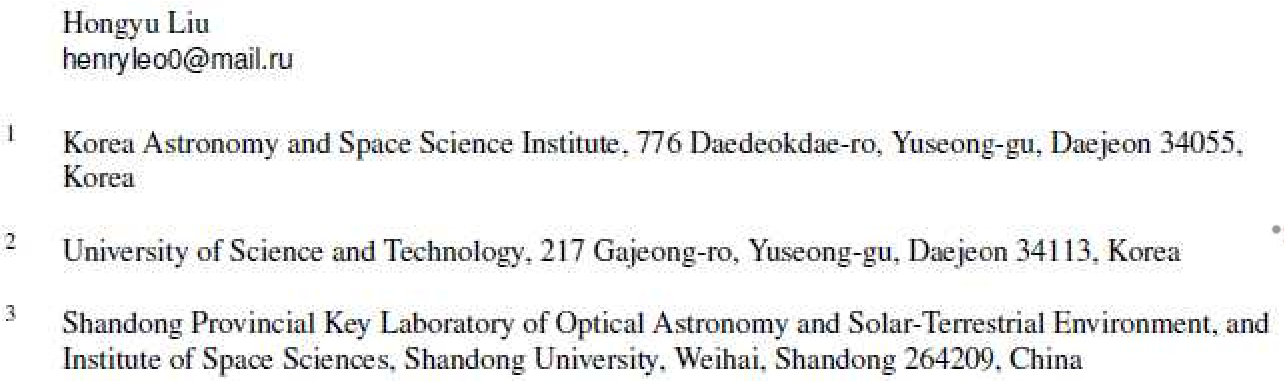
A Solar Stationary Type IV Radio Burst and its Radiation Mechanism

Hongyu Liu

Sep. 21, 2017 Jeju



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Outline

1 Introduction

2 Observations of Type IV Event on 20110924

3 Summary&Radiation Mechanism Interpretation

1 Introduction

1) Solar radio bursts and Type IV bursts

2) Important Physical parameters

3) Stationary Type IV general features

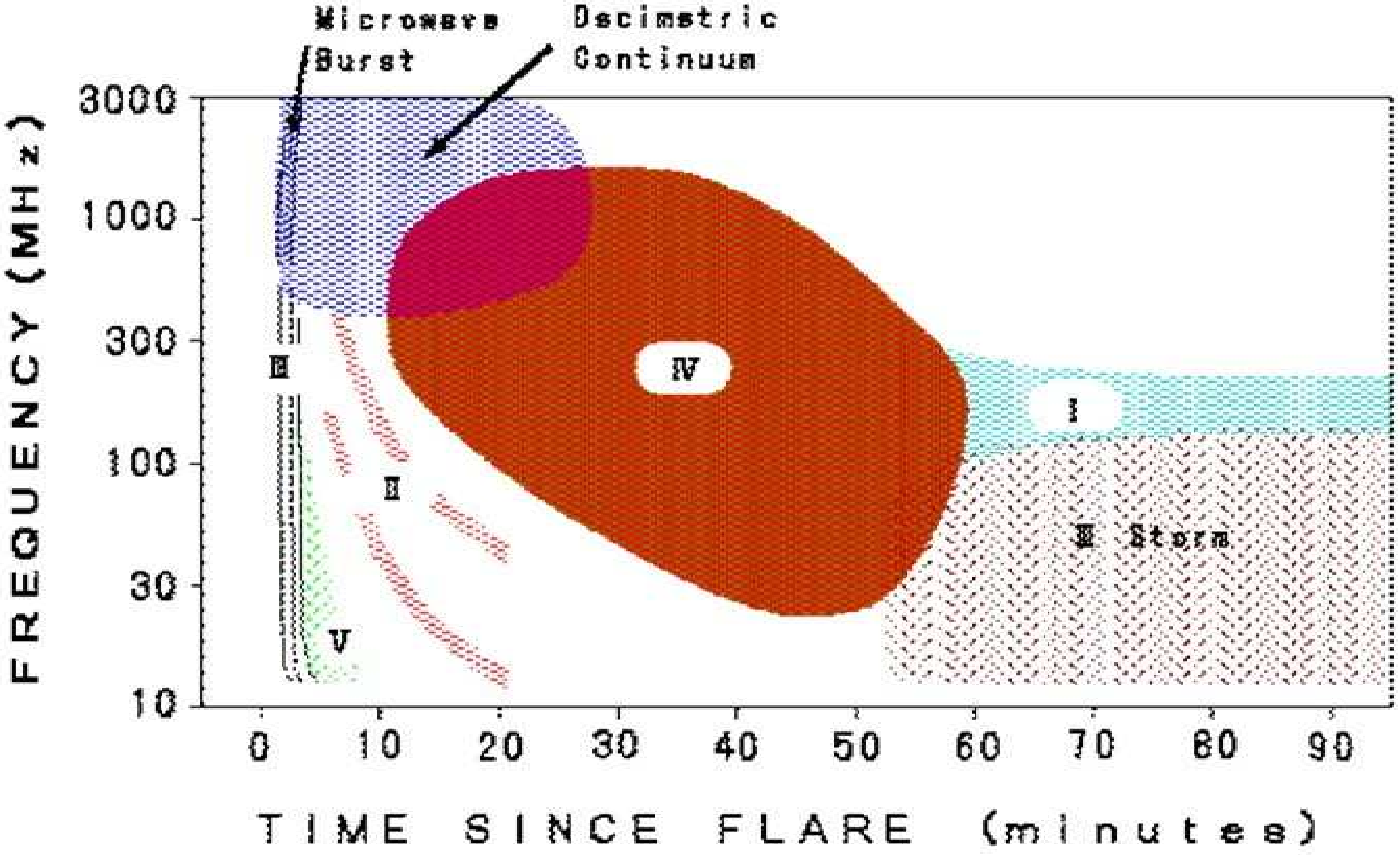
4) Gyrosynchrotron and plasma radiation

5) Solar radio spectrometer and radioheliograph

6) Previous similar study

What is Solar Radio Burst?

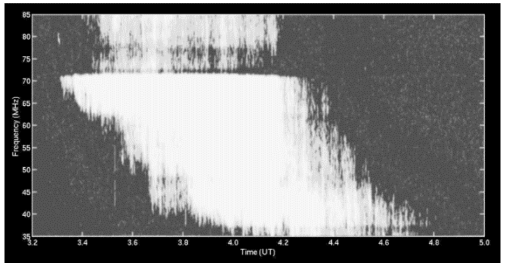
intense increase of radio frequency radiation induced by solar eruptions



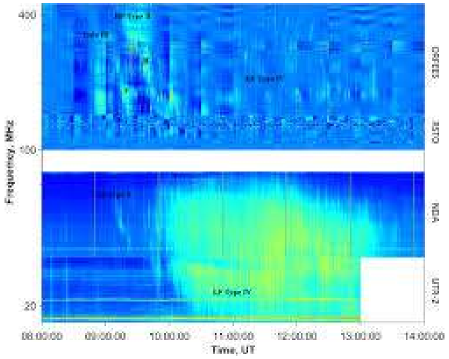
Type IV Radio Bursts

Broadband meter wavelength continuum which lasts for relatively long time.

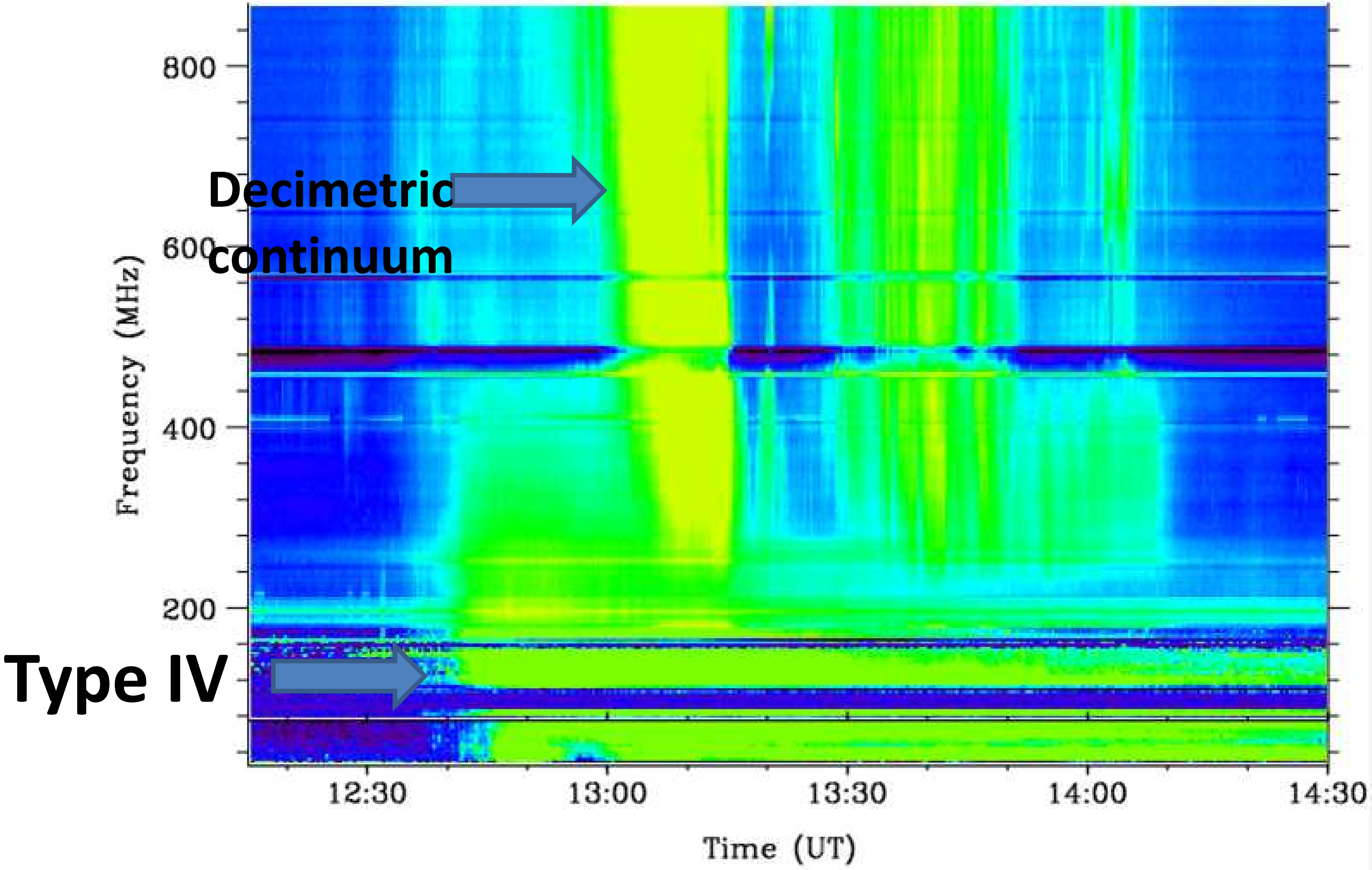
Moving Type IV(IVm) : Drift, Gyrosynchrotron,Plasma Radiation?



Stationary Type IV(IVs): No drift, Plasma Radiation?



Radio Dynamic Spectrum of 20110924



Important Physical Parameters

Brightness Temperature:Tb

Define a Temperature to indicate the intensity at a frequency that equals a **black body radiation**

Degree of Polarization: P

Stokes Parameters:I,Q,U,V, $Q^2 + U^2 + V^2 = I^2$ I~Intensity

Circular Degree of Polarization P=V/I

Spectral Index: α

Given frequency f and radiative flux S, spectral index α satisfies

$$S = f^{\alpha}$$

Stationary Type IV

Common fea

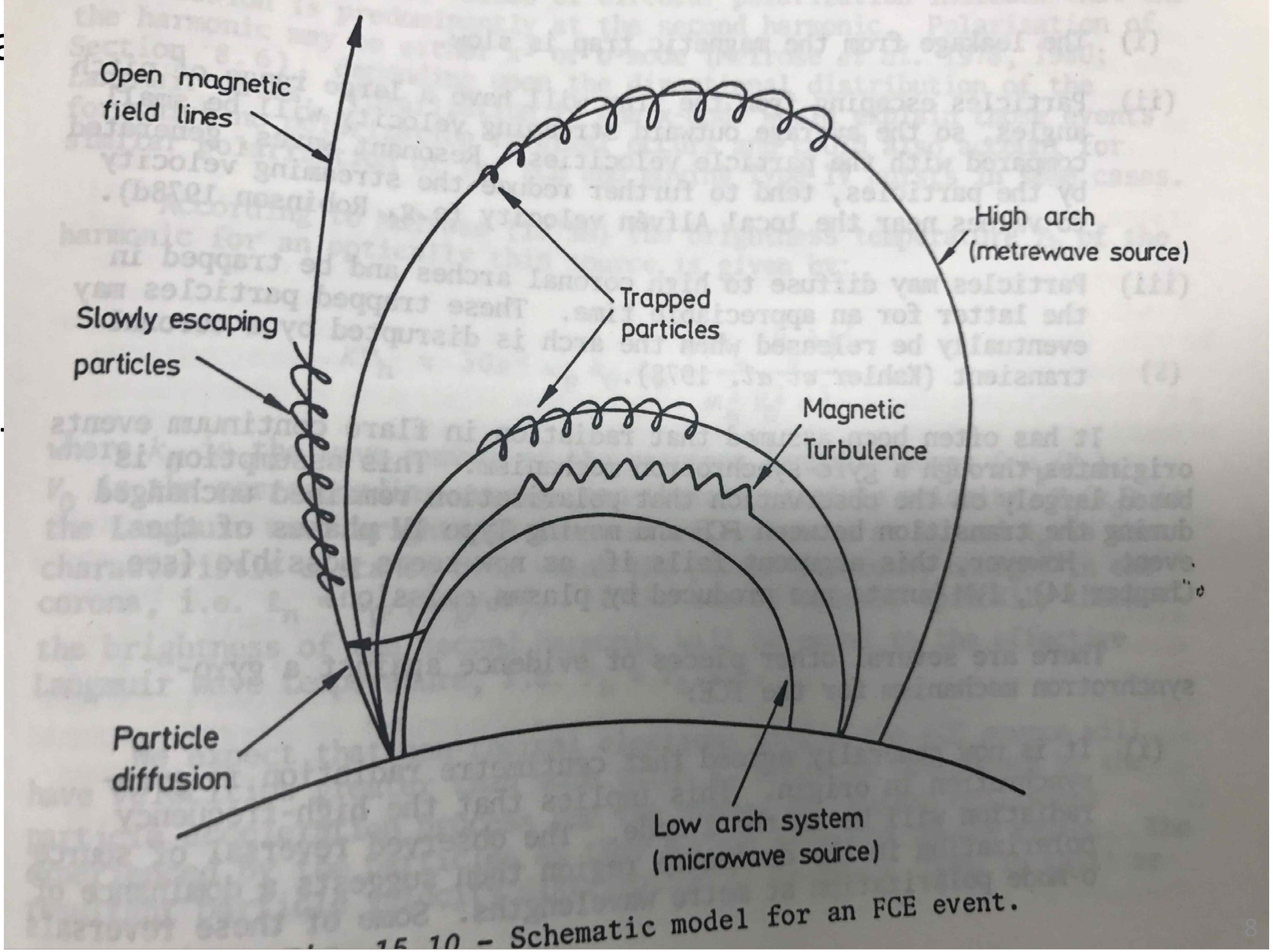
Polarization

Tb high

Continuous

Turn gradua

Mechanism



15.10 – Schematic model for an FCE event.

Radiation Mechanisms for Solar Radio Bursts

Synchrotron emission(fully relativistic)

Gyrosynchrotron radiation(partly relativistic)

Gyrosynchrotron: Cyclotron(non-relativistic) × Synchrotron

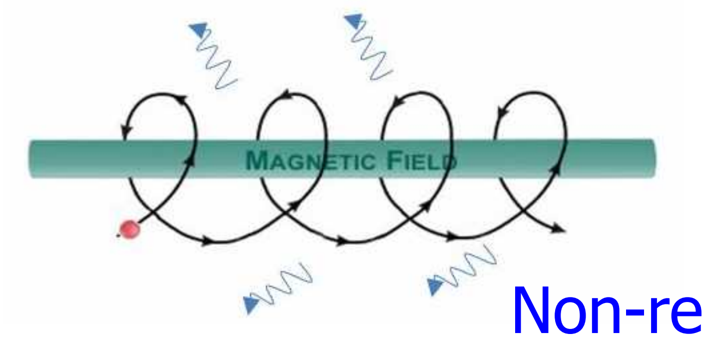
Plasma Emission(fundamental, harmonic)

ECME(Electron Cyclotron Maser Effect)

Incoherent <-----> coherent

Tb low(max~10^9) Tb high

Gyrosynchrotron radiation



Non-relativistic: γ-1<<1 (thermal)

cyclotron or gyroresonance radiation

Fully-relativisitic: γ-1>>1 (non-thermal)

synchrotron radiation

Mildly relativisitic: γ-1~1-5 (thermal/non-thermal)

gyrosynchrotron radiation

Radiation frequency: gyrofrequency

Tb: less than 10^9

(Stewart, 1978)

Gyrosynchrotron radiation(incoherent)

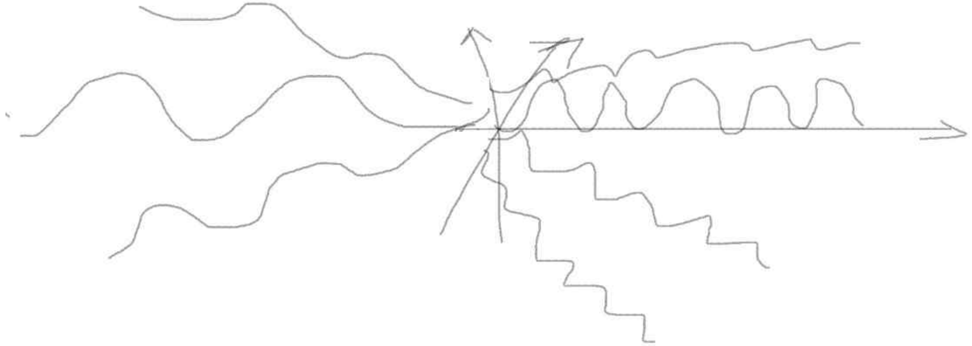
Cyclotron

Polarization:Any(elliptical)

Synchrotron emission(fully relativistic)

Polarization:

Linear Polarized (main reason:Doppler effect)



Gyrosynchrotron radiation:Any

Plasma Emission

$$f = 9000\sqrt{n_e} \qquad f_{2h} \approx 2f_f$$

Fundamental : high p, Tb low usually

Second harmonic: low p, Tb high

Lakhina et al. 1985 (SoPh)

For most type I, II, IVs, V

Fundamental can be **AMPLIFIED** to 10^16K

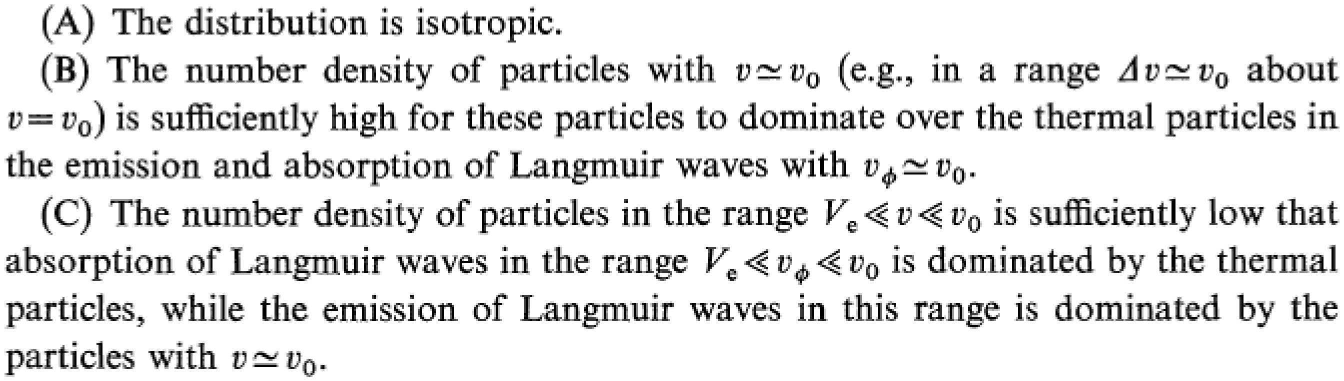
Second harmonic can be 10^13K

Melrose 1975(SoPh)

Amplification of Plasma Emission

Only Fundamental :

In case of a ***gap distribution***, fundamental can be AMPLIFIED to 10^16K . Gap distribution requires:



(A) The distribution is isotropic.

(B) The number density of particles with $v \simeq v_0$ (e.g., in a range $\Delta v \simeq v_0$ about $v = v_0$) is sufficiently high for these particles to dominate over the thermal particles in the emission and absorption of Langmuir waves with $v_\phi \simeq v_0$.

(C) The number density of particles in the range $V_e \ll v \ll v_0$ is sufficiently low that absorption of Langmuir waves in the range $V_e \ll v_\phi \ll v_0$ is dominated by the thermal particles, while the emission of Langmuir waves in this range is dominated by the particles with $v \simeq v_0$.

Not possible for ***power law*** distributions

Melrose
1975(SoPh)

Electron Cyclotron Maser(ECM) Emission

Twiss (1958) first pointed out the possibility of the ECM instability to directly amplify the high-frequency electromagnetic waves at frequencies close to the electron cyclotron frequency and its harmonics

Electron Cyclotron Maser(ECM) Emission

Wu & Lee (1979) suggested electron distribution function, which is responsible for the ECM instability, is a so-called loss-cone distribution with $\frac{\partial f}{\partial v} > 0$ in a certain region around the loss cone and considering relativistic effect.

(f-distribution function)

This made it possible to explain radio bursts

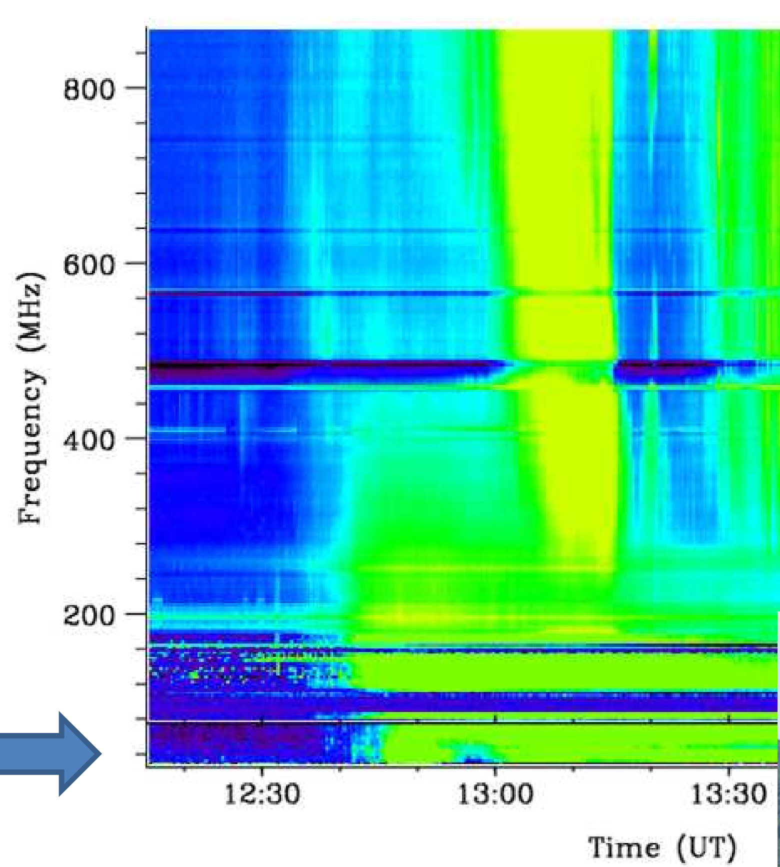
Solar Radio Spectrometer

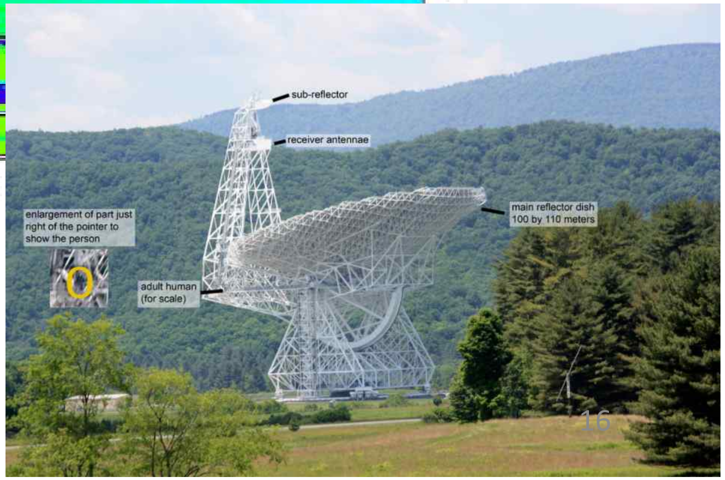
BLEN7M

100-900 MHz

SGMR

25-75MHz





Solar Radioheliograph

Nançay RadioHeliograph(NRH,Fr) Tb, Stokes I, V


24 Sep 2011

Starting hour : 12:00
Frame rate : 120 secs/frame
freq 150/164 MHz
nb of images : 240

13:05:52 24SEP2011 150.9MHz

Frame: Displaying 33 of 96
Speed: 12 (frames/sec)

Swing Mode: OFF

Others:

LOFAR(Netherland) MUSER(China) , GRAPH(India),UTR-2(Ukraine),MWA(Austalia)…

NoRH(17GHz&34GHz,Japan) SSRT(5.7GHz,Russia)…

Previous similar studies

My study will be conducted to

Get NRH&AIA combined data to locate the source

Tb,Polarization,particle distribution&Spectral index

Interpret radiation mechanism

previous:

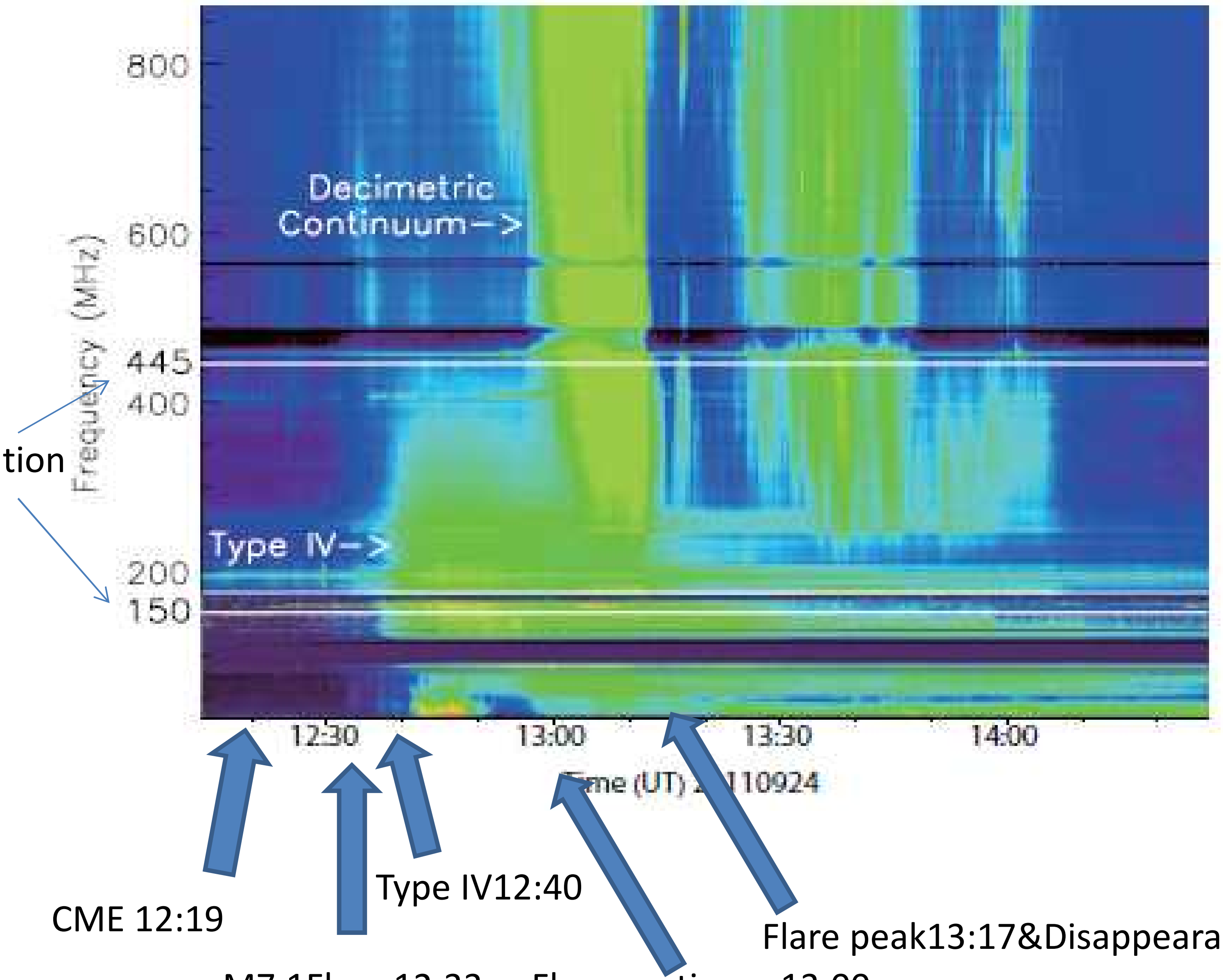
Bain, 2014 on a IVm, NRH&Stereo, Gyrosynchrotron

Vasanth, 2016 on a IVm, NRH&SDO, plasmoid, eruptive hot channel

Koval, 2016 IVs, UTR-2&NRH&AIA&LASCO-C2, focus on correlation with CME,no mechanism analysis

2 Study on Type IV

Radio Dynamic Spectrum of 20110924



NRH
observation
range

CME 12:19

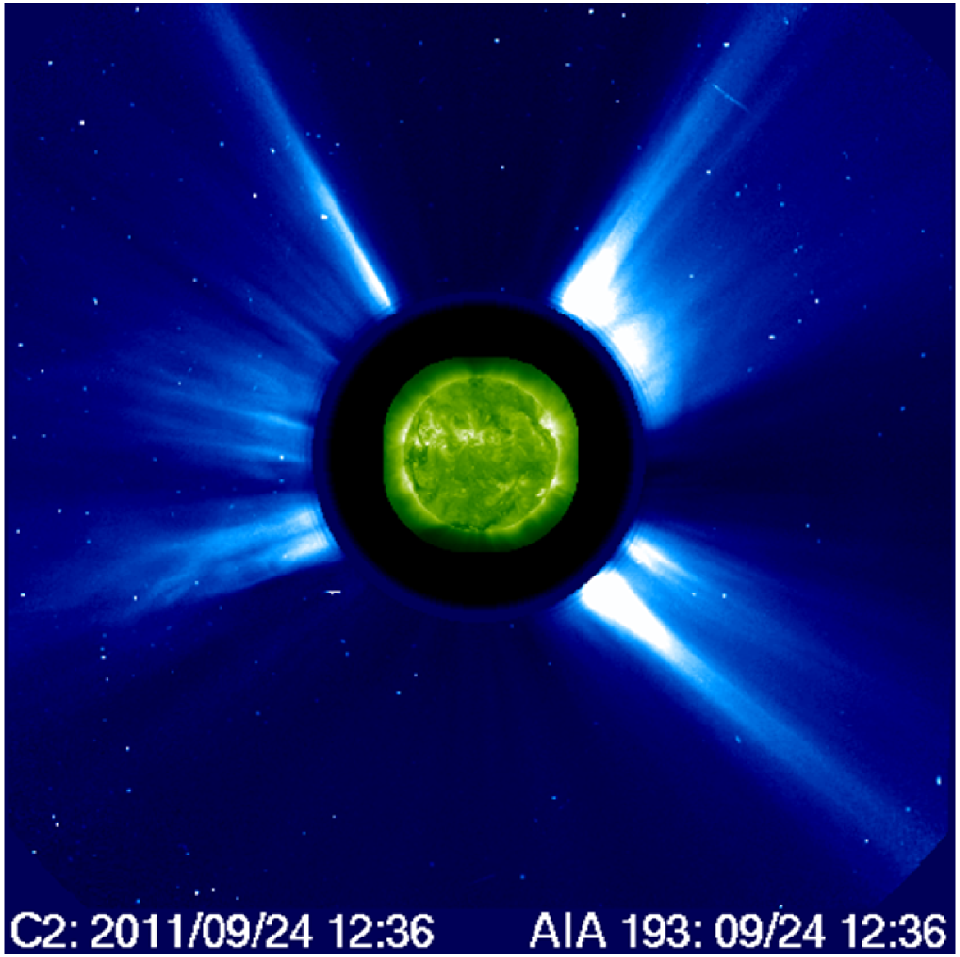
M7.1Flare 12:33

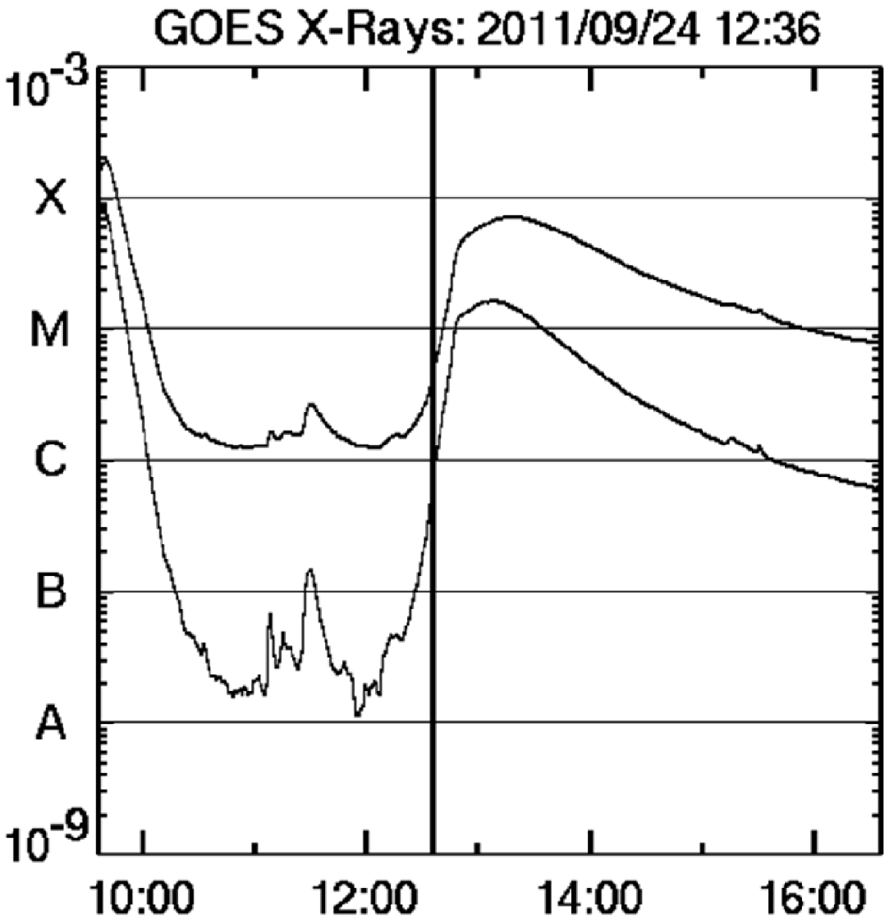
Type IV12:40

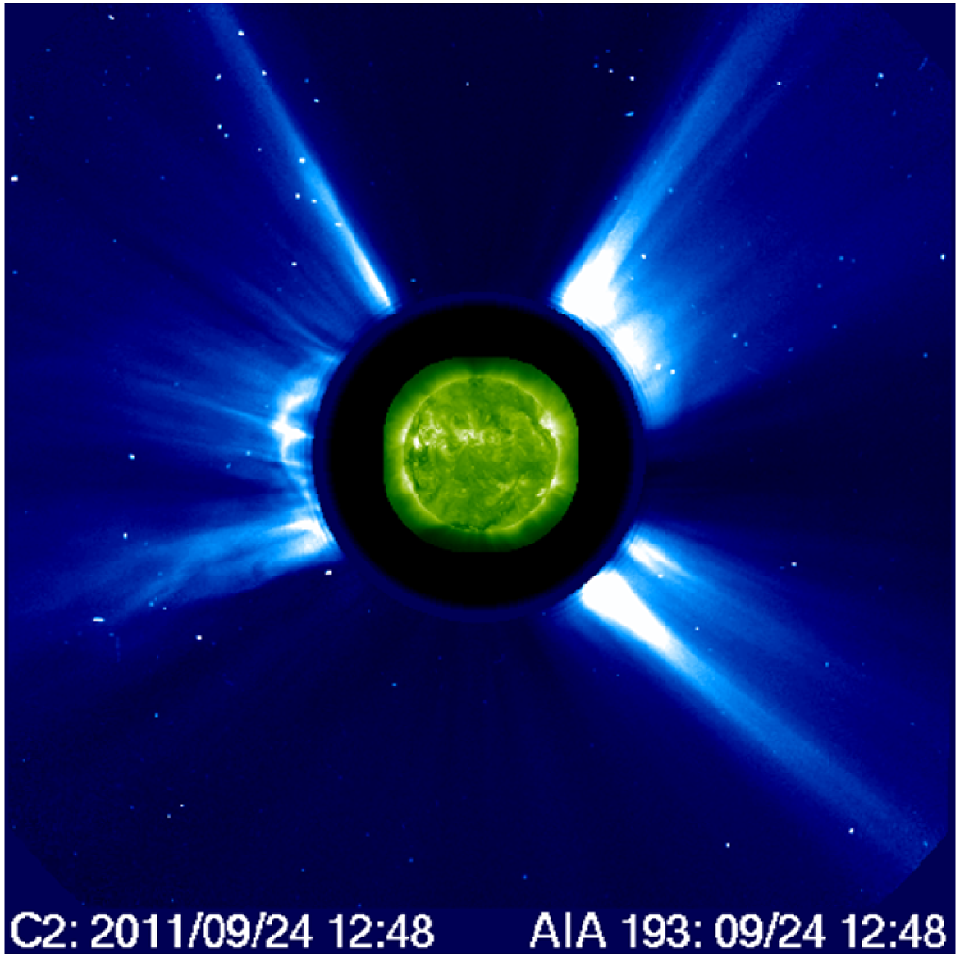
Flare contiuum 13:00

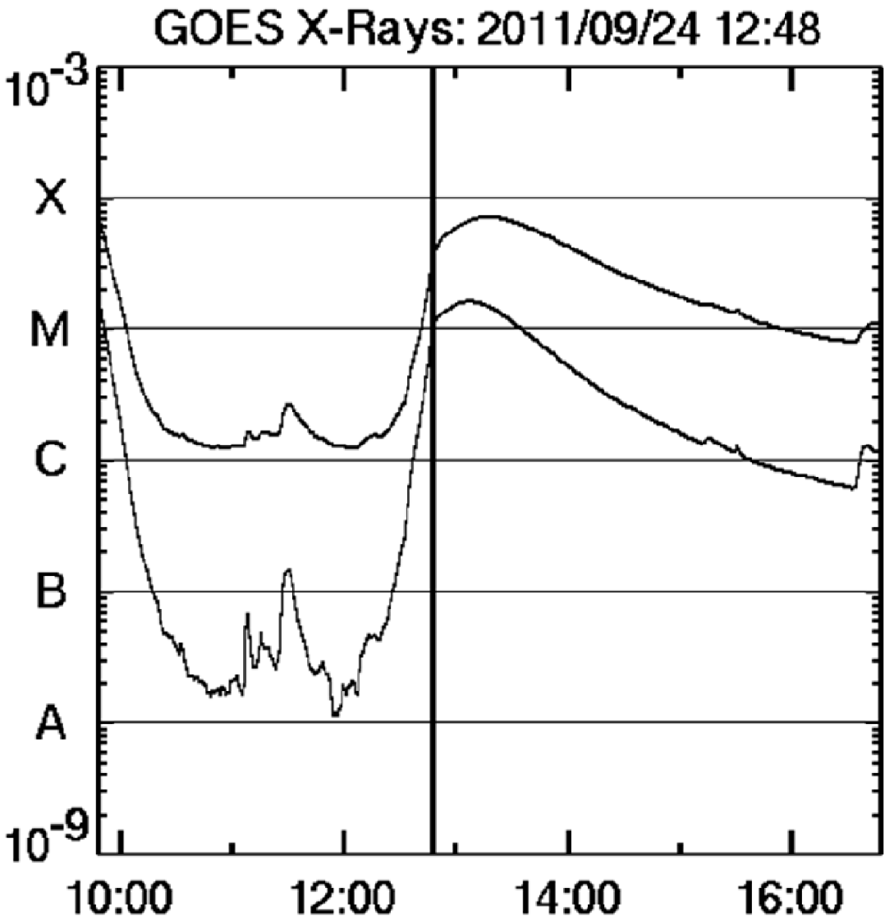
Flare peak13:17&Disappearance of FC

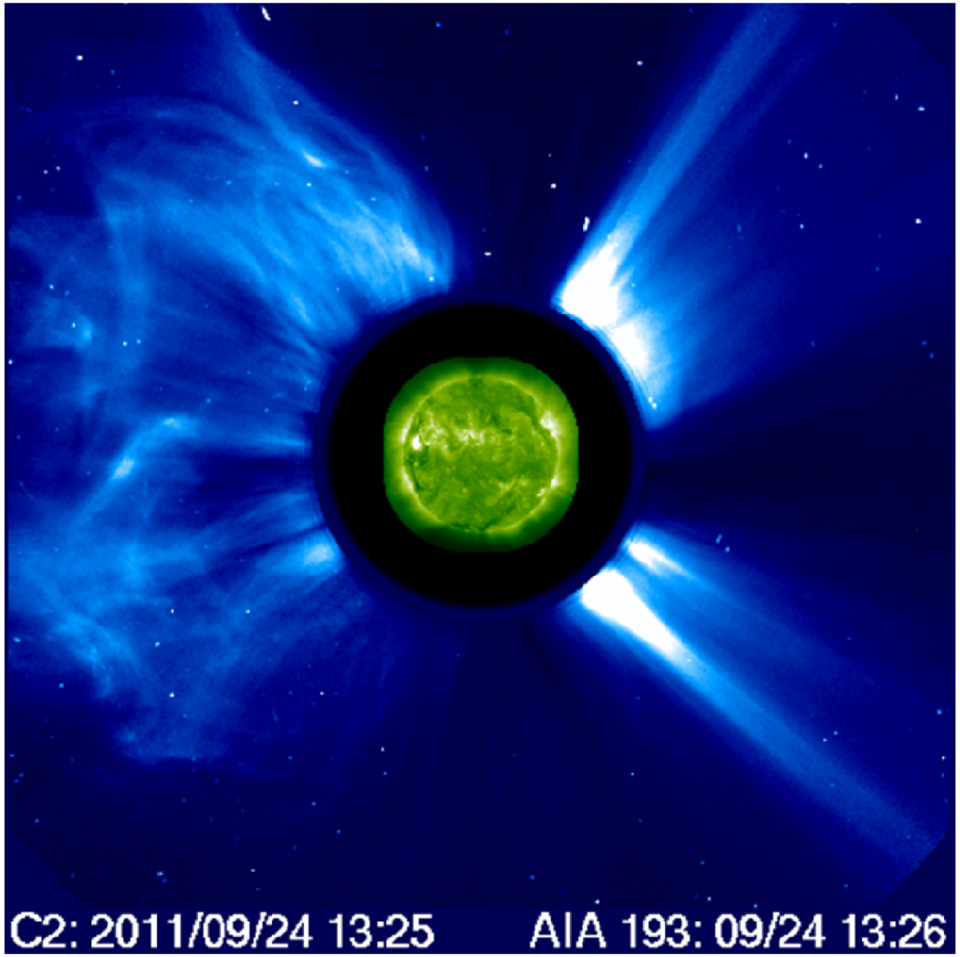
CME Before Type IV

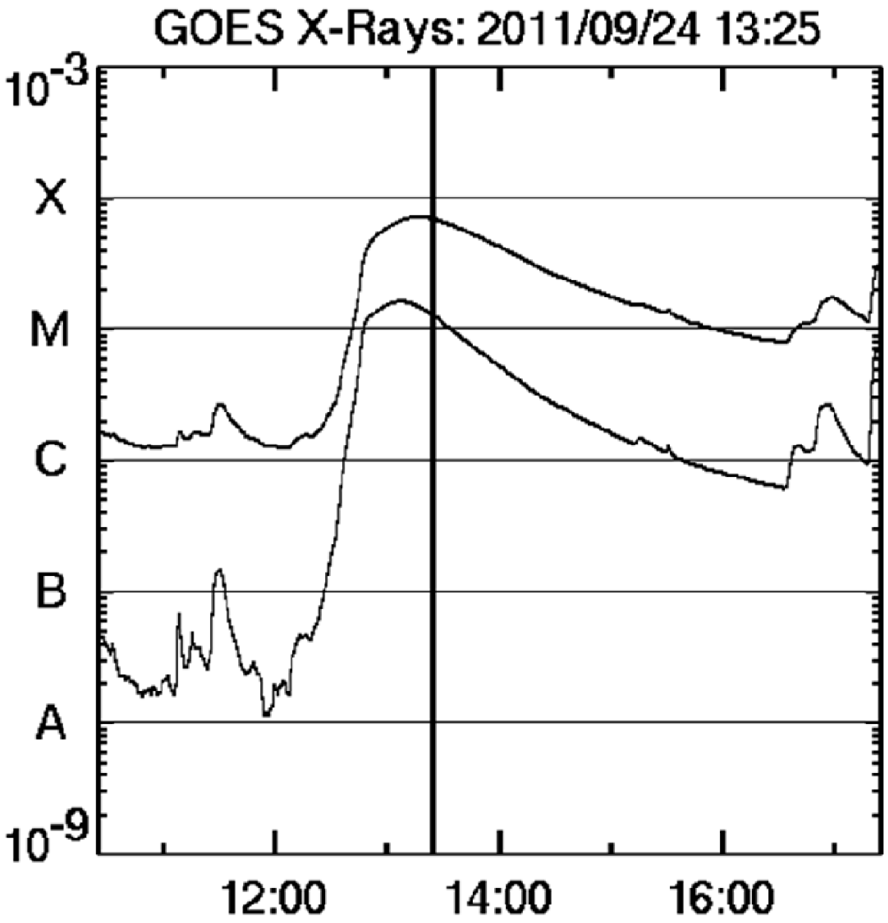


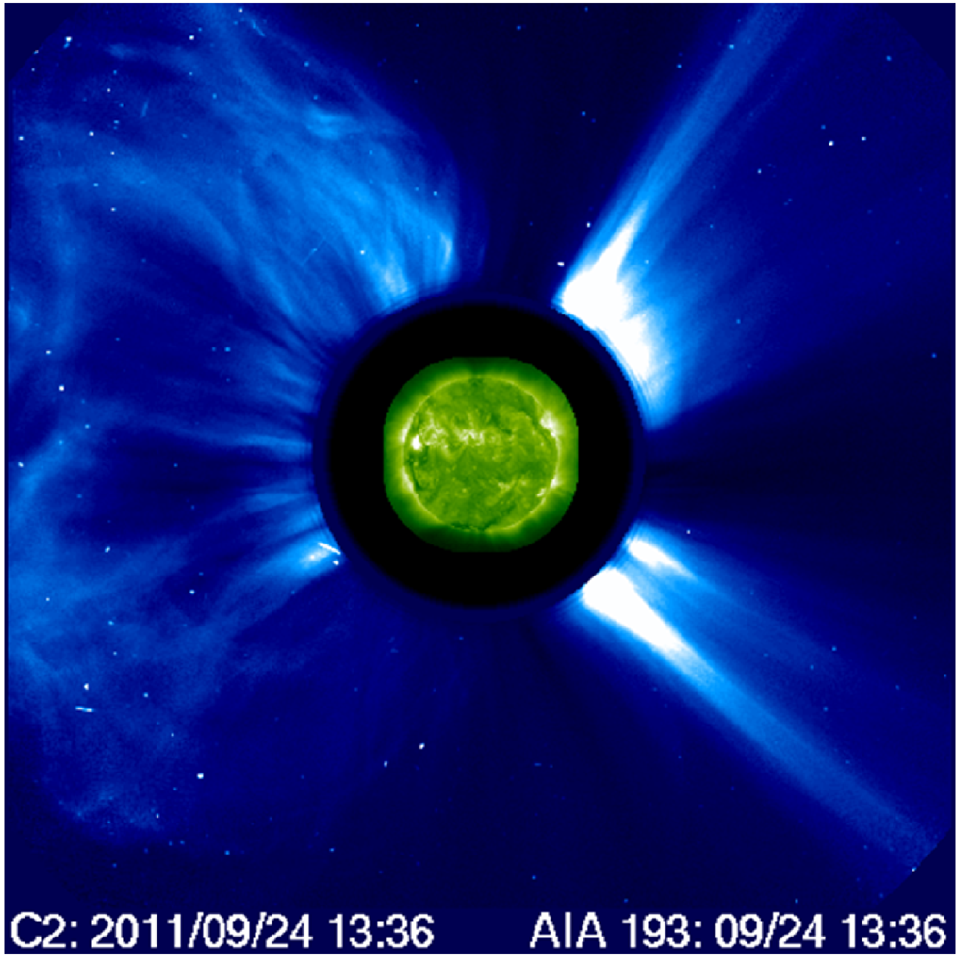


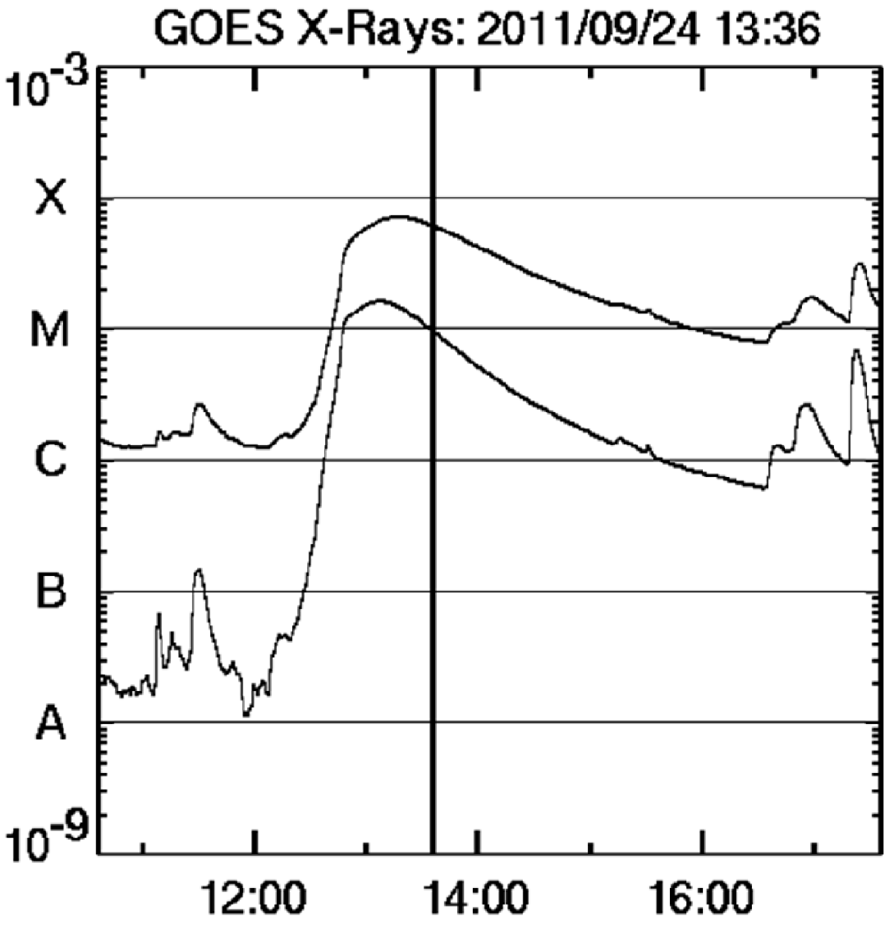

C2: 2011/09/24 12:48
AIA 193: 09/24 12:48


GOES X-Rays: 2011/09/24 12:48
10^{-3}
X
M
C
B
A
10^{-9}
10:00
12:00
14:00
16:00


C2: 2011/09/24 13:25
AIA 193: 09/24 13:26


GOES X-Rays: 2011/09/24 13:25
10^-3
X
M
C
B
A
10^-9
12:00
14:00
16:00


C2: 2011/09/24 13:36
AIA 193: 09/24 13:36


GOES X-Rays: 2011/09/24 13:36
10^{-3}
X
M
C
B
A
10^{-9}
12:00
14:00
16:00

AIA-NRH movie

94

131

171

1, stationary

2, sources on a open field line, from the foot point, Slowly escaping particles

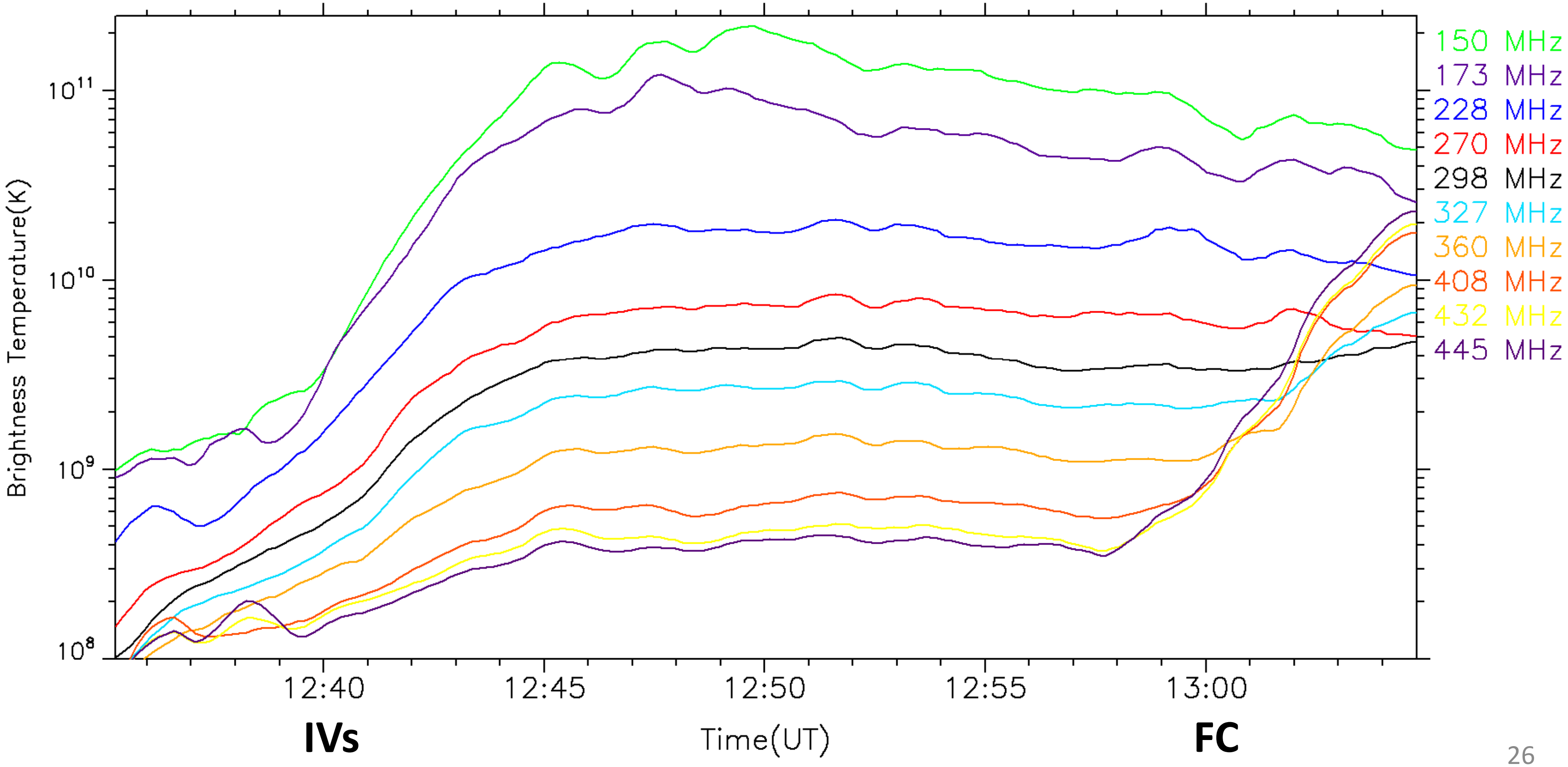
Brightness temperature calculation

Read directly from NRH fits file

Highest over 10^{11} K

frequency high, Tb low

Over 10^{8} K

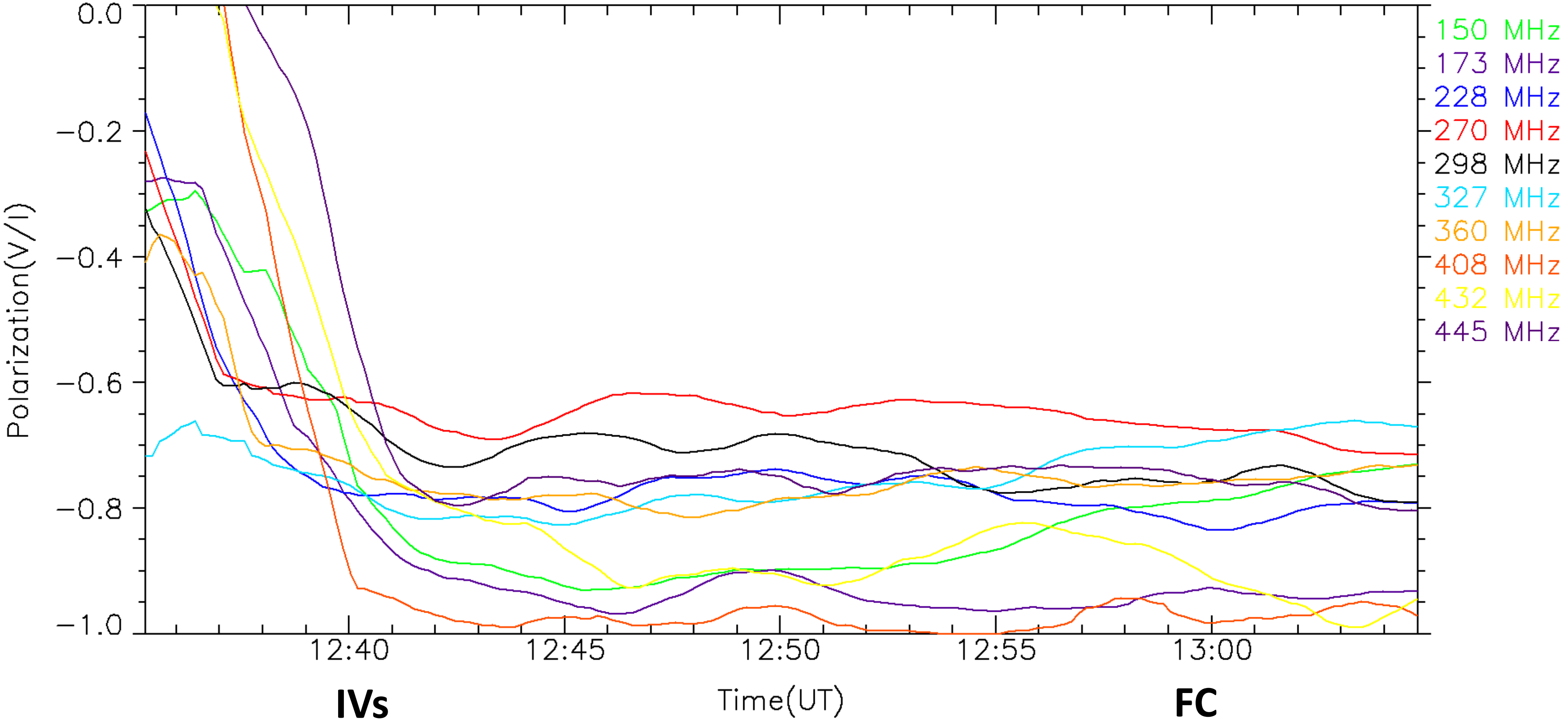


Degree of Polarization(circular) calculation

Read Stokes I and V from NRH fits file

P=V/I

Polarizations from 60% to 100%   left-hand polarized



Flux-Frequency relation(distribution):

Read flux directly from NRH fits file

Type IV 12:40

Flare continuum 13:00

Always follows power-law distribution

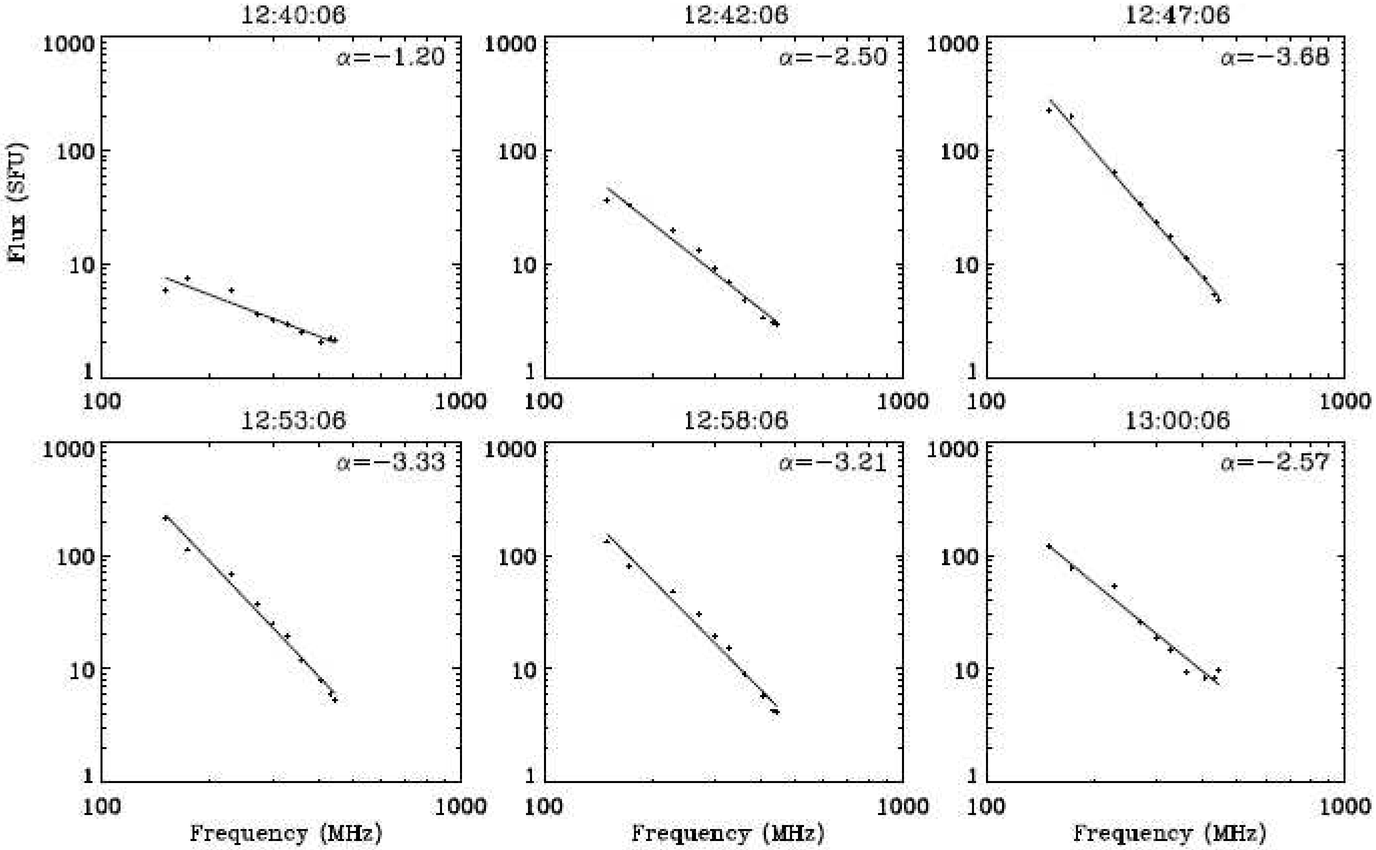


Figure 5. Linear fit of flux-frequency spectrum using NRH 10-frequency data from 12:40 UT to 13:00 UT. The dots are the flux data of 10 NRH frequencies in S.F.U. Spectral index (α) is shown on the upper right corner.

Spectral Index

Given frequency f and radiative flux S, spectral index α satisfies

$$S = f^{\alpha}$$

spectral index between -3 and -4

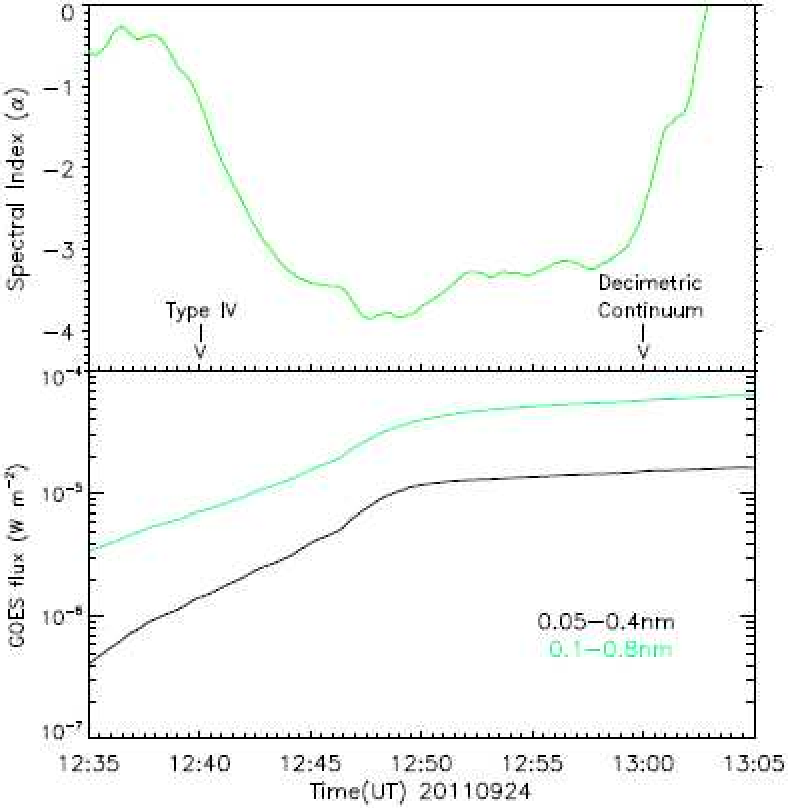


Figure 6. Temporal variation of the spectral index from 12:35 UT to 13:05 UT. GOES X-ray data are also plotted in the lower panel. The flare starts at 12:33 UT, and peaks at 13:17 UT, which means that the whole process happens during the rising phase of the flare. IVs occurs at 12:40 UT, and a decimetric continuum appears at 13:00 UT.

3 Summary and Radiation Mechanism Interpretation

Summary

*IVs with Tb > 10^8K,sometimes 10^11K; high P~100% left handed(-); power law distribution, with spectral index α -3~-4

*slowly escaping energetic particles along magnetic field line, source from loop foot point

Radiation Mechanism

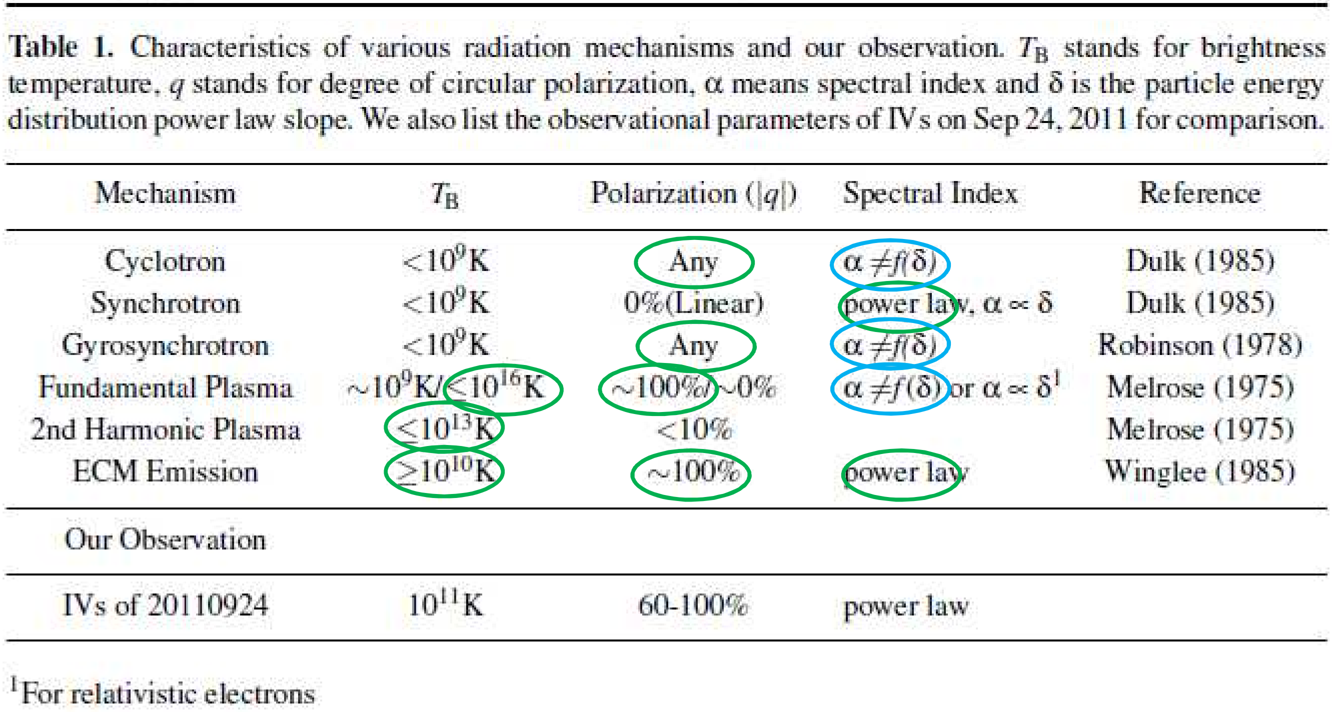


Table 1. Characteristics of various radiation mechanisms and our observation. T_B stands for brightness temperature, q stands for degree of circular polarization, α means spectral index and δ is the particle energy distribution power law slope. We also list the observational parameters of IVs on Sep 24, 2011 for comparison.

Mechanism	T_B	Polarization ($\|q\|$)	Spectral Index	Reference
Cyclotron	$<10^9$K	Any	$\alpha \neq f(\delta)$	Dulk (1985)
Synchrotron	$<10^9$K	0%(Linear)	power law, $\alpha \propto \delta$	Dulk (1985)
Gyrosynchrotron	$<10^9$K	Any	$\alpha \neq f(\delta)$	Robinson (1978)
Fundamental Plasma	$\sim 10^9$K/$\leq 10^{16}$K	$\sim$100%/$\sim$0%	$\alpha \neq f(\delta)$ or $\alpha \propto \delta^1$	Melrose (1975)
2nd Harmonic Plasma	$\leq 10^{13}$K	$<$10%		Melrose (1975)
ECM Emission	$\geq 10^{10}$K	$\sim$100%	power law	Winglee (1985)
Our Observation				
IVs of 20110924	10^{11}K	60-100%	power law	

[1] For relativistic electrons

Tb is high,so there should be considerable relativistic effect

For relativistic electrons, for plasma radiation, $\alpha \propto \delta$ (Kaplan and Tsytovich, 1969).

fundamental plasma radiation can't be amplified by power law electrons

ECM Emission!

Radiation Mechanism

ECM emission usually exhibits small time-scale spikes, which is less than 0.1s (Aschwanden, 2004).

However, we reiterate that long duration continuum has also been explained by ECM emission(Winglee and Dulk, 1986).

Moreover, Zhao et al. (2013) has developed a theory to explain the type I radio burst with the ECM mechanism, which is also long duration continuum.

Type I Burst(Noise Storm)

Common features:

Long duration

Continuum emission

Polarization high~ 100%

Tb High

Conclusion

IVs

Source region along magnetic field line(open or high lying loop)

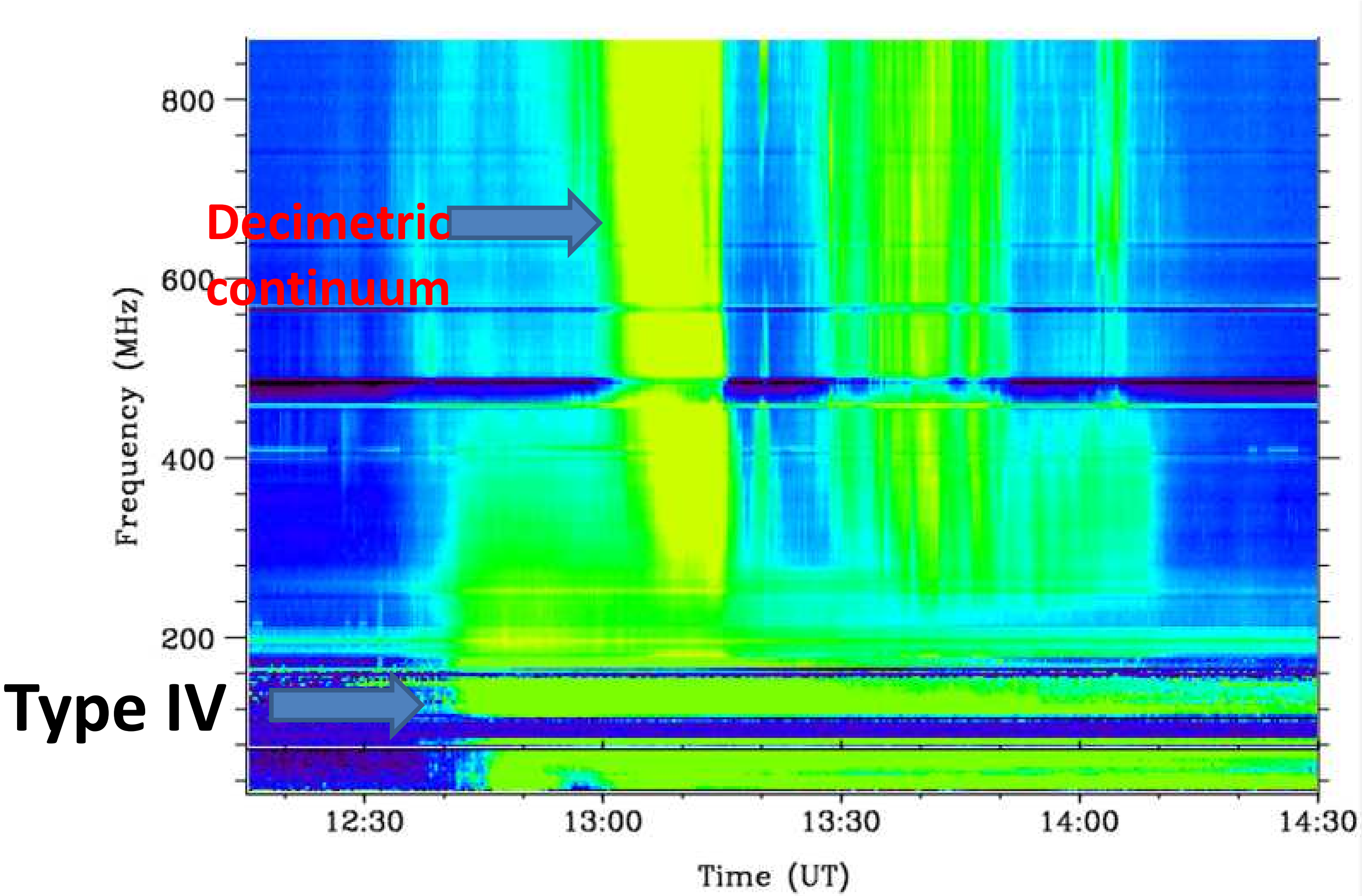
Tbis high 10^8~10^11K

Degree of circular polarization -60~ -100%

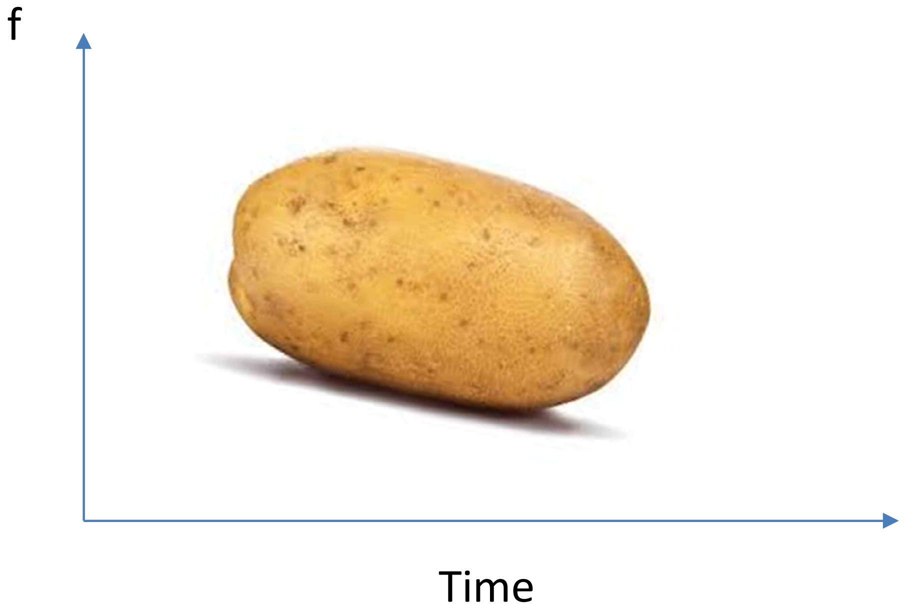
Power law, spectal index -3~-4

ECM emission mechanism

Discussion


Decimetric continuum
Type IV
800
600
400
200
Frequency (MHz)
12:30
13:00
13:30
14:00
14:30
Time (UT)

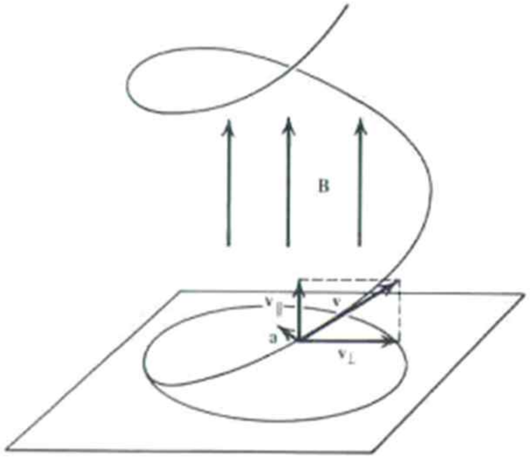
Sorry for the long post



Gyroemission

Gyroemission is due to the acceleration experienced by an electron as it gyrates in a magnetic field due to the Lorentz force. The acceleration is perpendicular to the instantaneous velocity of the electron.

When the electron velocity is nonrelativisitic ($v<<c$ or $\gamma-1<<1$) the radiation pattern is just the dipole pattern.



Non-relativistic: γ-1<<1 (thermal)

cyclotron or gyroresonance radiation

Mildly relativisitic: γ-1~1-5 (thermal/non-thermal)

gyrosynchrotron radiation

Ultra-relativisitic: γ-1>>1 (non-thermal)

synchrotron radiation

Radiation frequency: gyrofrequency

Tb: less than 10^9
(Stewart, 1978)

Gyrosynchrotron radiation(incoherent)

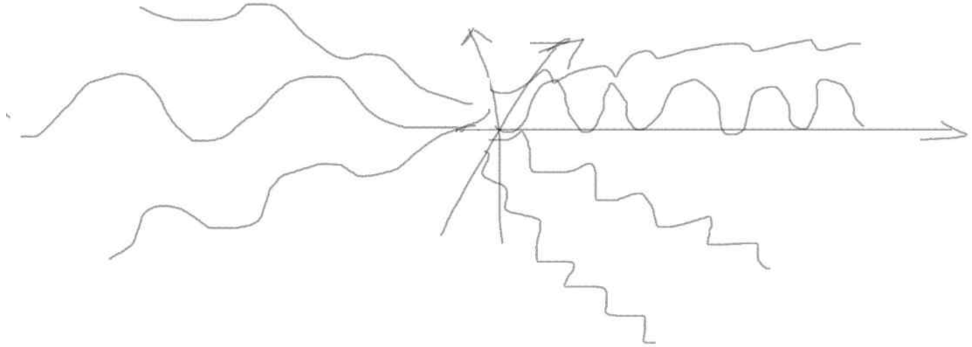
Cyclotron non-relativistic

Polarization:Any(elliptical)

Synchrotron emission(fully relativistic)

Polarization:

Linear Polarized (main reason:Doppler effect)



Gyrosynchrotron radiation:Any

Plasma radiation

Plasma oscillations (Langmuir waves) are a natural mode of a plasma and can be excited by a variety of mechanisms.

In the Sun's corona, the propagation of electron beams and/or shocks can excite plasma waves.

These are converted from longitudinal oscillations to transverse oscillation through nonlinear wave-wave interactions.

The resulting transverse waves have frequencies near the fundamental or harmonic of the local electron plasma frequency: i.e., ν_{pe} or $2\nu_{pe}$.

Plasma radiation

Plasma radiation is therefore thought to involve several steps:

Fundamental plasma radiation

- A process must occur that is unstable to the production of Langmuir waves
- These must then scatter off of thermal ions or, more likely, low-frequency waves (e.g., ion-acoustic waves)

$\omega_L + \omega_S = \omega_T$ and $k_L + k_S = k_T$ coalescence

or $\omega_L = \omega_S + \omega_T$ $k_L = k_S + k_T$ decay

Plasma radiation

Plasma radiation is therefore thought to involve several steps:

Harmonic plasma radiation

- A process must occur that is unstable to the production of Langmuir waves
- A secondary spectrum of Langmuir waves must be generated
- Two Langmuir waves can then coalesce

$$\omega_L^1 + \omega_L^2 = \omega_T \quad \text{and} \quad k_L^1 + k_L^2 = k_T << k_L$$

$$\omega_T \approx 2\omega_L \qquad k_L^1 \approx -k_L^2$$