# Statistical Characterization of GNSS Signal Carrier Doppler Frequency Deviations During Ionospheric Scintillation

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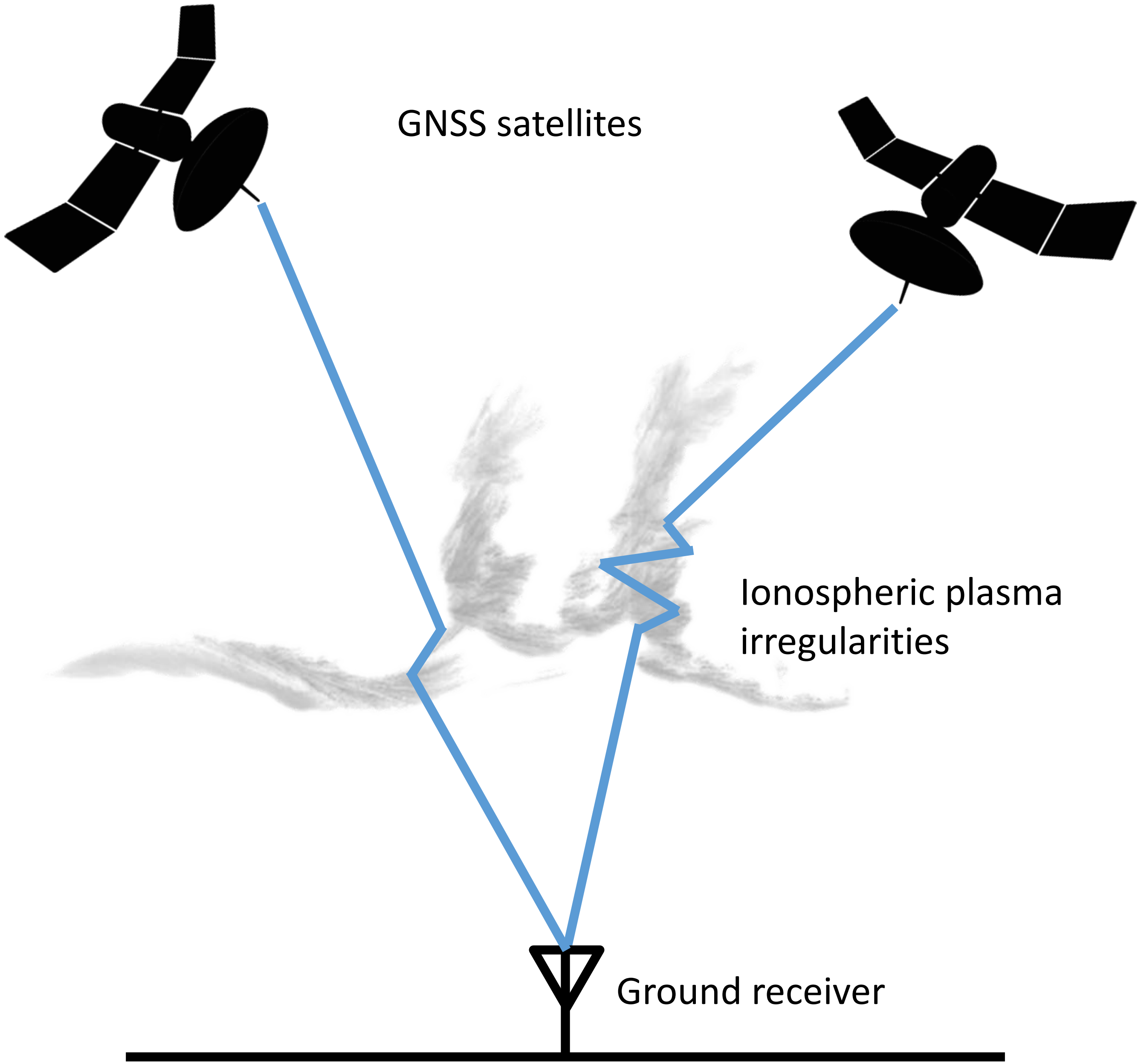
# Outline

- Overview of ionospheric scintillation
- Motivation: GPS receiver carrier tracking
- Experiment setup
- Description of data processing procedure
- Low and high latitude results
- Future work

# Ionospheric Scintillation

Small-scale irregularities in the density of electrons cause fluctuations in the **amplitude**, **phase**, and **frequency** of a GNSS signal.



# Ionospheric Scintillation Indices

Ionospheric scintillation indices are statistical measures of the severity of scintillation.

$S_4$, defined as the normalized standard deviation of the detrended signal intensity, quantifies the effect of scintillation on signal amplitude:

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

$\sigma_\phi$, defined as the standard deviation of the detrended carrier phase, quantifies the effect on signal phase:

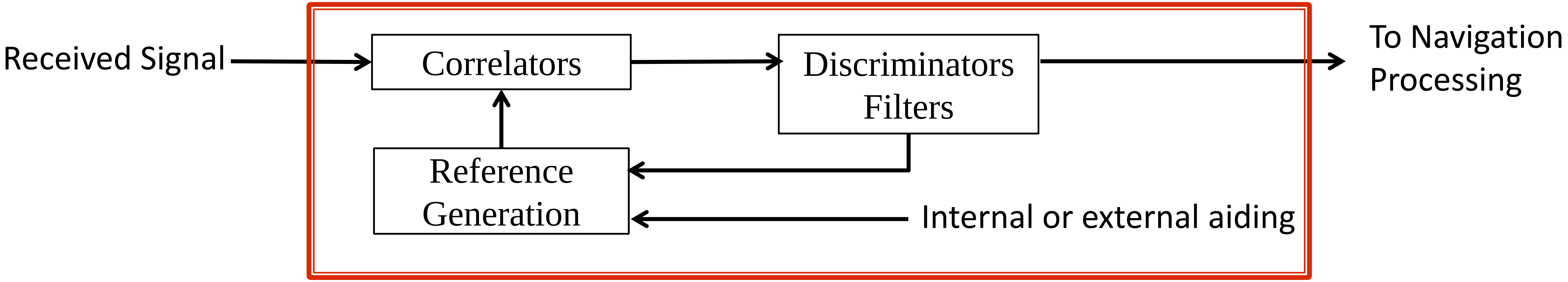
$$\sigma_\phi = \langle \phi^2 \rangle - \langle \phi \rangle^2$$

**Low latitudes** experience deep amplitude fading ($S_4$) and large phase fluctuations ($\sigma_\phi$).

At **high latitudes**, scintillation effects are dominated by phase fluctuations ($\sigma_\phi$).

The effect of scintillation on **carrier Doppler frequency** is less studied.

# Receiver Carrier Tracking




| Processing Component | Correlator | Estimator | Filter |
|---|---|---|---|
| Example Design Parameters | Integration Time | Estimator Type | Bandwidth |
| **Deep Fade → Weak Signal** | **Long** | **Phase** | **Narrow** |
| **Fast Carrier Phase Change → Highly Dynamic Signal** | **Short** | **Frequency** | **Wide** |

# Experiment Setup

GPS L1 (1575.42 MHz) Data

**Ascension Island**
7.93˚S, 14.37˚W

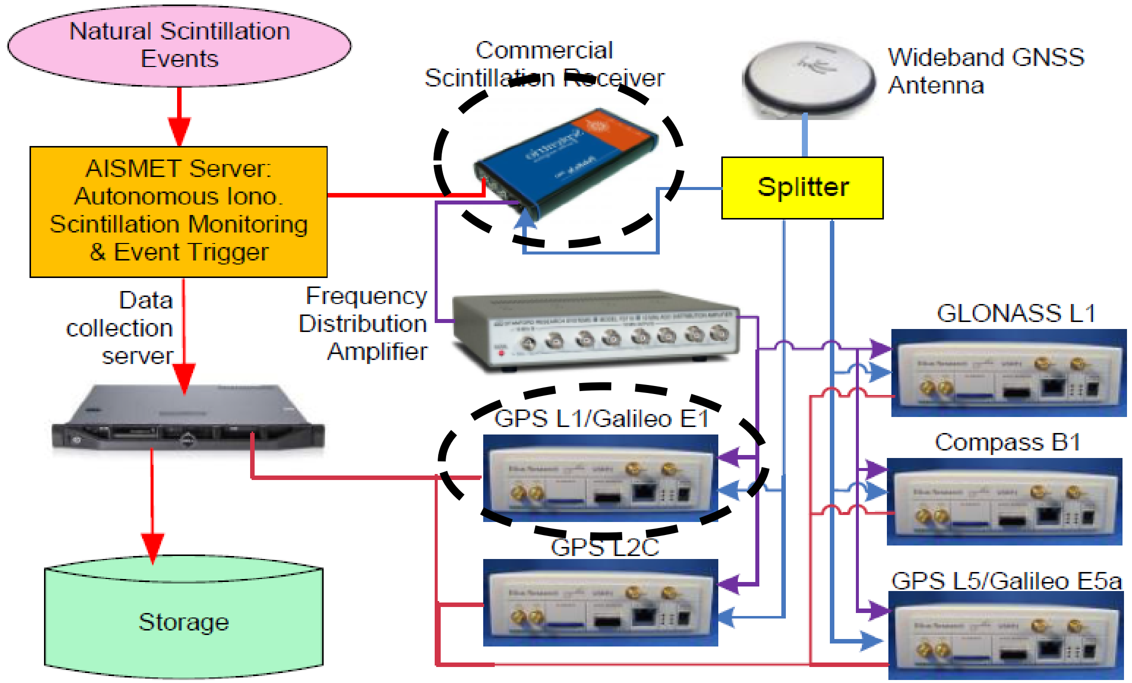



*Figure: Mark Carroll*

About 5 hours of total data:

- PRN 24 on 03/08/13
- PRN 29 on 03/09/13
- PRNs 24 and 31 on 03/10/13

Collected with Septentrio PolaRxS receiver and custom hardware

# Experiment Setup

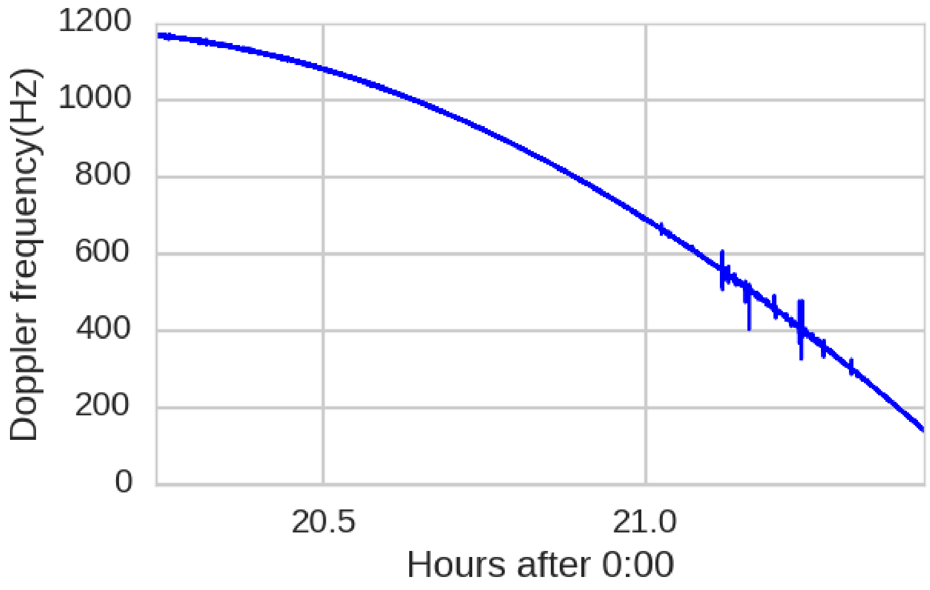
**Poker Flat Research Range, Alaska**
65.14˚N, 148.01˚W

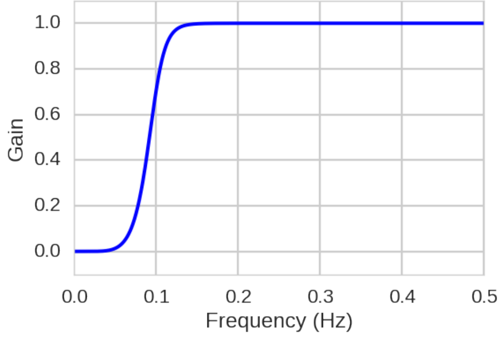
One full day (12/20/2015) of data collected by Septentrio PolaRxS receiver

# Data Processing Procedure – Doppler Detrending

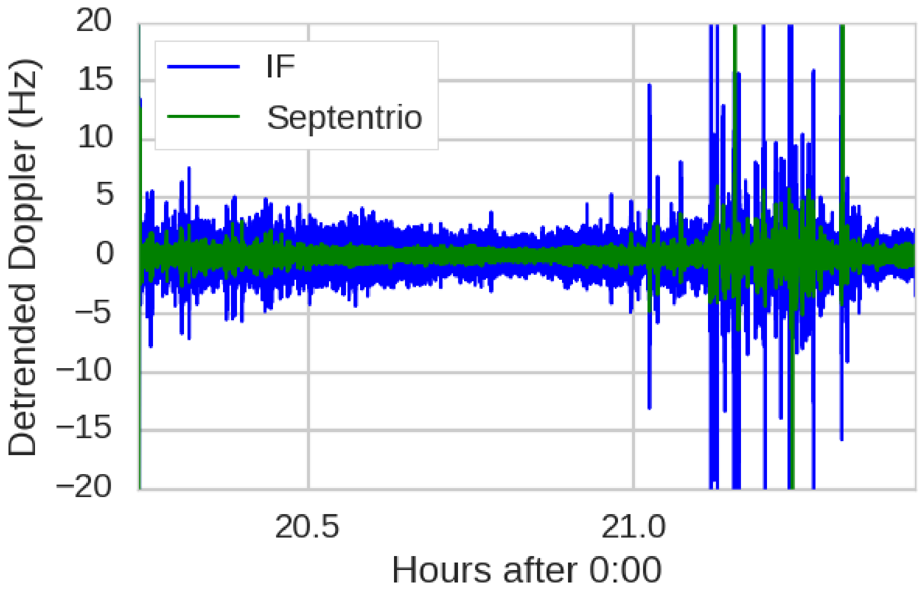
**Example low-latitude data** (PRN 24 passing over Ascension Island on 03/10)

1. Differentiate the carrier phase to find Doppler frequency



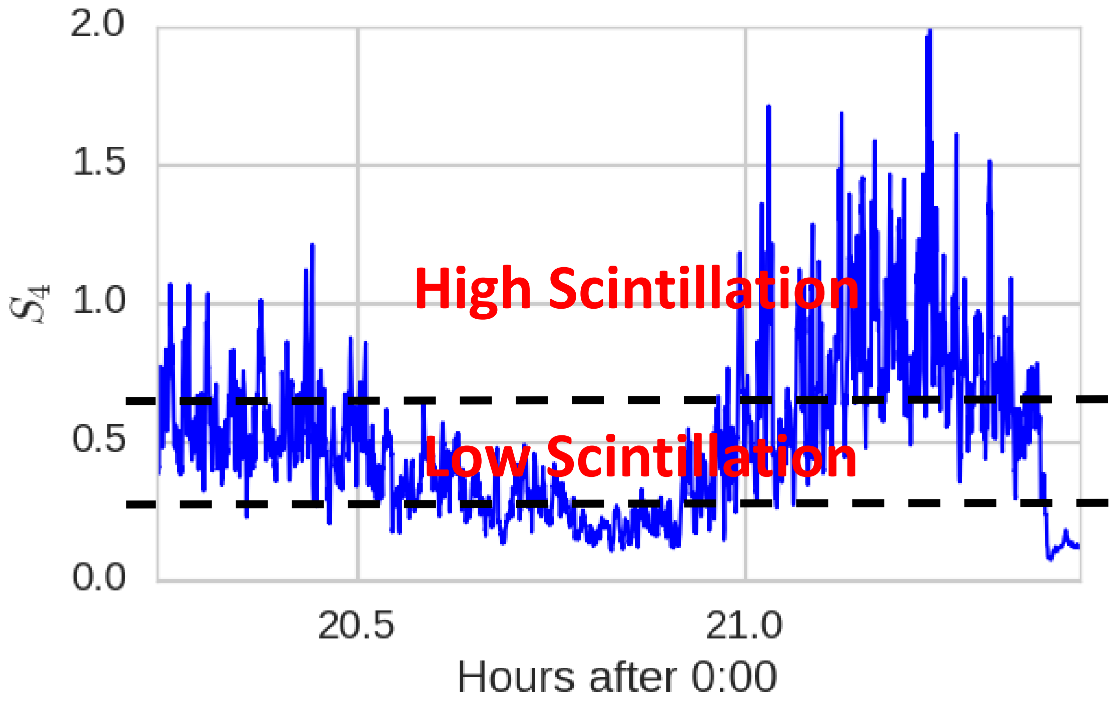




2. Detrend using a sixth-order Butterworth Filter



# Data Processing Procedure – Scintillation Index

**3** Calculate the appropriate scintillation index




Low latitude data: $S_4$

High latitude data: $\sigma_\phi$

**4** Categorize Doppler deviations per corresponding level of scintillation

**Low scintillation regime:**

$0.3 \leq S_4 < 0.6$ or $0.2$ rad $\leq \sigma_\phi < 0.5$ rad

**High scintillation regime:**

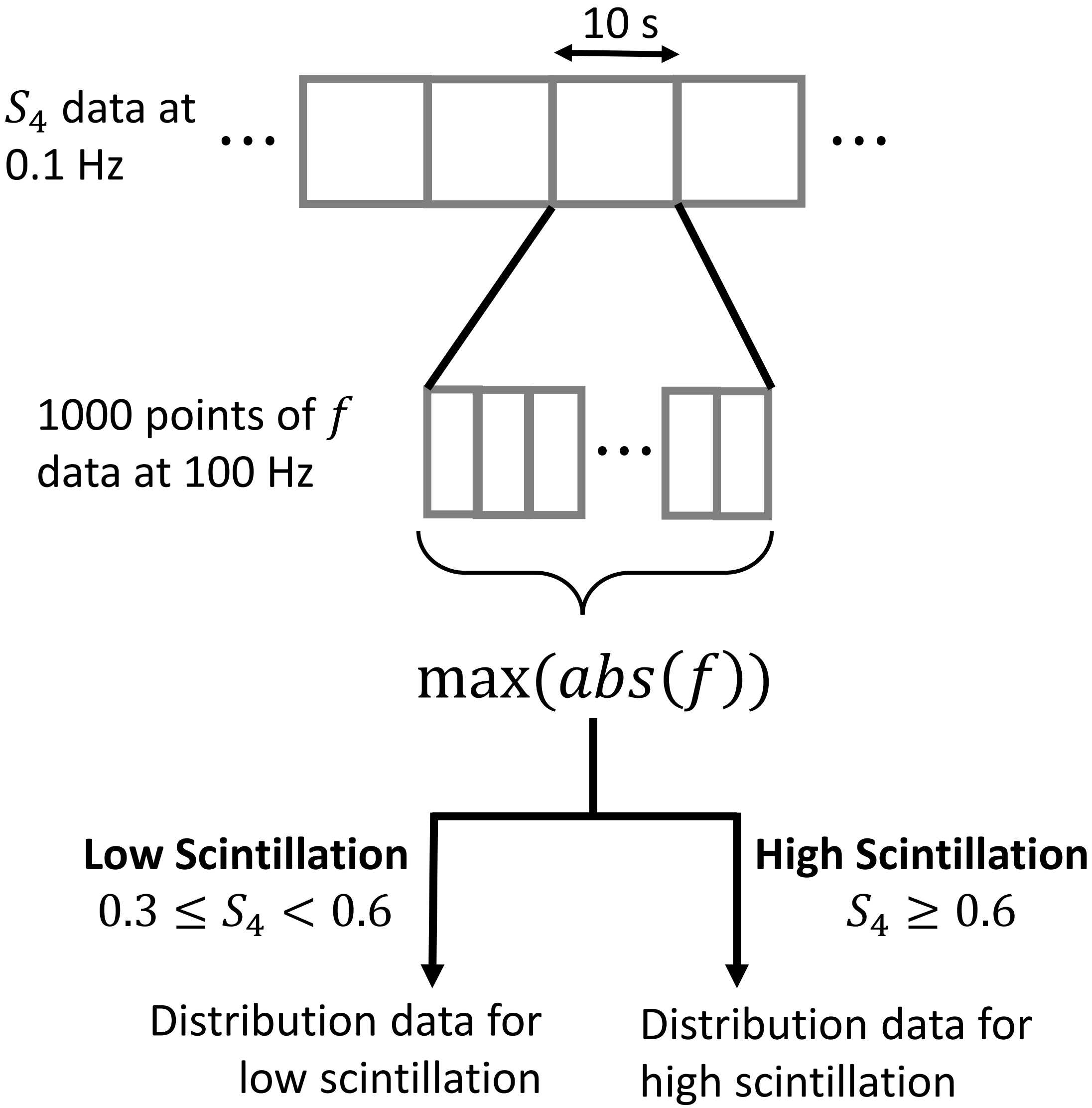
$S_4 \geq 0.6$ or $\sigma_\phi \geq 0.5$ rad

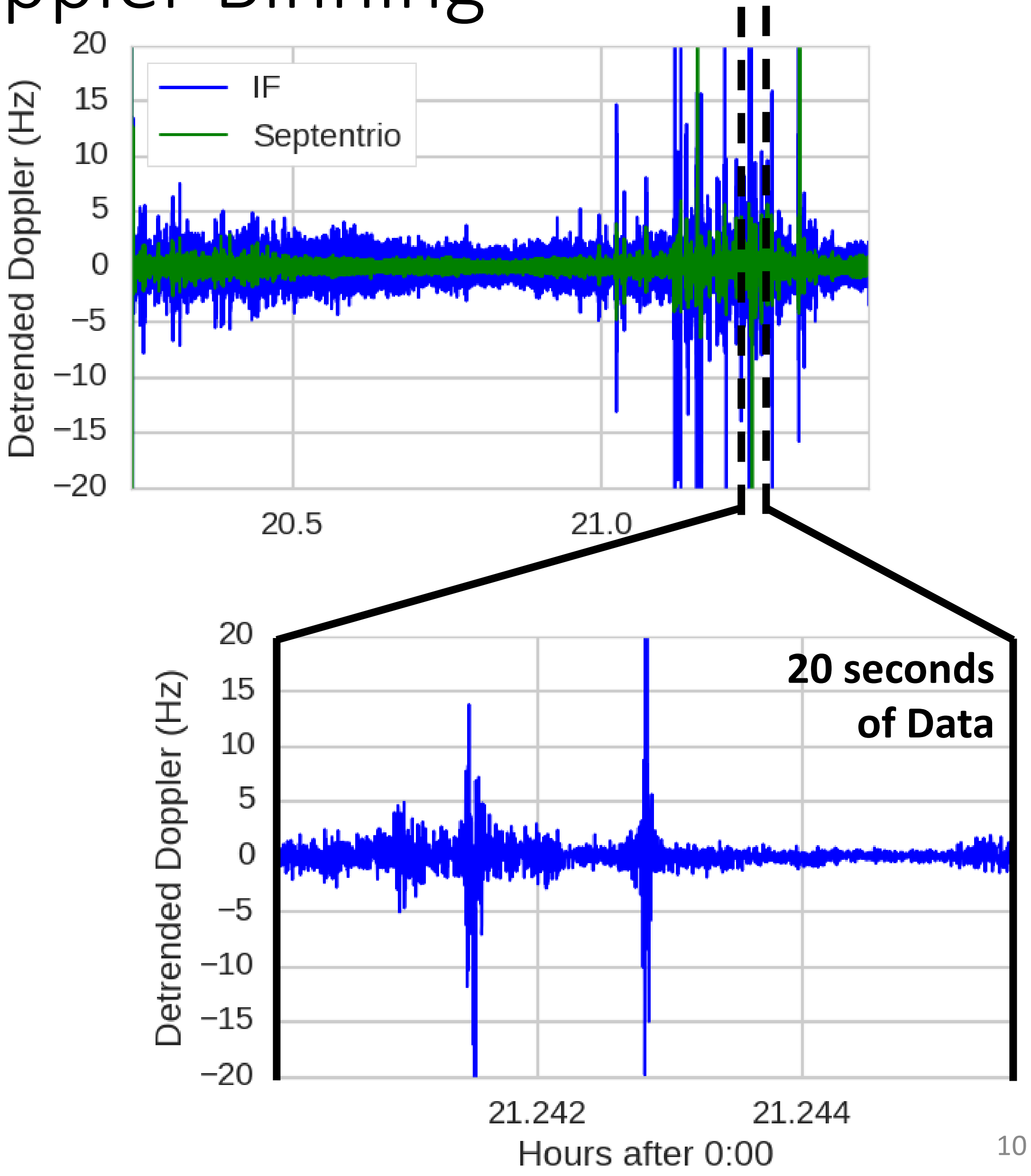
The rate of $S_4$ and $\sigma_\phi$ is 0.1 Hz

The rate of detrended Doppler is 100 Hz

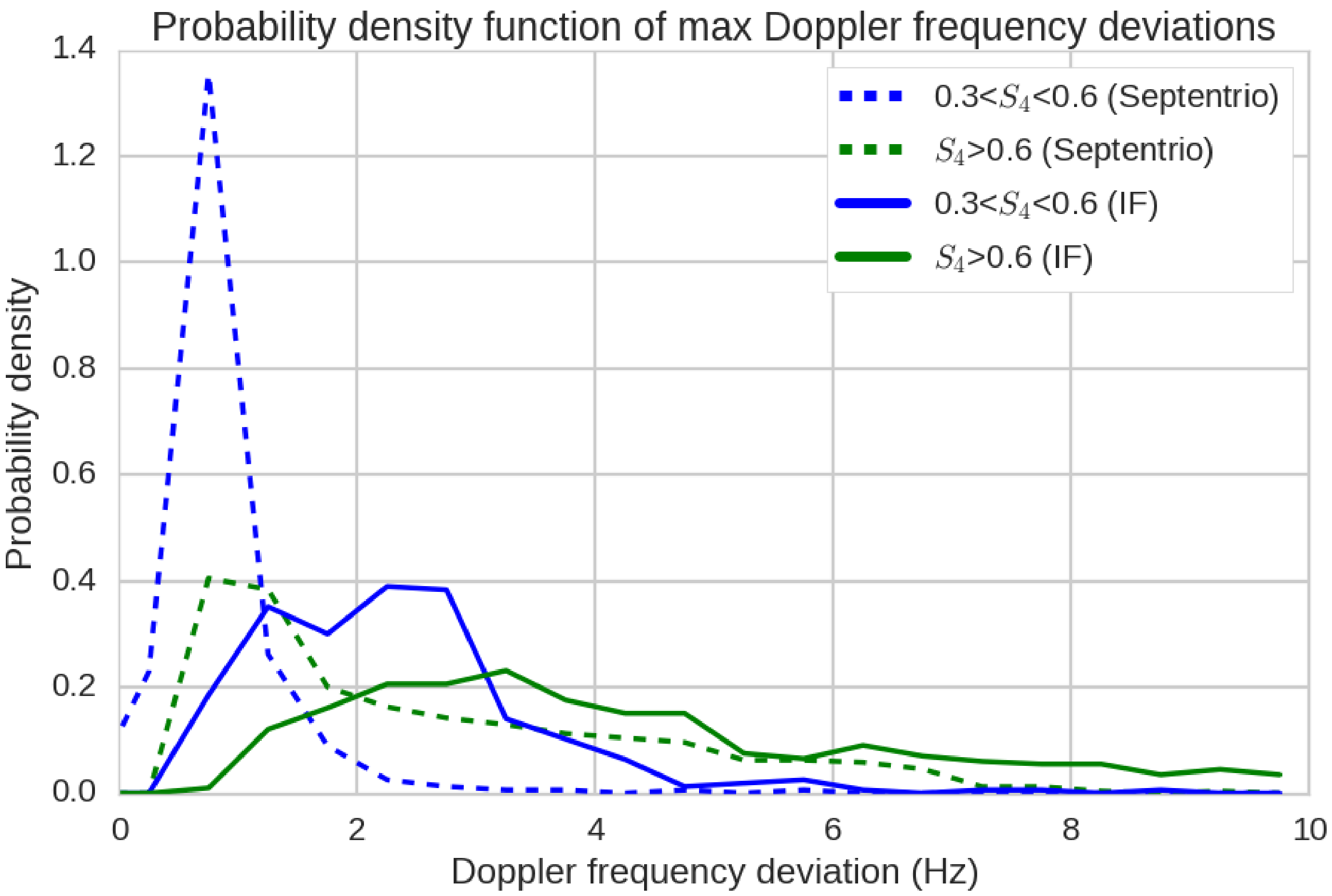
**1000 points of Doppler for each point of the scintillation index**

# Data Processing Procedure – Doppler Binning



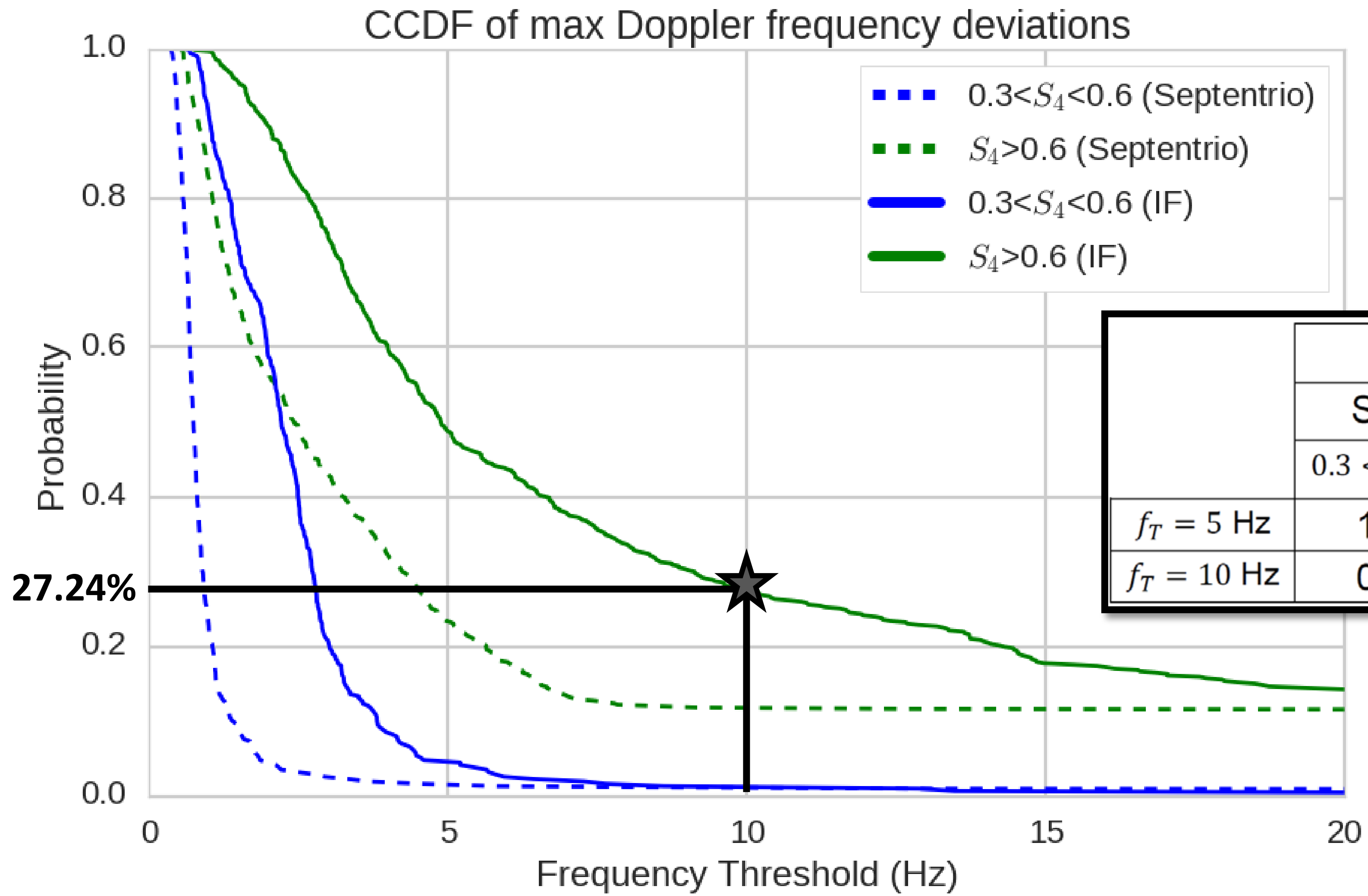
# Low Latitude Results




- Higher magnitude Doppler frequency deviations are **more probable** in the **high scintillation regime** than in the low scintillation regime
- Septentrio measurements underestimate the magnitude of the deviations

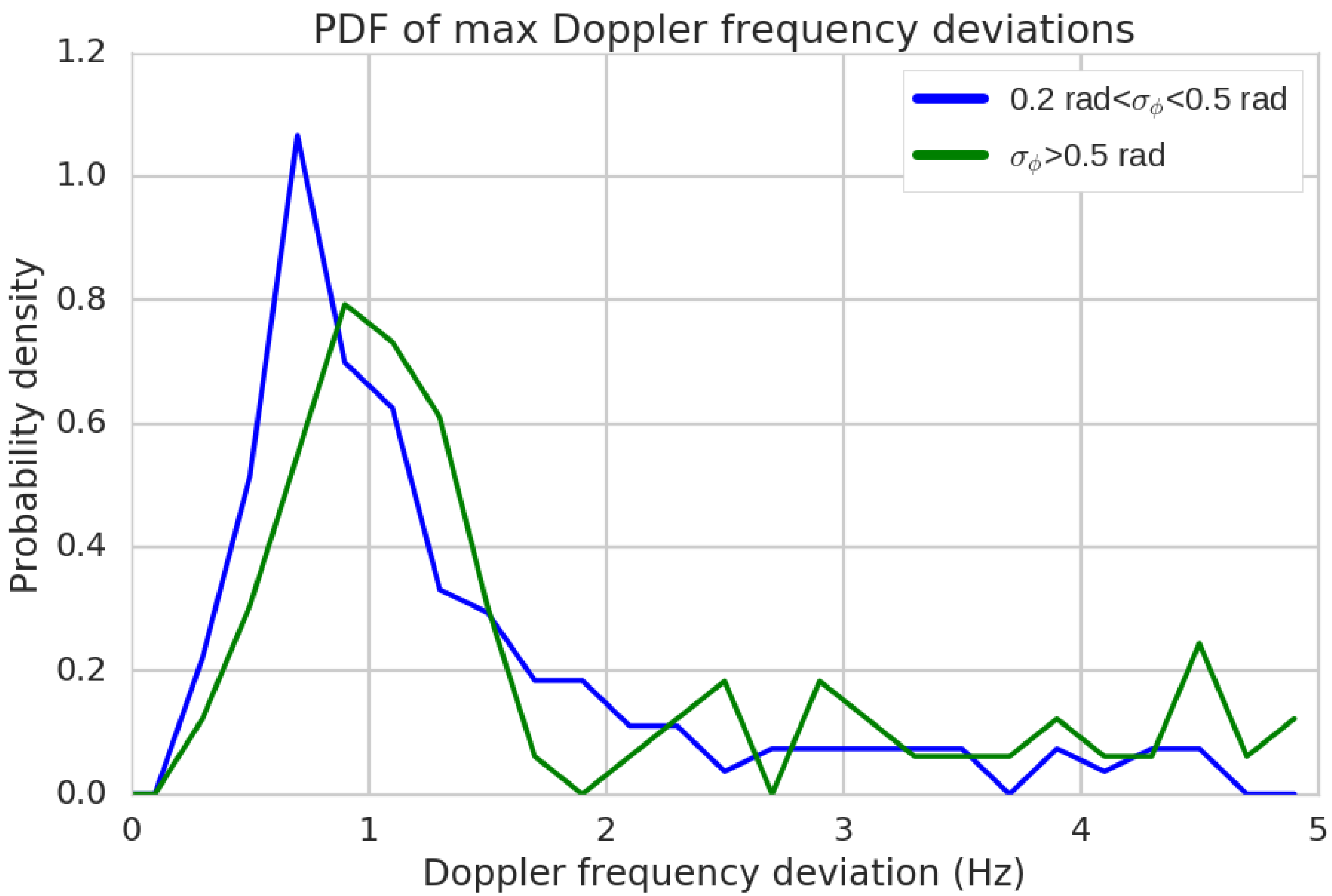
# Low Latitude Results

Complementary continuous distribution function: **What is the probability that the detrended Doppler frequency will experience a deviation greater than some threshold value?**




| | $P(f > f_T)$ | | | |
|---|---|---|---|---|
| | Septentrio Data | | IF Data | |
| | $0.3 < S_4 < 0.6$ | $S_4 > 0.6$ | $0.3 < S_4 < 0.6$ | $S_4 > 0.6$ |
| $f_T = 5$ Hz | 1.26% | 23.25% | 4.43% | 48.63% |
| $f_T = 10$ Hz | 0.95% | 11.62% | 0.95% | 27.24% |

# High Latitude Results




Higher magnitude Doppler frequency deviations are **more probable** in the **high scintillation regime** than in the low scintillation regime.

# Future Work

- Process signals from GPS L2 and L5 bands
- Process signals from other GNSS constellations (Galileo, GLONASS, BeiDou)
- Use data from a wider range of days throughout the year
  - Explore seasonal variation
- Collect data from a variety of different locations

# Questions? Comments?

# Bibliography

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# Graphics Credit

- Satellite: http://www.clker.com/cliparts/f/b/n/e/r/3/satellite-hi.png
- Globe: https://img.clipartfest.com/10869fa307ba19d6d13aef9e906b5c0a_transparent-world-globe-globe-world-clipart_4021-4021.png
- Pin: http://www.clipartbest.com/cliparts/niB/GXK/niBGXKRxT.png
- Spread f: http://landau.geo.cornell.edu/data/F040223.gif
- Poker flat: http://www.thelivingmoon.com/45jack_files/04images/Poker_Flat/2577899.jpg
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