Citizen radio science: An analysis of Amateur Radio transmissions with e-POP RRI

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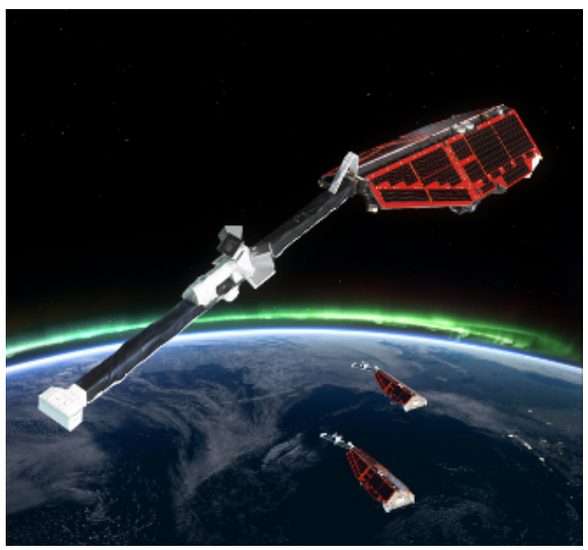
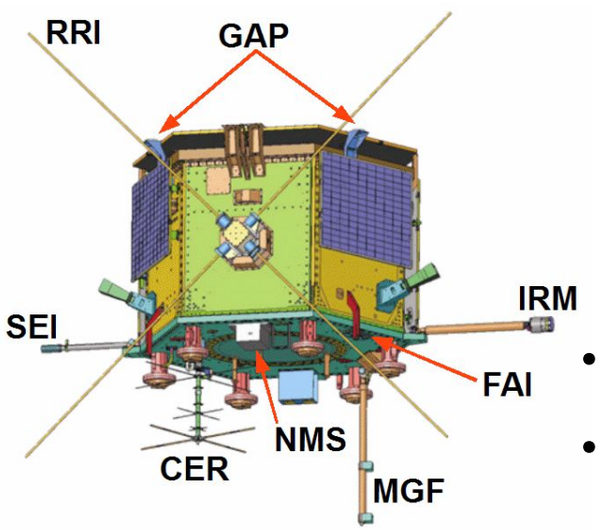
CASSIOPE/e-POP and now Swarm-E

- **CASSIOPE** (CAScade, Smallsat and IOnospheric Polar Explorer)
  - Launched September 29, 2013.
  - ~~1500 x 325 km polar orbit~~.
  - 1310 x 349 km polar orbit.
- **e-POP** (enhanced Polar Outflow Probe)
  - 8 instruments (5.5 working).
  - Small scale ionospheric plasma dynamics.
- Swarm (ESA) is a 3-satellite constellation with a geophysics focused primary science mission.
  - Complementary science payloads with e-POP.
  - Accommodating orbital profiles.
- e-POP is now Swarm-Echo
- Swarm is now a 4-satellite constellation.
  - Swarm-Alpha, -Beta, -Charlie and now Swarm-Echo (e-POP).

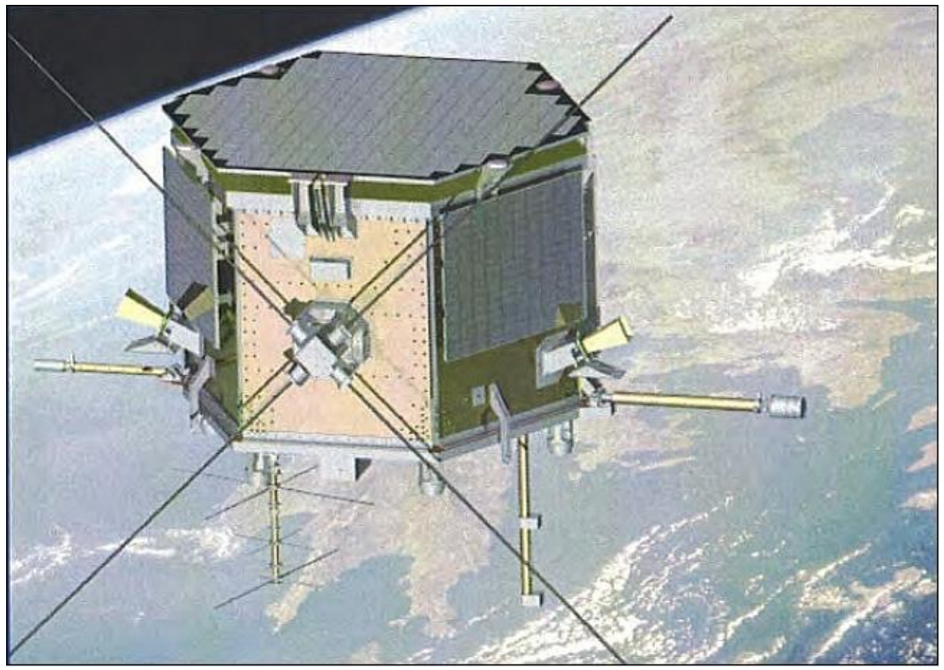


Swarm



e-POP
(now Swarm-E)

The Radio Receiver Instrument (RRI)



- **RRI** (Radio Receiver Instrument)
  - 4, 3-m monopole antennas.
  - Study radio emissions at 10 Hz to 18 MHz.
  - 31 kHz bandwidth.
  - 62.5 kHz sampling.
  - Target: natural and artificial radio emissions.
  - Natural: whistlers, auroral hiss, etc…
  - Artificial: radars (over the horizon), HAARP, etc…
- Study HF radio propagation in the ionosphere.
- Study F-region density structures.

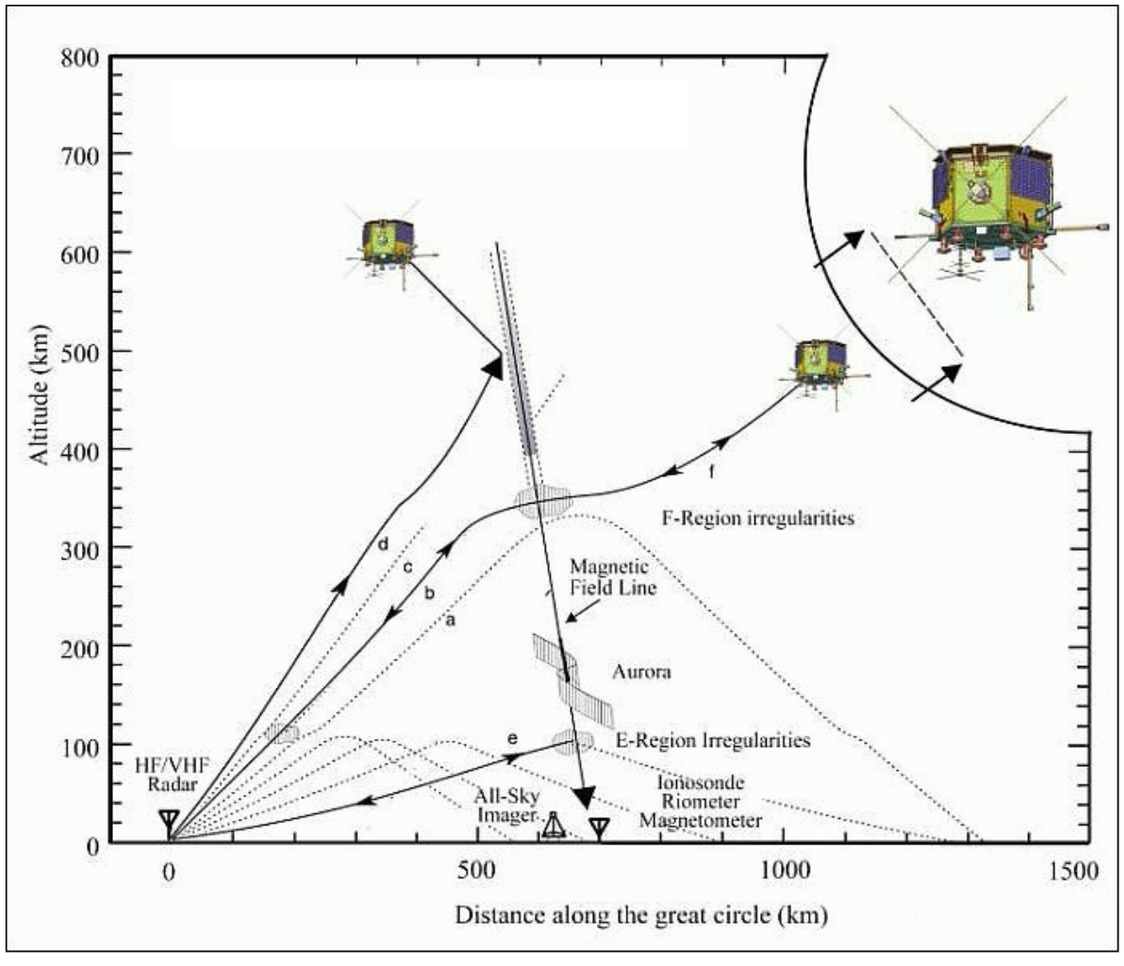


Image credit: University of Calgary, CSA, MDA

The Radio Receiver Instrument (RRI)

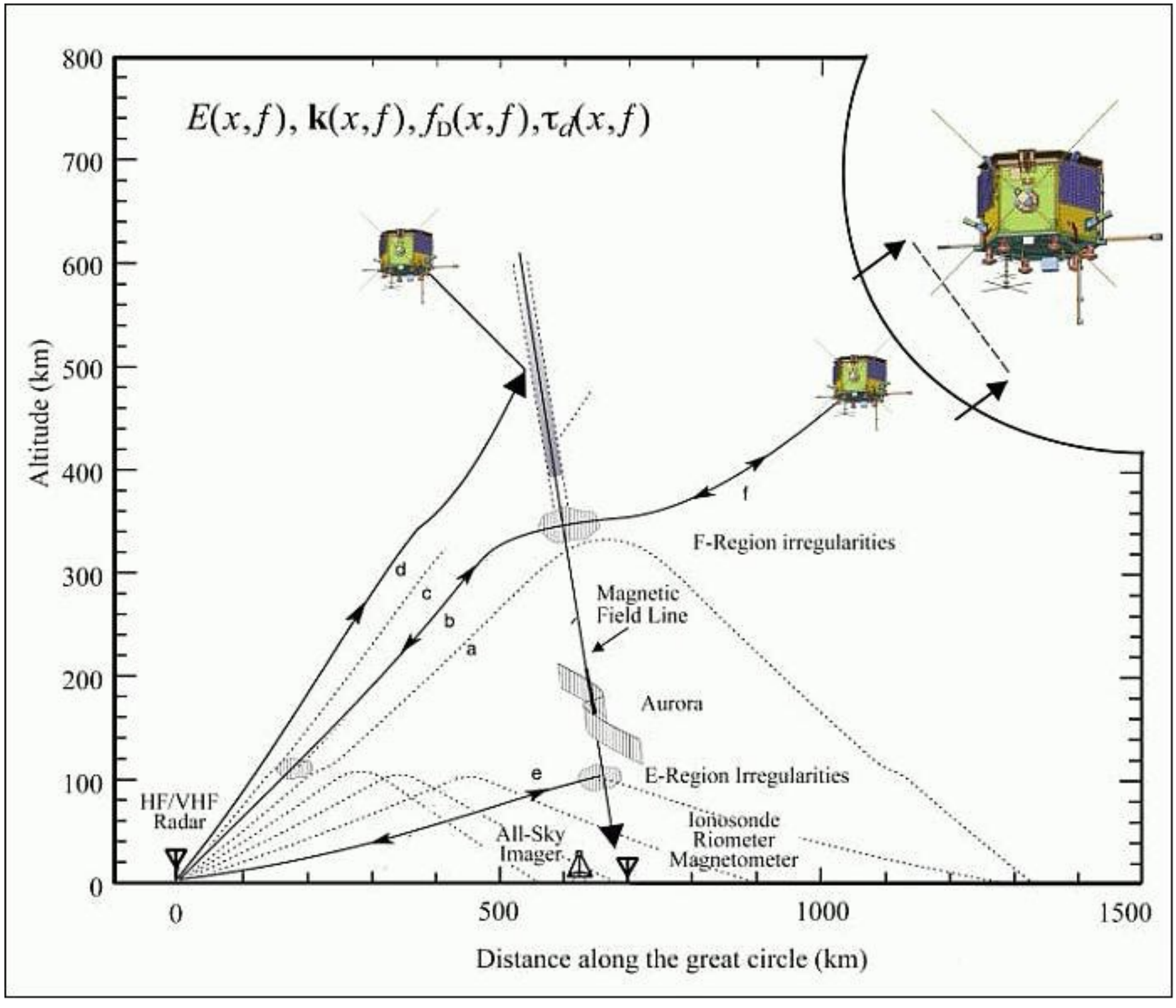


Image credit: University of Calgary, CSA, MDA

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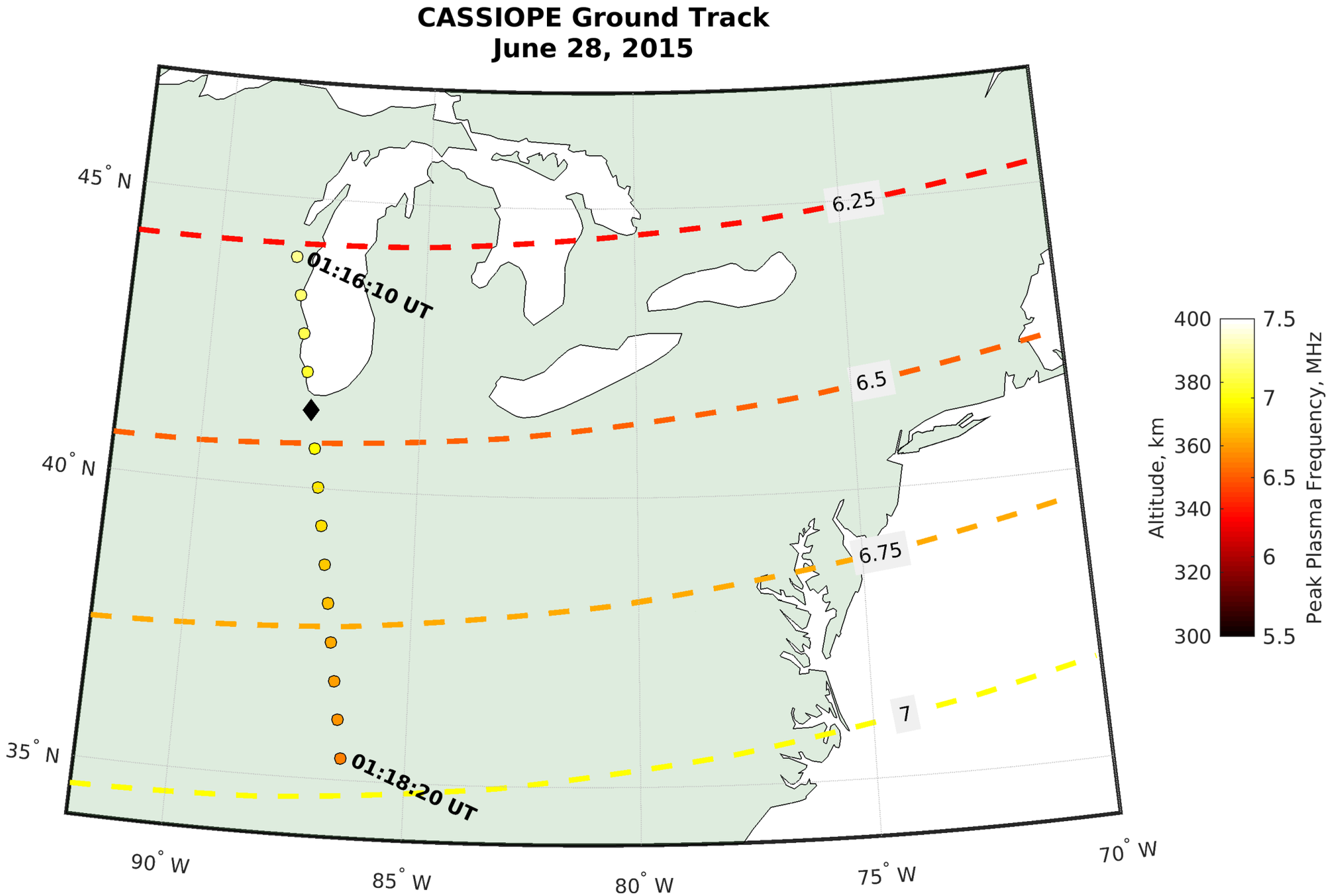
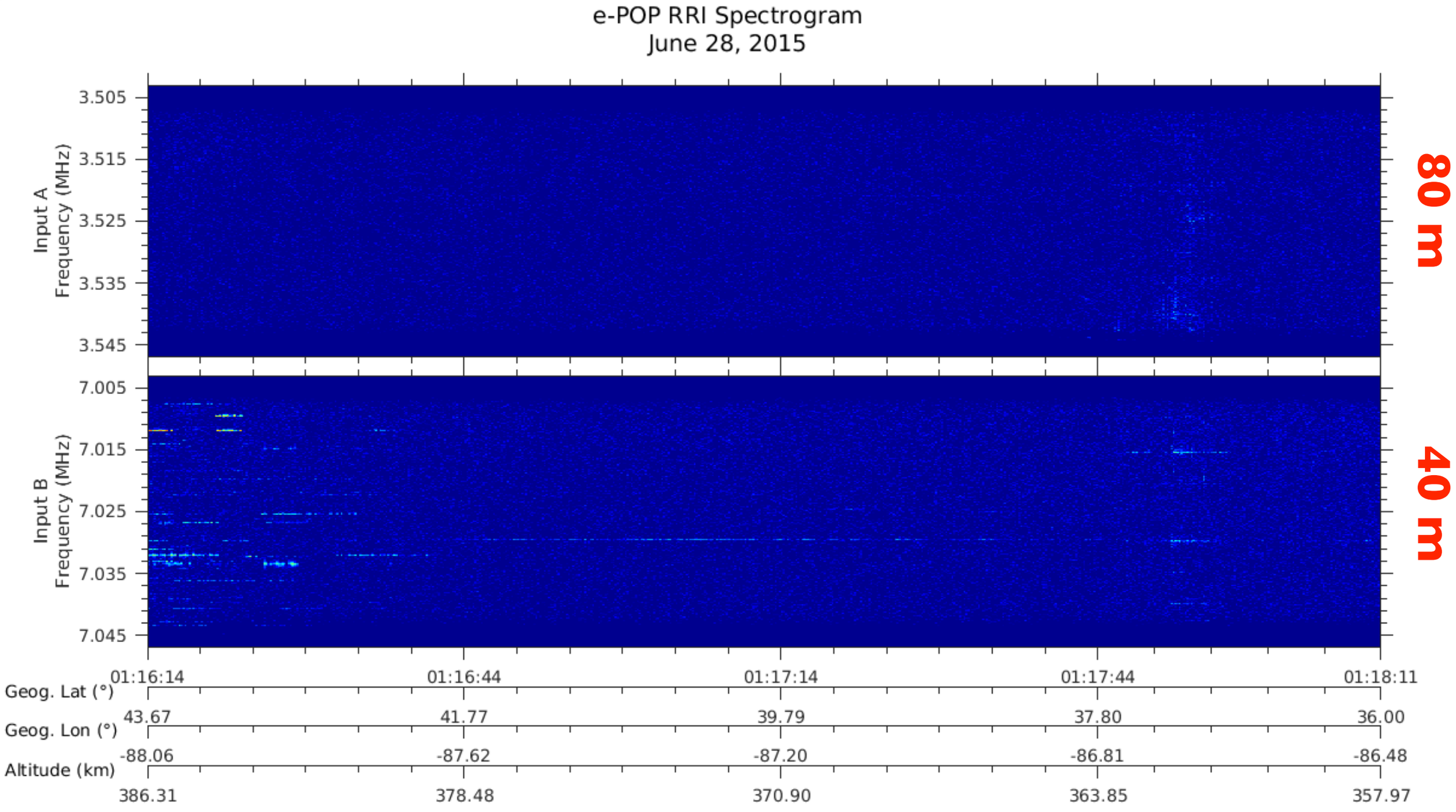
2015 ARRL Field Day Experiment



What RRI recorded: hams



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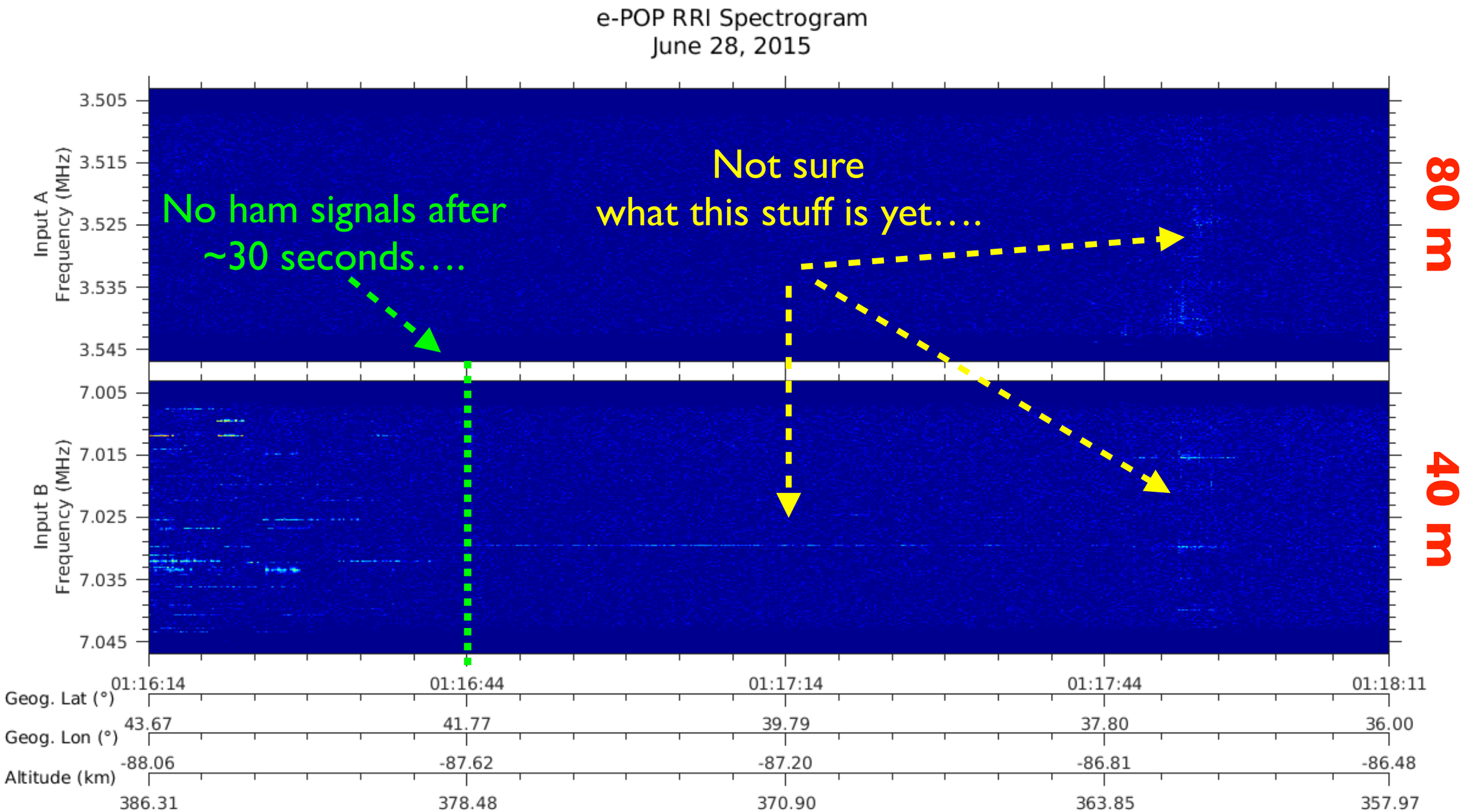
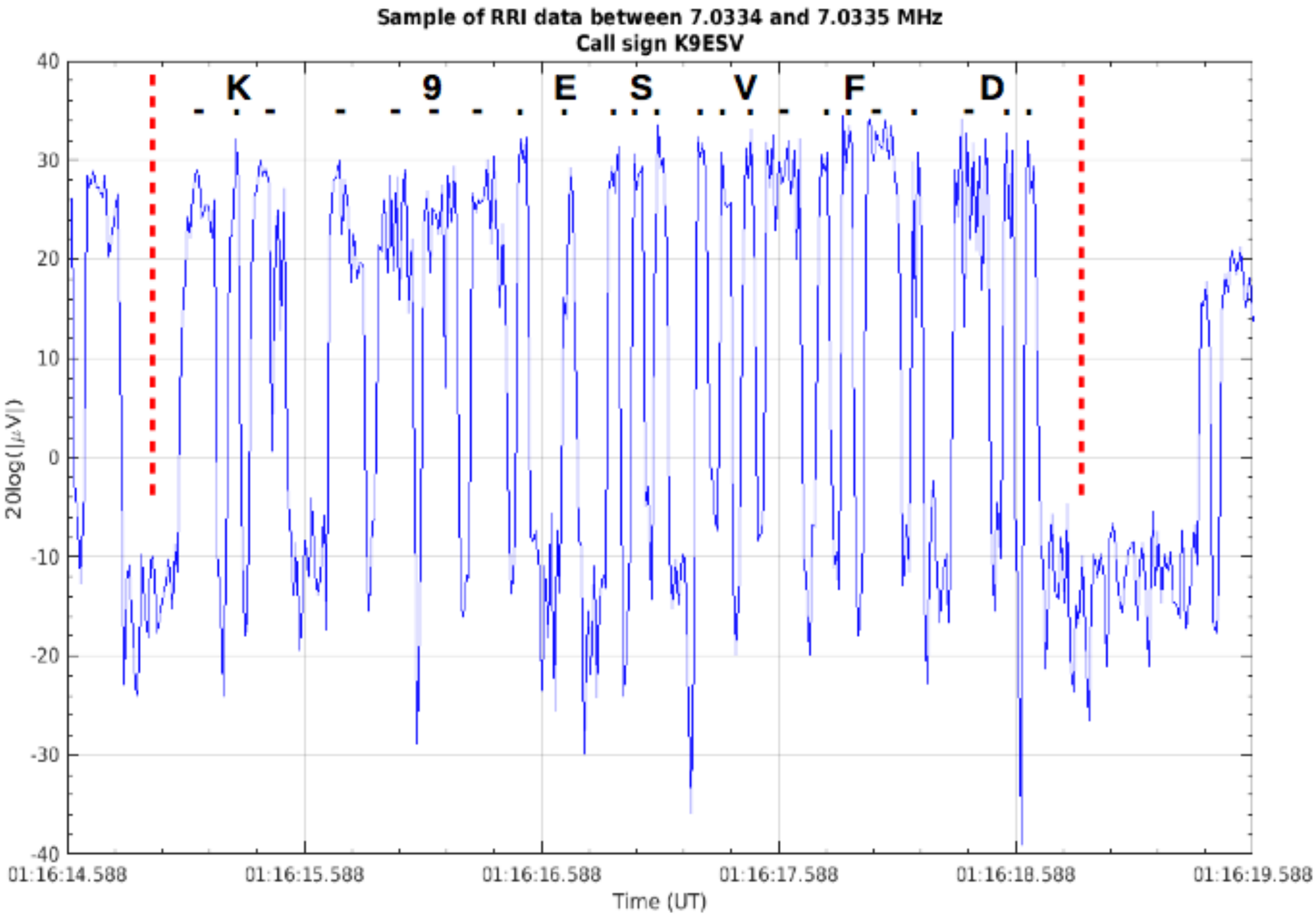


Identify and locate the hams

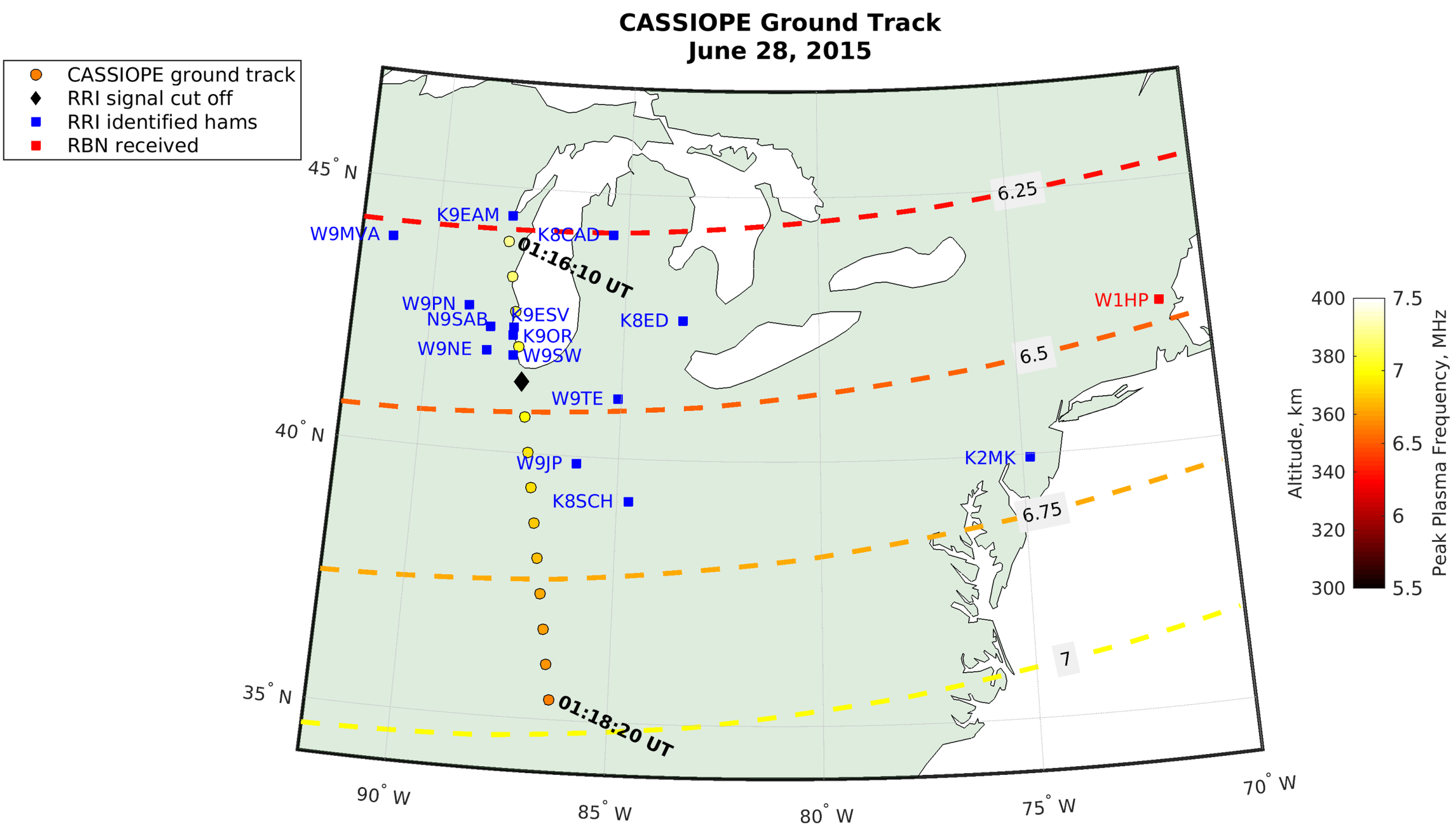
Call Sign	Geog. Latitude (°)	Geog. Longitude (°)	Freq. (MHz)
W9NE	41.90	-88.49	7.00949
K8CAD	44.22	-85.40	7.01138
W9PN	42.72	-89.03	7.01168
W9MVA	43.87	-91.18	7.01453
W9TE	41.13	-85.09	7.02227
W9JP	39.87	-86.04	7.02676
W9SW	41.84	-87.81	7.02676
K9EAM	44.46	-88.09	7.0325
K9ESV	42.34	-88.44	7.03349
K8SCH	39.19	-84.72	7.0361
N9SAB	42.36	-87.83	7.03905
K8ED	42.65	-83.51	7.04339
K9OR	42.21	-87.85	7.04483
K2MK	39.94	-74.88	7.04483
W1HP*	42.69	-71.22	7.006

- Call signs were aurally decoded.
- Hams were contacted by e-mail and asked to confirm their 2015 Field Day location.
  - 14 confirmed.
- W1HP not identified by RRI, but the Reverse Beacon Network (RBN).

Decoded example: K9ESV

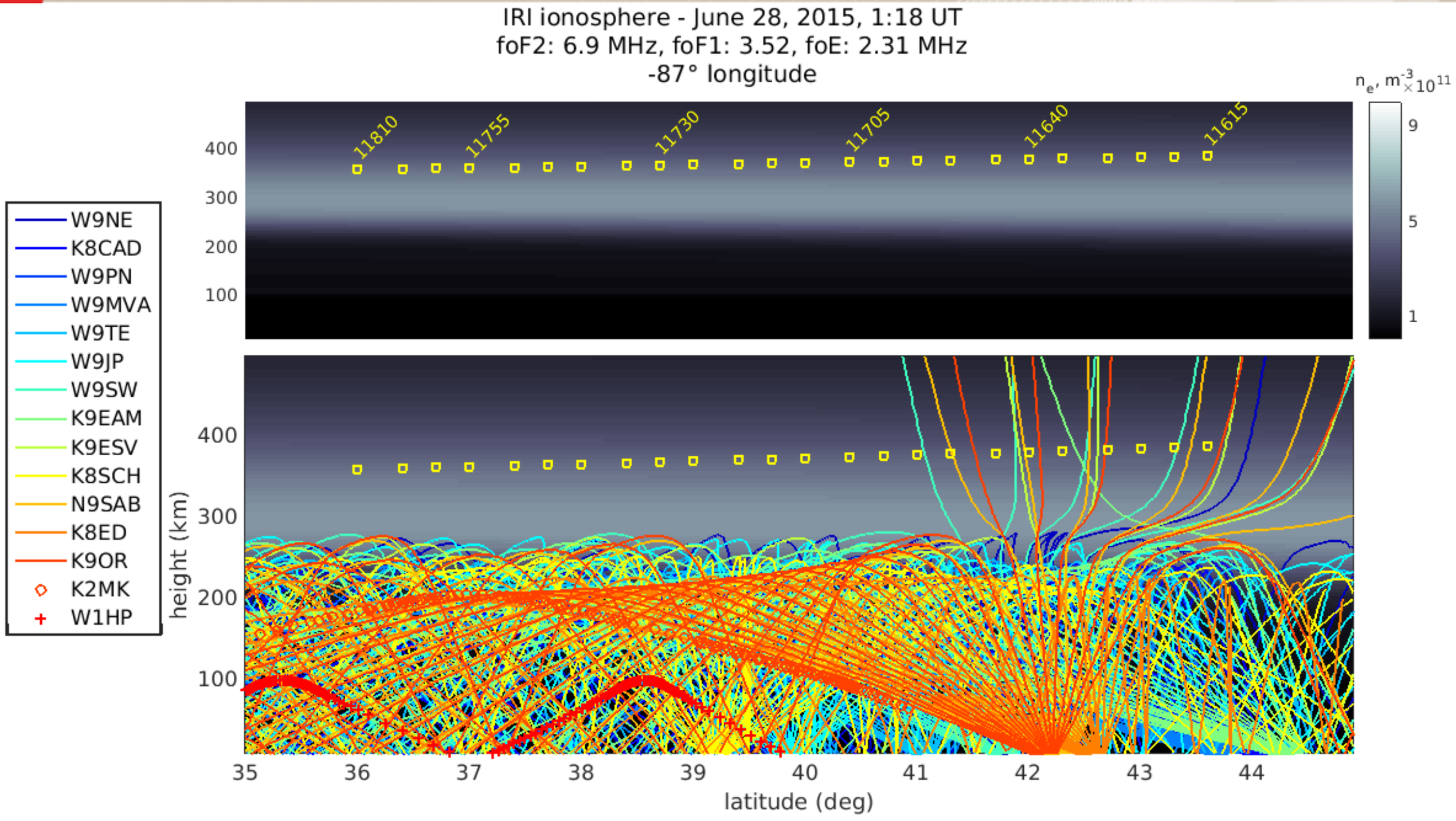


Locate the hams



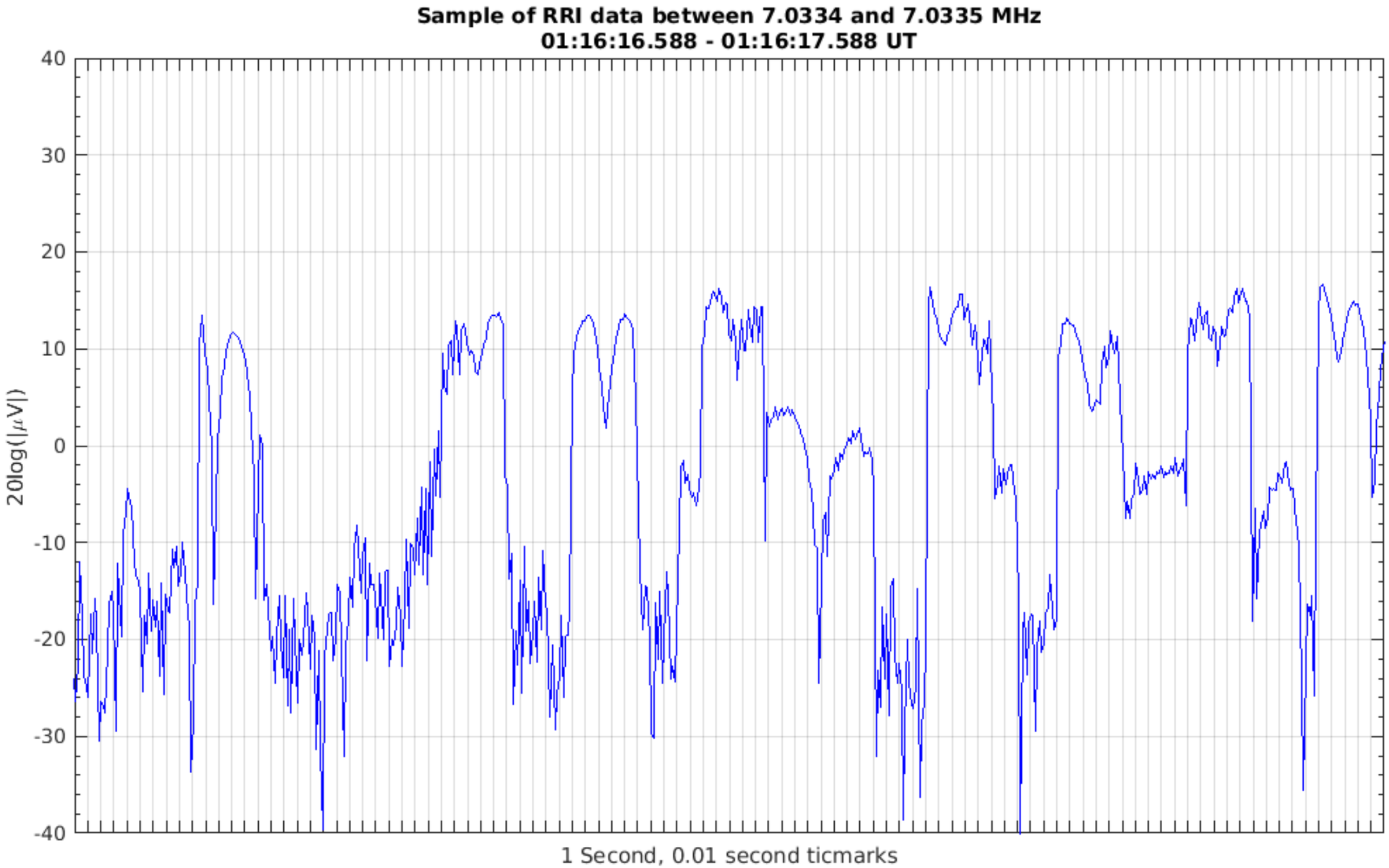
- Why did the ham transmissions cutoff after 30 seconds?
- RBN tells us that they didn’t stop transmitting.
- What does the ray tracing say?

Ray tracing the hams with PHaRLAP



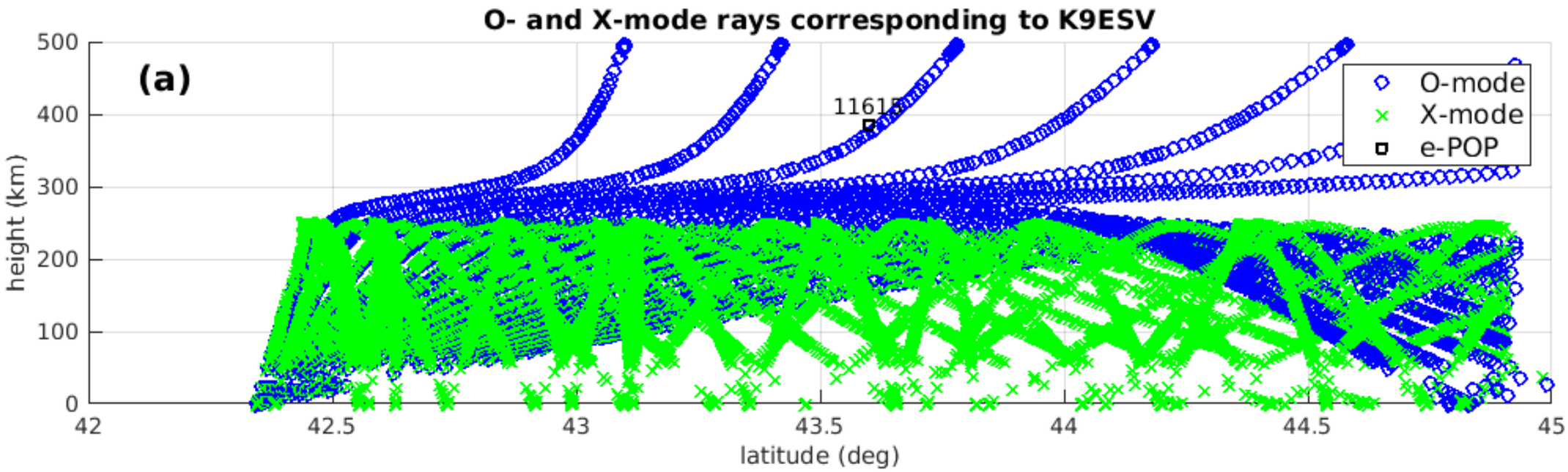
- Ray tracing predicts cutoff after 45 seconds.
- We saw cutoff after 30 seconds.

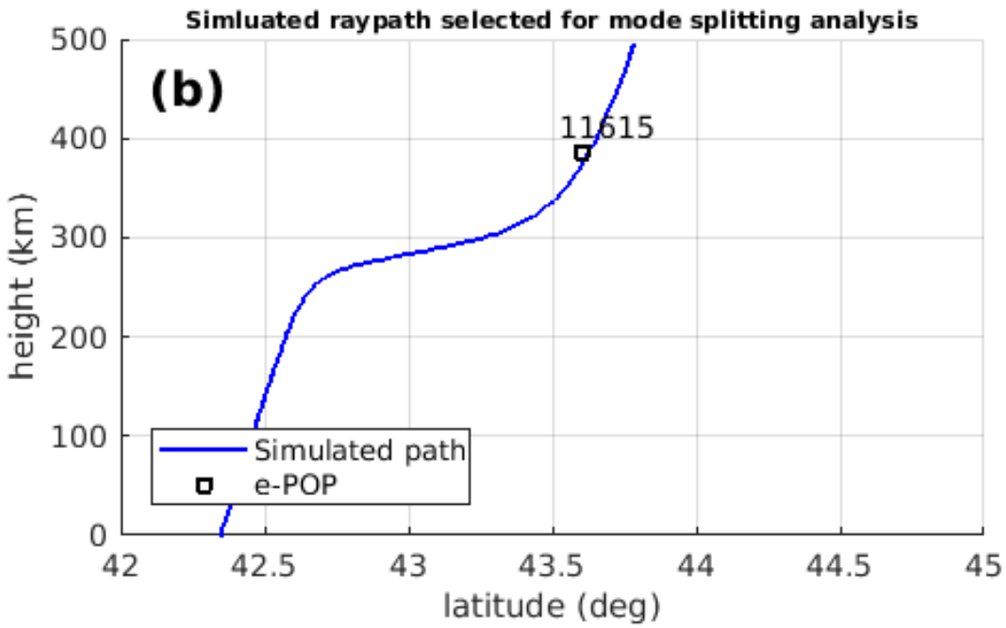
Digging deeper: a closer look at K9ESV's signal

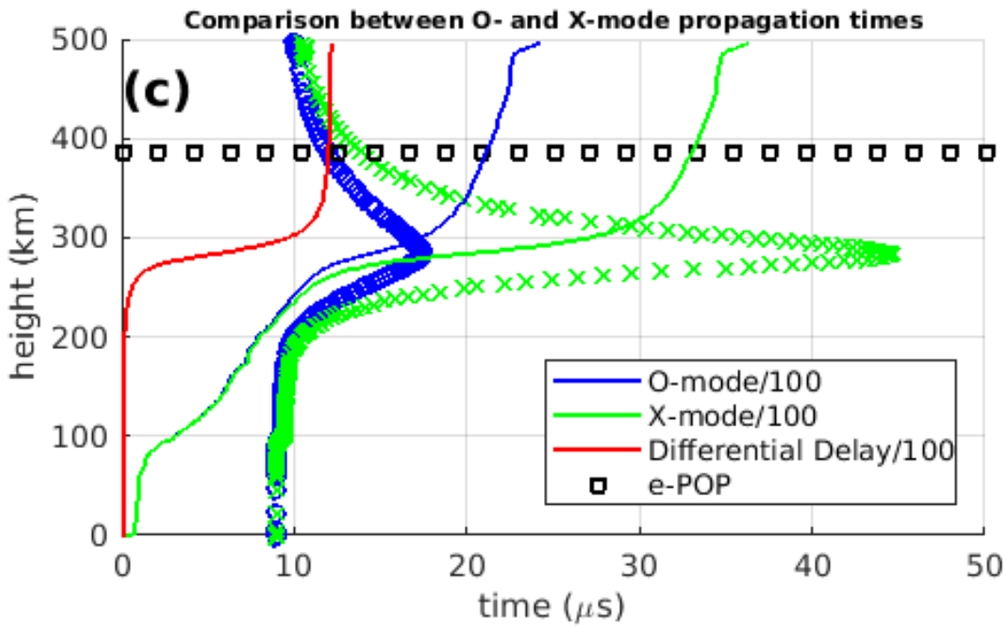


- Oscillation on top of the signal at ~33 Hz.

Hypothesis: O- and X-mode splitting

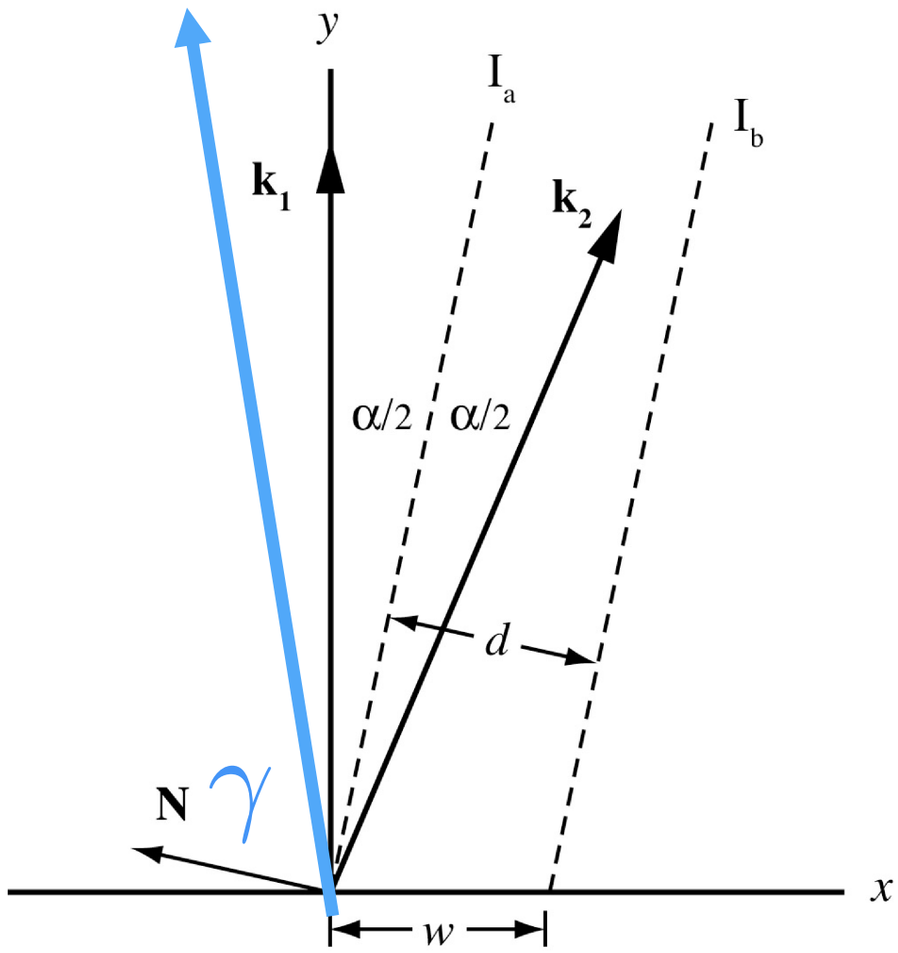






- Is the oscillation due to differential mode delay (between the O- and X-modes)?
  - NO, according to ray tracing.

Hypothesis: Self mode fades



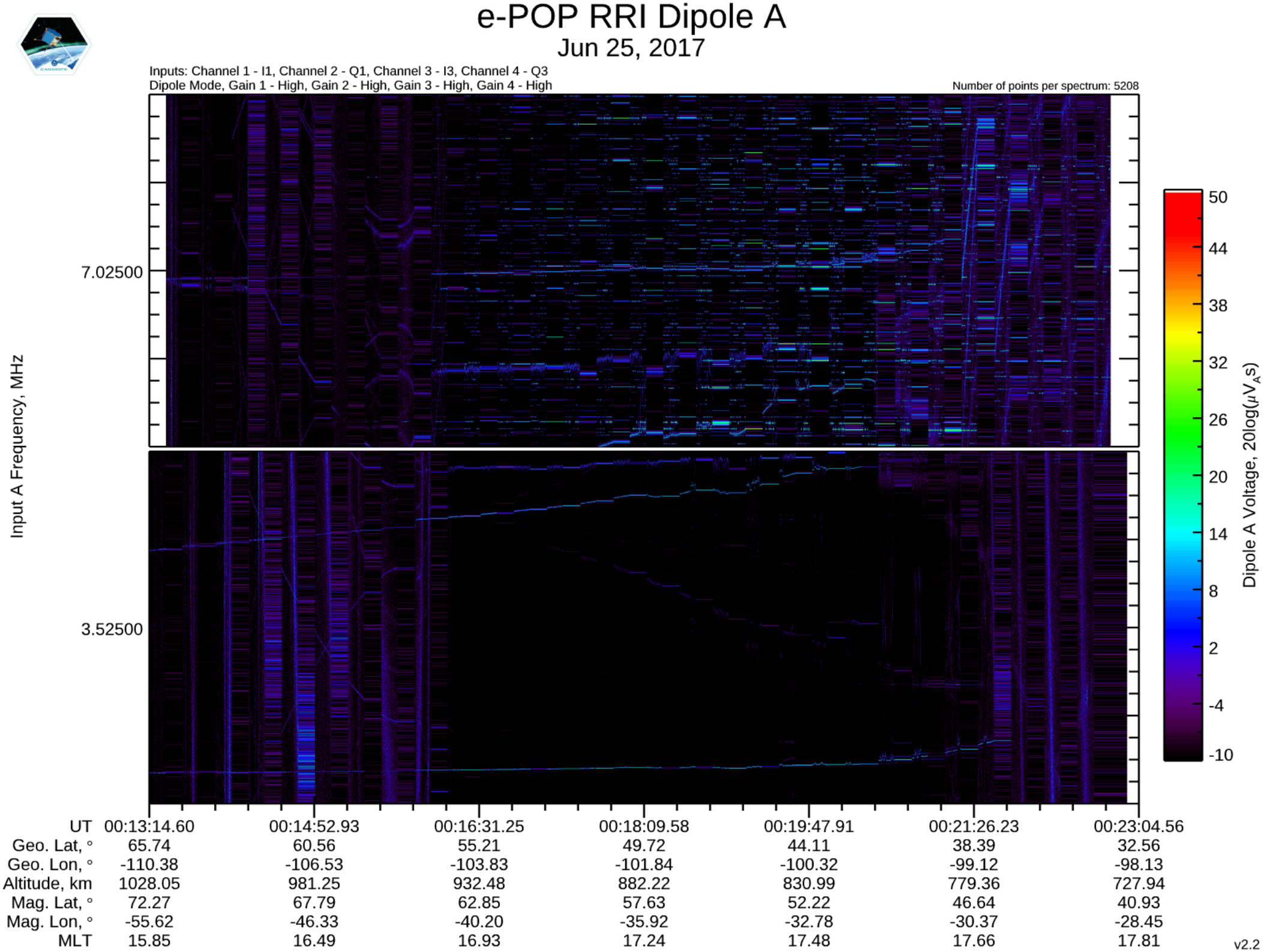
$$F = \frac{2v \sin(\alpha/2) \cos\gamma}{\lambda}.$$

v - spacecraft velocity; 7926 m/s.
α - 15°
γ - 45°
λ - wavelength.
F ~ 36 Hz; close to 33 Hz oscillation observed.

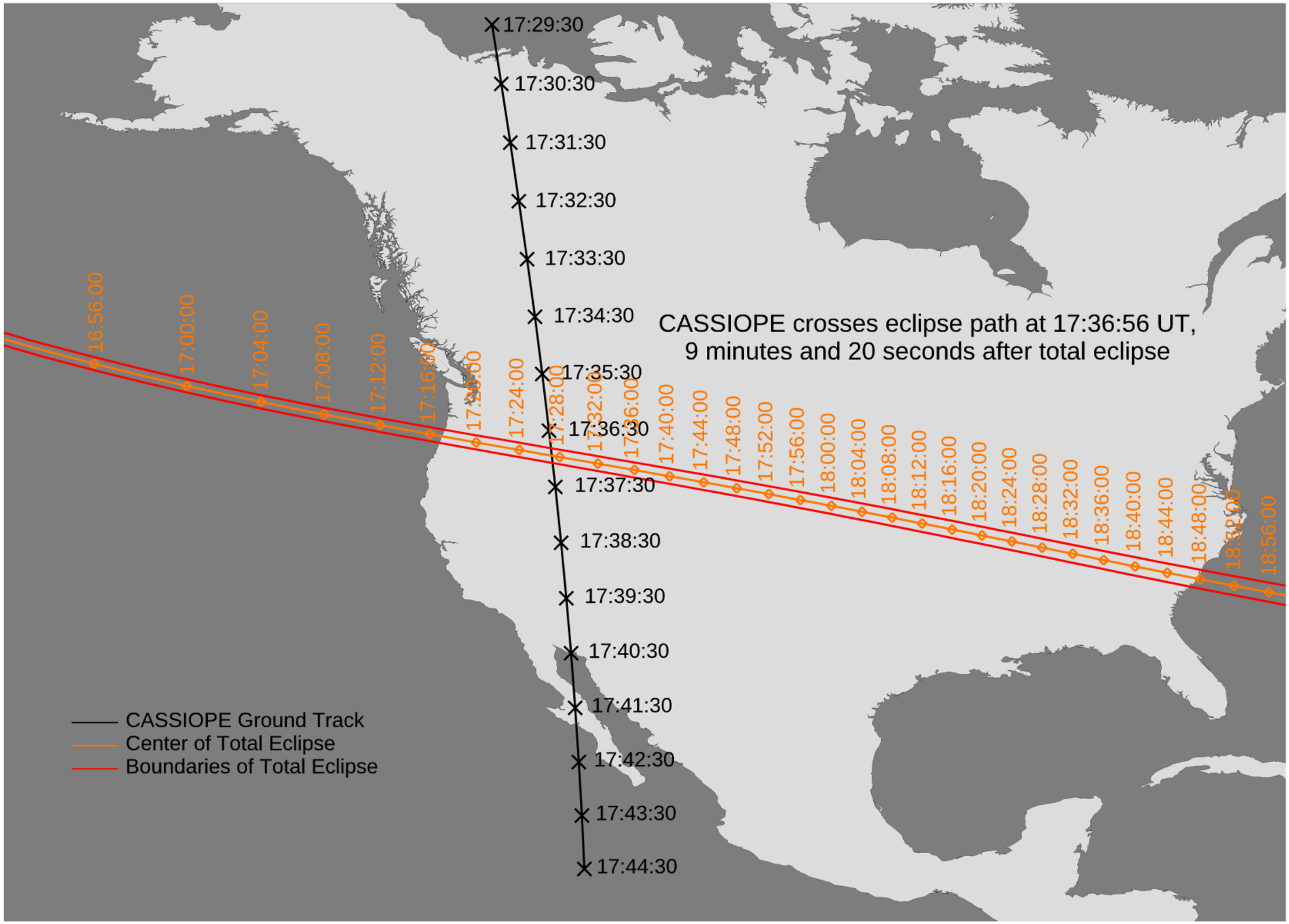
- Interference patterns can be setup by non-parallel rays.
- Regions of destructive interference: *fades*.
- 33 Hz oscillation in K9ESV is consistent with self fades.

James, H. G., Gillies, R. G., Hussey, G. C., & Prikryl, P. (2006). HF fades caused by multiple wave fronts detected by a dipole antenna in the ionosphere. Radio Science, 41(4), RS4018. http://doi.org/10.1029/2005RS003385

What's next: decoding the 2017 ARRL Field Day



August 21, 2017 solar eclipse



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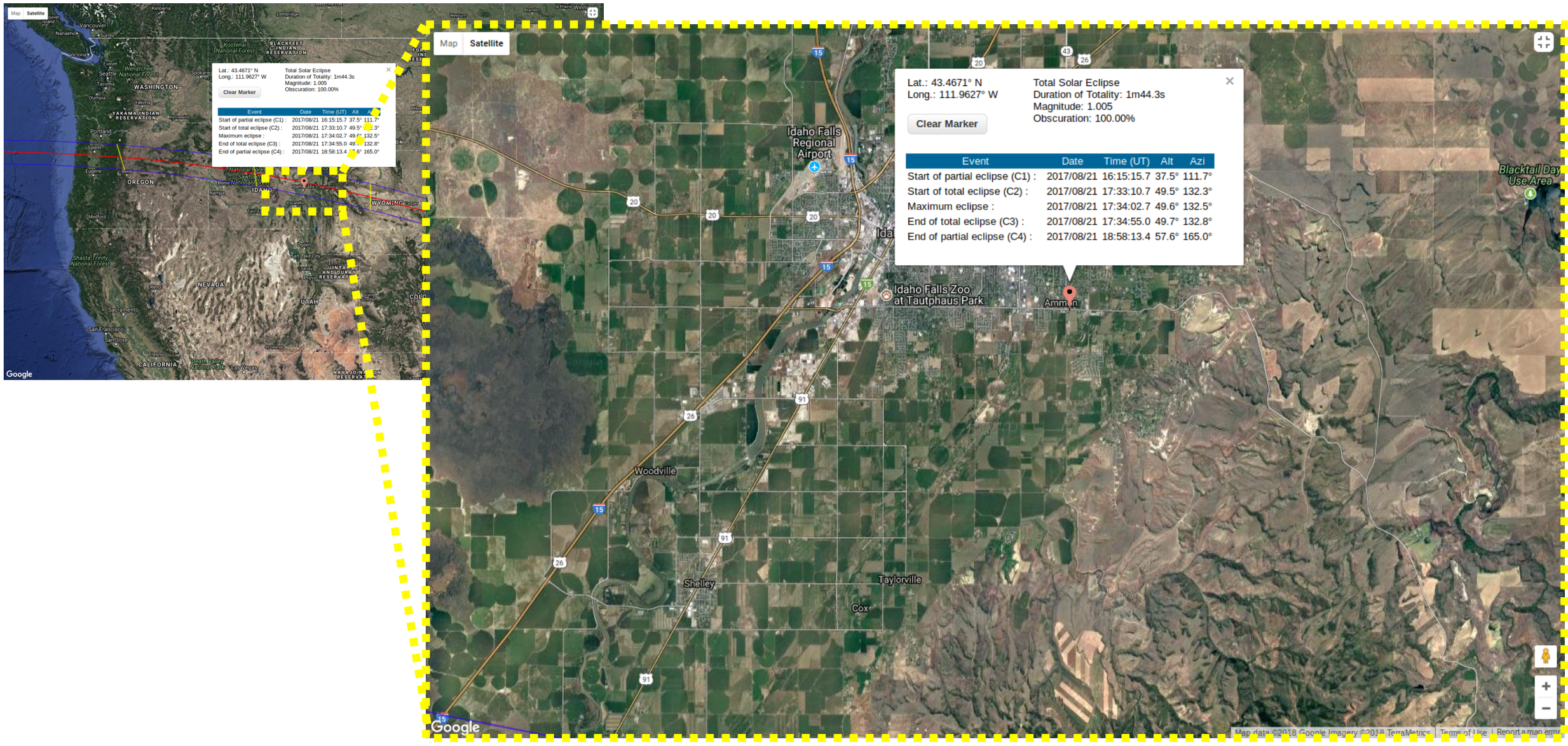
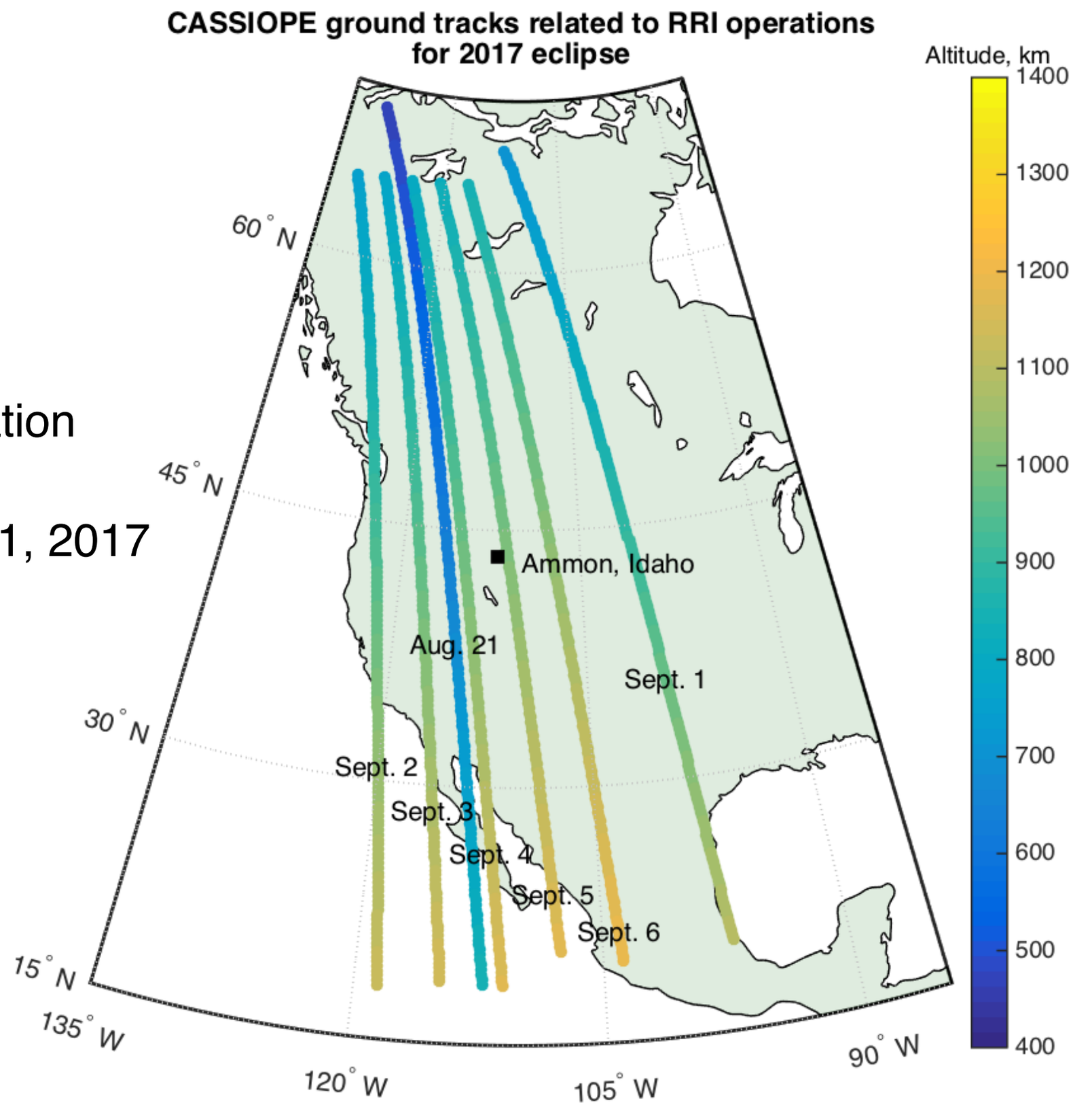


- An HF transmitter was operated from Ammon, Idaho (43.48°, -111.96°, geographic).
  - 14.2 MHz; LFM chirp waveform; PRF 250 Hz; BW: 25 kHz.
  - Operated by radio enthusiast, Robert Farrow (N7MZI).
- **Transmitter was first operated on August 21, 2017.**
- **Data from August 22—31 was lost due to a CASSIOPE “single-event-upset”**
- **“Baseline” data was collected between September 1–6.**

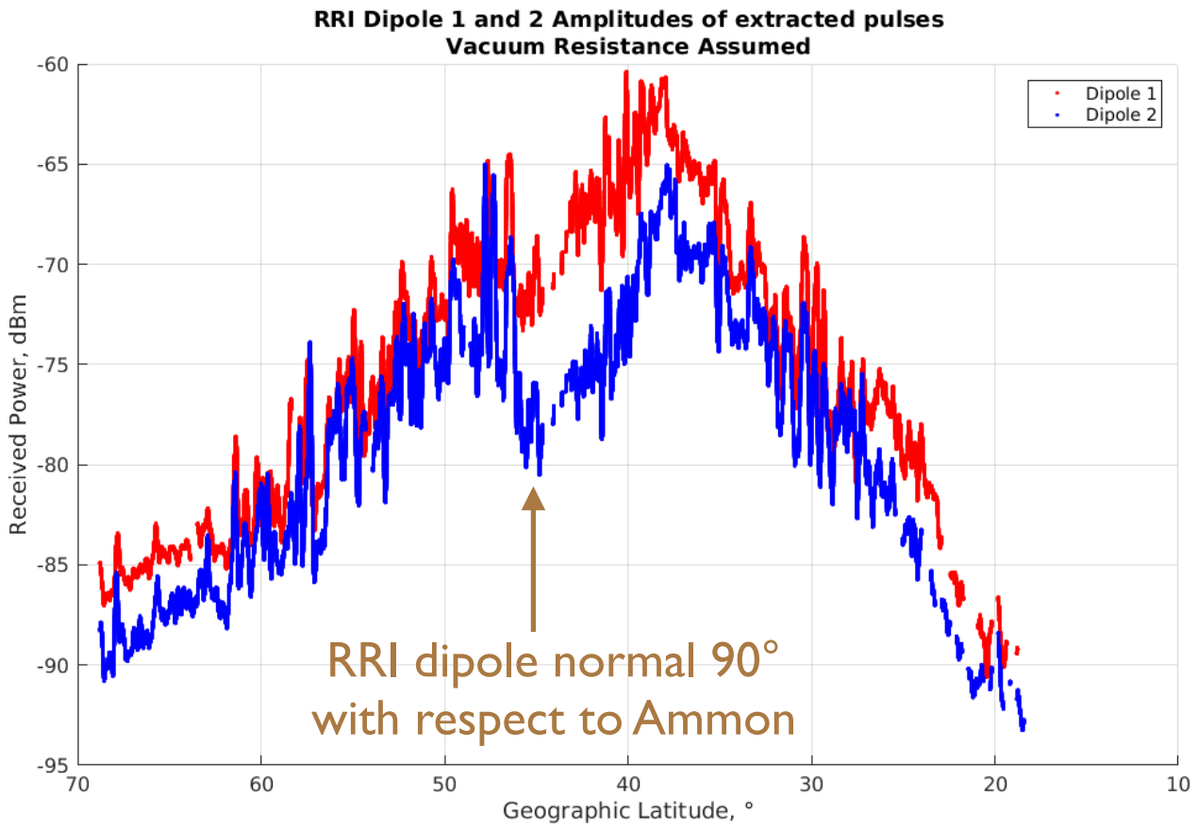
August 21, 2017 solar eclipse

- Minimum ground separation between Ammon and CASSIOPE on August 21, 2017 was ~450 km.

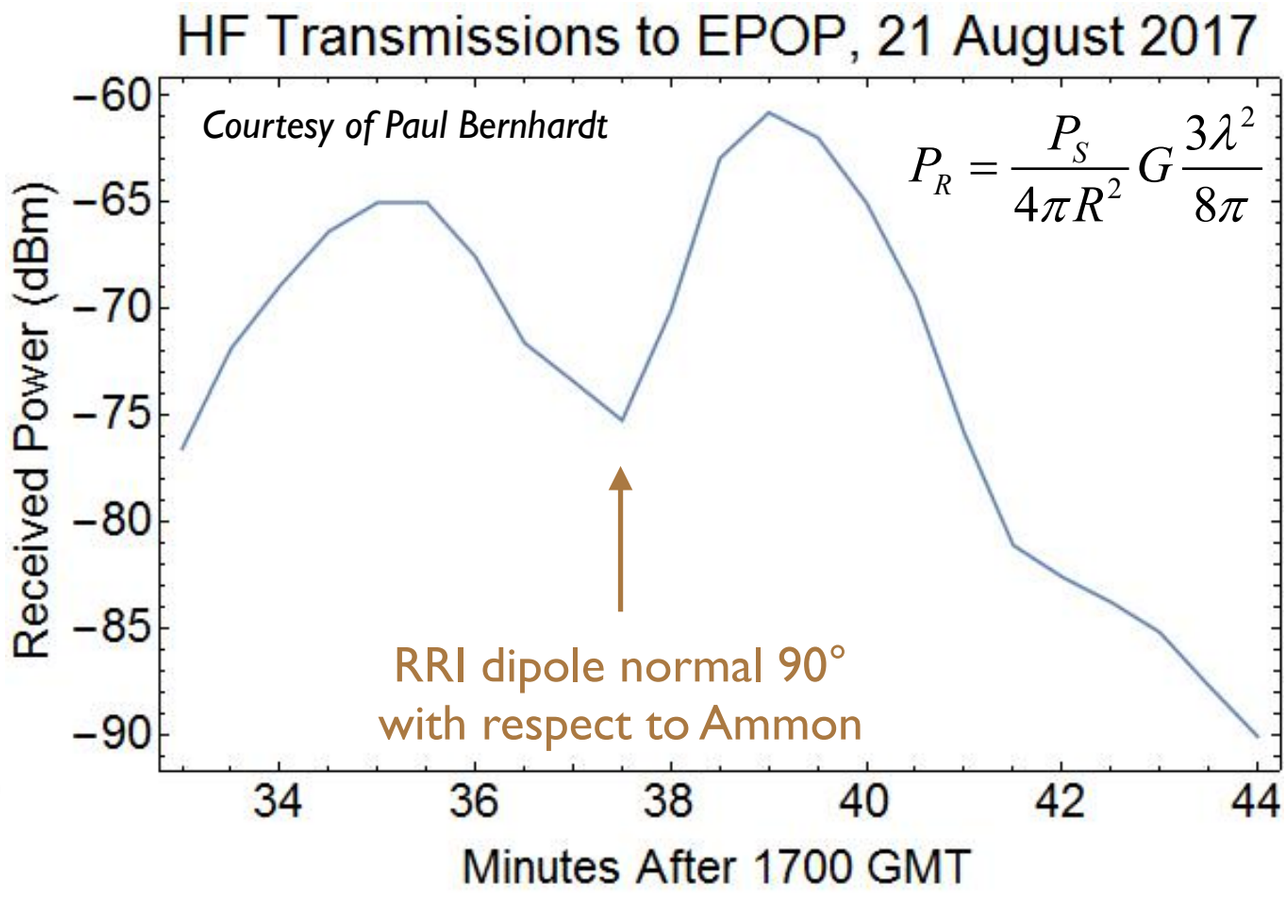


August 21, 2017 solar eclipse - data

Eclipse conjunction data

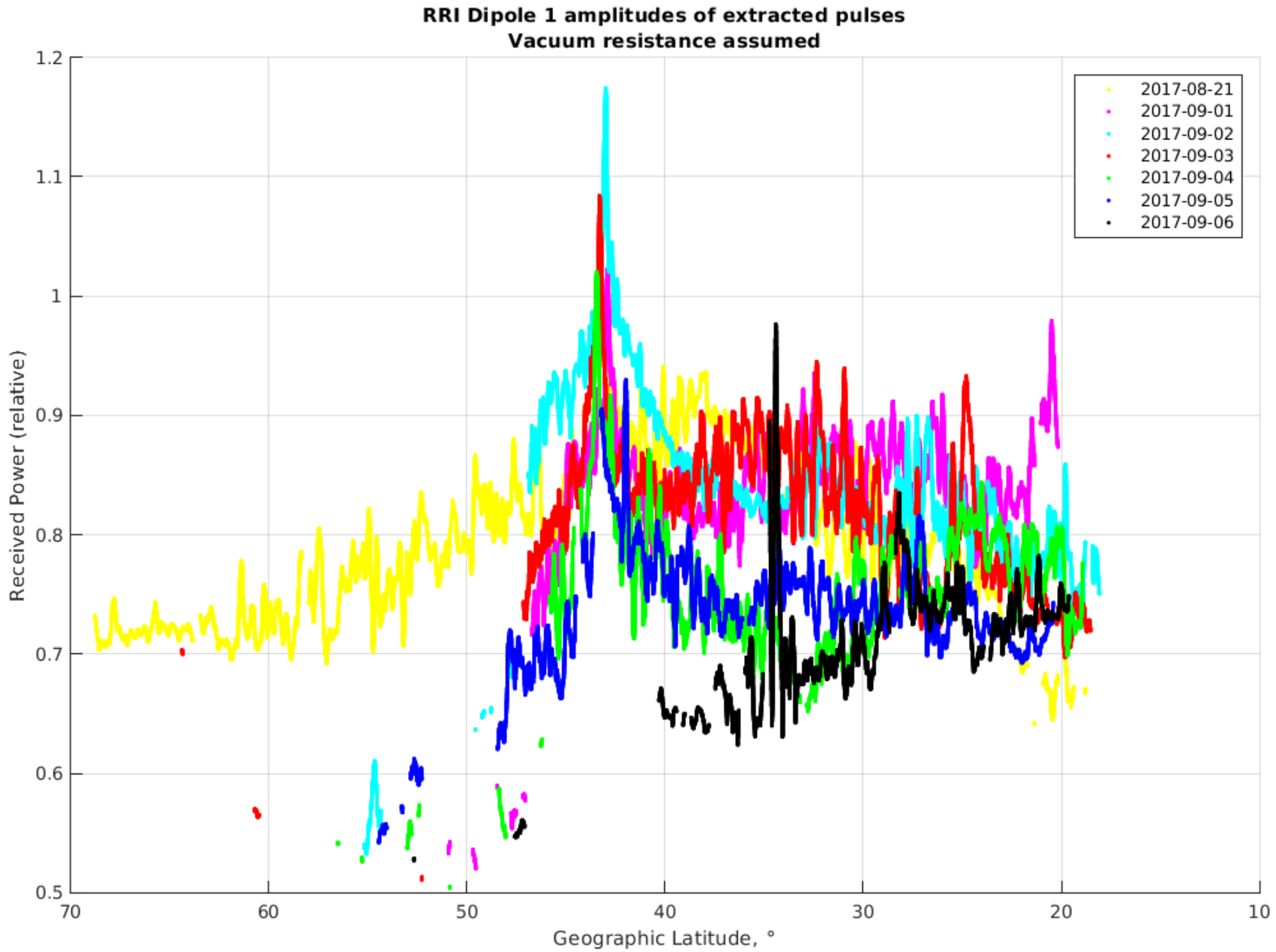


Eclipse conjunction model



- A matched filter technique was used to extract Ammon's pulses from RRI's signal.
- The data (left) shows very good agreement with modelled predictions (right).

Eclipse passes and baseline passes



- During eclipse: Ammon's pulses detected north of 50°.
  - **Not the case** for baseline passes.
  - Meridional radio propagation conditions were symmetric during eclipse, asymmetric otherwise.

Summary

- We can do radio science using ham transmissions as an HF source.
  - Large scale radio propagation experiment with multiple sources.
  - Magnetoionic effects (self mode fades) can studied as well.
- Hams are a great resource and ally for solar-terrestrial physics.
- *Future work*
  - Develop more efficient way of decoding ham transmission from RRI data stream.
  - Validate participation of large group of hams for HF ray tracing studies.
  - More operations with hams!

Swarm-E website: https://epop.phys.ucalgary.ca

Swarm-E data: https://epop-data.phys.ucalgary.ca

Acknowledgements

CASSIOPE/e-POP spacecraft operators at the University of Calgary:

- Greg Enno, Andrew Howarth, Andrew White, Jamie Roberts, and Troy Kachor.
- The raytrace results shown here were obtained using the HF propagation toolbox, PHaRLAP, created by Dr. Manuel Cervera, Defence Science and Technology Group, Australia (manuel.cervera@dsto.defence.gov.au). This toolbox is available by request from its author.