Distributed High-Frequency Soundings of the Ionosphere and Other Observations During the 2017 Solar Eclipse

L. J. Kordella, G. D. Earle, M. Moses, X. Han, D. Sweeney, R. W. McGwier, W. Lloyd, J. M. Ruohoniemi, N. Frissell, T. Bullett, and J. Mabie

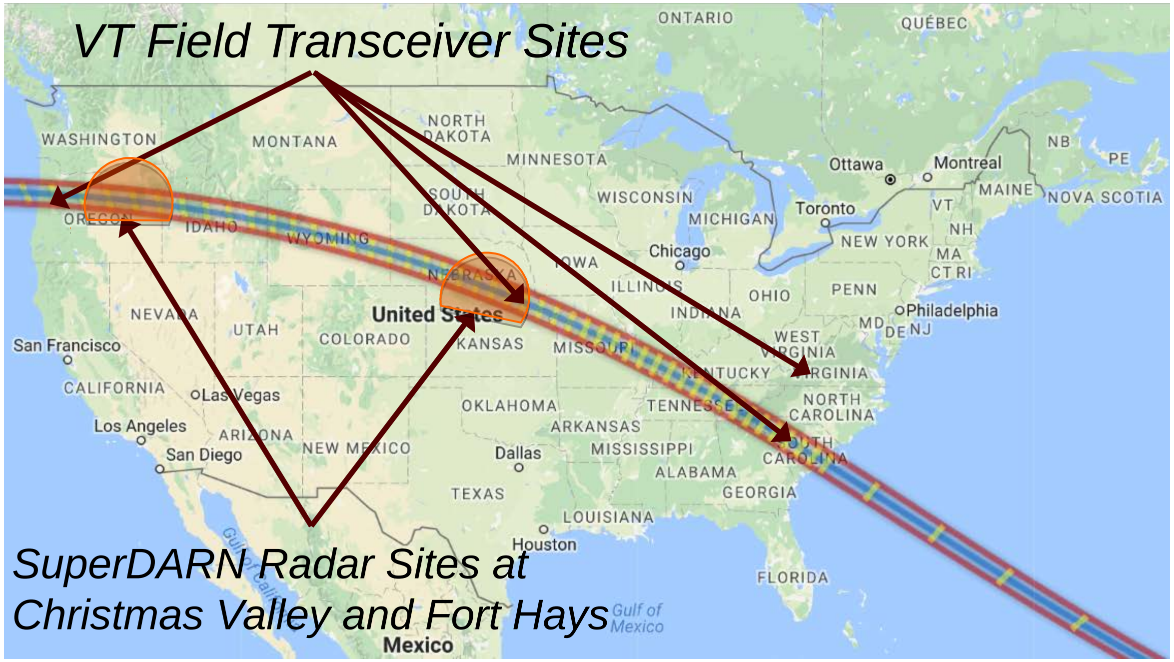
Space Systems Group

VIRGINIA TECH

Introduction

Fundamental Eclipse Science Questions

- How large is the region of the ionosphere affected?
- How does the F region respond in the umbra and penumbra?
- What radio propagation & scintillation effects are produced?



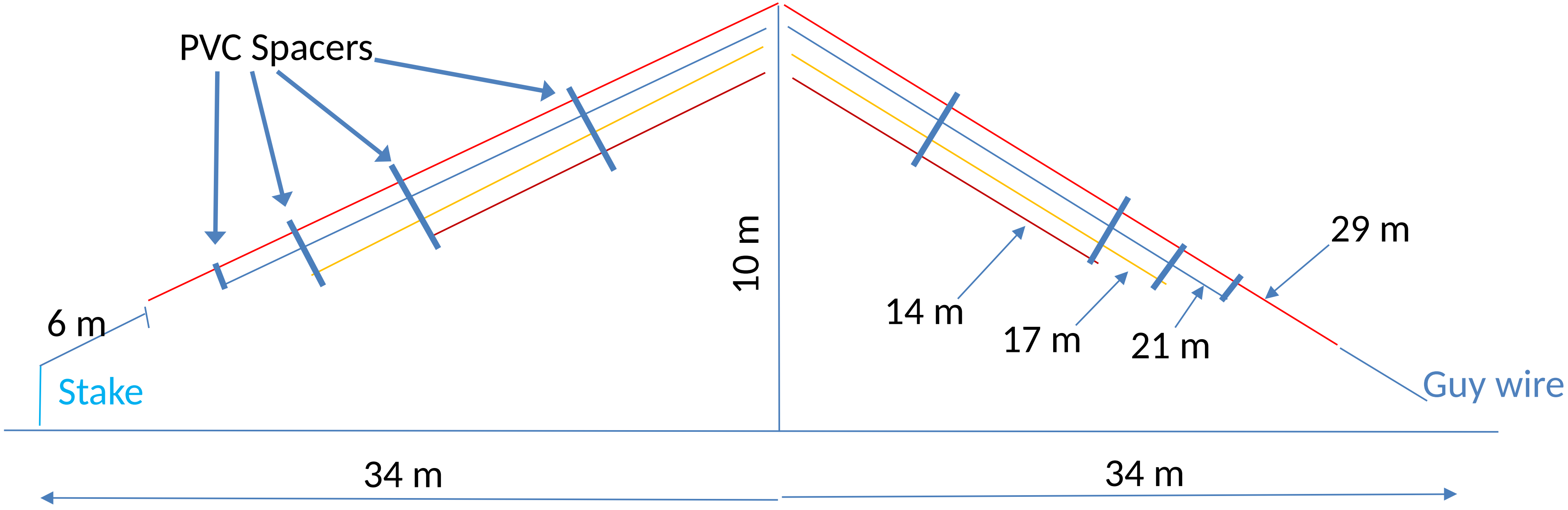
Elements of the VT Experiment

- SuperDARN in Kansas and Oregon
- Four HF field sites across the US
- Scintillation receiver looking through the eclipsed F region at a UHF satellite beacon
- HAM radio (with N. Frissell from NJIT)
- SAMI-3 modeling (with D. Drob & J. Huba from NRL)
- Dynasondes in Boulder and in Lusk, Wyoming (T. Bullett and J. Mabie)
- GPS receivers (deployed at field sites for A. Coster)

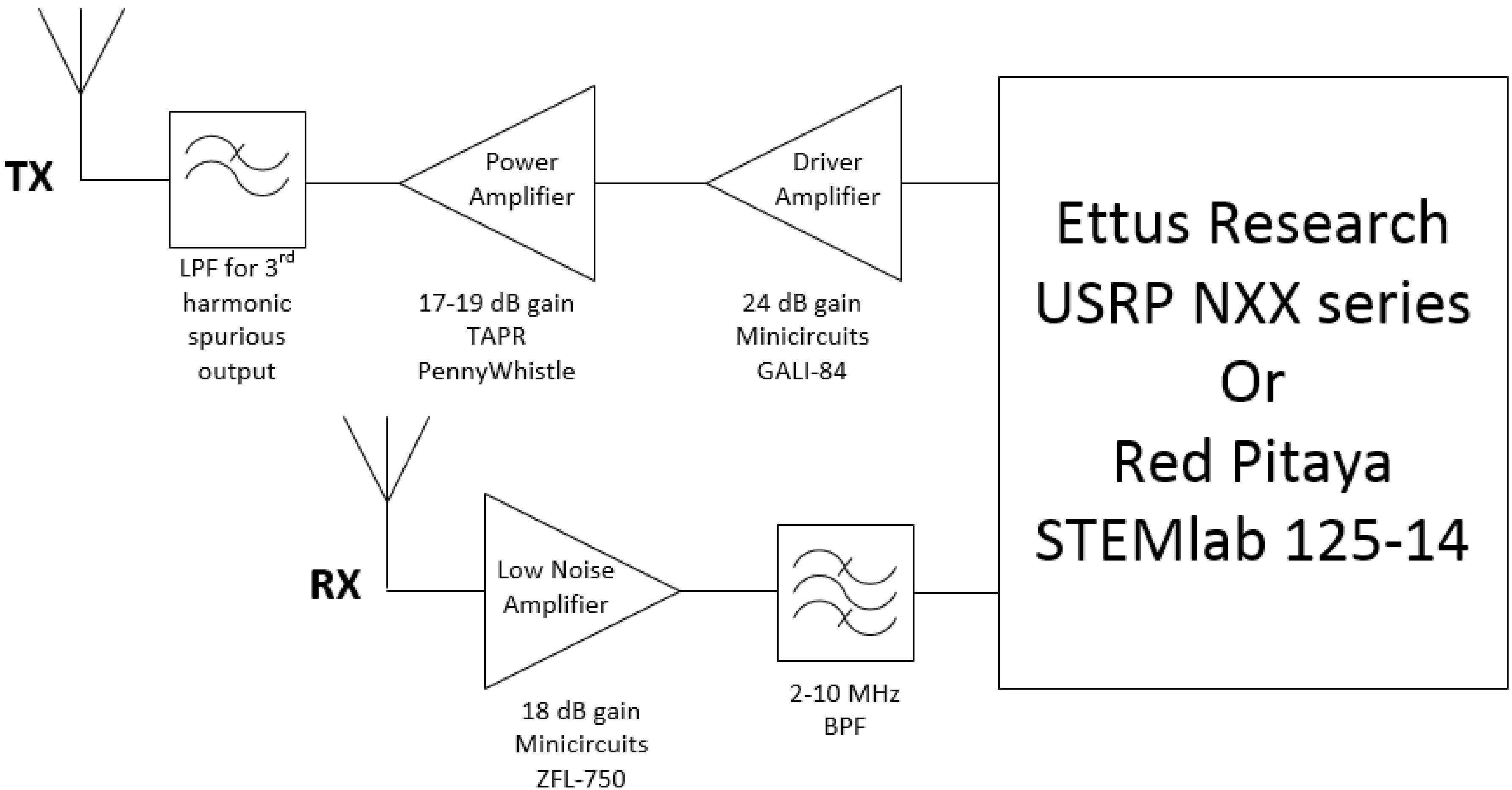
HF Field Sites

Bi-static systems with identical Tx and Rx fan dipole antennas

	~ λ	λ/2	Element Length
2.6 MHz	116 m	58 m	29 m
3.6 MHz	84 m	42 m	21 m
4.5 MHz	66 m	33 m	~17 m
5.5 MHz	54 m	27 m	~14 m



Radio Front End Design



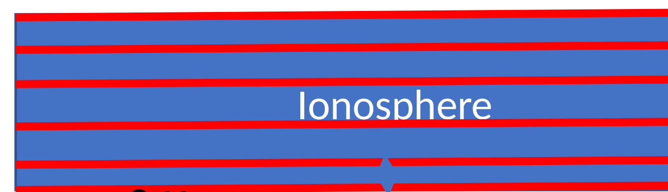
Range Extent & Range Resolution

- Min Range set by pulse length; max range by waveform rep rate

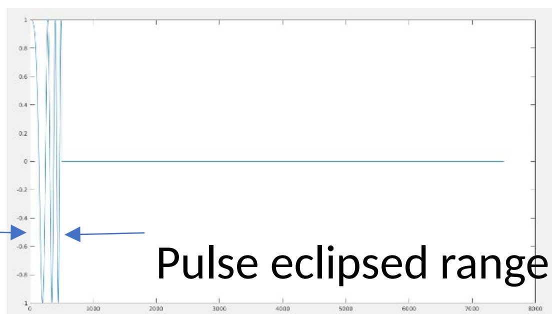
pulse duration		t	250	microseconds	0.00025	seconds
min range		Rmin = ct/2	37500	meters		37.5	Km

- Range-resolution (DR) determined by the effective pulsewidth (t)

swept bandwidth (B)	20	KHz	20000	Hz
effective pulse length (1/B)	50	microseconds	0.00005	seconds
range resolution (DR=ct/2)	7.50E+03	meters	7.5	Km

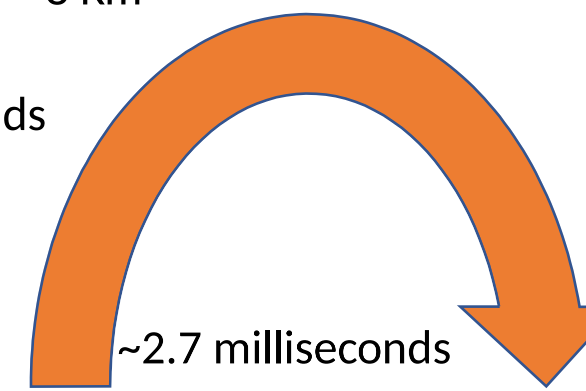


20 KHz Chirp

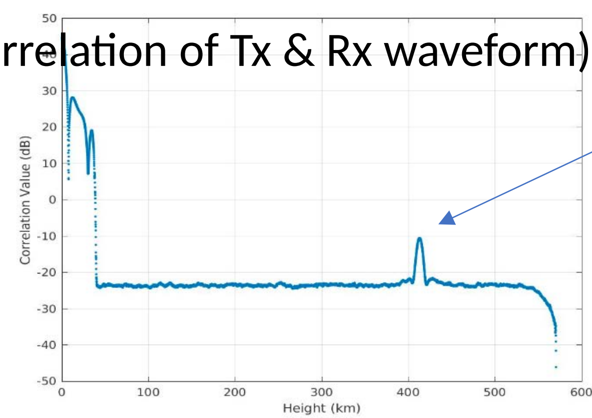


Pulse eclipsed range ~ 38 Km

Waveform Repetition Interval ~ 3.5 milliseconds

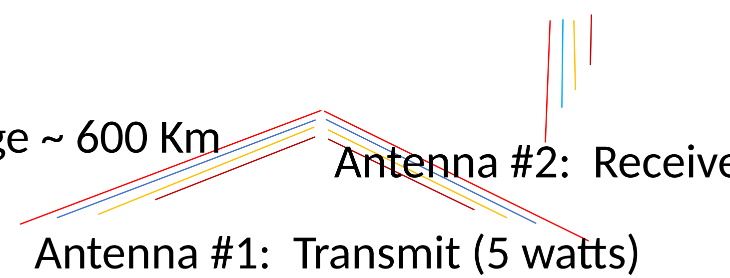


20 log (correlation of Tx & Rx waveform)



Return at ~ 400 Km F-layer?

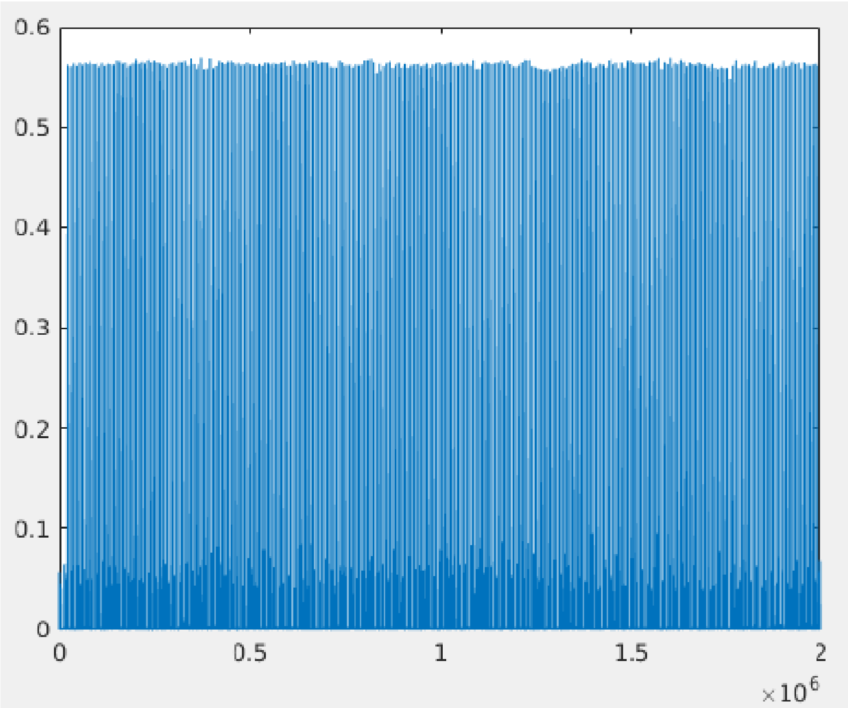
Maximum Range ~ 600 Km

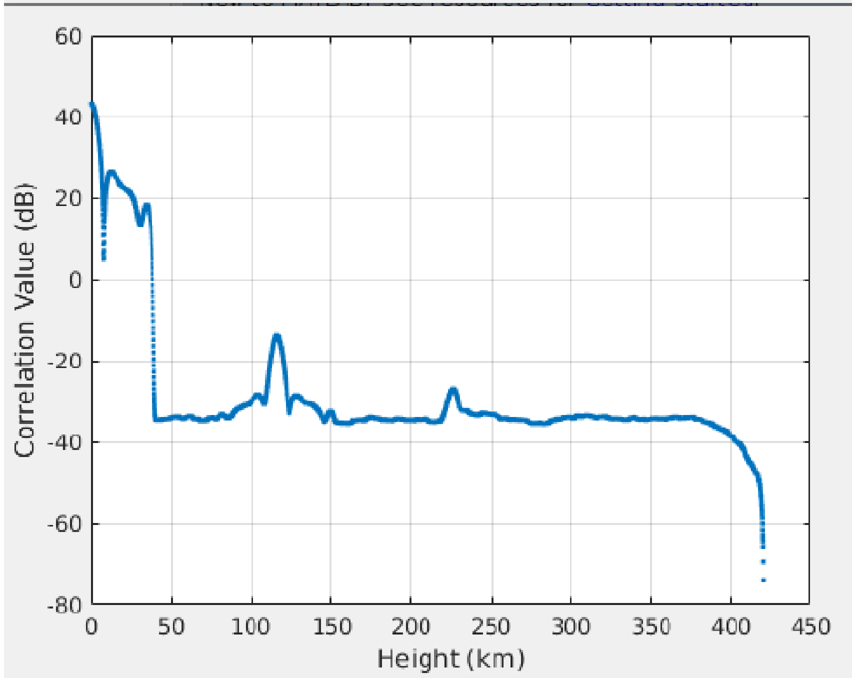


Processing

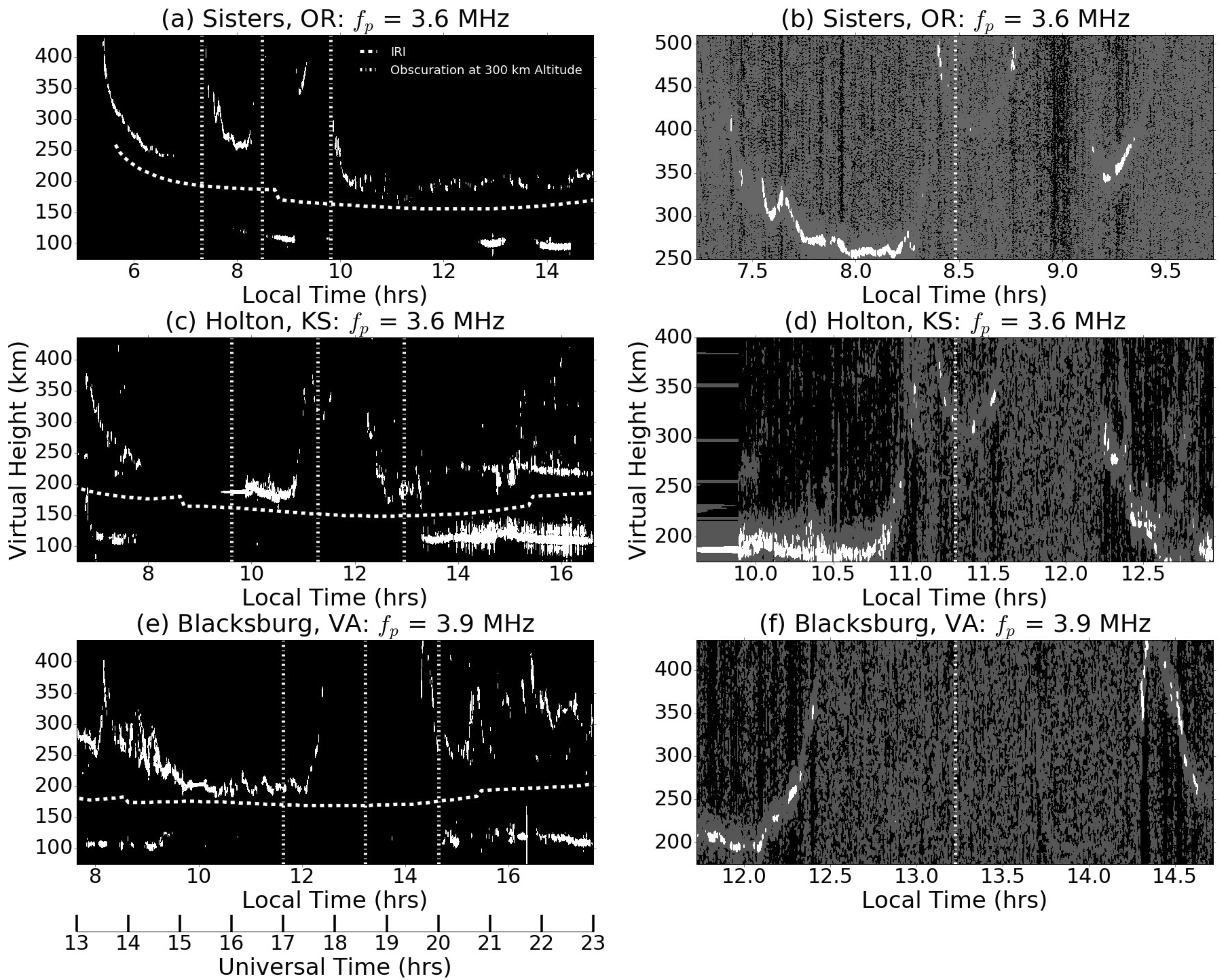
<ALGORITHM>

1. Import IQ data and store frequency and time information
2. Find the start of ground wave
3. Store GW samples and full period
4. XCORR the two vectors
5. Add XCORR output to sum vector
6. Move ahead and repeat 1-5
7. Average, plot & store



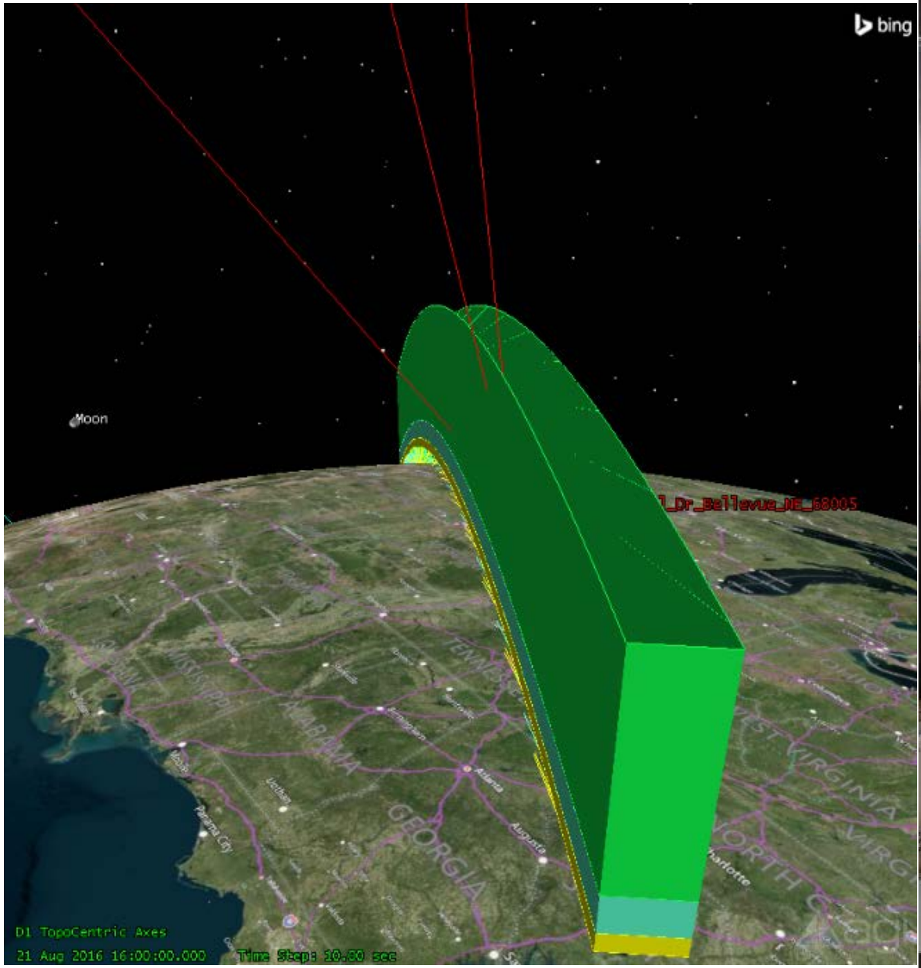


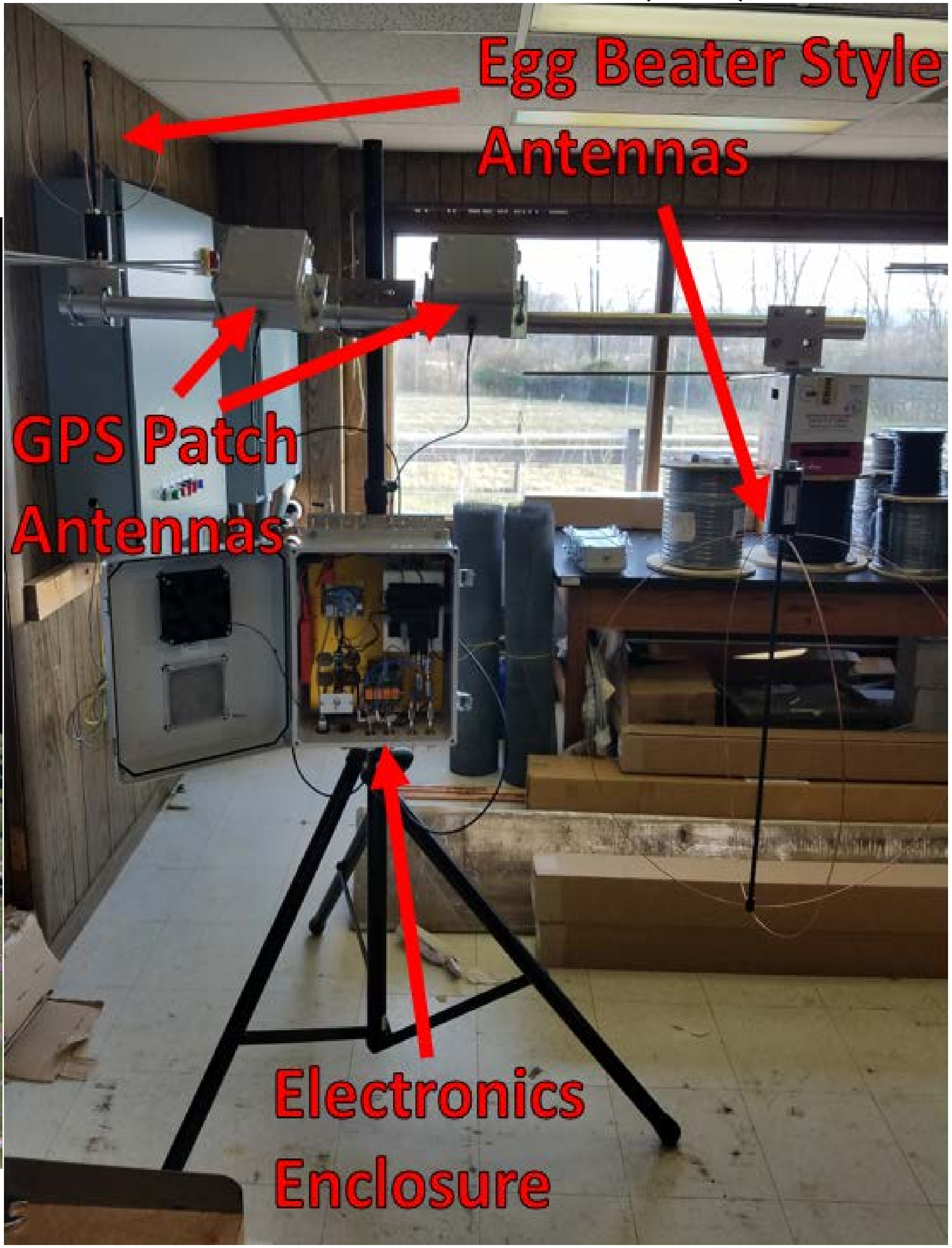
Field Site in Oregon


(a) Sisters, OR: f_p = 3.6 MHz
IRI
Obscuration at 300 km Altitude
(b) Sisters, OR: f_p = 3.6 MHz
(c) Holton, KS: f_p = 3.6 MHz
(d) Holton, KS: f_p = 3.6 MHz
(e) Blacksburg, VA: f_p = 3.9 MHz
(f) Blacksburg, VA: f_p = 3.9 MHz
Virtual Height (km)
Local Time (hrs)
Universal Time (hrs)

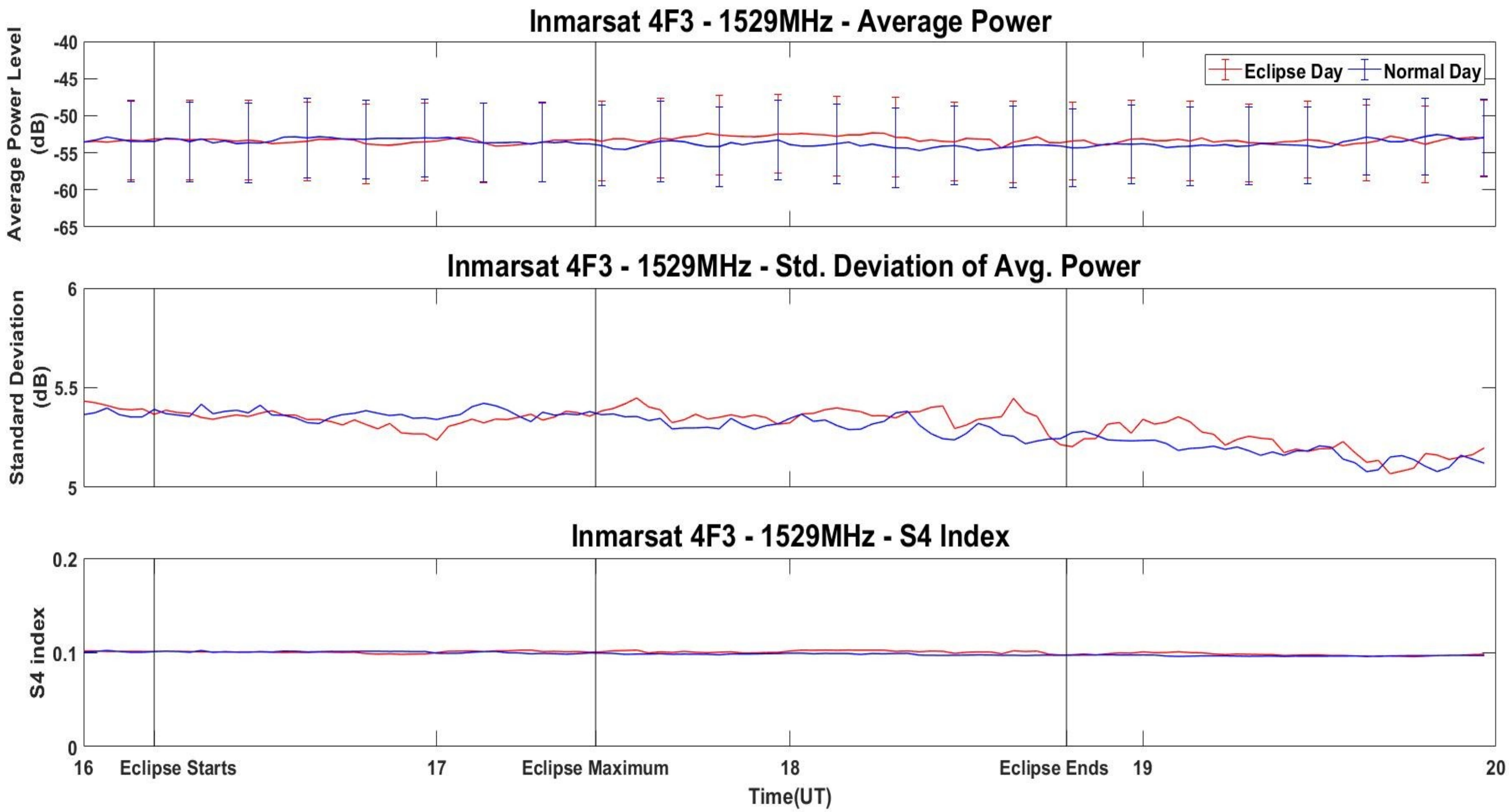
Scintillation Receivers

Credit: Harry Han (VT)





Scintillation Receiver Observations



SuperDARN in Fort Hays Kansas

Christmas Valley Oregon – NW Beam near 10 MHz

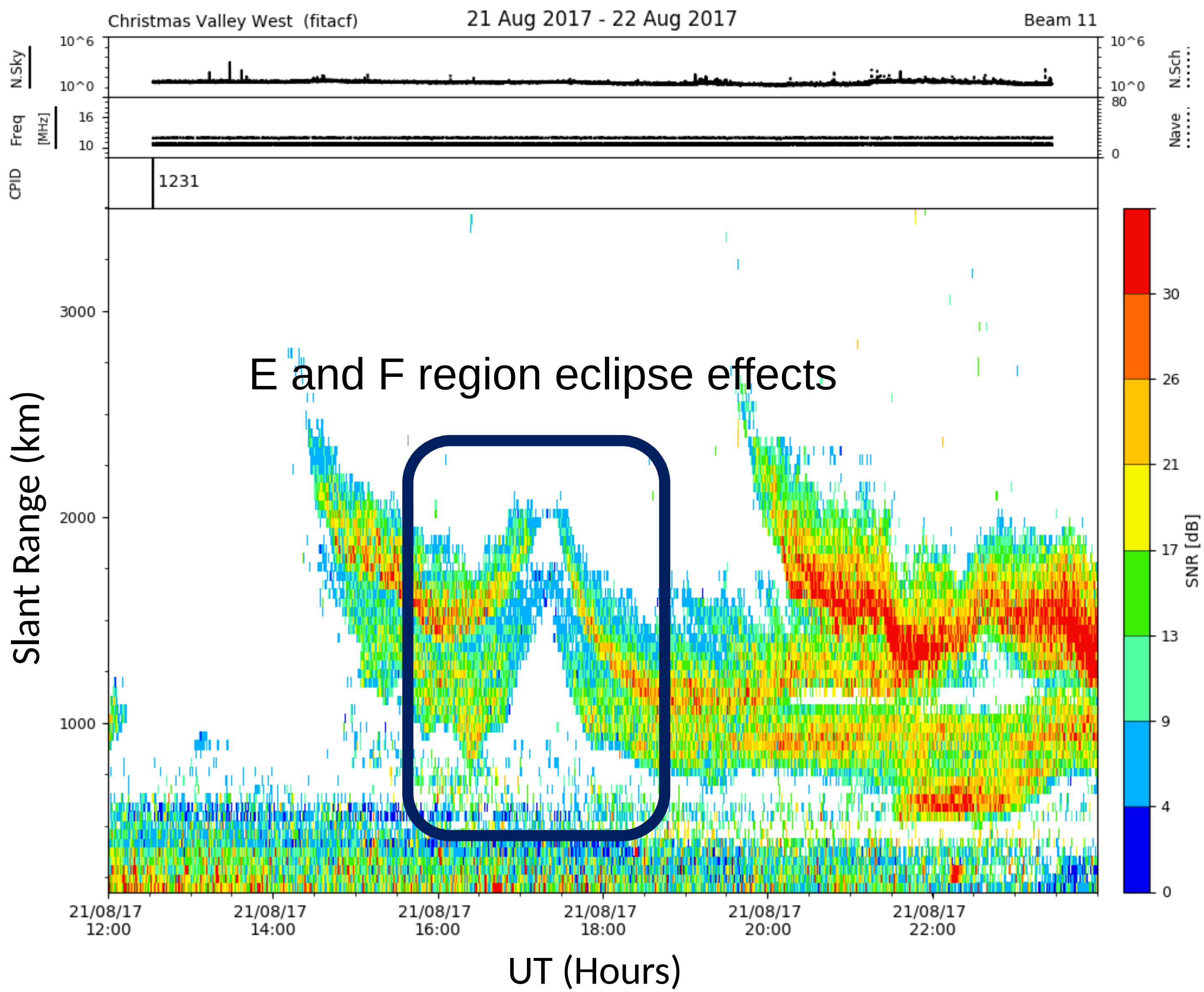
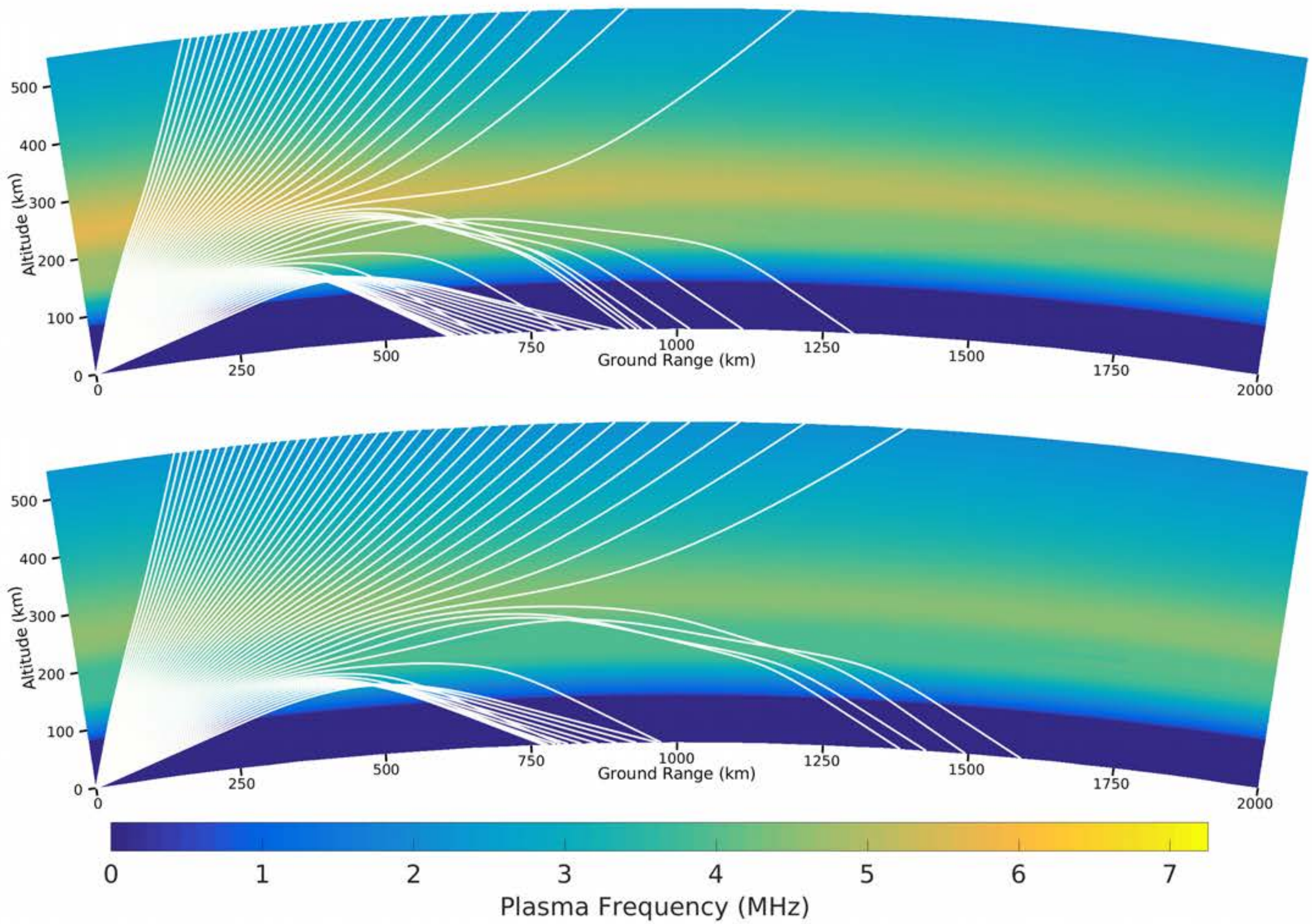


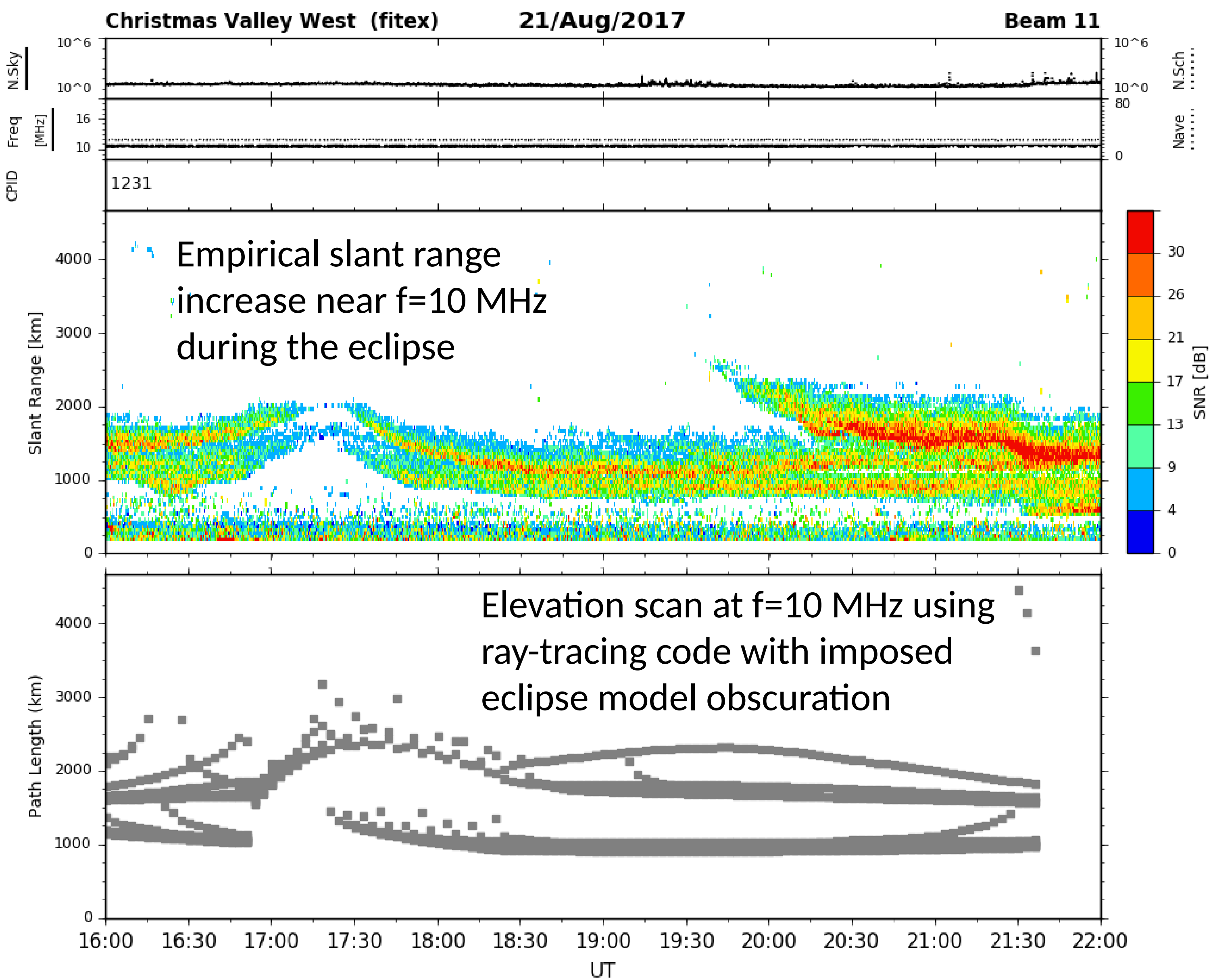
Figure provided by K. Sterne

PHaRLaP Ray-Tracing Results



Ray-tracing with PHaRLaP allows us to estimate how the HF propagation paths were affected. The top plot shows the ray paths for normal conditions; bottom plot shows the ray paths predicted based on our current understanding of how the eclipse changes the plasma density in the E and F regions.

SuperDARN-PHaRLaP Comparison



Fort Hays Kansas – NE Beam Near 10 MHz

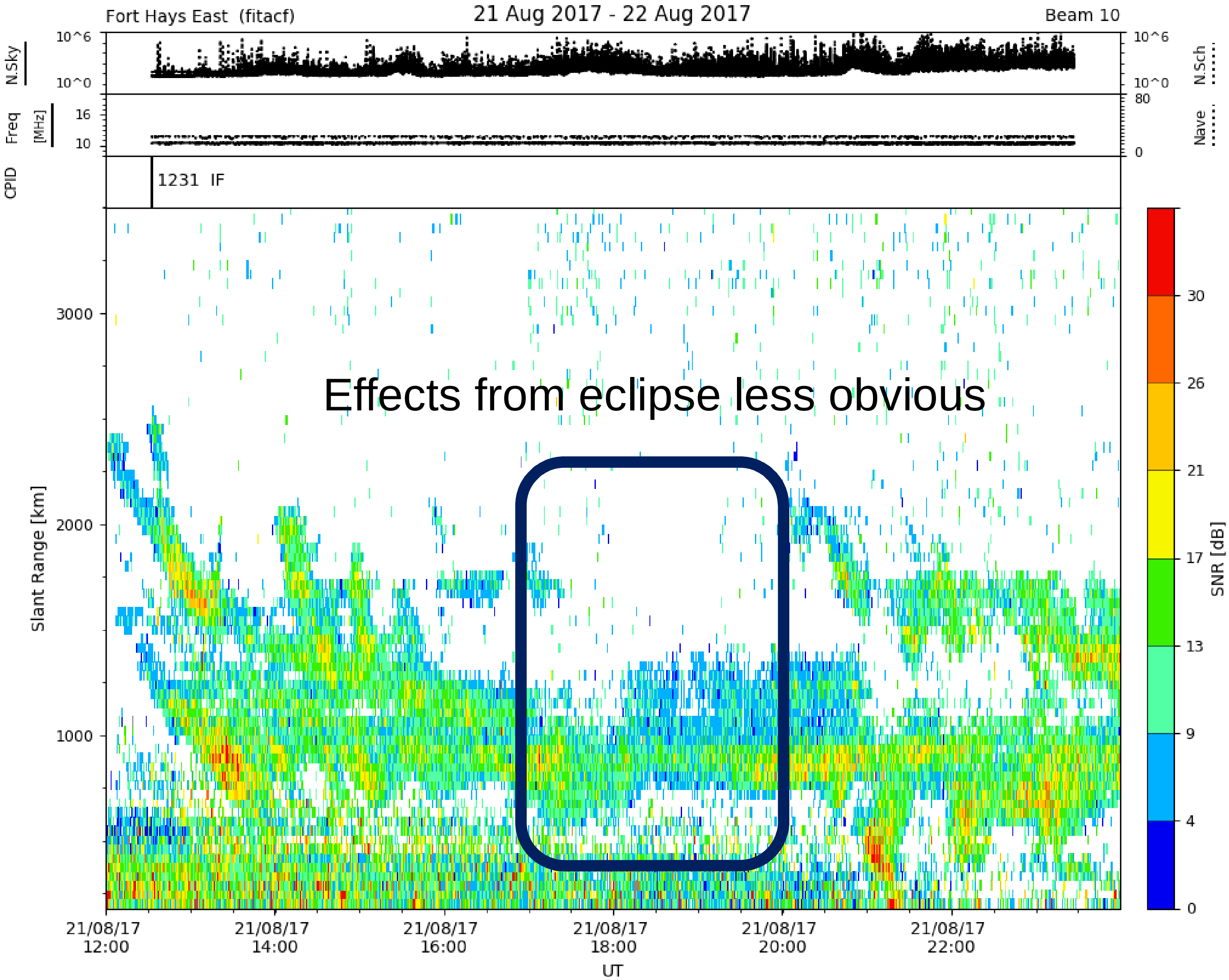


Figure provided by K. Sterne

Conclusions & Ongoing Work

- Many of the expected behaviors were observed:
  - No observable scintillation at GHz frequencies
  - Ducting of low-elevation HF signals (SuperDARN and Ham) over very long horizontal distances. Ham band communication from SC to CA at long wavelengths (20 and 30 m) was demonstrated during the eclipse

- There are many more questions we can address – for example:
  - Why are SuperDARN data from Kansas and Oregon so different?
  - Were gravity waves launched by the eclipse?
  - What causes the observed asymmetries in the F-region morphology & dynamics during the eclipse onset and recovery periods?

- Ongoing work:
  - Comparison of the PHaRLaP ray-tracing model to SuperDARN data using SAMI3 to estimate ionospheric conditions throughout the eclipse (Moses & Kordella)
  - SAMI-3 modeling to study asymmetric F-region dynamics (Kordella, Drob, and Huba)
  - Assimilation of our HF observations with TEC results, ham-radio RBN studies, and inter-satellite GPS occultation observations (Frissell, Psiaki, et al.)

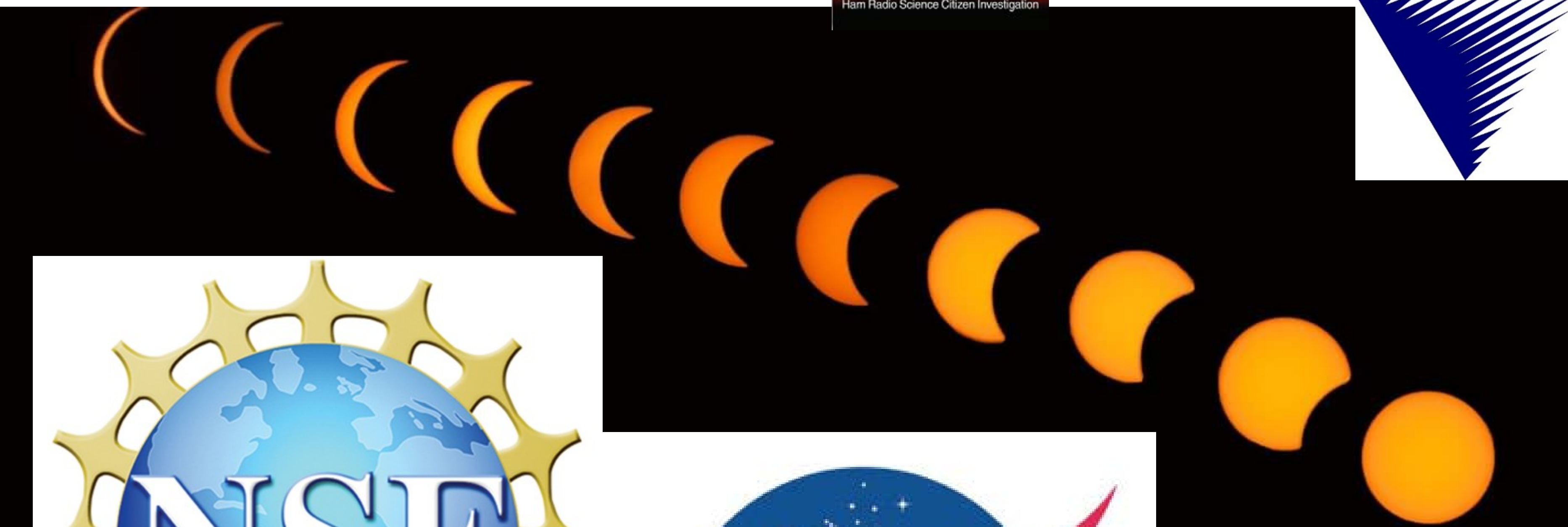
QUESTIONS/COMMENTS?

Space @ Virginia Tech
Center for Space Science and Engineering Research

HamSCI
Ham Radio Science Citizen Investigation

NJIT
New Jersey Institute of Technology

VIRGINIA SPACE GRANT CONSORTIUM



NSF

NASA

U.S. NAVAL RESEARCH LABORATORY

Expected F-Region Behavior During Eclipses

- Both the plasma density (N_e) and the electron temperature (T_e) should decrease in the eclipsed region, and these effects should maximize in the umbra at the peak of the eclipse.
- The scale height (H) in the topside ionosphere should decrease in proportion to the changes in T_e.
- We therefore expect changes in both the density and height of the F_2 peak during eclipses, driven by changes in both topside diffusion and bottomside recombination.
- Parallel diffusion speeds are expected to vary as a function of magnetic latitude, because the ΔP along the affected flux tubes is a strong function of dip angle.