
“High Data-Rate” Communications for DICE

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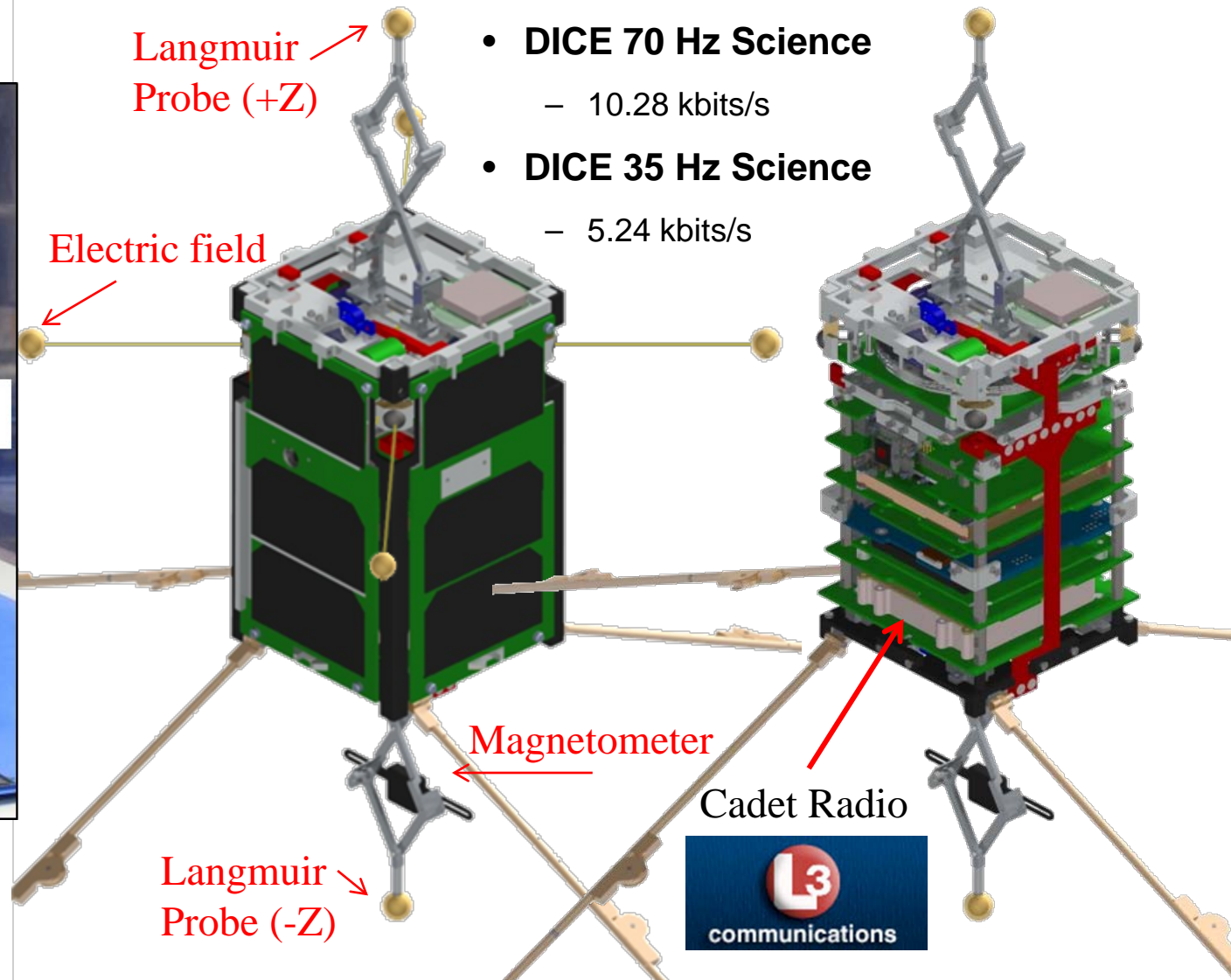
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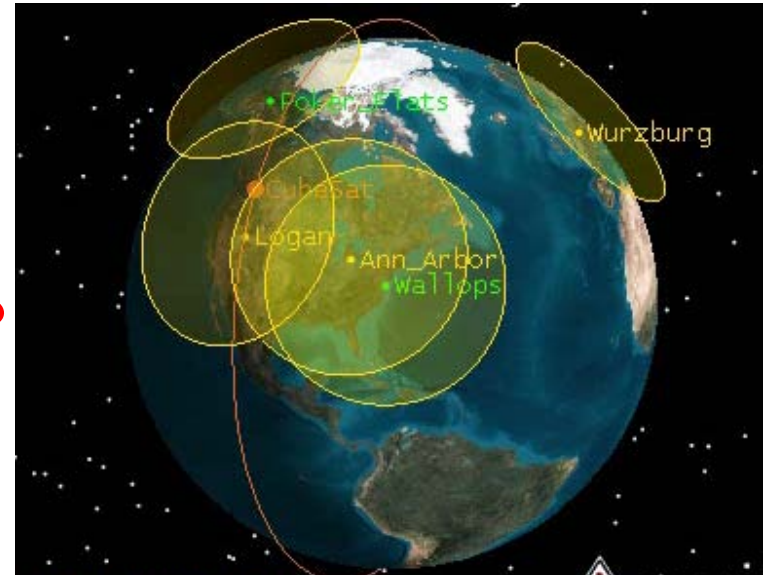
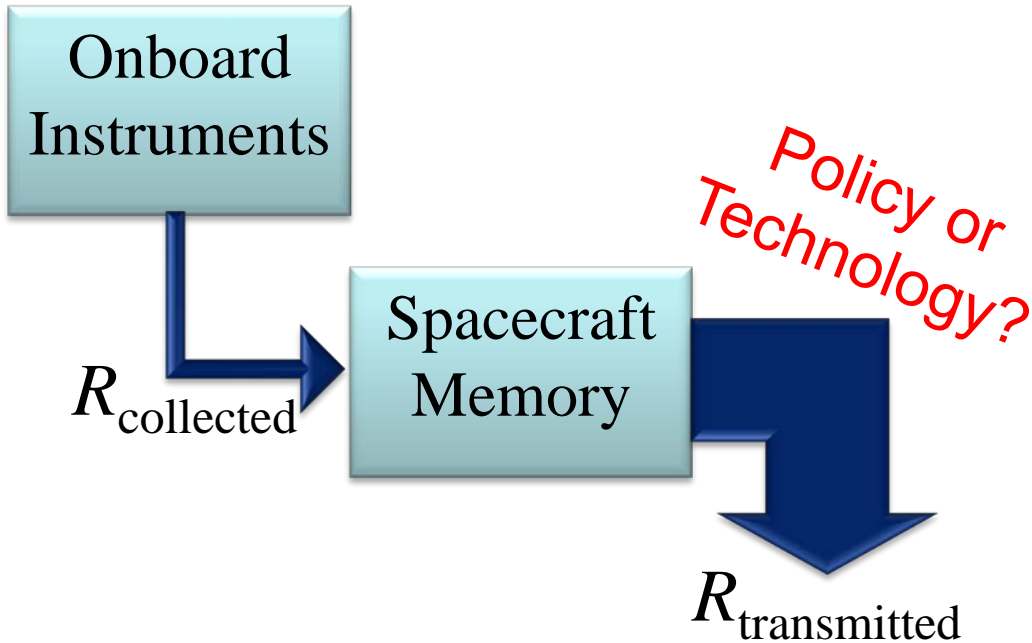
Dynamic Ionosphere CubeSat Experiment (DICE)



**Satellite Telemetry
Systems are Limited by
Regulation and Policy
and *NOT* by Technology**

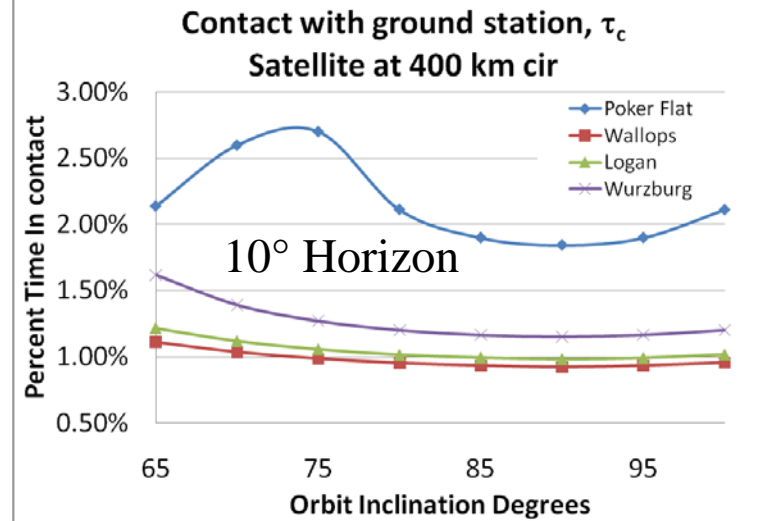


Store and Forward Fundamentals



$$\tau = \frac{T_{\text{contact}}}{T_{\text{period}}} = \alpha \frac{R_{\text{collected}}}{R_{\text{transmitted}}}$$

Factor of Safety



What does this mean?

- DICE-Wallops operates on a 8 hour work day 5-days/week
 - $1/\alpha \approx 25\%$ (factor of safety of 4)
- Automated Ground Station
 - $1/\alpha \approx 100\%$
- DICE 70 Hz Science
 - 10.28 kbits/s
- DICE 35 Hz Science
 - 5.24 kbits/s

Assuming 1% Access to Satellite

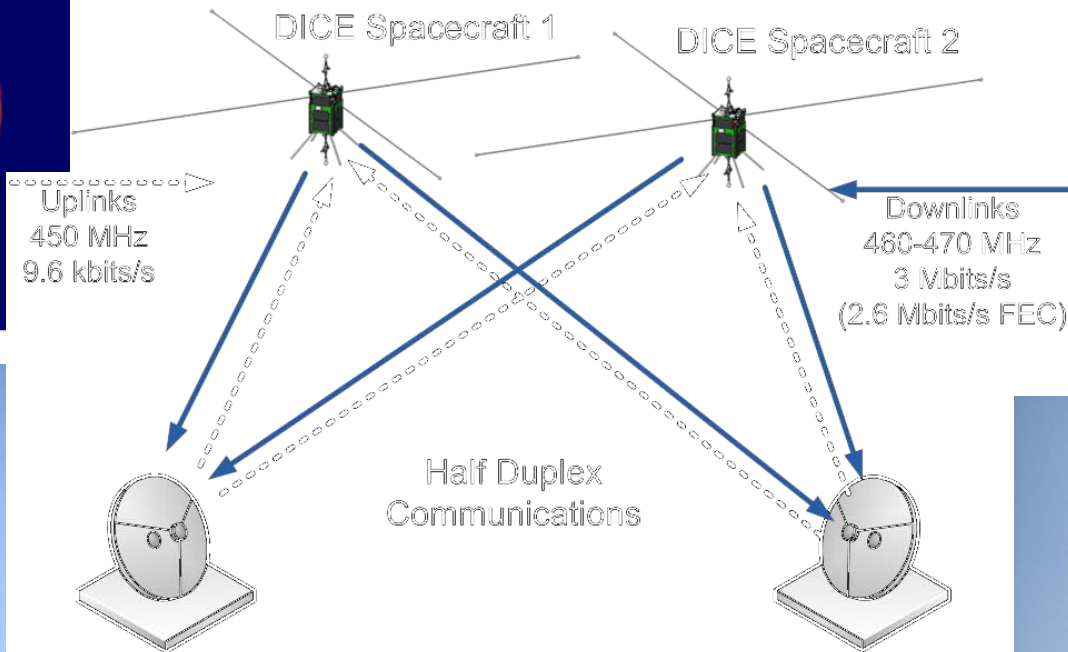
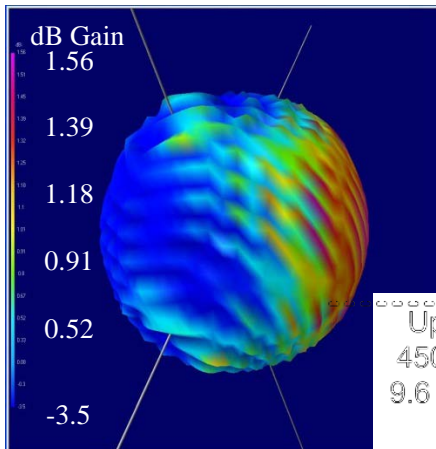
<i>DICE Telemetry System</i>			<i>16 Bit InSitu</i>		<i>512x512x16 image</i>	
Transmitted Rate Mbits/s	Factor %	Collection Rate kbits/s	Samples Hz	Samples m	s/Image s	km/image km
2.63	25%	6.58	411	18.3	638	4784
2.63	100%	26.30	1644	4.6	159	1196
5.00	25%	12.50	781	9.6	336	2517
5.00	100%	50.00	3125	2.4	84	629
10.00	25%	25.00	1563	4.8	168	1258
10.00	100%	100.00	6250	1.2	42	315

Regulations on 460 to 470 MHz

- 5.289 **Earth exploration-satellite service** applications, other than the meteorological-satellite service, may also be used in the bands **460-470 MHz** and 1690-1710 MHz for space-to-Earth transmissions **subject to not causing harmful interference to stations operating in accordance with the Table.**
- US201 In the band **460-470 MHz**, space stations in the Earth exploration-satellite service may be authorized for **space-to-Earth transmissions on a secondary basis** with respect to the fixed and mobile services. When operating in the meteorological-satellite service, such stations shall be protected from harmful interference from other applications of the Earth exploration-satellite service. **The power flux-density produced at the Earth's surface by any space station in this band shall not exceed -152 dBW/m²/4 kHz.**

10 MHz Bandwidth available

DICE Telemetry Systems (3 Mbit/s)



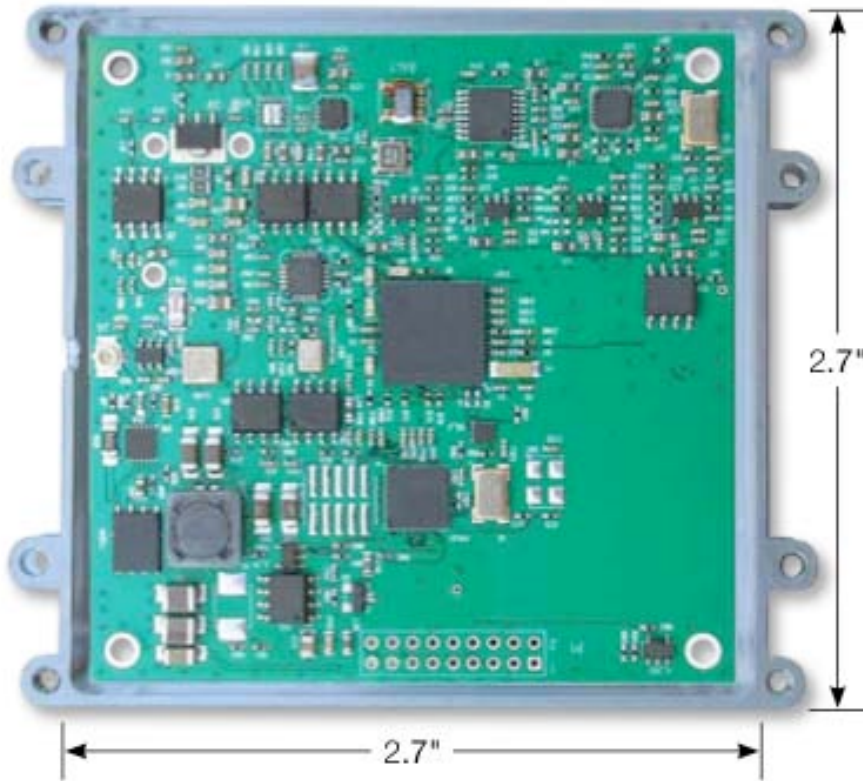
SRI (18.3 m Dish)
latitude 37.40303 °N ,
longitude 122.17423 °W,
altitude 156.47 m



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

With FEC the Downlink
Data Rate is 2.63 Mbps

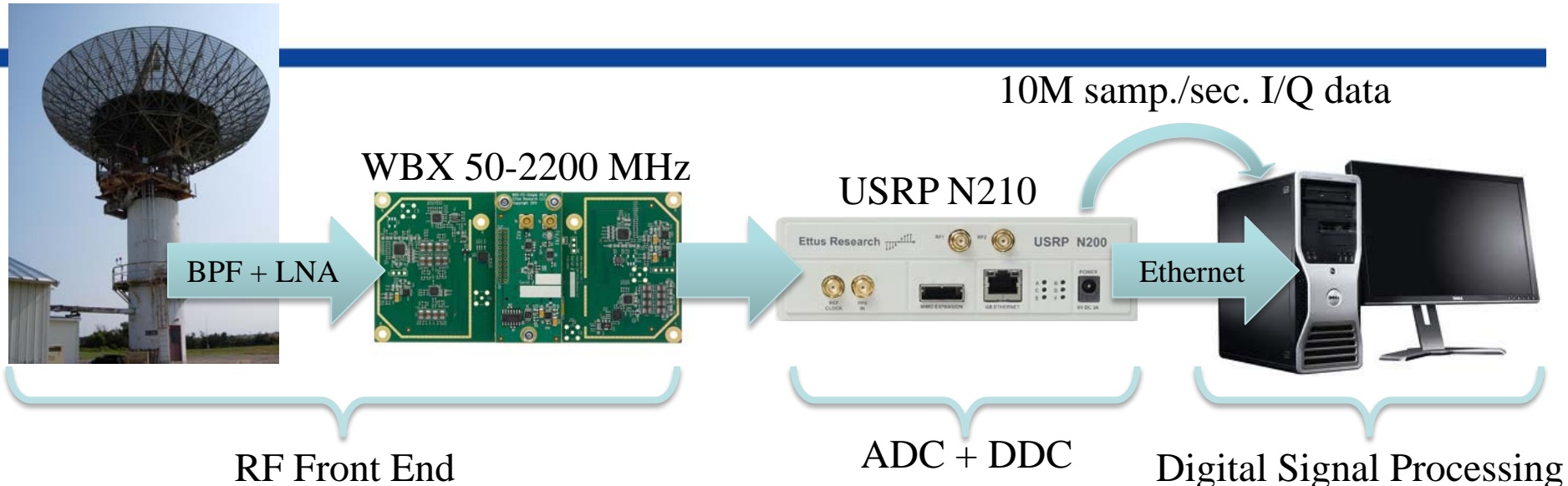
Telemetry COTS: L3 Cadet Radio



- UHF or S-Band
- Downlink: 1-20 Mbps
- Uplink: Up to 250 kbps
- Size: 2.7" x 2.7" x 0.53"
- Weight: 7.6 oz
- Transmit: 8-12 Watts
- Receive: 0.3 Watts
- Memory: 4 GB Flash

Source: http://www.l-3.com/csw/ProductsAndServices/DataSheets/Cadet_Nanosatellite_Radio_WEB.pdf

DICE SDR



DICE Software Defined Radio (SDR)

- Too much DSP pushed on to PC
- PC could not meet real-time schedule
- Record data during overpass
- Post-process data

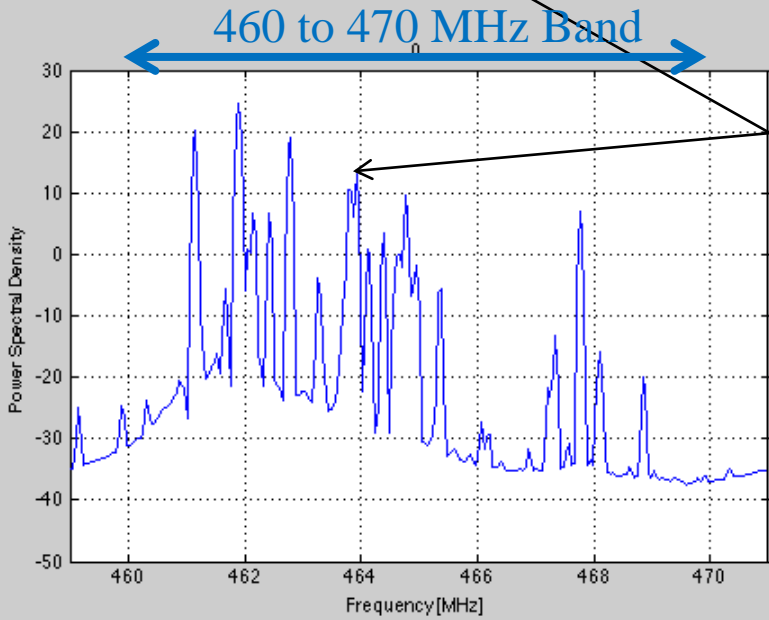
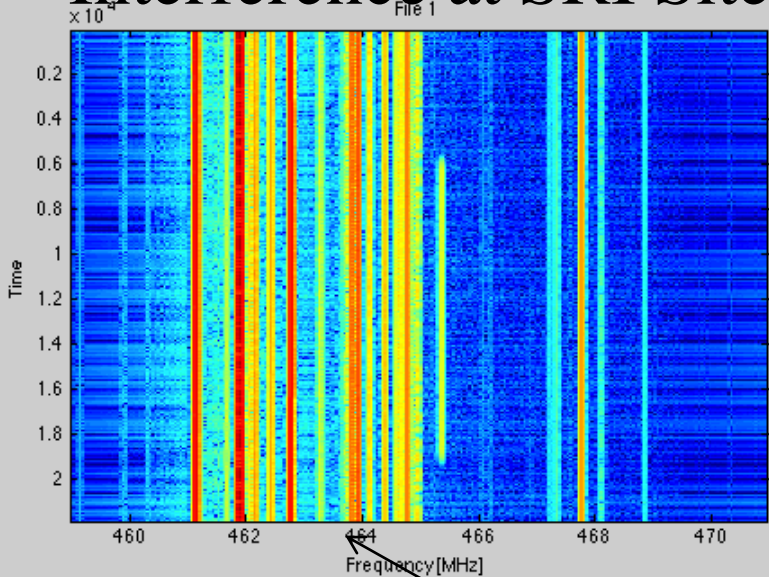
Real-time processing needs

- Move DSP back to FPGA or add DSP/GPU
- Move away from USRP-based solution: not enough user space on FPGA

Digital Signal Processing

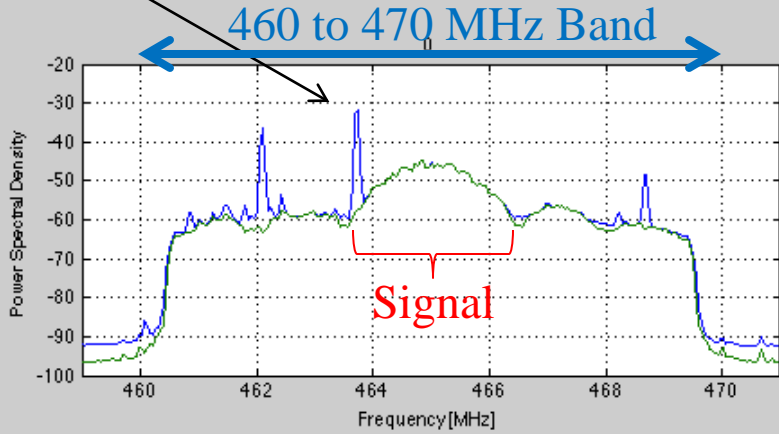
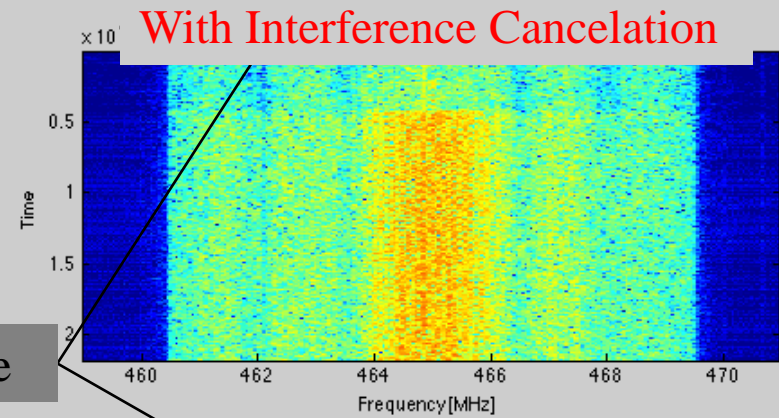
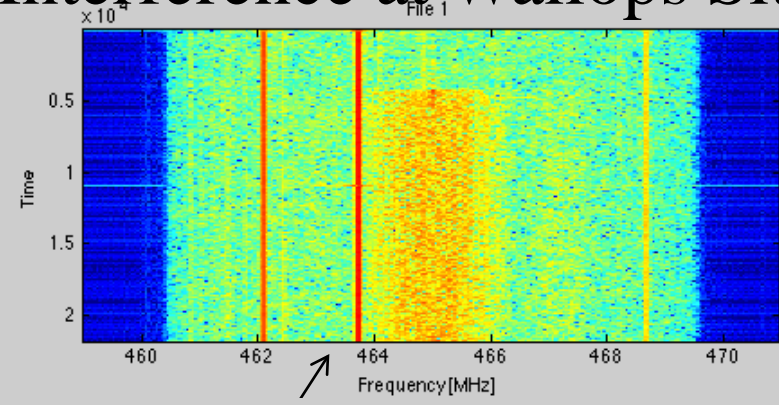
- Detection
- Interference cancel.
- Doppler correction
- Synchronization
- Demodulation
- FEC decoding
- Back-end services
- MSQl database

Interference at SRI Site



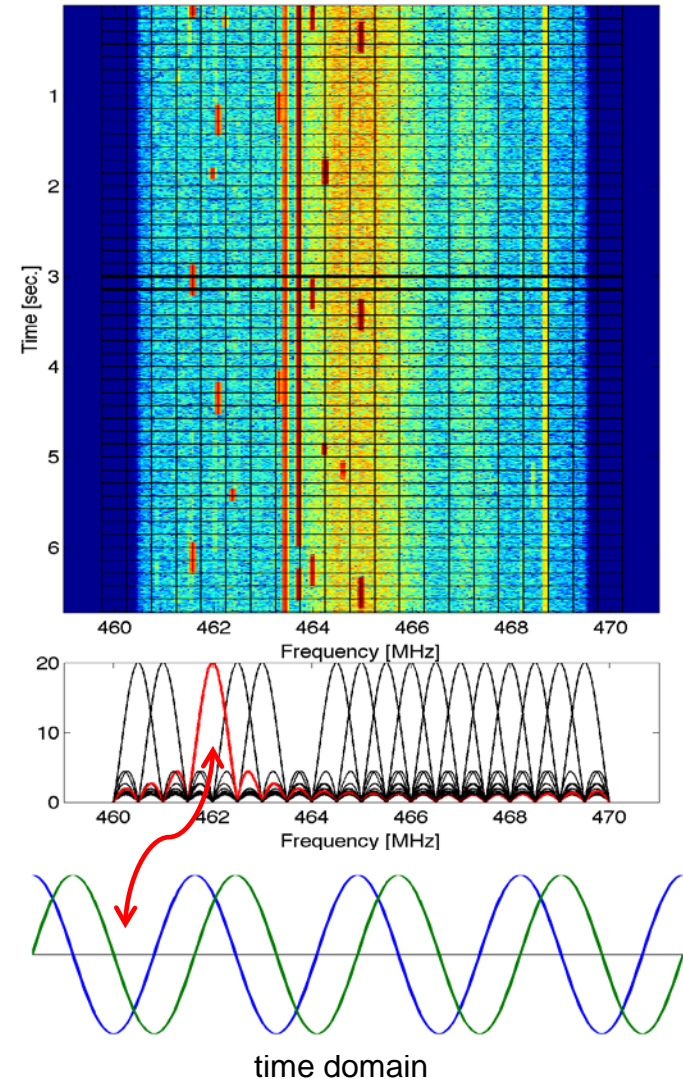
Interference

Interference at Wallops Site

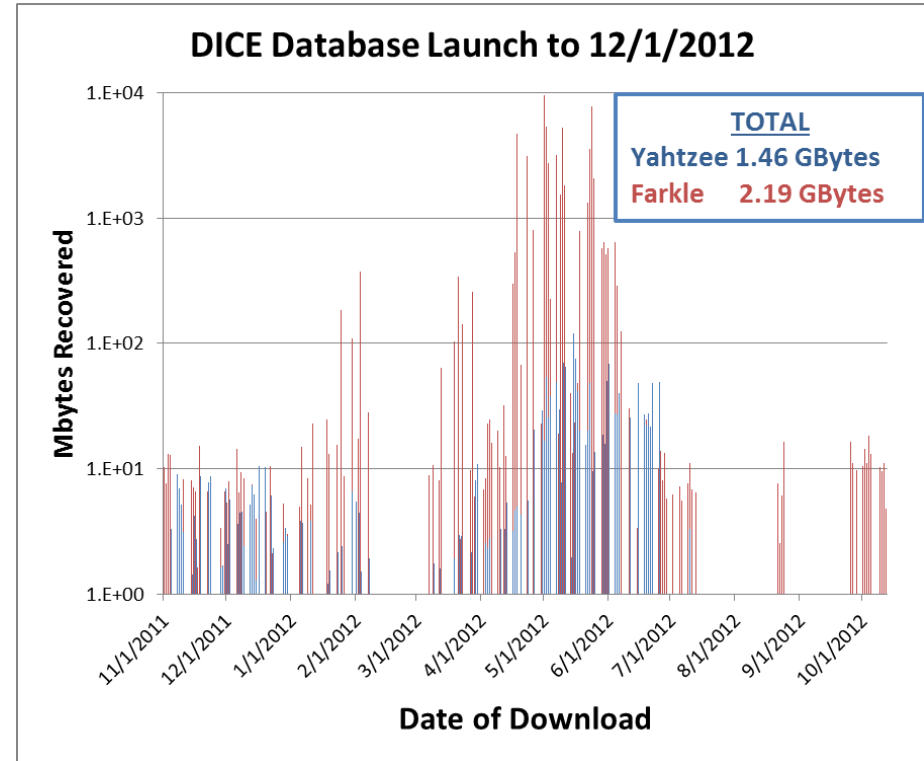
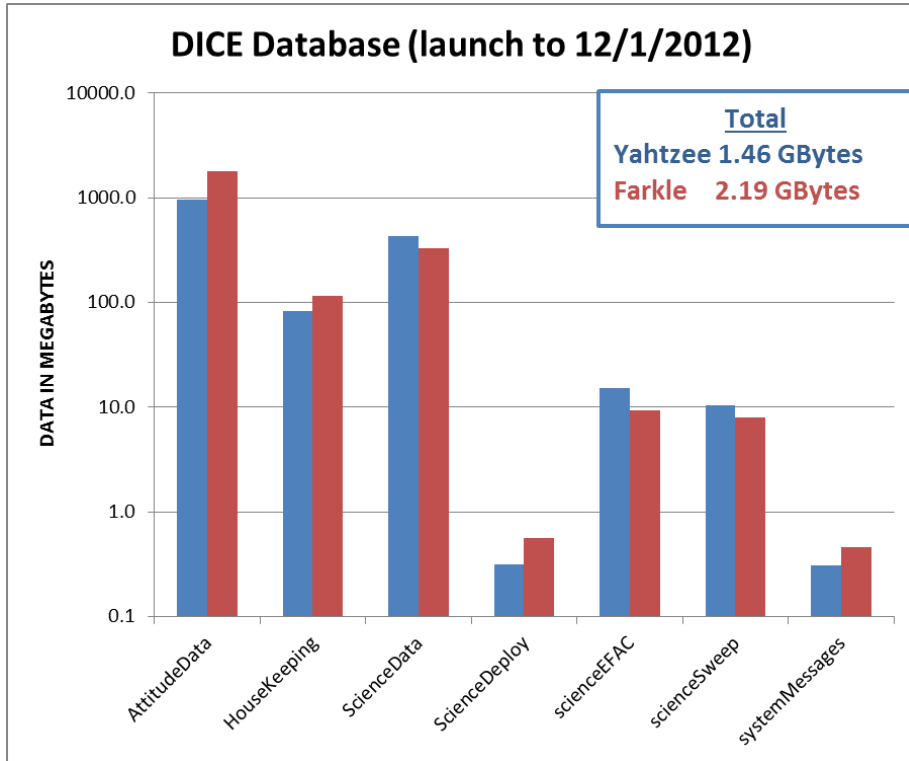


Cognitive Radio

- **Be proactive toward interference rather than reactive**
- **Concept: Divide spectrum into 100s or 1000s of narrow spectral sub-channels**
- **Cognitive radio**
 1. Ground station measures interference in each sub-channel
 2. List of clear channels sent to spacecraft
 3. Spacecraft transmits on clear sub-channels
- **Makes best use of available bandwidth**
- **Achieves highest data rate**
- **FEC across sub-channels to overcome unanticipated interference**



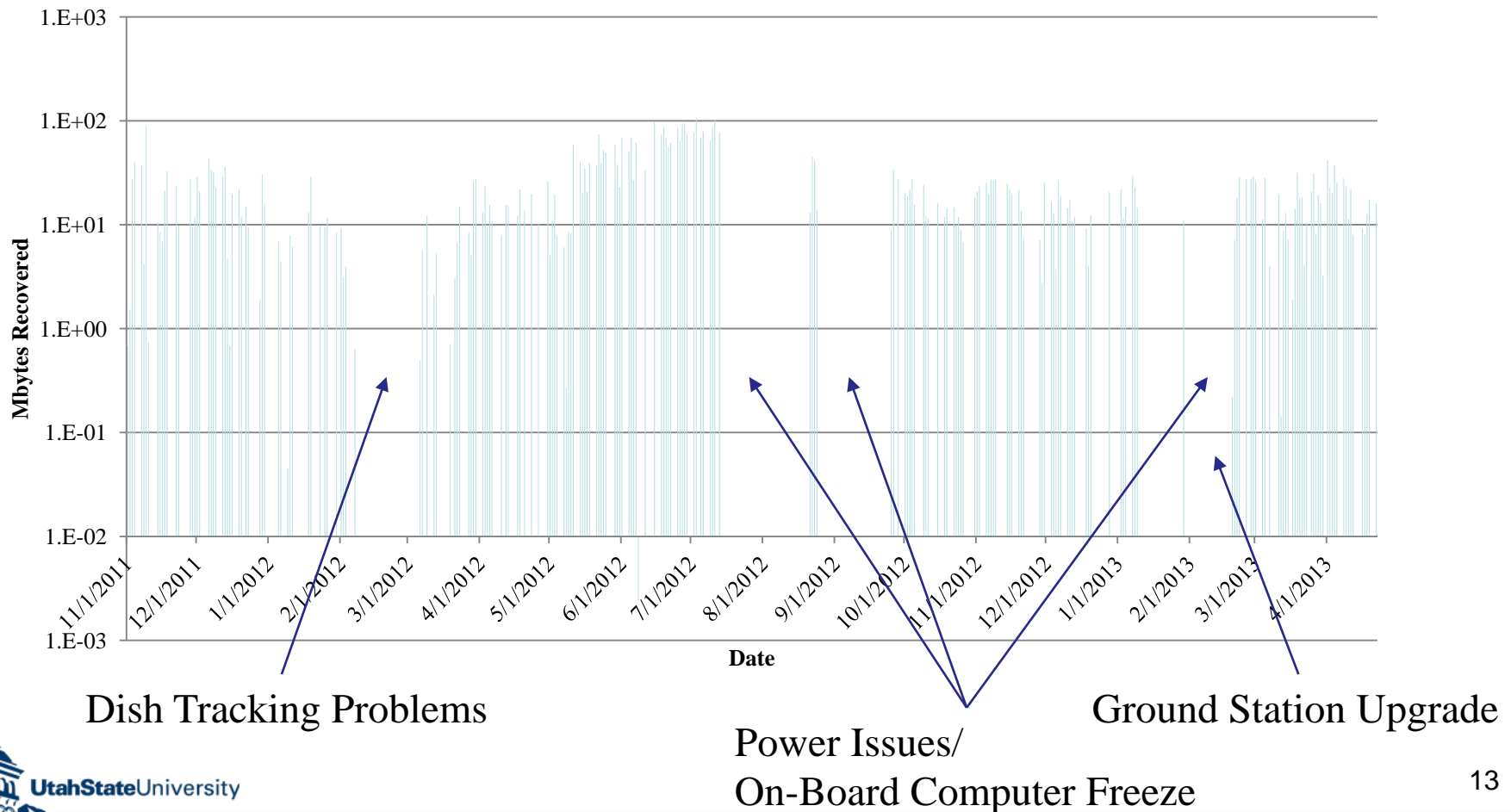
DICE Results



Farkle Data Recovered

- 5.13GBytes of data recovered and stored in a MySQL database

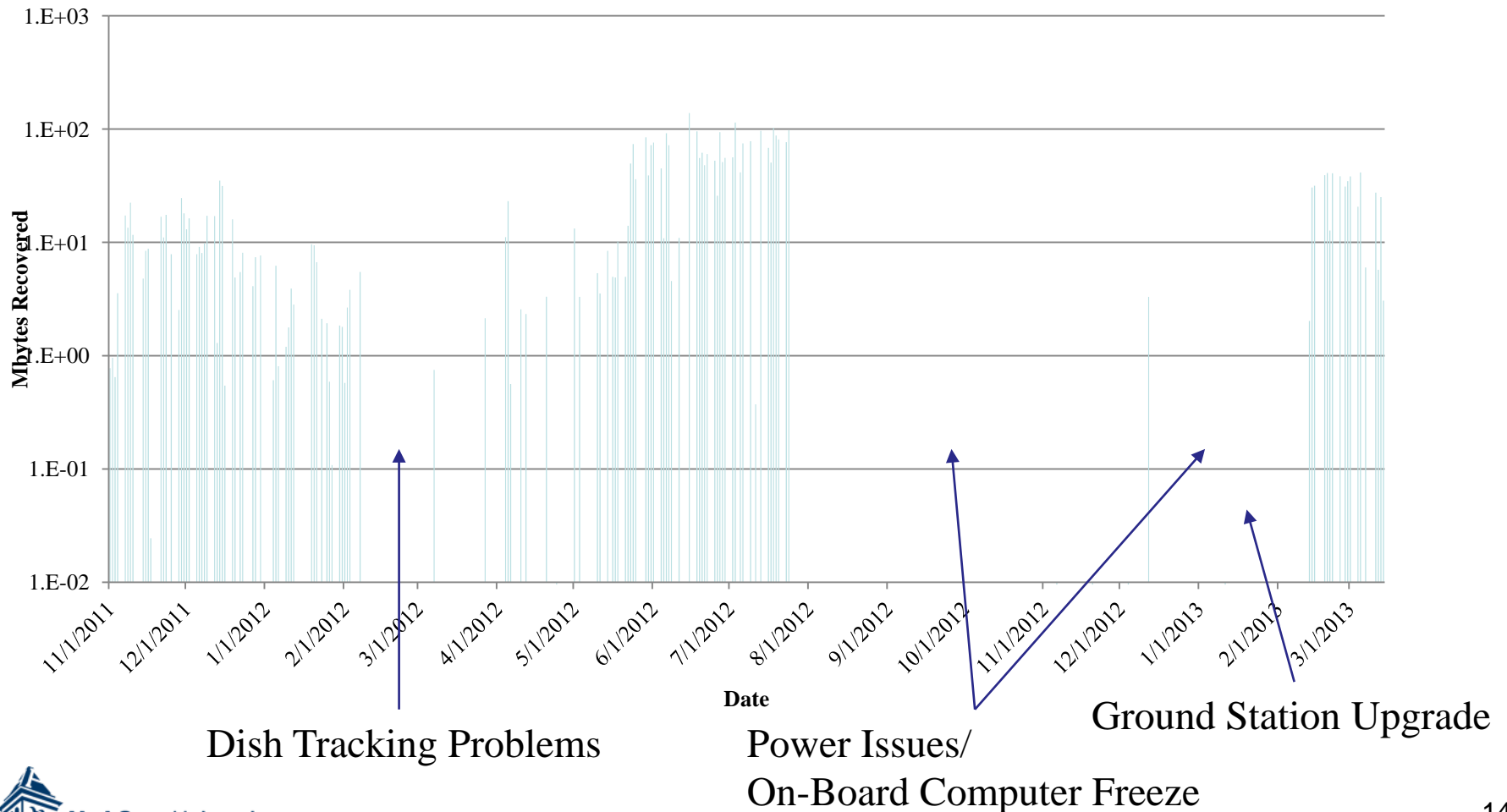
Farkle Data Downloaded



Yahtzee Data Recovered

- 3.26GBytes of data recovered and stored in a MySQL database

Yahtzee Data Downloaded



Odds & Ends

- **26 Terabytes of raw I/Q samples from USRP have been stored at SDL**
- **Ran a 2 part Science campaign with ISR groups around the world in early March**

DICE SCIENCE

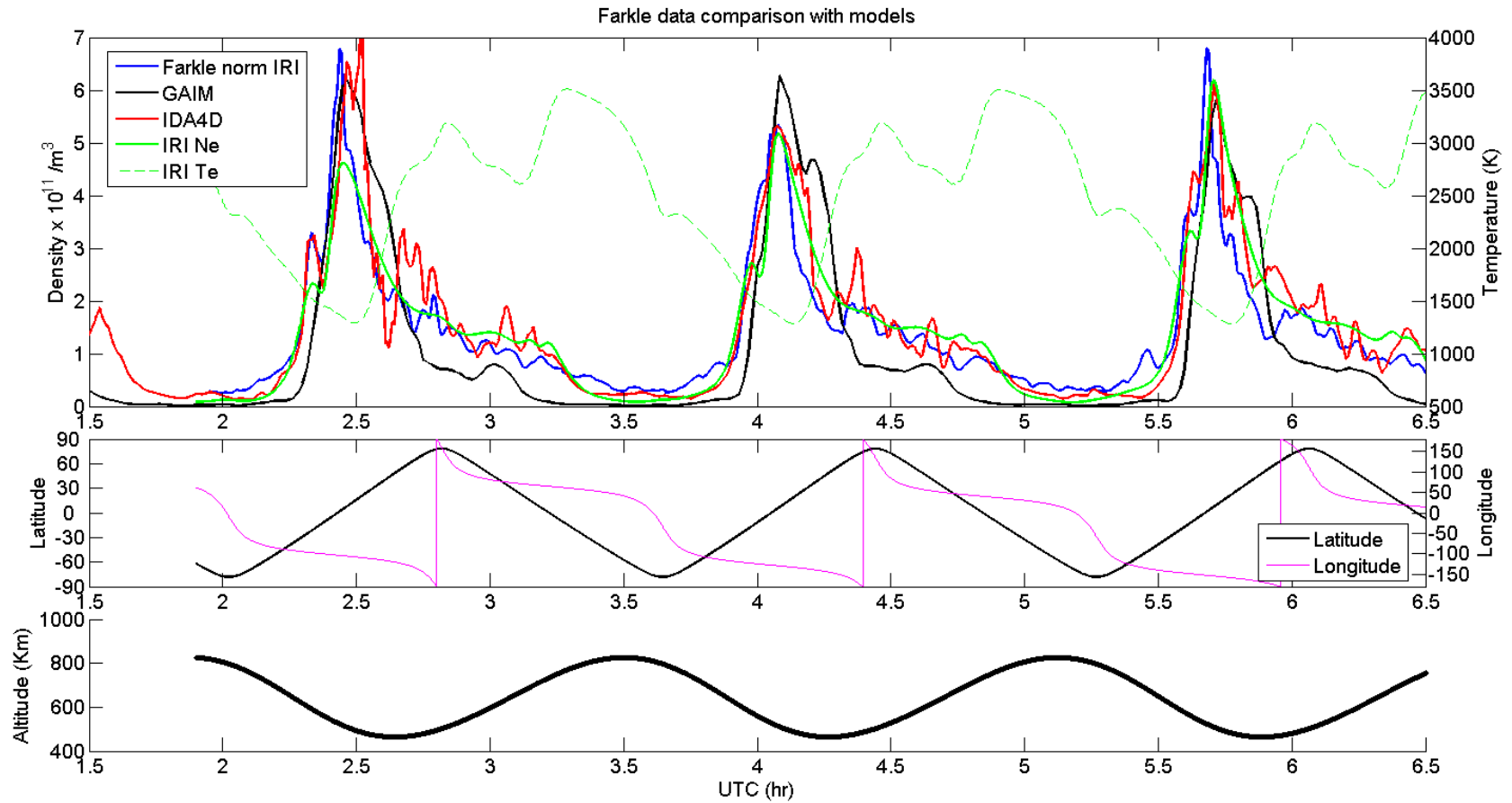
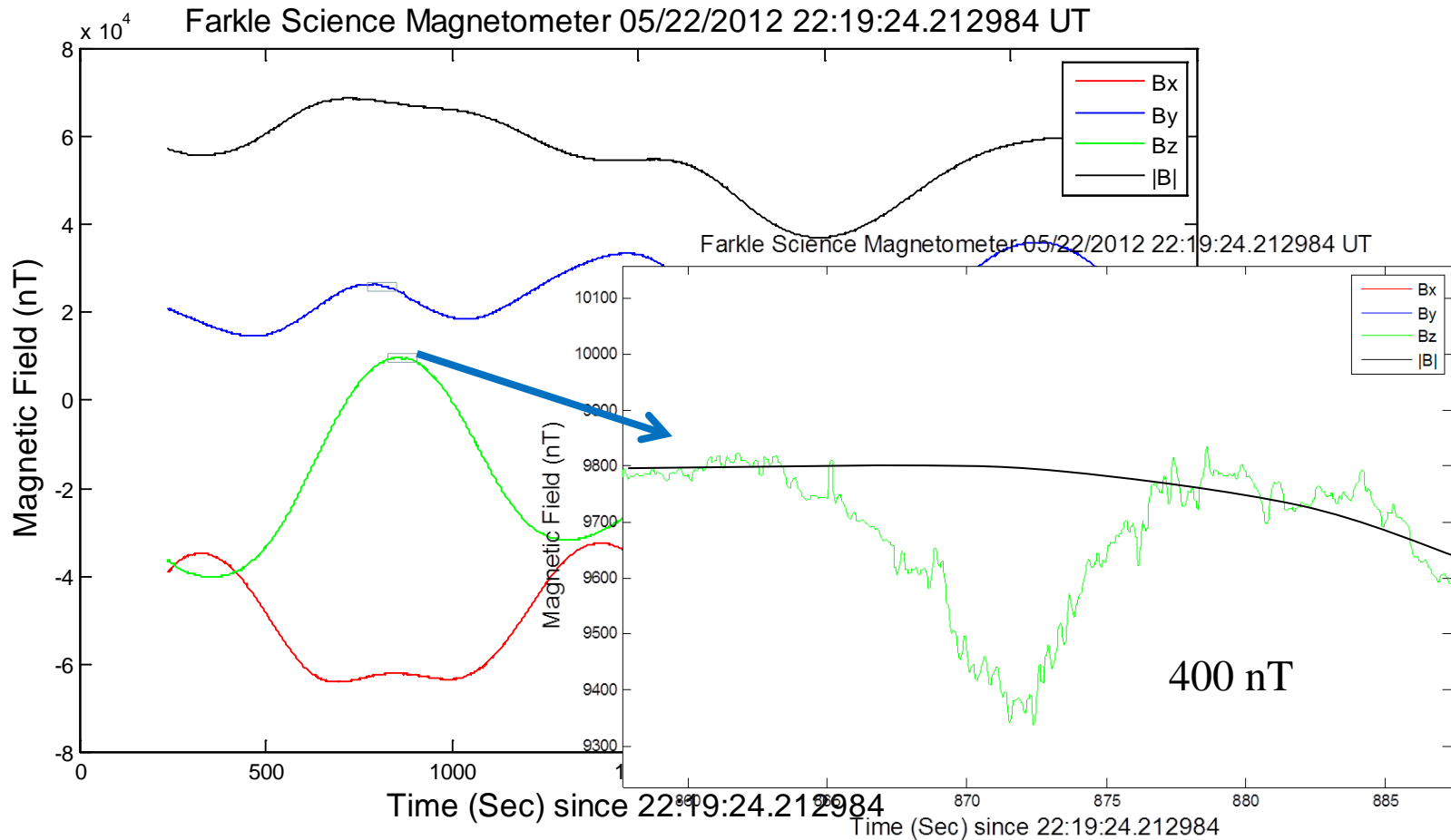


Figure Courtesy Aroh Barjatya

DICE Magnetometer Data



Summary

- **Currently satellite telemetry limited by policy not technology**
- **DICE demonstrated that downlink rates $> 1\text{Mbps}$ are possible from CubeSats**
- **Higher data rates technically feasible**
- **Cognitive radio concept can work around interference**

Questions