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Solar radio emission as a disturbance of aeronautical radionavigation
Perturbation du contrôle radar aérien par un sursaut radio solaire

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Abstract:
We present an overview of a solar radio burst that perturbed air traffic control radar in Sweden and other European countries on 4th November 2015. The spectral features of the radio burst are described. It is shown that it is particularly bright because of coherent emission processes. Such events are not predictable today. A systematic study of such events and the understanding of their impact on aviation will need a close cooperation between research and air traffic authorities.

Résumé:
Nous présentons un sursaut radio solaire qui a perturbé le contrôle radar aérien en Suède et d'autres pays européens, le 4 Novembre 2015. Nous décrivons les caractéristiques du spectre radio, montrant que l'émission est particulièrement forte parce qu'elle est cohérente. Il n'est pas possible aujourd'hui de prévoir de telles événements. Une collaboration étroite entre les chercheurs et les autorités de contrôle aérien sera nécessaire pour une étude systématique et la compréhension de l'importance pour l'aviation qu'a ce type d'émission radio.

1 An air traffic control incident in Sweden, 4th November 2015

On 4th November 2015 secondary air traffic control radar was strongly disturbed in Sweden and some other European countries. At some Swedish airports airplanes were not allowed to start during about one hour, and incoming aircraft were diverted. Belgian air traffic control noted disturbances when the radar antennas were pointing sunward, in particular in two time intervals lasting some minutes each, near 14:20 and 14:46 UT. The reasons for the disturbances were searched in a space weather event. The Sun was rapidly suspected as the source of the problem. It occurred at a time when the Sun was close to the horizon in Stockholm.

2 The solar radio burst

Secondary air traffic control radar is operated at frequencies of 1030 and 1090 MHz. A major solar flare occurred on the Sun at the time of the disturbances. The time evolution of the X-ray emission is shown in the bottom panel of Figure 1. The observations are from the *Geostationary Operational Environmental Satellite* (GOES) spacecraft operated by NOAA. The X-rays reflect the heating of a region in the corona overlying a sunspot group, from the usual ambient temperature of one to two million K to a few tens of millions of K. The time history shows an initial impulsive heating during the rise, lasting about 10 minutes, and a subsequent decrease of the heat input and a long-lasting cooling phase during the decay of the emission. The peak is reached near 13:50 UT. The top panel of Figure 1 shows the whole Sun radio flux observed by spectrographs at Humain (Royal Observatory Belgium; 1000-1500 MHz) and Nançay (Paris Observatory; ORFEES, 140-1000 MHz). Observations were also taken at Bleien (ETH Zürich), but are not shown here. The observations are presented as a dynamic radio spectrum. The radio flux is given by the shading in the time-frequency plane, dark shading meaning bright emission.

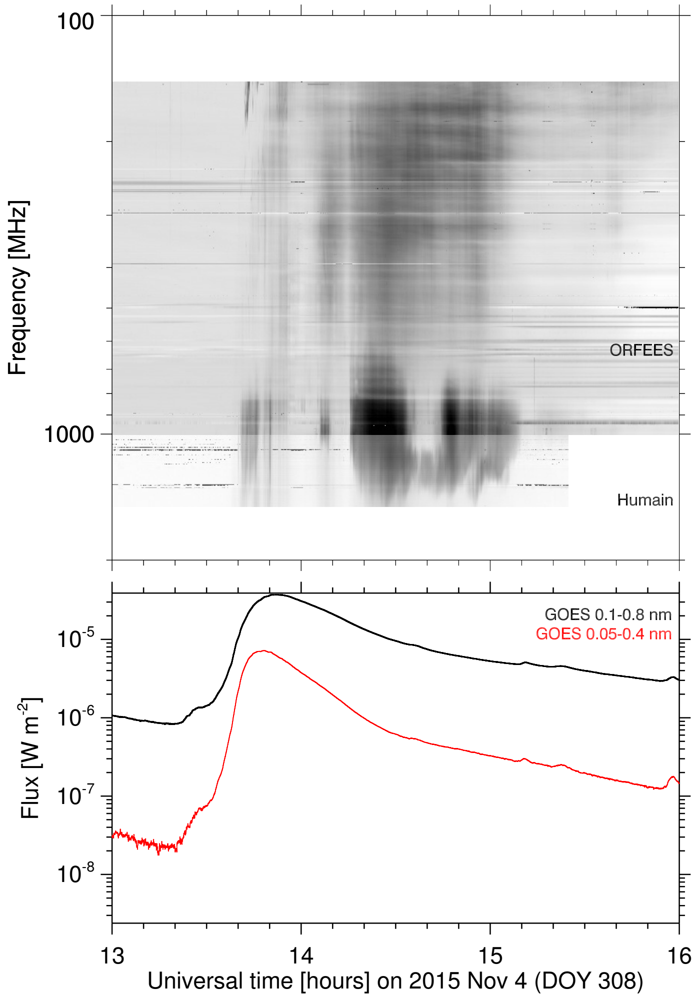

Figure 1 – Time history of the solar X-ray (bottom panel; GOES) and radio emission (top panel; spectrographs at Humain and Nançay radio observatories) on 4th November 2015. Strong radio fluxes are indicated by dark shading. Horizontal stripes are residuals of terrestrial emitters, which could not be fully remove from the data.

Like the X-rays, the radio emission has a duration of more than an hour. The timing is, however, quite different from the X-rays: the strongest radio emission occurs during the decay of the soft X-ray burst. The emission is brightest at frequencies between about 800 and 1400 MHz. A more detailed analysis of the Humain observations shows flux densities as high as 150,000 sfu (1 sfu = solar flux unit is 10^{-22} W m^{-2} Hz^{-1}) in the range 1030-1090 MHz, which is indeed exceptionally high. The time evolution shows two particularly bright periods, between 14:20 and 14:30 UT and 14:40 and 14:50 UT. Upon closer inspection the time history is actually a series of very short bursts across all or part of the (800-1400) MHz band, with individual durations below 1 s.The exceptional brightness of this burst in a frequency range that includes the operational frequencies of the air traffic control radar, and the time coincidence between the brightest radio emission in this range and the radar disturbances identified in Belgium are strong arguments that the solar radio burst was the reason of these disturbances.

The question is then how the Sun can produce such a high flux density at radio frequencies. Like other solar radio bursts at frequencies near and below 1000 MHz, this event shows a strong modulation both in frequency and in time, with narrow-band features and short individual bursts. This is not consistent with incoherent synchrotron emission from mildly relativistic electrons (a few hundreds of keV to some MeV), which is the mechanism considered at work at higher frequencies. Bright emission rather suggests some coherent, maser-like feature, while series of short bursts suggest that the conditions for this behaviour are not maintained for long times, but are reproduced in a repetitive way. Spectral fine structure finally suggests that the emission occur at some characteristic frequency of the coronal plasma. The basic idea is that energetic electrons confined in coronal magnetic fields develop anisotropic velocity distributions, with less electrons moving at small angles with respect to the magnetic field direction than at large angles (i.e., 90°). This is natural in a magnetic trap built by magnetic fields emanating from the solar interior, since electrons moving along the magnetic field do not experience the Lorentz force and can freely travel into the low and dense layers of the solar atmosphere, where they lose their energy by collisions. In this situation maser-like processes develop, where excess energy in the vertical motion of the energetic electrons is transferred to the plasma, creating upper hybrid waves, or even directly to electromagnetic waves that escape from the corona, creating electron cyclotron maser emission. Both the directly escaping electromagnetic waves and electromagnetic waves resulting from coupling processes of the upper hybrid waves can achieve high energy densities, i.e. strong radio bursts. The details of these processes are far from being fully understood. But favorable conditions, with energetic electrons being trapped in coronal magnetic loops, occur in the aftermath of the development of a coronal mass ejection (CME), where a large-scale magnetic field structure is driven out of the corona. The magnetic field then relaxes through magnetic reconnection, which creates new magnetic loops and also provides the context of the electron acceleration. The rail burst on 4th November 2015 was indeed accompanied by such a CME.

The radio emission on 4th November 2015 was associated in time with rapidly evolving activity occurring above an area with strong solar magnetic fields. This may be an argument for cyclotron maser emission, which is favored when the cyclotron frequency is higher than the plasma frequency. However, it is not clear if this can actually be the case in the solar corona. The type of the radio emission is not unique to this specific flare. Similar, and even stronger, radio bursts were reported in the literature to have interfered with GPS signals. The record holder was nearly two orders of magnitudes stronger than the 4th November event. For the time being we are not aware of any indication observable before the burst, for instance a particular configuration of sunspots, that could allow us to predict the strong radio emission.

3 Conclusion

The disturbance of Secondary Control Radar in Sweden and elsewhere on 4th November 2015 is generally attributed to space weather. From the timing and the exceptional nature of the emission, the solar radio burst is a most plausible candidate. The emission is particularly strong due to its coherent character, produced by anisotropic distributions of energetic electrons that are trapped in coronal magnetic fields. We have so far no means to forecast this kind of radio emission.

Explanations to the public are still lacking of why the air traffic was much more strongly disturbed in Sweden than in other countries, where the Sun was also in the beam of the radar antennas. The radio burst was very strong, but still stronger events were detected in the past. They were visible as disturbances of GNSS communications, but do not seem to have produced major problems with air traffic control radar. There is a need for further research and a thorough assessment of past incidents, which must have been recorded by air traffic control authorities, but which imply data that are not made public. This requires a close cooperation between the authorities and research. In the meantime, well-calibrated monitoring instruments of whole Sun radio fluxes covering the UHF band could at least provide a real-time identification of the origin of a disturbance.

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