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Solar Observations with LOFAR

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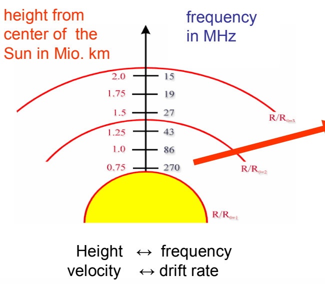
Solar radio radiation

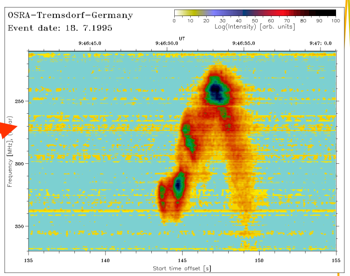
The Sun is an intense radio source. The thermal emission of the 10^6 K hot outer atmosphere, the corona, is superimposed by bursts of non-thermal radio radiation caused by energetic electrons, that are produced by the phenomena of the active Sun, like flares and coronal mass ejections (CMEs).

Solar radio radiation in LOFAR's frequency range of 30 – 80 MHz is plasma emission. The frequency of these radio waves is determined by the local plasma frequency at the source, that only depends on the electron number density:

$$f = \sqrt{N_e e^2/(m_e \epsilon_0)}/(2\pi)$$

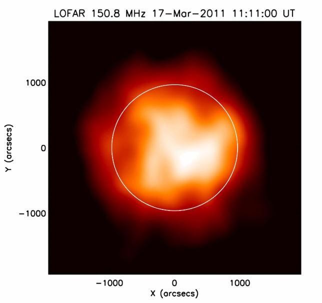
So a density model of the solar corona provides a link between frequency and height:

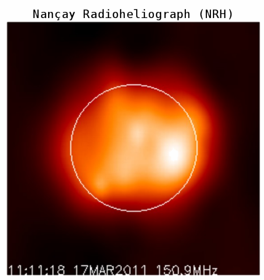




Imaging the Sun with LOFAR

The plasma in the solar corona is turbulent, and its refractive index is very small near the sources of nonthermal radio emission. Therefore, solar radio radiation is strongly scattered within the corona. This limits the angular resolution of solar radio images to a few 10s of arcseconds. Therefore, only LOFAR's core and nearest remote stations are used for solar imaging.



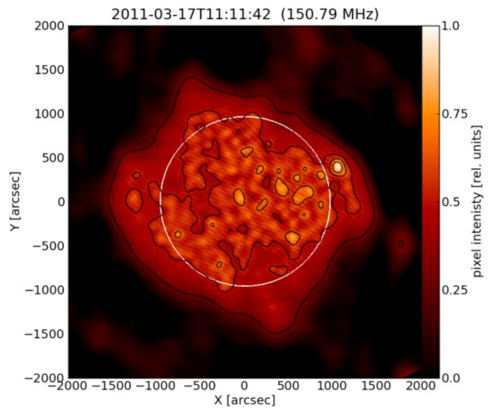


Observation time start:	2011-03-17T11:11:00
Frequency range (MHz):	150.708 - 150.879
Wavelength range (m):	1.988 - 1.986
Subband width (KHz):	170.9
Integration time (s):	1.0
Subband no.:	183
Duration (min):	3.0
No. of antennas:	31
Max baseline (km):	25

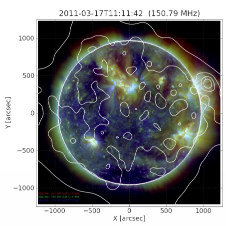
LOFAR (left) and Nançay (right) image of the radio Sun taken on 17 March 2011.

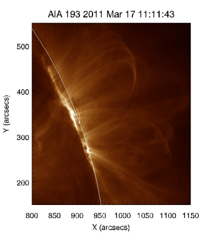
Solar imaging comes with the special challenge that the Sun is a bright, extended source that changes in time. This needs to be considered in the calibration step of the solar imaging pipeline. The above image was obtained with a Gaussian intensity distribution as inital sky model.

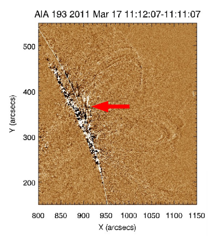
First LOFAR solar radio burst observation



On 17 March 2011 at 11:11:42 UT, a short solar radio burst was recorded during a commissioning observation. It is visible off the western limb in the figure above.



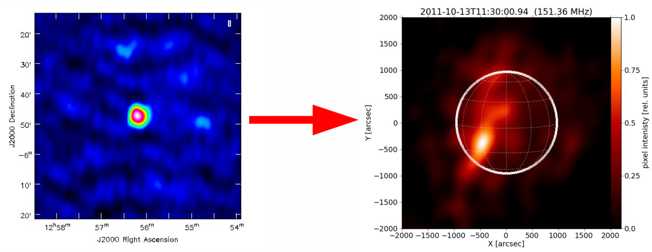




The left image shows the LOFAR isolines plotted over an EUV image of the Sun recorded in the 17.1nm FeIX/X line by the AIA instrument onboard NASA's *Solar Dynamics Observatory* (SDO) spacecraft. The active region responsible for the burst is enlarged in the middle image. Closed loops connecting areas of opposite magnetic polarity are nicely seen.

The running difference AIA image to the right, obtained over the same time period as the burst, reveals that a faint plasma jet is occuring during the burst. Such a jet appears as the result of magnetic reconnection.

Use of external calibration sources



Solar imaging can be greatly improved by the use of external calibration sources. The above example shows 3C279 (left) as calibrator for the Sun during an observation on 13 October 2011. Use of external calibration removes the need for an initial model for the unkown spatial distribution and intensity of solar radio radiation, and allows for a more precise localisation of radio sources on the solar disk.