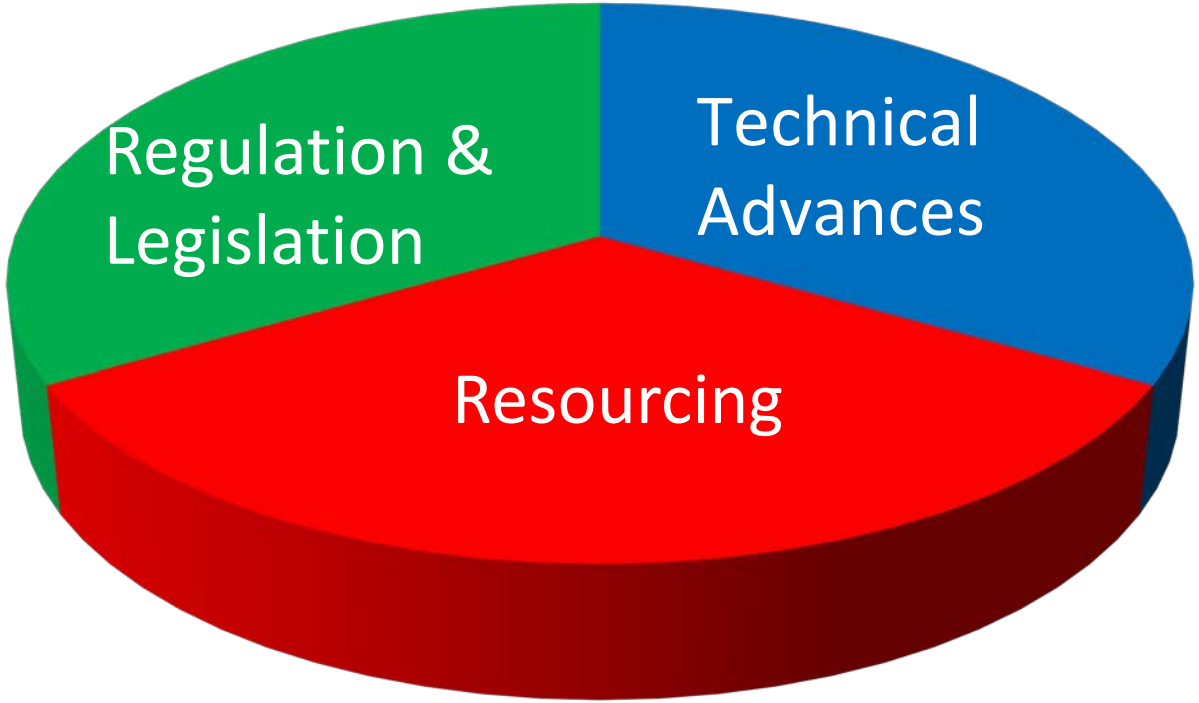
The Next Decade of ESM & RFI

Anthony Beasley – National Radio Astronomy Observatory/AUI

Today's Speakers

- Introduction to Spectrum Management and Recent Successes/Failures
  Harvey Liszt, NRAO
- Overview of the Current Regulatory Framework Nationally/Internationally
  Liese vanZee, Indiana University, Bloomington
- A National Science Foundation Perspective
  Ashley Zauderer, NSF
- New Technologies/Techniques in Radio Frequency Interference Mitigation
  Alan Erickson, NRAO

ESM: Key Factors….



Astro2020: Statement of Task

- *The National Academies of Sciences, Engineering, and Medicine shall convene an ad hoc survey committee and supporting study panels to carry out a decadal survey in astronomy and astrophysics. The study will generate consensus recommendations to implement a comprehensive strategy and vision for a decade of transformative science at the frontiers of astronomy and astrophysics.*

RFI – not explicitly mentioned in the survey charge (?), but a critical environmental resource issue for radio astronomy…

Congress, the Agencies and Industry – respond to the Survey. Speak!

ASTRO2010

Spectrum Management – RMS Panel

The radio spectrum is a precious resource for radio astronomy and for communication in the modern world. Without continued vigilance to protect some of this resource for passive scientific use, radio astronomy from Earth's surface will become increasingly difficult. The traditional approach of seeking protection for small, defined segments of the spectrum for radio astronomy is no longer adequate because of the wide bandwidths needed for sensitivity and the broad frequency coverage needed for spectral-line studies at high redshifts. Resources must be made available to develop modern technologies for radio-interference mitigation and for sharing the spectrum through time- and frequency-multiplexing methods.

ASTRO2000

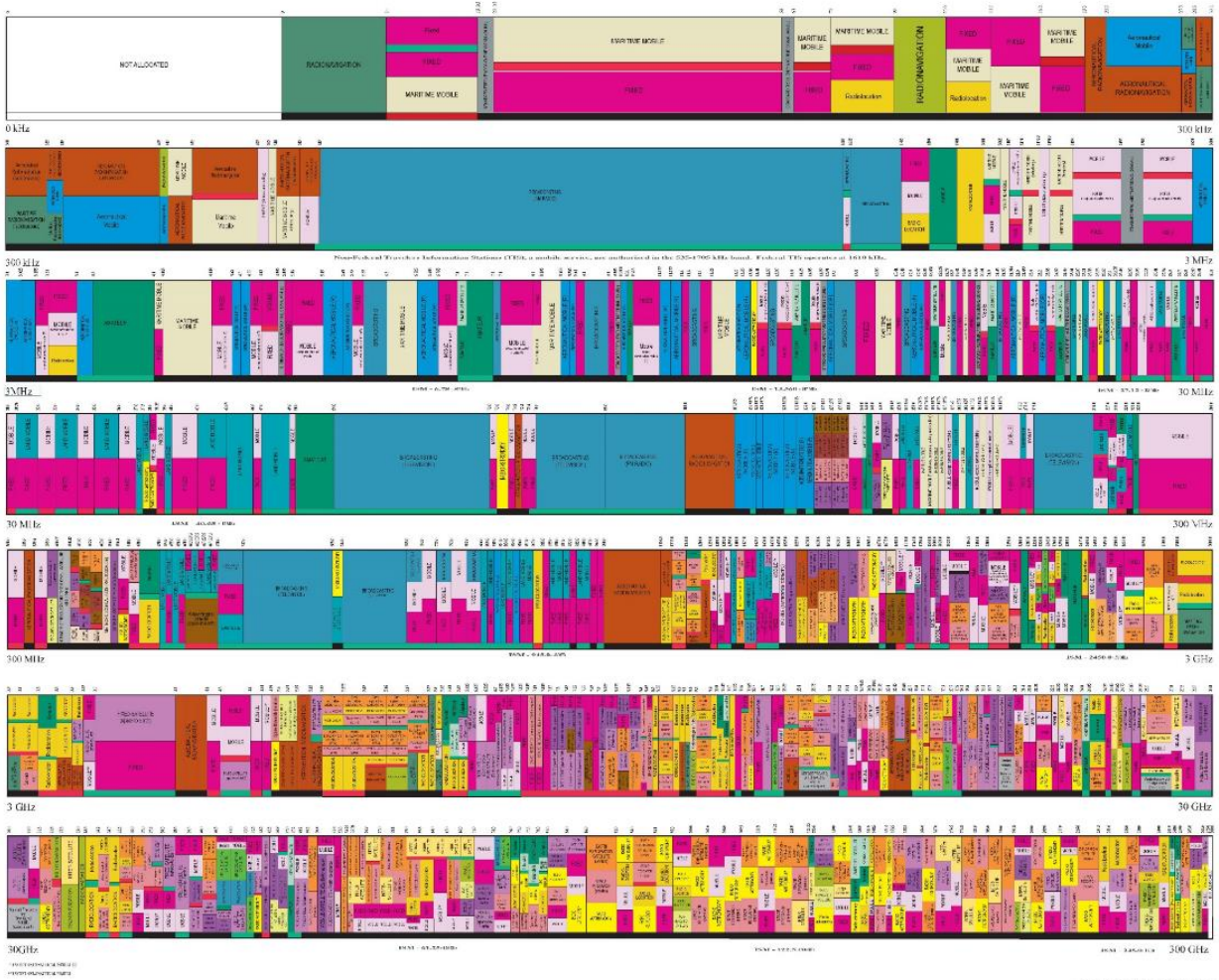
RMS Panel

The panel further recommends an aggressive and vigorous **program of technology development**. SKA development activities should focus on low-cost, high-performance electronics and processors, techniques and technologies for radio frequency interference (RFI) identification and compensation, array optimization, and radio-wave adaptive optics. For future space missions, development should emphasize inexpensive large apertures, large-format arrays, receivers with the lowest possible noise, high-capacity, space-qualified refrigerators, and enhanced telemetry bandwidth.

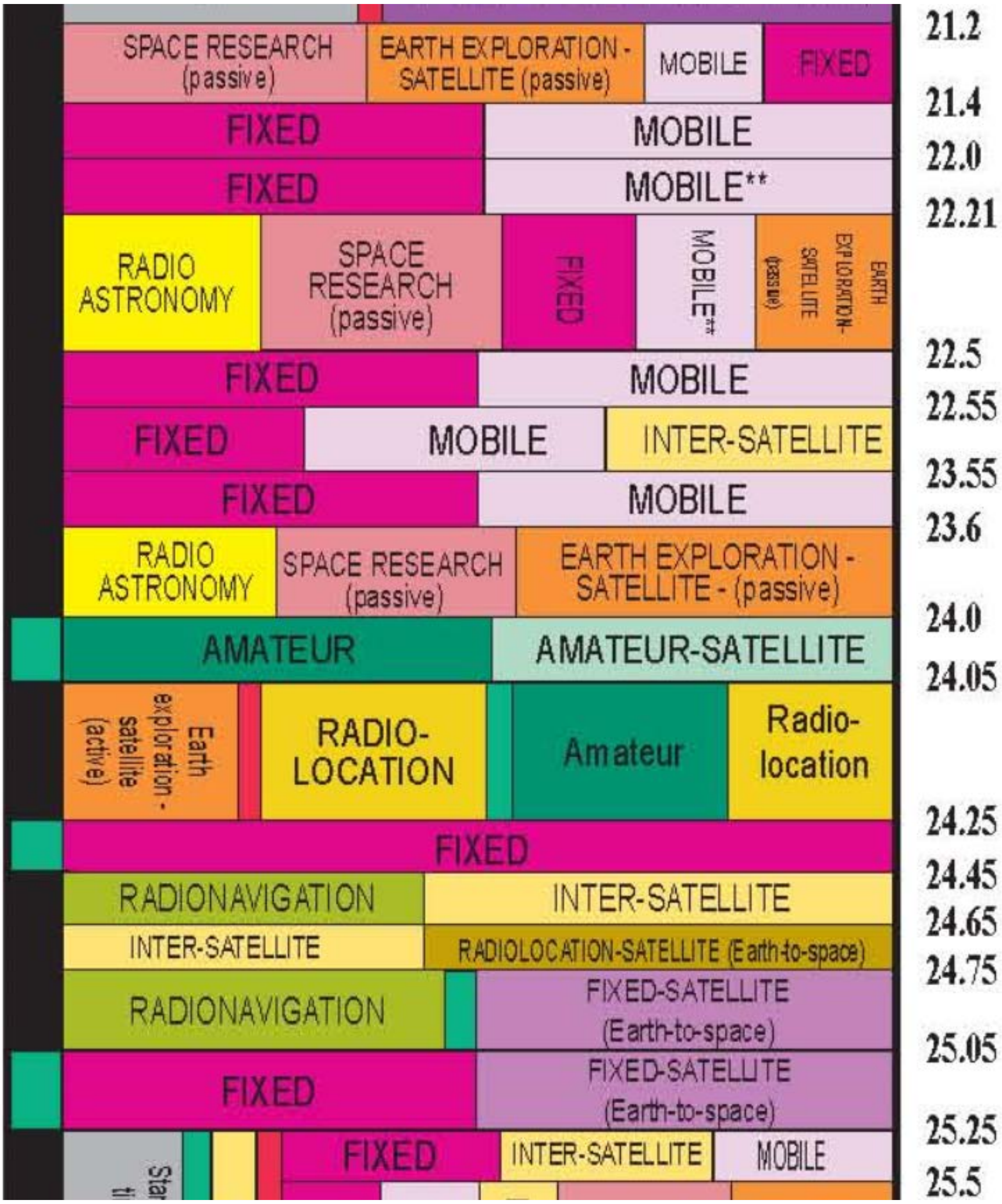
The panel emphasizes that preservation of portions of the spectrum for future radio astronomical research is vital. The NSF plays a critical role in setting spectrum management policy and in increasing public awareness of its importance. Continued vigilance is required at both the national and international levels to ensure that spectrum allocation balances commercial and research interests. At the same time, investments must be made in the development of hardware and signal-processing techniques to mitigate the effects of human-generated radio interference, which will otherwise drown out the much weaker cosmic radio signals.

UNITED STATES FREQUENCY ALLOCATIONS

THE RADIO SPECTRUM

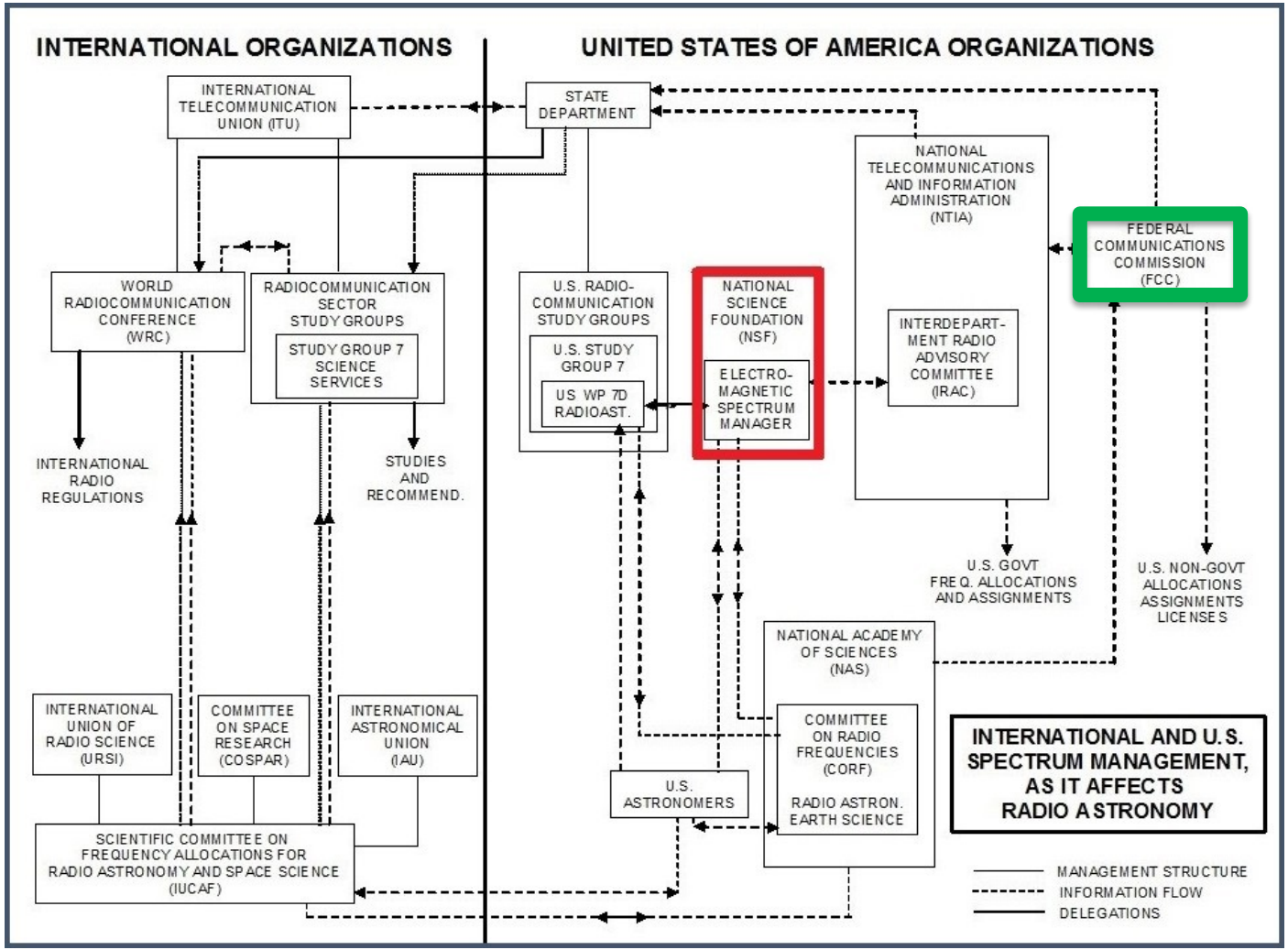


R&L



21.2
SPACE RESEARCH (passive)
EARTH EXPLORATION - SATELLITE (passive)
MOBILE
FIXED
21.4
FIXED
MOBILE
22.0
FIXED
MOBILE**
22.21
RADIO ASTRONOMY
SPACE RESEARCH (passive)
FIXED
MOBILE**
EARTH EXPLORATION-SATELLITE (passive)
22.5
FIXED
MOBILE
22.55
FIXED
MOBILE
INTER-SATELLITE
23.55
FIXED
MOBILE
23.6
RADIO ASTRONOMY
SPACE RESEARCH (passive)
EARTH EXPLORATION - SATELLITE - (passive)
24.0
AMATEUR
AMATEUR-SATELLITE
24.05
Earth exploration - satellite (active)
RADIO-LOCATION
Amateur
Radio-location
24.25
FIXED
24.45
RADIONAVIGATION
INTER-SATELLITE
24.65
INTER-SATELLITE
RADIOLOCATION-SATELLITE (Earth-to-space)
24.75
RADIONAVIGATION
FIXED-SATELLITE (Earth-to-space)
25.05
FIXED
FIXED-SATELLITE (Earth-to-space)
25.25
FIXED
INTER-SATELLITE
MOBILE
25.5

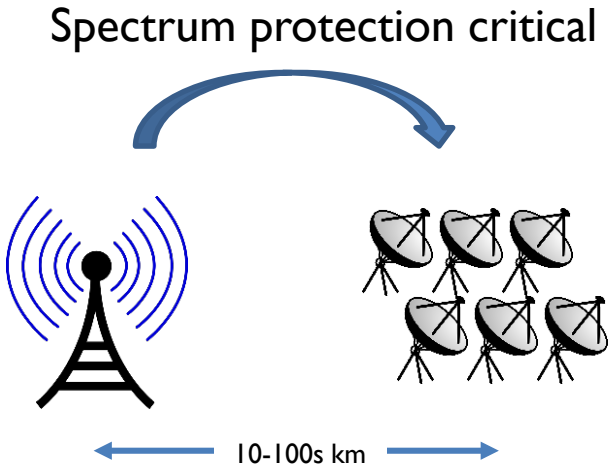
GHz


INTERNATIONAL ORGANIZATIONS
UNITED STATES OF AMERICA ORGANIZATIONS
INTERNATIONAL TELECOMMUNICATION UNION (ITU)
STATE DEPARTMENT
NATIONAL TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION (NTIA)
FEDERAL COMMUNICATIONS COMMISSION (FCC)
WORLD RADIOCOMMUNICATION CONFERENCE (WRC)
RADIOCOMMUNICATION SECTOR STUDY GROUPS
STUDY GROUP 7 SCIENCE SERVICES
U.S. RADIO-COMMUNICATION STUDY GROUPS
U.S. STUDY GROUP 7
US WP 7D RADIOAST.
NATIONAL SCIENCE FOUNDATION (NSF)
ELECTRO-MAGNETIC SPECTRUM MANAGER
INTERDEPART-MENT RADIO ADVISORY COMMITTEE (IRAC)
INTERNATIONAL RADIO REGULATIONS
STUDIES AND RECOMMEND.
U.S. GOVT FREQ. ALLOCATIONS AND ASSIGNMENTS
U.S. NON-GOVT ALLOCATIONS ASSIGNMENTS LICENSES
NATIONAL ACADEMY OF SCIENCES (NAS)
INTERNATIONAL UNION OF RADIO SCIENCE (URSI)
COMMITTEE ON SPACE RESEARCH (COSPAR)
INTERNATIONAL ASTRONOMICAL UNION (IAU)
COMMITTEE ON RADIO FREQUENCIES (CORF)
RADIO ASTRON. EARTH SCIENCE
U.S. ASTRONOMERS
INTERNATIONAL AND U.S. SPECTRUM MANAGEMENT, AS IT AFFECTS RADIO ASTRONOMY
SCIENTIFIC COMMITTEE ON FREQUENCY ALLOCATIONS FOR RADIO ASTRONOMY AND SPACE SCIENCE (IUCAF)
MANAGEMENT STRUCTURE
INFORMATION FLOW
DELEGATIONS

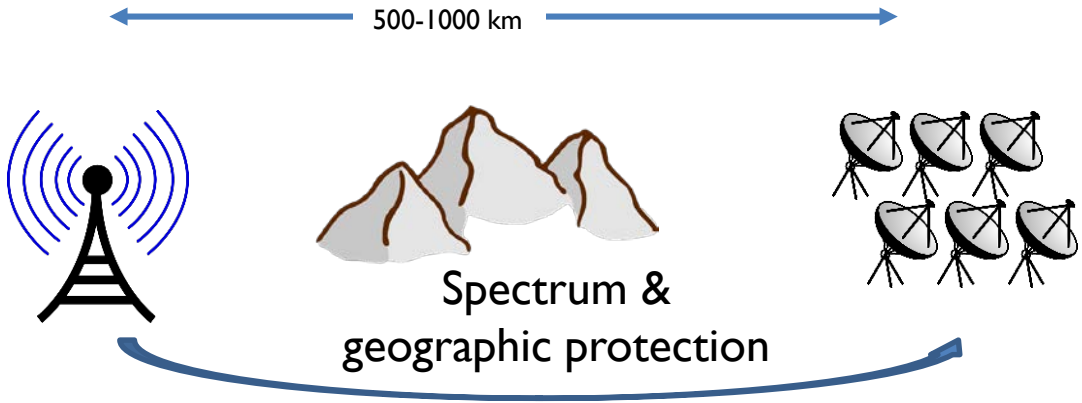
Regulation & Legislation

- Suggest explicitly note and support the roles of the key scientific committees in the R&L process. NSF-AST – support.
- Highlight/strengthen the importance of NSF's role as steward of scientific spectrum uses – example: require NSF Director approval of US rule changes impacting scientific spectrum.
- Quiet zones, Coordination Zones, one-day: Dynamic Zones
- Additional support for R&L activities (now: NSF: SII-Center)
- Increased awareness of R&L role, importance (see Education)
- More participation by the community – US processes.

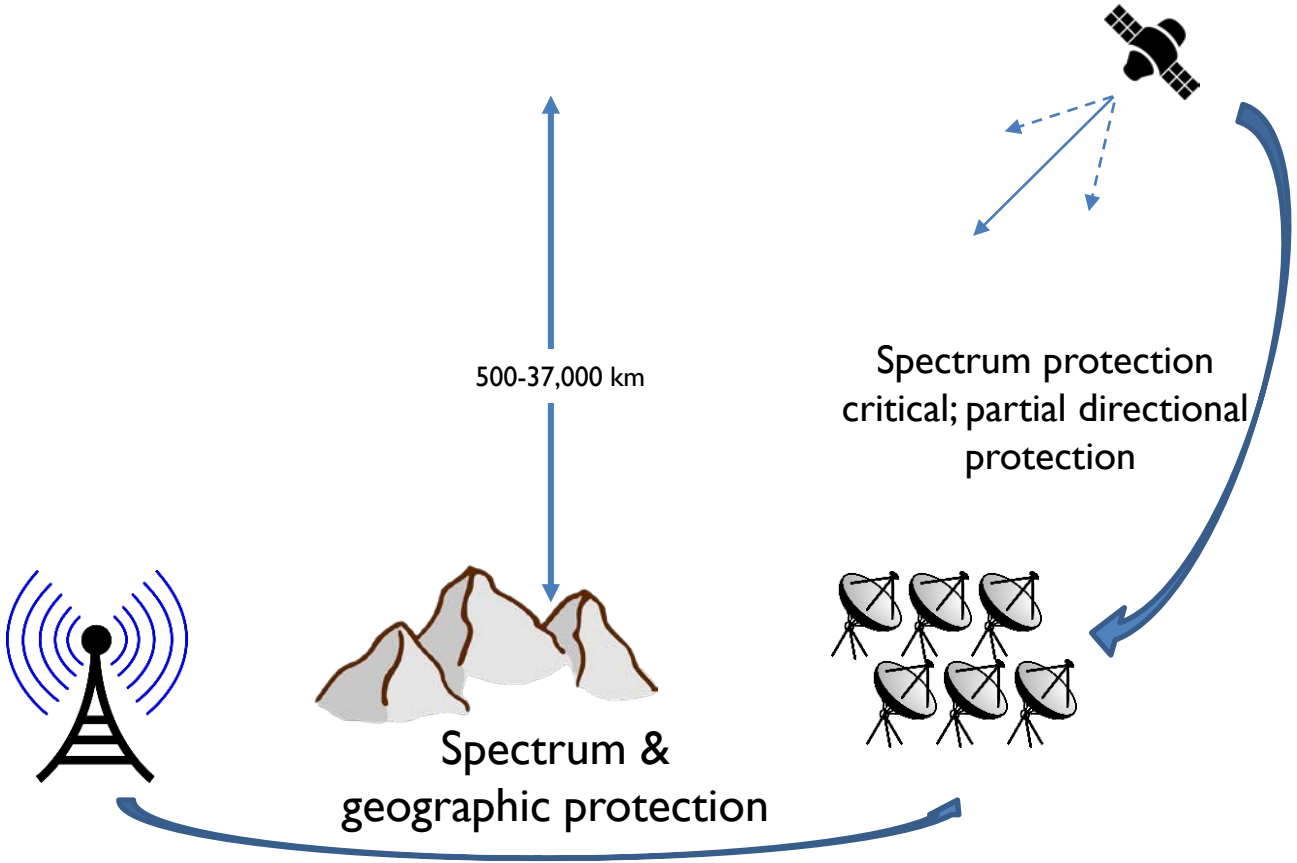
Technology – Radio Astronomy



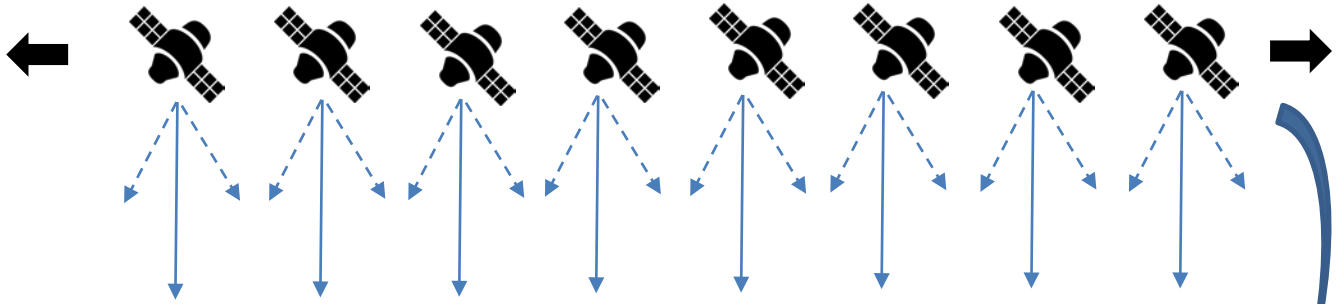
RFI Mitigation – Radio Astronomy – Remote Sites



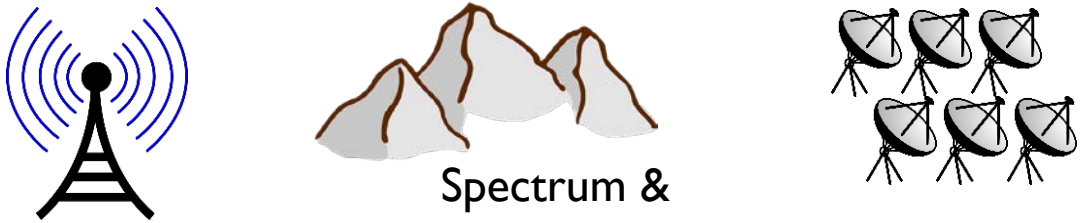
RFI Mitigation – Radio Astronomy – Satellite



RFI Mitigation – Radio Astronomy – Constellations



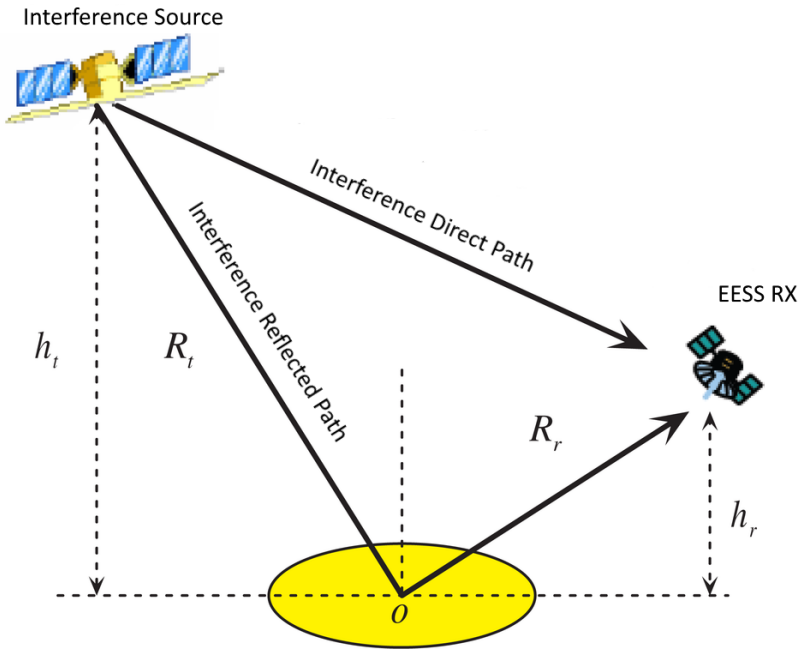
Spectrum protection MORE
critical given loss of directional filtering
spatial summation
in sidelobes is complex & variable

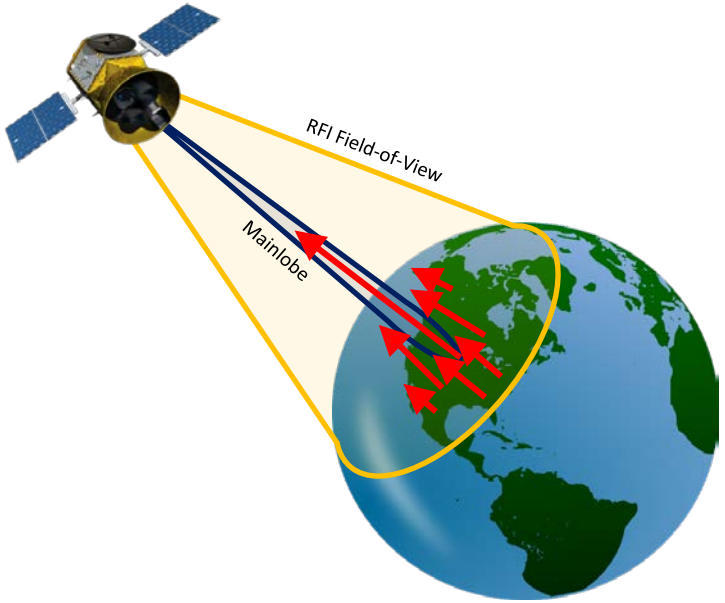


Spectrum &
geographic protection

+5G, IOT,
Smart Cities

RFI Mitigation – Earth Exploration-Satellite





Passive Services: Radio Astronomy & Earth Sensing – Different Impacts.
Spectrum protection critical for Earth Sensing.

Technical Advances

- Numerous strategies available to detect/mitigate RFI – many successful experiments over past two decades, but low implementation… b/c minimal losses incurred.
- Little standardization or coordination of RFI survey results … radiometry is always tough, but we lack a framework to share and collaborate in. Harder to assess environment in radio.
- Robust instruments vs key protected areas? (Answer: both).
- Entire sky/spectrum threatened in next decade – ngso, mmWave
- Passive (RAS/EES): need to actively define needs, drive solutions.

Education

- Radio spectrum is invisible to citizens despite daily impacts – cellphones, WiFi, Bluetooth etc. … cf OIR vs SpaceX
- Greater efforts needed to educate the general public and policymakers on uses/management of the spectrum, issues etc. ..develop a sense of value, need for protection.
- ESM is a complex, detail-rich topic. Needs careful packaging.
- NRAO, SKA & collaborators – developing plans; broad topics needs mention and support from the Decadal Survey.
- ES is similar to natural resource education … water, air, etc. Access is eroding; bandwidth needs increasing.

next generation Very Large Array

- **1.2 - 116 GHz** Frequency Coverage
- **Main Array**: 214 x 18m offset Gregorian Antennas.
  - Fixed antenna locations across NM, TX, AZ, MX.
- **Short Baseline Array**: 19 x 6m offset Greg. Ant.
  - Use 4 x 18m in TP mode to fill in (*u, v*) hole.
- **Long Baseline Array**: 30 x 18m antennas located across continent for baselines up to 8860km.

Band #	Dewar	f_L GHz	f_M GHz	f_H GHz	f_H: f_L	BW GHz
1	A	1.2	2.35	3.5	2.91	2.3
2	B	3.5	7.90	12.3	3.51	8.8
3	B	12.3	16.4	20.5	1.67	8.2
4	B	20.5	27.3	34.0	1.66	13.5
5	B	30.5	40.5	50.5	1.66	20.0
6	B	70.0	93.0	116	1.66	46.0

Passive Sensing: US Investment for a Global Benefit

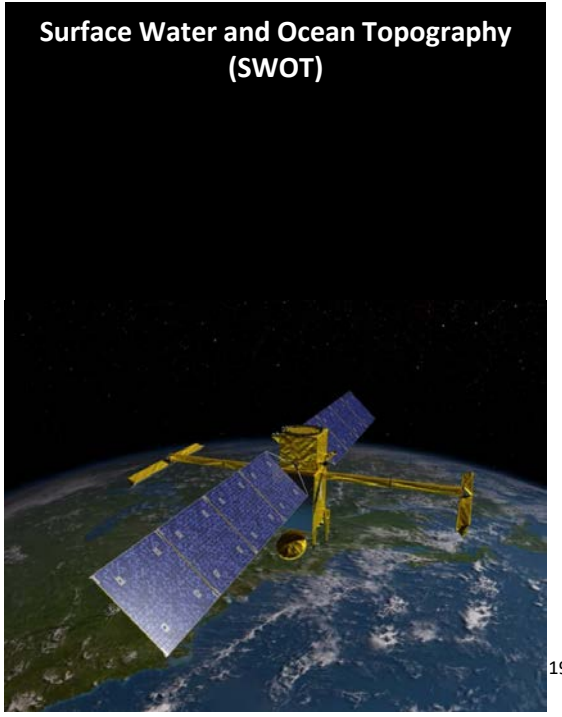
Tens of billions of dollars worth of US taxpayer investment generate passive sensing data used to benefit our nation's and planet's essential products and services, including:

- Forecasting severe weather events (e.g., hurricanes, tornadoes and blizzards) days in advance.
- Assessing environmental hazards such as droughts, forest fires, poor air quality, and harmful coastal waters.
- Advancing our understanding of Earth's water and energy cycle.
- Extending current capabilities in the generation of accurate and timely precipitation information to directly benefit society.

Global Precipitation Measurement (GPM)

Joint Polar Satellite System (JPSS 1/2/3/4)

Surface Water and Ocean Topography (SWOT)



The Future

- Investment Reality $$: NSF x 10 = DoD

  DoD x 10 = Industry *Technology, Advocacy*

- **Investments**
  - **Technology + environmental** – robust instruments, quantitative monitoring, quiet/dynamic zones, dynamic spectrum allocation, …
  - **Advocacy** – support regulatory committees, and provide information resources to coordinate the community, and further inform Congress and agencies of our needs.
  - **Education** – materials and tools to create understanding of the ES uses and issues, create a deeper appreciation of the importance of this natural resource – NSF ramping up, broader support important…

Decadal Survey – suggest: describe detailed landscape (radio/OIR); discuss key issues and future trends; recommend multiple avenues for progress, including funding and regulatory changes; reinforce NSF's role.

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