The potential of near real-time solar observation at 1.4 GHz:

Validation of the SMOS mission for Space Weather operations

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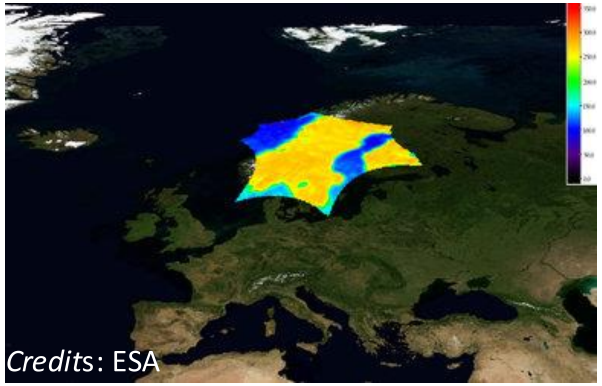
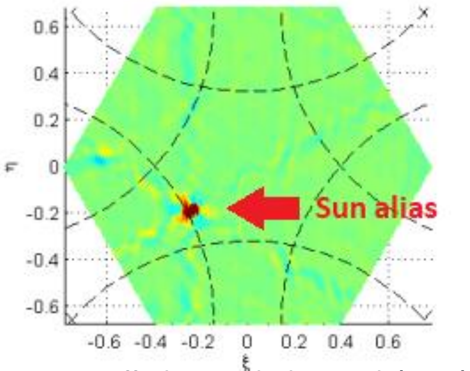
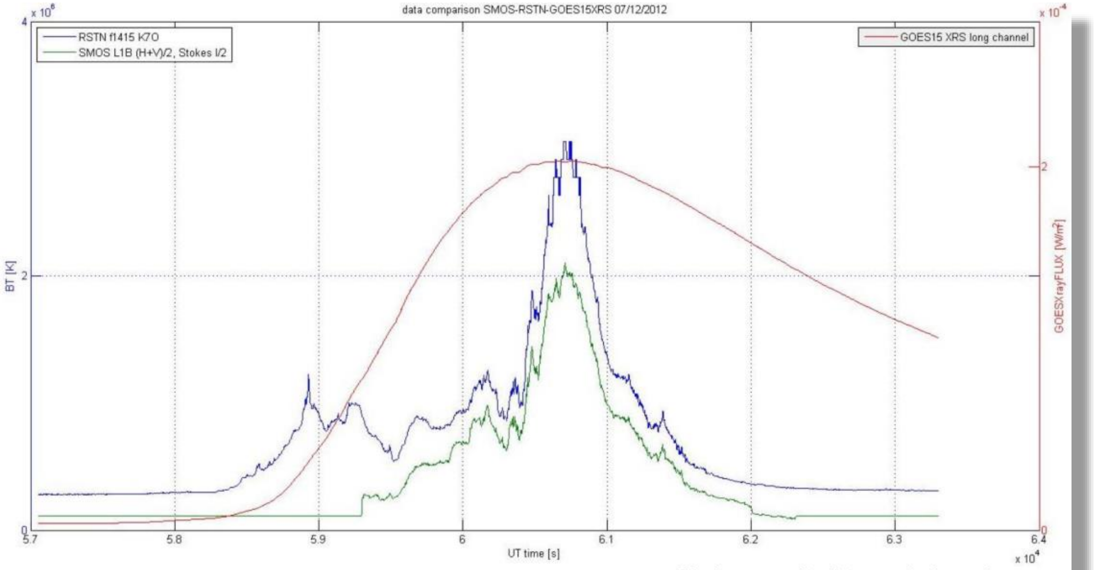
Abstract: The SMOS satellite is an ESA mission dedicated to making observations of soil moisture and oceans salinity, which raw data are known to be affected by a noise of solar origin. A close inspection of this noise reveals that it corresponds to solar thermal and non-thermal radiation. In this presentation we evaluate the SMOS mission as a source of solar radio observations for scientific and space weather applications. We found it to be particularly promising to nowcast CMEs produced by flares as well as interferences that could affect GNSS services and radar operations.

How SMOS sees the Sun


Credits: ESA

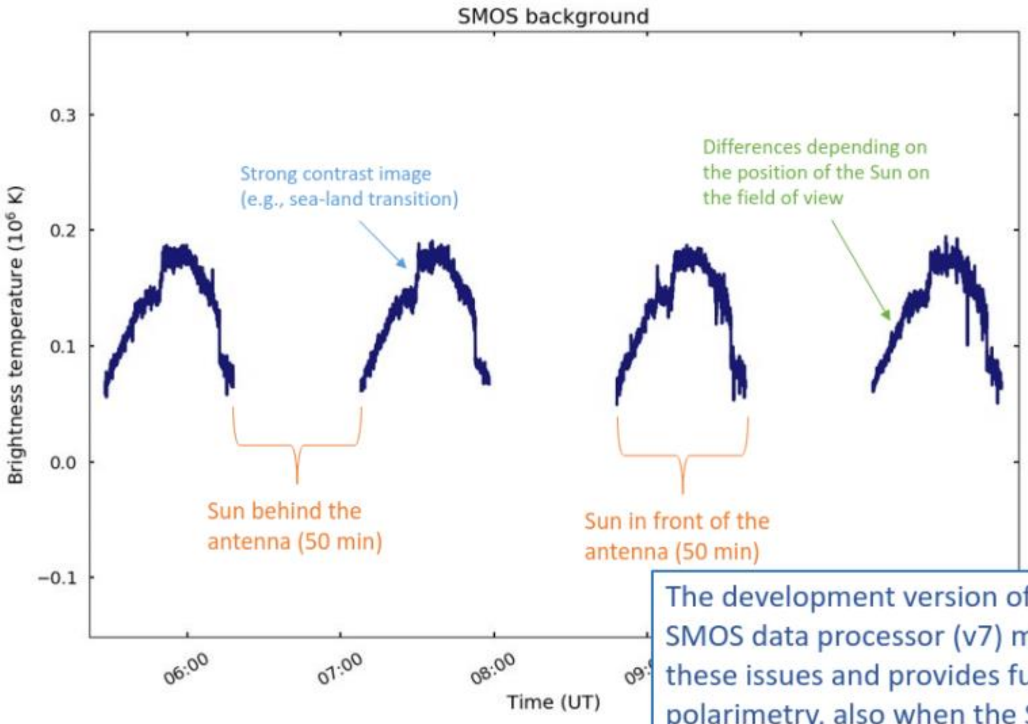


Raffaele Crapolicchio et al. (2016)



Raffaele Crapolicchio et al. (2016)

But noise recycling has its problems...



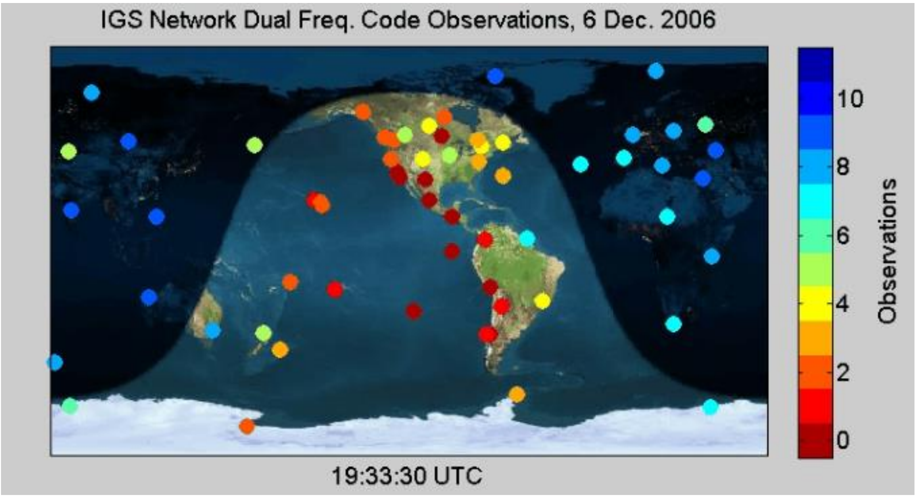
The development version of the SMOS data processor (v7) minimizes these issues and provides full polarimetry, also when the Sun is in the back of the antenna.

Earth images taken by SMOS are contaminated by a Sun alias.

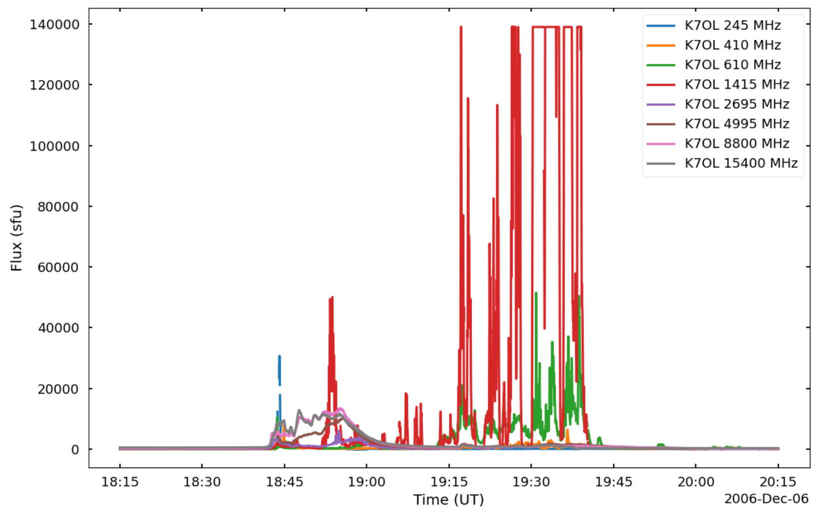
The temporal variation of the alias during solar flares agrees well with the 1.4 GHz radio bursts detected by the RSTN (Raffaele Crapolicchio et al. 2016).

Impact of strong 1.4 GHz bursts on radio-based systems

Global navigation satellite systems such as GPS or Galileo operate in frequencies in the range 1.1 - 1.6 GHz and are known to be affected by strong solar radio burst. The following example shows the impact of the 6 Dec. 2006 event, which had a large impact on GPS positioning (Carrano et al. 2009). Many IGS receivers did not meet operational requirements as they were tracking fewer than four satellites (Cerruti et al 2008). The 1.4 GHz radio burst was strong enough to saturate the K7OL/RSTN receiver.

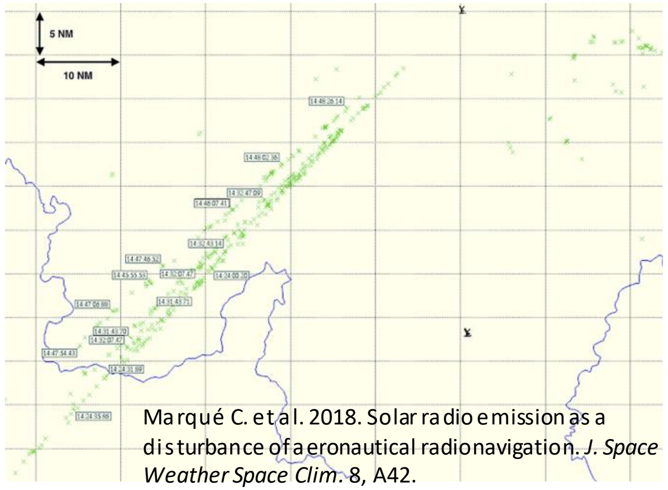


Credits: GPS Laboratory at Cornell University

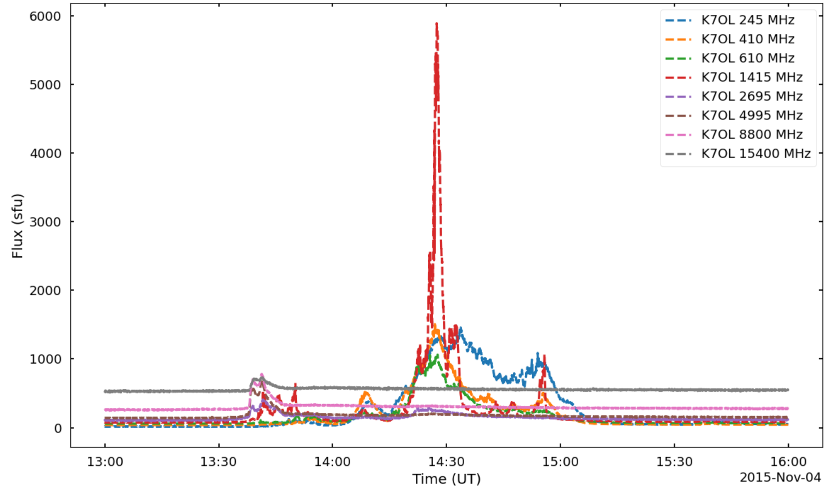


Near real-time observations at frequencies above 1 GHz are rarely available. Data of the same polarization state as the one used by radio-based systems usually don't even exist.

Solar radio burst can have negative effects on L-band air control radars. The following images show the false echoes observed at a Belgian radar station and the radio burst responsable of them. Note that the associated X-ray flare was just a GOES M3.7 flare.

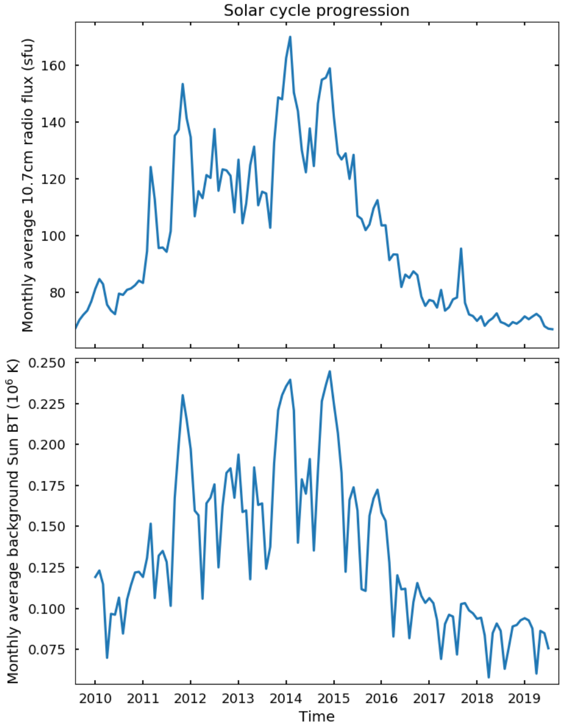


Marqué C. et al. 2018. Solar radio emission as a disturbance of aeronautical radionavigation. *J. Space Weather Space Clim.* 8, A42.

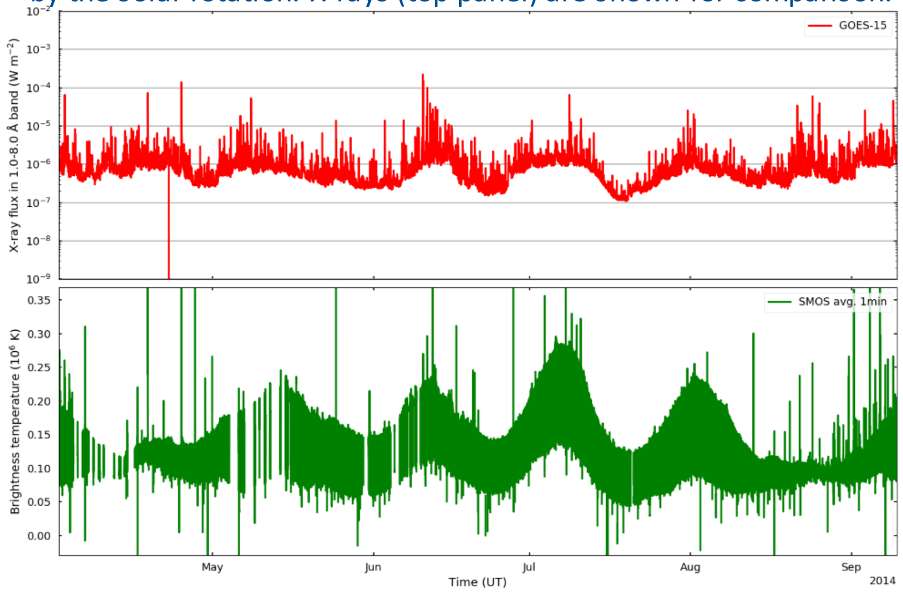


What SMOS can see

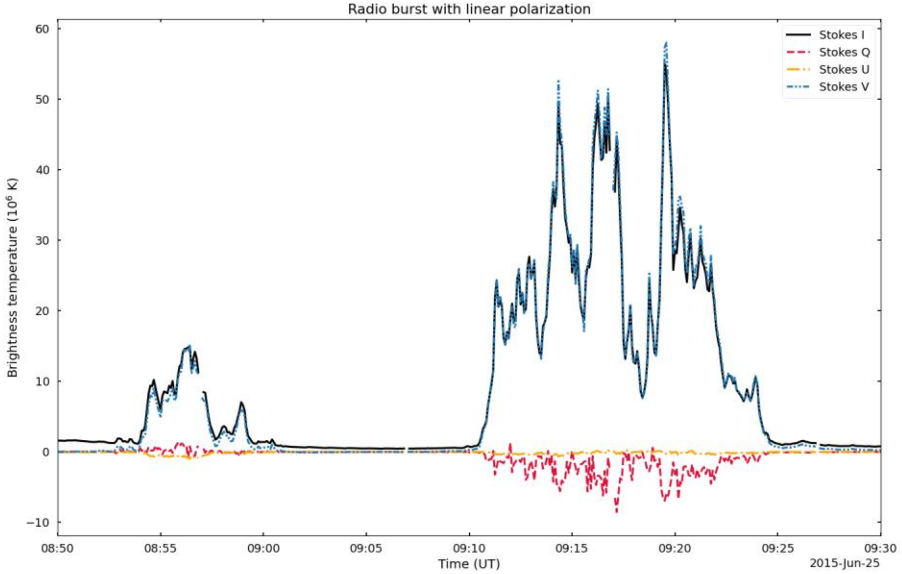
Progression of activity cycle. Data from the Canadian 10.7 cm solar flux monitors (top panel) are shown for comparison. The monthly average background Sun BT from SMOS (bottom panel) is somewhat affected by an orbital artifact.



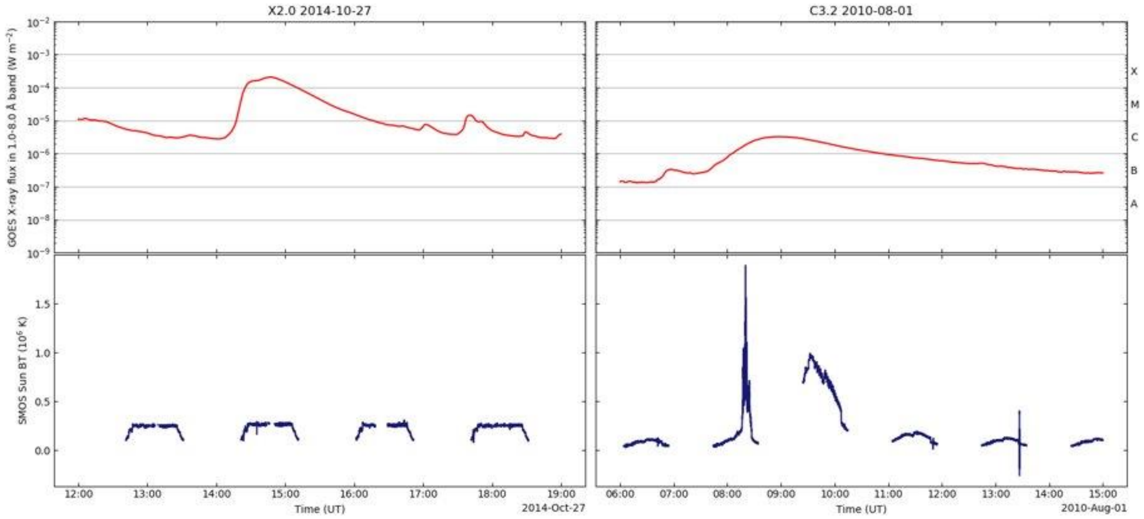
Periodic oscillations in the thermal emission of the Sun produced by the solar rotation. X-rays (top panel) are shown for comparison.



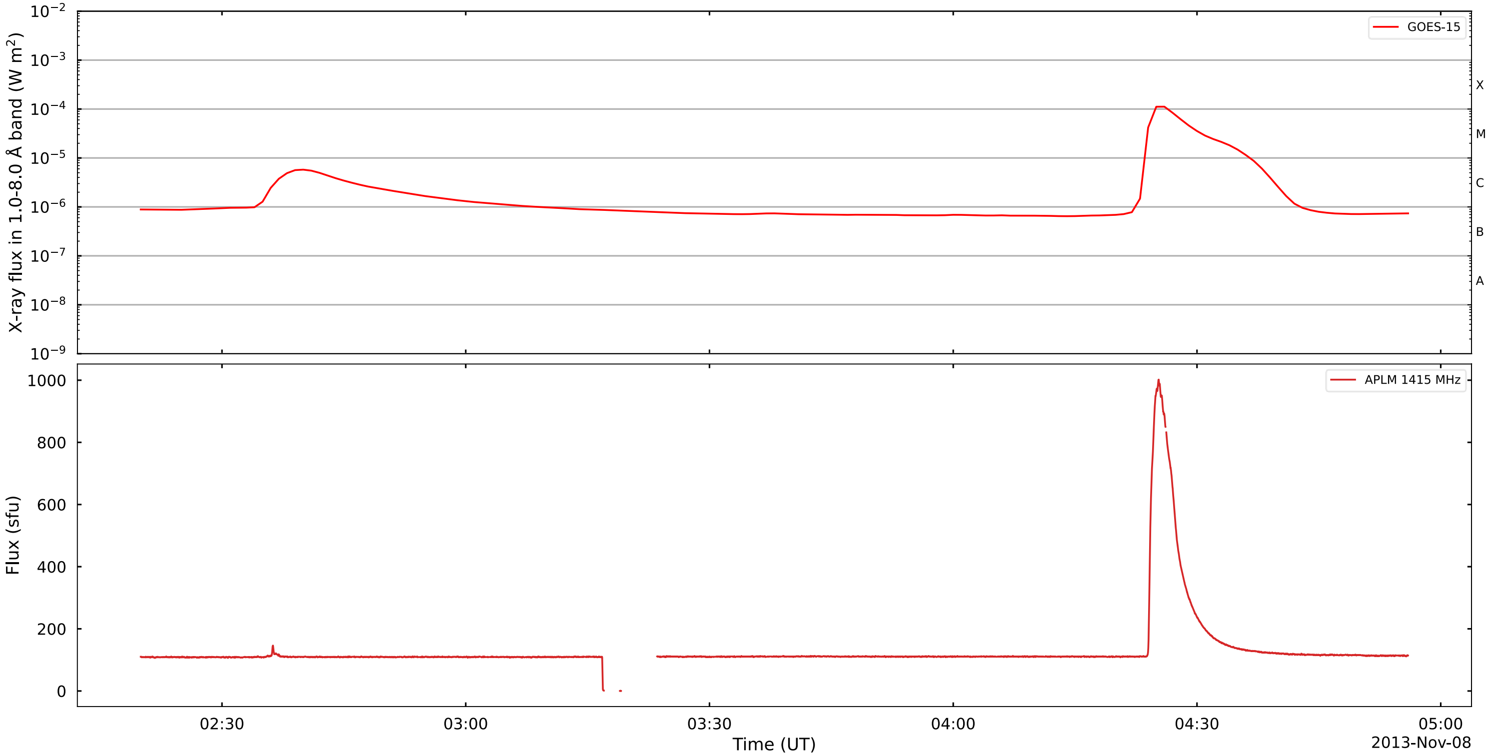
Linear polarization in radio bursts. So far only associated to Earth-directed CMEs, but the data sample with full Stokes polarimetry is still small (Stokes parameters are not yet calibrated).

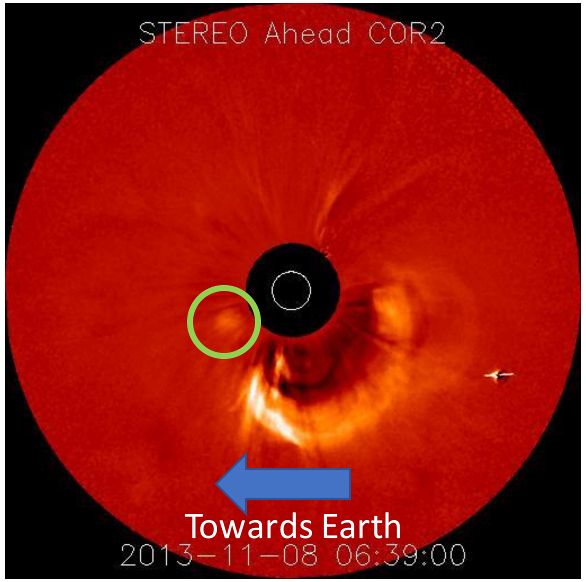


Alert scales for radio blackouts are currently based on GOES X-ray brightness. Nonetheless these show sometimes little correlation with problematic space weather conditions. The left panels show a strong X-ray flare (top panel) that triggered a R3 alert but ended having no important effects. SMOS detected nothing (bottom panel). The right panels show on the other hand a weak X-ray flare that did not trigger any alert, but which effects were noted on Earth's environment. SMOS detected moderately strong radio bursts.



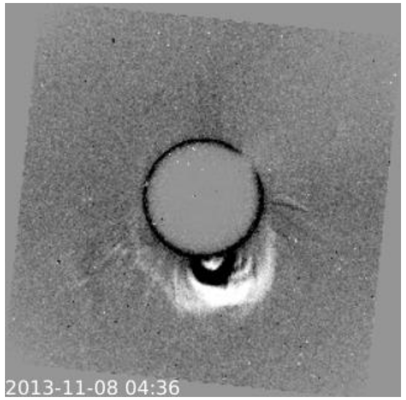
1.4 GHz bursts as counterpart to CMEs from the visible hemisphere: Example case

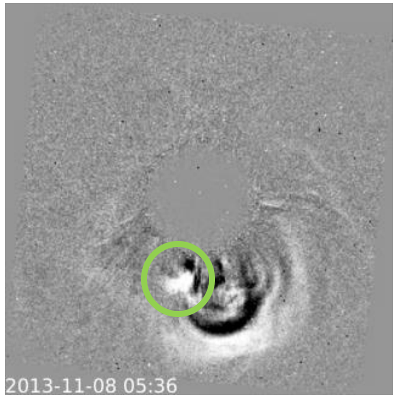




3) STEREO data confirm the two CMEs scenario, one on each side of the Sun.

1) Slow CME detected by LASCO/C2 at 03:24, right after a minor C-class flare. Negligible radio emission at 1.4 GHz suggests that the CME could have nothing to do with the flare but that it could be originated on the backside of the Sun.





2) A second flare, this time a X1.1, occurs one hour later. Despite the moderately strong 1.4 GHz radio burst, neither automatic nor manual CME catalogs report a second CME. Careful inspection reveals nonetheless that there is indeed a second CME hiding right in front of the first one (green circle).

Conclusions

The SMOS Sun BT data have a rather unusual origin but have proved to be a promising instrument for space weather.

SMOS has the potential of providing:

- 24 hours a day of near real-time observations at 1.4 GHz with full polarimetry
- Sensitivity comparable to that of solar radiotelescopes, even though SMOS was never designed for that purpose
- Continuous monitoring of solar interferences affecting GNSS, radar and L-band wireless communications (e.g., mobile telephony)
- Early assessment of flares geoeffectiveness

But there are also some problems. In its current state, the SMOS Sun BT is not really a product but just a by-product of the SMOS data reduction algorithm. As such it is affected by lack of calibration, not properly flagged (non-solar) radio frequency interferences and some inconsistencies depending on data extraction method. In order to provide an optimal data source for space weather services SMOS would require a dedicated product for solar observations.

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