Precision Expandable Radar Calibration Sphere (PERCS) for HF and Laser System Calibration

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EISCAT Radar School
1 September 2010

PERCS Overview

- PERCS Applications
  - SuperDARN Radar Calibrations
  - High Power HF Systems
  - Satellite Laser Imaging Calibration
- Satellite Based HF Calibration Components
  - √ Ground Transmitters
  - √ PERCS Calibration Sphere
  - √ Ionospheric Refraction
  - √ Ground HF Receiving Systems
- Laser Target Components
  - √ Ground Laser
  - √ PERCS Retro Reflectors in Orbit
  - √ Ground Telescope
  - √ Photon Counting Detector

Precision Expandable Radar Calibration Target (PERCS) Objectives

(1) Provide *HF Radar Calibration Target* Using Spherical Wire Frame

- a. Purpose: Calibration of System Sensitivity and Antenna Patterns for Ground HF Radars
- b. Construct Model for Monostatic RCS Testing
- c. Construct Spaceflight Version
- d. Launch into Low Earth Orbit
- e. Validate PERCS Concept Using SuperDARN Radars

(2) Validate *HF High Power Transmitters* Beam Patterns

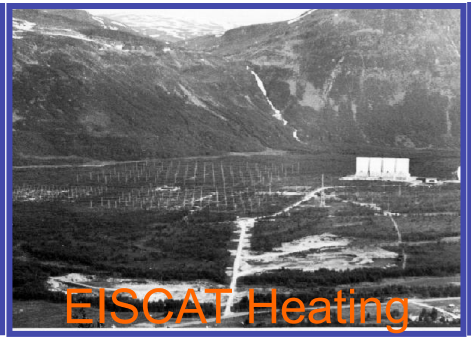
- a. Purpose: HF Interaction Transmitter Tests
- b. Model and Measure Ionospheric Modification Signals
- c. Schedule Ground HF Transmitters such EISCAT, HAARP, and Arecibo

(3) Provide Optical Calibrator for *Laser Satellite Imaging* with Array of Corner Reflectors

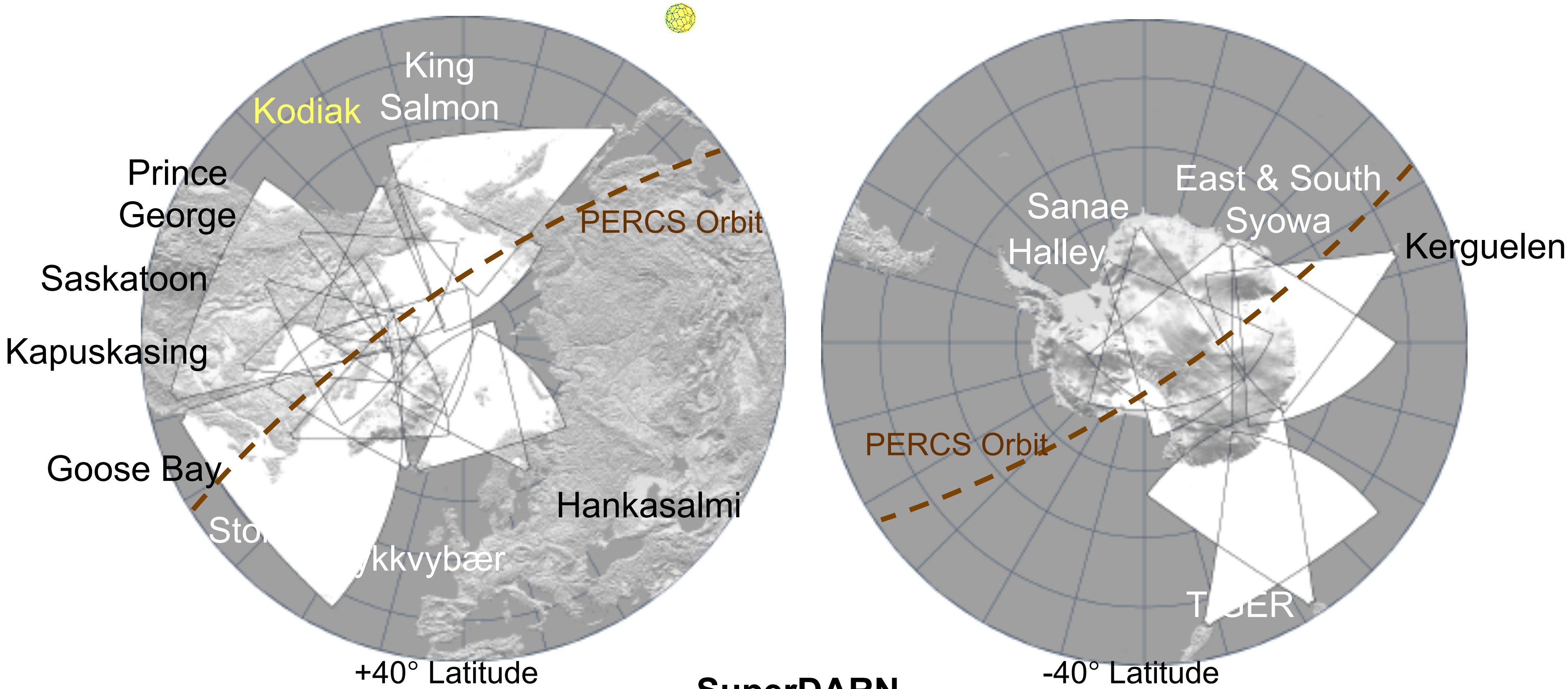
- a. Purpose: Calibrate Laser Imaging Systems
- b. Add Corner Cube Reflectors to Each Vertex of Wire Frame
- c. Measure Deployed Size of PERCS Sphere
- d. Support Operational Laser Ranging, Tracking and Imaging Systems

High Power HF Transmitters Available for HF Scatter From PERCS

Transmitter Name	Identification	Geog. Lat.	Geog. Lon.	Transmit Power	Transmit Heading
HAARP, Alaska	HAARP	62.4°N	145.2°W	3.6 MW	Zenith ± 30°
Tromso, Norway	EISCAT	69.59º N	19.23º E	1.0 MW	Zenith ± 15°
Arecibo, Puerto Rico	Arecibo	18.33°N	66.74°W	0.6 MW	Zenith ± 15°
Kodiak	SuperDARN	57.6°N	152.2°W	20 kW	30.0°



PERCS Calibrates NSF SuperDARN Radar Systems



SuperDARN

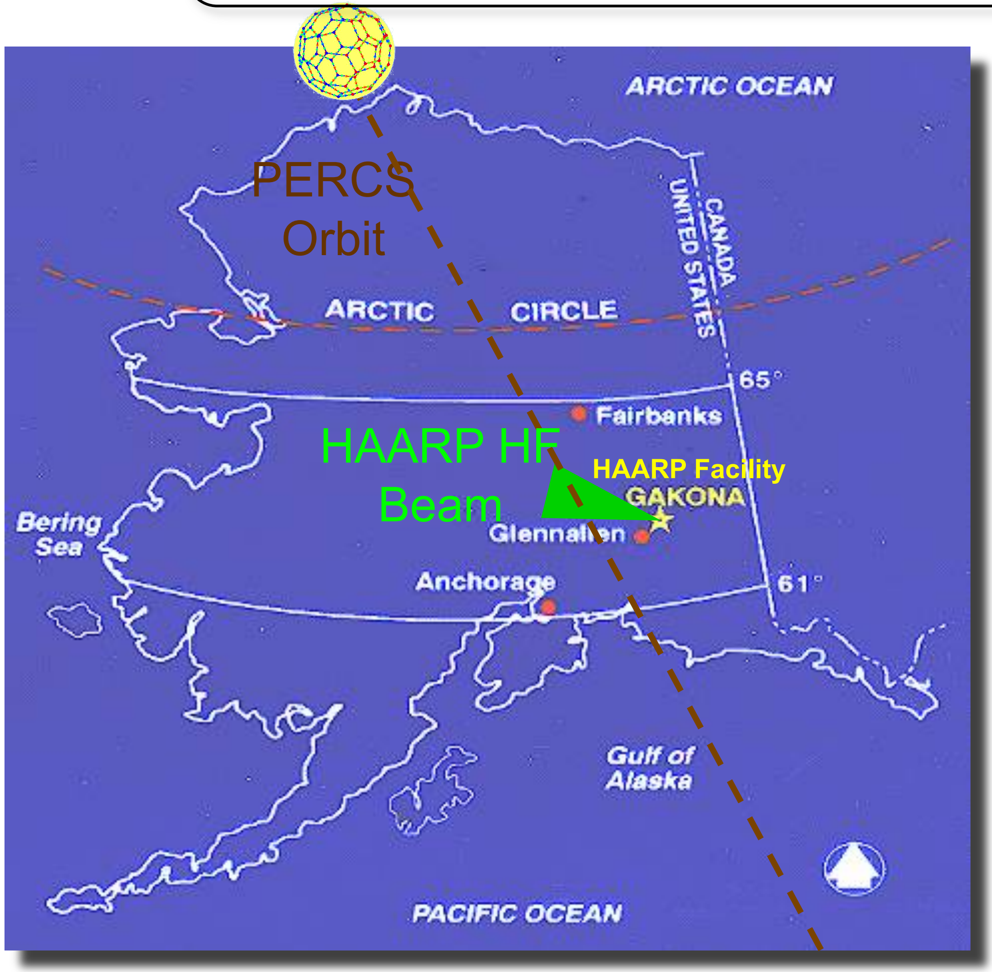
An International Radar Network for Studying the
Earth's Upper Atmosphere, Ionosphere, and Connection into Space

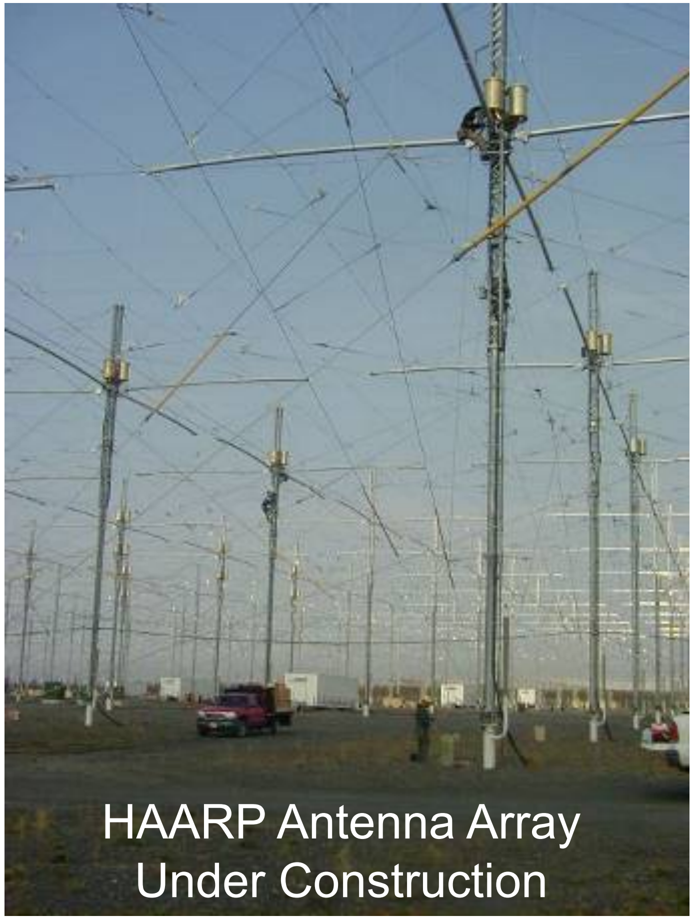
Requirement: Accurate Characterization of HF Antennas and Receiver Sensitivity for Global Installations

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

(2) Characterize Effects of Ionospheric Refraction

Operational Utility for PERCS Scatter from HAARP HF Transmission Array System

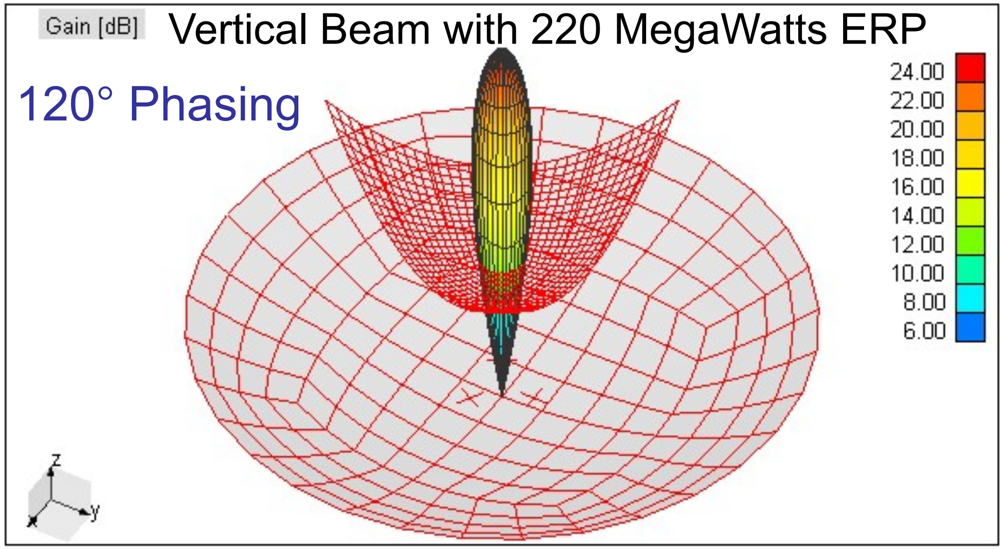


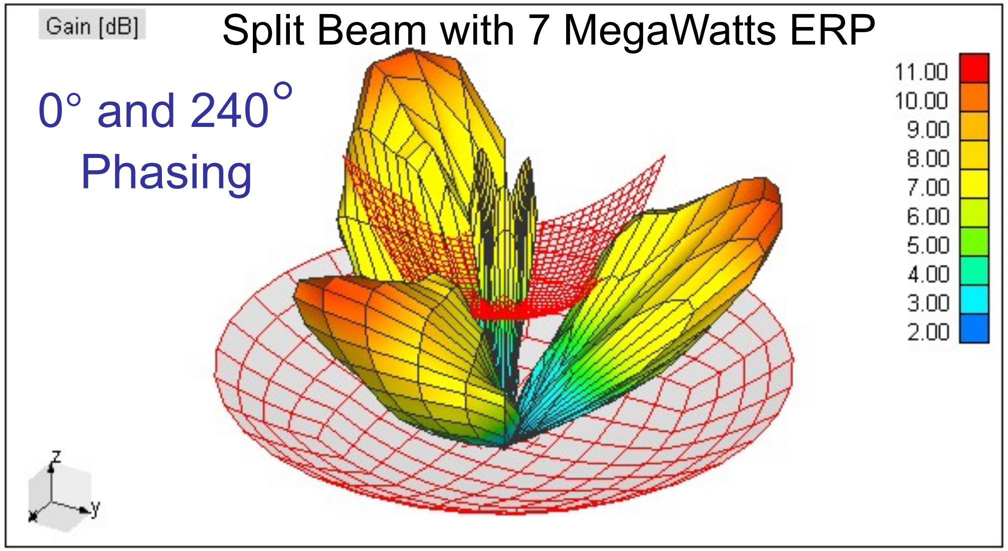


- Transmission of 1 to 4 GW ERP from HF Phased Array
- Absolute Calibration of HAARP Antenna Pattern from 2.8 to 10 MHz

Arecibo HF Facility Antenna Pattern at 8.175 MHz

- Arecibo HF Facility
  - 5.1 and 8.175 MHz
  - 300 m Dish Primary Reflector
  - Suspended Mesh Secondary Reflector
  - Three Cross-Dipole Source Antennas
  - Phased Control of Beam Shape
- Maximum Power 220 Megawatts ERP (Transmitter Power x Antenna Gain)
- Operational Starting Mid 2011

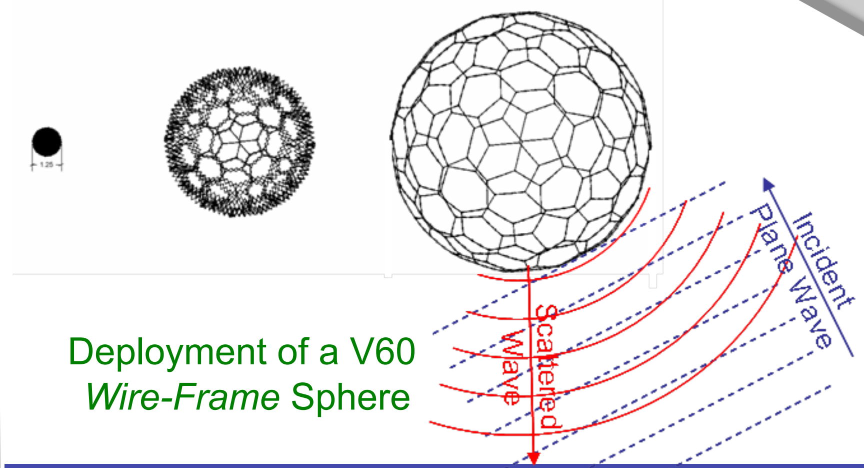




Plasma Physics Division, Radar Division, Space Science Division, Naval Center for Space Technology

Naval Research Laboratory

PERCS (NRL-0708) Precision Expandable Radar Calibration Sphere (PERCS) Experiment Concept



Deployment of a V60 *Wire-Frame* Sphere

Description: HF Radar Calibration Target in Space

TECHNICAL APPROACH and OBJECTIVES

- Wire Frame Calibration Target for HF Radar Systems in Low Earth Orbit with Known Radar Cross Section (RCS)
- Deployment of Large Polyhedral Structure in Space with ~ 5 Year On-Orbit Operations
- Low Atmospheric Drag Using Open Frame Configuration with No Impact on RCS Properties
- Corner Cube Reflectors at the Vertices of Spherical Polyhedron Provides Optical Calibration Source
- Baseline Design: 10 Meter Diameter Target with Operational Radio Frequencies Up to 40 MHz

Previous SERB Priority

- Navy SERB: 5 of 30 in 2008
- DoD SERB: 11 of 62 in 2008

OPERATIONAL CAPABILITY ADDRESSED

- Develop Aspect Insensitive Target for Calibration of Ground HF Radars and HF High Power Transmitters
  - Over the Horizon Radar (OTHR)
  - Shipboard HF/DF Calibration
  - High Frequency Active Auroral Research Program (HAARP)
  - Space Weather Radar Systems (SuperDARN)
- Optical Target for Ground Laser Imaging Systems

Comparisons to Alternatives

- Metal Balloon in Low Earth Orbit
  - High Atmospheric Drag Limits Lifetime
  - High Fabrication and Materials Cost
- Aircraft HF Radar Calibration Limited in Area
- Existing Objects in Low Earth Orbit (LEO) are NOT Usable for HF Radar Calibration
  - Existing Radar Calibration Spheres are Too Small (ANDE – 1 meter diameter)
  - Large Satellites have Irregular Cross Section (e.g. Space Shuttle, Space Station)

Complementary Experiments: ANDE

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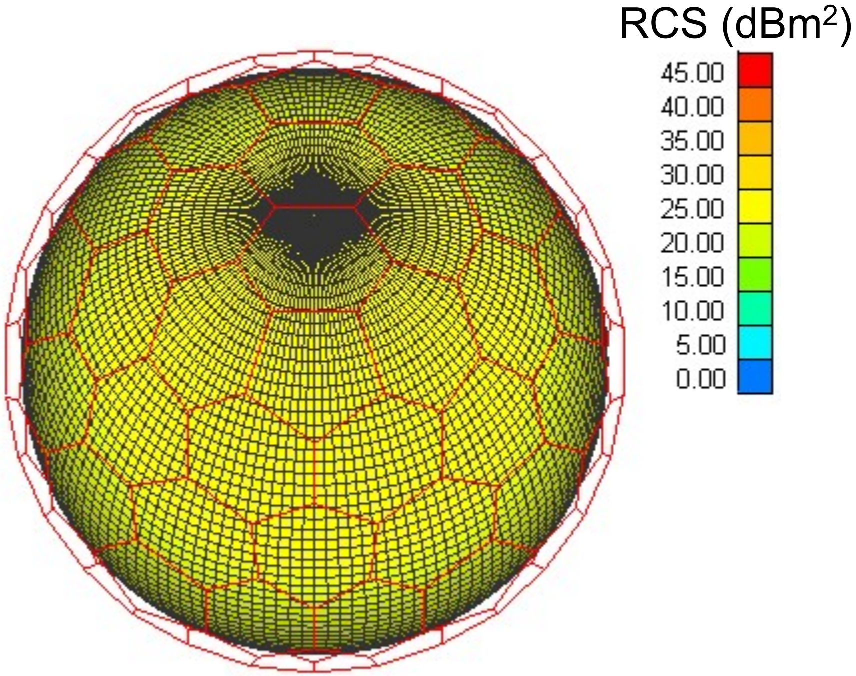
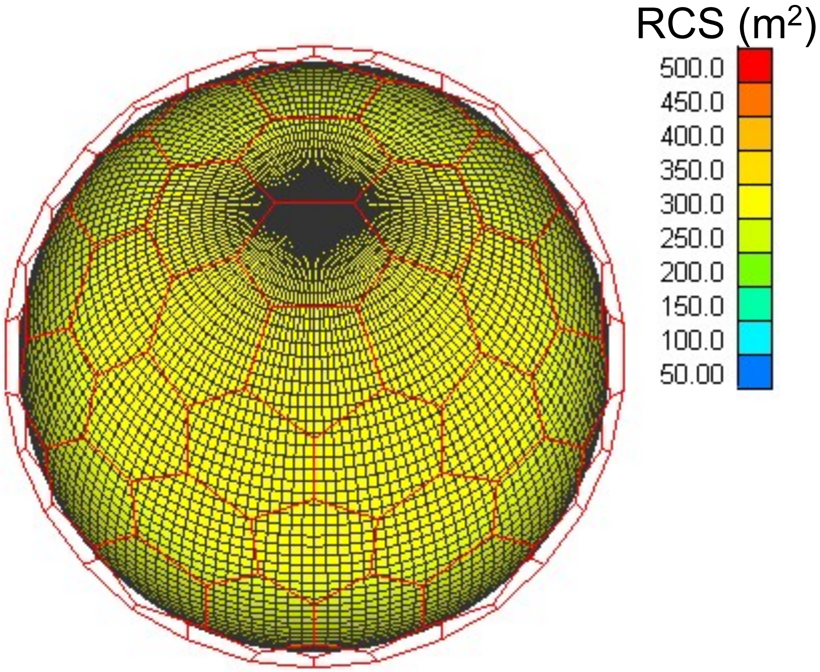
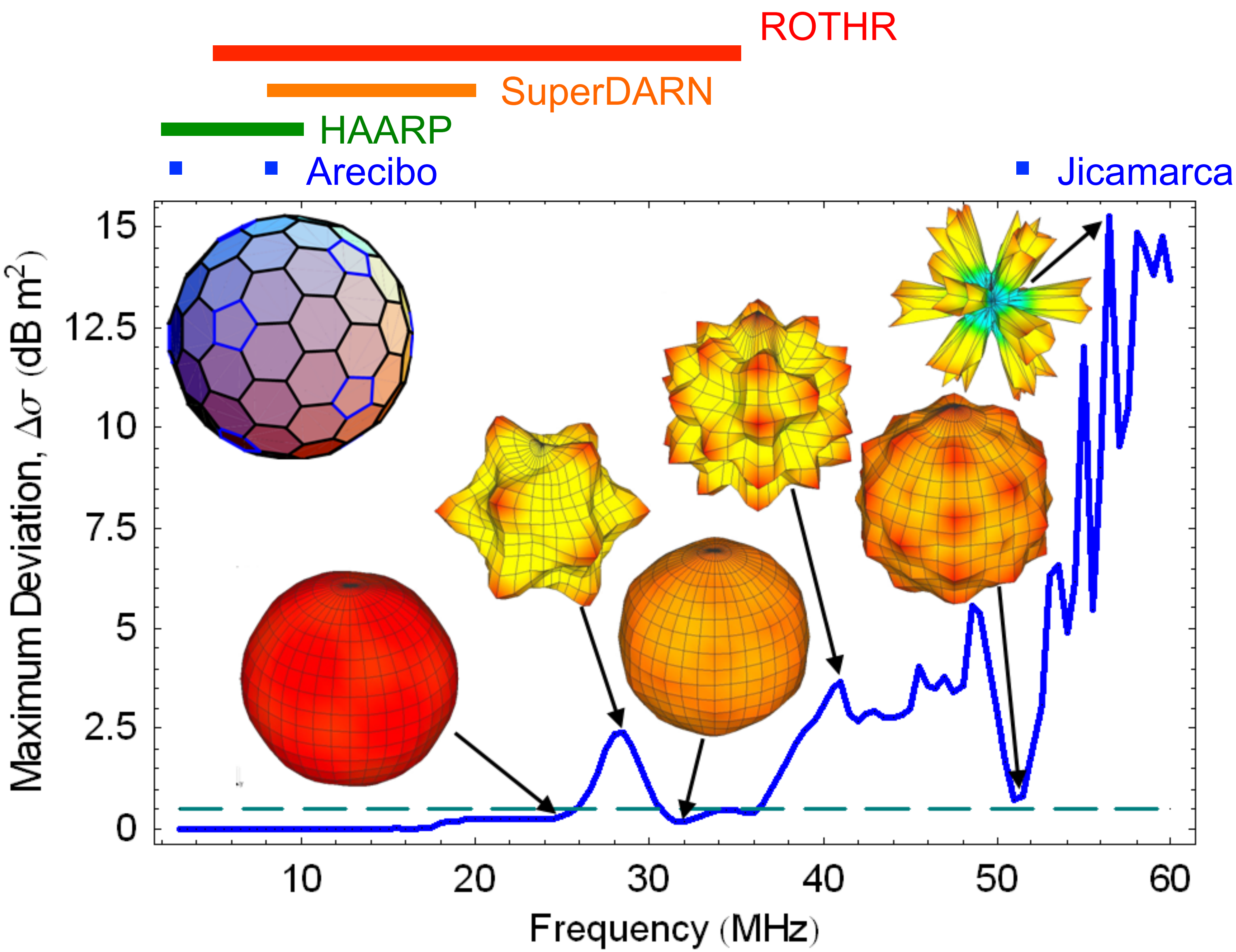
Radar Cross Section at 10 MHz



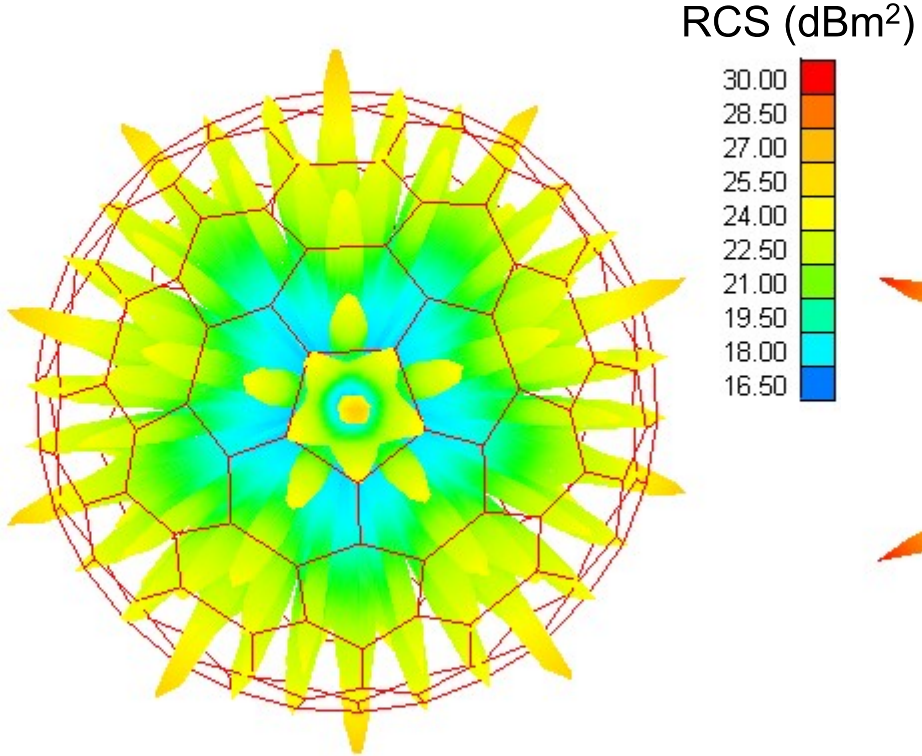


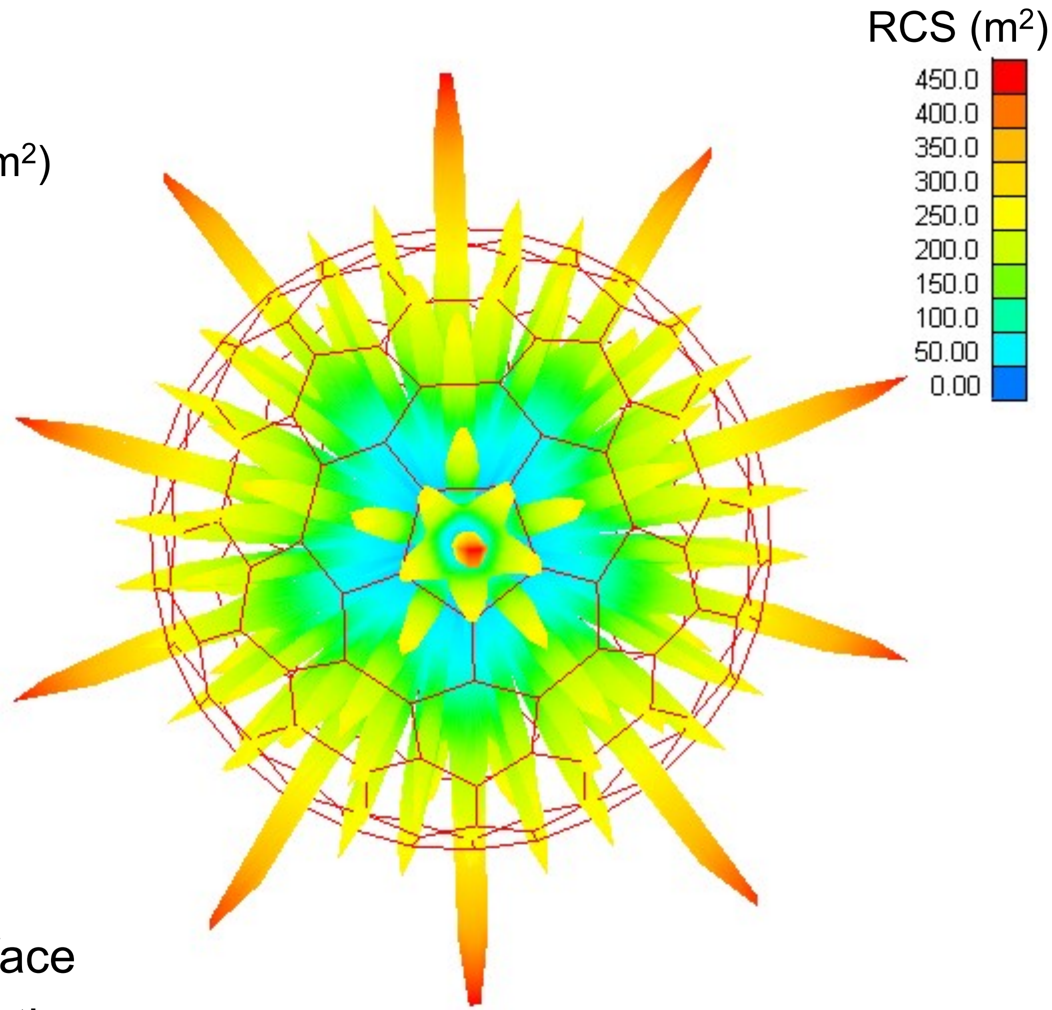
- Uniform Reflection for All Orientations

Radar Backscatter Patterns for HF/VHF System Calibration
V180 Radar Target with 0.39, 0.40, and 0.44 Meter Edges



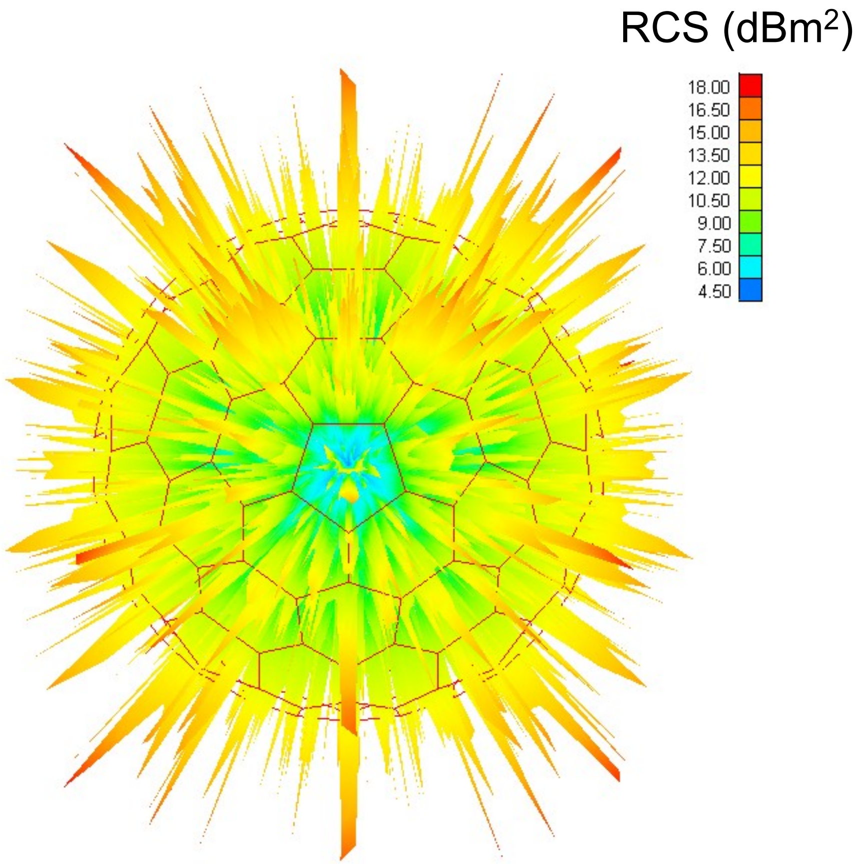
Radar Cross Section at 100 MHz

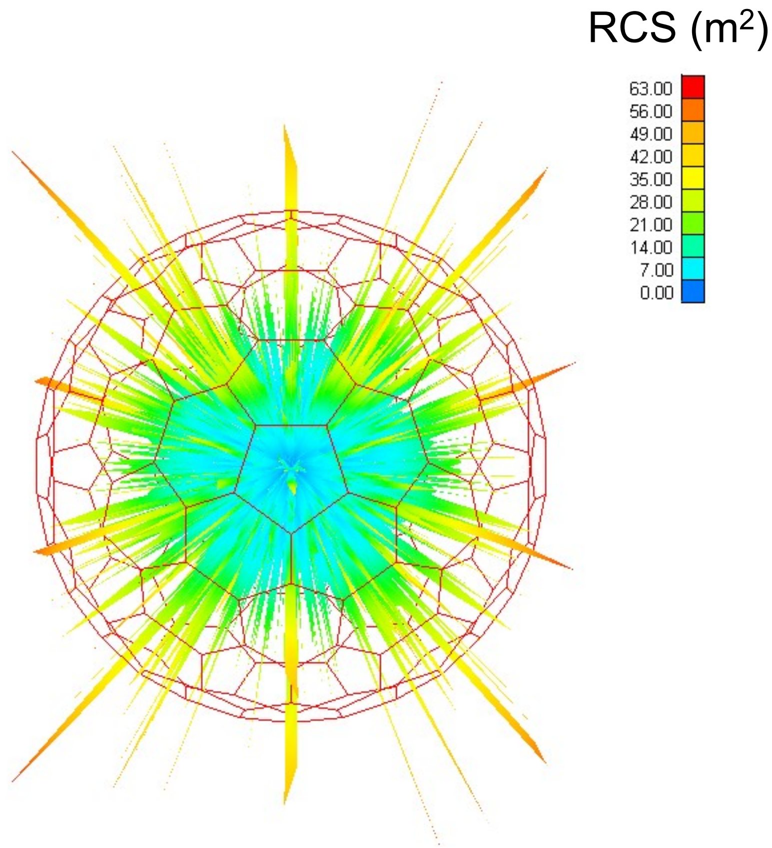




- Peak Reflection at Polygon Surface
- Peak Reflection at Pentagon Vertices

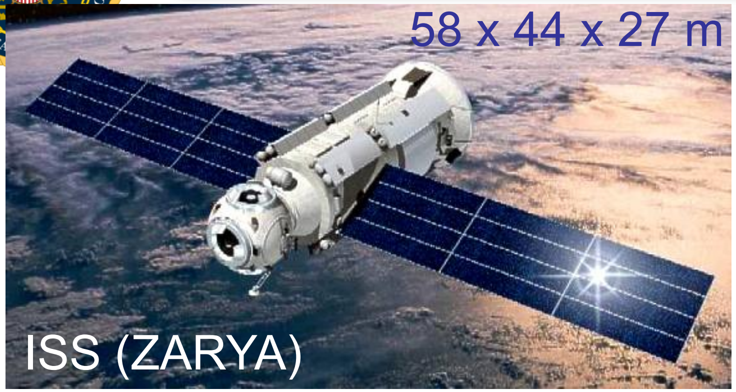
Radar Cross Section at 1000 MHz

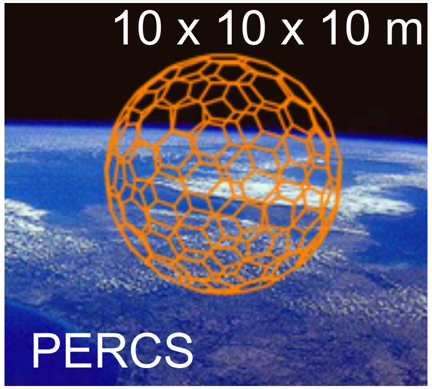


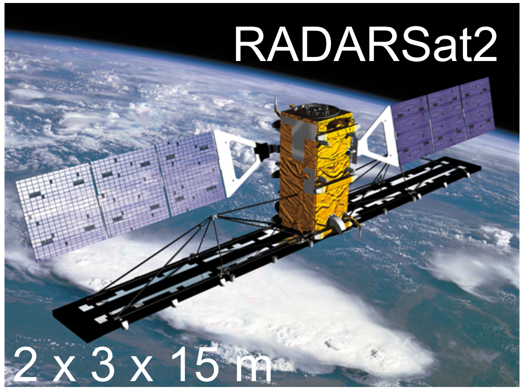


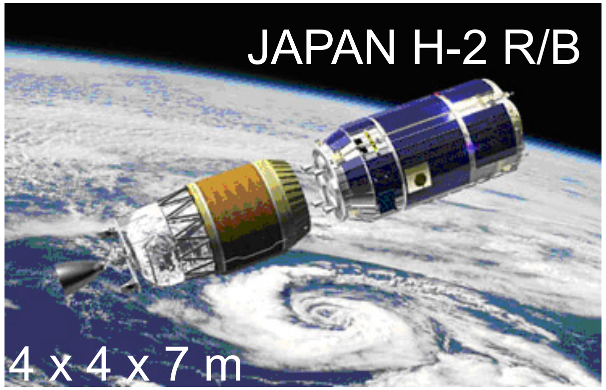
- Peak Reflection at Pentagon Surface

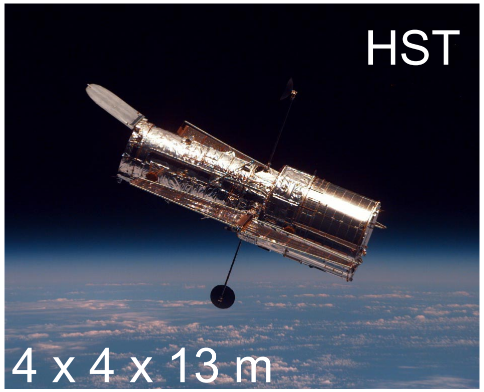
Largest Satellites in Low Earth Orbit

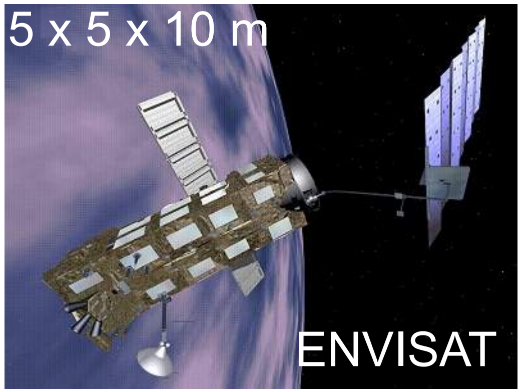


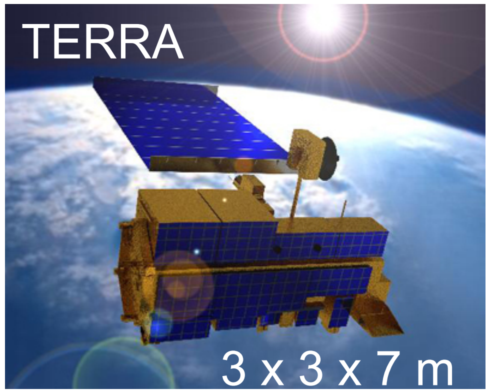






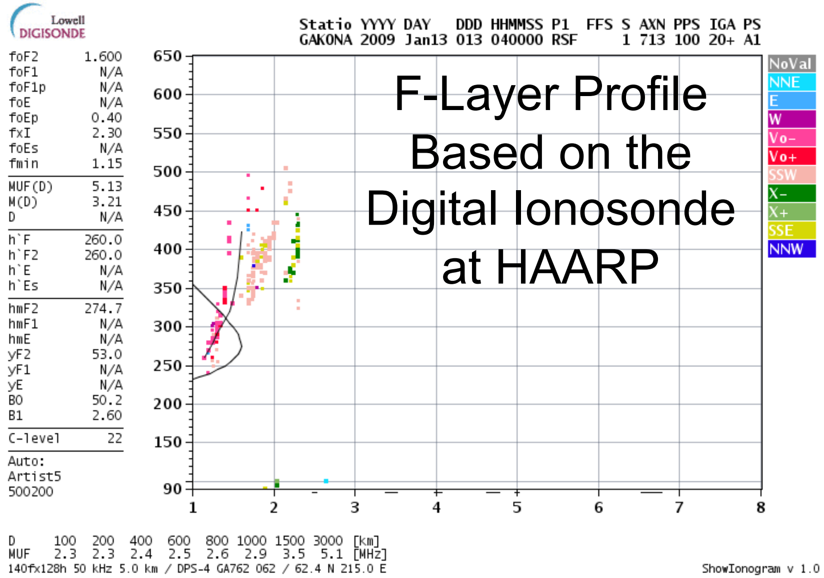


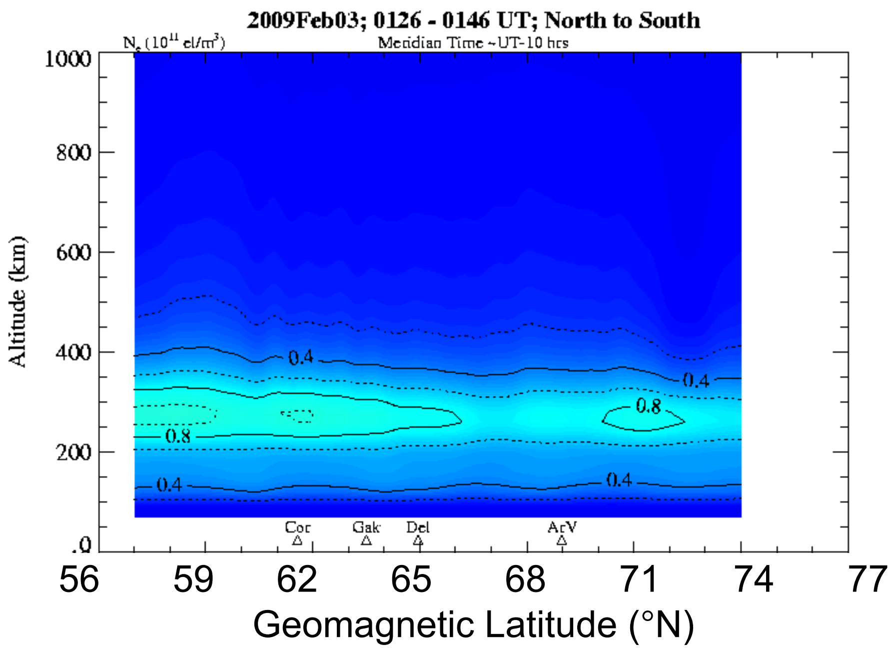




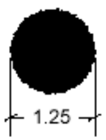
Mitigation of Ionospheric Refraction Effects

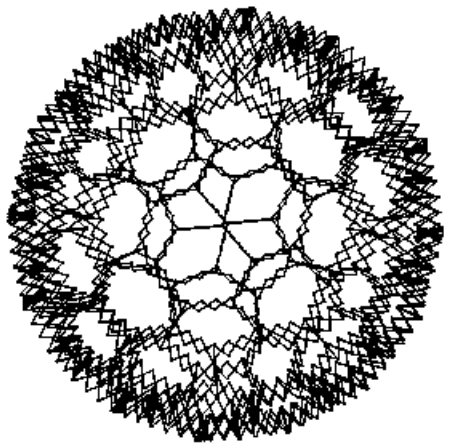
- **Operate at Night**
  - **Low Ionospheric Densities**
    - **Current Winter, Solar Minimum**
    - **HAARP Ionosphere Examples**
    - **Critical Frequency < 1.5 MHz**
    - **Peak Density < 2.8 x 10^4 cm^{-3}**
    - **Minimum Low Elevation Ray Path Bending**
  - **Additional Advantages for Night Time Operations:**
    - **Manmade HF Noise Minimum with the Lack of Ionospheric Reflection.**
    - **No D-Region Absorption → Strong HF Signal to PERCS**
- **Compensate for HF Ray Bending with F-Region Profile Measurements**
    - **Ground Ionograms**
    - **Digital Ionosondes and Radio Beacon Tomography at HAARP**



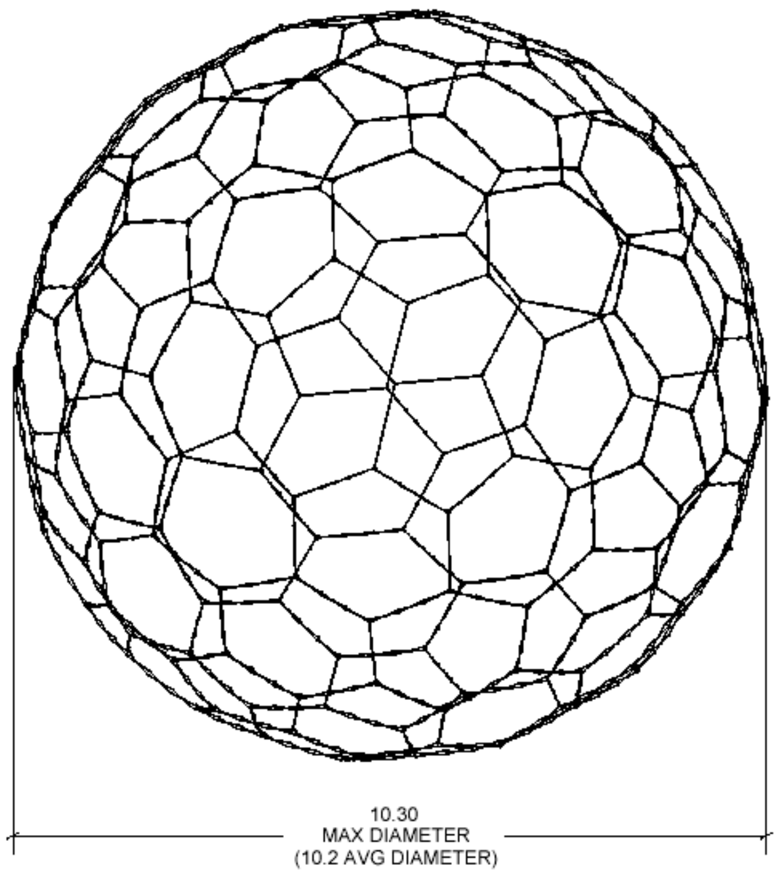


PERCS V180 with 1000-Fold Increase in Volume

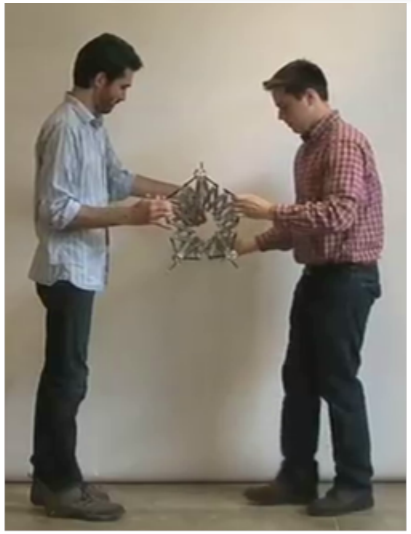
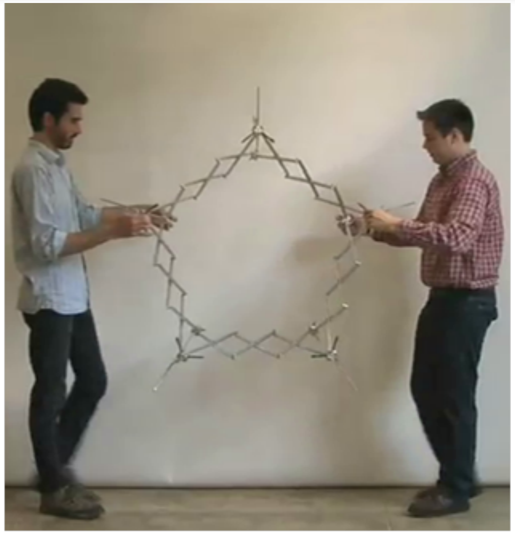
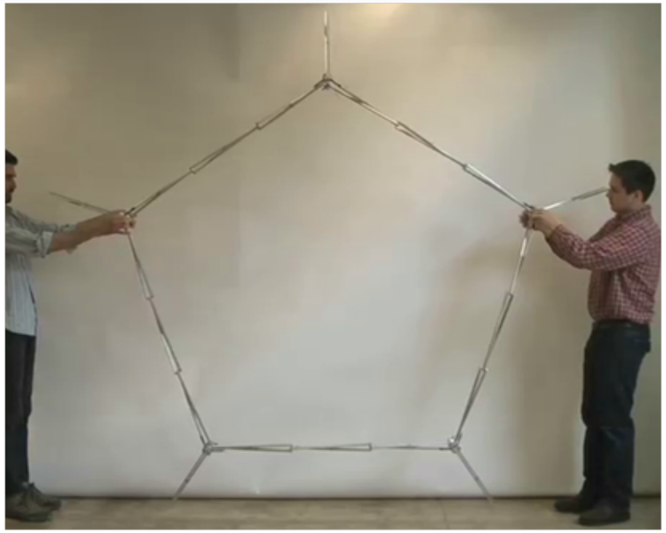
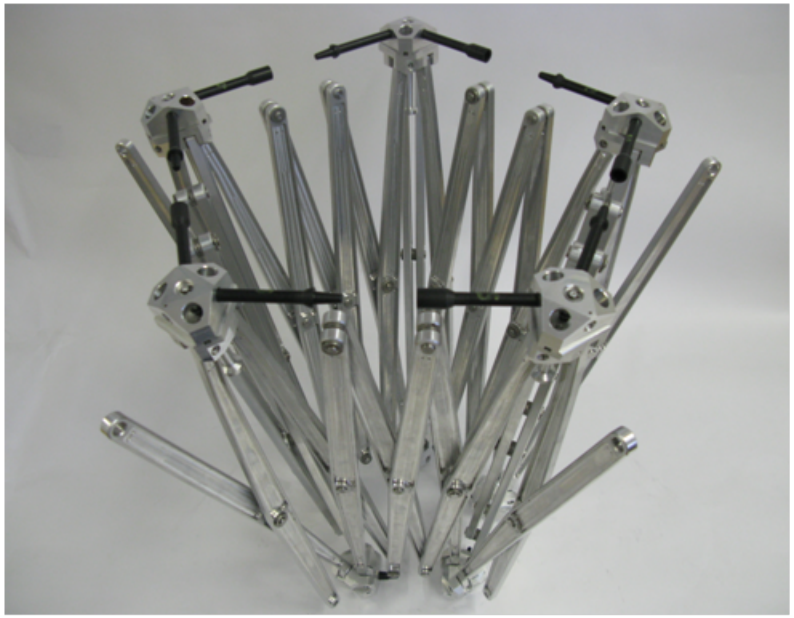
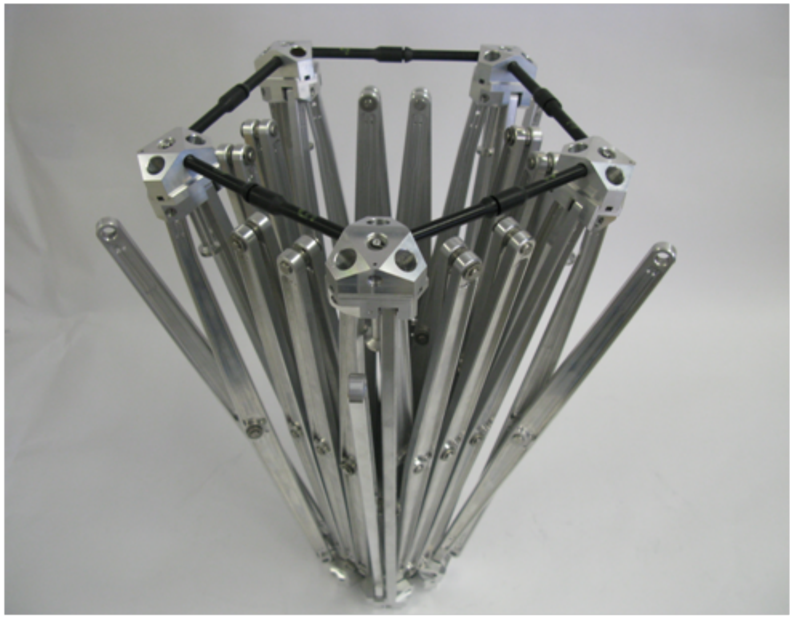




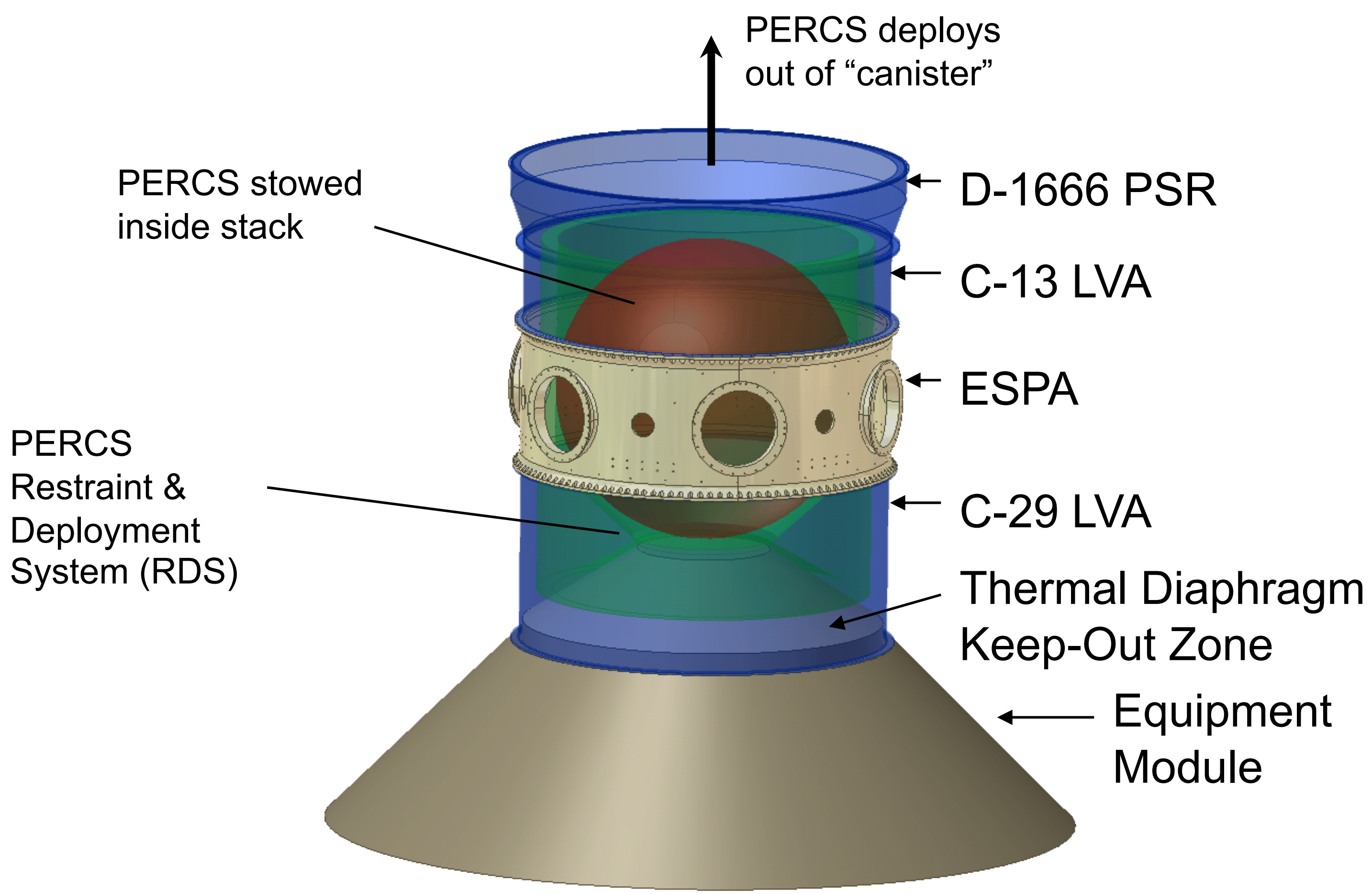
PERCS Current Design (142 kg)



PERCS Pentagon Test Section

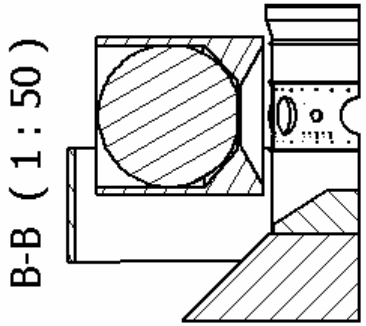
PERCS Restraint & Deployment System (RDS) Concept

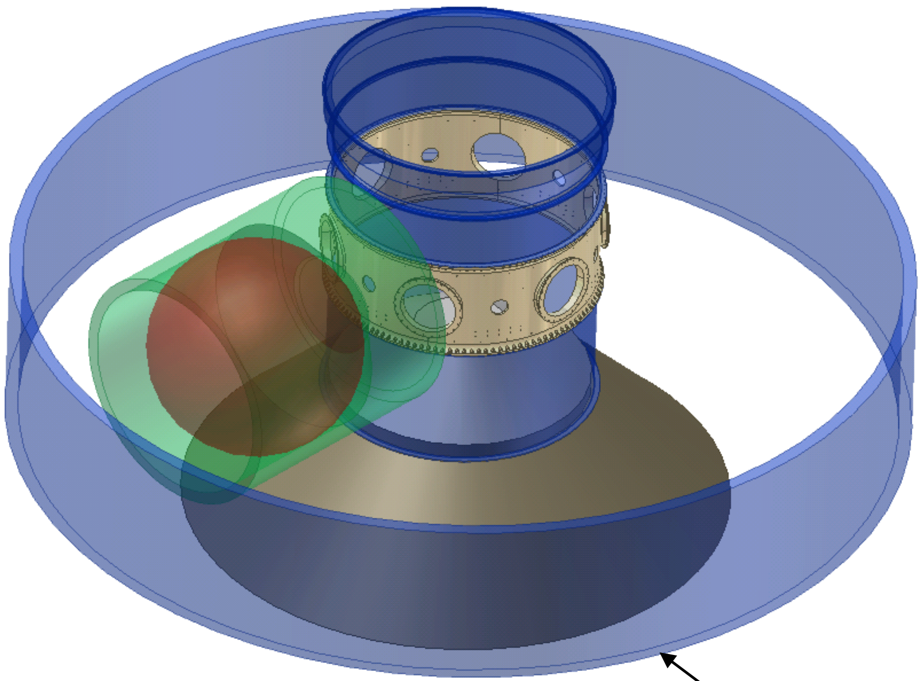


LVA – Launch Vehicle Adaptor
PSR – Payload Separation Ring

PERCS Restraint & Deployment System (RDS) Concept

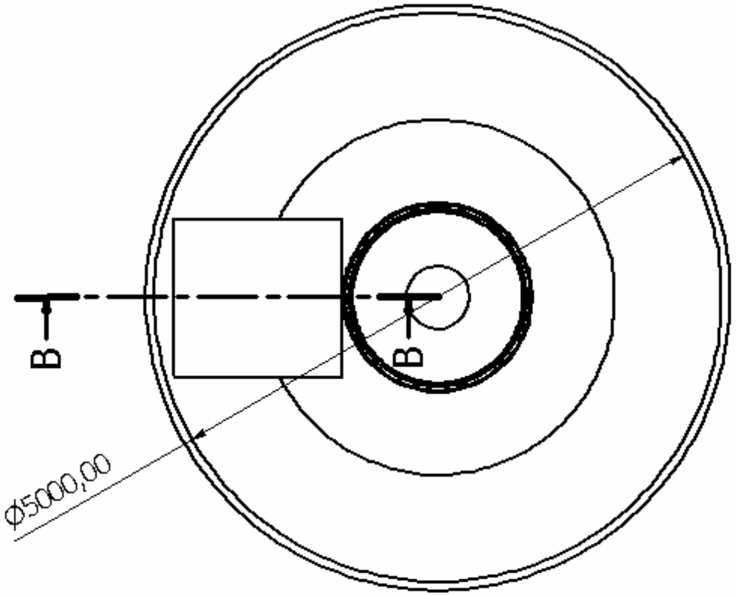
- Same RDS envelope could work for ESPA side-mounted configuration





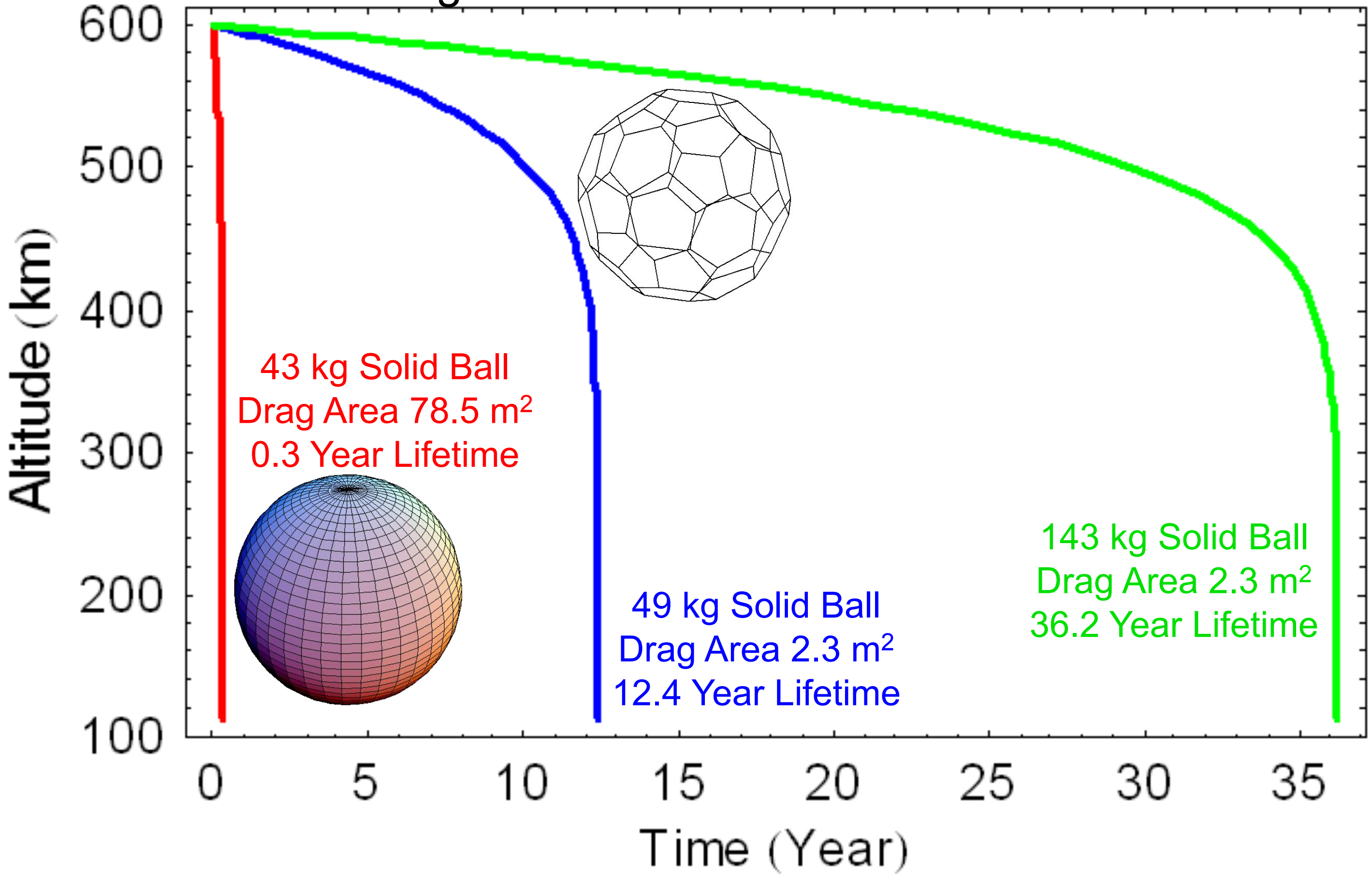
Dimensions in mm

5 meter fairing



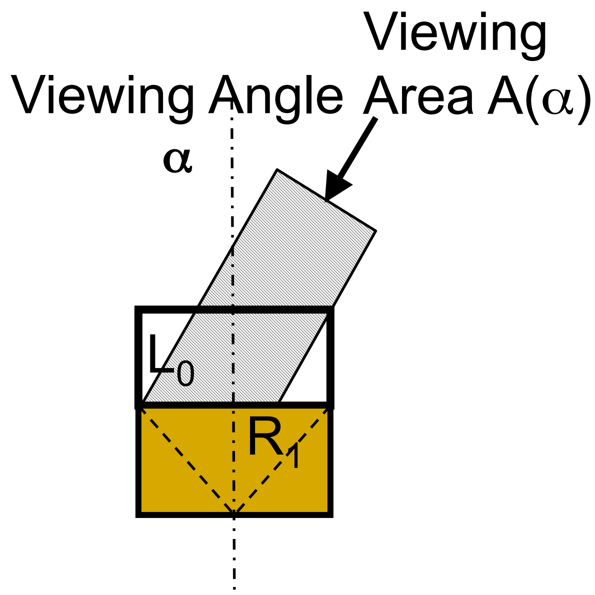
Drag Limitations on Lifetime of 10 meter Spherical Radar Target

PERCS V60 Sphere Released at 600 km Altitude
Drag Based on MSIS-90 Model for 2005



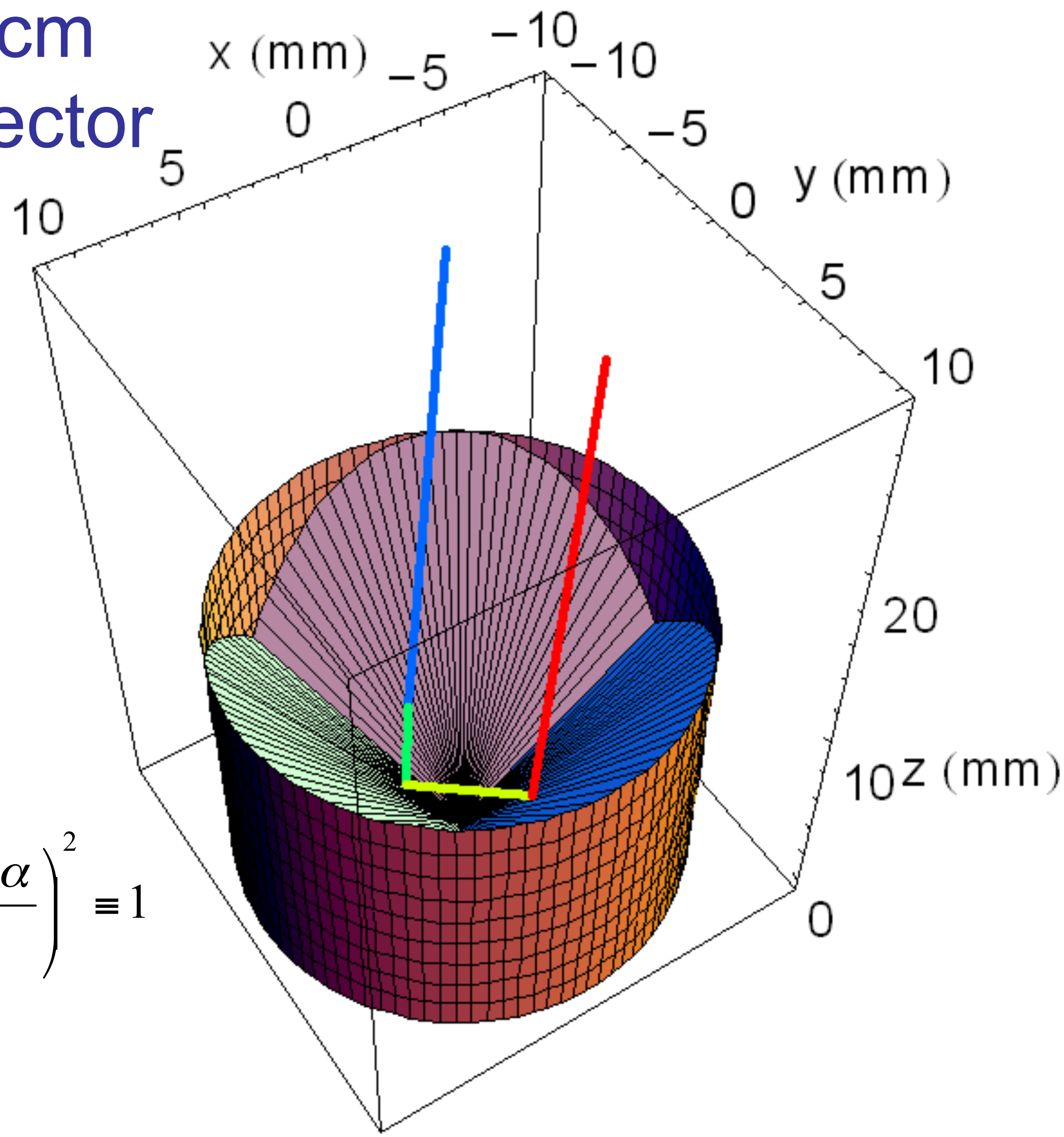
At the Orbit Altitude Between 600 and 800 km PERCS Will Last for More Than 10 Years

Ray Paths for 1 cm Corner Cube Reflector



$$\left(\frac{RCos\theta}{R_1}\right)^2+\left(\frac{2RSin\theta-L_0Sin\alpha}{2R_1}\right)^2\equiv 1$$

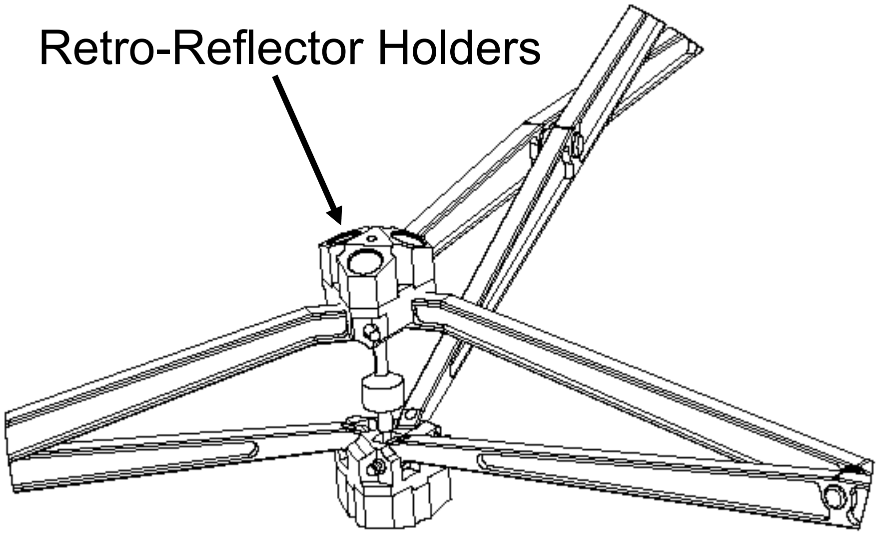
$$A(\alpha)=\int_0^{2\pi}\frac{R(\theta)^2}{2}d\theta$$

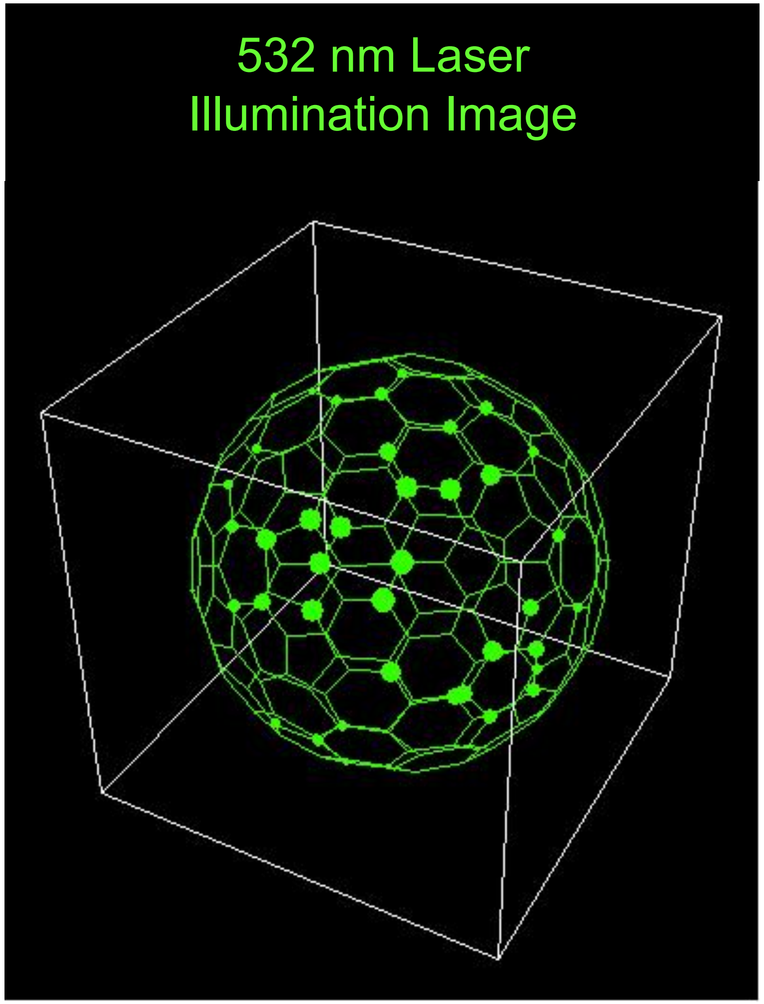


PERCS (NRL-0708) Laser Space Surveillance of Resolved and Non-Resolved Targets

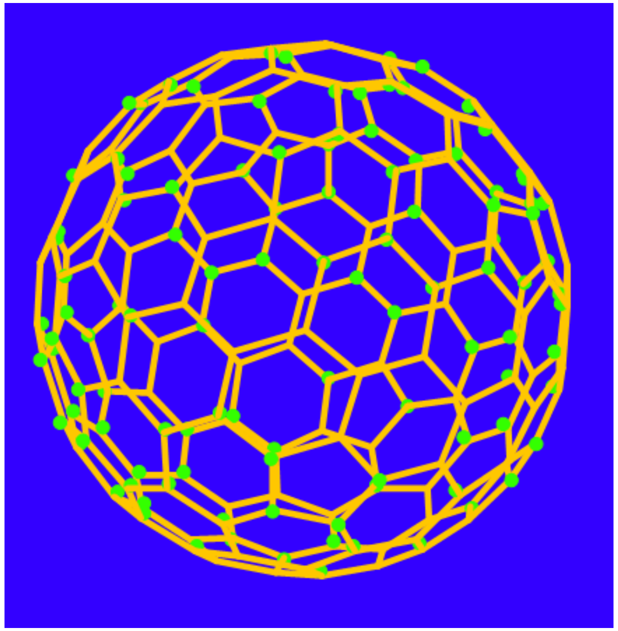
- One Corner Cube Reflector at Each External Vertex Hinge
  - Small Diameter to Match Hinge Size
  - Provides Precise PERCS Position using Laser Ranging and Tracking
  - Flight Heritage from ANDE-RR

Retro-Reflector Holders

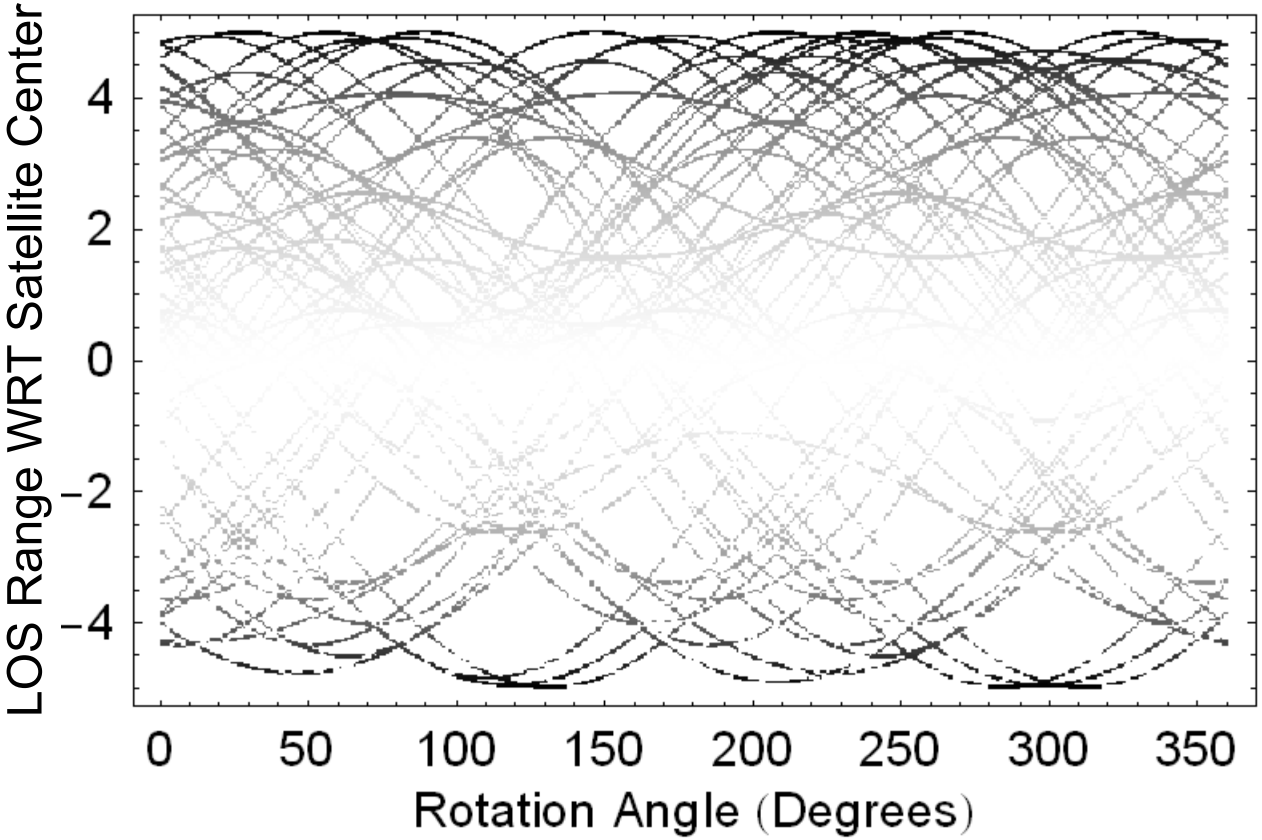




Pulsed Laser Return from PERCS
30° Tilted Retro-Reflectors



PERCS Satellite



PERCS Applications and Endorsements

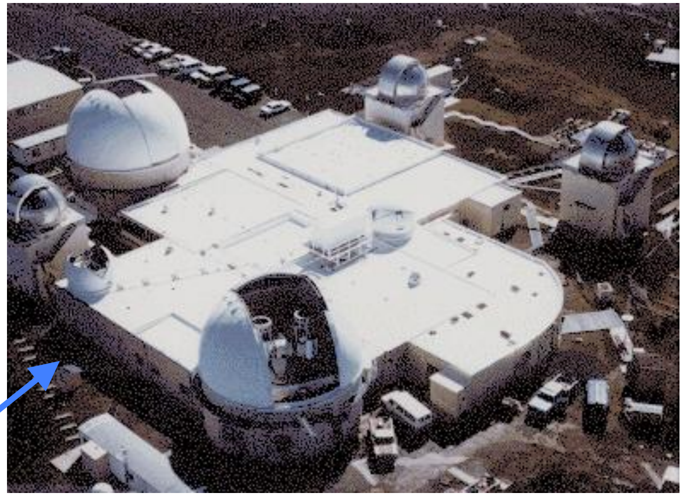
Global Needs:

- World Wide Calibration of SuperDARN
- Validation of HF Heater Patterns
- Laser Tracking and Imaging of Satellites
- Deployment of Large Structures in Space

Participants

- **SuperDARN and Space Weather Radars**:
  - Richard Behnke, NSF, United States
  - Bill Bristow, GI-UA, United States
  - Elsayed Talaat Ray Greenwald, APL, USA
  - J. Michael Ruohoniemi, Virginia Tech, USA
  - George Sofko, U. of Saskatchewan Canada
  - Terry Robinson, U. of Leicester, England
- **HAARP, EISCAT, Arecibo, SURA Heating**:
  - Craig Selcher, NRL, HAARP, United States
  - Paul Kossey, AFRL, HAARP, United States
  - Esa Turunen, EISCAT, Kiruna, Sweden
  - Mike Rietveldt, EISCAT, Tromso, Norway
  - Michael Kosch, U. of Lancaster, England
  - Mike Sulzer, Arecibo Observatory, Puerto Rico
- **Optical and Laser Tracking Sites**:
  - Linda Thomas, NRL Optical Test Facility (OTF), United States
  - Haleakala Optical Sites, Jim Riker, Hawaii

NRL Optical Test Facility (OTF) at the Midway Research Center



Maui Optical Site (AMOS)

Status and Issues

- PERCS Status
  - Design Complete
  - First Section Construction Finished
  - Launch on Falcon 9 Available in 2012 to 2015
- Issues
  - Can SuperDARN/Cutlass Radars See PERCS
    - 200 m^2 Radar Cross Section
    - 600 km Altitude
    - Try to View Large Orbiting Satellites
  - Funding
    - $ 800k Need for Final Construction and Testing Before Launch
    - $ 200 k Available from Australia


Naval Research Laboratory
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