Solaris

a smart Solar imaging system at high radio frequency for continuous Solar monitoring and Space Weather applications

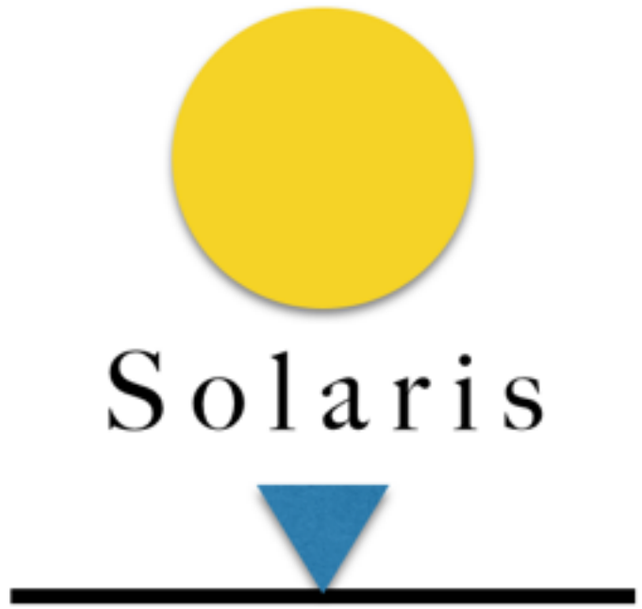
Alberto Pellizzoni - INAF-Osservatorio Astronomico di Cagliari

**approved by PNRA (Piano Nazionale di Ricerche in Antartide)
as a permanent observatory in Antarctica**

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

SCAR Astronomy and Astrophysics from Antarctica

September 19-21, 2023
Svalbard, Norway



The Solaris Team

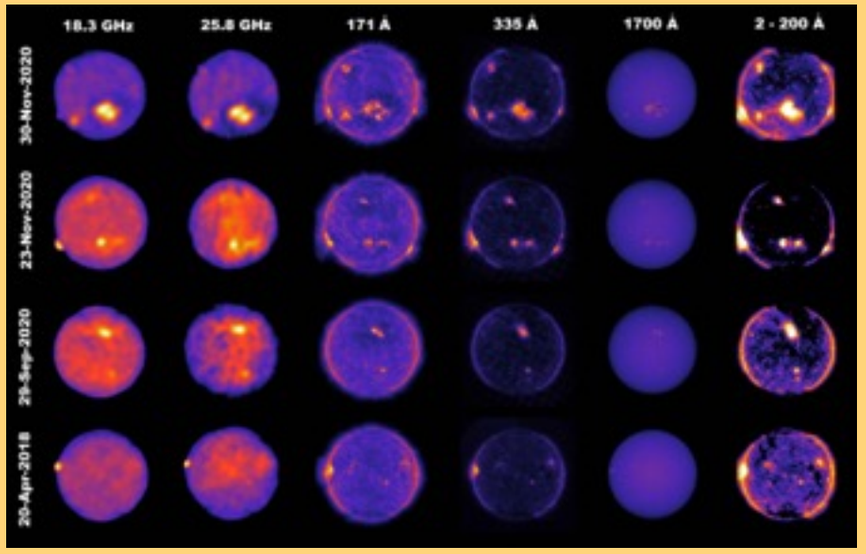
UNIMI: E. Boria, F. Cavaliere, W. Merli, B. Paroli, F. Pezzotta, **M. Potenza (co-PI)**, L. Teruzzi; **UNIMIB**: **M. Gervasi (co-PI)**, A. Limonta, A. Passerini, L. Scalcinati, M. Zannoni; **INFN-MIB**: S. Della Torre; **UNIROMA3**: G. Pizzo; **INAF-OAC**: M. Buttu, E. Egron, M. Marongiu, S. Mulas, A. Navarrini, **A. Pellizzoni (Principal Investigator)**, C. Tiburzi; **INAF-OAS**: I. Bruni, F. Cuttaia, S. Ricciardi, M. Sandri, D. Vergani, **F. Villa (co-PI)**; **ASI**: M.N. Iacolina, A. Saba, G. Serra, G. Valente; **INAF-IRA**: S. Righini; **INAF-TS**: M. Messerotti; **SKA Obs./INAF-IASF**: L. Stringhetti

Italian Radio-Band Assets for Solar Observations & Space Weather

TSRWC (Trieste Solar Radio Weather Centre):
spectropolarimetry, 1-18 GHz, 3.7m antenna

RSRWC (Rende Solar Radio Weather Centre):
spectropolarimetry, 1-18 GHz, 7m antenna

SunDish (Single-Dish Solar Imaging with INAF Radio Telescopes):
Solar imaging & spectropolarimetry, 18-26 GHz (up to 100 GHz), 32m/64m antenna



Solaris Observatory (a smart Solar imaging system at high radio frequency for continuous Solar monitoring and Space Weather applications):
Solar imaging, 100 GHz, 1.5/2.5m antenna (for Antarctic/Arctic sites)

LOFAR-IT (low frequency obs. @ Medicina) **CALLISTO** (low frequency obs. @ Trieste)

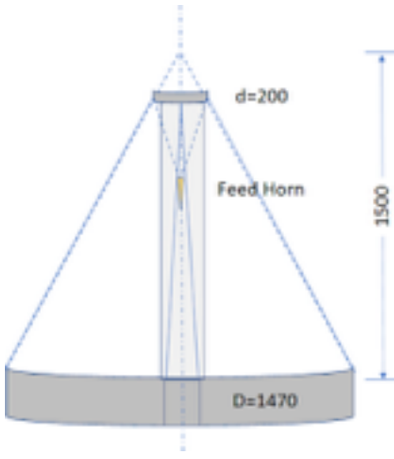
Solaris

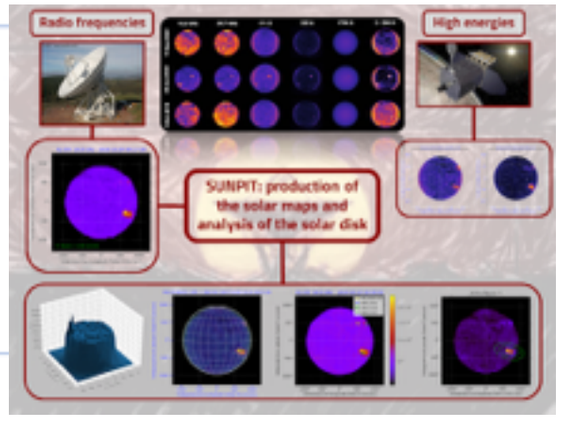
The SOLARIS observatory:
a smart Solar imaging system at high radio frequency for continuous Solar monitoring and Space Weather applications

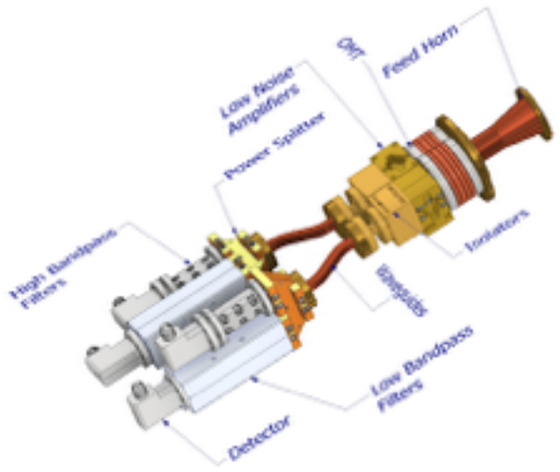
Team:
UNIMI, UNIMIB, INAF-OAC, INAF-OAS, INAF-IRA, UNIROMA3, UNICA, INFN

Small radio telescopes
(Milan, OASI/MZS, COCHISE/Concordia)
ALMA receivers technology
(100 GHz, 2 freq. channels)
Single-dish Solar imaging
(INAF "SunDish" network)

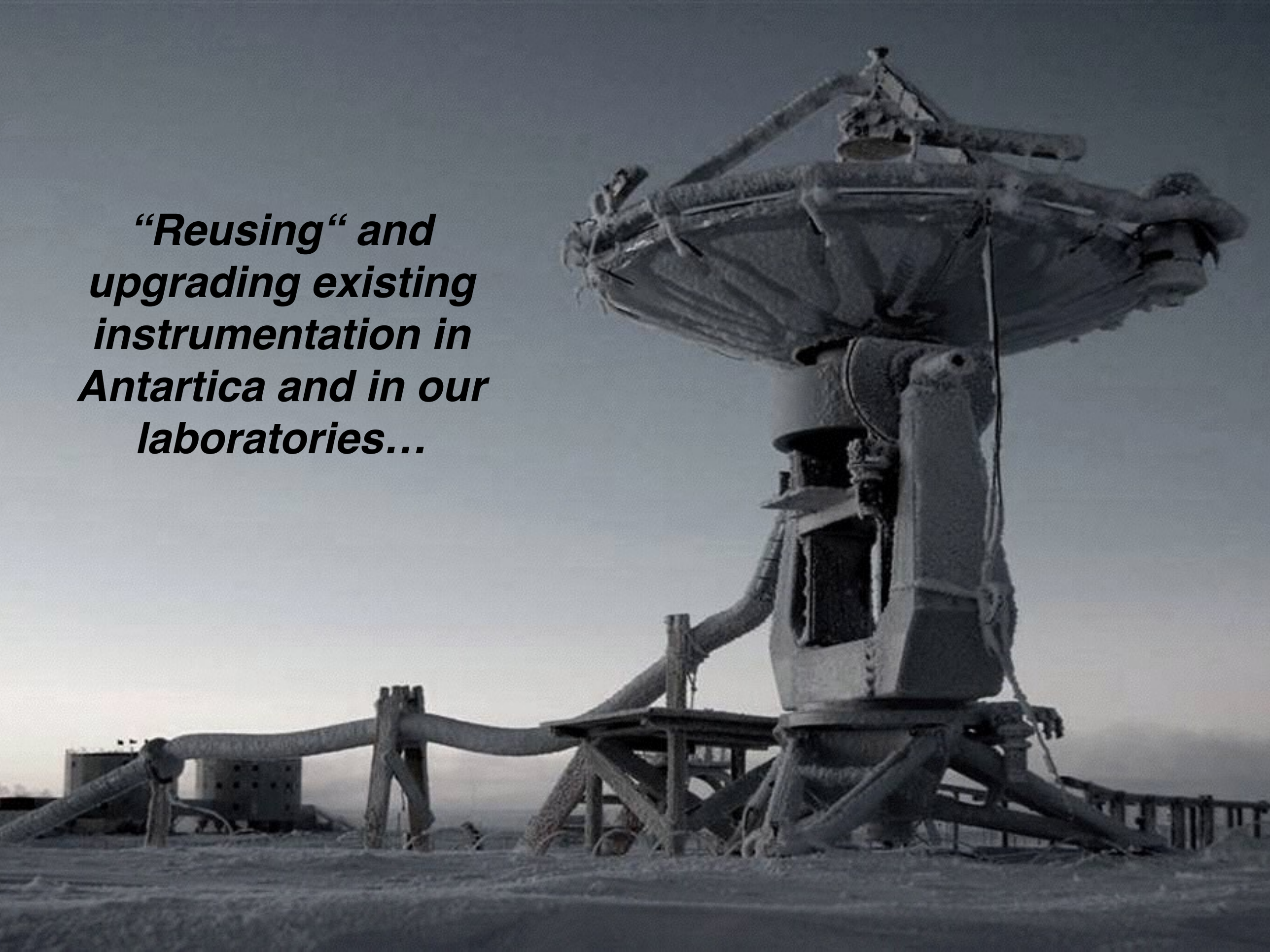
- Solaris is a scientific and technological project aimed at the development of **a smart Solar monitoring system at high radio frequencies based on single-dish imaging techniques**.
- It combines the implementation of a dedicated and interchangeable **100 GHz receiver on existing small single-dish radio telescope systems** (1.5/2.6m class) available in our laboratories in Milan and in Antarctica, to be adapted for Solar observations.
- Solaris can perform **continuous Solar imaging observations nearly 20h/day during Antarctic summer**, and it will be the only Solar facility offering continuous monitoring at 100 GHz.

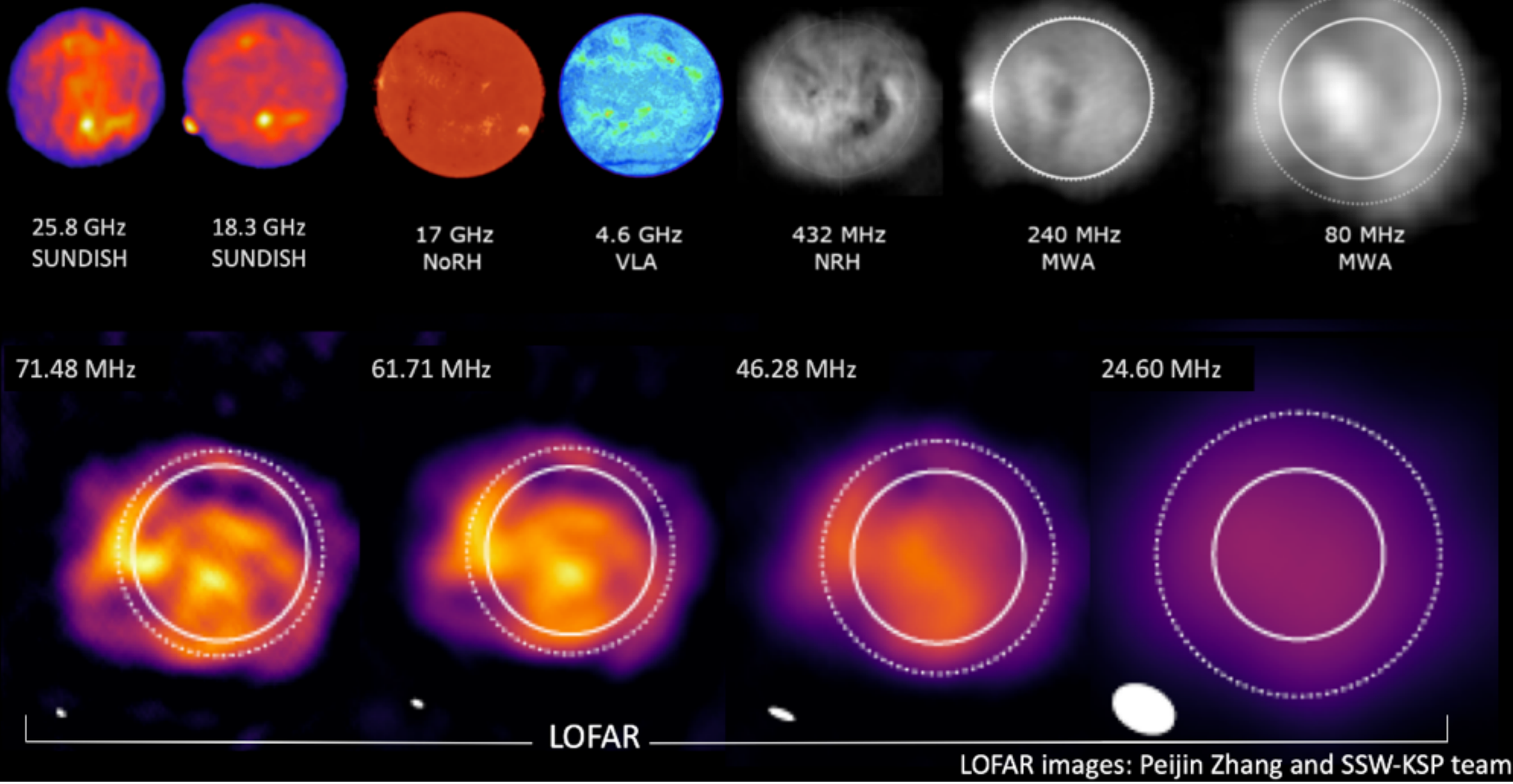






“Reusing“ and upgrading existing instrumentation in Antartica and in our laboratories…





LOFAR images: Peijin Zhang and SSW-KSP team

A. Miriametro, F. Cavaliere, L. Pizzo, G. Dall'Oglio, L. Valenziano. presso la Mario Zucchelli Station

Once upon a time (1989)…..
2.6m telescope @ OASI (Mario Zucchelli Station)
(Osservatorio Antartico Sub-millimetrico ed Infrarosso)
originally conceived for galactic and extragalactic science (cold dust, star forming regions…)

http://officina.fisica.unimi.it/wordpress/missioni/antartide/

…and more recently (2006)…..
2.6m telescope @ COCHISE (Concordia - Dome C)
(Cosmological Observations at Concordia with High-sensitivity Instrument for Source Extraction)
Sabbatini et al., 2010

http://officina.fisica.unimi.it/wordpress/missioni/antartide/

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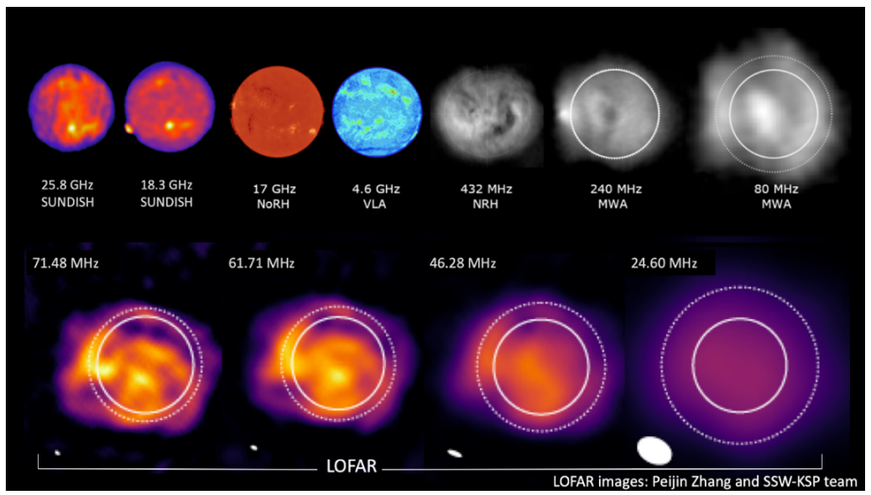
25.8 GHz
SUNDISH
18.3 GHz
SUNDISH
17 GHz
NoRH
4.6 GHz
VLA
432 MHz
NRH
240 MHz
MWA
80 MHz
MWA
71.48 MHz
61.71 MHz
46.28 MHz
24.60 MHz
LOFAR
LOFAR images: Peijin Zhang and SSW-KSP team

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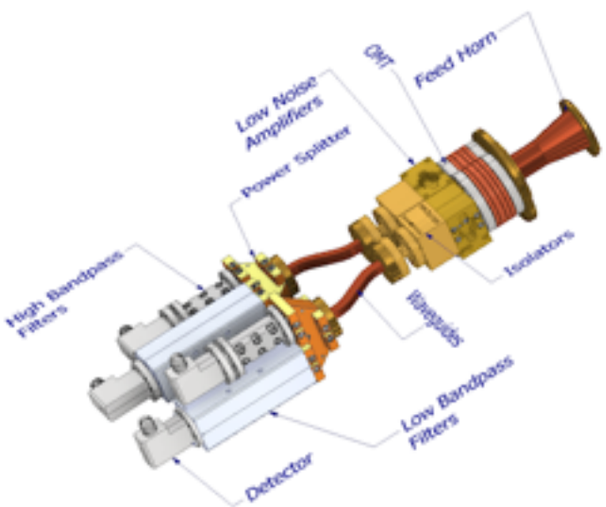
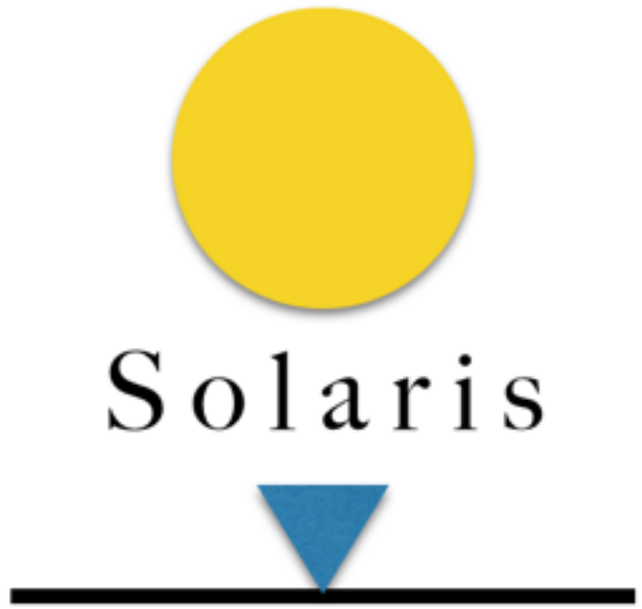

Low Noise Amplifiers
OMT
Feed Horn
Power Splitter
Isolators
High Bandpass Filters
Waveguide
Low Bandpass Filters
Detector

=

Solaris



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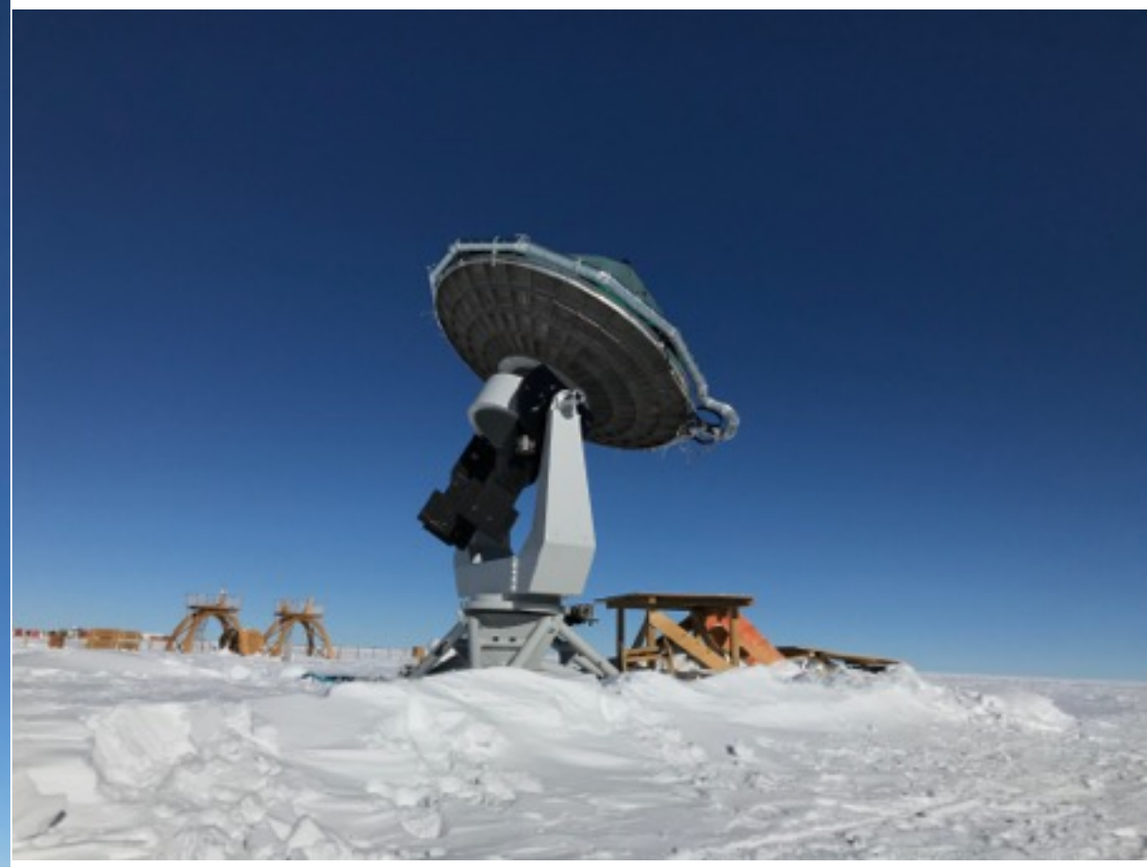
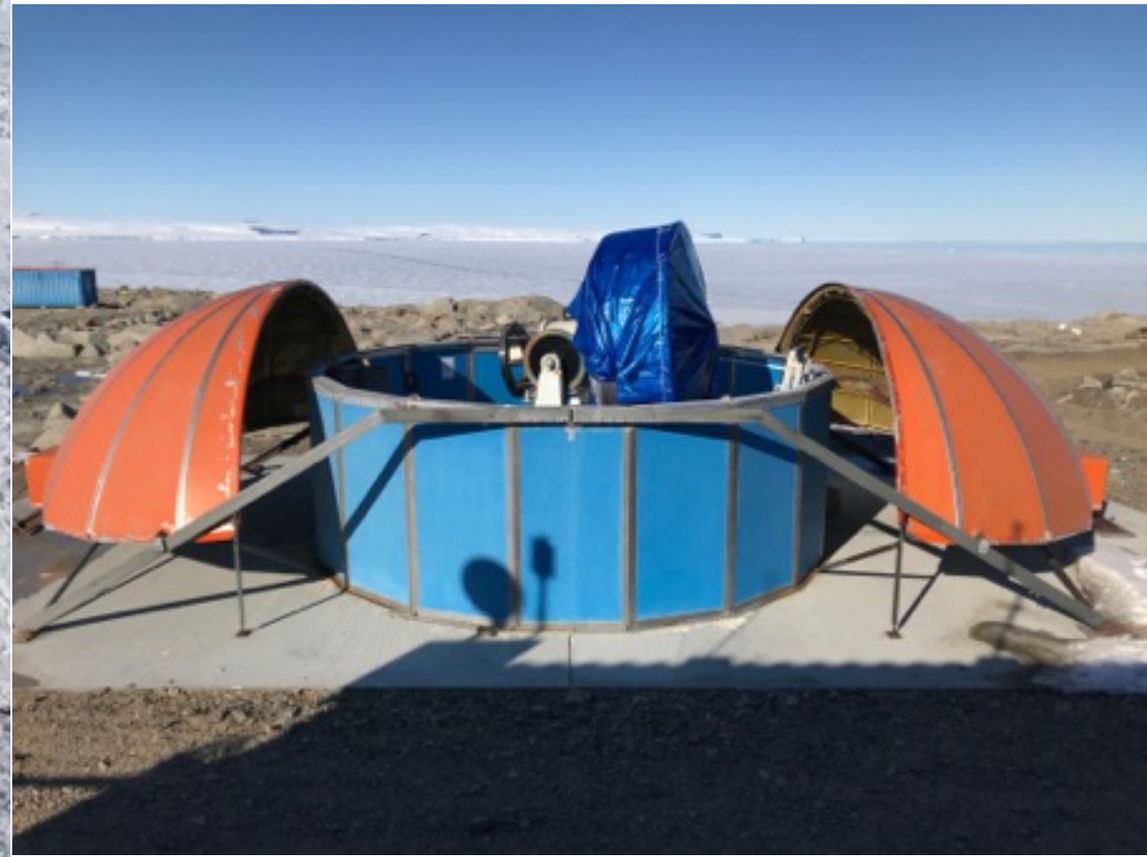




High-frequency radio imaging of large and bright sources is feasible though single-dish observations?

Sardinia Radio Telescope 64m

Medicina 32m

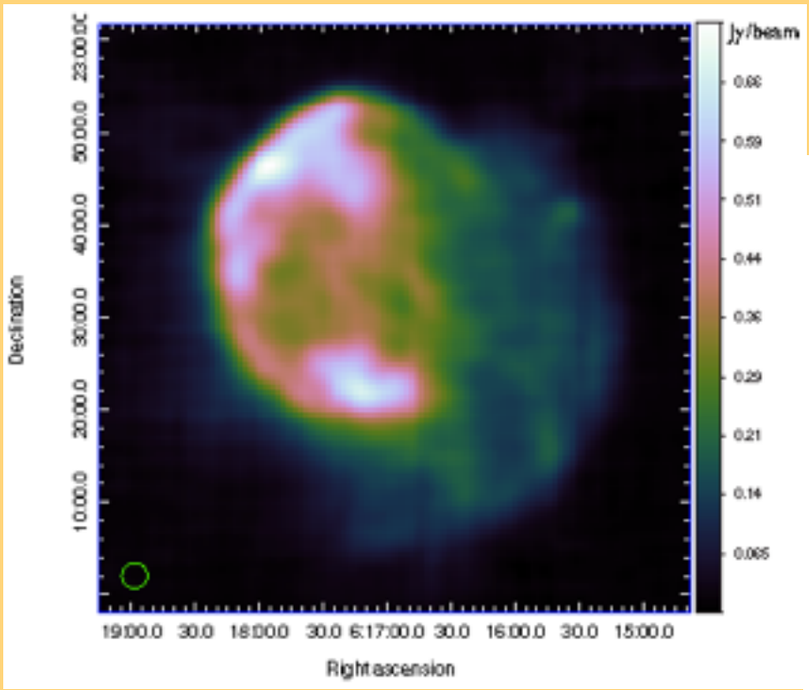
High-frequency radio imaging of large and bright sources is feasible though single-dish observations!

Our group improved On-The-Fly mapping techniques for different classes of Galactic Sources (e.g. Supernova Remnants) using SRT and Medicina radio telescopes.

Is it feasible to observe the Sun with large non-dedicated radio telescopes? YES WE CAN!

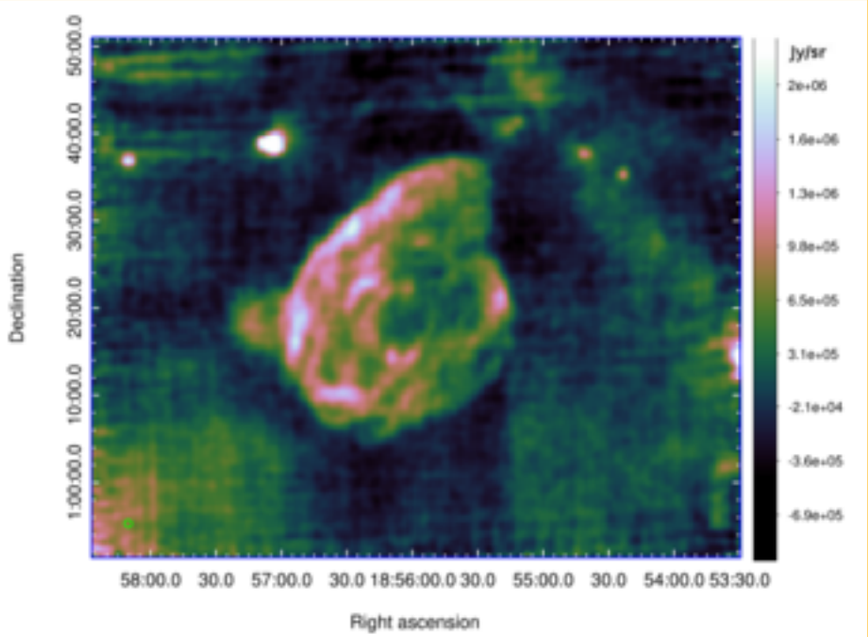
W44, IC443 L/C bands…

Egron, Pellizzoni, Iacolina et al. 2017



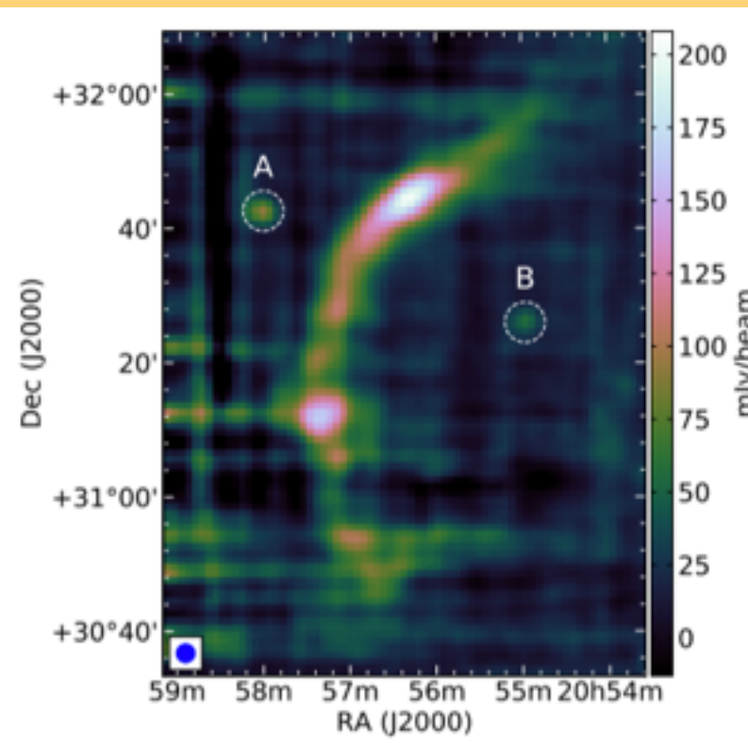
…then multi-feed K band…

Loru, Pellizzoni, Egron et al. 2019



…and new challenges with the Cygnus Loop

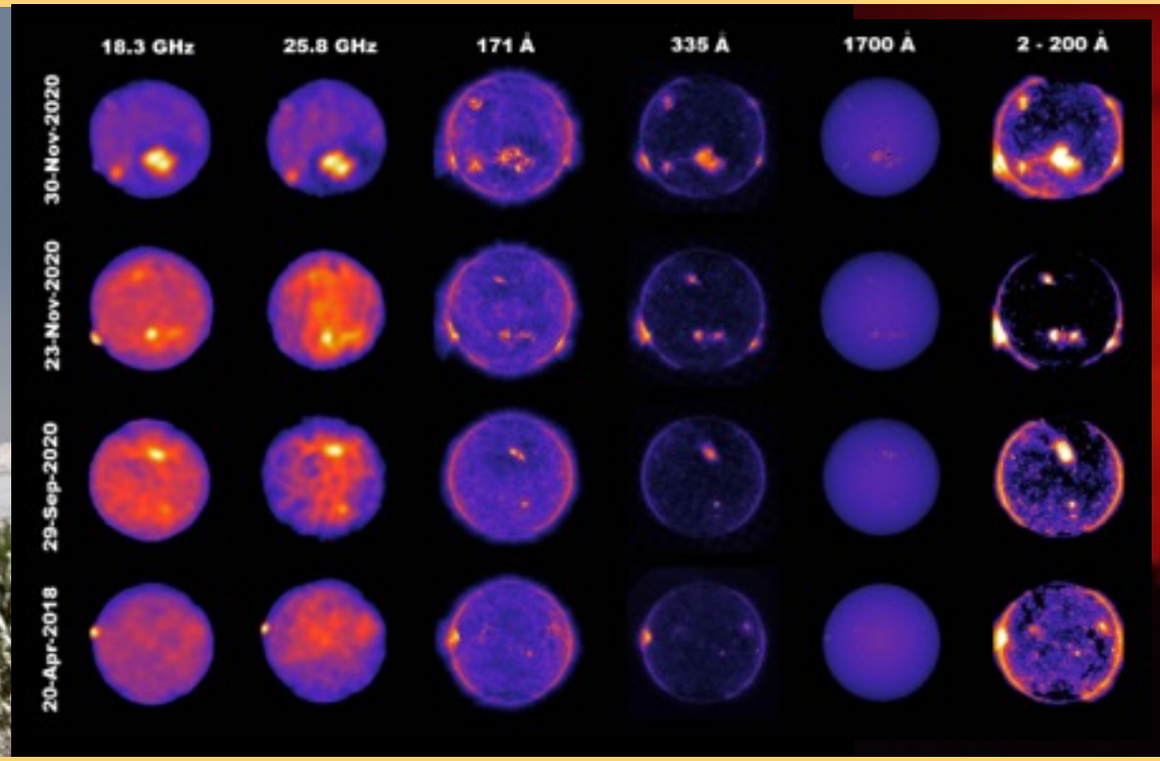
Loru, Pellizzoni, Egron et al. 2021



SunDish project:
Single-Dish Solar radio Imaging with INAF Radio Telescopes

Pellizzoni et al., 2022, Solar Physics (**arxiv.org/abs/2205.00197**)

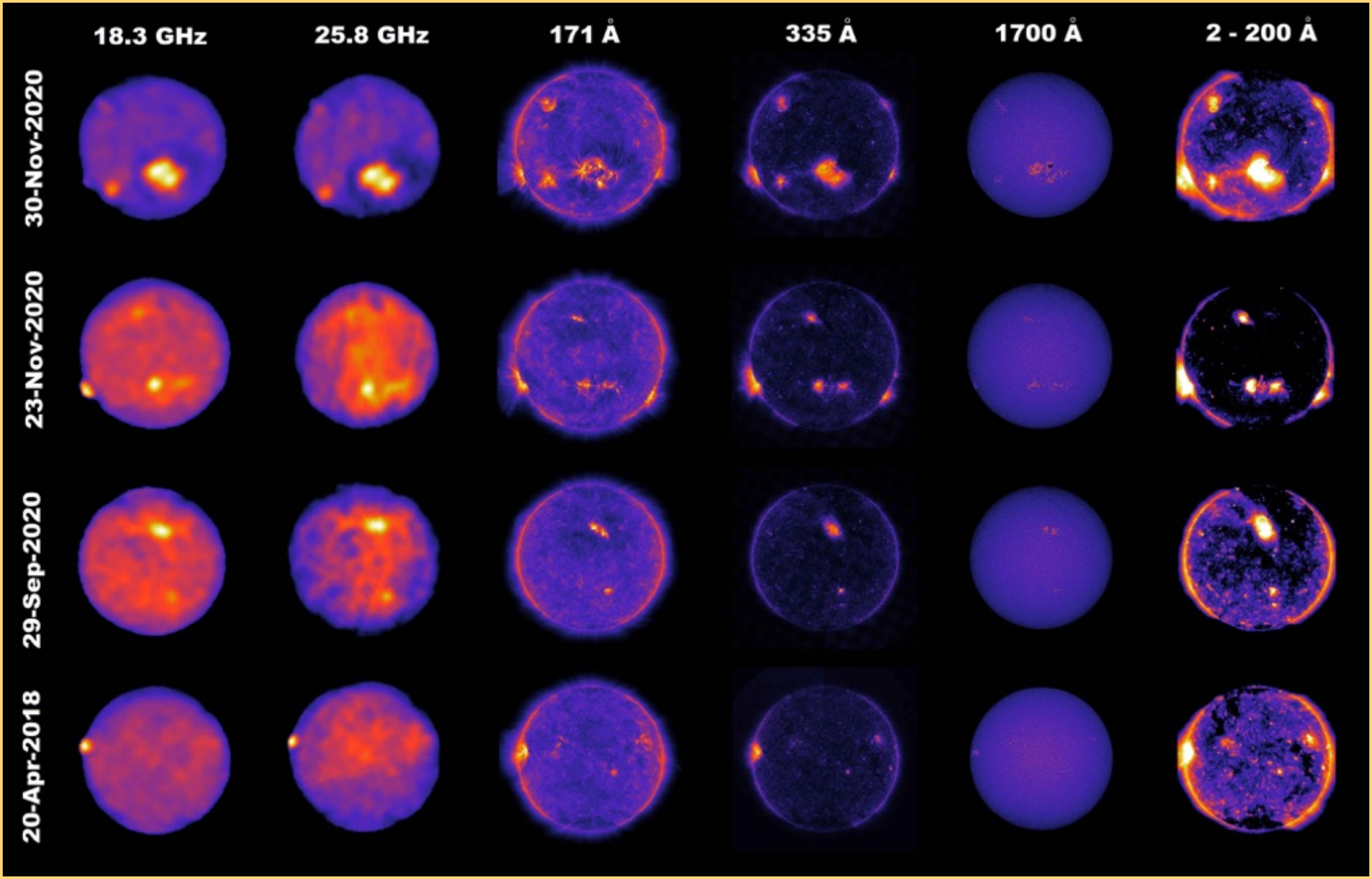
https://sites.google.com/inaf.it/sundish



OAC Osservatorio Astronomico di Cagliari

Agenzia Spaziale Italiana

INAF ISTITUTO NAZIONALE DI ASTROFISICA NATIONAL INSTITUTE FOR ASTROPHYSICS



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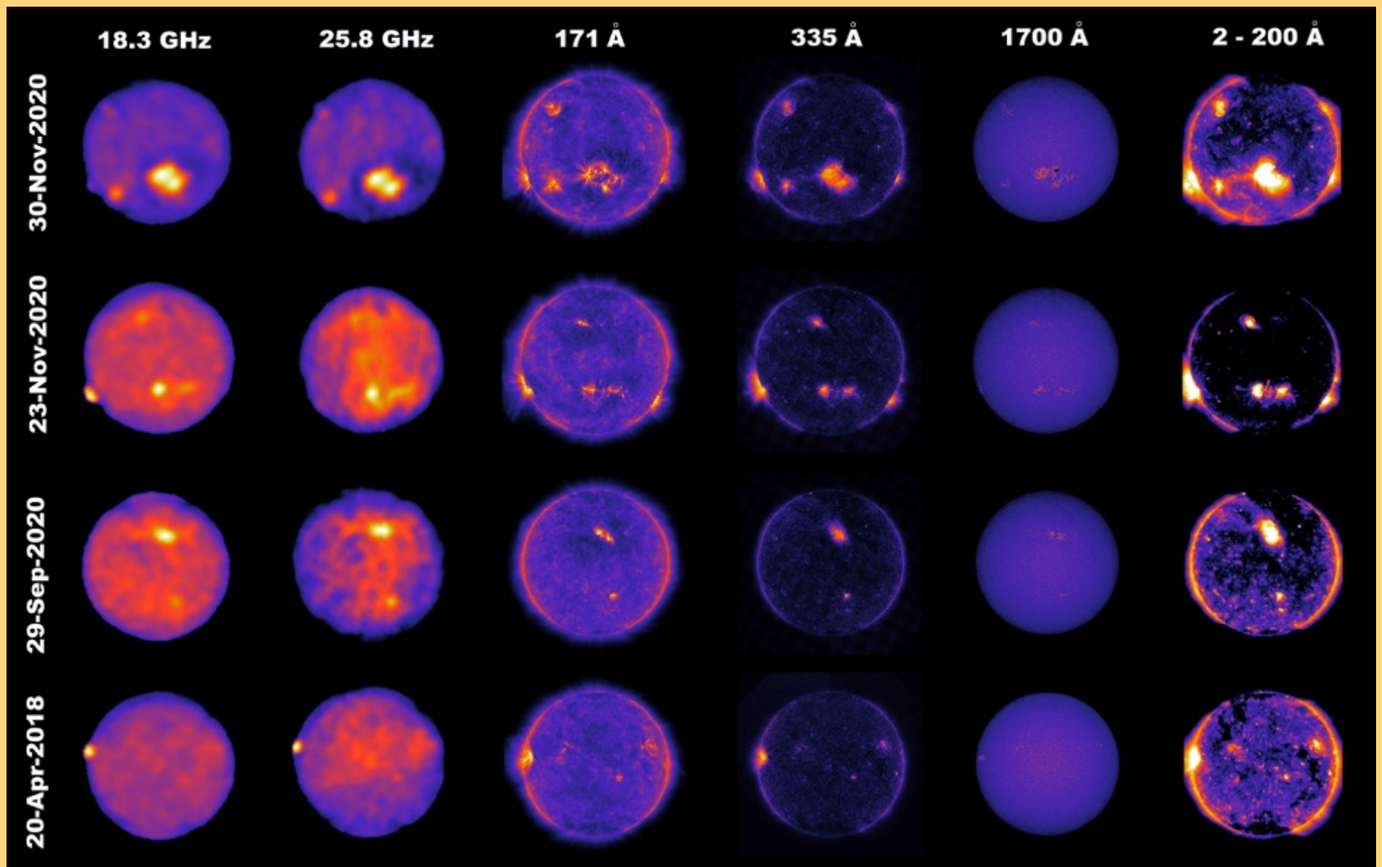
SunDish Project — SUMMARY

- Accurate **mapping of the brightness temperature of the Sun in the 18-26 GHz range** (up to 100 GHz in perspective): **about 300 solar maps obtained so far.**

- Characterisation of the **flux density of the active regions and coronal holes and their spectral properties and evolution.**

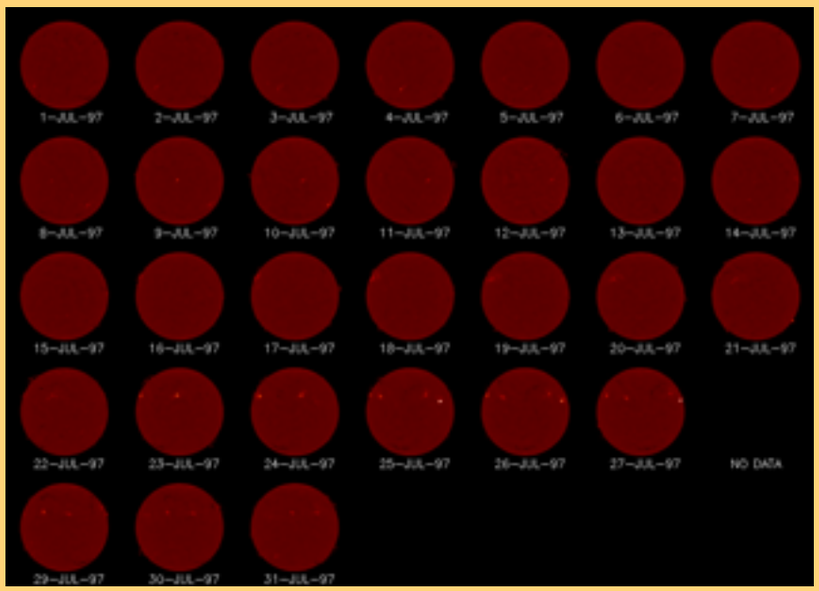
- **Space Weather applications.** Significant spectral variations of solar active regions could be an important factor in predicting powerful flares and coronal mass ejections.

- **Solar radio images and related parameters are published** on a dedicated publicly available web site including project information: ***https://sites.google.com/inaf.it/sundish***

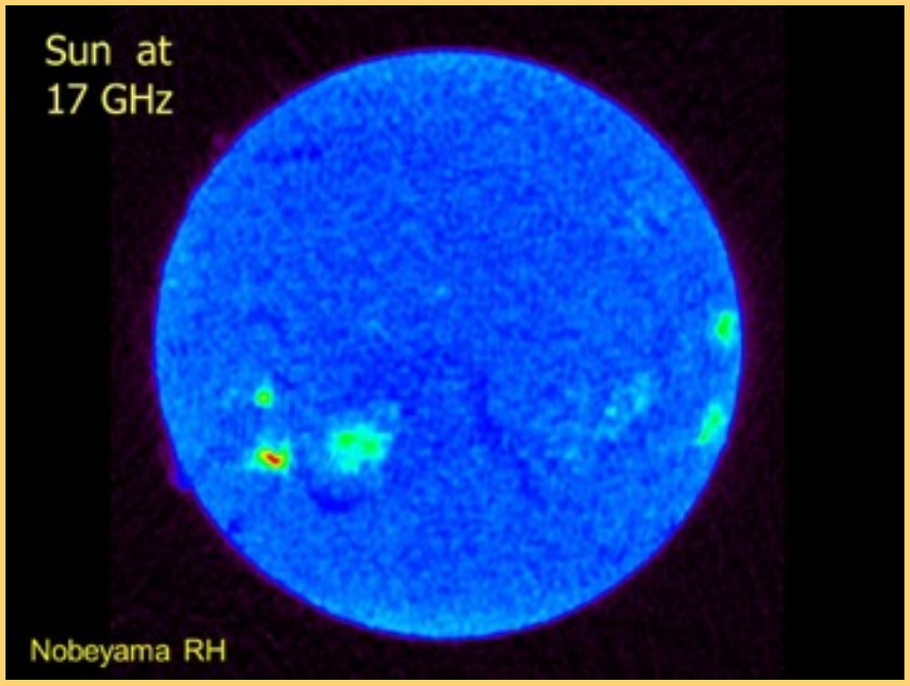


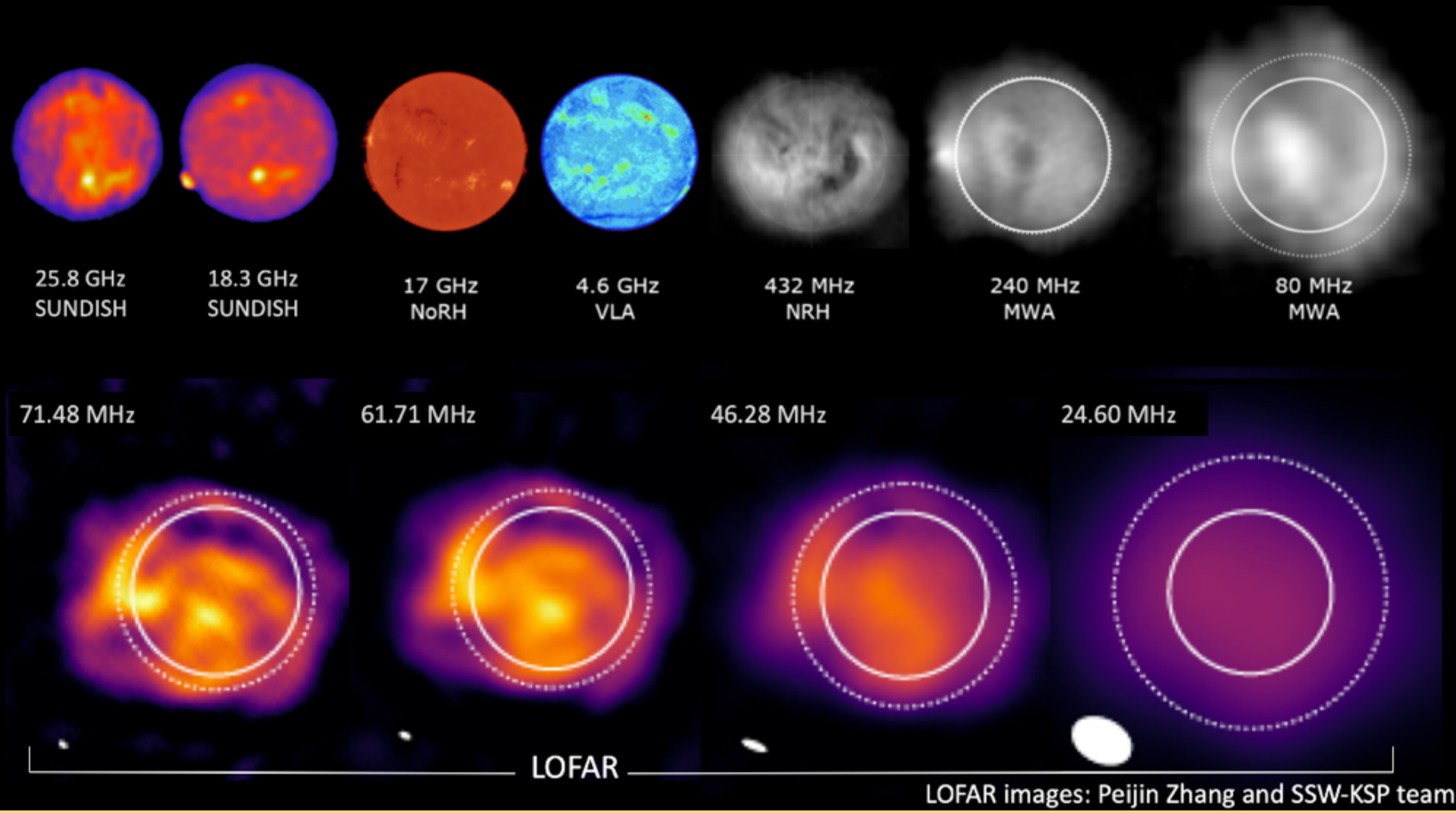
Nobeyama Radio Heliograph imaging at 17 and 35 GHz

…to be compared with SunDish 50’’ resolution at 26 GHz



10’’ resolution

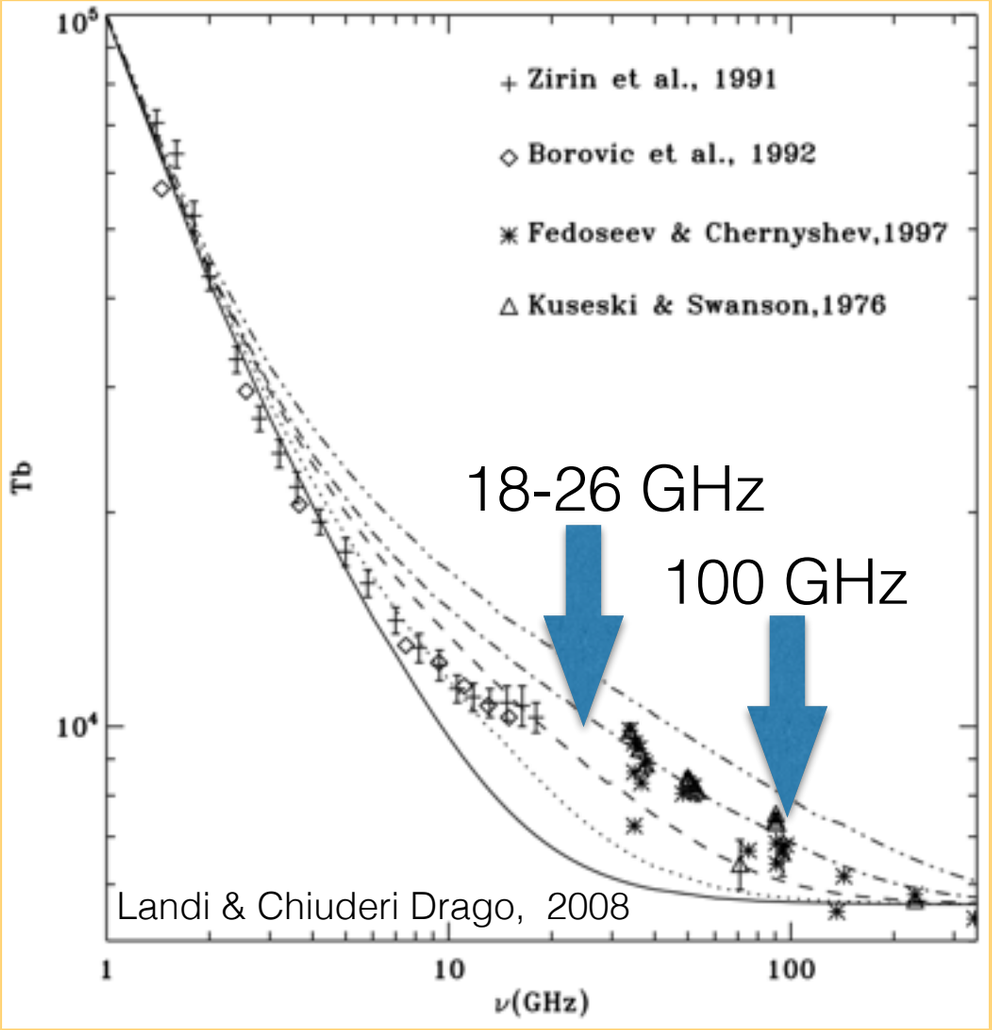




Daily Image @ ASTRON

Single-Dish vs. Interferometric imaging in K-band

- Single-Dish imaging of large structures in the 10-30 GHz is relatively easy and accurate for all resolved spatial scales (no calibration/baselines issues).
- Typically lower sensitivity (mJy) and spatial resolution (arcmin) compared to interferometry.



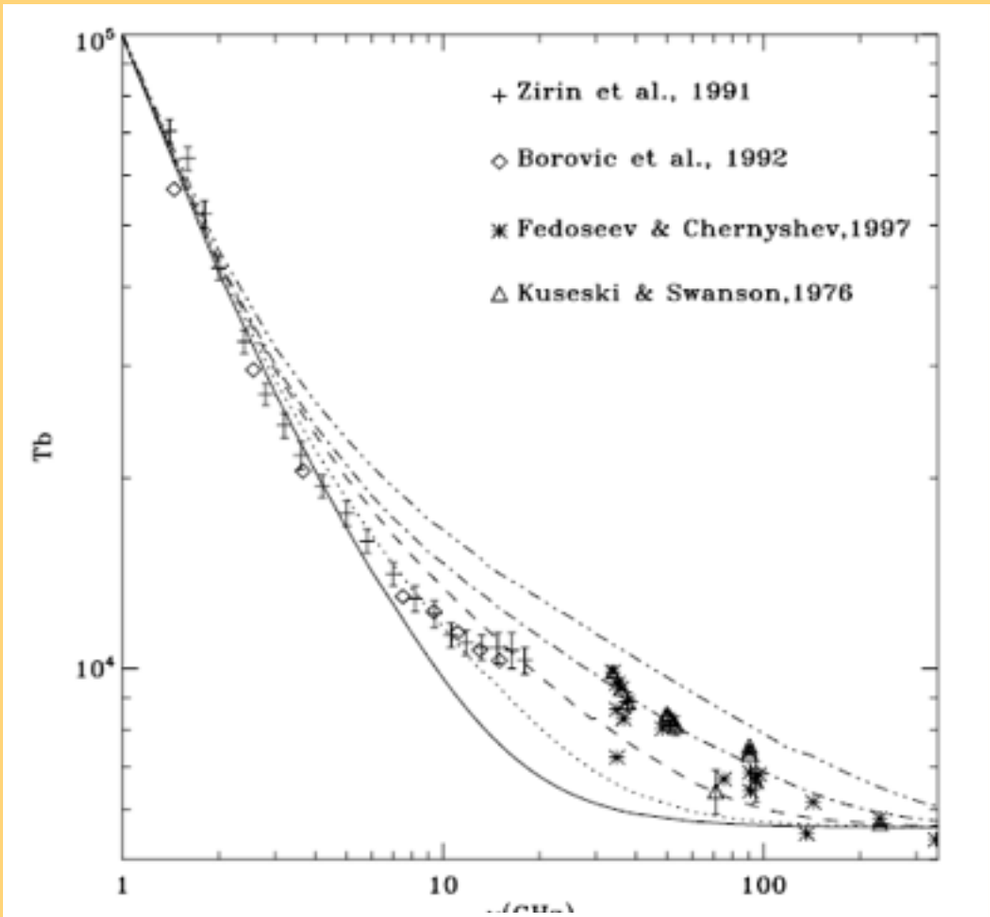
Single dish imaging in K-band is well suited for QS component studies and global monitoring of active regions at arcmin level.

We are providing QS brightness measurements with errors of a few % in the 18-26 GHz range:

18.8 GHz: 10099 +/- 154 K
24.7 GHz: 9799 +/- 268 K
25.5 GHz: 9764 +/- 223 K
Pellizzoni et al., 2022; Mulas et al., 2022

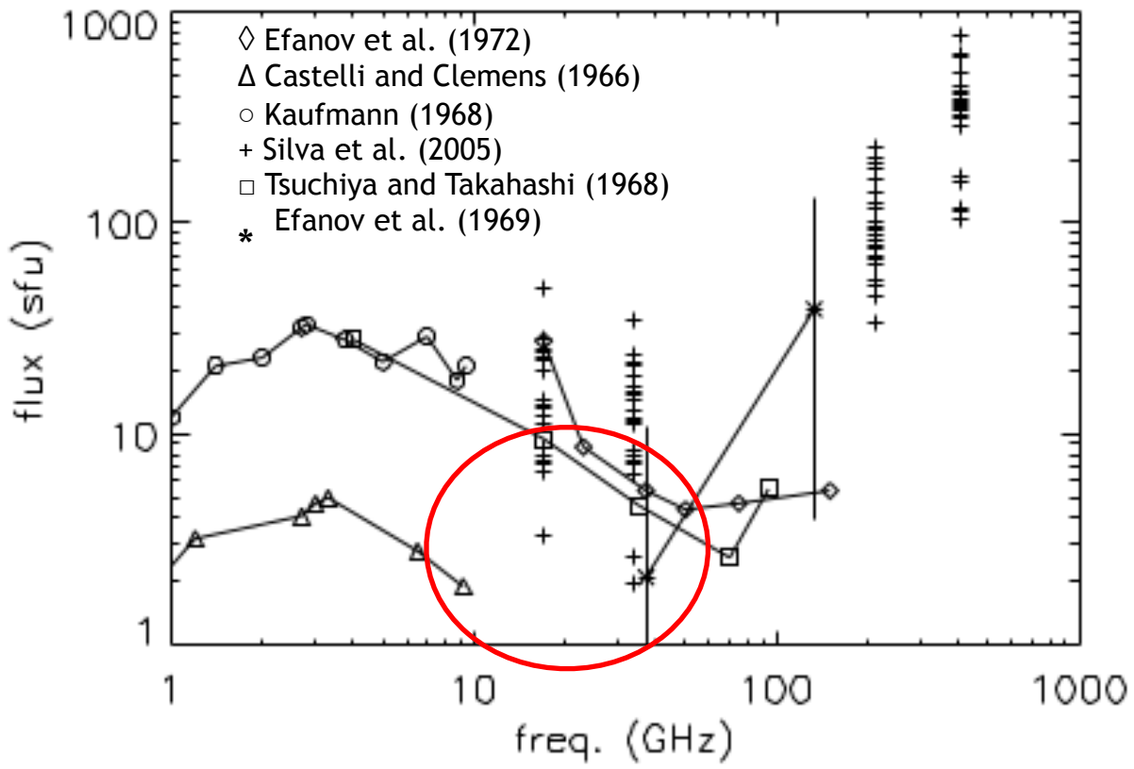
Radio Sun QS and Ars in K-band (18-26 GHz)

Quiet Sun



(E. Landi, F. Chiuderi Drago 2008)

Active regions



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

Spectral index inversion? → Possible prediction tool for energetic phenomena?

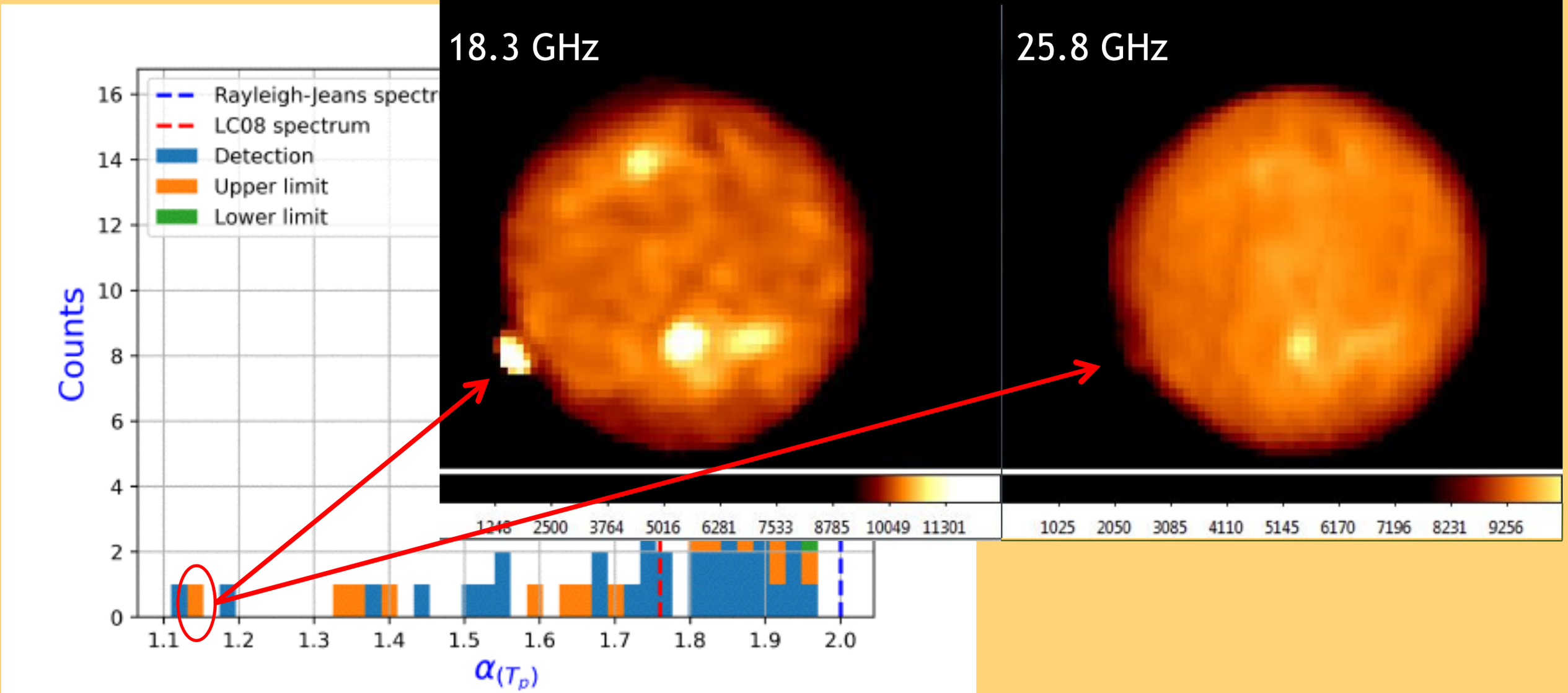
Spectral index

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

S1 flux at frequency v1
S2 flux at frequency v2

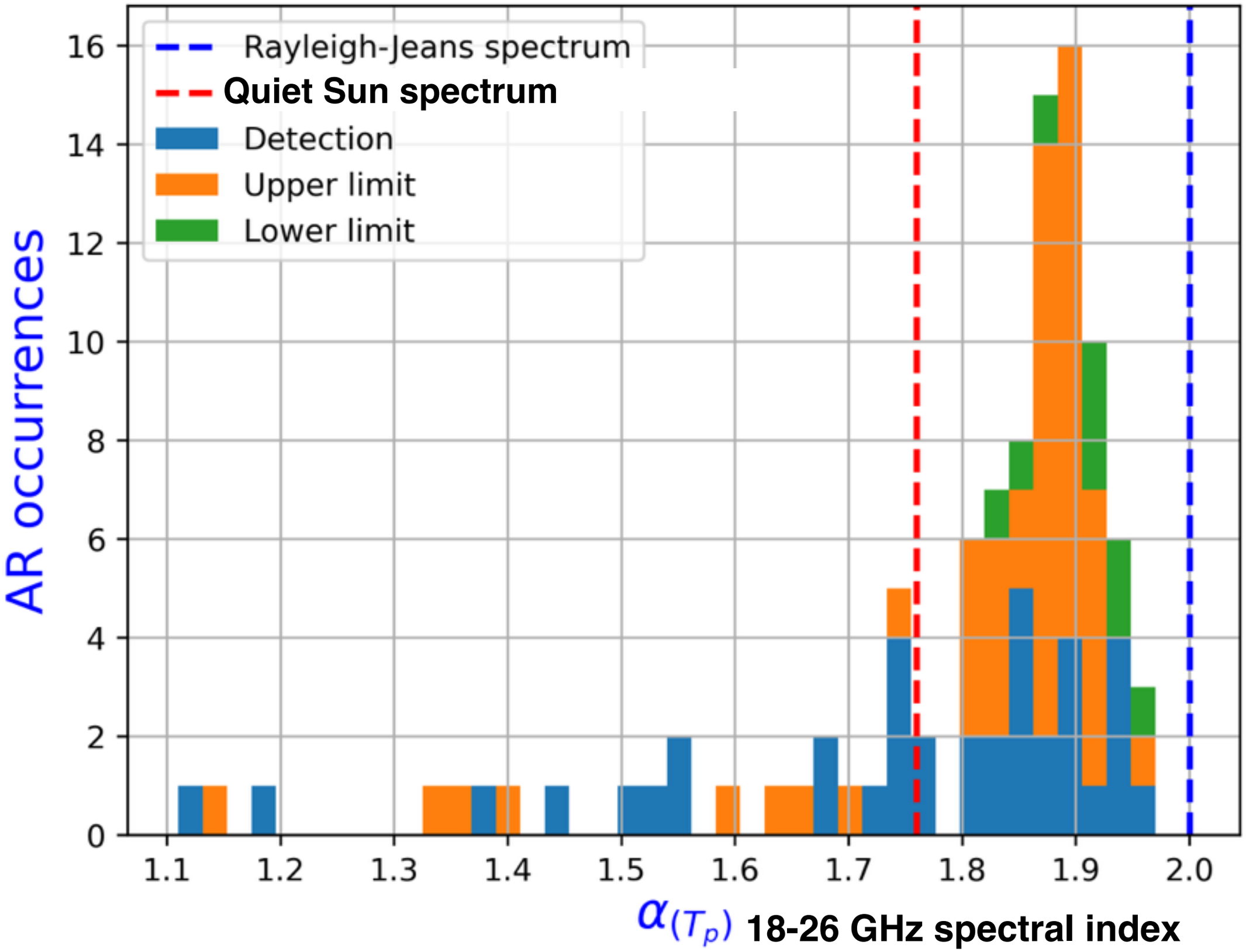
Credits Sara Mulas

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.

Credits Sara Mulas


Rayleigh-Jeans spectrum
Quiet Sun spectrum
Detection
Upper limit
Lower limit
AR occurrences
0
2
4
6
8
10
12
14
16
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
$\alpha_{(T_p)}$ 18-26 GHz spectral index

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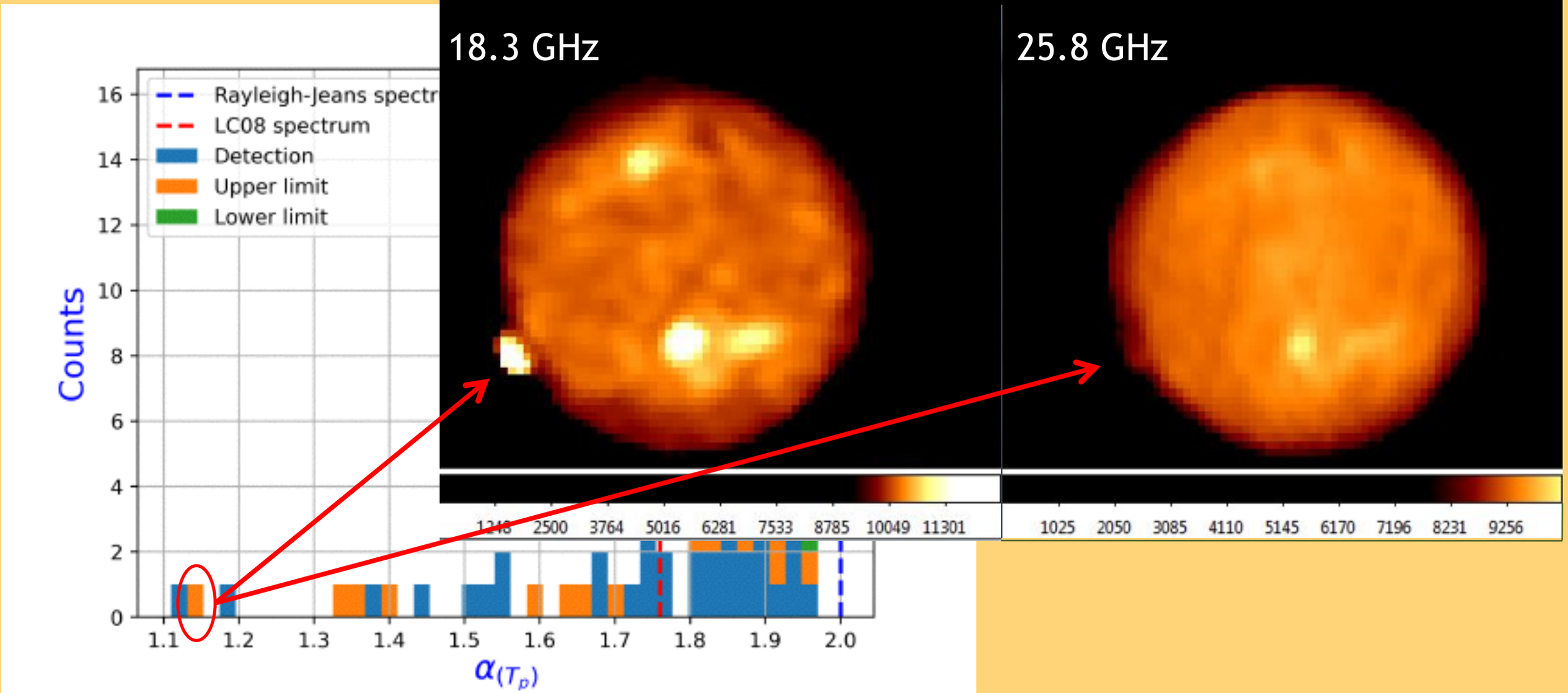

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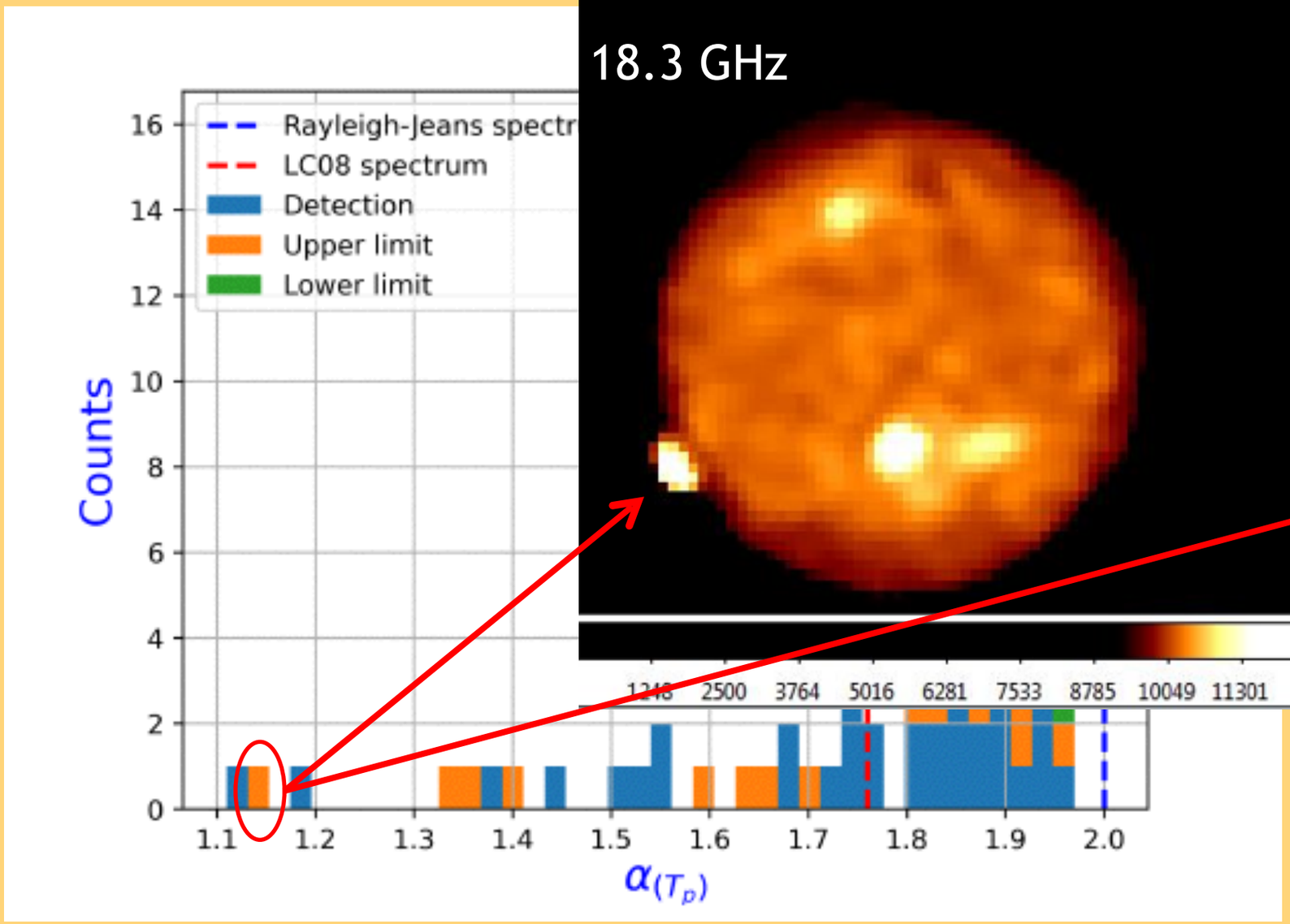

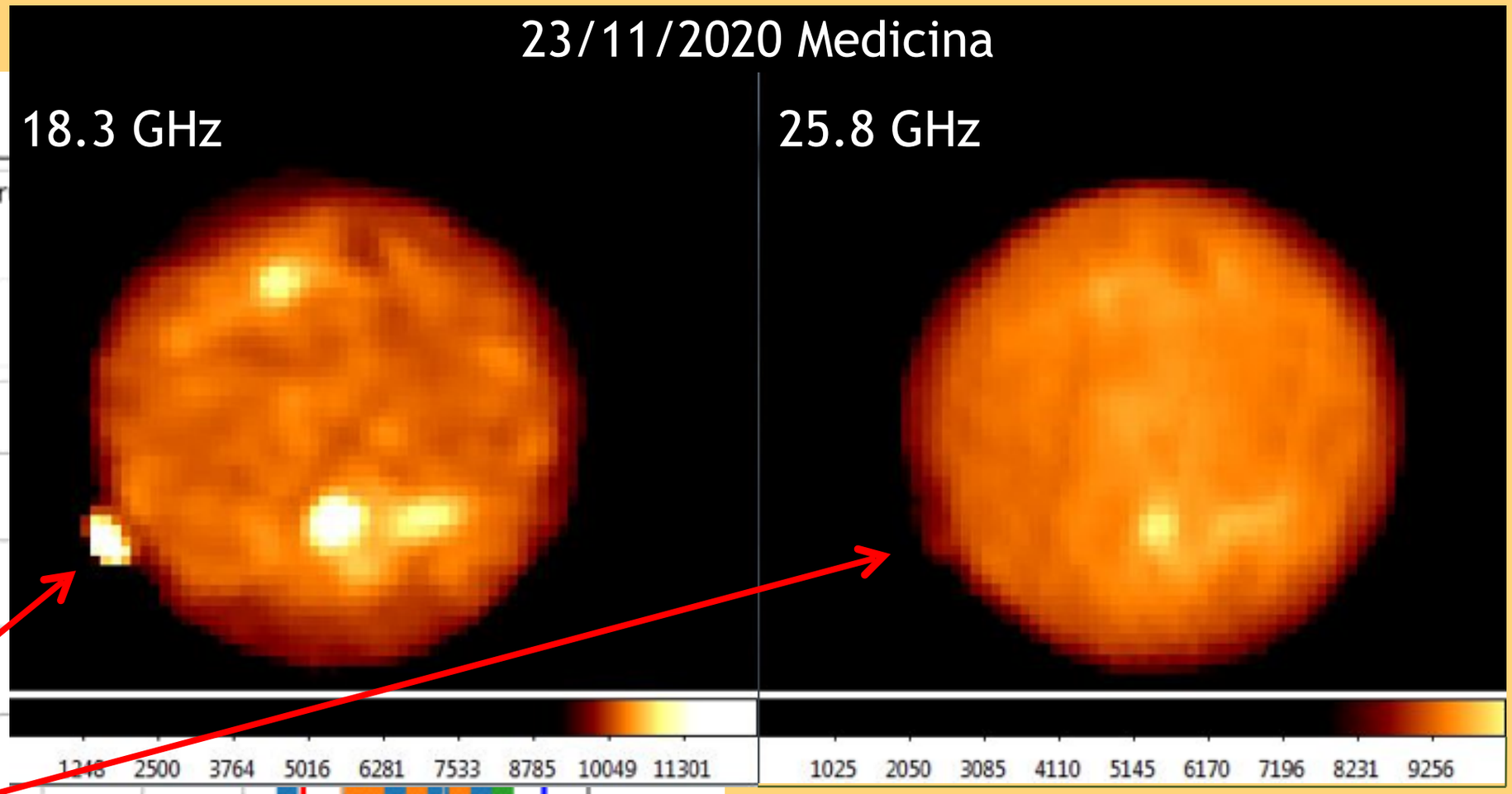

A flare originated from the AR few hours later.
Strong gyro-magnetic emission contribution?

Credits. Sara Mulas

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

Perspectives:

- Data analysis: solar radius, coronal holes, polar brightnening, quiet-sun, …
- Science and Space Weather applications: Active Regions spectral status vs. flare occurrences.
- Full-stokes polarimetric imaging.
- New receivers: X (8-9 GHz), K (25.5-27 GHz), Ka (31-33 GHz), Q(33-50 GHz), W(75-116 GHz).
- Synergies with LOFAR-IT and the other INAF assests.
- NEED FOR CONTINUOUS MONITORING & GOOD WEATHER —-> Solaris !

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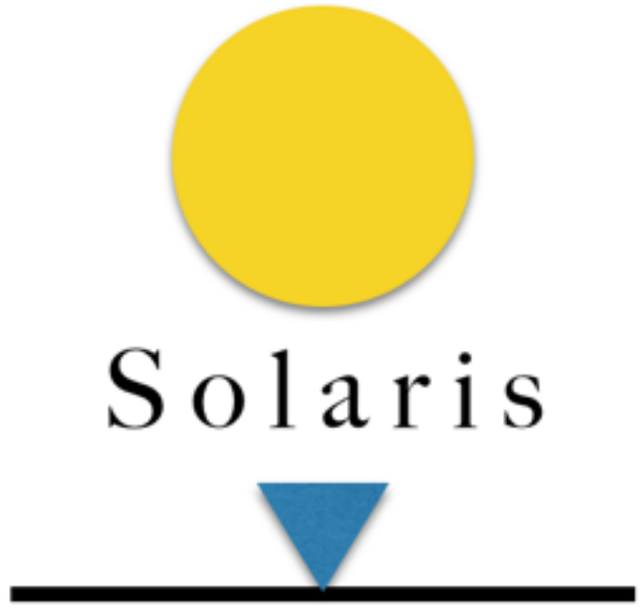

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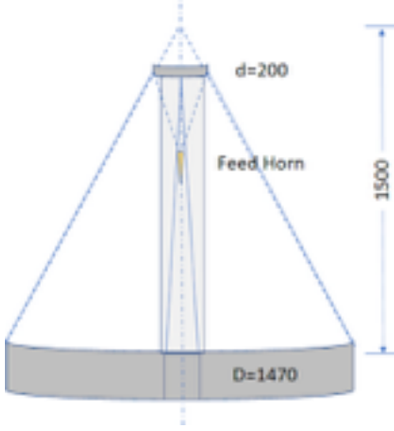

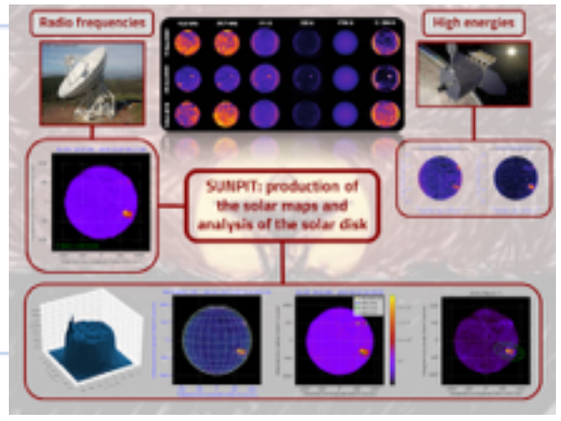

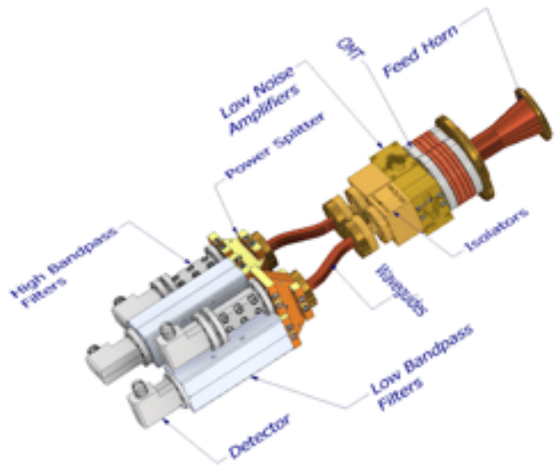

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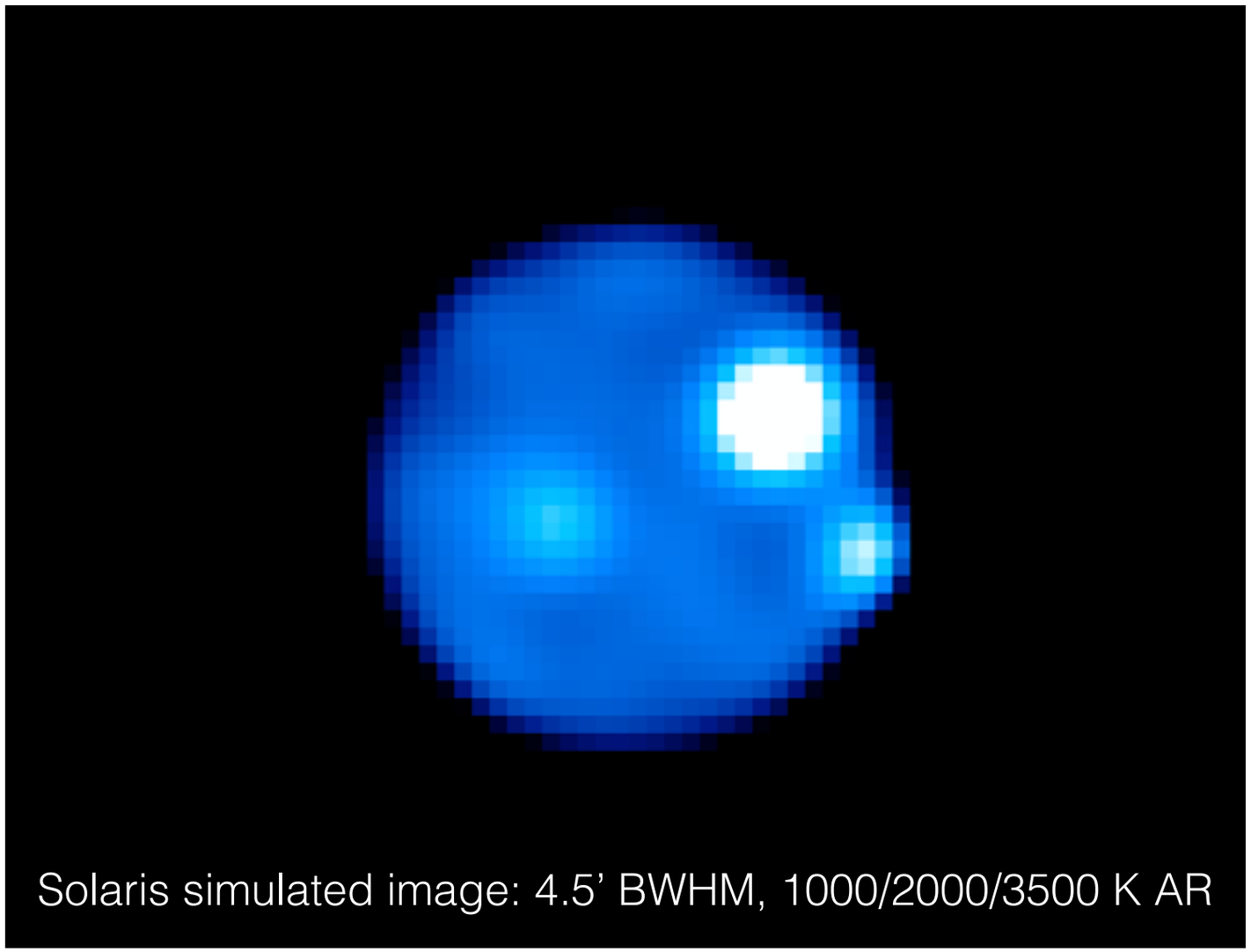

Solaris simulated image: 4.5’ BWHM, 1000/2000/3500 K AR

24h/day monitoring during Antarctic summer!

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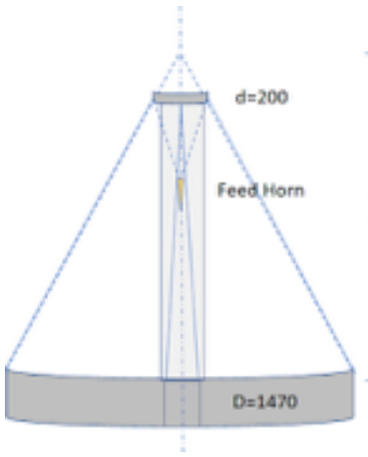
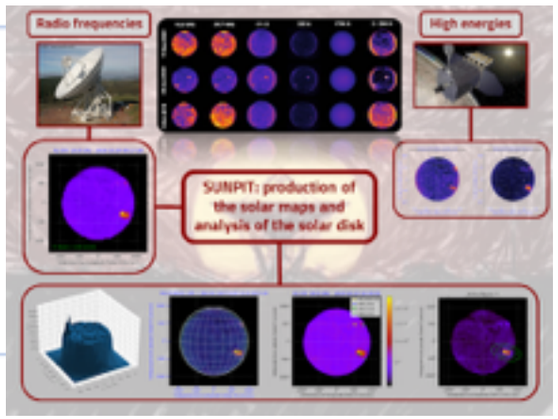
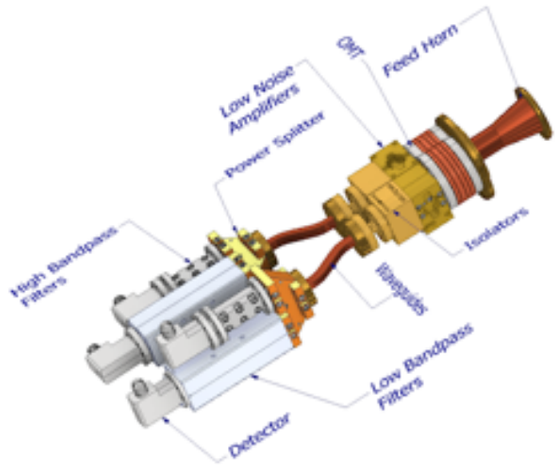






Solaris

Main Scientific Goals & Applications:

- Unprecedented continuous solar monitoring at high radio frequency in optimal observing conditions (sky opacity & visibility).

- Constraining purely non-thermal emissions in the Quiet Sun and Active Regions components.

- Active Regions flux and spectral variability monitoring.

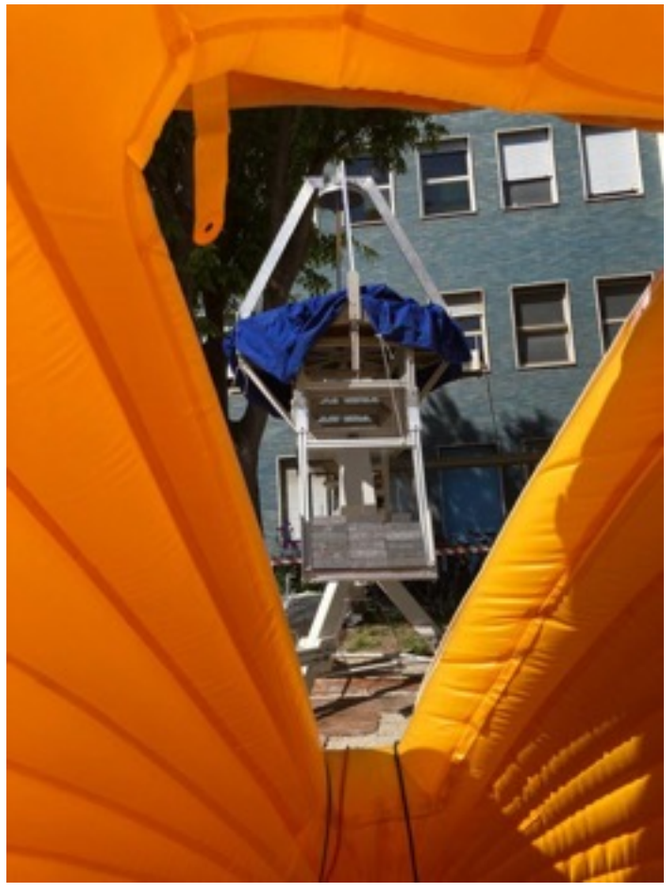
- Solar Flares detection and observations.

- Study of Flare precursors (Space Weather Forecast).

- Trigger for high-resolution follow-ups with other facility (including “zoom-in” with SRT 64m)

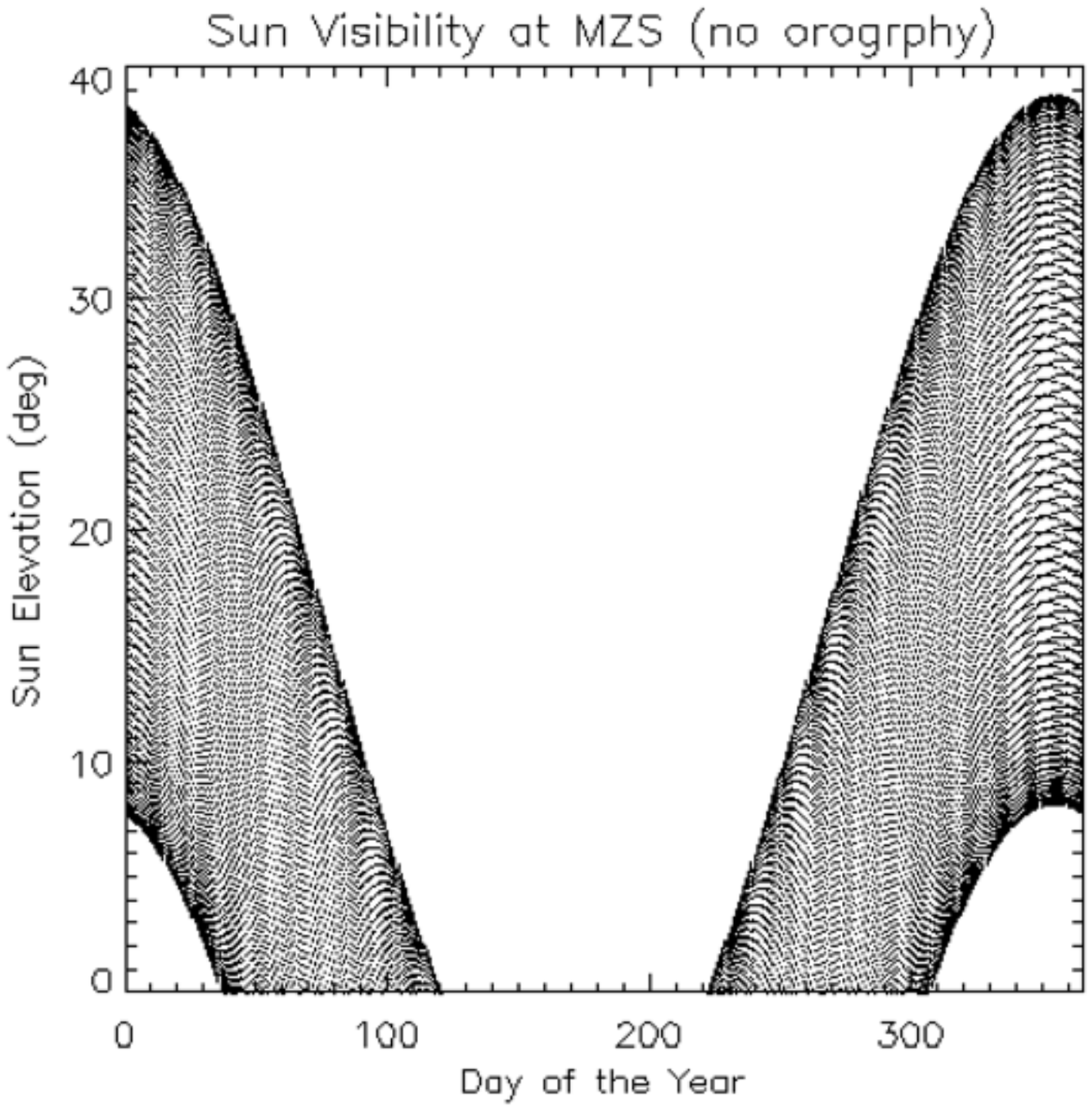
Solaris

Solaris Prototype (1.5m, UNIMI, Italy)

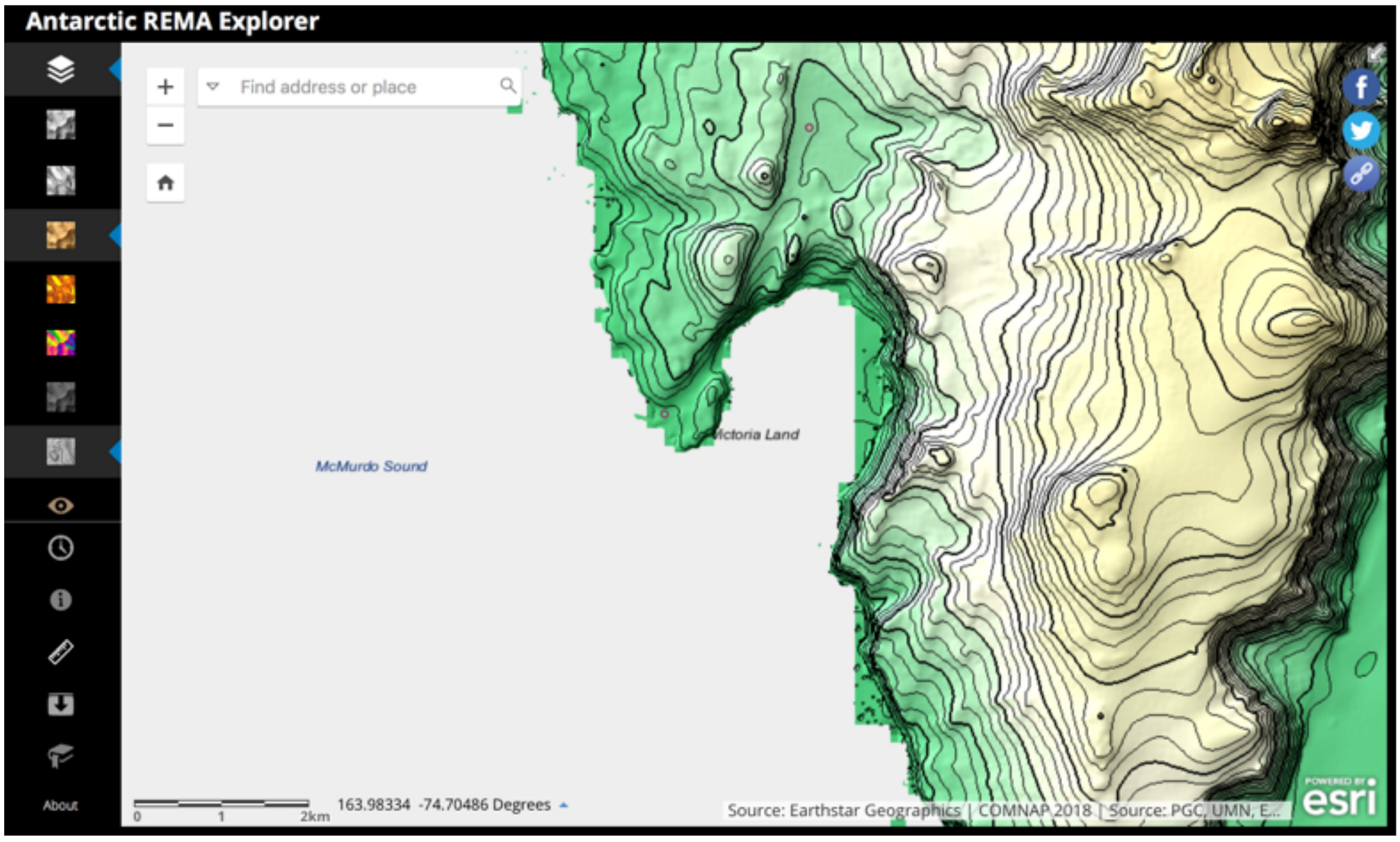


Great Sun Visibility at MZS & Concordia in Antarctica!

>0 deg el.: 179 days
>10 deg el.: 113 days



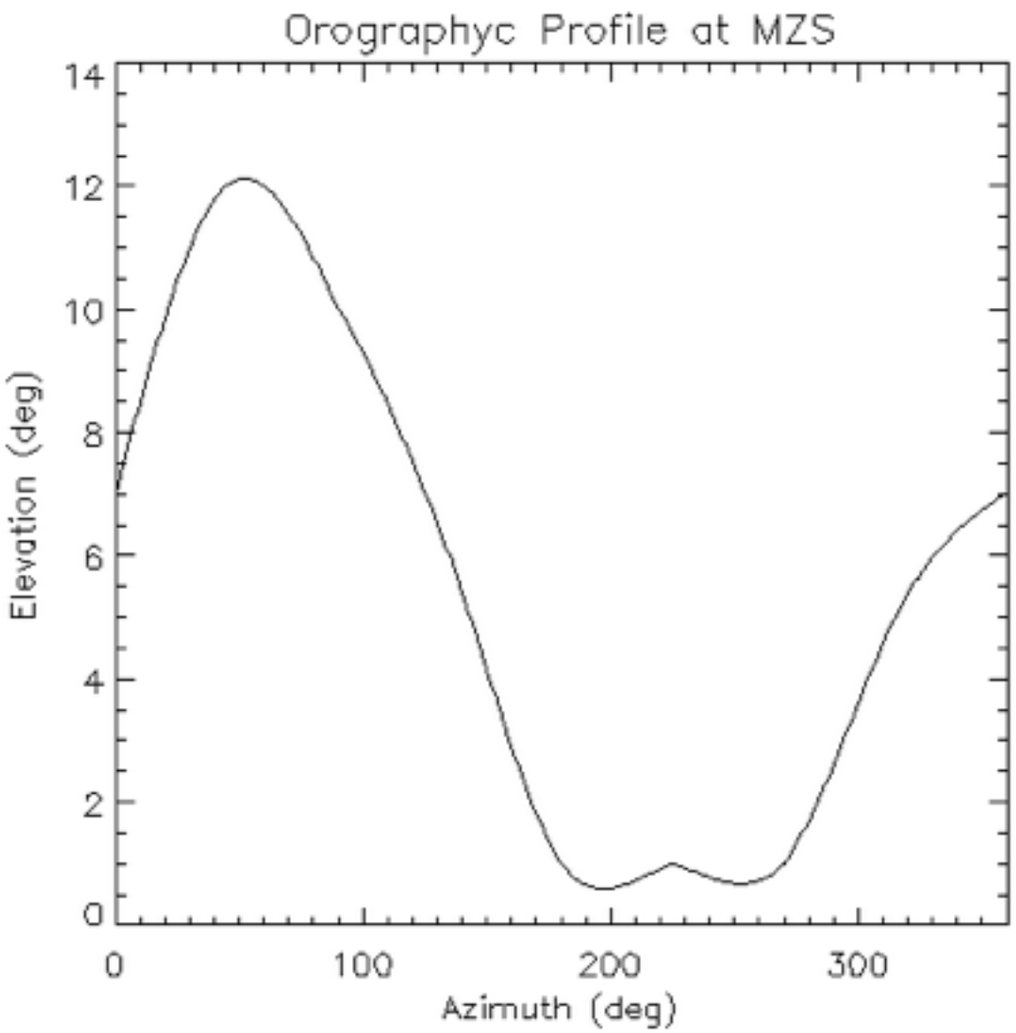
Reference Elevation Model of Antarctica (REMA)

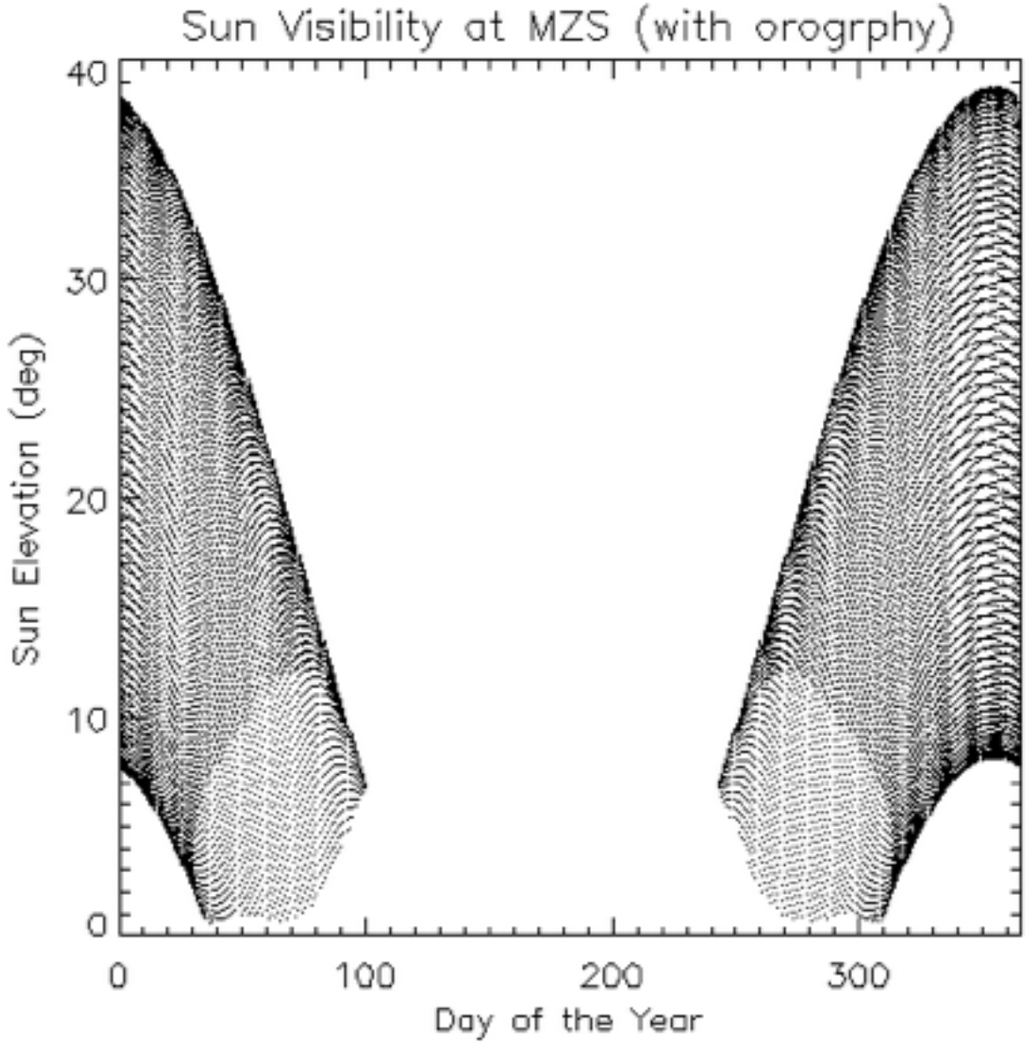


https://www.pgc.umn.edu/data/rema/

PRELIMINARY!

148 days (nov.-feb.)



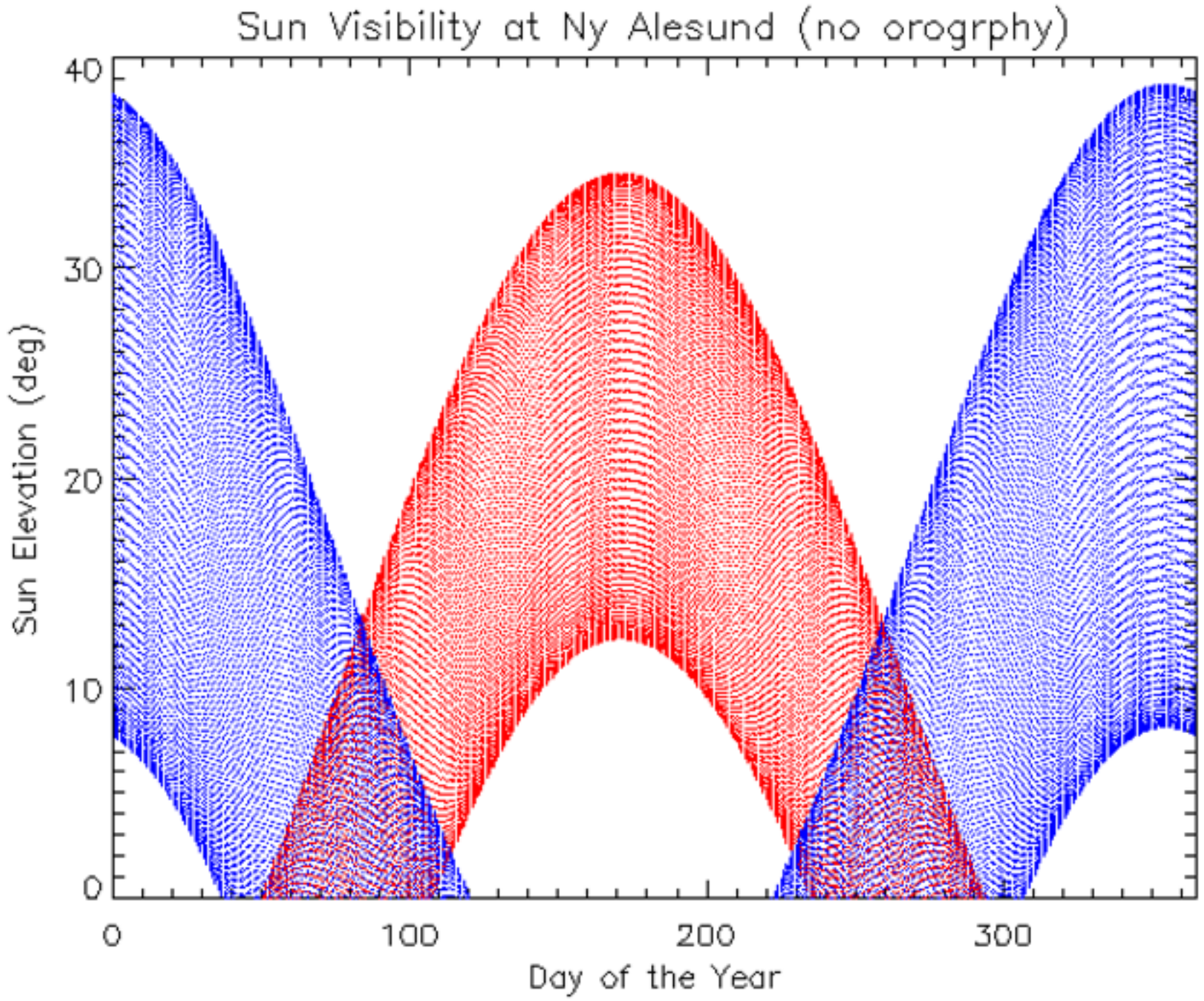


Arctic, Ny Alesund (Svalbard, Norway)

Radiotelescope(s) (Geodesy, VLBI): https://archello.com/project/earth-observatory

CNR facility: https://www.isac.cnr.it/it/node/13369

MOSE @ MZS
MOSE @ Ny Alesund



SOLARIS: a smart Solar imaging system at high radio frequency for continuous Solar monitoring and Space Weather applications

Solaris

Solaris Program

Solaris Prototype
(1.5m, UNIMI, Italy)

testing phase
mostly "reusing" existing instrumentation

Solaris in Antarctica
(2.6m, PNRA, MZS, Concordia)

approved by PNRA
as permanent observatory,
exploiting existing
on-site radiotelescopes

Solaris Alpine
(2.6m, CNR, Testa Grigia Mountain, Italy)

exploiting existing
on-site radiotelescope.
Best site for R&D

Solaris North
(Norway? Sweden?)

from scratch? Or using 1.5m prototype

…and when it is night in winter time?

Solaris “by night”?
Radio transient monitoring

Solaris

Solaris Program Summary

- Unprecedented continuous solar monitoring at high radio frequency in optimal observing conditions (sky opacity & visibility).

- Multi-messenger/Multi-disciplinary applications (not just an astronomical tool!).

- In perspective h24/365 days high-frequency solar monitoring.

- Space Weather Forecast and Nowcasting.

- A leap forward in the study of Earth-Sun connection

Solaris

Thank You!