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

Tim Neilson 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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<tbody>
<tr>
<td>Farkle</td>
<td>97.35</td>
<td>101.72</td>
<td>808</td>
<td>456</td>
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<tr>
<td>Yahtzee</td>
<td>97.34</td>
<td>101.72</td>
<td>807</td>
<td>456</td>
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On Orbit Housekeeping Data
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
Yahtzee 04/05/2012
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

![Graph showing magnetic field over time](image)
Langmuir Probe Data

[Graph showing plasma density over orbit number with data points from IRI and DICE Langmuir Probe]
Farkle data comparison with models

- Farkle norm IRI
- GAIM
- IDA4D
- IRI Ne
- IRI Te

Density x 10^{11} /m^3

Temperature (K)

Latitude

Longitude

Altitude (Km)

UTC (hr)
DICE SensorSat Science Data

Farkle 06/29/12

Yahtzee 06/29/12

IRI IDA4D LP

Local Time (Hours)
Electrons / m³

1.00e+10 2.08e+11 4.07e+11 6.05e+11 8.03e+11 1.00e+12 1.20e+12

Space Dynamics Laboratory
Utah State University Research Foundation
SDL Proprietary
# DICE Telemetry Generation Rates

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<th>Rate (Hz)</th>
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<th>Sample Size (# Words)</th>
<th>Bit Rate (bits/s)</th>
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*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)

DICE Spacecraft 1

DICE Spacecraft 2

Half Duplex
Communications

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

Ethernet

Ettus Research

USRP N200

10 Msamp/s I/Q data

Software Defined Radio

MySQL Database
Narrow Band Interference Spectrogram

- Our signal
- NBFM interference
- Wallops Island, Virginia
NBI Filter: Before and After

Power Spectral Density

Frequency [MHz]

Time

Original

Frequency [MHz]
Cleaned

Frequency [MHz]
Improvement In Downlink Quality
Farkle Data Recovered

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

### Farkle Data Downloaded

![Graph showing data recovery](image)

- **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

Graph showing Yahtzee Data Downloaded with dates and data points:
- 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?
The authors gratefully acknowledge funding provided by NSF (grant numbers# ATM-0838059, AGS-1212381, AGS-1255782) and to the NASA ELaNa III group for launch services. The authors also gratefully acknowledge the countless hours of dedicated and passionate effort from the students on the DICE program. They indeed rose to the challenge. Without their energy and consistency, DICE would not have become a reality. Thank you Erik Stromberg, Weston Nelson, Crystal Frazier, Jaden Miller, Ben Byers, Cameron Weston, Mark Anderson, Steven Grover, Josh Martineau, Steven Burr, Keith Bradford, Russ LeBaron, Dan Allen, and Jon Tran.