



# Radio Frequency Interference on the SGP and Worldwide

Tom Clark, Scott Galbraith, Jeremy  
Hill, and Larry Hilliard

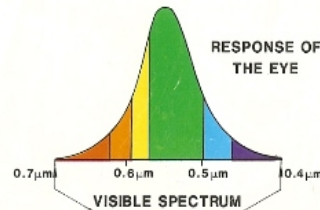
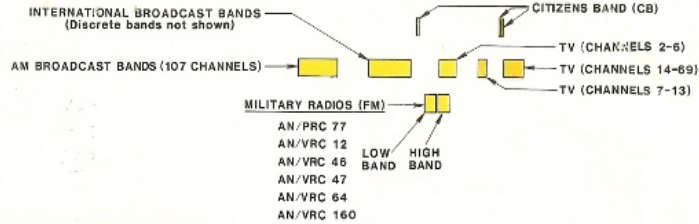
July 18<sup>th</sup>, 2012

# July 18<sup>th</sup>, SGP Intern Lunch time speaker Agenda

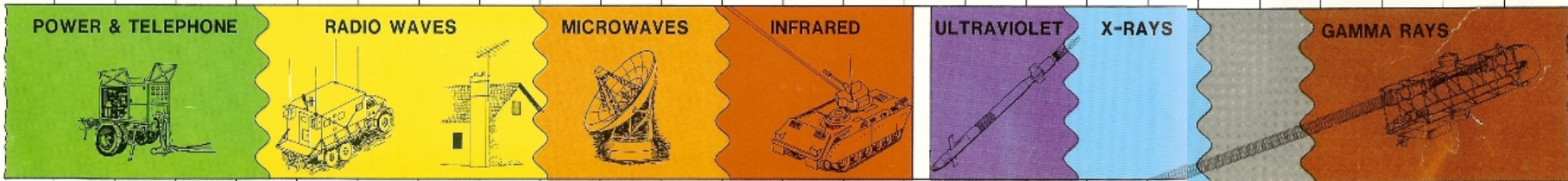
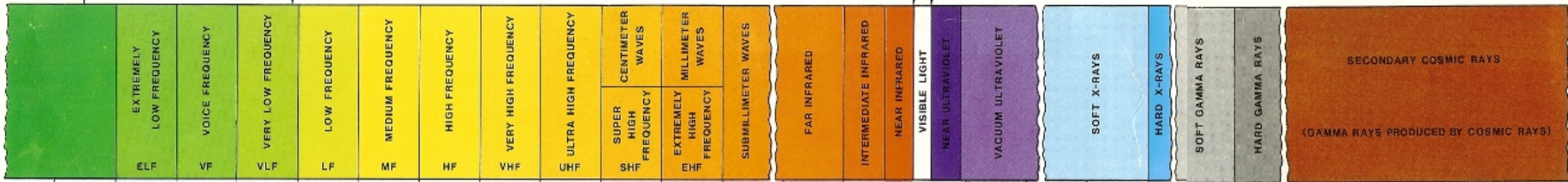
- ↪ Scott Galbraith – Spectrum Management at GSFC
- Larry - RFI experienced in Space borne Radiometers
- Larry – RFI on Space Geodesy Project introduction
  - Jeremy– Solving the RFI Problems at GGAO
- Tom – RFI on VLBI 2010 and legacy systems

# What are the competing uses of the spectrum?

## ELECTROMAGNETIC SPECTRUM

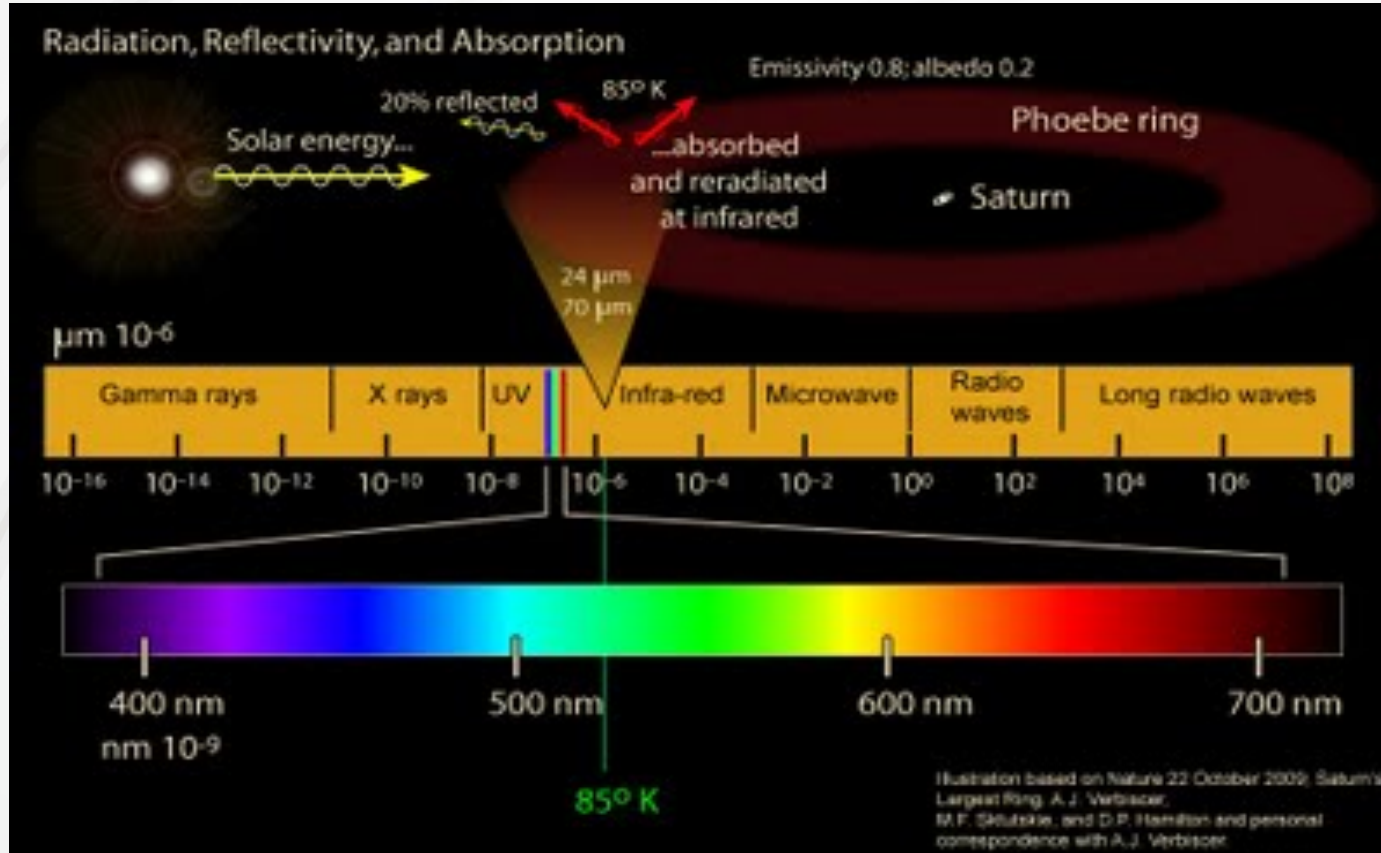


ONVERSION DATA		UNIT DESIGNATIONS		
	PREFIX	SYMBOL	UNIT	MEASURE
• speed of light	tera-	T	10 <sup>12</sup>	One trillion
$c = 3 \times 10^8$ meters/second	giga-	G	10 <sup>9</sup>	One billion
	mega-	M	10 <sup>6</sup>	One million
	kilo-	k	10 <sup>3</sup>	One thousand
	hecto-	h	10 <sup>2</sup>	One hundred
	deka-	da	10 <sup>1</sup>	Ten
	deci-	d	10 <sup>-1</sup>	One-tenth
	centi-	c	10 <sup>-2</sup>	One-hundredth
	milli-	m	10 <sup>-3</sup>	One-thousandth
	micro-	$\mu$	10 <sup>-6</sup>	One-millionth
	nano-	n	10 <sup>-9</sup>	One-billionth
	pico-	p	10 <sup>-12</sup>	One-trillionth
	femto-	f	10 <sup>-15</sup>	One-quadrillionth
	atto-	a	10 <sup>-18</sup>	One-quintillionth
	angstrom	$\text{\AA}$	10 <sup>-10</sup> m	One hundred millionth cm

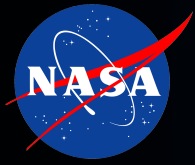


# Overview: What Is Spectrum?

- Spectrum is a conceptual tool used to organize and map the physical phenomena of electromagnetic (EM) waves. Visible light is an EM wave.
- EM waves propagate through space at different frequencies, and the set of all frequencies is called the electromagnetic spectrum.







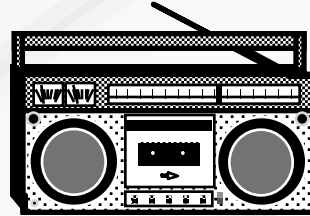
# Communications Theory

## Basic Concepts



*Transmitter and Receiver must use the same language*

Must be loud enough  
**Energy!**



Noise causes interference  
**(Identify and quantify)**

Sound Waves 'Carry' the information

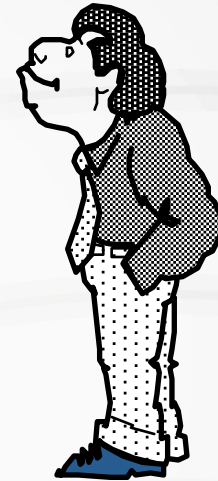
LET ME EXPLAIN

Distance weakens the sound  
**(calculate the loss)**

TRANSMITTER



CHANNEL

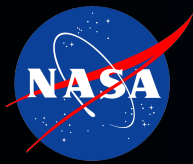


RECEIVER

Has to correctly interpret the message  
- the most difficult job

The fundamental problem of communications is that of reproducing at one point either exactly or approximately a message selected at another point.

-Claude Shannon



# Electromagnetic Waves Communication

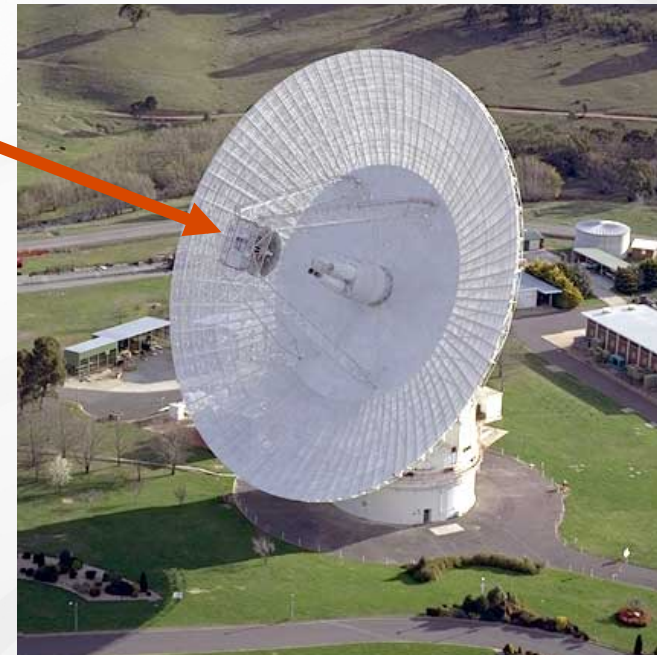


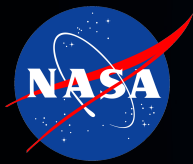
Satellite communications are carried on Electromagnetic Waves that travel between ground facilities and satellites in space. These electromagnetic waves travel at the speed of light ( $3 \times 10^8$  m/s through free space).



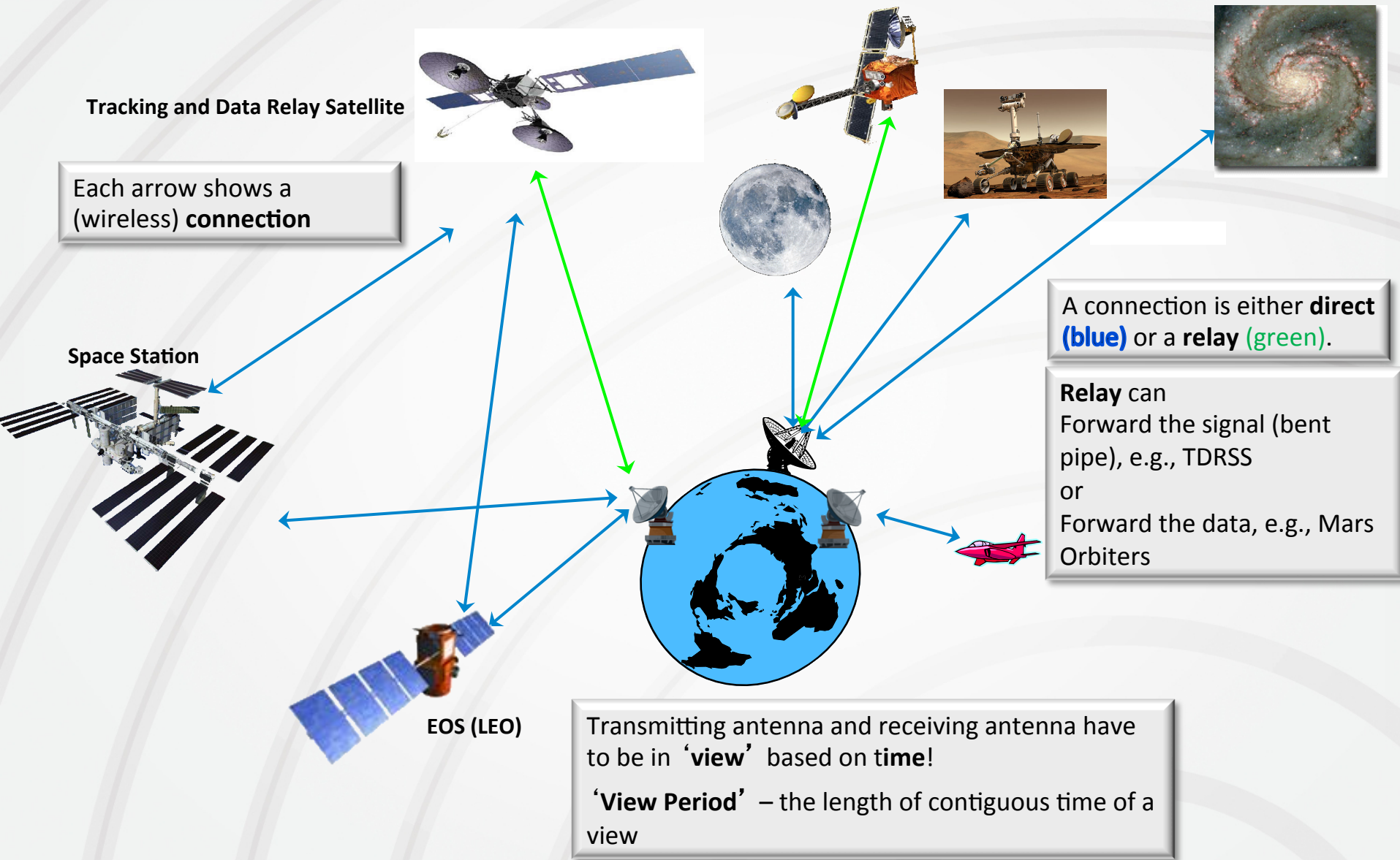
Wavelength is the length of one complete cycle of an electromagnetic wave.

Electromagnetic waves used for satellite communication are generally **cm** or **mm** in length. The wave shown here — is 5 cm in length — the wavelength of a 6GHz signal.





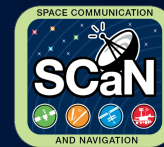
# Space Communications Environment



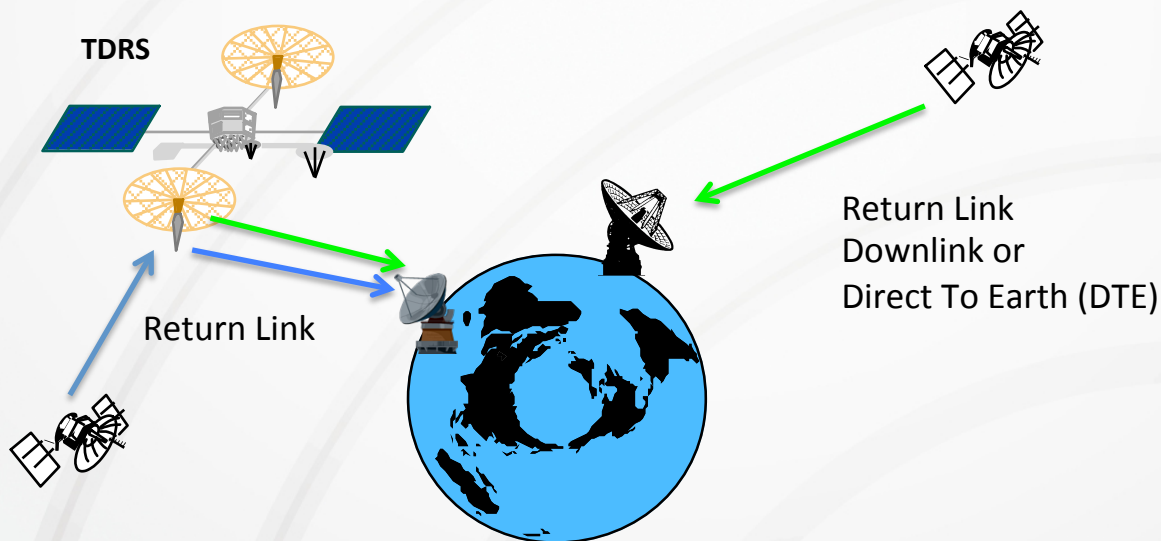




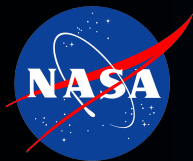
# Mission Requirements High Level (Continued)



- Get information from the spacecraft (s/c).
  - Data collected by the spacecraft (pictures, sensor data...).
  - Spacecraft information (status, performance...), protocol related information.
- The signal path is called:
  - **Return Link** – s/c to ground (can be through relays).
  - **Downlink or Direct to Earth (DTE)** – Direct connection from s/c to ground.



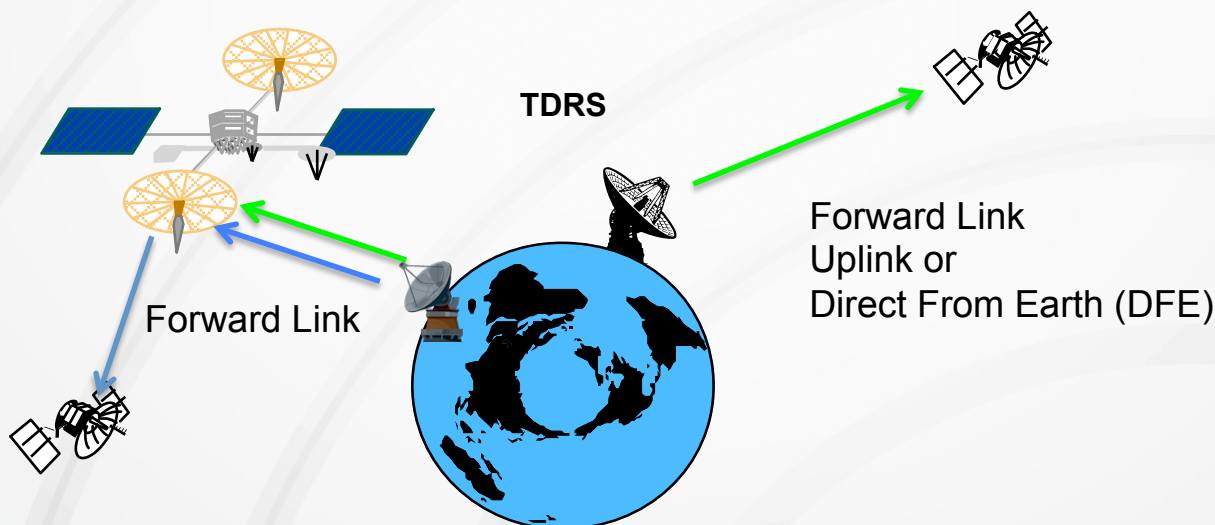
**Telemetry** – ‘Measurement at a distance’ – nowadays refers to operational data except in deep space communications.



# Mission Requirements High Level (Continued)

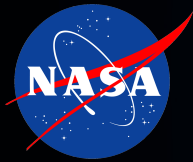


- Send information to the spacecraft.
  - Instructions to perform functions on the s/c (Command).
  - s/c parameters, protocol related information.
  - Software uploads.
- The signal path is called.
  - **Forward Link** - Ground to s/c (can be through relays).
  - **Uplink** or **Direct From Earth (DFE)** or **Commanding** – Direct connection ground to s/c.

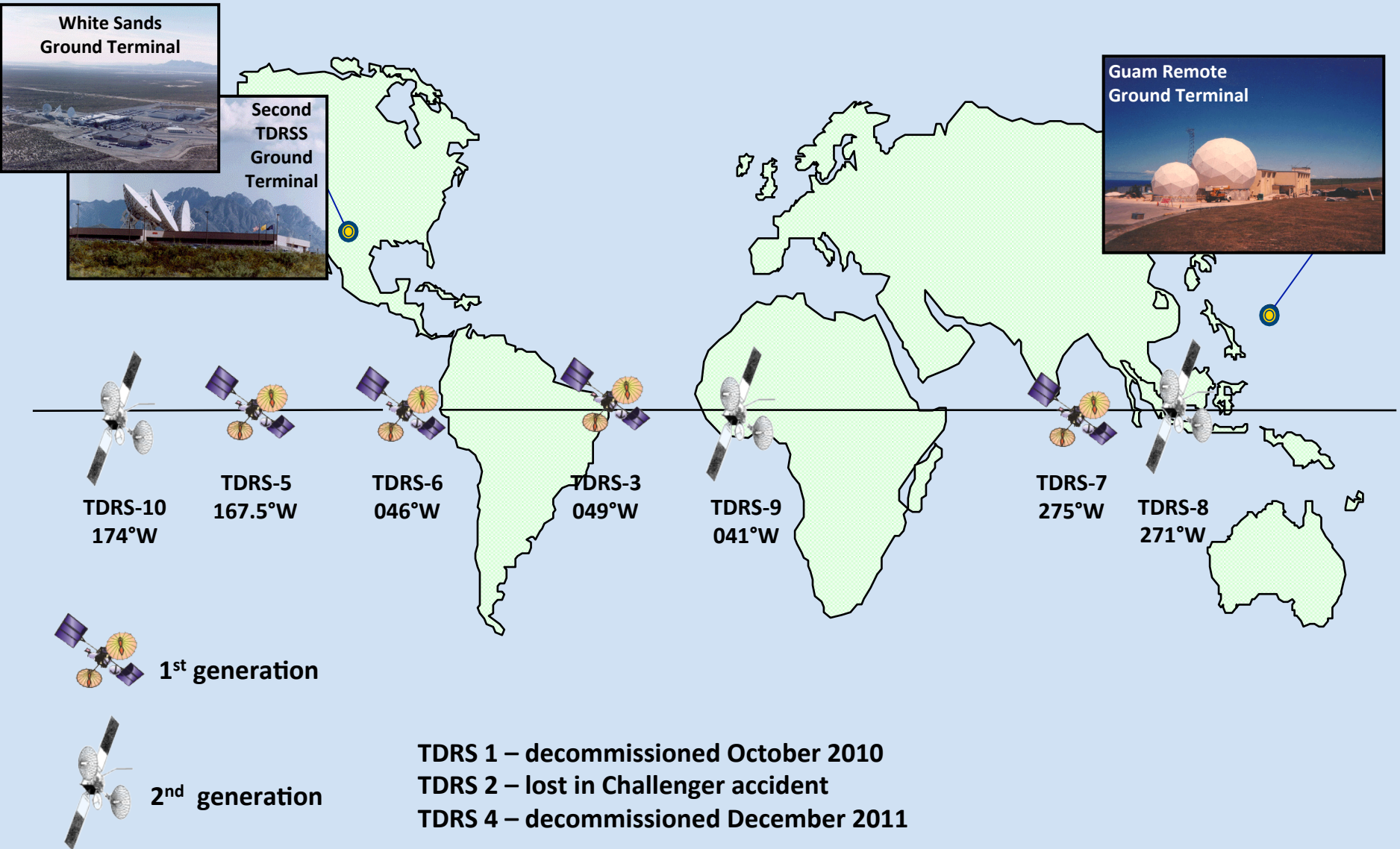


**Command** – Instructions sent to the spacecraft (TDRS commands on uplink).

**Sequence** – A set of commands with information about when and what to execute.



# Tracking and Data Satellite System

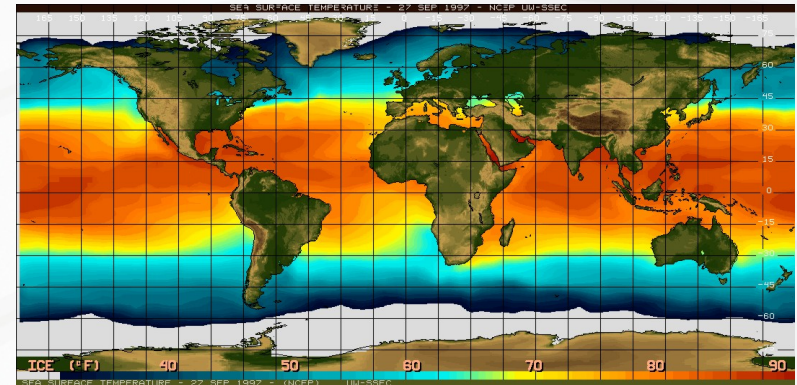
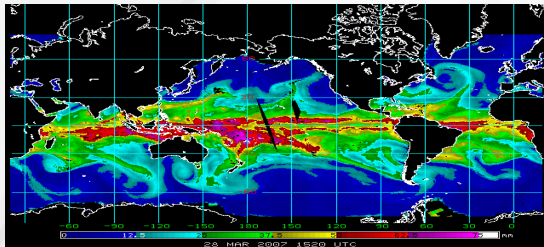


Active sensor: uses transmitter and receiver.

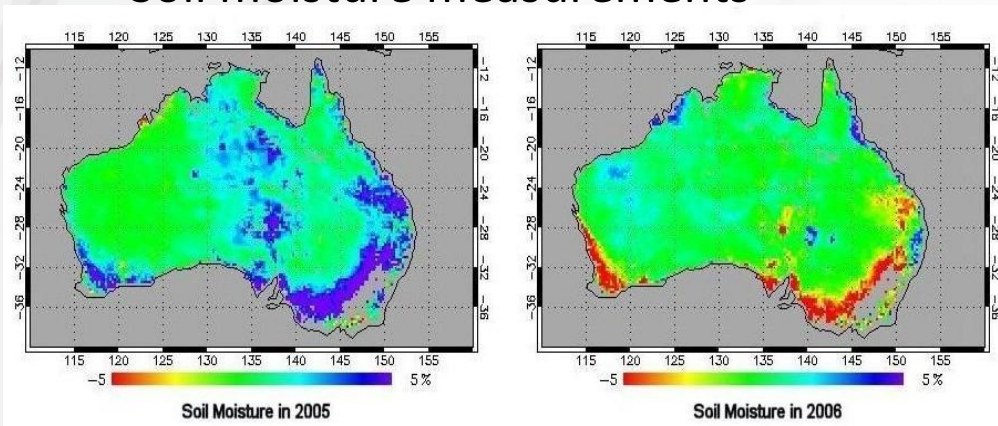
Passive sensor: uses only receiver.

Sea surface temperature measurements

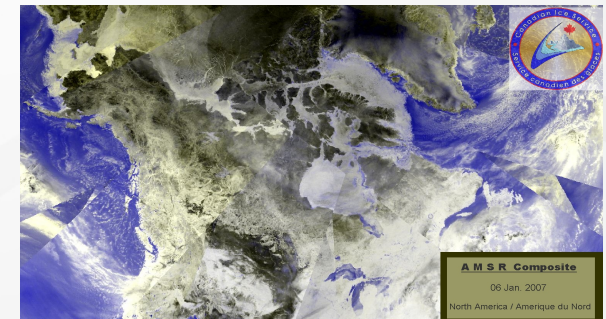
Atmospheric vertical water content

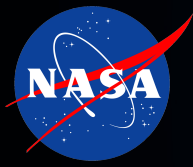


Soil moisture measurements



Sea ice over North America





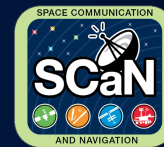
# Purpose of Spectrum Management



- Ensure that systems that use the radio frequency (RF) spectrum comply with national statutory and international treaty obligations
- Ensure that a system in which time and money has been invested for development provides the required quality of service upon deployment and installation
  - Ensure that systems operate as intended -- they neither create more interference than is acceptable nor experience more interference than is acceptable
- Apply order to the use of the orbit/spectrum resource
- Provide technical bases for coordination
- Promote the efficient use of the radio frequency spectrum
- Accommodate new services, applications, and technology



# GSFC Spectrum Management



- GSFC projects need to be aware that there are regulatory constraints that will affect their frequency authorization.
  - Internationally: ITU-R and related Treaties and Agreements
  - Domestically: NTIA and FCC
  - Agency: NPD 2570.5E and GPR 2570.1B
- The frequency allocations available to each mission depends on mission objectives
  - Generally, missions with Earth Exploration objectives operate under Earth Exploration Satellite Service (EESS) allocations
  - Generally, missions which have objectives to study space and objects external to the Earth operate under Space Research (SR) Service allocations
  - Both types of missions can use Space Operations (SO) allocations for space tracking, space telemetry, and space telecommand operations
- The width of the available allocations, as well as existing agreements between NASA and other administrations, may impose constraints on the maximum bandwidth available to the mission.
- GSFC project personnel should contact the GSFC spectrum manager early-on to ensure that project personnel fully understand which allocations are available for their mission, the constraints imposed on these allocations, and any issues that may affect the frequency authorization for their mission

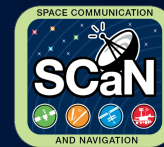




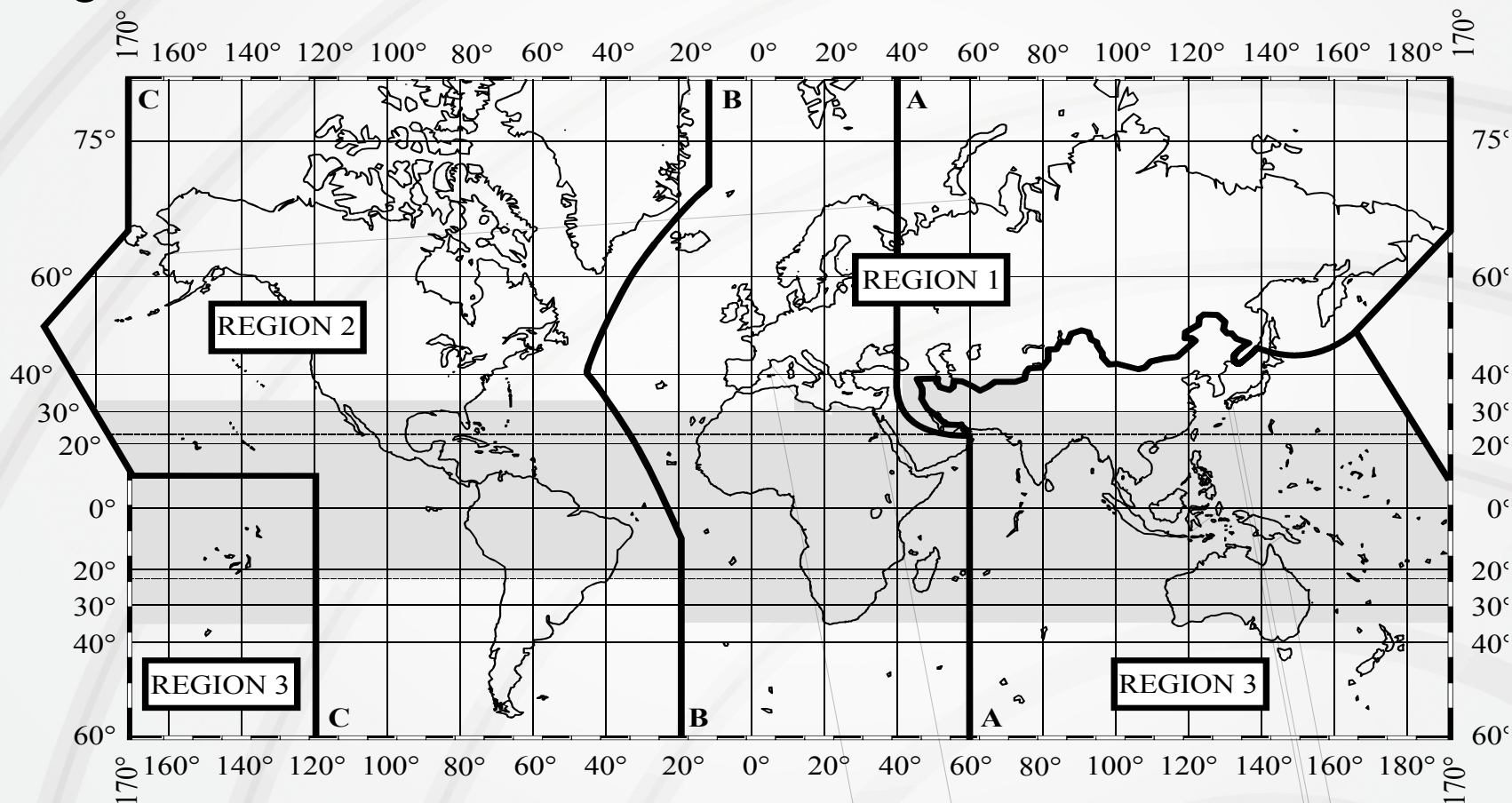




# International Spectrum Regulated



- ◆ The ITU-R Radio Regulations divides the world into three Regions



The shaded part represents the Tropical Zones as defined in Nos. S5.16 to S5.20 and S5.21.



# U.S. Frequency Allocations – VLBI?



Table of Frequency Allocations			2200-2655 MHz (UHF)		FCC Rule Part(s)
International Table			United States Table		
Region 1 Table	Region 2 Table	Region 3 Table	Federal Table	Non-Federal Table	
2200-2290 SPACE OPERATION (space-to-Earth) (space-to-space) EARTH EXPLORATION-SATELLITE (space-to-Earth) (space-to-space) FIXED MOBILE 5.391 SPACE RESEARCH (space-to-Earth) (space-to-space)			2200-2290 SPACE OPERATION (space-to-Earth) (space-to-space) EARTH EXPLORATION-SATELLITE (space-to-Earth) (space-to-space) FIXED (line-of-sight only) MOBILE (line-of-sight only including aeronautical telemetry, but excluding flight testing of manned aircraft) 5.391 SPACE RESEARCH (space-to-Earth) (space-to-space)	2200-2290	
5.392 2290-2300 FIXED MOBILE except aeronautical mobile SPACE RESEARCH (deep space) (space-to-Earth)			5.392 US303 2290-2300 FIXED MOBILE except aeronautical mobile SPACE RESEARCH (deep space) (space-to-Earth)	US303 2290-2300 SPACE RESEARCH (deep space) (space-to-Earth)	
2300-2450 FIXED MOBILE 5.384A Amateur Radiolocation	2300-2450 FIXED MOBILE 5.384A RADIOLOCATION Amateur		2300-2305 G122 2305-2310  US338 G122 2310-2320 Fixed Mobile US339 Radiolocation G2  US327 US338 2320-2345 Fixed Radiolocation G2  US327 2345-2360 Fixed Mobile US339 Radiolocation G2  US327 2360-2390 MOBILE US276 RADIOLOCATION G2 G120 Fixed	2300-2305 Amateur  2305-2310 FIXED MOBILE except aeronautical mobile RADIOLOCATION Amateur  US338 2310-2320 FIXED MOBILE US339 BROADCASTING-SATELLITE RADIOLOCATION  5.396 US327 US338 2320-2345 BROADCASTING-SATELLITE  5.396 US327 2345-2360 FIXED MOBILE US339 BROADCASTING-SATELLITE RADIOLOCATION  5.396 US327 2360-2390 MOBILE US276	Amateur Radio (97)  Wireless Communications (27) Amateur Radio (97)  Wireless Communications (27) Aviation (87)  Satellite Communications (25)  Wireless Communications (27) Aviation (87)  Aviation (87)



# U.S. Frequency Allocations – VLBI?



1/2008 (Rev. 9/2010)

4-41

4.1.3

			2390-2395 MOBILE US276	2390-2395 AMATEUR MOBILE US276	Aviation (87) Amateur Radio (97)
			2395-2400 G122	2395-2400 AMATEUR	Amateur Radio (97)
			2400-2417	2400-2417 AMATEUR	ISM Equipment (18) Amateur Radio (97)
			5.150 G122	5.150 5.282	
			2417-2450 Radiolocation G2	2417-2450 Amateur	
5.150 5.282 5.395	5.150 5.282 5.393 5.394 5.396		5.150	5.150 5.282	
2450-2483.5 FIXED MOBILE Radiolocation	2450-2483.5 FIXED MOBILE RADIOLOCATION		2450-2483.5	2450-2483.5 FIXED MOBILE Radiolocation	ISM Equipment (18) TV Auxiliary Broadcasting (74F) Private Land Mobile (90) Fixed Microwave (101)
5.150 5.397	5.150		5.150 US41	5.150 US41	
2483.5-2500 FIXED MOBILE MOBILE-SATELLITE (space-to-Earth) 5.351A Radiolocation	2483.5-2500 FIXED MOBILE MOBILE-SATELLITE (space-to-Earth) 5.351A RADIODETERMINATION- SATELLITE (space-to-Earth) 5.398 RADIOLOCATION	2483.5-2500 FIXED MOBILE MOBILE-SATELLITE (space-to-Earth) 5.351A RADIOLOCATION Radiodetermination-satellite (space-to-Earth) 5.398	2483.5-2500 MOBILE-SATELLITE (space-to- Earth) US319 US380 US391 RADIODETERMINATION-SATELLITE (space-to-Earth) 5.398	2483.5-2495 MOBILE-SATELLITE (space-to- Earth) US380 RADIODETERMINATION-SATEL- LITE (space-to-Earth) 5.398 5.150 5.402 US41 US319 NG147	ISM Equipment (18) Satellite Communications (25)
5.150 5.371 5.397 5.398 5.399 5.400 5.402	5.150 5.402	5.150 5.400 5.402	5.150 5.402 US41	2495-2500 FIXED MOBILE except aeronautical mobile MOBILE-SATELLITE (space-to- Earth) US380 RADIODETERMINATION-SATEL- LITE (space-to-Earth) 5.398 5.150 5.402 US41 US319 US391 NG147	ISM Equipment (18) Satellite Communications (25) Wireless Communications (27)
2500-2520 FIXED 5.410 MOBILE except aeronautical mobile 5.384A	2500-2520 FIXED 5.410 FIXED-SATELLITE (space-to- Earth) 5.415 MOBILE except aeronautical mobile 5.384A	2500-2520 FIXED 5.410 FIXED-SATELLITE (space-to-Earth) 5.415 MOBILE except aeronautical mobile 5.384A MOBILE-SATELLITE (space-to-Earth) 5.351A 5.407 5.414 5.414A	2500-2655	2500-2655 FIXED US205 MOBILE except aeronautical mobile	Wireless Communications (27)
5.405 5.412	5.404	5.404 5.415A			
2520-2655 FIXED 5.410 MOBILE except aeronautical mobile 5.384A BROADCASTING-SATELLITE 5.413 5.416	2520-2655 FIXED 5.410 FIXED-SATELLITE (space-to-Earth) 5.415 MOBILE except aeronautical mobile 5.384A BROADCASTING-SATELLITE 5.413 5.416	2520-2535 FIXED 5.410 FIXED-SATELLITE (space-to-Earth) 5.415 MOBILE except aeronautical mobile 5.384A BROADCASTING-SATELLITE 5.413 5.416 5.403 5.414A 5.415A			
5.339 5.405 5.412 5.417C 5.417D 5.418B 5.418C	5.339 5.417C 5.417D 5.418B 5.418C	2535-2655 FIXED 5.410 MOBILE except aeronautical mobile 5.384A BROADCASTING-SATELLITE 5.413 5.416 5.339 5.417A 5.417B 5.417C 5.417D 5.418 5.418A 5.418B 5.418C	5.339 US205	5.339	



# U.S. Frequency Allocations – VLBI?



1/2008 (Rev. 9/2010)

4-49

4.1.3

8650-8750 RADIOLOCATION	8650-9000 RADIOLOCATION G59	8650-9000 Radiolocation	Aviation (87) Private Land Mobile (90)
5.468 5.469 8750-8850 RADIOLOCATION AERONAUTICAL RADIONAVIGATION 5.470			
5.471 8850-9000 RADIOLOCATION MARITIME RADIONAVIGATION 5.472			
5.473 9000-9200 AERONAUTICAL RADIONAVIGATION 5.337 RADIOLOCATION	US53 9000-9200 AERONAUTICAL RADIONAVIGATION 5.337 Radiolocation G2	US53 9000-9200 AERONAUTICAL RADIONAVIGATION 5.337 Radiolocation	
5.471 5.473A 9200-9300 RADIOLOCATION MARITIME RADIONAVIGATION 5.472	US48 G19 9200-9300 MARITIME RADIONAVIGATION 5.472 Radiolocation US110 G59	US48 9200-9300 MARITIME RADIONAVIGATION 5.472 Radiolocation US110	Maritime (80) Private Land Mobile (90)
5.473 5.474	5.474	5.474	



# U.S. Frequency Allocations – VLBI?



Table of Frequency Allocations			2655-4990 MHz (UHF/SHF)		FCC Rule Part(s)
International Table			United States Table		
Region 1 Table	Region 2 Table	Region 3 Table	Federal Table	Non-Federal Table	
2655-2670 FIXED 5.410 MOBILE except aeronautical mobile 5.384A BROADCASTING-SATELLITE 5.208B 5.413 5.416 Earth exploration-satellite (passive) Radio astronomy Space research (passive)	2655-2670 FIXED 5.410 FIXED-SATELLITE (Earth-to-space) (space-to-Earth) 5.415 MOBILE except aeronautical mobile 5.384A BROADCASTING-SATELLITE 5.413 5.416 Earth exploration-satellite (passive) Radio astronomy Space research (passive)	2655-2670 FIXED 5.410 FIXED-SATELLITE (Earth-to-space) 5.415 MOBILE except aeronautical mobile 5.384A BROADCASTING-SATELLITE 5.413 5.416 Earth exploration-satellite (passive) Radio astronomy Space research (passive)	2655-2690 Earth exploration-satellite (passive) Radio astronomy US385 Space research (passive)	2655-2690 FIXED US205 MOBILE except aeronautical mobile Earth exploration-satellite (passive) Radio astronomy Space research (passive)	Wireless Communications (27)
5.149 5.412	5.149 5.208B	5.149 5.208B 5.420			
2670-2690 FIXED 5.410 MOBILE except aeronautical mobile 5.384A Earth exploration-satellite (passive) Radio astronomy Space research (passive)	2670-2690 FIXED 5.410 FIXED-SATELLITE (Earth-to-space) (space-to-Earth) 5.208B 5.415 MOBILE except aeronautical mobile 5.384A Earth exploration-satellite (passive) Radio astronomy Space research (passive)	2670-2690 FIXED 5.410 FIXED-SATELLITE (Earth-to-space) 5.415 MOBILE except aeronautical mobile 5.384A MOBILE-SATELLITE (Earth-to-space) 5.351A 5.419 Earth exploration-satellite (passive) Radio astronomy Space research (passive)			
5.149 5.412	5.149	5.149	US205	US385	
2690-2700 EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY SPACE RESEARCH (passive) 5.340 5.422			2690-2700 EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY US74 SPACE RESEARCH (passive) US246		
2700-2900 AERONAUTICAL RADIONAVIGATION 5.337 Radiolocation			2700-2900 METEOROLOGICAL AIDS AERONAUTICAL RADIONAVIGATION 5.337 US18 Radiolocation G2	2700-2900	Aviation (87)
5.423 5.424			5.423 G15	5.423 US18	