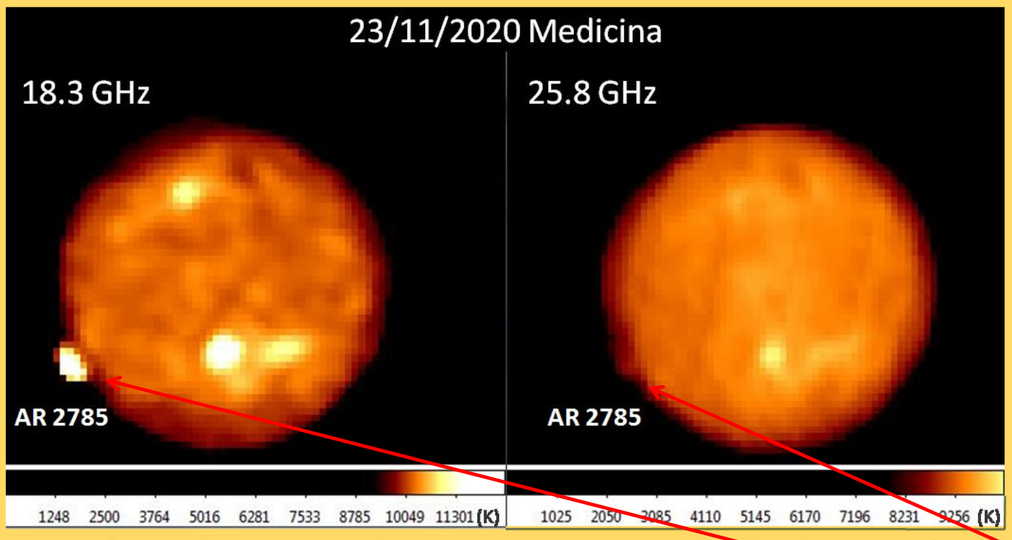
Exploring the variable spectra and magnetic fields of the Active Regions in the chromosphere through high-frequency radio imaging: gyro-resonance emission and flare forecasting

S. MULAS [1], A. PELLIZZONI [1], S. RIGHINI [2], M. MARONGIU [1], A. MARCUCCI [3]

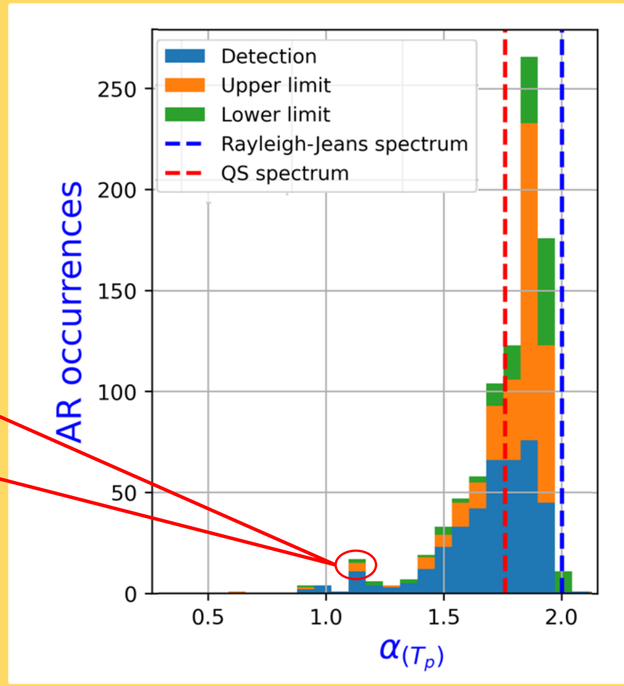
[1] Istituto Nazionale di Astrofisica (INAF) – OAC, [2] Institute of Radio Astronomy (IRA), [3] Aeronautica Militare (Centro Nazionale di Meteorologia e Climatologia Spaziale)

High-frequency radio observations with large single-dish radio telescopes of the INAF network, in the context of the SunDish project, provided ~450 solar images since 2018, useful to monitor the vertical structure and physical conditions of the solar chromosphere both for quiet and active regions, during their evolution at different phases of the solar cycle. Solar radio mapping in K-band (18-26 GHz) can probe the chromospheric magnetic field of the Active Regions (ARs) through the detection of gyro-resonance spectral components related to flare events. Enhanced magnetic fields determine a spectral flattening in the ARs compared to pure free-free emission. When this sporadic anomalous AR spectrum is detected, the probability of a strong flare occurrence within 1-2 days is >80%, further rising at >90% also requiring that AR brightness temperature exceeds ~50% the quiet Sun level.

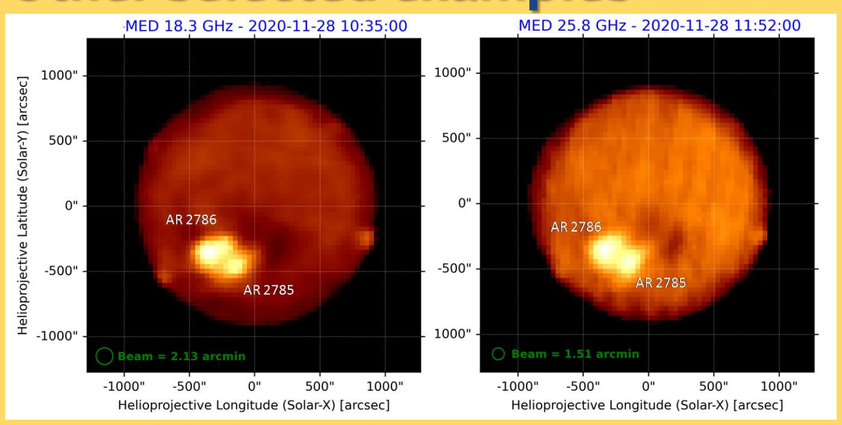
The SunDish is a project devoted to investigate and produce single dish radio maps of the solar atmosphere at high radio frequencies, up to 100 GHz in the future, with the Sardinia and Medicina radio telescopes (Pellizzoni et al, 2022). In the K-band (18-26 GHz) we are able to probe the chromospheric layer and its main features. This work is focused on the study of the Active Regions (ARs) and their spectral indexes (α) Between 2018 and 2023 we analysed more than 900 spectral index values (illustrated in the histogram). The majority (~85%) are compatible with a free-free type emission, while the rest present a peculiar softer α. We interpret this emission as thermal bremsstrahlung components combined with gyro-magnetic variable emission. In the example depicted above, we have two images taken with the Medicina radio Telescope at 18.3 and 25.8 GHz on the 23 November 2020. The AR 2785 presented a low value of α and few hours later a C4.3 flare originated from the same AR. From this case we started to investigate if the enhanced gyro-magnetic emission of the ARs, coupled with the peculiar α values, could be used as a precursor factor to flare occurrences. We compared our data with different flares catalogues to match the events (Plutino et. al, 2022, 2024; A. Ursi et al., 2023).



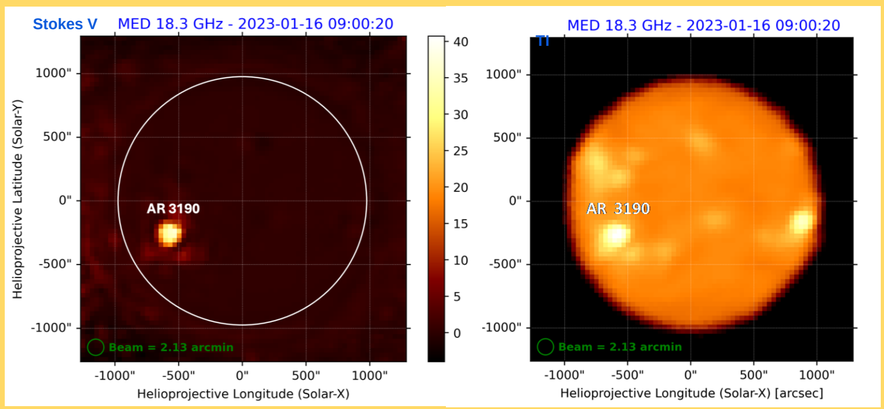
Histogram of the spectral index values calculated from the ARs maximum brightness temperature Tp.



Other selected examples



On 28 November 2020 we observed the Sun with the Medicina radio Telescope at 18.3 and 25.8 GHz. We observed a very soft spectrum in AR 2786 and an α compatibile with a Rayleigh-Jeans type emission in AR 2785. As in the previous example, a few hours later a cluster of C-class flares originated from AR 2786 with the peculiar α, while AR 2785 did not present significant activity in the previous or next few days. With our data, we are also able to extract information on the Stokes V parameter. We observed that the ARs with a flatter spectral index and a stronger gyro-magnetic emission, show on average a higher circular polarization compared to the ARs with a prominent free-free emission. Among all the data we analysed, AR 3190 in the solar map on 16 January 2023 exhibited the highest polarization percentage (>36%). A flare of M4.8 class took place a few hours (<20 hours) earlier from the same region. Through the polarization measurements, we estimated the intensity of the magnetic field as a few thousands Gauss.



Statistical analysis between anomalous spectral index values and flare occurrences

We obtained a high level of correlation between these spectra and the energetic events. The probability of a strong flare occurrence within 1-2 days of the observation is ~86%. Moreover, we have a low percentage of missed events (~1%) and false alarm (ARs with a peculiar α that did not host an energetic event ~10%). The combination of the relevant parameters for flare prediction can improve the forecast performances. If we couple the spectral information with the requirement of a strong AR peak brightness (>15500 K), the probability of a strong flare occurrence rises to more than 90%. However part of the strong flares would be missed. The inclusion of the Stokes V in a more complex index could be considered, although the circular polarization intensity is also related to geometrical and line-of-sight issues.

	Predicted Positive	Predicted Negative
Actual Positive	TP = 99	FN = 13
Actual Negative	FP = 12	TN = 816

Confusion Matrix obtained with our data. The cases are divided in four categories: True Positive (TP), False Negative (FN), False Positive (FP) and True Negative (TN)

By studying the chromosphere in the radio band, we were able to find that the spectra of the Active Regions can be used as a precursor factor to the high class flare occurrences. We obtained a high level of positive correlation between the α and the explosive events, with a low chance of missing a relevant event. With more frequent observations, at least one per day in double frequency, this method could be used as a forecast tool in the Space Weather field and hazard prevention.

Contacts
Sara Mulas
sara.mulas@inaf.it
Alberto Pellizzoni
(project SunDish PI)
alberto.pellizzoni@inaf.it