NRL Radio Beacon and Radar Calibration Instruments for Small Satellites

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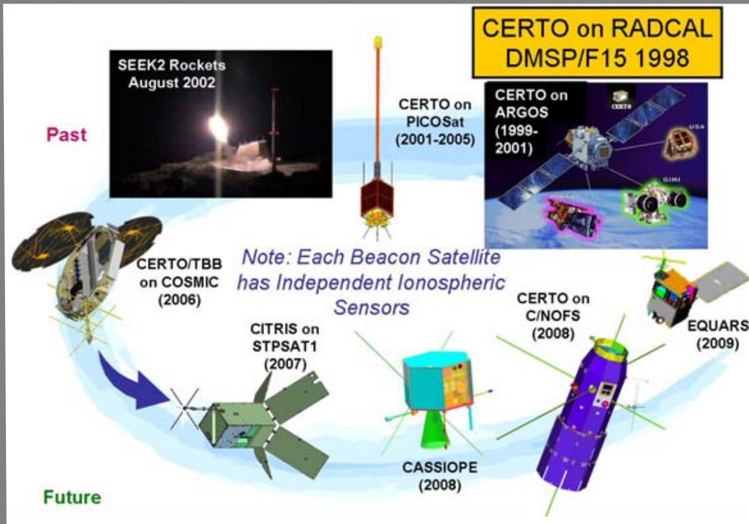
NRL Small Satellite Instruments

- Coherent Electromagnetic Radio Tomography (CERTO) Beacon
- Computerized Ionospheric Tomography Receiver in Space (CITRIS) Receiver
- Precision Expandable Radar Calibration Sphere (PERCS)

Coherent Electromagnetic Radio Tomography (CERTO)



PAST

NRL Radio CERTO Beacon Censors on LEO Sats.

Future

OPERATIONAL CAPABILITY ADDRESSED

- Provide Global Measurements Ionospheric Data to the Ionospheric Modelers
  - Total Electron Content with 0.05 TECU Resolution
  - Radio Scintillations at VHF, UHF, and L-Band
- Demonstrate Utility of the Multi-Band Receiver in Space for Updating Space Weather Models

TECHNICAL APPROACH and OBJECTIVES

- NRL Construct a Multi-Band Beacon for Operation in Low Earth Orbit
  - Transmit VHF/UHF/L-Band EM Waves to Ground from CERTO Receivers
  - Transmit VHF, UHF, and L-Band Transmissions to CITRIS Space-Based Receiver
- NRL Develop Software to Provide Ionospheric Data Products from CERTO Data
  - TEC and Reconstructed Ionospheric Densities
  - Radio Scintillation Indices
- Demonstrate Utility of Ionospheric Data Acquisition over Remote Areas
- Validate Space Based Measurements with Other Sensors

Mission Profile

- COSMIC Launched on Minotaur 14 April 2006
- CERTO Antennas Deployed on Nadir Face of COSMIC Satellites, 16 April 2006
- Start TBB/CERTO Data Collection,18 April 2006
  - Pacific Chain Deployed by Taiwan
  - Alaska, Puerto Rico and RADCAL Sites by USA
- Scheduled Operations with Arecibo and Jicamarca Incoherent Scatter Radar Sites
- Schedule Operations with NRL/CITRIS Receiver on STPSAT1

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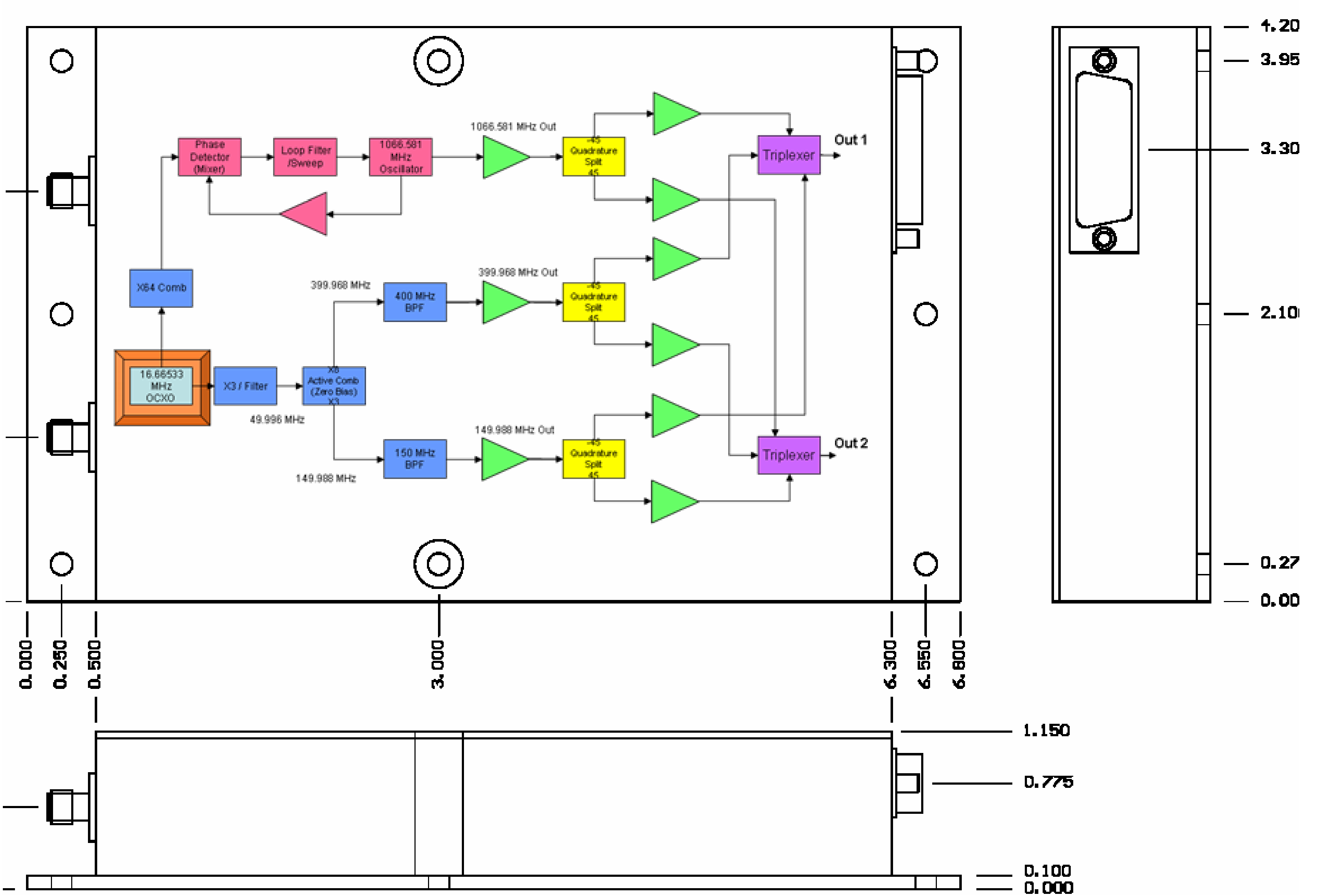
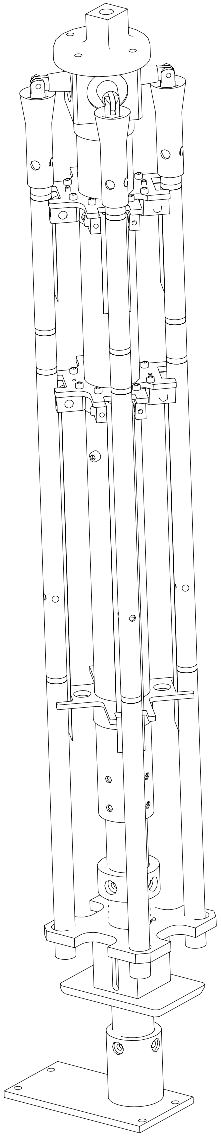
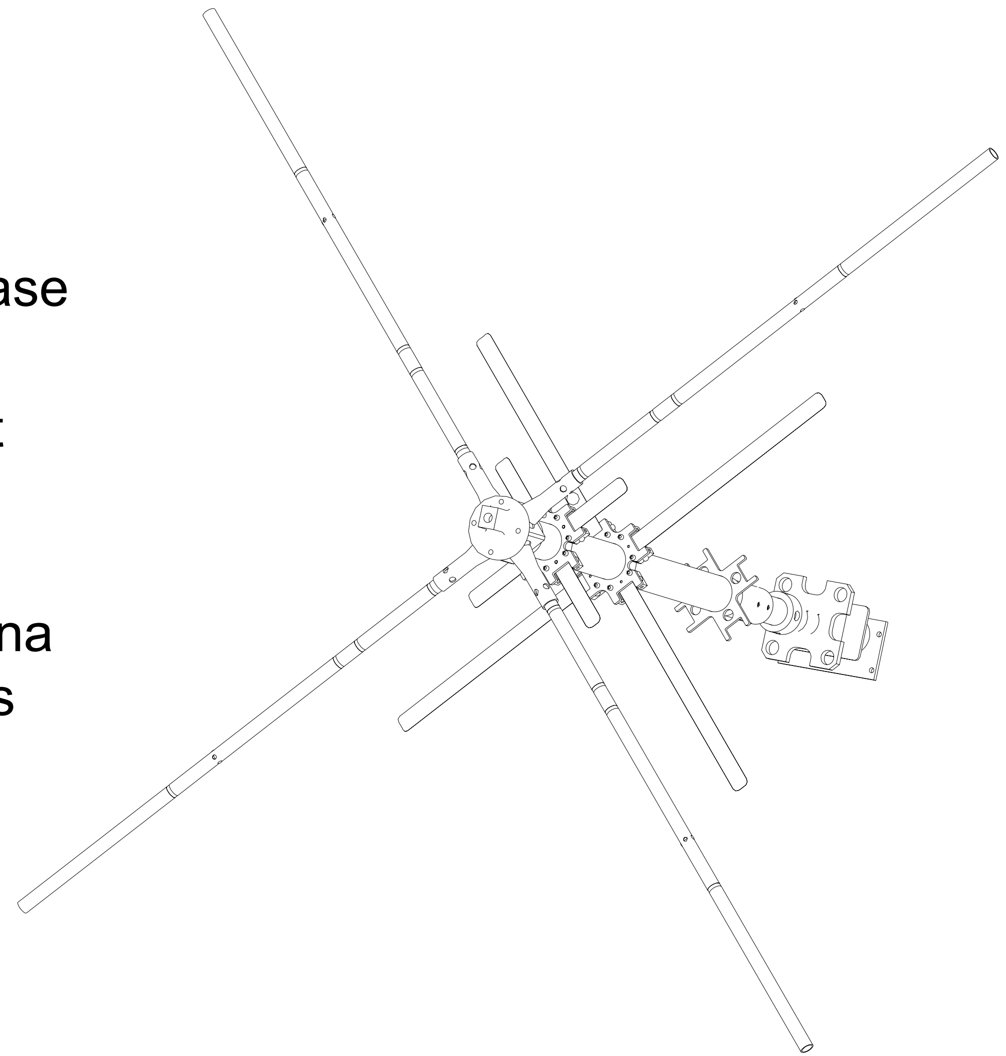
CERTO Beacon Mechanical Layout and Block Diagram



Design for CERTO Antenna on COSMIC, CASSIOPE and C/NOFS



- Pin-Puller Deployment
- Sleeve to Release Elements.
- Spring Hinge at Base
- Reflectors to Increase Antenna Gain Along Axis



CERTO System Mass and Power

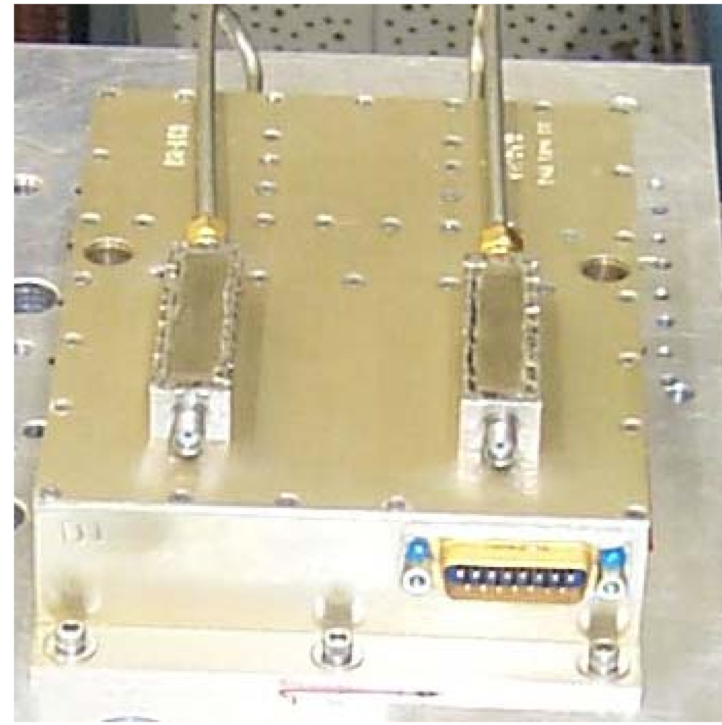
New CERTO	Mass
Beacon	0.807 kg
Low Pass Filter	0.0117 kg
Low Pass Filter	0.0117 kg
---	0 kg
Beacon to Filter Cables	0.064 kg for two
Antenna	~ 0.850 kg
--	1.7444 kg

Power Parameter	New CERTO Beacon
Standby Before Warm-up	5.60 Watts
Standby After Warm-up (AW)	2.23 Watts
150/400 MHz (VHF/UHF On, AW)	8.82 Watts
150/400/1067 MHz (All-On, AW)	16.73 Watts
150 MHz Output	30 dBm
400 MHz Output	30.5 dBm
1067 MHz Output	33.0 dBm

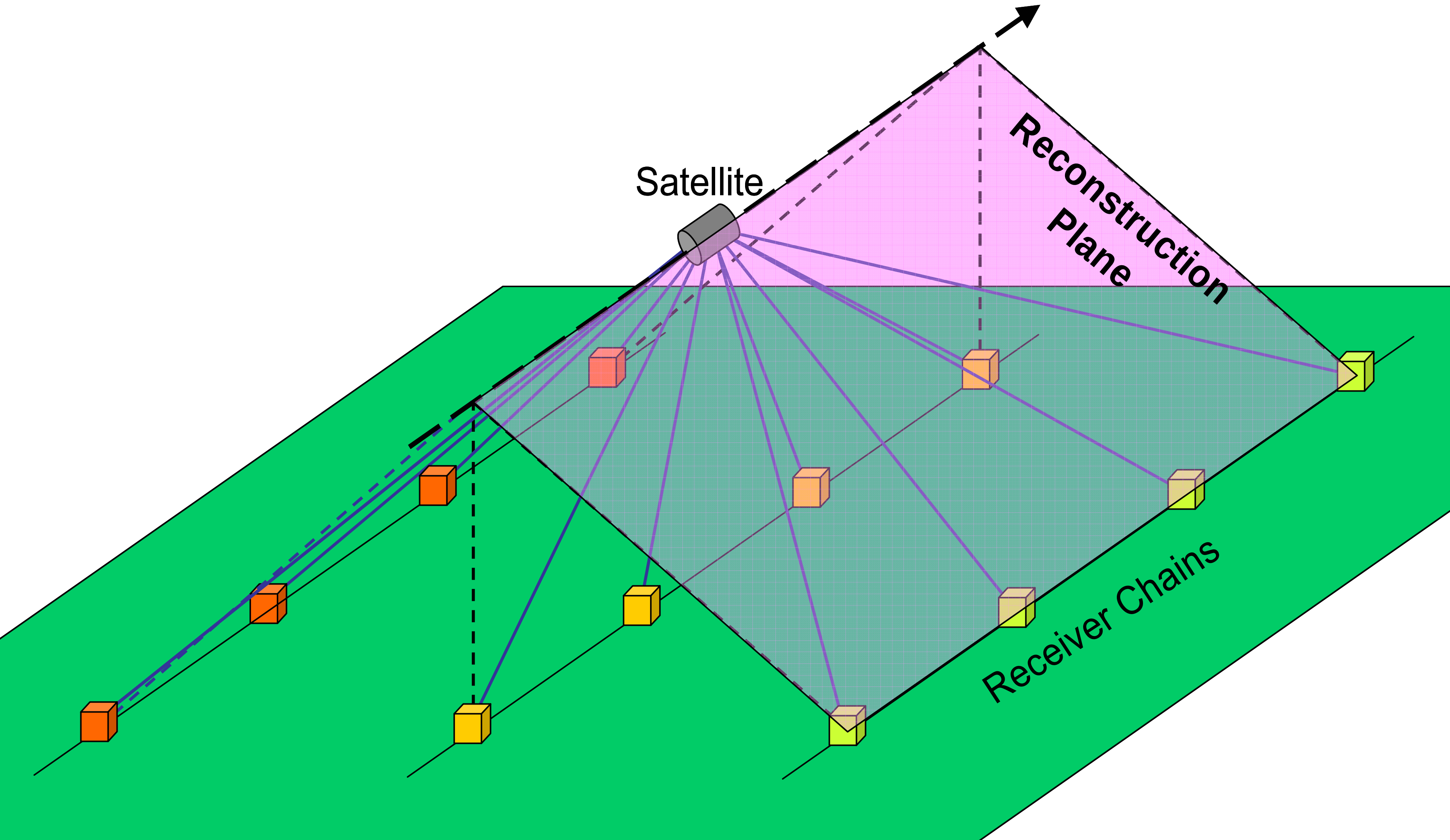
Quantitative Performance of CERTO

Instrument Performance

- Overall System Performance
  - 150 MHz
    - Radiated Antenna Gain = 5.0 dB
    - Absolute Phase Accuracy 6 Degree
  - 400 MHz
    - Radiated Antenna Gain = 4.4 dB
    - Absolute Phase Accuracy 6 Degree
  - 1067 MHz
    - Radiated Antenna Gain = 3.6 dB
    - Absolute Phase Accuracy 6 Degree
- Scintillation Measurements
  - Worst Case S_4 Accuracy 0.1
  - Worst Case σ_ϕ Uncertainty 6°
- TEC Measurements
  - Absolute TEC Ambiguity Resolution 10^{15} m^{-3}
  - Relative TEC Accuracy 10^{13} m^{-3}

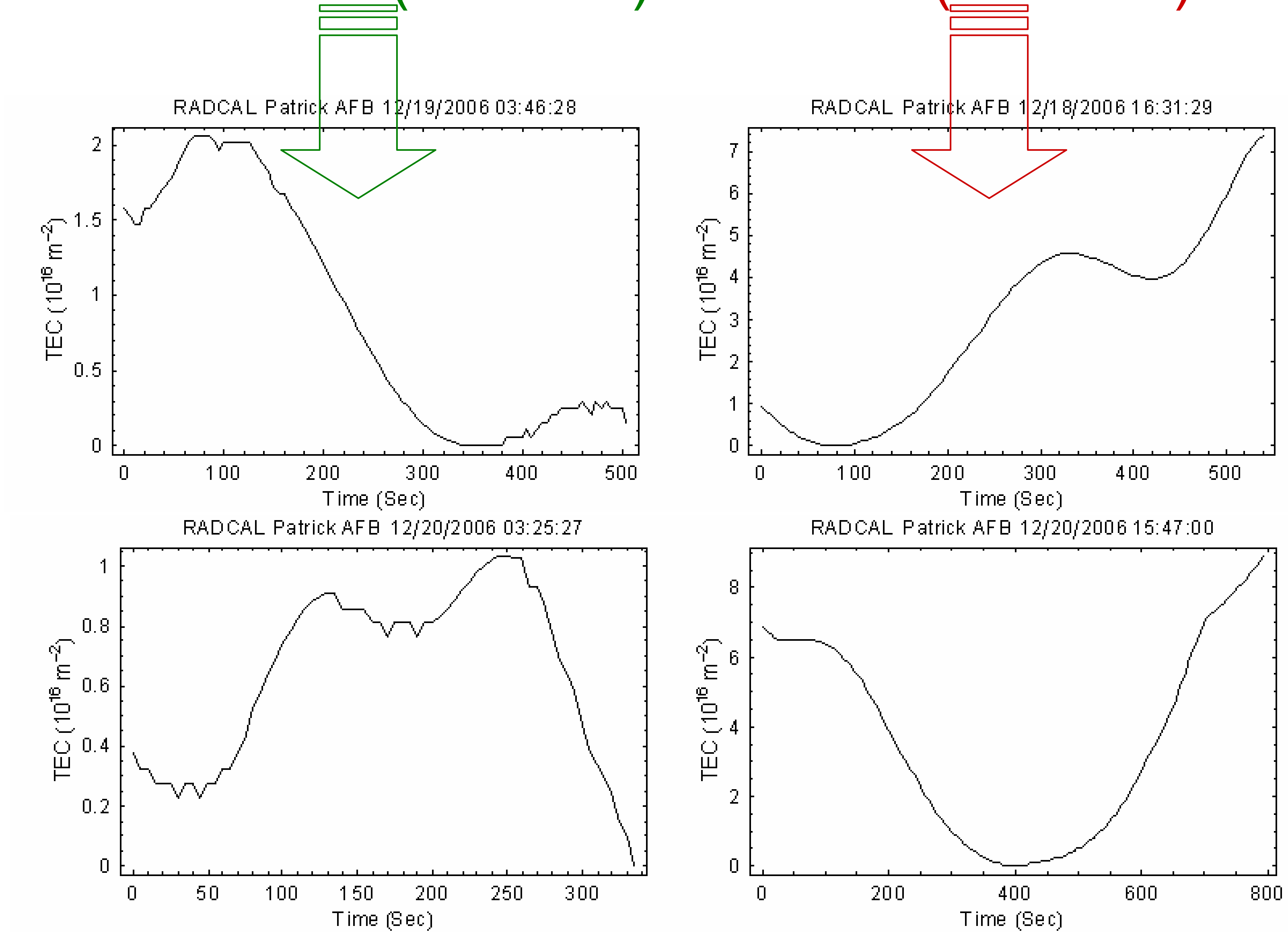


Down and Side Looking Measurement Geometry for Beacon Receiver Chains



DEC 2006 RADCAL TEC at Patrick AFB, FL

0330 UT (2230 LT)   1600 UT (0900 LT)



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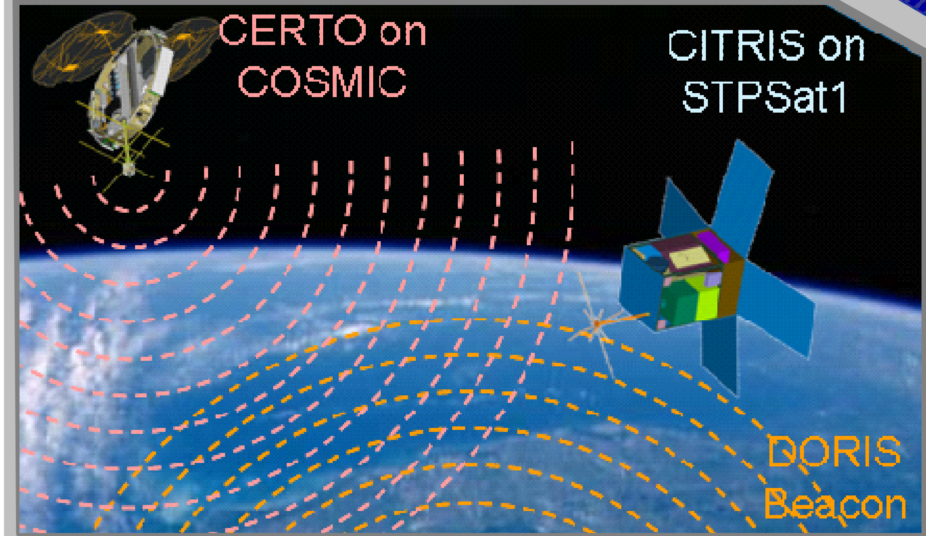
Coherent Electromagnetic Radio Tomography (CERTO) and Scintillation and TEC Receiver in Space (CITRIS)



OPERATIONAL CAPABILITY ADDRESSED

- Provide Global Measurements Ionospheric Data to the Warfighter
  - Total Electron Content with 0.05 TECU Resolution
  - Radio Scintillations at VHF, UHF, L-Band, and S-Band
- Demonstrate Utility of the Multi-Band Receiver in Space for Updating Operational Space Weather Models

TECHNICAL APPROACH and OBJECTIVES

- NRL Construct a Multi-Band Receiver for Operation in Low Earth Orbit
  - Record UHF and S-Band Transmissions from Ground DORIS Beacons
  - Record VHF, UHF, and L-Band Transmissions from CERTO and Other Satellite Beacons
- NRL Develop Software to Provide Ionospheric Data Products from CITRIS Data
  - TEC and Reconstructed Ionospheric Densities
  - Radio Scintillation Indices
- Demonstrate Utility of Ionospheric Data Acquisition over Remote Areas
- Validate Space Based Measurements with Other Sensors

Mission Profile

- Launched on Atlas V, 8 March 2007
- 35° Orbit Inclination at 560 km Altitude
- CITRIS Antenna Deployed on ram Face of STPSAT1, 9 March 2007
- Start CITRIS Data Collection,13 March 2007
  - Relative TEC from DORIS Beacons
  - Satellite to Satellite TEC from CERTO Beacons on DMSP/F15 and COSMIC Satellites
- Scheduled Operations with Arecibo and Jicamarca Incoherent Scatter Radar Sites

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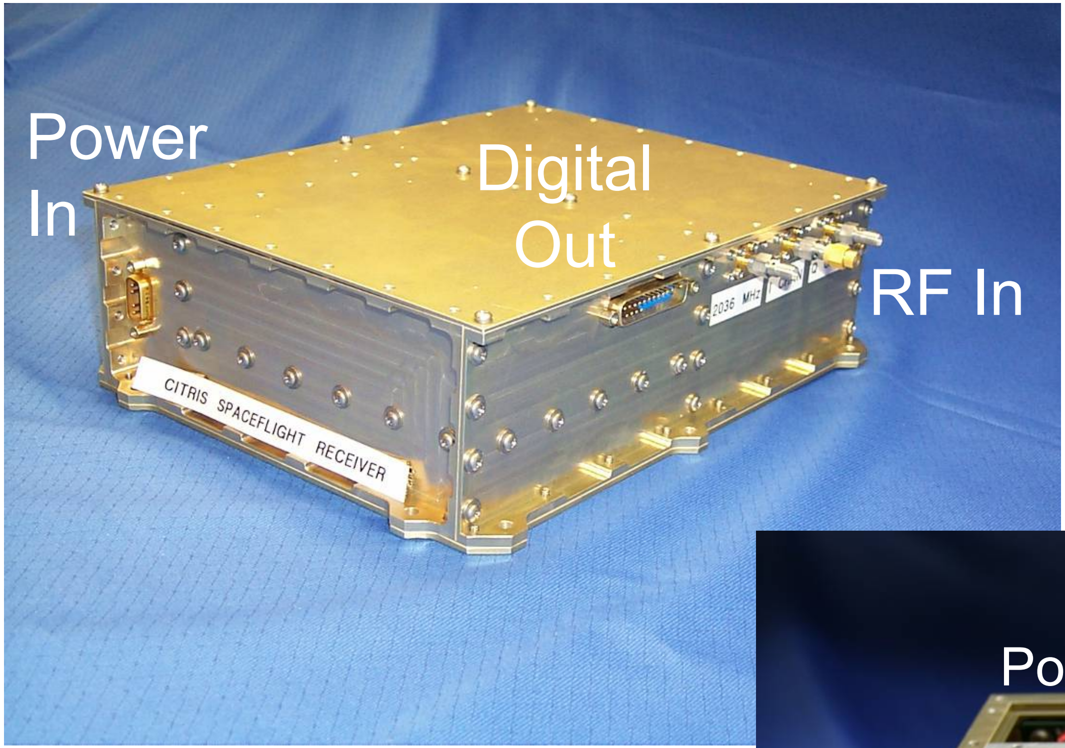
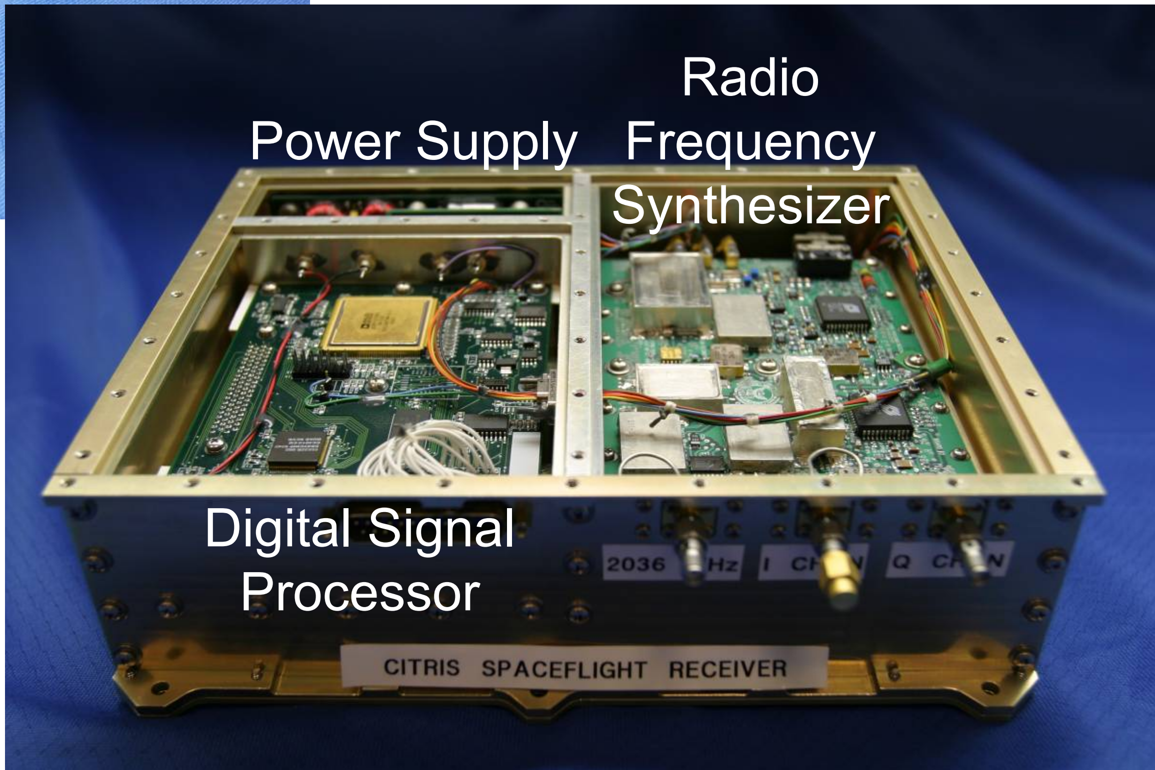
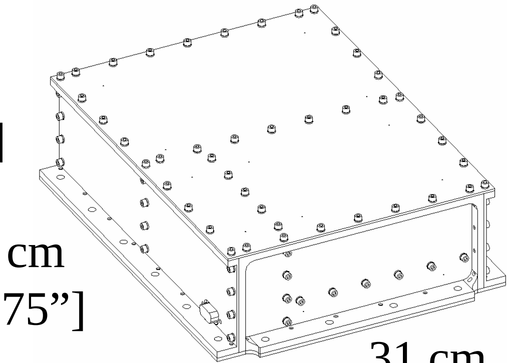
CITRIS Flight Receiver

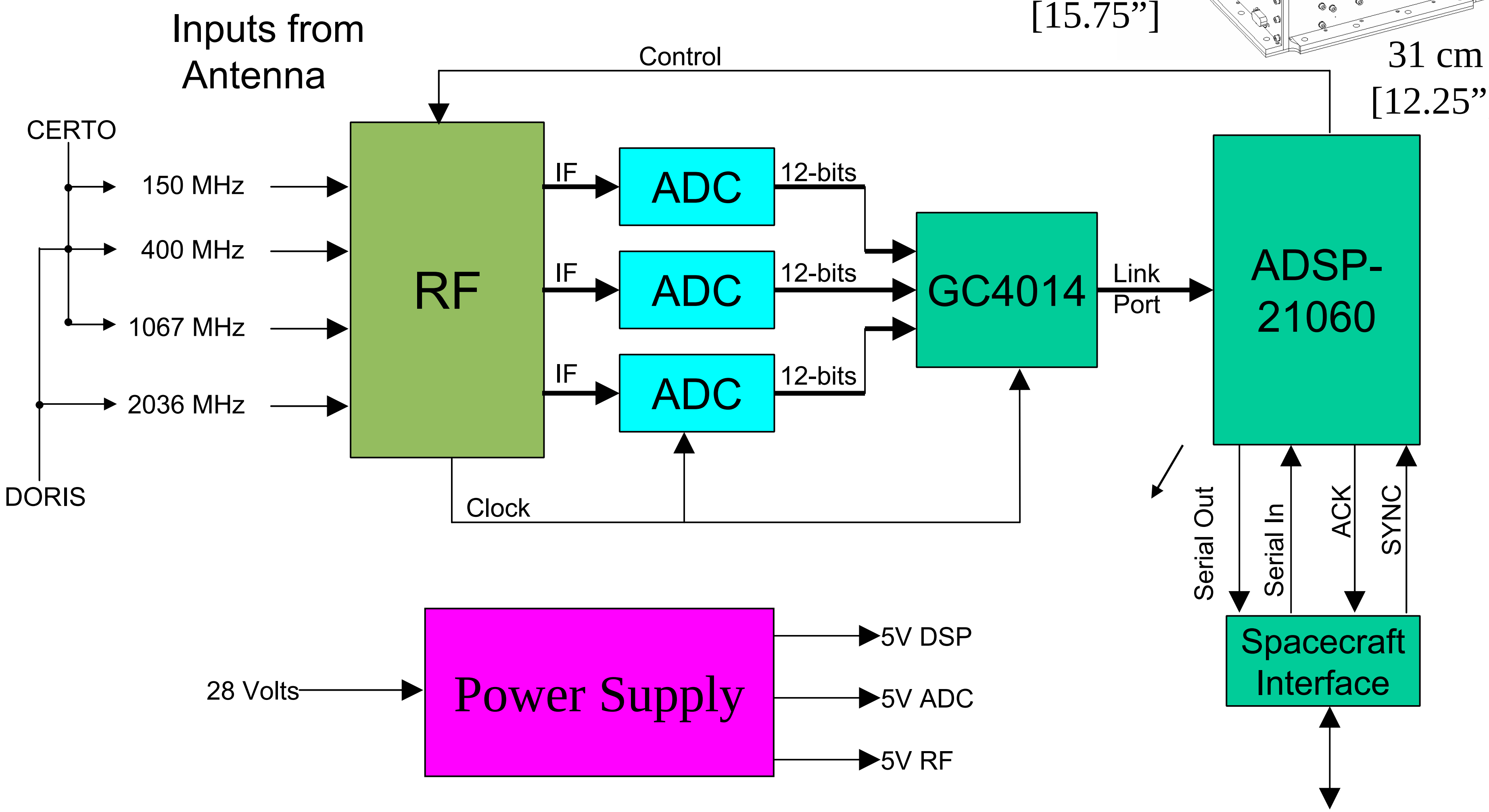


Item	Volume	Mass	Power
CITRIS Receiver	15,000 cm^3	4.5 kg	12.3 Watts
CITRIS Antenna	2,000 cm^3	0.7 kg	0.0 Watts

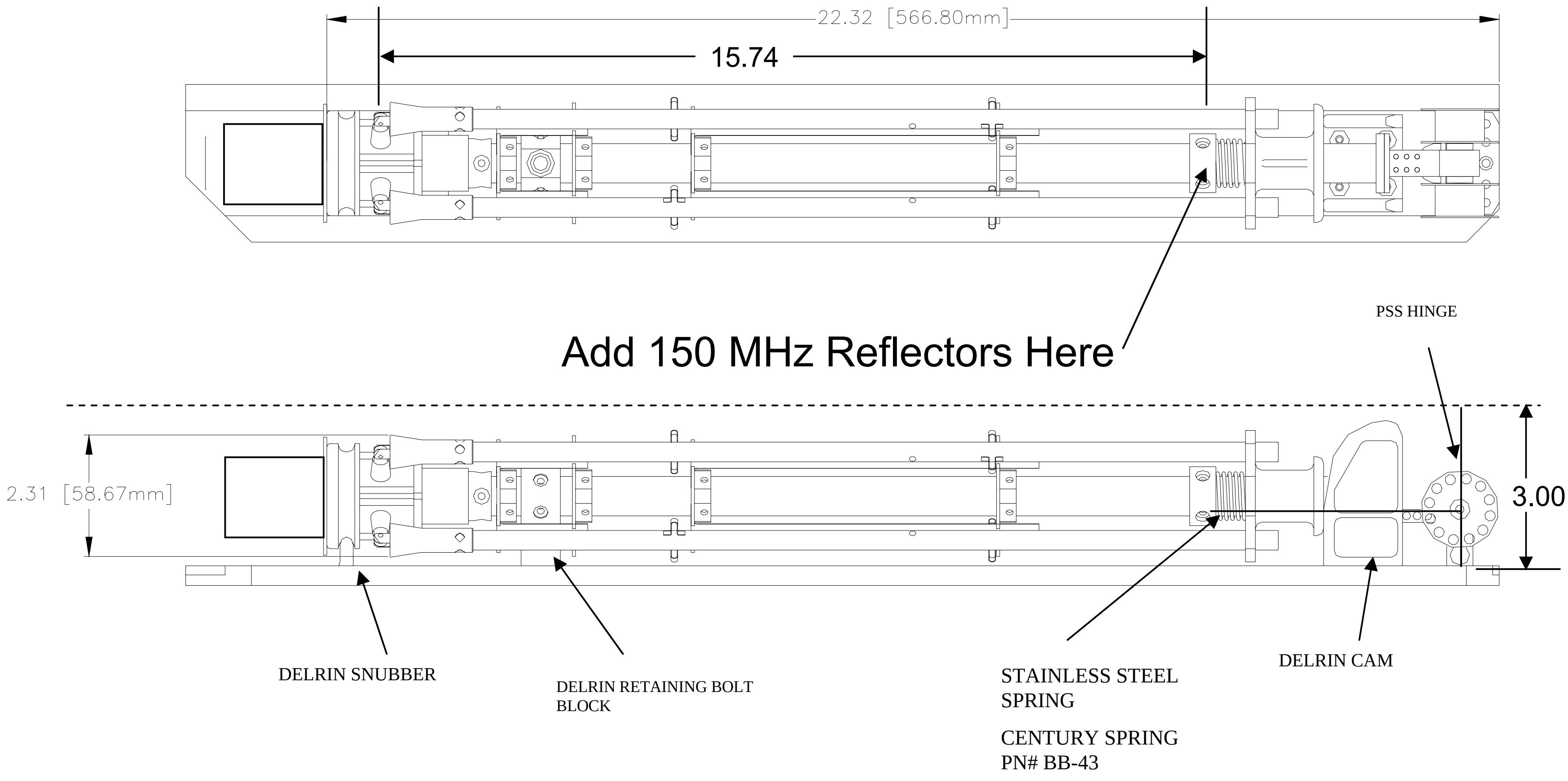


NRL DORIS/CERTO Receiver (CITRIS)

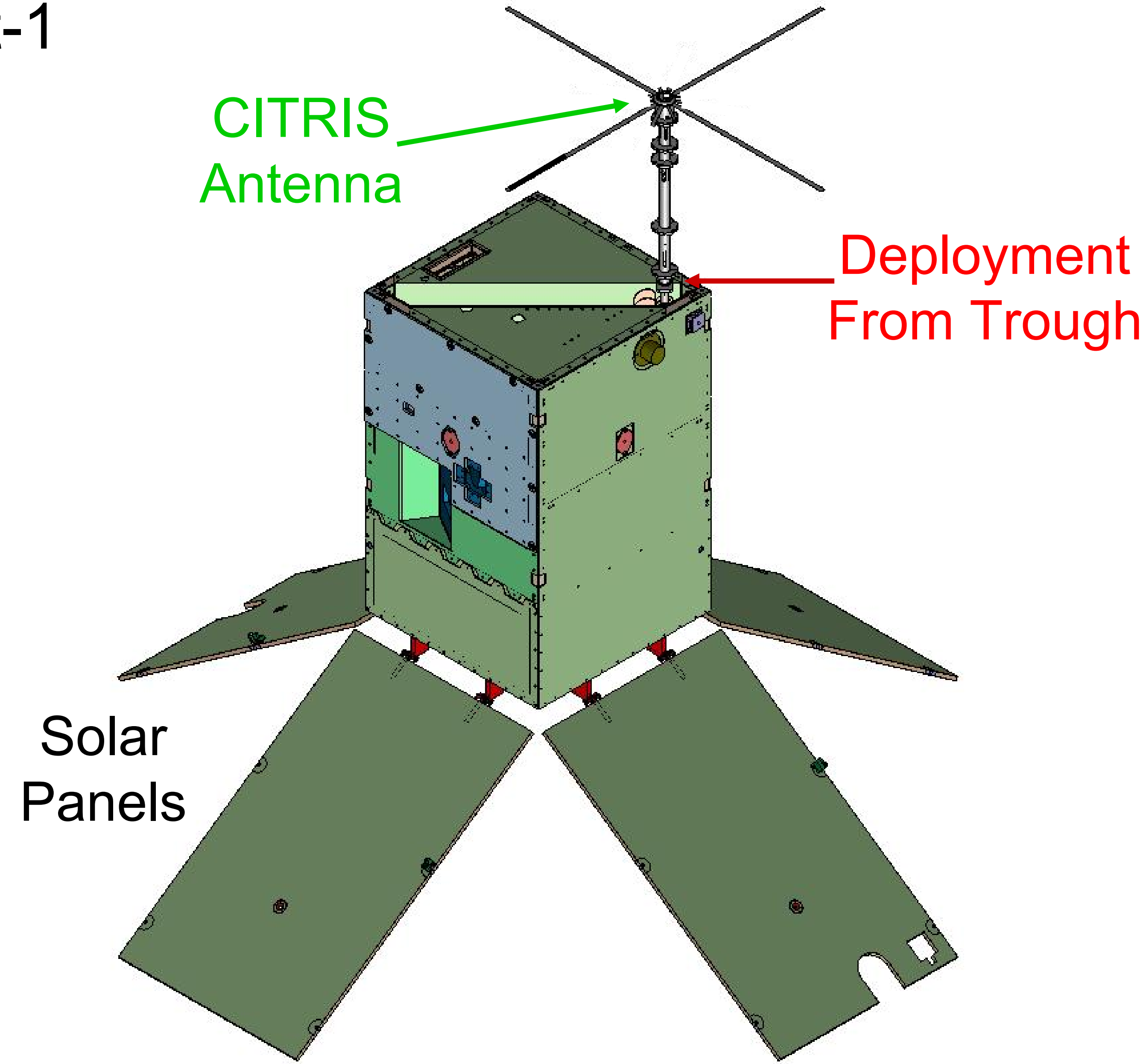




CITRIS Antenna and Boom



STPSat-1



NRL Anechoic Chamber with Satellite

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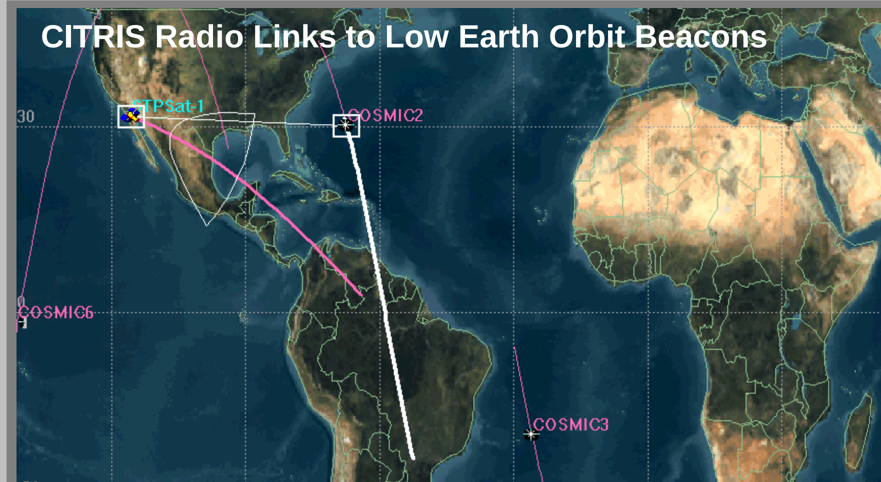
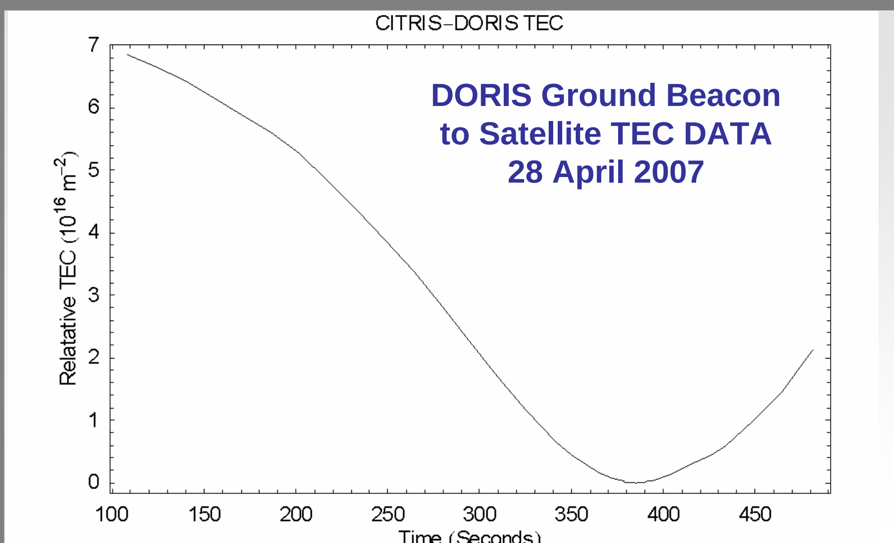
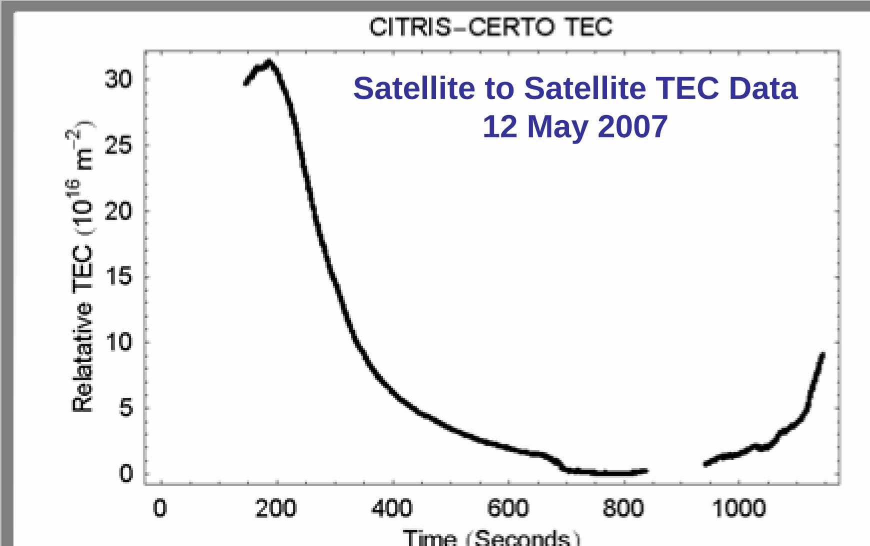
Scintillation and TEC Receiver in Space (CITRIS)

56 Ground DORIS Beacons







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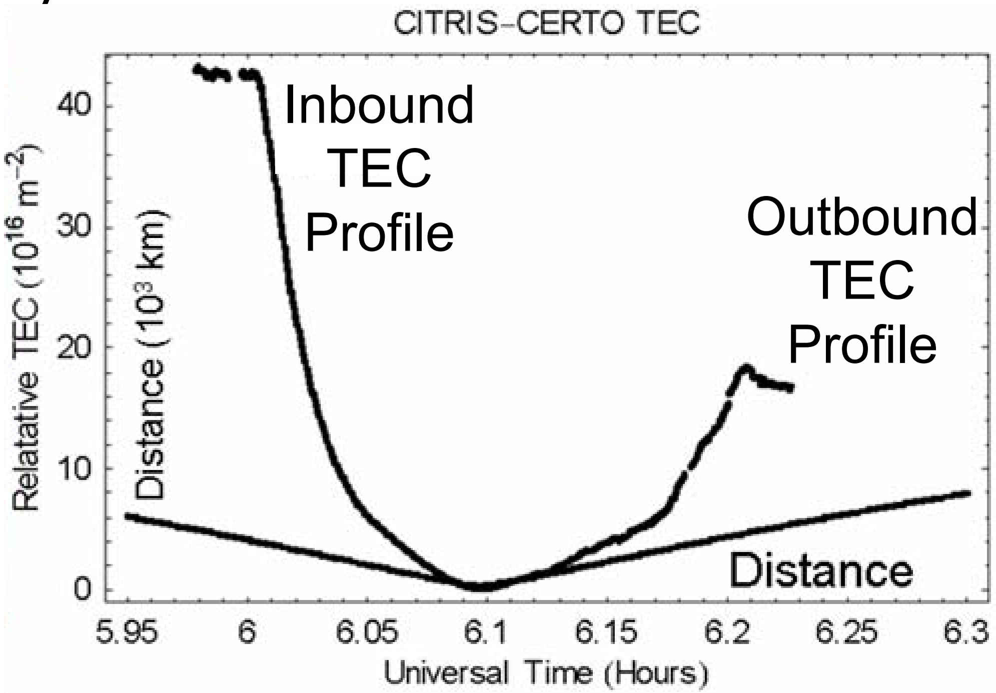
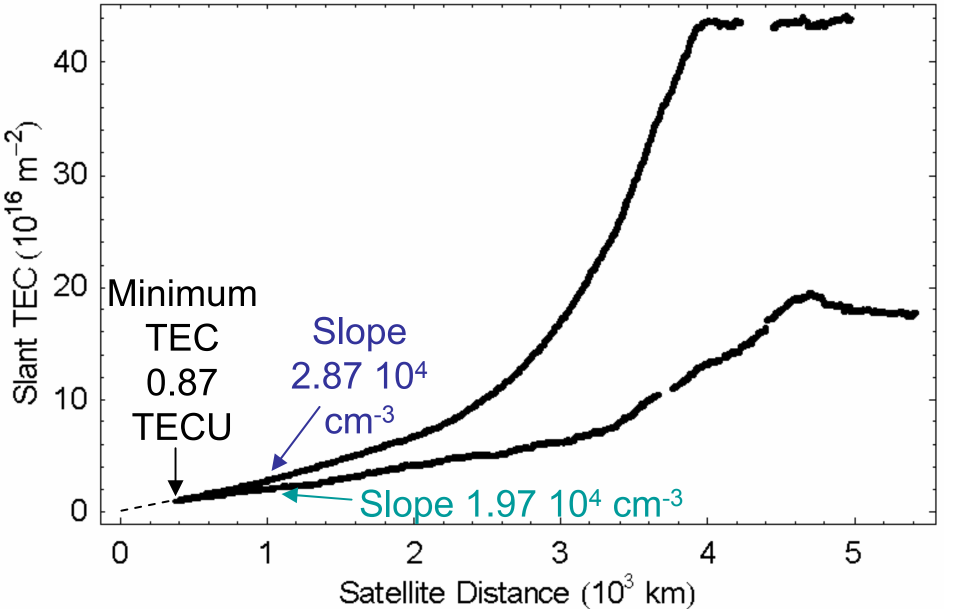
CERTO-CITRIS Measurements of Satellite-to-Satellite TEC
20 May 2007



- Low Earth Orbit Occultation
  - COSMIC FM5 CERTO at 830 km Altitude
  - STPSAT1 CITRIS at 560 km Altitude
  - Ionospheric TEC Profile at Low Inclinations



Plasma Physics Division, Radar Division, Space Science Division, Naval Center for Space Technology

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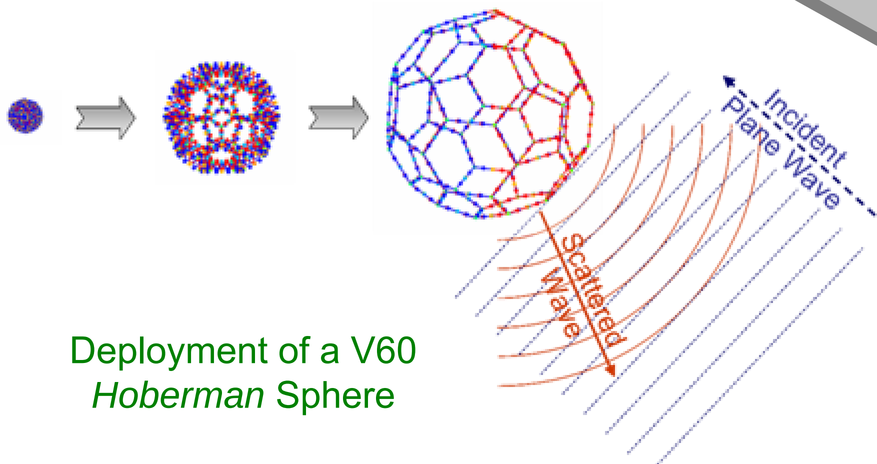
Precision Expandable Radar Calibration Sphere (PERCS)



HF Radar Calibration Target in Space

OPERATIONAL CAPABILITY ADDRESSED

- Develop Aspect Insensitive Target for Calibration of Ground HF Radars and HF High Power Transmitters
  - Space Weather Radar Systems (SuperDARN)
  - High Frequency Active Auroral Research Program (HAARP)

TECHNICAL APPROACH and OBJECTIVES

- Place Calibration Target for HF Radar Systems in Low Earth Orbit with Known Radar Cross Section (RCS)
- Demonstrate Deployment of Large Polyhedral Structure in Space
- Self Expanding Wire Frame using Hoberman Sphere Technology
- Low Atmospheric Drag Using Open Frame Configuration with No Impact on RCS Properties
- Baseline Design: 10 Meter Diameter Target with Operational Radio Frequencies Up to 40 MHz

PROGRAM APPROACH and OBJECTIVES

- Space Demonstration in FY10 (36-Month)
  - Science/Modeling, MicroSat (1), and Radar and Laser Ground Data Assessment
  - Launch into High Inclination 600 km Orbit
  - ~Five Years of On-Orbit Ops (Depends on Atmospheric Drag)
- Deliverables: Science & Modeling; One 60 or 240 Vertex Hoberman Sphere; System Integration/Test; Ground Data/Processing Systems
- Launch Vehicle by USAF/STP (Secondary Payload)

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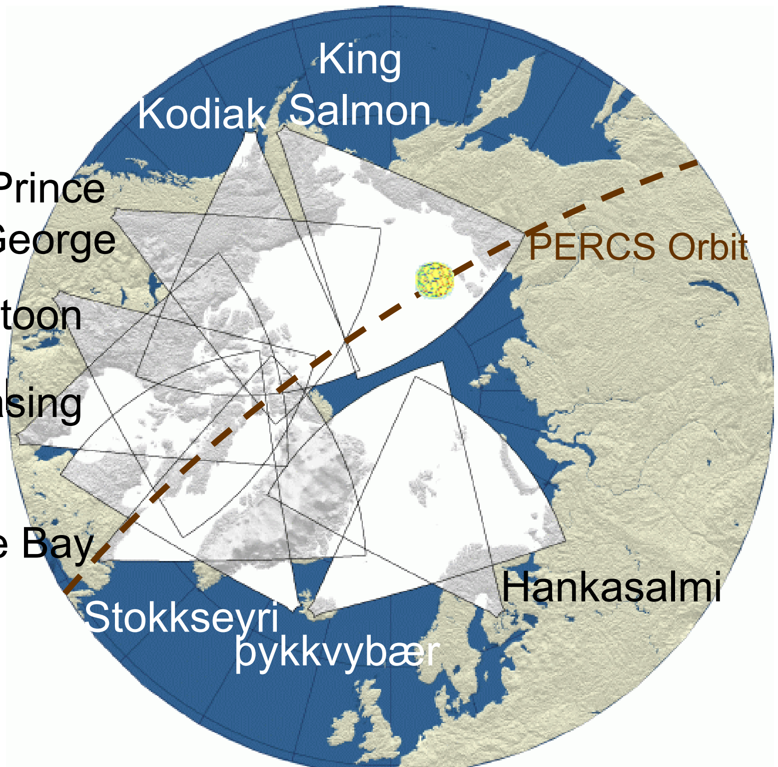
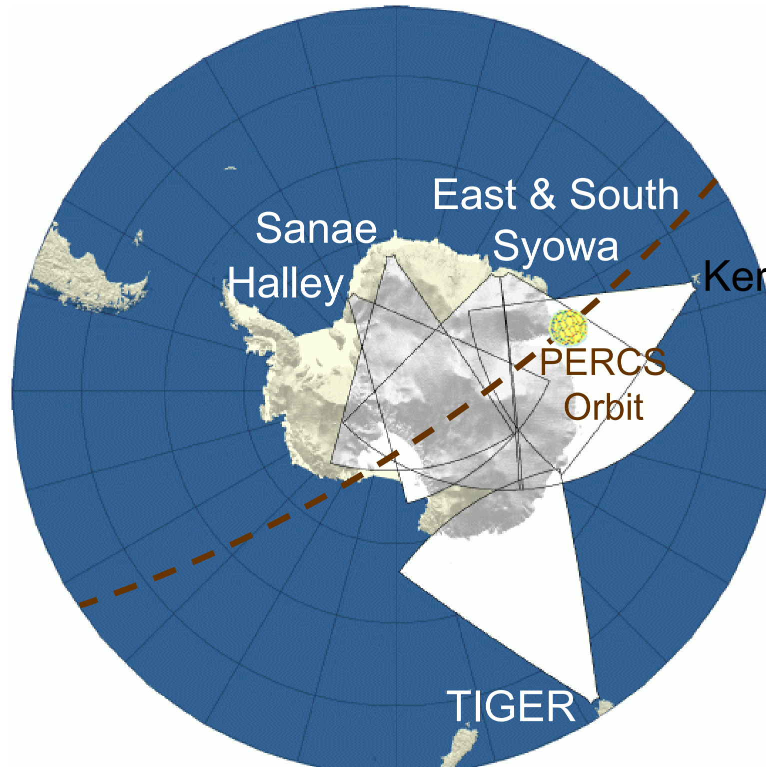
PERCS Calibration of the NSF SuperDARN Radar Systems





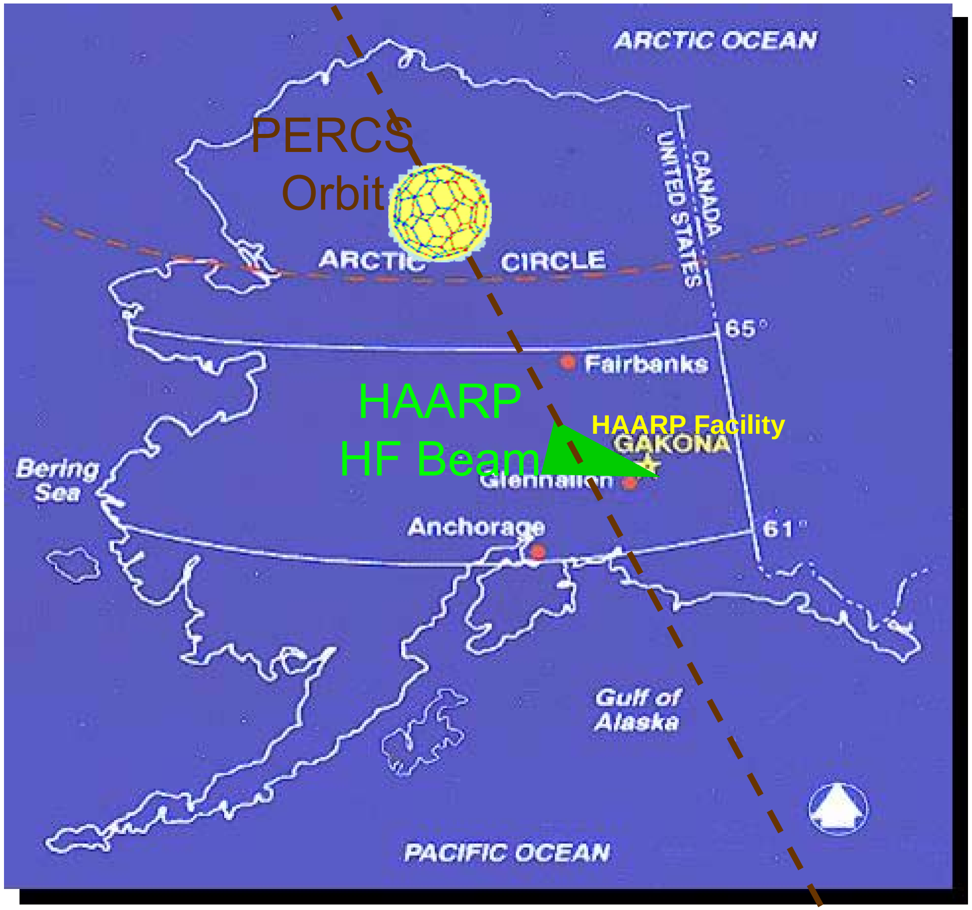
SuperDARN

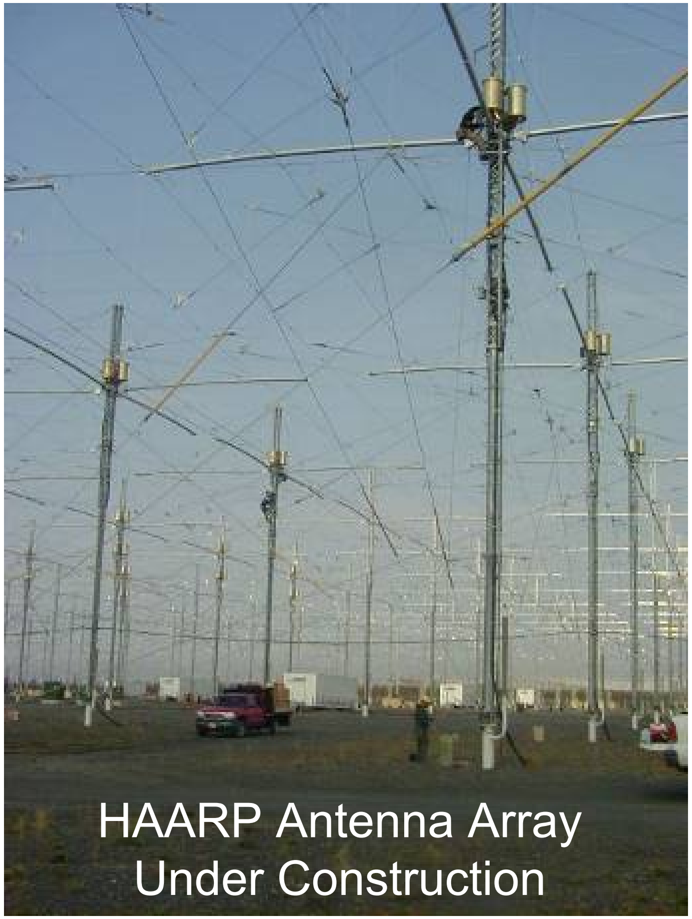
An International Radar Network for Studying the Earth's Upper Atmosphere, Ionosphere, and Connection into Space

PERCS Operational Utility: (1) Absolute System Calibration from 8 to 20 MHz

(2) Characterize Effects of Ionospheric Refraction

HAARP Instrument Experiments with the PERCS

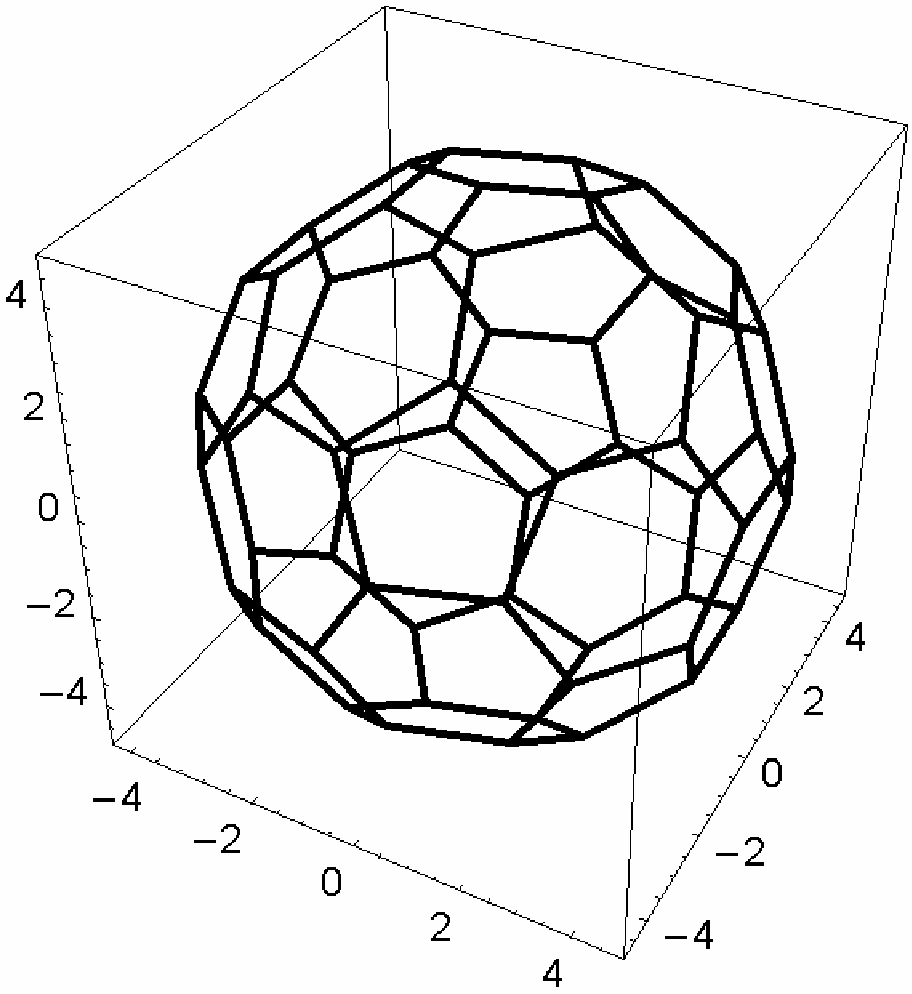




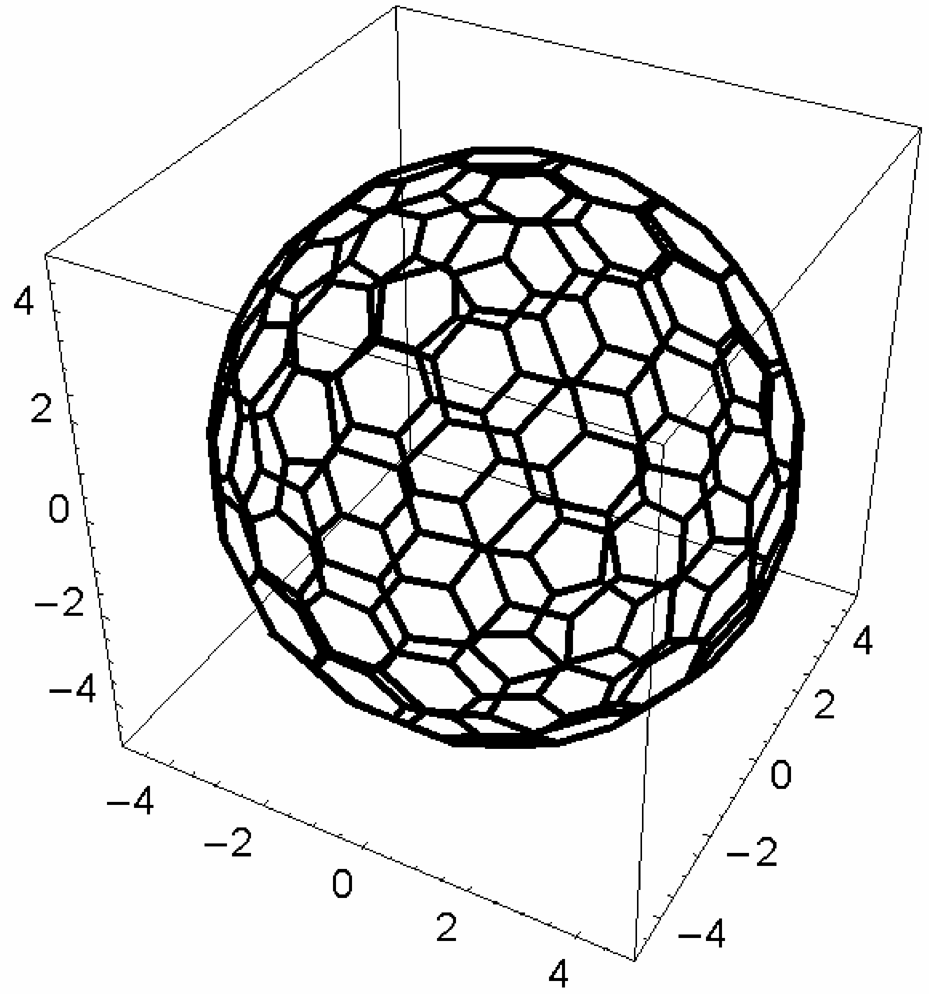
- PERCS Operational Utility
  - Absolute Calibration of HAARP Antenna Pattern from 2.8 to 10 MHz
  - Precise Measurements of Performance for HF Radars that Support HAARP

10-meter Wire Frame Radar Reflectors

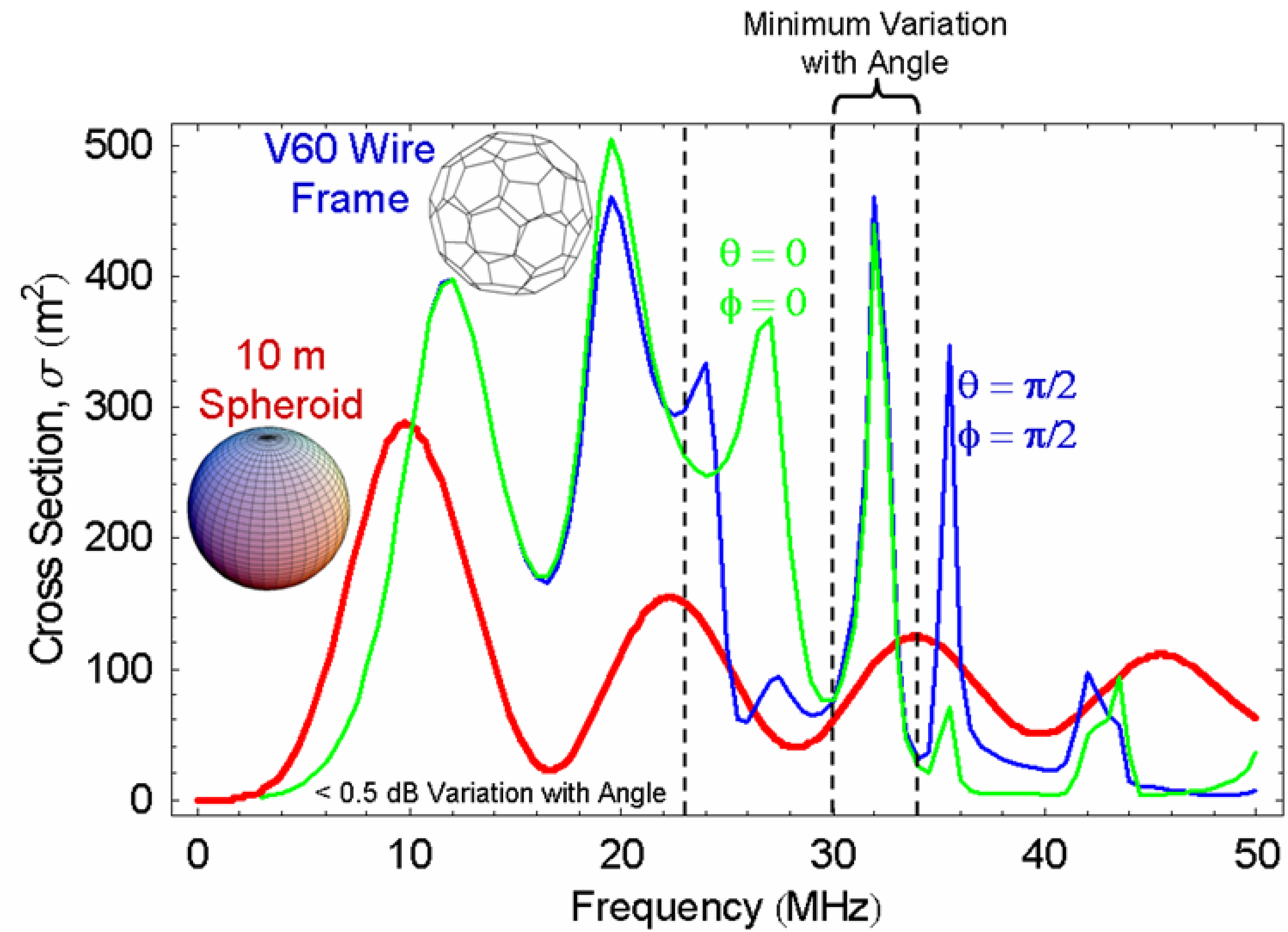
V60 Wire Frame



V240 Wire Frame



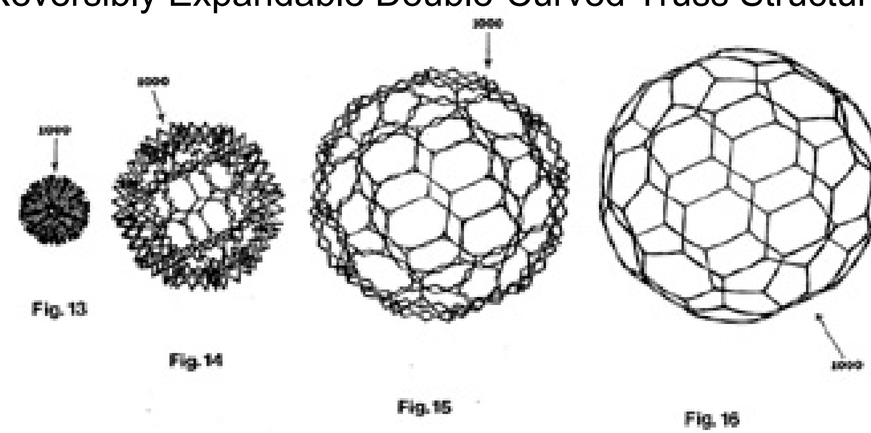
Computed Radar Cross Sections for Two Observation Directions



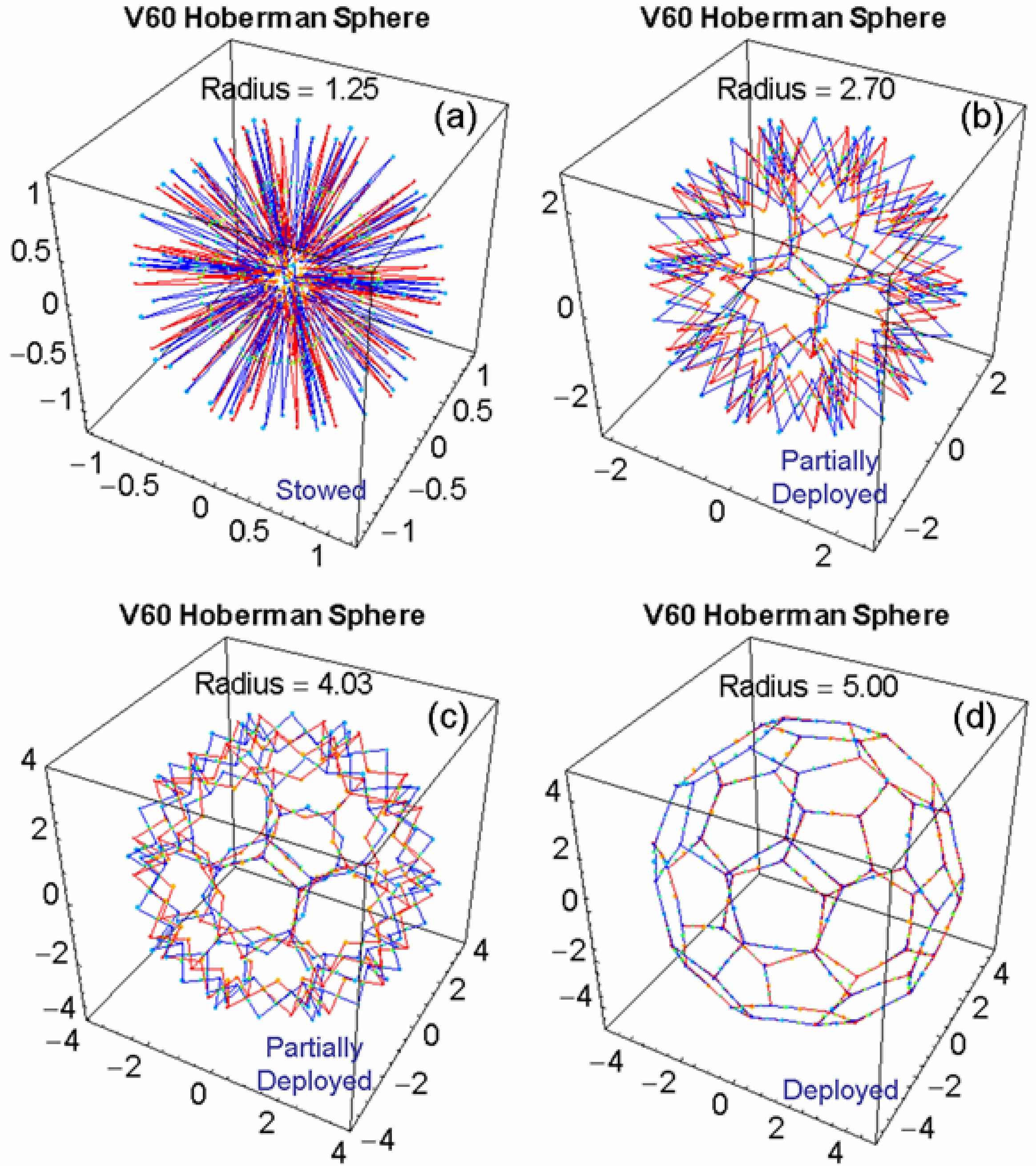
Hoberman Sphere as Radar Calibration Target

- **Hoberman Associates, Inc.**
  40 Worth Street, Suite 1680
  New York, NY 10013
  Tel: (212) 349 7919
  Fax: (212) 349 7935
  e-mail:
  associates@hoberman.com
- Concept and Tasks
  - Design Structure Based on Transformable Sphere
  - Calculate Radar Cross Section of Hoberman Sphere Wire Frame
  - Construct Sphere with Remote or Self Deployment
  - Launch in Rocket or Space Shuttle

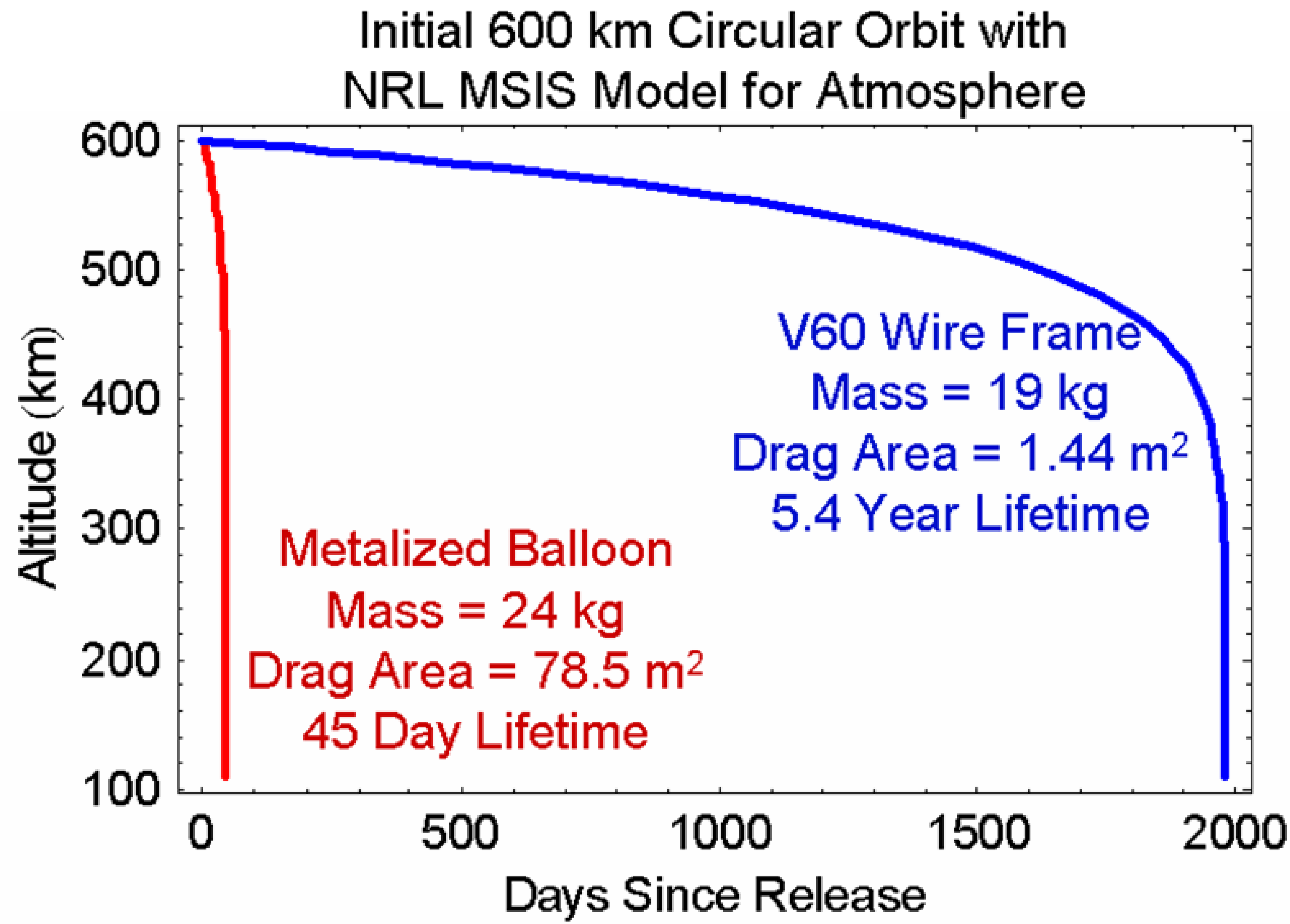
US Patent Number 4,942,700, Hoberman 1990
Reversibly Expandable Double-Curved Truss Structure



V60 Radar Reflector with Two Scissors per Edge



Drag Limitations on Lifetime of 10 meter Spherical Radar Target



Three NRL Devices Available for Small Satellites in Low Earth Orbi9t

- CERTO Beacon
  - Three Frequencies: 150, 400, 1066 $^{2}/_{3}$ MHz
  - Many Antenna Configurations: Monopole, Crossed Dipole, Helix, Patch
  - Ground Arrays in Place (US, Taiwan, Europe, Russia)
- CITRIS Receiver Provides Global Ionospheric Measurements
  - Ground DORIS Beacons (401.25 and 2036.25 MHz)
  - CERTO Space Beacons
  - Ionospheric Measurements
    - Total Electron Content
    - Ionospheric Scintillations
- PERCS Sphere
  - 5-meter Sphere Provides Calibration to 50 MHz
  - Radar/Transmitters that Could Use PERCS
    - *3-30 MHz* SuperDARN, HAARP, Meteor Radars
    - *50 MHz* Jicamarca, Mu, EAR,