DICE Mission Results from over a Year of On-Orbit Operations

Tim Neilsen et al
SmallSat CubeSat Workshop
August 10th, 2013
What is DICE?

Measuring density structures (plume and bulge) associated with Storm Enhanced Density (SED) features during Electromagnetic Storms in the Ionosphere.
DICE: Two 1.5U SensorSats

- Electric Field $\sim 0.2 \text{ mV/m}$, Double Probe Technique, 10 m tip-to-tip wire booms, 70 Hz sample rate
- Plasma Density $\sim 10^2 \text{ cm}^{-3}$, Dual Langmuir Probes, 70 Hz sample rate
- Magnetic Field $\sim 5 \text{ nT}$, 70 Hz sample rate
Delivery & Launch

- Delivered to CalPoly
  - Oct 5th 2011
- Launched on NASA ELaNa III program
  - Oct 28th 2011

<table>
<thead>
<tr>
<th>S/C</th>
<th>Period (min)</th>
<th>Inclination (°)</th>
<th>Apogee (km)</th>
<th>Perigee (km)</th>
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</thead>
<tbody>
<tr>
<td>Farkle</td>
<td>97.35</td>
<td>101.72</td>
<td>808</td>
<td>456</td>
</tr>
<tr>
<td>Yahtzee</td>
<td>97.34</td>
<td>101.72</td>
<td>807</td>
<td>456</td>
</tr>
</tbody>
</table>
On Orbit Housekeeping Data

- Inside Temperature (°C) vs Time in sec since (Week: 0 Millisecond: 457370) (10^3)
- Outside Temperature (°C) vs Time in sec since (Week: 0 Millisecond: 457370) (10^3)
- Volts (V) vs Time in sec since (Week: 0 Millisecond: 457370) (10^3)
- Currents (mA) vs Time in sec since (Week: 0 Millisecond: 457370) (10^3)
DICE ADCS Subsystem

- **Custom ADCS design**
  - ADCS-grade magnetometer
  - SDL Sun Sensor
  - NovAtel GPS
  - 3-axis Torque Coils

![Histogram of Error Angle Between Predicted and Measured Unit Sun Vector in J2000](image)
Comparing Science & ADCS Magnetometers

Yahtzee Science & ADCS Magnetometer Data

Noise floor comparison
- ScienceMag Floor: ~ 5-10 nT
Science Magnetometer Data

Geomagnetic disturbance measured by the Farkle SciMag on May 22, 2012

Farkle Science Magnetometer 05/22/2012 22:19:24.212984 UT

Magnetic Field (nT)

Time (Sec) since 22:19:24.212984

|B| ~400 nT
Langmuir Probe Data

Yahtzee 06/03/12

Plasma Density

IRI

DICE Langmuir Probe

Orbit Number
DICE SensorSat Science Data

Farkle data comparison with models

Density x 10^11 /m³

Temperature (K)

Latitude

Longitude

Altitude (Km)

UTC (hr)
DICE SensorSat Science Data

**Graphs:**
- **Farkle 06/29/12:**
  - Plasma Density vs. UTC: Multiple peaks at different times.
  - Lat.: Wavy line indicating latitude changes over time.

- **Yahtzee 06/29/12:**
  - Plasma Density vs. UTC: Similar pattern to Farkle.
  - Lat.: Similar wavy line as Farkle.

**Map:**
- **Farkle Yahtzee:**
  - Color-coded map showing electron density variations globally.
  - Marked points and regions labeled (a), (b), and (c).

**Legend:**
- **Electrons / m³:**
  - Color bar indicating electron density levels from 1.00e+10 to 1.20e+12.
## DICE Telemetry Generation Rates

<table>
<thead>
<tr>
<th>Channel Name</th>
<th>Rate (Hz)</th>
<th>Word Size (# bits)</th>
<th>Sample Size (# Words)</th>
<th>Bit Rate (bits/s)</th>
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**On orbit Rate (bits/s)** = **4889.99***

*Assumes an orbit period of 92.56 min; **Assumes a spacecraft velocity of 7.7 km/s
*** Does not include packet format overhead
DICE Telemetry Systems (3 Mbit/s)

Uplinks
450 MHz
9.6 kbits/s

Downlinks
460-470 MHz
3.0 Mbits/s
(2.69 Mbits/s FEC)
(2M69G1D)

Half Duplex Communications

DICE Spacecraft 1
DICE Spacecraft 2

SRI (18.3 m Dish)
latitude 37.40303 °N,
longitude 122.17423 °W,
altitude 156.47 m

NASA Wallops (18.29 m Dish)
latitude 37.854886 °N,
longitude 75.512936 °W,
altitude 3.05 m
SDL CubeSat Missions Operations Center

- Wallops and SRI ground stations controlled remotely from SDL headquarters
- Dual ground station coverage allows for 4 – 5, 15-minute communications overpasses per day
Downlink Telemetry System

WBX 50-2200 MHz Rx/Tx

LNA/BPF/Switch

Ettus Research

USRP N200

10 Msamp/s I/Q data

Software Defined Radio

MySQL Database

Ethernet
Narrow Band Interference Spectrogram

Our signal

NBFM interference
Wallop Island, Virginia
Interference at SRI Site

Interference at Wallops Site
NBI Filter: Before and After
Improvement In Downlink Quality

Data Availability

- >75% > 40 MB
- <75% < 40 MB
- < 50% < 30 MB
- < 25% < 20 MB
- < 1 orbit < 10 MB
- 0% 0 MB

12/09/11 01/22/12 03/06/12 04/19/12 06/02/12
Farkle Data Recovered

- 5.13GBytes of on-orbit data recovered and stored in MOC database

Farkle Data Downloaded

- Dish Tracking Problems
- Power Issues/On-Board Computer Freeze
- Ground Station Upgrade
Yahtzee Data Recovered

- 3.26GBytes of data recovered and stored in MOC database

**Yahtzee Data Downloaded**

- Dish Tracking Problems
- Power Issues/On-Board Computer Freeze
- Ground Station Upgrade
Programmatic Lessons Learned

- Great things can indeed come from humble settings
- Positive collaboration between government, academia, small business, and industry with a set of common goals can be very productive.
- The support of NASA ELaNa in providing launch services to the CubeSat community is invaluable.
Technical Lessons Learned

- Once the CubeSats have reached orbit, all semblances of “smallness” disappear. Mission ops are complicated and time consuming.

- The engineering challenge of producing well performing science instruments within the technical resource constraints of a CubeSat is every bit as valuable as seeing how big we can make our farthest seeing large telescopes.

- NSF and NASA-sponsored CubeSat programs in general can greatly benefit by using government requested communication bands and established GS sites at WFF & SRI.

- CubeSats should, and will be, the backbone of many future global multi-point measurement missions.
Questions?
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