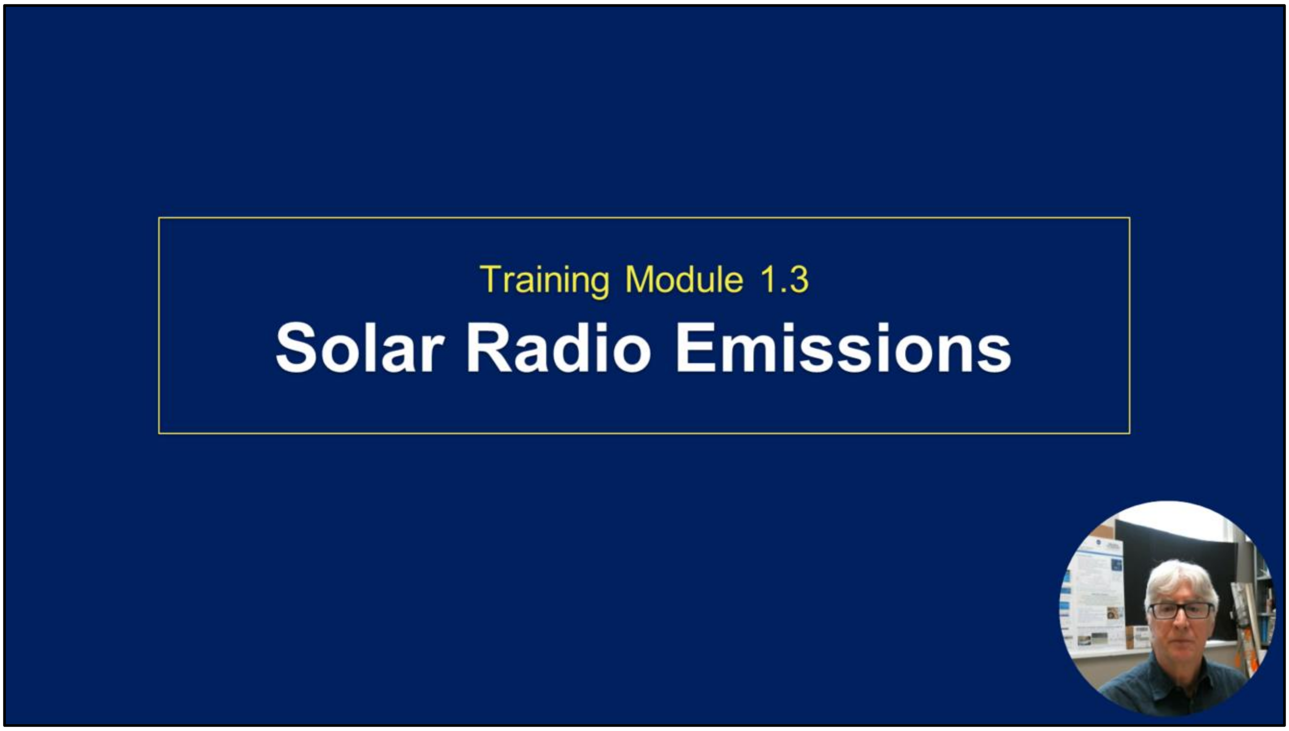
Welcome to The Radio JOVE Project Citizen Science Training Modules. I am Professor Chuck Higgins from Middle Tennessee State University and one of the leaders of The Radio JOVE Project.

These training modules are a partnership between the SunRISE mission team and The Radio JOVE Project. We acknowledge contributors to these modules as well as our funding sources of support.

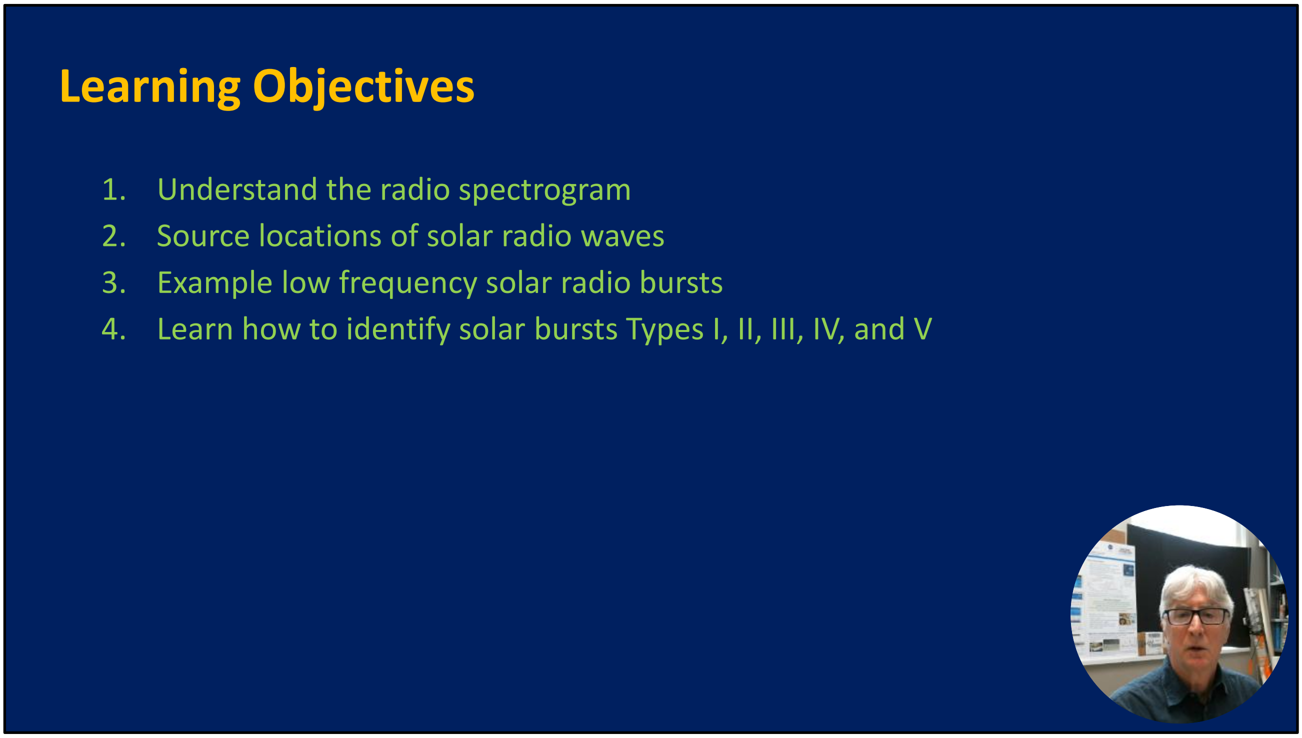


This is Training Module 1.3 – Solar Radio Emissions

Prerequisites for Training Modules

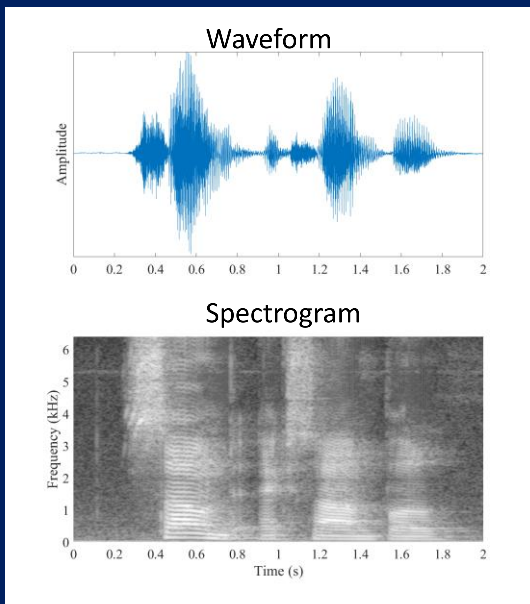
1. High School Reading Comprehension and General Science
2. Scientific Notation
3. Electromagnetic Spectrum
4. Speed, Wavelength, and Frequency of Waves
5. Graphical Interpretation of Data
6. Training Modules 1.0, 1.1, and 1.2

This is a list of prerequisites needed to be able to understand the material in this module.



This is a list of the learning objectives for this presentation. We first define and overview a radio spectrogram to help you understand how to interpret them. Then we give a brief summary of the radio emission source locations near the surface of the Sun, followed by a few examples of low frequency solar radio bursts. Finally, we define the five types of solar bursts and give examples to help you identify them.

What is a Spectrogram?



Waveform – An amplitude vs time graph showing the waveform of 2 seconds of the spoken words “sound example”.

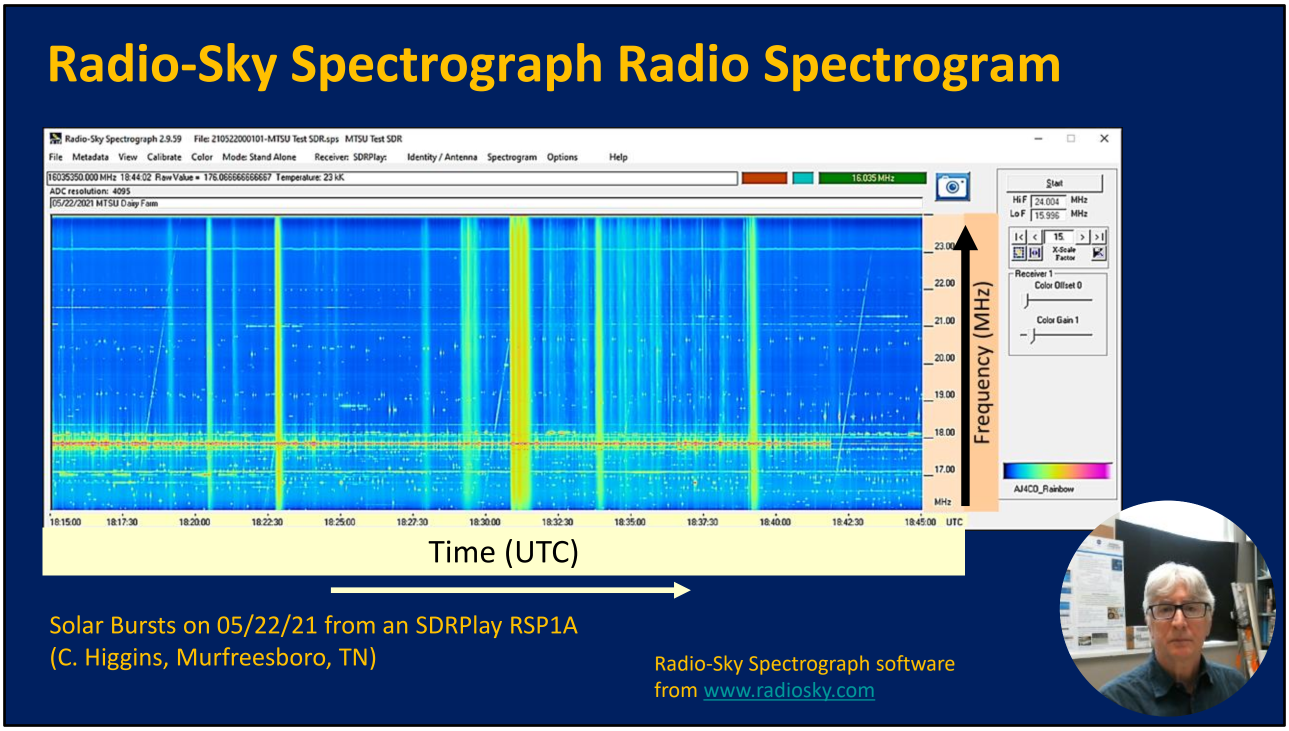
Spectrogram – A frequency vs time vs intensity graph, a spectrogram, of the same sounds. The amplitude of the sounds are given in grayscale. The louder sounds are depicted as white, quieter sounds in black.

https://wiki.aalto.fi/display/ITSP/Spectrogram+and+the+STFT

A waveform is an amplitude vs time graph of data, most often sound information; the top graph shows the waveform of 2 seconds of the spoken words “sound example”.

A spectrogram is a visual way of representing the signal strength, or “loudness”, of a signal over time at various frequencies present in a particular waveform. One can see where there is higher or lower energy at a particular frequency, and one also sees how energy levels vary over time. Spectrograms are commonly used to display frequency-time data.

In the example, a frequency vs time vs intensity graph of the spoken words “sound example” is given in the lower graph. The amplitude of the sounds are given in grayscale, and the louder sounds are depicted as white and quieter sounds in black.

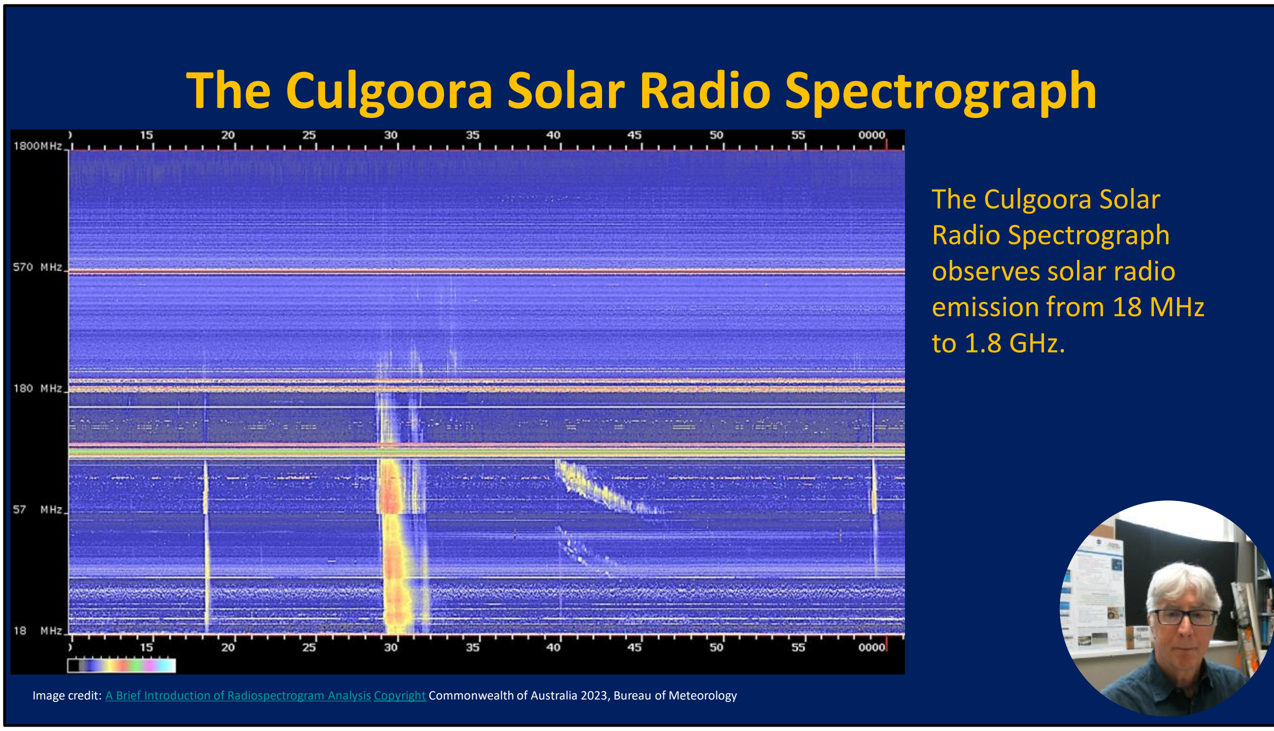


A radio spectrogram is typically three-dimensional graph of time, frequency, and intensity using a color scale.

Shown here is a Radio JOVE radio spectrogram of 30 minutes of radio astronomy data (18:15:00 to 18:45:00 UTC) over a bandwidth of 16-24 MHz. Time increases from left to right, frequency increases from bottom to top, and the intensity is represented by a rainbow color scale where black is zero and white is the maximum signal.

The near vertical bands of green, yellow, and red signals are solar radio bursts of varying intensity. The horizontal bands represent local interference or nearby or distant radio transmissions, typically narrowband emissions. The thin, slanting signals are radar signals that sweep through the frequency band sounding the ionosphere.

The Radio-Sky Spectrogram program used by Radio JOVE is freeware from Radio-Sky Publishing (https://www.radiosky.com/)

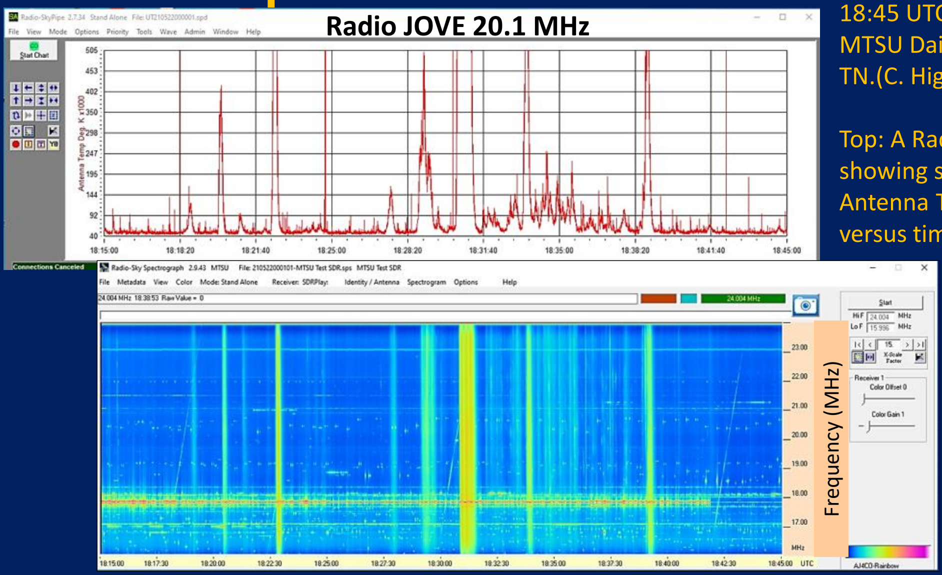


This is another example of a radio spectrogram, one from the Culgoora Solar Radio Observatory in Australia. They observe the radio emission of the Sun from 18MHz to 1.8GHz to show how solar flares can radiate energy over a very broad frequency range. Again, frequency increases from bottom to top, the time increases from left to right, and the amplitude is represented by a color palette. This image shows several different types of solar radio bursts.

Image credit: A Brief Introduction of Radiospectrogram Analysis Copyright Commonwealth of Australia 2023, Bureau of Meteorology

Australian Space Weather Alert System https://www.sws.bom.gov.au/Solar/2/2

Radio Stripchart



Radio-Skypipe (top) and Radio-Sky Spectrograph (bottom) software from Radio-Sky Publishing

Solar Bursts recorded from 18:15-18:45 UTC on 21 May 2021 at the MTSU Dairy Farm, Murfreesboro, TN.(C. Higgins).

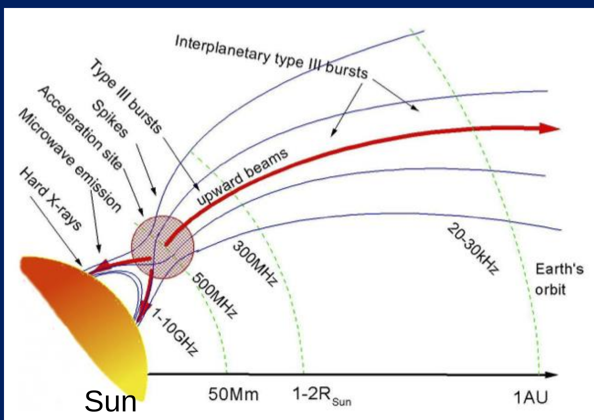
Top: A Radio Stripchart at 20.1 MHz showing signal strength displayed as Antenna Temperature (kiloKelvin) versus time.

Bottom: Same observation using multi-frequency radio at 16-24 MHz.

Radio astronomy data is often displayed as a radio stripchart, a two-dimensional graph of time and intensity at a particular frequency or frequency channel, Shown here is a graph of antenna temperature (a measure of signal strength) versus time. These graphs shows 30 minutes of data (18:15:00 to 18:45:00 UTC) from a Radio JOVE RJ1.1 receiver at 20.1 MHz (top) and from an SDRPlay RSP1A radio over a 16-24 MHz bandwidth (bottom). The graphs are aligned in time to give an example of how solar radio bursts appear in different graphical formats.

The Radio-Skypipe software and Radio-Sky Spectrogram program used by Radio JOVE are available from Radio-Sky Publishing (https://www.radiosky.com).

Solar Radio Source Locations



From: https://www.issibern.ch/teams/electronflare/

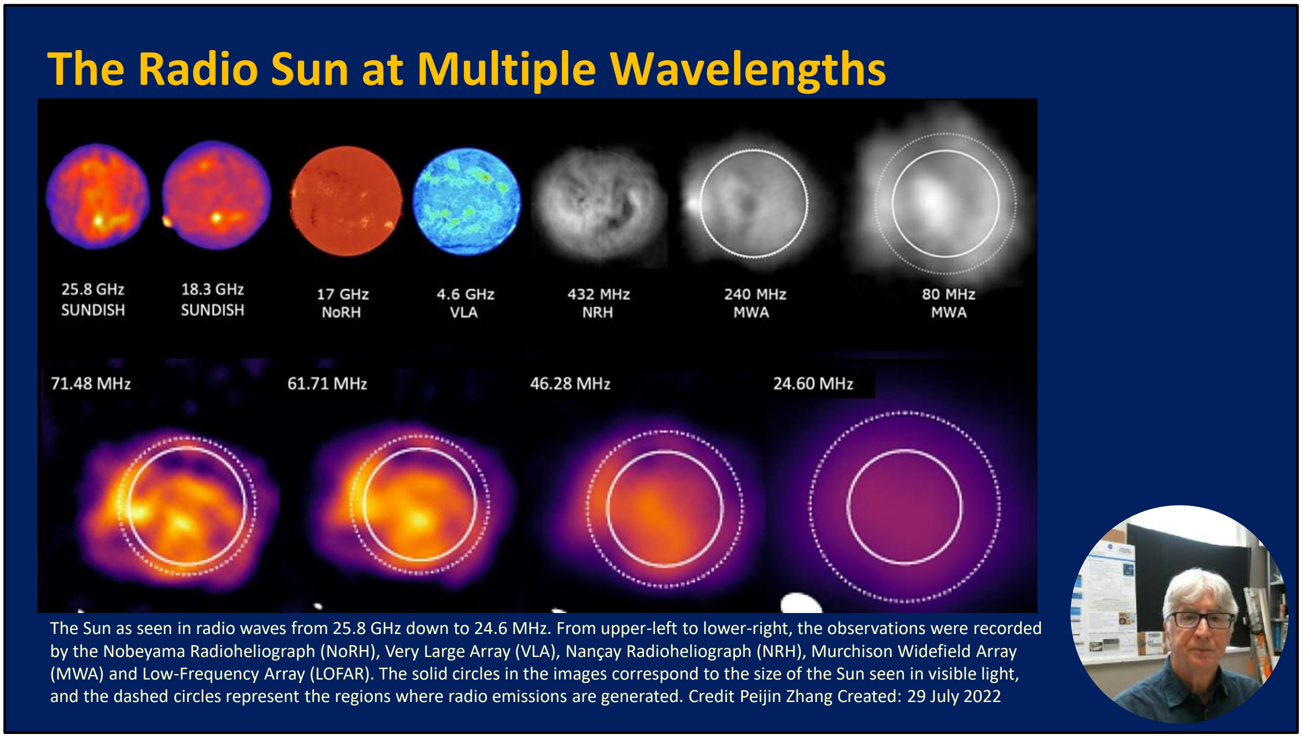
A schematic showing a solar flare region. A magnetic reconnection loop is shown at the particle acceleration site (circle). High energy x-rays and microwaves are generated near the solar surface.

Upward particle acceleration gives rise to solar radio bursts with lower frequency emissions generated farther out into the corona. The 15-30 MHz emissions come from regions about 1-2 solar radii above the photosphere.

A schematic showing a solar flare region. A magnetic reconnection loop is shown at the particle acceleration site (circle). High energy x-rays and microwaves are generated near the solar surface. Upward particle acceleration gives rise to solar radio bursts with lower frequency emissions generated farther out into the corona. The 15-30 MHz emissions come from regions about 1-2 solar radii above the photosphere.

During solar activity, the Sun effectively converts magnetic energy into kinetic energy of accelerated particles in solar flares. Understanding electron propagation and acceleration is one of the key elements of Sun-Earth connection studies and as such an important element of Space Weather.

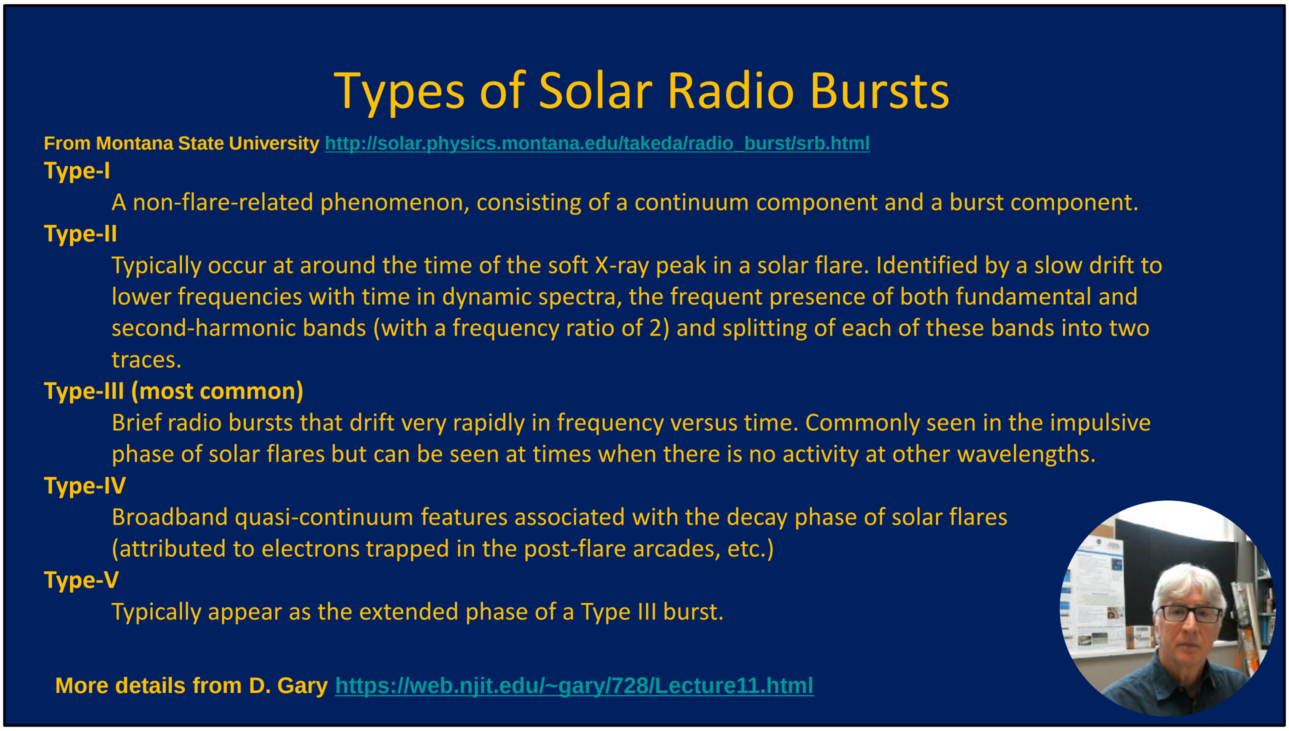
From: https://www.issibern.ch/teams/electronflare/



This figure shows the Sun imaged at multiple radio frequencies. The higher frequency, higher energy radio emissions shown in the upper left occur near regions of intense magnetic activity close the Sun's surface. At lower frequencies, the radio source regions occur farther out in the corona where plasma and magnetic fields are disturbed by solar flares or coronal mass ejection (CME) events. The solid line shows the size of the Sun in visible light and the dashed lines are the regions where radio emissions are generated at the frequency indicated. For Radio JOVE and/or SunRISE frequencies of interest (15-30 MHz), the figure in the lower right is the most relevant.

Figure Caption. The Sun as seen in radio waves from 25.8 GHz down to 24.6 MHz. From upper-left to lower-right, the observations were recorded by the Nobeyama Radioheliograph (NoRH), Very Large Array (VLA), Nançay Radioheliograph (NRH), Murchison Widefield Array (MWA) and Low-Frequency Array (LOFAR). The solid circles in the images on the right correspond to the size of the Sun seen in visible light and the dashed circles represent the regions where radio emissions are generated.

Credit: Peijin Zhang File:QuietSun RadioImaging.jpg Created: 29 July 2022



A brief description of the five types of solar radio bursts from Montana State University http://solar.physics.montana.edu/takeda/radio_burst/srb.html

Type-I A non-flare-related phenomenon, consisting of a continuum component and a burst component.

Type-II Typically occur at around the time of the soft X-ray peak in a solar flare. Identified by a slow drift to lower frequencies with time in dynamic spectra, the frequent presence of both fundamental and second-harmonic bands (with a frequency ratio of 2) and splitting of each of these bands into two traces.

Type-III (most common) Brief radio bursts that drift very rapidly in frequency versus time. Commonly seen in the impulsive phase of solar flares but can be seen at times when there is no activity at other wavelengths.

Type-IV Broadband quasi-continuum features associated with the decay phase of solar flares (attributed to electrons trapped in the post-flare arcades, etc.)

Type-V Typically appear as the extended phase of a Type III burst.

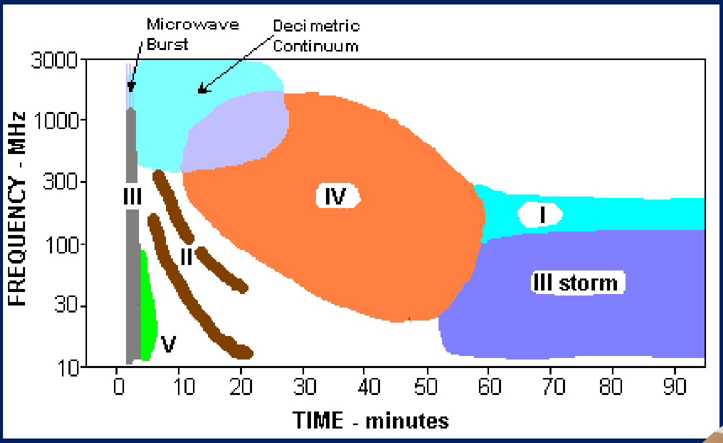
A more detailed description of the five types of solar radio bursts from Professor D. Gary at the New Jersey Institute of Technology. https://web.njit.edu/~gary/728/Lecture11.html.

Types of Solar Radio Bursts

This is an overview of the different types of solar radio bursts associated with a solar flare. Not all components are emitted/observed as the emission mechanisms are highly variable.

Because the HF band is below 30 MHz, not all types are seen.

Type IIIs are very common, while Type II, IV, and V are not common. Type I events are not observed at low frequencies.



https://www.spaceacademy.net.au/env/sol/solradp/solradp.htm

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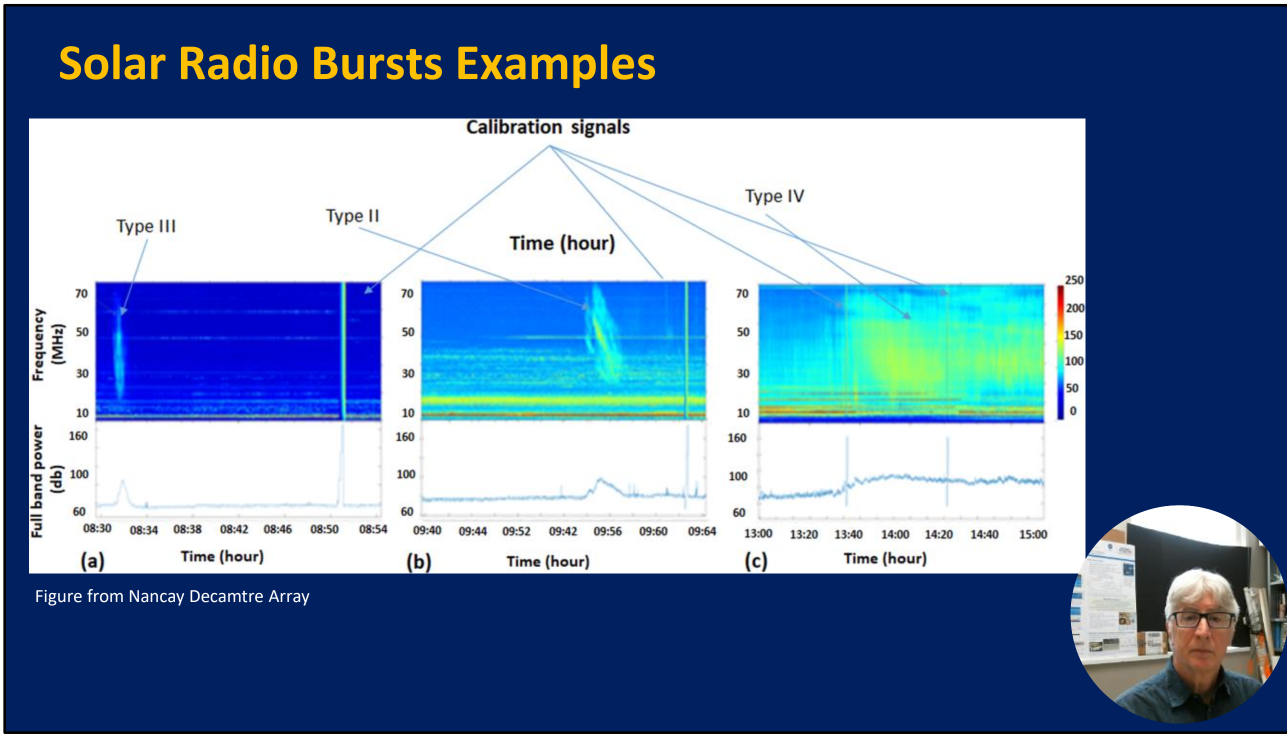
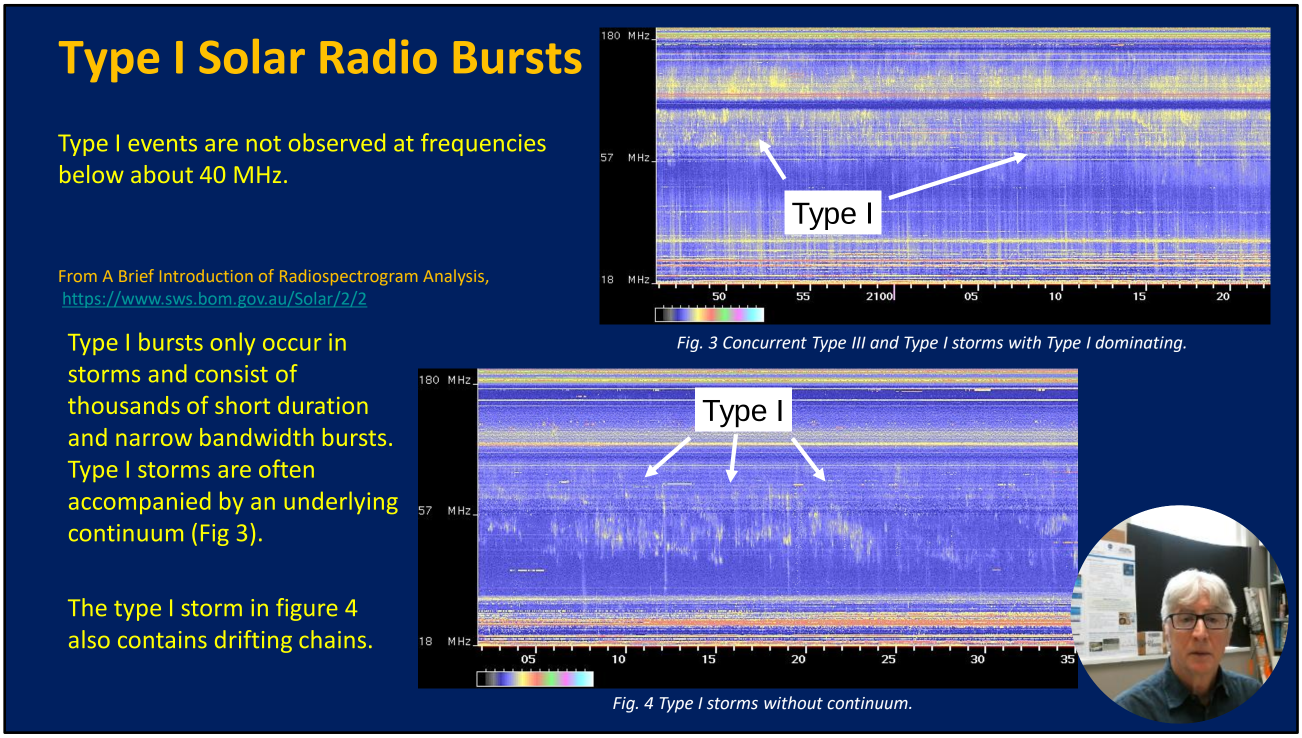


Example solar bursts from the Nancay Decameter Array in France. A Type III is seen on graph (a), a Type II on graph (b), and a Type IV on graph (c). Notice the frequency extent of these emissions as well as the timescale of each.

Figure from Nancay Decamtre Array, **A method for the automated detection of solar radio bursts in dynamic spectra**

Houssam Salmane[1,2*], Rodolphe Weber[1,3], Karim Abed-Meraim[1], Karl-Ludwig Klein[2] and Xavier Bonnin[2]

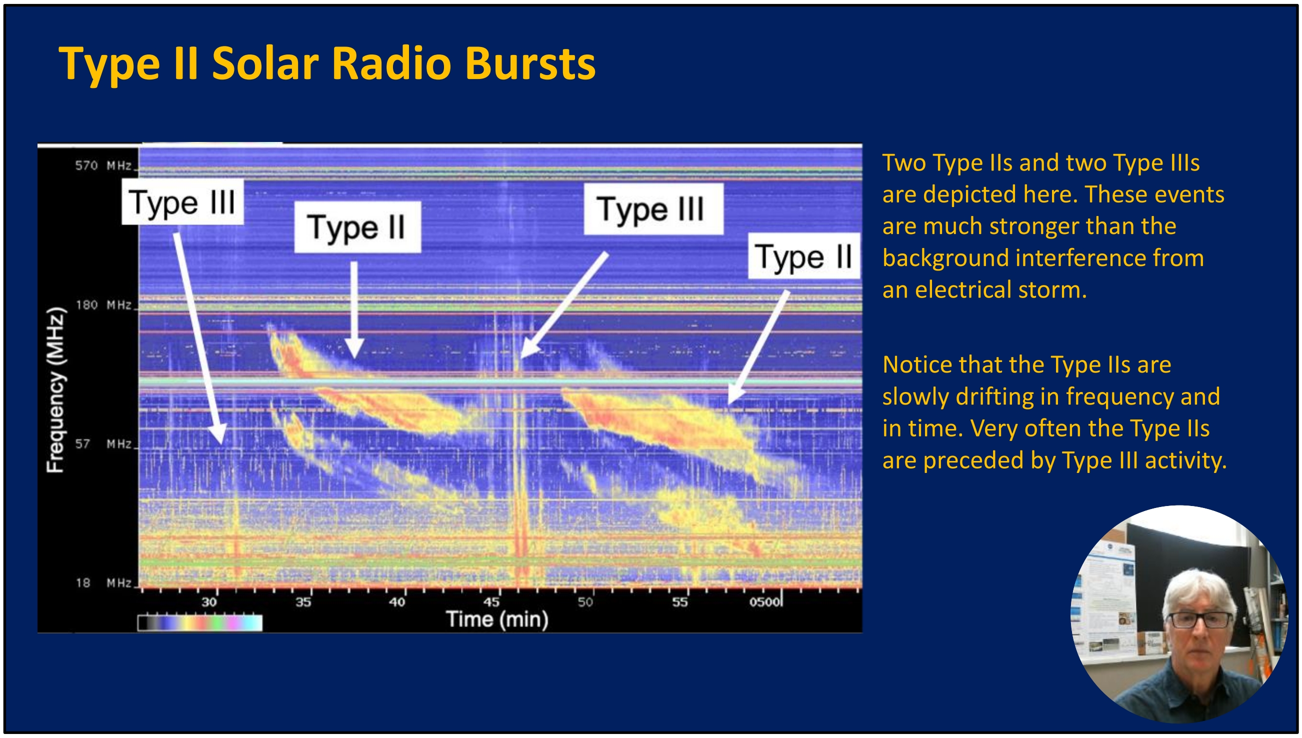
J. Space Weather Space Clim., 8 (2018) A43



Type I events are not observed at frequencies below about 40 MHz.

Type I bursts only occur in storms and consist of thousands of short duration and narrow bandwidth bursts. Type I storms are often accompanied by an underlying continuum (Fig 3). The type I storm in figure 4 also contains drifting chains.

From: A Brief Introduction of Radiospectrogram Analysis



Two Type IIs and two Type IIIs are depicted here. These events are much stronger than the background interference from an electrical storm. Notice that the Type IIs are slowly drifting in frequency and in time.

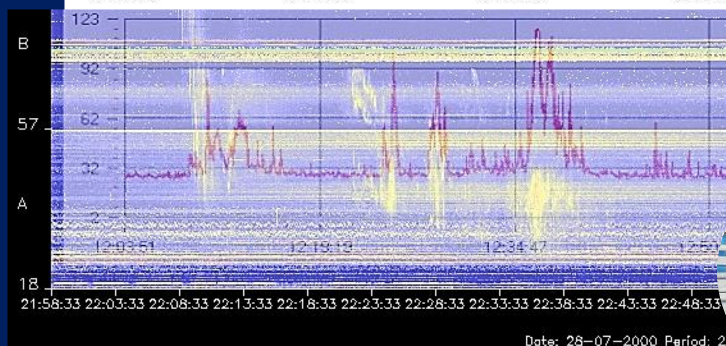
In addition to the fundamental/ harmonic structure, these events clearly exhibit band-splitting. This is where the components of a type II (fundamental and/or harmonic) are themselves split into two or more roughly parallel bands. Very often the Type IIs are preceded by Type III activity.

Image credit: https://en.wikipedia.org/wiki/Solar_radio_emission adapted from A Brief Introduction of Radiospectrogram Analysis Copyright Commonwealth of Australia 2023,

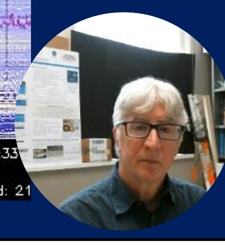
Type II Solar Radio Bursts

Type II solar bursts on a 20.1 MHz stripchart from Windward Community College, Oahu, HI on July 28, 2000, using an original Radio JOVE receiver and the standard dual dipole antenna.

This image superimposes the 20.1 MHz strip chart on an 18-100 MHz spectrograph taken at the Culgoora Radio Observatory in Australia. The images are time-aligned, and it is easy to see the correspondence in major (and some minor) aspects of the burst. Credit J. Sky, https://www.radiosky.com/type2solarburst.html.



Credit J. Sky, https://www.radiosky.com/type2solarburst.html.



This is an example of a Type II solar radio burst.

The stripchart at 20.1 MHz was captured at Windward Community College on the Island of Oahu in Hawaii on July 28, 2000, using an original Radio JOVE receiver and the standard dual dipole antenna.

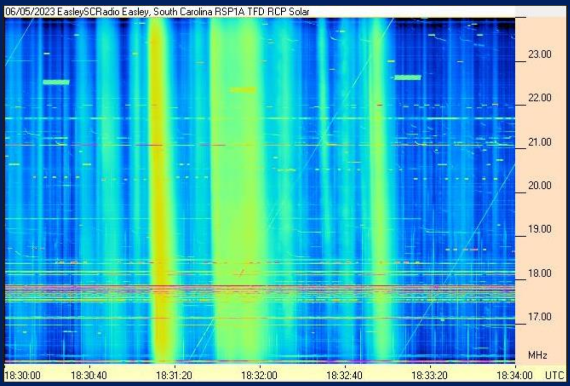
The second image is a superposition of the 20.1 MHz strip chart on an 18-100 MHz spectrograph taken at the Culgoora Radio Observatory in Australia. The images are time-aligned, and it is easy to see the correspondence in major (and some minor) aspects of the burst. Credit J. Sky, https://www.radiosky.com/type2solarburst.html.

Type III Solar Radio Bursts

Multiple Type III Solar Radio Bursts, June 5, 2023, John Cox, Easley, South Carolina. Note that Type III bursts are called fast drift bursts.

The graph below is a Type III solar burst showing a classic “shark fin” shape on an intensity-time stripchart. The red and blue plots are recorded at two difference frequencies.

December 24, 2013, Wes Greenman, Alachua, FL.

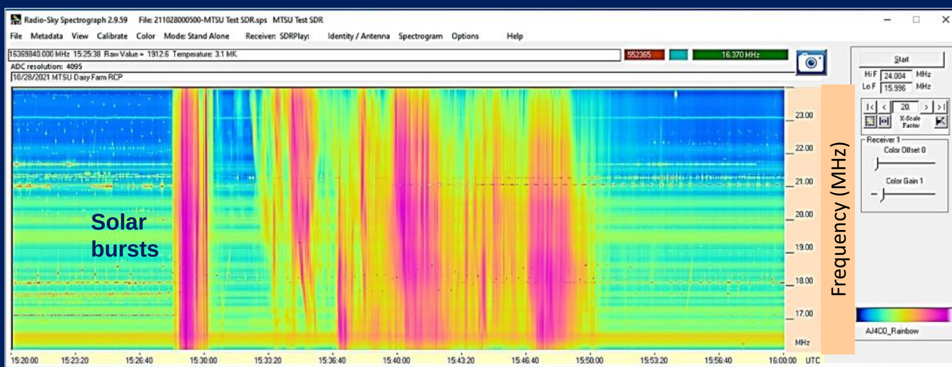


June 5, 2023, John Cox, Easley, South Carolina.

Multiple Type III Solar Radio Bursts recorded on June 5, 2023, John Cox, Easley, South Carolina. Note that Type III bursts are called fast drift bursts.

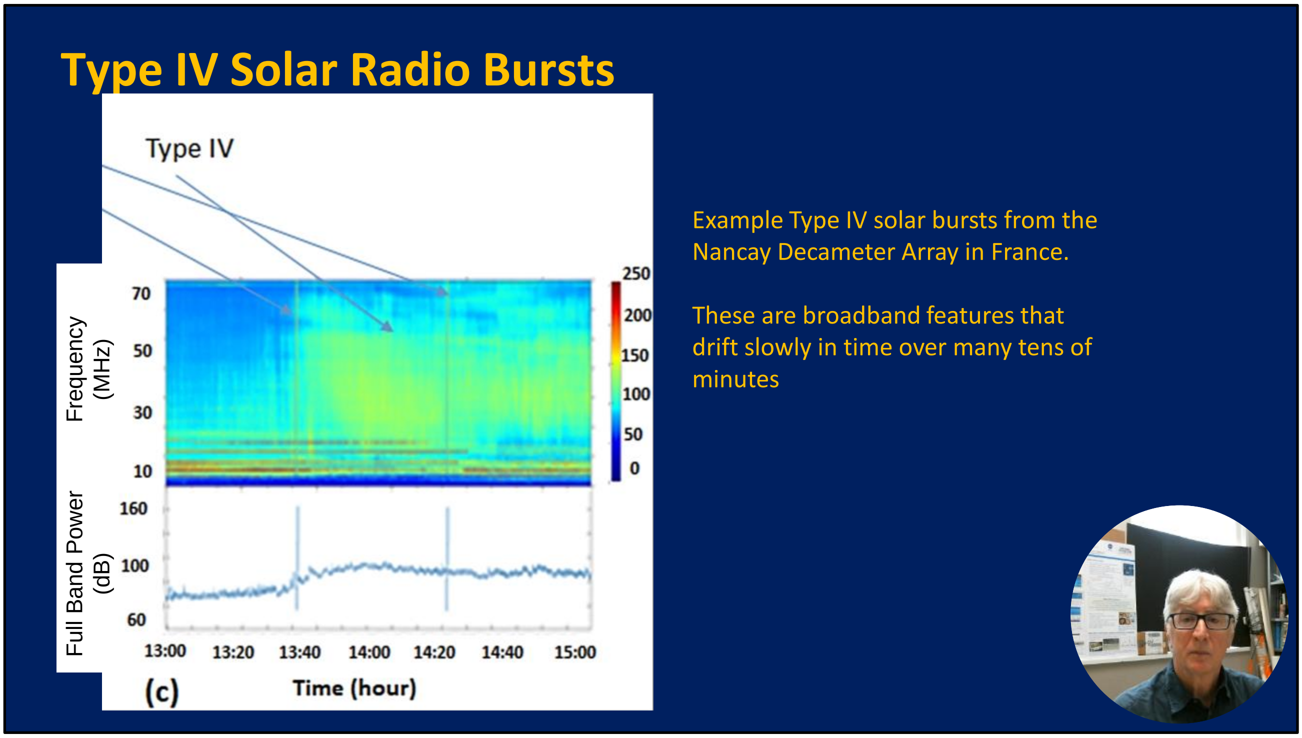
The graph below is a Type III solar burst showing a classic “shark fin” shape on an intensity-time stripchart. The red and blue plots are recorded at two difference frequencies.

Type III Solar Radio Bursts



Solar bursts from a radio spectrograph on 28-Oct-2021 from C. Higgins, Middle Tennessee State University Dairy Farm, Murfreesboro, TN. The 16-24 MHz spectrogram shows data from 15:20:00-16:00:00 UTC.

Example Type III solar bursts from a 16-24 MHz radio spectrograph on 28-Oct-2021 from C. Higgins, Middle Tennessee State University Dairy Farm, Murfreesboro, TN.



Example Type IV solar bursts from the Nancay Decameter Array in France. These are broadband features that drift slowly in time over many tens of minutes

Figure from Nancay Decamtre Array, **A method for the automated detection of solar radio bursts in dynamic spectra**

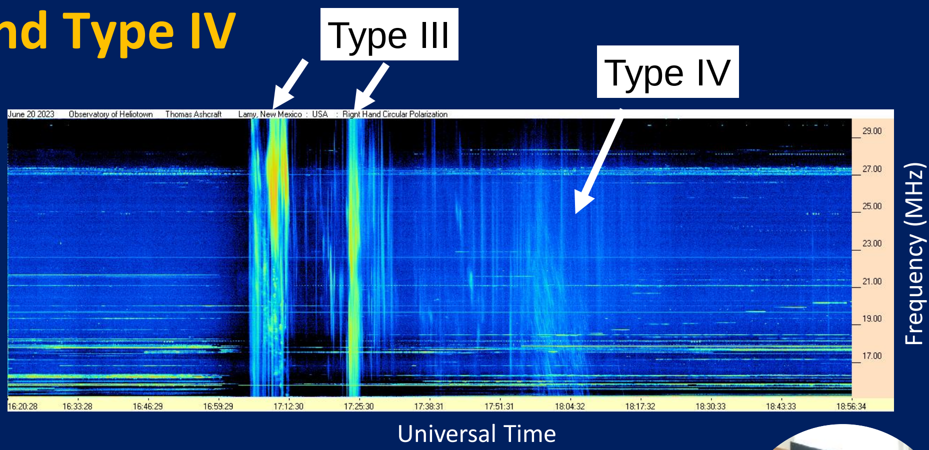
Houssam Salmane[1,2*], Rodolphe Weber[1,3], Karim Abed-Meraim[1], Karl-Ludwig Klein[2] and Xavier Bonnin[2]

J. Space Weather Space Clim., 8 (2018) A43

Type III and Type IV

Type III and Type IV solar bursts on June 20, 2023, from Tom Ashcraft, Lamy, NM.

The Type IIIs are associated with an X-class solar flare. We think this is a moving Type IV solar emission caused by post-flare plasma disturbances.



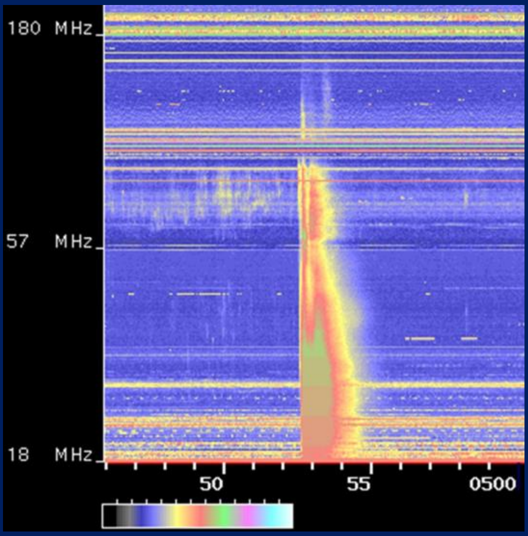
Solar Radio Bursts, June 20, 2023, Tom Ashcraft, Lamy, NM

Radio Spectrograph Software (RSS) from **Radiosky.com**

Type III and Type IV solar bursts on June 20, 2023, from Tom Ashcraft, Lamy, NM. The Type IIIs are associated with an X-class solar flare. We think this is a moving Type IV solar emission caused by post-flare plasma disturbances.

Type V Solar Radio Bursts

Type V events are always preceded by one or more type III bursts of at least moderate intensity as seen in this figure. This spectrogram is typical in that the type V begins at the same time as the type III and tends to persist longer at mid to low frequencies. Also typical is the less protracted duration at the lowest observable frequencies.



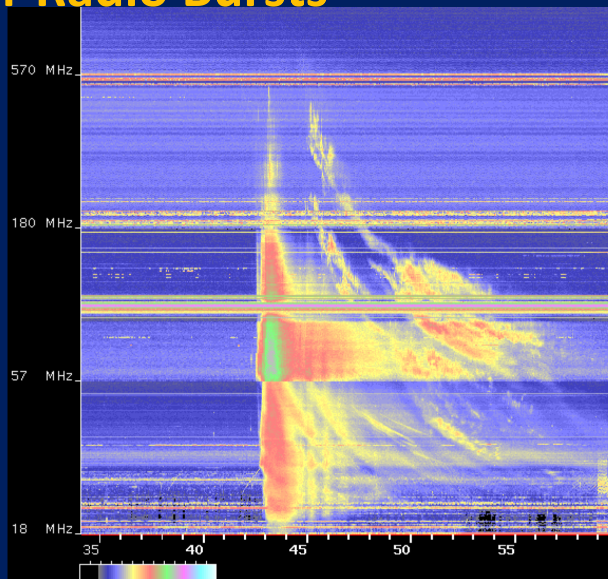
From: A Brief Introduction of Radiospectrogram Analysis Copyright Commonwealth of Australia 2023, Bureau of Meteorology

Type V events are always preceded by one or more type III bursts of at least moderate intensity as seen in this figure. This spectrogram is typical in that the type V begins at the same time as the type III and tends to persist longer at mid to low frequencies. Also typical is the less protracted duration at the lowest observable frequencies.

From: A Brief Introduction of Radiospectrogram Analysis Copyright Commonwealth of Australia 2023, Bureau of Meteorology.

Type V Solar Radio Bursts

This figure is a complex spectrogram showing a Type III with Type V and one (or two) Type II bursts.



From: A Brief Introduction of Radiospectrogram Analysis Copyright Commonwealth of Australia 2023, Bureau of Meteorology

This figure is a complex spectrogram showing a Type III with Type V and one (or two) Type II bursts.

From: A Brief Introduction of Radiospectrogram Analysis Copyright Commonwealth of Australia 2023, Bureau of Meteorology.

Resources

Solar Radio Burst Image Collection – Montana State University
http://solar.physics.montana.edu/takeda/radio_burst/srb.html

Monitoring the Radio Sun – Australian Space Academy
https://www.spaceacademy.net.au/env/sol/solradp/solradp.htm

Radio-Sky Publishing
https://www.radiosky.com/suncentral.html

Introduction to Radio Wave Propagation
https://www.sws.bom.gov.au/Educational/5/2/2

Australian Space Academy MONITORING THE RADIO SUN
https://www.spaceacademy.net.au/env/sol/solradp/solradp.htm

This is a short list of good resources on solar radio astronomy.

Thank you for watching

Next, we will examine Jupiter low frequency radio emissions …

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