International School of Space Science (ISSI)

The Polar Upper Atmosphere: From Science to Operational Issues, L'Aquila, Italy, 16-21 Sep. 2018

"OBSERVING THE IONOSPHERE-THERMOSPHERE-MESOPHERE SYSTEM"

by
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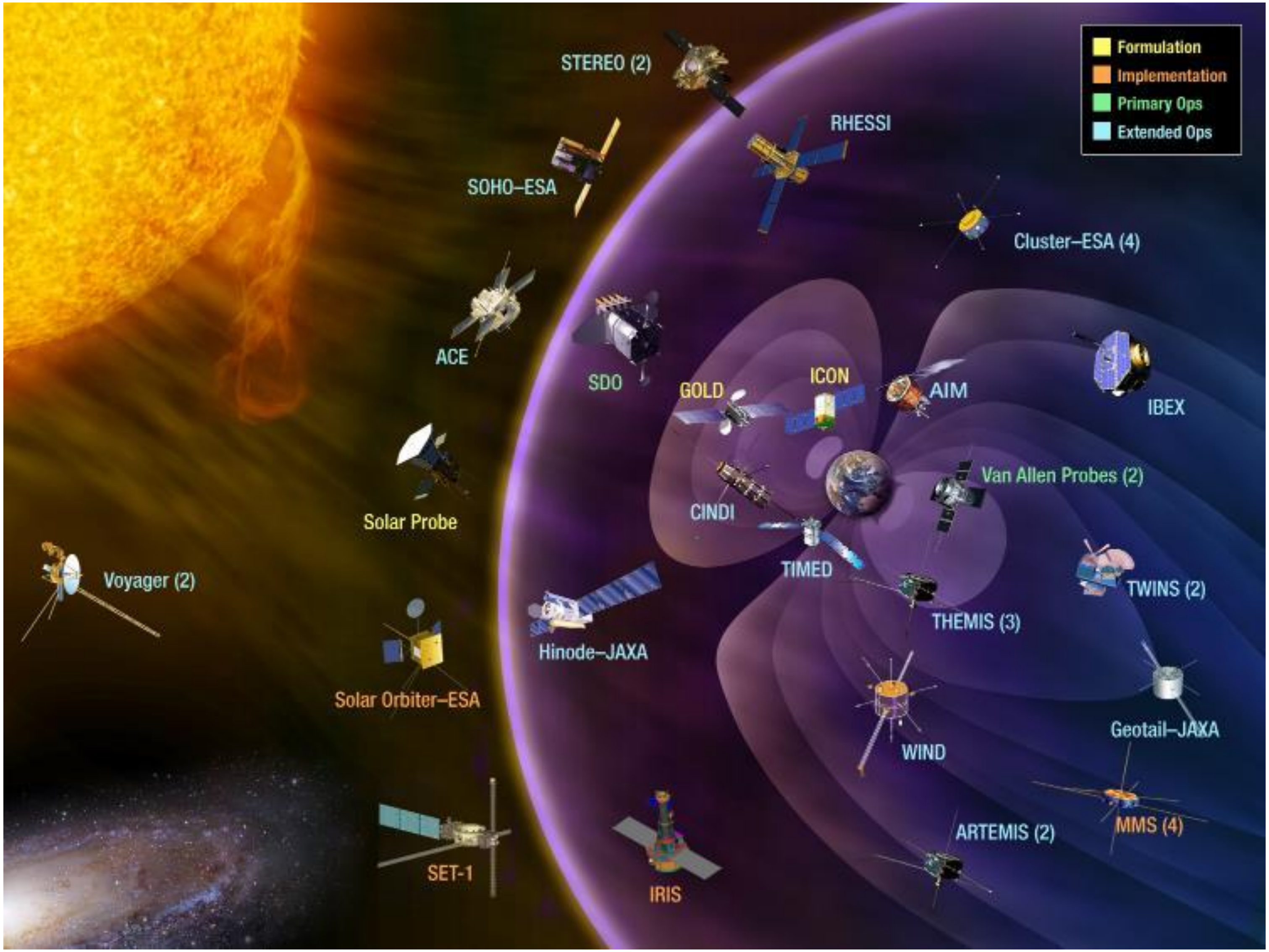
Observing the Ionosphere

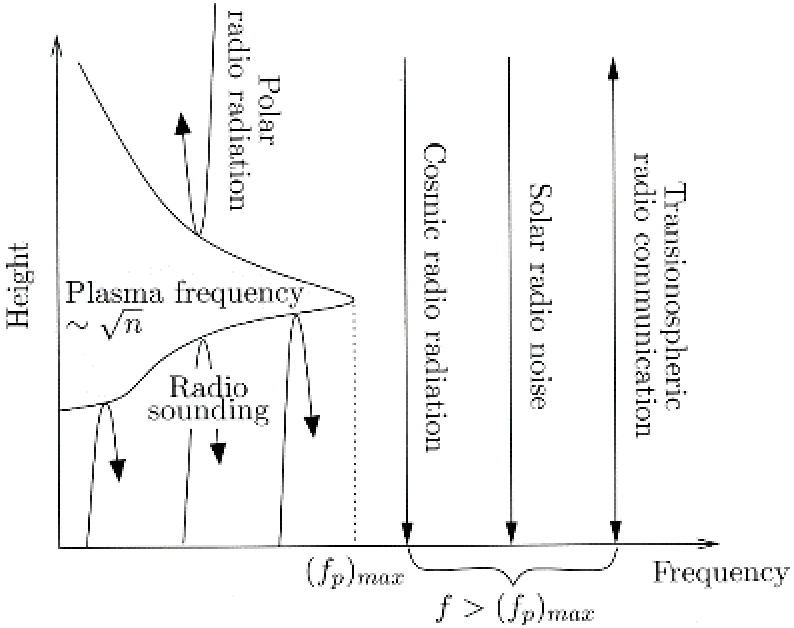
- Satellites → *In-situ*; → Remote Sensing
- Sounding Rockets → *In-situ*; → "Active Experiments"
- Ground-based Radio → Radars; → Trans-ionosphere (SAT → Ground; SAT → SAT)
- Ground-based Optical → Passive (Reception); → Active (Probing)

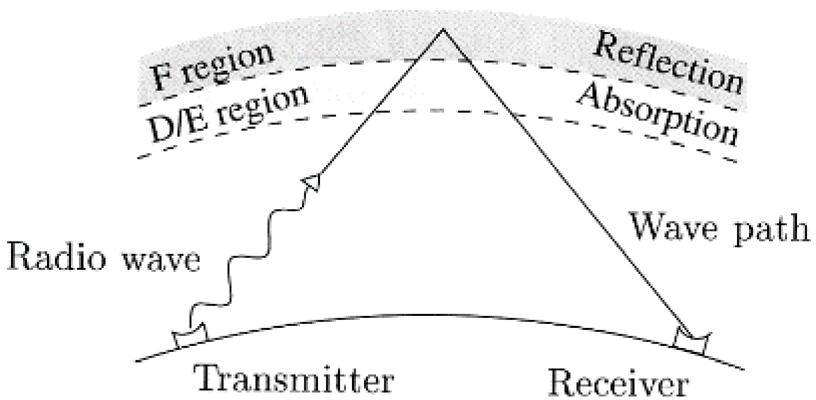
NASA's Space-based Observatories



Ground-based Ionospheric Measurements – Radio

- Reflection of radiowaves (f_{HF} ~ 3-30 MHz)



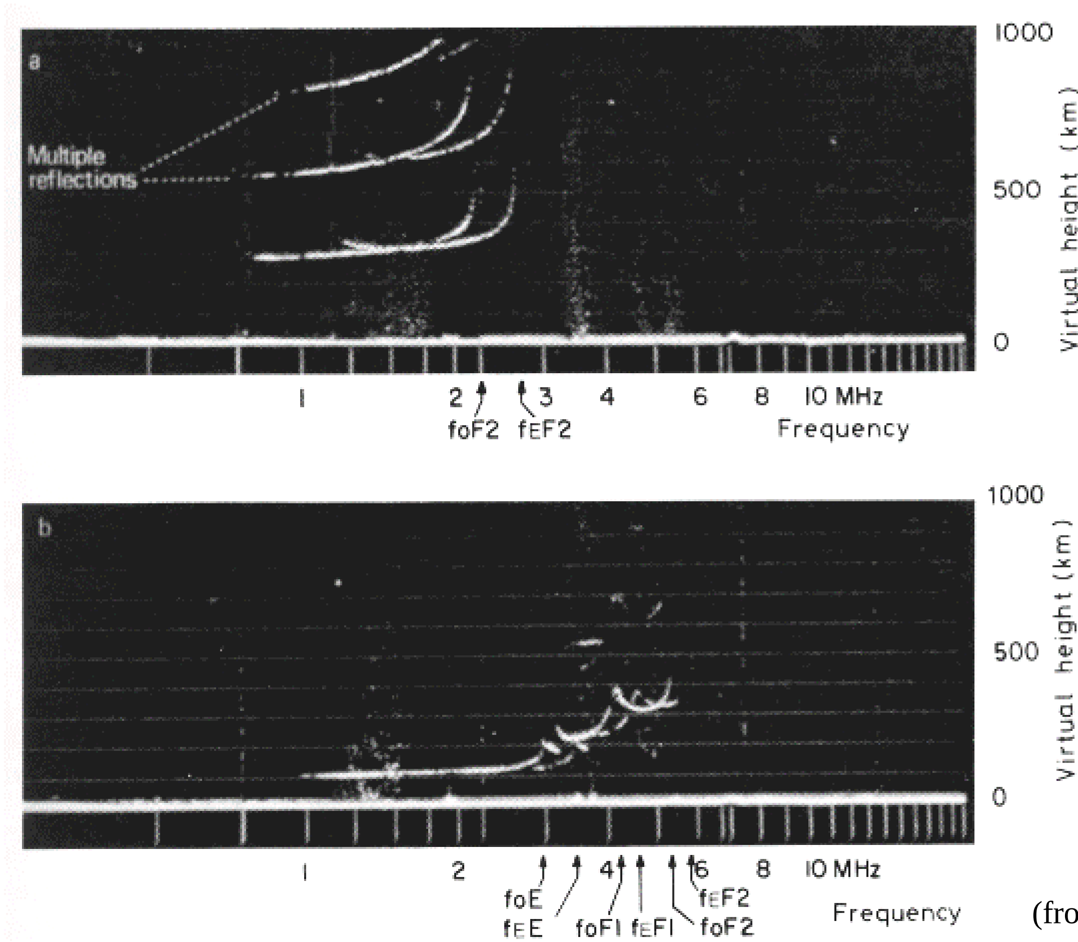


(from Prölss, '04)

Plasma frequencies → Layer peak densities

$[f_p\ (Hz)]^2 = 80.5\ N_e\ (m^{-3})$

Example of Ionogram



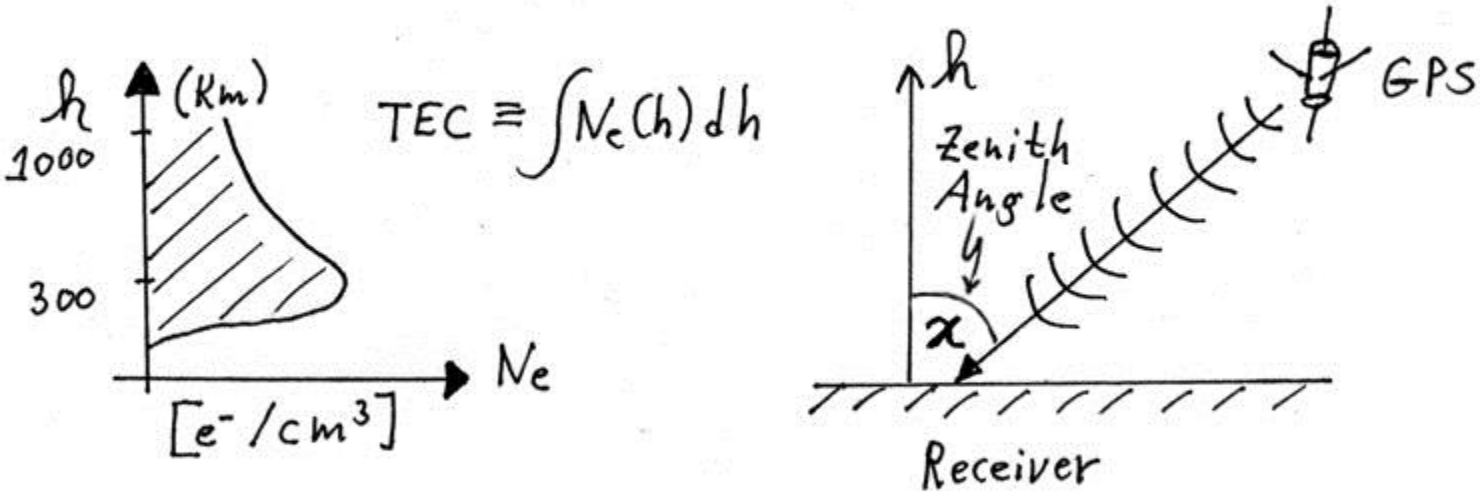
(from Hargreaves,' 92)

Network of ionosondes

Lowell Digisonde International: www.digisonde.com

INGV: www.eswua.ingv.it/ingv/i_ita.php

* Trans-Ionospheric Radiowaves (f_{VHF} ~ 30-300 Mhz)



Index of refraction (phase):

$$n^2 = 1 - \frac{\omega_p^2}{\omega^2}\text{; if } \frac{\omega_p^2}{\omega^2} << 1 \text{ then} \quad n \approx \left(\underbrace{1}_{\text{vacuum}} - \underbrace{\frac{40.3N_e}{f^2}}_{\text{effect of ionosphere}}\right)^{1/2}$$

(N_e in m^{-3} and f in Hz)

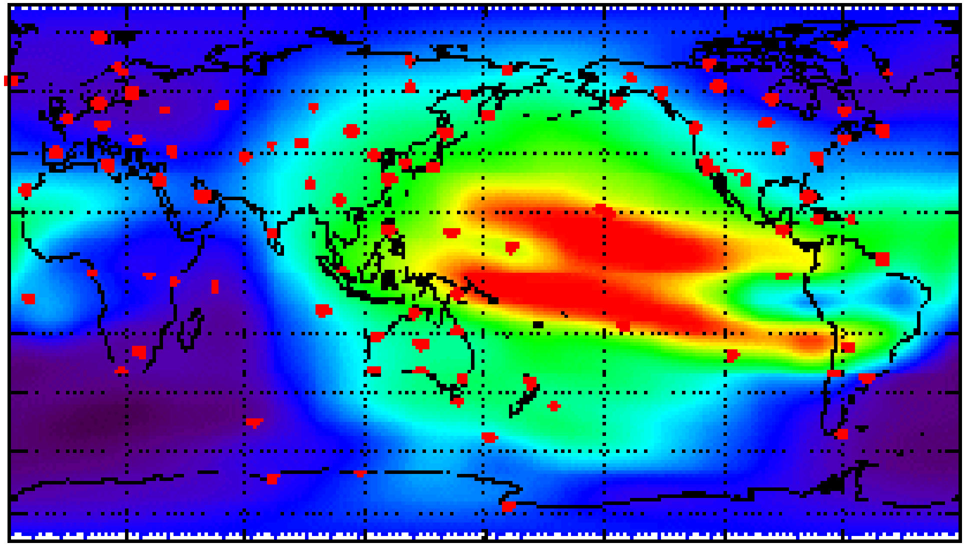
End result: wave is slowed down by plasma → Group Delay

The effect is cumulative $\rightarrow \int N_e(s)ds \rightarrow$ SLANT TEC

By measuring total group delay $\rightarrow$ STEC

Equivalent Vertical (for small spatial gradients) TEC

$$TEC = STEC \cos \chi$$



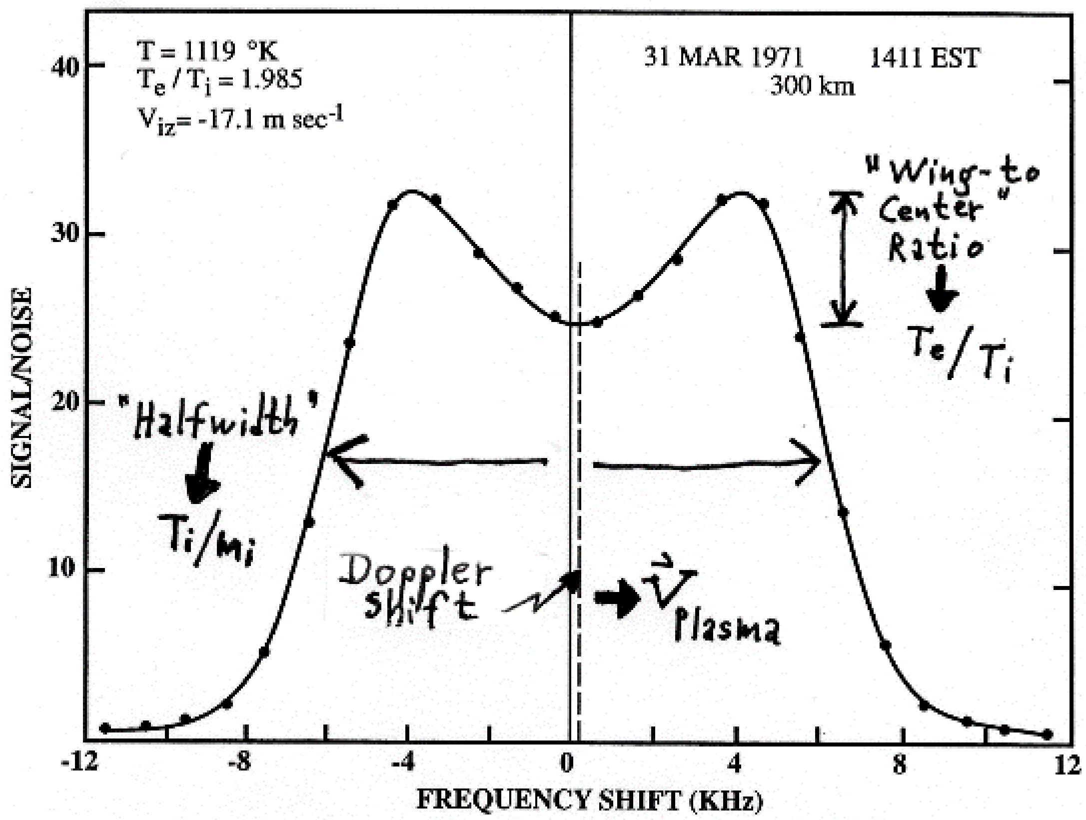
From GIM/JPL (http://iono.jpl.nasa.gov/gim.html)

Other sources: MIT Madrigal Database (http://cedar.openmadrigal.org/)

RING: (http://ring.gm.ingv.it/)

- Back-scattering of Radiowaves
  - Incoherent scatter Radars (ISRs)

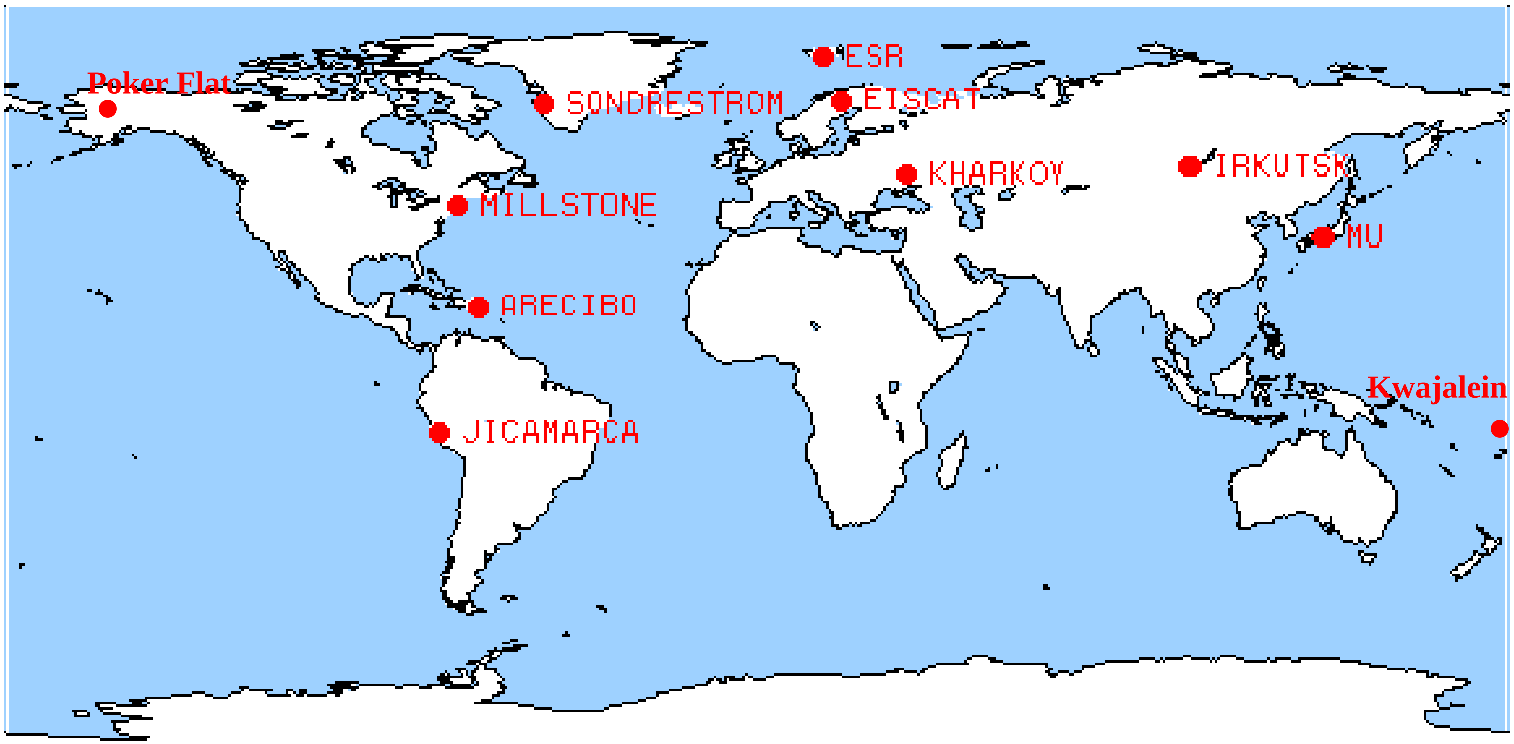
    The transmitted signal returns with a "spread in frequency" → ISR spectrum



(Adapted from Hunsucker, '91)

Physical parameters at each height:

- Total power $\rightarrow N_e$
- Peak/center spectrum $\rightarrow T_e/T_i$
- width of spectrum $\rightarrow T_i/m_i$

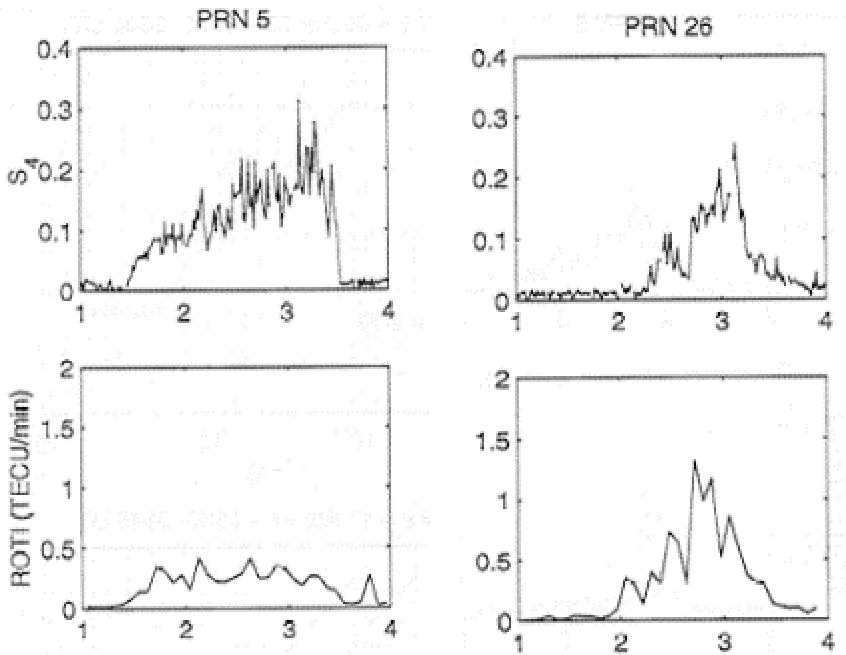


Data base at MADRIGAL site

(http://madrigal.haystack.mit.edu/madrigal/)

Ionospheric Effects on Technological Systems

Example #1 : GPS signal *Amplitude* and *Phase Scintillations* impact radio communications



amplitude

phase

(from Beach and Kintner, RS' 99)

Cause: *small-scale* ionospheric irregularities $\Delta N_e/<N_e>$ along raypath cause diffraction patterns (scale sizes from cm to 10's km)

Effect: "Loss of Lock" for signal by receiver. Inability to use GPS reliably for continuous position determinations

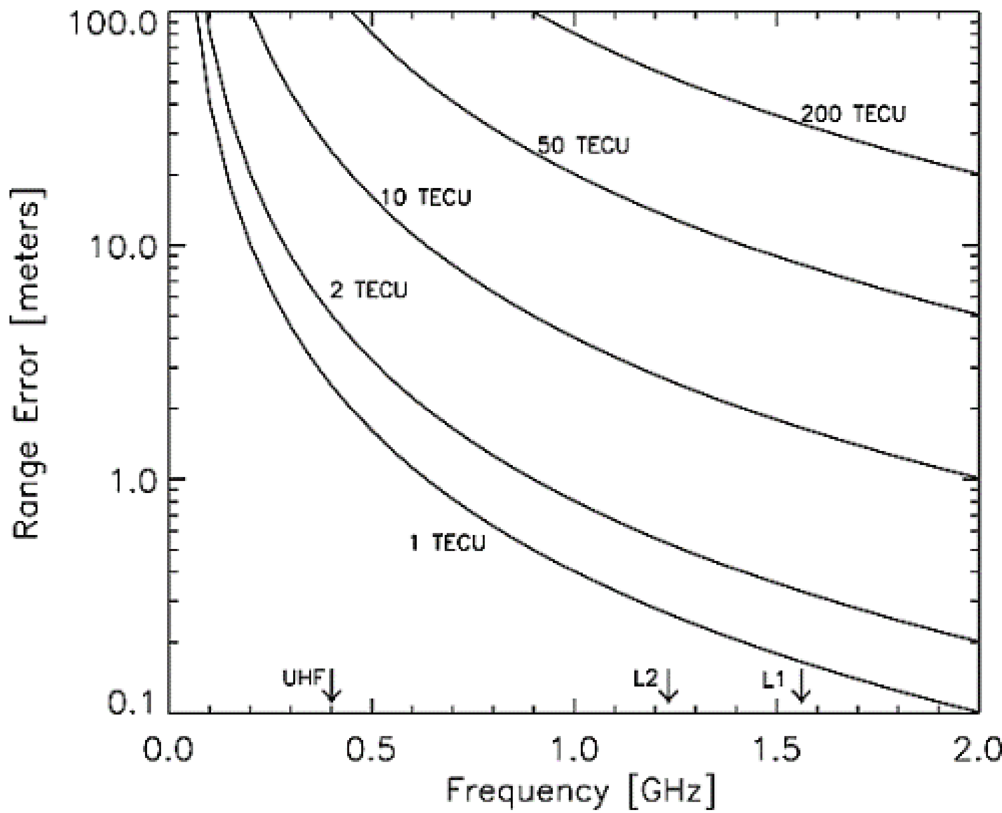
Example # 2 : Group Delay and Ranging Errors

- In vacuum, R = c x t (Range = speed of light x time)
- For trans-ionospheric radio path , v < c. So R' = v x t

  $\Delta R = R - R' \rightarrow$ "Ranging Error". ΔR thus depends on N_e along path $\rightarrow$ TEC (and χ)

$$\Delta R = 0.403\ \mathrm{TEC}/f^2$$

where TEC is in TECU (10^{16} el m^{-2}), f is in GHz, and ΔR is in meters.



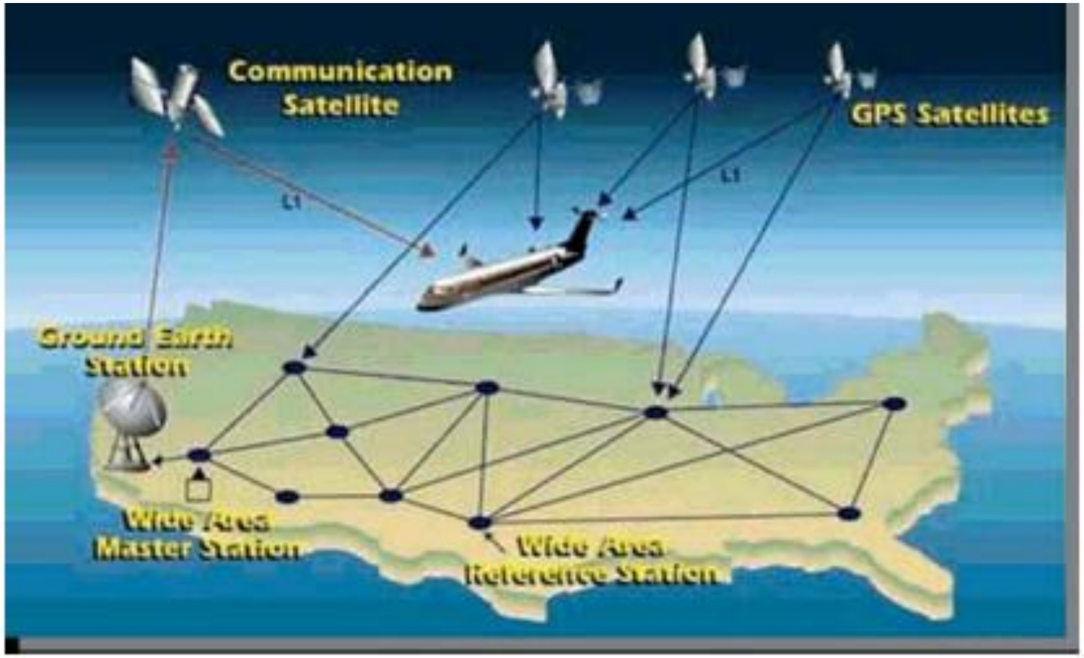
TEC can vary between ~ 2 to 200 TECU depending on LT, LAT, season and solar cycle

Solutions:

(a) TEC everywhere in real time from GPS receiver networks

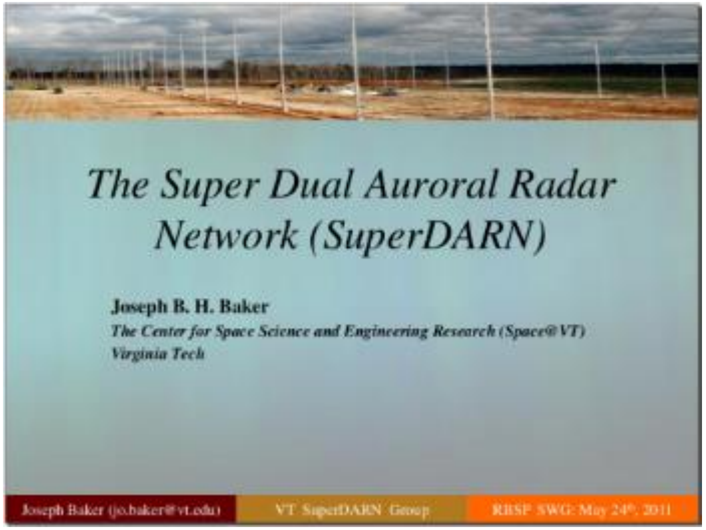
(b) TEC from models → data assimilation models

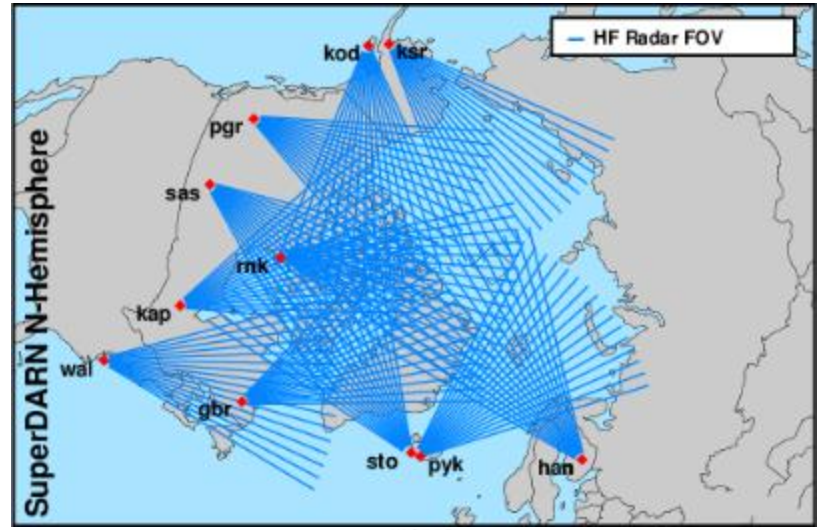
Major concern: ΔTEC during storms with strong spatial gradients in TEC → Positive Phase / Negative Phase

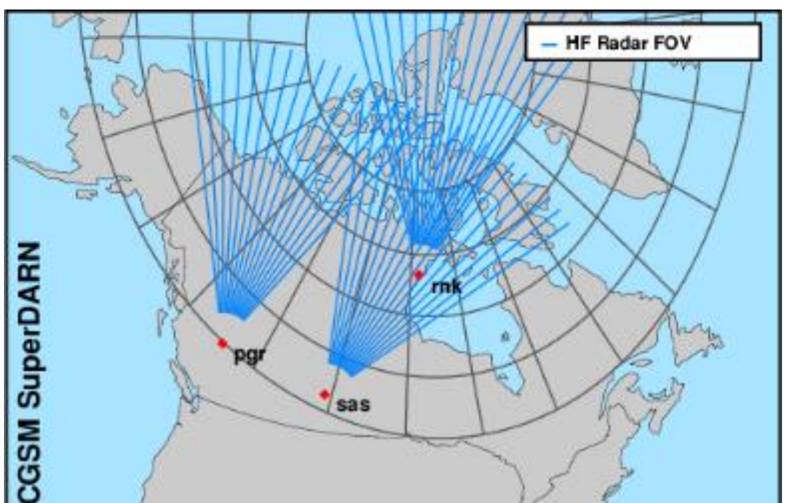


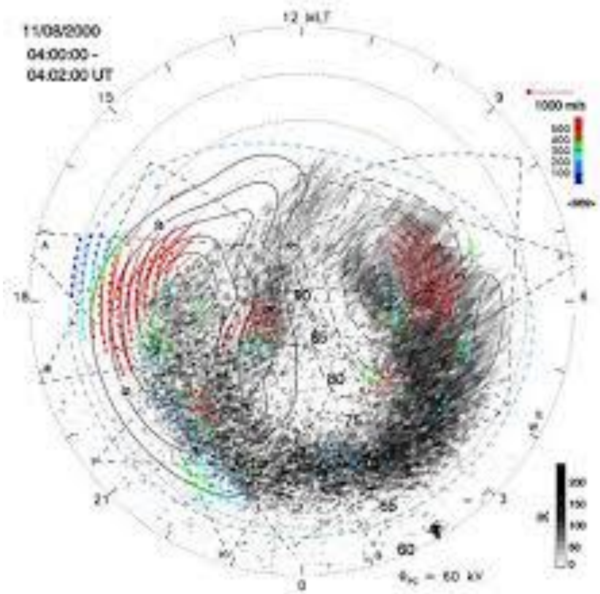
"How far down is the runway?"… "Look out the window !"

Superdarn


The Super Dual Auroral Radar Network (SuperDARN)
Joseph B. H. Baker
The Center for Space Science and Engineering Research (Space@VT)
Virginia Tech
Joseph Baker (jo.baker@vt.edu)
VT SuperDARN Group
RBSP SWG: May 24th, 2011


HF Radar FOV
SuperDARN N-Hemisphere
kod
ksr
pgr
sas
rnk
kap
wal
gbr
sto
pyk
han


HF Radar FOV
CGSM SuperDARN
rnk
pgr
sas


11/08/2000
04:00:00 -
04:02:00 UT
1000 m/s

Optical Aeronomy (Ground-based & Space-based)

LIDAR
(Light detection and Ranging)

↓

Structures & dynamics in Mesosphere

Fabry-Perot-Interferometer
(FPI)

↓

Neutral Winds & Temperatures

Spectrograph
(Brightness vs. Wavelength)

↓

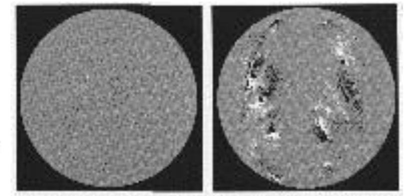
Identifies Species

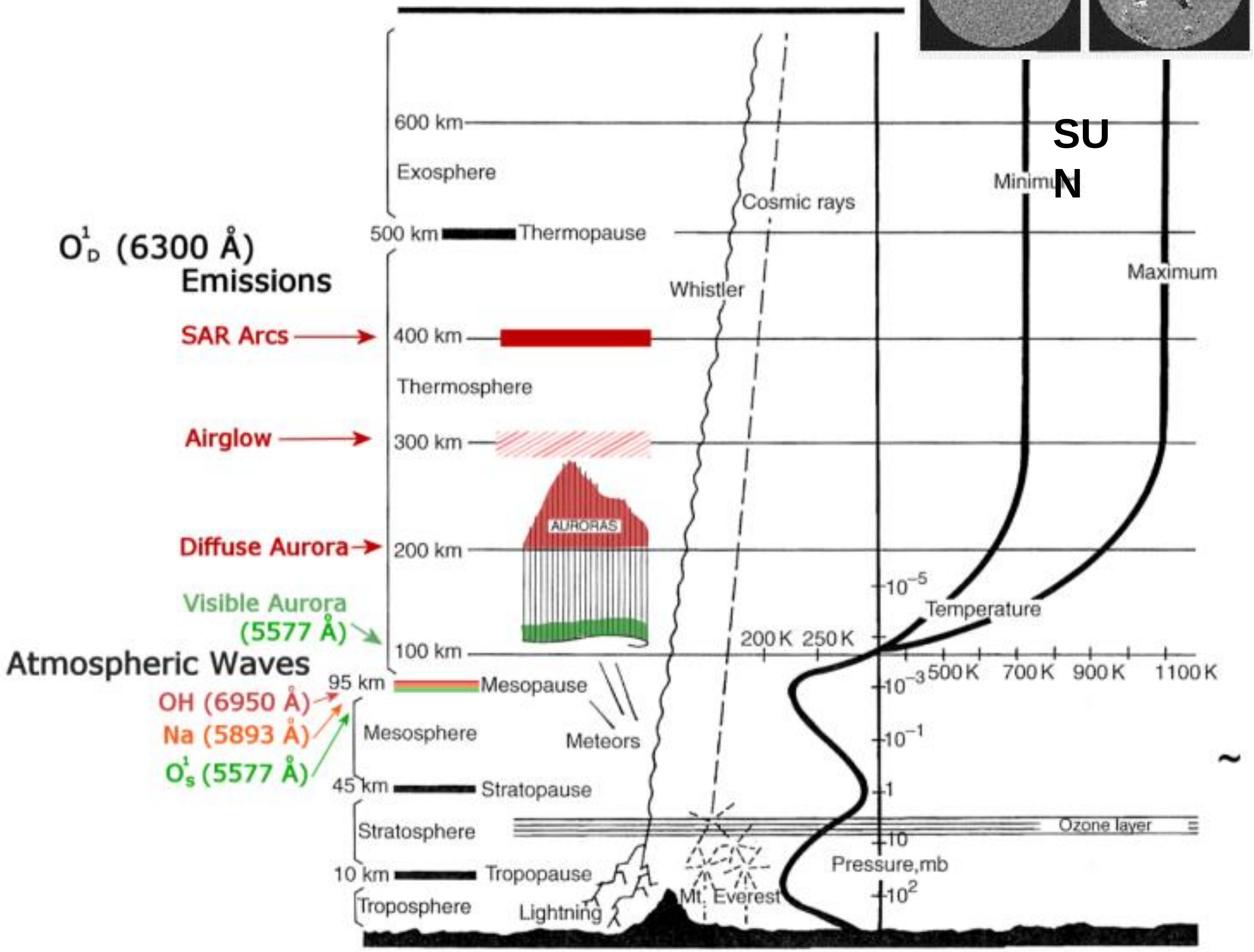
All-Sky-Imager
(ASI)

↓

Broad spatial patterns of structures & dynamics

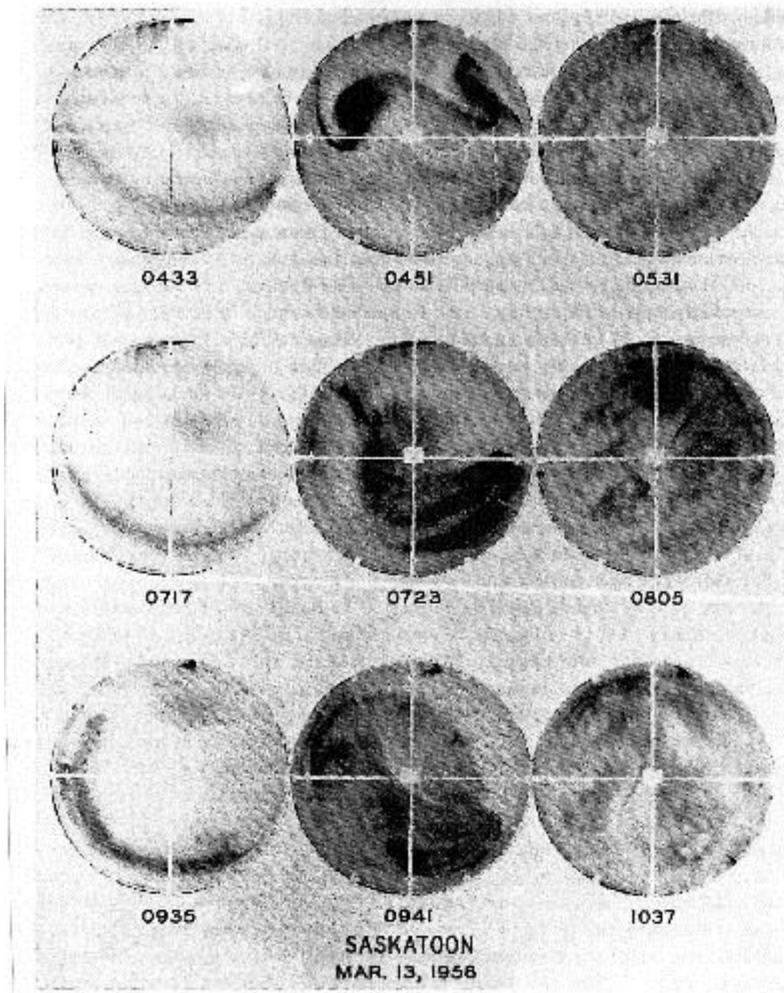
Where do the Photons come from?

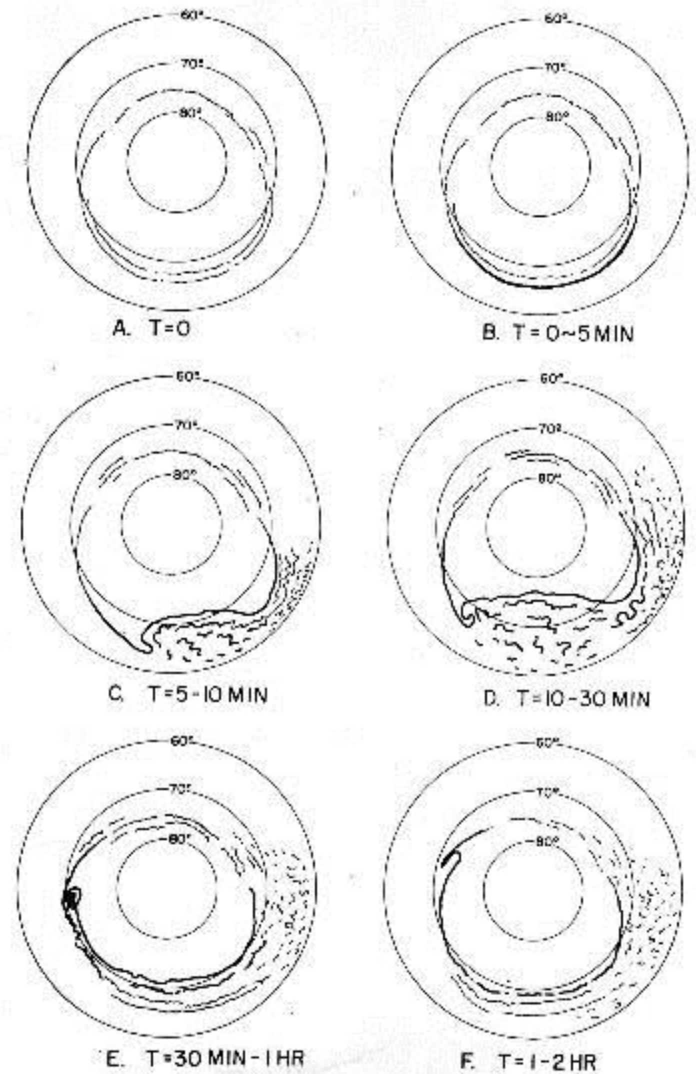




Contribution of Professor Syun-Ichi Akasofu (1960s)

All-Sky-Imager at single site → Global Pattern of Auroral Storms

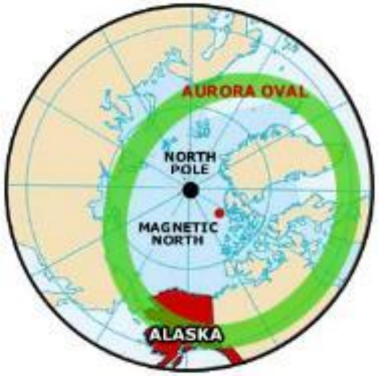


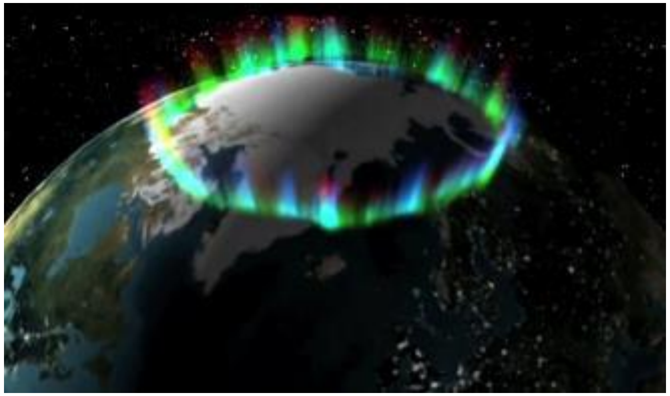


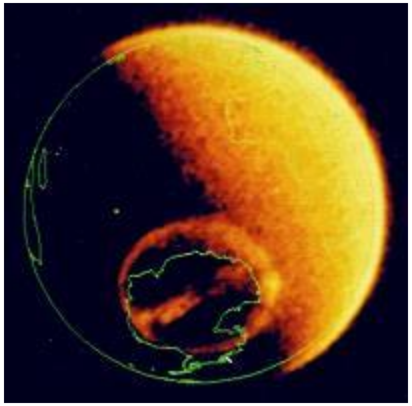
Images of Aurora

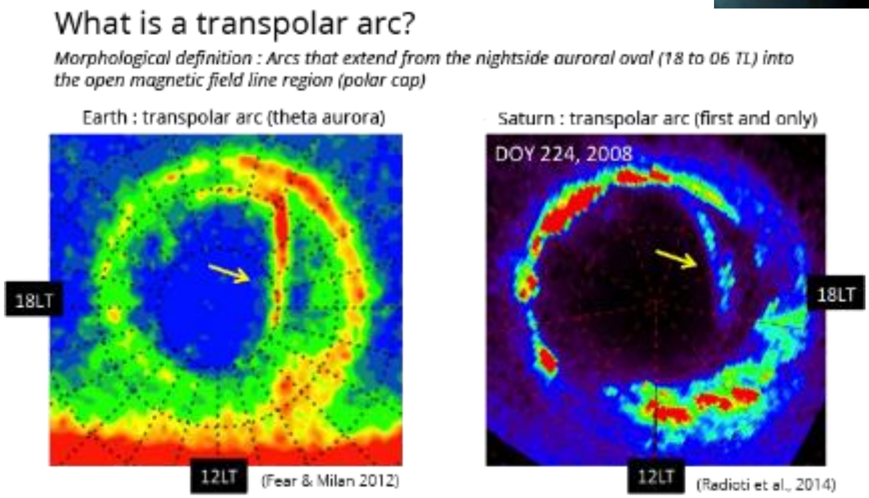
Movie

Auroral Oval



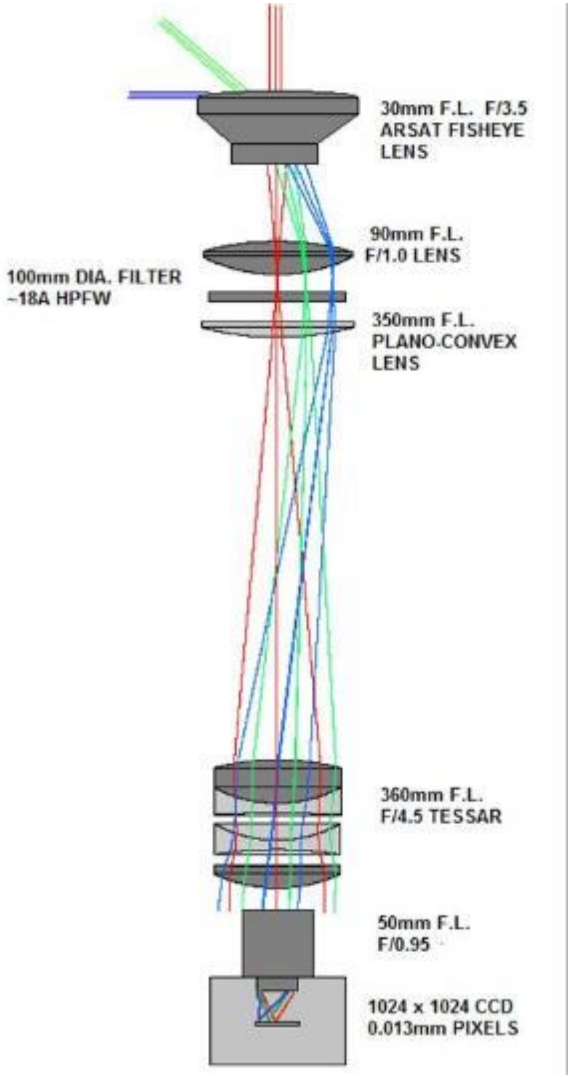






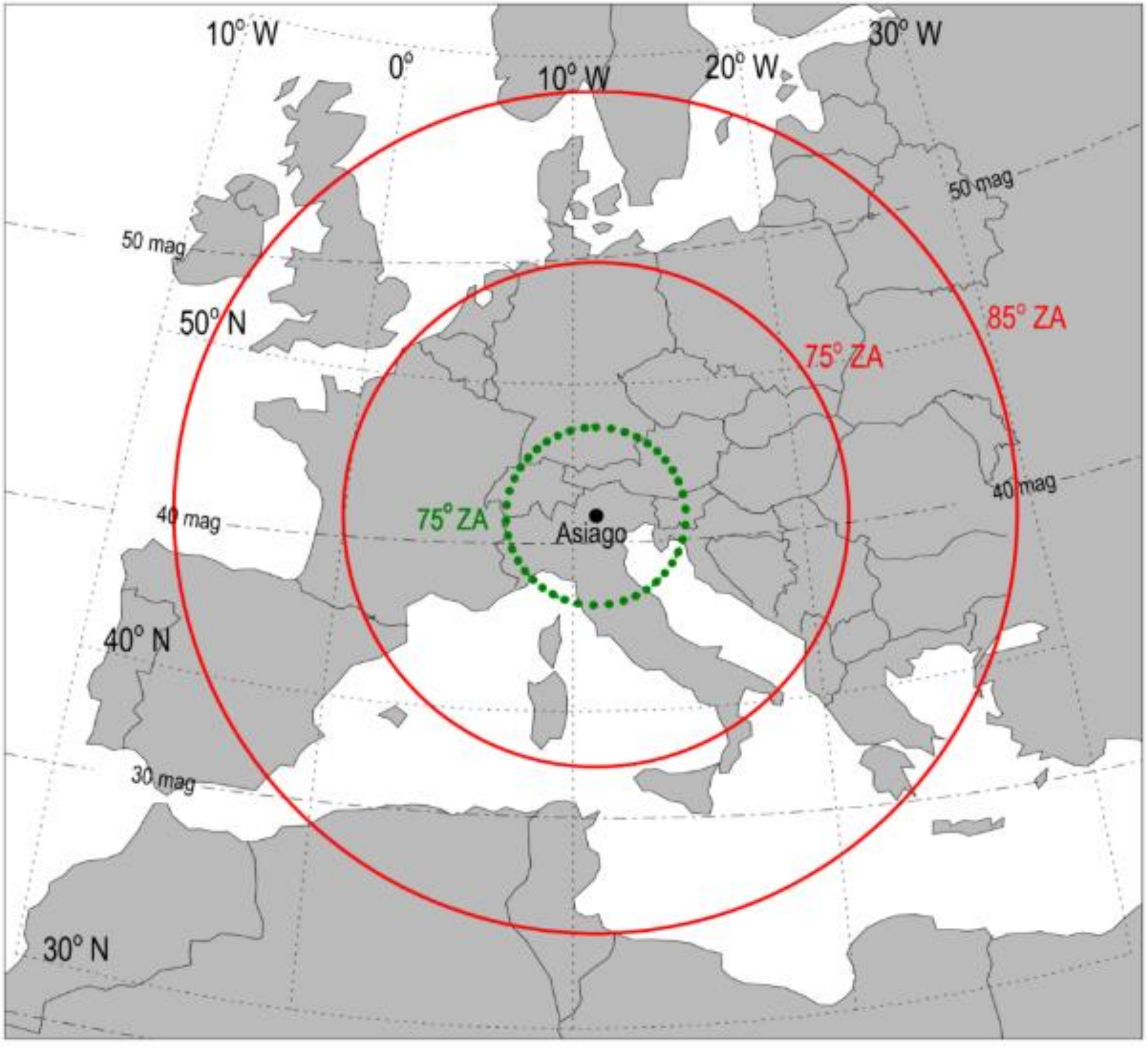
Auroral Polar Caps

What does an ASI look like?

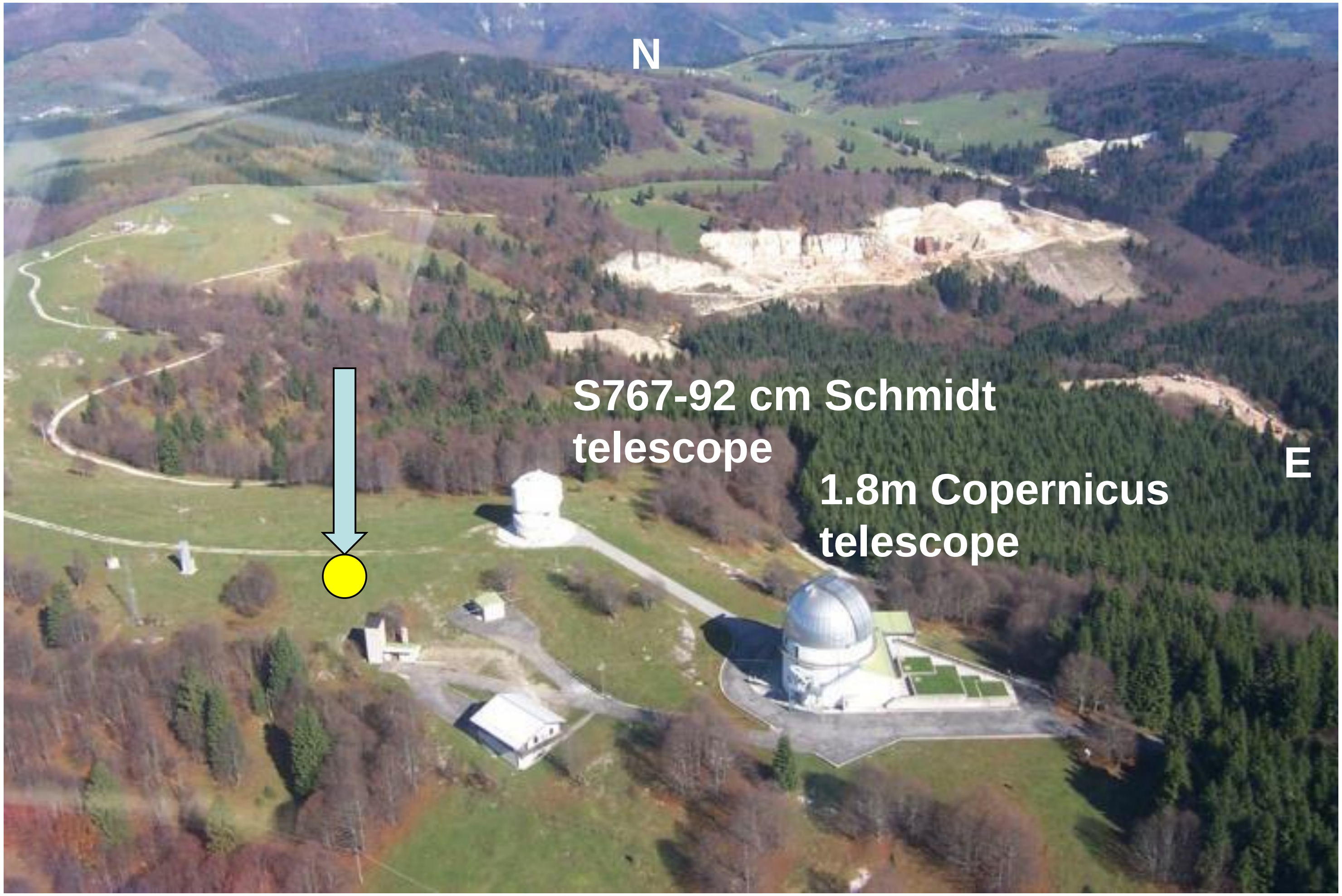


Horizon of ASIAGO in different spectral bands

Red = 6300 Å at 300 km Green = 5577 Å at 100 km ZA = Zenith Angle



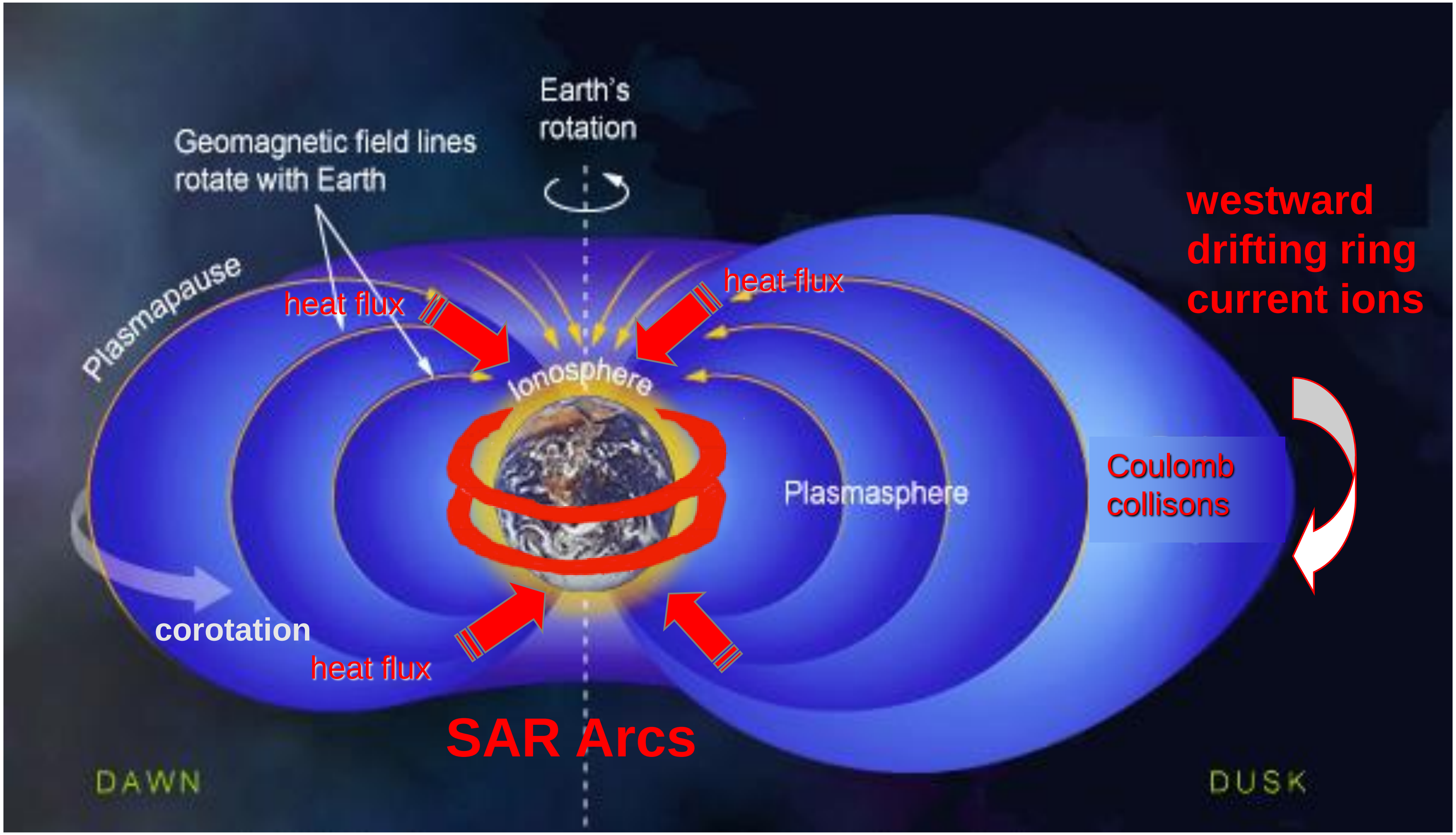
ASIAGO location at Cima Ekar



Housing

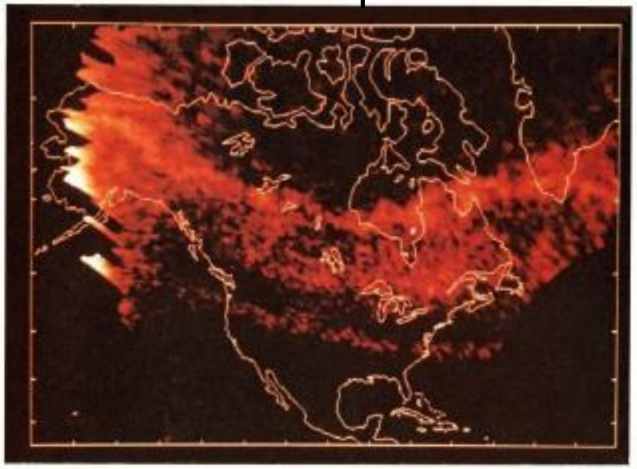
The BU camera is lodged in a small container, which has been equipped with temperature and humidity controls, and safety devices. Two telescopes can be sited inside the container. The glassy domes are permanently open. Only occasional maintenance operations are required by the Observatory technical staff.

Example: Formation of SAR Arcs



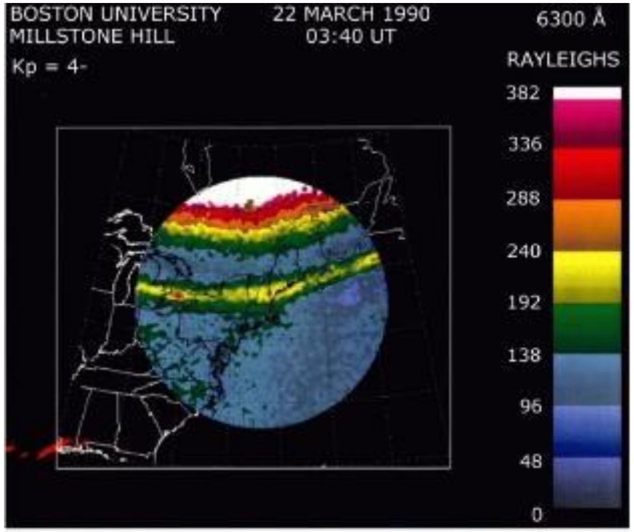
Sub-Auroral Inner Magnetosphere Science

SAR Arc from space



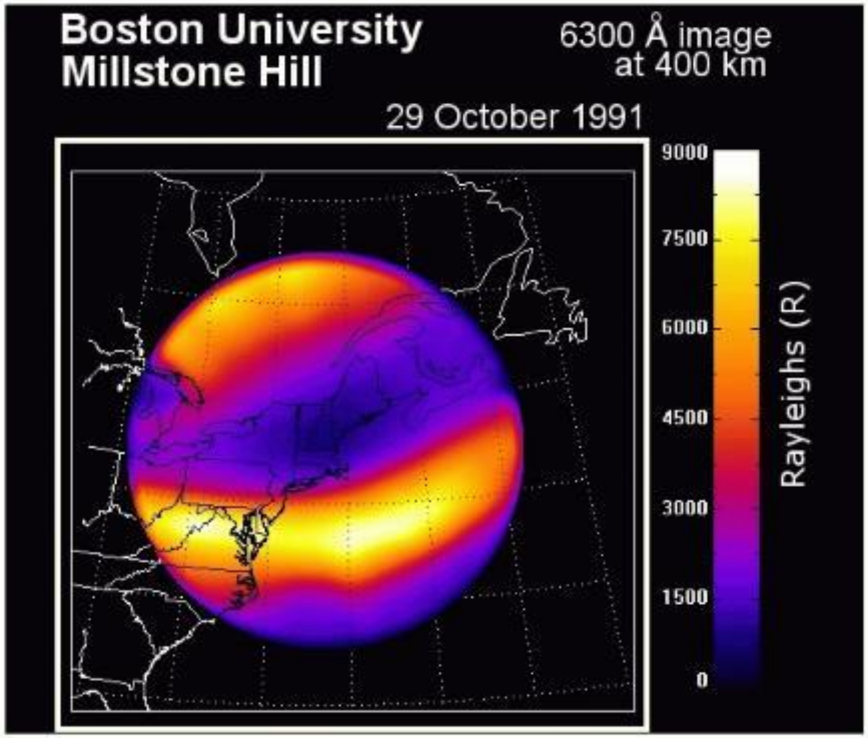
[Craven et al., 1980]

SAR Arc from Millstone Hill



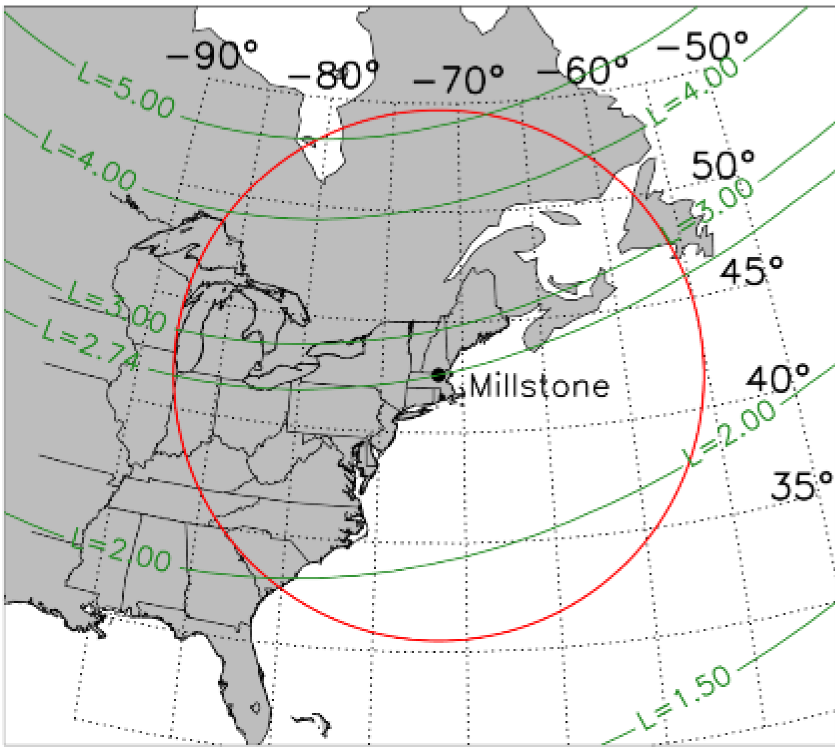
[Foster et al., 1994]

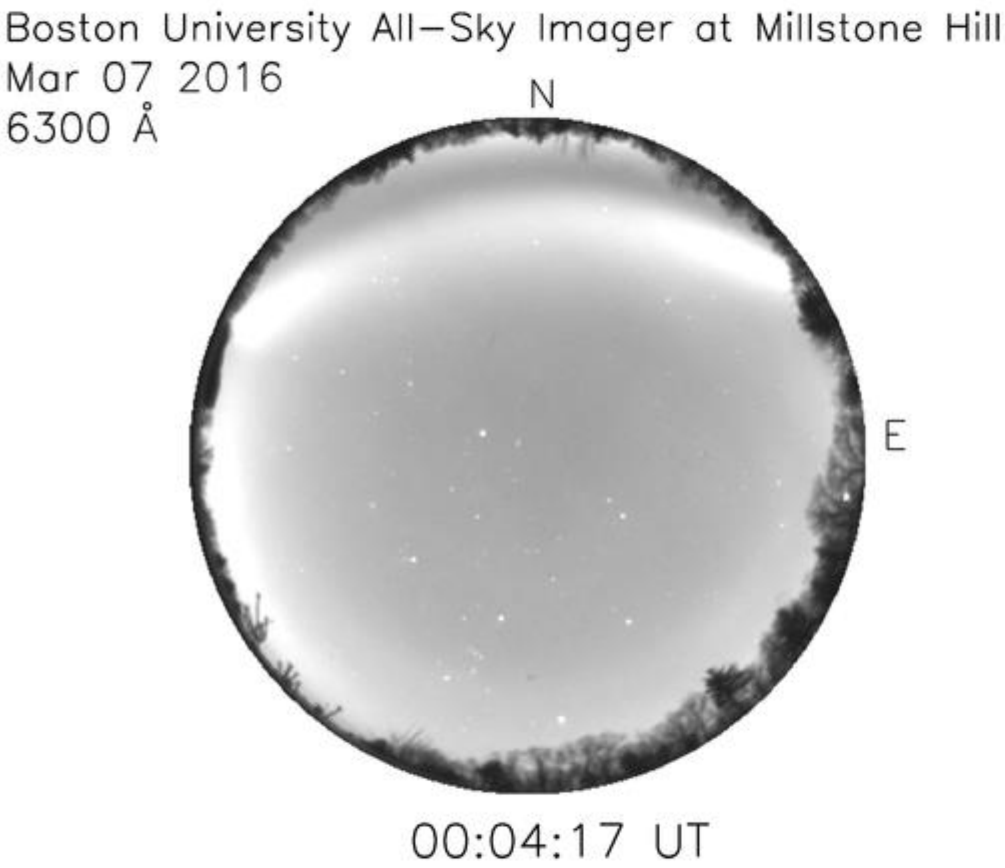
A SAR Arc of Visible Brightness



[Baumgardner et al., 2007]

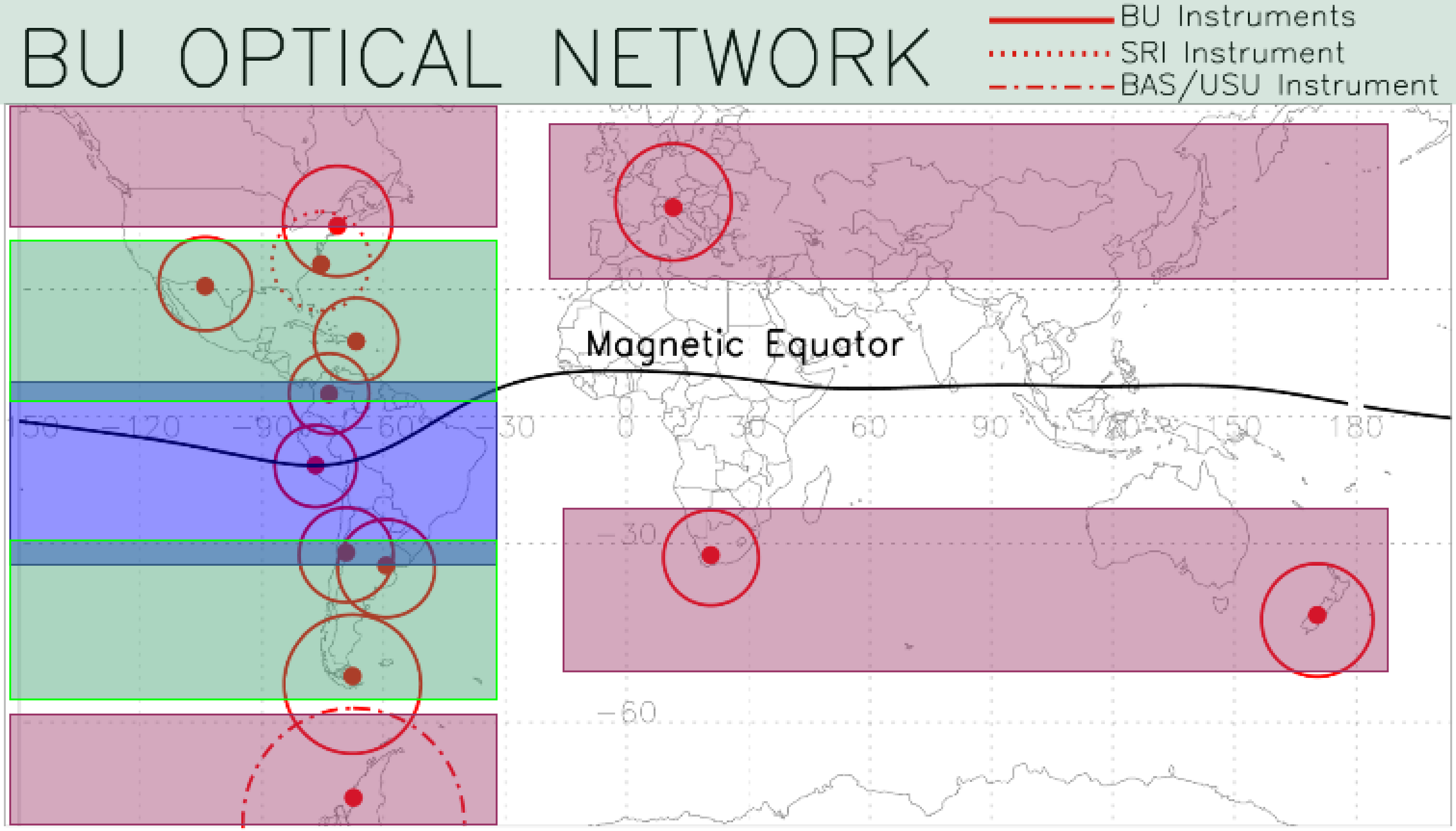
"Normal" SAR Arc





Networks of All-Sky-Imagers (ASIs) for ITM System Science

BU OPTICAL NETWORK



1. Equatorial and low latitude Ionosphere (from magnetic equator to the crests of the Appleton Anomaly). *ESF and MSTIDs, effects on trans-ionospheric radio signals using GPS and optical diagnosis.*

2. Mid latitude Ionosphere (poleward from Anomaly crests to ~ ± 40 mag lat). *Nighttime MSTIDs, E and F region coupling.*

3. Sub-auroral Ionosphere (latitudes below auroral ovals). *Stable auroral red (SAR) arcs (magnetic activity effects that transfer magnetospheric ring current energy into the I-T system)*

4. Mesospheric Dynamics *(above mountains, coastal & oceanic sites)*

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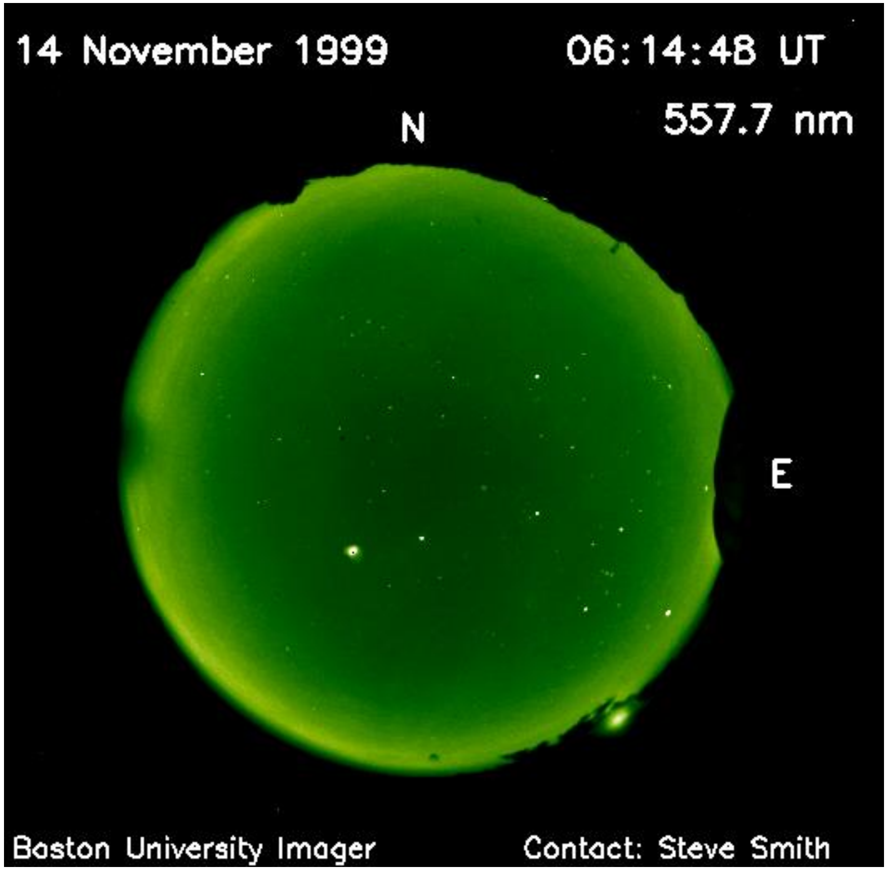
MLT Gravity Waves and M-T Dynamical Coupling Processes

Mesospheric Bores

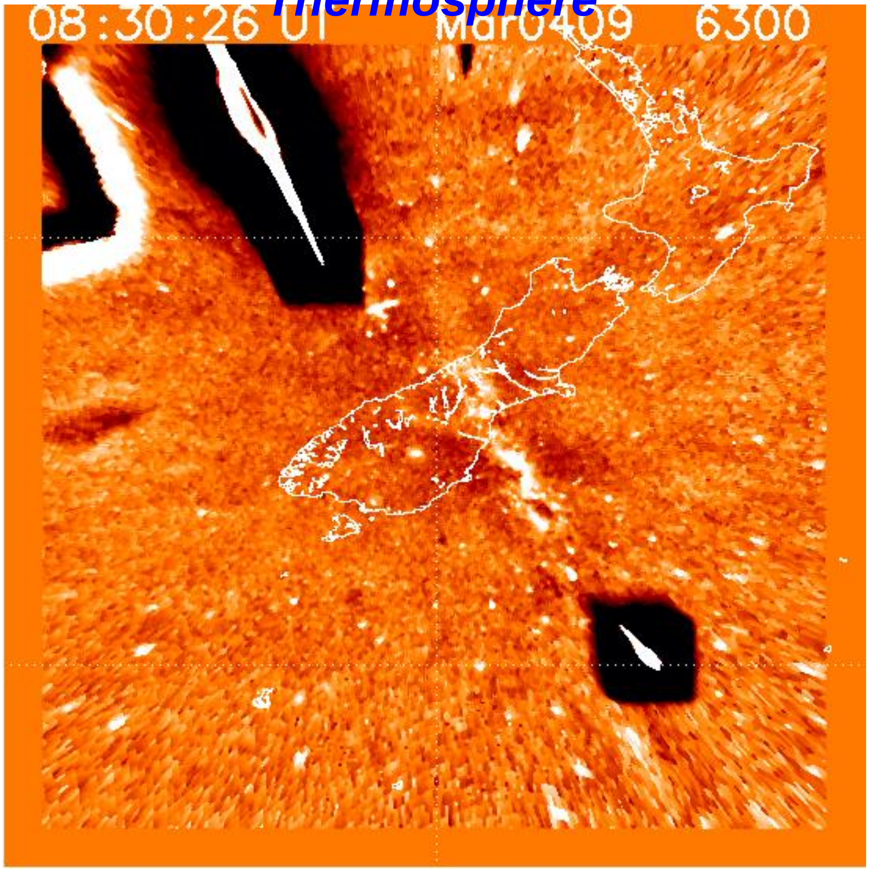


McDonald Observatory, Texas 14 November 1999

Large mesospheric bore disturbance in the 557.7 nm emission. Naked–eye visibility (Smith et al., 2003 JGR).

Indicated presence of stable temperature inversion layer near 90 km altitude spanning over 1100 km.

Secondary GW’s in Thermosphere



Mt. John Observatory, New Zealand 4 March 2009

Secondary thermospheric GW’s in 630.0 nm emission generated from breaking GW’s in the MLT (Smith et al., 2013 JGR).

- **Strong SE-ward waves 9:00-12:30UT** **Two simul. wave sets**
- **Weaker NW-ward waves 9:00-10:30UT** **prop. in opp. dirs**.

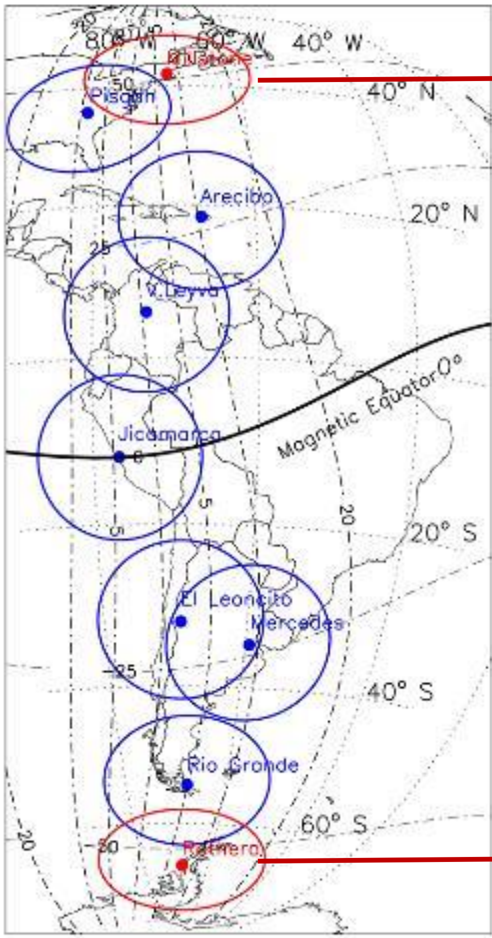
Clear example of dynamical coupling between mesosphere and thermosphere.

BOSTON UNIVERSITY

Boston University All-Sky-Imagers

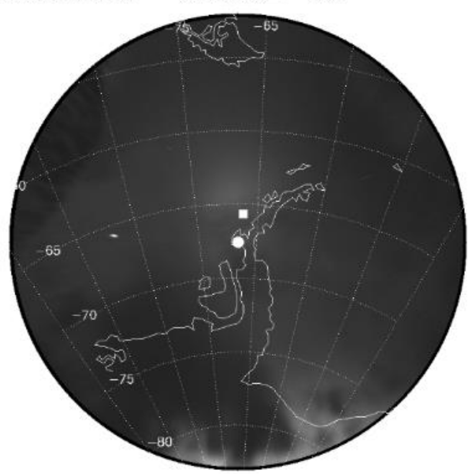
Geomagnetic Conjugate Science Feature: Stable Auroral Red (SAR) Arcs

1 June 2013



Millstone Hill 01:39:16 UT

Rothera 00:02 UT



6300 Å
Images

Similarities

- Both SAR Arcs at L= 2.74 R_e
- Same Separations from Diffuse Aurora

Differences

- Small scale structures along arcs
- Brighter in Southern Hemisphere
- Latitude gradients stronger in South

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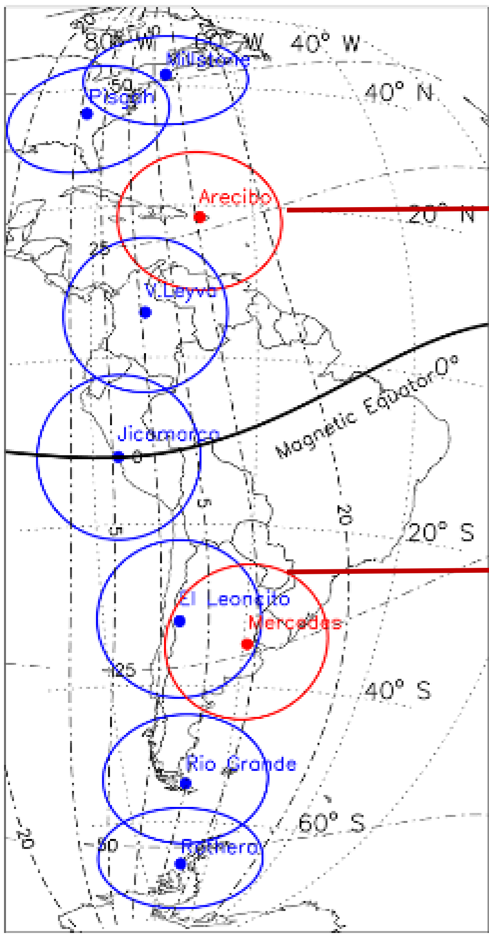
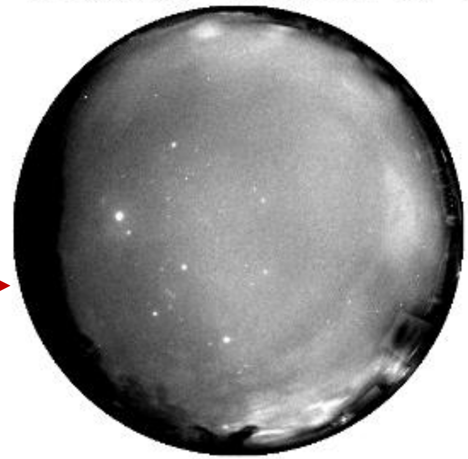
Boston University All-Sky-Imagers

Geomagnetic Conjugate Science Feature: Medium Scale Travelling Ionospheric Disturbances

9 Feb 2013

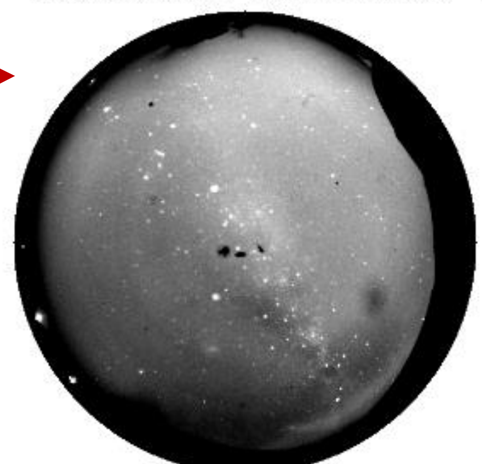


Arecibo 02:15:40 UT



6300 Å Images

Mercedes 02:10:59 UT



Similarities

- MSTIDs travel westward & equator-ward in both hemispheres: SW in north, NW in south
- Wave Crests & Troughs linked by same field lines

Differences

- Background airglow brighter in Summer (Southern) hemisphere
- Crest-to-trough brightness ratio higher in Winter (Northern) hemisphere
- Ionospheric radar data only available in Northern hemisphere

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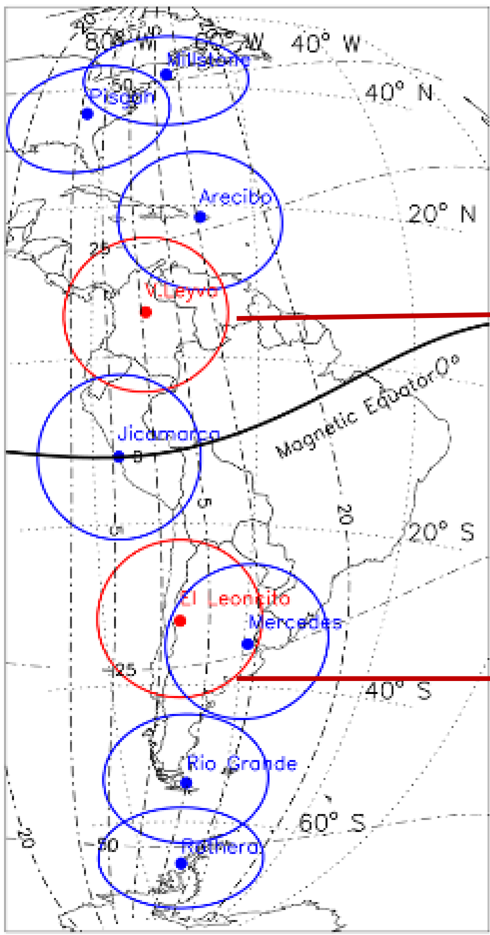
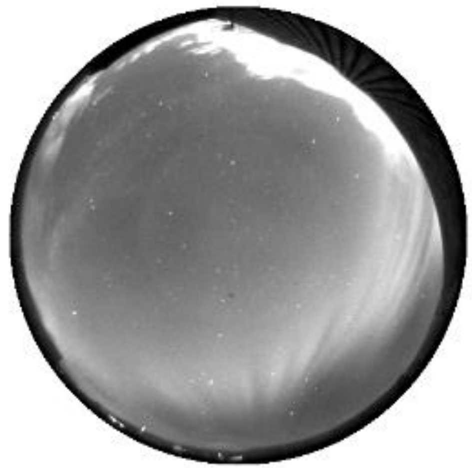
Geomagnetic Conjugate Science Feature: Airglow Depletions showing trans-equatorial Plasma Instabilities

18 November 2014



Villa de Leyva 00:19:48 UT



7774 Å
Images

El Leoncito 00:20:06 UT

Similarities

- Coherence of broad temporal & spacial occurrence patterns
- Broadly consistent zonal (E→W) drift patterns

Differences

- Fine structuring stronger in Southern hemisphere
- Bright-to-dark contrast greater in Winter (Northern) hemisphere
- Zonal drift patterns affected by South Atlantic magnetic field anomaly

Summary --- Conjugate Site ASIs

- First network of All-Sky-Imagers poised to contribute to studies of upper atmosphere phenomena linked by common electro-dynamical mechanisms along same geomagnetic field lines

- Upcoming NASA missions (ICON and GOLD) will focus attention on N-S hemisphere effect with high resolution provided by ASI networks

- Opportunities for international collaborations.

All BU imaging data available on website.

Collaborations Welcome!

Global ITM system Requires Global (Space-based & Ground-based) Observing Networks