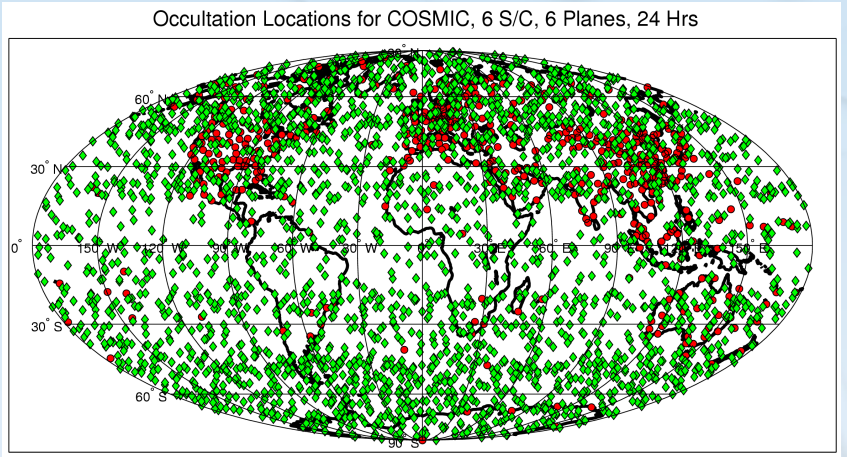
COSMIC-2: Satellite Constellation for Space Weather and Ionospheric Studies

Bill Schreiner and UCAR/COSMIC Team
UCAR COSMIC Program

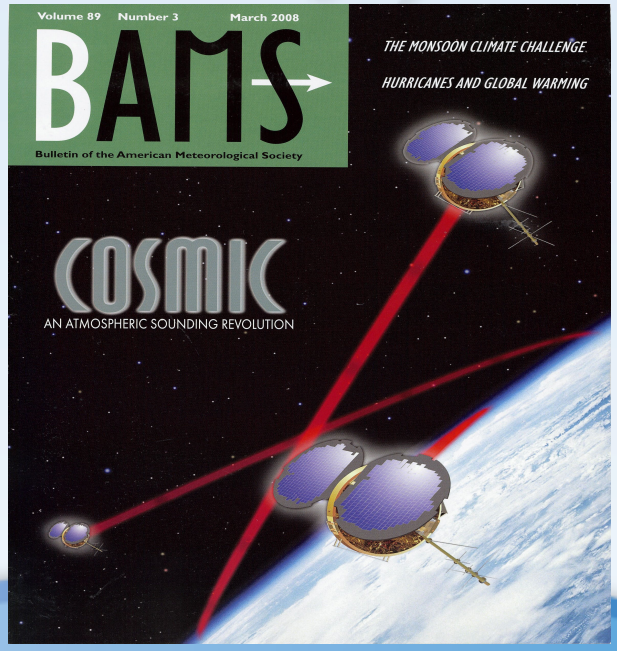
Acknowledgements: NOAA, USAF, NSPO, JPL, UTD, SRI, UCAR, AFRL, Aerospace Corporation

CEDAR Meeting
June 27, 2018

COSMIC (Constellation Observing System for Meteorology, Ionosphere and Climate)



- US/Taiwan Collaboration
- 6 Satellites launched in April 2006
- Three instruments:
  - GPS receiver, TIP, Tri-band beacon
- Weather + Space Weather data
- Global observations of:
  - Bending angle, Refractivity
  - Pressure, Temperature, Humidity
  - Ionospheric Total Electron Content (TEC) and Electron Density
  - Ionospheric Scintillation
- Demonstrate quasi-operational GPS sounding with global coverage in near-real time



BAMS, March 2008

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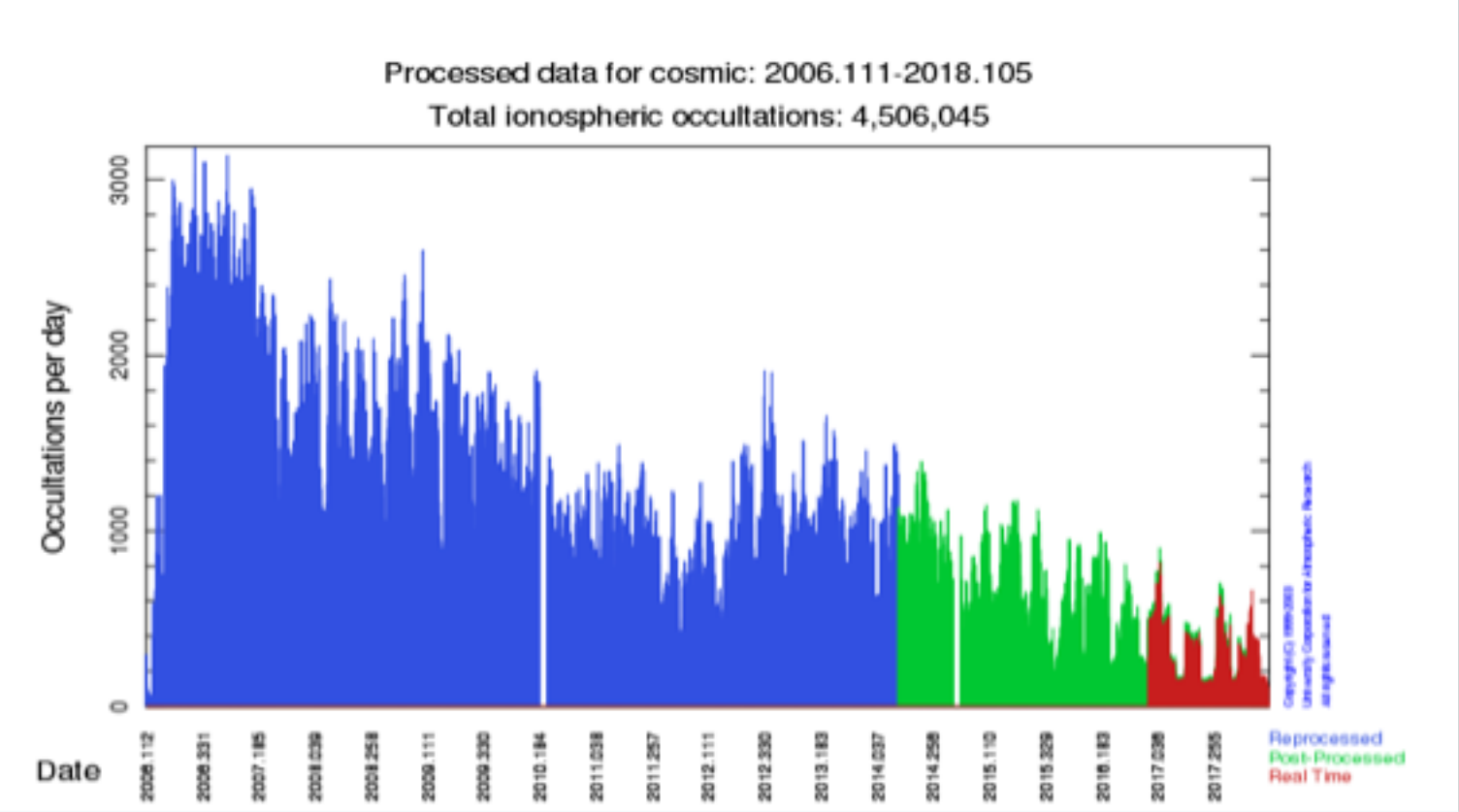
Scientific Uses of Radio Occultation Data

- **Weather**
  - Improve global weather analyses, particularly over data void regions such as the oceans, tropics, and polar regions
  - Improve skill of numerical weather forecasts, including hurricanes
  - Improve understanding of tropical, mid-latitude and polar weather systems and their interactions
- **Ionosphere and Space Weather**
  - Observe global electronic density distribution
  - Improve the analysis and prediction of space weather
  - Improve monitoring/prediction of scintillation (e.g. equatorial plasma bubbles, sporadic E clouds)
- **Climate**
  - Monitor climate change and variability with unprecedented accuracy - **world's most accurate, precise, and stable thermometer from space!**
  - Evaluate global climate models and analyses
  - Calibrate infrared and microwave sensors and retrieval algorithms

> 4.5 Million COSMIC Ionospheric Profiles

4/21/06 – 4/15/2018



COSMIC: Two of six still operating ten years after launch (design life: 2-3 yr)

COSMIC continues to provide up to 1,000 GPS Ionospheric RO soundings per day

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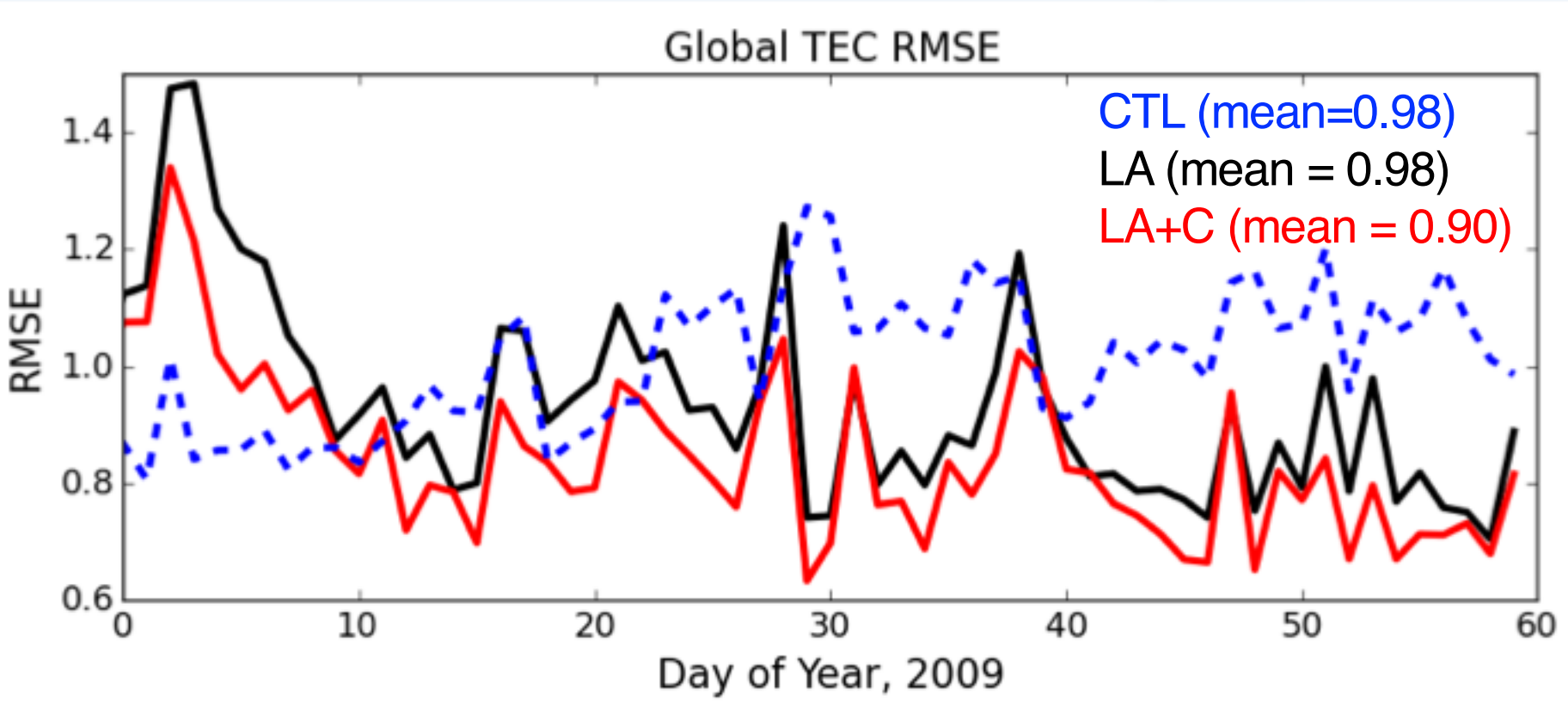
Impact of COSMIC Observations on Ionosphere Specification

WACCMX+DART OSSE



Courtesy:
Nick Pedatella
HAO

Assimilation of COSMIC observations leads to ~10% reduction in TEC error

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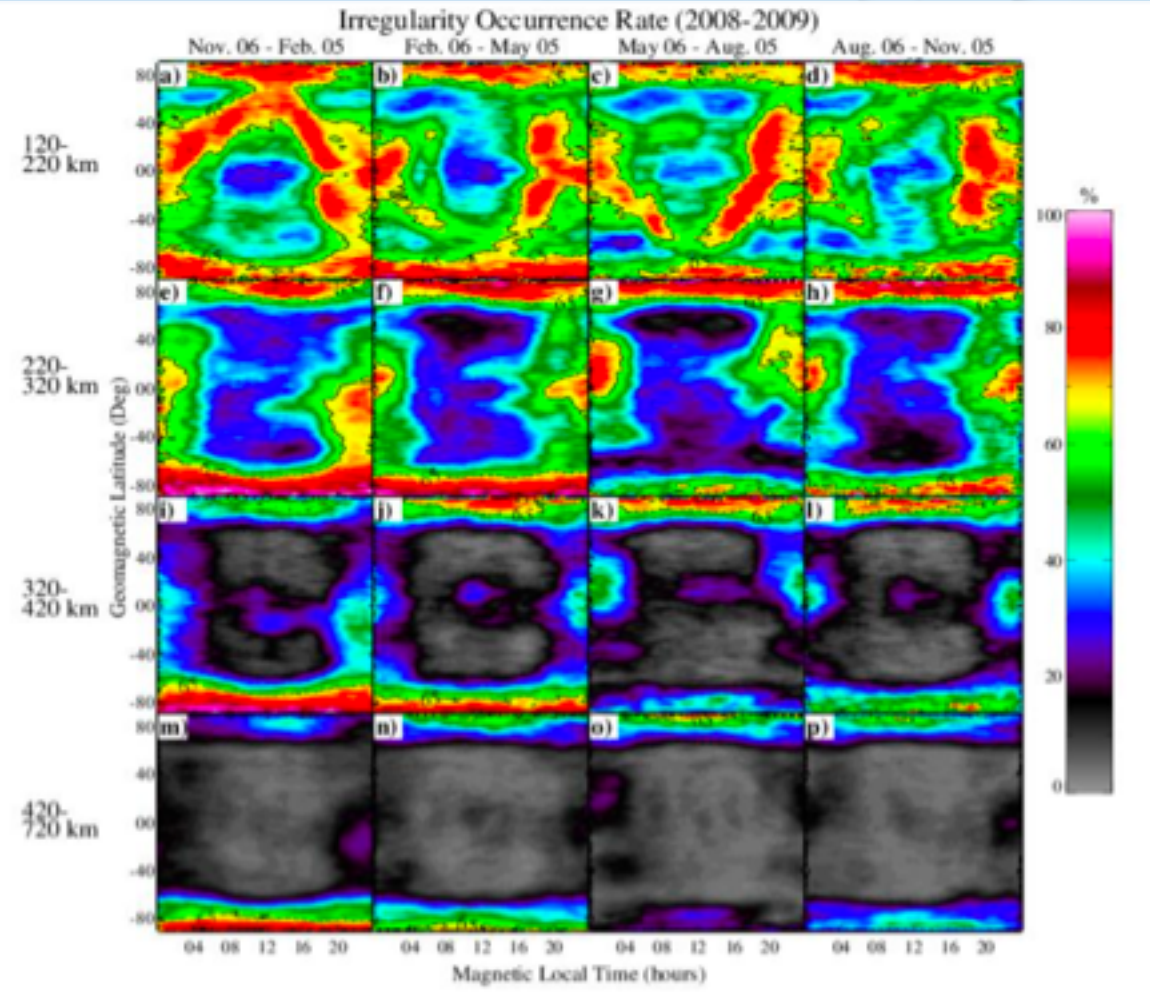
Climatology and Characteristics of Medium-Scale F-region Ionospheric Plasma Irregularities

- COSMIC TEC data used to study medium-scale (~2-50km) ionospheric irregularity occurrence rate
- Observations show more medium-scale irregularities near the terminators, suggesting that solar terminator waves lead to these irregularities

Watson and Pedatella, Submitted to JGR, 2018



Irregularity occurrence rate plotted in magnetic local time (MLT) and latitude (MLAT) for 2008-2009, organized according to season (horizontally) and tangent point altitude (vertically). Contours at 65% are highlighted by black lines.

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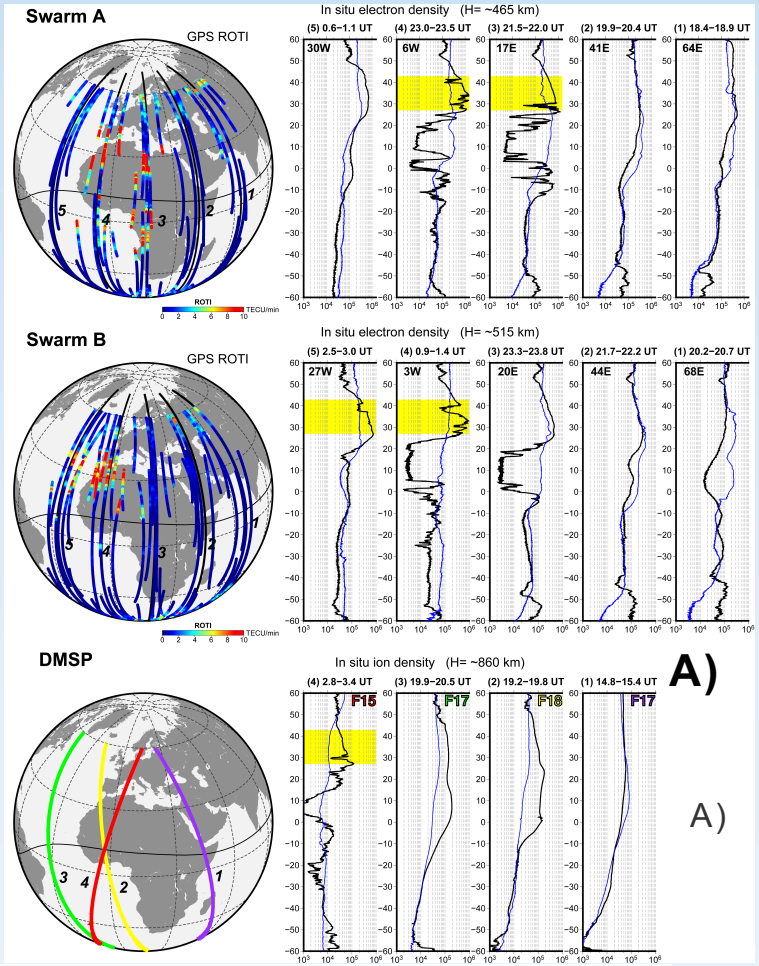
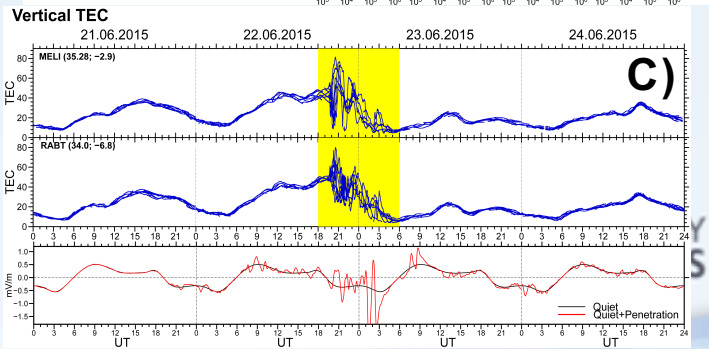
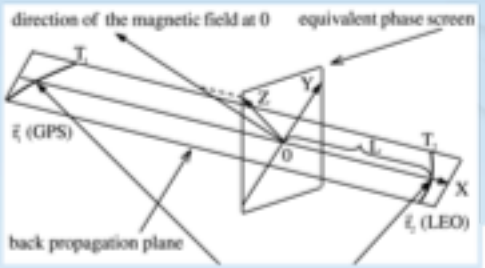
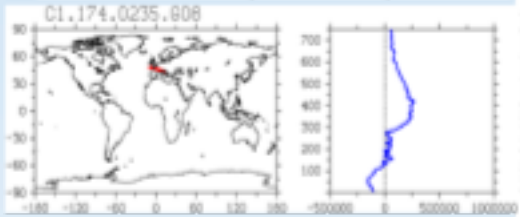
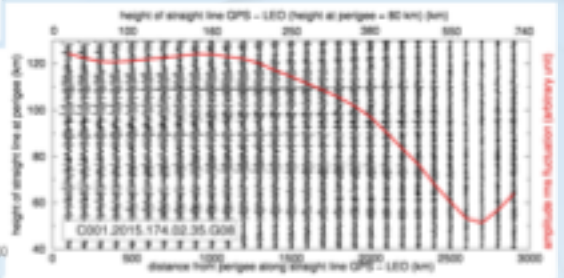
Storm-induced ionospheric irregularities at mid-latitudes

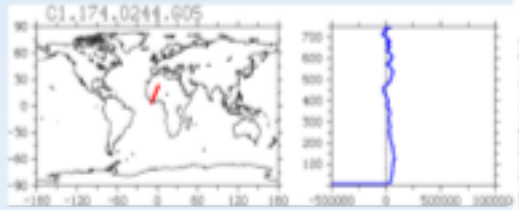


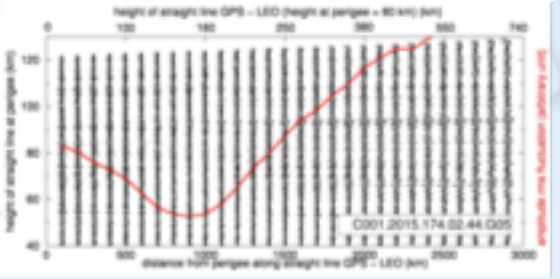












A) Swarm and DMSP satellites encountered a wide density depletion near the equator, as low as 1.5–2 orders of magnitude lower than normal quiet-time Ne distribution. Topside Ne enhancements extended farther poleward from the equatorial region. Equatorial plasma bubbles (EPB) occurred inside this density enhancement from ~30N to > 40N over Europe.

B) COSMIC RO back propagation analysis confirms ionospheric irregularities are localized near F2 layer peak and above 600 km.

C) The high-rate GNSS measurements demonstrates signatures of highly structured plasma with strong and sharp depletions associated with the plasma bubbles.

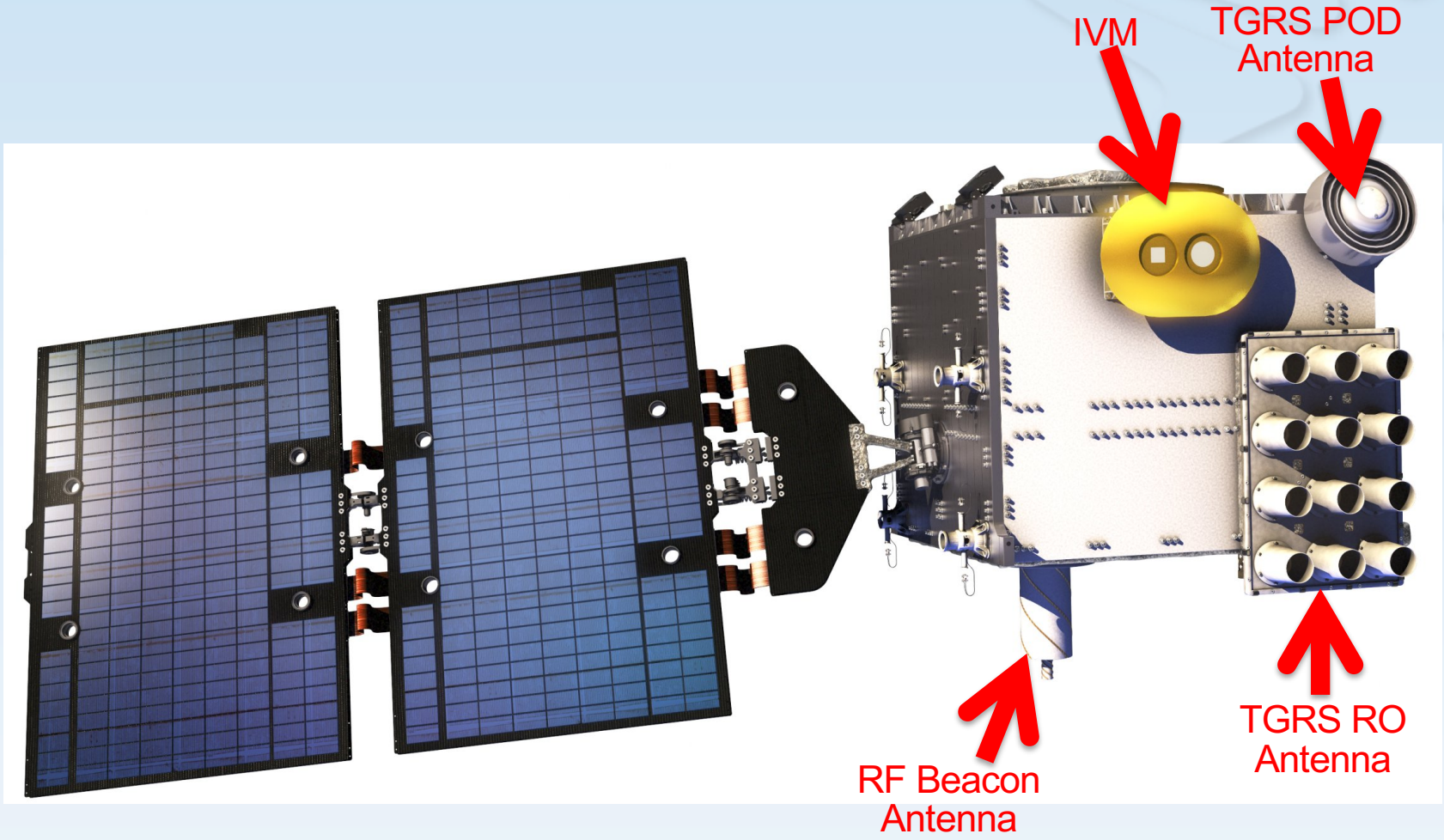
Courtesy: Iurii Cherniak

The COSMIC-2/FORMOSAT-7 Partnership

Organization	Responsibilities
Taiwan NSPO	• 12 Spacecraft (From SSTL) • Command & control (1 ground site) • Secondary sensors for polar SVs
NOAA	• Lead US agency • COSMIC-2 ground sites • TGRS ground processing • TGRS sensors for polar SVs
USAF	• All sensors for equatorial SVs • Launch • RF Beacon ground system • RF Beacon/IVM ground processing
NASA	• TGRS TriG Electronics Development at JPL

COSMIC-2/FORMOSAT-7 is jointly sponsored by NOAA and NSPO, as designated representatives of AIT and TECRO.

The COSMIC-2 Spacecraft

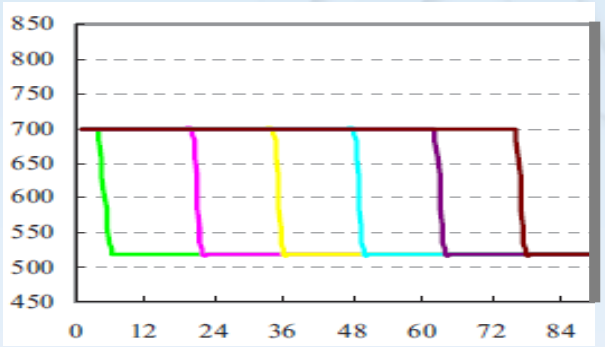


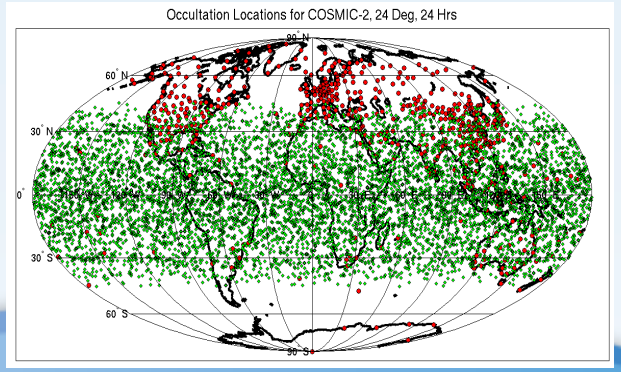
The COSMIC-2 spacecraft are being developed by Surrey Satellite Technologies Limited (SSTL) Under Contract to Taiwan's National Space Organization

Graphic courtesy SSTL

Launch and Deployment

- COSMIC-2 is the co-primary payload on the STP-2 mission
- Falcon Heavy vehicle out of Cape Canaveral
- Initial altitude: 700 km
- Final altitude: 520 km achieved w/ on-board propulsion
- Differential orbit precession separates the orbit planes, resulting in a uniformly spaced constellation (~18 months)
- Current launch date is Oct 30, 2018



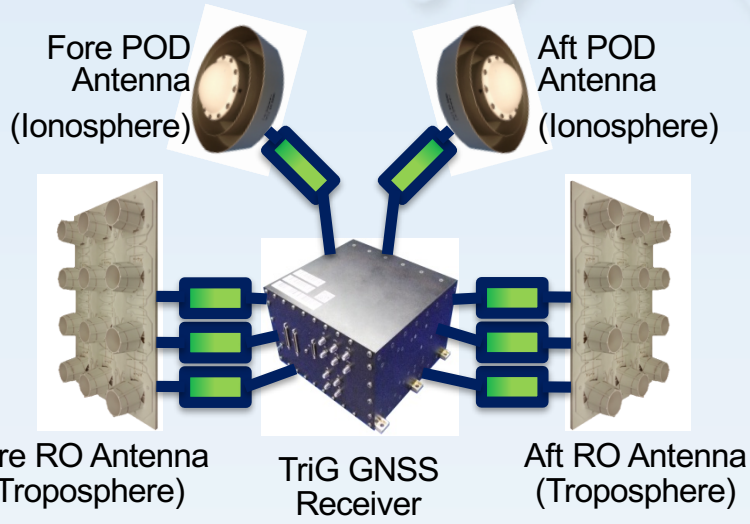


TGRS Description

- **Description**
  - Trig Radio Occultation receiver tracks GNSS signals across Earth's limb
  - TGRS is the primary instrument on COSMIC-2.
  - Provides neutral atmosphere and space weather data for global observational models and science users.
  - Will track GPS and GLONASS signals

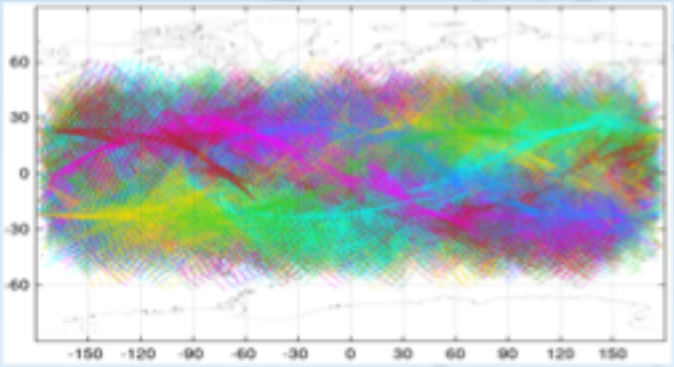
- **TGRS Components**
  - The TGRS instrument contains a single GNSS receiver, two Precise Orbit Determination (POD) antennas, and two Radio Occultation (RO) limb antennas.
  - The two POD antennas will be used to collect ionosphere data.
    - Data above spacecraft altitude is classified as an arc
    - Data from spacecraft altitude to 80 km is classified as an occultation

- **Heritage**
  - Trig receiver designed by JPL.
  - JPL has previously provided blackjack heritage instrumentation on multiple missions (COSMIC, C/NOFS, GRACE, etc)
  - Built by Moog/Broadreach Engineering



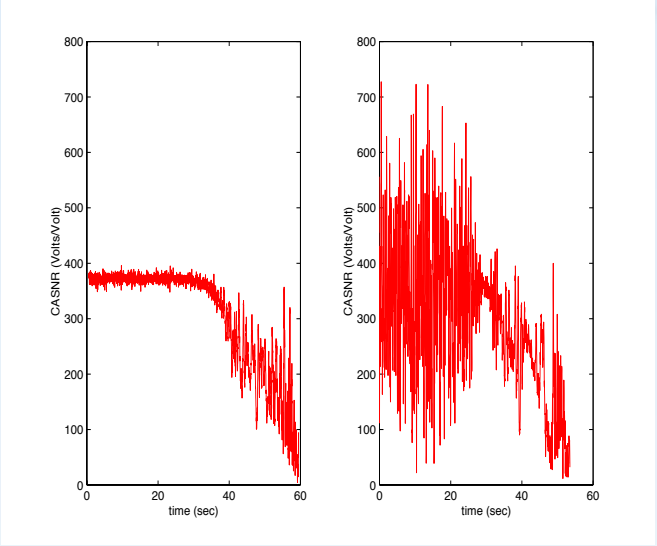
TGRS Space Weather Measurements

- TGRS TEC
  - GPS and GLONASS
  - TEC occultation data will provide data from S/C altitude to 80 km altitude
  - TEC arc data will provide data above S/C altitude
  - TGRS will slightly prioritize occultations over arcs



24-Hour LOS Limb TEC Coverage

- TGRS Scintillation
  - GPS and GLONASS
  - Will collect high rate phase and amplitude data for entire occultation when on-board S4 measurement exceeds a specified threshold.
  - Will allow for detailed investigation of scintillation (S4 and σ_φ)



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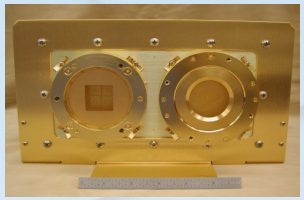
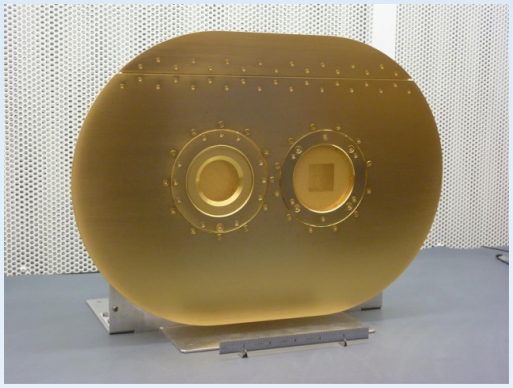
Ion Velocity Meter (IVM) Heritage

- 2-Sensor IVM Heritage
  - Successful deployment of multiple IVM-type instruments
  - Missions include AE, DE, DMSP, ROCSAT, C/NOFS, SSAEM, ICON

ROCSAT IPEI
(1999-2004)



CINDI C/NOFS IVM
(2008-2015)



COSMIC-2 IVM

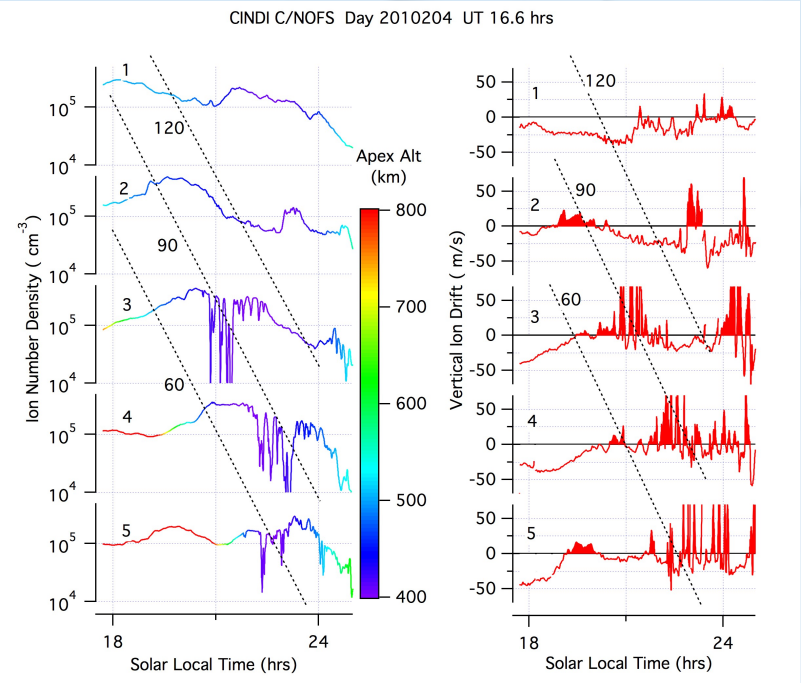
- Long-Duration Mission
- Robust Radiation Tolerant Design
- High Sensitivity
- Low Noise

University of Texas at Dallas
William B. Hanson Center for Space Sciences

Science Team: Rod Heelis, Russell Stoneback
Engineering Team: Mark Mankey, Michael Perdue, Matthew Depew, Zac Morgan, Larry Harmon, Ron Lippincott

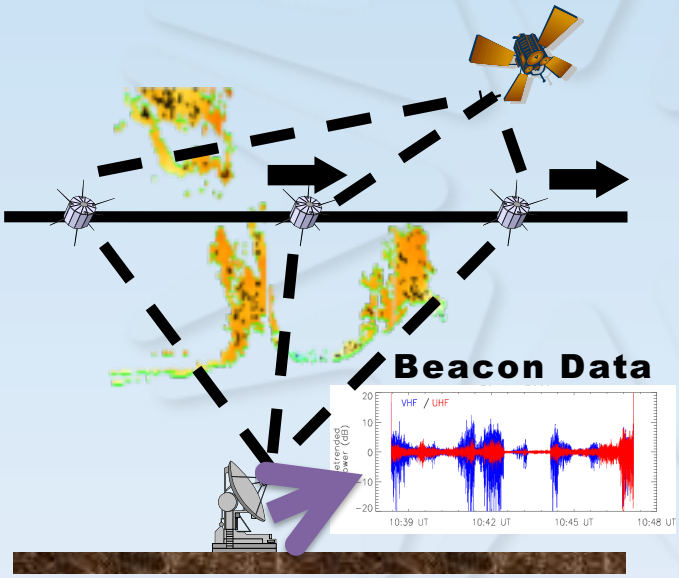
IVM Measurements for Operations

- Provide nighttime and near terminator drifts as input to equatorial scintillation prediction algorithms.
- Provide night/day specification of low latitude (±30° magnetic) plasma drifts as inputs to assimilative models for improvement of ionospheric specification.

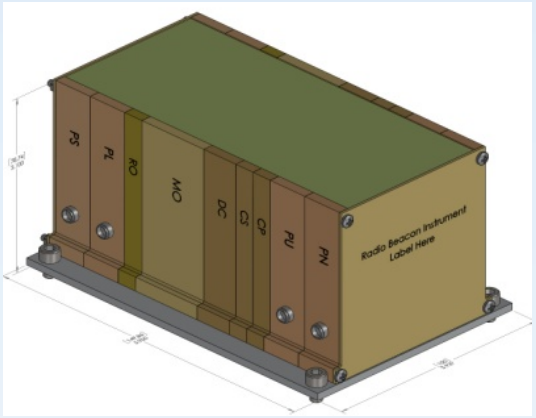


RF Beacon Sensor

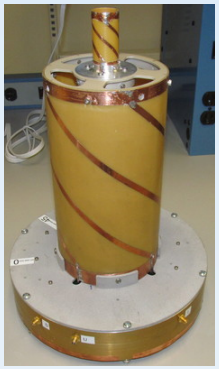
- Ground-based receivers measure RF Beacon signals (amplitude & phase) to determine scintillation environment
  - 400, 965, 2200 MHz signals
- Ancillary two-frequency TEC measurements provide data for ionospheric assimilative models
- Coupling North-South morphology of irregularity regions with East-West geometry of COSMIC-2 (Equatorial) orbit enables better scintillation region mapping (relative to polar orbits)
- Payload team: AFRL, SRI, SMI



Graphic courtesy AFRL



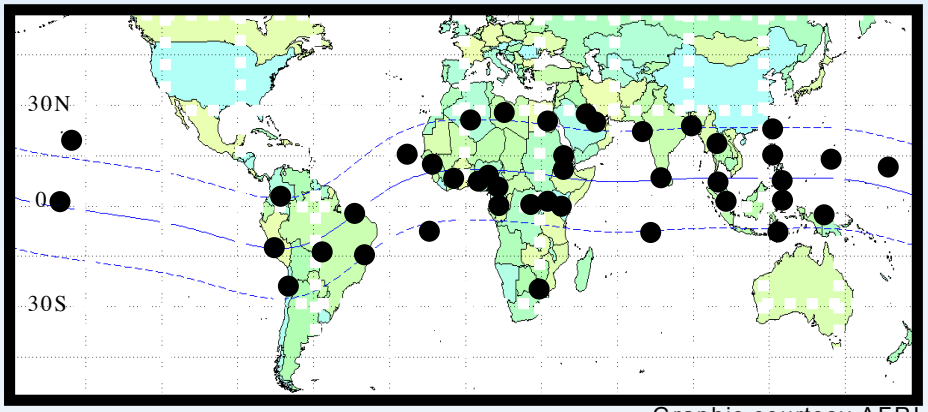
Beacon Electronics Unit



Antenna Unit

RF Beacon drawing/picture courtesy SRI

Potential RF Beacon Ground Sites



Graphic courtesy AFRL

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COSMIC-2 SW Product Requirements

Product	Description	Requirement	Sample Rate
TGRS TEC arcs	# of soundings/overhead arcs/day	1220/COSMIC-2 satellite (before QC)	1Hz
	Absolute TEC	3 TECU	
	Relative TEC	0.3 TECU	
TGRS Scintillation	S4/σ_ϕ measurement	0.1/0.1 radians	10 sec onboard S4 100 Hz (phase and amplitude)
IVM	In-situ ion density	5%	1 Hz
	In-situ Ion temperature	±10 %	1 Hz
	In-track ion drift	±10 m/s	1 Hz
	Cross-track ion drift	±5 m/s	4 Hz
	Constituent Mass Fraction	±5 %	1 Hz
RF Beacon Scintillation	Regional S4/σ_ϕ measurement	0.1/0.1 radians	1 Hz
RF Beacon TEC	Regional relative TEC	0.01 TECU	1 Hz
TGRS & IVM Latency	Median data latency	30 min	

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COSMIC Data Analysis and Archive Center, http://cdaac-www.cosmic.ucar.edu/cdaac/products.html

Summary

- COSMIC-2A is an equatorial mission of six spacecraft that will provide ionospheric sampling across the local day.

- Payload instruments:
  - TGRS (TEC and scintillation)
  - IVM (in-situ ionosphere sampling of ion density, drift, temperature, and mass fraction)
  - RFB (regional TEC and scintillation)

- Equatorial coverage will support research related to large, medium and small scale processes.

- Launch in late 2018

COSMIC Postdoctoral Program

- Support early career scientists with a research interest in GNSS remote sensing
- Appointment term up to two years
- Areas of research
  - Numerical weather prediction
  - Climate
  - Space weather
  - Weather and water
  - GNSS RO retrieval development
  - Emerging GNSS research opportunities, including GNSS reflectometry
- Apply by: July 15, 2018
- POC: John Braun

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