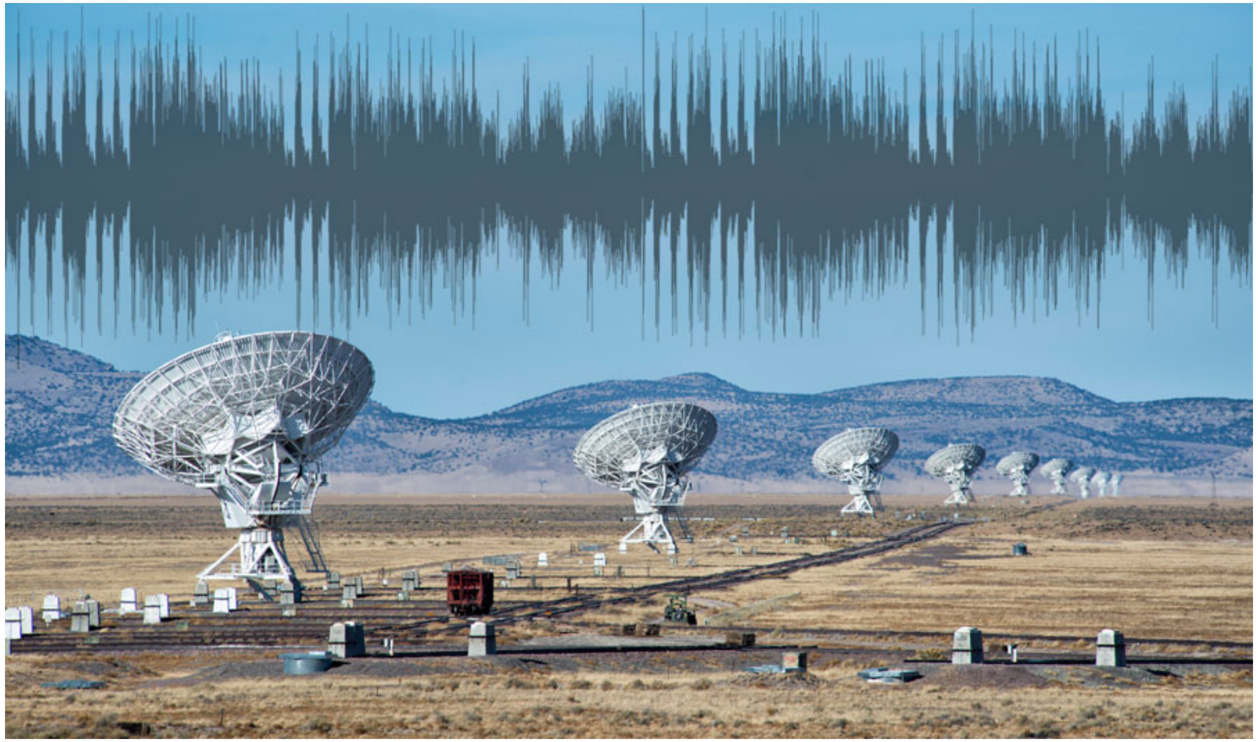

Passive and Active Spectrum Sharing (PASS)

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Passive and Active Spectrum Sharing: Outline

- Why spectrum sharing important for passive services (focus on Radio Astronomy, R.A.)
- Goals of the Passive and Active Spectrum Sharing (PASS) WG and project
- Current work and status: CBRS, 6 GHz AFC, Dynamic Protection Area (DPA) neighborhoods
- Forward activities: prototype deployment (HCRO), satellite inclusion
- Spectrum sharing for Science final thoughts

Passive and Active Spectrum Sharing: 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.

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Problem: Active emitters disrupt RA scientific observations

Slide 4

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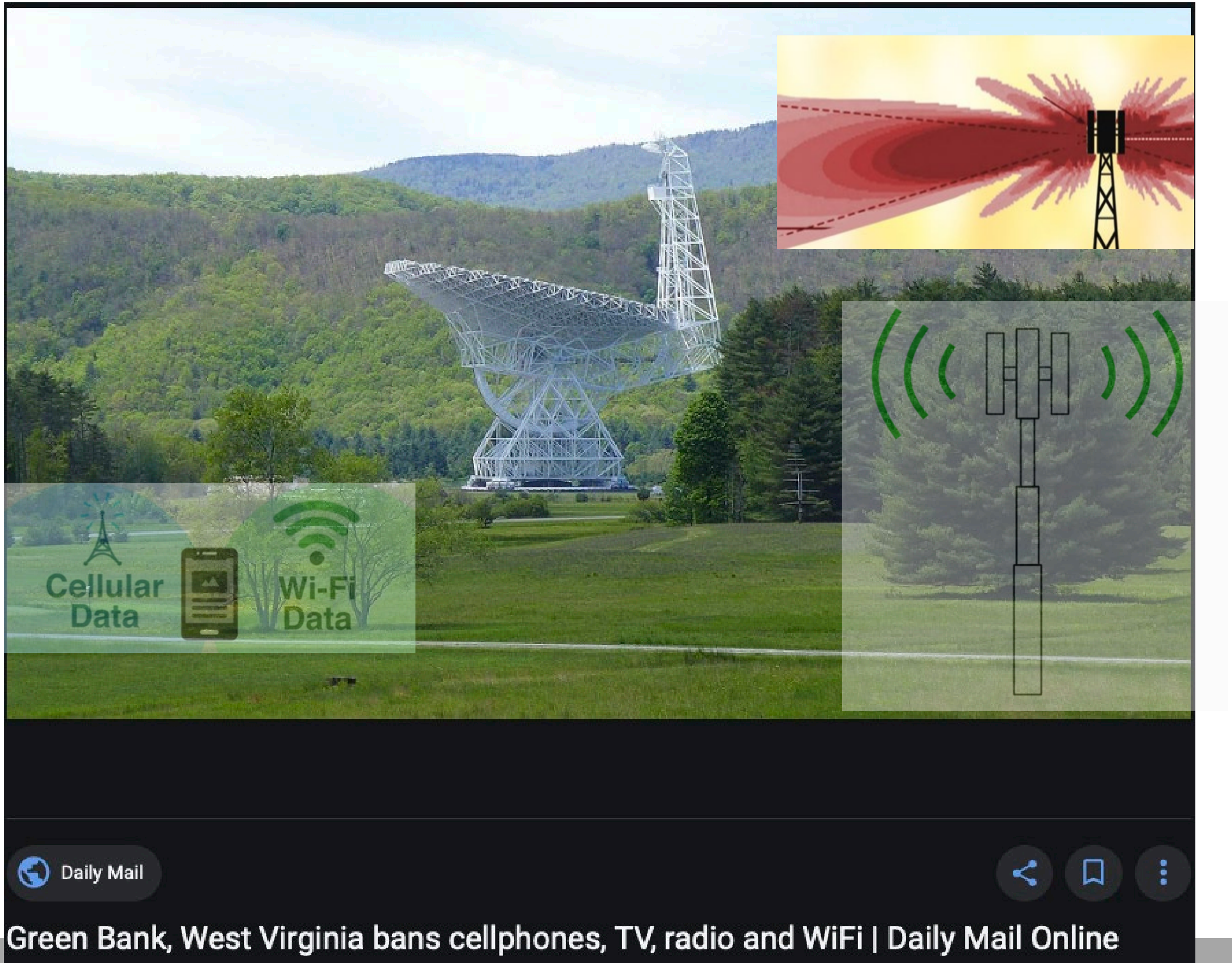
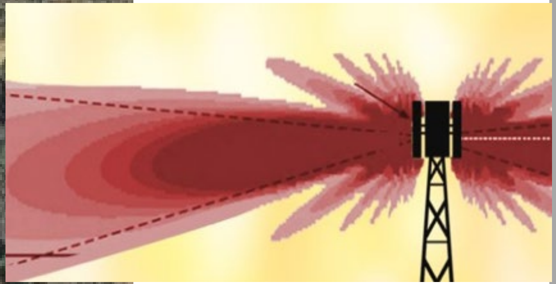
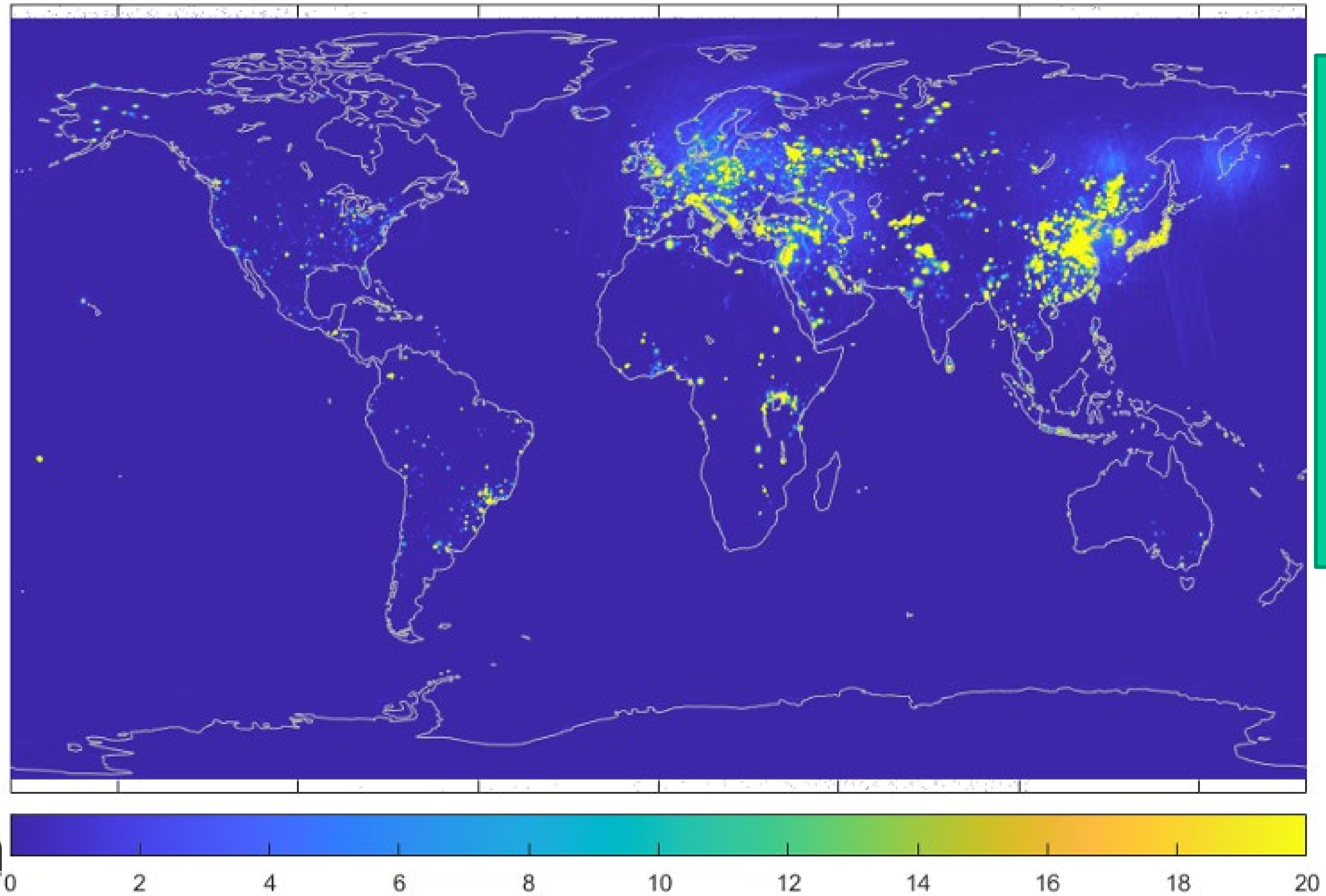
Problem: Active emitters disrupt RA scientific observations



Problem: Active emitters disrupt RA scientific observations



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).

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Wireless Innovation Forum

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

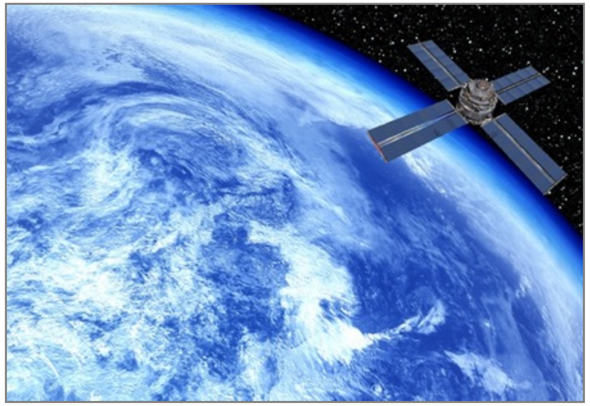
- **Passive radio frequency observations provide unique information that is of great value to scientific research and society (origins, climate, moisture, weather, etc.)**
- **The bands in which these observations are made are, in most cases, dictated by mother nature – they cannot be moved, or traded**
- **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)

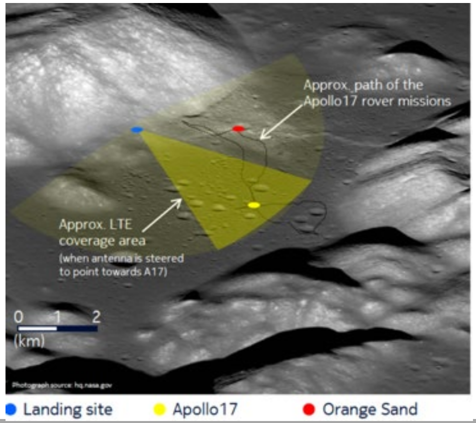
PASS Project Emphasis: Enable bi-directional spectrum sharing for R.A.

Enable bidirectional spectrum sharing:

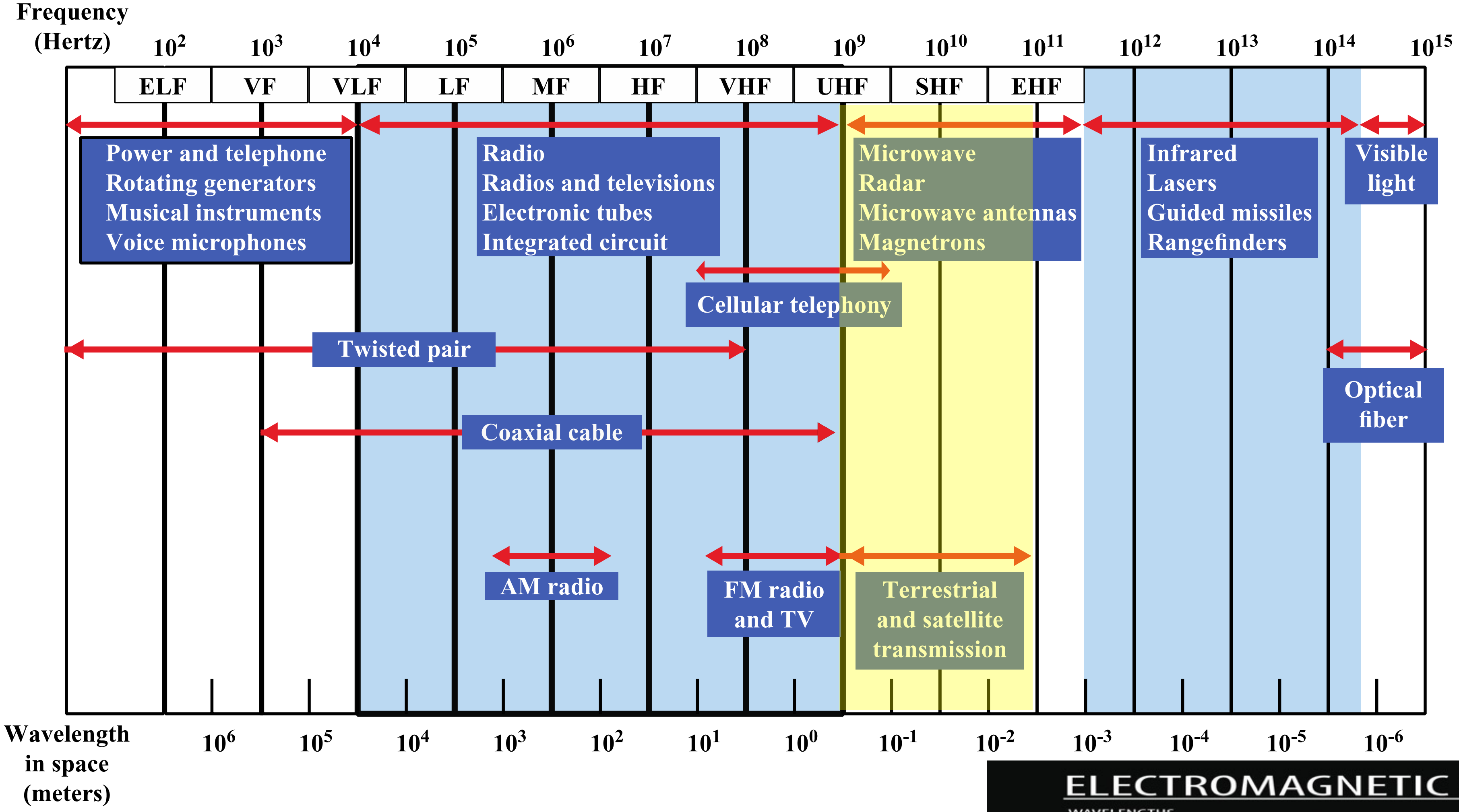
- **Multi-stakeholder emphasis**
  - Focus is on spectrum sharing: active Wireless comms: LTE, 5G, Wi-Fi
  - Sharing with passive Radio Astronomy (RA), Earth Exploration Satellite System (EESS)

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





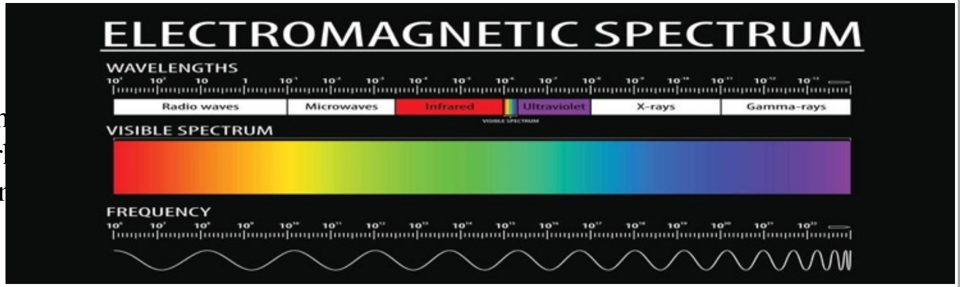
The Electromagnetic Spectrum



ELF = Extremely low frequency
VF = Voice frequency
VLF = Very low frequency
LF = Low frequency

MF = Medium frequency
HF = High frequency
VHF = Very high frequency

UHF = Ultrah
SHF = Superl
EHF = Extrem



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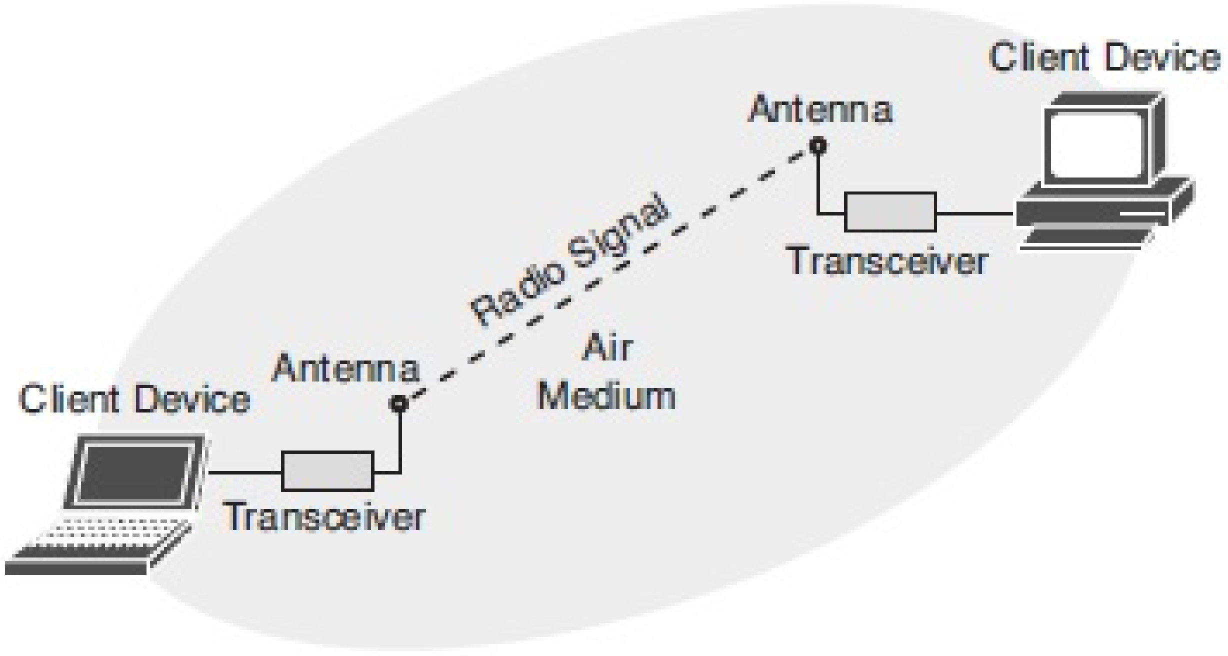
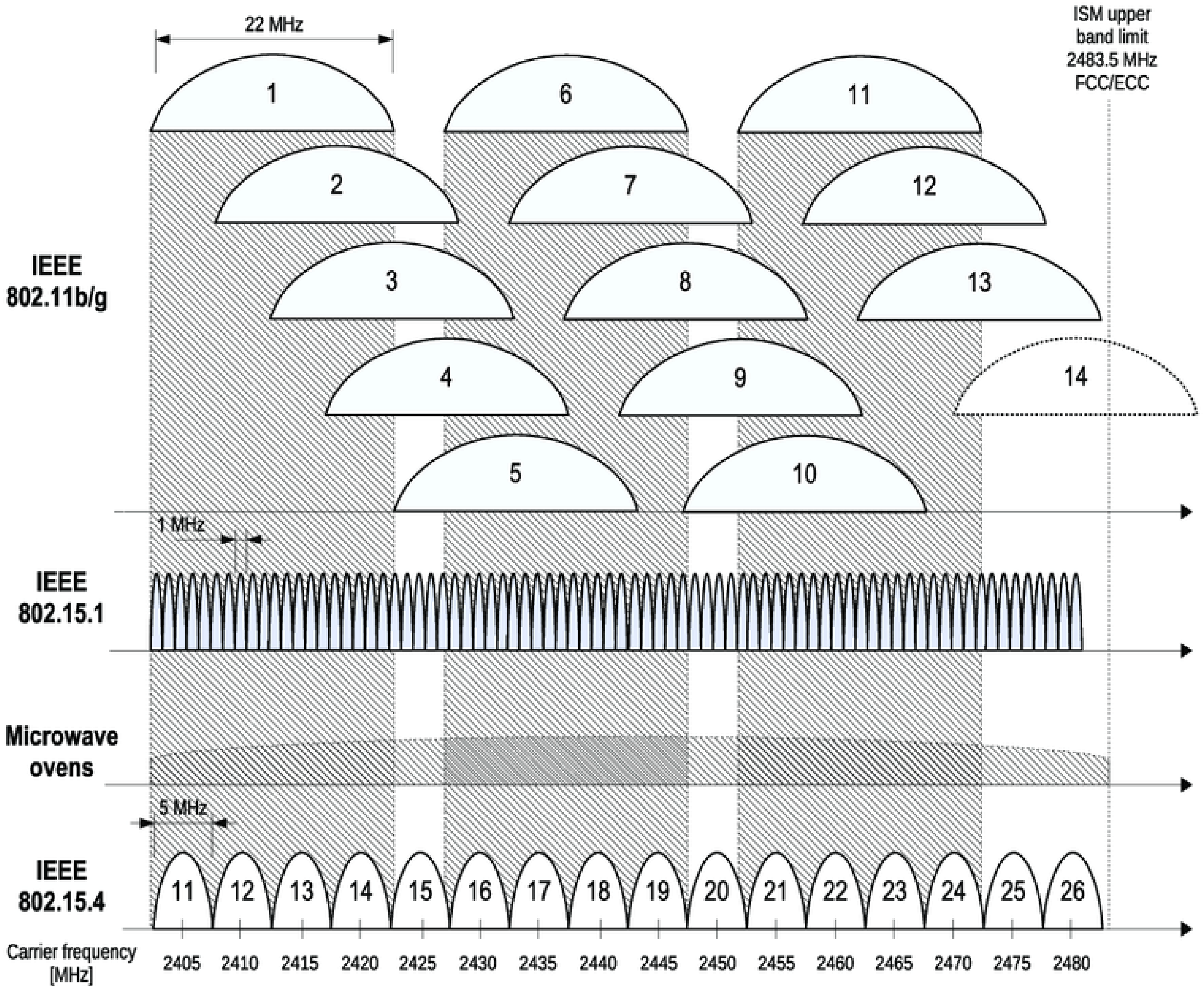
RF transmission between Tx and Rx (Wi-Fi)



Spectrum Sharing – Active systems: 2.4 GHz ISM band with Wi-Fi, Bluetooth, microwaves, wireless phones, LoRa, and more



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Slide 13

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United States (FCC and NTIA) Frequency Allocations

Slide 14

Spectrum Sharing general approaches

Sharing Approach	Description	Comments
Spectrum Sensing (SS)	Effectively a "listen-before-talk" approach which senses activity and seeks to use unoccupied bands.	• SS is subject to the "hidden node" problem in which a competing device may be actively using the spectrum, but at a power level too low to be sensed. • SS is not capable of sensing, and hence coordinating with, passive receivers.
Cooperative Spectrum Sensing (CSS)	SS nodes share information about sensed activity for a more complete picture.	• CSS reduces, does not eliminate, "hidden node" problem. • CSS is not capable of sensing, and hence coordinating with, passive receivers.
Geolocation Databases (GL-DB)	Each device senses its position and queries a database for spectrum availability.	• Passive nodes are addressed by adding "quiet zones" to the database. • Geographic regions are defined by worst case analysis to avoid interference.
Beacon Signaling (BeS)	A beacon is an active transmitter indicating spectrum use.	• Passive nodes are addressed by utilizing beacons to inform other devices. • Beacons represent additional infrastructure/spectrum use.
Command-and-Control (C2)	One or more master nodes actively control and coordinate spectrum assignments.	• All devices must be able to communicate with a master node and provide geolocation information. • A C2 node can actively re-assign spectrum use around a passive node or quiet zone.

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PASS Project Scope

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 DPA-like structures and considering predicted interference created by active systems.

POTENTIAL Additional topics to investigate

- RFI Hunting visualizations: Enhanced visualizations of RF Baseline noise survey I/Q data.

- The employment of data mining and associated data analytics techniques applied to high sensitivity RFI monitoring data from radio observatories to identify possible additional spectrum sharing opportunities.

- Reliability and applicability of long-range propagation models, which are particularly important in protecting RA facilities from terrestrial interference due to their extreme sensitivity.

- Extend spectrum sharing architecture for the protection of passive earth observation satellites (i.e., dynamic coordination with ground-based transmitters).

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Examples of Methods Used to Protect Incumbents in 3.5 GHz CBRS and 6 GHz AFC with Relevance to Passive/Active Spectrum Sharing

CBRS Overview

- We'll discuss 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

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CBRS Overview

- CBRS operates in 3550-3700 MHz and shares spectrum with government radars and fixed-satellite service downlinks
  - See this WInnForum webinar 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

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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

DPAs vs Exclusion Zones

- DPAs are not exclusion zones
  - DPAs are *where the incumbent operates*, not where secondary users might be prohibited from operating, or need to change their operating parameters, to protect the incumbent

- DPA neighborhoods 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

Use of DPAs for Incumbent Protection: **ESCs and IIC**

- 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) (See NTIA letter and FCC waiver)
  - 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 budding 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

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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

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How DPAs Work in CBRS: Step 4 – As You Were

- When and 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

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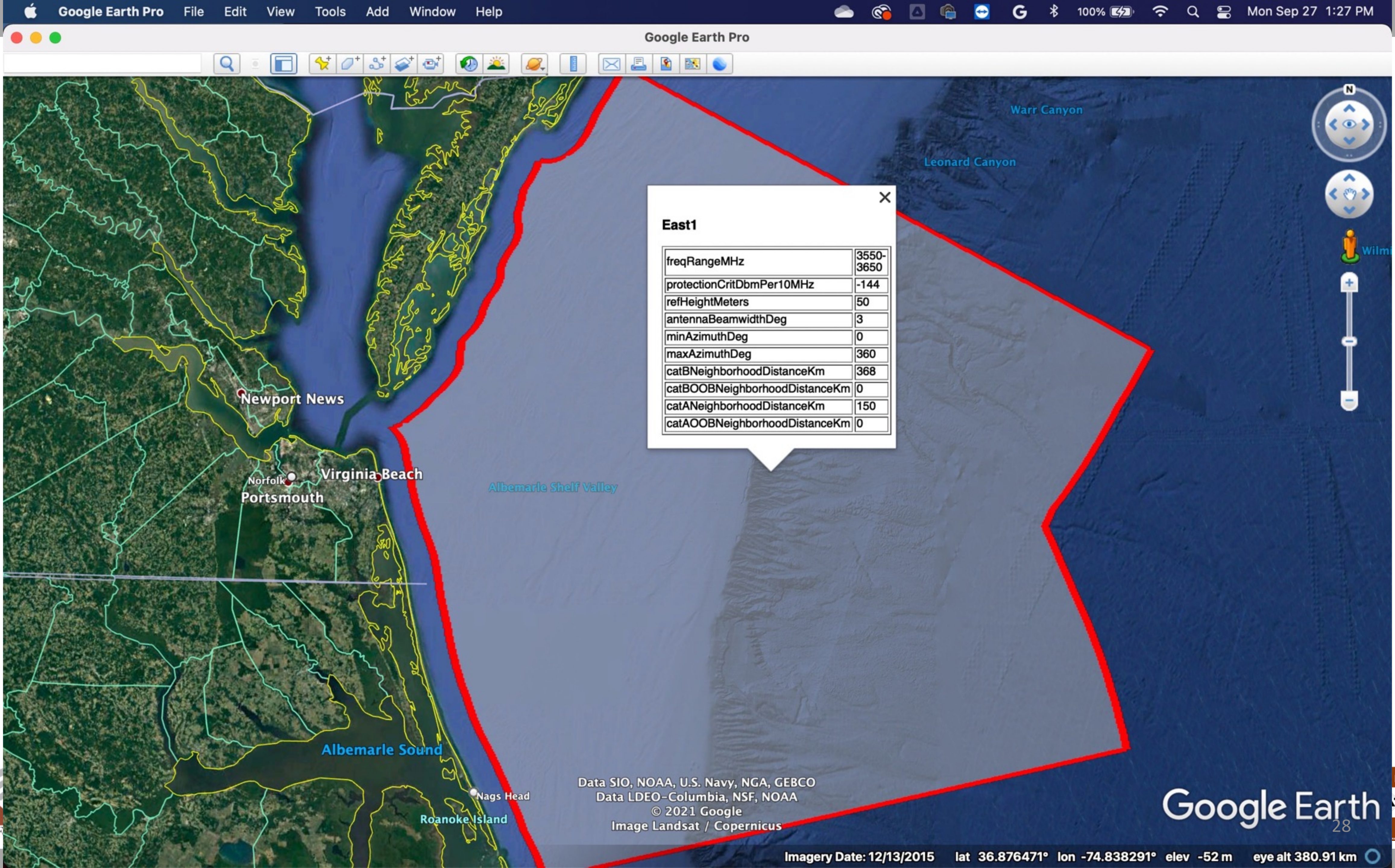
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minAzimuthDeg 0
maxAzimuthDeg 360
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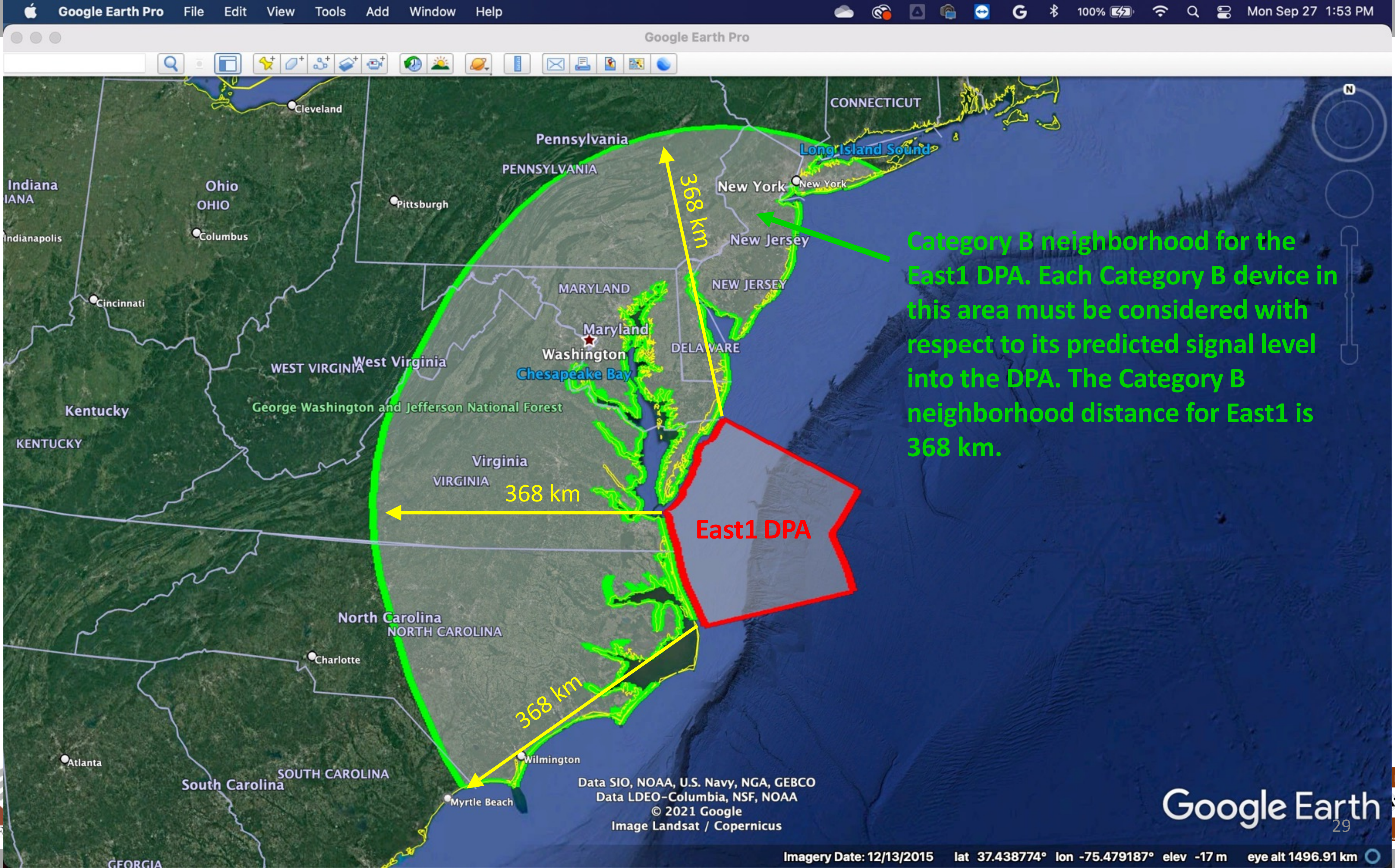
catBOOBNeighborhoodDistanceKm 0
catANeighborhoodDistanceKm 150
catAOOBNeighborhoodDistanceKm 0
Warr Canyon
Leonard Canyon
Newport News
Norfolk
Virginia Beach
Portsmouth
Albemarle Shelf Valley
Albemarle Sound
Nags Head
Roanoke Island
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Data LDEO-Columbia, NSF, NOAA
© 2021 Google
Image Landsat / Copernicus
Google Earth
Imagery Date: 12/13/2015 lat 36.876471° lon -74.838291° elev -52 m eye alt 380.91 km



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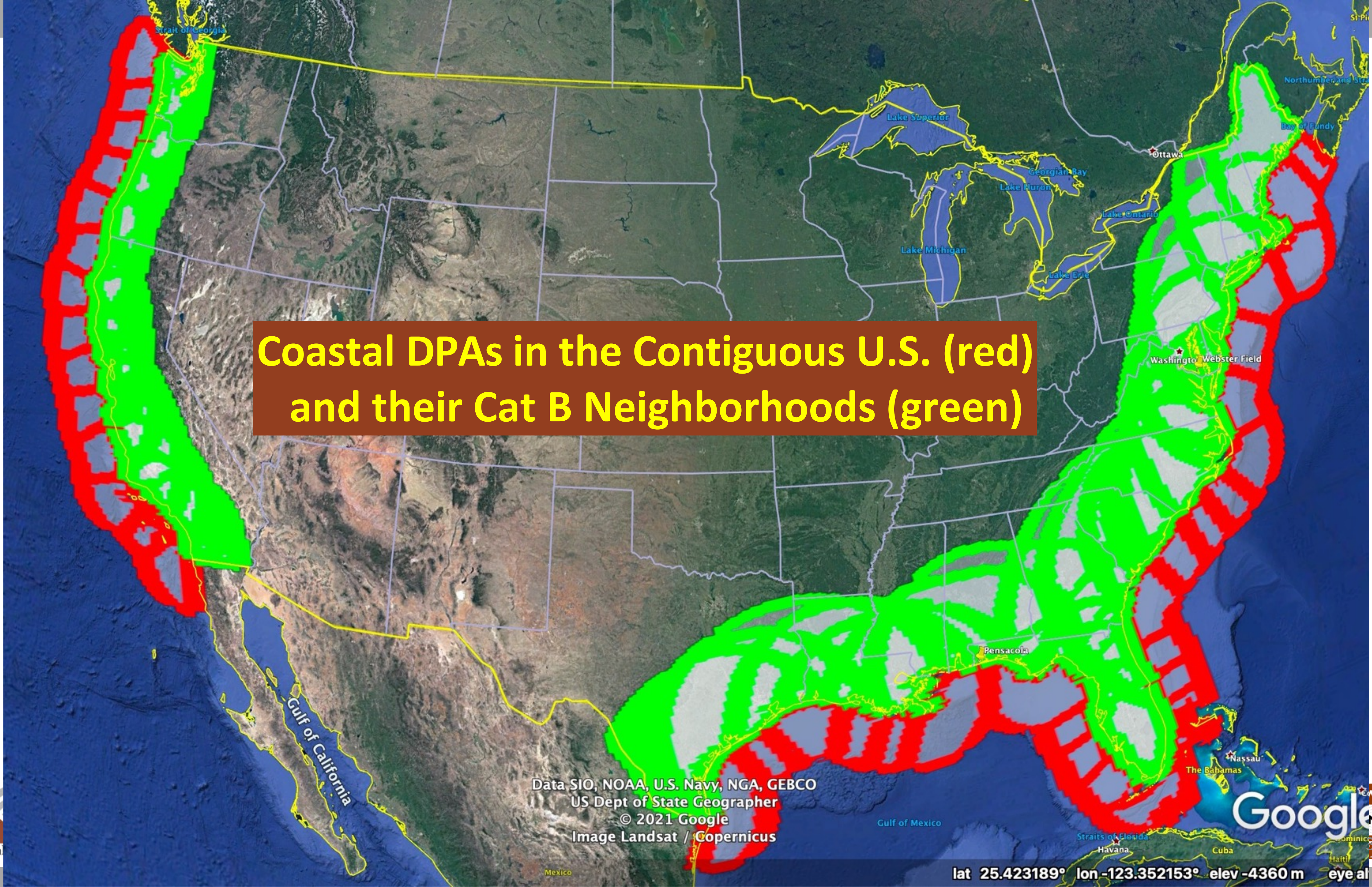
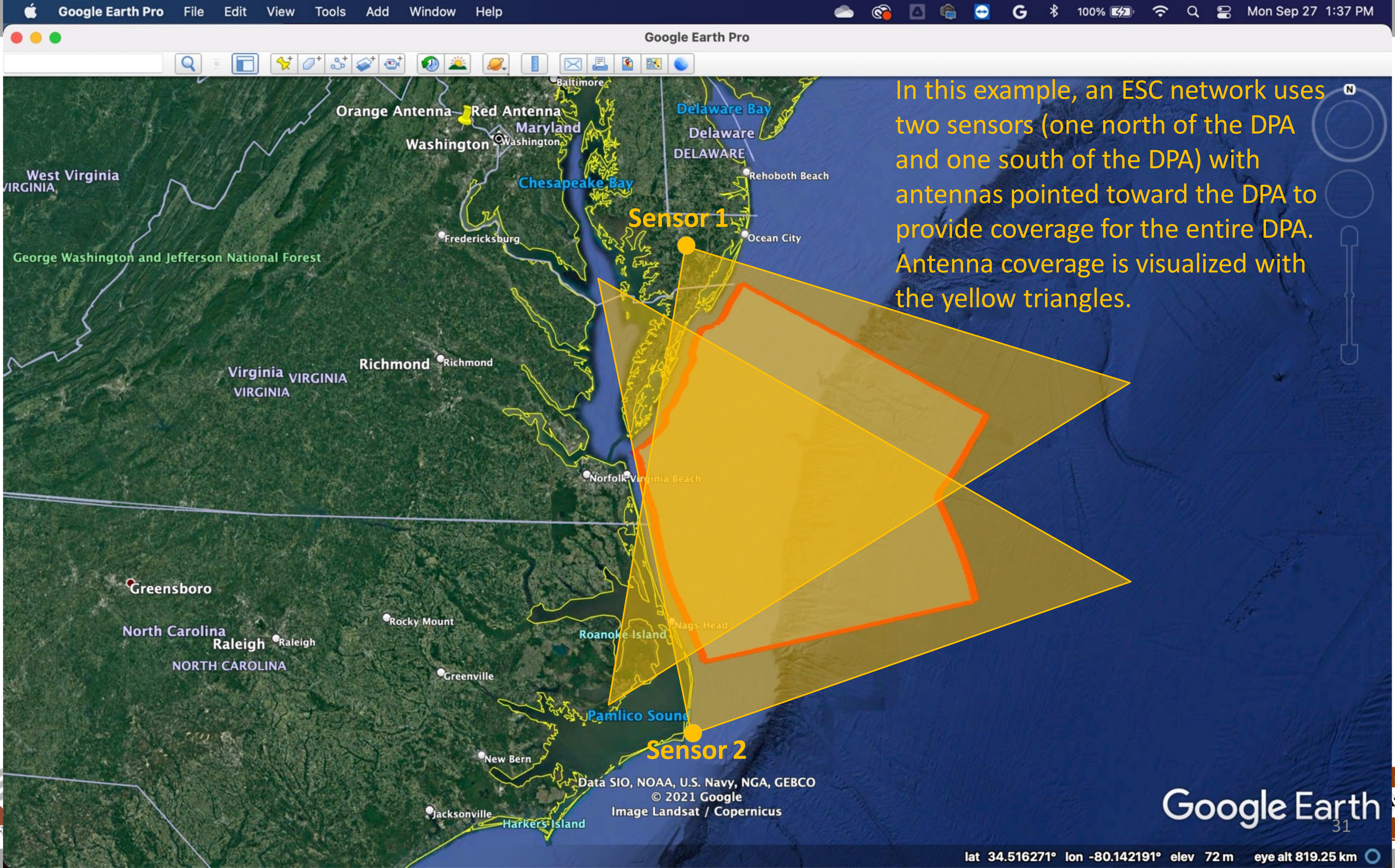
Category B neighborhood for the East1 DPA. Each Category B device in this area must be considered with respect to its predicted signal level into the DPA. The Category B neighborhood distance for East1 is 368 km.
East1 DPA
368 km
368 km
368 km
Cleveland
Pennsylvania
PENNSYLVANIA
CONNECTICUT
Long Island Sound
New York
New York
Indiana
Ohio
OHIO
Pittsburgh
Columbus
Indianapolis
New Jersey
NEW JERSEY
MARYLAND
Cincinnati
Maryland
Washington
DELAWARE
WEST VIRGINIA
West Virginia
Chesapeake Bay
Kentucky
George Washington and Jefferson National Forest
KENTUCKY
Virginia
VIRGINIA
North Carolina
NORTH CAROLINA
Charlotte
Atlanta
Wilmington
South Carolina
SOUTH CAROLINA
Myrtle Beach
GEORGIA
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Data LDEO-Columbia, NSF, NOAA
© 2021 Google
Image Landsat / Copernicus
Google Earth
Imagery Date: 12/13/2015 lat 37.438774° lon -75.479187° elev -17 m eye alt 1496.91 km

Coastal DPAs in the Contiguous U.S. (red) and their Cat B Neighborhoods (green)





In this example, an ESC network uses two sensors (one north of the DPA and one south of the DPA) with antennas pointed toward the DPA to provide coverage for the entire DPA. Antenna coverage is visualized with the yellow triangles.

Downsides of ESC

- The need to protect ESC sensors from interference creates dead zones ("whisper zones") around sensor sites where CBRS deployments must be prohibited or curtailed
  - WInnForum has released a Technical Report describing the issue. See TR-1015, "Potential Metrics for Assessing the Impact of ESC Sensors and Networks on CBRS Deployments"
- ESCs can be subject to false detections
- ESC could never be used to detect passive use of a band

SSC WG1 ESC Sensor Impact Task Group
ESC Sensor Impact Metrics
WINNF-TR-1015-V1.0.0

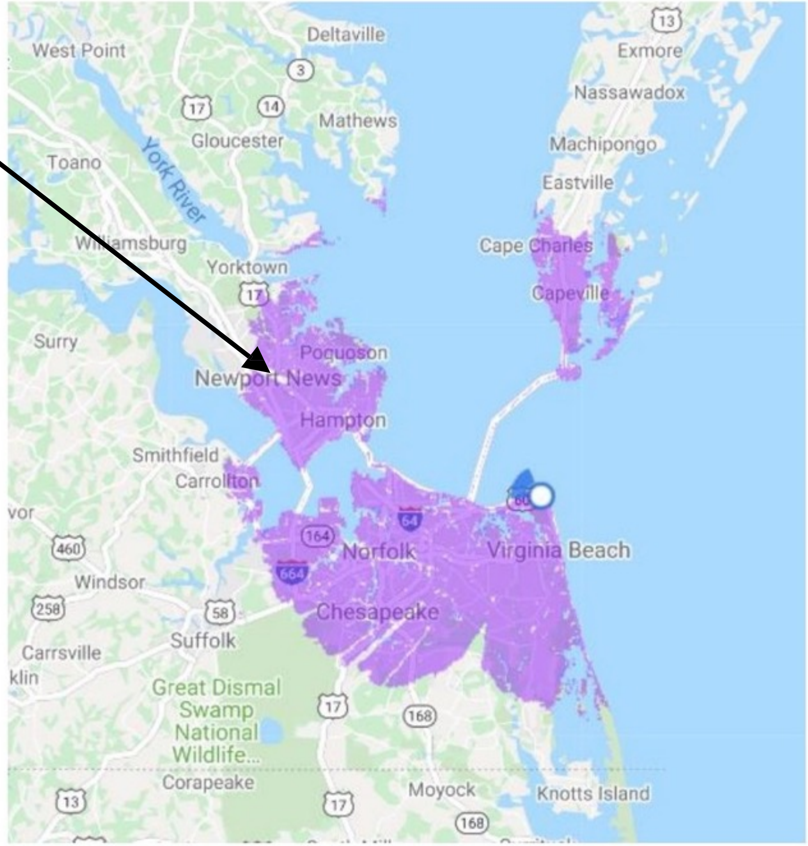


Figure 6: Impact (whisper zone) of the imaginary sensor atop the Cape Henry lighthouse.

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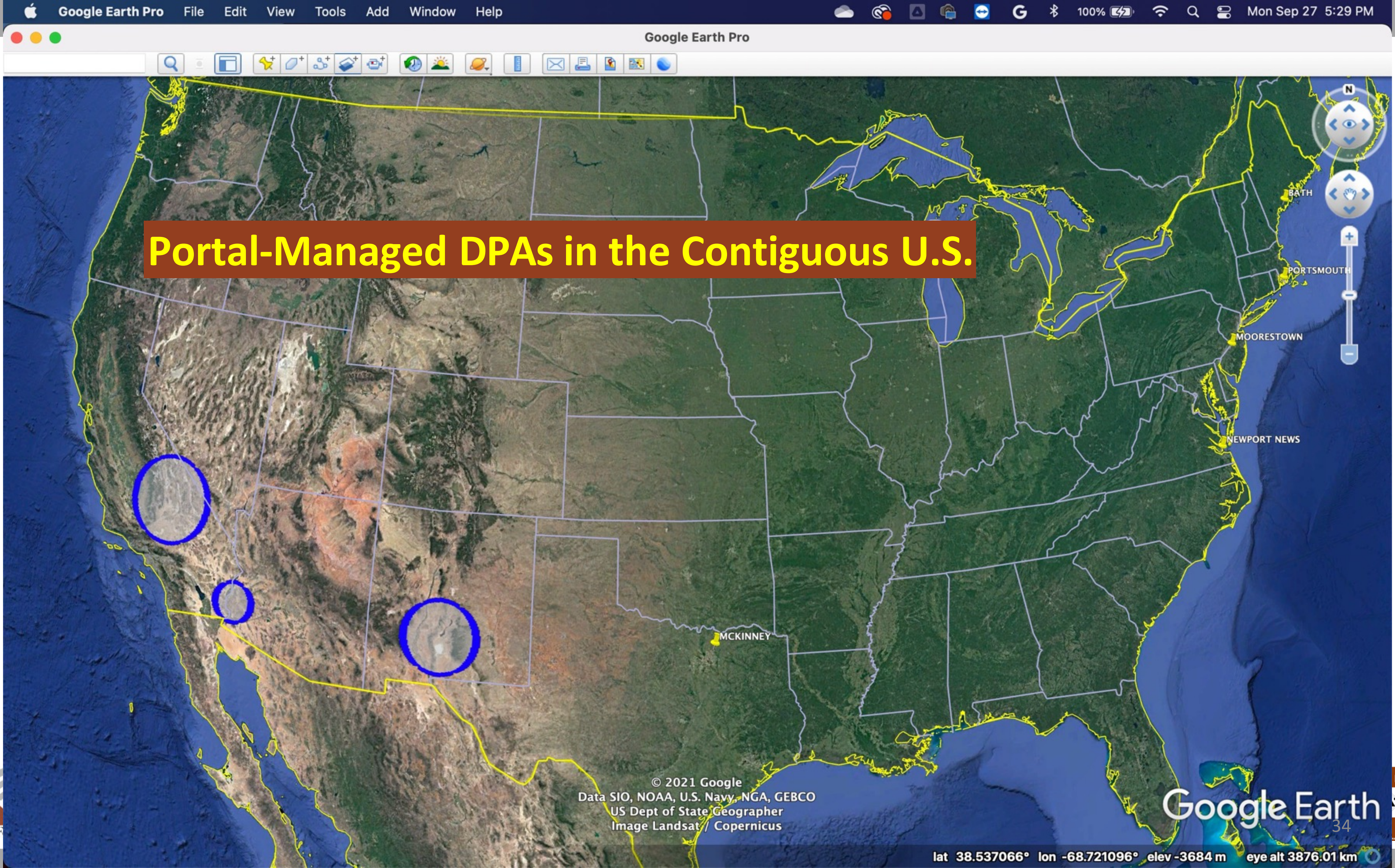
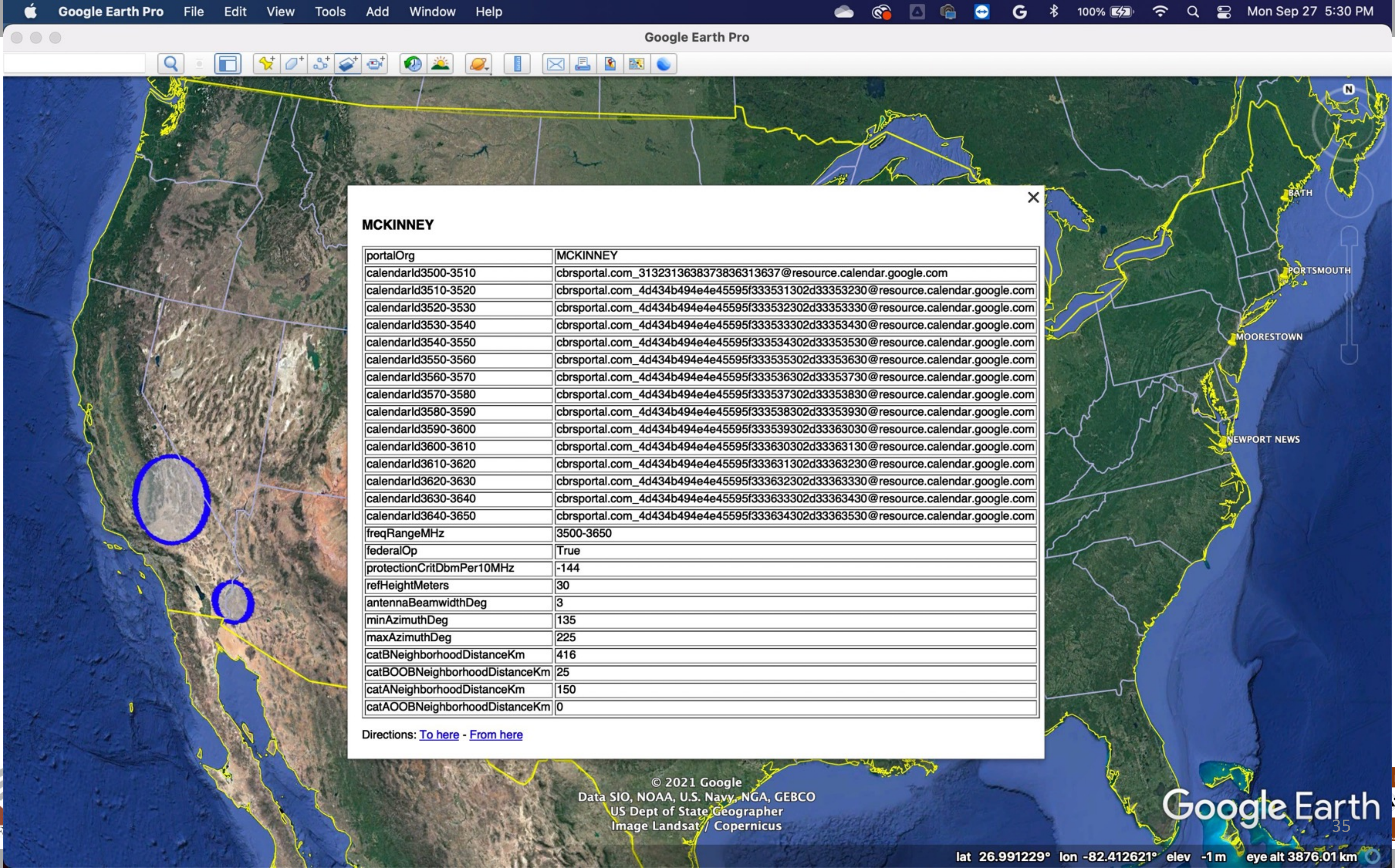
Alternative to ESC: Portal-Managed DPAs/IIC

- The use of a particular DPA at a particular frequency range can be notified through a calendar-like portal, instead of by sensing
- Avoids the pitfalls of ESC and allows for notification of passive spectrum use
- The incumbent controls the information flow
- Commonly referred to as Informing Incumbent Capability, or IIC
- Portal-managed DPAs/IIC are already being used in CBRS through a lightweight framework based on Google Calendar

Portal-Managed DPAs in the Contiguous U.S.





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portalOrg	MCKINNEY
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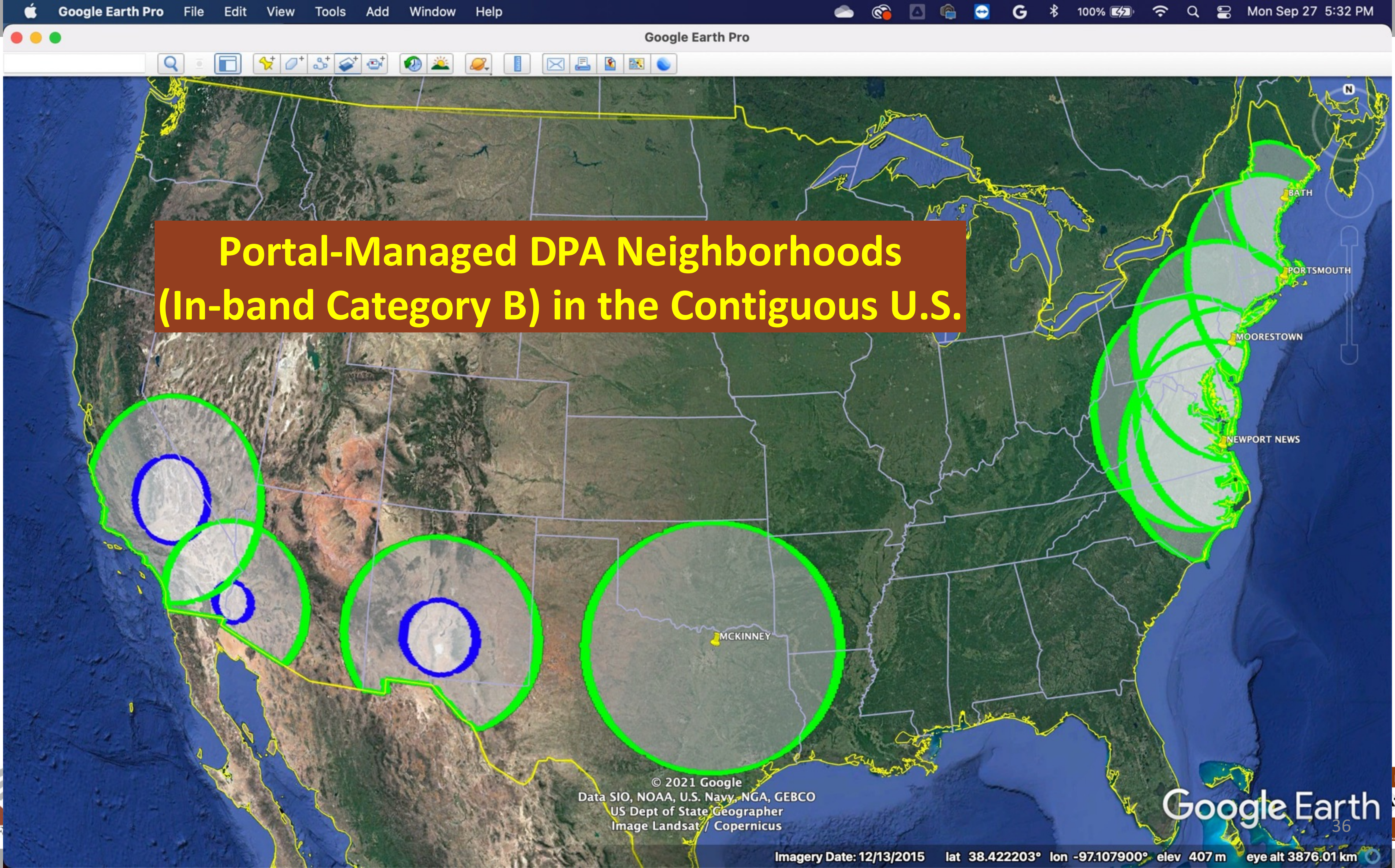
freqRangeMHz	3500-3650
federalOp	True
protectionCritDbmPer10MHz	-144
refHeightMeters	30
antennaBeamwidthDeg	3
minAzimuthDeg	135
maxAzimuthDeg	225
catBNeighborhoodDistanceKm	416
catBOOBNeighborhoodDistanceKm	25
catANeighborhoodDistanceKm	150
catAOOBNeighborhoodDistanceKm	0

Directions: To here - From here

Portal-Managed DPA Neighborhoods (In-band Category B) in the Contiguous U.S.



6 GHz Automated Frequency Coordination

- FCC recently opened the 6 GHz band for use by unlicensed devices
- The band is shared with ~150,000 fixed service point-to-point links, some transportable links, and satellite uplinks
- Low Power Indoor devices (<= 1 W EIRP) are allowed throughout the band (5925-7125 MHz), indoors only
- Standard Power Access Points (<= 4 W EIRP) are allowed indoors and outdoors in two portions of the band (U-NII 5, 5925-6425 MHz; and U-NII 7, 6525-6875 MHz) under management of an Automated Frequency Coordination (AFC) System (like a simplified SAS)
  - The AFC coordinates the SPAPs against fixed service incumbents

Radio Astronomy Protection in 6 GHz 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 RA Protection in Part 15E

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.

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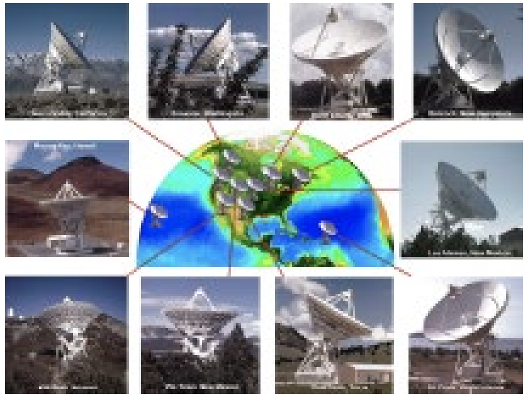
Protected Observatories

Arecibo

Green Bank

Very Large Array (NM)

ATA at HCRO



VLBA (all 10 sites)

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6 GHz Radio Astronomy Exclusion Zones for AP height = 6 m AGL

AFC RA Protections are Exclusion Zones

- 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 taken into account
  - 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

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 the portal calendar to enforce protections for the observatory

Benefits of IIC for General RA Protection

- 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
  - As pointed out by RA, they often need 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

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Could DPAs and IIC be Used for Satellite Protections?

- RA observatories are particularly vulnerable to satellite-based interference
- Passive EESS satellites see large swaths of ground as they pass over
- Could IIC be used 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
- Satellite ephemerides could be used to implement DPA protections by way of an IIC portal

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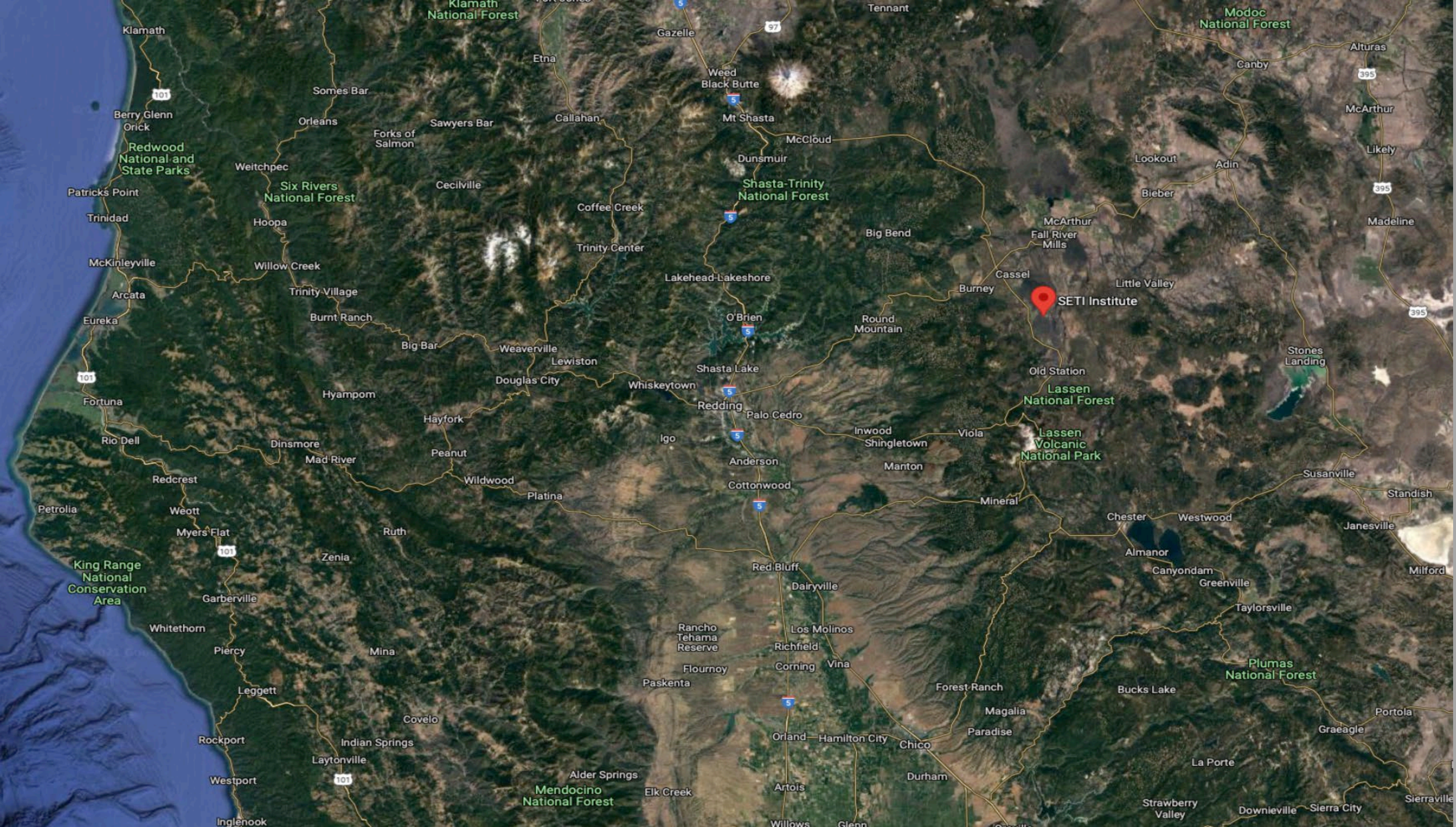
Conclusions

- DPAs have been successfully used in CBRS to protect incumbent federal radar operations, when and where they need protection
- DPAs are a more efficient protection method than exclusion zones and static coordination zones
- 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
  - A current NSF-funded project includes a proof-of-concept experiment in which an observatory will be "protected" by way of a DPA in a test SAS using an IIC portal, with possible extension to satellite protections


SETI Institute
Klamath National Forest
Modoc National Forest
Redwood National and State Parks
Six Rivers National Forest
Shasta-Trinity National Forest
Lassen National Forest
Lassen Volcanic National Park
King Range National Conservation Area
Plumas National Forest
Mendocino National Forest
Klamath
Somes Bar
Berry Glenn
Orick
Orleans
Forks of Salmon
Sawyers Bar
Etna
Callahan
Gazelle
Weed
Black Butte
Mt Shasta
McCloud
Dunsmuir
Tennant
Canby
Alturas
McArthur
Likely
Lookout
Adin
Bieber
Madeline
Weitchpec
Patricks Point
Trinidad
Hoopa
Cecilville
Coffee Creek
Trinity Center
Big Bend
Fall River Mills
McKinleyville
Willow Creek
Lakehead-Lakeshore
Cassel
Burney
Little Valley
Arcata
Trinity Village
Eureka
Burnt Ranch
O'Brien
Round Mountain
Big Bar
Weaverville
Lewiston
Shasta Lake
Old Station
Stones Landing
Douglas City
Whiskeytown
Fortuna
Hyampom
Redding
Palo Cedro
Hayfork
Igo
Inwood
Shingletown
Viola
Rio Dell
Dinsmore
Mad River
Peanut
Anderson
Manton
Susanville
Redcrest
Wildwood
Cottonwood
Mineral
Standish
Platina
Petrolia
Weott
Chester
Westwood
Myers Flat
Ruth
Janesville
Zenia
Almanor
Canyondam
Red Bluff
Milford
Greenville
Dairyville
Garberville
Taylorsville
Whitethorn
Rancho Tehama Reserve
Los Molinos
Piercy
Mina
Richfield
Flournoy
Corning
Vina
Paskenta
Leggett
Forest Ranch
Bucks Lake
Magalia
Portola
Covelo
Graeagle
Paradise
Rockport
Indian Springs
Orland
Hamilton City
Chico
Laytonville
La Porte
Durham
Alder Springs
Westport
Elk Creek
Artois
Strawberry Valley
Downieville
Sierra City
Sierraville
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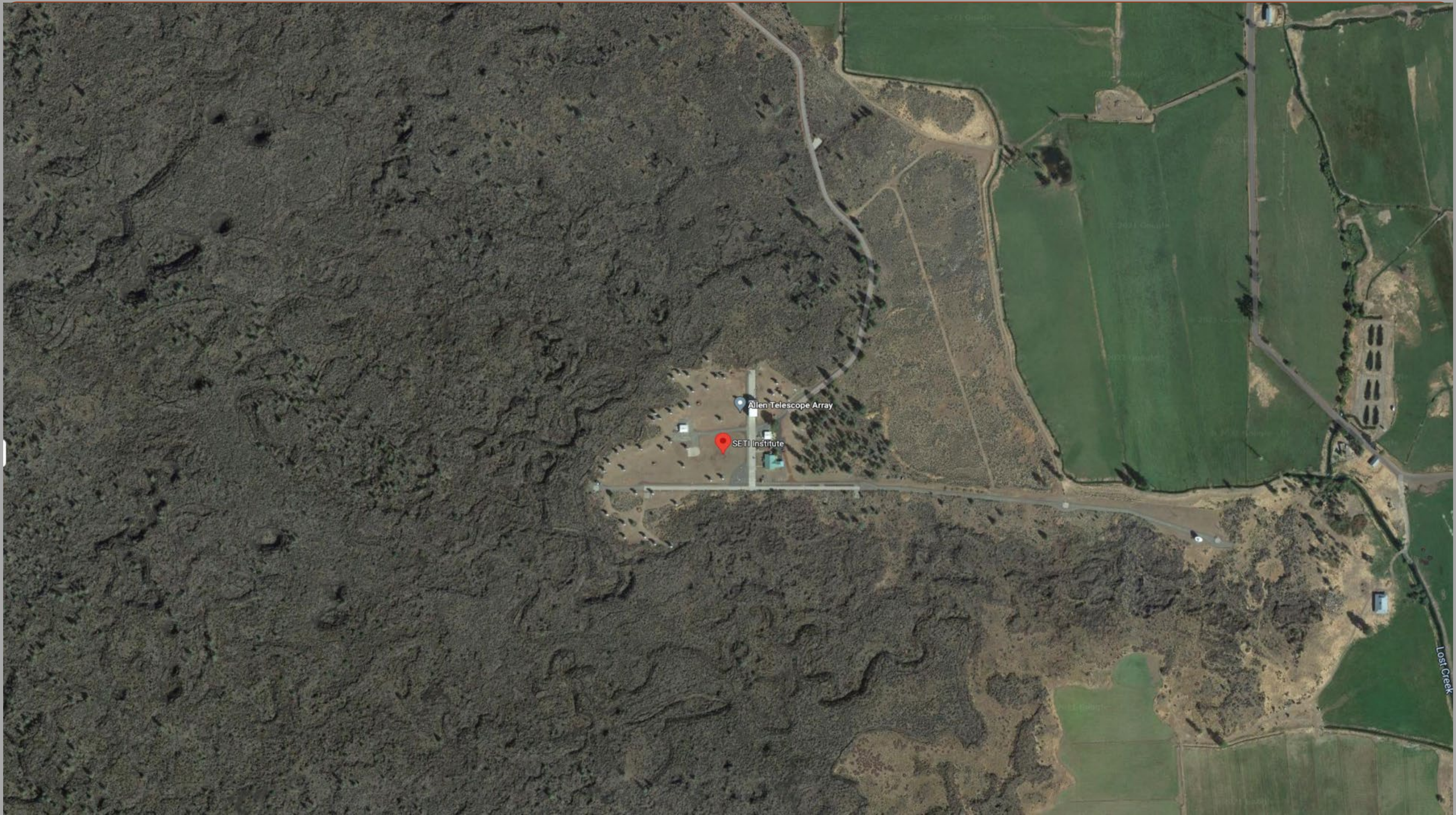
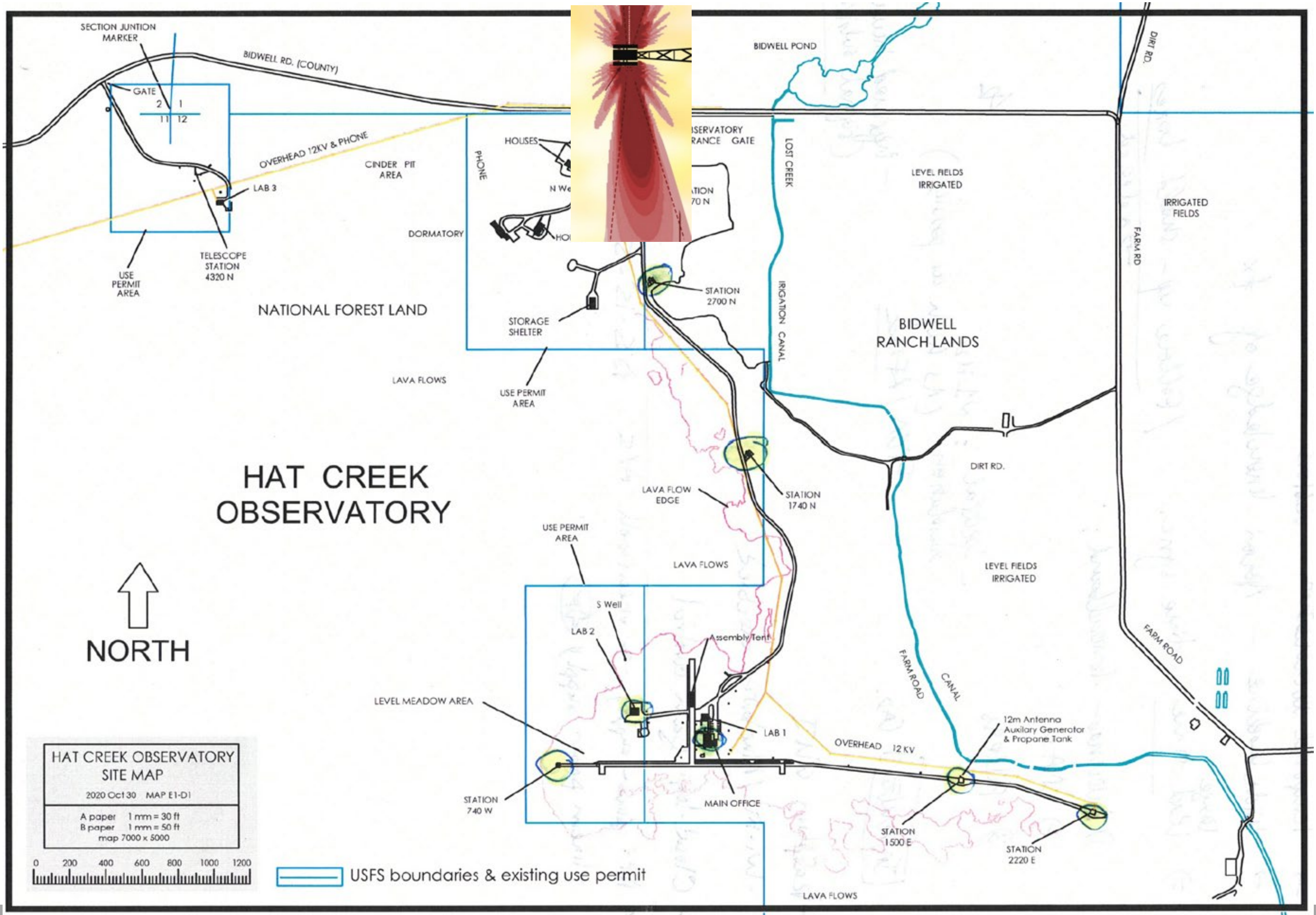
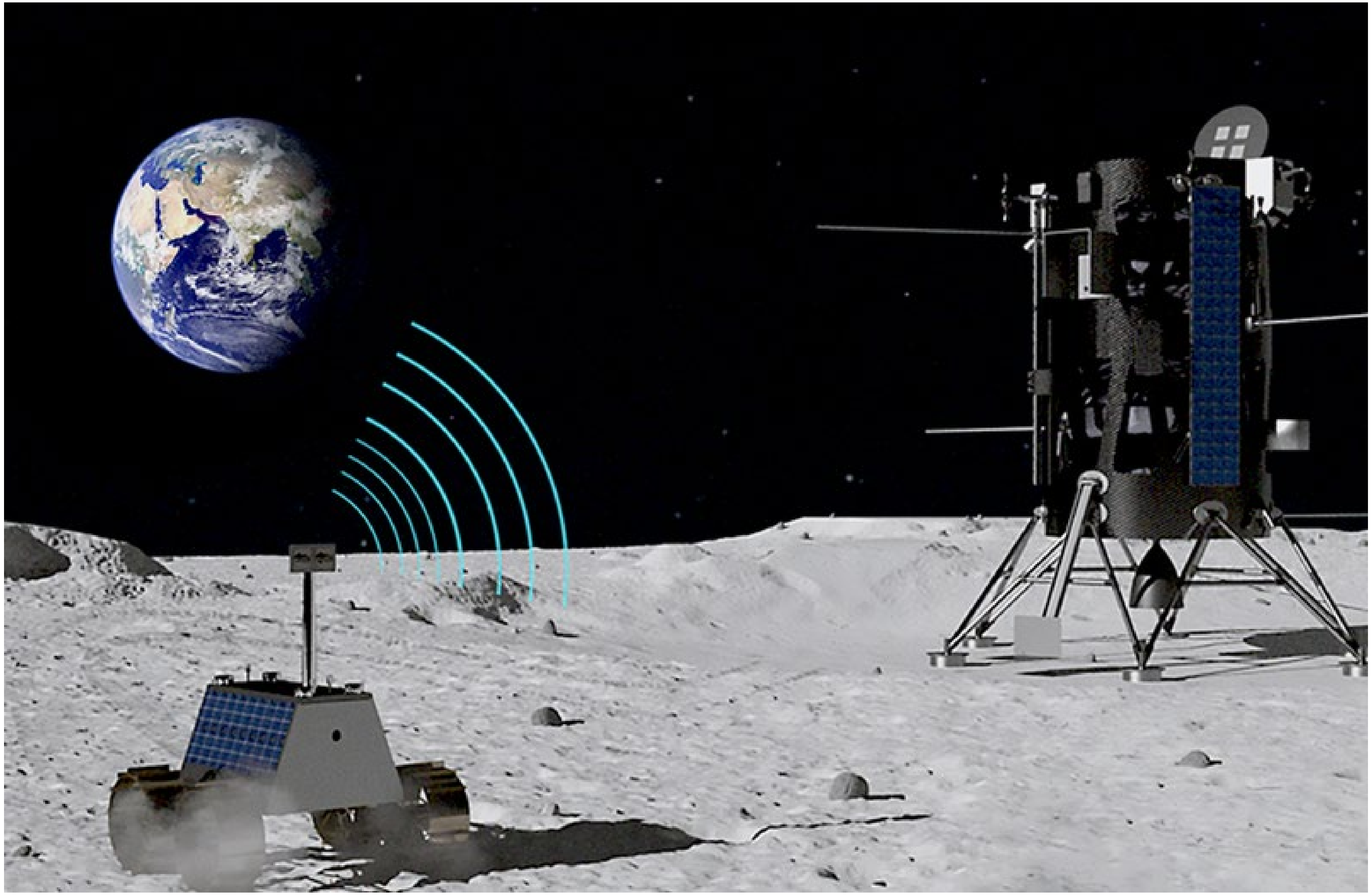

Allen Telescope Array
SETI Institute
Lost Creek

HCRO-NRDZ RF Baseline Sensors initial layout



NASA Tipping Point LTE-on-the-Moon (Nokia Bell Labs)



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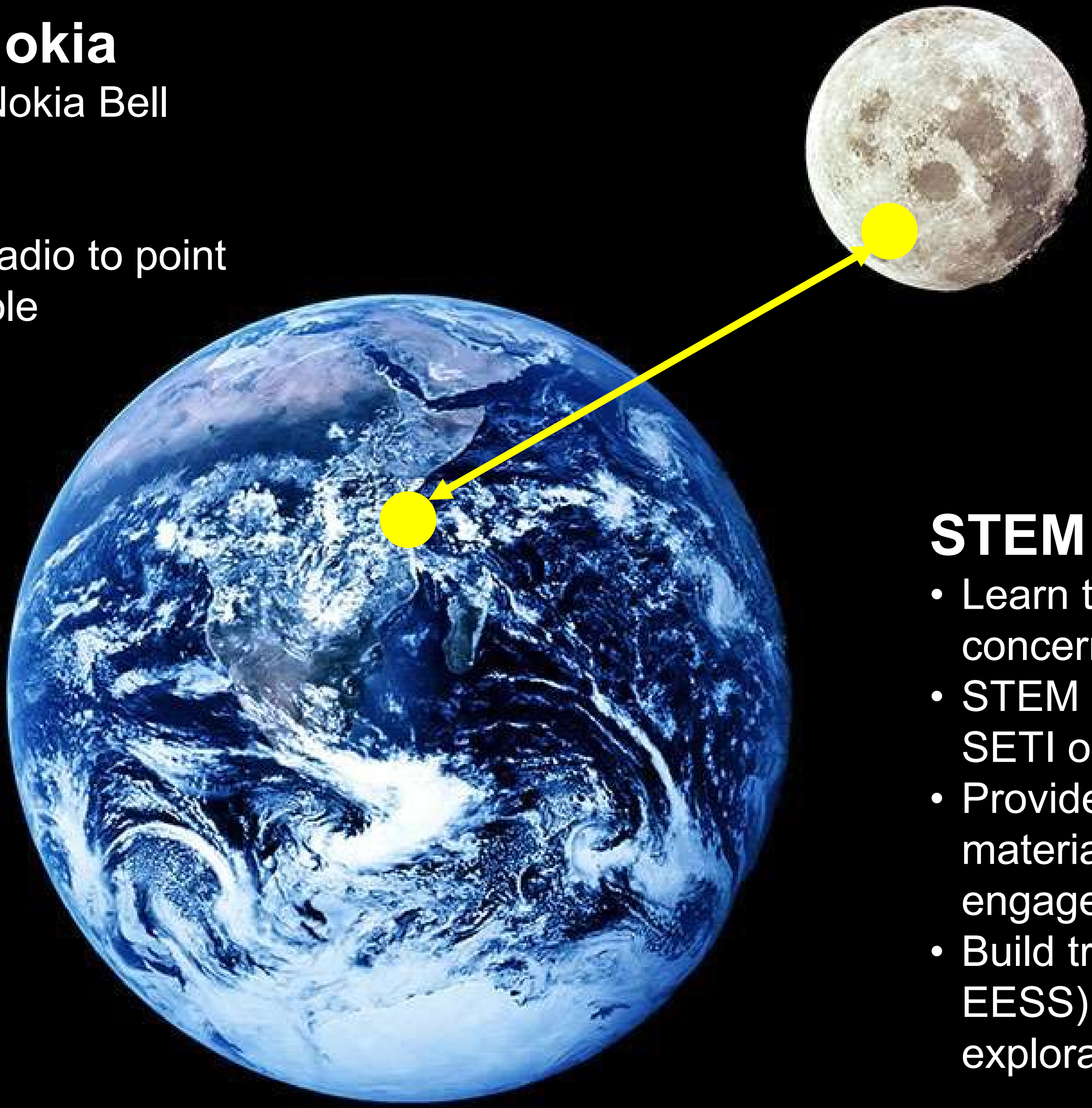
Spectrum Sharing for increased Science

HCRO/SETI/NASA/Nokia

- Use HCRO ATA to detect Nokia Bell Labs rover-to-lander LTE communications
- Utilize open-source Gnu-Radio to point ATA telescopes to south pole

- Detect signal
- Demodulate signal
- Verify communications



STEM Outreach partners

- Learn the lunar SZM and RA concerns
- STEM opportunity for NASA, RA, SETI outreach
- Provide open-source learning materials for broad educational engagement
- Build trust between passive (RA, EESS) and active (NASA exploration missions) activities

Back up slides

Risk Assessment

Buy-in from respective stakeholder communities. Mitigation will be to have a strong outreach and communications plan to bring stakeholder communities to the table (+academia)

Technical issues:

- Architecture augmentation (low risk, mitigated through confidence in development team)
- Compilation of satellite emitter data, passive satellite information into a coherent and accurate database (medium risk, same issues as with the FCC ULS database will be encountered; risk is known to exist and expect to buy down risk by design and iterative development/inclusion of reliable satellite orbit and frequency data sources)

Testing and deployment issues: (mitigate by deploying at Hat Creek Radio Observatory/SETI)

- Proper test area and facilities

Resource availability issues: (plan properly, verify resource commitments)

- Technical development
- Prototype testing and verifications

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