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# STUDY OF SOLAR BRIGHTNESS PROFILES IN THE 18 - 26 GHZ FREQUENCY RANGE WITH INAF RADIO TELESCOPES: EVIDENCE FOR CORONAL EMISSION

**Speaker**
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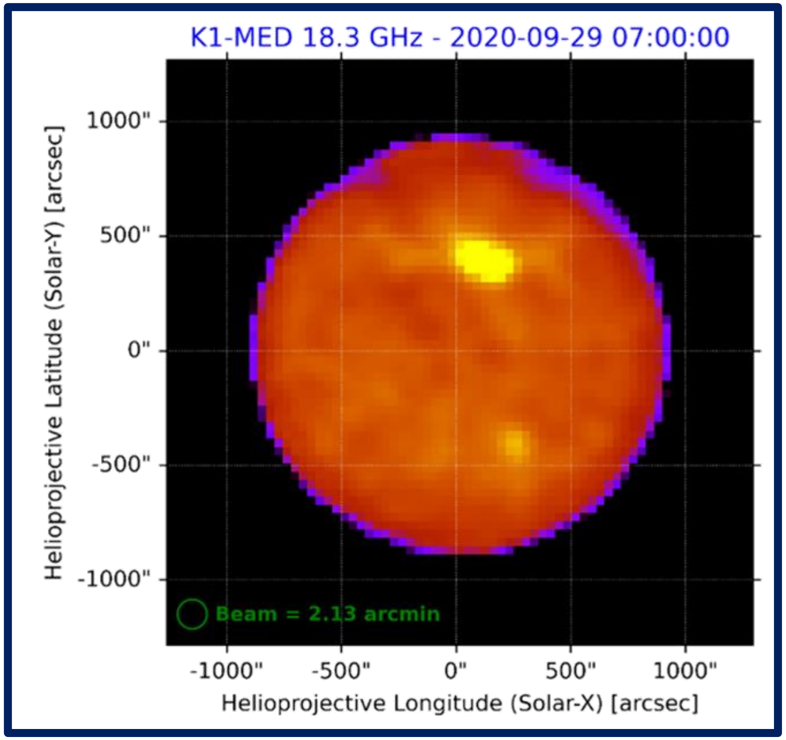
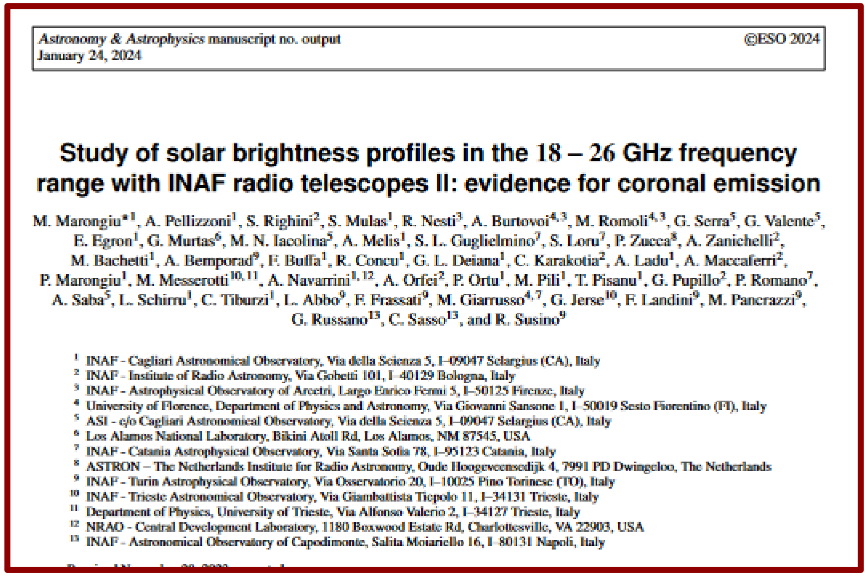



Credits: SunDish project

# Analysis of the solar corona

## SunDish Project
## INAF radio telescopes



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**Study of solar brightness profiles in the 18 – 26 GHz frequency range with INAF radio telescopes II: evidence for coronal emission**

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## Data reduction & Data analysis

## Short overview about our first results (density and temperature distributions of the solar atmosphere/corona)

## Comparison of our results with Metis data

# Why do we observe in radio frequency?

**At radio frequencies the quiet Sun is characterised by bremsstrahlung emission at local thermal equilibrium**

**Thanks to the opacity we can investigate several layers of the Sun**

**In this frequency domain, there are many models that describe the atmosphere of the Sun and its structure**

**At radio frequencies we can observe the gyro-resonance emission from the Active Regions**

**We can study the spectral variations of the Active Regions, that can predict the solar flares at least a few hours in advance**

**We can study the polarization of the radio emission**


**PI of the SunDish Project: Alberto Pellizzoni, INAF-Osservatorio Astronomico di Cagliari**

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

# SunDish project: solar setup

**It is possible to observe large and bright sources - as the Sun - through single-dish observations with large non-dedicated radio telescopes…**

**…but with a specific assessment of the set-up for safe and efficient observations**

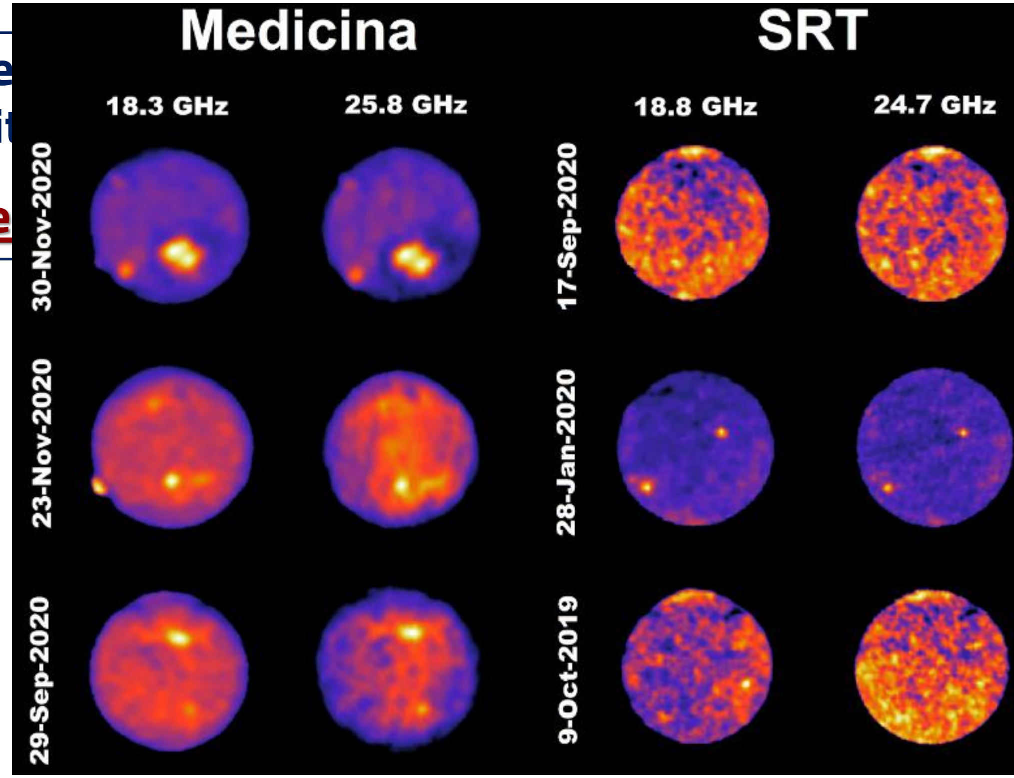

Credits: S. Righini (INAF-IRA)

**We adopt the On-The-Fly mapping technique to observe the Sun**

**It is possible to observe large**
**dish observations wit**

**...but with a specific assessme** **s**


Credits: S. Righini (INAF-IRA)




# OUR DATASET

## Medicina (2018-2023)

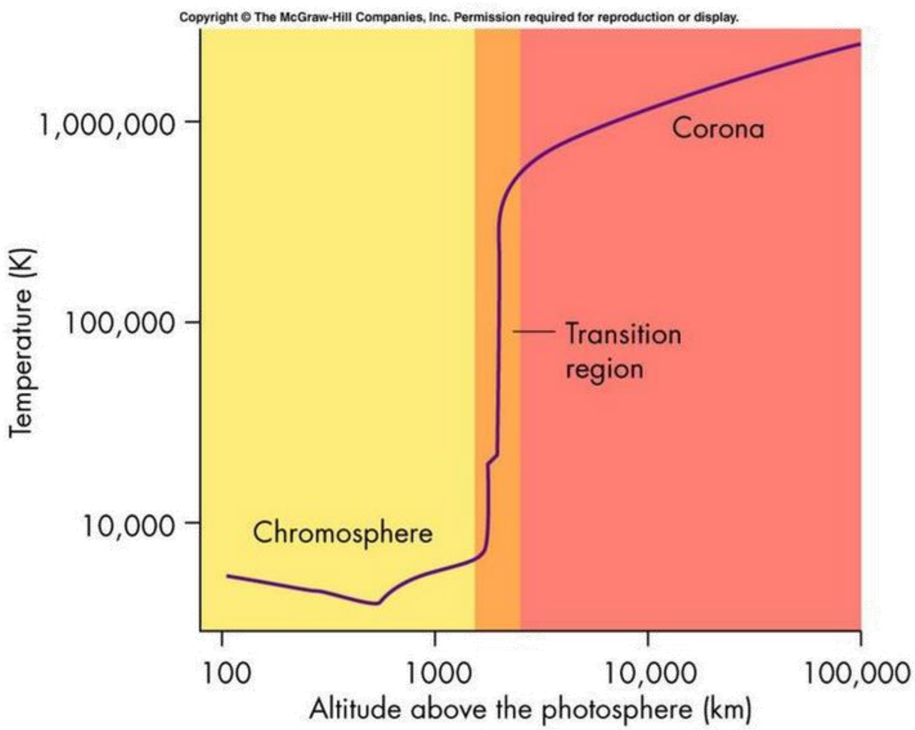
**287 solar maps - 142 at 18.3 GHz and 106 at 25.8 GHz**

**(39 maps at other frequencies in the range 18-26 GHz)**

## SRT (2019-2021)

**17 solar maps - 10 at 18.8 GHz and 7 at 24.7 GHz**

**Multi-frequency observations are crucial to study the solar atmosphere**




**Mainly thermal bremsstrahlung radiation**

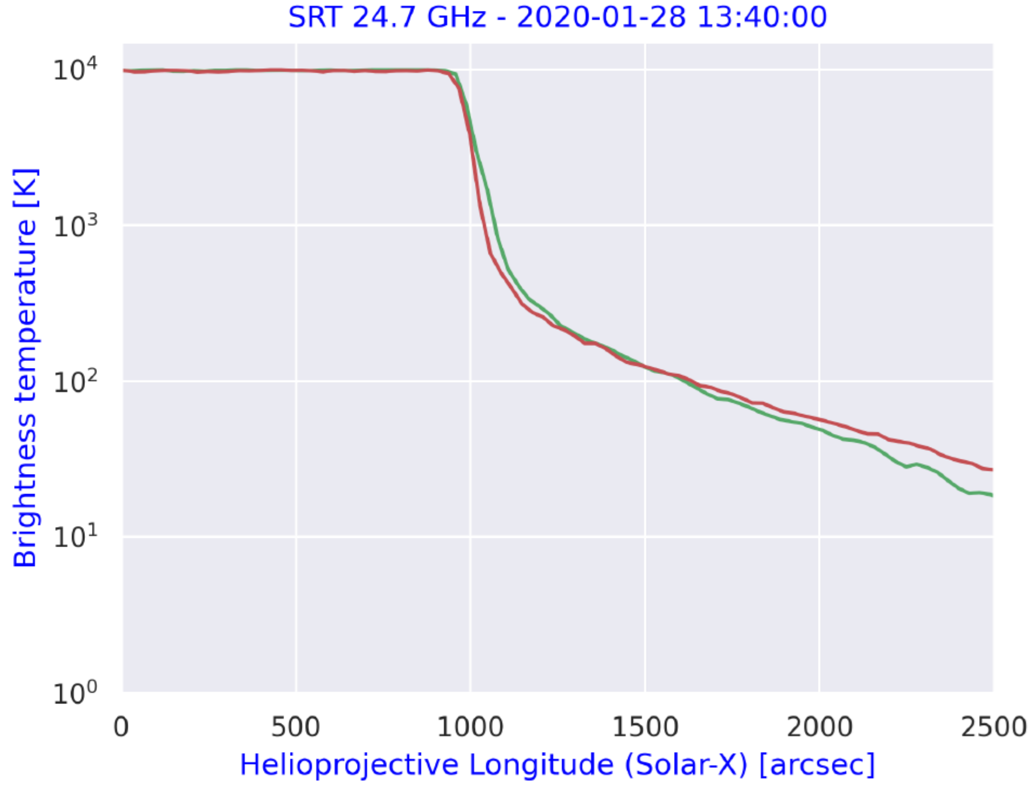
**Many atmospheric models are developed**

↓

**Analysis of the solar atmosphere in terms of the temperature and density distributions**

**The comparison between the model and the real data is crucial to improve the modelling of the solar atmosphere!**

# Data analysis: observed tails in our maps




- ✓ **Constant over time and isotropically distributed for each observing frequency**
- ✓ **The level of this tail at 25 GHz is higher than the tail at 18 GHz: thermal emission**
  **(preliminary estimation of the spectral index: 1.5 - 5)**
- ✓ **No correlation between this tail and the elevation δ of the Sun (δ = 20 - 60 deg) during the observations**

# Data analysis: the antenna beam pattern

**Degrading effect of the antenna beam pattern on the solar signal**

- Assess the quality of our solar maps
- Assess the quality of our radius determinations
- Probe the physical nature of the coronal emission in our maps

### Study of solar brightness profiles in the 18 – 26 GHz frequency range with INAF radio telescopes I: solar radius


M. Marongiu★[1], A. Pellizzoni[1], S. Mulas[1], S. Righini[2], R. Nesti[3], G. Murtas[4], E. Egron[1], M. N. Iacolina[5], A. Melis[1], G. Valente[5], G. Serra[5], S. L. Guglielmino[6], A. Zanichelli[2], P. Romano[6], S. Loru[6], M. Bachetti[1], A. Bemporad[7], F. Buffa[1], R. Concu[1], G. L. Deiana[1], C. Karakotia[2], A. Ladu[1], A. Maccaferri[2], P. Marongiu[1], M. Messerotti[8,9], A. Navarrini[1,10], A. Orfei[2], P. Ortu[1], M. Pili[1], T. Pisanu[1], G. Pupillo[2], A. Saba[5], L. Schirru[1], C. Tiburzi[1], and P. Zucca[11]

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**ABSTRACT**

*Context.* The Sun is an extraordinary workbench, from which several fundamental astronomical parameters can be measured with high precision. Among these parameters, the solar radius $R_\odot$ plays an important role in several aspects, such as in evolutionary models. Moreover, it conveys information about the structure of the different layers that compose the solar interior and its atmosphere. Despite the efforts in obtaining accurate measurements of $R_\odot$, the subject is still debated and measurements are puzzling and/or lacking in many frequency ranges.

*Aims.* We aimed to determine the mean, equatorial, and polar radii of the Sun ($R_c$, $R_{eq}$, and $R_{pol}$) in the frequency range 18.1 – 26.1 GHz. We employed single-dish observations from the newly-appointed Medicina "Gavril Grueff" Radio Telescope and the Sardinia Radio Telescope (SRT) throughout 5 years, from 2018 to mid-2023, in the framework of the SunDish project for solar monitoring.

*Methods.* Two methods to calculate the radius at radio frequencies – the half-power and the inflection-point – are considered and compared. To assess the quality of our radius determinations, we also analysed the possible degrading effects of the antenna beam pattern on our solar maps, using two 2D-models (ECB and 2GECB). We carried out a correlation analysis with the evolution of the solar cycle through the calculation of Pearson's correlation coefficient $\rho$ in the 13-month running means.

*Results.* We obtained several values for the solar radius – ranging between 959 and 994 arcsec – and $\rho$, with typical errors of a few arcsec. These values constrain the correlation between the solar radius and the solar activity, and allow us to estimate the level of the Sun prolatness in the centimetric frequency range.

*Conclusions.* Our $R_\odot$ measurements are consistent with values reported in literature, and provide refined estimations in the centimetric range. The results suggest a weak prolatness of the solar limb ($R_{eq} > R_{pol}$), although $R_{eq}$ and $R_{pol}$ are statistically compatible within $3\sigma$ errors. The correlation analysis using the solar images from the Grueff Radio Telescope shows (1) a positive correlation between the solar activity and the temporal variation of $R_c$ (and $R_{eq}$) at all observing frequencies, and (2) a weak anti-correlation between the temporal variation of $R_{pol}$ and the solar activity at 25.8 GHz.



**Key words.** Astronomical instrumentation, methods and techniques; Methods: data analysis; The Sun; Sun: radio radiation


(Marongiu+24)

**Beam pattern test: we excluded relevant systematic errors of the antenna**

**Updated version of the atmospheric SSC model**

**(Selhorst+ 2005, 2019, Zhang+ 2022)**

↓

**Extended SSC model (eSSC)**

**Coronal plasma up to $\sim 4 \cdot 10^6$ km above the solar surface** → **YES**

**Effects of the strong magnetic fields in active regions, the spicules, the special features observed at the polar regions, and the geometry of radio wave refraction within the solar corona** → **NO**

**The main purpose of this model is to reproduce the full quiet Sun disk and atmosphere from the photosphere to the corona**

## Strategy

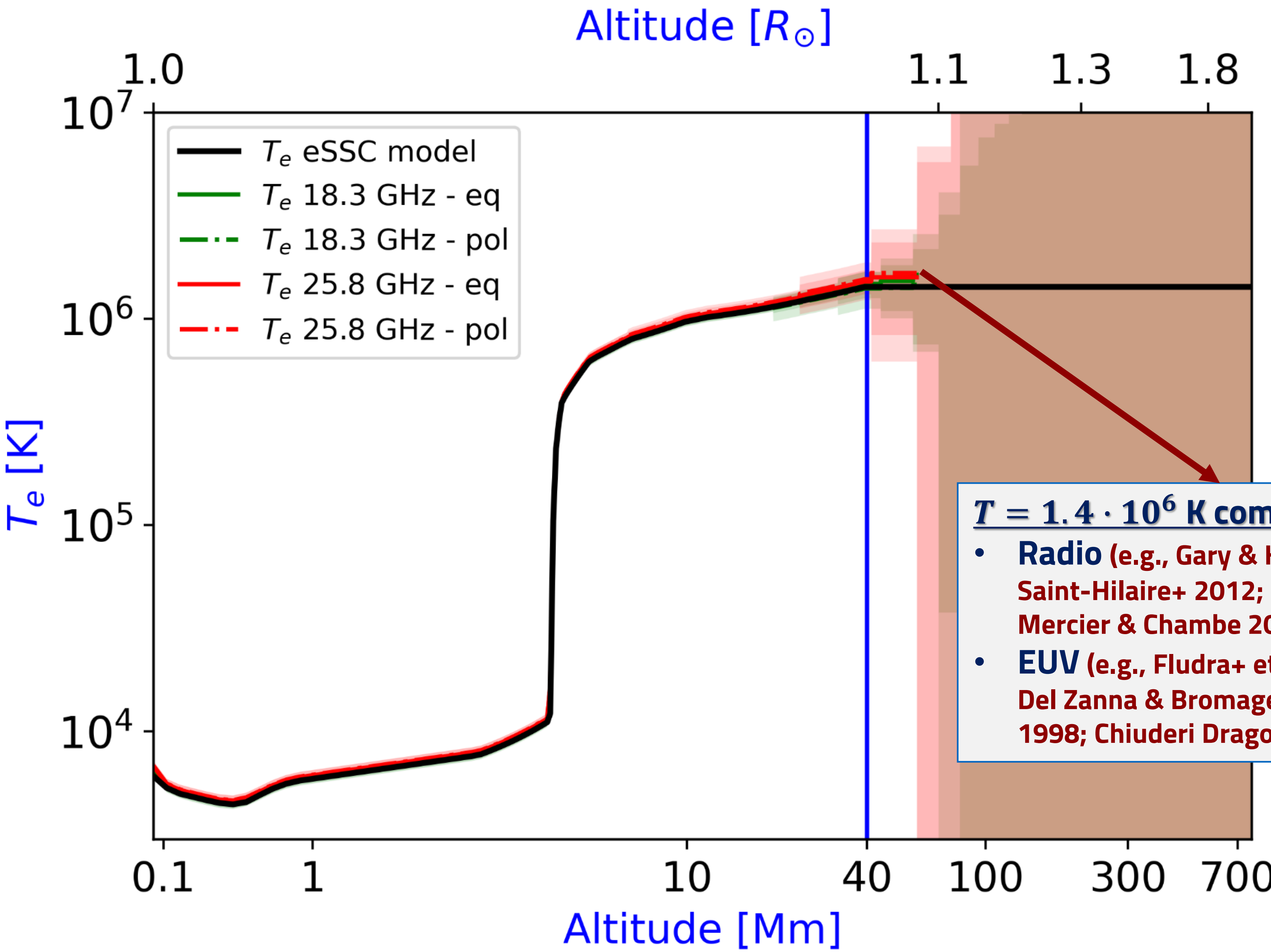
We analysed the brightness temperature profiles along the equatorial and polar diameters of the quiet Sun during the minimum solar activity (2018–2020), and we compared the modelled and the observed profiles

- Modelled profiles: eSSC model
- Observed profiles: averaged solar maps at 18.3 and 25.8 GHz with Medicina radio telescope

We estimated the density and temperature distributions suited for our INAF observations

**The density distributions are obtained assuming true the T distribution of the eSSC model, and vice versa**

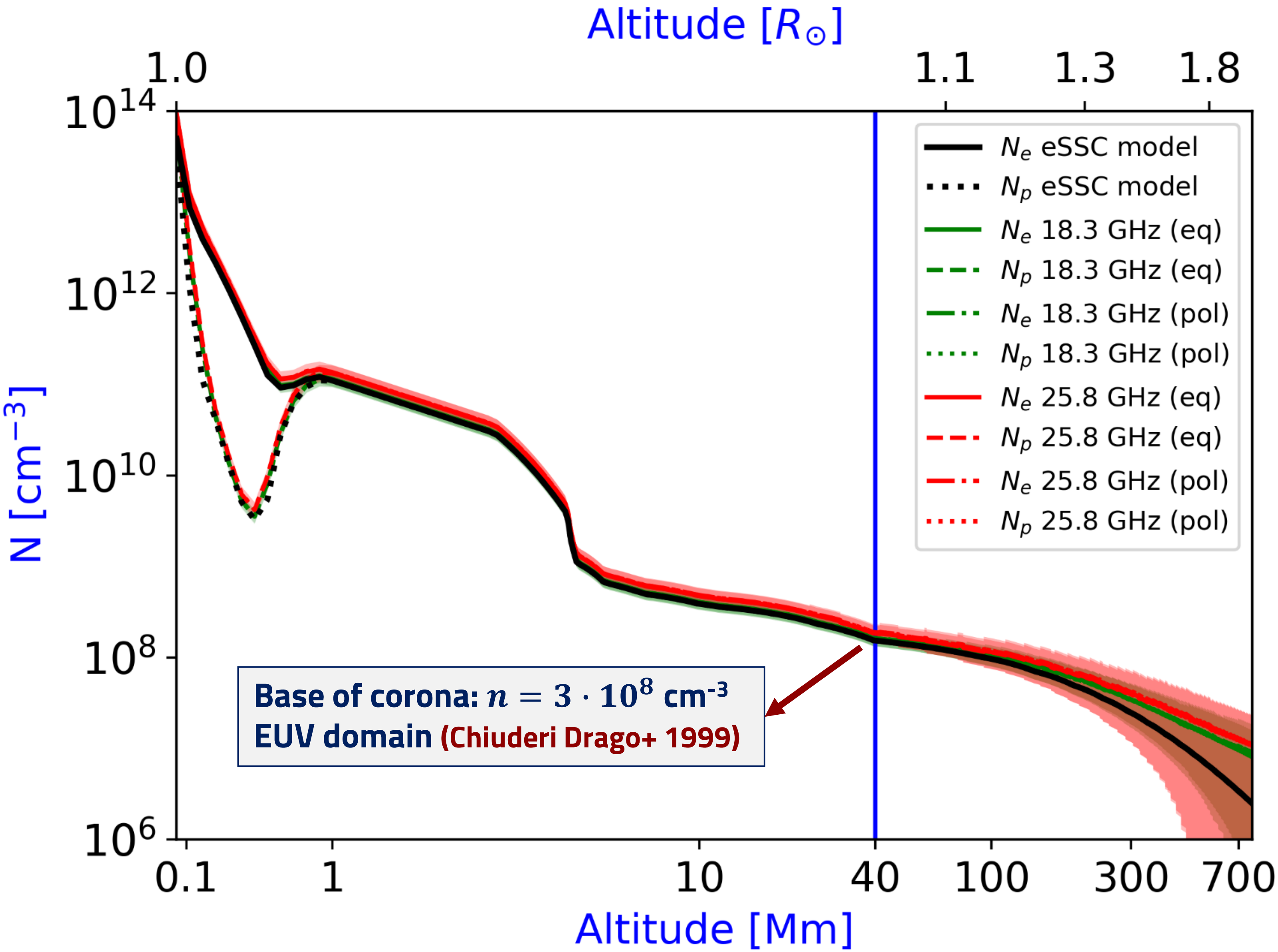
# Results: coronal emission

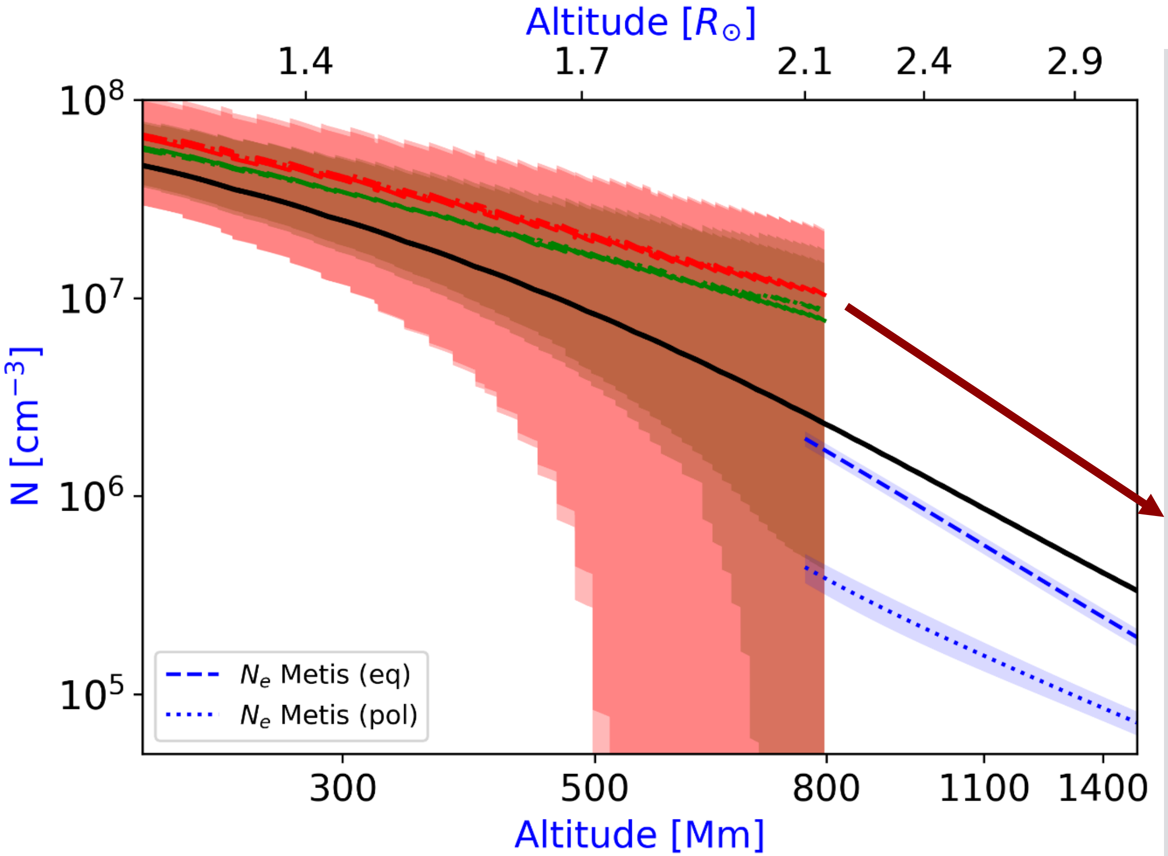



**$T = 1.4 \cdot 10^6$ K compatible with:**

- **Radio** (e.g., Gary & Hurford 1987; Saint-Hilaire+ 2012; Vocks+ 2018; Mercier & Chambe 2015)
- **EUV** (e.g., Fludra+ et al. 1997, 1999; Del Zanna & Bromage 1997, David+ 1998; Chiuderi Drago+ 1999)

# Results: coronal emission






**eSSC model could provide an overestimate of T and N caused by:**

- ✓ the worse angular resolution at our radio frequencies than the higher frequencies (e.g., visible, EUV, X-rays) (e.g., Chiuderi Drago+ 1999)
- ✓ the likely presence of additional emission components (e.g., gyromagnetic emission) or other effects (e.g., weak plasma emission, spicules and refraction effects), neglected in the SSC/eSSC model

**eSSC model too simple to describe the atmosphere at high altitudes?**

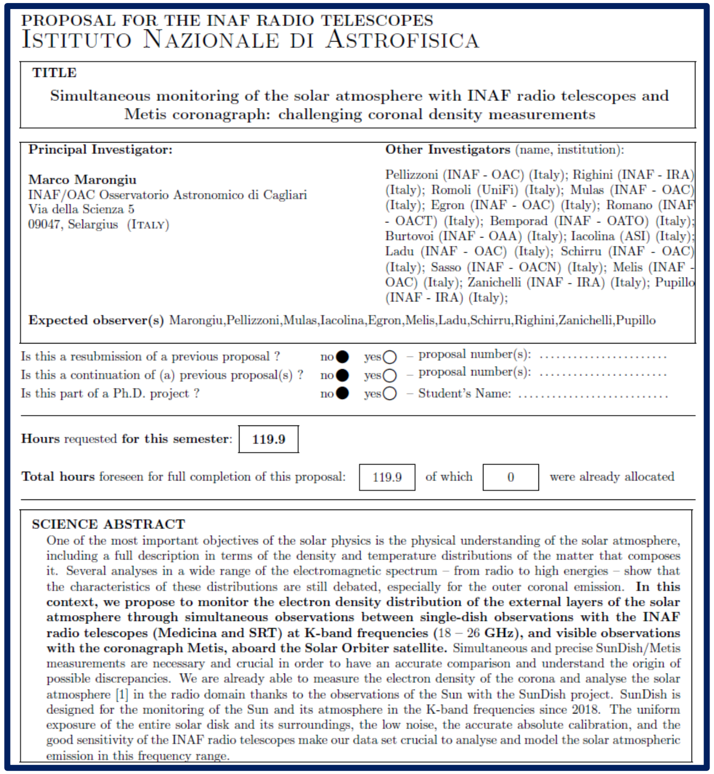
# Our INAF Proposal

**Metis** | **Medicina** | **SRT**

**+**

**+**

Credits: www.esa.int



PROPOSAL FOR THE INAF RADIO TELESCOPES
ISTITUTO NAZIONALE DI ASTROFISICA

**TITLE**

**Simultaneous monitoring of the solar atmosphere with INAF radio telescopes and Metis coronagraph: challenging coronal density measurements**

**Principal Investigator:**

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**Other Investigators** (name, institution):

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**Expected observer(s)** Marongiu,Pellizzoni,Mulas,Iacolina,Egron,Melis,Ladu,Schirru,Righini,Zanichelli,Pupillo

Is this a resubmission of a previous proposal ? no ● yes ○ – proposal number(s): ......................
Is this a continuation of (a) previous proposal(s) ? no ● yes ○ – proposal number(s): ......................
Is this part of a Ph.D. project ? no ● yes ○ – Student's Name: ..........................

**Hours** requested **for this semester**: 119.9

**Total hours** foreseen for full completion of this proposal: 119.9 of which 0 were already allocated

**SCIENCE ABSTRACT**

One of the most important objectives of the solar physics is the physical understanding of the solar atmosphere, including a full description in terms of the density and temperature distributions of the matter that composes it. Several analyses in a wide range of the electromagnetic spectrum – from radio to high energies – show that the characteristics of these distributions are still debated, especially for the outer coronal emission. **In this context, we propose to monitor the electron density distribution of the external layers of the solar atmosphere through simultaneous observations between single-dish observations with the INAF radio telescopes (Medicina and SRT) at K-band frequencies (18 – 26 GHz), and visible observations with the coronagraph Metis, aboard the Solar Orbiter satellite.** Simultaneous and precise SunDish/Metis measurements are necessary and crucial in order to have an accurate comparison and understand the origin of possible discrepancies. We are already able to measure the electron density of the corona and analyse the solar atmosphere [1] in the radio domain thanks to the observations of the Sun with the SunDish project. SunDish is designed for the monitoring of the Sun and its atmosphere in the K-band frequencies since 2018. The uniform exposure of the entire solar disk and its surroundings, the low noise, the accurate absolute calibration, and the good sensitivity of the INAF radio telescopes make our data set crucial to analyse and model the solar atmospheric emission in this frequency range.

**INAF proposal accepted!**
**Simultaneous campaign in March and April 2024**
**(120 hours, PI: Marongiu)**

# Take-home messages

We focused on the study of the coronal emission

The analysis of the degrading effect of the antenna beam pattern on the solar signal allowed us to probe the physical nature of the coronal emission in our maps

The eSSC model is a good approximation of our solar maps up to about 60 Mm of altitude

Future analysis will allow us to improve our comprehension of the solar atmosphere, in particular thanks the forthcoming multi-facility simultaneous sessions Medicina/SRT/Metis

# Future works

Detailed analysis of the solar atmosphere suited for our maps

Quiet-Sun analysis

Analysis of the limb/polar brightening

Analysis of the coronal holes

Long-term evolution of physical parameters

Multi-frequency combined analysis of the solar images

(from radio to high-energy frequencies)

Prediction of powerful flares through the detection of peculiar spectral variations in the Active Regions

# *Thank you for your attention!*

**<u>Seeking collaborations for:</u>**

- **Simultaneous/coordinated observations at lower/higher frequencies**
- **Data analysis improvement**
- **Science and Space Weather applications exploitation**

**SunDish PI contact: alberto.pellizzoni@inaf.it**

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