Radio Bursts Originating in the Solar Corona

When, What, Why ???

Radio Bursts Originating in the Solar Corona

Aim: To describe the theory for the origin of the solar radio bursts, and to introduce some of the observational and theoretical characteristics of the bursts:

- Recognize the basic types of Solar Radio Bursts on dynamic spectra.
- Have a basic understanding of the Solar Radio Bursts exciters.
- Understand the association of Radio Bursts with Energetic Phenomena of the Sun (Flares & CMEs). .
- Derive Heliocentric burst driver height calculated from plasma frequency using different atmospheric density models.

Solar Radio Bursts : When??

Background and brief history: The possibility of existence of Solar Radio Waves

Solar Radio Bursts : When??

In the early 1890's Ebert (**1893**) suggested that the solar corona was a visible electric discharge and concluded that "*if the Sun is really the seat of electromagnetic disturbances then it must necessarily be the source of electromagnetic radiation*." A few years later Sir Oliver Lodge (**1900**) was among those who tried unsuccessfully to detect such radiation.

These attempts failed because radio techniques were inadequate at that time.

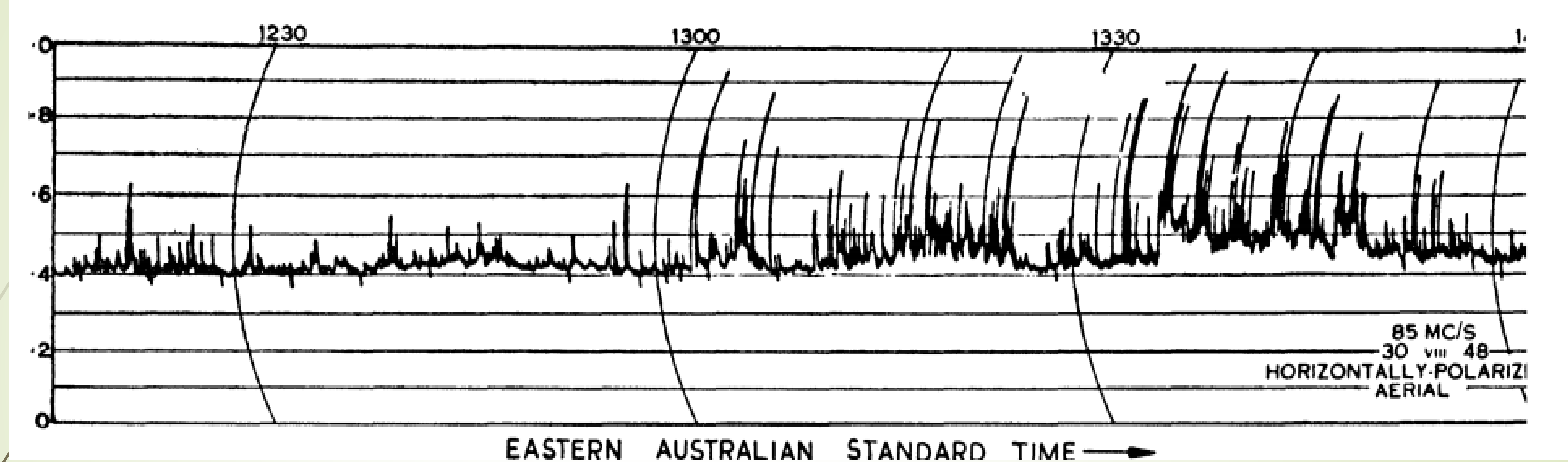
Solar Radio Bursts : When??

In **1942**, two observers independently observed and identified solar radio waves. In England, Hey (**1946**) showed that certain exceptional disturbances observed on radar equipment operating on **meter wave lengths** came from the direction of the sun. The intensity of radiation was vastly greater than that to be expected from the sun, assuming it to radiate as a black body at a temperature 6000 K, and associated the exceptional occurrence with a giant sunspot present at that time!!

Solar Radio Bursts : When??

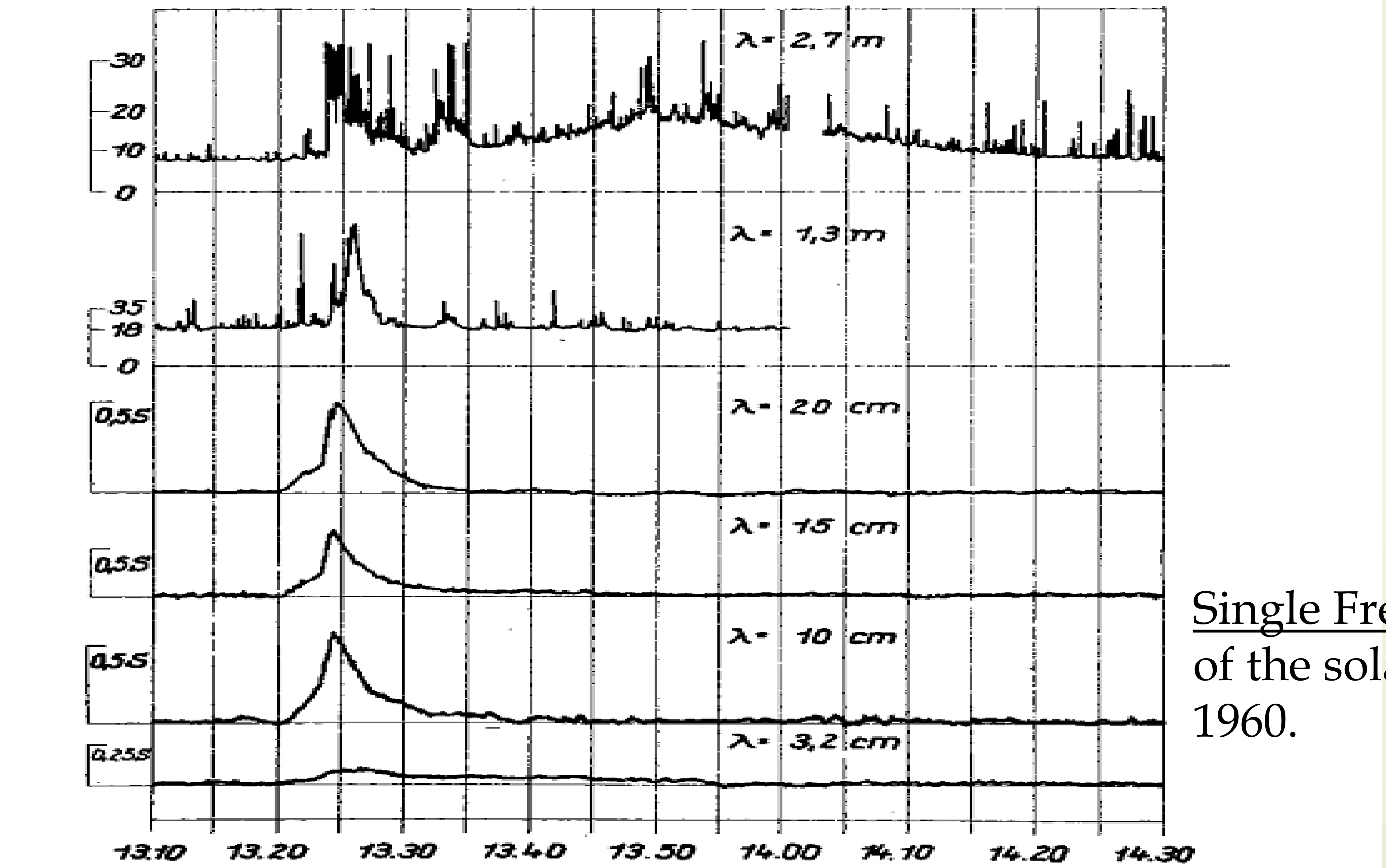
In US, Southworth (**1945**), using newly developed microwave radar receivers, looked for an extension of the far infrared spectrum and found steady radiation on wave lengths of 3 and 10 centimeters which corresponded in intensity to black-body radiation from the sun at 18,000 K. Publication of these results was delayed for reasons of military secrecy until the end of the second World War in 1945.

Solar Radio Bursts : When??



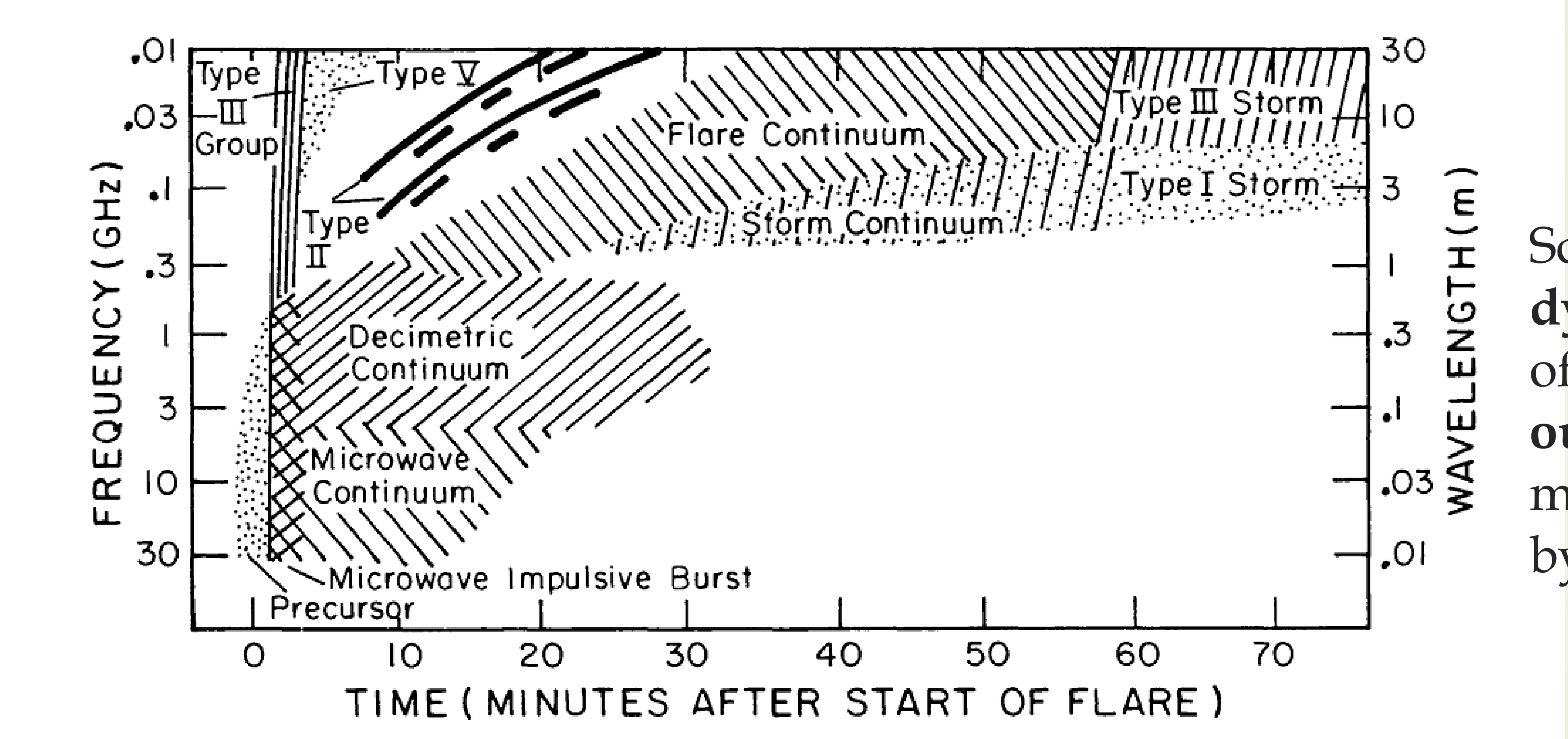
Typical record of enhanced radiation (Payne-Scott, **1949**)

Solar Radio Bursts : When??



Single Frequency recording of the solar burst May 23, 1960.

Solar Radio Bursts : What??



Schematic **dynamic spectrum** of a **solar radio outburst** such as might be produced by a large flare.

Alternate names: microwave continuum = Type **IVg**,; decimetric continuum = Type **IVdm**; flare continuum = **IVmA**, Moving Type **IV** (if motion is observed); storm continuum = **IVmB**, Type **I** storm, noise storm, stationary Type **IV** ; Type **Ill** storm = decametric continuum.

Solar Radio Bursts : What?? : From Plasma Frequency to Exciter Velocity

The general idea behind a number of bursts (type **II**, type **III**, moving type **IV**, type **V**) is that they are created by a propagating exciter: **Langmuir waves** are excited by electron beams produced in this exciter and the waves are then converted into escaping radio waves.

The emission mechanism is **plasma emission** near the fundamental and harmonic frequencies. The **plasma frequency** $\mathbf{f_p}$(*Hz*) at the fundamental is directly related to the **electron density** $\mathbf{n_e}$ (cm^{-3}) by $\mathbf{f_p = 9000\sqrt{n_e}}$ and a frequency drift toward the lower frequencies shows that the electron density is falling.

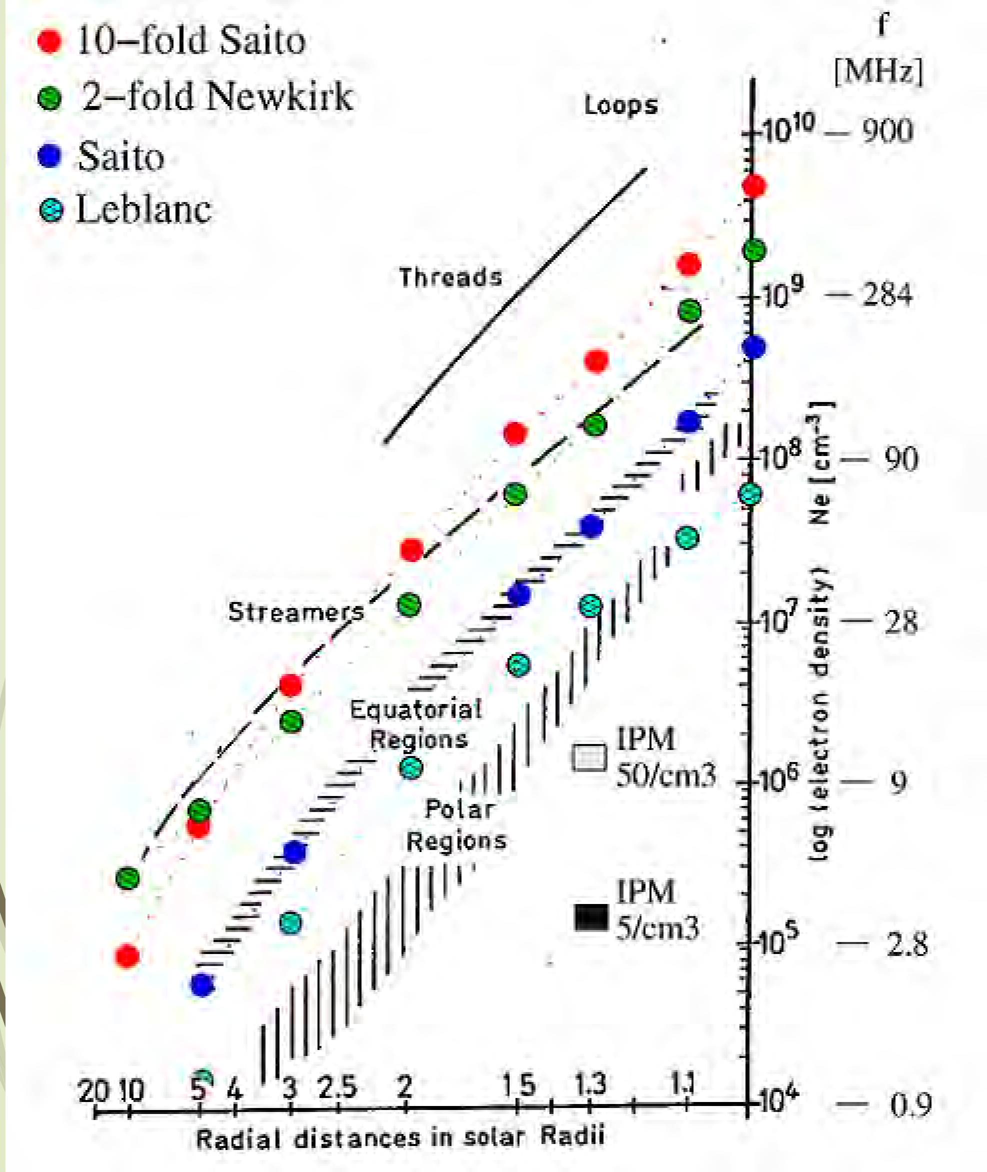
This change is usually attributed to the burst driver moving in the solar atmosphere toward lower densities and larger heights.

Solar Radio Bursts : What?? :
From Plasma Frequency to Exciter Velocity

After calculation of the electron density from the plasma frequency at the fundamental, the next step is to find a corresponding height for the emitting source with the help of atmospheric density models.

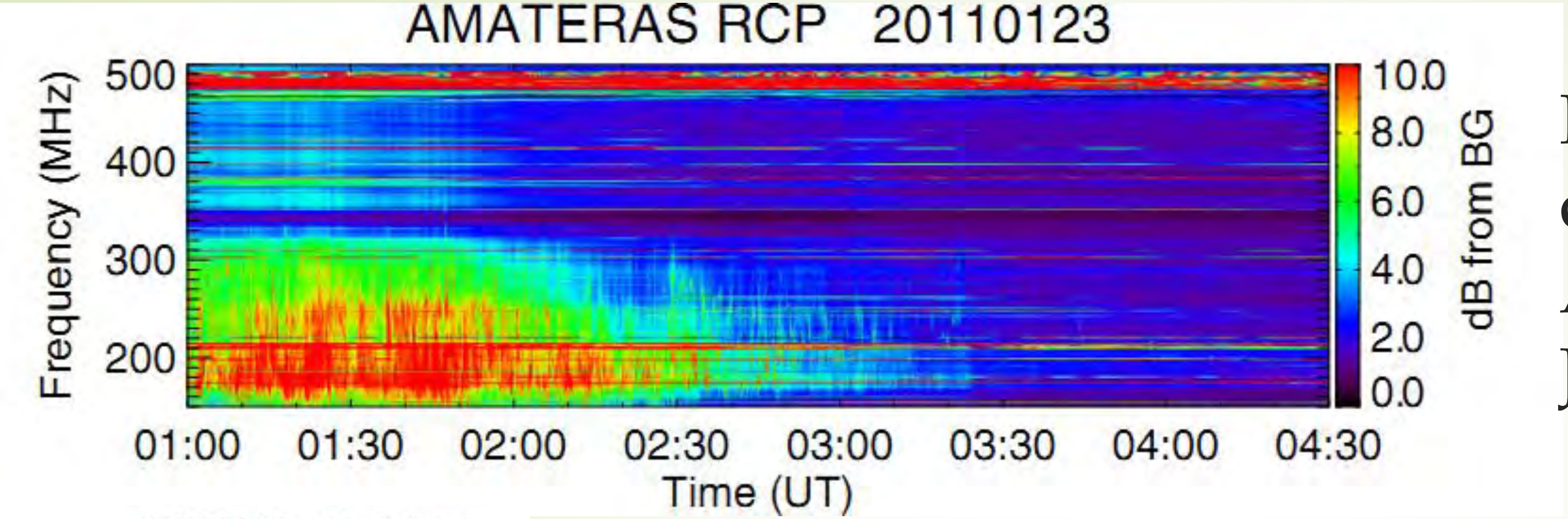
Model to Use: The Figure in the next slide shows how density depends strongly on coronal conditions: It is important to know whether the disturbance is propagating in a less-dense equatorial region, inside a dense streamer region, or in even denser coronal-loop structures. Also the after flows of a previous CME can affect the densities. The most widely used density models are by Newkirk (**1961**) and Saito (**1970**). In the Newkirk model, the electron number densities stay high at large distances from the Sun since the model is a hydrostatic one (see Figure, Next Slide)

Solar Radio Bursts : What?? : From Plasma Frequency to Exciter Velocity

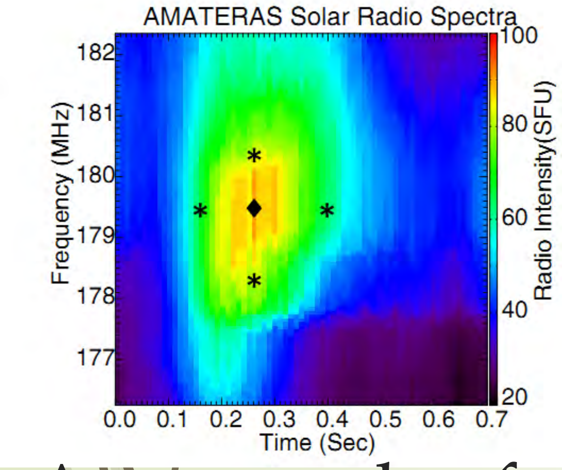


Electron density in different parts of the corona from eclipse photometry. Dark blue circles: coronal densities according to the Saito (1970) model, red circles: densities according to the ten-fold Saito model, green circles: densities according to the two-fold Newkirk (1961) model; light blue circles: densities according to the Leblanc&al (1998) model. IPM-labeled boxes indicate electron densities at $1.3R_{\odot}$ according to the IP density model, with near-Earth electron densities of 5 cm^{-3} (solar minimum) and 50 cm^{-3} (solar maximum).

Solar Radio Bursts : What?? Type I Radio Bursts



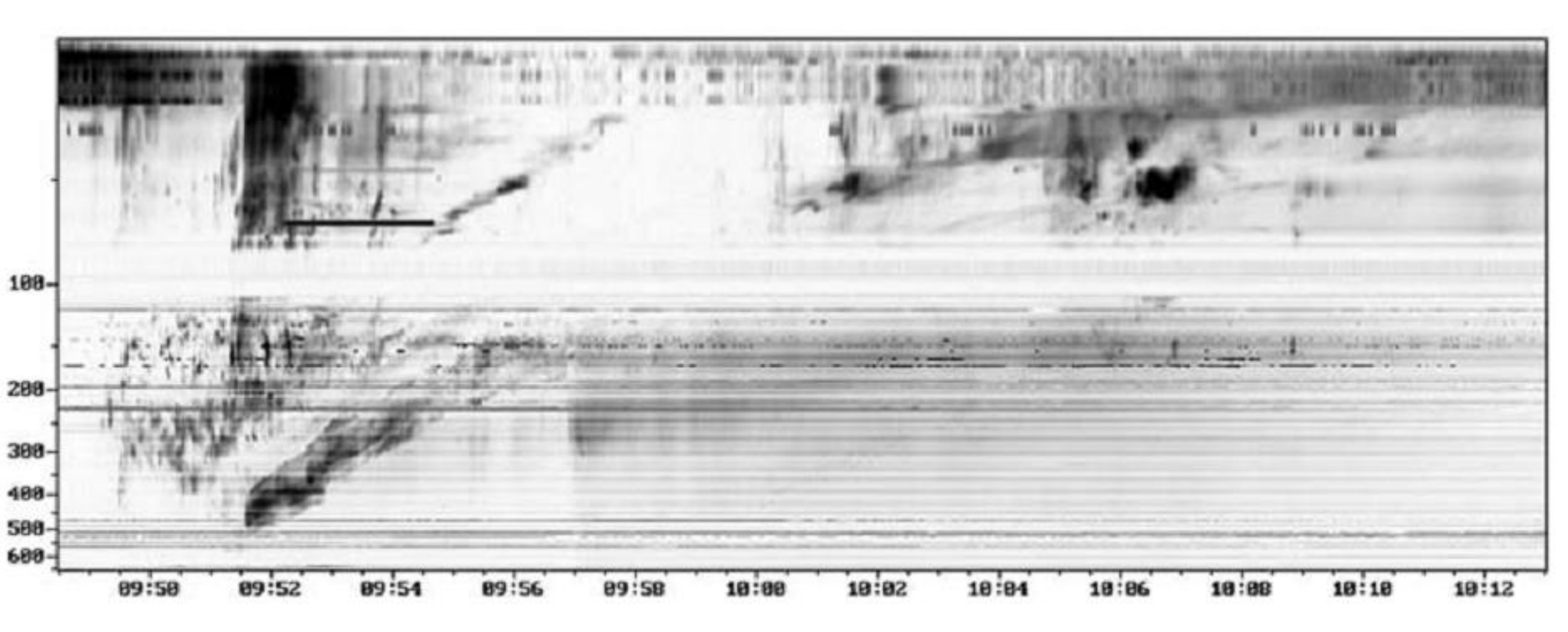
Radio dynamic spectrum observed with AMATERAS on 2011 January 16



An example of a type-**I** burst element

It is generally believed that nonthermal electrons generated in the corona are trapped in a closed magnetic loop and excite the plasma waves which are converted to radio waves and finally observed as **type-I**. The detailed generation processes of type-**I** are not well understood, but it is thought that a newly emerging magnetic field interacts with a pre-existing coronal magnetic field and their reconnections could produce nonthermal electrons.

Solar Radio Bursts : What?? Type II Radio Bursts



Dynamic spectrum of the 3 November 2003 event obtained by **Artemis-JLS(IV).**

Coronal type II bursts occur at around the time of the peak in a flare and often appear as **two bands with a frequency ratio ~2** in the range ~20–400 MHz that drift downward in frequency. Under the assumption that the exciter propagates radially the drift rate yields speeds of 500–1000 kms^{-1}; they are thought to be **generated by MHD shocks**. The shock moves through the corona and radio emission is produced at the plasma fre quency and its harmonic by nonlinear processes involving **Langmuir waves**, which are driven by **electron beams accelerated at the shock**. Each band can be further split into **upper and lower bands** thought to be caused by the **density jump** in the shock

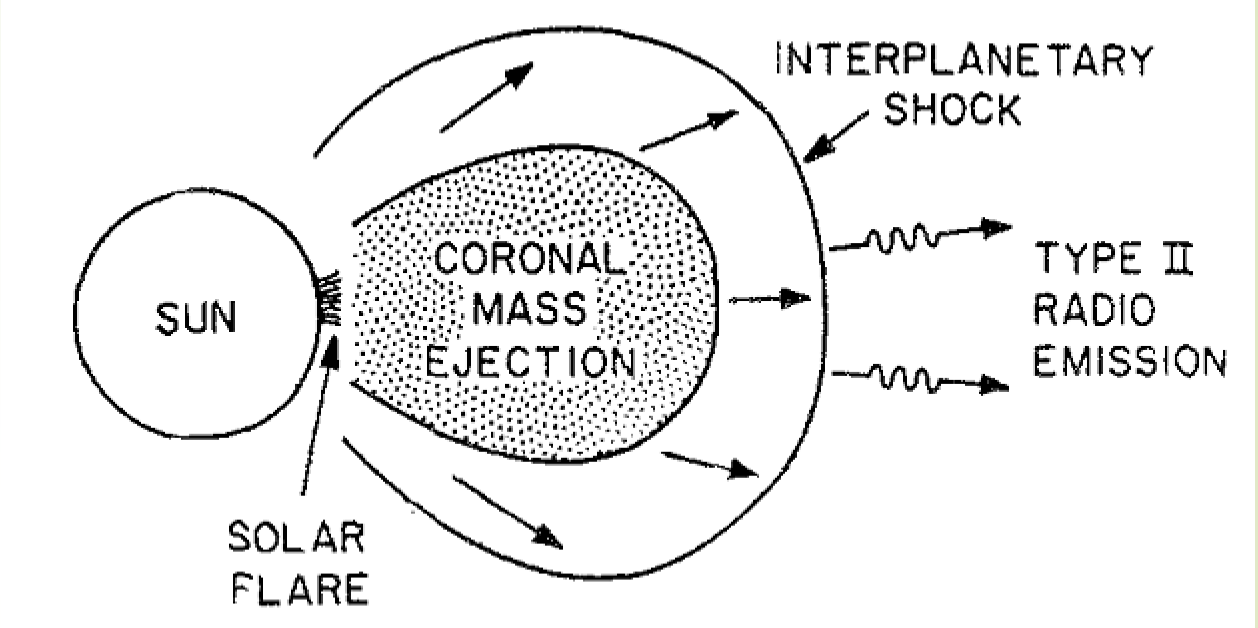
Solar Radio Bursts: What?? Type II Radio Bursts

The Origin of Coronal Type II Shocks: The launch of coronal shocks requires a sudden disturbance in the corona that will propagate faster than the local Alfvén speed. Coronal shocks can be classified into two groups.

Blast shocks: The initial perturbation has the form of a large-amplitude disturbance, which propagates as a nonlinear wave; the wave profile steepens until a shock is formed. As it propagates its amplitude drops due to geometrical expansion, dissipation, and the widening of the perturbation profile and ultimately it decays to a small-amplitude wave. The **origin of blast waves** in the corona is generally **ascribed to explosive energy conversion in flares**.

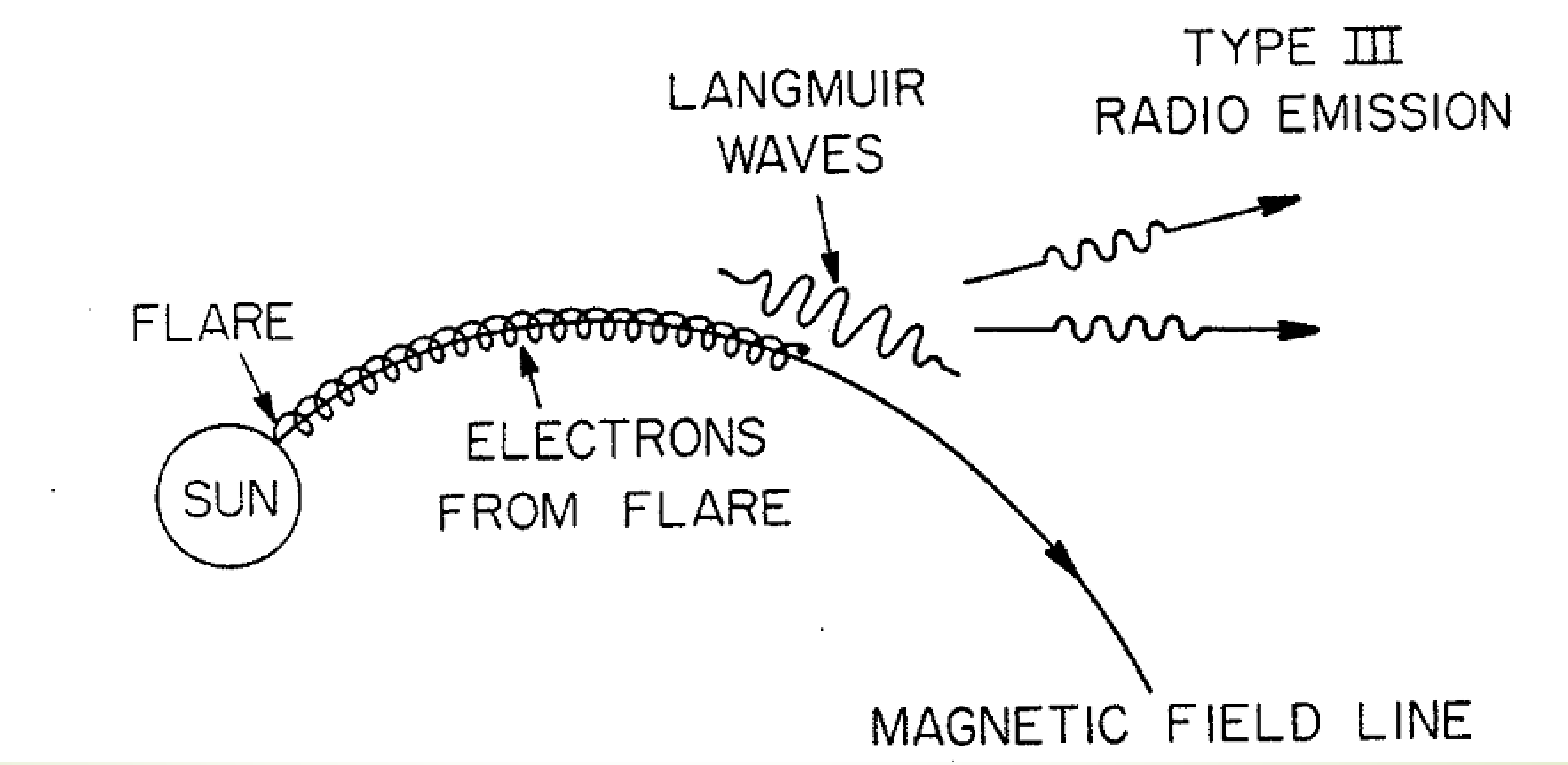
Solar Radio Bursts: What?? Type II Radio Bursts

Driven shocks: They are constantly supplied with energy by a driver or piston; they are **attributed to CMEs**, with the more or less explicit idea that the type II emission comes from their bow shock.



Type II solar radio burst produced by MHD shocks driven by coronal mass ejection.

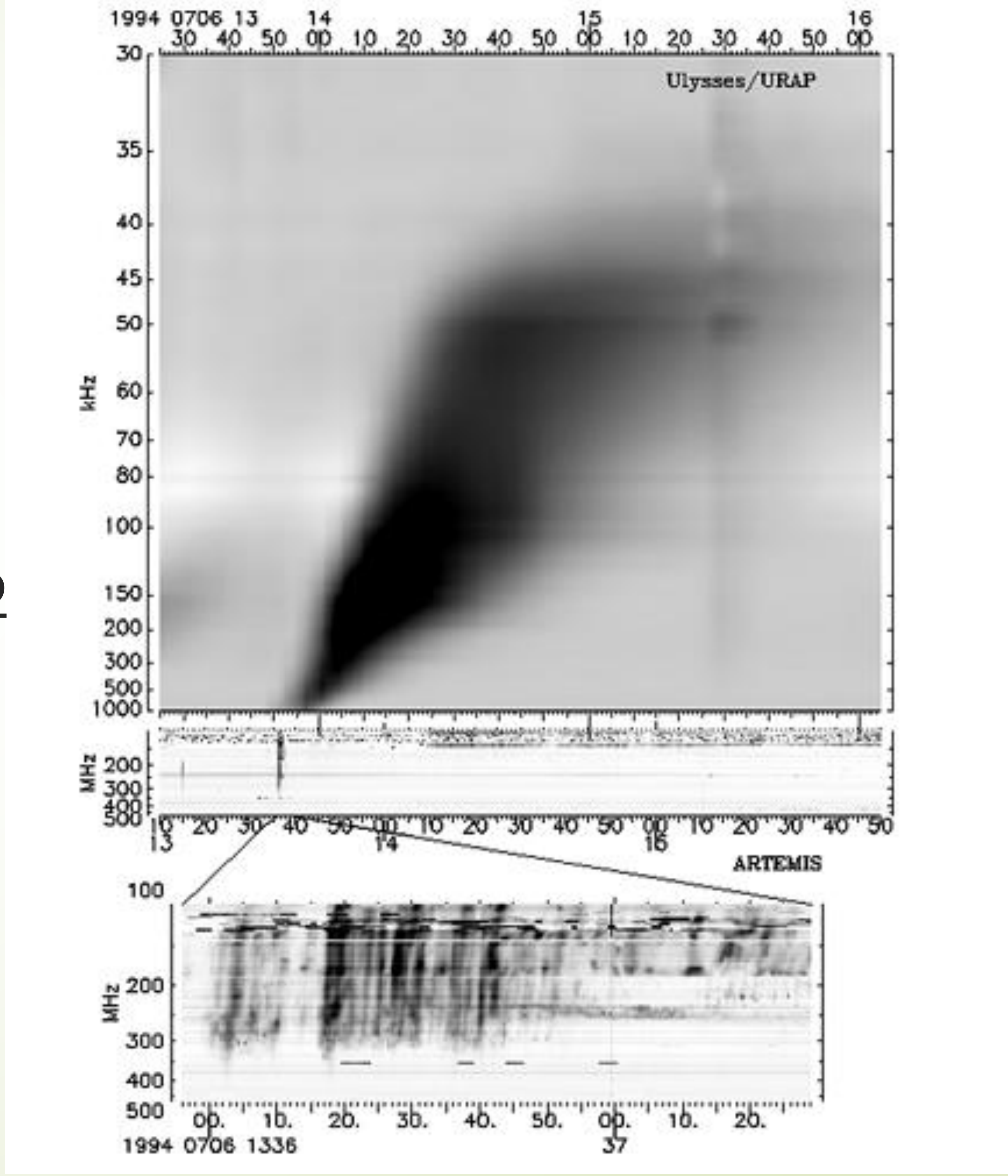
Solar Radio Bursts : What?? Type III Radio Bursts



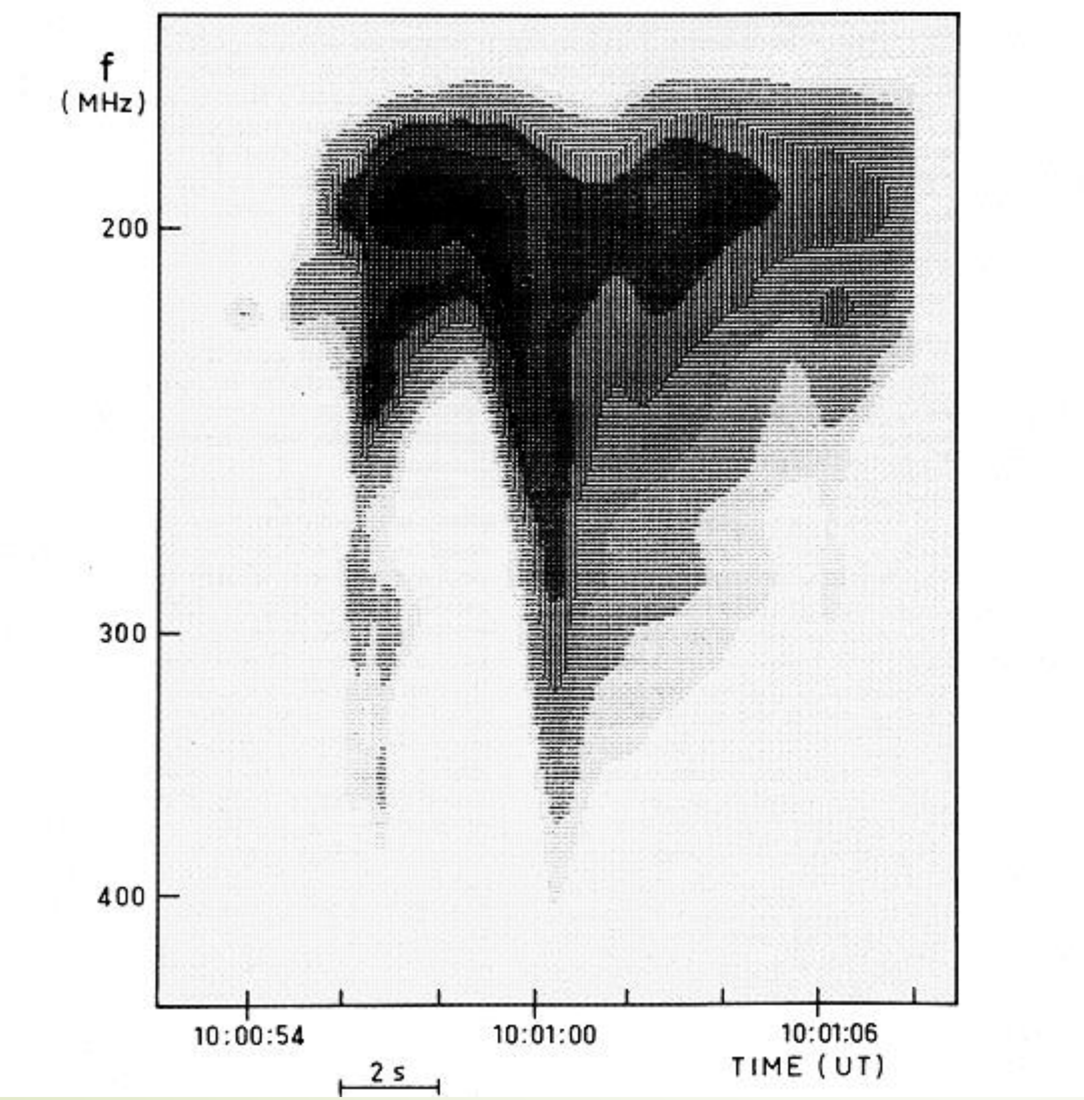
Type III radio bursts are produced by **energetic electrons** from solar flares. The electrons stream outward from the Sun along the solar wind magnetic field lines and produce electrostatic oscillations called **Langmuir waves**. The Langmuir waves then mode convert to electromagnetic radiation via nonlinear wave-wave interactions.

Solar Radio Bursts : What?? Type III Radio Bursts

Artemis I observations of a group of coronal type III bursts (middle panel) and the corresponding IP type III radio burst from Ulysses (top panel). The bottom panel shows **details of the group** of the coronal type III bursts.

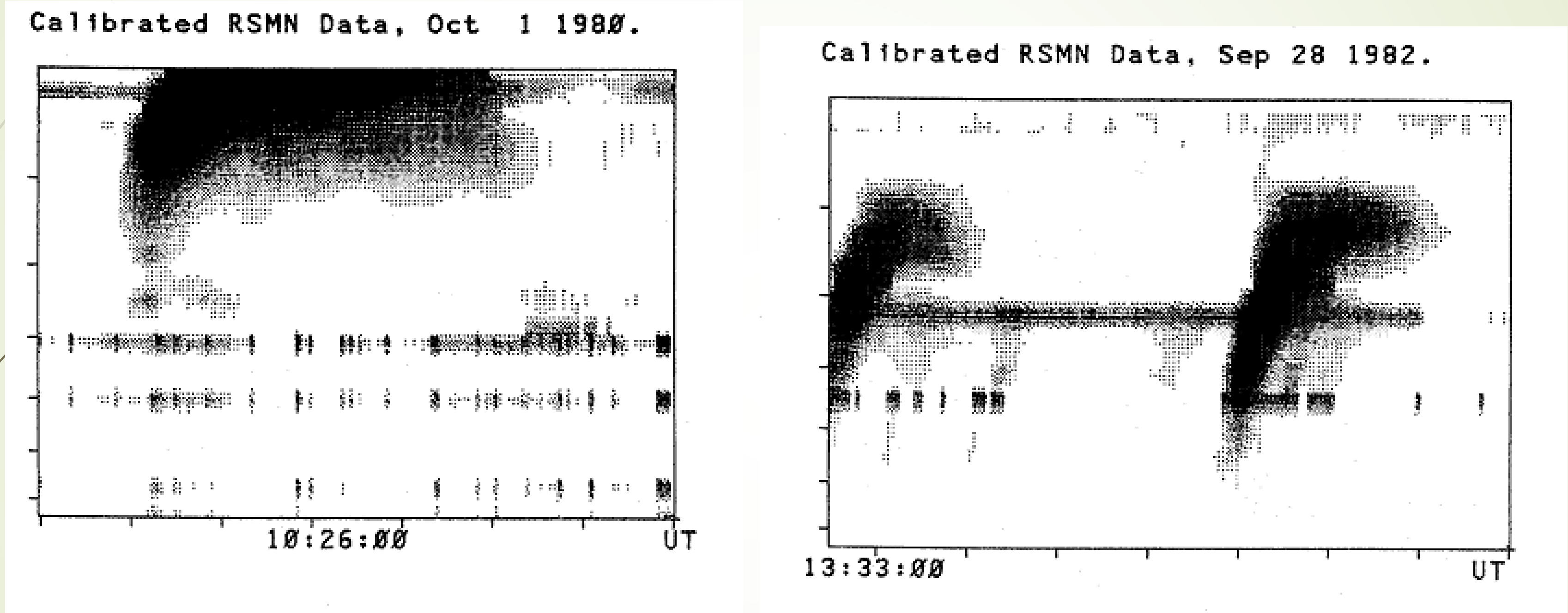


Solar Radio Bursts : What?? More on Type III Radio Bursts



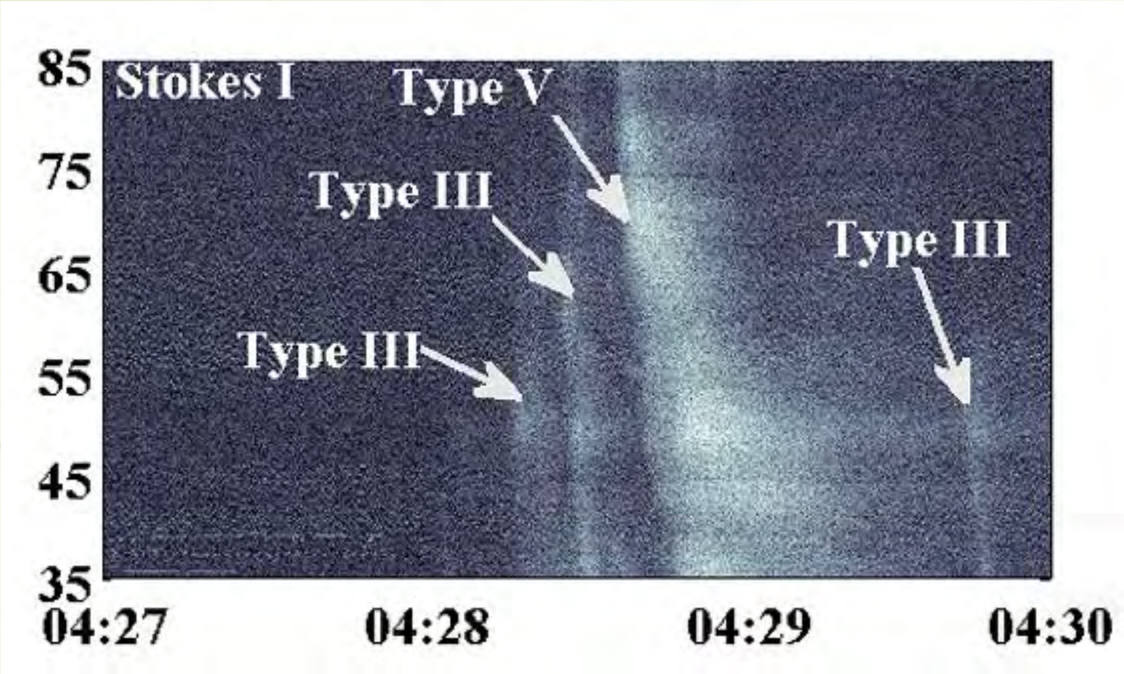
Type **Ill** radio bursts are result of the propagation of beams of mildly relativistic electrons along open magnetic field lines in the solar corona, while **U** bursts evidence their propagation in closed magnetic field lines. Some **U** bursts have a very faint descending branch and appear as an inverted letter **J**. A fourth member of the type **Ill** family are the so called **N bursts** (see Figure) the dynamic spectra of which provide evidence for reflection of the beam at the other end of the loop.

Solar Radio Bursts : What?? More on Type III Radio Bursts



Dynamic Spectra of type **U** and **J** Bursts

Solar Radio Bursts : What?? Type V Radio Bursts

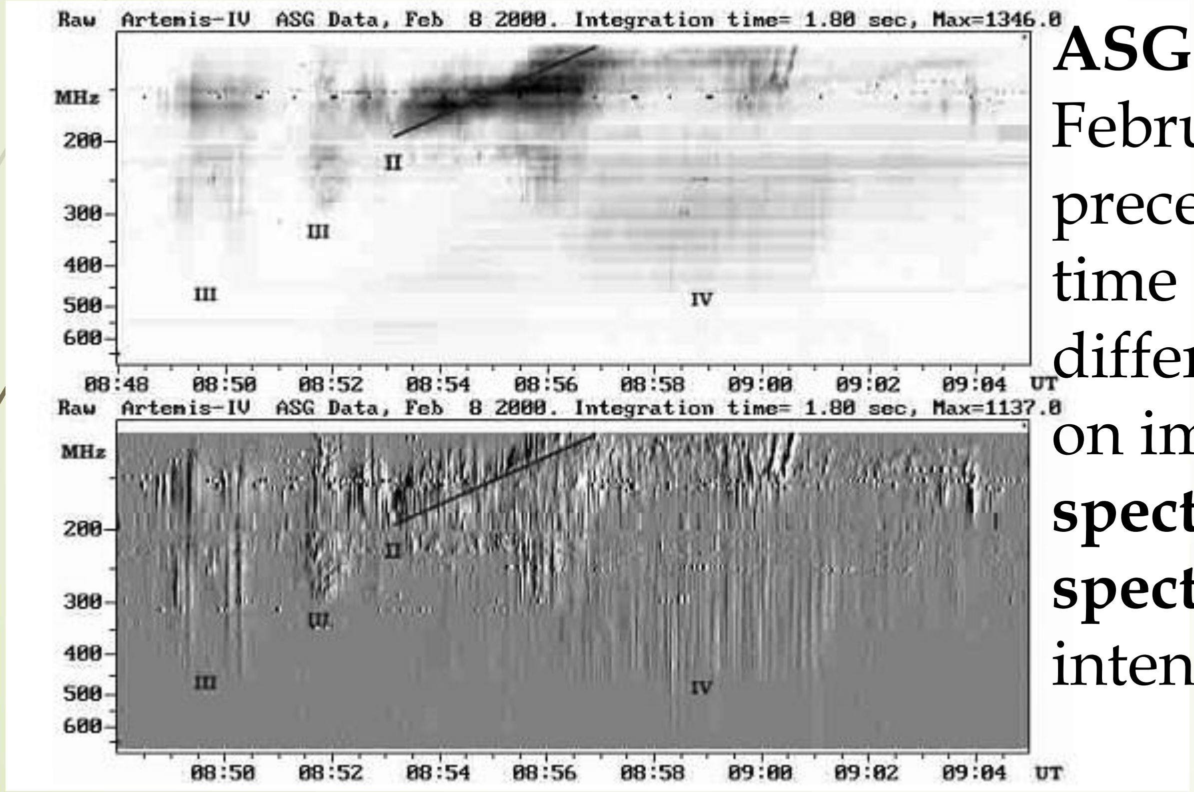


Dynamic spectra of the type **III** and type **V** bursts observed with the Gauribidanur RAdio SpecTro Polarimeter on 2014 December 14.

The type **V** bursts are relatively unusual solar radio transients. They appear as diffuse continuum following some of the type **III** bursts. The emission is due to plasma **processes similar to the type III bursts** excited by energetic electrons that propagate outwards through the solar atmosphere from the flaring region.

Solar Radio Bursts : What?? Type IV Radio Bursts

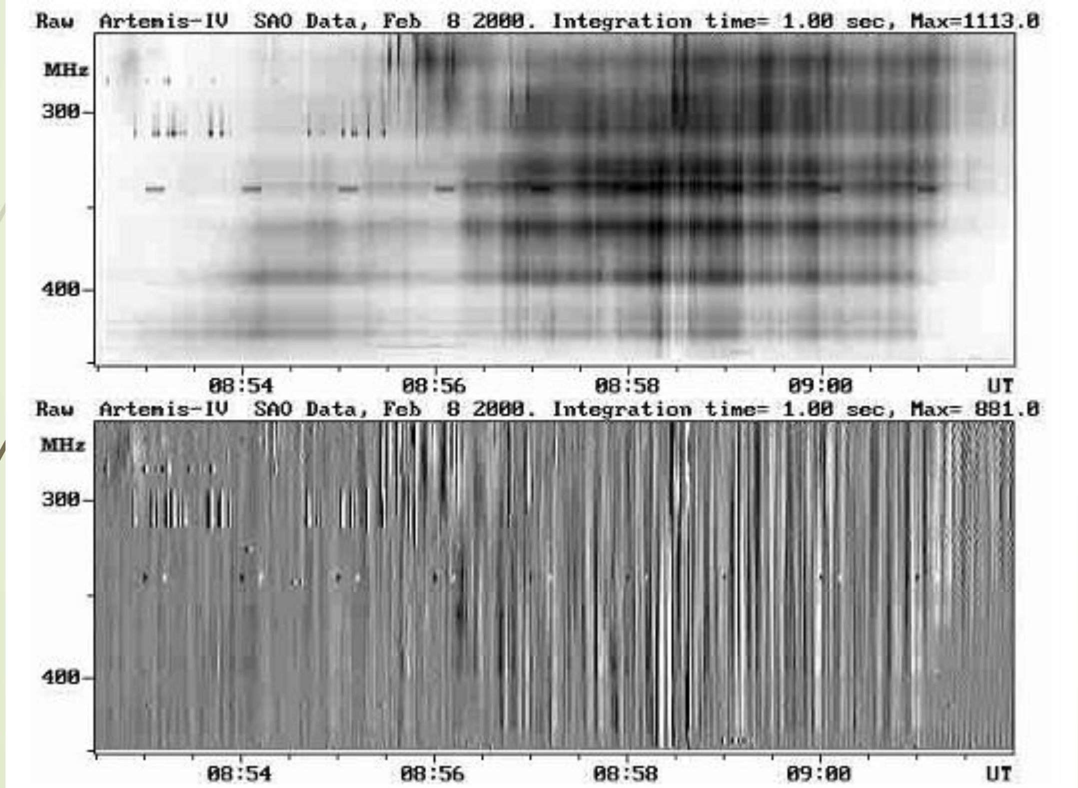
- The continua observed during periods of activity, represent the radiation of <u>energetic electrons trapped within magnetic structures and plasmoids</u> (i.e. blobs of dense plasma containing their own magnetic field) and they appear under the name **type IV bursts**.



ASG dynamic spectrum of the 2000 February 8 type II/IV event, preceded by a type III group with time resolution 1.0 s. The bursts of different types have been annotated on image. <u>Upper panel</u>: **intensity spectrum**, <u>Lower panel</u>: **differential spectrum** (time derivative of intensity).

Solar Radio Bursts : What?? Type IV Radio Bursts

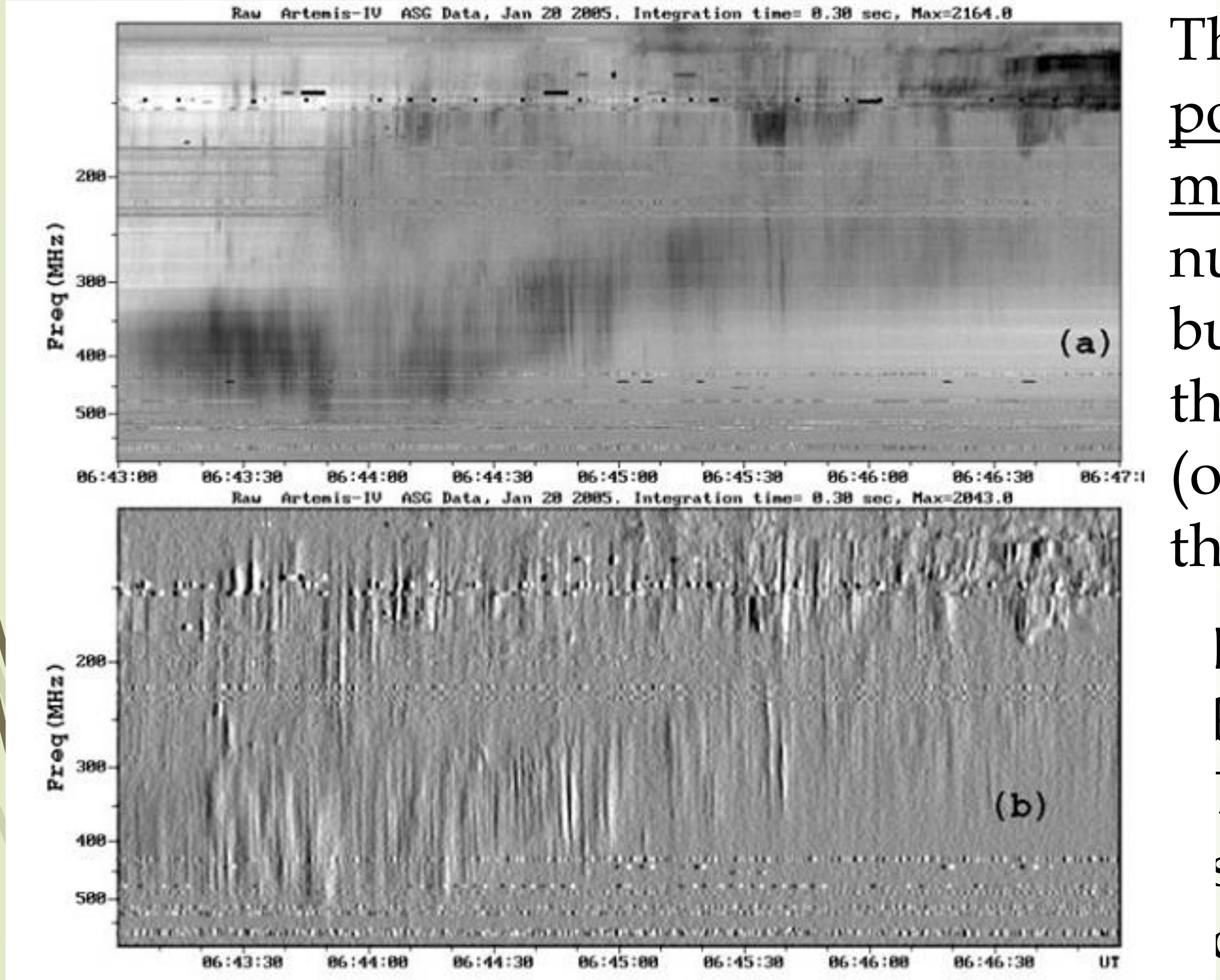
The stationary type IV bursts (IV mB) emanate from magnetic structures usually located above active regions.



SAO dynamic spectrum of the type IV burst of the 2000 February 8 complex event shown in Fig. 1. Upper panel: intensity spectrum, Lower panel: differential spectrum, which enhances the fine structure (pulsating) of the type IV continuum.

Solar Radio Bursts : What?? Type IV Radio Bursts

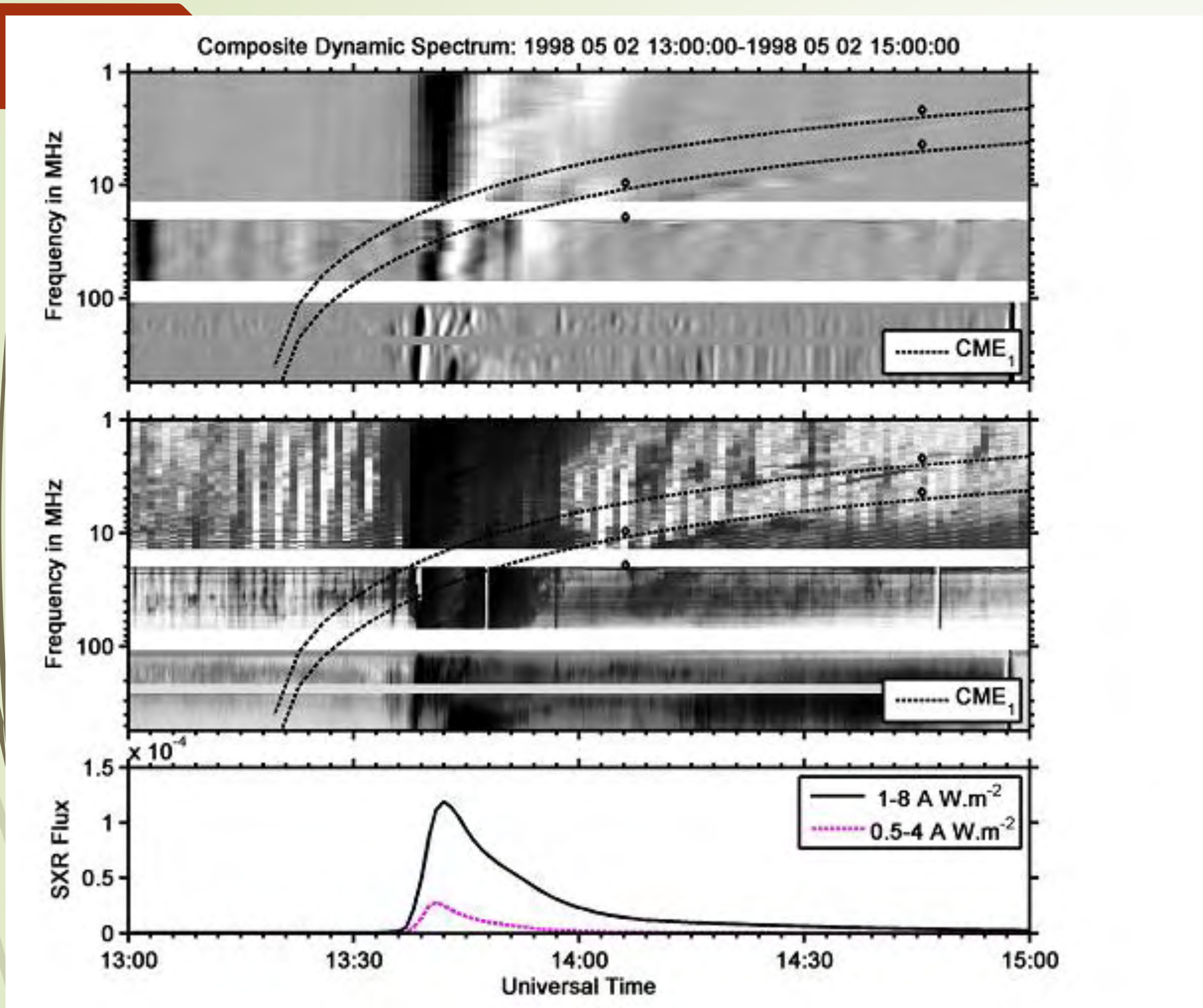
The moving type IV bursts are emitted from sources of meter wave continuum which move outwards at velocities ~100−1000 kms^{-1}; they sometimes last more than 10 min.



They originate from energetic electron populations trapped in expanding magnetic arches or plasmoids. A number of moving **type IV (IV mA)** bursts are believed to originate within the densest substructures of CMEs (often the erupting prominences within the CMEs).

Fig: ARTEMIS-IV Spectra of II, **IV mA**, bidirectional Type III and reverse-drift Type III bursts; (a) ASG dynamic spectrum (06:43 – 06:47 UT) (b) ASG differential spectrum,

Solar Radio Bursts : What?? Type IV Radio Bursts



02 May 1998 event. Top panel: Wind/WAVES and ARTEMIS-IV differential spectrum. Middle panel: dynamic spectrum. The frequency–time plots derived from the linear fit to the front trajectory of the associated CME and an empirical density model for the fundamental and harmonic (thick-dotted curves) plasma emission are overlaid on the spectra. Bottom panel: the profiles of GOES SXR 1 – 8 Å (solid black line) and 0.5 – 4 Å (thick-dotted magenta line) flux.

Interplanetary type IV mA burst within CME structure