Atmospheric Neutral Density Experiment
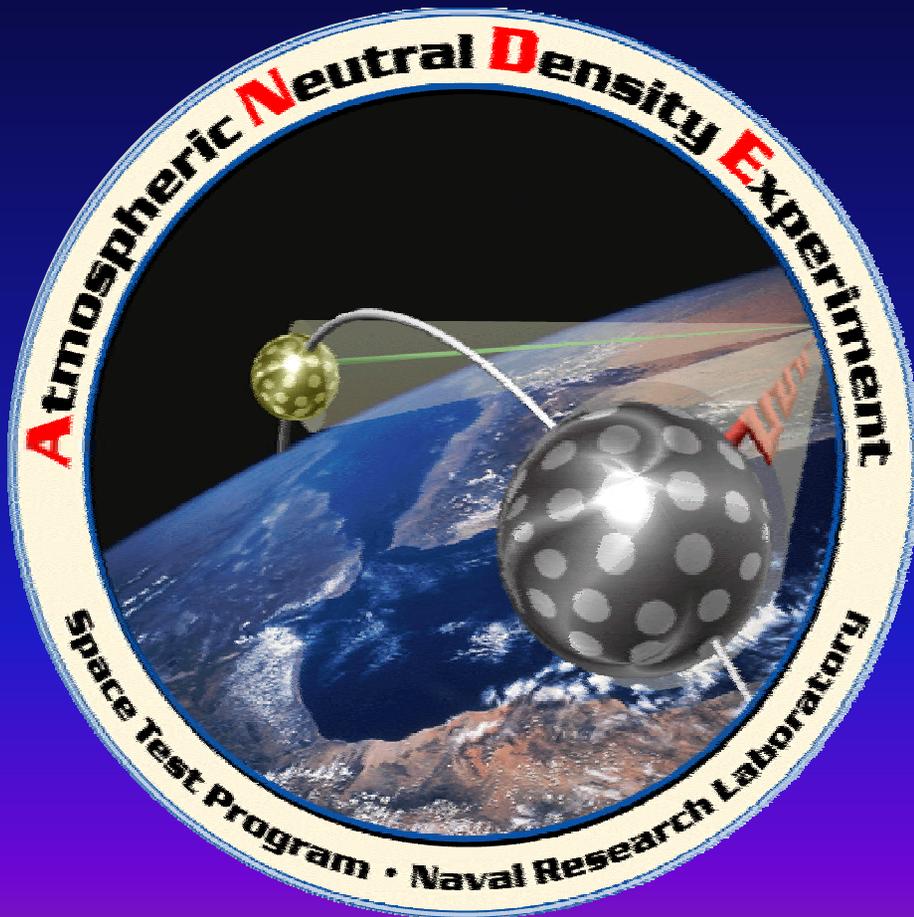# & Modulating Retro Array in Space

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Objectives:

1. **Provide Total Atmospheric Density for Orbit Determination and Collision Avoidance**
2. **Space to Ground Optical Communication Demo**
3. **Validate Fundamental Theories on the Calculation of the Drag Coefficient**
4. **Provide Calibration Object for Radar Fence Upgrade**
5. **Establish a Method to Validate Neutral Density & Composition Derived from DMSP Sensors.**
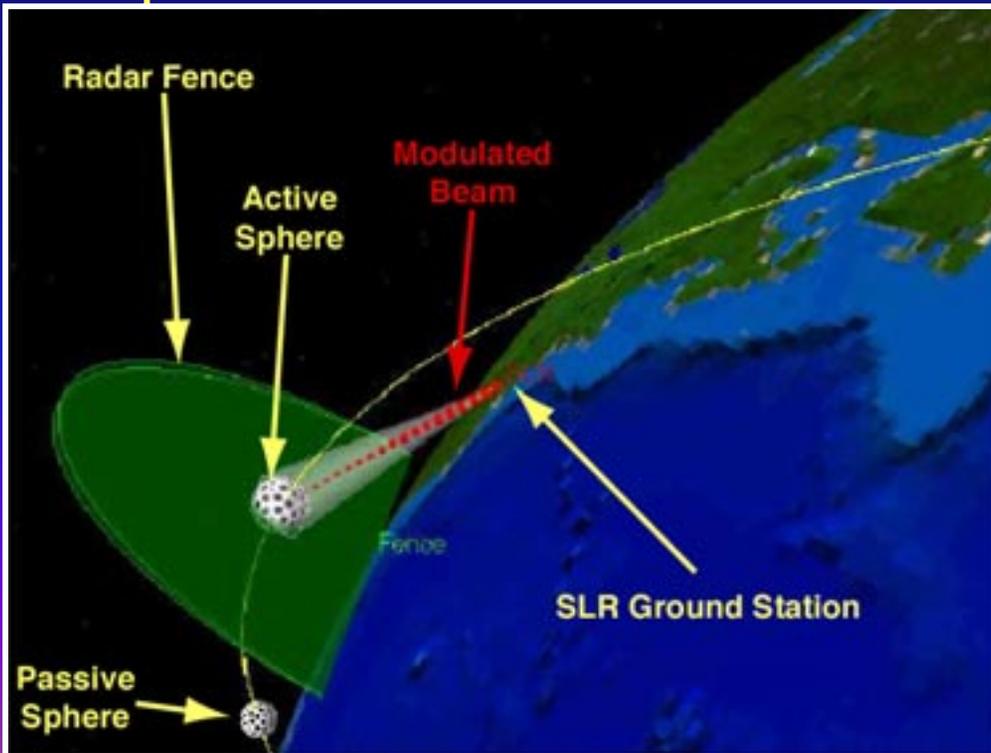
- **Description:**

- **Fly two 19" spheres in lead-trail orbit**
  - **400 km orbit**
  - **51 Degree inclination**

- **25 kg Sphere (alum. w/ Kapton)**
  - **Observed with SSN and SLR; variation in observed position used to determine in-track total density**

- **50 kg Sphere (glass coated)**
  - **Test Communications with Modulated Retro-Reflectors (MRR)**
  - **Determine position wrt to passive sphere**
    - **Compute total density**
    - **Validate C_D models**
  - **Use on-board instrumentation to calculated density and composition**
  - **Launch via Shuttle in CY05**

- Two Way Optical Communication Using Single Laser Transmitter
- Simple and Compact Optical Data Transfer
- Data Rates approximately 10 Kbit/Sec (LPI) (Link Dependent)
- Low Power and Low Mass

Experimental Objectives:

- **Obtain** <u>**B**</u>**it** <u>**E**</u>**rror** <u>**R**</u>**ate as a function of modulation and atmospheric effects;**

- **Obtain Power Spectrum of signal fluctuations through channel for different modulation frequencies;**

- **Determine impact of asymmetry on data link in terms of BER & signal fluctuations;**

- **Obtain insight into effects of partial coherence combined with scintillation on signal return;**

- **Obtain performance statistics over at least a calendar year to assess seasonal factors.**

- **Provide a low power, compact method of communications for ANDE**

Laser Interrogation Beam

Modulated Laser Reflections
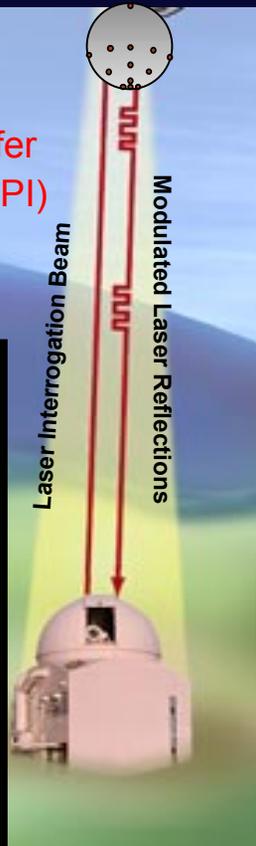
Objectives:

- Provide a simple, compact, lightweight means of effecting optical data transfer in free space by obviating the need to fly a laser and gimbaled telescope;

- Measure atmospheric channel effects affecting the optical (near-infrared) link;

- Demonstrate Multiple-Quantum Well Retroreflector Array as an enabling <u>compact , low power</u> technology for optical data transfer through space to ground for a viable mission.

Description:

Illuminate from ground retromodulators which are Specifically distributed on ANDE spacecraft;modulate Multiple Quantum Well shutter and measure intensities in theTx & Rx signals through ground-to-space-to-ground channel;

Payload:

- 16 retromodulators
- OnBoard Opto-Electronic Detectors
- ANDE instruments

- **Launch and launch integration sponsored by DoD Space Test Program (STP)**

- **Launch Vehicle: Space Shuttle**

- **Orbit Insertion: Shuttle via DoD unique payload ejection system**
  - **Required $\Delta v = 5$ fps**

- **Orbit:**
  - **Circular between 400-450 km**
  - **51.6° Inclination**

- **Lifetime: Depending on solar activity & initial insertion altitude,**
  - **1-3 years (50 kg)**
  - **~1 year (25 kg)**

Optical Retro-Reflector
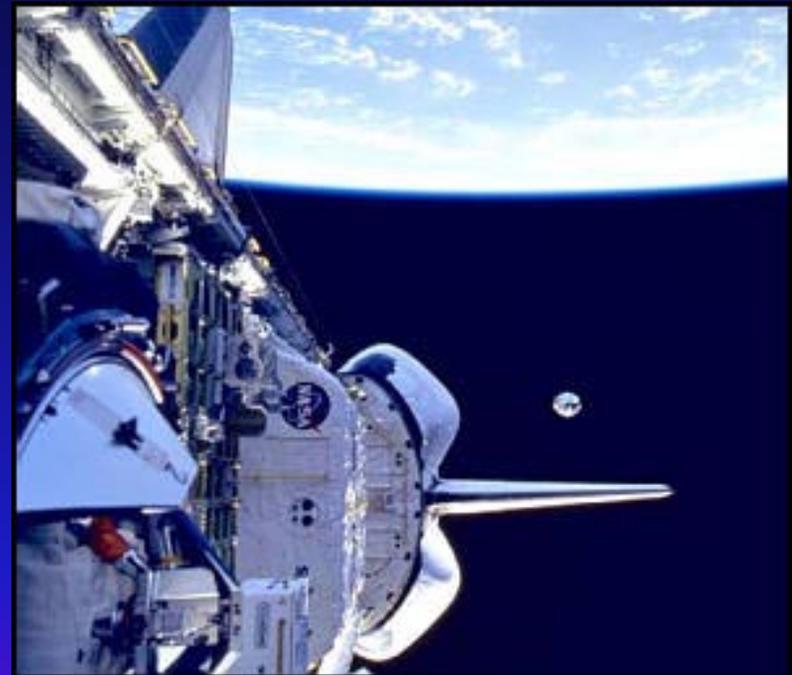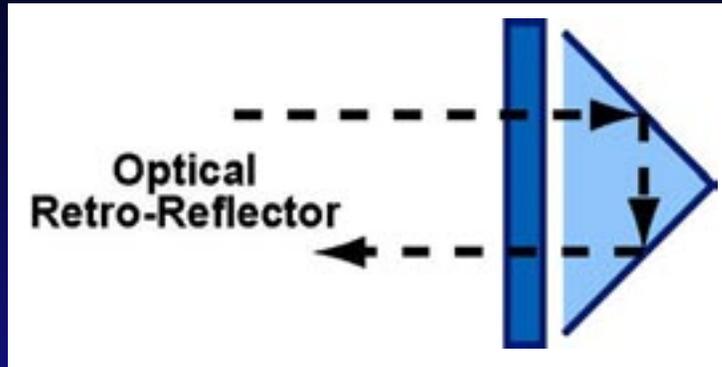
- Optical retro-reflector returns photons back along their original angle of incidence
- 30 optical retro-reflectors (562 nm) distributed at latitudinal bands on sphere
  - One at ±90.0°
  - Six at ±52.5°
  - Eight at ±15.0°
- Simulation of retro signal for 51.6° inclination at 400 km altitude NASA MOBLAS site
- $\sigma_{LRCS} \geq 10^4 \text{ m}^2$
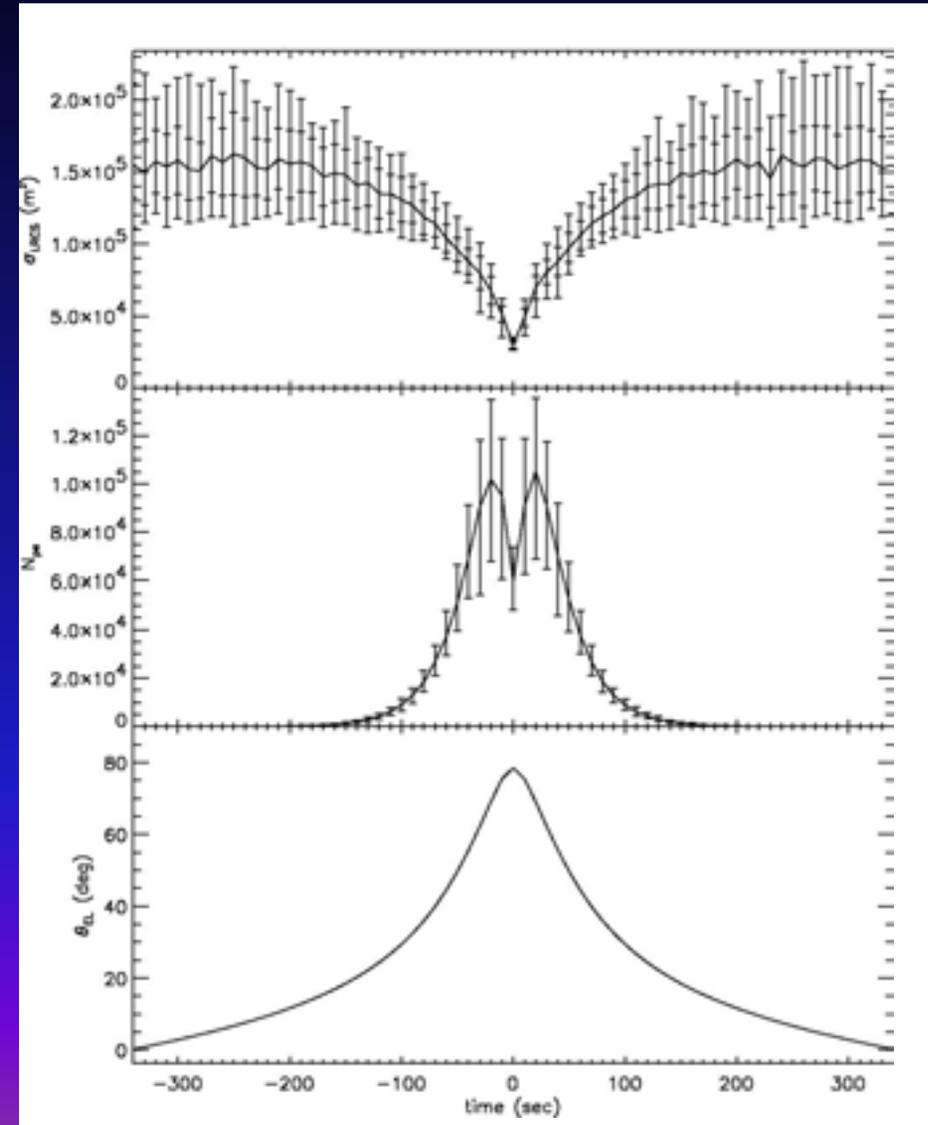
- **Same Dimensions as the Passive Sphere**
  - **Diameter = 0.4826 m , Area = 0.1829 m^2**
  - **Mass = 50 kg, Coated in Fused Silica**
- **On-board Instrumentation & Components**
  - **Modulating Retro-Reflector (MRR) Array**
    - **Final layout analysis in progress**
      - One hemisphere densely populated
      - One hemisphere with single MRR
  - **Thermal Control System (± 5 C)**
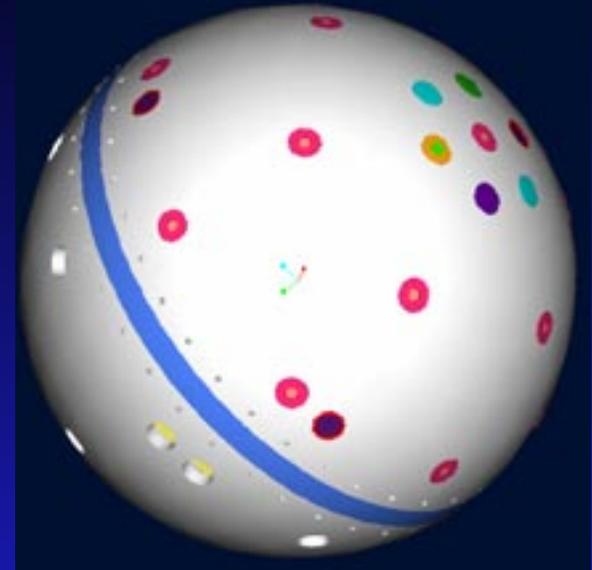 - **Thermal Monitoring System (TMS) (≤ 1C)**
  - **Global Positioning Sensor (GPS)**
  - **Wind and Temperature Spectrometer (WATS) (1-46 amu)**
  - **Backup Communications System**
  - **Photovoltaic Arrays**
  - **Lithium Ion Batteries**
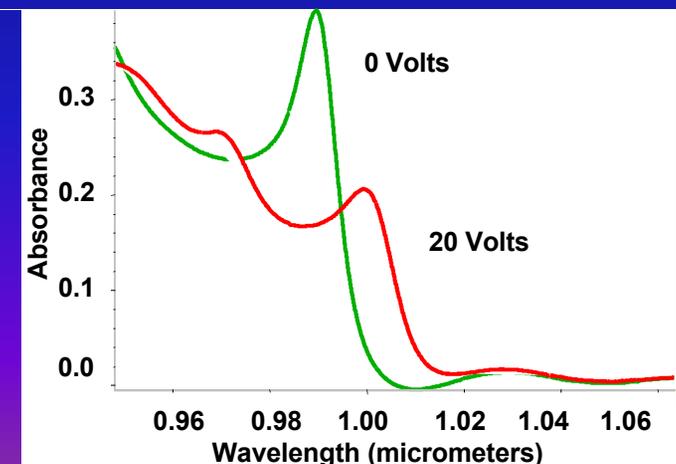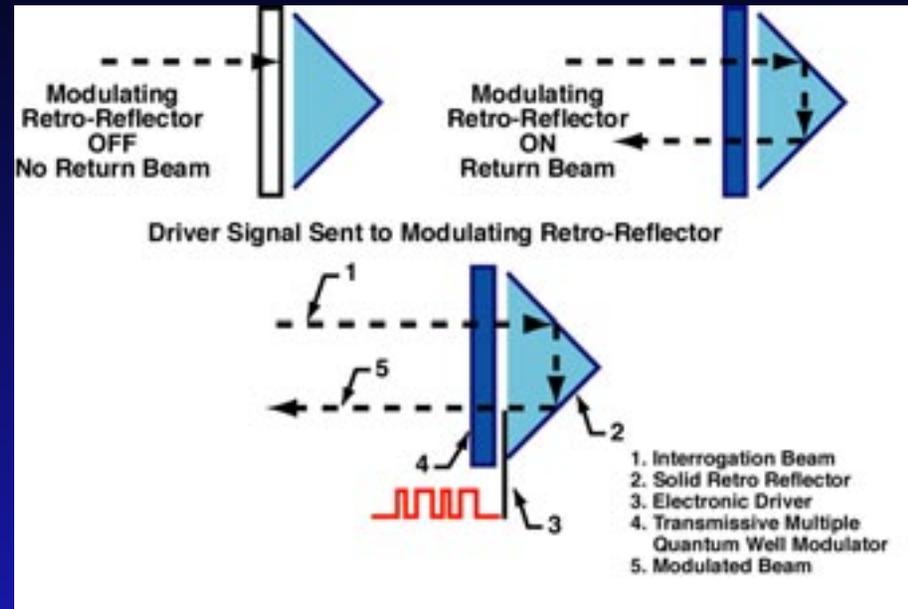
Modulating Retro-Reflector

• **Couples an optical retro-reflector with a Multiple Quantum Well (MQW) electro-optic shutter**

- –1 cm aperture
- –Operates at 980 nm or 1.06 μm
- –Runs at 10-18 Volts
- –Draws ~130 mW per device
- –Field-of-View = ~45° FWHM
- –10 Kbits/s nominal mode
- –1 Mbit/s testing mode
- –Identify which retro is illuminated to determine satellite's spin rate
- –US Patent No. 6,154,299
- –POC:Charmaine Gilbreath
    NRL Code 7215
    Gilbreath@rsd.nrl.navy.mil

Modulating Retro-Reflector OFF No Return Beam

Modulating Retro-Reflector ON Return Beam

Driver Signal Sent to Modulating Retro-Reflector

1. Interrogation Beam
2. Solid Retro Reflector
3. Electronic Driver
4. Transmissive Multiple Quantum Well Modulator
5. Modulated Beam

0 Volts

20 Volts

Absorbance

Wavelength (micrometers)

Mission Timeline

Launch

Orbit Insertion

Orbit Determination Period

COMMs Experiment

Density Measurements

Expected

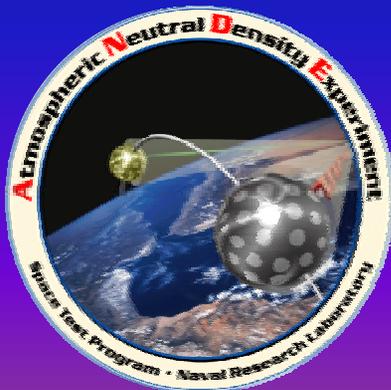Actual
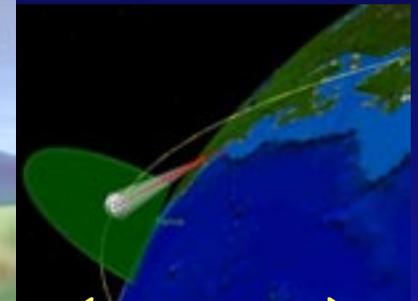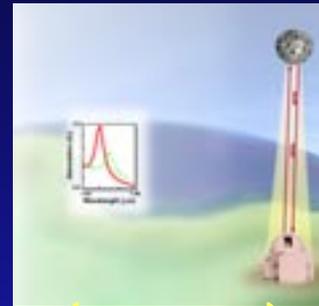
Early 2005

L+ 8-10 Days

2 Weeks

2-4 Weeks

1-3 Years

Mission Science Objectives

Comms Experiment

Density Experiment

Mission Timeline

Goals: 1. **Test CAPE System**

2. **Determine spin rate & spin vector of sphere**

3. **Prototype NSC calibration target for radar fence**

Science: Total neutral density, C_D studies, geomagnetic storm effects, fence calibration

Two spheres (Launch in late 2003)

- **1st Sphere: Same size/mass/form factor as ANDE Active sphere**
  - **48 cm diameter, 50kg [3]**
  - **Allows for testing of CAPE with sphere similar to ANDE active [1]**
  - **Retros for SLR (solar glint for spin) [2]**
  - **Polarizing & non-polarizing paint scheme [2]**
  - **Laser diodes [2]**
  - **Test backup communications system for ANDE active**
  - **Space qualify new photovoltaic arrays [2]**
  - **Thermal monitoring system**
- **2nd Sphere: Design driven by NSC need for radar fence sensitivity needs [3]**

RR MAA Sphere Status

- **Layout of retros finalized, two hemispheres**
  - Two densely populated (15 retros per hemisphere)
    - Retros located in latitudinal bands (no touch zones: 2 in. wide centered at lat.)
      - one at $\pm 90°$; six at $\pm 52.5°$; eight at $\pm 15°$
- **Locations of six ~1.0 in² photovoltaic arrays**
  - Photovoltaic array: ITN energy systems thin film Copper Indium Gallium Diselenide (CIGS) (bi-axial curvature)
- **Laser diodes (6) locations**
  - Wavelength of 808 nm, 500 mW optical output, pulsed 0.5-3.25 Hz, 2.7 W power
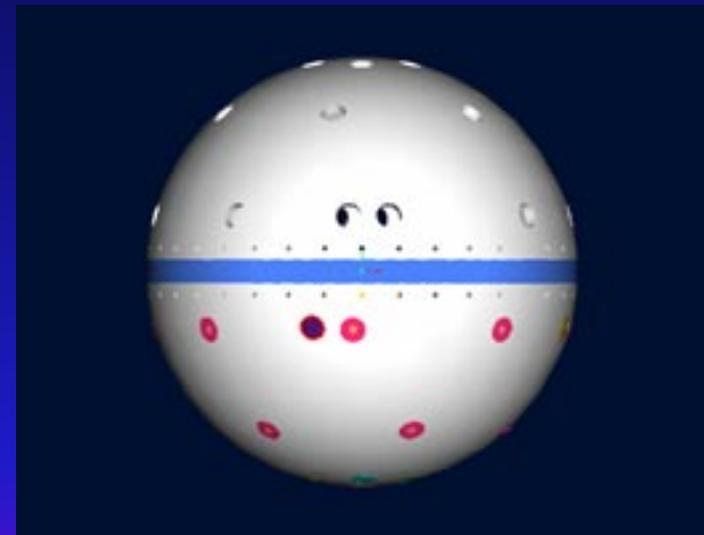 - Duty Cycle of 5 minutes; activated on passes over Maui with elevation > 20°
- **Polarization study via HI-Class**
  - Anodized Aluminum (randomizes)
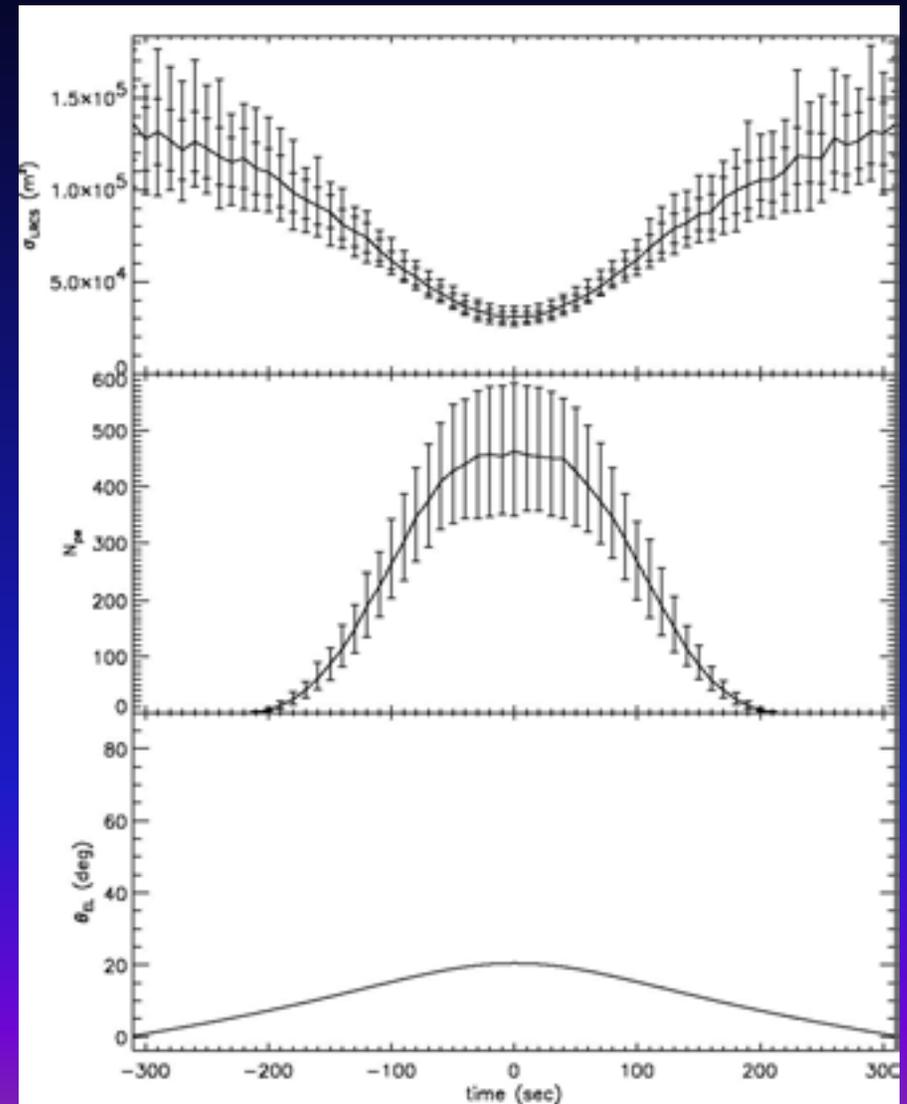 - Aeroglaze A276 Gloss White paint (preserves)
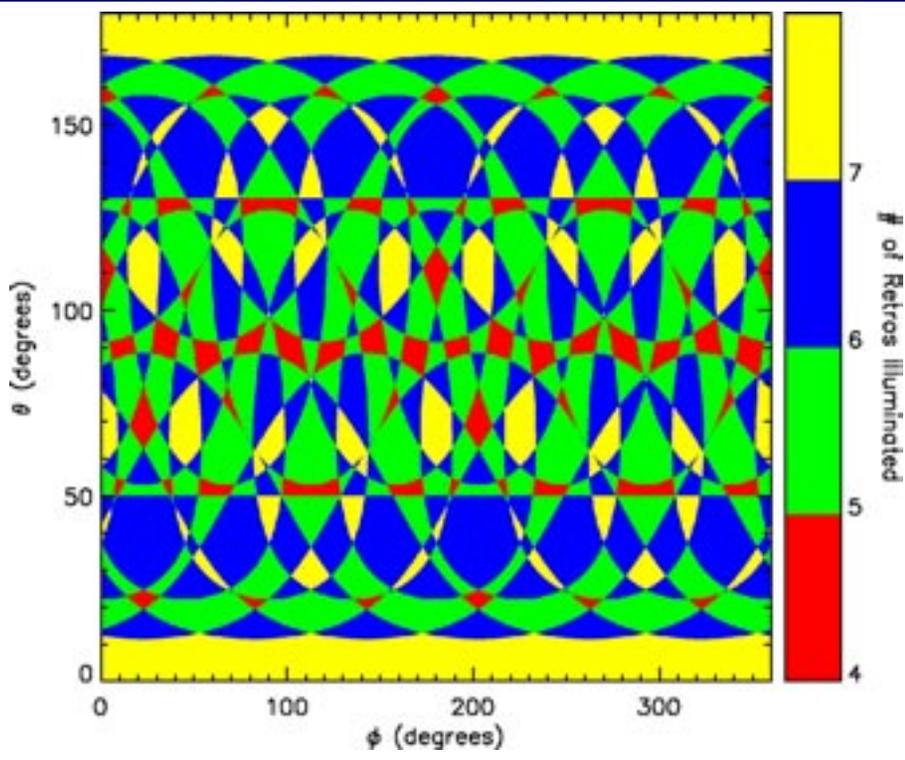 - Samples being tested in Maui
  - Paint pattern pending thermal analysis

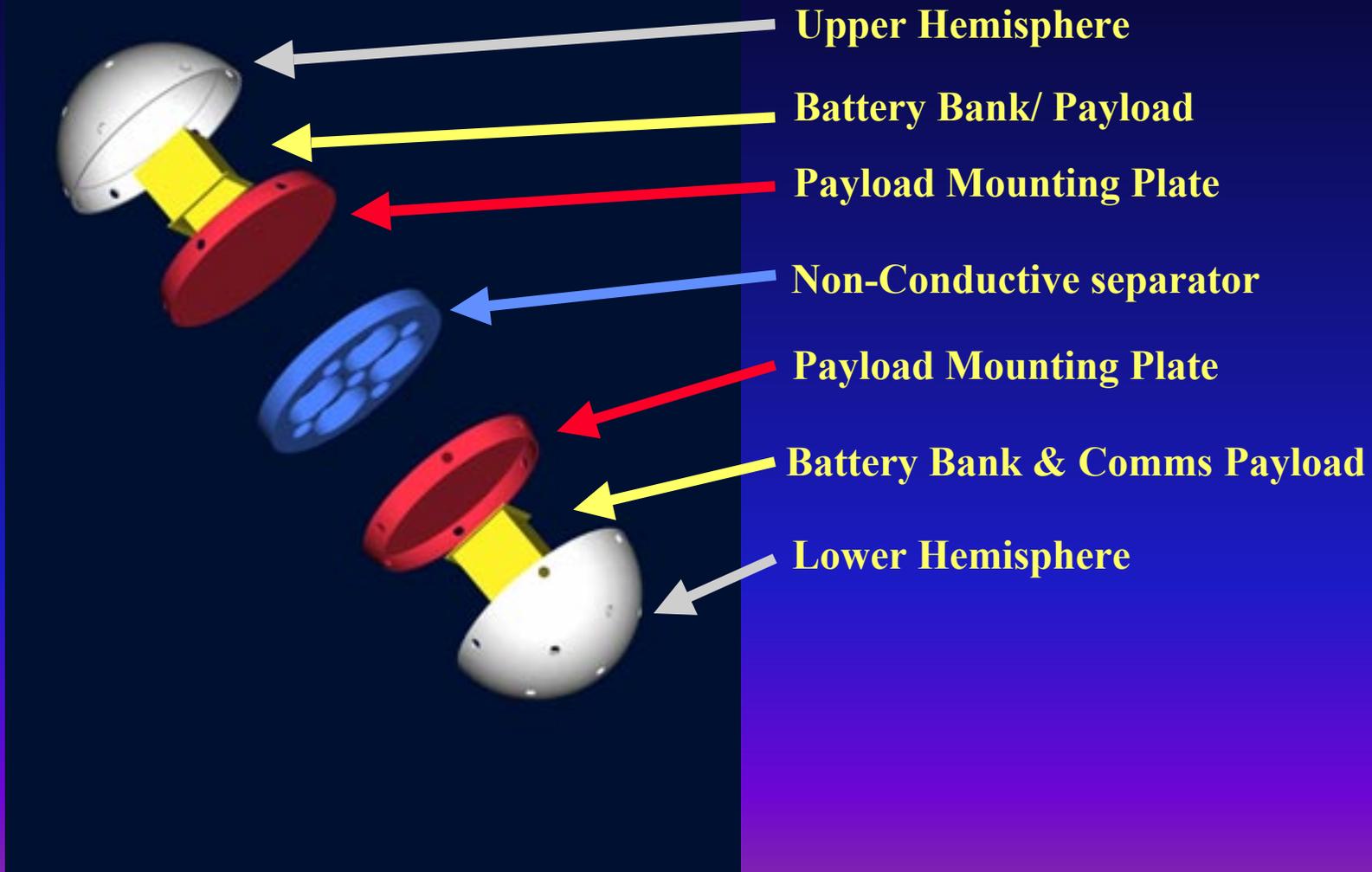- LRCS calculated for:
  - 532 nm
  - Worst case pass shown: elevation 20°
  - NASA MOBLAS laser ranging site efficiency

Upper Hemisphere

Battery Bank/ Payload

Payload Mounting Plate

Non-Conductive separator

Payload Mounting Plate

Battery Bank & Comms Payload

Lower Hemisphere

Backup Communications

- **Communications system: Based on PCSat design (USNA)**
  - Uses symmetry of spacecraft as antenna (non-conducting separator between conducting hemispheres). Operates @ 145 MHz
  - Send "Heartbeat" telemetry every 2 minutes
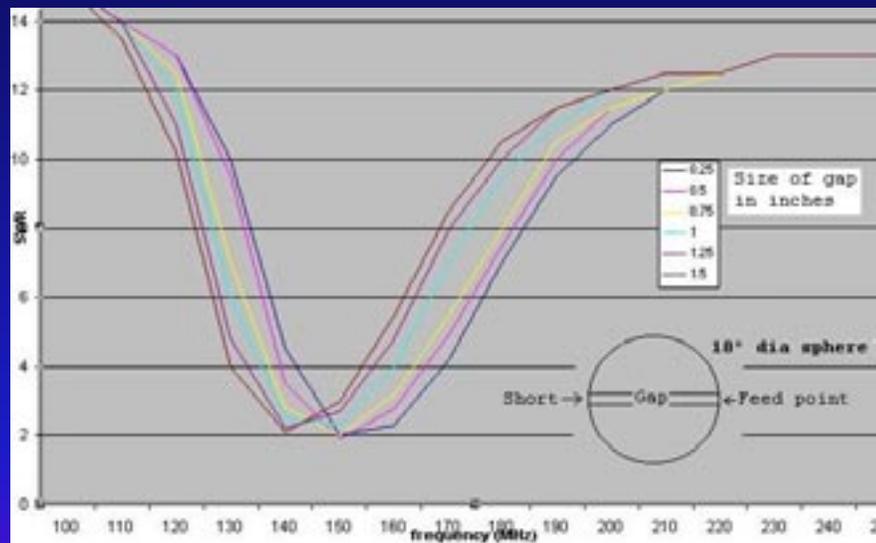
Heartbeat Telemetry to Consist of:

•Temperature, Current, Voltage, and time from 6 photovoltaic arrays

•All tagged to location on sphere and time to allow for spin rate/axis determination.

•Can be collected worldwide

Instrument / Science Obj.	SSN & SLR	MRR	TMS	WATS	GPS	Model	Instrument or Mission
Total Neutral Density	A & P			A	A	MSIS, J70, TMC	SSULI, CHAMP GRACE, STARSHINE
Proof of Concept		A		A			
C_D Studies	A & P	A	A&P	A		Raytheon	CHAMP, GRACE, STARSHINE
Attitude Determination	A & P	A		A*	A*		
Neutral Composition				A		MSIS	SSULI
Neutral Temperature				A		MSIS	SSULI
Cross-Track Winds				A		HWM	CHAMP
Atmospheric Effects BER		A					RME
Partial Coherence Studies		A					
Geomagnetic Storm Effects	A & P		A&P	A	A	MSIS	SSULI, CHAMP GRACE, STARSHINE
Fence Calibration	A & P				A		

A = Active Sphere   **P = Passive Sphere & RR**   *** = Inferred**

1. Scientists at NRL have developed new methods of measuring total mass density along the orbital track, based on observations and element sets. Until the recent launches of the AF ARGOS, NASA TIMED and European CHAMP missions, no thermospheric science missions had been flown for nearly two decades. Even with those missions, the database is incredibly sparse, making the SLR data analysis both unique and valuable for answering key questions about the thermosphere. ANDE objects are particularly amenable to this analysis because of their spherical shapes. These factors render the ANDE-derived density data superior to data that could be derived from most LEO objects in the US Space Command and Naval Space Command catalogs.

2. Scientists at NRL, AFRL, and the space commands are presently assimilating space object observations to enhance significantly the accuracy of orbit determination for selected satellites. SLR orbit data on the ANDE satellites will provide an important standard by which to evaluate and validate this improvement in the accuracy of operational special perturbations (SP) state vectors. The ANDE density data could also be assimilated into the operational databases as a calibration object producing improved state vectors.

3. The ANDE satellites will sample the region of space in which the International Space Station and shuttle. Using the technique mentioned above, atmospheric density can be computed to estimate atmospheric drag experienced by manned platforms and by that require collision avoidance maneuvers. By combining the improved precision orbit determination mentioned in item (2) with an improved characterization of the drag uncertainties in position can be reduced. Improved position knowledge may help to prevent unnecessary maneuvers when a collision is suspected.

4. Present-epoch total mass density data, when combined with the NRLMSISE-00 and similar empirical models, will improve the accuracy of the global thermospheric density specification for use in initializing and constraining physics-based simulations of thermospheric and ionospheric response to solar and geomagnetic forcing. These simulations will be useful in analysis of scientific data (e.g., from ARGOS, TIMED, and CHAMP) and in studies of upper atmospheric mechanisms and phenomenology.
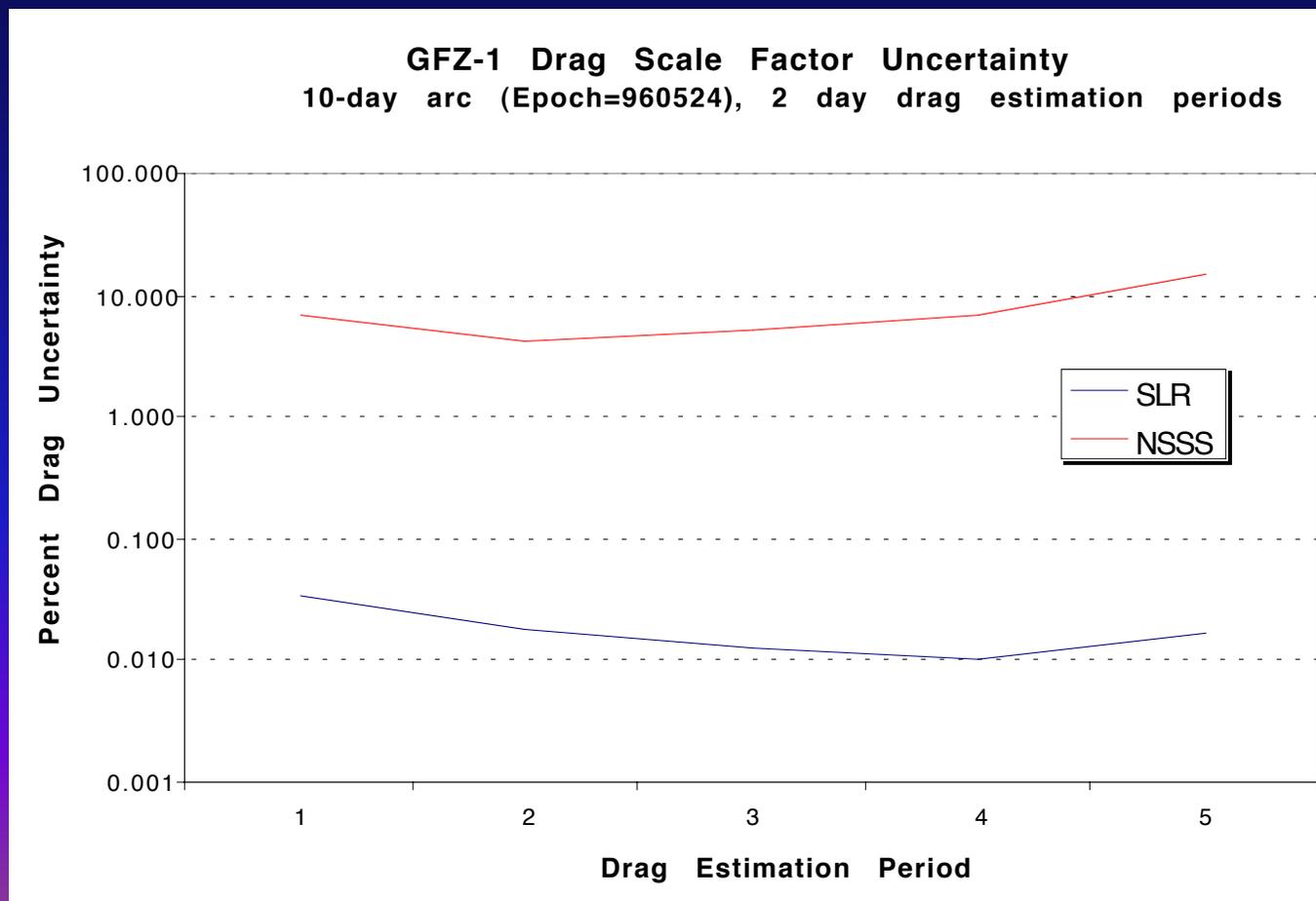
C_D estimated every 2 days using SLR obs. & NSSS obs.

a priori weighting of the data is such that the weighted RMS of Fit to the two data types is the same

SLR Data: 1100 SLR observations from 52 passes over 10 days per day , data weight of 1m

ANDE A/M about 10x that of GFZ-1   (Analysis courtesy of Chris Cox, Raytheon)

GFZ-1 Drag Scale Factor Uncertainty
10-day arc (Epoch=960524), 2 day drag estimation periods

- **Risk Reduction Mission Objectives**
  - **Test deployment system**
  - **Test backup communications system**
  - **Space qualify new photovoltaic arrays**
  - **Track with HI-CLASS & AEOS systems**
  - **SLR Tracking request in preparation**
- **Status: Preliminary Design Review in October 2002**
- **Launch in late 2003**

- **ANDE Flight Objectives**
  - **Provide Total Atmospheric Density for Orbit Det. and Collision Avoidance**
  - **Space to Ground Optical Communication Demo**
  - **Validate Fundamental Theories on the Calculation of the Drag Coefficient**
  - **Provide Calibration Object for Radar Fence Upgrade**
  - **Establish a Method to Validate Density & Composition from DMSP Sensors.**
- **Status: Initial Design Phase**
- **Launch in 2005**

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Supplemental Slides

- **US Space Surveillance Network (SSN) will track the two satellites after orbit insertion and provide accurate orbital state vectors for each sphere to the SLR sites**
- **Satellite Laser Ranging (SLR) sites, both domestic and international, can then acquire the two spacecrafts and make routine SLR observations**
- **Access simulation for the NRL site in Quantico, VA (will also use Maui, HI)**
  - **Elevation angle constraints $20° < elev < 85°$**
  - **Night observations**
  - **Beginning of Life:**   **alt = 400 km**   **access = 3-4 minutes**
  - **End of SLR tracking life:**   **alt = 300 km,**   **access = 2-3 minutes**

Access Analysis
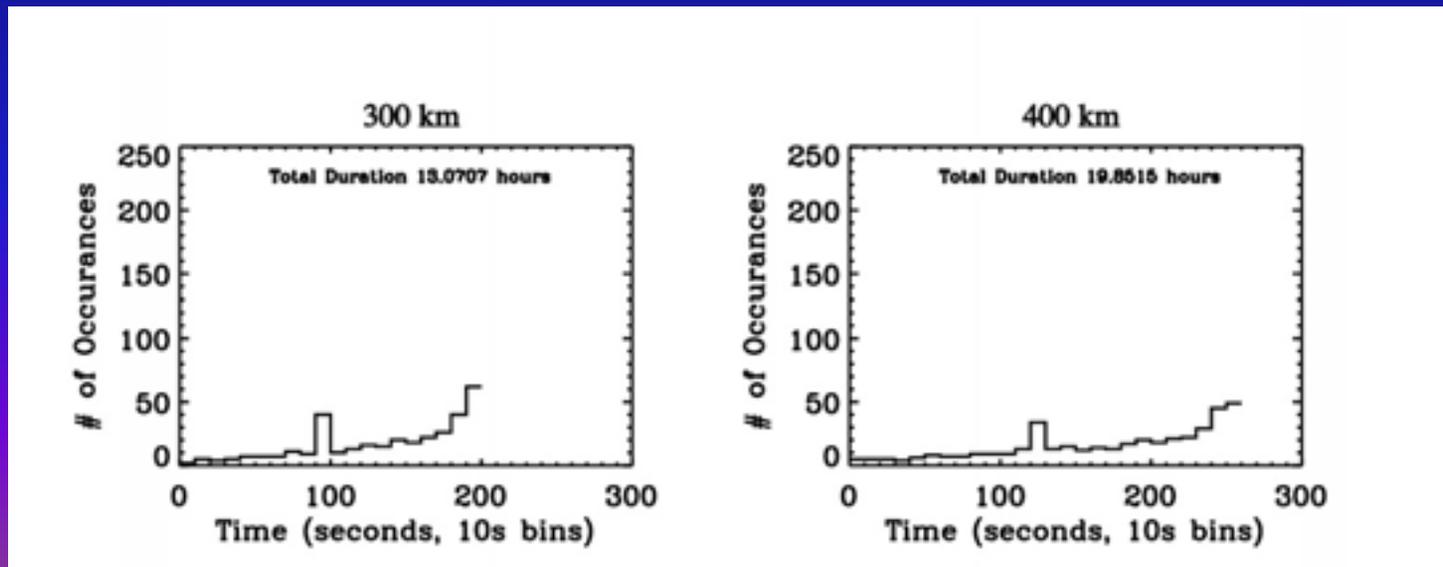
- **SLR at Midway Research Center**
  - **38.466º Lat, 282.6273º Lon, 0.0418 km Alt**
- **Four Constraint Scenarios**
  - **Twilight: MRC in darkness, ANDE in sunlight**
  - **Day: Both in sunlight**
  - **Night: Both in darkness**
  - **All: no restrictions**
- **Two satellite altitudes: 400 km, 300 km**
- **Elevation Angle Constraints**
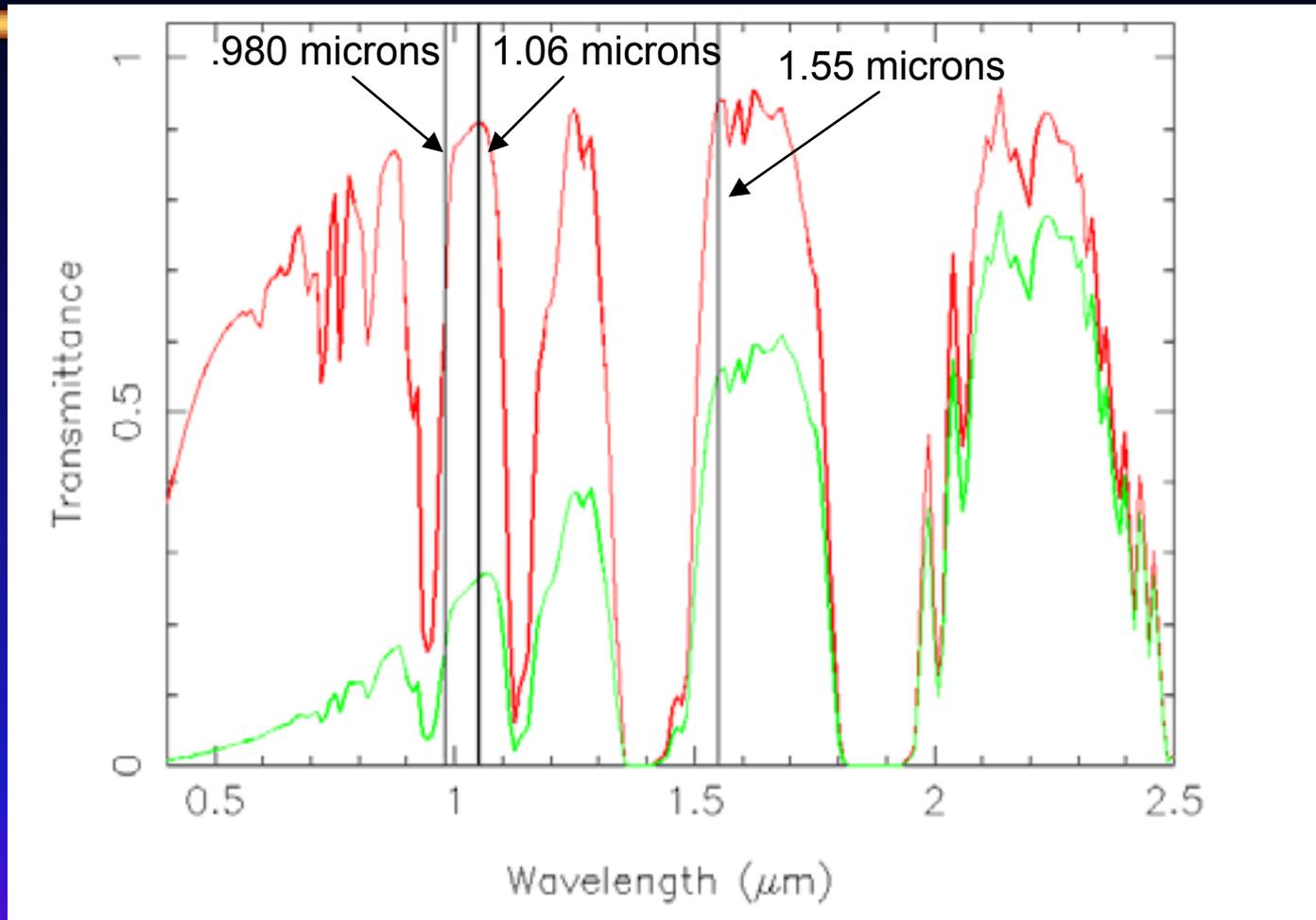 - **30º < elevation <85º**
  - **20º < elevation <85º**

Obscuration Mitigation

Terrain through clouds and smoke at 450 nm.   **Terrain through clouds & smoke at 1.55 μm**

Data obtained over town in California using JPL AVIRIS multi-wavelength camera.

Obscuration Mitigation

— Aerosol Optical Depth of .1 at .55 microns   — Aerosol Optical Depth of 1.6 at .55 microns

This graph shows transmittance through atmosphere for a clear day (red trace) and for a misty day (green trace). The transmittance is two-way, vertical, and include absorption, Rayleigh scattering, & Mie scattering (aerosol) (tropospheric).

Impact of Scintillation on Retroreflected Signal
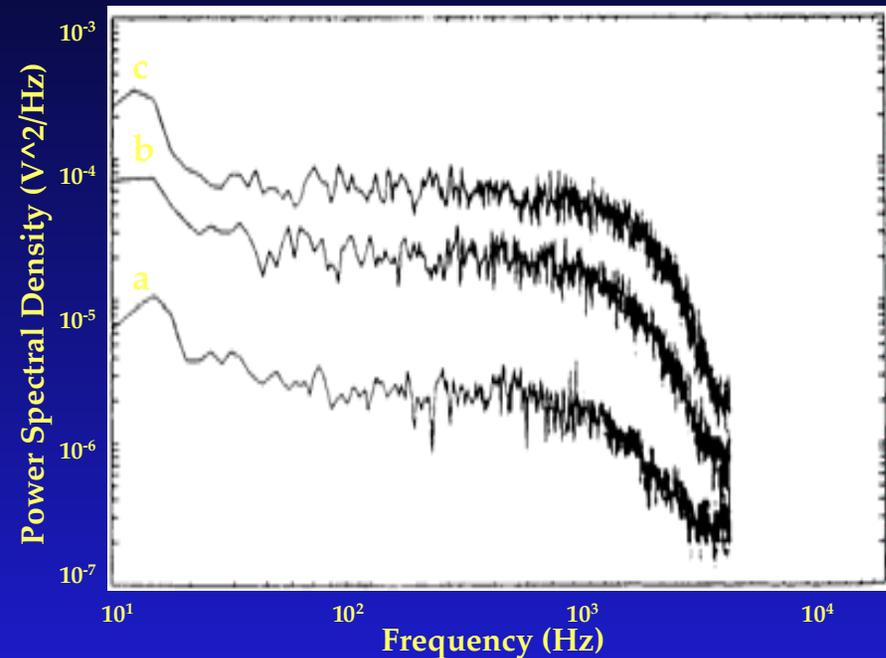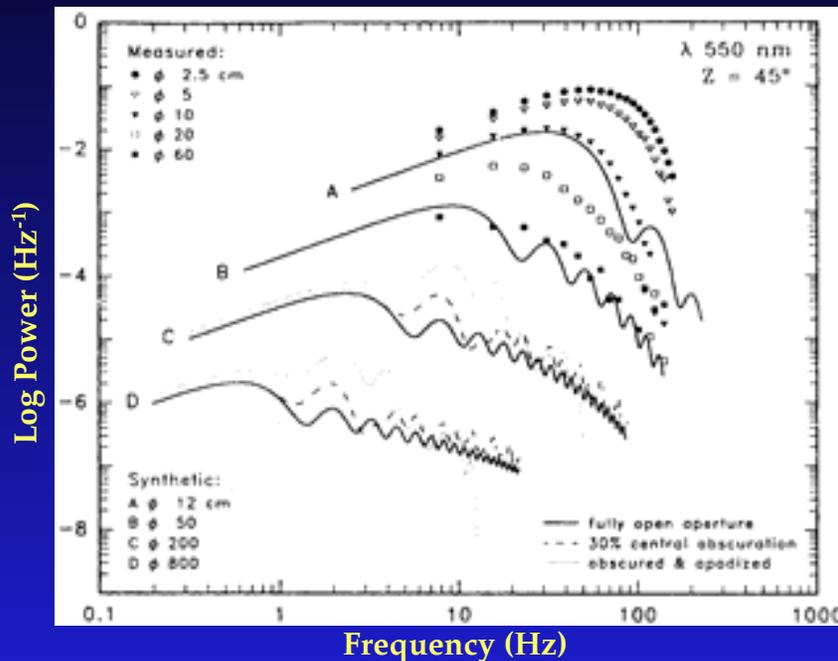
Power spectral content of scintillation in different apertures
(amount of integ. power as a function of scintillation frequency)

3. Dainis Dravins, Lennart Linegren, and Eva Mezey, PASP, 110,
   pp 610-633 (1998).

The power spectra for retroreflected signals:
 a. weak (1.9V); b. moderate (3.8V); c. strong (4.9)

4. Paul A. Lightsey, Opt. Eng., 33(8), pp. 2535-2543 (1994)

Energy = 0.1   (Joules)

Efficiency of Transmitter = 0.66

Efficiency of Receiver = 0.54 (0.635 w/o daylight filter)

Quantum Efficiency = 0.18

Divergence = 0.00005 (radians half angle)   100urad beam full

Pointing Accuracy= 0.000001

Receiver Diameter = 0.7185 (meters)