NSF HCRO NRDZ

Hat Creek Radio Observatory
National Radio Dynamic Zone
Project Overview

David DeBoer (UCB), Kevin Gifford (CU), Arvind Aradhya (CU), Andrew Clegg (Google), Steve Croft (UCB), Wael Farah (SI), Mark Lofquist (CU), Tim O'Shea (DS), Alexander Pollak (SI), Andrew Siemion (UCB), Georgiana Weihe (CU), Nathan West (DS)

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

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Take Away Messages

- 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.
- We need to start now to figure out what may work for RA.
- Risk mitigation, as well as potential opportunity.

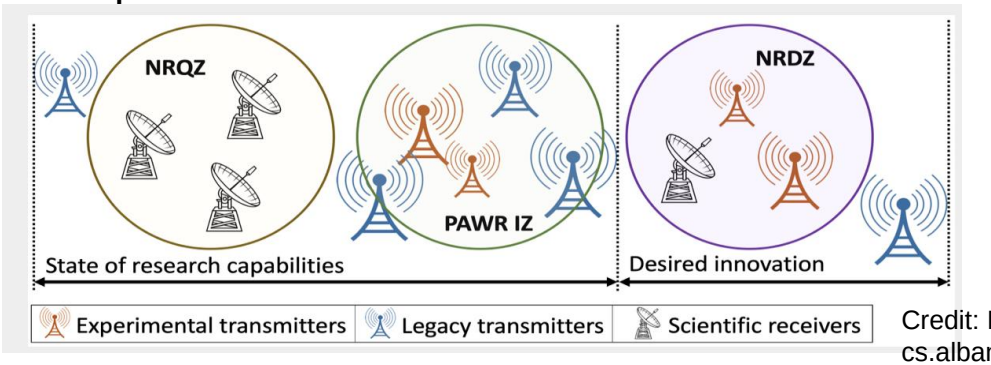
Hat Creek Radio Observatory: A Prototype National Radio Dynamic Zone

Outline

- Goals of the NSF HCRO *National Radio Dynamic Zone* Project
- RF Baseline Surveys (RFBS), RF Open Data Sets, RFI visualization
- Spectrum sharing: 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

What is a National Radio Dynamic Zone

- Being defined now
- Advocated by NSF/NASA
- Distinct from a Radio Quiet Zone
  - Limit licensed transmitters operating within
  - Limit power transmitted into



Credit: NSF NRDZ Workshop
cs.albany.edu

- Require
  - Comprehension -- understand full picture, monitoring
  - Communication -- standards and structures
  - Coordination -- mechanism/means

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

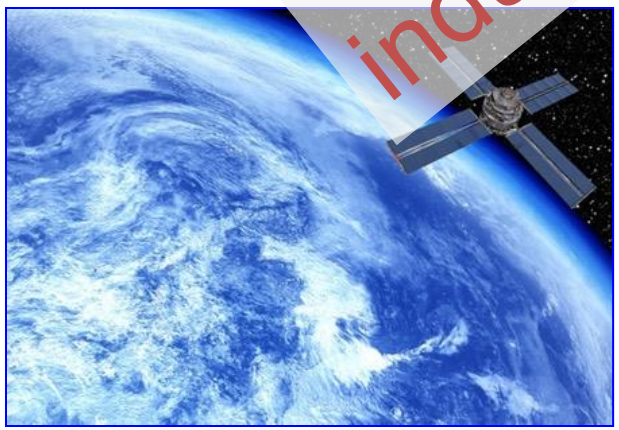
- CBRS operates in 3550-3700 MHz and shares spectrum with government radars and fixed-satellite service downlinks
  - CBRS: Citizens Broadband Radio Service
  - See the WInnForum for an introduction to CBRS
- There are no passive services in the CBRS band, but there are incumbents that must be protected from harmful interference
- A cloud-based controller called a Spectrum Access System (SAS) manages CBRS devices 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

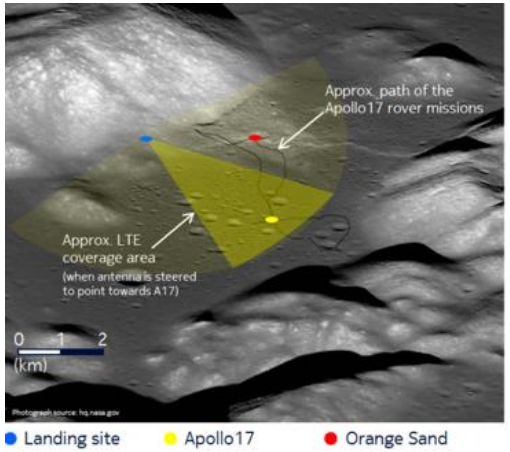
HCRO NRDZ Emphasis: bi-directional spectrum sharing

Enable bidirectional spectrum sharing:

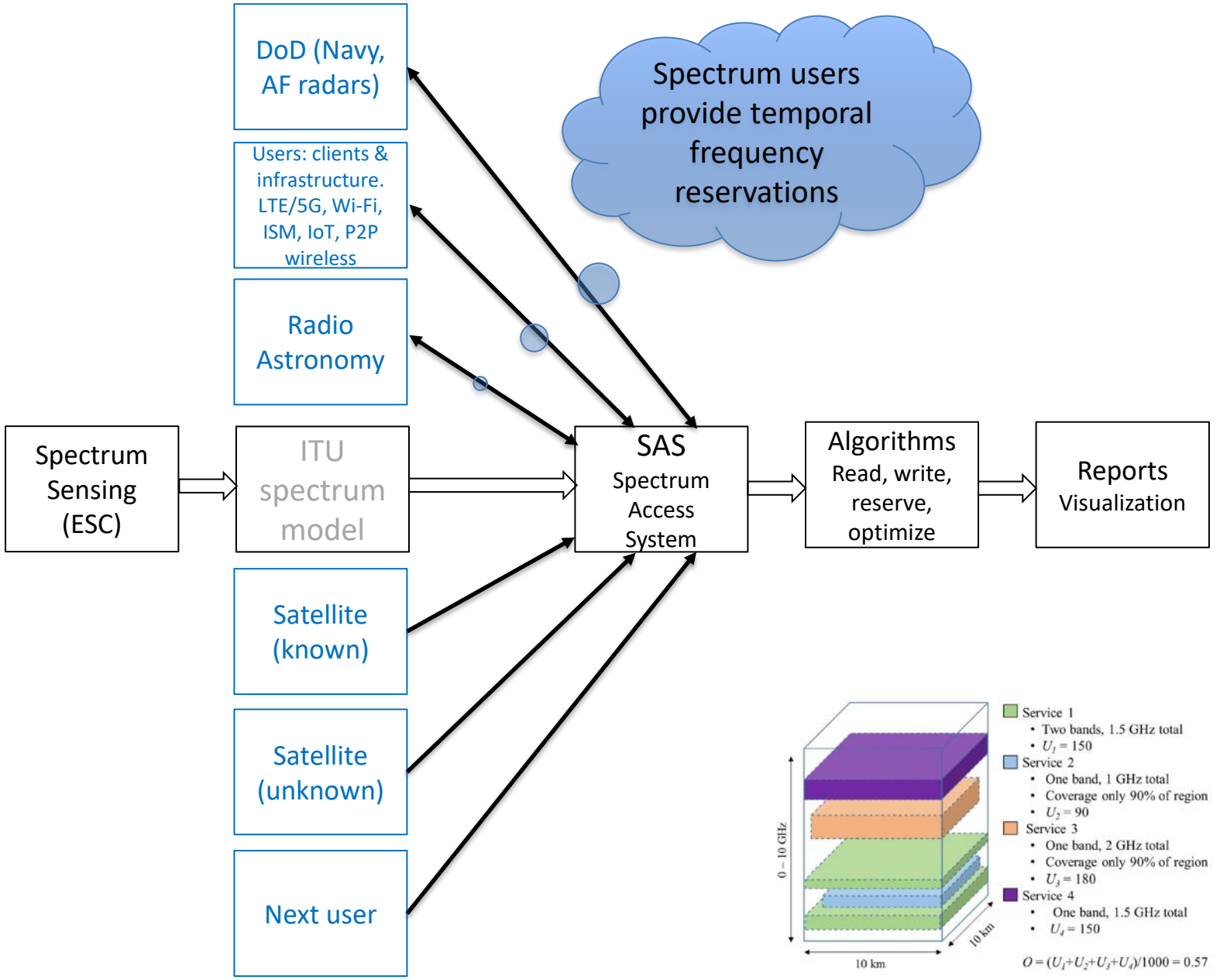
- Multi-stakeholder emphasis
  - Focus is on spectrum sharing: active Wireless comms: LTE, 5G, Wi-Fi
  - Sharing with passive Radio Astronomy (RA), Earth Exploration Satellite System (EESS)
- Radio Astronomy (RA) and Earth Exploration Satellite Service (EESS) are passive RF systems: no Tx, Rx only

But very industrious people!





Spatial-temporal spectrum sharing model



HCRO NRDZ: Four (4) Primary R&D Activities

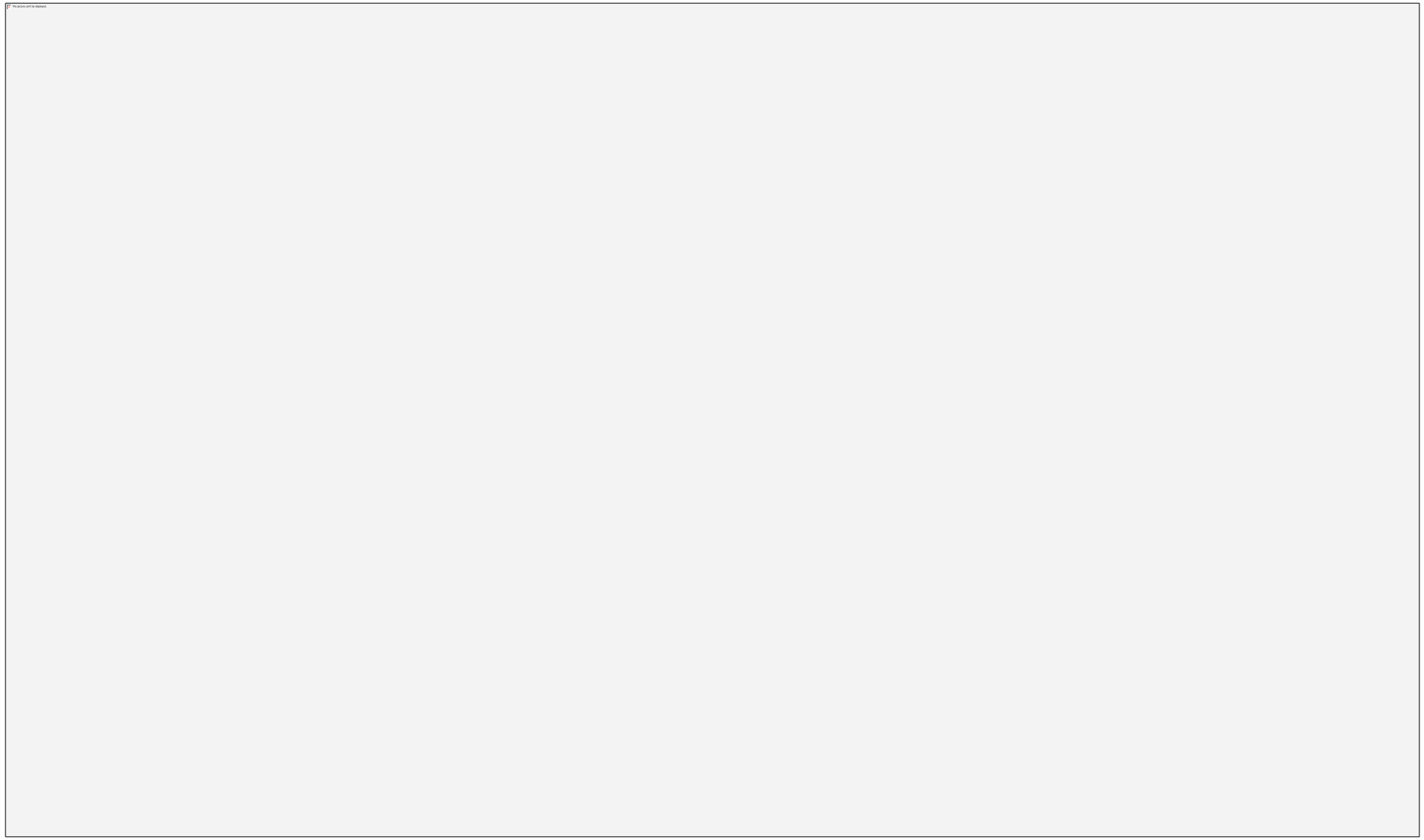
HCRO environmental spectral assessment: RF interference sources to be identified and investigated are anticipated to be relevant to all radio observatories and provides early lessons learned *("RFI hunting").*

HCRO environmental spectrum measurement: RF baseline noise surveys in selected bands of interest will be permanently deployed with automated baseline noise survey equipment, remotely managed, and all RF baseline noise data to be publicly available online (with PII excision).

Deployment of SAS (Google): Extend elements of the CBRS and/or AFC spectrum sharing architectures to compute RA receiver interference from all active emitters in the RA geolocation surroundings, with a target spectrum frequency range from 1 to 15 GHz. Extending the SAS framework to include satellite coordination will be investigated.

Spectrum sharing architectures research: Will be conducted with a specific focus upon 3-Tier (CBRS), Automated Frequency Coordination (AFC), Informing Incumbent Capability (IIC) in parallel with an Operations Research theoretical research focus .

Problem: Active emitters disrupt RA scientific observations



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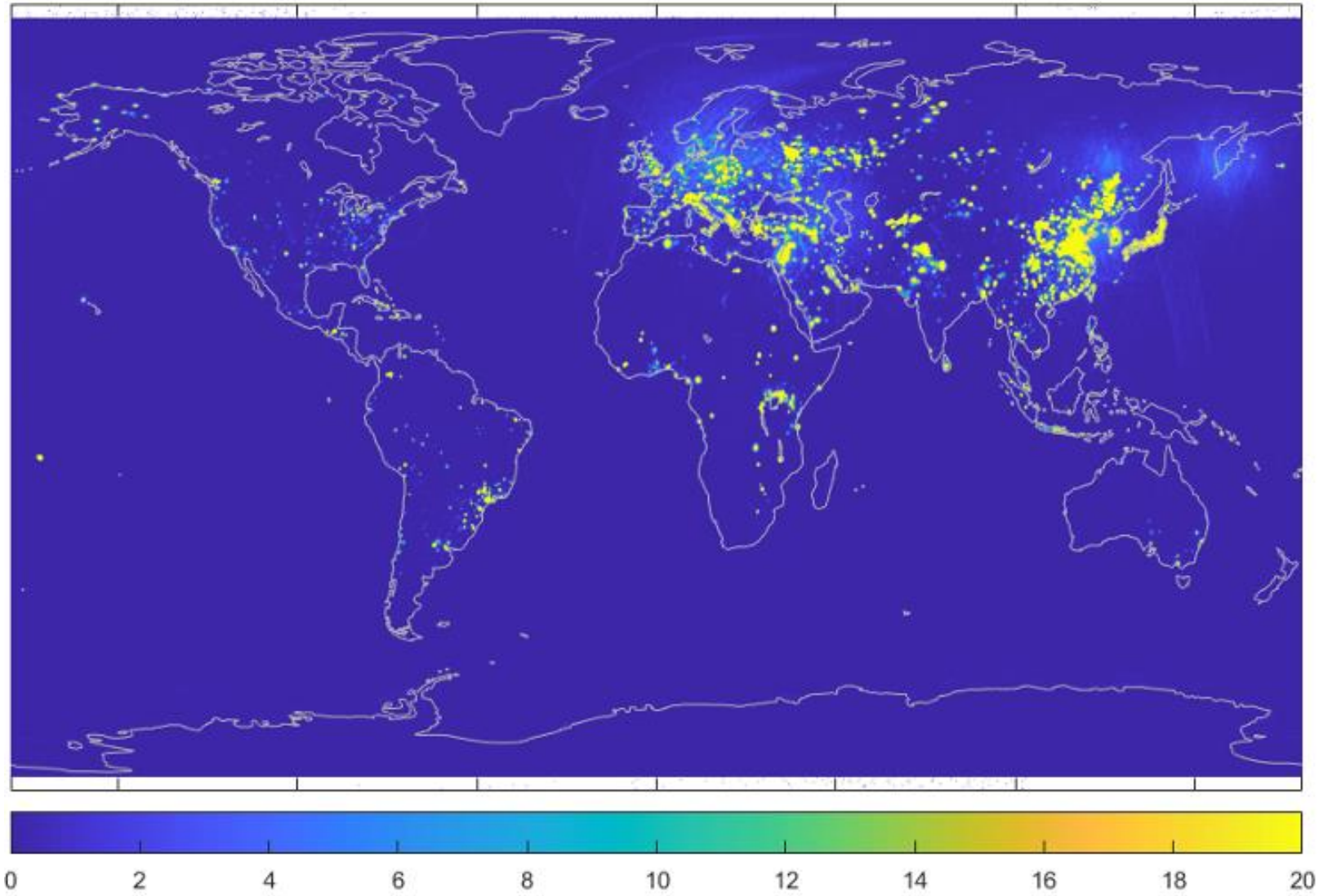


Percent of time that the 1.413 GHz passive microwave sensor on NASA's SMAP mission detects RFI level of > 5 K between April 2015 and March 2016. ITU recommended interference limit is 0.05 K.

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

Spectrum Demand

Active emitters disrupt R.A. observations, but demand for radio frequency spectrum is exploding!

- Proliferation of wireless devices
  - In 2014, Americans used 4.1 terabytes on 355.4 million cellular devices[1]
  - 69% of adults access the Internet on a smartphone[2]
  - Nearly half of U.S. homes have only cellular phones[3]
  - By 2020, 50 billion “smart” devices will connect to the internet[4]
  - By 2025, >95% of connections will be wireless[5]
- Increasing demand for high-bandwidth data on mobile devices
  - Video: Standard definition -> high definition -> 4K
  - Augmented Reality / Virtual Reality

[1] http://www.ctia.org/ your-wireless-life/how-wireless-works/annual-wireless-industry-survey
[2] http://www.leichtmanresearch.com/press/120315release.html
[3] http://www.cdc.gov/nchs/data/nhis/earlyrelease/wireless201512.pdf
[4] https://safeatlast.co/blog/iot-statistics/
[5] M. K. Weldon, The Future X Network: A Bell Labs Perspective (2016)

Passive RF systems summary concerns

- Passive radio frequency observations provide unique information that is of great value to scientific research and society (origins, climate, moisture, weather, etc.)

- The bands in which these observations are made are, in most cases, dictated by mother nature – they cannot be moved, or traded

- The signals being measured are very small, and thus particularly susceptible to interference, which corrupt observations

- Some areas of concern for the passive community:
  - Out of band and spurious emission into passive-only bands
  - In-band emission in to shared bands (e.g., when previously ground-based transmissions are allowed to become airborne)
  - Increased utilization of mobile transmissions that (interference from fixed sources is generally far easier to ameliorate)

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.

HCRO NRDZ Spectrum Sharing

Extend elements of the CBRS and/or AFC spectrum sharing architectures to compute RA receiver interference from all active emitters in the RA geolocation surroundings, with a target spectrum frequency range from 1 to 15 GHz. Elements will include:

- **Create a database of RA facilities in the United States and US Territories**, including their location, the bands in which they are capable of observing, the nature of their operations, and other co-existence-related characteristics. *The proposed Passive and Active Spectrum Sharing WG (PASS-WG) will leverage existing databases; however, most are incomplete, out-of-date, and/or inaccurate.*

- **Create a database of Earth observation (LEO, MEO, GEO) satellites, both active and passive**, including satellite orbit information (ephemeris orbit, two-line element (TLE)), satellite uplink and downlink frequencies, and corresponding satellite ground station geolocations.

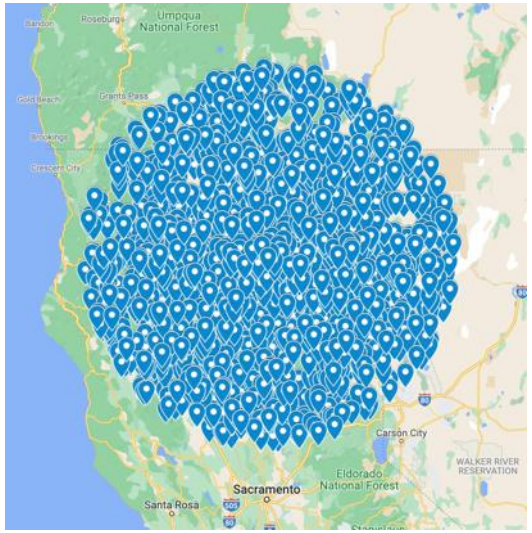
- **Investigate methods and protocols for automatically ingesting RA observing schedules**, satellite ephemeris data, etc.

- **Propose spectrum sharing approaches and algorithms** for determining “spectrum grant”-equivalent actions, by treating RA observatories as Dynamic Protection Area (DPA) structures and considering predicted interference created by active systems.

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

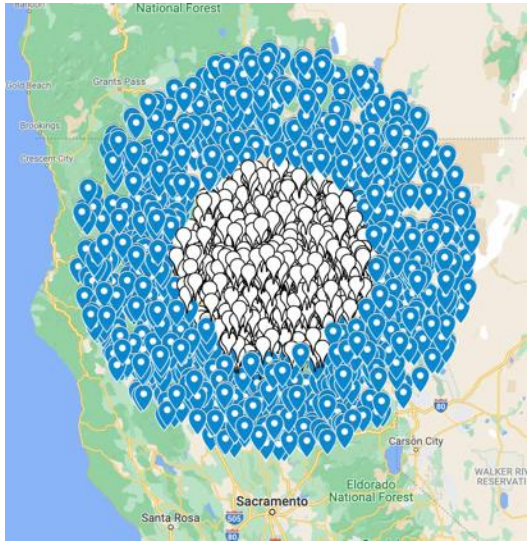
- A DPA is a pre-defined area (or a point) in/at which an incumbent operates on a dynamic basis (i.e., operations change with time and frequency)
- When an incumbent is operating in a DPA, secondary users in the *neighborhood* of the DPA could be required to change their operating parameters to protect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



200 km and random emitters

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

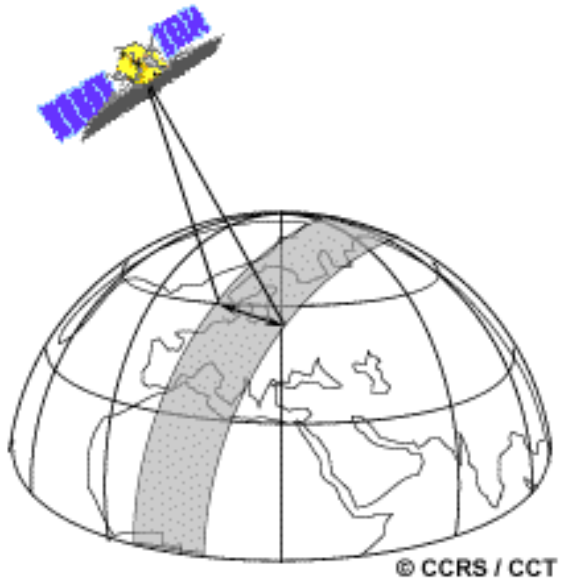
- Secondary users outside of the DPA are not expected to cause interference and are not affected by the presence of the DPA
- The size of the neighborhood is based on assumed deployment models, the DPA interference criterion, and a standardized propagation model



200 km and 100 km DPA

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)

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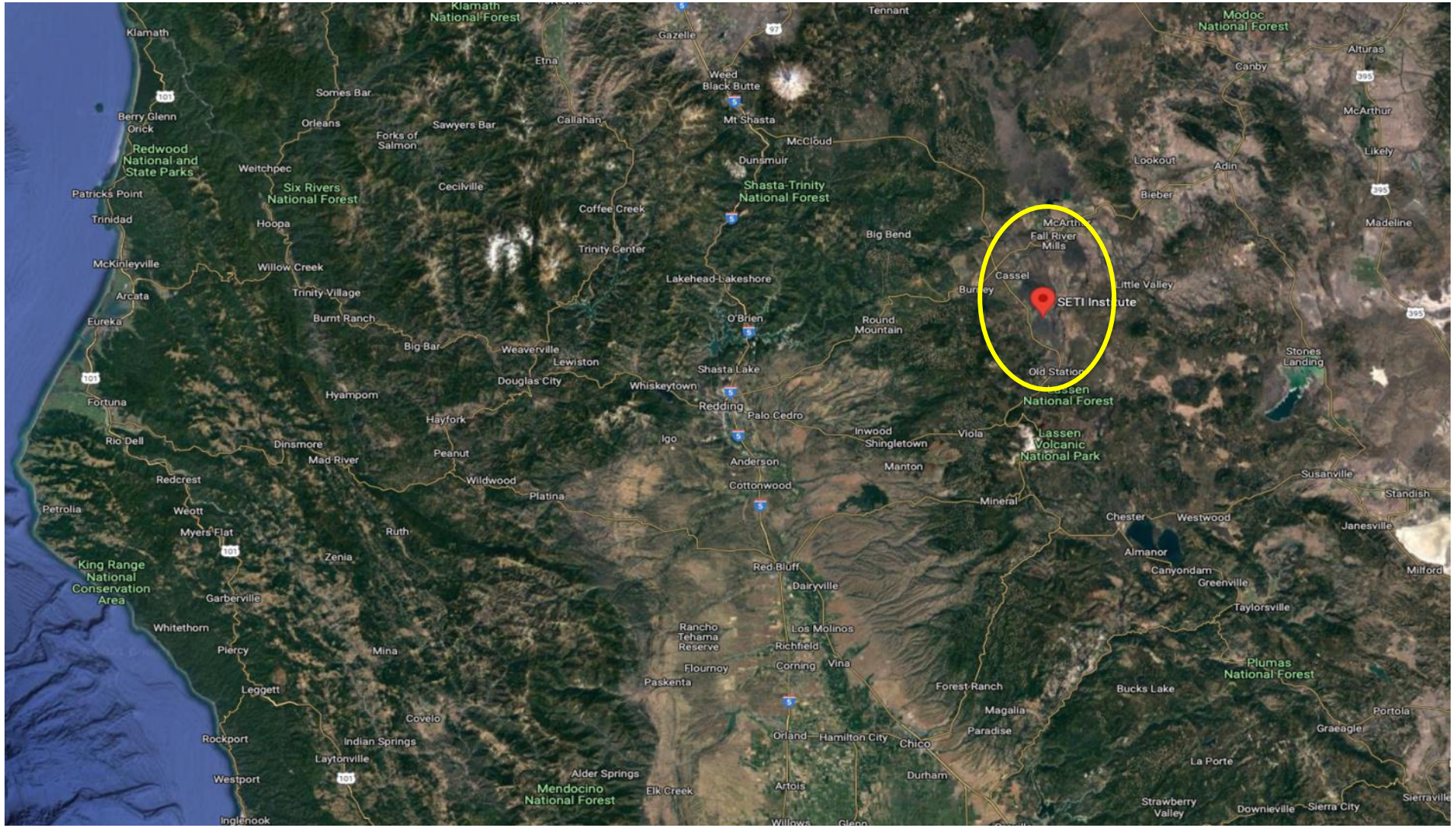

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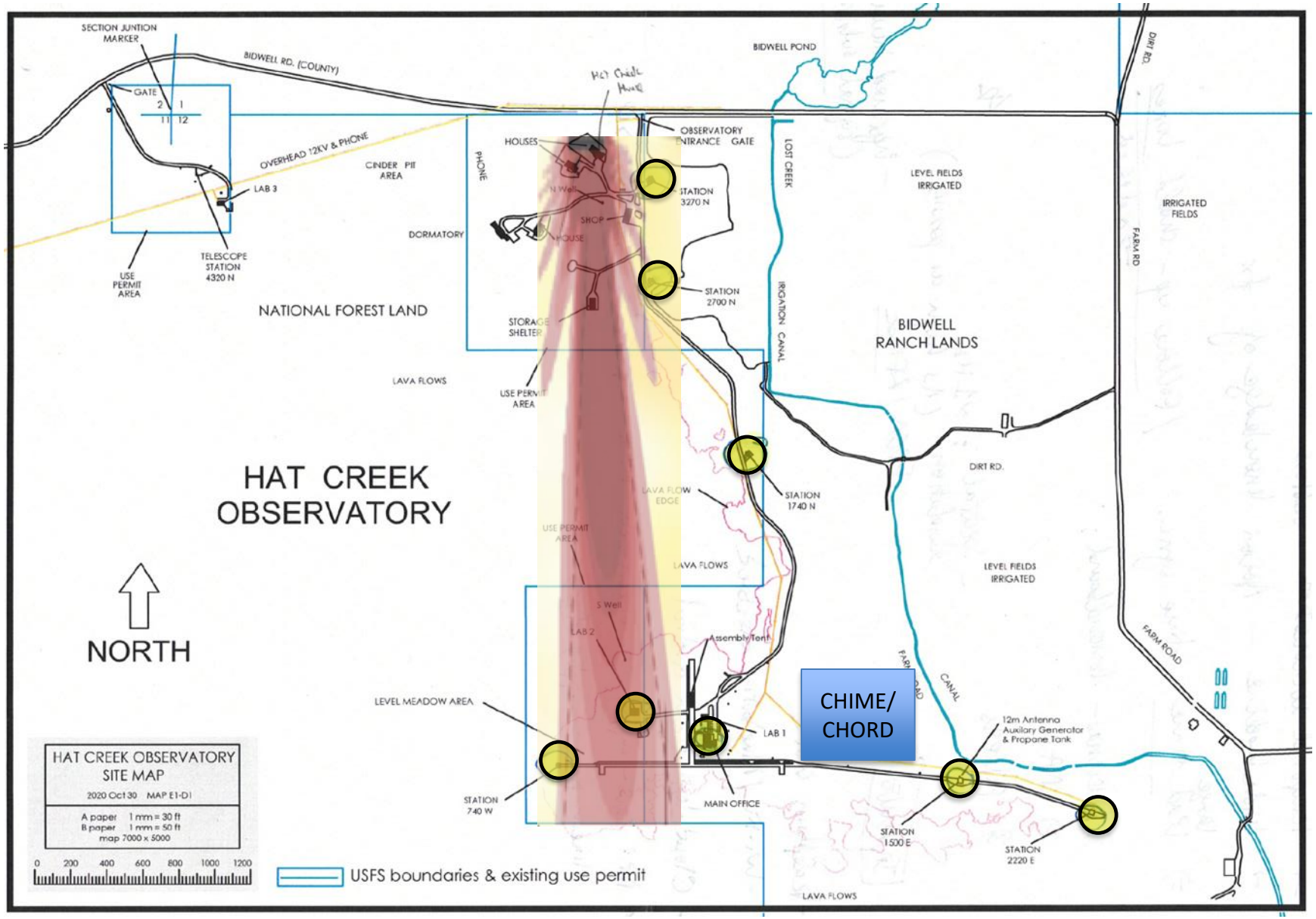
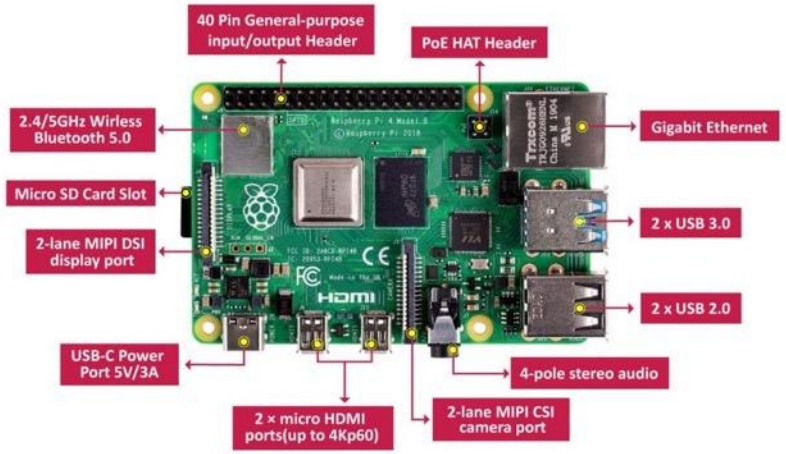
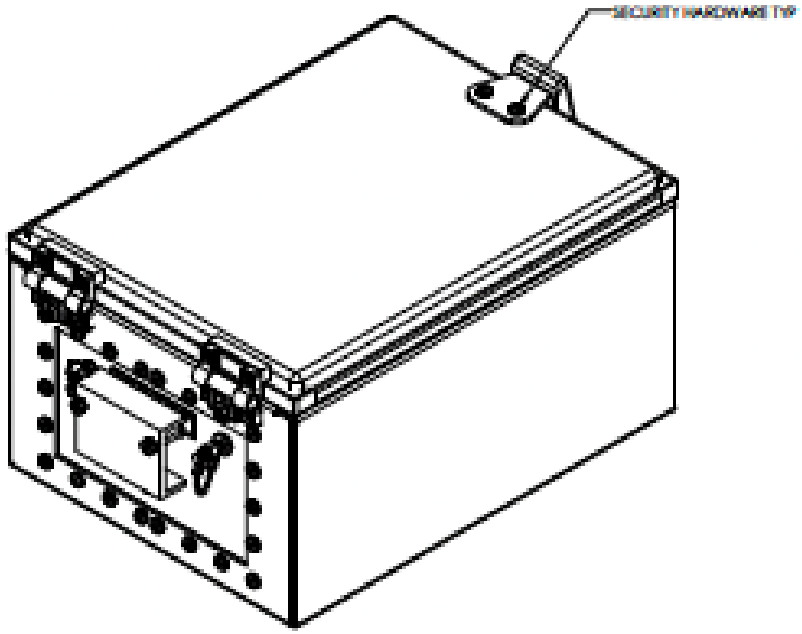


HCRO-NRDZ RF Baseline Sensors initial layout

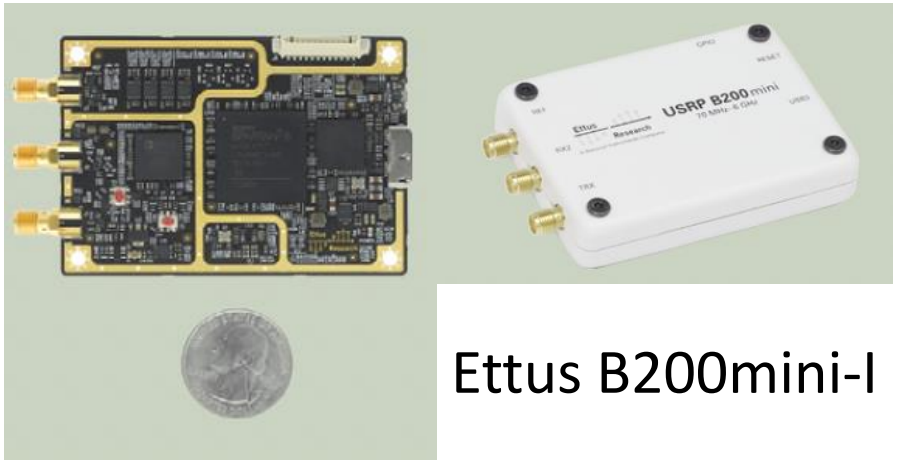
RF Baseline Sensor design for RFI Hunting



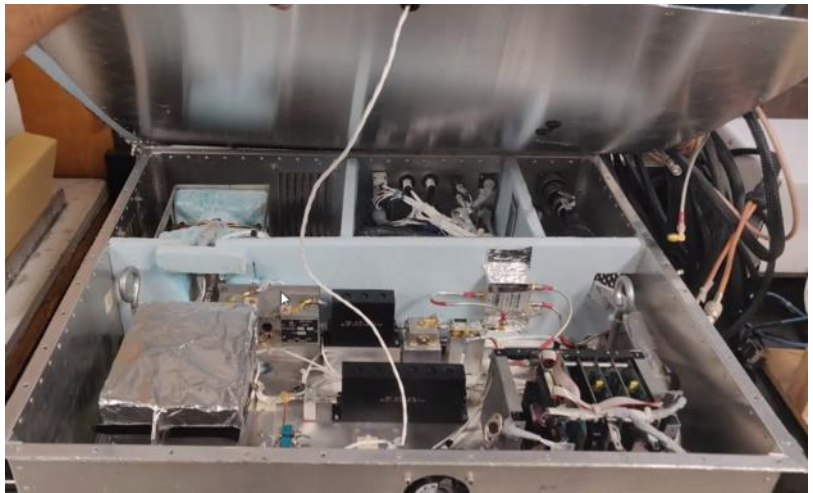
Raspberry Pi 4



EMI enclosure (TC)



Ettus B200mini-I



Spectrum Sharing

Musings on approach/standards

Standards and pipeline to collect, share and analyze RF data across instruments and platforms. Goal would be to install the pipeline on every radio telescope as well as monitors etc. Leverage all of the great work to make a shareable standard. Note that the goal is RF characteristics/characterization, not astronomical scientific research. These two things are not necessarily exclusive of each other, but design choices will favor characterization.

- Level 0 - base structure definition, minimal meta-data
- Level 1 - low-level spectral and temporal data sets at native or near-native resolutions, other instrument specifications
- Level 2 - lower resolution spectra, spectral occupancy statistics: min-hold, 10%ile, 50%ile, 90%ile, max-hold, mean, variance; derived either from Level 1 or Level 2 data.
- Level 3 - “feature sets” of derived data (either Level 1 or Level 2). Maybe spectral/temporal occupancy at a lower resolution standard or excised RFI info, or more niche like “FM radio in South Africa”. The idea is to make this an open source library for people to use and contribute to. ML, triggered, classified data, etc
- Level 4 - public. A high-level web-based archive of data that is accessible for public/education/etc

Software to write, read, manipulate, transfer, archive etc as part of standard pipelines. Local users can set knobs for e.g. archive data rates etc. The hope is that installations run their local version and archive what they can, but then also transfer some data products to a “central” database for wider use.

NSF HCRO NRDZ Project Anticipated Results

The HCRO NRDZ Passive and Active Spectrum Sharing project directly addresses the problem of protecting passive users while enabling secure, dynamic spectrum sharing between passive and active systems. The PASS project will:

1. Systematically survey RF noise across multiple environments, including a functional radio observatory, and compile a baseline, public dataset for collaboration with other organizations;
2. Analyze and characterize RF noise and interference sources and evaluate hardware and software mechanisms to mitigate noise;
3. Explore new and innovative approaches to dynamic spectrum sharing between passive and active systems;
4. Analyze and quantitatively evaluate the effectiveness of mechanisms to coordinate bi-directional spectrum sharing between passive and active systems;
5. Explore hardware and software approaches to enhance the effectiveness and security of spectrum sharing; and
6. Define the requirements and initial processes to maintain a National Radio Dynamic Zone (NRDZ);
7. Further, the project will develop data structures, processes, and software to enable future multi-institutional collaboration on RF noise measurement and modeling.

The results from this project will:

- Provide experimental and analytical evidence to inform future policy decisions on spectrum sharing
- Enable more effective dynamic utilization of spectrum
- Inform the creation of a National Radio Dynamic Zone: NRDZ
- Provide standards for observing sharing (schedule, spectra, features, …)

Thanks!!

Questions…