# Technology, Service, Education: Globalstar 24/7 for LEO

**12th Annual CubeSat Developers' Workshop, Cal Poly, April 22, 2015**


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# Acknowledgements


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- *Taylor University general TSAT student support*
- *Dr. Bob Twiggs for PocketQub Drawings and Discussions*
- *Dr. Art White and Dr. Stefan Brandle for Duplex Work and Data System*

# Abstract

New technical capacities for real time global satellite-to-satellite communication, rapid satellite development turnaround, constellations, and business focused solutions for reliable and certified parts are critical for small-sat advancement. The 2-Unit CubeSat TSAT flown as part of the NASA ELaNa-5 program was recently launched 18 April 2014 and demonstrated the capability and global coverage of the Globalstar low power Simplex unit with omni patch antenna as a powerful 24hr/7day FCC commercial data link. No cubesat ground station or operation was required and first contact packets were received 11 seconds after TSAT was turned on over the remote South Pacific Ocean.

More recently a 3U AFRL Globalstar Experiment And Risk Reduction Satellite (GEARR-Sat) was developed from kickoff to final qualification in 3 months by NSL and was launched to the Space Station (ISS) in July 2014. It was finally launched from the ISS February 4, 2015. GEARRS includes a simplex unit (36 Bytes/s rate) and Duplex unit (700 Bytes/s) for testing and data link. The Duplex unit can send commands and command files and has a higher data rate capability. It uses a combined transmit and active receive surface patch antenna.

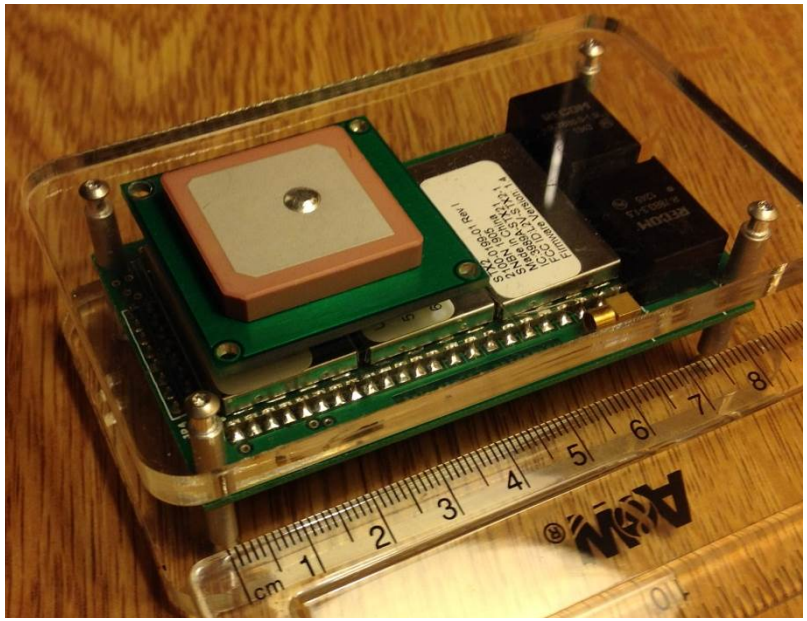
More recently a 3U AFRL GEARRS-2 satellite was developed by NSL and delivered in six weeks and is scheduled for a May 2015 Atlas rocket launch. The planned orbit is 700 by 350 km altitude elliptical orbit at 55 degree inclination. GEARRS -2 includes an ARM processor with Lenox for efficient file transfer and commanding. General data capacity and coverage and geo-location features of Globalstar will also be studied.

All of these satellites include Li-Polymer battery pack, FCC commercial license, 3-axis magnetometer, Langmuir Probe, temperature array, solar cell array, aerodynamic and magnetic passive control. NearSpace Launch Inc. (NSL) is a private endeavor that provides unique services and products for small satellites for predominately LEO orbits. The new NSL Globalstar modem product (EyeStar) is critical for early Con-Ops to successfully secure a spacecraft with near real time global coverage, greatly simplify reliable satellite communication systems, and reduce requirements for expensive ground stations links. EyeStar links are particularly good for constellations of small satellites for multipoint measurements using a common ground station format and time ordered data MySQL data base.

# *"size does matter"*

1. EyeStar Small and low power integrated **Globalstar** satellite radios give "Anytime and Anywhere" coverage (24/7) of CubeSats with reliable and commercial license
2. Omni directional small patch antenna communicates to G* **constellation**
   - NO deployable antennas
3. First Simplex Unit tested on 2U **TSAT** April-May 2014 with excellent results
4. First Duplex Unit with commanding tested on **GEARRS #1** Sat in February, 2015
   - *Globalstar Experiment and Risk Reduction Satellite (GEARRS)*
5. Second Duplex unit **GEARRS #2** Sat scheduled for launch in May 2015
6. Globalstar enables **low altitude capability** for communication down to the 110 km (ELEO Region)
7. No CubeSat Ground station required (Small).
8. Globalstar radios fit well in small **Pocketqub** more powerful and lower in cost
9. Small satellites allow for **rapid build** (3U in 90 days and 45 days)
10. **Small NSL EyeStar** radios are **flight designed** ,certified, firmware modified, ARM multicore processor control, include FCC License, and available. Radio Astronomy frequencies avoided in spectrum.

# EyeStar Integrated Globalstar Radios



## Simplex Unit

ICD Available

**www.nearspacelaunch.com**

## Duplex Unit

ICD Available

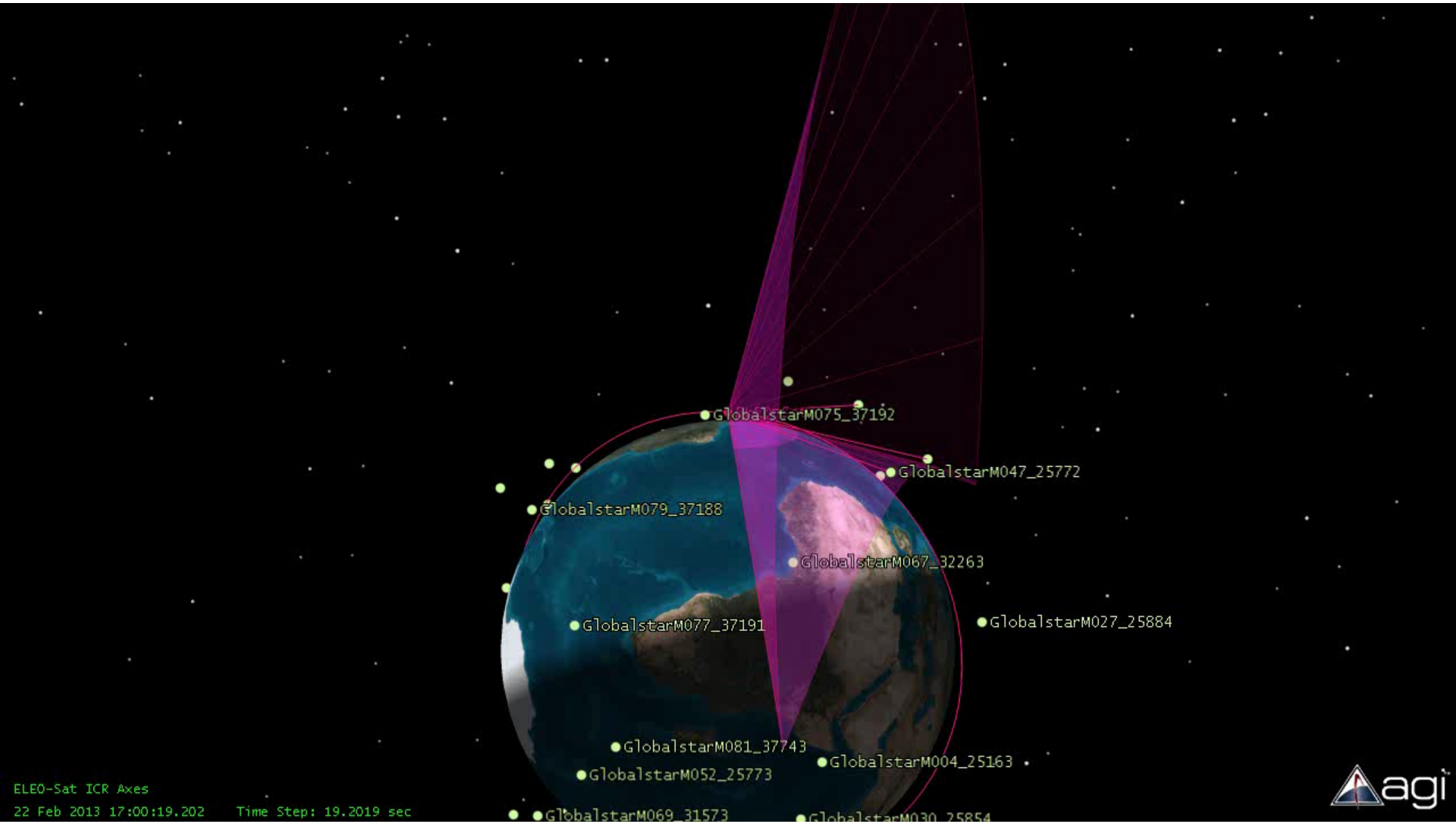
# GlobalStar Radios


- GlobalStar Constellation ($2B )
  - 32 plus LEO Satellites (1400 km)
  - Provides global data and voice services for
    - ~ 300,000 customers
- Used primarily for infrastructure/wildlife monitoring
  - Oil Rigs and Gas pipe-lines
  - Shipping Containers and Endangered animals

- **EyeStar** developed by NSL for satellites & **EyePod for** high-altitude ballooning
  - NSL developed relationship with GlobalStar and now Value Added Reseller (VAR) and
  - NSL has flown three EyeStar units (100%) & > 350 balloon launches with 99% data/recovery
  - Data links via the GlobalStar and NSL network (Simplex and Duplex)
    - Code division multiple access (CDMA)
    - Payload commanding
    - Data downlinks
    - Recovery tracking (with GPS)

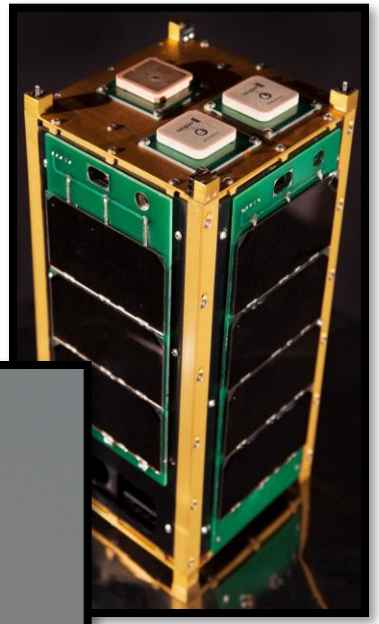
**EyeStar Simplex System Fits in CubeSat and PocketQub Sat**

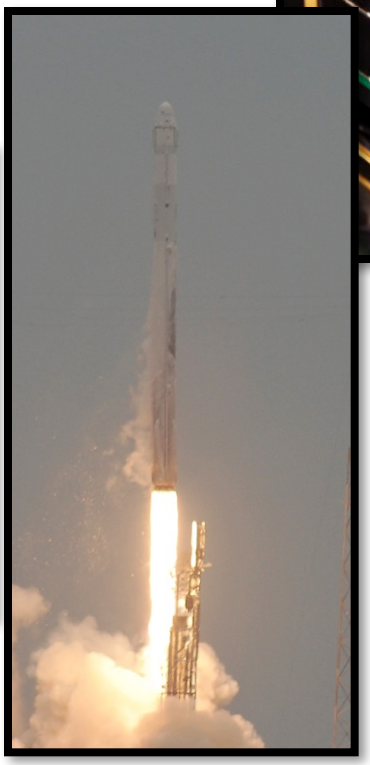
# Globalstar with EyeStar Simulations
## ("*Bent Pipe*" distributed data downlink)



# TSAT
## Taylor, Technology and TEST Satellite

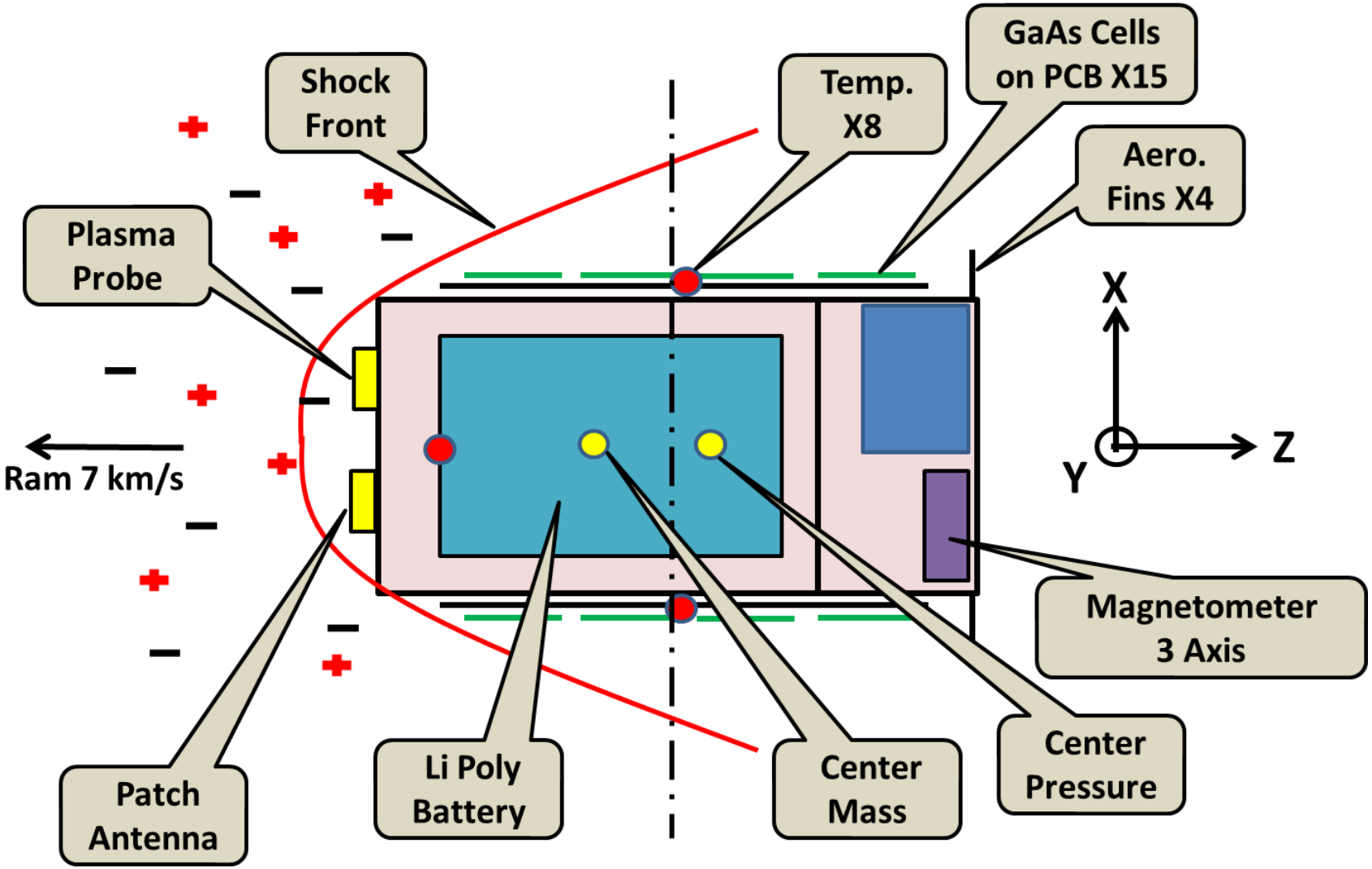
- Taylor University 2U Spacecraft
  - Demonstrating the EyeStar Radio (Beacons only)
  - Plasma Data
  - Started in 2012 as a Senior Capstone project
- TSAT was launched on 4/18/14 (1 year ago!)
  - SpaceX CRS-3
  - NASA ElaNa 5
  - Built by Taylor University and Near Space Launch





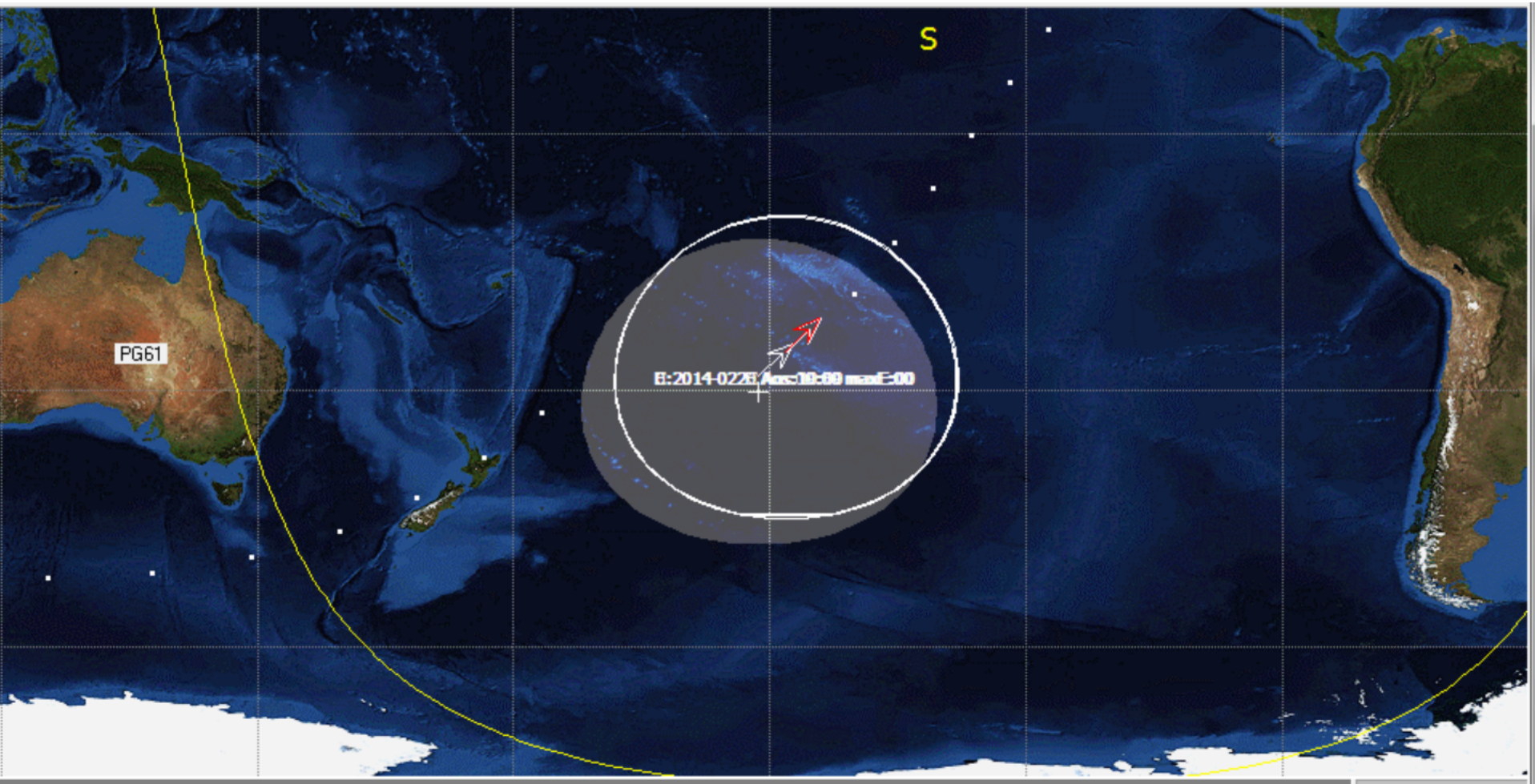
**TSAT launched with EyeStar Simplex Unit on CRS**

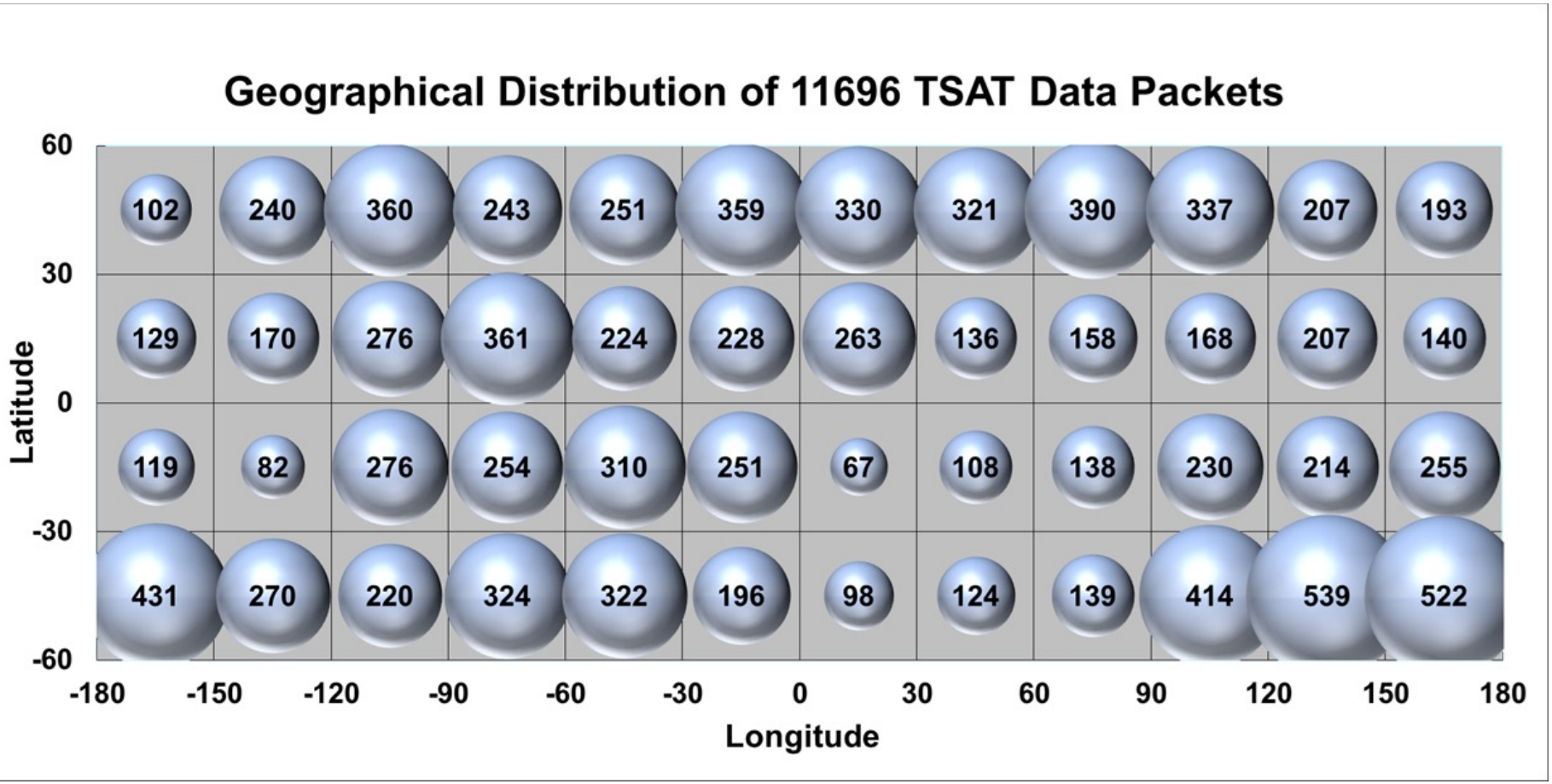
# TSAT Concept Diagram

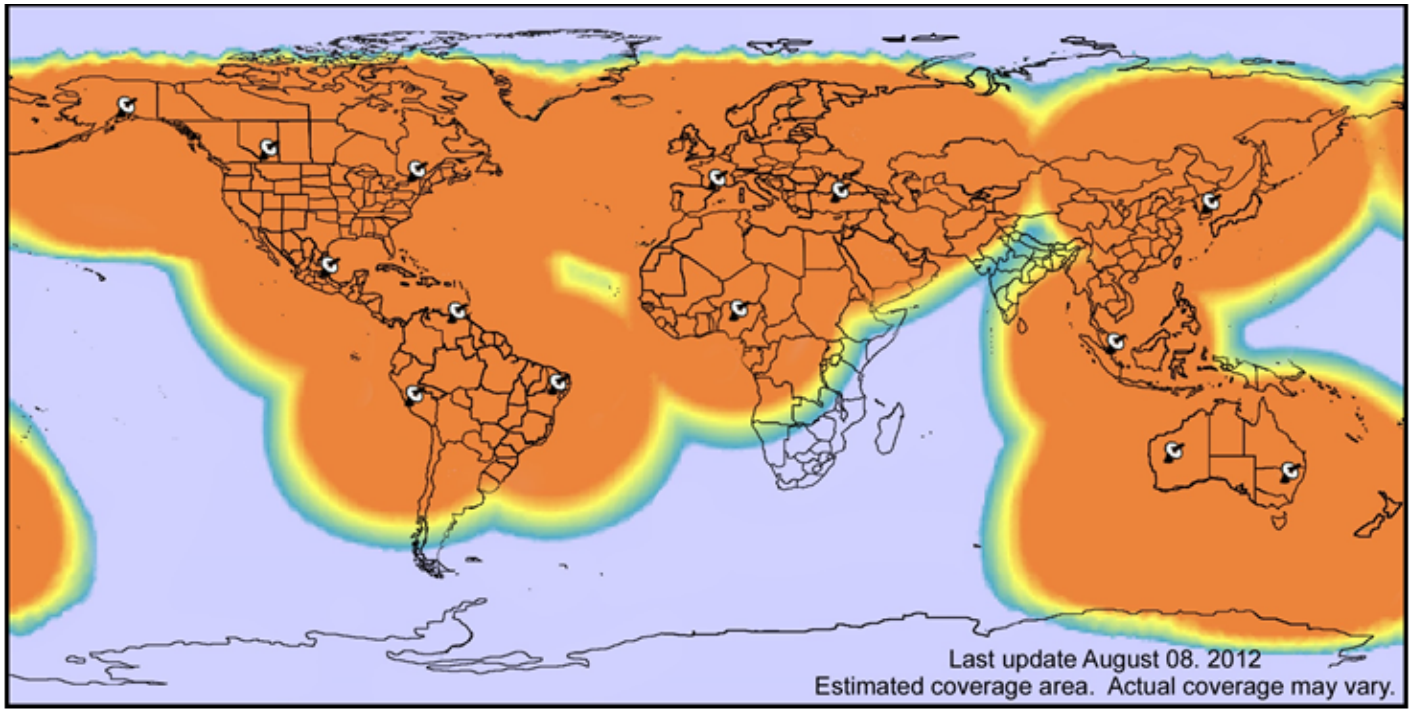


# Location of first TSAT Transmission Packets after 11s Radio Turn On and at 36 Bytes/s

Application: Just sending basic GPS, Health/Safety, and sensor data at very low data rates is on the order of $10/orbit data costs and gives much mission success




Geographical Distribution of 11696 TSAT Data Packets
60
30
0
-30
-60
Latitude
102 240 360 243 251 359 330 321 390 337 207 193
129 170 276 361 224 228 263 136 158 168 207 140
119 82 276 254 310 251 67 108 138 230 214 255
431 270 220 324 322 196 98 124 139 414 539 522
-180 -150 -120 -90 -60 -30 0 30 60 90 120 150 180
Longitude



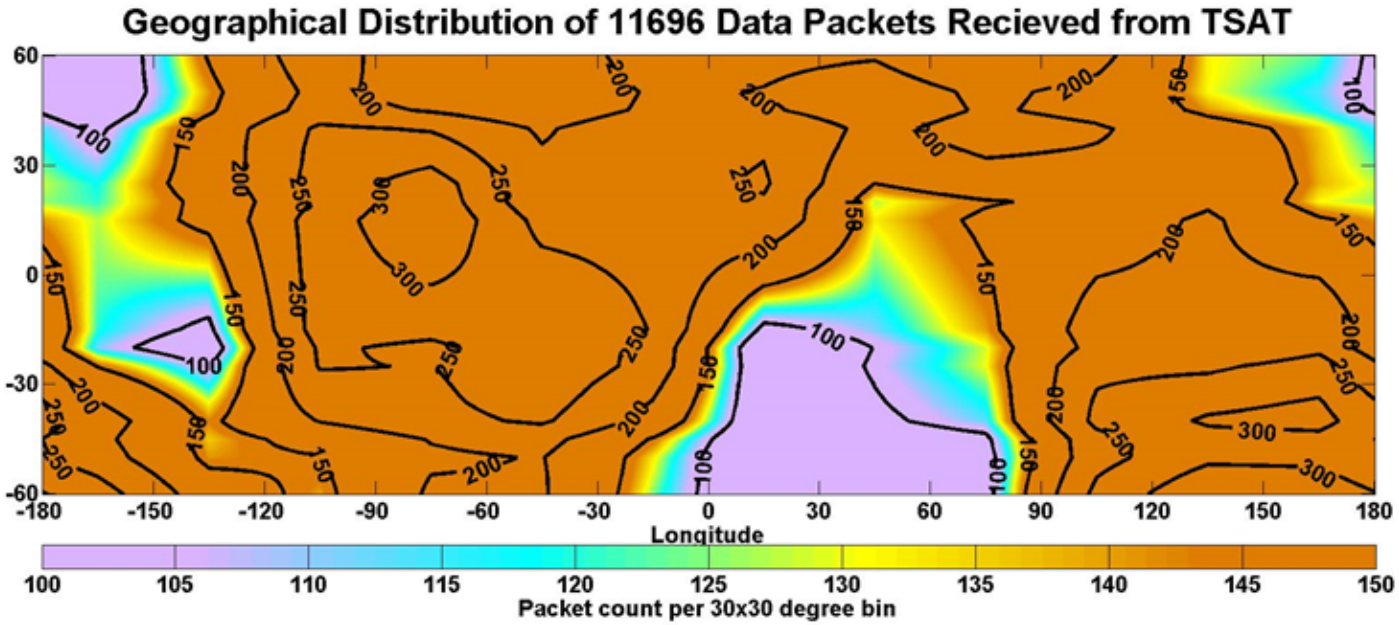




**Figure 7: Comparison of Globalstar projected coverage and normalized TSAT results**

See presentations of First Results (11th Annual CalPoly) and Aug. Workshop, UT
Also paper and presentation at Utah CubeSat Workshop, Aug. 2014

SSC14-WK-6

# TSAT Globalstar ELaNa-5 Extremely Low-Earth Orbit (ELEO) Satellite

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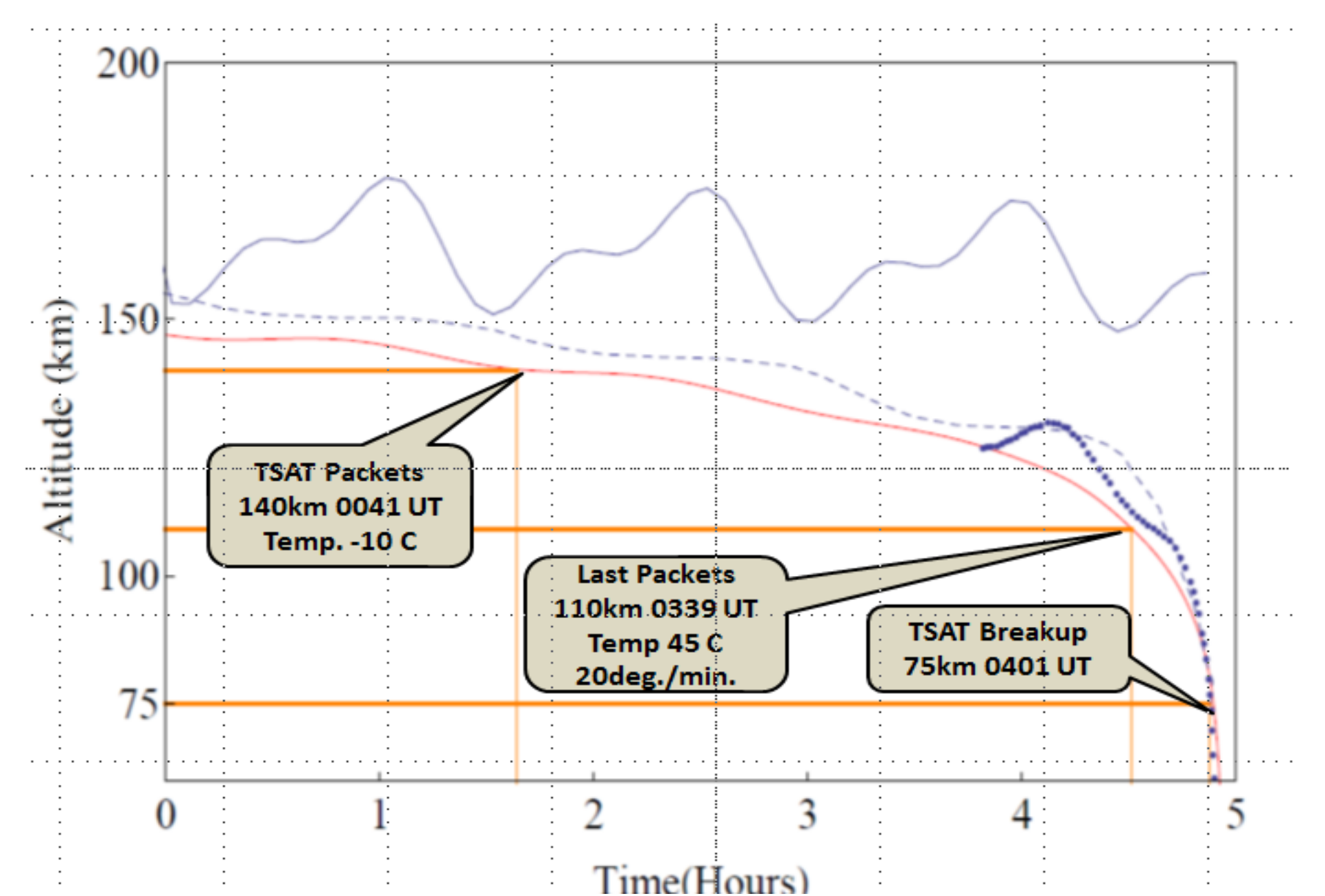
## ABSTRACT


200
150
100
75
Altitude (km)
0
1
2
3
4
5
Time(Hours)
TSAT Packets
140km 0041 UT
Temp. -10 C
Last Packets
110km 0339 UT
Temp 45 C
20deg./min.
TSAT Breakup
75km 0401 UT

# Low Altitude TSAT Last Packet

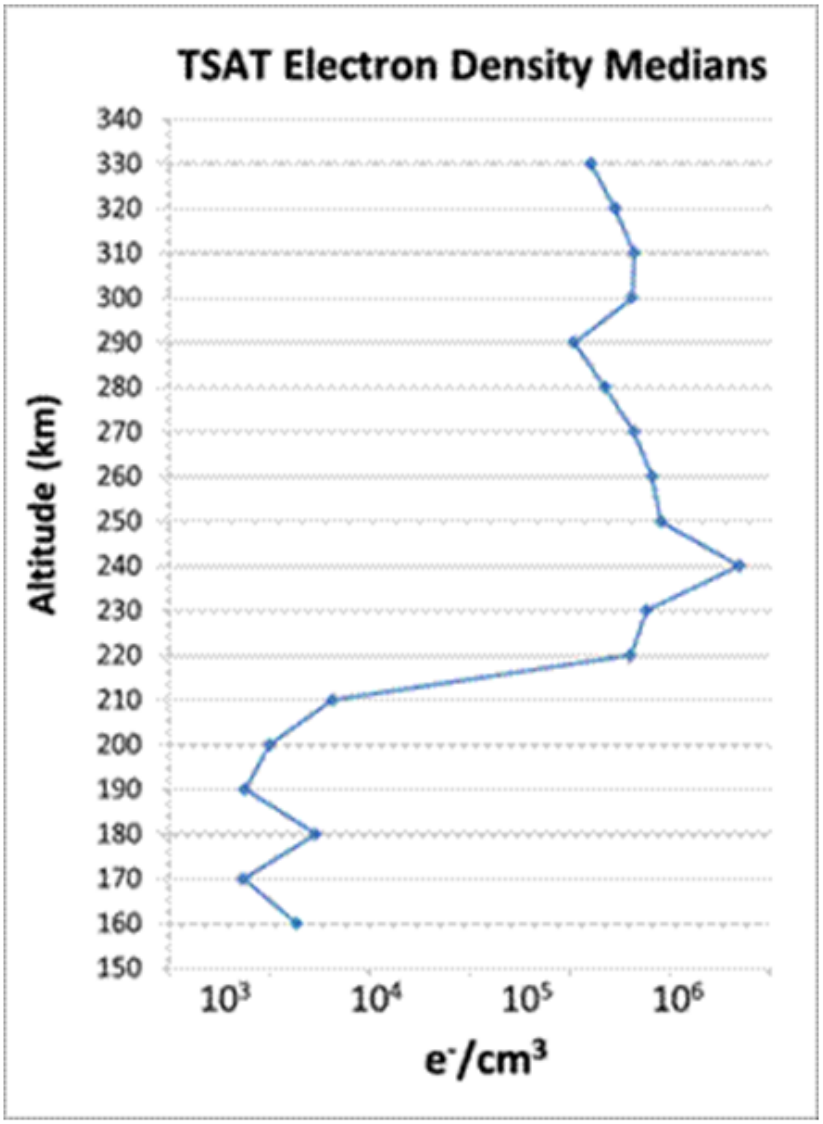



**Figure 19: Mission medians of electron density for various orbit altitudes (10km bins). The higher density in the F-region transitions to the lower density in E-region at about 215 km.**

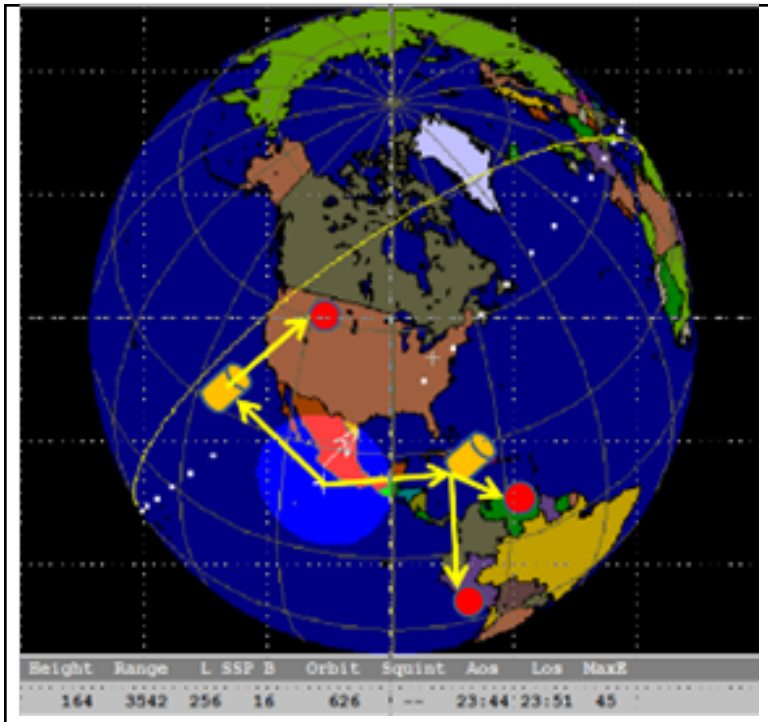
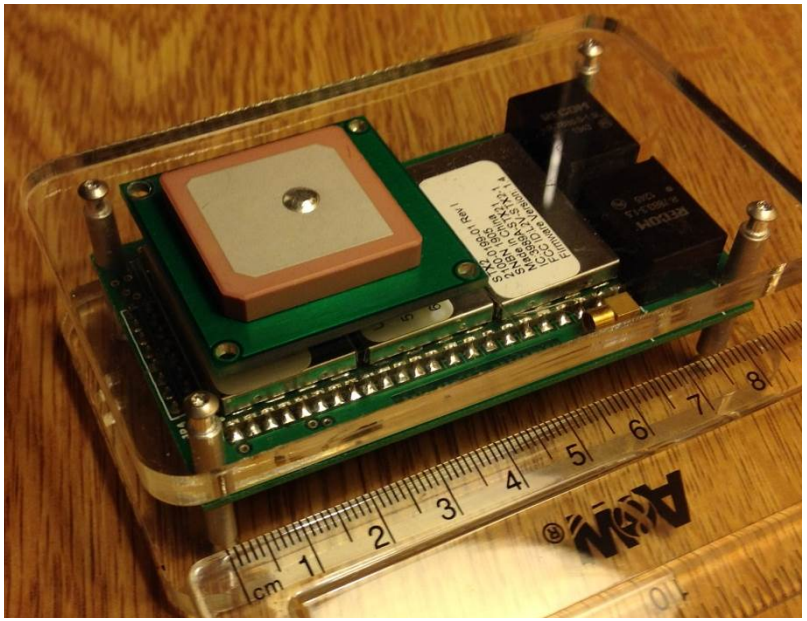



Figure 17: **TSAT location of last data packets (~110km) and illustrated bent pipe data paths to the Globalstar satellites to gateways in Peru, Venezuela, and Canada. (17)**

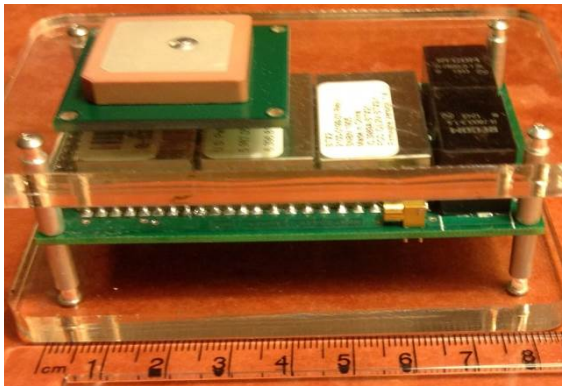
# Simplex EyeStar Features

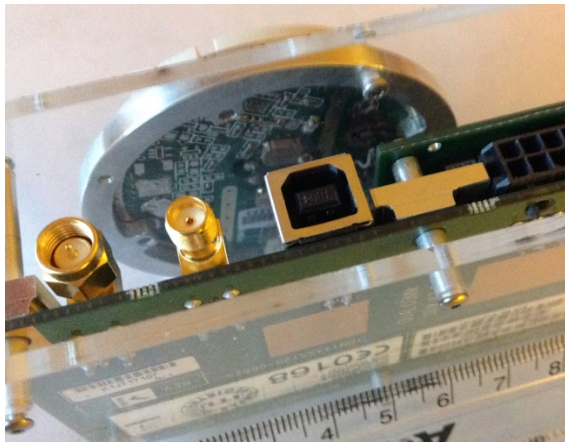
- Small form factor
  - Power
    - Accepts 6.5 V to 20 V
    - 200 mW Tx power
  - Volume
    - 44 mm x 81 mm
    - PocketQub form factor
  - Beacon Data Inputs
    - TTL Data Protocol serial
    - 8 Analog Inputs
    - 8 Digital Inputs
    - GPS input



EyeStar Simplex is a little Beacon Spacecraft with comm., antenna, flight processor, Software, Temp and 8 analogs , EPS regulation

# EyeStar Product Features





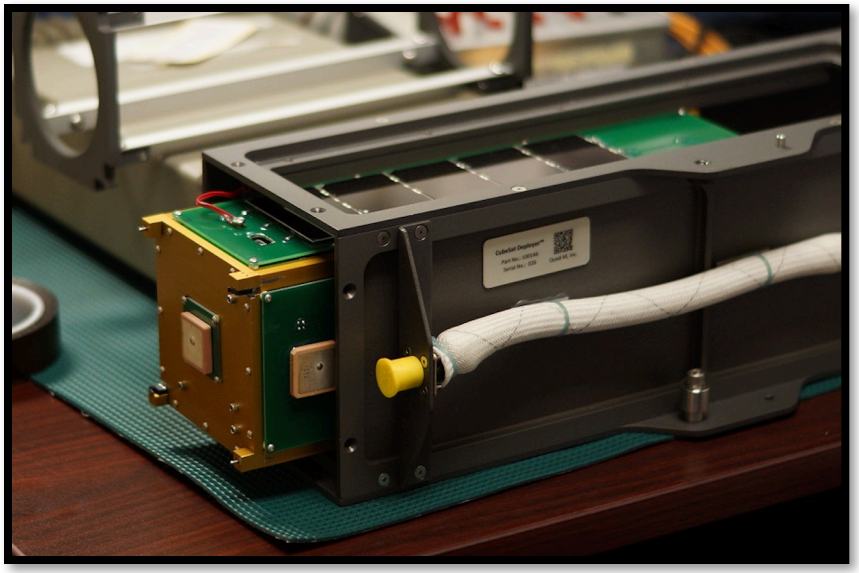
- Simplex Data Rates up to 36 Bytes/s
- No deployables
  - 2 cm x 2 cm patch for simplex
  - 7 cm diameter circular patch for duplex
- Rapid acquisition
  - TSAT beacons 11 seconds after turn-on
- Not ITAR Restricted
- Duplex Higher data rates up to 9600 kbps maximum (advertised)
  - GEARRS will investigate actual data rates, cost, can commanding limits
  - Possible Geolocation for CubeSats
  - EyeStar intended to complement traditional high speed radios

# GEARRS

## GlobalStar Experiment and Risk Reduction Satellite

- GEARRS
  - Testing full NSL EyeStar products
    - Duplex and Simplex
    - Higher data rates
    - Higher altitude mapping
  - A Collaboration between NSL and AFRL Space Vehicles Directorate
  - 94 day CubeSat development Cycle
    - Kickoff: December 17th , 2013
    - Delivery to NanoRacks: March 21st 2014
  - Launching on Orb-2
    - July to ISS and Feb ISS Deployment
  - 18 AHr Battery without charge for 1 yr.
  - Because Launch Uncertain Developed GEARS #2

Enabled by incredible support from AFRL, the DoD Space Test Program, and NanoRacks



# GEARRS #1 Snapshot Results

- GEARRS 1 was designed as a 48 Hr. Mission on just Battery Power (7.2 Volt, 20 AHr Li-Poly Battery)
- Battery was dead when deployed from ISS
- After one Sunlit Orbit (arrays) GEARRS fully turned ON!
- All 4 processors, two Simplex Units, one Duplex unit, all spacecraft functions (3-Axis Mag. and Attitude, solar EPS, antennas, Inhibits), and science sensors worked.
- However, because we were power limited the Duplex Final power amp could not work at full duty cycle.
- Resulted in limiting Mapping but all main objectives were satisfied.

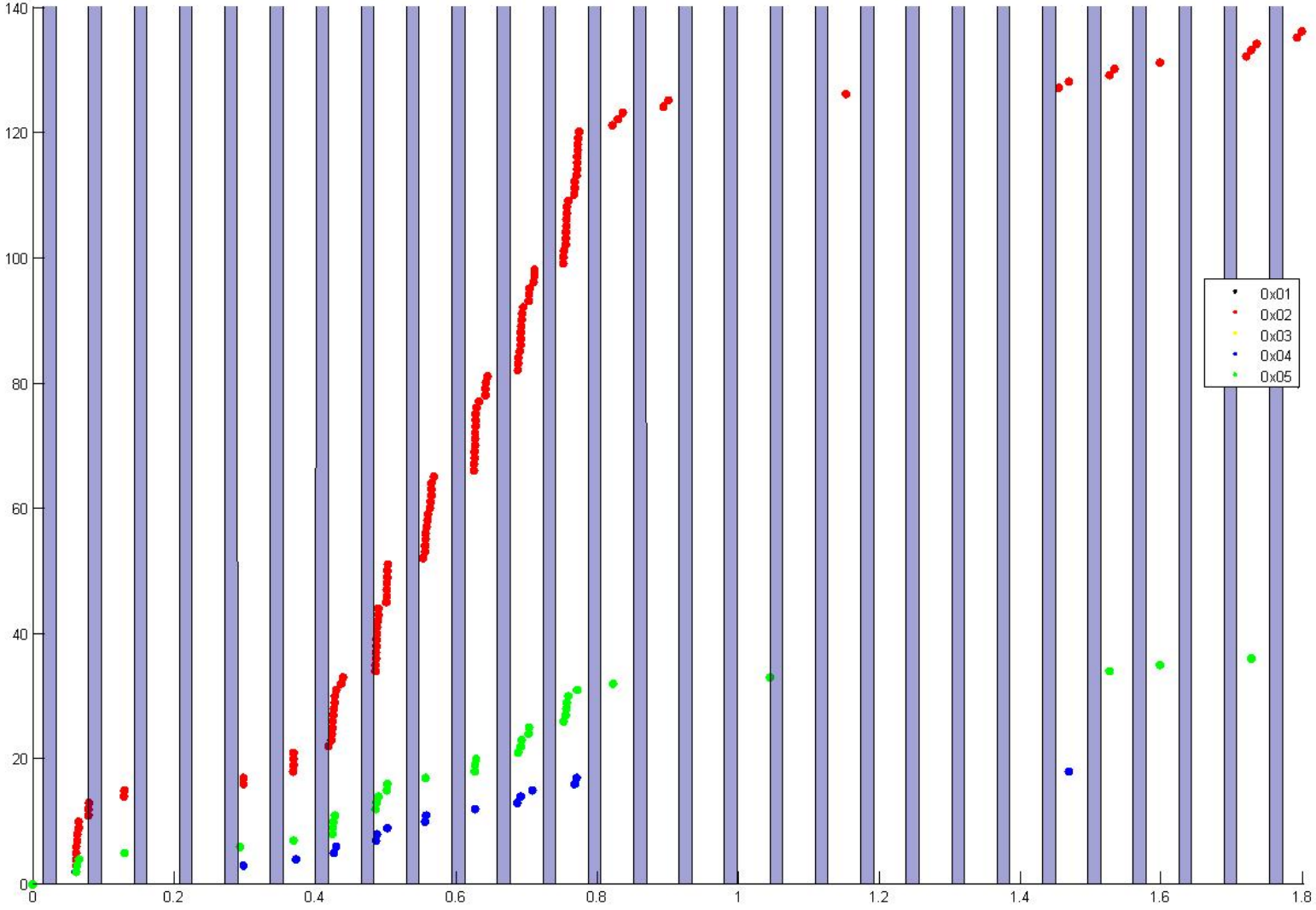
# GEARRS Summary

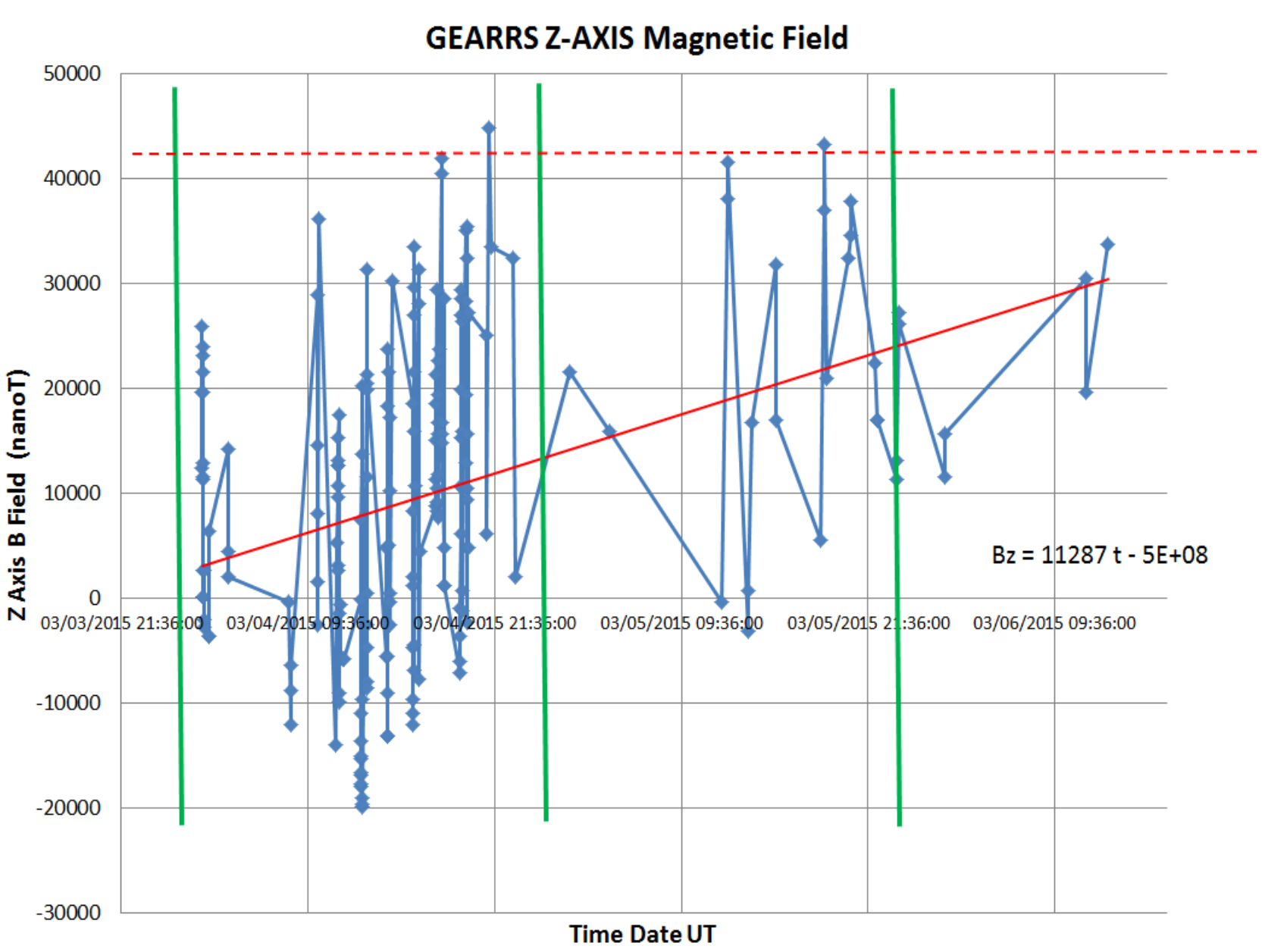
1. GEARRS demonstrated a fast turn, 94 day, development from kickoff to delivery
2. GEARRS completely worked as an integrated system (as designed and tested) with much valuable data in spite of low battery. (All inhibits, EPS, four processors, two EyeStar Globalstar simplex units, one EyeStar Globalstar duplex unit, solar array panel, instruments, flight software, and ground system)
3. For the first time the Globalstar Duplex unit works in space with high-gain active hybrid antenna. It was tested for commanding and data quality with validation of command and backhaul of command on simplex. Valuable data was obtained on Duplex initialization times, CDMA operation, and Gateway handoffs.
4. In one hour, 12 of 19 sequential commands were received and validated (63%) by the duplex unit at low power over all latitudes. Antenna was likely pointed down 30% of time and had 2 min. coning period and rotation. Commanding was validated.
5. First dual EyeStar Globalstar simplex unit in space with dual patch antennas working well.
6. Now three-for-three EyeStar Globalstar units working on orbit

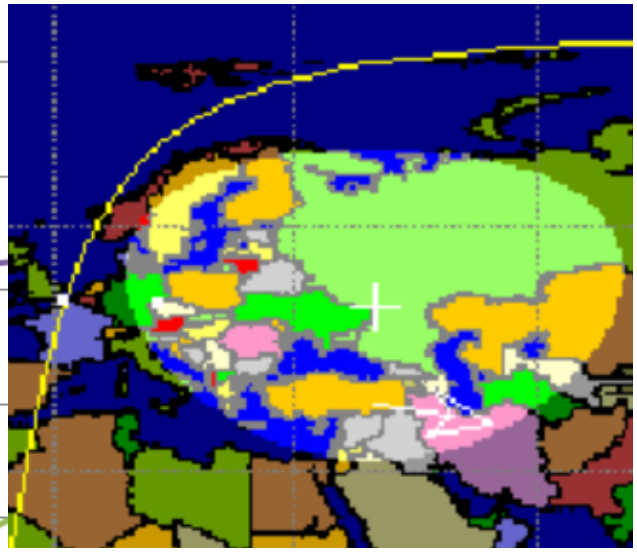
# GEARRS #1 Summary Continue

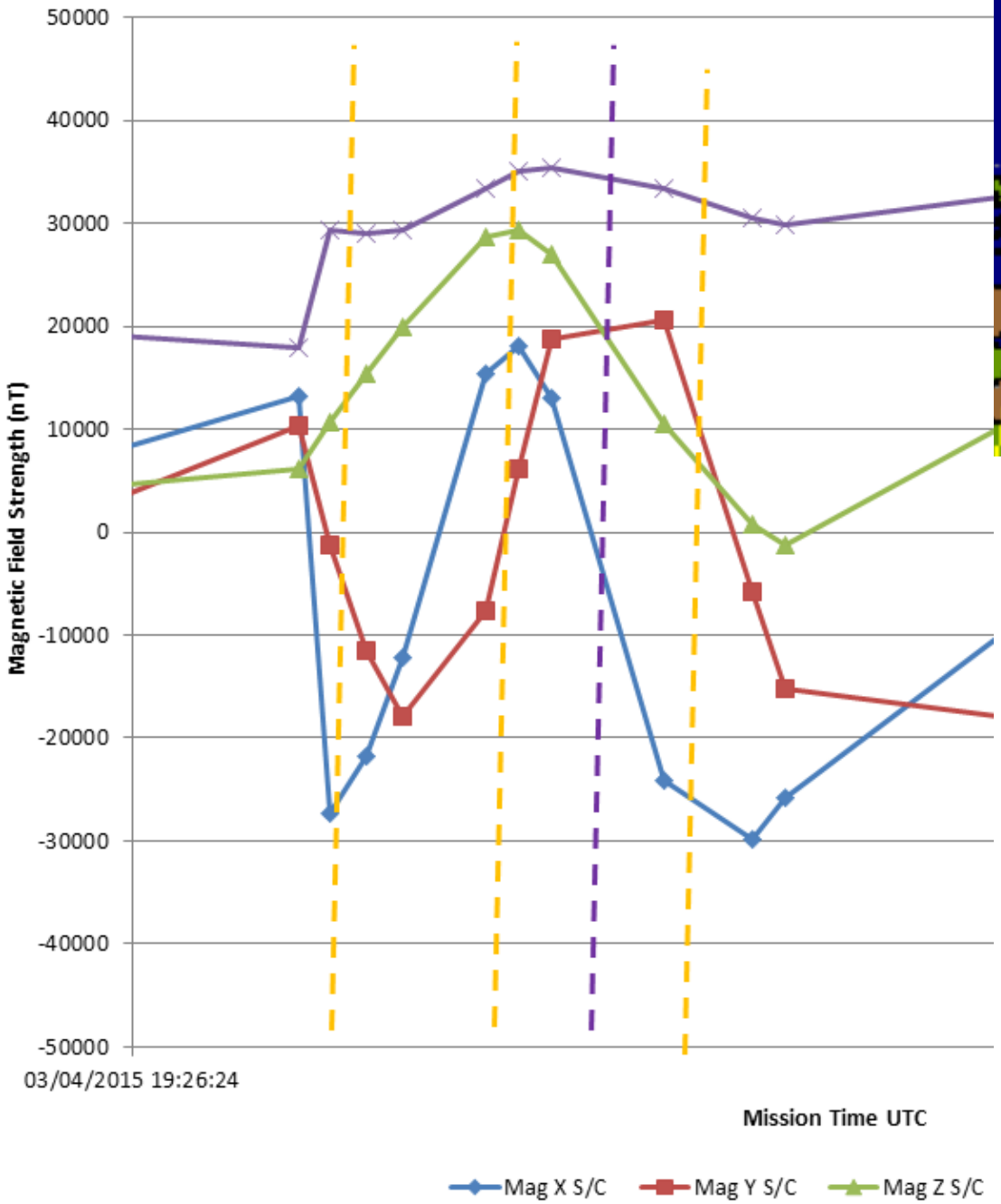
7. CONOPS end-to-end real operations and testing validated
8. Solar Arrays worked and kicked the satellite on in first orbit with its much depleted batteries and continued to add power to the batteries during flight.
9. All flight Beacon, Duplex, and EPS processor hardware and software working and flight tested for Current Missions (Risk Reduction).
10. All data transfer ground segment paths were validated through Satellite-to-satellite, Satellite-to-Gateways, Gateways to NSL servers, MySQL Data storage, Ground software displays, and AFRL near real-time data access.
11. Ground segment and Commanding Script data software tested and working on orbit.
12. Visualization software for GEARRS data was tested and improved (Console).
13. Much more information available for Globalstar duplex costing and understanding more efficient modes of data transfer
14. GEARRS went into low data mode as programmed. All sequences worked as programmed.
15. Indiana's first Commercial satellite
16. Langmuir Probe sensor worked and High gain AC mag field
17. Passive permanent magnetic (0.3 $Am^2$) attitude observed to rotate spacecraft along B field direction in correct direction after release from spacecraft

# GEARS Data Transmissions: Sun and Eclipse




GEARRS Z-AXIS Magnetic Field
50000
40000
30000
20000
10000
0
-10000
-20000
-30000
Z Axis B Field (nanoT)
03/03/2015 21:36:00
03/04/2015 09:36:00
03/04/2015 21:36:00
03/05/2015 09:36:00
03/05/2015 21:36:00
03/06/2015 09:36:00
Time Date UT
Bz = 11287 t - 5E+08



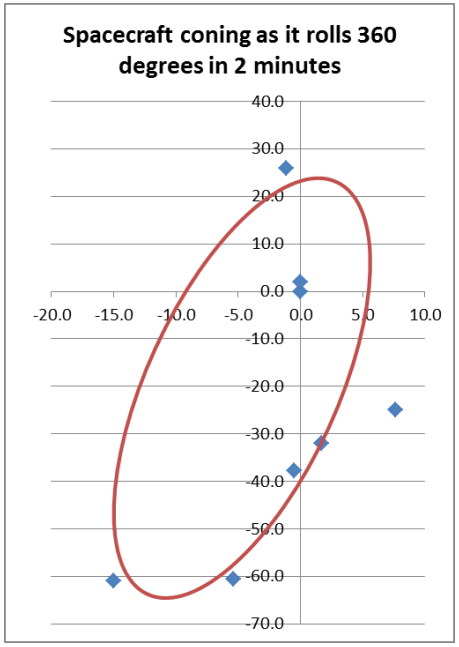

50000
40000
30000
20000
10000
0
-10000
-20000
-30000
-40000
-50000
Magnetic Field Strength (nT)
03/04/2015 19:26:24
Mission Time UTC
Mag X S/C
Mag Y S/C
Mag Z S/C

# 3-Axis Mag

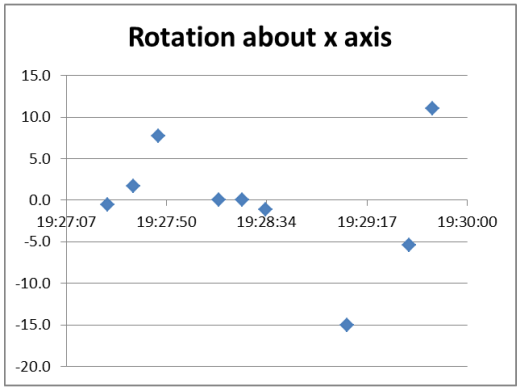
# GEARRS Heading calculations

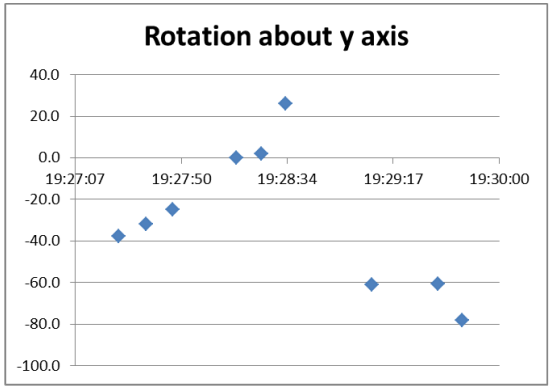
## Magnetometer Data used to calculate GEARRS attitude. Based on Lat/Long of 48N 45E, 410KM altitude

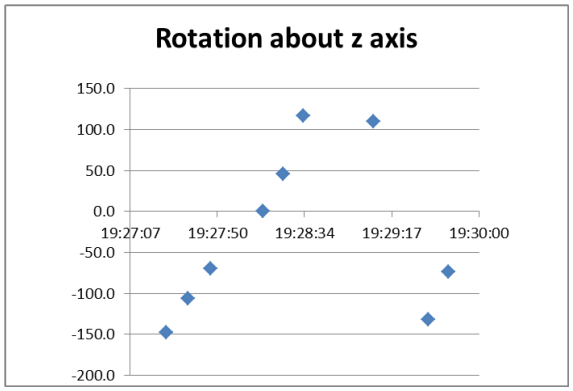
| DT_GatewayReceived | Magnetometer (nT) | | | | | |
|---|---|---|---|---|---|---|
| Time | Mag Z | Mag Y | Mag X | Rotation About X | Rotation About Y | Rotation About Z |
| | | | | | | |
| 7:27:25 PM | 10725.05 | -1273.04 | -27291.8 | -0.5 | -37.7 | -148.0 |
| 7:27:36 PM | 15326.1 | -11519.1 | -21795.4 | 1.7 | -32.0 | -106.0 |
| 7:27:47 PM | 19927.15 | -17824.4 | -12111.4 | 7.7 | -24.9 | -70.0 |
| 7:28:13 PM | 28587.95 | -7578.32 | 15370.23 | 0.0 | 0.0 | 0.0 |
| 7:28:23 PM | 29399.9 | 6083.12 | 17987.53 | 0.0 | 2.0 | 46.0 |
| 7:28:33 PM | 26964.05 | 18693.68 | 13014.66 | -1.1 | 26.0 | 117.0 |
| 7:29:08 PM | 10454.4 | 20532.72 | -24151 | -15.0 | -61.0 | 110.0 |
| 7:29:35 PM | 711 | -5739.28 | -29909.1 | -5.4 | -60.6 | -132.1 |
| 7:29:45 PM | -1183.55 | -15197.2 | -25721.4 | 11.0 | -79.0 | -74.0 |




Satellites is rolling 360 about the Z axis while coning +11 to -15 degrees about X and from +26 to -61 degrees about y.

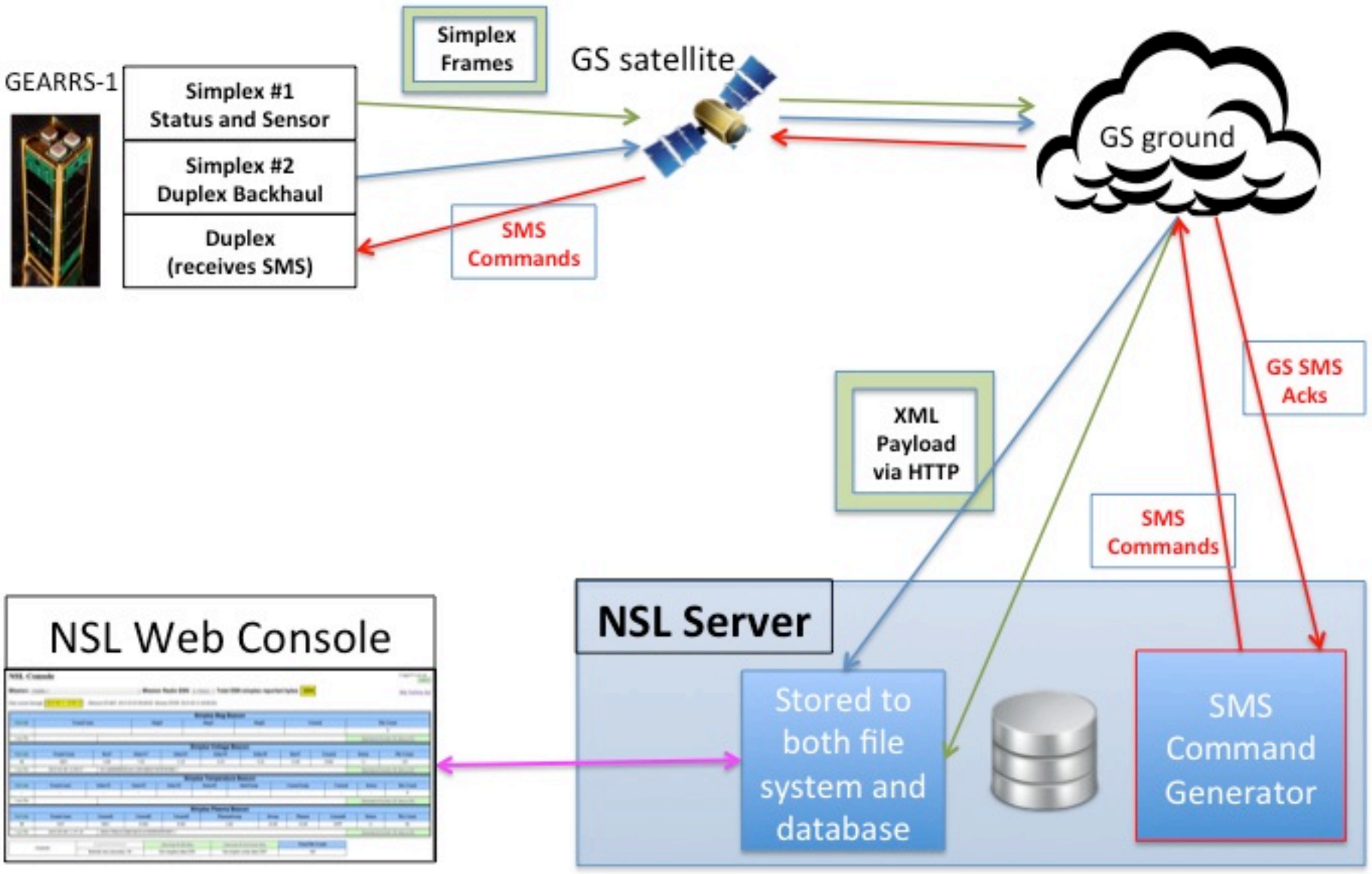


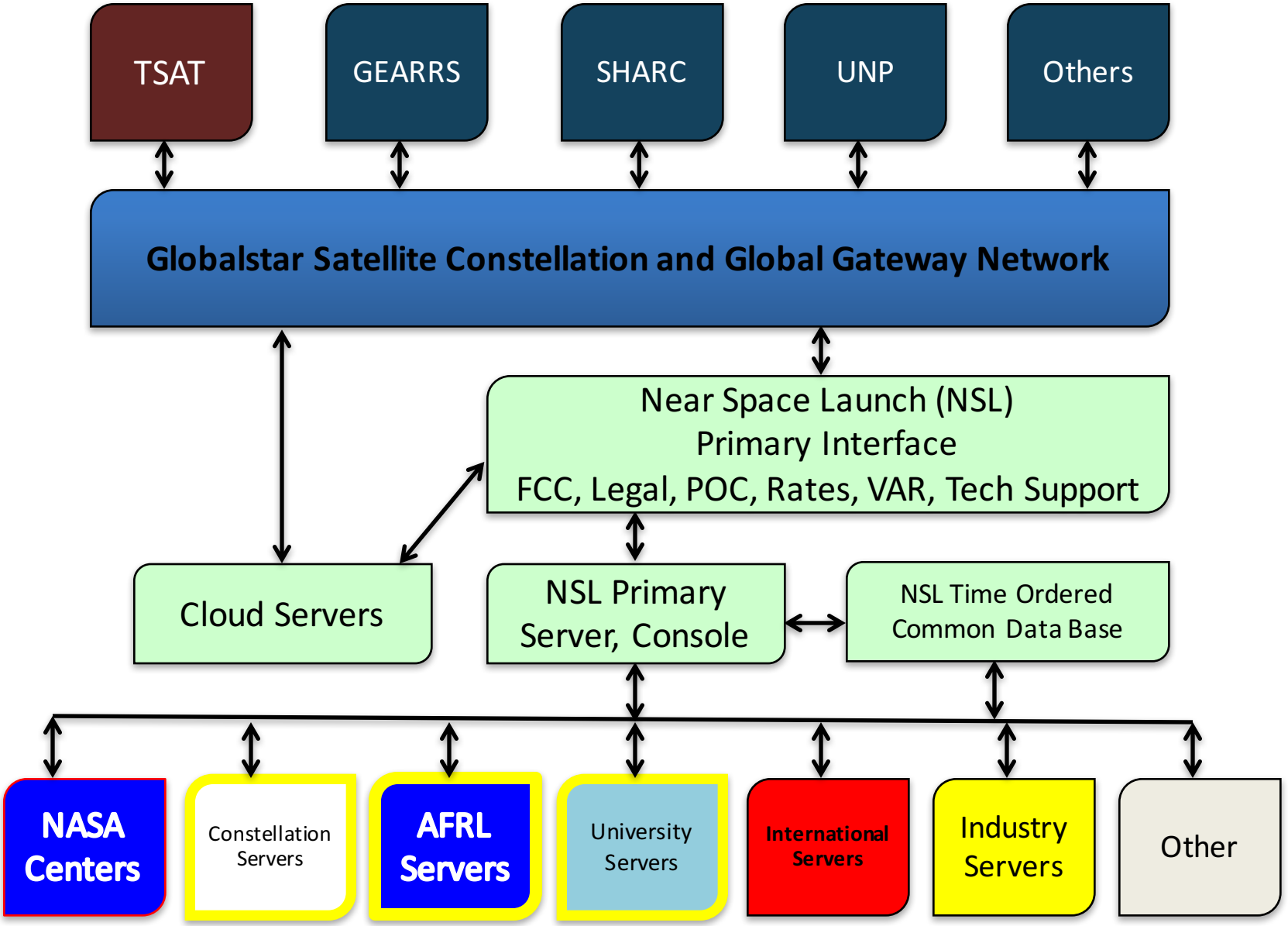




Angles computed using TRIAD algorithm. [Black, H. D. (1964)."A passive system for determining the attitude of a satellite."AIAA J., 2(7), 1350–1351. ]

# GEARRS-1 Data Link Model

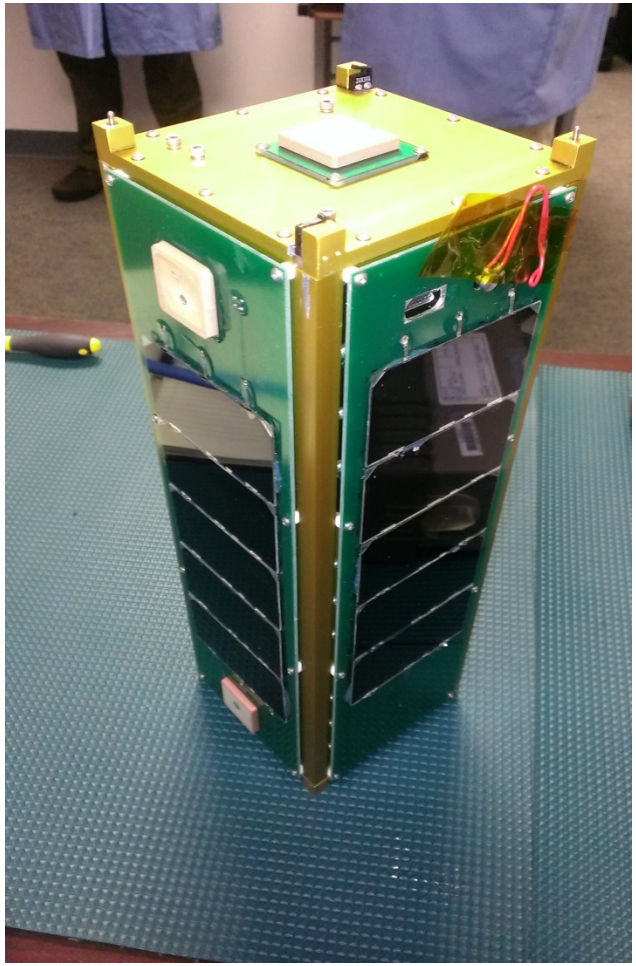


# Satellite-Globalstar-Server Data Network Operational



# GEARRS #2

- 45 Day Turn-around, 20-30 g
- GEARRS at delivery showing a simplex patch antenna on the solar array panel and the plasma probe on the end cap. The second simplex unit is on the down facing end cap, and the duplex antenna is not shown.
- GEARRS #2 to study full end-to-end space and ground segment for G*
- GEARRS #2 study duplex coverage maps, costs, commanding rates/latency, file transfer rates and size, geolocation, much more.

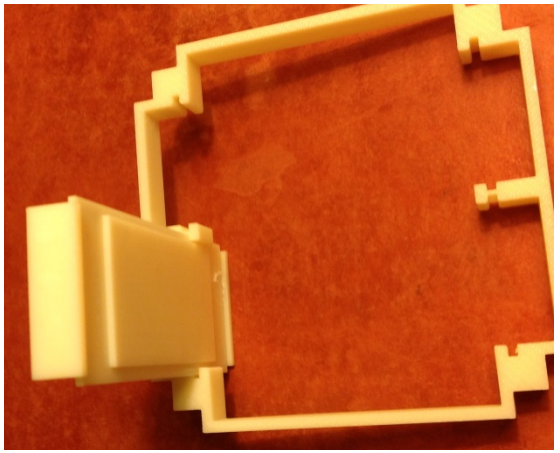


# GEARRS #2

- Launch after May 20, 2015 from Cape Canaveral on Atlas 5
- The planned orbit is 700 by 350 km altitude elliptical orbit at 55 degree inclination. GEARRS #2 includes an ARM processor with Lenox for efficient file transfer and commanding. General data capacity, earth coverage and geo-location features of Globalstar will also be studied.
- Includes some sensors: Magnetometer, Langmuir Probe, and PIN SSD particle detector

# Globalstar in PocketQub

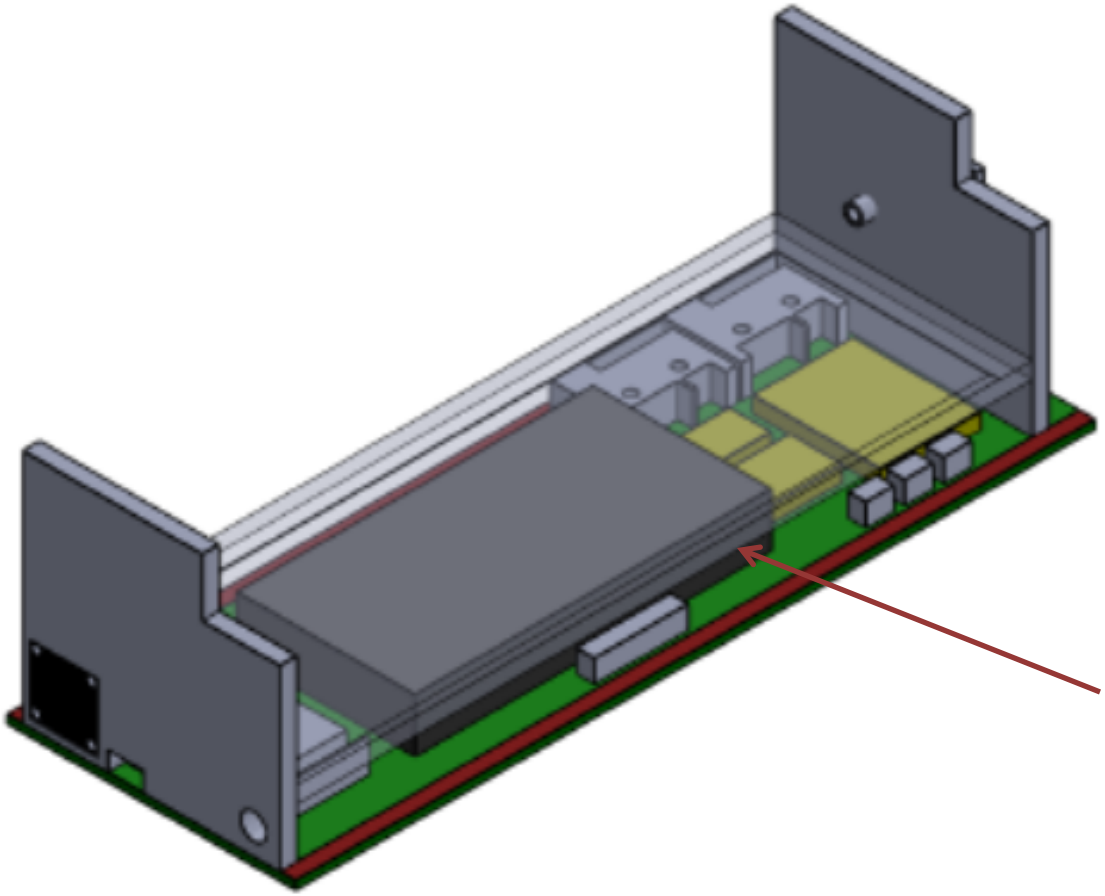
15 cm (6 inch) version



10 cm (4 inch) version

POCKET SAT

Scale 1:1



**Features**

- Globalstar Simplex Comm. and antenna / Coax
- Inhibits
- Solar Array 2 triple junction
- Three PPT and plug for arrays
- EPS Power system
- Li-Poly Battery 2AH, 4V
- Temperature Mux
- Flight Beacon Processor
- Density probe option
- PIN particle detector option

**ALL-IN-One:** 5 x 5 x 15 cm PQ: Footing or Slab ~ 25% of Volume: Combined PCB, Rail Structure, Solar Array, EPS, Comm., Antenna, Processor, Inhibits, Monitors, Sensors, 75% Volumn for Payloads

# Constellations

- Globalstar system Ideal for Constellations of satllites.
- Globalstar has much Capacity and can handle 1000s of Satellites
- Natural Time ordered and unified data base of constellation satellites with no cubesat Ground Stations for basic data.
- EyeStar integrated Globalstar radio links complement high data rate S-Band links
- More info on **www.nearspacelaunch.com**