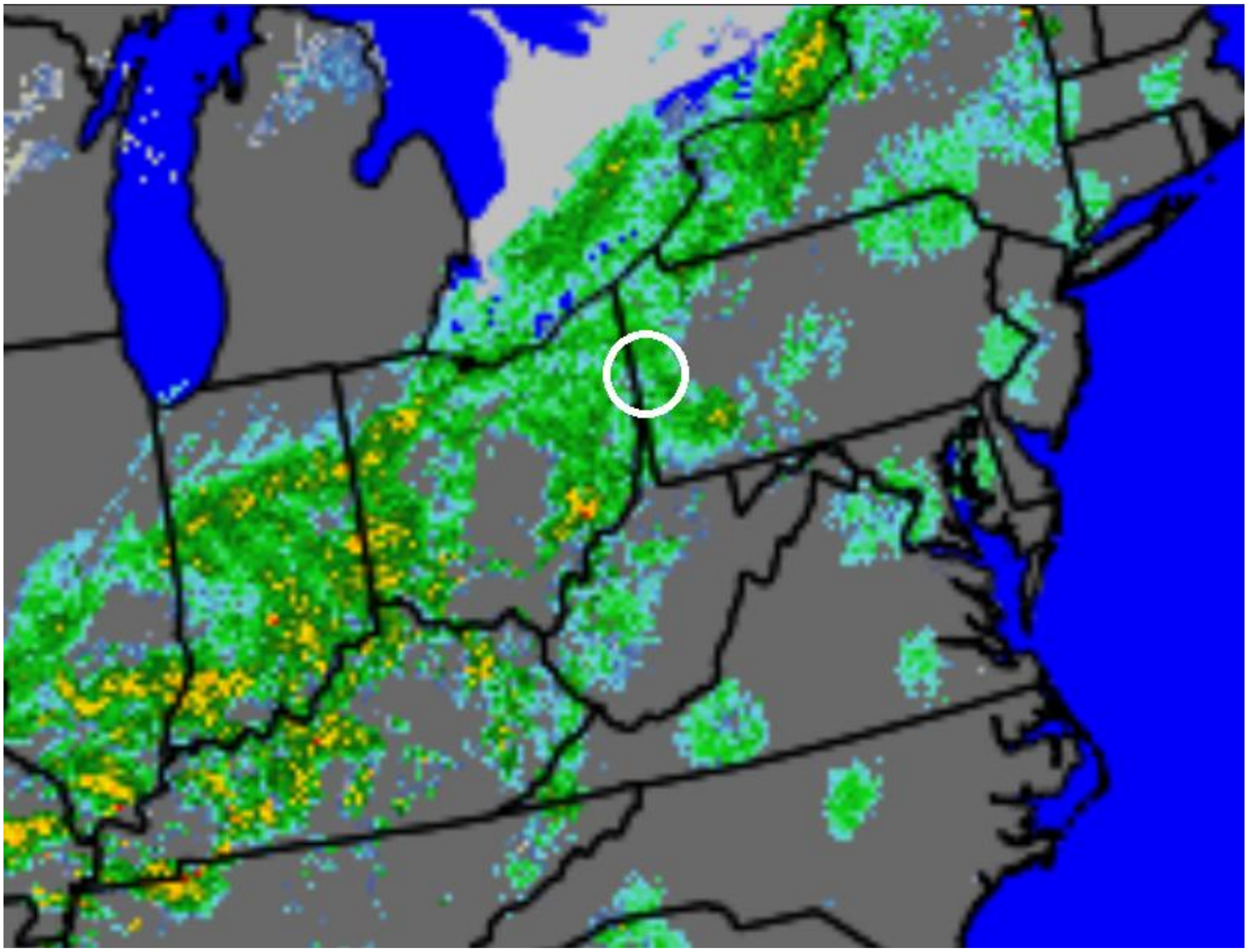

Figure 2

Radar image from May 6 showing the storm system crossing western Pennsylvania. The white circle marks the approximate location of the Hawks Nest Radio Astronomy Observatory

Several instances of precipitation static were observed during the storm as can be seen in the strip chart record of Figure 3. The precipitation static sound heard on the JOVE receiver was a smooth increase in noise, although others have reported precipitation static as a choppy sound. This paper focuses on the interval from approximately 0310 UT to 0630 UT, shown in Figure 4. During that interval, heavy rain was falling, and the noise floor rose noticeably as the storm passed overhead, with fluctuations corresponding to different rain bands moving through.

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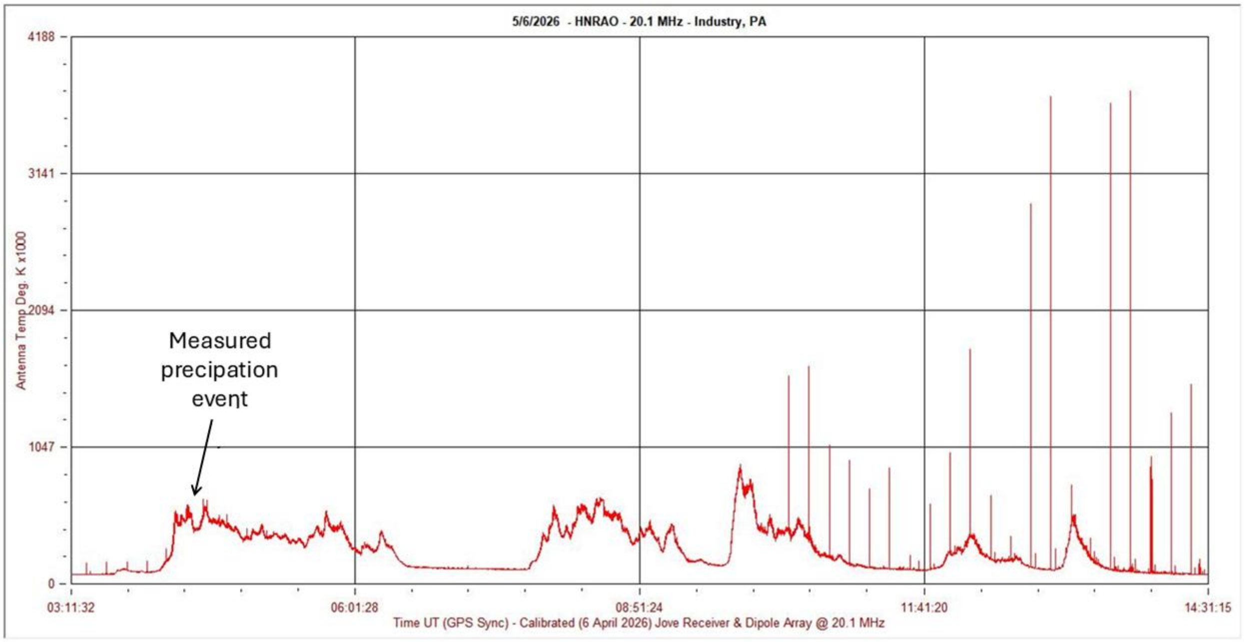

Figure 3

SkyPipe record from 0311 to 1431 UTC on May 6, 2026, showing the approximately 11-hour precipitation-static event. The measured interval discussed in this paper is highlighted and occurred during the early portion of the rainstorm.

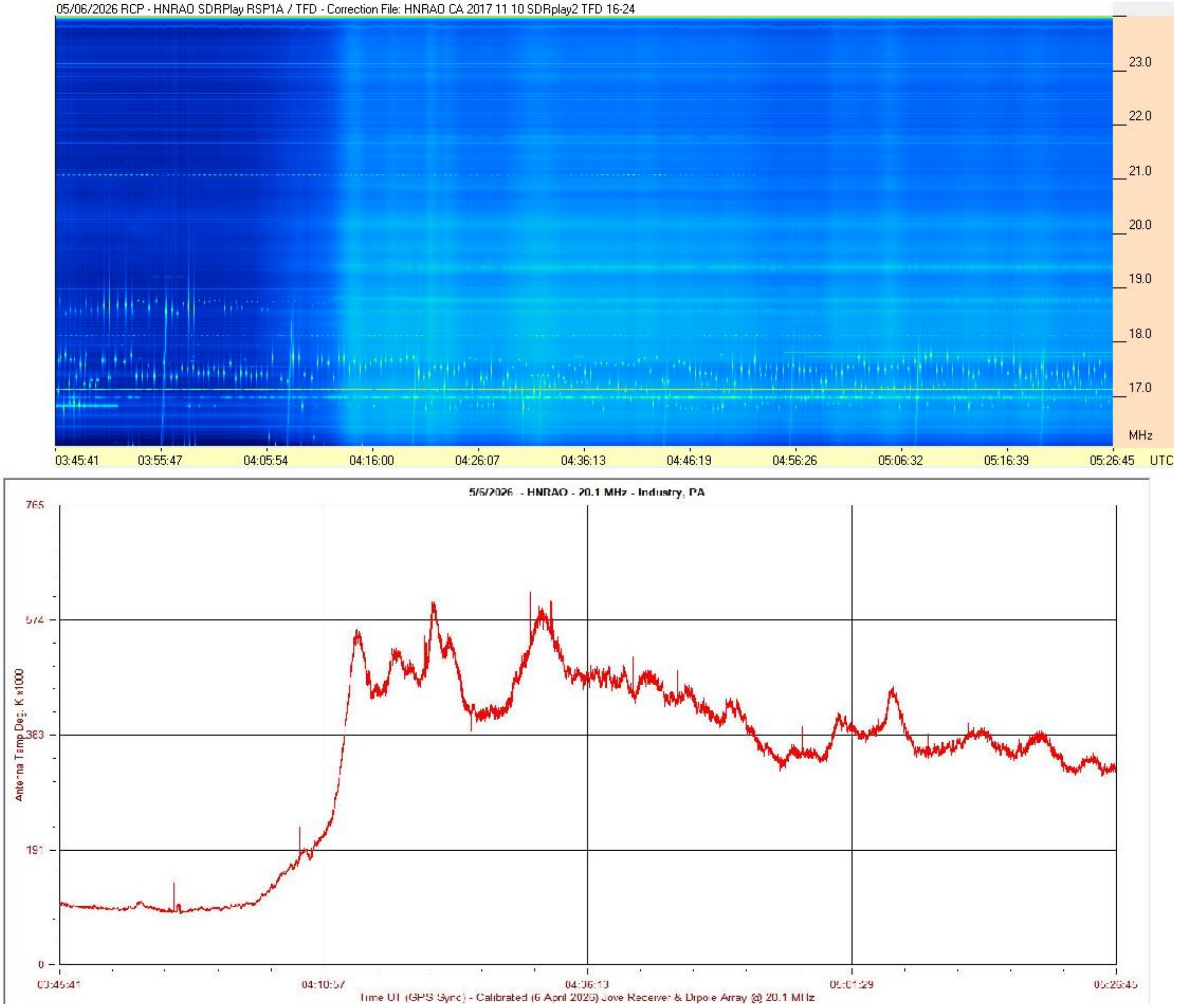

Figure 4

Measured interval.

In the expanded interval shown in Figure 4, the SkyPipe chart at 20.1 MHz and the Radio Sky Spectrograph record from 16–30 MHz show the measured background rising from approximately 75 kK at about 0310 UT to a peak of approximately 600 kK near 0415 UT.

Since the SkyPipe chart had been calibrated earlier in the day, the equivalent antenna temperature values displayed by SkyPipe, expressed here in kK, provide reasonably accurate measurements for this event. Because the Radio JOVE receiver does not use automatic gain control, the recorded

SkyPipe output preserves changes in received noise level directly rather than partially suppressing them through receiver gain correction

The rise in the noise floor can be calculated from the measured galactic background and peak antenna-temperature values.

Measured Noise Increase

A period that was quiet before the rainstorm was measured from the SkyPipe chart and taken as the galactic background, and a similar measurement was taken from the chart in a quiet period following the rainstorm when the galactic background was about the same value. This established a reasonably accurate T_1 value.

T_1 was compared against the greatest peak value (T_2) shown in the SkyPipe chart, Figure 4, of the chosen section of the rainstorm. Equivalent antenna temperature is proportional to received power, so the decibel change can be calculated using the standard power ratio formula:

$\text{dB} = 10 \times \log_{10}(T_2 / T_1)$

Where:

- T_1 = baseline ≈ 75 kK
- T_2 = peak ≈ 600 kK
- Ratio = 600 kK / 75 kK = 8
- $10 \times \log_{10}(8) \approx 9$ dB

So, the precipitation static during this part of the rainstorm brought the noise floor up by approximately 9 dB. (For reference, 10 dB rise represents a 10-fold increase in received power.).

Conclusion

This event demonstrates that precipitation static can produce a significant broadband increase in the received background level and should be considered when interpreting short-term rises in radio astronomy data during local precipitation events at this observatory, similar increases are commonly observed during precipitation events, including snow showers.

Acknowledgement

The author expresses sincere appreciation to Richard Flagg for his guidance, critical review, and assistance throughout this work.

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The author acknowledges the use of ChatGPT and Grok AI-assisted tools for editing and refinement of the manuscript.

Reference

Radio JOVE Project, NASA Goddard Space Flight Center, “The Radio JOVE Project,” https://radiojove.gsfc.nasa.gov/

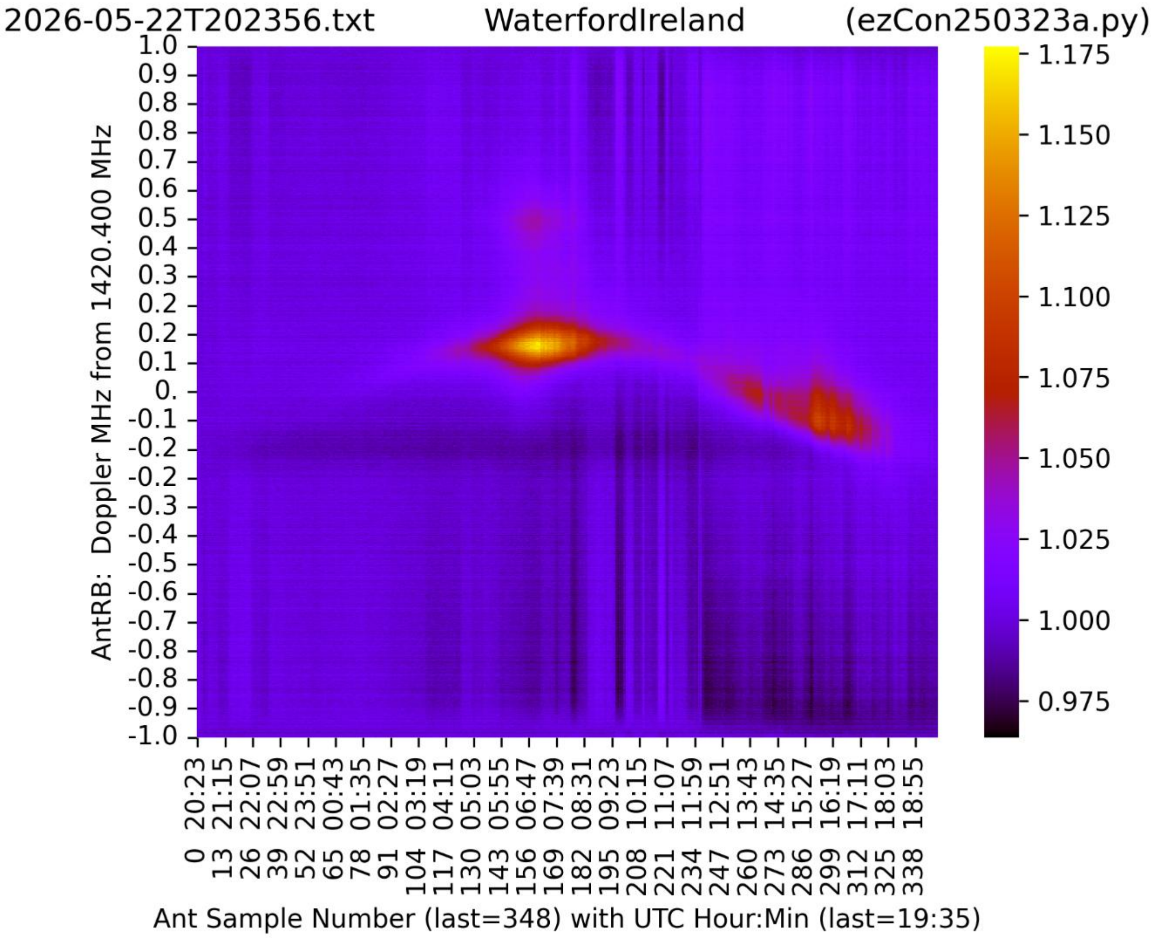
Sky, J. (n.d.). *Radio SkyPipe (RSP) and Radio-Sky Spectrograph (RSS)* [Computer software]. Radio-Sky Publishing. https://radiosky.com/specdownload.html

Observation Reports

HI Observation Report 23rd May 2026 – Waterford, Ireland

Cathal O'Donghaile

I ran my horn antenna radio telescope through the night from the 22nd-23rd of May 2026. It picked up Sagittarius A+ and the Crab Nebula parts of the Milky Way at 06:47 and 16:49 UTC respectively. I generated this graph using EzCon.



My antenna is located in Waterford city, Ireland and it was pointed at Az 255 at 65 Alt Something else appeared at doppler 0.5 at 06:49. 2 possible sources. One is that it is the outer arm of our galaxy. Another is that it is the HVC cloud that sits above the Galactic Plane.

I collect my data using the rtl_power utility running on a Raspberry Pi 4. I use the NooElec Smartee V5 SDR with the cased Sawbird H1+. In order to reduce RFI, the Pi and SDR were placed inside a static bag:

My antenna is a horn antenna made from display board and single use oven material. There is a 10m coaxial run between the antenna and data collector. After 3 years of trying out various designs, I finally got a functioning H-line radio telescope.

Type IV Solar Radio Emissions Observed on 16 May 2026

Whitham D. Reeve

Long duration solar Type IV radio emissions were observed at Cohoe and HAARP Radio Observatories in Alaska as well as many other stations in the e-CALLISTO Solar Radio Spectrometer Network {e-CALLISTO}. Type IV radio bursts are believed to be produced by electrons that have been accelerated by a flare but trapped in post-flare magnetic loops or in the moving magnetic structures associated with coronal mass ejections (CME). The emissions usually are identified as continuous electromagnetic radiation appearing after the flare and often follow Type II slow radio sweeps caused by the CME shock waves. The detected emissions shown in spectrograms below appear to include elements that are sometimes called moving and stationary Type IV but no Type II sweeps are obvious. Table 1 and table 2 provide generalized Type IV technical details and are from https://reeve.com/Solar/Solar.htm and associated references.

Table 1 ~ Solar Radio Burst Spectral Classifications ~ General. Only Type IV shown.

Characteristics	Duration	Frequency (MHz)	Associated Phenomena
Stationary Type IV: Broadband continuum with fine structure	Hours – days	20 – 2000	Flares, proton emission
Moving Type IV: Broadband, slow frequency drift, smooth continuum	0.5 – 2 hours	20 – 400	Eruptive prominences, magneto-hydrodynamic shockwaves
Flare Continuum: Broadband, smooth continuum	3 – 45 minutes	10 – 200	Flares, proton emission

Table 2 ~ Solar Radio Bursts ~ Summary of Major Characteristics. Only Type IV shown.

(source: Table 1, Radio emission from the sun and stars, Dulk, 1985, http://adsabs.harvard.edu/abs/1985ARA&A..23..169D)

Type	Duration at 100 MHz	Temperature (K)	Polarization	Frequency range/Bandwidth	Height range/ Magnetic topology	Association	Emission mechanism
IV moving	~ 30 min	$10^8 – 10^9$	low → high x-mode	200 → 10 MHz/ > 10 MHz	0.5 - few R_0 / plasmoid	small flare	gyrosynchronous and/or plasma

IV flare continuum	~ 20 min	$10^8 – 10^{12}$	0 – 40% o-mode ?	200 → 10 MHz/ 100 MHz	0.1 – 1 R_0/ closed ?	moderate to large flare, initial phase	plasma ?
IV storm continuum	few hours	> 10^8	60 – 100% o-mode	50 – 300 MHz/ 100 MHz	0.1 – 0.6 R_0/ closed ?	flare, late phase	fundamental plasma

According to Space Weather Prediction Center (SWPC) Forecast Discussion, active region 4436 produced an M1.9 flare at 1612 UTC that was followed by an M1.3 flare at 1629. These events were associated with Type IV radio emissions that began at approximately 1605 UTC. SWPC also reported a filament eruption that was centered at approximately N21W07 and resulted in a complex CME. Other types of solar radio bursts occurred over a very wide frequency range throughout the interval, but it is interesting that no Type II slow sweep bursts were reported by SWPC for this event.

The flares and radio storms were observed from the local morning to afternoon. The Sun's elevations and azimuths as seen at the observatories varied during the period as follows:

- Cohoe Radio Observatory: Elevation 22° → 46°; Azimuth 89° TN → 211° TN
- HAARP Radio Observatory: Elevation 25° → 43°; Azimuth 96° TN → 217° TN

Stations: Geographic details for the two radio observatories are provided in figure 1. The observatories have identical Callisto stations consisting of an active crossed-dipole LWA Antenna, dual channel LWA Power Coupler with Quadrature Coupler, dual channel UPC-590L-M Up-Converter and two Callisto instruments (one for each polarization). Instrument power is provided by 12 and 15 Vdc linear power supplies. The instruments are programmed to operate during daylight hours. Observing schedules are updated every couple of weeks during spring and fall and approximately monthly during winter and summer.

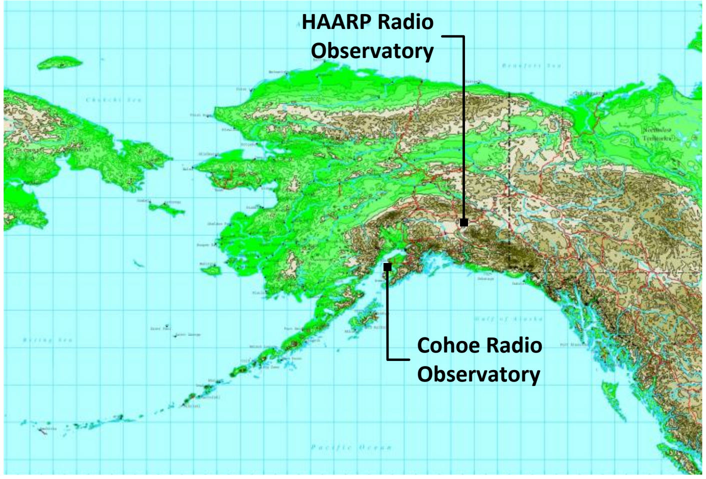


Figure 1 ~ Station details

Cohoe Radio Observatory, Cohoe, Alaska
USA
22 m AMSL elevation
60° 22' 5.34" N, 151° 18' 55.74" W
geographic

HAARP Radio Observatory, Gakona, Alaska
USA
562 m AMSL elevation
62° 23' 21.00" N, 145° 8' 15.18" W
geographic

Underlying map source: USGS

The Callisto instruments at Cohoe and HAARP are configured to monitor the frequency range 5 to 85 MHz, but the emissions were observed no lower than about 30 MHz. Two series of 15 minute spectrograms from Cohoe Radio Observatory are provided below that cover the time periods 1630 to 1830 UTC (figure 2) and 2130 to 2330 UTC (figure 3). The spectrograms at HAARP Radio Observatory about 300 km away (not shown) are nearly identical. The storm starts very weak at about 1640. There is a 3 h gap in the two spectra series, which could be a temporary storm subsidence or the end of one storm and the later beginning of another, unrelated event. A similar gap is seen in the spectra from the Mexico e-CALLISTO station MEXICO-FCFM-UNACH located in Tuxtla Gutiérrez, Chiapas, so the gap is not unique to the two Alaska stations.

The spectra below are arranged in two vertically sequential columns with left-hand circular polarization (LHCP) in the left column and right-hand circular polarization (RHCP) in the right. The Type IV emissions appear as vertical streaks or structures, which sometimes are called stationary Type IV, or continuum. Some streaks are slanted and these suggest moving Type IV. In these particular events, LHCP was much stronger than RHCP. The RHCP spectra were mostly void of radio spectra but some very weak indications can be seen in the earlier set of spectrograms. The irregular horizontal lines at the lower frequencies are distant terrestrial shortwave transmissions that are propagated in during the daylight observing hours.

Acknowledgements:

e-CALLISTO: https://e-callisto.org/ (network website)

Astrodoncel Data Center: https://astrodoncel.uah.es/dashboard/index.php (data host and spectrograms)

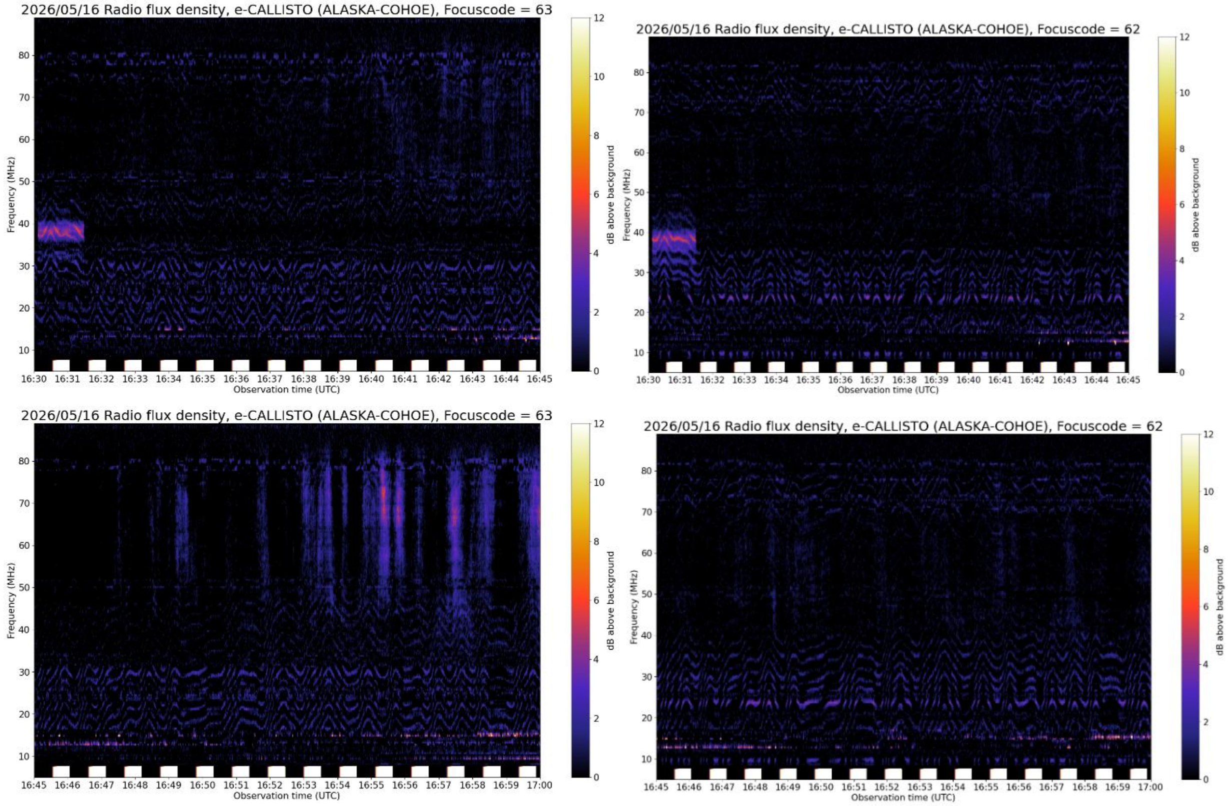
Institute for Data Science FHNW Brugg/Windisch, Switzerland (e-CALLISTO data host)

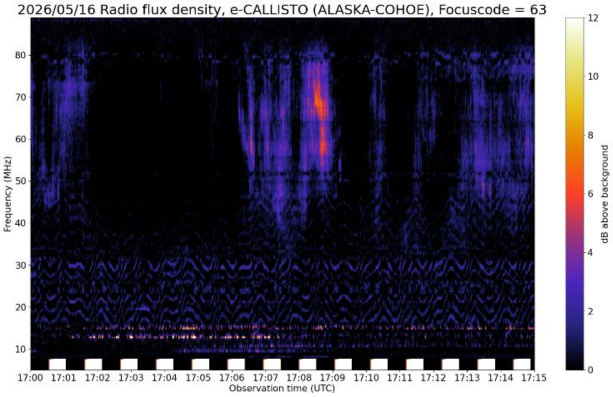
Space Weather Prediction Center: https://www.swpc.noaa.gov/ (Forecast Discussion and Events Report)

Figure 1 ~ Type IV, 1630 → 1830 UTC (elapsed time 2 hr 0 min)

Left-Hand Circular Polarization (FC 63)

Right-Hand Circular Polarization (FC 62)

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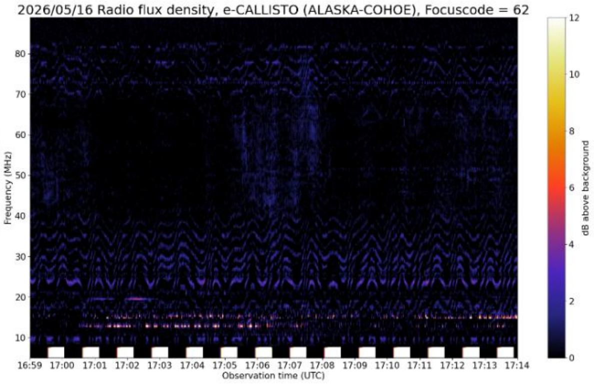
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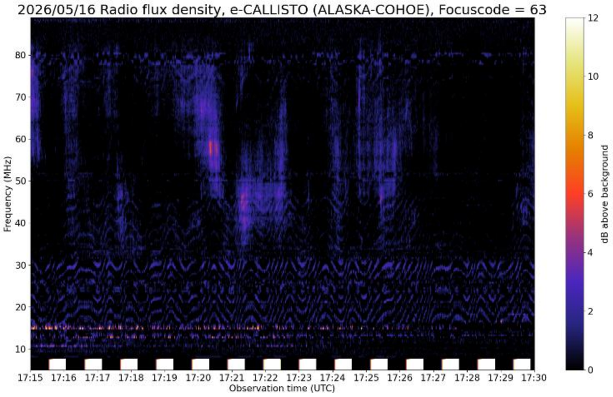
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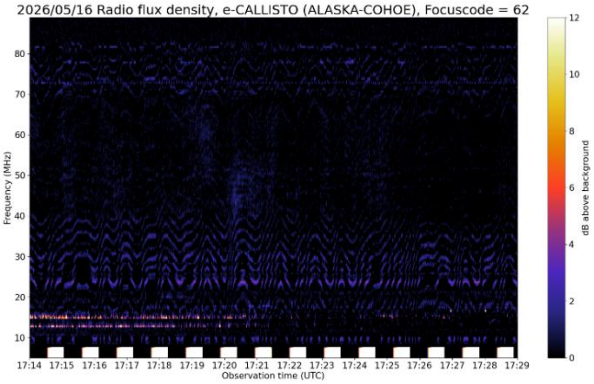
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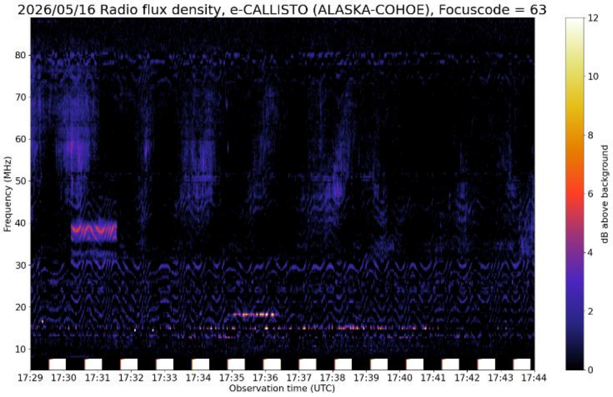
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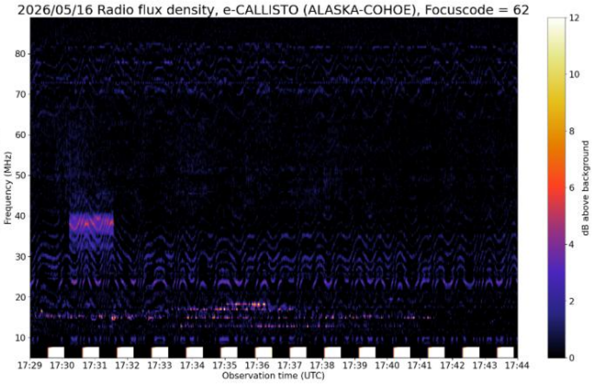
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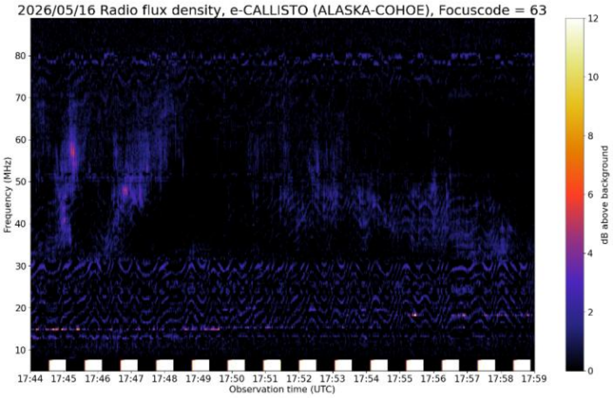
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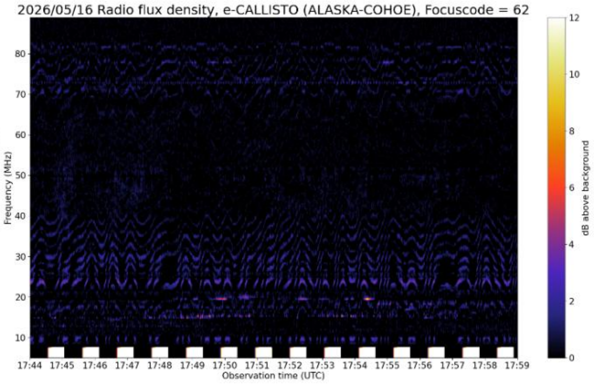
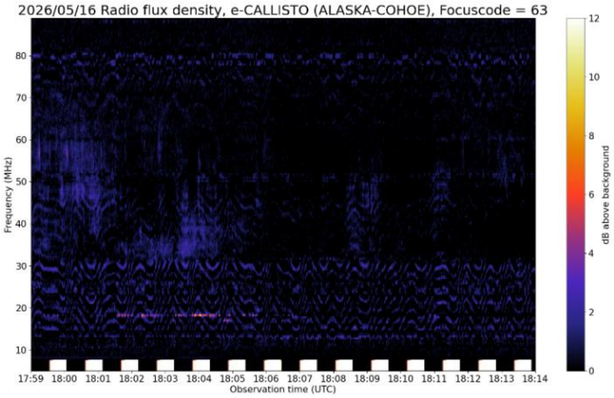

2026/05/16 Radio flux density, e-CALLISTO (ALASKA-COHOE), Focuscode = 62



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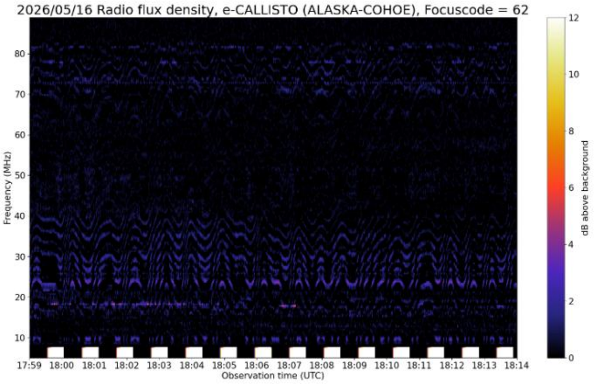

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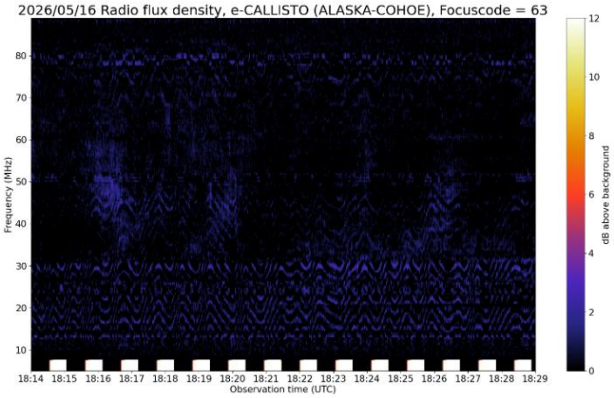

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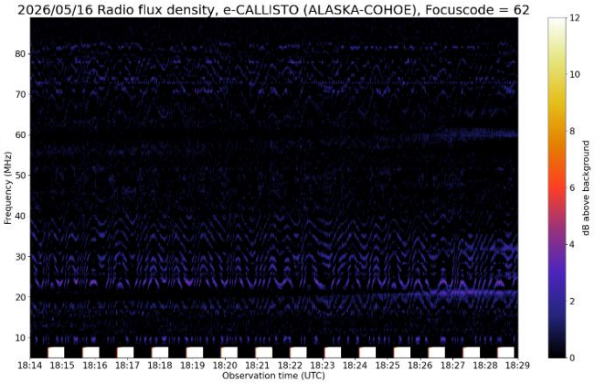
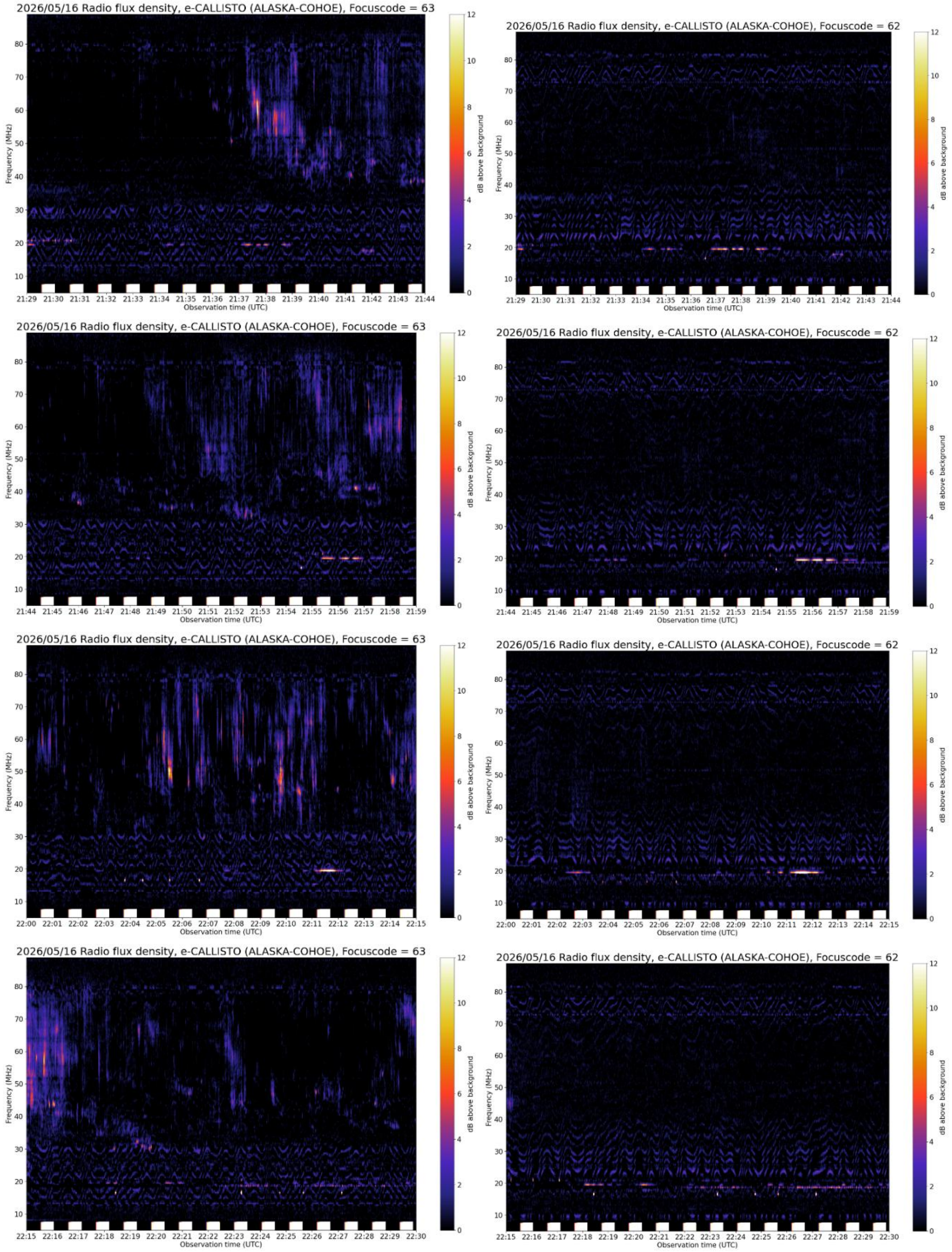


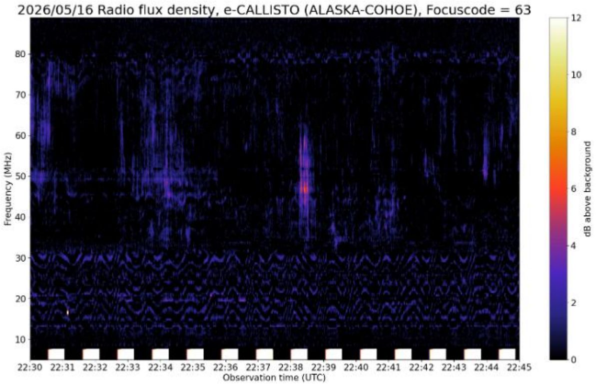
2026/05/16 Radio flux density, e-CALLISTO (ALASKA-COHOE), Focuscode = 62

Figure 2 ~ Type IV, 2130 → 2330 UTC (Elapsed time 2 h 0 min)

Left-Hand Circular Polarization (FC 63)

Right-Hand Circular Polarization (FC 62)

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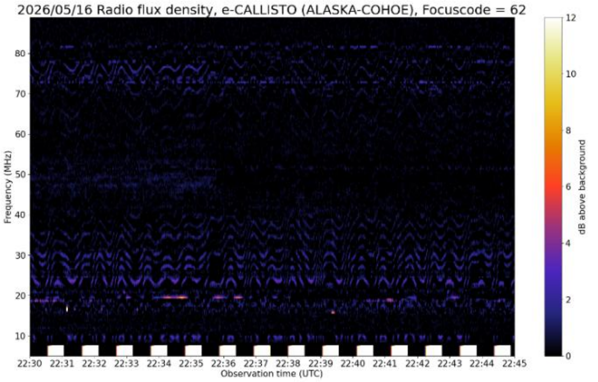
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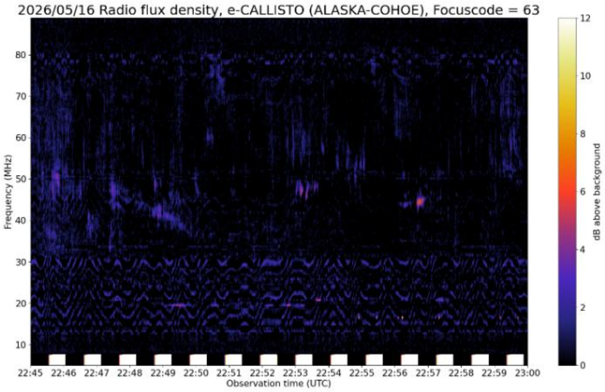
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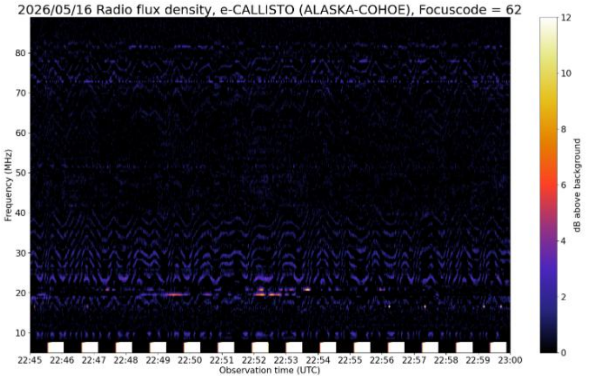
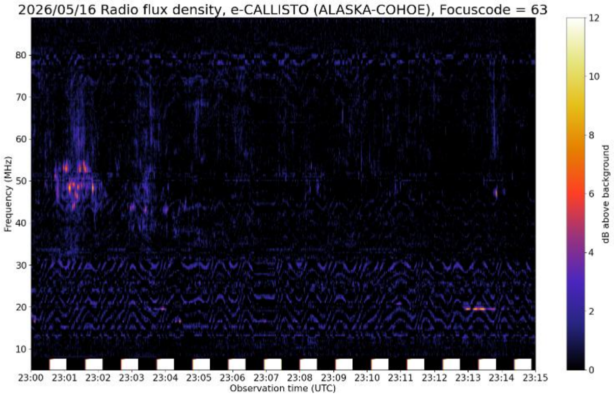
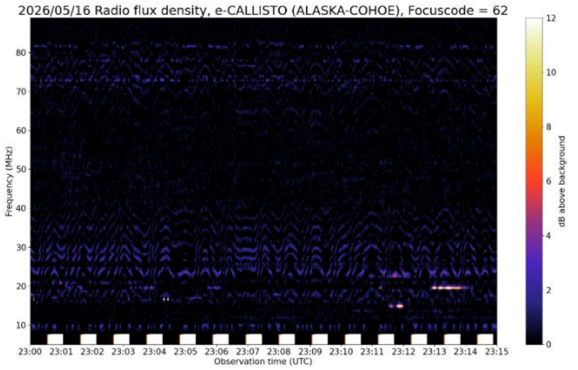
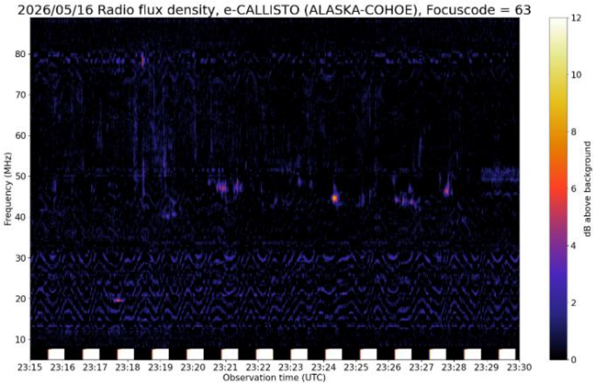
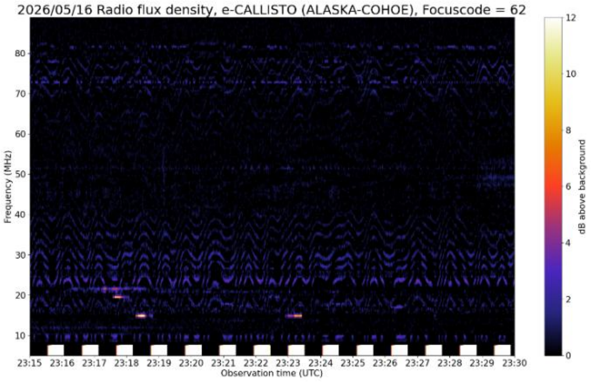

2026/05/16 Radio flux density, e-CALLISTO (ALASKA-COHOE), Focuscode = 62


2026/05/16 Radio flux density, e-CALLISTO (ALASKA-COHOE), Focuscode = 63


2026/05/16 Radio flux density, e-CALLISTO (ALASKA-COHOE), Focuscode = 62

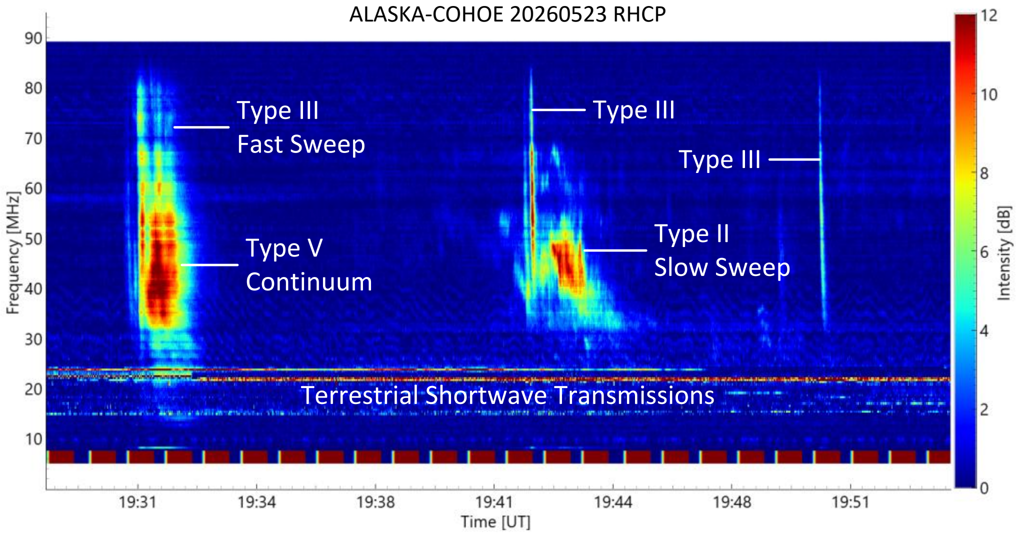

2026/05/16 Radio flux density, e-CALLISTO (ALASKA-COHOE), Focuscode = 63

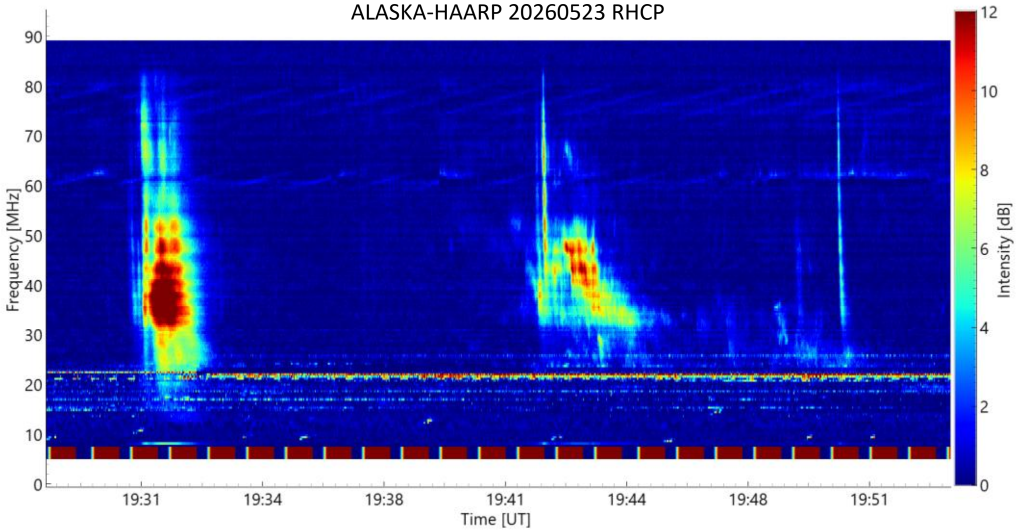

2026/05/16 Radio flux density, e-CALLISTO (ALASKA-COHOE), Focuscode = 62

Solar Radio Activity on 23 May 2026

Whitham D. Reeve

The two spectrograms below show solar radio busts observed at HAARP and Cohoe Radio Observatories in Alaska between 1930 and 1953 UTC. The plotted time scales are slightly different so the spectra do not line up perfectly. The upper image is annotated to indicate the radio burst types. Additional information on each burst type is provided at the end of this article. Only right-hand circular polarization (RHCP) is shown; the bursts were unpolarized or very weakly polarized.





Local times:

AKDT: 11:30 am to 11:53 am, approximately 2 hours before local solar noon (1:40 pm)

Station details (the two observatories are about 300 km apart):

Cohoe Radio Observatory, Cohoe, Alaska USA

22 m AMSL elevation

60° 22' 5.34" N, 151° 18' 55.74" W geographic

HAARP Radio Observatory, Gakona, Alaska USA

562 m AMSL elevation

62° 23' 21.00" N, 145° 8' 15.18" W geographic

Solar positions at 1940 UTC:

Cohoe: Elevation 43°, Azimuth 132° TN

HAARP: Elevation 44°, Azimuth 141° TN

SWPC Events report, partial (see Key below):

#Event	**Begin**	**Max**	**End**	**Obs**	**Q**	**Type**	**Loc/Frq**	**Particulars**	**Reg#**
4620	1931	////	1933	PAL	C	RSP	025-084	V/2	
4640 +	1941	////	1949	PAL	C	RSP	025-067	II/2	2524
4640	1942	////	1942	PAL	C	RSP	025-157	III/2	

Key:

Event:	Arbitrary event number assigned by SWPC (→ 4620, 4640), a plus sign (+) after the event number indicates that more than one report was received for this event
Begin:	Begin time for this event (→ UTC)
Max:	Maximum time for this event (//// → Missing time for this event)
End:	End time for this event (→ UTC)
Obs:	Reporting Observatory (PAL → Palahua, HI, USA)
Q:	Quality factor (C → Corrected Report)

Type:	Event type (RSP ➞ Sweep frequency radio burst)
Loc/Frq:	Location or Frequency (➞ MHz)
Particulars:	Additional information from the report, chosen on the basis of the report type (V/2 ➞ Brief continuum burst, generally associated with Type III bursts/Relative intensity 2 ➞ Significant (II/2 ➞ Slow drift burst/Relative intensity 2➞ Significant (III/2 ➞ Fast drift burst/Relative intensity 2➞ Significant
Reg:	Solar region number assigned by SWPC (➞ 2524)

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

Post processing assistance: C. Monstein, Monstein Radio Astronomy Support

Space Weather Prediction Center: http://ftp.swpc.noaa.gov/pub/indices/events/20260523events.txt

The following details (table 1, table 2) are from https://reeve.com/Solar/Solar.htm and associated references.

Table 1 ~ Solar Radio Burst Spectral Classifications ~ General. Only Type II, III, V shown

Type	Characteristics	Duration	Frequency Range (MHz)	Associated Phenomena
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
V	Smooth, short-lived continuum. Follows some type III bursts. Never occurs in isolation	1 – 3 minutes	10 – 200	Same as type III bursts

Table 2 ~ Solar Radio Bursts ~ Summary of Major Characteristics. Only Type II, III, V shown.

(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**	**Temperature (K)**	**Polarization**	**Frequency range/ Bandwidth**	**Height range/ Magnetic topology**	**Association**	**Emission mechanism**
II	≥ 10 min	$10^8 – 10^{11}$	usually unpolarized	200 → 1 MHz/ 10 MHz	0.2 – 200 R_0 / open	flare/CME 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 → 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
V	> 1 min	$10^8 – 10^{11}$	< 10% x-mode	100 → 10 MHz/ 50 MHz	0.5 – 2 R_0 / open ?	follows some Type IIIs	harmonic plasma

Sudden Impulse and Geomagnetic Storm Observed 5 June 2026

Whitham D. Reeve

A Sudden Impulse was observed at 0507 UTC at Anchorage, Alaska and followed 7 hours later by a geomagnetic storm starting at about 1200. The Sudden Impulse resulted when a mixture of three coronal mass ejections (CME) collided with Earth's magnetosphere. The CMEs erupted from the Sun over a 10 hour period on 3 June following M9.3, M7.7 and X1.0 x-ray flares. The CMEs had different speeds but they had magnetic and plasma components that could combine enroute and intercept Earth in its orbit.

The near-Earth space weather conditions in the first plot on the next page were recorded on 5 June by the ACE spacecraft located 1.5 million kilometers from Earth on the Earth-Sun line. The magnetogram following the ACE plot was produced by the Anchorage SAM-III Magnetometer. The images are arranged so their time scales are aligned, and both images are annotated to highlight significant aspects in the plotted parameters.

<u>Discussion</u>:

1) The transient from the CMEs is first indicated in the ACE data at 0424, 43 minutes before the Sudden Impulse at Earth. The Interplanetary Magnetic Field (IMF) total flux density (Bt) and the north-south component (Bz) increased rapidly from 7 and 6 nT to 17 and 16 nT, respectively. The solar wind speed, density and temperature also showed rapid increases at the same time;
2) Space Weather Prediction Center reported the Sudden Impulse at 0511, 4 minutes later than it was observed at Anchorage. The station they used was Meanook, Alberta in Canada. The time difference probably is due to data interpretation;
3) The Sudden Impulse was strongest in Earth's Bx (north-south) component but also significant in By (east-west). It was not obvious in Earth's Bz (vertical). Note that the Earth Bz component is not the same as the IMF Bz but they have the same name;
4) The IMF Bz rotated southward (negative Bz) a little after 1000, and stayed there for over an hour, allowing the IMF to merge with Earth's northward magnetic field. Approximately 1.6 hours were required for the movement of open field lines blown over Earth to the magnetotail where they reconnected and caused the geomagnetic field disturbance;
5) The sawtooth and periodic patterns in Earth's Bx and By components after 1200 are an interesting feature thought to be related to energy loading from the solar wind and magnetic

substorms. The large negative deflection in Earth's Bz component is another interesting feature – it possibly is related to the northward position of the Auroral Electrojet with respect to the Anchorage ground magnetometer and fluctuating current. The electrojet significantly affects high latitude ground magnetic field measurements;

6) The storm was the strongest (highest K-index) during the 1200 to 1500 and 1500 to 1800 UTC synoptic time periods. These periods correspond to the local post-midnight to morning sectors at the Anchorage observatory. Generally, the Auroral Electrojet is westward during those times.

Station details:

Anchorage Radio Observatory, Anchorage, Alaska USA

Magnetic sensor elevation: 11 m AMSL

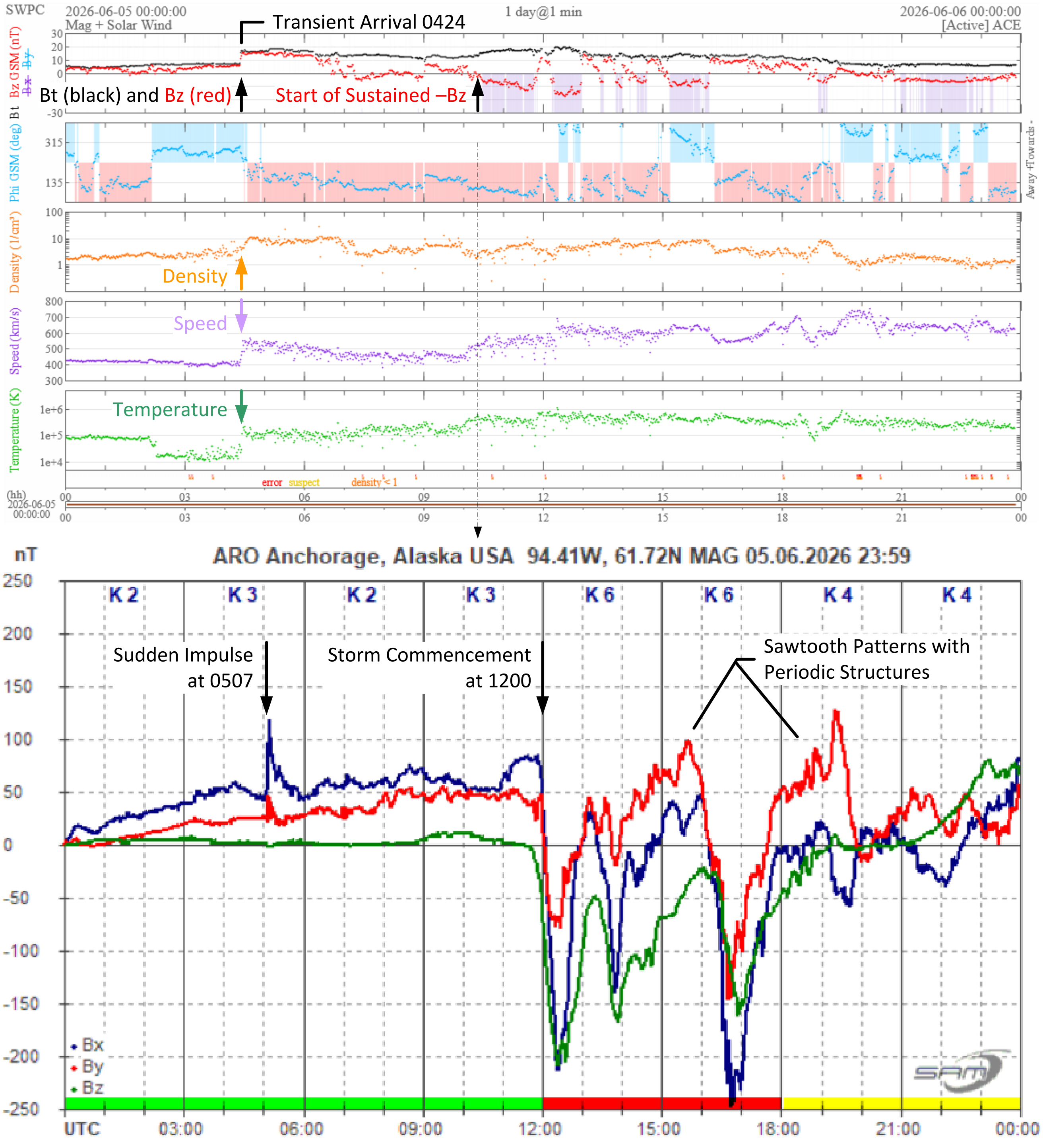
Geographic coordinates: 61.19928 °N : 149.95652 °W

Geomagnetic coordinates: 61.75 °N : 94.04 °W (2026)

Acknowledgements:

Space Weather Prediction Center (ACE Real-Time Solar Wind):
https://www.swpc.noaa.gov/products/real-time-solar-wind

Space Weather Prediction Center (Forecast Discussion):
ftp://anonymous@ftp.swpc.noaa.gov/pub/forecasts/discussion/



SWPC
2026-06-05 00:00:00
Mag + Solar Wind
1 day@1 min
2026-06-06 00:00:00
[Active] ACE
Transient Arrival 0424
Bt (black) and Bz (red)
Start of Sustained –Bz
Bz GSM (nT)
Bt
Phi GSM (deg)
Away +Towards -
Density (1/cm³)
Density
Speed (km/s)
Speed
Temperature (K)
Temperature
error
suspect
density < 1
(hh)
2026-06-05
00:00:00
00
03
06
09
12
15
18
21
00
nT
ARO Anchorage, Alaska USA 94.41W, 61.72N MAG 05.06.2026 23:59
K 2
K 3
K 2
K 3
K 6
K 6
K 4
K 4
Sudden Impulse
at 0507
Storm Commencement
at 1200
Sawtooth Patterns with
Periodic Structures
250
200
150
100
50
0
-50
-100
-150
-200
-250
Bx
By
Bz
UTC
03:00
06:00
09:00
12:00
15:00
18:00
21:00
00:00
SAM

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.

President: Dr. Rich Russel, AC0UB, https://www.radio-astronomy.org/contact/President

Vice President: Marcus Fisher, https://www.radio-astronomy.org/contact/Vicepresident

Secretary: Brian O'Rourke, https://www.radio-astronomy.org/contact/Secretary

Treasurer: Tom Jacobs, https://www.radio-astronomy.org/contact/Treasurer

Past President: Dennis Farr (Acting Treasurer)

Founder Emeritus and Director: Jeffrey M. Lichtman, KI4GIY, jeff@radioastronomysupplies.com

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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=rBZlPOLNX9E
British Astronomical Association – Radio Astronomy Group http://www.britastro.org/baa/	Shirleys Bay Radio Astronomy Consortium marcus@propulsionpolymers.com
Forum and Discussion Group http://groups.google.com/group/sara-list	SARA Twitter feed https://twitter.com/RadioAstronomy1
GNU Radio https://www.gnuradio.org/	SARA Web Site http://radio-astronomy.org
SETI League http://www.setileague.org	Simple Aurora Monitor: Magnetometer http://www.reeve.com/SAMDescription.htm
NRAO Essential Radio Astronomy Course http://www.cv.nrao.edu/course/astr534/ERA.shtml	Stanford Solar Center http://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.

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

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

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


SOCIETY OF AMATEUR RADIO ASTRONOMERS


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I ❤ Radio Astronomy


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SOCIETY OF AMATEUR RADIO ASTRONOMERS
EST. 1981


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My gma
is a radio
astromonomer


Ask me
about my
antennas


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My gpa
is a radio
astronomer


Ask me
about my
antennas


I'M A RADIO
ASTRONOMER...
BECAUSE
ALIENS
WON'T TEXT
ME BACK.


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Radio
JOVE


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Society of Amateur Radio Astronomers & Radio Jove
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SARA Brochure

Membership Information

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

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

Name: ______________________________

Email Address : ______________________________
(required for electronic Journal delivery)

Ham call sign: ____________________ (if applicable)

Address: ______________________________

City: ______________________________

State: ______________________________

Zip: ______________________________

Country: ______________________________

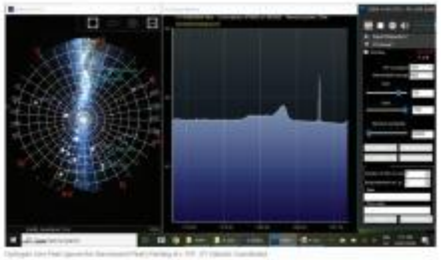
Phone: ______________________________

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

For further information, see our website at:
http://radio-astronomy.org/membership

How to get started?

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



Society of Amateur Radio Astronomers, Inc.

Founded 1981

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

Knowledge through Common Research, Education and Mentoring

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

http://radio-astronomy.org

Why Radio Astronomy?

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

The Society of Amateur Radio Astronomers

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

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

SARA members have many interests, some are as follows:

SARA Areas of Study and Research:

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

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

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

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

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

How do I get started?

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

How do amateurs do radio astronomy?

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

Is amateur radio astronomy instrumentation expensive?

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

What are amateurs actually looking for in the received data?

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

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

SARA Members discussing the IBT (Itty Bitty Telescope)