Low-Latitude Coupled Density Structures Observed by the LLITED CubeSat Mission

R. L. Bishop[1], S. Debchoudhury[2], J. Clemmons[3], D. Swanson[3], A. Barjatya[2]

[1]The Aerospace Corporation,
[2]Embry-Riddle Aeronautical University,
[3]University of New Hampshire

12 February 2026

Approved for public release. OTR 2025-00325.

Bus Overview

Structure;

- 1.5U Aluminum structure and deployable solar wings

Mechanisms:

- *Aerospace-developed deployment mechanism (resettable muscle wire)*

Electric Power System:

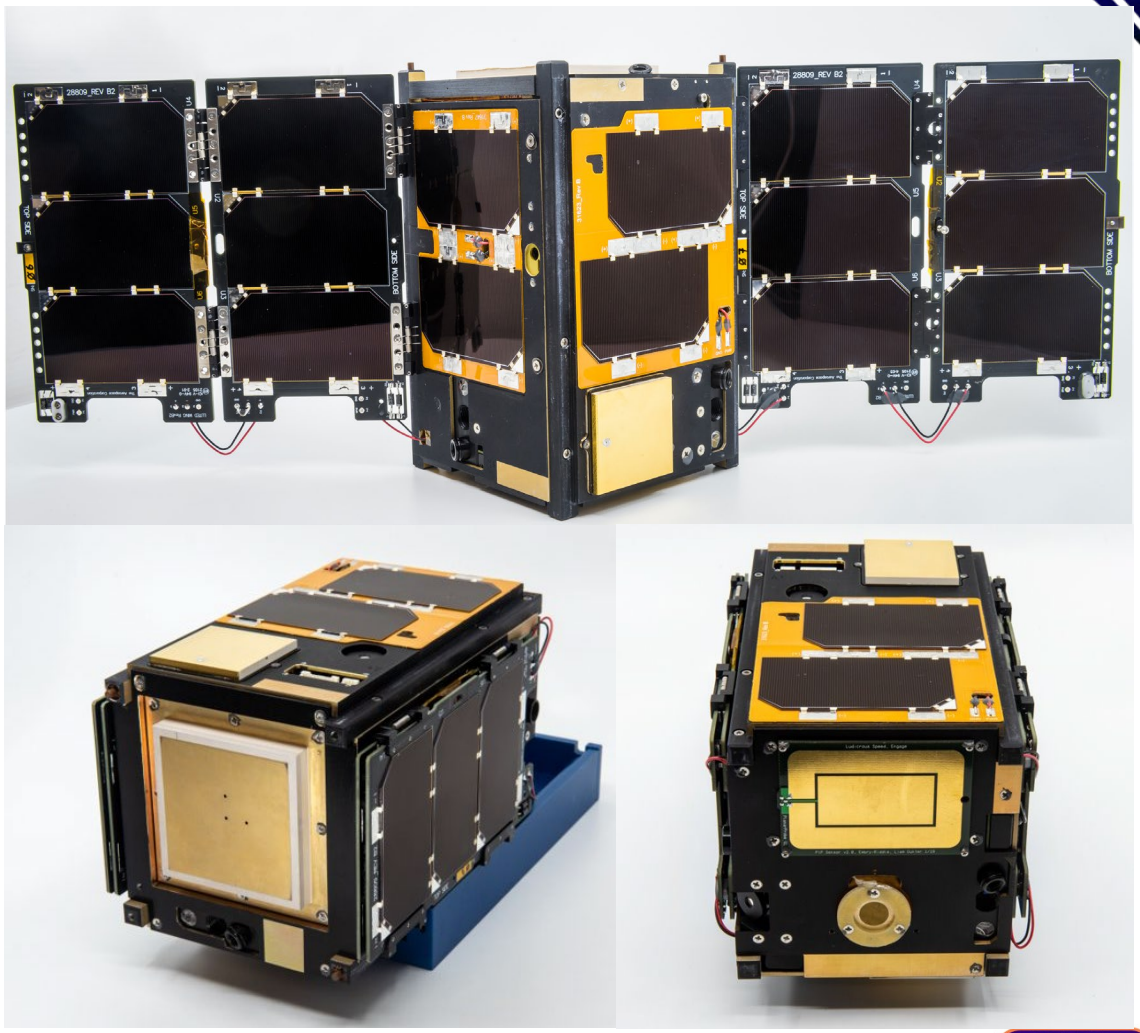
- *Deployed solar wings provides 13.2 W Max power*
- *Body-mounted cells provide 3.1 W Max power*
- *9 W-Hr Li Ion batteries for EPS board (X4)*

RF Communications

- *915 MHz ADV Radio plus GPS plus flight computer board*
- *915 MHz Software Defined Radio*
- *Backup radio*

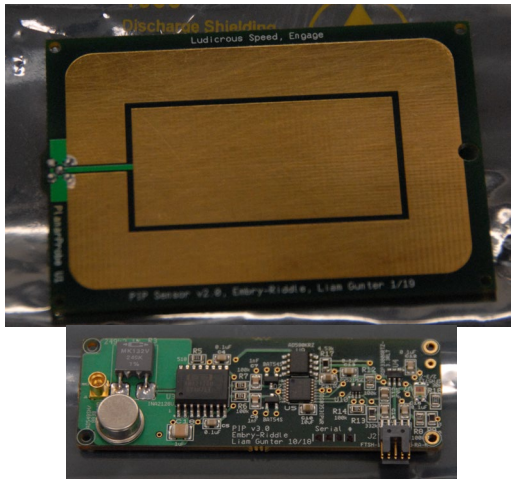
Thermal – Passive control with heaters on key subsystems

- *Battery system heaters*



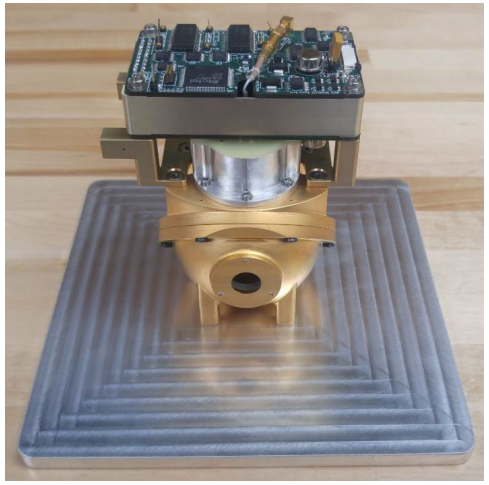
Planned orbit: 96.5 inclination, 496 km circular, non-sun synchronous, precess through 1700-2000 LT window NLT 3-4x over lifetime

Sensor Overview



Planar Ion Probe (PIP)

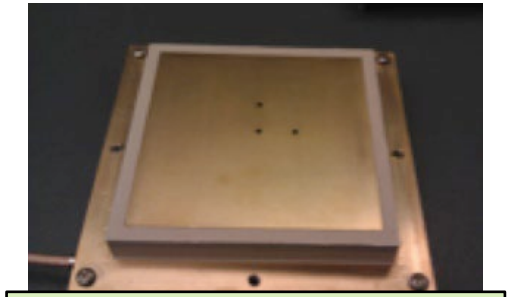
- PI: Aroh Barjatya, ERAU
- Fixed bias Langmuir probe
  - Bias fixed at -7V relative to CubeSat bus
  - Operates in the ion saturation region
- Measurement Range: $2x10^{9}$ to $2x10^{13}$ m^{-3}
- Resolution: $2x10^{8}$ m^{-3}



Miniature Ionization Gauge Space Instrument (MIGSI)

PI: James Clemmons, UNH

- Ionization Gauge measures pressure
- Convert to density and neutral wind measurements
- Measurement range: 10^{-3} to 10^{-8} torr



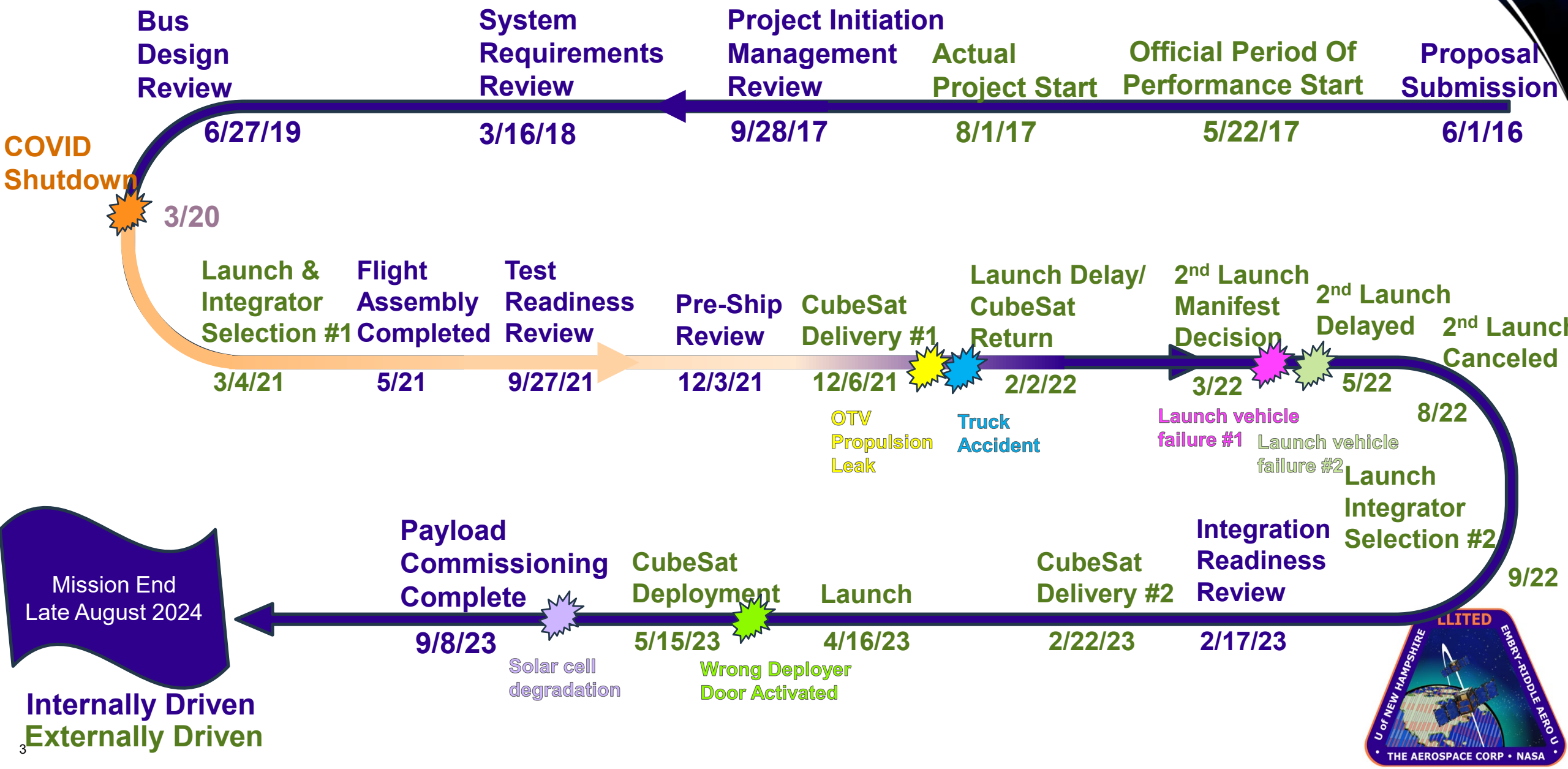
Flight computer/ GPS receiver/ Advanced Radio Board

Compact Total Electron Content Sensor- Aerospace (CTECS-A)

PI: Rebecca Bishop, Aerospace

- GPS radio occultation
- Dual frequency (L1 C/A, L2 P(Y)
- Closed Loop tracking
- Obtains TEC

LLITED Mission…A Lesson in Practicality and Patience



LLITED Mission…A Lesson in Practicality and Patience

Bus Design Review 6/27/19

System Requirements Review 3/16/18

Project Initiation Management Review 9/28/17

Actual Project Start 8/1/17

Official Period Of Performance Start 5/22/17

Proposal Submission 6/1/16

COVID Shutdown 3/20

Launch & Integrat… Selectio… 3/4/21

Flight … Test …

Contracted Orbital Target:
- Inclination: 96.5
- 496 km circular
- Non-sun-synchronous
- Precess through 1700-2000 LT window 3-4x over lifetime

…ubeS… …eliver… 12/6/2…

OTV Propu… Leak

Launch Delay/… 2nd Launch …st …on

Final Orbital Placement:
- Inclination: 97.4
- Apogee: 513.8 km
- Perigee: 495.7 km
- LTDN: 2230
- Nearly sun-synchronous

2nd Launch Delayed 5/22

2nd Launch Canceled 8/22

…icle …Launch vehicle …failure #2

Launch Integrator Selection #2 9/22

Integration Readiness Review 2/17/23

CubeSat Delivery #2 2/22/23

Launch 4/16/23

CubeSat Deployment 5/15/23

Wrong Deployer Door Activated

Payload Commissioning Complete 9/8/23

Solar cell degradation

Mission End Late August 2024

Internally Driven

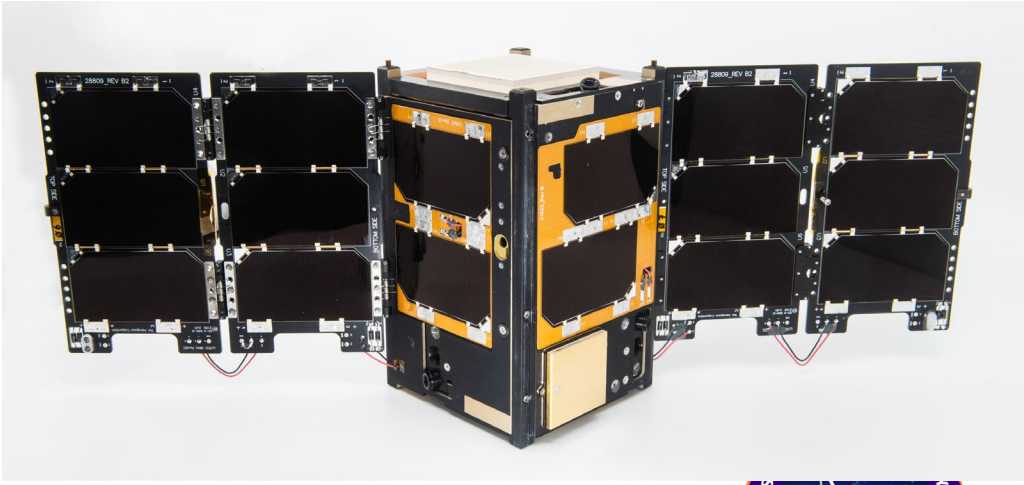
Externally Driven

Modified LLITED Science Mission

Science Questions:

1. **What is the *short-term* (<45 min) mesoscale variability of the *Midnight Density Maximum (MDM)* during elevated solar cycle conditions as a function of season, and longitude/latitude as well as its relationship to EIA heating?**
2. **What is the relationship between neutral wind (i.e., tides) and the *pre-midnight* EIA zonal structure?**
3. **Are the small-scale wave fluctuation in neutral atmosphere quantities, such as those observed by earlier missions exhibited in the ionospheric density *closer to midnight*?**

- Final orbit required modification of mission science focus
- Reduction in power generation resulted in modified ConOps:
  - Nearly daily vehicle commanding vs more autonomous controlling
  - Implementation of focused observations and science studies
  - Reduction in sensor duty cycle
  - Prioritization of MIGSI and PIP data collects between 2 spacecraft
  - Natural s/c separation



Initial phrasing and focus of science questions/objectives essential for adaptability.

Focused Science Studies

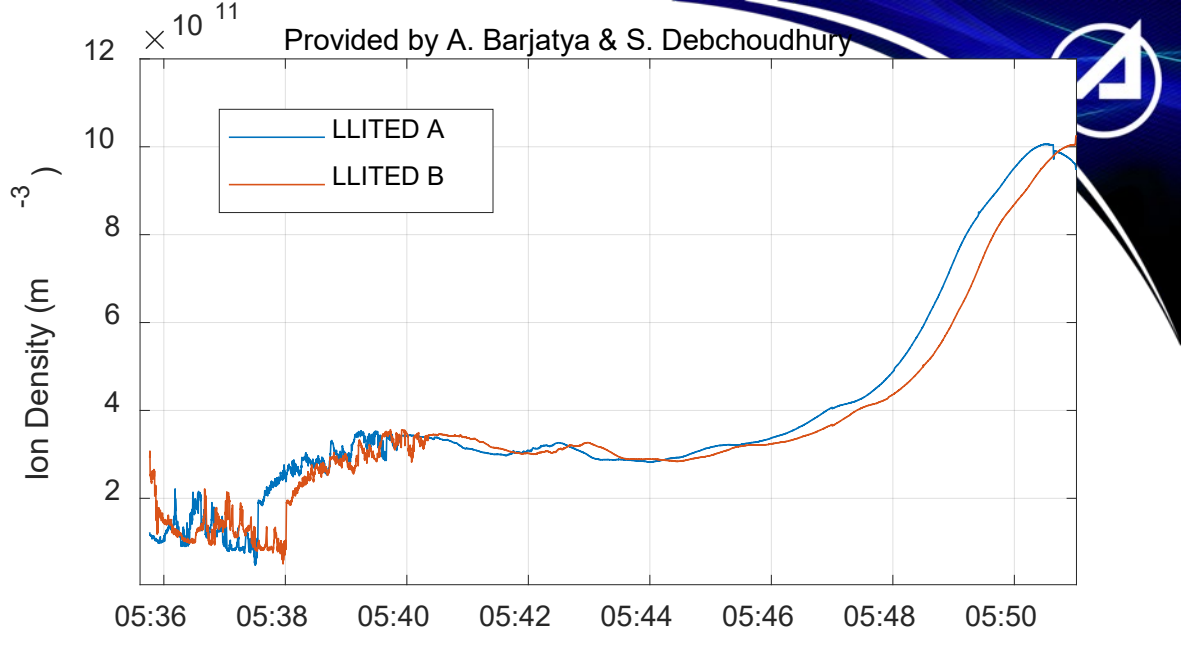
1. Investigate density changes during the October 2023 Partial Eclipse
2. Explore high latitude neutral density variations over a solar rotation
3. Provide contextual information in support of the 2023 Dissipation Rocket Campaign
4. Investigate plasma and neutral density changes immediately before and after April 2024 eclipse annularity
5. Apply the differential drag technique to the two s/c to extract neutral density
6. Utilize coincident MIGSI/LLITED-B and PIANO/ISS (gravity wave) observations to investigate vertical propagation of neutral density structures
7. Investigate the evolution and stability of small-scale plasma density structures
8. Explore the coupling between observed high latitude neutral and plasma density structure

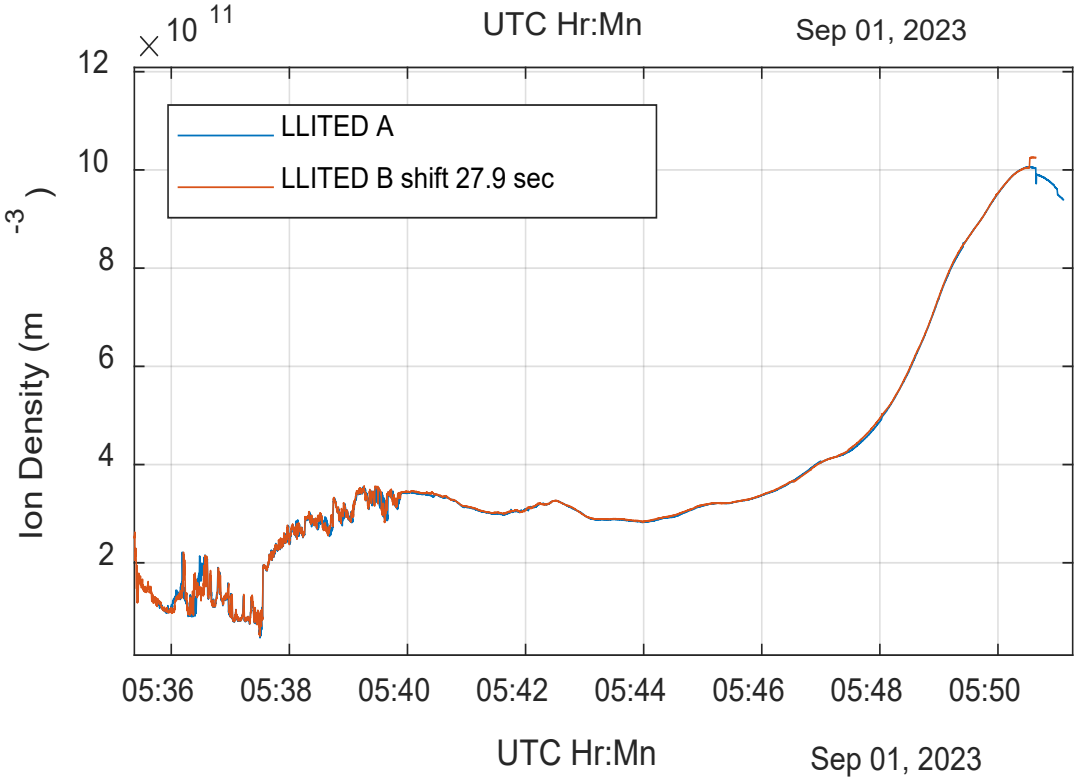
Focused Science Studies

1. Investigate density changes during the October 2023 Partial Eclipse
2. Explore high latitude neutral density variations over a solar rotation
3. Provide contextual information in support of the 2023 Dissipation Rocket Campaign
4. Investigate plasma and neutral density changes immediately before and after April 2024 eclipse annularity
5. Apply the differential drag technique to the two s/c to extract neutral density
6. Utilize coincident MIGSI/LLITED-B and PIANO/ISS (gravity wave) observations to investigate vertical propagation of neutral density structures
7. Investigate the evolution and stability of small-scale plasma density structures
8. Explore the coupling between observed high latitude neutral and plasma density structure

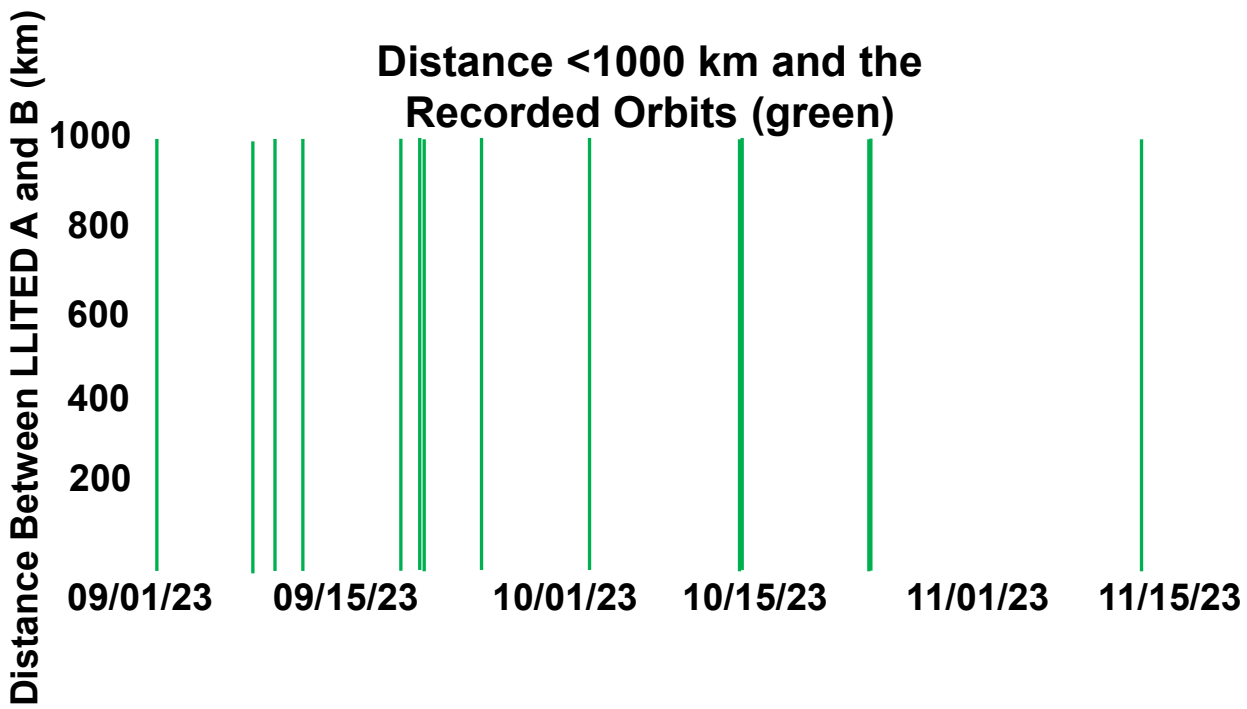
Highlights #1: *Small-scale Ionospheric Density Structure Stability*

- Both satellites carry the same fixed bias planar Langmuir probe enabling two-point 100 Hz density measurement
- For science measurements, PIP sensors need to be within RAM pointing for +/-10 degrees to keep error bar under 10%
- PIP operated 18 minutes over mid to high latitudes
- LLITED B is trailing A by 27.9 seconds (~230 km)





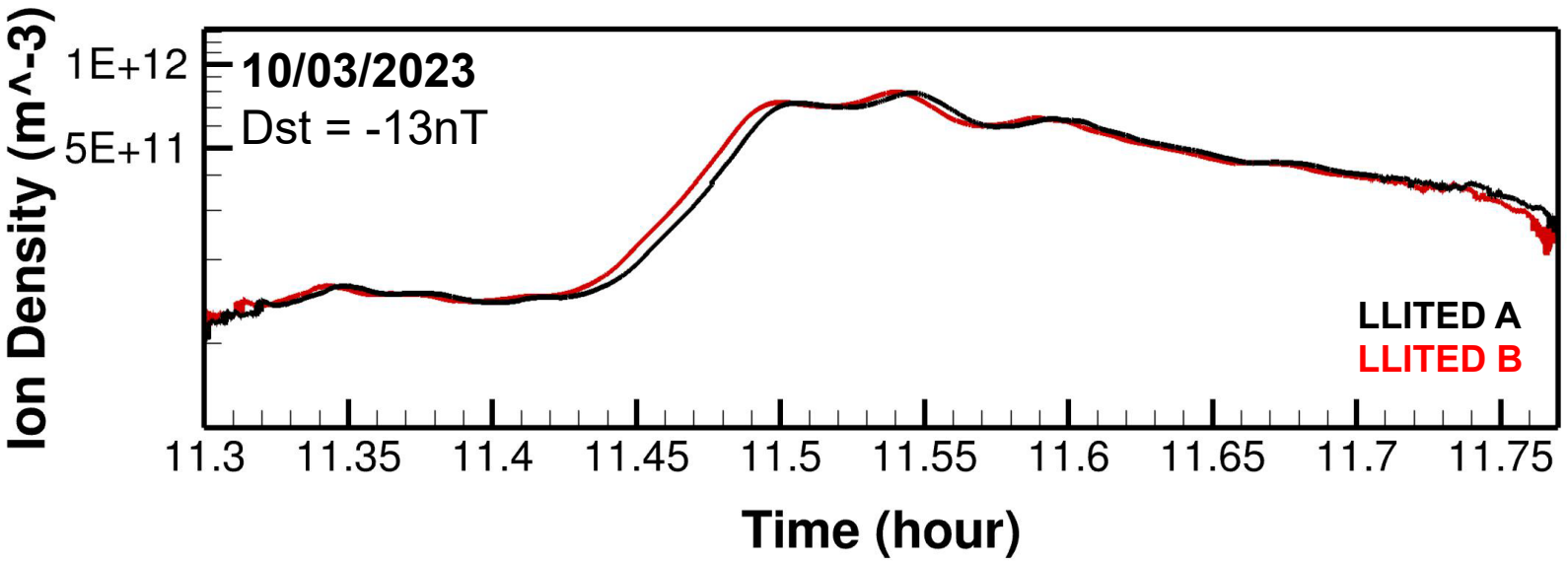
Low-Latitude Ionospheric Density Structures



Date	UTC Overlap Range	Magnetic Latitude Range (°)	Magnetic Low-latitutde Range (°)	Dst (nT)
09/01/2023	05:35 – 05:42	45 to 67	NA	2
09/08/2023	11:03 – 11:19	-85 to -36	NA	3
09/10/2023	03:33 – 03:49	10 to 67	10 to 20	3
09/12/2023	0:52 – 06:13	-13 to 60	-13 to 20	14
09/19/2023	10:51 – 11:13	-19 to 61	-19 to 20	-55
09/20/2023	21:27 - 21:48	-13 to 61	-13 to 20	-12
09/21/2023	03:38 – 03:59	20 to 79	NA	-9
10/03/2023	11:14 – 12:01	-69 to 65	-20 to 20	-13
10/14/2023	15:16 – 15:45	-20 to 82	-20 to 20	-2
10/14/2023	16:56 – 17:21	1 to 62	1 to 20	1
10/14/2023	18:29 – 18:53	-5 to 67	-5 to 20	1
10/24/2023	06:38 – 07:25	-86 to 84	-20 to 20	-5
10/24/2023	08:13 – 09:00	-82 to 81	-20 to 20	-6
11/13/2023	09:52 – 10:02	-87 to 83	-20 to 20	-22

Density Difference Quantification

- Quantified as a functions of minimum separation distance, S, and minimum separation time, δ.
- Focus on orbits with horizontal distance separation of a few kilometers and altitude separation of less than a kilometer

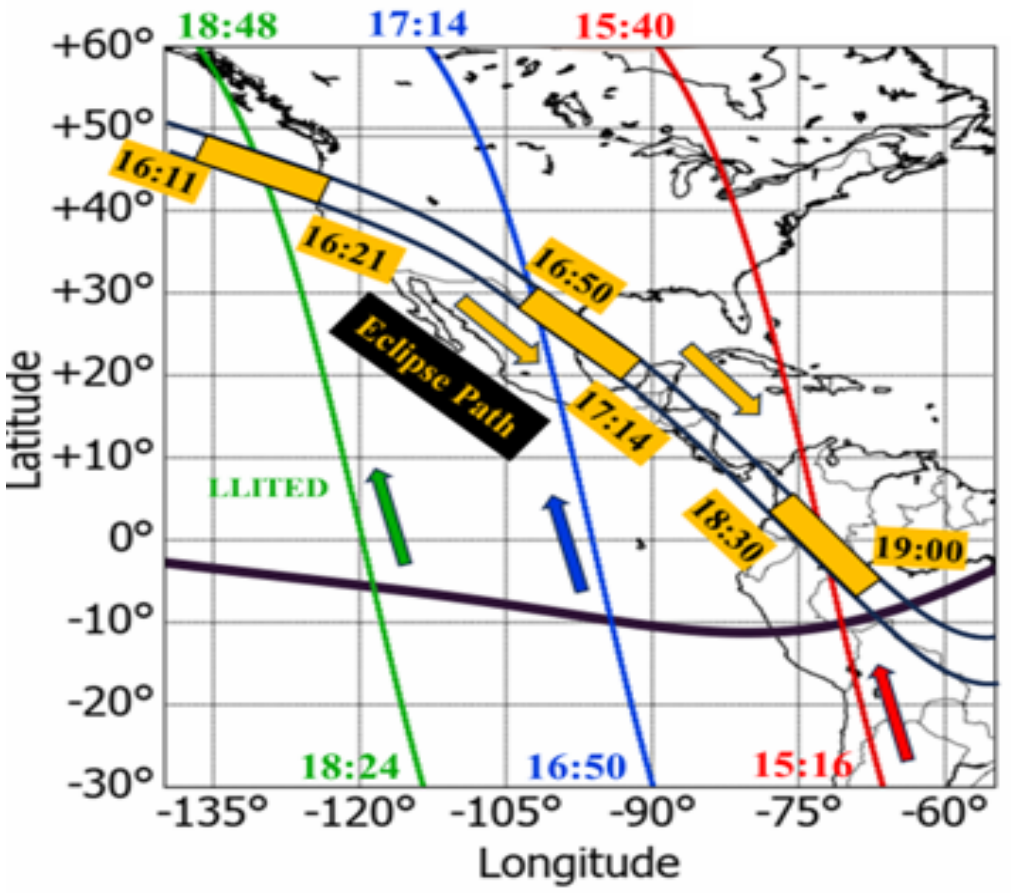


Statistical Difference in Ni (<20 mlat)

Mean	Median	Max	Standard Deviation
1.35%	0.83%	123.3%	3.75%

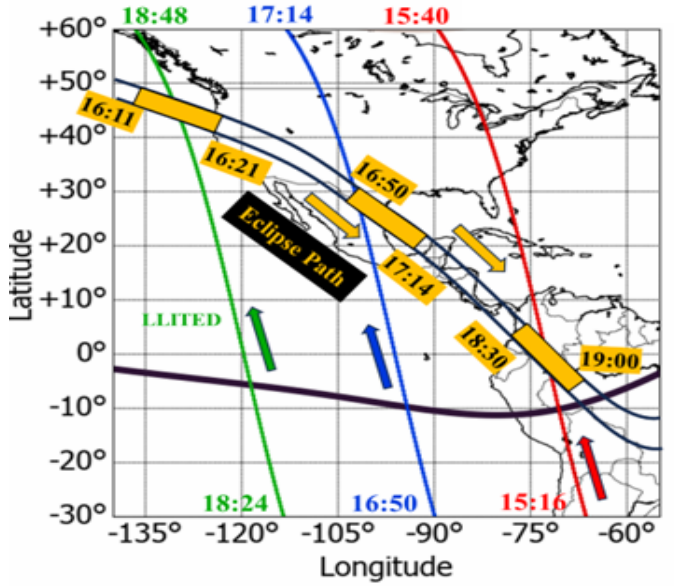
Highlights #2: *14 October 2023 Partial Solar Eclipse*

- Partial solar eclipse occurred October 14, 2023
- LLITED operated for 3 orbits centered on eclipse over New Mexico
- LLITED passes are roughly 11:00 am local time, thus similar solar zenith angle.
- LLITED profiles signify ionosphere measurements:
  - Red is pre-eclipse by 3 hrs
  - Blue is during peak eclipse
  - Green is post-eclipse by 2 hrs



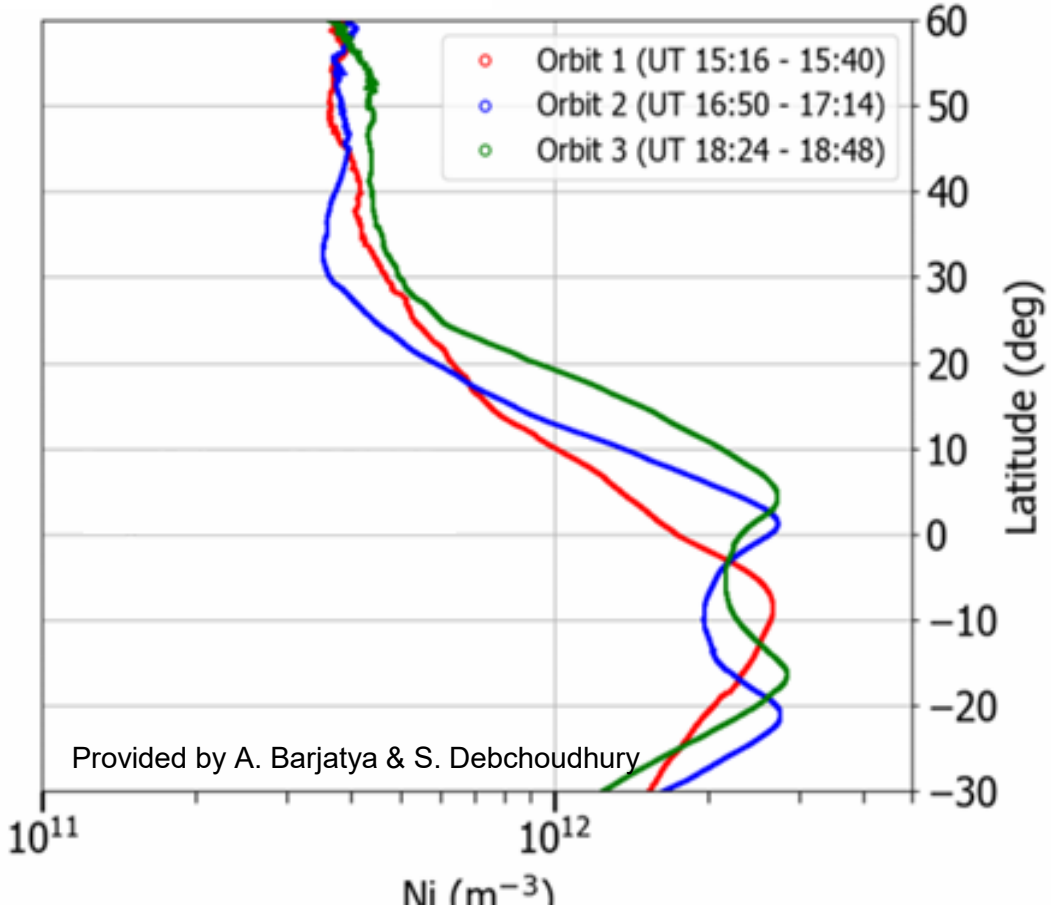
Highlights #2: *14 October 2023 Partial Solar Eclipse*

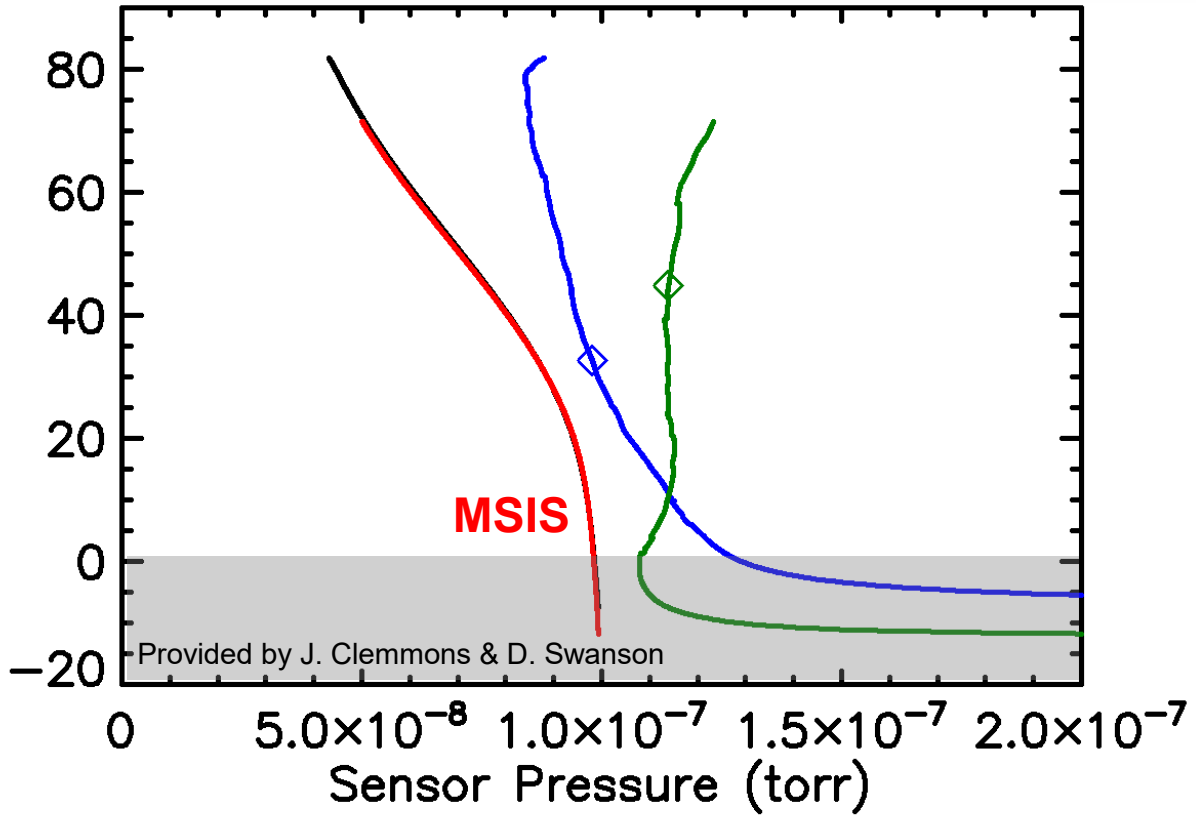
Passage	Orbit #1 (red)		Orbit #2 (blue)		Orbit #3 (green)	
	UT	LT	UT	LT	UT	LT
Eclipse	18:30-19:00	13:30-14:00	16:50-17:14	9:50-11:50	16:11-16:21	7:11-8:21
LLITED	15:16-15:40	10:16-10:40	16:50-17:14	10:50-10:14	18:24-18:48	10:24-9:48



Note: flares occurred at

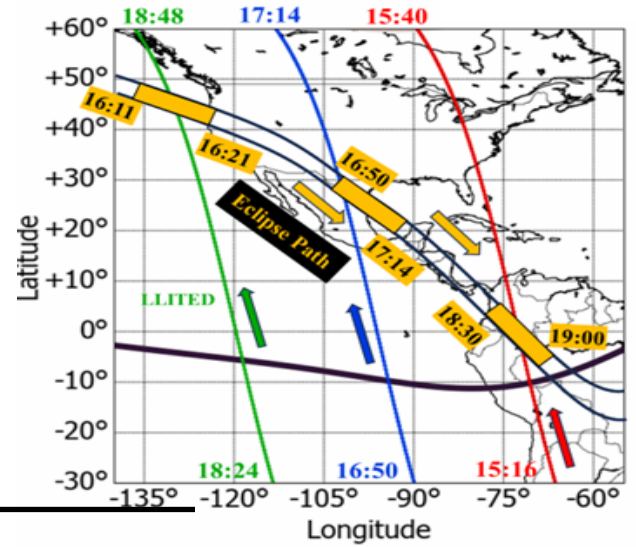
- 05:06 UT (C-class)
- 16:27 UT (B-class)

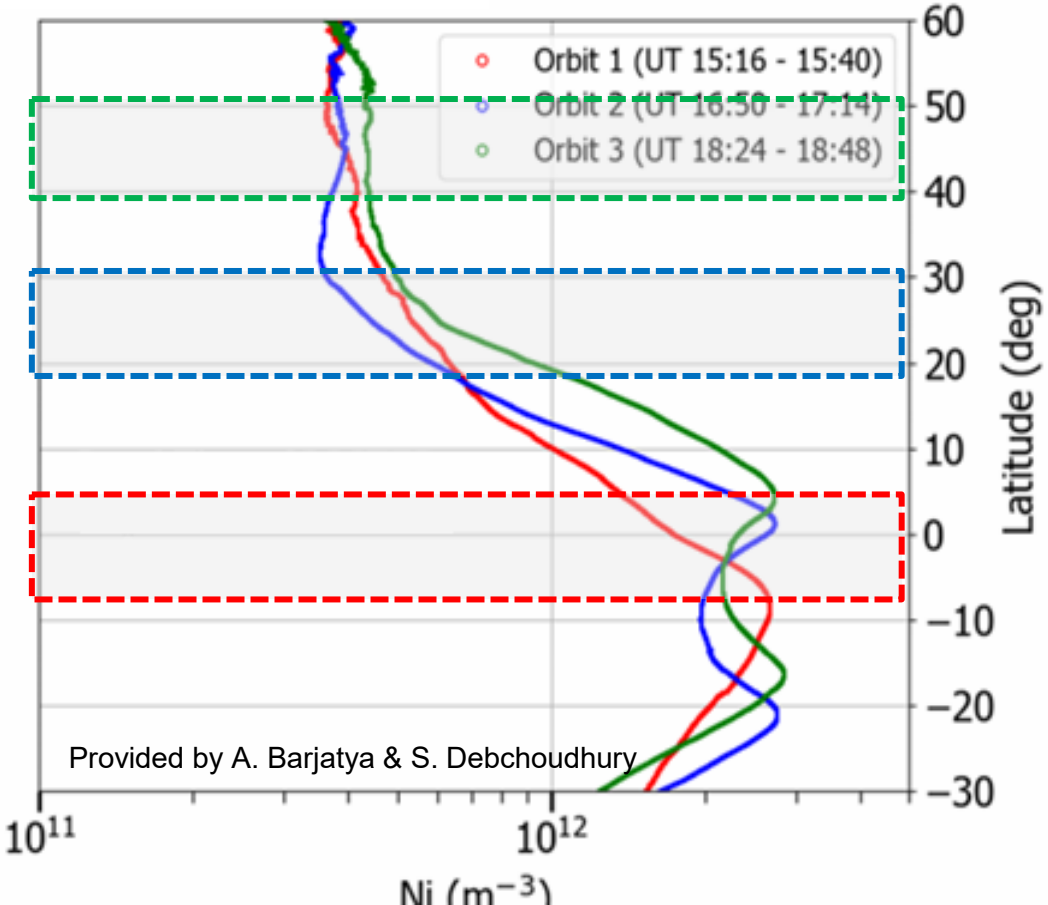


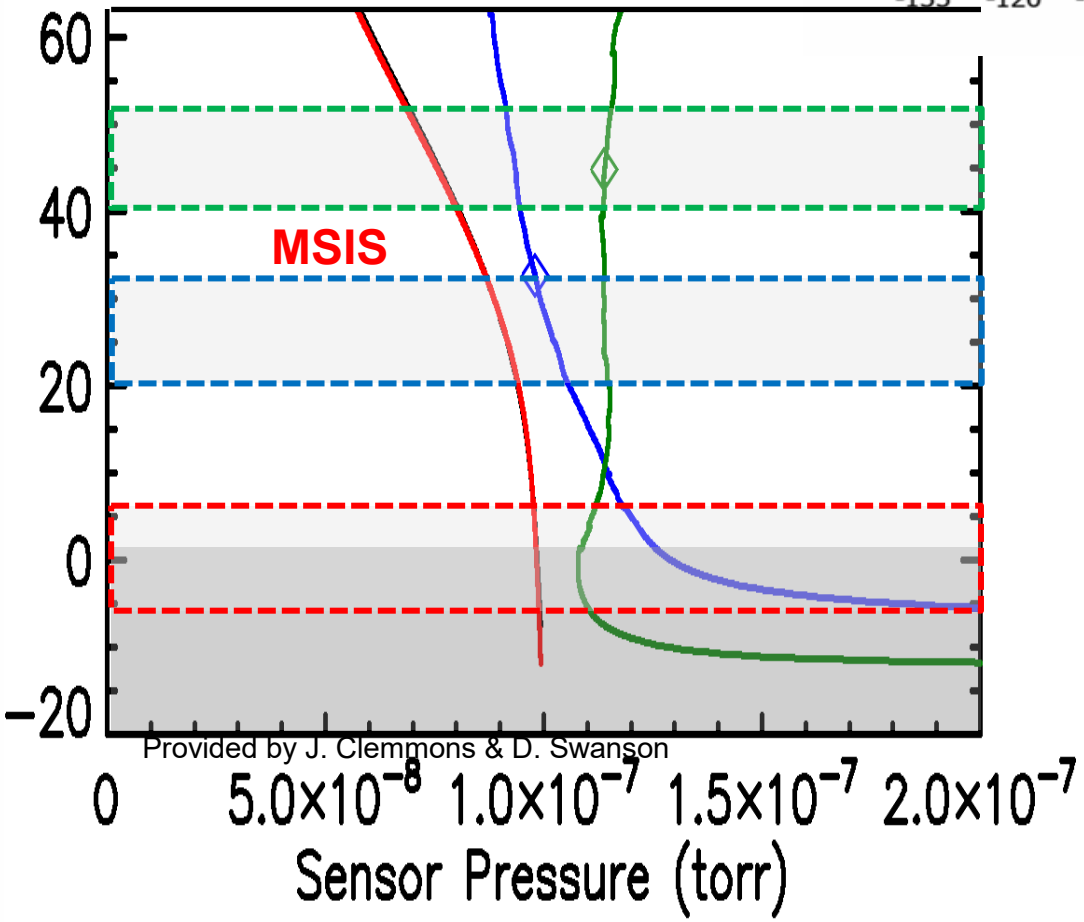


Highlights #2: *14 October 2023 Partial Solar Eclipse*

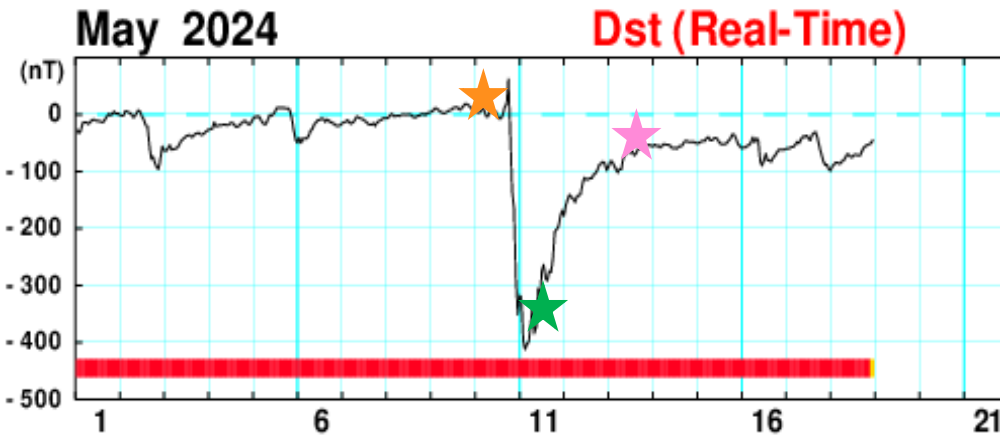
- Eclipse Conjunction:
  - Overall decrease in Ni during eclipse conjunction (blue)
  - Little structure in neutral density profiles during conjunction
  - No small-scale plasma structures observed on the edge

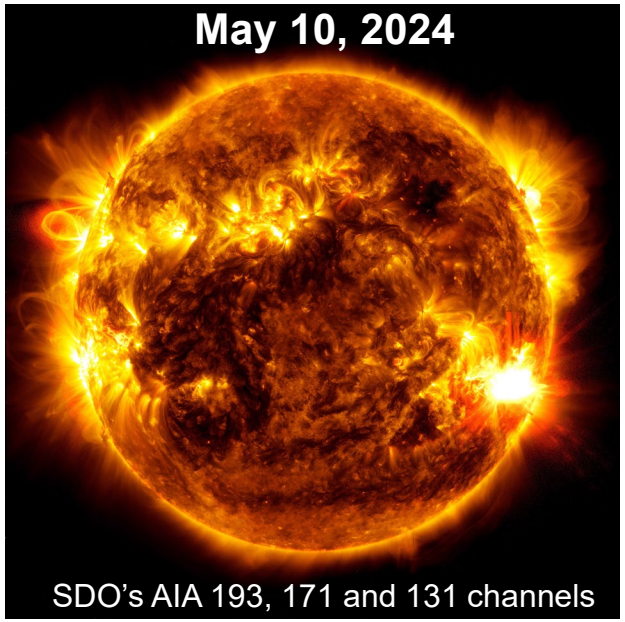






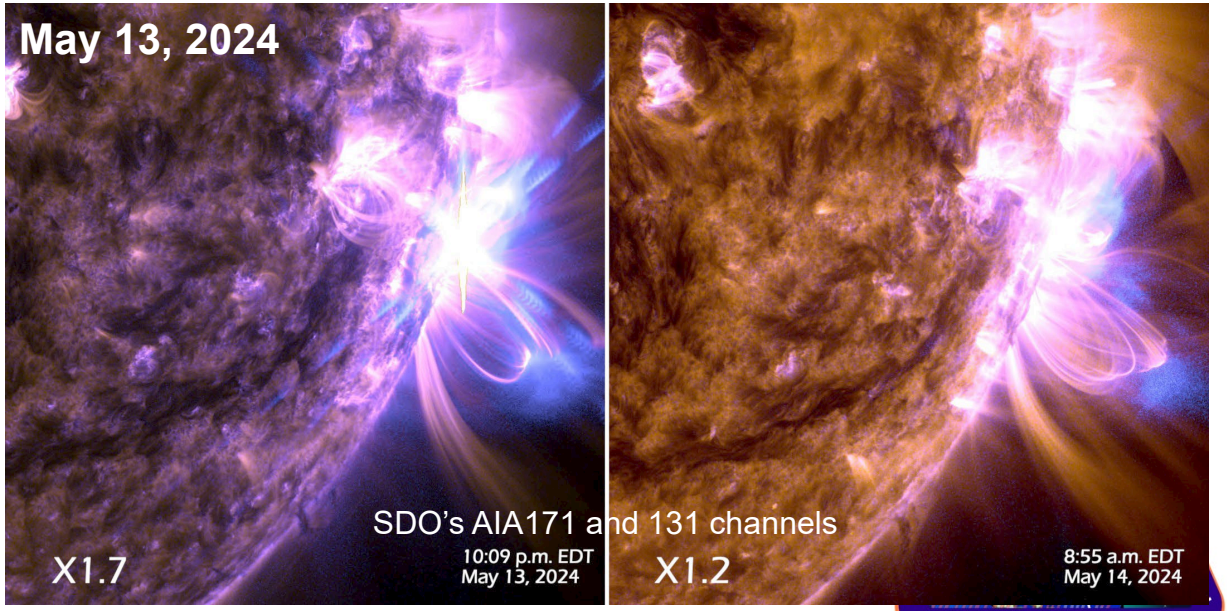
Highlight #3: *Gannon Storm Plasma/Neutral Density Effects*





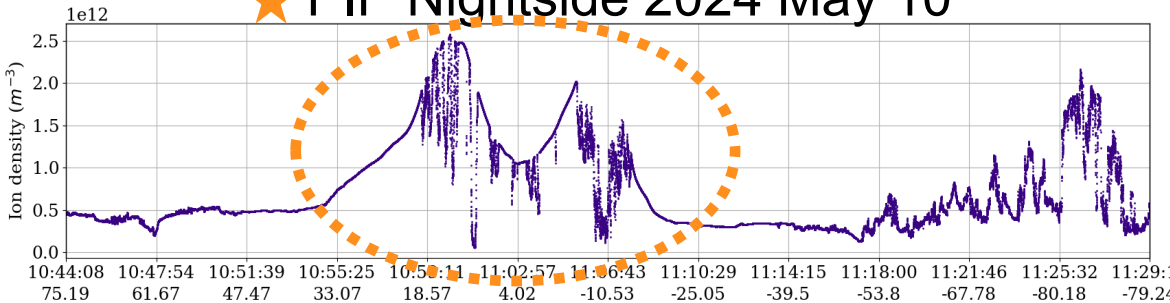
Images Courtesy of NASA

- Occurred May 10-14, 2024
- X1.7 and X1.2 Class Flares
- Minor disturbances preceded the week prior to Gannon Storm
- Aurora observed at mid-latitudes
- Significant heating of thermosphere occurred
  - Expansion resulting in increased drag at low Earth orbits
  - LLITED-A/B lost 8-12 km over the span of a week



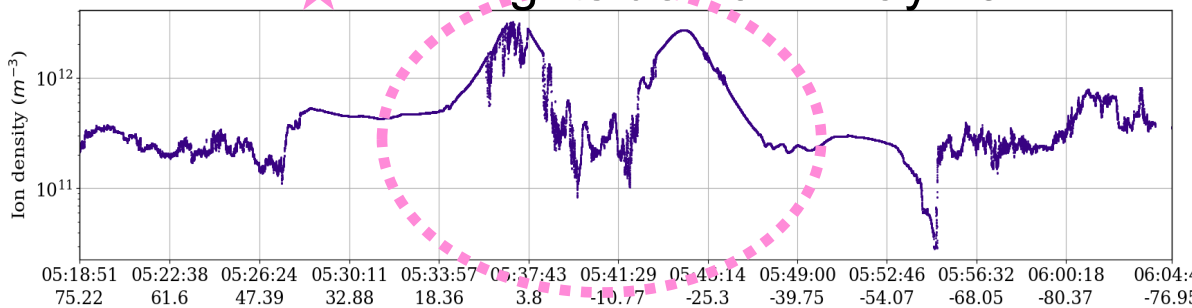
Highlight #3: *Gannon Storm Plasma/Neutral Density Effects*

★ PIP Nightside 2024 May 10

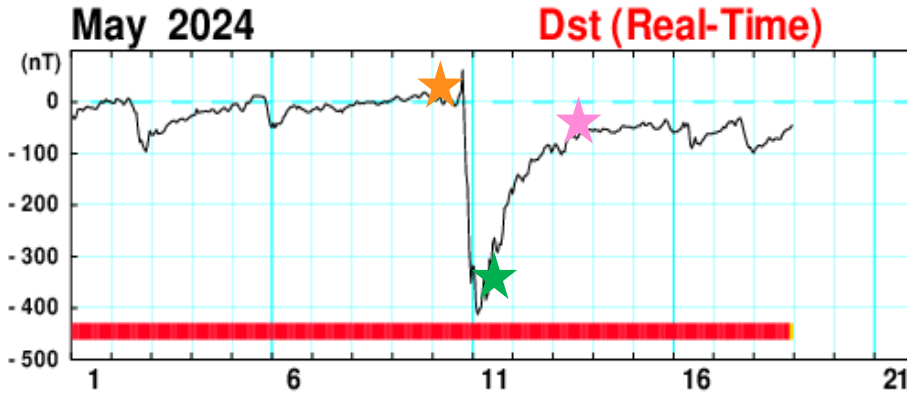


UT 05/10	10:44:08	10:47:54	10:51:39	10:55:25	10:59:11	11:02:57	11:06:43	11:10:29	11:14:15	11:18:00	11:21:46	11:25:32	11:29:18
Lat (deg)	75.19	61.67	47.47	33.07	18.57	4.02	-10.53	-25.05	-39.5	-53.8	-67.78	-80.18	-79.24
Lon (deg)	-149.63	-165.86	-172.53	-176.73	13.68	177.11	174.28	171.26	167.69	162.72	153.55	123.0	32.53
Alt (km)	429.32	426.86	423.44	420.1	417.89	417.62	419.66	423.77	429.18	434.75	439.3	441.82	441.78
MLAT (deg)	74.41	59.7	44.97	30.23	18.8	0.77	-13.95	-28.67	-43.38	-58.07	-72.76	-87.33	-77.8

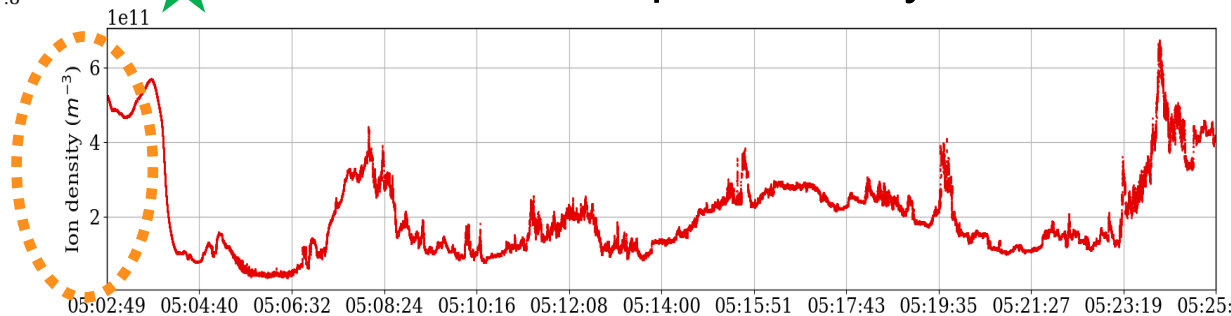
★ PIP Nightside 2024 May 13



UT 05/13	05:18:51	05:22:38	05:26:24	05:30:11	05:33:57	05:37:43	05:41:29	05:45:14	05:49:00	05:52:46	05:56:32	06:00:18	06:04:45
Lat (deg)	75.22	61.6	47.39	32.88	18.36	3.8	-10.77	-25.3	-39.75	-54.07	-68.05	-80.37	-76.95
Lon (deg)	-68.15	-84.48	-91.14	-95.35	-98.61	-101.51	-104.34	-107.36	-110.96	-115.97	-125.29	-156.89	104.89
Alt (km)	426.27	423.59	420.02	416.53	414.27	414.02	416.14	420.36	425.92	431.66	436.38	439.07	438.92
MLAT (deg)	84.27	70.39	55.84	41.13	26.48	11.82	-2.84	-17.49	-32.15	-46.79	-61.42	-76.01	-86.05



★ PIP Southern Cusp 2024 May 11



05:02:49	05:04:40	05:06:32	05:08:24	05:10:16	05:12:08	05:14:00	05:15:51	05:17:43	05:19:35	05:21:27	05:23:19	05:25:11
-41.68	-48.78	-55.82	-62.79	-69.6	-76.03	-81.28	-82.29	-77.97	-71.76	-65.04	-58.12	-51.1
-99.83	-102.16	-105.1	-109.13	-115.33	-126.7	-152.92	155.19	120.07	105.5	98.11	93.54	90.31
426.87	429.7	432.38	434.77	436.74	438.19	439.04	439.25	438.8	437.74	436.12	434.03	431.59
-33.19	-40.41	-47.63	-54.84	-62.03	-69.19	-76.27	-83.01	-86.29	-80.86	-73.93	-66.81	-59.63

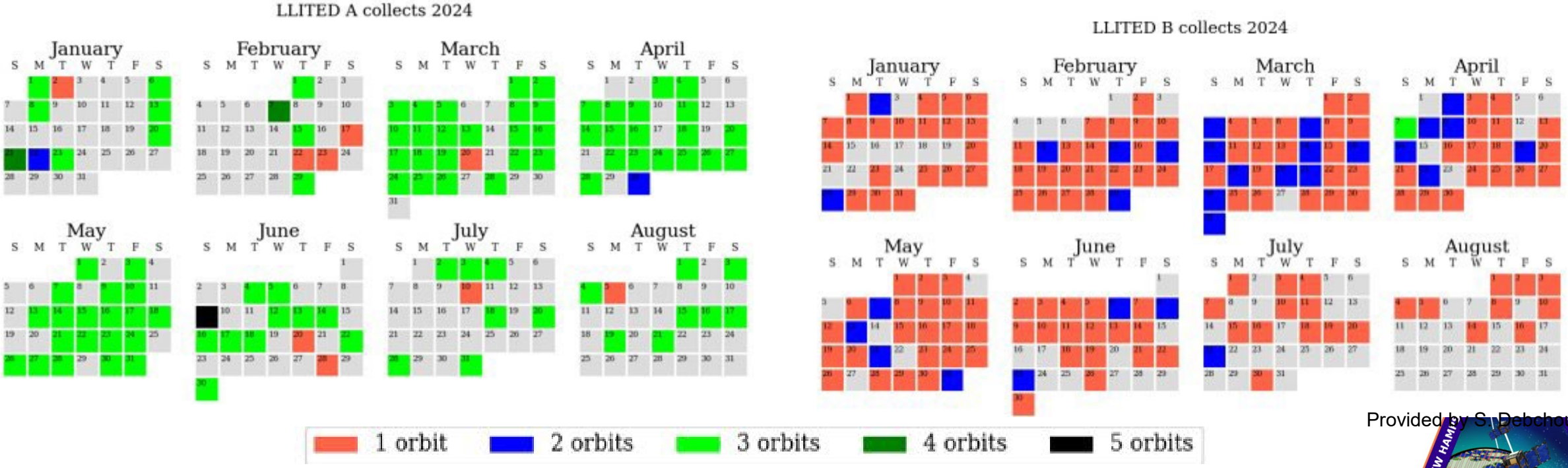
Provided by A. Barjatya & S. Debchoudhury

- +/- 35 mlat highlighted.
- Significant density depletions/scintillation preceding onset
- Wave-like structures during and post-storm between 20-35 mlat

Summary

LLITED mission has experienced many challenges. However, it made very useful observations that will contribute to our growing knowledge of the Ionosphere/Thermosphere!

- Publicly released in netCDF format
  - Located on NASA SPDF site
  - Level 2 PIP and MIGSI data released
  - Satellite ephemeris and attitude information



Provided by S. Debchoudhury

Acknowledgement: This work supported through NASA cooperative agreement 80NSSC17K044.