

# The influence of spicules in the solar radius at multiple radio wavelengths

Caius L. Selhorst<sup>1,2</sup>, Adriana Silva-Válio<sup>2</sup>, Priscila A. Martins<sup>2</sup>,  
Daiane B. Seriacopi<sup>2</sup>, Pierre Kaufmann<sup>2</sup> and Hugo Levato<sup>3</sup>

<sup>1</sup>IP&D - Universidade do Vale do Paraíba - UNIVAP, Av. Shishima Hifumi, 2911  
Urbanova, São José dos Campos, SP 12244-000, Brasil  
email: caius@univap.br

<sup>2</sup>CRAAM, Universidade Presbiteriana Mackenzie, São Paulo, SP, Brasil  
<sup>3</sup>CASLEO, San Juan, Argentina

**Abstract.** In this work, we analyze observations of the solar radius at 22 and 43 GHz obtained with the 13.7 m antenna of the Itapetinga Radio Observatory (Atibaia, Brazil) and at submillimeter-wave frequencies, 212 and 405 GHz, obtained by the Solar Submillimeter-wave Telescope (SST) (El Leoncito, San Juan, Argentina). The radius is defined as the limb position where the intensity is equal to half of the quiet Sun value. These measured radii are then compared with those predicted by a model of the solar atmosphere proposed by Selhorst, Silva, and Costa (2005). The results show that at 22 and 43 GHz, the emission comes from regions high in the chromosphere. Furthermore, the Itapetinga observations yield radii of  $985'' \pm 5''$  and  $981'' \pm 6''$ , at 22 and 43 GHz respectively, consistent with the theoretical positions in the atmosphere. On other hand, the submillimeter observations resulted in a mean radius of  $972'' \pm 3''$  and  $975'' \pm 5''$  at 212 and 405 GHz, respectively, considered equal within the uncertainties. The latter results can be explained by the origin of the emission being very close to the region of minimum temperature, between the photosphere and chromosphere. This is a dynamic region largely affected by many solar features, like spicules and plages.

**Keywords.** Sun: radio radiation, Sun: radius, Sun: spicules

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## 1. Introduction

The observations of solar radius at multiple radio wavelengths provide an important tool to study the structure of the solar atmosphere, since different frequencies are formed at distinct atmospheric heights. Moreover the height, with respect to the solar surface, where the emission originates increases with wavelength.

Costa *et al.* 1999 and Selhorst *et al.* 2004 showed that the solar radius measured at the chromosphere and layers above it, reflects the solar atmospheric heating during the solar cycle. In the atmospheric model SSC proposed by Selhorst *et al.* 2005, the authors used the observations of solar radius at 17 GHz to adjust the model, and concluded that the presence of spicules increase the the solar radius at this frequency.

In this work, we observe the solar radius at 4 distinct frequencies (22, 43, 212, and 405 GHz) studding the solar emission at different atmosphere heights.

## 2. Observations

The observations at 22 and 43 GHz were obtained with the 13.7 m antenna of the Itapetinga Radio Observatory (Atibaia, Brazil) between 10 and 14 March of 2006, which resulted in 37 maps.

A total of 92 azimuth maps, obtained by the Solar Submillimeter-wave Telescope (SST) (El Leoncito, Argentina) at 212 and 405 GHz (June - August/2005) were analyzed here.

We defined the solar radius as follow:

- The quiet Sun was take as the most common intensity in the solar disk;
- For each intensity profile the limb was defined as the position where the intensity is half the quiet Sun value taken in two points for each scan;
- These points are then fit by a circumference, which yields a mean radius value.

**Table 1.** Observational Radius

Frequency (GHz)	Radius (arcsec)
22	985 ± 6
43	981 ± 6
212	972 ± 3
404	975 ± 5

The results of mean solar radius are summarized in Table 1. Except for the 405 GHz radius, the observations show that the radius reduces with the increase of the frequency, which agrees with the theory.

### 3. Atmospheric Model

The SSC is a numerical atmospheric model (Selhorst, Silva & Costa 2005) proposed to reproduce the radio frequencies observations. The authors suggested that an extended chromosphere (up to 3500 km) is necessary to reproduce the radio observation, which represents the average effect of small size atmospheric features, such as spicules, for example.

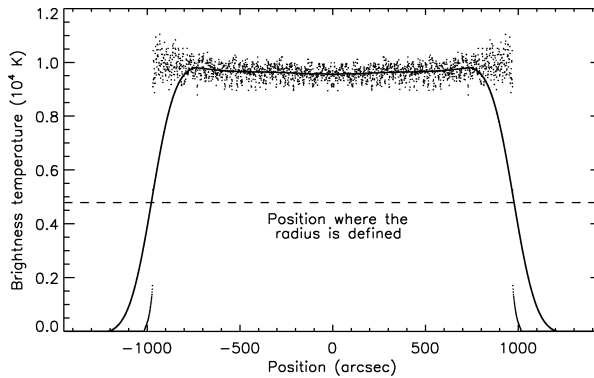
Table 3, summarizes the radius and limb brightening results at the frequencies studied here, after the convolution with a Gaussian beam similar to the antenna resolution. A small limb brightening is predict in the simulations, however, it is not clearly defined by the observations. The simulated radius at 22 and 405 GHz are compatible with the observations, while the radius at 43 and 212 GHz are 1 arcsec outside the measurements even when the error bars are considered.

**Table 2.** Simulated Radius

Frequency (GHz)	HPBW (arcmin)	Quiet Sun (K)	Limb Brightening (% above the Quiet Sun)	Simulated Radius (arcsec)	Observed Radius (arcsec)
22	4	9890	5	983	985 ± 6
43	2	8750	7	974	981 ± 6
212	4	6680	5	976	972 ± 3
404	3	5690	7	976	975 ± 5

Although the SSC model represents a mean atmosphere, including the influence of atmospheric features, the spicules influence close to the limb differs from those at disc center, since they can reach coronal heights.

The spicules characteristics (density, temperature, height, inclination, and position in the surface) are attributed using the Monte Carlo Method (for more details see Selhorst2005). Figure 1 shows the simulation result for an atmosphere with spicules calculated at 22 GHz. The black dots represent the simulation with 1 arcsec resolution, whereas the black curve is the result convolved with a 4' Gaussian beam.



**Figure 1.** Simulation result for an atmosphere with spicules calculated at 22 GHz. The black dots represent the simulation with 1 arcsec resolution, whereas the solid black curve is the result convolved with a 4' Gaussian beam.

In the simulations, we used the spicules physical parameters used in Selhorst *et al.* 2005 at 17 GHz. For these type of spicules the results are:

- reduction of the limb brightening at all frequencies studied;
- increase of the radius at submillimeter waves (212 and 405 GHz);
- the radius at 22 and 43 GHz were smaller than in the simulations without spicules.

**Table 3.** Simulated Radius with spicules

Frequency (GHz)	HPBW (arcmin)	Quiet Sun (K)	Limb Brightening (% above the Quiet Sun)	Simulated Radius (arcsec)	Observed Radius (arcsec)
22	4	9600	2	977	985 ± 6
43	2	8690	3	973	981 ± 6
212	4	6740	4	979	972 ± 3
404	3	5790	7	980	975 ± 5

## 4. Summary

The results of the simulations can be separated in two parts:

- Model without spicules:
  - agrees with the observations of radius at 22 and 405 GHz, while at 43 and 212 GHz are 1 arcsec outside of the measured with the error bars;
  - presented small limb brightening, between 5 and 7% above the quiet Sun. These values are within the noise level of the data.
- Spicules influence:
  - the spicules reduce the limb brightening in the simulations, except for 405 GHz;
  - spicules increase the radius at submillimeter frequencies, and reduce the microwave ones. However, the results without spicules are in better agreement with the observations.

## References

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