Naval Research Laboratory

The CERTO/TBB Instrument for Ionospheric Tomography and Scintillation Region Imaging

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FORMOSAT-3/COSMIC Science Summer Camp
Central Weather Bureau
Taipei, Taiwan
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Space Based Beacons and Receiver

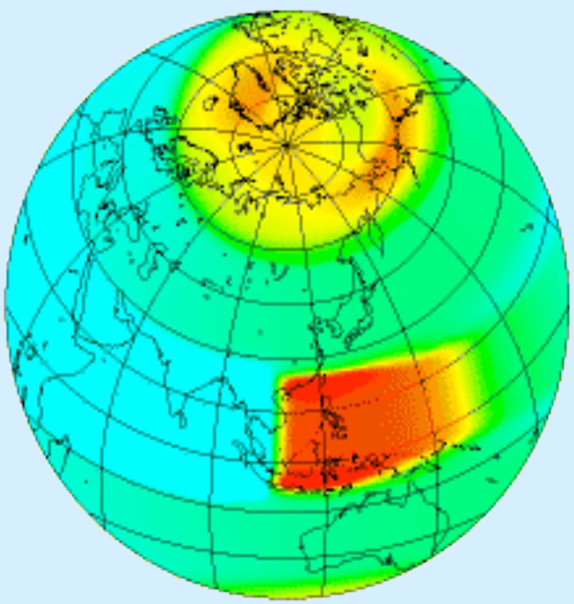
- CERTO Beacon System Objectives
- CERTO Space-Based Transmitter
- CITRIS Space-Based Receiver
- Science Operations
- Satellites, Inclinations and Launch Dates
- Ground Receivers
- Conclusions

Radio Beacon Experiment Objectives

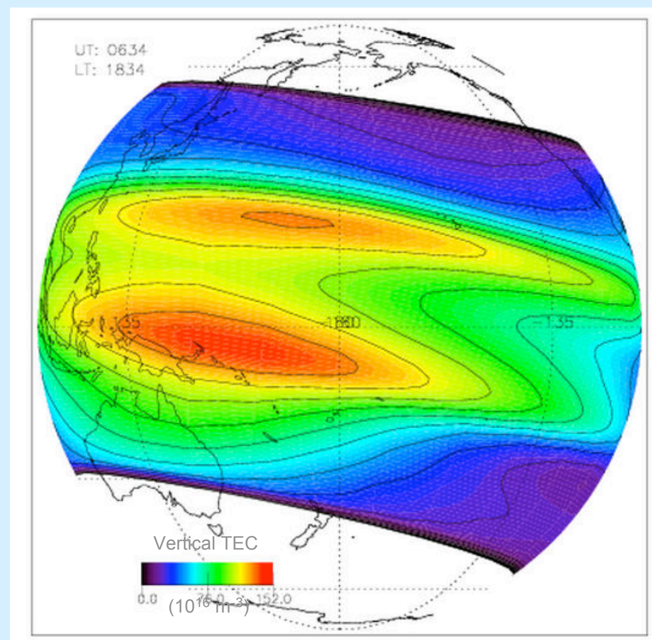
Program Goals

- Detect When and Where Radiowave Propagation Through the Ionosphere Is Adversely Affected by Scintillation and Refraction
- Provide a Global Map of Ionospheric Densities and Irregularities to Improve Current Models of the Ionosphere

NWRA SCINTMOD
Scintillation Predictions



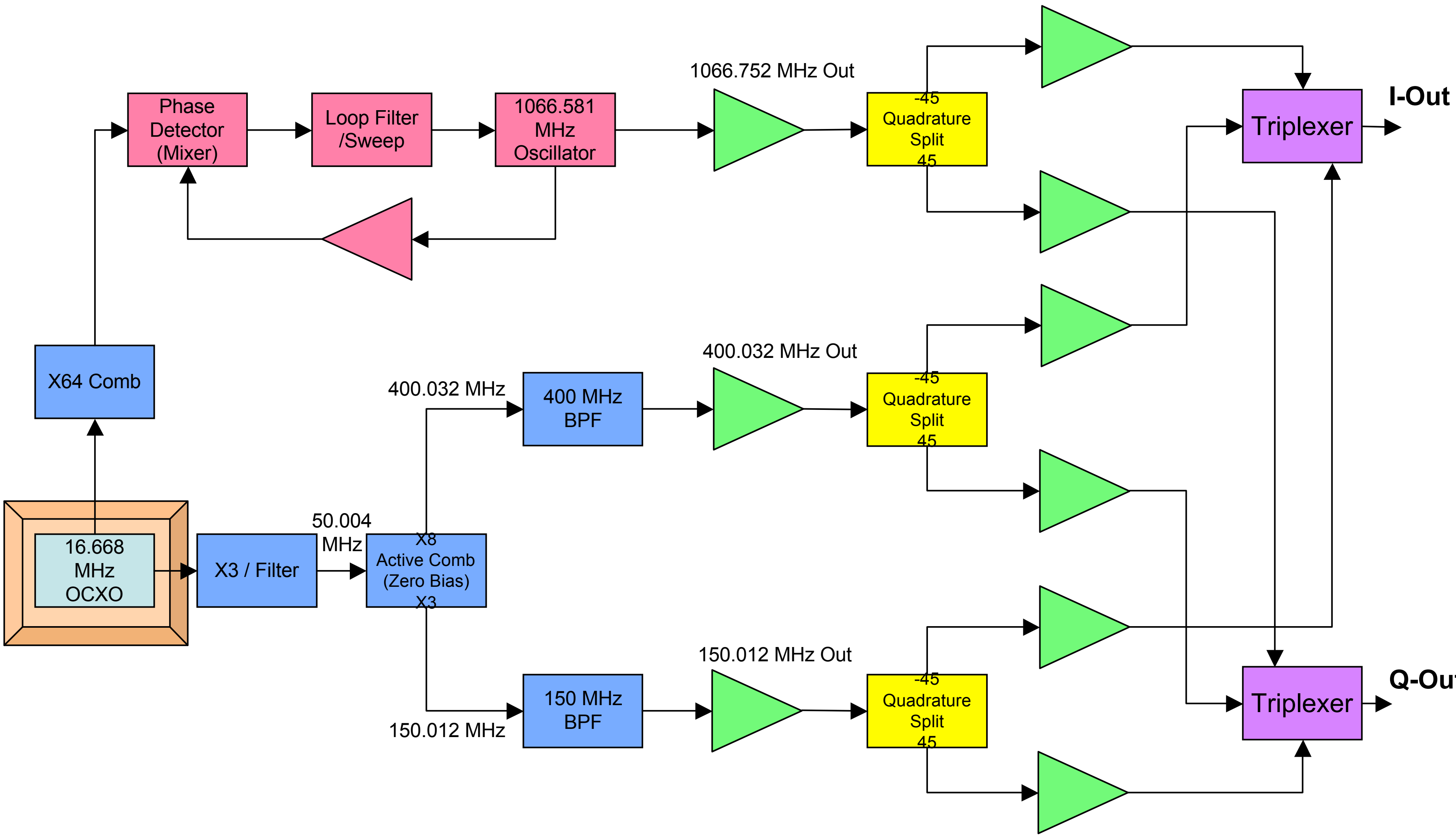
NRL SAMI3
TEC Predictions



Coherent Electromagnetic Radio Tomography (CERTO) Science

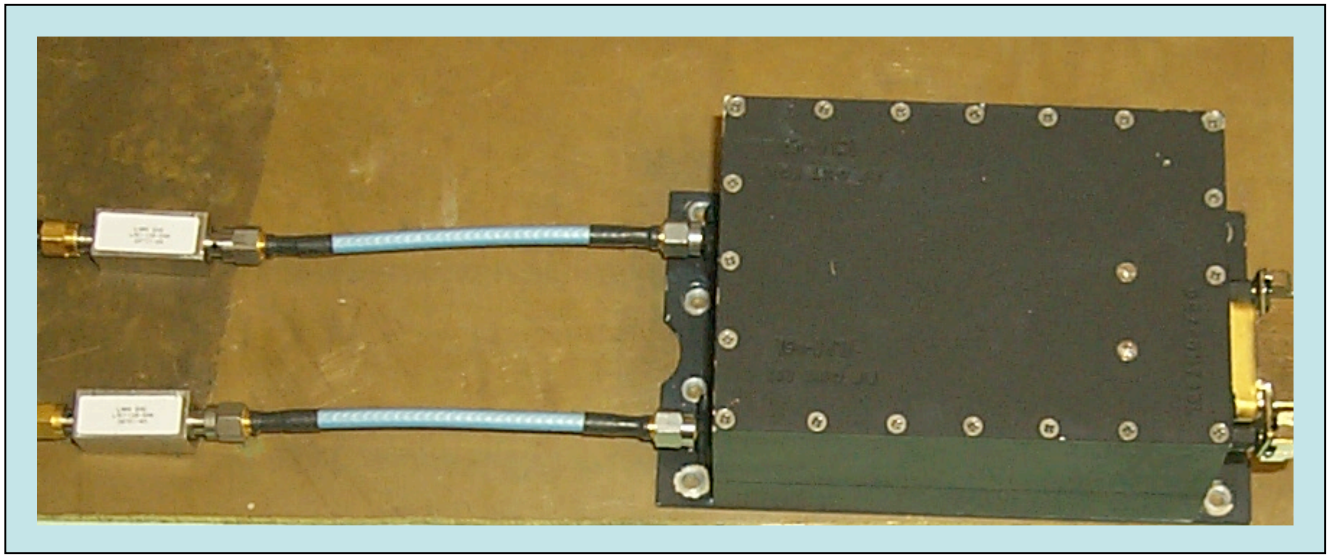
- Three Frequency Beacon Transmissions
  - Frequencies: 150.012, 400.032, 1066.752 MHz
  - Output: 1 – 2 Watts ERP with RHC Polarization
  - No Modulation
- Total Electron Content
- Two Dimensional Ionospheric Imaging
  - Radio Beacons in Low Earth Orbit
  - Data from Vertical and Oblique Paths Through the Ionosphere
  - Additional Data from GPS Occultations
  - Reconstructions Using Computerized Ionospheric Tomography
- Scintillation Monitoring
  - VHF, UHF, and L-Band radio Frequency Ranges
  - Phase and Amplitude Fluctuations from Radio Source
  - Regional Maps of Radio Signal Disruptions

New CERTO on CERTO
Tri-Band Beacon Block Diagram
(One Phase Locked Loop)

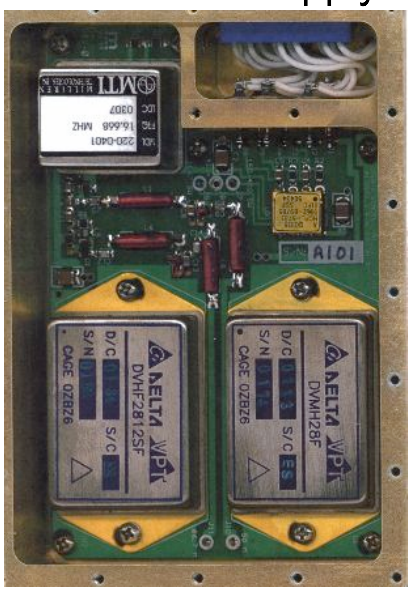


Model Number SMNRL00TS03C

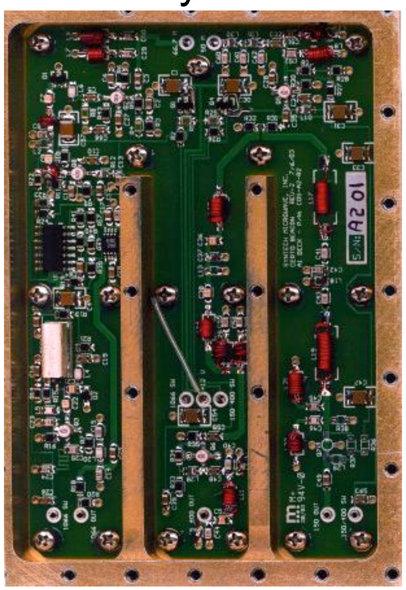
CERTO-D Beacon (w/Low-Pass Filters)



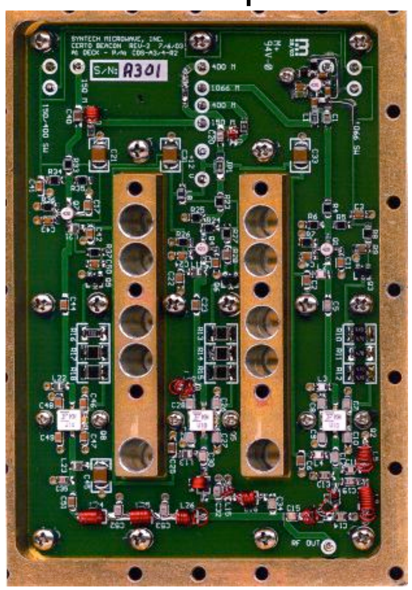
DC Power Supply



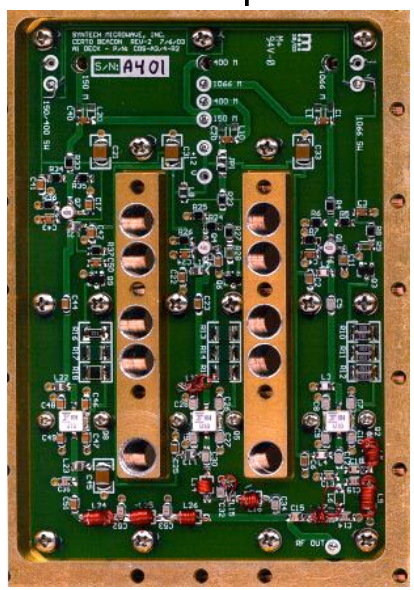
RF Synthesis



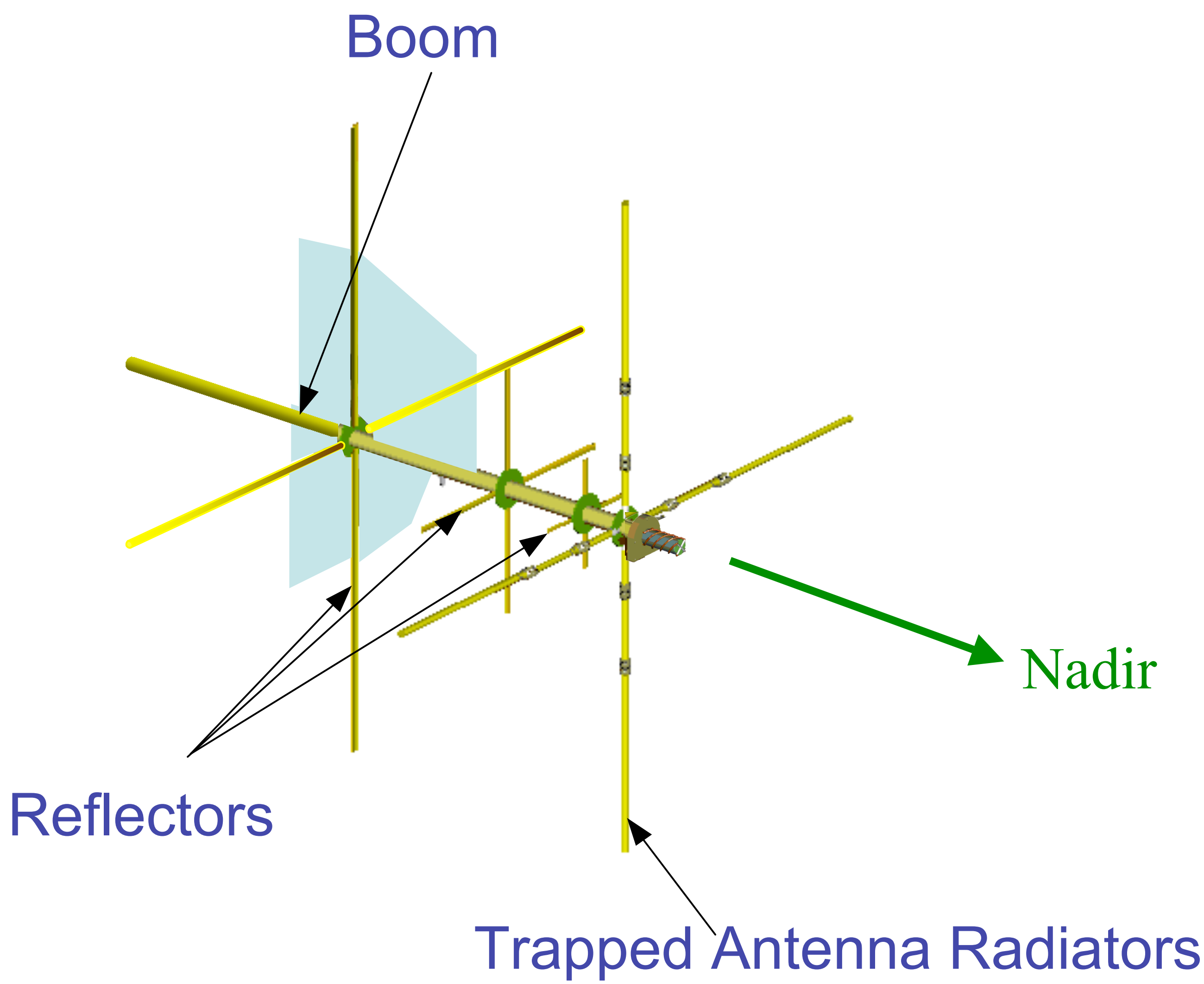
Power Amplifier 1



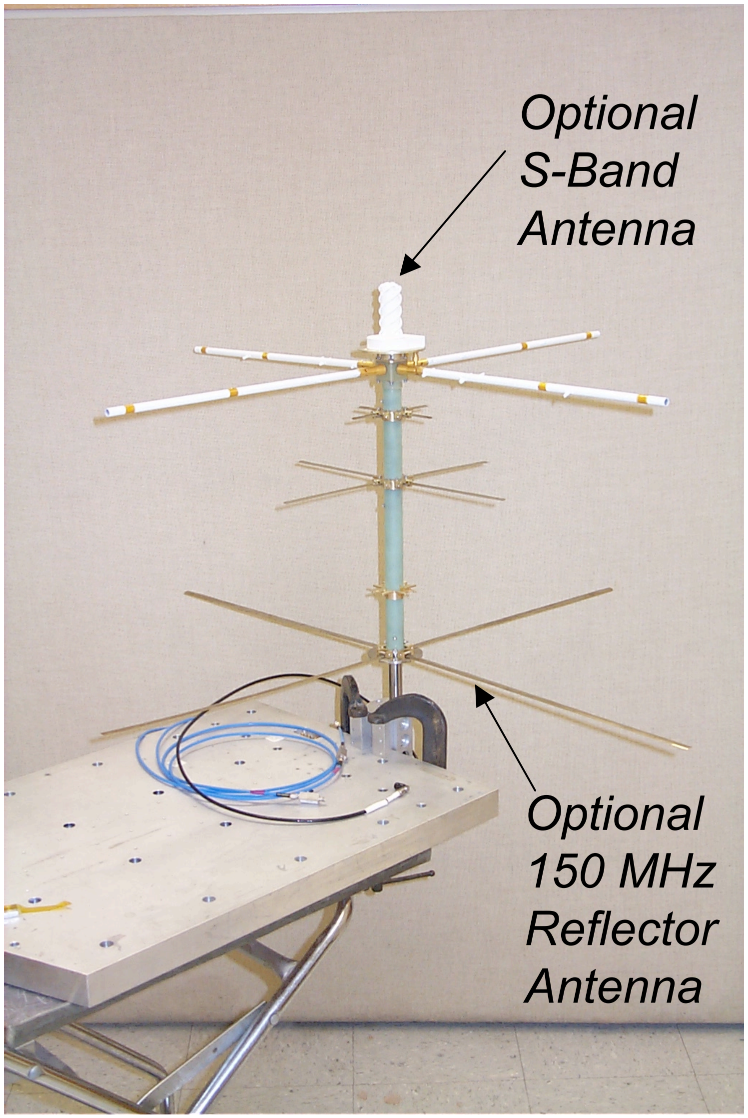
Power Amplifier 2

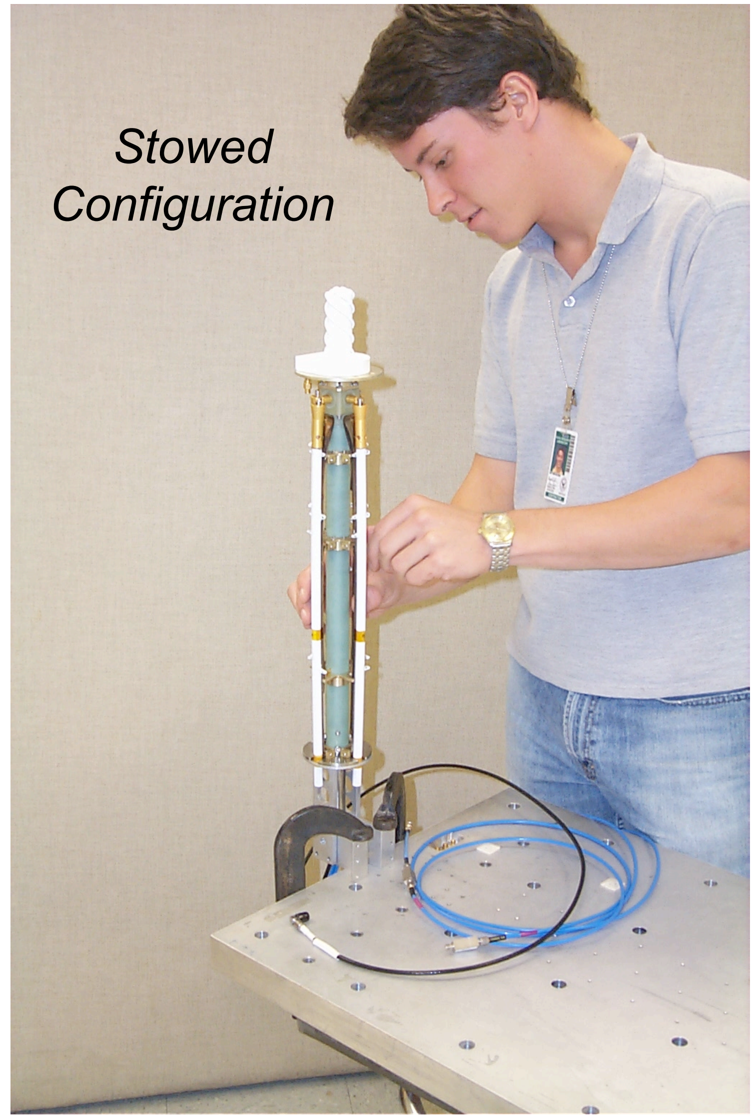


CERTO Beacon Antenna



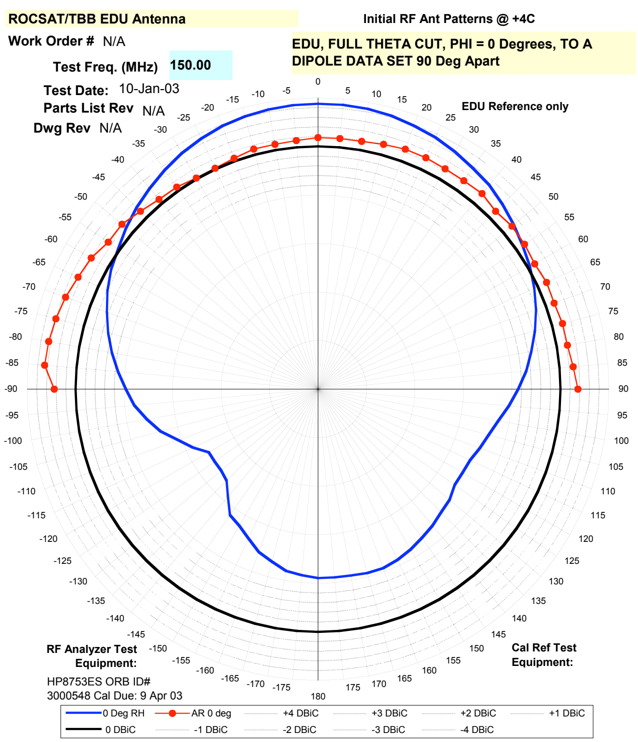
CERTO Beacon Antenna



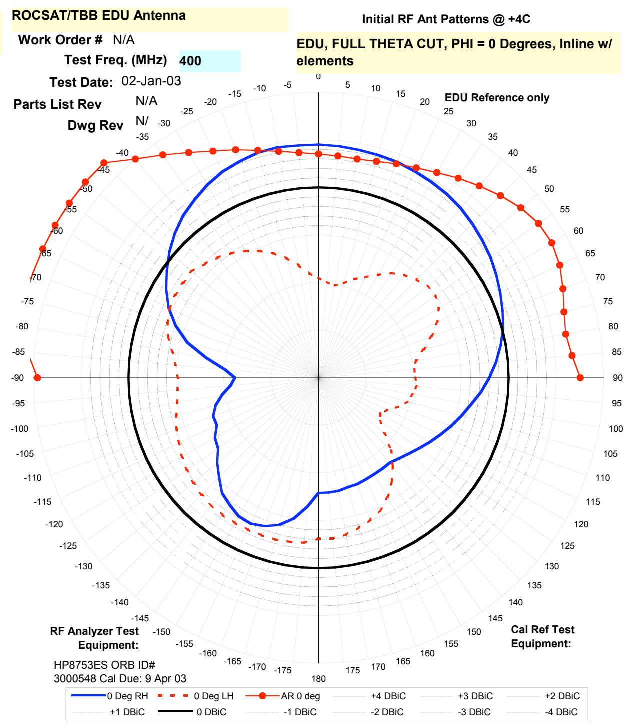


CERTO Antenna Deployment on Formosat-3/COSMIC

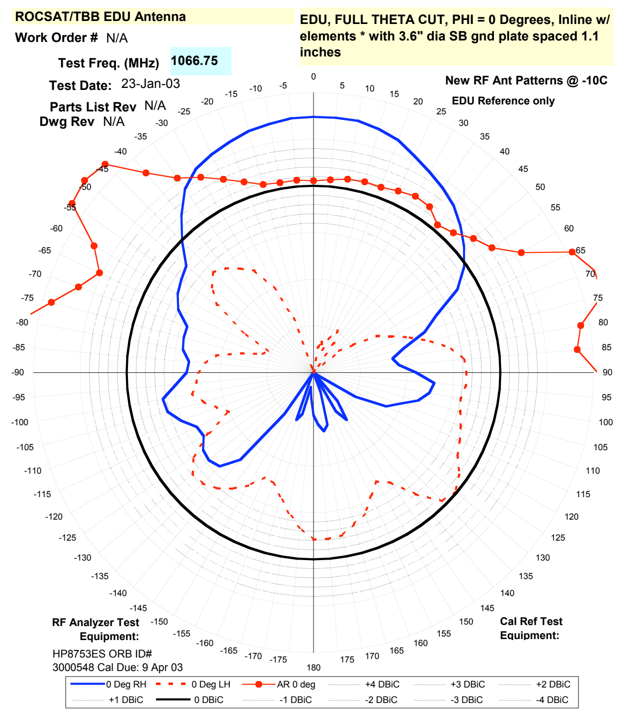
Antenna Performance
VHF/UHF/L-Band Patterns



150 MHz



400 MHz



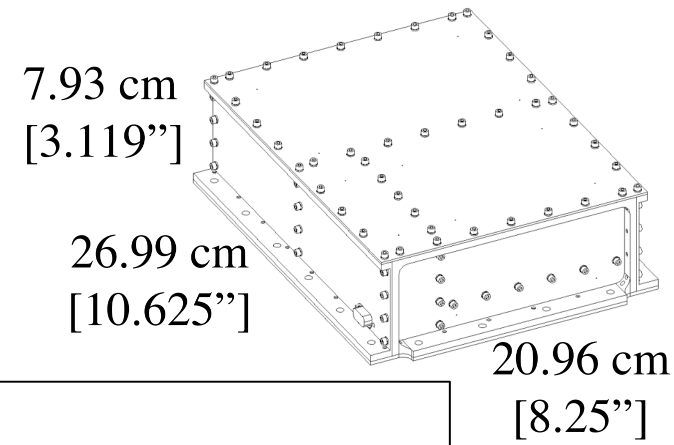
1066 MHz

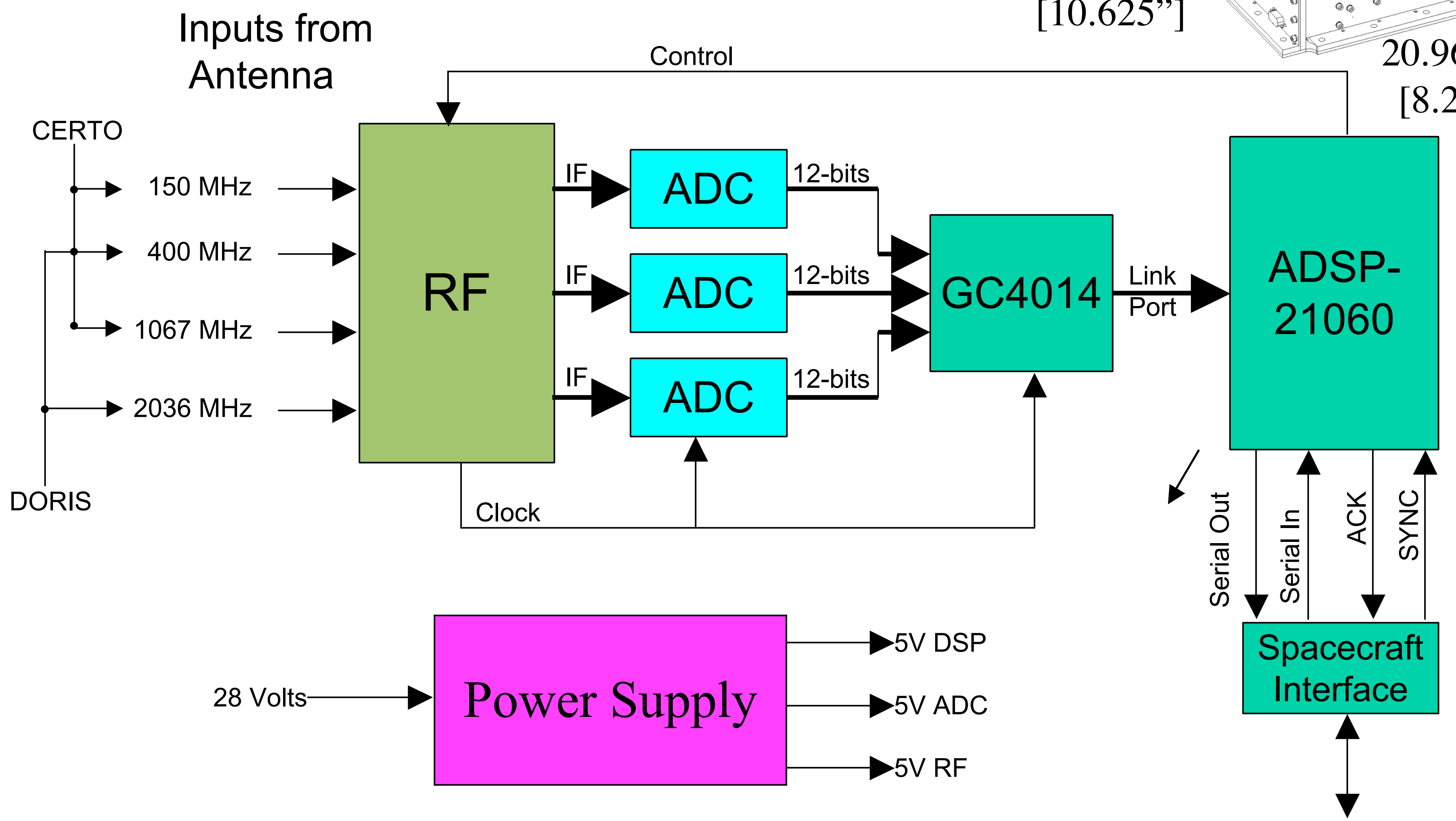
CERTO Antenna

sCintillation and Tomography Receiver in Space (CITRIS) Summary

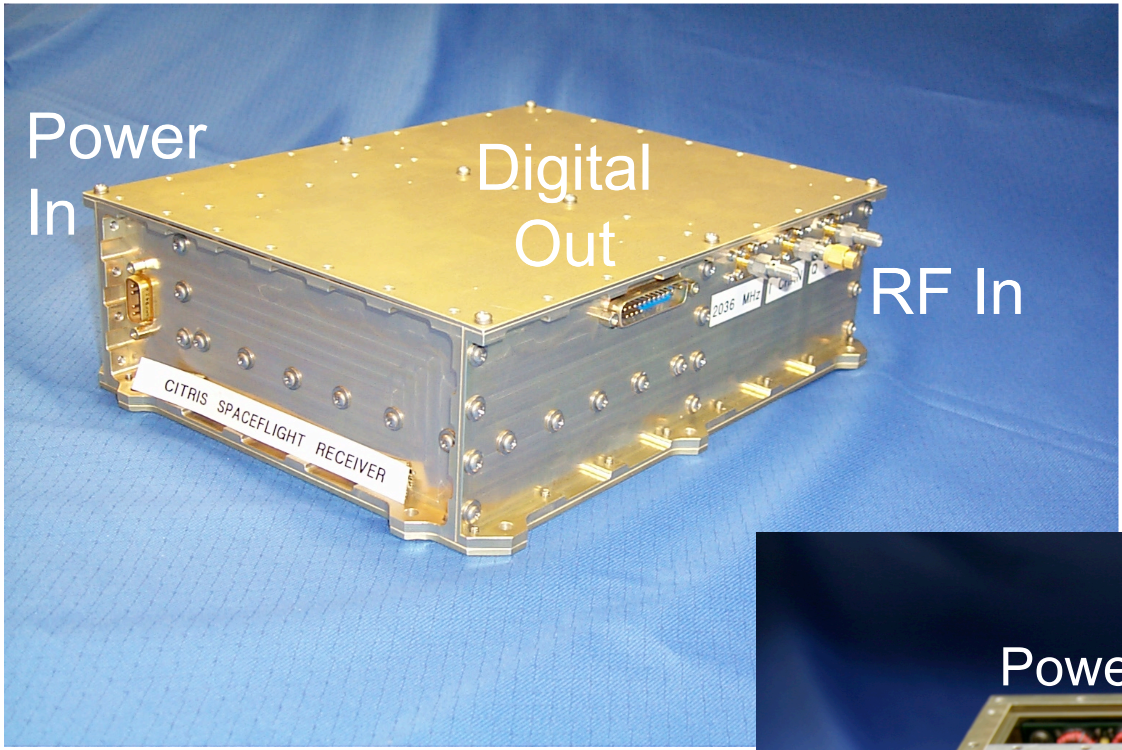
- CITRIS Receiver will Provide Global Ionospheric Measurements
  - Ground DORIS Beacons (401.25 and 2036.25 MHz)
  - Simultaneous CERTO (150.012, 400.032, and 1067.752 MHz) and DORIS Measurements
  - Occultation Measurements with CITRIS on STPSAT1 Receiving the CERTO Beacon on NPSAT1
- Status
  - CITRIS Instrument Assembly Complete
  - Testing Underway and Delivery in Early July 2005
  - STPSAT1 Launch Scheduled Late 2006

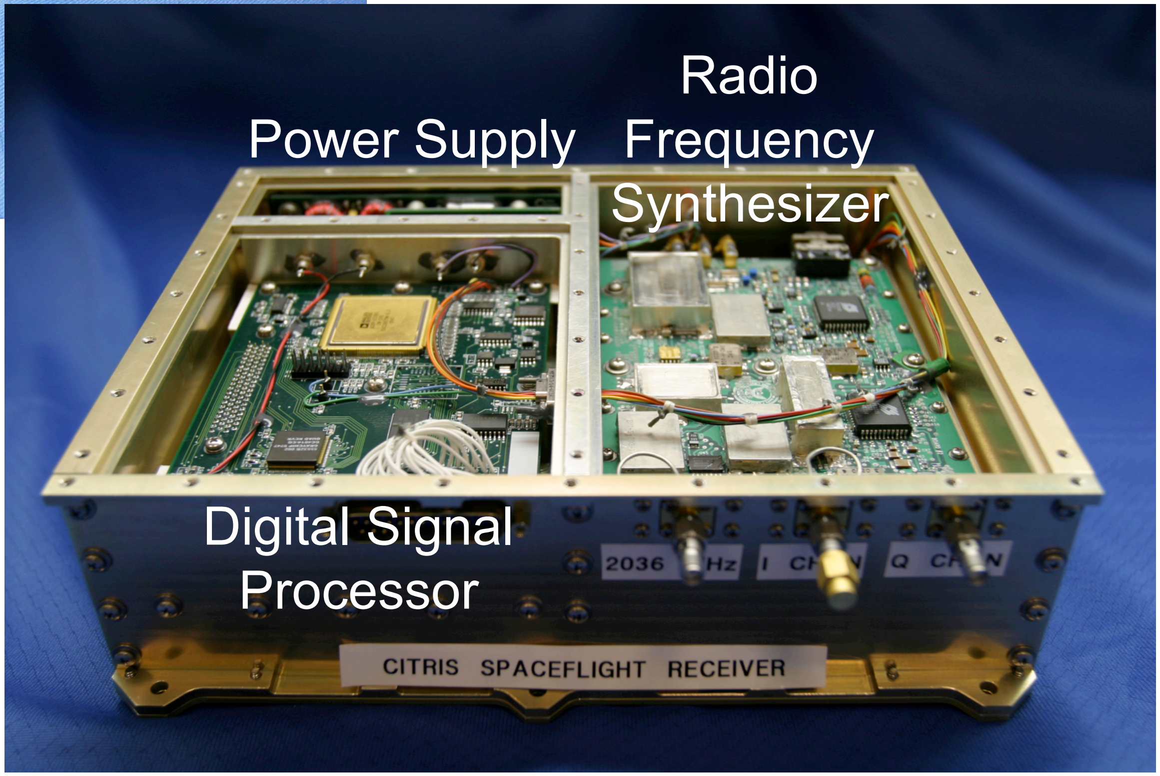
CITRIS Receiver



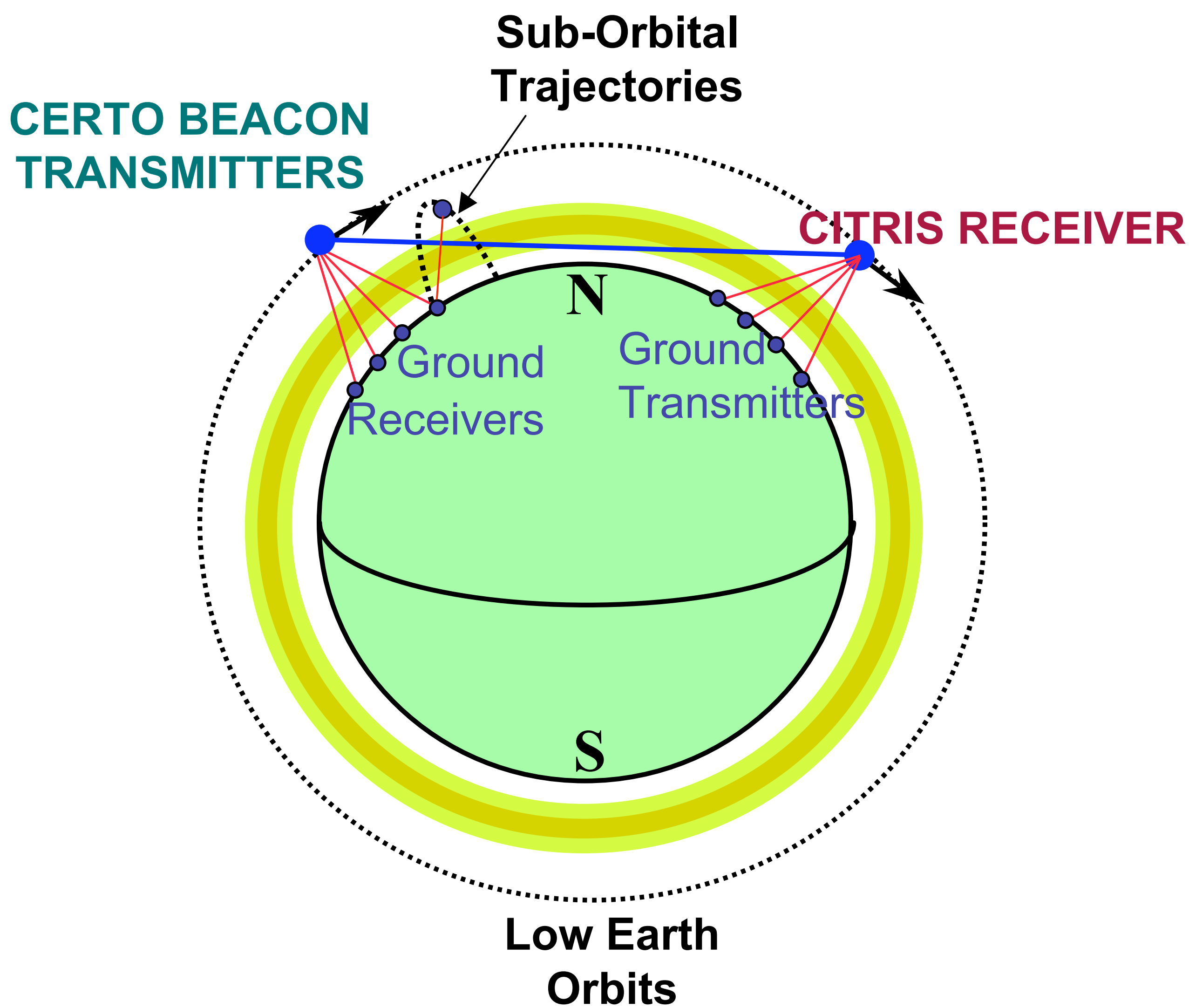


CITRIS Flight Receiver





CERTO RADIO BEACON GEOMETRY FOR TEC AND SCINTILLATION MEASUREMENTS



Two Frequency Differential Phase Measurements of TEC

- Phase Path (Wavelengths)

$$P = \left(S - \int \frac{\text{å}\,N}{f^2}\,ds\right)\frac{f}{c}$$

- Two Frequency Differential Phase Removes Path Length

$$P_{ab} = P_a - P_b\,\frac{f_a}{f_b} = \frac{(f_a - f_b)(f_a + f_b)\,\text{å}}{c f_a f_b^2}\int N\,ds$$

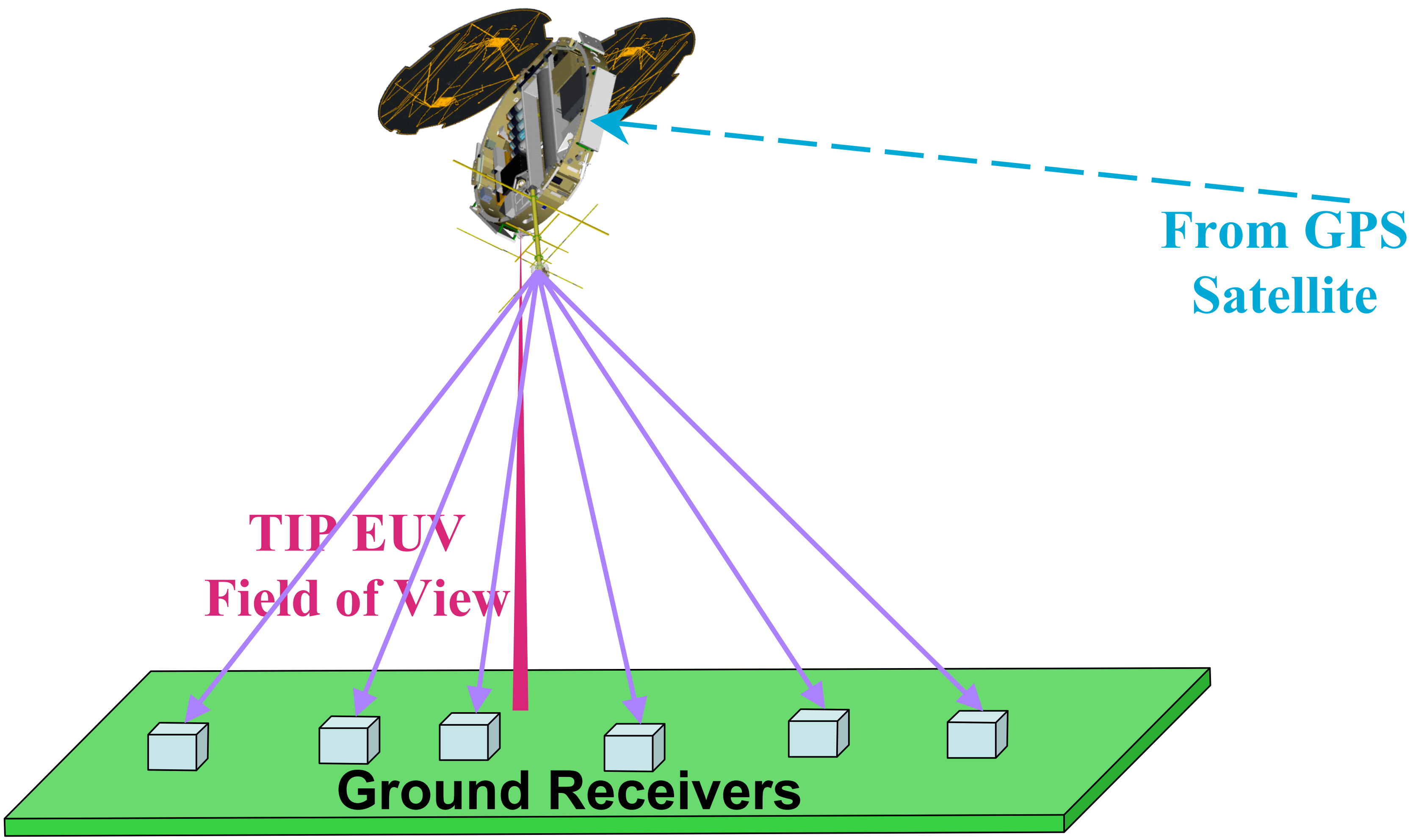
- Integer Derived Frequencies: $f_a = n_a\,f_0$, $f_b = n_b\,f_0$, etc.

$$P_{ab} = \frac{(n_a^2 - n_b^2)\,\text{å}}{n_a\,n_b^2\,c\,f_0}\int N\,ds$$

- Total Electron Content from 2 Frequency Differential Phase

$$\int N\,ds = \frac{n_a n_b^2\,c\,f_0}{(n_a^2 - n_b^2)\,\text{å}}\,P_{ab} = 7.44\,10^6\,f_0\,\frac{n_a n_b^2}{n_a^2 - n_b^2}\,P_{ab}\,m^{-2}$$

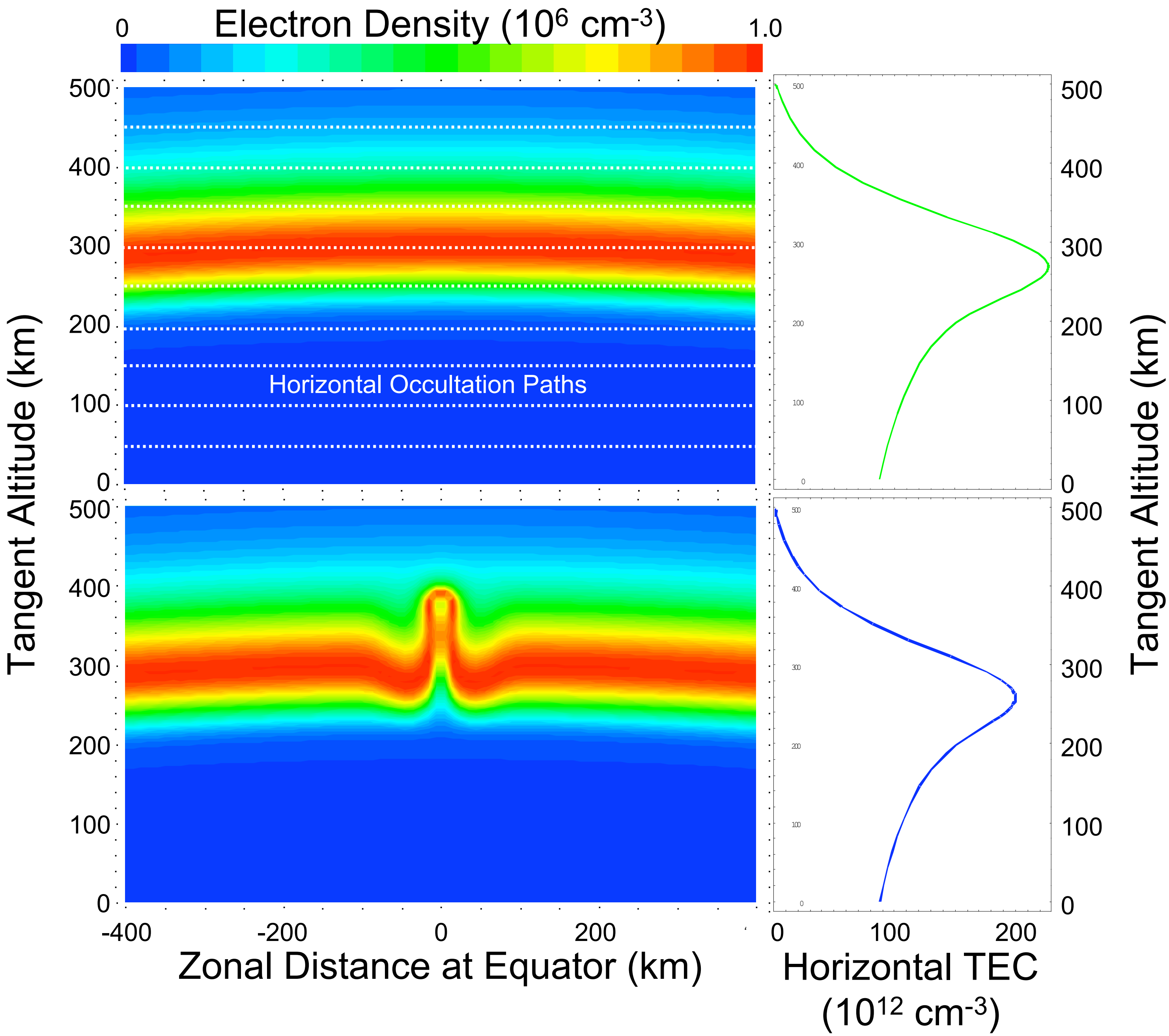
JOINT CERTO/TBB, GPS-GOX, TIP OPERATIONS ON COSMIC



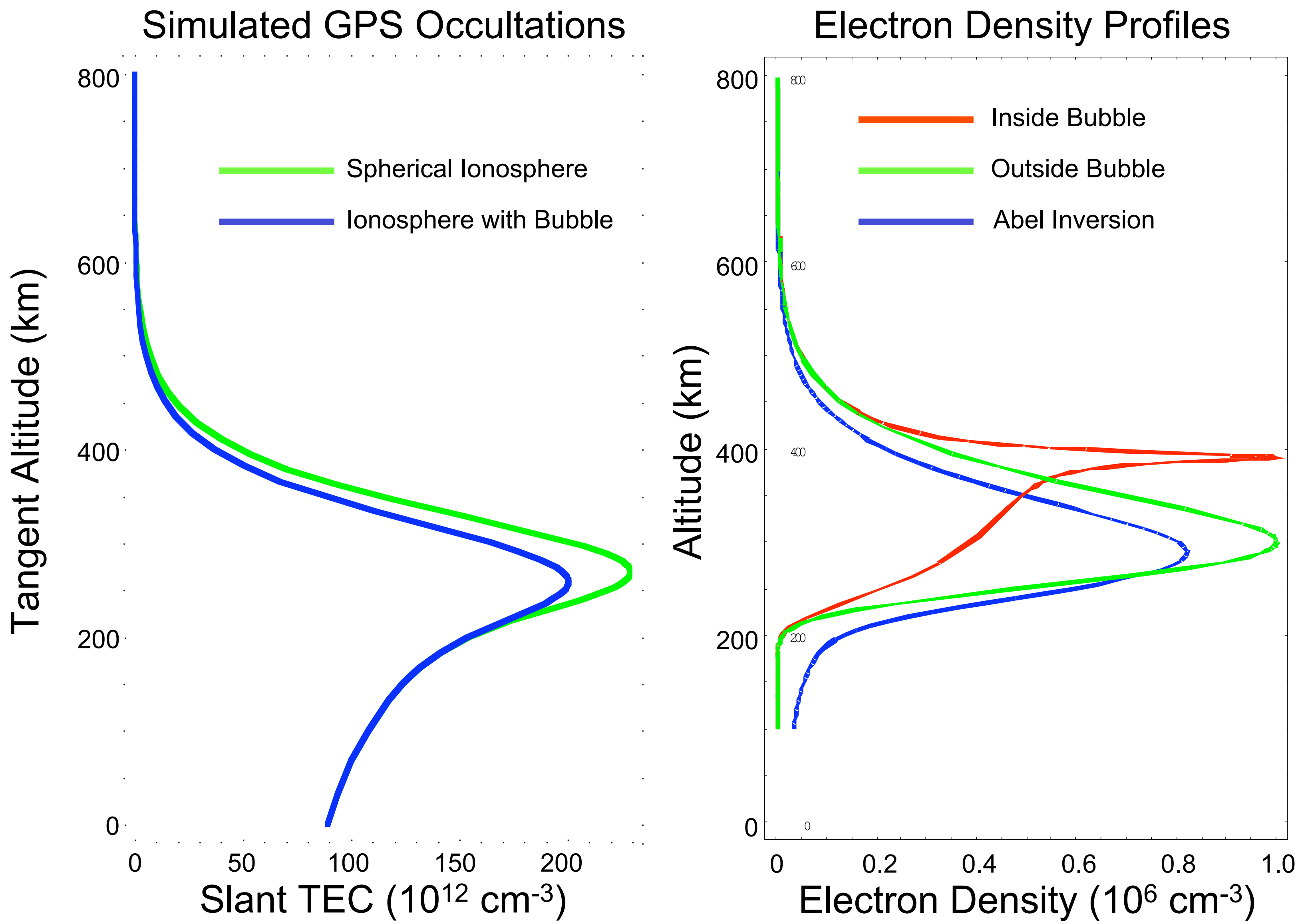
Limitations of GPS Occultation for a Disturbed Ionosphere

- Abel Inversion Assumes Spherical Symmetry
- Horizontal Gradients are Averaged by Occultation
- Incompressible Transport Produces Ionospheric Irregularities
- Occultation Data May Not Show Anomalies in Ionospheric Structures
- Abel Inversions Yield Incorrect Results
- Additional Horizontal Structure Using TIP and TBB Identifies Irregularities
- Adding TIP and TBB data to Occultation Measurements Allows Reliable Imaging of Ionospheric Irregularities

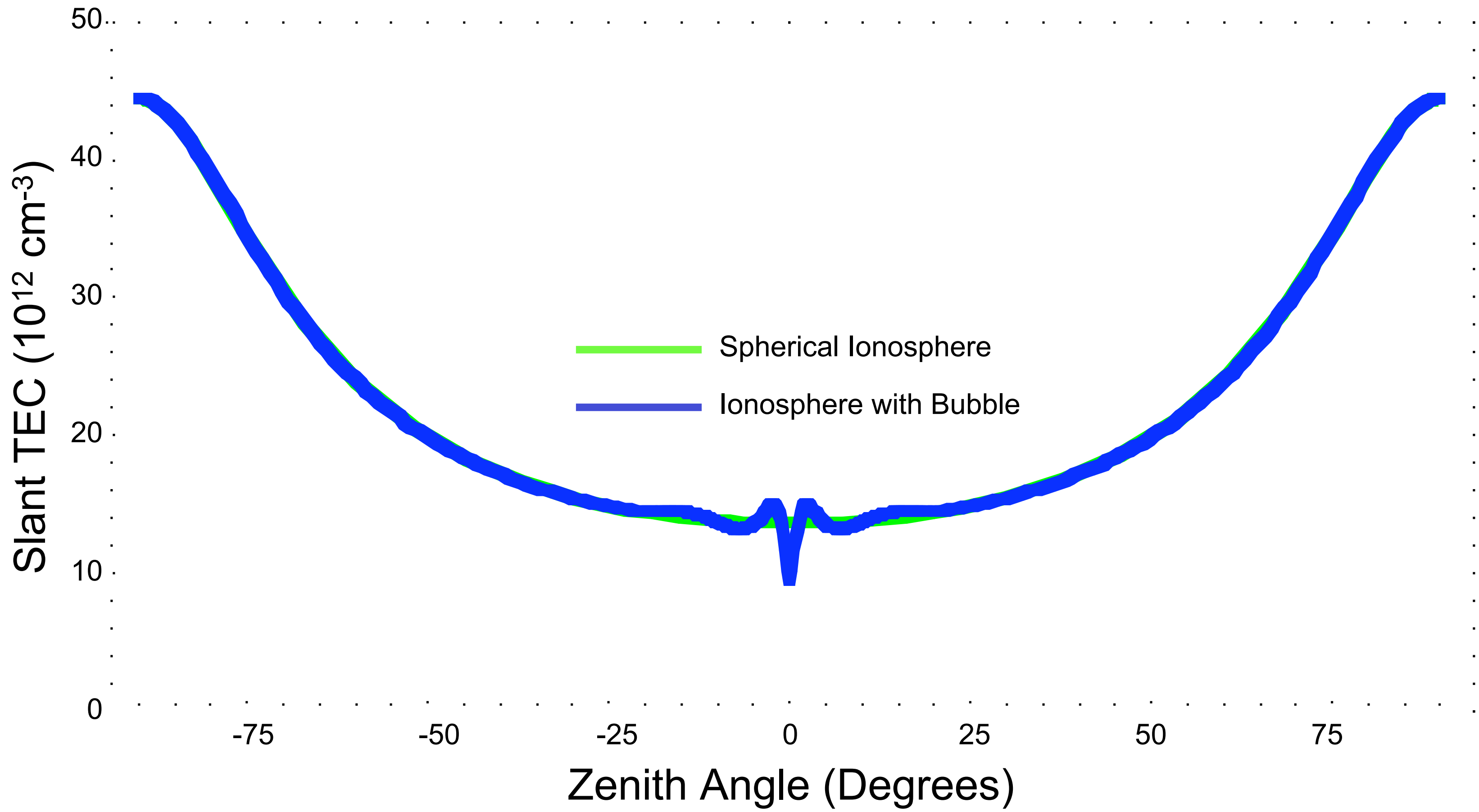
Model Ionosphere for Satellite Occultation Studies



Errors from GPS Occultation Data Using Abel Inversions in the Disturbed Ionosphere



Satellite to Ground TEC



Quasi-Analytic Model of Total Electron Content from Evolving Ionospheric Bubbles

- Prediction of CERTO Instrument Data
- Ionospheric Bubbles Rise Through the Ionosphere
- Bubble Changes During Satellite Transit
- Tomographic Image May be Distorted
- Simulation with Equatorial Bubble Model
- Spatial and Temporal Variations

Layer Model

- Analytic Model for Background Ionosphere
  – Modified Chapman Layer

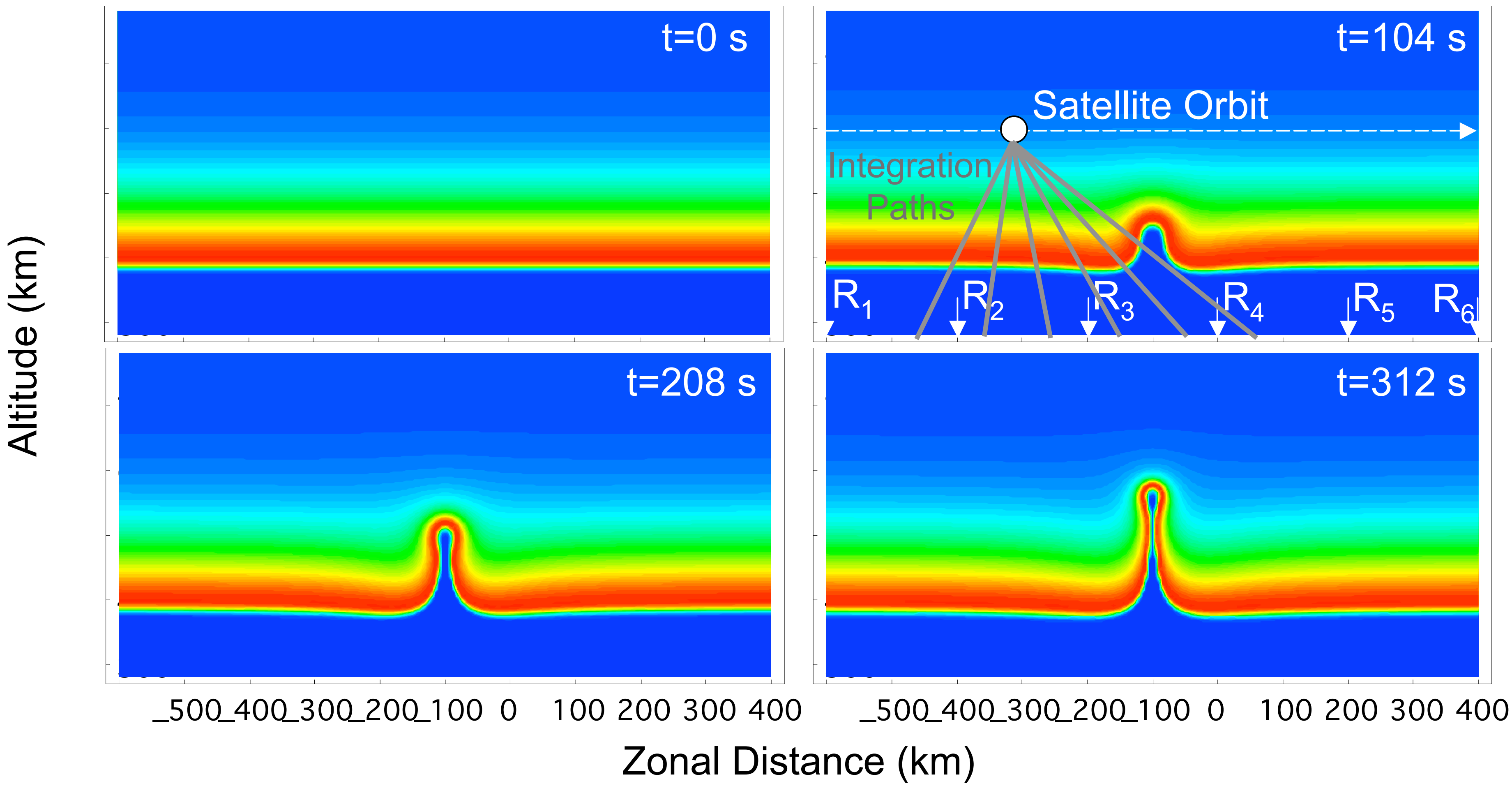
$$N_e(y) = N_{e0}\ \mathrm{Exp}[1 - z - \mathrm{Exp}(z)]$$

$$z = \frac{y - H_P}{H_0}$$

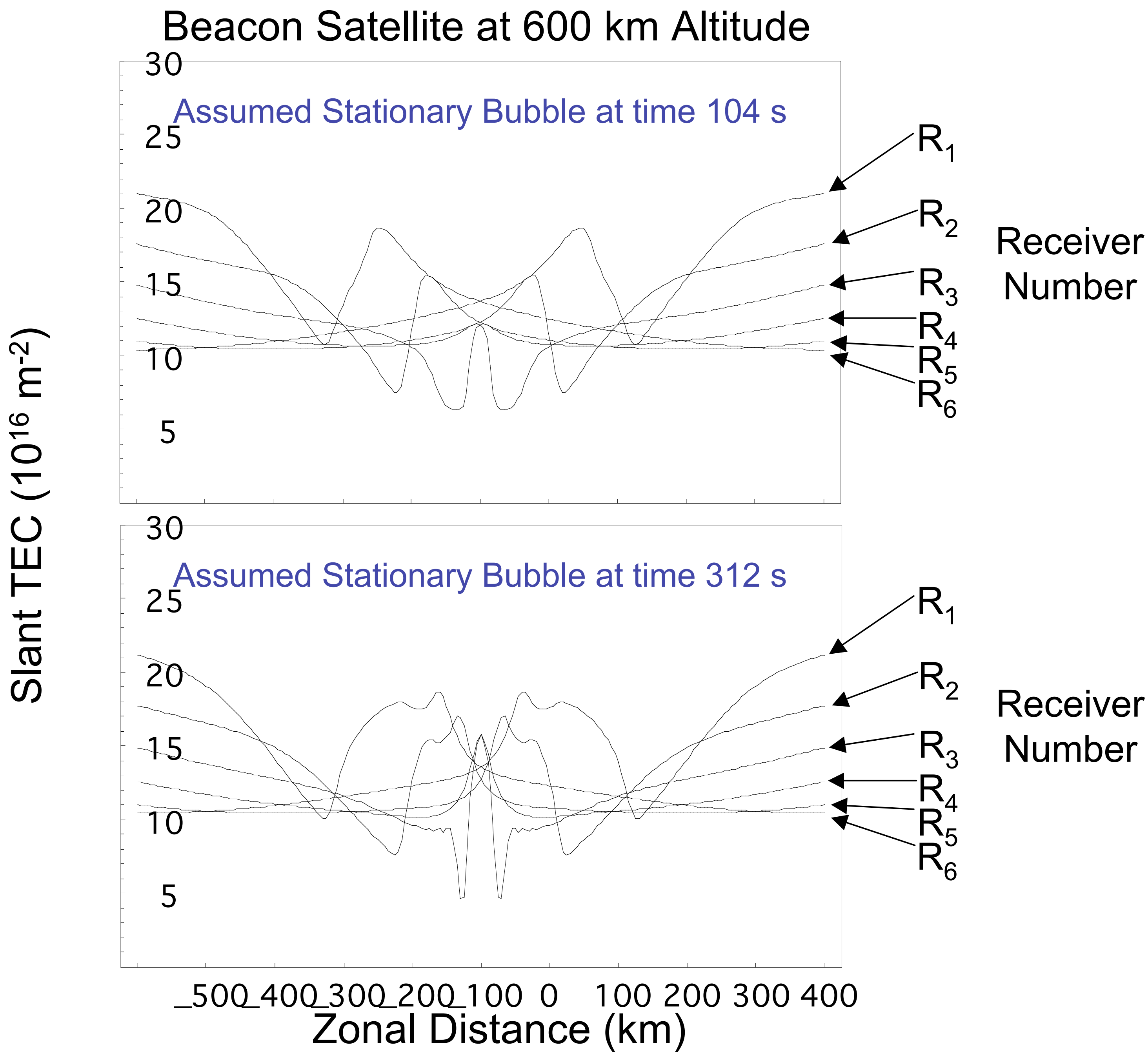
$$H_0 = H_{01} + [0.5 + \mathrm{Tan}^{-1}(\frac{y - H_P}{H_2}) / \partial\,]\,H_{02}$$

  – Parameters: Scale Heights and Layer Peak
    - On Bottom H_{01} = 6 km
    - On Top H_{02} = 50 km
    - Transition H_2 = 10 km
    - H_P = 400 km
    - $N_{e0} = 10^6$ cm^{-3}

Fast Rising Bubble Used for Simulated Tomographic Data for Transmissions to Six Ground Receivers (R_1 to R_6)



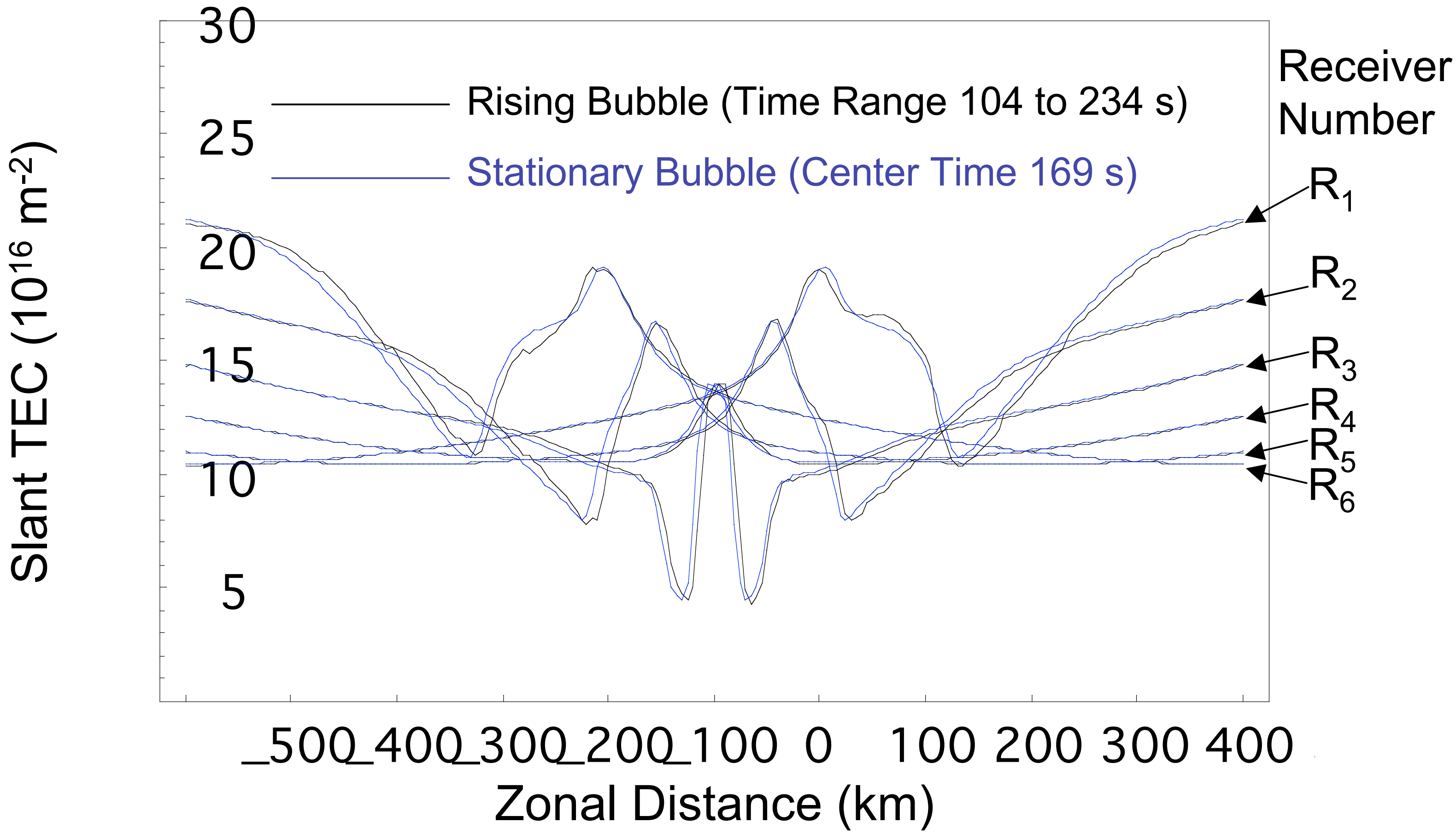
TEC for Stationary Bubble



TEC Comparison
Rising Bubble Versus Stationary Bubble

V_{Sat} = 7.7 km/s at 600 km Altitude

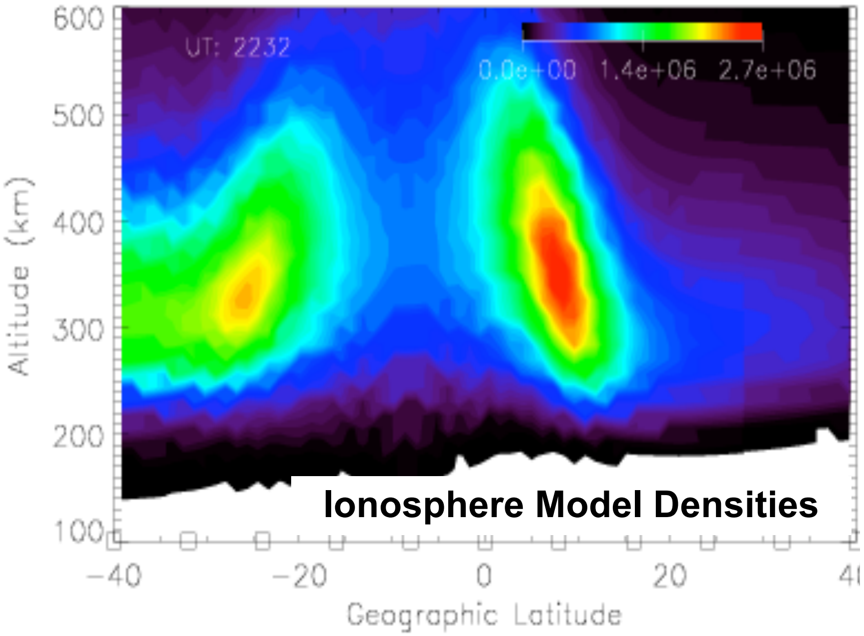
V_{Rise} = 0.6 km/s at Bubble Center

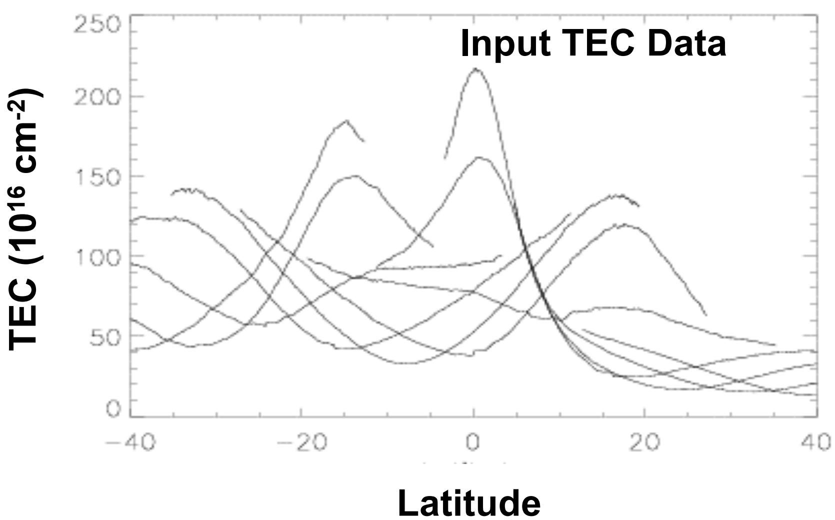


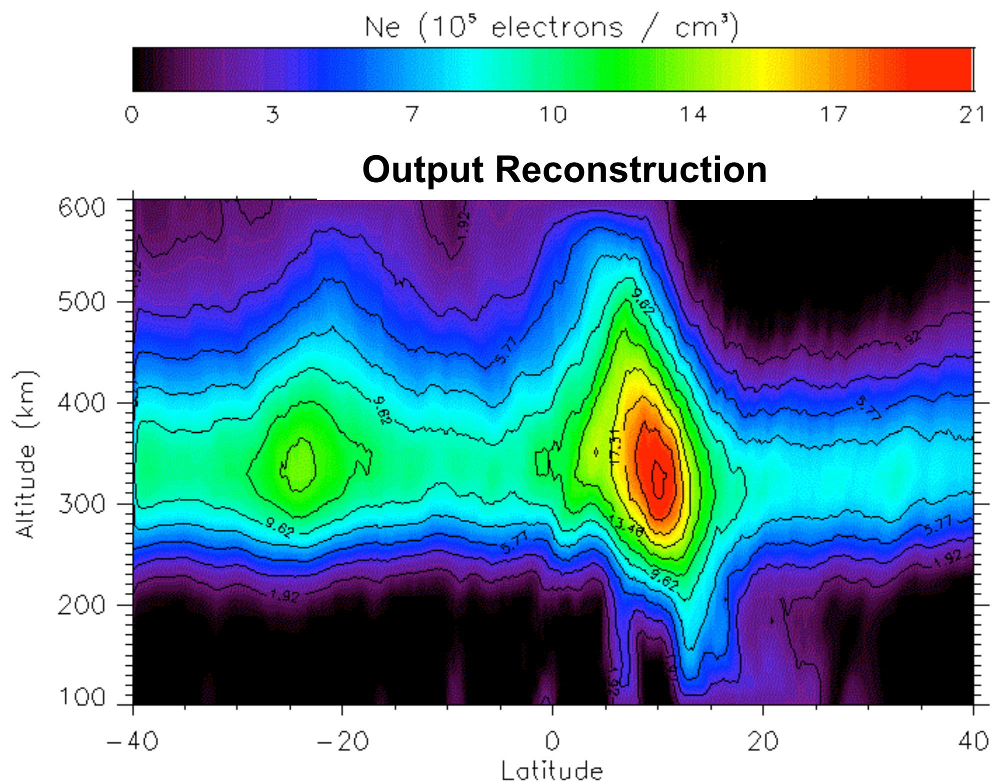
Tomographic Algorithm Development and Testing

Ionospheric Reconstruction

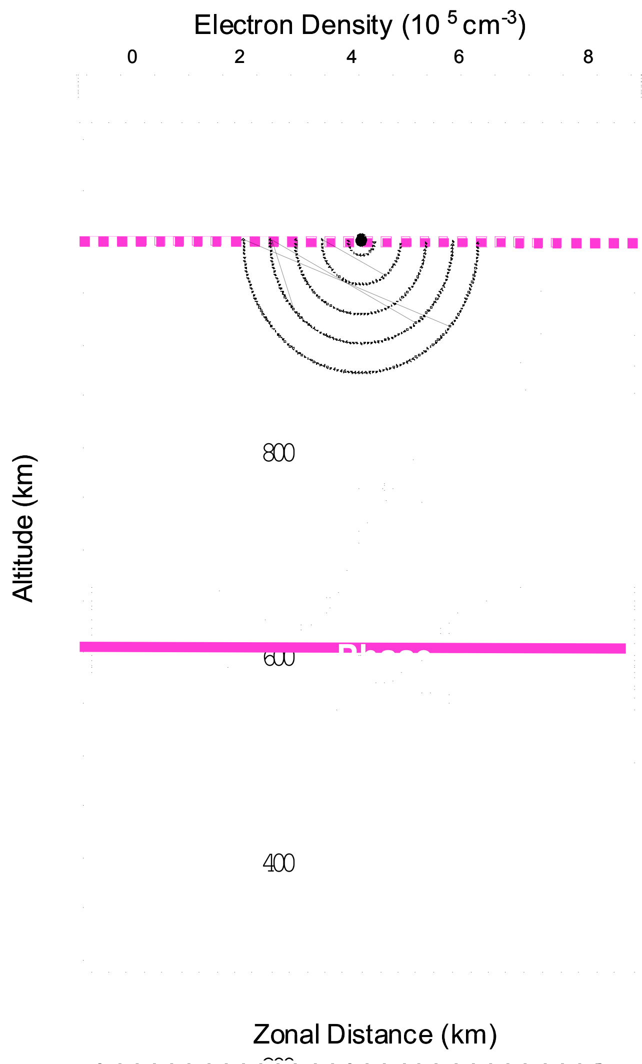
- Synthetic Electron Density Data from SAMI3 Model
- Derived TEC for Ground Receivers
- Reconstructed Electron Densities

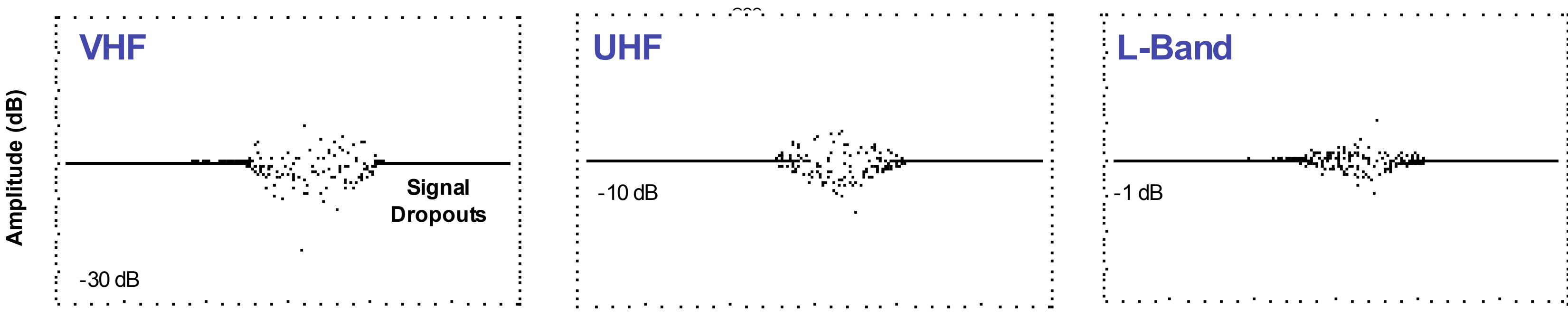






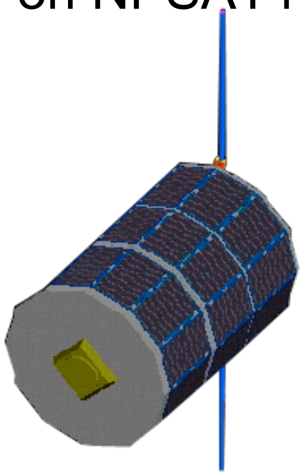
Scintillation Prediction for TBB Operation



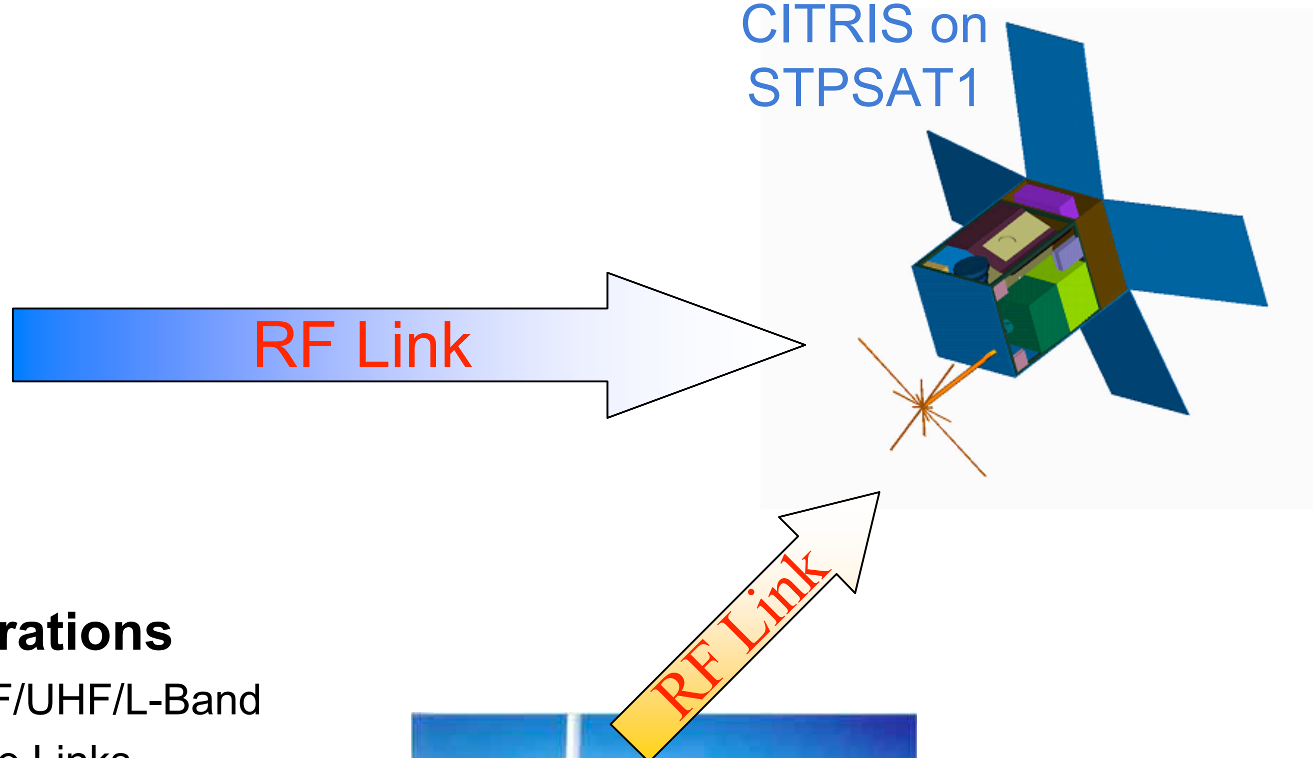


Scintillation and Ionospheric Tomography Radio Instrument in Space (CITRIS): Space Based Monitor of DORIS Ground Beacons or Tandem Operations of NPSAT1 and STPSAT1

CERTO/LP
on NPSAT1



CITRIS on
STPSAT1

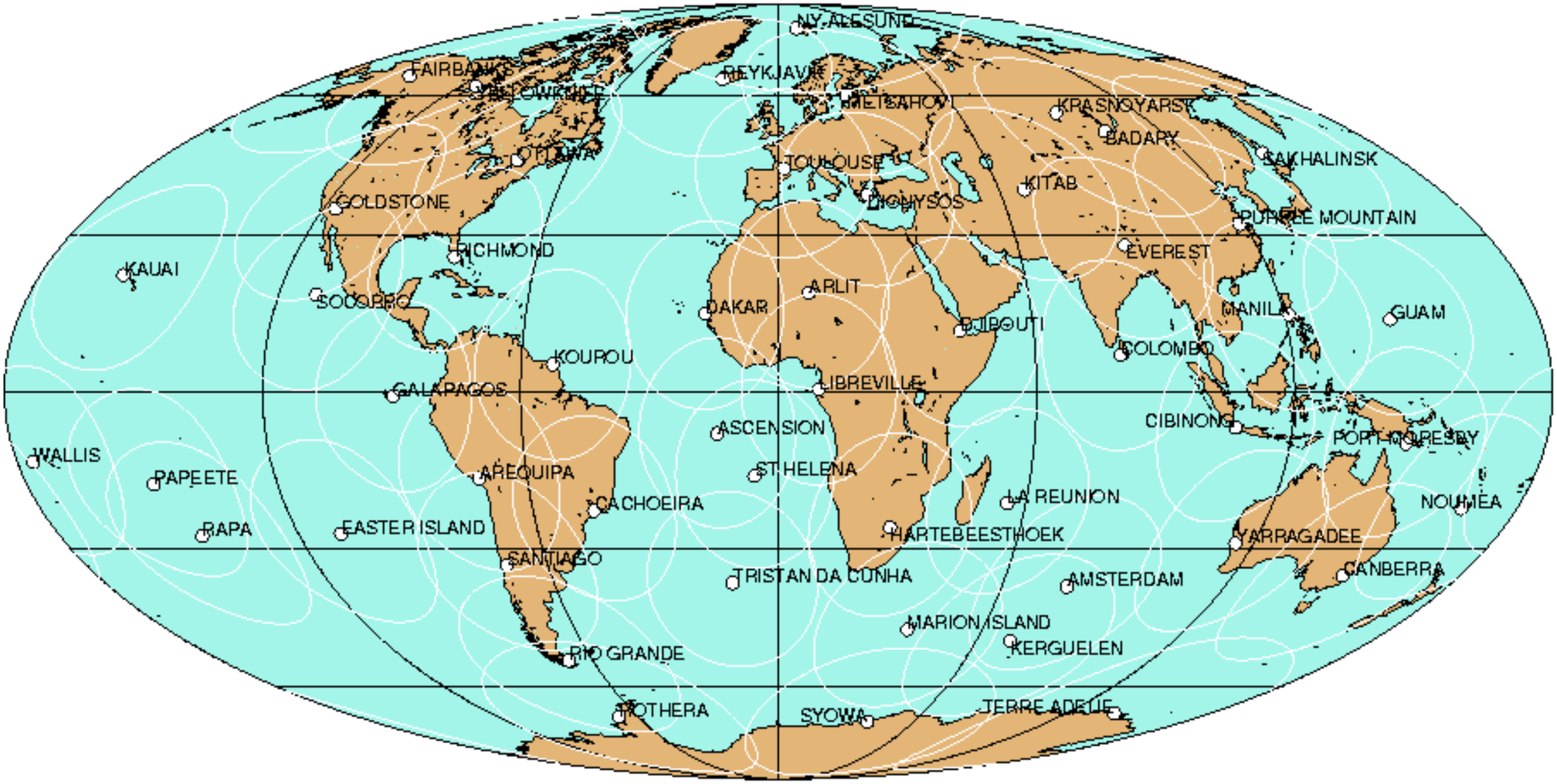


CERTO/CITRIS Operations

- Simultaneous VHF/UHF/L-Band
- Satellite to Satellite Links
- Up to Two Days Continuous Operation
- TEC Inputs to Space Weather Models
- Global Scintillation Monitor

DORIS
Station in
Australia

DORIS UHF/S-Band Beacons at Ground Sites



Global Map of 56 DORIS Transmitters at 401 $^{1}/_{4}$ and 2036 $^{1}/_{4}$ MHz

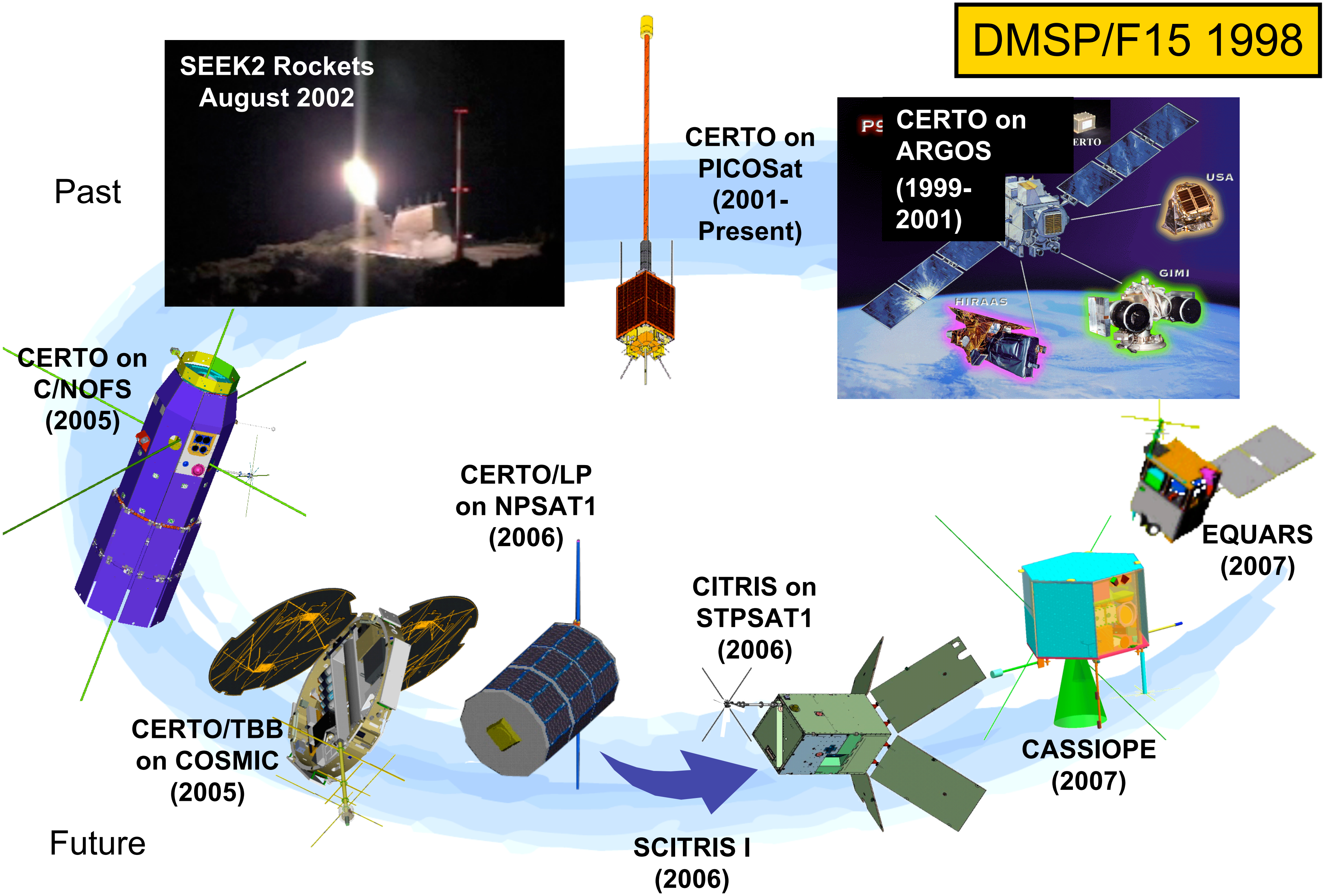
CW Transmissions with 0.8 s Modulation Every 10 m.

Latitude Range: - 70^{o} to + 80^{o}

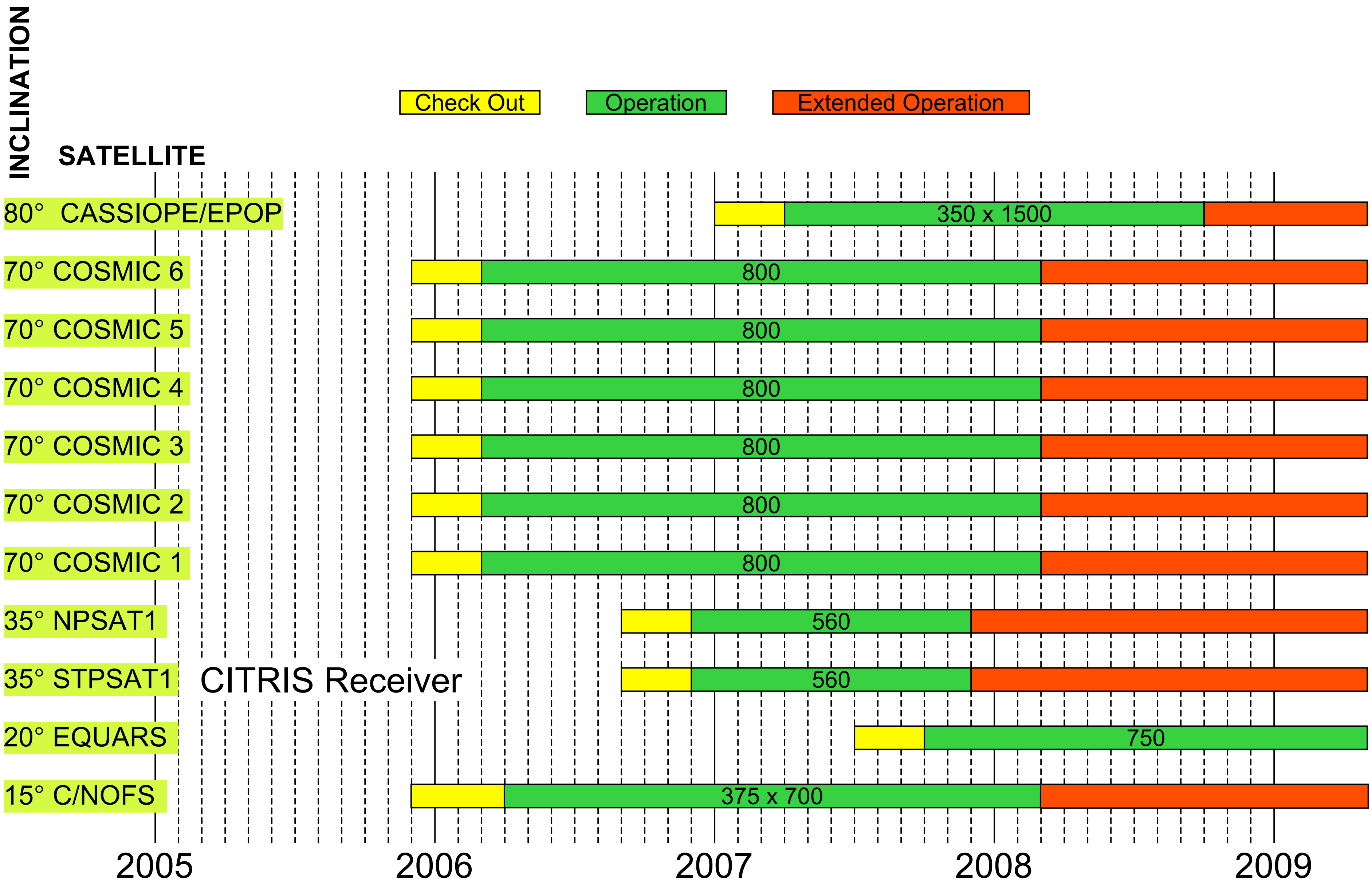
Data Records: Absolute TEC (Differential Phase +Group Delay)

UHF and L-Band Scintillations

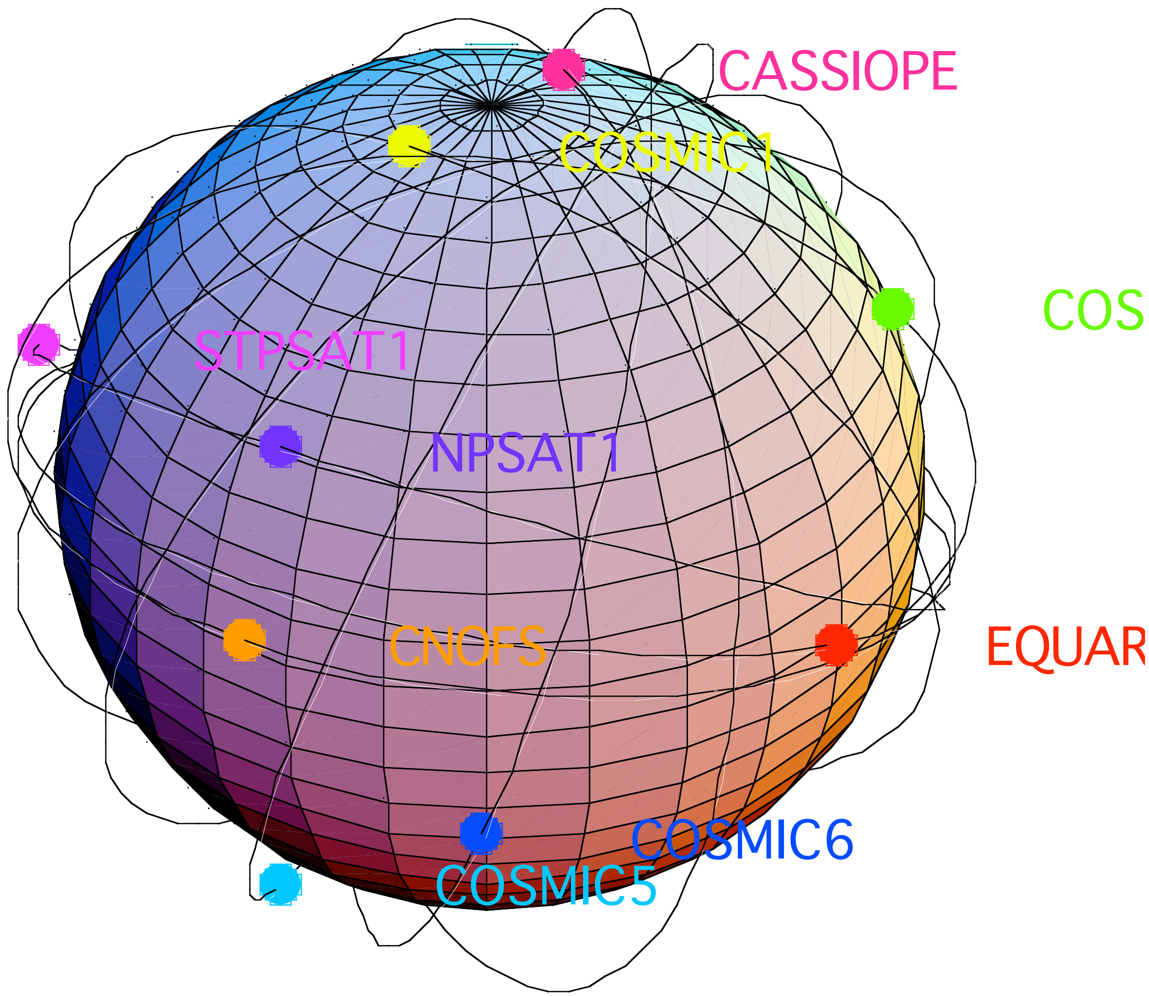
NRL Radio Beacon Sensors



NRL CERTO Radio Beacons and CITRIS Receiver



CERTO Beacon Orbits



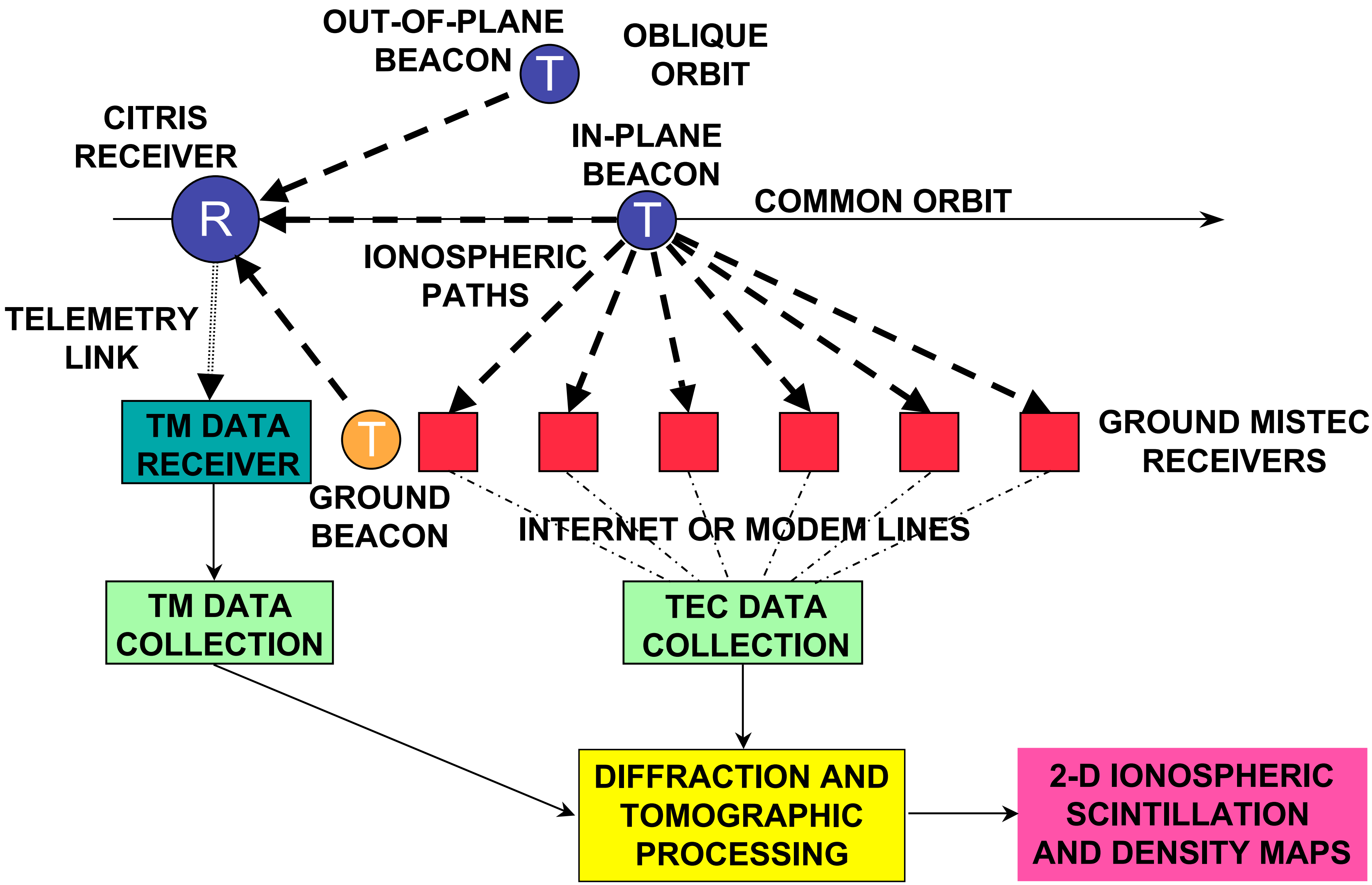
Advantages of CERTO Measurements on Instrumented Satellites

- CERTO Beacon, GPS Occultation, EUV Photometer, Langmuir Probe, etc. Together
  - Additional Horizontal and Vertical Path Data from GPS and EUV Sensors
  - Local Density from Langmuir Probe
  - Independent Measurements of the Ionosphere
  - Added Data for Computerized Ionospheric Tomography
- Unique Orbit Inclination
  - NIMS Beacons in Polar Orbit at a Fixed Local Time
  - CERTO Beacons in Wide Ranges of Latitudes and Local Times

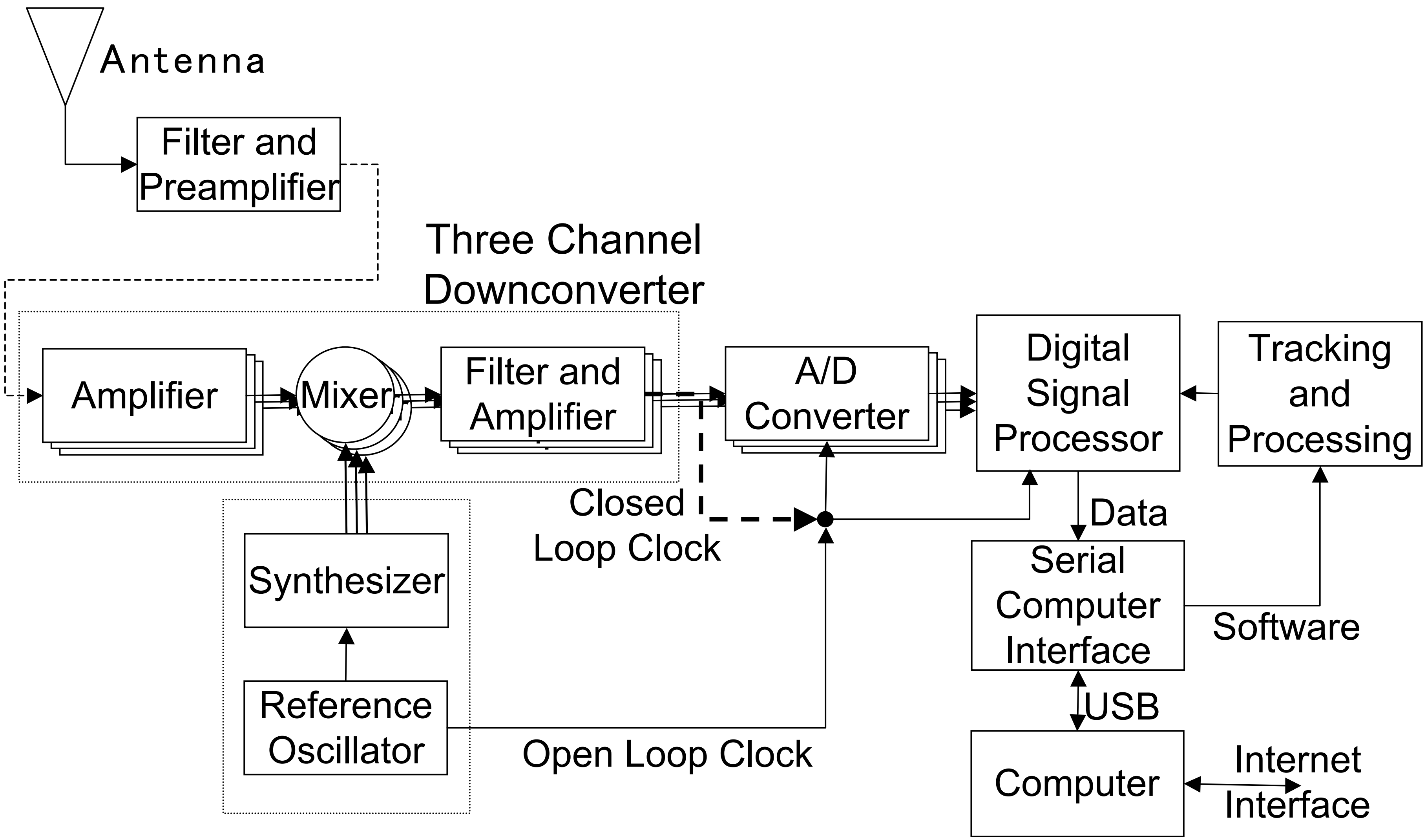
CERTO Beacons with Plasma Instrumentation

Satellite	Radio Beacon	GPS Occultation	Optical Instruments	Plasma Probes	Other Instruments	Comments
C/NOFS	CERTO-C	CORISS	None	Langmuir Probe	B-Field E-Field	CERTO VHF/UHF On Continuous, L-Band On at Night
COSMIC (Six Separate Orbits)	CERTO-C	IGOR	TIP-EUV Photometer	None	None	CERTO in VHF/UHF or UHF/L-Band Because of GPS Receiver Interference
NPSAT1	CERTO-C	No	None	Langmuir Probe	None	CERTO Only On 2 Hours per Day From Power Limitations
CASSIOPE	CERTO-D	GAP	FAI-Auroral Imager (Visible, IR)	IRM, SEI Plasma Densities, Drifts, and Temperature	Plasma Wave B-Field Neutral Mass Spectrometer	CERTO Two or Three Frequency Modes Scheduled
EQUARS	CERTO-D	IGOR+	OH, O_2 Imagers	Langmuir Probe	Energetic Particles	CERTO 400 MHz Limited Because of Telemetry Interference

CERTO DATA ACQUISITION



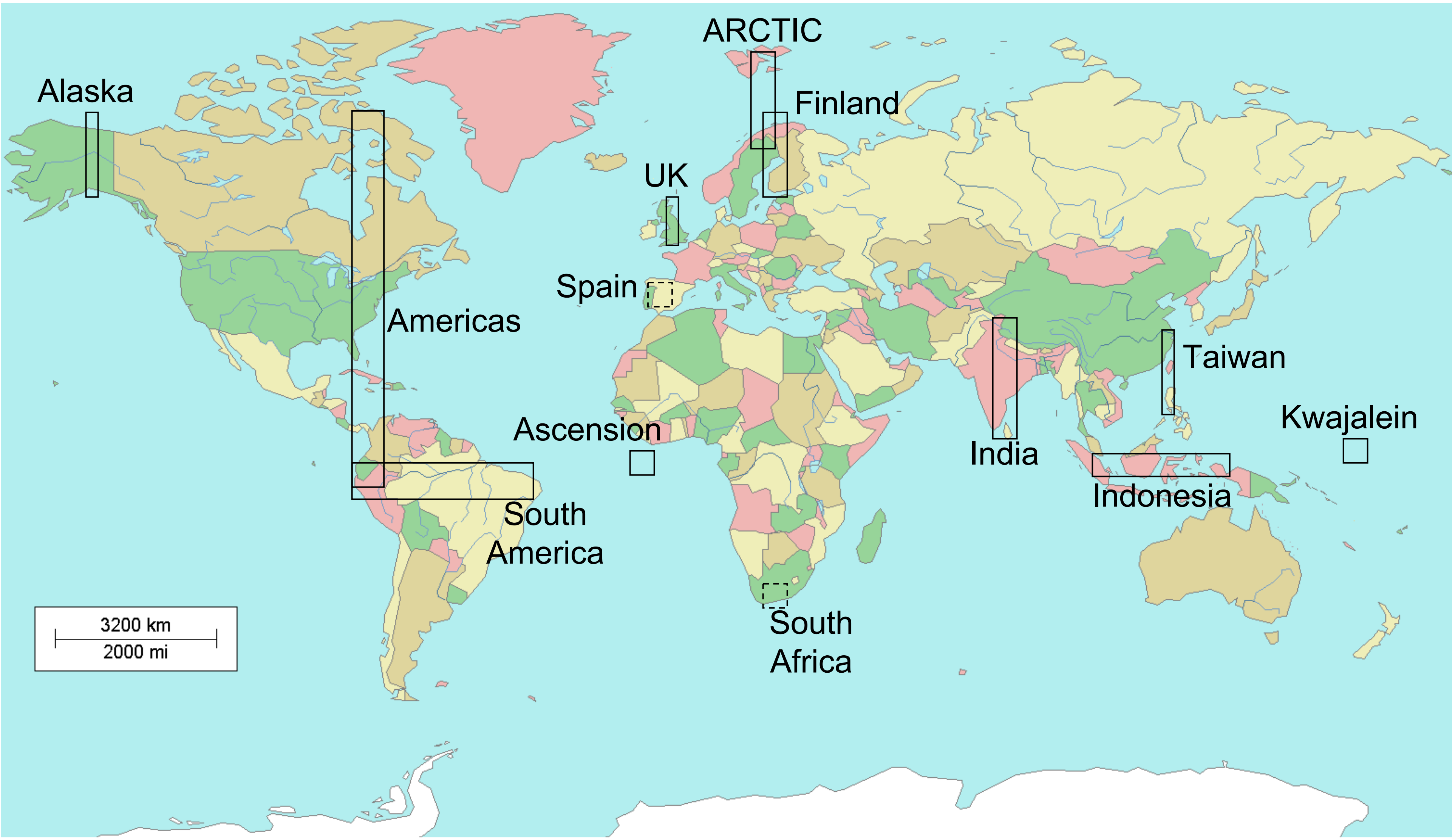
CERTO Beacon Ground Receiver



Receiver Development for CERTO Beacons

- TBB Ground Receiver
  - Operating Frequencies: 150/400/1067 MHz
  - Amplitude and Phase Scintillations Plus TEC
  - Primary Users
    - Taiwan NSPO Receiver Chain in Asia
    - India CRABEX Chain
    - North and South America Chain
    - European Chains in Scandinavia, United Kingdom, Spain
    - South Africa Chain
- SCION-3 Receiver (Bob Livingston Design)
  - Developed for AFRL SCINDA Network
  - Design Complete and Prototype Tested
  - Hybrid (Analog/Digital) Open Loop Tracking
  - Deployment of 2 Receivers for C/NOFS Program by November 2004
- ITS30S Receiver (NWRA – Frank Smith)
  - Hardware Design Complete and Software Development Almost Done
  - Hybrid (Analog/Digital) Closed Loop Tracking
  - Antenna Provided by NWRA with Small Contributions by NRL
  - Three Frequency Model Operational by 1 October 2004
- CITRIS-G Receiver for COSMIC (Cornell Design)
  - Receiver Design in Progress
  - Open Loop Tracking
  - Antenna from NRL
  - Direct RF Sampling with Digital Tracking
- CIDR-3 Receiver (Applied Research Laboratory/University of Texas at Austin)
  - Upgraded Two Frequency Receiver Design
  - TEC/scintillations to 20/30 Hz
  - Design Complete and Being Tested
  - Quadrifilar Antenna or Crossed Dipole

Radio Beacon Receiver Chains to Observe CERTO Beacons



Scheduling of CERTO Operations with Ground Receivers

- CERTO Radio Beacons are NOT Operating Continuously
- Overflight of Ground Receivers
  - Two or Three Frequencies Chosen from VHF/UHF/L-Band
  - GPS Occultation Data if GPS Satellite in Proper Location
  - Simultaneous Beacon and In Situ Probes with C/NOFS and NPSAT1
- Supporting Ground Systems
  - 50 MHz Radar: Jicamarca, Peru
  - 430 MHz Radar: Arecibo, Puerto Rico
  - All Sky Optical Imagers
  - Digital Ionosondes
- Send Receiver Locations and Turn-On Requests to Paul Bernhardt (bern@ppd.nrl.navy.mil)
- CERTO Beacon Satellite Updates Distributed Through IITC from NWRA

Summary

- Ten or more CERTO beacon systems in low earth orbit will have ability to determine the TEC and multi-band scintillations.
- The CERTO frequencies were chosen to optimize resistance to noise, resolution of TEC ambiguities, and scintillation coverage.
- The resolution of the CERTO system is ~ 10^{-3} TEC Units
  - Important to Track Small Ionospheric Fluctuations Such as Traveling Ionospheric Disturbances (TID's), Scintillation Instability Onsets, Wave Refraction Effects, etc.
- The ambiguity of the 3 Frequency CERTO system
  - 8.3 TEC units (48 π)
  - Required to Determine Absolute TEC
  - Improves Reliability of Tomography Processing
  - Permits Restoration of Absolute TEC After Signal Drop Out
  - Improved Resistance to TEC Receiver Noise
- CERTO beacons on C/NOFS, COSMIC, NPSAT1, CASSIOPE, EQUARS etc. will complement each other for operations with inclinations from 15 to 80 degrees providing wide range of spatial and temporal sampling of the ionosphere.
- Ground receivers are needed.