ASTRA

Space Dynamics LABORATORY
Utah State University Research Foundation

EMBRY-RIDDLE Aeronautical University

UtahStateUniversity

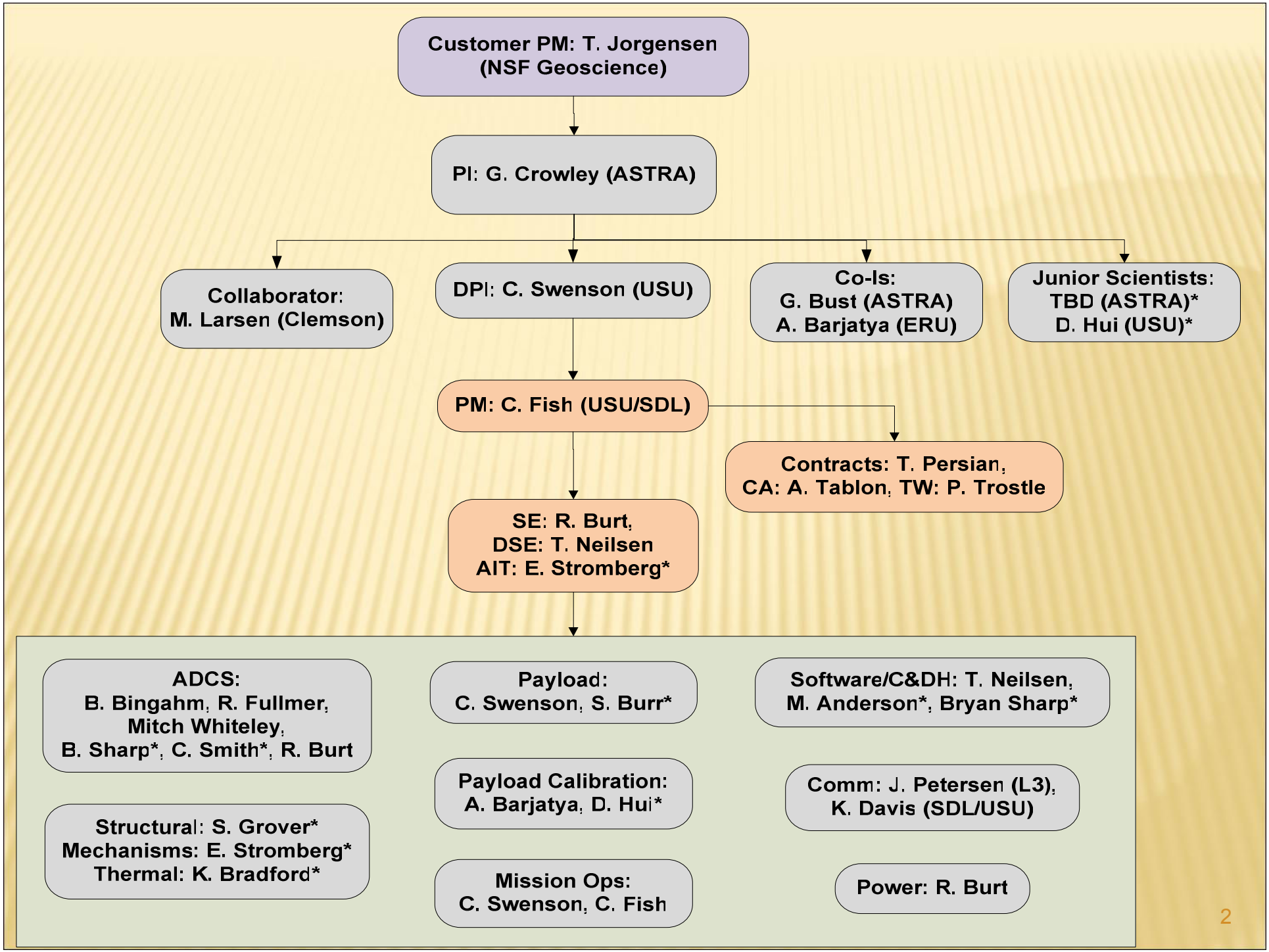
CLEMSON UNIVERSITY

Geoff Crowley, Chad Fish, Charles Swenson, Gary Bust, Aroh Barjatya, Miguel Larsen, and USU Student Team

DYNAMIC IONOSPHERE CUBESAT EXPERIMENT

NSF-Funded Dual-satellite Space Weather Mission

Project Funded October 2009 (6 months ago)


Customer PM: T. Jorgensen
(NSF Geoscience)
PI: G. Crowley (ASTRA)
Collaborator:
M. Larsen (Clemson)
DPI: C. Swenson (USU)
Co-Is:
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A. Barjatya (ERU)
Junior Scientists:
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D. Hui (USU)*
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CA: A. Tablon, TW: P. Trostle
SE: R. Burt,
DSE: T. Neilsen
AIT: E. Stromberg*
ADCS:
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Mitch Whiteley,
B. Sharp*, C. Smith*, R. Burt
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Mechanisms: E. Stromberg*
Thermal: K. Bradford*
Payload:
C. Swenson, S. Burr*
Payload Calibration:
A. Barjatya, D. Hui*
Mission Ops:
C. Swenson, C. Fish
Software/C&DH: T. Neilsen,
M. Anderson*, Bryan Sharp*
Comm: J. Petersen (L3),
K. Davis (SDL/USU)
Power: R. Burt

PRELIMINARY DESIGN REVIEW: JAN 25, 2010

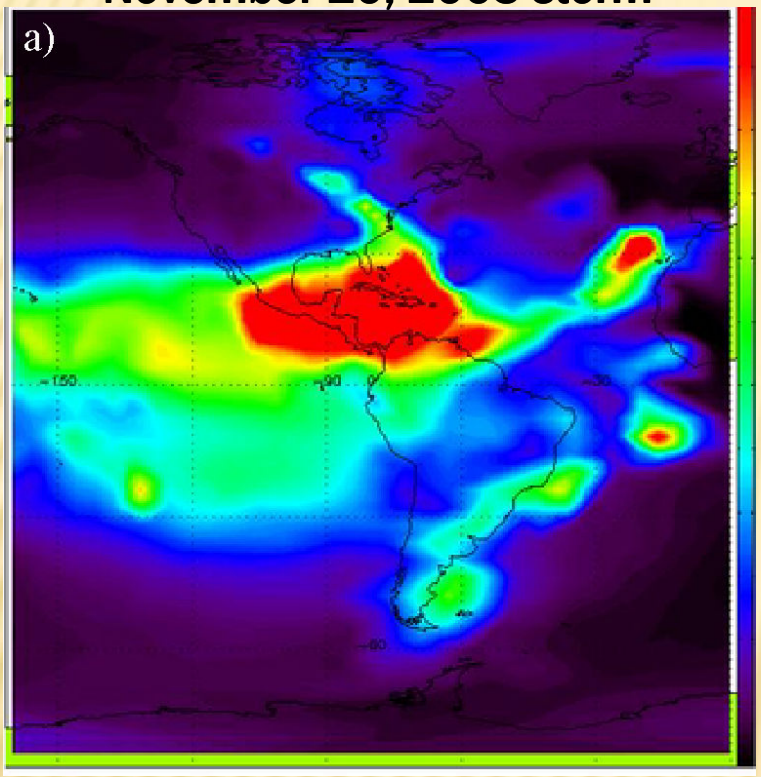
- 11 Students & 5 professionals
- Review Panel (7 SDL Staff)

DICE STUDENT TEAM

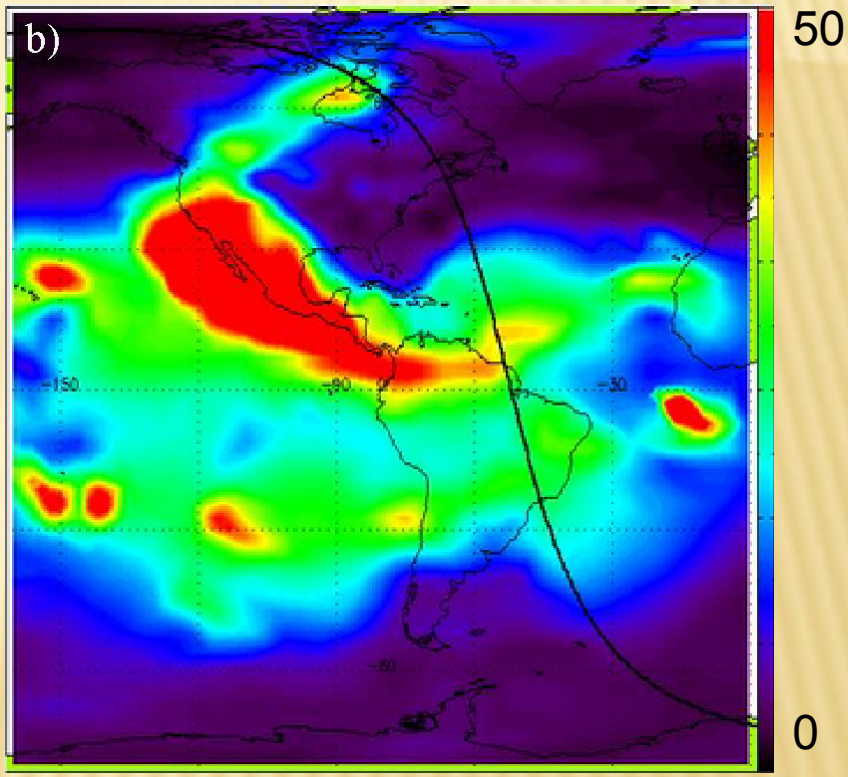
10+ Students and ~5 Professionals

SCIENCE MOTIVATION

November 20, 2003 storm



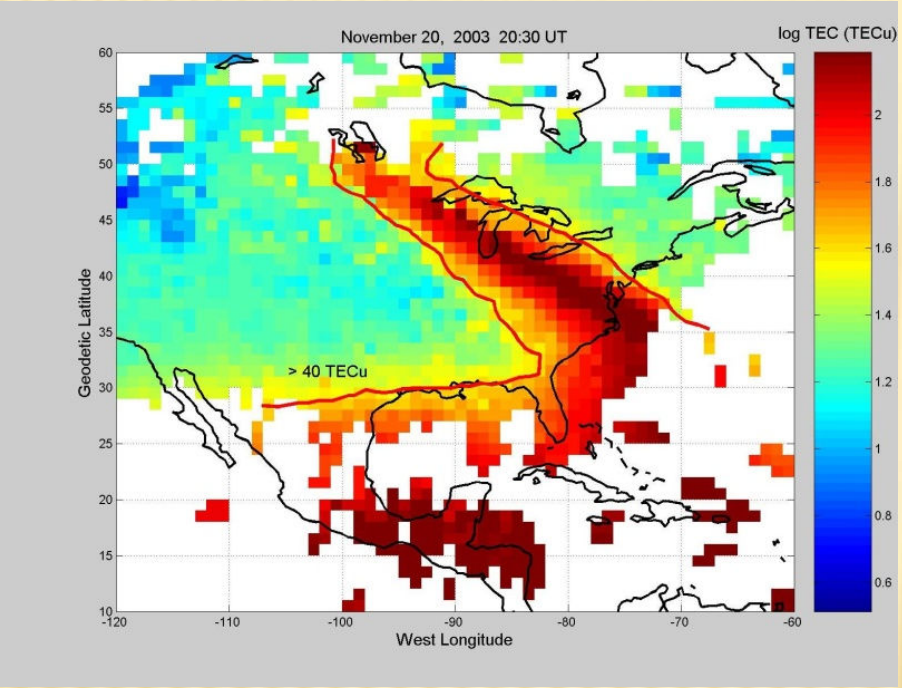
October 30 2003 storm

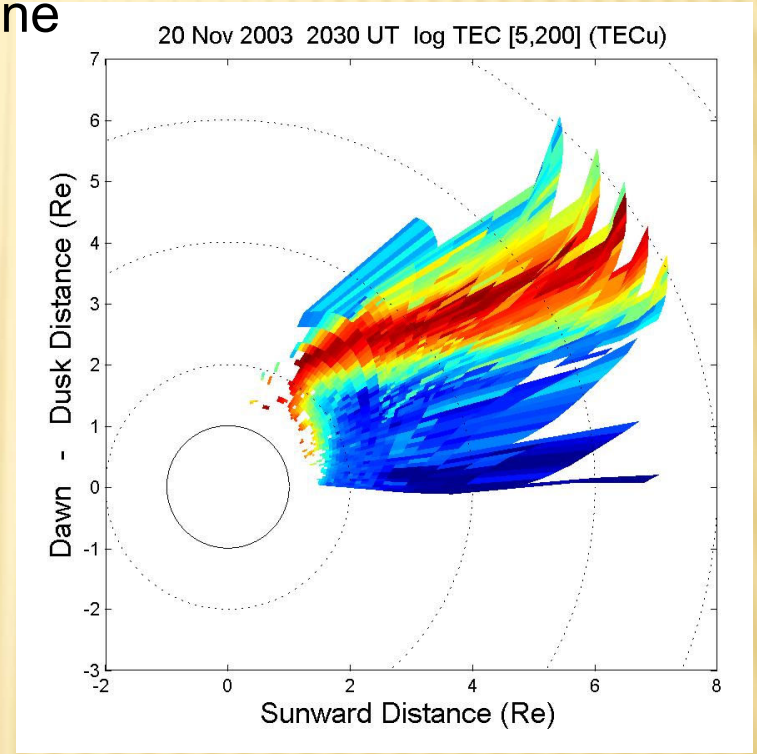


Horizontal distribution of peak electron density from 4D simulations

SCIENCE MOTIVATION

TEC Plume Mapped to Equatorial Plane

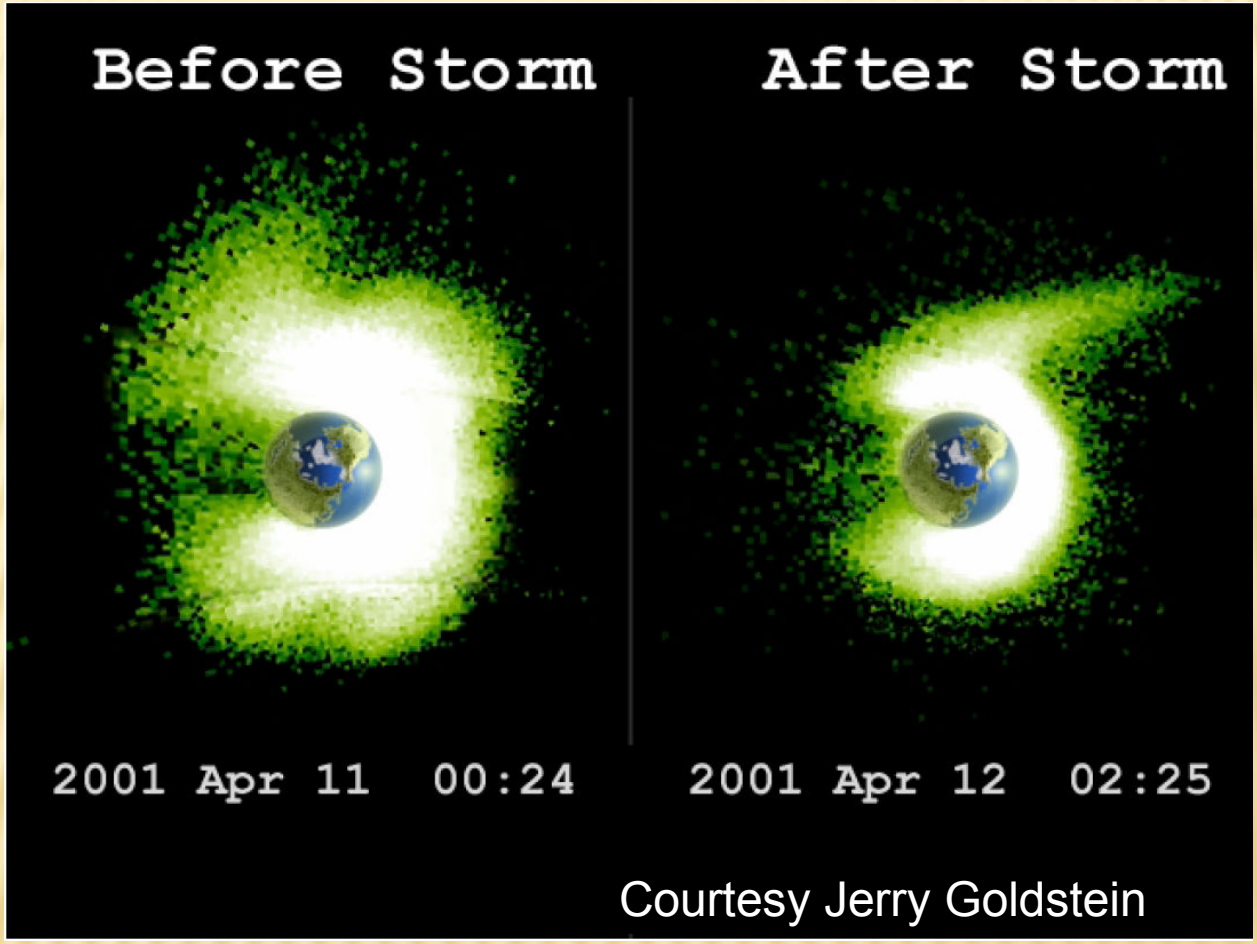




Foster et al, JGR 2004

John Foster
MIT Haystack Observatory

DICE SCIENCE OVERVIEW

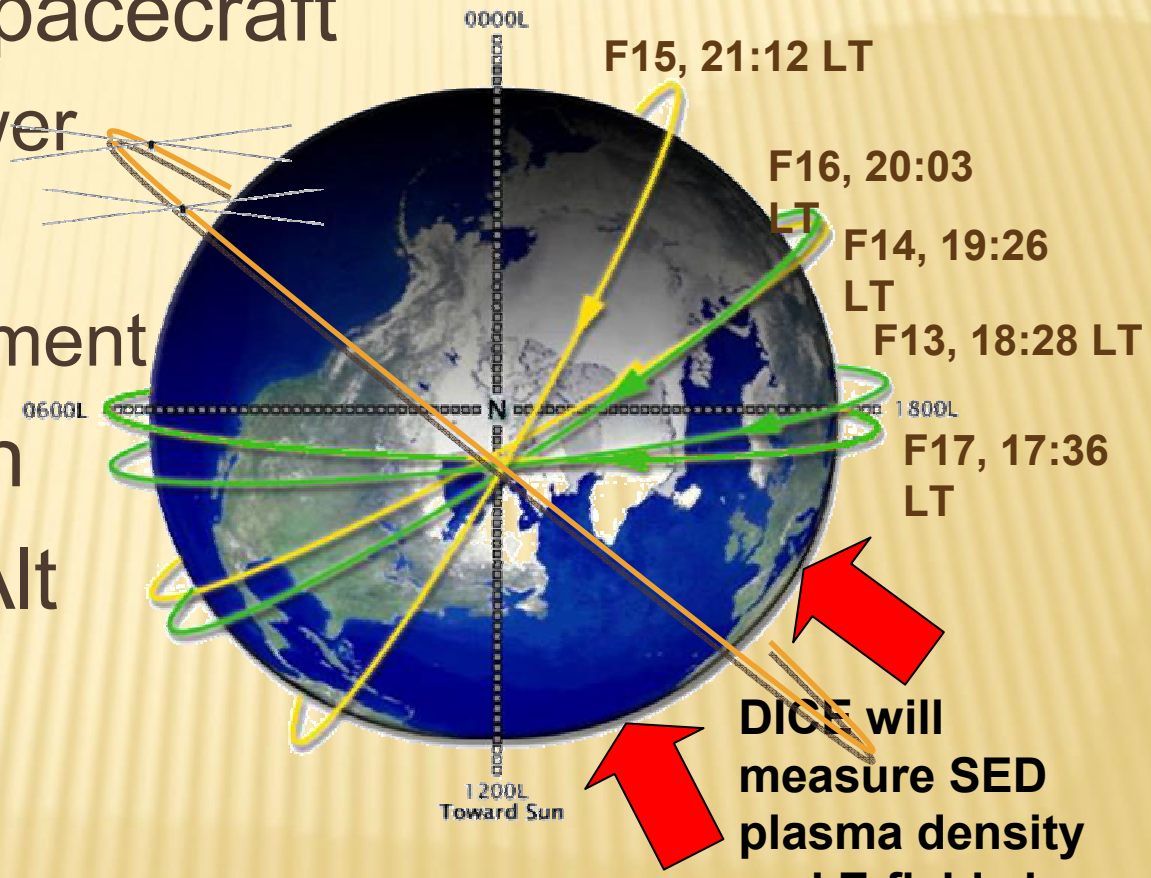


SCIENCE OBJECTIVES

1. Investigate the physical processes responsible for formation of the geomagnetic Storm Enhanced Density (SED) bulge in the noon to post-noon sector during magnetic storms.
2. Investigate the physical processes responsible for the formation of the SED plume at the base of the SED bulge and the transport of the high density SED plume across the magnetic pole.
3. Investigate the relationship between the penetration electric fields and the formation and evolution of SED:

MISSION

- Two spinning spacecraft
  - Leader – follower
  - ~0.2 Hz
  - Geodetic alignment
- > 55º Inclination
- 350 – 550 km Alt
- 90 day mission
  - Goal 180 day



DICE will measure SED plasma density and E-fields in key afternoon sector.

SCIENCE REQUIRMENTS

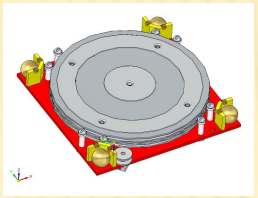
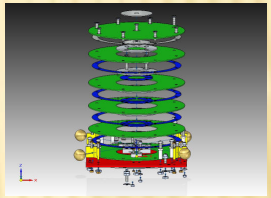
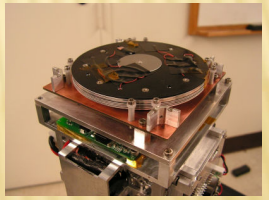
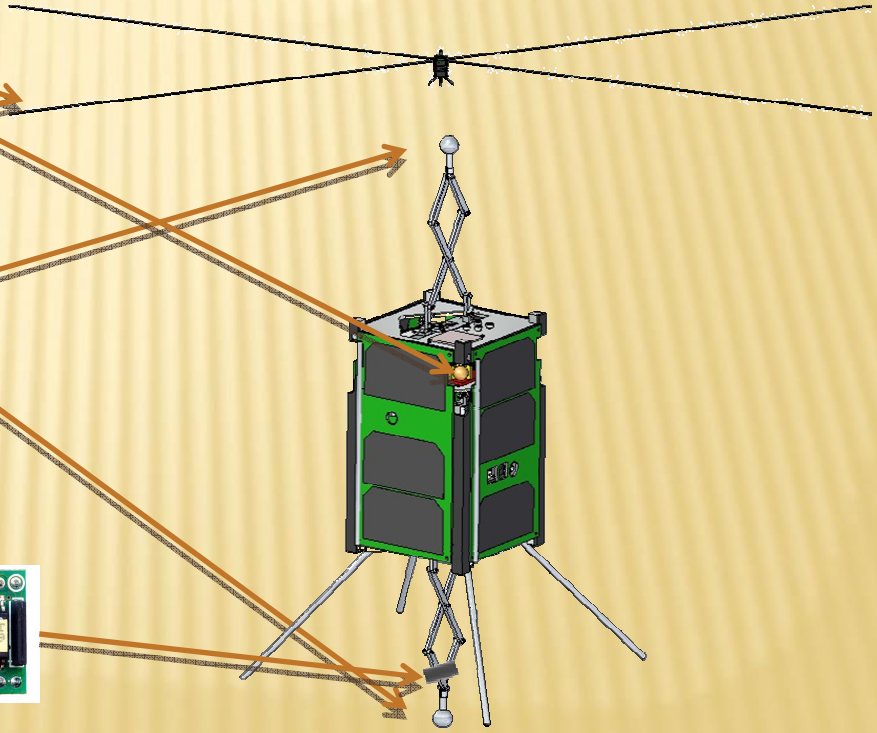
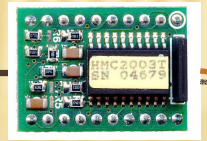
- Measure Electron Density
- Measure E-fields (plasma drift)
- Sun-synchronous orbit in the 12-16LT range is ideal
- Time-resolution of the measurements matches the scale-size of the features to be observed (1000km@ 7km/s = 14 s; cadence of 0.5 to 1 seconds for the plasma and electric field measurements)
- AC electric field spectrum measurements (irregs)

- Expect 1 SED per month
- 6-mo mission yields 6 SED events

- Two 1.5U (10 x 10 x 15 cm) CubeSats
- Common high-inclination pearls-on-a-string orbit.
- The two satellites will remain within ~300 km of one another for up to six months, allowing temporal-spatial deconvolution
- Each satellite will carry identical instrumentation:

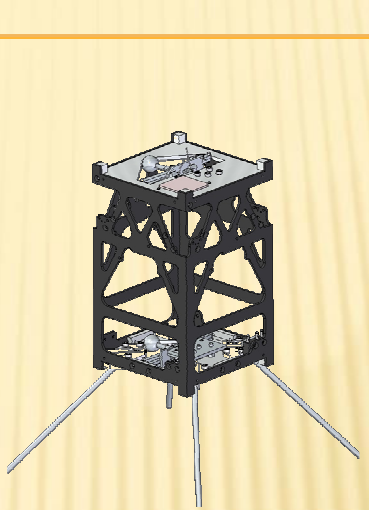
INSTRUMENTATION

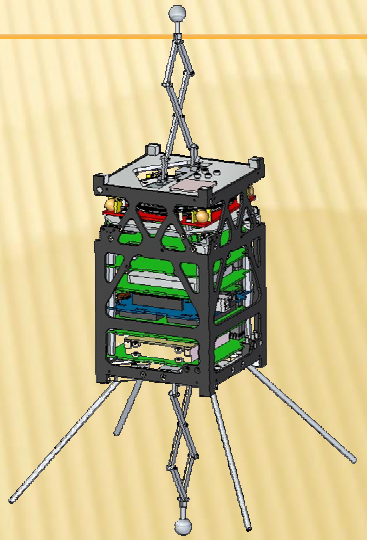
- Electric Field ~0.2 mV/m
  - Double Probe Technique
  - 10 m wire booms
  - ~80 Hz sample rate
- Plasma Density ~$10^2 cm^{-3}$
  - Dual Langmuir Probes
  - ~80 Hz sample rate
- Magnetic Field ~5 nT
  - Dual Magnetometers
  - ~80 Hz sample rate

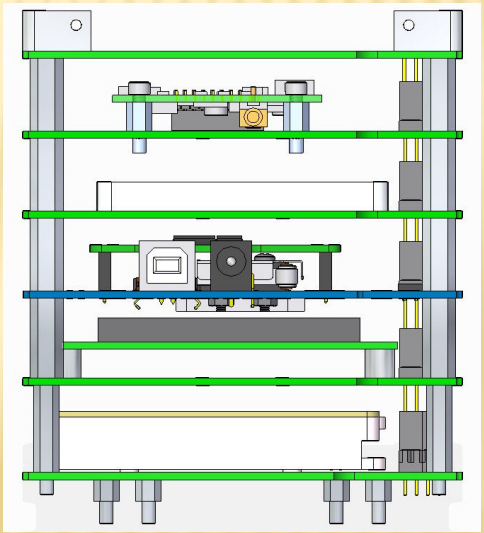






DICE SPACECRAFT

- Pumpkin C&DH System
- SDL/USU Science board
- L3 Radio
  - 1.5 Mbit/s down link
- Sun + Magnetometer
  - 0.1º Post flight
- Power
  - ~1.5 W spacecraft
  - ~200 mW payload







Instrument Electronics

ADCS Board with GPS Modul

Z-axis Torque coil

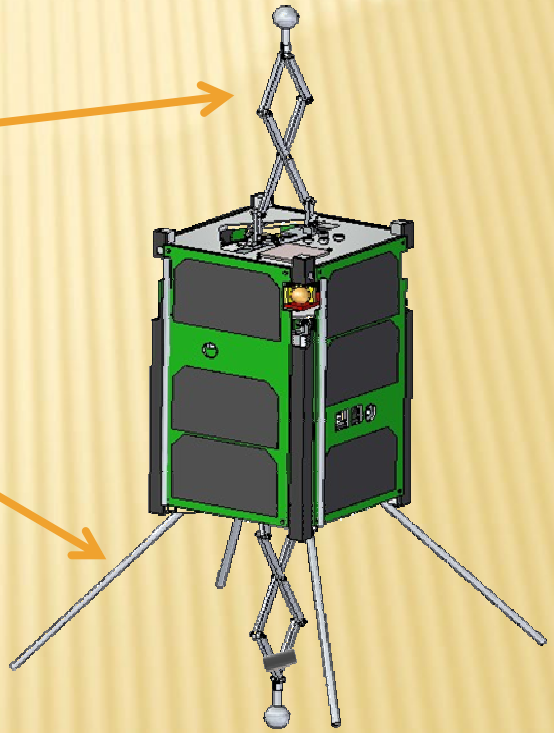
C&DH Board with Processor

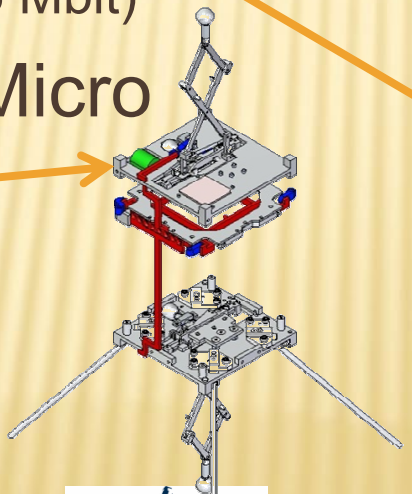
EPS and Battery Board

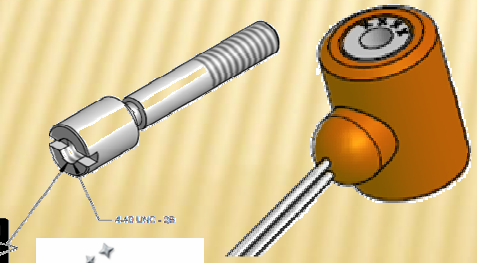
Comm Board with L3 Radio

ANTENNAS AND BOOMS

- EFP Booms - 5m
  - 10 m tip to tip
- DCP + Mag- 8cm
- UHF Comms – 14cm
  - (460 – 470 MHz, 1.5 Mbit)
- TiNi Aerospace Micro Frangibolt







DICE ASTRA USU/SDL Clemson Embry Riddle

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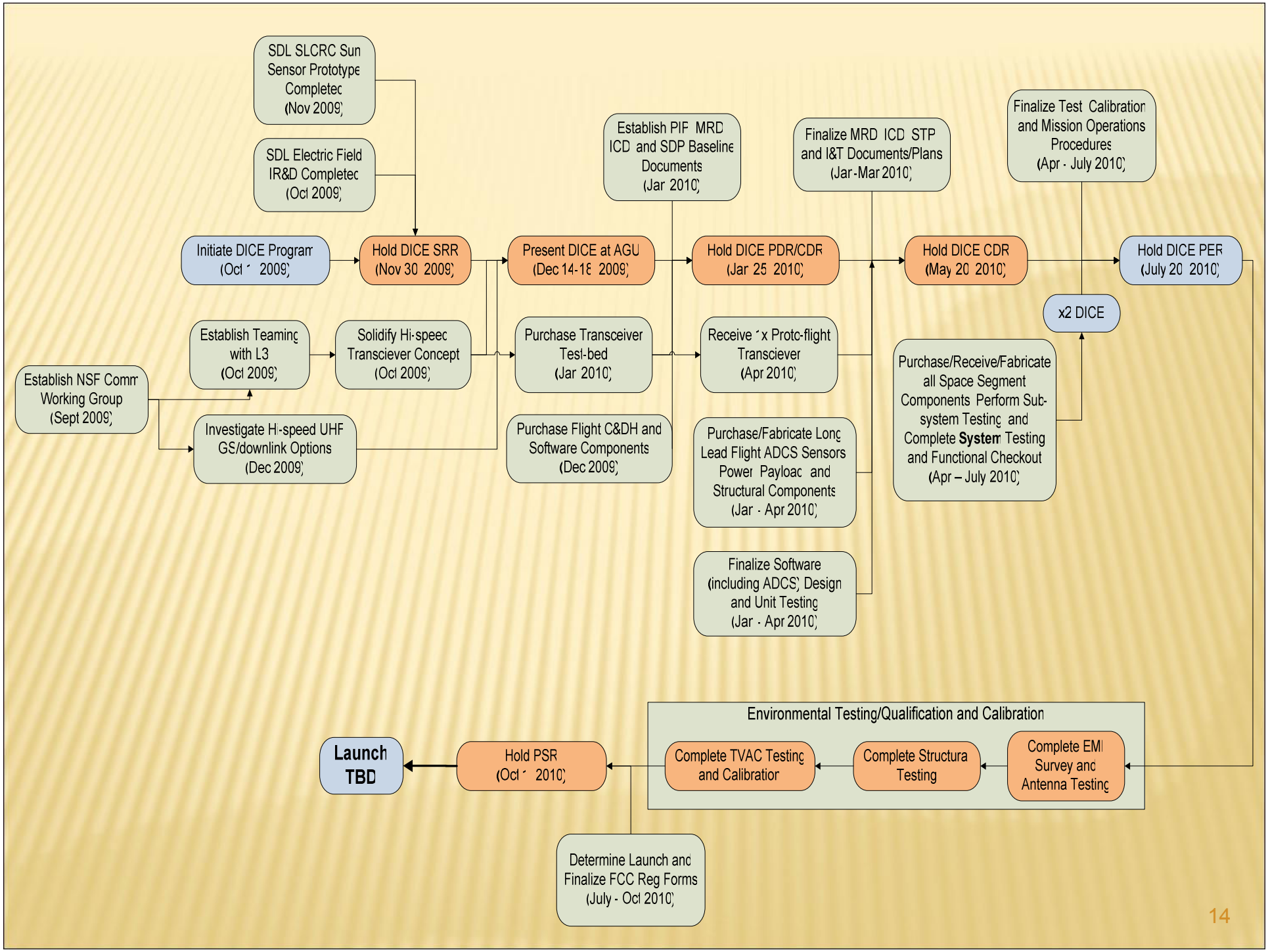
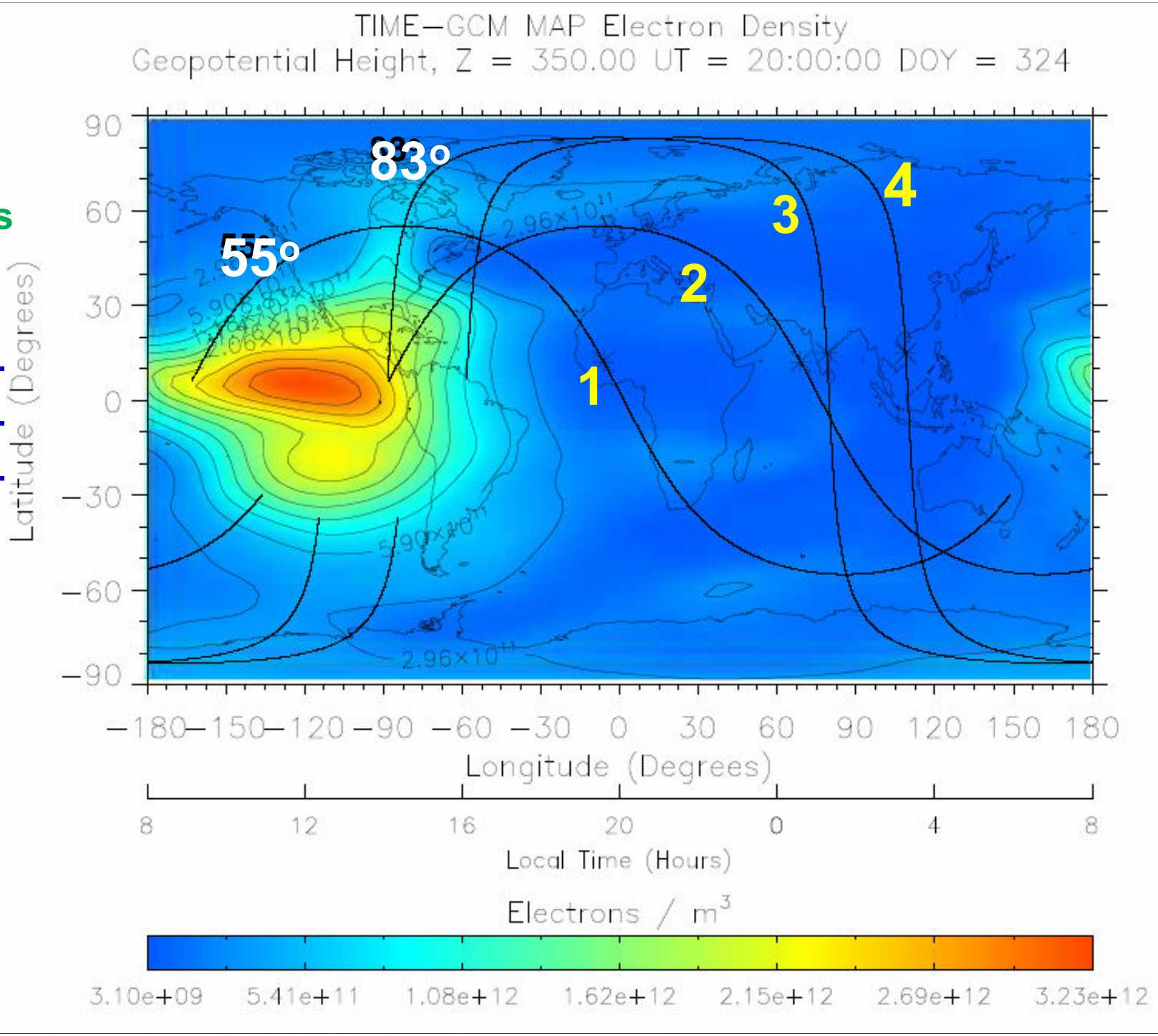

SDL SLCRC Sun Sensor Prototype Completec (Nov 2009)
SDL Electric Field IR&D Completec (Oct 2009)
Establish PIF MRD ICD and SDP Baseline Documents (Jar 2010)
Finalize MRD ICD STP and I&T Documents/Plans (Jar-Mar 2010)
Finalize Test Calibration and Mission Operations Procedures (Apr - July 2010)
Initiate DICE Program (Oct 2009)
Hold DICE SRR (Nov 30 2009)
Present DICE at AGU (Dec 14-18 2009)
Hold DICE PDR/CDR (Jar 25 2010)
Hold DICE CDR (May 20 2010)
Hold DICE PER (July 20 2010)
x2 DICE
Establish Teaming with L3 (Oct 2009)
Solidify Hi-speec Transciever Concept (Oct 2009)
Purchase Transceiver Test-bed (Jar 2010)
Receive x Protc-flight Transciever (Apr 2010)
Purchase/Receive/Fabricate all Space Segment Components Perform Sub-system Testing and Complete System Testing and Functional Checkout (Apr – July 2010)
Establish NSF Comm Working Group (Sept 2009)
Investigate Hi-speed UHF GS/downlink Options (Dec 2009)
Purchase Flight C&DH and Software Components (Dec 2009)
Purchase/Fabricate Long Lead Flight ADCS Sensors Power Payloac and Structural Components (Jar - Apr 2010)
Finalize Software (including ADCS) Design and Unit Testing (Jar - Apr 2010)
Environmental Testing/Qualification and Calibration
Complete TVAC Testing and Calibratior
Complete Structura Testing
Complete EMI Survey and Antenna Testing
Launch TBD
Hold PSR (Oct 2010)
Determine Launch and Finalize FCC Reg Forms (July - Oct 2010)

DICE TIMELINE AND STATUS

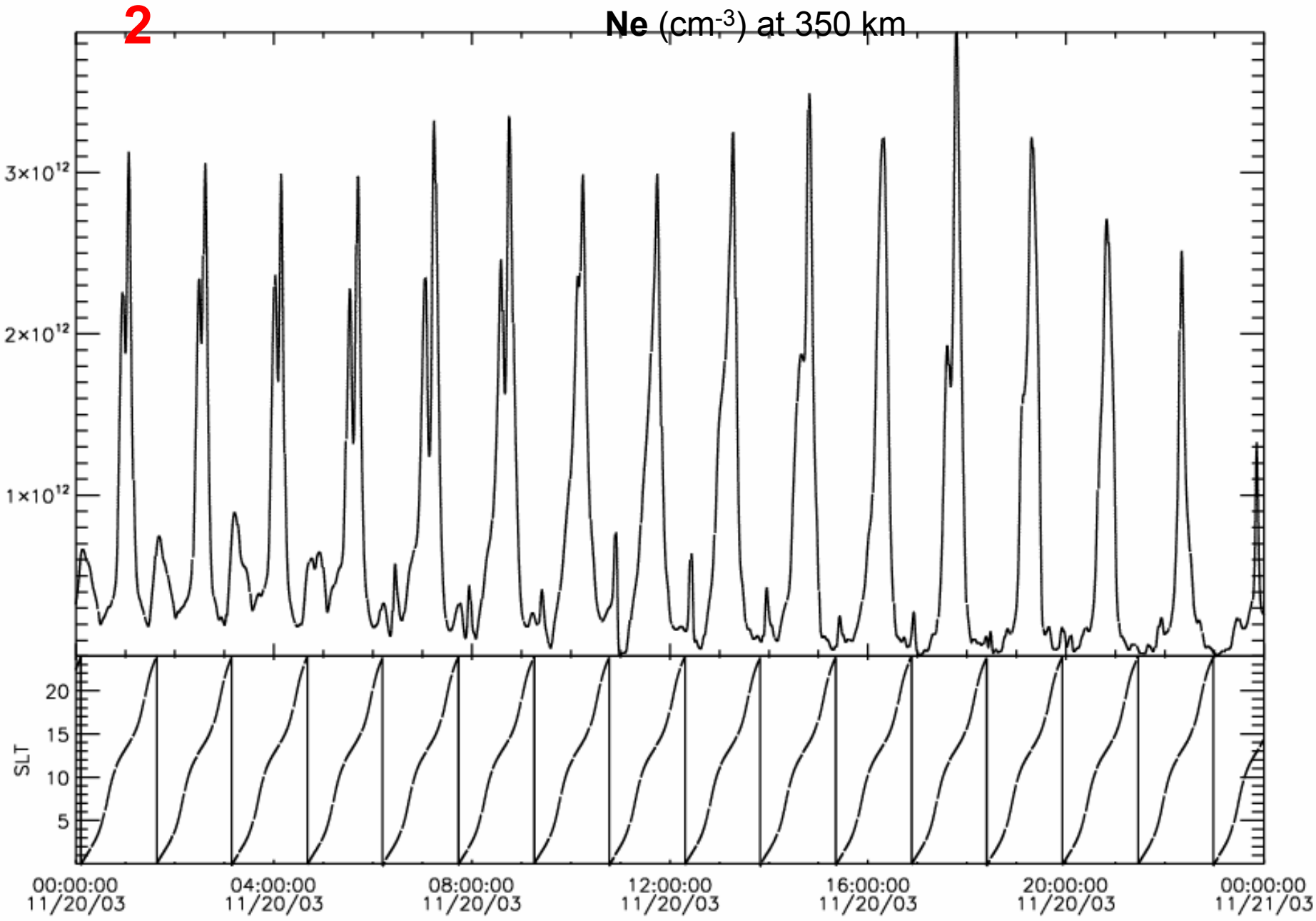
- NSF funding started 10/1/09
- Student team assembled (12 located at SDL)
- Design and Team conference calls - weekly
- Science team conference calls – as needed
- Science, Mission and Software requirements completed
- PDR Design Review 1/25/10
- Mechanisms, DC probe-boom etc complete
- Structural analysis complete; thermal analysis in progress
- Solar arrays to be delivered Late April 2010
- Science Instruments and ADCS electronics in layout / fabrication
- Radio licensing spectrum allocation through NSF in progress
- Majority of hardware expected to be fabricated by May 2010
- CDR planned for May 20, 2010
- Spacecraft/Instrument delivery Oct 2010

N-S cross

1- 9 SLT
2- 14 SLT
3- 14 SLT
4- 16 SLT



2


Ne (cm-3) at 350 km
3×10¹²
2×10¹²
1×10¹²
SLT
20
15
10
5
00:00:00 11/20/03
04:00:00 11/20/03
08:00:00 11/20/03
12:00:00 11/20/03
16:00:00 11/20/03
20:00:00 11/20/03
00:00:00 11/21/03

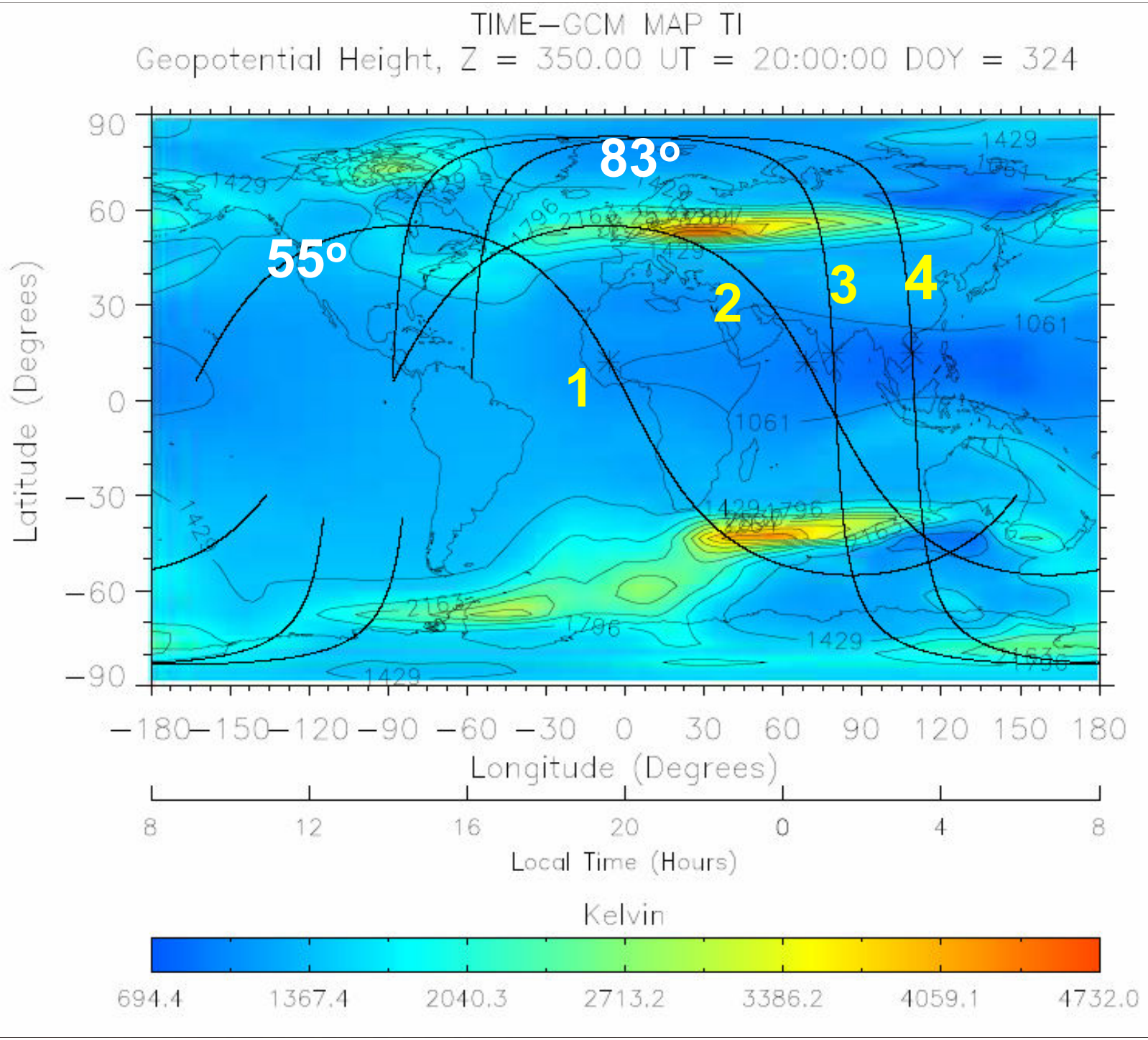
N-S cros

1- 9 SLT

2- 14 SLT

3- 14 SLT

4- 16 SLT



SOFTWARE: STATUS OF VARIOUS SUBSYSTEMS

- Device Drivers - Testing Complete
- Messaging - Testing Complete
- Timed Messaging - Testing Complete
- Telemetry Module - Individual Testing Complete
- Attitude Determination Software - Testing Complete
- Attitude Control Software – Testing in progress
- Mode Manager - Implementation Complete. Testing in progress
- Uplink Task - Implementation in progress
- Device Control Library - Implementation in progress
- Ground Station Software - Implementation in progress

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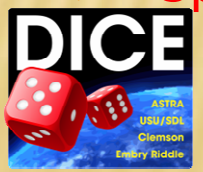


QUESTIONS

BACKUP SLIDES

ABSTRACT

- **Dynamic Ionosphere Cubesat Experiment (DICE)**
  G. Crowley[1]; C. S. Fish[2]; G. S. Bust[1]; C. Swenson[2]; A. Barjatya[3]; M. F. Larsen[4]
  1. ASTRA, San Antonio, TX, United States.
  2. Utah State University/Space Dynamics Laboratory (USU/SDL), Logan, UT, United States.
  3. Embry-Riddle Aeronautical University, Daytona Beach, FL, United States.
  4. Clemson University, Clemson, SC, United States.

- The Dynamic Ionosphere Cubesat Experiment (DICE) mission has been selected for flight under the NSF "CubeSat-based Science Mission for Space Weather and Atmospheric Research" program. The mission has three scientific objectives: (1) Investigate the physical processes responsible for formation of the midlatitude ionospheric Storm Enhanced Density (SED) bulge in the noon to post-noon sector during magnetic storms; (2) Investigate the physical processes responsible for the formation of the SED plume at the base of the SED bulge and the transport of the high density SED plume across the magnetic pole; (3) Investigate the relationship between penetration electric fields and the formation and evolution of SED.

  The mission consists of two identical Cubesats launched simultaneously. Each satellite carries a fixed-bias DC Langmuir Probe (DCP) to measure in-situ ionospheric plasma densities, and an Electric Field Probe (EFP) to measure DC and AC electric fields. These measurements will permit accurate identification of storm-time features such as the SED bulge and plume, together with simultaneous co-located electric field measurements which have previously been missing. The mission team combines expertise from ASTRA, Utah State University/Space Dynamics Laboratory (USU/SDL), Embry-Riddle Aeronautical University and Clemson University.

SOURCE OF PLUMES

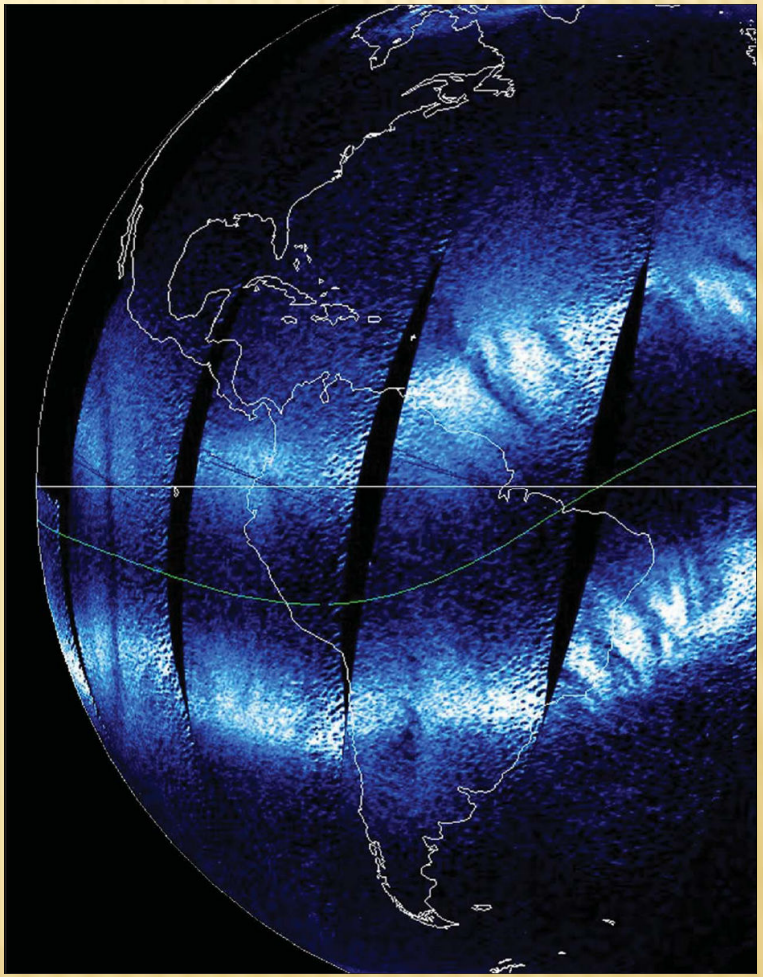
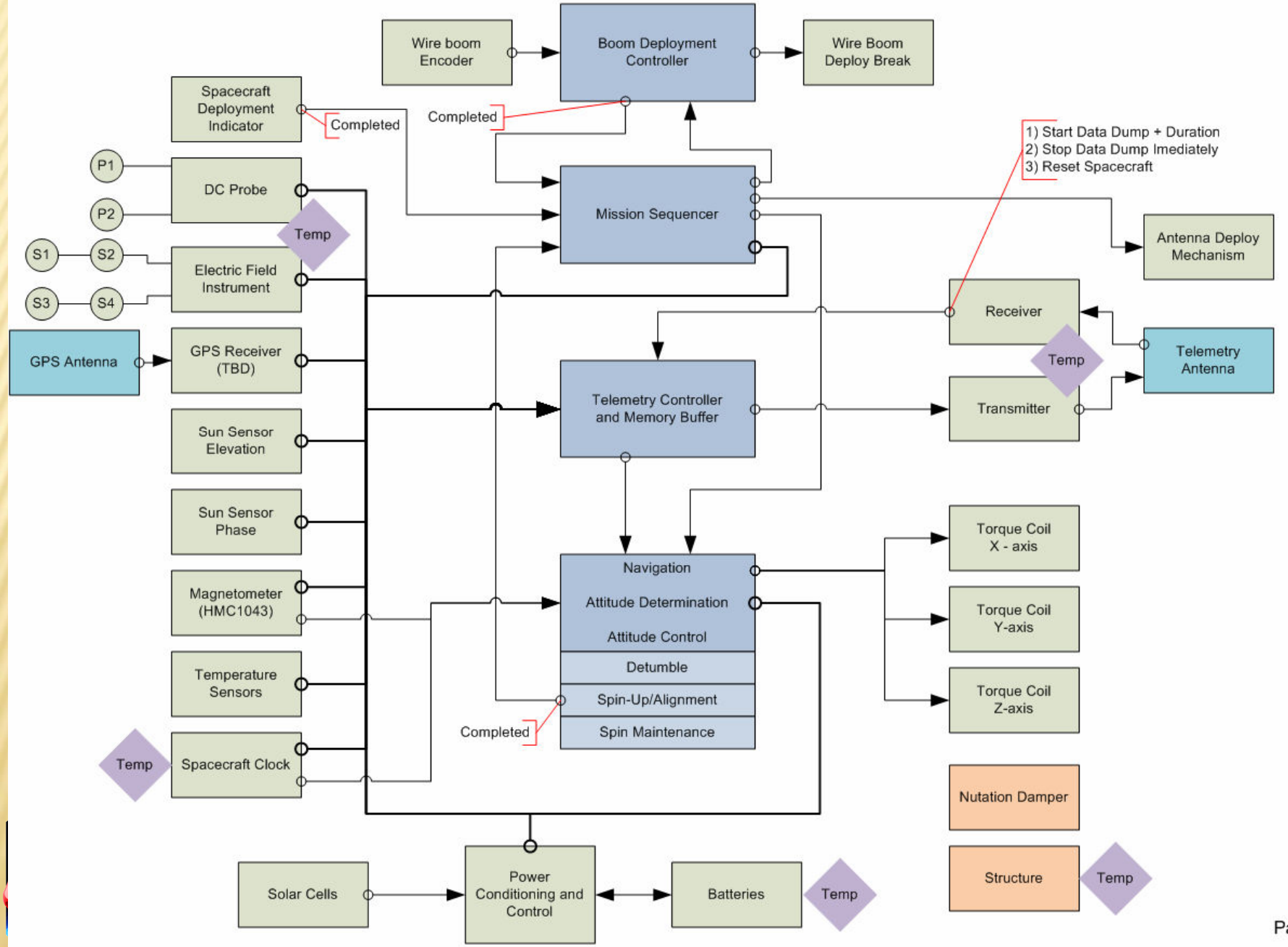


Table 1: Science to Mission Functionality Requirements Traceability Matrix

Science Objective 1: Investigate formation of the SED bulge over the USA		
Measurement Requirements	**Instrument Requirements**	**Mission Requirements**
Measure RMS Fluctuations in Electric Field and Plasma Density: 1. Make co-located DC electric field and plasma density measurements at a ≤ 10 km on-orbit resolution 2. Make < 10 meter (AC) resolution electric field measurements at a ≤ 10 km on-orbit resolution 3. Make measurements on a constellation platform of ≥ 2 spacecraft that are within 200 km of each other	**Electric Field**: 1. Max range of ± 0.6 V/m 2. Min threshold of 0.6 mV/m 3. Min resolution of 0.15 mV/m 4. DC sample rate ≥ 4 Hz 5. Telemeter DC data at ≥ 4 Hz 6. AC sample rate ≥ 4 kHz 7. Telemeter AC FFT power information at ≥ 1 Hz (3 points) **Plasma (Ion) Density**: 1. Range of $2x10^{9}$ - $2\ x10^{13}$ m^{-3} 2. Min resolution of $3\ x10^{8}$ m^{-3} 3. Sample rate ≥ 1 Hz 4. Telemeter data at ≥ 1 Hz	1. Constellation size ≥ 2 satellites 2. Spacecraft spin ≥ 0.8 Hz 3. Spacecraft spin axis aligned to geodetic axis to within 10 º (1σ) 4. Spacecraft spin stabilized to within 1º (1σ) about principal spin axis 5. Spacecraft knowledge to within 1º (1σ) 5. Constellation time synchronization ≤ 1 second 6. Orbital insertion inclination between 55 - 98 º (ideally sun-synchronous at 14-16LT) 7. Orbital insertion altitude between 350 - 800 km 8. Circular orbits with eccentricity of ≤ 0.015 9. Spacecraft separation speed of ≤ 20 km/month 10. Storage/downlink ≥ 31 Mbits/day. 11. Lifetime ≥ 6 months
Science Objective 2: Investigate formation of the SED plume over the USA		
Measurement Requirements	**Instrument Requirements**	**Mission Requirements**
Same as Science Objective 1	Same as Science Objective 1	Same as Science Objective 1 (downlink included in Objective 1)
Science Objective 3: Investigate correlation of PPE with formation and evolution of SED		
Measurement Requirements	**Instrument Requirements**	**Mission Requirements**
Same as Science Objective 1	Same as Science Objective 1	Same as Science Objective 1 (downlink included in Objective 1)

DICE Block Diagram

Tuesday, October 06, 2009



TELEMETRY CHANNELS

Channel Name	Rate Hz	Word Size bits	Bit Rate bits/s	Sample Period #/Orbit	Sample Period spatial (km)
Electric Field V12	80	16	1280	444276	0.10
Electric Field V34	80	16	1280	444276	0.10
Density DC Probe 1	80	16	1280	444276	0.10
Density DC Probe 2	80	16	1280	444276	0.10
Magnetometer X-Axis	80	18	1440	444276	0.10
Magnetometer Y-Axis	80	18	1440	444276	0.10
Magnetometer Z-Axis	80	18	1440	444276	0.10
GPS Receiver	0.00072	4096	2.95	4	10646.86
Sun sensor elevation	1.00	16	16.00	5553	7.67
Sun phase sensor	1.00	48	48.00	5553	7.67
Power system (battery)	0.03	48	1.60	166604	230.06
Temp Monitor 1	0.03	8	0.27	166604	230.06
Temp Monitor 2	0.03	8	0.27	166604	230.06
Temp Monitor 3	0.03	8	0.27	166604	230.06
Temp Monitor 4	0.03	8	0.27	166604	230.06
Temp Monitor 5	0.03	8	0.27	166604	230.06
Spacecraft Clock	1.00	48	48.00	5553	7.67
Everything else	0.03	128	4.27	166604	230.06
Rate collected on orbit		**Total**	9562.15	**bits/s**	

Required Down Link

Design Element	Symbol	Value	Units
Rate collected on orbit	$R_{collected}$	9562.15	bits/s
Downlink telemetry rate	$R_{transmitted}$	1.50E+06	bits/s
Packet overhead		7%	Unitless
Available telemetry rate		1388672	Bits/s
Factor of Safety	α	1.05	Unitless
Contact Time Percent	τ_c	0.75%	Unitless
Down link rate	R_d	1338701	bits/s
Telemetry Margin		4%	Unitless

Estimated Daily Downlink

Average Daily Data Dump	103.41	M Bytes
Required Daily Data Dump	98.49	M Bytes
Average Contact Time per Day	648.00	s
Estimated contacts/day	2	
Estimated usable contacts duration	324.00	s
Estimated usable contacts duration	5.40	min
Estimated Dump/Contact	51.71	M Bytes

Required Telemetry Buffer

Design Element	Symbol	Value	Units
Onboard Collection Rate	R_c	9562.15	bits/s
Factor of Safety	α	4	
Max Time Between Contacts	τ_c	58482	s
Required Telemetry Buffer		2.E+09	Bits
Required Telemetry Buffer		266.65	M Bytes
Required Telemetry Buffer		2133.23	M Bits

Required Transmitter Power

Design Element	Symbol	Value	Units
Transmitter RF Power		1	Watts
Transmitter Efficiency		25%	
Transmitter Power		4.00	Watts
Orbit Average On time		41.65	S
Orbit Average Power		30.00	mW

Required Ground Station Storage

Design Element	Symbol	Value	Units
Baseband Bandwidth		10	MHz
Digitization bits		8	bits
Baseband Sampling Rate		40	MHz
Baseband Sampled Data Rate		320	Mbits/s
Average Data in an Overpass		103680	Mbits/s
Storage Required Per Pass		12.66	G bytes

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