Operationally Responsive Satellite System CuSat - Nanosat with an Attitude

Presenters: Mr. Greg Shreve, Northrop Grumman Corp.
Mr. Andrew Kwas, Northrop Grumman Corp.
Co author: Mr. Albert Ren, Cornell University

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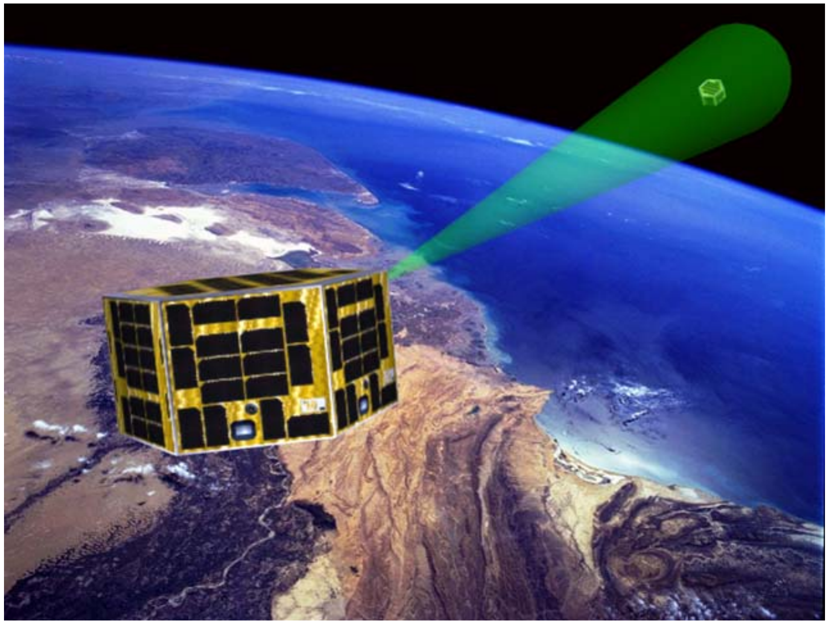
Objectives and Agenda

- **Mission Objectives**
- **Key Attributes**
- **System Overview**
- **GSAW relevance**
- **Mission Details**
  - *CDGPS, Inspection details, etc.*
- **Ground Segment specifics**
- **Upcoming Launch Opportunity**
  - *Details of Falcon 1, when, where, orbit, pass times, etc*
- **CUsat meets ORS needs**
- **Summary**

Mission Objectives



CUSat demonstrates an end-to-end autonomous on orbit inspection system. Centimeter-level accurate Carrier-phase Differential GPS (CDGPS) enables CUSat to navigate and use its cameras to gather target-satellite imagery. In the Ground Segment, image-processing techniques verify the CDGPS relative distance and orientation estimates and provide a 3D model of the target satellite for the user.

Key Attributes

Demonstrate that on orbit Carrier-phase Differential GPS can support inspection operations.

- *Objective Motivation:* CDGPS makes centimeter-accurate relative position determination possible. This technology enables:
  - Close-proximity navigation for specific uses in
  - On orbit inspection
  - On orbit construction
- A common solution for a wide variety of orbits and mission architectures.
- Increase TRL of CDGPS real-time calculations in space
- A modularized architecture for absolute and relative positioning that can be easily integrated into a wide variety of missions.

Key Attributes

Demonstrate an end-to-end autonomous on orbit visual inspection system.

- *Objective Motivation:* CUSat is an end-to-end system that autonomously inspects objects on orbit and transmits, processes, and formats this inspection data. This system has the following benefits:
  - In-space surface failure detection and diagnosis
  - Monitoring target system health and operations
  - Increases the TRL of GPS-based inspection/navigation systems through actual flight demonstration

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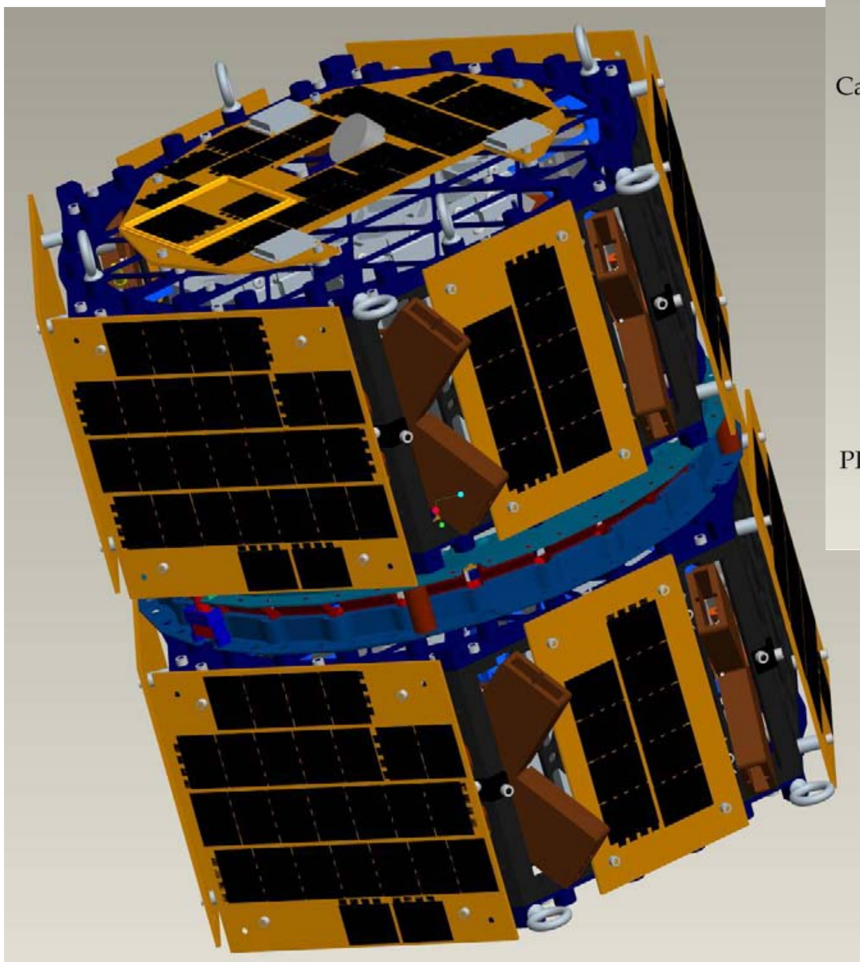
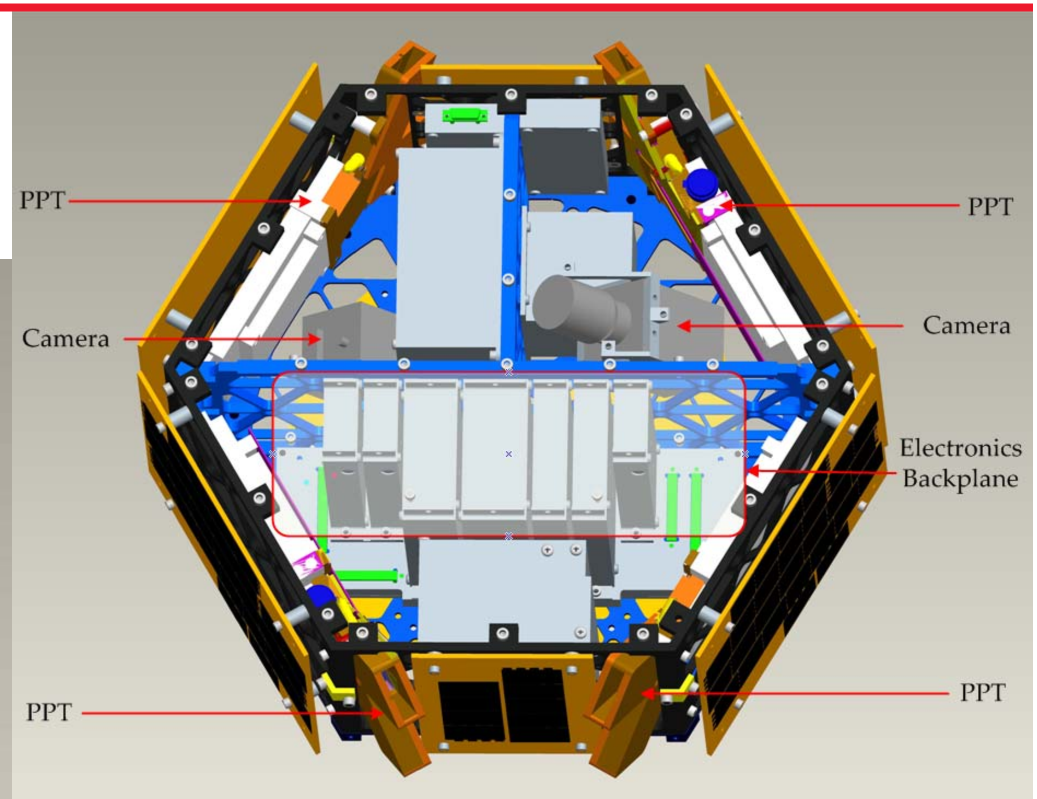
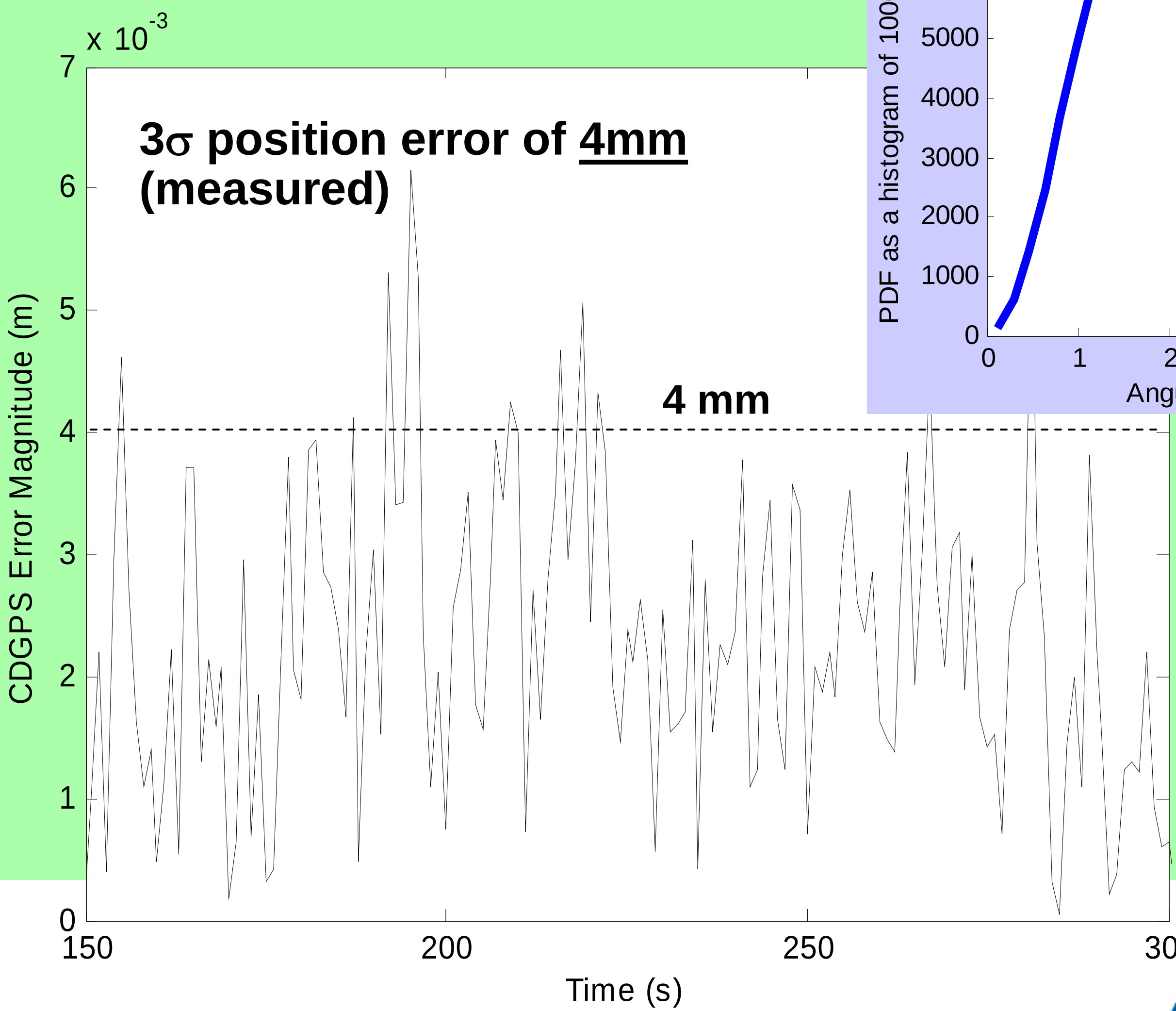
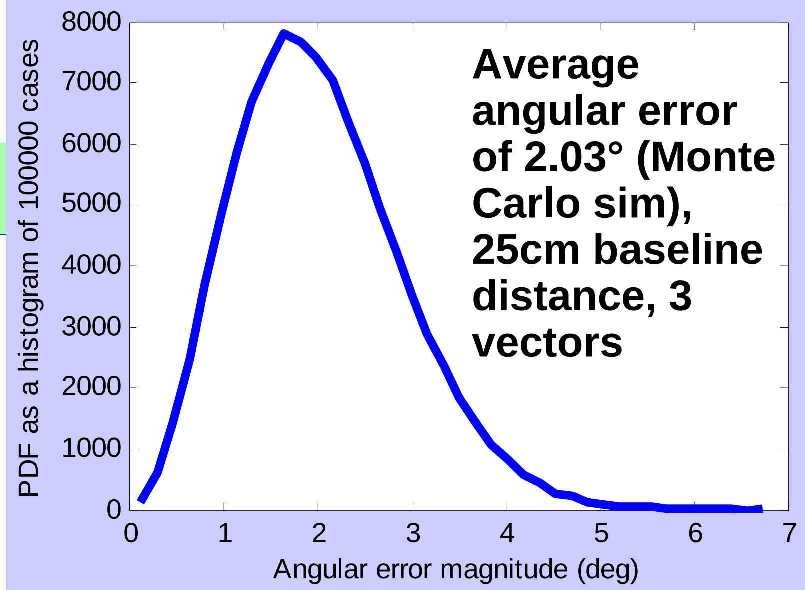
System Overview

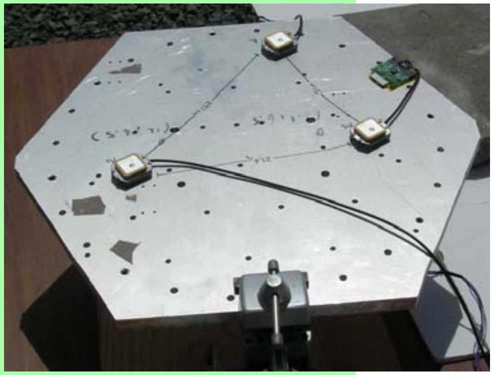




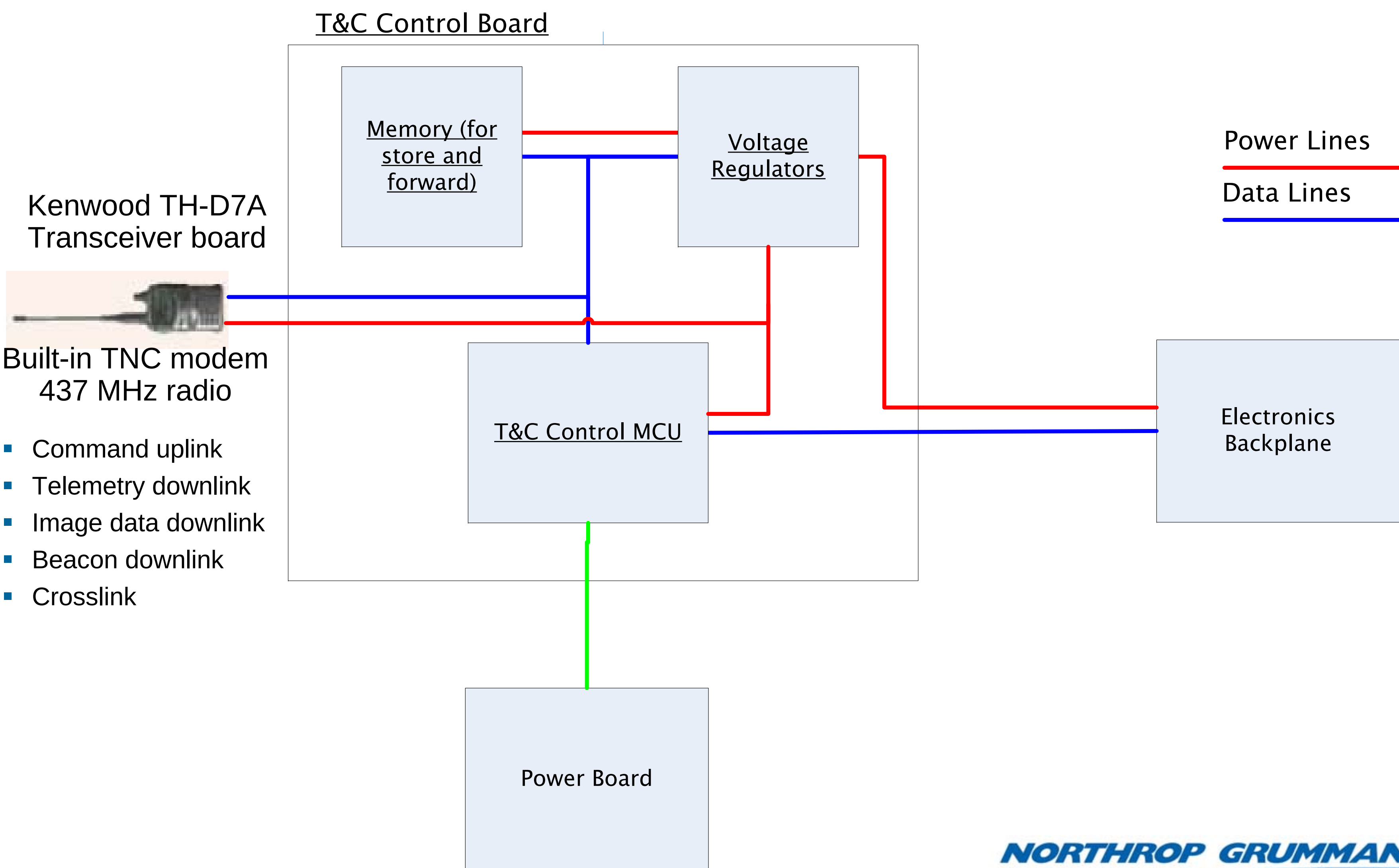
CDGPS Performance







CUSat Spacecraft Communication Hardware



- Command uplink
- Telemetry downlink
- Image data downlink
- Beacon downlink
- Crosslink

GSAW focus areas addressed

- Net-centric and service-oriented architectures
- Frameworks and infrastructure
- Space and ground communication architectures
- Off-the-shelf and open-source components and software reuse
- Operations and sustainment
- Autonomy and automation

CUSat Ground Segment

- **CONOPS and Mission Operation**
- **Components**
  - Space Communications HW
  - Ground Communications HW
- **Architecture & Dataflow View**
- **Control & Data Processing Software**
- **Ground Data Products**

CONOPS and Mission Operation

- **Mission Management Center (MMC) at Cornell**
- **Mission Management software: InControl**
  - Provided by L-3 West Telemetry
- **MMC interfaces with remote ground stations via VPN over Internet**
- **LEO satellite provides several ~10 minute pass opportunities per day over ground stations**
  - Ground stations are placed to maximize pass opportunities
- **Digital communications via UHF packet radio**
  - Commands are uplinked to schedule or initiate next inspection sequence or other spacecraft operations
  - Beacons, telemetry and image data and are stored and downlinked on schedule

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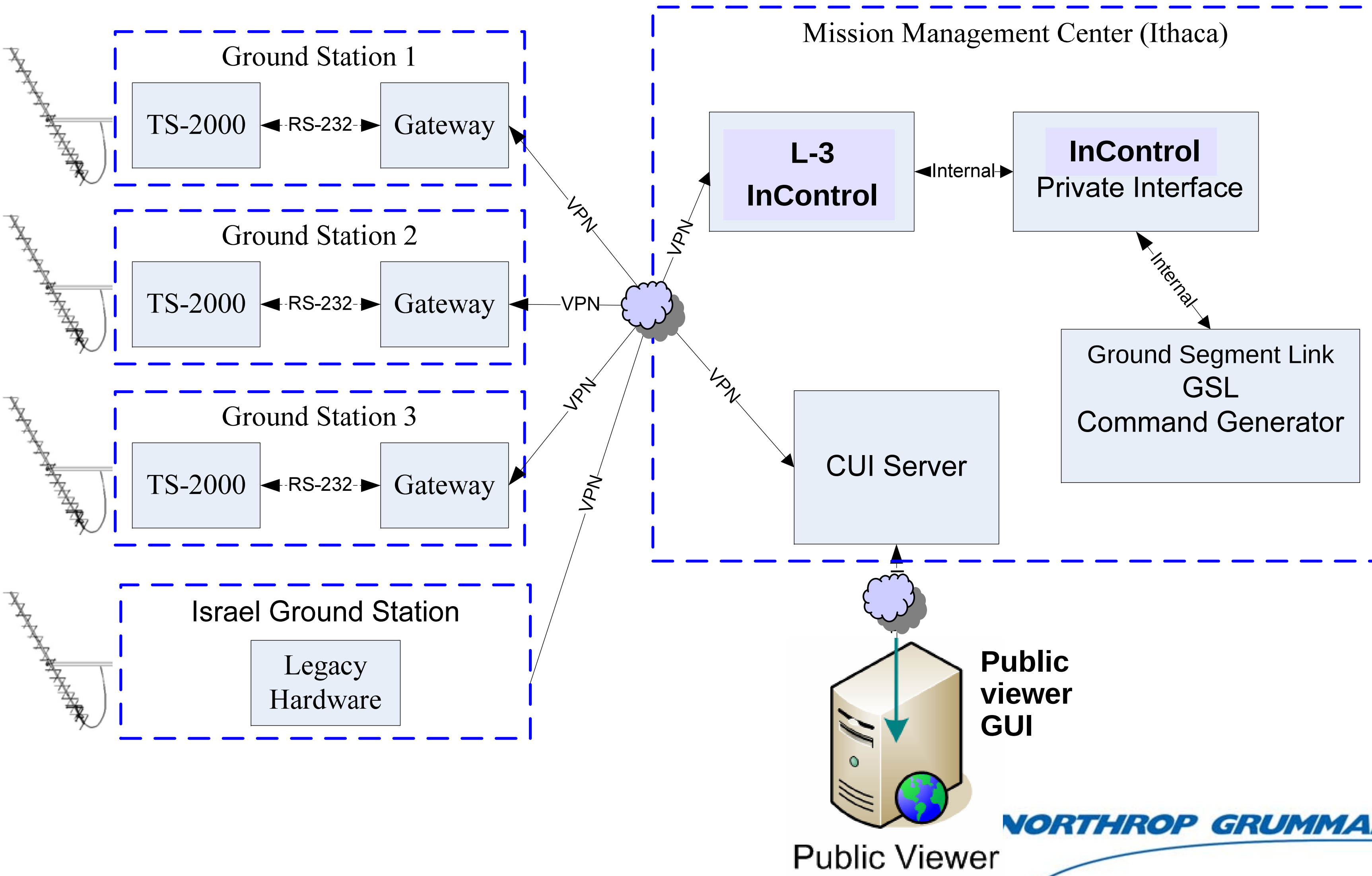
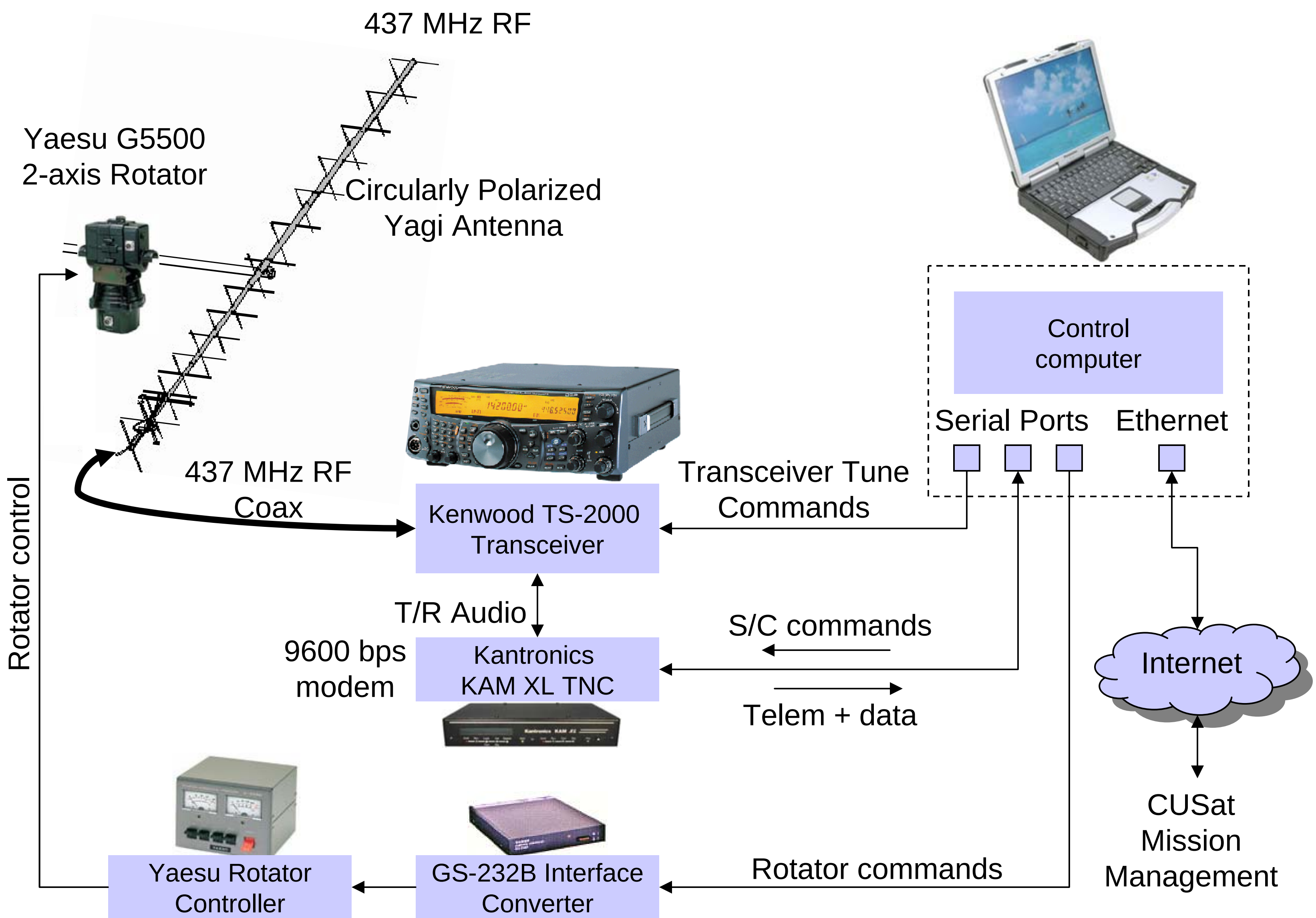
Ground Segment Software Architecture

Multiple Ground Stations are supported by the server software

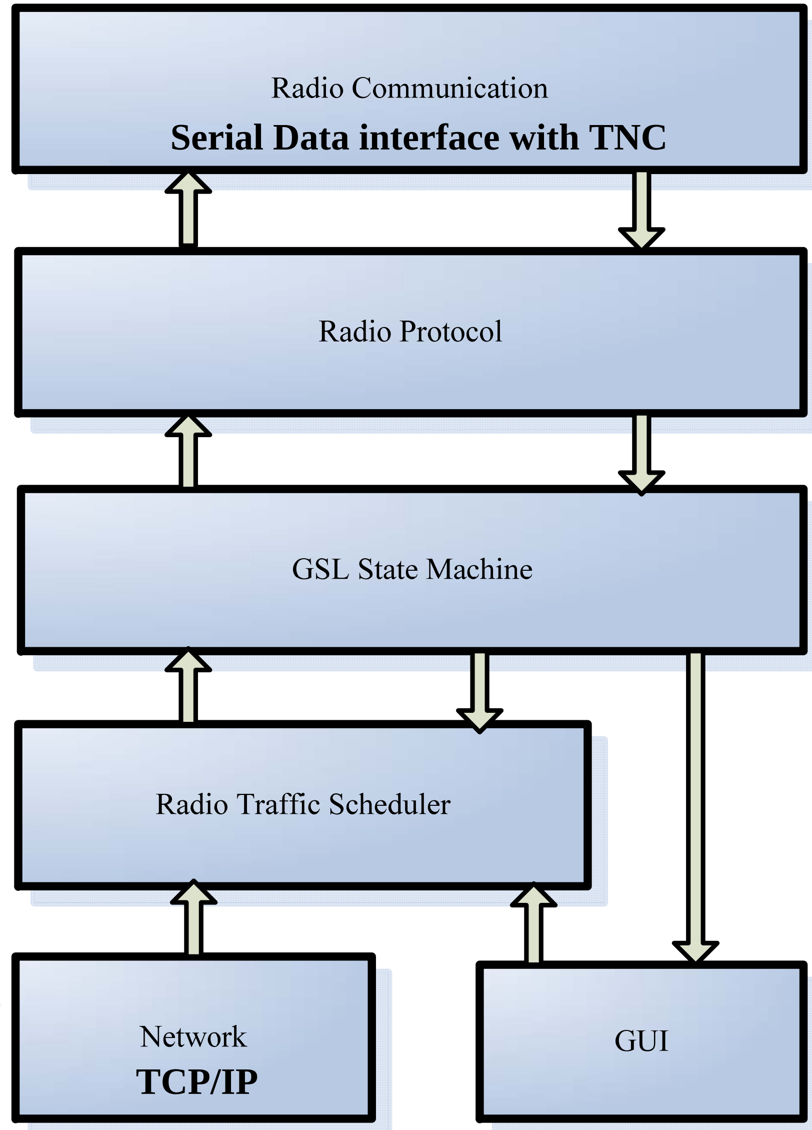


CUSat Ground Station Hardware Diagram



Gateway Software in Ground Station

- Each Ground Station has Gateway copy
- The Gateway receives commands from MMC via Internet
- The Ground Segment Link (GSL) State Machine provides intelligence at the ground that responds to spacecraft modes
- Radio Traffic Scheduler works with GSL State Machine to manage traffic to and from the spacecraft



To Mission Management Center

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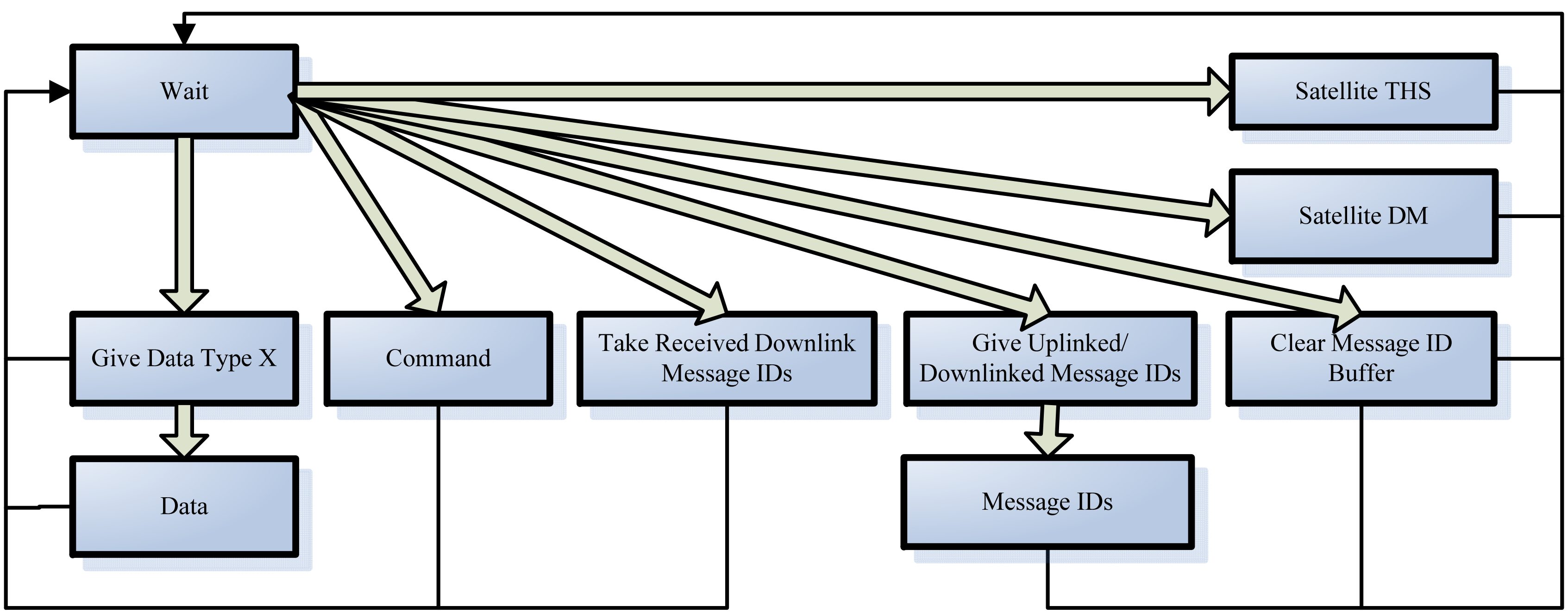
Ground Segment Link State Machine

- High level logic for controlling interaction with the satellites
- Interacts with spacecraft states to ensure proper operation and response to contingencies



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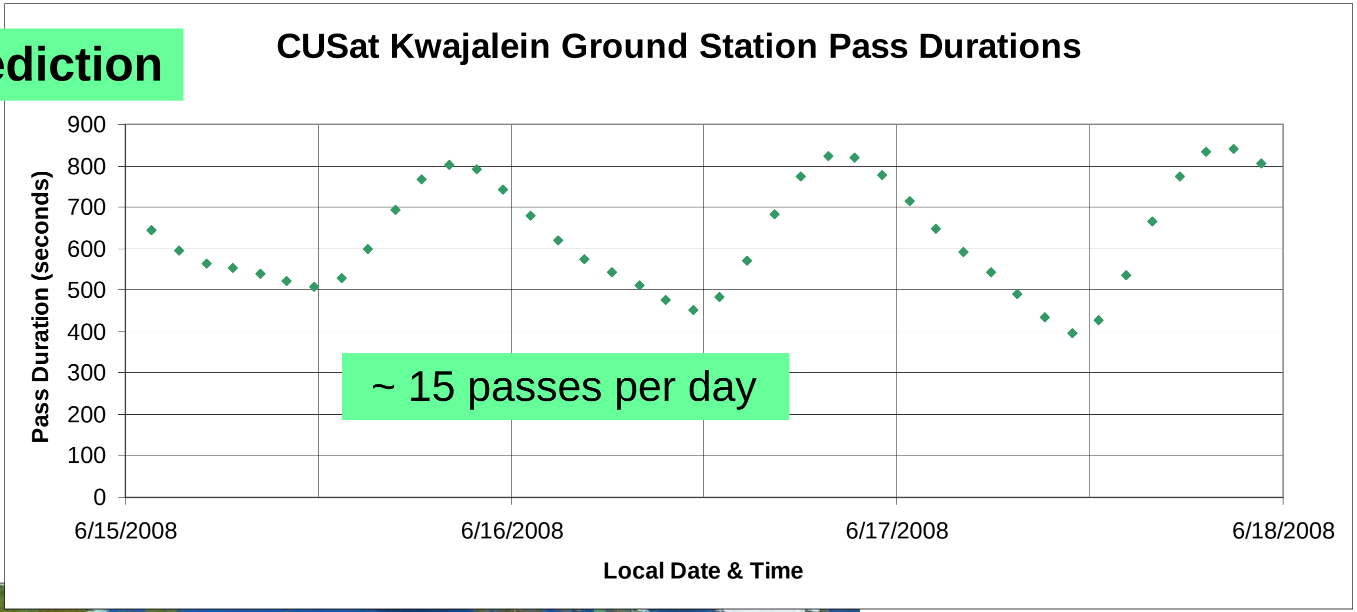
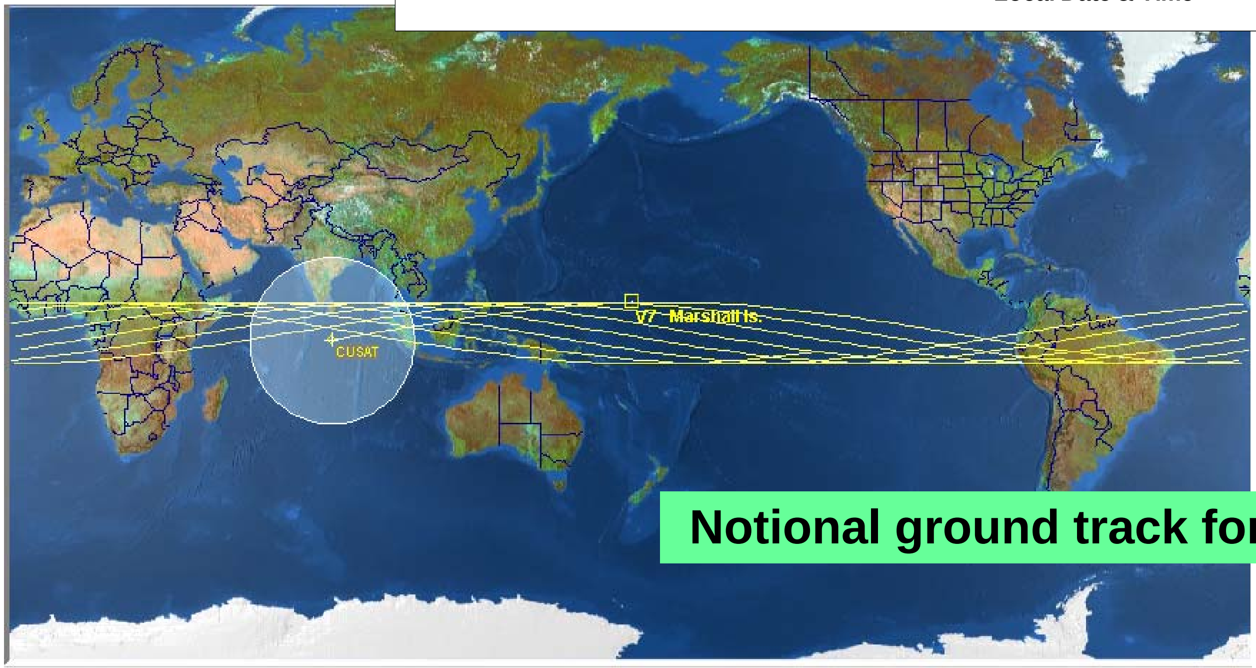
Communications Datalink Scheduling

- **CUSat rides on available launch opportunity**
- **Original expectation was polar orbit or other high inclination**
  - Ground station plan included 3 CONUS sites plus existing station in Israel
  - Provided 4 to 6 pass opportunities per day
- **Recent change – new launch opportunity is Space-X Falcon 1, Flight 3**
  - 330 x 685km 9 degree orbital inclination
  - Requires equatorial Ground Stations
  - The good news is that one Ground station catches as many as 15 pass opportunities per day

9° Equatorial Orbit Pass Opportunities

STK Prediction





Notional ground track for 9° inclination

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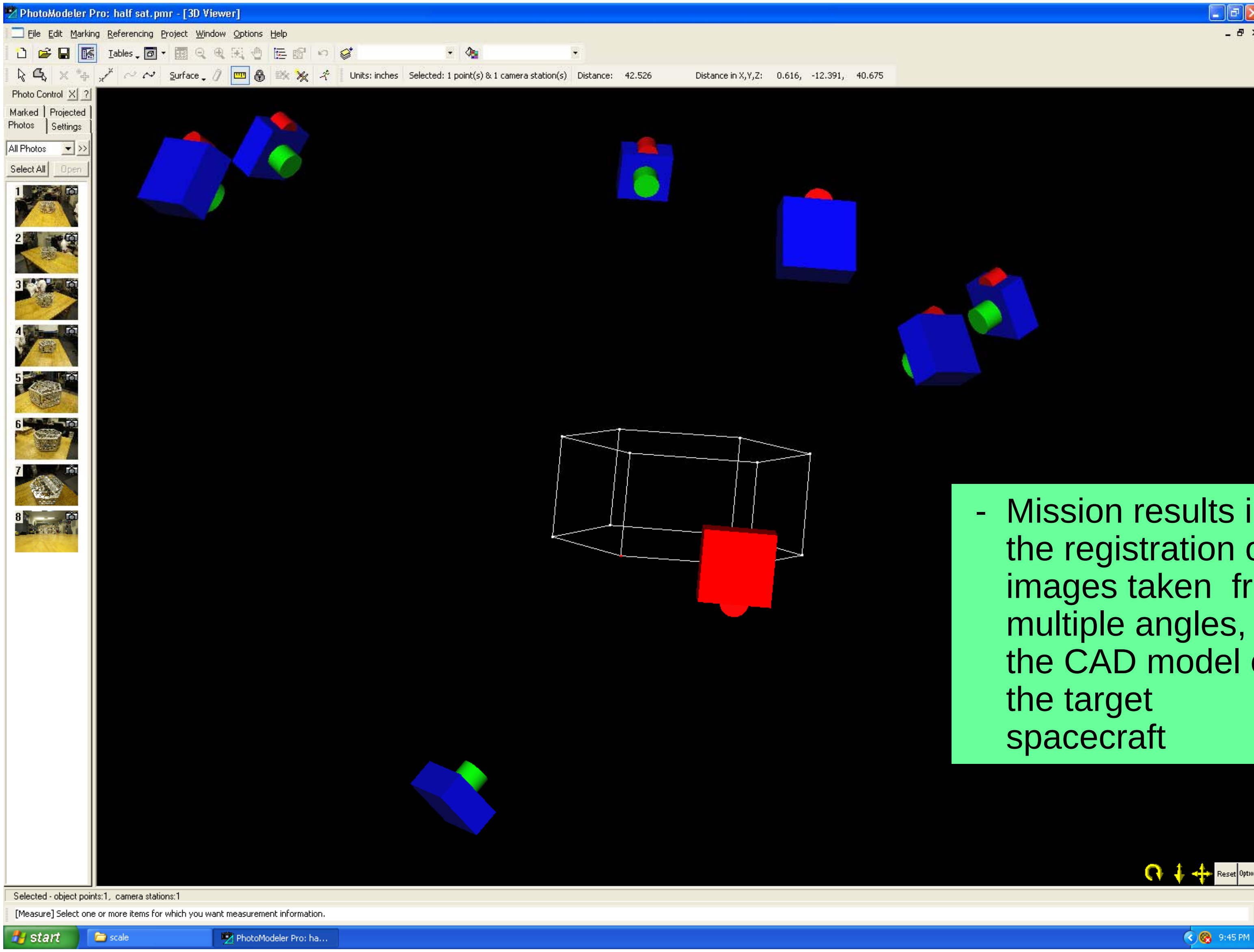
Ground Data Products

- **Most satellite passes are beacons or command / telemetry opportunities**
  - Data is not downlinked on every pass because satellite TX duty cycle is limited by solar power budget
- **Each satellite pass that is dedicated to downlinking of stored image data can yield between 200k to 400K bytes of data**
  - 9600 bit/second physical layer TNC modulation rate
  - 400 to 800 seconds per pass

Ground-based 3D Reconstruction and Distance Verification



- Mission results in the registration of images taken from multiple angles, to the CAD model of the target spacecraft

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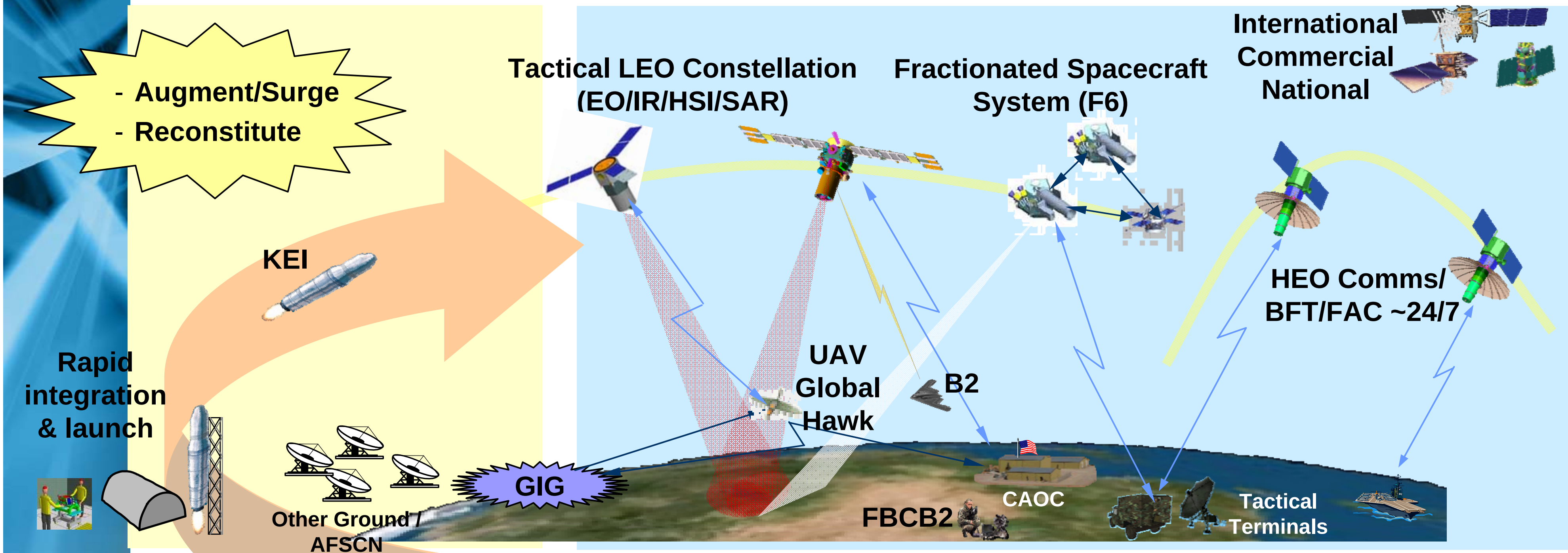
Space systems integrated into a common infrastructure for ORS



Operationally Responsive Space Tier Approach

Tier 1	Tier 2	Tier 3
Employ it • On demand with existing assets • Minutes to hours	**Launch/Deploy it** • On call with ready to field assets • Days to weeks	**Develop it** • Rapid transition from dev to field of new/mod capabilities • Months

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CuSat meets most of the ORS Near term objectives

Responsive Range and Launch

- Minimize Call-up to Launch ☺
- Increase Automation ☺
- Assess Commonality and Standardization ☺
- Improve Specific Range Operations ☺
- Structural Loads Analysis Risk Reduction ☹

Responsive Buses and Payloads

- Modular Payload Architecture and standards ☺
- Modular RF and EO Payload Technology Development ☺
- Rapid Assembly, Test and Integration Concepts for rapid call up to launch ☺

Multi mission modular spacecraft

- Common core of optical payload and bus elements ☺
- Rapidly replaceable/modifiable elements ☺
- Base on non-proprietary industry standards ☺

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Examples of CuSat ORS Utility Features

Demonstrates ORS Tier 3 objective

- **ATP to flight in 3 years. Virtually all of subsystem assembly and system integration was demonstrated on prototype hardware 2 years after ATP.**

Demonstrates ORS Tier 2 Assembly, Integration, and Test

- **Integration of the complete system starting from discrete configuration end-items takes 2 weeks.**
- **The integration of assembled subsystems into a complete system, ready for environmental test, requires less than 48 hours**

Enhanced Automation

- **Operators make key decisions, e.g. providing a go-ahead for spacecraft-to-spacecraft separation and permitting the first entry into normal mode. Decisions about charging and ground contact can be left to the flight computer.**
- **Operator tasks can be simplified to the point where a warfighter need only click on an icon representing an image to be downloaded from the flight computer.**

Examples of CuSat ORS Utility Features

Carrier phased Differential GPS as an enabler technology

- **First demonstration of CDGPS for simultaneous attitude and relative navigation for satellites and closed-loop formation flight and inspection of another spacecraft.**
- **6 DOF CDGPS works in any LEO orbit and in any attitude, making it readily implemented on any satellite with 6DOF relative-navigation requirements.**

Other Enabling s/c Technologies

- **Modular electronic design**
- **SOA pulsed plasma thrusters**
- **6DOF relnav sensors exploit the attitude- and orbit-independent performance of CDGPS for continuous, gyroless attitude and position knowledge.**
- **Self contained miniature reaction wheels developed by Intellitech Microsystems Inc. via DARPA.**

Space Situational Awareness to the warfighter with a direct means to observe a cooperative target spacecraft.

- **CUSat's imagery of the target satellite is stored on board until the ground requests a download. The user in the field makes the ultimate decision about the data of interest to him.**

Examples of CuSat ORS Utility Features

Responsive CONOPS

- **Combination of COTS flight hardware and ground-station equipment provides the capability to set up ground stations within weeks and to run operations from anywhere with an appropriate internet connection.**

CUSat inoperable until needed

- **Launched with zero state of charge in its batteries. Wake up after sufficient exposure to the sun but to begin operations only after positive confirmation of separation.**

Launch-Vehicle Independent Design

- **No volatile materials in its construction, no pressurized containers, no umbilicals. Uses standard TT&C subsystems and ground segment h/w.**

Low Cost

- **The combined cost of the space, ground, and operations segments is less than $1M.**
- **Off the shelf components are used where possible, e.g. the CDGPS susbsystem components, the Adimec 2000 cameras, and the lightband separation system.**
- **The low cost, size and mass of the system allows the end user the luxury of deploying several CuSats for a mission, thereby accepting the potential of a single unit failure without compromising the overall mission success.**

Summary

- CuSats ORS enabling technologies will demonstrate the key features of interest in the GSAW focus for 2008
- CDGPS and simple ground system architectures can produce an inexpensive but high pay off concept that compliments "Big Space" systems.
- Flight demonstration on a Falcon 1 SpaceX mission this June will be a major step forward for smallsat/nanosat future.