HamSCI Personal Space Weather: Architecture and Applications to Radio Astronomy

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HamSCI
http://hamsci.org

SARA East Conference
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Introduction

- The **HamSCI Personal Space Weather Station** is a National Science Foundation (NSF) and Amateur Radio Digital Communications (ARDC)-funded project to develop a ground-based system for observing space weather that can be used by amateur and professional scientists alike.
- It is designed especially for the Amateur Radio and Space Science / Ionospheric communities.
- At its core, it will have a very flexible, precision Software Defined Radio (SDR) instrument known as the TangerineSDR.
- The TangerineSDR will meet key requirements needed for scientific use that are not found in typical consumer-grade communications SDRs, and hence will likely also be of interest to the radio astronomy community.

Outline

- Amateur Radio, Radio Propagation, and Space Science
- HamSCI Personal Space Weather Station
- TangerineSDR Architecture
- RadioJove: A Use Case for the TangerineSDR
- Considerations for Radio Astronomy in General

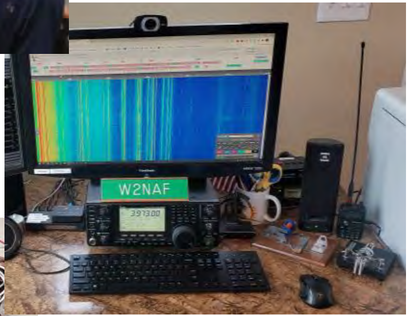
What is Amateur (Ham) Radio?

- **Hobby for Radio Enthusiasts**
  - Communicators
  - Builders
  - Experimenters
- **Wide-reaching Demographic**
  - All ages & walks of life
  - Over 760,000 US amateurs; ~3 million Worldwide

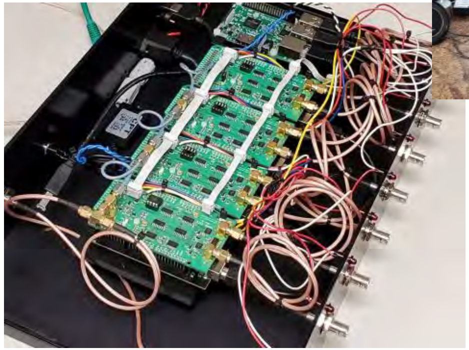
(http://www.arrl.org/arrl-fact-sheet)

- **Licensed by the Federal Government**
  - Basic RF electrical engineering knowledge
  - Licensing provides a path to learning and ensures a basic interest and knowledge level from each participant
  - Each amateur radio station has a government-issued "call sign"
- **Ideal Community for Citizen Science**

University of Scranton Students at W3USR



W2NAF Home Station



N8UR multi-TICC: Precision Time Interval Counter

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HamSCI Ham radio **S**cience **C**itizen **I**nvestigation

hamsci.org/dayton2017

Founder/Lead HamSCI Organizer:
Dr. Nathaniel A. Frissell, W2NAF
The University of Scranton

A collective that allows university researchers to collaborate with the amateur radio community in scientific investigations.

Objectives:

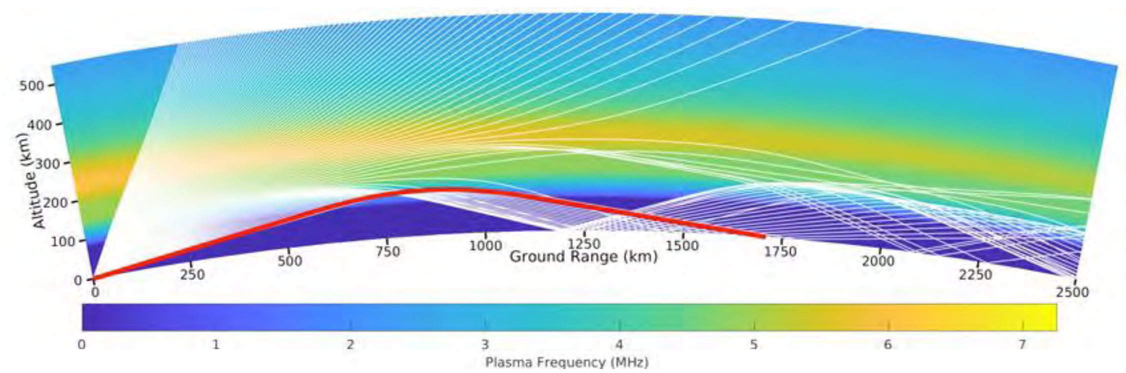
1. **Advance** scientific research and understanding through amateur radio activities.
2. **Encourage** the development of new technologies to support this research.
3. **Provide** educational opportunities for the amateur radio community and the general public.

Large citizen science community organized through e-mail lists, regular telecons, and the annual HamSCI workshop. See https://hamsci.org/get-involved.

Amateur Radio Frequencies and Modes

Eclipsed SAMI3 - PHaRLAP Raytrace

1600 UT 21 Aug 2017 • 14.03 MHz • TX: AA2MF (Florida) • RX: WE9V (Wisconsin)



PHaRLAP: Cervera & Harris (2014), https://doi.org/10.1002/2013JA019247
SAMI3: Huba & Drob (2017), https://doi.org/10.1002/2017GL073549
Amateur Radio and the Eclipse: Frissell et al. (2018), https://doi.org/10.1029/2018GL077324

- **Amateurs routinely use HF-VHF transionospheric links.**
- **Often ~100 W into dipole, vertical, or small beam antennas.**
- **Common HF Modes**
  - Data: FT8, PSK31, WSPR, RTTY
  - Morse Code / Continuous Wave (CW)
  - Voice: Single Sideband (SSB)

	Frequency	Wavelength
LF	135 kHz	2,200 m
MF	473 kHz	630 m
	1.8 MHz	160 m
HF	3.5 MHz	80 m
	7 MHz	40 m
	10 MHz	30 m
	14 MHz	20 m
	18 MHz	17 m
	21 MHz	15 m
	24 MHz	12 m
	28 MHz	10 m
VHF+	50 MHz	6 m
	And more…	

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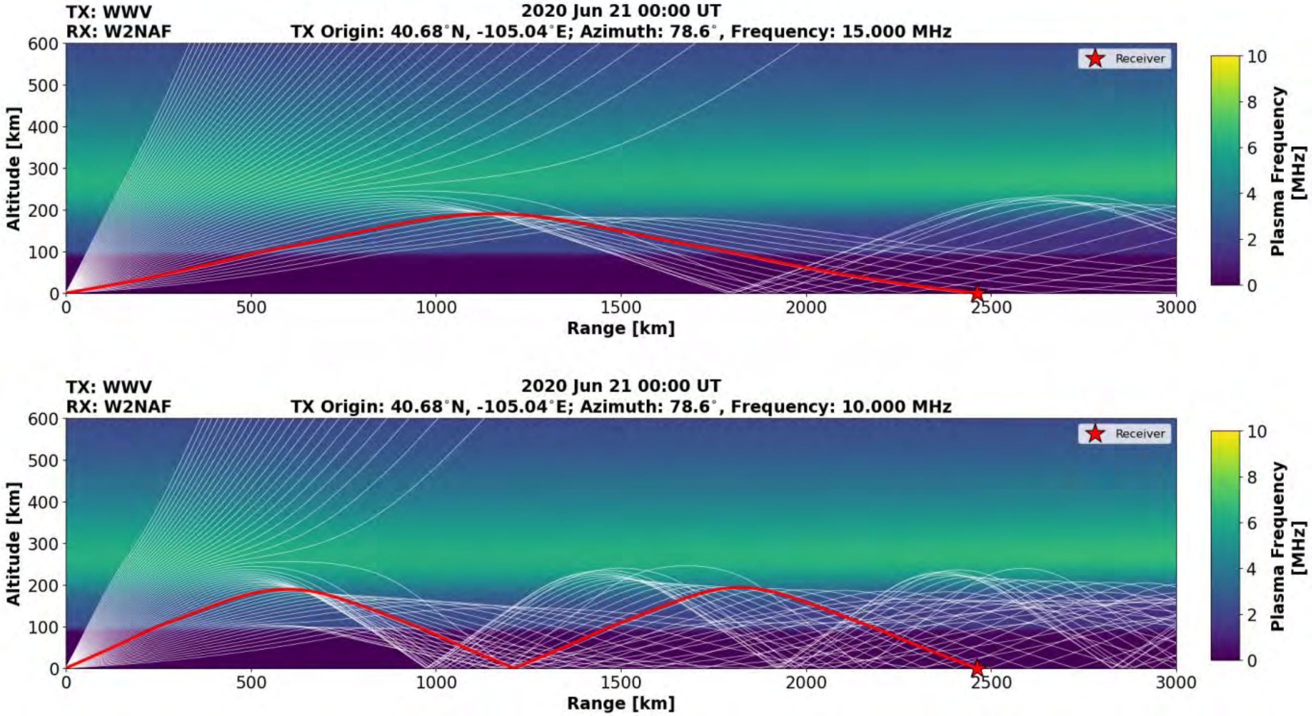
HF Radio Refraction



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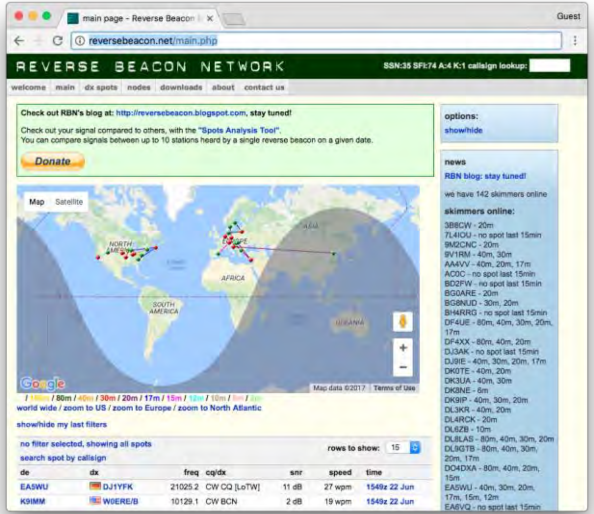
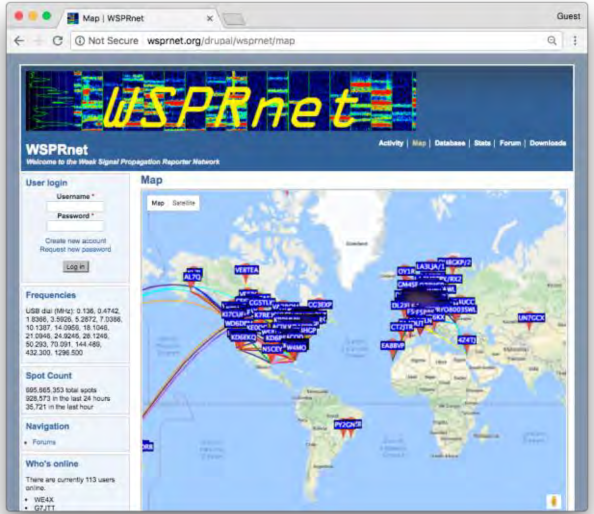
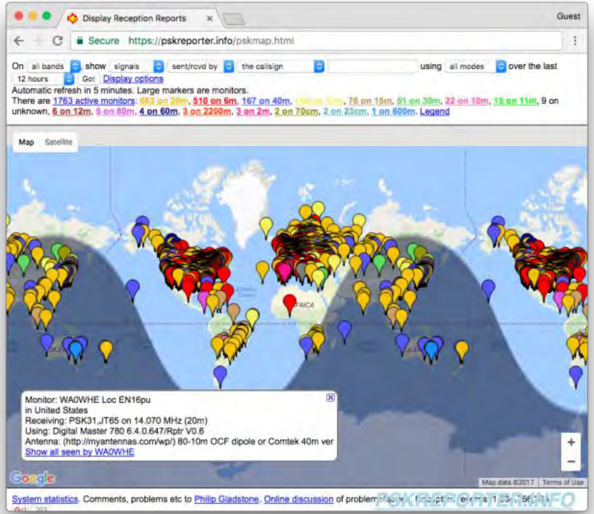
Ham Radio Observation Networks



Reverse Beacon Network (RBN)
reversebeacon.net



WSPRNet
wsprnet.org



PSKReporter
pskreporter.info

- Quasi-Global
- Organic/Community Run
- Unique & Quasi-random geospatial sampling
- Data back to 2008 (A whole solar cycle!)
- Available in real-time!

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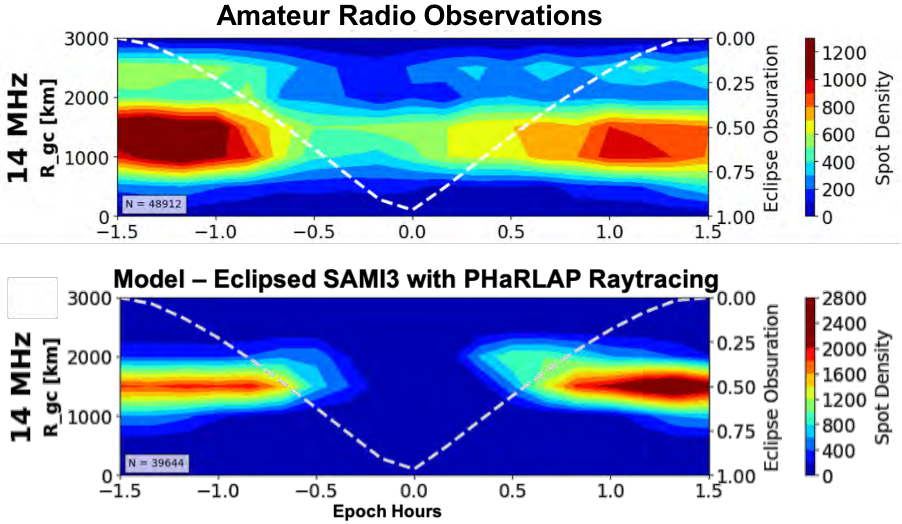
Examples of Amateur Radio Research

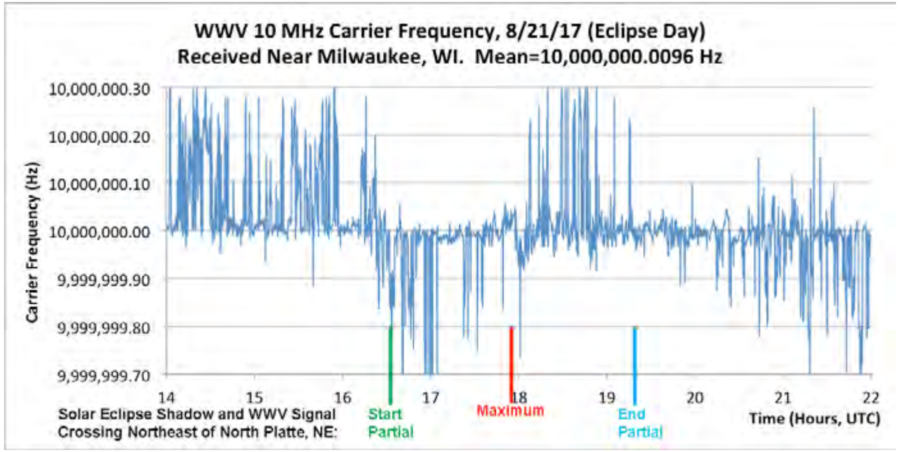
- Existing amateur radio observation networks, not specifically designed for scientific use, have already enabled ionospheric observations using amateur radio.

2017 Eclipse Continental US Observations



[Frissell et al., 2018, https://doi.org/10.1029/2018GL077324]

2017 Eclipse WWV Doppler Shift Observations



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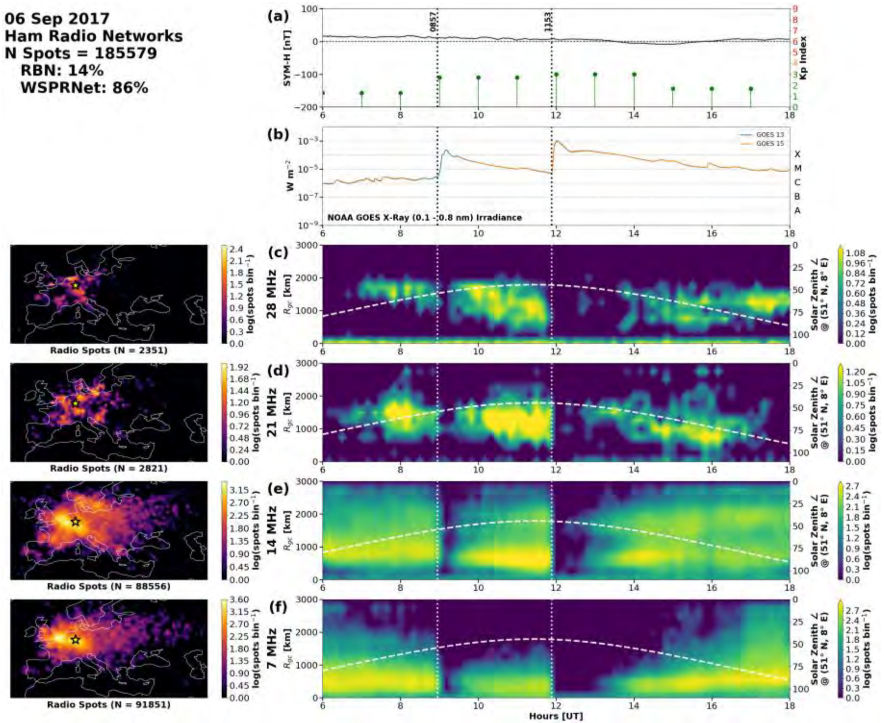
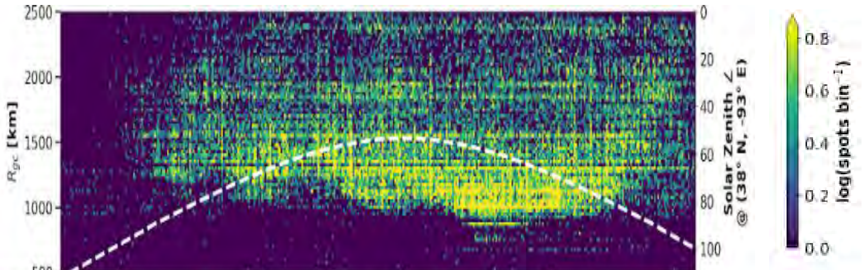
Examples of Amateur Radio Research

HF Amateur Radio Response to Solar Flares

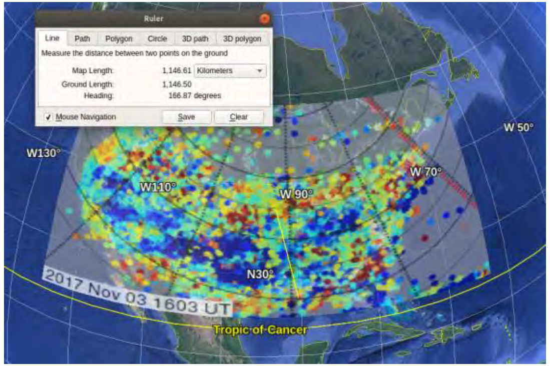


[*Frissell et al.*, 2019, https://doi.org/10.1029/2018SW002008]

HF Amateur Radio (RBN & WSPR) TID Observations



Bin Size
2 min x 25 km

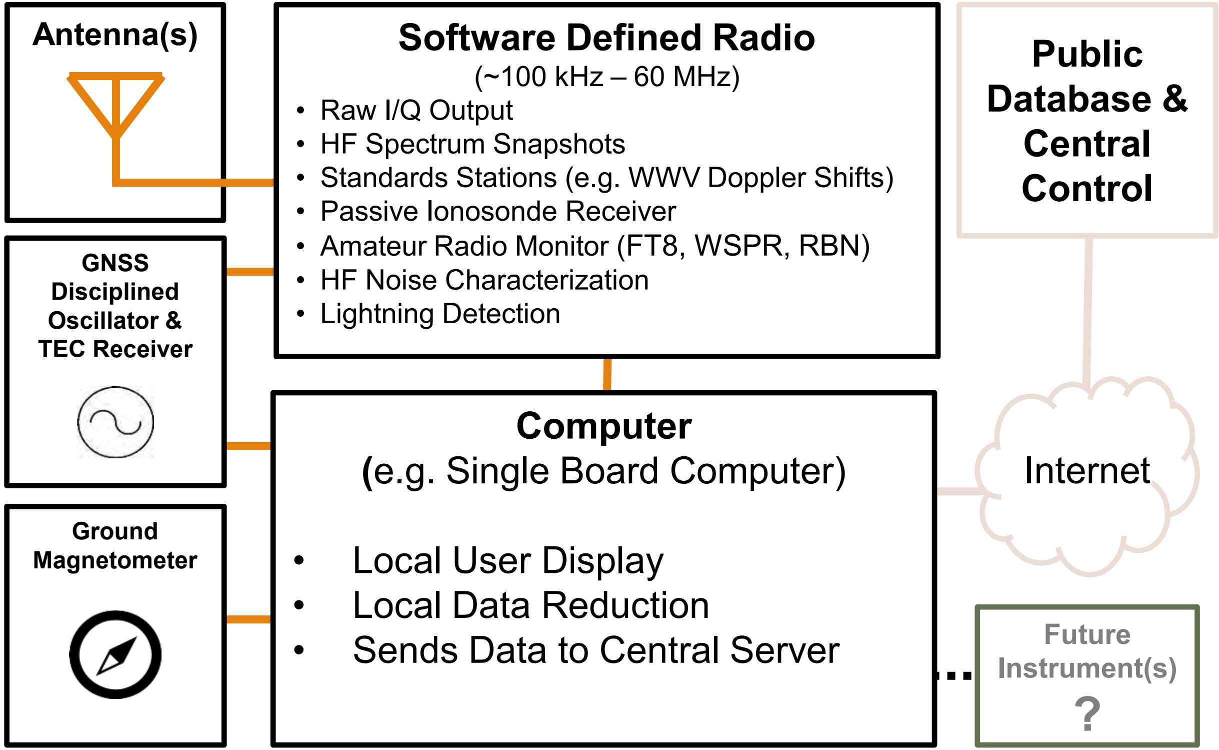


$\lambda_h \approx$ 1,100 km
$v_p \approx$ 950 km/hr
$T \approx$ 70 min
$\Phi_{Azm} \approx 135°$

TEC Courtesy of
A. Costar /
MIT Haystack

HamSCI Personal Space Weather Station

- **The PSWS is a multi-instrument, ground-based device designed to observe space weather effects** both as a single-point measurement and as part of a larger, distributed network.
- It is "Personal" because it is being designed such that an individual should be able to purchase one and operate it in their own backyard.
- The PSWS design also works to take into account the needs of both amateur radio operators and professional researchers.



For more information, visit http://hamsci.org/psws

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What is the purpose of the PSWS?

The **PSWS aims to support two primary groups of users, space scientists and amateur radio operators**. Each of these groups have different but related needs:

- **Space Science Researchers**
  - Observe, characterize, and understand ionospheric variability on small temporal and spatial scales
  - Understand coupling between the neutral atmosphere, ionosphere, and magnetosphere
  - Validate and improve models with the goals of prediction and understanding
- **Amateur Radio Operators**
  - Understand and predict radio propagation to support amateur radio communications, including public/emergency service operations, contesting, and DX (long distance) communications.
  - Study space weather and propagation for personal edification and to contribute back to science and the radio art.

Where will the PSWSs be deployed?

- Currently, the PSWS is funded on a DASI Track 1 to develop prototypes, rather than deploy a network.
- There is significant interest from the amateur radio community in this project. So, we will be looking to encourage voluntary adoption of these devices by amateurs to create an ad-hoc network.
- The amateur radio community is global, but is heavily weighted towards North America and Europe. Initial adoption will likely be in these regions.
- A number of amateurs at high latitudes (Alaska, Northern Canada, Norway and Svalbard) have also expressed interest in the project.
- Low cost and SDR-based versions of the PSWS are being designed to help maximize adoption.

What are the science goals we are after?

- **Broadly, we are trying to design a general device that will be useful for many different science targets:**
  - Solar Flare Impacts
  - Geomagnetic/Ionospheric Storms
  - Internal Ionospheric Electrodynamics
  - Short time scale/small spatial scale ionospheric variability
  - Connections with Lower Atmosphere

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PSWS Teams

University of Scranton
- **Nathaniel Frissell W2NAF (PI)**
- Dev Joshi KC3PVE (Post-Doc)
- Veronica Romanek KD2UHN (Undergrad)
- Cuong Nguyen (Undergrad)

Responsibilities
- Lead Institution
- HamSCI Lead
- Radio Science Lead

TAPR & Zephyr Engineering
- **Scotty Cowling WA2DFI (Chief Architect)**
- Tom McDermott N5EG (RF Board)
- John Ackerman N8UR (Clock Module)
- David Witten KD0EAG (Magnetometer)
- Jules Madey K2KGJ (Magnetometer)
- David Larsen KV0S (FPGA Code/Website)

Responsibilities
- TangerineSDR (High Performance)
- Ground Magnetometer

University of Alabama
- **Bill Engelke AB4EJ (Chief Architect)**
- Travis Atkison (PI)

Responsibilities
- Central Database
- Central Control Software
- Local Control Software

Case Western Reserve University
Case Amateur Radio Club W8EDU
- **Kristina Collins KD8OXT**
- **David Kazdan AD8Y**
- **John Gibbons N8OBJ**
- Christian Zorman (PI)
- Skylar Dannhoff KD9JPX
- Aidan Montare KB3UMD

Responsibilities
- Low Cost PSWS System

MIT Haystack Observatory
- **Phil Erickson W1PJE**

Responsibilities
- Science Collaborator

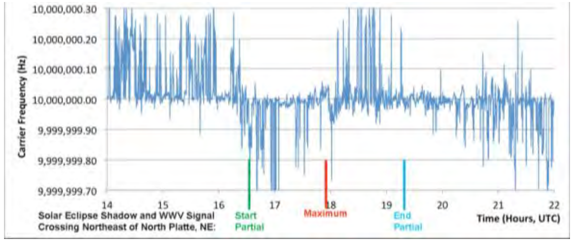
New Jersey Institute of Technology
- **Hyomin Kim KD2MCR (PI)**
- Gareth Perry KD2SAK
- Andy Gerrard KD2MCQ

Responsibilities
- Ground Mag Oversight & Testing
- Science Collaborators

Low-Cost "Grape" PSWS

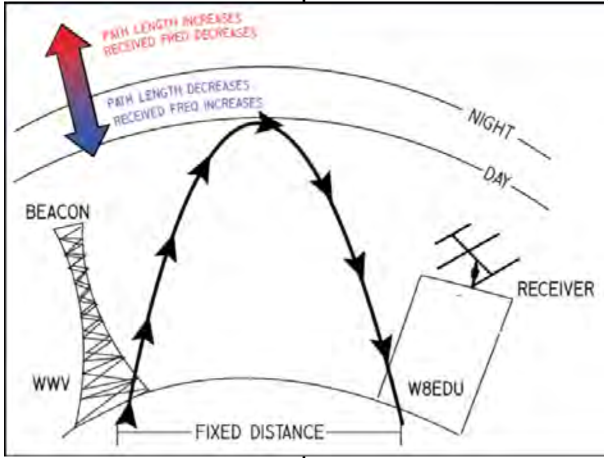
- HF "Doppler Shift" Monitoring
- Main components: Raspberry PI, GPSDO, Custom low intermediate frequency (IF) receiver board
- Cost: ~US$300
- Developed by Case Western

10 MHz Doppler During 2017 Eclipse
TX: WWV RX: WA9VNJ (Milwaukee)



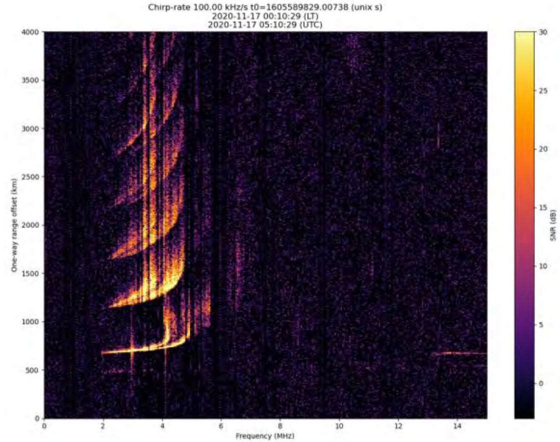
SDR-Based "Tangerine"

- HF FPGA-based Software Defined Radio
- Precision timing and frequency measurement
- 2 to 4 coherent, phase-locked receive channels
- Cost ~US$500 to $1000
- Developed by Amateur Radio Group TAPR



[Collins et al., 2021]

Oblique Ionograms
(Currently on Ettus N200 but will be ported to Tangerine)



Movie by Dev Joshi
GNUChirpsounder2 by Juha Vierinen

Ground Magnetometer

Developed by TAPR and NJIT

Purpose

- To establish a densely-spaced magnetic field sensor network to observe Earth's magnetic field variations in three vector components.

Target performance level

- ~10 nT field resolution
- 1-sec sample rate (note: Earth's magnetic field ranges from 25,000 to 65,000 nT)

Sensors

- PNI RM3100 magnetometer module
  - 3 axis magneto-inductive measurement module
  - Low cost (≤ $20) allows widespread deployment
  - Very small (25.4 x 25.4 x 8 mm)
- MCP9808 temperature sensor

Prototypes have been made and deployed

Software driver development

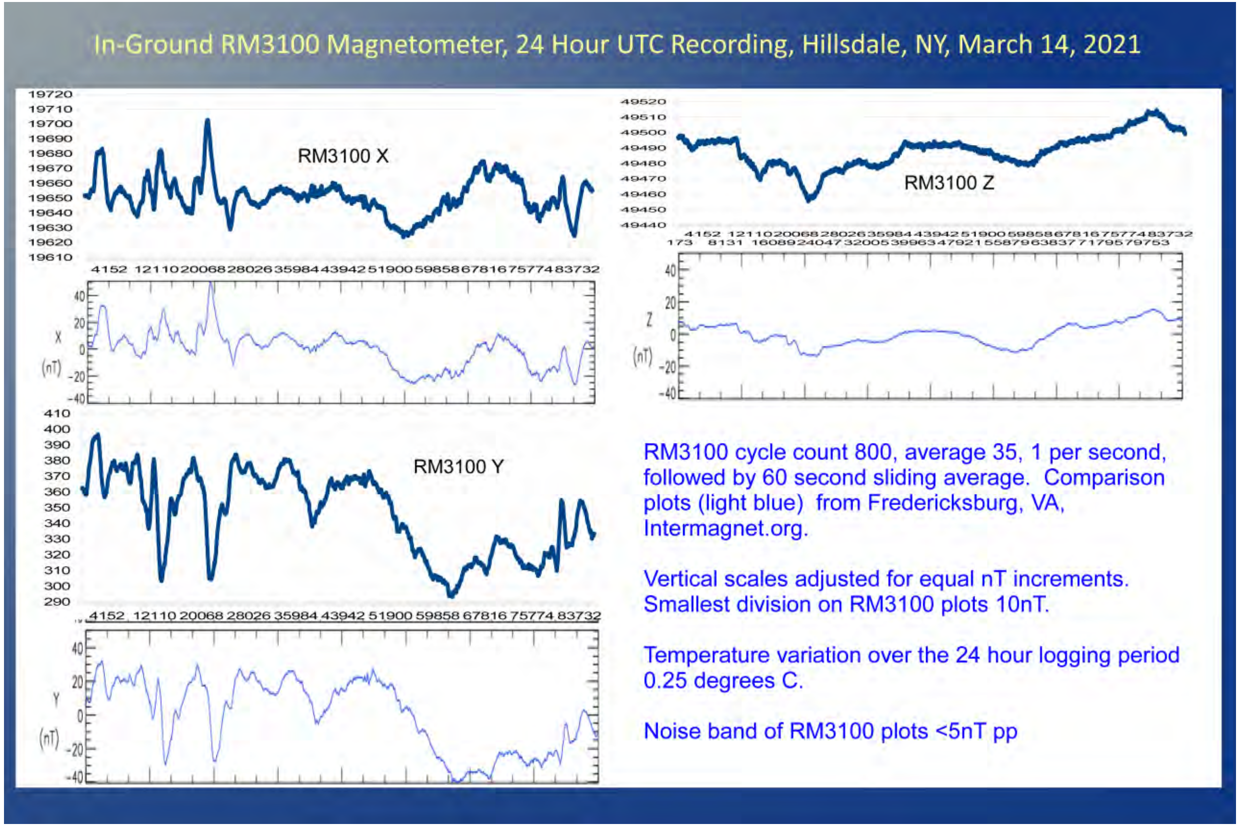
- Current low-level software is rudimentary
- Both low-level and user facing software must be created to support further characterization and optimization of the sensors.

Planned Testing

- Testing at established quiet sites.
- Comparison with calibrated sensors of established quality.

Magnetometer prototype designed by David Witten KD0EAG at the 2020 HamCation conference in Orlando, FL

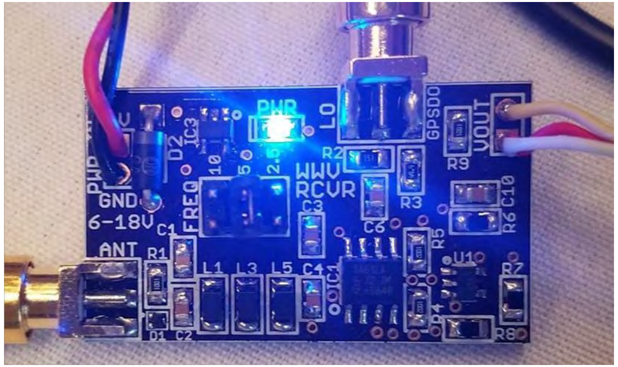
Ground Mag Example



Hillsdale, NY data and data comparison by
Jules Madey K2KGJ

Low-Cost PSWS Status

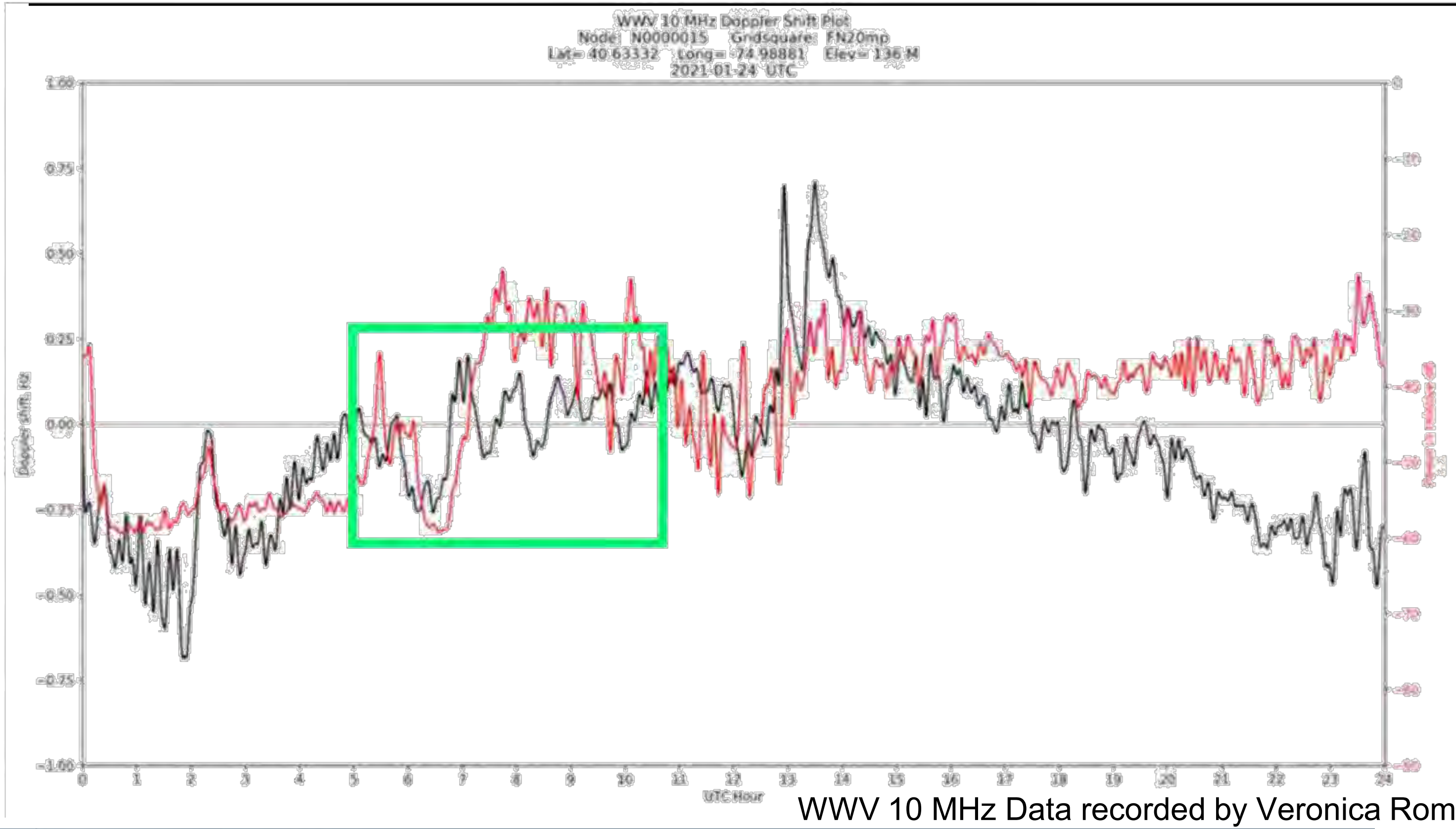
- **Developed as the "Grape" Receiver by Case Western Reserve University and Case Amateur Radio Club W8EDU.**
- **Primary objective** is to measure Doppler Shift of HF standards stations such as WWV and CHU.
- **Cost of Grape v1 is ~$300 (not including antenna).**
- **Several stations** are currently deployed.
- Grape v1 build documentation is available at hamsci.org/grape1.
- Doppler shift data is collected via spectrographs and frequency estimation algorithms**.**
- Grape V2 is currently under development.
- Grape V2 will be capable of monitoring 4 HF channels simultaneously.



"Grape Receiver" Generation 1 by J. Gibbons N8OBJ

Raspberry Pi 4 with Switched Mode Power Supply for Grape Receiver and GNSS Disciplined Oscillator

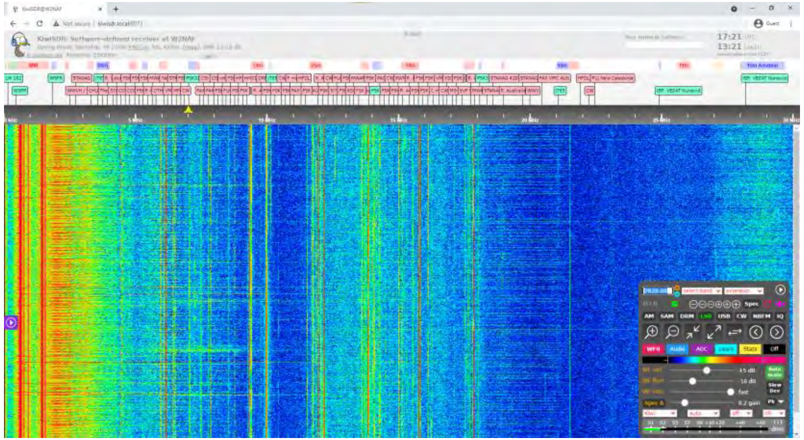
Grape Data Example



WWV 10 MHz Data recorded by Veronica Romanek KD2UHN, Hampton, NJ

Why Software Defined Radio (SDR)?

- A **software defined radio (SDR)** is a radio that performs a significant portion of its signal processing tasks in software.
- This allows tremendous flexibility in how the signals are processed and enables the radio characteristics and purpose to be changed via software.
- By contrast, **analog radios** use purpose-built circuits for specific applications.
- Analog systems are often narrowband and hence limited in the amount of spectrum they can collect; SDRs are often wideband.

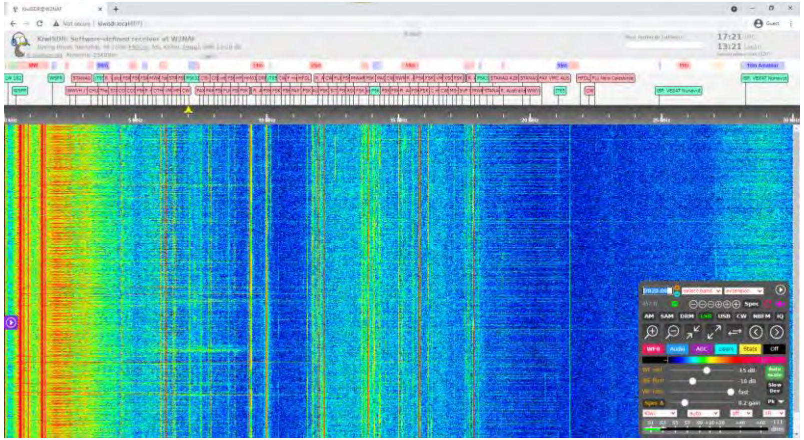


RTL SDR

KiwiSDR

Science Needs of an SDR

- **While SDRs are heavily defined by their software, hardware design is still extremely important and ultimately limits what the SDR can be used for.**
- There are many excellent commercial SDRs on the market, but most (all?) do not meet the needs of the scientific user.
- When commercial solutions do exist, they are often outside of the budget of amateurs.



RTL SDR

KiwiSDR

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Science Needs of an SDR

There are numerous requirements for scientific applications that are less stringent in communications applications:

- Highly Stable Clock
- Precision Timestamping
- Phase-locked measurements from multiple antennas
- Facility for processing and transporting wideband data
- Measure signal and noise calibrated amplitude
- Open Software and Hardware Architecture

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TangerineSDR: A Modular Approach

To accommodate many different use cases, the TangerineSDR uses a modular approach:

1. **Data Engine (DE)**

   Design Engineer: Scotty Cowling, WA2DFI

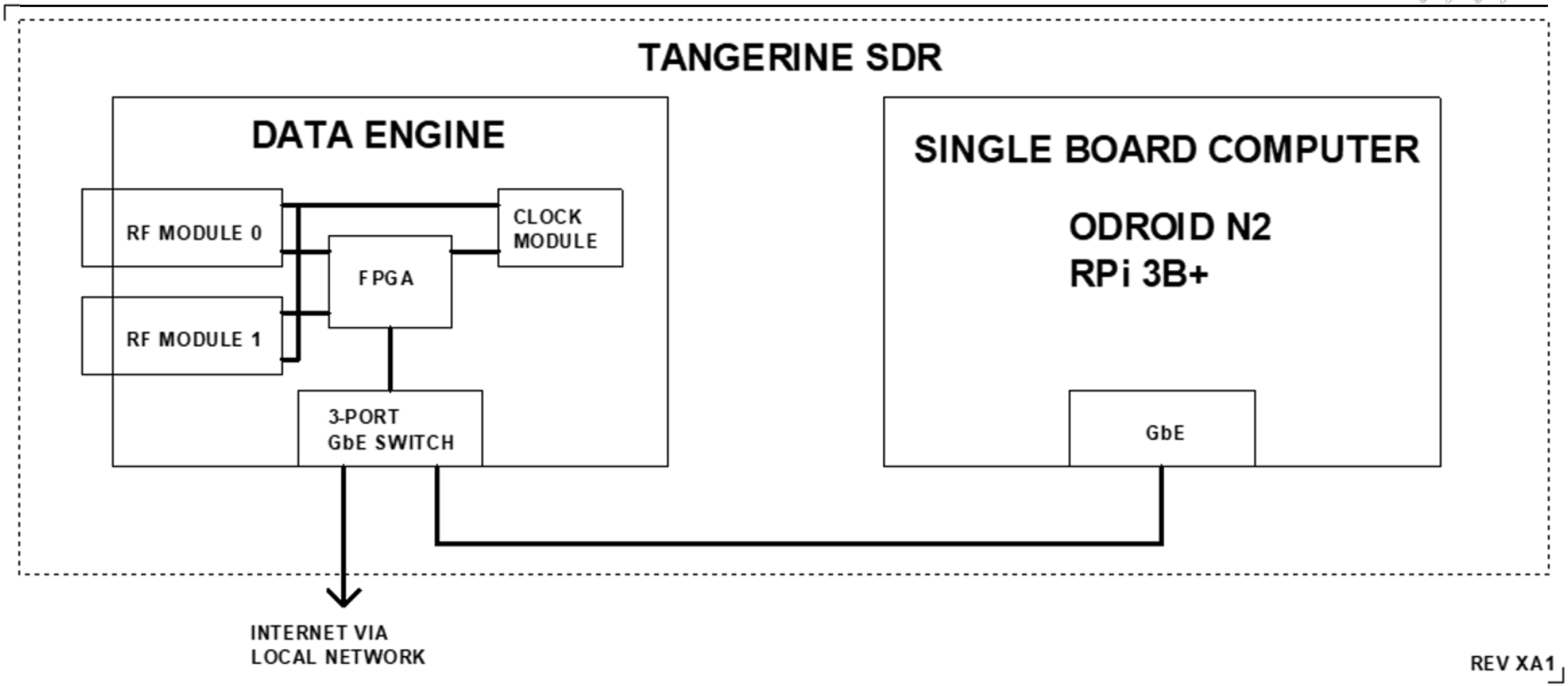
2. **Clock Module (CKM)**

   Design Engineer: John Ackermann, N8UR

3. **Radio Frequency Module (RFM)**

   Design Engineer: Tom McDermott, N5EG

TangerineSDR Block Diagram



Scientific SDR (TangerineSDR)

Developed as "TangerineSDR" by TAPR

Data Engine (DE) Specifications
- Altera/Intel 10M50DAF672C6G FPGA 50K LEs
- 512MByte (256Mx16) DDR3L SDRAM
- 4Mbit (512K x 8) QSPI serial flash memory
- 512Kbit (64K x 8) serial EEPROM
- µSDXC memory card up to 2TByte

Data Engine (DE) Features
- 11-15V wide input, low noise SMPS
- 3-port GbESwitch (Dual GbEdata interfaces)
- Cryptographic processor with key storage
- Temperature sensors (FPGA, ambient)
- Power-on reset monitor, fan header

RF Module (RMF)
- AD9648 125 dual 14 bit 122.88Msps ADC
- 0dB/10dB/20dB/30dB remotely switchable attenuator
- LTC6420 20 20dB LNA
- Fixed 55MHz Low Pass Filter
- Optional user defined plug in filter
- On-board 50Ω calibration noise source
- On-board low noise power supplies
- Dual SMA antenna connectors

Clock Module (CKM)
- Precision timestamping ($\pm$50 ns accuracy)
- Frequency reference (Parts in 10^{13} over 24 hr)

Current Status
- Prototypes waiting on availability of FPGA chips
- More information at tangerinesdr.com

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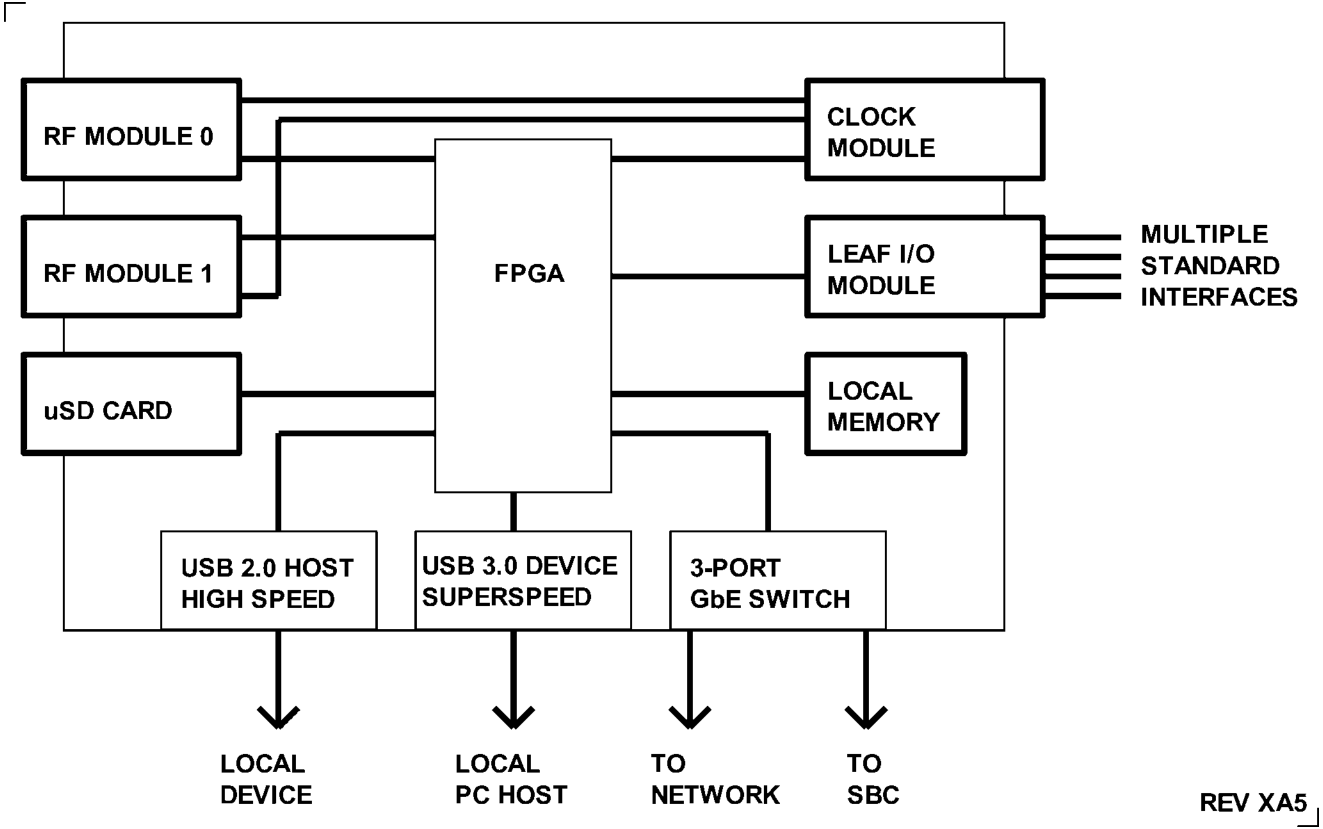
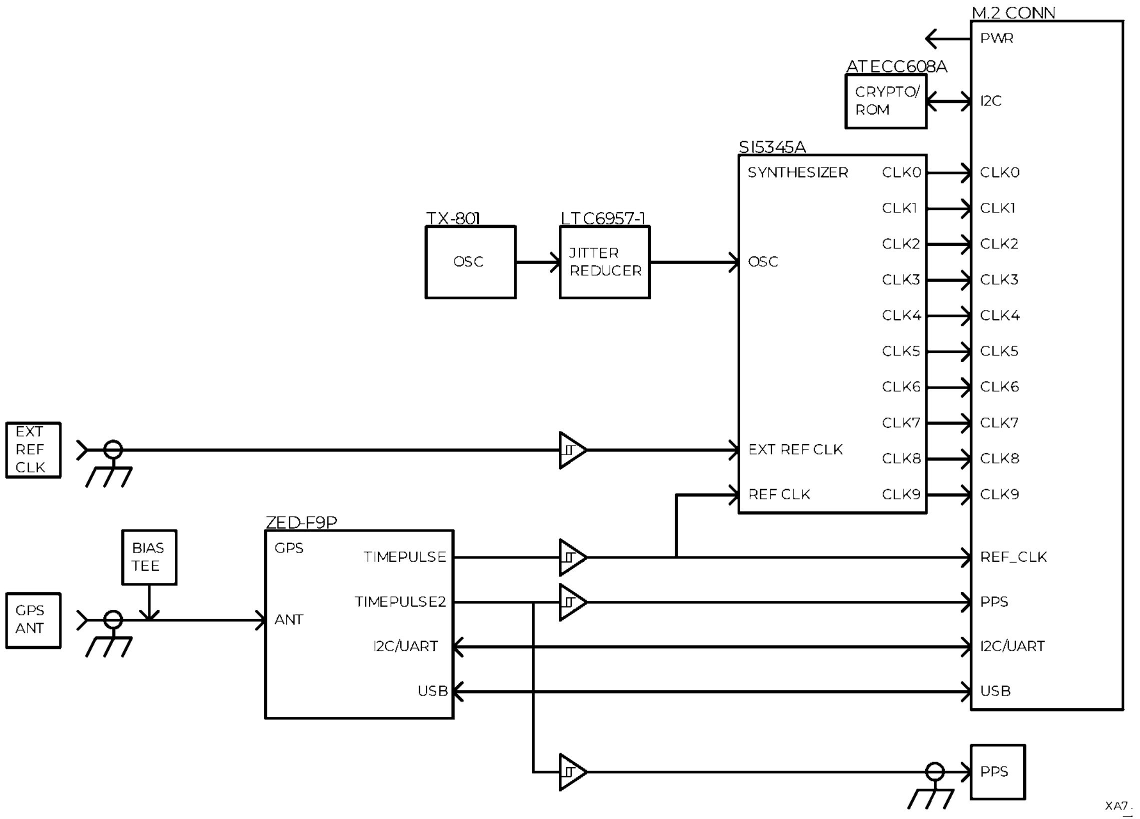
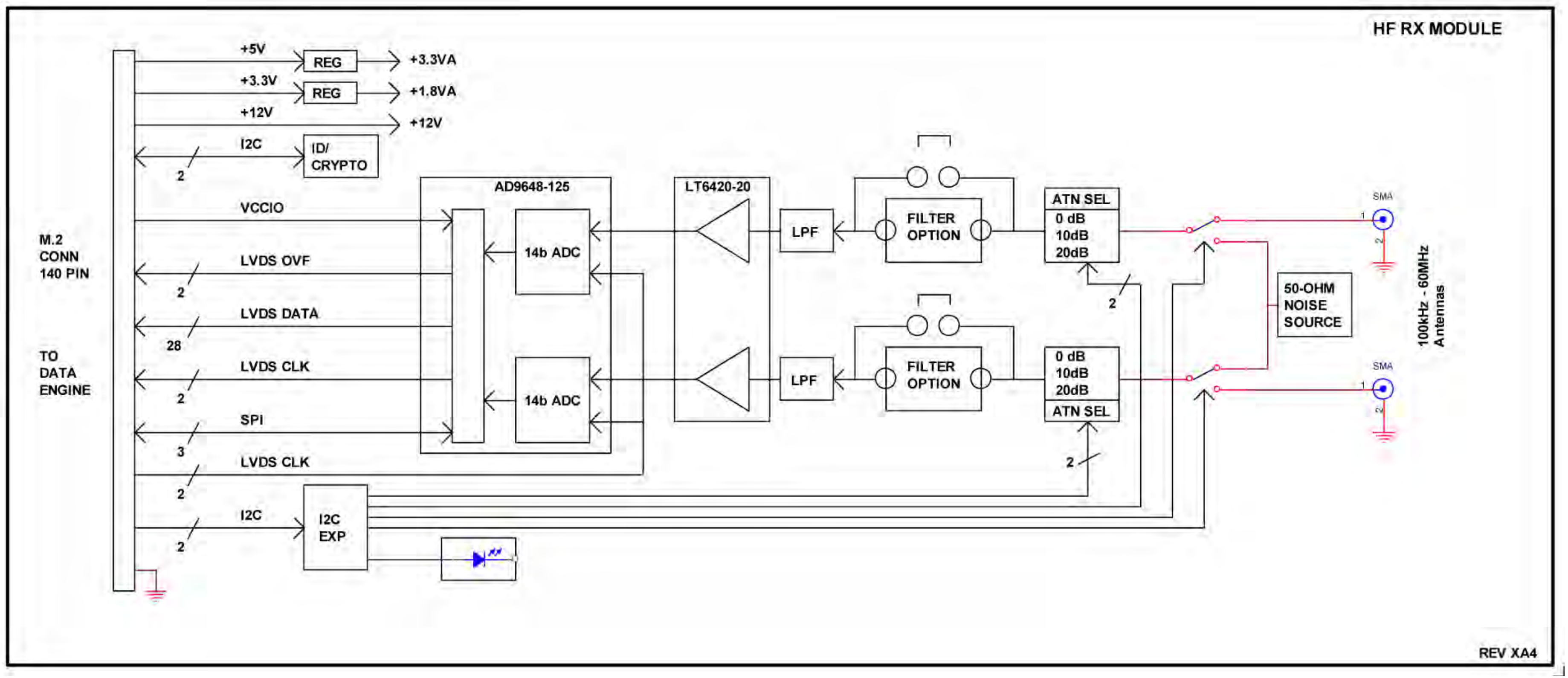
Data Engine Block Diagram



Clock Module Block Diagram



RF Module Block Diagram



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Radio JOVE

- Radio JOVE is a NASA-supported citizen science project started in 1998 to study radio emissions from Jupiter and the Sun.
- Standard Radio JOVE system receives a single narrow-band signal at 20.1 MHz.
- Advanced users often wish to observe wideband spectra to gain significantly greater physical insight to physical processes.

RJ 1.1 receiver, battery, amplifier, and recorder [NASA]

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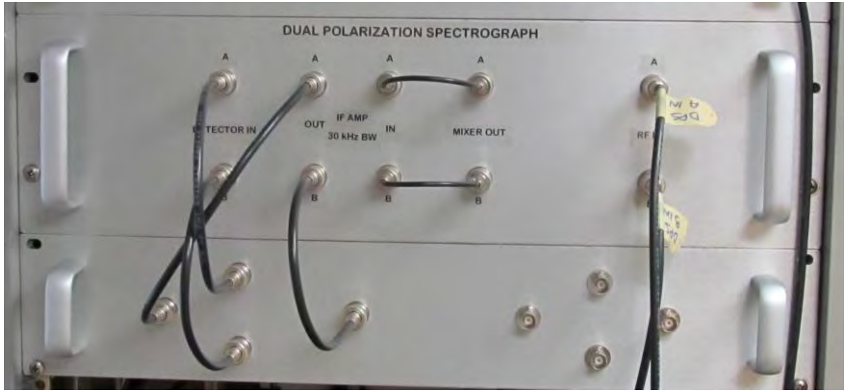
Dual Polarization Spectrograph (DPS)

- Developed by Richard Flagg AH6NM, Jim Sky KH6SKY, and Dave Typinski AJ4CO
- Dual Swept-Frequency Receivers
- Sweeps 300 30 kHz BW channels from 32 MHz down to 16 MHz at a rate of 6.7 sweeps per second
- 12-bit ADC
- 50 dB Dynamic Range
- 7 dB (1.2 kK) Noise Figure

  (insignificant compared to galactic background of 100 kK at 15 MHz and 18 kK at 30 MHz)

(Typinski, 2014)

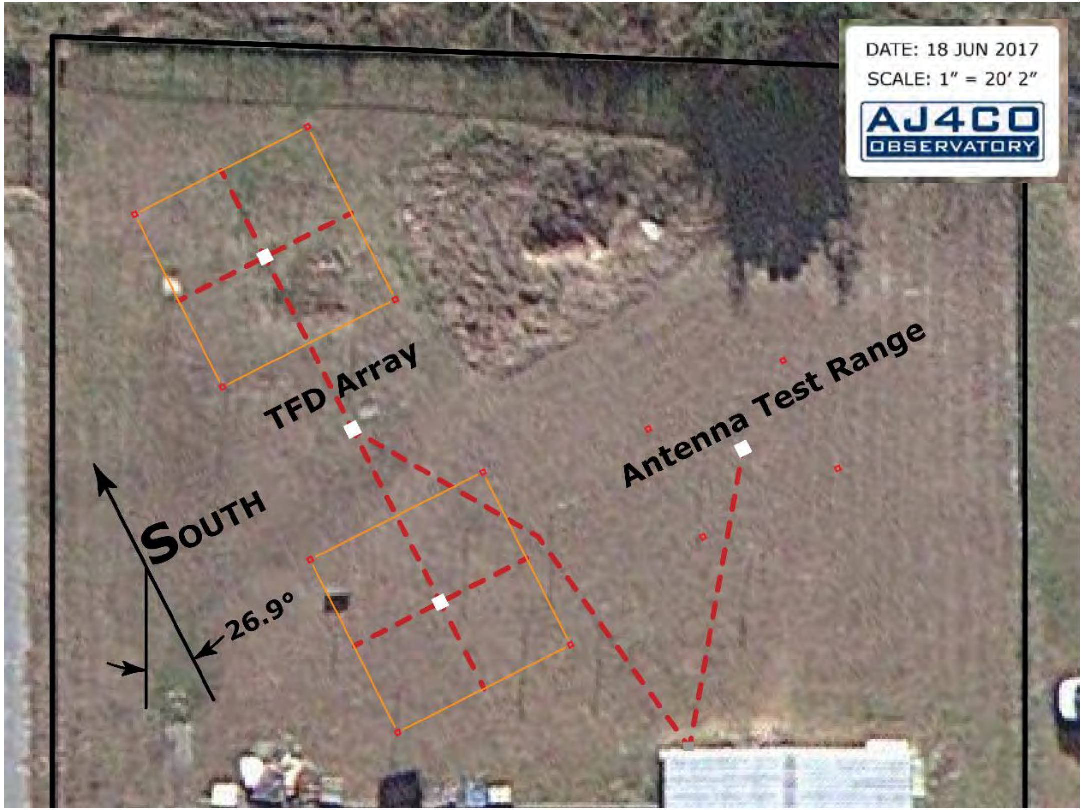


AJ4CO Observatory, High Springs, Florida

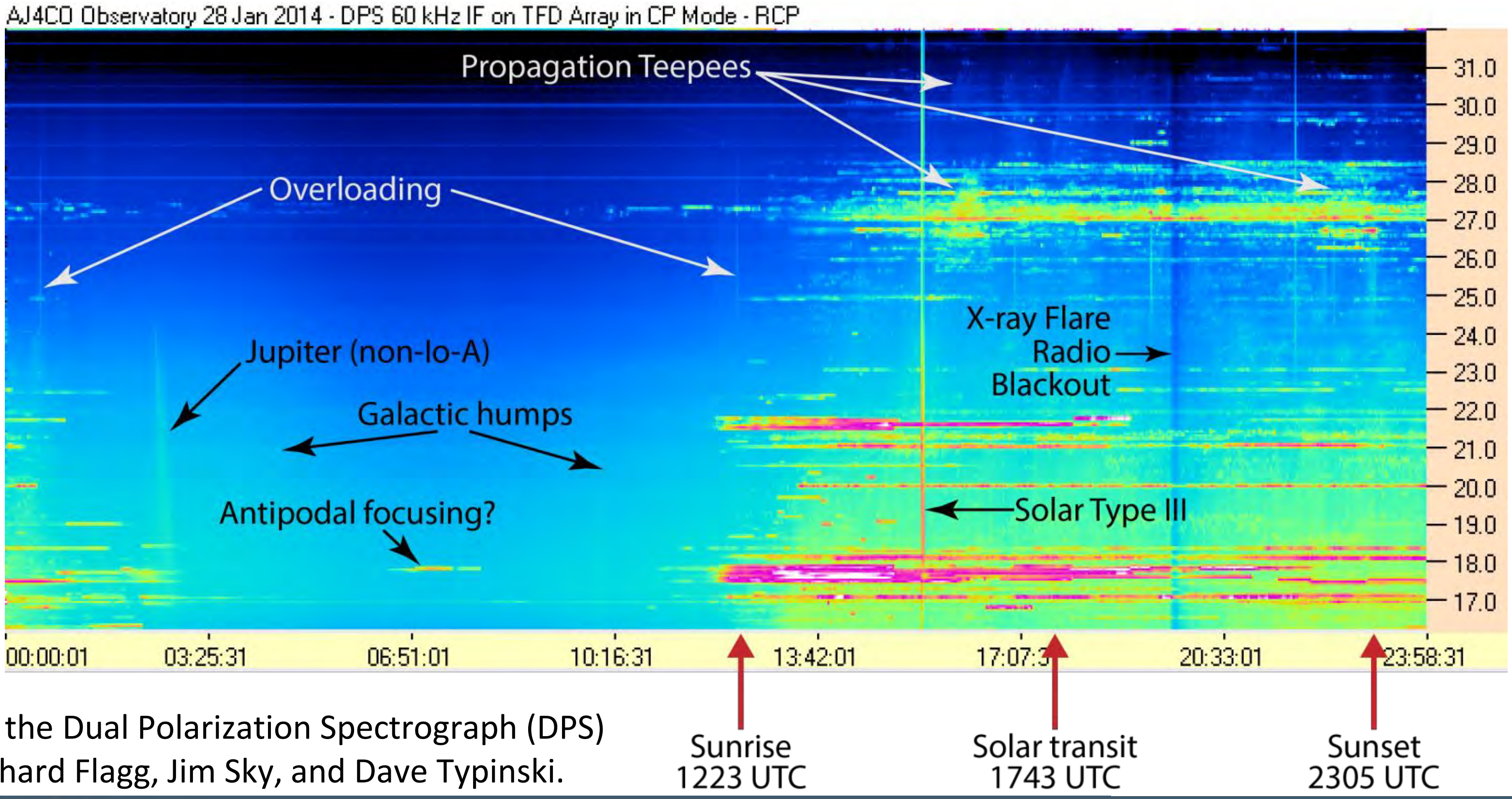
AJ4CO Terminated Folded Dipole Array

- Dual-square, 8-element array
- Steerable
- Separate outputs for Right-hand Circular Polarization (RCP) and Left-hand Circular Polarization (LCP)
- Wideband
- Decent Gain
- Low Cost

(Typinski, 2014)



AJ4CO Example HF Spectrogram



Produced using the Dual Polarization Spectrograph (DPS) designed by Richard Flagg, Jim Sky, and Dave Typinski.

Jovian Decametric Emissions

- **Plasma processes within Jupiter's magnetosphere naturally produce radio emission with frequencies between 3 and 40 MHz.**

  (Burke and Franklin, 1955; Zarka et al., 2001; Alexander et al., 1981; Clarke et al., 2014)

- These are known as Jovian Decametric Emission (Jovian DAM), because it comes from Jupiter and have wavelengths tens of meters long.
- Jovian DAM above 10 to 15 MHz can penetrate the Earth's ionosphere and is observable from the ground.
- Jovian DAM is within the range of the current TangerineSDR RFM design.

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Jovian-L (Long) Bursts

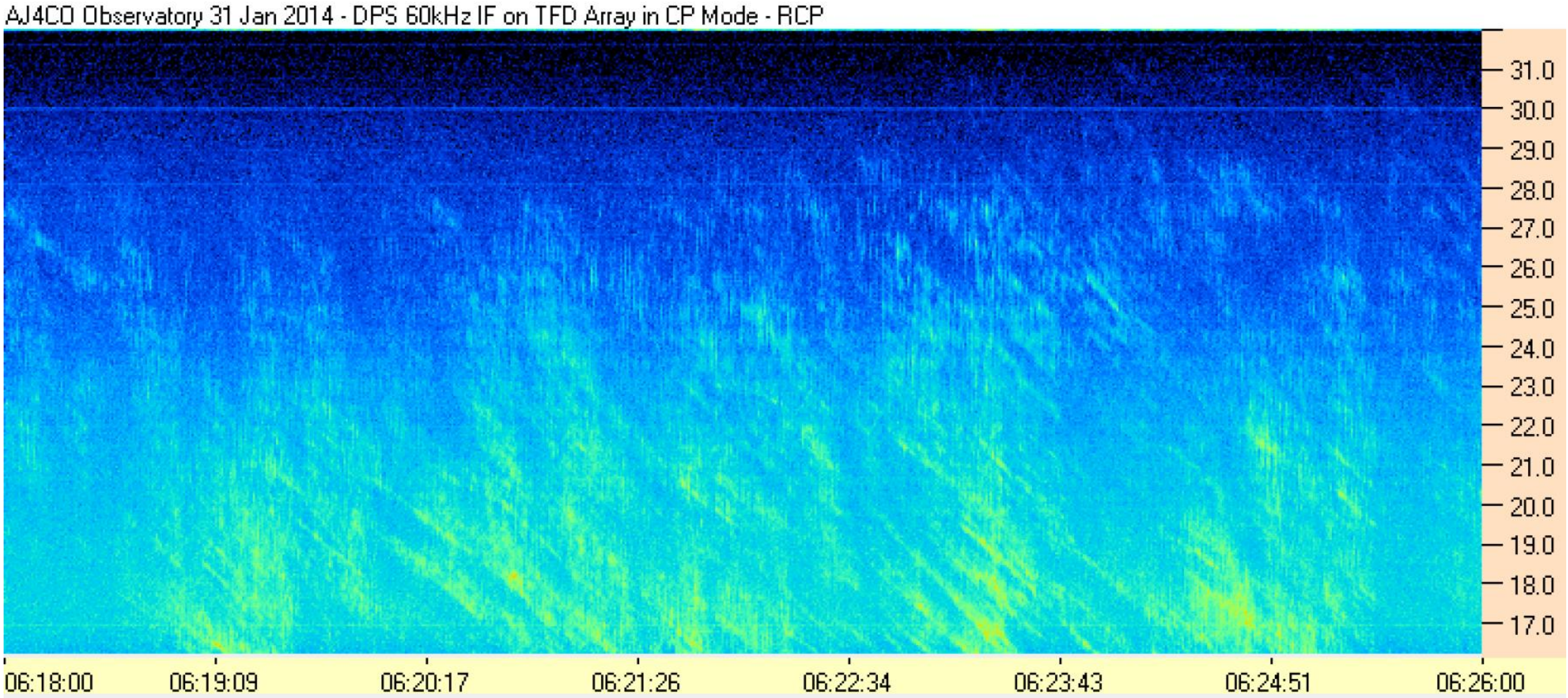
- Gaussian noise with an intensity periodicity of 2 to 10 s.
- Poorly defined spectral structure.

(Carr and Reyes, 1999)

- Longer, more vertical lanes are a combination of
  - the natural variation in the emission source
  - scintillation due to propagation through the terrestrial ionosphere.
- Diagonal lanes modulating L bursts are thought to be produced by propagation through density variations within the Io plasma torus.
- Io plasma torus is a large ring of plasma around Jupiter consisting mostly of ionized volcanic gases from the moon Io.

(Imai et al., 1992)

Jovian L-Bursts



Produced using the Dual Polarization Spectrograph (DPS) designed by Richard Flagg, Jim Sky, and Dave Typinski.

Jovian S (Short) Bursts

- Sharply defined spectral structure.
- Typically appear for intervals of a few seconds with a repetition rate of 2 to 400 s^{-1}, most commonly around 20 s^{-1}.
- Individual bursts typically have a negative frequency drift rate on the order of -20 MHz s^{-1}.

(Carr and Reyes, 1999)

- Due to the high repetition rate and well-defined spectral structure, a high temporal cadence is a requirement for proper S-burst observation.
- The DPS used for the previous two spectrograms is too slow to sufficiently resolve the S-bursts.

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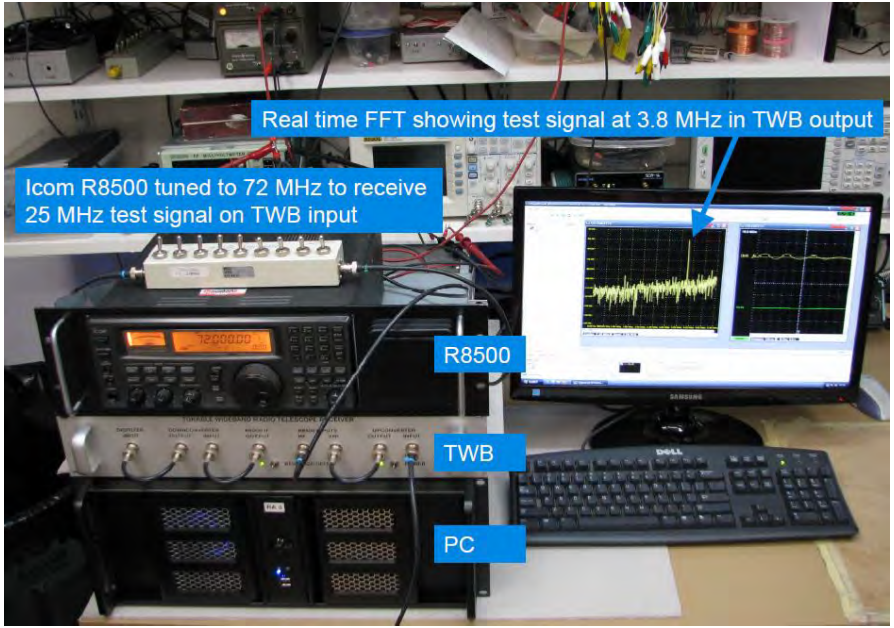
Tunable Wideband Receiver (TWB)

- SDR Instrument with 2 MHz Bandwidth
- Capable of resolving spectrum at 205 μs cadence for 250 ms at a time.
- Designed by Dave Typinski, Richard Flagg, and Wes Greenman

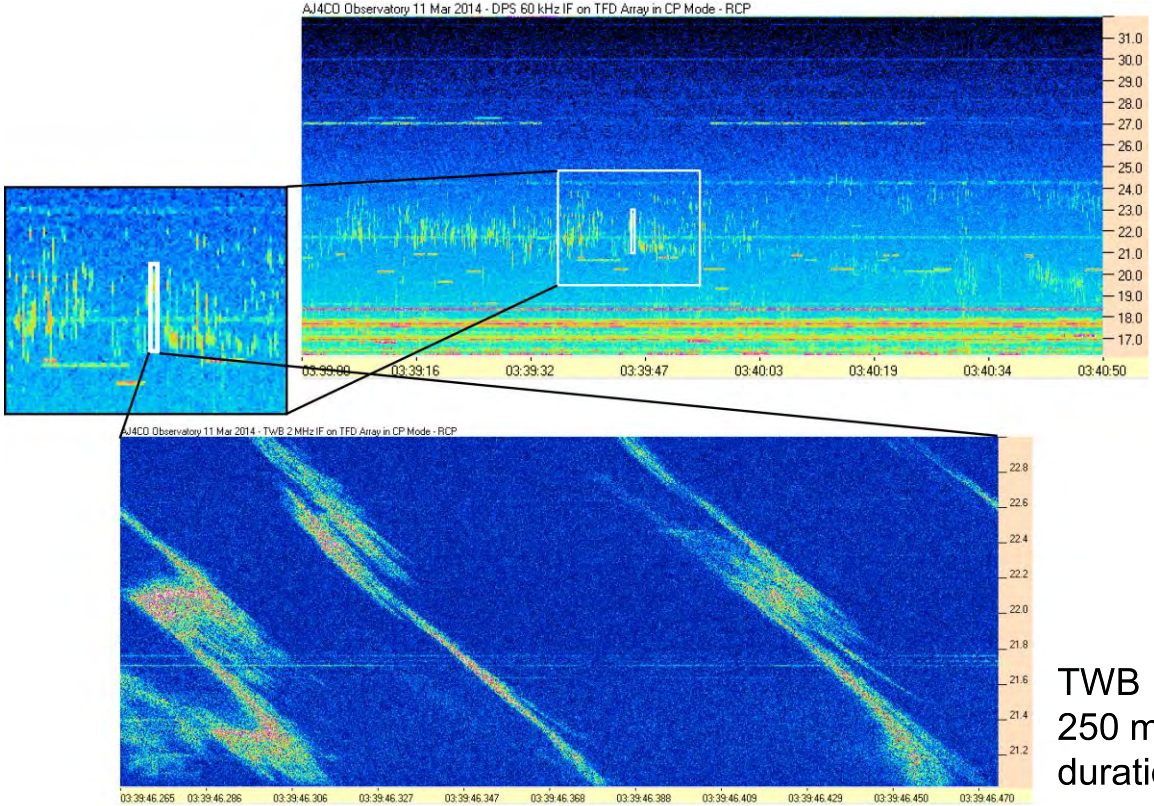
(Typinski et al., 2014)

- Although limited in bandwidth and duration, the spectral structure of S-bursts can now be well resolved.



AJ4CO Tunable Wideband Receiver

Jovian S-Bursts



DPS
2 minute
duration

TWB
250 ms
duration

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TangerineSDR Selected Key Specifications

Requirement	Technical Approach	Value
Highly Stable Clock	• GNSS Disciplined Oscillator with TCXO	• parts in 10^{-10} (1 sec averaging) • parts in 10^{-12} (1000 sec averaging)
Precision Timestamping	• GNSSDO PPS with Timestamping in FPGA	• ±50 ns accuracy
Phase-locked measurements from multiple antennas	• Up to 4 phase-locked RF inputs per data engine • CKM has clock signal input/output to synchronize multiple DEs	
Facility for processing and transporting wideband data	• Intel MAX10 FPGA 50k LE • Gigabit Ethernet	• 20 – 30 MHz bandwidth
Measure signal and noise calibrated amplitude	• On-board Switchable Noise Source	• Switching time < 15 ms • Fixed Excess Noise Ratio (ENR) close to 15 dB (9.6 kK)
Open Software and Hardware Architecture	• Software GPLv3 • Hardware TAPR Open Hardware License	

PSWS Open Hardware/ Software Philosophy

- While the PSWS is ultimately being designed to create a network of stations that work together under central control for space weather observations, the system is open and allows for the owner to take full control of their local node if desired.
- Even with the standard software, the TangerineSDR will be able to provide raw/minimally processed wideband IQ streams over gigabit ethernet.
- This allows the system to be used for radio astronomy and other applications.

Additional Radio Astronomy Applications

- Immediately, the TangerineSDR will be usable for Radio Astronomy applications in the range of 0.1 – 60 MHz, such as RadioJove.
- The system can also be used on other frequencies with appropriate front-end filters, low-noise amplifier, and downconverter, or in an undersampling mode with appropriate filters.
- In this manner, other potential Radio Astronomy use cases include:
    - Pulsar detection in VHF through microwave bands
    - Study of galactic neutral hydrogen clouds using Doppler shift around 1.42 GHz to infer the galactic rotation curve to infer the presence of dark matter
    - Study of the age of re-ionization neutral hydrogen observations around 70 MHz

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Future Work

- Beyond the scope of the PSWS, TAPR intends to create additional versions of the different TangerineSDR modules, including:
  - A data engine (DE) with a larger FPGA and 10 GbE, allowing for wider bandwidth data.
  - RF modules with different frequency ranges and with transmit capabilities.

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Current Status

- Design of the TangerineSDR is complete.
- Almost all parts for the TangerineSDR are purchased and are in storage ready for an initial prototype build of 25 units.
- Due to the global chip shortage, we are waiting for delivery of the FPGAs critical to the data engine. Current FPGA delivery estimate February 2022.
- In the meantime, we do have Intel MAX10 FPGA development boards we are planning to use as substitute data engines.
- This will allow for FGPA code development and testing of RFMs and CKMs.
- If all goes well, we will have fully working prototypes within one year.

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Summary

- HamSCI is a collective that aims to bring together the amateur radio and professional space science research communities for mutual benefit.
- In an effort to improve the scientific usability of amateur radio observations, HamSCI is developing a Personal Space Weather Station designed with science requirements in mind from the very beginning. These modular systems will include:
  - HF Radio Receivers for studying the ionosphere using signals of opportunity
  - Ground Magnetometer with ~10 nT resolution
  - GNSS Receivers for precision timestamping and frequency stability
  - Target price between $300 - $1000, depending on capabilities.
- The TangerineSDR will have broad applicability to Radio Astronomy applications, especially RadioJove.
- Goal is to have working prototypes within a year.

Acknowledgments

We are especially grateful for the

- support of NSF Grant AGS-2002278, AGS-1932997, and AGS-1932972.
- support of Amateur Radio Digital Communication (ARDC).
- amateur radio community volunteers who have contributed engineering, testing, and data collection efforts to the PSWS project.
- amateur radio community who voluntarily produced and provided the HF radio observations used in this paper, especially the operators of the Reverse Beacon Network (RBN, reversebeacon.net), the Weak Signal Propagation Reporting Network (WSPRNet, wsprnet.org), PSKReporter (pskreporter.info) qrz.com, and hamcall.net.
- use of the Free Open Source Software projects used in this analysis: Ubuntu Linux, python (van Rossum, 1995), matplotlib (Hunter, 2007), NumPy (Oliphant, 2007), SciPy (Jones et al., 2001), pandas (McKinney, 2010), xarray (Hoyer & Hamman, 2017), iPython (Pérez & Granger, 2007), and others (e.g., Millman & Aivazis, 2011).
- This presentation includes results that were obtained using the HF propagation toolbox, PHaRLAP, created by Dr Manuel Cervera, Defence Science and Technology Group, Australia (manuel.cervera@dsto.defence.gov.au). This toolbox is available by request from its author.

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Thank You!

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Abstract

The Ham Radio Science Citizen Investigation (HamSCI) Personal Space Weather Station (PSWS) project is a citizen science initiative to develop a new modular set of ground-based instrumentation for the purpose of studying the structure and dynamics of the terrestrial ionosphere, as well as the larger, coupled geospace system. PSWS system instrumentation includes radio receivers sensitive to frequencies ranging from the very low frequency (VLF) through very high frequency (VHF) bands, a Global Navigation Satellite System (GNSS) receiver to provide Total Electron Content (TEC) measurements and serve as a precision time and frequency reference, and a ground magnetometer sensitive to ionospheric and geospace currents. Although the PSWS is designed primarily for space weather and space science, its modular and open design in both hardware and software allows for a variety of use cases. The core radio instrument of the PSWS, the TangerineSDR, is a wideband, direct sampling 100~kHz to 60~MHz field programmable gate array (FPGA)-based software defined radio (SDR) receiver with direct applicability to radio astronomy. In this paper, we describe the PSWS and TangerineSDR architecture, show examples of how the TangerineSDR could be used to observe Jovian decametric emission, and discuss the applicability of the TangerineSDR to radio astronomy in general.

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Backup Slides

PSWS Current Engineering Status

- **Tangerine Data Engine (MAX10)**
  - Schematic capture: 100% complete
  - BOM: 100% complete
  - Component placement: 100% complete
  - Almost all parts delivered
  - Next step: Waiting for FPGA and USB chip delivery
- **Tangerine RF Module (dual-channel 0.1-54MHz)**
  - Schematic capture: 100% complete
  - BOM: 100% complete
  - Component placement and routing: 100% complete
  - Update will be required for DE compatibility
- **Tangerine Clock Module (ZED-F9T SynthDO)**
  - Schematic capture: 100% complete
  - BOM: 100% complete
  - Component Placement: 100% complete
- **MagnetoPi Hat**
  - Schematic capture: 100% complete
  - BOM: 100% complete
  - PC Board placement and layout: 100% complete
  - Compatibility review with LC-PSWS: 100% complete
  - Prototype build of 50 units: 100% complete

- **Low Cost PSWS (Grape)**
  - Grape Generation 1 consists of
    - Leo Bodnar GPSDO frequency standard
    - low IF receiver
    - USB based A/D converter
    - RaspberryPi running a modified version of FLDIGI
  - Several Grape V1 stations operational, and build instructions available at hamsci.org/grape1.
  - Grape v2 Design in Progress, will be capable of receiving 4 HF channels simultaneously.

- **Control Software and Database**
  - Prototype of local control software exists
  - Runs on Odroid N2 Single Board Computer
  - Uses data from a TangerineSDR Simulator (FlexRadio with GPSDO + DAX IQ output)
  - Can monitor up to 16 band segments at a time
  - 4 types of data collection: Snapshotter, Ring Buffer, Firehose(L+R), and FT8/WSPR Propagation Monitoring
  - Proof of concept code working for all modes except WSPR and Firehose L (supercomputer interface)

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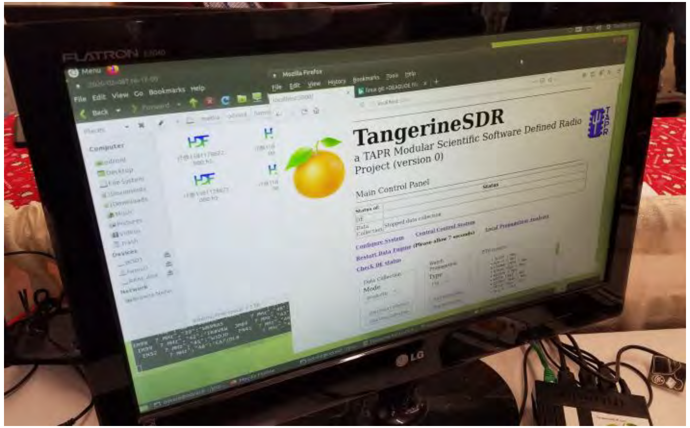
PSWS Control Software and Database

Developed by University of Alabama

Primary objective

- Local Control Software for Tangerine SDR
- Central Control System for PSWS Network
- Central Database to collect observations

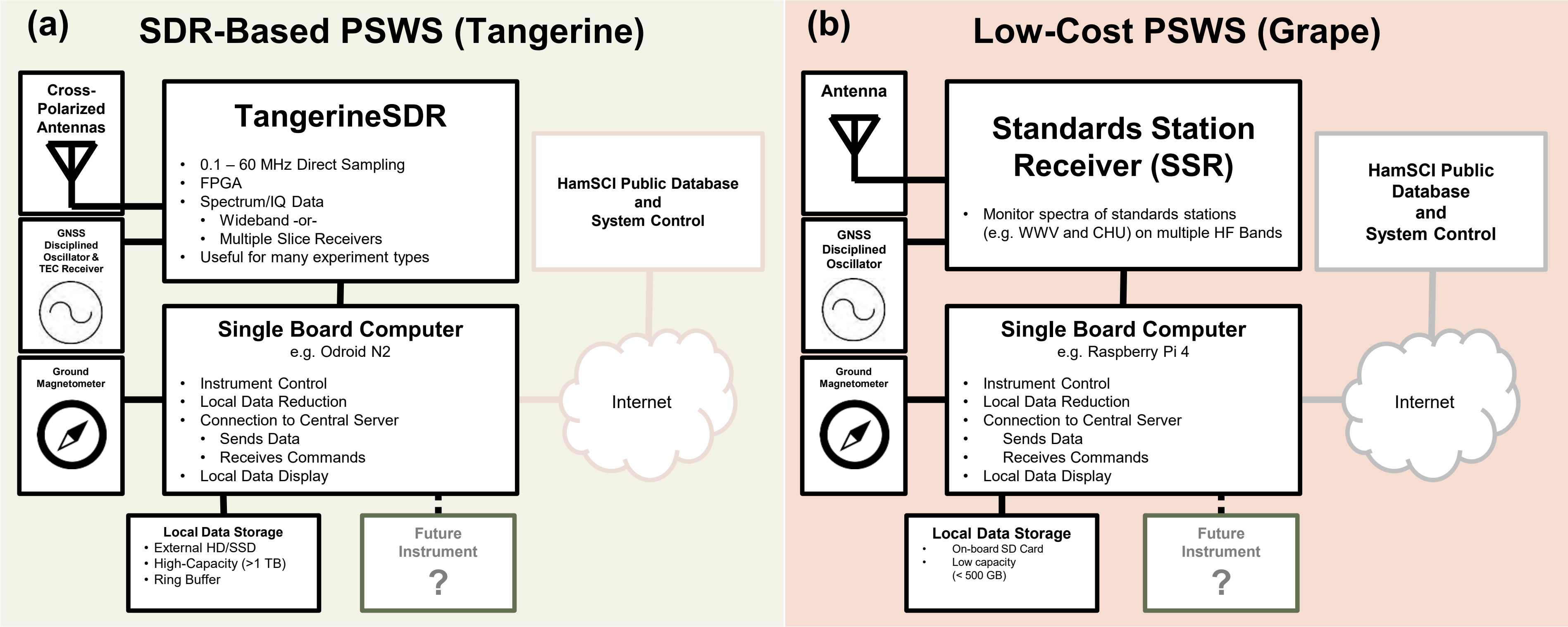


Bill Engelke AB4EJ demonstrates early versions of the TangerineSDR Local Control Software and Simulator at 2020 HamCation in Orlando, FL.

Current Status

- Prototype of local control software exists
- Runs on Odroid N2 Single Board Computer
- Uses data from a TangerineSDR Simulator
- Can monitor up to 16 band segments at a time
- 4 types of data collection
    - **Snapshotter:** wideband high frequency spectrograms at a 1 second cadence.
    - **Ring Buffer:** Continuous local storage of IQ samples for 24 hours, then upload on request from Central Control (with throttling)
    - **Firehose:** Continuous transfer IQ samples to a local computer
    - **Propagation Monitoring:** Decoding of FT8 and WSPR amateur radio digital modes on up to 8 bands at a 1 minute cadence

SDR-Based and Low-Cost PSWS Versions



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Motivation

- Ability to advance knowledge in radio astronomy and space science is increasingly dependent on the ability to process large amounts of high-quality, broadband radio spectrum measurements from numerous receivers, potentially spread across a large geographical domain.
- Technologies such as software defined radio and advancements in computers and networking are now making this possible, even for amateurs and citizen science.

Green Bank 100 m Radio Telescope
https://commons.wikimedia.org/wiki/File:GBT.png

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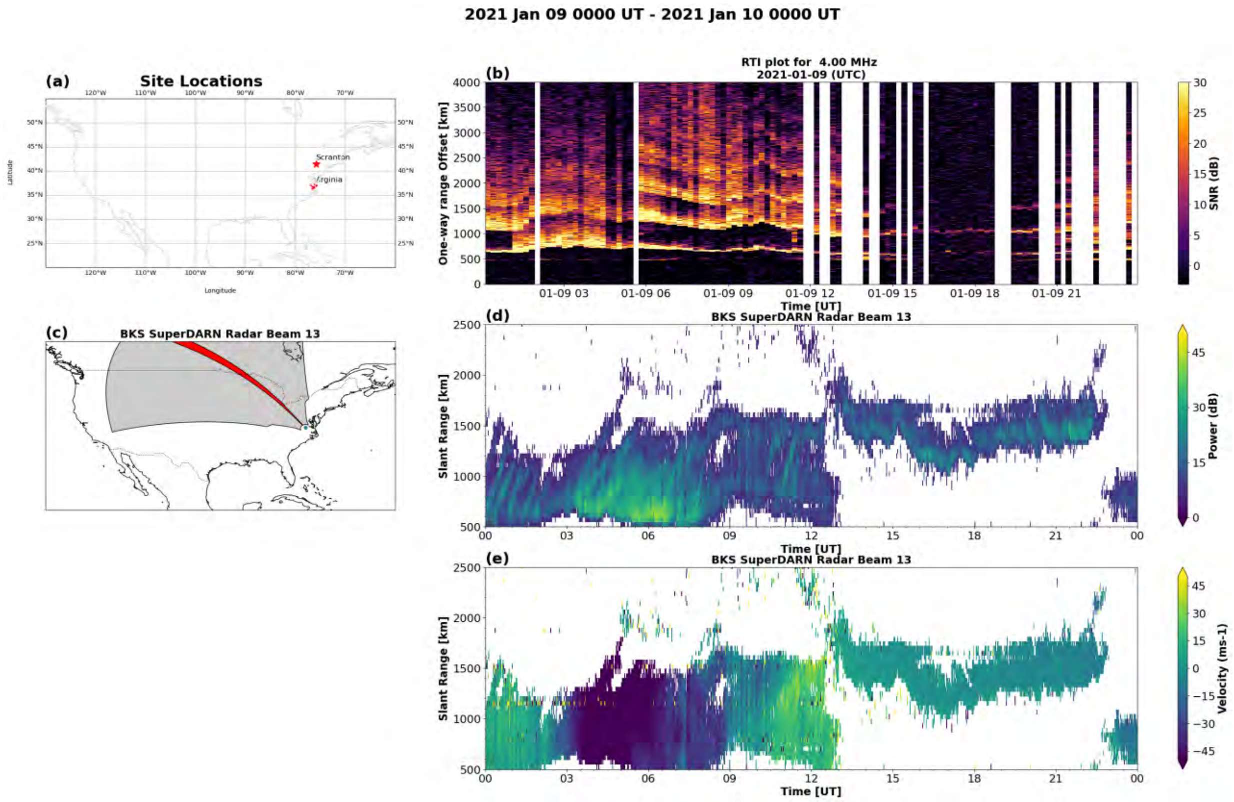
Chirpsounder Example



Science Needs of an SDR

- Dodd et al. (2019) of the RadioJove Spectrograph Users Group (SUG) put out a SDR design specifications document as guidance for Scientific SDR requirements.