The Possible Suppression of Natural Ionospheric Irregularities with Artificial Plasma Injection

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Outline

- MOSC Concept
- ALTAIR Observations
- Interactions with the background plasma
- A Beacon View
- Summary

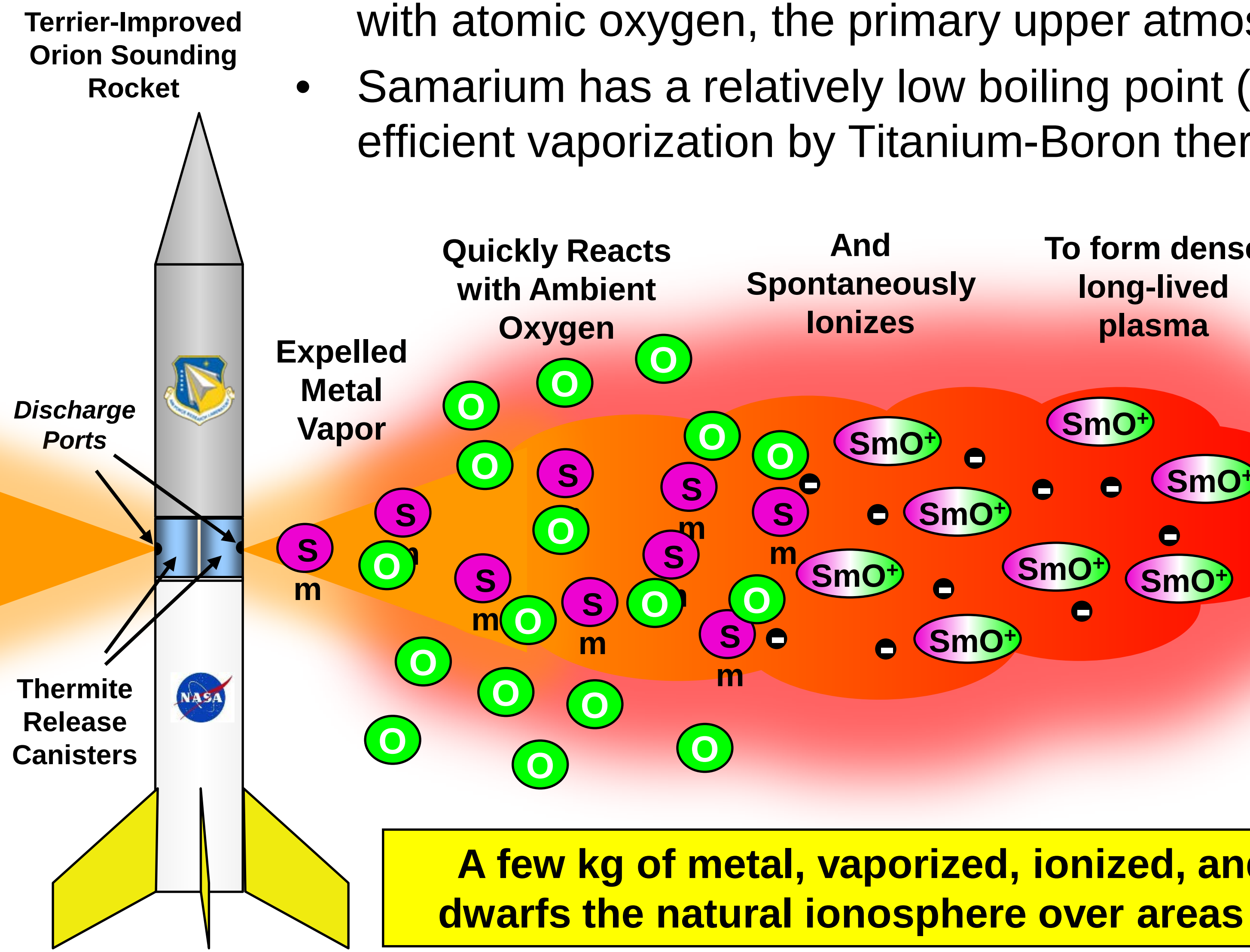
AFRL MOSC Experiment

Two Successful Launches from Kwajalein Atoll in May 2013

- Experiment to investigate potential for active mitigation of ionospheric scintillation effects on radio waves through **artificial ionospheric modification**.
- Mission team included AFRL, STP, BC, UK DSTL, NASA, NRL
- MOSC Team just beginning data analysis
- Payload for each rocket included
  - Two canisters of samarium (5 kg yield)
  - Dual Frequency RF Beacon (NRL CERTO)
- Ground diagnostics from 5 sites included:
  - Incoherent Scatter Radar, GPS/VHF Scintillation Rxs, All-Sky Cameras, Optical Spectrograph, Ionosondes, Beacon Rx, HF Tx/Rx

AFRL MOSC Experiment
Samarium Release

- Many Lanthanide metals spontaneously ionize upon reaction with atomic oxygen, the primary upper atmospheric constituent
- Samarium has a relatively low boiling point (2021K), allowing efficient vaporization by Titanium-Boron thermite (~3500K)



Predicted artificial density after 1 hour:

10^8/cc

Typical natural density:

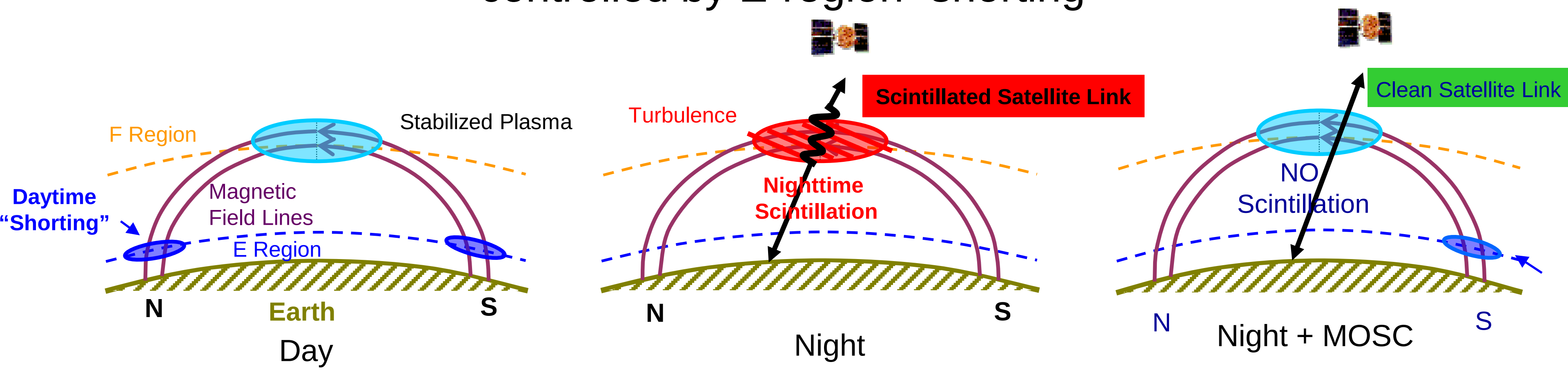
10^6/cc

Actual burst-disc release canister

A few kg of metal, vaporized, ionized, and dispersed, dwarfs the natural ionosphere over areas up to 100 km

AFRL MOSC Experiment
Scintillation Suppression?

Natural equatorial ionospheric scintillation routinely occurs – controlled by E-region “shorting”

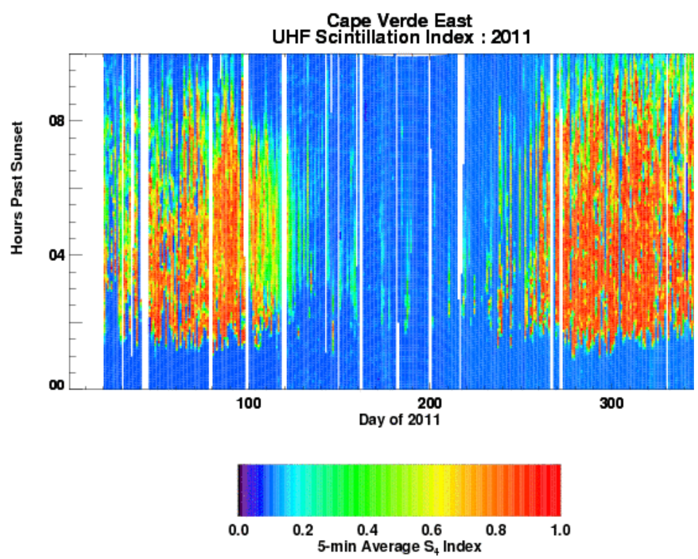


Exponential RT Growth Rate

$$A = A_0 e^{\gamma t}$$

$$\gamma \approx \frac{\Sigma_F}{\Sigma_F + \Sigma_E}\left[\frac{E \times B}{B^2} + U_n + \frac{g}{\nu^{eff}}\right]\frac{\partial N}{\partial h}$$

E Region Conductance



Can “shorting” generated by rocket release stabilize extended region?

Can we mimic the “solstice” effect?

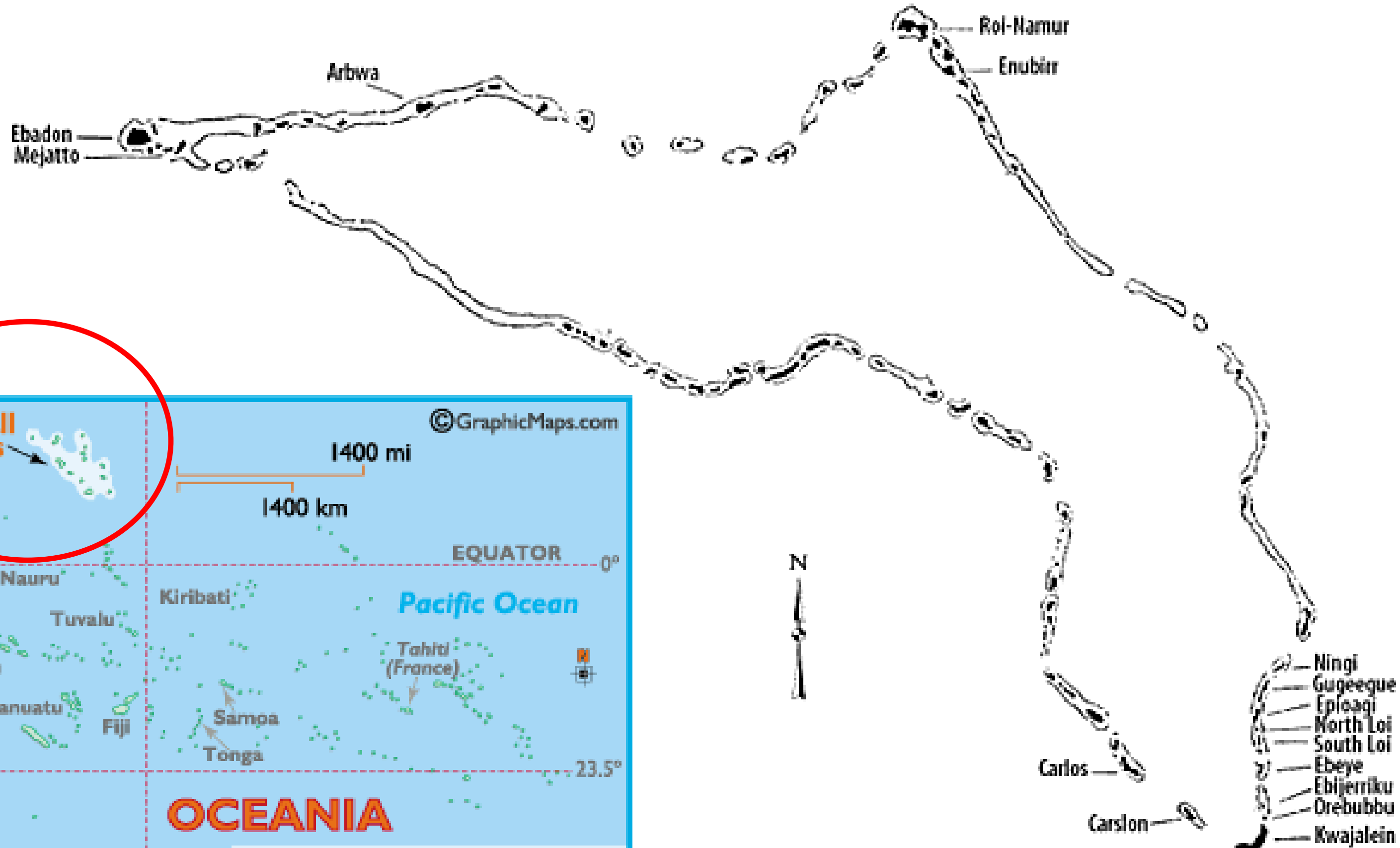
Primary Objectives

Two Successful Launch Criteria

1. Fully characterize the ionized samarium cloud to include ionization levels, rates and evolution in space and time

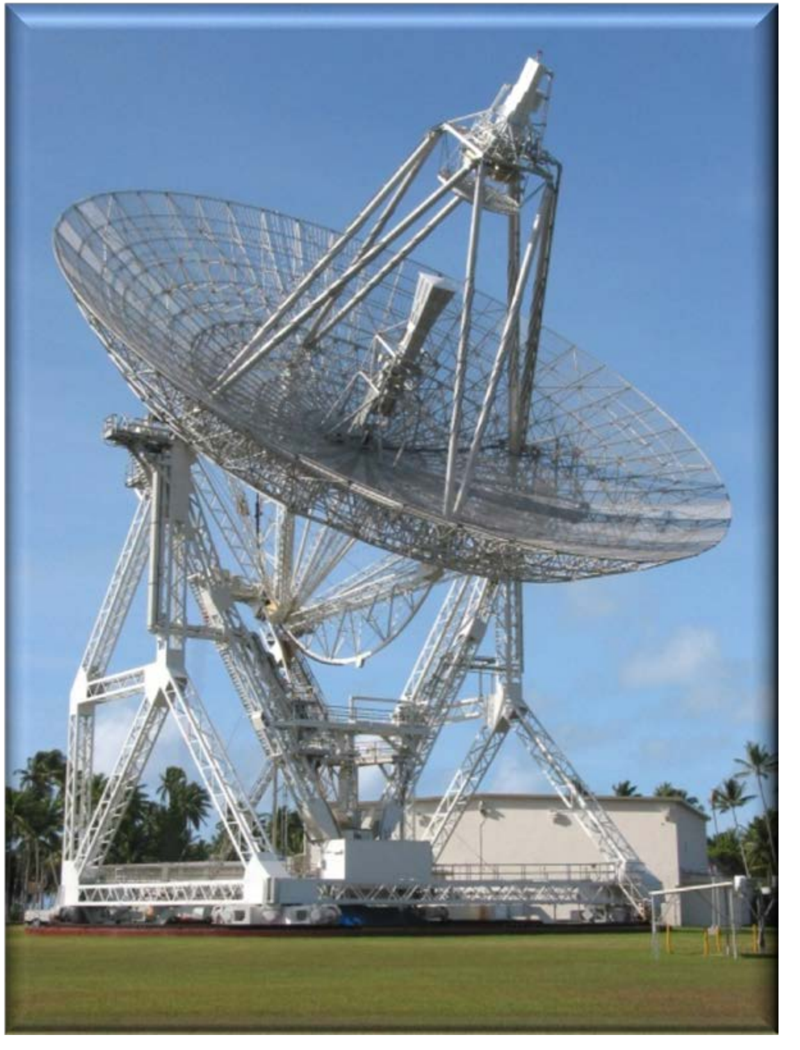
2. Test the hypothesis that samarium plasma injection may inhibit natural scintillation

Kwajalein Atoll



Kwajalein Atoll & ALTAIR

Roi-Namur

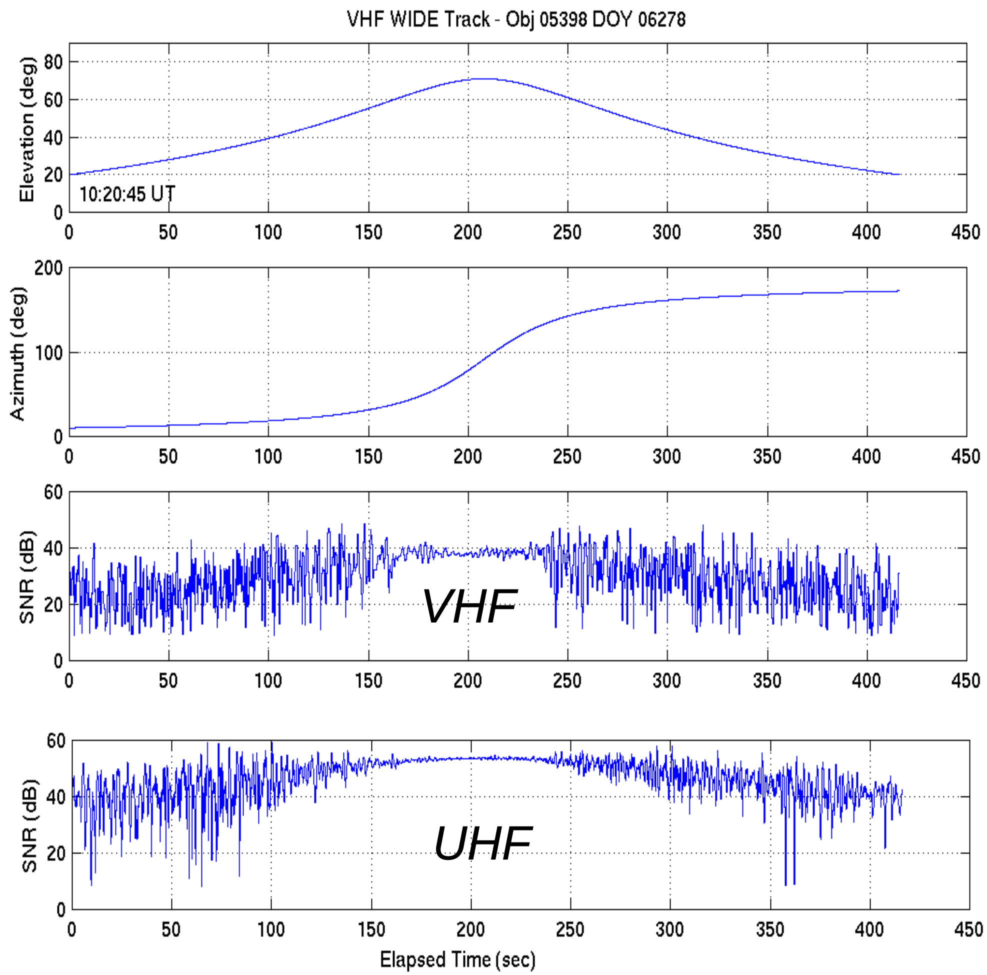


ALTAIR

Ionospheric Scintillation Effects on ALTAIR Tracking Data

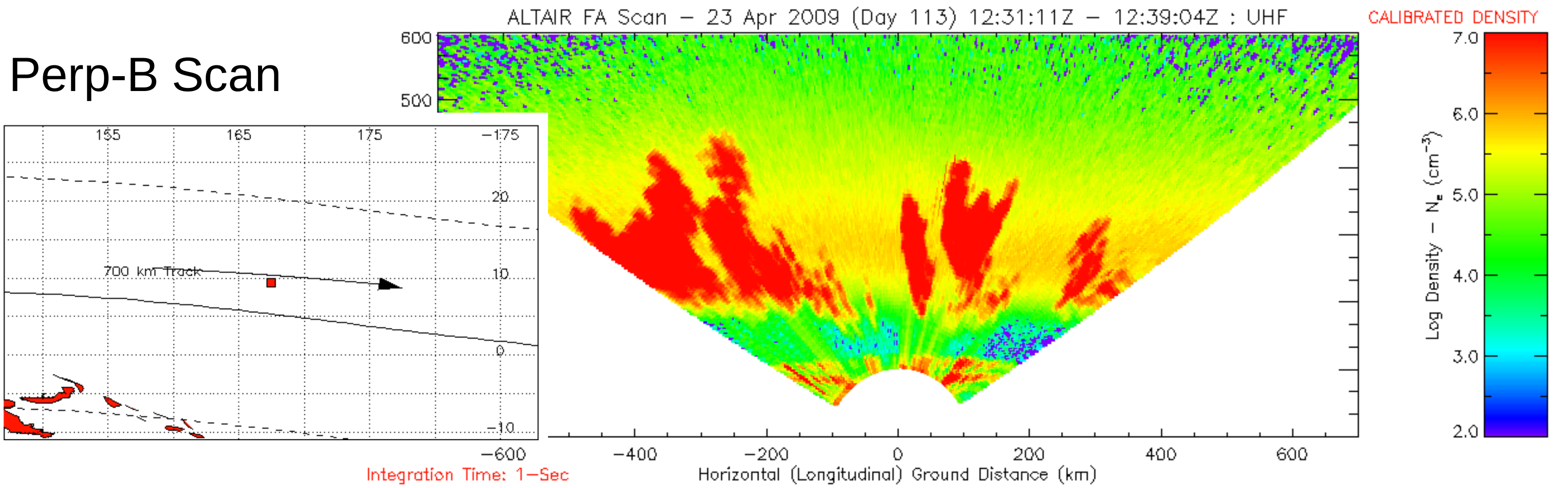
- Ground-based cal-sphere track data provides actual 2-way phase and amplitude effects
- Large phase and amplitude effects, even at solar min
- Tracking is the primary mission of the radar, but it can also be used to measure incoherent (Thompson) scatter from ionospheric electrons

ALTAIR VHF and UHF calibration sphere track data from Day 278 2006

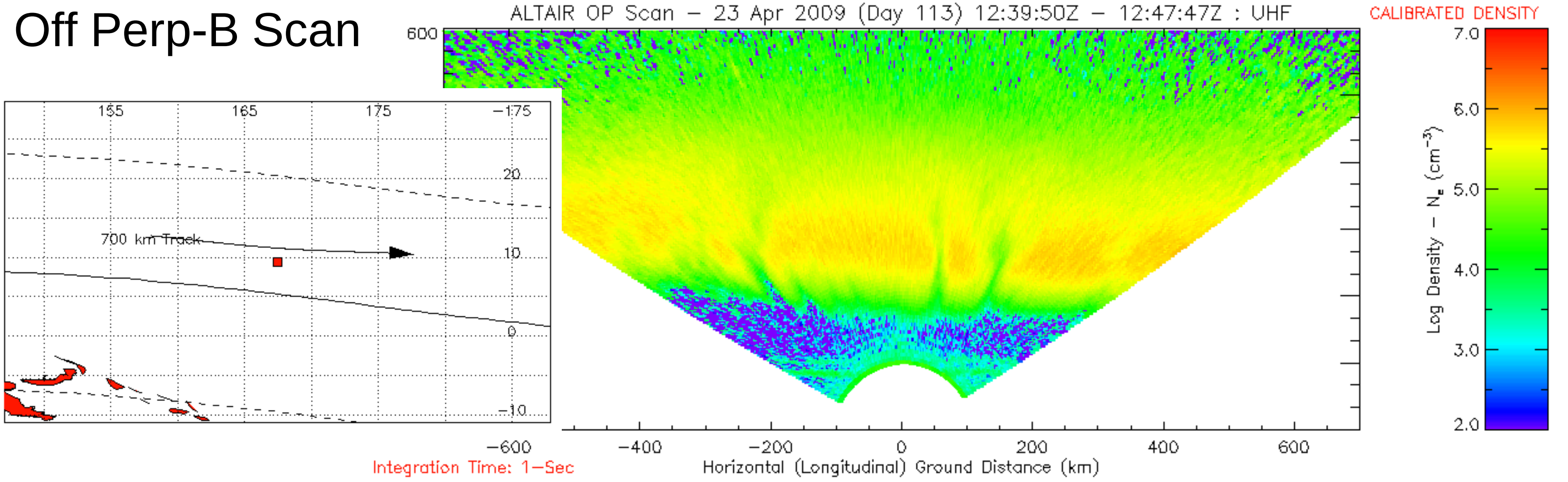


Incoherent and Coherent Scatter: Ionospheric Observations

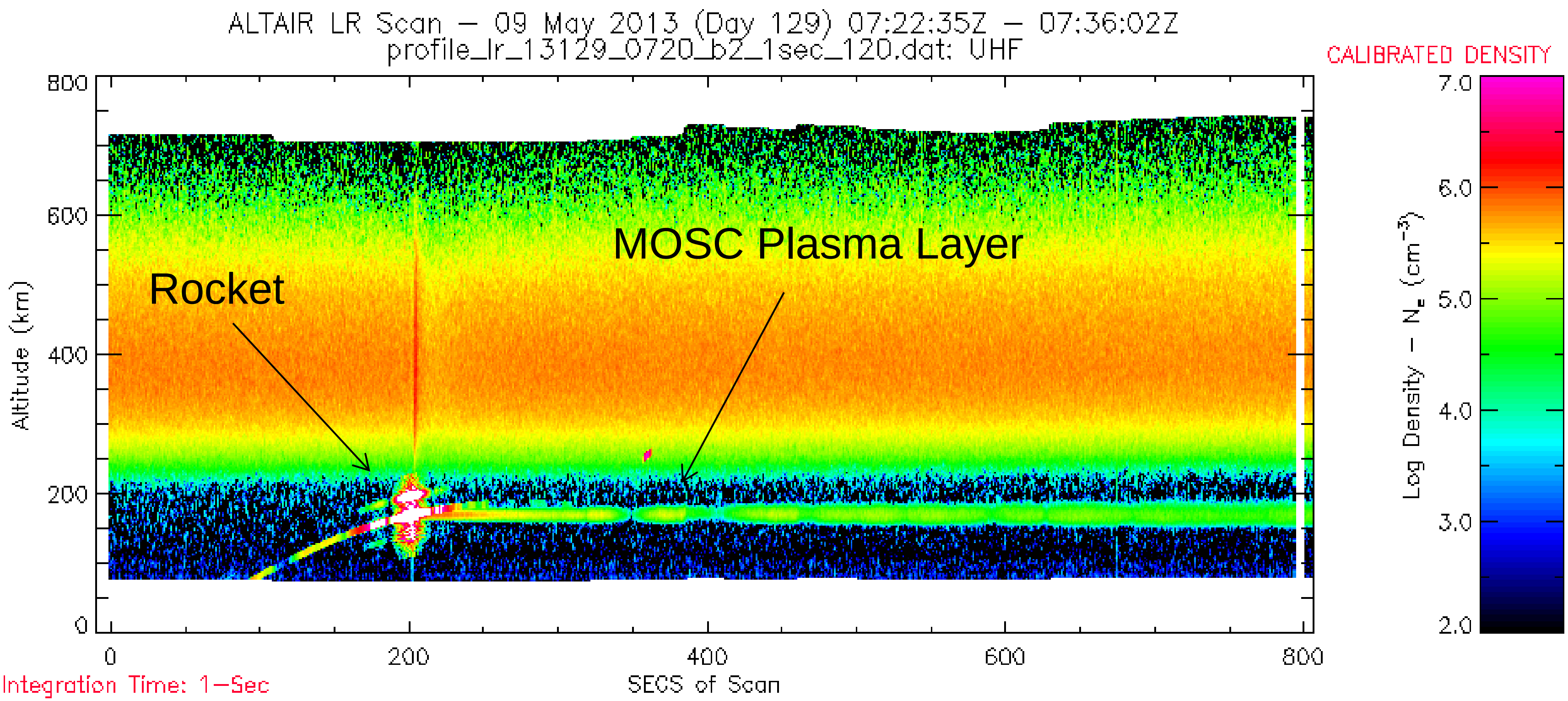
Perp-B Scan



Off Perp-B Scan

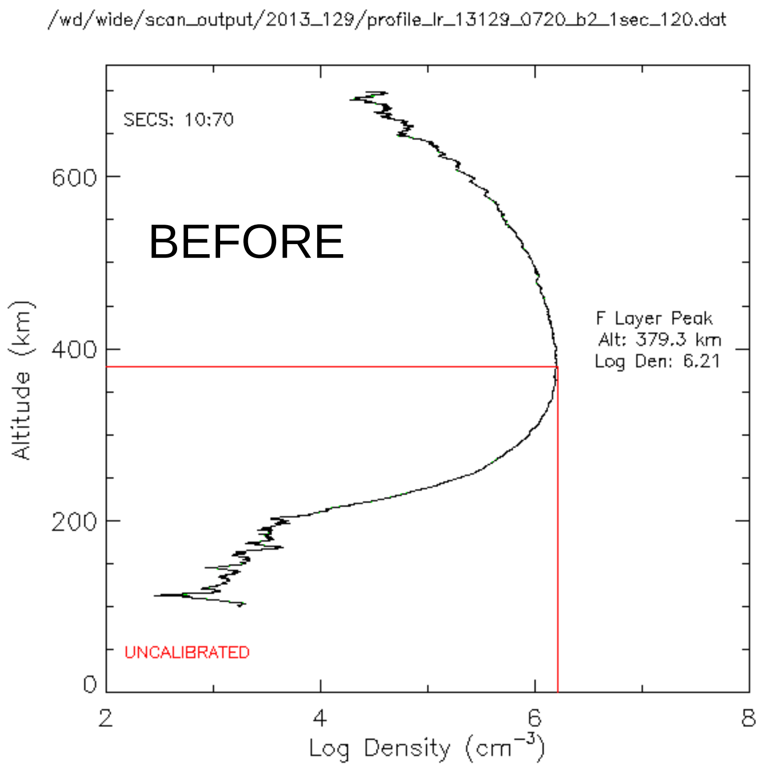


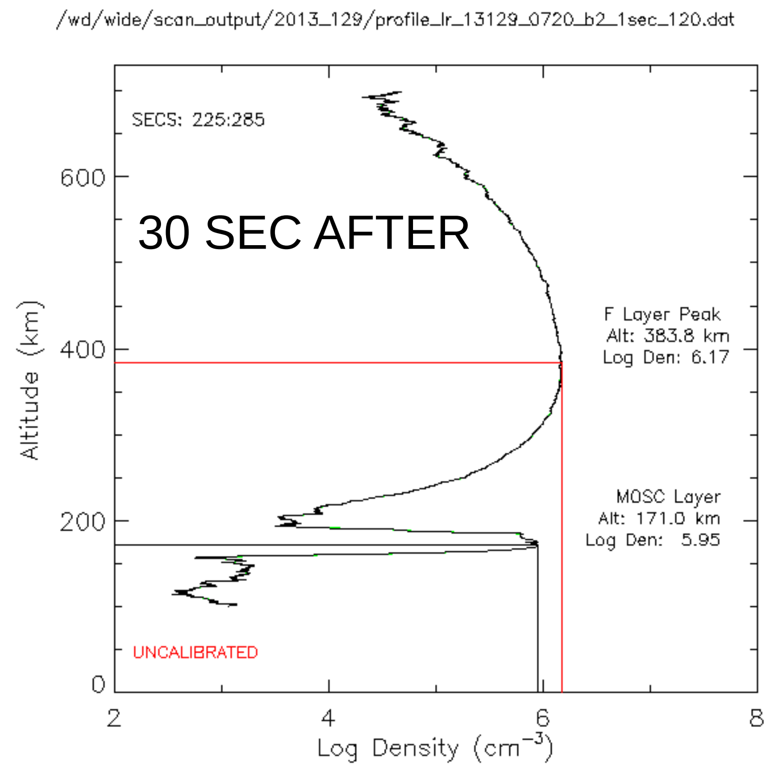
MOSC Launch 2: May 9, 2013 Samarium Release



- Initial peak density of samarium plasma cloud is comparable to natural ionosphere

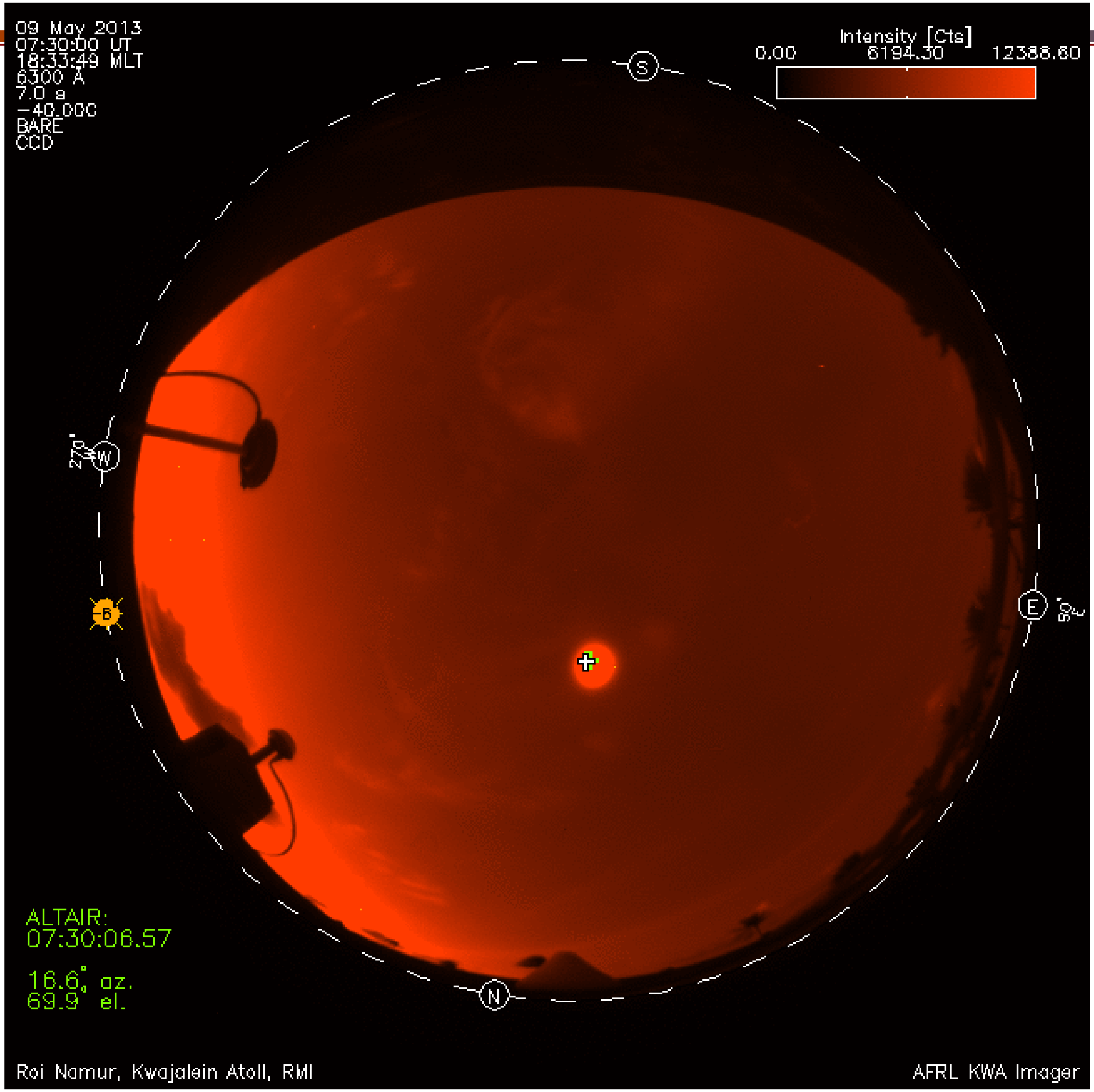
MOSC Launch 2: May 9, 2013 Samarium Release



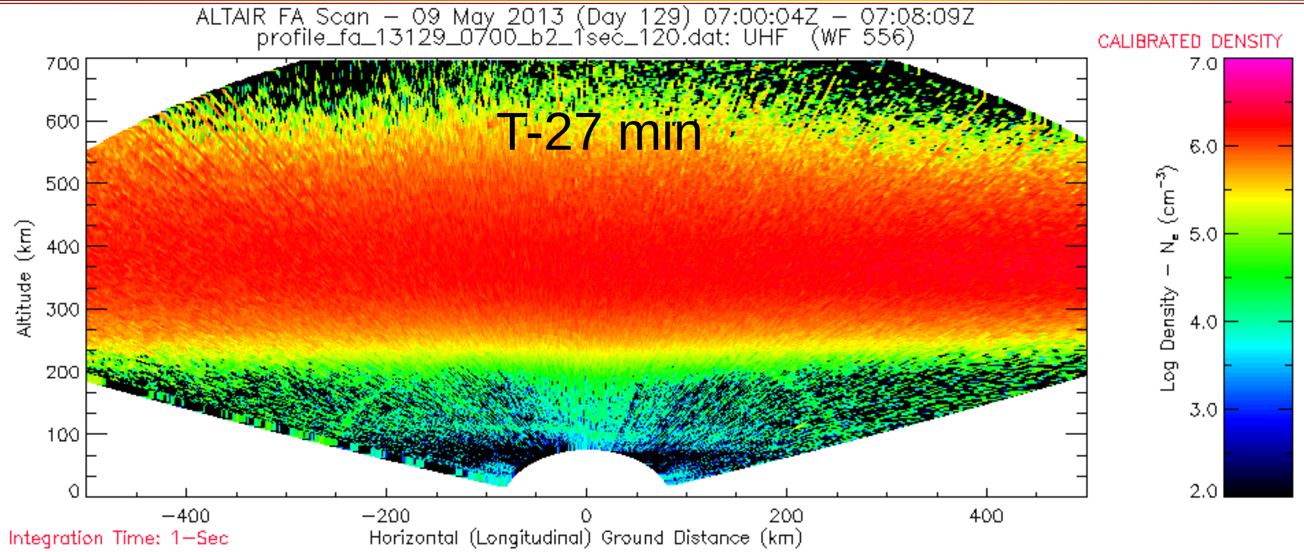


- Approximately 30 seconds after release the MOSC cloud has a peak density of about 10^6 e^-/cc, slightly less than the background ionosphere (Ne = 10^6 corresponds to a plasma frequency of 9 MHz)
- The layer is about 30 km in diameter by this time

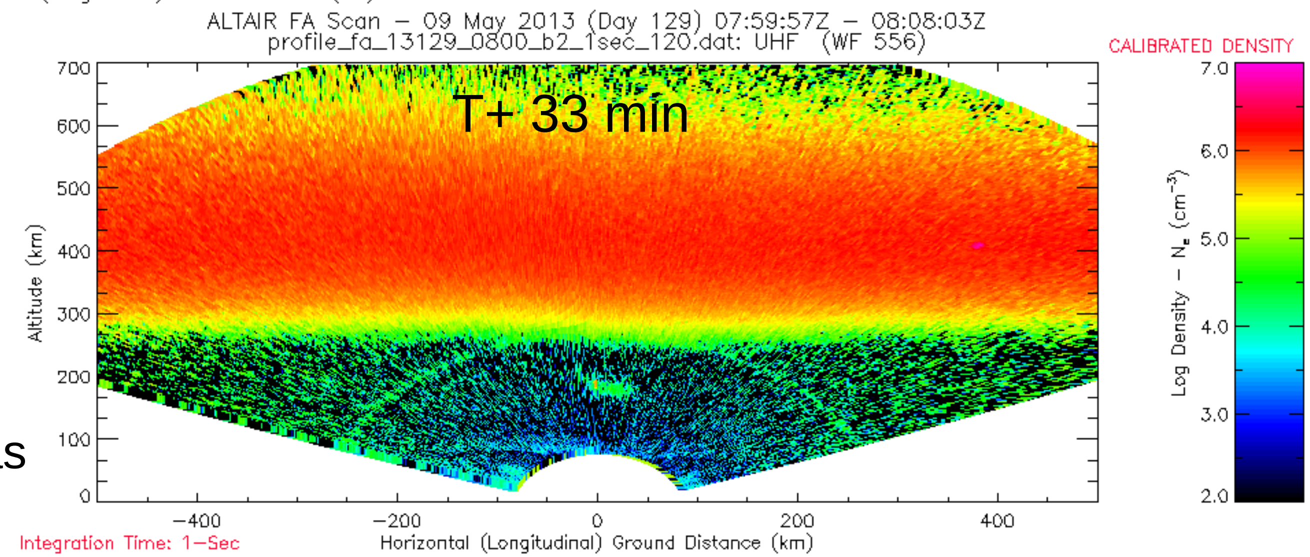
6300 all-sky camera vs ALTAIR



MOSC Launch 2: May 9, 2013
Evolution of Cloud & Ionosphere



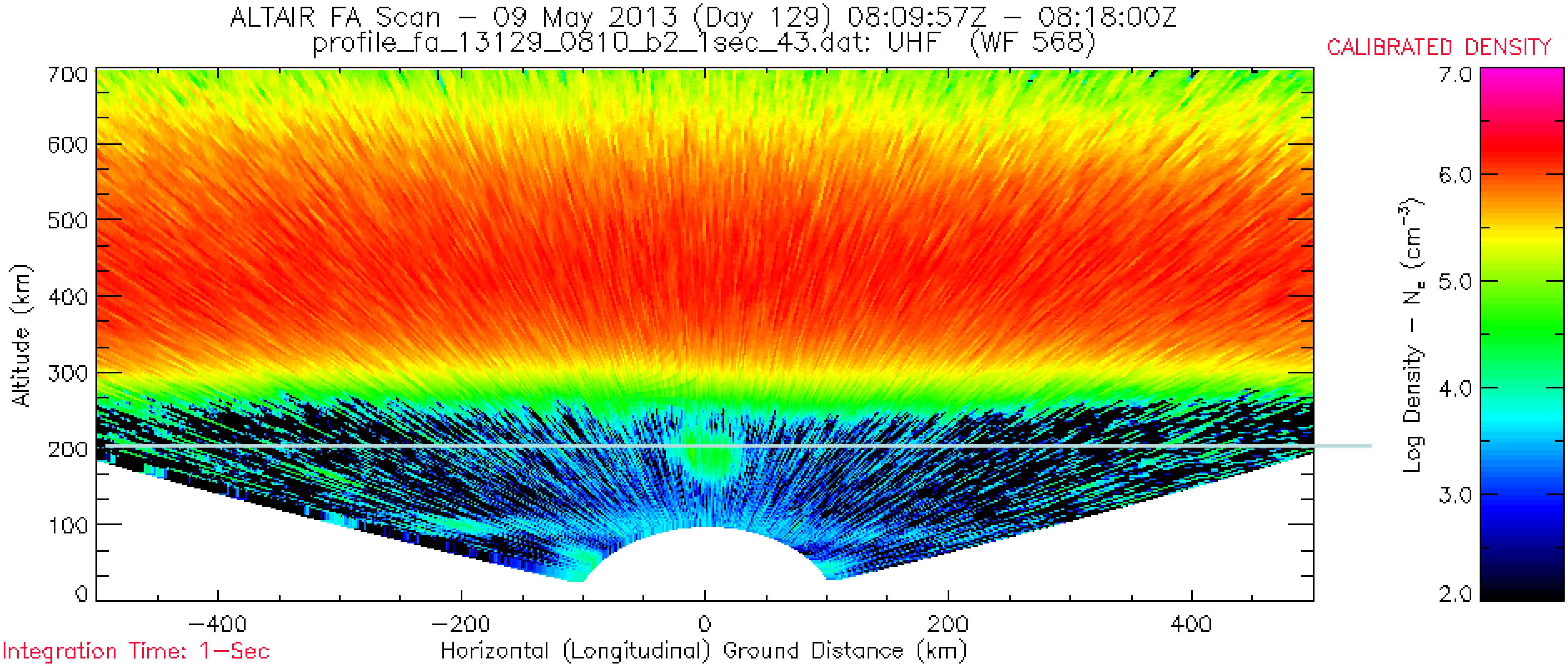
Smooth background ionosphere as sunset approaches



- Still appears smooth an hour later, but samarium cloud is weakly evident
- Note that base of layer has risen (~50 km); peak density has decreased ~10%

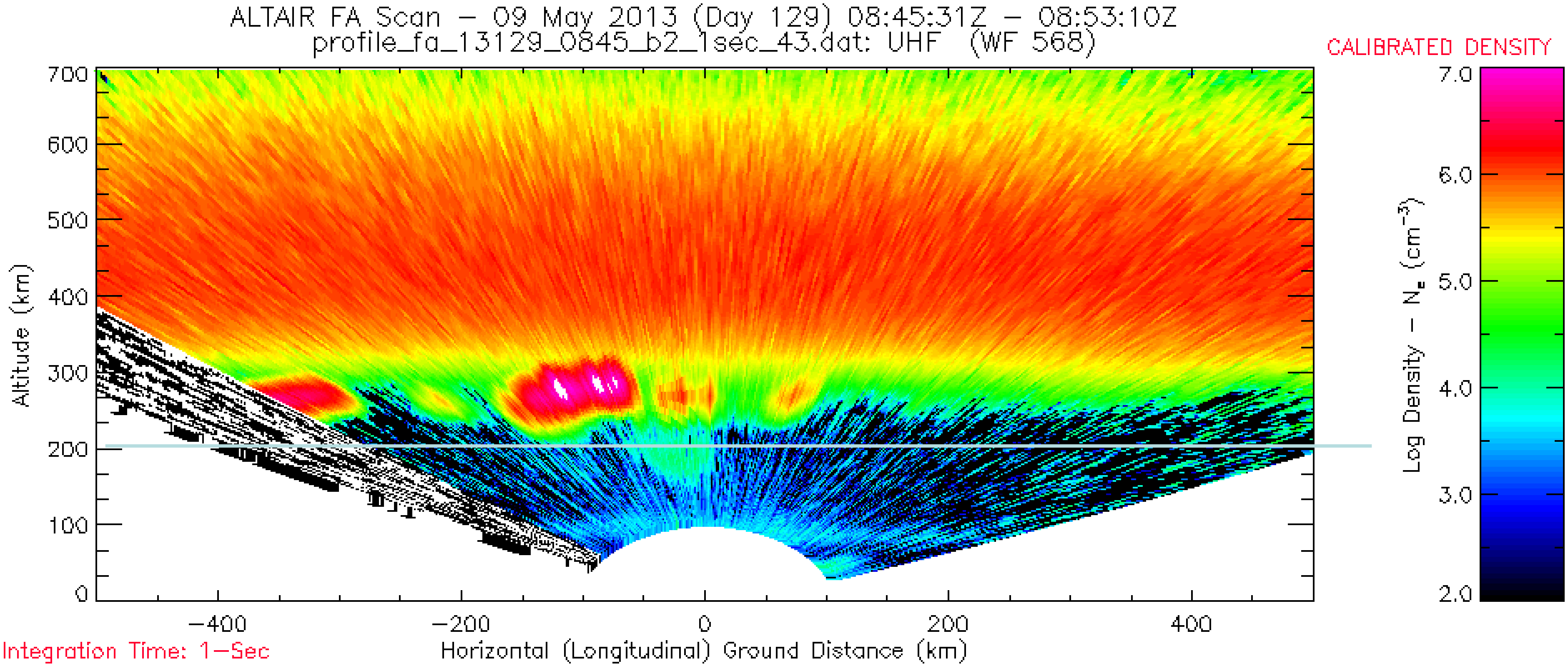
UHF Perp-B Coherent Scatter Scans

08:10 UT to 08:18 UT



UHF Perp-B Coherent Scatter Scans

08:45 UT to 08:53 UT



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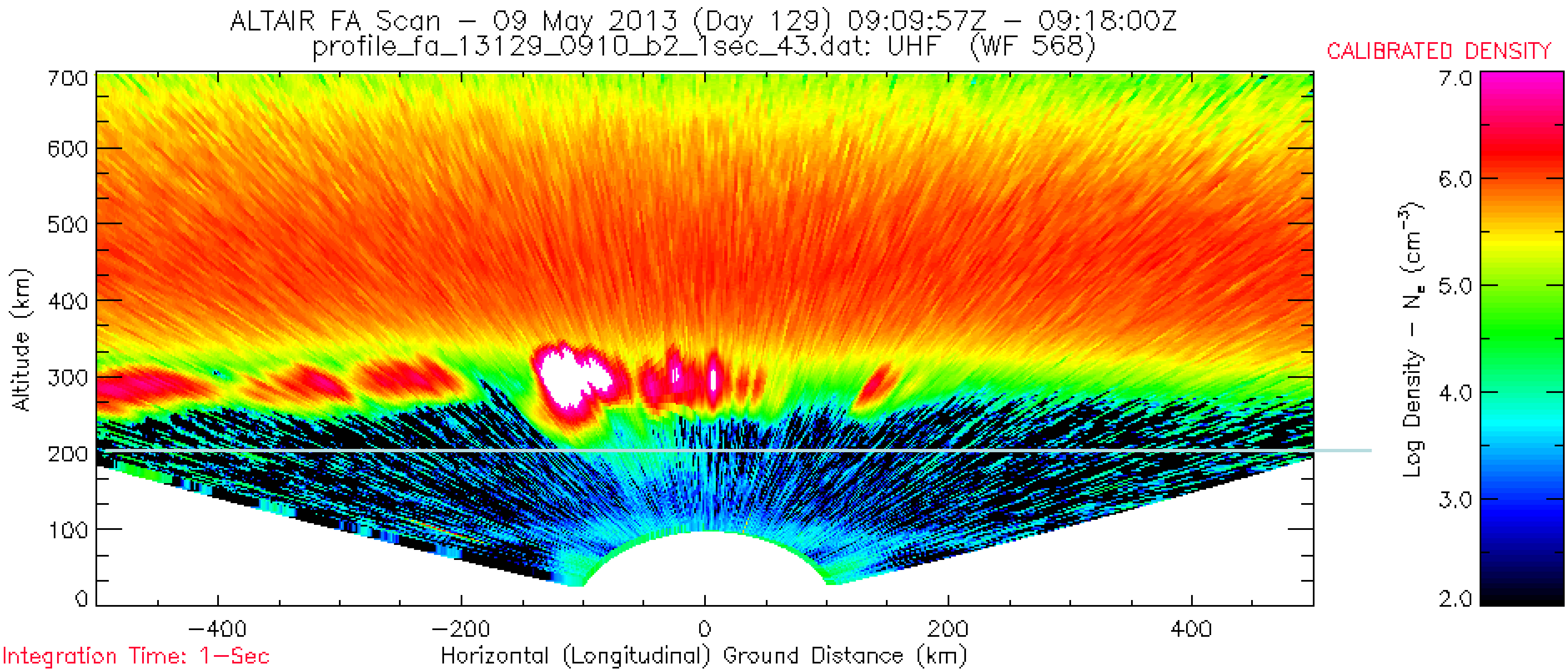
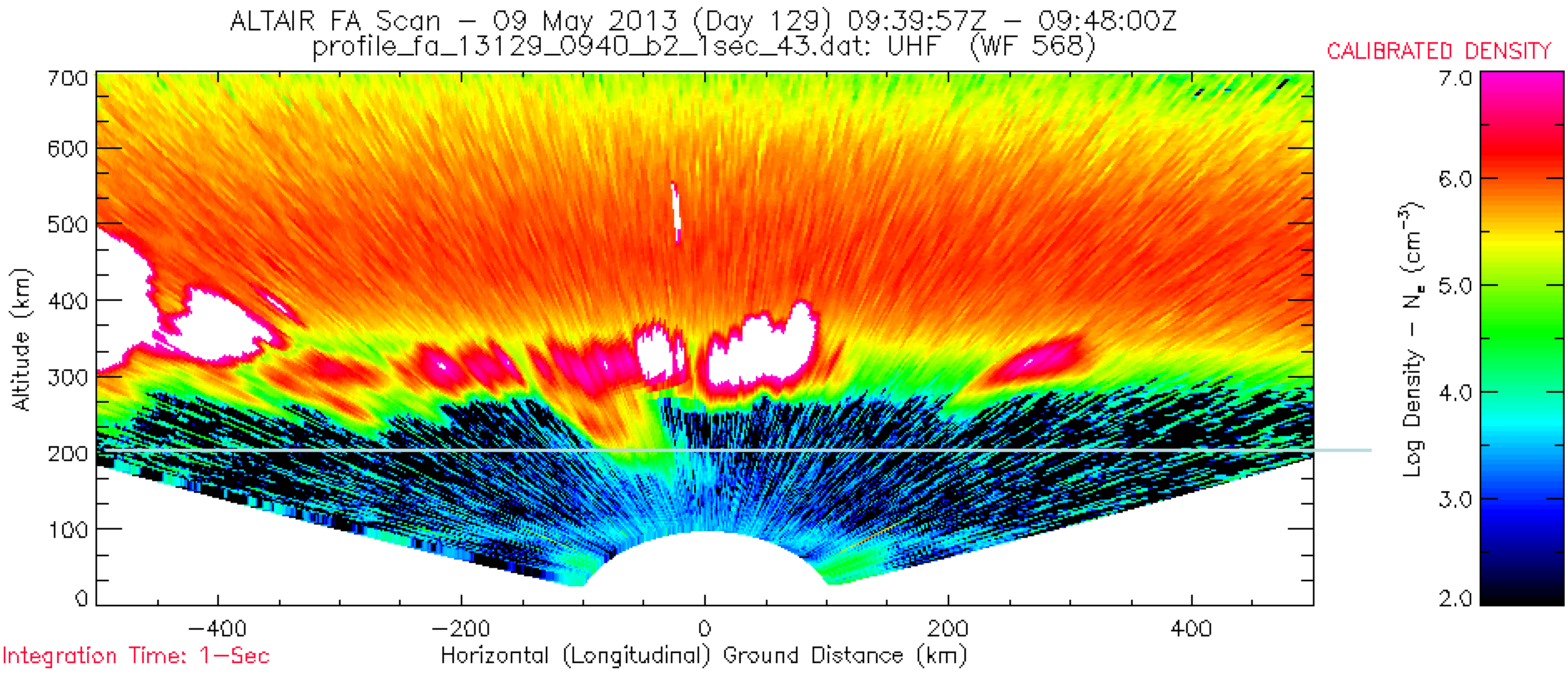


UHF Perp-B Coherent Scatter Scans

09:40 UT to 09:53 UT



UHF Perp-B Coherent Scatter Scans

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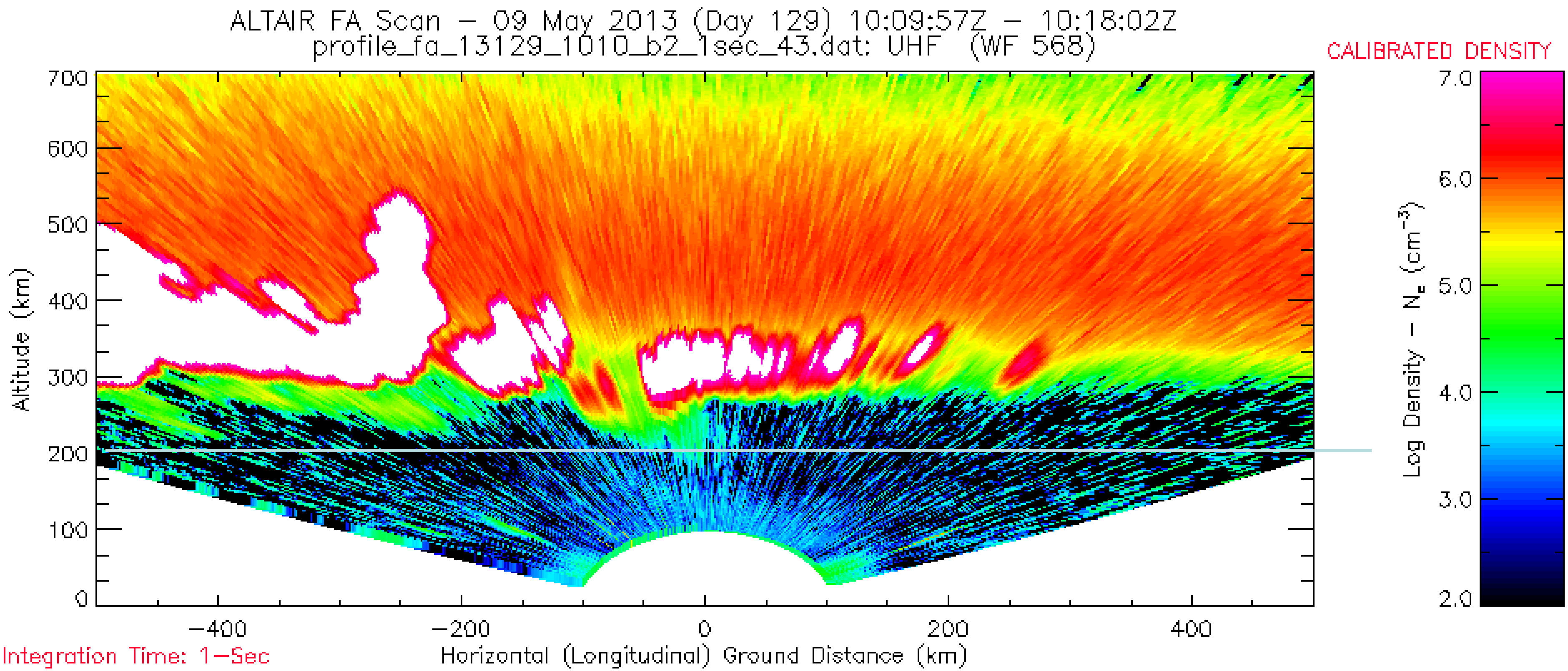
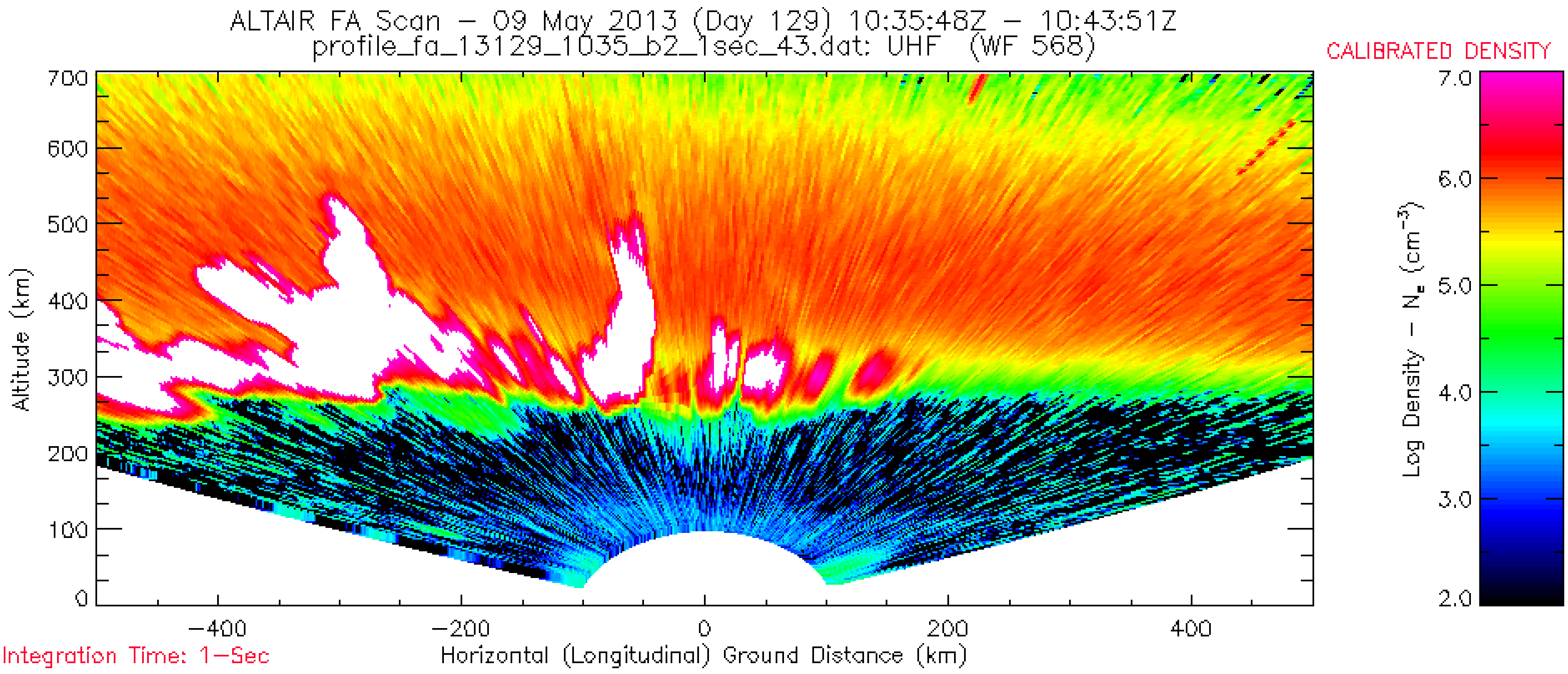


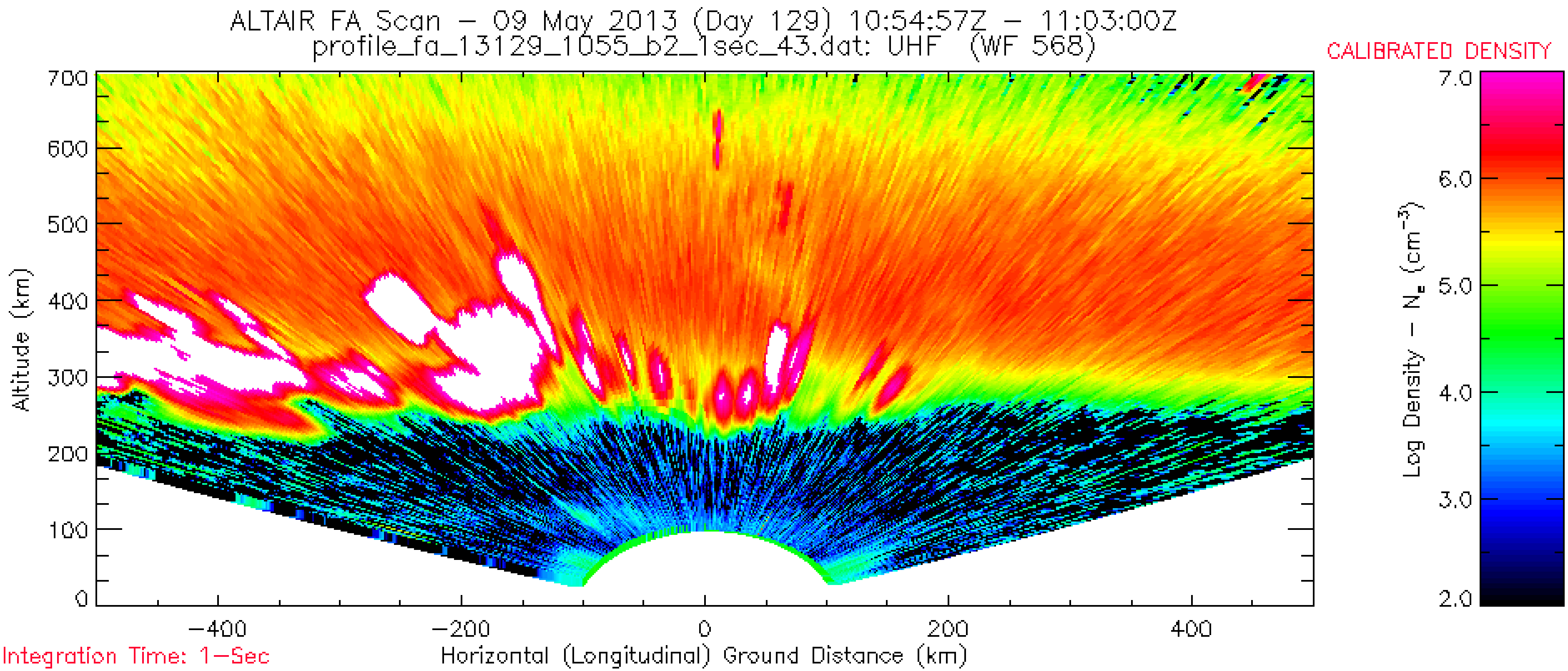
UHF Perp-B Coherent Scatter Scans

10:36 UT to 10:44 UT



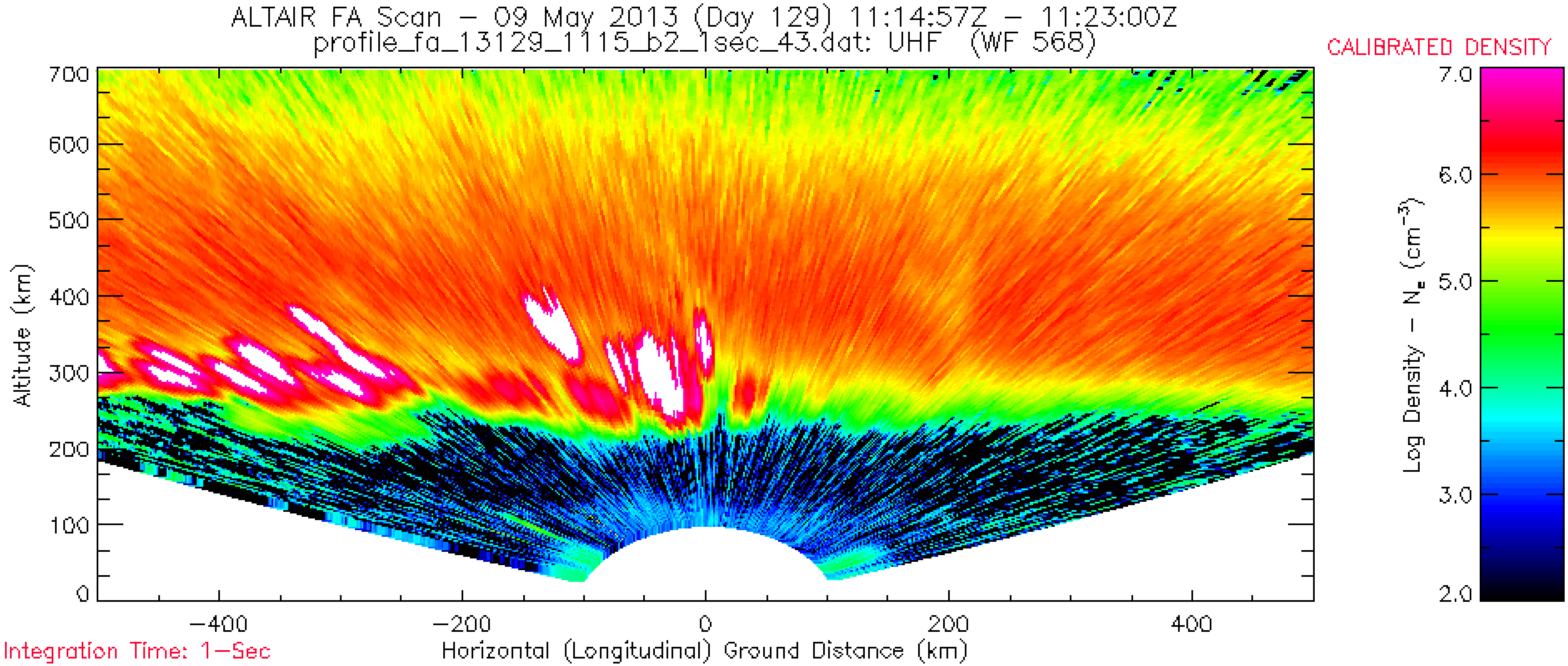
UHF Perp-B Coherent Scatter Scans

10:55 UT to 11:03 UT



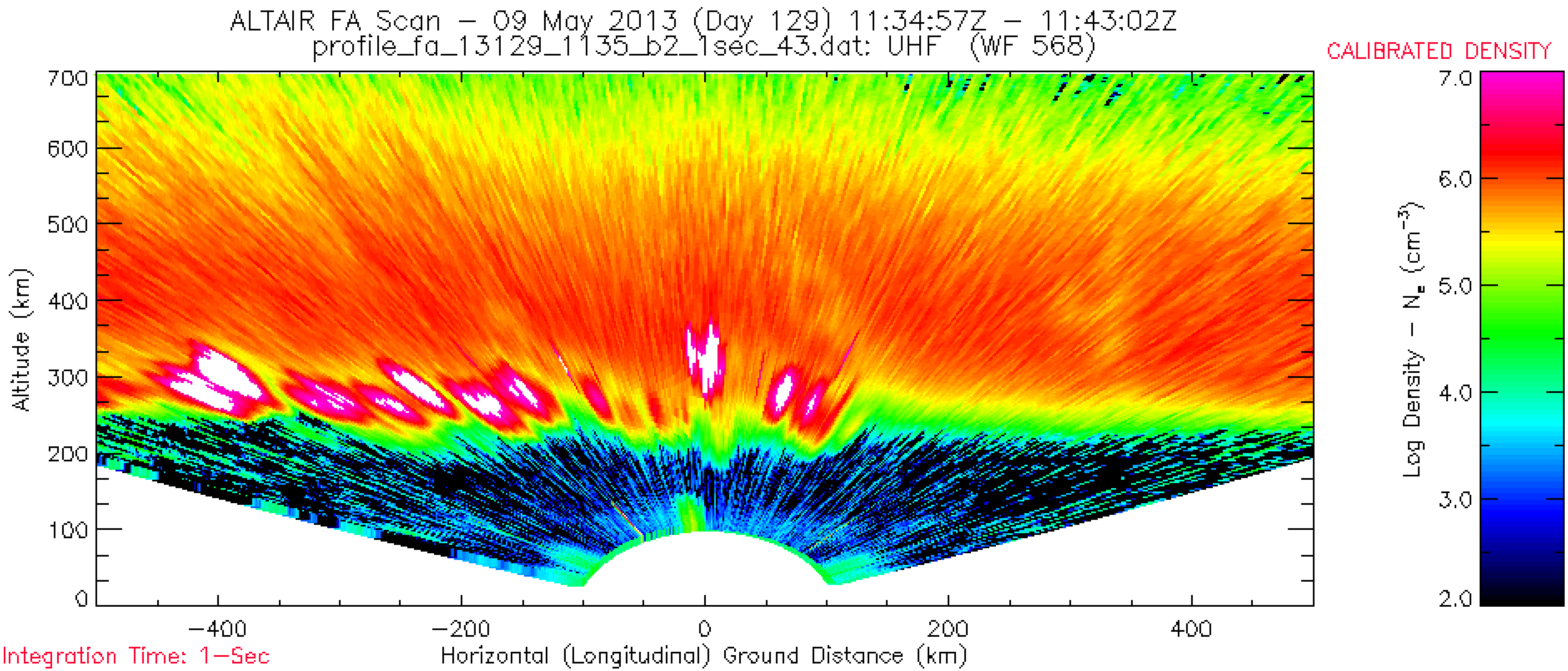
UHF Perp-B Coherent Scatter Scans

11:15 UT to 11:23 UT



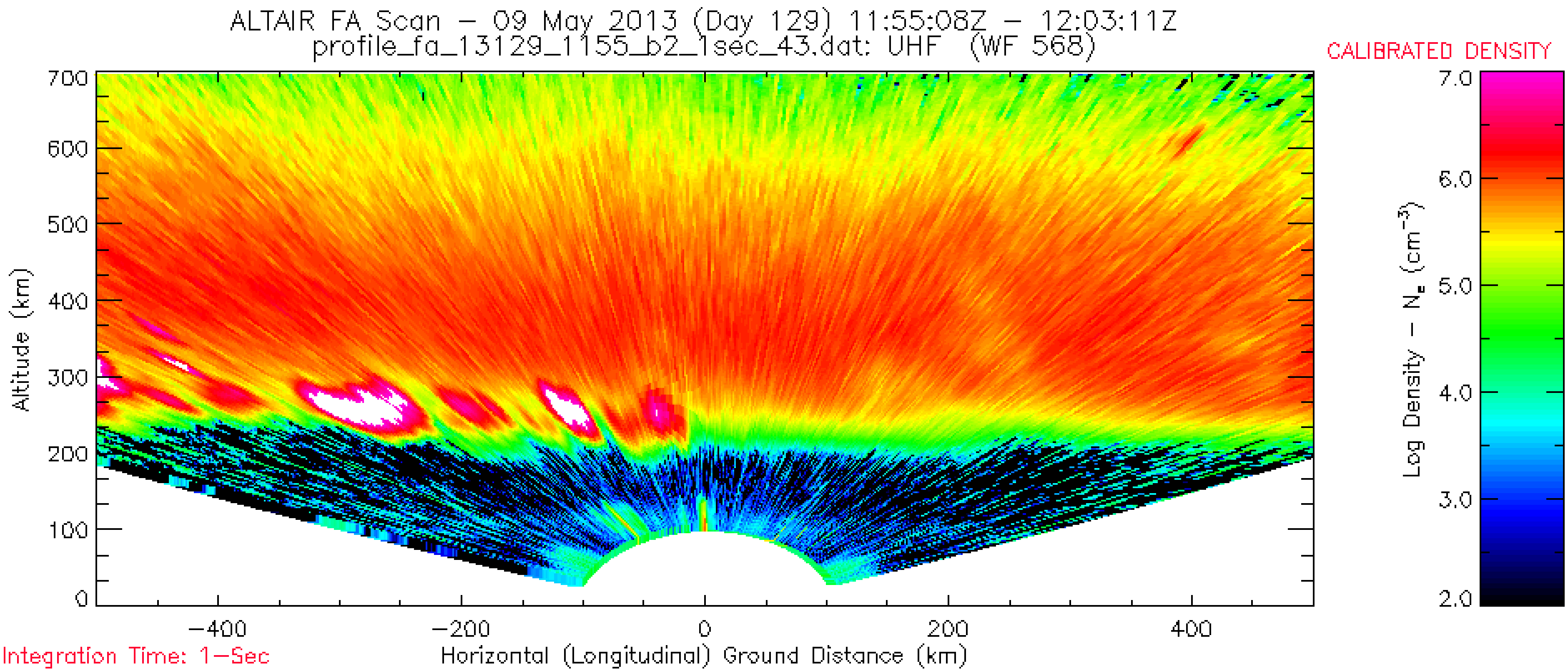
UHF Perp-B Coherent Scatter Scans

11:35 UT to 11:43 UT



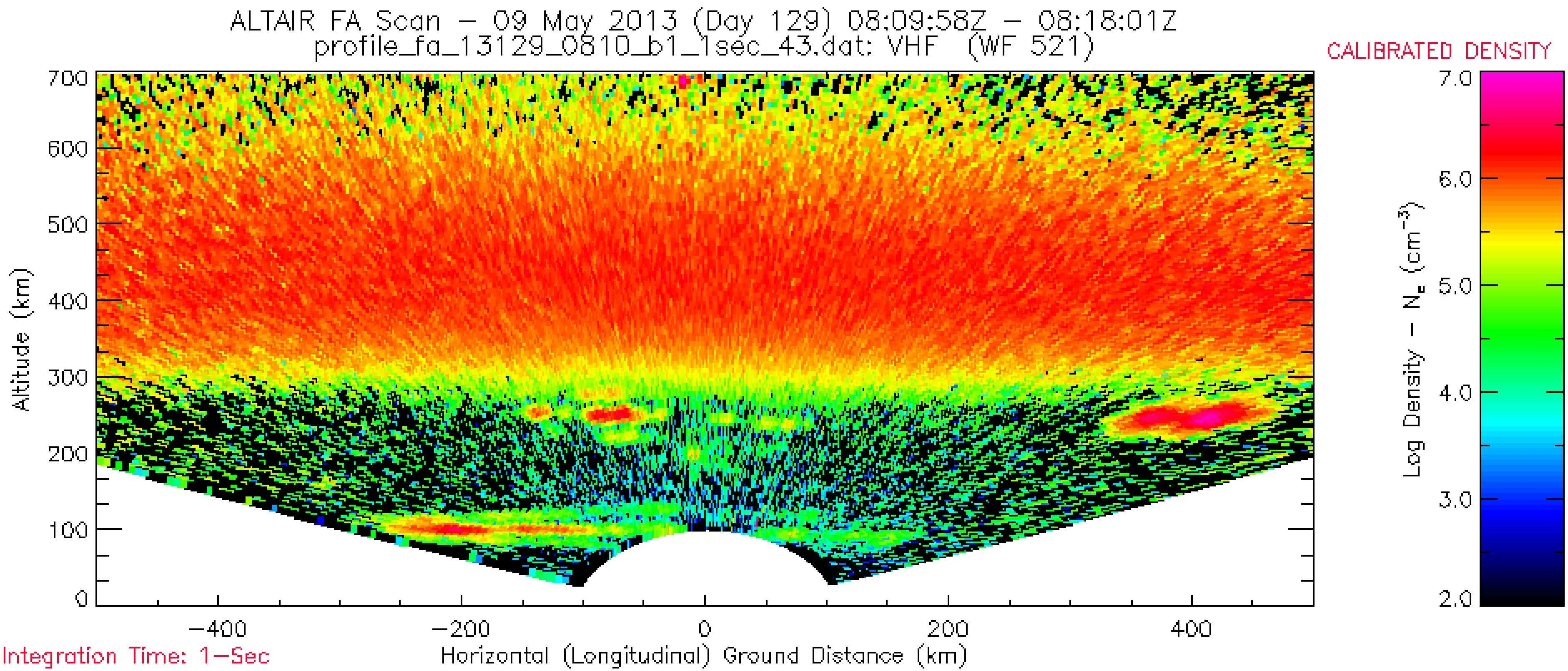
UHF Perp-B Coherent Scatter Scans

11:55 UT to 12:03 UT



VHF Perp-B Coherent Scatter Scans

08:10 UT to 08:18 UT



VHF Perp-B Coherent Scatter Scans

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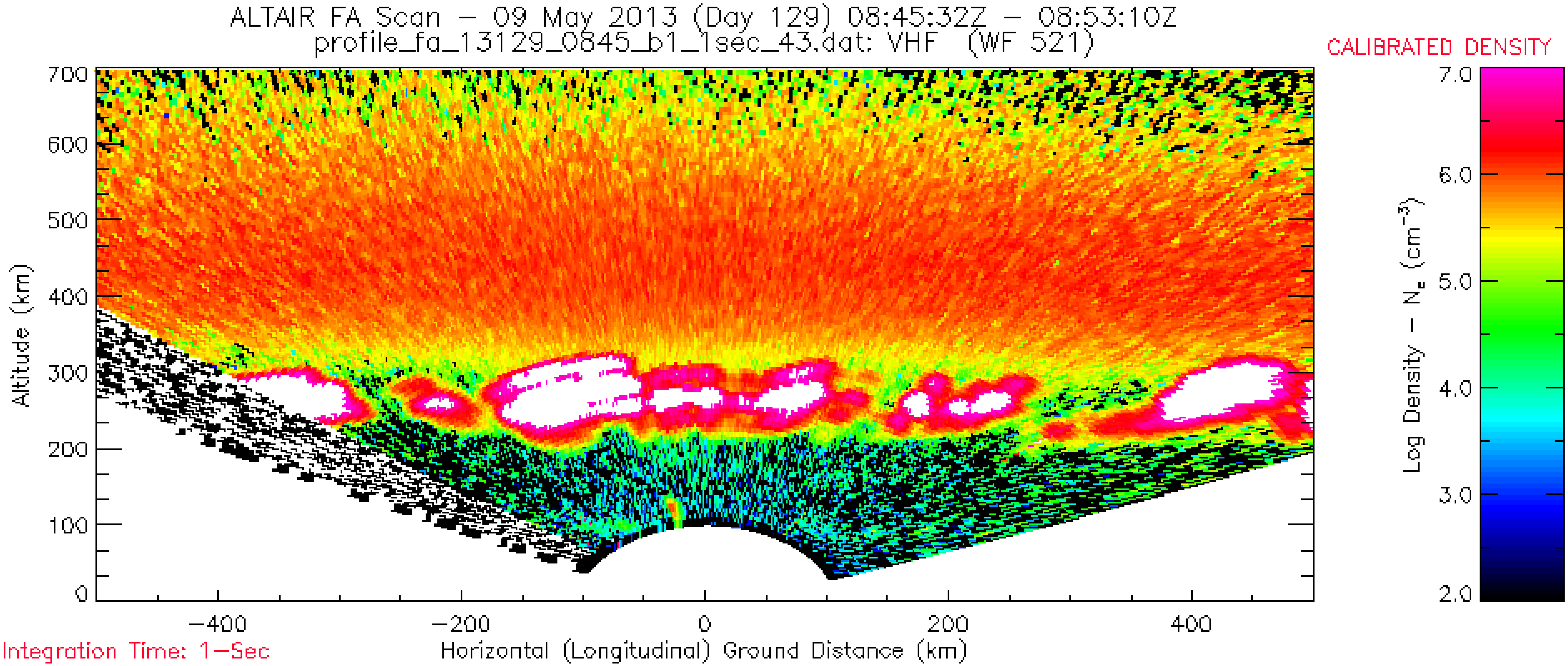

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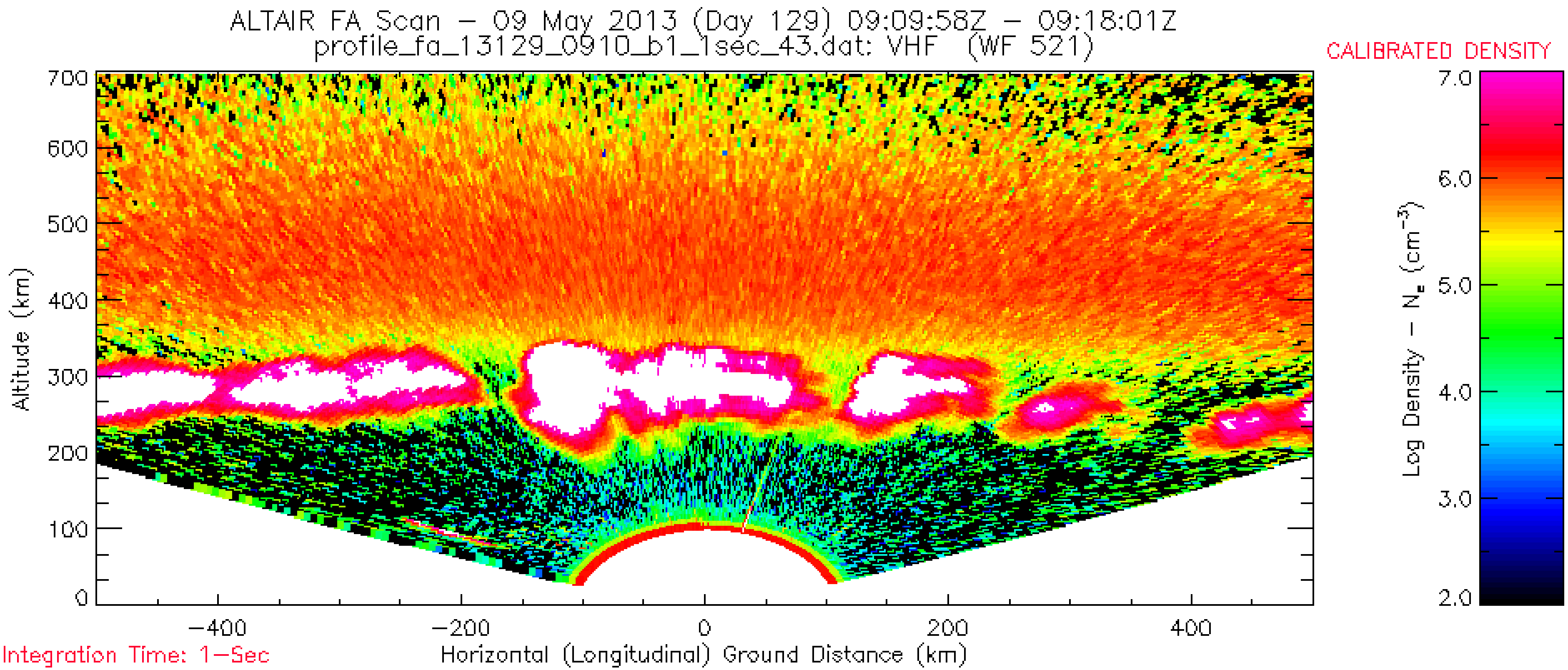
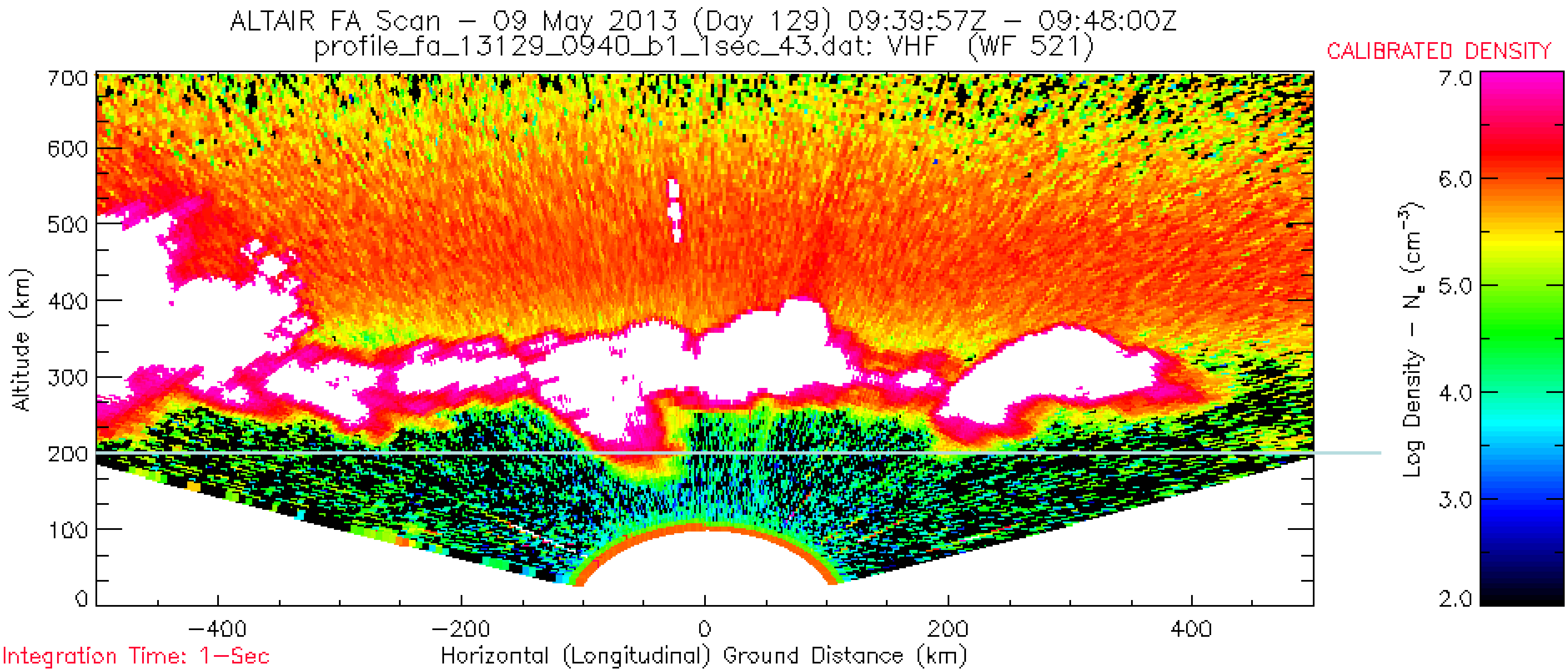


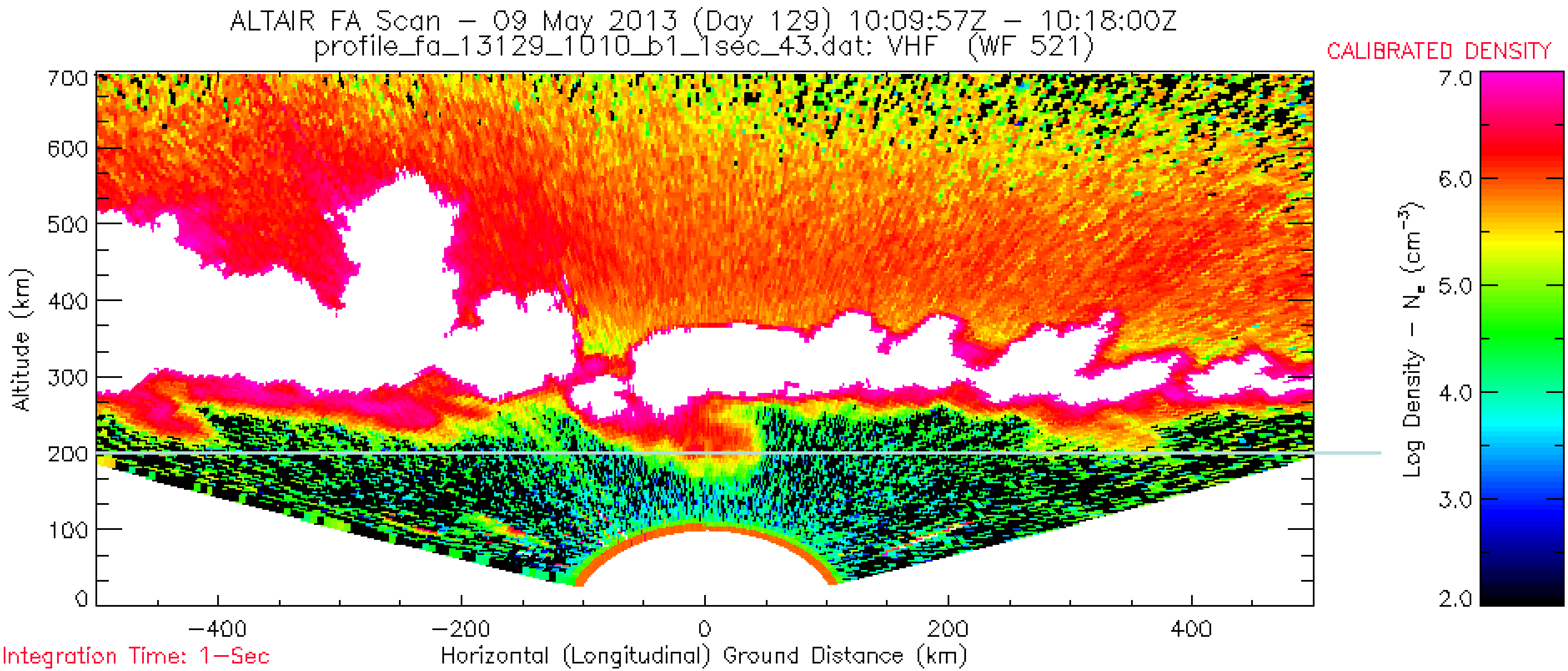
VHF Perp-B Coherent Scatter Scans

09:40 UT to 09:48 UT



VHF Perp-B Coherent Scatter Scans

10:10 UT to 10:18 UT



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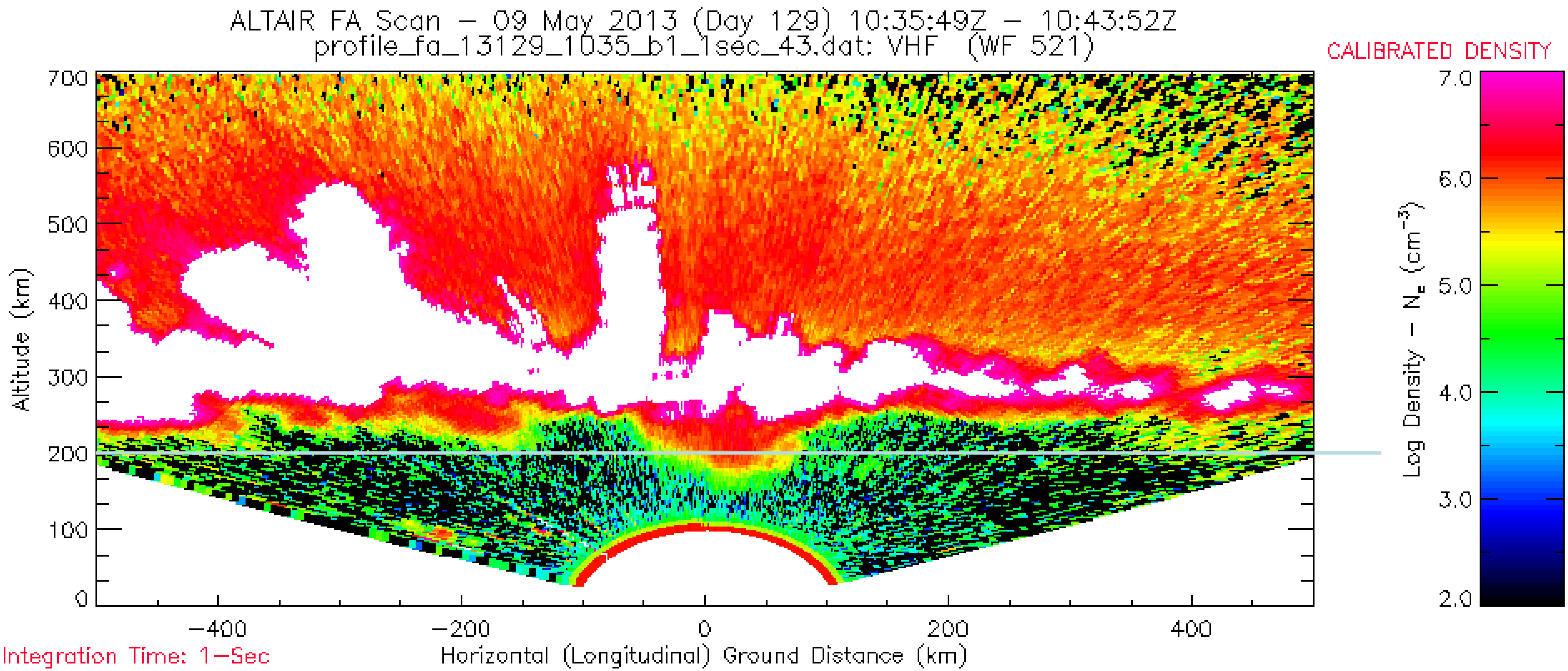

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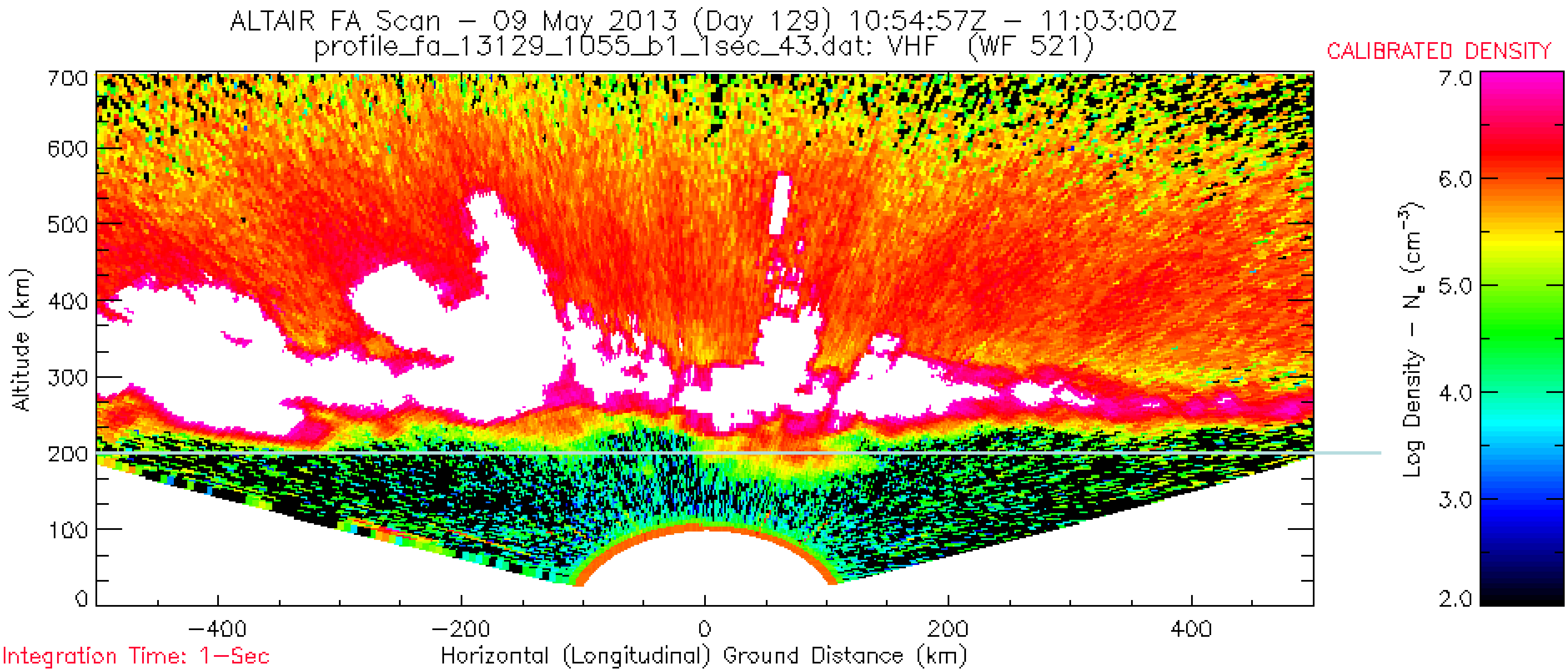

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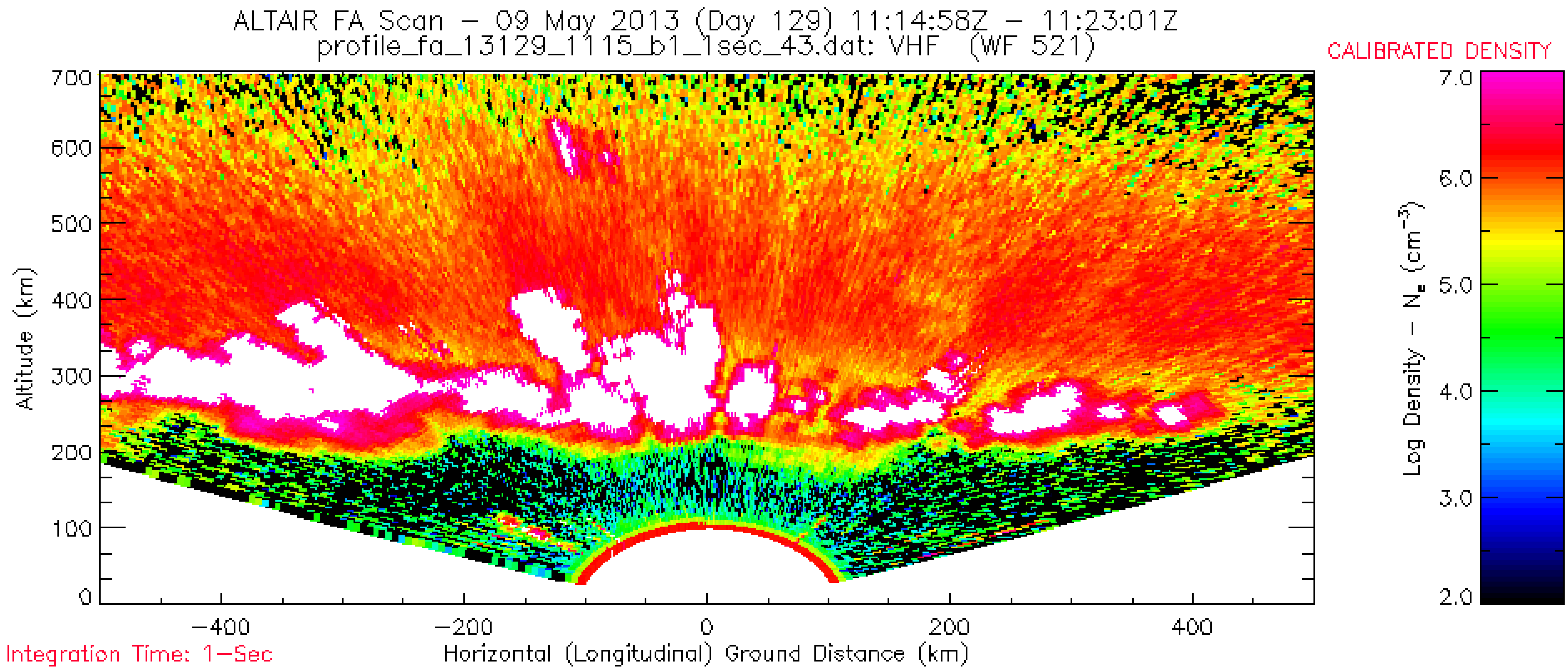

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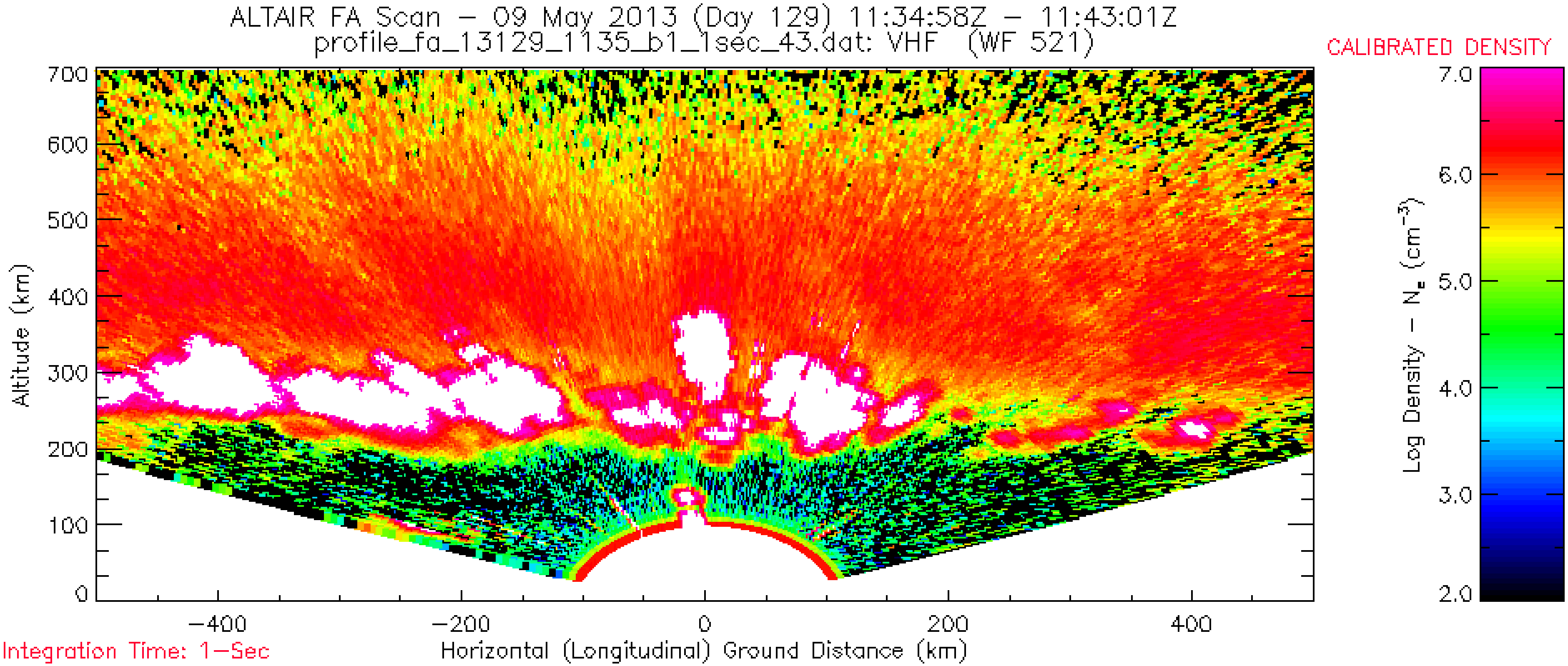
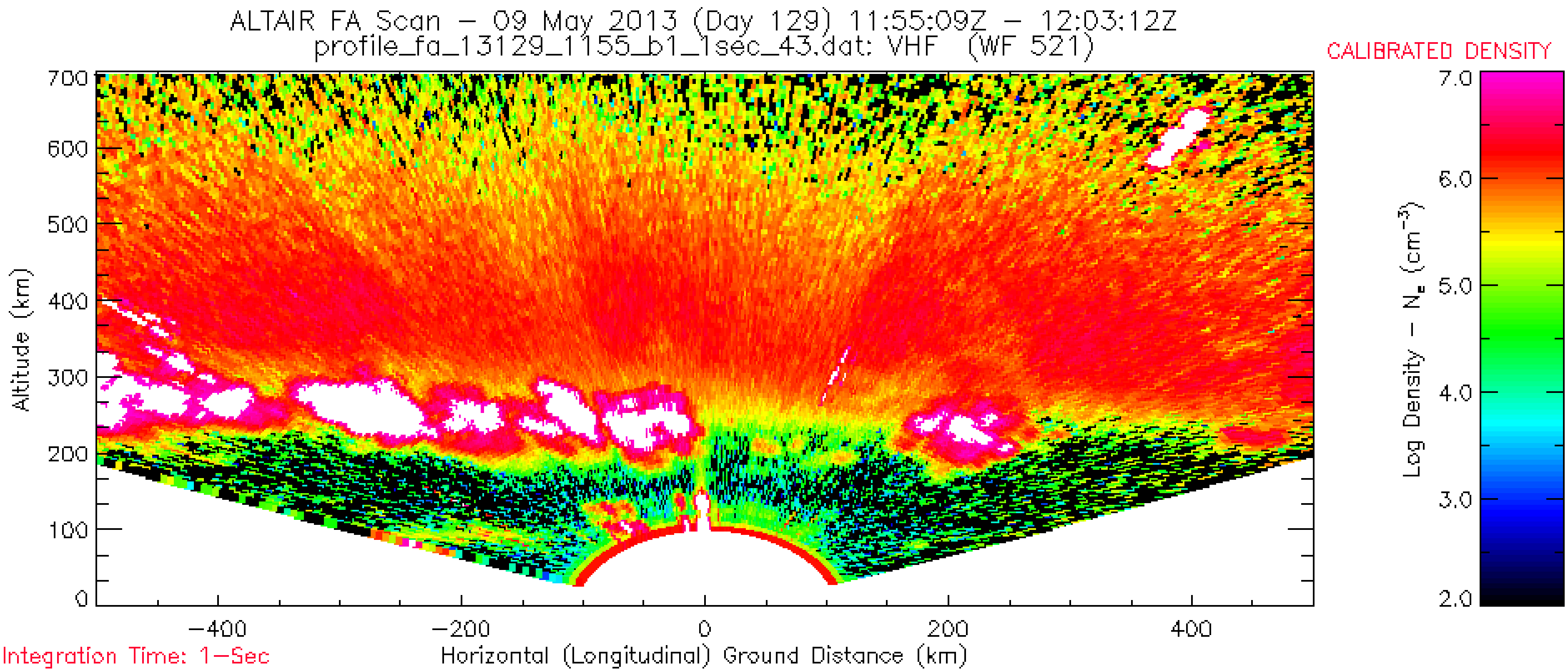


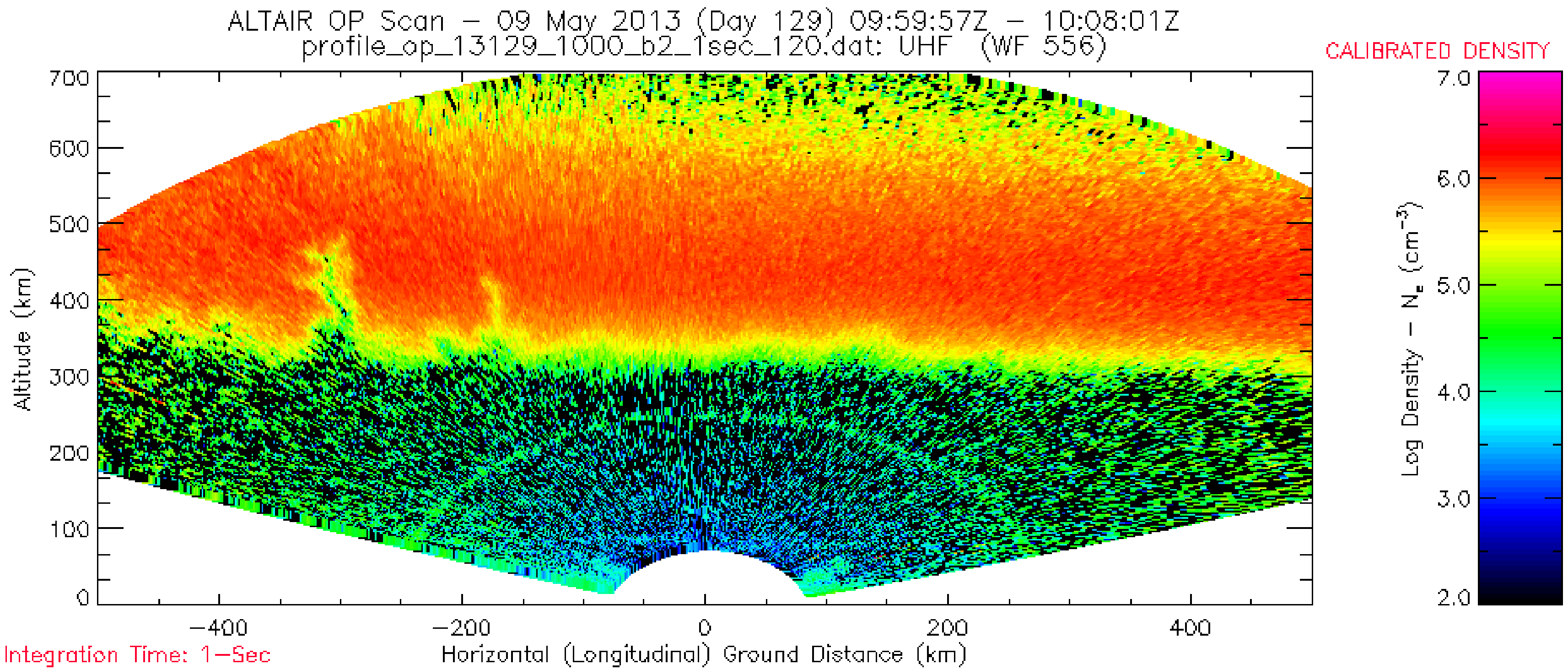
VHF Perp-B Coherent Scatter Scans

11:55 UT to 12:03 UT



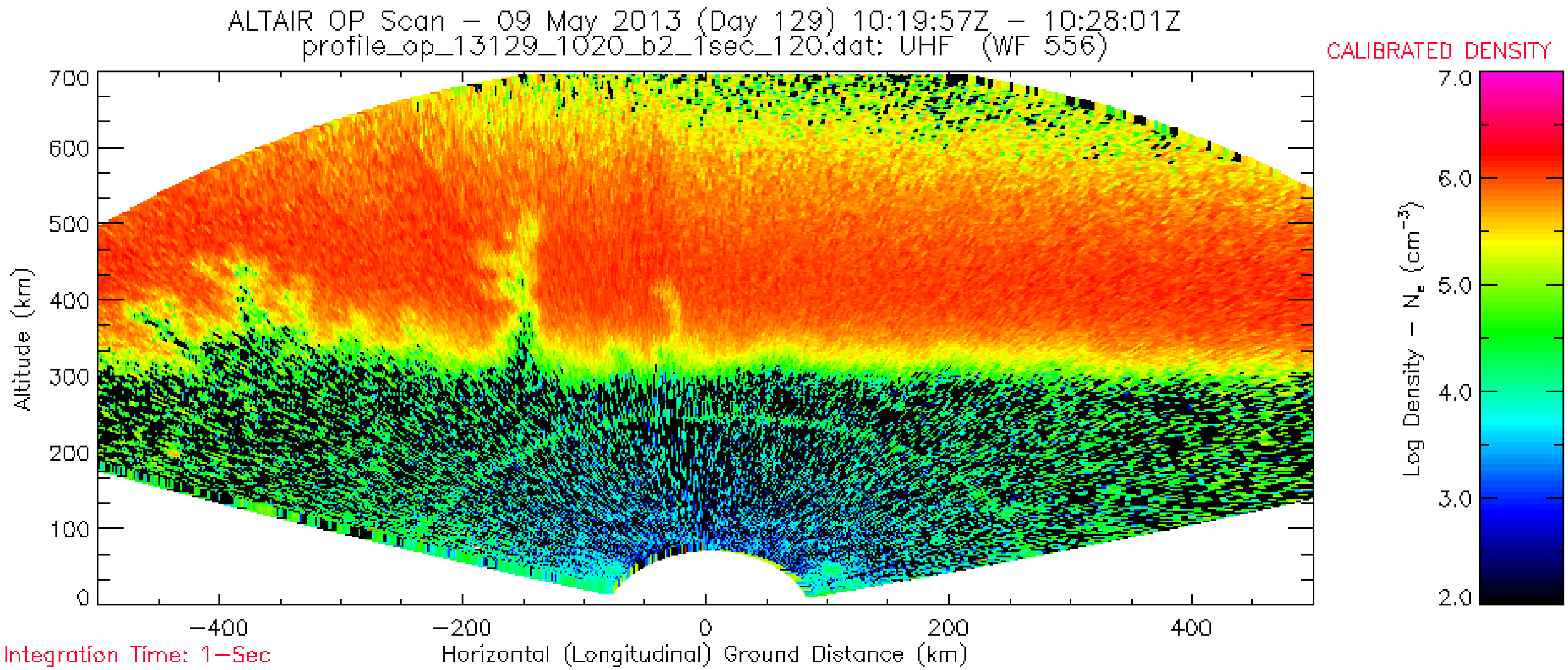
Off-Perp Incoherent Scatter Scans

10:00 UT to 10:08 UT



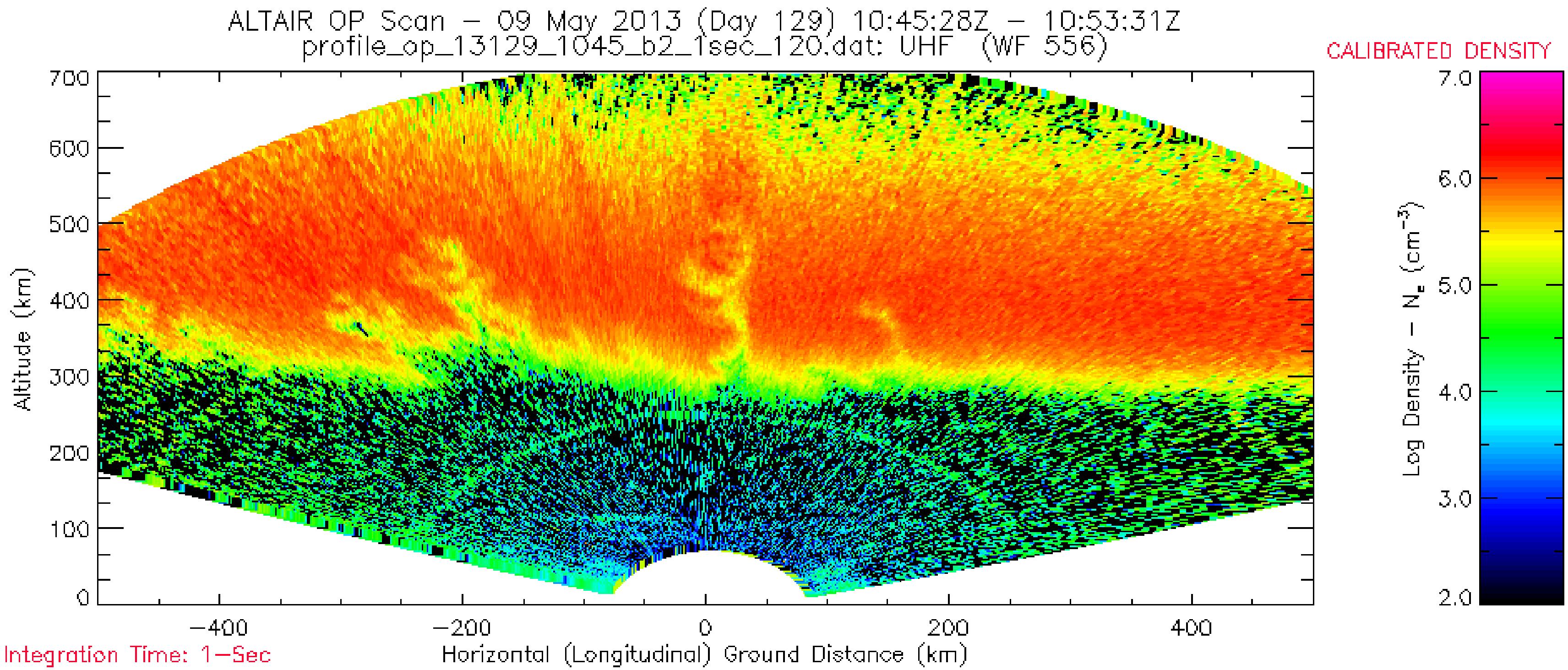
Off-Perp Incoherent Scatter Scans

10:20 UT to 10:28 UT



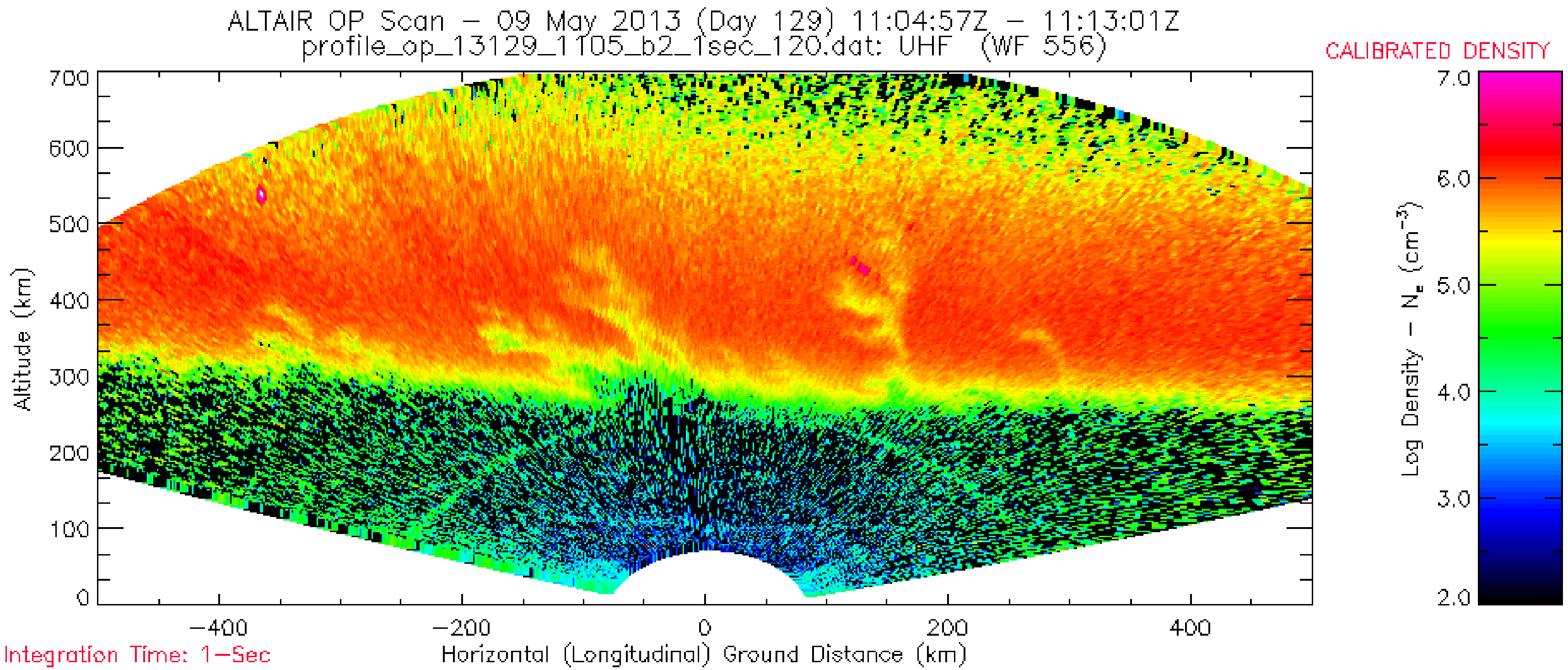
Off-Perp Incoherent Scatter Scans

10:45 UT to 10:53 UT



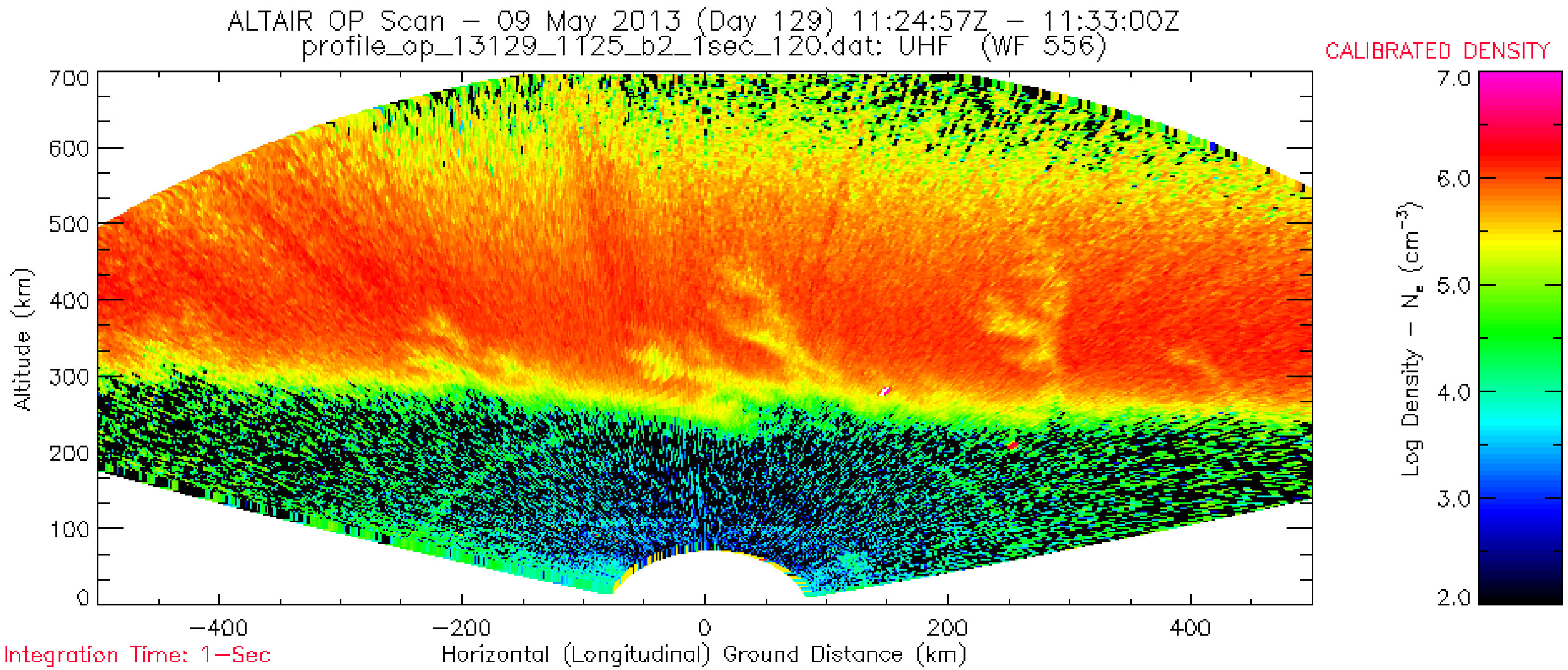
Off-Perp Incoherent Scatter Scans

11:05 UT to 11:13 UT



Off-Perp Incoherent Scatter Scans

11:25 UT to 11:33 UT



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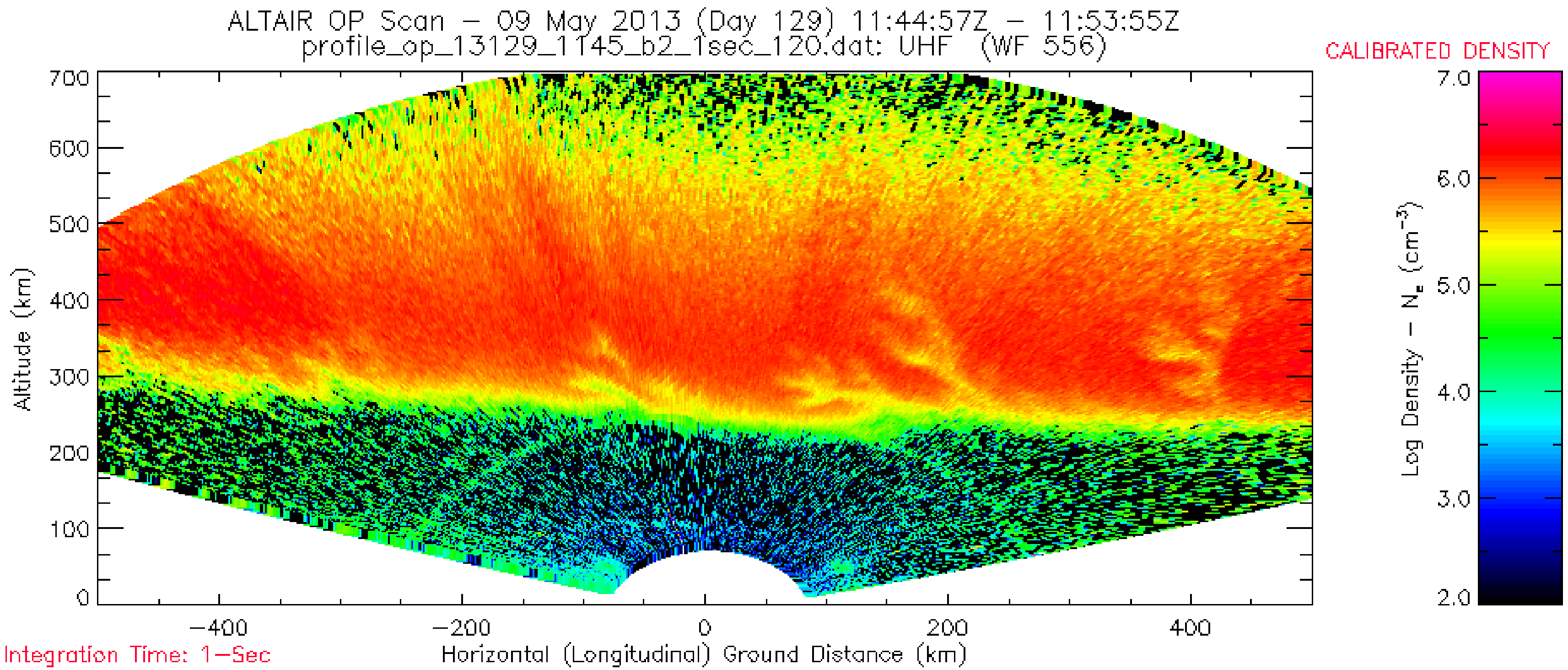
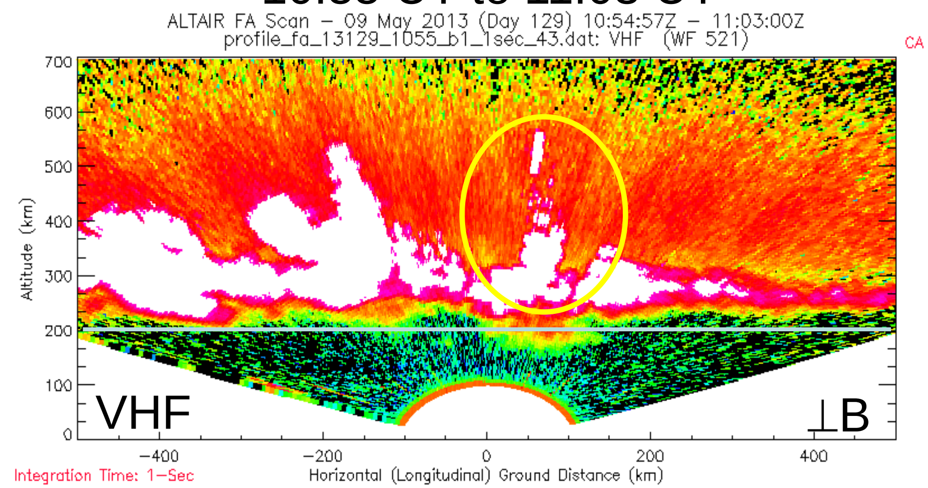


Combined View Needed to Understand Physics

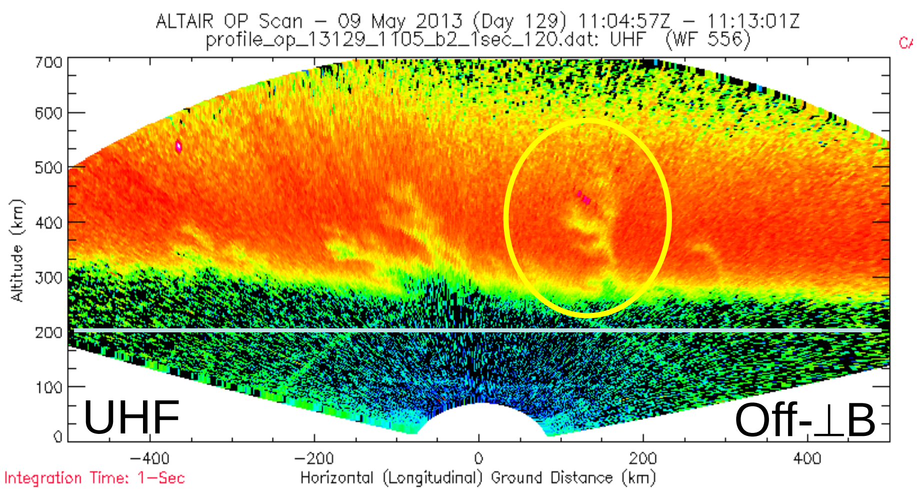
Three remarkable views of the same plasma!

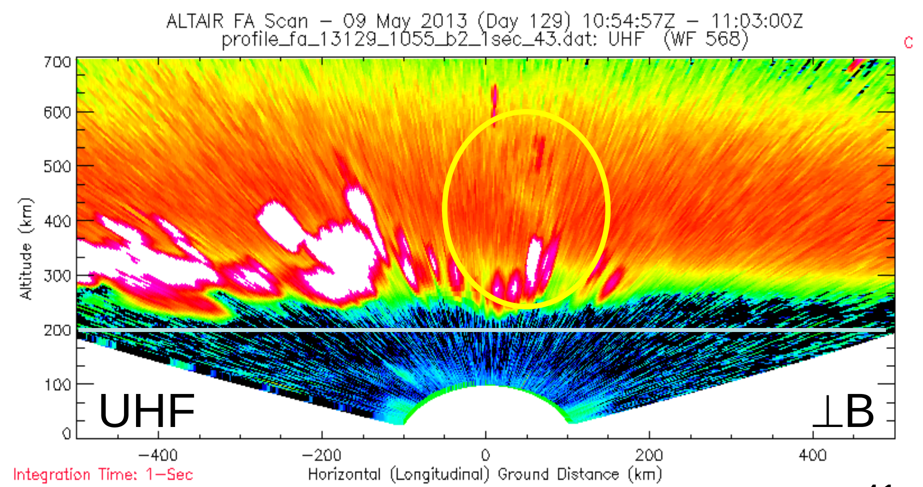
- Clearly illustrates existence of large-scale structure with an irregularity (turbulence) spectrum rapidly decaying at short-scales
- Preliminary investigation indicates this anomalous behavior is a result of MOSC

10:55 UT to 11:03 UT

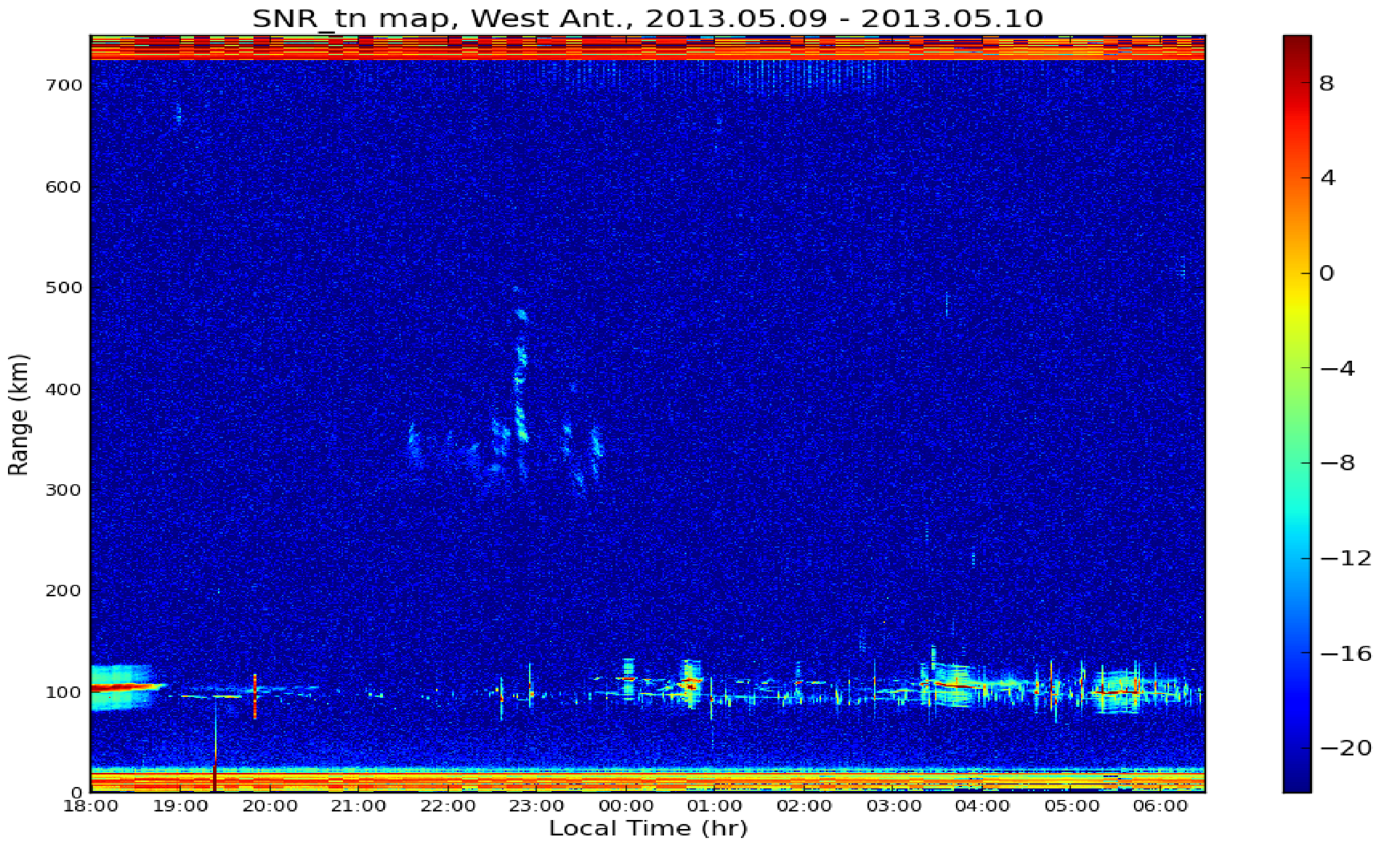


11:05 UT to 11:13 UT





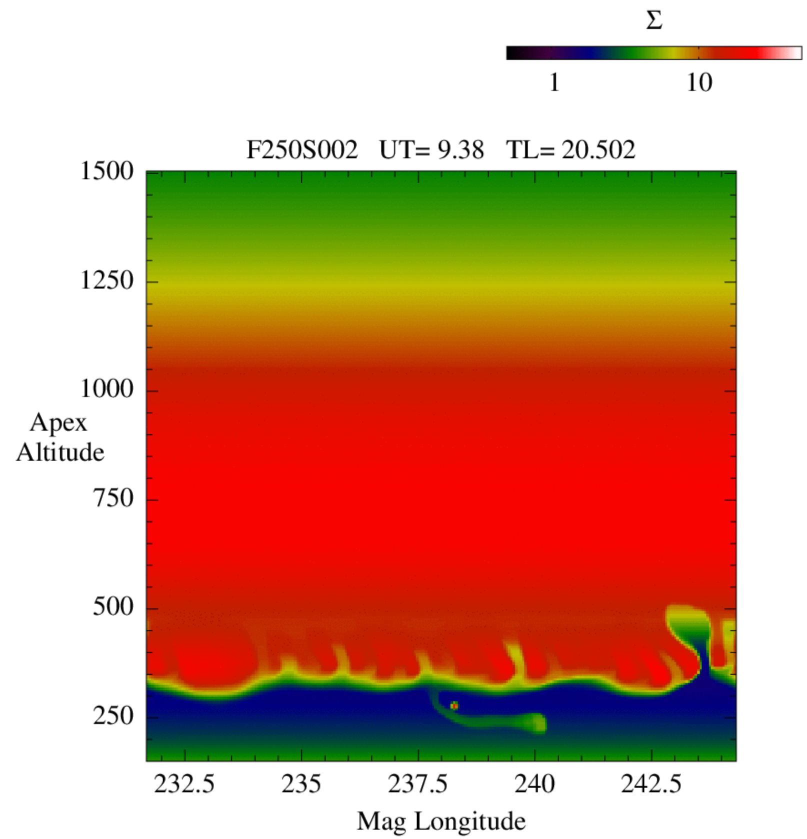
More Evidence: VHF Coherent Radar



- 50 MHz coherent backscatter radar echoes of plumes during this period were much weaker than usual (E. Kudeki, private communication)

Modeling Results

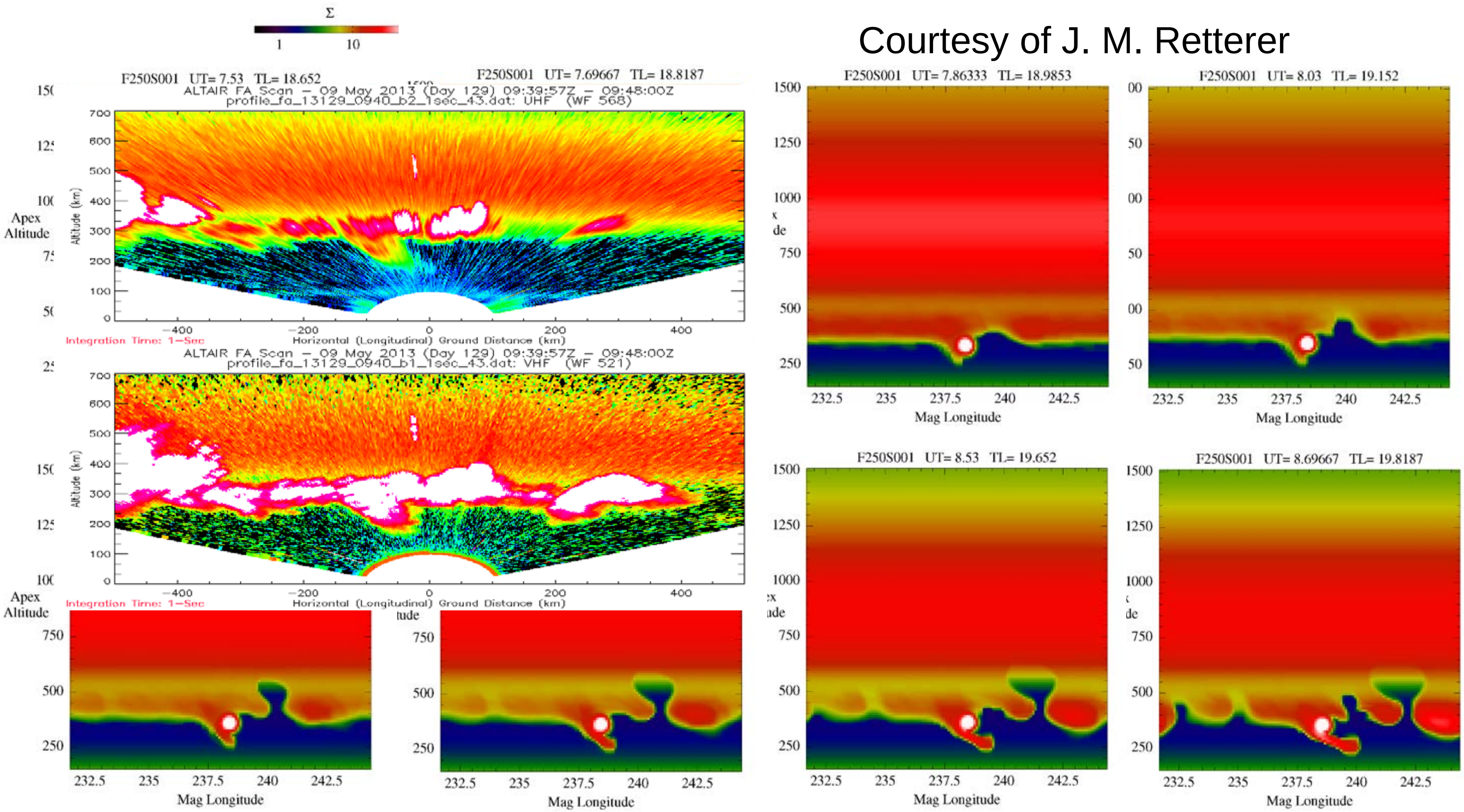
- John Retterer's preliminary analysis showed the potential to short circuit plumes depending on the altitude of the release and total density of the cloud
- The model would not show any effect from a 0.5 kg Sm release at 170 to 180 km
- There is much work to do in this area to understand the observations



7-kg Sm release initially confined to a 4-km radius shows an ability to inhibit scintillation-scale irregs

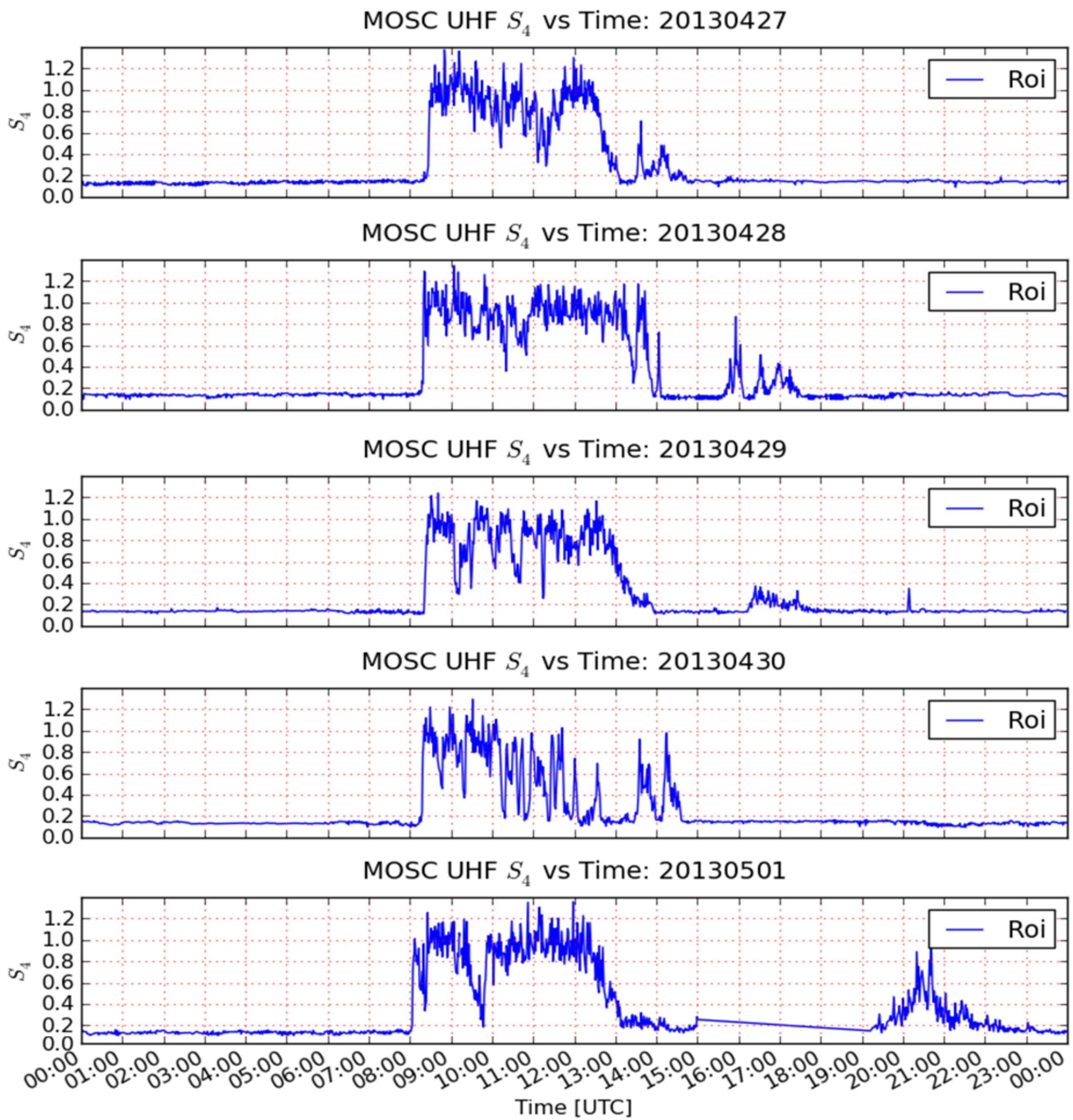
An Impressive Prediction

Courtesy of J. M. Retterer



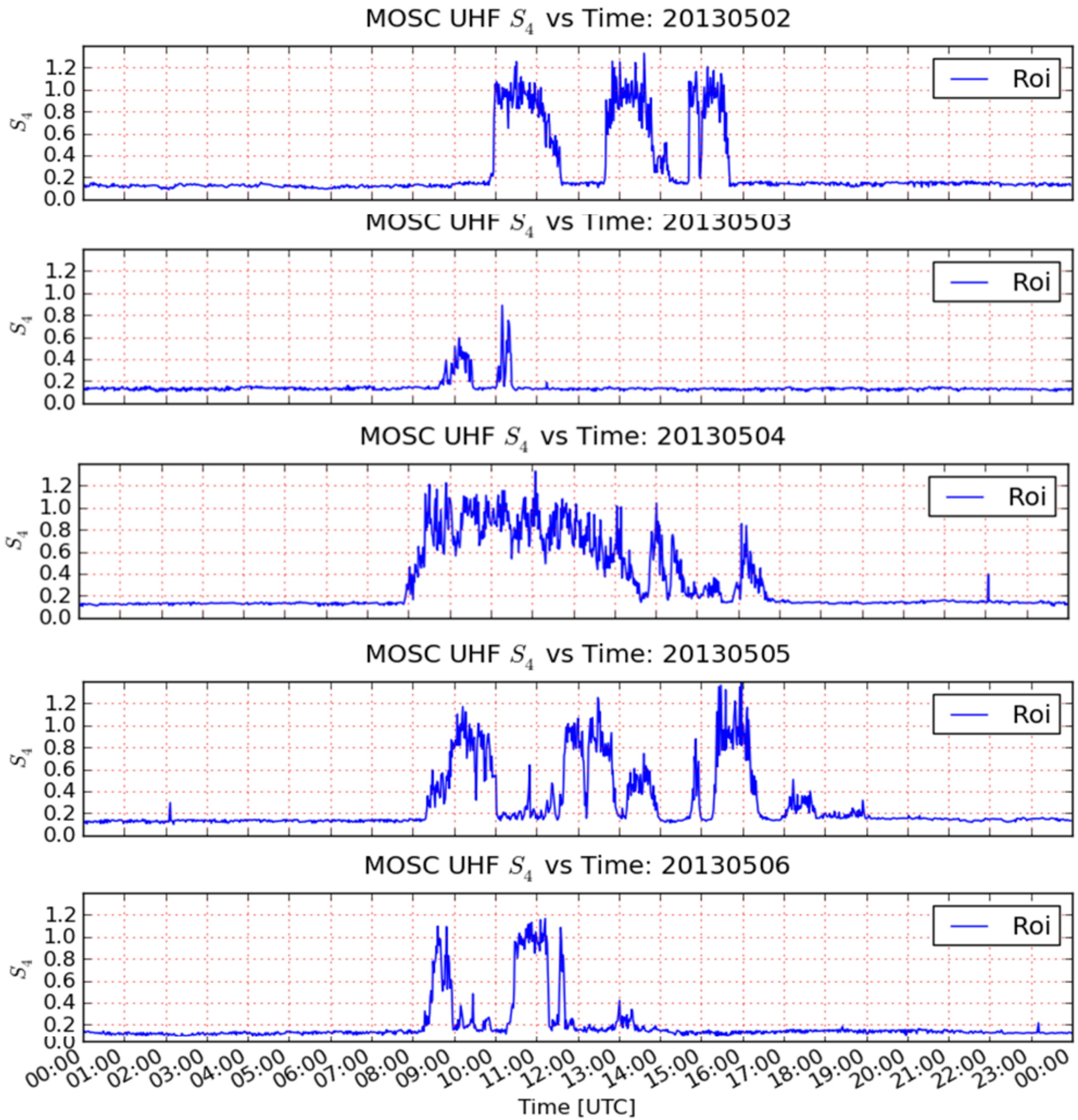
SmO+ released at 250 km apex altitude generates “comma” feature observed with ALTAIR during both MOSC releases

UHF SATCOM Scintillation 27April to 01 May

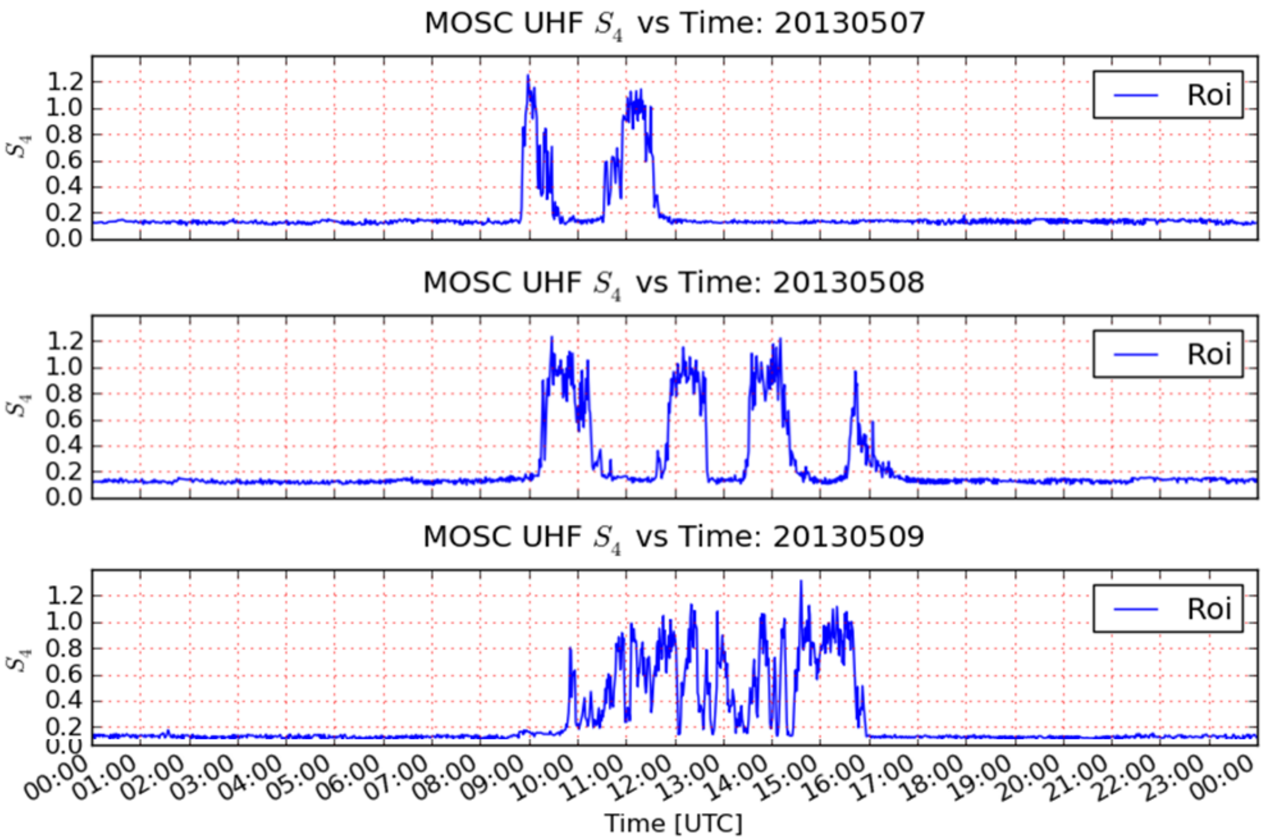


Launch Night

UHF SATCOM Scintillation 02 May to 06 May



UHF SATCOM Scintillation 07 to 09 May



Launch Night

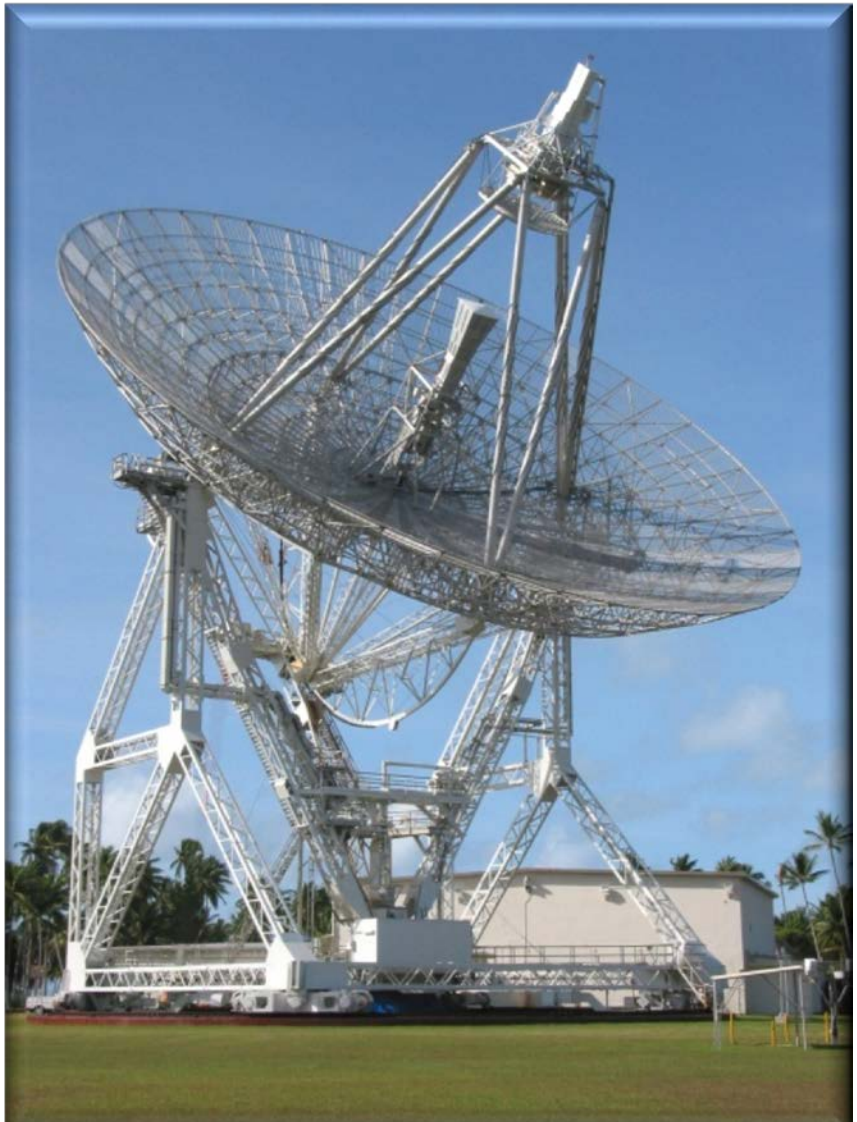
Summary

- ALTAIR radar successfully characterized plasma characteristics of ionized samarium in space
- The samarium plasma appears to have had a remarkable influence on the ambient ionosphere
  - Damping growth of short-scale irregularities and possibly modifying the development of the large-scale bubbles
- More analysis and modeling is needed to verify these results, but so far it appears promising!

A small amount of ionized material may have had an oversized impact on the upper atmosphere!

Back-up Slides

ALTAIR Deep Space Tracking Radar



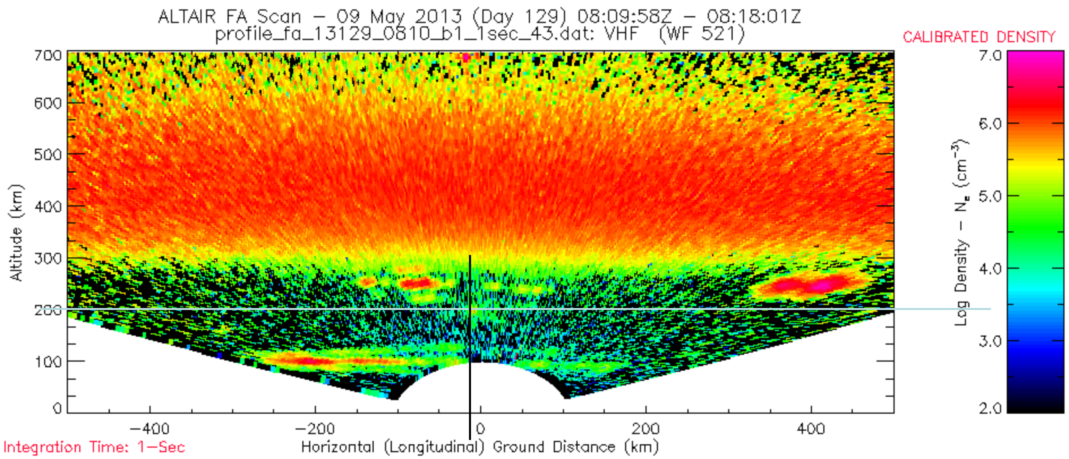
Advanced Research Project Agency (ARPA) Long-range Tracking and Identification Radar (ALTAIR)

- Dual Frequency:
  150 MHz/422 MHz
- Max Bandwidth:
  7 MHz/18 MHz
- 46 m dish
- Peak Power
  VHF: 6.0 MW
  UHF: 6.4 MW
- Incoherent Scatter: Direct scatter from electrons in the ionosphere (10^{-40} dBsm; equivalent to a ~dime!)

Special acknowledgment to Robert Linstead and Robert Ferguson

MOSC Launch 2: May 9, 2013 UHF/VHF Comparisons (T+33 min)

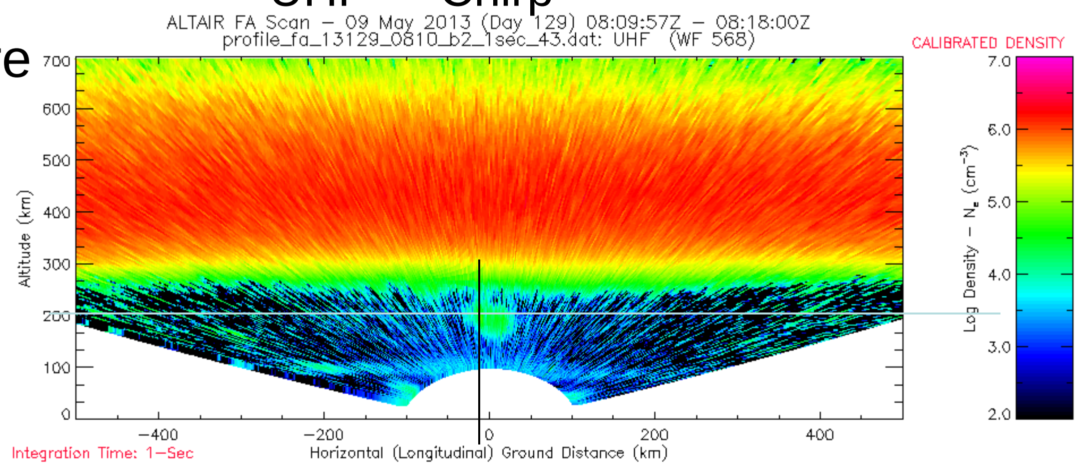
VHF -- 300 μsec (3-bit Barker)



- VHF beam is 3x wider than UHF (3° vs 1°) and measures turbulence scales 3x larger (~1m vs 0.35m)

- UHF has greater overall sensitivity, but VHF far more sensitive to field-aligned coherent scatter
- UHF detects almost no coherent scatter but does measure samarium plasma incoherently

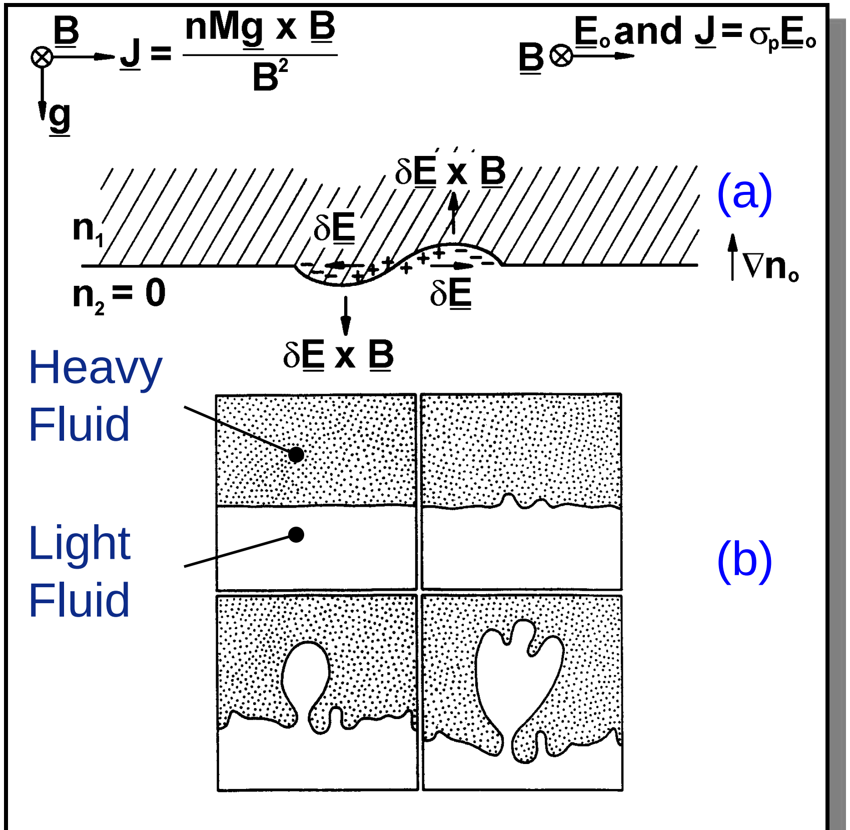
UHF -- Chirp



What Is Instability Process?

Basic Plasma Instability

View along bottomside of ionosphere
(E-W section, looking N from equator)



from *Kelley* [1989]

Plasma supported by horizontal field lines against gravity is unstable

(a) Bottomside unstable to perturbations (density gradient against gravity)

(b) Analogy with fluid Rayleigh-Taylor instability

Perturbations start at large scales (100s km)

Cascade to smaller scales (200 km to 30 cm)

GPS Positioning Errors During Solar Max

Scintillation can cause rapid fluctuations in GPS position fix;
Typical night from field experiments during solar maximum