SOLARNET
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# SOLAR RADIUS MEASUREMENTS AND EVIDENCE FOR CORONAL EMISSION IN THE 18 – 26 GHZ FREQUENCY RANGE THROUGH IMAGING OBSERVATIONS WITH INAF RADIO TELESCOPES

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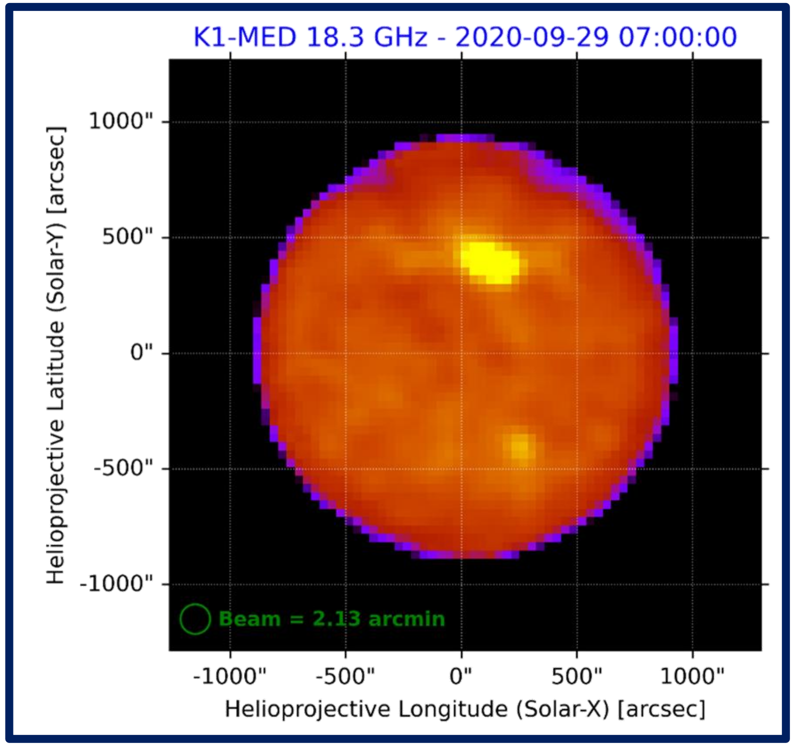
# Summary



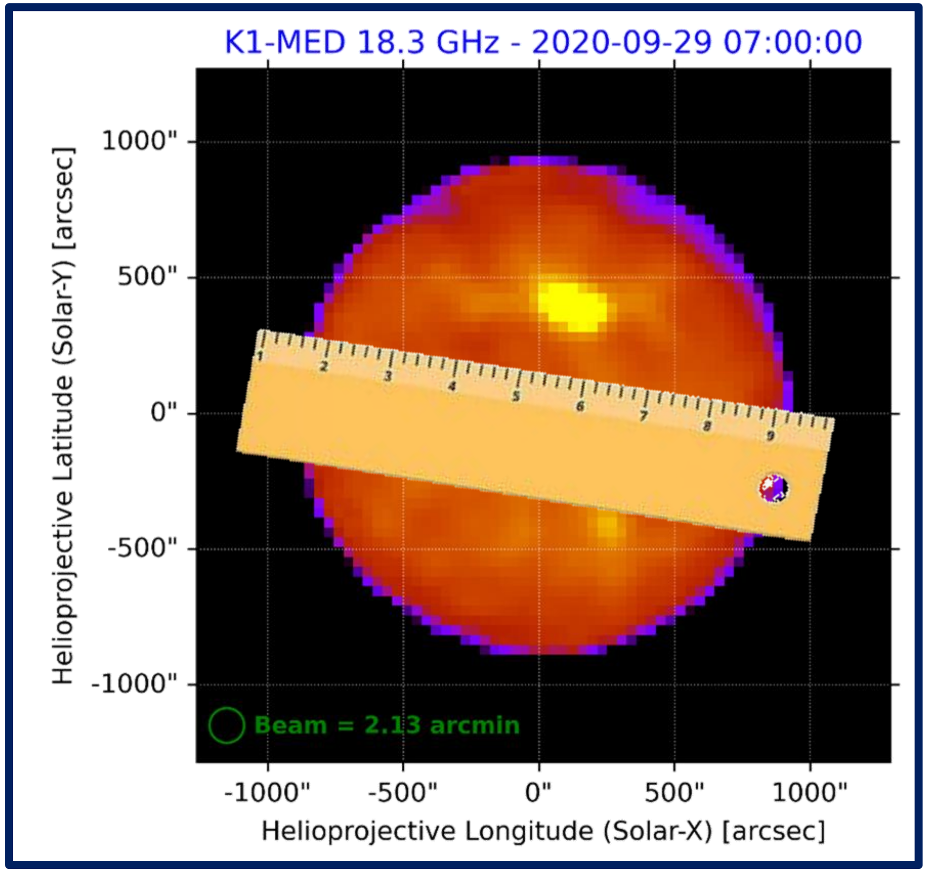

**Credits: SunDish project**

## Analysis of the solar radius and the corona

**SunDish Project**
**INAF radio telescopes**

**Data reduction & Data analysis**

**Short overview about our first results (radius and its behaviour over time, density and temperature distributions of the solar atmosphere/corona)**




**Several physical information**

- Structure of the solar atmosphere
- Behaviour over time
- Sphericity

**Still a matter of debate in the literature**

**Discrepancies**

- Different facilities
- Different measurement techniques
- Variable phenomenology close to the limb

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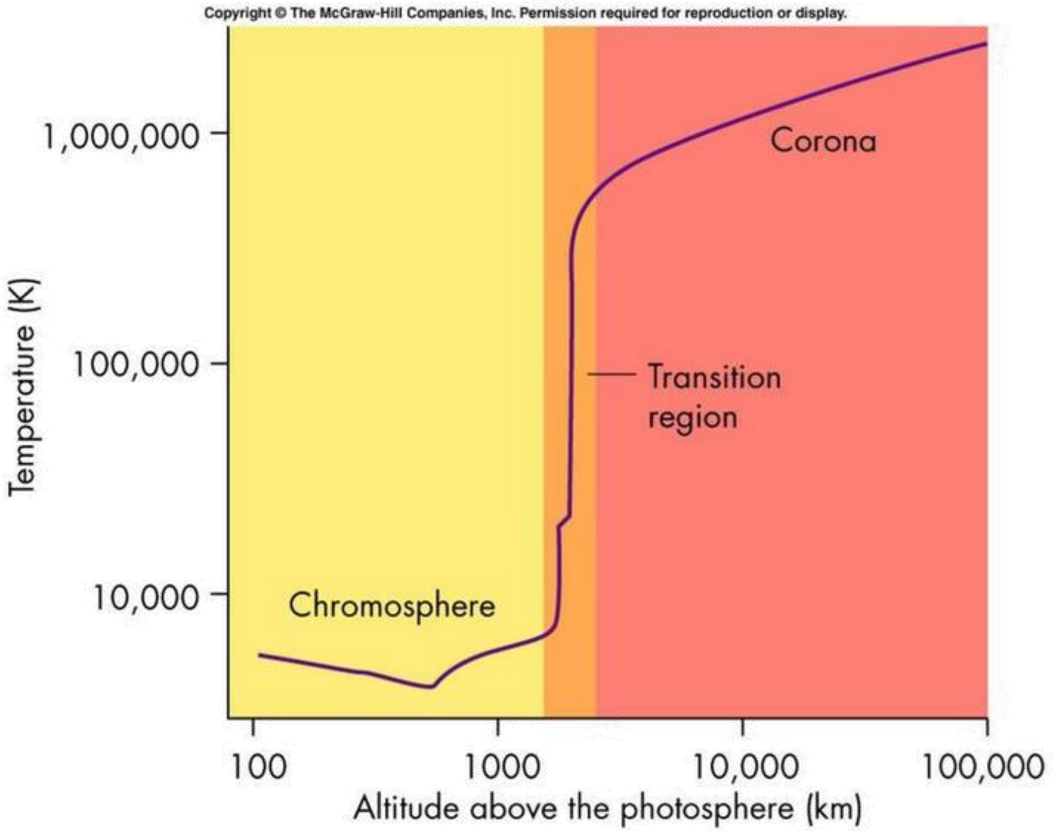
# Multi-frequency observations are crucial to study the solar atmosphere




**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!**


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

# SunDish project: INAF Network

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


## 32 m - Medicina Radio Telescope
Medicina (Emilia Romagna)

## 32 m - Noto Radio Telescope
Noto (Sicily)


# 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**

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

## 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)

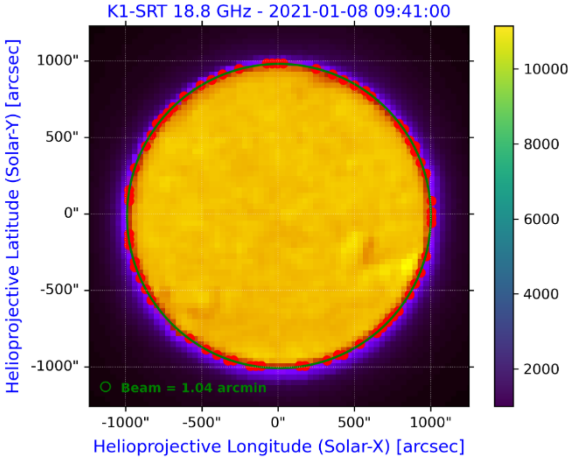
**SRT (2019-2021)**

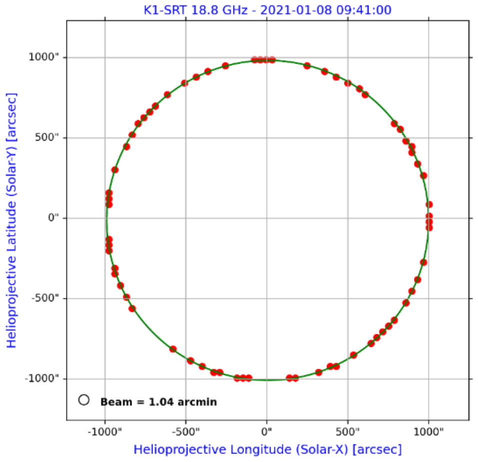
17 solar maps - 10 at 18.8 GHz and 7 at 24.7 GHz

# Data analysis: the solar radius

**Half-power method**

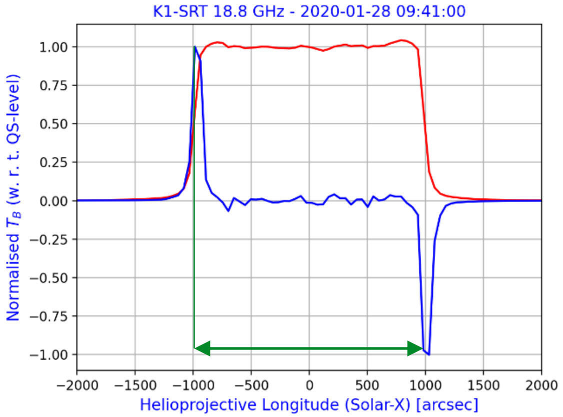
**50% of the Quiet Sun level**



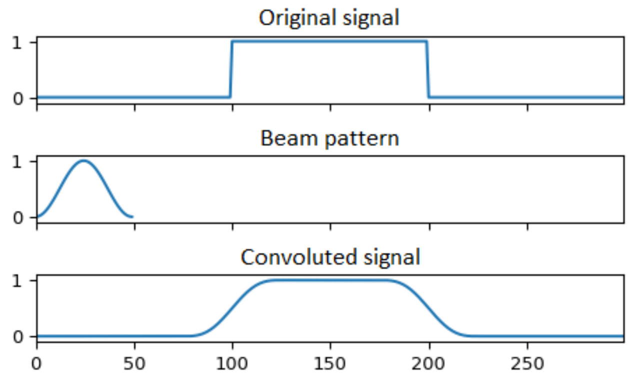

**Inflection-point method**

**Adopted to avoid extracting limb points associated with ARs, or affected by weather and seasonal effects, instrumental errors, or high atmospheric opacity**



# Data analysis: the antenna beam pattern

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




→ **Assess the quality of our radius determinations**

→ **Probe the physical nature of the coronal emission in our maps**

**2D models** → **Beam pattern with:**

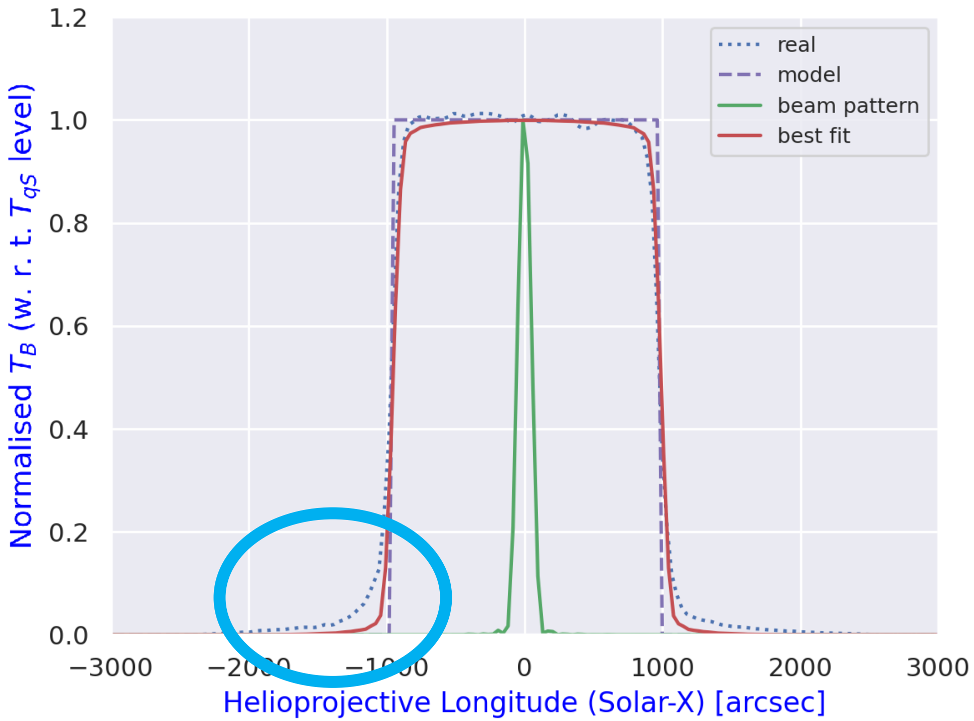
- **Elliptical-based Cylindrical Box (ECB-model)**
- **ECB-model + 2D-Gaussian function (2GECB-model)**

**Observed map**

**Beam pattern**

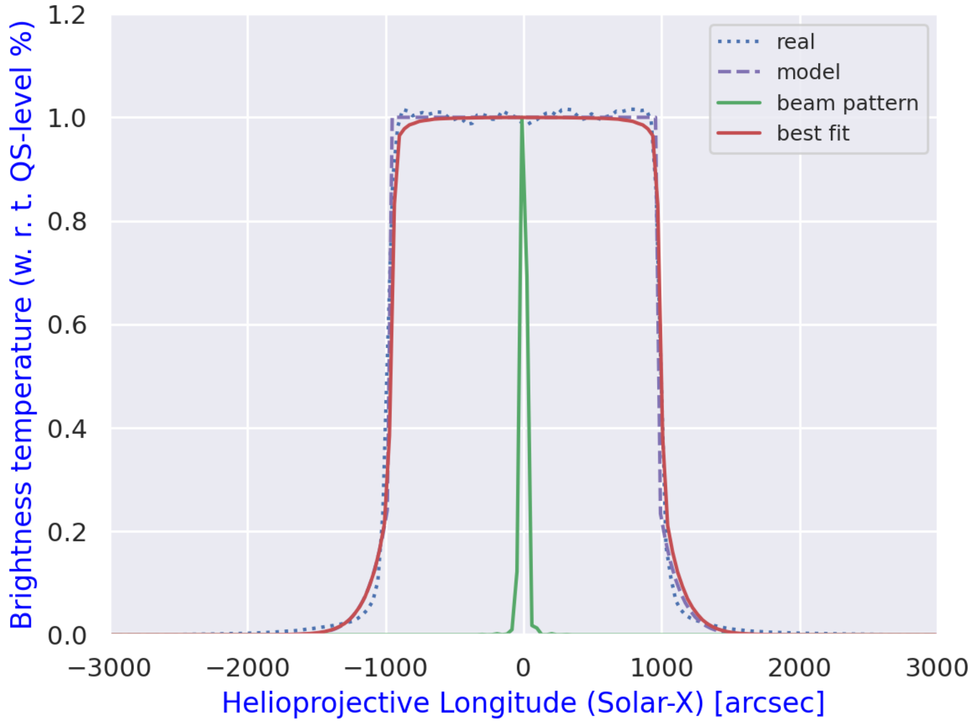
→ **"True" solar signal**

# Data analysis: the antenna beam pattern




**ECB-model**

**2GECB-model**



# Data analysis: coronal emission

- ✓ **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 degrees) during the observations**


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

# Data analysis: coronal emission

**Updated version of the atmospheric SSC model**

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

↓

**Extended SSC model (eSSC)**

Coronal plasma up to $\sim 2 \cdot 10^6$ 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**

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## Strategy

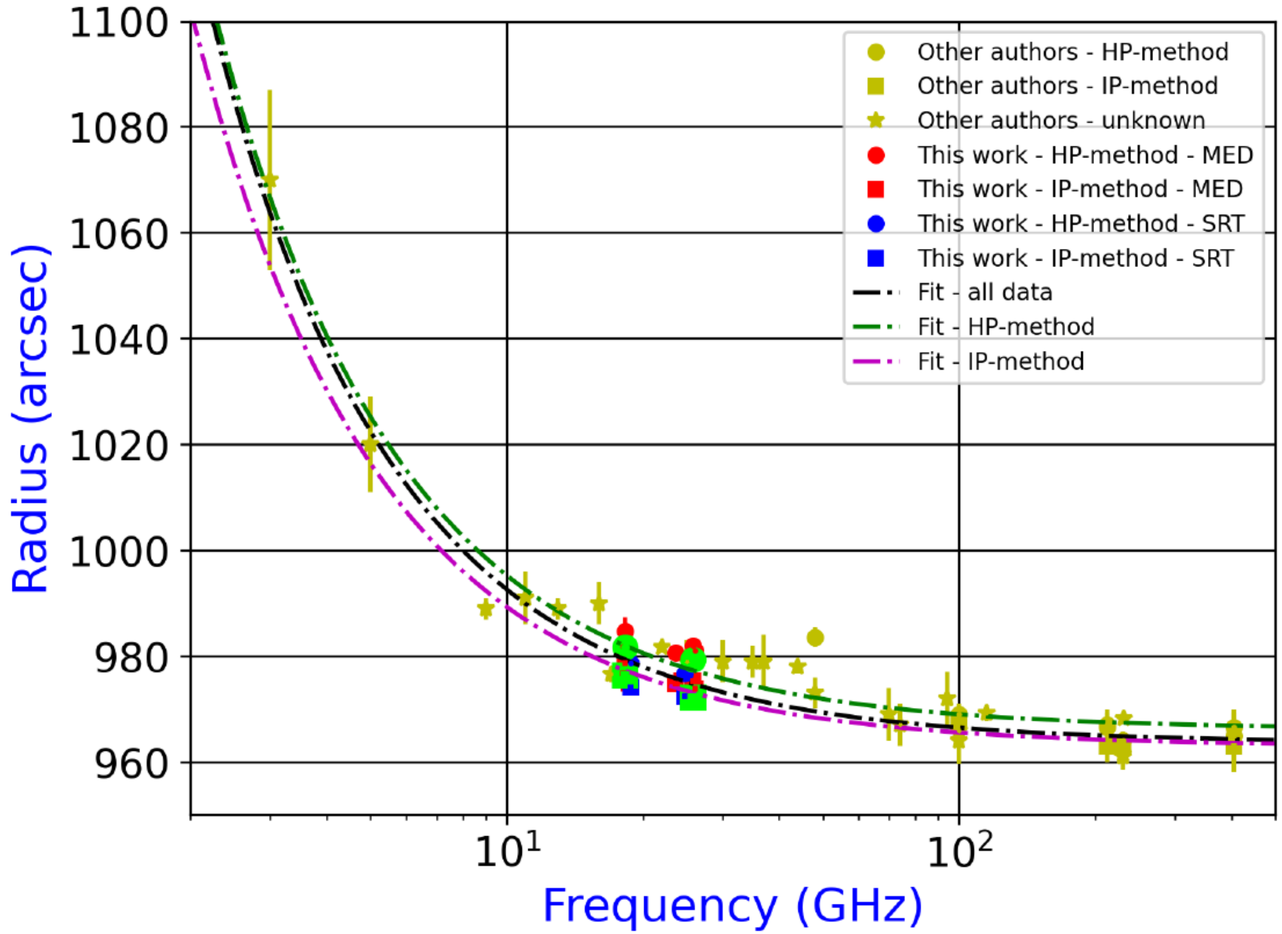
We analysed the brightness temperature profiles along the equatorial and polar diameters of the quiet Sun during the minimum solar activity (2018–2020), and we compared the modelled and the observed profiles

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

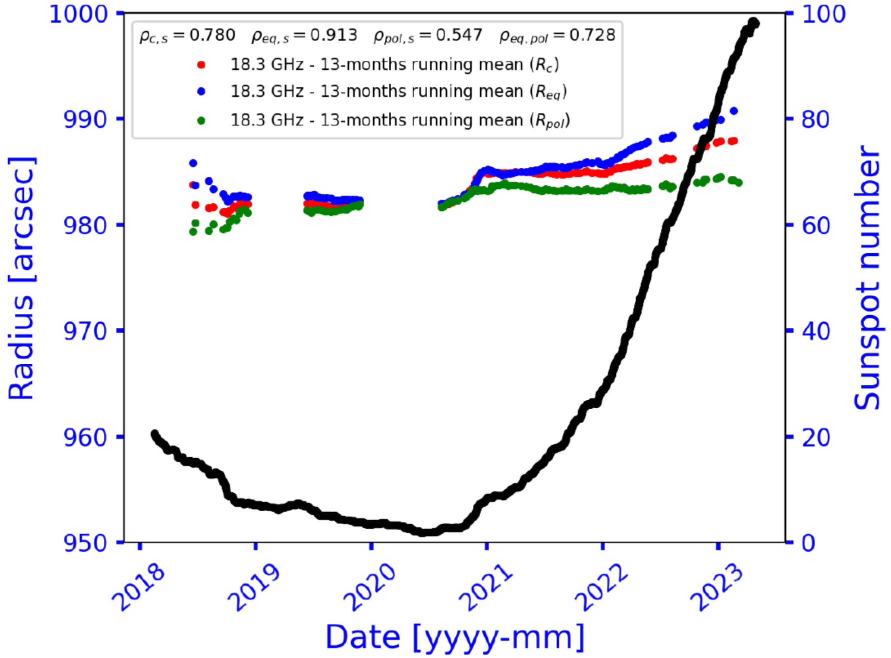
We estimated the density and temperature distributions suited for our INAF observations

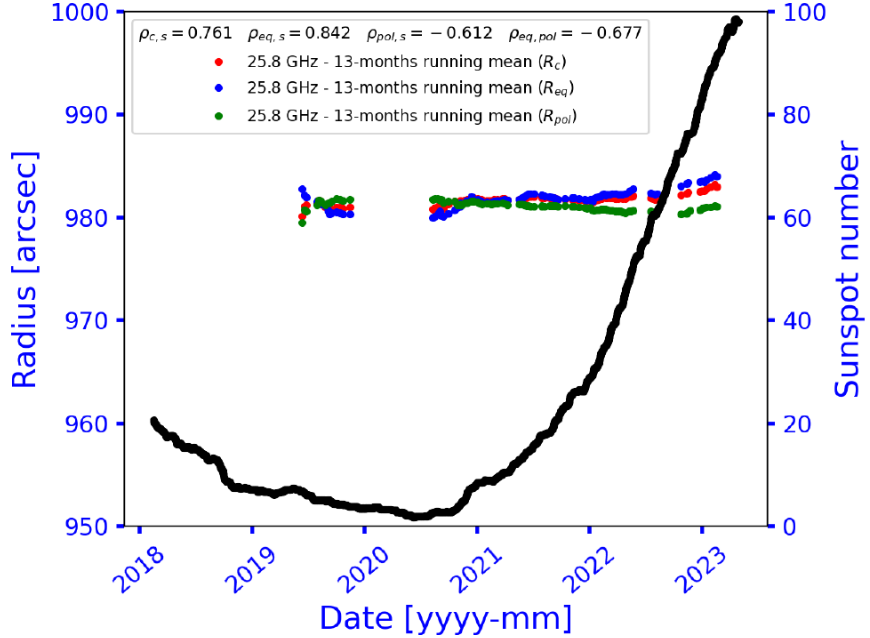
The density distributions are obtained assuming true the T distribution of the eSSC model, and vice versa

# Results: solar radius




**Our measurements show that the equatorial radius is slightly greater than the polar radius, but these measures are statistically comparable**



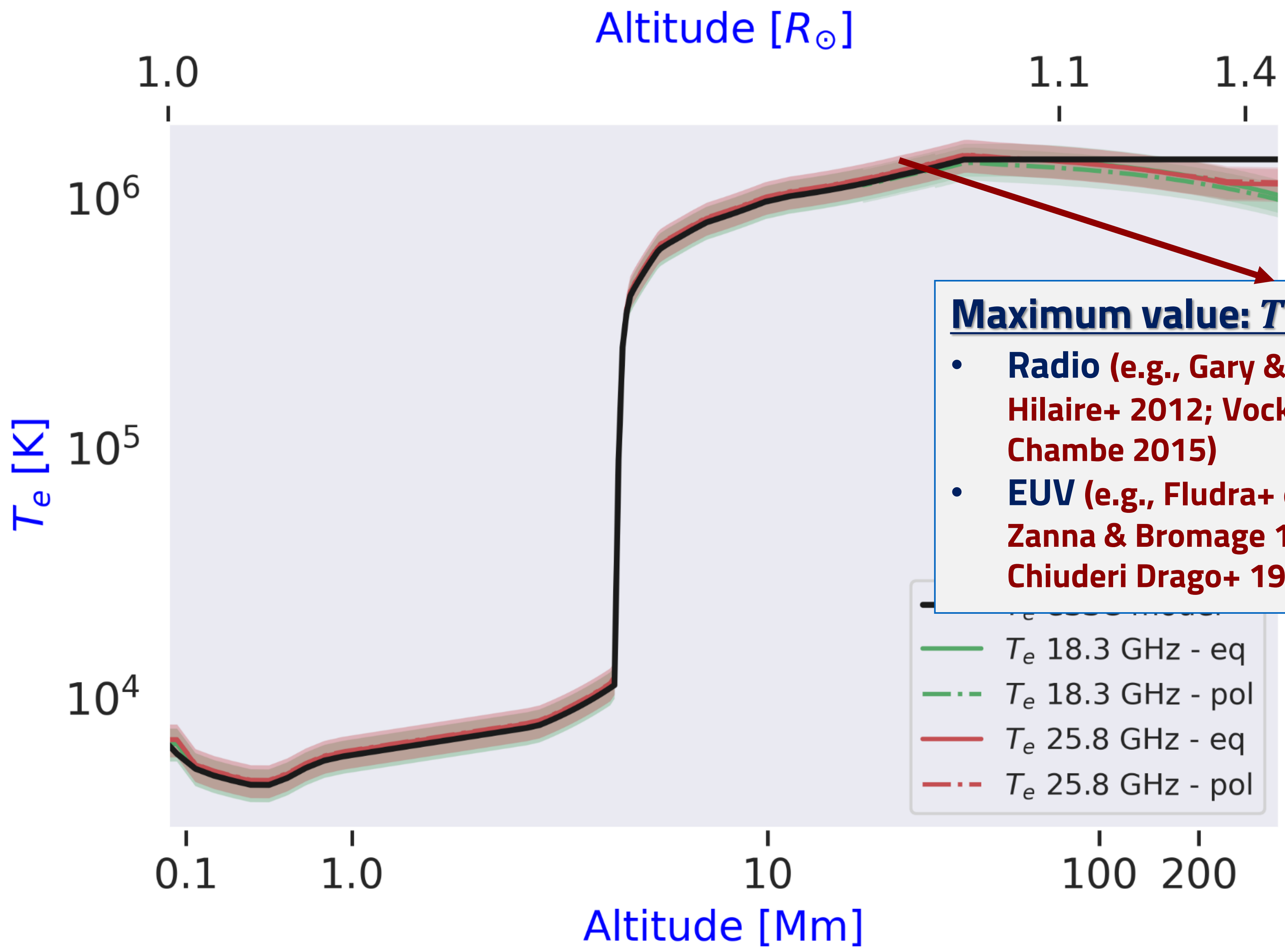




- ✓ **Correlation between the mean (and the equatorial) radius and the solar activity**
- ✓ **Anti-correlation between the polar radius and the solar activity**

**In agreement with the analysis presented in the literature for similar radio frequencies**

**(e.g., Costa+ 1999; Selhorst+ 2004, 2011, 2019)**

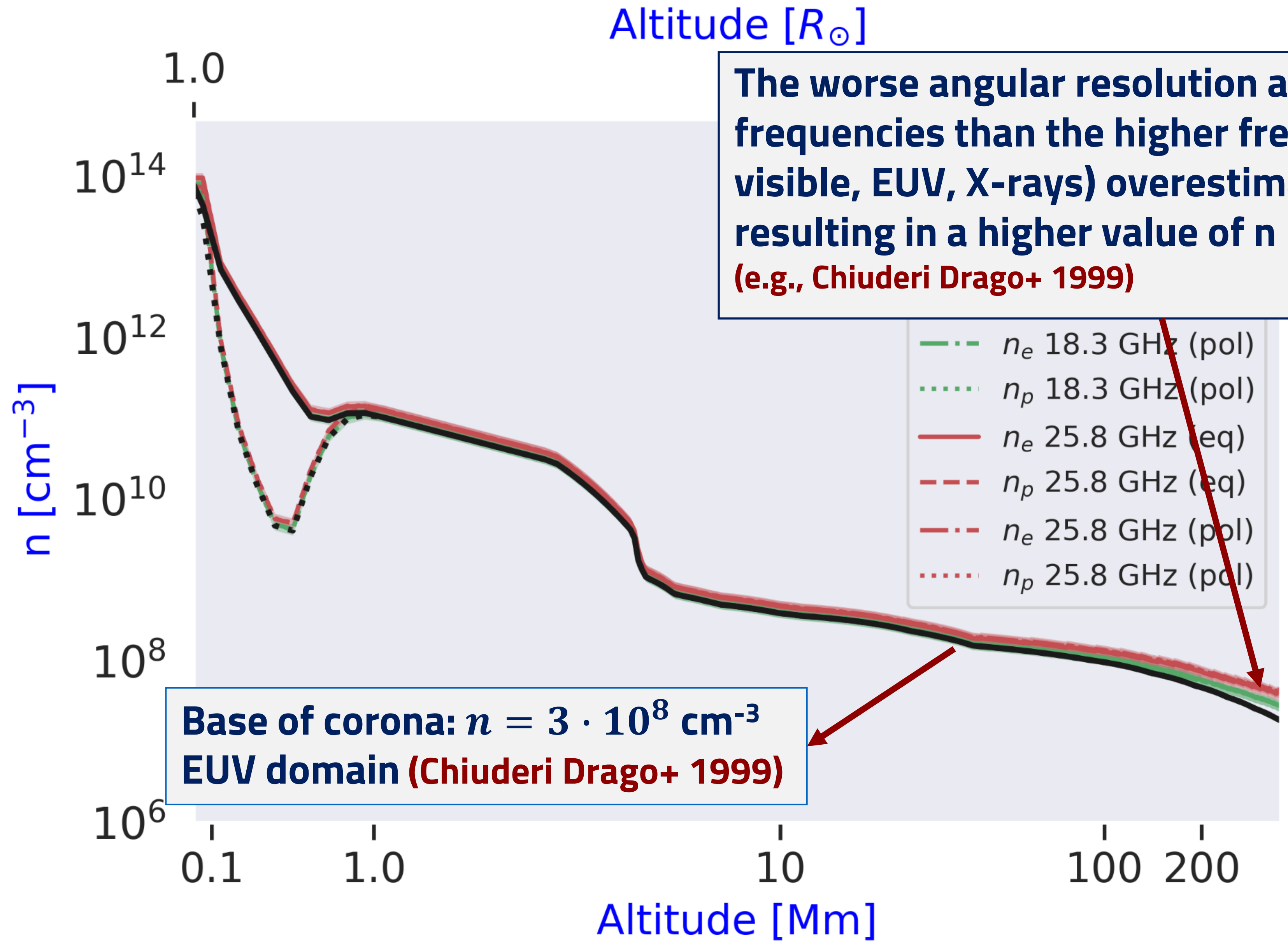
# Results: coronal emission




**Maximum value: $T = 1.4 \cdot 10^6$ K**

- **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




**The worse angular resolution at low frequencies than the higher frequencies (e.g., visible, EUV, X-rays) overestimates the radio $T_B$ resulting in a higher value of n in the corona**
**(e.g., Chiuderi Drago+ 1999)**

**Base of corona: $n = 3 \cdot 10^8$ cm$^{-3}$**
**EUV domain (Chiuderi Drago+ 1999)**

# Take-home messages

We focused on the measurement of the solar radius and its behaviour over time (also with respect to the solar activity), and the study of the coronal emission

The Sun is approximatively a sphere in the range 18 – 25 GHz

The correlation analysis using the radii and the solar activity show a positive correlation between the equatorial radius and the solar activity, and an anti-correlation between polar radius and the solar activity

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

# Future works

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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