COSMIC-2 Early Orbit Space Weather Data Assessment and Validation Activity

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UCAR, The Aerospace Corporation, The Jet Propulsion Laboratory, Boston College, Air Force Research Laboratory, USAF

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COSMIC-2A Partners

Lead Taiwan Agency
Spacecraft
Command & Control

Lead US Agency
Ground sites
TGRS ground processing

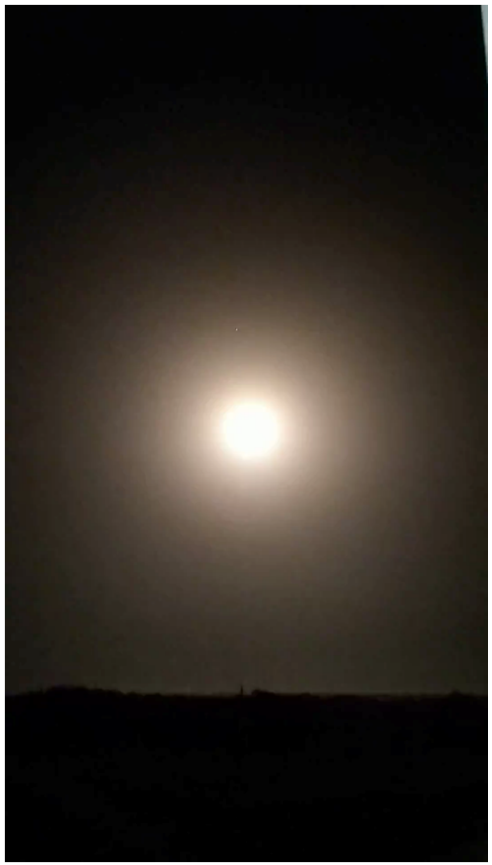
Payloads
Launch
RF Beacon ground system
RF Beacon/IVM ground processing

Payloads: NASA JPL (BRE/MOOG), UTD (BATC), AFRL (SRI, SMI)
Data Processing Center and Mission Operations: UCAR
Science Support: UCAR, Aerospace Corporation, NASA JPL, UTD, AFRL, Boston College

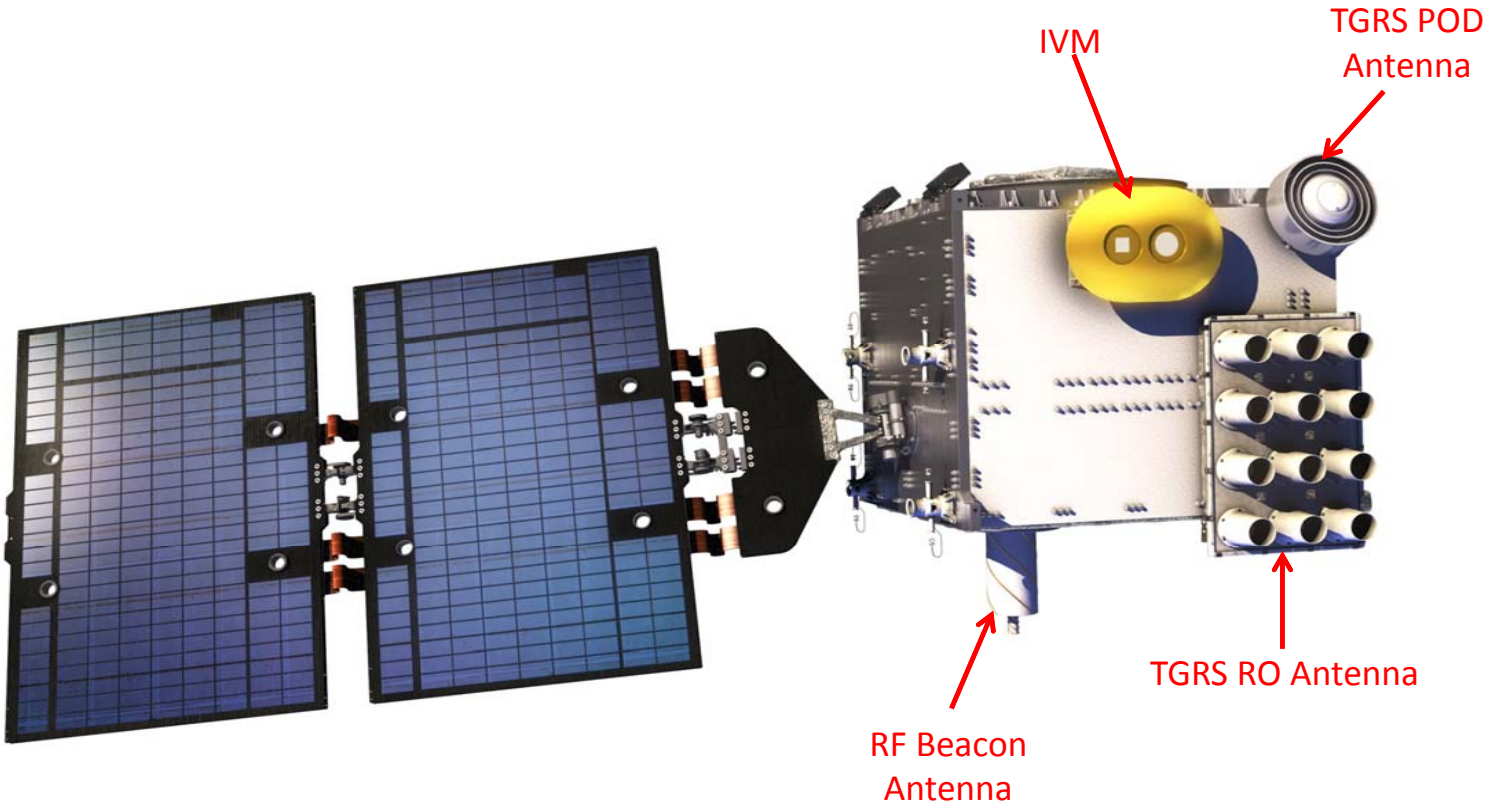
Outline

- Launch + Spacecraft summary
- Space Weather Level 1 requirements
- Instrument summaries
  - TGRS
  - IVM
  - RFB
- Space Weather Cal/Val
  - TEC
  - Scintillation
- Summary

Video courtesy of E. Barlow (now at StSci)



COSMIC-2 Spacecraft



TGRS space weather EDR collected with fore and aft POD antennas

POD antennas mounted at 15 degrees from horizontal

GPS data collected using traditional PLL tracking

GLONASS data collected using "pseudo closed loop" data derived from open loop tracking

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

COSMIC-2 Space Weather 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	$S4/\sigma_\phi$ 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 $S4/\sigma_\phi$ 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	

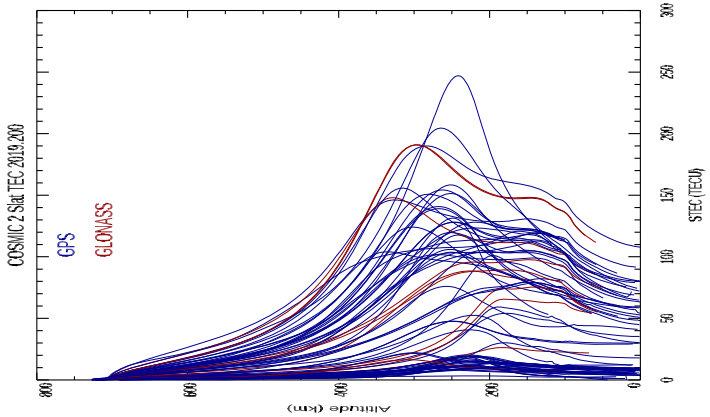
COSMIC-2 has Space Weather Requirements for all three payloads (TGRS, IVM, RFB).

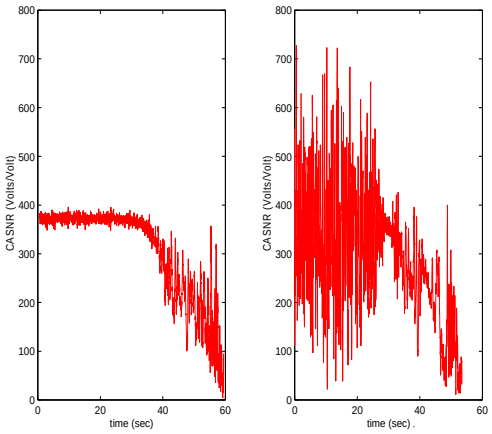
TGRS Space Weather Measurements

- 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

- 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)

- TGRS V4.4 software (end 2019/early 2020) update will improve space weather performance
  - Increase number of ionosphere arcs + occultations
  - Improve high rate scintillation data.



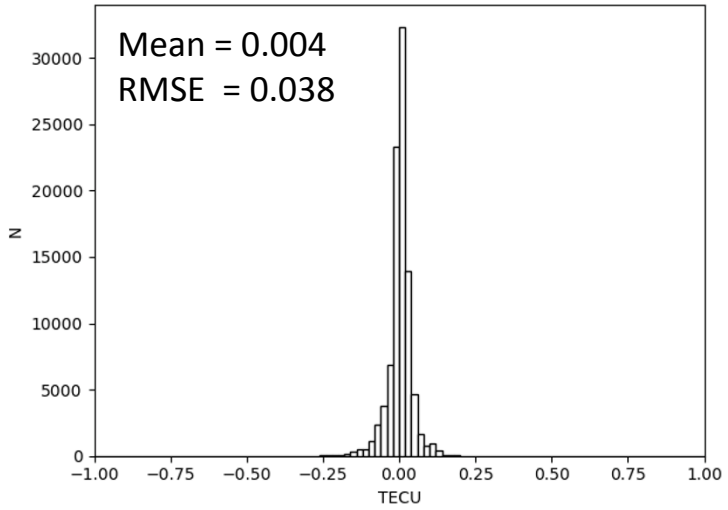


C2 vs C1 Relative GPS TEC Precision from Collocations

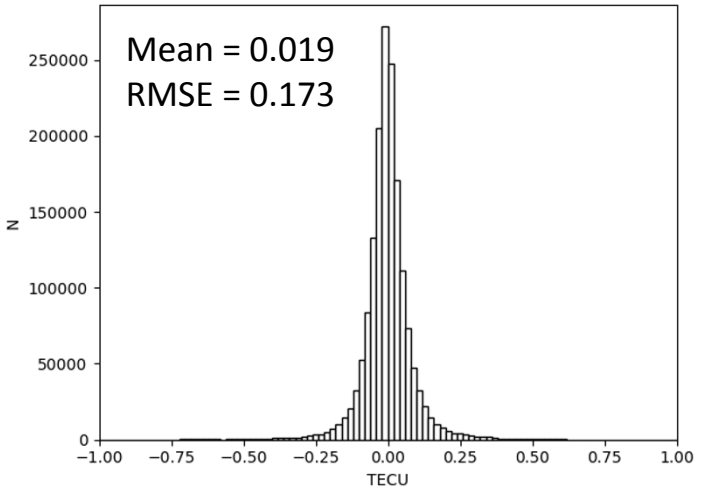
- We use closely collocated observations from two COSMIC-2 satellites from the initial stages of the mission to estimate precision of the LEO relative TEC observations
- We determine the relative TEC by subtracting the TEC value from each arc at the time they initially overlap.
- COSMIC-2 relative TEC arcs are compared for YYYY.DDD days 2019.200-202, and 2019.207-214
- The RMSE for GPS relative TEC for COSMIC-2 pairs is 0.038 TECU. Similar measurement for C1 is 0.173
- Since these numbers are for the difference of two tracks, the average uncertainty for 1 satellite is closer to 0.027 TECU and 0.12 TECU for C-2 and C-1, respectively
- Acknowledgements: Nick Pedatella (UCAR)

Initial relative TEC precision better than COSMIC-1

COSMIC-2 GPS Relative TEC



COSMIC-1 GPS Relative TEC



C2 Relative TEC Precision from Collocations (GLONASS and same LEO)

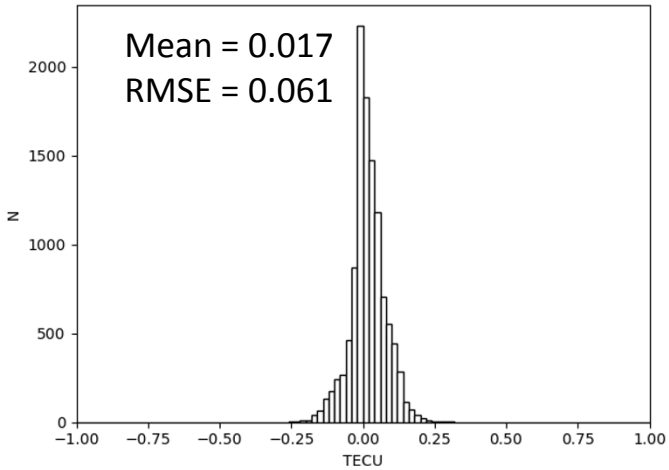
- GLONASS TEC collected using ”quasi-closed loop” tracking.
- RMSE for COSMIC-2 GLONASS pairs is 0.061 TEC. Single satellite uncertainty is 0.044 TEC. (C-2 GPS is 0.027).

GLONASS relative TEC similar to GPS for C2.

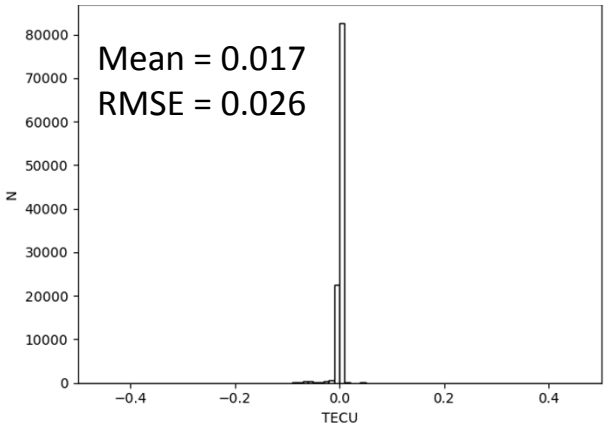
- In early orbit operations, COSMIC-2 satellites occasionally tracked the same GPS satellite from both POD antennas.
- The RMSE for GPS relative TEC for COSMIC-2 pairs observed by same LEO is 0.0264 TEC. Single satellite uncertainty is 0.019 TEC.
- Acknowledgements: Nick Pedatella (UCAR)

GPS TEC from same LEO is below 0.02 TEC (req is 0.3).

COSMIC-2 GLONASS Relative TEC

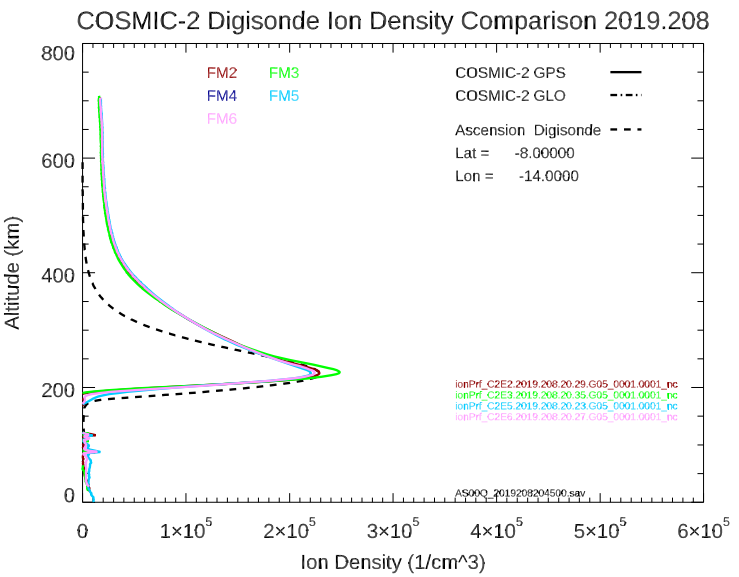


COSMIC-2 GPS Relative TEC, SAME LEO

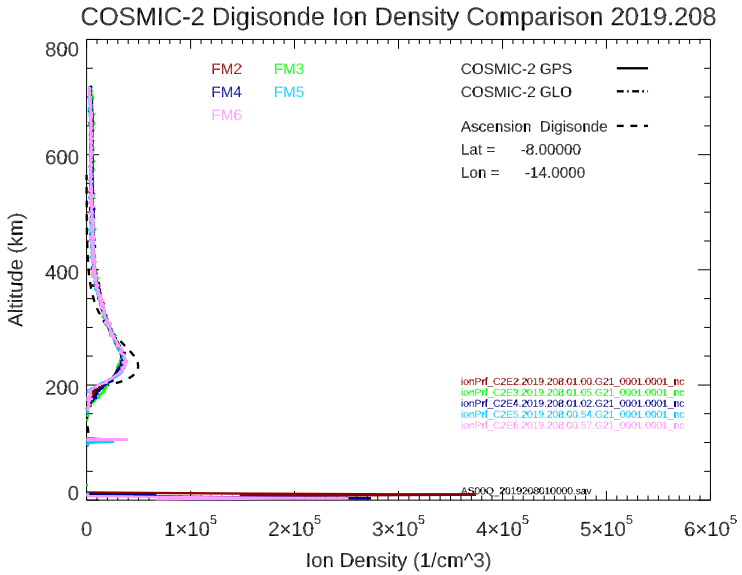


C2 Ion Density Profiles and Digisondes

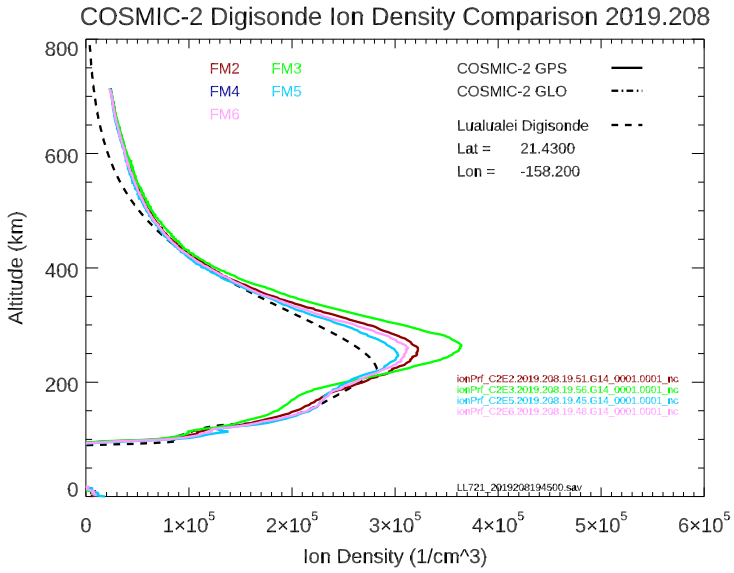
Daytime GPS Over Ascension Island



Nighttime GPS Over Ascension Island



Daytime GPS Over Hawaii



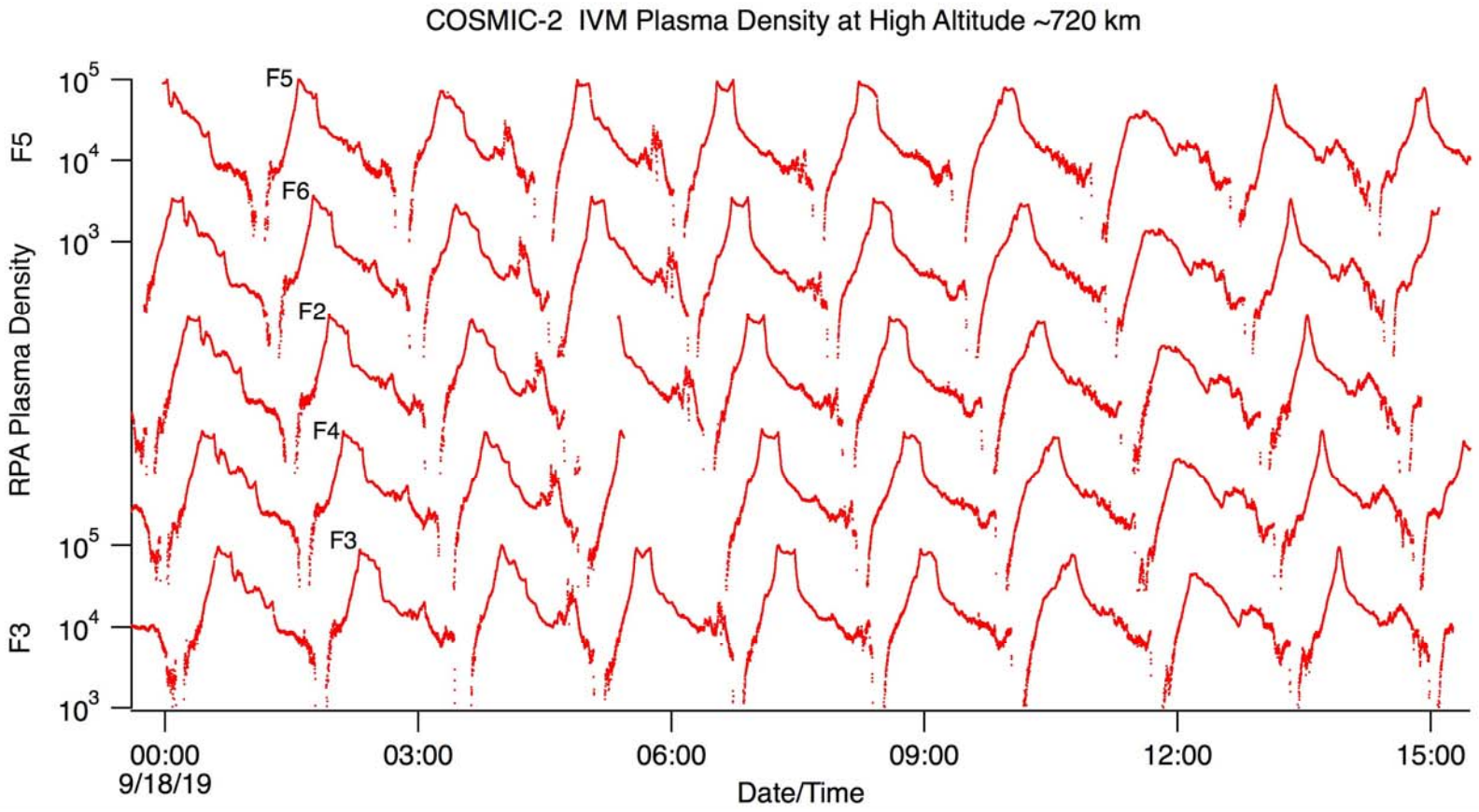
C2 density profiles compare well to Digisondes.
Note: electron density profiles are not part of C2 requirements.

Acknowledgements: Qian Wu, UCAR

W,B. Hanson
Center For Space Sciences

COSMIC-2 Early Orbit IVM Plasma Density

UT DALLAS
School of Natural Sciences and Mathematics

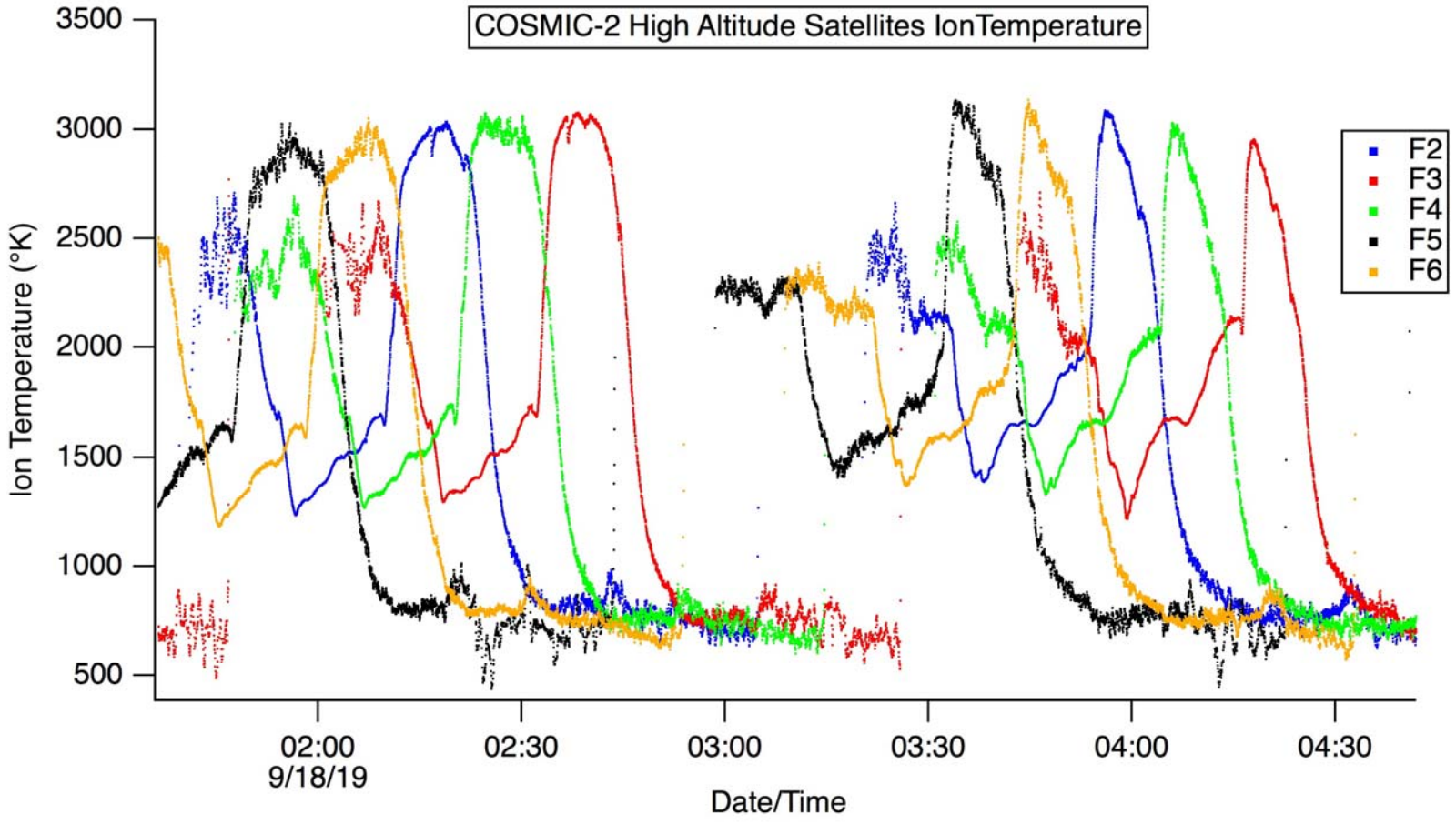


- COSMIC-2 Satellites in ”string of pearls”
- Consecutive satellites show preserved wave forms indicating static structures
- Consecutive orbits show variations in longitude and magnetic latitude
- Acknowledgements: R. Heelis, et al. UTD

W,B. Hanson
Center For Space Sciences

COSMIC-2 Early Orbit IVM Ion Temperature

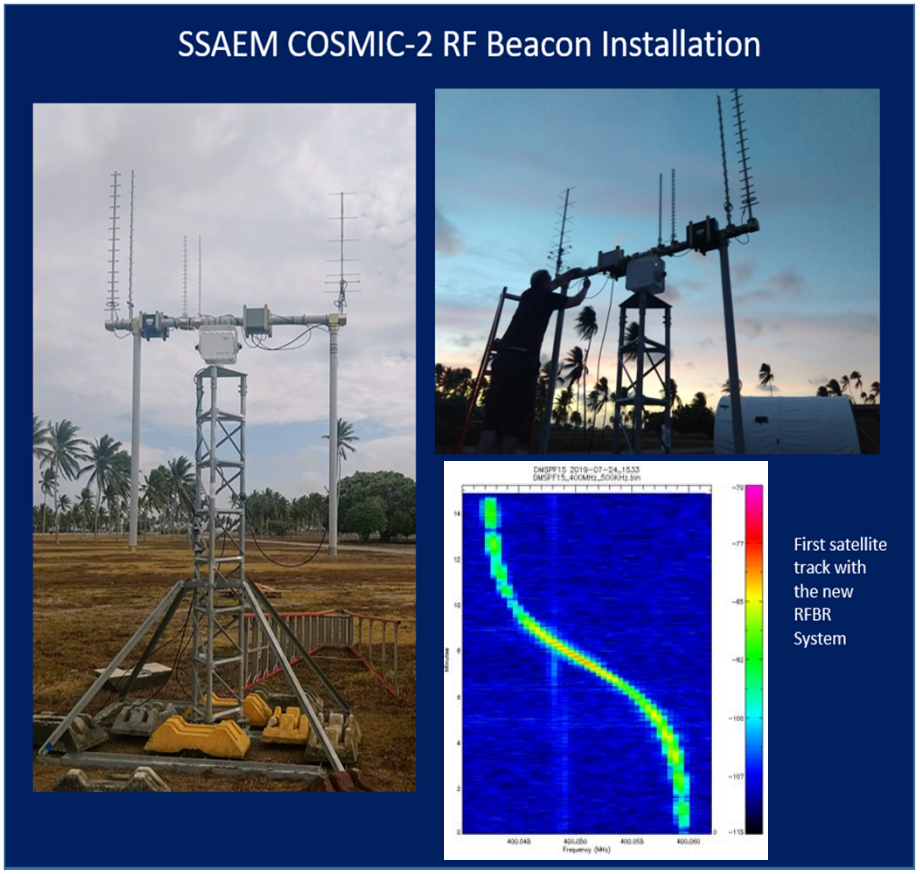
UT DALLAS
School of Natural Sciences and Mathematics



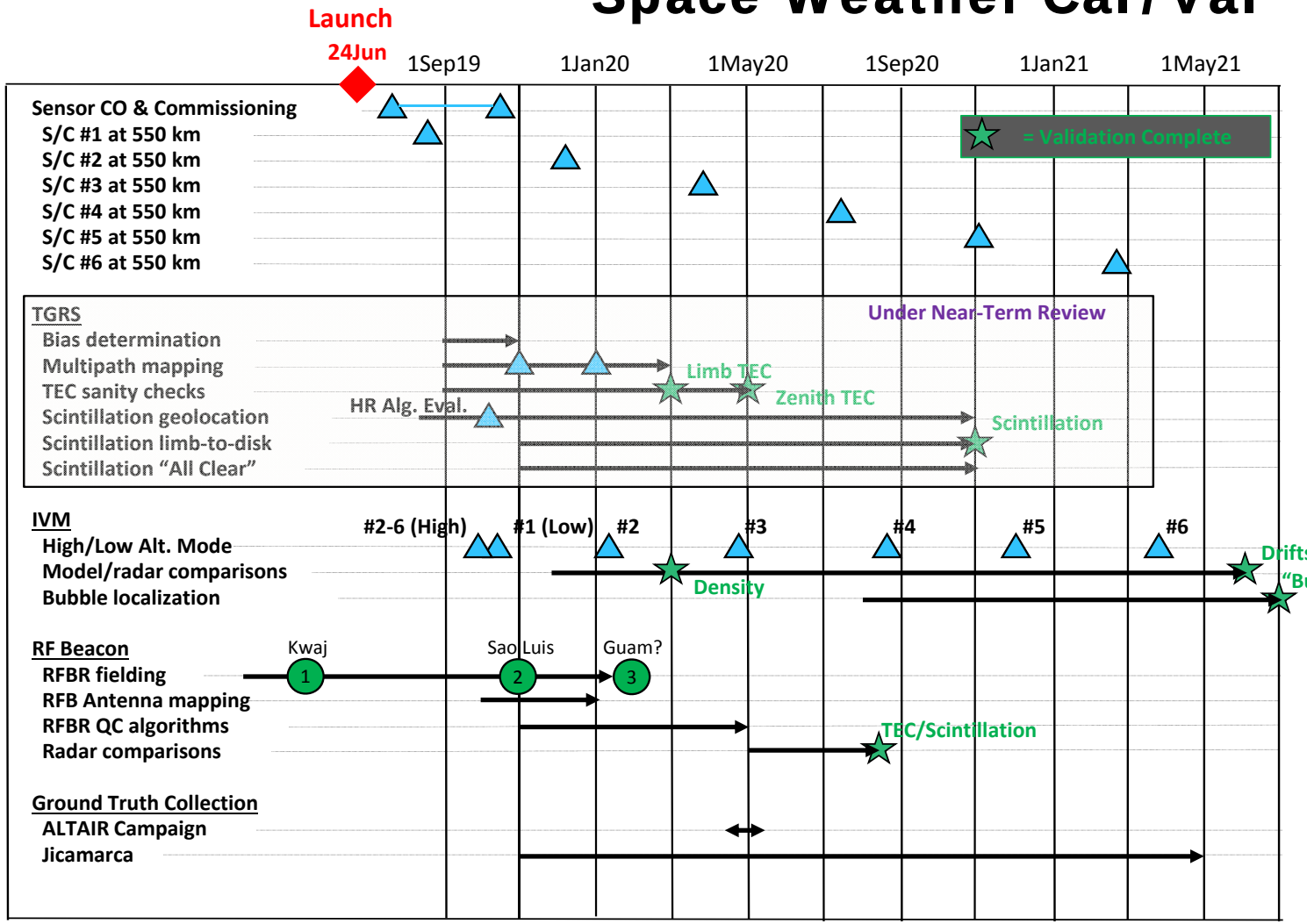
- Ion Temperatures show daytime values near 3000 °K in H+
- Nighttime Ion Temperature near 700°K … Very low temperature at solar minimum
- Detailed comparison of consecutive satellite passes show wave features
- Acknowledgements: R. Heelis, et al. UTD

RFB Receiver (RFBR) Installation

- The first RFBR was installed at Kwajalein Atoll with a high gain steerable antenna.
- The RFBR system collects and records raw data at each frequency with a bandwidth of 500 kHz along with processed data sets including S_4, σ_φ, and TEC in real-time
- Initial tests with RFBR were performed using tracks of available 400 MHz beacons in polar orbit from DMSP5 satellite.
- Field campaign to collect data began on 7/Sept/2019.
- All RFB payloads (and all transmitted signals) were tracked by RFBR.
- AFRL is evaluating Kwajalein data for signal quality.
- RFB payloads now transmitting on all spacecraft.
- Acknowledgements: Ron Caton, AFRL



Space Weather Cal/Val



USAF and Aerospace Corp (Paul Straus) leads US Space Weather cal/val

Partners include:

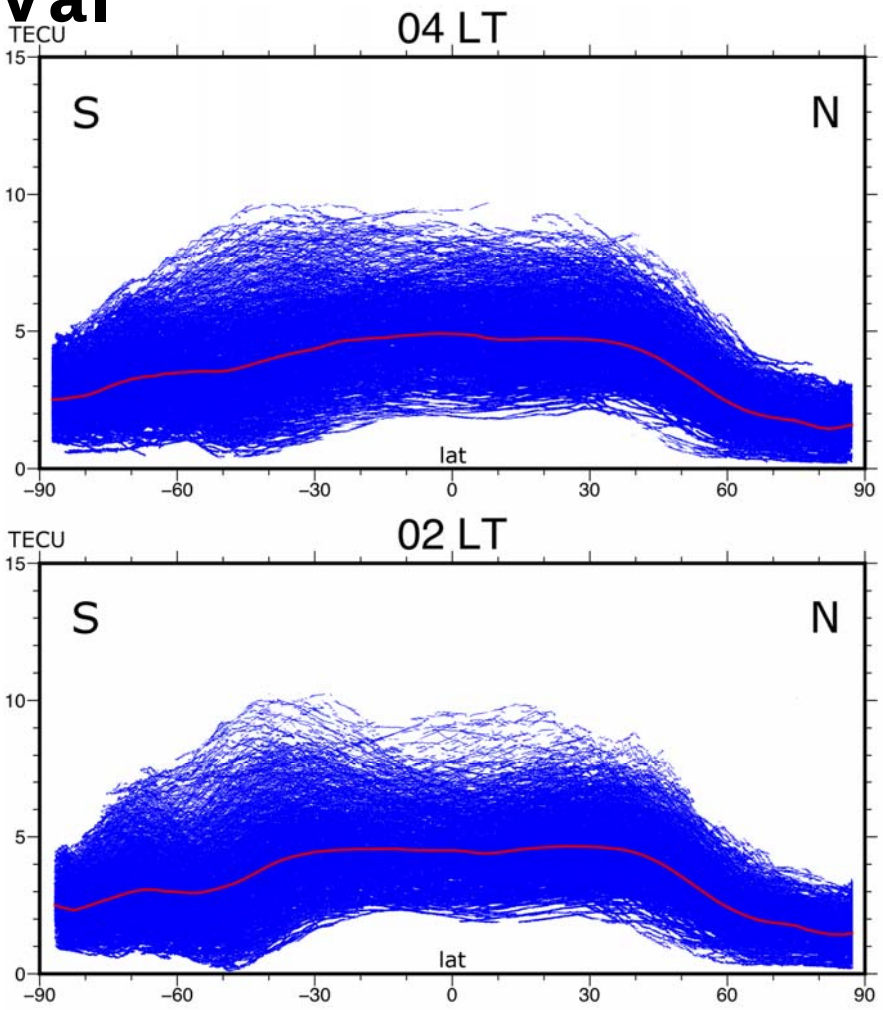
- UTD
- Boston College
- Aerospace Corporation
- UCAR
- NOAA/SWPC
- Utah State

End of cal/val targeted mid 2021

- Related to end of orbit phasing

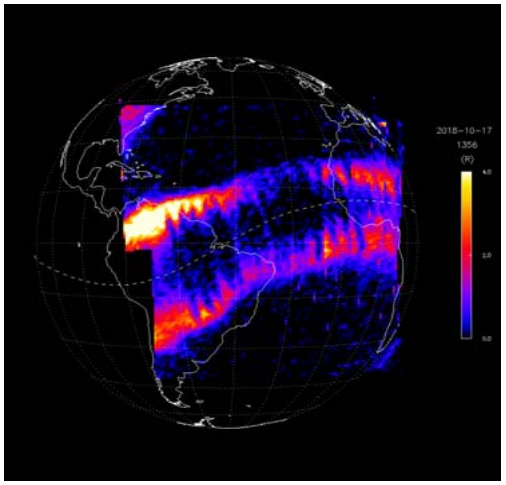
TGRS TEC Cal / Val

- Absolute TEC requirement is 3 TEC.
- Challenges to validated requirement include:
  - multipath, DCB estimation, thermal noise, antenna phase center variations.
- Proposed validation strategy includes use of TEC from polar orbiting satellites at similar altitude to C2 (ie SWARM-B with similar orbit altitude).
  - Compare TEC from nighttime low SA period
- Acknowledgements: Iurii Cherniak (UCAR)



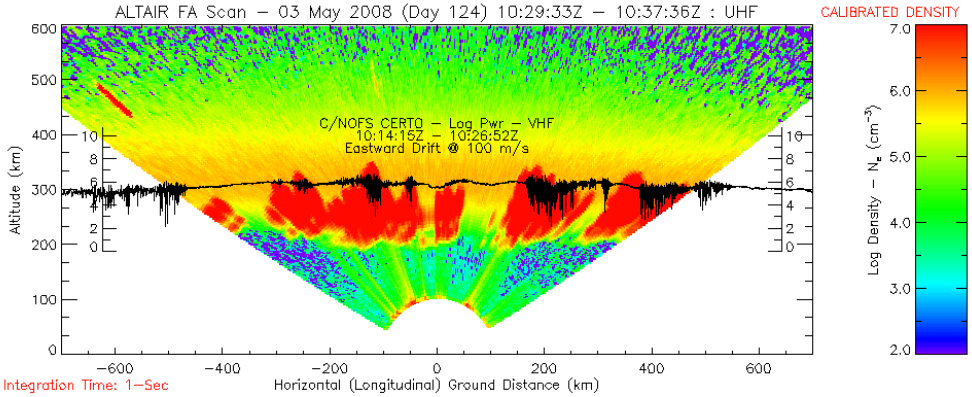
Scintillation Cal / Val

- Scintillation Cal/Val will include comparisons to ground and space instruments: ground and space comparisons:
  - GOLD satellite
  - Ground radar (ALTAIR, Jicamaraca)
  - IVM and TGRS scintillation collocation comparisons.
- End-to-end validation including development of advanced algorithms to incorporate RF beacon data into real-time ionospheric specification tools
- Cal/Val to include:



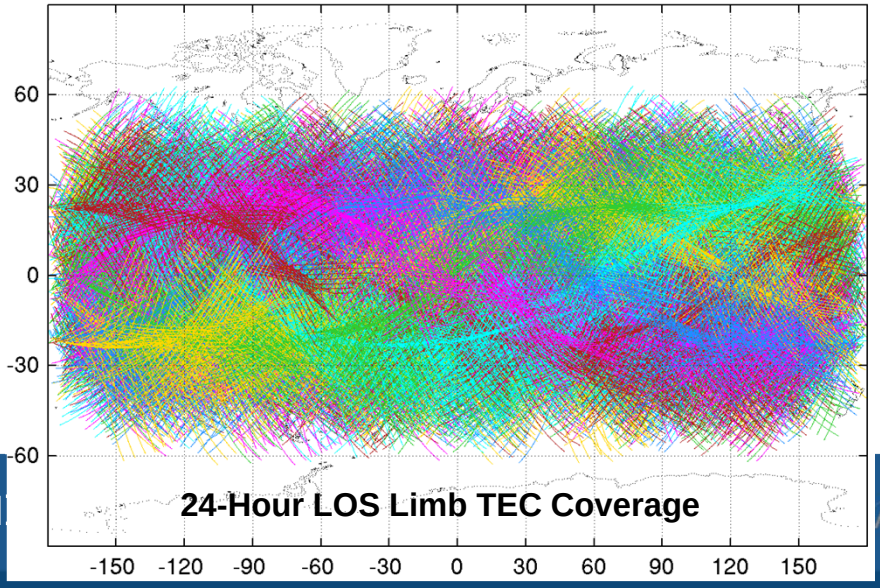
GOLD nighttime O 135.6 nm emission data.

Courtesy of
Stan Solomon, NCAR,
preliminary data



Constellation Capabilities and Summary

- COSMIC-2 will observe longitude variations with ~30° spacing at 12 local times.
- Multiple observation types including GNSS limb and overhead TEC (TGRS), in-situ data (IVM), and regional ground TEC (RFB) provide exceptional low latitude coverage for data assimilation and analysis.
- Will provide data to resolve large, medium, and small scale ionospheric structure.
- Will support tidal decomposition and daily variability of electric fields, field-aligned plasma drifts and plasma density in topside ionosphere.



24-Hour LOS Limb TEC Coverage