Study of Martian Dust Storms with Deep Space Network Antennas

CASPER Workshop, August 19th, 2010

Santa Martínez

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Scientific Perspective - Why?
DSN Planetary Electrostatic Discharges (PESD) Program
Kurtosis Detector for the DSN based on CASPER Technology
Scientific Motivation

Triboelectric charging of saltating and colliding dust particles occurs when small dust particles rub against large particles. In this process negative charges are transferred from large to small particles during collisions.

This results in two phenomena of interest:

- A strong electric field is generated in the storm.
- Electric discharges resulting from charge separation produce non-thermal radiation.

(Renno et al., 2003)
Kurtosis is the degree of peakedness of a distribution, defined as the ratio of the fourth central moment of a curve to the second moment squared.

\[ R = \frac{\langle x^4(t) \rangle}{\langle x^2(t) \rangle^2} \]

A kurtosis of 3 indicates a Gaussian distribution. Thermal microwave emissions, like what is observed in background noise, have a Gaussian distribution. Any other value of the kurtosis would indicate a non-Gaussian distribution i.e. non-thermal microwave emissions.

The kurtosis is extremely sensitive to the presence of non-thermal radiation, but insensitive to variations in the intensity of the thermal radiation or in the gain of the radiometer receiver.
Electric Discharges in Martian Dust Storms

- Tuned to 8.47-8.49 GHz with 8 x 2.5 MHz spectral channels
- Kurtosis and power spectra measured while tracking Mars with DSN DSS-13
- 5 hr/day Mars observations for 12 days
- Deep dust storm on Earth-facing side of Mars observed on 8 June 2006

Discharge Signature
On 8 June 2006, 19:14 - 22:40 UTC

(Ruf et al., 2009)
Kurtosis vs. Power

Mars Power Obs, 8 Jun 2006

Mars Kurtosis Obs, 8 Jun 2006

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Prominent harmonics at exact integer multiples of the first three SR modes suggest a coupling of the microwave discharge to the quasi static Schumann resonant electric field.

Mars Shumann Resonance

<table>
<thead>
<tr>
<th>Mode</th>
<th>DSN Data</th>
<th>Models</th>
<th>$f_1 = f_n \sqrt{\frac{2}{n(n + 1)}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_1$</td>
<td>9.6</td>
<td>8.8 to 14.3</td>
<td>9.6</td>
</tr>
<tr>
<td>$f_2$</td>
<td>19.2</td>
<td>16.1 to 25.8</td>
<td>11.1</td>
</tr>
<tr>
<td>$f_3$</td>
<td>27.8</td>
<td>23.6 to 37.4</td>
<td>11.3</td>
</tr>
<tr>
<td>$f_4$</td>
<td>31.7</td>
<td>-</td>
<td>10.0</td>
</tr>
</tbody>
</table>

(Ruf et al., 2009)
Monitoring Planetary Electrostatic Discharges (PESD) with the DSN

PESD Observations with the DSN
Results from Observations
Objectives

Ultimate Goal:
Study the behavior of non-thermal radiation emissions from Mars and contribute to understand the electrical activity in dust storms and the dependency on environmental parameters.

Specific Objectives:

- Verify that interferometric observations to monitor Mars for electrical activity manifested by non-thermal electromagnetic radiation could be done using the Wideband VLBI science receivers installed in the DSN.
- Automate the acquisition, data reduction and event detection.
- Add value to the data analysis with the interferometric observations applying DDOR techniques to improve spatial resolution in one direction.
- Evaluate if a custom designed Kurtosis-detector for use in the DSN would add value to the DSN tracking operations.
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Same-beam Interferometry (SBI)
Wideband VLBI Science Receiver (WVSR)

IF Switch

WVSR 1A

WVSR 1A

WVSR

Channel 1
Channel 2
Channel 3
Channel 4

4 Sub channels

Data Storage

Analog centered at 315 MHz

640 MHz BPF
1280 Msamp/s
8-bit samples

16 MHz BPF
16 Msamp/s
8-bit samples I & Q

1kHz to 16MHz BPF
1 to 16-bit samples I & Q

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1 kHz to 16 MHz BPF
1 to 16-bit samples I & Q

0 kHz

1 kHz

640 kHz

Variable with 1 MHz steps

Variable with ~ 1 Hz steps

UP TO FOUR SUBCHANNELS
(two narrow and two wide)

Variable width: 1 kHz to 16 MHz, I & Q
Variable samples: 1 bit to 16 bits
Planetary Electrostatic Discharge (PESD) Program

7-Day Schedule Overlap Selection

Projects: MO10, MER1/MER2, MEX, MRO

Restrictions:
- Minimum overlap of 30min
- No Delta-DOR activities
Planetary Electrostatic Discharge (PESD) Program

7-Day Schedule
Overlap Selection

PESD Scheduling

WVSR Acquisition

Statistics

Kurtosis Analysis / SR Detection

PESD Scheduling
Configuration scripts for the WVSR receivers and schedule of acquisition and data reduction tasks.
Planetary Electrostatic Discharge (PESD) Program

7-Day Schedule
Overlap Selection

PESD Scheduling

WVSR Acquisition

Statistics

Kurtosis Analysis / SR Detection

Data Reduction and Analysis

1 ms signal statistics of the USB and LSB
1 s averaged statistics for quick look analysis

Event Detection Criteria:
  - Kurtosis > 3
  - FFT of the Kurtosis for SR detection
PESD Interferometric Observations (Pilot Test)

- Ro (DSS-55) - Go (DSS-26) + DSS-13 Observation
  - Week 21, DOY 147, 20:00 – 22:45
    - X-band 8406 MHz, 8440 MHz
    - Ka-band 31980 MHz, 32214 MHz
Kurtosis Detector for the DSN based on CASPER Technology

Precursors
Kurtosis Detector for the DSN based on CASPER Technology
Precursors: ADA (U. Michigan)

Xilinx Virtex-II Pro
24MHz, H/V-pol
110 Msamples/s, 7-bit signed
8 channels, 3MHz
Integration time: 36ms
Precursors: Mars Lightning Machine (CASPER)

ATA
104.8 MHz (500MHz – 6GHz)
dualpol, 8-bit
1024 channels
Integration time: 10μs – 10ms
**Requirements:**

- 2 IF (X, S or Ka band), 400 MHz, 8-bit samples
- 128 channels
- Compute four first moments \( <t> <m^2> <m^3> <m^4> \) in <1 ms
- Event Detection Software

**DSN Kurtosis Data Acquisition System**

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**Credits:** Andrew Siemion
Next Mars Dust Storm Season

Sols = 178  
Ls = 90°  
2010 May 13

Sols = 142  
Ls = 180°  
2010 Nov 13

Sols = 154  
Ls = 270°  
2011 Apr 09

Sols = 194  
Ls = 0°  
2011 Sep 14

Northern Summer /  
Southern Winter

Northern Autumn /  
Southern Spring

Northern Winter /  
Southern Summer

Northern Spring/  
Southern Autumn

Martian dust storm season starts
Thank you