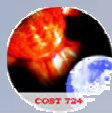


# Geoeffectivity of SRFs near solar minimum: Analysis of m-dm flares detected by TSRS in 2005 and 2006

M. Messerotti<sup>1,2</sup>

<sup>1</sup>INAF-Astronomical Observatory of Trieste, IT

<sup>2</sup>Dept. of Physics, University of Trieste, IT

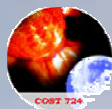


SEE 2007 Athens 24 Sept. 2007



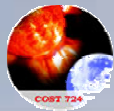
# Outline of the Talk

- The TSRS-Trieste Solar Radio System
- TSRS near-real-time data products
- Radio diagnostics for Space Weather
- Effects of SRBs on Wireless Systems
- Effects of SRBs on GPSs
- Relevant SRFs observed in 2005-2006
- Conclusions





# The Basovizza Observing Station



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# The New Labs



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# The TSRS Antenna Systems



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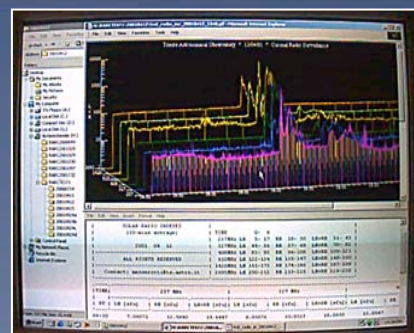
SWARM



TSRS WWW



DVD Juke-box



SOLRA Server



NRTAnalyzer

TSRS Control System



# TSRS Receivers Room



## SPECIFICATIONS

- Metric Multichannel Solar Radio Polarimeter (mMSRP)

- 10m mesh parabolic antenna, equatorial mounting.
- Log-periodic feeder.
- Left- and Right-handed Circular Polarization.
- 4 receiving frequencies:
  - 237 MHz
  - 327 MHz
  - 408 MHz
  - 610 MHz

- DeciMetric Multichannel Solar Radio Polarimeter (dmMSRP)

- 3m parabolic antenna, alt-az mounting.
- Log-periodic feeder.
- Left- and Right-handed Circular Polarization.
- 2 receiving frequencies:
  - 1420 MHz
  - 2695 MHz

- High time resolution (1 ms) digital data acquisition system
- Relational Data Base Management system with real-time data ingestion
- Real-time solar radio indices time evolution and nowcasting publication



## OPERATIONAL FEATURES

### • OPERATING MODE:

- Radio surveillance
- Automatic start-up and shutdown
- Daily observations
- 1 ms routinary sampling time

### • STATUS:

- Fully operational in Space Weather automatic mode since June 2000

### • DATA PROCESSING:

- Real-time online calibration
- Real-time data graphing
- Real-time solar radio indices
- Real-time data archiving
- Real-time data publishing

### • PROBLEMS:

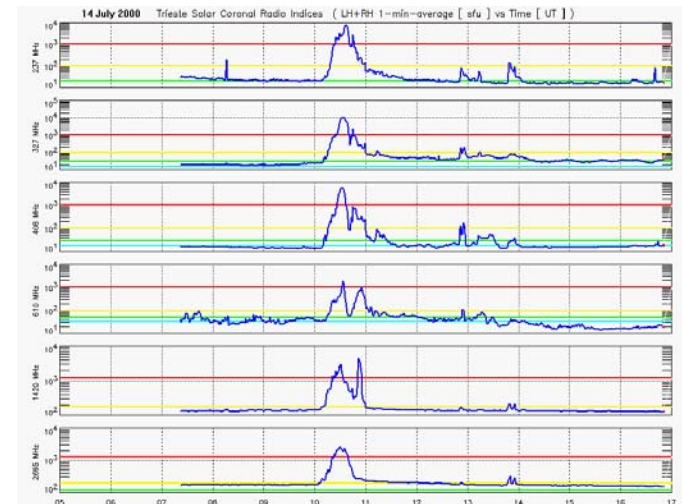
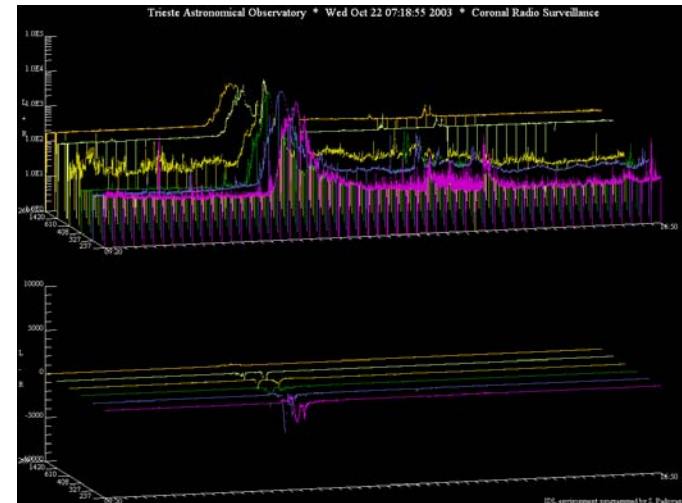
- Strong man-made interferences at the following frequencies:
  - 237 MHz                   sporadic
  - 327 MHz                   sporadic
  - 610 MHz                   continuous





## DATA PRODUCTS FOR SPACE WEATHER

- Multichannel Synoptic Graph
  - 1 s downsampled data
  - updated every 10 minutes
- Solar Radio Indices Graphs
  - 1-min-average values
  - 1-min-max values
  - 1-min-ahead forecast
  - updated every 10 minutes
- Solar Radio Indices Files
  - ASCII
  - Binary
  - FITS



## DATA PUBLICATION AND ACCESS

• Internet

<http://radiosun.ts.astro.it>

• Mobile Phones (WAP)

<http://radiosun.ts.astro.it/wap/en.wml>

**Trieste Solar Radio System**

Near Real-Time Radio Data | Coronal Radio Surveillance

- Monitor
- Indices
- Radio Archive
- Web Cam
- Operational Status

Coronal Radio Surveillance

- News
- Project
- Instrumentation
- Sample Data
- Space Weather
- Italiano

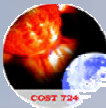
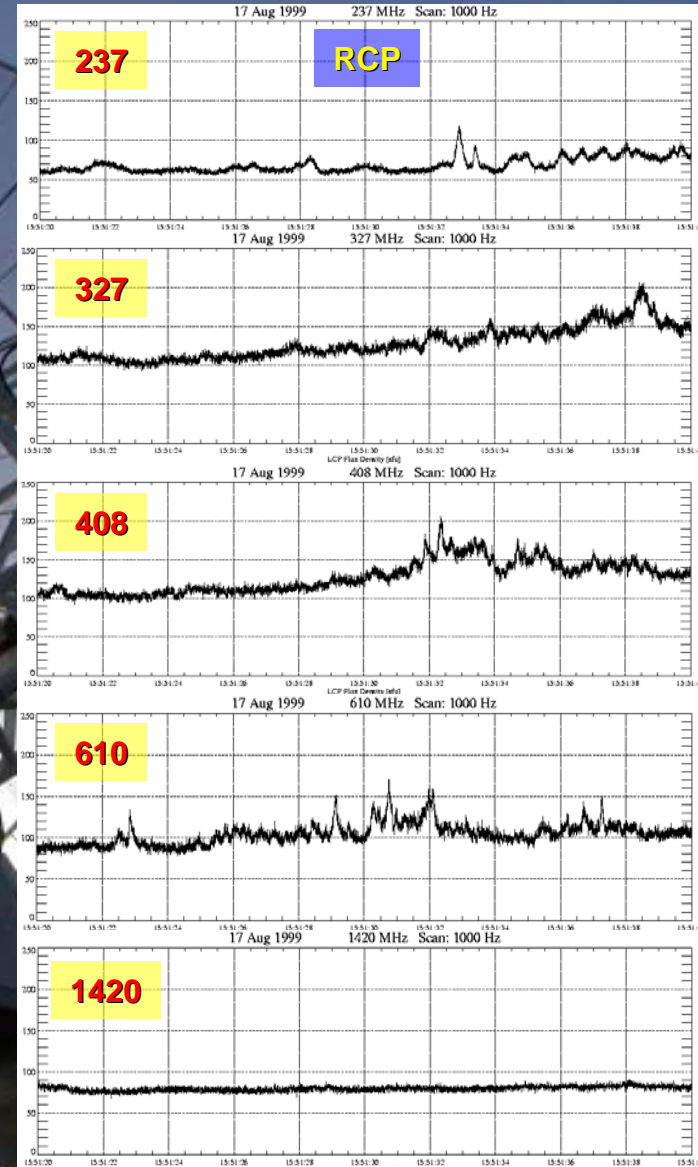
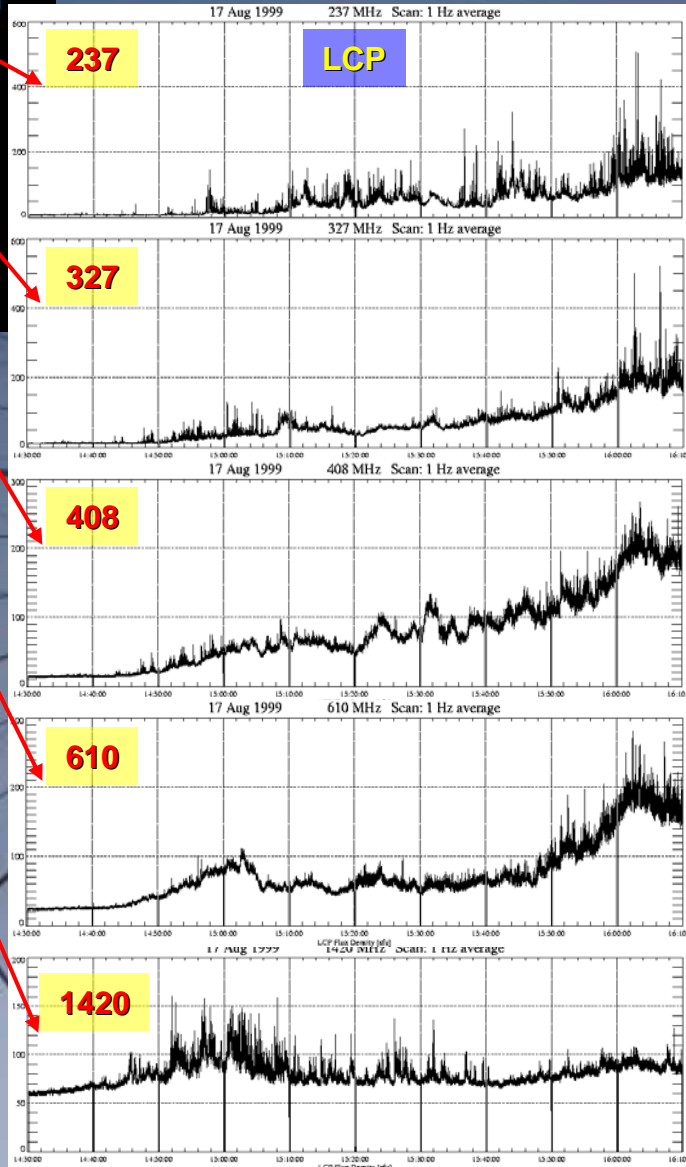
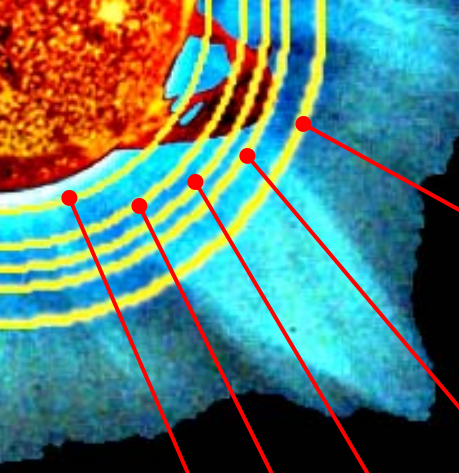
[::EGSO\\_SolarEventCatalogue](#)
[:: Links](#)
[:: Contacts](#)
[:: Data policy](#)
[:: Disclaimer](#)
[:: Credits](#)

NRT Solar Radio Noise						
Freq [MHz]	237	327	408	610	1420	2695
SRN	L	L	L	L	L	L
predicted	M	L	L	M	L	L

Last update: 23 Apr 2004 11:38 UTC



# Onset of a Strong Type IV Burst



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# TSRS DATA PRODUCTS

- 1-min-average and 1-min-max radio indices
- 237, 327, 408, 610, 1420, 2695 MHz
- FLUX DENSITY & CIRCULAR POLARIZATION
- [  $W / m^2 / Hz$  ] & [  $dBm / Hz$  ]
- Observed and 1-min-ahead Predicted Values
- Single polarization channels & sum of channels



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# TSRS Solar Radio Noise (SRN) Level

- The Solar Radio Noise (SRN) level is derived according to a specific thresholding at each receiving frequency, which is based on the respective Quiet Sun levels via a multiplicative factor as

$$\text{SRN} = (\text{Quiet Sun level}) * (\text{Activity Factor})$$

- SRN is therefore classified as Low, Moderate, High
- Observed and predicted SRN values are published on the web site in NRT

# The TSRS Homepage

**Trieste Solar Radio System**

Near Real-Time Radio Data

Coronal Radio Surveillance

- Monitor
- Indices
- Radio Archive
- Web Cam
- Operational Status

Coronal Radio Surveillance

- News
- Project
- Instrumentation
- Sample Data
- Space Weather
- Italiano

[::EGSO\\_SolarEventCatalogue](#) [:: Links](#) [:: Contacts](#) [:: Data policy](#) [:: Disclaimer](#) [:: Credits](#)


NRT Solar Radio Noise						
Freq [MHz]	237	327	408	610	1420	2695
SRN	Q	Q	Q	M	Q	L
predicted	L	Q	L	M	L	L

Last update: 17 Jun 2007 16:58 UTC

[Details](#)



# The TSRS Solar Radio Noise Panel


Trieste Solar Radio System

Near Real-Time Radio Data

Coronal Radio Surveillance

## NRT Solar Radio Noise

Frequency [MHz]	Mean [SFU]	Max [SFU]	Mean [dBm/Hz]	Max [dBm/Hz]	SRN	Predicted [SFU]	Predicted [dBm/Hz]	Predicted SRN
237	3	60	-216	-204	Q	32	-206	L
327	9	31	-215	-209	Q	14	-213	Q
408	11	58	-215	-208	Q	24	-212	L
610	142	333	-208	-204	M	172	-207	M
1420	36	48	-221	-220	Q	47	-220	L
2695	59	84	-225	-223	L	79	-224	L

**Last update: 17 Jun 2007 16:58 UTC**

*SRN: Solar Radio Noise*  
*Q=Quiet sun*  
*L=Low*  
*M=Moderate*  
*H=High*

*SFU: Solar Flux Unit*

- Monitor
- Indices
- Radio Archive
- Web Cam
- Operational Status

# SOLRA The TSRS real-time solar radio archive

**Trieste Solar Radio System**

**SOLRA - SOLar Radio Archive**

Trieste Solar Radio System

any time  
 selected time interval

Starting date: 2007 June 17 00:00  
Ending date: 2007 June 17 23:59

*Time intervals are based on the UTC reference system*

Data type: ALL

*The data type depends on file contents: sampling rate, frequencies and polarization of the observed data, etc.*

File format: ALL

*The file format depends on how the file is physically stored. There are compressed or uncompressed files, text, binary or graphic files, etc.*

File name:   
(substring search)

*Insert a string to search on matching file names, exactly or partially*

- Monitor
- Indices
- Radio Archive
- Web Cam
- Operational Status

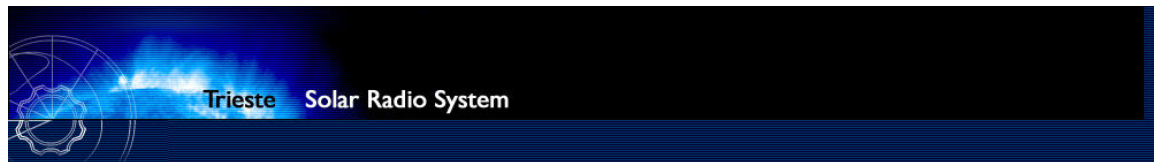
- News
- Project
- Instrumentation
- Sample Data
- Space Weather

Near Real-Time Radio Data

Coronal Radio Surveillance

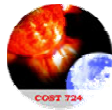
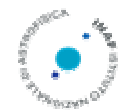
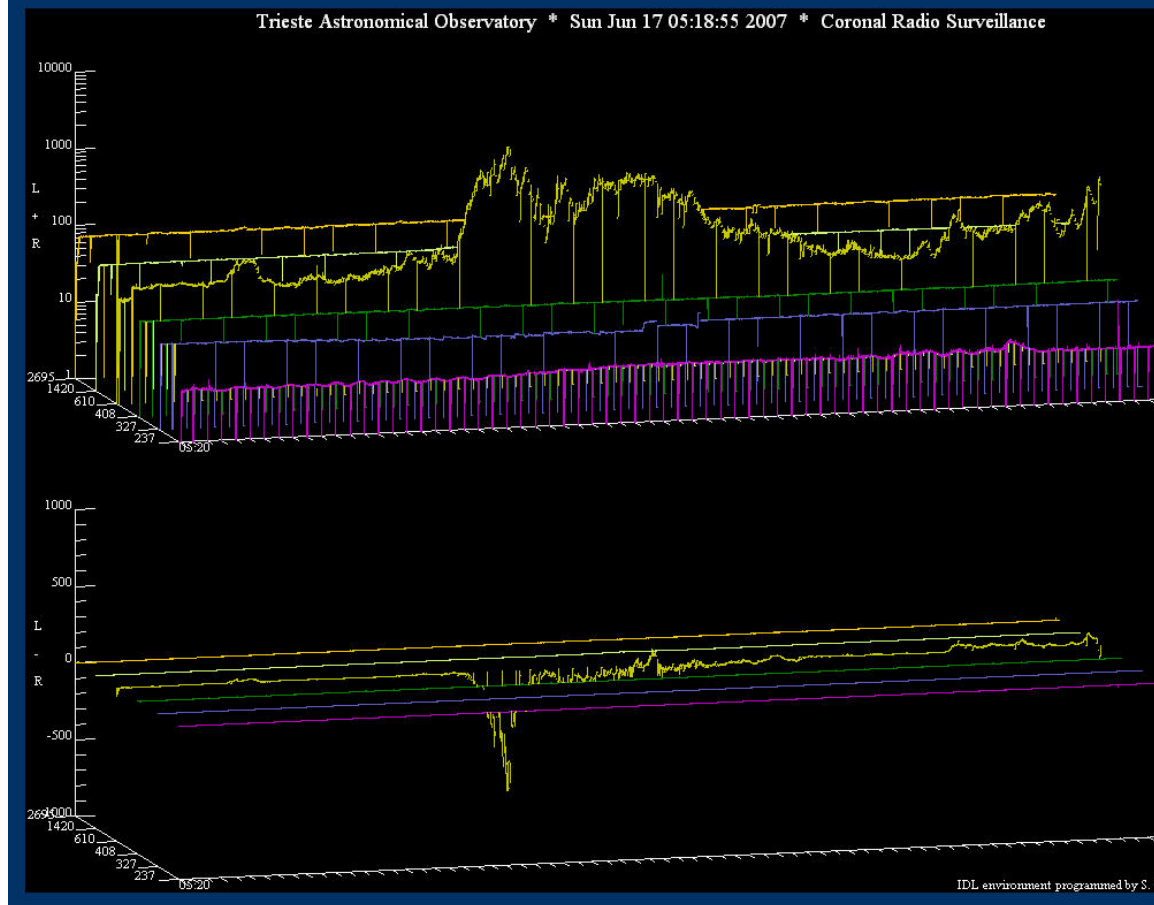


# A Multichannel Synoptic Graph



The graph represents the output of the Metric and the Decimetric Multichannel Solar Radio Polarimeters. It is generated with a time cadence of 10 minutes and is automatically updated. The upper panel shows the time evolution of the total (LH + RH) radio flux density for all the receiving channels, whereas the lower panel shows the difference (LH - RH) of the two polarization channels for each channel, i.e., the circular polarization of the signal.

Graphs of the previous days are available in the [Solar Radio Archive](#).



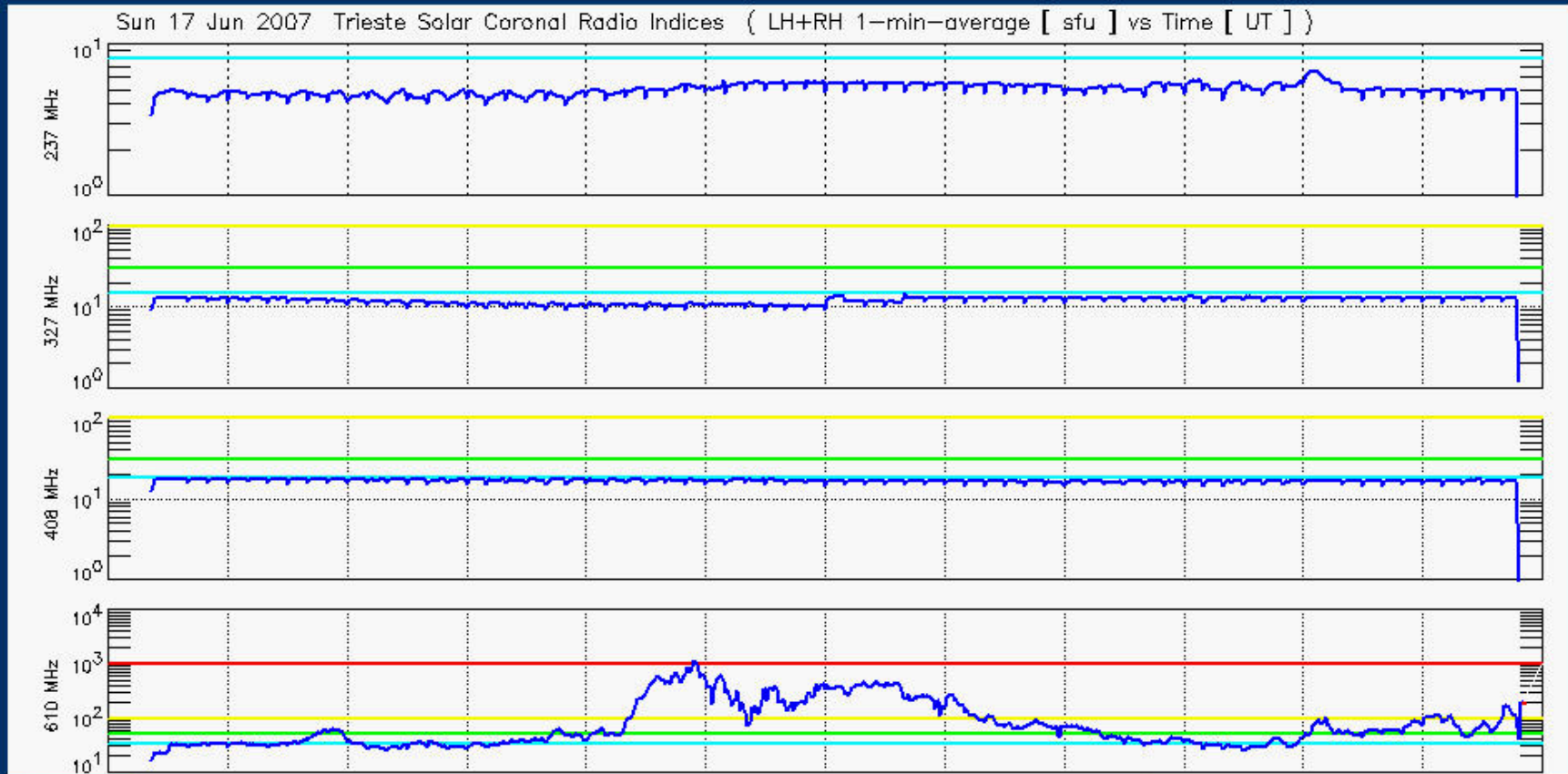
SEE 2007 Athens 24 Sept. 2007



# Multichannel 1-min Averaged Radio Index Graph

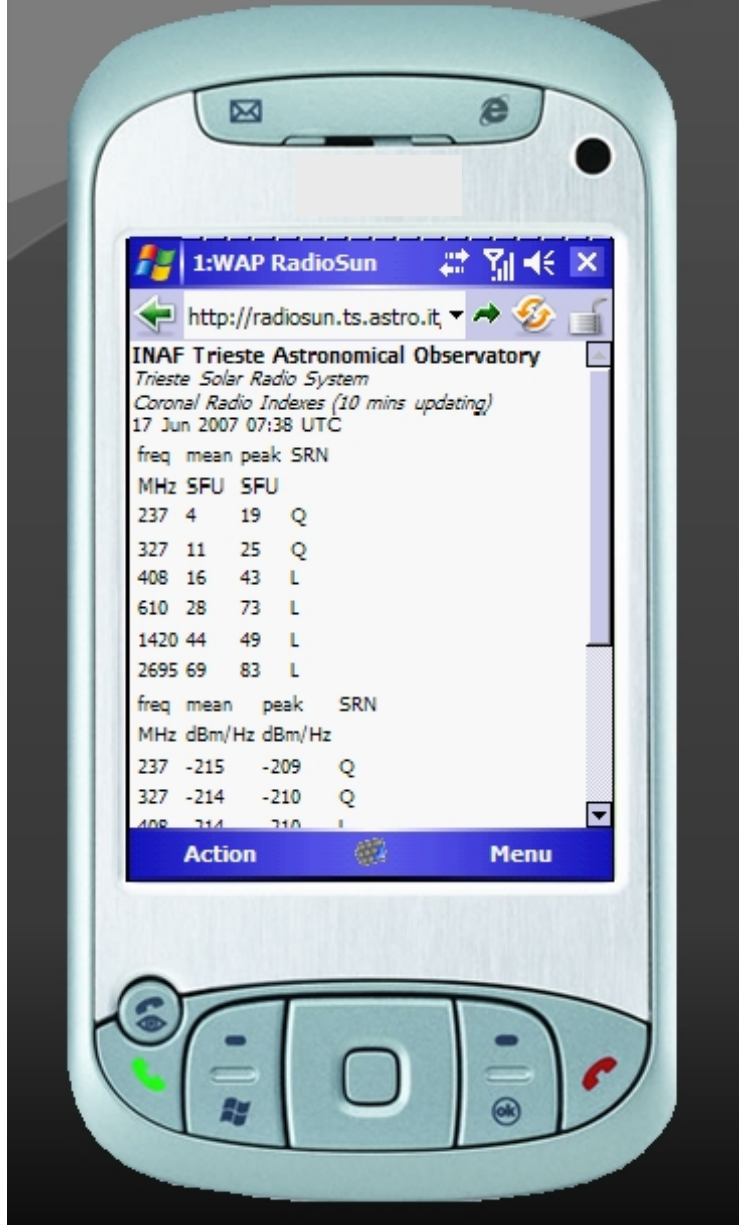


Trieste Solar Radio System

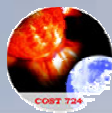




# TSRS on Mobile Phones



# TRIESTE SOLAR RADIO SYSTEM



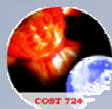
SEE 2007 Athens 24 Sept. 2007



# TSRS Real-Time Data Products in ESA/SWENET

- 1-min-average solar radio index
  - 237, 327, 408, 610, 1420, 2695 MHz (6 frequencies)
  - LH, RH, LH + RH (3 polarization values)
    - SFU, dBm/Hz (2 measurement units)
      - » Observed, 1-min-ahead Predicted (2 data categories)
- 1-min-max solar radio index
  - 237, 327, 408, 610, 1420, 2695 MHz
  - LH, RH, LH+RH
    - SFU, dBm/Hz
      - » Observed, 1-min-ahead Predicted

144 Real-Time Data Products






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# ESA/SWENET Homepage

**SWENET Contents**

- Introduction
- SWENET Services ▾
- Look for Services
- Latest Data
- Space Weather Data ▾
- Data Browsing ⊕
- FTP Mirror
- Latest SEC Plots
- Latest Indices
- Statistics ⊕
- Daily Reports ▾
- Message of the Day ⊕
- Report Browsing ⊕
- Resources ▾
- Documentation
- Release Information
- WebService
- User Area ▾
- Login ⊕
- Register

go to ESA Space Weather Web Server

## Welcome to SWENET Space Weather European Network

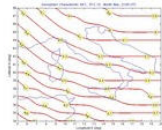
With the increasing importance of space weather aspects in space missions, it is important to provide industry and other users with the means to access space weather data and services. The Service Development Activities (SDA) being currently developed as part of ESA's Space Weather Applications Pilot Project will provide a series of applications, services and data products involving all space weather aspects for a wide range of users. The products resulting from these activities will form the Space Weather European Network - SWENET.

The SWENET Infrastructure is a central resource centre for space weather activities, providing interested users access to space weather data and services.

To access the different sections of the SWENET Infrastructure use the menu on the left.

**Nowcast of foF2 over Central Mediterranean**  
*Provided by GIFINT (IFS1)*

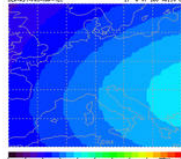
Map of the ionospheric F region critical frequency foF2 over Central Mediterranean area



Last update: 2007-06-30 23:00

**TEC Maps over Europe**  
*Provided by SWIPPA (DLR)*

TEC maps with a 5 minute resolution presenting the vertical TEC (in TECU) over Europe.



Last update: 2007-06-17 06:30

**Current Space Weather Forecast, provided by SIDC (ROB/BIRA)**

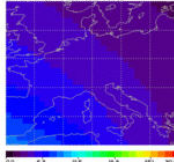
icted AP index: 007    visit us at <http://www.sidc.be>    SIDC/RWC-

**SWENET Services**

- Ground Effects ▾
- Ionospheric Effects ▾
- Spacecraft Effects ▾

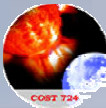
**IRI TEC Map**

Previous 24 hours ▾



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You can contact us by [clicking here](#)



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# TSRS as a SWENET SDA

**SWENET**  

**SWENET Contents**

- Introduction
- SWENET Services
- Look for Services
- Latest Data
- Space Weather Data
- Data Browsing
- FTP Mirror
- Latest SEC Plots
- Latest Indices
- Statistics
- Daily Reports
- Message of the Day
- Report Browsing
- Resources
- Documentation
- Release Information
- WebService
- User Area
- Login
- Register

**Related items**

- Latest SDA Data
- SDA Image Data
- SDA Text Data
- Project Website
- ESA SWENET ToR

**SWENET Services**

- Ground Effects
- Ionospheric Effects
- DIFS
- GIFINT
- GPS Validation
- Ionosfera
- Scintillation Quickmaps
- SFC
- SIDC
- SOARS
- SPECTRE
- STIF
- SWIPPA
- TSRS
- Spacecraft Effects

**TSRS**

**Radio Surveillance of the Solar Corona for Communication Service Providers**

**Developer**

INAF - Osservatorio Astronomico di Trieste

**Technical Group**

Ionospheric Effects & Activity Forecast

**Products**

- High time resolution radio flux density evolution in FITS format
- Multichannel synoptic graphs in PNG format
- 1-min-average solar radio indices (radio noise level) in graphic (PNG), text (ASCII) and binary format
- Nowcasting and forecasting is presently available only in real-time graphs
- Warning messages in automatic mode via different systems (e.g. email, SMS)

**Link to Project WebSite**

<http://radiosun.ts.astro.it/>

**SDA description**

TSRS performs a surveillance of the radio emission of the solar corona on a routinary basis in automatic mode. It will provide real-time radio indices measuring the level of solar radio activity at the different receiving frequencies.

**Contact / Manager**

**Dr. Mauro Messerotti**

*Address:* Trieste Astronomical Observatory  
Basovizza Observing Station  
Basovizza, 302  
I-34012 Trieste  
Italy

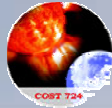
*Email:* [messerotti@ts.astro.it](mailto:messerotti@ts.astro.it)

*Telephone:* +39-040-226176 / 226761

*Fax:* +39-040-226630 / 30941

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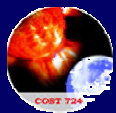
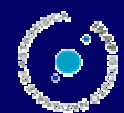
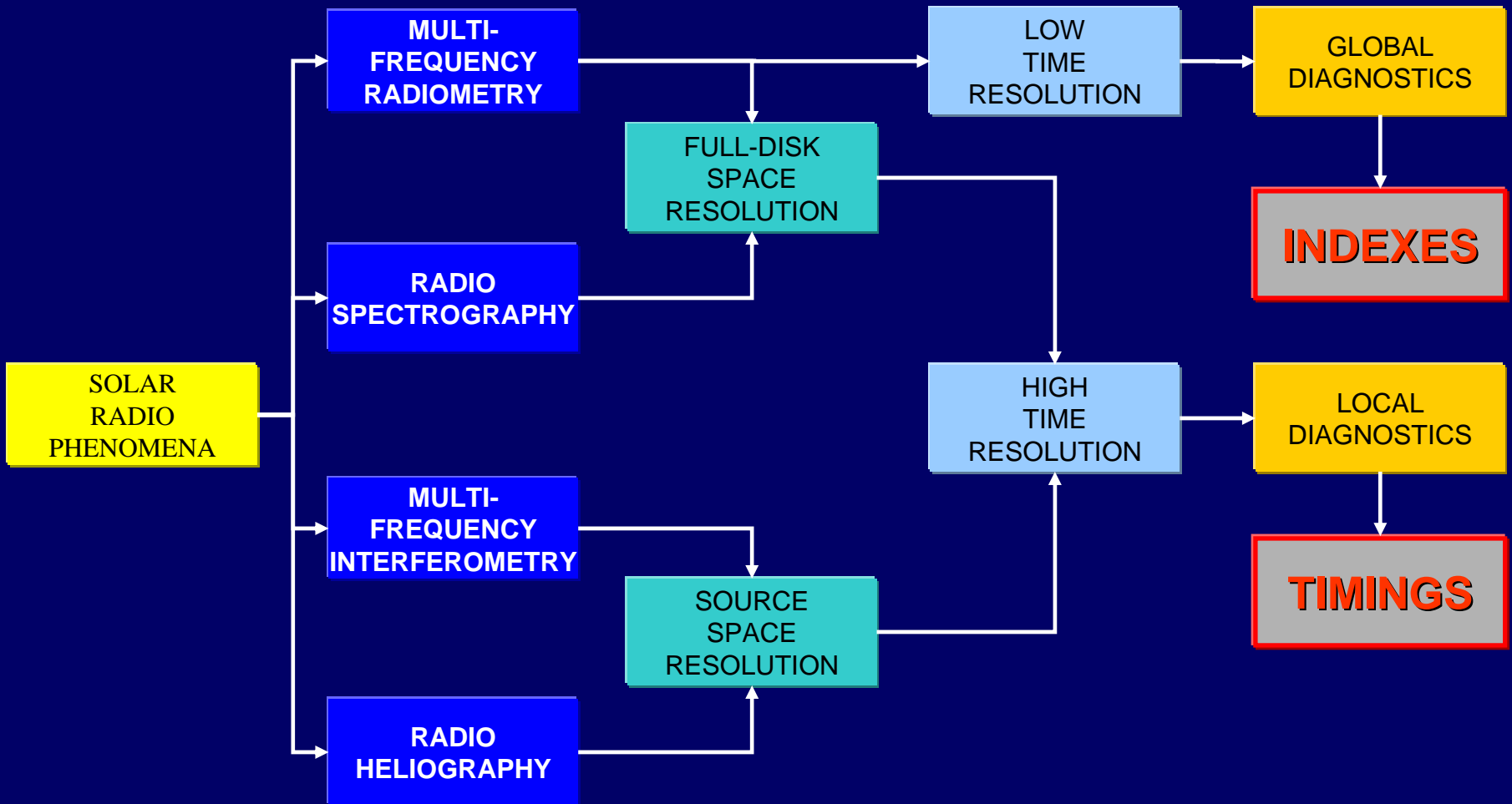
# The Sun as a Radio Noise Source

- The Sun is a radio source
- Solar radio noise can
- Enhanced solar radio noise can perturb

**MIL!**

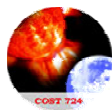
**UMTS!**

# RADIO DIAGNOSTICS RELEVANT TO SPACE WEATHER APPLICATIONS



2000 06 06 1525UTC X3/2B

- 2,300 SFU TENFLARE

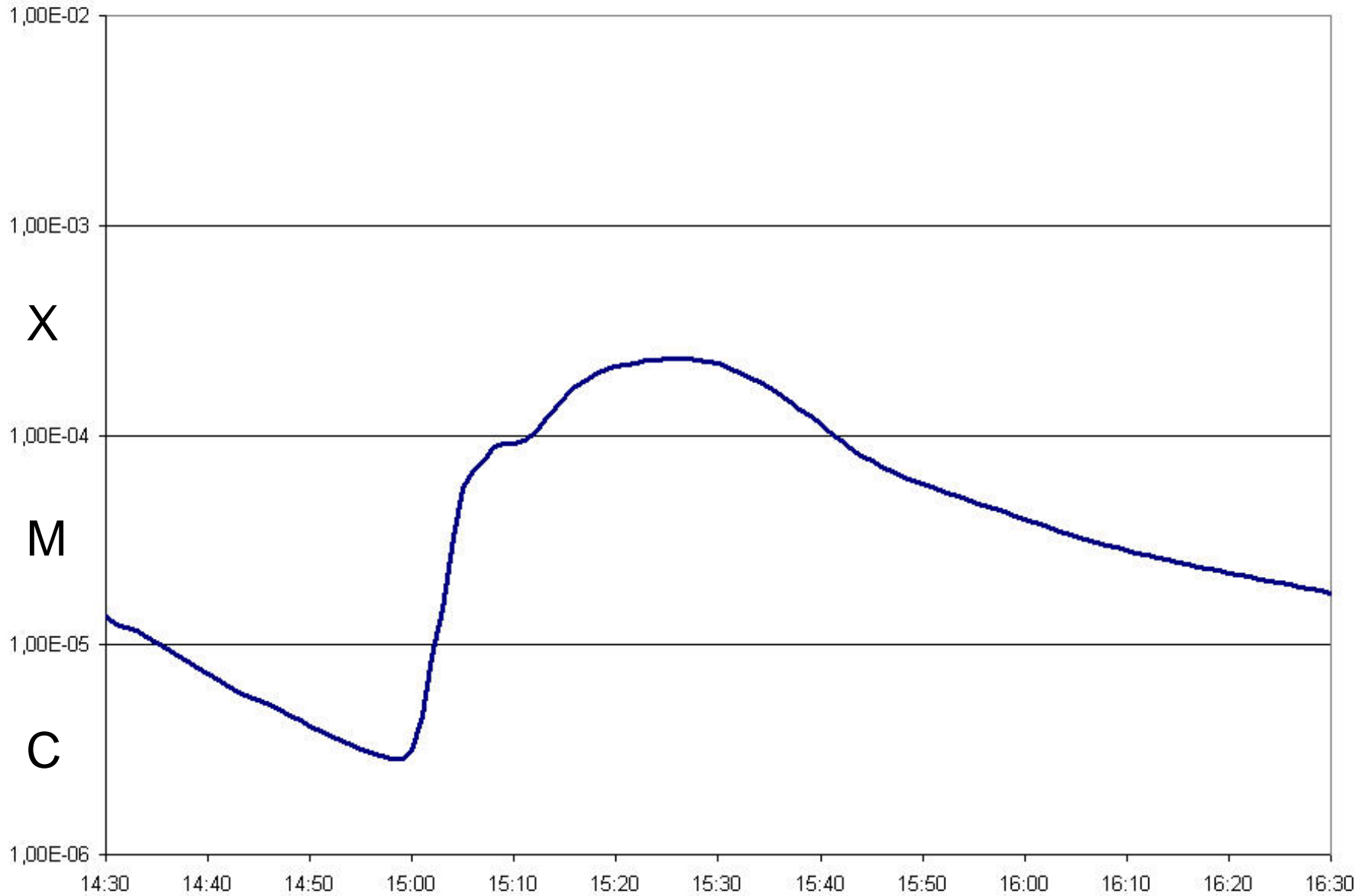


SEE 2007 Athens 24 Sept. 2007

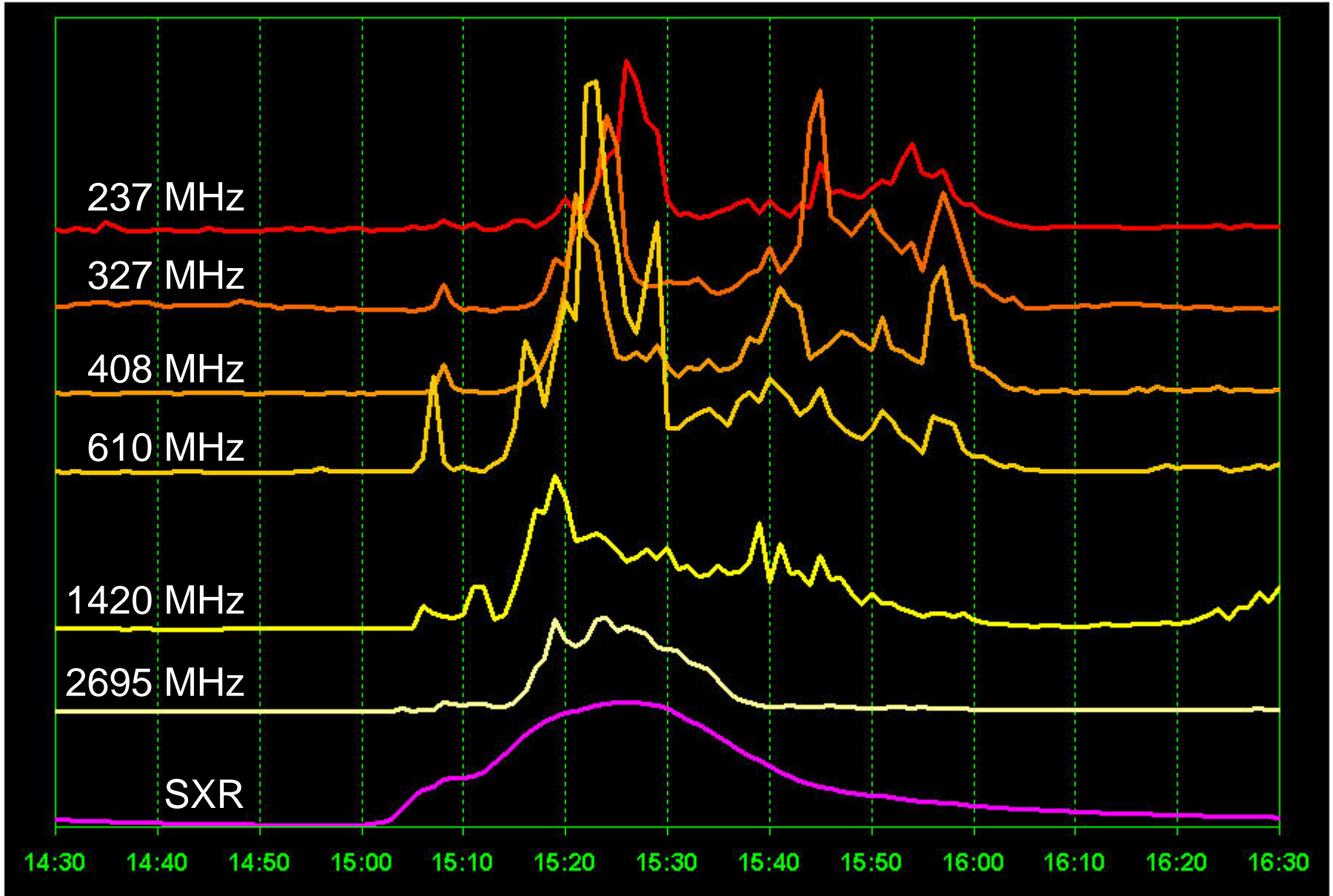




# GOES SXR

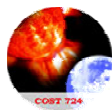
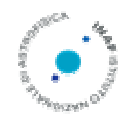


# TSRS RADIO AND GOES SXR TIMINGS



2000 07 14 1024UTC X5/3B

- 2,600 SFU TENFLARE

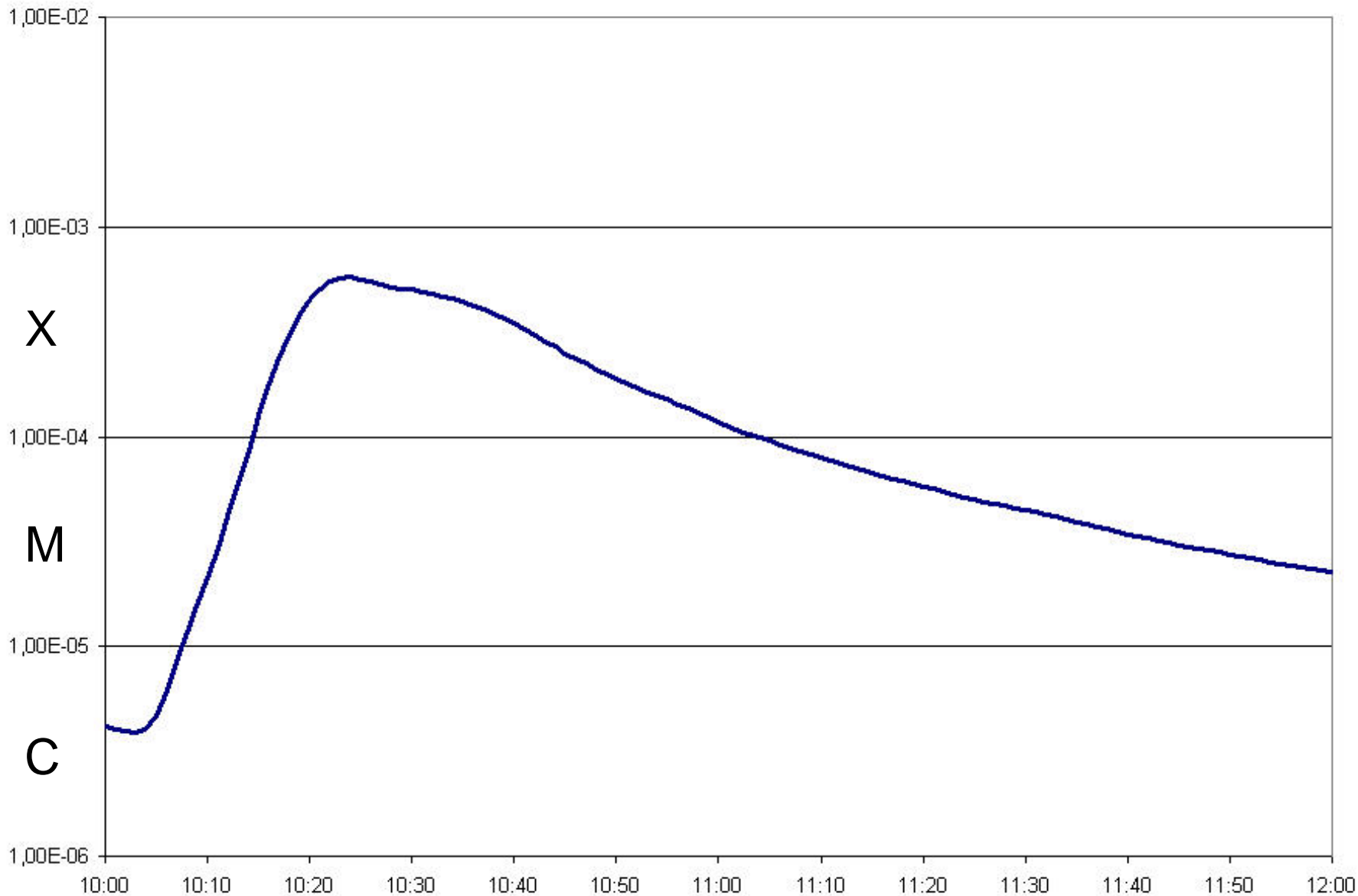


SEE 2007 Athens 24 Sept. 2007





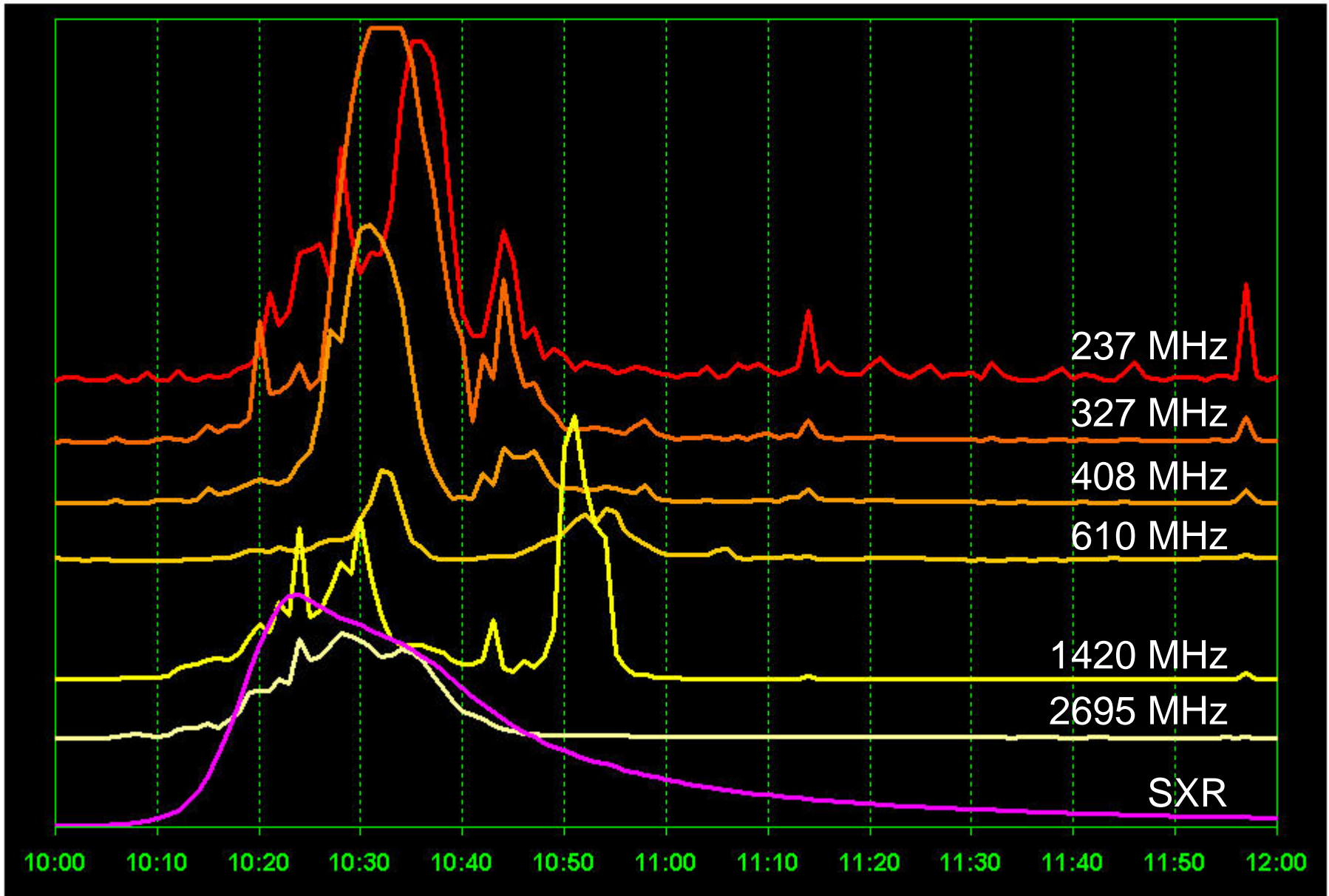
# GOES SXR



SEE 2007 Athens 24 Sept. 2007

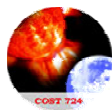


# TSRS RADIO AND GOES SXR TIMINGS



2001 04 15 1350UTC X14/2B

- 48,000 SFU TENFLARE

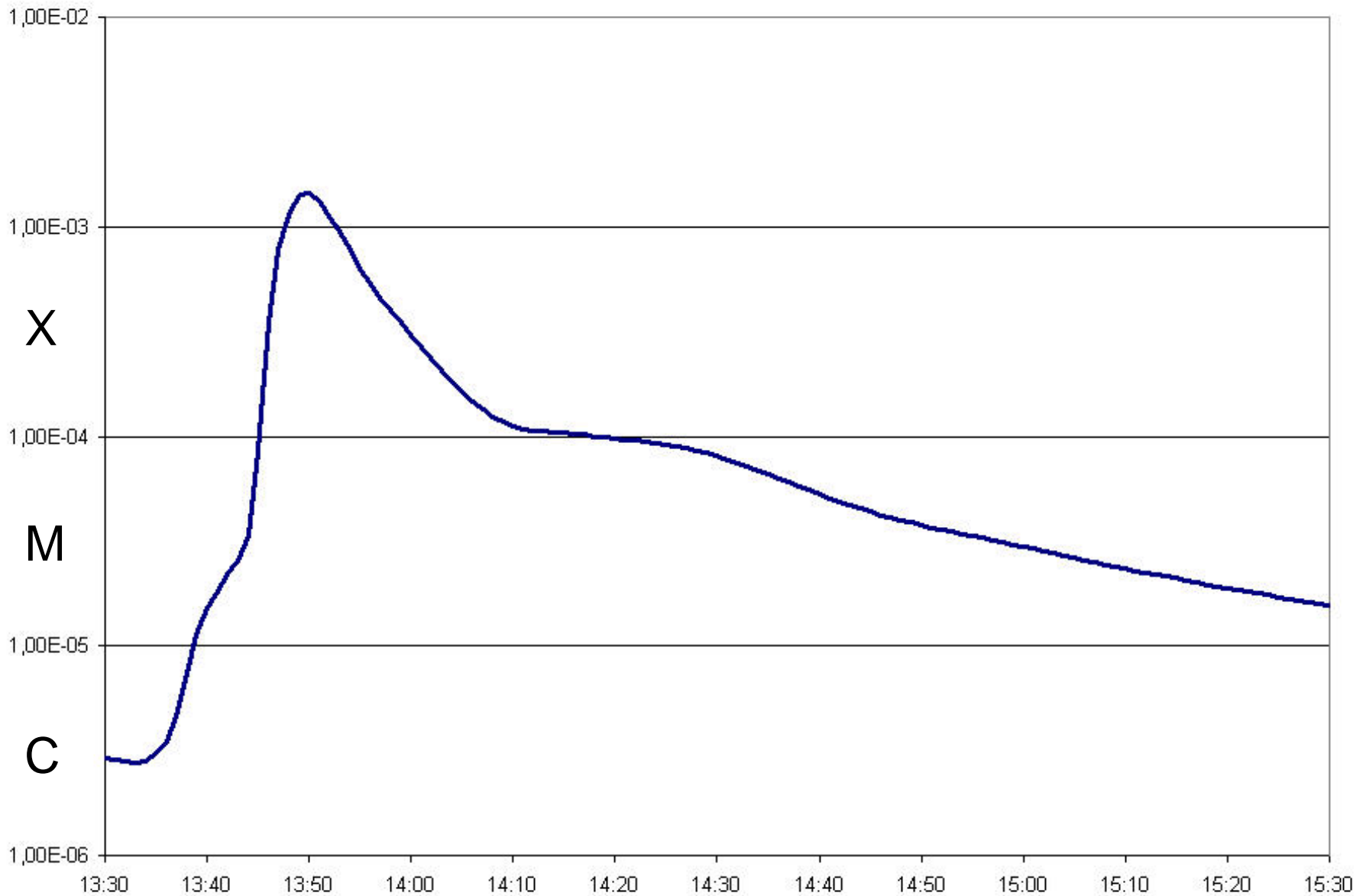


SEE 2007 Athens 24 Sept. 2007





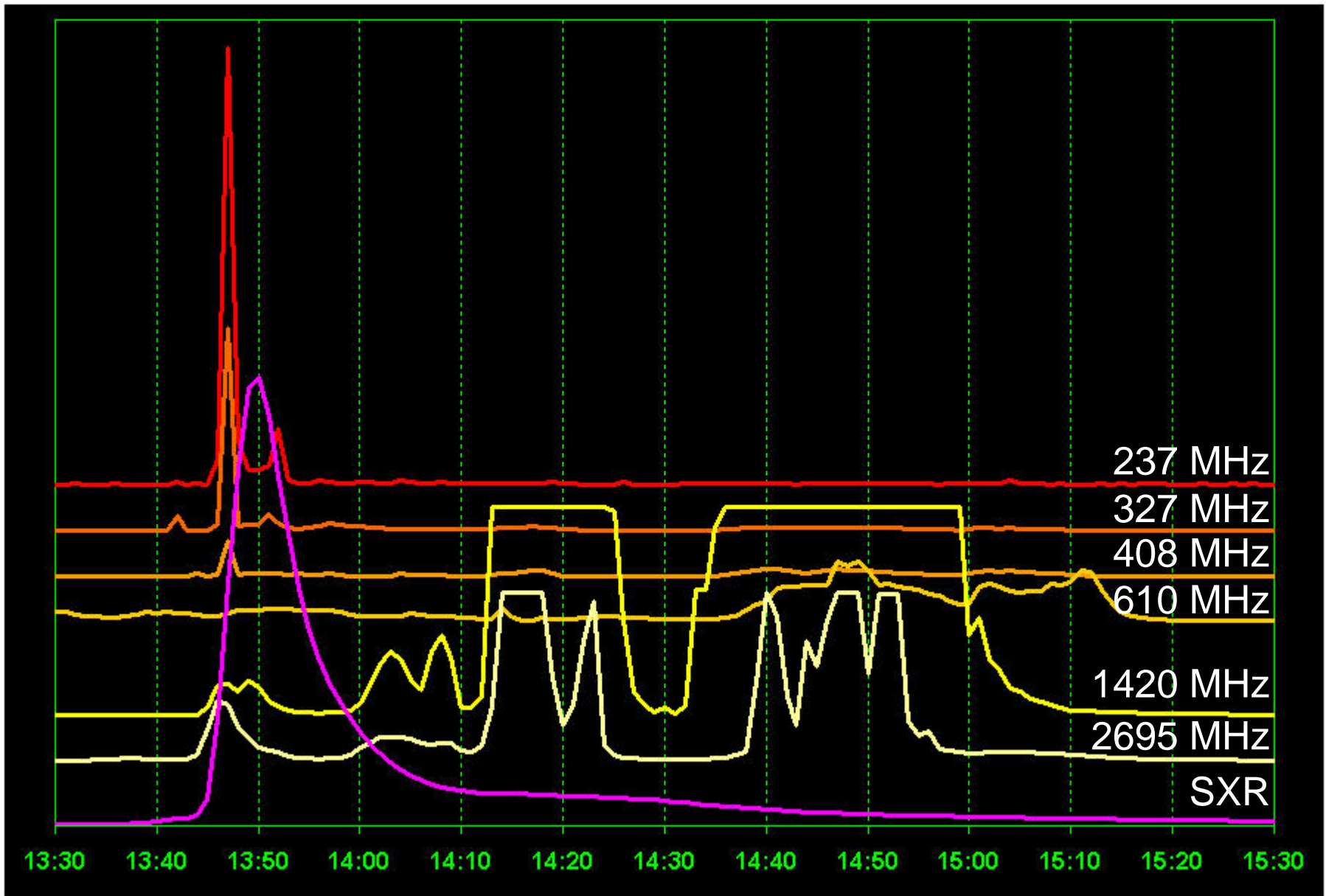
# GOES SXR



SEE 2007 Athens 24 Sept. 2007



# TSRS RADIO AND GOES SXR TIMINGS



# Effects of SBRs on Wireless Systems

- Bala et al. (2002):
  - For a cellular base station operating at 900 MHz , the equivalent solar flux (thermal noise=solar noise level)  $F_{eq} \sim 960$  SFU  $\rightarrow$  more than twice the thermal noise power.
  - For a base station operating at 2.4 GHz,  $F_{eq} \sim 6000$  SFU.
  - The bit error rate (ber) changes rapidly with the S/N power ratio. (0.75 dB change  $\rightarrow$  10x in ber).
  - Assuming an SRB effectivity threshold of 1,000 SFU, the statistics over 4 decades indicates a probability of interference every 10-20 days on average per year, modulated by the solar cycle.





# Effects of SRBs on GPS

- Cerruti et al. (2006):
  - Observed reduced carrier-to-noise ratio in sunlit GPS receivers over the duration of SRB (8700 SFU RHCP → 2.3 dB loss; 2005.09.07)
  - Estimated L1  $C/N_0$  fade of 3 dB and L2  $C/N_0$  fade of 5.2 dB for commonly used GPS antennas with a gain of 4 dBic, from a SRB of 10,000 SFU
  - SRB are a potential threat to life-critical systems based on a Global Navigation Satellite System (GNSS): a 80,000 SFU SRB can determine a 12 dB fade at L1 and a 26.2 dB fade on the L2 channel → loss of lock in semi-codeless receivers.
- See also Klobuchar et al. (1999)

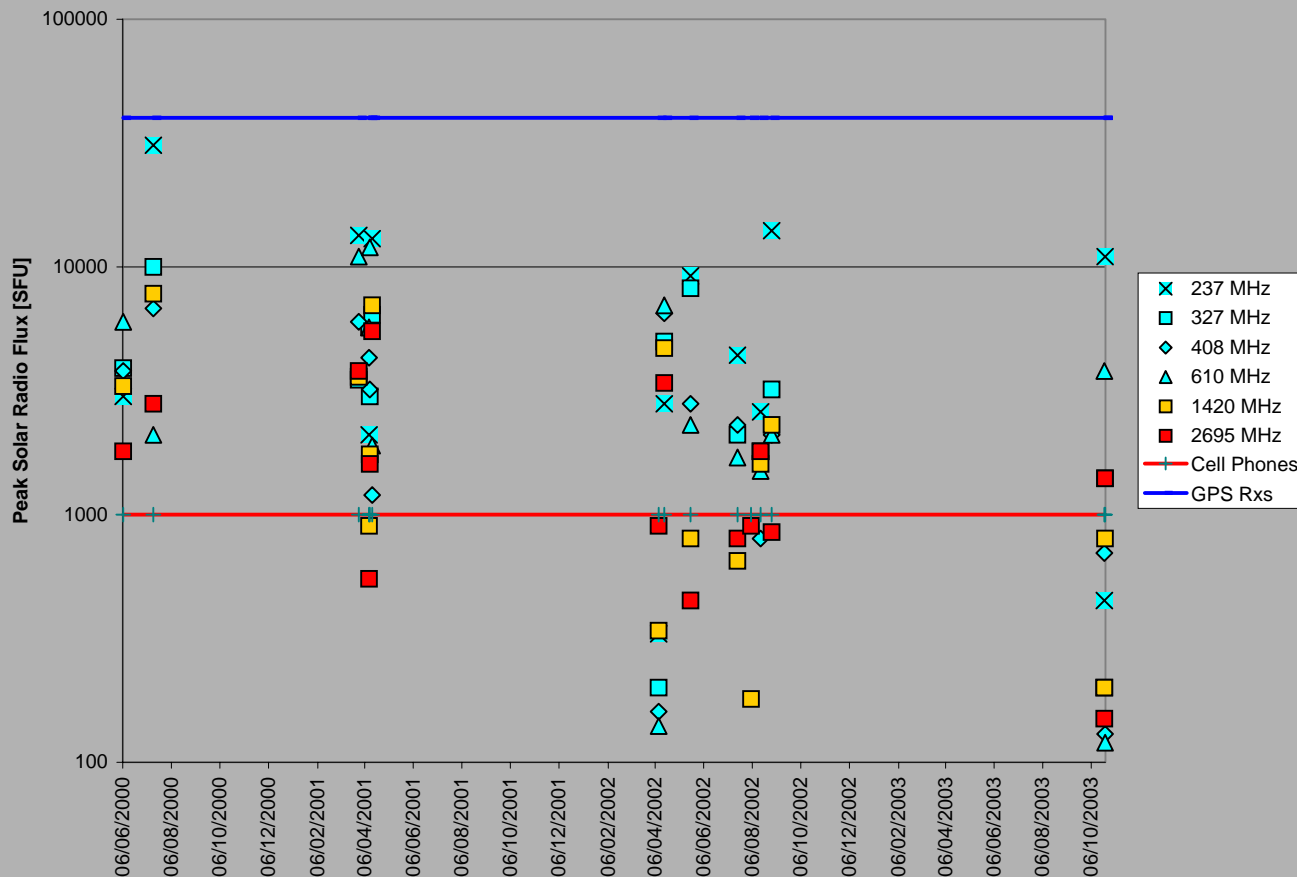


# Solar Radio Outbursts as Potential Radio Communications Jammers: Analysis of Selected Cases

M. Messerotti<sup>1,2</sup>, P. Zlobec<sup>1</sup>, I. Coretti<sup>1</sup>, M. Iurcev<sup>1</sup>, S. Padovan<sup>1</sup>

<sup>1</sup> INAF, Trieste Astronomical Observatory, Trieste, Italy

<sup>2</sup> Department of Physics, University of Trieste, Trieste, Italy



- Solar radio bursts can lower the SNR in wireless comms
- Attention level is:
  - 1,000 SFU for mobiles
  - 40,000 SFU for GPSs
- We analyzed 15 outbursts detected by TSRS in 2000-03
- 1,000 SFU was exceeded by
  - 80% 237 MHz events
  - 80% 327 MHz events
  - 67% 408 MHz events
  - 80% 610 MHz events
  - 53% 1420 MHz events
  - 53% 2695 MHz events
- No event at 1420 MHz found larger than GPS threshold

# Effects of SRBs on 5-6 Dec 2006

- P. Kintner (Cornell University):
  - Large number of receivers stopped tracking GPS signal over the entire sunlit side of the Earth
  - First quantitative measurement of the effect
- P. Doherty (Boston College):
  - The 6 Dec SRB was the first one ever detected on the civil air navigation system (WAAS, Wide Area Augmentation System)

Source: GPS Daily (<http://www.gpsdaily.com>)



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# Tenflare > 1,000 SFU [2005]

Table obtained via EGSO/SEC search on GEV catalog (<http://sec.ts.astro.it>)

Date	Time Start	Time Max	Time End	AR	Latitude	Longitude	SXR Class	OPT Class	245 MHz	2800 MHz	Type II	Type IV
15/01/2005	5.54.00	6.38.00	7.17.00	10720	11	-6	M8.6	sf	41000	3000	TRUE	TRUE
17/01/2005	6.59.00	9.52.00	10.07.00	10720			X3.8	2f	39000	1200	TRUE	TRUE
19/01/2005	5.10.00	5.26.00	5.35.00	10720	12	44	C7.2	sf		3500		
19/01/2005	6.58.00	7.31.00	7.55.00	10720	19	47	M6.7	2n		5000		
19/01/2005	10.19.00	10.24.00	10.29.00	10720	18	47	M2.7	1n	1400	2900		
20/01/2005	6.36.00	7.01.00	7.26.00	10720	12	58	X7.1	2b		8400	TRUE	TRUE
13/05/2005	16.13.00	16.57.00	17.28.00	10759	12	-12	M8.0	2b	420	2900	TRUE	TRUE
09/07/2005	21.47.00	22.06.00	22.19.00	10786	11	27	M2.8	1n	1200	1500		
10/07/2005	21.47.00	22.06.00	22.19.00	10786	11	27	M2.8	1n	1200	1500	TRUE	
13/07/2005	14.01.00	14.49.00	15.38.00	10786			M5.0		6600	2000		
14/07/2005	10.16.00	10.55.00	11.29.00	10786			X1.2		5400	3400	TRUE	
07/09/2005	17.17.00	17.40.00	18.03.00	10808	-6	-89	X17.	3b	3200	2700	TRUE	TRUE
09/09/2005	19.13.00	20.04.00	20.36.00	10808	-10	-58	X6.2	2b	690	4200	TRUE	TRUE
10/09/2005	21.30.00	22.11.00	22.43.00	10808			X2.1		910	1600	TRUE	TRUE
11/09/2005	21.30.00	22.11.00	22.43.00	10808			X2.1		910	1600	TRUE	TRUE
13/09/2005	19.19.00	19.27.00	20.57.00	10808	-9	-10	X1.5	2b	700	4900		
17/09/2005	5.58.00	6.05.00	6.15.00	10808	-10	39	M9.8	2n		1000		

**17 EVENTS ∈ [ 1000, 8400 ] SFU**

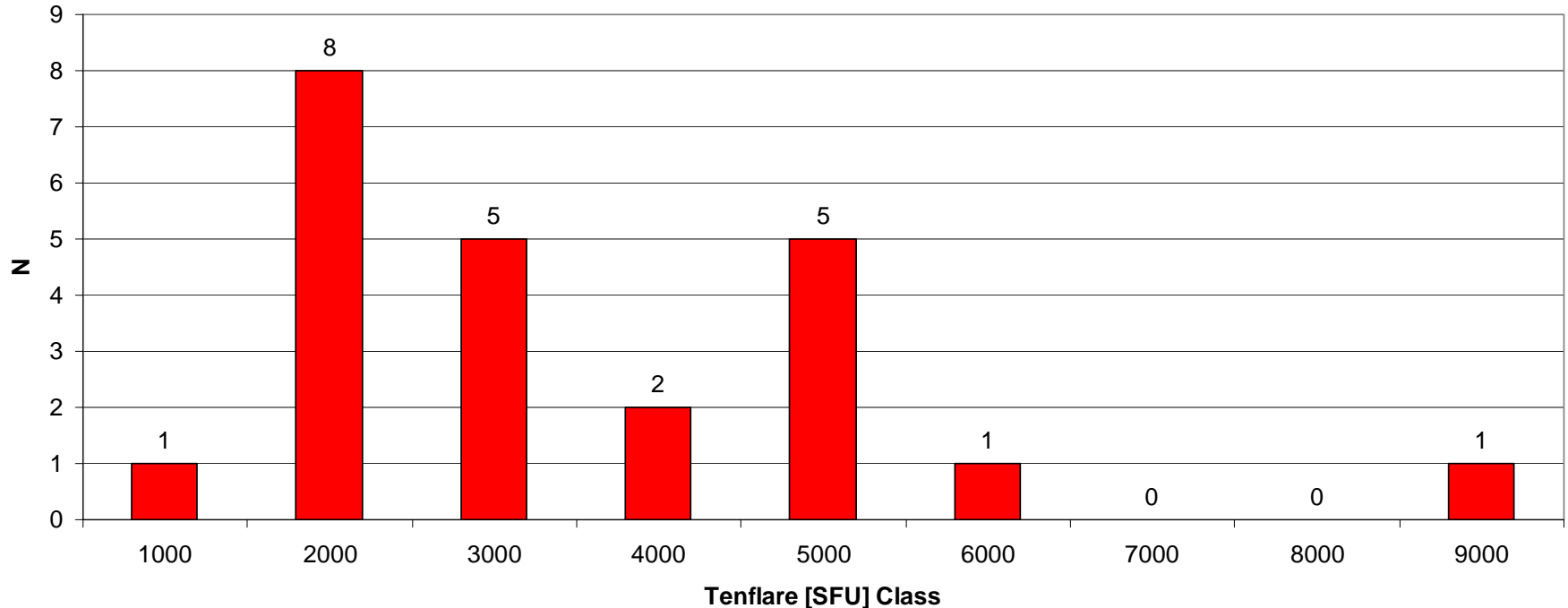
# Tenflare > 1,000 SFU [2006]

Table obtained via EGSO/SEC search on GEV catalog (<http://sec.ts.astro.it>)

Date	Time Start	Time Max	Time End	AR	Latitude	Longitude	SXR Class	OPT Class	245 MHz	2800 MHz	Type II	Type IV
05/12/2006	10.18.00	10.35.00	10.45.00	10930	-7	-79	X9.0	2n	210000	<b>1200</b>	TRUE	TRUE
06/12/2006	18.29.00	18.47.00	19.00.00	10930	-6	-63	X6.5	3b	30000	<b>5800</b>	TRUE	TRUE
07/12/2006	18.20.00	19.13.00	19.33.00	10930	-7	-47	M2.0	1n	85	<b>2600</b>		
13/12/2006	3.55.00	3.57.00	4.04.00						460	<b>1500</b>		
13/12/2006	2.14.00	2.40.00	2.57.00	10930	-6	24	X3.4	4b		<b>4400</b>	TRUE	TRUE
14/12/2006	2.14.00	2.40.00	2.57.00	10930	-6	24	X3.4	4b		<b>4400</b>	TRUE	TRUE

**6 EVENTS ∈ [ 1200, 5800 ] SFU**

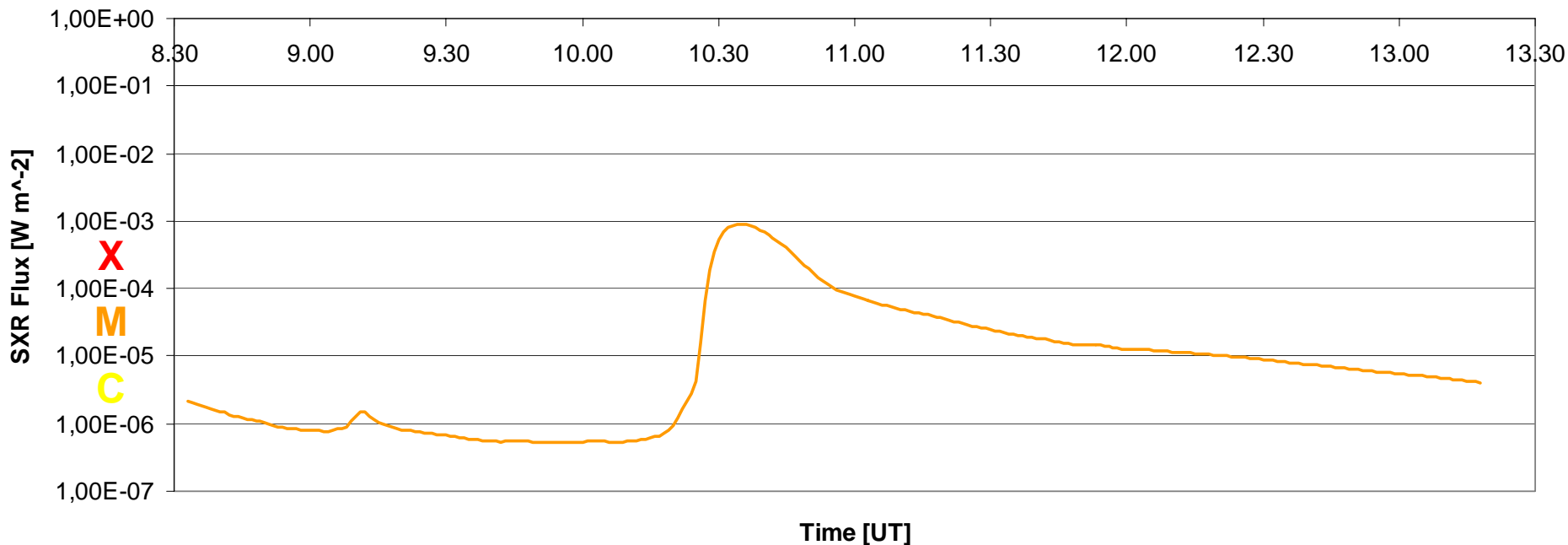
# Statistics of Tenflare > 1000 SFU 2005-06



In the proximity of SOLAR ACTIVITY MINIMUM !

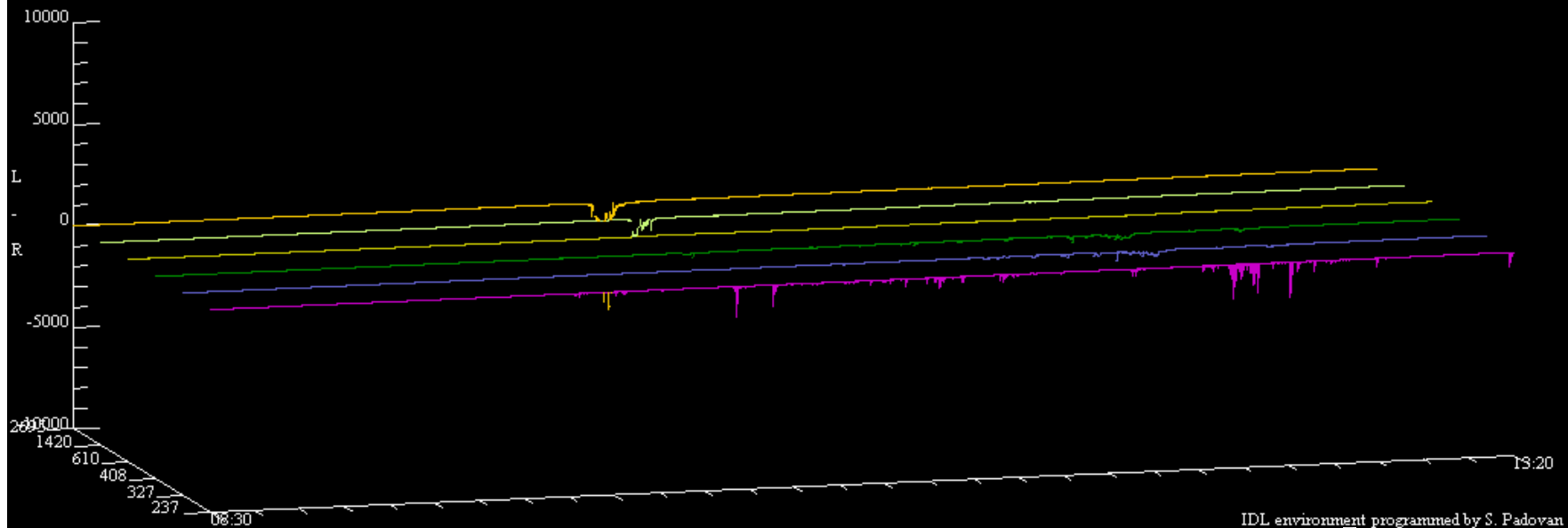
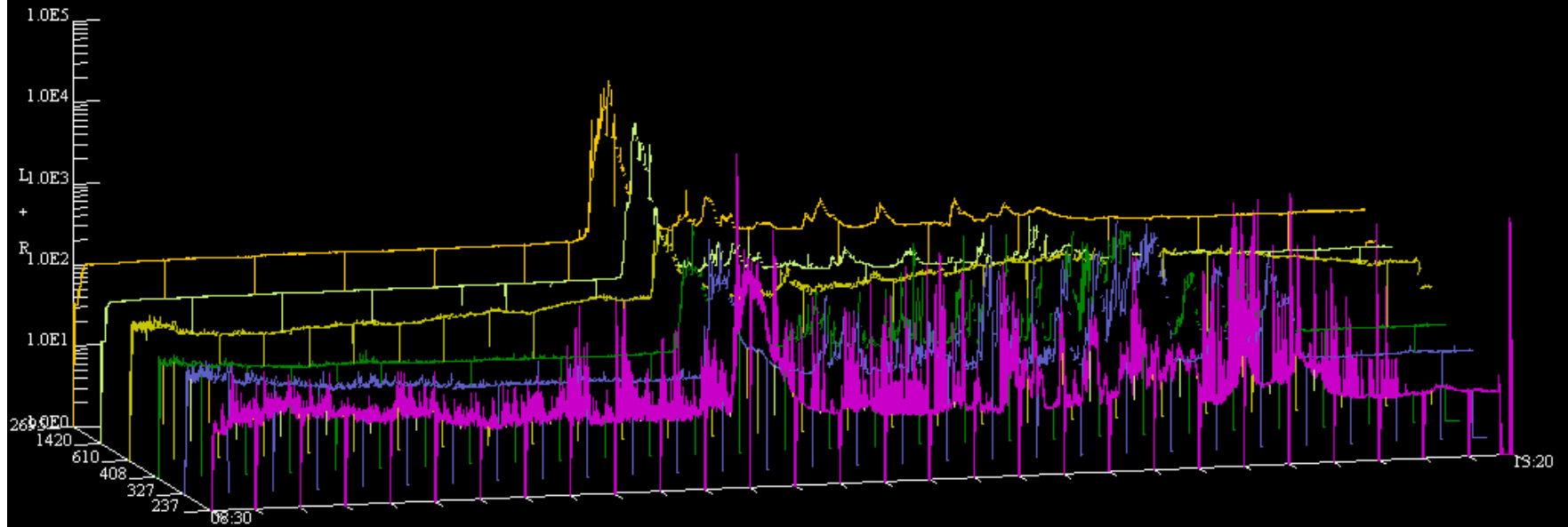
# GOES SXR Lightcurve

GOES SXR Flux 2006.12.05

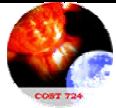


Date	Time Start	Time Max	Time End	AR	Latitude	Longitude	SXR Class	OPT Class
05/12/2006	10.18.00	10.35.00	10.45.00	10930	-7	-79	X9.0	2n





IDL environment programmed by S. Padovan

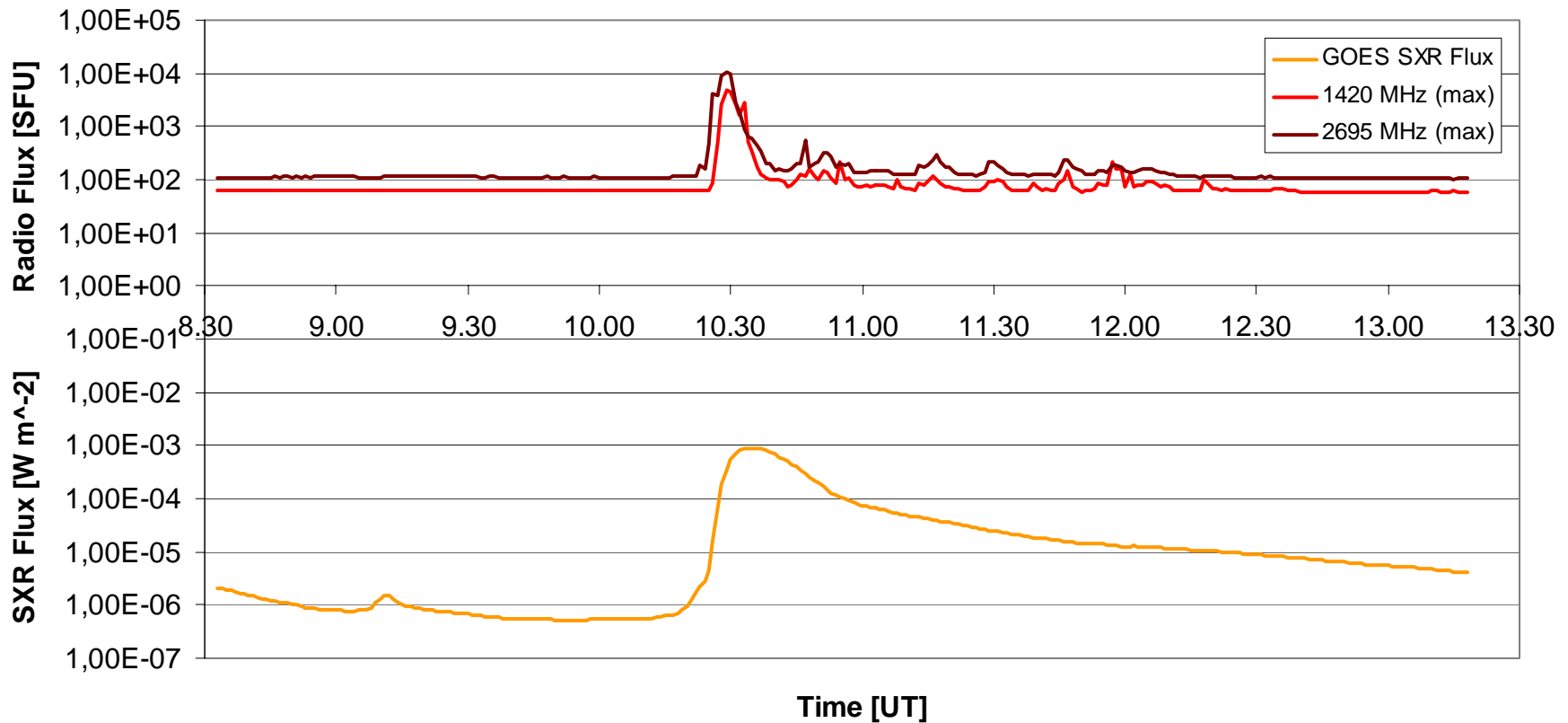


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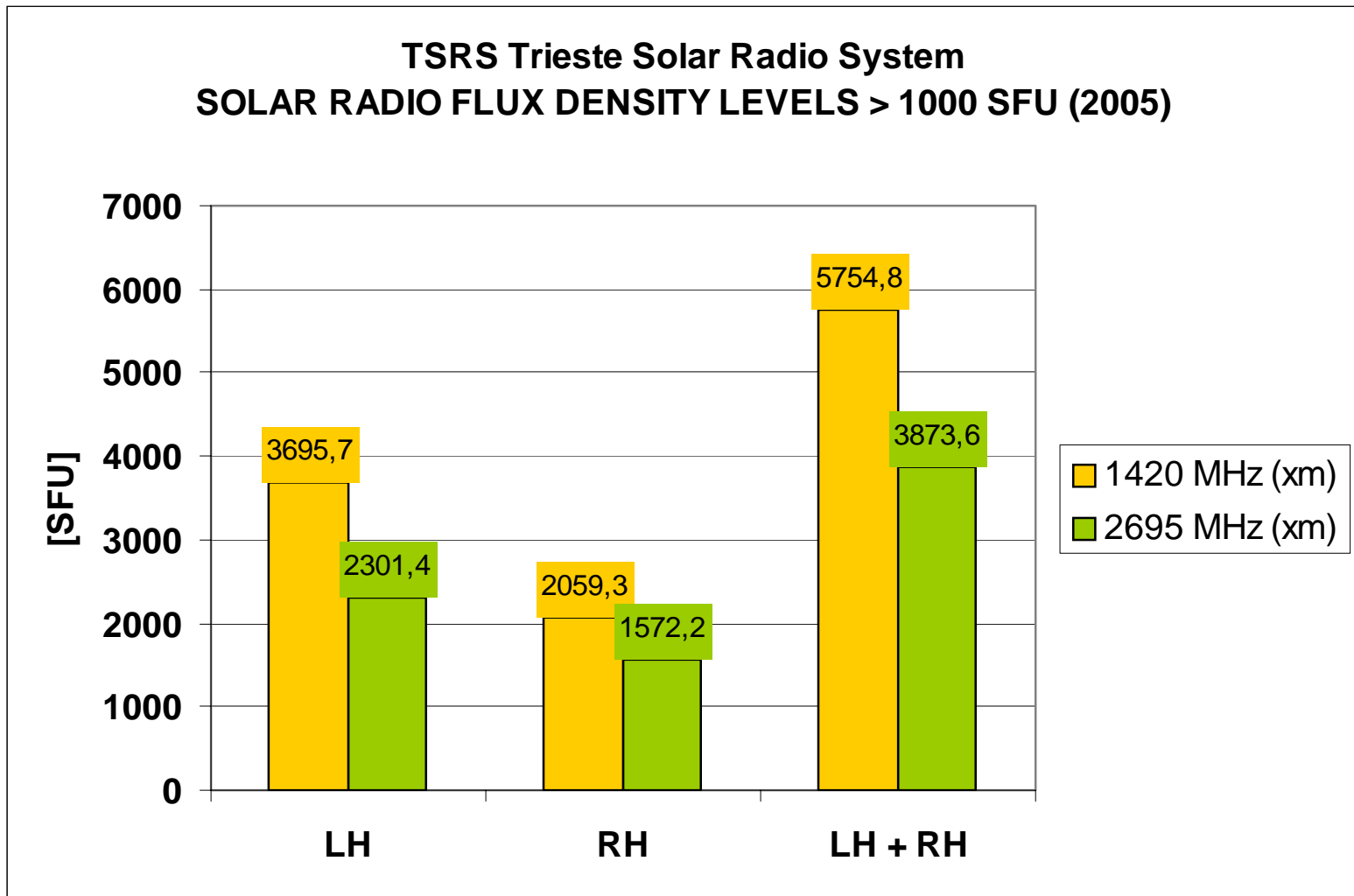
# TSRS 1-min radio flux density levels at 1420 Mhz and 2695 MHz



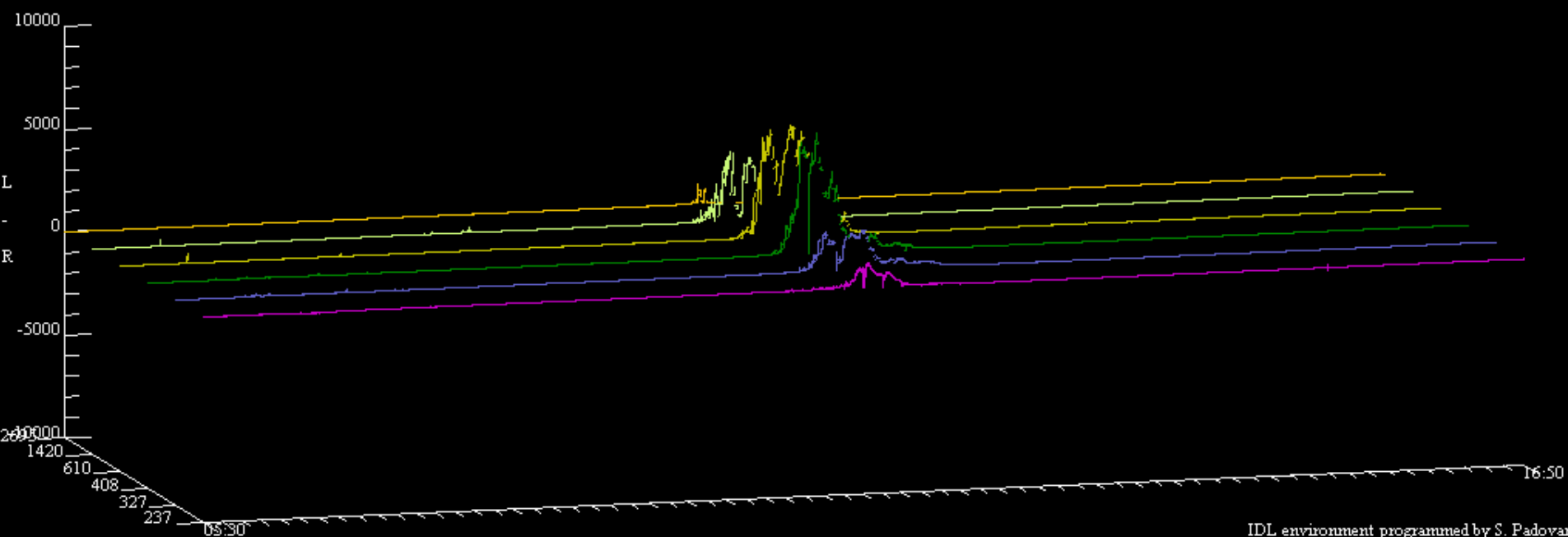
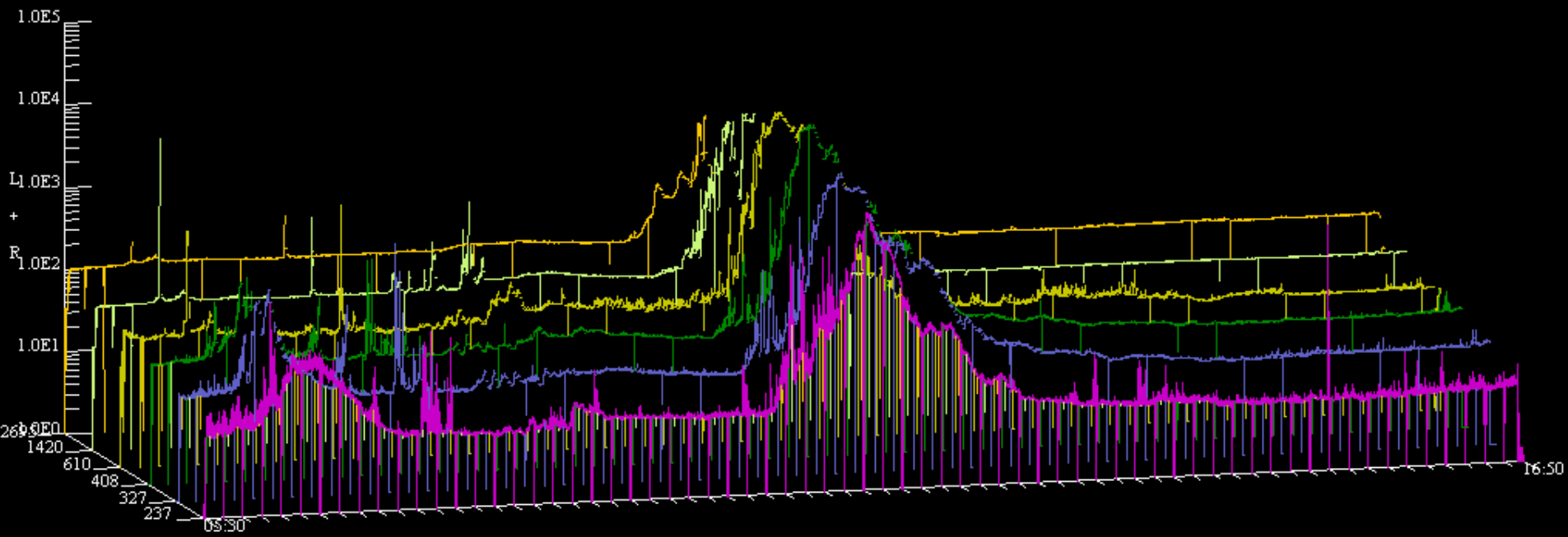
Observed maximum radio flux density significantly exceed reported levels:

$$S_{2695_{\max}} = 10,391 \text{ SFU} \quad S_{1420_{\max}} = 4,870 \text{ SFU}$$

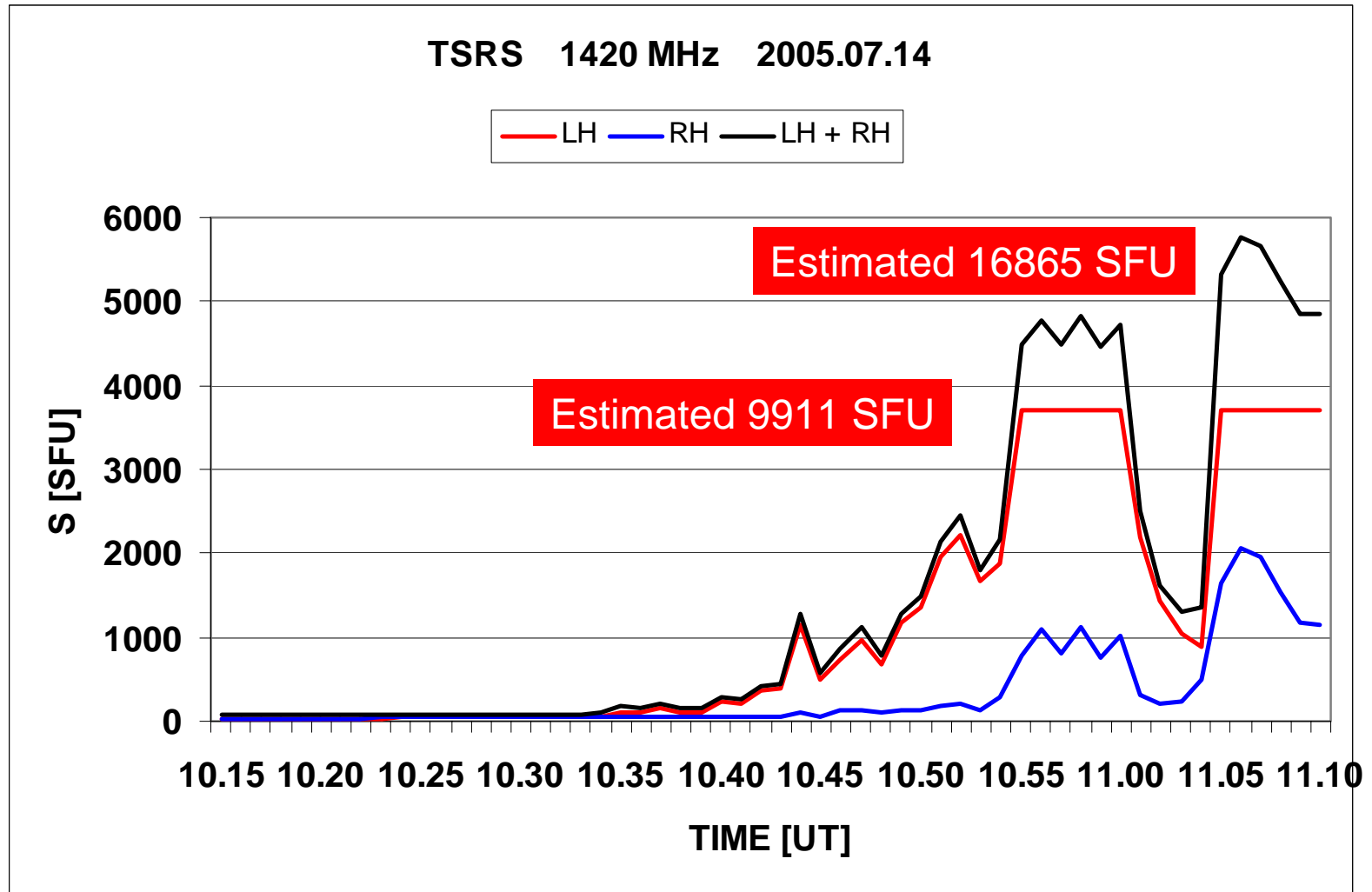
# Statistics of Max dm RFs 2005



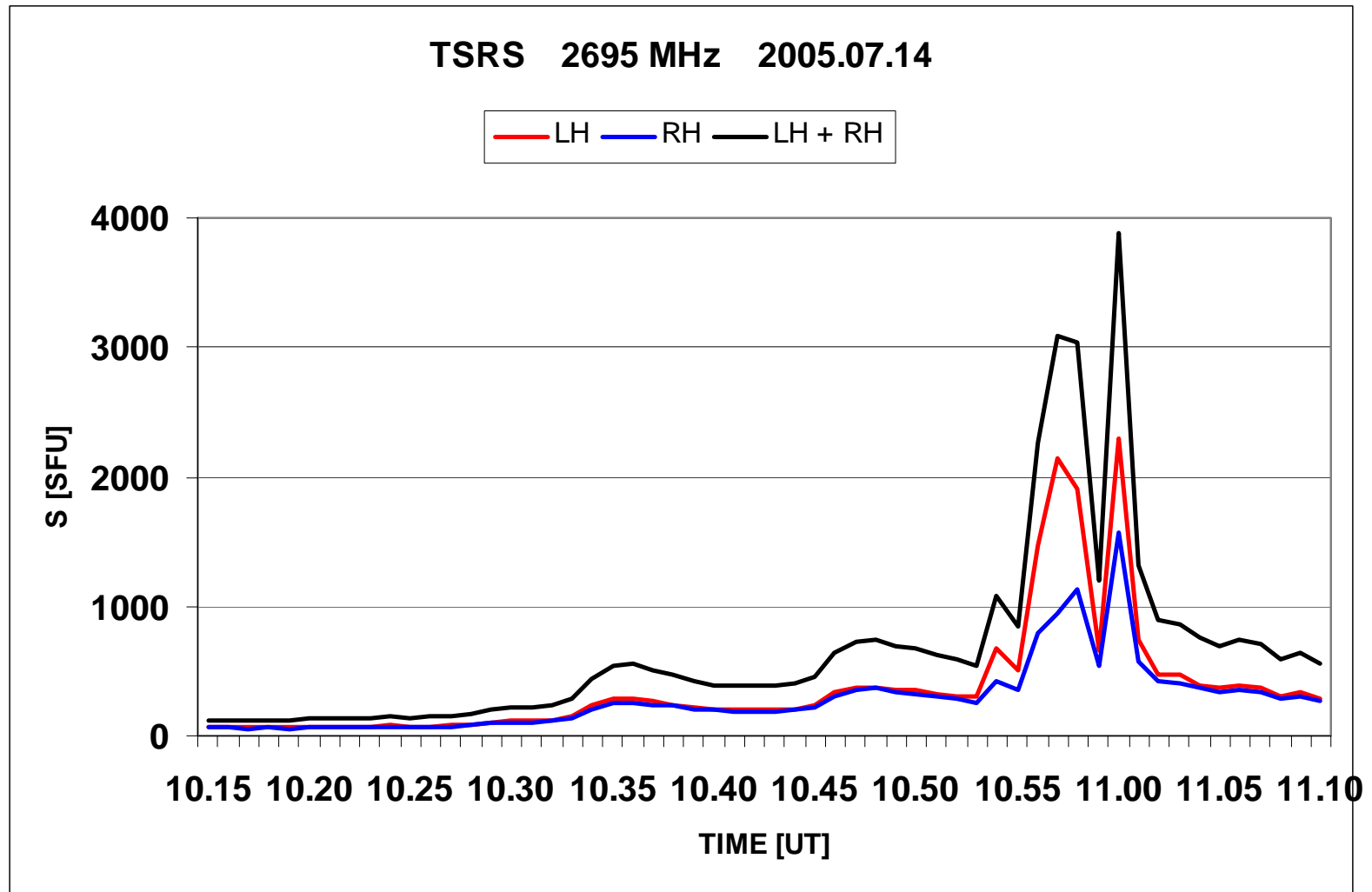




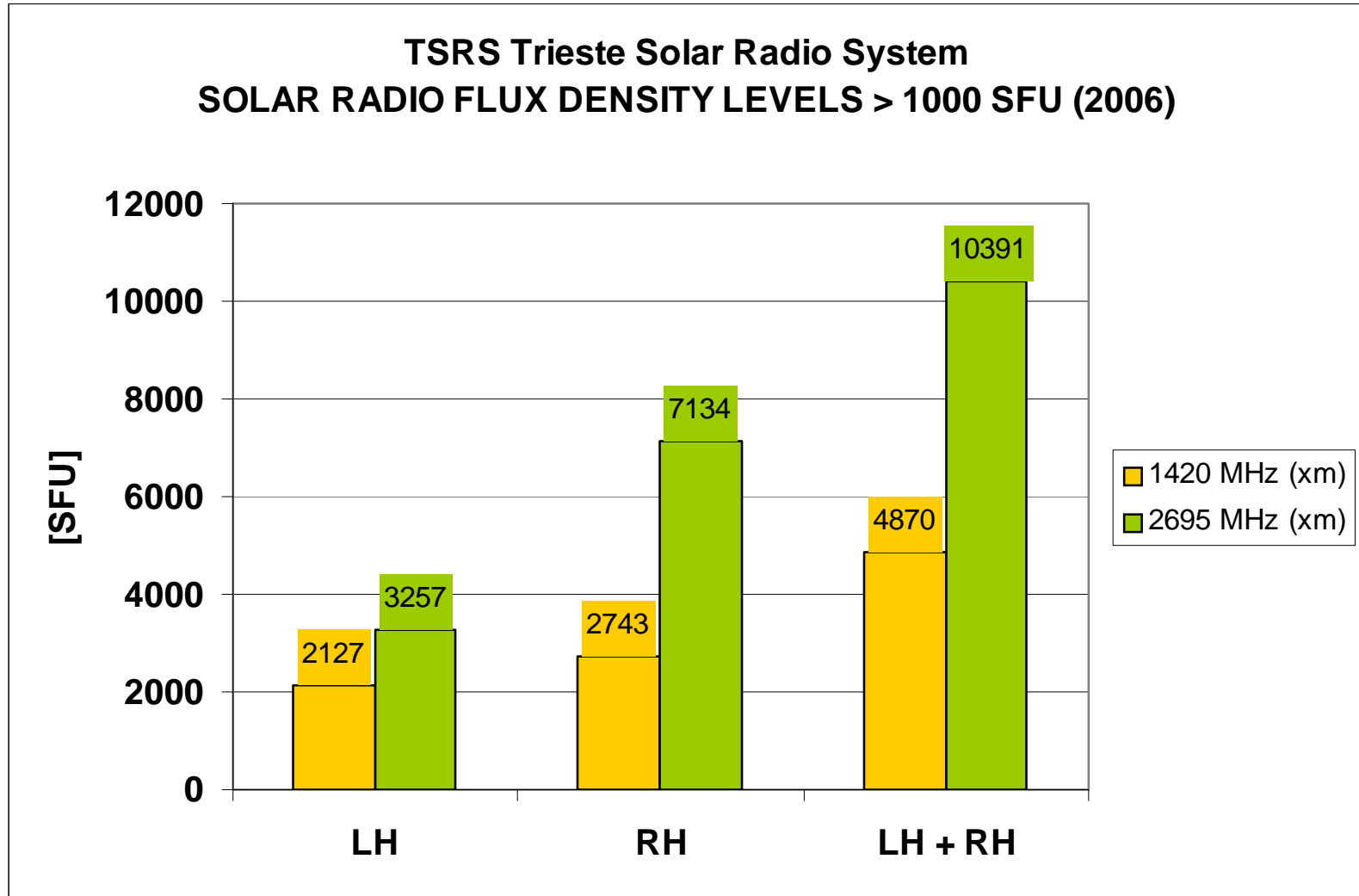
# TSRS 2005.07.14 1420 MHz



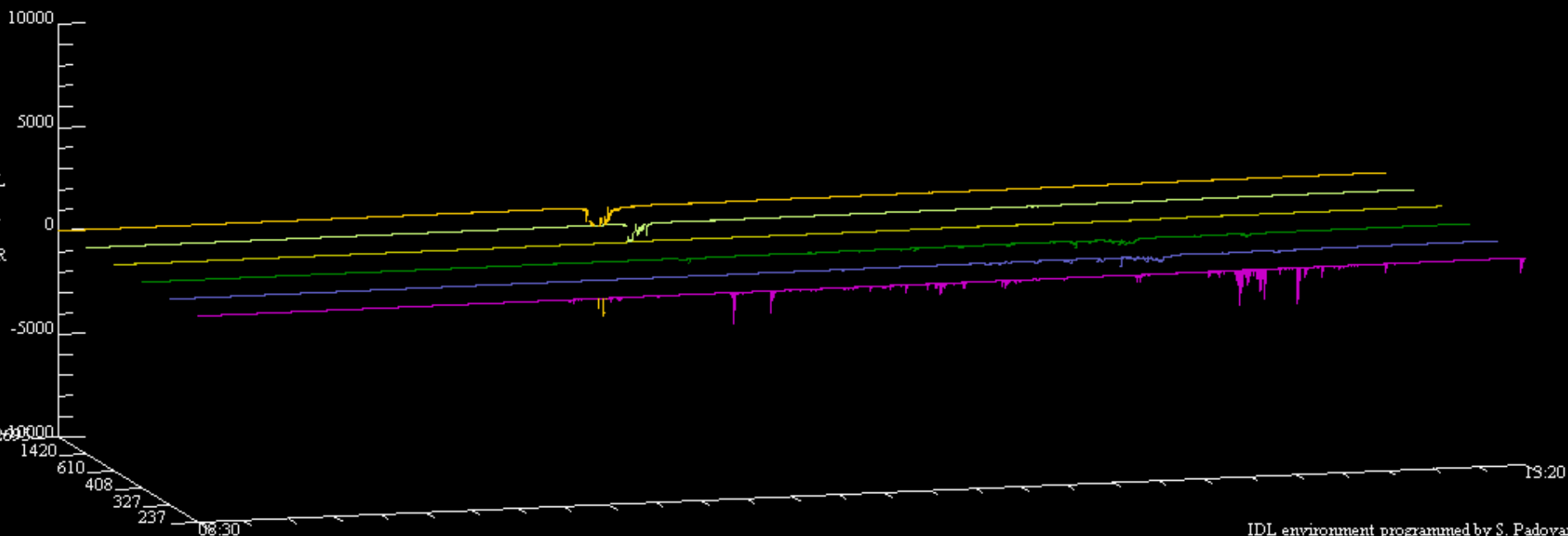
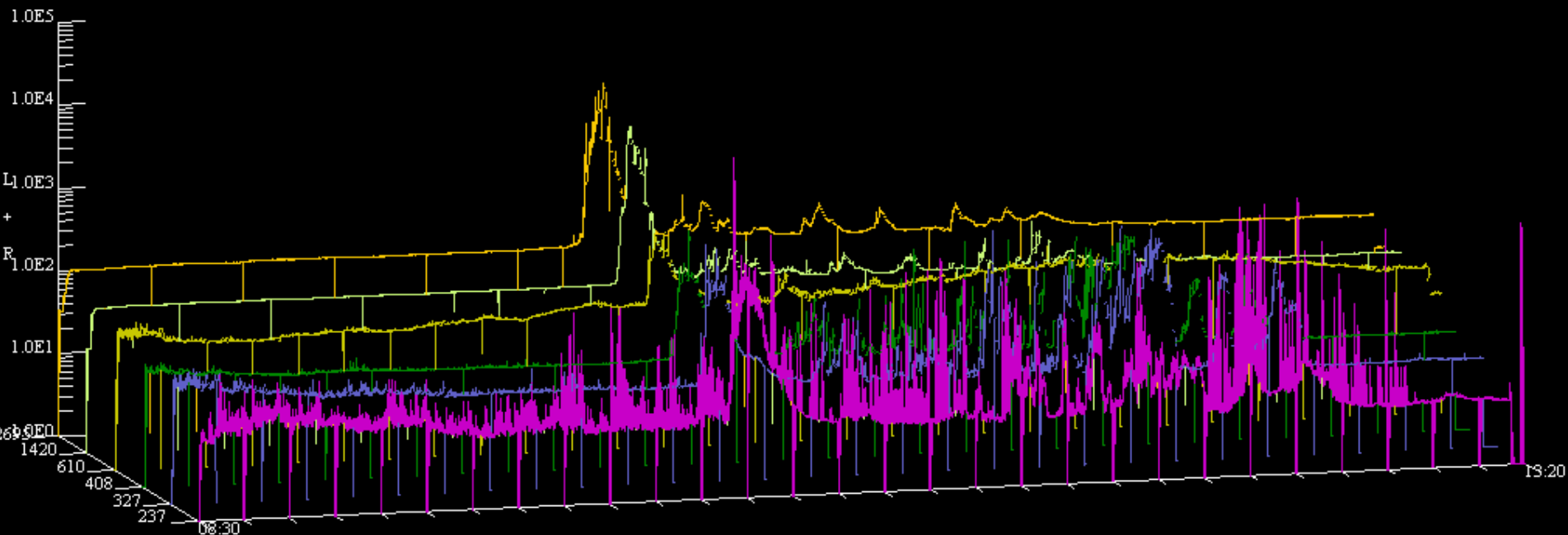
# TSRS 2005.07.14 2695 MHz



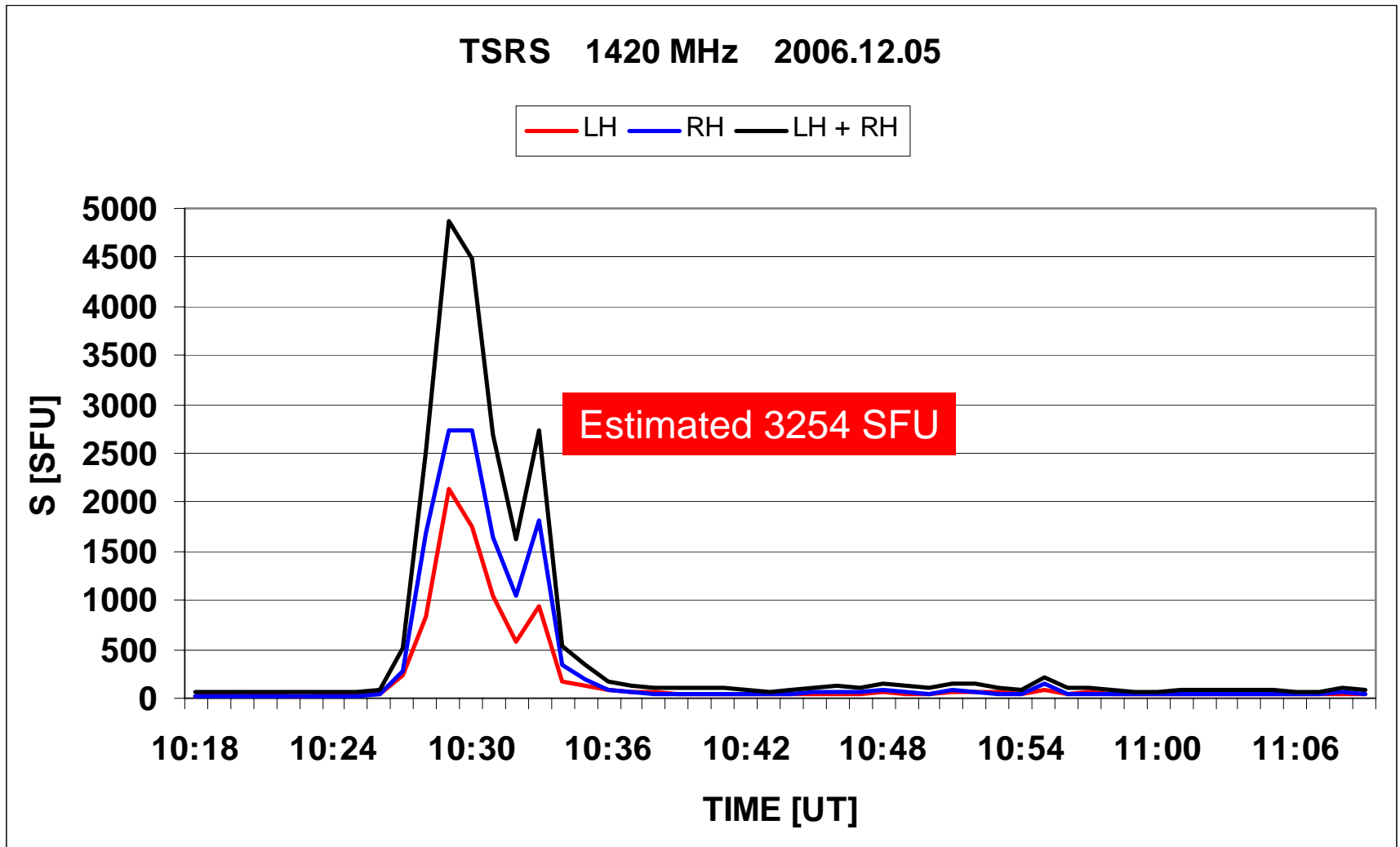
# Statistics of Max dm RFs 2006



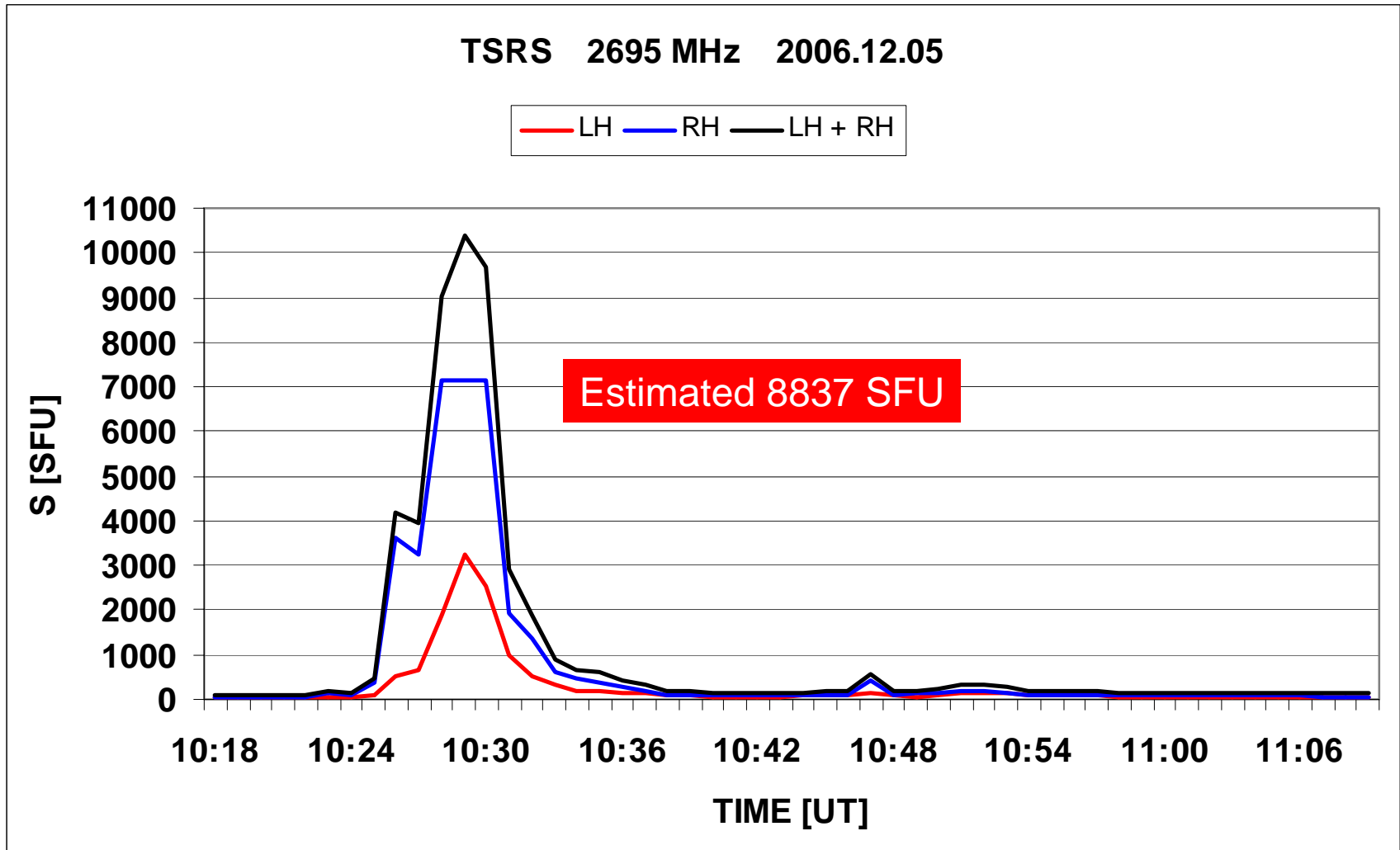




# TSRS 2006.12.05 1420 MHz



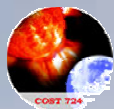
# TSRS 2006.12.05 2695 MHz



# Conclusions

1

- Theoretical estimations and experimental evidences indicate that the Sun can directly interfere communication and navigation systems
- Detailed studies of the solar radio noise have to be performed via diachronic radio observations in order to better specify the effects of SRBs on wireless systems and on GNSS
- TSRS is an effective tools for Space Weather applications as it measures the solar radio emission in near-real-time at different frequencies with high time cadence and near-real-time data ingestion
- TSRS can provide significantly new information in this framework due to its particularly suitable operating mode



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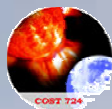




# Conclusions

2

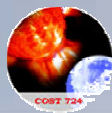
- The maximum radio flux density values published on data catalogs often differs from that obtained by precise, high time resolution, diachronic measurements
- The use of real-time multichannel solar radio polarimeters is a key issue for an appropriate analysis of the geoeffectivity of radio flares.



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# Thank you for your attention!



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