THE SUBTERAHERTZ SUN

EQUATORIAL AND POLAR RADII FROM SST AND ALMA
THE SUBTERAHERTZ SUN
EQUATORIAL AND POLAR RADIi FROM SST AND ALMA
Why?

- Related to solar activity
- Its variations over time indicate changes in the solar atmosphere
- Important parameter to improve solar atmosphere models
- Gap of subterahertz frequencies in the measurements of the solar radius and other parameters of the atmosphere
Why?

- Related to solar activity
- Its variations over time indicate changes in the solar atmosphere
- Important parameter to improve solar atmosphere models
- Gap of subterahertz frequencies in the measurements of the solar radius and other parameters of the atmosphere

F. M. Menezes
menezes.astroph@gmail.com
Why?

- Related to solar activity
- Its variations over time indicate changes in the solar atmosphere
- Important parameter to improve solar atmosphere models.
- Gap of subterahertz frequencies in the measurements of the solar radius and other parameters of the atmosphere
Why?

- Related to solar activity
- Its variations over time indicate changes in the solar atmosphere
- Important parameter to improve solar atmosphere models
- Gap of subterahertz frequencies in the measurements of the solar radius and other parameters of the atmosphere
Why?

- Related to solar activity
- Its variations over time indicate changes in the solar atmosphere
- Important parameter to improve solar atmosphere models.
- **Gap of subterahertz frequencies** in the measurements of the solar radius and other parameters of the atmosphere
Solar Radius

- $R_{\odot}^N = 6.957 \times 10^8$ m
- Centuries of measures
  - Vaquero et al. (2016) - 233 years
  - Gilliland (1981) - 265 years
- Radio wavelengths started some decades ago
Solar Radius

- \( R_\odot^N = 6.957 \times 10^8 \text{ m} \)
- Centuries of measures
  - Vaquero et al. (2016) - 233 years
  - Gilliland (1981) - 265 years
- Radio wavelengths started some decades ago
### Solar Radius

<table>
<thead>
<tr>
<th>ν (GHz)</th>
<th>R (Mm)</th>
<th>ν (GHz)</th>
<th>R (Mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>719</td>
<td>48 b</td>
<td>713.4</td>
</tr>
<tr>
<td>16</td>
<td>718</td>
<td>70</td>
<td>703</td>
</tr>
<tr>
<td>17</td>
<td>708.3</td>
<td>74</td>
<td>701</td>
</tr>
<tr>
<td>22</td>
<td>712</td>
<td>94</td>
<td>705</td>
</tr>
<tr>
<td>25</td>
<td>710</td>
<td>100 c</td>
<td>699.2</td>
</tr>
<tr>
<td>30</td>
<td>710.0</td>
<td>100 d</td>
<td>701</td>
</tr>
<tr>
<td>35</td>
<td>709.9</td>
<td>231</td>
<td>702.2</td>
</tr>
<tr>
<td>44</td>
<td>708.5</td>
<td>239</td>
<td>697.1</td>
</tr>
<tr>
<td>48 a</td>
<td>705.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Graph showing solar radius variation](image-url)
## Solar Radius

<table>
<thead>
<tr>
<th>( \nu ) (GHz)</th>
<th>( R ) (Mm)</th>
<th>( \nu ) (GHz)</th>
<th>( R ) (Mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>719</td>
<td>48 b</td>
<td>713.4</td>
</tr>
<tr>
<td>16</td>
<td>718</td>
<td>70</td>
<td>703</td>
</tr>
<tr>
<td>17</td>
<td>708.3</td>
<td>74</td>
<td>701</td>
</tr>
<tr>
<td>22</td>
<td>712</td>
<td>94</td>
<td>705</td>
</tr>
<tr>
<td>25</td>
<td>710</td>
<td>100 c</td>
<td>699.2</td>
</tr>
<tr>
<td>30</td>
<td>710.0</td>
<td>100 d</td>
<td>701</td>
</tr>
<tr>
<td>35</td>
<td>709.9</td>
<td>231</td>
<td>702.2</td>
</tr>
<tr>
<td>44</td>
<td>708.5</td>
<td>239</td>
<td>697.1</td>
</tr>
<tr>
<td>48 a</td>
<td>705.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Graph showing the variation of solar radius with frequency](image)

F.M. Menezes
menezes.astroph@gmail.com
Correlation to solar activity

- Costa et al. (1999)
  - Rádio Observatório de Itapetinga (ROI)
  - 48 GHz single-dish
  - 1991 - 1993 (3 yrs)
Correlation to solar activity

- Costa et al. (1999)
  - Rádio Observatório de Itapetinga (ROI)
  - 48 GHz single-dish
  - 1991 - 1993 (3 yrs)

\[
\frac{R_{48}}{R_{26}} = 1.029 - 0.0015(\text{year} - 1990)
\]
Correlation to solar activity

- Selhorst et al. (2004)
  - 17 GHz from NoRH
  - 1992 - 2003 (1 cycle)
  - Correlation coefficient: 0.88
  - Polar radius: corr. coef.: -0.64
Correlation to solar activity

- Selhorst et al. (2004)
  - 17 GHz from NoRH
  - 1992 - 2003 (1 cycle)
  - Correlation coefficient: 0.88
  - Polar radius: corr. coef.: -0.64
Correlation to solar activity

- Selhorst et al. (2004)
  - 17 GHz from NoRH
  - 1992 - 2003 (1 cycle)
  - Correlation coefficient: 0.88
  - Polar radius: corr. coef.: -0.64
Correlation to solar activity

- Selhorst et al. (2004)
  - 17 GHz from NoRH
  - 1992 – 2003 (1 cycle)
  - Correlation coefficient: 0.88
  - Polar radius: corr. coef.: -0.64

F. M. Menezes menezes.astroph@gmail.com
Goals

- Average solar radius at 0.212 and 0.405 THz
- Height above photosphere where these emissions are being mainly created
- Variation of the solar radius in relation to the solar cycle
Goals

- Average solar radius at 0.212 e 0.405 THz
- Height above photosphere where these emissions are being mainly created
- Variation of the solar radius in relation to the solar cycle
Goals

- Avarage solar radius at 0.212 e 0.405 THz
- Height above photosphere where these emissions are being mainly created
- Variation of the solar radius in relation to the solar cycle
Goals

- Avarage solar radius at 0.212 e 0.405 THz
- Height above photosphere where these emissions are being mainly created
- Variation of the solar radius in relation to the solar cycle
Solar Submillimeter Telescope

- CASLEO - San Juan, Argentina (Andes, 2550 m)
- from 1999 to 2017
- 0.212 THz: 4 beams, HPBW = 4'
- 0.405 THz: 2 beams, HPBW = 2'
- Time resolution: 5 millisec.
Solar Submillimeter Telescope

- CASLEO - San Juan, Argentina (Andes, 2550 m)
- from 1999 to 2017
- 0.212 THz: 4 beams, HPBW = 4'
- 0.405 THz: 2 beams, HPBW = 2'
- Time resolution: 5 millisec.
Solar Submillimeter Telescope

---

ADC

- quiet Sun

limb

background

---

F. M. Menezes
menezes.astroph@gmail.com
Background, quiet sun & limb levels

- Background is the most common value (mode)
- Quiet Sun level is the most common value within the solar disk (second peak in the histogram)
- Limb level is the half of the quiet Sun level
Background, quiet sun & limb levels

- Background is the most common value (mode)
- Quiet Sun level is the most common value within the solar disk (second peak in the histogram)
- Limb level is the half of the quiet Sun level
Background, quiet sun & limb levels

- Background is the most common value (mode)
- Quiet Sun level is the most common value within the solar disk (second peak in the histogram)
- Limb level is the half of the quiet Sun level
Background, quiet sun & limb levels

- Background is the most common value (mode)
- Quiet Sun level is the most common value within the solar disk (second peak in the histogram)
- Limb level is the half of the quiet Sun level
Get the coordinates corresponding to the limb level

Made for every scan of the map

Background, quiet sun & limb levels
Background, quiet sun & limb levels

- Get the coordinates corresponding to the limb level
- Made for every scan of the map
Background, quiet sun & limb levels

- Get the coordinates corresponding to the limb level
- Made for every scan of the map

F. M. Menezes
menezes.astroph@gmail.com
Get the coordinates corresponding to the limb level

Made for every scan of the map
Background, quiet sun & limb levels

- Get the coordinates corresponding to the limb level
- Made for every scan of the map
Background, quiet sun & limb levels

- Get the coordinates corresponding to the limb level
- Made for every scan of the map
Background, quiet sun & limb levels

- A circle (red line) is fitted using the limb points
- Correction due to Earth’s orbit eccentricity
Background, quiet sun & limb levels

- A circle (red line) is fitted using the limb points
- Correction due to Earth’s orbit eccentricity
Results

0.212 THZ

0.405 THz
## Results

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Radius (arcsec)</th>
<th>Radius ($R_\odot$)</th>
<th>Radius (10$^8$ m)</th>
<th>Altitude (10$^6$ m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>212 GHz</td>
<td>966 ± 2.7</td>
<td>1.007 ± 0.003</td>
<td>7.01 ± 0.02</td>
<td>5.0 ± 2.0</td>
</tr>
<tr>
<td>405 GHz</td>
<td>966 ± 2.6</td>
<td>1.007 ± 0.003</td>
<td>7.01 ± 0.02</td>
<td>5.0 ± 2.0</td>
</tr>
<tr>
<td>Optical</td>
<td>959.63</td>
<td>1</td>
<td>6.957</td>
<td>0</td>
</tr>
</tbody>
</table>

F. M. Menezes
menezes.astroph@gmail.com
ALMA

- 0.239 THz
- 2015 Dec 17

<table>
<thead>
<tr>
<th>0.2 THz</th>
<th>( R ) (arcsec)</th>
<th>( R ) ((10^8 \text{ m}))</th>
<th>Height ((10^6 \text{ m}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>SST</td>
<td>966 ± 2.7</td>
<td>7.01 ± 0.02</td>
<td>5.0 ± 2.0</td>
</tr>
<tr>
<td>ALMA</td>
<td>962.9 ± 1.9</td>
<td>6.980 ± 1.3</td>
<td>2.3 ± 1.3</td>
</tr>
</tbody>
</table>
Results

![Graph showing results with various data points and labels.](image-url)
Correlation to the sunspot cycle

\[
\rho_{R_u, S_{act}} = -0.755
\]

\[
\rho_{R_u, S_{act}} = -0.862
\]

0.212 THz

0.405 THz
Equatorial and polar radii

- Equatorial radius
- Polar radius
### Equatorial and polar radii

<table>
<thead>
<tr>
<th></th>
<th>All pts.</th>
<th>Equat.</th>
<th>Polar</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ALMA (0.2 THz)</strong></td>
<td>962.9 ± 1.9</td>
<td>964.2 ± 1.9</td>
<td>962.1 ± 1.1</td>
</tr>
<tr>
<td><strong>SST (0.2 THz)</strong></td>
<td>966 ± 2.7</td>
<td>966 ± 3.3</td>
<td>966 ± 3.5</td>
</tr>
<tr>
<td><strong>SST (0.4 THz)</strong></td>
<td>966 ± 2.6</td>
<td>967 ± 3.2</td>
<td>966 ± 3.4</td>
</tr>
</tbody>
</table>

- **Equatorial radius**
- **Polar radius**
Correlation to the sunspot cycle

0.212 THZ

0.405 THz
Correlation to the sunspot cycle

<table>
<thead>
<tr>
<th>SST</th>
<th>All pts.</th>
<th>Equat.</th>
<th>Polar</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2 THz</td>
<td>-0.75</td>
<td>-0.40</td>
<td>-0.54</td>
</tr>
<tr>
<td>0.4 THz</td>
<td>-0.86</td>
<td>0.28</td>
<td>-0.80</td>
</tr>
</tbody>
</table>

- Equatorial radius
- Polar radius
Final remarks

- Mean solar radii at both frequencies, \( R = 966'' \pm 3'' \)
- Between 2500 - 7500 km above photosphere (chromosphere - corona)
- Solar atm. models predict these freq. to be at the chromosphere
- Polar radii at both freq. are anticorr. to sunspot cycle
- At 17 GHz there are a significant increase of polar limb brightening during solar minimum (Selhorst, 2004)
- High solar activity is associated with increased magnetic fields, which would lead to a reduced energy flux transported by convection (Gilliland, 1981).
- 0.405 THz equat. radius weakly correlated to sunspot cycle
- 0.212 THz equat. radius anticorrelated to sunspot cycle