Solar radio observations

Silja Pohjolainen

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Solar structure

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Solar radio observations
Fig. 4.12 The variation of temperature with height in the solar atmosphere up to the transition region for an average quiet-sun region. Also indicated are the height ranges over which the Hα and Ly-α, Ca II H and K, and Mg II h and k lines are formed. (After Vernazza, Avrett and Loeser (1981))

- 13 mm radio emission (quiet Sun, plasma limit)
- 3 mm radio emission (quiet Sun, plasma limit)
Temperatures and densities in the solar atmosphere

Temperature is increasing outward:

![Graph showing temperature increase with height above the convection zone in the solar atmosphere]
Density is decreasing outward:

\[ R = \text{solar radius}, \text{ Earth is at distance } 214 \ R \]

Plasma limit (in gaussian units): $\nu_p \approx 9000 \sqrt{n_e}$
Emission mechanisms and frequency ranges

Solar Geophysical Data: Radio burst classification

Spectral type --
I = storm bursts
II = slow drift bursts
III = fast drift bursts
IV = prolonged continuum
V = brief continuum (normally following Type III burst)

CONTINUUM = continuum in close association with Type III burst storms, often with reverse drift bursts and often, but not always, associated with noise storms on metric wavelengths (used by SWG). One metric burst may produce a group of contiguous continuum features.

DCIM = decimetric burst defined by very fast drift spike or group of spikes with very high degree of polarization extending usually less than one octave in or close to decimeter range.

UNCLF = unclassified activity.
Quiet Sun brightness temperature $T_b$

![Graph showing the relationship between $T_b$ and wavelength $\lambda$.](image)

**Fig. 5.**—Selected brightness temperature observations of the Sun at millimeter wavelengths

Vernazza, Avrett & Loeser, 1981
Example: Solar flux density

\[ S = \frac{2k\nu^2}{c^2} \int T_b \, d\Omega \quad (W \, m^{-2} \, Hz^{-1}) \]

\[ T_b \approx 7200 \, K \text{ at } f = 37 \, GHz \]

\[ D(\text{sun}) \approx 0.5^\circ, \Omega_{\text{sun}} \approx D^2 = 7.6 \times 10^{-5} \, \text{sr} \]

\[ S = 2.3 \times 10^{-19} \, W \, m^{-2} \, Hz^{-1} = 2300 \, \text{sfu} \]

\[ \text{sfu} = 10^{-22} \, W \, m^{-2} \, Hz^{-1} = 10^4 \, \text{Jy} \]
Example: Observed solar flux density

\[ D(\text{antenna}) = 14 \text{ m} \]
\[ A = \pi r^2 = 154 \text{ m}^2 \]
\[ A_{ef} = 0.5 \times 154 = 77 \text{ m}^2 \]

\[ f = 37 \text{ GHz}, \quad \lambda = \frac{c}{f} = 0.008 \text{ m} \]
\[ \text{beam (HPBW)} \quad \theta \approx 1.02 \times \frac{\lambda}{D} = 0.00058 \text{ rad} = 0.03^\circ \]
\[ D(\text{sun}) \approx 0.5^\circ \text{ (Sun > beam)} \]

\[ T_A \approx T_b \approx 7200 \text{ K} \text{ (Earth atmosphere ignored)} \]

\[ S_0 = \frac{2kT_A}{A_{ef}} \]

\[ = 2.6 \times 10^{-21} \text{ W m}^{-2} \text{ Hz}^{-1} = 26 \text{ sfu} \]

For a 2-m antenna with similar efficiency \( S_0 = 1266 \text{ sfu} \)
\( (\theta \approx 0.23^\circ) \)
Calibration

- Absolute calibration using radio sources and hot+cold loads
- No calibration, using units relative to quiet Sun level

The method of using relative solar flux units provides the advantage of removing atmospheric and radome effects (variable attenuation) and instrumental effects, but it is more sensitive to errors in quiet Sun level determination.

Furthermore, the true source size of the radio emitting region in solar flares is not always known and it can vary from a few arc seconds to several arc minutes.
Relative radio brightness

\[ T_{b,\nu} = X \text{ Kelvin} \] (quiet Sun brightness temperature at frequency \( \nu \) from literature or absolute calibrations)

\[
\text{On-Sun} - \text{Off-Sun} = Y \text{ mV} \\
\implies Y \text{ mV} \equiv X \text{ Kelvin}
\]
Solar flares, ejections, and shock waves

NASA/SDO

Silja Pohjolainen

Solar radio observations
Solar flares, ejections, and shock waves

From: Warmuth, Lecture Notes in Physics 725, 2007
Emission from flare loops at micro- and mm-waves

A simple model for a flare loop and associated emission (Gurman, 1987)
Radio emission can be produced by a two-stepped process, where electrostatic oscillations are first excited at or near the plasma frequency (e.g. by an energetic electron beam) and after that the **Langmuir wave** energy is converted to electromagnetic radiation via non-linear wave-wave interactions.

Plasma radiation occurs at or just above the plasma frequency $\nu_p$ and its second harmonic $2\nu_p$, but rarely at higher harmonics.
Shock wave $\rightarrow$ accelerated electrons $\rightarrow$ plasma oscillations, Langmuir waves $\rightarrow$ radio emission observed in dynamic spectra.
Determining shock speed from radio dynamic spectra

\[ \nu_p \approx 9000 \sqrt{n_e} \]

01:50:10 UT – 100 MHz – \(1.2 \times 10^8\) cm\(^{-3}\) \(\rightarrow h = 209\,000\) km

01:53:20 UT – 70 MHz – \(6.0 \times 10^7\) cm\(^{-3}\) \(\rightarrow h = 313\,000\) km

\(\Delta h = 104\,000\) km, \(\Delta t = 190\) s \(\rightarrow v \approx 550\) km/s
Radioheliograph imaging of particle streams

The Nancay Radioheliograph is an interferometer that consists of 44 antennas, sizes ranging from 2 to 10 meters, spread over two arms (EW and NS) with respective lengths of 3200 m and 2440 m.

NRH observes 7 hours per day with up to 10 frequencies between 150 and 450 MHz.

Background image: magnetogram with potential field lines
Solar ALMA observations: Opportunities and issues

- **The Sun is very bright radio source**
  - Good S/N can be reached with very short observing times
  - ALMA is sensitive, we (usually) need attenuation
  - How does it compare to relatively much weaker calibrators?

- **The Sun is highly VARIABLE source**
  - ALMA sensitivity and Sun's brightness (and proximity $\rightarrow$ small linear sizes of sources) enable study of dynamics at short timescales
  - How to cope with unpredictable but extremely interesting transient events?
  - Current version of AOT seem not to support 'movie' regime
  - Will we have sufficient # of baselines for short scans?

Solar ALMA-related talks at
http://www.astro.gla.ac.uk/~eduard/solarALMA/program.html
Future of solar observations at high frequencies

Solar ARC Node in Czech Republic
Bartosz Dabrowski
Marian Karlicky
Miroslav Barta
ALMA Regional Centre, Czech Republic

Solar ALMA Workshop
Glasgow, 14 – 17 January 2013