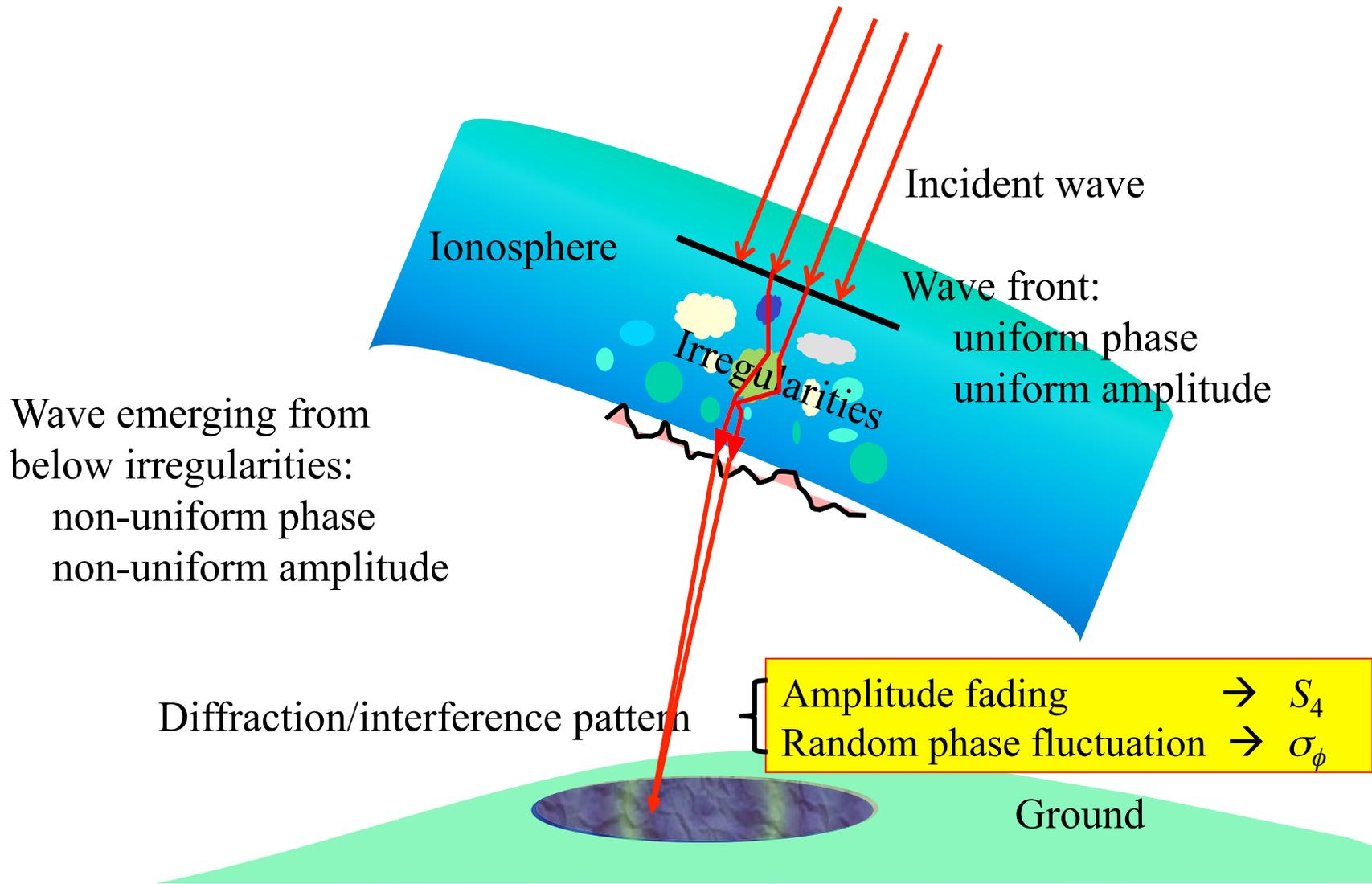
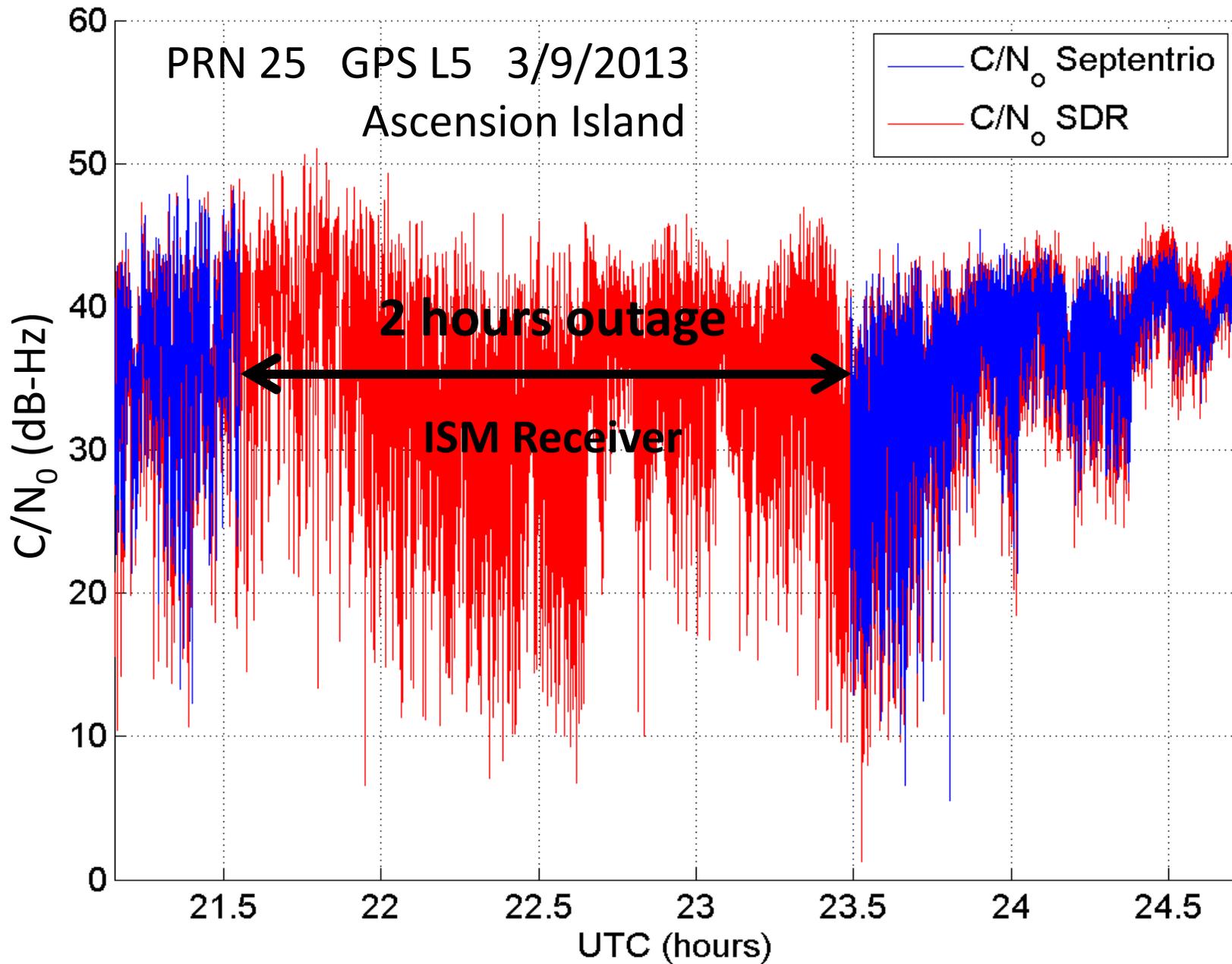

Characterization Mitigation and Utilization of Ionosphere Effects on GNSS

Joy Jiao, Jade Morton, Harrison Bourne, Brian Breitsch, Steve Taylor,
Jun Wang, Dongyang Xu, Mark Carroll*, Hang Yin*

Colorado State University

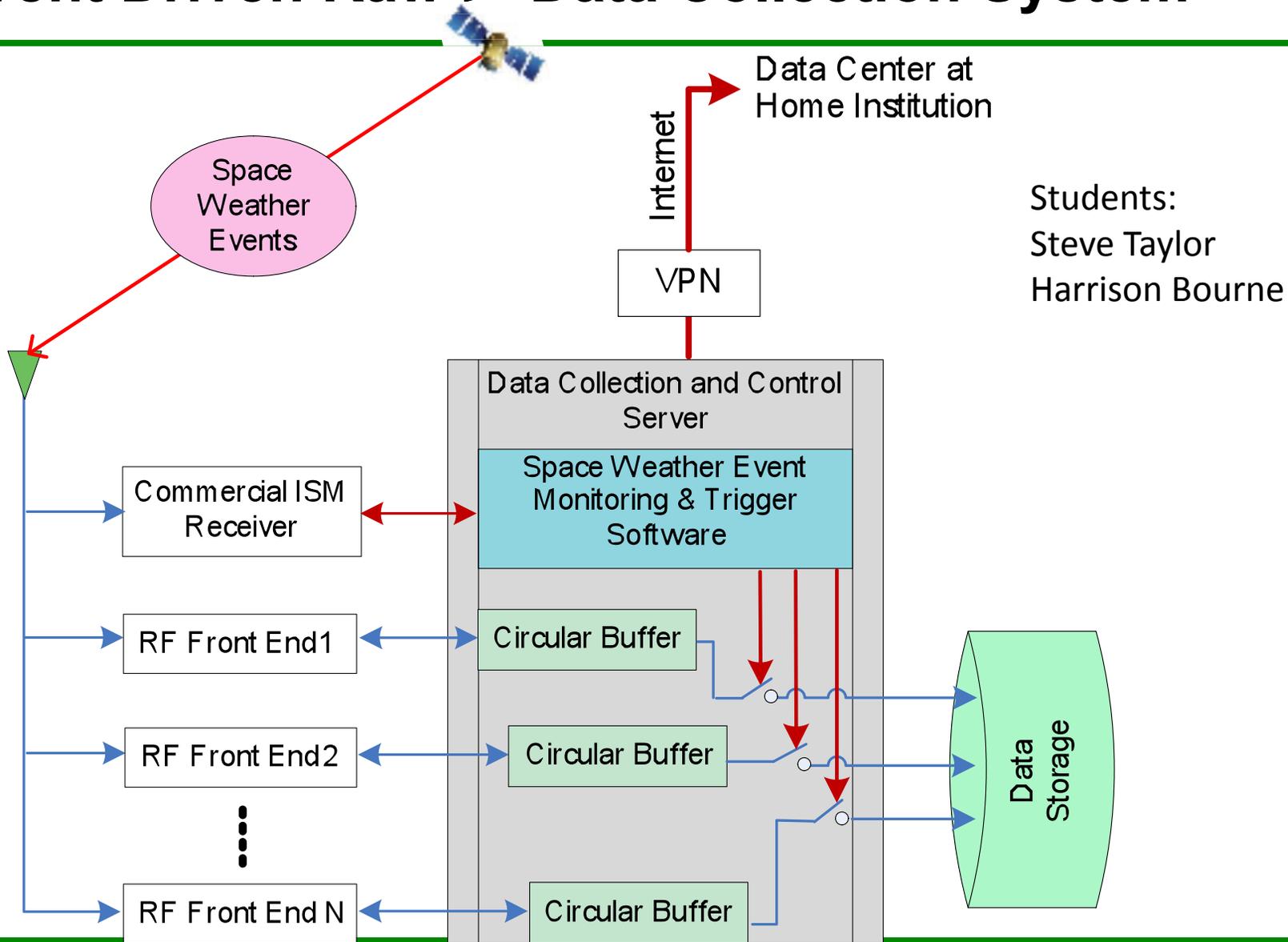
Introduction – Scintillation Phenomena



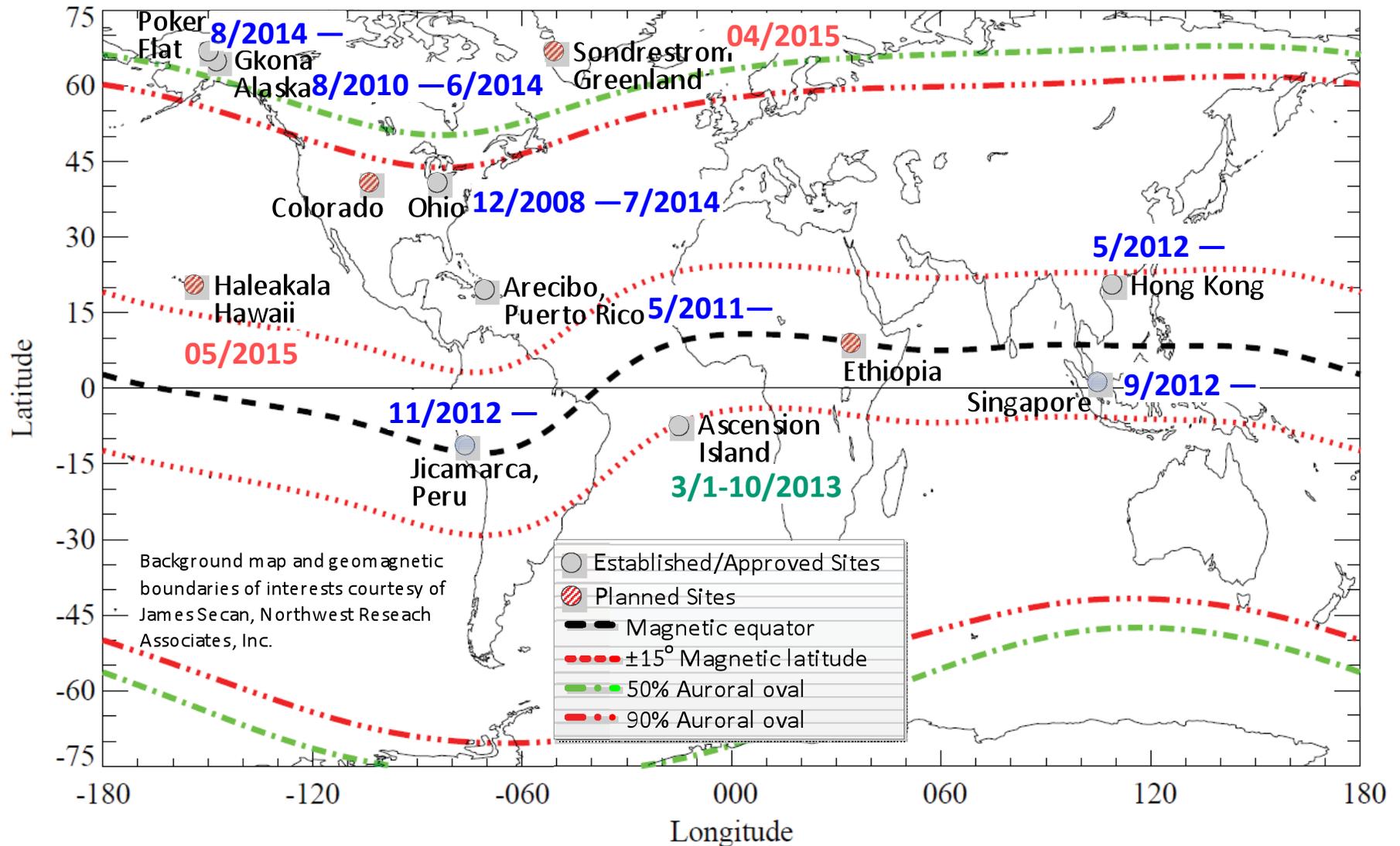


➤ **Characterization**

Event Driven Raw IF Data Collection System

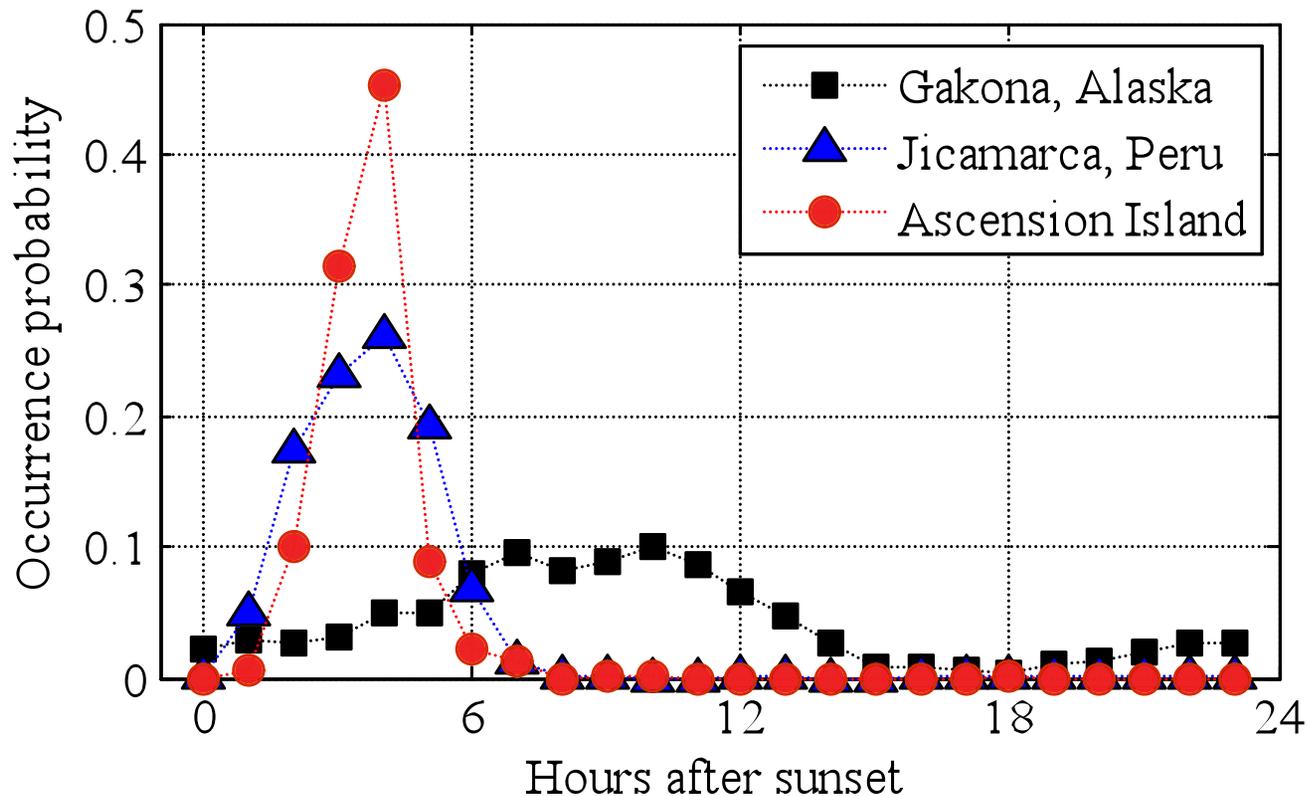


Event-Driven GNSS Data Collection Systems



Scintillation Occurrence Frequency - Diurnal

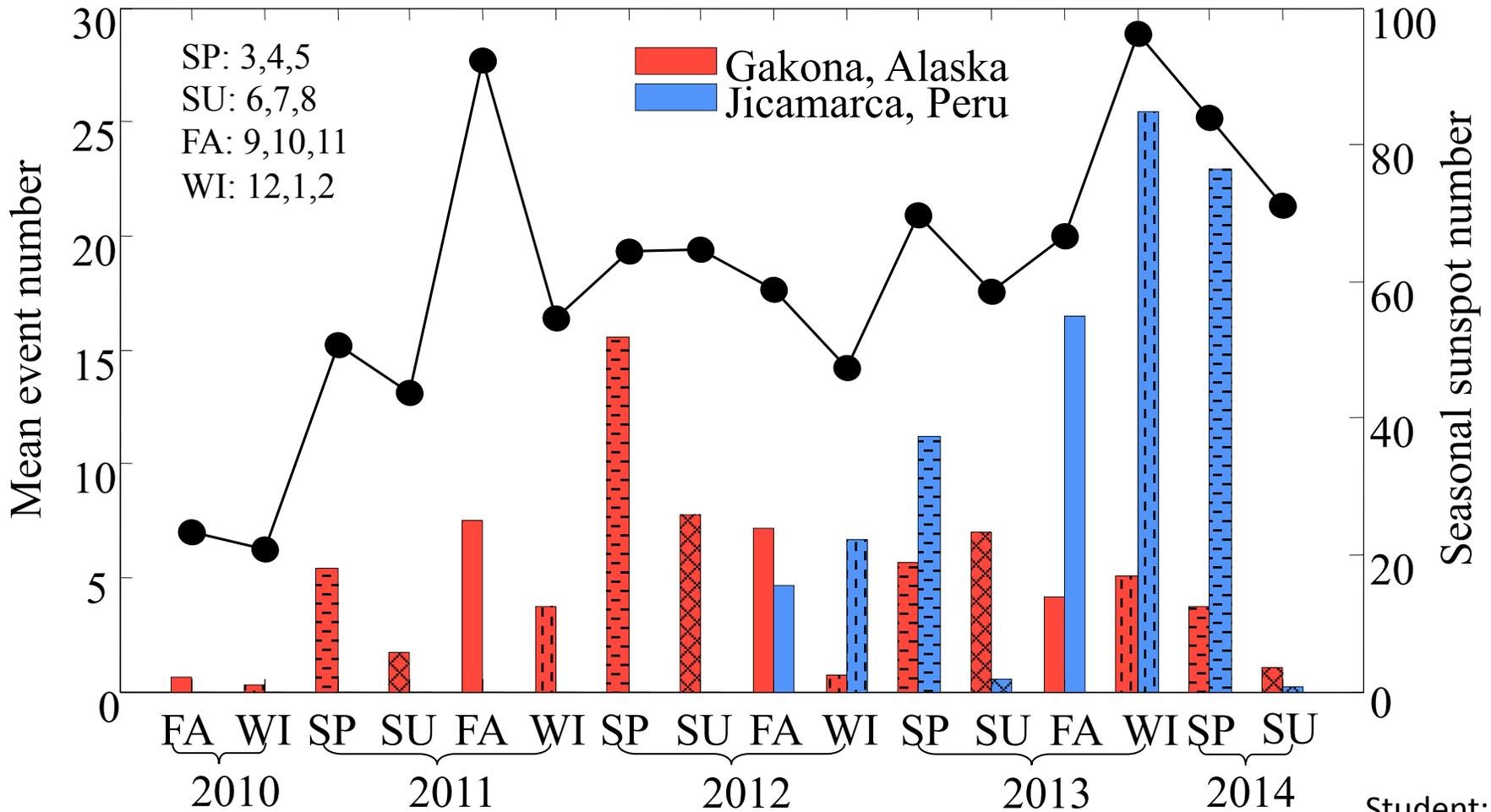
- High latitude: night time
- Low latitude: 1-6 hours post local sunset



HAARP: LT = UTC - 5; Jicamarca: LT = UTC + 8; Ascension: LT = UTC

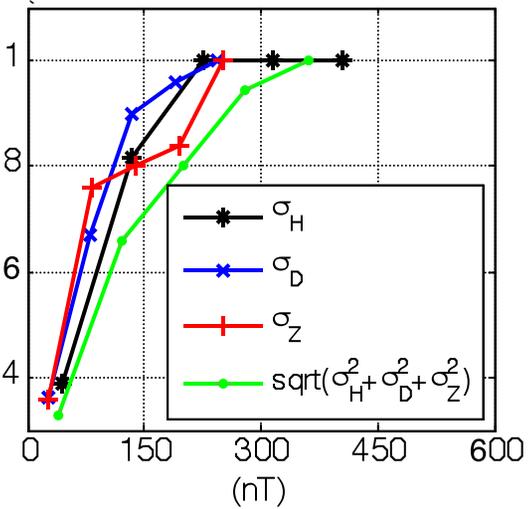
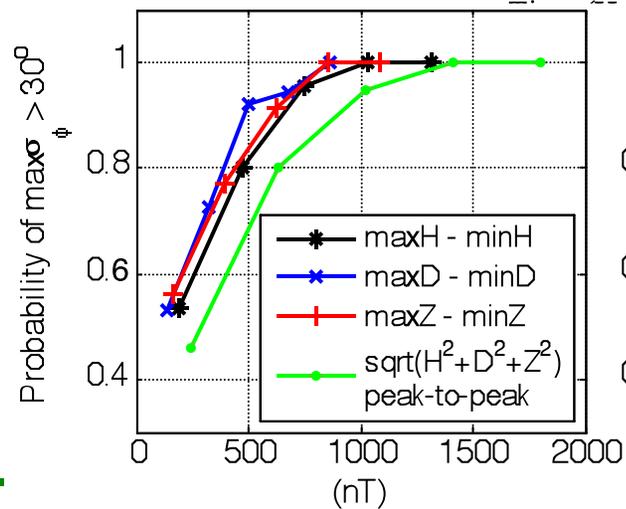
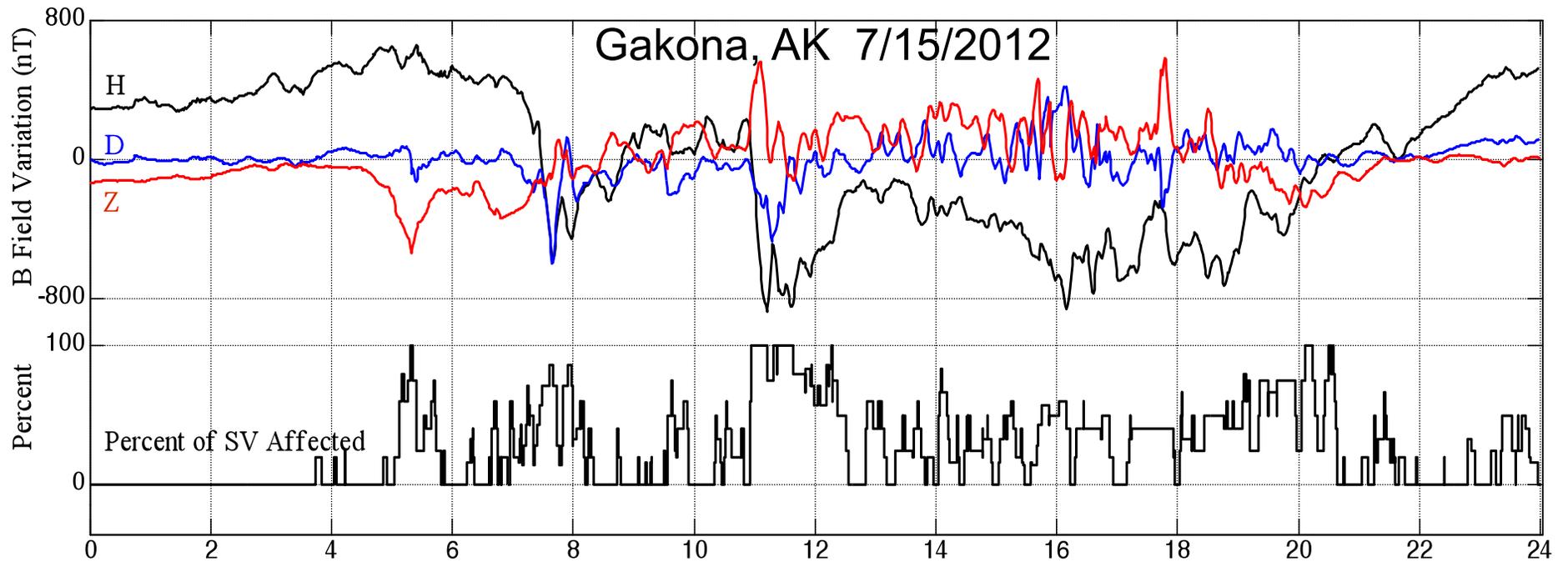
Students:
Joy Jiao

Scin Occurrence vs. Seasons & Solar Activity



Student:
Joy Jiao

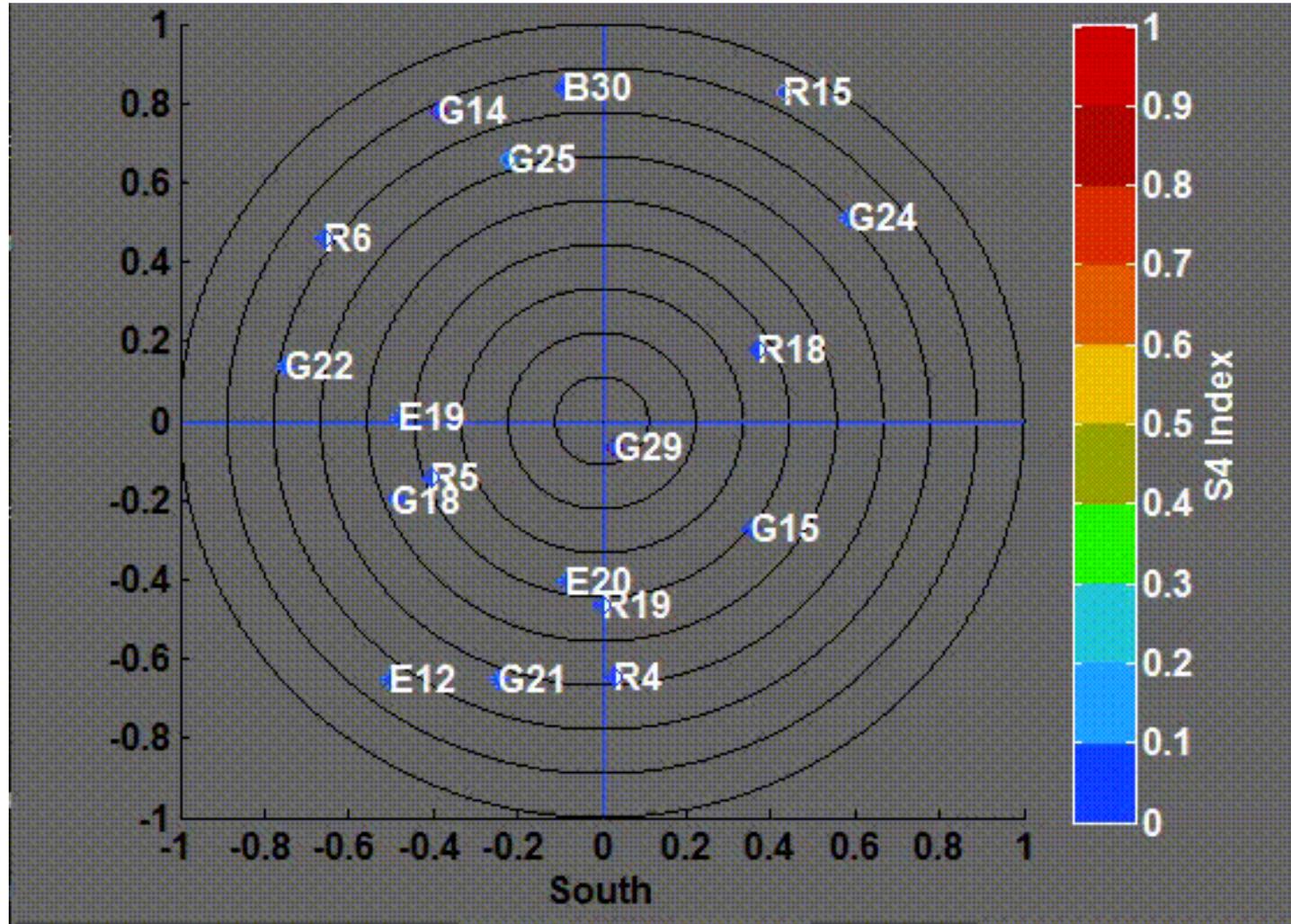
Geomagnetic Disturbance at High Latitude



Student:
Joy Jiao

Equatorial Scintillation Spatial Distribution

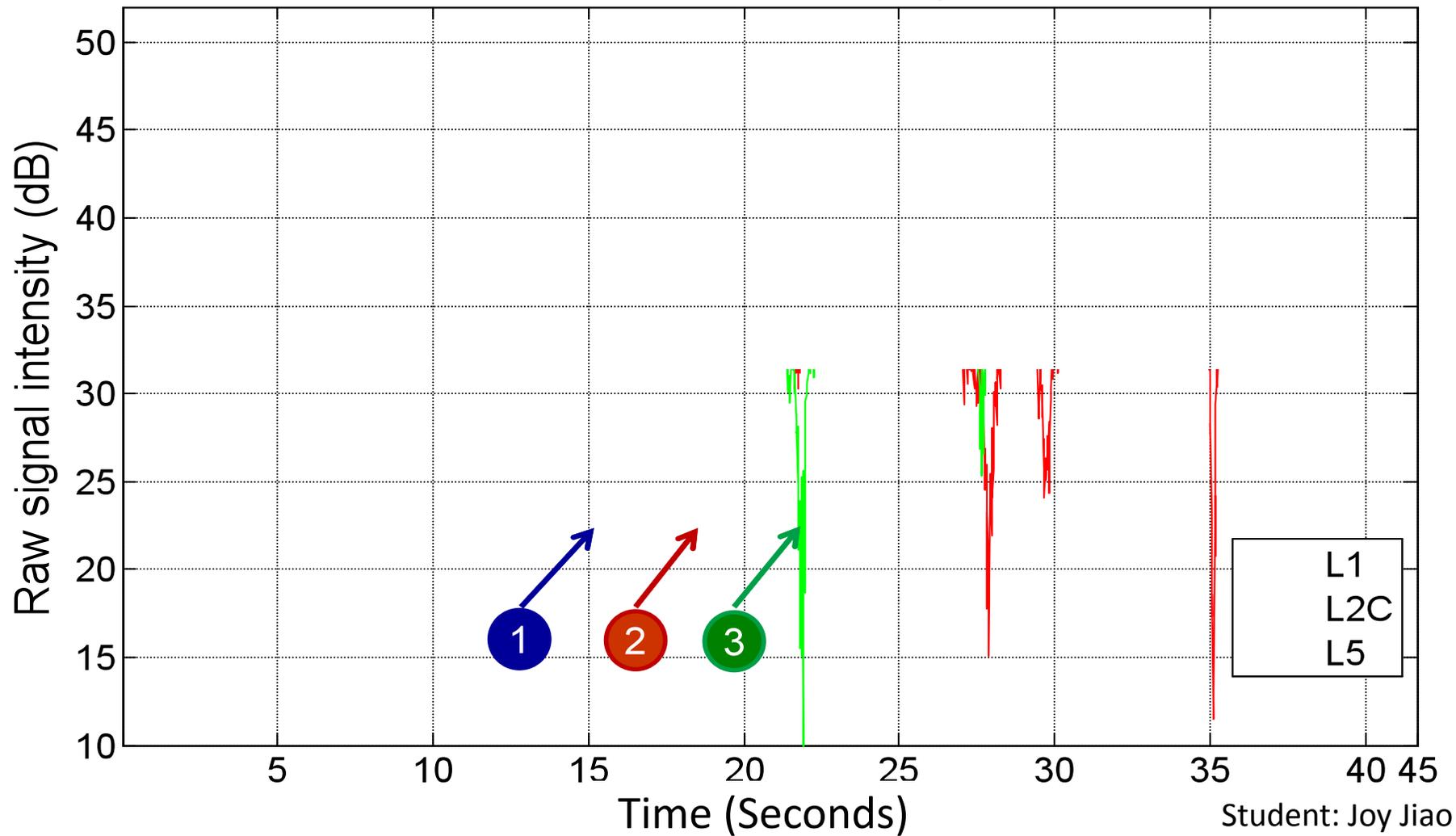
20:00:00 UTC 3/10/2013 — 01:00:00 UTC 3/11/2013 Ascension Island



Students:
Mark Carroll
Dongyang Xu
Nazelie Kassabian

Frequency Diversity: Selective Fading

Ascension Island - 2013/03/05 Starting at 04:10 UT- PRN25



Triple-frequency Fading Overlap

Threshold of detrended signal intensity: -15dB

Fading band	L1	L2C	L5
L1 only	95.3%	/	/
L2C only	/	82.9%	/
L5 only	/	/	80.7%
Concurrent L1 and L2C	3.0%	1.3%	/
Concurrent L1 and L5	1.4%	/	0.7%
Concurrent L2C and L5	/	15.7%	18.5%
Concurrent L1, L2C and L5	0.2%	0.1%	0.1%

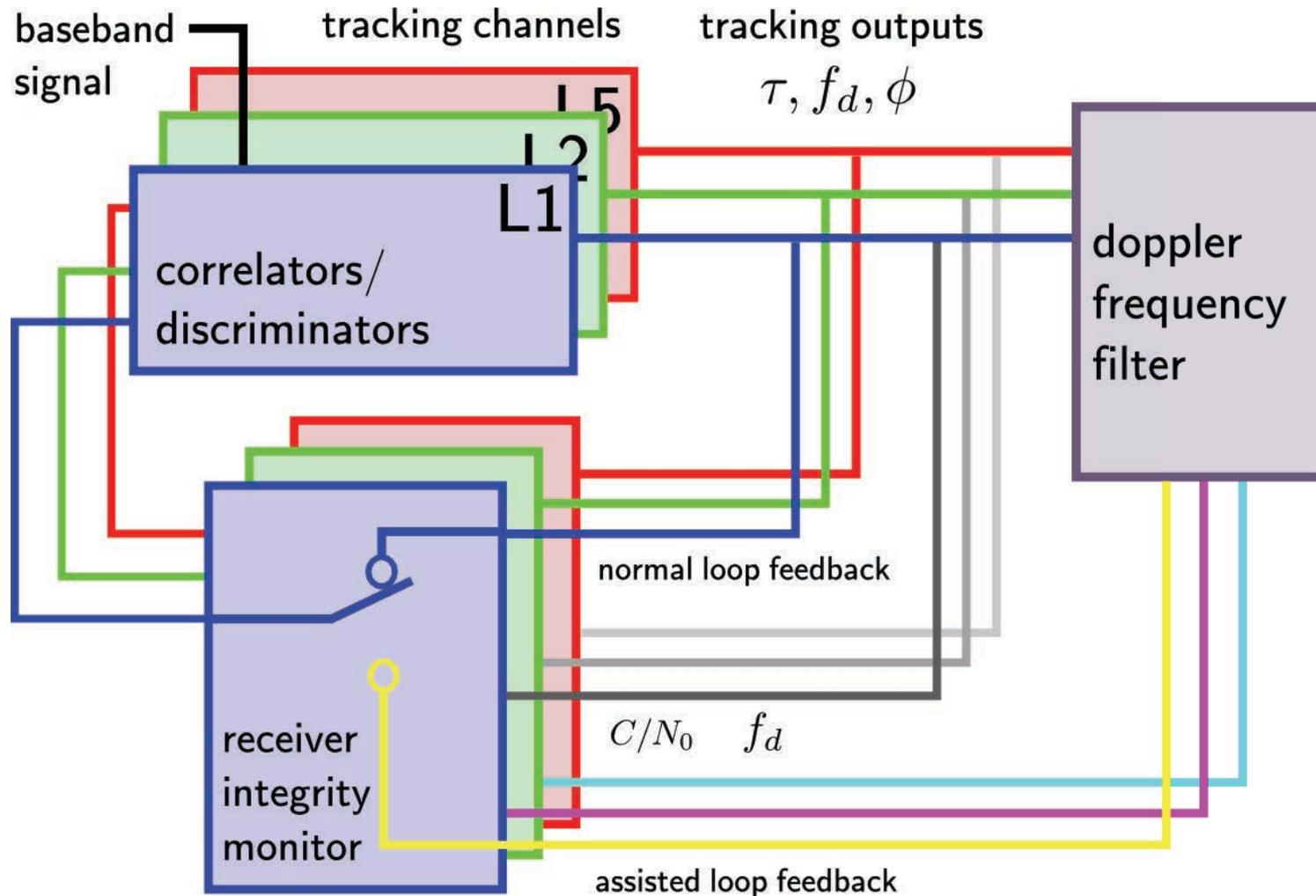
	Fading Number
L1	1,791
L2C	4,591
L5	1,584
Total	7,966

← Very small percentage

➤ Mitigation

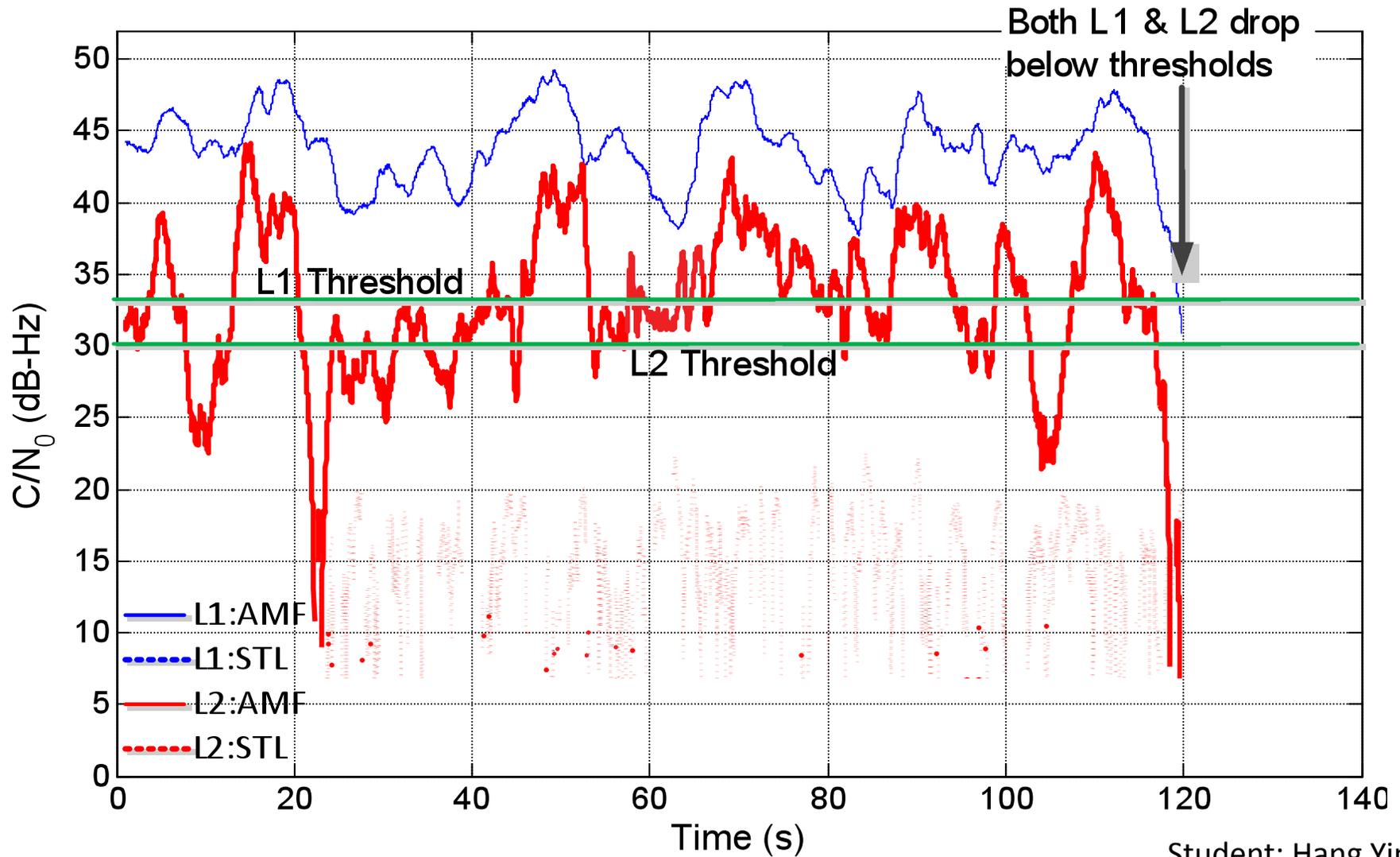
- **Optimization of conventional tracking** (Mark Carroll)
- **Adaptive multi-frequency filtering** (Hang Yin)
- **Multi-constellation vector tracking** (Dongyang Xu)

Adaptive Multi-Frequency (AMF) Carrier Tracking



Student: Hang Yin

Adaptive Multi-Frequency (AMF) Carrier Tracking

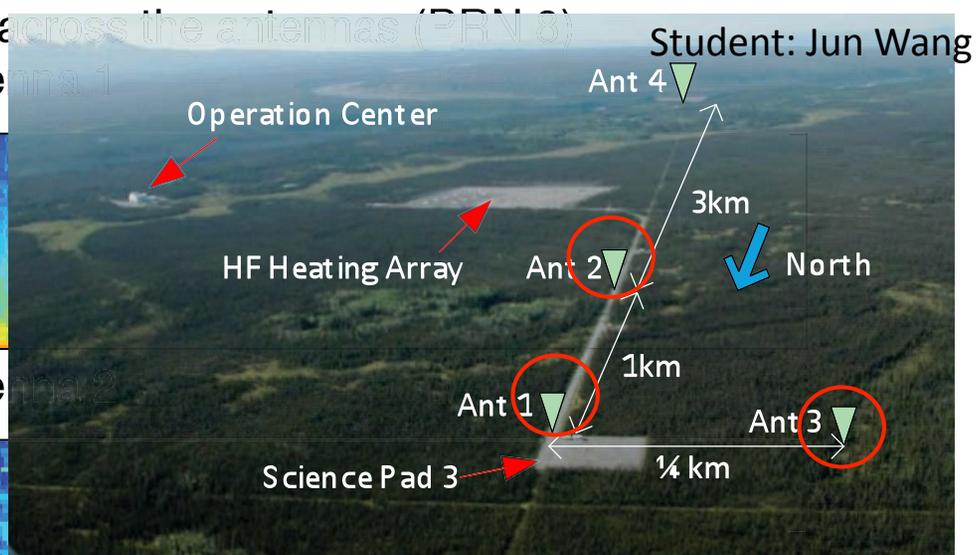
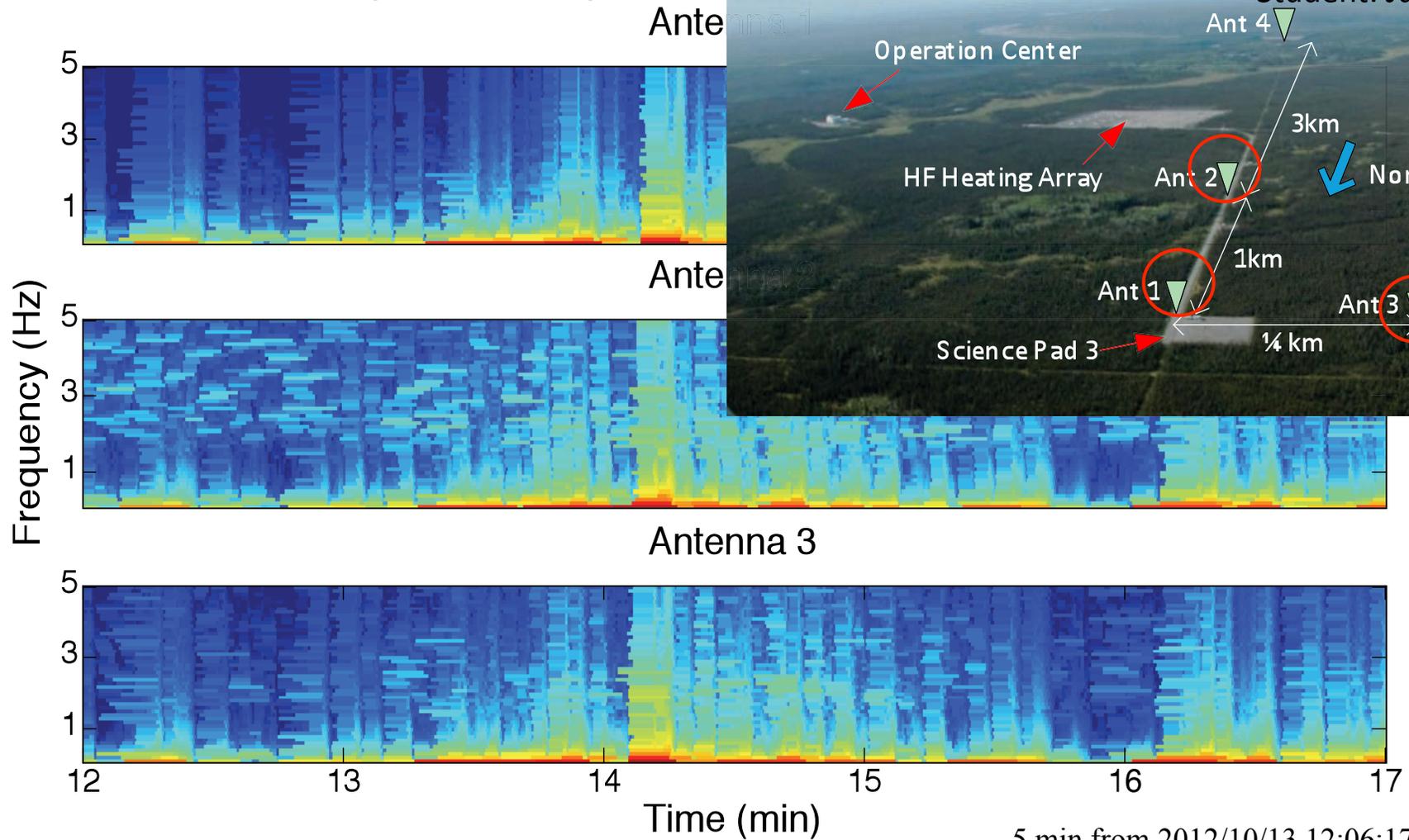


➤ Utilization

- **Ionospheric structure: TEC, TEC gradient mapping**
- **Plasma turbulence mapping**

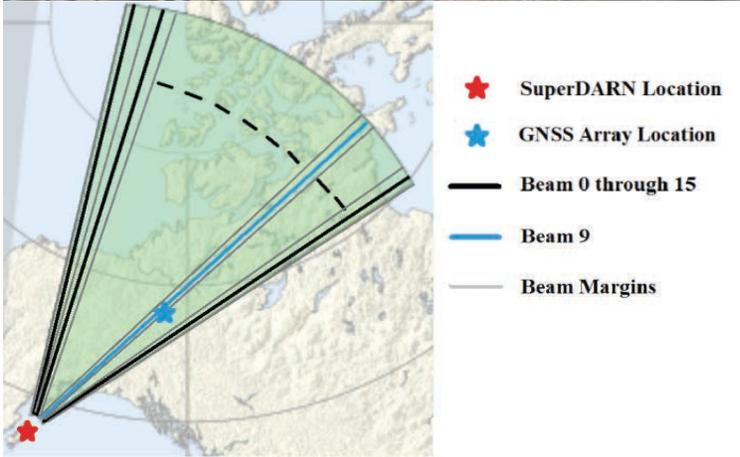
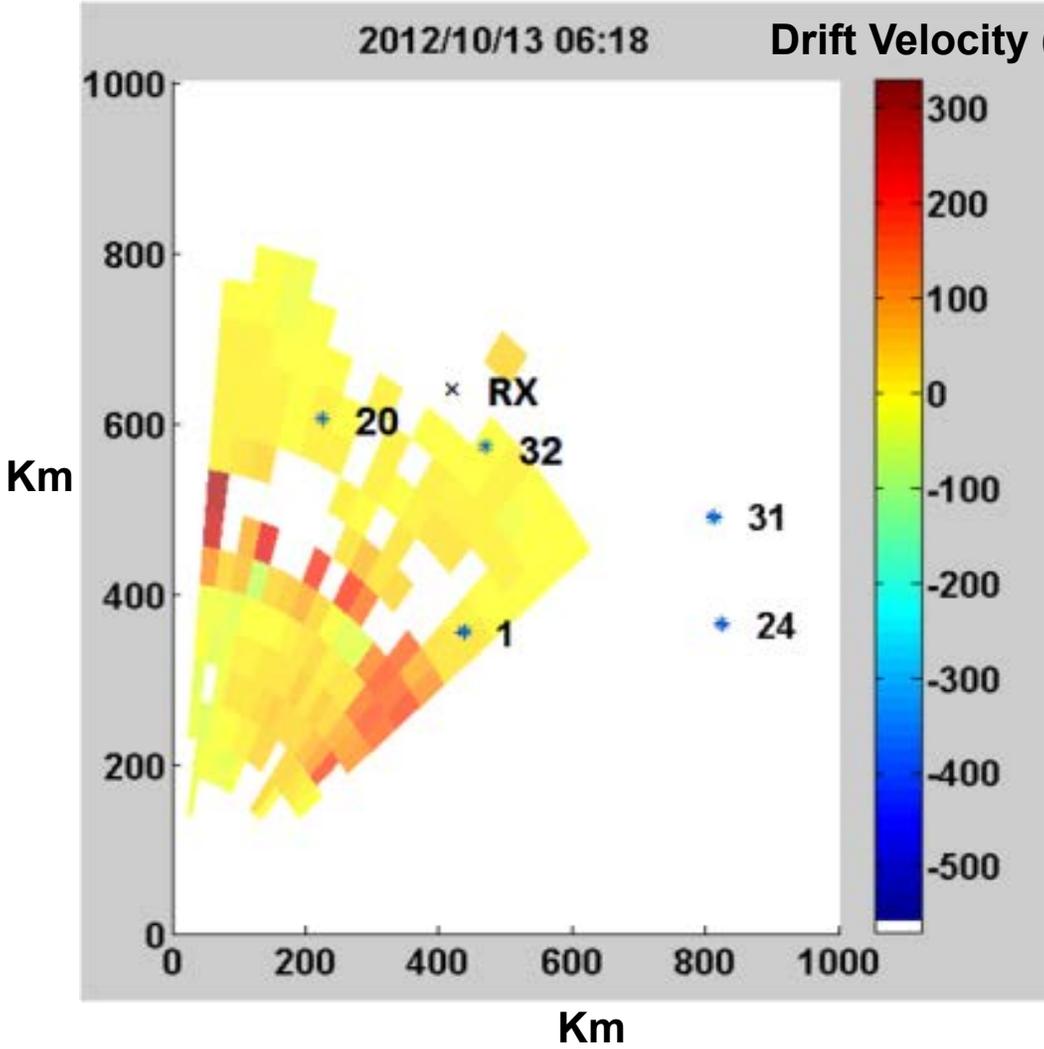
APT Time-Frequency Analysis

APT spectrum comparison across the antennas (PRN 8)

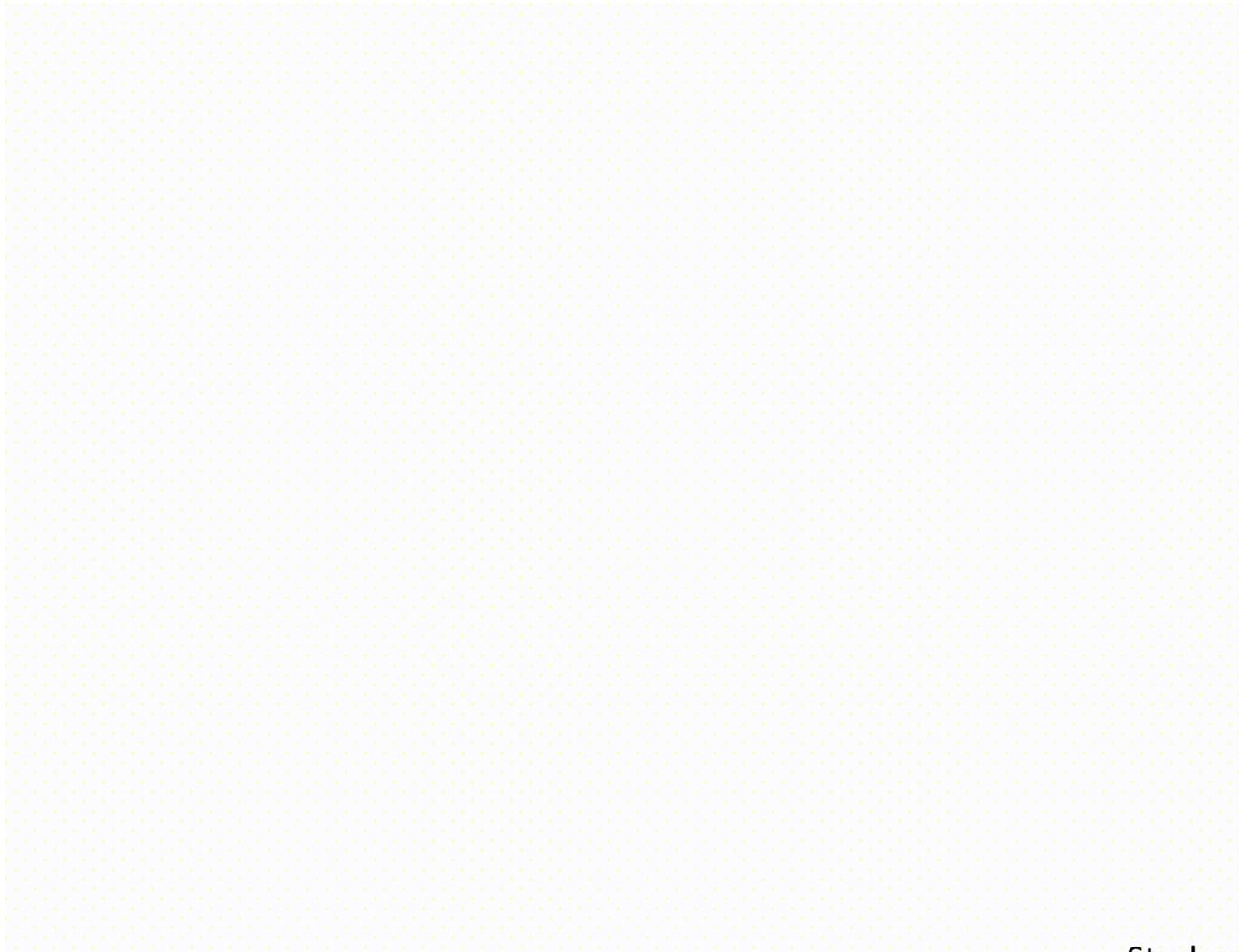


5 min from 2012/10/13 12:06:17 UTC

GNSS vs. SuperDARN



Plasma Drift – Gakona, AK



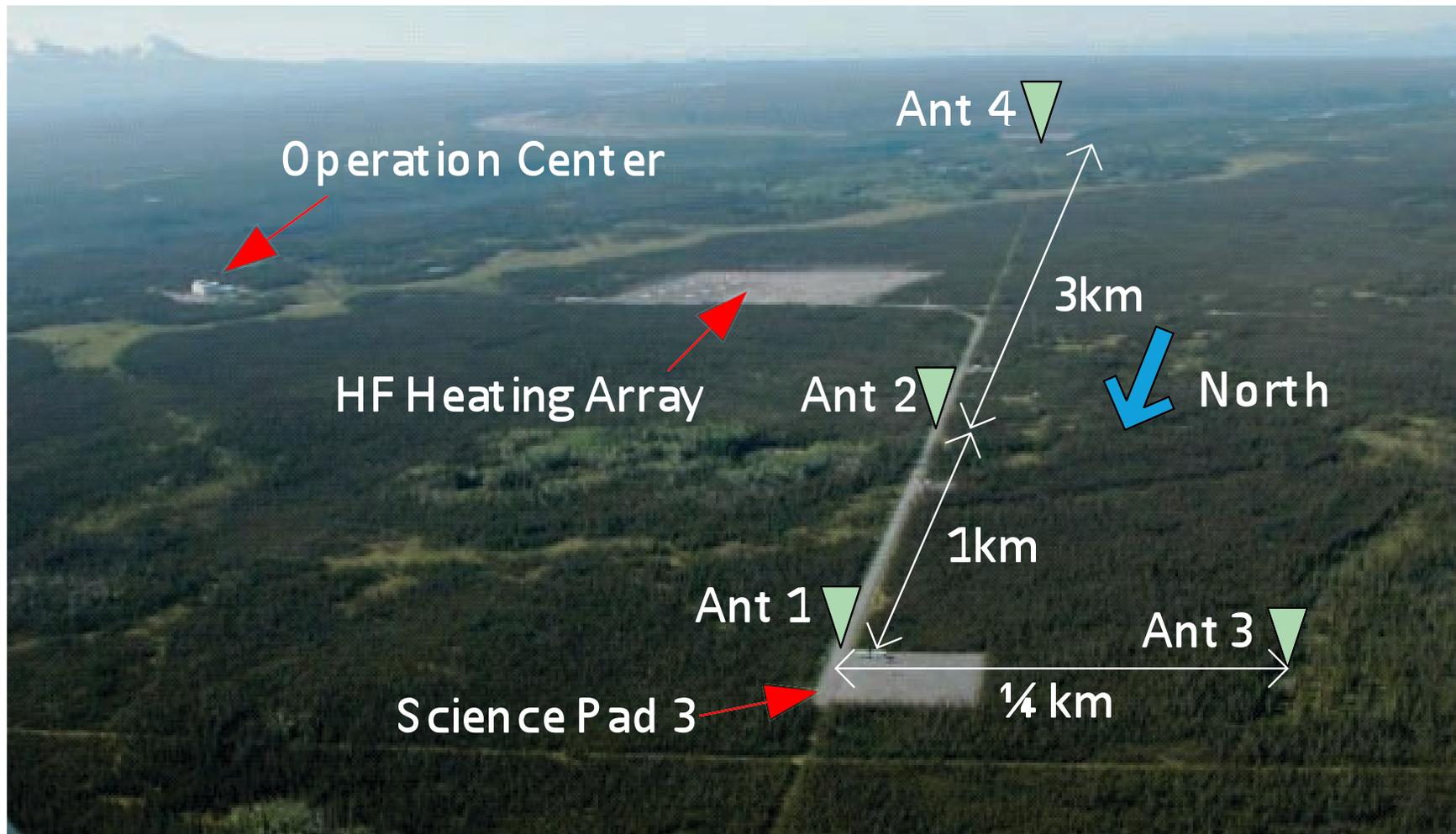
Student: Jun Wang

Summary of Future Plan

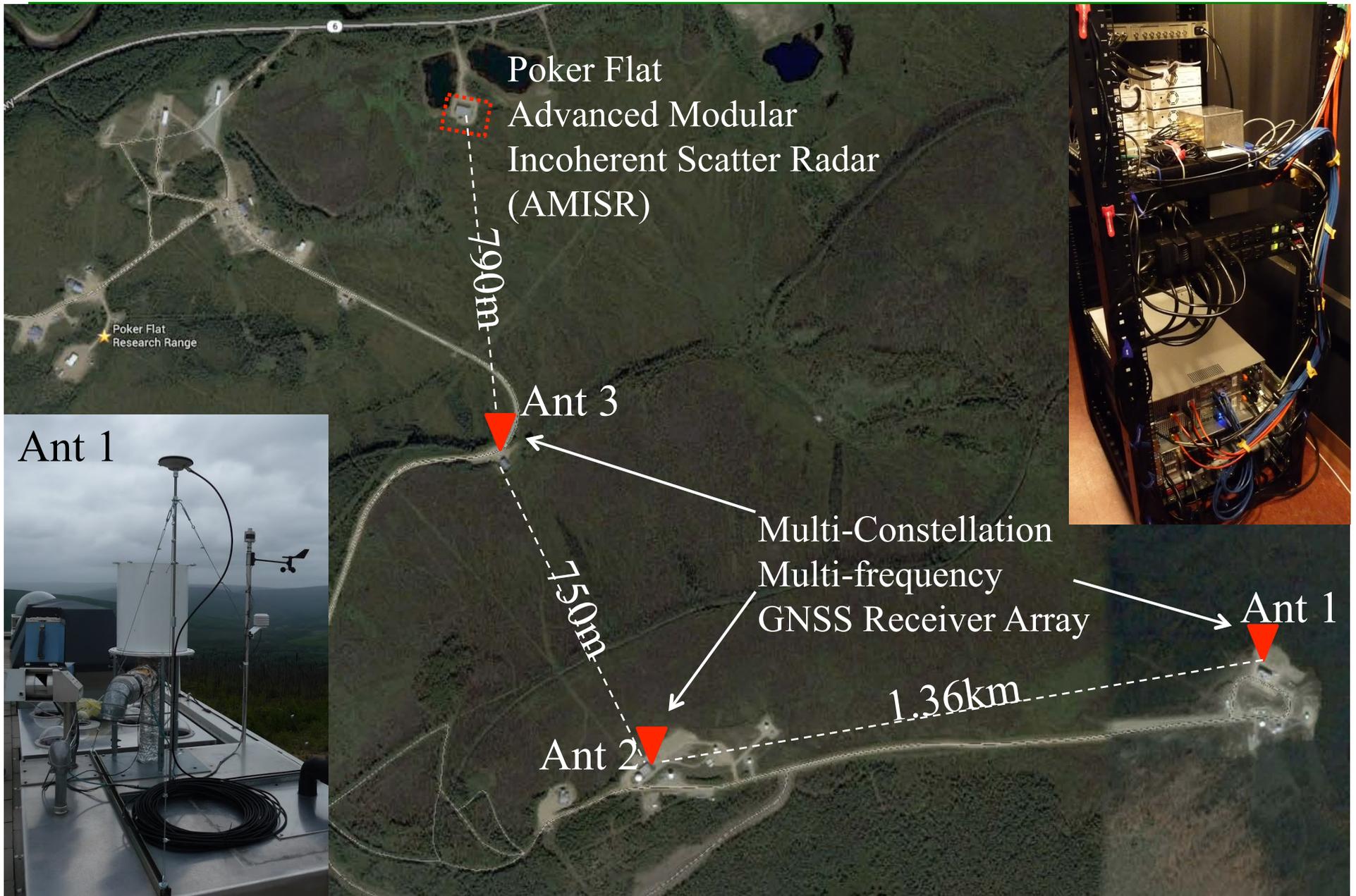
- Multi-constellation, multi-band GNSS will be a **major enabler** for ionosphere space weather studies
 - High quality raw IF data is needed to facilitate the study
 - Accurate receiver processing algorithms are critical to maintain lock of signals during space weather events and to preserve true space weather signature on GNSS signal parameters

Thank you!
Q&A

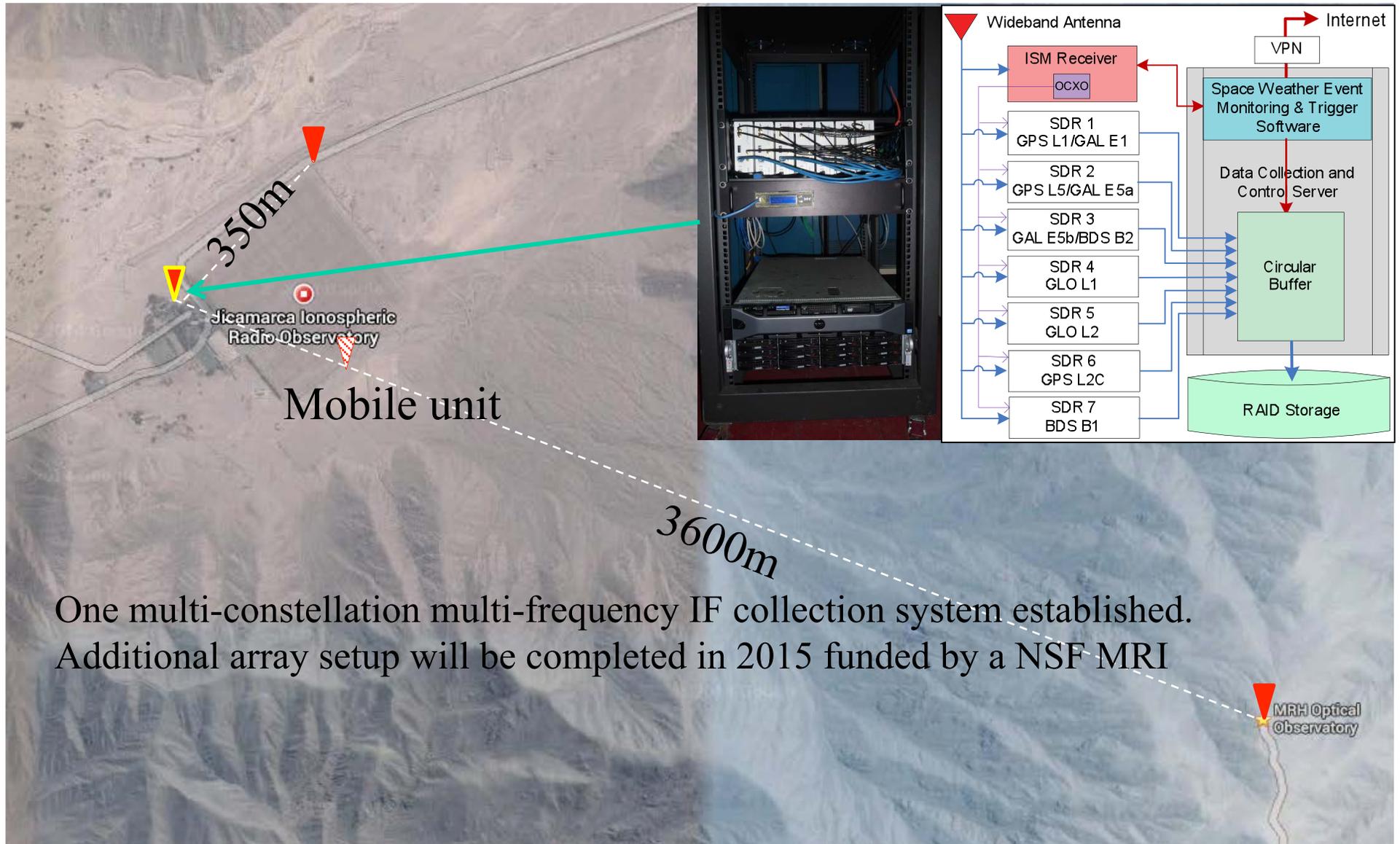
Gakona, Alaska (HAARP)



Poker Flat Research Range, Alaska

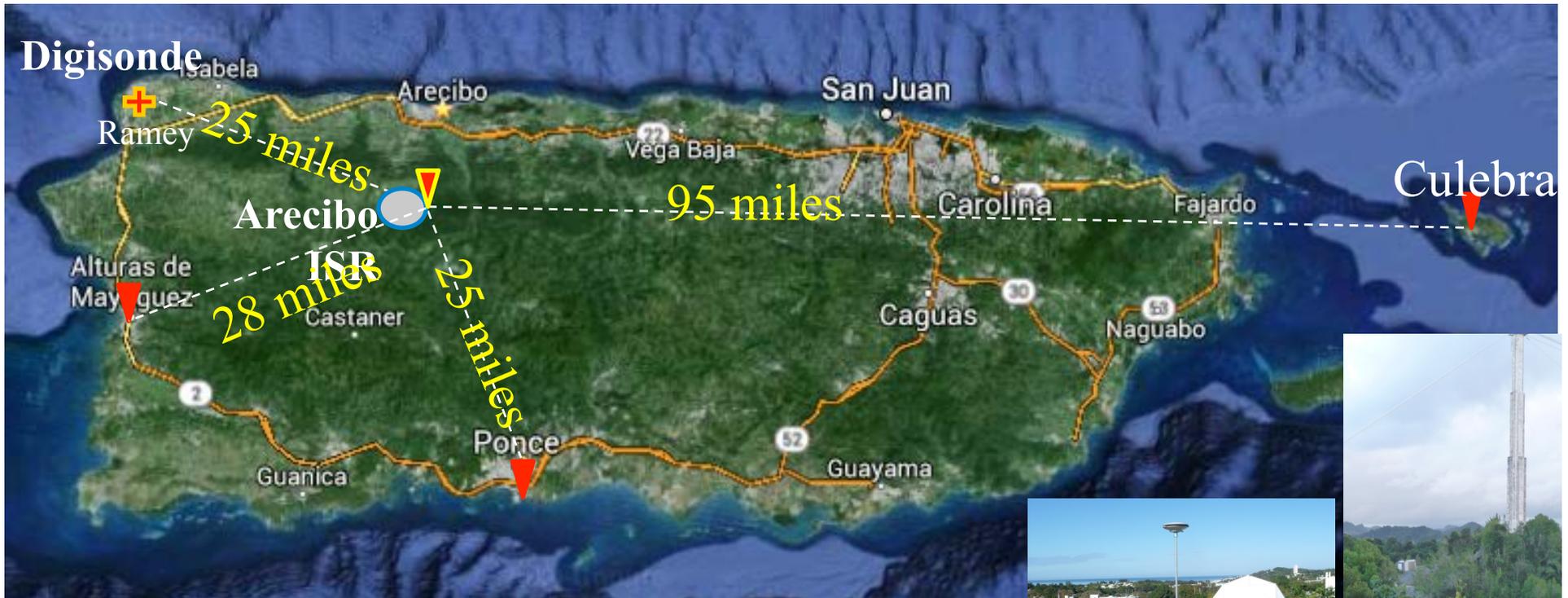


Jicamarca Radio Observatory, Peru

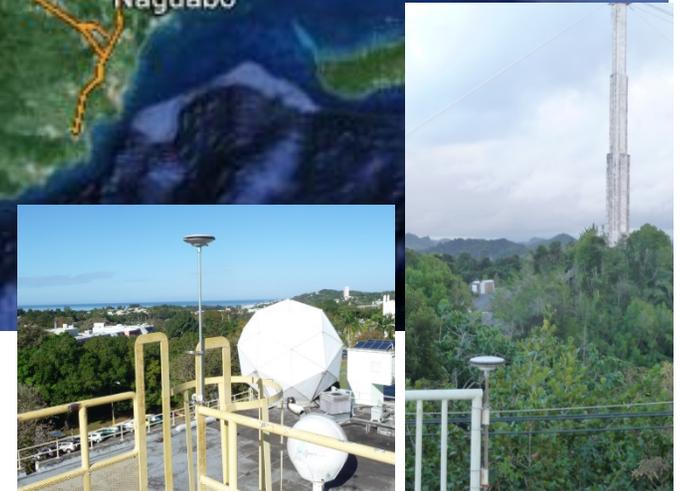


One multi-constellation multi-frequency IF collection system established.
Additional array setup will be completed in 2015 funded by a NSF MRI

Arecibo Observatory, Puerto Rico



- ▼ Multi-Constellation GNSS Array.
To be completed in 2015 funded by NSF MRI



Arecibo Observatory: Magnetometer, Optical Observatory, artificial HF heating

Available Data at Gakona, Alaska

Year	2010		2011		2012		2013		2014		
Month	Day #	%	Day #	%	Day #	%	Day #	%	Day #	%	
Jan.	Not available		31	100	8	25	22	70	0	0	
Feb.			28	100	20	68	28	100	25	89	
Mar.			23	74	15	49	31	100	31	100	
Apr.			29	96	0	0	30	100	30	100	
May			31	100	0	0	14	45	31	100	
June			30	100	22	74	30	100	22	73	
July			17	55	28	90	31	100	Not available		
Aug.	6	19	21	68	27	87	31	100			
Sept.	28	90	0	0	30	100	30	100			
Oct.	15	48	6	19	31	100	31	100			
Nov.	29	97	14	47	30	100	25	83			
Dec.	31	100	19	60	8	26	20	64			
Total	109	71	249	68	219	60	323	88	139	77	
Grand total in 2010 - 2014									1,038	73	

Available Data at Jicamarca, Peru

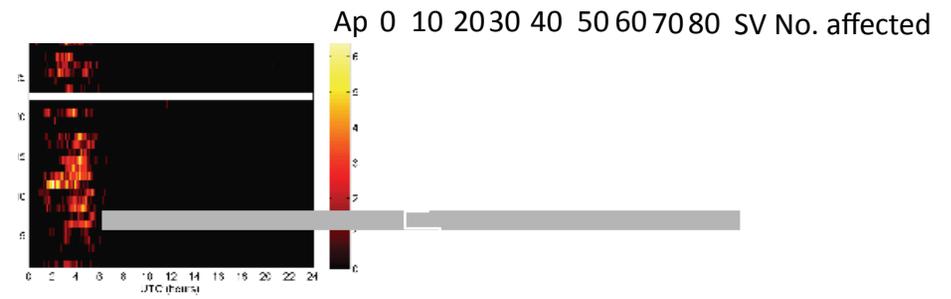
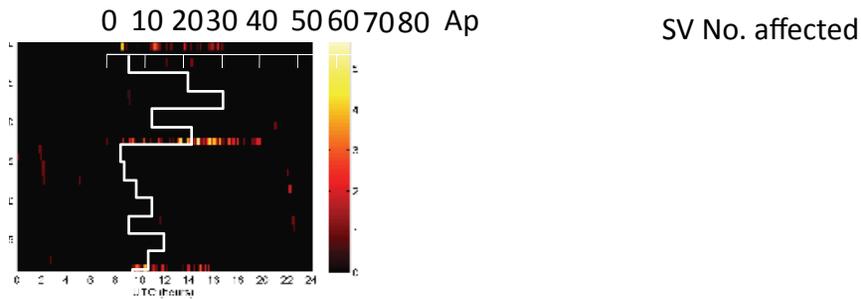
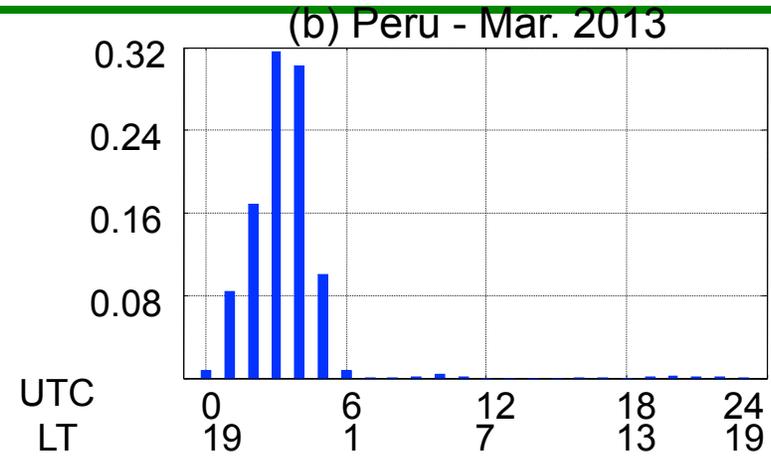
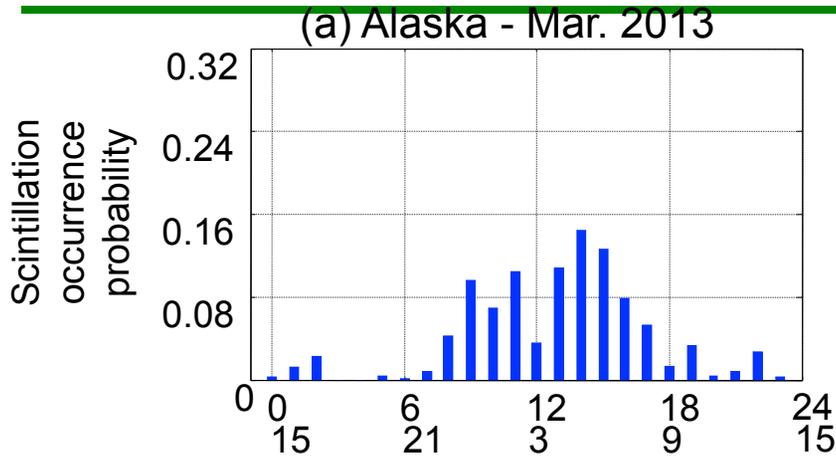
Year	2012		2013		2014	
Month	Day #	%	Day #	%	Day #	%
Jan.	Not available		30	95	0	0
Feb.			28	100	7	25
Mar.			30	97	24	77
Apr.			29	95	24	80
May			23	73	0	0
June			13	42	0	0
July			0	0	30	96
Aug.			5	17	Not available	
Sept.			14	47		
Oct.			27	86		
Nov.	8	27	12	39		
Dec.	31	100	0	0		
Total	39	64	209	57	85	40
Grand total in 2012 - 2014					333	52

Scintillation Event Criteria

1. Elevation $\geq 30^\circ$
2. Alaska: $S_4 \geq 0.15$ OR $\sigma_\phi \geq 15^\circ$
Peru/Ascension:
 $S_4 \geq 0.2$ OR $\sigma_\phi \geq 15^\circ$
3. Duration ≥ 30 seconds
4. Two events detected within 5 minutes are counted as one
5. Scintillations experienced by multiple PRNs simultaneously are recorded separately

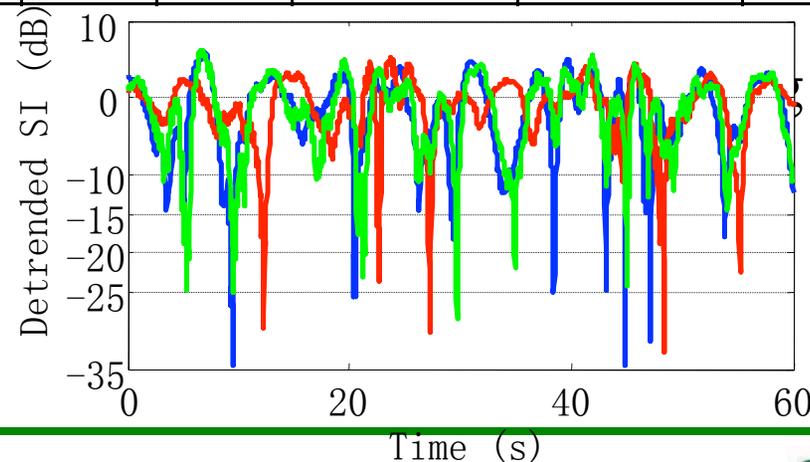
$$S_4 = \sqrt{\frac{\langle I^2 \rangle - \langle I \rangle^2}{\langle I \rangle^2}}$$

Scintillation Event Frequency



Detrended SI Fading Overlap – Triple-frequency

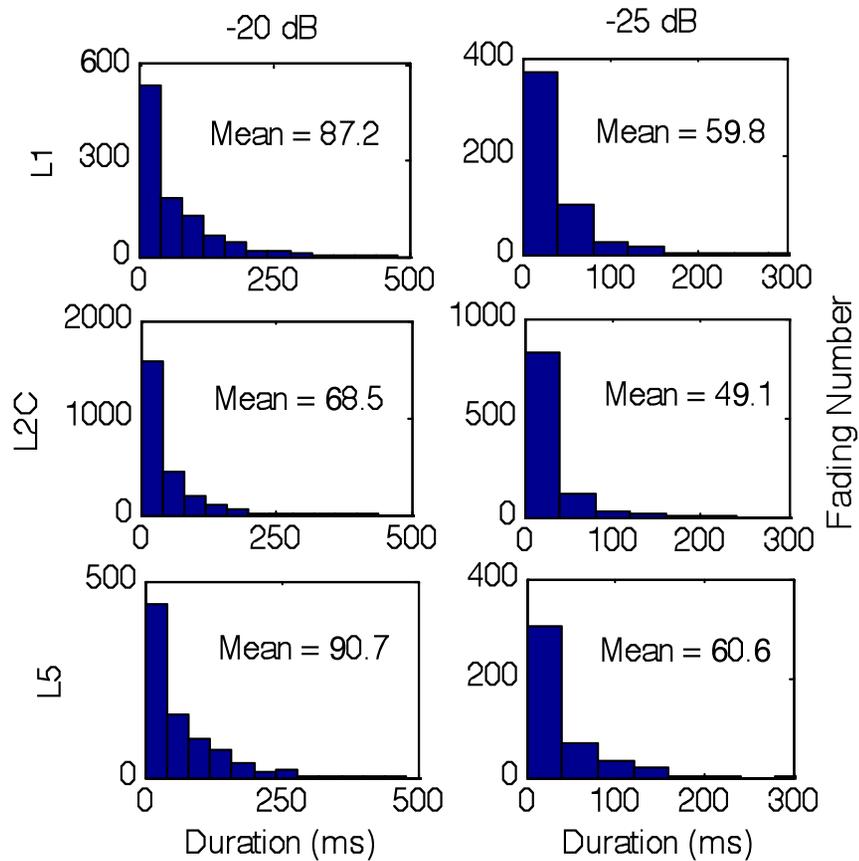
Fading band	Threshold	L1 only	L2C only	L5 only	Concurrent L1 and L2C	Concurrent L1 and L5	Concurrent L2C and L5	Concurrent L1, L2C and L5
L1	-10 dB	86.1%	/	/	7.5%	4.5%	/	1.9%
	-15 dB	95.3%	/	/	3.0%	1.4%	/	0.2%
	-20 dB	97.9%	/	/	1.4%	0.6%	/	0
	-25 dB	99.8%	/	/	0.2%	0	/	0
L2C	-10 dB	/	68.7%	/	3.7%	/	26.7%	0.9%
	-15 dB	/	82.9%	/	1.3%	/	15.7%	0.1%
	-20 dB	/	90.5%	/	0.6%	/	8.9%	0
	-25 dB	/	94.7%	/	0.1%	/	5.2%	0
L5	-10 dB	/	/	66.7%	/	2.4%	29.8%	1.0%
	-15 dB	/	/	80.7%	/	0.7%	18.5%	0.1%
	-20 dB	/	/	89.5%	/	0.3%	10.2%	0
	-25 dB	/	/	95.4%	/	0	4.6%	0



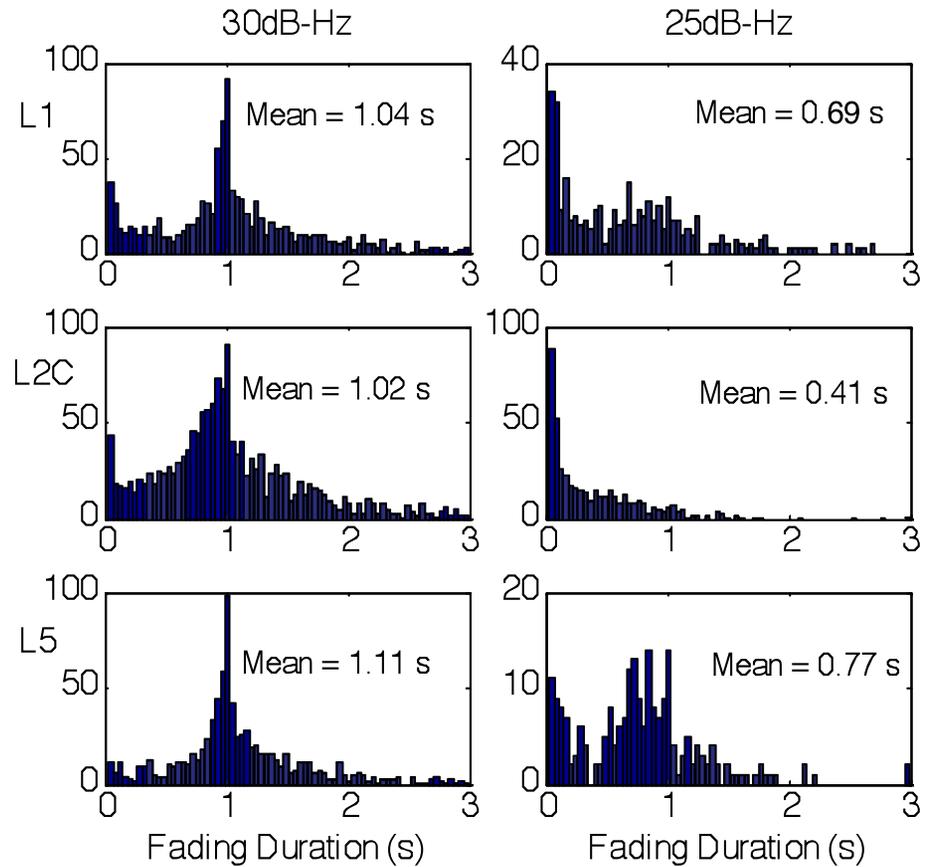
PRN 24, 3/10/2013

Fading Duration Statistics

Detrended SI Fading



C/N₀ Fading



Drift Velocity Comparison

2012/10/09 06:02 - 06:20 UTC Alaska

