Winn Comm 2022

NSF SWIFT: Passive Active Spectrum Sharing (CU-PASS)

HCRO NRDZ: Hat Creek Radio Observatory National Radio Dynamic Zone

NSF SII-NRDZ HCRO-NRDZ Field Deployment

CU-Boulder | UC-Berkeley | HCRO SETI | Google

2022-12-14

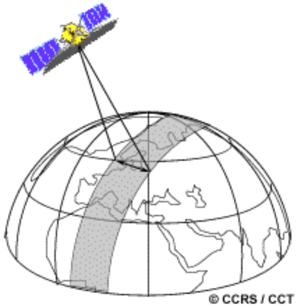
CU-Boulder, HCRO, Google SII-NRDZ Project Summary: *Radio Astronomy Dynamic Satellite Interference and Spectrum Sharing (RADYSIS)*

PIs/Co-PIs: K. Gifford (CU), D. DeBoer (HCRO), A. Pollak (HCRO), K. Gremban (CU), E. Eichen (CU), A. Clegg (Google)

The RADYSIS Prototype activities build upon the original NSF SWIFT University of Colorado Passive and Active Spectrum Sharing (NSF Award #2030233) key objectives:

- Analysis and characterization of RF noise with respect to the environment to identify patterns.
- Explore new approaches to dynamic spectrum sharing between passive & active services.
- Quantitative analysis of spectrum sharing mechanisms between passive and active services.
- Explore approaches to optimize the efficiency and security of dynamic spectrum sharing.
- Exploration of operational mechanisms for a National Radio Dynamic Zone (NRDZ).

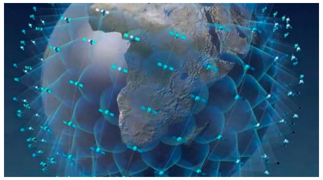
The overarching project goal is to prototype and deploy an automated spectrum sharing system for field trials at HCRO as an example NRDZ that will improve spectrum access for terrestrial RA facilities and for low-earth-orbit-observing (e.g., EESS) passive satellites.



- Design and deploy the in-orbit EESS passive satellite spectrum sharing system.
- Design and deploy the RA dynamic protection spectrum sharing system.
- Evaluation and evolution of deployments at the Hat Creek Radio Observatory.

The RADYSIS Project will make multiple specific contributions to the scientific community, including:

- Dynamic protection for RA to mitigate RF interference (RFI) from satellite transmissions.
- Bi-lateral spectrum sharing between RA and mobile broadband cellular services.
- Mitigation of interference to satellites via spectrum sharing with terrestrial wireless providers.
- Deployment of spectrum sharing prototype systems to (1) protect RA terrestrial observatories, and (2) protect LEO passive earth-observing satellites from increasing interference.
- Tools and metrics for quantitative analysis of dynamic spectrum sharing effectiveness.
- Processes for optimizing the effectiveness and security of dynamic spectrum sharing.
- Preliminary operational definition and requirements for a NRDZ.
- Lessons-learned for the general NRDZ research community as an example NRDZ site.



Presentation Outline

- Teaming importance and members
- Goals of SII-NRDZ and related spectrum sharing projects including NSF SWIFT and NSF HCRO-NRDZ

- Functional Block Diagram (FBD)
- SII-NRDZ specific activities
  - Satellite dynamic protection for terrestrial RA
  - Rogue RFI emitter detection and geolocation
  - LEO satellite spectrum sharing – project kick-off
- Questions and Discussion

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SII-NRDZ: Study Area Topics

Study Area Proposed Topic	NSF 22-579 Study Area Type	RDZ Function	NSF 22-579 Priority Scenarios alignment with Proposed Topic
(1) Passive/active EESS satellite spectrum sharing	SII-NRDZ-STUDY AREA 1: Prototyping and risk analysis of an end-to-end generally applicable spectrum sharing solution for NRDZ field trials	Dynamic Protection Dynamic Coexistence	Satellite-based active/passive RF sensing for terrestrial, environmental and space research Research and experimentation on advanced comms, sensing, and spectrum management systems
(2) Satellite interference mitigation for Radio Astronomy	SII-NRDZ-STUDY AREA 2: Investigation of applications and sites	Dynamic Protection	Radio telescope observations Research and experimentation on advanced comms, sensing, and spectrum management systems
(3) Field Testing of proposed topics (1) and (2) at Hat Creek Radio Observatory	SII-NRDZ-STUDY AREA 3: Field Testing	Dynamic Protection Dynamic Coexistence	Satellite-based active/passive RF sensing for terrestrial, environmental and space research Research and experimentation on advanced comms, sensing, and spectrum management systems

NSF Priority Activities for Fall 2022, CY2023

NSF SWIFT (Through 8/31/2023)

- RFBS subsystem (#1) Evolve documentation and self-calibration, set new demo
- RF Open Data Sets (#2) RFDataFactory (discussion on SigMF, HDF5, etc.); evolve

NSF HCRO-NRDZ (Through 9/30/2023)

- SAS initial deployment/testing (#3)
  - Spring 2023 demos
- Satellite dynamic protection for terrestrial RA (#4)
  - TARDyS3 evolution, Spring 2023 demos

NSF SII-NRDZ (Through 9/30/2025)

- Satellite dynamic protection for terrestrial RA (#4)
  - Spring 2023 demos
- Rogue RFI emitter detection and geolocation (#5)
  - Spring 2023 demos at CU-Boulder, then demo at HCRO
- LEO satellite spectrum sharing – project kick-off (#6)

Take Away Messages

We can’t hide.

We must share.

Take Away Messages II

- The EM spectrum is a finite, shared resource. Sharing is happening already - both deliberately and incidentally.
- These trends will accelerate.
- There are many axes of sharing[4,5,6].
- We need to start now to figure out what may work for RA[1,2,3].

[1] Gifford, K.K. and DeBoer, D., et al, "Hat Creek Radio Observatory National Radio Dynamic Zone Project Overview", USNC-URSI National Radio Science Meeting, Boulder, CO, January 2022

[2] DeBoer, Croft, Siemion, University of California, United States; Gifford, Aradhya, Lofquist, Weihe, University of Colorado, United States; Clegg, Google, United States; Farah, Pollak, SETI Institute, United States; O'Shea, West, DeepSig, United States, "Hat Creek Radio Observatory (HCRO): A Prototype National Radio Dynamic Zone", UNSC-URSI RFI 2022, Cambridge, UK, March, 2022. https://www.usnc-ursi-archive.org/nrsm/2022/papers/2322.pdf

[3] Clegg, A., "Towards Innovative Spectrum Sharing Technologies", National Information Technology Research and Development (NITRD) Wireless Spectrum R&D Senior Steering Group (WSRD SSG), https://www.nitrd.gov/pubs/WSRD_Workshop_I_Report.pdf, 2011.

[4] NTIA, "Feasibility of Commercial Wireless Services Sharing with Federal Operations in the 3100-3550 MHz Band", July 2020.

[5] NTIA, "Technical Feasibility of Sharing Federal Spectrum with Future Commercial Operations in the 3450-3550 MHz Band", January 2020.

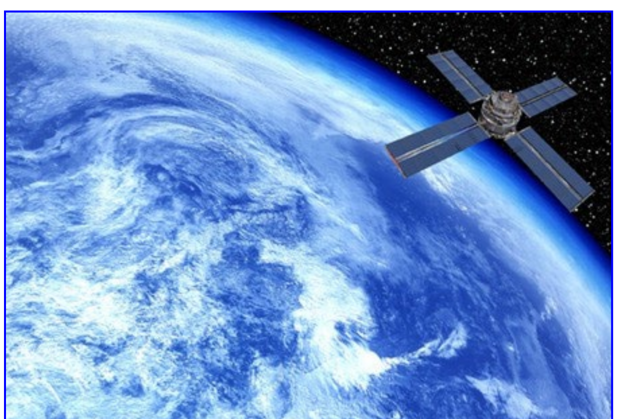
[6] DiFrancisco, M., Drocella, E., Ransom, P., and Cooper, C., "NTIA Report: Incumbent Informing Capability (IIC) for Time-Based Spectrum Sharing", NTIA Report, February 2021.

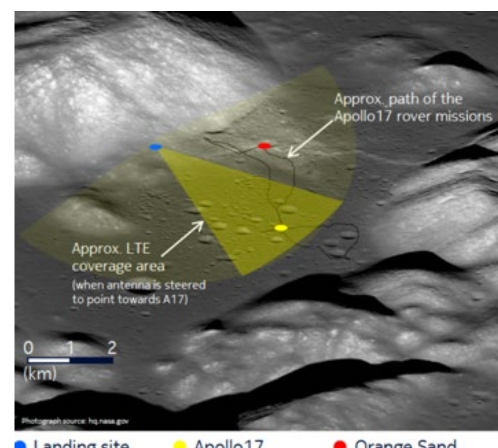
HCRO NRDZ Emphasis: bi-directional spectrum sharing

Enable bidirectional spectrum sharing:

- Multi-stakeholder emphasis
  - Focus is on spectrum sharing: active Wireless comms: LTE, 5G, Wi-Fi
  - Sharing with passive Radio Astronomy (RA), Earth Exploration Satellite System (EESS)

- Radio Astronomy (RA) and Earth Exploration Satellite Service (EESS) are passive RF systems: no Tx, Rx only





Hat Creek Radio Observatory: A Prototype National Radio Dynamic Zone: **Outline**

- Goals of the NSF HCRO NRDZ Project

- RF Baseline Surveys (RFBS), RF Open Data Sets, RFI visualization

- Spectrum sharing for RA: Dynamic Protection Area (DPA) concept
  - Citizens Broadband Radio Sharing (CBRS), 6 GHz Automated Frequency Coordination (AFC)

- Forward activities: prototype deployment (HCRO), satellite inclusion, sharing standards, outreach & collaboration

HCRO NRDZ: Executive Summary

Problem: Active emitters disrupt RA scientific observations

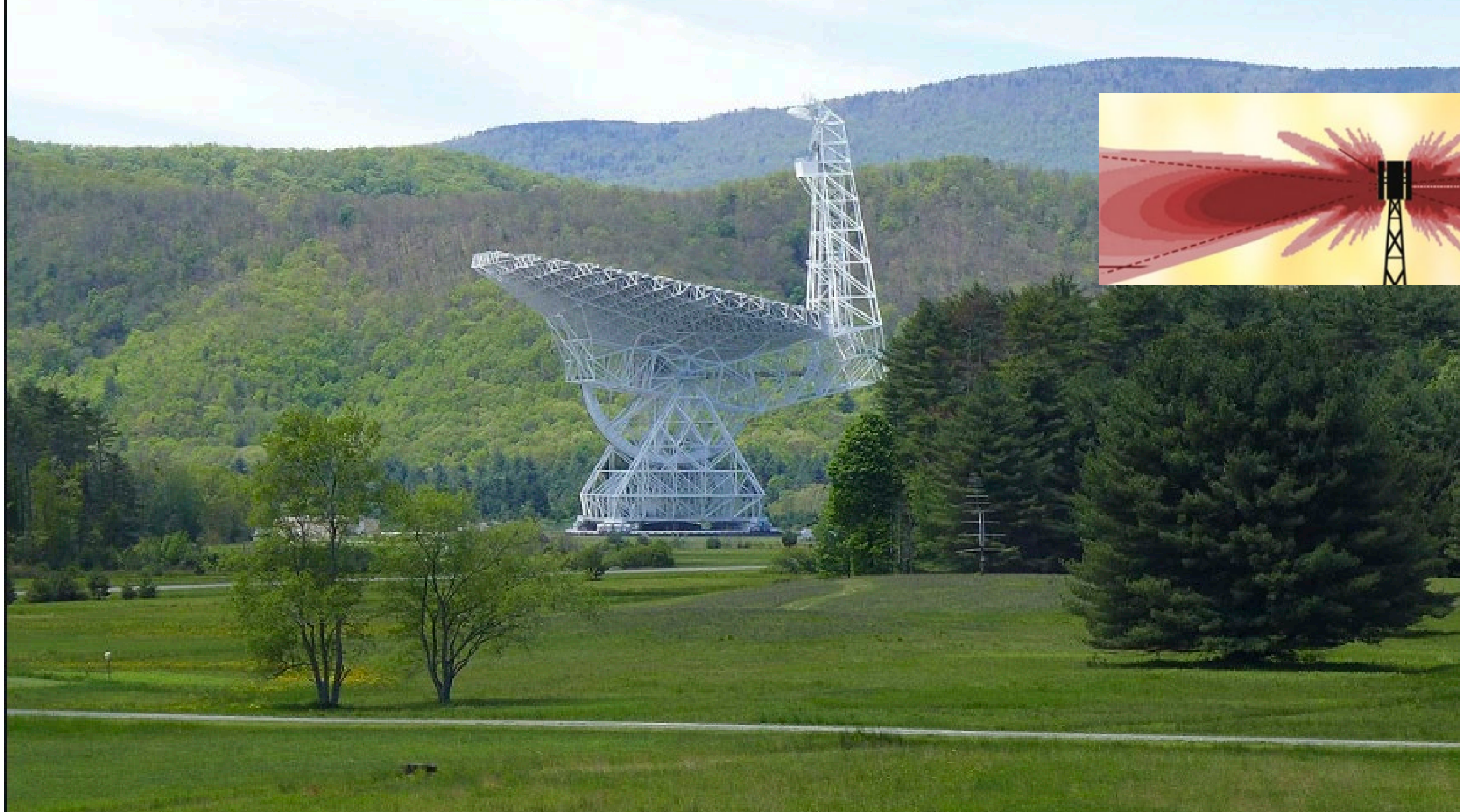
- A generalized spectrum sharing architecture has the potential to both protect RA and assist RA in observations outside of RA-protected bands.
- Coordination/sharing with terrestrial emitters is a primary goal.
- Inclusion of satellites (orbit and transmission frequency information) can be utilized by the RA facilities for coordinated scientific observations in non-protected RA bands. Satellites are particularly problematic interference sources for radio astronomy.

Goal: To increase available spectrum for both passive and active services by dynamic spectrum sharing.

- The inclusion of Radio Astronomy (RA) passive RF users and Earth (LEO, MEO, GEO) satellite active emitters into a generalized (passive and active) spectrum sharing architecture for bi-directional spectrum sharing will assist to protect and maximize RA science return and enable commercial access to some RA protected bands when not in use.

Problem: Active emitters disrupt RA scientific observations

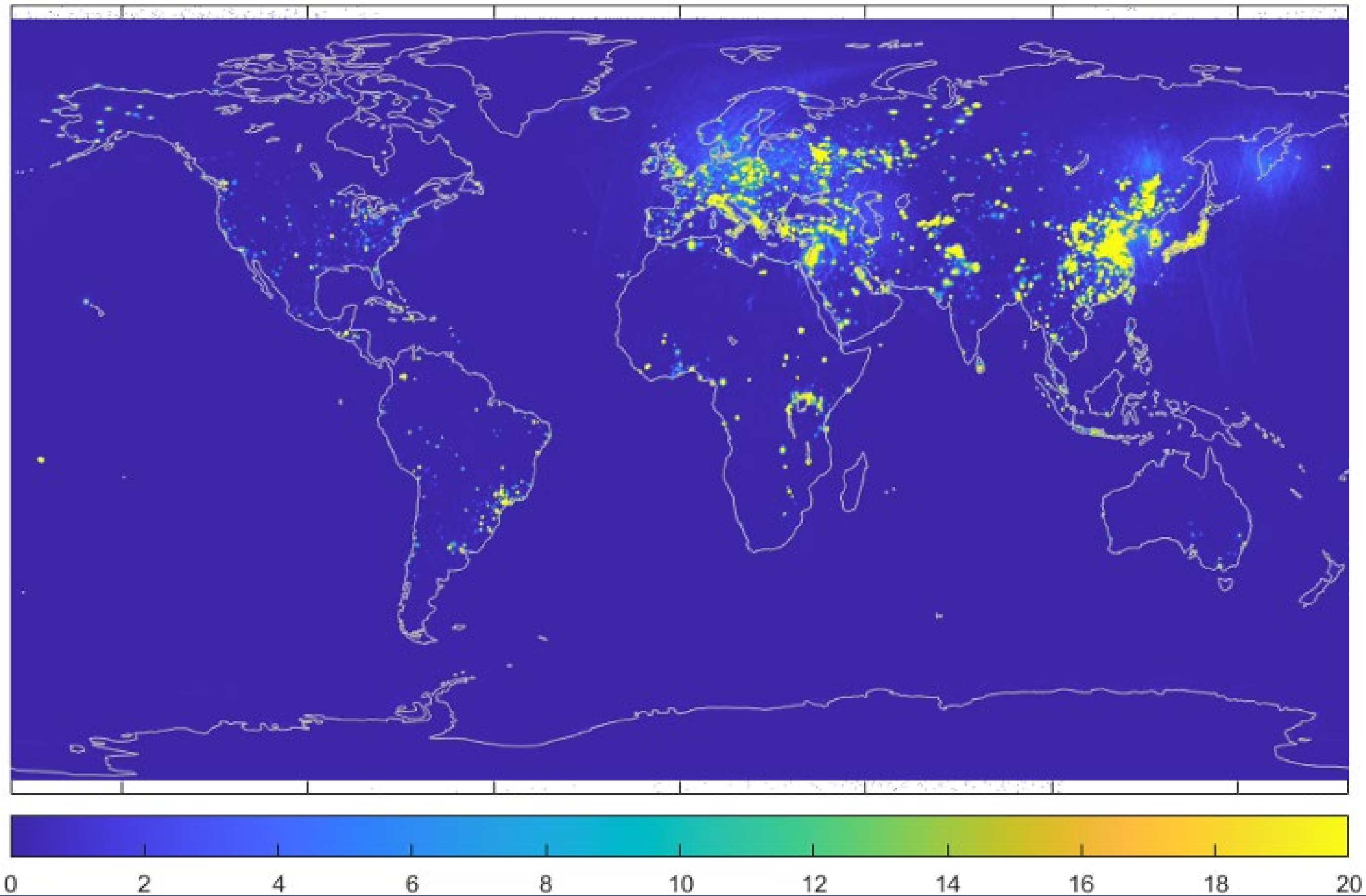
Bucktin, C., “Telescope Town can hear to within second of the Big Bang but won’t let locals use mobiles”, Mirror, 28 July 2015.



Daily Mail

Green Bank, West Virginia bans cellphones, TV, radio and WiFi | Daily Mail Online

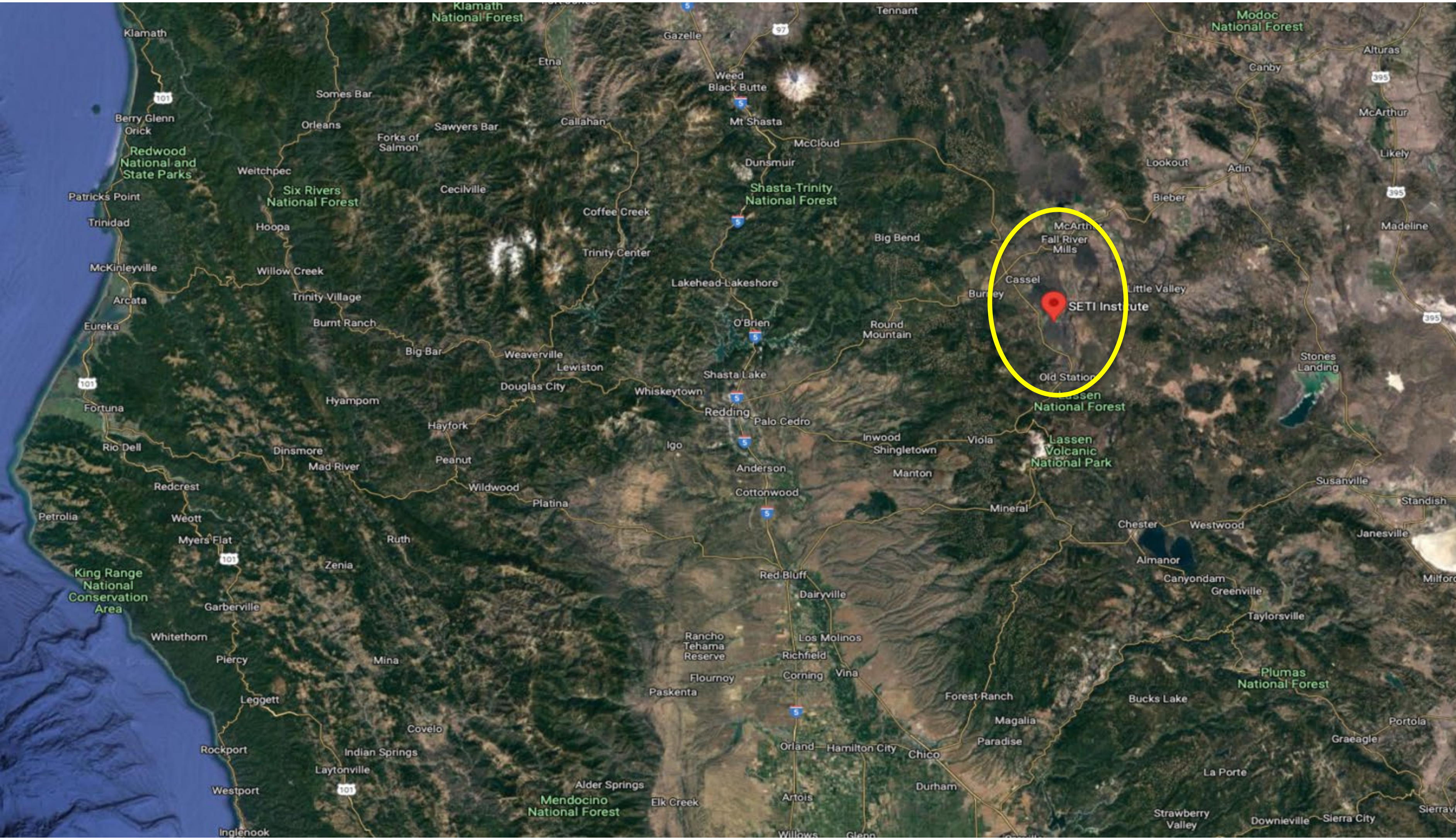
Problem: Active emitters disrupt RA scientific observations



Percent of time that the 1.413 GHz passive microwave sensor on NASA's SMAP mission detects RFI level of > 5 K between April 2015 and March 2016. ITU recommended interference limit is 0.05 K.

(*Mohammed et al., IEEE Trans. Geosci. Remote Sens.*, 2016, cited in CORF publications).

Hat Creek Radio Observatory / ATA / SETI Institute



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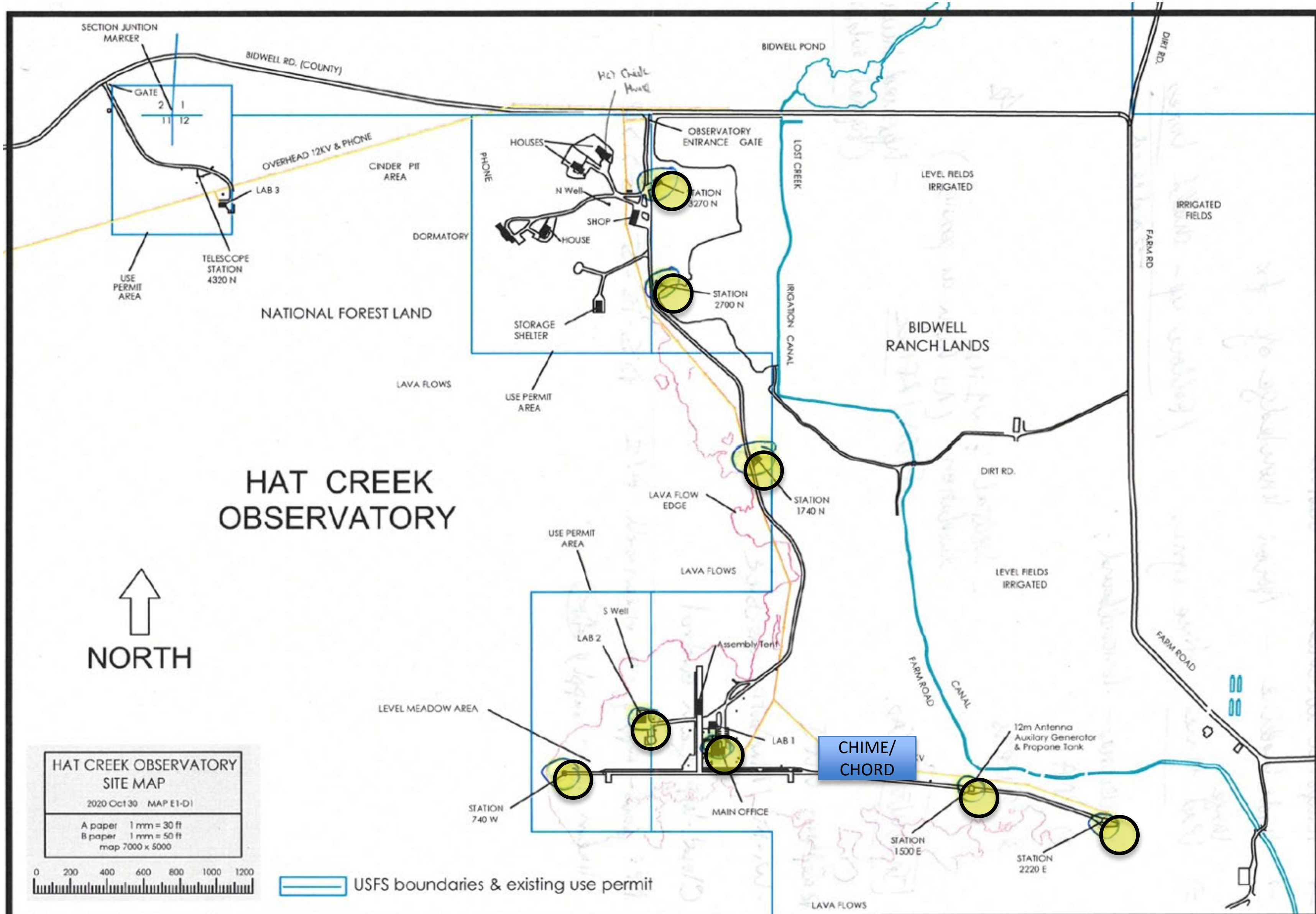
Hat Creek Radio Observatory / ATA / SETI Institute

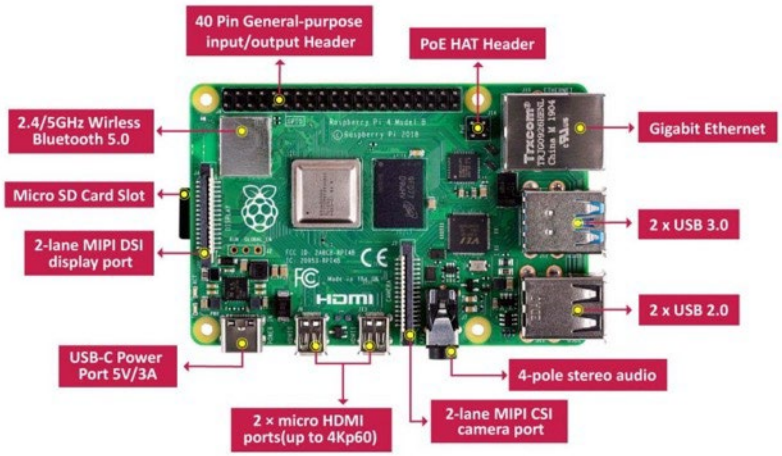
Hat Creek Radio Observatory / SETI in northern California

Hat Creek Radio Observatory / ATA / SETI Institute

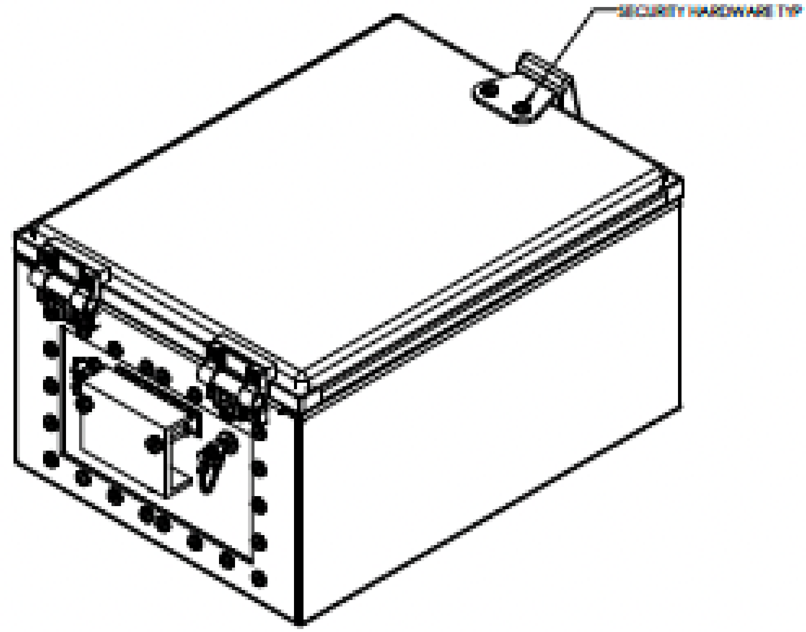


HCRO-NRDZ RF Baseline Sensors initial layout

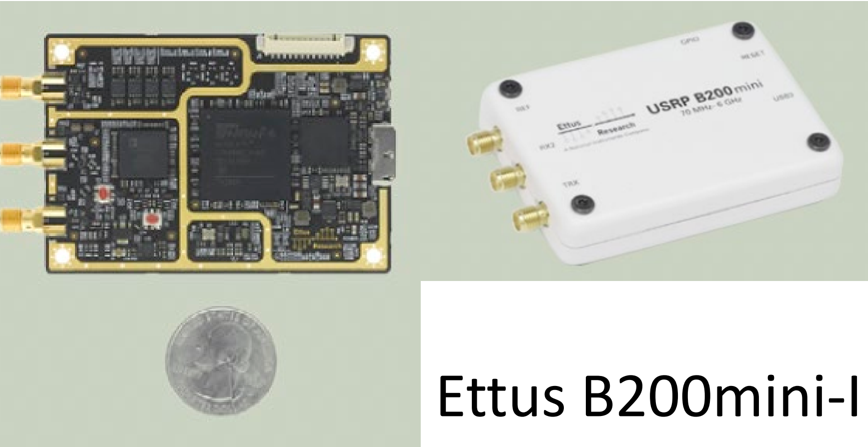
RF Baseline Sensor (RFBS) design for RFI Hunting, Tschimben, Aradhya, Pollak



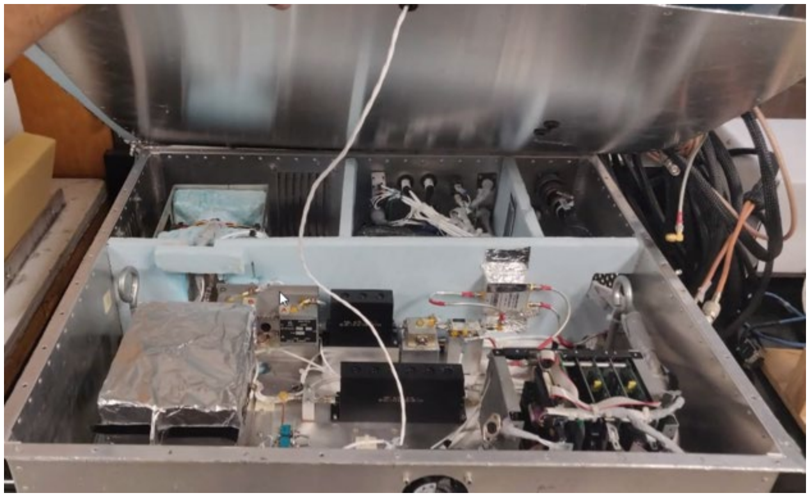
Raspberry Pi 4



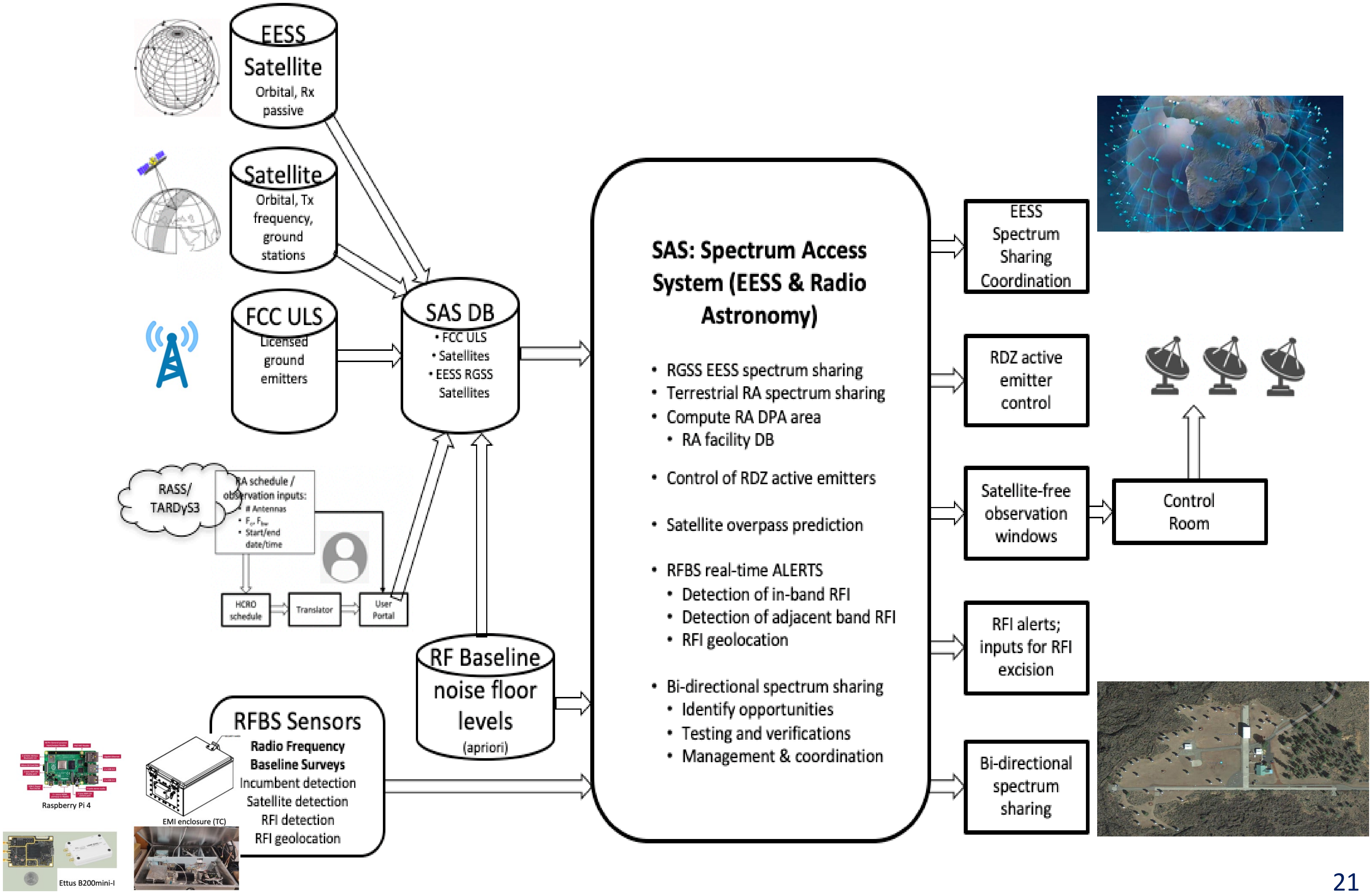
EMI enclosure (TC)



Ettus B200mini-I



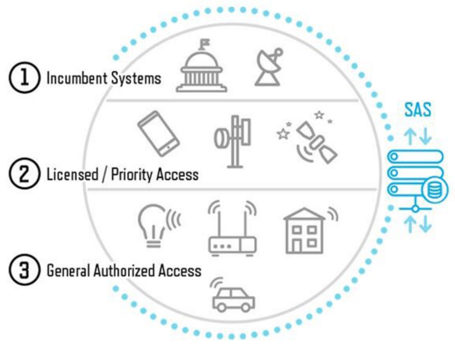
HCRO NRDZ: Functional Block Diagram



Examples of Methods Used to Protect Incumbents in 3.5 GHz CBRS and 6 GHz AFC with Relevance to Passive/Active Spectrum Sharing (*Andy Clegg, Google & WInnForum*)

CBRS Brief Overview

Overview of aspects of incumbent protections in the 3.5 GHz Citizens Broadband Radio Service (CBRS) and 6 GHz Automated Frequency Coordination (AFC) bands that are relevant to passive/active coexistence



- CBRS operates in 3550-3700 MHz and shares spectrum with government radars and fixed-satellite service downlinks
  - CBRS: Citizens Broadband Radio Service
  - See the WInnForum for an introduction to CBRS

- There are no passive services in the CBRS band, but there are incumbents that must be protected from harmful interference

- A cloud-based controller called a Spectrum Access System (SAS) manages CBRS devices (“CBSDs”) so that they do not cause interference to incumbents

- Federal government incumbents (i.e., DoD radar) are protected predominantly by a concept called Dynamic Protection Areas (DPAs)

- Fixed-satellite service (FSS) receive-only earth stations are protected through the use of coordination areas, which are effectively “non-dynamic” Dynamic Protection Areas

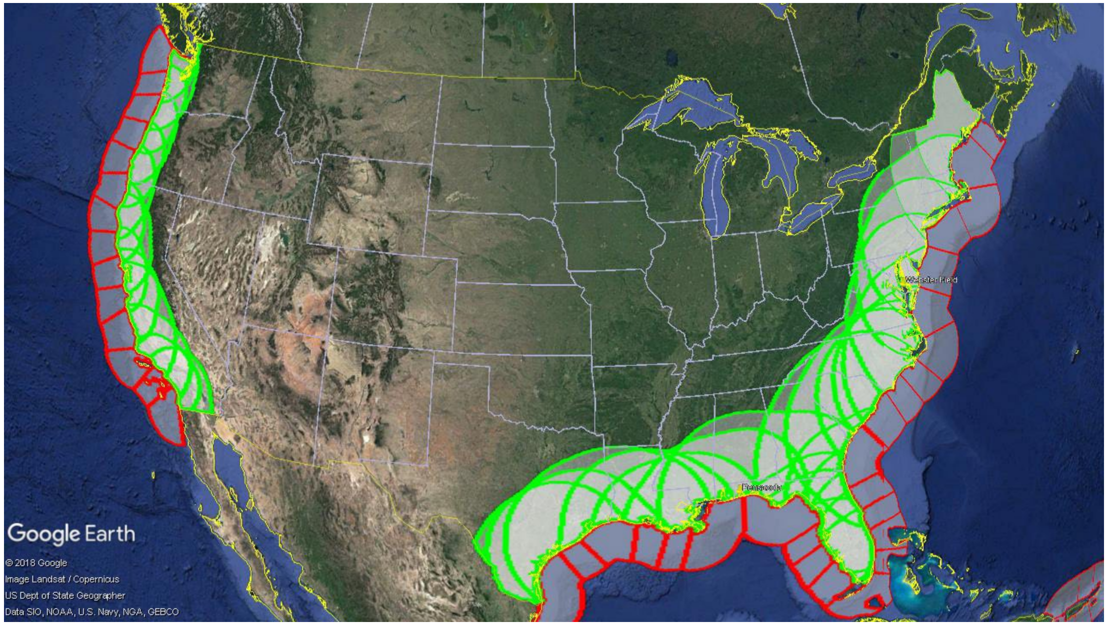
Dynamic Protection Area (DPA)

Dynamic Protection Areas (DPAs) are used to protect incumbent users from harmful interference due to secondary users sharing the same or adjacent frequencies

- A DPA is a pre-defined area (or a point) in/at which an incumbent operates on a dynamic basis (i.e., operations change with time and frequency)
- When an incumbent is operating in a DPA, secondary users in the *neighborhood* of the DPA could be required to change their operating parameters to protect the DPA
  - For example, a secondary user's device may need to change its frequency and/or power to protect the incumbent

A **DPA neighborhood** is a pre-defined area surrounding the DPA in which a secondary user could in theory contribute to producing harmful interference to the incumbent, typically based on worst-case assumptions

- Secondary users outside of the DPA are not expected to cause interference and are not affected by the presence of the DPA
- The size of the neighborhood is based on assumed deployment models, the DPA interference criterion, and a standardized propagation model



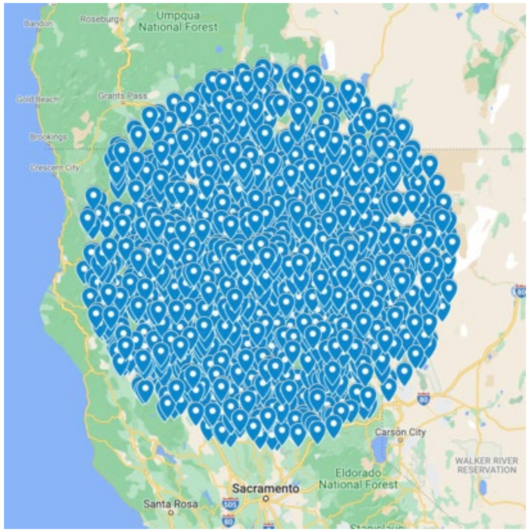
Dynamic Protection Area (DPA)

<u>DPAs</u> are not exclusion zones

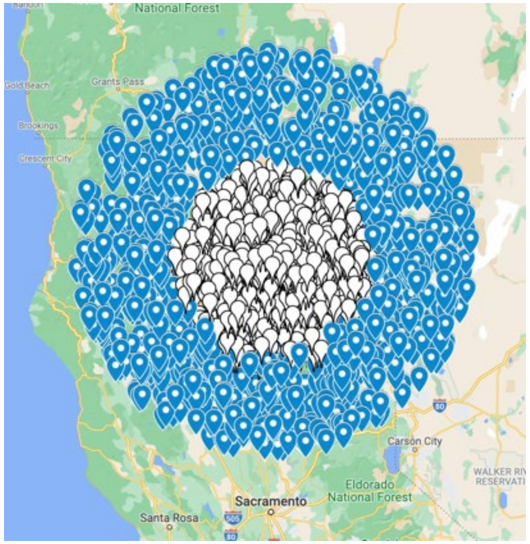
- DPAs are *where the incumbent operates*

<u>DPA neighborhoods</u> are not exclusion zones

- Whether a particular secondary device is or isn't allowed to operate in a DPA neighborhood depends on a number of factors, including its predicted contribution to harmful interference into the DPA
- A given secondary user may be able to continue operating as is, or continue operating after a change of parameters (e.g., frequency or power), in a DPA neighborhood
- Under certain situations a secondary user may need to cease operation altogether while the incumbent is operating in the DPA



200 km and random emitters



200 km and 100 km DPA

DPAs vs Exclusion Zones

Knowledge as to whether an incumbent is operating in its DPA, and at which frequency or frequencies, may be determined by at least two methods

- Sensing: Receivers in or near the DPA listen for incumbent activity in the DPA (i.e., CBRS **Environmental Sensing Capability, or ESC**)
  - Obviously, sensing would not work for passive services
- **Informing Incumbent Capability (IIC)**: The incumbent notifies secondary users when it plans to operate in a DPA, and at which frequency or frequencies (i.e., CBRS portal-controlled DPAs)

DPAs are used to protect federal government radar incumbents in the Citizens Broadband Radio Service (CBRS)

- ESC is used to detect DPA activity in most coastal DoD operating areas
  - ESC sensors must be able to detect pre-ordained radar signatures
- IIC is used to inform DPA activity in 11 inland radar sites, and American Samoa
  - Some radar activities in the inland areas are experimental and cannot be effectively detected by pre-ordained detection algorithms, and some activities in these areas that require protection are receive-only

Note: Periodic Use Areas (PUAs) in the new 3.45 GHz band (3450-3550 MHz) may share some characteristics of DPAs

How DPAs Work in CBRS: Step 1 – DPA info

A CBRS Spectrum Access System (SAS) obtains geographic and technical descriptions of DPAs

- Geographic and other technical information about DPAs that must be monitored by ESC is contained in an NTIA-maintained file*, e-dpas.kml
- Similar information for DPAs that must be monitored by an IIC portal is contained in an NTIA-maintained file*, p-dpas.kml
- In addition to the geographic definition of the DPAs, the files contain metadata related to DPA protection, such as protection criteria, DPA neighborhood size, etc.
- A SAS reads these files on a regular basis from the NTIA website, but their contents are not expected to change frequently (i.e., advance notice from DoD is expected if the DPA descriptions are to be changed)

* kml files are text files containing standardized geographic information and metadata, which can be read and displayed by common programs such as Google Earth, and can be opened by standard text editors such as Notepad and Word

How DPAs Work in CBRS: Step 2 – DPA Activation

A SAS becomes aware of incumbent activity in a DPA

- In the case of ESC, a message is sent from the ESC network to the SAS telling it which DPA the incumbent is operating in, and which frequency ranges the incumbent is operating over
- In the case of a portal-controlled DPA, a DoD spectrum manager responsible for operations at the given portal DPA site logs into a calendar and specifies when, and at which frequencies, they plan to operate. SASs read the portal DPA calendars on a regular basis and protect the DPAs accordingly when an operating event is scheduled

The DPA is considered to be "activated" in that frequency range when the incumbent is operating

If a SAS does not have access to an ESC or the ESC has suffered a failure, or there is a problem with the SAS accessing the portal, the respective DPA must be assumed to be active on all unmonitored frequencies ("fail safe")

How DPAs Work in CBRS: Step 3 – Interference Protection

When a DPA is activated, SASs reconfigure CBSDs within the DPA neighborhood such that the DPA's interference criterion is not predicted to be exceeded at any point in the DPA at the frequency range in which the incumbent is operating

- Interference predictions are based on standardized pre-established propagation models and other standardized methodologies
- CBRS DPA neighborhoods are defined by a maximum distance from the boundary of the DPA
  - Cat A (in/outdoors, <= 1 W EIRP) and Cat B (outdoor only, <= 50 W EIRP) CBRS devices have different neighborhood distances (Cat B neighborhood distances are >= Cat A neighborhood distances)
  - For some DPAs, neighborhood distances are established for out-of-band emissions that impact federal incumbent operations below 3550 MHz

How DPAs Work in CBRS: Step 4 – Back to Normal

When an ESC no longer detects activity, or a scheduled event in the portal IIC expires, the SAS reconfigures CBRS use in the neighborhood back to normal

- In the case of ESC-detected activity, a two-hour delay after last activity is added, in part to avoid hysteresis effects

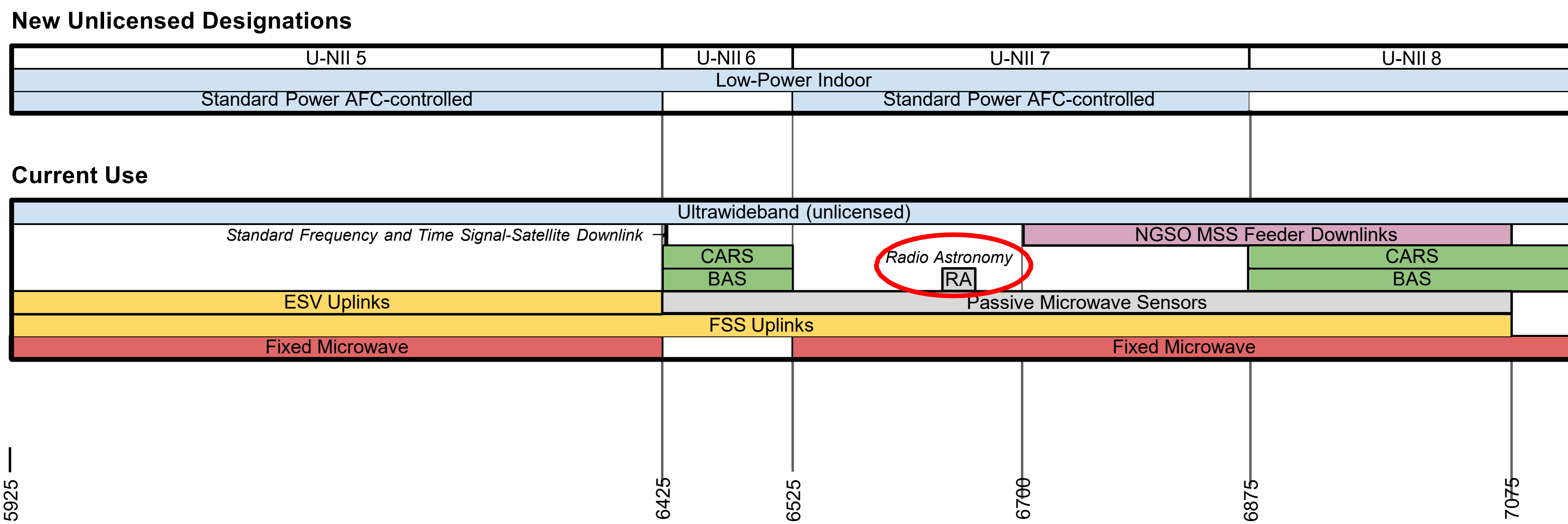
6 GHz Automated Frequency Coordination (AFC)

A portion of the bands in which SPAPs operate under AFC management is noted to be used for radio astronomy observations in the 6650-6675.2 MHz range

- Footnotes US342 to the allocation table notes frequency range; footnotes US131 and US385 provide coordinates

The Part 15 rules under which 6 GHz devices and AFC systems operate require protection of designated radio astronomy by way of exclusion zones whose size depend on the heights (AGL) of the RA receiver and the AP

- Based on mutual radio horizon calculation, but does not take terrain into account



6 GHz Band (AFC)

47 CFR 15.407(m)

Incumbent Protection by AFC system: Radio Astronomy Services. The AFC system must enforce an exclusion zones to the following radio observatories that observe between 6650-6675.2 MHz: Arecibo Observatory, the Green Bank Observatory, the Very Large Array (VLA), the 10 Stations of the Very Long Baseline Array (VLBA), the Owens Valley Radio Observatory, and the Allen Telescope Array. The exclusion zone sizes are based on the radio line-of-sight and determined using4/3 earth curvature and the following formula:

dkm_los = 4.12 * (sqrt(Htx) + sqrt(Hrx)),

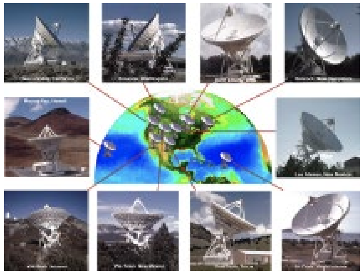
where Htx is the height of the unlicensed standard power access point or fixed client device and Hrx is the height of the radio astronomy antenna in meters above ground level. Coordinate locations of the radio observatories are listed in section 2.106, notes US 131 and US 385 of this part.


Arecibo


ATA at HCRO


Green Bank


Very Large Array (NM)


VLBA (all 10 sites)

Protected Observatories

No consideration for terrain, clutter, or other factors

No consideration for case-by-case predicted level of interference

No consideration for dynamic operations of the RA observatories

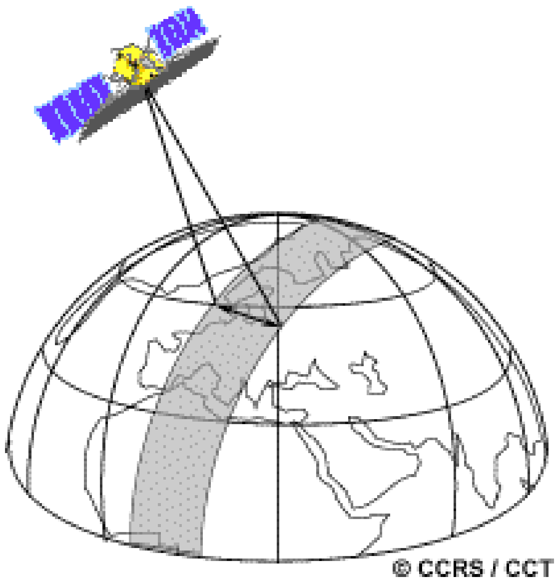
- Actual use of the 6 GHz band for observing is not considered
- Based on available data, percentage of time that the 6 GHz band is used for RA is extremely low (*e.g., effectively 0% utilization of the 6 GHz band at Green Bank from 2003-2011 based on study by Clegg et al., 2012*)

Exclusion zones like these are typically worst-case and can be vastly over- protective

Protections would be much more efficiently implemented by way of Dynamic Protection Areas

Extension of DPAs for Satellite Protections

- RA observatories are particularly vulnerable to satellite-based interference
- Passive EESS satellites see large swaths of ground as they pass over
- Extend DPAs to synchronize satellite and ground-based passive and active spectrum use
  - Turn off ground-based emitters in satellite field of view during brief overpasses
  - Alert RA telescope of upcoming satellite passes to avoid acquiring data during noisy (or potentially dangerous!) overpasses



- **DPAs are a promising method for passive/active spectrum sharing**
- **Observatory schedules and satellite ephemerides could be connected to a portal-based informing incumbent capability to effect protections via cloud-based sharing systems** (similar to AFC and SAS)

Dynamic protection of terrestrial Radio Astronomy facilities to mitigate satellite radio frequency interference (RFI)

RASS/TARDyS3 Scheduling Standard

The SII-NRDZ HCRO NRDZ RADYSIS project will leverage the Defense Information Systems Agency (DISA) Telecommunications Advanced Research and Dynamic Spectrum Sharing System (TARDyS3) draft specification as the basis for the Radio Astronomy Spectrum Sharing (RASS) standard development and implementation.

The new spectrum scheduling system, RASS/TARDyS3, will augment the calendar-based portal that is currently maintained by a spectrum access administrator that reserves spectrum for systems that do not have permanent spectrum access.

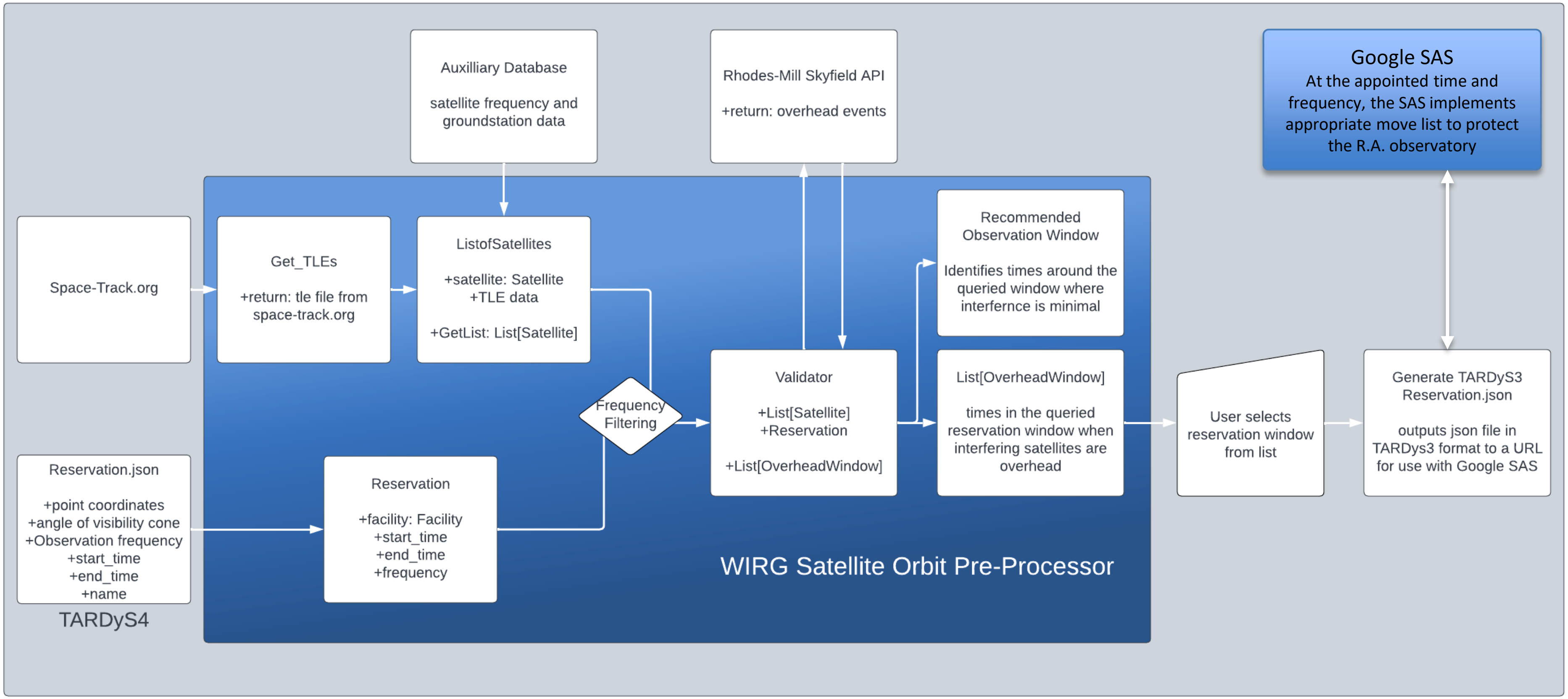
- *Prevent interference by integrating best practices and spectrum planning* data to evaluate likelihood of interference. A user-facing website may show bulletins highlighting sources of potential interference planners should avoid, for example.
- *Identify potential electromagnetic interference if preventative measures fail* through reports from spectrum-sharing users, incumbents (e.g., DoD radar systems) and/or environmental sensor networks.
- *Quickly resolve interference incidents through an automated negotiation service* that exchanges relevant data between federal and non-federal systems and manages user interactions in case the automated negotiation services fail to resolve the interference.
- *Accommodate spectrum-sharing users to access schedules and interference analyses*. Commercial users will need to access these same schedules and interference analysis but are anticipated to request spectrum reservation resource allocation in near-real-time.

RASS/TARDyS3 Scheduling Standard

Field Name	Type	Required	Example	Purpose	Notes
transactionId	UUID	Yes	0b5de183-afe5 44a1-b323-56c680b2c7b5	Unique identifier to track transaction	UUIDv4
dateTimePublished	DateTime String	Yes	2021-11-17 T01:00:00.000Z	Date and time the schedule was published to proxy	ISO 8601 UTC Timestamp
dateTimeCreated	DateTime String	Yes	2021-11-17 T00:00:00.000Z	Date and time schedule generated	ISO 8601 UTC Timestamp
checksum	String	Yes	a35cf7d9	If this value is inconsistent or missing the update is invalid	CRC-32 checksum of ScheduledEvents array in hexadecimal format
ScheduledEvents	Array	Yes		All active and future events	Details of each event are in ScheduledEvent Field

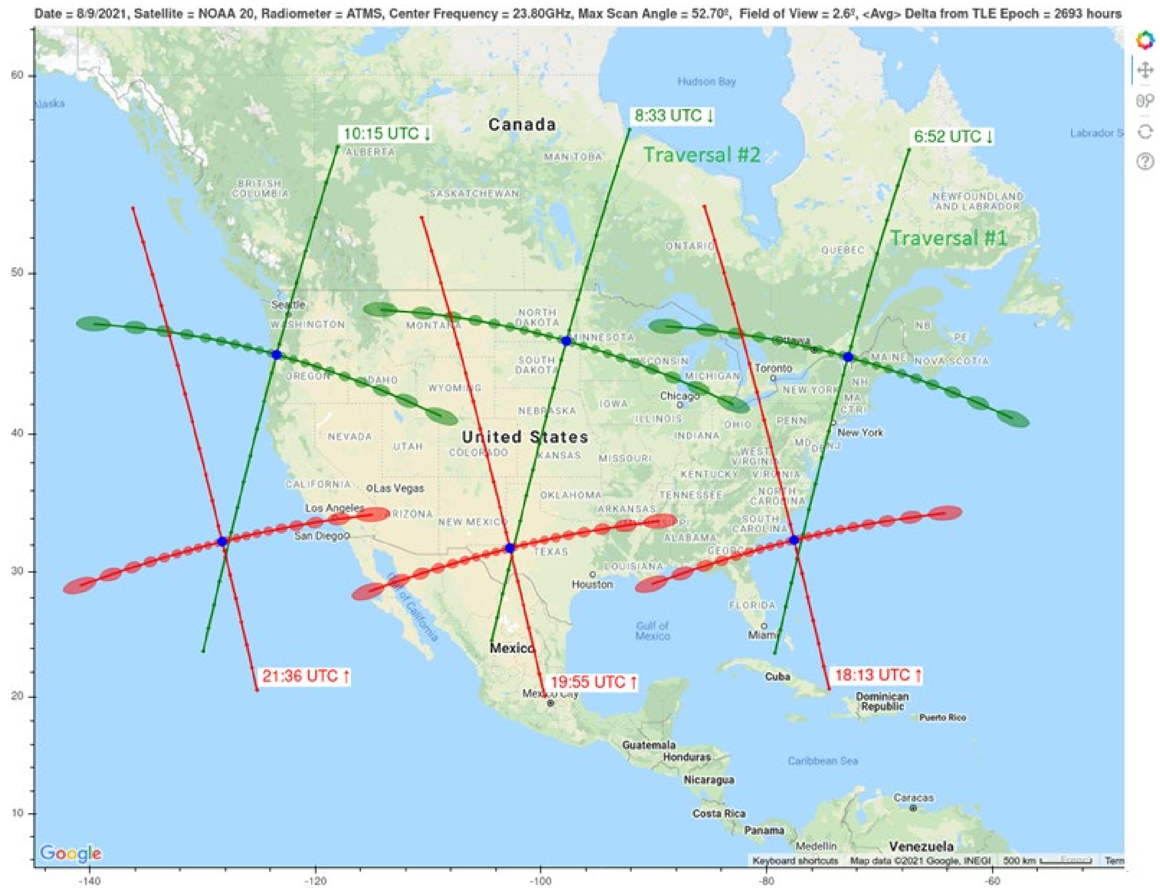
Field Name	Type	Required	Example	Purpose	Notes
eventId	UUID	Yes	c4c6f07b-e1a9-4a7c-a05e-09d186967e9b	Unique identified for a given scheduled event	UUIDv4
dpaId	Enum<DPA UUID>	Yes	ddda9e28-18e0-4ab7-9270-4f477045f32d	The UUID of the DPA for the event	See "P-DPA" IdentifiersUUIDv4
dpaName	Enum<DPA Name>	Yes	HAT CREEK RADIO OBSERVATORY	The plain text name of the DPA	Valid values are the enumerated DPA names
dateTimeStart	DateTime	Yes	2021-11-17 T00:00:00.000Z	The start time for the scheduled event	ISO 8601 UTC Timestamp
dateTimeEnd	DateTime	Yes	2021-11-17 T00:00:00.000Z	The end time for the scheduled event	ISO 8601 UTC Timestamp
recurrence	String	No	RRULE:FREQ=DAILY; INTERVAL=10;COUNT=5	(Optional) Recurrence pattern for the event.	iCalendar (RFC 5545) Recurrence
AntennaArrayID	String	Yes	"HCRO-Array-01"	Identify antenna array	Site dependent
AntennaID	String	Yes	"HCRO-Antenn1-01"	Identify antenna	Site dependent
AntennaAzimuth	Float	Yes	0.0 to 360.0 degrees	Antenna azimuth	RA observation attribute
AntennaElevAngle	Float	Yes	0.0 to 90.0 degrees	Antenna angle	RA observation attribute

HCRO NRDZ: Satellite Dynamic Protection for Radio Astronomy



RGSS: Real-Time Geospatial Spectrum Sharing

- A 5G/6G antenna on the earth is within a sounder's eFOV (effective Field of View) for ≈10-20 msec.
- A pixel (footprint defined by eFOV) can be predicted with a very high degree of accuracy (~ ±1 pixel).
- Three modes of operation for any given sounder, traversal & deployed network :
  - Identify bad pixels (eliminates corrupted data, but does not remove interference):
  - Pause (or move traffic to alt bands) all network traffic while Tx antennas are within the eFOV
  - Reduce & move traffic Tx power so that $P_r^{5G} < P_r^{sounder}$
- Network availability = availability Σ over all satellite/traversals. Worst case availability (pausing all transmissions in 24GHz NR2 band) > 99% based on all currently operational sounders operating @ 23.8GHz ±100 MHz.



E. Eichen, "Performance of Real-Time Geospatial Spectrum Sharing (RGSS) between 5G Communication Networks and Earth Exploration Satellite Services," *2021 IEEE International Symposium on Dynamic Spectrum Access Networks (DySPAN)*, 2021, pp. 73-79, doi: 10.1109/DySPAN53946.2021.9677268.

RGSS: Real-Time Geospatial Spectrum Sharing

- Conceptually simple, software based, lots of details
- Compelling compared to traditional hardware based (ITU) methods for preventing inference:
  - Cheap ($)
  - Quickly adopts to new network components (e.g., high power fixed-wireless access CPE, integrated access backhaul, and potential for duplex transmission)[1] and new/additional satellites with more sensitive sensors.
  - Reuses existing (CBRS) spectrum sharing system, architectures, & protocols. Potential to integrated with O-RAN standards.
  - Enables carriers to run networks with *better performance & coverage* while *decreasing* interference.
  - Single system supports all mm & sub-mm wave bands
  - Can be implemented on a national (rather than int'l) basis – can augment ITU baseline recommendations
  - Utilizes newer 3GPP (rel17?) band transfer standards.
- All models require deployed network infrastructure data. Network availability (NA) depends on RGSS mode & the # of EESS satellites operating within a given band. Dense cube-sate deployments will reduce NA of the "Pause" model.

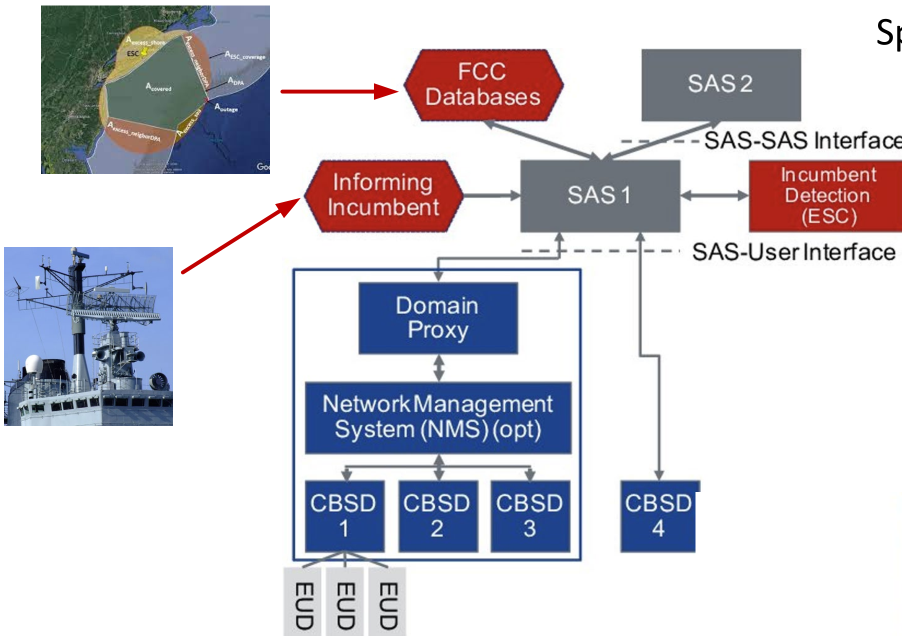
Model	**CBRS- 5G Network Integration**	**RFI Propegation Model**	**Reduce or Elliminate RFI**	**EESS Data Filtering**
Identify	X	X	X	✓
Pause	✓	X	✓	X
Reduce	✓	✓	✓	X

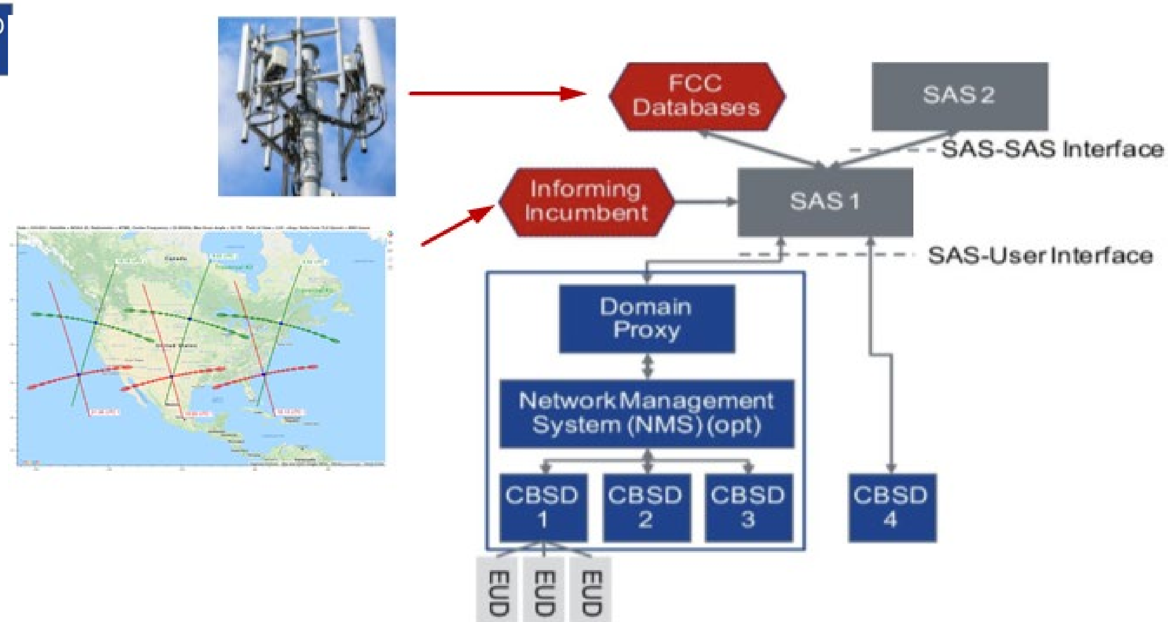
	CBRS	**RGSS**
deployment status	operational	proposed
frequency band	mid-band (3.55-3.7 MHz). Proposed use 6Ghz	mm to sub-mm (20 GHz - 200GHz)
incumbant spectrum users	DoD Radar, EESS downlinks, radio-astronomy, legacy broadband	EESS passive radiometers
network availability	~ 99.9%	>= ~99.6 (estimated)
outage windows	~ minutes-hours. Fewer, longer windows.	~ msec - seconds. Frequent, shorter windows.
outage dynamics	intermittent and "scheduled"	"scheduled"
architecture	SAS	SAS (proposed)
security concerns	high, accomodated by SAS	high, accomodated by SAS

[1] E.Eichen, "Impact of new 5G network components on out-of-band emissions at 23.8 GHz", RFI 2022 Proceedings of the Union Radio-Scientifique Internationale http://www.ursi.org/ proceedings/2022/rfi2022/EEichenRRI2022PD65LXR9BW.pdf

RGSS: Leverage CBRS Spectrum Access System

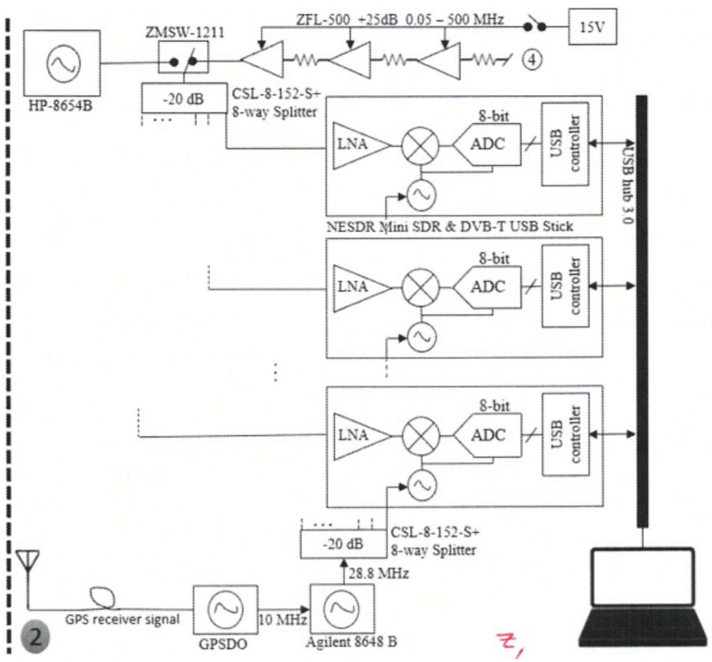
Currently deployed CBRS (3.55-3.7 GHz)
Spectrum Access System architecture

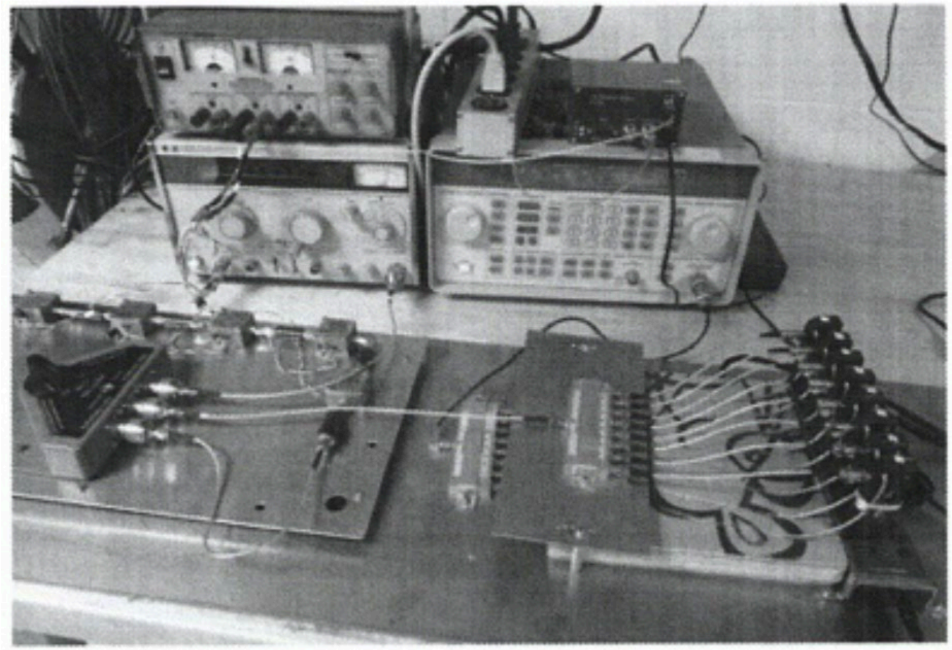


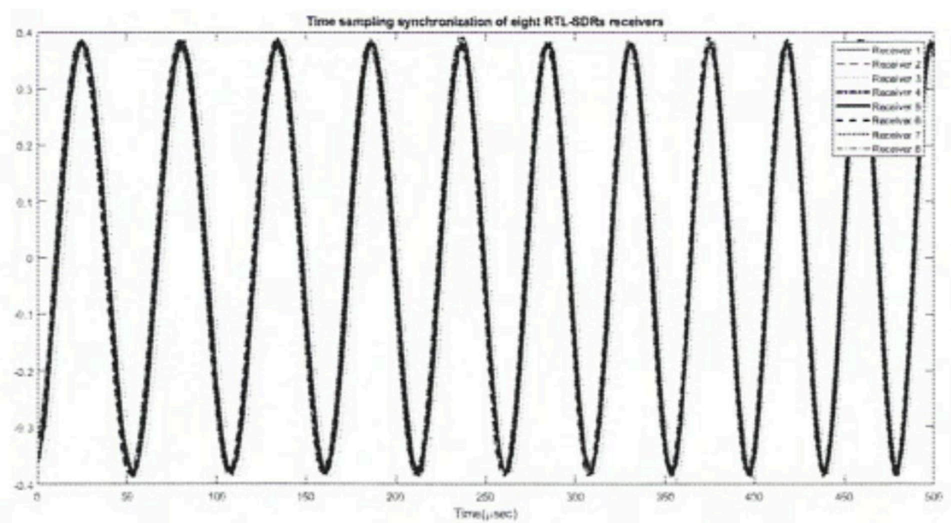


Extend existing Spectrum Access System architecture to support mm-wave and submm-wave frequencies. The outage calculation engine in CBRS is replaced by a swarth calculation engine for RGSS.

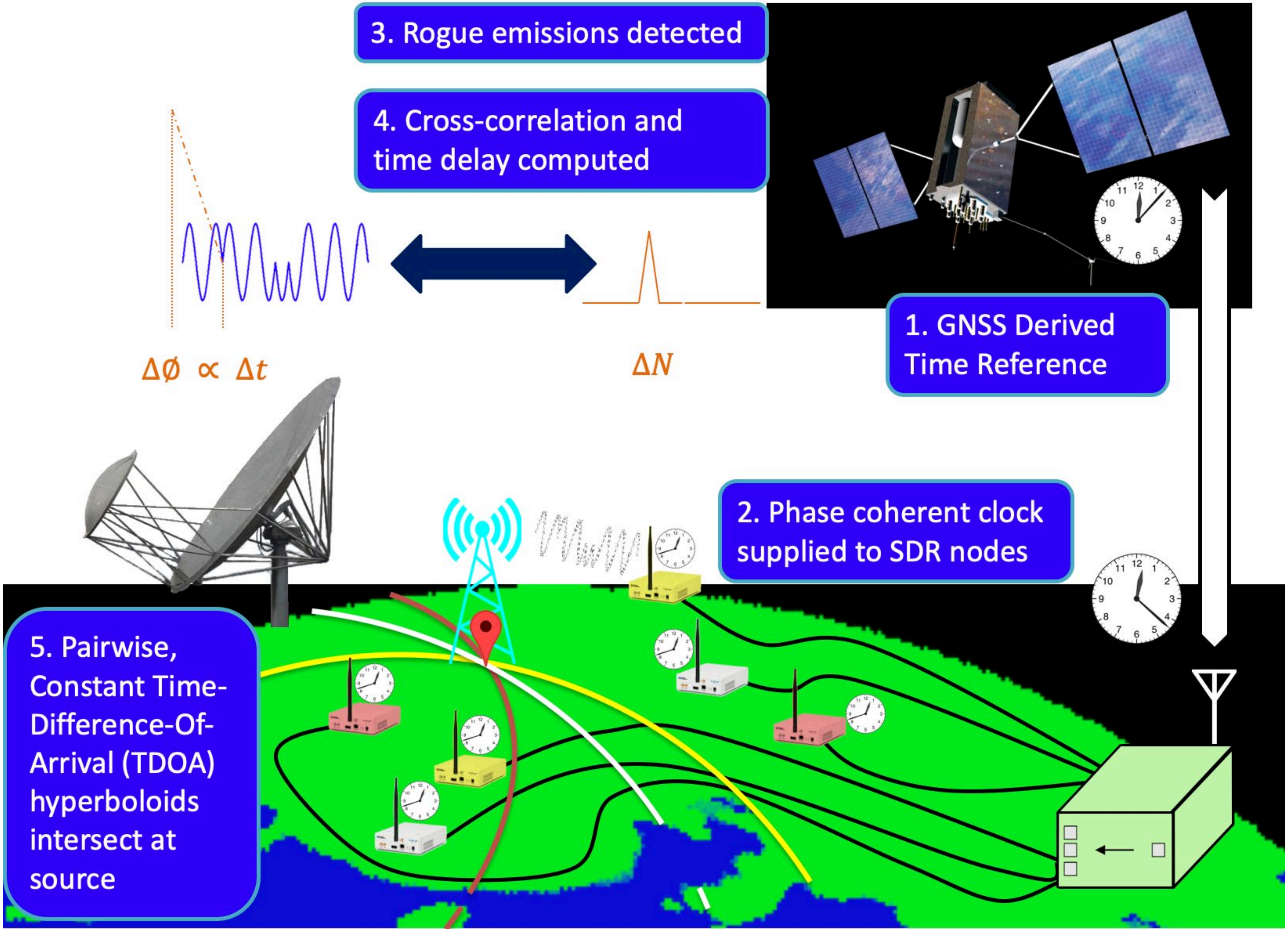
SDR Coherency: Evariste Some and Albin Gasiewski, IEEE Aerospace 2023







Inexpensive coherent SDR sensing array



Zero Trust Architecture for RA: Motivation

"Researchers must be confident that their data has not been compromised to ensure data integrity and reproducibility", Von Welch, project director, Indiana University

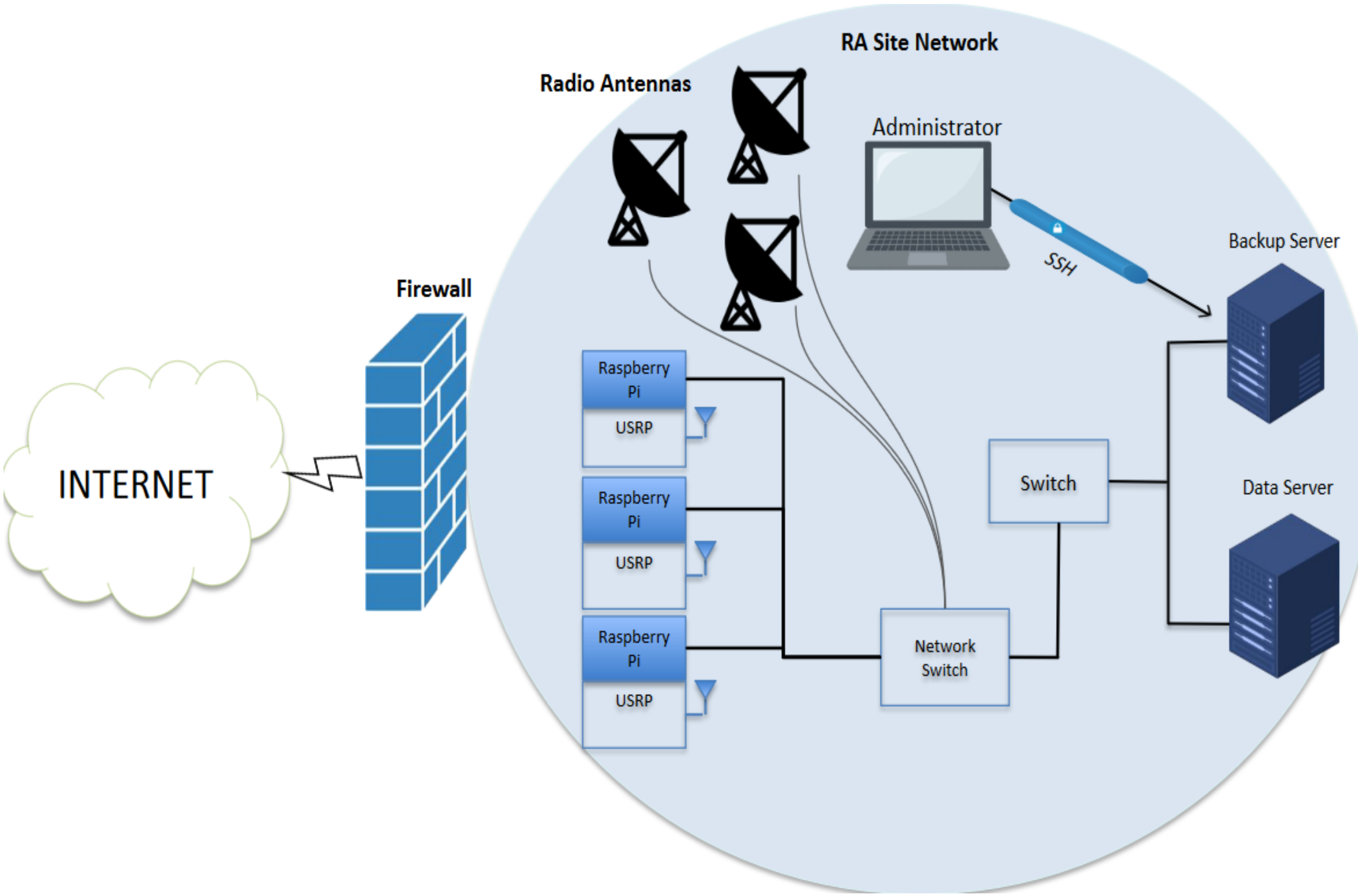
- Radio astronomy facilities and research facilities are complex and highly collaborative institutions with specialized infrastructure and access requirements.
- The complex nature of these facilities can leave them susceptible to attack, potentially causing the loss of valuable scientific data or risking the integrity of findings.

Attacks on research infrastructure

- 2017: A virus disabled University of Western Australia's Zadko telescope disrupting researchers ability to track an exceedingly rare kilanova [3].
- 2014: NOAA's websites attacked, disrupting the flow of satellite data to the National Weather Service [4].
- 2013: Malware found on NIST servers shuts down vulnerability database for nearly a week [5].

Many in the R.A. community recognize this growing threat and are taking steps to improve the security of these facilities.

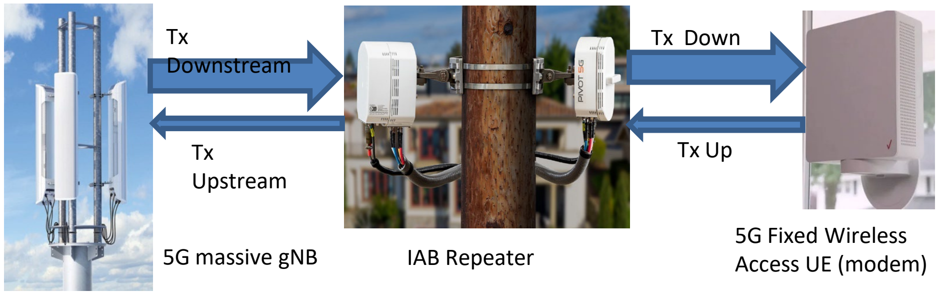
ZTA-for-RA greenfield architectural concept "R1B1"

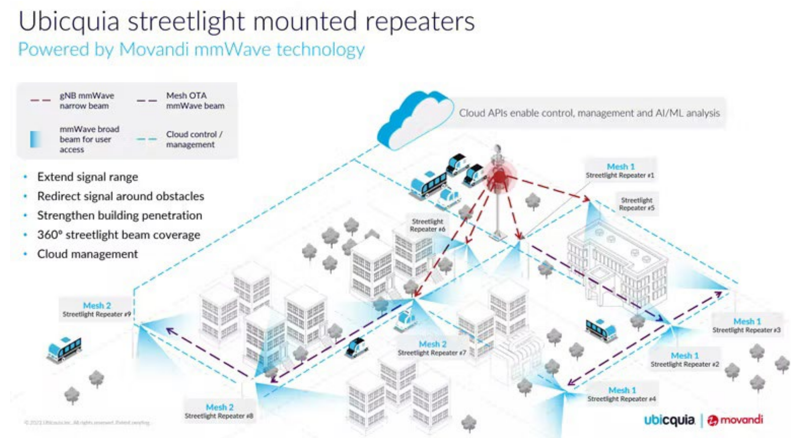


A greenfield resource diagram to identify resources for ZTA

Questions?

Increase in OOB emissions from new 5G/6G network elements (not included in ITU WRC-19 limits)





- Integrated Access Backhaul (IAB): (gNB ⇔UE + gNB ⇔ gNB)
  - Significantly improves 5G economics: better coverage + less fiber backhaul. Currently deployed @ 28 and 37 GHz, expected @ 24 GHz.
  - More base station "like" antennas => more interference than modeled by ITU. Additional interference ~10log(1+F) [dB] where F = the number of repeater transmitters. What is F? (potential for F ~10 as repeaters become deployed on lampposts – Ericson, Ubicquia, etc.)
  - Many vendors. FCC regulates repeaters as "Class B industrial signal boosters " & has not discussed extending WRC-19 OOB emission recommendations to cover repeaters.

- High Power (3GPP Power Class 1) fixed-wireless access (FWA) UEs
  - ITU assumes smartphone/cell-phone power class 3 (22.4 dBm EIRP). Current FWA UEs are power class 1 (> 40 dBm EIRP). Because of battery saving UE algorithms, interference for UEs depends on UE Tx power (e.g. NASA/NOAA sharing studies, or ITU-R M.2101-0)
  - If FWA UEs *may* not implement battery saving (FWA UEs do not require batteries!). If so, increase in OOB emissions potentially > 10 dB.
  - FWA UE vendors have requested FCC exception from ITU OOB UE emission recommendations. This is a little like setting highway speed limits for cars at 65 MPH, but exempting eighteen wheelers (semi tractor-trailers) from speed limits.

E.Eichen, "Impact of new 5G network components on out-of-band emissions at 23.8 GHz", The RFI 2022 Workshop at ECMWF, 14 - 18 February 2022, 2022 URSI International Union of Radio Science (pre-print)

A Proposed Method to Protect RA Sites in a Shared Spectrum Environment

Utilize DPAs to protect RA sites

Establish a point-DPA at the location of the telescope

Establish a corresponding neighborhood based on actual terrain and clutter data and predicted path loss from each point to the DPA

Automatically connect the observatory's observing schedule to a portal-based informing incumbent capability

- E.g., a script that reads the observatory's schedule on a regular basis and places API calls to enter reservations into the portal calendar
- Updates portal at least 24 hours in advance

Cloud-based sharing systems such as AFC utilize a portal calendar to enforce protections for the observatory

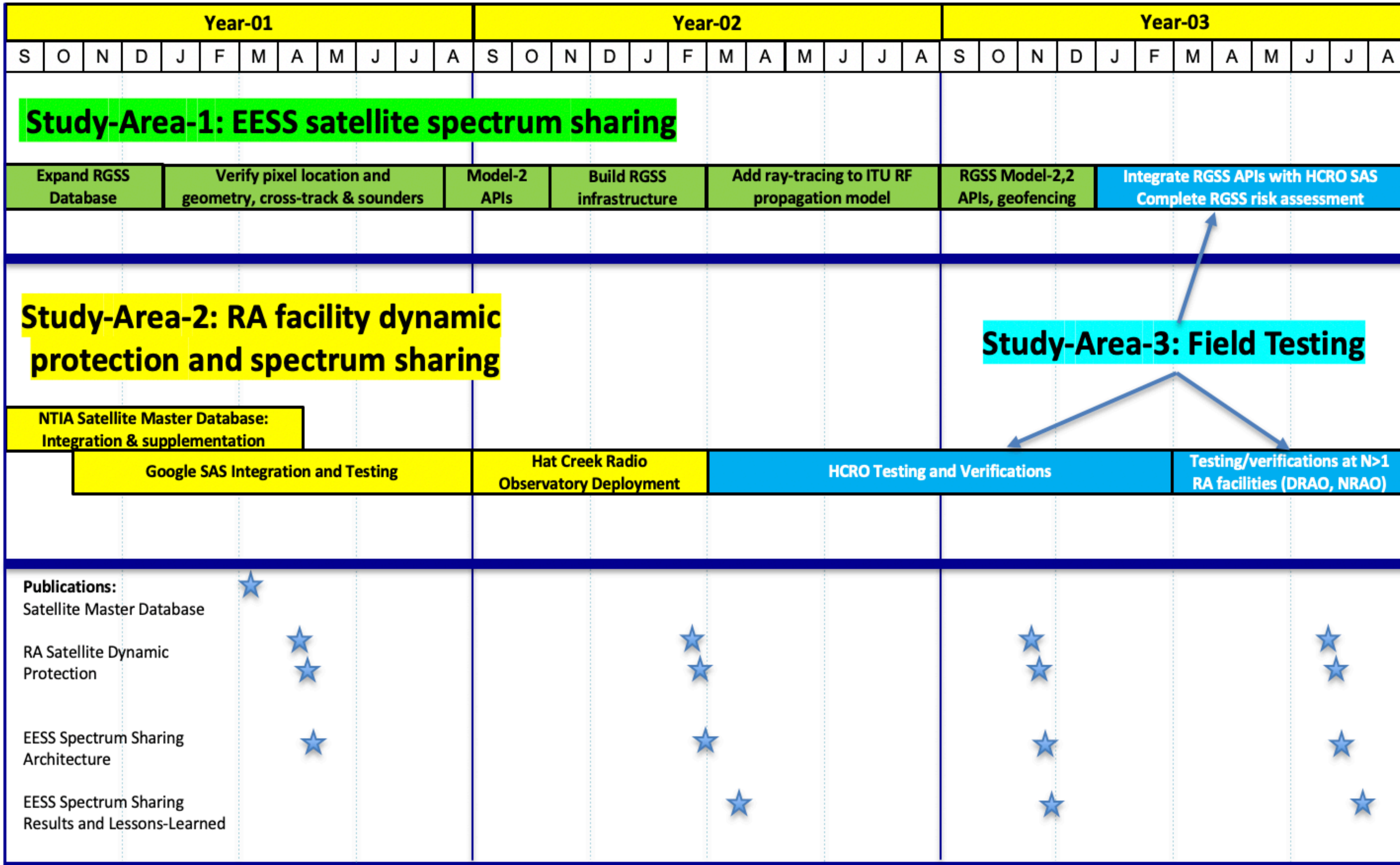
A Proposed Method to Protect RA Sites in a Shared Spectrum Environment

- Allows efficient use of a shared band while fully protecting the observatory when needed

- Could enable RA access to active bands on an opportunistic basis
  - RA often requires access to bands not allocated for RA, for example to observe doppler-shifted spectral lines or fill coverage gaps in continuum observations to better determine spectral shape

- Could enable active use of RA bands on an opportunistic basis in exchange for other considerations (lease payments, equipment, etc.)
  - This could meet temporary surges in demand, for example in emergency situations such as storms (e.g., Hurricane Maria in PR); or help meet need for IoT spectrum, in which devices are readily able to take advantage of opportunistic access

SII-NRDZ Projects Schedule



NSF CU-PASS and HCRO-NRDZ Projects Schedule (02-Nov-2021)