UV Observations of the Ionosphere from the ISS

from the LITES instrument

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May 21, 2019
ISWI Workshop, Trieste, IT

Acknowledgments

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NRL: Andrew Stephan (PI), Scott Budzien

LITES was integrated and flown on the International Space Station as part of the Space Test Program – Houston 5 (STP-H5) payload under the direction of the DoD Space Test Program.

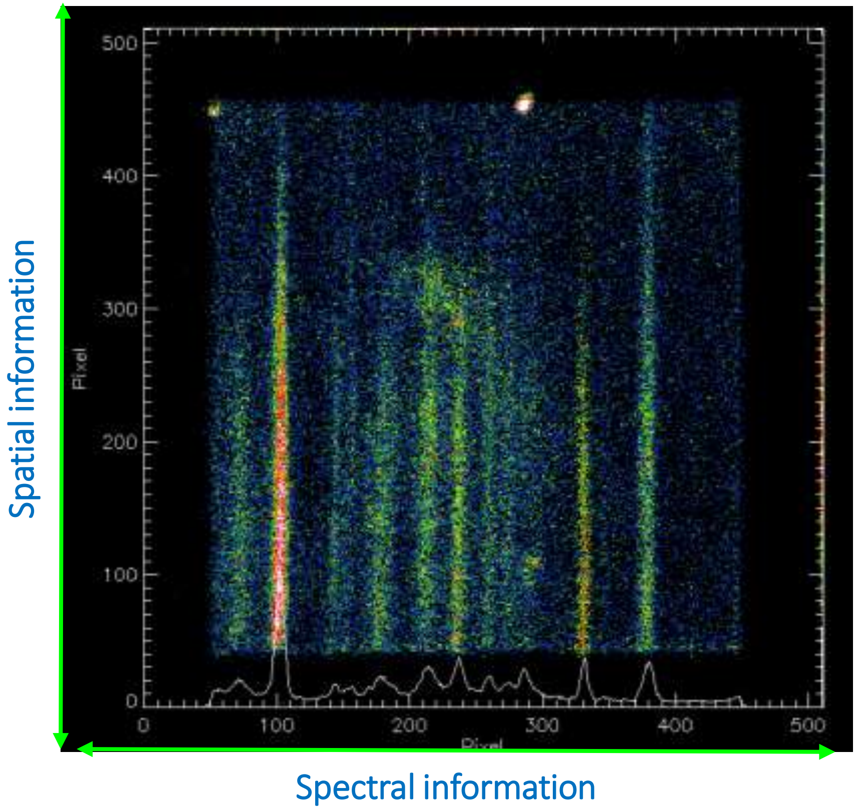
Funding for the refurbishment of the LITES sensor was provided to the University of Massachusetts Lowell by the Office of Naval Research and the National Science Foundation.

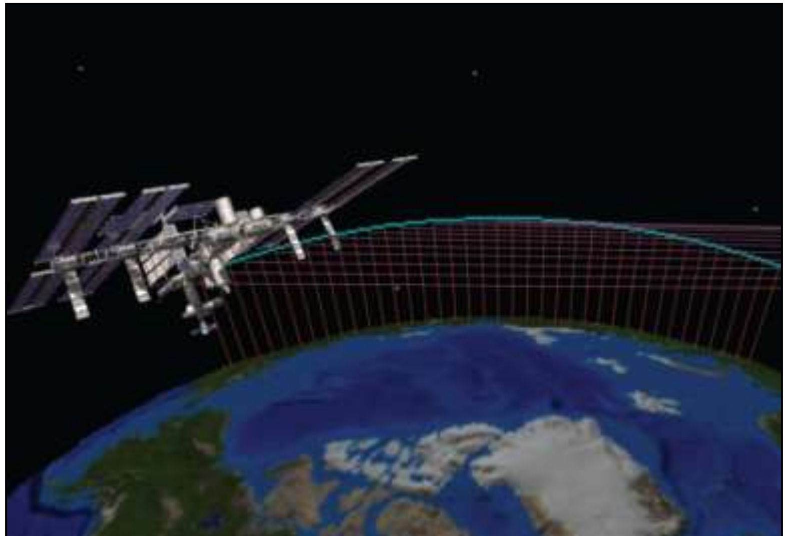
Research at the U.S. Naval Research Laboratory was supported by the Chief of Naval Research as part of the NRL Basic Research Program. Integration and testing support for LITES was provided by STP.

LITES

Limb-imaging Ionospheric And Thermospheric Extreme-ultraviolet Spectrograph

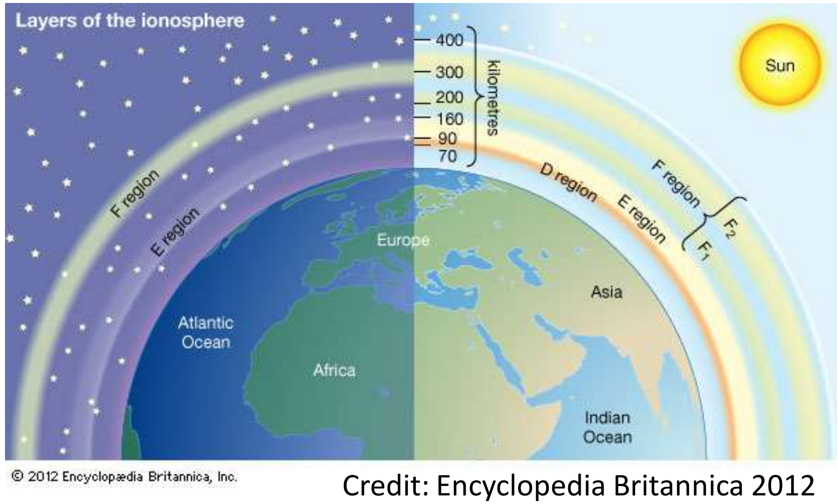
- Imaging spectrograph returns one-dimensional vertical (altitude) airglow profiles from Earth's limb
- Looks at the trailing limb behind the International Space Station (ISS) as it orbits
- *Description:*
  - Spectrograph that images vertical (altitude) profiles
  - 10° x 10° field of view, 0.4° resolution in the vertical
  - 600-1400 Å, ~15 Å (FWHM) resolution
  - Compact, lightweight design with no moving parts



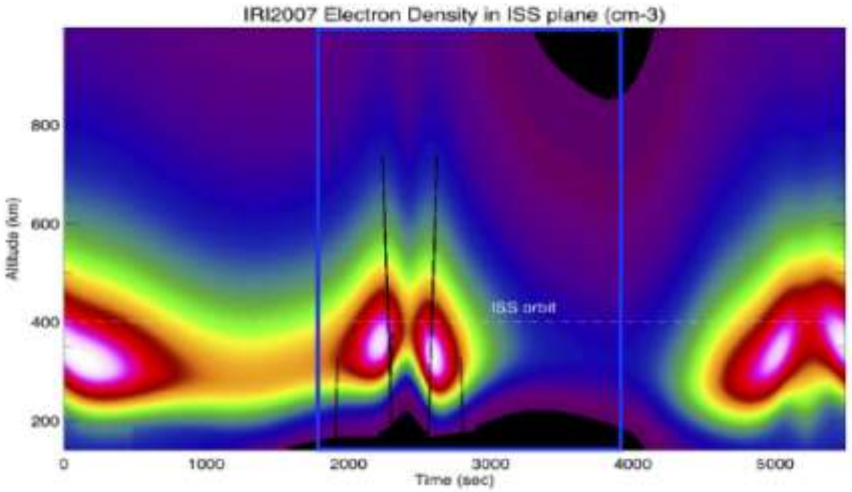


LITES Science

- Ionosphere is complex and dynamic
  - Sparse plasma
  - Transient structures
  - Depletions
  - Bubbles
  - Irregularities
- Plasma irregularities create fluctuations in electron density at low and middle latitudes over a wide range of size scales
- Effects:
  - Navigation problems
  - Communication outages
  - Interference



Credit: Encyclopedia Britannica 2012

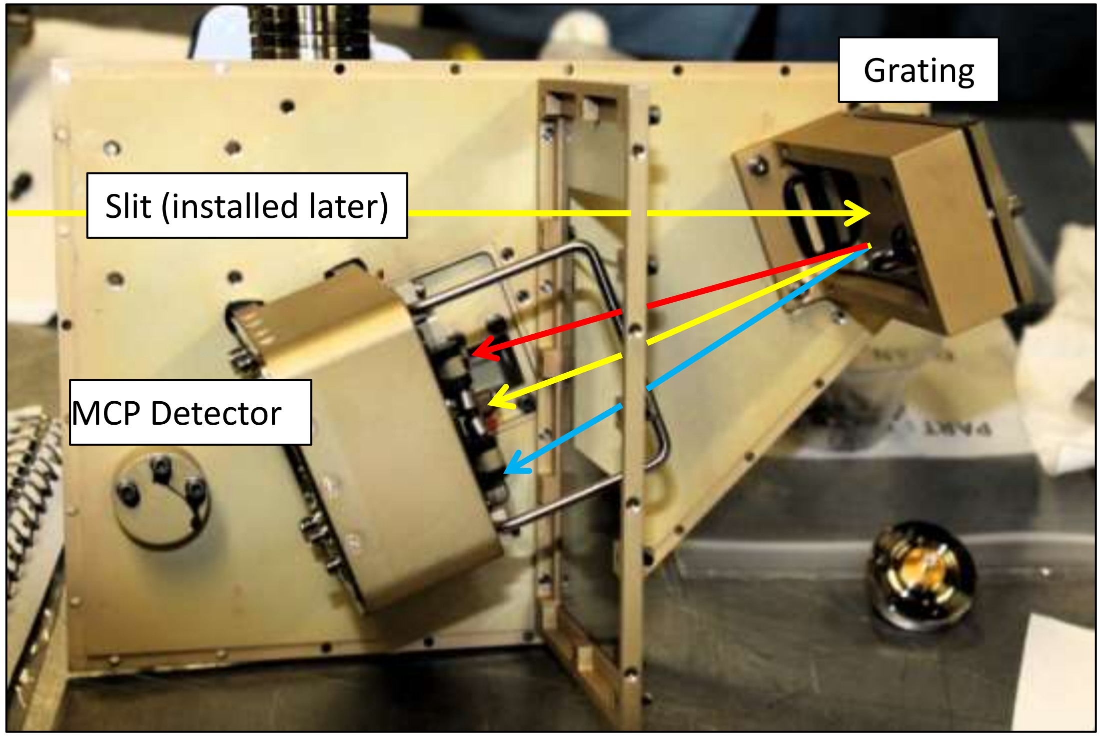


S. Budzien

LITES

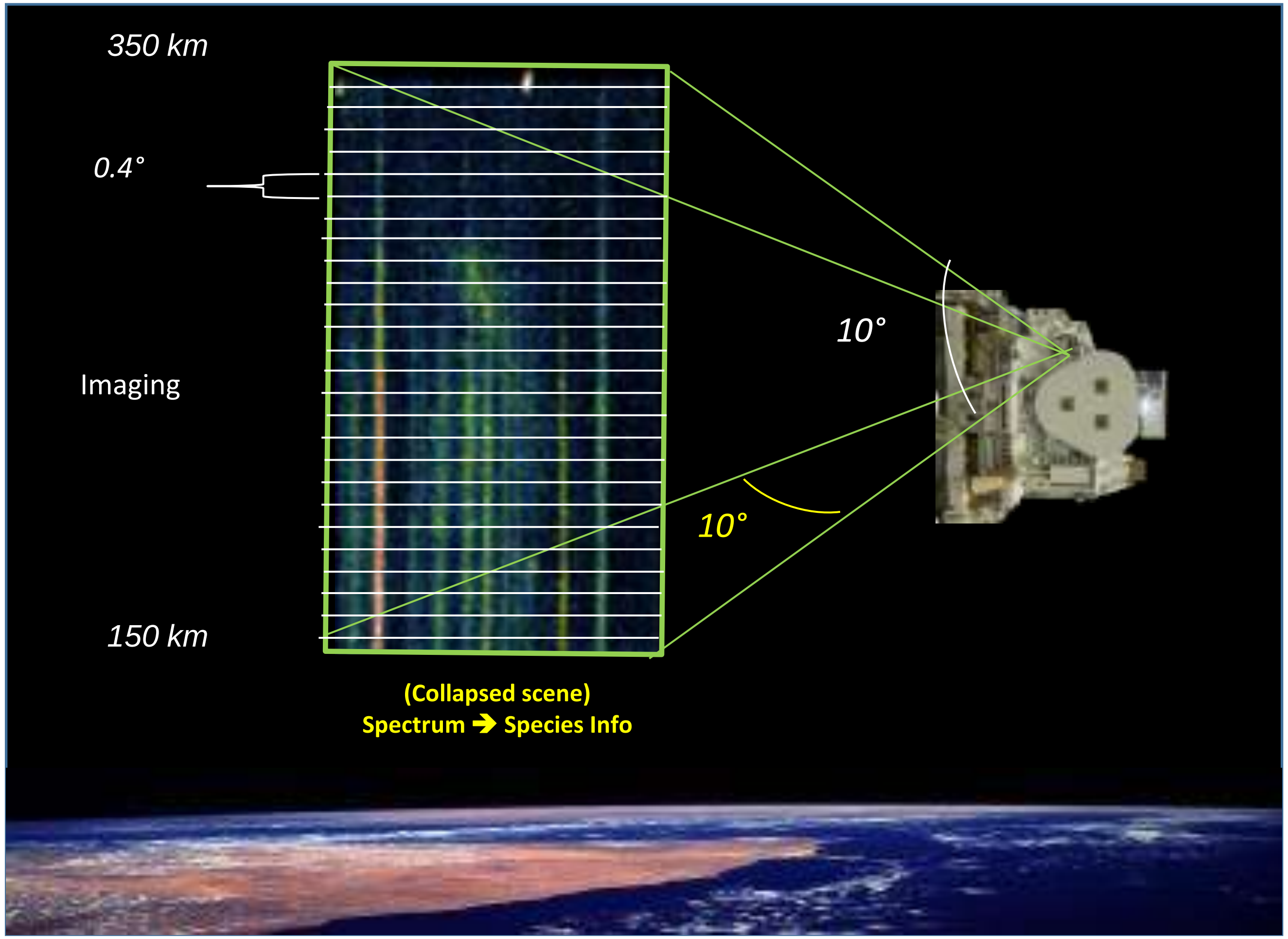
Limb-imaging Ionospheric And Thermospheric Extreme-ultraviolet Spectrograph

- Imaging spectrograph:
  - Light enters entrance slit
  - Light reflects off of toroidal grating
  - Light is dispersed and imaged onto the microchannel plate (MCP) detector
    - Horizontal dimension: wavelength
    - Vertical dimension: spatial/altitude
    - KBr coating, Ly α mask



LITES

- LITES views the trailing limb of Earth as the ISS orbits
- Imaging spectrograph returns one-dimensional vertical (altitude) airglow profiles of Earth's limb
- Oriented to optimize coverage of tangent altitudes between 150 and 350 km
- 3 second cadence ≈ 25 km in-track resolution
- Collects data in daytime and nighttime conditions



LITES Spectrum

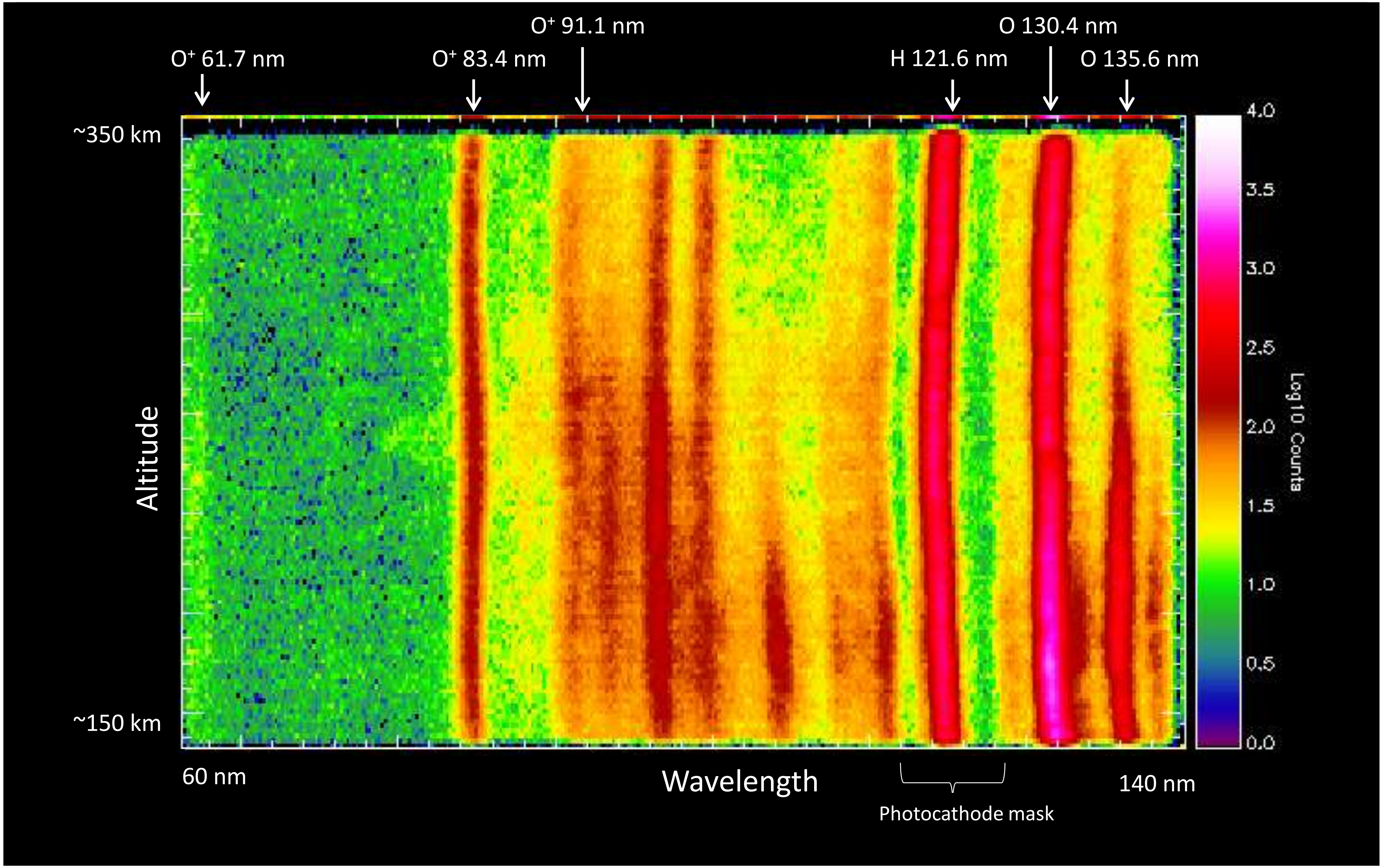
- LITES operates continuously observing the dayside and nightside ionosphere
- LITES observes neutrals and ions simultaneously

Physical Quantity/Objective	**Measurement**	**Excitation Process(es)**
$[e^-]$, $[O^+]$ Ionospheric density	*Nighttime:* OI 91.1 nm cont., 135.6 nm	$O^+ + e^- \rightarrow O + h\nu$
$[O]$, T_n Atomic oxygen composition	*Daytime:* OI 98.9, 130.4, 135.6 nm	$O + e^- \rightarrow O^* + e^-$
$[O^+]$ Ionospheric density	*Daytime:* OII 61.7, 83.4 nm	$O + h\nu \rightarrow O^{+*} + e^- + h\nu$ (61.7 nm) $O + h\nu \rightarrow O^+ + e^- + h\nu$ (83.4 nm)
$[N_2]$, T_n Thermosphere N_2 density	*Daytime:* N_2 LBH, 127.0-140.0 nm	$e^- + N_2 \rightarrow e^- + N_2^*$

LITES Launch

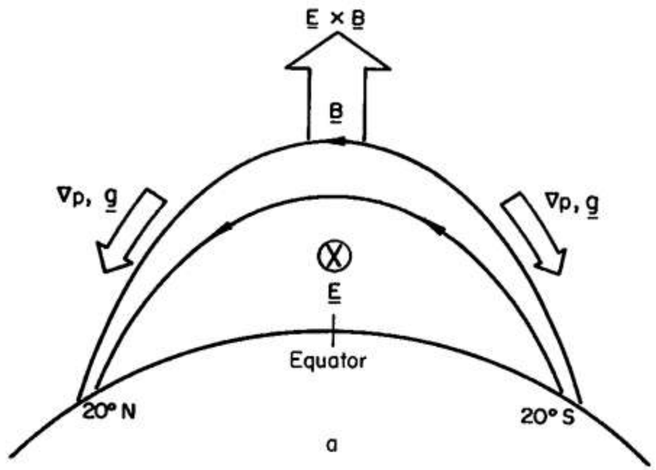
- LITES launched February 19, 2017 as part of the Space Test Program Houston 5 (STP-H5) payload on a SpaceX Falcon 9 commercial resupply mission to the International Space Station (ISS).

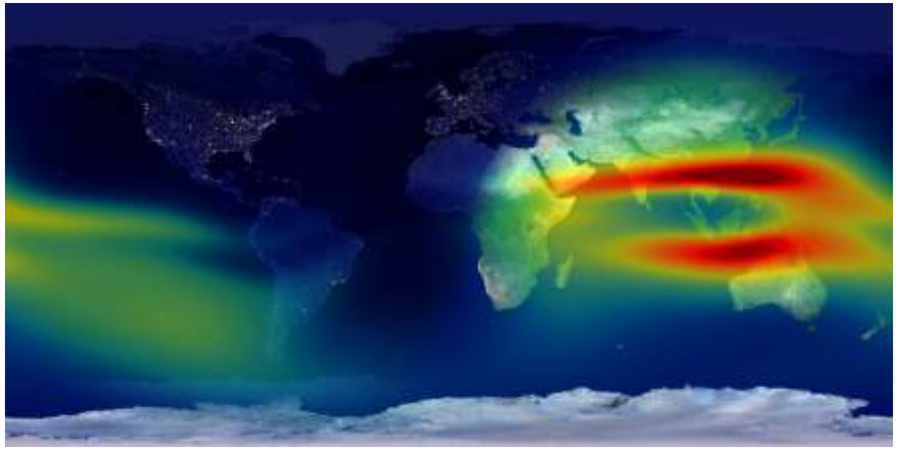
LITES Spectrum



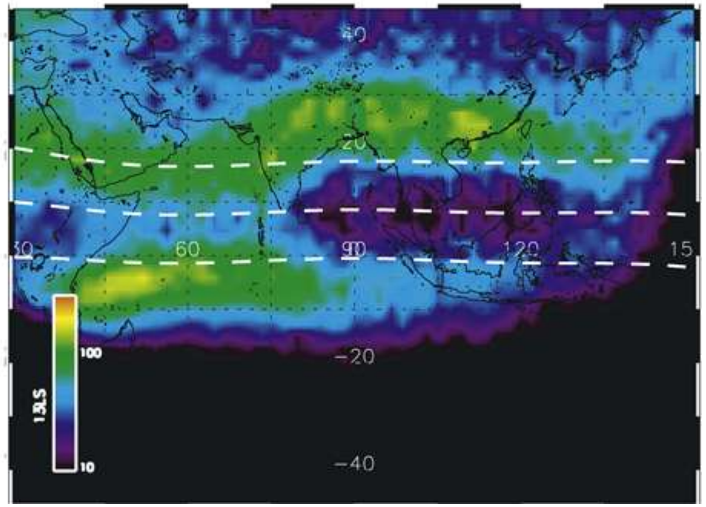
Equatorial Arcs

- Equatorial arcs are a persistent feature in the ionosphere north and south of the magnetic equator
- Due to eastward electric field and northward magnetic field
    - ExB drift causes plasma to flow upward at the magnetic equator
    - Plasma then “fountains” down along field lines creating higher density crests on either side of equator





NASA IRI visualization of equatorial anomaly



1356Å IMAGE observation, Sagawa et al. 2005

Nighttime emission

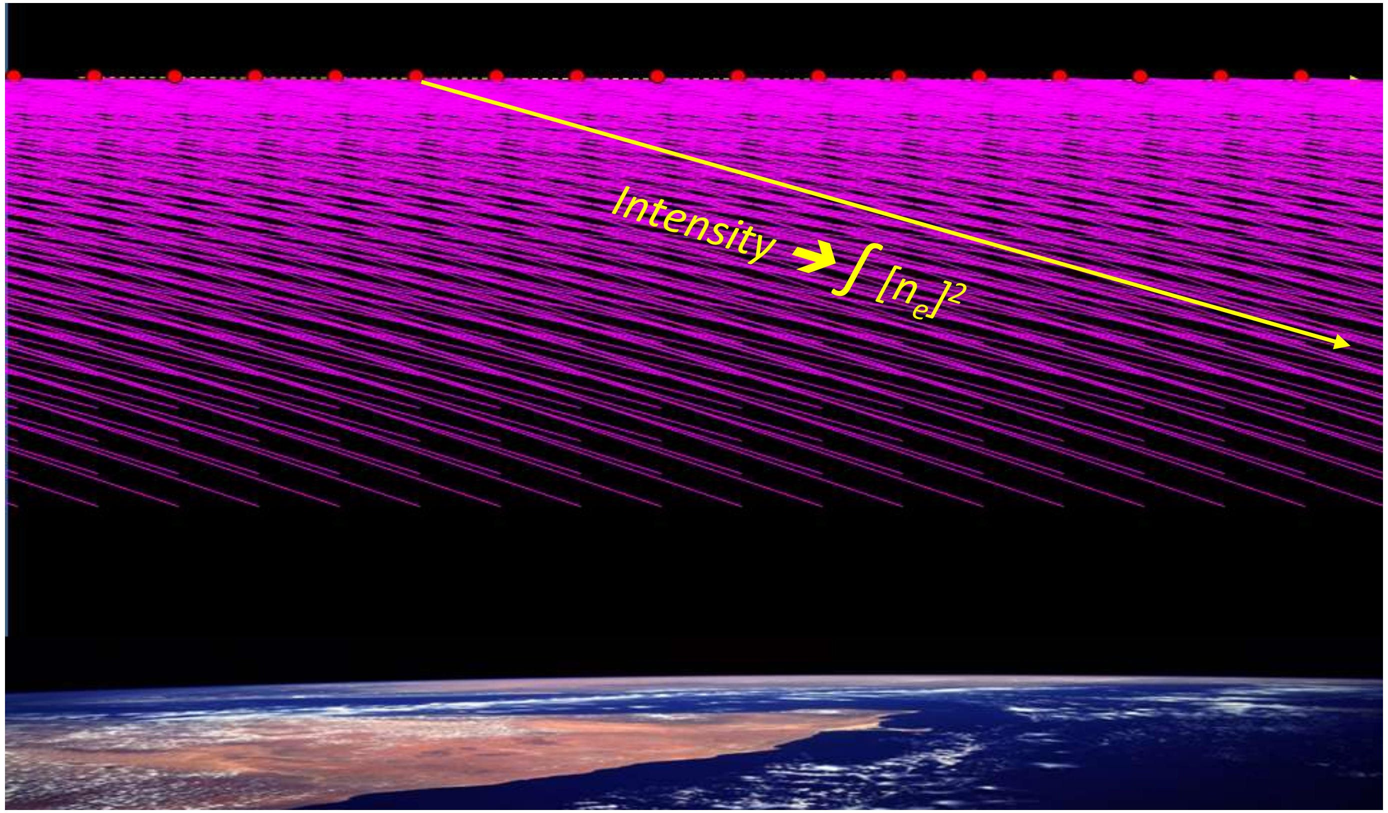
- Two UV emissions, 911Å and 1356Å, derive directly from recombination of $O^+ + e^-$
- Line-of-sight brightness is proportional to electron density in the F-region ionosphere

$$O^+ + e^- \rightarrow O(\,^3P) + h\nu_{911}$$

$$O^+ + e^- \rightarrow O(\,^5S) + h\nu_{1356}$$

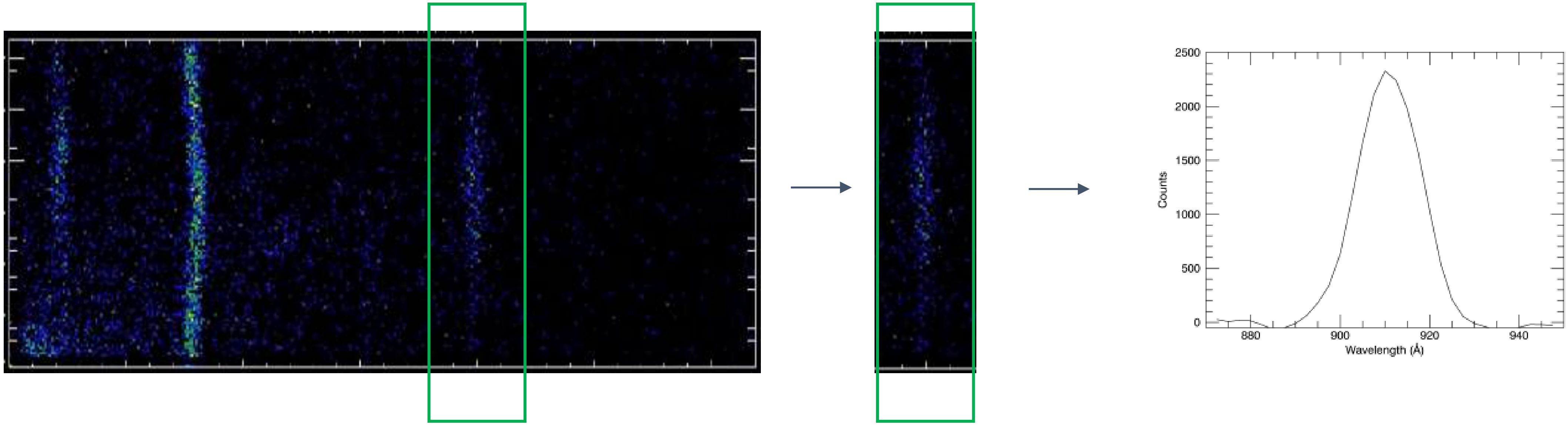
$$J = \alpha n_e n_{O^+} \approx \alpha {n_e}^2$$

$$4\pi I = 10^{-6}\int_0^{\infty} J(z)dz = 10^{-6}\int_0^{\infty} \boldsymbol{n_e}^{\boldsymbol{2}}(\boldsymbol{z})dz$$

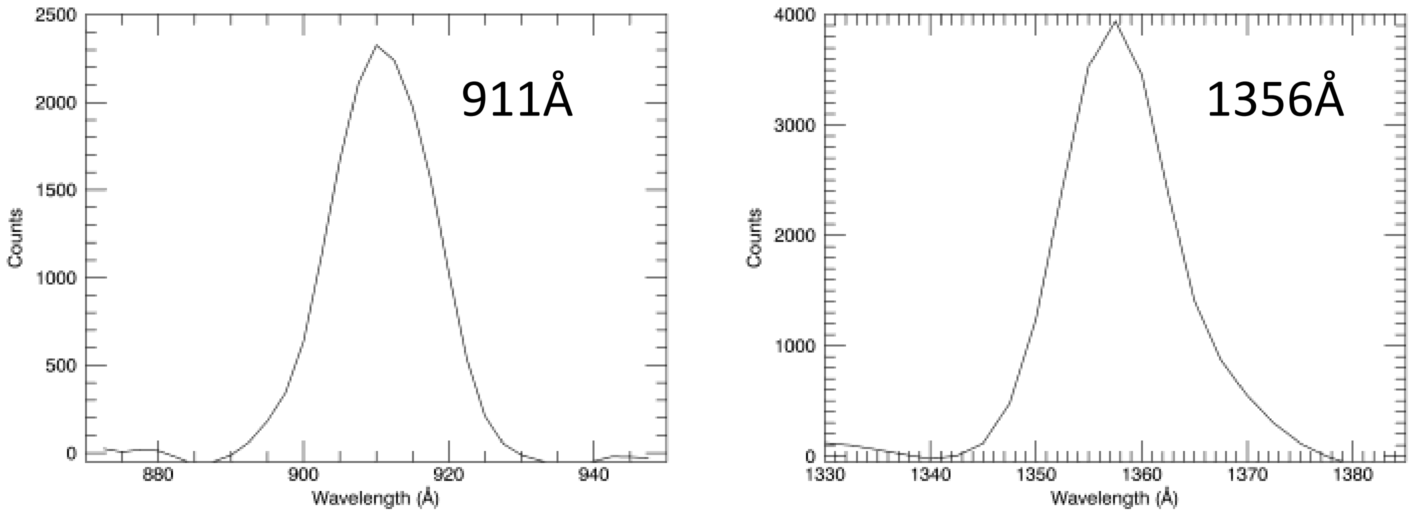


- Proportional to the path integral of density **squared**, making this emission very sensitive to ionospheric gradients

Nighttime UV Airglow

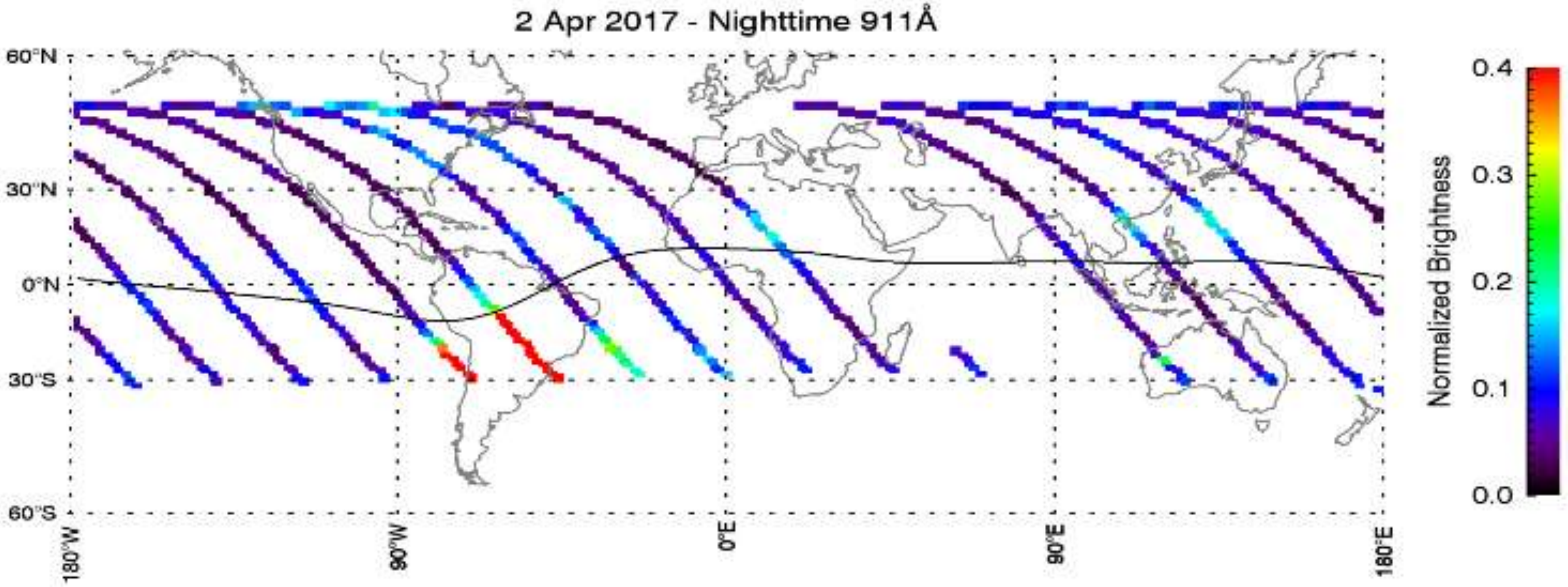


- Integrate 911Å emission over all altitudes
- (Shown right: integrated over 2 orbits)
- Nighttime data were chosen to have solar zenith angle (SZA) greater than 110°



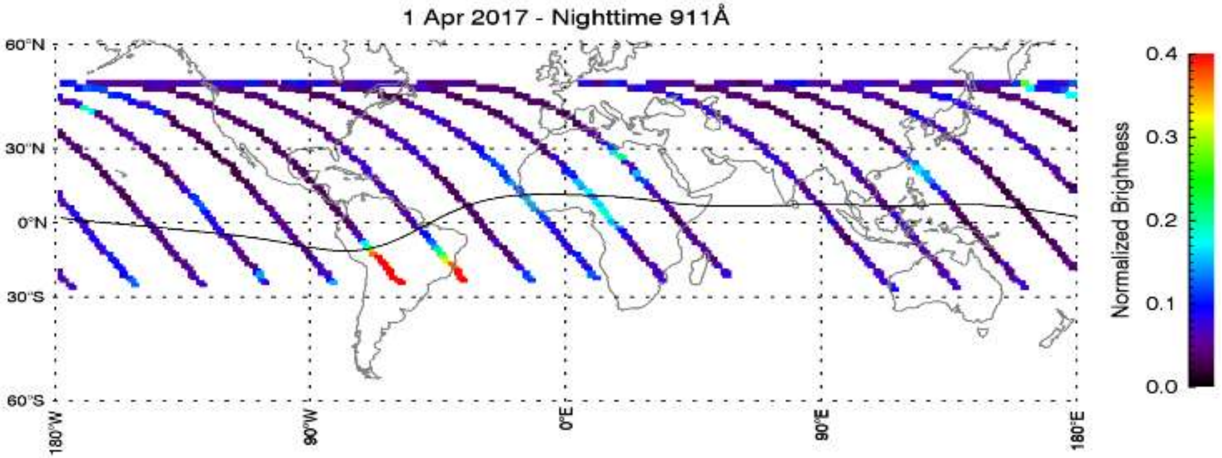
911Å nighttime brightness over a full day

- Integrated 911Å emission over ISS orbital track for one day (Apr 2, 2017)
- One orbit every 90 minutes
- Binned into 30sec data points, plotted at tangent point



911Å, nighttime April 2017

Apr 1



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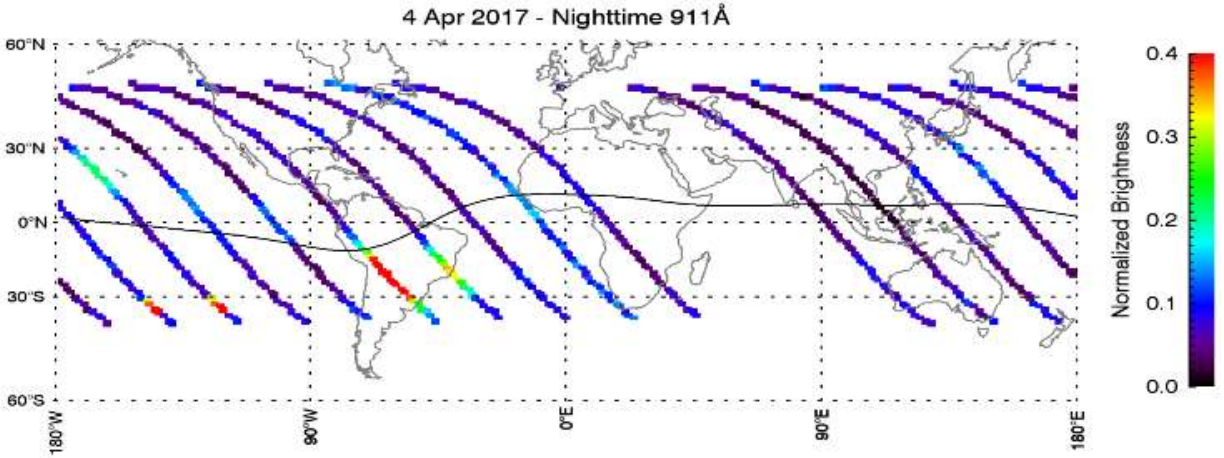

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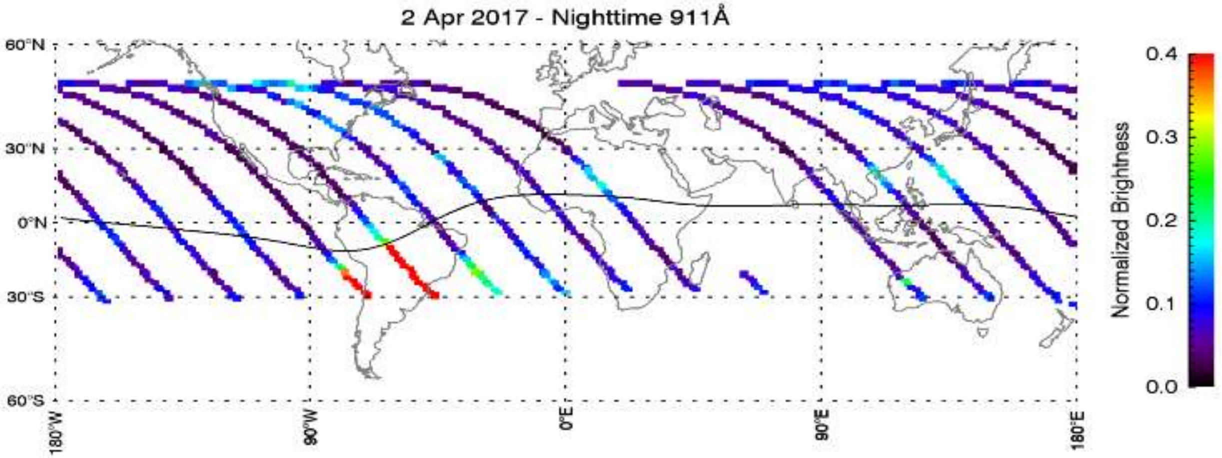

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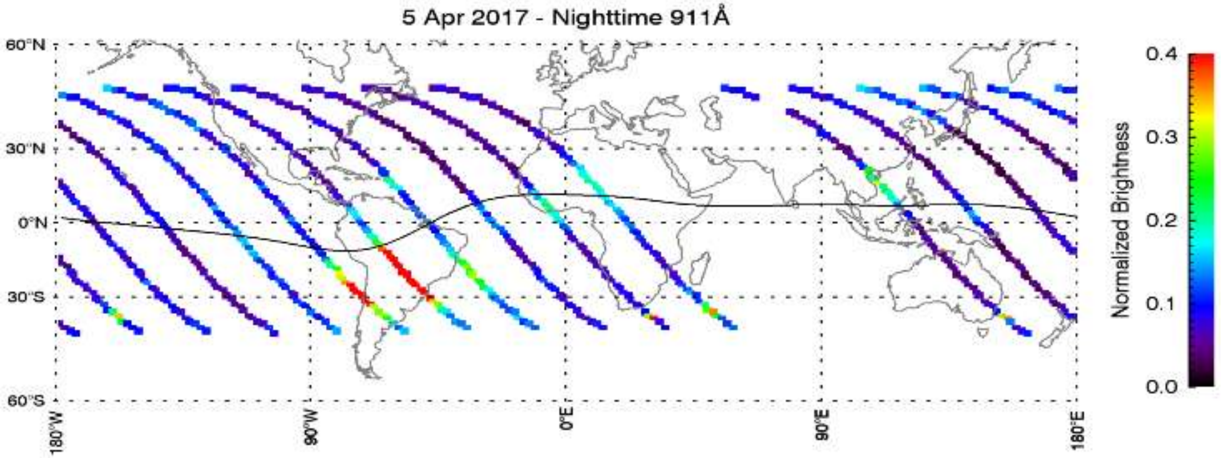
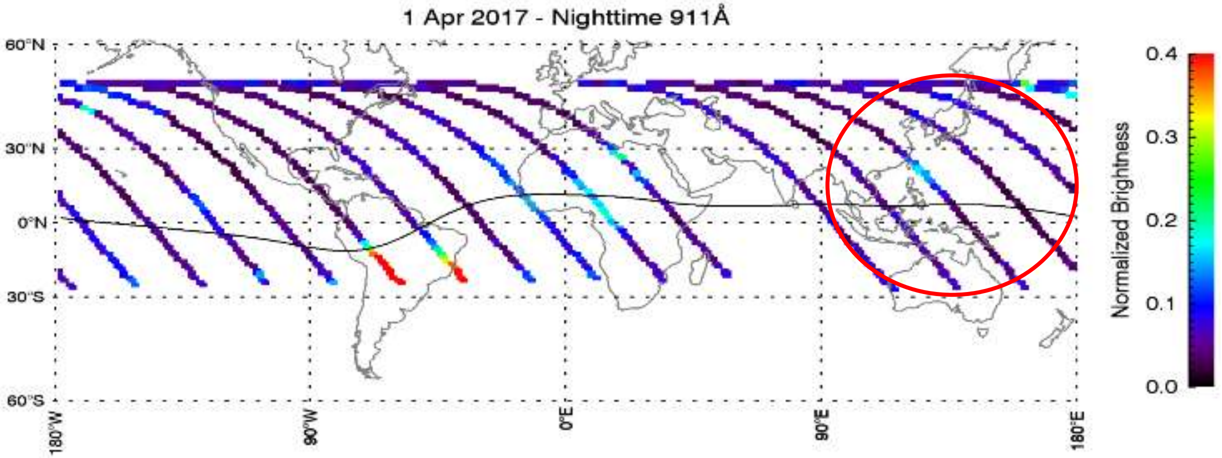


911Å, nighttime April 2017

Apr 1



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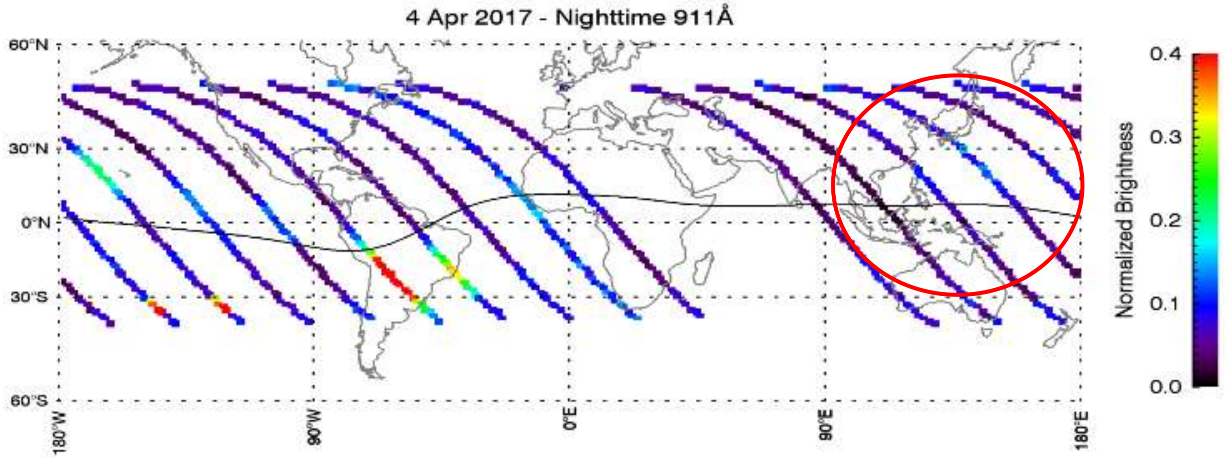

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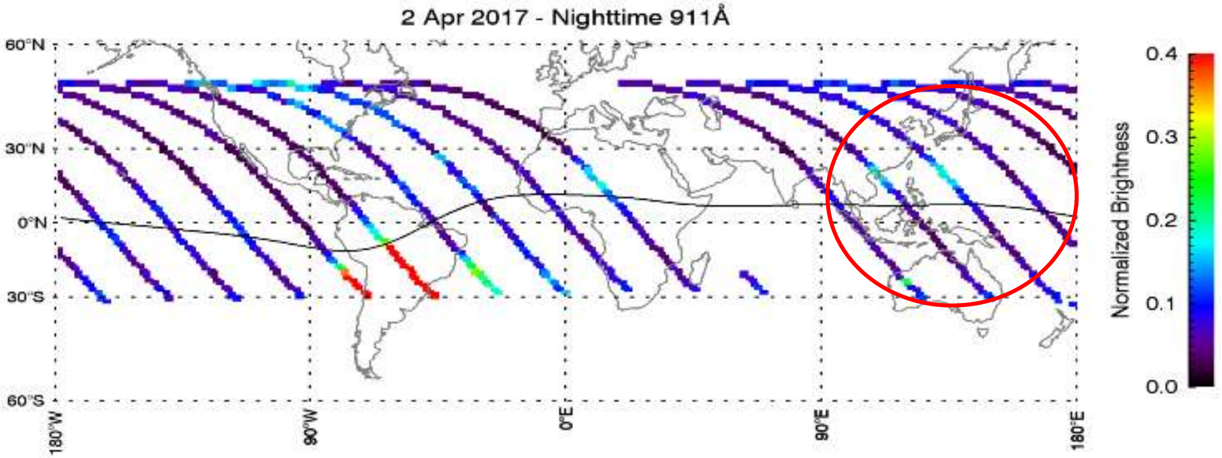

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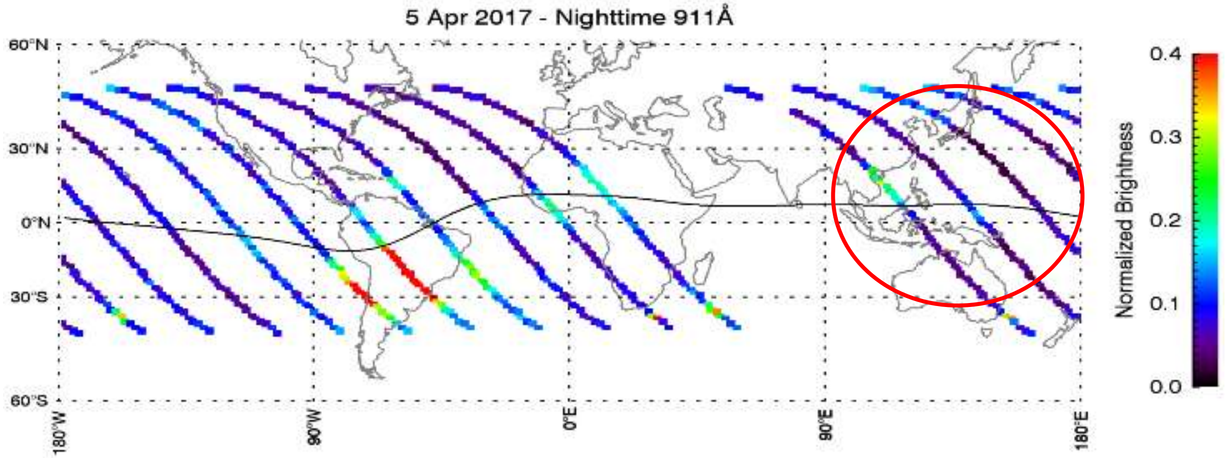
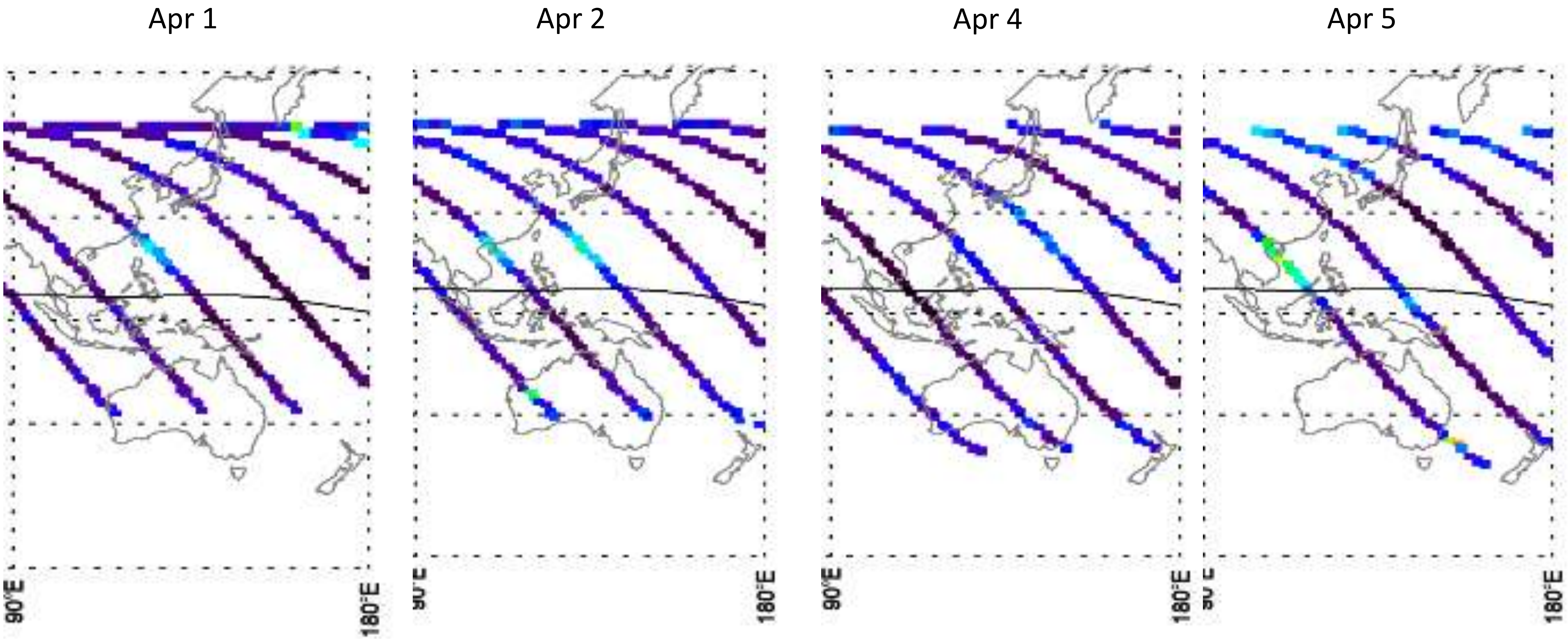


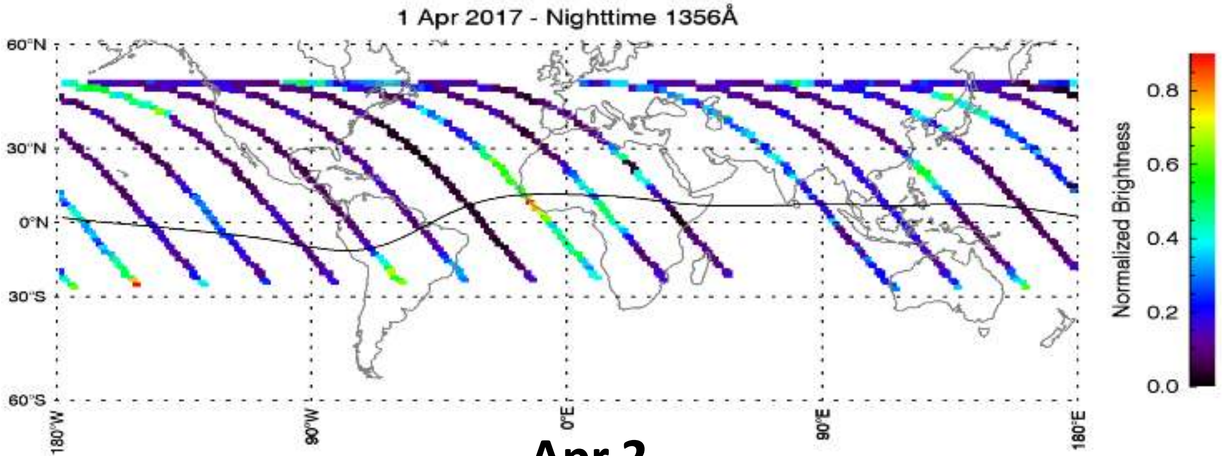
911Å, nighttime April 2017



- North-south asymmetry
- Day-to-day variability (not fixed-local-time)

1356Å, nighttime April 2017

Apr 1



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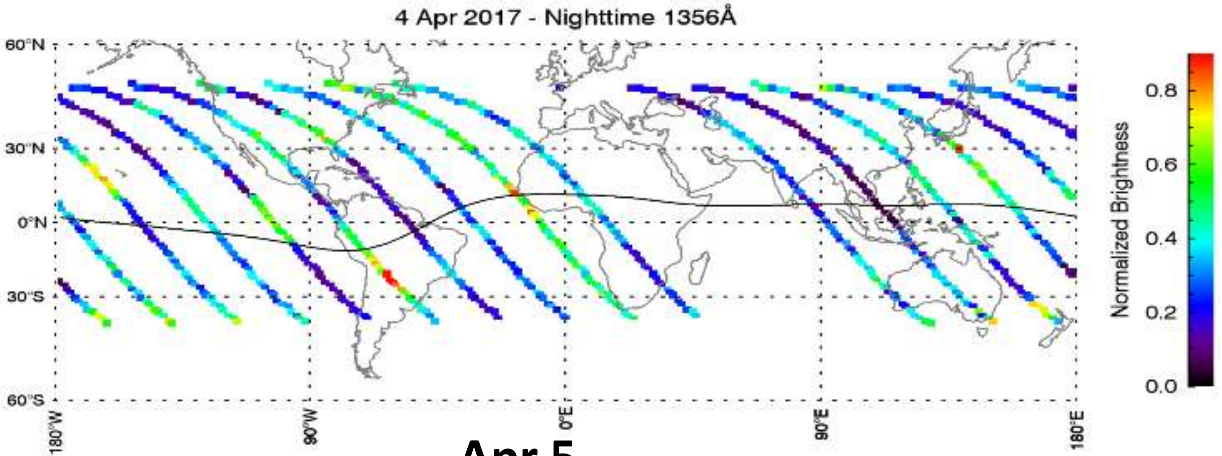

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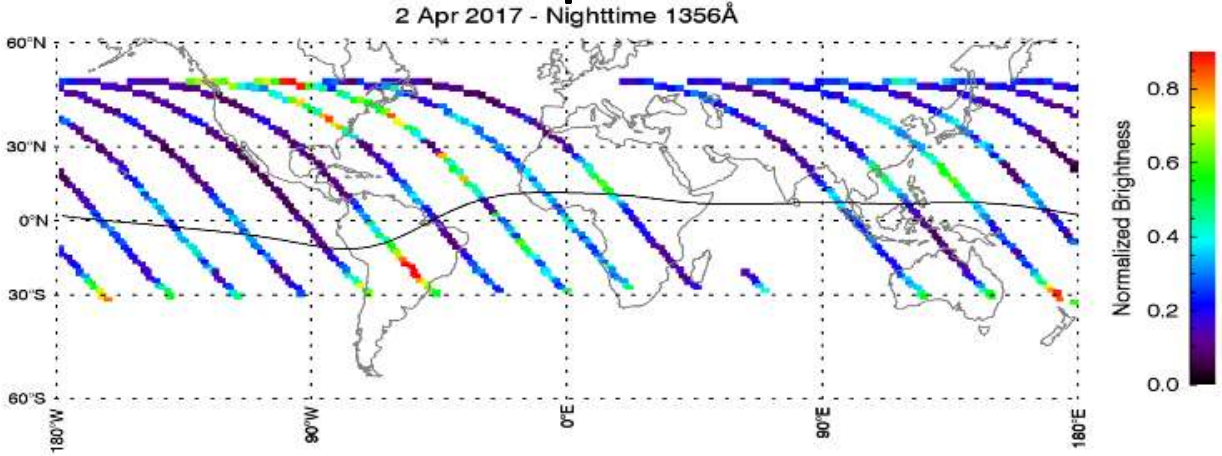

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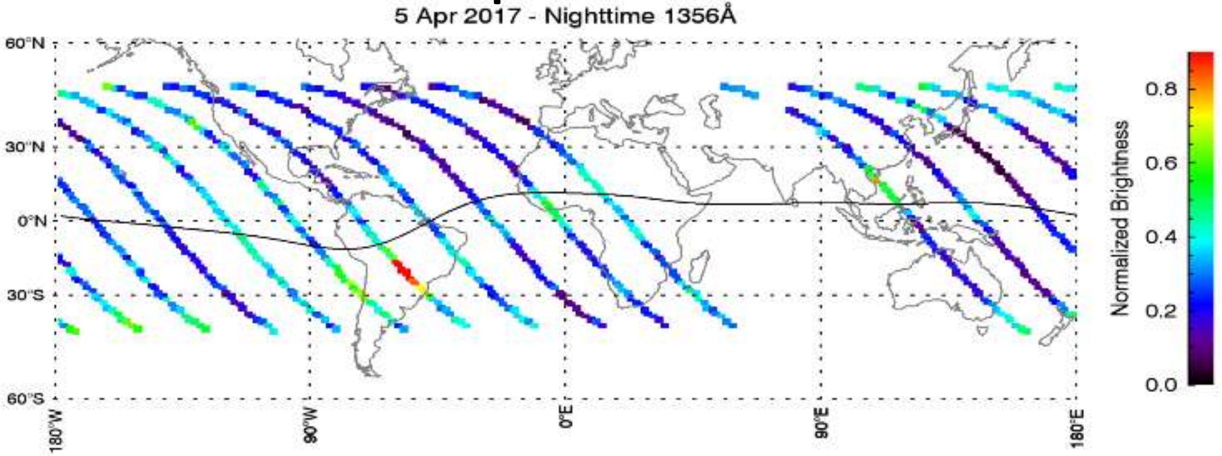

911Å

1356Å

Apr 1

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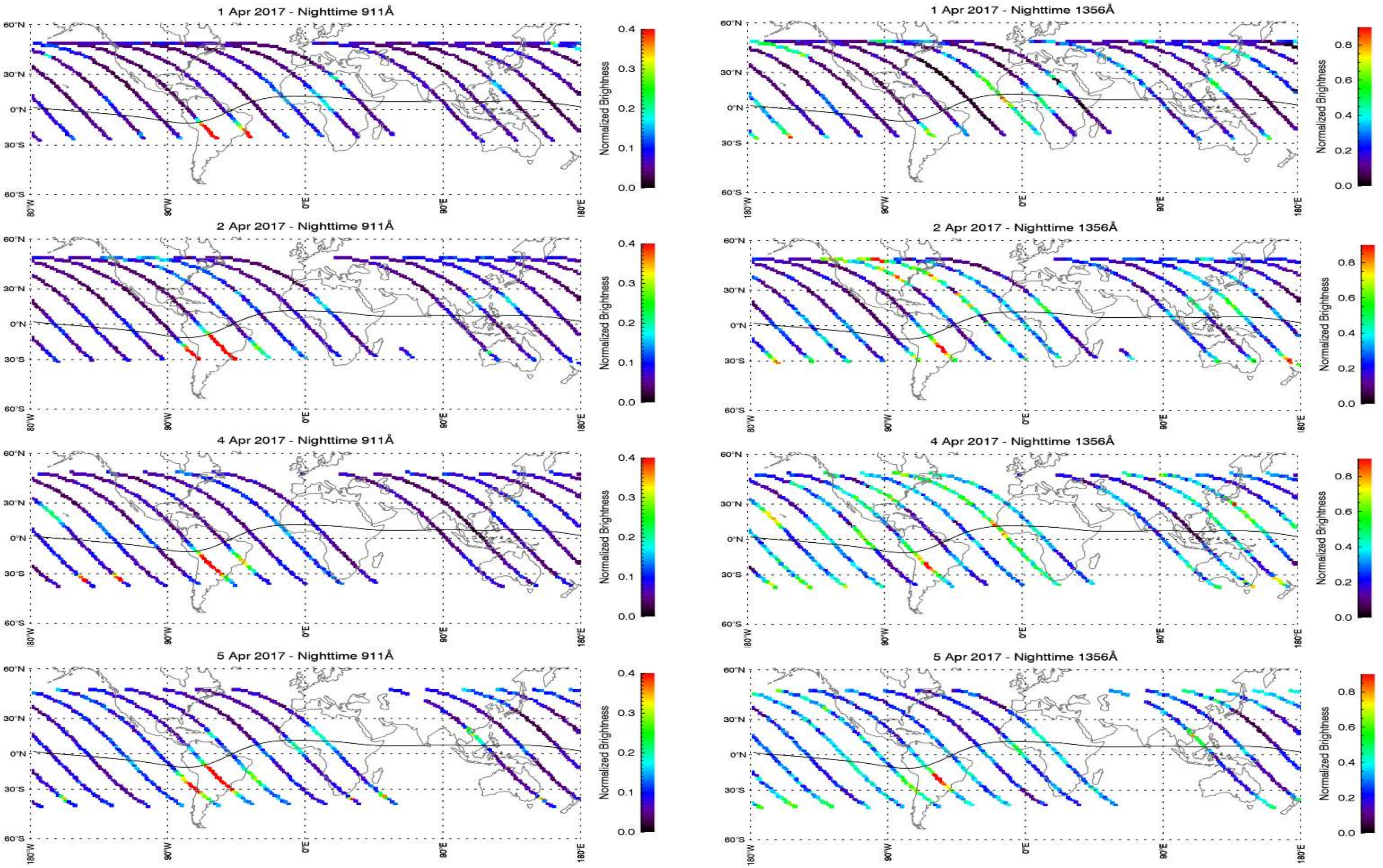

911Å **1356Å**

Apr 1

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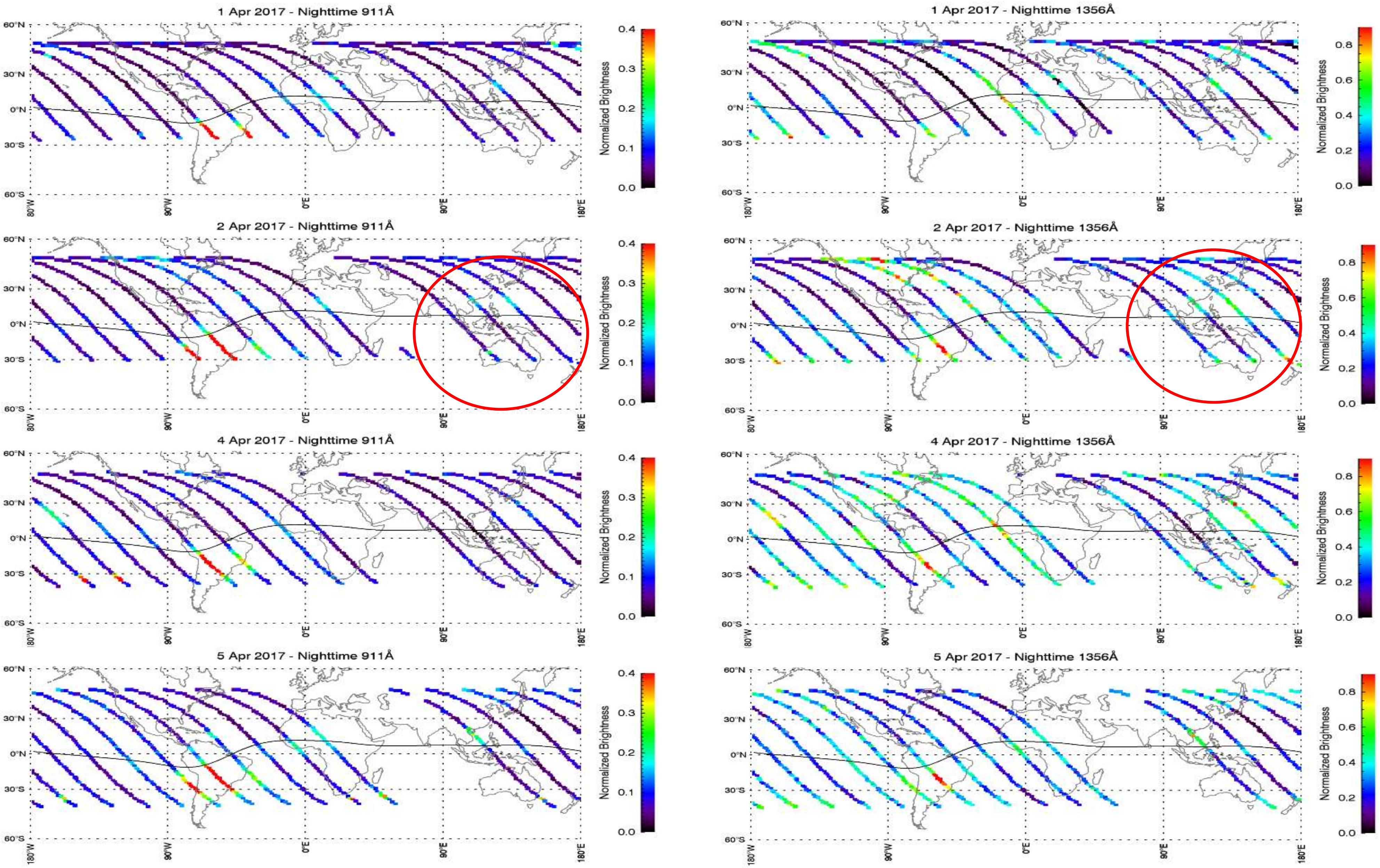
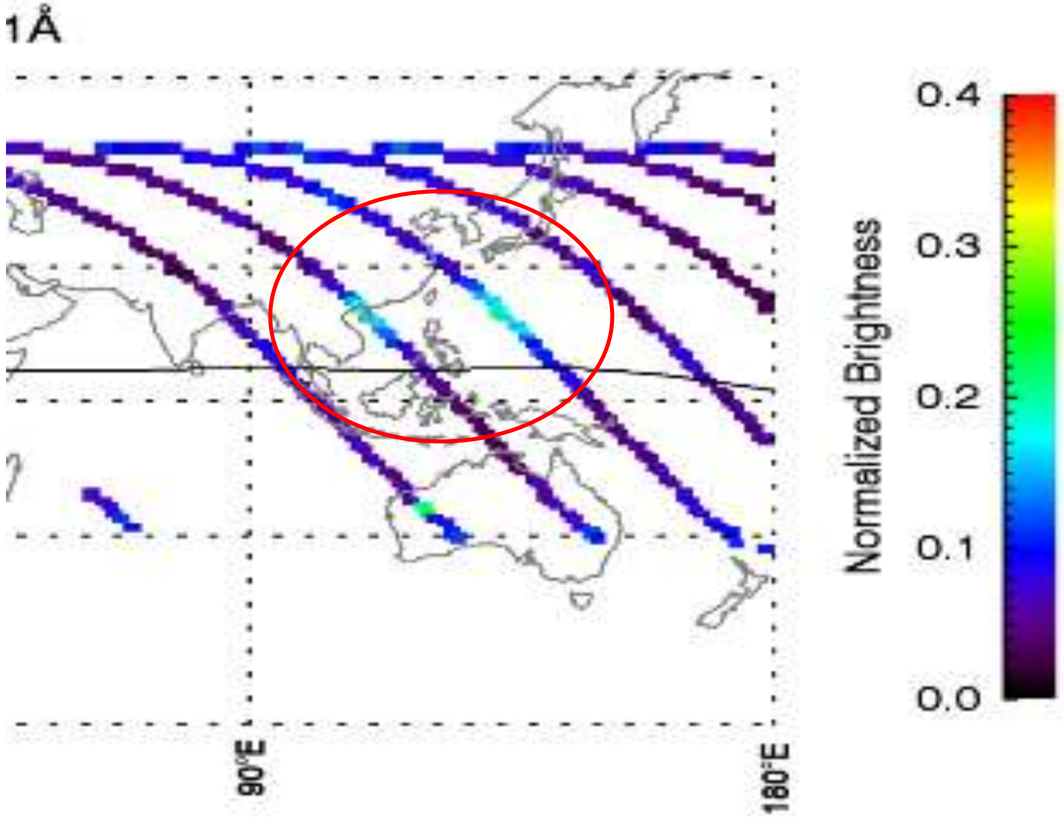
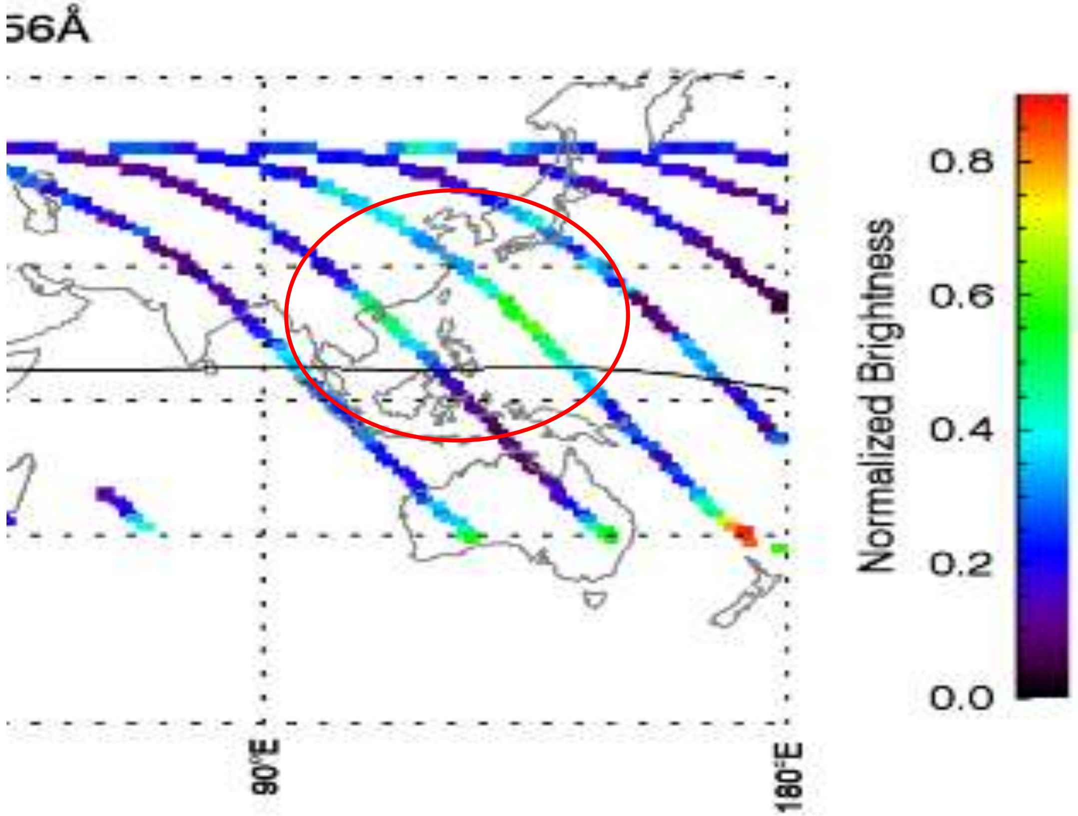


911Å

1356Å

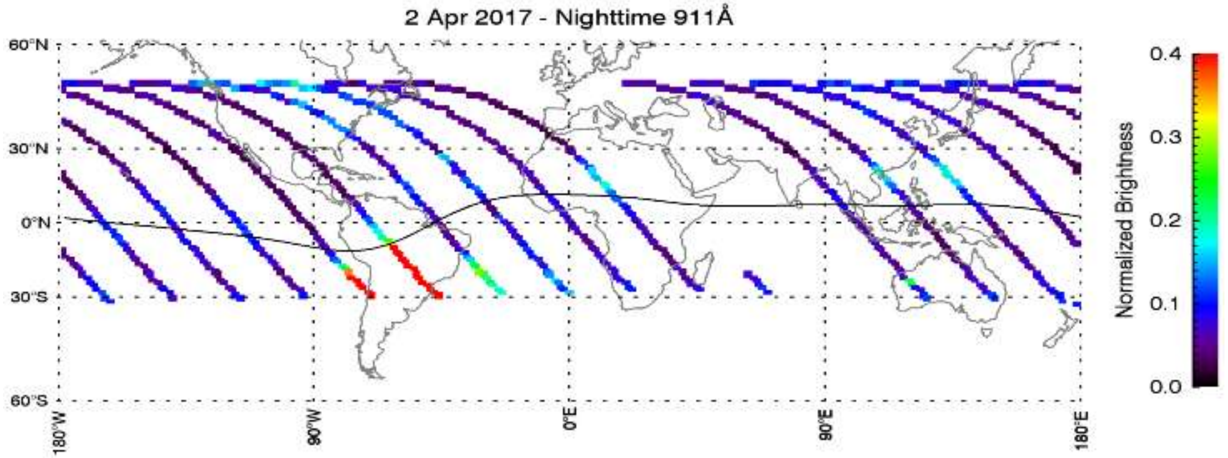




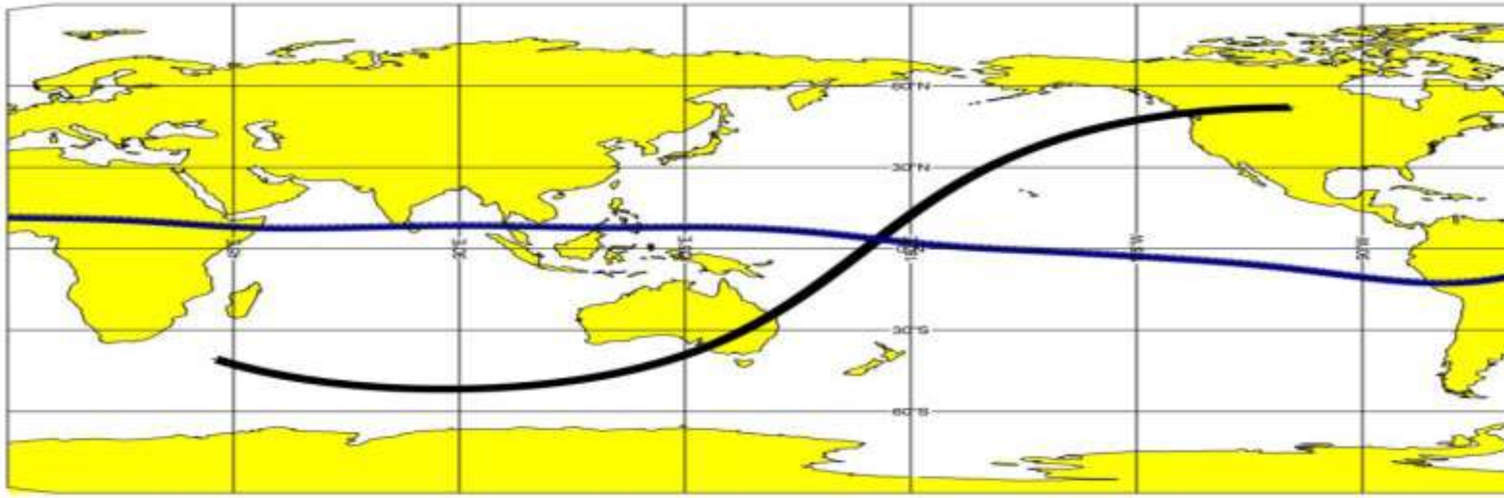
- North-south asymmetry

Nighttime Observation

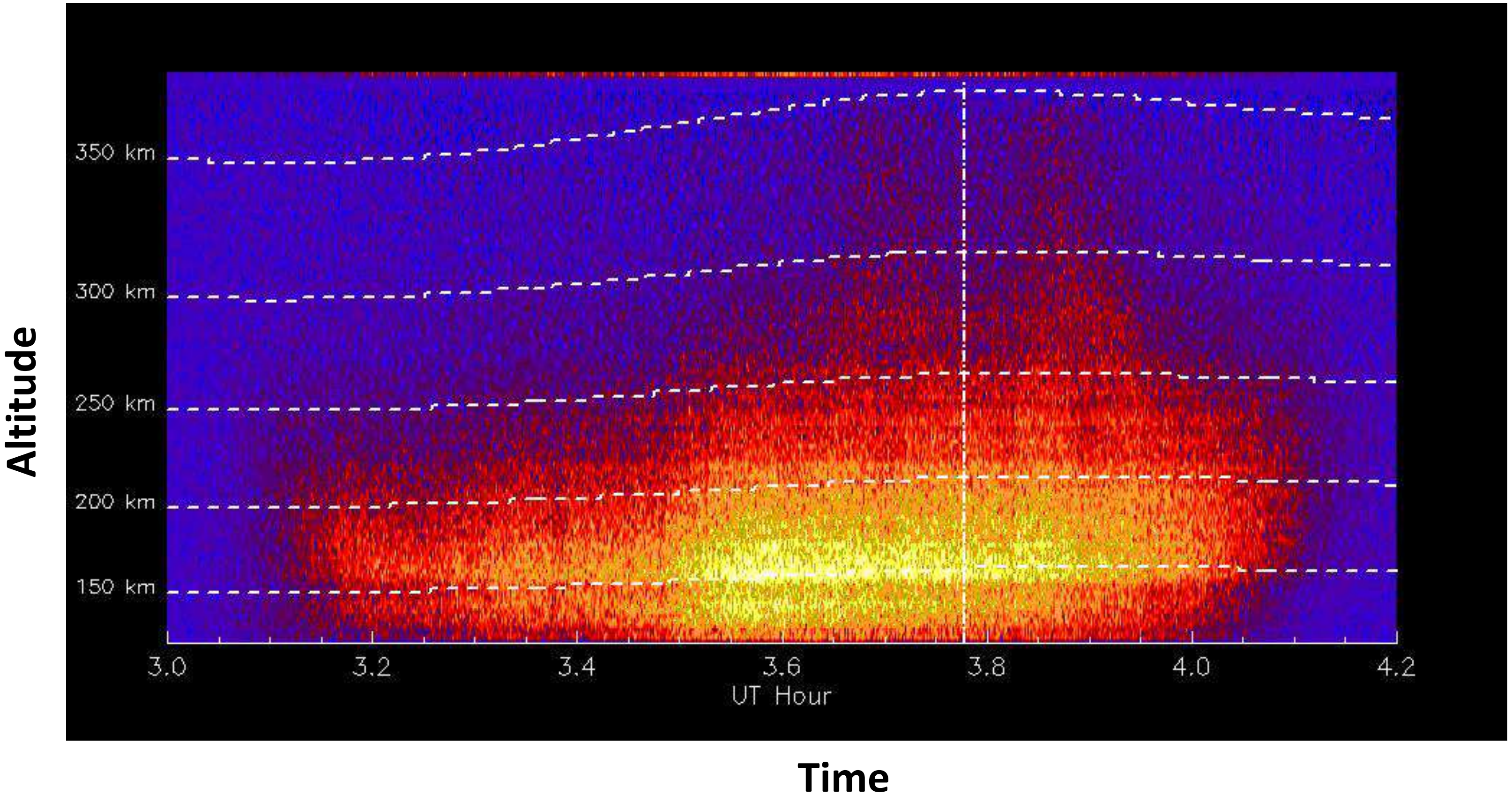
- 911 and 1356Å emission trace the density of the plasma in the ionosphere at night
- Equatorial arcs are visible in observations from early April 2017
- North-south asymmetry in the arcs
- Observations over longer time periods will trace changes (seasonal) in morphology of the arcs
- LITES can track the arcs from daytime into nighttime



Daytime 1356Å

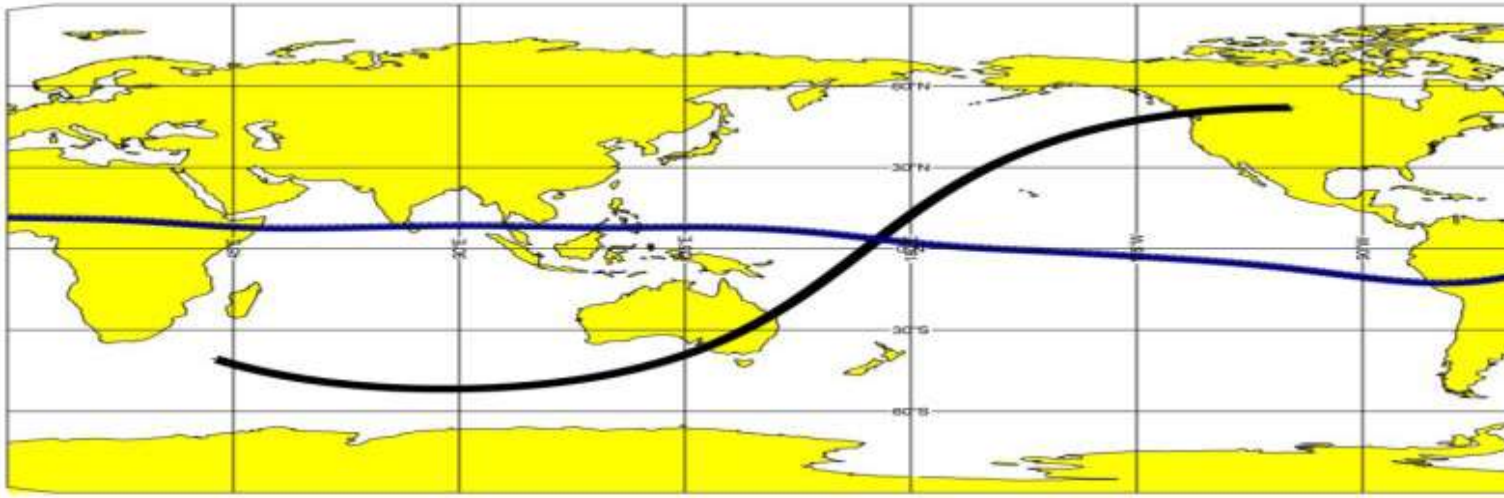


- During the daytime, solar EUV creates photoelectrons which collisionally excite thermospheric O1356Å
- Collisional excitation dominates at lower altitudes (<~250-300 km)

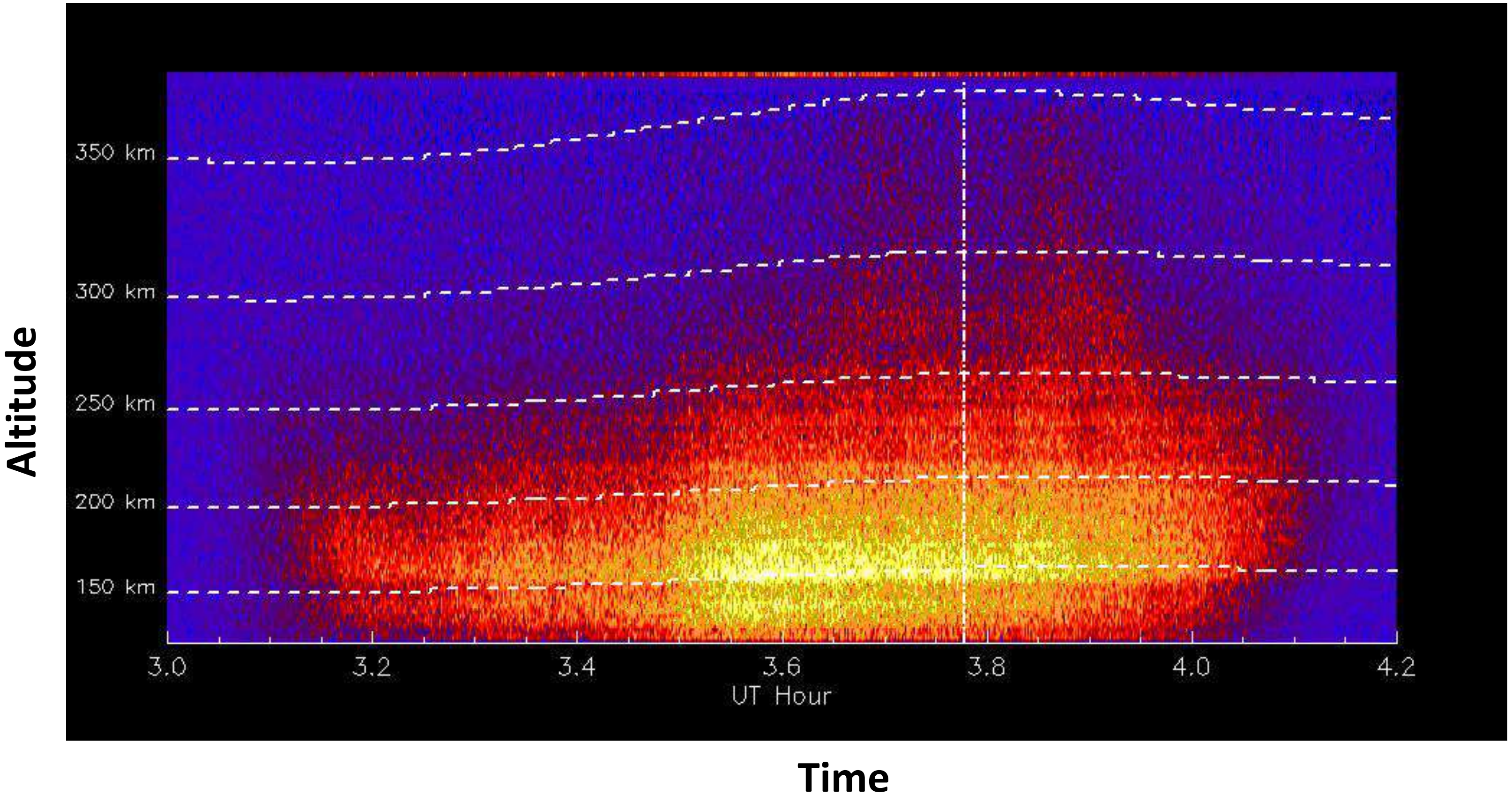


Stephan et al., submitted

Daytime 1356Å

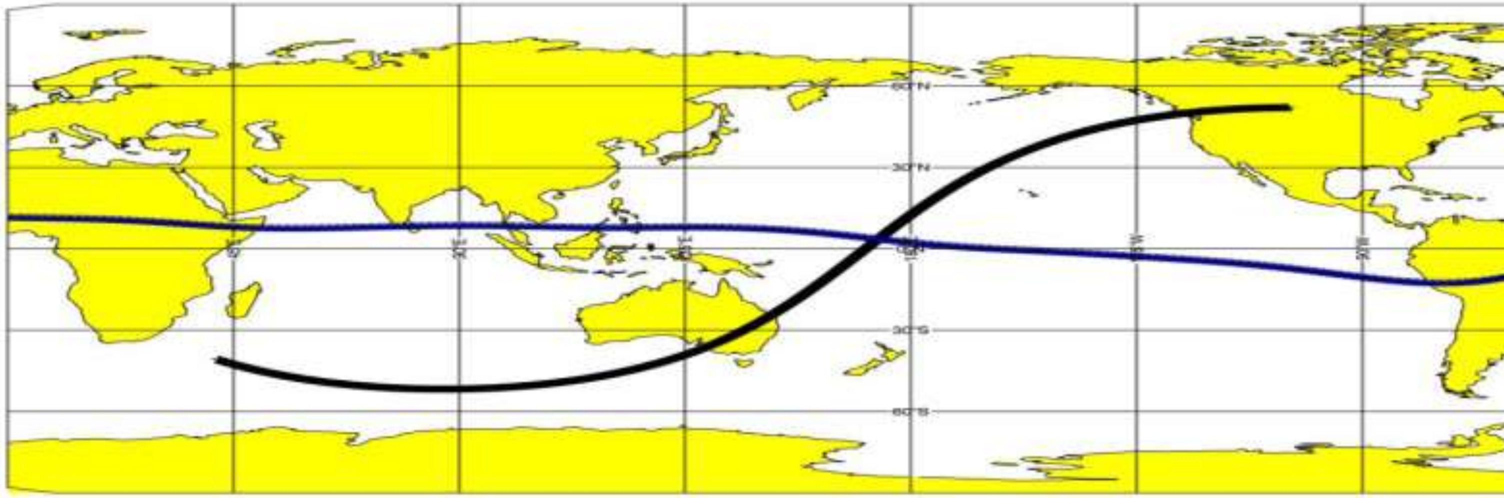


- Relative OI 1356 Å emission brightness measured by LITES during one daytime pass on 2 April 2017
- Tangent altitude contours are shown (horiz. white dashed)
- The vertical dashed line identifies the time when the tangent point at 300 km was located at the magnetic equator



Stephan et al., submitted

Daytime 1356Å



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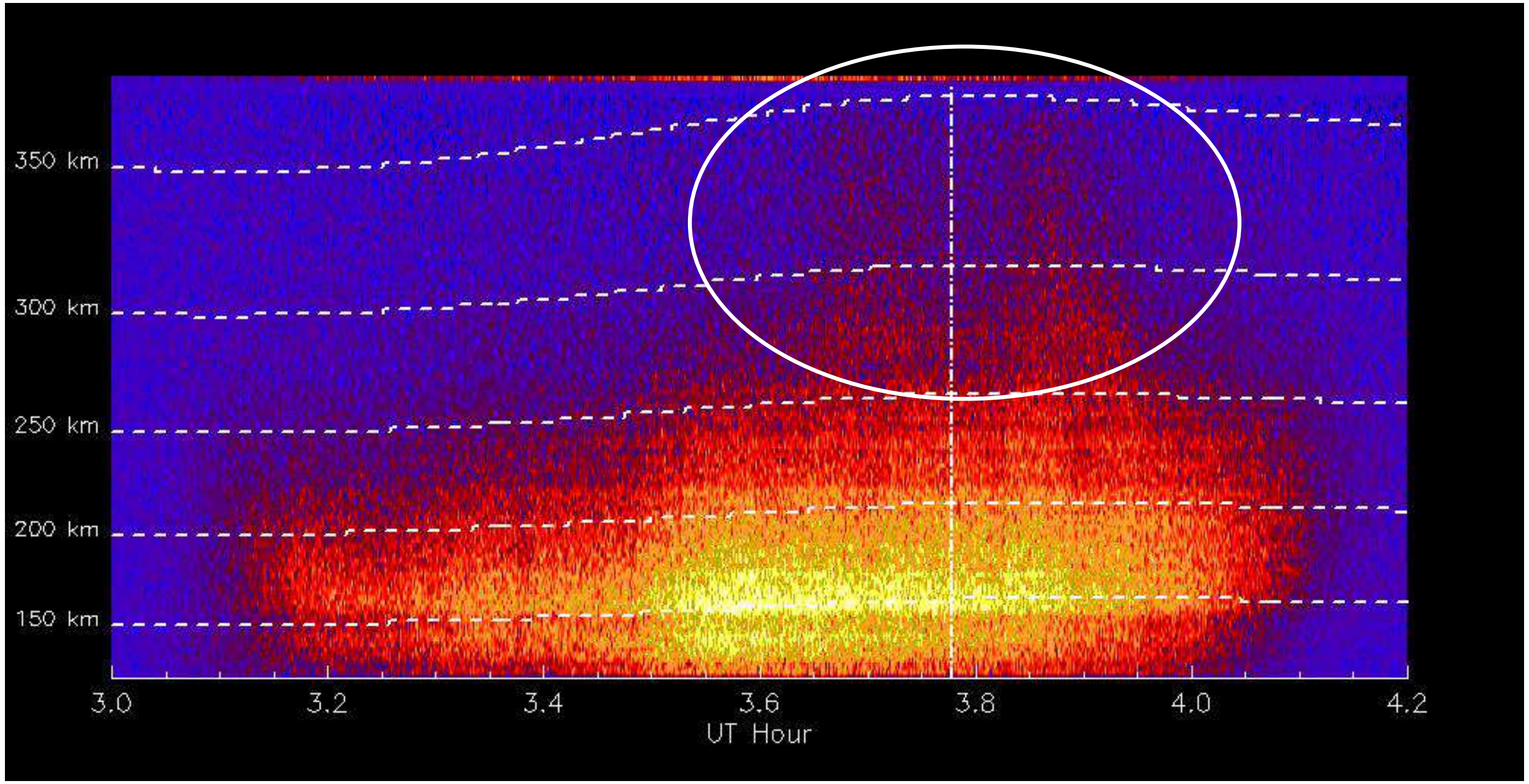
Altitude

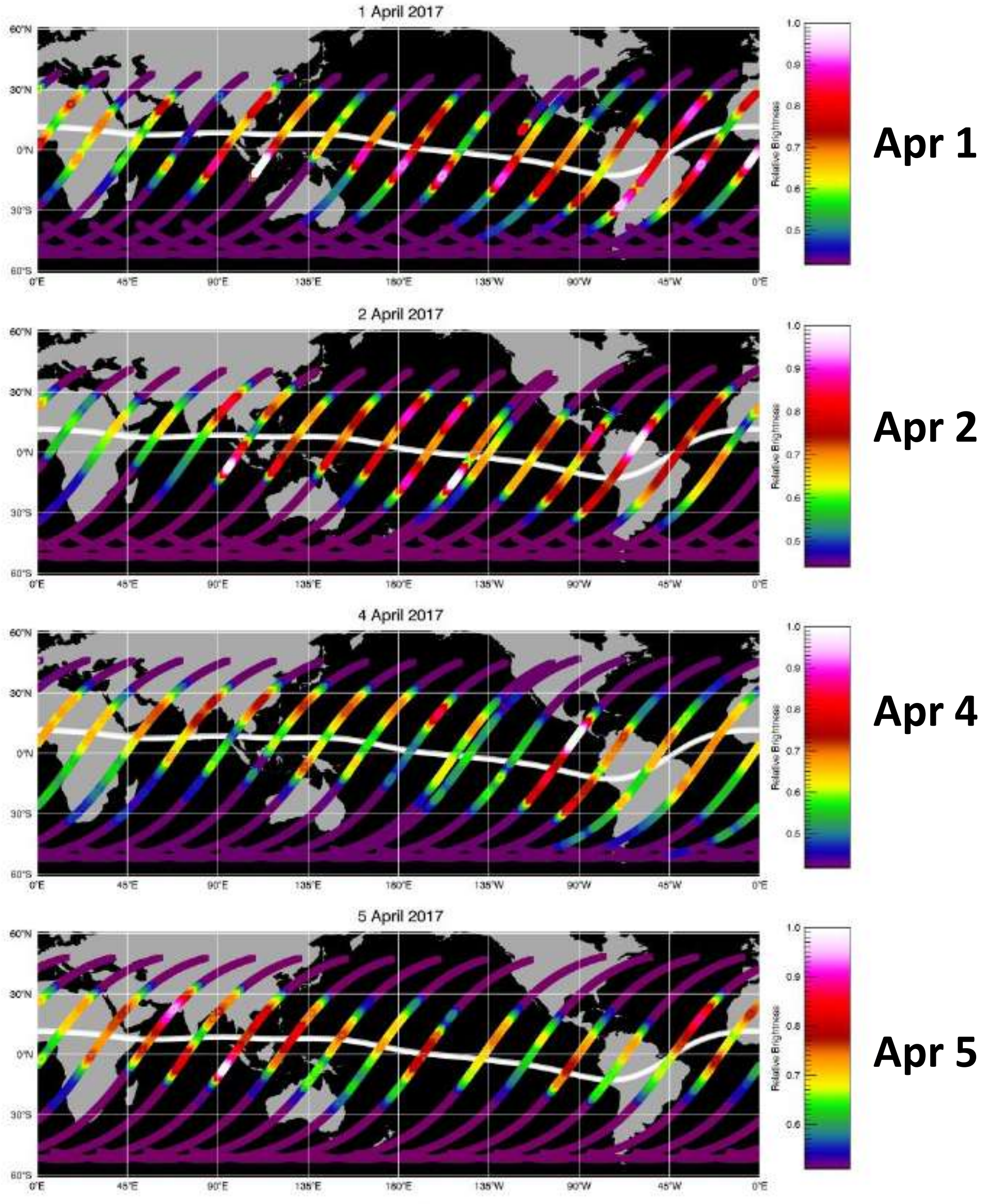


Time

Stephan et al., submitted

1356Å, daytime April 2017

- 1356Å, 250-350km



Stephan et al., submitted

1356Å, daytime April 2017

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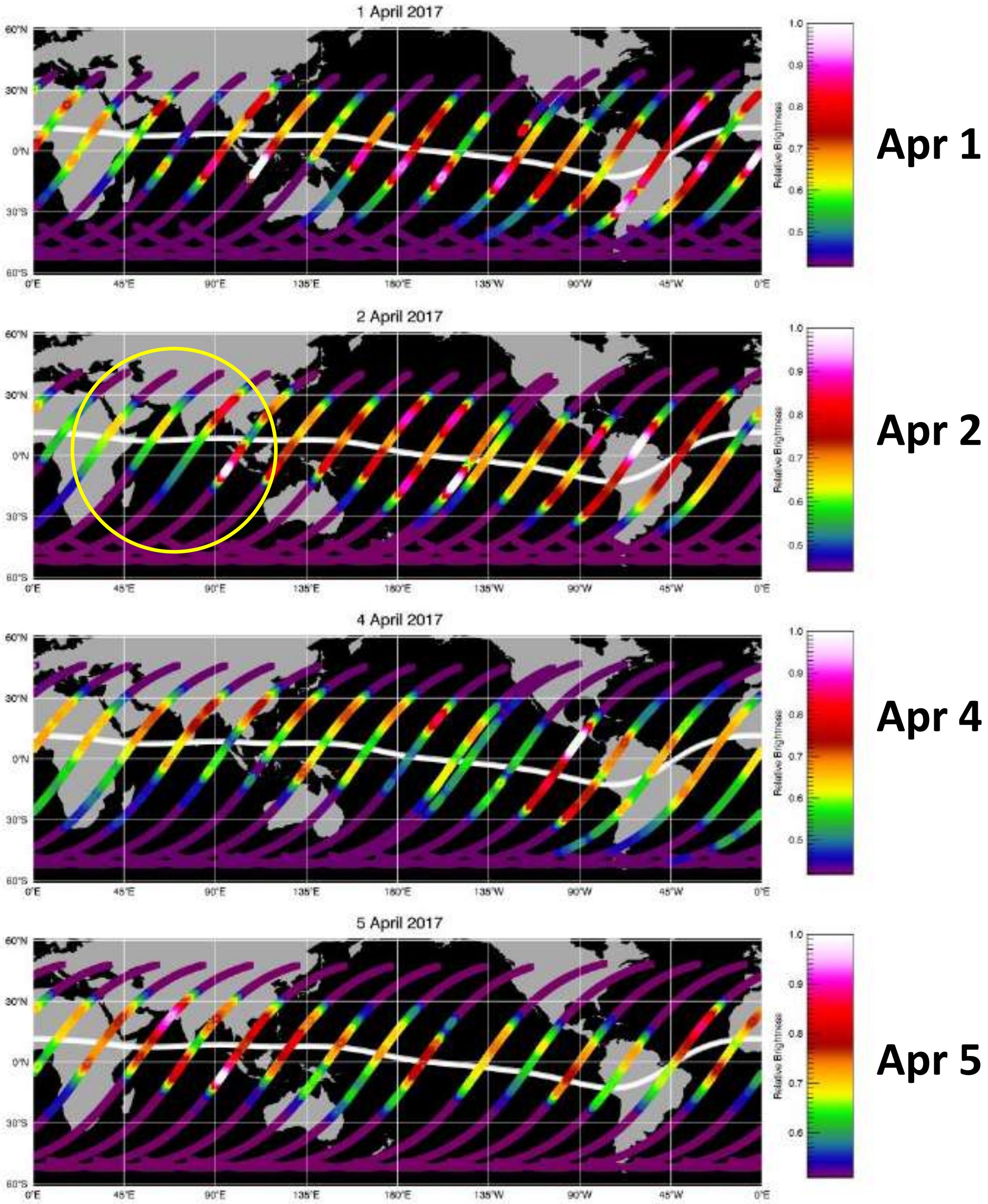
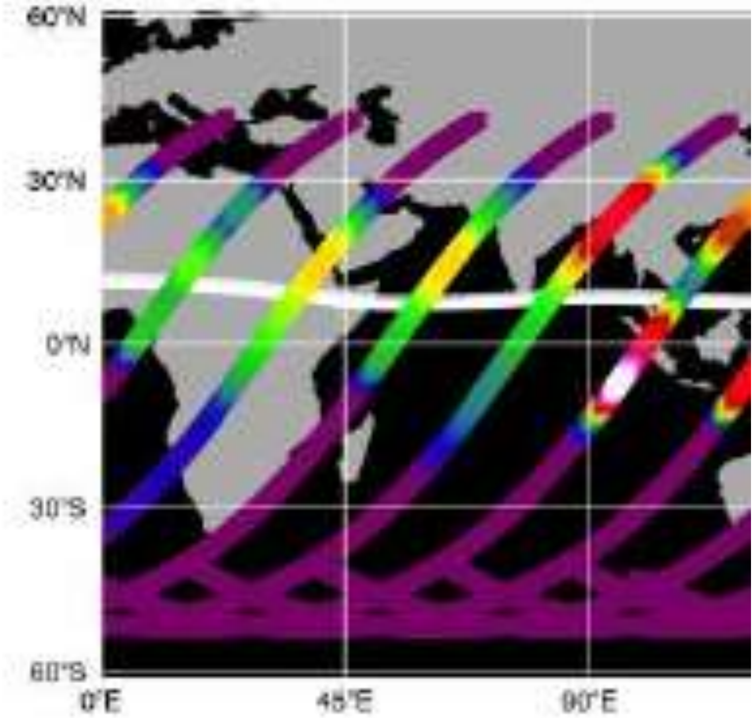


Stephan et al., submitted

1356Å, daytime April 2017

- 1356Å, 250-350km
- North-south asymmetry seen
  - Meridional winds?
  - Mild geomagnetic activity?



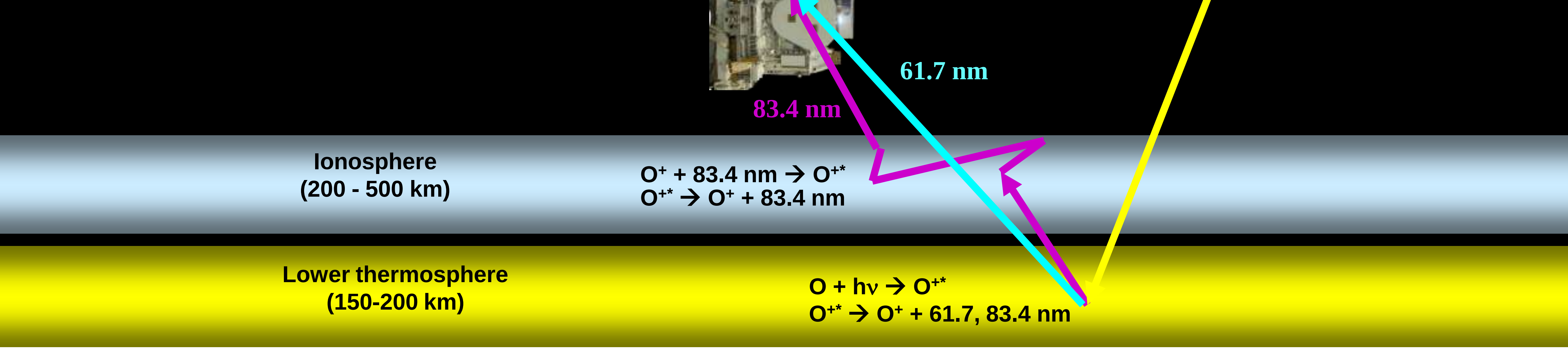
Stephan et al., submitted

834Å Daytime Emission

OII 834Å emission is produced in the lower thermosphere primarily through solar photoionization of atomic O:

$$O + h\nu \rightarrow O^{+*} \rightarrow O^{+} + h\nu_{83.4}$$

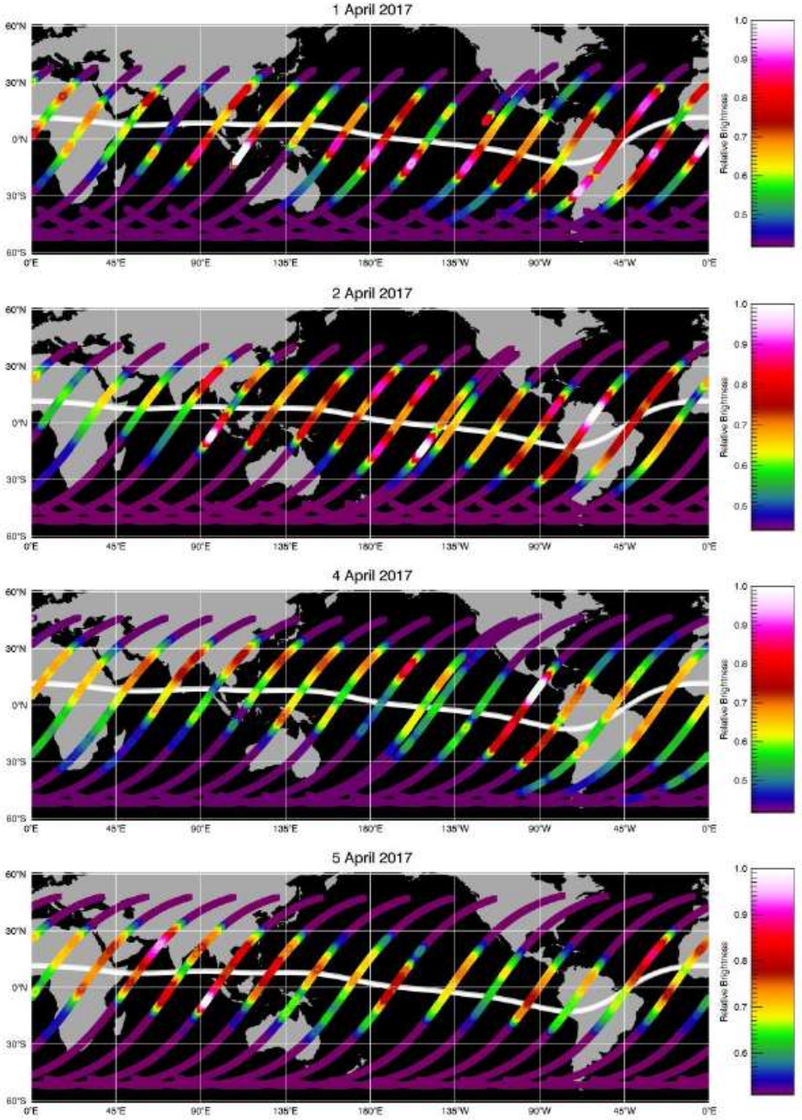
Photons then resonantly scatter with O^{+}



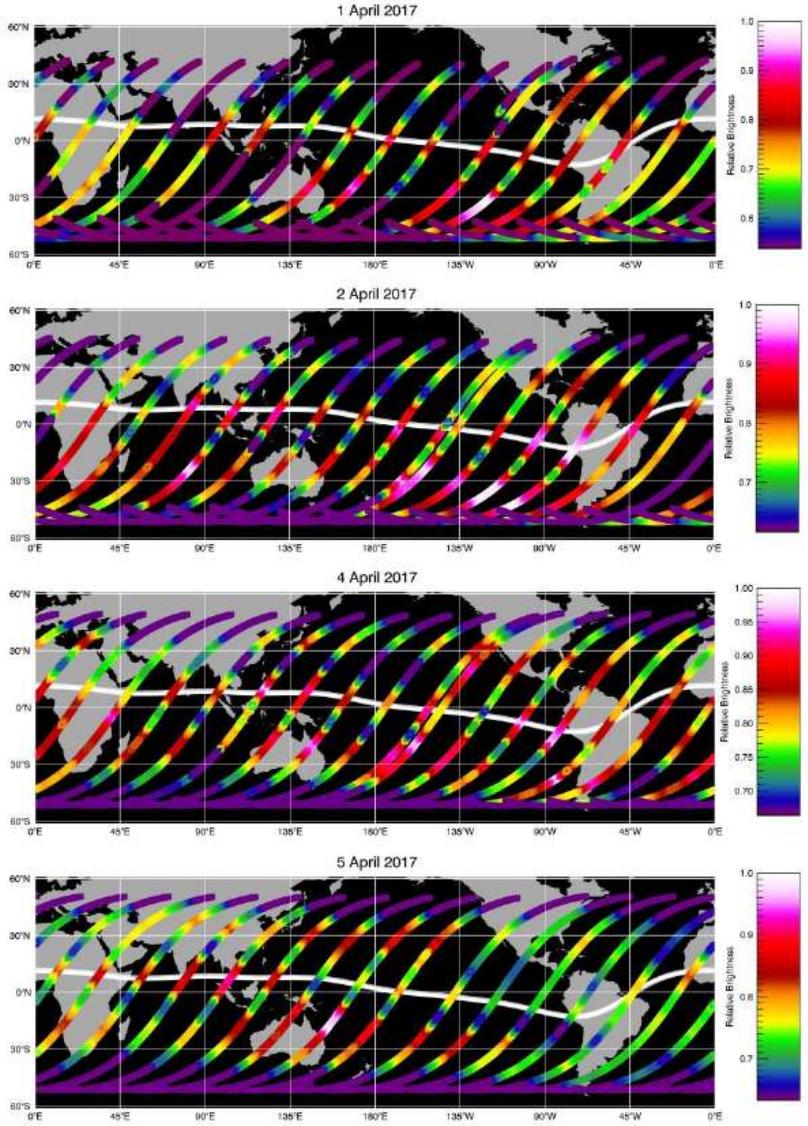
- Ionospheric profiles can be derived by inversion of 834Å limb profiles (see, e.g., Geddes et al. 2016)
- From the vantage point of LITES through the equatorial arcs, the 834Å emission is effectively scattered out of the line of sight (essentially creating an absorption feature).

Daytime

1356Å



834Å



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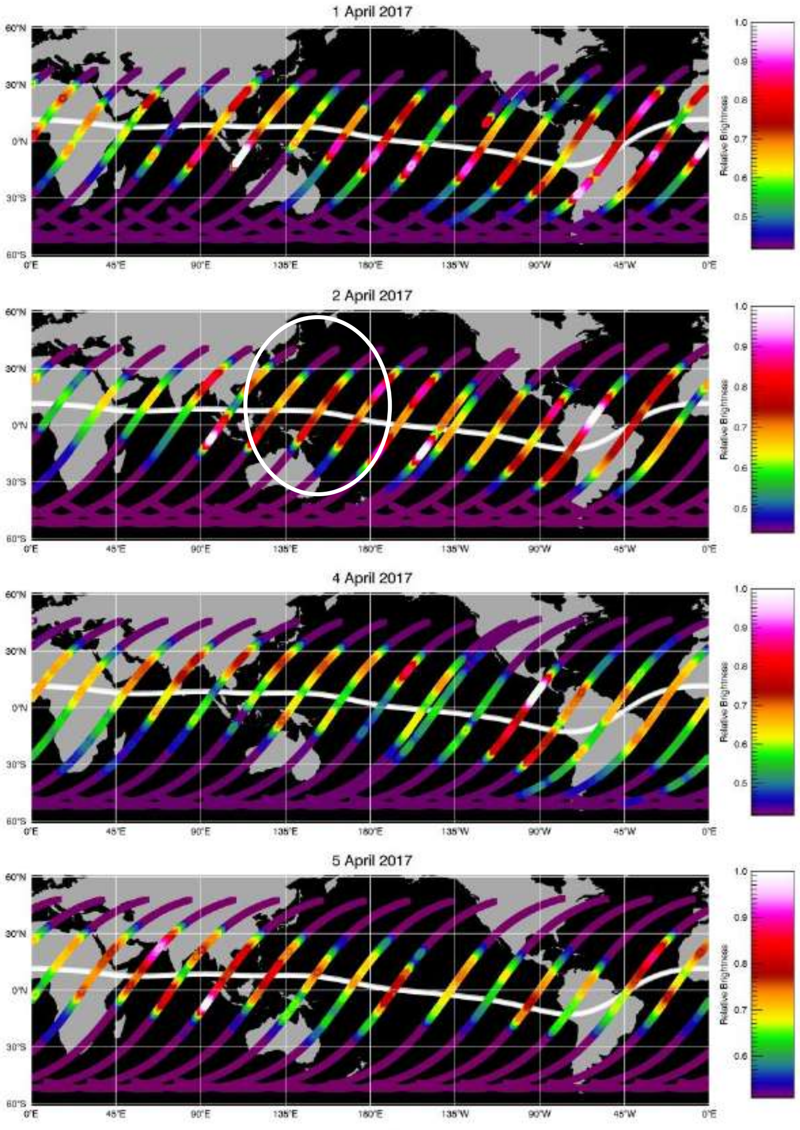
Stephan et al., submitted

Daytime

1356Å



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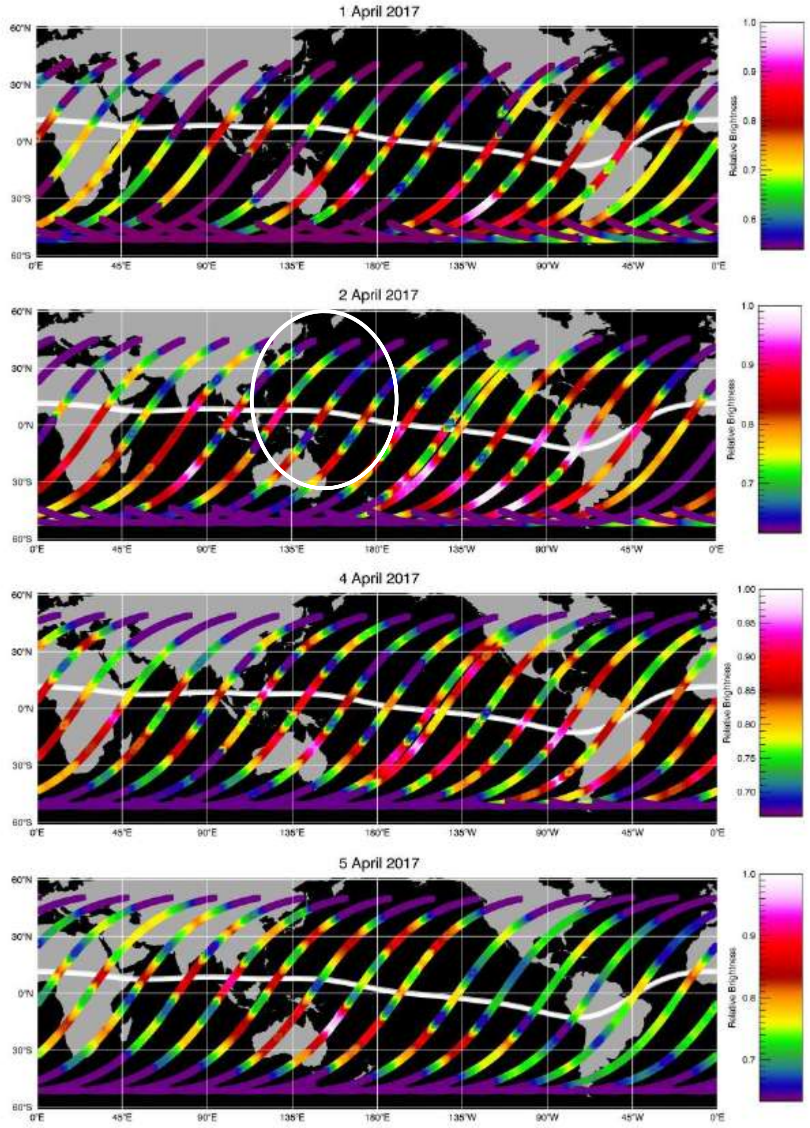
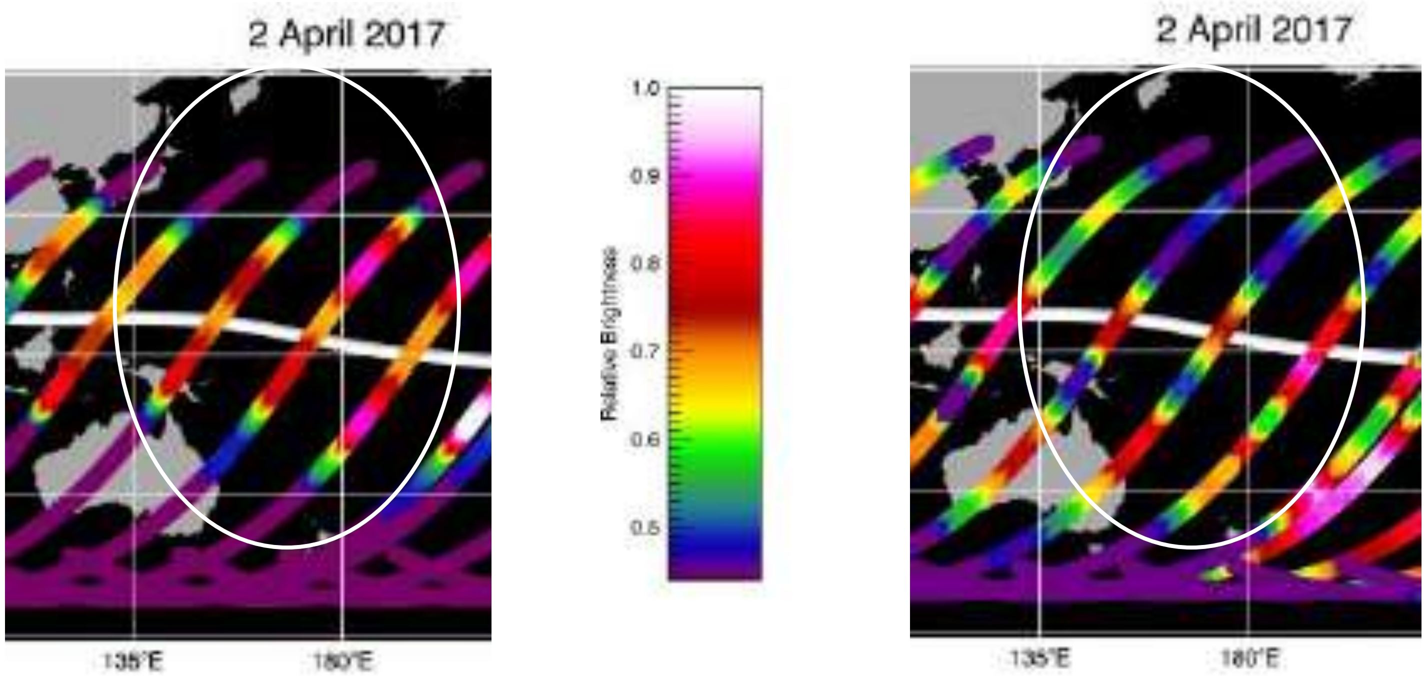
834Å



Stephan et al., submitted

Daytime

1356Å **834Å**



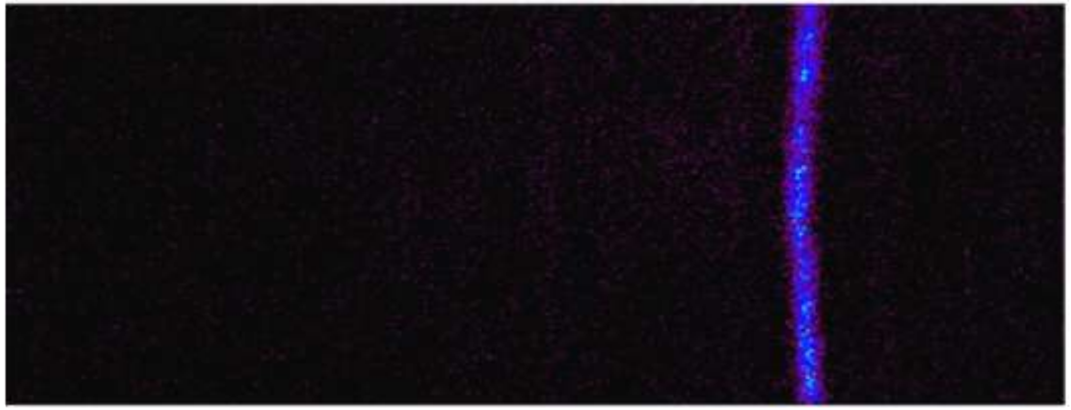
- 1356Å brightness above 250km traces arcs
- 834Å shows depletion in arcs

Stephan et al., submitted

Aurora

- LITES detected both ions and emission lines from the southern auroral zone.

Nighttime
April 16 2017



350 km

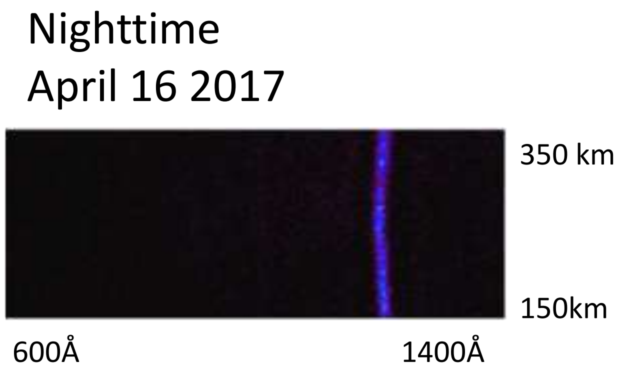
150km

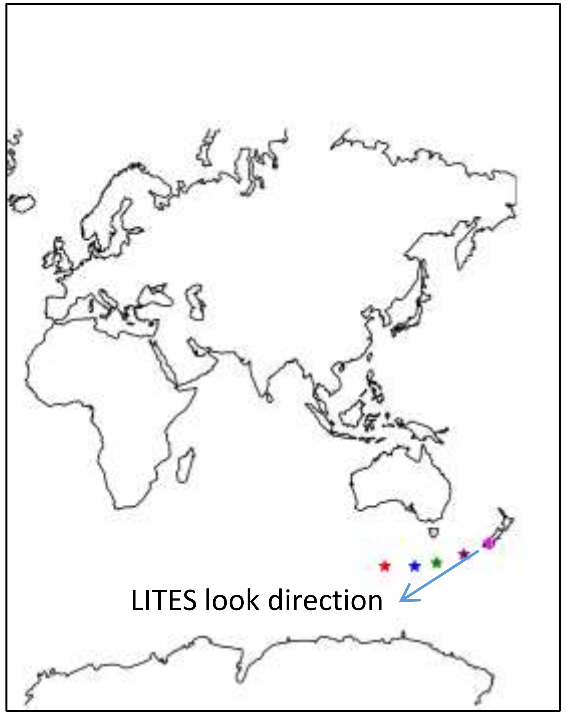
600Å

1400Å

Aurora

- LITES detected both ions and emission lines from the southern auroral zone.





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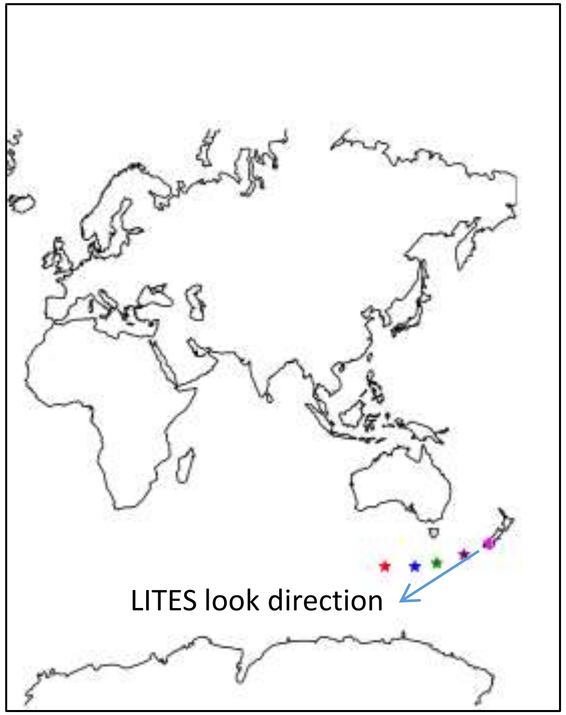
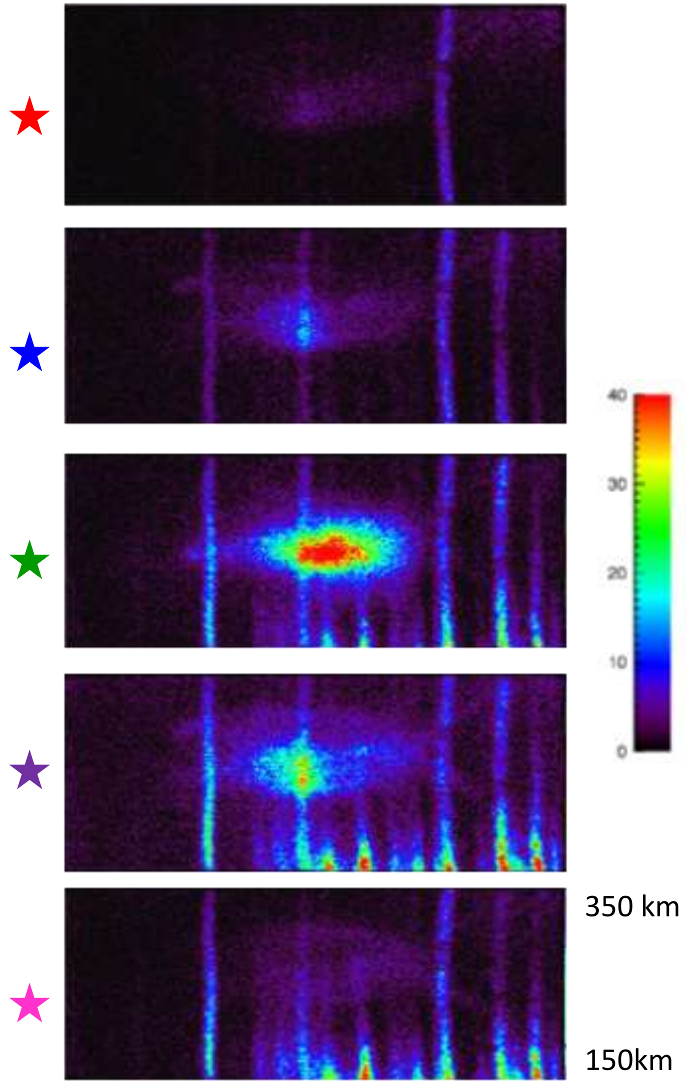
Nighttime
April 16 2017



Nighttime April 21 2017



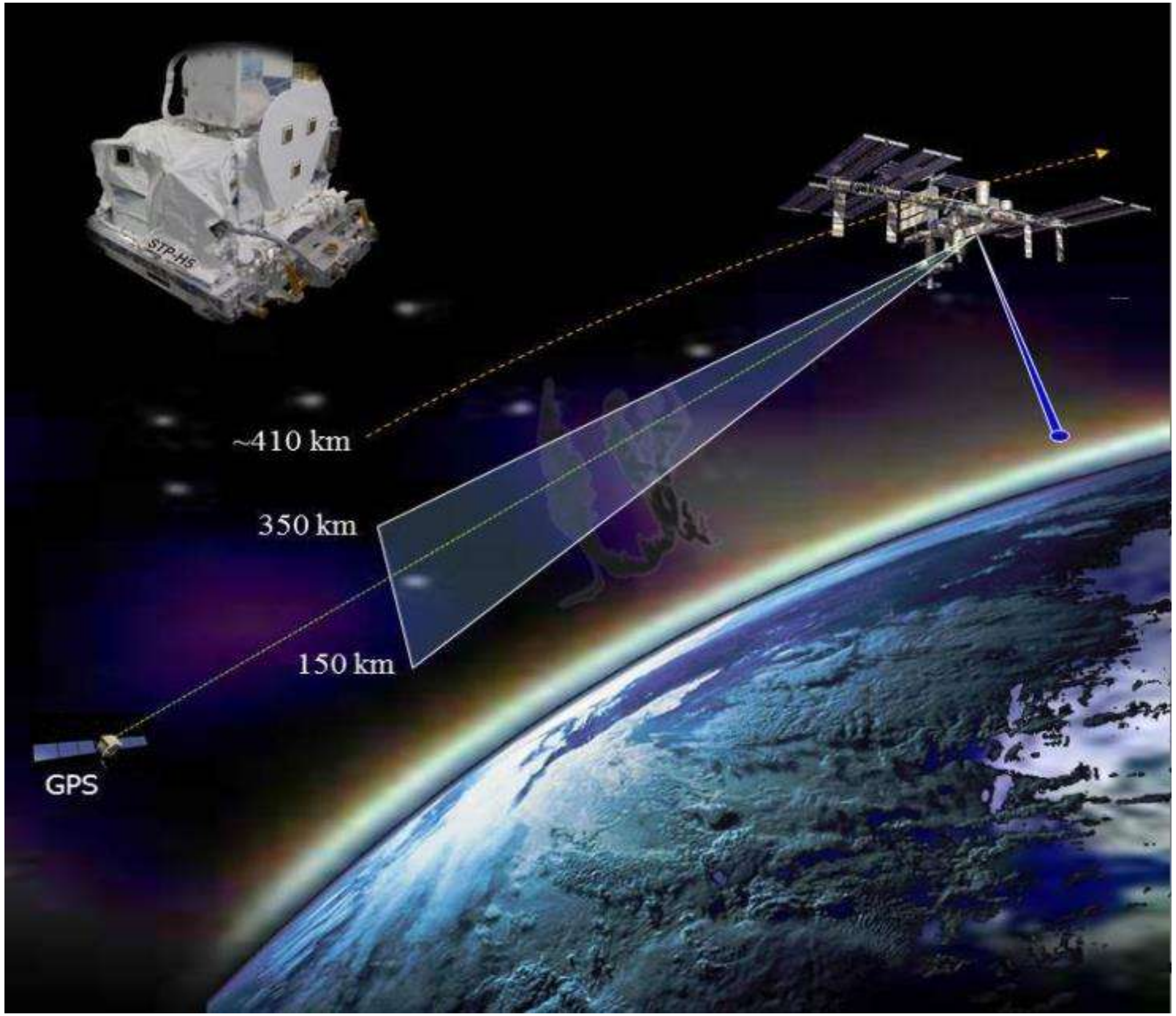
LITES and GROUP-C

LITES is part of a suite of ionospheric instruments on the payload along with:

GPS **R**adio **O**ccultation and **U**ltraviolet **P**hotometry-**C**olocated (GROUP-C)

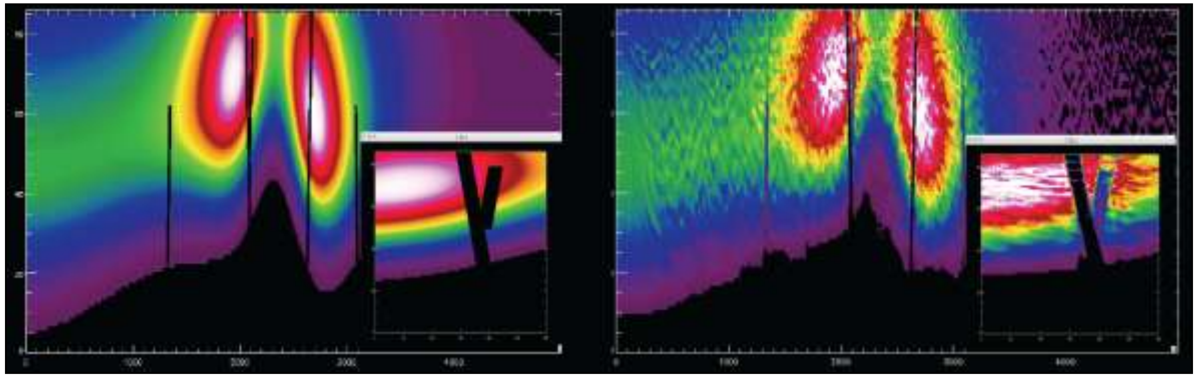
- Nadir-viewing UV photometer (TIP)
- GPS receiver (FOTON)

LITES imaging spectrograph and the GPS receiver view the same ionospheric volume imaged by the nadir photometer approximately 200 seconds later



Tomography

- The capability of LITES to continuously image over all altitudes in its FOV along with the nadir imaging of TIP (GROUP-C) allows better tomographic imaging than has ever been achieved
- The LITES and GROUP-C UV sensors can reconstruct ionospheric ion density gradients and bubbles



(Left) Model 1356Å O^{+}+e volume emission for a LITES/GROUP-C nightside pass.

(Right) Retrieved morphological features from synthesized measurements.

From S. Budzien

In Summary . . .

- LITES is an EUV ionospheric imaging spectrograph that launched early 2017
- LITES collected ~1.5 years of UV airglow observations daytime and nighttime
- The equatorial arcs are easily visible in LITES data, and LITES observations over longer timescales can be used to trace morphology
- LITES provides complementary observations to observatories at different orbits, ICON and GOLD