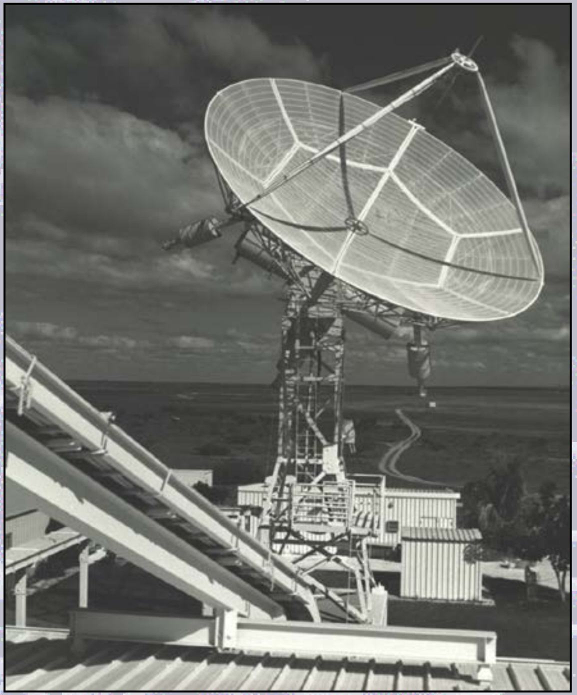
Radio Solar Telescope Network



Based on a talk by SWPC forecaster, Ken Tegnell, on 31 Mar 2016

Topics

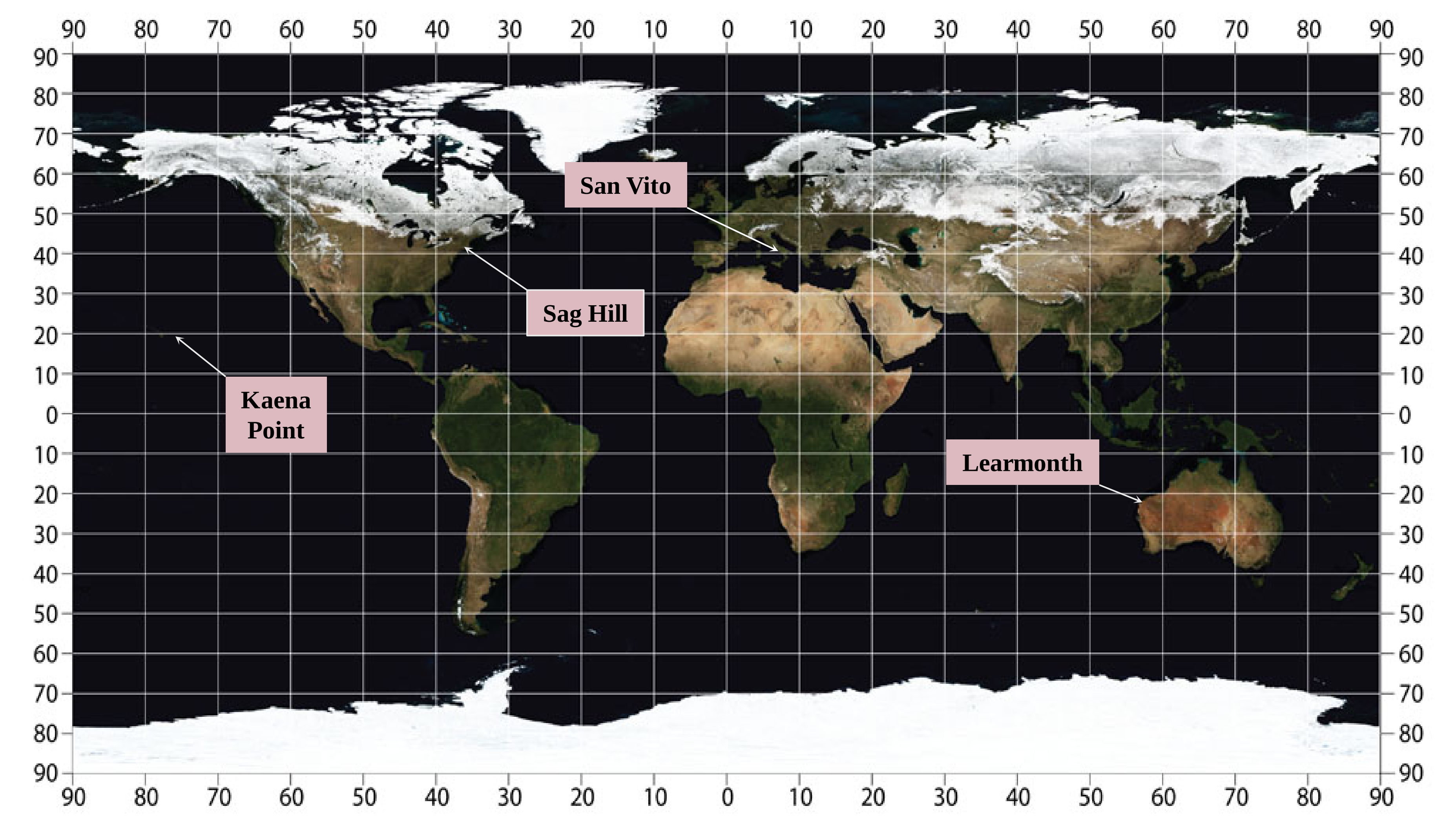
- RSTN Locations
- RSTN Antennas
- Radio Stuff
- Sweep / Burst Stuff
- Rules of Thumb

Terrestrial Wx / Space Wx Background

Ken Tegnell - Bio

- **1977 – 1980: Army Support – *Wx Forecaster / Forward Air Controller***
  - **Fort Ord, CA**
- **1984 – 1987: Air Force – *Solar Radio Chief***
  - **Learmonth, Western Australia**
- **1987 – 1991: Air Force – *Wx Forecaster, Chief Wx Operations***
  - **Ellsworth AFB, SD**
- **1991 – 1993: Air Force – *Chief, Space Wx Operations***
  - **Learmonth, Western Australia**
- **1993 – 1996: Air Force – *NCOIC, Space Wx Forecaster***
  - **Boulder, CO**
- **1996 – Present: SEL / SESC / SEC / SWPC – *Space Weather Forecaster***
  - **Boulder, CO**

RSTN Radio Observatories



RSTN Radio Observatories

Learmonth, Western Australia

- **Established in 1979**
- ***Dual optical and radio site***
- **Jointly managed by IPS & USAF**

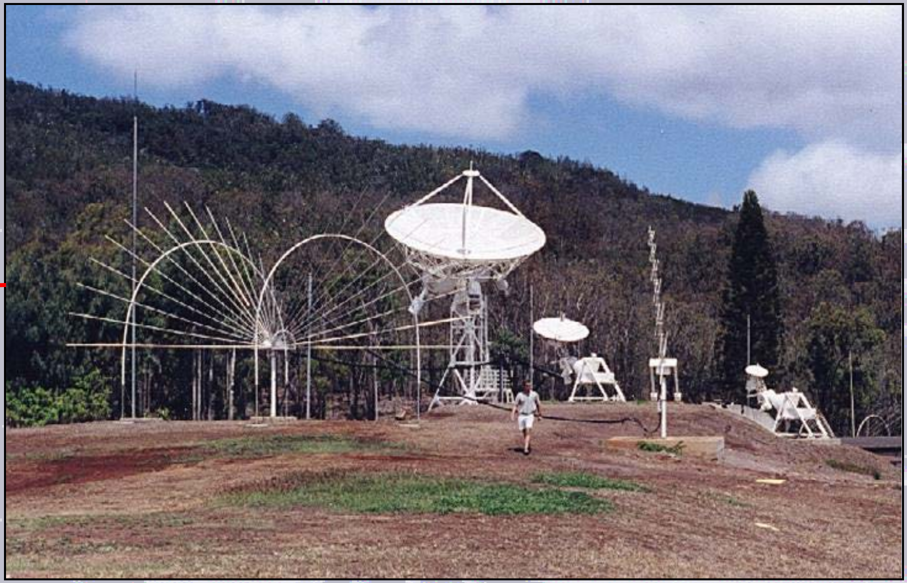
RSTN Radio Observatories

San Vito, Southern Italy

- Established in 1985
- *Dual optical and radio site*
- Managed by a civilian contract

RTN Radio Observatories

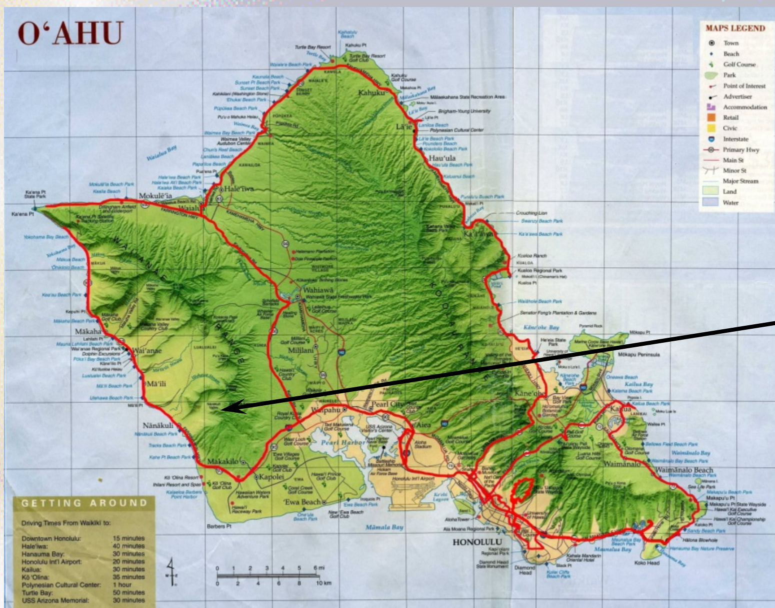
Sagamore Hill, Massachusetts, USA



- Established in 1966
- *Radio only site*
- Associated with AFRL

RSTN Radio Observatories

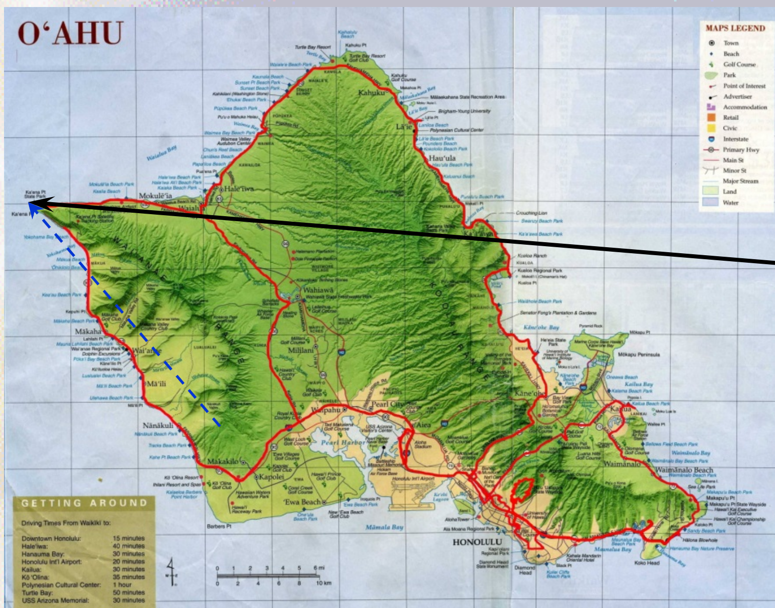
Palehua, Hawaii, USA



- **Established in 1979**
- ***Radio only site***
- **Located on former NIKE missile site**

RSTN Radio Observatories

Kaena Point, Hawaii, USA



- **Moved from Palehua - Spring 2011**
- ***Radio only site***
- **"Jumping-off" point for souls leaving this world**

RSTN Radio Observatories

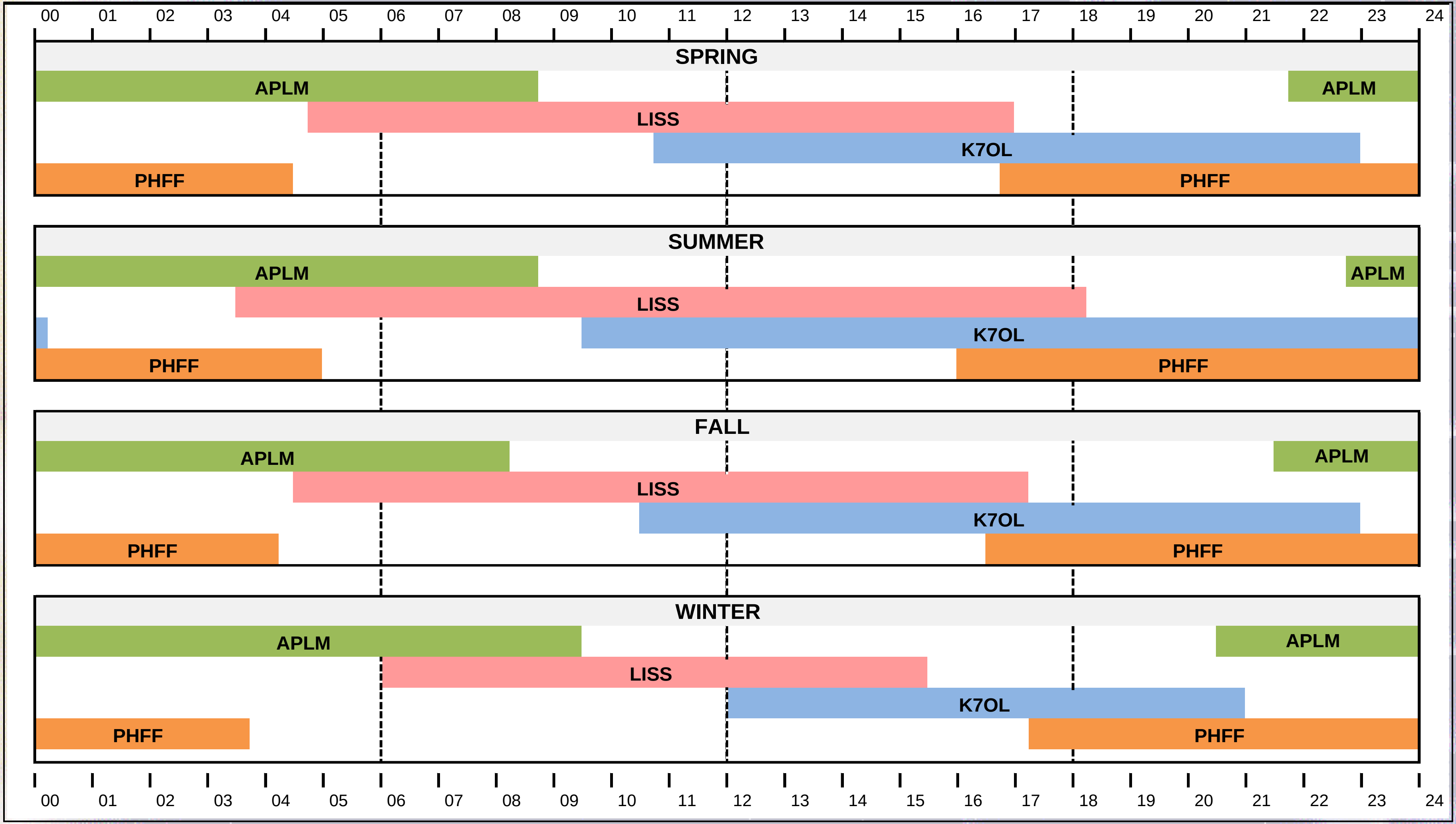
Learmonth, Western Australia

Really, really old monitors!

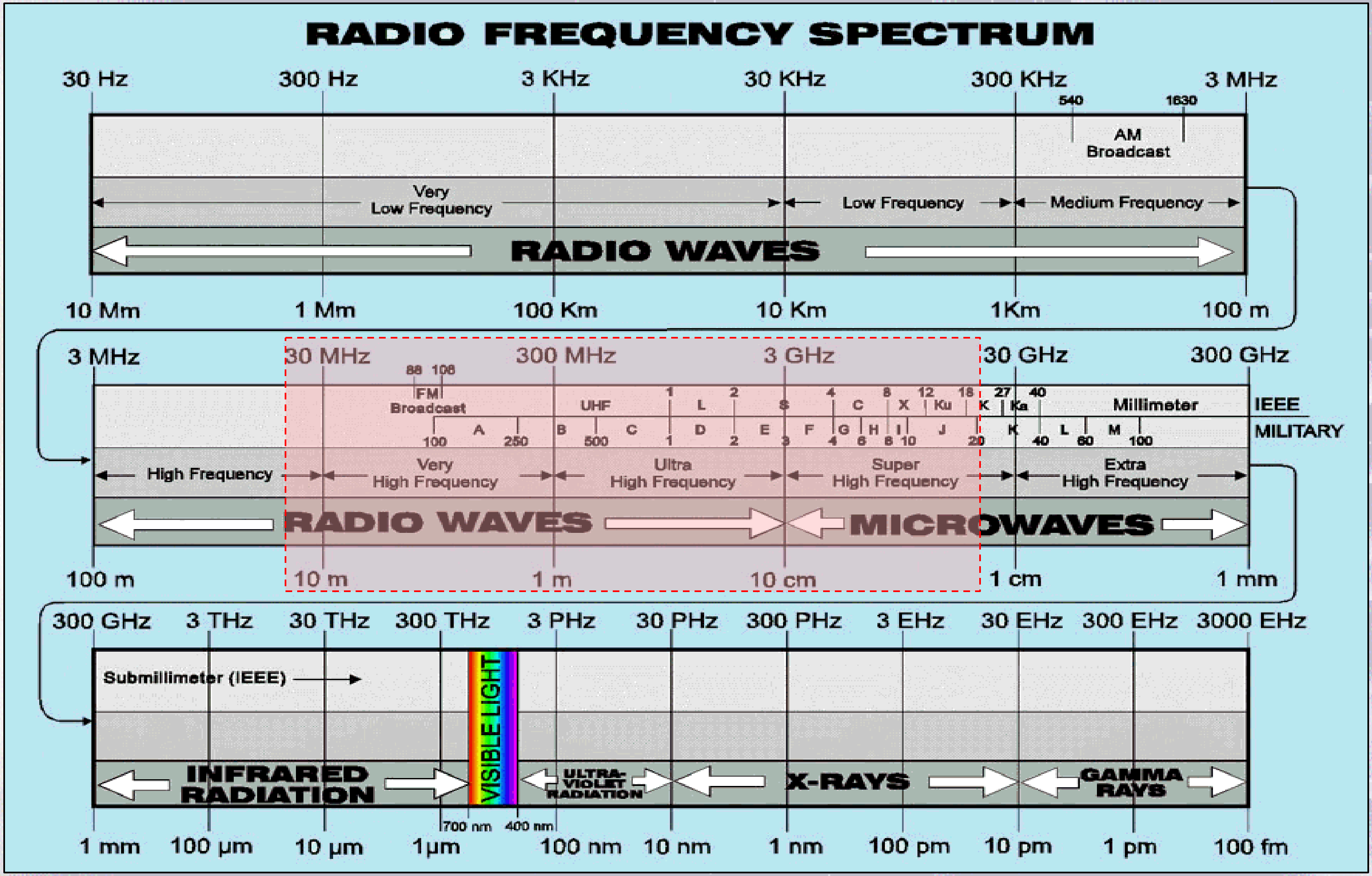
This is an interior view of the RSTN Observatory at Learmonth.

- **5 racks of equipment can be seen. From left to right these are:**
  - ***0.9 m antenna controller***
  - ***2.4 m antenna controller***
  - ***8800 MHz radiotelescope***
  - ***4995 MHz radiotelescope***
  - ***2695 MHz radiotelescope***

RSTN Observing Coverage



Radio Frequency Spectrum



Radio Frequency Spectrum

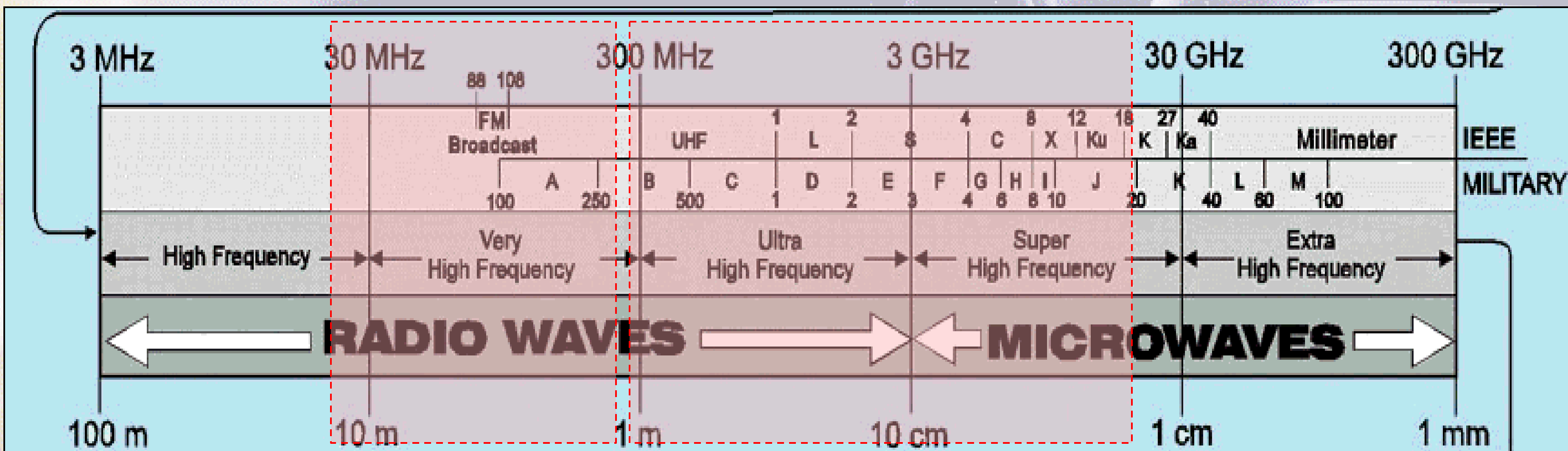
18 MHz to 15.4 GHz

Spectral

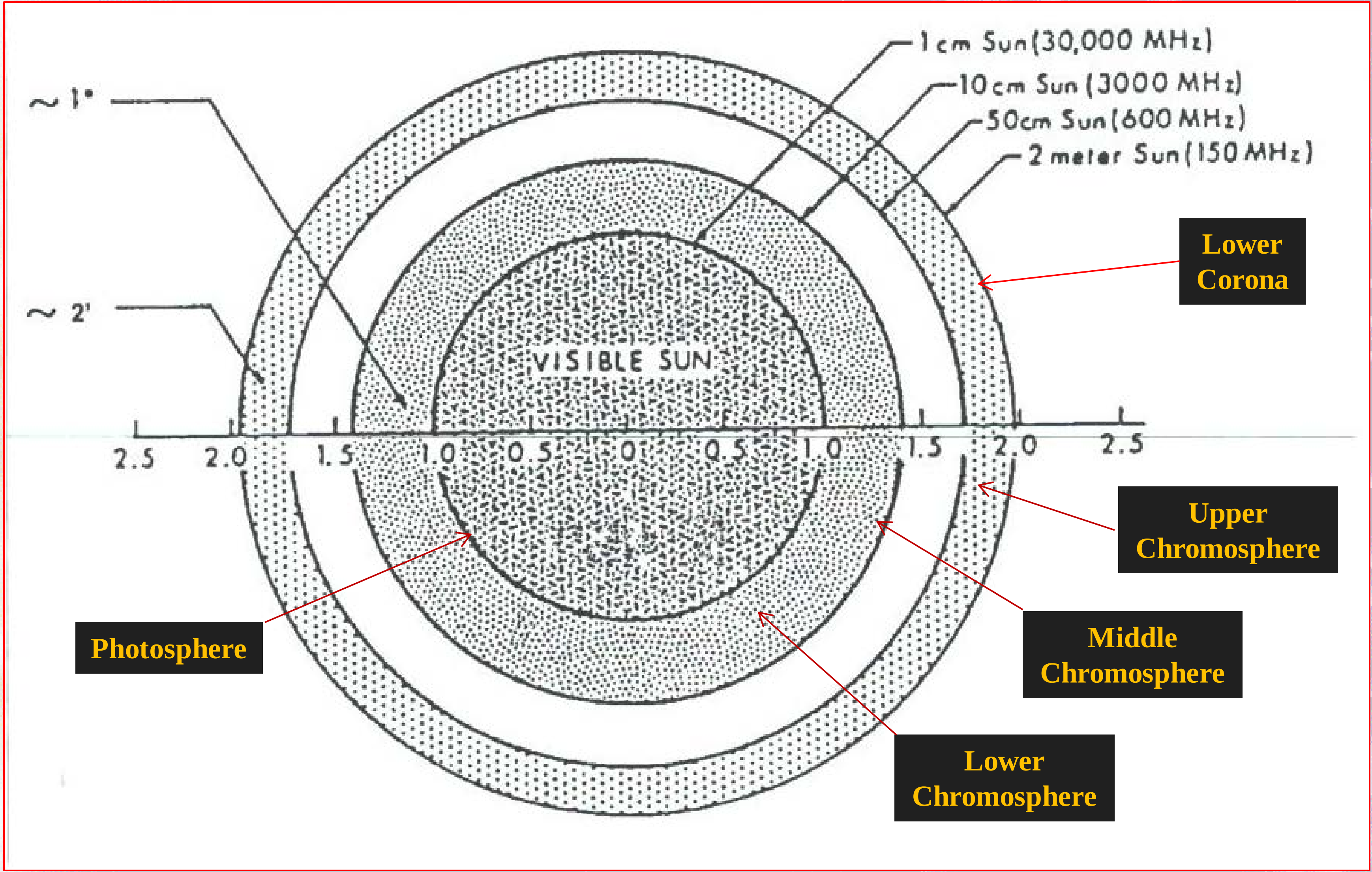
18 – 180 MHz

Discrete

245 MHz – 15.4 GHz

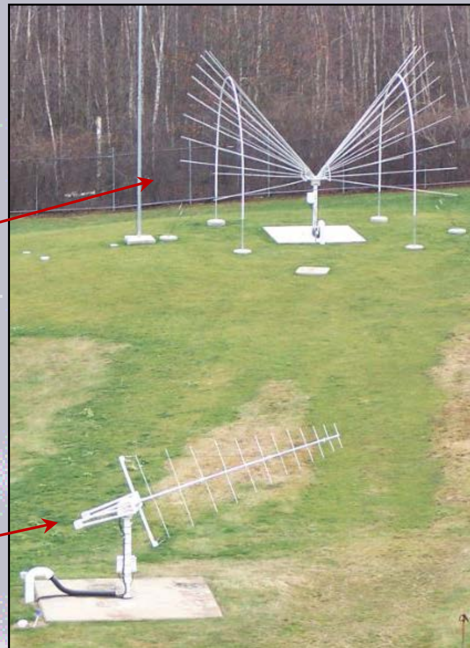


The Radio Sun



Solar Radio Spectrograph
(SRS)

18-75 MHz
(low band)
Note: Old Swept Frequency Interferometric Radiometer (SFIR) Bicone Antenna



75-180 MHz
(high band)

18-75 MHz

75-180 MHz

16.7 – 4.0 m Middle Corona

- Maritime radio, Radio buoys

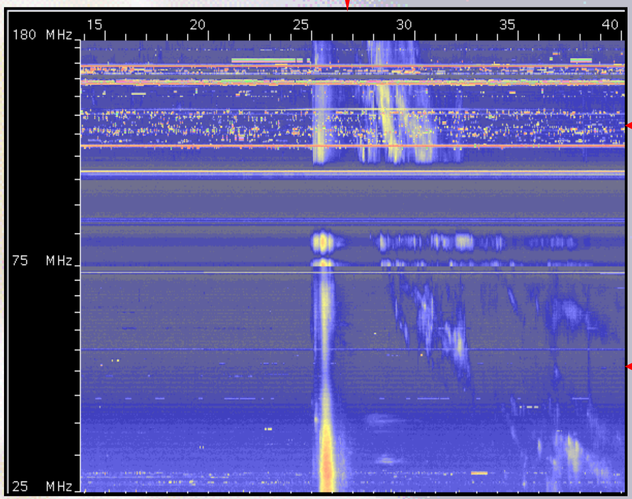
4.0 – 1.7 m Lower Corona

- FM radio, Marine HF radio

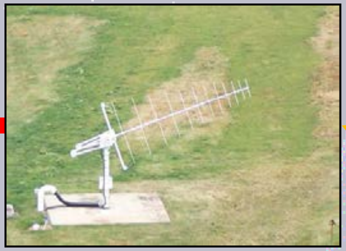
Solar Radio Spectrograph
(SRS)

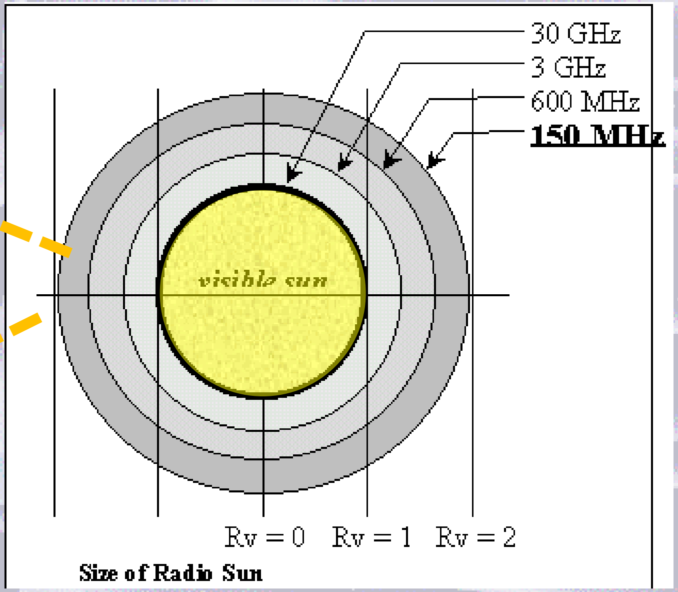
Each antenna measures radio flux originating from a different layer of the solar atmosphere.

SRS Display

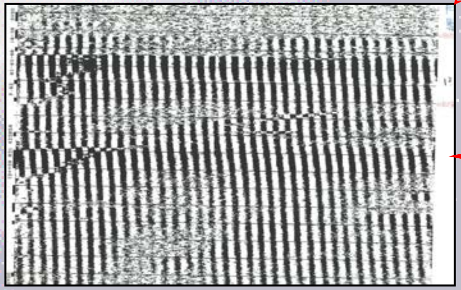


High band
75 – 180 MHz





Low band
18 – 75 MHz



SFIR Display

28 ft Antenna
(8.5 m)

245 MHz → **1.2 m - Lower Corona**
(TV Bands, FM Radio, Military)

410 MHz → **73.2 cm - Upper Chromosphere**
(Search and Rescue, DMSP)

610 MHz → **49.2 m - Upper Chromosphere**
(Cell phones, Wireless LAN)

8 ft Antenna
(2.4 *m*)

1415 MHz

21.2 cm - Upper Chromosphere
(Satellites, GPS, Bluetooth, Wireless LAN)

2695 MHz

11.1 cm - Middle Chromosphere
(XM Radio, Wx radar, Missile telemetry)

4995 MHz

6.0 cm - Middle Chromosphere
(Satellites, Microwave relays)

8800 MHz

3.4 cm - Lower Chromosphere
(Microwave relays, Radar)

3 ft Antenna

(0.9 m)

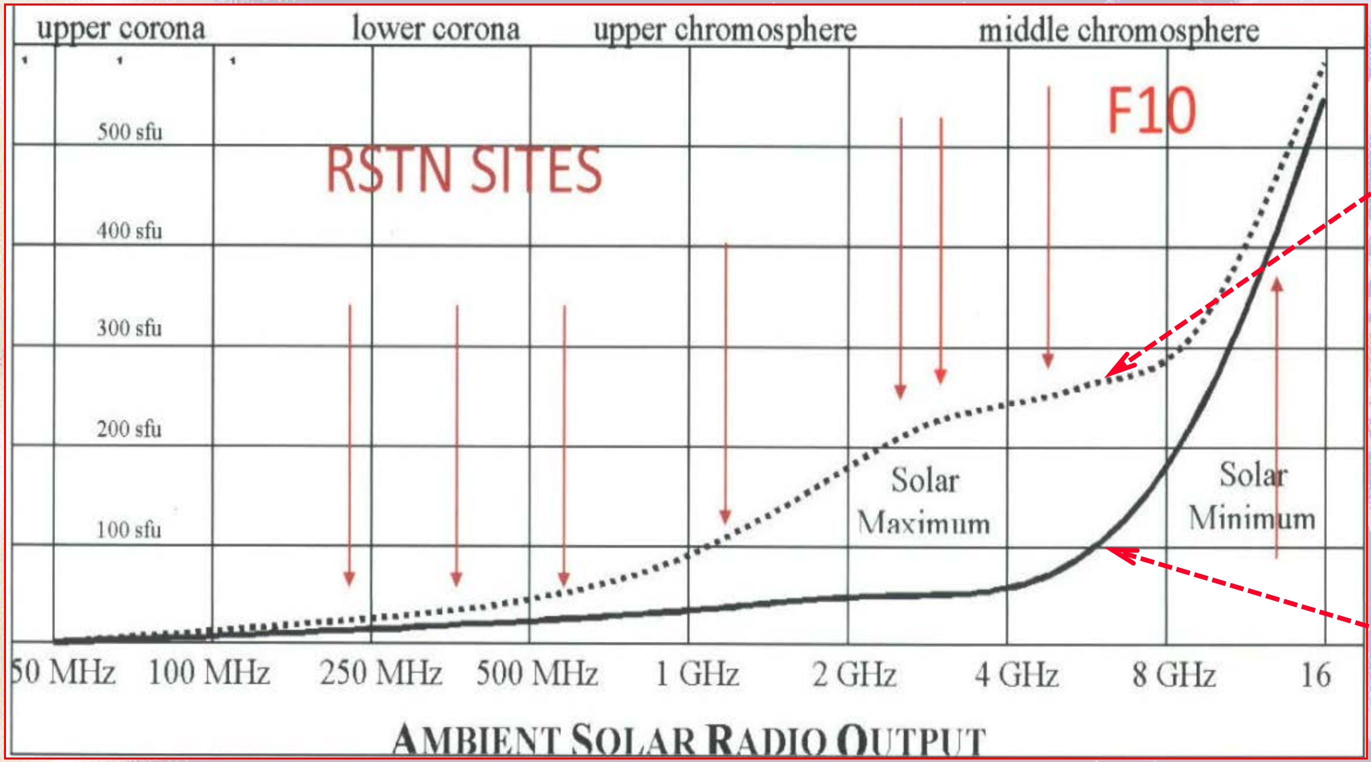
1.94 cm - Lower Chromosphere

(Satellite TV, Police Radar)

15,400 MHz
or
15.4 GHz

Ambient Solar Radio Output

Ambient output has 2 components

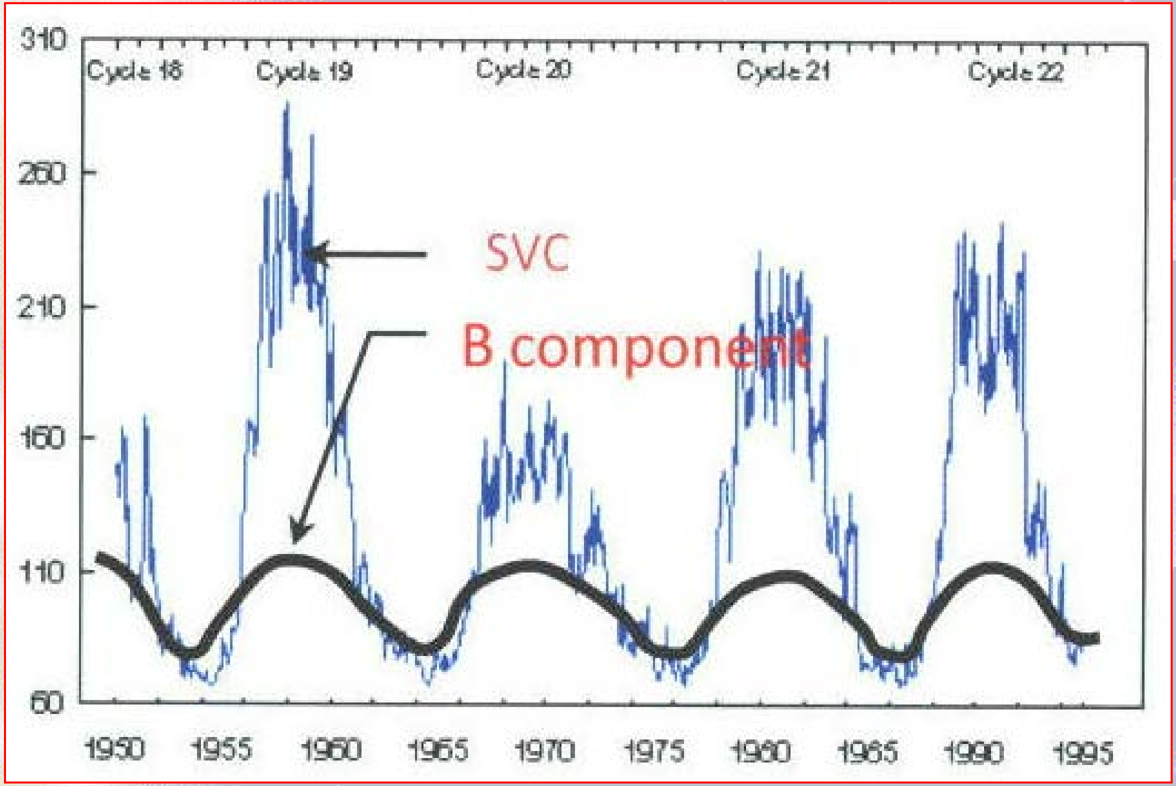


SVC
Slowly Varying Component

B
Background Component

Background Component *(B)*

Monthly Mean 2800 MHz Observed Flux



- **Contributes to a majority of the energy for IFLUX**
- ***Produced by the thermal motion of free electrons***
- **Varies during the course of the solar cycle**
- ***12% to 68% greater at maximum than minimum***

Radio Spectrum Variation with Altitude

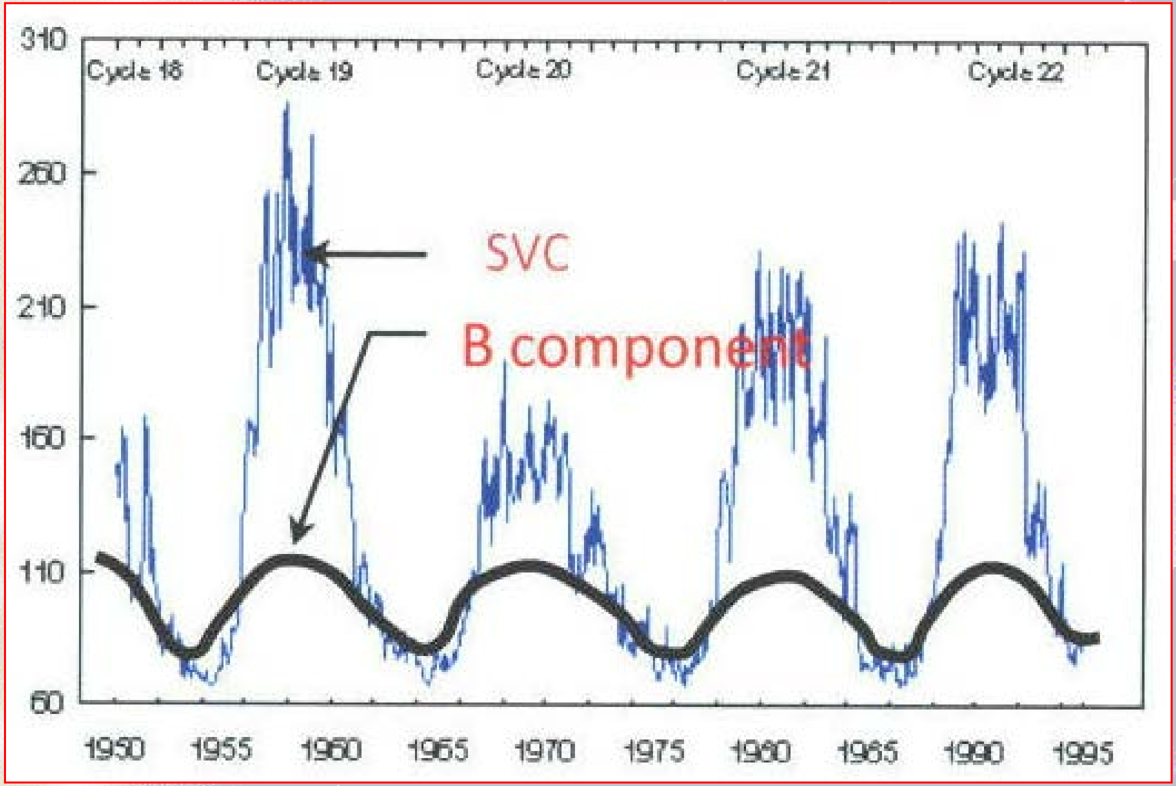
IFLUX variations between solar minimum and solar maximum

Table 5.1. Variation of the Solar Radio Spectrum with Altitude.

Level of Origin	Frequency (MHz)	Wavelength	Typical IFLUX Value (SFUs) at Solar Minimum		Typical IFLUX Value (SFUs) at Solar Maximum
lower chromosphere	15400	1.9 cm	525	12 %	590
	8800	3.4 cm	230	24 %	300
middle chromosphere	4995	6.0 cm	110	59 %	265
	2695	11.1 cm	70	68 %	215
upper chromosphere	1415	21.2 cm	55	60 %	135
	610	49.2 cm	35	57 %	80
	410	73.2 cm	20	55 %	45
lower corona	245	1.2 m	10	50 %	20
upper corona	75 to 25	4.0 m to 12.0 m	N/A		N/A

Slowly Varying Component (SVC)

Monthly Mean 2800 MHz Observed Flux

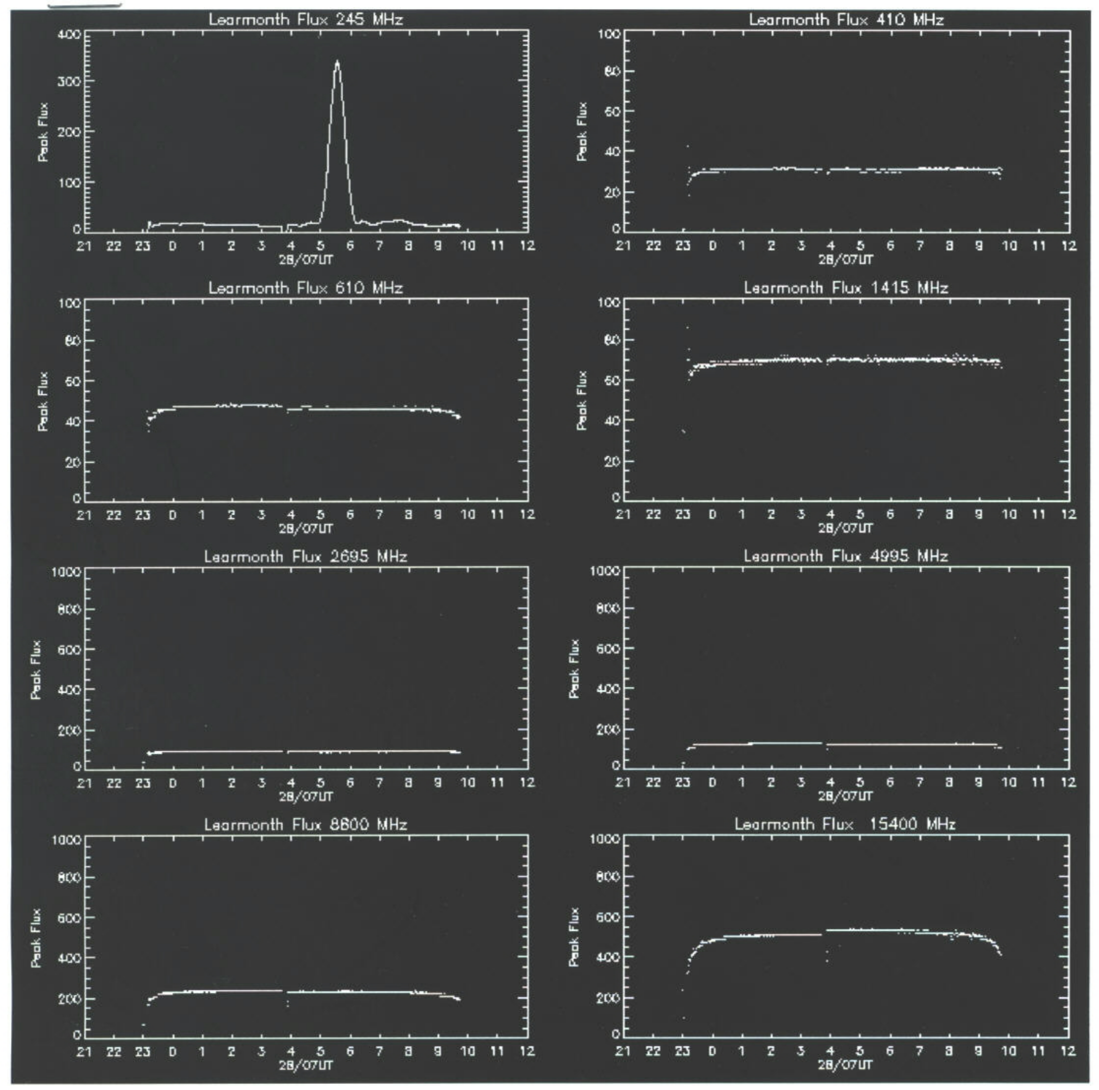


- **SVC represents the extra thermal energy produced by active regions.**
- ***SVC varies over a time scale of days-to-weeks as active regions grow and decay.***
- **Since active regions are concentrated in the chromosphere, their contribution is most noticeable near 2800 MHz.**

Radio Burst Classifications

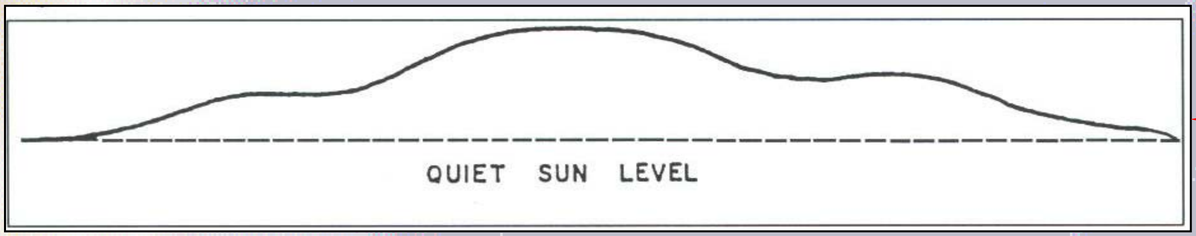
Type	Characteristics	Duration	Frequency Range	Associated Phenomena
I	Short, narrow-bandwidth bursts. Usually occur in large numbers with underlying continuum.	Single burst: ~1 sec Storm: Hours - days	80 – 200 MHz	Active regions, flares, eruptive prominences.
II	Slow frequency drift bursts. Usually accompanied by a stronger second harmonic. Drift from high to low frequencies.	3 – 30 min	Fundamental: 20 – 150 MHz	Flares, proton emission, shockwaves.
III	Fast frequency drift bursts. Can occur singularly or in groups.	Single burst: 1 - 3 sec Group: 1 - 5 min	10 kHz – 1 GHz	Active regions, flares.
IV	Stationary Type IV: Broadband continuum. Drift from high to low frequencies.	Hours – days	20 MHz – 2 GHz	Flares, proton emissions.
V	Smooth, short-lived continuum. Follows Type III bursts and never occur in isolation.	1 – 3 min	10 – 200 MHz	Active regions, flares.

Discrete Frequency Activity Monitor

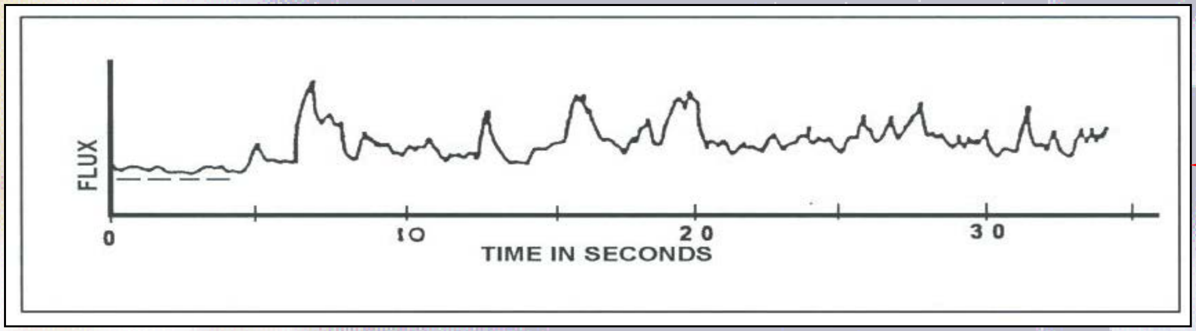


Microwave Burst Classifications

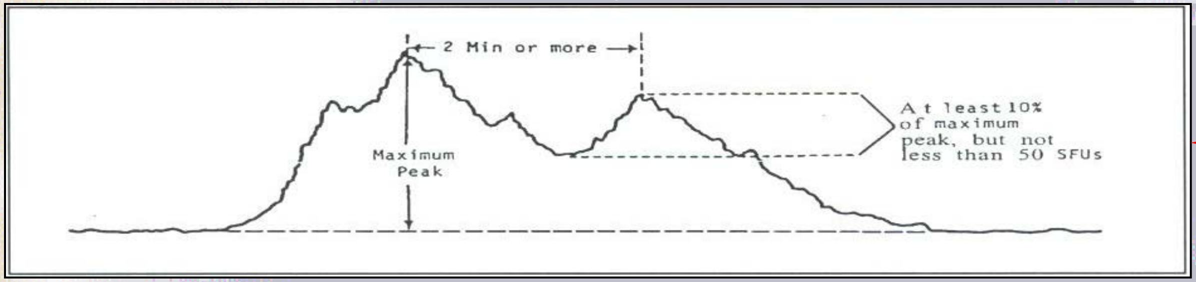
(300 to 30,000 MHz)



Gradual Rise and Fall Burst



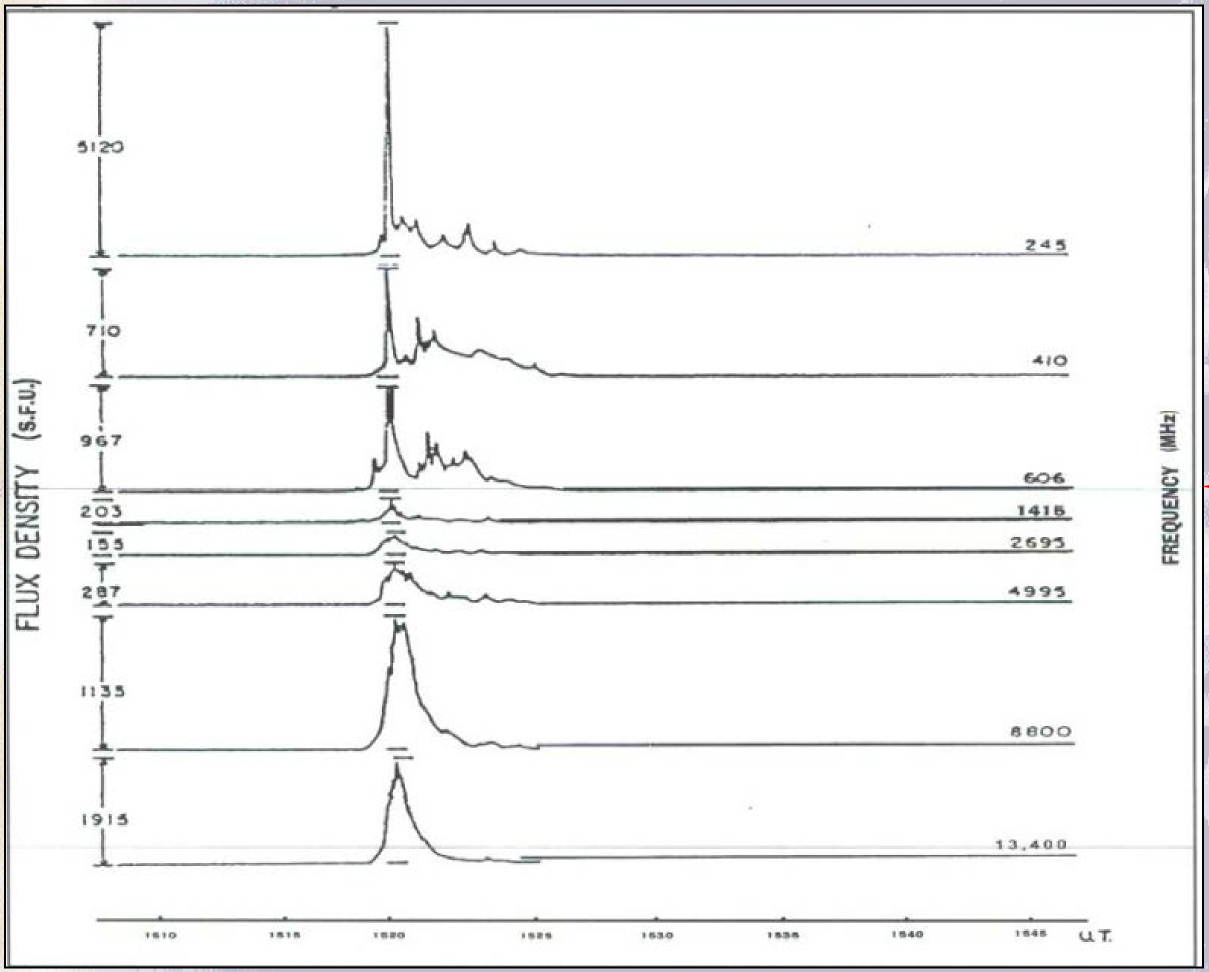
Noise Storm Burst



Complex Burst

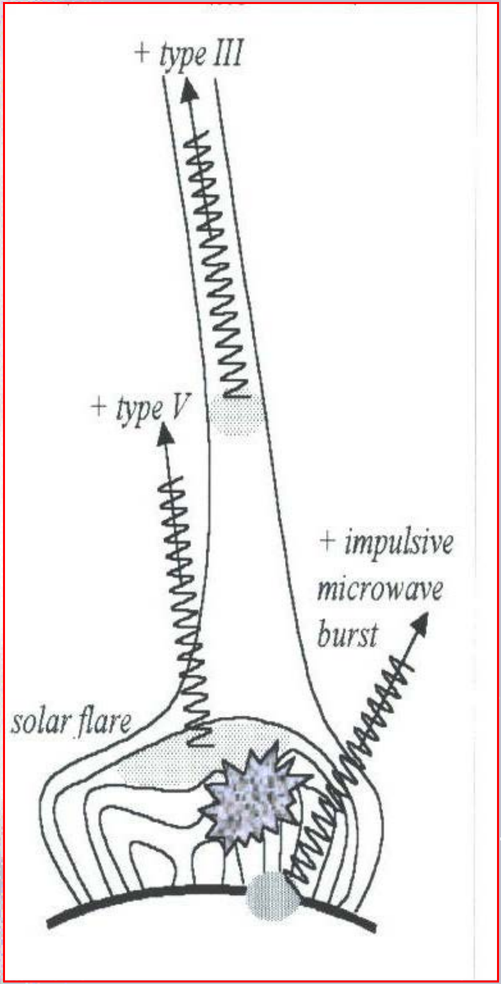
Microwave Burst Classifications

(300 to 30,000 MHz)



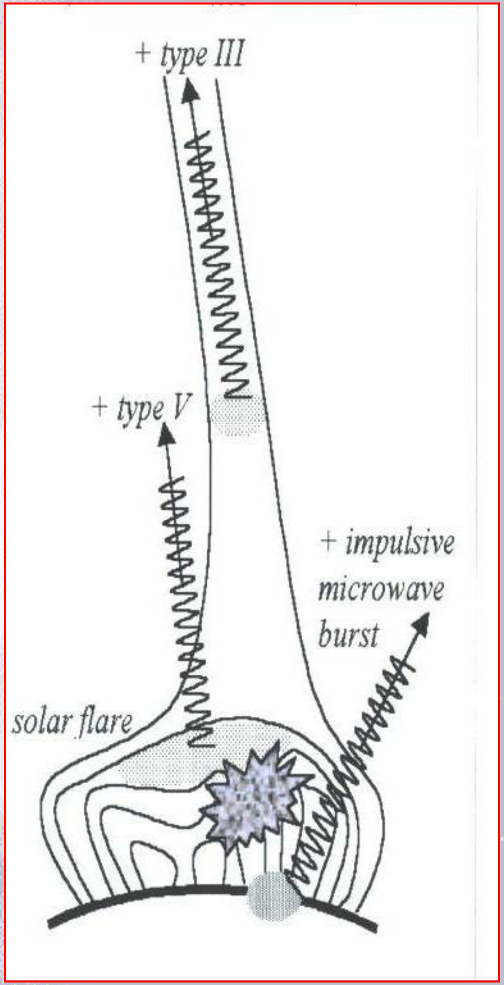
Castelli-U Spectral Burst

Type III Sweeps



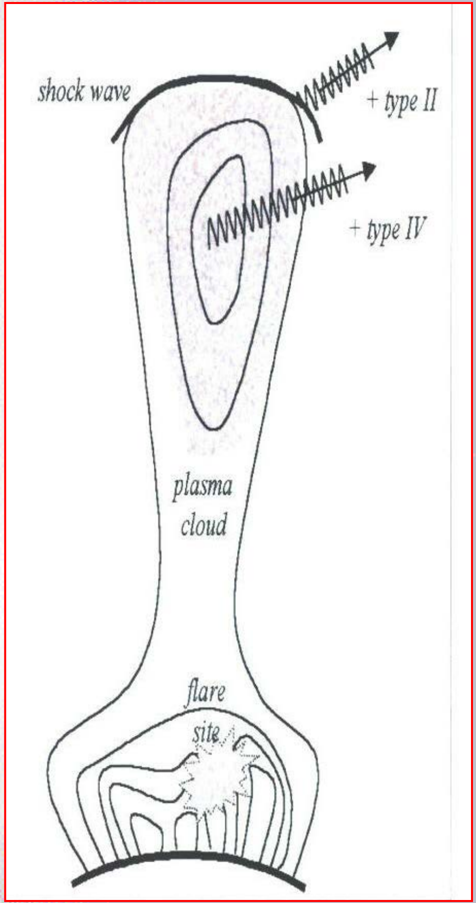
- Type III Sweeps
  - **Produced by packets of electrons ejected by a flare into the corona along open field lines**
  - ***Occurs at about 300 MHz drifting to 3 MHz***
  - **Last about 5 seconds.**
  - ***Tend to occur in groups that may persist for several minutes.***

Type V Sweeps



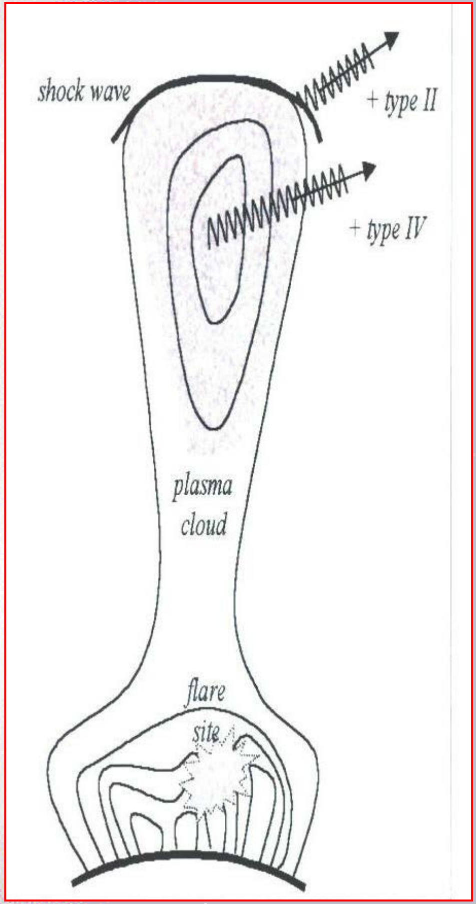
- **Type V Sweeps**
  - **Produced by packets of electrons ejected by a flare into coronal magnetic field loops which temporarily trap the electrons**
  - ***A Type V follows a Type III about 10% of the time.***
  - **Generally occurs between 5 MHz and 150 MHz that lasts for several minutes.**

Type II Sweeps



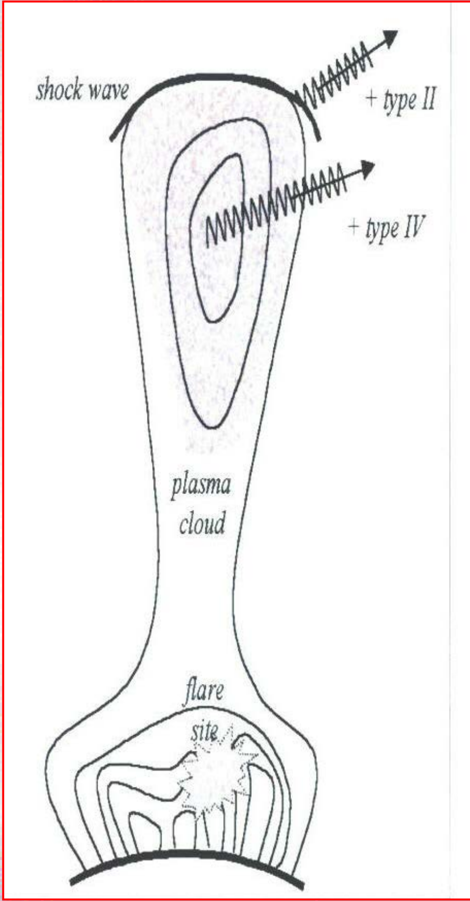
- **Type II Sweeps**
  - **After a large solar flare produces Type III and V sweeps, it may eject a large cloud of plasma that moves outward through the corona.**
  - ***This cloud differs from the material that causes the Type III and Type V sweeps in that a plasma cloud is denser, slower and carries its own magnetic field.***
  - **The cloud moves through the corona at 400 to 3000 km/s which causes a shock wave to form ahead of the plasma cloud.**

Type II Sweeps



- **Type II Sweeps *(cont'd)***
  - **The plasma waves, which result from the plasma cloud shock wave, generate radiowaves starting at roughly 300 MHz and drifting to 3 MHz over time.**
  - ***A Type II lasts roughly 5 to 20 minutes.***
  - **Only the largest flares are energetic enough to eject a cloud of plasma.**
  - ***Only 1% of importance 1 flares produce Type II sweeps.***
  - **30% of flares with importance 3 produce Type II sweeps.**

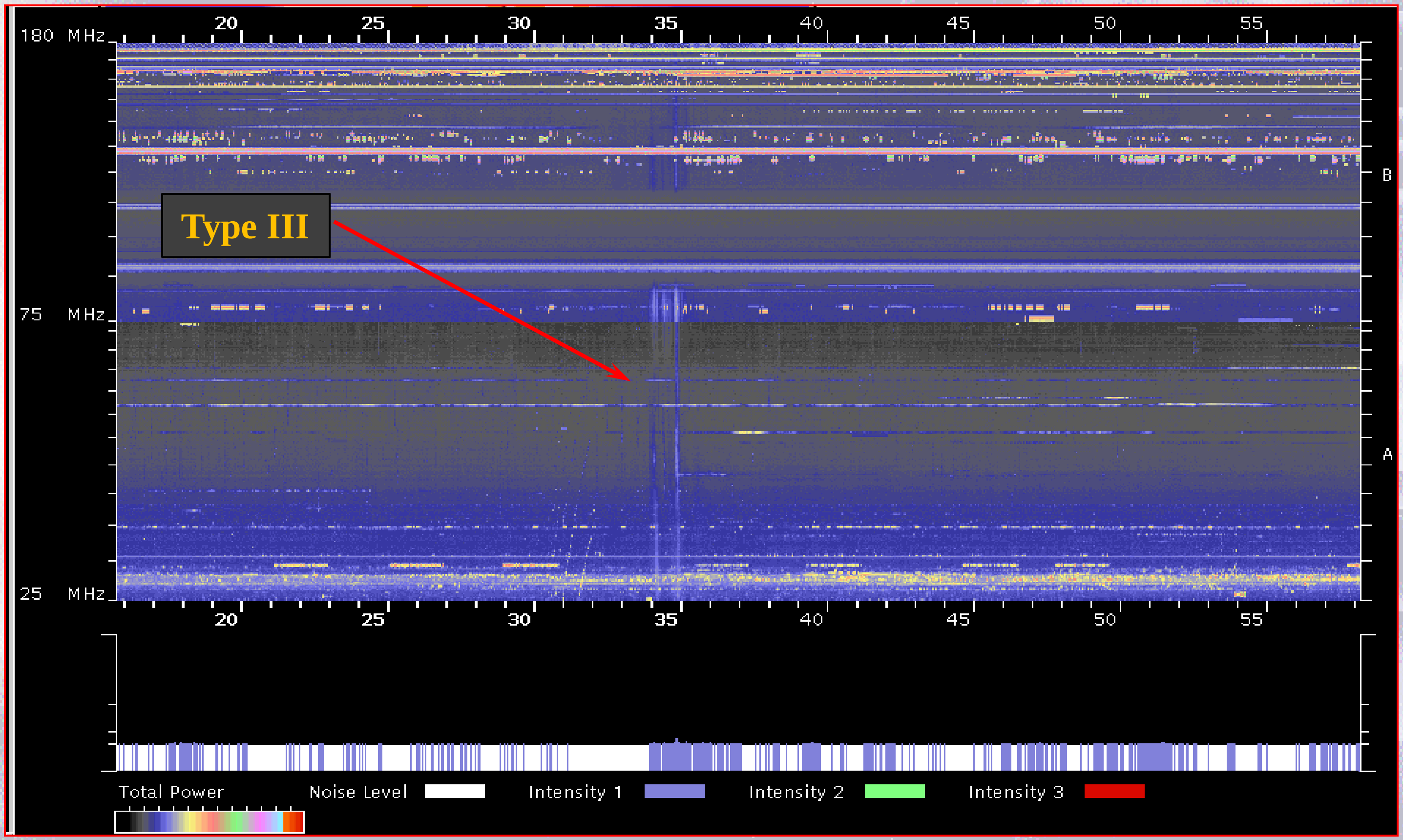
Type IV Sweeps



- **Type IV Sweeps**
  - **Often occur simultaneously with Type II sweeps.**
  - ***A Type IV is emitted from within the plasma cloud.***
  - **The plasma cloud emits all radio frequencies at once, but as the cloud moves outward, the density of the corona determines which frequencies escape.**
  - ***Type IV sweeps can last anywhere from 10 minutes to many hours.***

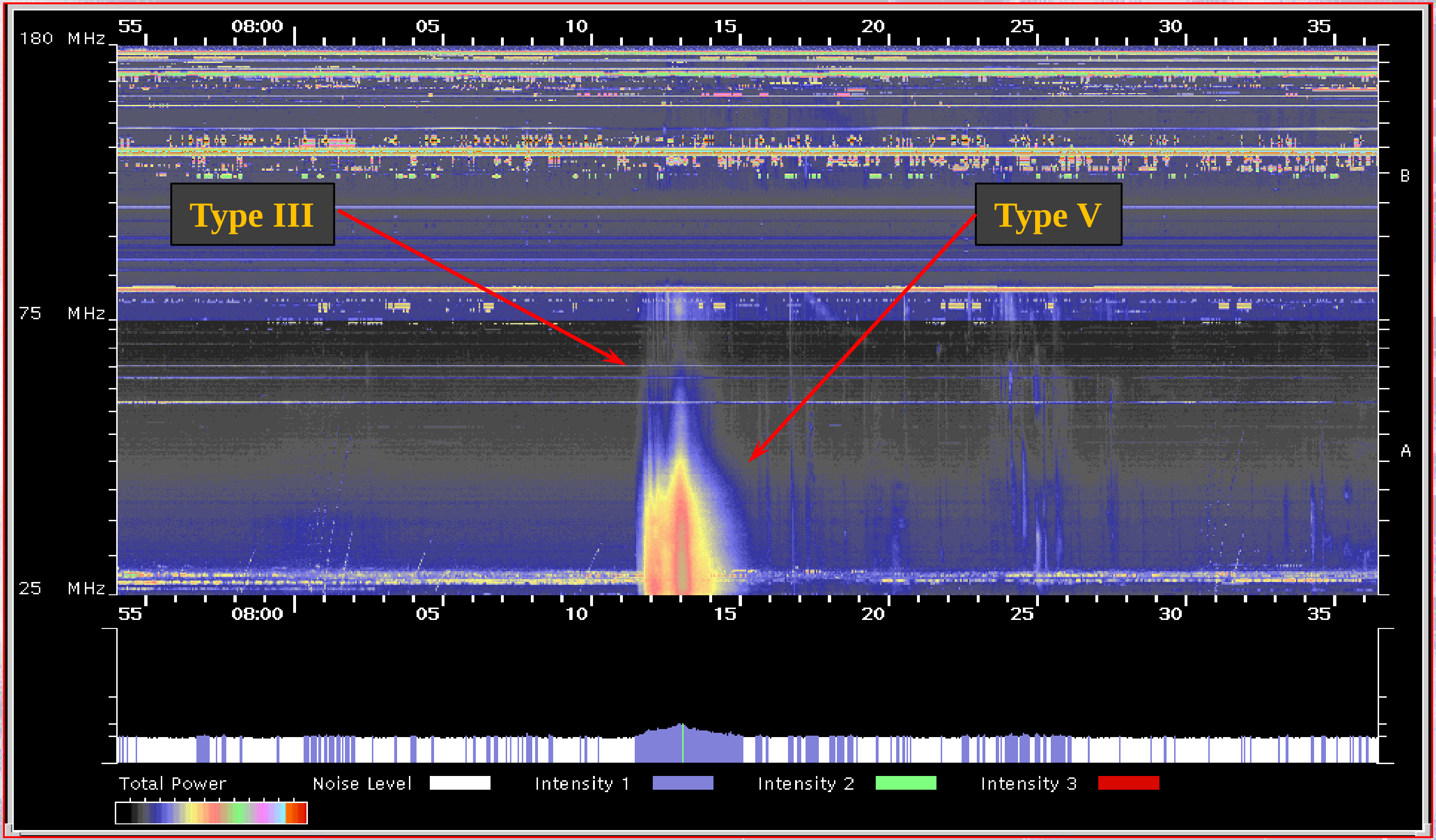
SRS Imagery *(Type III)*

Type III sweeps have uniform start and end times across their frequency range. They often occur in groups and frequently precede other sweeps (Types II, IV, and Vs). They are generally less than a minute in duration.



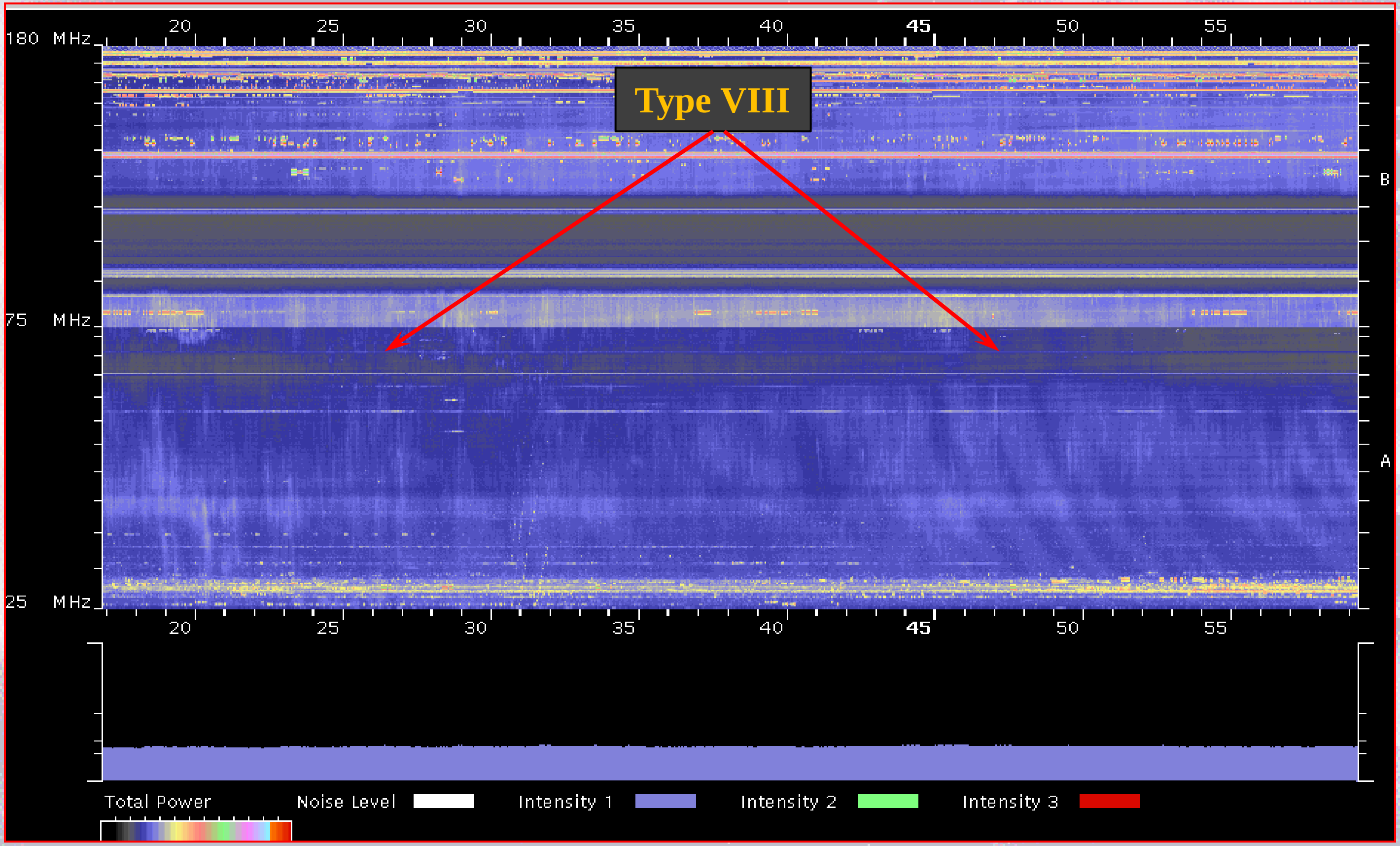
SRS Imagery *(Type V)*

Type V sweeps generally have uniform start times but exhibit a continuum "tail" at the lower frequencies. Type V sweeps generally last 1-3 minutes and usually follow a Type III sweep. They also frequently precede Type II / Type IV sweeps.



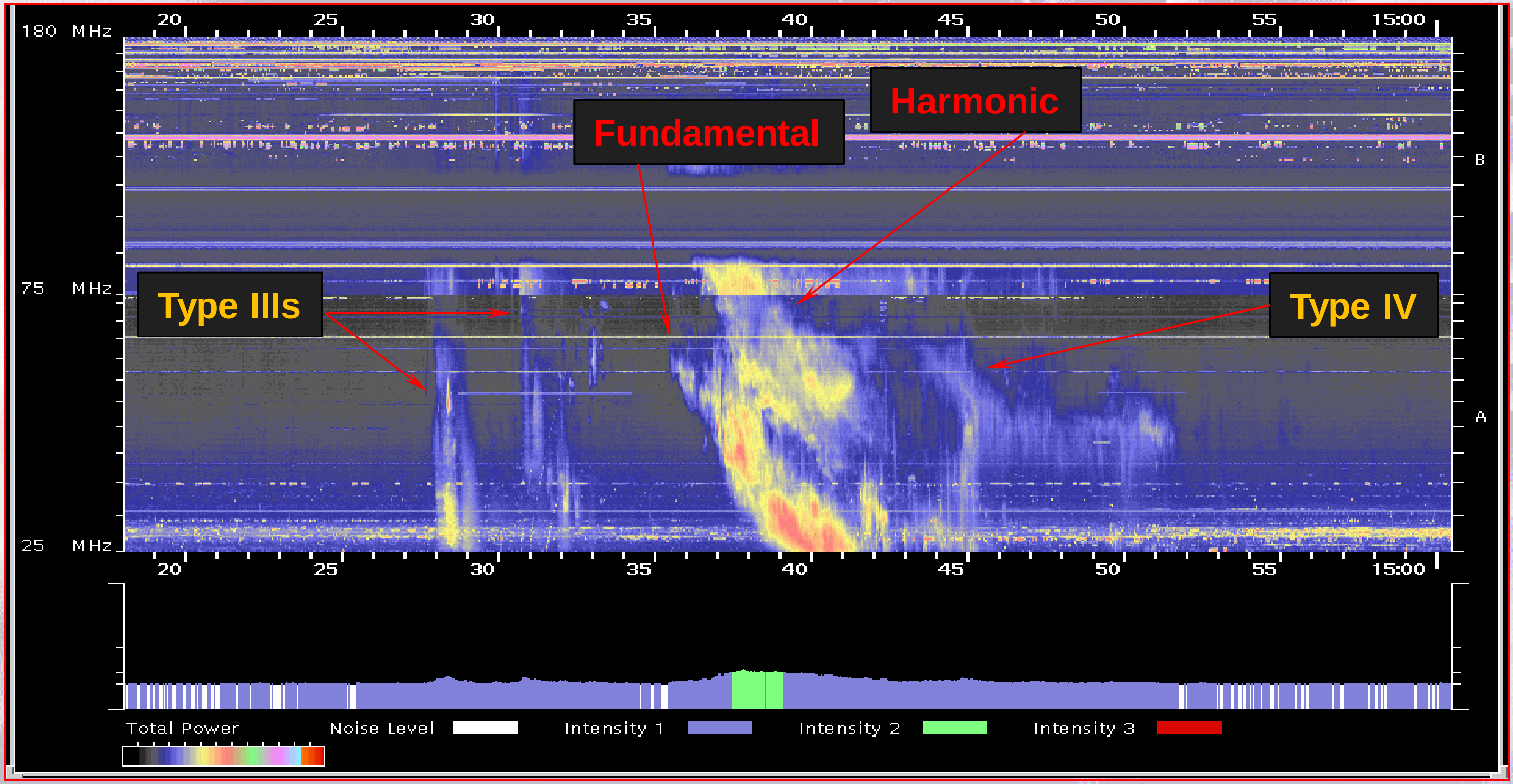
SRS Imagery *(Type VIII)*

A Type VIII Continuum is a broadband continuous emission lasting from minutes to days with a slight drift in frequency over time.



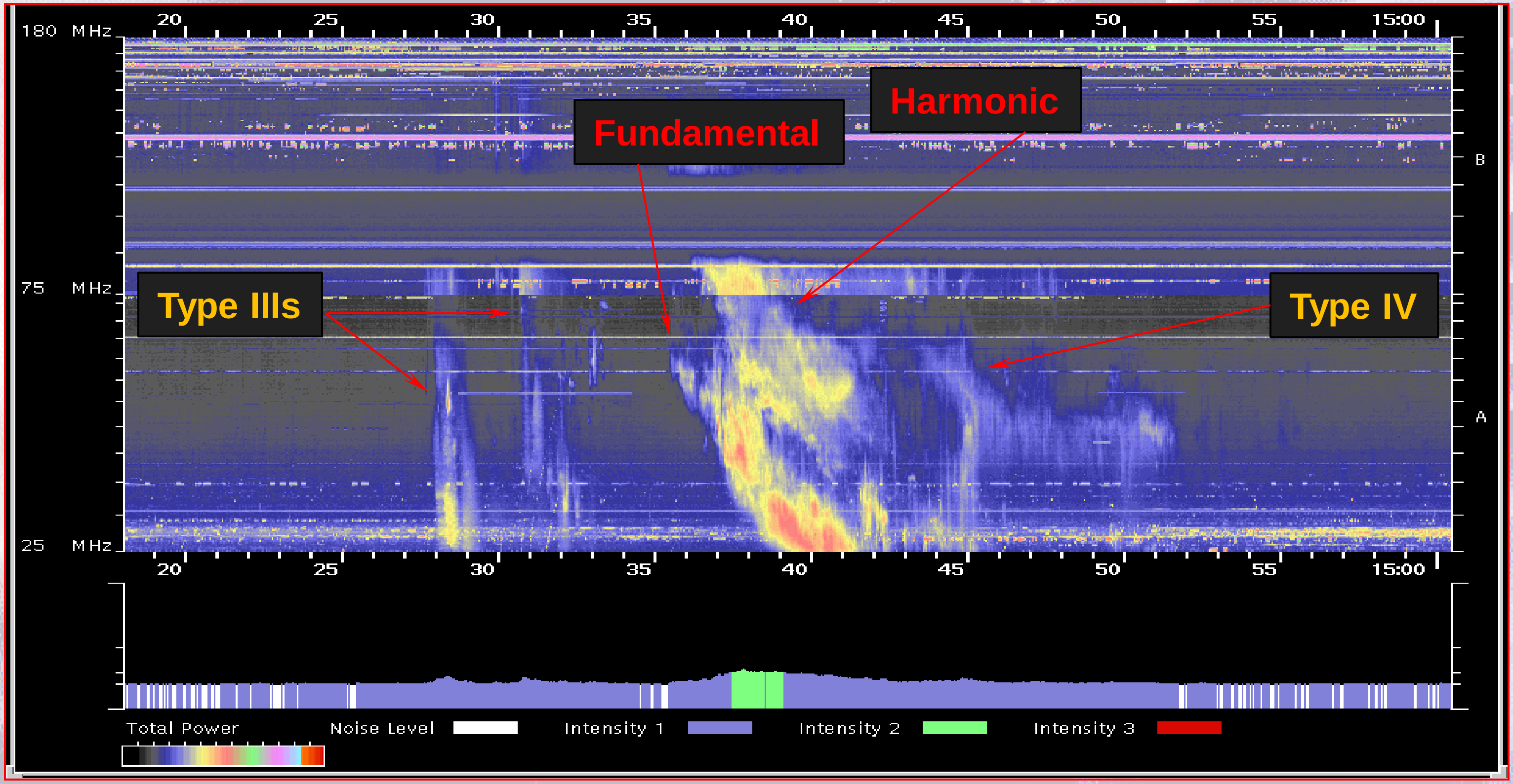
SRS Imagery *(Type II)*

- *Type II's drift from higher to lower frequencies over time. Roughly half of Type II sweeps are observed to have a second shock (harmonic).*
- *The shockwave produces radio energy emission at the primary (fundamental) frequency and at roughly twice that frequency (harmonic).*



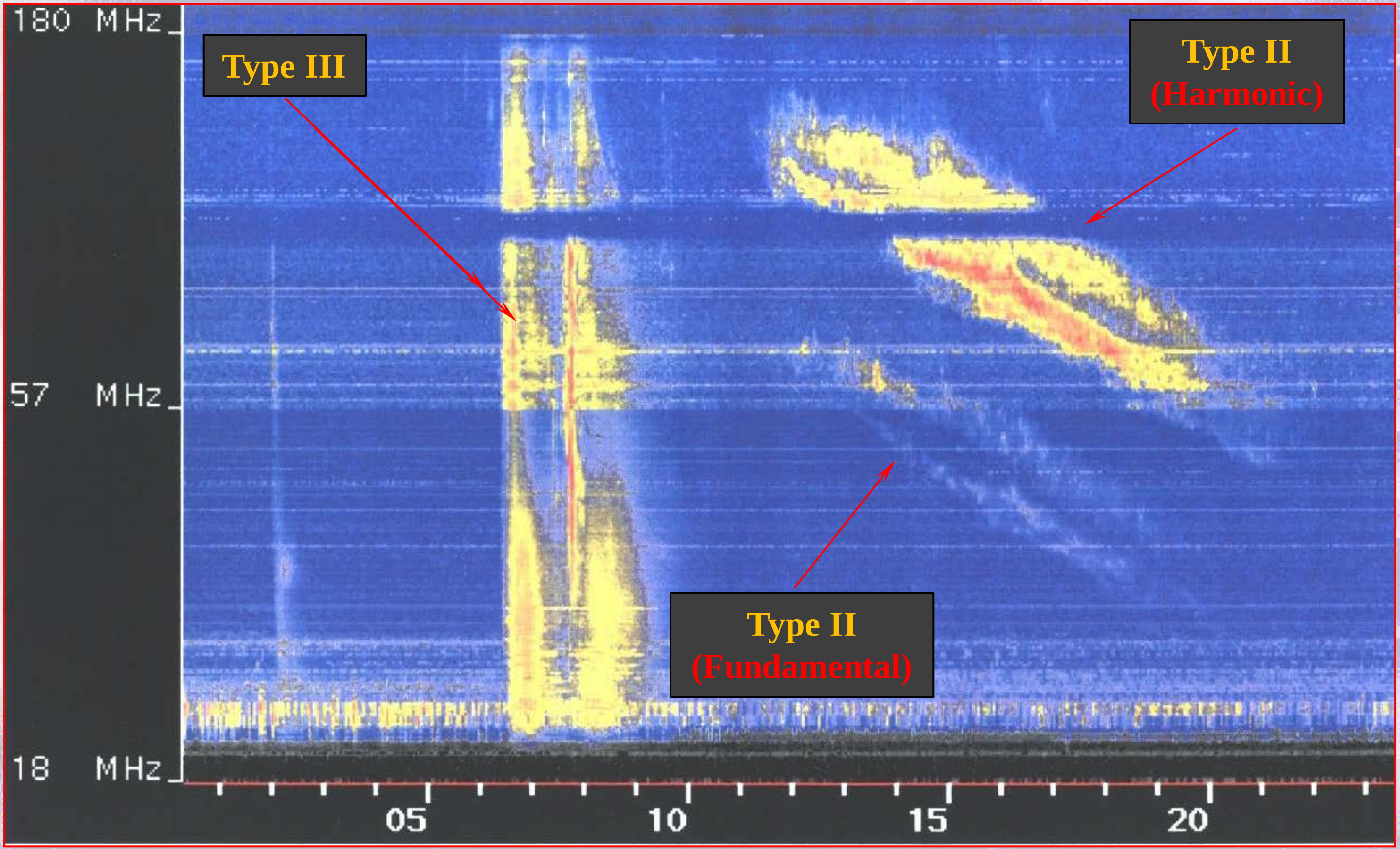
SRS Imagery *(Type II)*

- *Since the plasma region where the flare occurs is permeated by the magnetic field of the sunspot group, a magnetic splitting analogous to the Zeeman Effect may be responsible for the observed band splitting (Fundamental and Harmonic).*
- *Shock speed is measured on the leading edge of the Sweep.*



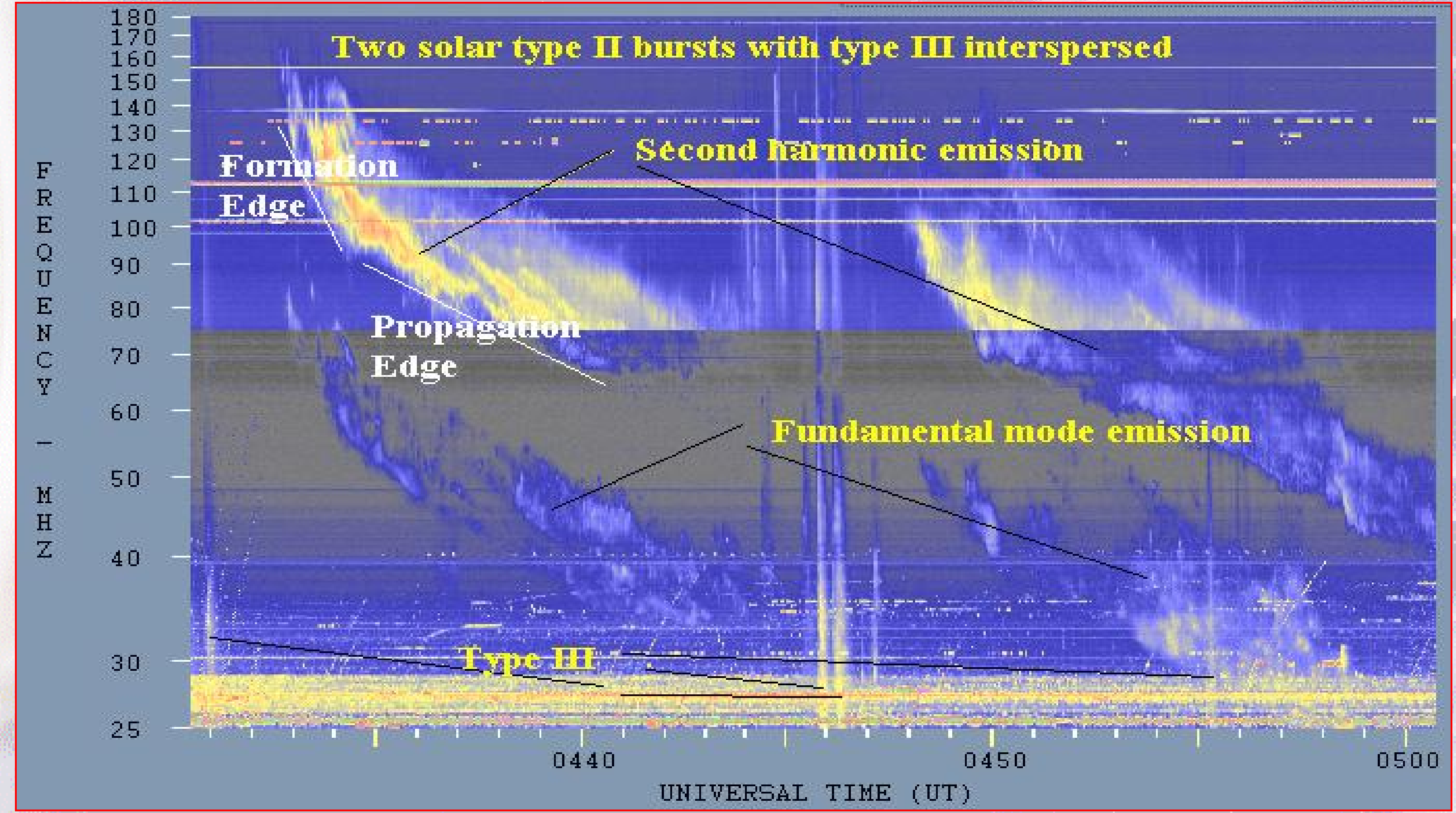
SRS Imagery *(Type II and Type III)*

A series of Type III (fast drift) solar radio bursts followed by a Type II (slow drift) burst. RFI is visible preceding the first Type III.



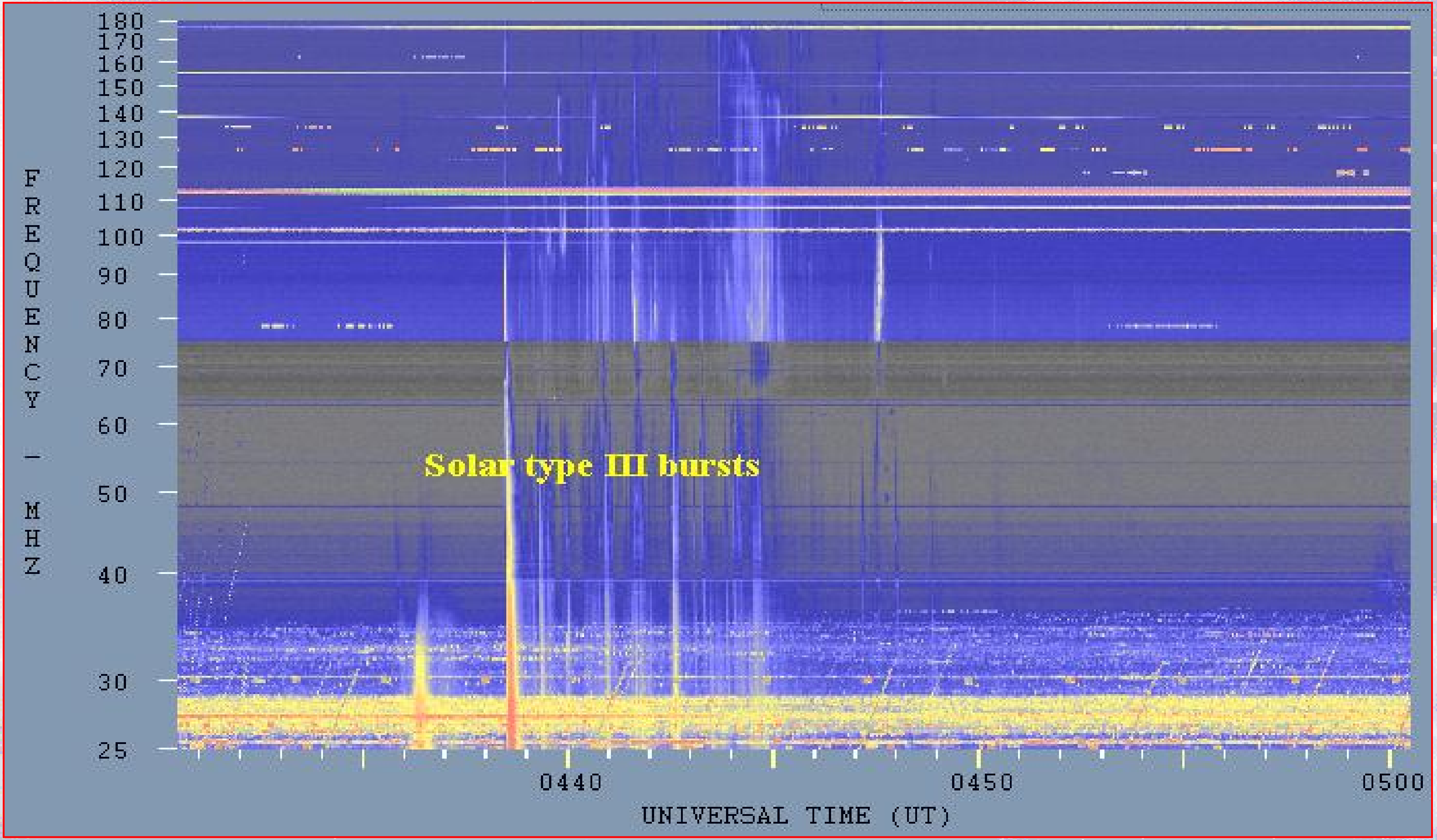
SRS Imagery *(Type II and Type III)*

Two Type II (slow drift) solar radio bursts with a Type III interspersed. It is very rare to see two sequential intense Type II's.



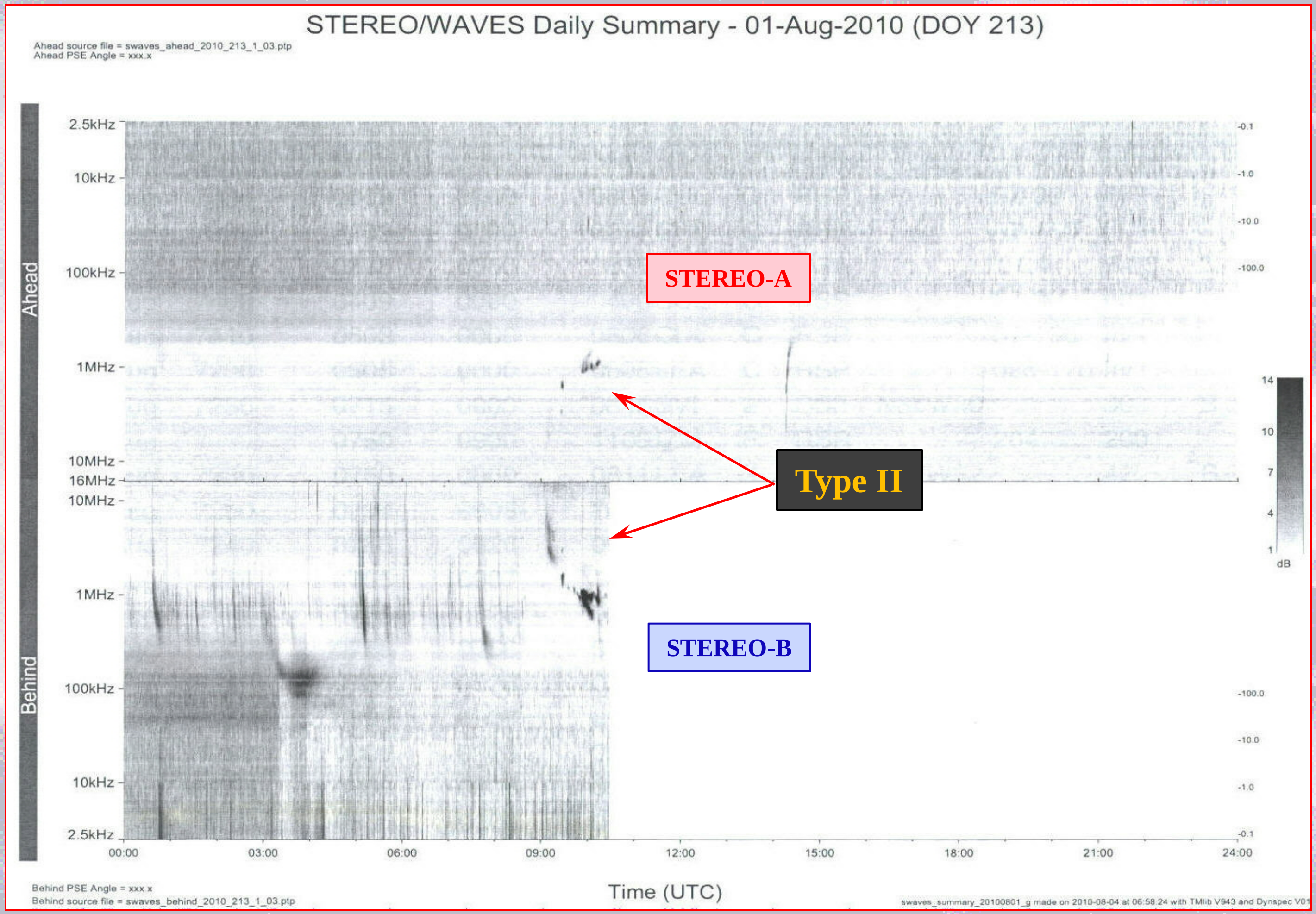
SRS Imagery *(Type III)*

A series of Type III (fast drift) solar radio bursts. These are the most common type of radio signal produced by the Sun.



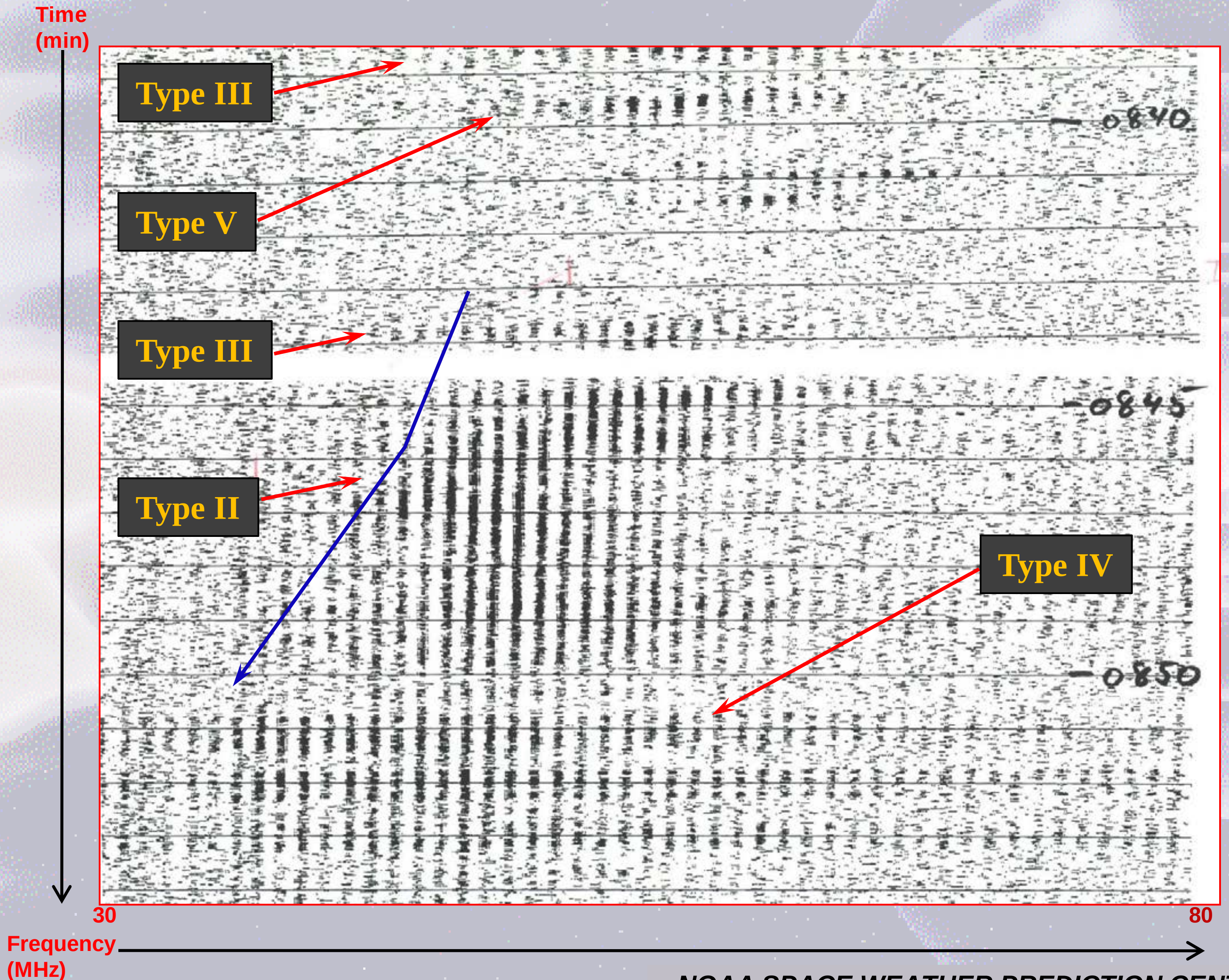
STEREO/WAVES Type II

Type II burst seen in STEREO-A and STEREO-B



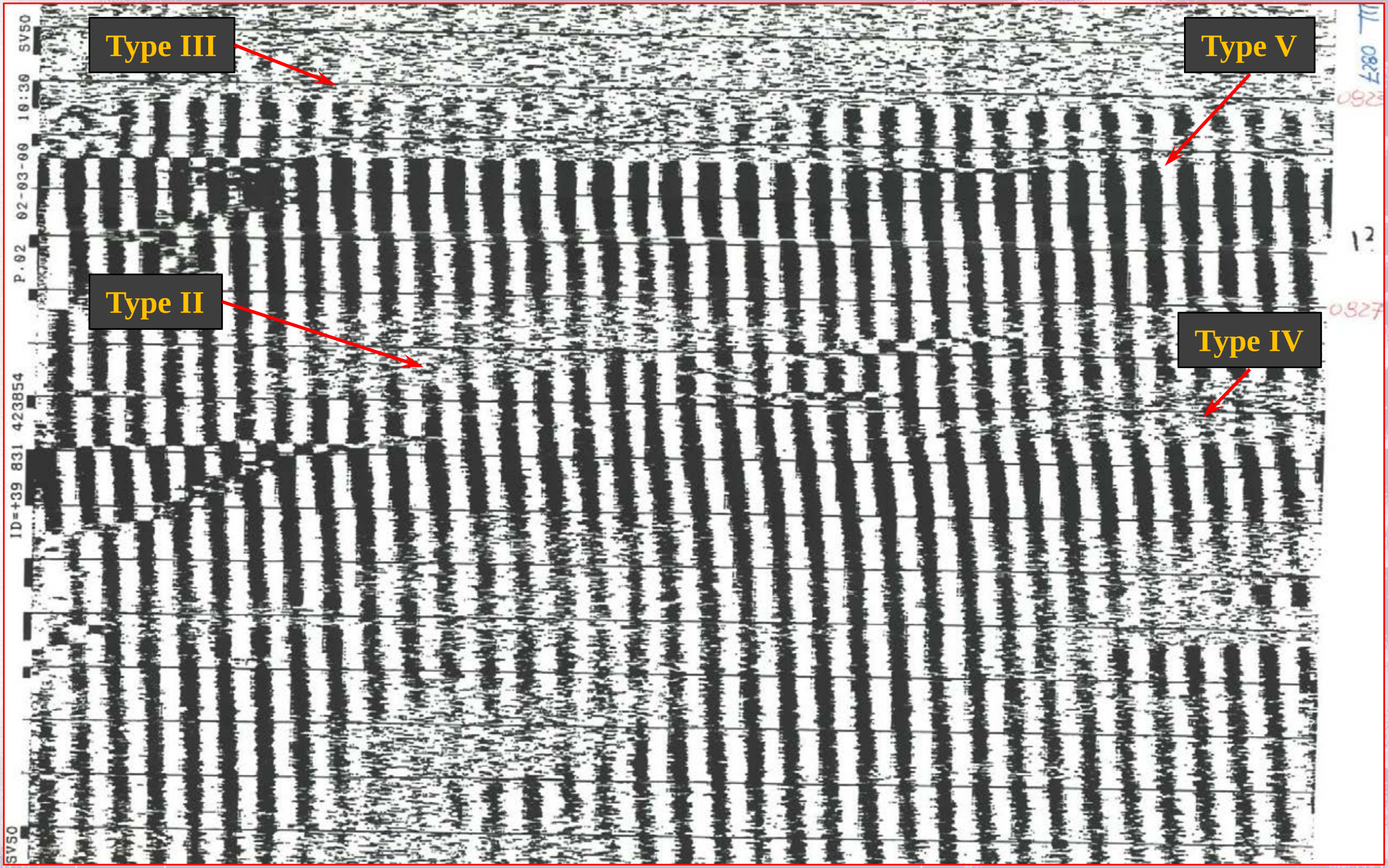
SFIR *(Types II, III, IV and V)*

Type II bursts drift from higher to lower frequencies over time. Shock speed is measured on the leading edge of the Sweep.



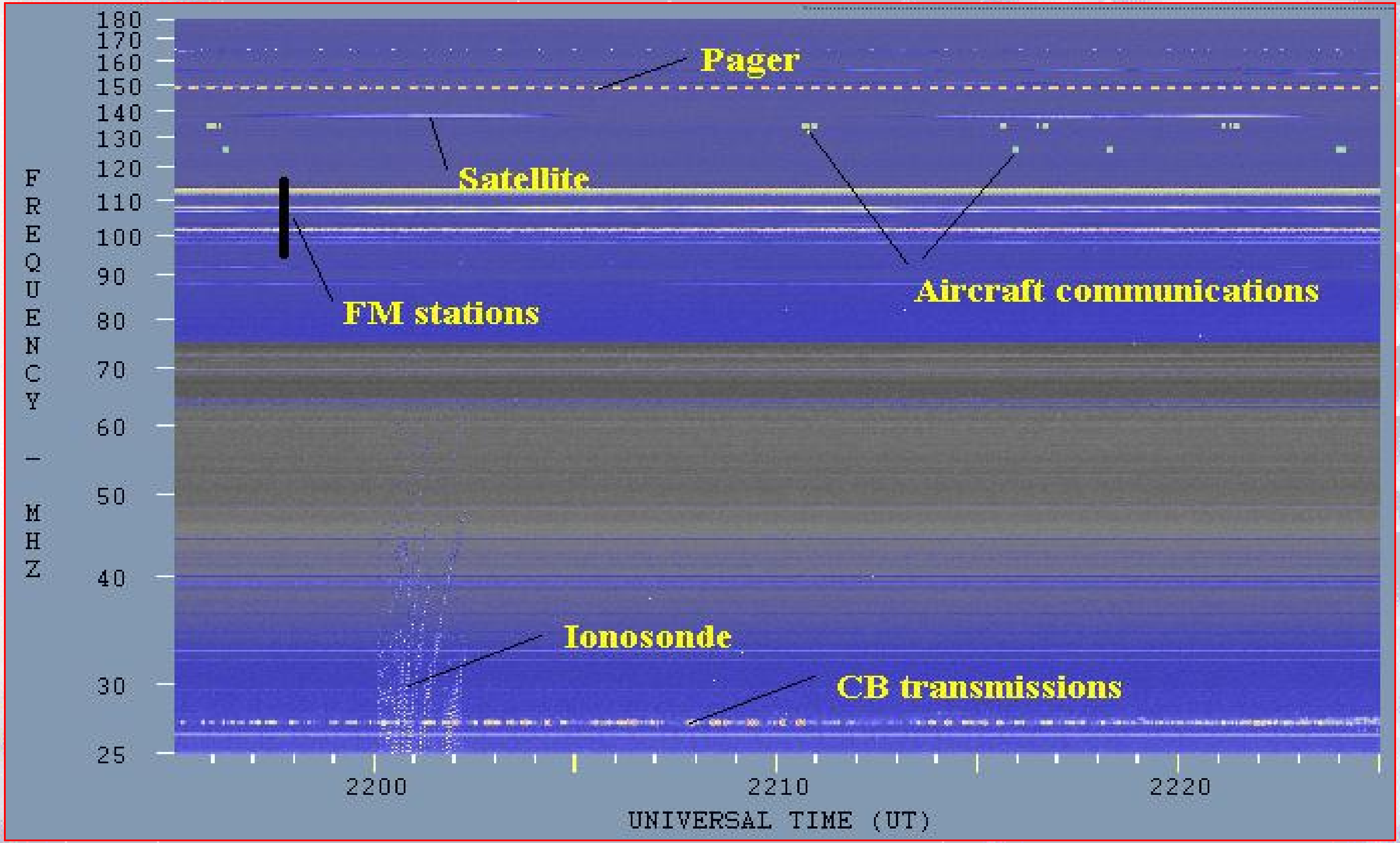
SFIR *(Types II, III, IV and V)*

Type II bursts drift from higher to lower frequencies over time. Shock speed is measured on the leading edge of the Sweep.



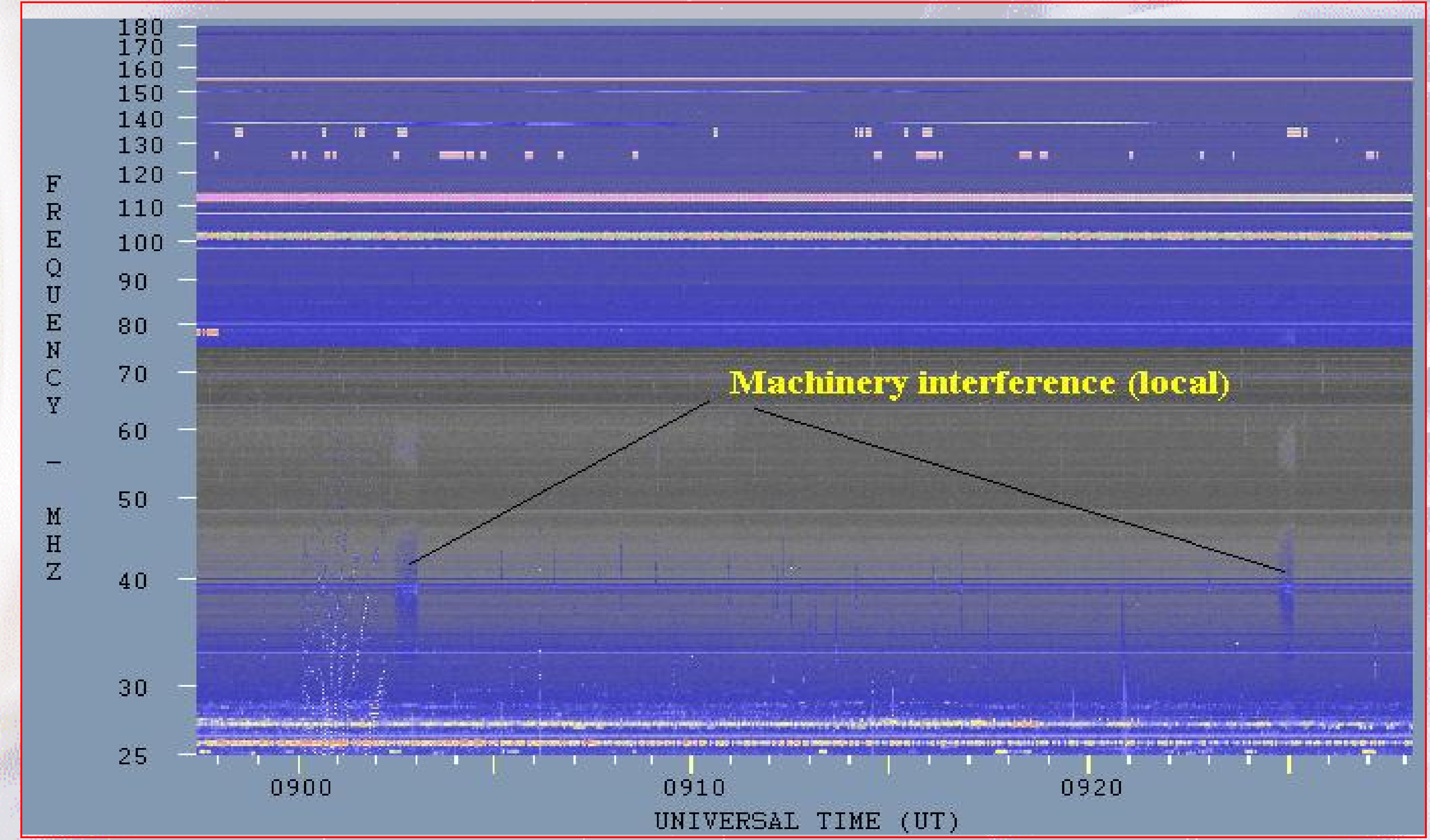
SRS Imagery *(RFI)*

Typical <u>non-solar</u> signals that might be seen



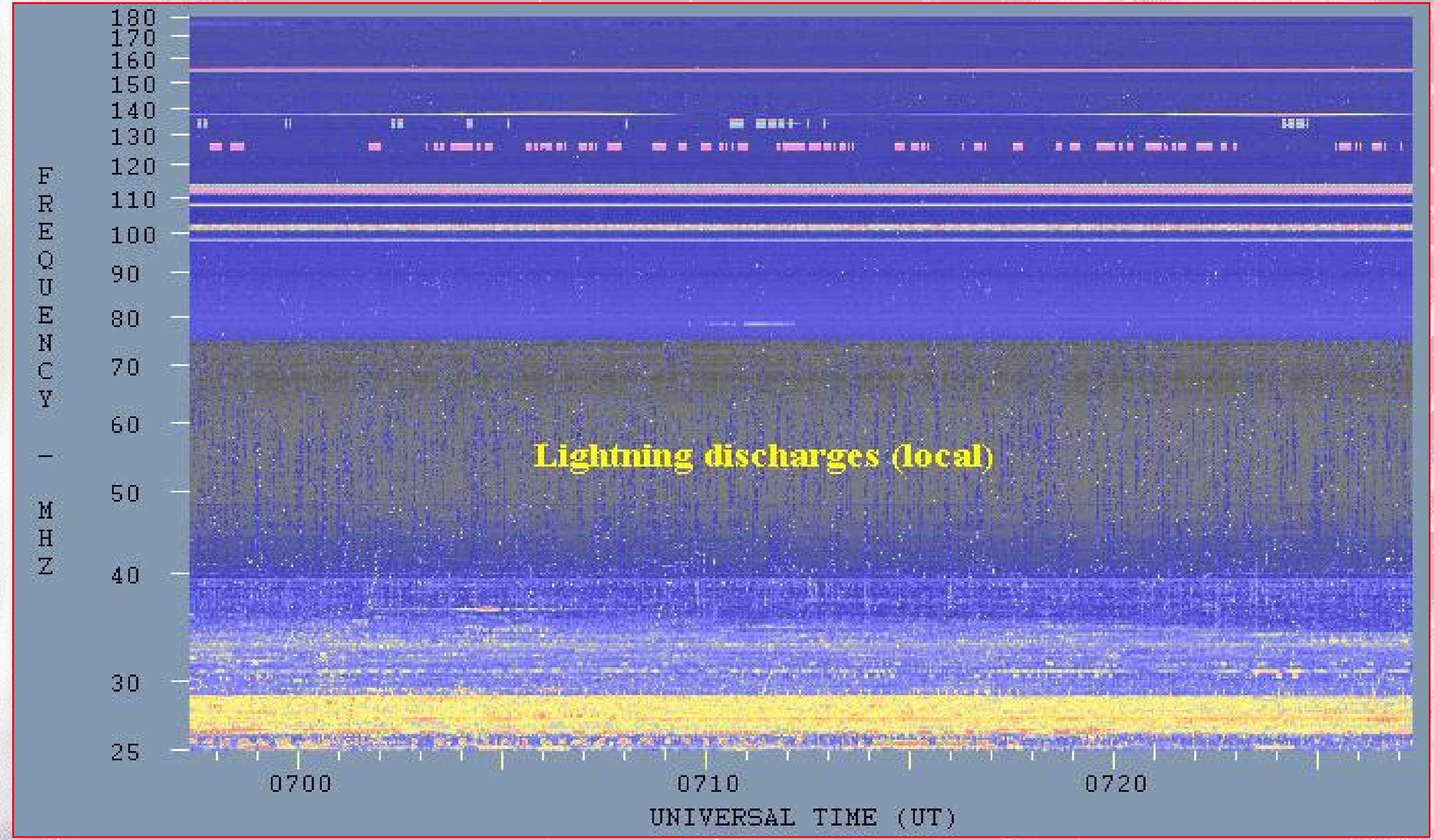
SRS Imagery *(RFI)*

This type of signal is local interference



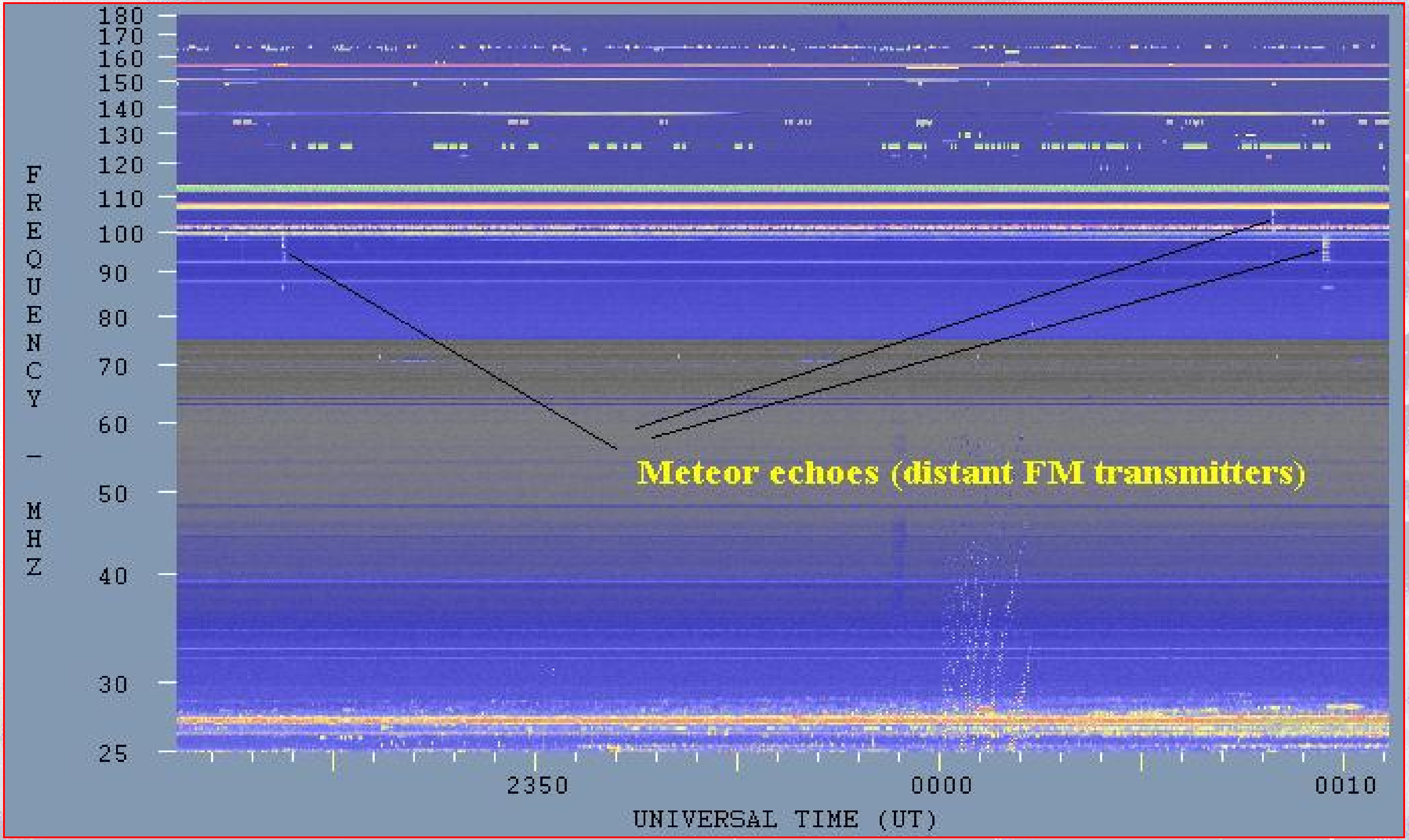
SRS Imagery *(RFI)*

Electrical storms may occur in summer and afternoon hours



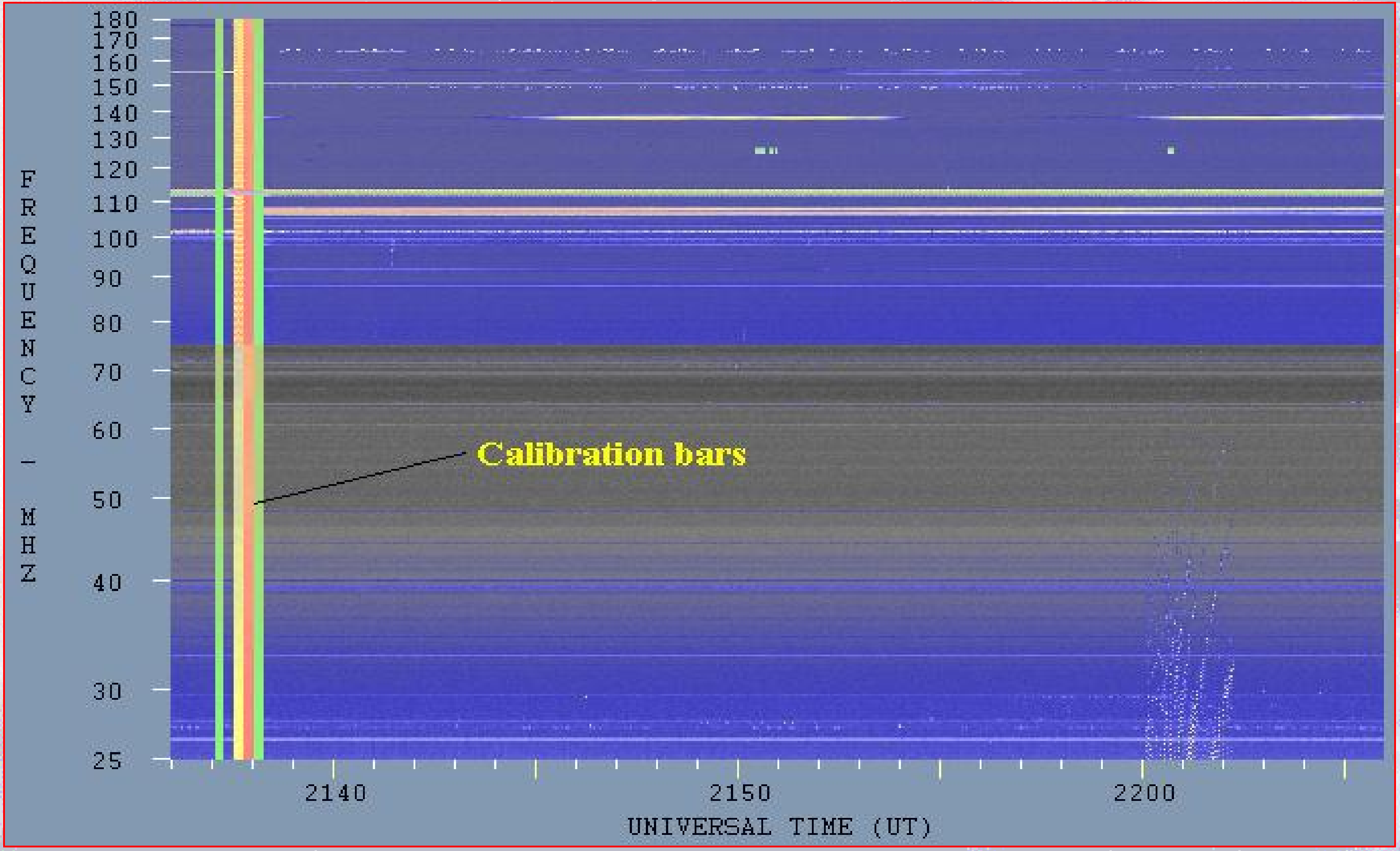
SRS Imagery *(RFI)*

Meteors are seen as echoes from distant transmitters, often in the FM band. They may appear as dots, or short vertical lines, if several transmitters are involved.



SRS Imagery *(RFI)*

Each day, a minute after startup, the SRS system automatically performs a self calibration, which is seen as a sequence of vertical bars.



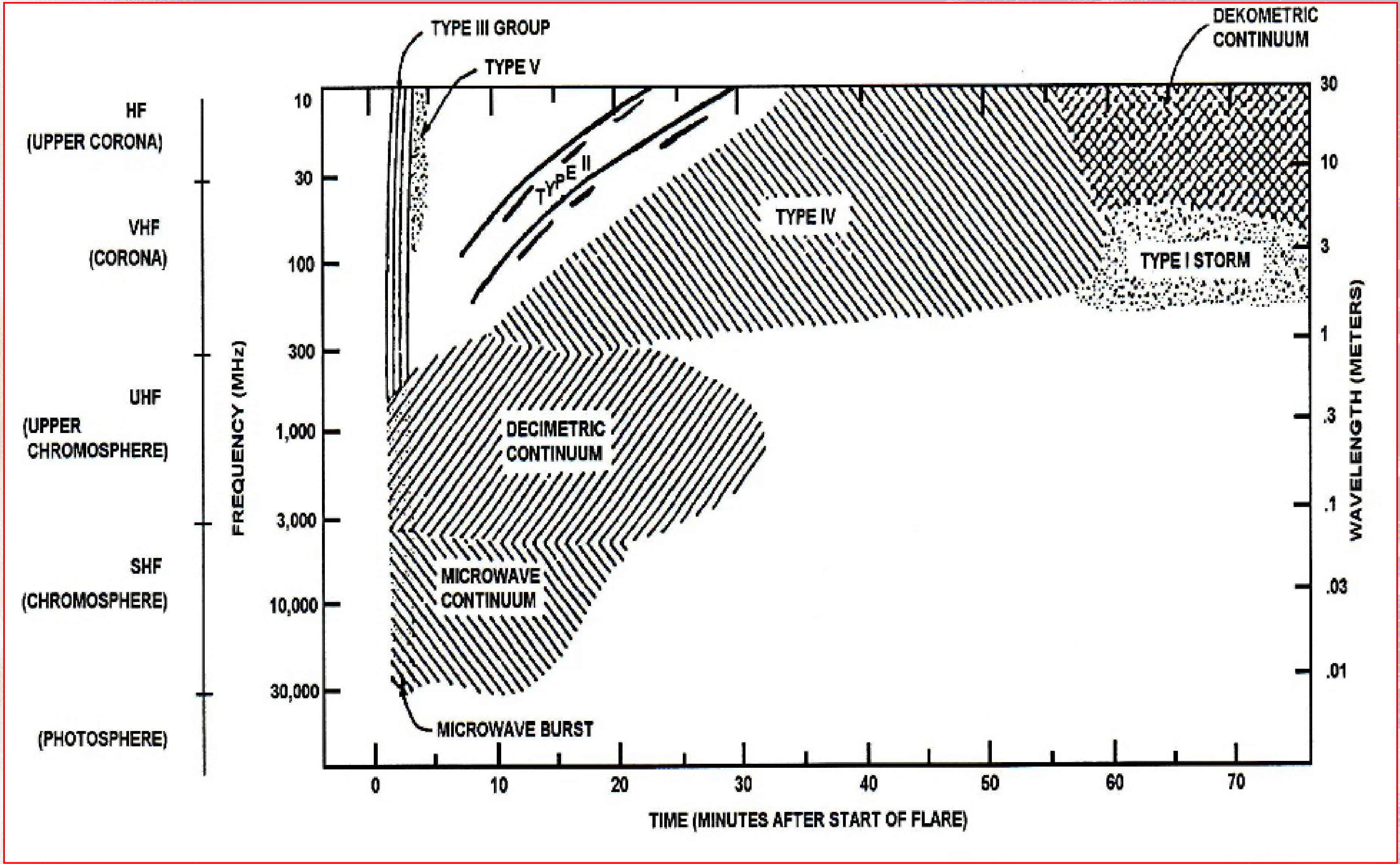
Rules of Thumb

- **Bursts**
  - – **Large Bursts rarely occur on a single discrete frequency**
  - – ***Duration of Bursts are generally > 5 minutes***
  - – **Verify Bursts with more than one observatory**
  - – ***RFI affects lower frequencies (245 – 610 MHz)***
  - – **Weather affects higher frequencies (8800 – 15400 MHz)**

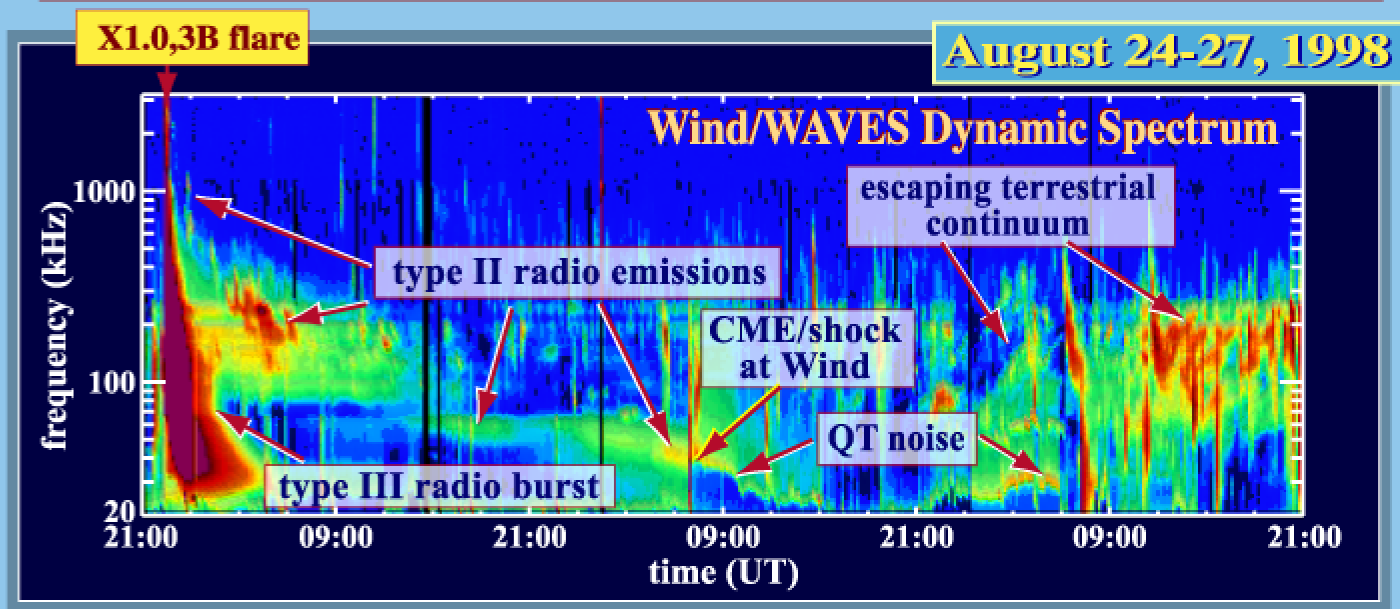
Rules of Thumb

- **Sweeps**
  - **Verify Type II Sweeps with more than one site**
  - ***Not all Type IV Sweeps are preceded by a Type II, nor or all Type II Sweeps followed by a Type IV. However, there is a close correlation between the two.***
  - **Type IV Sweeps are long-lasting**
    - **As sites come online, they may start a new Type IV**
    - **Unless there is a new major event, it's the same Type IV**
  - ***Don't rush sending Type II & IV Alerts***
    - ***Wait for final and then make sure it's not cancelled***
  - **Sweep intensity is subject to many factors**
    - **Depends on local equipment performance & observing conditions**

Typical Spectrum from a Large Flare



Radio Signatures of a Solar-Terrestrial Event

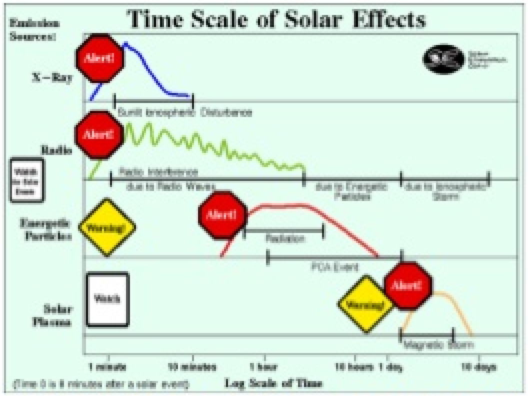


Solar - Terrestrial Radio Paradigm

Physical Process:	Flare/ CME →	Coronal shock (CME, Flare) →	Interplanetary shock (CME) →	Shock arrival at Earth (1AU) →	Magnetospheric response
	↓	↓	↓	↓	↓
Radio Signature:	Complex type III	Coronal type II	Interplanetary type II	Quasi-Thermal (QT) noise	Escaping continuum, AKR

Summarizing Response Time and Effects

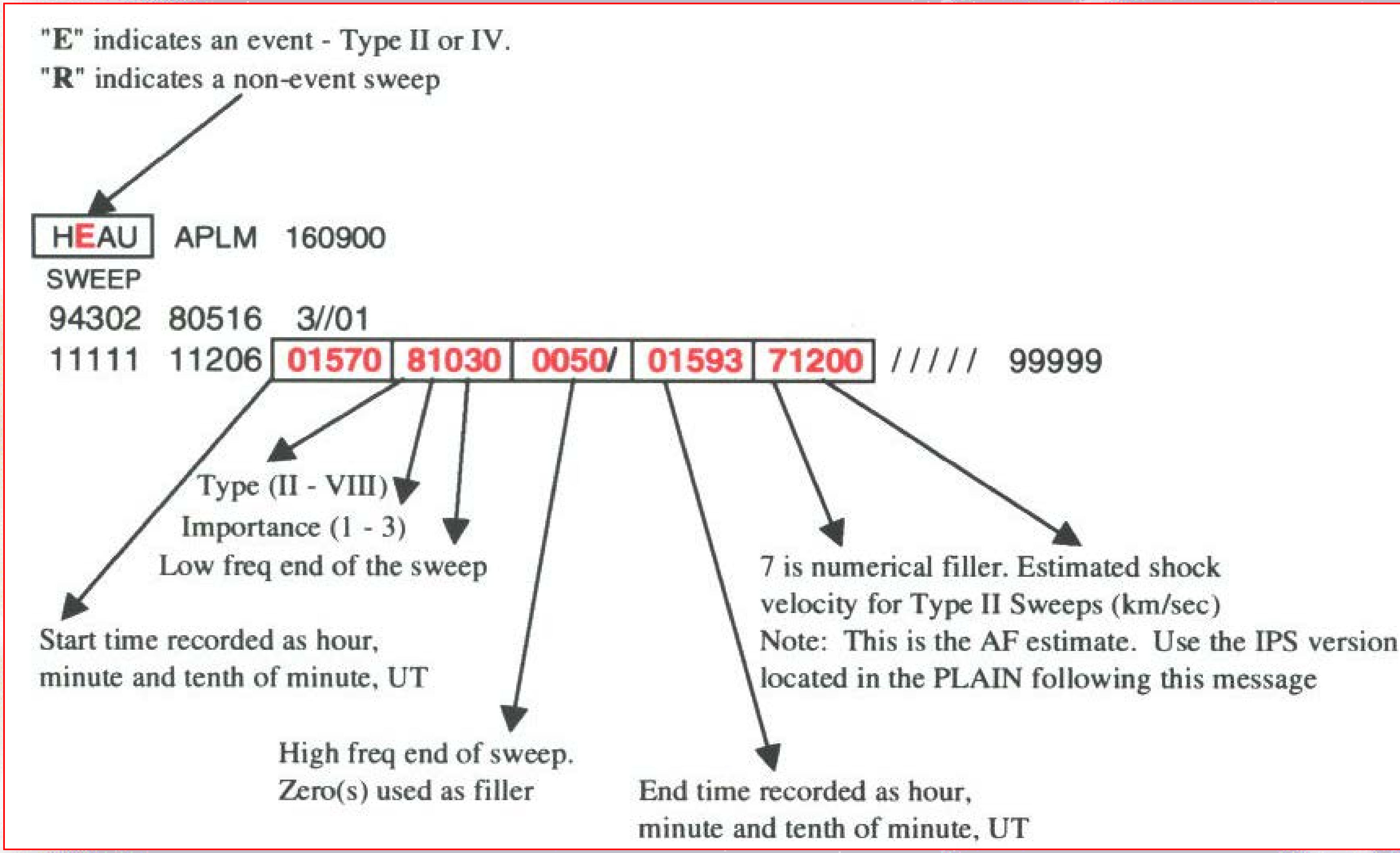
- **Solar Radiation** (X-rays, Radio, EUV)
  - Arrives in 8 minutes
  - Duration: 1-2 days
  - Satellite communications interference
  - Radar interference
  - HF radio blackout
  - Geolocation errors
  - Satellite orbit decay
- **Energetic Particles**
  - Arrives 15 minutes
  - Duration: hours to days
  - High altitude radiation hazards
  - Spacecraft damage
  - Satellite disorientation
  - False sensor readings
  - Degraded HF communications



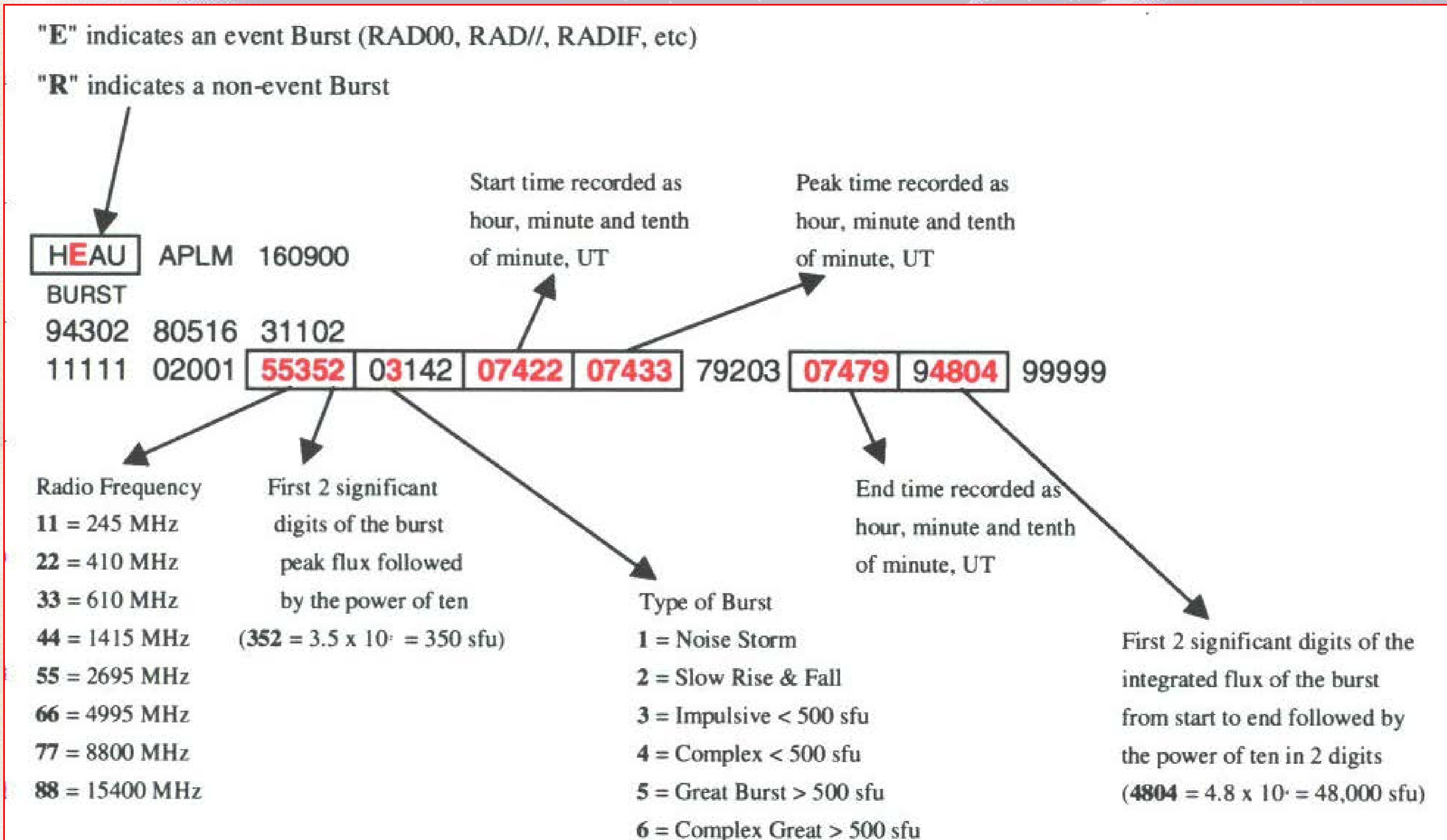
(Integrating Space Weather Observations & Forecasts into Aviation Operations)

- **Solar Plasma**
  - Arrives 1-3 days, duration days
  - Spacecraft charging and drag
  - Geolocation and tracking errors
  - Radar interference
  - Radio propagation anomalies
  - Power grid failures

Radio SWEEP Code



Radio BURST Code



The End

Thank You