Redundant observation and correlation of solar radio bursts

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1. Introduction

Solar radio burst spectrograms very often show an interrupting structure (or banding) along the frequency axis, leading to the assumption that there are instrumental insufficiencies. By analysis of parallel observations of the same burst one can demonstrate that this effect is most probably not instrumental but lies in the nature of the burst. A physical explanation is currently not obvious, and this phenomenon needs further analysis and study.

2. Redundant observation

On October 26, 2013 there was an x-ray triggered solar radio burst (see table 1) observed with instruments of the e-Callisto [Monstein1] network by two completely different observatories in the USA. One observation was carried out by W. D. Reeve in Anchorage, Alaska, see figure 1a. By chance Stan Nelson observed the same burst in Roswell, New Mexico with identical time resolution, identical frequency resolution, identical integration and identical bandwidth, see figure 1b. Usually, people first think of standing waves in the antenna or in cabling between the antenna and preamplifier as the cause of the banded structure. By performing an image correlation analysis [Correlation] on figures 1a and 1b, one may conclude they are almost identical with a high degree of probability. In this case the correlation factor is 84.7%

A **correlation function** is a statistical, mathematical process between random variables at two different points in space or time, usually as a function of the spatial or temporal distance between the points. Here, we use correlation in a two-dimensional way (frequency and time domain).

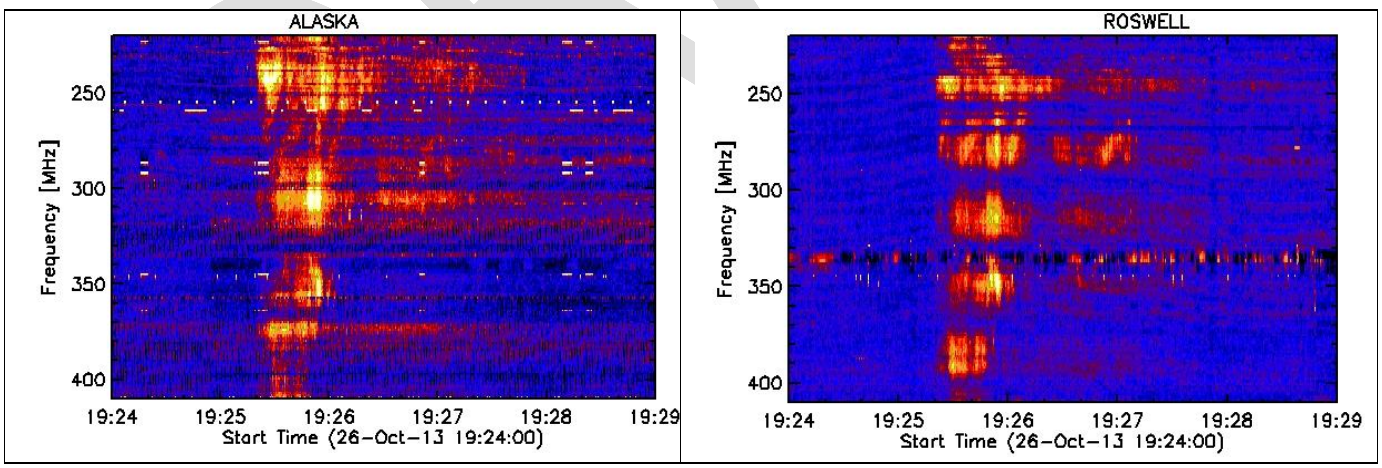

Figure 1 ~ One solar radio burst observed at the same time in Alaska (left) and New Mexico (right). Alaska suffers more radio frequency interference (RFI), nevertheless both plots look very similar.

3. Correlation

The high degree of correlation shown in figure 2 tells us that the interrupted burst structure cannot originate in standing waves because the standing waves would be completely different between the two stations and correlation would be very low. It's extremely unlikely that both stations have identical antennas, identical cable lengths, identical dielectric constant in the cables, identical connectors, and so on, so the only plausible conclusion is that the interruptions in the frequency domain are caused by a physical process either during the 'production' of the burst or during its travel through the interplanetary medium and Earth’s ionosphere.

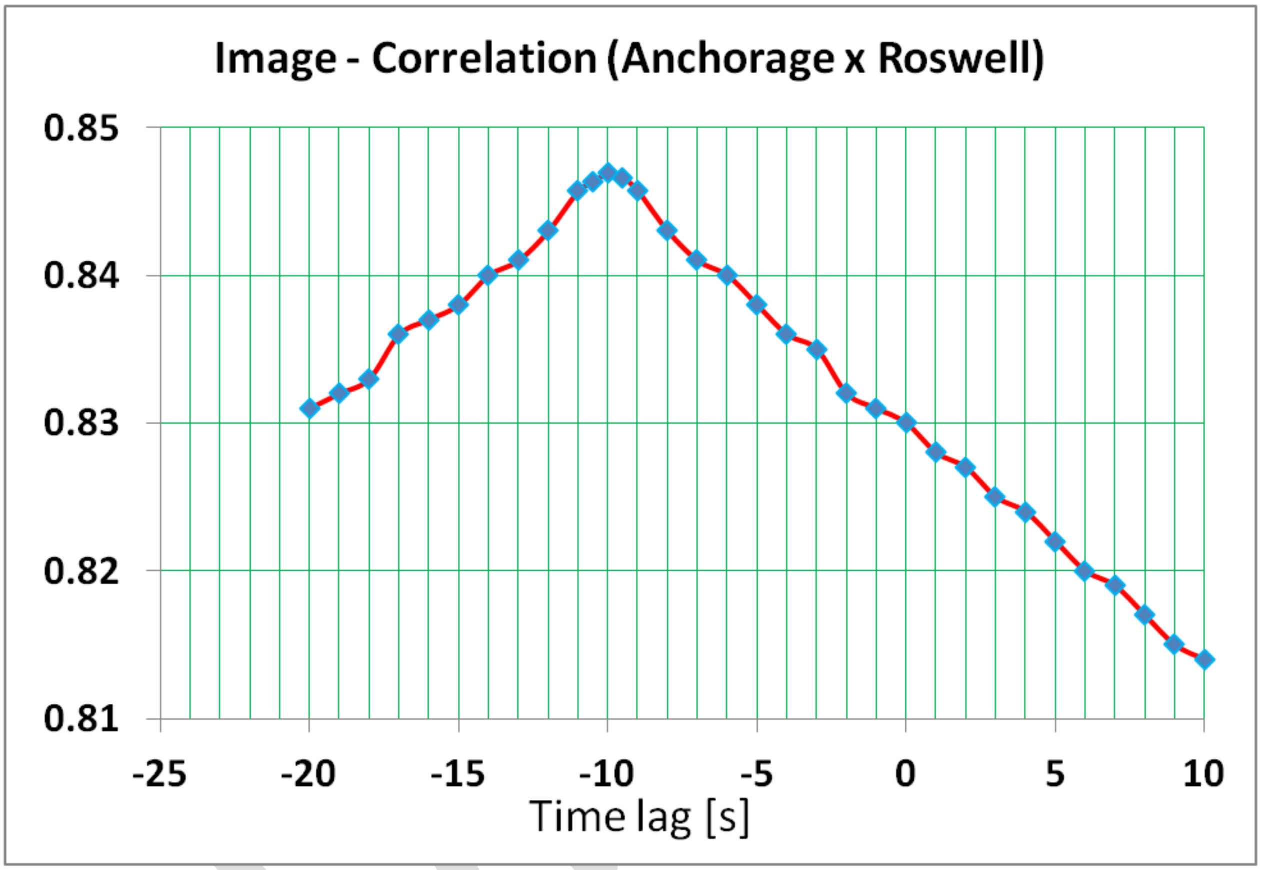

Figure 2 ~ Correlation factor between Alaska and New Mexico by shifting the time-axis a few seconds. Shown here is the time shift applied to New Mexico with respect to Alaska.

The correlation of the original data between Alaska and New Mexico was not perfect due to a timing error either in Alaska, New Mexico or both. To identify the 'wrong' one we would at least need a third observation. To determine the value of timing error, the correlation was done with different time-lags; in our case starting from -20 s up to 10 s. The best correlation is attained when the time lag is exactly 10 s. By shifting New Mexico with respect to Alaska by 10 s we obtain the best correlation of 84.8%, which is a 'good' value in the sense that both plots are very similar.

The correlation was conducted with a software tool called IDL (Interactive Data Language). The two individual images were generated from the Callisto FITS (Flexible Image Transport System) data file from each station, added together and stored on the disk. The sum of Alaska and New Mexico data is shown in figure 3. By treating observations in this way, we can obtain a better signal-to-noise ratio in the output image when the two burst observations are correlated. RFI, which is not correlated, contributes by a factor of only 1/2 to the correlation. Statistical (Gaussian distributed) noise in the data also is not correlated, and it contributes to the correlation only by a factor equal to the geometric mean of the two.

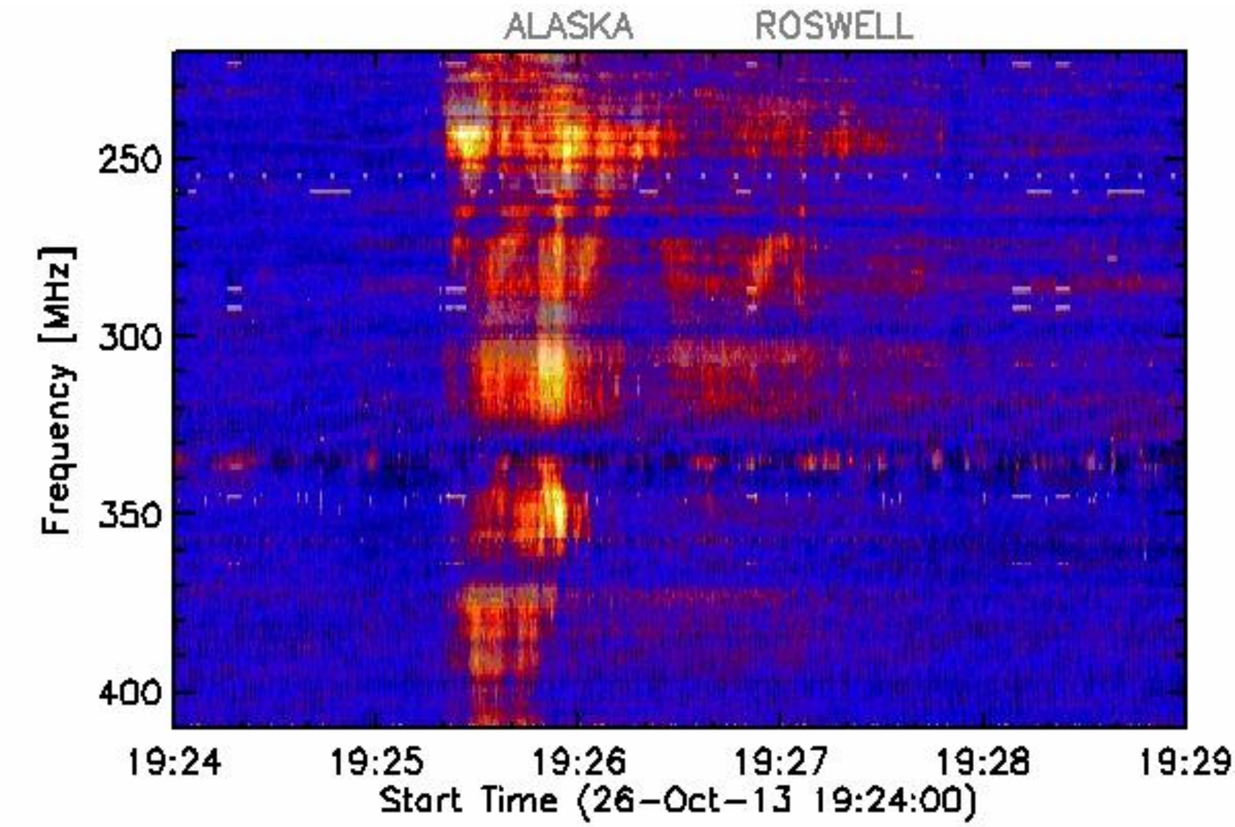

Figure 3 ~ Sum of the Alaska and New Mexico data showing more detailed burst structure compared to individual plots shown in figures 1a and 1b.

Table 1 ~ NOAA event list of a major x-ray flare M3.1 on 26 October 2013 leading to broadband radio bursts. Definitions of the column labels may be found at http://www.swpc.noaa.gov/ftpdir/indices/events/README.

Event	Begin	Max	End	Obs	Q	Type	Loc/Frq	Particulars		Reg#
1710 +	1919	1925	1928	SAG	G	RBR	245	830		1884
1710 +	1919	1925	1927	SAG	G	RBR	410	1300		1884
1710	1924	1931	1938	HOL	3	FLA	S09E81	SF	DSD	1884
1710 +	1924	1927	1930	G15	5	XRA	1-8A	M3.1	9.8E-03	1884
1710 +	1924	1926	1927	SAG	G	RBR	8800	230		1884
1710 +	1924	1925	1927	SAG	G	RBR	15400	220		1884
1710 +	1925	1926	1927	SAG	G	RBR	610	230		1884
1710 +	1925	1926	1927	SAG	G	RBR	4995	140		1884

4. Conclusions

It was demonstrated that the interrupted structure with respect to frequency often seen in solar radio bursts is not necessarily due to instrumental causes. In some cases, an unknown physical process modulates the burst leading to structures that look like standing waves. Therefore, it is of fundamental importance to the study of this phenomenon that as many observatories as possible observe the same processes at different longitudes and latitudes. It also is very important that the instruments are locked to either a GPS timing system or a network time-server to ensure precise time stamps in the data files.

6. References and further reading

[Monstein1] **Callisto – A New Concept for Solar Radio Spectrometers,** Arnold O. Benz, Christian Monstein, Hansueli Meyer , http://link.springer.com/content/pdf/10.1007%2Fs11207-005-5688-9

[Correlation] http://en.wikipedia.org/wiki/Correlation_function

e-Callisto data access and technical information can be found here: http://www.e-callisto.org/

Meet the author: Christian Monstein is a native of Switzerland and lives in Freienbach. He obtained Electronics Engineer, B.S. degree at Konstanz University, Germany. Christian is a SARA member and is licensed as amateur radio operator, HB9SCT. He has experience designing test systems in the telecommunications industry and is proficient in several programming languages including C and C++. He presently works at ETH-Zürich on the design of digital radio spectrometers (frequency agile and FFT) and is responsible for the hardware and software associated with the e-CALLISTO Project. He also has participated in the European Space Agency space telescope Herschel (HIFI), European Southern Observatory project MUSE for VLT in Chile, and NANTEN2 (delivery of the radio spectrometer for the Submillimeter Observatory at Pampa la Bola, Chile). Currently he is quite involved in rfi-monitoring in Switzerland, Ireland and Uruguay. He plays also the role of a coordinator of SetiLeague in Switzerland and he is also representing Switzerland within CRAF.
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