Communications for the TechEdSat/PhoneSat Missions

NASA Ames Research Center

Presentation to Small Satellite Pre-Conference Workshop

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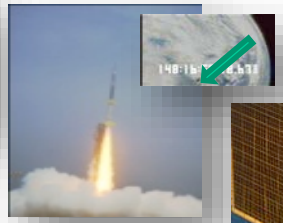
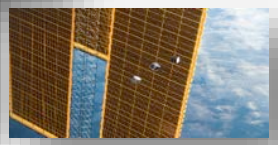
SOAREX/TechEdSat/PhoneSat Teams

Flight Experiments of Recent Years (2008-2017):
9 Flights

SOAREX-6 (2008)



SOAREX-7 (2009)



TES-1 Oct 4, 2012

TES-2 PhoneSat Iridium-test Aug 21, 2013

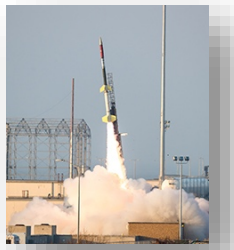
TES-3 Aug 3, 2013 (6 wk de-orbit)

TES-4 Mar 3, 2015 (4 wk de-orbit)

TES-5 Mar 6, 2017 (deorbited Jul 29)

TES/PS Team, 2014

SOAREX-8 (2015)



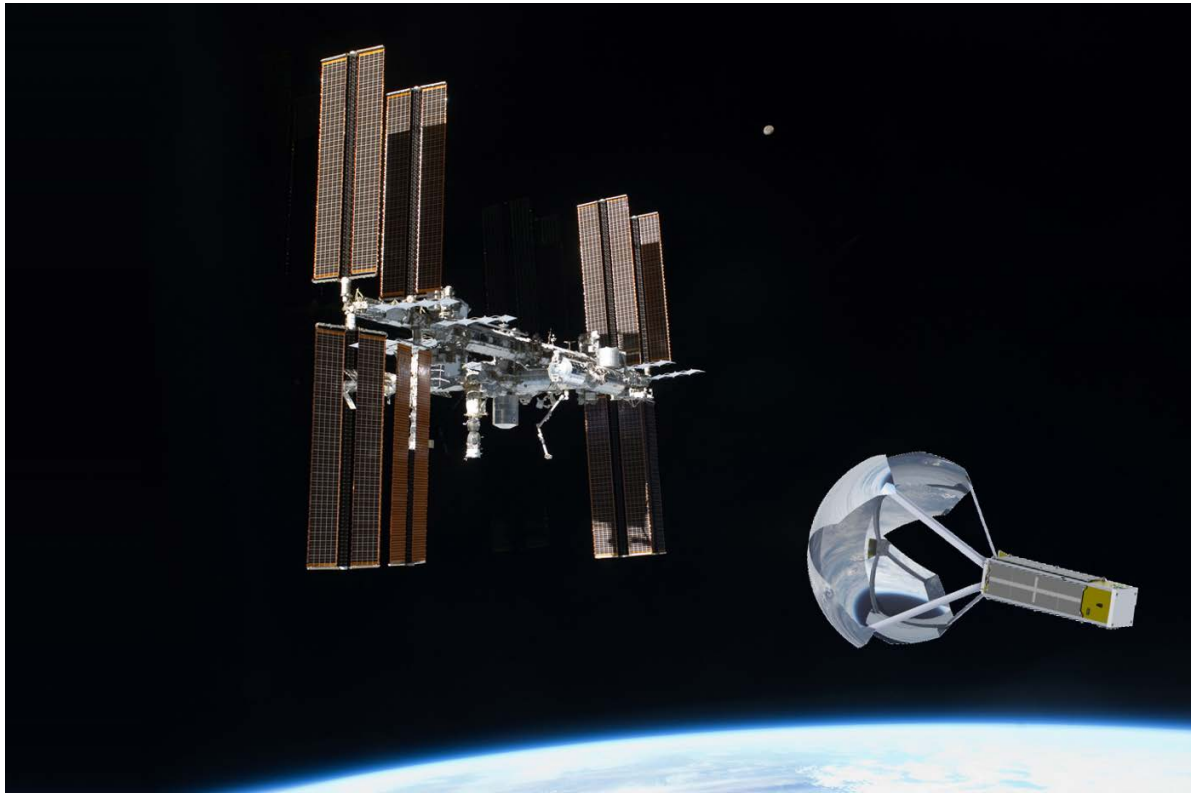
SOAREX-9 (2016)

TES/PS Team, Summer 2017

What is an Exo-Brake…?

Simple, drag-modulated de-orbit system based on tension elements

TechEdSat5 was deployed from ISS on March 6, 2017 by NanoRacks



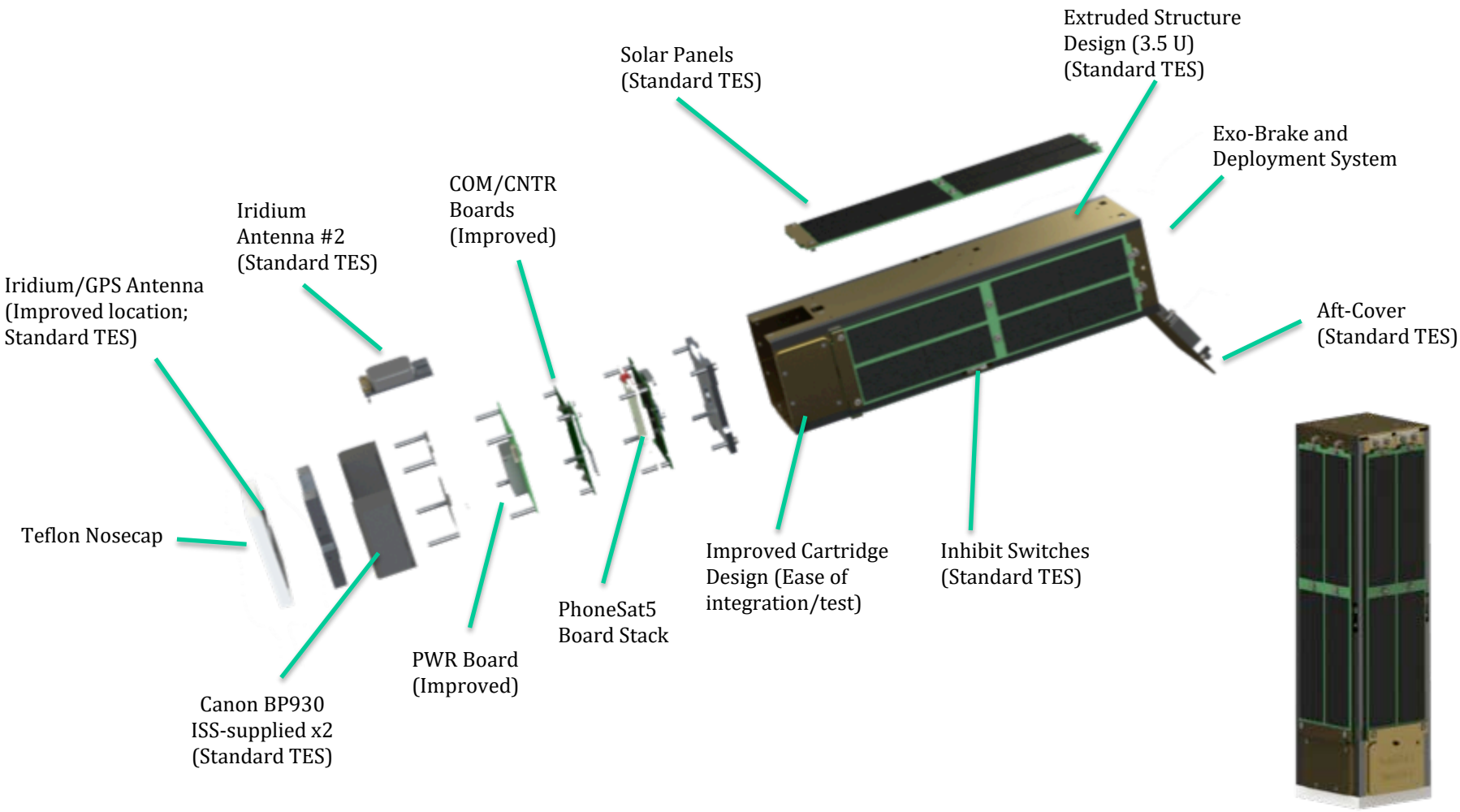
The TechEdSat 5 Exo-Brake Experiment

- The Exo-Brake is an exo-atmospheric braking and de-orbit device which has successfully flown twice before in a fixed configuration on TechEdSat-3 and 4
- The TechEdSat rapid prototype flight series is conducted as a hands-on training environment for young professionals and university partners
- The project helps verify Entry Systems Modeling by gathering real-world data aboard sounding rockets and CubeSats
- In the future, passive Exo-Brake systems may be used for small-sat disposal and the development of technologies to permit on-demand sample return from Low Earth Orbit (LEO) scientific/manufacturing platforms

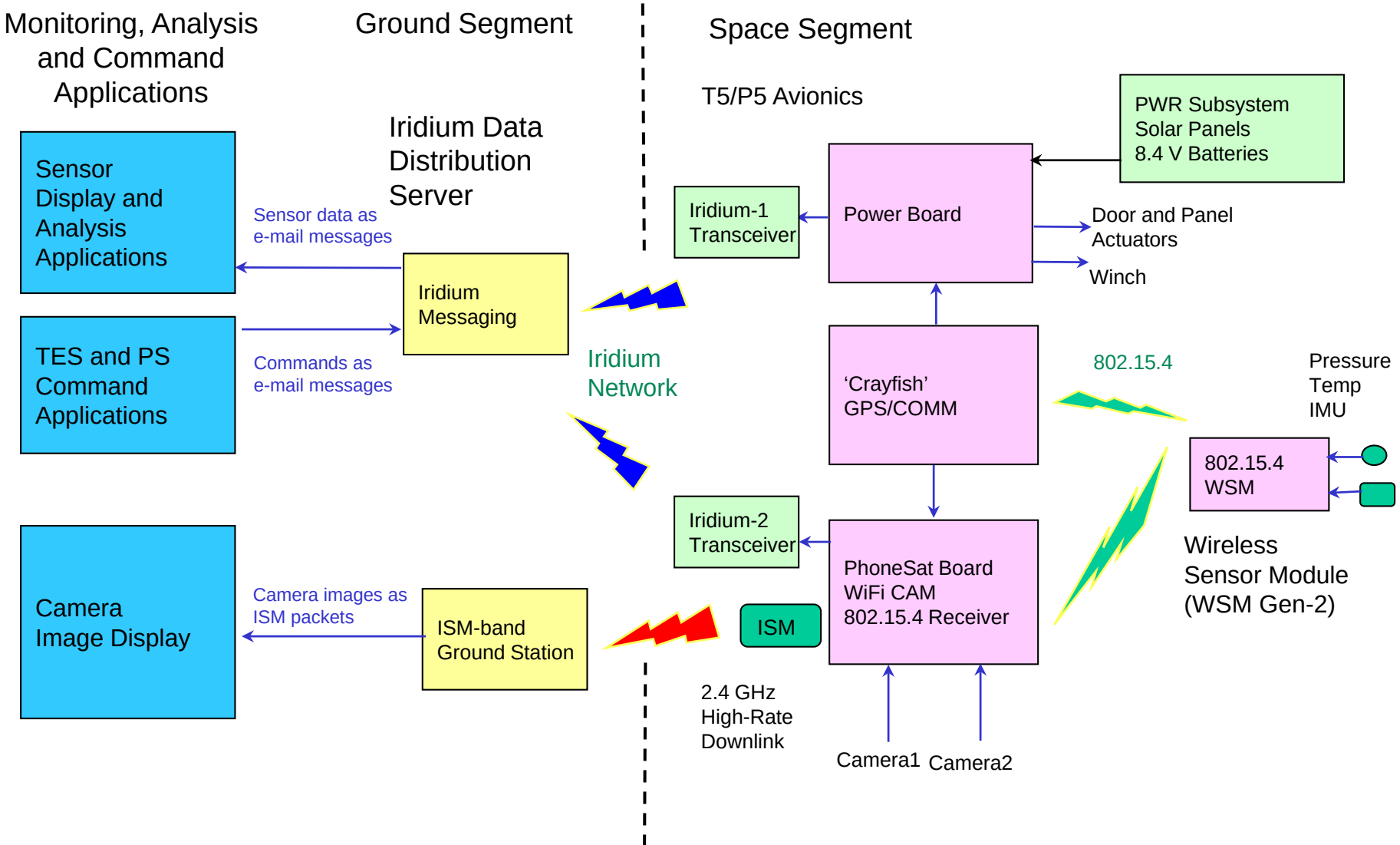
TechEdSat 5 (TES5)
Avionics, Software and Communications

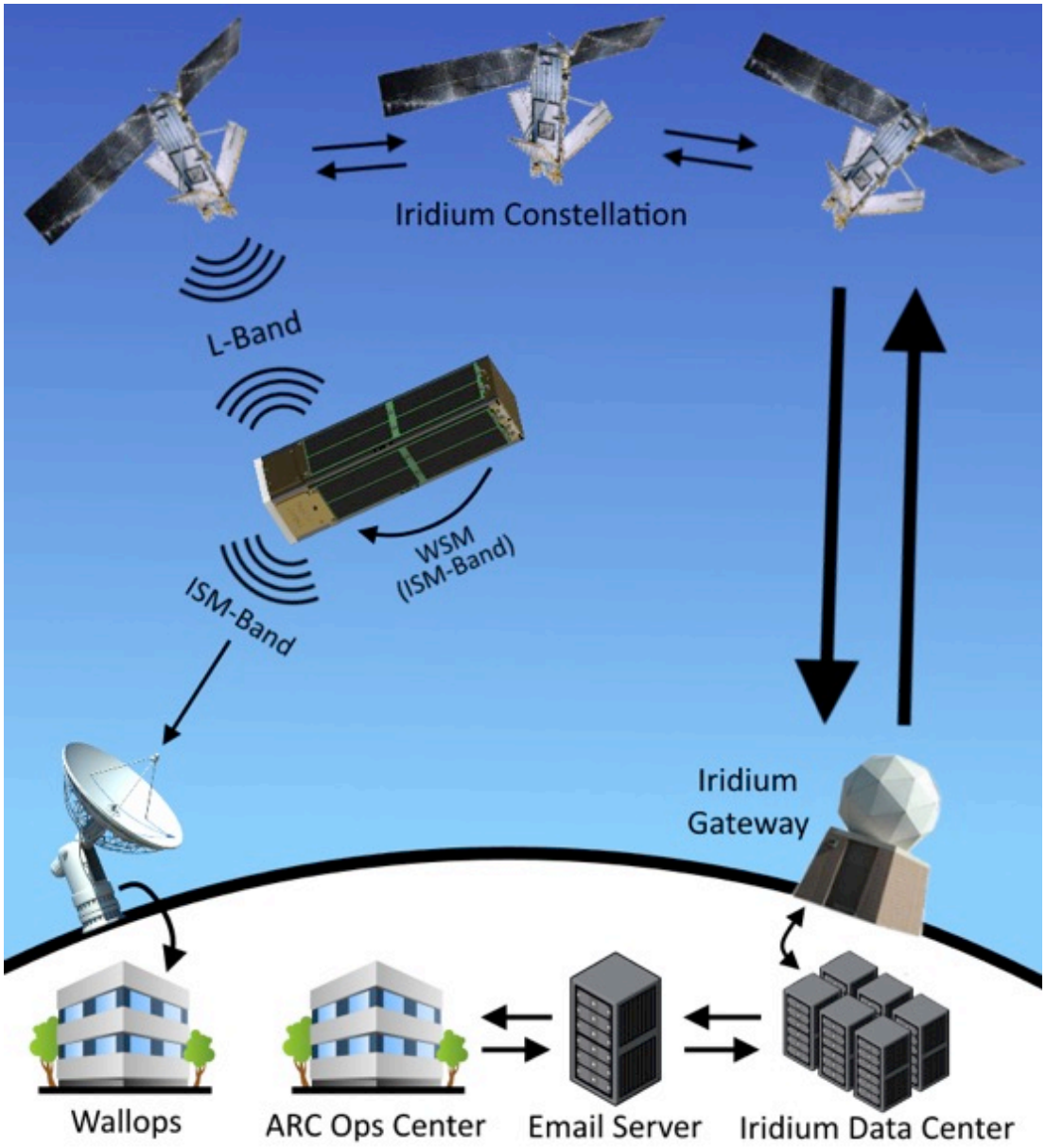
- The 3.5 U CubeSat contains a low-level AVR microprocessor for power control and a high-level Atom processor for fast data processing
- The primary Command and Telemetry (C&T) link is provided by the Iridium constellation through on-board Short Burst Data (SBD) modems.
- A modified Wi-Fi transceiver allows scheduled downlink at 1 Mbps when over our Wallops Island ground station
- TES5 includes a Wireless Sensor Module for inertial, magnetic, air pressure and temperature sensing.
- TES5 had two cameras which downlinked images via Wi-Fi or, with heavy compression, via Iridium constellation

TechEdSat-5 Anatomy



T5/P5 Flight System Architecture and Dataflow



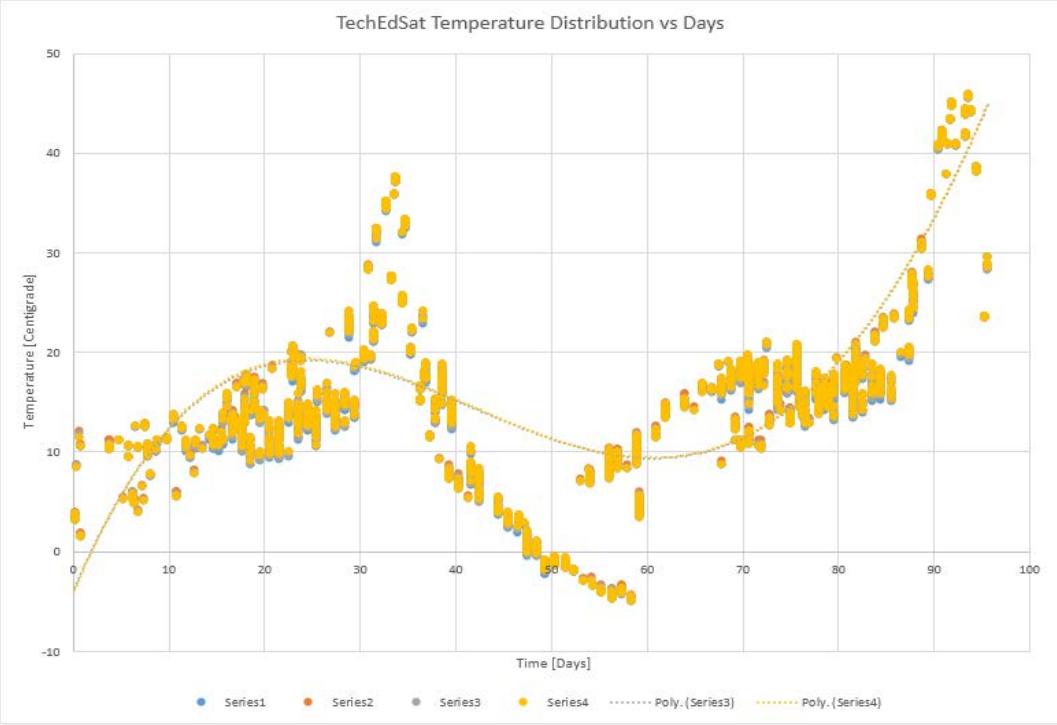


TechEdSat-5 Communications Overview

FEATURING:
Iridium SBD Modems
ISM-Band high-rate downlink

Previous Experience: TES-2

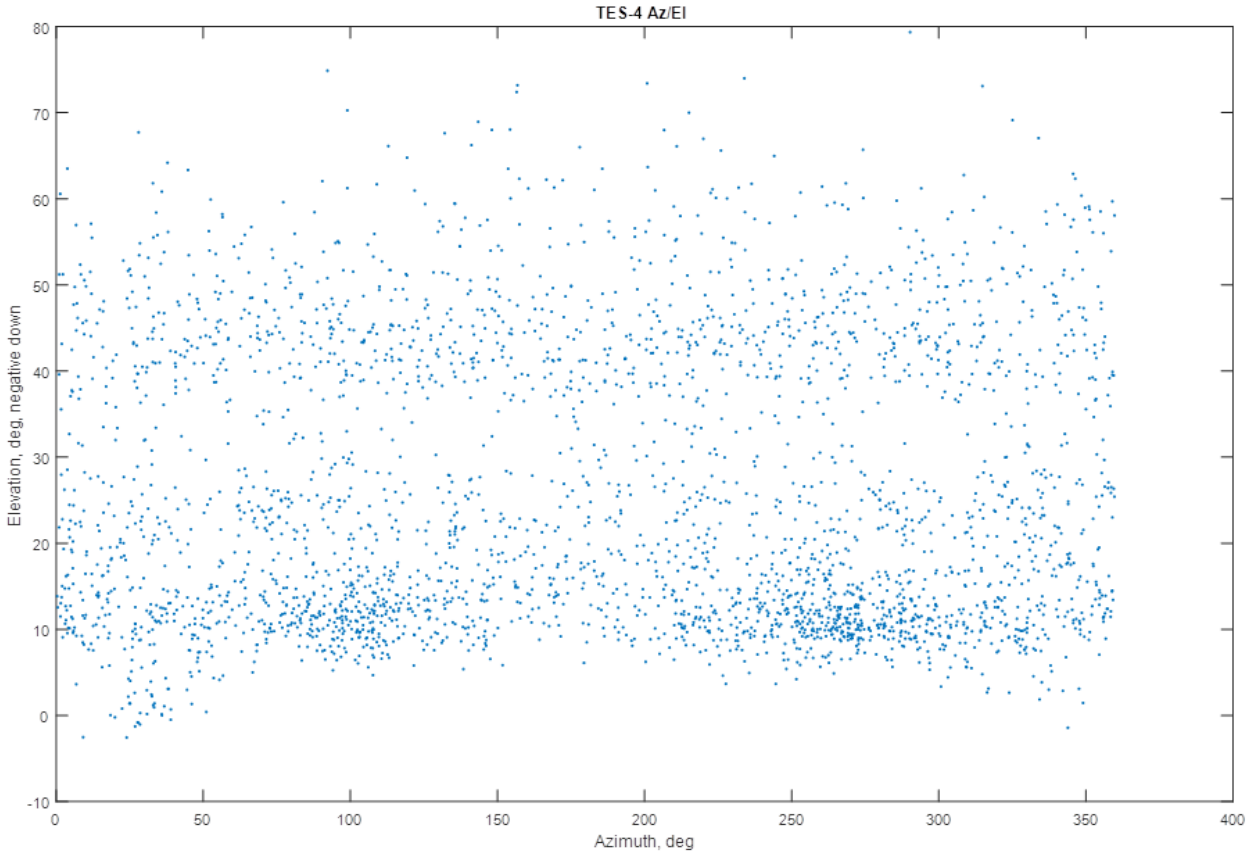
First successful Iridium in-space nanosat experiment



Shows distribution of handshakes over 100 hours (fwd patch; tumbling)

Previous Experience – TES-4

Direction from the Iridium Constellation Perspective

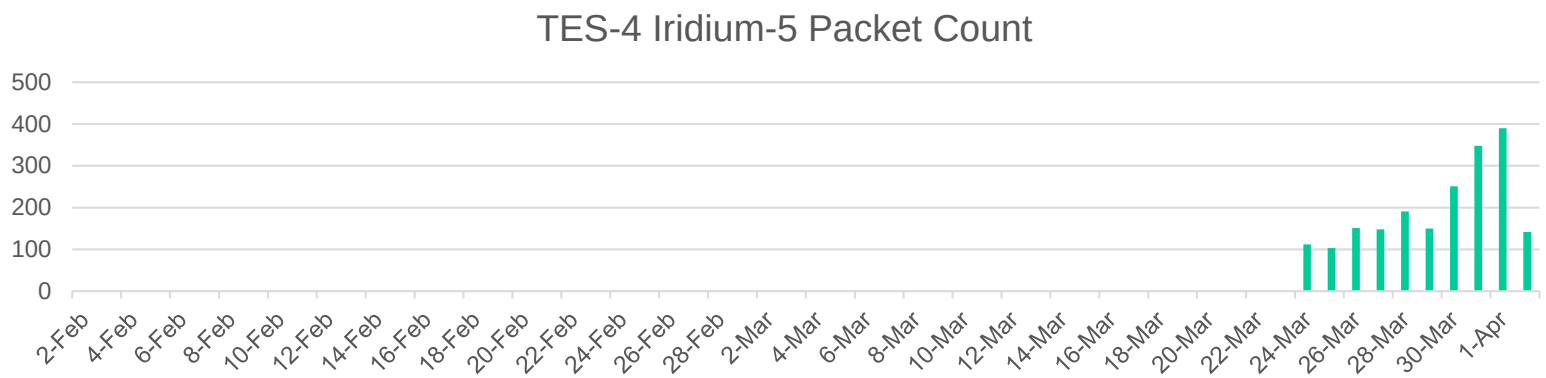


TES-4 messages vs. elevation and azimuth (from forward patch antenna)

Sent ~100 packets per day; received 25 out of 25 commands sent

Previous Experience – TES-4 Ortho Antenna

100-400 hits/day when the 2nd level Avionics was turned on



Note: Orthogonal patch antenna orientation zenith was not known, but was expected to be slowly rotating

Data Packets from T5/P5 via Iridium

Initial Data from TES/PS show "IT WORKS"

- ✓ WSM-"Cricket"
- ✓ GPS
- ✓ PhoneSat

WSM-Cricket

MOMSN>1271

41 88 07 ad de ef be be ba 0f 00 52 5f 6a 00 15 07 00 00 5b 0a 2e ff 0c ff 05 ff fe ff ff 00 07 00 07 ff fc 00 16 ff bb 00 51 00 19 40 00 fc 3c 62

CricketID: BABE

TimeStamp (s): 5398.378

PacketNumber: 5383

Pressure (kPa): 0.091

OnBrdTemp (°C): 26.06 Temp1 (°C): -24.4 Temp2 (°C): -25.1

Accel (G): -0.002, -0.001, 0.007 Gyro (Deg/s): 0.07, -0.04, 0.22

Mag (uT): -10.346, 12.146, 3.749 Light (lux): 0.00 Bat (V): 3.26

Temp1 is the thermocouple on the solar panel and Temp2 is the one embedded in the Teflon nose cap.

TES5 Health Data

```
TES5 Iridium Packet Interpreter

Packet:
5,1a831,21dc,3d1,404,446,495,1f,20,848,0,,1d,be6

Powerboard information:
packetNumber: 5
elapsedTime: 108593
batteryVoltage: 8.668
spVoltage1: 0.977
spVoltage2: 1.028
spVoltage3: 1.094
spVoltage4: 1.173
batteryCurrent: 0.031
safeMode: OFF
exobrakeDeployed: TRUE
deployingExobrake: FALSE
regulators: 0000
timeExobrake: 2120
timeLastCommand: 0
commandResponse:
iridiumDelay: 29
attemptedTransmits: 3046

Note: GPS string is not present.
```

Phonesat GPS

Iridium metadata:
MOMSN>1268 MTMSN>0
session_time>1488832376552 lat>0.07239 lon>72.99772
Onboard GPS data: time: 1488831732 (Mon Mar 6 12:22:12 PST 2017) px: 3736540.5672 py: 4480193.2322 pz: -3455134.8574 vx: -2187.0305 vy: 5348.8718 vz: 4570.3105

TES5 Status – End of Mission

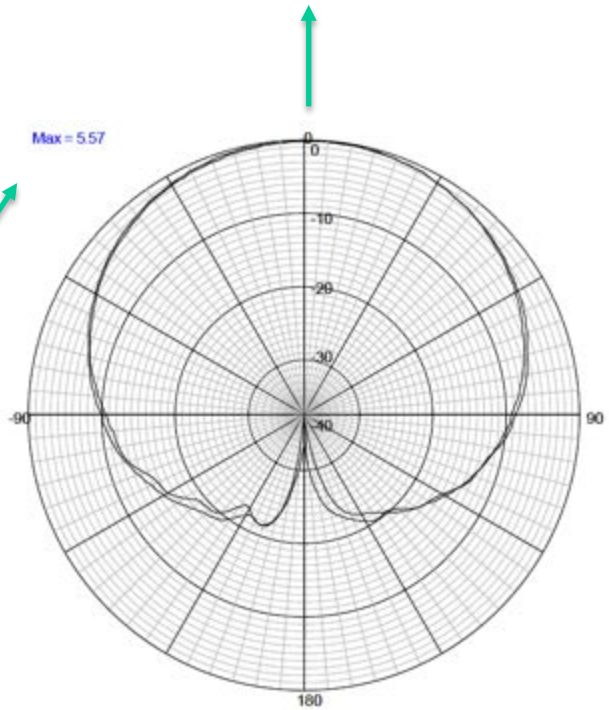
Desired

(As-designed, nose forward)

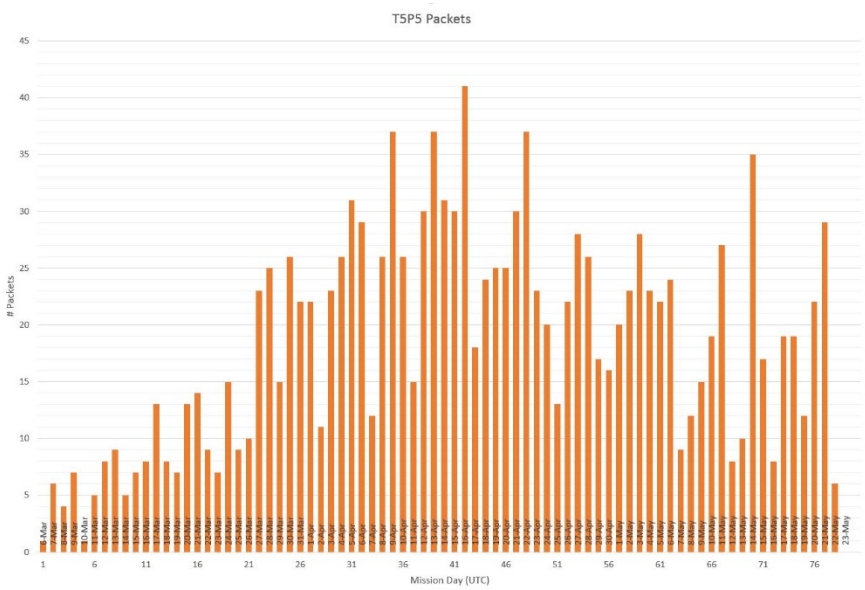
Trending?

Actual

(Nose down)



Iridium Antenna Radiation Pattern



TES-5 is in a 'nose-down' orientation, Iridium antenna provides -10 dB gain at 180 degrees

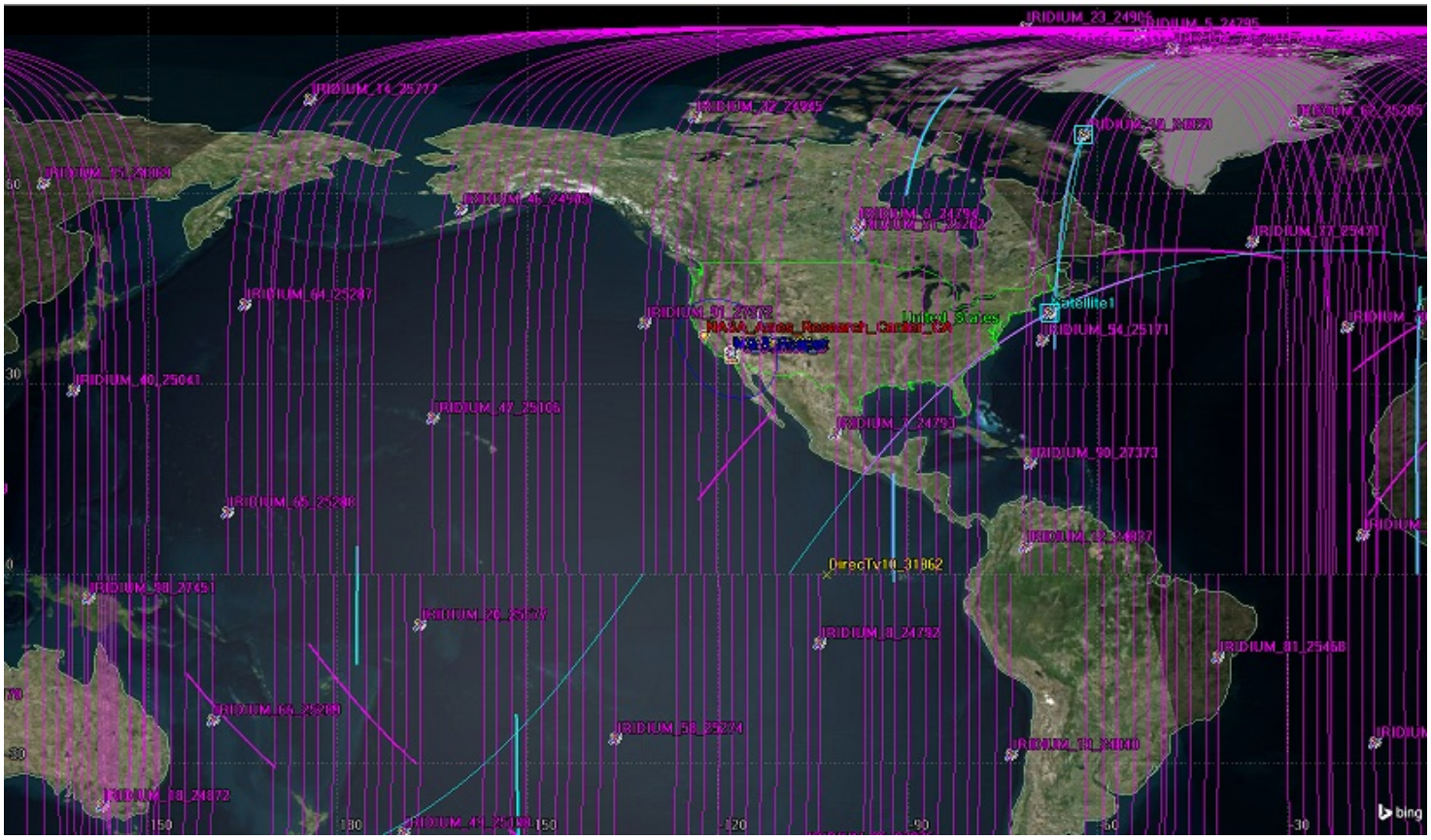
Link margin analysis shows nose-down attitude compromises communication

Number of packets/day was slowly changing, perhaps due to slow changes in AoA

STK Iridium Comms Analysis – Coverage

Active Iridium Satellite Constellation Ground Tracks

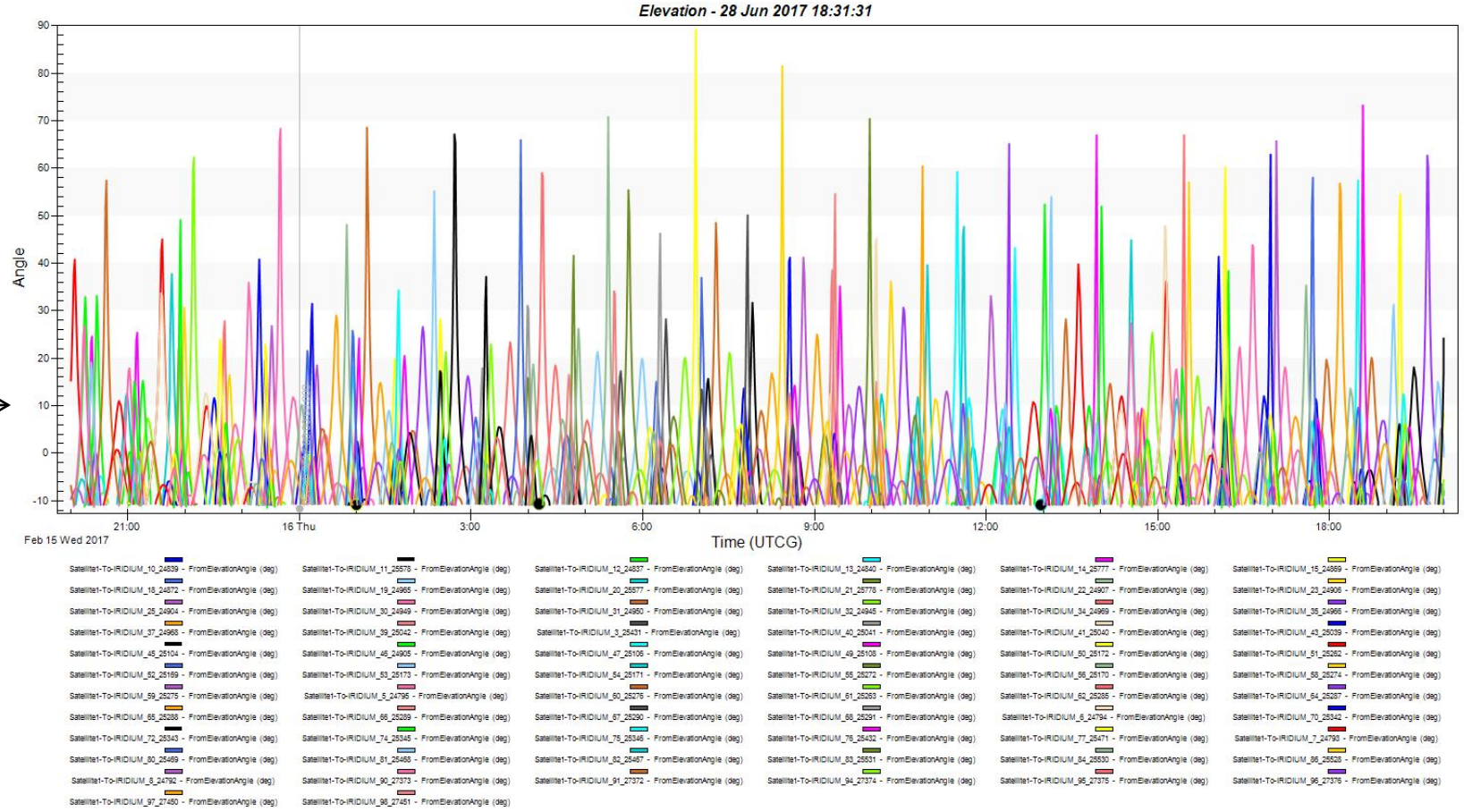
Six belts of eleven Iridium satellites in polar orbit



Pattern offers 100% ground coverage

Iridium Comms Analysis – TES5 Forward

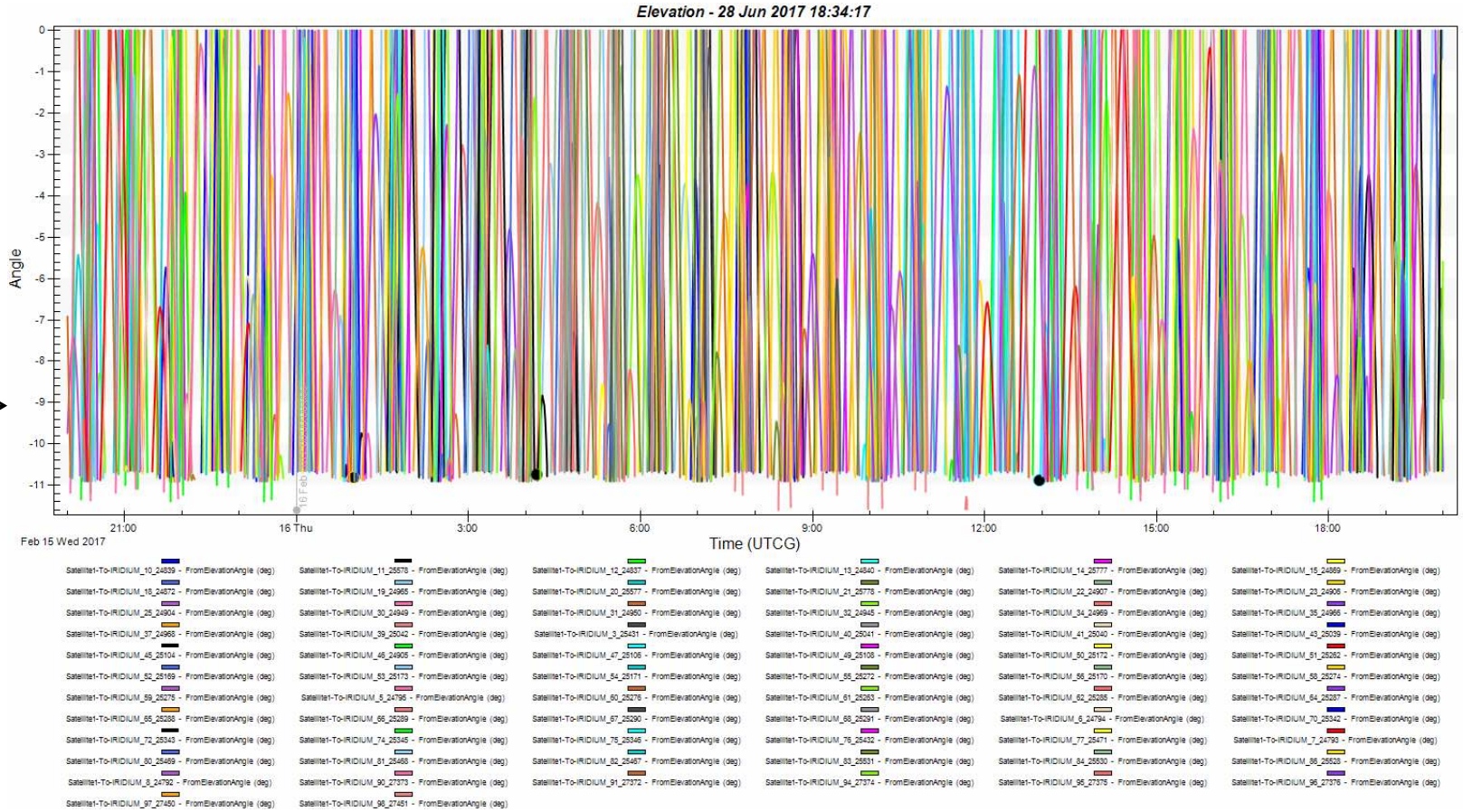
Elevation from TES5 to all Iridium satellites – 4000 Km maximum range



For FWD attitude: all possible contacts are from -12 degrees to ~80 degrees – good telemetry and command links

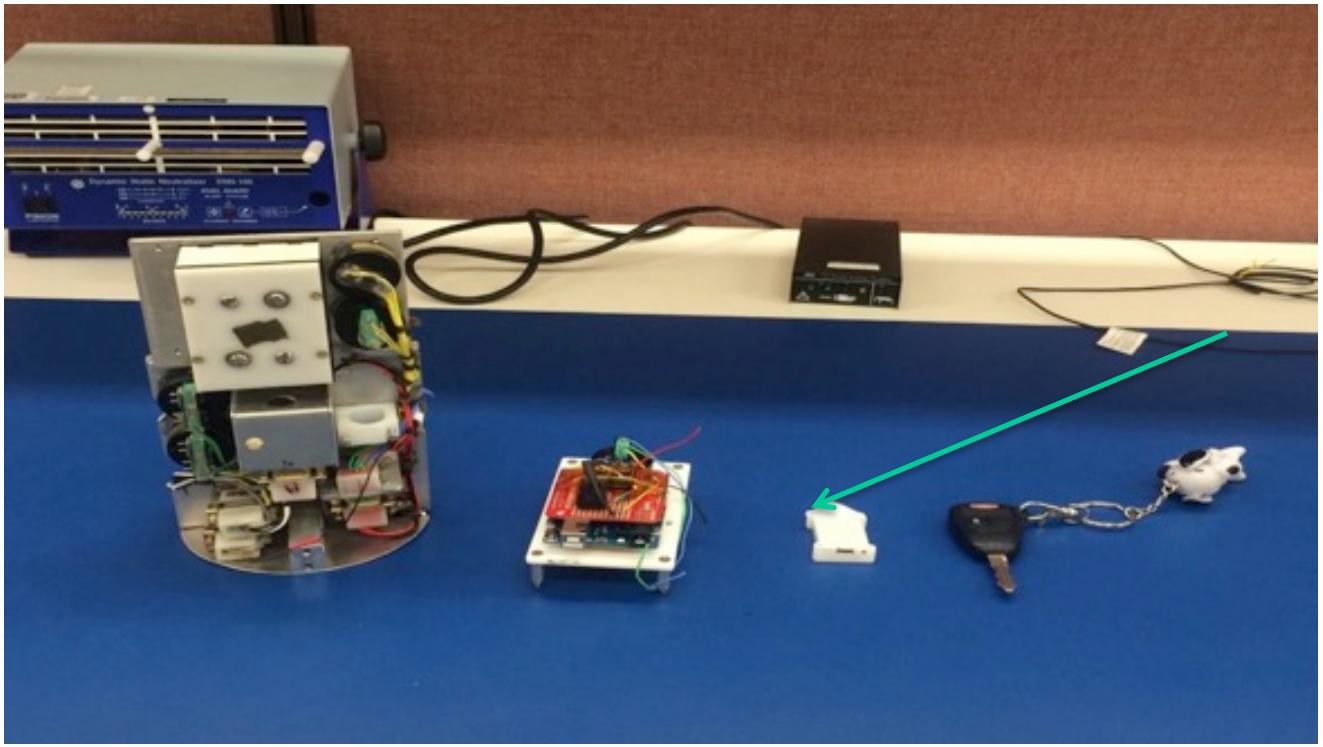
Iridium Comms Analysis – TES5 Nadir

Elevation from TES5 to all Iridium satellites – 4000 Km maximum range



For nose-down attitude: all contact from 0 to -11 degrees: link margin constraints show lower probability of successful handshake

Wireless Sensor Module Experiment



Evolution of Wireless Sensor Module

Far left: Original SOAREX-1 data acquisition module
Second from left: SOAREX-8 WSM concept trial version
Third from left: currently developed system for SOAREX9 and TES-5
Fourth from left: Marc's key chain

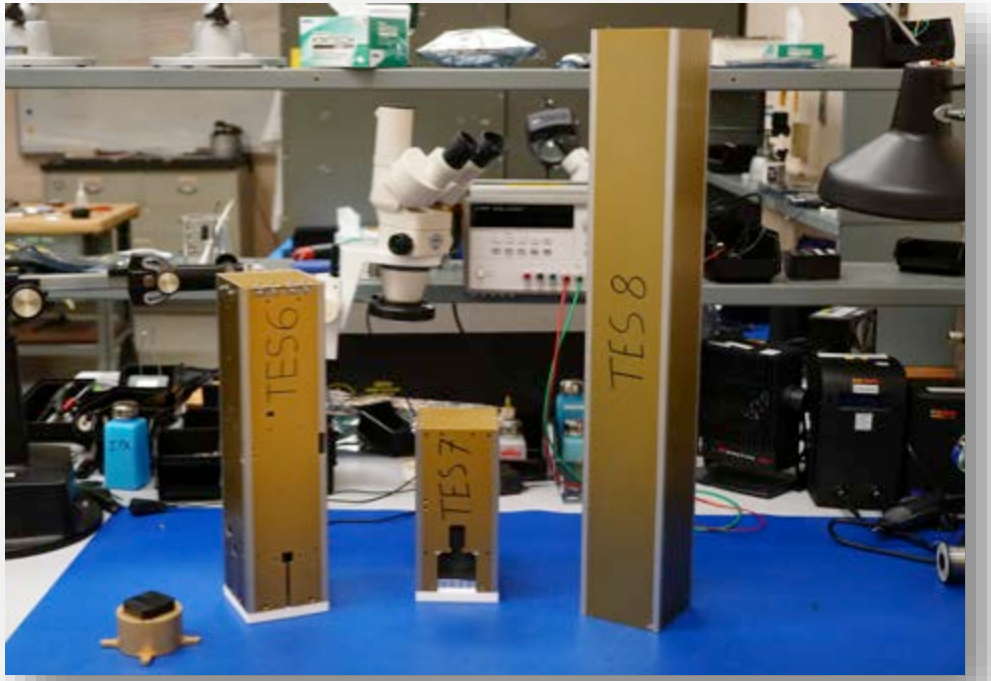
Future Missions: TechEdSat 6, 7, 8

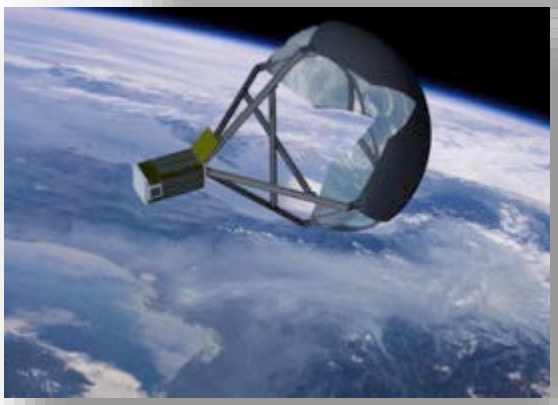
TechEdSAt-6 [*3U*]
2nd Modulated Exo-Brake Test
Improved Exo-Brake Tensioner
New Ops/Schedule Plan
Drag Coeff. = 5 kg/m2
CUBIT-1 Test

TechEdSat-7 [*2U*]
High Packing-Density Exo-Brake
Novel strut design – no modulation
Drag Coeff. = 1 kg/m2
CUBIT-2 Test

TechEdSat-8 [*6U*]
'Hot' Exo-Brake
Modulated with beta=4 kg/m2
'Deep Dive' into atmosphere
Drag Coeff. = 5 kg/m2
Novel Comm. Equipment

* All CSLI Approved





Communications Summary

Objectives Met:

- Telemetry was received every day for 78 days
- Telemetry downlink rate (mobile-originated) was about 30 packets per day, representing about 1% completion rate
- No commands were received, although many were sent
- Each successful downlink resulted in a command transmission – problem was reception by TES5

Objectives not Met:

- Minimal PS5 Iridium interaction – telemetry received
- No ISM-band downlink – requires commanding