

# Monitoring Mars for Electrostatic Disturbances

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The DSN radio telescope DSS-13 was used to monitor Mars for electrostatic discharges from 17 February to 11 April, 2010, and from 19 April to 4 May, 2011, over a total of 72 sessions. Of these sessions, few showed noteworthy results and no outstanding electrostatic disturbances were observed on Mars from analyzing the kurtosis of radio emission from Mars. Electrostatic discharges on Mars were originally detected in June of 2006 by Ruf et al. using DSS-13. The kurtosis (normalized fourth moment of the electrical field strength) is sensitive to non-thermal radiation. Two frequencies bands, either 2.4 and 8.4 GHz or 8.4 and 32GHz were used. The non-thermal radiation spectrum should have peaks at the lowest three modes of the theoretical Schumann Resonances of Mars. The telescope was pointed away from Mars every 5 minutes for 45 seconds to confirm if Mars was indeed the source of any events. It was shown that by including a down-link signal in one channel and by observing when the kurtosis changed as the telescope was pointed away from the source that the procedure can monitor Mars without the need of extra equipment monitoring a control source.

## 1. Introduction

Evidence for the emission of non-thermal microwave radiation generated by a deep Martian dust storm was originally discovered on the 8<sup>th</sup> of June 2006, and reported in July 2009. A special detector was installed at 34 m radio telescope, DSS-13, at Goldstone by Ruf et al., a team from the University of Michigan. This detector can detect the difference between the thermal and non-thermal radiation emitted from Mars by measuring the high order moments of its electric field strength. Using Fourier methods on the kurtosis (the 4<sup>th</sup> order standardized moment) it was found that the electrical field strength resonates at the frequencies of the three lowest modes of the Martian Schumann Resonance (SR), the circum-planet light travel time. The receivers on the DSS-13 which were used measured at 2.3, 8.4, and 32GHz (the S, X, and Ka bands respectively). The goal of this project was to analyze the previous year's data and report on any notable events that had not been mentioned yet, as well as start new observations with the DSS-13 and improve the post processing to allow for more efficient and automated analysis.

## 2. Background Theory

The electrostatic discharges cause by dust storms are the source of Schumann resonance on Mars. The cavity between the surface and ionosphere behaves like a waveguide, amplifying the frequency of very long wavelengths at distinct frequencies which are related to the diameter of Mars.

Recent observations have the complex (i.e. real and imaginary) signals being collected at 1 MHz sampling rate and are averaged into 1000 sample size bins where the first 4 statistical moments are calculated for each millisecond (mean, variance, skew, kurtosis). The data are distributed such that the first and third moments (and in fact all odd moments) should be zero, which leaves the variance and kurtosis which both have important and unique meanings. The variance is proportional to the power, which will spike if there is some sort of radiation emission in the selected frequency. However, just the variance value is unable to distinguish from thermal and non-thermal radiation; the latter being the desired one when looking for electrostatic discharges.

The kurtosis resolves the two emission types because thermal radiation is normally distributed where as non-thermal radiation does not have to be. The Schumann Resonances produce a positive kurtosis which has a narrower distribution of signal with wider tails. Often a negative kurtosis will be detected from spacecraft signals which makes this one of the first signs to distinguish if a non-zero kurtosis signal is a non-thermal source from Mars.

As mentioned the kurtosis is a standardization of the fourth statistical moment. The definition of the fourth moment is shown in Equation 1:

$$\text{Eq. (1): } \mu_4 = E [(X - E[X])^4]$$

In order for it to be standardised it must be divided by the variance squared. A normal distribution will yield a kurtosis of 3. By convention this is then subtracted by 3 to give the excess kurtosis. All kurtosis values represented in this paper will be given as excess kurtosis so a normal distribution will have a kurtosis of 0.

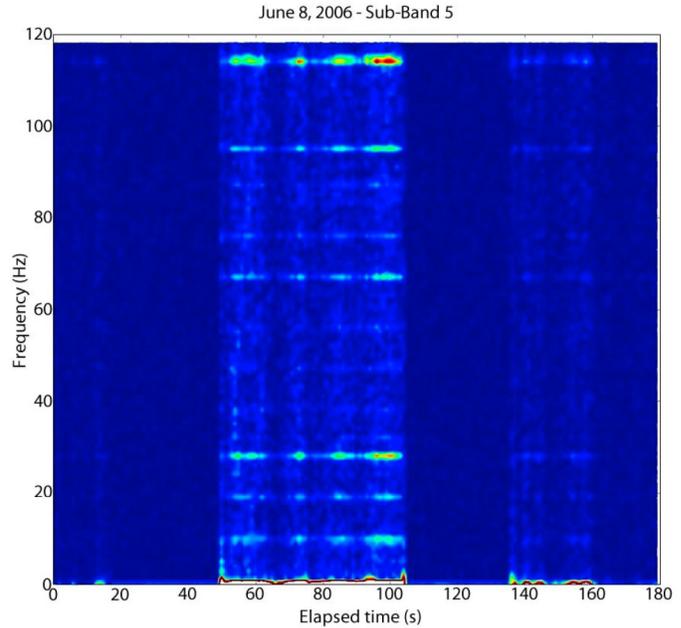
### 3. 2006 Observations

The goal for sequential observation is to find and report on any possible discharges on Mars using the 2006 observation as a stencil example for possible diagnosis. Studying it is crucial to understand the mathematics and statistics of observing electrostatic discharges.

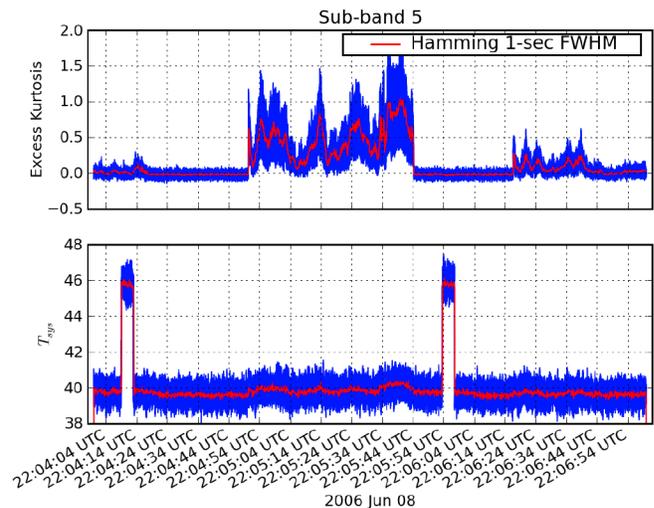
As of this report, the June 8<sup>th</sup> 2006 session is the only confirmed event in which Martian dust storms generated an electrical discharge when observed. Most of the analysis of the event was reported in the Ruf et al. paper; therefore a quick summary of the results will be mentioned in order to create a basis for the comparison and analysis of the results found over the past year.

**Figure 1** shows the changing spectrum over a 3 minute time span, which is derived from the kurtosis measurements, shown in **Figure 2**. This second figure clearly shows when the discharges have occurred. In general a kurtosis change greater than 0.1 is significant statistical evidence (~3 standard deviations) that some sort of non-thermal radiation has been detected, but not always (and, as found through observation, mostly not) of Martian origin. Determining its origin can be done by analyzing the spectrum, because resonating frequencies do not always exist.

The time interval used in this case was approximately 4.2 milliseconds, each spectra consisted of enough points to span 1 second of time, giving a



**Figure 1. Spectrum over time from the June 8 2006 observation of Mars from the Ruf et al report. Each individual spectrum spans over 1 second of data. The first 3 modes of the Schumann Resonance can be seen as well as various overtones. The discharge can be seen as the amplitude peaks at distinct the Schumann Resonances of Mars. The effect of aliasing is also present at the 115Hz region.**



**Figure 2. The kurtosis over time of one of the 8 sub-bands from the 2006 observation. The positive change of kurtosis is a sign of non-thermal radiation, but can only be confirmed by analyzing the spectrum in that region of time. The temperature graph supports the legitimacy of the results.**

maximum frequency of 120 (half the reciprocal of 0.0042). The first three modes are seen in the first figure at  $f_1=9.6$  Hz,  $f_2 = 27.8$  Hz and  $f_3 = 31.7$  Hz, as well as several of the harmonics. What was not mentioned in the 2009 paper was the evidence of aliasing at the 115Hz frequency (however it was mentioned that the data was alias free up to 110Hz). At lower sampling rates and high frequencies this effect can be apparent but in general it is only a minor issue and can be ignored.

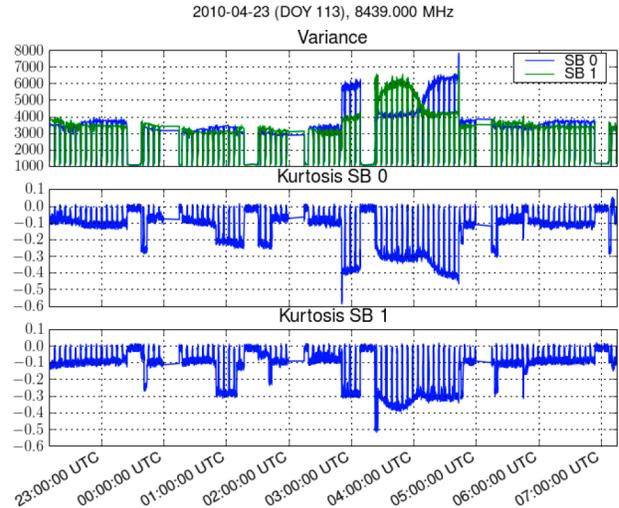
#### 4. 2010 Observations

The 2010 observing season saw many tools and methods established and refined throughout the year, and Mars was observed for a total of 43 sessions. Preprocessing tools written in Python allows tracks to be setup in quickly and even days in advance. Data reduction tools were created to calculate the statistical moments of the 1000 sample size and stored in two ways. The first is a millisecond time interval stats file stored in binary (was previously in ASCII but changed to conserve storage space) and unpacked using the STATS module. This file is large and cannot be moved with ease, but it is the key to creating spectrum and finding resonances in the data. The other takes one second of data (1000 samples from the binary data) and calculates the mean of the four statistical moments. This is far more useful when constructing a general time versus kurtosis graph or examining the data for high kurtosis values.

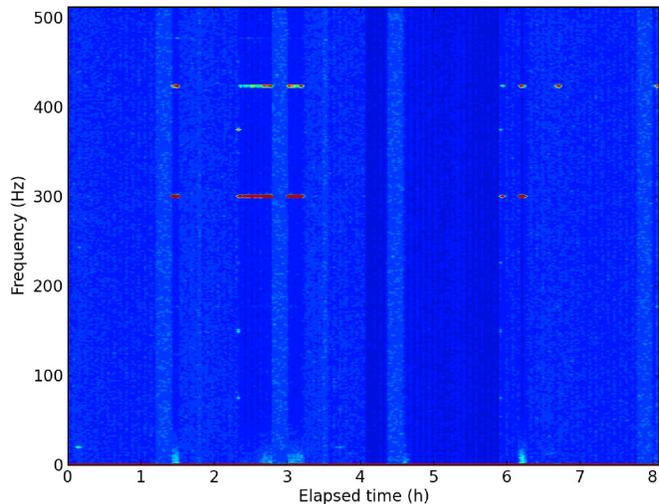
The results from the year varied from unusable and wrong to correct but uninteresting, and in rare cases interesting and worth reporting on.

Earlier sessions were more prone to errors which are expected as the system was being developed at the time. The behavior of the errors in the data ranged from quick and dirty fixes to not being usable in any way. The fixable ones were a result of a coding problem in the millisecond interval data where the first millisecond of every second was consistently many magnitudes higher than what is expected. This resulted in kurtosis slightly higher than average when analyzed as a one second mean. When identified, this problem was fixed and does not appear in later data sets.

Most of the data had no significant kurtosis increases. The dust storms on mars producing electrostatic discharges significant enough to excite the Schumann Resonances are exceptionally rare. Interferences often occurred, most of which are terrestrial. Emitting transmitters will be picked up causing a non-zero kurtosis change. In rare occasions there will be a resonance detected from the interference. In particular a satellite downlink which produces a strong negative kurtosis change as shown in **Figure 3**. The effect of alternating on and off the source is present as the kurtosis and variance drop to a value which mirrors a blank sky value. This immediately confirms that the target is indeed the source of the non-thermal radiation emission. A more common example of interference can be seen in **Figure 5**, where there is a large variance change but no change



**Figure 3. Non-thermal emission from a satellite. The kurtosis returning to zero every 5 minutes is due to the implemented look away which confirms if the emission source is from the targeted source.**



**Figure 4. The spectrum of the non-thermal emission from a satellite. While most of the time the kurtosis is non-zero only parts of it produce resonance. The brighter blue vertical lines signify the moving of the telescope every 5 minutes.**

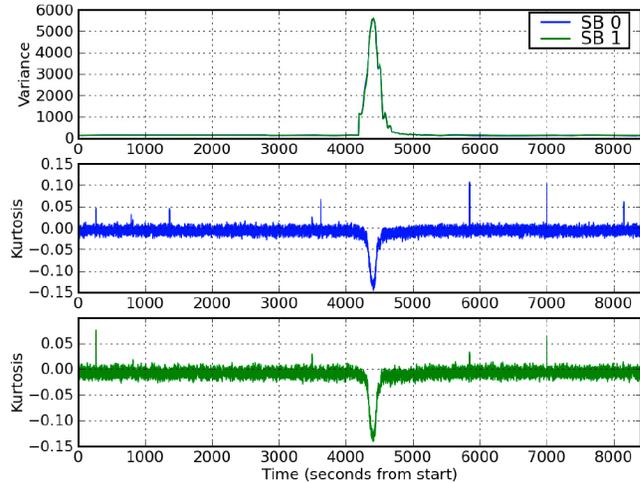
when the telescopes moves from the target every 5 minutes indicating it is a terrestrial source of radiation.

The spectrum of the kurtosis over time shows more interesting results as shown in **Figure 4**. The peaks in the spectrum are not consistently present over time, compared to the change in the kurtosis which is non-zero for the entirety of the track. Reasons for this are not entirely known however if the kurtosis change was due to the Schumann Resonance it is expected that the time regions of spectrum peaks would correlate to the locations of positive kurtosis.

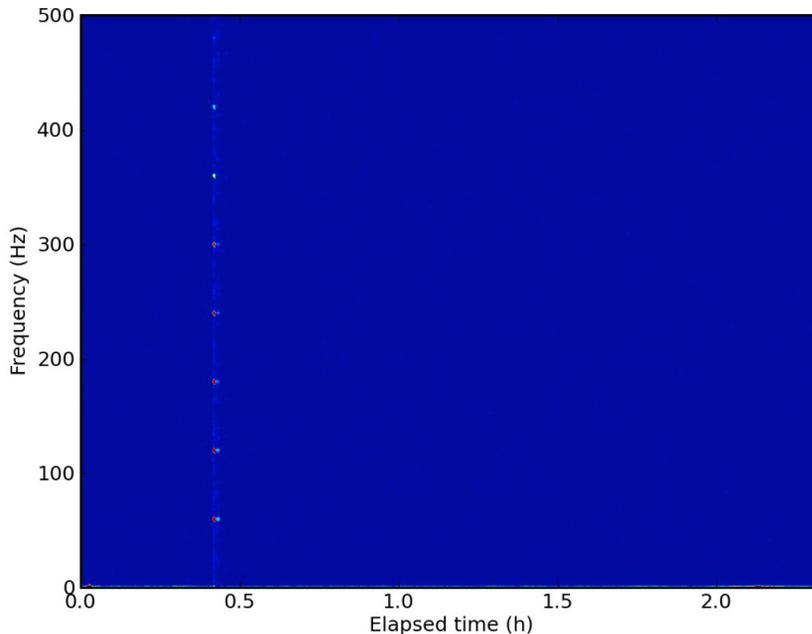
**5. 2011 Observations**

The goal for this year’s observations was to further refine the post-processing tools to allow for faster and more efficient evaluation of observation sessions. Ideally, the project will run flawlessly without any sort external human influence and report on any significant results or if there were any notable malfunction with the equipment or environment. A pipeline which conducts the following procedures automatically for any particular observation session, when the scripts for the day are created, should be included:

- Raw files moved to Ravi2 (Radio Astronomy VSR Interface 2) automatically and removed from VSR when completed
- Kurtosis plots generated from 1 second mean to be done automatically
- Detection of high kurtosis being noted and contour plots of the spectrum over time being generated from the binary stats files
- Plot of system temperature over time which is an indication of how the track went and the weather at the time
- Adjust the time to account for the bore sight



**Figure 5. An example of a strong interfering terrestrial emission which does not produce any resonance. The source of the interference is unknown.**



**Figure 5. An example of terrestrial interference caused by a nearby AC power source giving the peaks in the spectrum.**

This is difficult to implement retroactively, however past data can be used to construct such tools for future use. These tools are yet to be added to the scripts, however many of these parts have been constructed and tested. For example many of the graphs generated in this report have been produced manually by codes which will soon be made so that they will run after the observation session had completed.

Observations have started for this year and new results are incoming each day, however no sessions have shown any sort of outstanding result. A new type of interference has been detected which produces a positive kurtosis and resonance (Figure 5) however the kurtosis and variance change is relatively small (Figure 6), which would probably not be detected using an automated system which searched for outlier kurtosis. The source of the interference was a 60Hz alternating current.

## 6. Conclusion

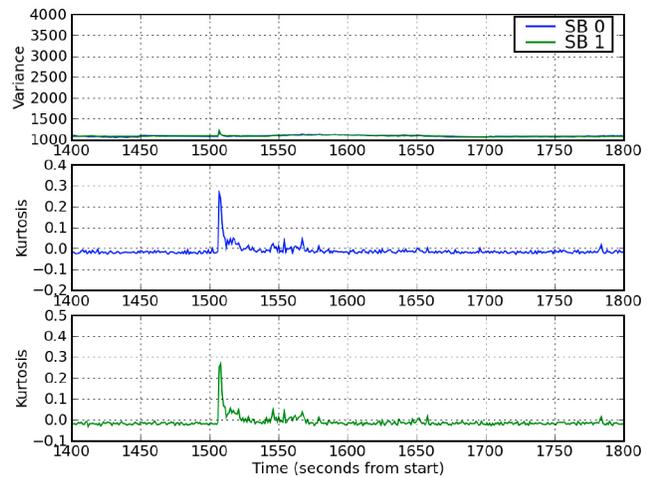
The three main goals outlined in the introduction were: analysis of the previous year's results, restart observations for the year, and create a more automated system for observing Mars. Of these points, the analysis of the previous year's results was concluded and a firmer understanding of what was observed was established. Observations are well underway and so far the hardware and software are performing well. However development of the automated system, possibly the most desired goal, is still in progress because the observations began later than expected.

## Acknowledgements

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**Figure 6. The kurtosis change from the alternating current interference. The kurtosis increase is remarkably small relative to what would be expected.**