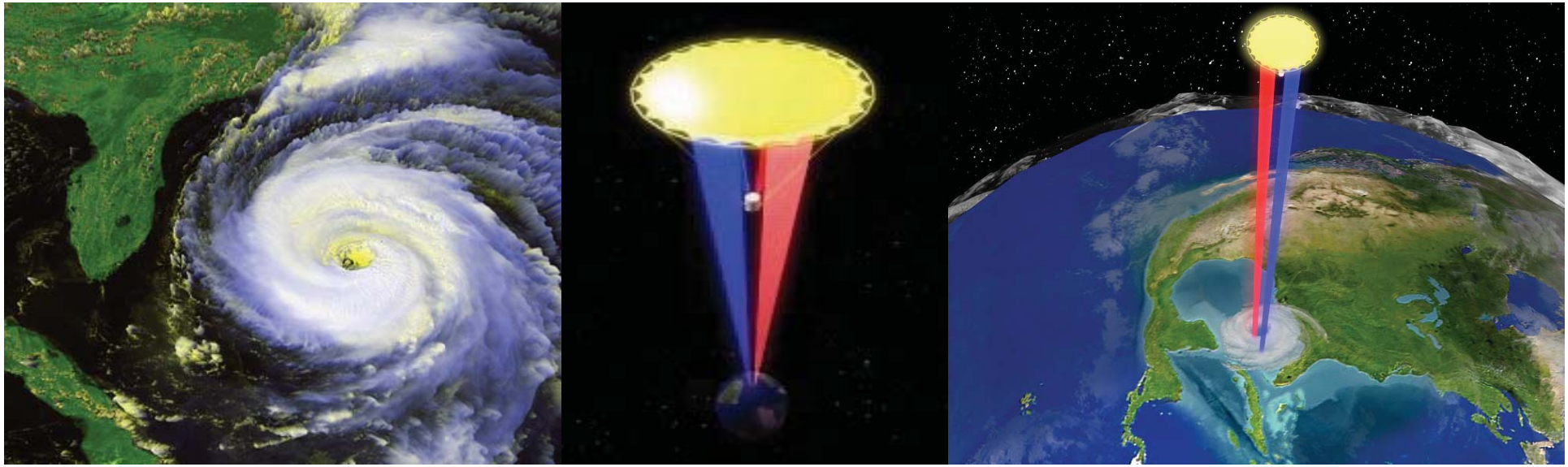
NEXRAD In Space (NIS):
A Geostationary Orbiting Doppler Radar for Hurricane Monitoring and Studies



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NIS Mission concept was motivated by:

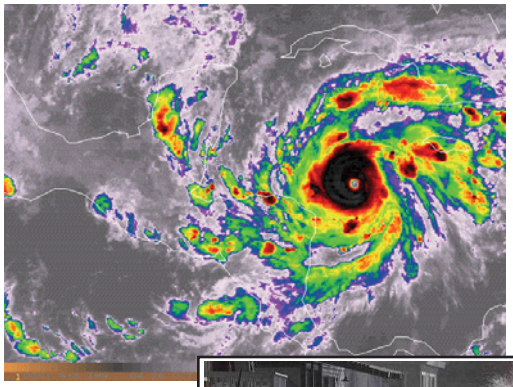
- Ground-based Doppler weather radars (e.g., NEXRAD)
  - Their superb ability to monitor local weather and track landfalling hurricanes
  - Their inability to observe TCs and developing/evolving hurricanes that are far out at sea
- Aircraft remote sensing instruments
  - Their ability to observe systems that are in open oceans
  - Their limited ability in temporal sampling
- Current Geostationary weather satellites
  - Their ability to provide superb temporal sampling
  - Their inability to see into the inner-structures of TCs and hurricanes
- LEO TRMM satellite instruments
  - Their ability to penetrate and measure vertical structures
  - Their inability to provide frequent temporal sampling
- New and emerging technologies in spaceborne radars and large space structures

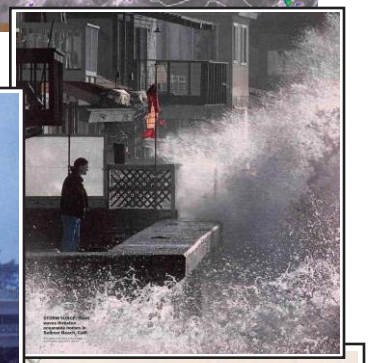
GEO Doppler Weather Radar for Hurricane Studies

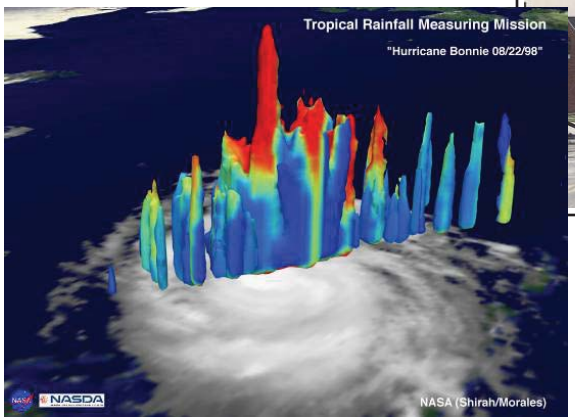
- **Objectives:**
  - Measure hurricane rainfall intensity, dynamics, and life cycle for improved model prediction of track, intensity, and rain rate
  - Provide data for improved prediction of hurricane-induced floods

- **Practical Benefits:**
  - Life saving and enhanced public safety
  - Emergency response capability enhancement
  - False-alarm and evacuation cost reduction
  - Other economic impacts (e.g., insurance coverage…)

- **GEO Radar Advantages**
  - Frequent sampling
  - Penetrate all clouds
  - 3-dimensional profiling critical parameters and dynamics which control and/or determine the hurricane formation and evolution
    - Rain intensity
    - Vertical motion
    - Cloud process
    - Latent heat release

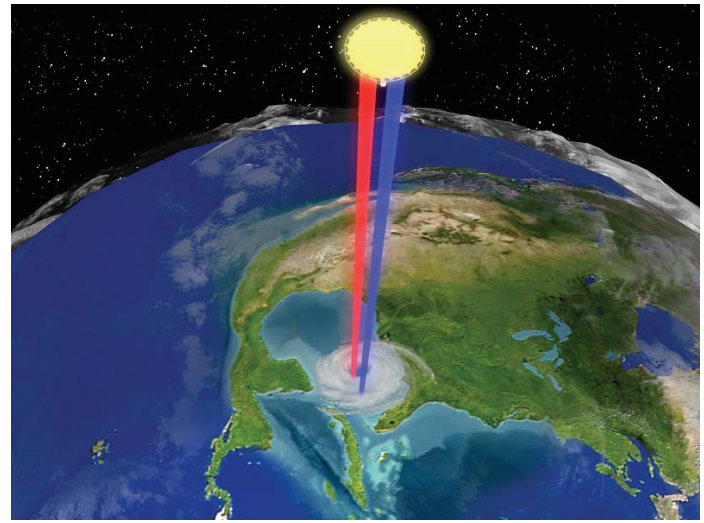


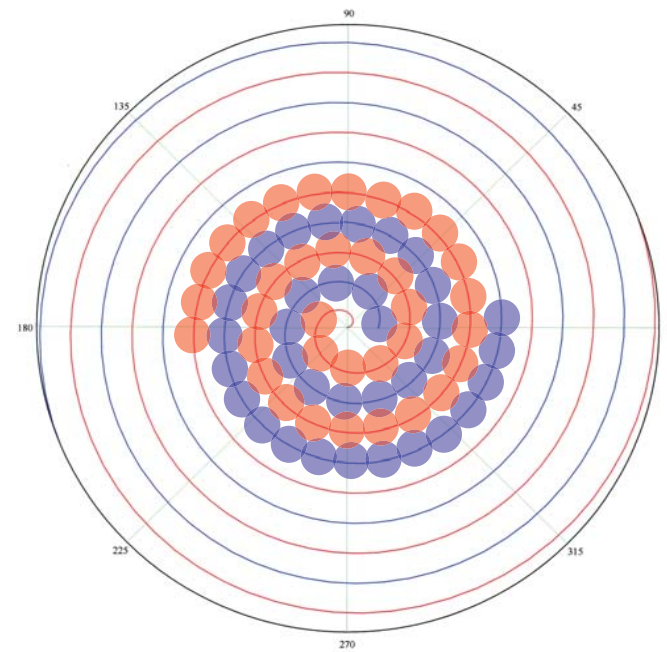




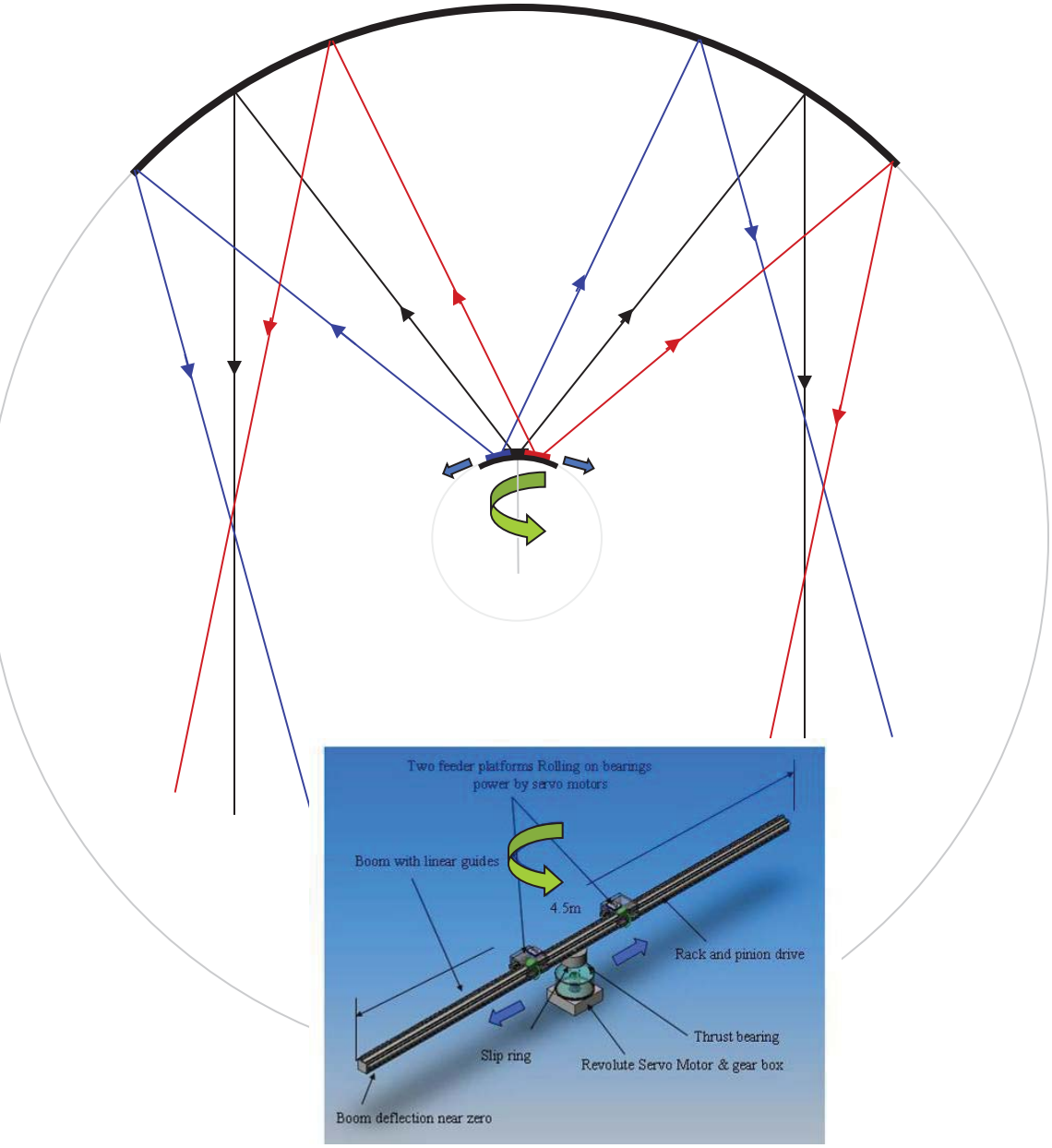
NIS Notional Concept and Innovations

- Operating in geostationary orbit (alt. ~ 36,000 km)
- Using a lightweight, deployable, 35-m spherical antenna to achieve good horizontal resolution and detection sensitivity
  - Illuminating 28-m sub-apertures of the antenna to obtain 12-14 km horizontal resolution
  - Extra antenna reflector surface is needed for scanning
- Using a combination of spherical antenna reflector and spirally scanning antenna feeds to cover 5300 km diameter of earth surface disk area
  - Equivalent to a coverage of 48° latitude x 48° longitude
  - Additional coverage can be achieved by small articulation of spacecraft (e.g., a fixed 2° satellite pointing will extend coverage to 38°N)
- Spiral scan achieved by linear motion of 2 sets of transmit/ receive feed pairs along a rotating track
  - 1 transmit feed and 1 receive feed with fixed spacing to compensate for pulse delay
- Vertical resolution of 250 m using pulse compression
- Rain detection sensitivity: ~ 5 dBZ
  - ~12 dB more sensitive than the TRMM radar
- Line-of-sight Doppler velocity: 0.3 m/s (rms) accuracy
- One 3-D full-scan image once per hour
- Real-time processing to reduce downlink data volume/rate





Innovative Antenna Strategy to Achieve Spiral Scanning



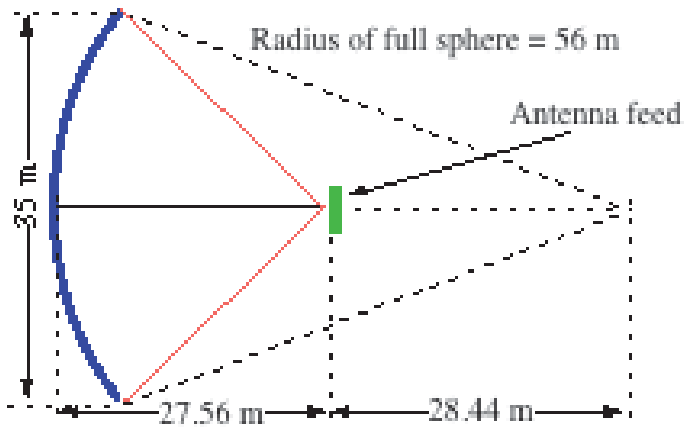
- With spherical antenna reflector, the desired off-boresight pointing can be achieved by placing the feed at appropriate position and by correcting the spherical aberration (Rahmat-Samii, 1989)
- For NIS, this concept is extended to obtain spiral scanning up to 4° from boresight
  - By moving two sets of transmit/receive feed pairs at opposing sides from the center of a rotating arm
- Advantages over other scanning approaches:
  - 2-D electronic scan would require millions of phase shifters and T/R modules
  - Mechanical rotation of entire antenna would create unacceptable torque
  - Spacecraft rotation would require custom-made, usually very expensive spacecraft bus articulation mechanism

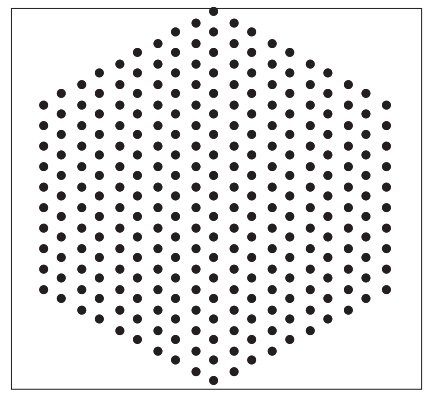
Space Operation Concept: An Illustration

NIS Antenna Conceptual Design

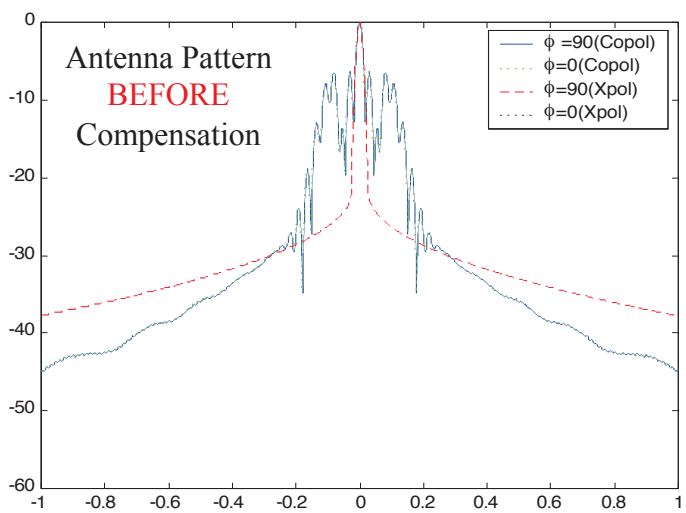
- Spherical antenna reflector allows 2-dimensional scan with minimum degradation
- 271-element feed array with designed phase distribution to compensate for spherical aberration.
- 28 m aperture, larger physical size to allow for scanning (35 m), F/D of ~ 1

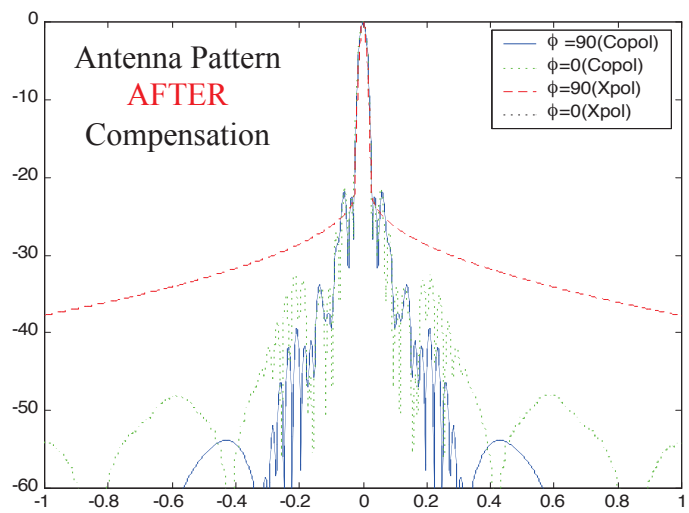
Spherical reflector



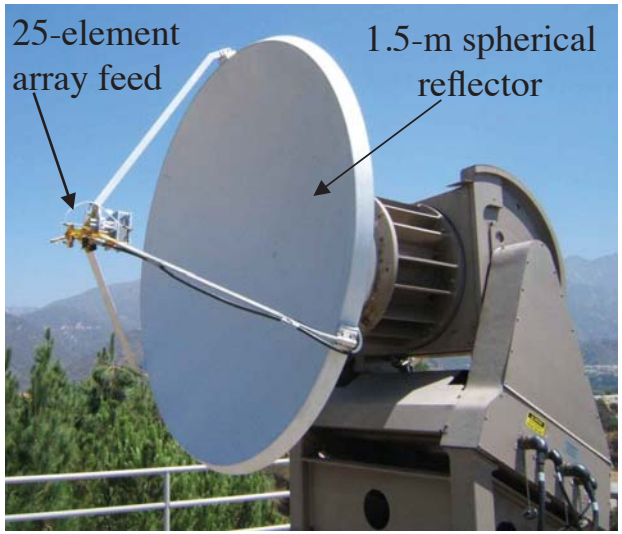


271-element feed array
(element spacing: 0.9 λ)





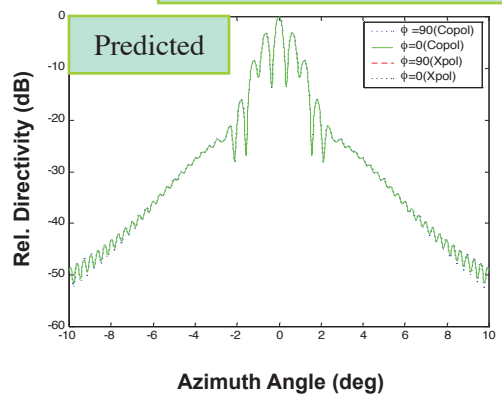
Spherical Reflector Antenna Technology Prototype

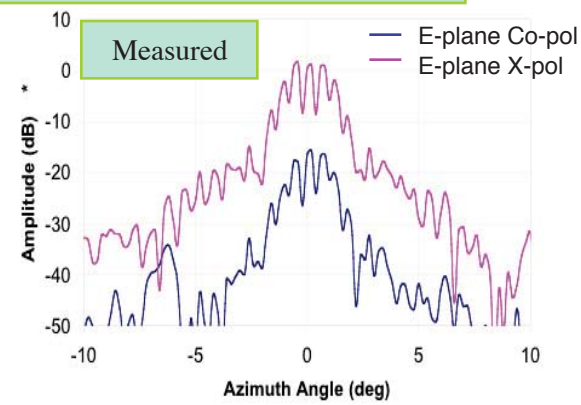


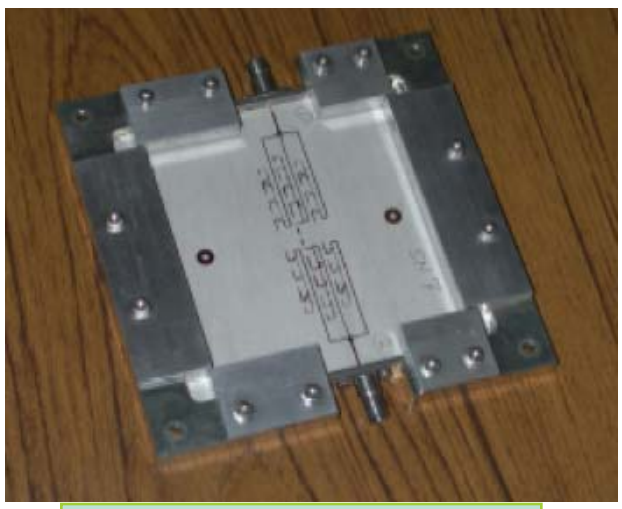
Objectives: Demonstrate feasibility of the NIS antenna approach

- Correction for spherical aberration
- Pointing up to 4° from boresight

Far-field patterns of 1.5-m reflector with horn feed

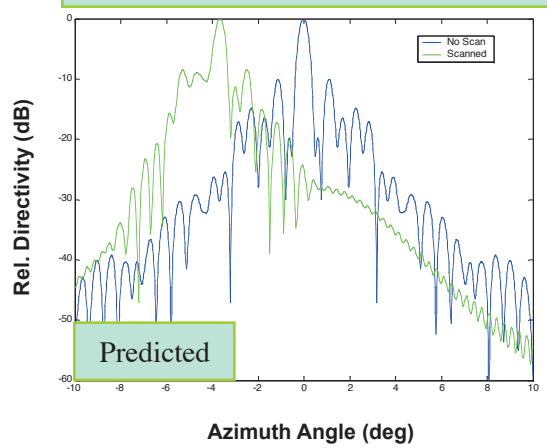


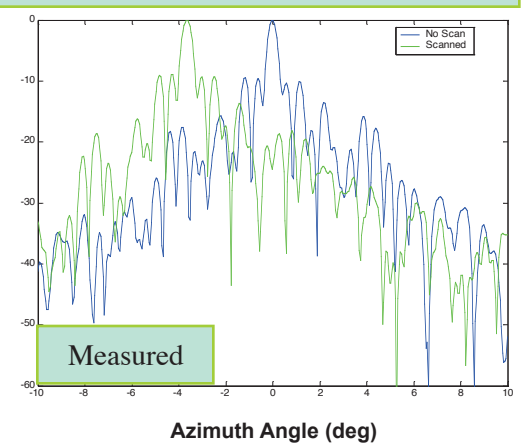




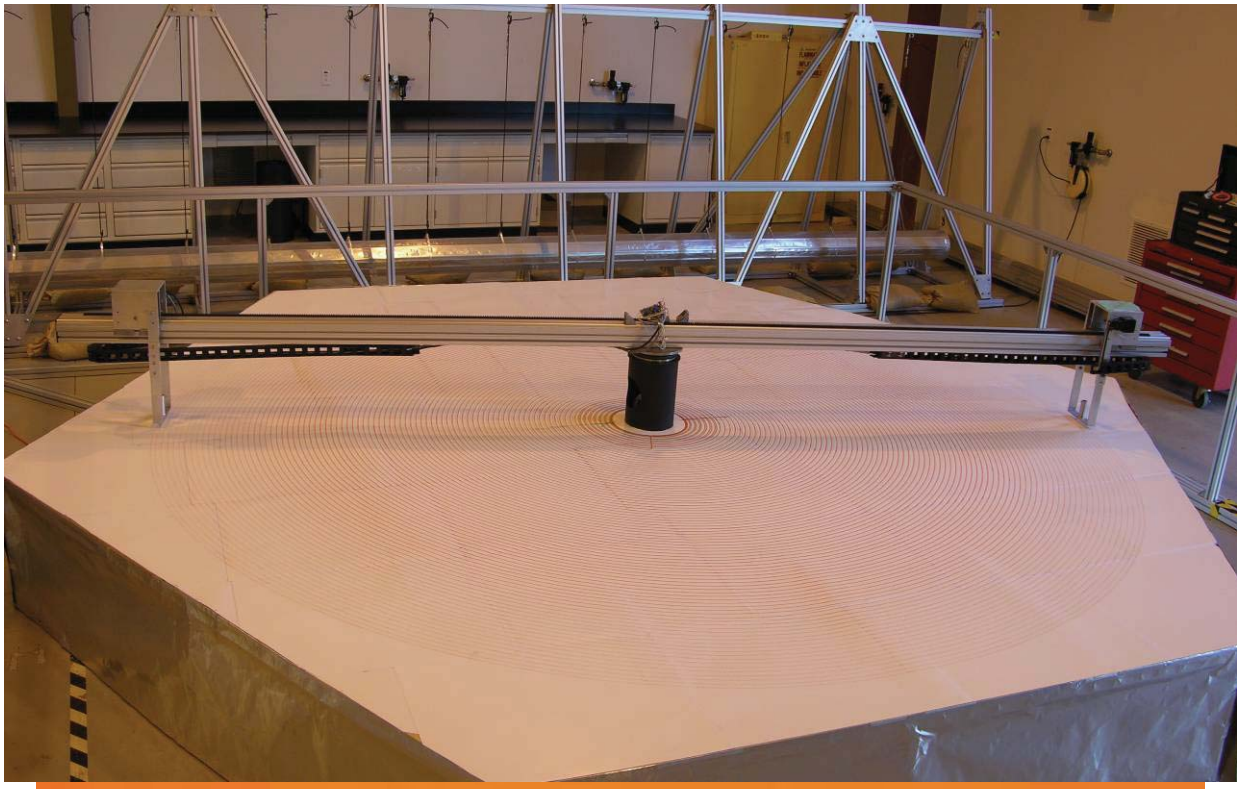
25-element array feed

Far-field patterns of 1.5-m reflector with 25-element array feed





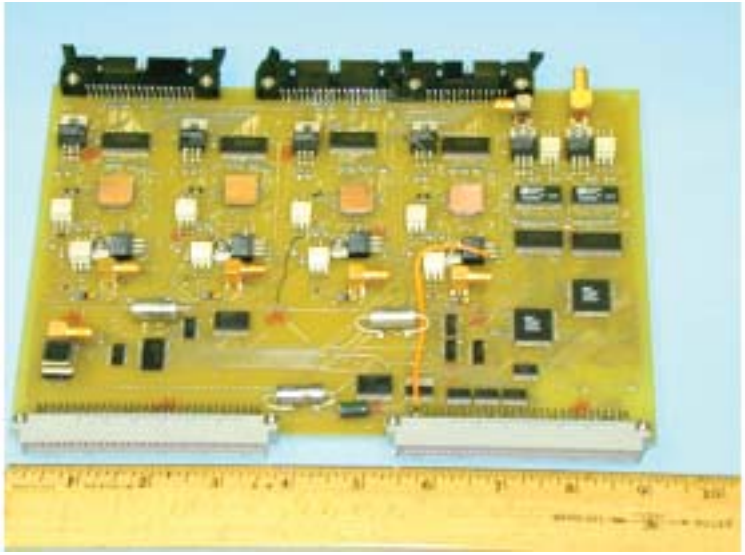
Spiral Feed Structure Prototype (full-size)

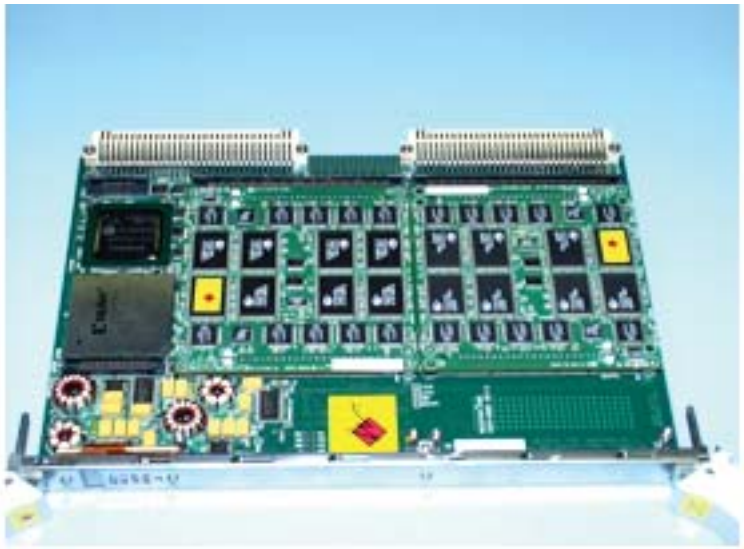


4.5-m Spiral Feed Structure

- Central rotating arm
- Two linear motioned feed sets

NIS will leverage off Spaceborne Atmos Radar Technology (1)



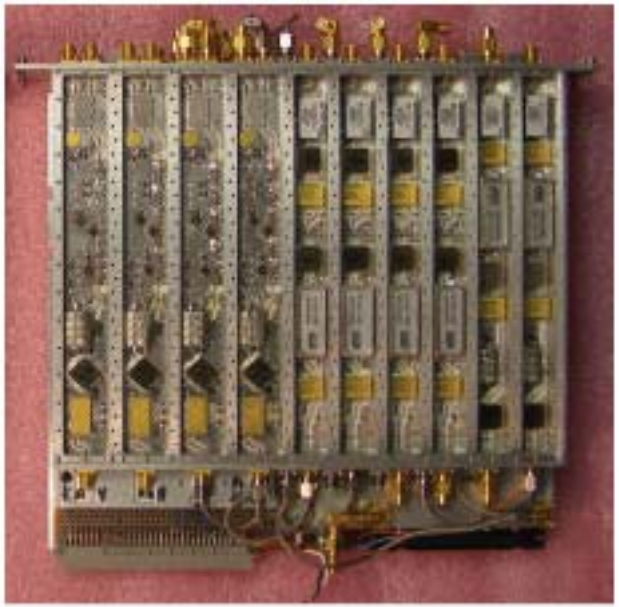


- ADC/AWG
  - 12- bit ADC and Arbitrary Variable Waveform Generator (AWG) cluster
  - ADC oversamples 2 times for improved sample filtering
  - AWG includes pre-distortion function to reduce pulse compression sidelobe

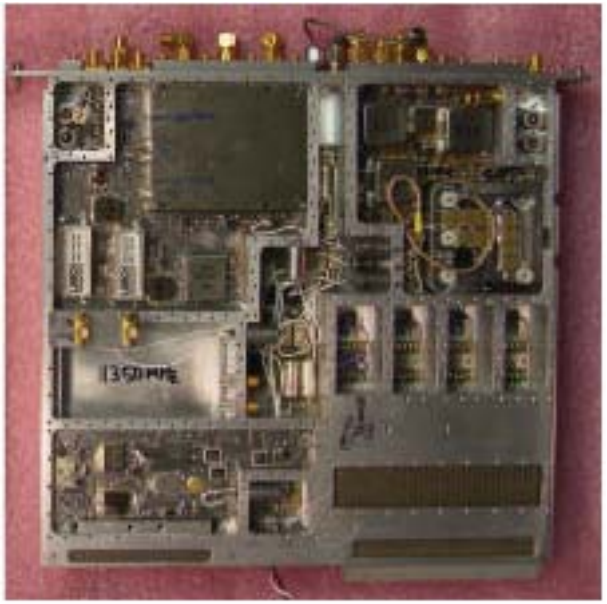
- FPGA-based Data Processor
  - Real-time processing
    - Adaptive scan
    - Pulse compression
    - Pulse-Pair Doppler processing
  - Double buffer
  - Computer power:
    - 20 billion multiplications
    - 20 billion additions

NIS will leverage off Spaceborne Atmos Radar Technology (2)

Front



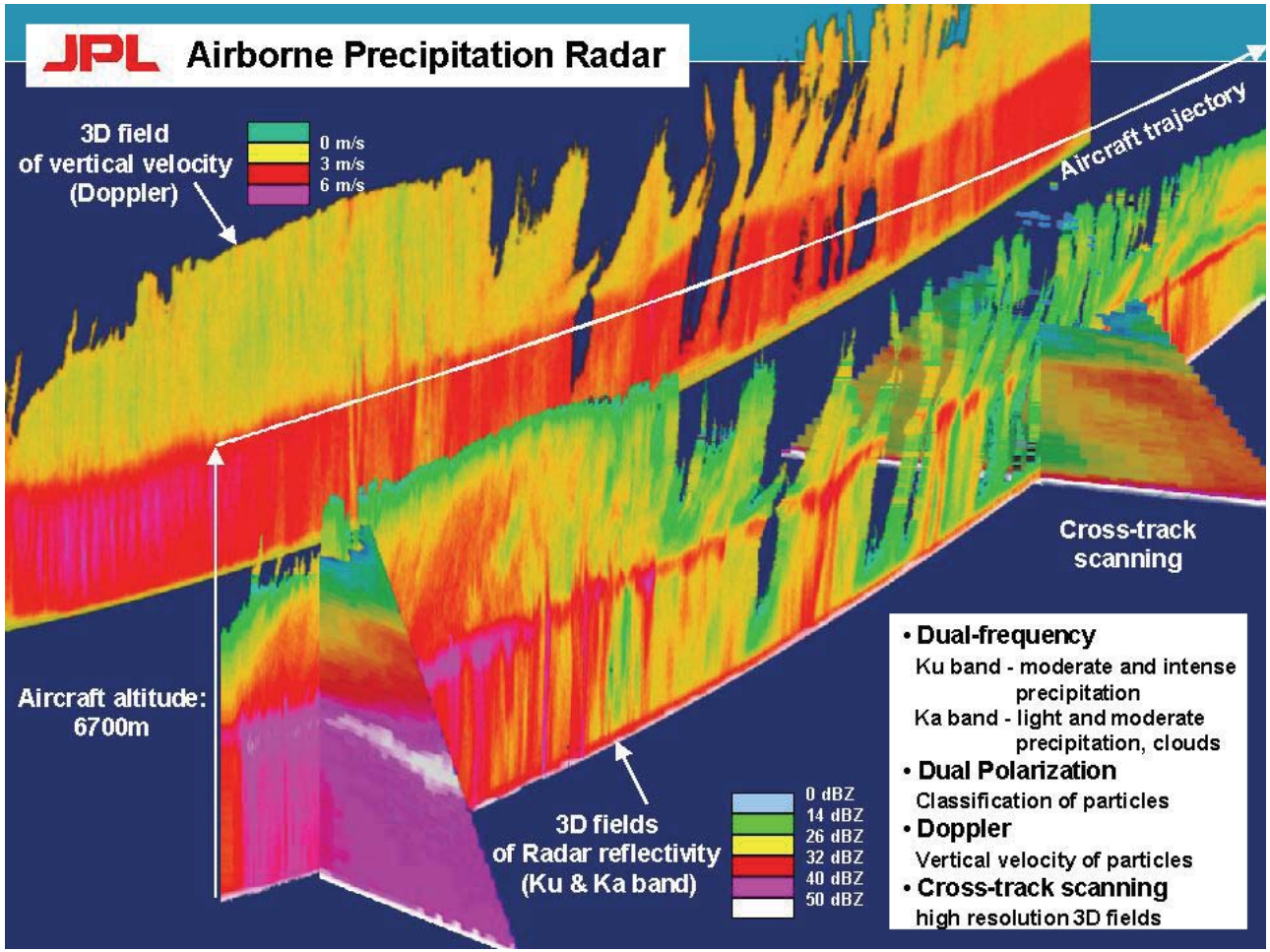
Back



- Multi-channel Radar IF/Local Oscillator Module
  - Two transmit channels, four receiver channel
  - 10 MHz MO, 40MHz LO, 1350 MHz LO, 1360 MHz LO
  - Designed for space flight
    - Compact (23 cm x 20 cm x 4.5 cm) and fits in 2 VME card slots
    - Light weight (3.6 kg)
    - Excellent EMC characteristics with thorough subcircuit shielding
    - Conduction cooled
    - Easy access for serviceability and reconfiguration

Airborne PR-2 Simulator

- LO/IF module, real-time pulse compression and digital processing module were prototyped as airborne simulator, and flown on NASA DC-8 in 2001/2003/2006, and on NASA P-3 in 2003.

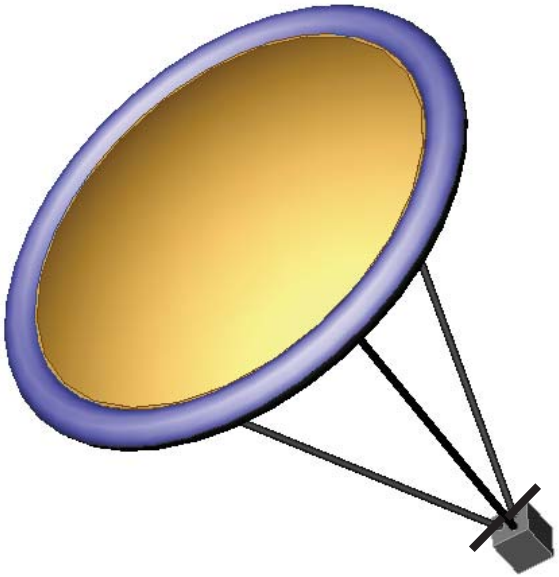


Further Works are Required!!

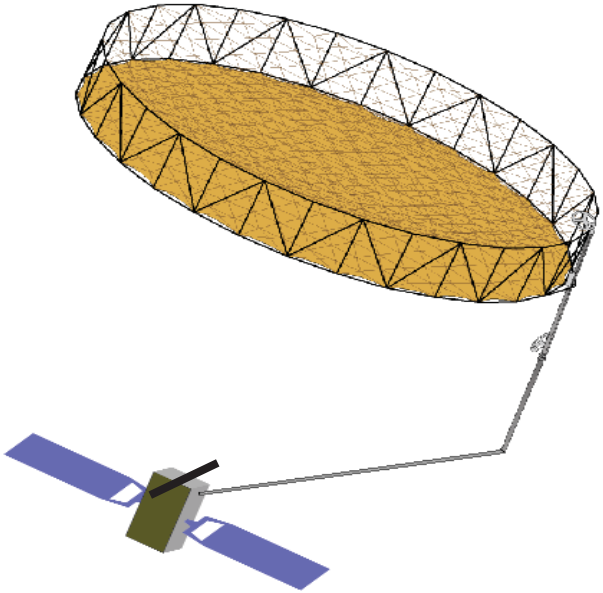
- So far, the framework for the NIS mission concept has been established. But this is just the beginning. A lot more work are required before the NIS mission can be realized……..

- From the instrument technology prospective, the following are examples of some critical areas that need further development:
  - Science requirements
  - Design trade and optimization
  - Lightweight, deployable antenna reflector
  - Antenna feed design trade and optimization
  - Antenna deployment
  - In-flight antenna surface shape control

Lightweight, Deployable Antenna Reflectors



(1) Membrane reflector



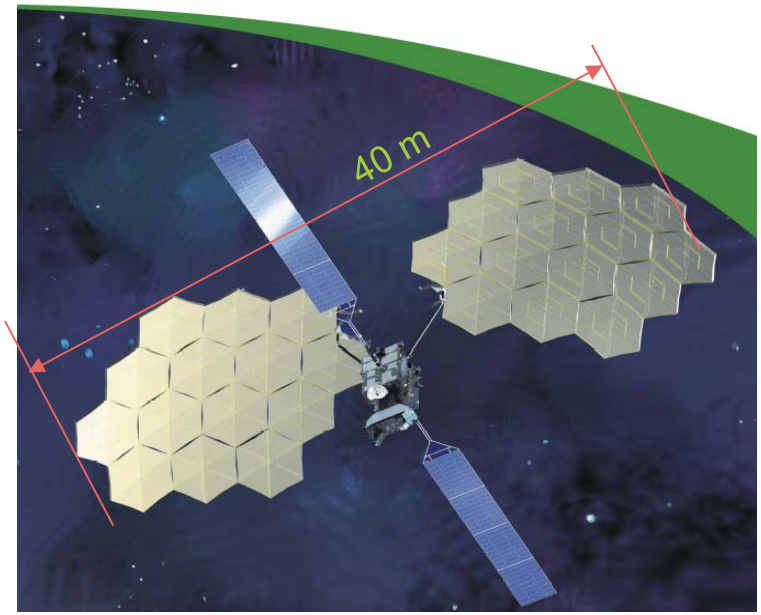
(2) Mesh reflector

(3) Hybrid: uses the mesh to deploy a reflective thin-film antenna aperture?

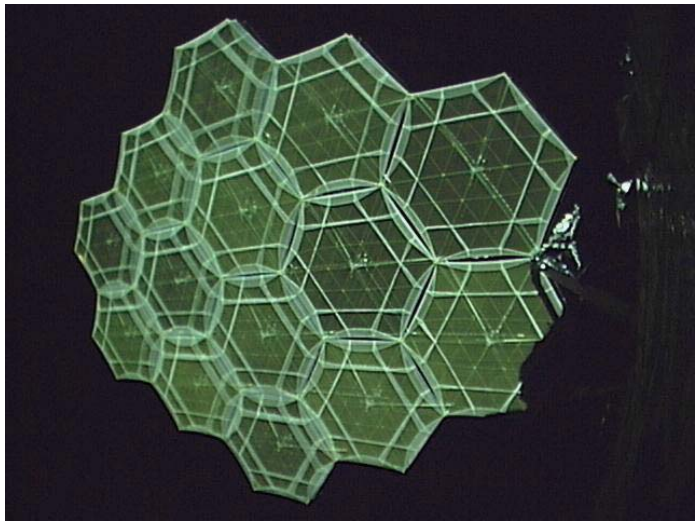
JAXA ETS-VIII (a.k.a. KIKU No.8): Large, S-band Mesh Antennas

技術試験衛星Ⅷ型—ETS-Ⅷ

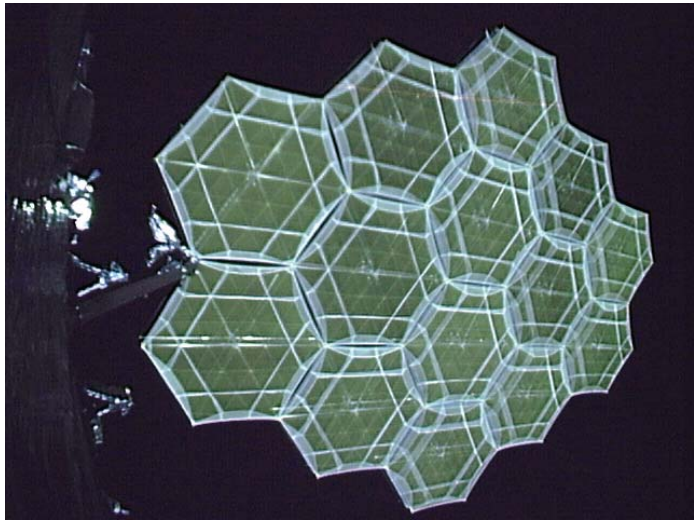
ETS-Ⅷ:Engineering Test Satellite-Ⅷ



- ETS-VIII is a geostationary satellite with two large, deployable antennas
- Each antenna measures 19m x 17m
  - Consists 14 hexagonal modules
  - S-band (3-cm wavelength)
- Japan's H-IIA launch vehicle
- Launch: 12/18/06 2006
- Geostationary orbit injection: 1/8/07



Receive antenna deployed 12/25/06



Transmit antenna deployed 12/26/06

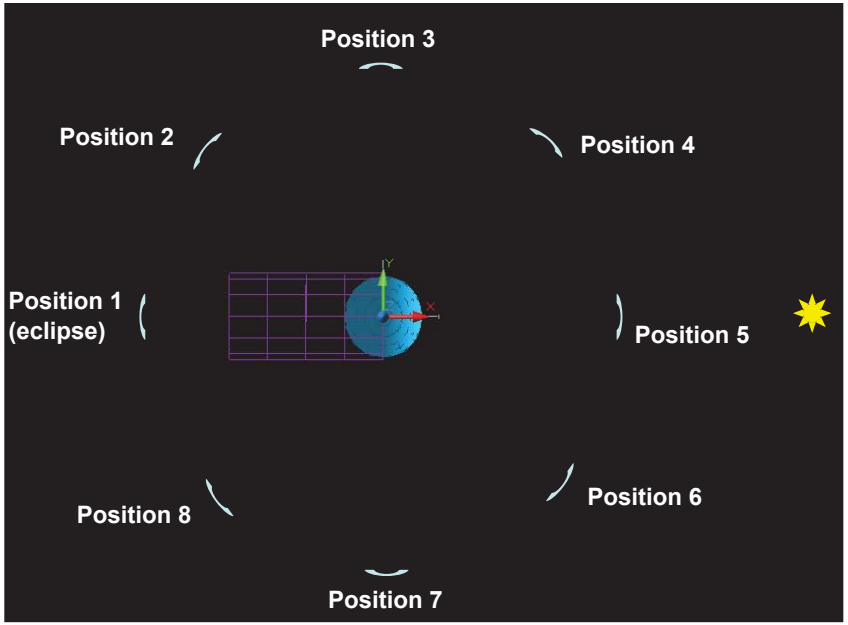
Shaped-Memory Composite (SMC) Membrane Reflector

- For membrane reflector, SMC allow the reflector to put under high packaging strain
- To deploy (i.e., shape recovery):
  - Heat above glass transition temperature to releases strain
  - the reflector will return to pre-packaging shape

- A 0.5-m one-dimensionally curved reflector by ILC Dover
  - Mass: 0.3 kg

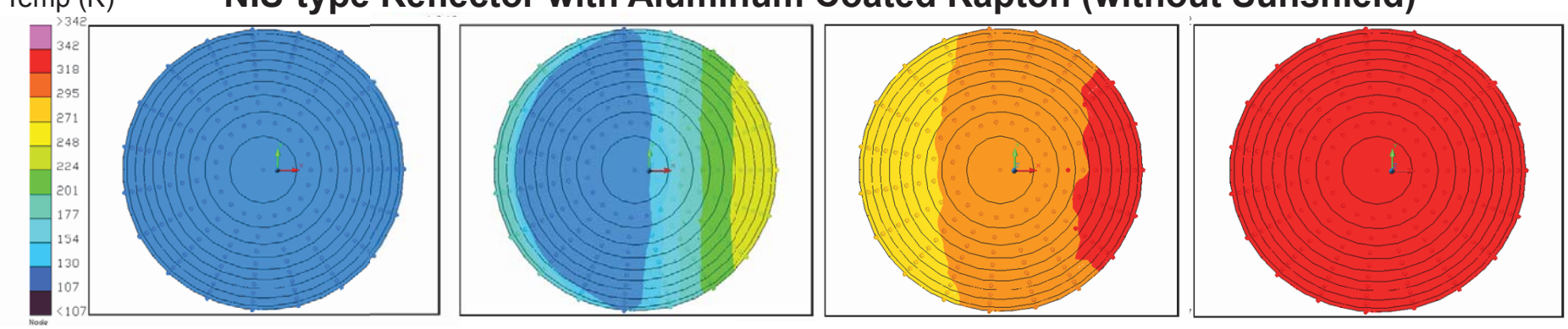
- From here to there:
  - 0.5m --> 35 m
  - Material longevity
  - Material with desirable glass transition temperature and uses least heat (energy) to deploy

In-flight Correction of Thermally-induced Shape Distortion



- Antenna reflector will experience large temperature excursion from eclipse to direct sun exposure
- Thermal gradient across antenna made of flexible material (e.g., thin membrane) will introduce shape distortion and affect longevity
- Examples of expanded studies in future:
  - Techniques and technologies to correct for shape distortion
  - Reflector material, thermal blanket, sunshield, etc., to reduce thermal effects

NIS-type Reflector with Aluminum Coated Kapton (without Sunshield)

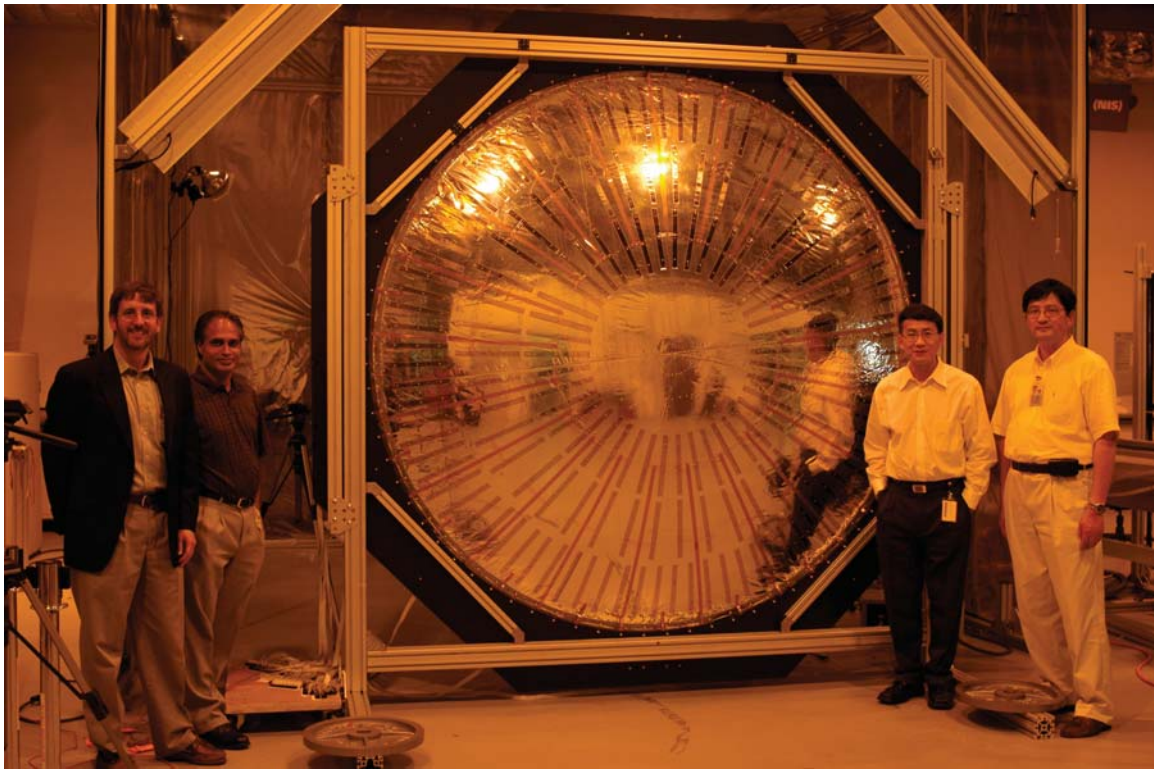


Position 1 Position 3 Position 4 Position 5

2.4-m Spherical Inflatable Membrane Antenna Prototype

Front view

Back view

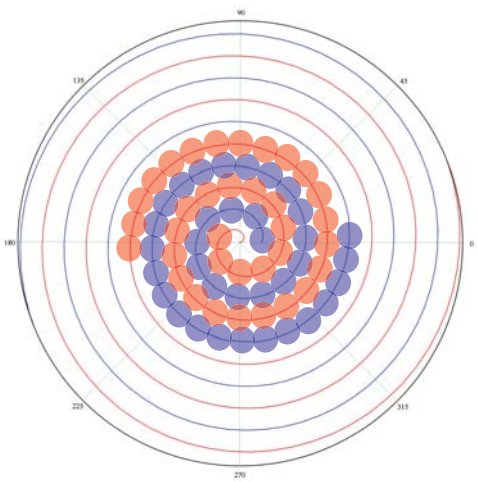


The 2.4-m diameter prototype model consisting of:

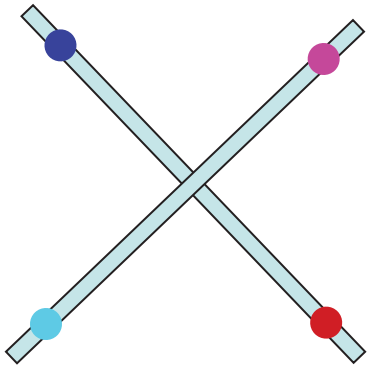
- inflatable membrane reflector,
- 168 pizo-electrical actuators with embedded flexible voltage supply circuits for voltage supply
- 735 photogrammetry targets for surface accuracy measurements
    - Measured accuracy: 0.19 mm RMS (meet the l/30=0.3-mm requirement)

Some Thoughts on Improving Time Sampling of Hurricanes

- Current concept:
  - 1 rotating arm
  - 2 sets of feeds
    - Forms 2 radially-adjacent spirals
  - < 15 rpm
  - ~1 hour sampling



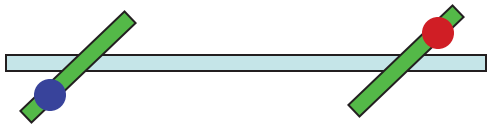
- Idea #1: *add more arms*
  - E.g., add one cross arm will cut down sampling time by half



- Idea #2: *increase arm's rotational speed*
  - More torque
  - Less dwell time

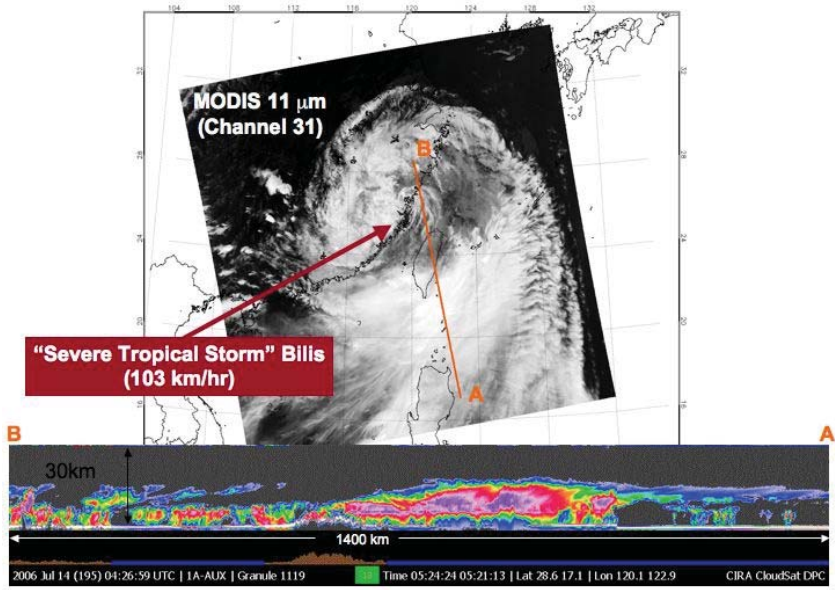
- Idea #3: *add 2 rotating "short-arms"*
- During normal, large areal coverage mode
  - Long arm rotates
  - Short arms slide in and out
  - Feeds does not move
  - Same as current concept

- Adaptive hurricane tracking mode
  - Long arm rotates to position and stops
  - One short arm slides to position; the other short arm slides in the same fashion at opposing side of long arm
  - Both short arms then rotate
    - One observes hurricane, the other balance the motion
  - Feeds slide along short arms to form smaller spirals



Some Thoughts on Improving Horizontal Resolution

- Current concept:
  - 35-GHz radar frequency, 28-m illuminated antenna aperture
  - Resulting horizontal resolution: 12 km
- Since horizontal resolution is proportional to frequency. Using a 94-GHz radar will improve the resolution to 5 km
- The spaceborne radar electronics technology at this frequency is mature
  - The 94-GHz CloudSat radar has been in operation for 1 full year and the in-flight performance meets all requirements



- NIS could evolve into a 35/94-GHz dual-frequency Doppler radar eventually
  - NASA is initiating a 35/94-Doppler radar study for the ACE Mission (in response to the NRA Earth Science Decadal Survey

Summary & Remarks

- Ground-based Doppler weather radars (e.g., Nexrad radars) have proven to be highly effective in monitoring and studying landfalling hurricanes
- Putting a Nexrad radar in a Geostationary orbiting satellite is highly desirable
  - It enables observations of the hurricane life cyles for model studies and research
- With recent technological advances in radar and large deployable antenna, a geostationary Doppler weather radar can be realized in a foreseeable future
  - The Nexrad-In-Space (NIS) concept is born
- NIS uses an innovative spiral scanning approach to achieve large spatial coverage and 1-hourly sampling
- In the past four years, several critical technologies have been prototyped to demonstrate their feasibility
- Further technology development is required before a flight mission can be implemented
  - Concerted effort by both science and technology communities is required
- The purpose of this workshop is to bring the two communities together to begin developing a sound roadmap that leads to an eventual mission
- In order to make real progress, continuous collaboration between scientists, technologists, and program executives will be crucial