Large Electron Densities in the Early Morning Equatorial Ionosphere Observed with UV Instruments from Space

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Abstract

The equatorial ionosopheric anomalies (EIA) at night are the slowly recombining remnants of the dayside ionosphere, and charged particle densities slowly decay during the course of the night. Thus the electron density in ionosphere in the early morning (0300-0400 Local time) is usually very low and the ionospheric UV 135.6 nm O+ recombination emission is rarely detectable from current UV remote sensing instruments. However, there are times when the EIA have unusually high density even during these morning times and are observable by the DMSP/SSUSI and TIMED/GUVI instruments. By using other UV 'colors' - 130.4 nm (from monatomic Oxygen) and N2 Lyman Birge Hopfield bands - we can establish that this emission is definitely from the ionosphere recombination emission. We will show examples of this phenomenon, and correlate these occurrences to geomagnetic storm events. We estimate the electron density in the early morning EIA and compare with other ionosphere observations and climatological models. In the figure below, we show the 135.6 nm radiance seen by DMSP F16 SSUSI as it crosses the equator around 210 degrees longitude (over the Pacific Ocean) at 03:45 local time. The equatorial anomaly peaks are clearly visible in the SSUSI data. These radiances are background subtracted, which is not perfect and introduces a small (-1 Rayleigh) bias to the resulting radiances. DMSP = Defense Meteorological Satellite Program, SSUSI = Special Sensor Ultraviolet Spectrographic Imager; TIMED = Thermosphere, Ionosphere, Mesosphere Energetics and Dynamics, GUVI = Global UltraViolet Imager

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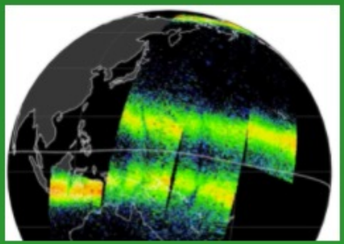
Space Exploration Sector, Johns Hopkins University Applied Physics Laboratory

UV Observations of the ionosphere



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Ionosphere UV Emission Over the Course of the Night

•Dayside solar EUV hitting the upper atmosphere ionizes the neutral atoms and creates an ionosphere

•After sunset, Ions and electrons slowly combine over the course of the night

•This recombination causes UV emission, notably the 135.6 nm Oxygen line emission

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Emissions and plasma density during geomagnetic storms - w…

•During a geomagnetic storm additional energy is pumped into the ionosphere.

•The plasma density increases during and after storm

•During the storm of Oct 13, 2016, the plasma density increased on the storm day and peaked the second day of the storm.

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GUVI and SWARM-A observations - confirmation

•The Oct 13, 2016 storm was observed by GUVI and SWARM-A both of which happened to be in 04:00 local time orbits

•GUVI observations of 135.6 nm emission shows the same pattern as SSUSI, confirming the effect.

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Imaging vs Stare Mode

•There are two modes implemented for the GUVI/SSUSI spectrographic imagers:

•Image scanning mode

•Spectrographic stare mode

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Pre Dawn Observations

Progression of the Storm Observed by F16 SSUSI at 04:00 local time for the Oct 13th 2016 storm

- The next few slides show the progression of the storm showing all passes during the day before, during, and two days after the storm.
- You will see dim emission before and after the storm, but the equatorial ionosphere lights up during and immediately after the storm

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Conclusions

•Typically pre-dawn UV emission from ionospheric recombination is too dim to be visible to the current generation of UV imagers

•Putting imagers like SSUSI and GUVI into spectrographic mode increases sensitivity by about two orders of magnitude

•Geomagnetic Storms can enhance equatorial ionosphere plasma density by factors of several, which causes UV

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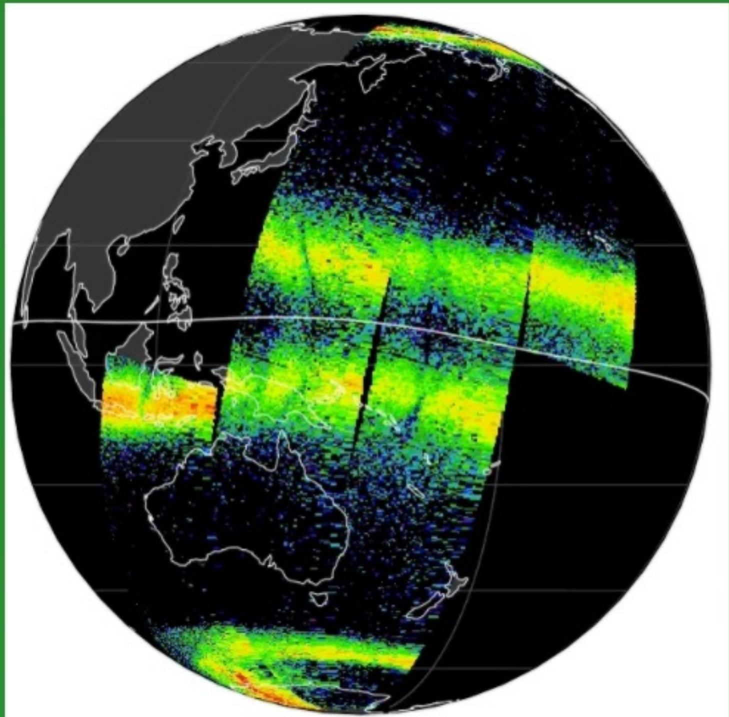
ABSTRACT

The equatorial ionosopheric anomalies (EIA) at night are the slowly recombining remnants of the dayside ionosphere, and charged particle densities slowly decay during the course of the night. Thus the electron density in ionosphere in the early morning (0300-0400 Local time) is usually very low and the ionospheric UV 135.6 nm O+ recombination emission is rarely detectable from current UV remote sensing instruments. However, there are times when the EIA have unusually high density even during these morning times and are observable by the DMSP/SSUSI and TIMED/GUVI instruments. By using other UV "colors" - 130.4 nm (from monatomic Oxygen) and N2 Lyman Birge Hopfield bands - we can establish that this emission is definitely from the ionosphere recombination emission. We will show examples of this phenomenon, and correlate these occurrences to geomagnetic storm events. We estimate the electron density in the early morning EIA and compare with other ionosphere observations and climatological models.

In the figure below, we show the 135.6 nm radiance seen by DMSP F16 SSUSI as it crosses the equator around 210 degrees longitude (over the Pacific Ocean) at 03:45 local time. The equatorial anomaly peaks are clearly visible in the SSUSI data. These radiances are background subtracted, which is not perfect and introduces a small (-1 Rayleigh) bias to the resulting radiances.

DMSP = Defense Meteorological Satellite Program, SSUSI = Special Sensor Ultraviolet Spectrographic Imager; TIMED = Thermosphere, Ionosphere, Mesosphere Energetics and Dynamics, GUVI = Global UltraViolet Imager

UV Observations of the ionosphere

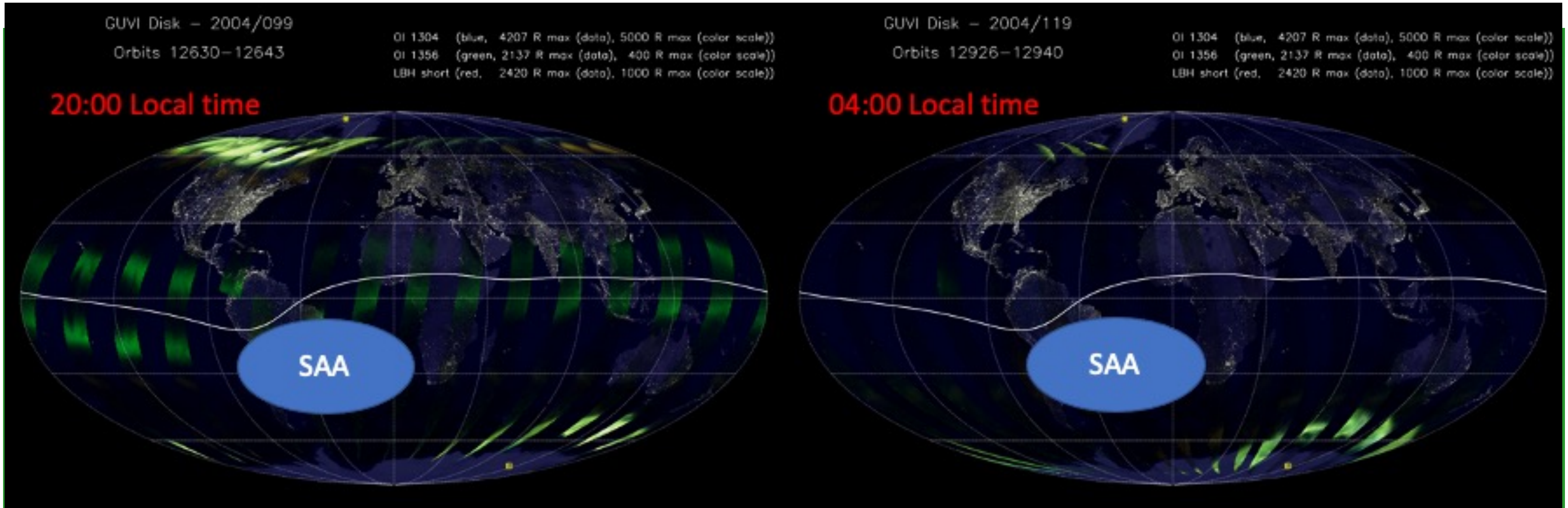


An example of GUVI imaging observations of the equatorial ionosphere emission at 135.6 nm from 3/25/2002. The ionosphere emission is the near equatorial glow. Also visible in the figure above is auroral emission in the polar zone.

- The ionosphere is a region of the upper atmosphere where ions and electrons are abundant.
- It is important to know the state of the ionosphere because it affects communications, GPS signals, satellite signals, and radar propagation
- The dynamics of the ionosphere coupled to the upper atmosphere and magnetosphere are complex and an active area of scientific study
- The recombination of electrons and O+ ions in the ionosphere produces UV radiation whose intensity is proportional to the product of O+ and e- densities (no+ and ne)
- This radiation can be detected by UV imagers that provide snapshots of the state of the ionosphere over a large area.
- UV imagers on NASA satellites (GUVI, ICON FUV, GOLD) and Defense Meteorological Satellites (DMSP SSUSI and SSULI) can image this UV radiation.
- In this study we focus on observations of the SSUSI and GUVI instrumets during the October 13, 2016 storm
- SSUSI and GUVI are both scanning imaging spectrographs, but in stare mode during the Oct 13, 2016 storm

Ionosphere UV Emission Over the Course of the Night

- Dayside solar EUV hitting the upper atmosphere ionizes the neutral atoms and creates an ionosphere
- After sunset, Ions and electrons slowly combine over the course of the night
- This recombination causes UV emission, notably the 135.6 nm Oxygen line emission
- As recombination lowers the ion/electron densities, the UV intensity decreases (UV 135.6 nm recombination radiance is roughly proportional to the sqaure of the electron density (n_e^2) – see UV nighside example from GUVI below.
- **Predawn, the ion & electron densities have decreased to the point where UV radiance has dropped by about two orders of magnitude or so and is harder to detect with UV imagers.**



•With about two orders of magnitude improved sensitivity in stare mode (see section on Imaging vs Stare Mode) – SSUSI and GUVI can see storm enhanced pre-dawn ionospheric signals.

Imaging vs Stare Mode

- There are two modes implemented for the GUVI/SSUSI spectrographic imagers:
- Image scanning mode
- Spectrographic stare mode

- Imaging mode spends little time (~0.1 s) on each pixel, while stare mode integrates over a much longer timescale (3 s) – 30 times longer than imaging mode,
- Data is binned spatially
- Imaging mode: 100 km x 100 km bins
- Stare mode: 20 km X 100 km

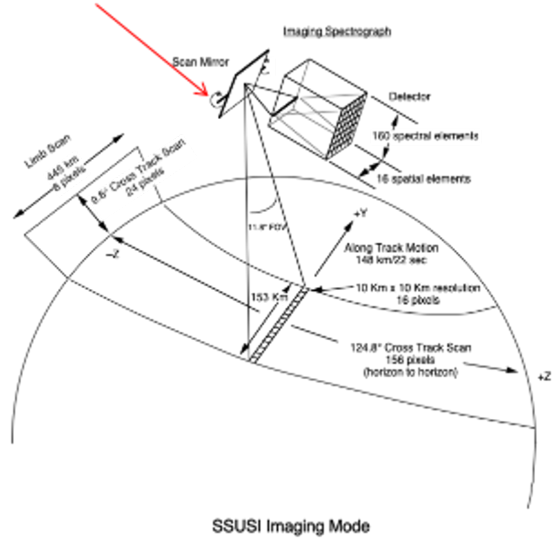
Sensitivity in spatially binned stare mode products is 2 orders of magnitude greater than per pixel sensitivity in imaging mode.

- Allows us to see small radiances down to ~1 Rayleigh

SSUSI UV Imaging vs. Spectrograph Modes

Imaging mode – the detector spends little time on each part of a big area

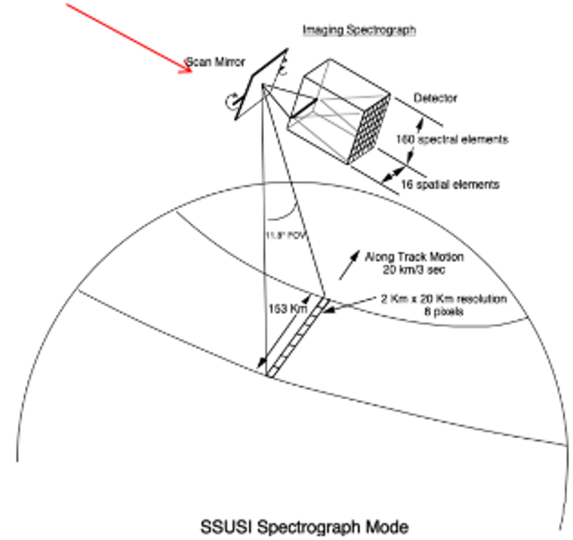
Mirror sweeps driven by scan motor



IMAGING SCAN PATTERN

Spectrograph mode – the detector spends big amounts of time scanning a little area

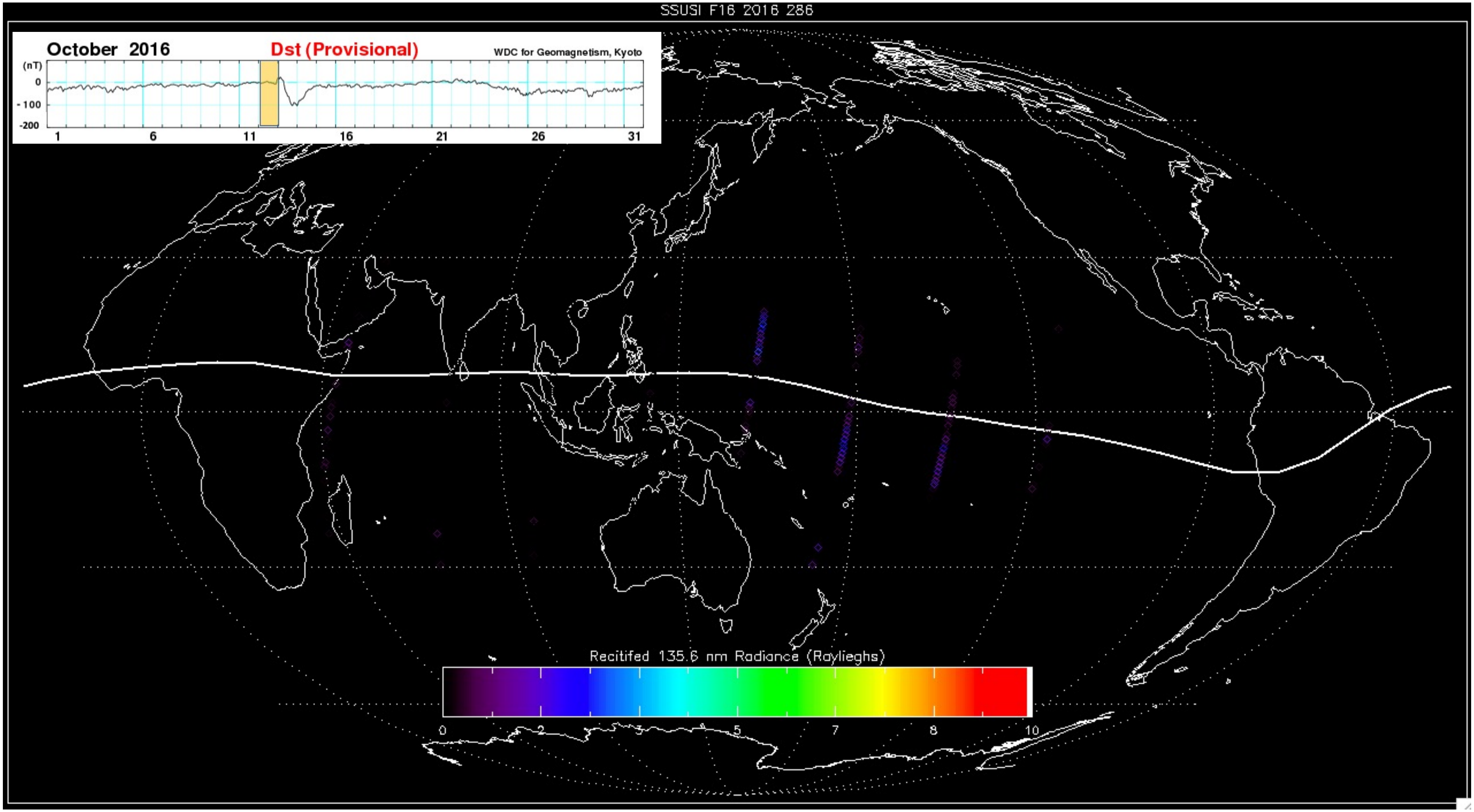
Mirror stays fixed



SPECTROGRAPH STARE PATTERN

Progression of the Storm Observed by F16 SSUSI at 04:00 local time for the Oct 13th 2016 storm

- The next few slides show the progression of the storm showing all passes during the day before, during, and two days after the storm.
- You will see dim emission before and after the storm, but the equatorial ionosphere lights up during and immediately after the storm.
- Also shown are the values of the Dst index for each day.
- The Dst index goes below -100 during the storm day.
- Note filters applied in the following plots:
  - Night. Solar zenith angle > 110 degrees
  - No aurora. | Latitude | < 30 degrees (non-auroral, no conjugate electron glow)
  - No SAA contamination. Longitude > 30, longitude < 250


SSUSI F16 2016 286
October 2016
Dst (Provisional)
WDC for Geomagnetism, Kyoto
(nT)
0
- 100
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Recitifed 135.6 nm Radiance (Rayliegha)
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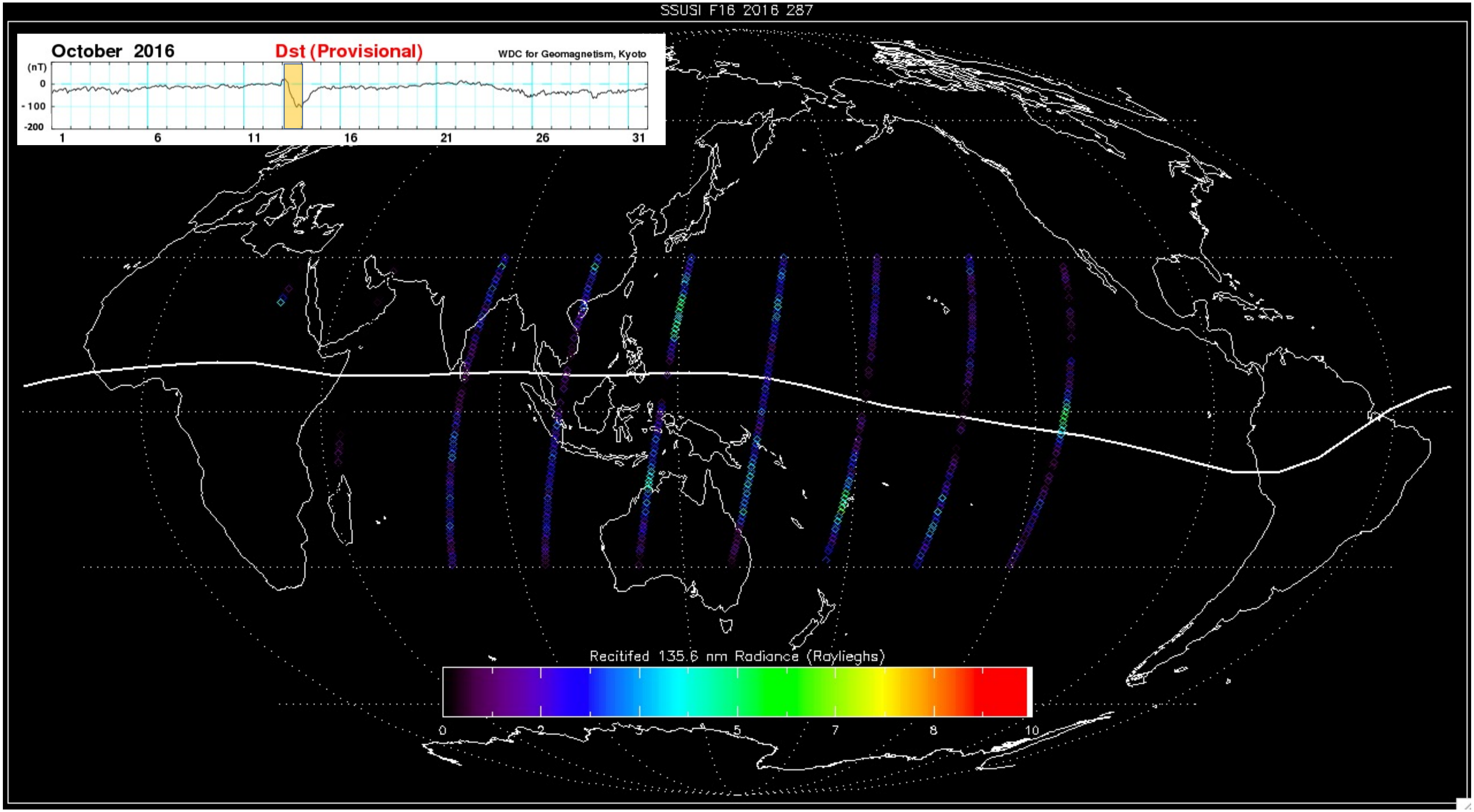
SSUSI F16 2016 287
October 2016
Dst (Provisional)
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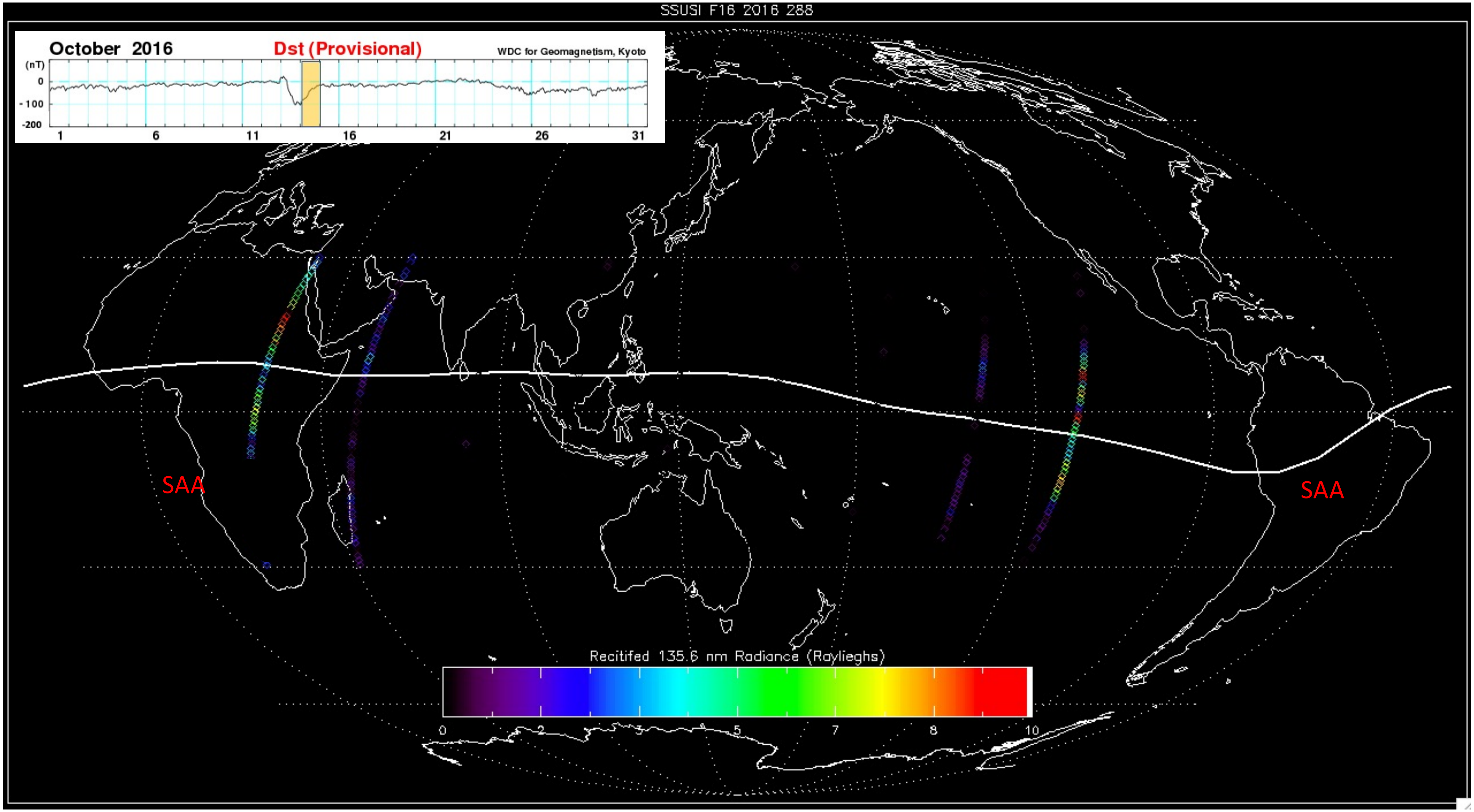

SSUSI F16 2016 288
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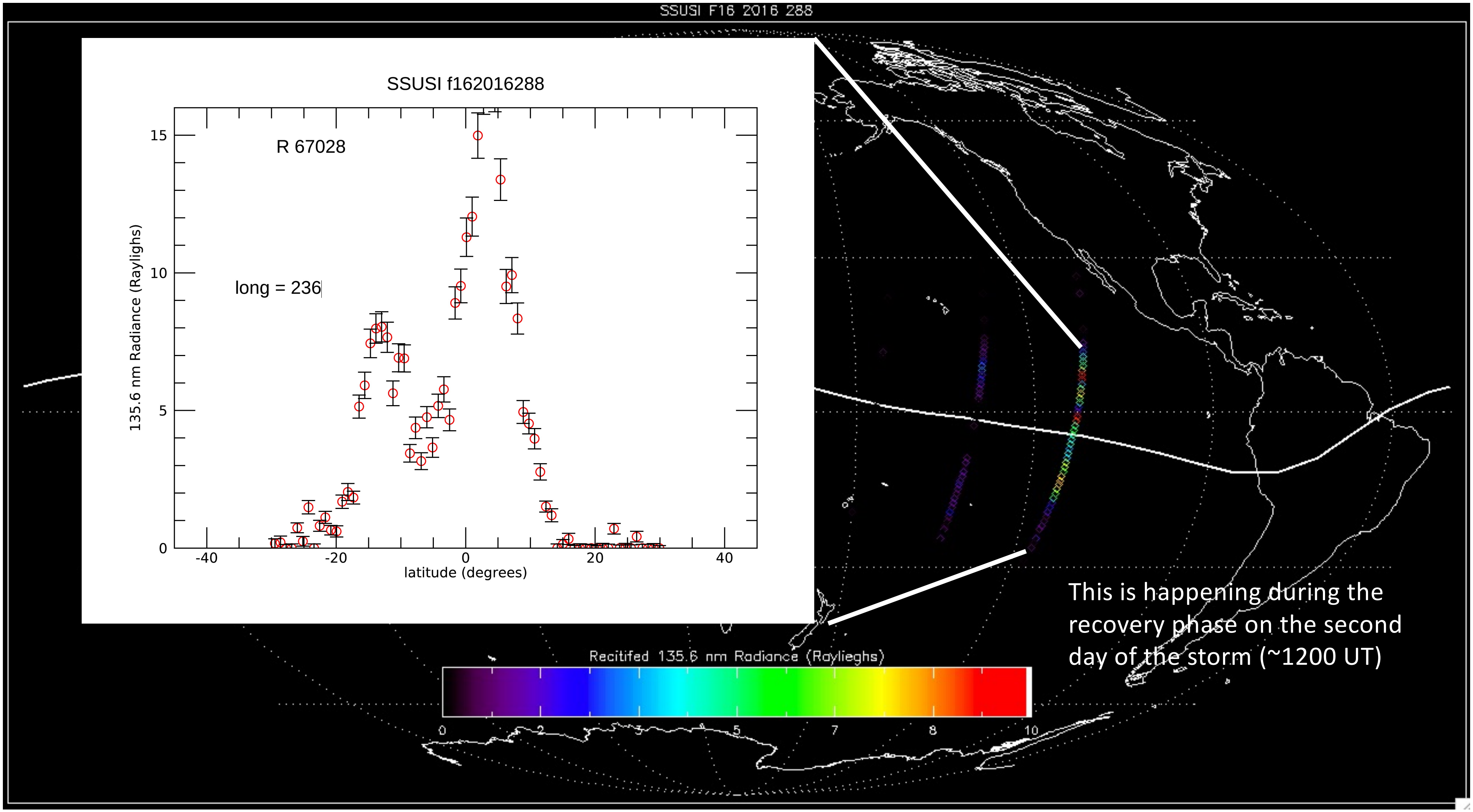
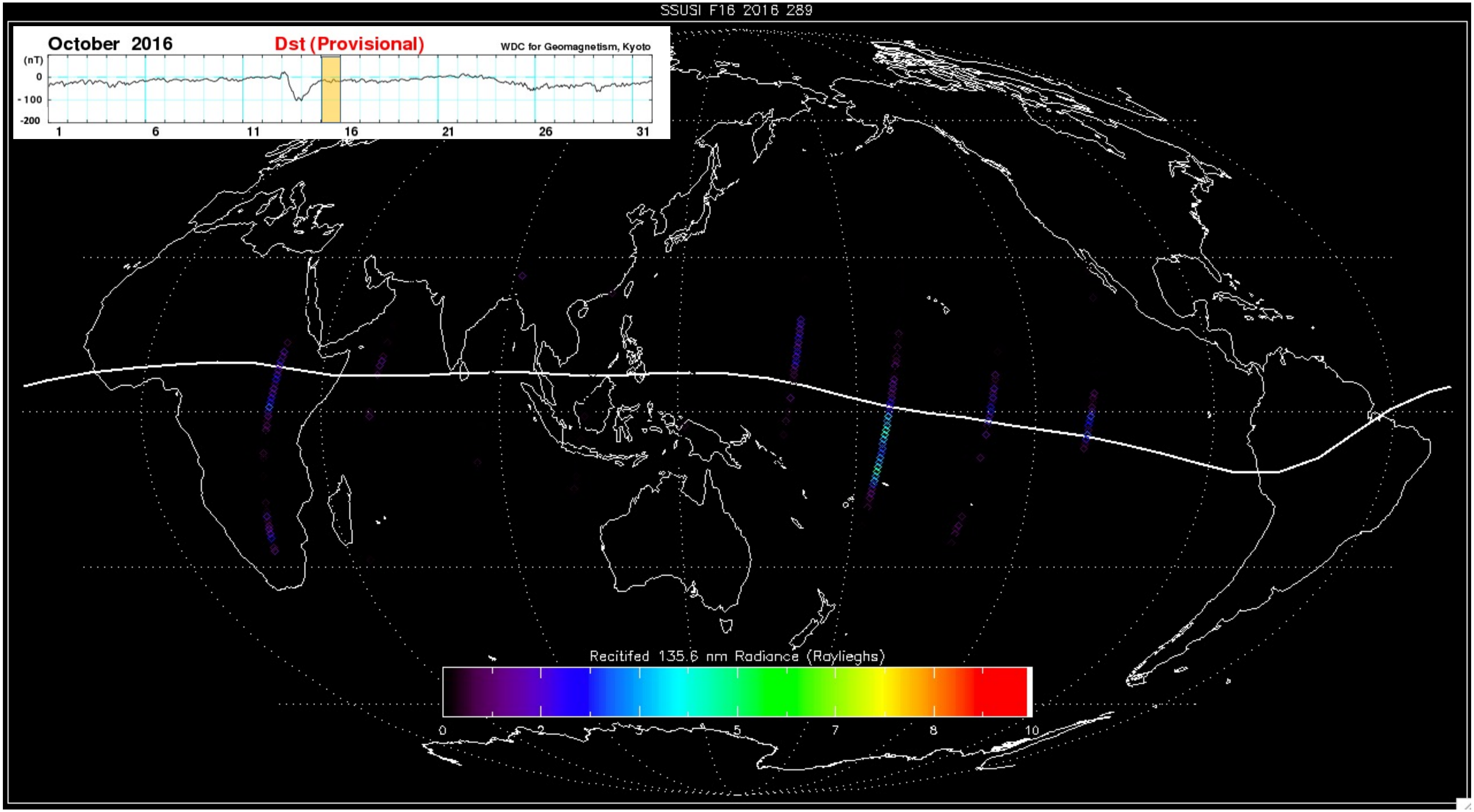


This is happening during the recovery phase on the second day of the storm (~1200 UT)


SSUSI F16 2016 289
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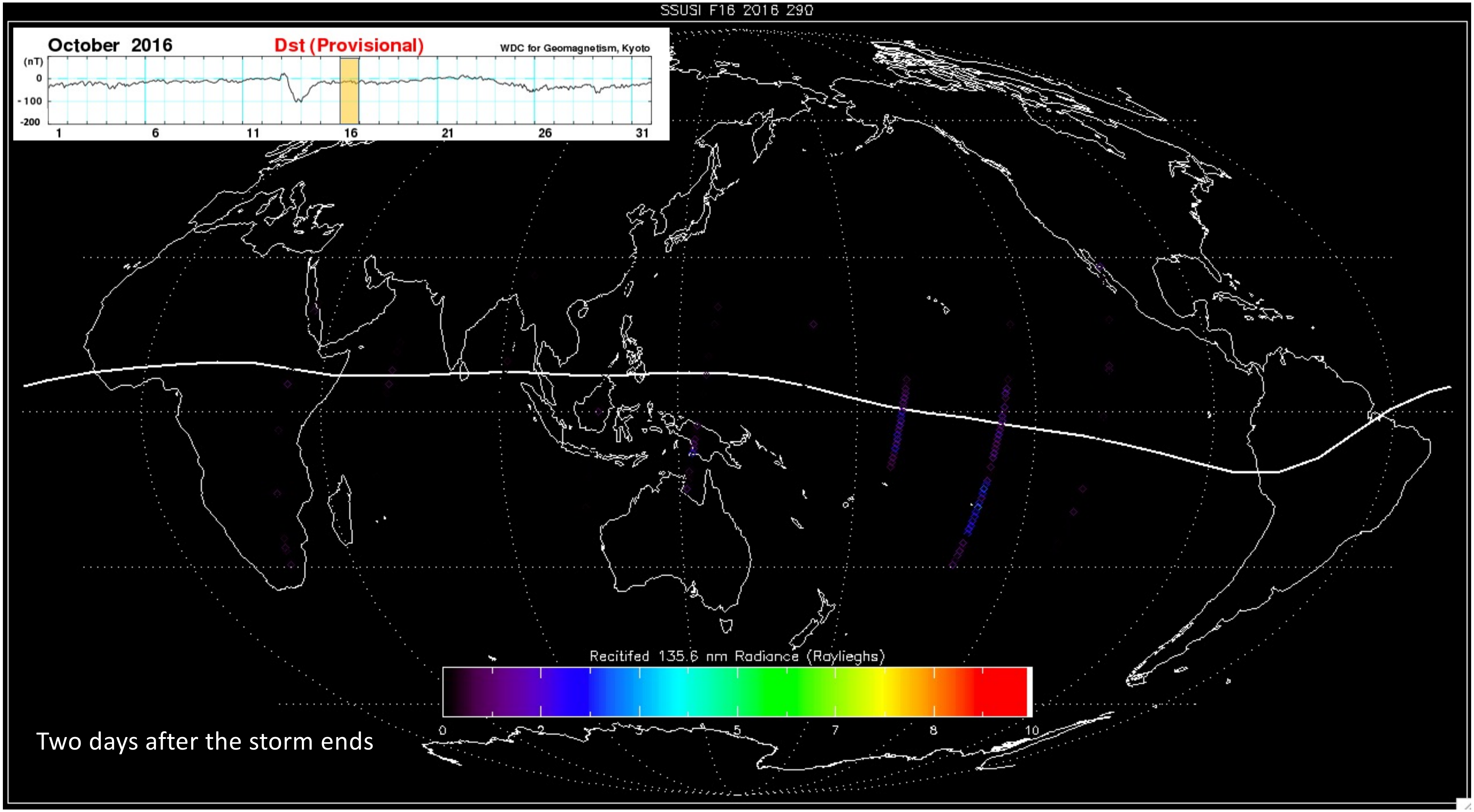
SSUSI F16 2016 290
October 2016
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Recitifed 135.6 nm Radiance (Rayleighs)
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Two days after the storm ends

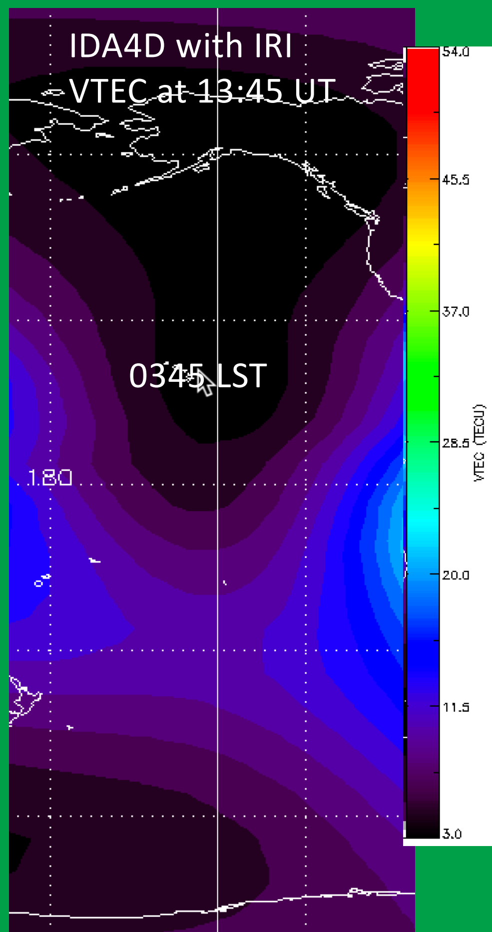
Progression of the Storm Observed by F16 SSUSI at 04:00 local time for the Oct 13th 2016 storm

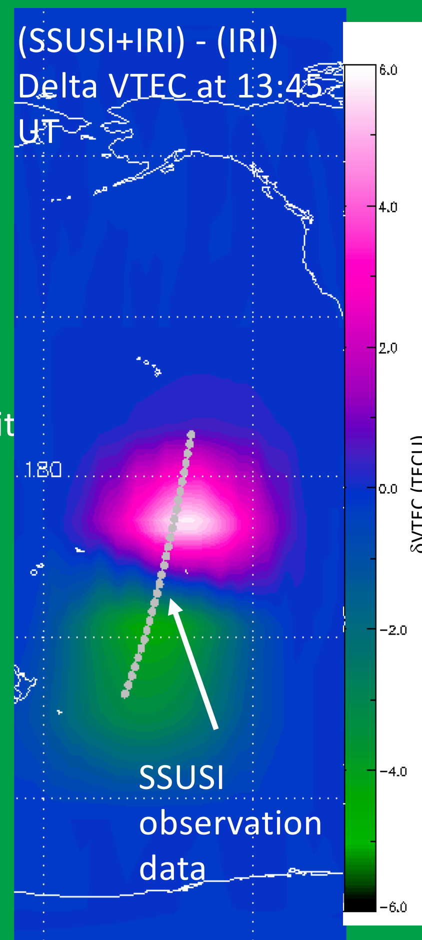
- To summarize the previous slides:
- The ionosphere emission at 135.6 nm at 04:00 local time is so dim as to not normally be seen by the UV imagers GUVI and SSUSI,
- Even in the much more sensitive spectrograph mode.
- As a geomagnetic storm evolves and increases the ionosphere plasma density, the recombination emission becomes bright enough to be seen
- UV instruments can monitor these storm enhanced ionosphere densities
- While there is not space in this poster – the spatial dependence of the ionosphere density in different storms is quite interesting and can highlight different dynamics in the upper atmosphere.

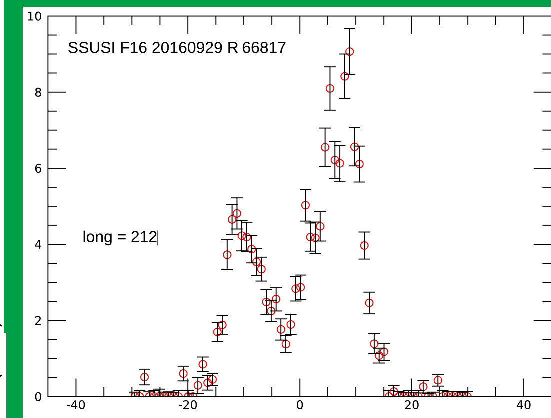
Emissions and plasma density during geomagnetic storms - why observe this?

- During a geomagnetic storm additional energy is pumped into the ionosphere.
- The plasma density increases during and after the storm
- During the storm of Oct 13, 2016, the plasma density increased on the storm day and peaked the second day of the storm.
- This plasma density enhancement increases the UV radiance, which although still weak, can be seen in spectrographic mode.
- During this storm we have a remarkable coincidence of three satellite observations from F16 SSUSI, GUVI and SWARM-A; all in orbits at 04:00 local time.
- While the plasma density is enhanced, it usually deviates in location and altitude from climatology so it is useful to be able to monitor this behavior because of its consequences for communication, radar, and GPS.

Difference from Climatology. Comparison of Vertical Integrated Total Electron Content (VTEC) from the International Reference Ionosphere at the left, (climatology), and the difference between it and the ionosphere after assimilating SSUSI early morning data into IDA4D. The difference shows that the equatorial ionosphere location and density is different than climatology. Images from a storm on Sept 29, 2016



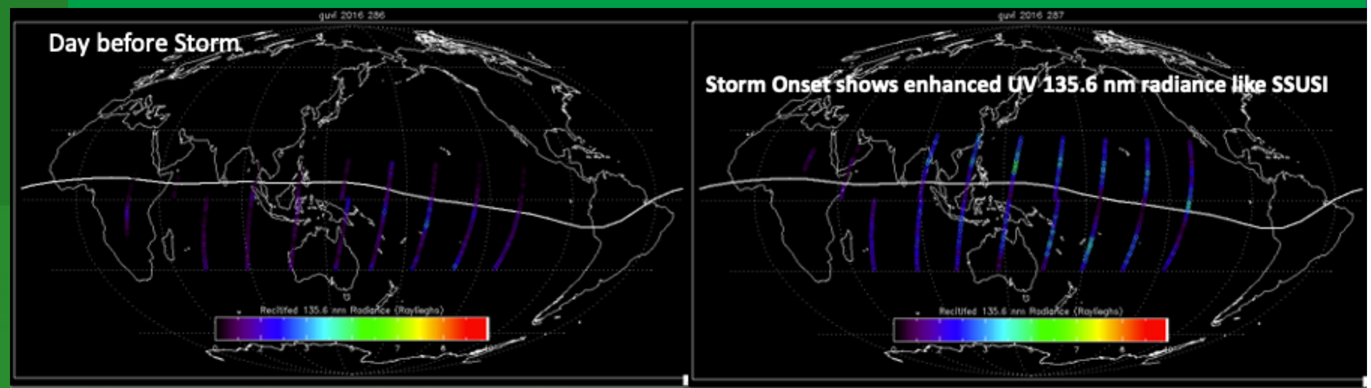




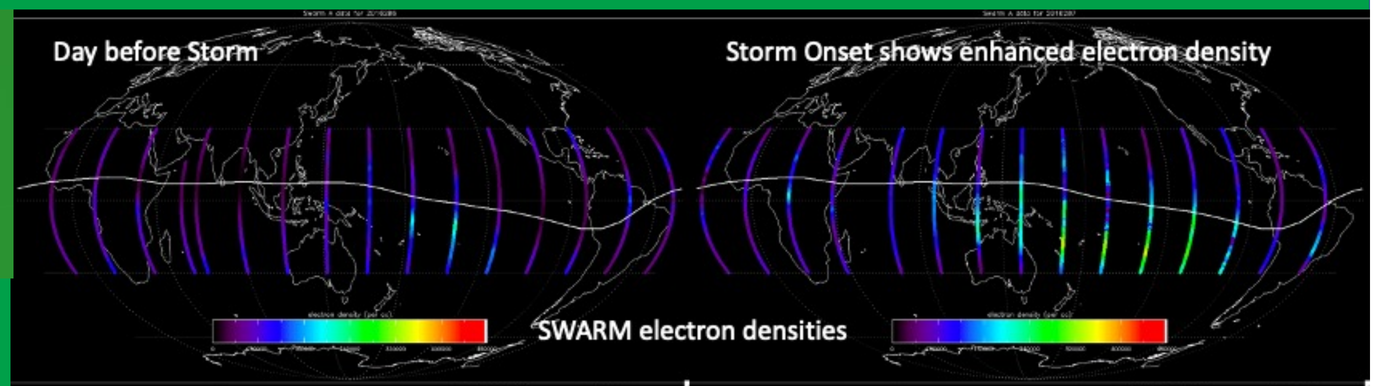
SSUSI 135.6 nm radiance (Raylieghs) as a function of geographic latitude on September 29, 2016. This data was assimilated into the IDA4D model to the left.

GUVI and SWARM-A observations - confirmation

- The Oct 13, 2016 storm was observed by GUVI and SWARM-A both of which happened to be in 04:00 local time orbits
- GUVI observations of 135.6 nm emission shows the same pattern as SSUSI, confirming the effect.



- SWARM-A shows that the electron density is enhanced over the prestorm values at 04:00 local time
- Note that SWARM-A is in an orbit at ~ 500 km altitude, somewhat above the peak of the UV emission; SWARM-A also is measuring in situ electron density where GUVI and SSUSI are measuring column integrated recombination radiation.



Conclusions

•Typically pre-dawn UV emission from ionospheric recombination is too dim to be visible to the current generation of UV imagers

•Putting imagers like SSUSI and GUVI into spectrographic mode increases sensitivity by about two orders of magnitude

•Geomagnetic Storms can enhance equatorial ionosphere plasma density by factors of several, which causes UV radiance by factors of $(\text{several})^2$

•Case study of the Oct 13, 2016 storm show that SSUSI and GUVI, both in spectrograph stare mode observed the increase in UV emission at the pre-dawn times.

•Nearly coincident data from SWARM-A shows a plasma density enhancement consistent with the increase in UV 135.6 nm radiance.

•In this paper, we have focused on the Oct 13, 2016 storm; many other storms exhibit equatorial plasma enhancements whose recombination emission is visible to SSUSI and GUVI in spectrograph mode.

By having UV imagers that have flexible observing modes we can observe more ionospheric phenomena and monitor important events even in the pre-dawn hours.

REFERENCES

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S. C. Buchert *et al.*, "First results from the Langmuir Probes on the Swarm satellites," *2014 XXXIth URSI General Assembly and Scientific Symposium (URSI GASS)*, 2014, pp. 1-1, doi: 10.1109/URSIGASS.2014.6929846.

Data used in this study is available from

SSUSI data - https://ssusi.jhuapl.edu

GUVI data - https://guvitimed.jhuapl.edu

SWARM data - https://swarm-diss.eo.esa.int