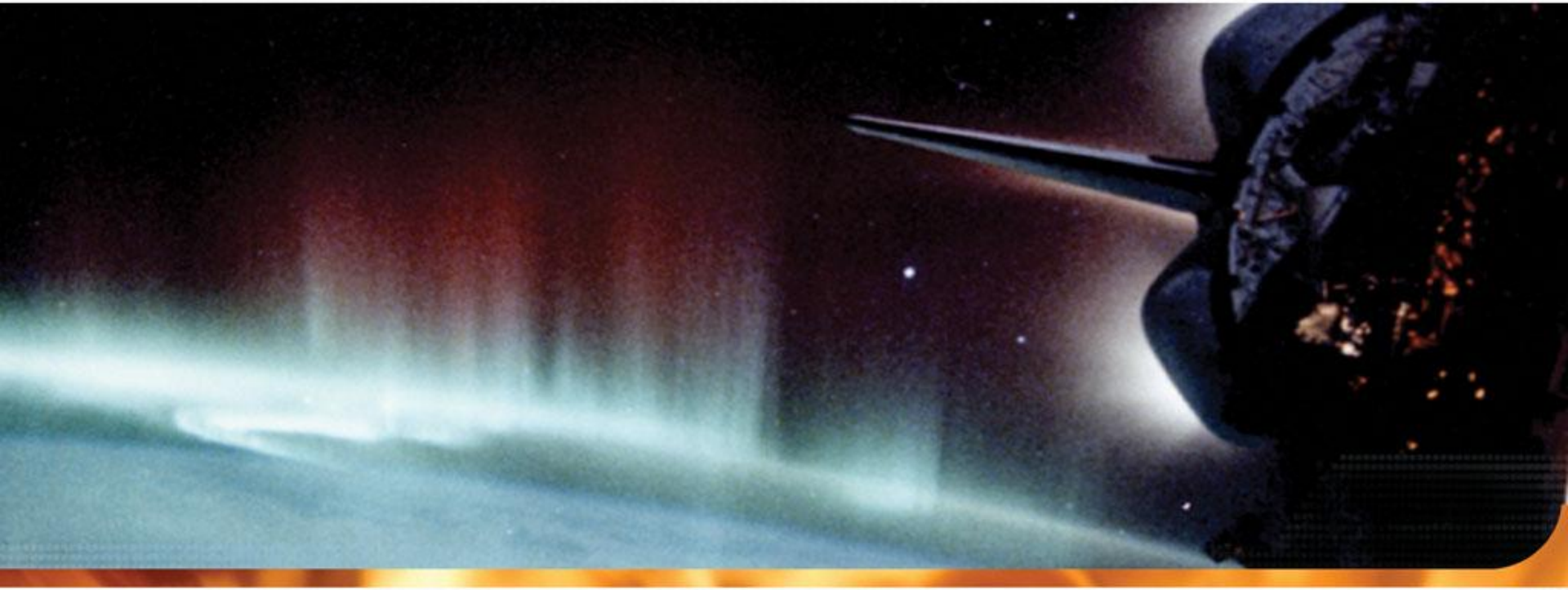
Space Dynamics Laboratory
Utah State University Research Foundation

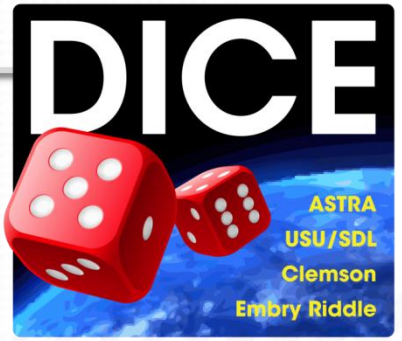
UtahState University



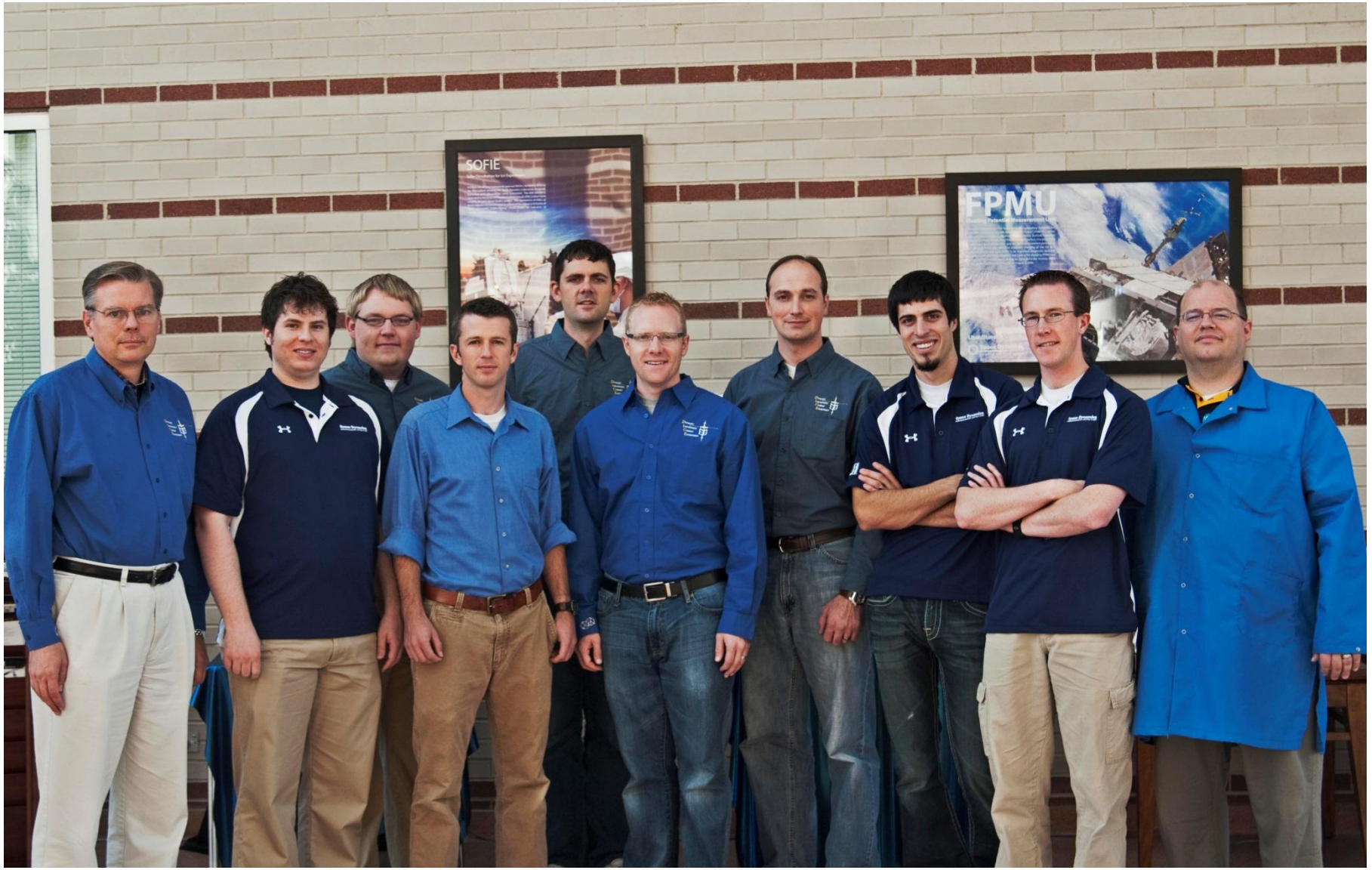
DICE Mission Results from over a Year of On-Orbit Operations

Tim Neilsen et al

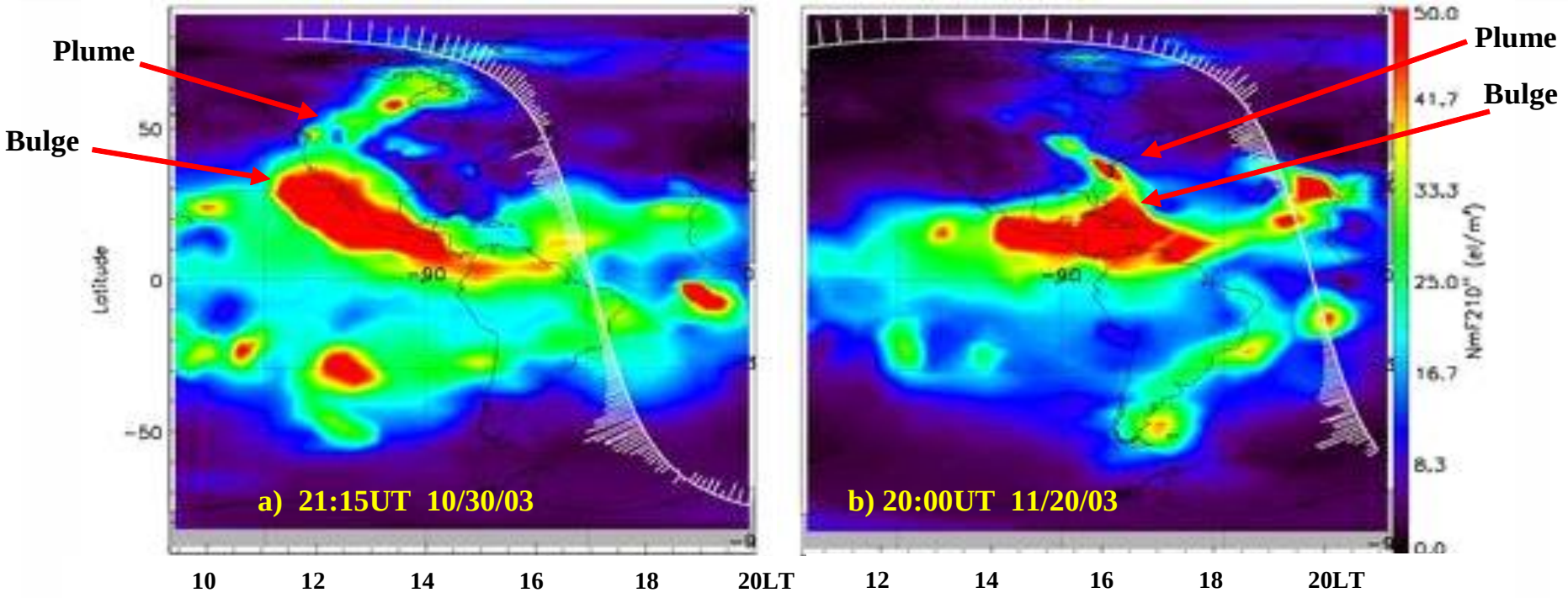
SmallSat CubeSat Workshop
August 10th, 2013



DICE Team Photo



What is DICE?

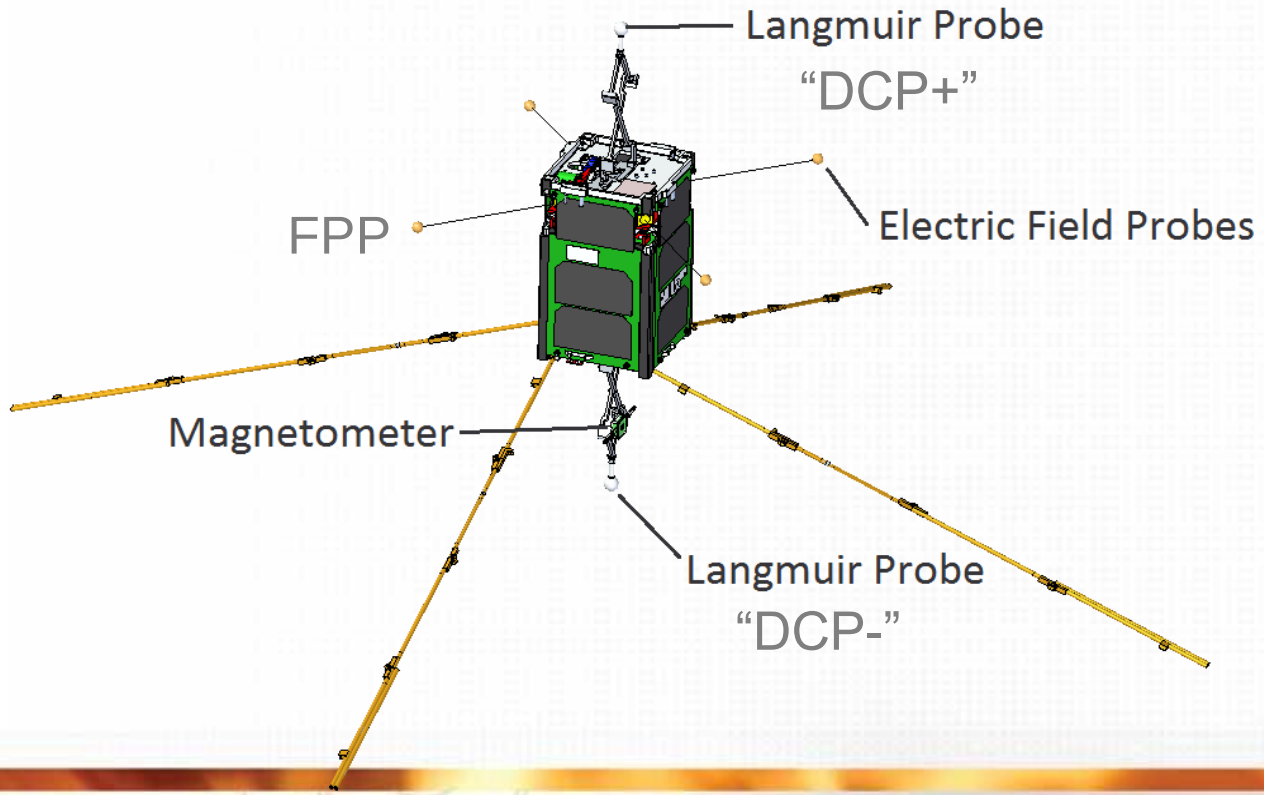


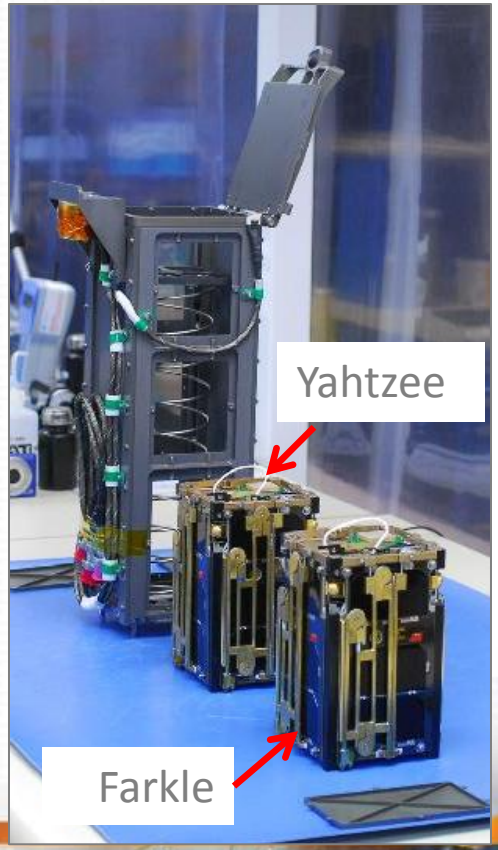
Measuring density structures (plume and bulge) associated with Storm Enhanced Density (SED) features during Electromagnetic Storms in the Ionosphere.

SDL Proprietary

DICE: Two 1.5U SensorSats

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





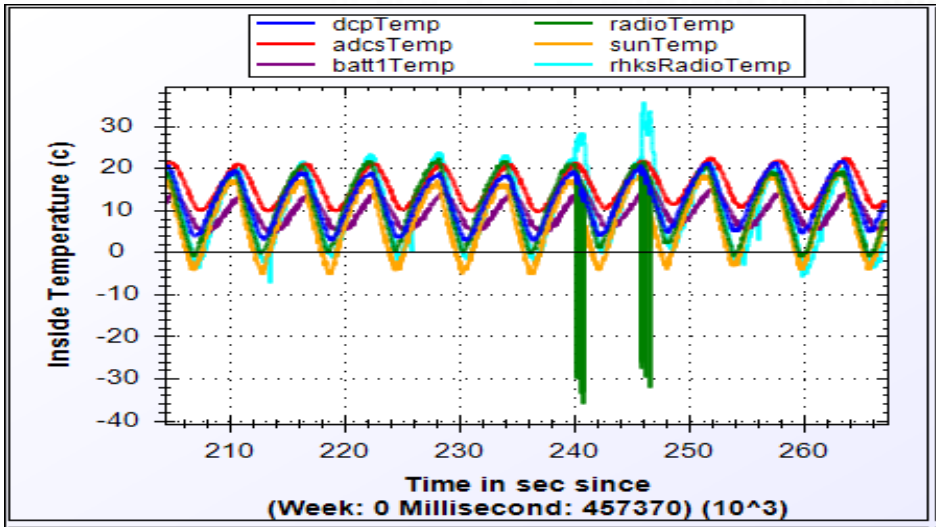
SDL Proprietary

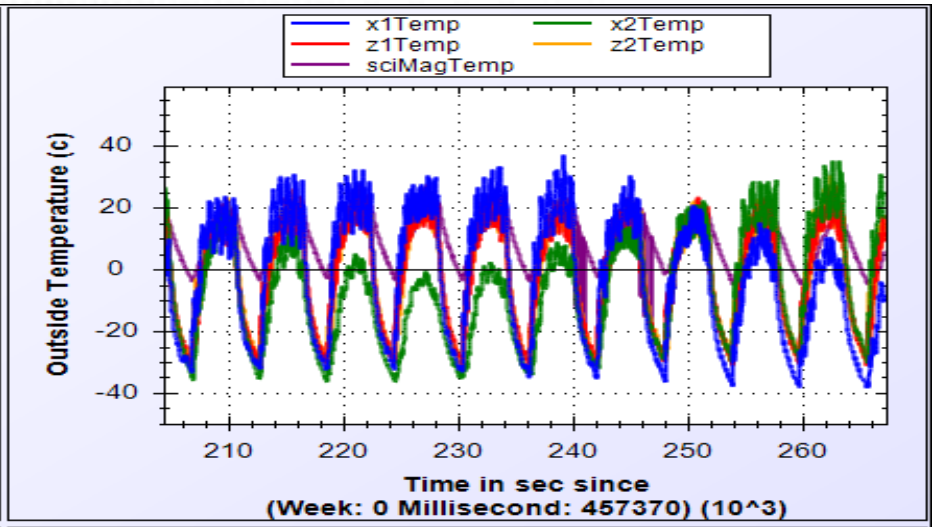
Delivery & Launch

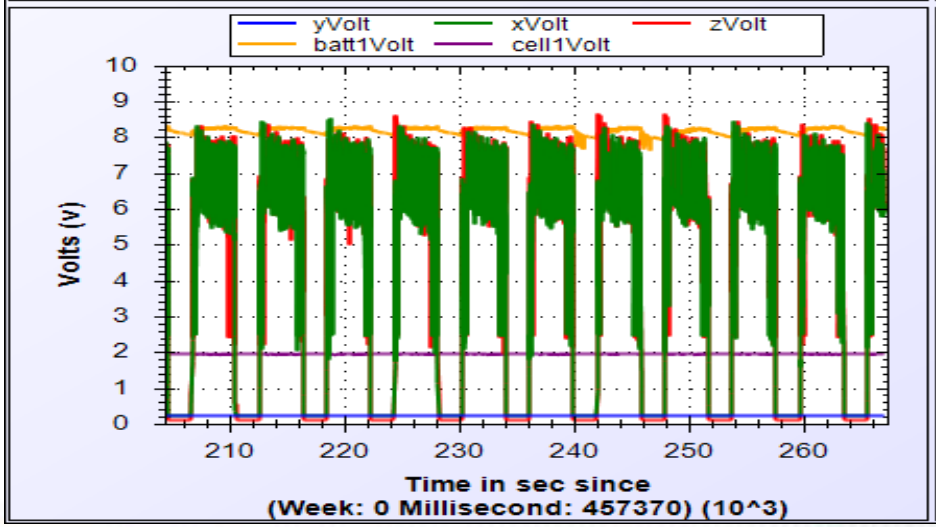
- **Delivered to CalPoly**
  - Oct 5th 2011
- **Launched on NASA ELaNa III program**
  - Oct 28th 2011

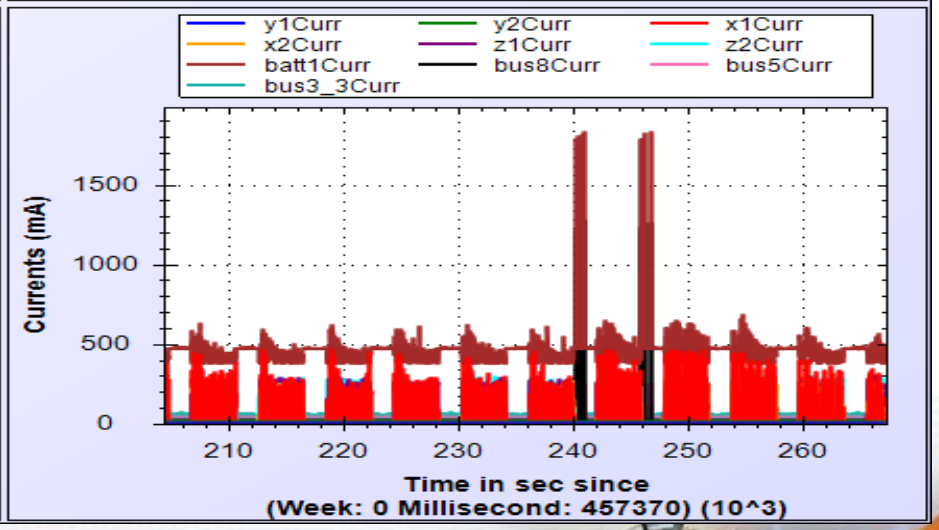
S/C	Period (min)	Inclination (°)	Apogee (km)	Perigee (km)
Farkle	97.35	101.72	808	456
Yahtzee	97.34	101.72	807	456

On Orbit Housekeeping Data



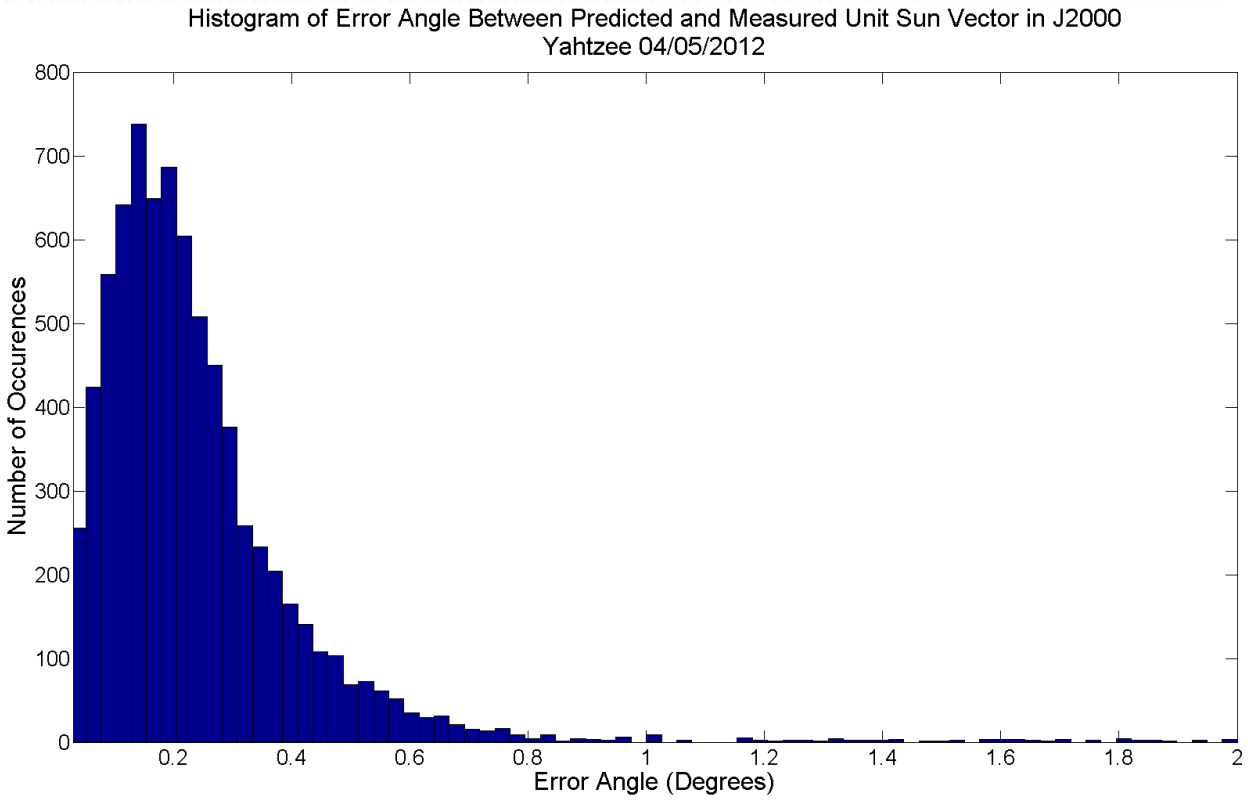






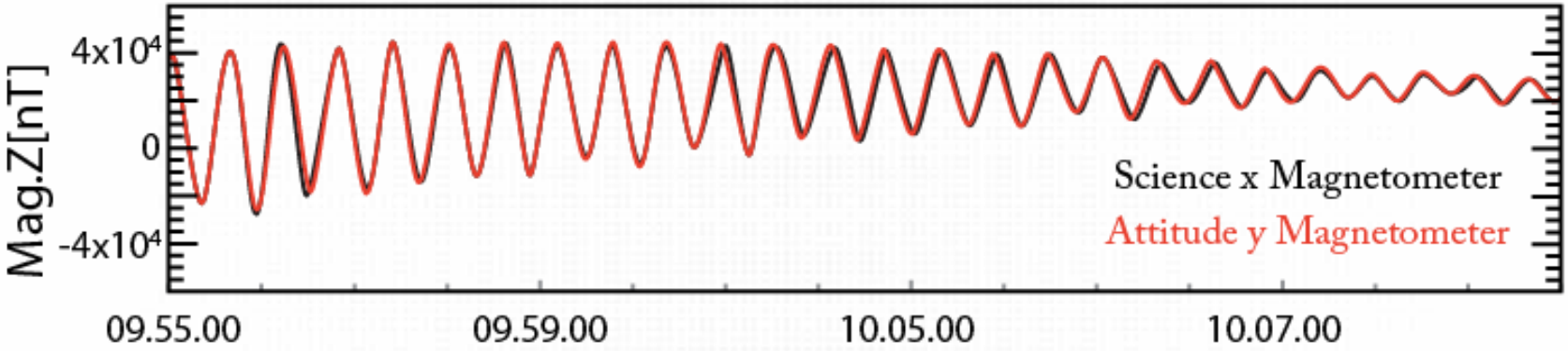
DICE ADCS Subsystem

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

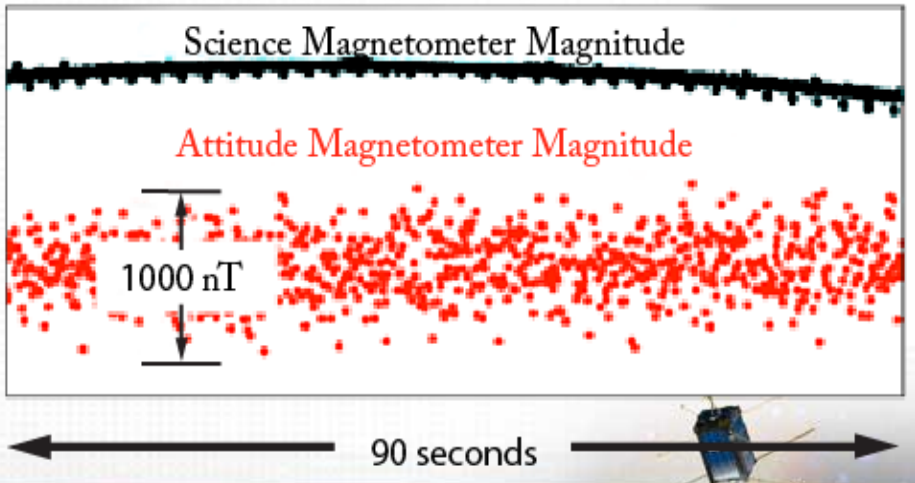


Comparing Science & ADCS Magnetometers

- **Yahtzee Science & ADCS Magnetometer Data**

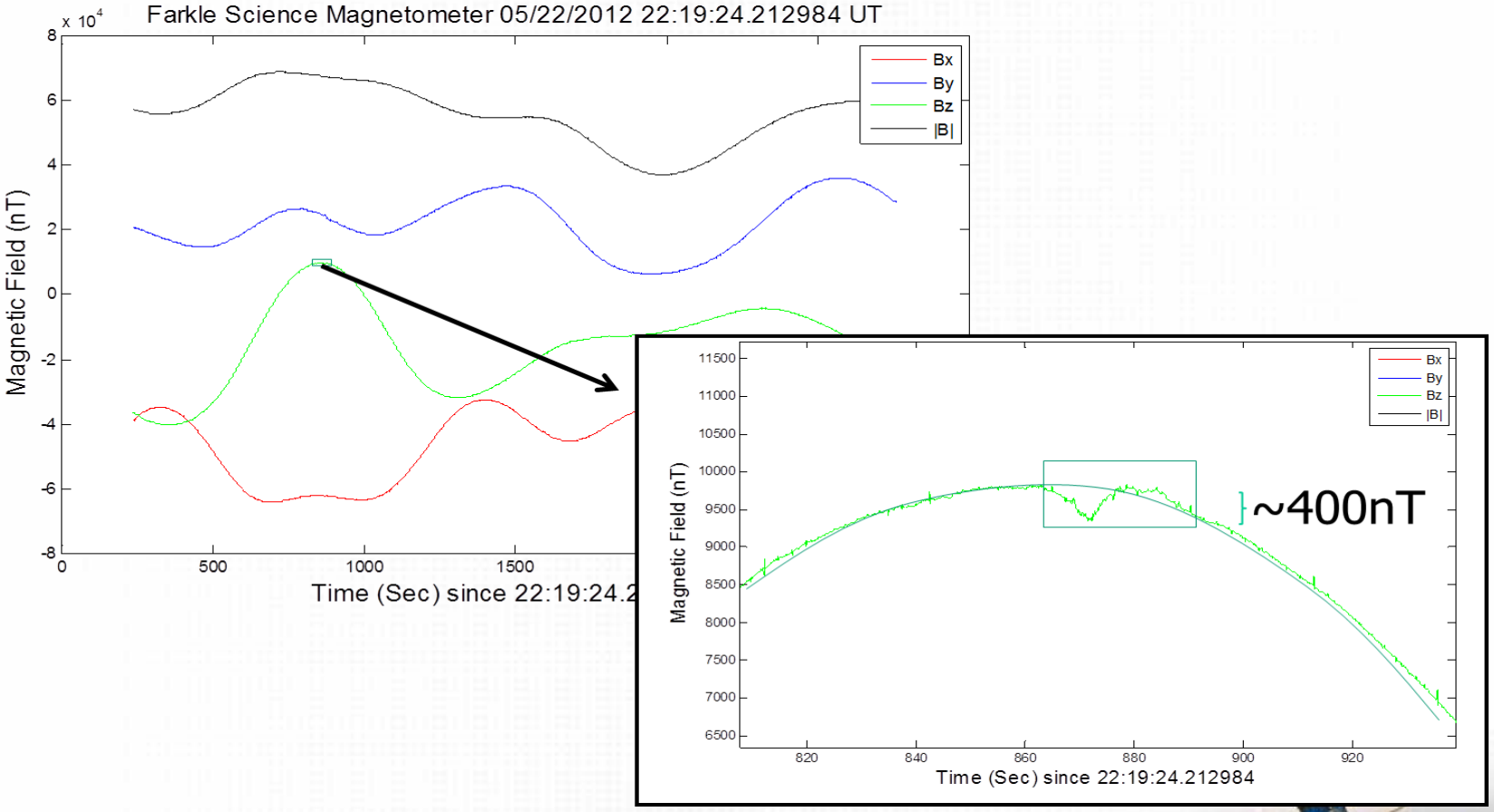


- **Noise floor comparison**
  - ScienceMag Floor: ~ 5-10 nT



Science Magnetometer Data

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



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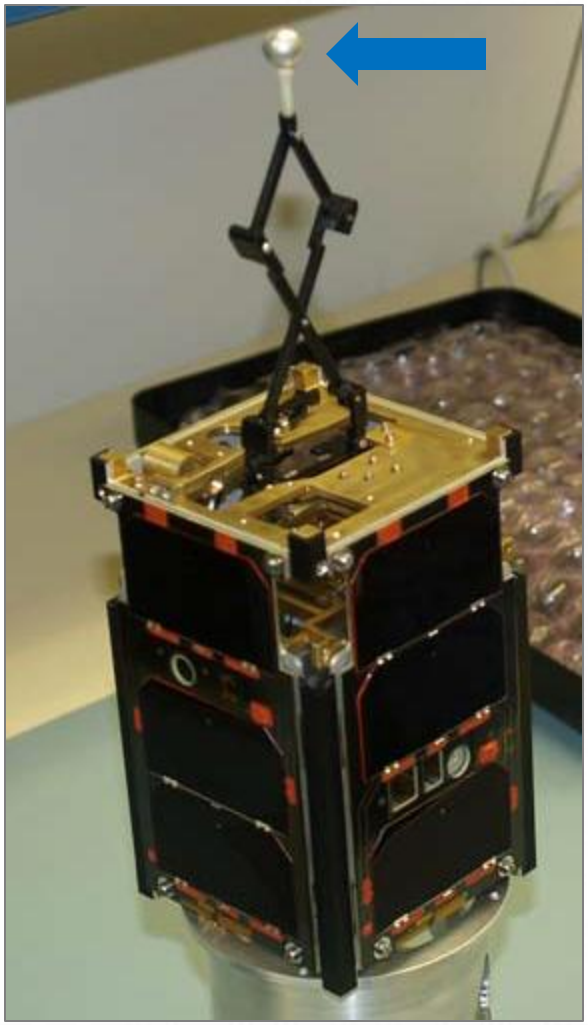
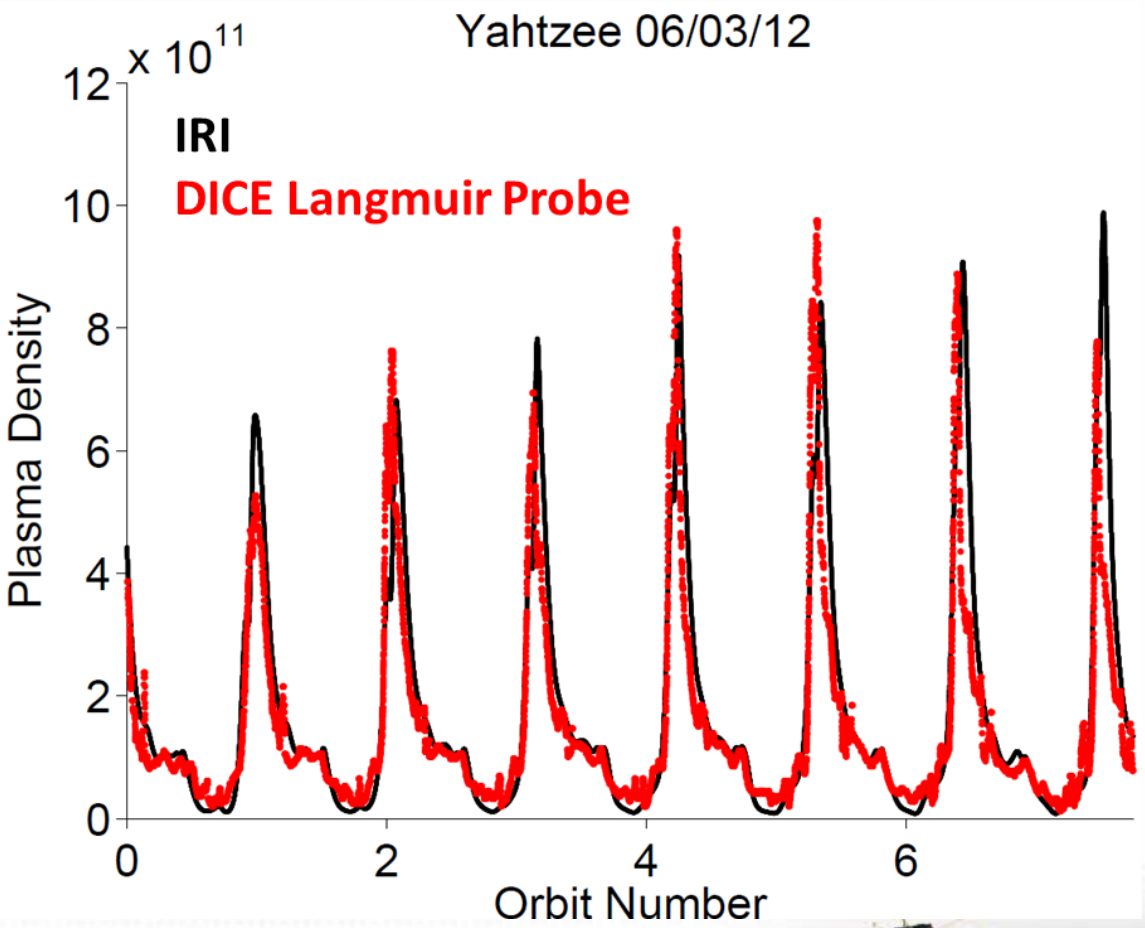
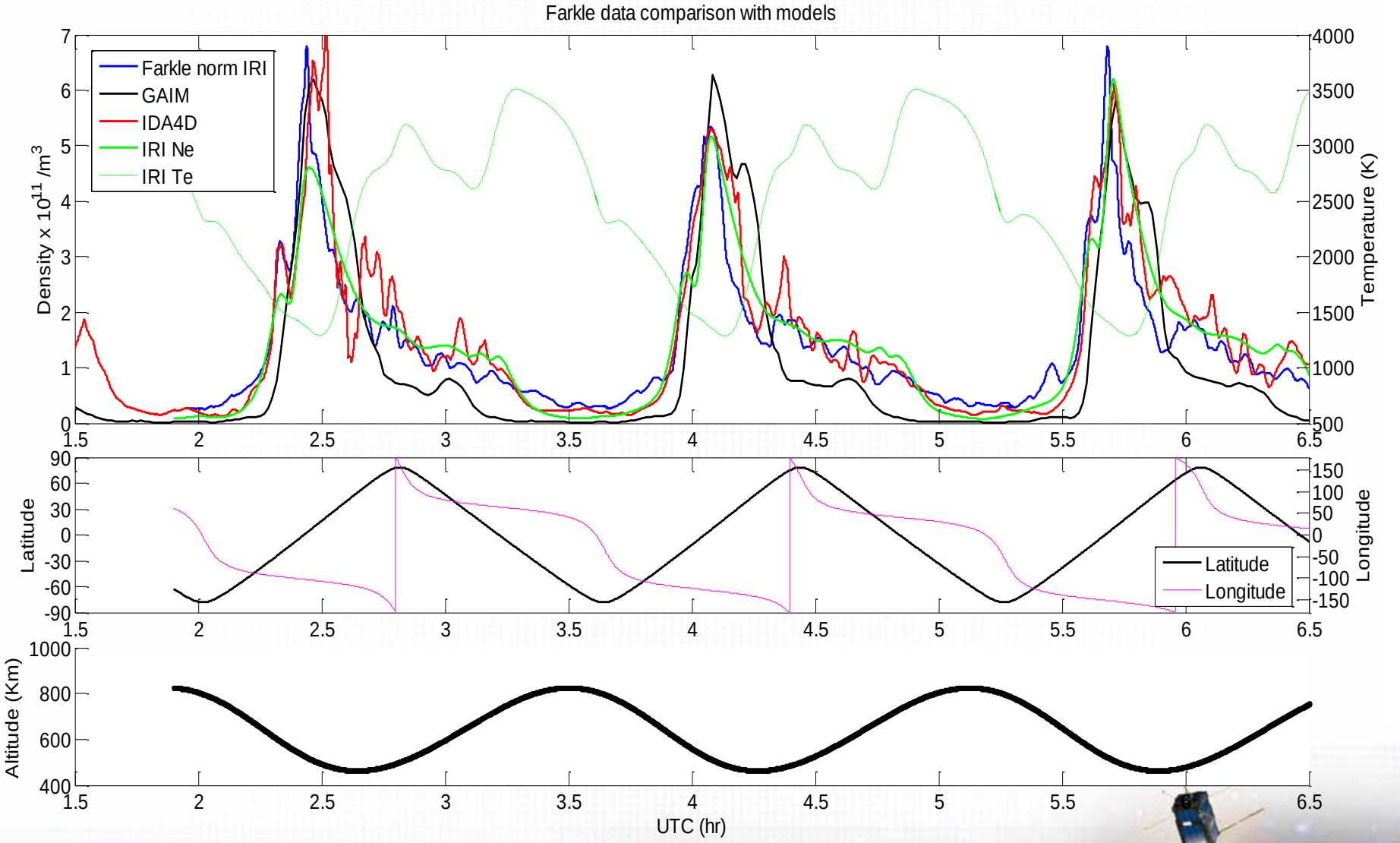
Langmuir Probe Data





DICE SensorSat Science Data



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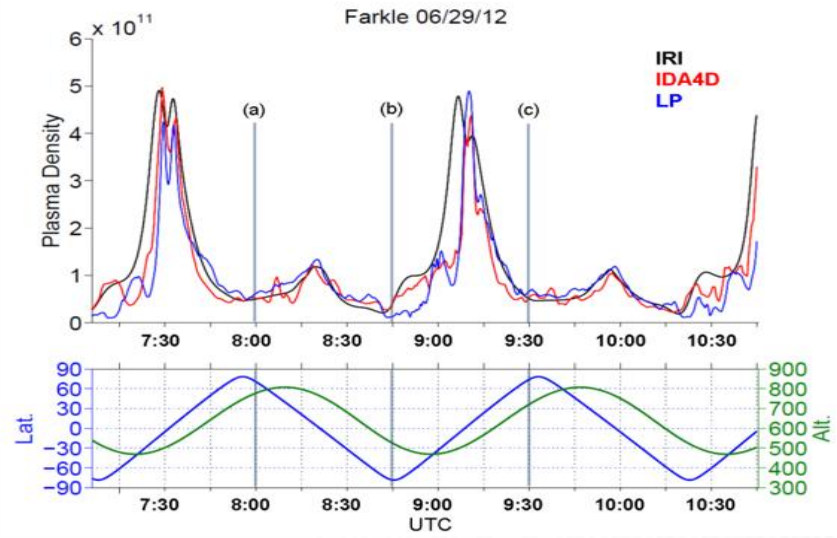
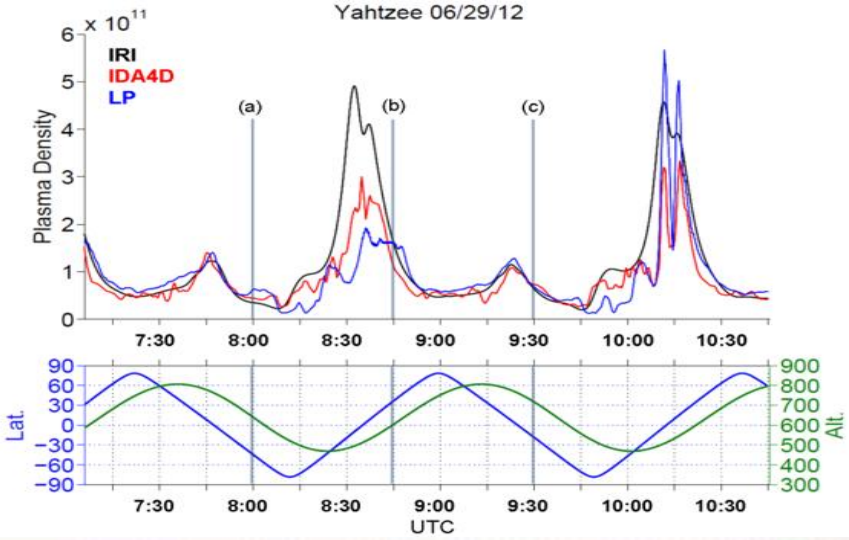
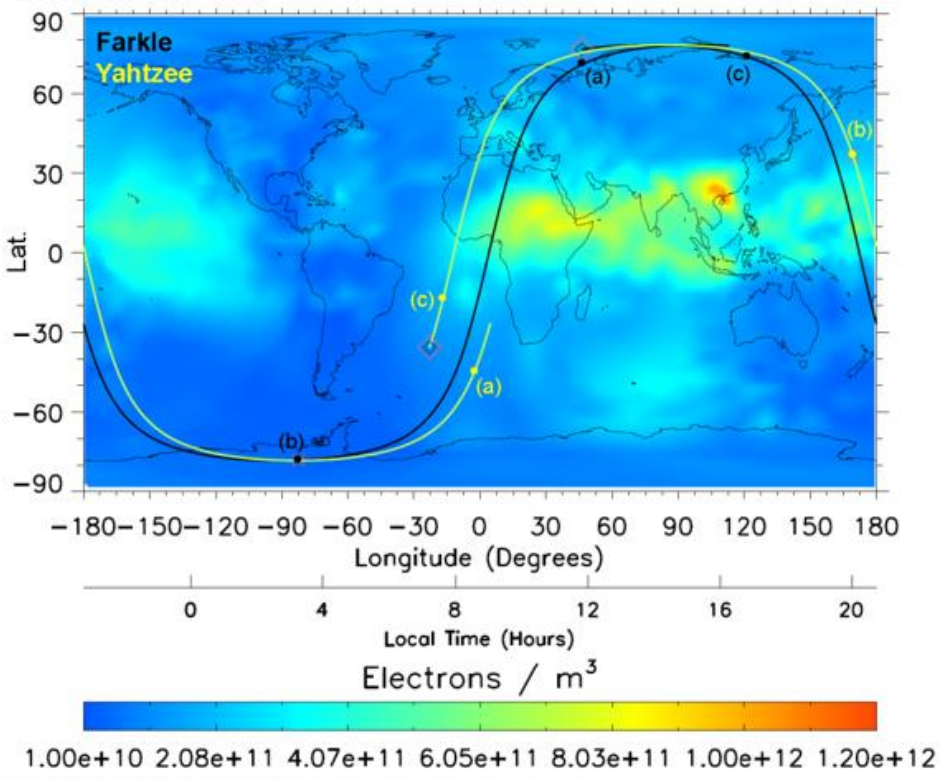
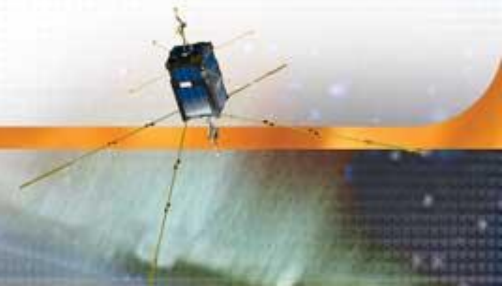
DICE SensorSat Science Data









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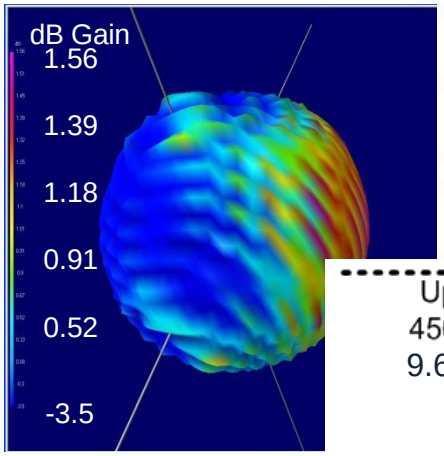
DICE Telemetry Generation Rates

Channel Name	Rate (Hz)	Word Size (# bits)	Sample Size (# Words)	Bit Rate (bits/s)	Sample Period	
					#/Orbit*	Spatial (km)**
EF Probe DC Pair 1_2	35.00	16.00	1.00	560.00	194376.00	0.22
EF Probe DC Pair 3_4	35.00	16.00	1.00	560.00	194376.00	0.22
EF Probe AC Wave Power	1.00	16.00	4.00	64.00	5553.60	7.70
Floating Potential Probe	35.00	16.00	1.00	560.00	194376.00	0.22
Langmuir Probe 1	35.00	16.00	1.00	560.00	194376.00	0.22
Langmuir Probe 2	35.00	16.00	1.00	560.00	194376.00	0.22
Sweeping Probe 1	0.01	16.00	512.00	67.99	46.09	927.71
Sweeping Probe 2	0.01	16.00	512.00	67.99	46.09	927.71
Science Mag X-Axis	35.00	18.00	1.00	630.00	194376.00	0.22
Science Mag Y-Axis	35.00	18.00	1.00	630.00	194376.00	0.22
Science Mag Z-Axis	35.00	18.00	1.00	630.00	194376.00	0.22
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)



DICE Spacecraft 1

DICE Spacecraft 2

Uplinks
450 MHz
9.6 kbits/s

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

Half Duplex
Communications

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

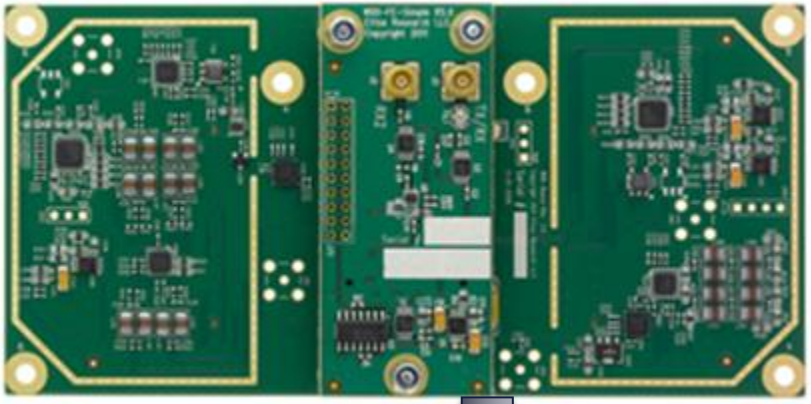
NASA Wallops (18.29 m Dish)
latitude 37.854886 °N ,
longitude 75.512936 °W,
altitude 3.05 m

SDL CubeSat Missions Operations Center

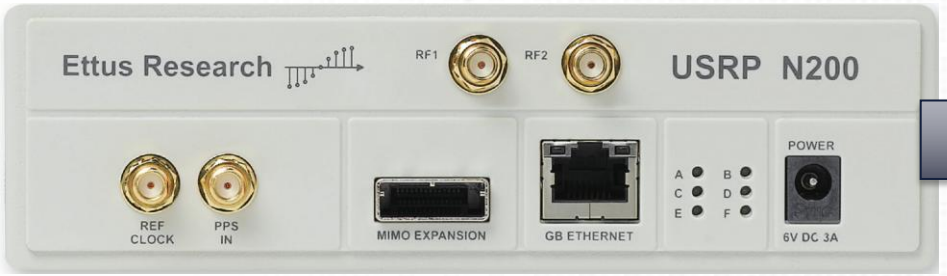
- Wallops and SRI ground stations controlled remotely from SDL headquarters
- Dual ground station coverage allows for 4 – 5, 15-minute communications overpasses per day

Downlink Telemetry System

WBX 50-2200 MHz Rx/Tx



LNA/BPF/Switch



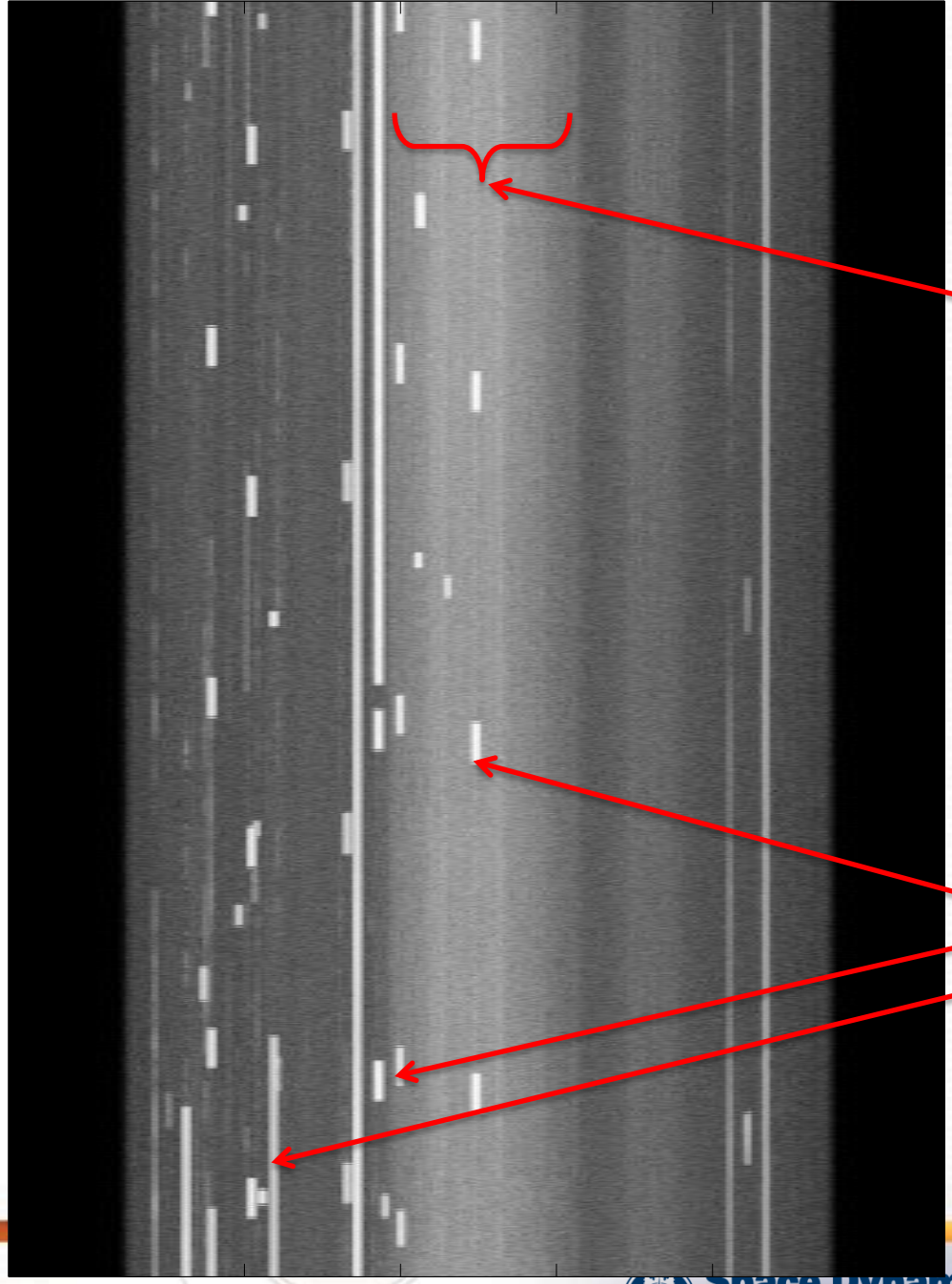
Ethernet

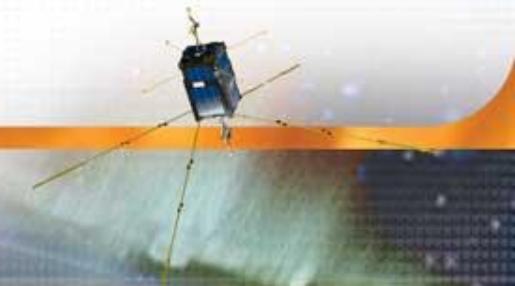
10 Msamp/s I/Q data

Software Defined Radio

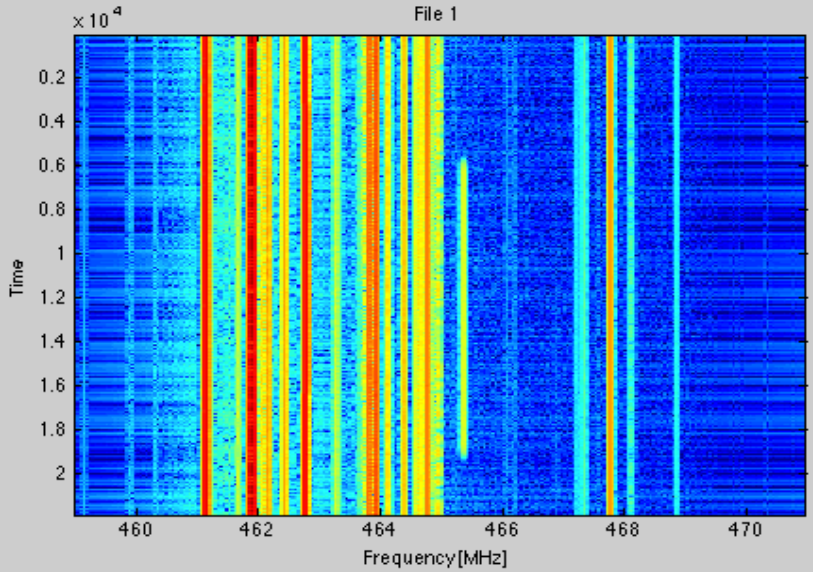
MySQL Database

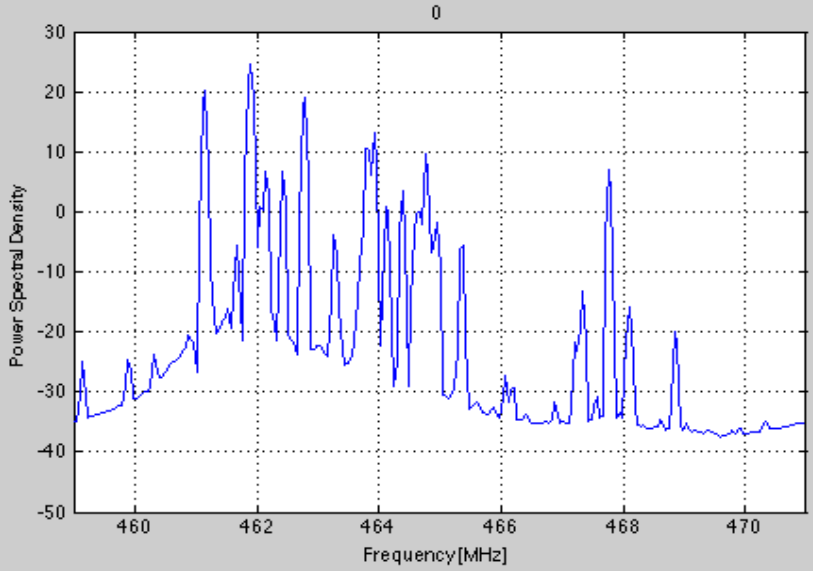
Narrow Band Interference Spectrogram



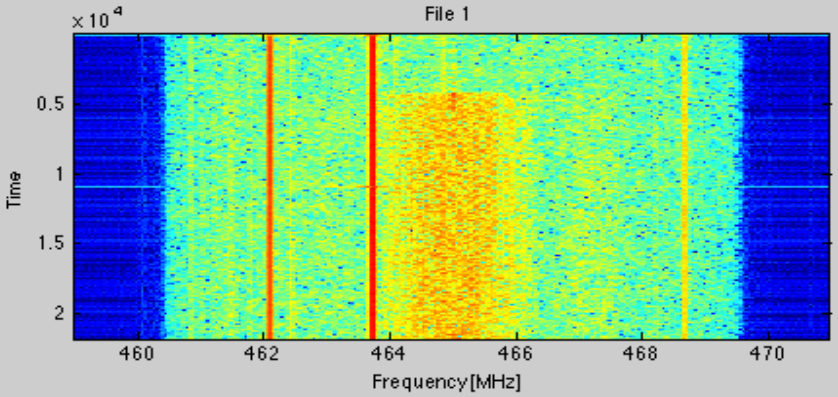


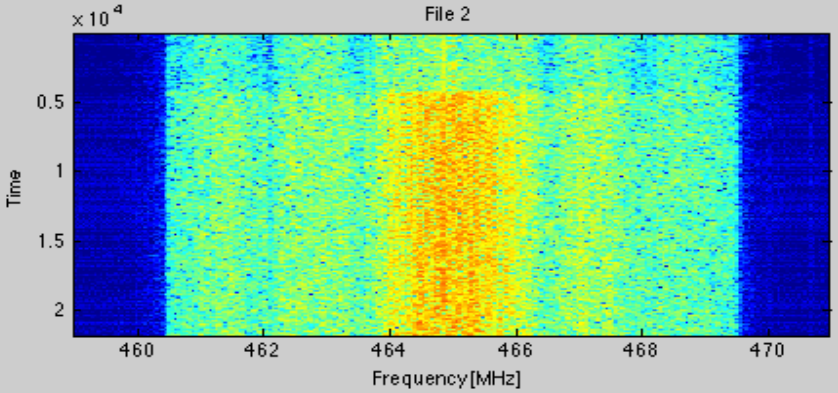
Interference at SRI Site

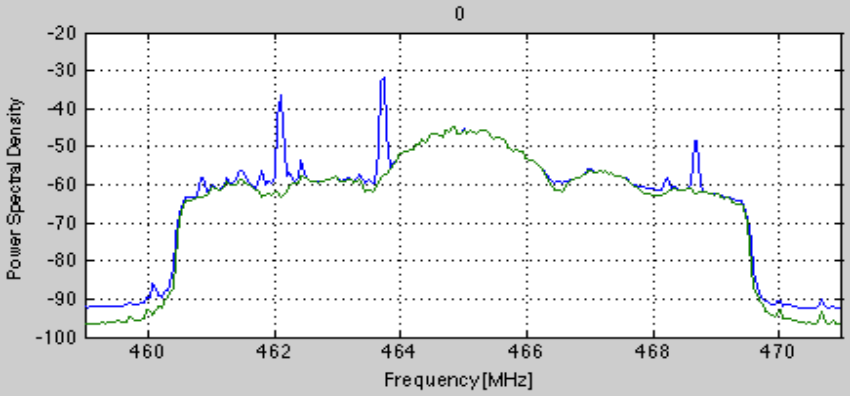




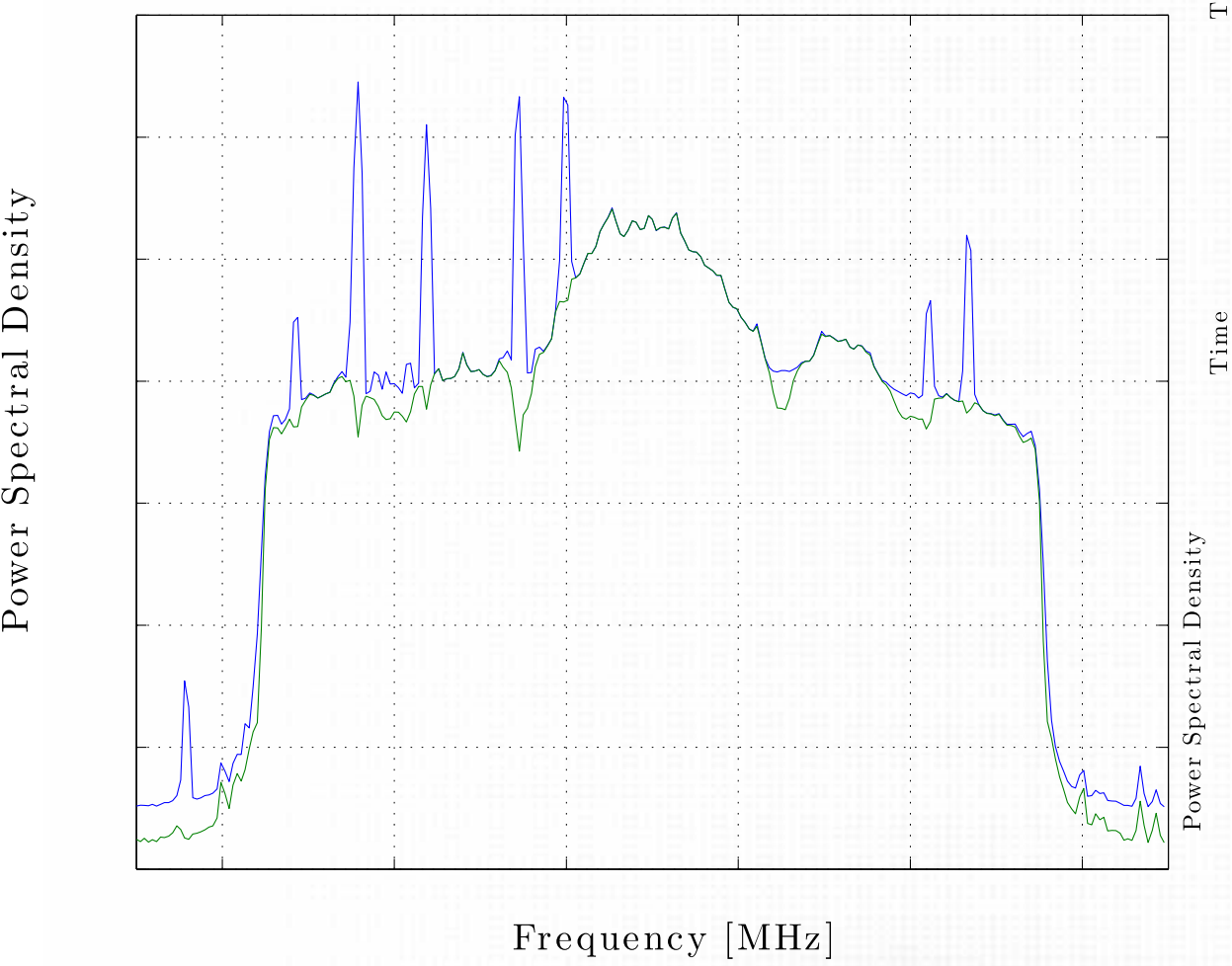
Interference at Wallops Site

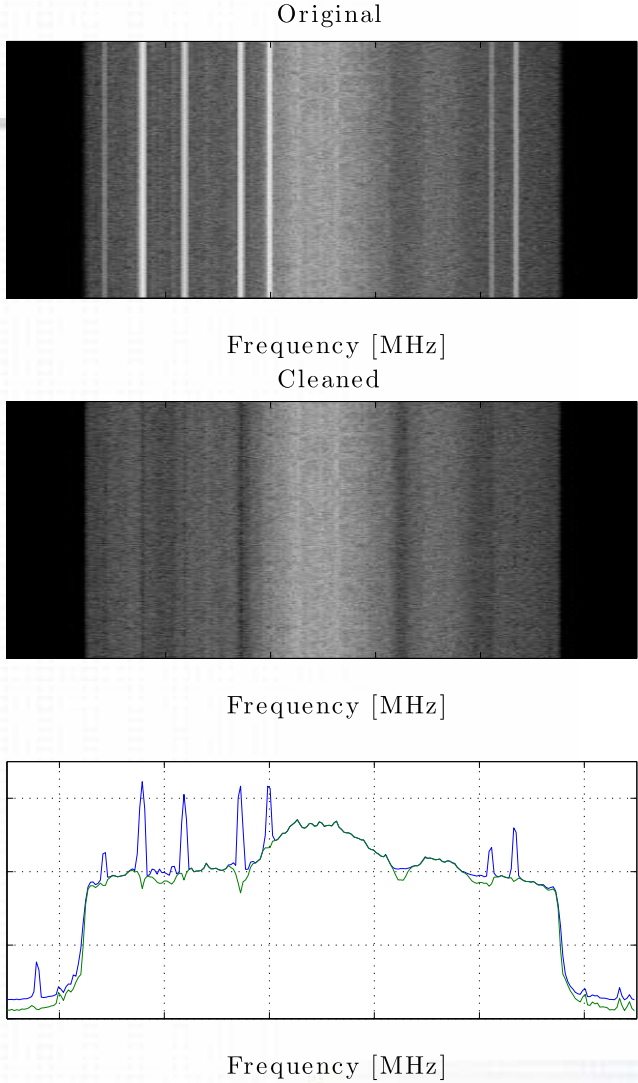




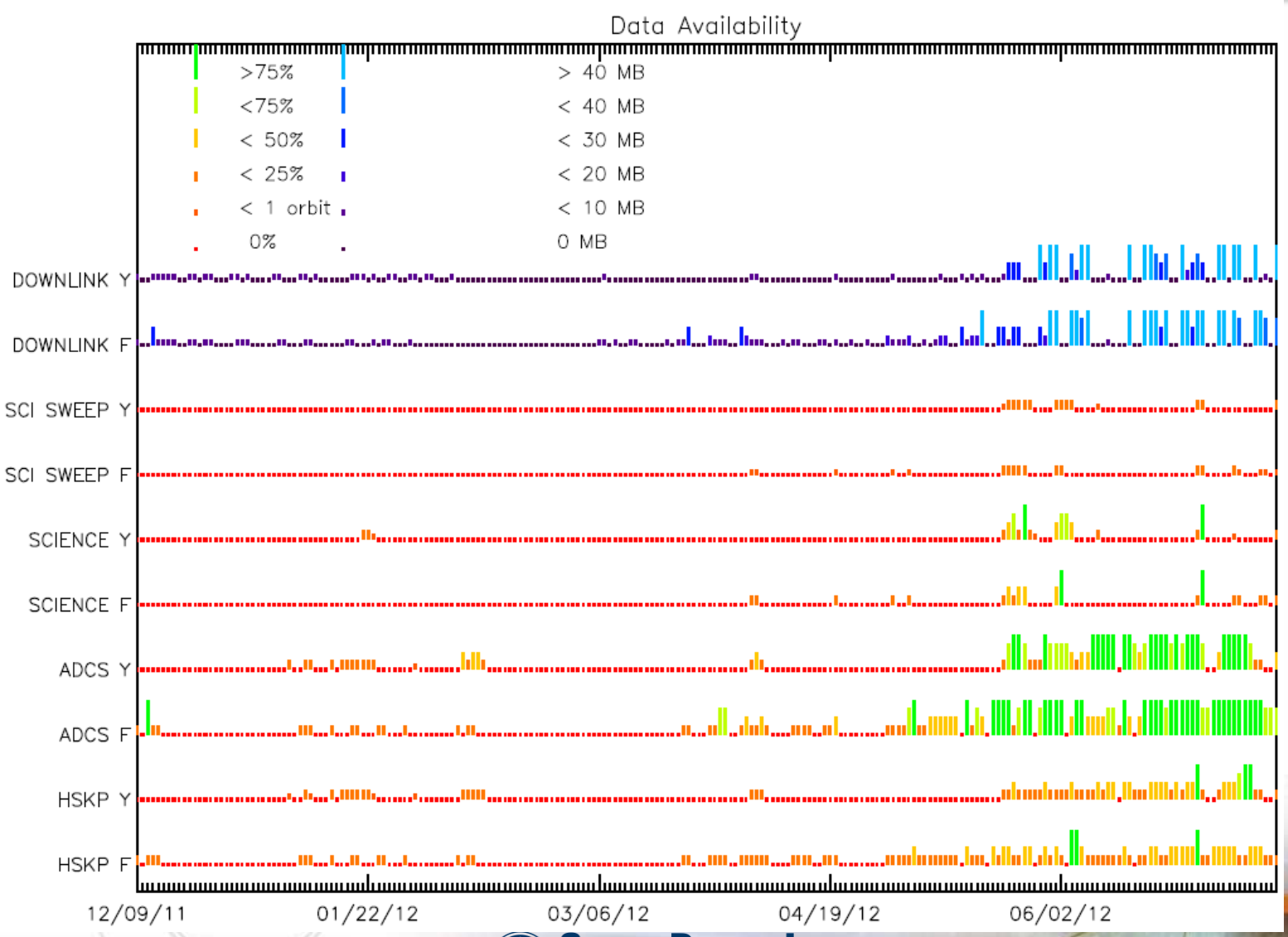


NBI Filter: Before and After





Improvement In Downlink Quality



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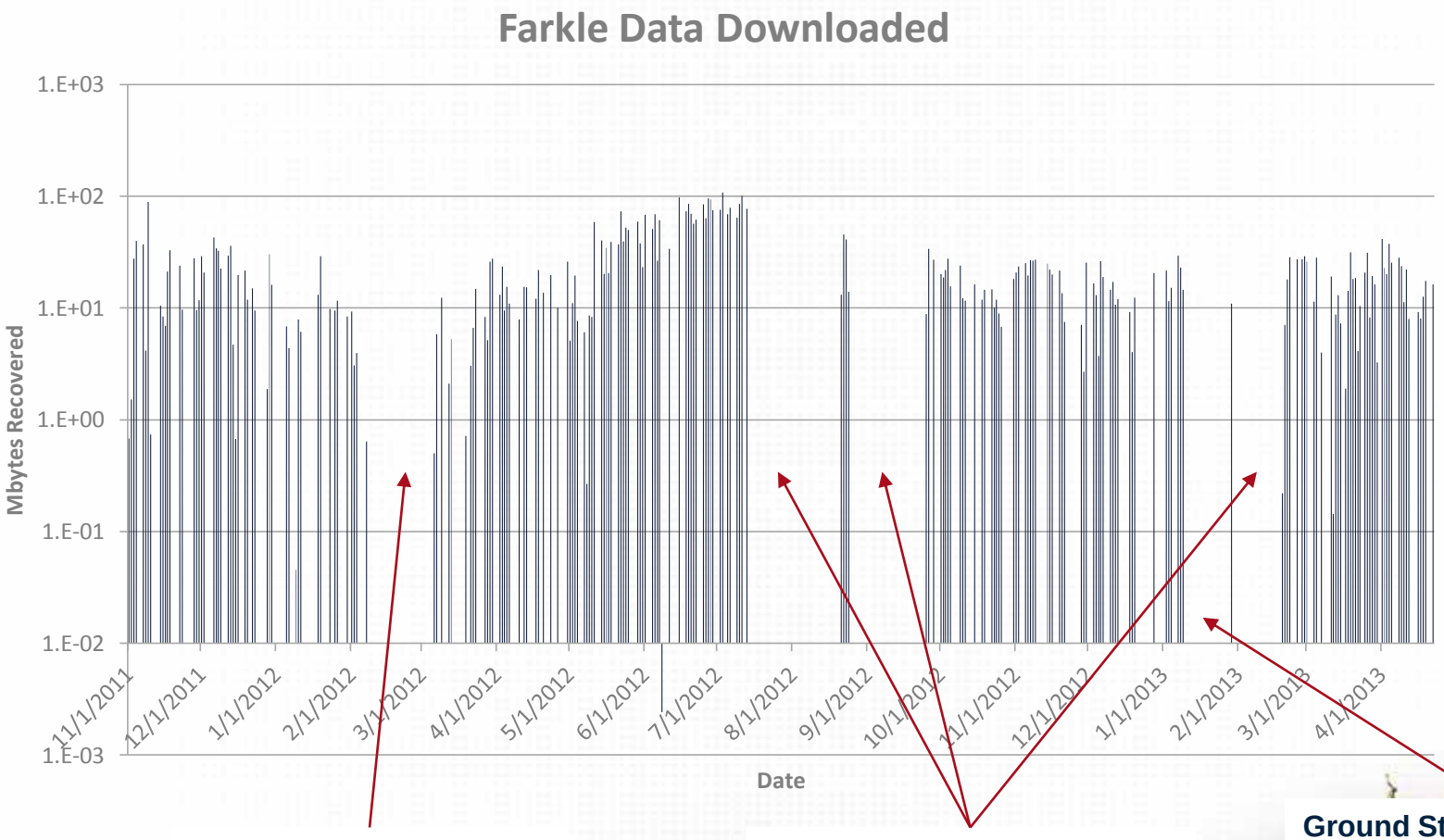
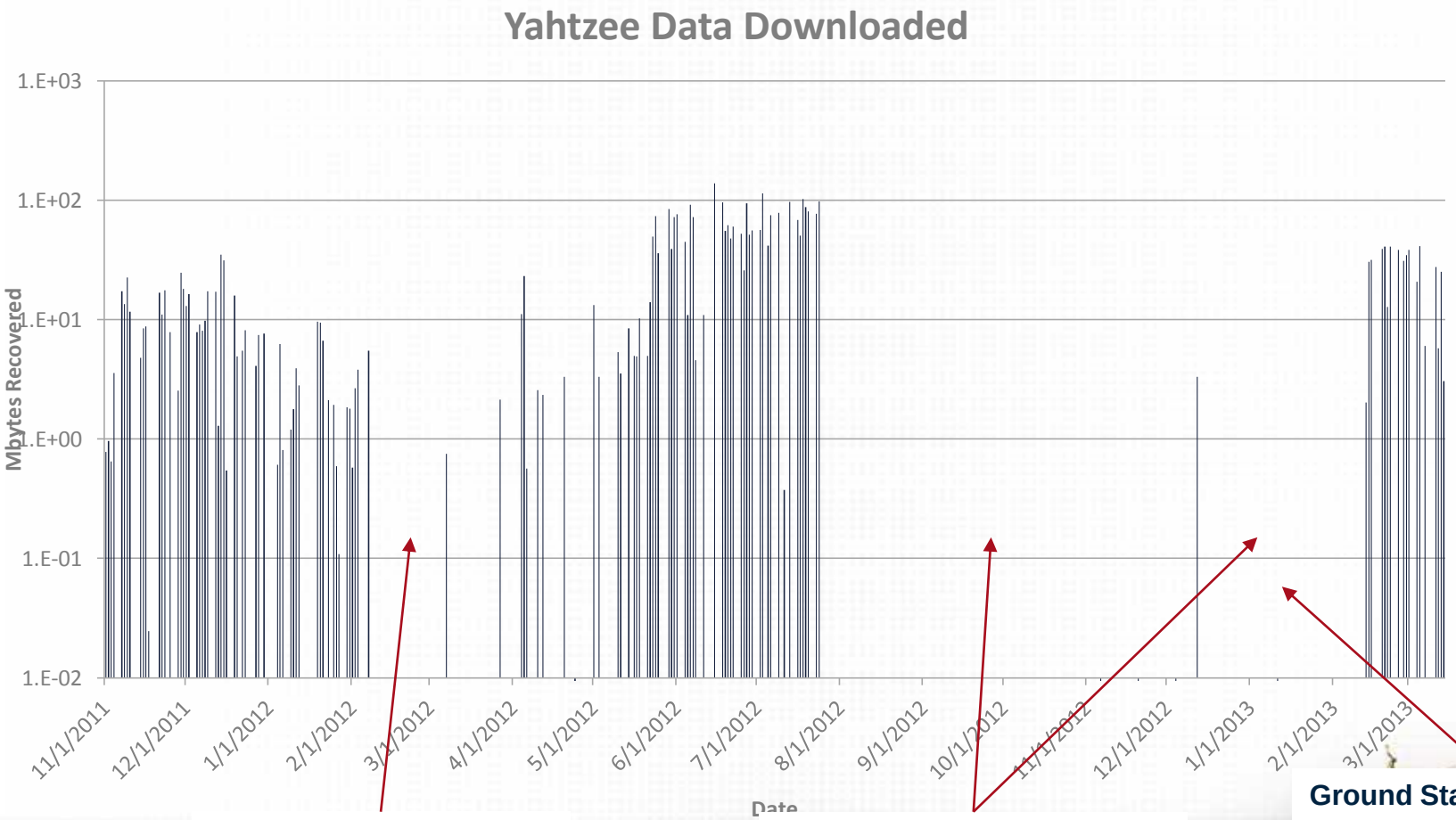
Farkle Data Recovered

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



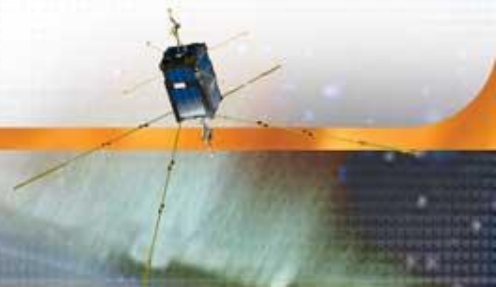
Yahtzee Data Recovered

- 3.26GBytes of data recovered and stored in MOC database



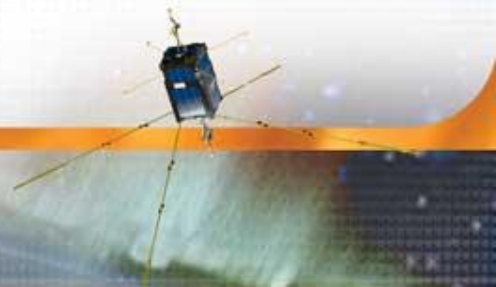
Programmatic Lessons Learned

- 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.

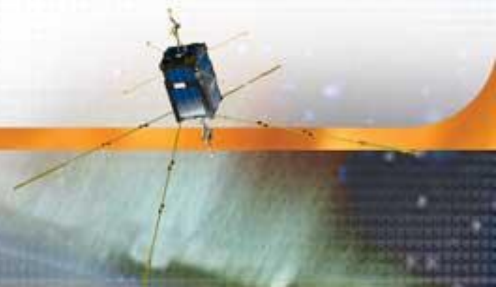


Technical Lessons Learned

- 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?



SDL Proprietary

Acknowledgments

- 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.