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# Serendipitous Observations of GPS Interference by GROUP-C on the ISS

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# Bottom Line Up Front

- The GROUP-C experiment on the ISS routinely collects GPS signals for the purpose of radio occultation sensing of the Earth's ionosphere
- On May 24, 2018 the GROUP-C experiment collected high-fidelity GPS data which serendipitously included anomalous signals
- Follow-up data collections and analysis revealed that the anomalous signals were GPS interference
- We report on the characteristics of the interference signals

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# GROUP-C Summary

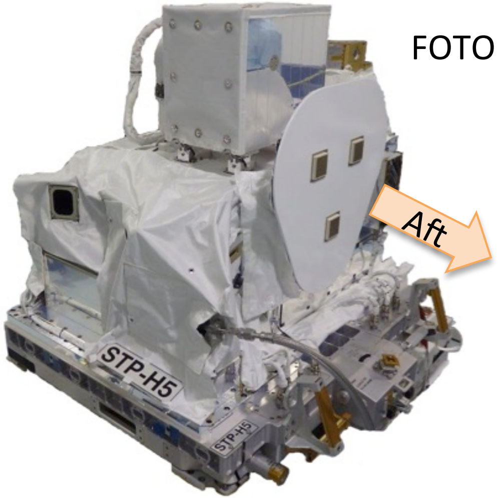
## GPS Radio Occultation and Ultraviolet Photometry—Colocated

- is an unclassified DoD Space Test Program experiment aboard the ISS, part of the STP-H5 payload
- demonstrates a second-generation compact ultraviolet photometer and a software-defined-radio GPS receiver for advanced ionospheric remote sensing.
- launched aboard the SpaceX CRS-10 Falcon 9 on 2017-Feb-19 14:39 UT.
- routinely collects GPS signals for the purpose of radio occultation sensing of the Earth's ionosphere

**Sponsor:** NRL
**Partners:** Cornell Univ., The Aerospace Corp.
**End Users:** NRL, Univ. Texas—Austin, (others TBD)

## Objective

Acquire ionospheric occultations and high-sensitivity measurements of ultraviolet airglow on the Earth's disk to demonstrate advanced ionospheric specification with second-generation sensors.



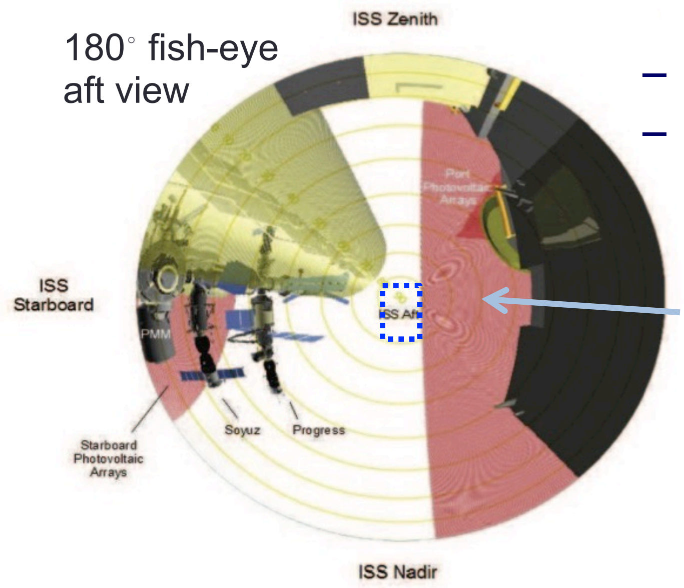

FOTON receiver
- L1, L2C dual frequency
- 100 Hz samples
- Software-defined radio
- 300 kbps data rate
- "Raw capture" capability
- New firmware can be uploaded

Fast Orbital TEC, Observables, and Navigation (FOTON) GPS receiver on STP-H5/GROUP-C

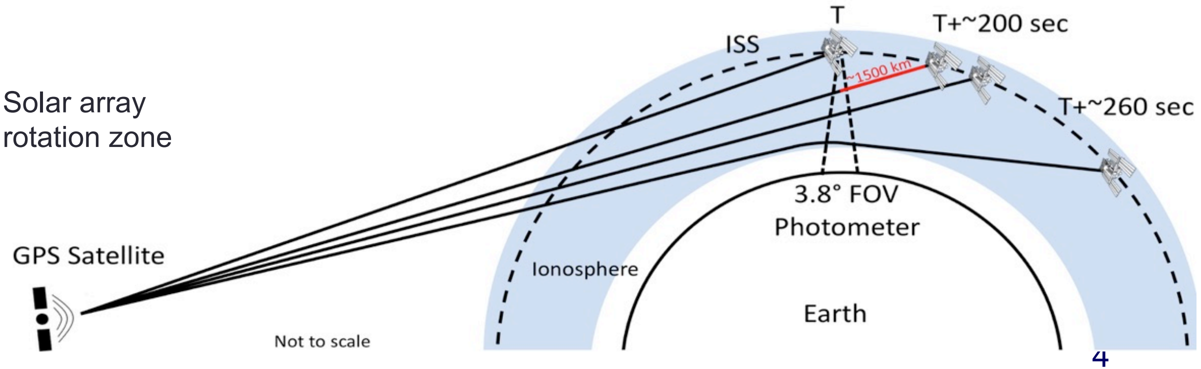
# Observations with FOTON

- Looking aft and toward limb, the orbital motion of ISS causes a GPS satellite to appear to set – an occultation
  - Fundamental measurement – difference in carrier phase between GPS L1 and L2C signals and difference in pseudoranges yield integrated electron content (TEC) along line-of-sight
  - GPS Tracking begins above the ionosphere (dashed box)
    - ~15° x 10° field-of-view
  - TEC profile of ionosphere is obtained over ~1 minute
  - ~250 GPS ionospheric occultations are observed each day.

180° fish-eye aft view




Solar array rotation zone



# FOTON Quicklook Analysis

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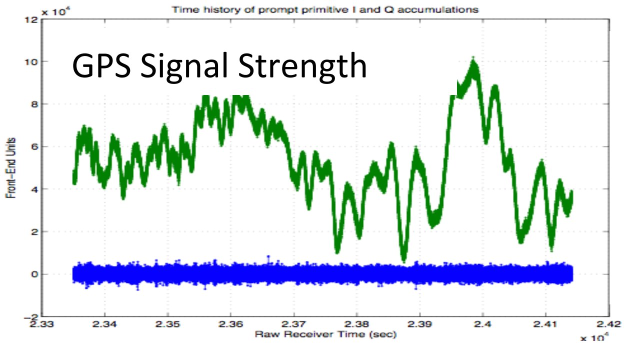
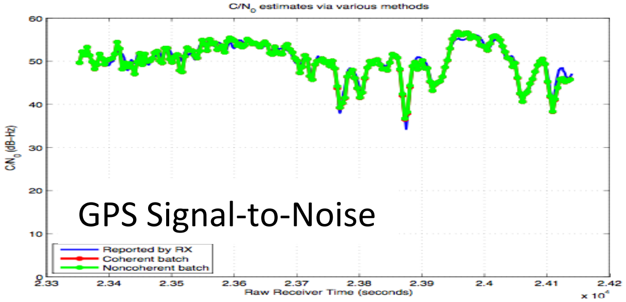
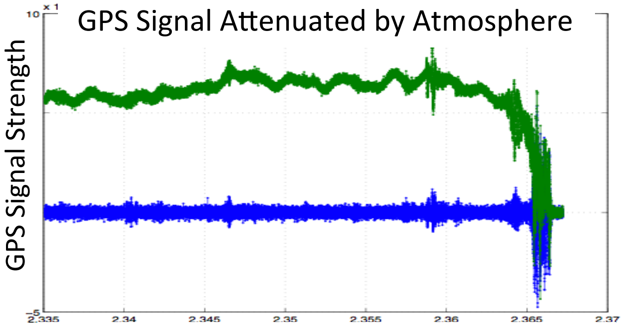
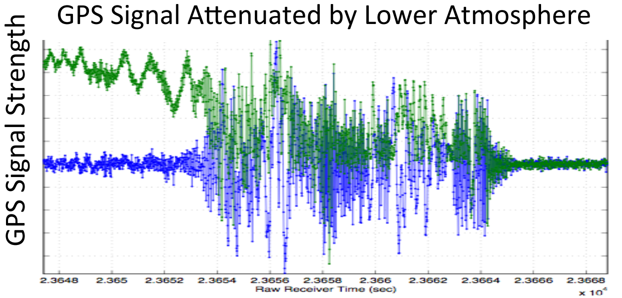
2017/02/28

2017/03/02

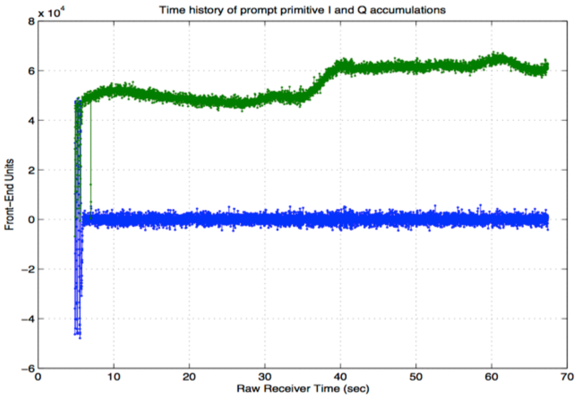


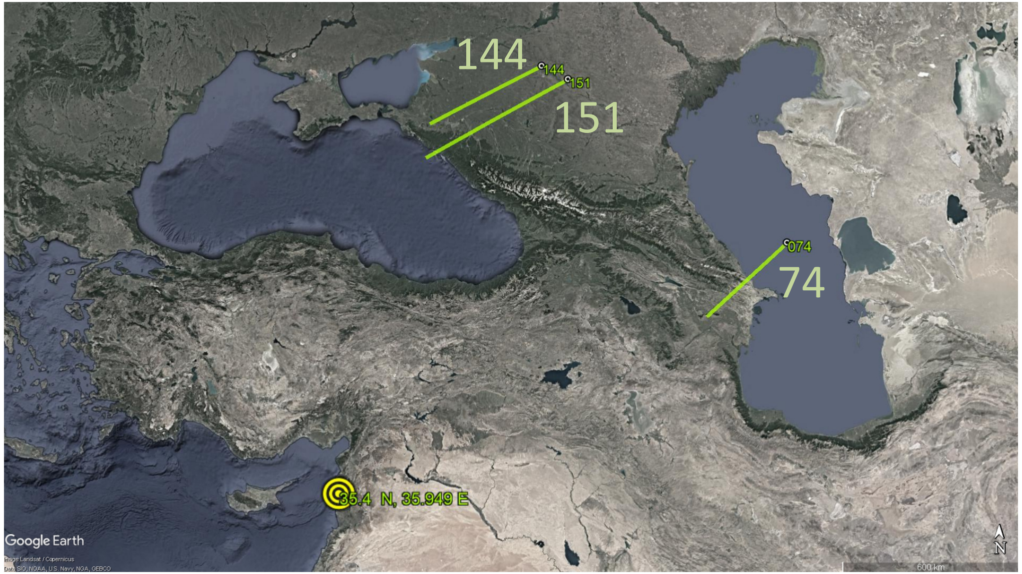




- First raw RF front-end data capture from PRN 11
  - Displays strongest signal. Processed on ground.
  - Not an occultation




- Some signals exhibit fairly strong amplitude fluctuations even while maintaining good C/N0 (Carrier-to-Noise). This may indicate multipath or blockage from ISS structures.
- FOTON has a special mode to capture and dump GPS signals from the radio A/D front end. (Capture 70 sec, 3.5 hours to download)

# Raw Capture of GNSS Interference




- Ground tracks for interference-affected raw captures on days 74, 144, and 151 of 2018.
- Each capture spans approximately 70 seconds.

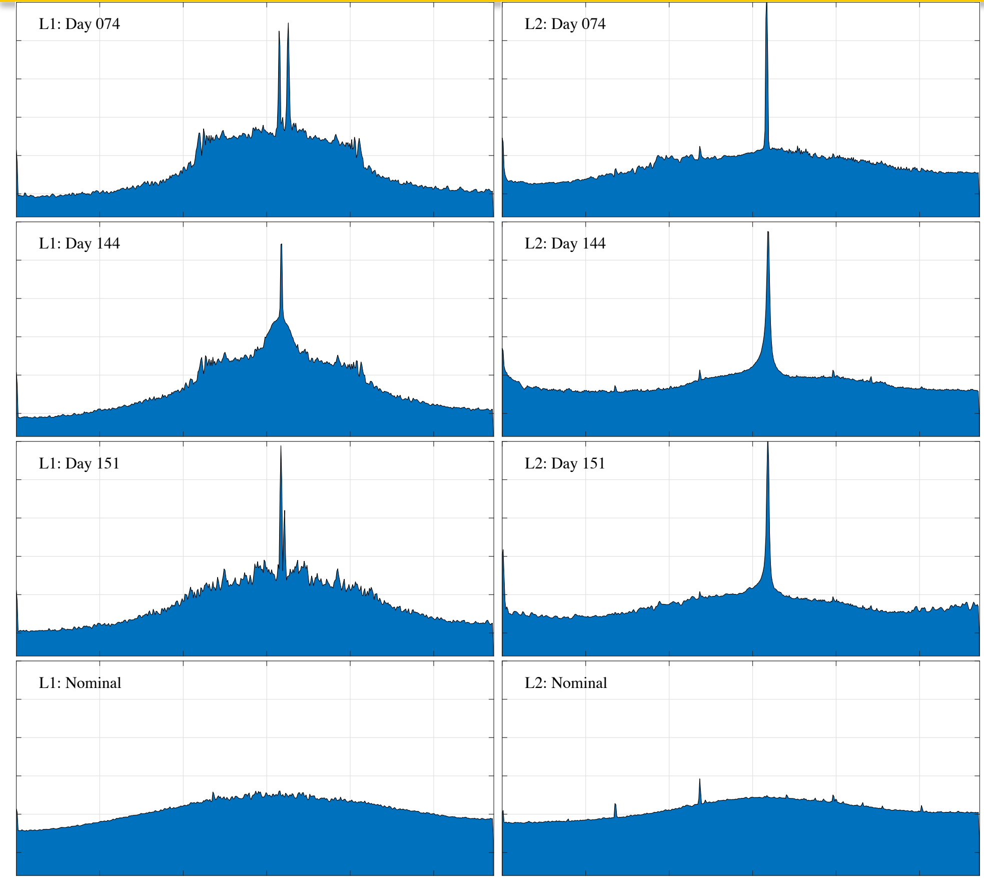
- Some raw capture data acquired by FOTON in 2018 included strong interference signals
- This seriously degraded the the scientific utility of occultations for atmospheric sensing
- Strong interference has important implications for civil and military GNSS applications

# Interference Signal Characteristics

- All GPS L1 C/A spreading codes from 1-32 were present in the interference data
- All signals spread by the GPS L1 C/A spreading codes exhibited nearly-common and constant carrier frequencies near GPS L1
- No discernable navigation data were modulated on the signals
- No false Galileo signals were detected

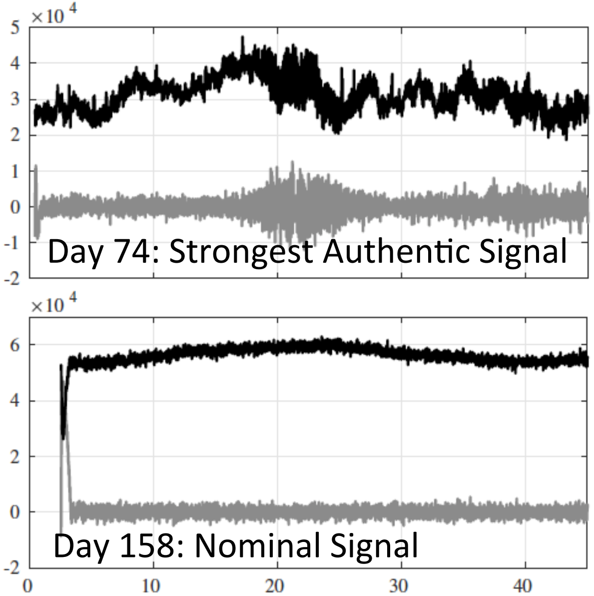
- Civil GPS signals at L2 were subject to narrowband interference, but were not spoofed as on L1
- The false signals on L1 exhibited unexplained fading and spectral characteristics

# L1 and L2 Power Spectra

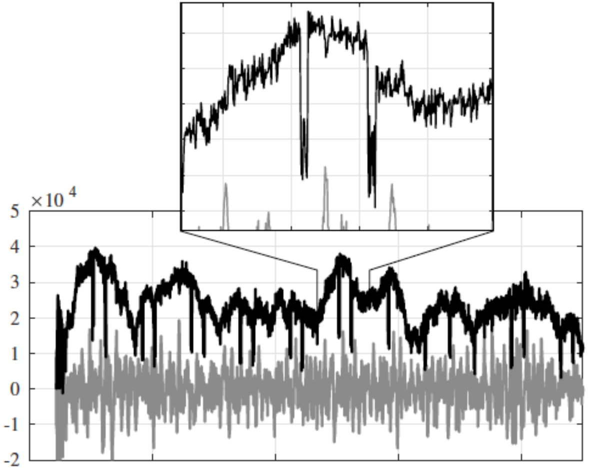



- Power spectra exhibit broad-band interference on L1 and narrowband interference on L2 (top 3 rows) compared to nominal GPS signals (bottom)
- Horizontal axis 3MHz frequency range, vertical axis dB scaled for comparison.

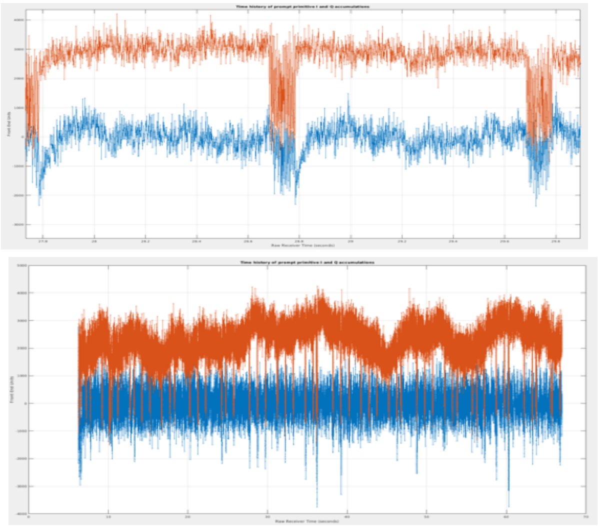
# L1 Interference Time Variability




Day 74: Strongest False Signal

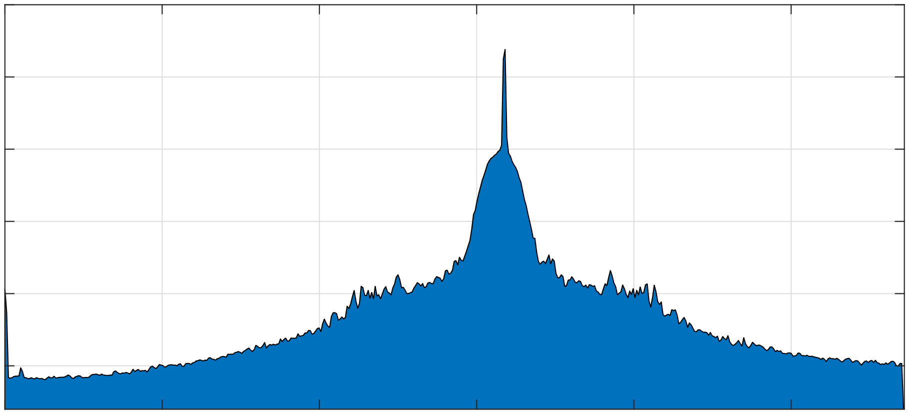


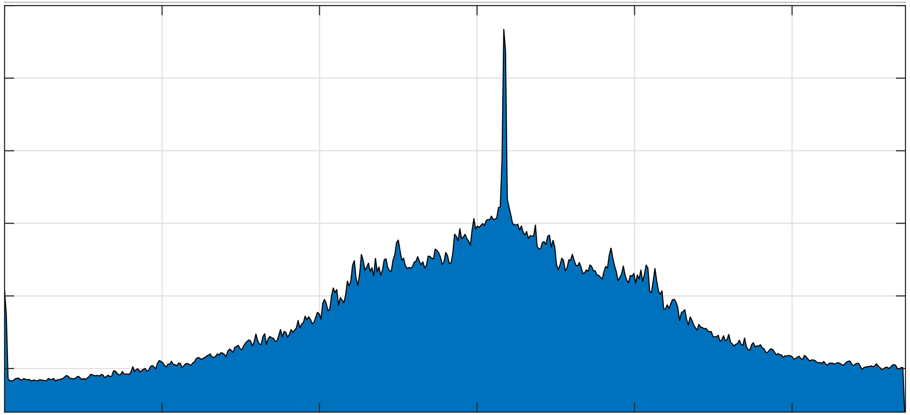

Day 144: False PRN 17 Signal



- The I-Q accumulation time histories are punctuated by intervals of unstable phase
- In-phase (black) and quadrature (gray) 10-ms accumulations are shown. The inset shows a magnified view of two sudden amplitude fades in the false signal.
- The 1-ms accumulations of PRN 17 false signals from day 144 exhibit roughly a 1-sec periodic phase instability

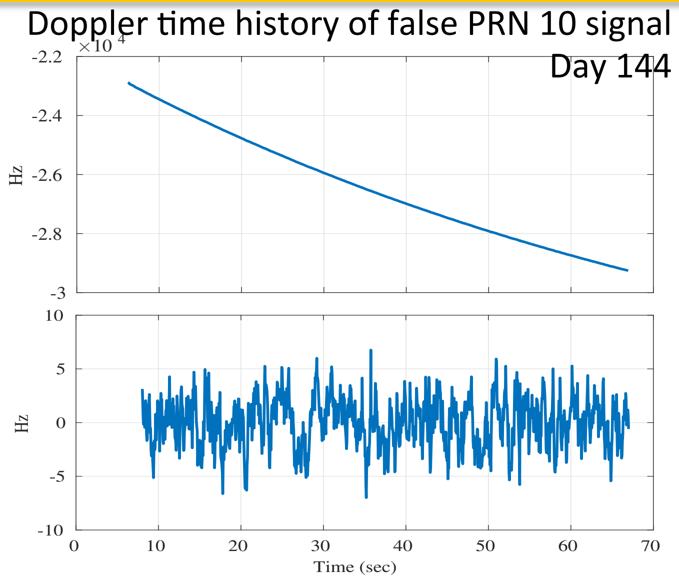
# Variability in Interference Power Spectra

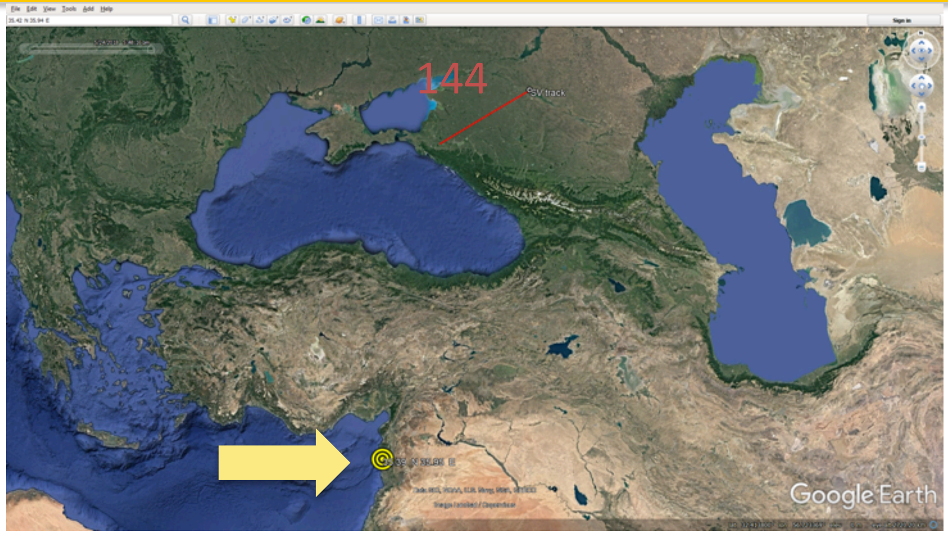




- The day 144 interference includes a central interference signature that waxes and wanes
- Oscillation period is approximately 5 seconds
- The power spectra near L1 for the maximum (left) and minimum (right) phases of the waxing and waning wideband (0.25 MHz) central interference prominence.
- L1 spectrum for day 144 on previous slide was taken 2 seconds after a maximum.

# Locating the Interference Source




Assumptions

1. The interference source is on the Earth surface
2. The frequency difference between the Rx and Tx oscillators is constant over a 70 sec raw capture

- The location of the interference source can be derived within <10 km
- Source of interference is geolocated to the Eastern Mediterranean

# Strength of the Interference

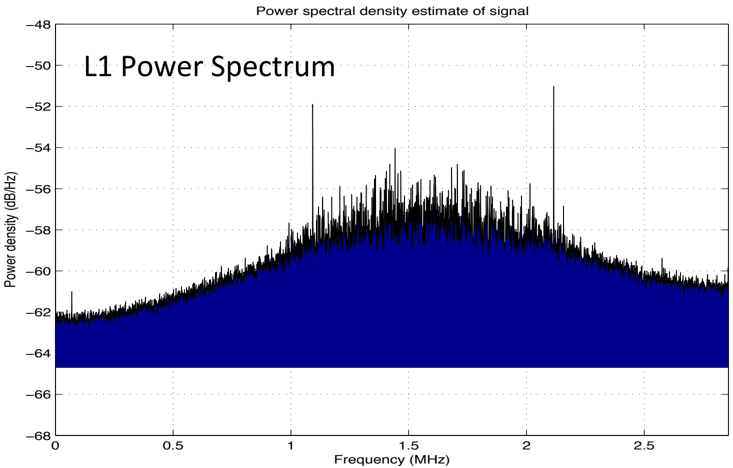
- We now know the origin of the interference signal, and can estimate its strength and impact
- The interference at L1 caused 6dB of C/N0 degradation of authentic GNSS signals for a narrowband (3 MHz) receiver at a distance of 1340 km
- Assuming standard path loss and a uniform antenna pattern, for a commercial aircraft at 10 km altitude
  - Direct overflight would cause over 100 dB of C/N0 degradation
  - At least 32.5 dB degradation for any aircraft within line-of-sight of the transmitter (<360 km distance)
  - This would prevent use of GPS L1 C/A signals anywhere within line-of-sight of the transmitter

# Summary

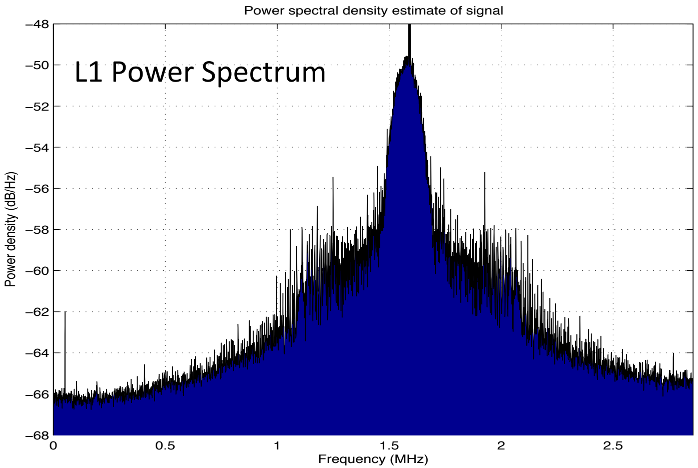
- The GROUP-C experiment on the ISS routinely collects GPS signals for the purpose of radio occultation sensing of the Earth's ionosphere
- On May 24, 2018 the GROUP-C experiment collected high-fidelity GPS data which serendipitously included anomalous signals
- The GROUP-C FOTON receiver collected GPS data on several days in 2018 which exhibited GPS interference signals
- Follow-up data collections and analysis provided information about the nature, origin, and potential impact of these signals.
- Analysis revealed that the anomalous signals were GPS interference

# Verification of Interference Signal

## 2017 Raw Capture, Carribean Sea




## 2017/05/24 Raw Capture, Black Sea




A 2017 raw capture over the Carribean exhibits a typical GPS L1 power spectrum.

The day 144, 2018 raw capture shows conspicuous broad-band interference

The interference signal is not a receiver problem.

# Acknowledgements

Research at the U.S. Naval Research Laboratory is supported by the Chief of Naval Research.

STP-H5/GROUP-C is integrated and flown under the direction of the Department of Defense Space Test Program.