U.S. NAVAL RESEARCH LABORATORY

Early results and ionospheric observations from GROUP-C on the ISS

Scott Budzien[1], Steve Powell[2], Brady O'Hanlon[2], Rebecca Bishop[3], Todd Humphreys[4], and Andrew Stephan[1]

[1]Naval Research Laboratory, Washington DC [2]Cornell University, Ithaca, NY
[3]The Aerospace Corporation, El Segundo, CA [4]The University of Texas at Austin, TX

U.S. NAVAL RESEARCH LABORATORY

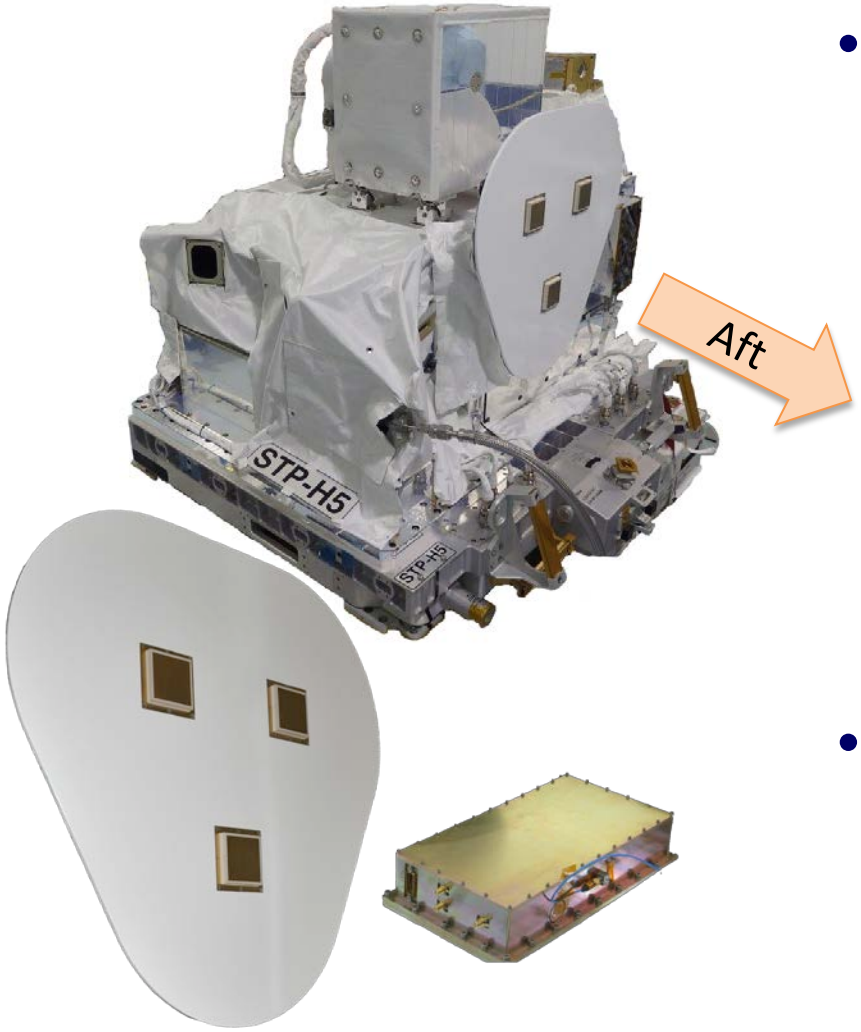
What is GROUP-C?

GROUP-C Experiment

GPS Radio Occultation and Ultraviolet Photometry—Colocated

- is a DoD Space Test Program experiment to the ISS, one of thirteen DoD and NASA experiments aboard the STP-H5 payload.
- will demonstrate performance of a second-generation UV photometer and a software-defined-radio GPS receiver for ionospheric sensing.
- is paired with NRL's LITES experiment to test UV tomography techniques for the lower ionosphere.
- launched aboard the SpaceX CRS-10 Falcon 9 on 2017-Feb-19 14:39 UT.
- has a nominal 2-year mission.

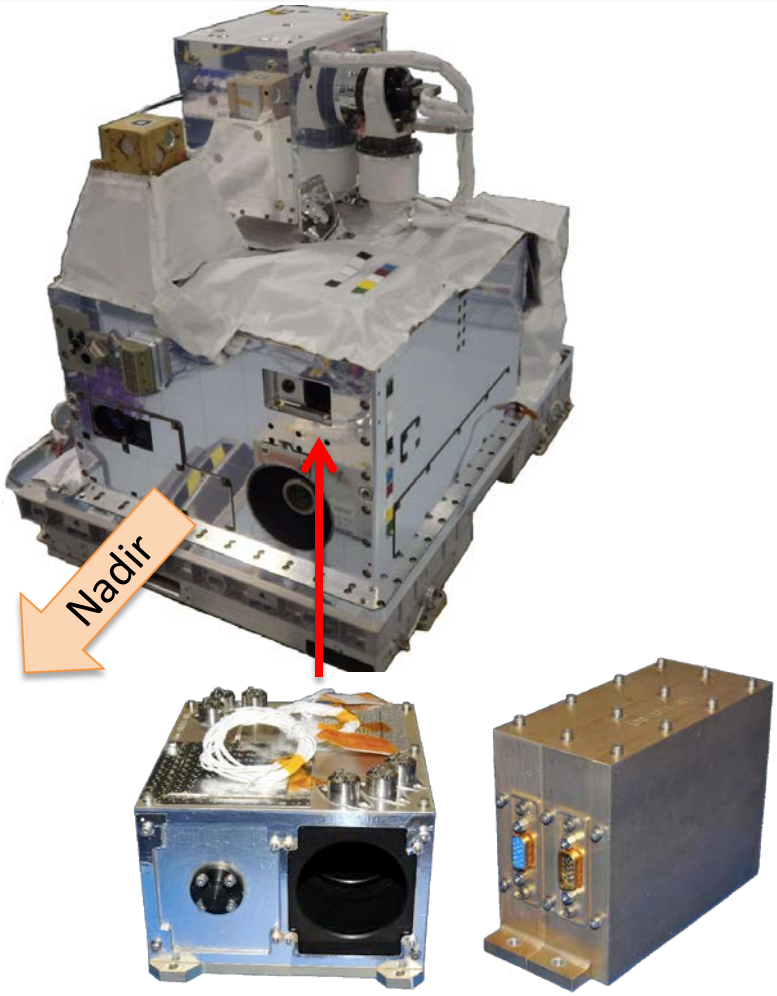
GROUP-C Sensors: FOTON



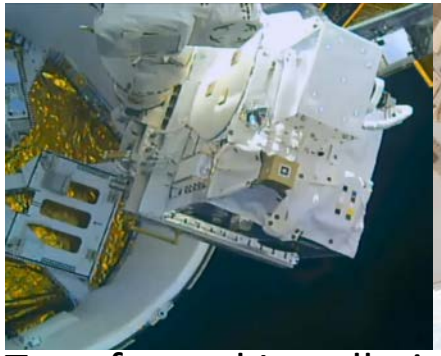
- Fast Orbital TEC, Observables, and Navigation (FOTON) GPS receiver
  - L1, L2C dual frequency
  - 100 Hz samples
  - Software-defined radio
  - 300 kbps data rate
  - New firmware can be uploaded
  - Provided by Cornell University
  - Heritage: MICA 2012 sounding rocket and CASES receivers
- Patch Antennas
  - Space rated
  - Provided by The Aerospace Corp., El Segundo, CA
  - Heritage: CTECS 2011 and SENSE 2013 cubesats

GROUP-C Sensors: TIP

- Tiny Ionospheric Photometer
  - High-sensitivity far-ultraviolet photometer 135.6 nm (1100 counts/sec/Rayleigh)
  - 5-deg FOV (14 km diam. at 250 km)
  - Senses O^+ through nighttime UV recombination emission
  - Measures horizontal ionospheric gradients viewing nadir in the ISS orbital plane
  - Provided by Naval Research Lab
  - Heritage: COSMIC mission 2006, with upgraded optical design



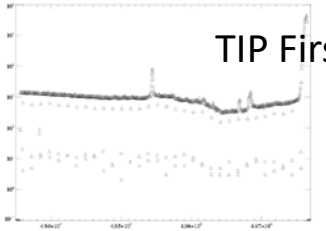
GROUP-C Mission Status



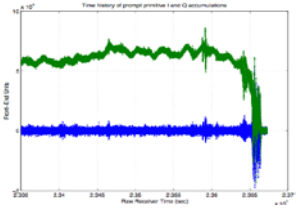
Launch
2017 Feb 19

Transfer and Installation, Feb 24-28

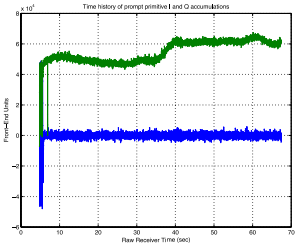
TIP First Light
Mar 1



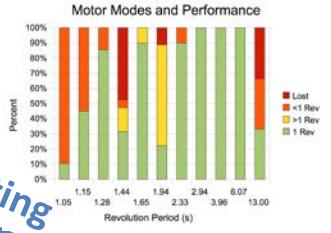
FOTON Occultation
Analysis Mar 2



FOTON Raw Capture
Apr 6



TIP Operations Testing



Early Orbit Tests
Complete Apr 28

Cal-Val

U.S. NAVAL RESEARCH LABORATORY

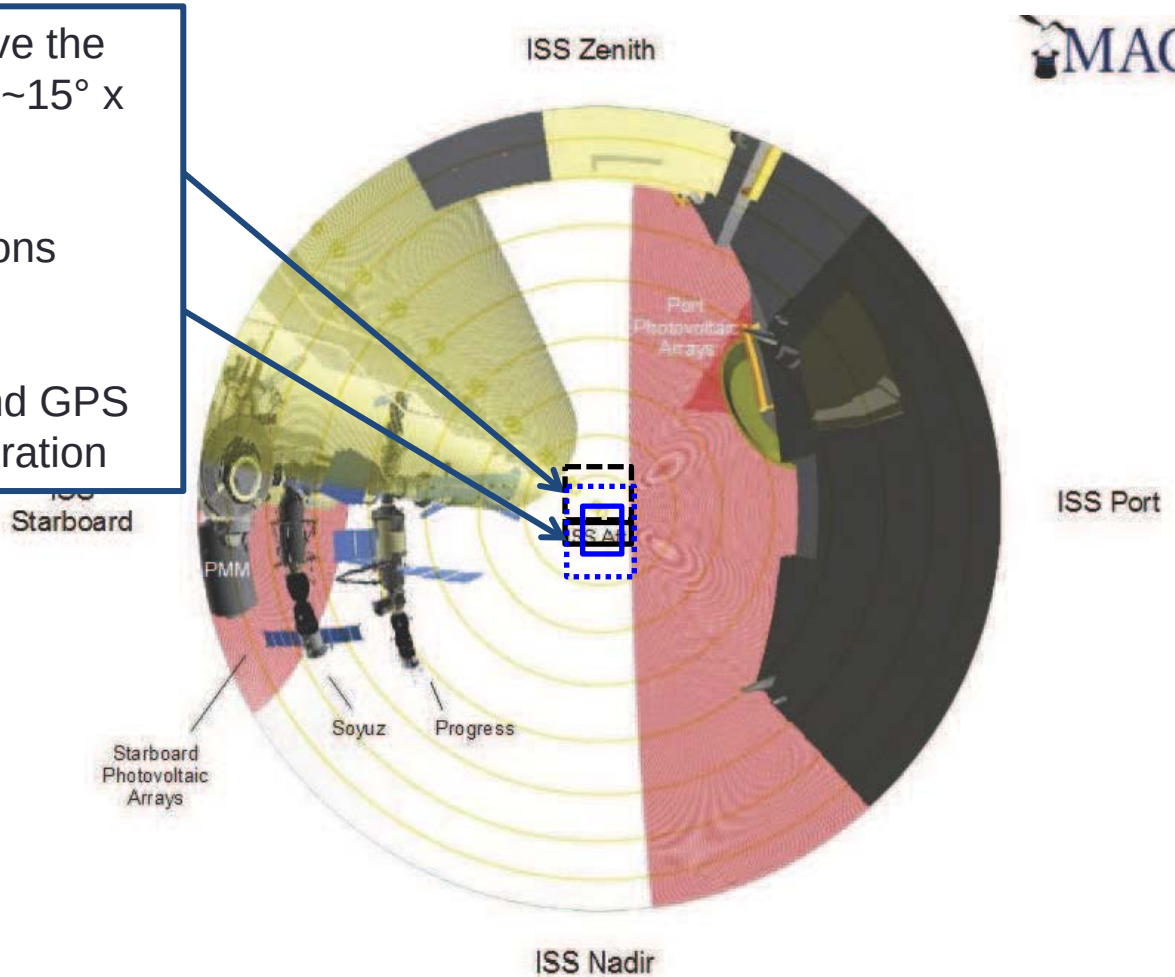
Where's Waldo? STP-H5 Location on the ISS

U.S. NAVAL RESEARCH LABORATORY

GROUP-C GPS Field of View

The most interesting aft setting GPS L1/L2C occultations will be unobstructed. Solar arrays do transit through the field of regard.

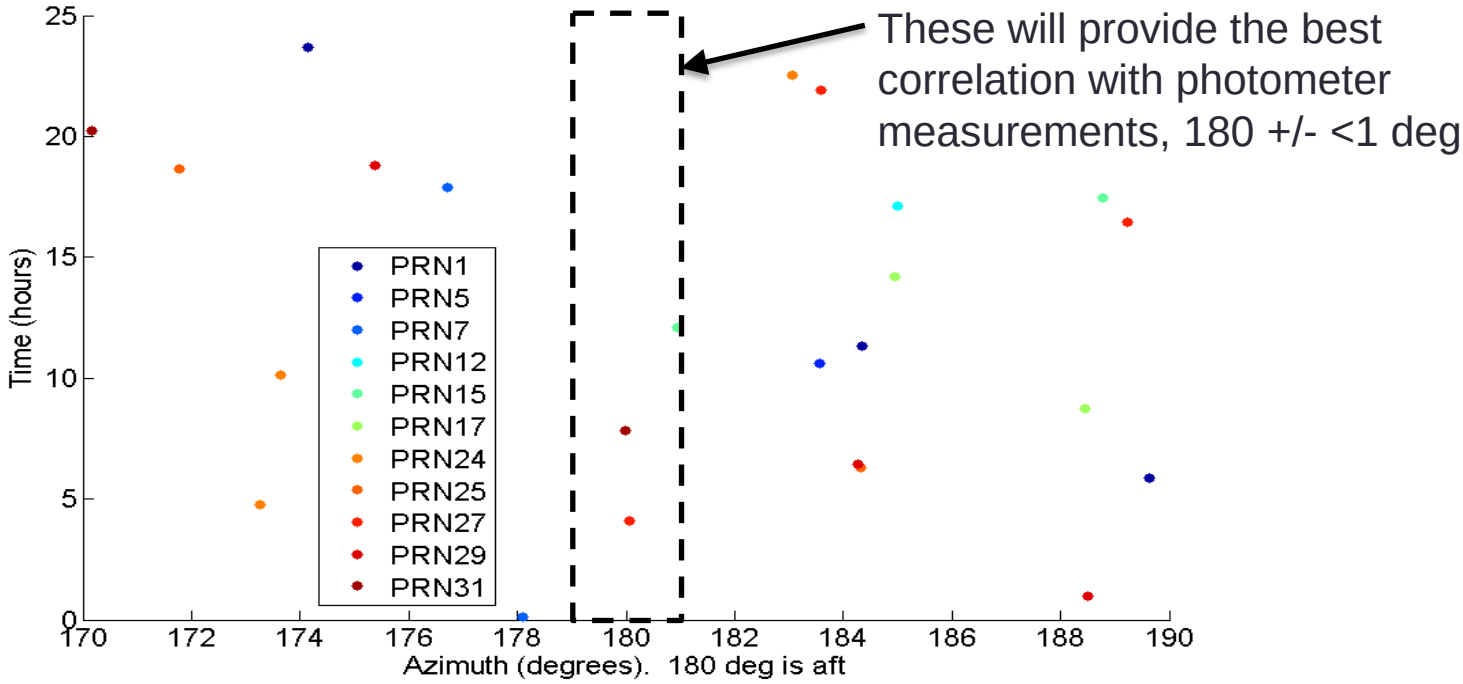
- GPS tracking begins above the ionosphere (dashed box) ~15° x 10° field of view
- Most interesting occultations (solid box) ~5° x 10°
- Overlap of LITES FOV and GPS FOV will allow cross-calibration



U.S. NAVAL RESEARCH LABORATORY

GPS Occultations near ISS Orbit Plane

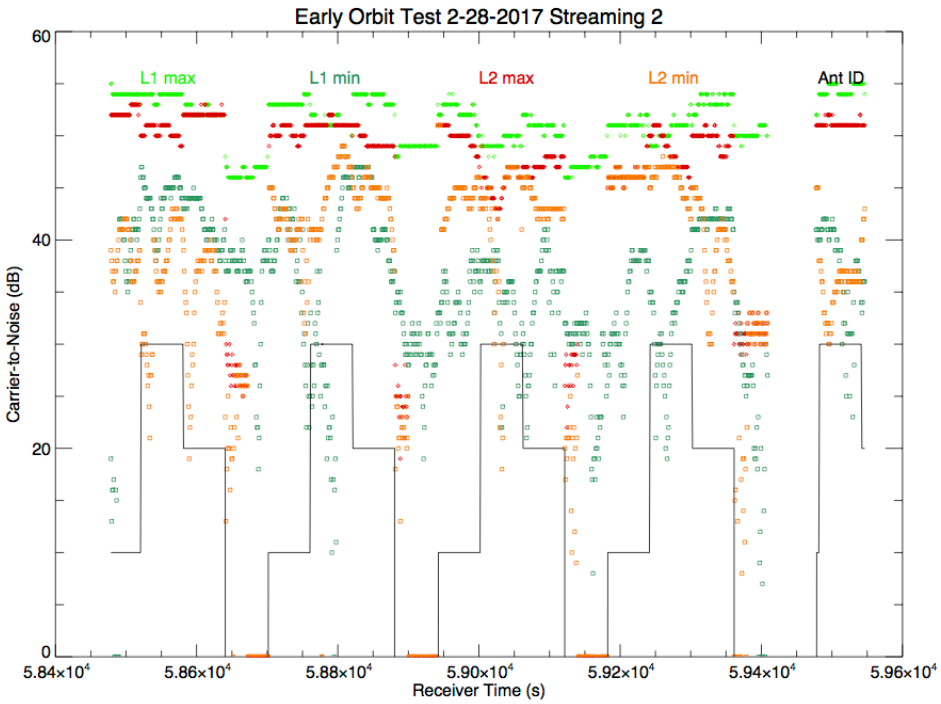
- How often do the most interesting aft setting GPS L1/L2C occultations occur as seen from ISS?
  - ~24 in typical 24 hour period, for 180 +/- 10 deg



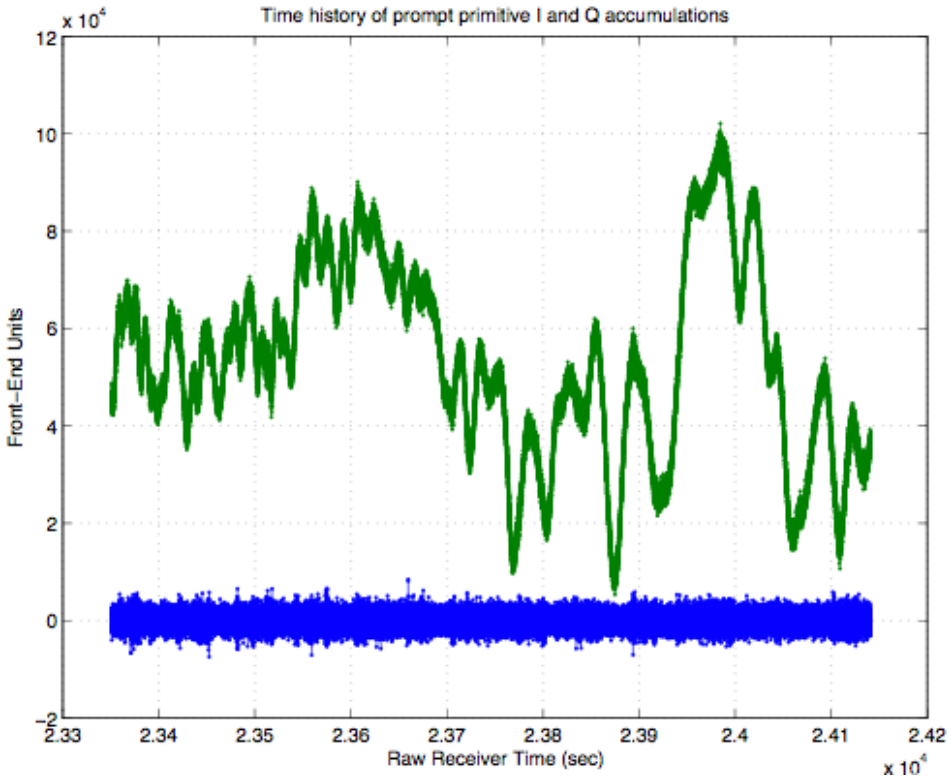
Source: Cornell U. simulation using GPS & ISS ephemerides

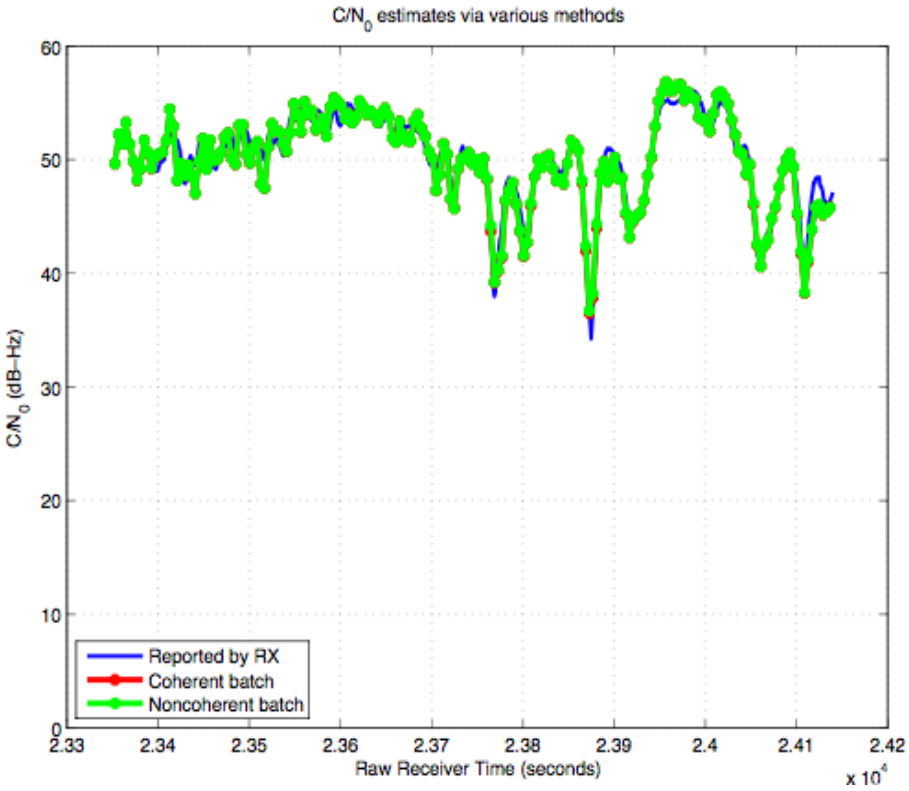
FOTON I-Q Stream Observations

- FOTON default data stream is 100 Hz I-Q data for ground processing
  - Early tests cycling among the 3 patch antennas on the 4-element RF switch showed very similar performance among them
  - Carrier-to-Noise ratios peak at 53-55 dB-Hz for L1 and L2C
  - FOTON FOV is restricted by ground plane and Earth disk
  - Typically tracking about 7 satellites on L1 and 2-4 on L2C



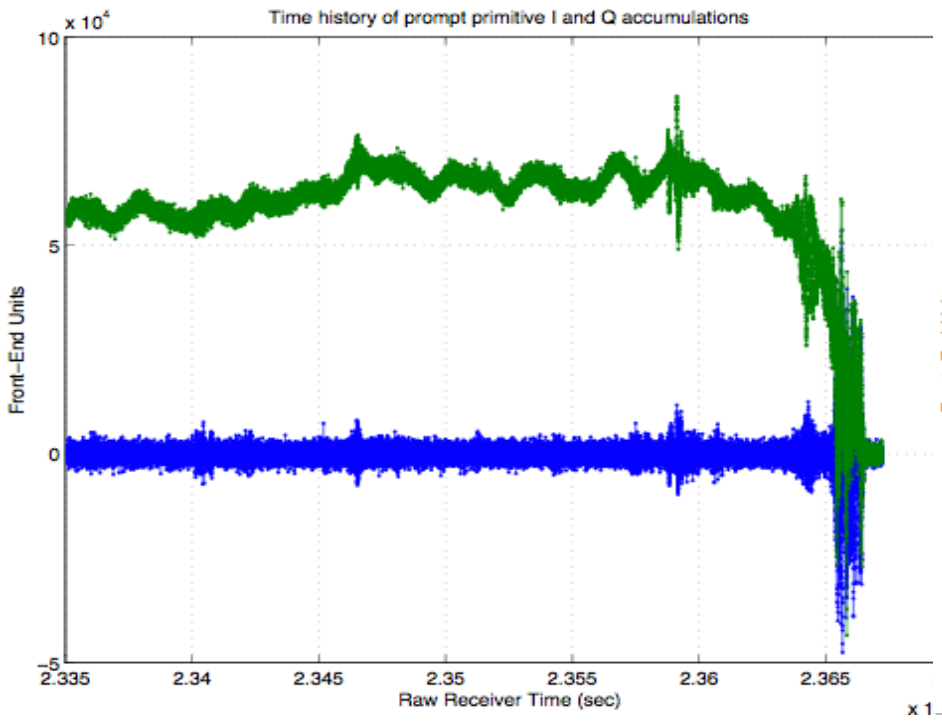
FOTON I-Q Quicklook Analysis

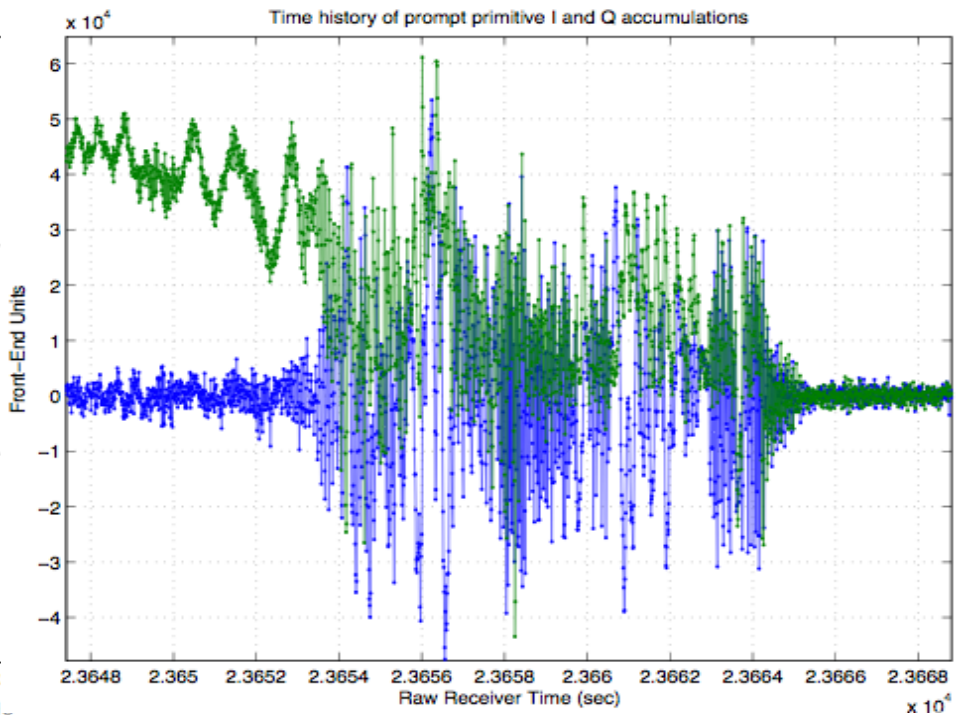




- Some signals maintain fairly strong amplitude fluctuations even while maintaining good C/N_0. This may indicate multipath or blockage from ISS structures.
- C/N_0 reported by the receiver closely matches that computed from the statistics of I-Q accumulations

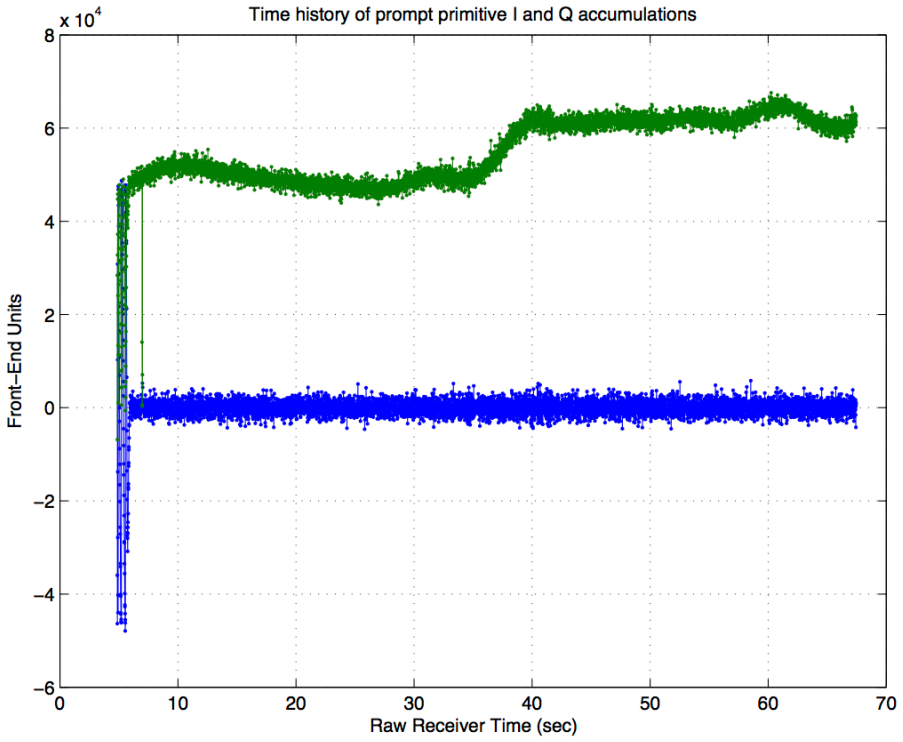
FOTON I-Q Occultation Example





- This example shows I-Q data for an occultation, with the final 21 seconds zoomed.
- The I-Q data show power present in the signal right up until near the end when it completely collapses
- FOTON uses closed-loop tracking. The FOTON PLL tracks the signal quite well until vary rapid signal changes occur deep in the troposphere.

FOTON Raw Capture Quicklook



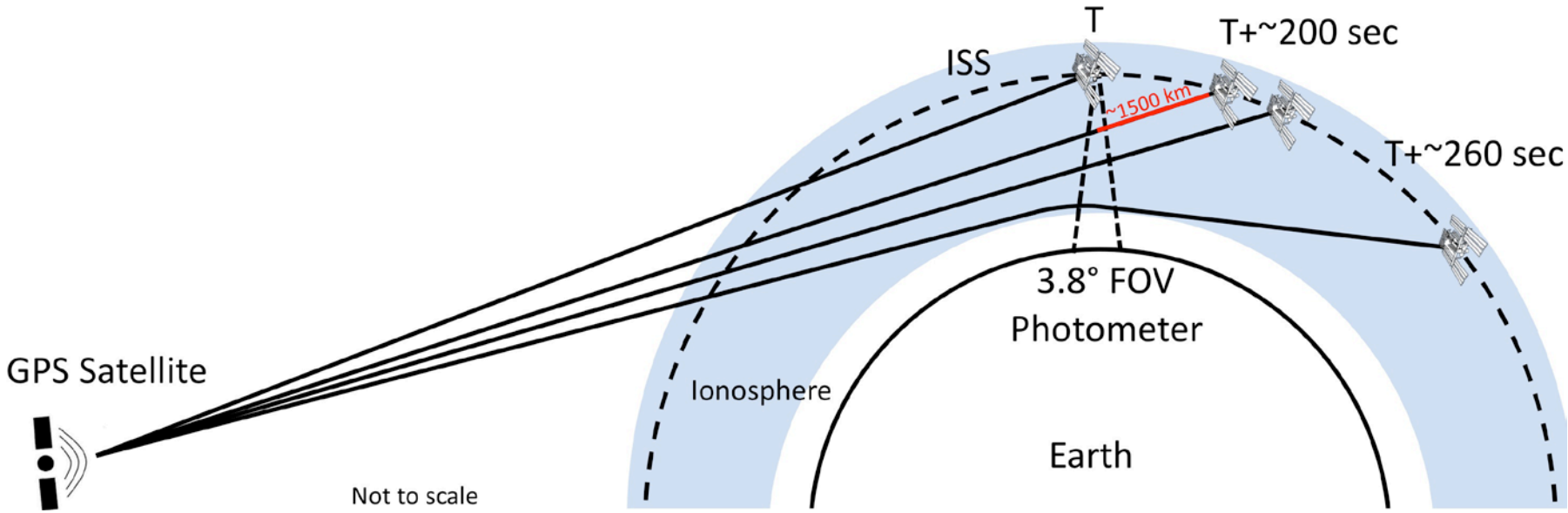
- First raw RF front-end data capture from FOTON
- Not an occultation, just 100 Hz SDR outputs from 67 seconds of RF data
  - 3.5 hours to download 200 MB observation
  - Processed on ground using a software receiver application
- 10-ms correlation values for the strongest signal, GPS PRN 11
- Among other signals the software receiver analysis was able to track 2 Galileo SVs

- Having the ability to access the raw data will facilitate understanding the detailed performance of the receiver and help understand GPS occultation in the ISS environment.

U.S. NAVAL RESEARCH LABORATORY

Joint observations with FOTON and TIP

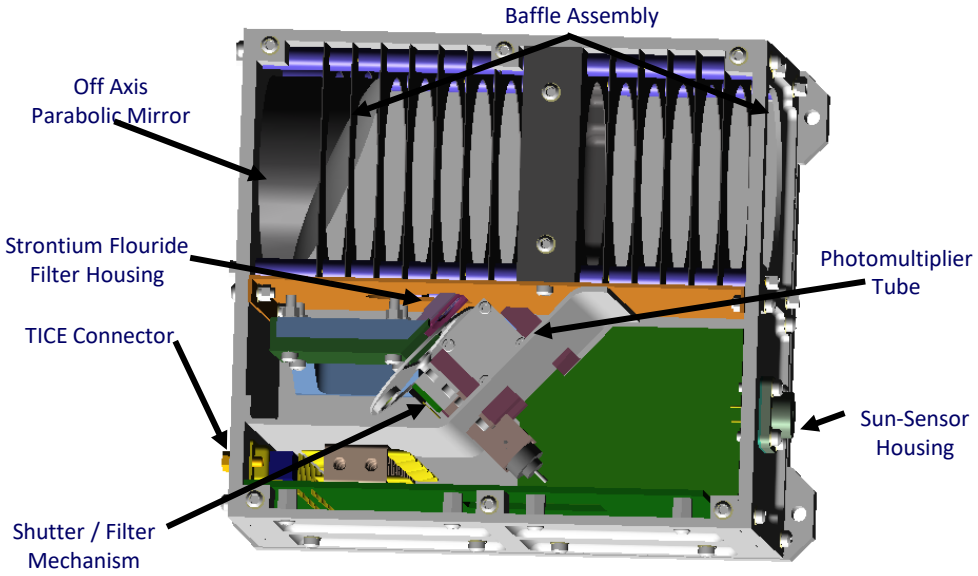
- Looking aft & toward limb, orbital motion of ISS causes a GPS satellite to appear to set – occultation
  - Fundamental Measurement – difference in carrier phase between GPS L1 and L2C signals and difference in pseudoranges yield integrated electron content (TEC) along line-of-sight
  - TEC profile of ionosphere is obtained over ~1 minute
- Nadir-viewing UV photometer measures electron density from UV airglow of nighttime O+ ions recombining with electrons
  - Samples same region ionosphere as GPS approx. 200 sec earlier

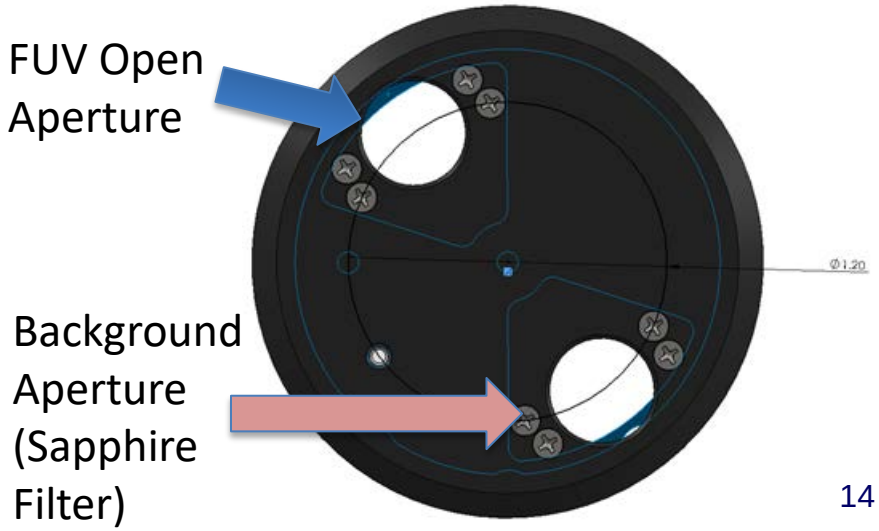


TIP Photometer Operation

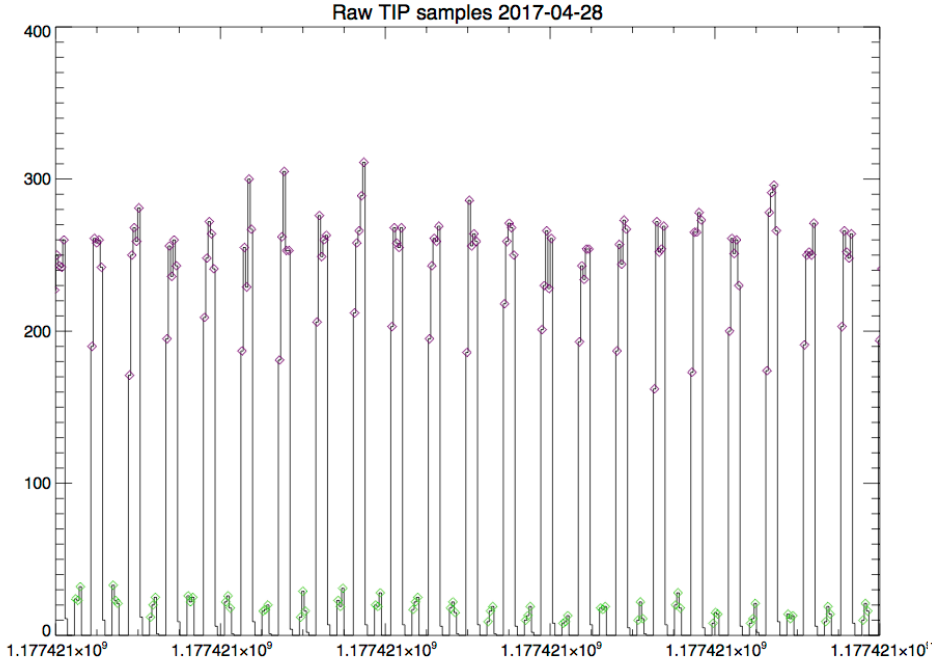
- TIP uses a solar-blind* PMT to detect FUV photons

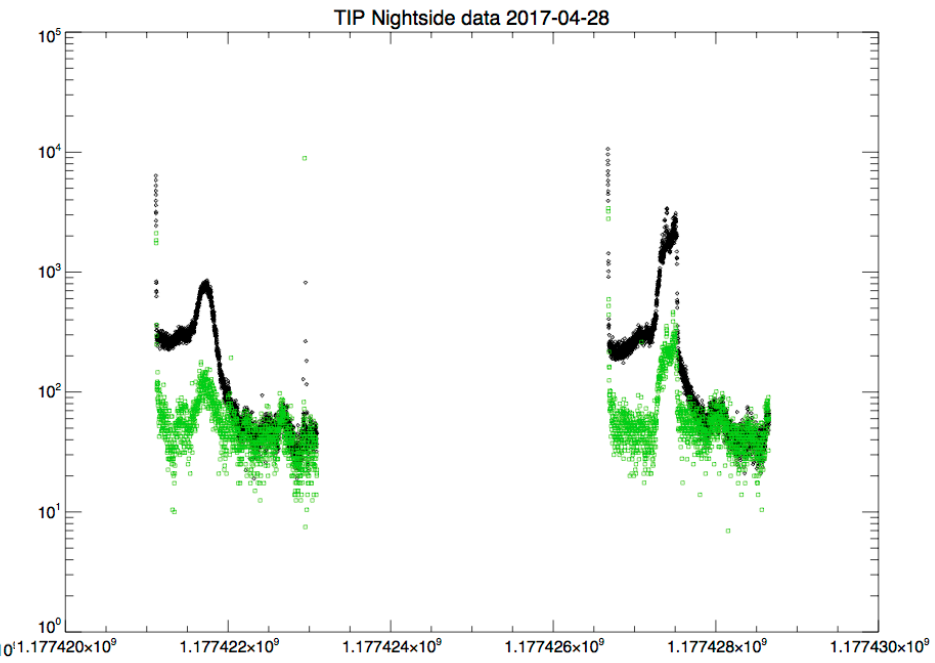
  *kinda-sorta solar blind
- Due to residual PMT sensitivity to visible light a “red-leak” monitor filter was added
- TIP chops between 135.6 nm FUV and visible long-pass filters
  - 4-second chop period
  - ~30 km spatial resolution
- During moon-down periods, TIP can operate without background monitoring
  - 1-second samples
  - 15-km continuous spatial resolution





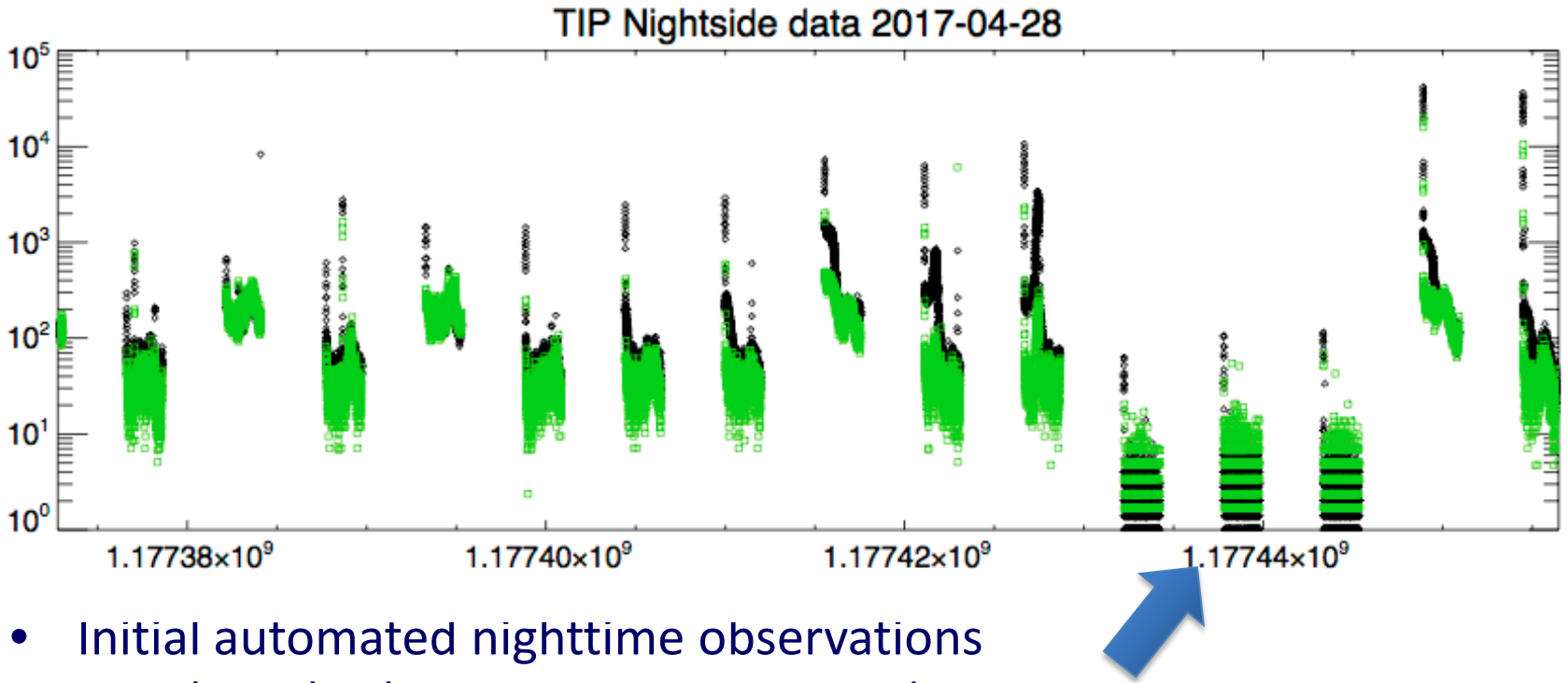
TIP Nightside Quicklook Observations





- These are raw 0.28-sec samples using TIP.
  - Sample will be coadded to 1.14-sec bins to improve S/N
- 2017-04-28 TIP observations demonstrate the value of chopped sampling
- Background is distinguished from UV signal
- Variability in UV is apparent between orbits
- Some instrument-scattered light at the evening terminator is observed

Daily Observations with TIP



- Initial automated nighttime observations
  - Filter wheel operation may require adjustment.
- Next steps for TIP operations and processing
  - Rebinning and accurate background subtraction
  - Geolocation
  - Comparison with LITES and FOTON observations

U.S. NAVAL RESEARCH LABORATORY

GROUP-C Experiment Summary

- GROUP-C Early Orbit Testing completed Apr 28
- GROUP-C is currently acquiring science data for calibration and validation activities
- The FOTON GPS occultation sensor is performing very stably with good performance.
  - Antenna and receiver performance is excellent.
  - Continuous I-Q stream (default data)
  - Occasional raw RF-front end capture
- The TIP photometer is now routinely collecting nighttime airglow signals.
- Coordinated observations and cross-calibration using FOTON, TIP, and LITES are very promising
- Experiment Team focus now shifts to routine data processing and analysis software development for calibration and validation.
- Data are received in real-time through TDRSS, enabling the potential for real-time space weather monitoring to feed operational models

GROUP-C Science Team!

- **Science Team**
  - Scott Budzien, Andy Stephan
  - Steve Powell, Brady O'Hanlon
  - Rebecca Bishop
  - Todd Humphreys
  - Jason Gross
- Collaborators
  - The LITES Team, Mark Psiaki, David Hysell

Acknowledgements

GROUP-C is integrated and flown as part of the Space Test Program—Houston #5 payload under the direction of the DoD Space Test Program (STP).

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

The Office of Naval Research supported FOTON integration at Cornell University and The Aerospace Corporation.