Ionospheric Applications of the Scintillation and Tomography Receiver in Space (CITRIS) used with the DORIS Radio Beacon Network

Paul A. Bernhardt, Carl L. Siefring, Ivan J. Galysh,

Thomas F. Rodilosso, Douglas E. Koch, Thomas L. MacDonald

Plasma Physics and Space Systems Development Divisions,
Naval Research Laboratory, Washington, DC 20375

Matthew R. Wilkens, G. Paul Landis

SFA Incorporated, Crofton, MD 21114

IDS WORKSHOP, Venice, Italy

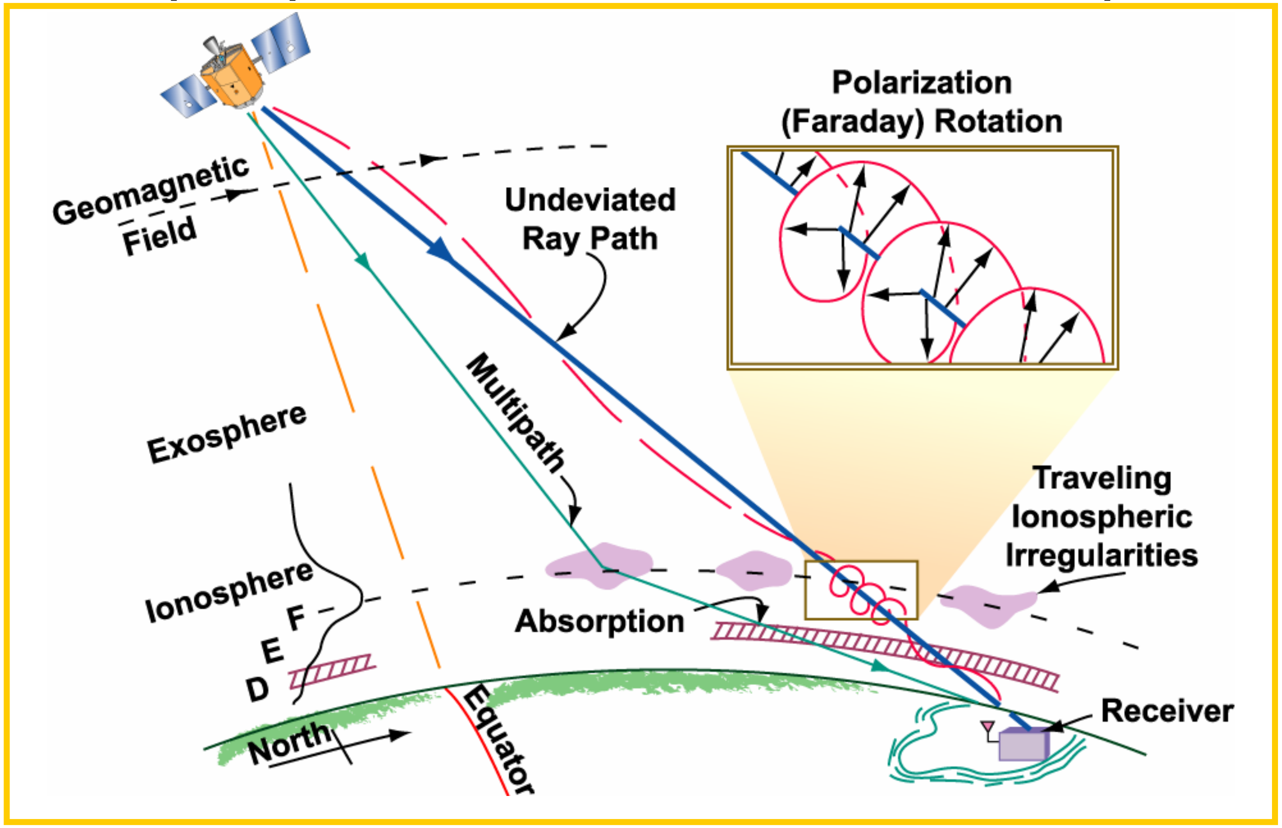
15 March 2006

Characterization of Ionospheric Phase Screens with the CITRIS Receiver on STPSAT1

- Objective: Reconstruct Real-Time Phase Screens for Multiple Frequency Scintillation Estimation
- New Satellites, Inclinations and Launch Dates
- CERTO: Space to Ground Measurements
  - Orbiting Beacon to Ground Receiver
  - TEC and Scintillations
  - Sampled Projections of Many Phase Screens
- CITRIS: Ground to Space Measurements
  - Ground Beacon to Orbiting Receiver
  - TEC and Scintillations
  - Sampled Projections from One Phase Screen
- CITRIS Space-Based Receiver
- Conclusions

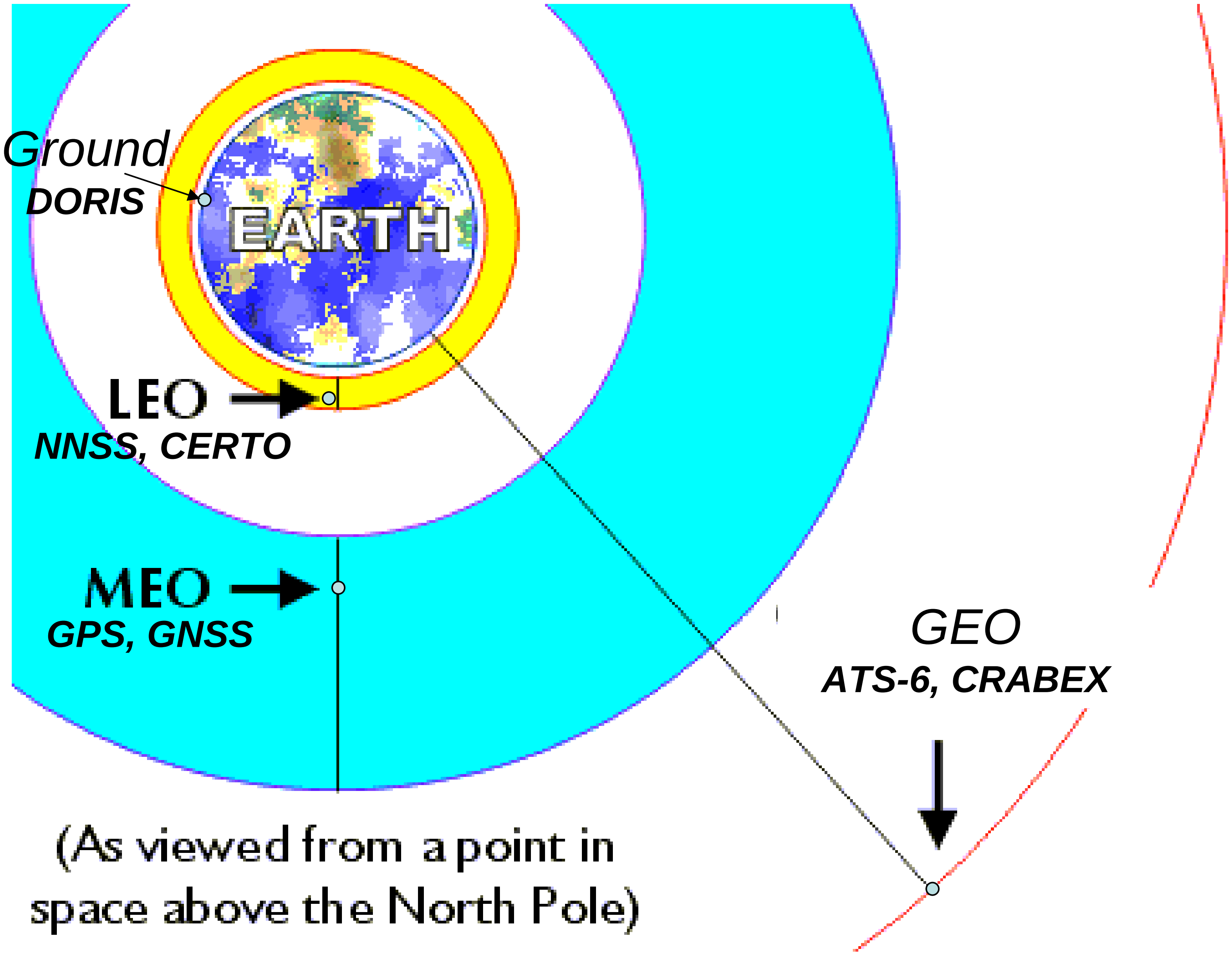
Major Ionospheric Propagation Effects on Space-to-Ground Links

(*Ionospheric Radio*, Kenneth Davies, IEE, 1990)

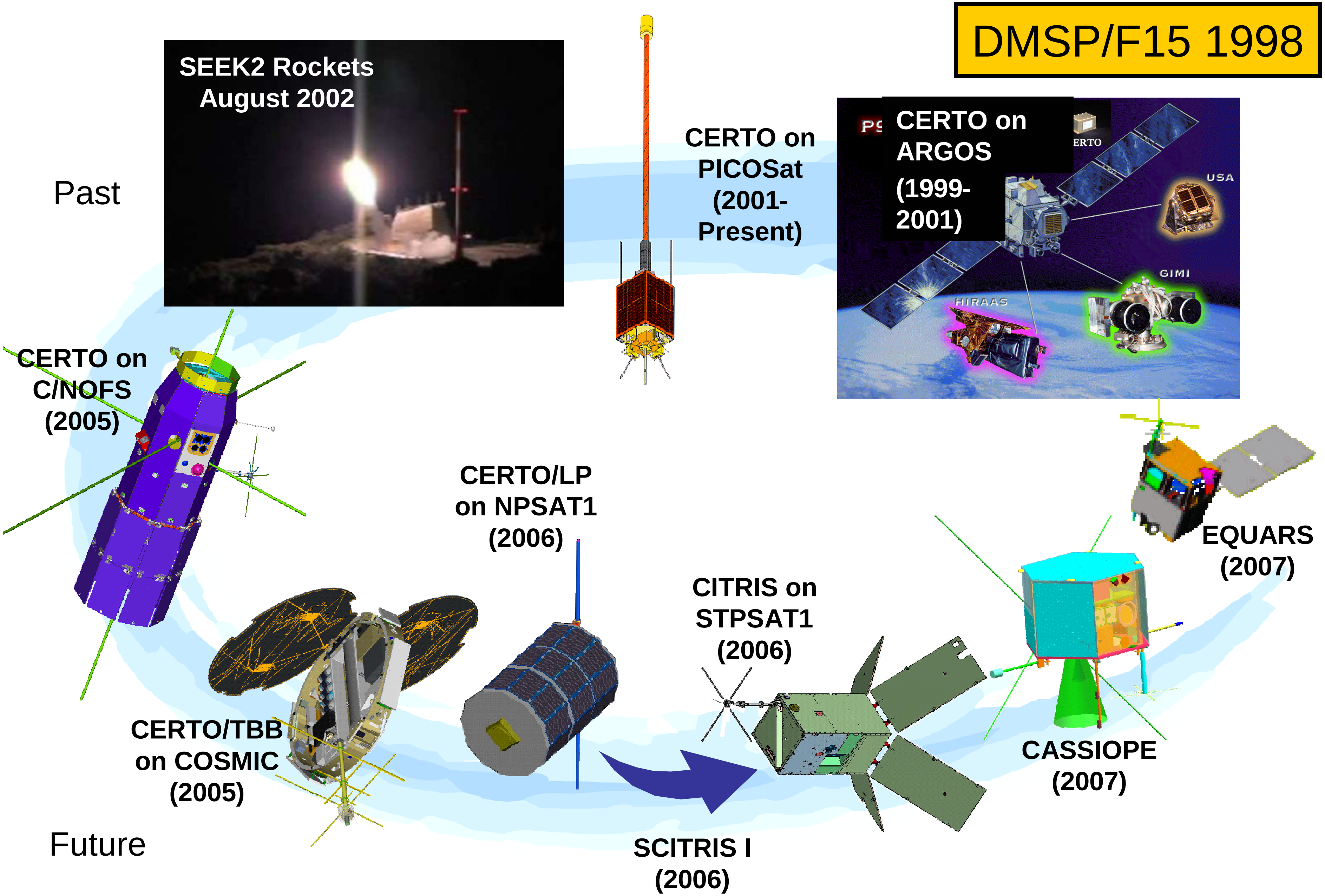


- Phase Fluctuations
- Amplitude Fluctuations
- Absorption
- Frequency Shifts
- Faraday Rotation
- Group Delay
- Scattering
- Multipath

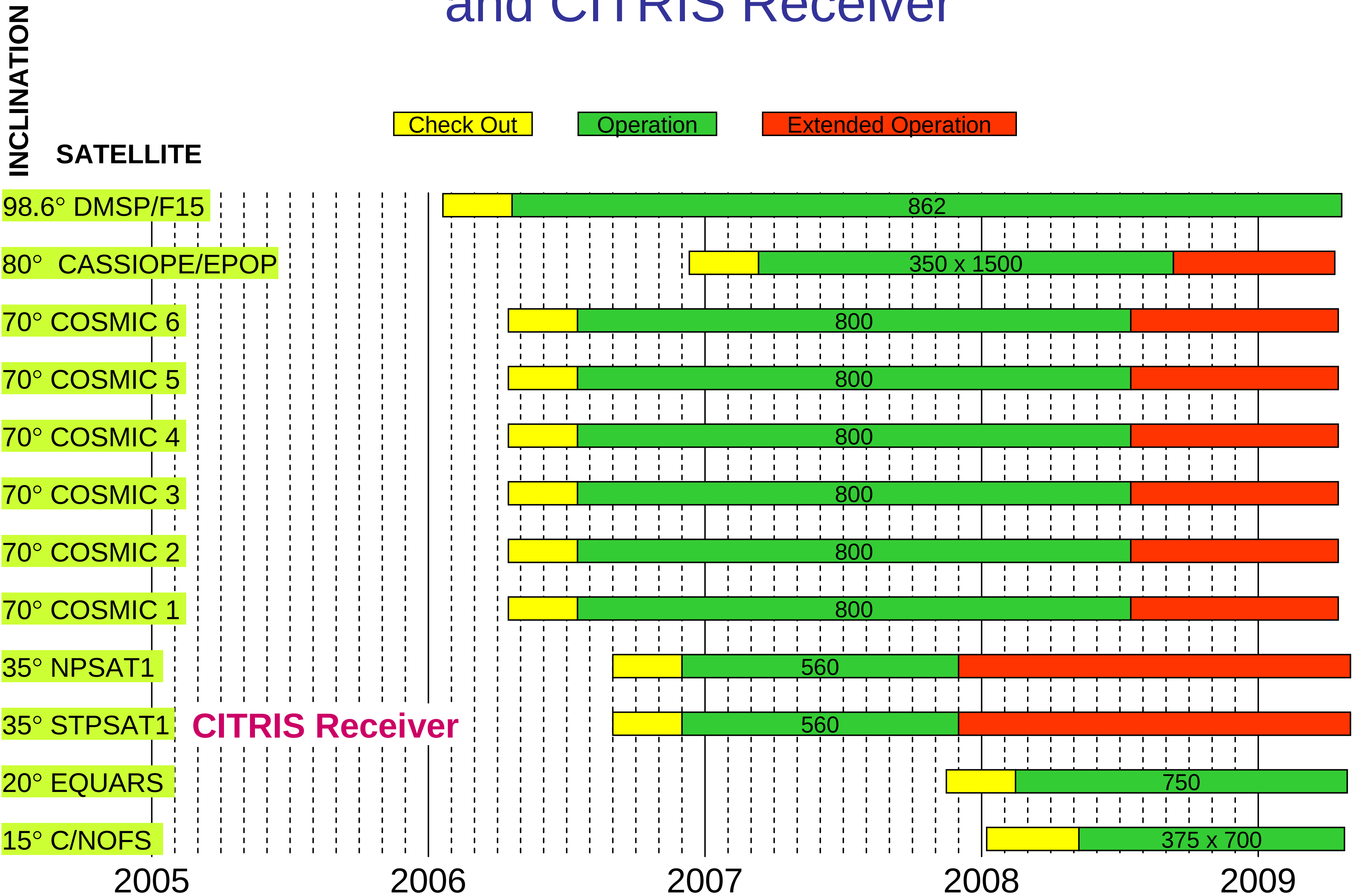
Radio Beacons for Ionospheric Characterization



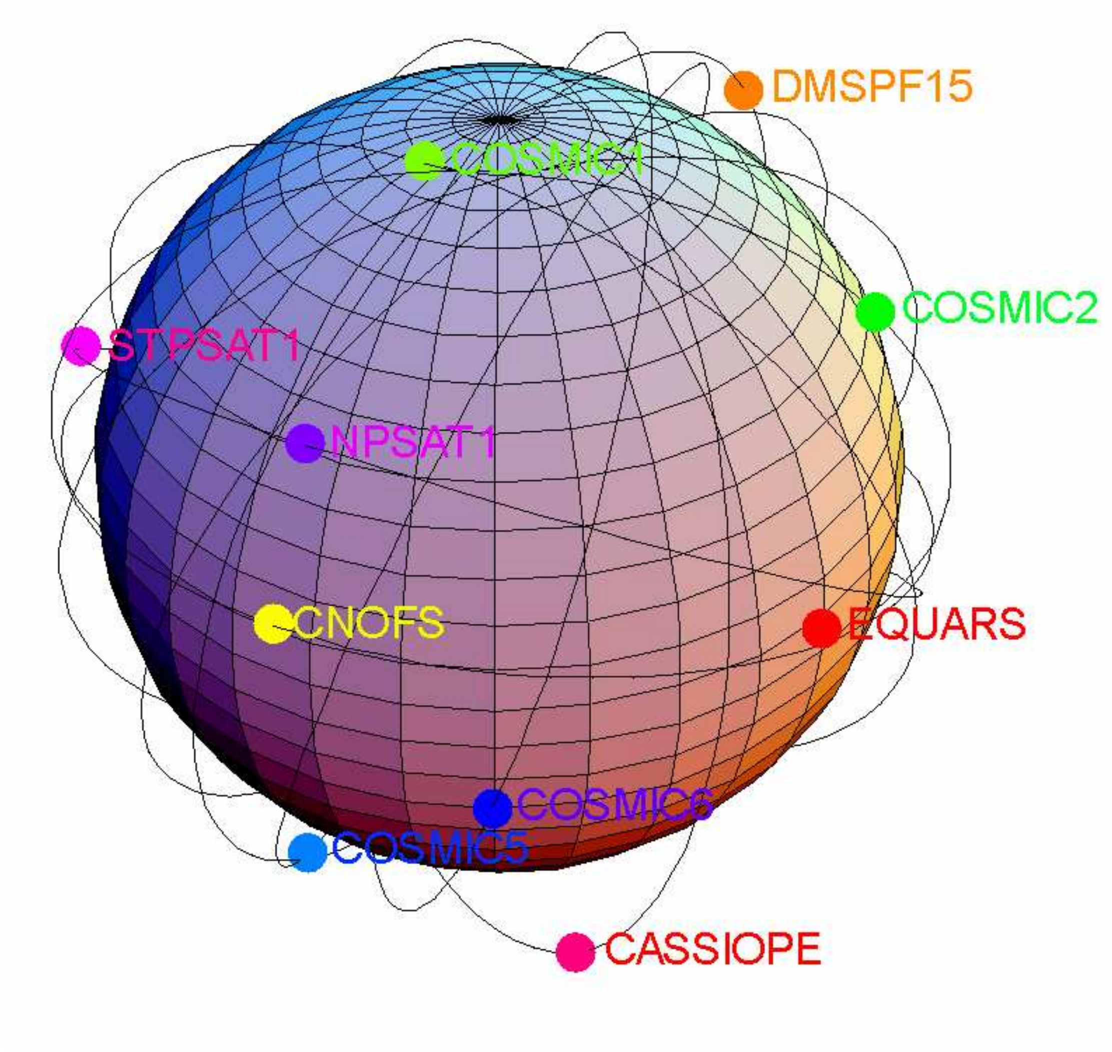
NRL Radio Beacon Sensors



NRL CERTO Radio Beacons and CITRIS Receiver



CERTO Beacon Orbits

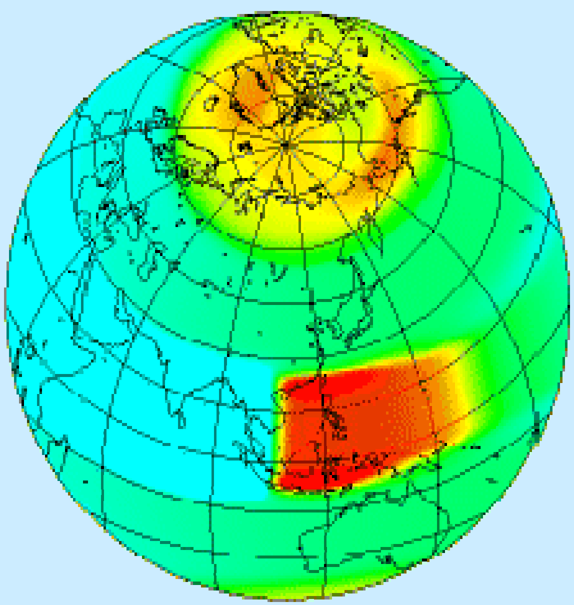


Radio Beacon Experiment Objectives

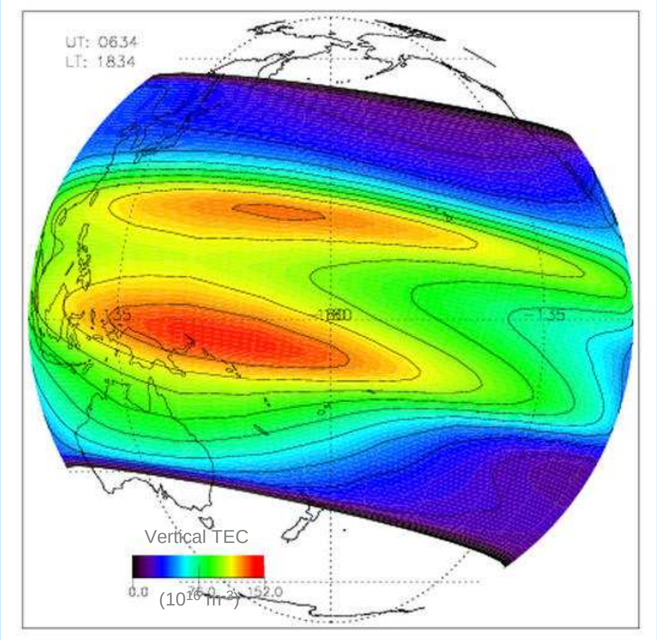
Program Goals

- 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

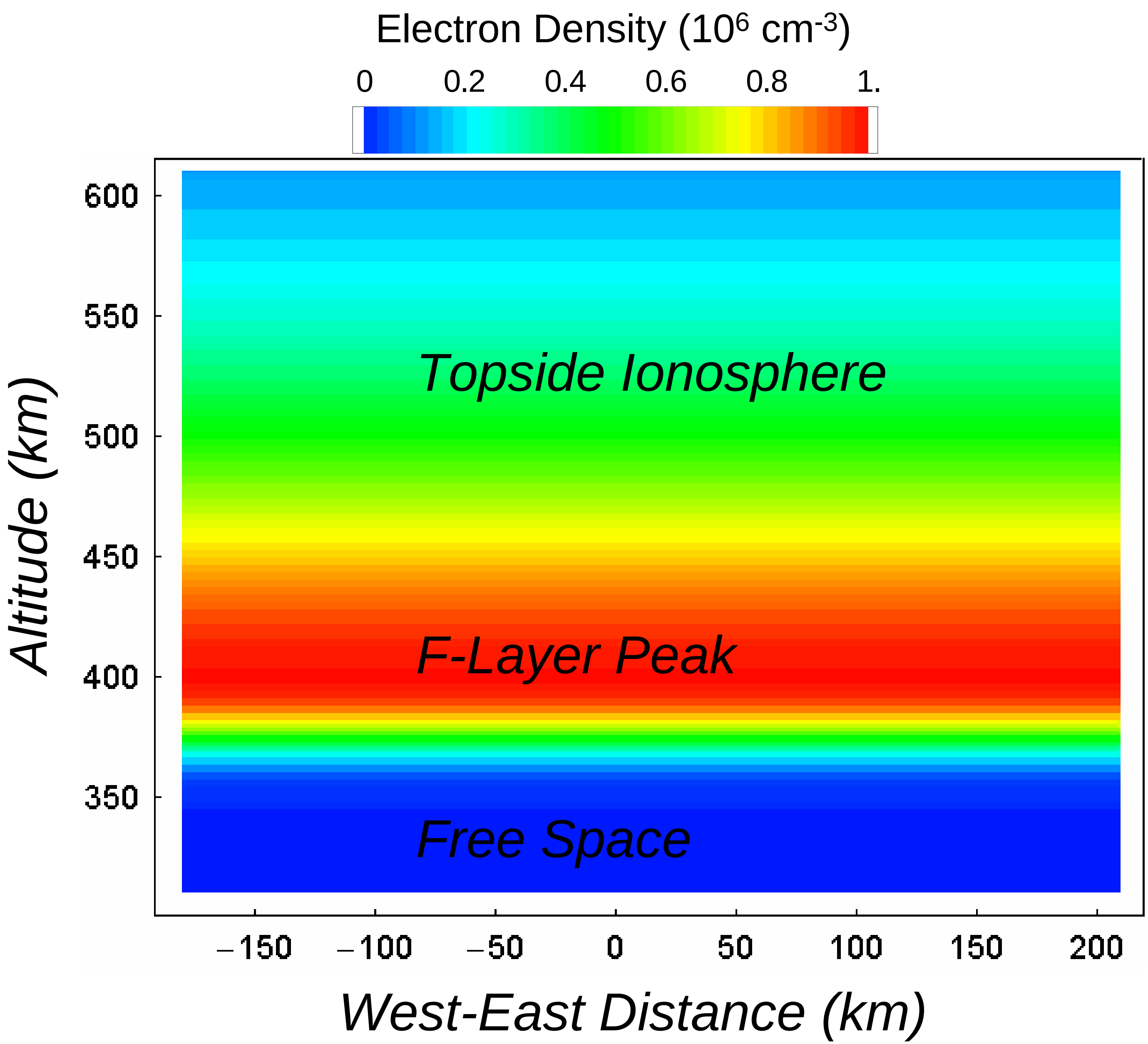
NWRA SCINTMOD
Scintillation Predictions



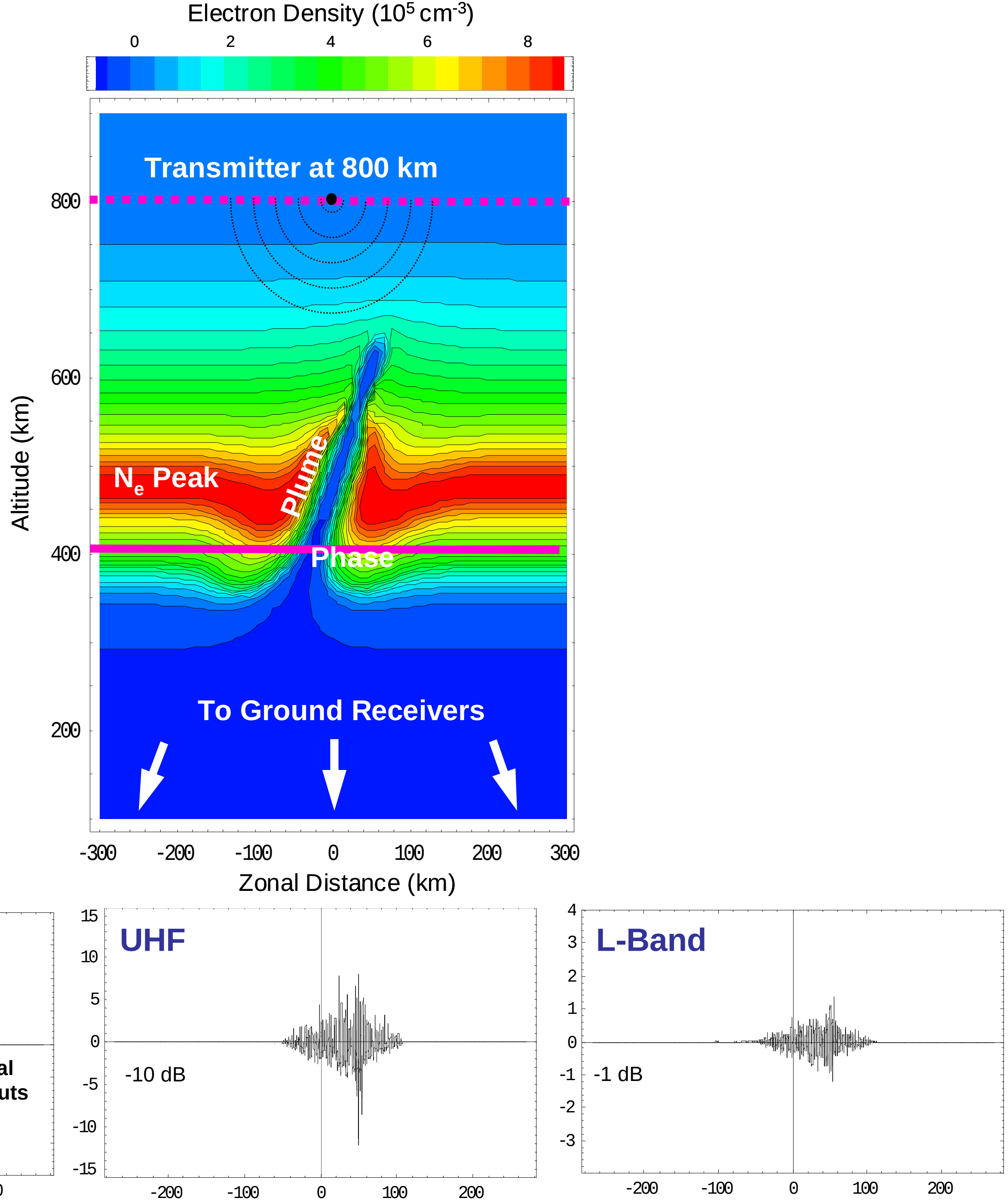
NRL SAMI3
TEC Predictions



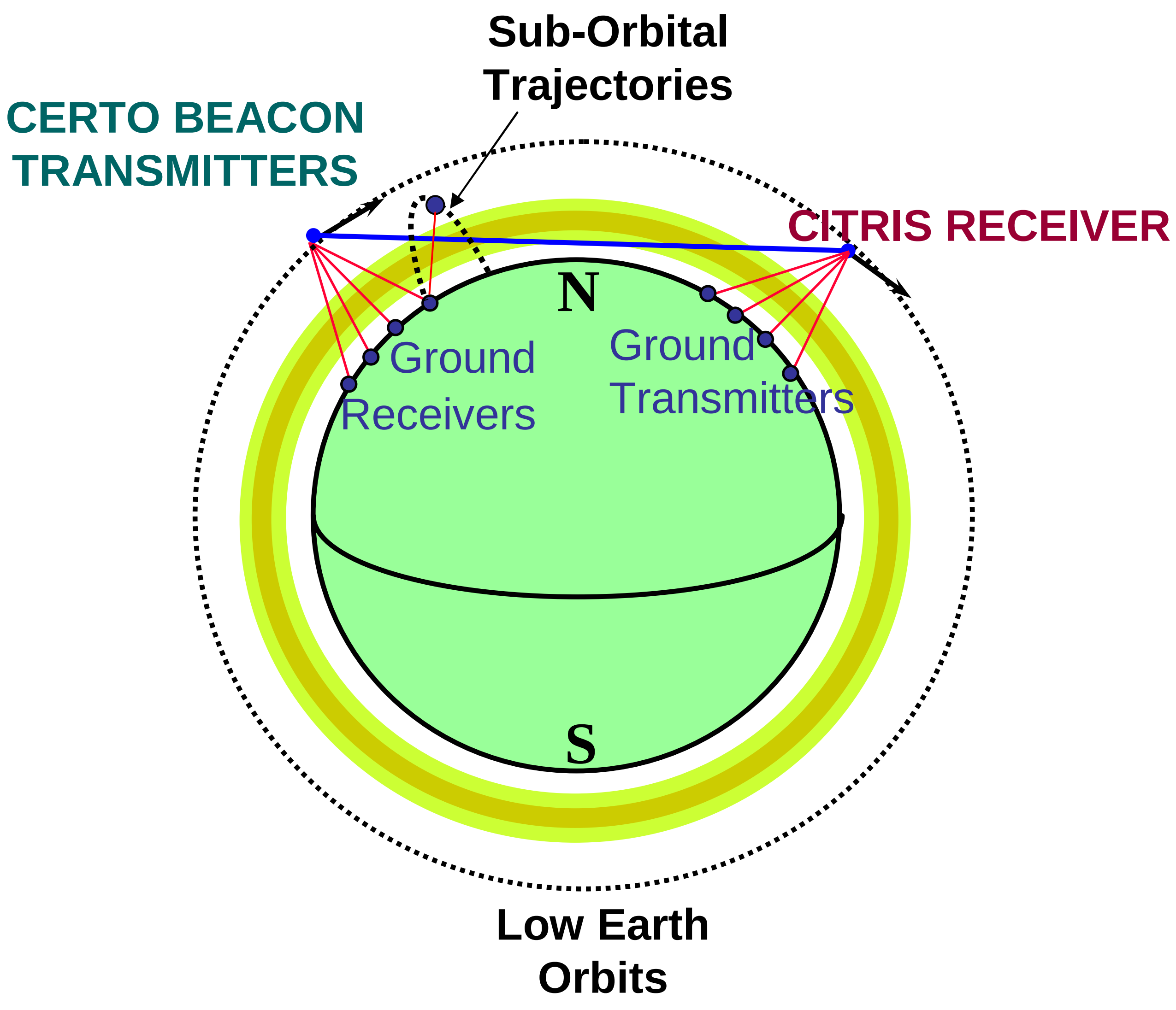
Ionospheric Bubbles Dynamics



Scintillation Prediction for CERTO Beacon Operation



CERTO RADIO BEACON GEOMETRY FOR TEC AND SCINTILLATION MEASUREMENTS



Digital Propagator for Diffracted Waves

Received Signals: Diffracted Wave

$$U_1(x, R+z; \lambda_k) = FFT^{-1}\left\{FFT\left[U_0(R, x)\right]\left(f_x\right)\exp[-j\pi f_x^2 \lambda_k z]\right\}$$

Beacon Transmission: Spherical Wave Front

$$U_0(R) = A_0 \frac{e^{j(2\pi R/\lambda + \phi)}}{R^2}$$

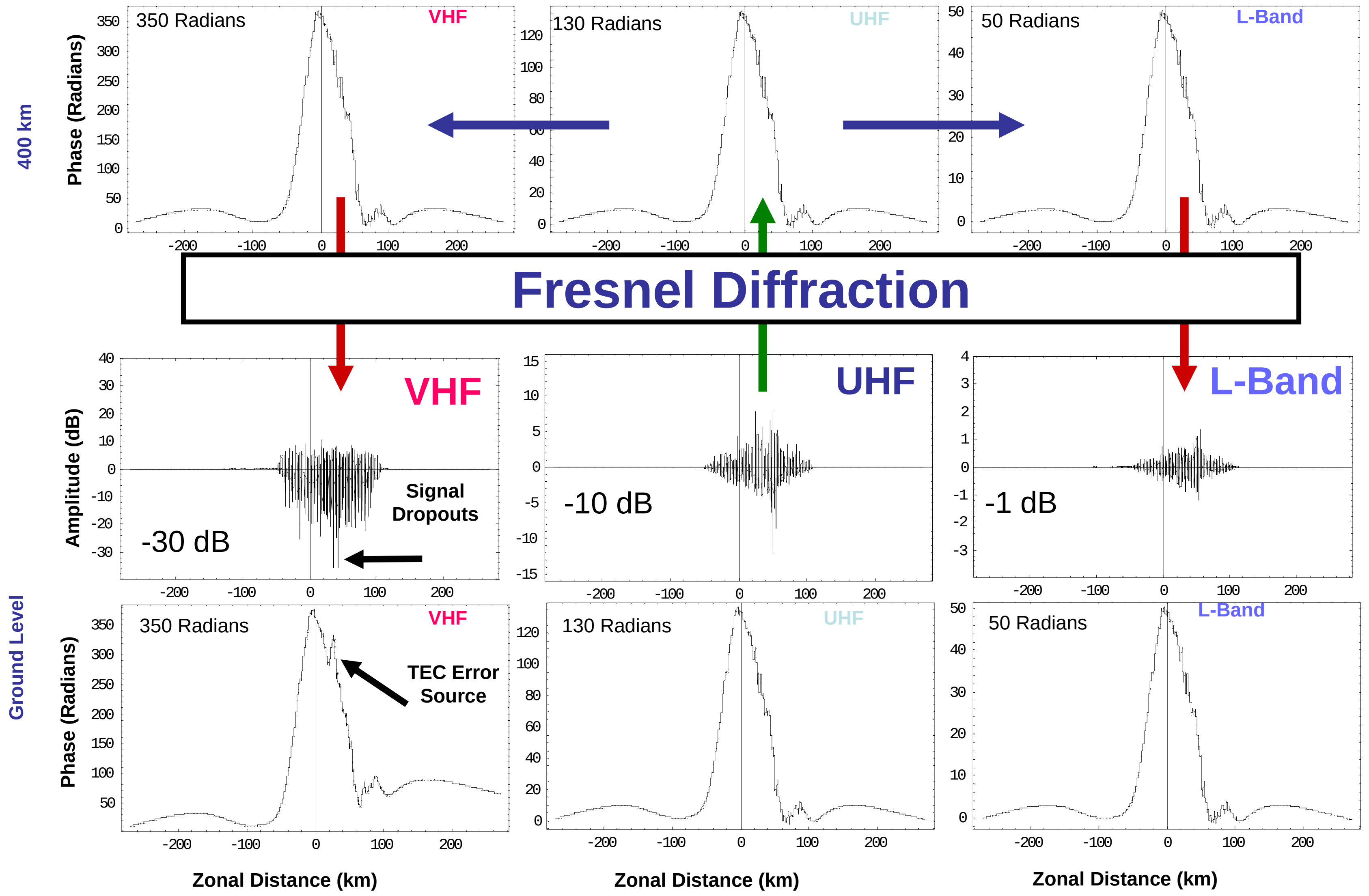
Ionospheric Phase Screen: Radio Wavelength λ_k

$$\phi(x) = \frac{-2\pi(40.3)\int_S n_e ds}{c^2/\lambda_k}$$

Formulation for Both Forward and Inverse Diffraction Calculations

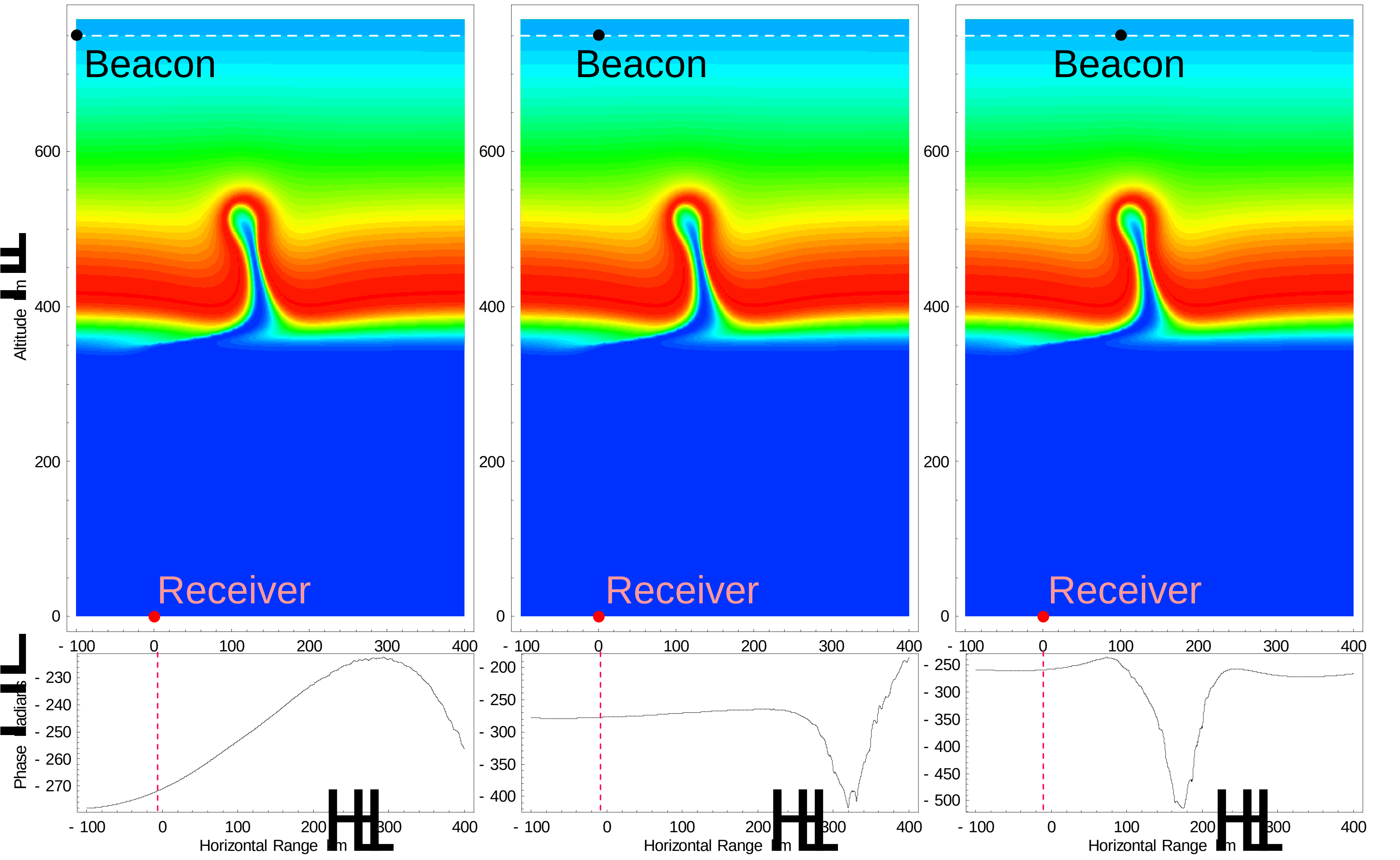
Scintillation Prediction from Single Frequency Measurements

Scintillation Screen Estimation

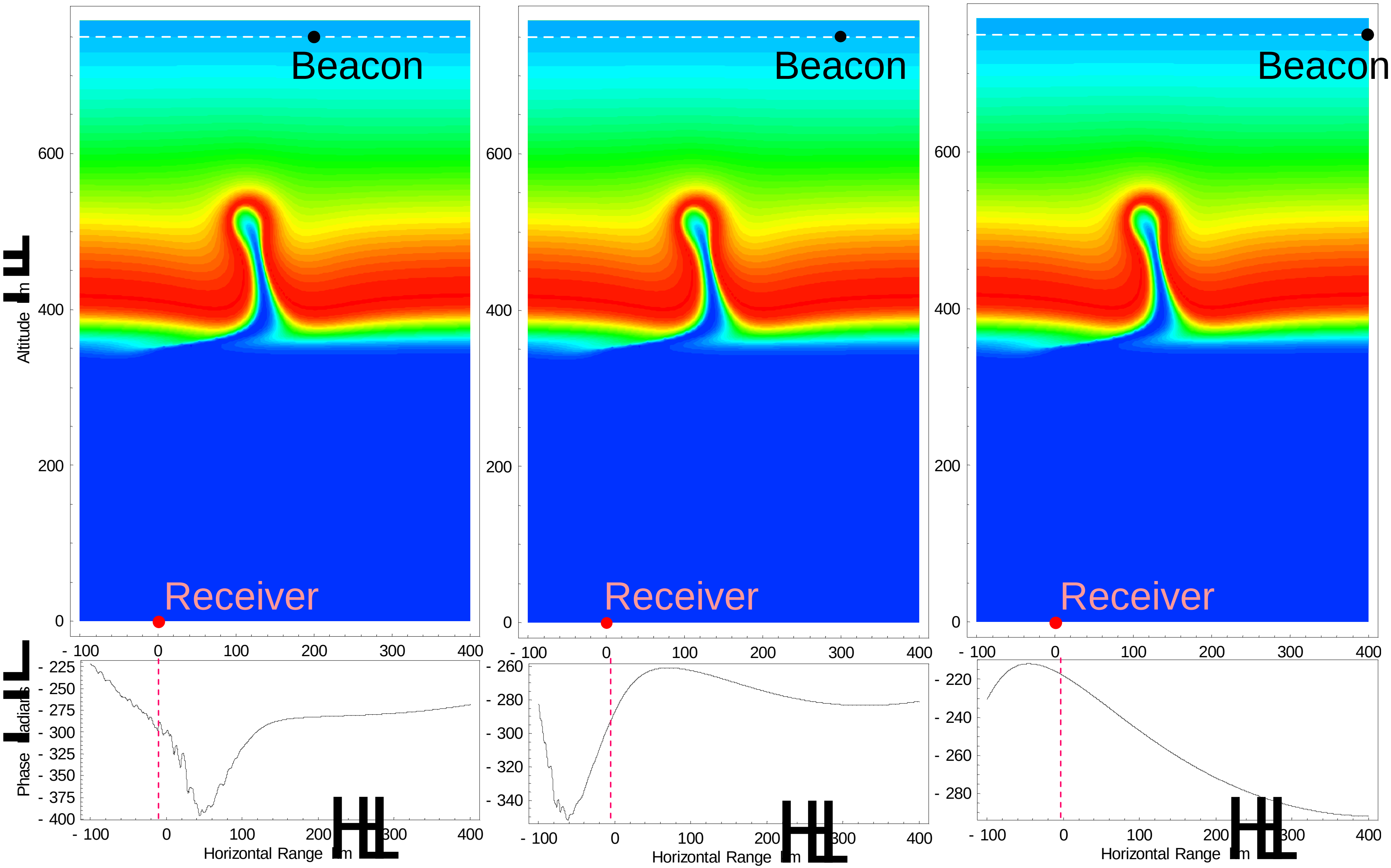


Prediction Measurement Prediction

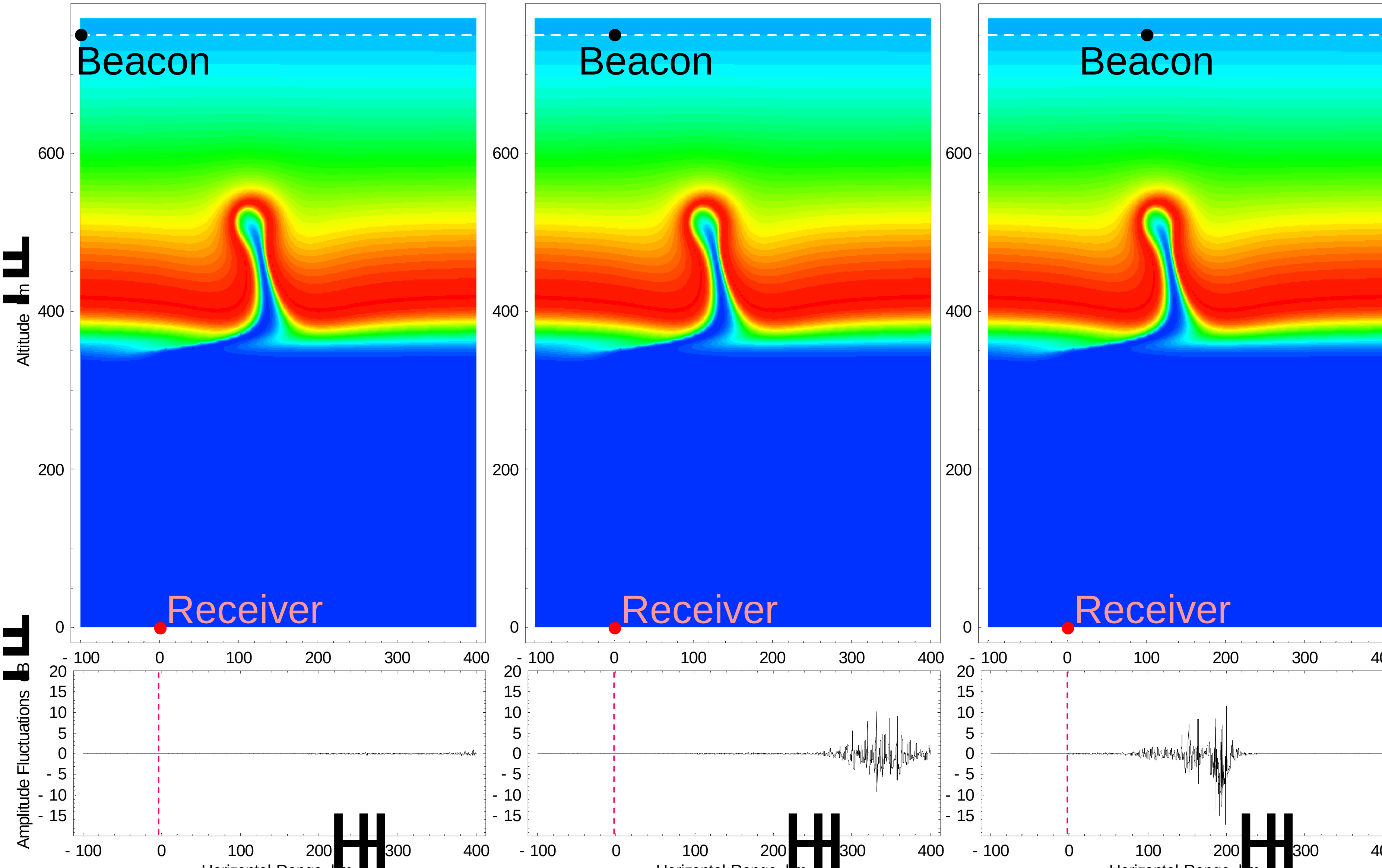
400 MHz Phase Projected from Satellite Beacon to the Ground



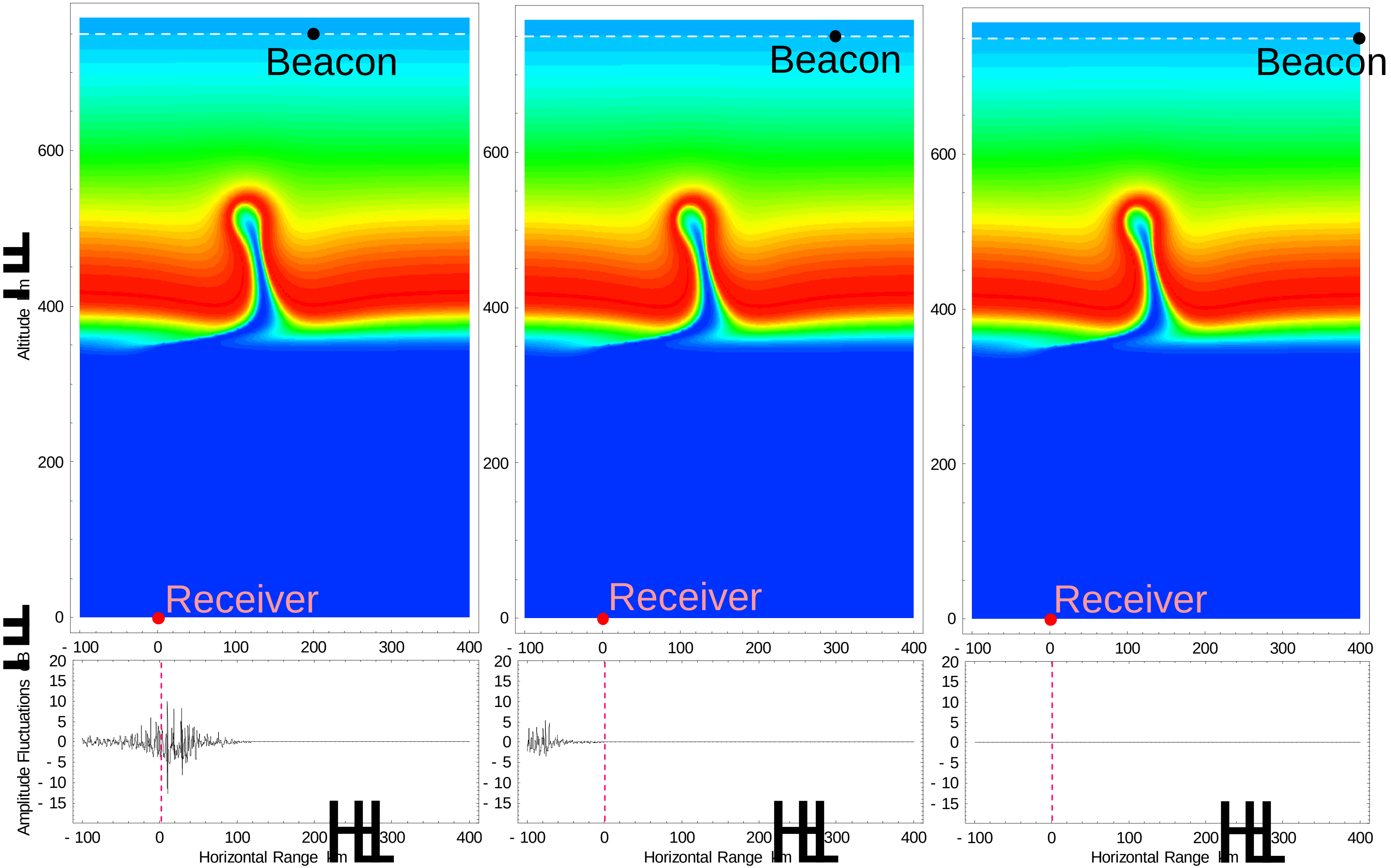
400 MHz Phase Projected from Satellite Beacon to the Ground



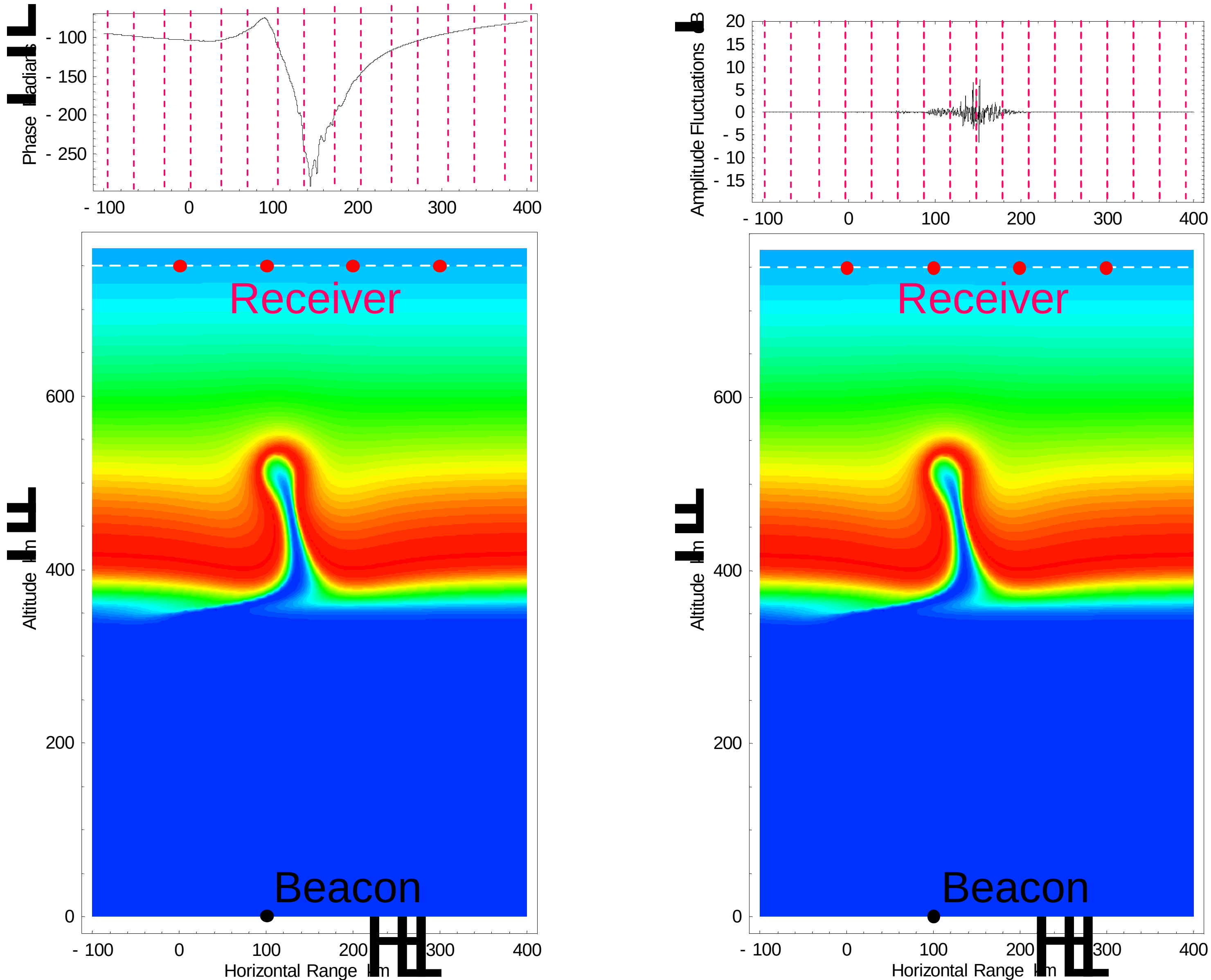
400 MHz Amplitude Scintillations Projected from Satellite Beacon to the Ground



400 MHz Amplitude Scintillations Projected from Satellite Beacon to the Ground



400 MHz Phase and Amplitude at Satellite Receiver from Ground Beacon

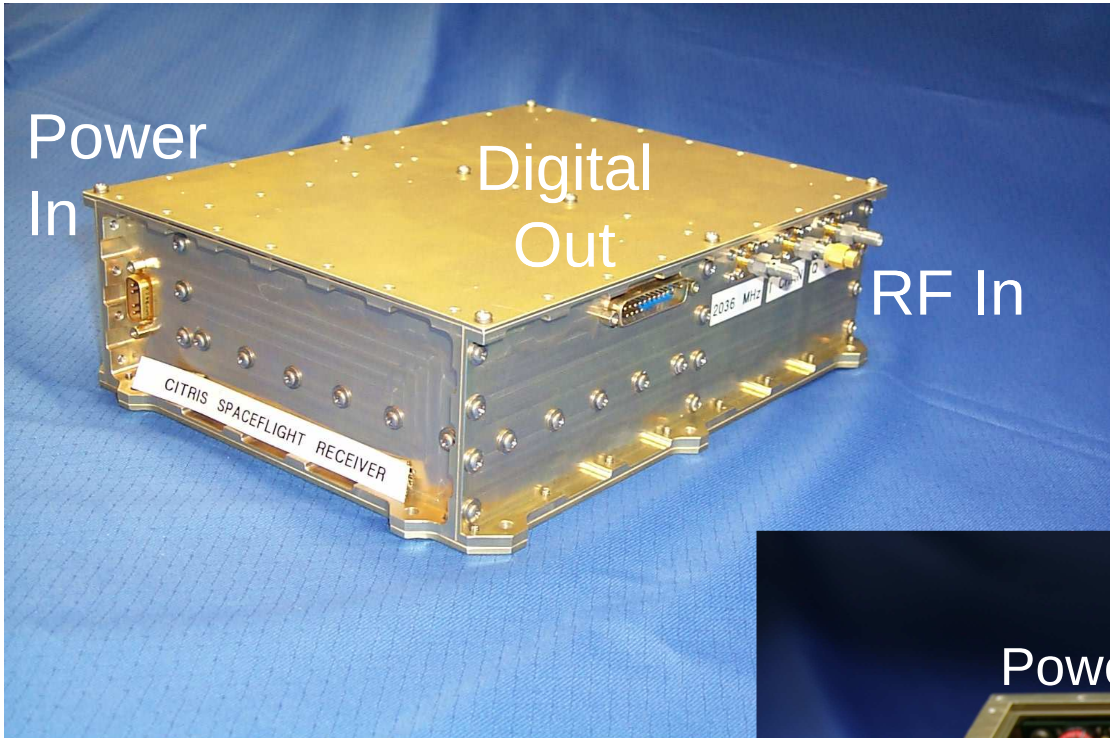


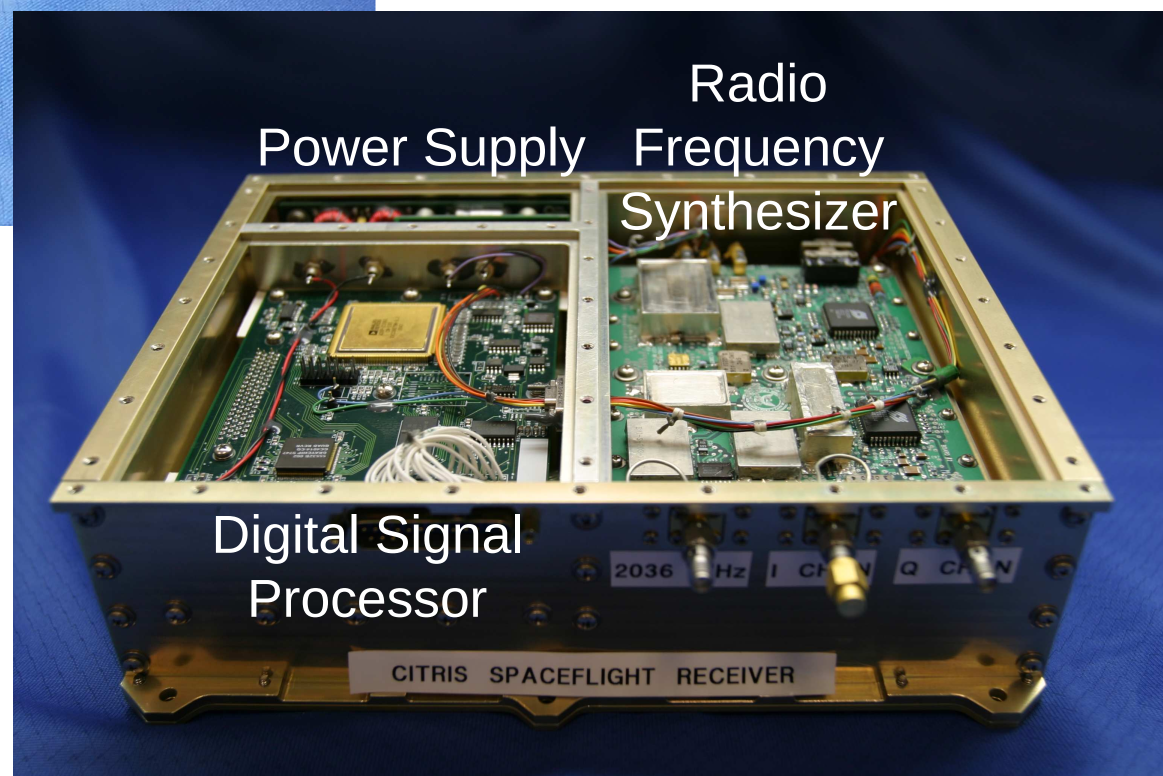
CITRIS Host Satellite: STPSAT1

sCintillation and Tomography Receiver in Space (CITRIS) Summary

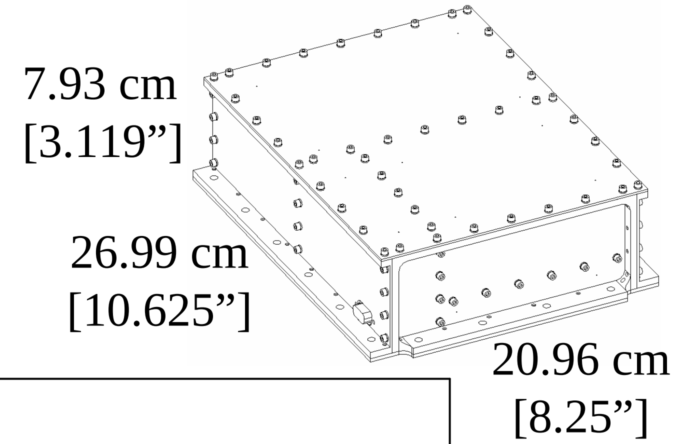
- CITRIS Receiver will Provide Global Ionospheric Measurements
  - Ground DORIS Beacons (401.25 and 2036.25 MHz)
    - 200 Samples Per Second
    - Ground Doppler Predictions Uploaded to Receiver Every 2 or 3 Days
  - Measurements of Either DORIS or CERTO (150.012, 400.032, and 1067.752 MHz) Frequencies
  - Occultation Measurements with CITRIS on STPSAT1 Receiving the CERTO Beacon on NPSAT1
- Status
  - CITRIS Instrument Assembly Complete
  - Integration and Test of CITRIS Finished March 2006
  - STPSAT1 Launch Scheduled November 2006
  - Operations: Data Acquisition Either 40 Minutes per Day or Continuous for 48 Hours Four Times Per Year

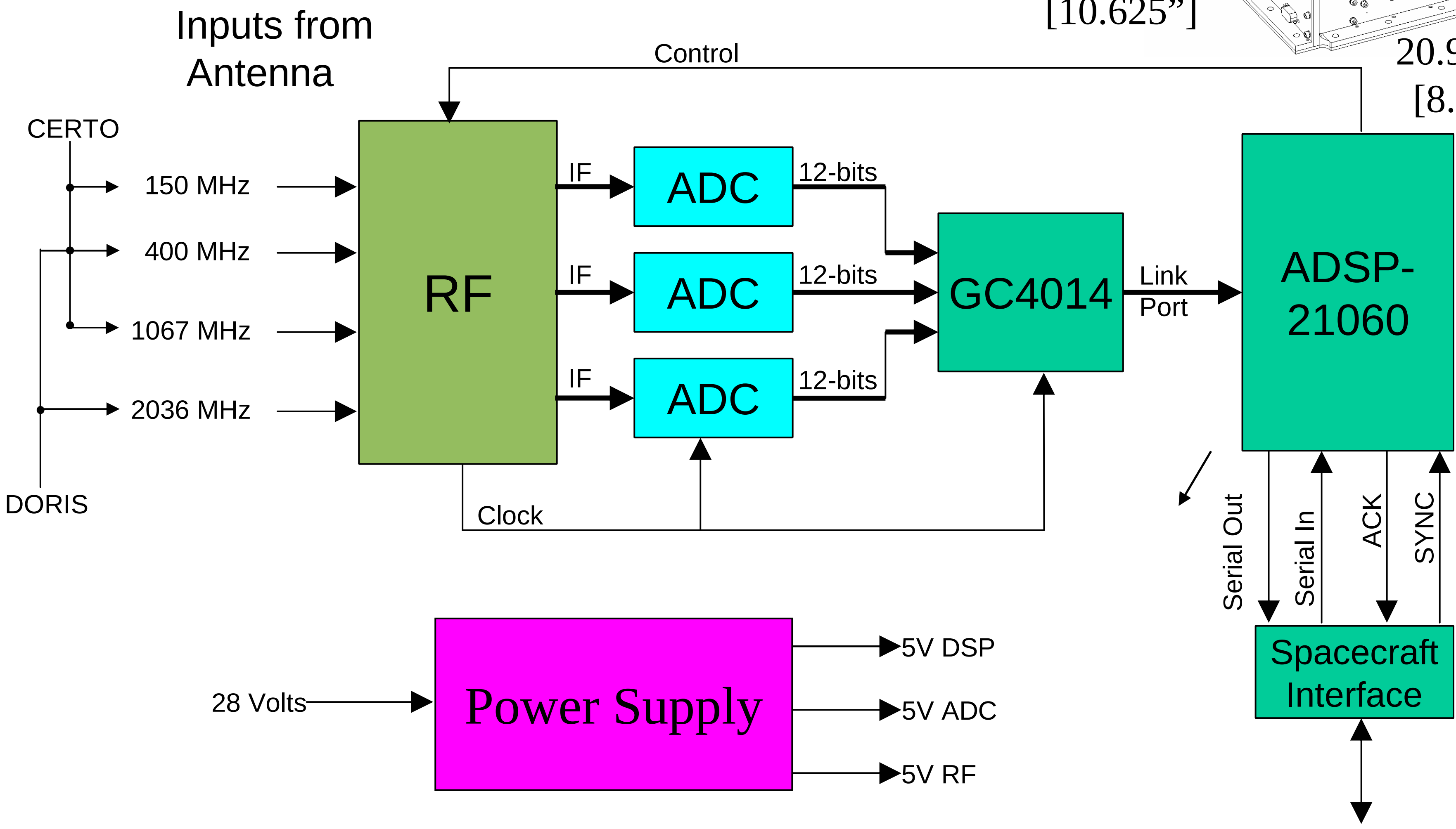
CITRIS Flight Receiver



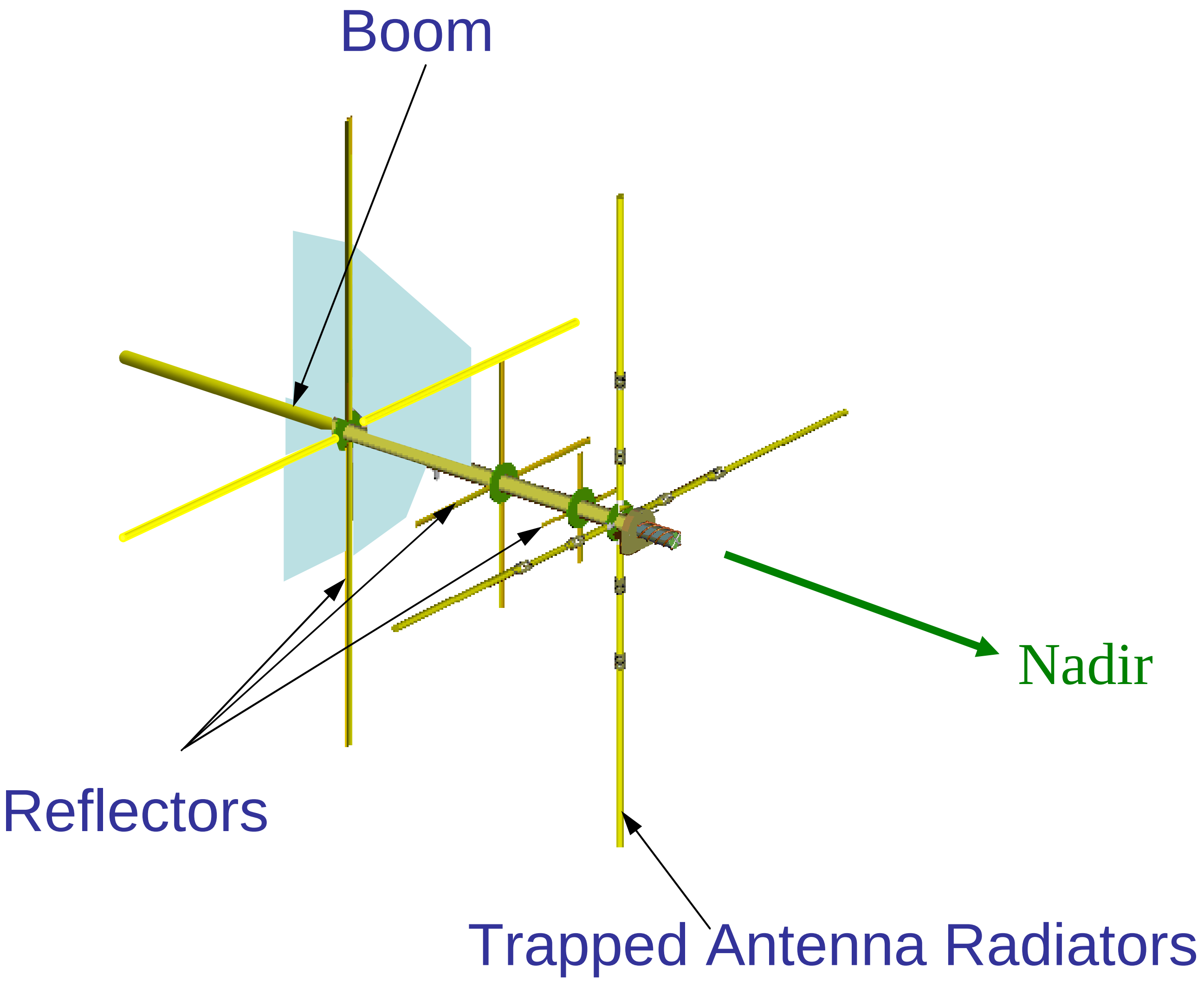


CITRIS Receiver





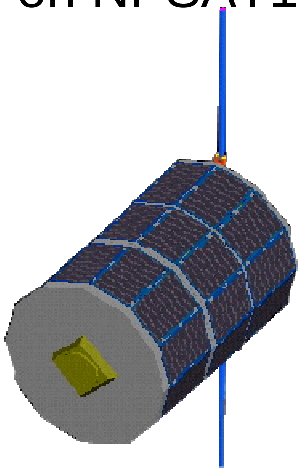
CITRIS Receiver Antenna



CITRIS Antenna Deployment on STPSAT1

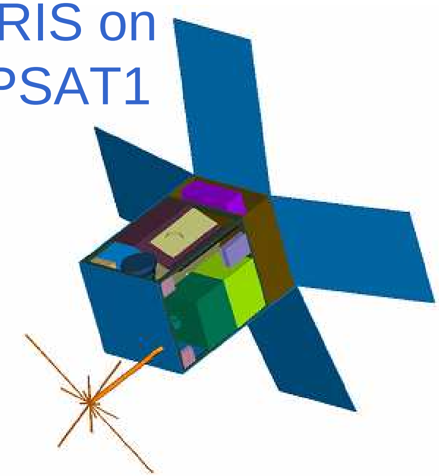
Scintillation and Ionospheric Tomography Radio Instrument in Space (CITRIS):
Space Based Monitor of DORIS Ground Beacons or Tandem Operations of NPSAT1 and STPSAT1

CERTO/LP
on NPSAT1



RF Link

CITRIS on
STPSAT1



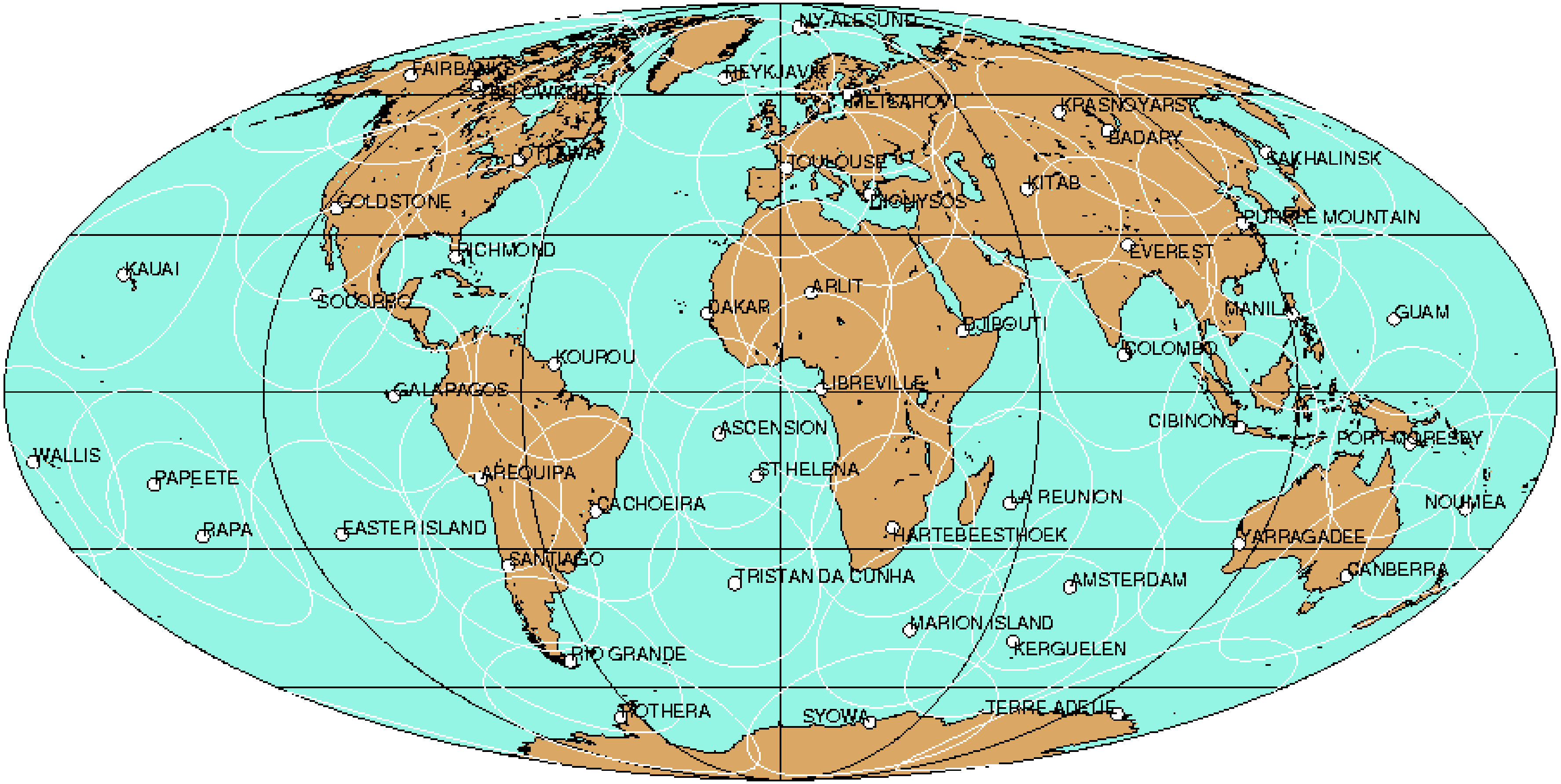
RF Link

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: - 70º to + 80º

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

UHF and L-Band Scintillations

Summary

- Orbiting Beacons and Ground Receivers Provide Sparse Samples of Radio Diffraction Patterns
  - Each Pattern Represents Beacon Position and Propagation Direction to Ground Receiver
  - Reconstruction of a Single Phase Screen is not Possible
- An Orbiting Receiver Fully Samples Phase and Amplitudes from Ground Beacon
  - Single Pattern that is Uniform Along Magnetic Meridian
  - Reconstruction of Phase Screen by Inverse Diffraction
  - Scintillations at Any Frequency Determined from Propagation Through the Reconstructed Phase Screen
- Scintillation Now-Casting Algorithm to be Tested Using CITRIS Data form DORIS Beacons
  - Scintillation and Tomography Receiver in Space (CITRIS)
  - Ground DORIS Beacons at 401.25 and 2036.25 MHz
  - Validation with CERTO and GPS Beacons
- CITRIS Flown on Air Forced Space Test Program STPSAT1
  - November 2006 Launch
  - 35° Inclination at 560 km Altitude

Items Requested from IDS by CITRIS

- DORIS Beacon Transmissions
  - Format of 0.8 Second Identification Repeated Every 10 Seconds
  - Start Time of Identification in UTC
  - Accuracy of Start Time for Identification
- Location and Frequency of Shifted DORIS Beacons
- Point of Contact for Engineering Questions

CITRIS Collaboration with IDS

- CITRIS Data from DORIS Beacons
  - Ionospheric TEC and Scintillations at 200 Samples/Second
  - Corrected Doppler for POD
- Host Additional DORIS Beacons to Support CITRIS
  - Kwajalein, Marshall Islands
  - Others
- Science Sharing on the Ionosphere and POD Data