SOLARNET

SUN IN SCIENCE AND SOCIETY 11-15 September, 2023 VENICE/MESTRE, ITALY

Correlation investigation and statistical studies between Active Regions' radio spectral evolution and solar flares occurrences

Speaker **Sara Mulas**

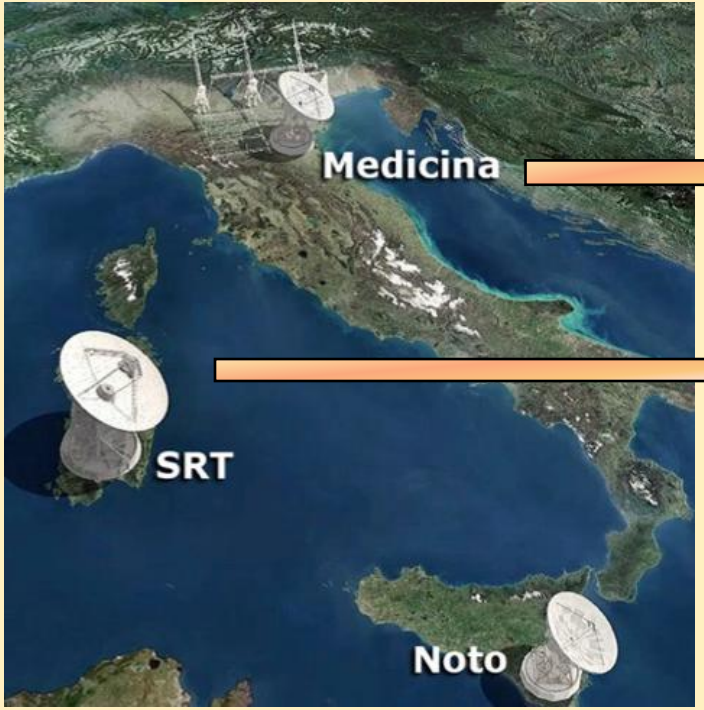
INAF-Osservatorio Astronomico di Cagliari

sara.mulas@inaf.it

A. Pellizzoni (Principal Investigator, INAF-OAC), **S. Righini** (co-PI, INAF-IRA), **M.N. Iacolina** (co-PI, ASI), **M. Marongiu** (INAF-OAC), **S. Mulas** (INAF-OAC), **G. Murtas** (Los Alamos National Laboratory), **G. Valente** (ASI), **E. Egron** (INAF-OAC), **M. Bachetti** (INAF-OAC), **F. Buffa** (INAF-OAC), **R. Concu** (INAF-OAC), **G.L. Deiana** (INAF-OAC), **S.L. Guglielmino** (UniCT), **A. Ladu** (INAF-OAC), **S. Loru** (INAF-OACt), **A. Maccaferri** (INAF-IRA), **P. Marongiu** (INAF-OAC), **A. Melis** (INAF-OAC), **A. Navarrini** (INAF-OAC), **A. Orfei** (INAF-IRA), **P. Ortu** (INAF-OAC), **M. Pili** (INAF-OAC), **T. Pisanu** (INAF-OAC), **G. Pupillo** (INAF-IRA), **A. Saba** (ASI), **L. Schirru** (INAF-OAC), **G. Serra** (ASI), **C. Tiburzi** (INAF-OAC), **A. Zanichelli** (INAF-IRA), **P. Zucca** (ASTRON, NL), **M. Messerotti** (INAF-OATS).

The SUNDISH Project

Monitor and produce single dish radio imaging of the solar atmosphere at high radio frequencies (K-band 18-26 GHz). Up to 100 GHz in the future (**Pellizzoni et al, 2022**)



Medicina Radio Telescope 32 m
Medicina (Emilia Romagna)

Sardinia Radio Telescope 64 m
San Basilio (Cagliari, Sardinia)

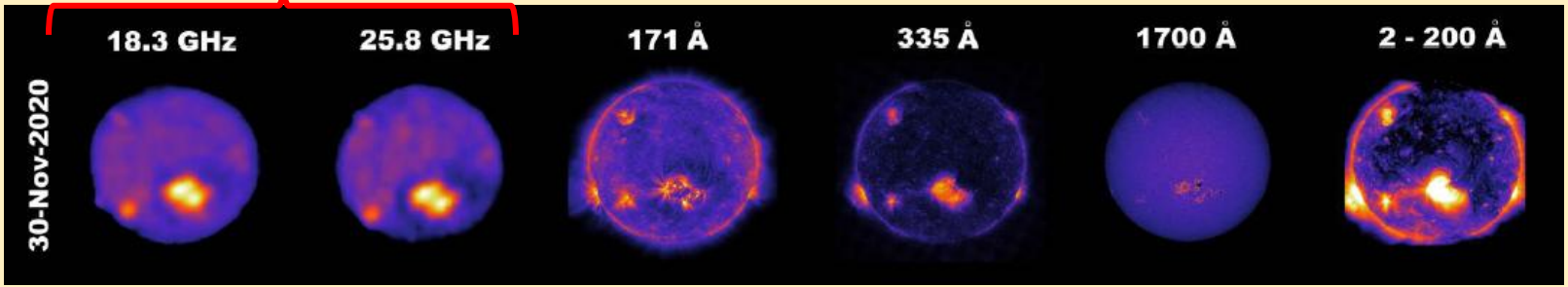
Need to design a specific solar attenuation set up for each radio telescope

https://sites.google.com/inaf.it/sundish

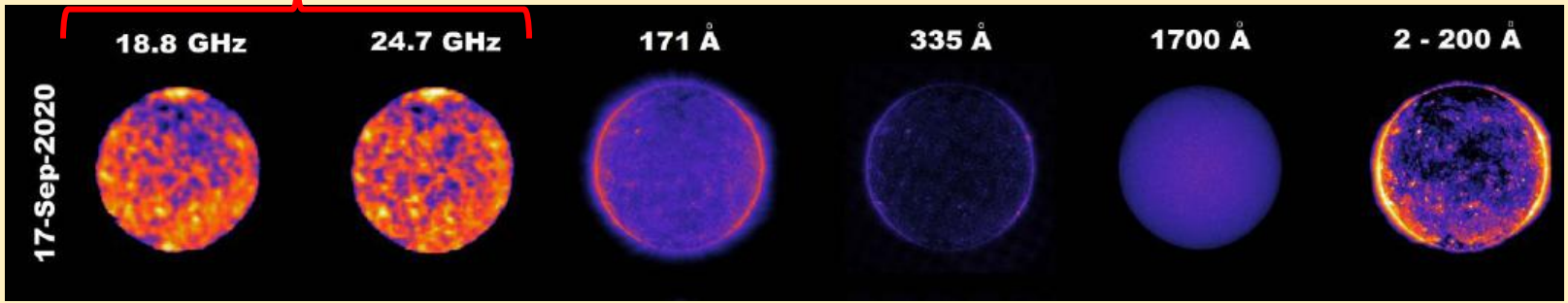
The SUNDISH Project

Monitor and produce single dish radio imaging of the solar atmosphere at high radio frequencies (K-band 18-26 GHz). Up to 100 GHz in the future (**Pellizzoni et al, 2022**)

Medicina Radio Telescope

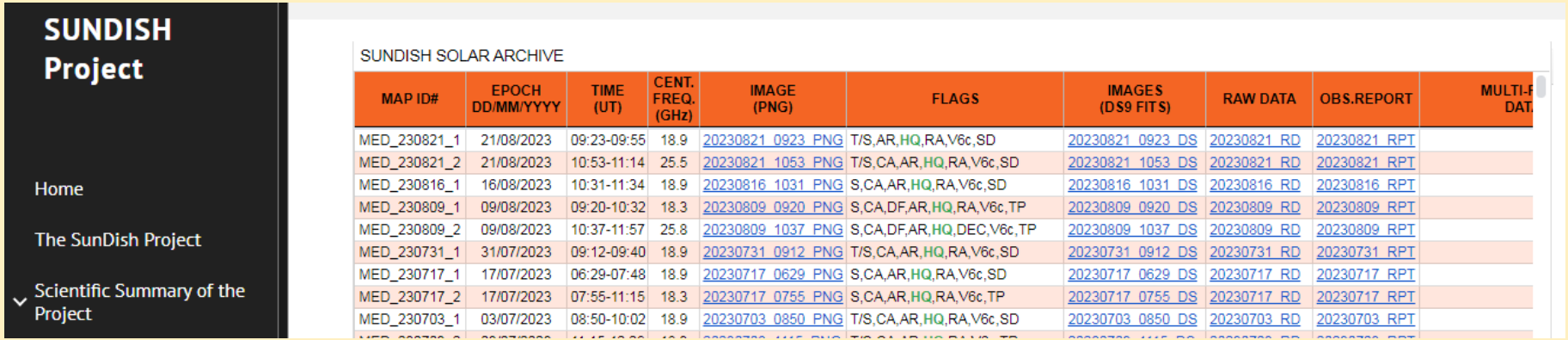


Srdinia Radio Telescope



Images Archive and SUNPIT

To date we acquired more than 350 solar maps, **one every week on average**



MAP ID#	EPOCH DD/MM/YYYY	TIME (UT)	CENT. FREQ. (GHz)	IMAGE (PNG)	FLAGS	IMAGES (DS9 FITS)	RAW DATA	OBS.REPORT	MULTI-F DAT.
MED_230821_1	21/08/2023	09:23-09:55	18.9	20230821_0923_PNG	T/S,AR,HQ,RA,V6c,SD	20230821_0923_DS	20230821_RD	20230821_RPT	
MED_230821_2	21/08/2023	10:53-11:14	25.5	20230821_1053_PNG	T/S,CA,AR,HQ,RA,V6c,SD	20230821_1053_DS	20230821_RD	20230821_RPT	
MED_230816_1	16/08/2023	10:31-11:34	18.9	20230816_1031_PNG	S,CA,AR,HQ,RA,V6c,SD	20230816_1031_DS	20230816_RD	20230816_RPT	
MED_230809_1	09/08/2023	09:20-10:32	18.3	20230809_0920_PNG	S,CA,DF,AR,HQ,RA,V6c,TP	20230809_0920_DS	20230809_RD	20230809_RPT	
MED_230809_2	09/08/2023	10:37-11:57	25.8	20230809_1037_PNG	S,CA,DF,AR,HQ,DEC,V6c,TP	20230809_1037_DS	20230809_RD	20230809_RPT	
MED_230731_1	31/07/2023	09:12-09:40	18.9	20230731_0912_PNG	T/S,CA,AR,HQ,RA,V6c,SD	20230731_0912_DS	20230731_RD	20230731_RPT	
MED_230717_1	17/07/2023	06:29-07:48	18.9	20230717_0629_PNG	S,CA,AR,HQ,RA,V6c,SD	20230717_0629_DS	20230717_RD	20230717_RPT	
MED_230717_2	17/07/2023	07:55-11:15	18.3	20230717_0755_PNG	S,CA,AR,HQ,RA,V6c,TP	20230717_0755_DS	20230717_RD	20230717_RPT	
MED_230703_1	03/07/2023	08:50-10:02	18.9	20230703_0850_PNG	T/S,CA,AR,HQ,RA,V6c,SD	20230703_0850_DS	20230703_RD	20230703_RPT	

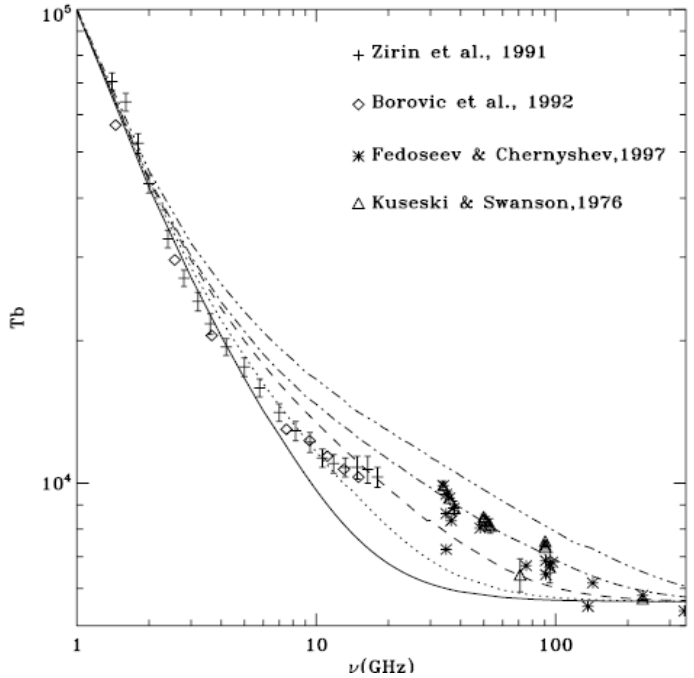
Solar Image Archive: https://sites.google.com/inaf.it/sundish/sundish-images-archive/sundish-solar-archive

For access to raw data and possible collaborations, please contact the PI A. Pellizzoni (alberto.pellizzoni@inaf.it)

Dedicated solar pipeline SUNdish PIpeline Tool for imaging and data analysis (Marongiu et al., 2021/2022)

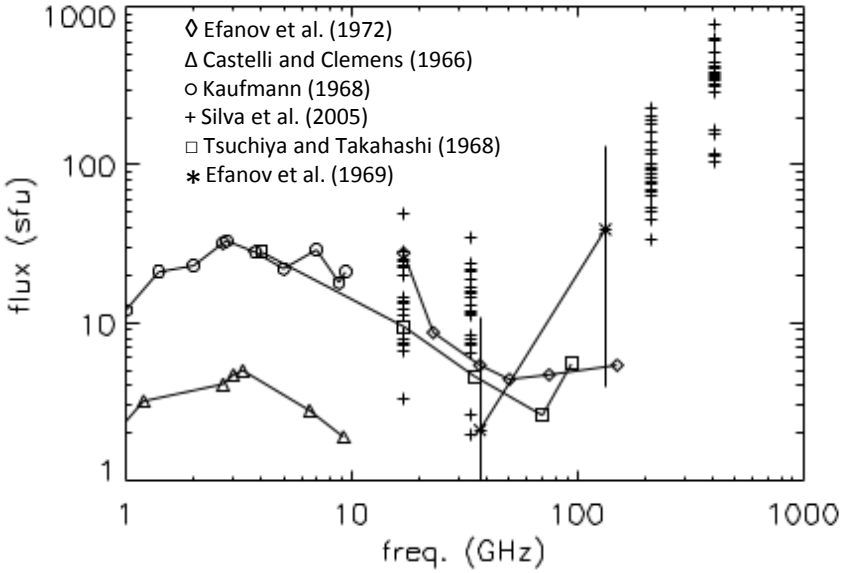
Radio Sun QS and ARs in K-band (18-26 GHz)

Quiet Sun



(E. Landi, F. Chiuderi Drago 2008)

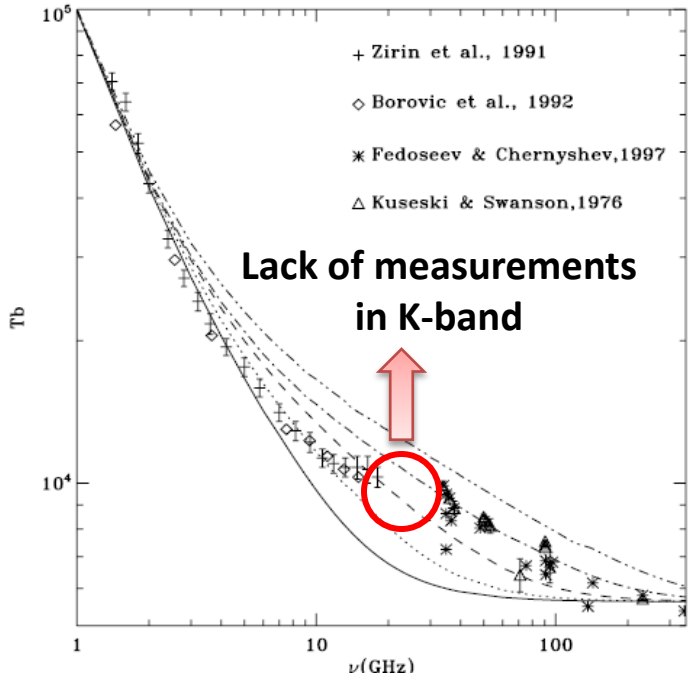
Active Regions



(A. V. R. Silva et al, 2005)

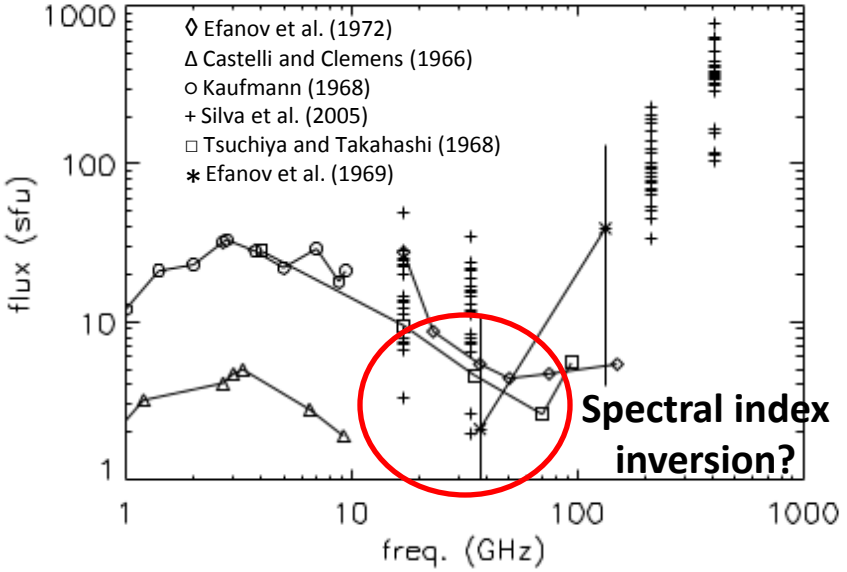
Radio Sun QS and ARs in K-band (18-26 GHz)

Quiet Sun



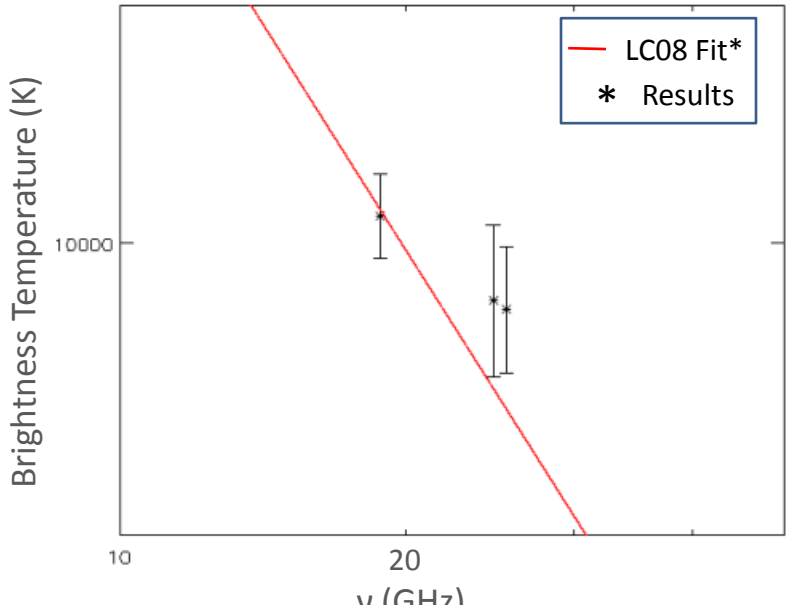
(E. Landi, F. Chiuderi Drago 2008)

Active Regions



(A. V. R. Silva et al, 2005)

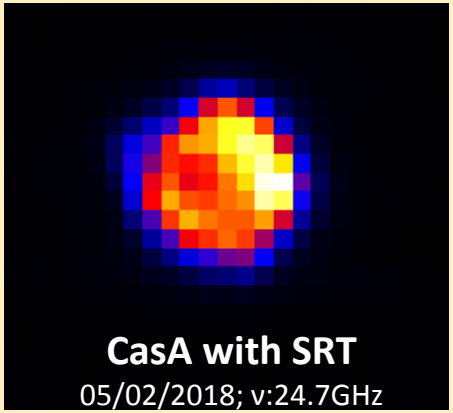
QS absolute calibration with Cas A



ν_{obs} [GHz]	$Cas\ A_f$ [Jy]	T_{QS} [K]	Fit_{dev} [%]
18.8	247.9 ± 5.7 (Oct–2020)	10099 ± 154	0.24
24.7	205.3 ± 4.8 (Oct–2019)	9799 ± 268	3.24
25.5	201.1 ± 4.7 (May–2019)	9764 ± 223	3.65

First accurate measurements of the QS level in 18-26 GHz range

Original and innovative absolute calibration procedure with the **Supernova Remnant Cassiopeia A (Cas A) with SRT solar data**

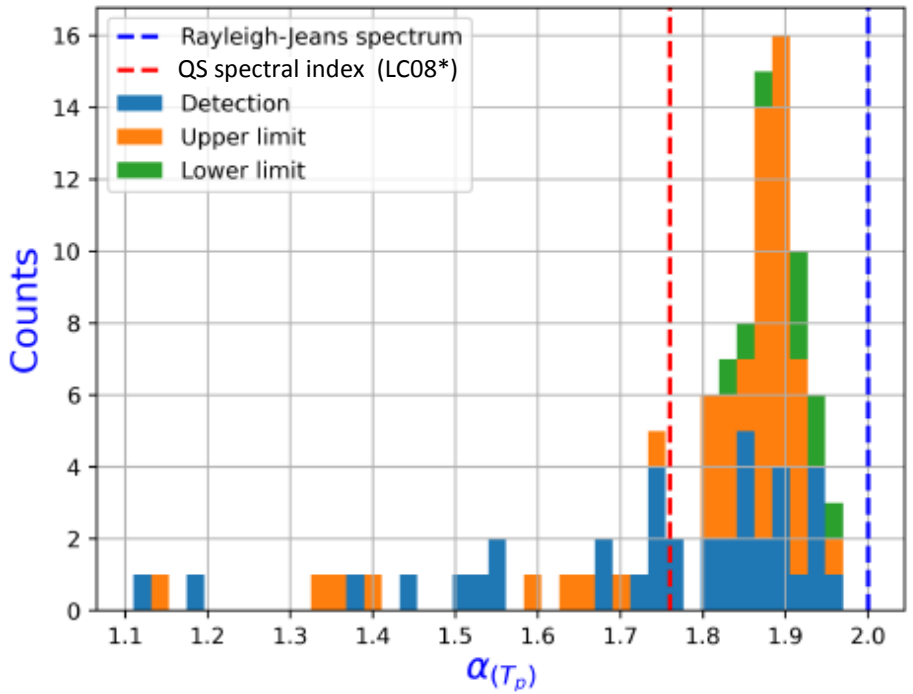


This calibration based on CasA is a reliable method to calibrate the QS and in return the Sun maps (Mulas et al, 2022; Pellizzoni et al, 2022)

Sara Mulas

*Landi & Chiuderi Drago 2008 fit (LC08)

ARs Spectral index results



Histogram of the spectral index values calculated from the maximum brightness temperature Tp. The data are binned in 40 bins. Blue counts indicate detections; orange and green counts show upper limits and lower limits, respectively.

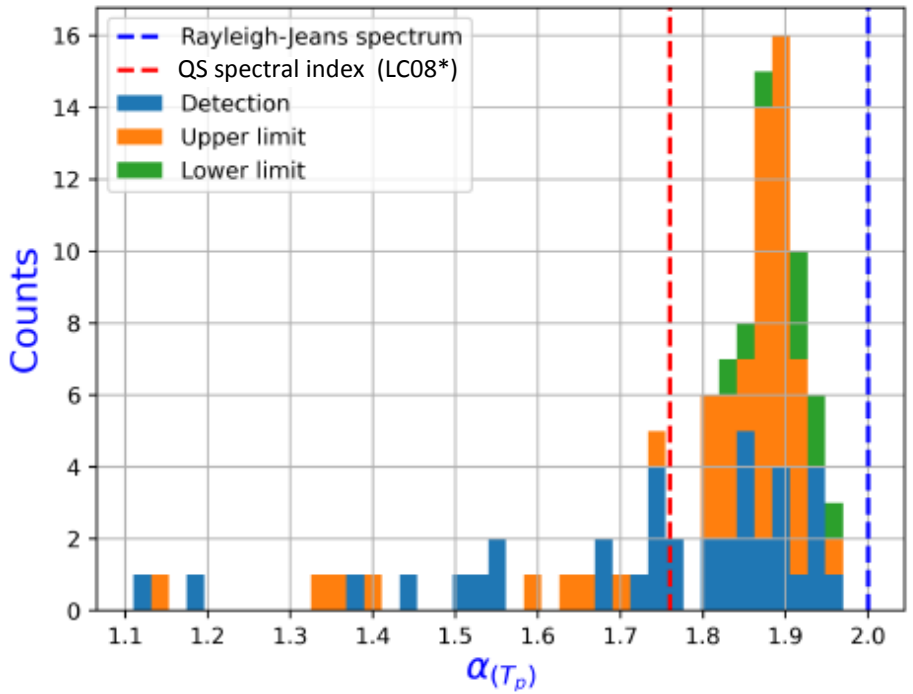
Spectral index

$$\alpha = \frac{log(S_{\nu_1}/S_{\nu_2})}{log(\nu_1/\nu_2)}$$

S1 flux at frequency v1
S2 flux at frequency v2

*Landi & Chiuderi Drago 2008 fit (LC08)

ARs Spectral index results



Histogram of the spectral index values calculated from the maximum brightness temperature Tp. The data are binned in 40 bins. Blue counts indicate detections; orange and green counts show upper limits and lower limits, respectively.

Spectral index

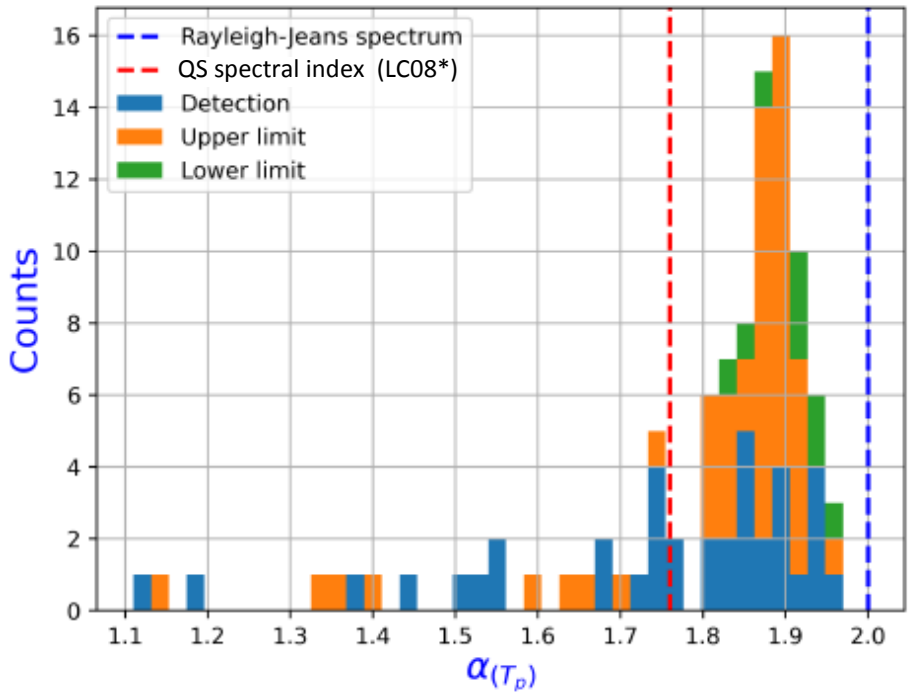
$$\alpha = \frac{log(S_{\nu_1}/S_{\nu_2})}{log(\nu_1/\nu_2)}$$

S1 flux at frequency v1
S2 flux at frequency v2

Hypothesis: concurring presence of sporadic gyro-magnetic components in the ARs emission could contribute to spectral softening

*Landi & Chiuderi Drago 2008 fit (LC08)

ARs Spectral index results



Histogram of the spectral index values calculated from the maximum brightness temperature Tp. The data are binned in 40 bins. Blue counts indicate detections; orange and green counts show upper limits and lower limits, respectively.

Spectral index

$$\alpha = \frac{log(S_{\nu_1}/S_{\nu_2})}{log(\nu_1/\nu_2)}$$

S1 flux at frequency v1
S2 flux at frequency v2

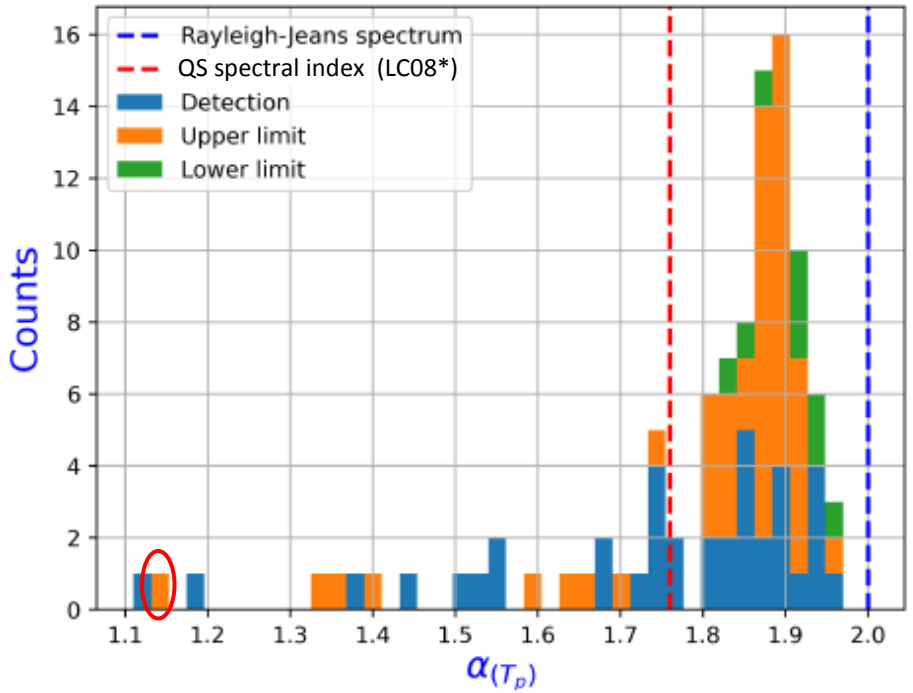
Hypothesis: concurring presence of sporadic gyro-magnetic components in the ARs emission could contribute to spectral softening

Gyro-resonance emission has been proven to peak up to 20 GHz (Selhorst et al., 2008)

Depending on the dimension of the gyro-resonance source, it could be not resolved at our frequencies

*Landi & Chiuderi Drago 2008 fit (LC08)

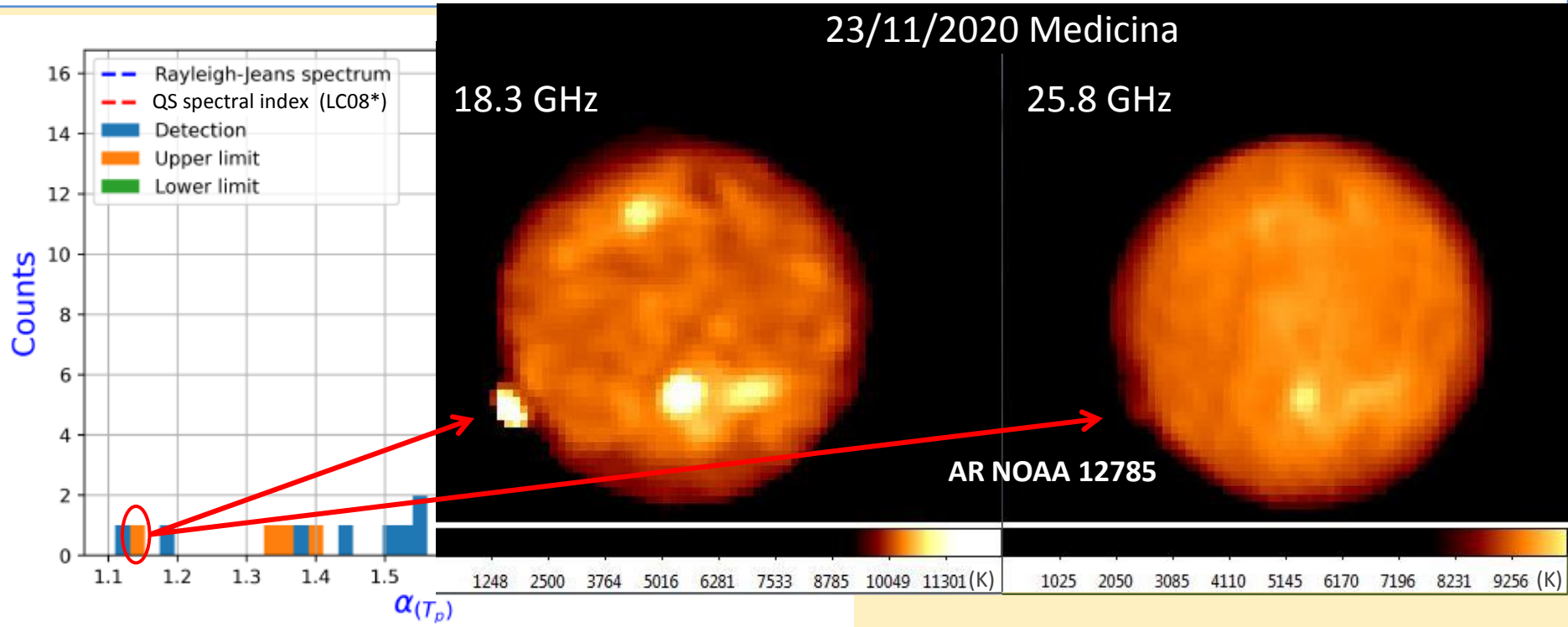
ARs Spectral index results: an interesting case



Histogram of the spectral index values calculated from the maximum brightness temperature Tp. The data are binned in 40 bins. Blue counts indicate detections; orange and green counts show upper limits and lower limits, respectively.

*Landi & Chiuderi Drago 2008 fit (LC08)

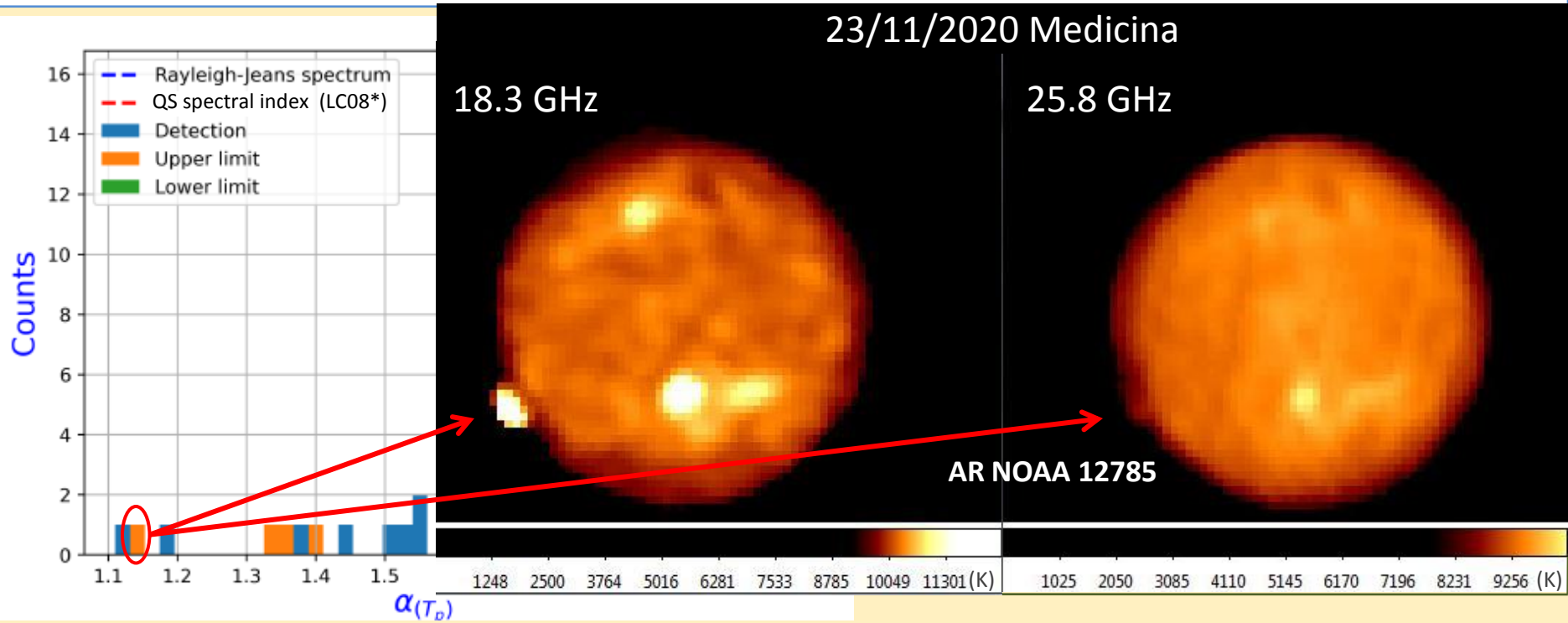
ARs Spectral index results: an interesting case



Histogram of the spectral index values calculated from the maximum brightness temperature Tp. The data are binned in 40 bins. Blue counts indicate detections; orange and green counts show upper limits and lower limits, respectively.

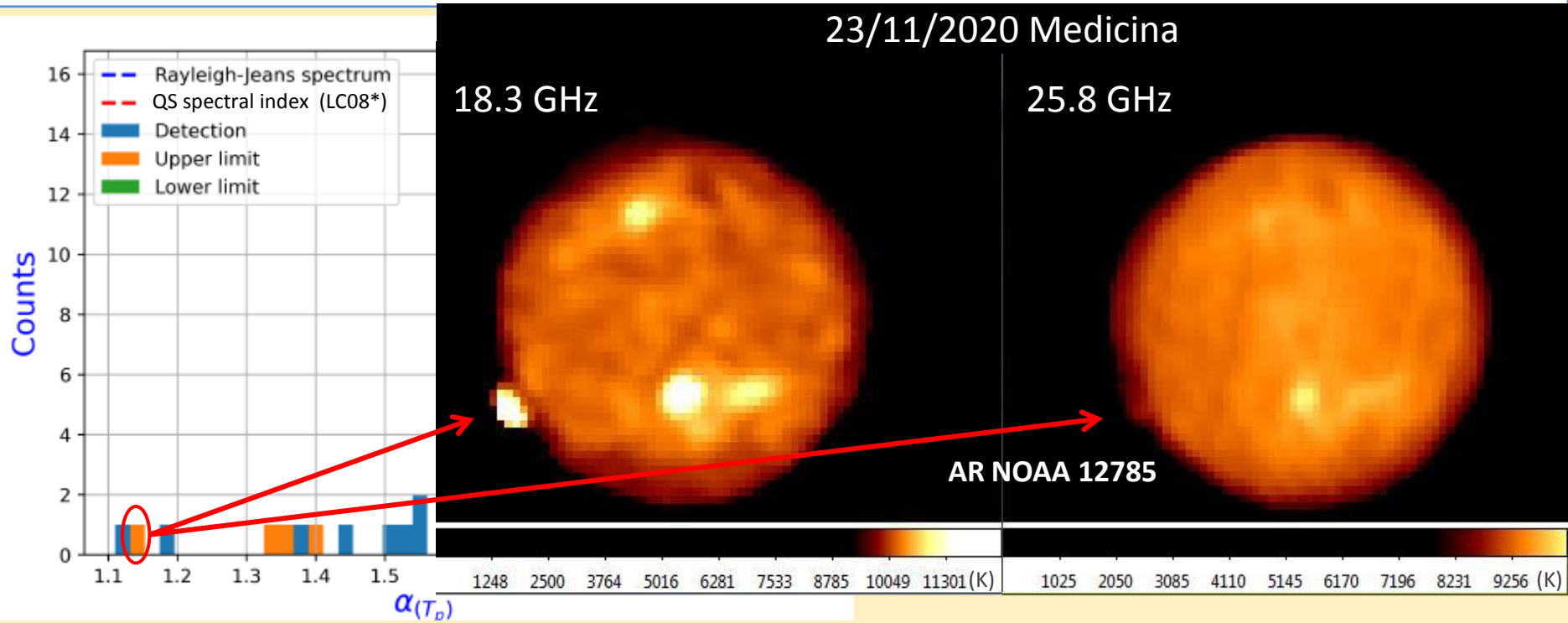
*Landi & Chiuderi Drago 2008 fit (LC08)

ARs Spectral index results: an interesting case



A C4.3 flare originated from the same AR few ours later. Strong gyro-magnetic emission contribution?

ARs Spectral index results: an interesting case



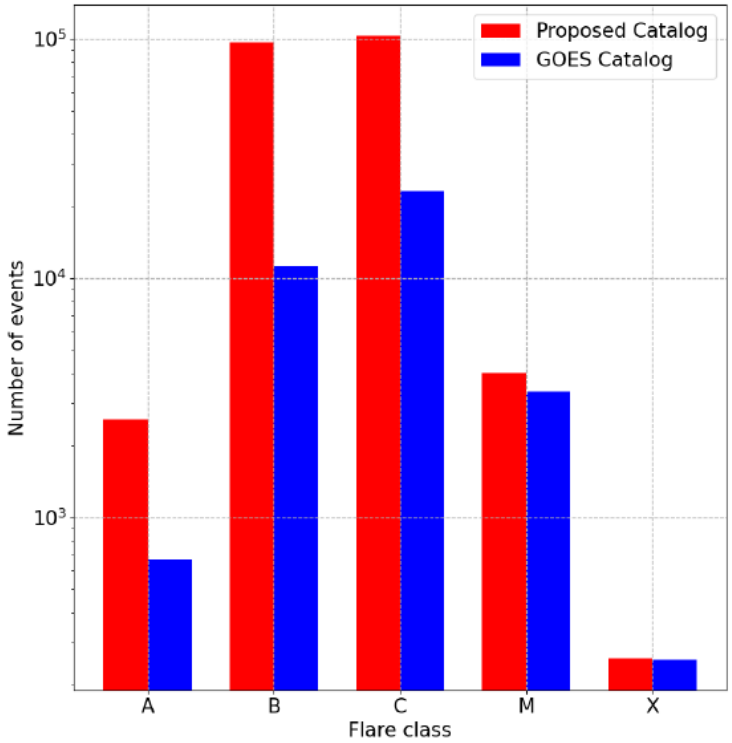
Low α values in the Radio K-band could be used as a flare prognostic tool?

Flare catalogues: GOES data

A new catalogue of solar flare events from soft x-ray GOES signal in the period 1986-2020

Nicola Plutino, Francesco Berrilli*, Dario Del Moro, Luca Giovannelli

Department of Physics, University of Rome Tor Vergata, Via della Ricerca Scientifica, 1, Rome 00133, Italy



Histogram of the number of flares by classes for the period from 1998 to 2020. The catalogue produced by their procedure increases the statistics of the events of all classes with respect to the events listed in the GOES catalogue.

The increase of events in the different classes can be appreciated by observing the number of events listed in our catalogue (red bars) compared to those associated with the GOES catalogue (blue bars).

https://github.com/nplutino/FlareList

Sara Mulas

Flare catalogues: AGILE

The First AGILE Solar Flare Catalog

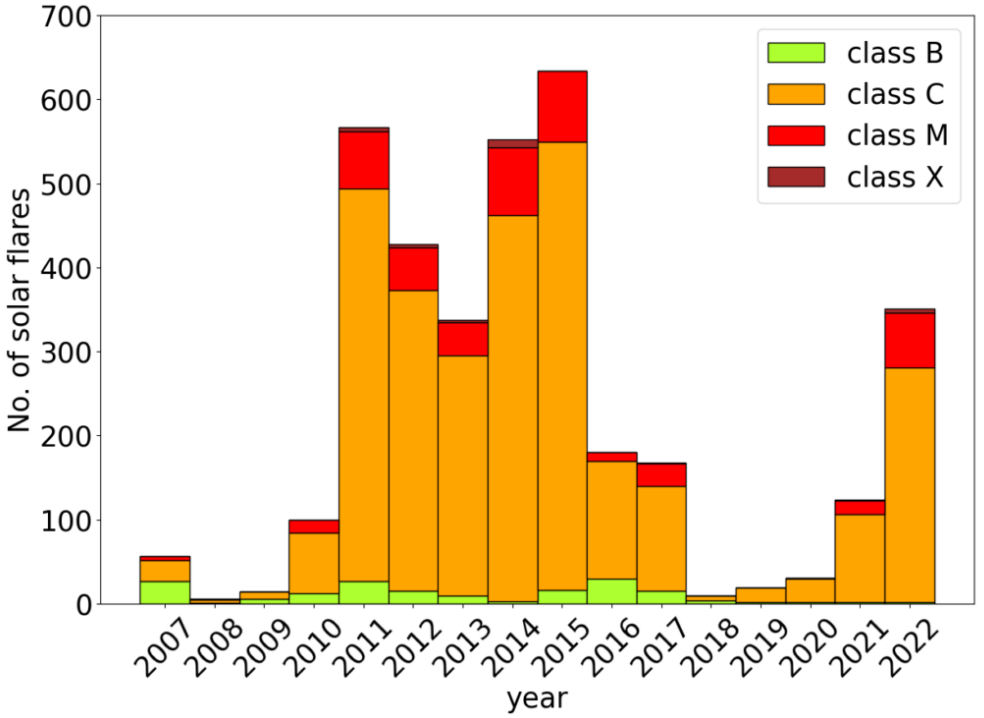
A. Ursi,[1,2] N. Parmiggiani,[3] M. Messerotti,[4] A. Pellizzoni,[5] C. Pittori,[6,7] F. Longo,[8] F. Verrecchia,[6,7] A. Argan,[1] A. Bulgarelli,[3] M. Tavani,[1,9] P. Tempesta,[10] and F. D'Amico[2]

Occurrence rate of the 3572 solar flares, detected by AGILE(**A**strorivelatore **G**amma a **I**mmagini **Le**ggero) between 2007 May and 2022 August.

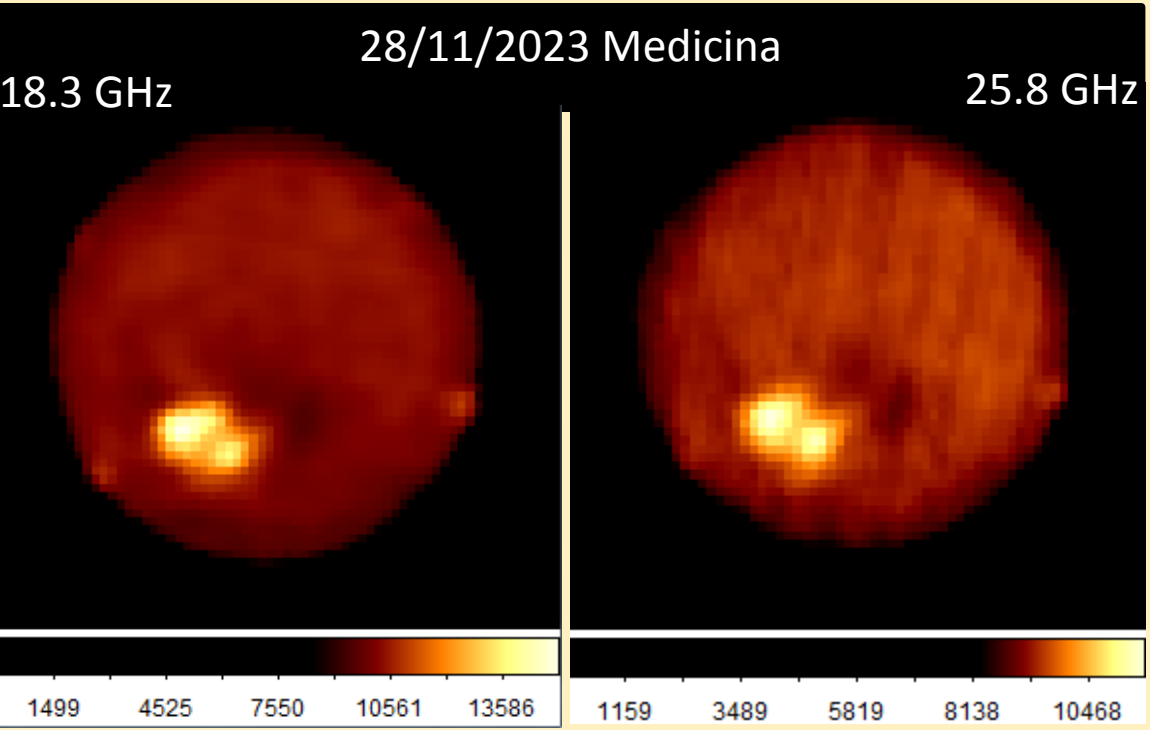
Different colors denote different flare classes, as obtained from GOES.

https://www.ssdc.asi.it/agilesolarcat/

11/09/2023



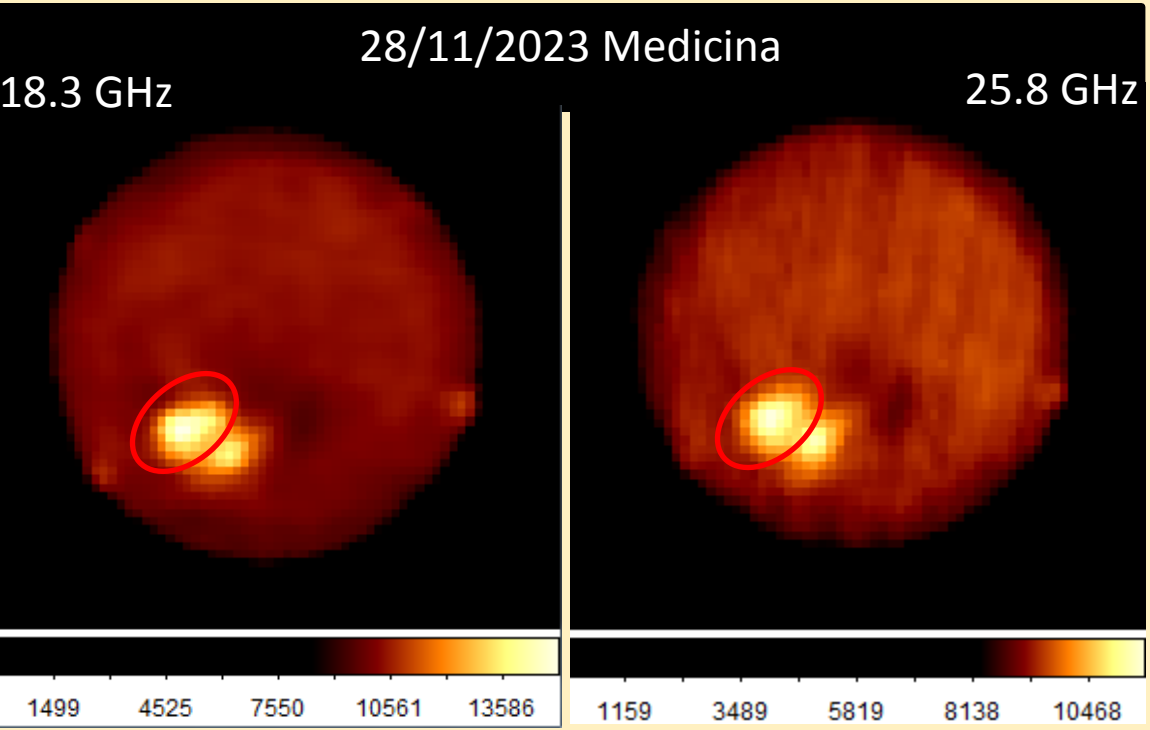
NOAA 12786 - 28/11/2023



11/09/2023

Sara Mulas

NOAA 12786 - 28/11/2023



Observing time SunDish maps

18.3 GHz: 10:35-11:49

25.8 GHz: 11:52-13:04

Radio Spectral Index: 1.24

Flare parameters

Class: C3.1

Start time: 22:59

Peak time: 23:18

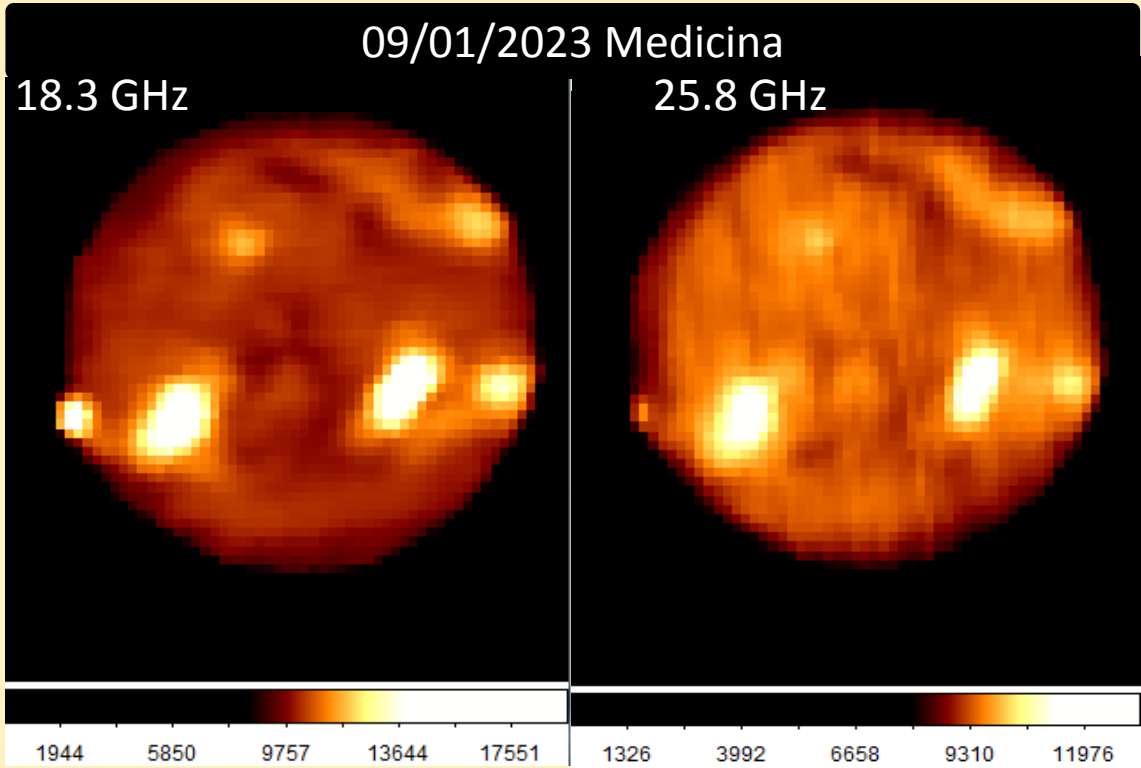
End time: 23:32

Distance between observation and flare maximum ~ **12-10 h**

11/09/2023

Sara Mulas

NOAA 13184 – 09/01/2023



11/09/2023

Sara Mulas

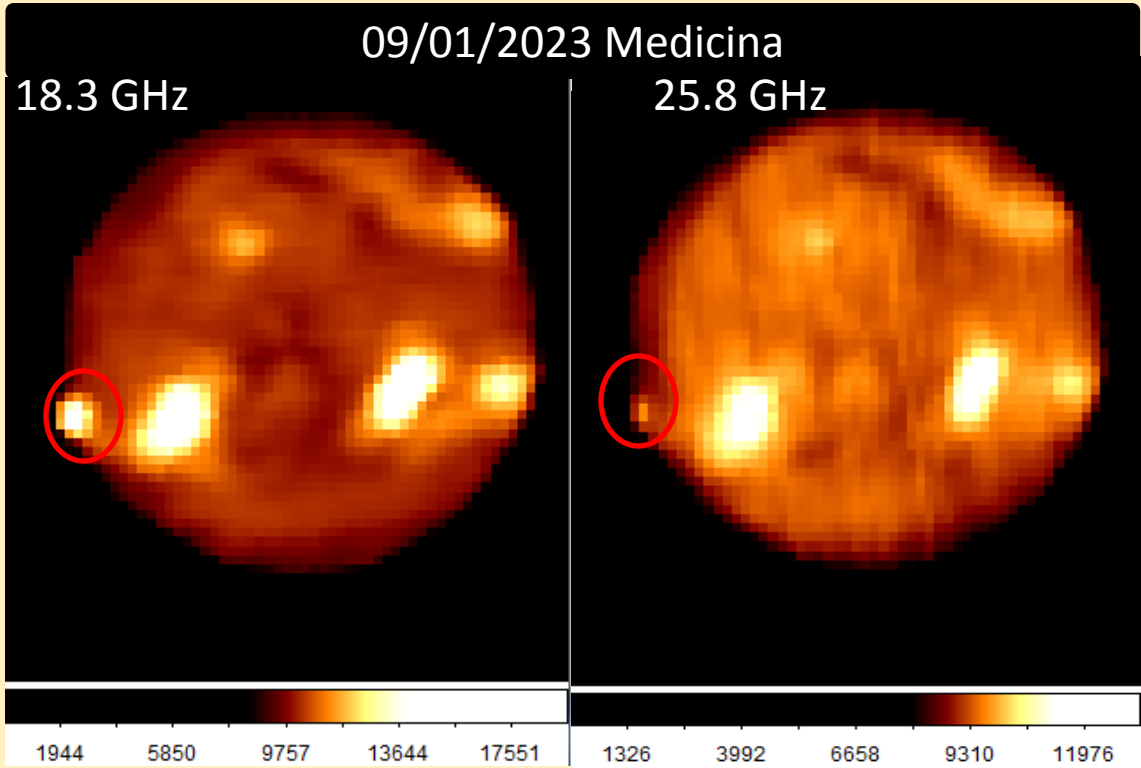
NOAA 13184 – 09/01/2023

Observing time SunDish maps
18.3 GHz: 10:15-11:29
25.8 GHz: 11:32-12:47

Radio Spectral Index: 0.76

Flare parameters
Class: X1.9
Start time: 18:37
Maximum: 18:50
End time: 18:57

Distance between observations and flare maximum ~ **8-6 h**



11/09/2023

Sara Mulas

Other cases

AR: NOAA 12781
Date: 06/11/2020

Observing time SunDish maps
18.3 GHz: 08:35-09:49
25.8 GHz: 09:52-11:07

Radio Spectral Index: 1.11

Flare parameters
Class: C1.3
Start time: 10:30
Peak time: 10:34
End time: 10:39

Distance between observation and flare maximum **~ 0.5-0 h**

AR: NOAA 12816
Date: 19/04/2021

Observing time SunDish maps
18.3 GHz: 09:30-10:44
25.8 GHz: 10:47-12:02

Radio Spectral Index: 1.33

Flare parameters
Class: M1.1
Start time: 23:19
Peak time: 23:42
End time: 23:59

Distance between observation and flare maximum ~ **14-11 h**

AR: NOAA 12992
Date: 19/04/2022

Observing time SunDish maps
18.3 GHz: 09:30-10:44
25.8 GHz: 10:47-12:02

Radio Spectral Index: 1.71

Flare parameters
Class: M3.7
Start time: 20:39
Peak time: 20:49
End time: 20:58

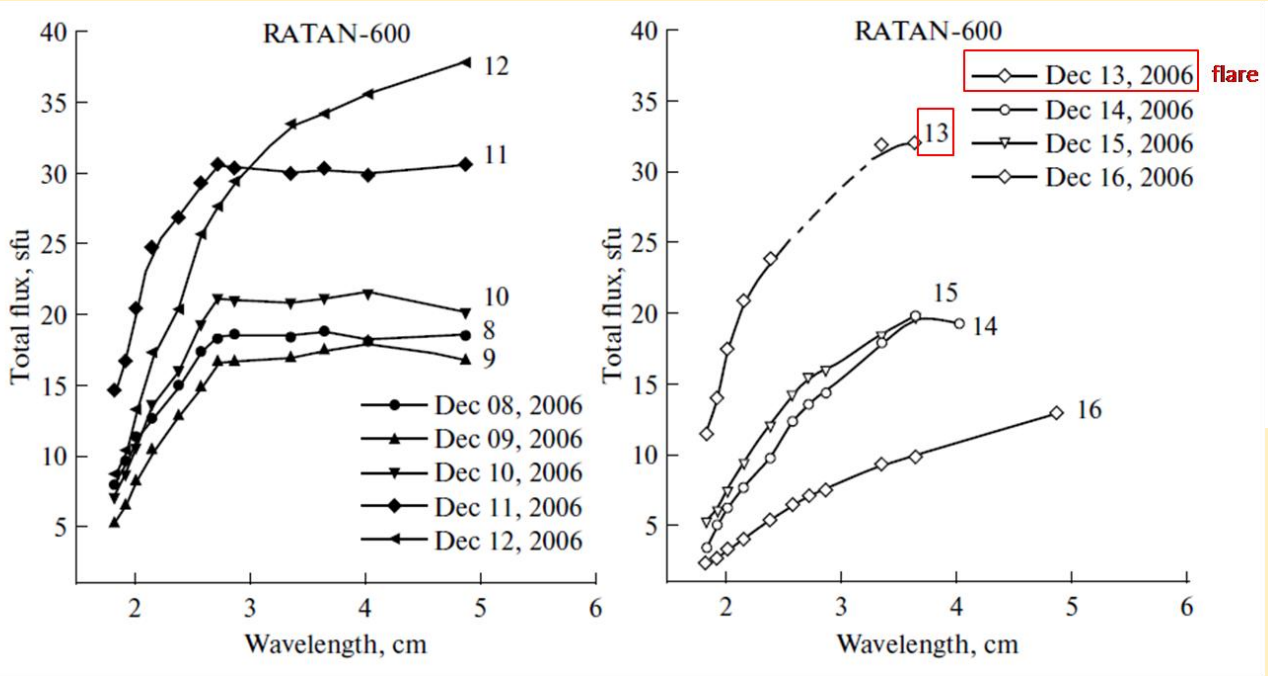
Distance between observation and flare maximum ~ **11-9 h**

Roadmap of the future investigations

- Research on correlation and statistical investigation between solar flares occurrences and ARs' radio **flux**;

Roadmap of the future investigations

➢ Research on correlation and statistical investigation between solar flares occurrences and ARs' radio **flux**;



Flux density spectra of a local radio source associated with NOAA 10930 from RATAN600 observations on December 8-16, 2006 (**Borovik et. al, 2012**).

Roadmap of the future investigations

- Research on correlation and statistical investigation between solar flares occurrences and ARs' radio **flux**;
- wider correlation and statistical investigation between solar flares occurrences and ARs' radio **spectral index;**
- **multi-frequencie**s comparisons;
- research on correlation and statistical investigation between solar flares occurrences and ARs' radio **total flux?**
- Suggestions?

SOLARIS project

SOLARIS antenna opto-mechanical components

➢ **SOLARIS project (PI A. Pellizzoni)** aims to develop a smart Solar monitoring system at W-band (~100 GHz) based on single-dish imaging techniques to observe nearly h24 during Antarctic summer

SOLARIS was recently approved by the PNRA as a permanent observatory in Antarctica

➢ We are planning to not only **monitor the Active Regions** at high radio frequencies but also to **directly detect the flare event**

https://sites.google.com/inaf.it/solaris

Thanks for your attention

Sara Mulas
INAF-Osservatorio Astronomico di Cagliari
sara.mulas@inaf.it