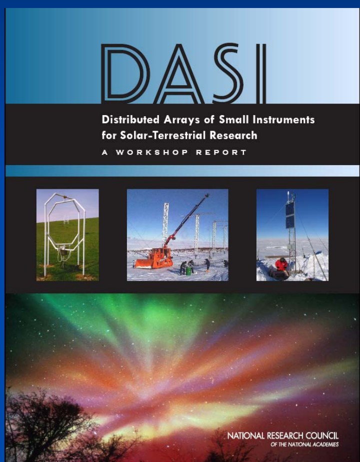
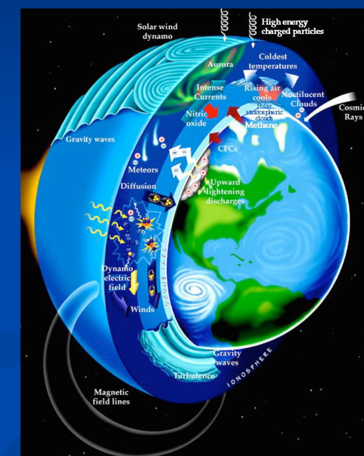
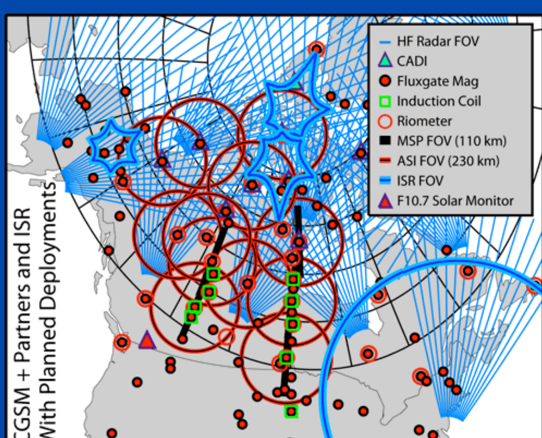
Next-Generation Instruments for Geospace Science

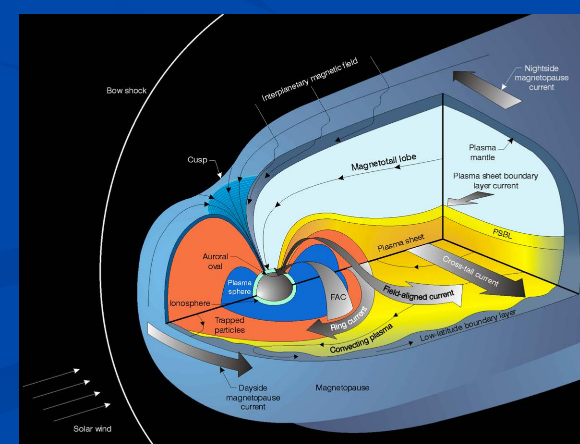


John Foster
MIT Haystack Observatory

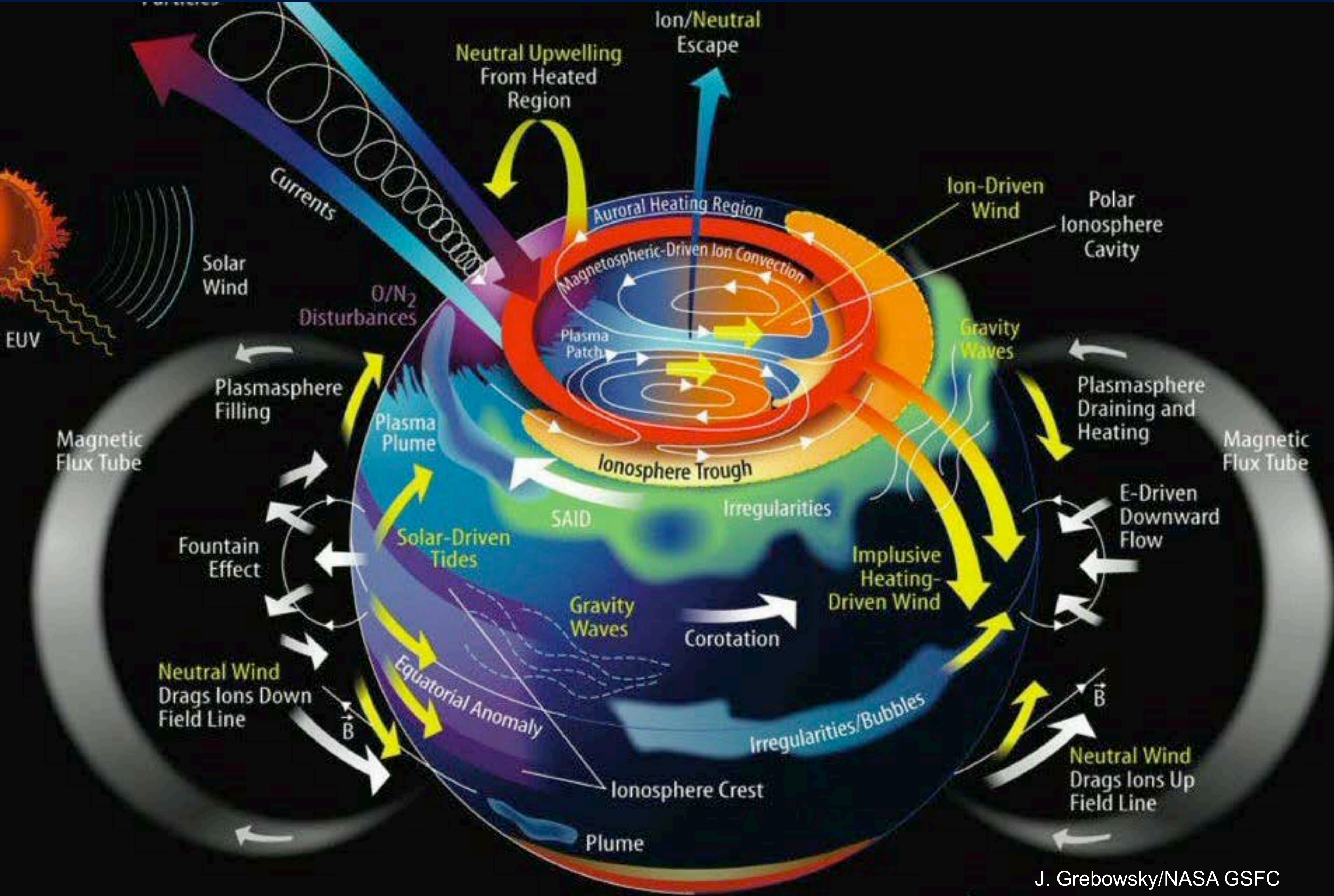
CEDAR Student Workshop
June 2009





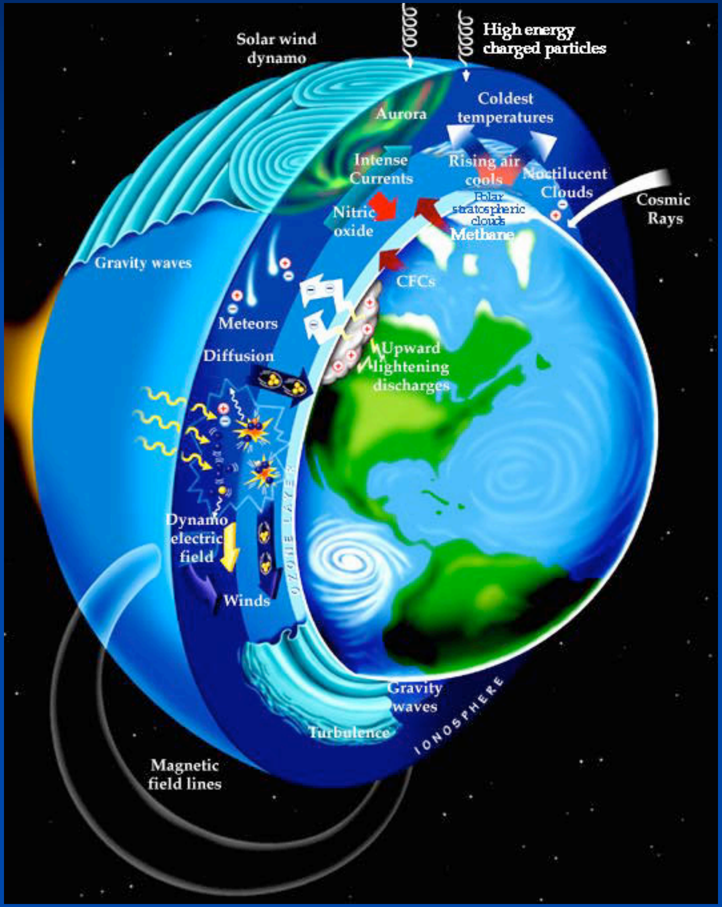


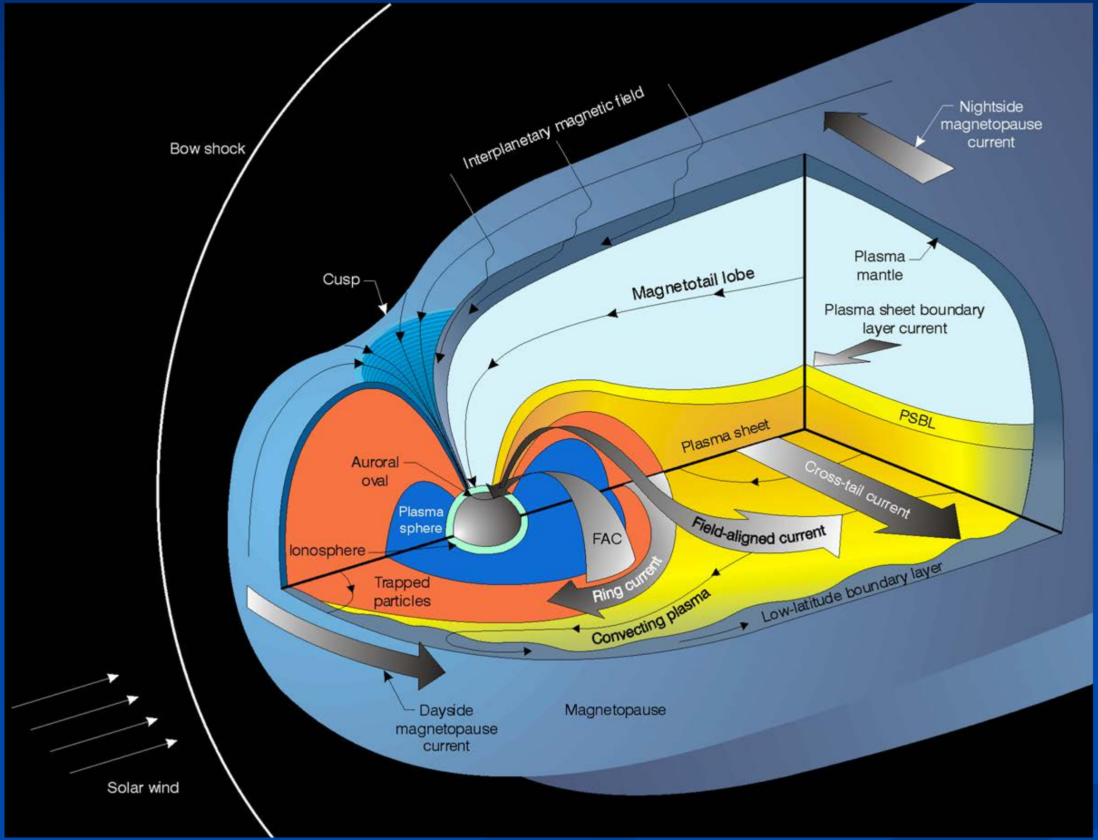
Geospace is a System



J. Grebowsky/NASA GSFC

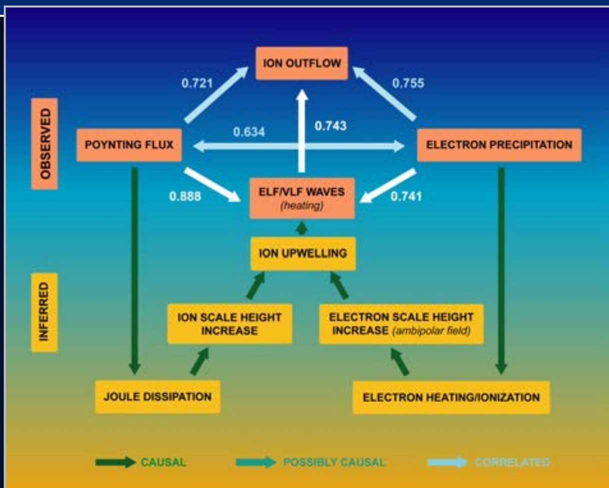
Individual Features and Instruments Reveal Parts of the Complex Geospace System





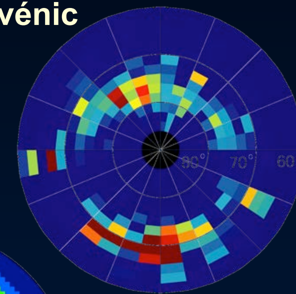
Understanding the System poses many Questions

How do ionospheric outflows impact magnetosphere-ionosphere system dynamics? [Lotko et al., 2007]

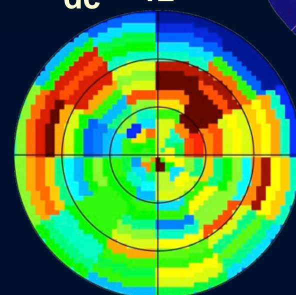


electrodynamic–inertial linkage

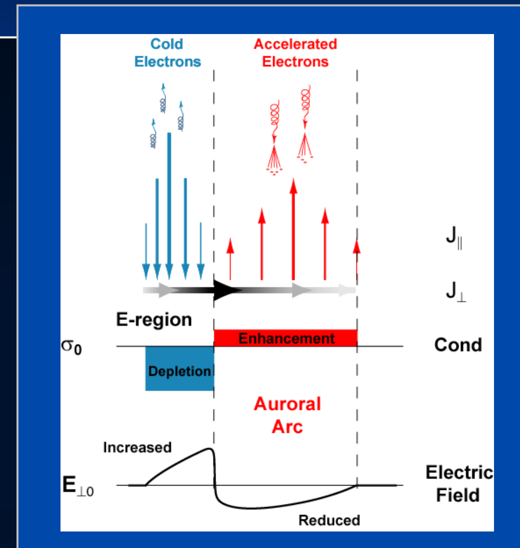
Alfvénic 12



dc 12

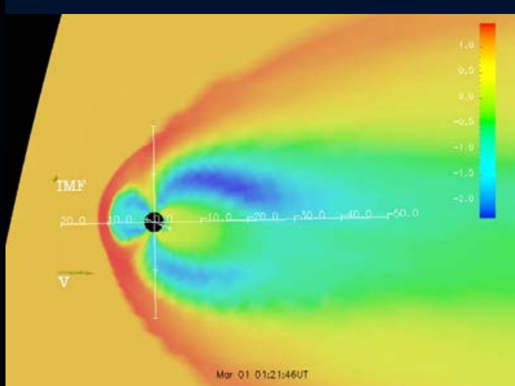


EM power flows



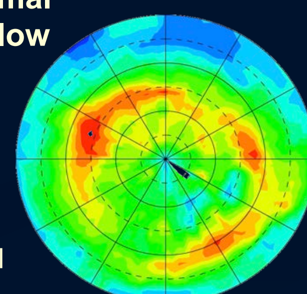
coupling and feedback

global modeling

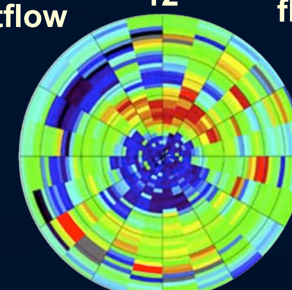


thermal outflow 12

$V_{\parallel}$

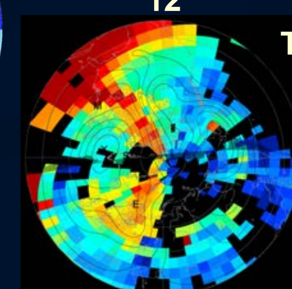


superthermal outflow 12 flux



mass transport

12 TEC



What Will the Future Look Like?

- **Improved Instruments** to push the envelope of what can be measured.
- **Minaturization**: cost-effective instruments in large quantities
- **Distributed Arrays**: interconnected regional and global multi-user instrument arrays
- **Integrated space and ground-based** observing capabilities

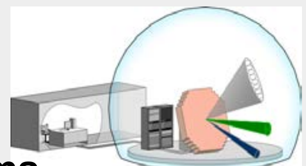
Thought-Provoking Radio Arrays

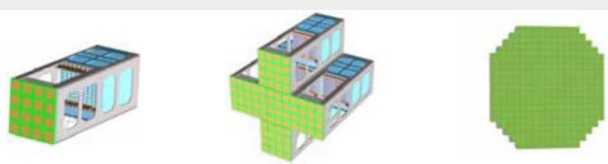
What is a Modern Radio Instrument? (Frank Lind)

- All Digital RF Technology enables extensive capabilities
  - Combine array radar and array radio telescope approaches
  - Broadband, adaptable, all digital electromagnetic interface
  - Transform applications through applied computing power
  - Array must be affordable -> Low per element cost
  - Interleaved missions on a fine scale – adaptive response to conditions

Modern Digital Array Radar

Narrowband
Single Aperture
Planar geometry
100 to 200 RX beams





Element, brick, sub-array, array

RF MCM
(multichip module)

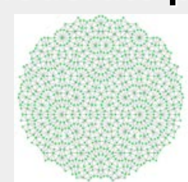
RF MEMS

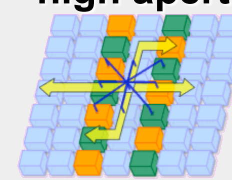
Software Radar

Supercomputing

Advanced Digital Radar System

Broadband – Distributed
All Digital Elements
Adaptive beams : TX and RX
Simultaneous TX / RX - 1000 beams
Deep per element data buffers
Moderate power - high aperture





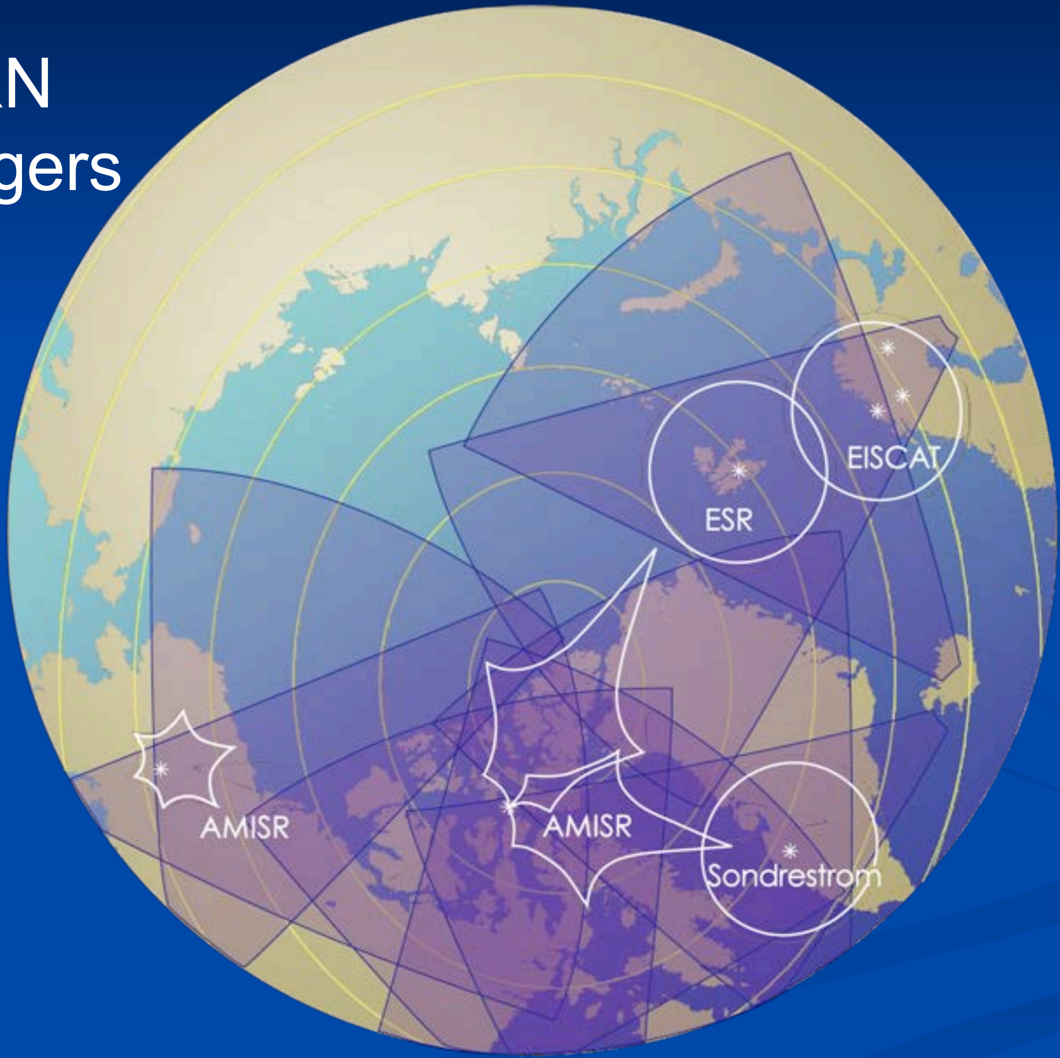
Key enabling technologies

Advanced Modular ISR (AMISR)

- New NSF ISRs
- Modular/Transportable/Reconfigurable
- Phased array / rapid steering
- Solid state / No warmup

AMISR Coverage – Global Context

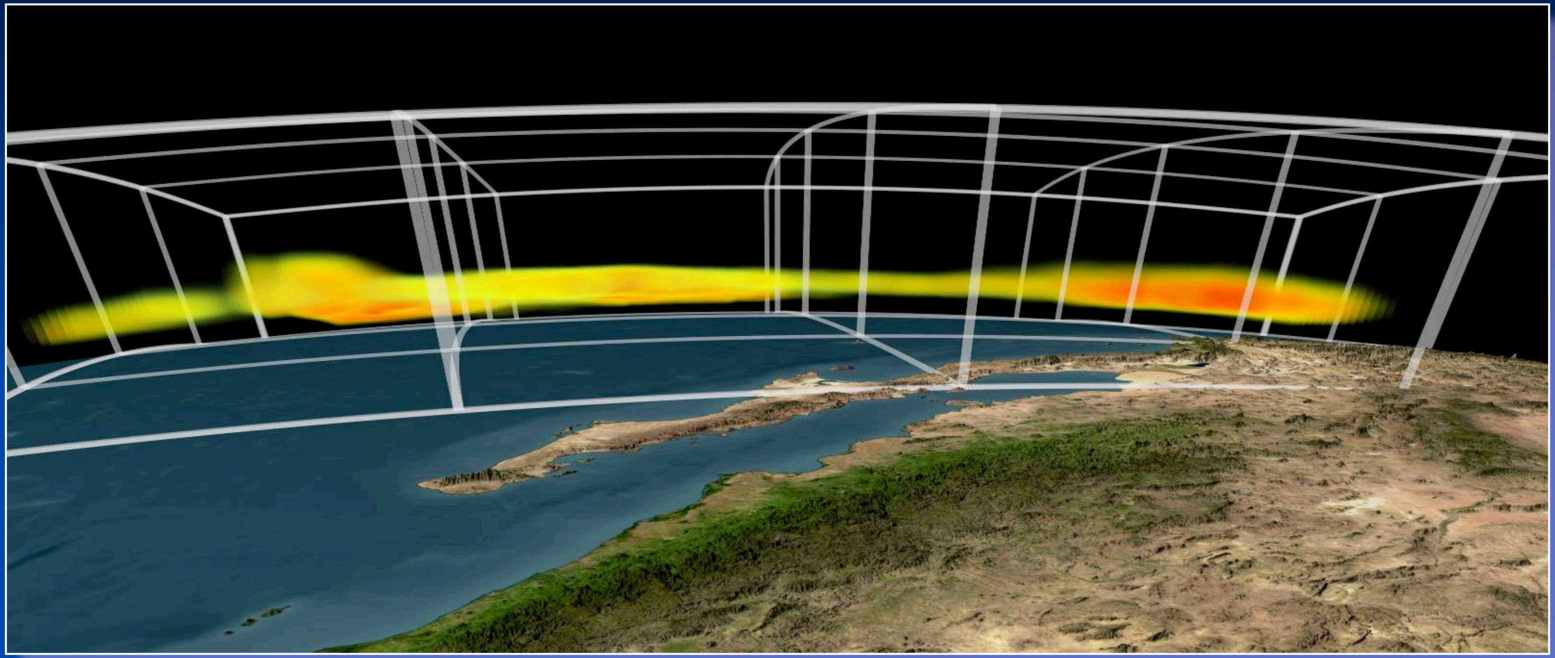
ISRs
SuperDARN
Allsky Imagers
Satellites



Employ Instruments in Unison

EISCAT_3D

EISCAT_3D is Different



EISCAT_3D will give accurate, large-scale, three dimensional measurements of the ionosphere and atmosphere for the first time

EISCAT_3D will give unprecedented temporal and spatial information about the plasma environment – essential to understanding crucial and societally relevant problems in the geospace environment, in space weather, and in the global energy budget and related climate change

MIDAS-Mobile Coherent Software Radio System

Advanced digital receivers
- ECDR-GC314FS
- Six analog inputs (2 cards)
- Up to 24 simultaneous RF channels

Ultra stable GPS locked oscillators
- Wide area coherence
- Absolute alignment of data to UTC
- 1 part in 1E11, 20 nsec alignment
- Low phase noise

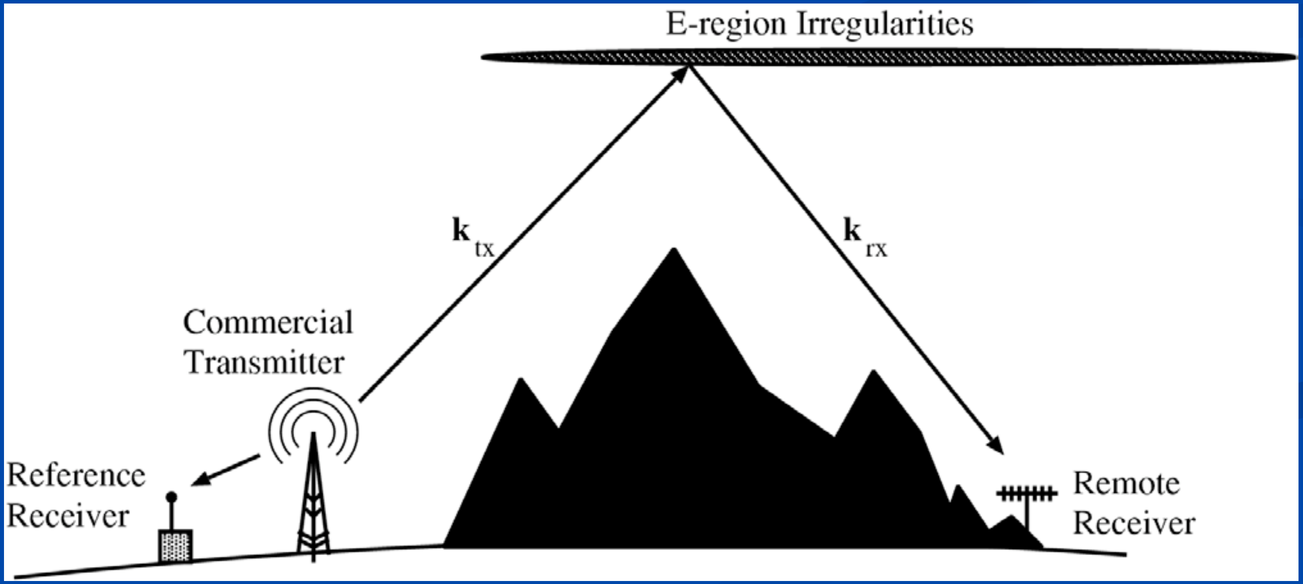
High integration UHF Radar Tuners
- DC to 1500 MHz (with external filters)
- 30 MHz down-converted bandwidth

Fully remote Internet based operation
- Realtime web based visualization
- Grid Computing
- Remote power control

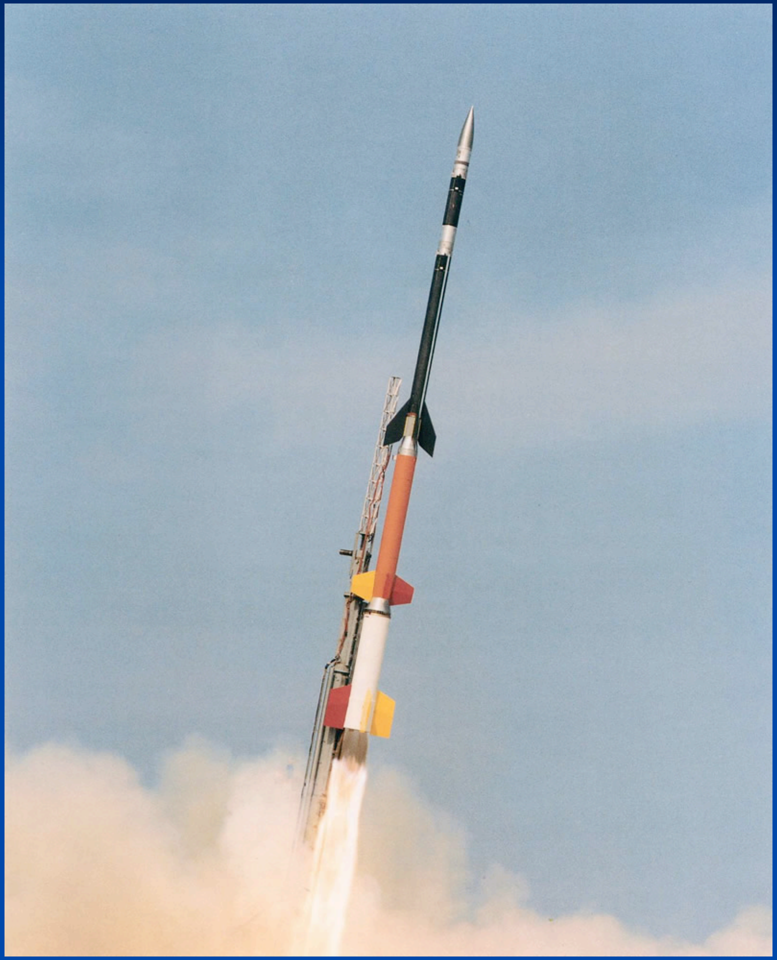
- MIDAS-M : Latest Millstone Data System
  - Millstone UHF Radar and ISIS Array
  - Software Radar Architecture : Raw Voltage Based Processing
  - Realtime signal processing, analysis, database, and visualization
  - Production quality IS radar ion line processing
  - Active and Passive Radar, Monostatic/Multistatic, Satellite Beacons, Spectral Monitoring

ISIS
Distributed Software Radio Array

- Radar Using Intercepted Signals as the Transmitter Source
- Coherent Scatter from Ionospheric Irregularities and Meteors
- Dynamic Range From Multistatic Architectures
- Precise Synchronization Using GPS Signals
- Transmitter and Scattered Signal Coherent Digitization
- Wide Area Network Transport of Raw RF Data
- Numerically Intensive Data Processing



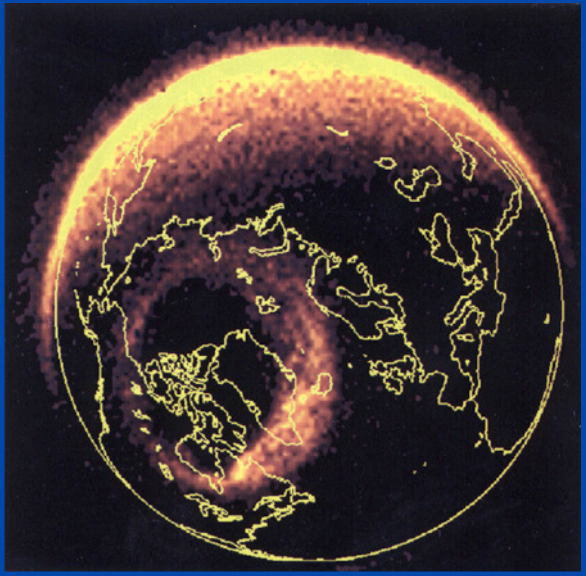
Rockets for Tomorrow's Sub-Orbital Program
(What Will They Be Like?)

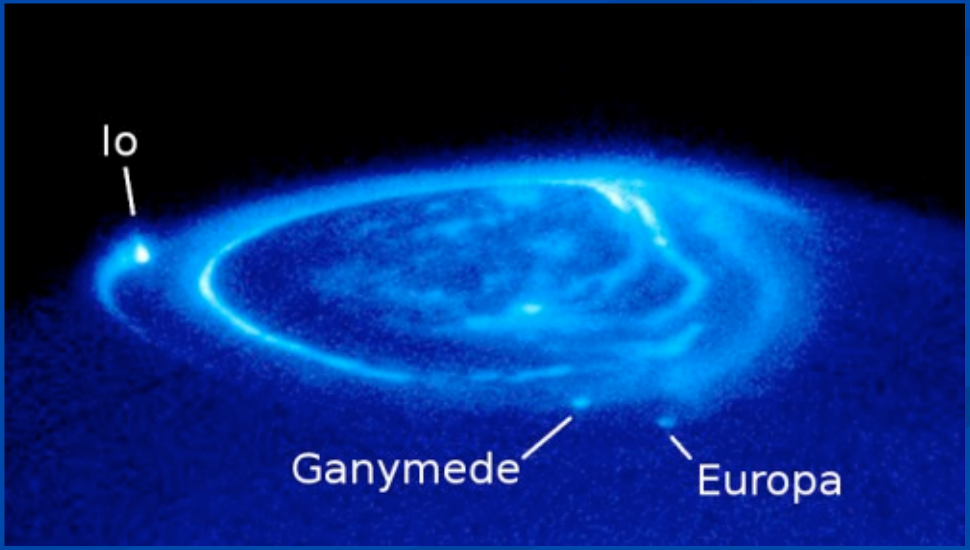


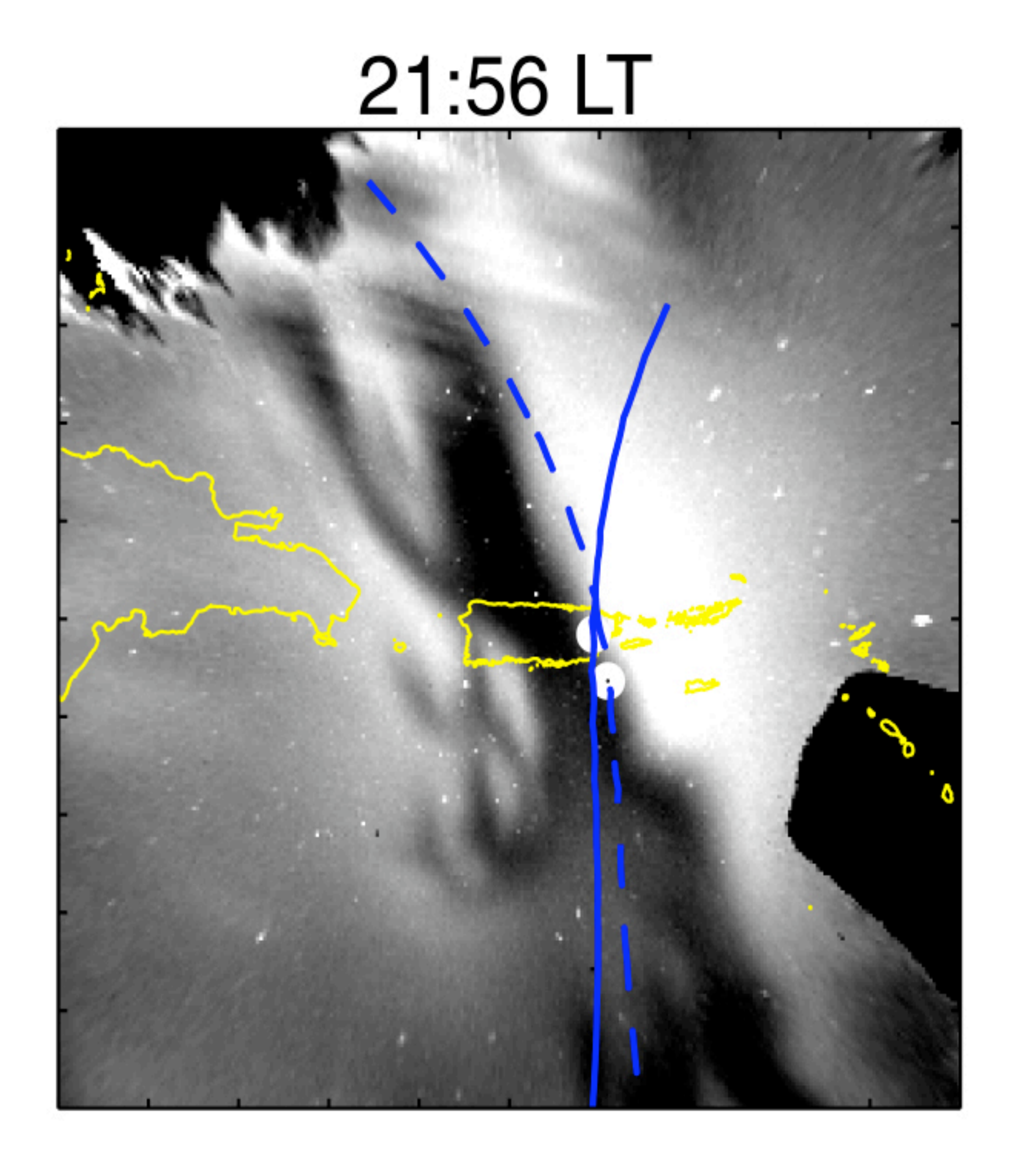
Optical Sensors

Ground Based

(But New Ground to Break)





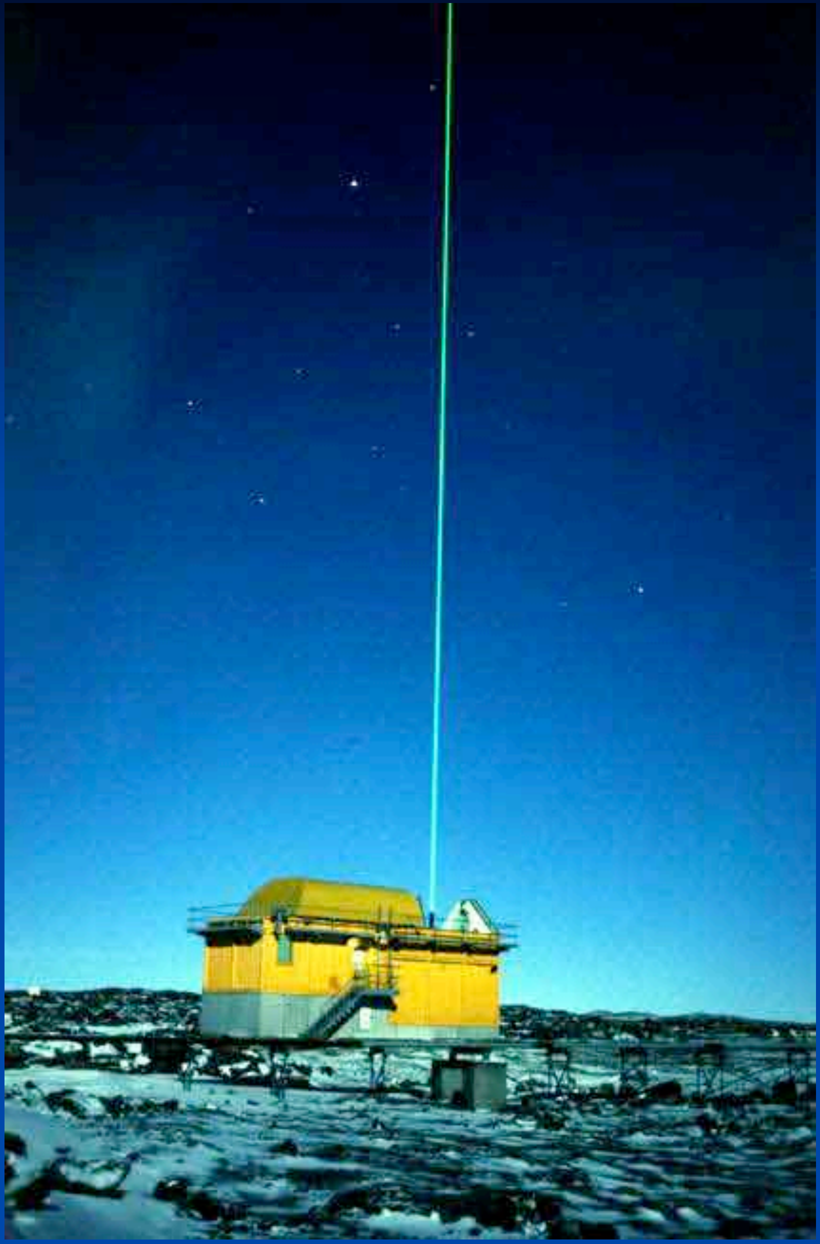


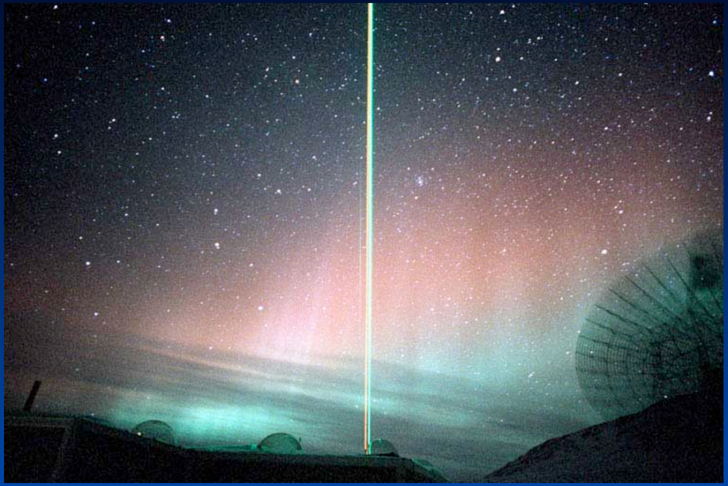
(Courtesy: J. Makela)

Images of Geospace Optics, GPS TEC & IS Radar

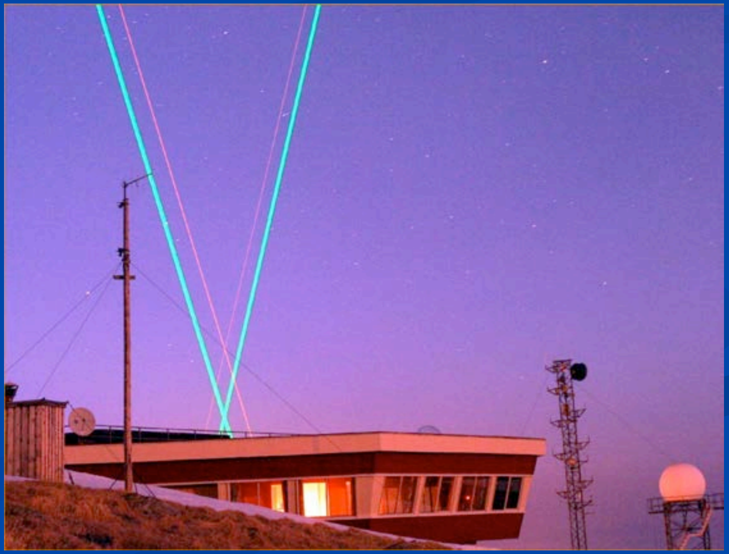
Equatorial Uplift Destabilizes Plasma

Spread F (Bubbles) in Enhanced TEC Region





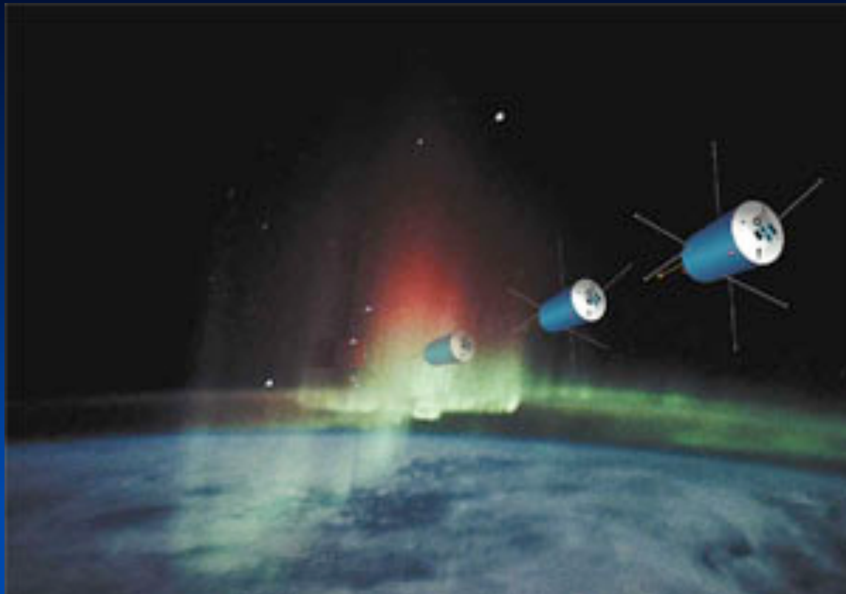
Middle Atmosphere Lidars



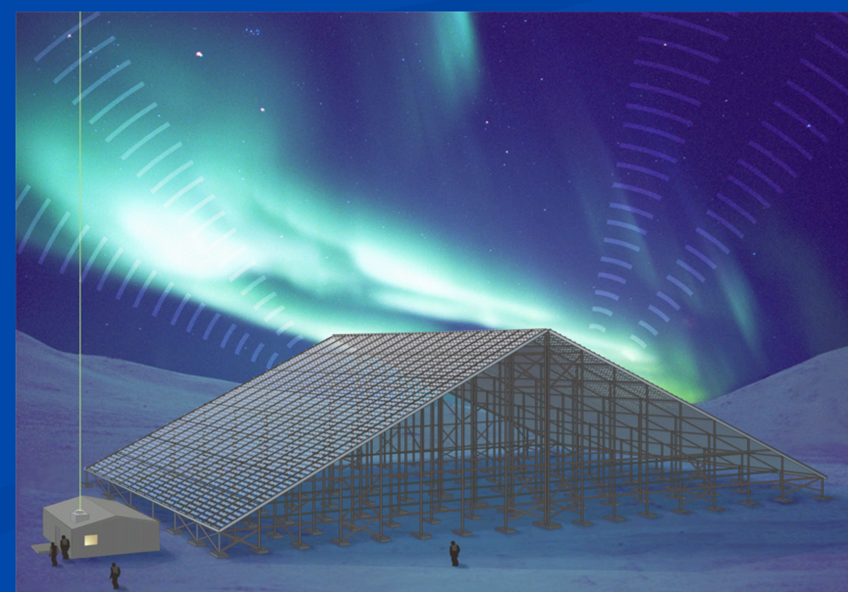
Future Directions (Jon Makela)

- We are studying a global system
  - Land masses are becoming increasingly well instrumented
  - What about the oceans?
- Multiple-instrument clusters provide more comprehensive measurements than individual instruments
  - Can we assemble a "menu" of instruments that a PI setting up a site can choose from?
  - Is it time to deploy a community-driven/supported array? This is a *large* logistical undertaking
- To not be constrained by where we can plug in our instruments, we need to be able to deploy off grid
  - Requires development of lower-powered (but not less-capable) instruments
  - Requires cellular/satellite communications to get data back

Off-the-Grid Deployment



Technologies for Remote Deployment



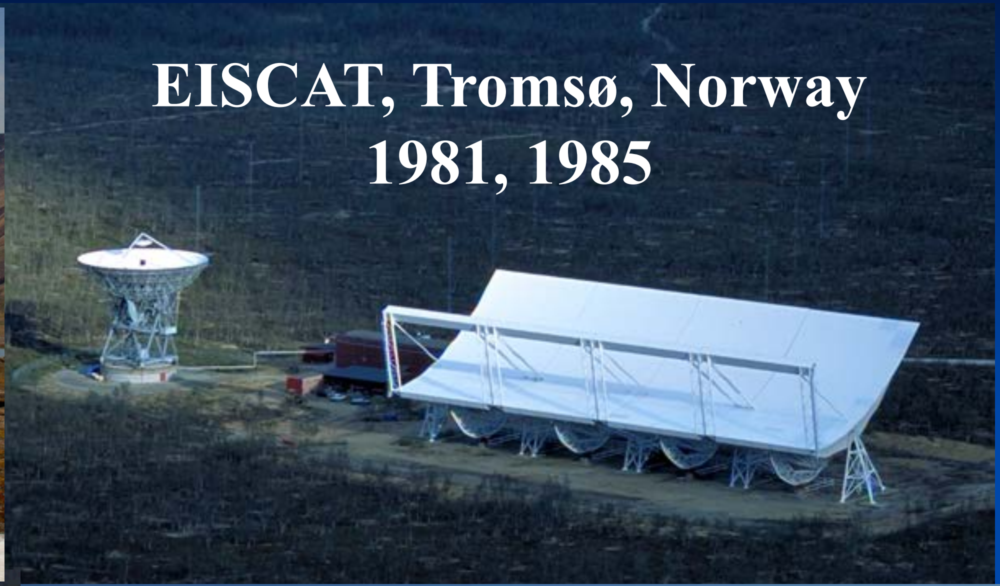
System Science

System Science is an approach to understanding the natural and physical world that recognizes how various phenomena are interconnected.

For the first time, scientists have easy access to massive amounts of information by which to study the interconnectedness of diverse phenomena.

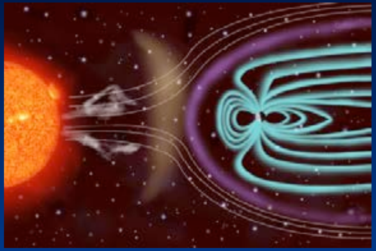
The system itself is a frontier – we must identify and understand its characteristics and components.

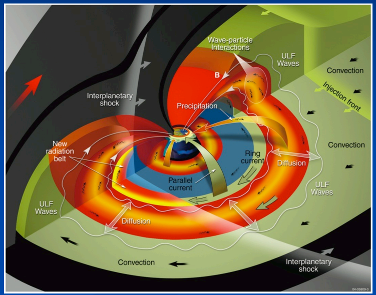
Class I Facilities – Old and New

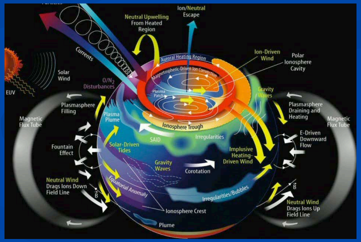


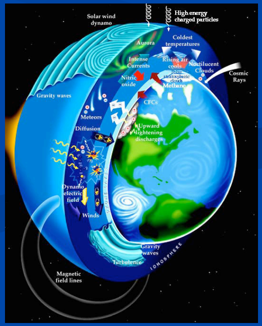
UAF Observatories Probe the Boundaries of Geospace

UAF Geospace Observatories	ITM Regions	Magnetospheric Regions
		Solar Wind
RISR	Polar Cap	Magnetosheath
PFISR Sondrestrom	Auroral	Outer Magnetosphere
Millstone Hill	Sub-Auroral	PBL
Arecibo	Mid-Latitude	Inner Magnetosphere
Jicamarca	Equatorial	Ion/Neutral Boundary









UAF Geospace Observatories

- Span altitudes across the ion-neutral transition
  - Earth's threshold to space
- Span latitudes mapping all regions of geospace
- Positioned at major boundary layer (BL) locations
  - observe universal BL processes
- Ground-based: continuous/repeatable coverage
- Coordinated observations: snapshots of geospace
  - interconnectivity of processes

- Magnetopause BL /cusp: RISR, Sondrestrom
- Open/Closed B-field BL: RISR, Sondrestrom, PFISR
- Plasmasphere BL (PBL): Millstone Hill
- Ion-Neutral BL: Jicamarca, Arecibo, high-lat ISRs

Equatorial ISR
Unique Coverage and Phenomena

Jicamarca Radio Observatory, near Lima, Peru
18,432 dipoles, 50 MHz, 1961

System Science Requires Global Coordinated Observations

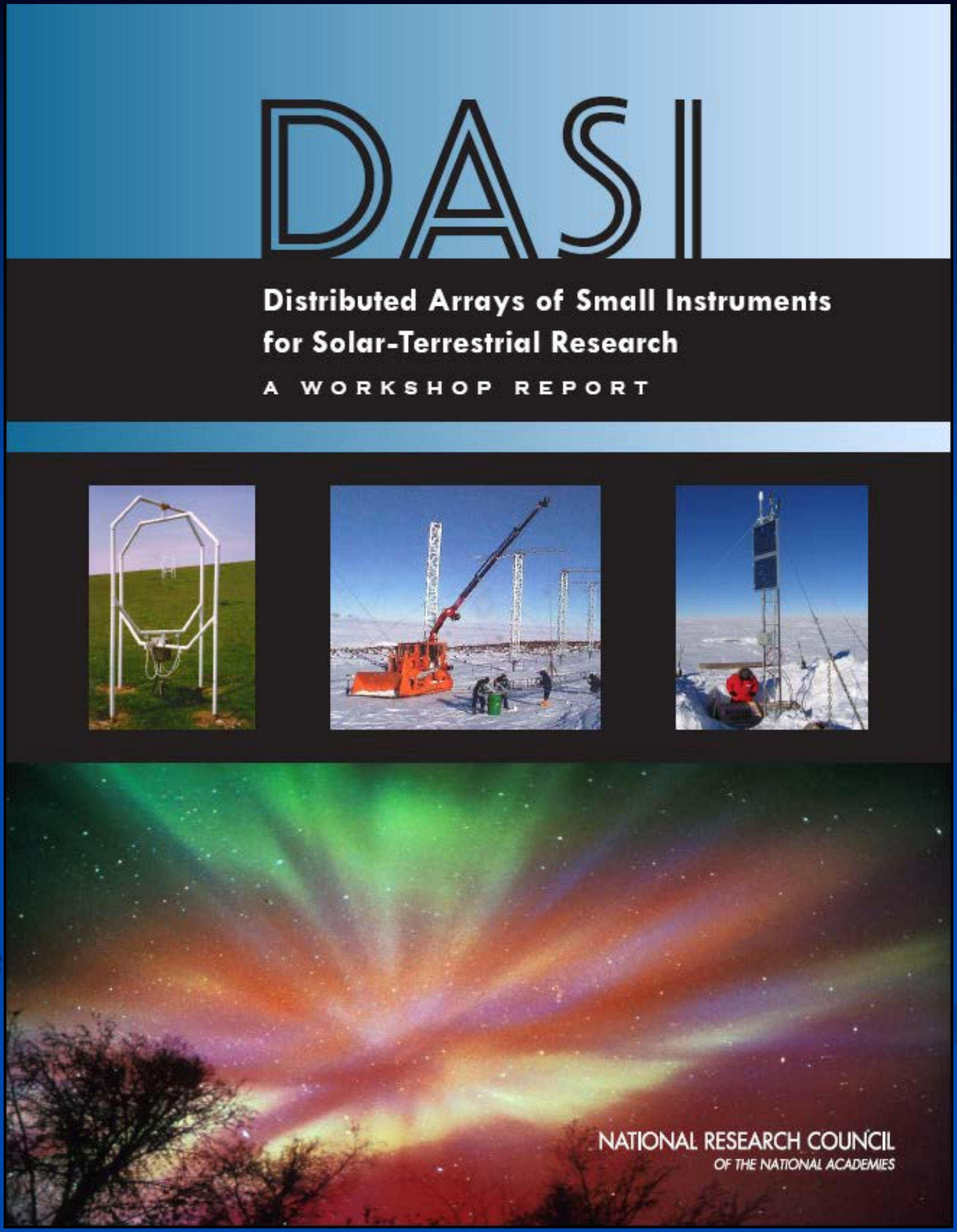
The latitude and altitude regions of the upper atmosphere are coupled in complex ways and behave as a dynamic system.

Meso-scale (1000-km) features associated with the redistribution of thermal plasma from the low-latitude ionosphere to the auroral and polar regions and its outflow and acceleration into the magnetosphere provide a striking example of coupled-system interactions. Solar disturbances driving prompt penetration electric fields impact the state of the ionosphere from the poles to the equator, intermingling the effects of neutral-ion coupling with magnetosphere dynamics over the planet-wide upper atmosphere on short (10-min) time scales.

Such complex behavior requires distributed system-wide observations to address the processes involved in both regional and larger-scale effects. Individual observing techniques and facilities (e.g. the SuperDARN radars or the ISRs) provide only a portion of the needed coverage. Coordinated observations among instrument types and with good spatial distribution are needed to view, diagnose, and understand the overall global system.

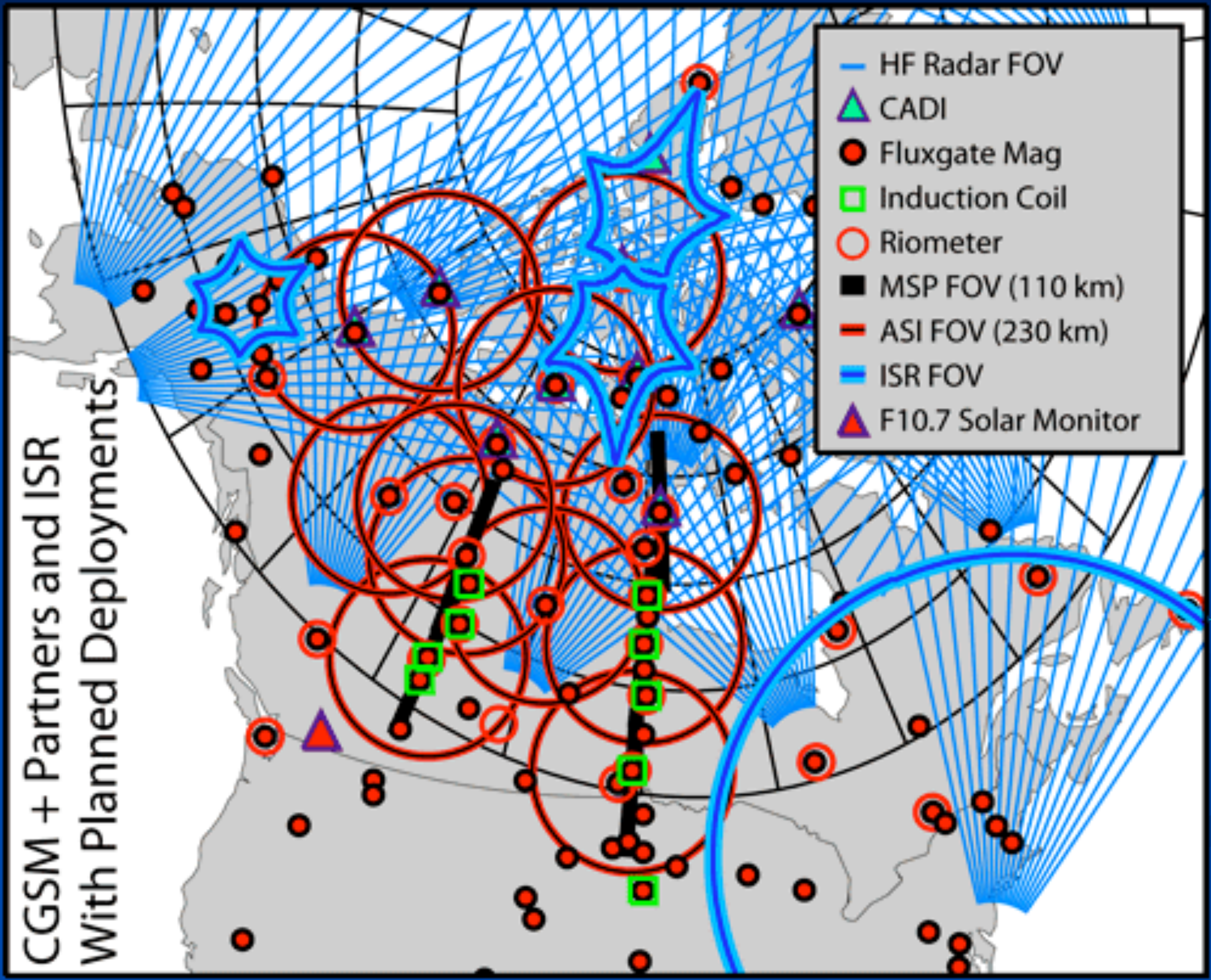
DASI: A Framework for Community Collaborative Research

- Geospace is a System
- System Science: Distributed Realtime Observations Needed
- Insufficient Data: New Instruments
- Multi-Instrument Collaboration provides New Views of Geospace
- Time to Get Started!



Regional DASI to address System Science

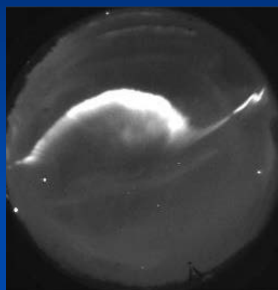
SuperDARN (Polar, Auroral, Mid-Latitude), ISR, THEMIS GBO, ISIS, etc.

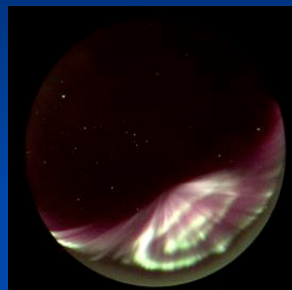


Next-Generation Instrument: Regional DASI

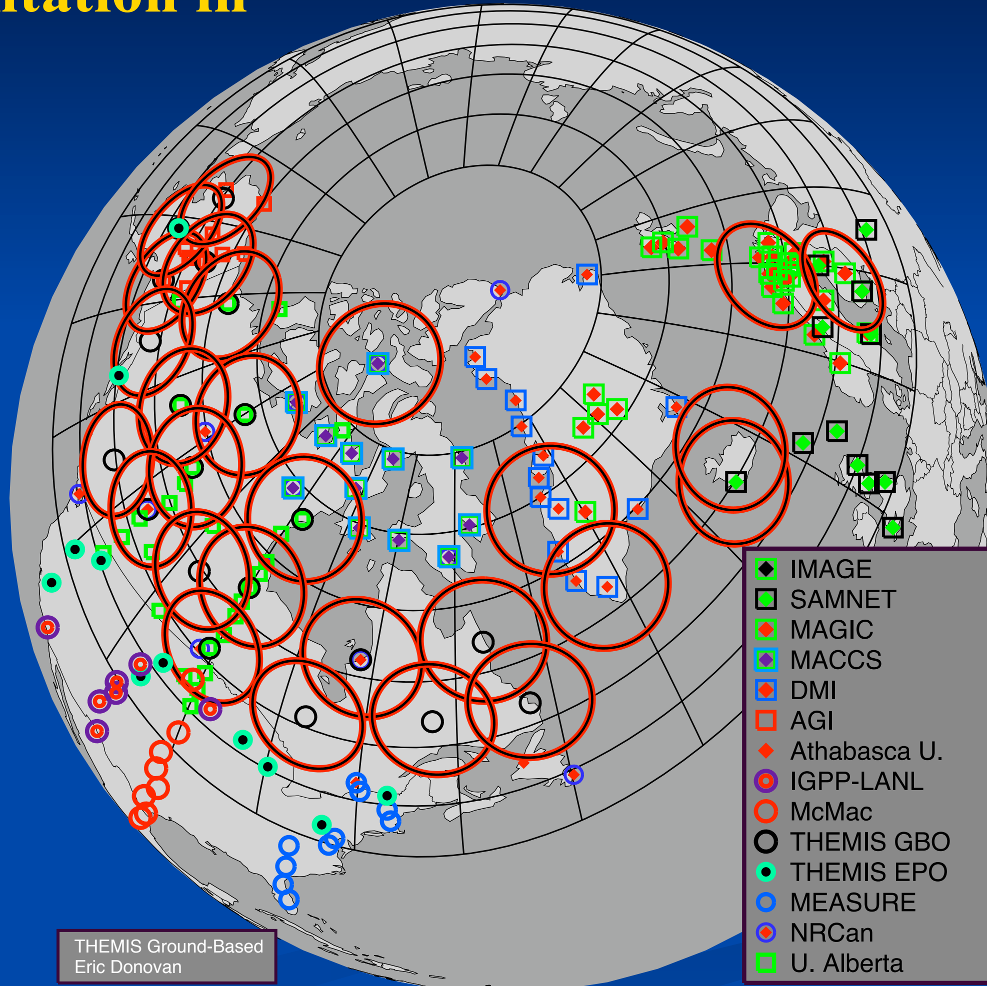
- Combine existing distributed arrays and Class I instrument clusters
- North American arrays span polar, auroral, sub-auroral, and mid latitudes
- Multi-technique facilities: Magnetometers, Imagers, ISRs, HF Radars, Rockets
- Communications infrastructure is in place

Ground-Based Instrumentation in North America





UC Berkeley
U Calgary
U Saskatchewan
EISCAT
U Tromso
FMI
DMI
SRI
Astronomy North
Lancaster U

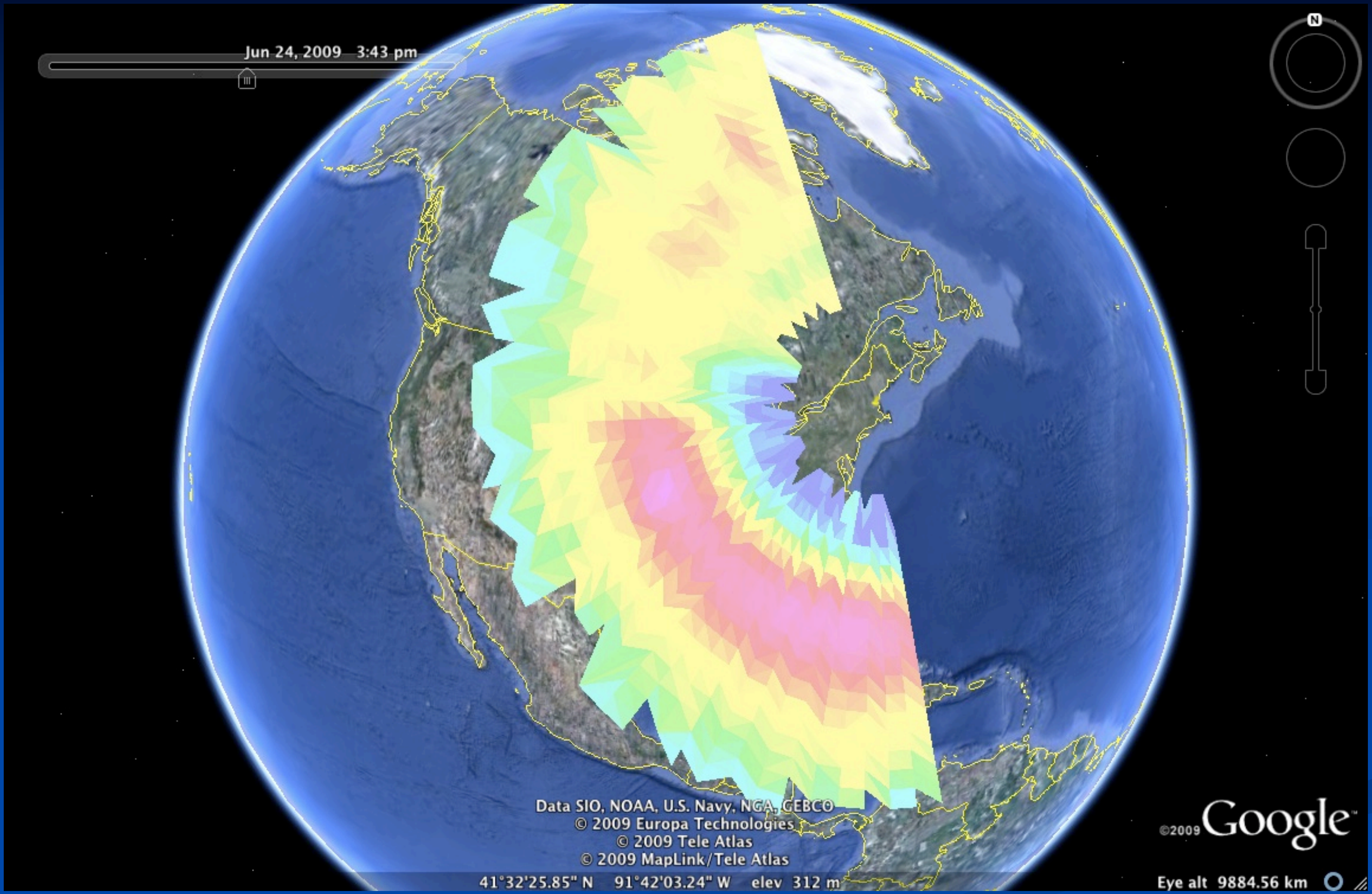


- Class I Facilities Anchor North American Array
- Key Locations for System Science

Mid-Latitude Large Dish ISRs

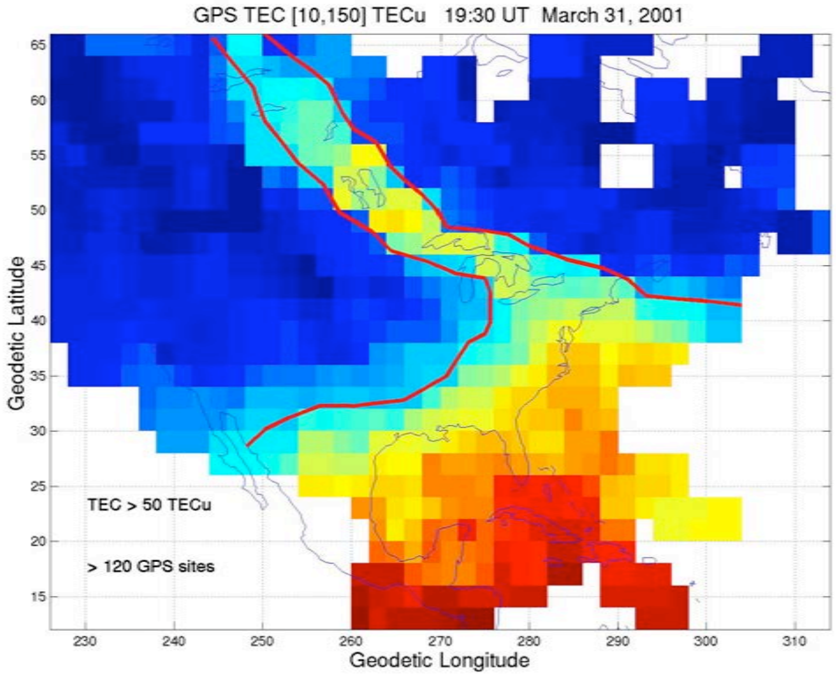
Arecibo, Puerto Pico

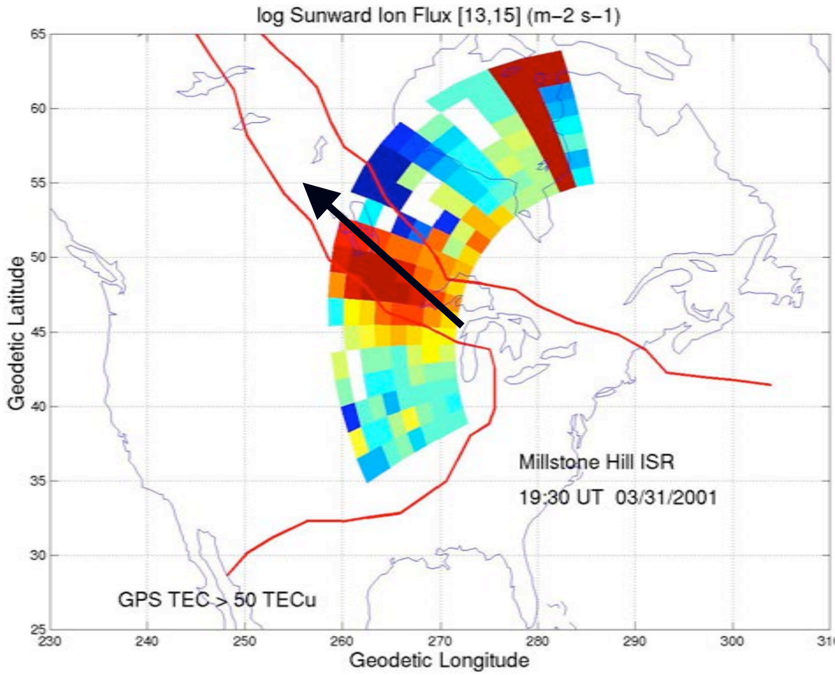
Millstone Hill, Mass.

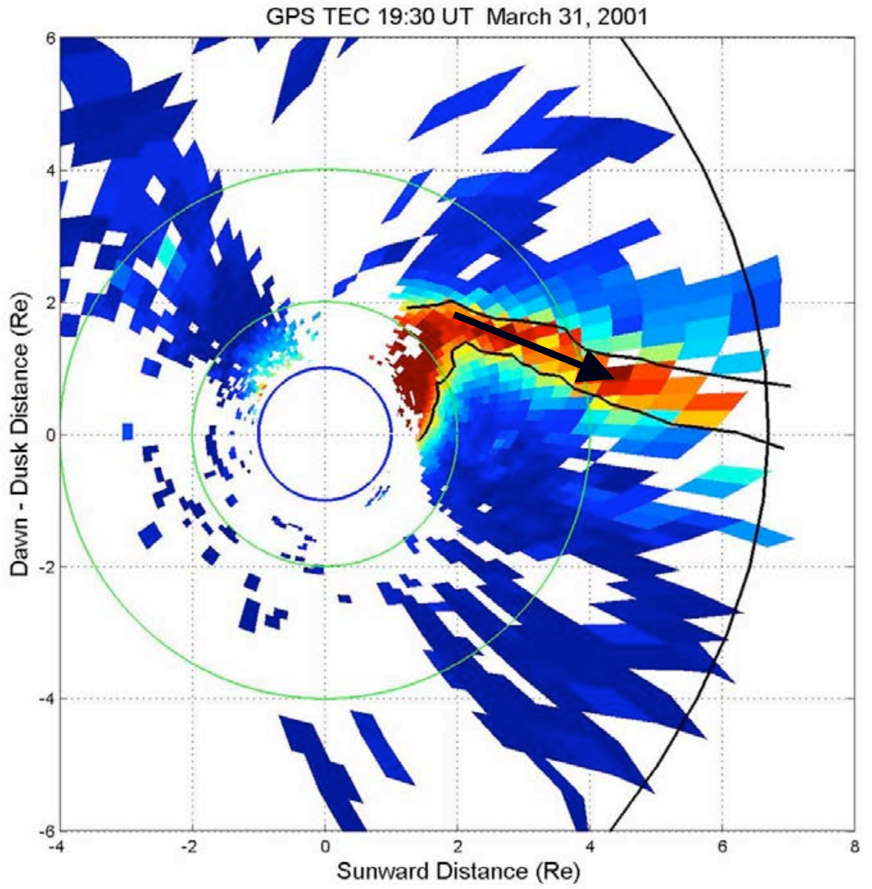


Millstone Hill ISR Mid-Laitude Field of View

Radar & GPS TEC Arrays Map Ionospheric Structure & Dynamics

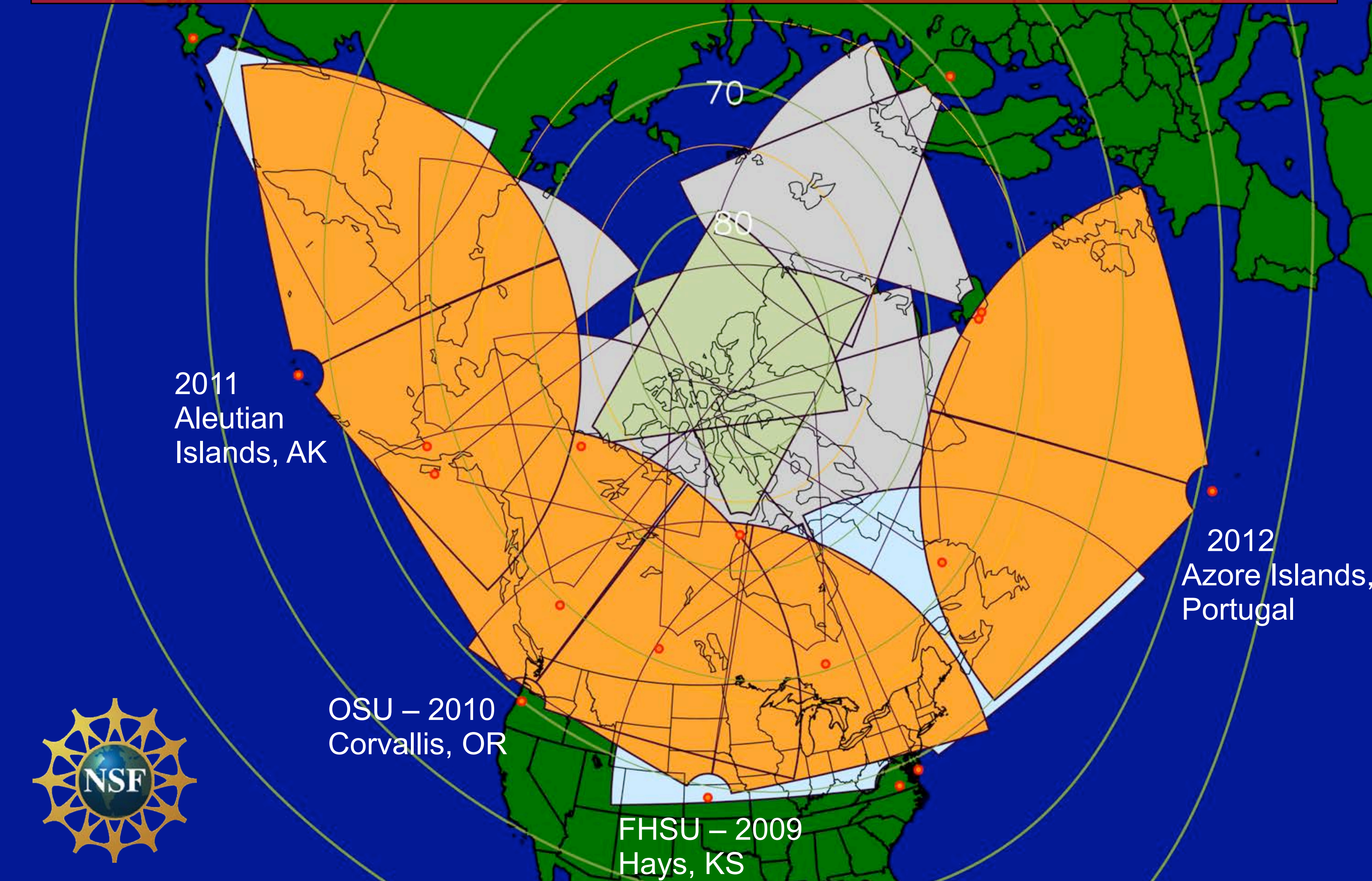




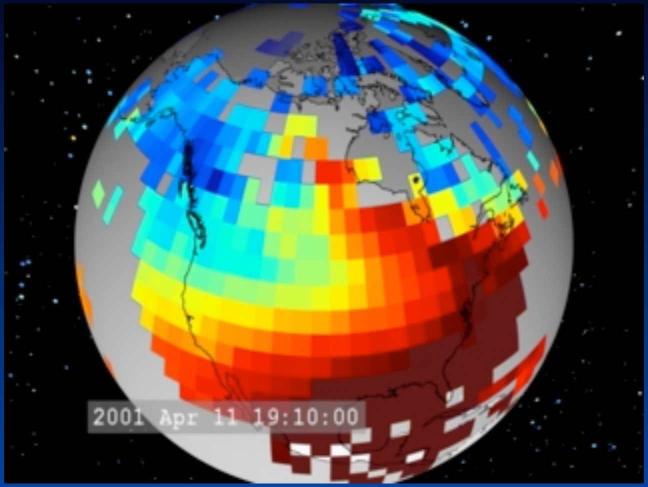


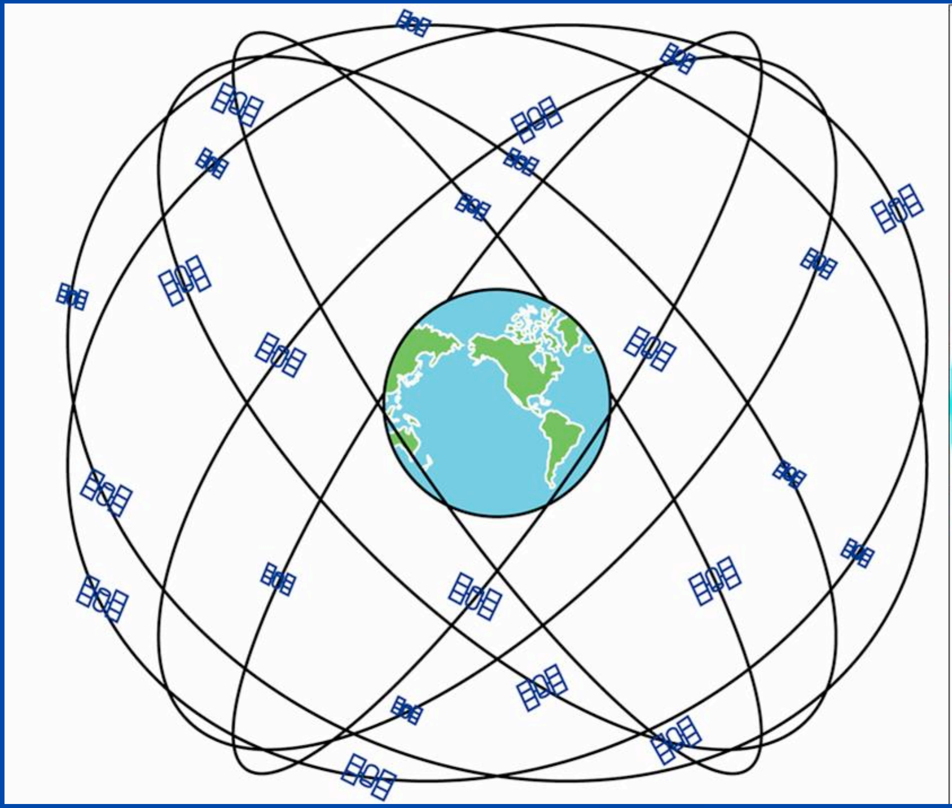
Monitoring the Ionosphere: SuperDaRN Radar Arrays

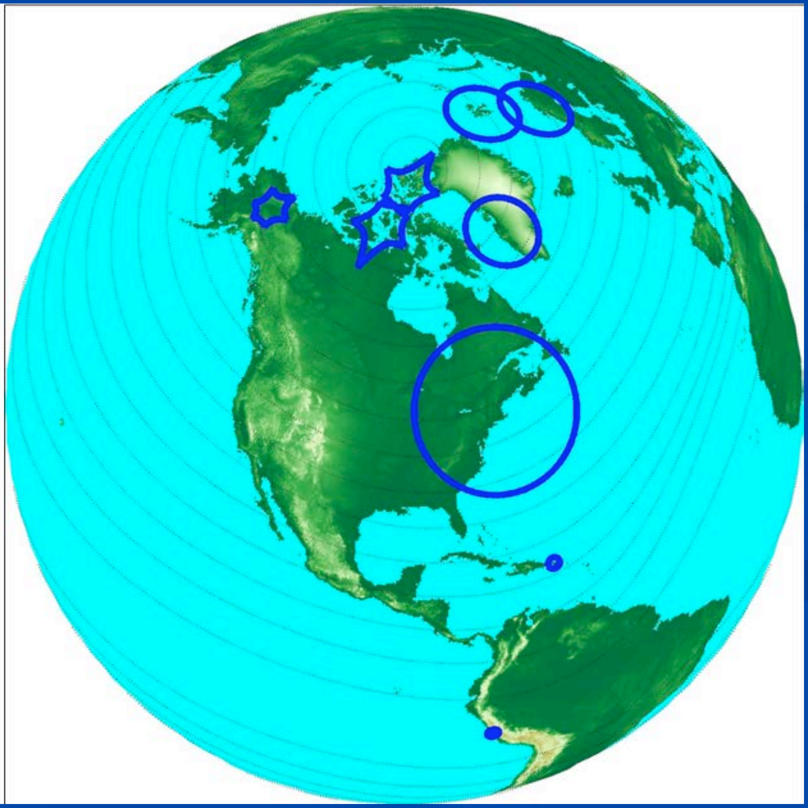
Mid-Latitude SuperDARN
Global-Scale Ionospheric Electrodynamics and Processes



Ground and Space-Based Arrays for Geospace Studies



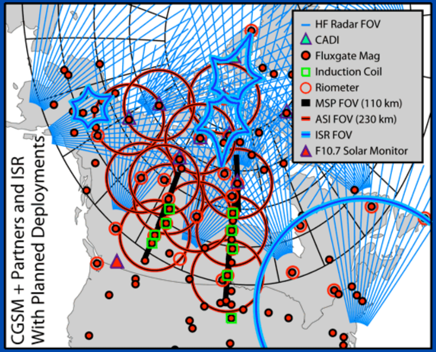


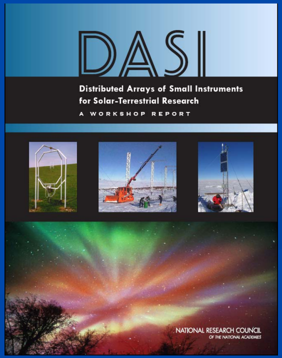


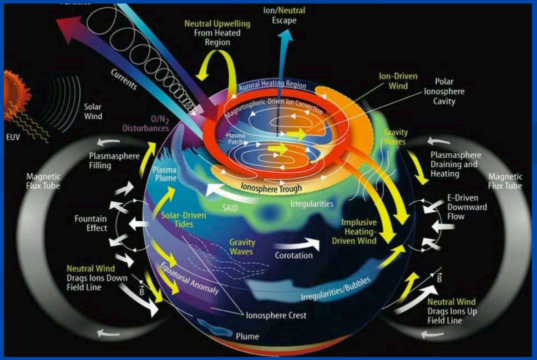
Next-Generation Instruments

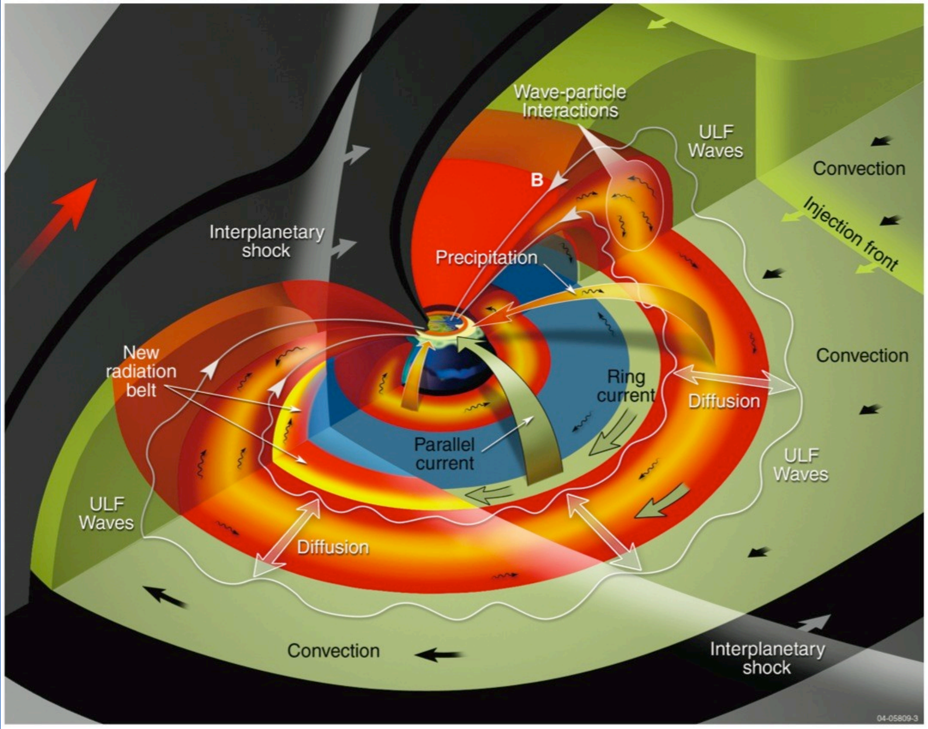
Our next-generation instruments will evolve from our current capabilities, taking advantage of technological developments to improve their sensitivity, capability, and operational efficiency.

The breakthrough will come in our ability combine the output of the available instruments in ways which address the processes and characteristics of the Geospace System taken as a whole.









Wave-particle Interactions
ULF Waves
Convection
B
Injection front
Interplanetary shock
Precipitation
Convection
New radiation belt
Ring current
Diffusion
Parallel current
ULF Waves
ULF Waves
Diffusion
Convection
Interplanetary shock
04-05809-3