SOLAR FLARES AND CMES OBSERVED IN LINEAR AND CIRCULAR POLARISATION WITH THE CALLISTO AND OTHER INSTRUMENTS

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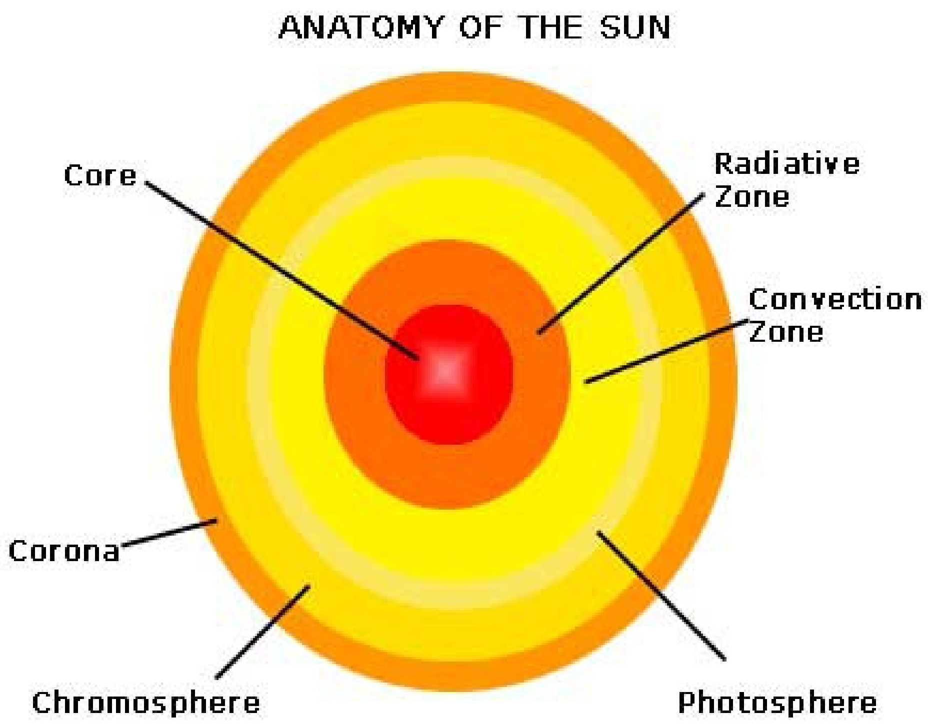
AIMS

- Monitoring Solar Flares and CMEs in both linear & circular polarisation with the CALLISTO (Range: 45 to 870 MHz)
- Classifying the FITS files containing solar flares into different flare types.
- Conducting background subtraction, addition and comparison of data using Python scripts in SunPy.
- Analysing CALLISTO data in conjunction with Nobeyama, Nançay and LASCO data.
- Observation of the 2 hour long (6:30 to 8:30 UT), 15.03.2013 M1 class CME, in 2 linear polarisations.

SOLAR PHYSICS

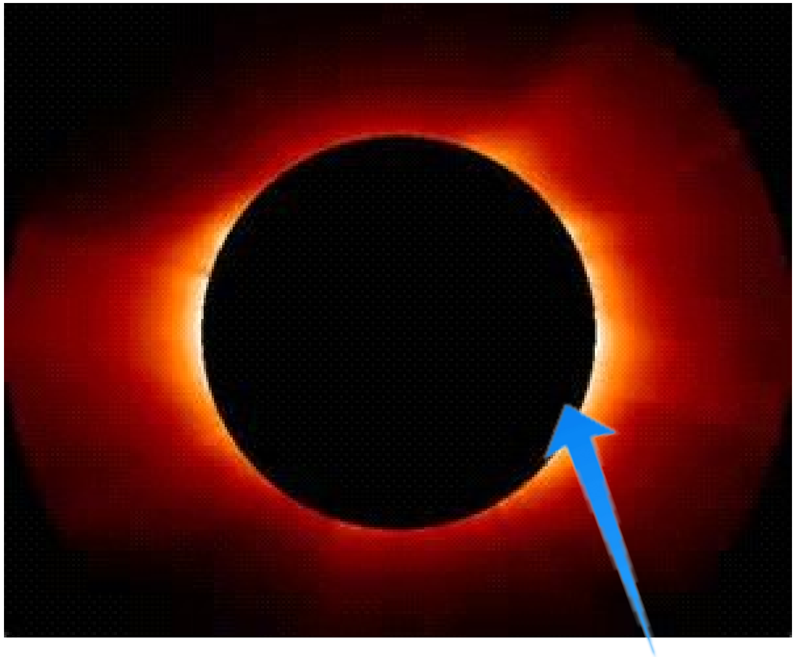


http://www.astronomyknowhow.com/sun.htm

- The core (15×10^6 ^{0}C)
- The radiative zone (15×10^6 – 1×10^6 ^{0}C)
- The convective zone (1×10^6 – 6000 ^{0}C)
- The photosphere (5500 ^{0}C)
- The chromosphere (6000 – 5×10^4 ^{0}C)
- The corona (1 – 2×10^6 ^{0}C) (the outermost region)

THE CORONA

- Final layer of the three regions that make up the sun's atmosphere.
- Widest region of sun's atmosphere.
- Extends over several million kilometres from the photosphere and chromosphere.
- ~ 2 million degrees Kelvin, and hottest layer of Sun.
- Best seen in X-ray images and during solar eclipses.



http://www.qrg.northwestern.edu/projects/vss/docs/space-environment/3-what-is-solar-wind.html

HEATING PROBLEM OF THE CORONA

- The temperature should decrease with height above the Sun. Instead, it increases.
- For this high temperature to exist, there must be a permanent heating mechanism.
- Complex Magneto-hydro-dynamic (MHD) problem
- Two theories for the heating mechanism:

1. Wave heating theory
2. Magnetic reconnection theory

SOLAR FLARES

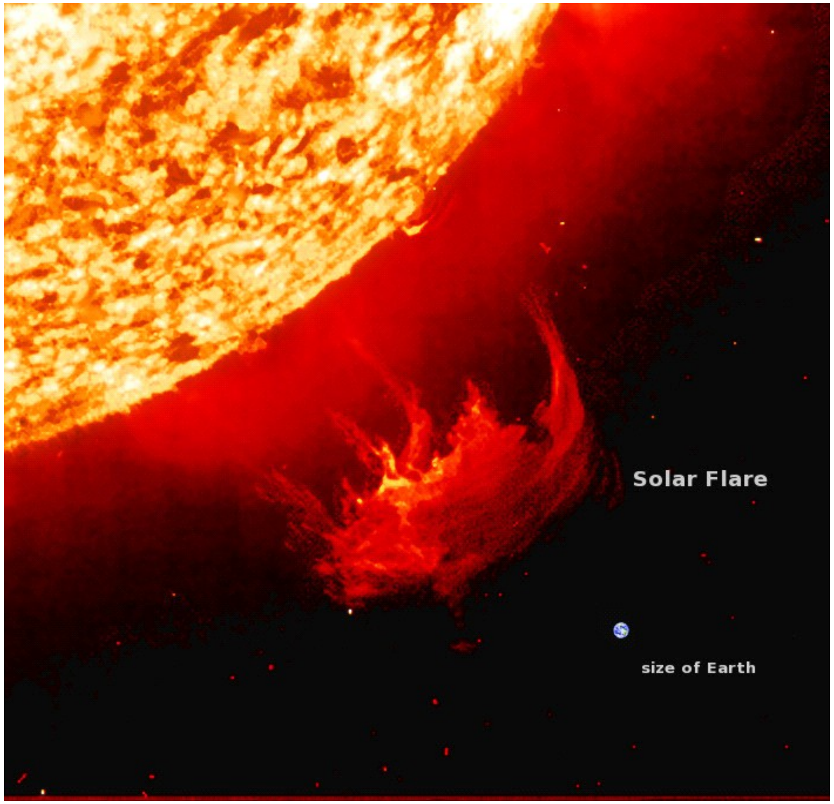
- A flare is defined as a sudden, quick, and strong distinction in brightness of the Sun.

- Solar flare development:

- Twisted magnetic field lines produce very strong localised magnetic fields.

- Breaking of tangling field lines produce sunspot.

- Thus, solar flares occur when magnetic energy that has built up.



http://www.wpclipart.com/space/solar_system/sun/solar_flare_earth_compared.jpg.html

CLASSIFICATION OF SOLAR FLARES

Five types of flare importance classification are known:

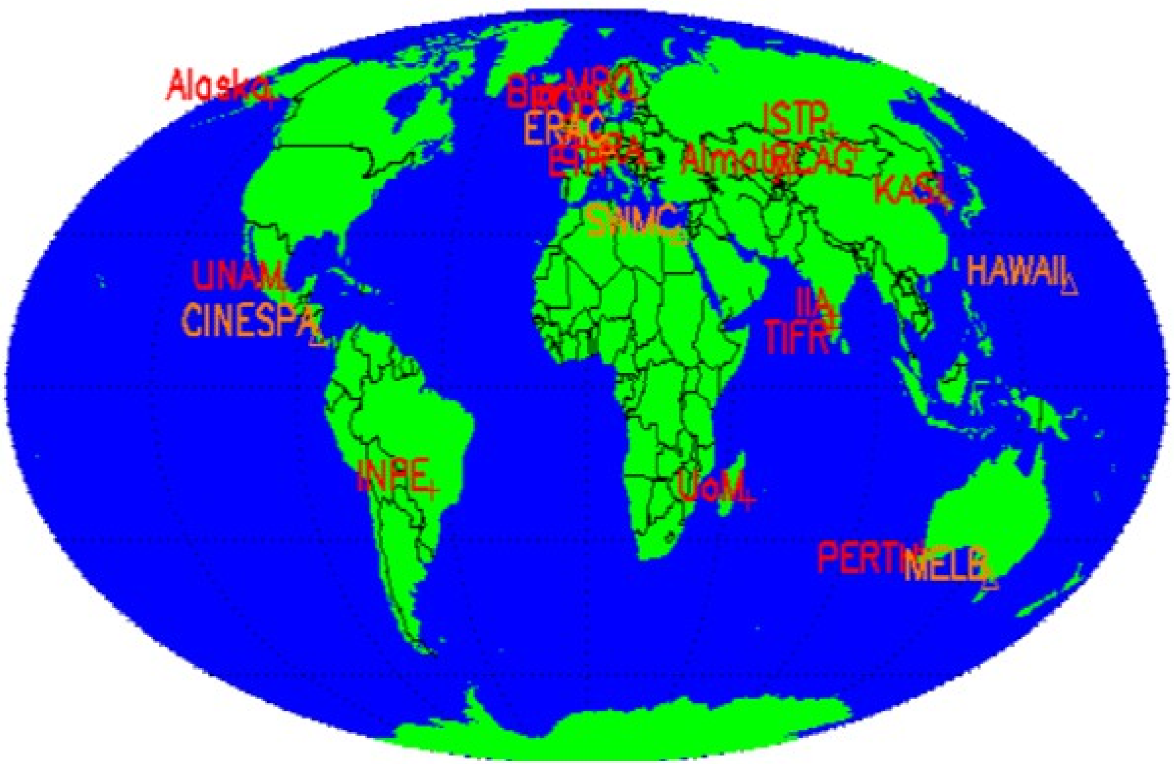
- H-alpha importance (scale 0-3)
  Here, we observe the behavior of the Sun's in the mid chromosphere.
- 10.7 cm solar radio flux magnitude
- Solar Radio Spectral Type
- Magnitude of 200 MHz flux
- Sudden Ionospheric Disturbance importance (scale 0-3)

THE CALLISTO

CALLISTO:

- Compound
- Astronomical
- Low-Cost
- Low-Frequency
- Instrument for
- Spectroscopy &
- Transportable
- Observatory

The e-CALLISTO Map Coverage (28 active stations):

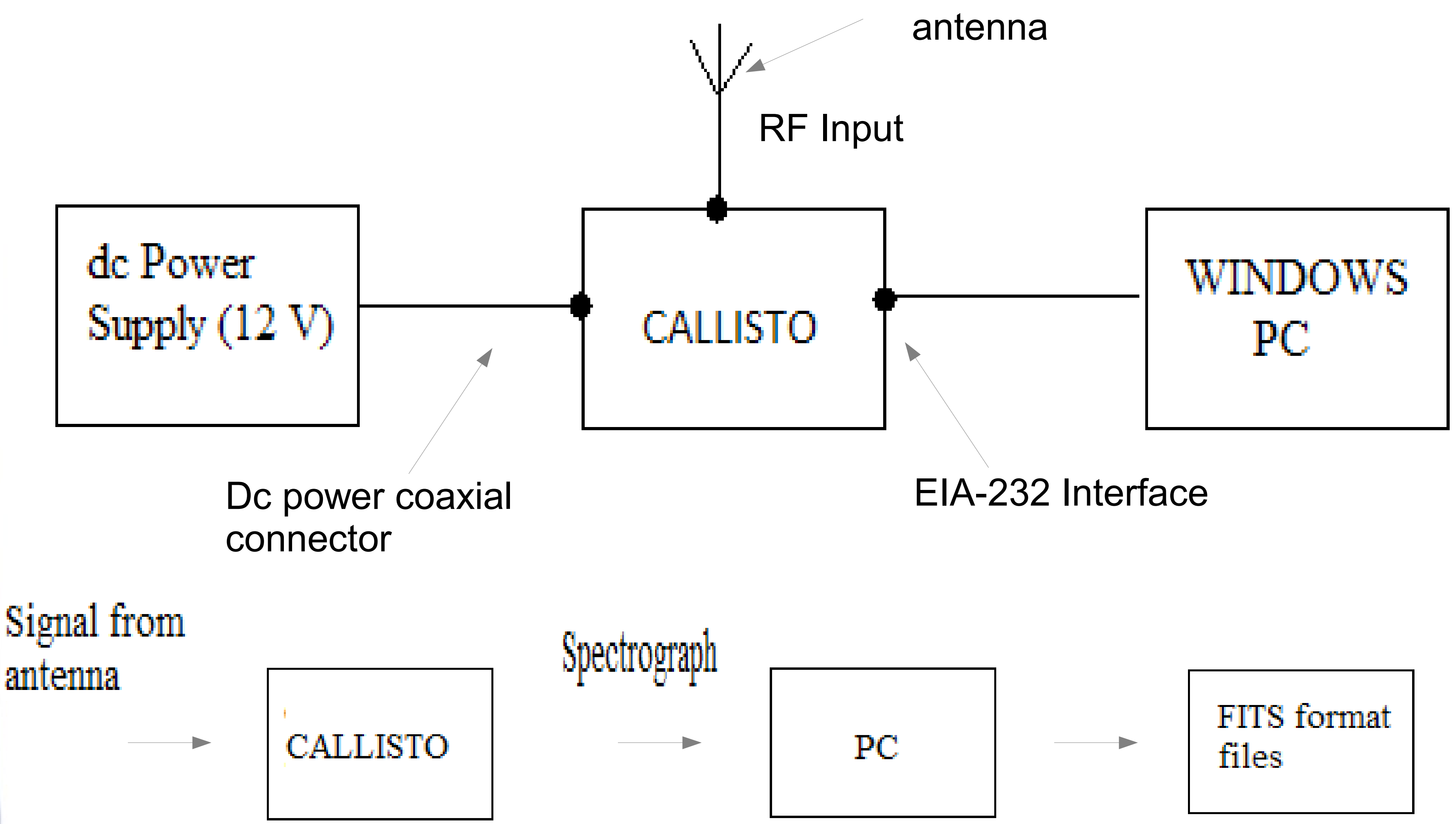


http://www.astro.phys.ethz.ch/astro1/Users/cmonstei/instrument/callisto/Callisto_World.png

MAIN SPECIFICATIONS

Parameter	Specification
Frequency range	45.0–870.0 MHz (in three sub-bands)
Frequency resolution	62.5 KHz
Radiometric bandwidth	300 KHz at -3 dB
Dynamic range	$\sim$50 dB at -70 to -30 dBm maximum rf level
Sensitivity	25 ± 1 mV/dB
Noise figure	<10 dB (measured at the rf input connector)
Maximum sampling rate	Internal clock 800 S/s, external clock 1,000 S/s
Number of channels	Selectable 1–500, nominal 200 frequencies per sweep
Power supply	DC 12 ± 2 V/225 mA
Weight	$\sim$800 g
Dimensions	110 mm $\times$ 80 mm $\times$ 205 mm
Material cost	<200 US$
Input data	Three files (configuration, frequency, scheduler)
Output data	Two files (one FITS-file per 15 min and one log file per day)

HOW DOES THE SPECTROMETER WORK? I



HOW DOES THE SPECTROMETER WORK? II

- Signals from the feed are fed into the receivers.
- They convert to a first intermediate frequency of 37.7 MHz by two local oscillators.
- The signal is down converted to 10.7 MHz for filtering and amplification, detected by logarithmic device, and low pass filtered.
- The logarithmic domain is more than 45 db.

HOW DOES THE SPECTROMETER WORK? III

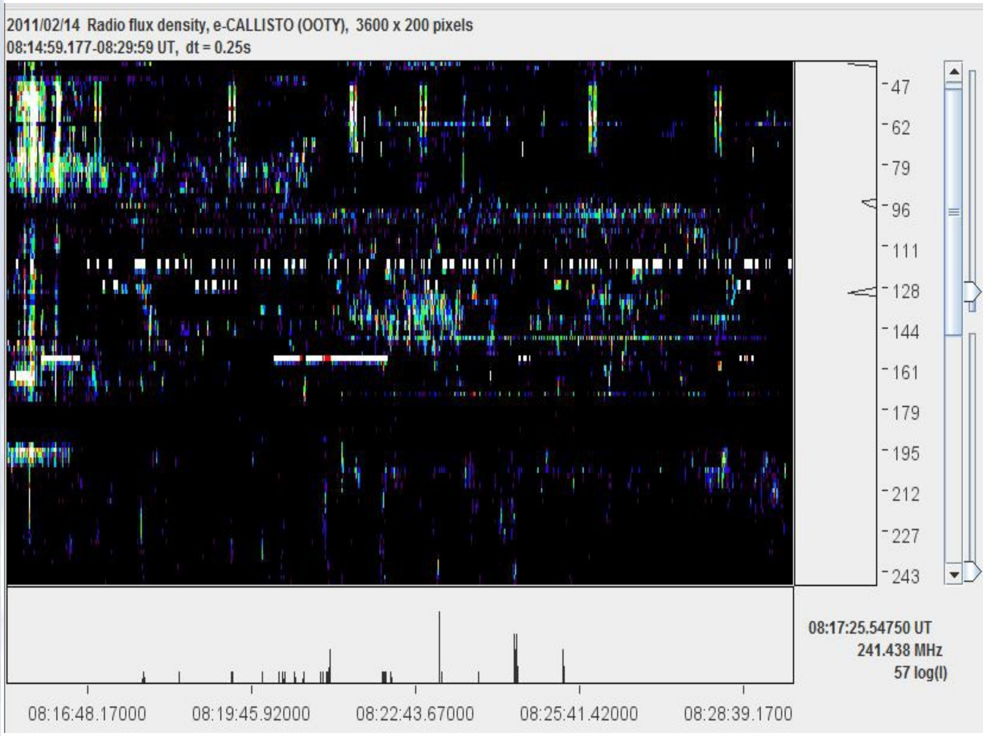
- Data acquisition for both receivers and the interface to the PC are on a separate board.
- The measurements are made in a two step process.
- In the first step a receiver is tuned to a frequency, in the second step the signal is measured.
- The receivers can also be configured to measure the same polarization and to alternate: while one is measuring, the other is tuned to a new frequency.

FITS FILE HEADER

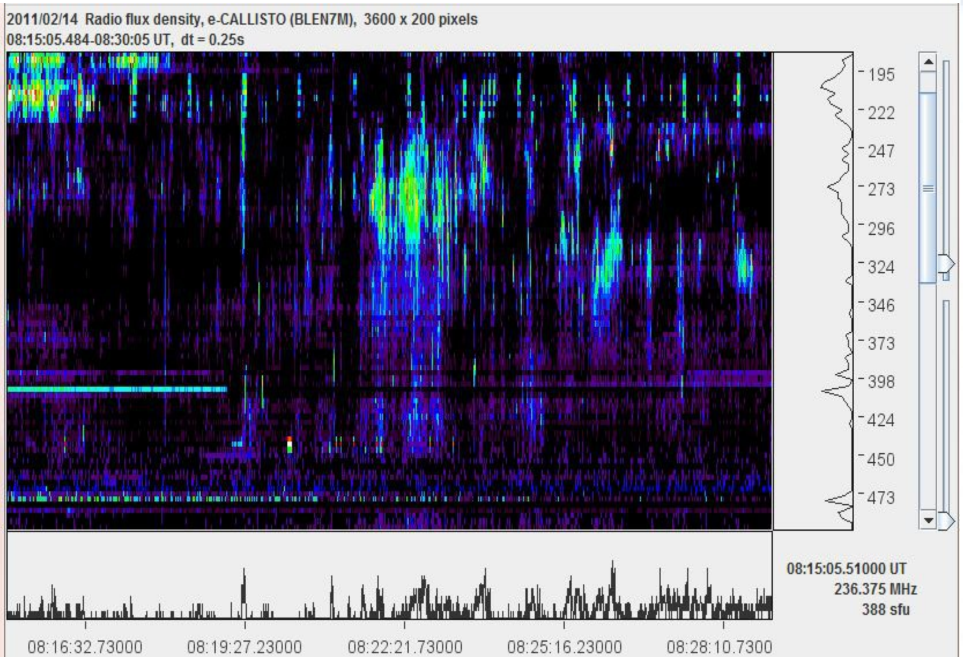
```
SIMPLE  =                    T / file does conform to FITS standard
BITPIX  =                    8 / number of bits per data pixel
NAXIS   =                    2 / number of data axes
NAXIS1  =                 3600 / length of data axis 1
NAXIS2  =                  200 / length of data axis 2
EXTEND  =                    T / FITS dataset may contain extensions
COMMENT = 'Warning: the value of CDELT1 may be rounded!'
COMMENT = 'Warning: the frequency axis may not be regular!'
COMMENT = 'Warning: the value of CDELT2 may be rounded!'
COMMENT = '         '          / empty comment
DATE    = '2013-01-13'         / Time of observation
CONTENT = '2013/01/13  Radio flux density, e-CALLISTO (MRT2)' / Title of image
ORIGIN  = 'Mauritius_Radio_Telescope' / Organization name
TELESCOP= 'Radio Spectrometer' / Type of instrument
INSTRUME= 'MRT2     '          / Name of the spectrometer
OBJECT  = 'CALLISTO'           / object description
DATE-OBS= '2013/01/13'         / Date observation starts
TIME-OBS= '08:29:59.765'       / Time observation starts
DATE-END= '2013/01/13'         / date observation ends
TIME-END= '08:44:59'           / time observation ends
BZERO   =                 114. / scaling offset
BSCALE  =    0.223529413342476 / scaling factor
BUNIT   = 'digits   '          / z-axis title
DATAMIN =                    0 / minimum element in image
DATAMAX =                  255 / maximum element in image
```

TYPES OF FLARES

- Type I
  - Duration: Seconds
  - Freq. Range : 80 – 200 MHz



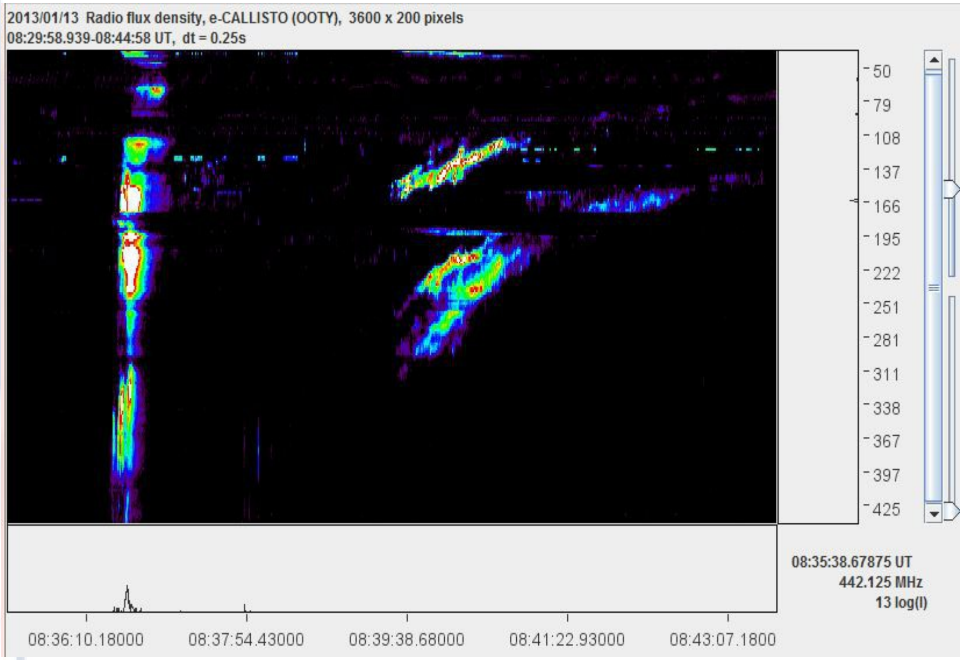
Linear pol: Ooty



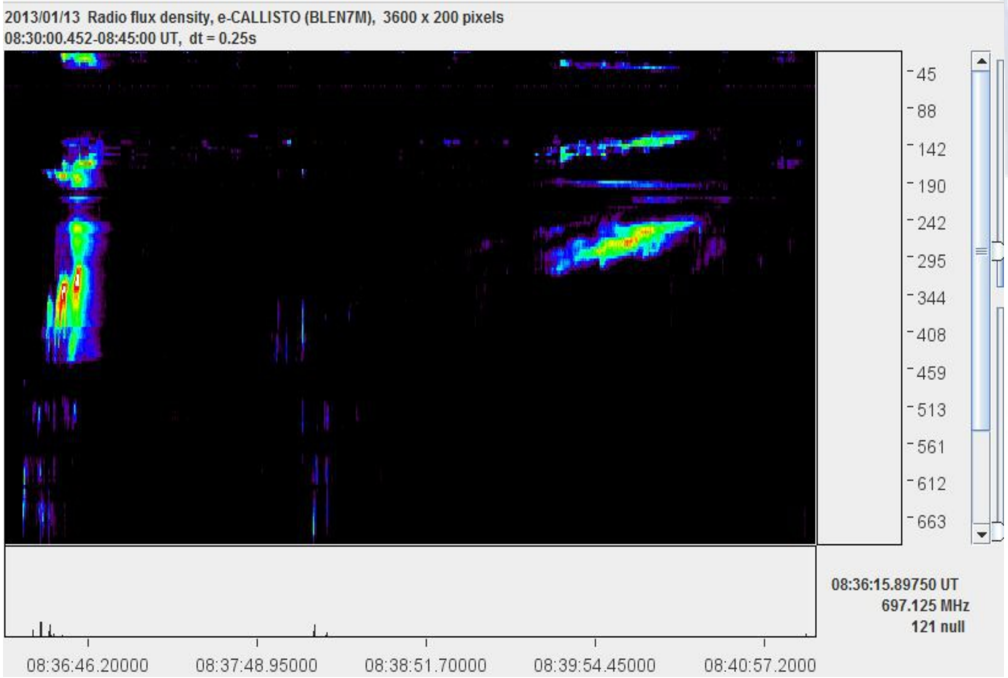
Circular pol: Bleinen 7 m

TYPES OF FLARES

- Type II
  - Duration: Minutes
  - Freq. Range : 20 – 50 MHz



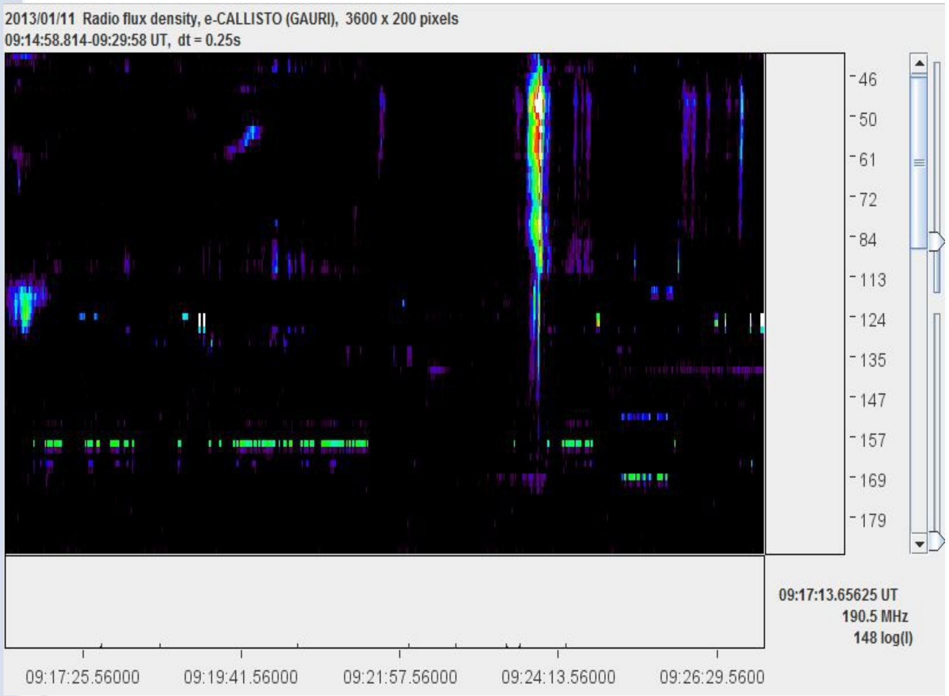
Linear pol: Ooty



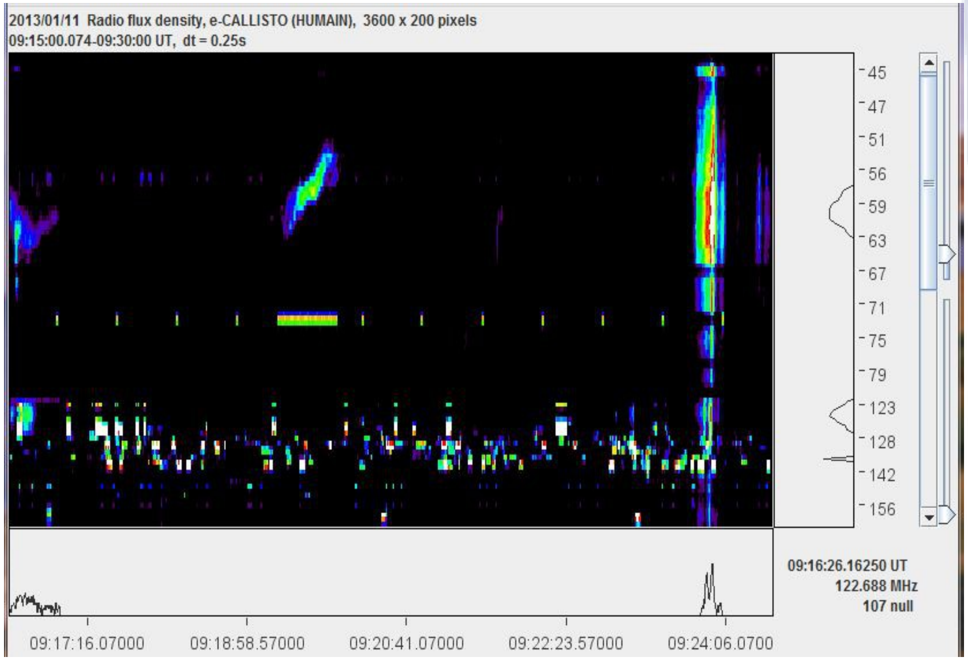
Circular pol: Bleinen 7 m

TYPES OF FLARES

- Type III
  - – Duration: Seconds or Hours
  - – Freq. Range :10 KHz – 1 GHz



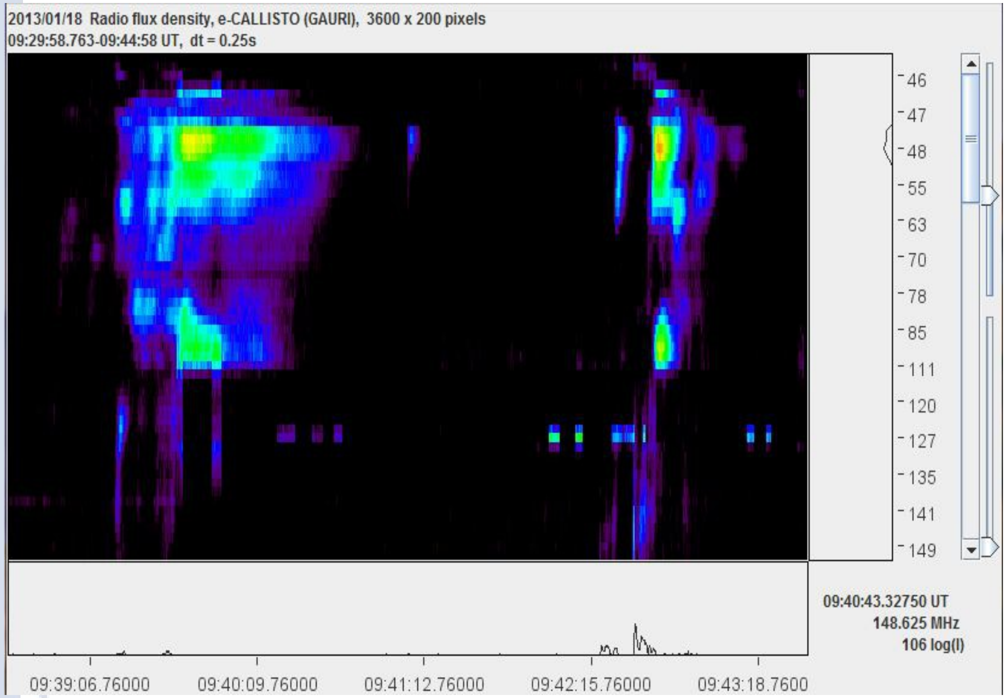
Linear pol: Gauri

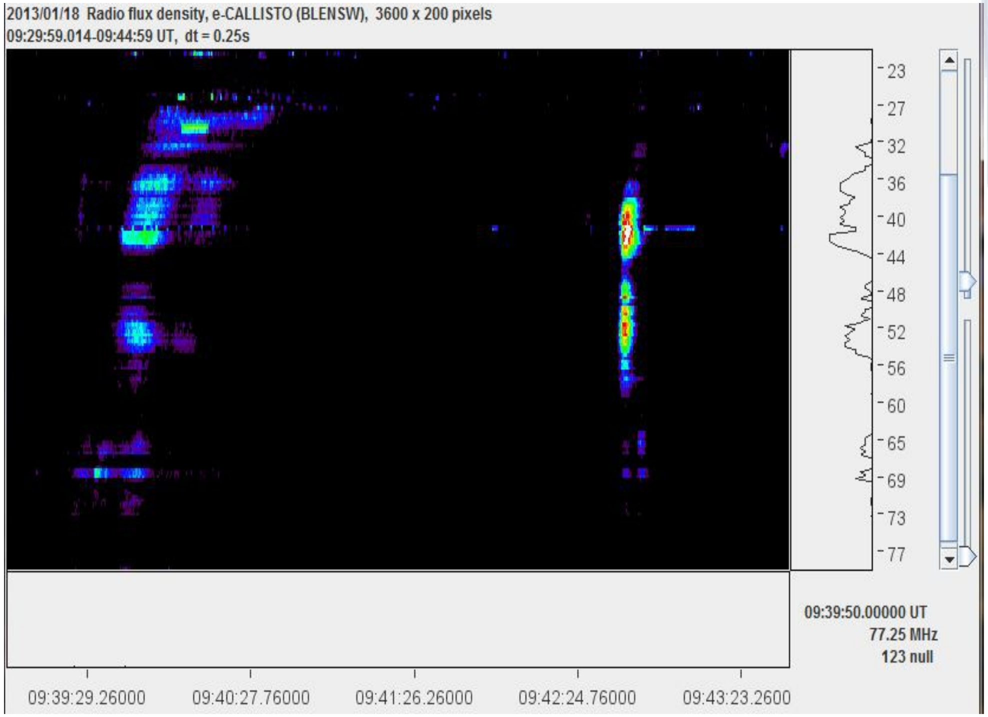


Circular pol: Bleinen 7 m

TYPES OF FLARES

- Type IV
  - – Duration: Hours
  - – Freq. Range: 20 MHz – 2 GHz



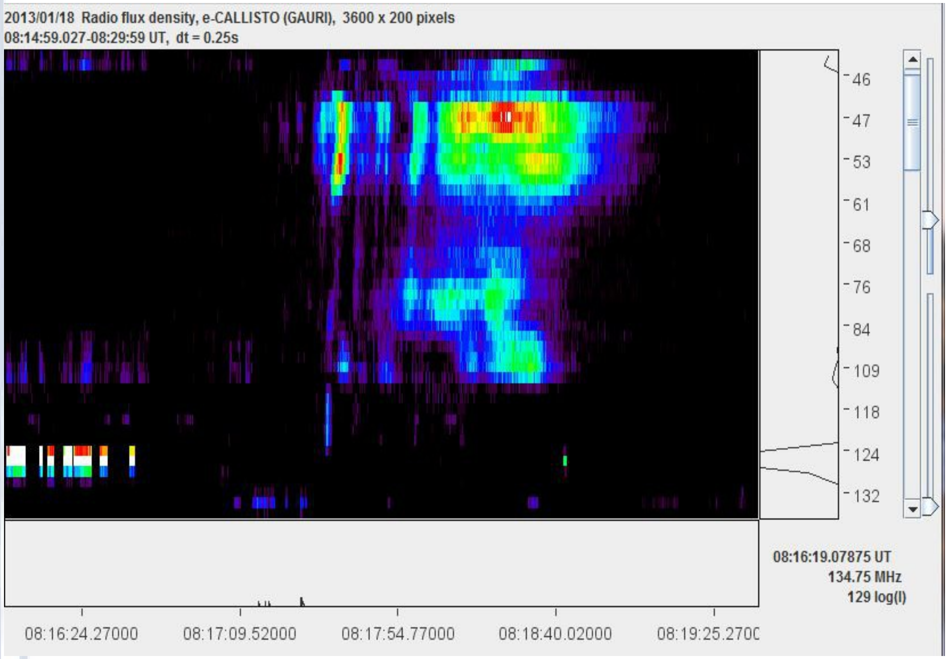


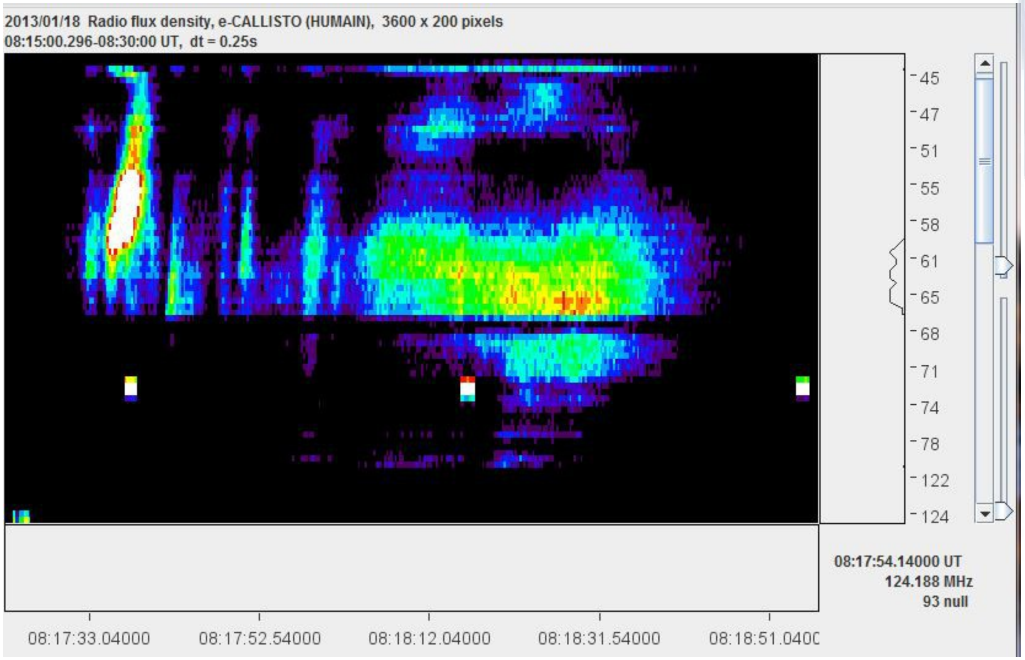
Linear pol: Ooty

Circular pol: Bleinen 7 m

TYPES OF FLARES

- <u>Type V</u>
  - – Duration: Hours
  - – Freq. Range : 10 MHz – 20 MHz





Linear pol: Ooty

Circular pol: Bleinen 7 m

YEAR 2011 SOLAR FLARES STATISTICS

Types	I	II	III	IV	V
Linearly Polarised	38	25	171	2	5
Circularly Polaried	62	192	548	27	12

PARTIAL LIST OF FLARES FOR DIFFERENT STATIONS

Datecode	Time		Type	Frequency range/MHz		Location code
	Start	*Stop*		*Highest*	*Lowest*	
04-01-13	14:48:18	14:48:26	I	363	223	BLEN7M
07-01-13	08:46:28	08:47:56	I	1750	1209	PHOENIX-B1
17-02-13	10:35:30	10:36:24	I	420	175	BLEN7M
04-01-13	12:55:46	12:55:58	II	126	55	HUMAIN
04-01-13	14:48:21	14:48:37	II	123	47	HUMAIN
05-01-13	09:30:13	09:30:39	II	1193	1076	PHOENIX-B1
07-01-13	08:47:36	08:47:41	II	3650	3200	PHOENIX-

CALLISTO STATIONS

All stations were contacted for information. Only 15 responded. The following facts were gleaned:

- the type of antenna used.
- any measurement of VSWR.
- any measurement of main & side lobes.
- the net gain of amplifiers.
- the frequency filtering, if used.

PARTIAL CALLISTO STATIONS RESPONSE SUMMARY TABLE

Stations	Type of Antenna	Measurement of VSWR	Measurement of lobes	Gain of Amplifier	Filtering Frequency
ETHZ, Switzerland :	**BLEN7M_24** : Right hand circular polarization RHCP **BLEN7M_25** : Left hand circular polarization LHCP **BLENSW** : short wave spectrometer below 100 MHz connected to a biconical antenna		The beam efficiency (depending on frequency) is in the order of 0.45 +/- 0.05		
Metsähovi Radio Observatory	**Antenna** attached to the rim of a **microwave telescope dish** (Radio Flux at 11.2 GHz) **RHS antenna** is for the lower observing band (50 – 850 MHz) **LHS** for the higher band (800 – 1450 Mhz)	**< 2.1 type 1.5 – 1**		**Low – Band** : typical gain 17.5 dB , typical Noise figure : 1.1 dB **High – Band :** typical gain 18.2 dB , typical Noise figure : 3.5 dB	**Low – Band** : low pass filter , typical Insertion loss : 0.5 Db(before pre-amplifier) **High – Band** : high pass filter , typical Insertion loss : 0.5 Db(before pre-amplifier)

ANALYSIS OF SOLAR DATA USING SUNPY

- SunPy is a free and open-source software.
- It uses Python programing language.
- It builds upon science packages available for Python including NumPy, SciPy and matplotlib.
- Programs were written for data analysis using this software.

ANALYSIS OF SOLAR DATA USING SUNPY

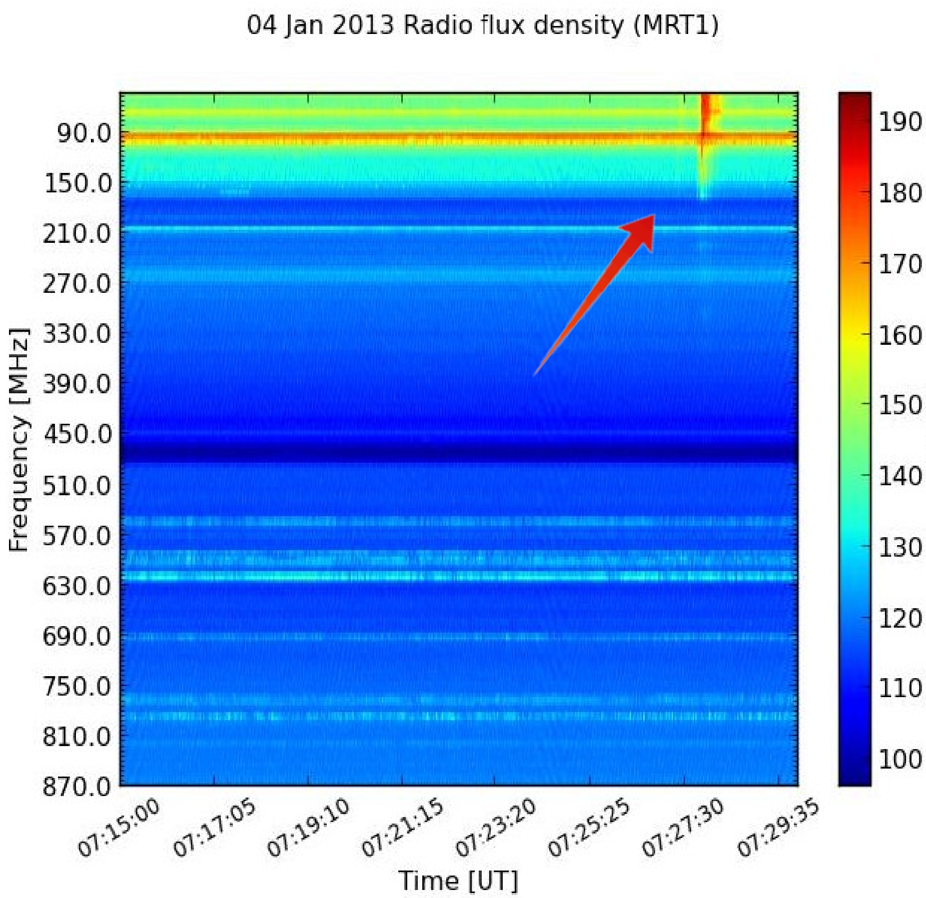
```
sagar@ubuntu:~$  python
Python 2.7.3 (default, Aug  1 2012, 05:16:07)
[GCC 4.6.3] on linux2
Type "help", "copyright", "credits" or "license" for more information.
>>> from matplotlib import pyplot as plt

>>> import sunpy
>>> from sunpy.spectra.sources.callisto import CallistoSpectrogram
>>> c1 = CallistoSpectrogram.read("/media/disk/INTEGRATED/JOIN III/BLEN7M_201301
11_090000_25.fit.gz")
>>> c2 = CallistoSpectrogram.read("/media/disk/INTEGRATED/JOIN III/BLEN7M_201301
11_091500_25.fit.gz")
>>>
>>> c = CallistoSpectrogram.join_many([c1, c2])
>>> c.show()
<sunpy.spectra.spectrogram.SpectroFigure object at 0xb81be8c>
>>> nobg = c.subtract_bg()
>>> nobg.show(min_=5)
<sunpy.spectra.spectrogram.SpectroFigure object at 0xc08040c>
>>>
```

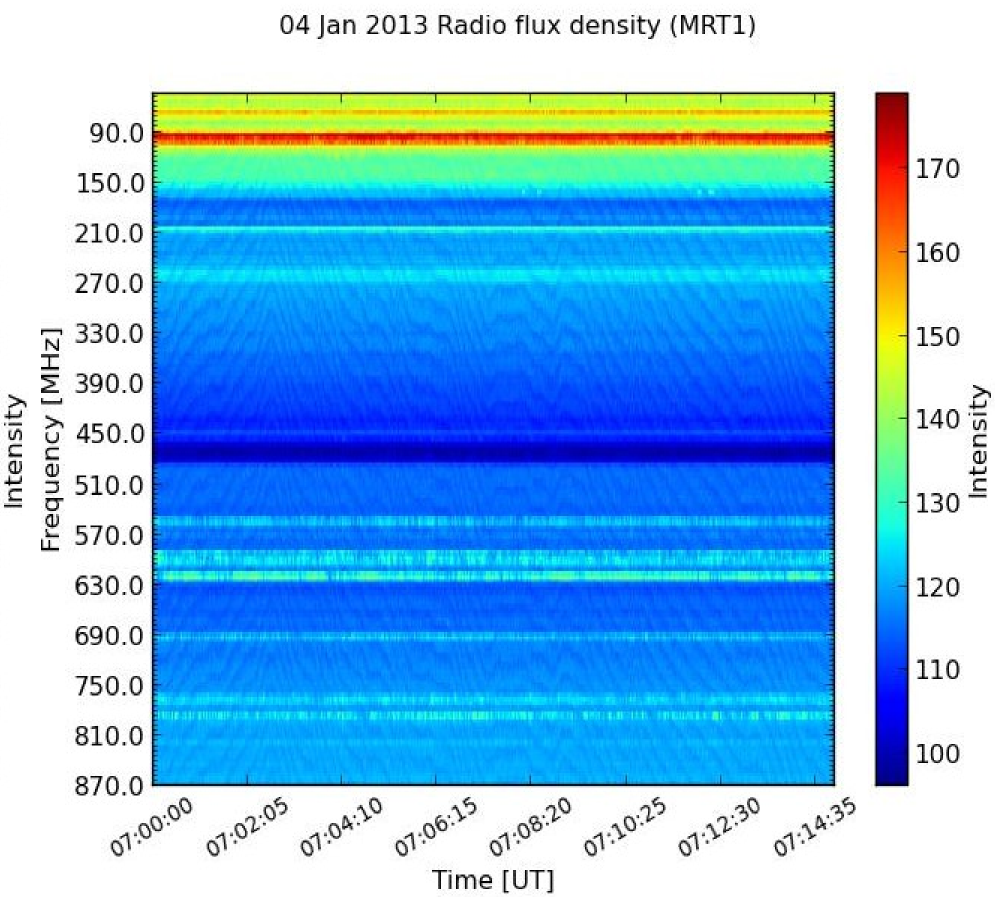
The above is a screenshot of a program(partial) run in ubuntu for the joining of fits files.

DATA ANALYSIS FOR LINEAR POLARISED ANTENNAS

BACKGROUND REMOVAL FOR E-POLARISATION



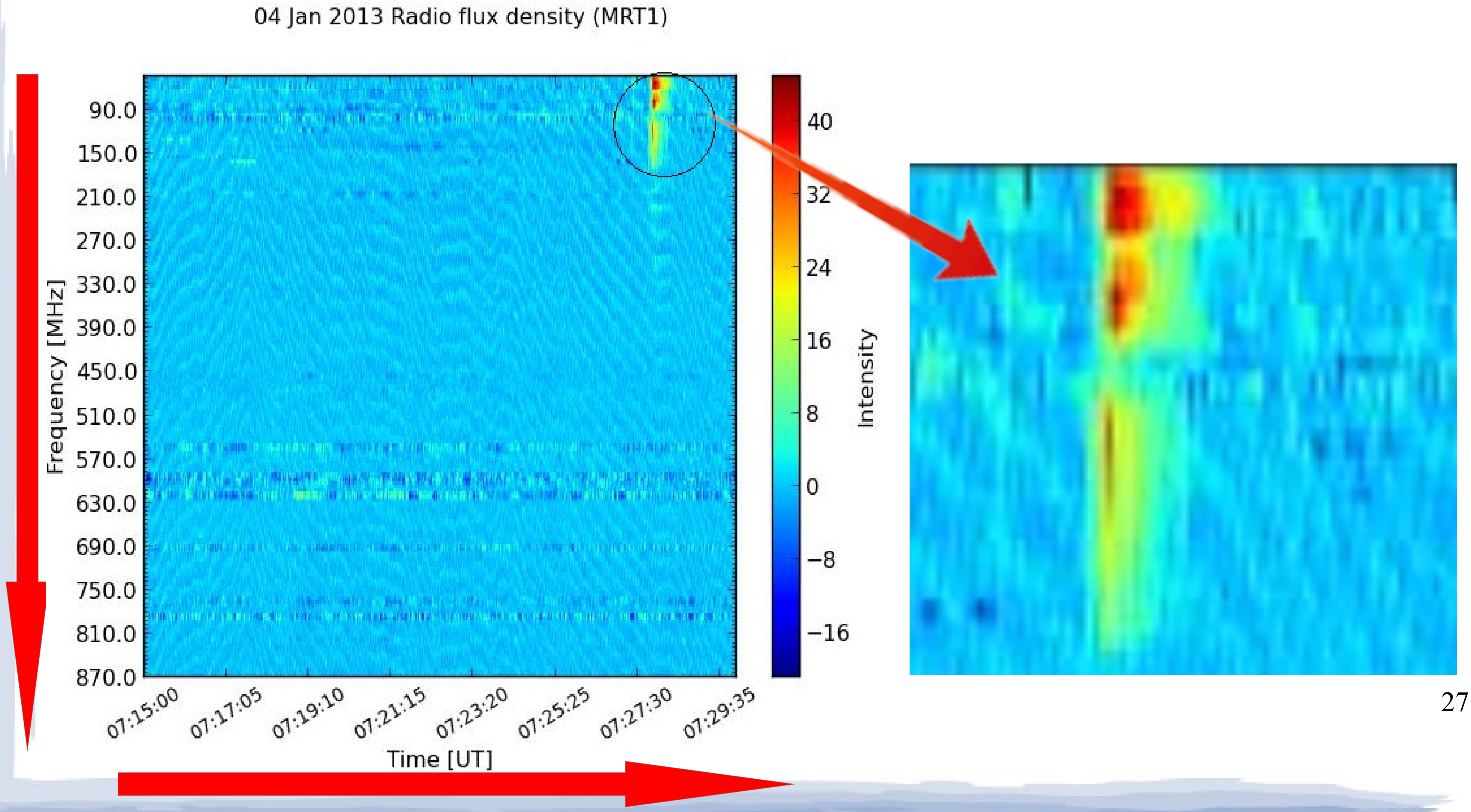
The 04/01/13 MRT1 flare with background



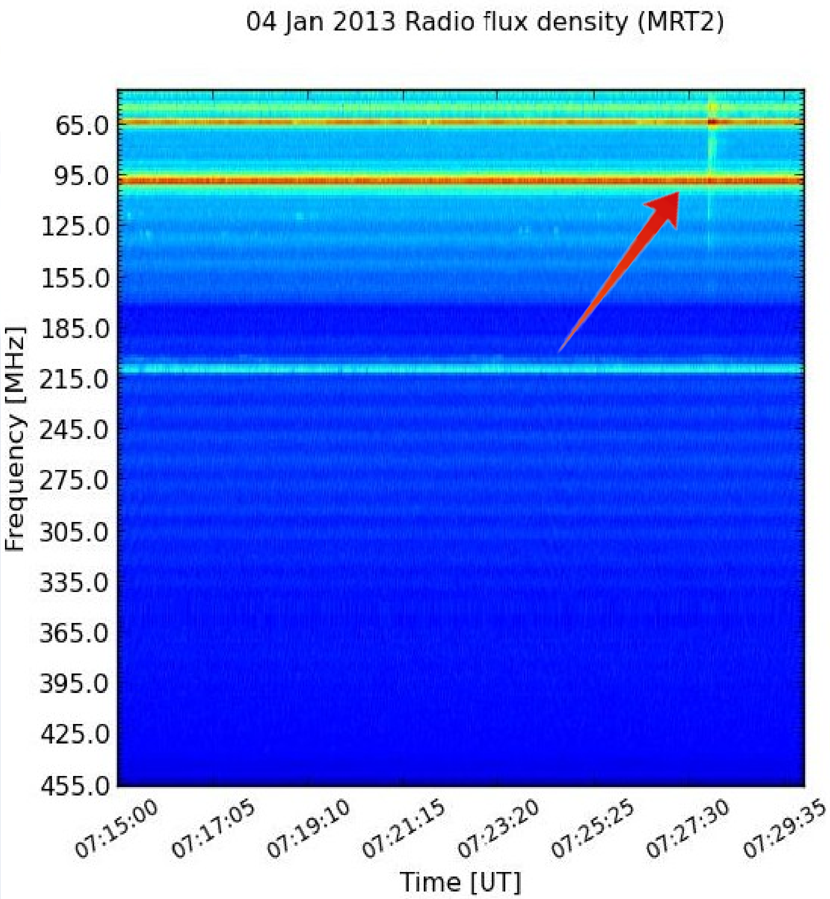
A MRT1 file with background only

Note varying background

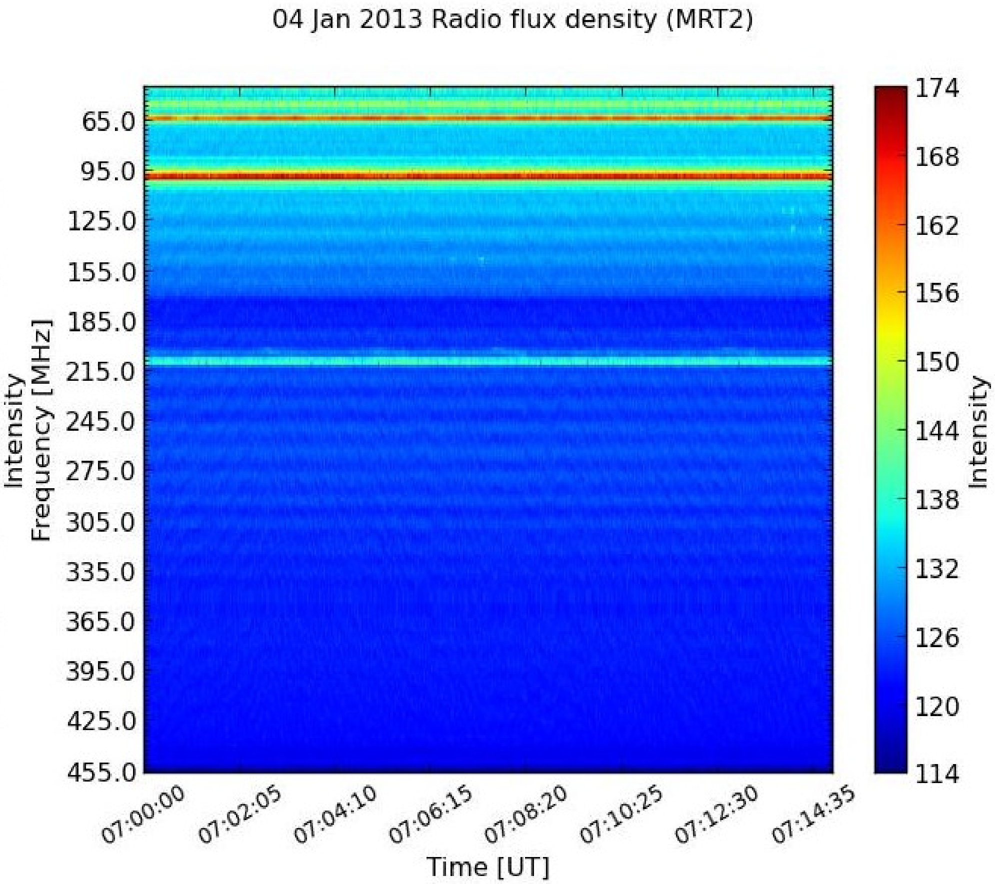
SUBTRACTING THE BACKGROUND (RIGHT) DATA FROM THE FLARE CONTAINING ONE(LEFT), WE GET :



BACKGROUND REMOVAL FOR H-POLARISATION

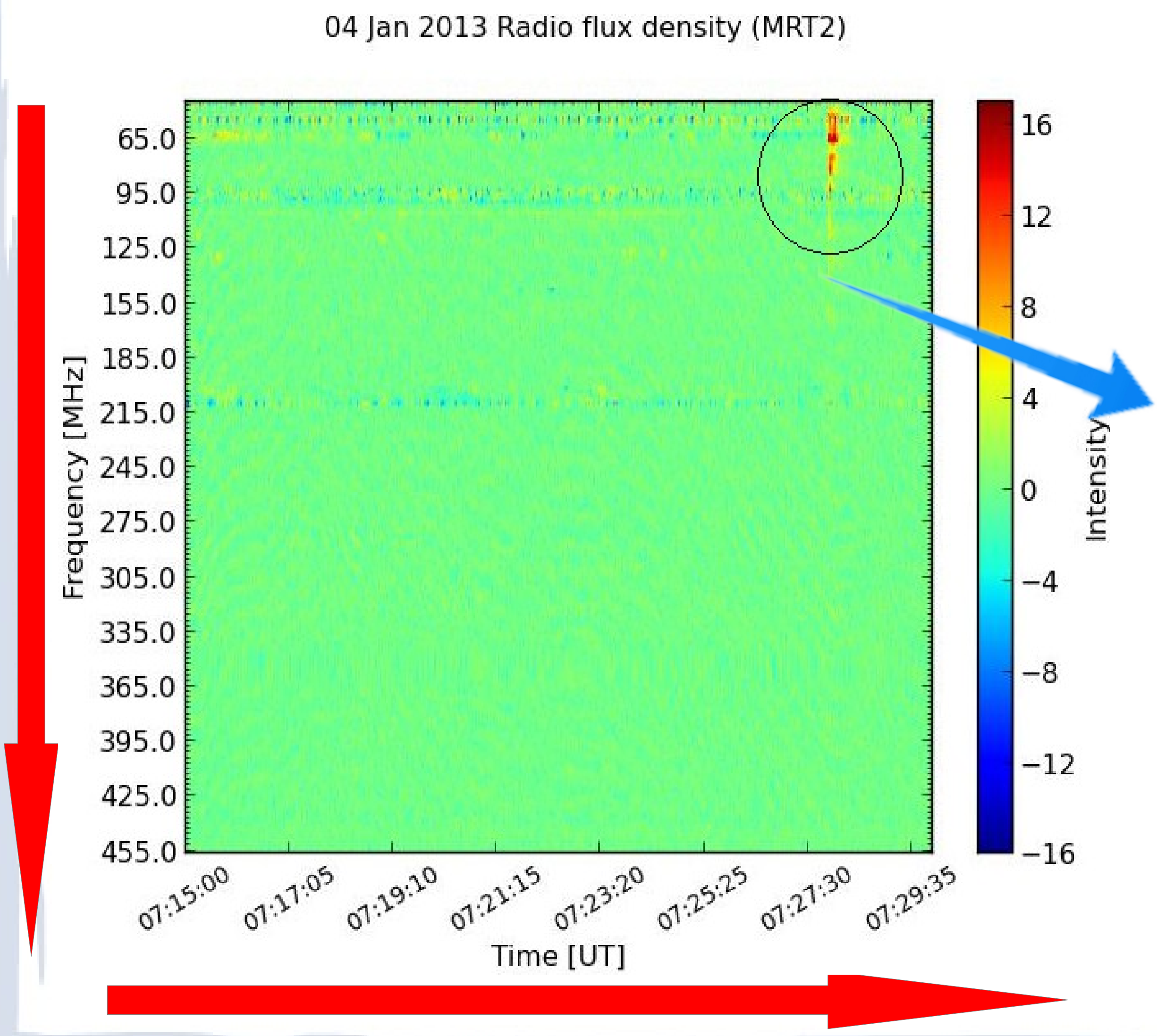


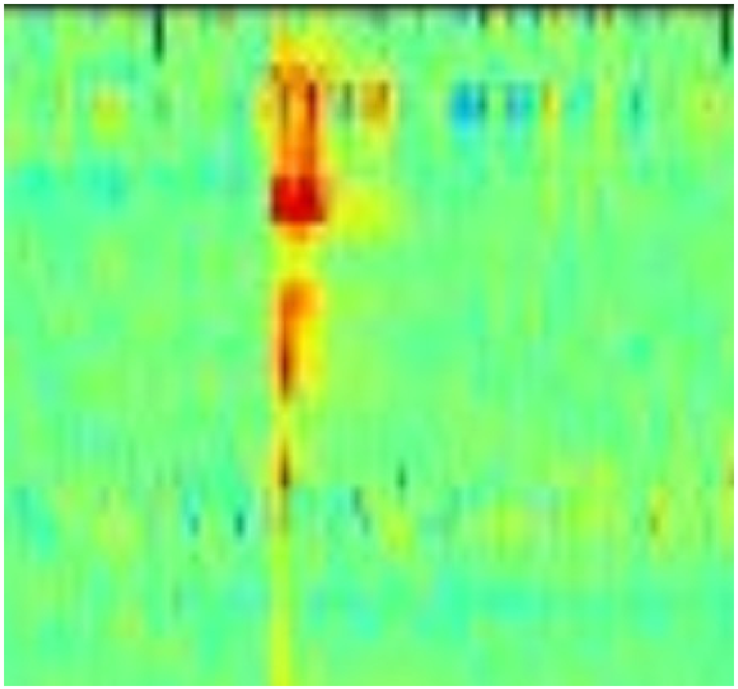
The 04/01/13 MRT2 flare with background



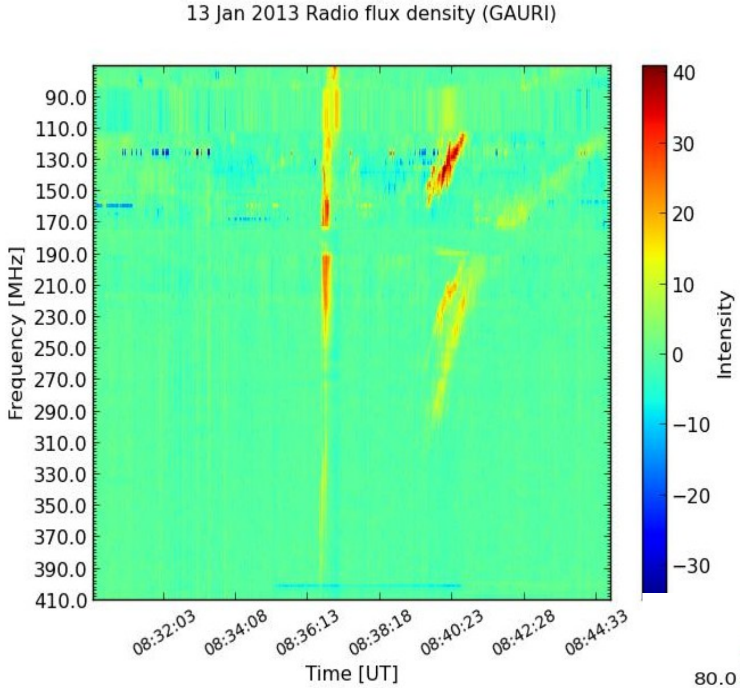
A MRT2 file with background only

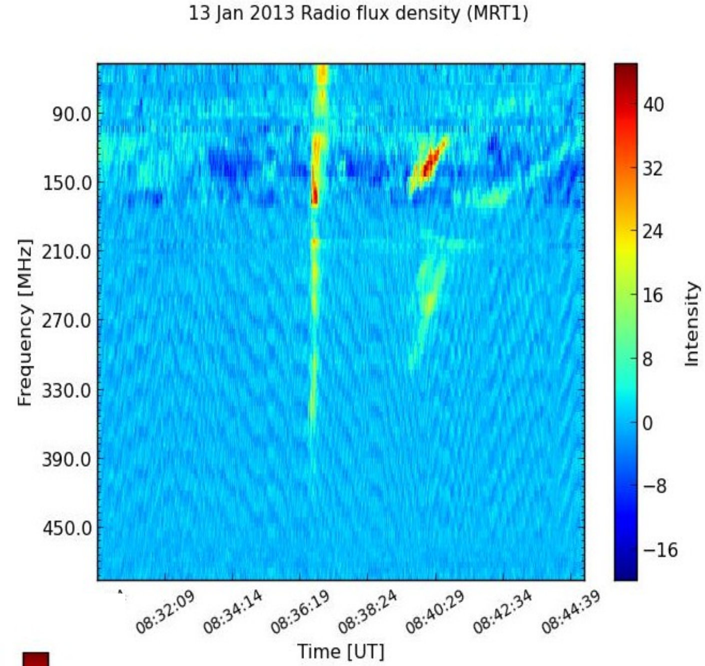
SUBTRACTING THE BACKGROUND (RIGHT) DATA FROM THE FLARE CONTAINING ONE(LEFT), WE GET:



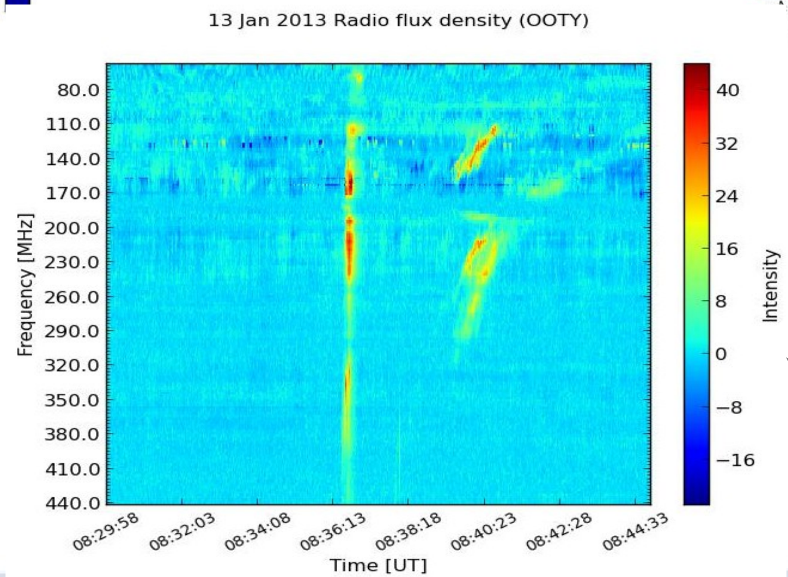


MRT1, OOTY1 & GAURIBIDANUR HAVE SIMILAR ANTENNAS WITH SAME E-POLARISATION





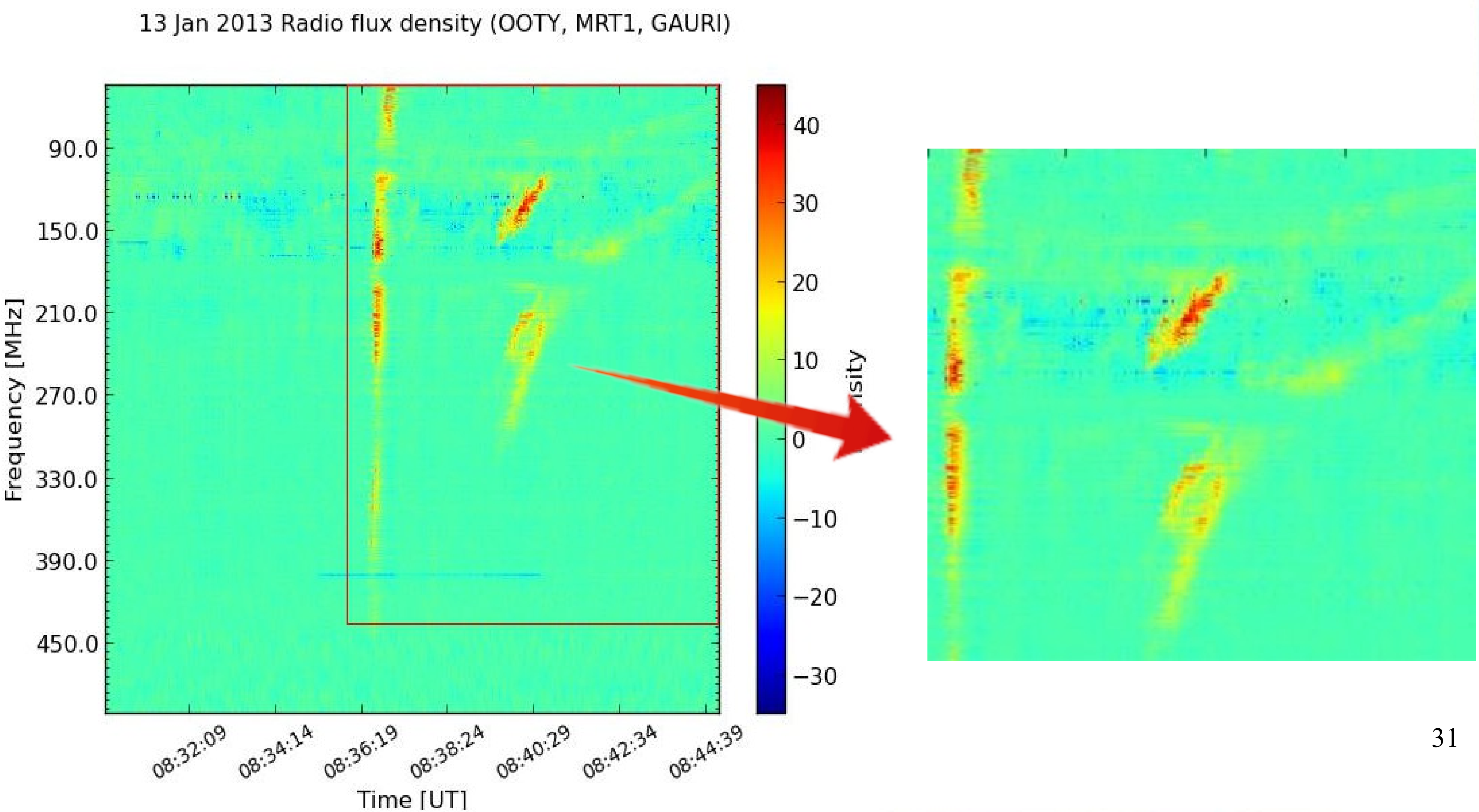
MRT1 13/01/13 file from 0830 to 0844 E-polarisation



Gauribidanur 13/01/13 file from 0832 to 0844 E-polarisation

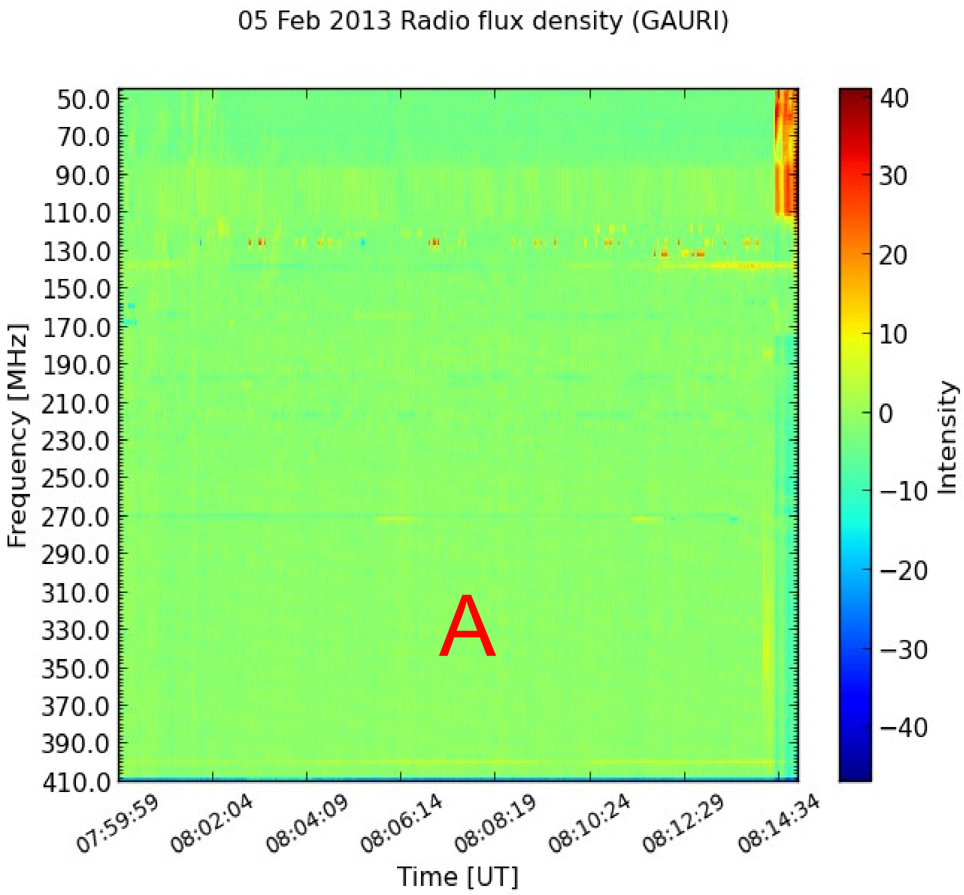
Ooty1 file from 0829 to 0844 E polarisation

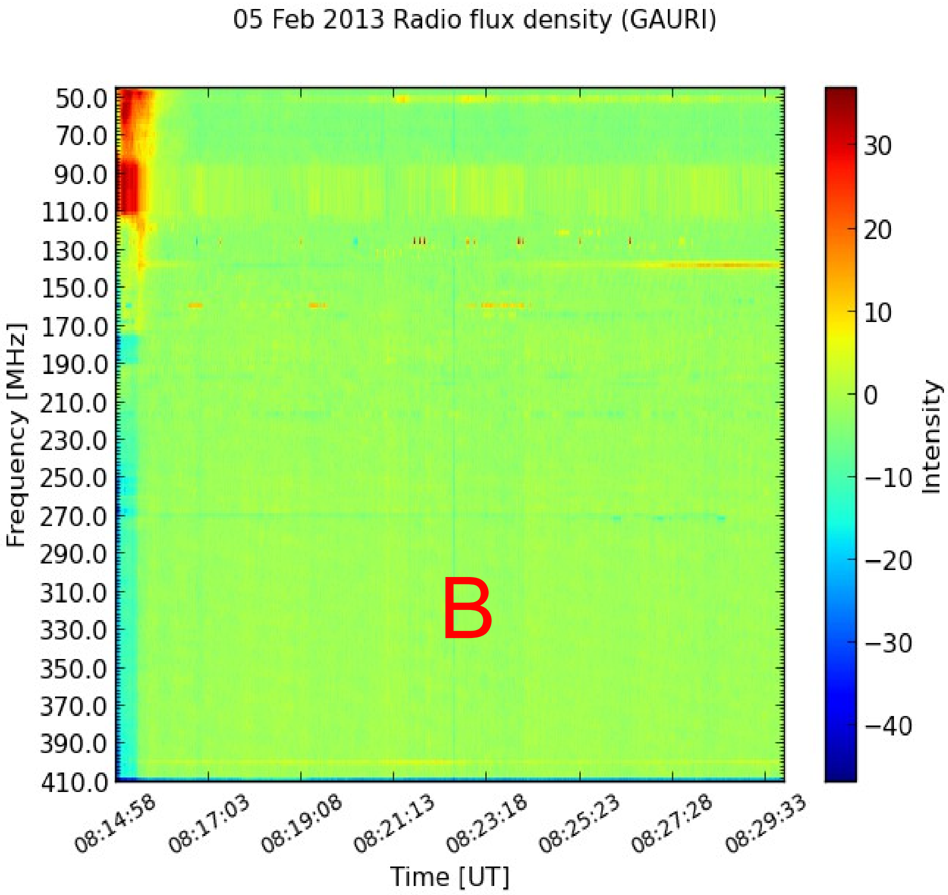
Co-ADDING FITS FILES AFTER REMOVING BACKGROUND FOR E POLARISATION



JOINING FITS FILES IN TIME

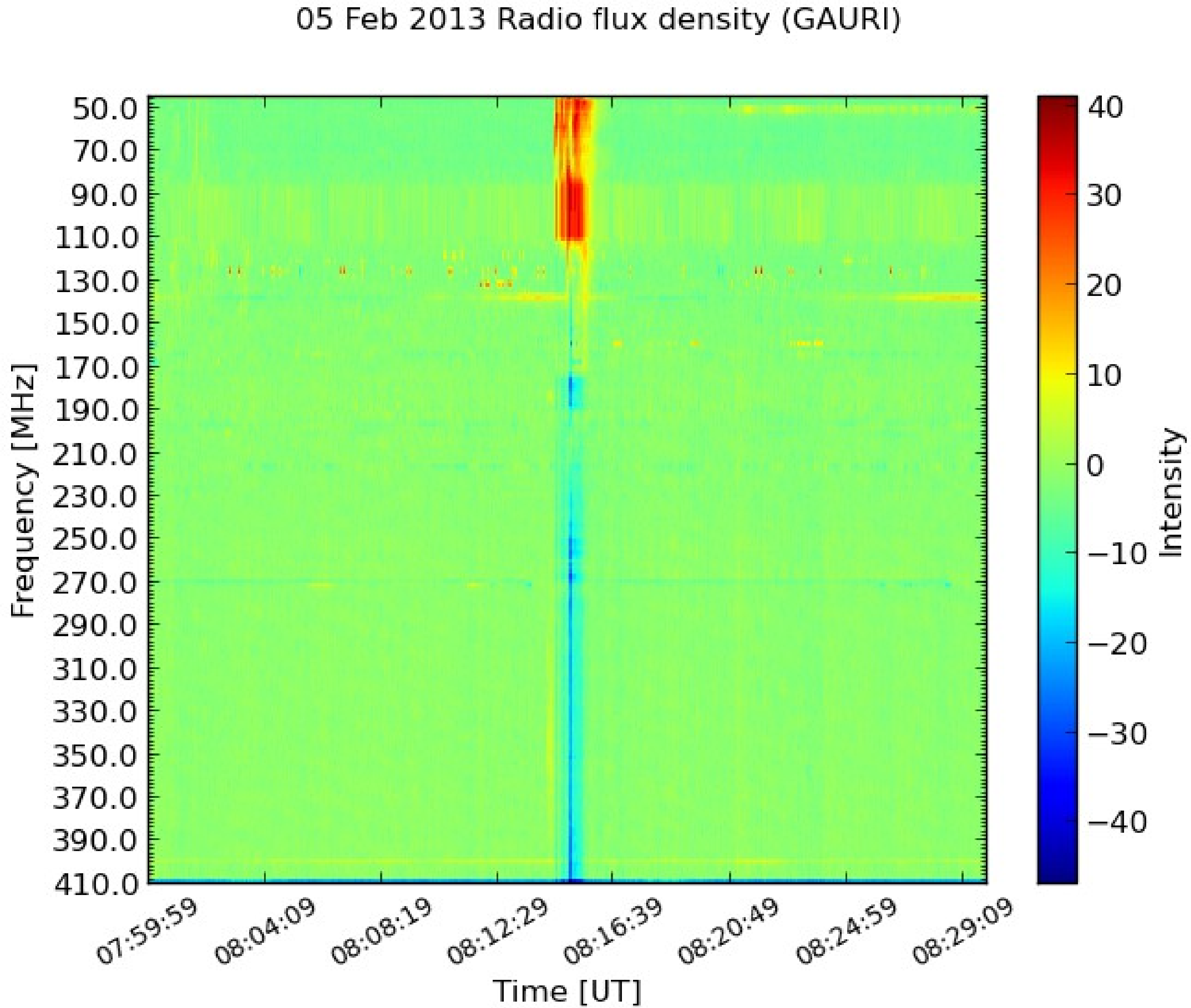
The two consecutive 15 min files were joined after subtraction of background:





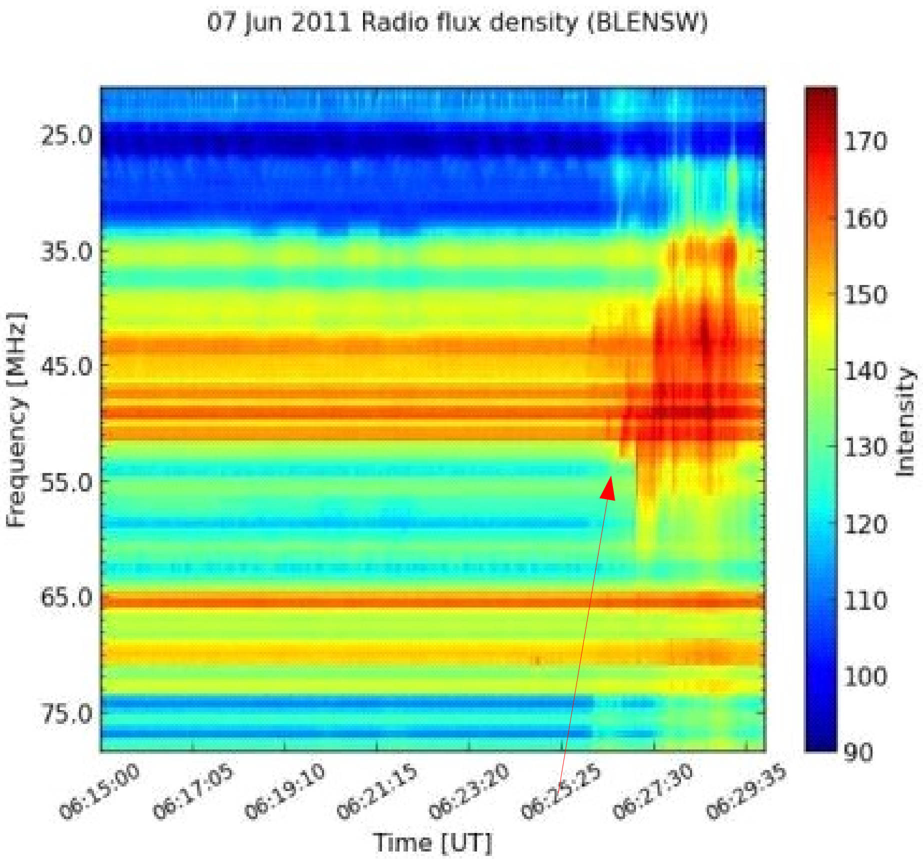
AFTER JOINING:

(Please note artefact):

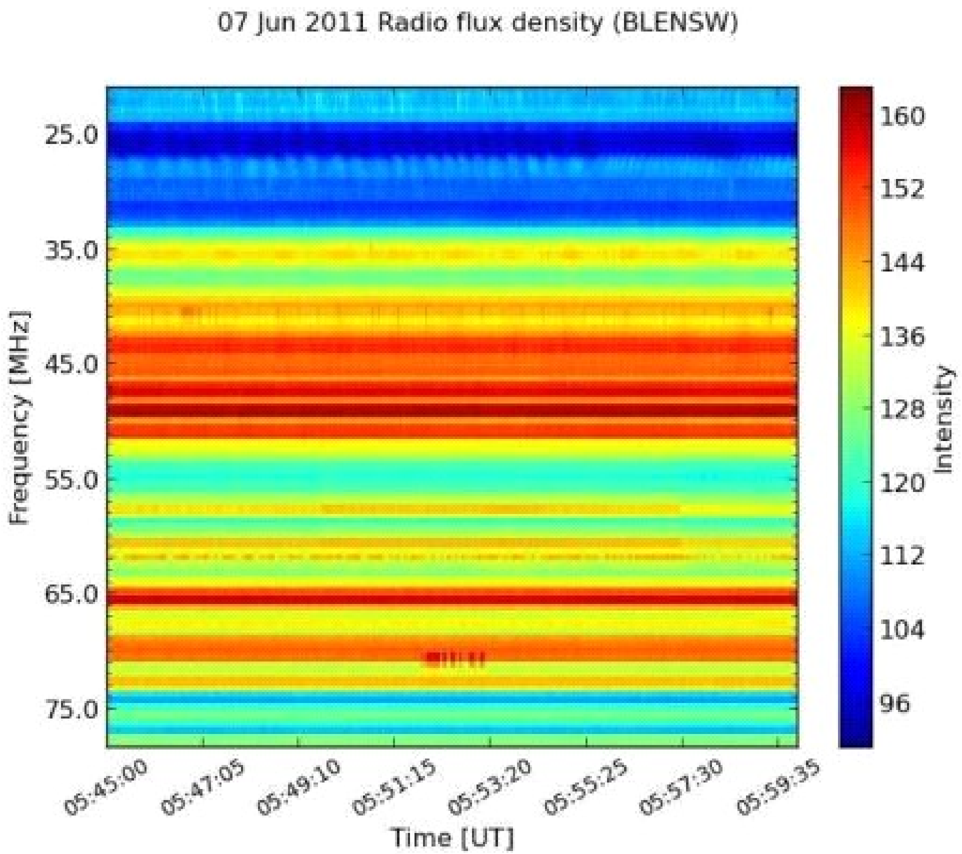


DATA ANALYSIS FOR CIRCULAR POLARISED ANTENNAS

FLARE OBSERVED AT BLENSW

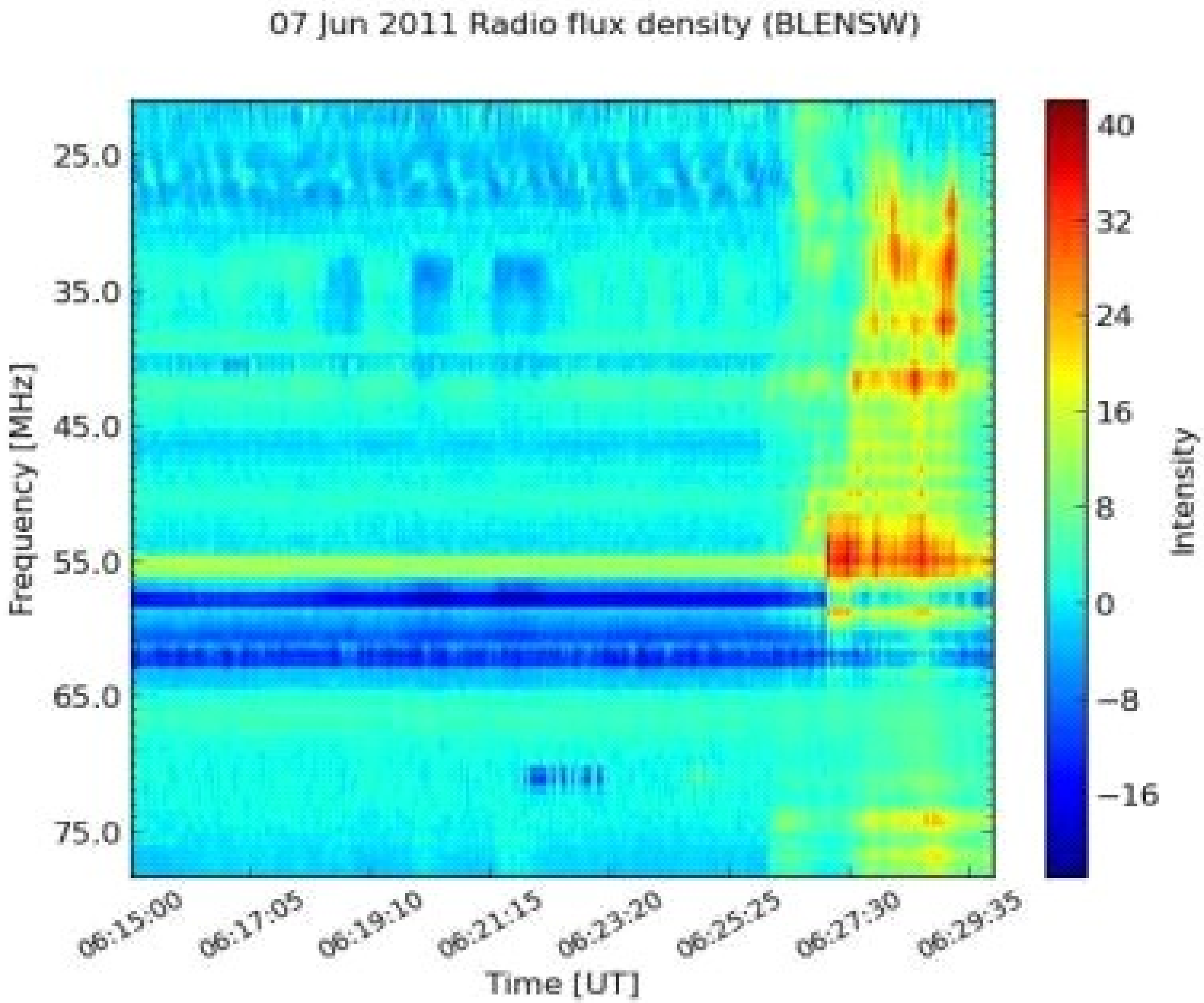


The Blensw with flare and background



The Blensw with background only

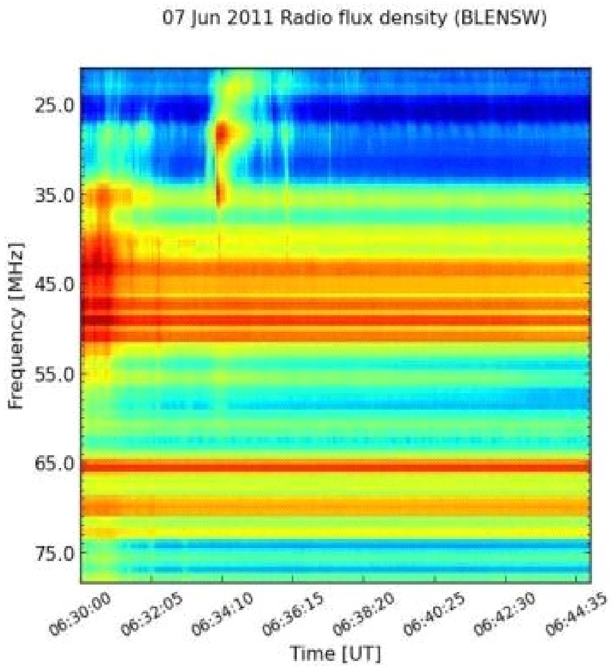
BACKGROUND REMOVAL



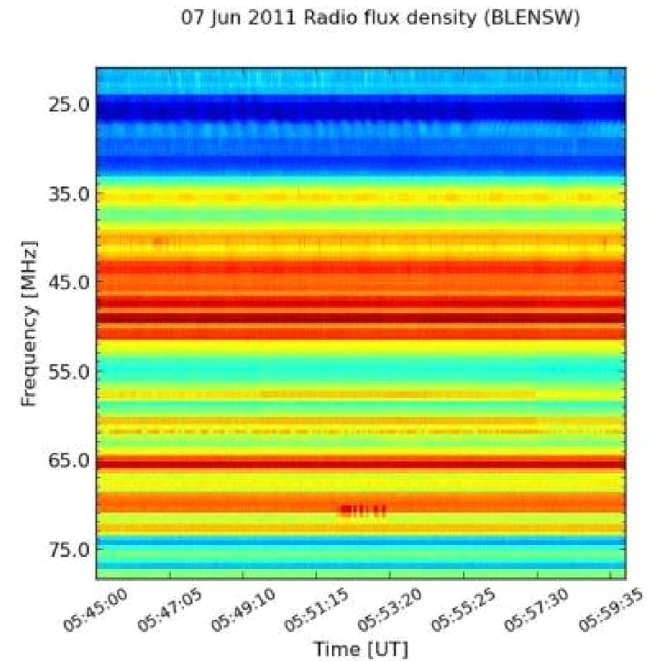
A

Note varying & stronger background

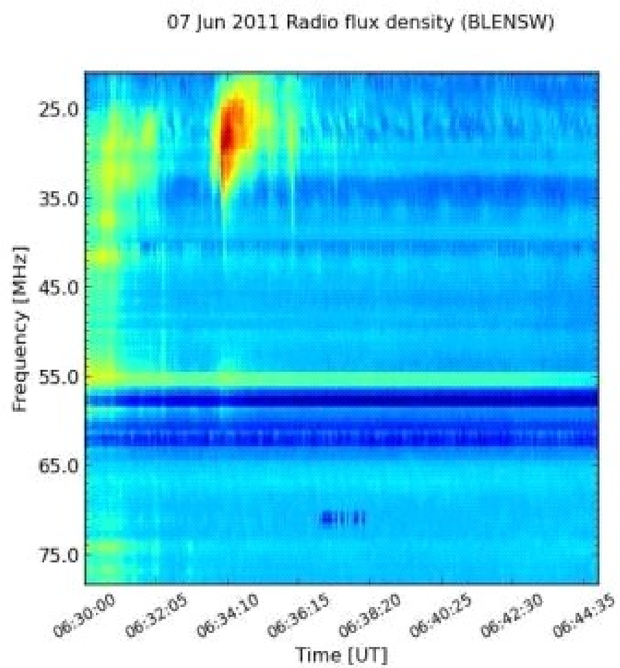
DIFFERENT FLARE BLEINENSW



B1



B2

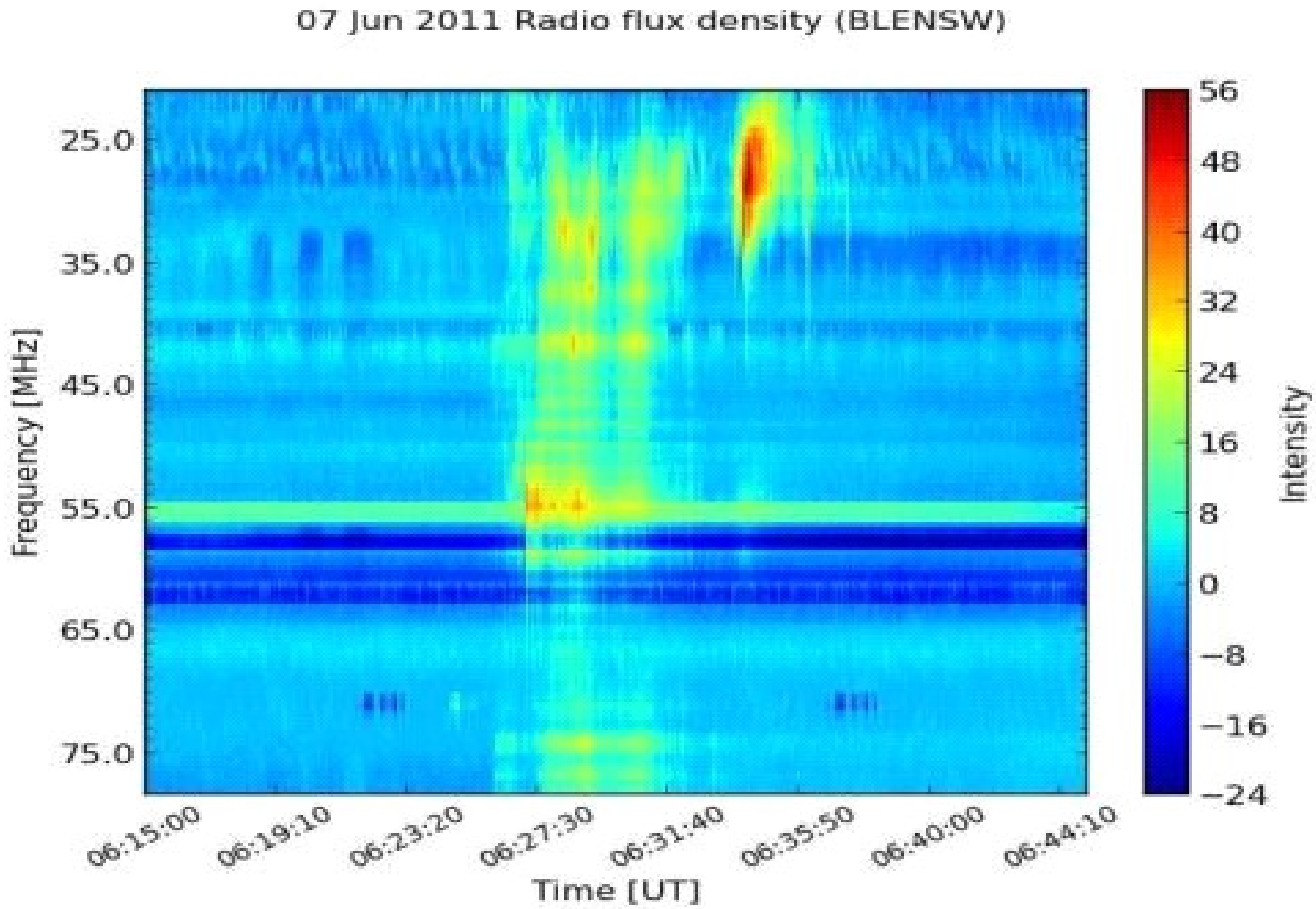


B

Note varying & stronger background

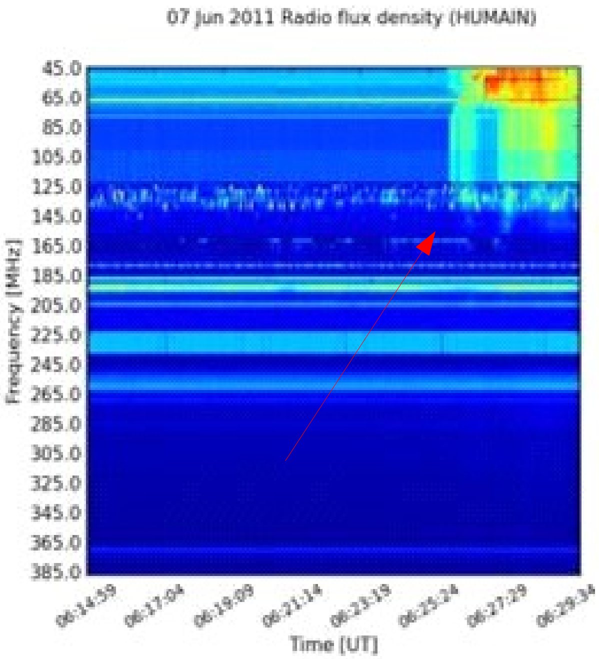
B= B2-B1

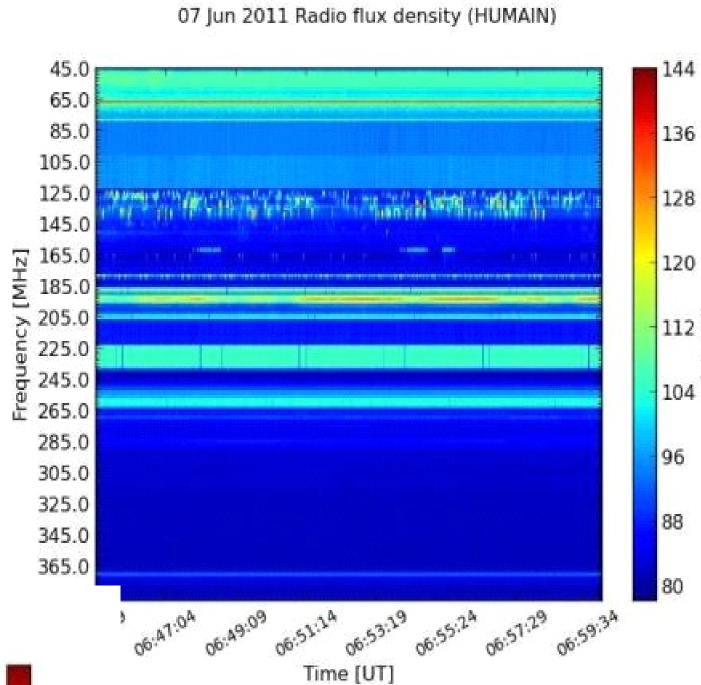
JOINING A AND B IN TIME

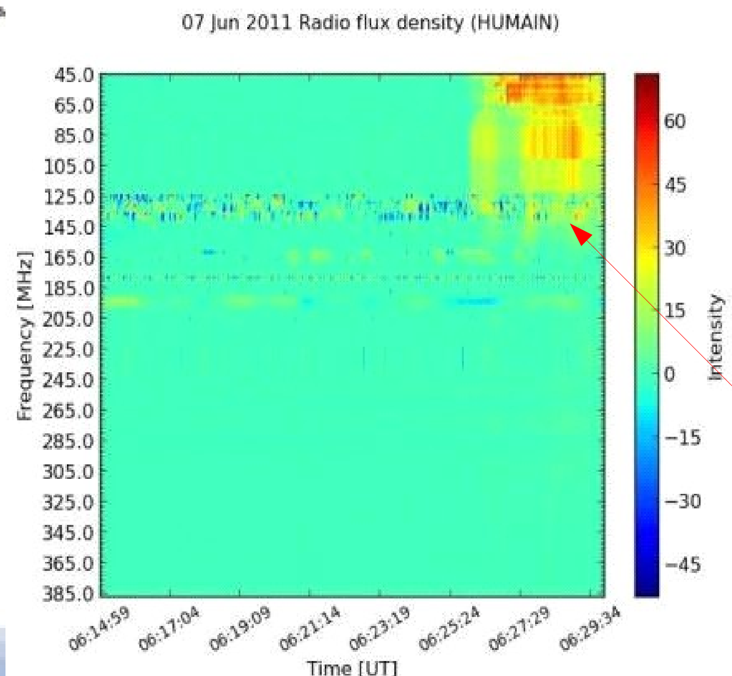


After joining the two BLENSW, the timescale is from 06:15 to 06: 45

SAME FLARE FOR HUMAIN

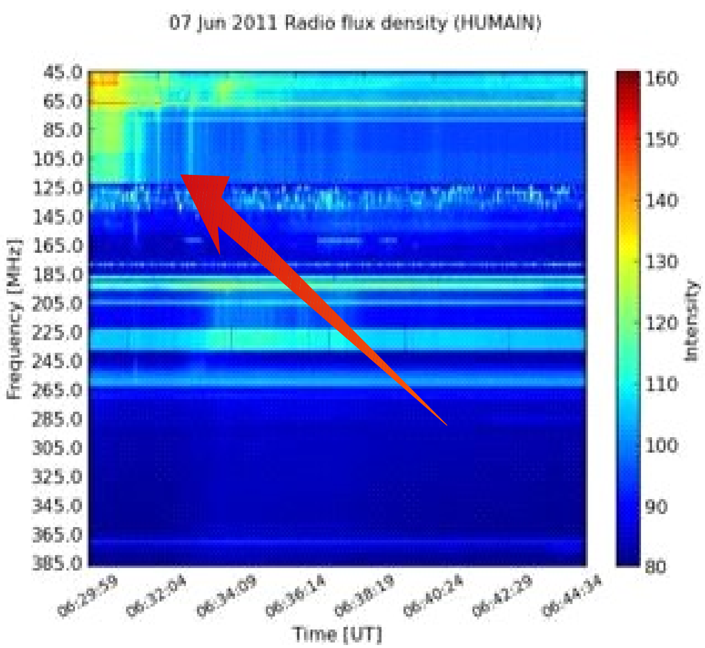


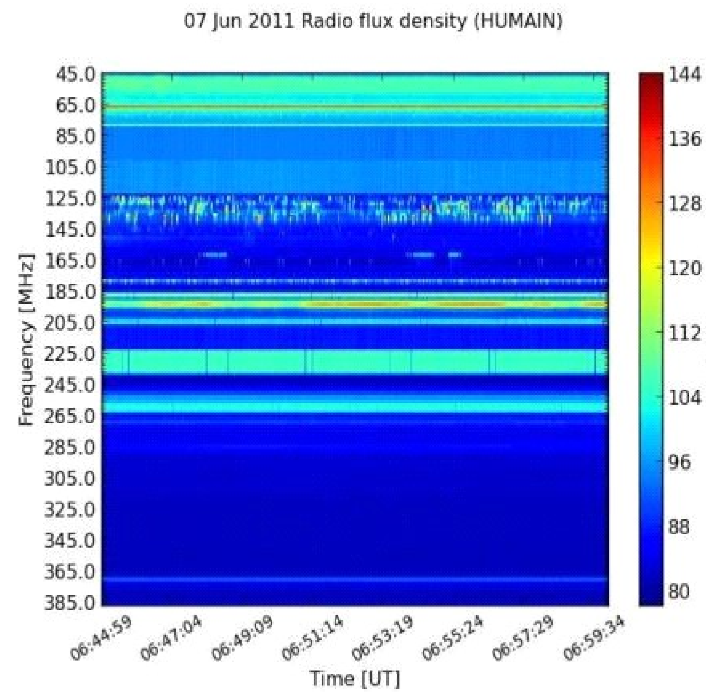


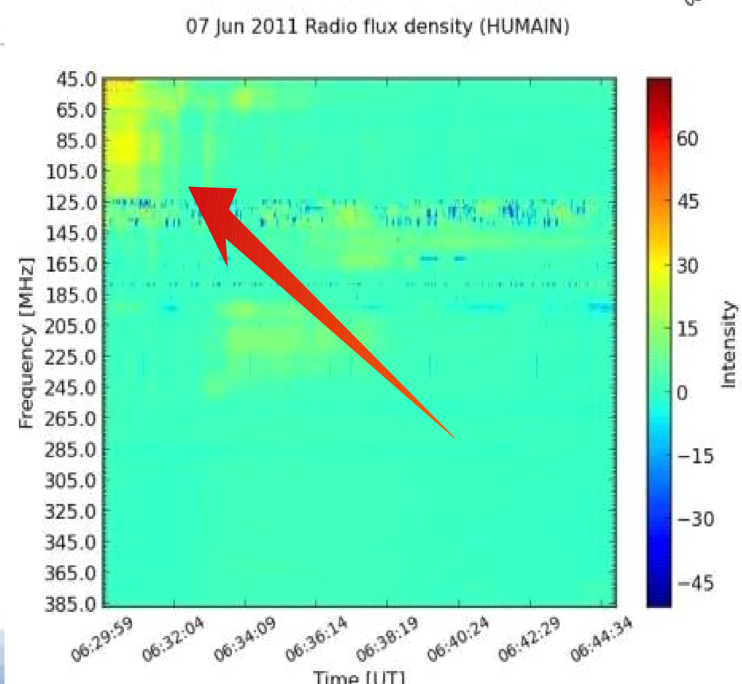


C

SAME FLARE FOR HUMAIN

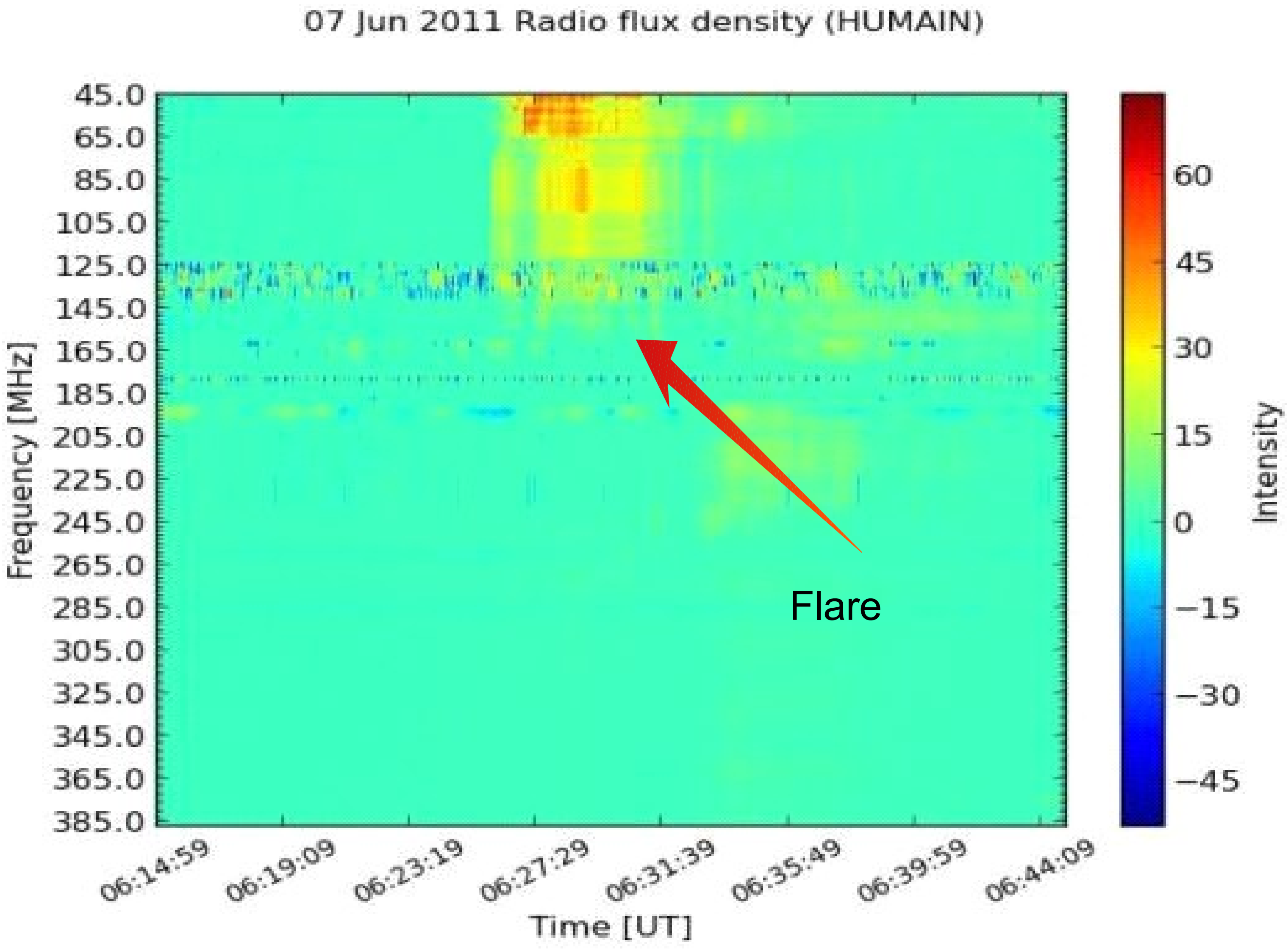




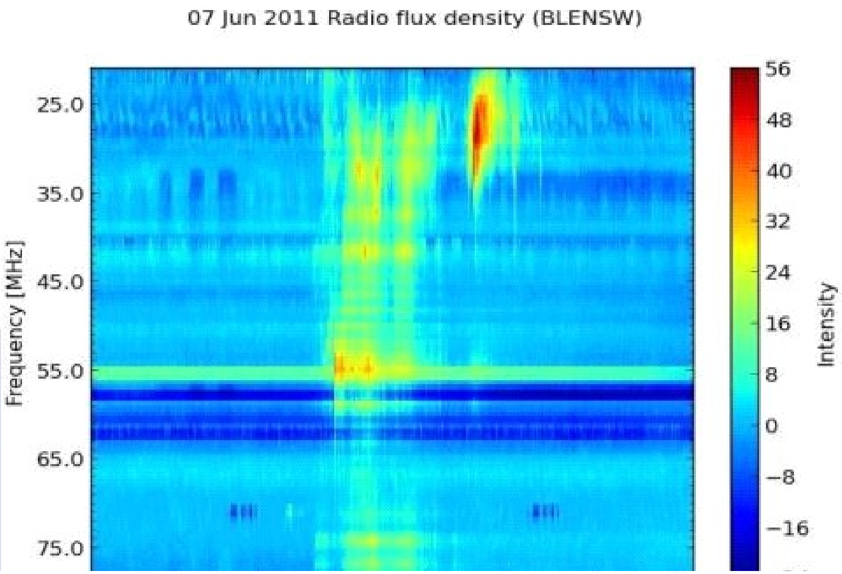


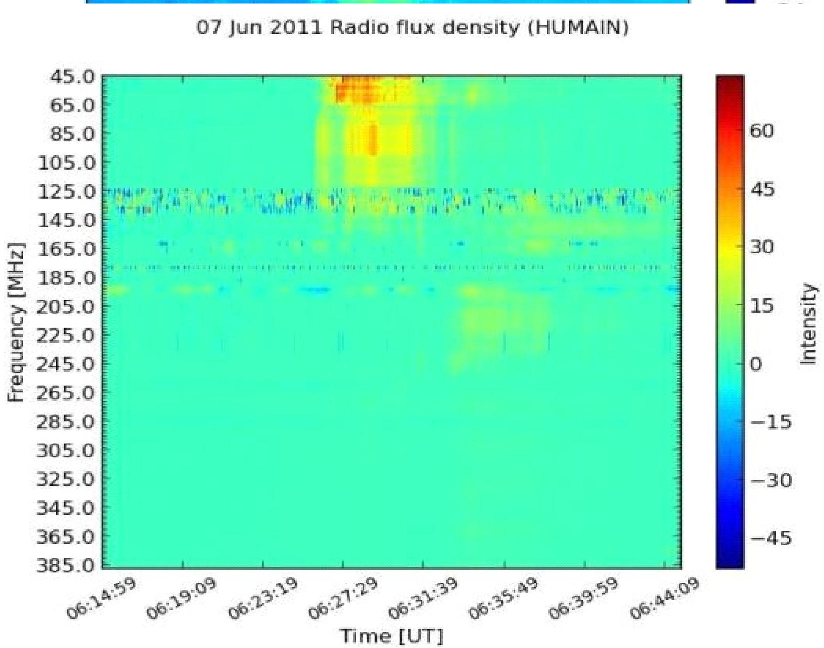
D

FLARE

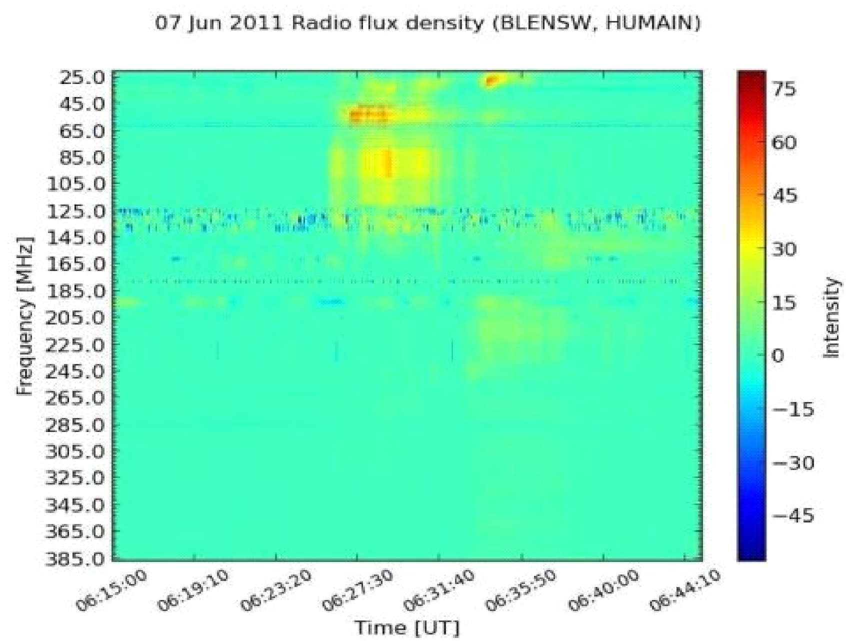

07 Jun 2011 Radio flux density (HUMAIN)
Frequency [MHz]
45.0
65.0
85.0
105.0
125.0
145.0
165.0
185.0
205.0
225.0
245.0
265.0
285.0
305.0
325.0
345.0
365.0
385.0
06:14:59
06:19:09
06:23:19
06:27:29
06:31:39
06:35:49
06:39:59
06:44:09
Time [UT]
Intensity
60
45
30
15
0
−15
−30
−45
Flare

ADDITION OF HUMAIN & BLENSW FILES AFTER BACKGROUND REMOVAL

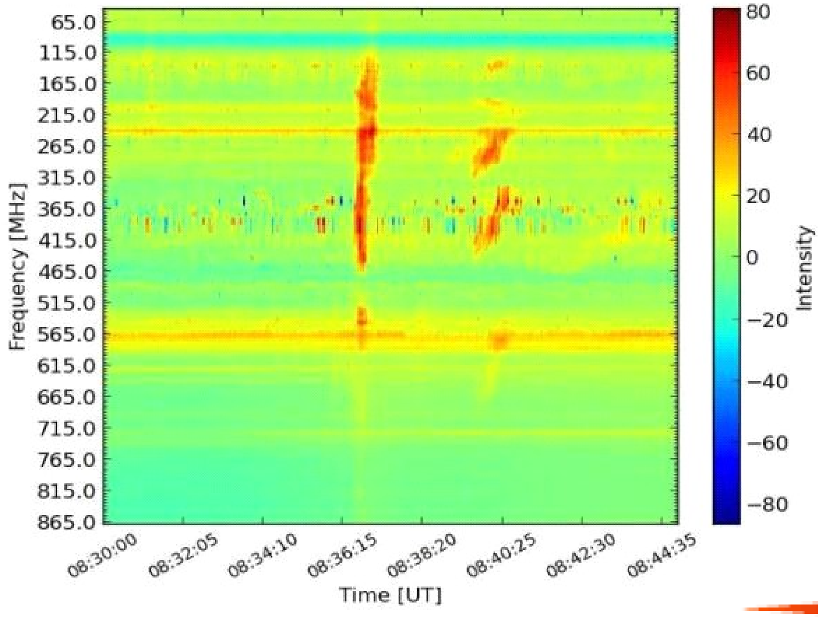




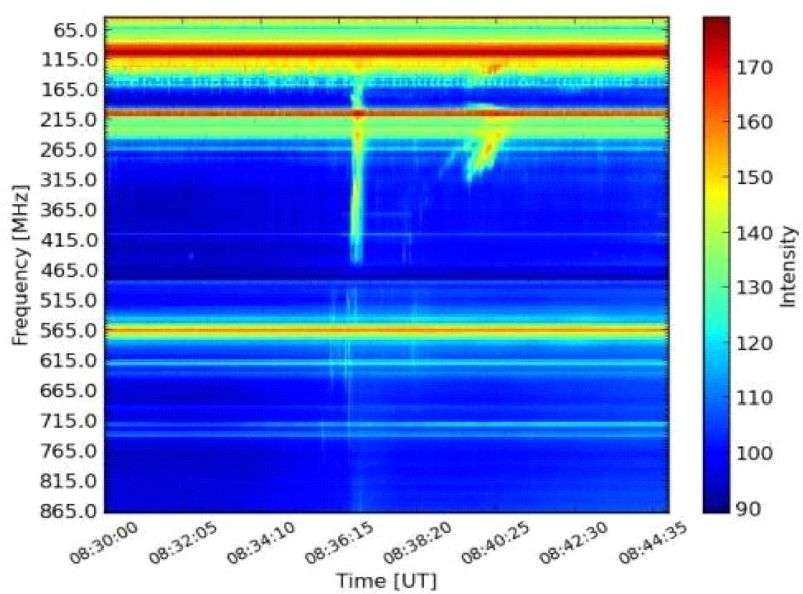
Plus



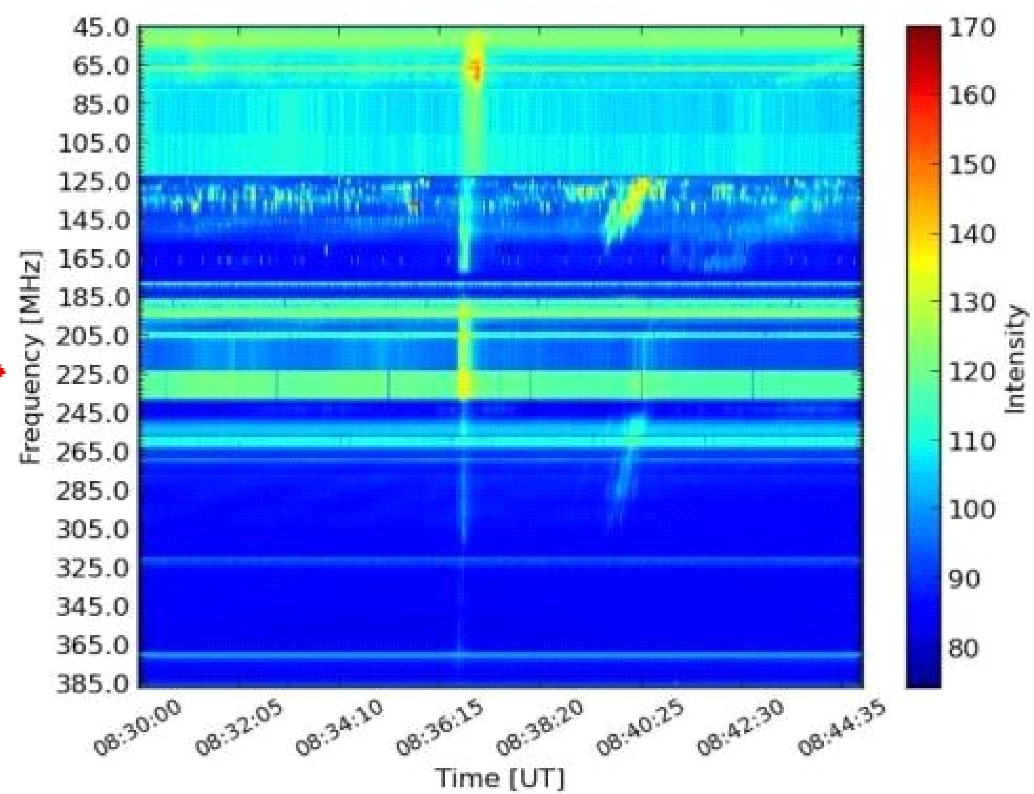
ADDITION OF BLEN7M & HUMAIN



13 Jan 2013 Radio flux density (BLEN7M)



13 Jan 2013 Radio flux density (HUMAIN)

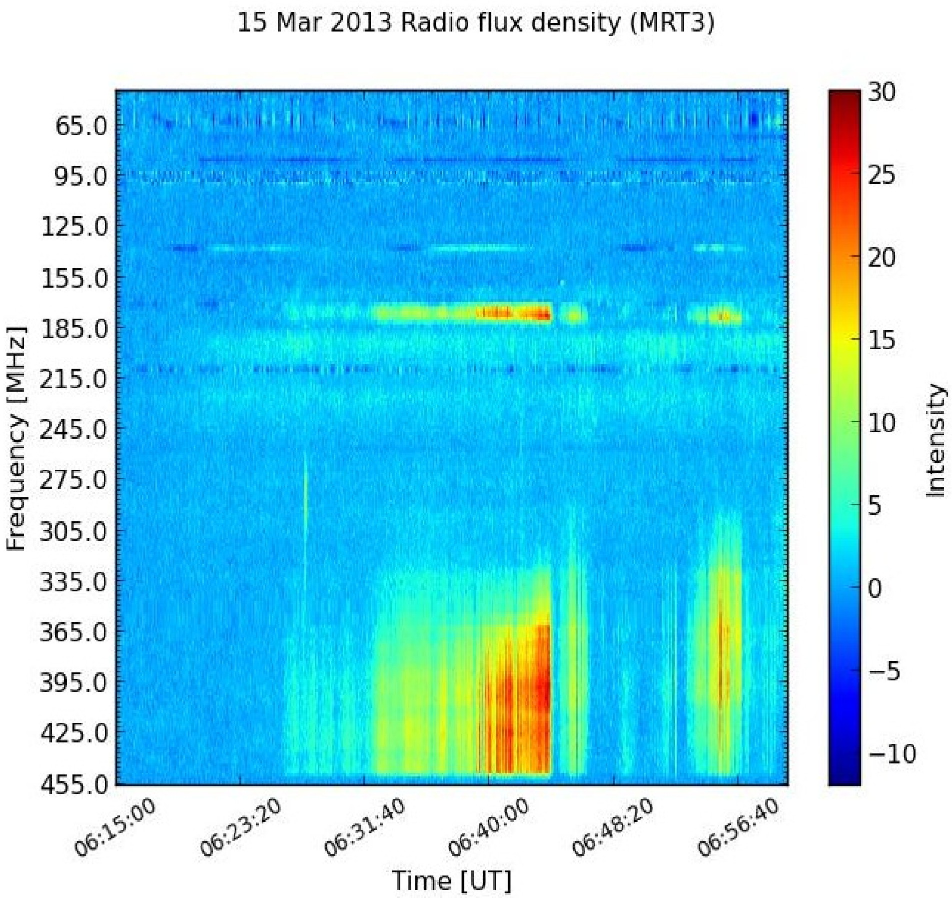


CORONAL MASS EJECTIONS

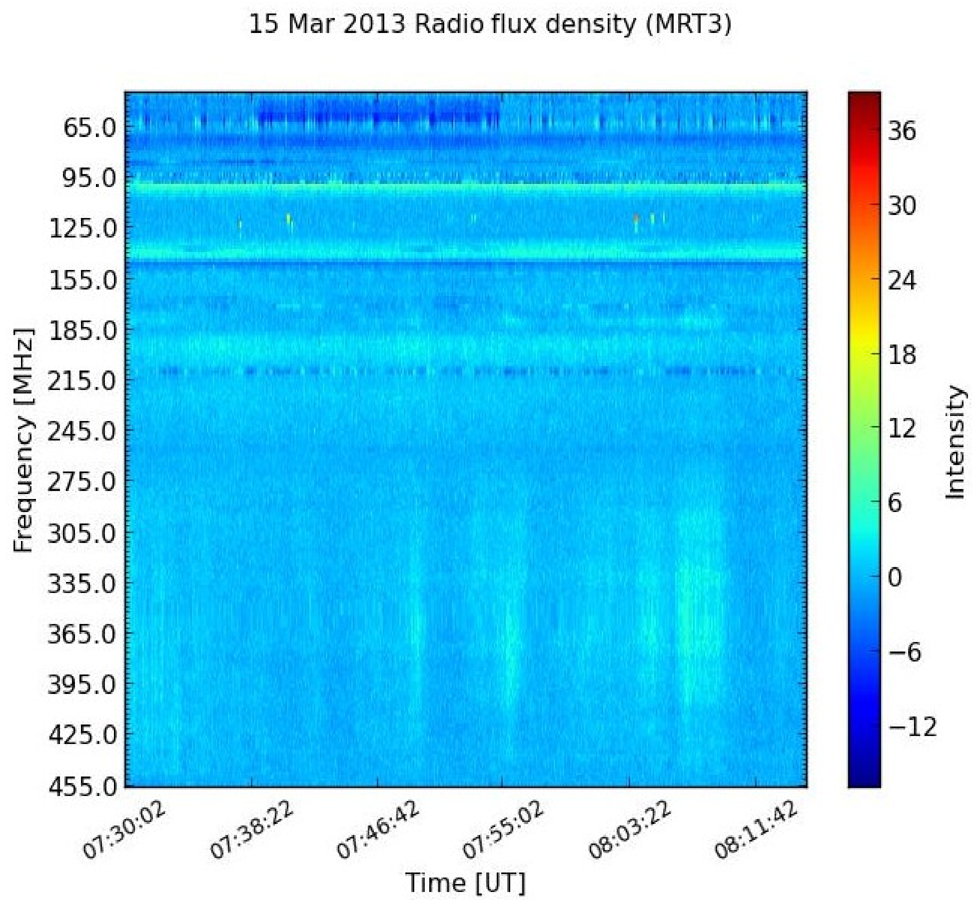
- Strong and energetic outbursts occurring on the Sun's surface.
- Controlled by strong magnetic fields.
- Due to instabilities in the magnetic field of the Sun, the restricted solar atmosphere abruptly eject heated bubbles of gas, i.e. the CMEs.
- With the MITRA antenna recently constructed at the MRT, a 2 hour long CME was observed on the 15th March 2013.

THE MRT3 CME :

The first three files were joined, giving the following:



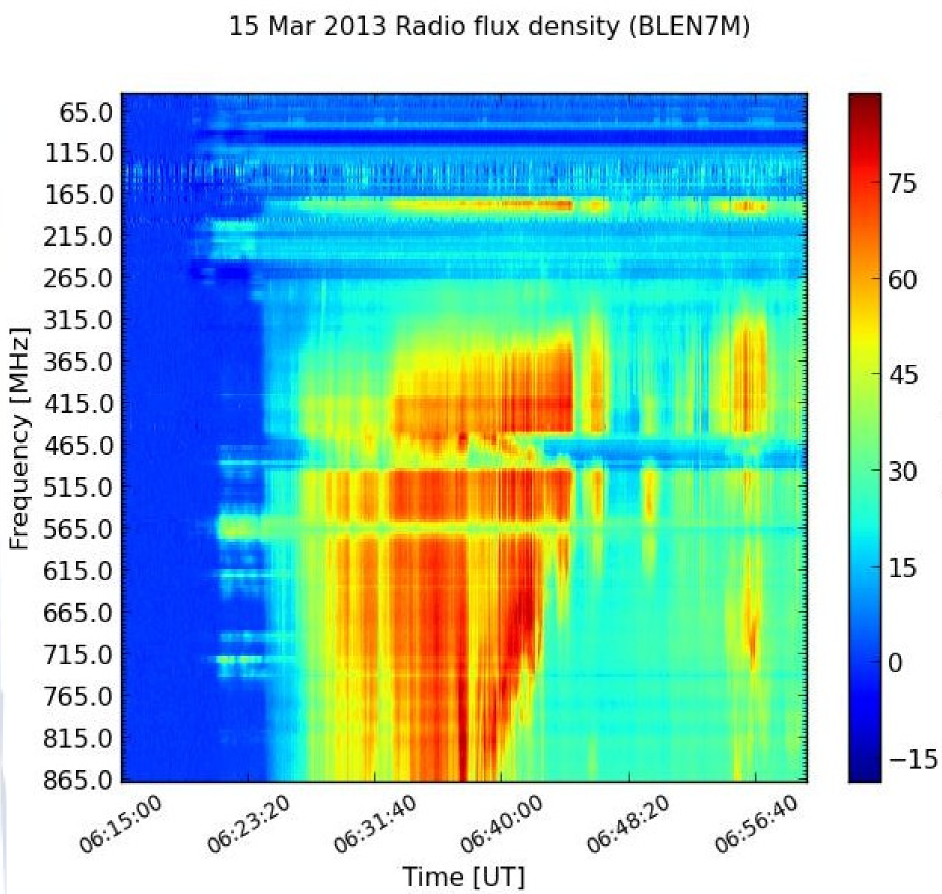
The CME between 07 30 UT and 08 30 UT.

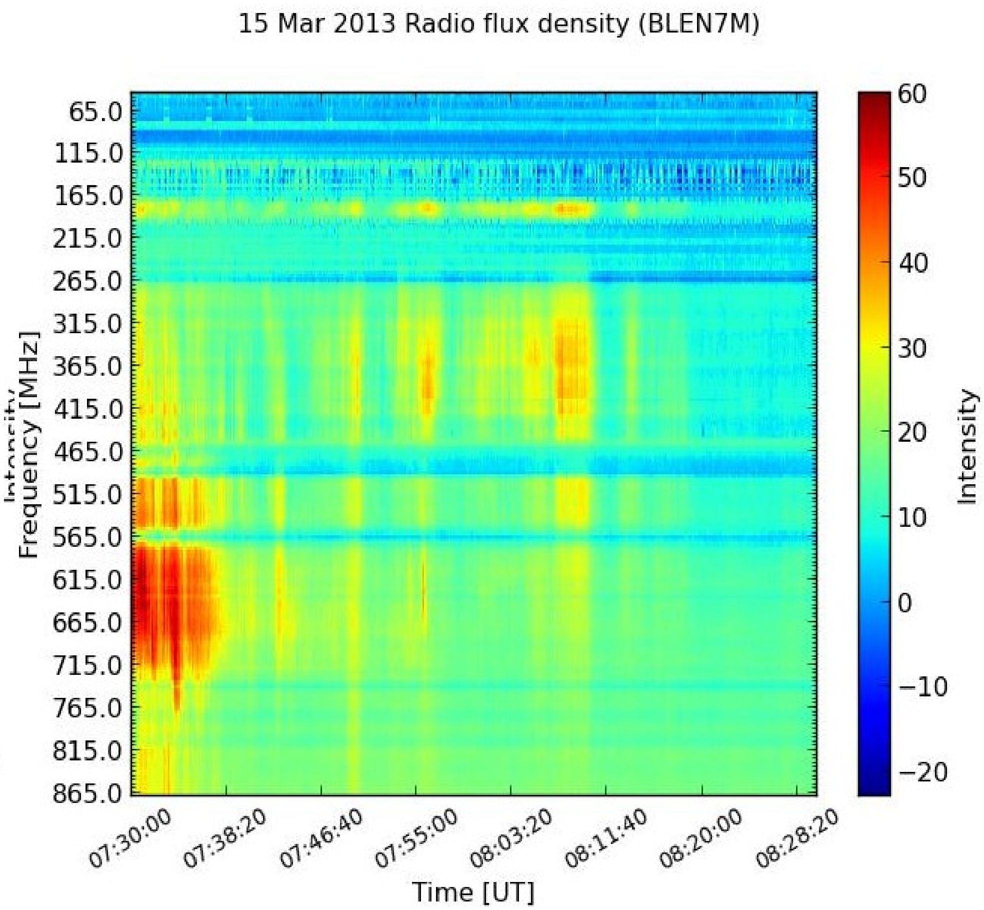


THE CME OBSERVED BY BLEN7M

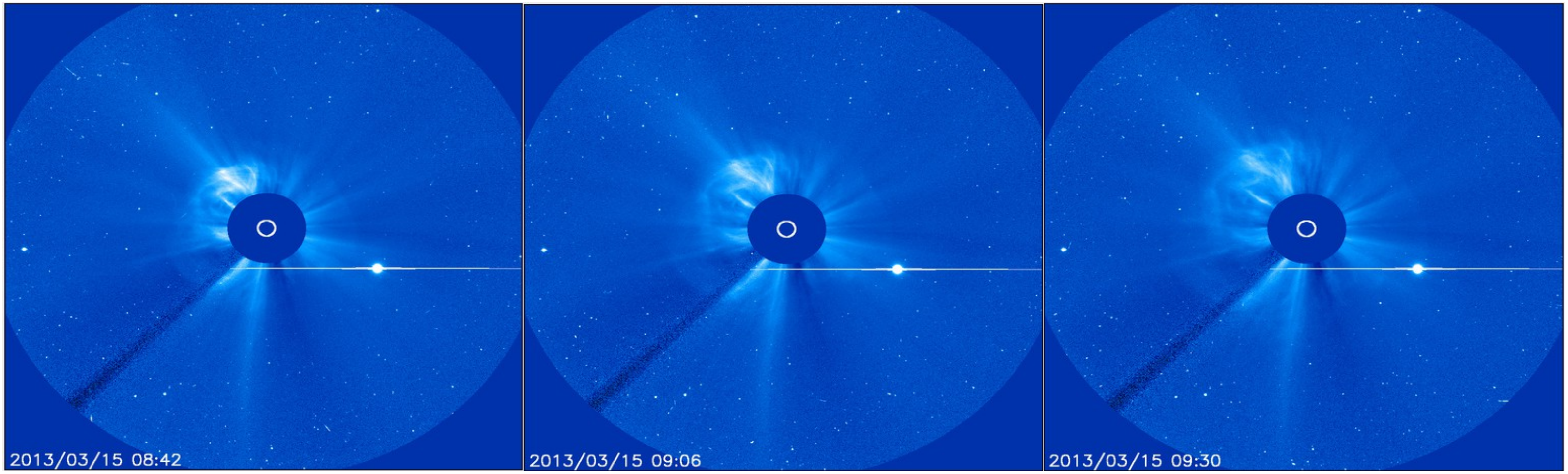
The first 3 files from 0615 to 0700

The CME between 0730 to 0830



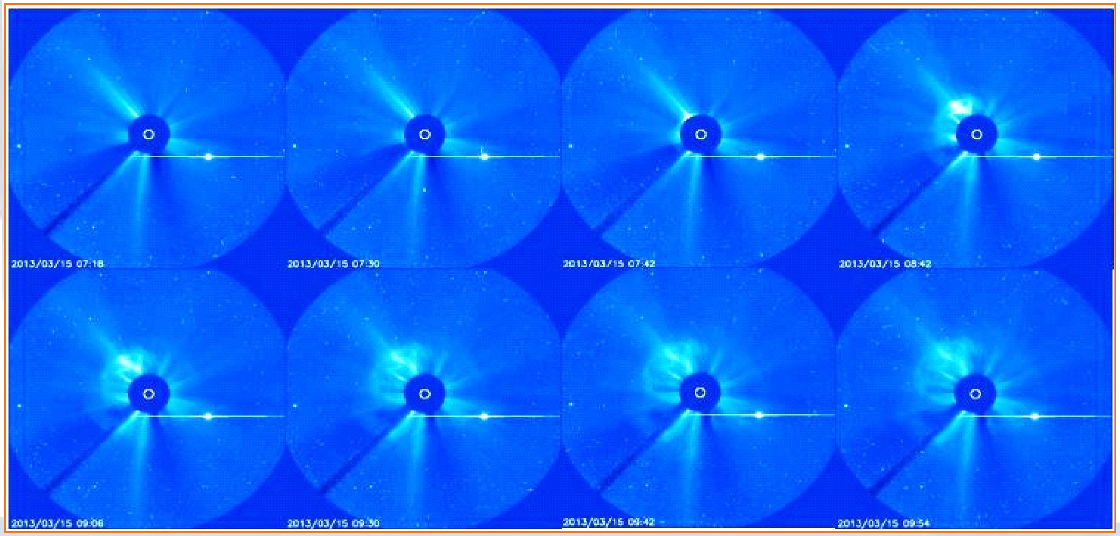


LASCO



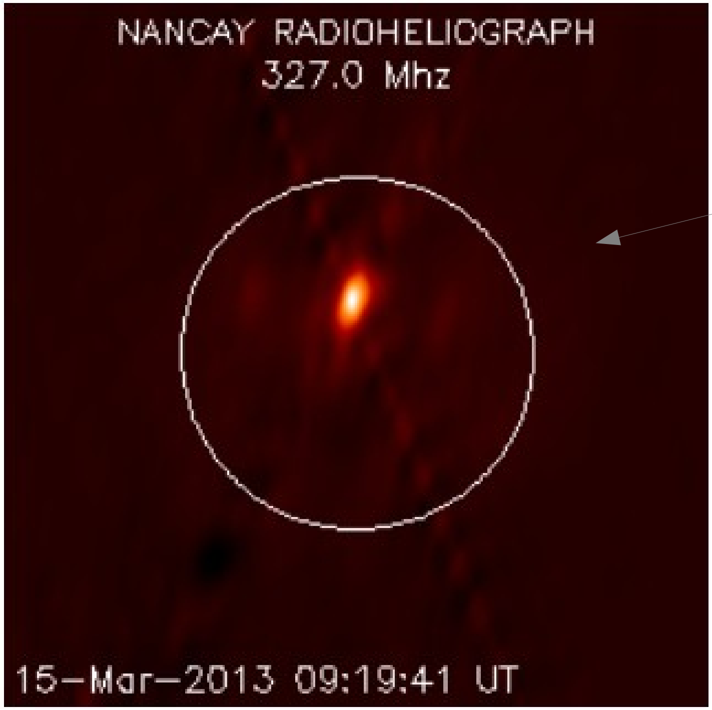
The above is showing part of the CME observed by LASCO

Large Angle and Spectrometric Coronagraph (LASCO) which studies the structure and evolution of the corona by creating an artificial solar eclipse.



CME observed on 15 March 2013

NANCAY

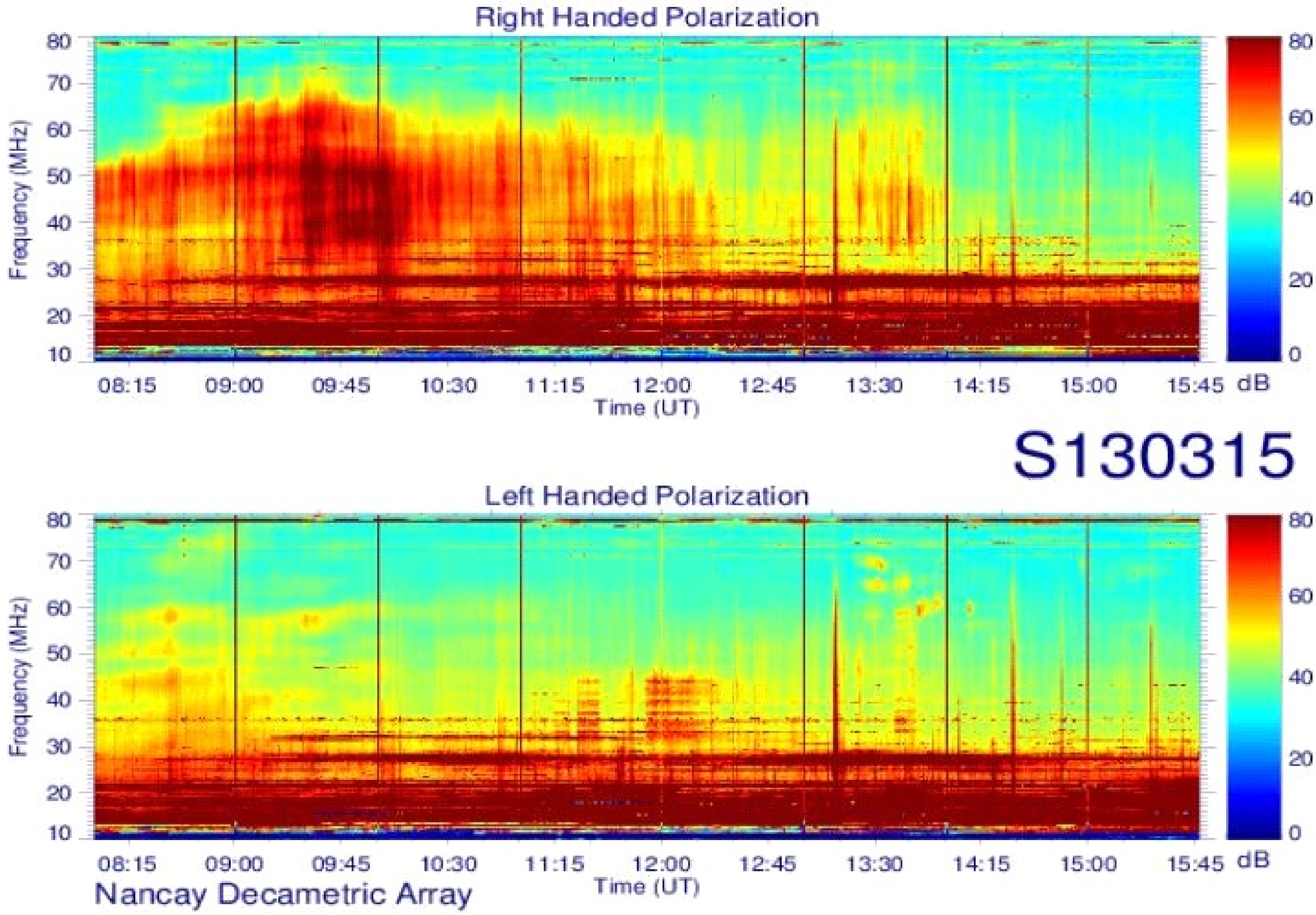


This is how it was seen by the NANCAY Radioheliograph.

Nançay Radioheliographe (NRH) is an interferometer composed of 48 antennas observing at meter-decimeter wavelengths. The radioheliographe is installed at the Nançay Radio Observatory (France).

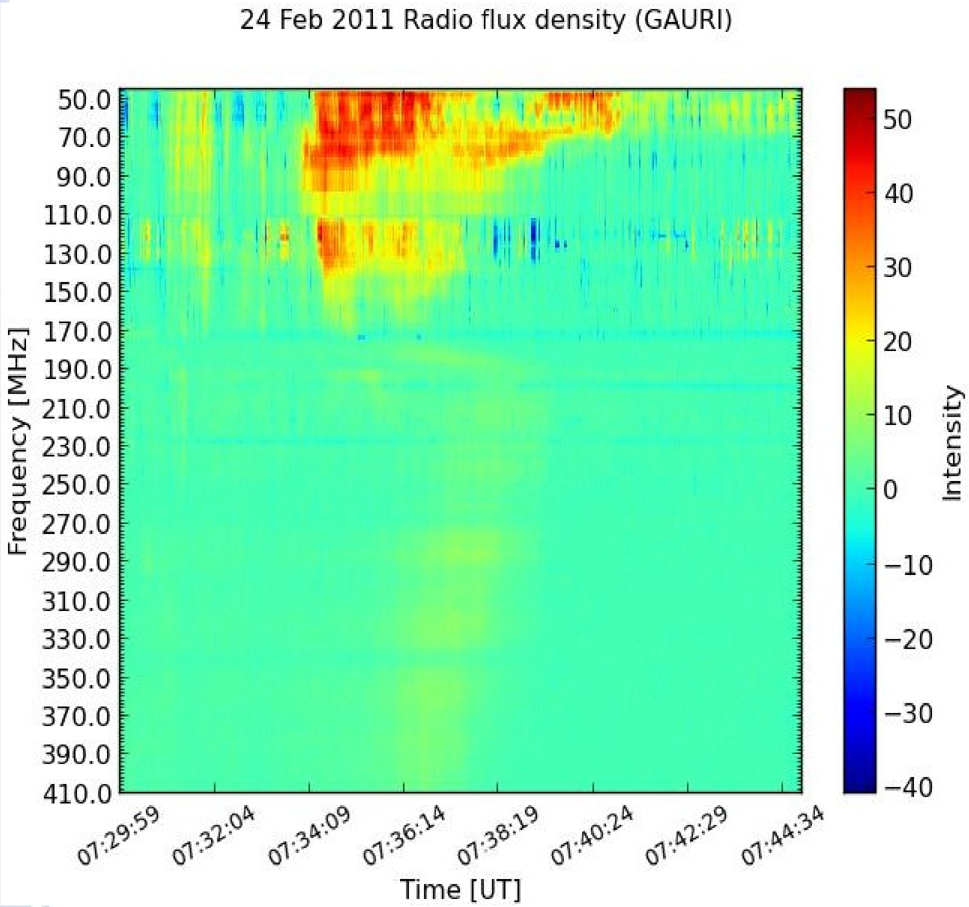
It observes up to 10 frequencies, between 150 and 450 MHz, for approximately 7 h per day

CME OBSERVED BY DIFFERENT INSTRUMENTS

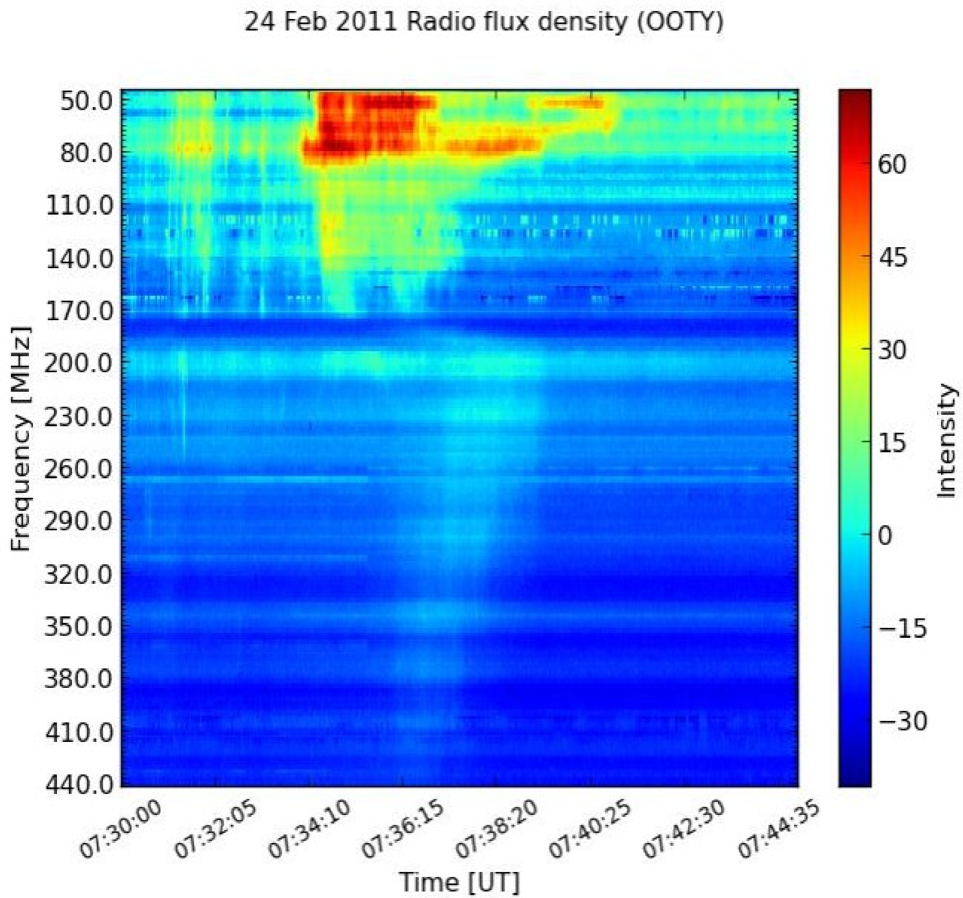


Nancay decametric array

INSTRUMENTAL DIFFERENCE

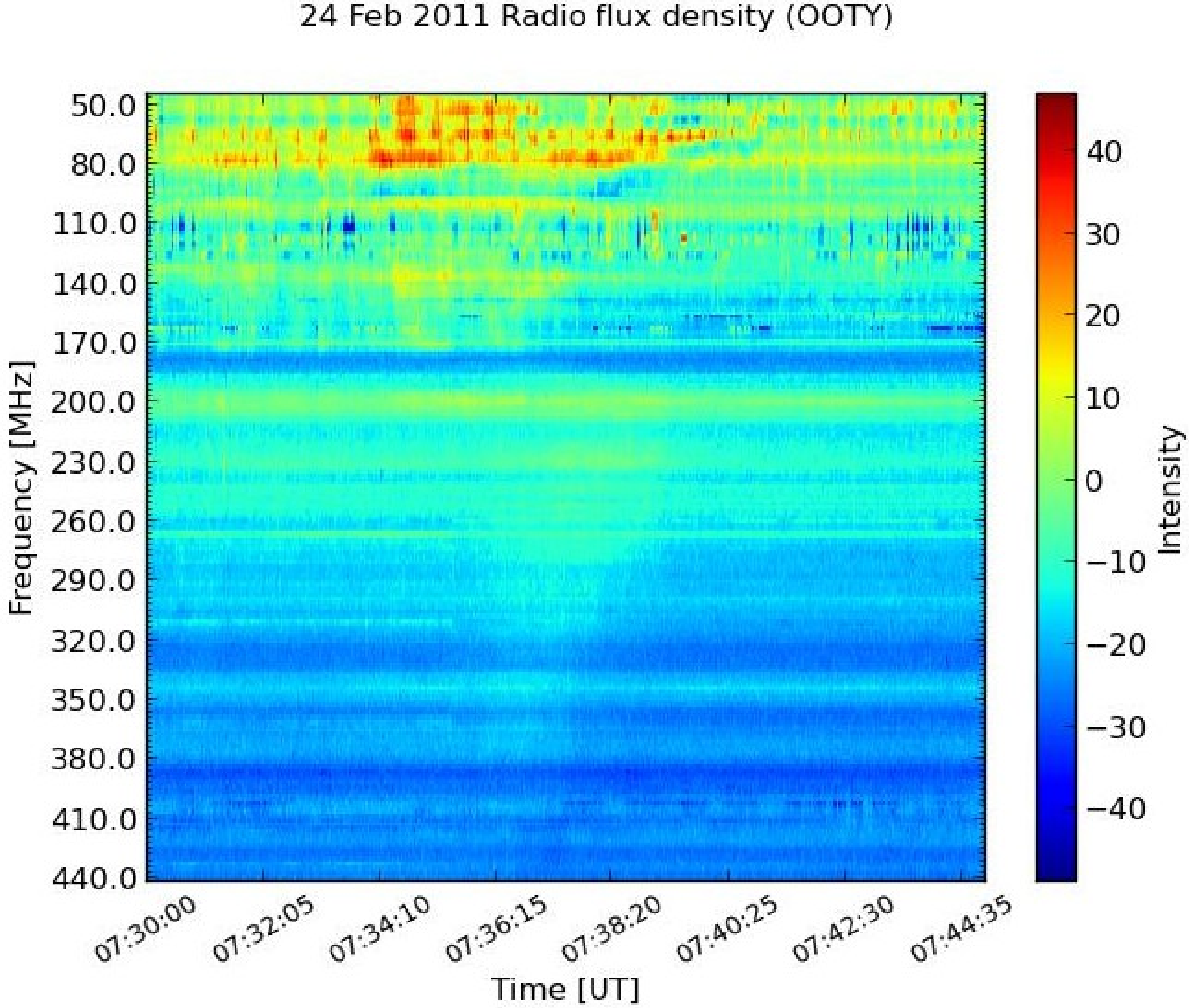


A GAURI flare without background



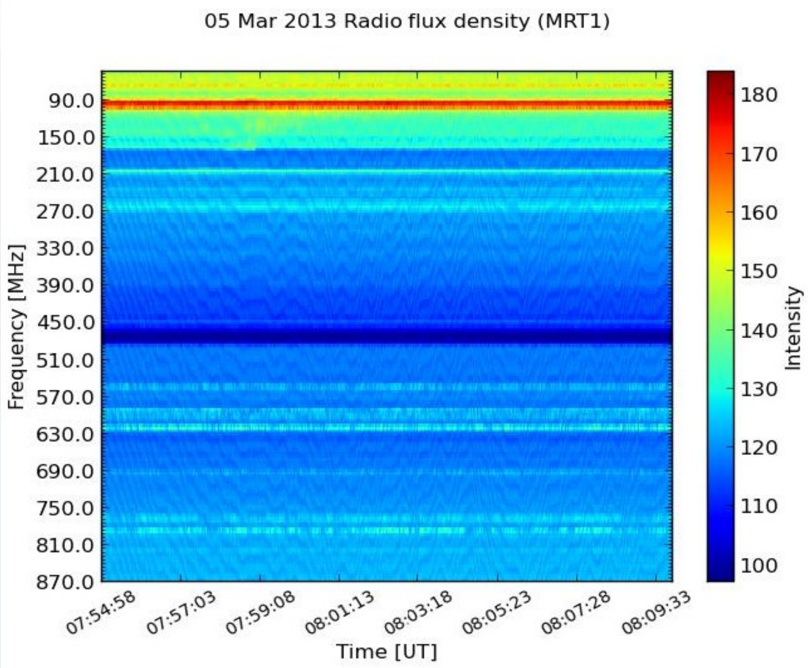
A OOTY flare without background

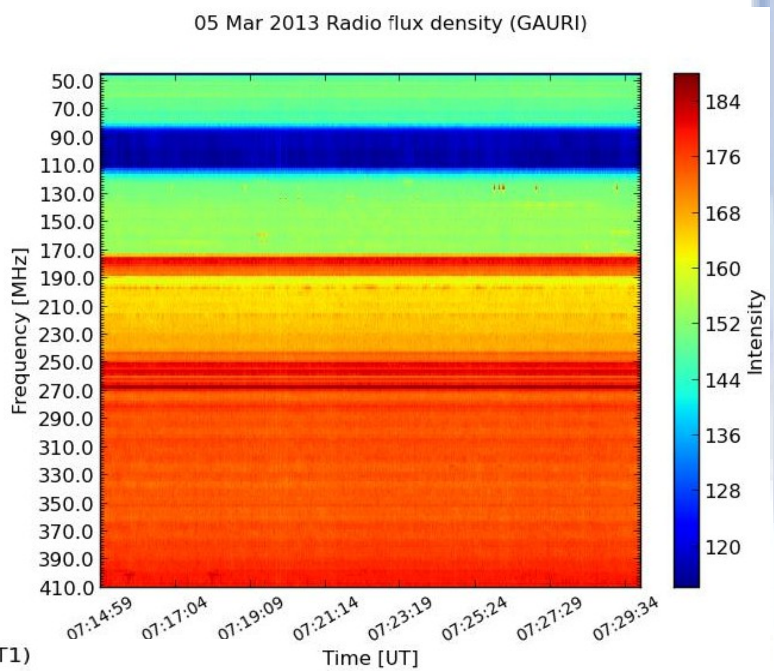
THE DIFFERENCE BETWEEN THE PREVIOUS FILES

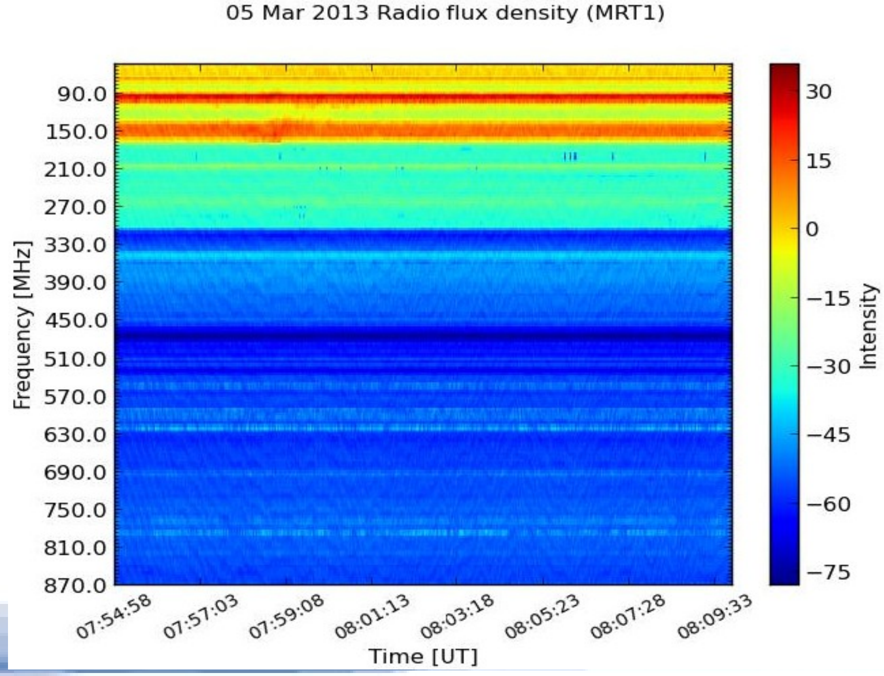


This graph was obtained by subtracting the GAURI file from the OOTY one.

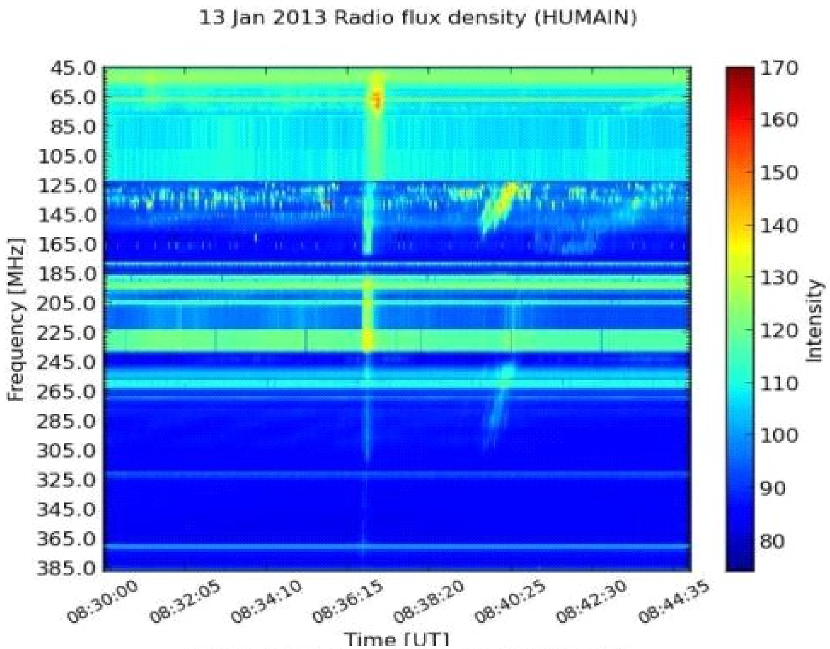
DIFFERENCE BETWEEN THE BACKGROUNDS OF GAURI & MRT1 FLARE

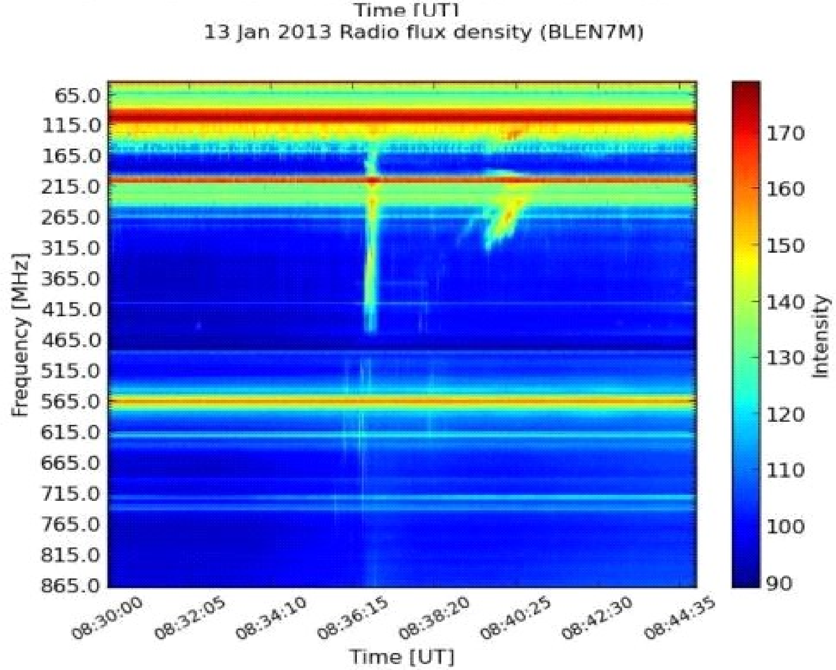


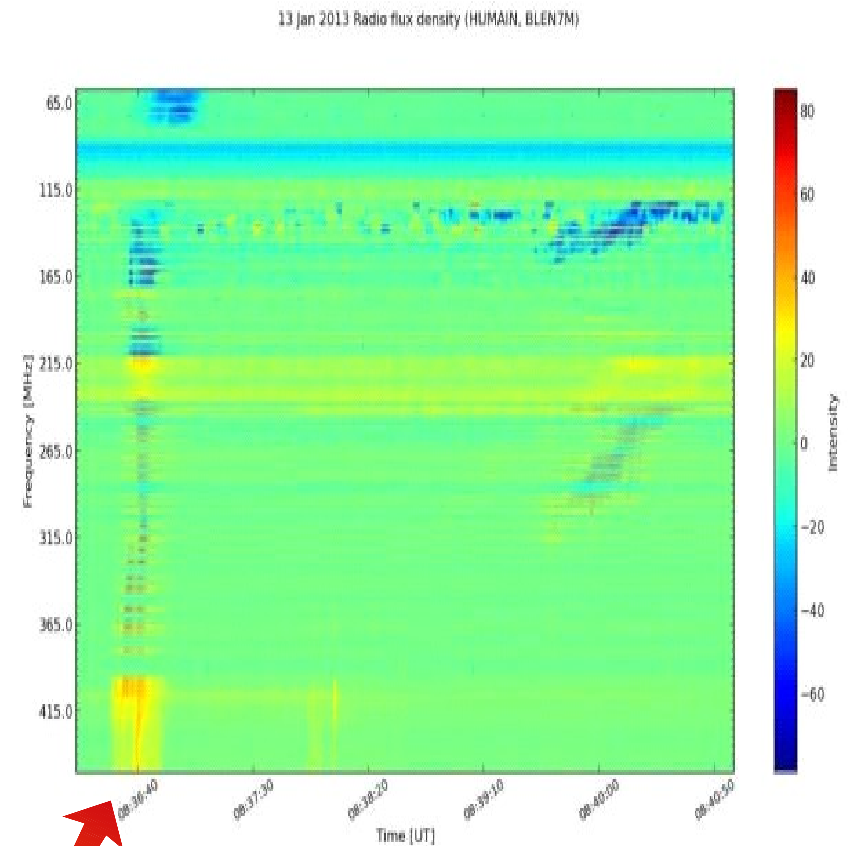




INSTRUMENTAL DIFFERENCE: HUMAIN & BLEN7M

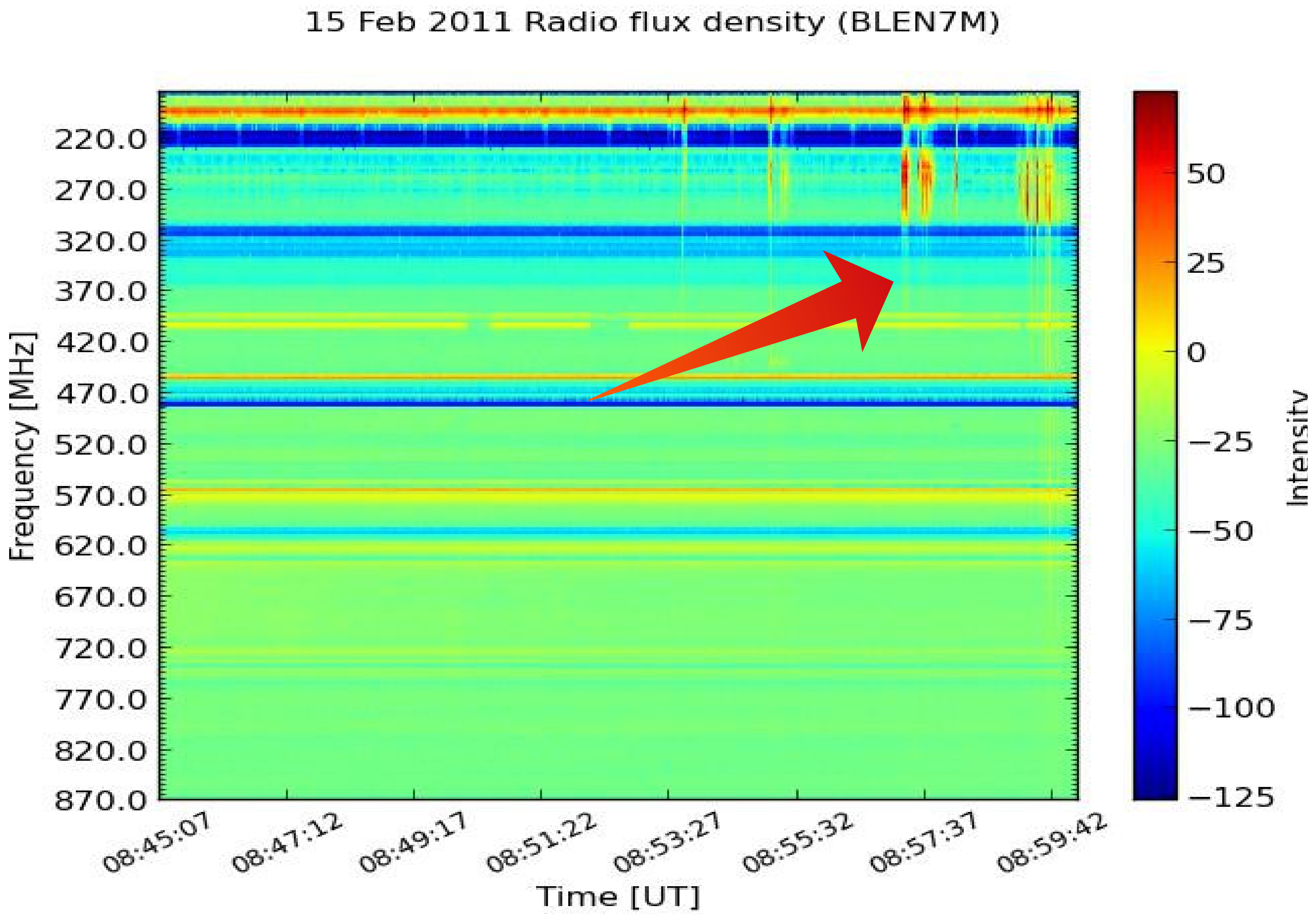






Flare effect seen due to Instrumental difference

BLEN7M + 2 times HUMAIN



WEAK BURSTS IN THE SOLAR CORONA IN ABSENCE OF X RAY EMISSION

- Observations of weak, circularly polarized, structureless type III bursts from the solar corona (in absence of H/X-ray flares and other related activity).

- CALLISTO Mauritius:
- emission from 50 to 120 MHz & drift rate ~ -30 Mhz/s

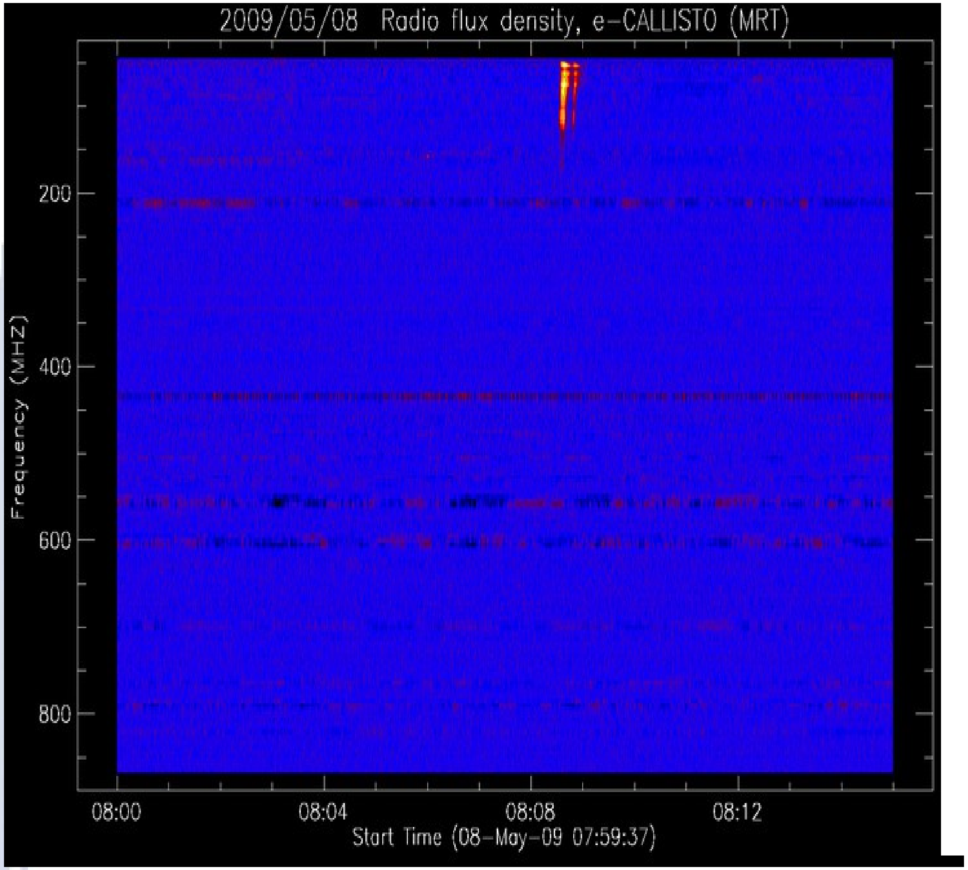
- Imaging 2-D data from Gauribidanur radioheliograph at 77 MHz: burst at 1.5 Ro in solar atmosphere

- Gauribidanur East-West polarimeter: magnetic field ~2.5G

- Energy of non thermal electrons ~1.1×10^{24} ergs (X-ray nicroflare ~ 10^{26} ergs). Nature unknown.

(APJL 719:L41:L44, 2010 August 10 R. Ramesh , C. Kathiravan , Indrajit V. Barve , G. K. Beeharry , and G. N. Rajasekara)

WEAK BURSTS IN THE SOLAR CORONA IN ABSENCE OF X RAY EMISSION



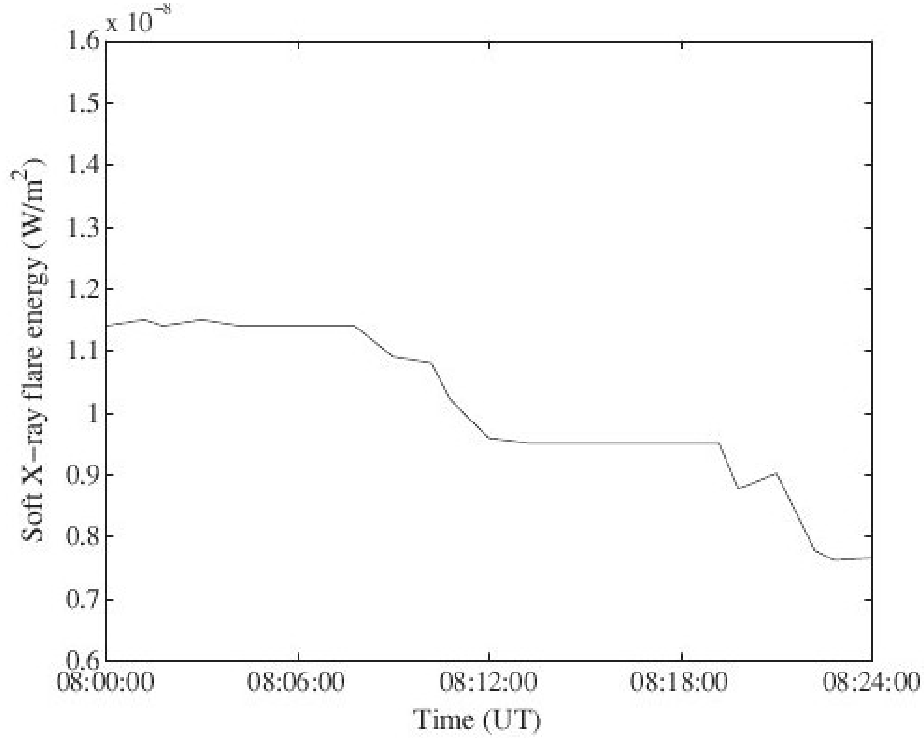


Figure 2. Soft X-ray (0.5–4 Å) flare energy observed from the whole Sun during the interval 08:00–08:24 UT on 2009 May 8 with the X-ray sensor onboard *GOES 10*. The integration time is ≈1 minute.

(APJL 719:L41:L44, 2010 August 10 R. Ramesh , C. Kathiravan , Indrajit V. Barve , G. K. Beeharry , and G. N. Rajasekara)

WEAK BURSTS IN THE SOLAR CORONA IN ABSENCE OF X RAY EMISSION

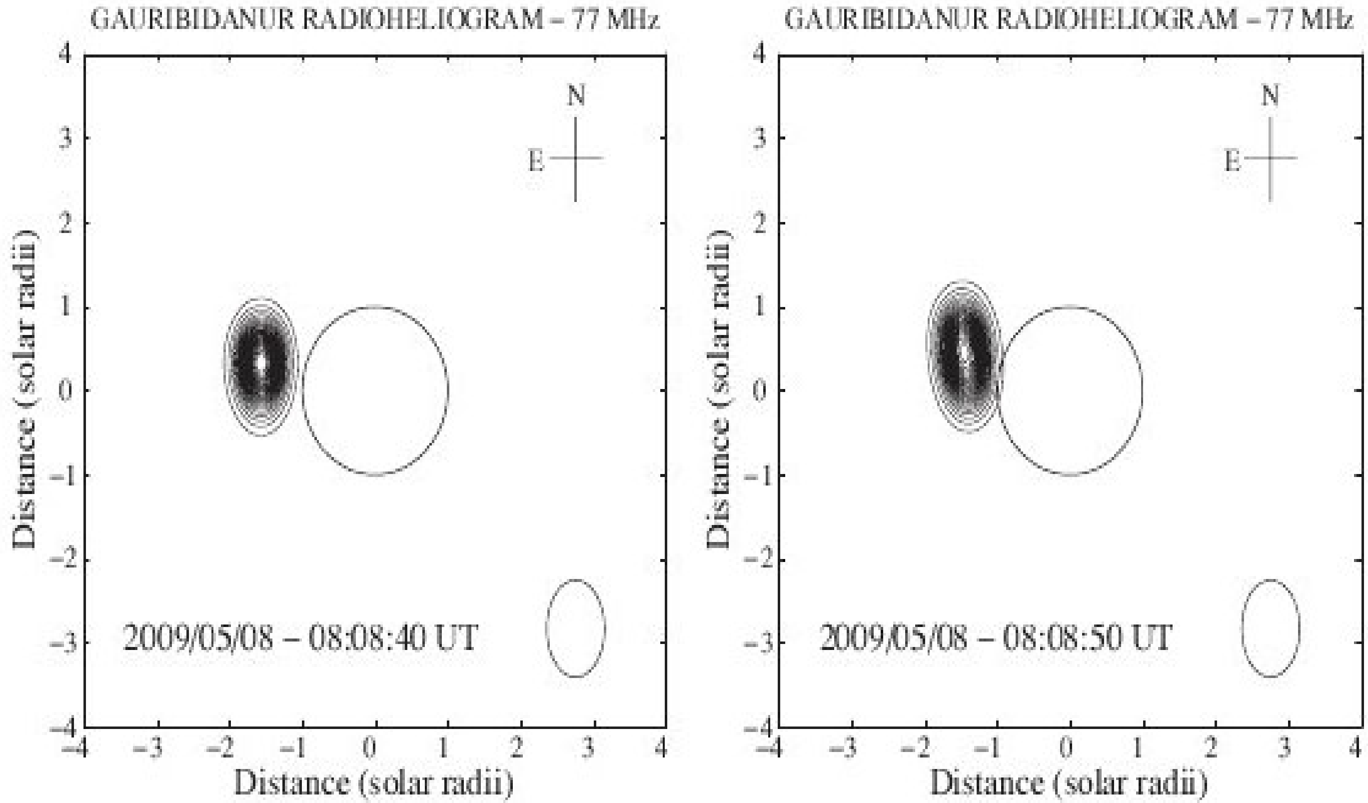


Figure 3. Snapshot images of the solar corona at 77 MHz obtained with the GRH on 2009 May 8 at 08:08:40 UT (left panel) and 08:08:50 UT (right panel). The integration time is ≈1 s. The estimated peak brightness temperatures (T_b) of the bursts are $\approx 1.7 \times 10^8$ and 0.9×10^8 K, respectively. The circle at the center in both the images represents the limb of the solar photosphere. The ellipse near the bottom right corner corresponds to the GRH beam size at 77 MHz.

CONCLUSION & FUTURE WORK

The data analysis of flares and CMEs has been successfully carried out using a new technique. This work will be furthered by the following improvements in the algorithms:

- Using the detail antenna patterns to correct for the flares in CME emissions.
- In optimizing techniques to combine data from different instruments with similar antenna patterns.
- In developing new techniques to use data from different instrument with dissimilar antenna patterns.
- Flux calibration for each instrument.
- Correction for instrumental effect in spectrum.

REFERENCES

- *http://itsabeautifulearth.com/2013/02/23/nasas-solar-dynamics-observatory-captures-beautiful-solar-flare/*
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- *http://www.e-callisto.org*
- *http://sohodata.nascom.nasa.gov/cgi-bin/data_query*
- *http://bass2000.obspm.fr/search.php?step=2*