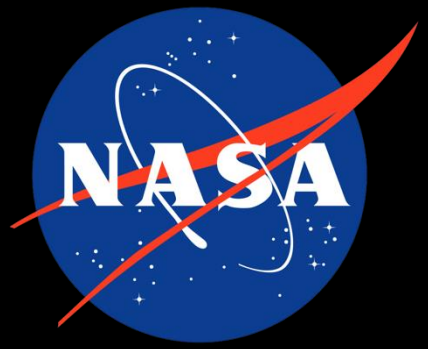


THE CATHOLIC UNIVERSITY OF AMERICA

Punch and the High –Altitude Aurora

Bea Gallardo-Lacourt, Nicki Viall, Larry Kepko, Doug Rowland, and Craig DeForest

Atmospheric Emissions at Earth: What Could PUNCH Observe?

Earth Shine?

Airglow/Nightglow?

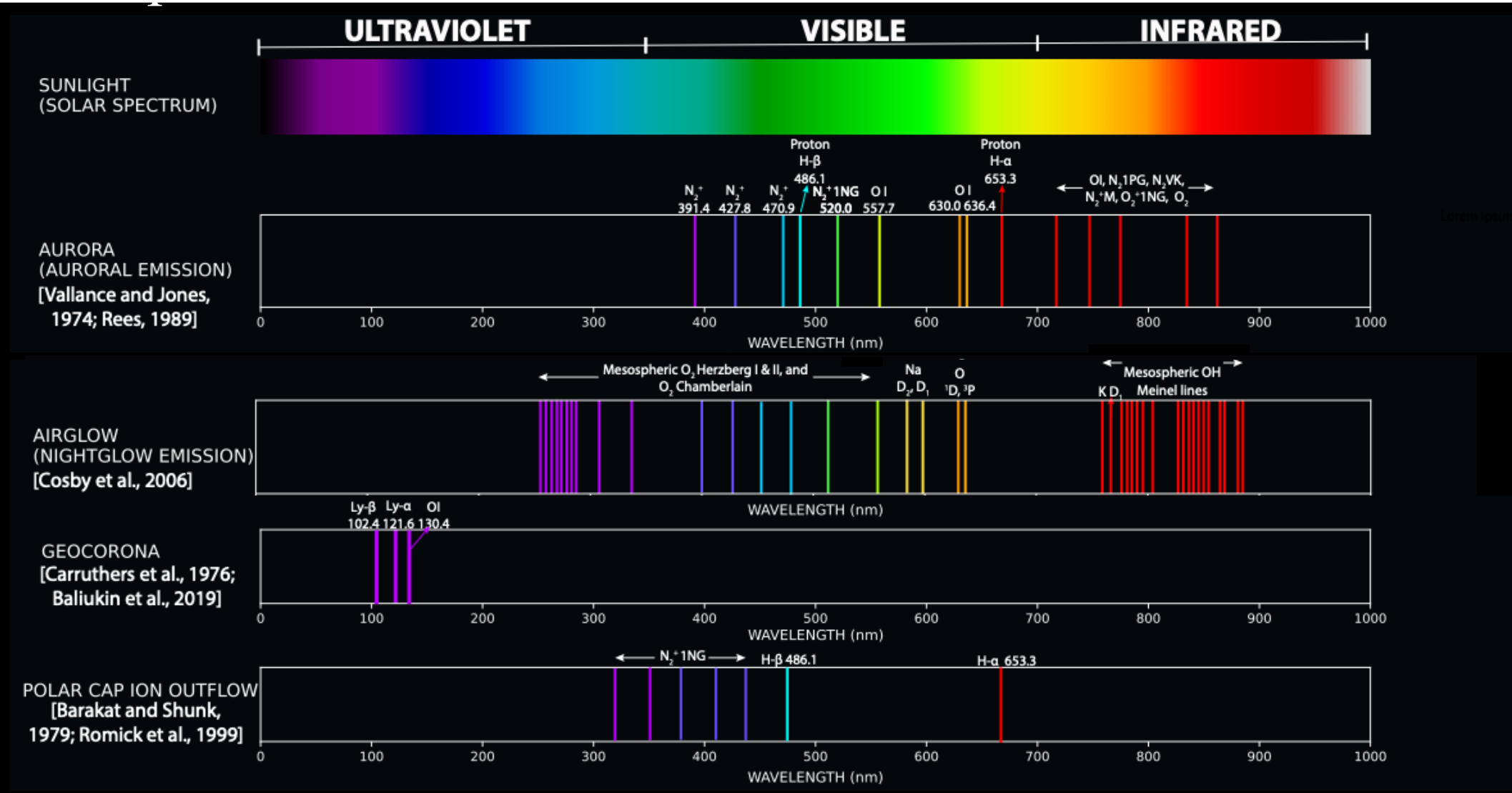
Geocorona?

Aurora?

Ion Outflow?

What are these emissions?

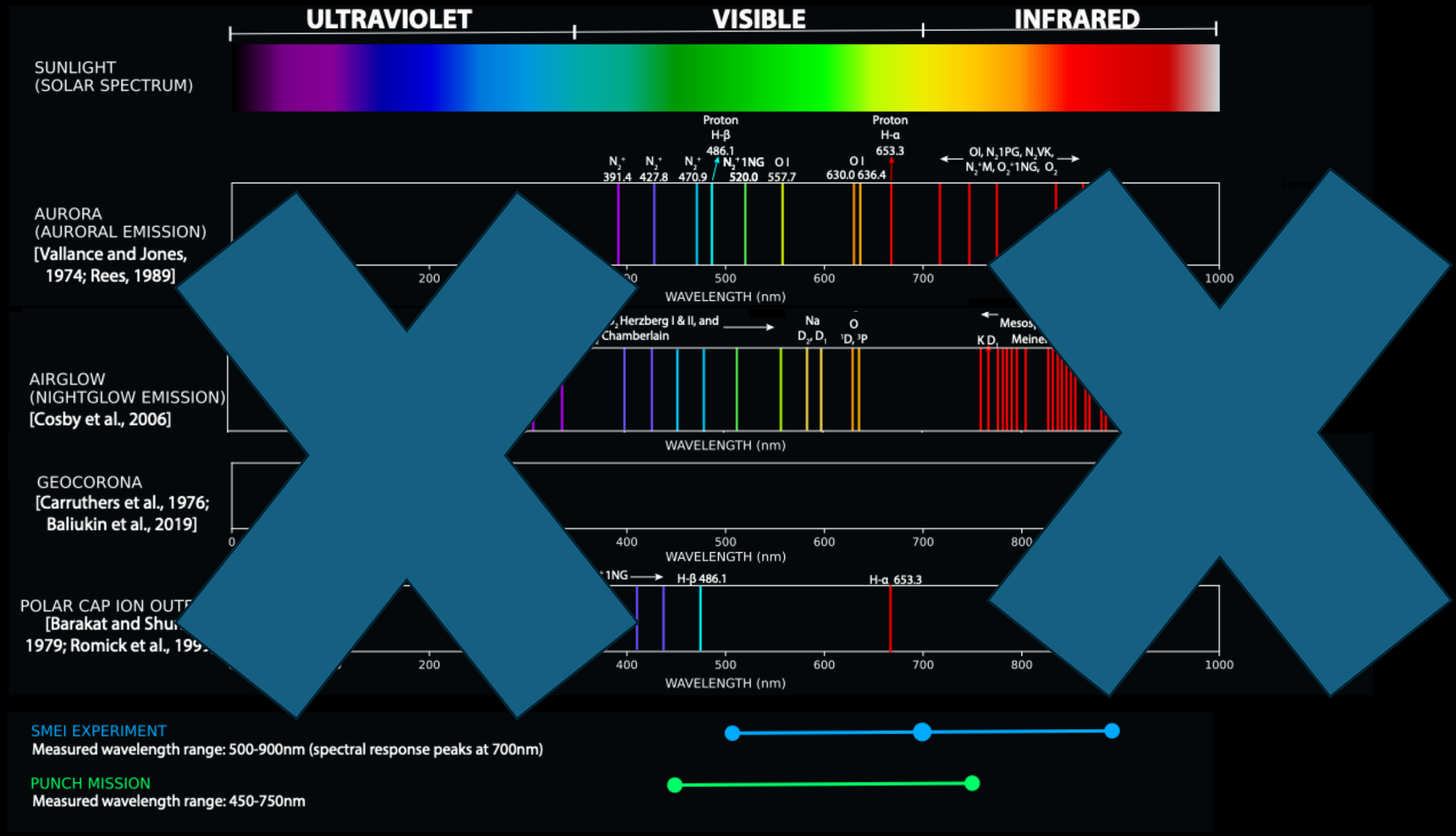
Atmospheric Emissions at Earth: What Could PUNCH Observe?



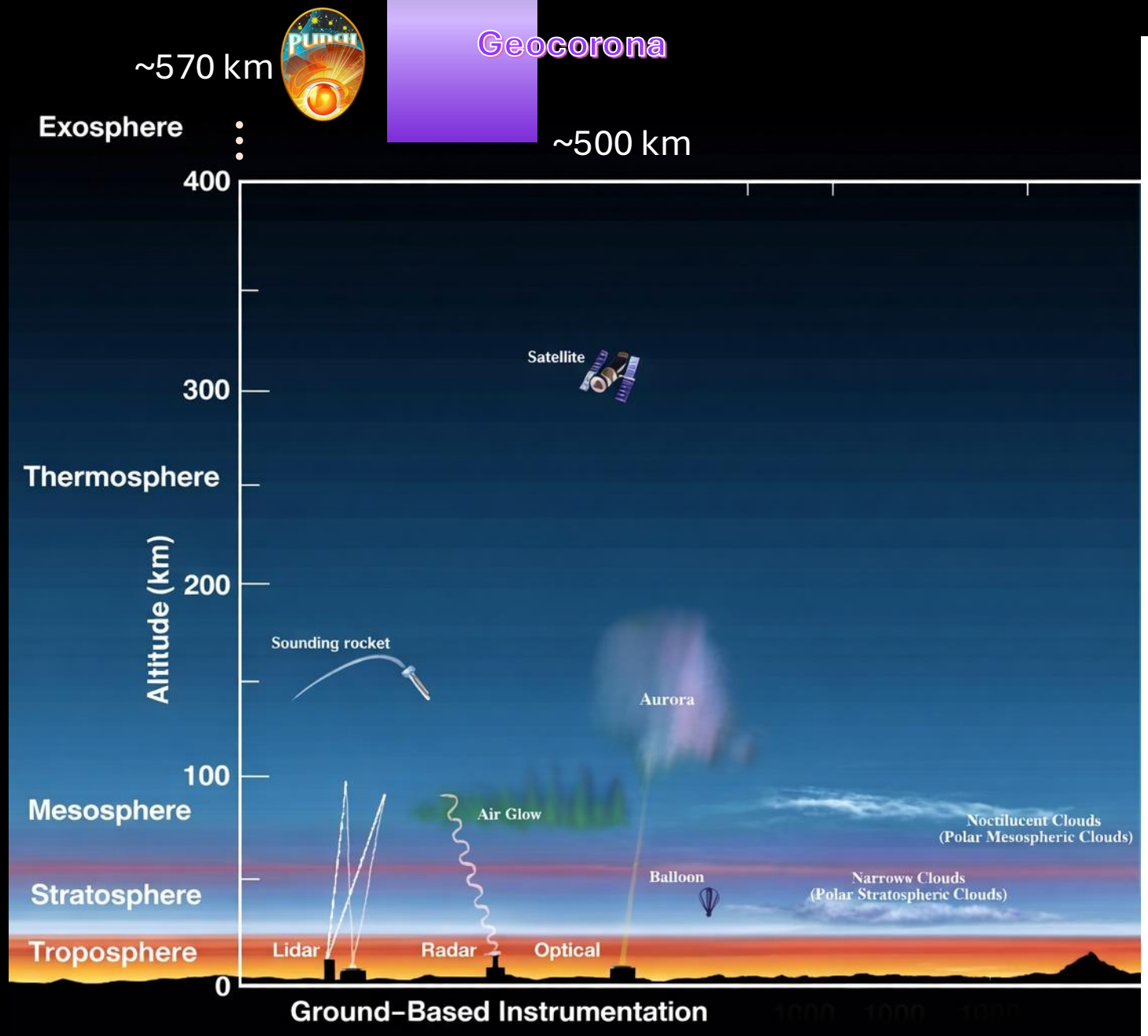
SMEI EXPERIMENT
Measured wavelength range: 500-900nm (spectral response peaks at 700nm)

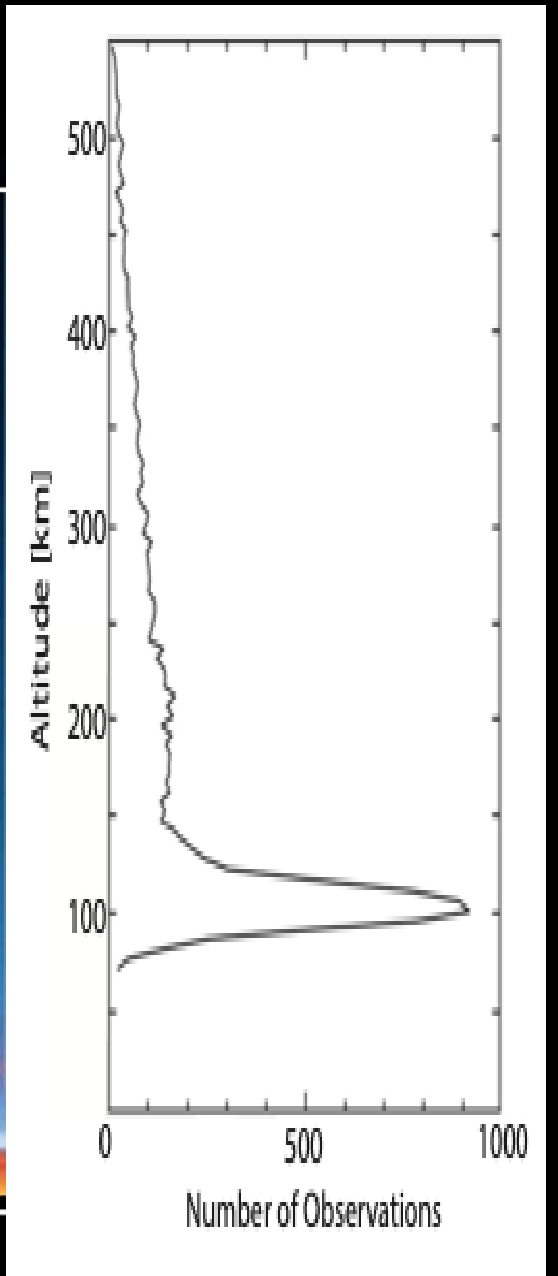
PUNCH MISSION
Measured wavelength range: 450-750nm

Atmospheric Emissions at Earth: What Could PUNCH Observe?



Atmospheric Emissions at Earth: What Could PUNCH Observe?





Where do these phenomena occur in altitude?

While the aurora is shown between ~100–200 km, this reflects the most common occurrence. Red-line auroral emission span a much broader range, from ~150 km to above 400 km [e.g., Solomon et al., 1988]

Height distribution of auroras based on over 12000 observations by Stormer and Colleagues (after Egeland and Burke, 2023)

WFI inner FOV never sees below ~650 km

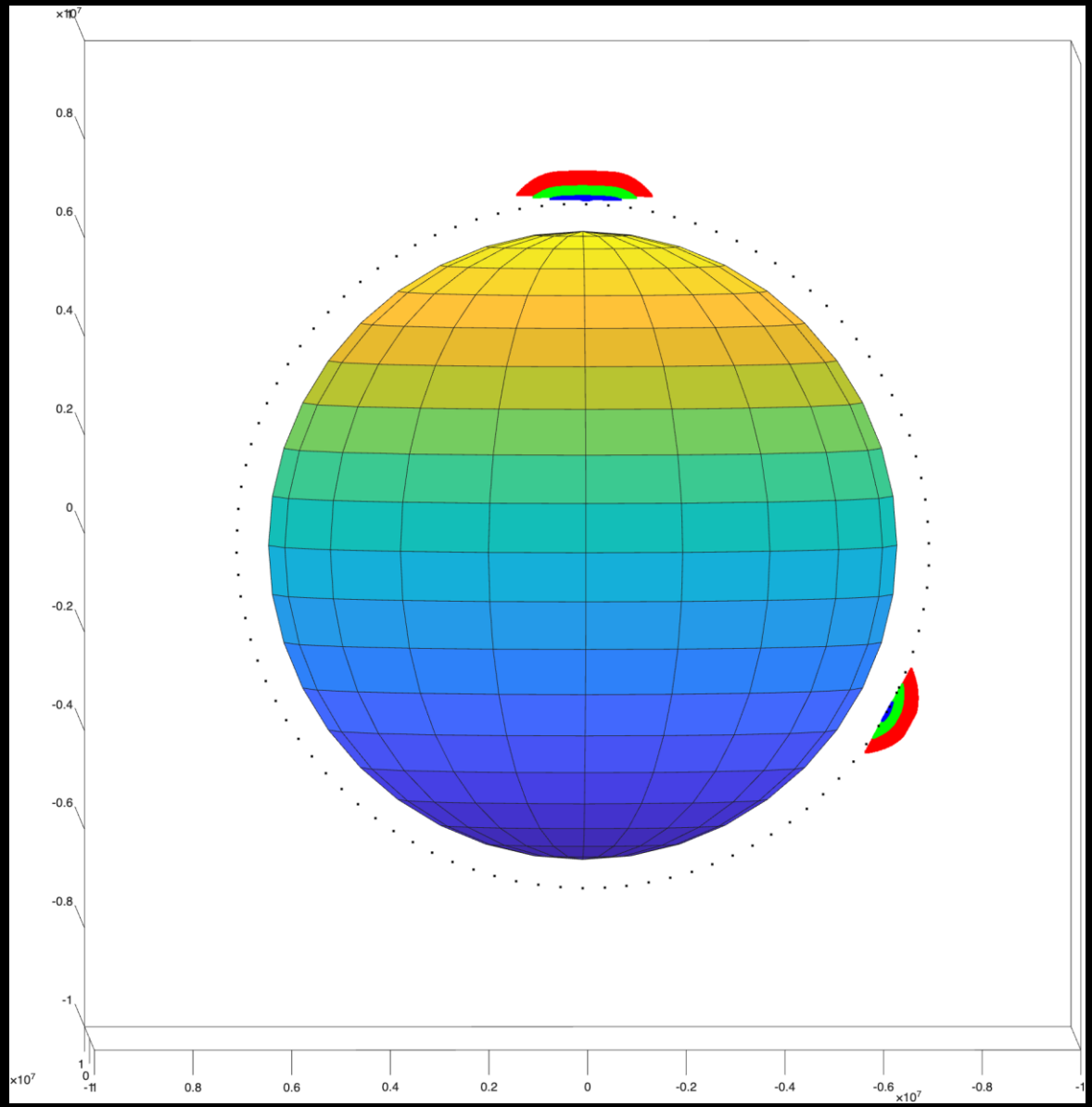
WFI outer FOV sees at least up to ~1200km

The blue, green, and red polygons show the intersection of the various WFI pixel look directions with:

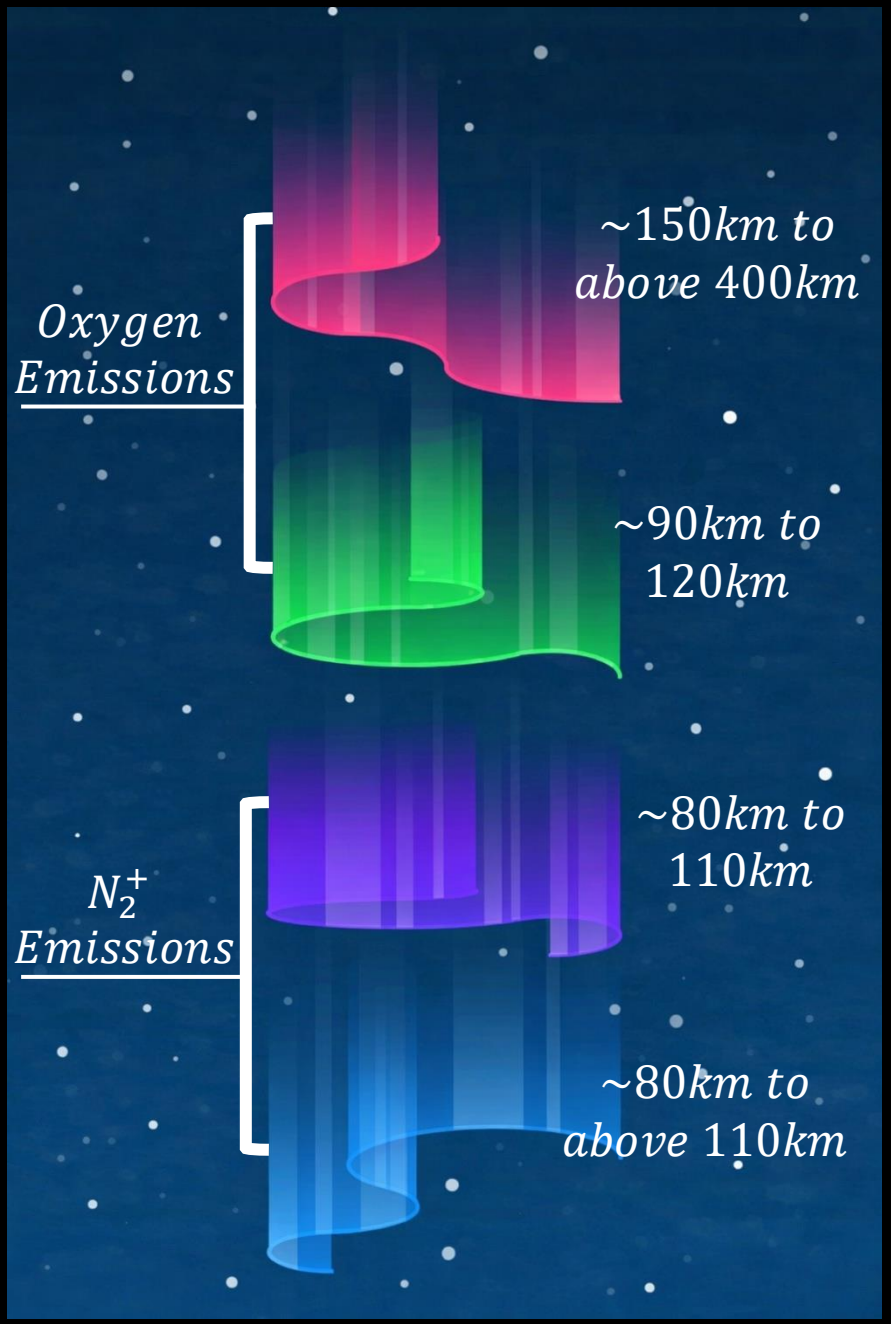
700 km geocentric altitude (blue)

900 km geocentric altitude (green)

1200 km geocentric altitude (red)



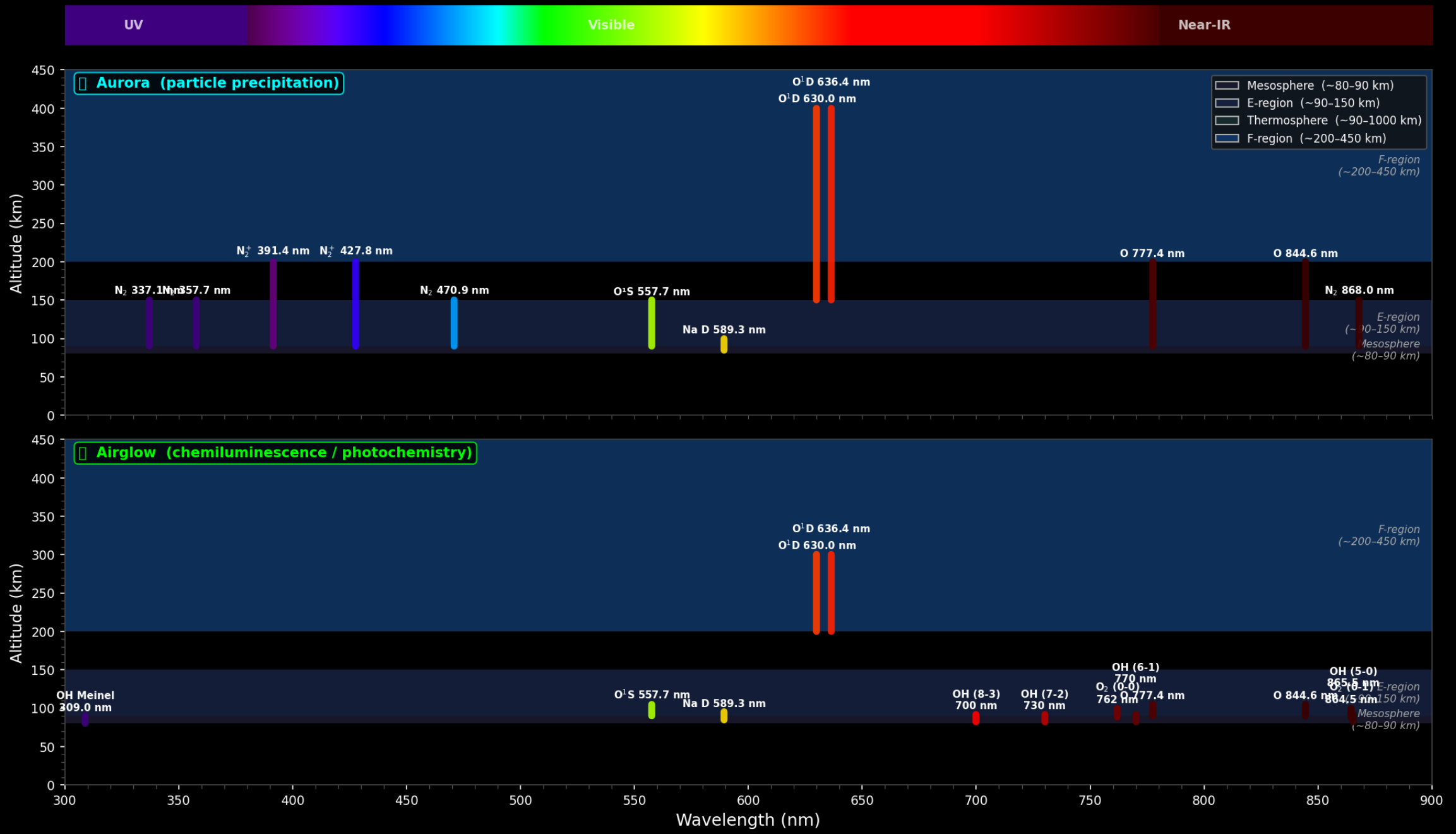
Atmospheric Emissions at Earth: What Could PUNCH Observe?

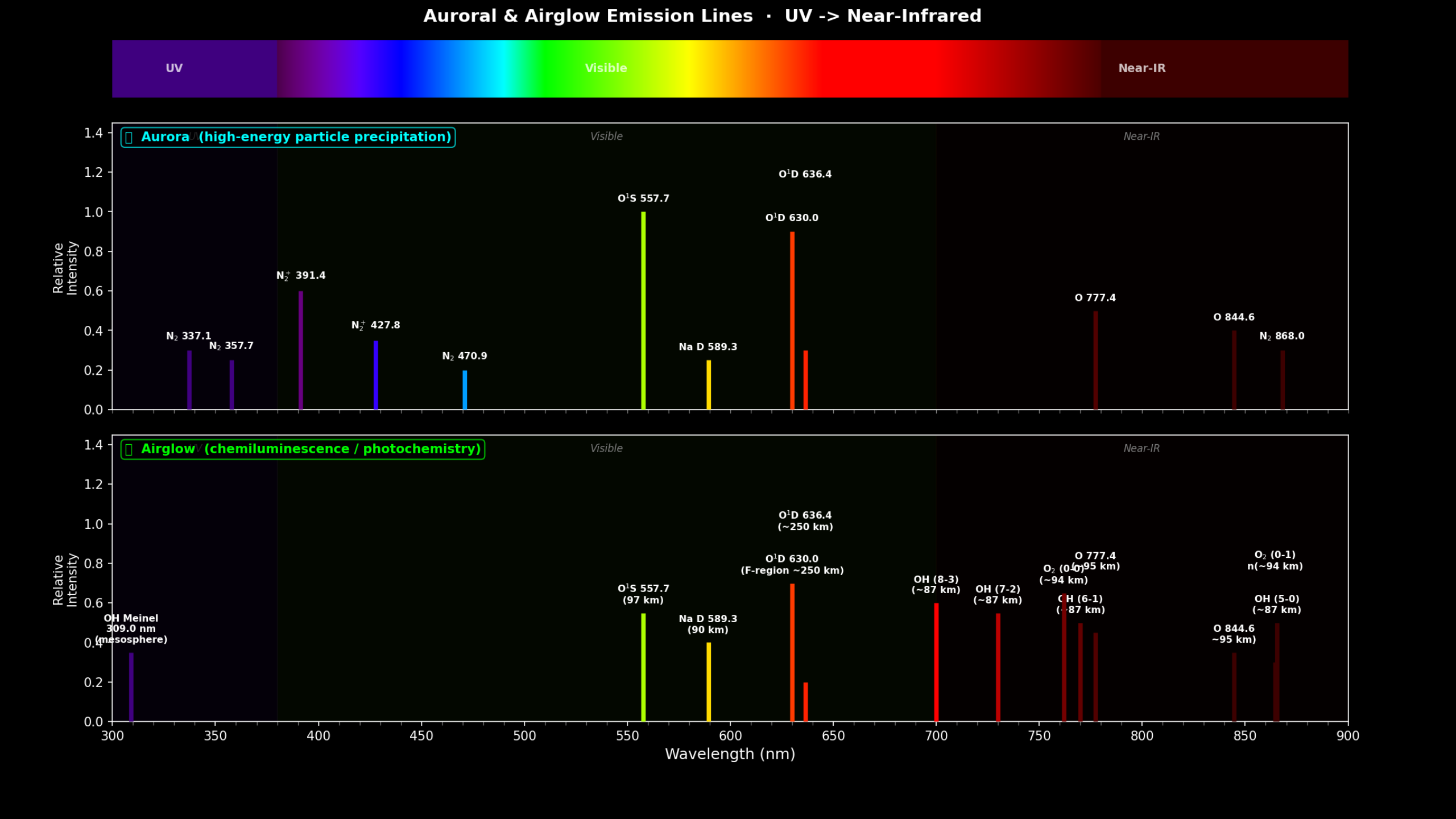


Example of the altitude of auroral emissions from ARCTICS-SMILE system

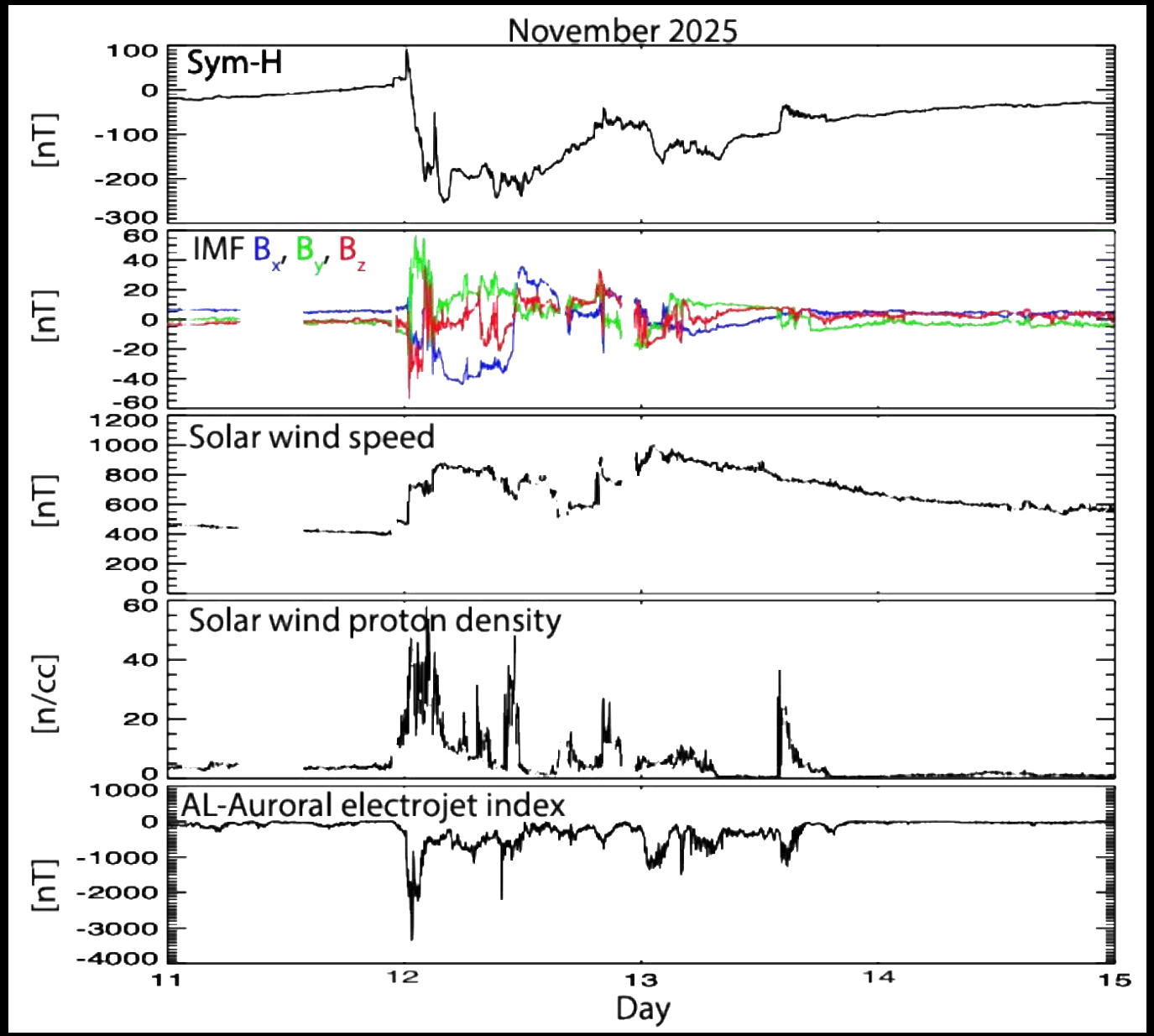
Note that this system measures the aurora sideways to study their altitudinal profiles

- The green-line emission (557.7 nm) occurs at altitudes below the region of interest for PUNCH
- However, this emission is a valuable diagnostic tool as it can be used to identify the location of the auroral oval
- They also help determine whether observations are occurring inside or outside the auroral oval


Auroral & Airglow Emission Altitude Ranges · UV -> Near-Infrared
UV
Visible
Near-IR
Aurora (particle precipitation)
Airglow (chemiluminescence / photochemistry)
Mesosphere (~80–90 km)
E-region (~90–150 km)
Thermosphere (~90–1000 km)
F-region (~200–450 km)
Altitude (km)
Wavelength (nm)
O¹D 636.4 nm
O¹D 630.0 nm
N₂⁺ 391.4 nm
N₂⁺ 427.8 nm
N₂ 337.1 nm
N₂ 357.7 nm
N₂ 470.9 nm
O¹S 557.7 nm
Na D 589.3 nm
O 777.4 nm
O 844.6 nm
N₂ 868.0 nm
OH Meinel 309.0 nm
OH (8-3) 700 nm
OH (7-2) 730 nm
O₂ (0-0) 762 nm
OH (6-1) 770 nm
OH (5-0) 865.5 nm
O₂ (0-1) 864.5 nm


Auroral & Airglow Emission Lines · UV -> Near-Infrared
UV
Visible
Near-IR
Aurora (high-energy particle precipitation)
Airglow (chemiluminescence / photochemistry)
Relative Intensity
Wavelength (nm)
N2 337.1
N2 357.7
N2+ 391.4
N2+ 427.8
N2 470.9
O1S 557.7
Na D 589.3
O1D 630.0
O1D 636.4
O 777.4
O 844.6
N2 868.0
OH Meinel 309.0 nm (mesosphere)
O1S 557.7 (97 km)
Na D 589.3 (90 km)
O1D 630.0 (F-region ~250 km)
O1D 636.4 (~250 km)
OH (8-3) (~87 km)
OH (7-2) (~87 km)
O2 (0-0) (~94 km)
O 777.4 (~95 km)
OH (6-1) (~87 km)
O2 (0-1) n(~94 km)
OH (5-0) (~87 km)
O 844.6 ~95 km)

The November 2025 Storm

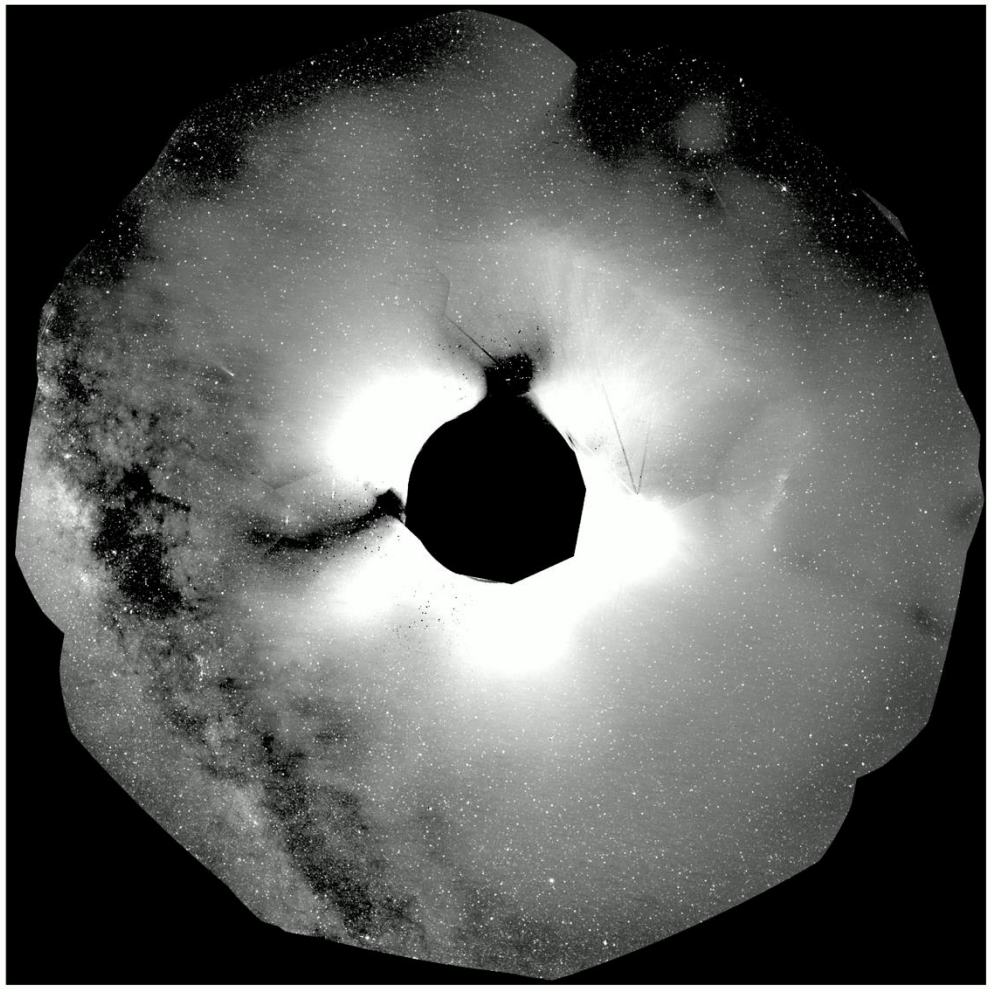


- In November 2025, a series of consecutive CMEs associated with X-class solar flares impacted Earth
- This produced highly active auroral conditions
- Auroral activity can be tracked using the Auroral Electrojet (AL) index (see last panel)
- Strong activity is observed on November 12–13
- Quiet conditions are present prior to the storm (November 11), and again on November 14, during the recovery phase.

November 13-14, 2025

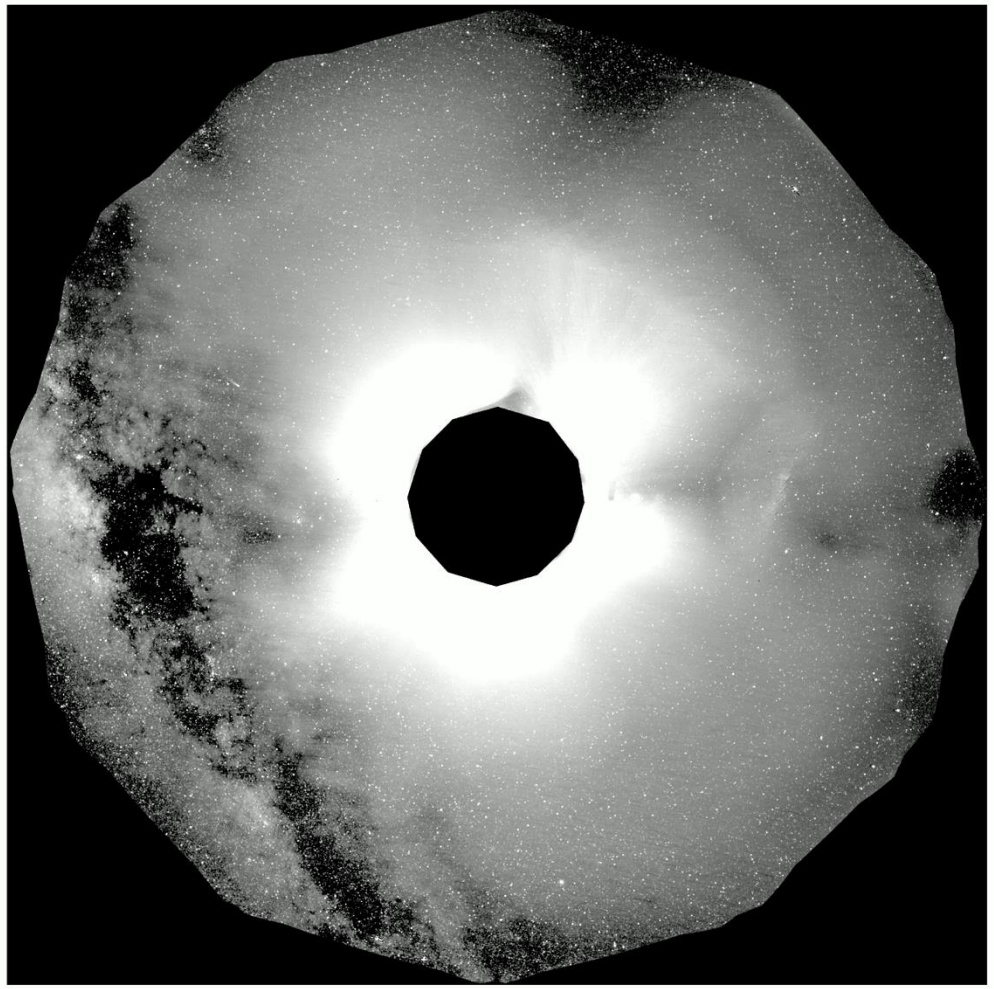
Level 3 PUNCH data

2025-11-13



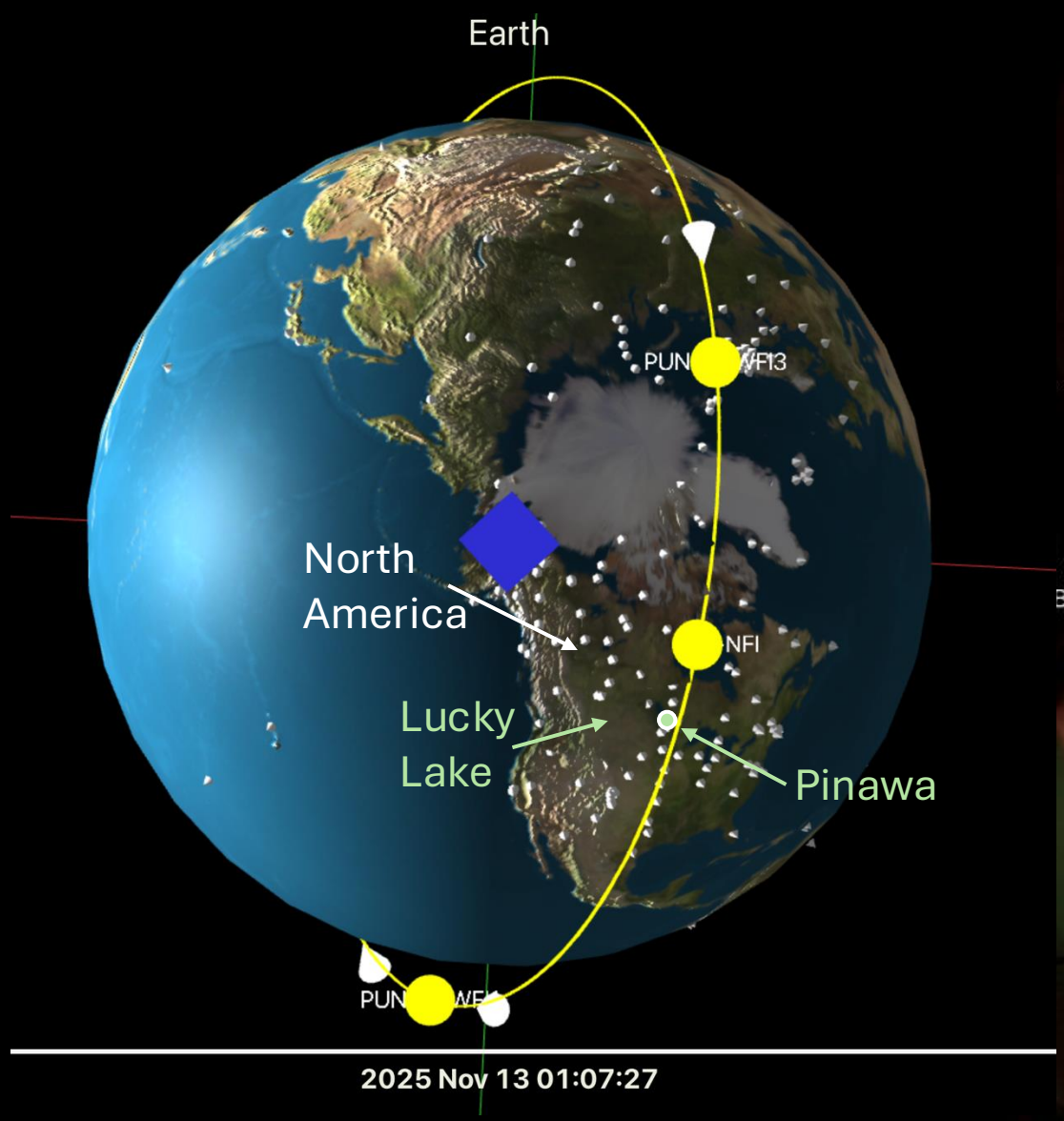
2025-11-13/00:16:00

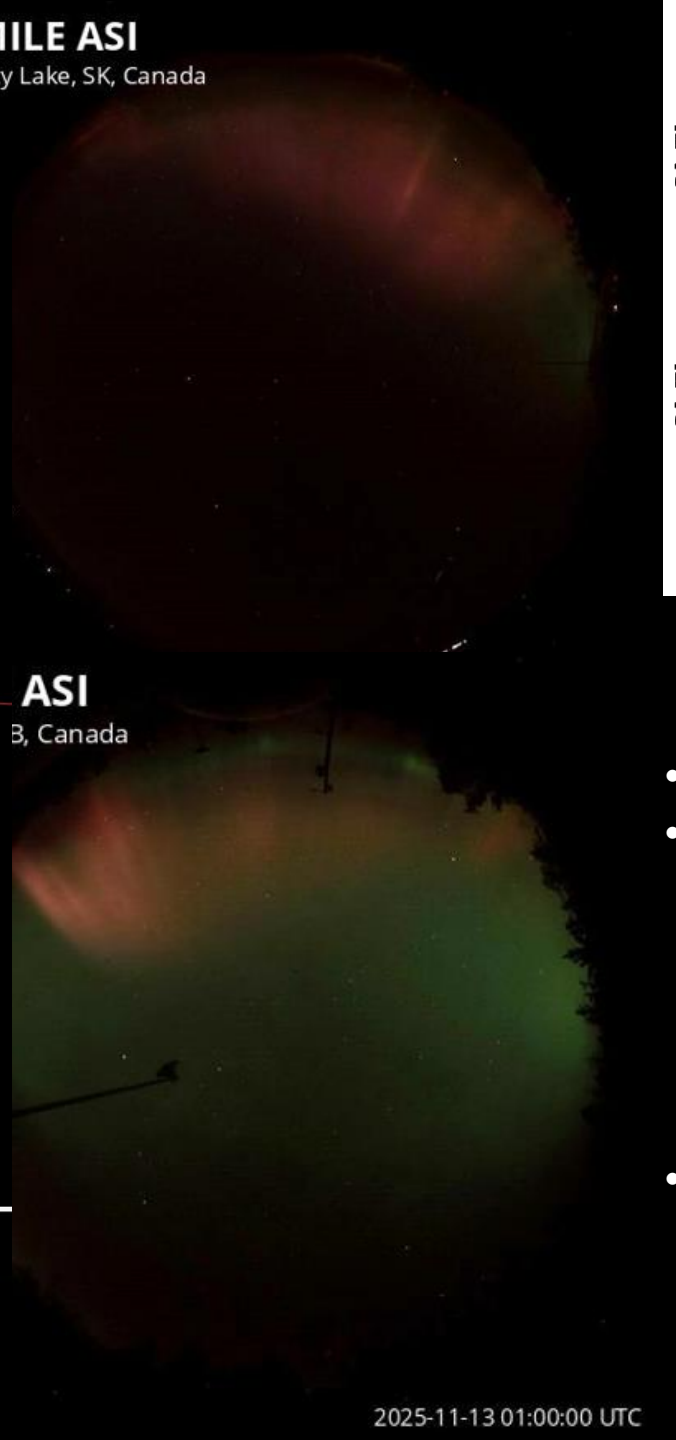
2025-11-14

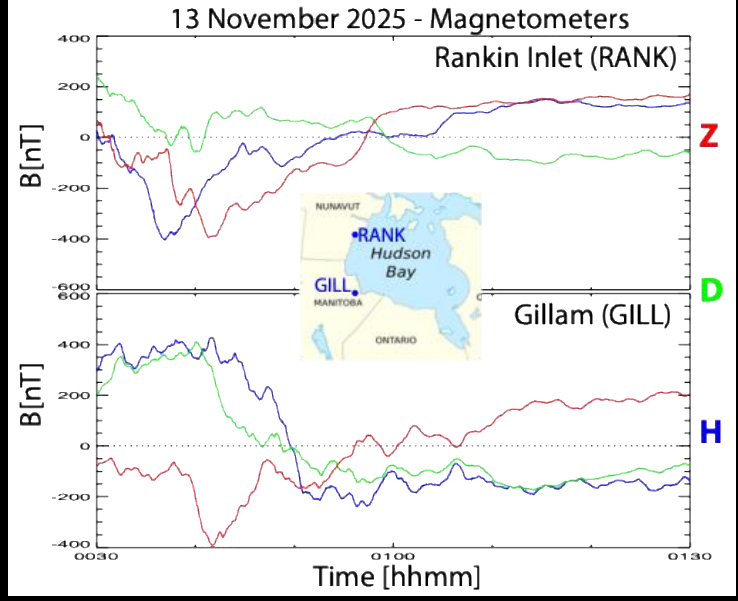


2025-11-14/00:16:00

Event 1

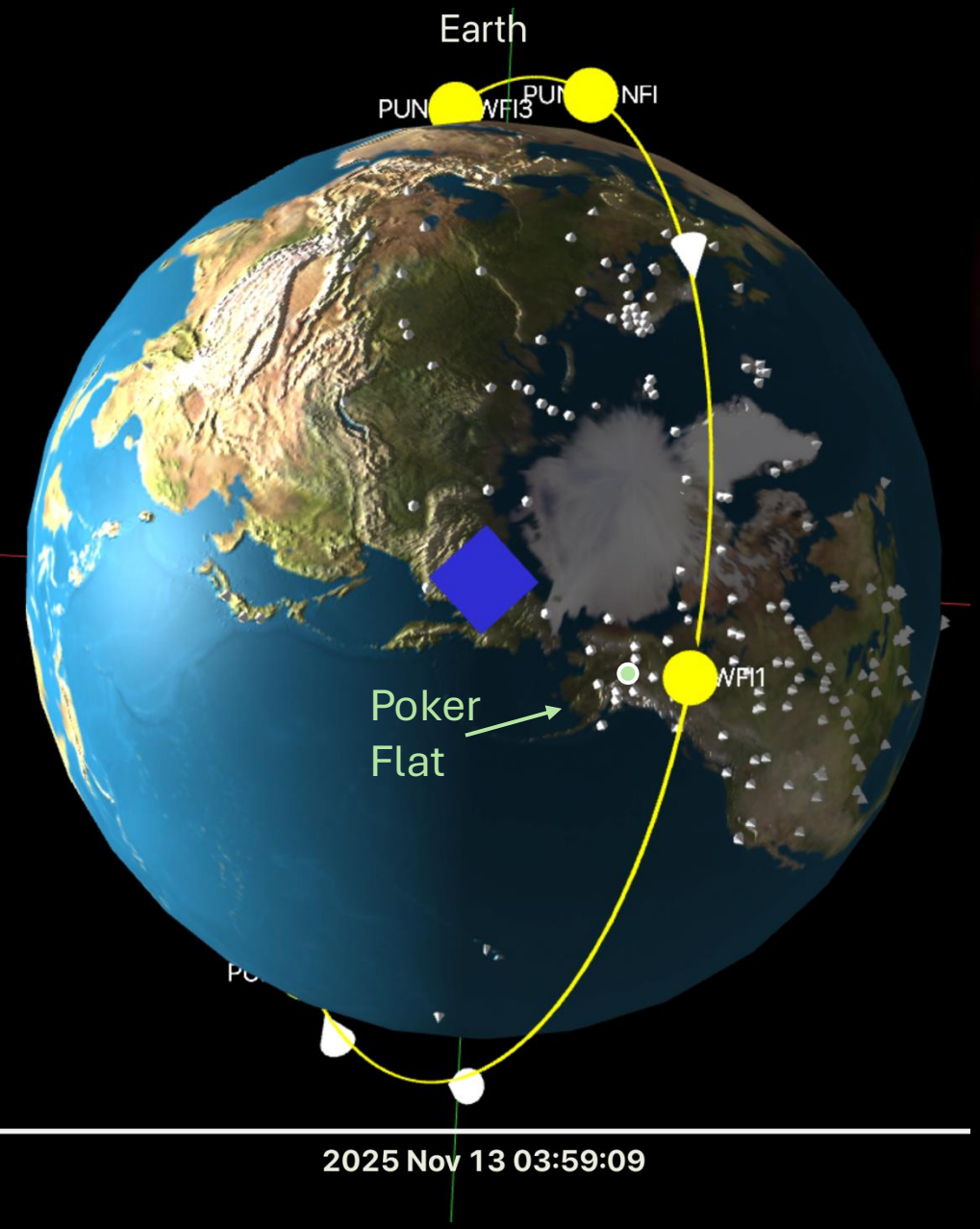




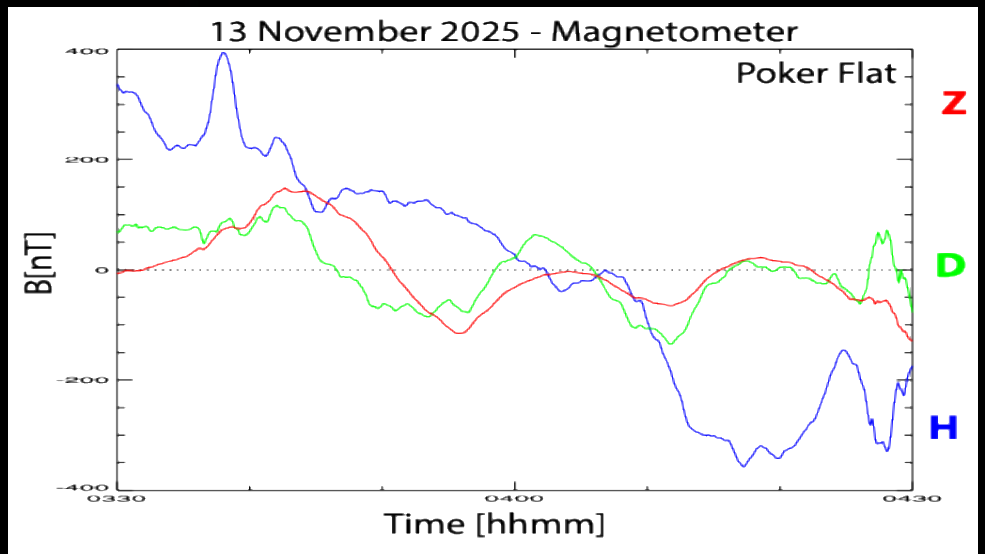


- The aurora is highly active
- Ground-based cameras at Rankin and Gillam (near NFI's mapped location) appear to be cloudy out at this time, but magnetometer observations show clear oscillations
- These signatures indicate an active auroral oval

Event 2



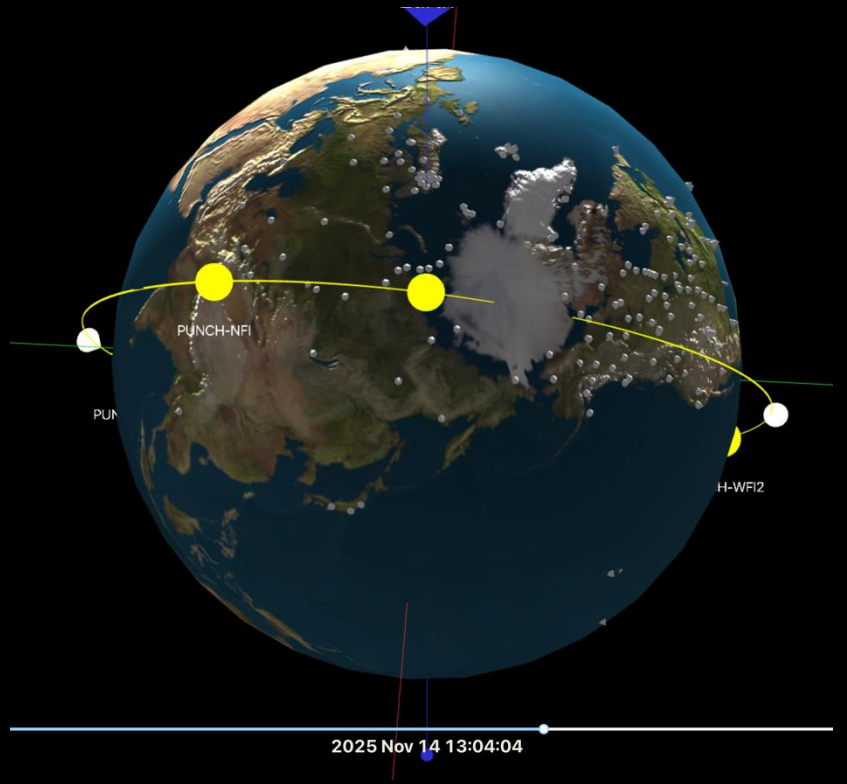
- Like the previous event, the aurora is very active
- Magnetometer station near WFI1 in Alaska show strong perturbations reaching magnitudes of ~400 nT
- These signatures indicate intense auroral activity in the region.

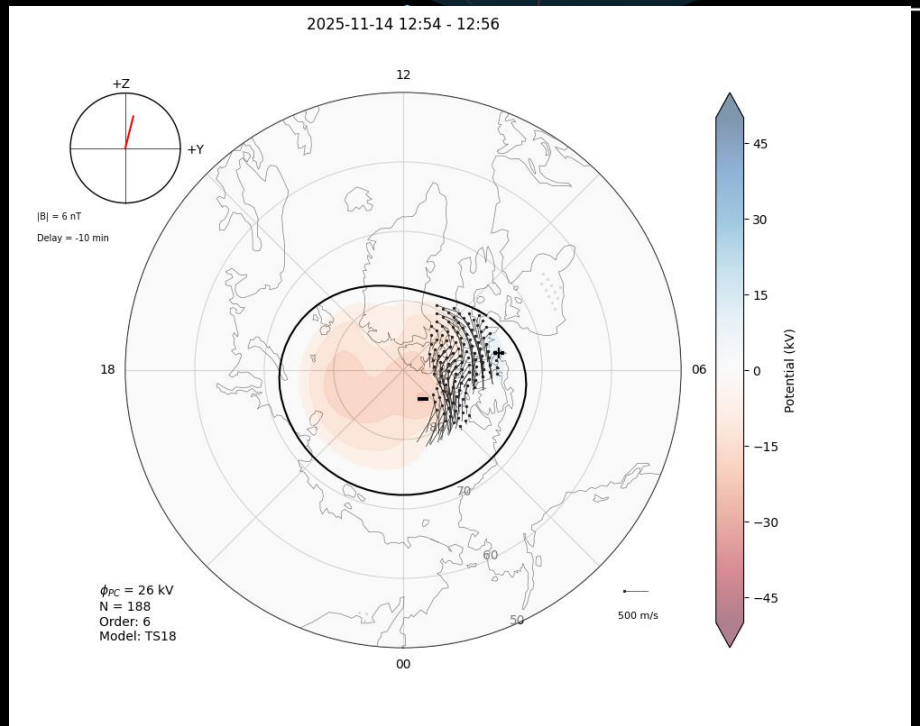


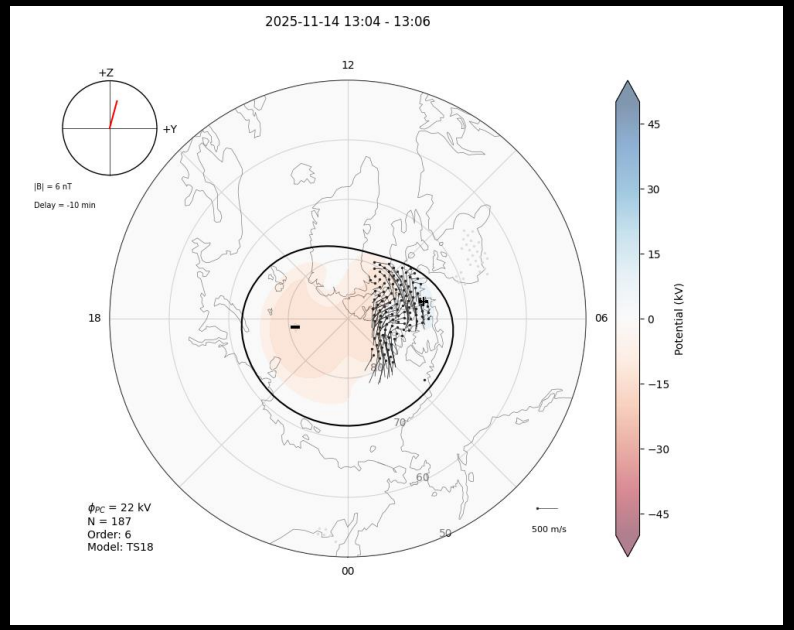
Summary

- Based on bandpass and FOV of PUNCH (WFI-focused so far) is most likely to observe auroral and airglow red emission lines
- Key emissions include the red doublet (630.0 and 636.4 nm) and H-α emission associated with proton precipitation
- Polar cap ion outflow (AKA ‘cusp aurora’) from N2 and Hydrogen if it is solar illuminated could be visible too.
- The sensitivity of the WFI and NFI instruments is critical for identifying detectable signals and ruling out emissions below the detection threshold
- Scattered light from airglow and aurora below the FOV?
- Best path forward: start with geomagnetic events e.g. ASIs and other ground-based instrumentation


Earth
NFI
PUNCH-WFI
PUNCH-WFI3


PUNCH-NFI
H-WFI2
2025 Nov 14 13:04:04


2025-11-14 12:54 - 12:56
+Z
+Y
|B| = 6 nT
Delay = -10 min
12
18
06
00
ϕ_{PC} = 26 kV
N = 188
Order: 6
Model: TS18
500 m/s
Potential (kV)
45
30
15
0
−15
−30
−45


2025-11-14 13:04 - 13:06
+Z
+Y
|B| = 6 nT
Delay = -10 min
12
18
06
00
ϕ_{PC} = 22 kV
N = 187
Order: 6
Model: TS18
500 m/s
Potential (kV)
45
30
15
0
−15
−30
−45

Extra slides

Nightglow

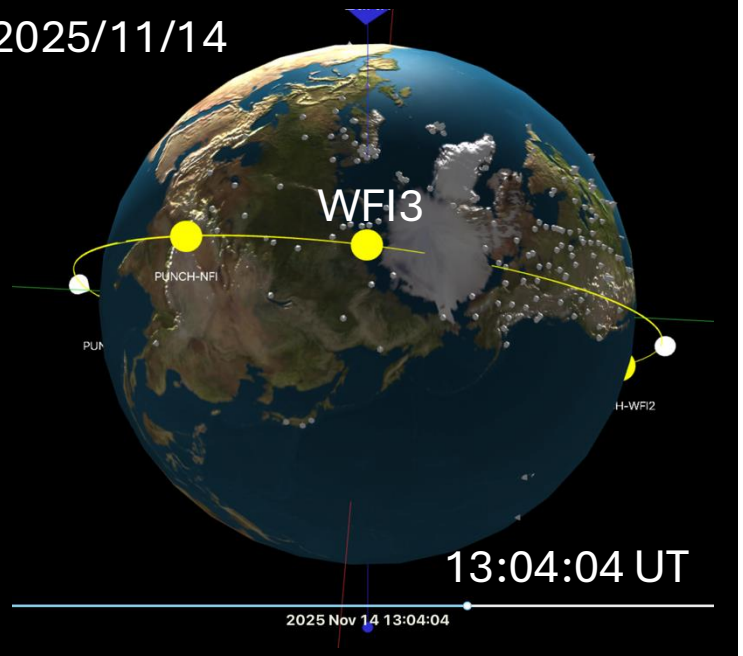
Table 1. Nightglow Emission Systems

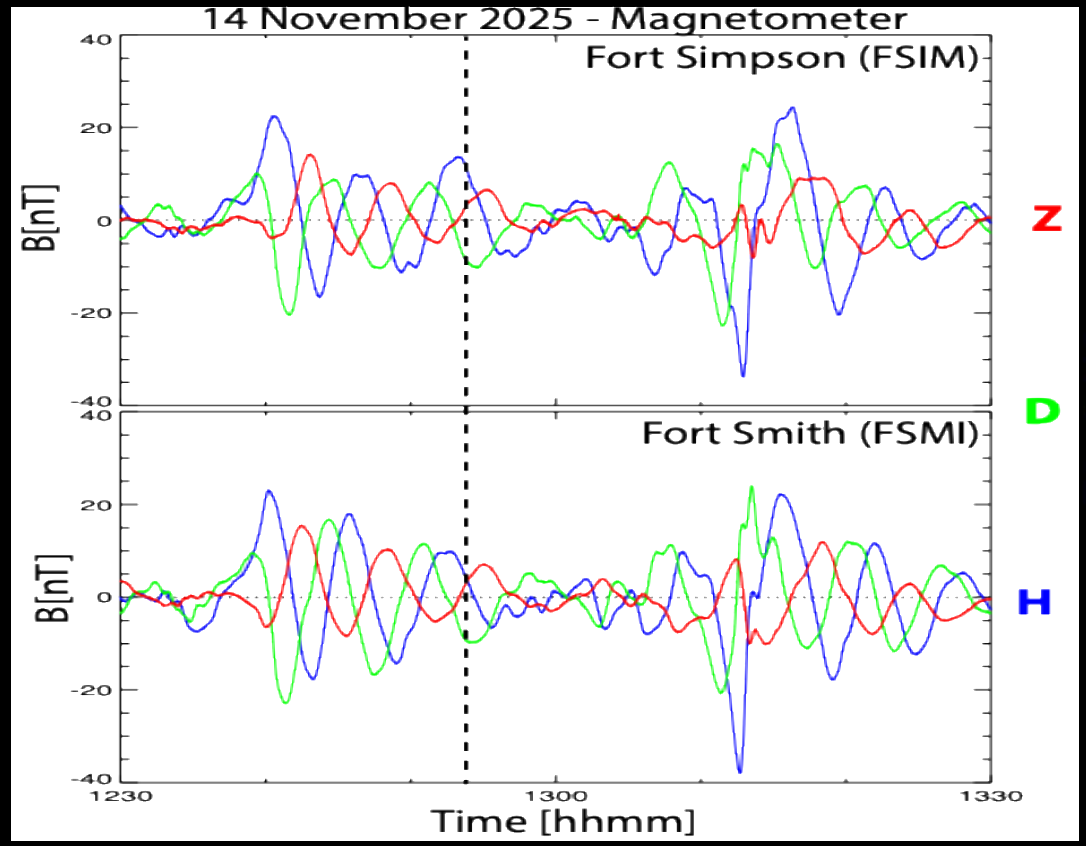
Cosby et al, 2006

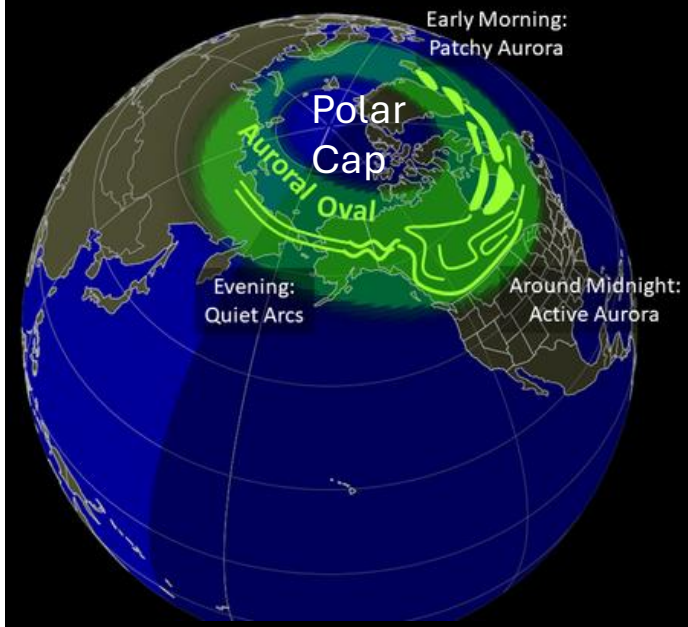
Features	Wavelengths, nm
Mesopause (80–100 km)	
OH Meinel	>467
O_2(*A*-*X*) Herzberg I	260–550
O_2(*A′*-*a*) Chamberlain	310–550
O_2(*c*-*b*)	390–450
O_2(*c*-*X*) Herzberg II	260–400
Na(D_2, D_1)	589.0, 589.6
K(D_1)	769.9
Mesosphere/Thermosphere	
O(^1S-^1D)	557.7
O_2(*b*-*X*) Atmospheric	650–1100
Ionosphere (≥200 km)	
O(^1D-^3P)	630.0, 636.4
O(Rydberg)	395–1200
N($^2D^o$-$^4S^o$)	519.8,520.0

Equatorial region (see Slanger et al., 2004)

Event 2







- For this event, WFI3 is likely crossing the polar cap boundary (estimated from radar data)
- This boundary marks the poleward edge of the auroral oval
- The magnetic field topology transitions here from closed field lines (within the oval) to open field lines (polar cap)
- However, on November 14, geomagnetic conditions were very quiet
- While magnetometer data show some oscillations, the amplitudes are small (~4 nT) at the time of the satellite crossing

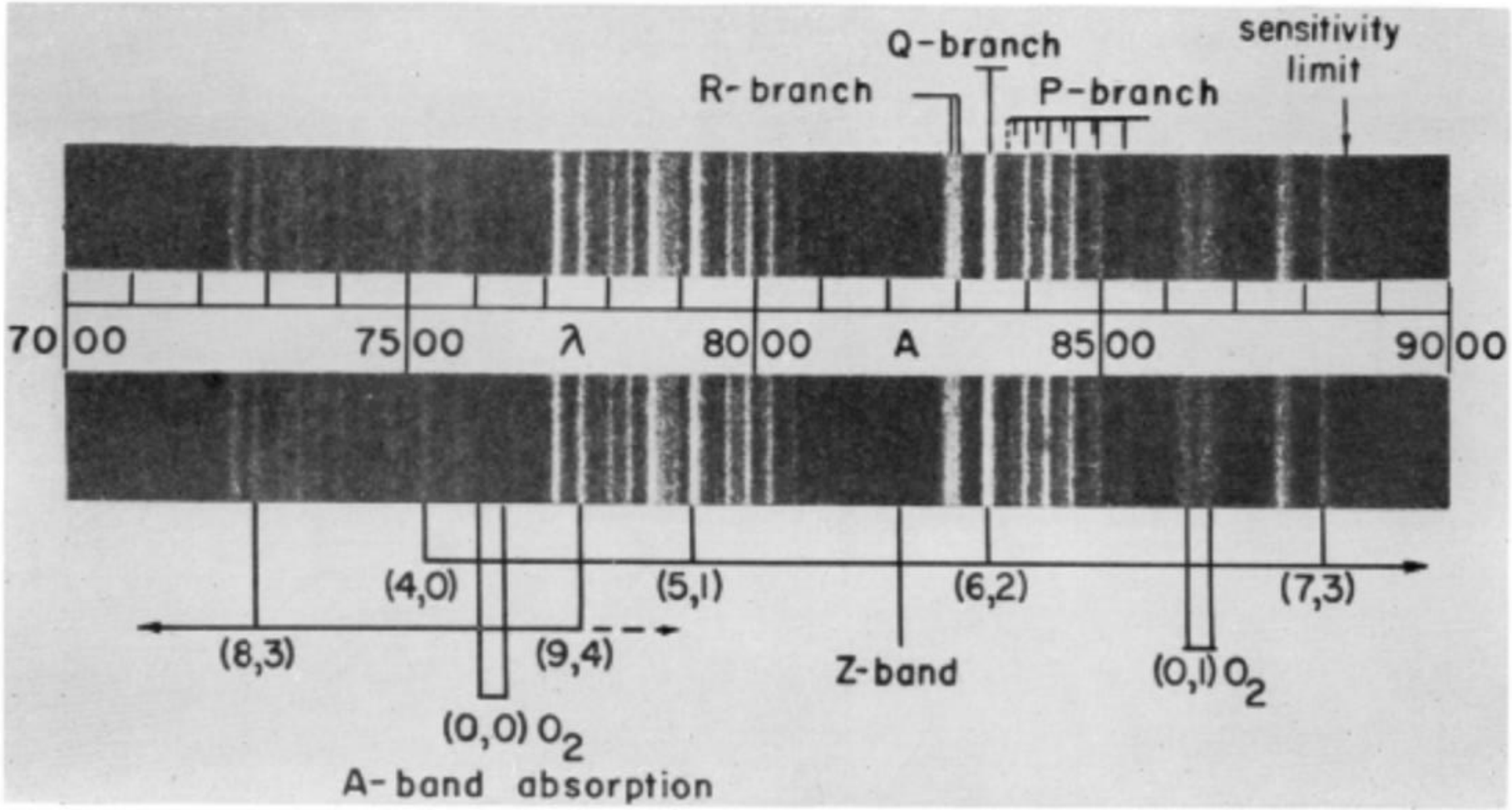
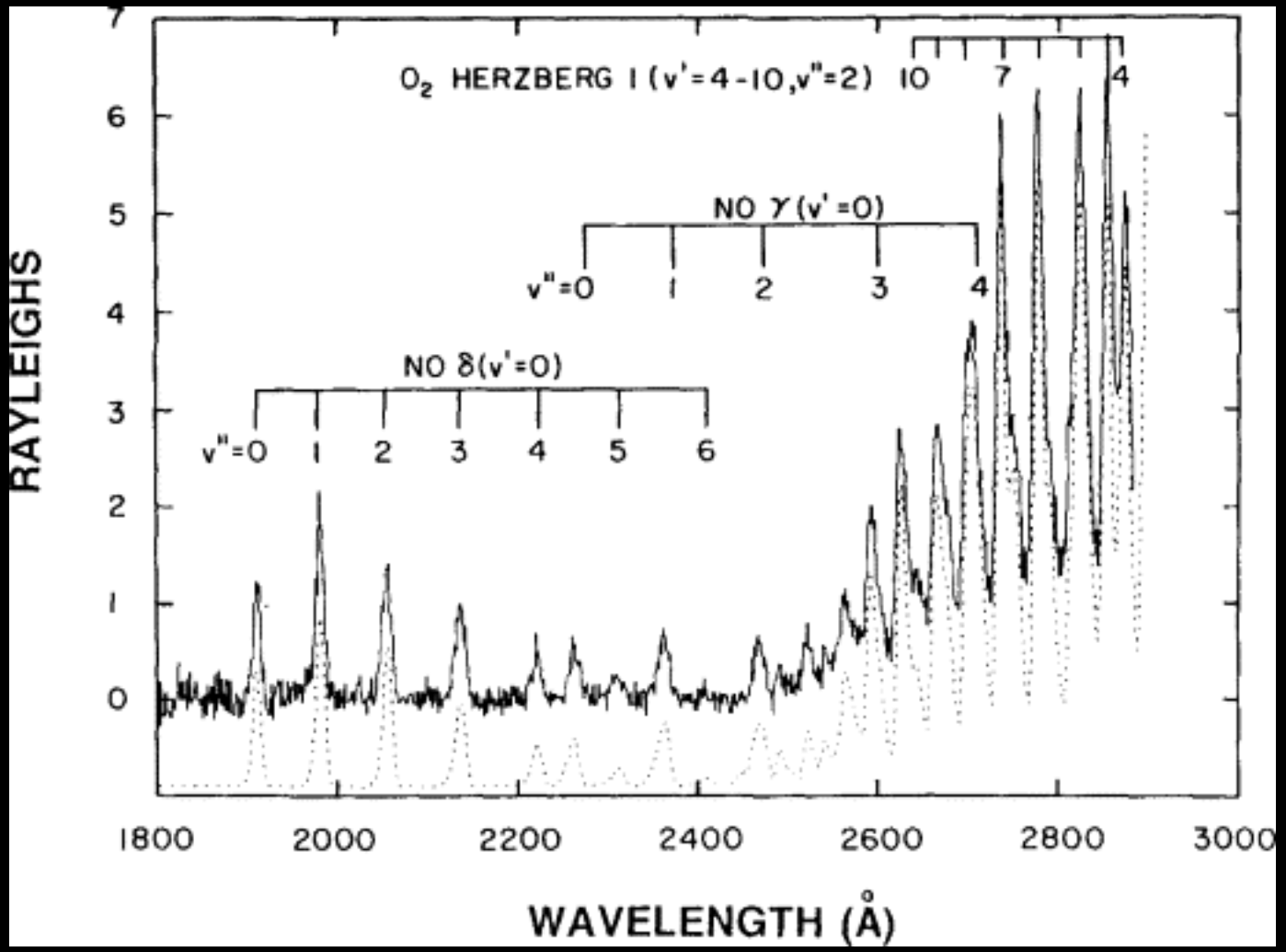
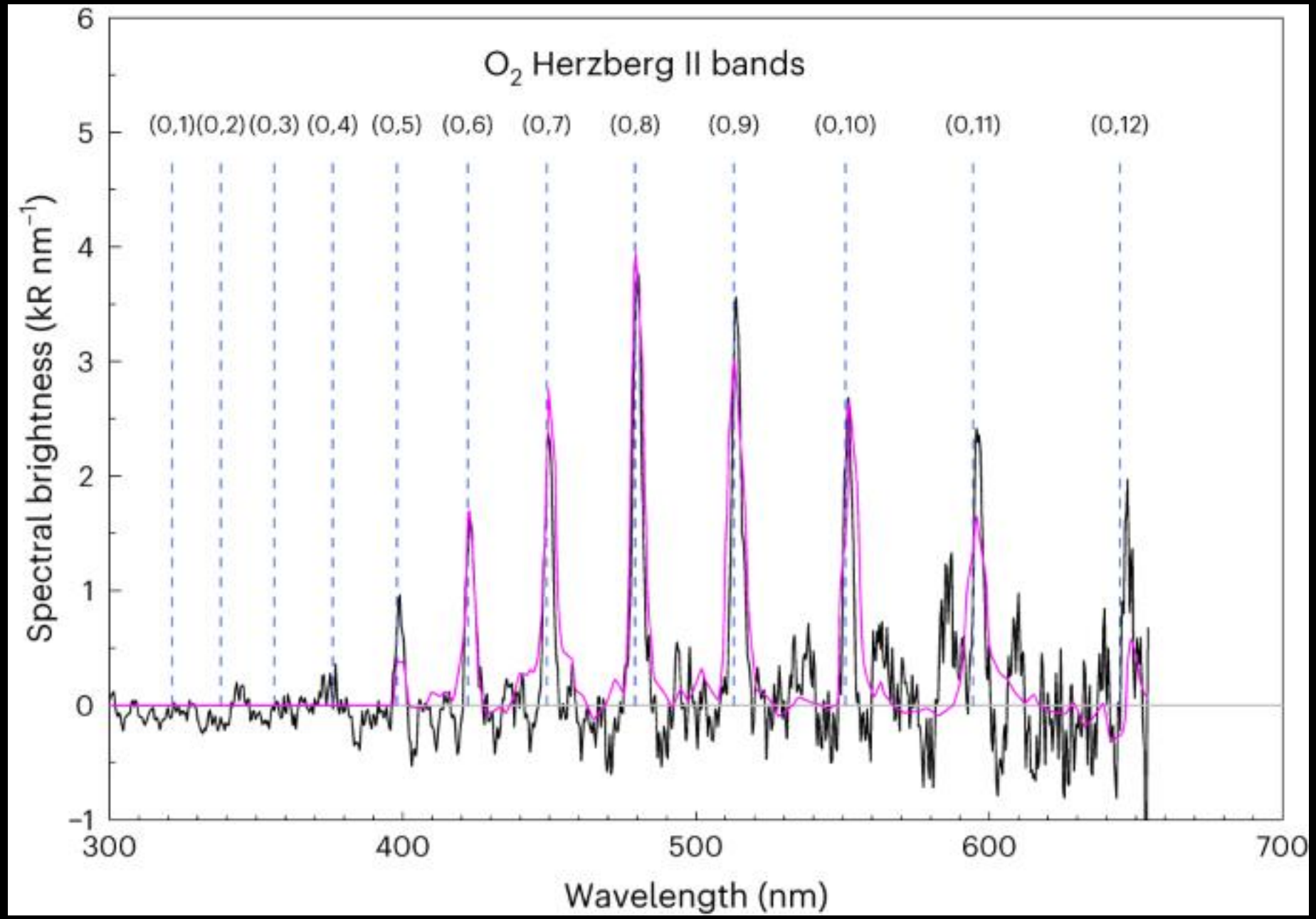


FIG. 1.—Infrared spectrum of the night sky, 7000–9000 A

Meinel, 1950


O_2 HERZBERG I (v'=4-10,v"=2)
10
7
4
NO γ(v'=0)
v"=0 1 2 3 4
NO δ(v'=0)
v"=0 1 2 3 4 5 6
RAYLEIGHS
0 1 2 3 4 5 6 7
1800 2000 2200 2400 2600 2800 3000
WAVELENGTH (Å)


O_2 Herzberg II bands
(0,1)
(0,2)
(0,3)
(0,4)
(0,5)
(0,6)
(0,7)
(0,8)
(0,9)
(0,10)
(0,11)
(0,12)
Spectral brightness (kR nm^{-1})
6
5
4
3
2
1
0
−1
300
400
500
600
700
Wavelength (nm)

The aurora spectrum 380.5 nm-1160.0nm (Physics of the Aurora and Airglow—Chamberlain)

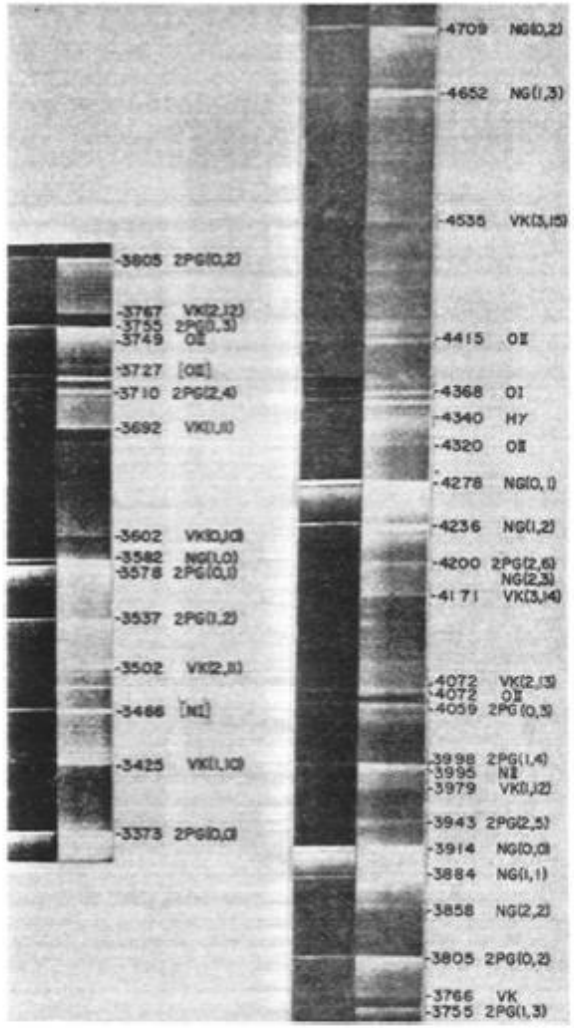


FIG. 5.2. Auroral spectra, 3340-4710 A, obtained with a dispersion of 28 A/mm. Tracings are shown in Figs. 5.8 and 5.9. After Petrie and Small [1952a]; courtesy University of Chicago Press.

FIG. 5.3. Auroral spectra, 3700-4750 A. The spectrum 3700-4430 A was obtained with a dispersion of 22 A/mm during the great red aurora, 11 February 1958. The one on the right is from an ordinary green aurora, 10 November 1956; dispersion 33 A/mm. From Yerkes Observatory plates nos. 128 and 77. Tracings are shown in Figs. 5.11, 5.12, and 5.13.

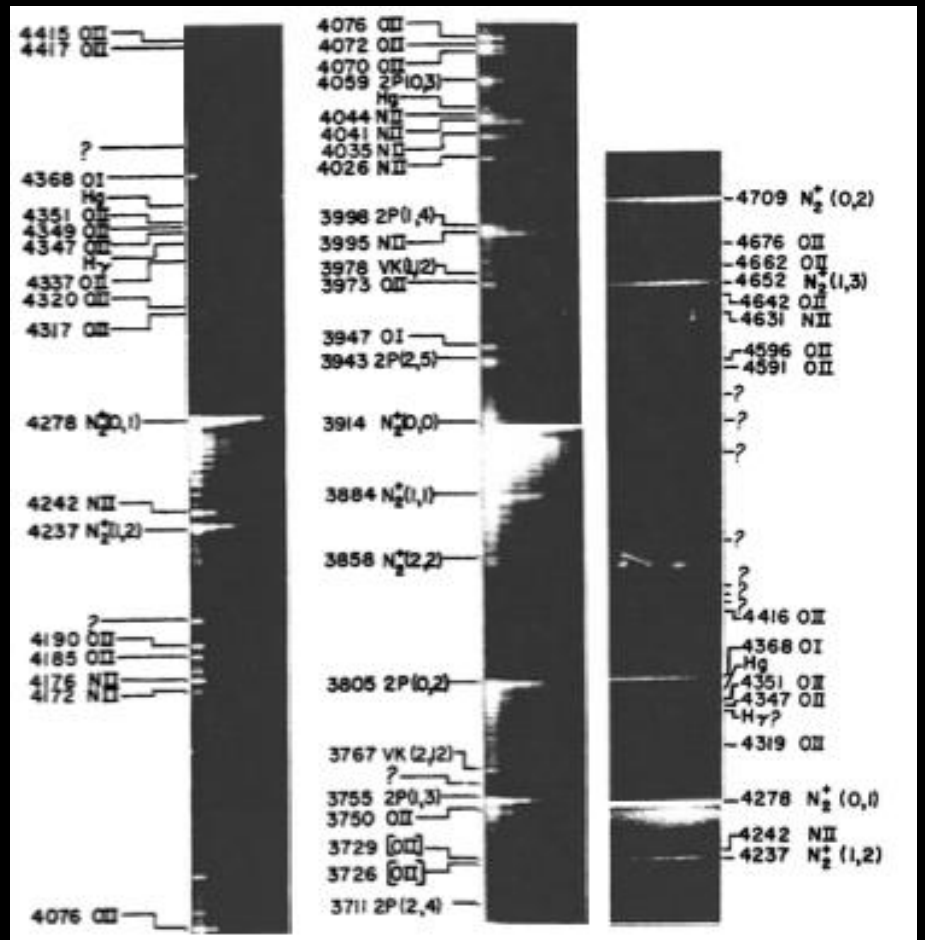


FIG. 5.3. Auroral spectra, 3700-4750 A. The spectrum 3700-4430 A was obtained with a dispersion of 22 A/mm during the great red aurora, 11 February 1958. The one on the right is from an ordinary green aurora, 10 November 1956; dispersion 33 A/mm. From Yerkes Observatory plates nos. 128 and 77. Tracings are shown in Figs. 5.11, 5.12, and 5.13.

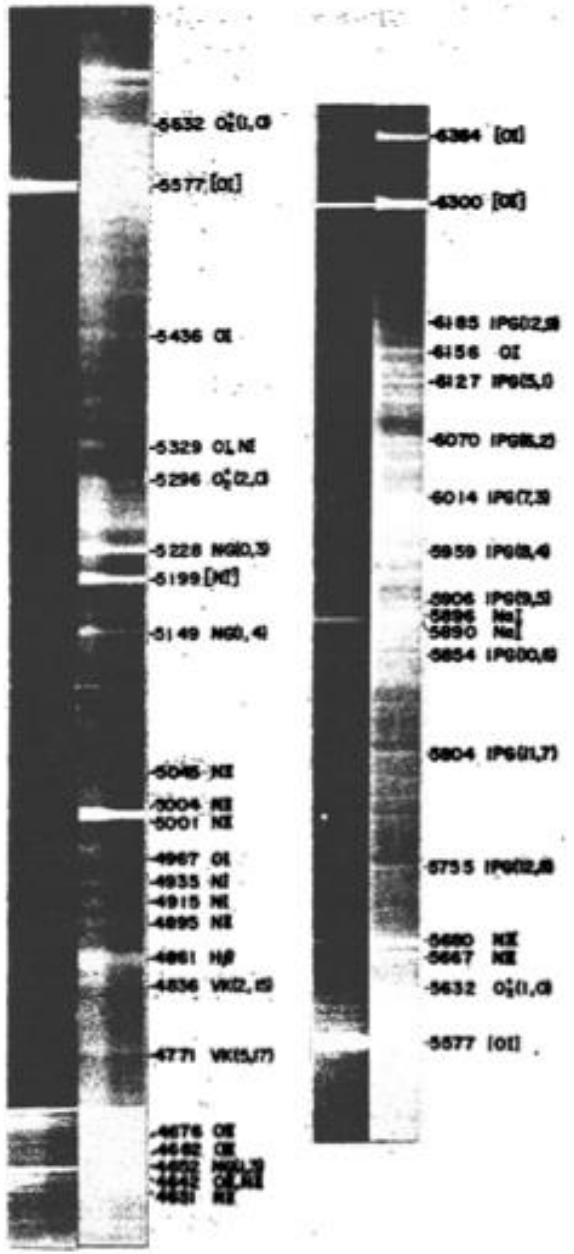


FIG. 5.4. Auroral spectra, 4620-6370 A, with a plate dispersion of 43 A/mm. Tracings are shown in Figs. 5.14, 5.15, and 5.16. After Petrie and Small [1952a]; courtesy University of Chicago Press.

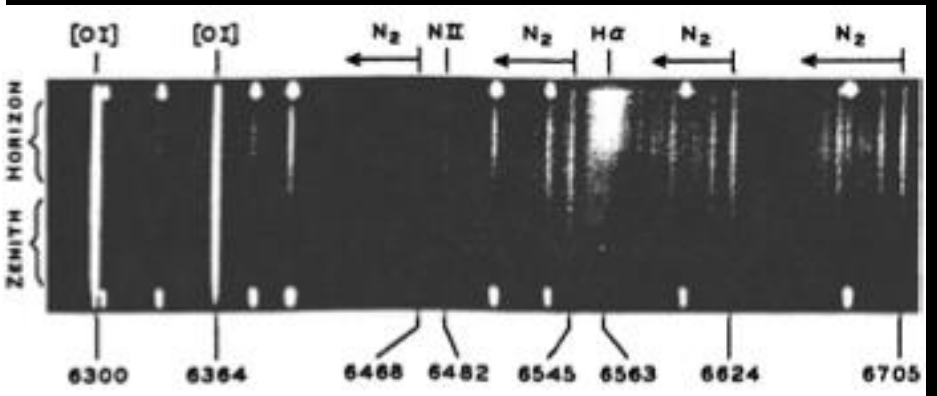


FIG. 5.5. Auroral spectra, 6290-6710 A, from the aurora of 2 March 1957, with dispersion 33 A/mm. Compare with the low-dispersion spectrum of the same aurora in Fig. 5.1. The upper part of this spectrum was photographed with light from near the north horizon, while the lower part shows the spectrum near the magnetic zenith, which was fainter. The central portion is a mixture. Faint neon lines from advertising signs in a neighboring village contaminate the upper half, but can be identified with the aid of the neon comparison spectrum at the top and bottom edges. Tracings of Hα are shown in Fig. 5.19. From Yerkes Observatory plate no. 92.

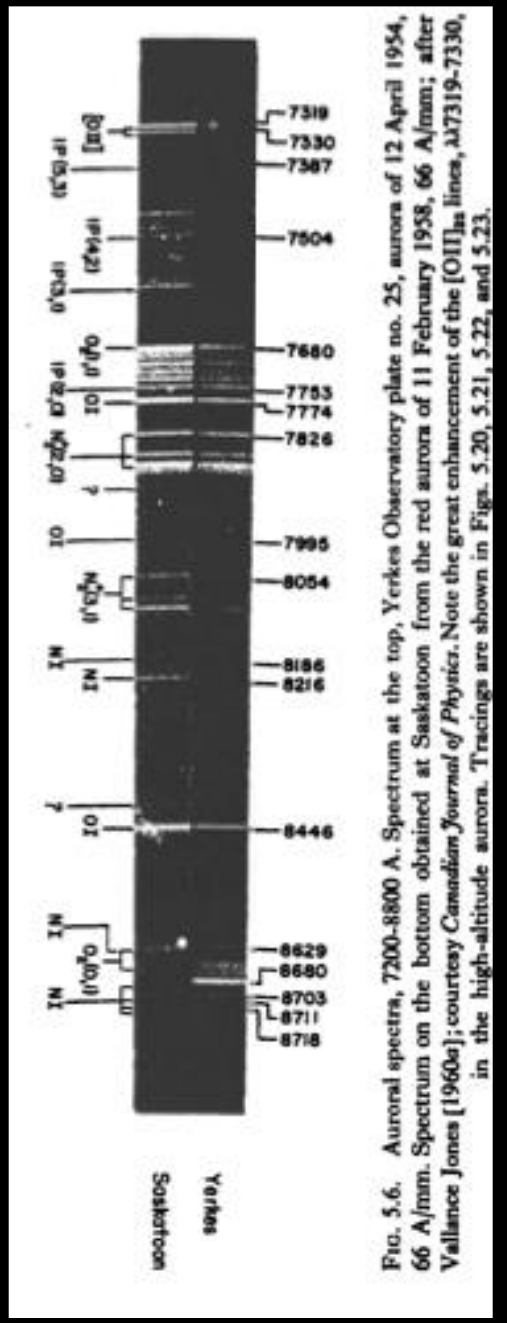


FIG. 5.6. Auroral spectra, 7200-8800 A. Spectrum at the top, Yerkes Observatory plate no. 25, aurora of 12 April 1954, 66 A/mm. Spectrum on the bottom obtained at Saskatoon from the red aurora of 11 February 1958, 66 A/mm; after Vallance Jones [1960a]; courtesy *Canadian Journal of Physics*. Note the great enhancement of the [OII]$_{3s}$ lines, λλ7319-7330, in the high-altitude aurora. Tracings are shown in Figs. 5.20, 5.21, 5.22, and 5.23.

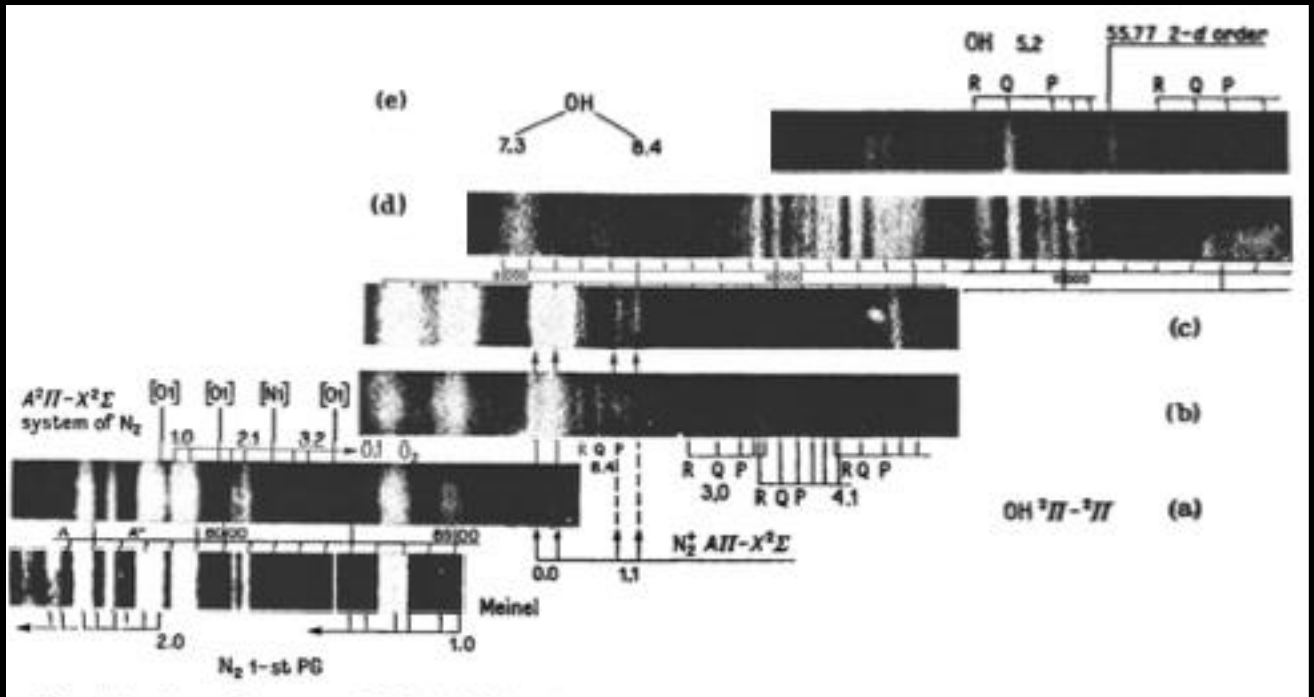
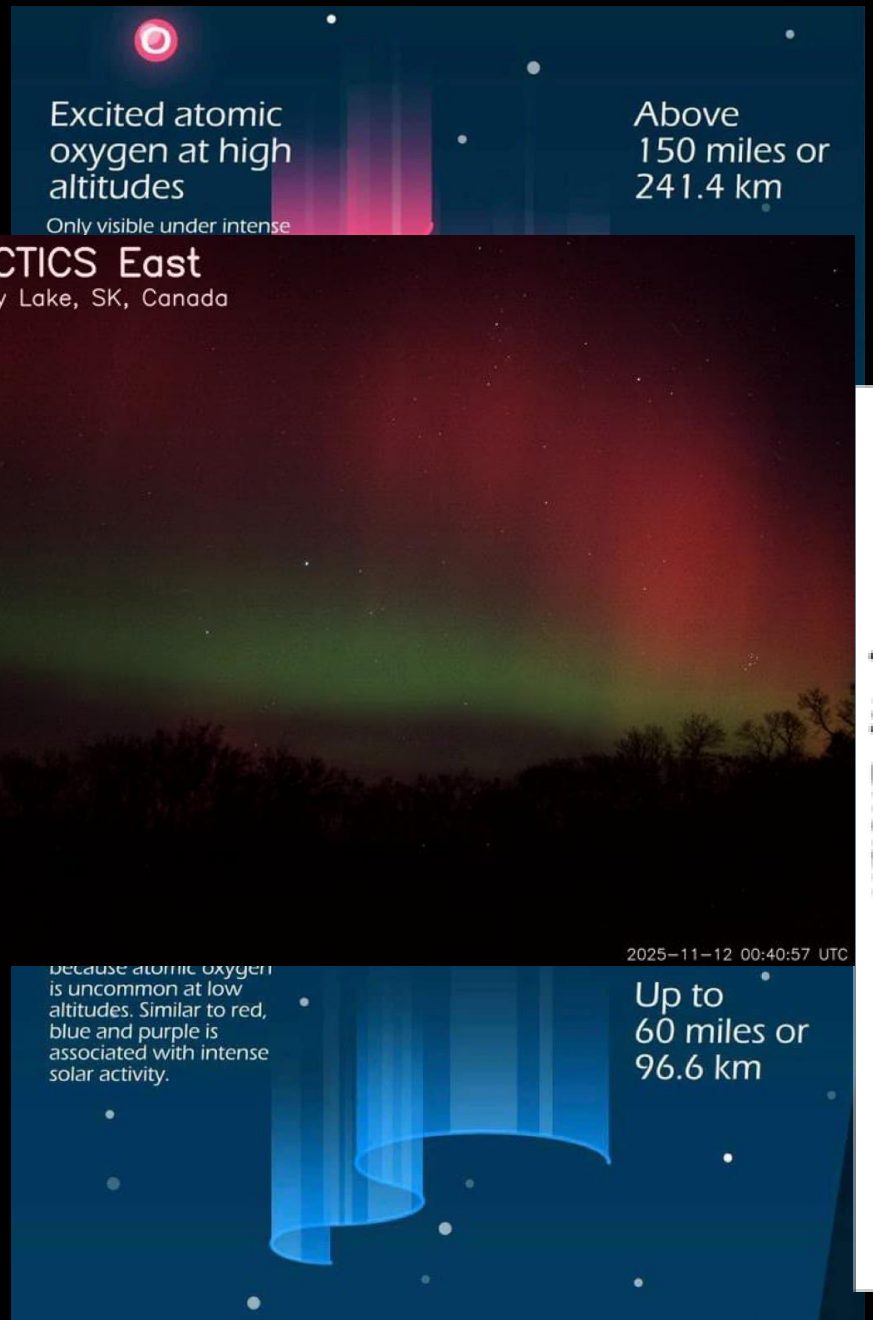
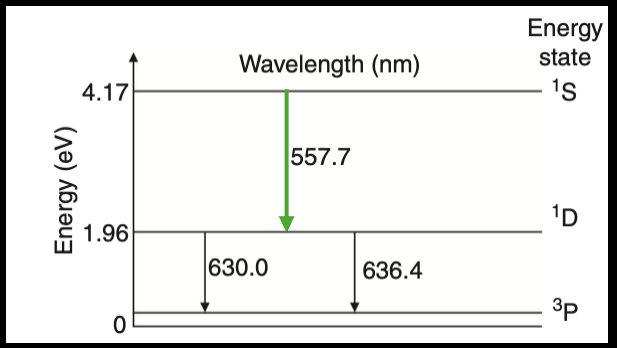


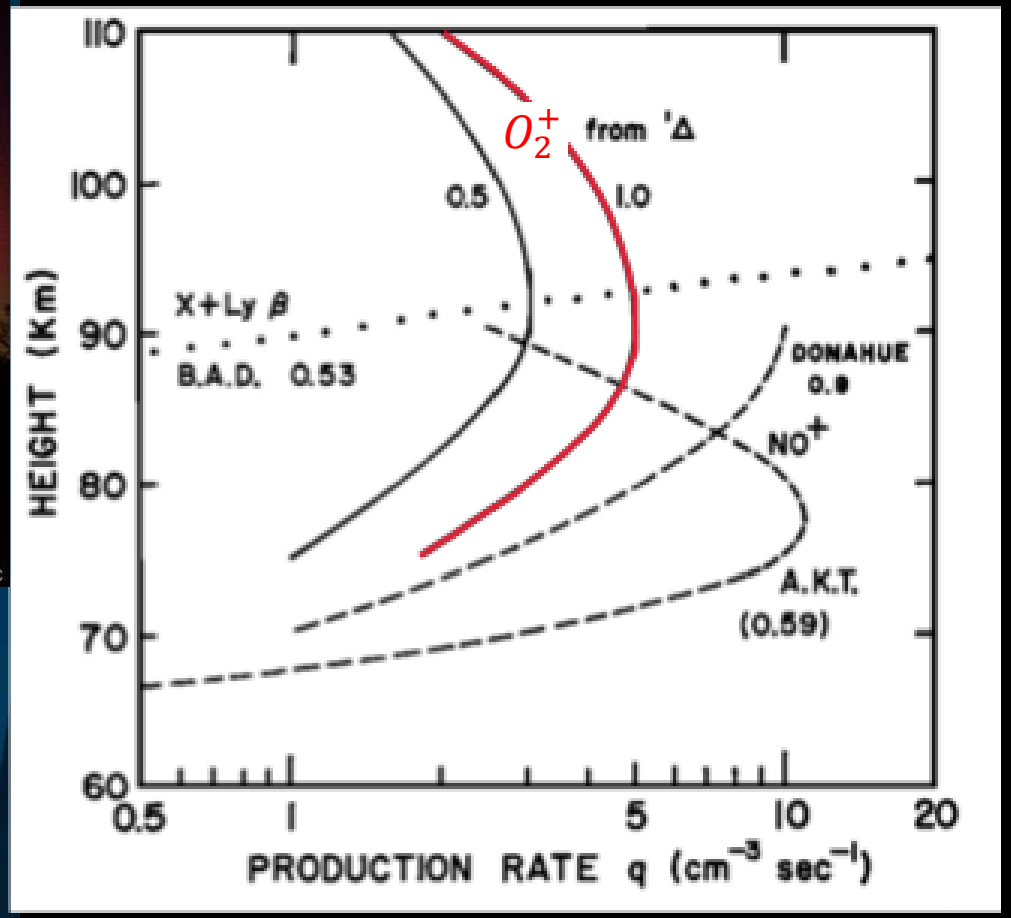
FIG. 5.7. Auroral spectra, 7200-11,600 A, obtained with a grating spectrograph and image converter. After Bagariatskii and Fedorova [1956a]; courtesy Pergamon Press.

Atmospheric Emissions at Earth: What Should PUNCH Observe?



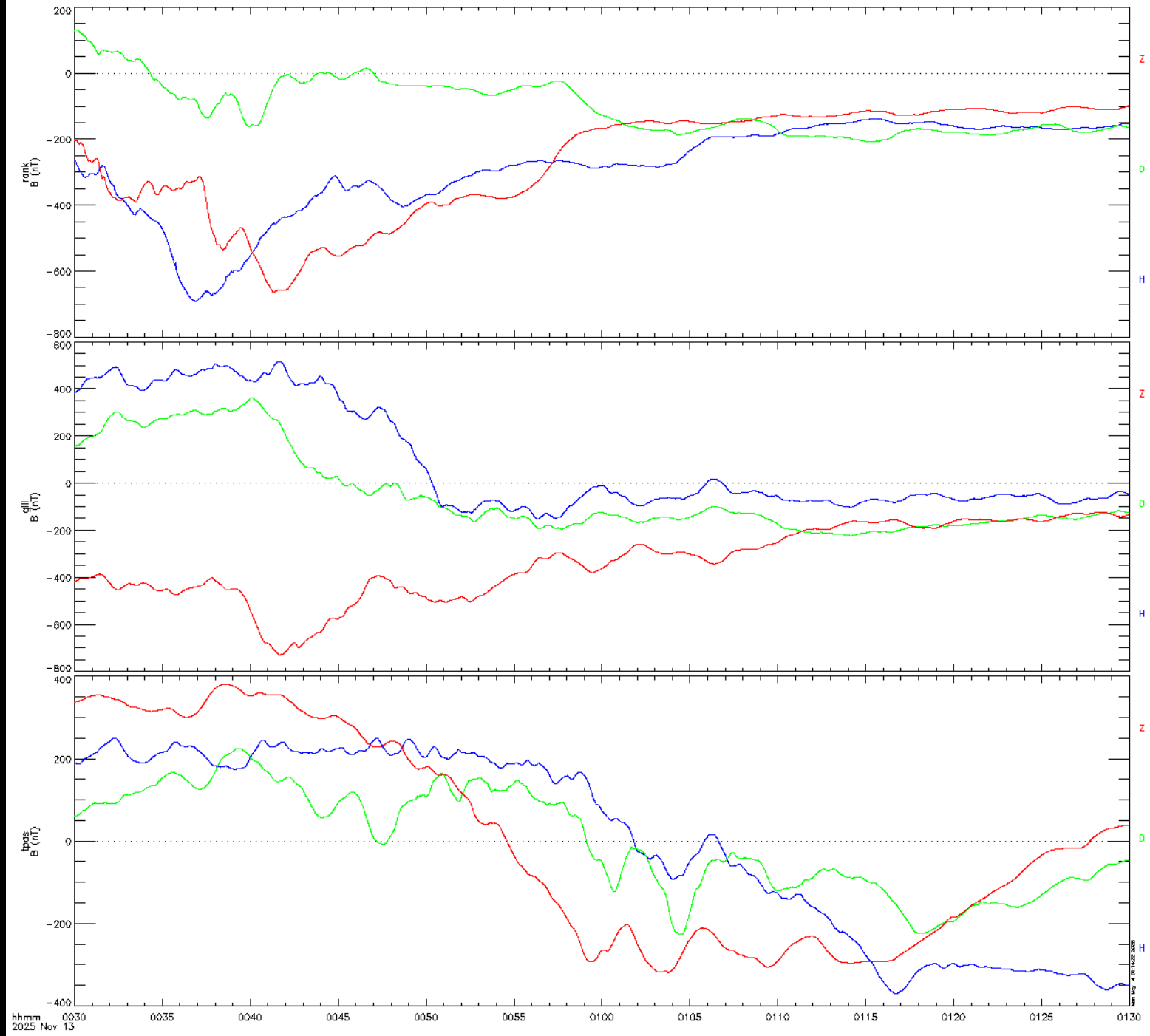
- The dominant source of O(¹S) — the transition responsible for the green-line emission (557.7 nm) — is dissociative recombination of O_2^+ (Whiter et al., 2023)



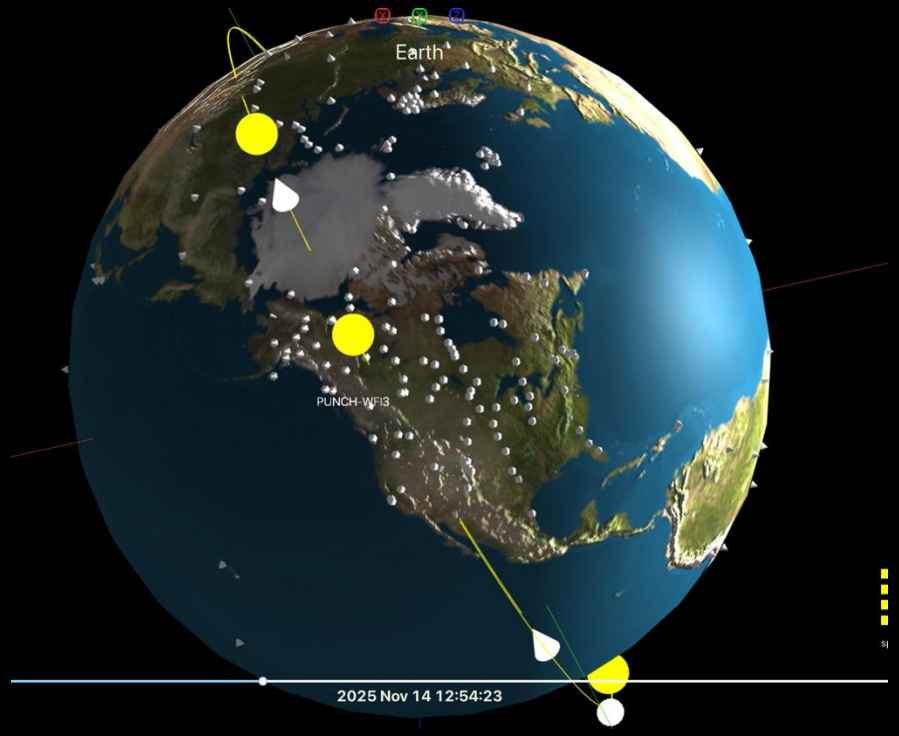


- O_2^+ peaks at ~90–110 km altitude (Hunter and McElroy, 1968)
- This sets the typical altitude of the green-line emission

- **Therefore, the green-line emission occurs below the altitude range most relevant for high-altitude auroral observations by PUNCH.**



Magnetometer data for Nov 13


Earth
PUNCH-WFI3
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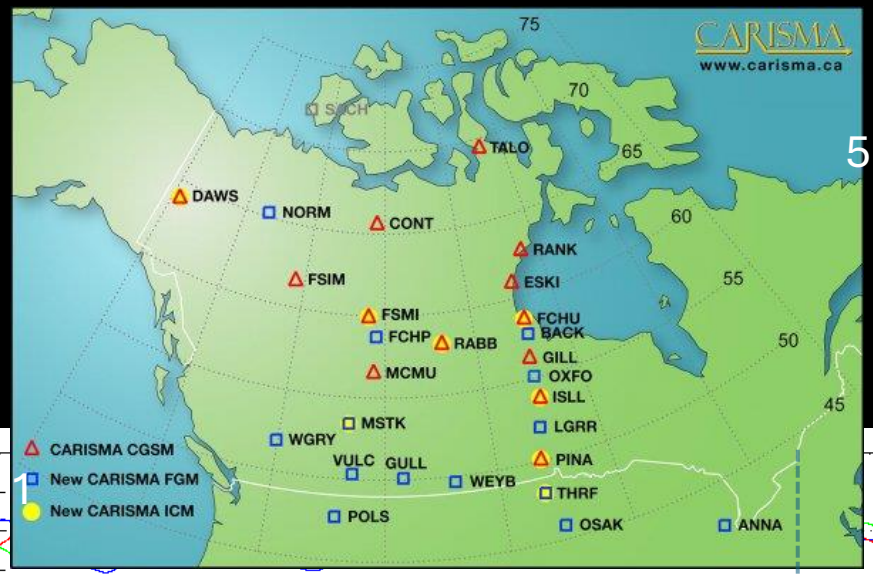
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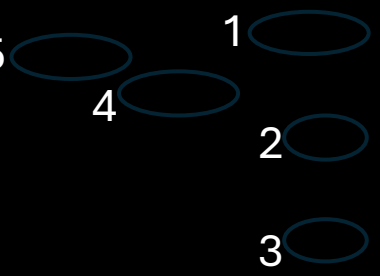
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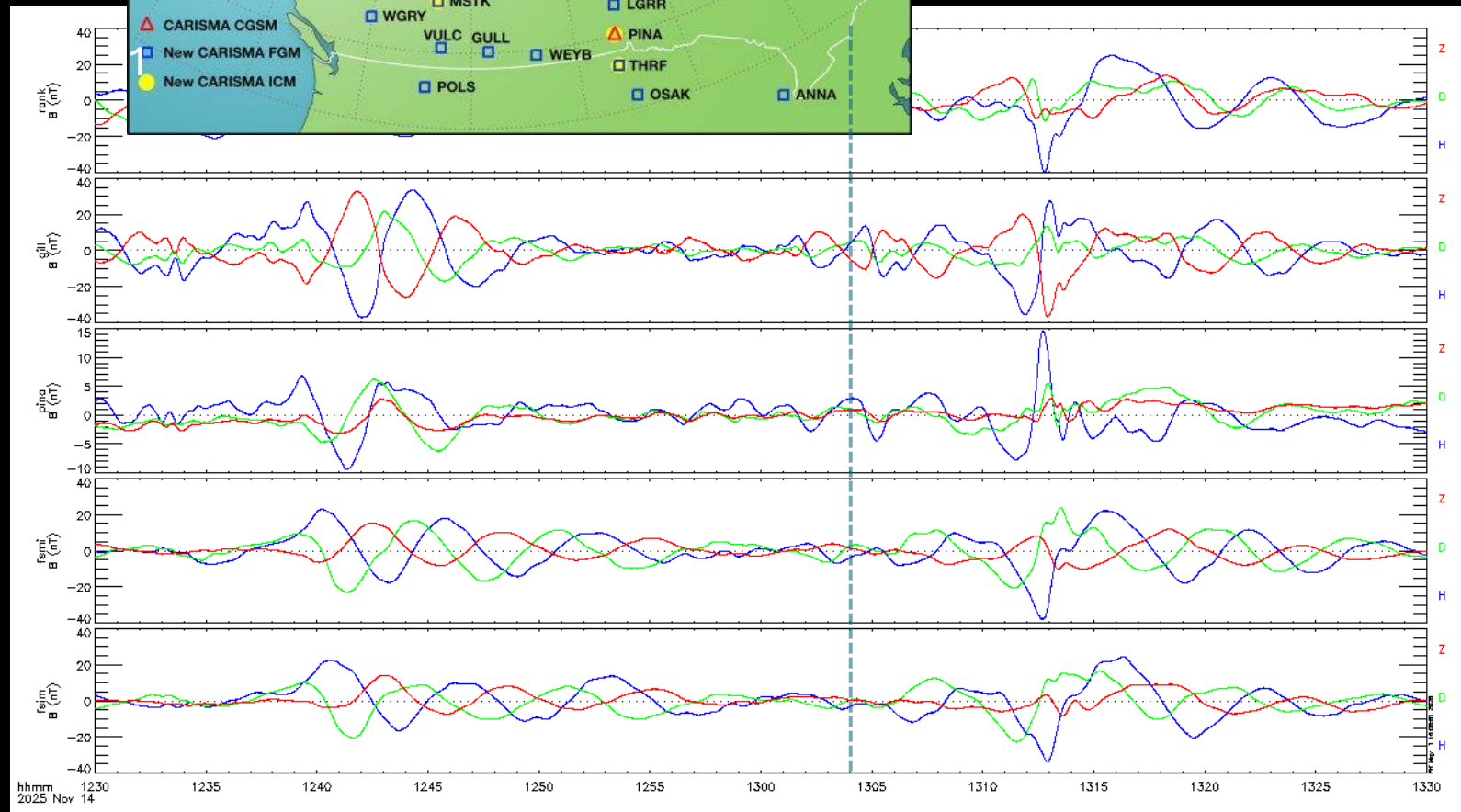
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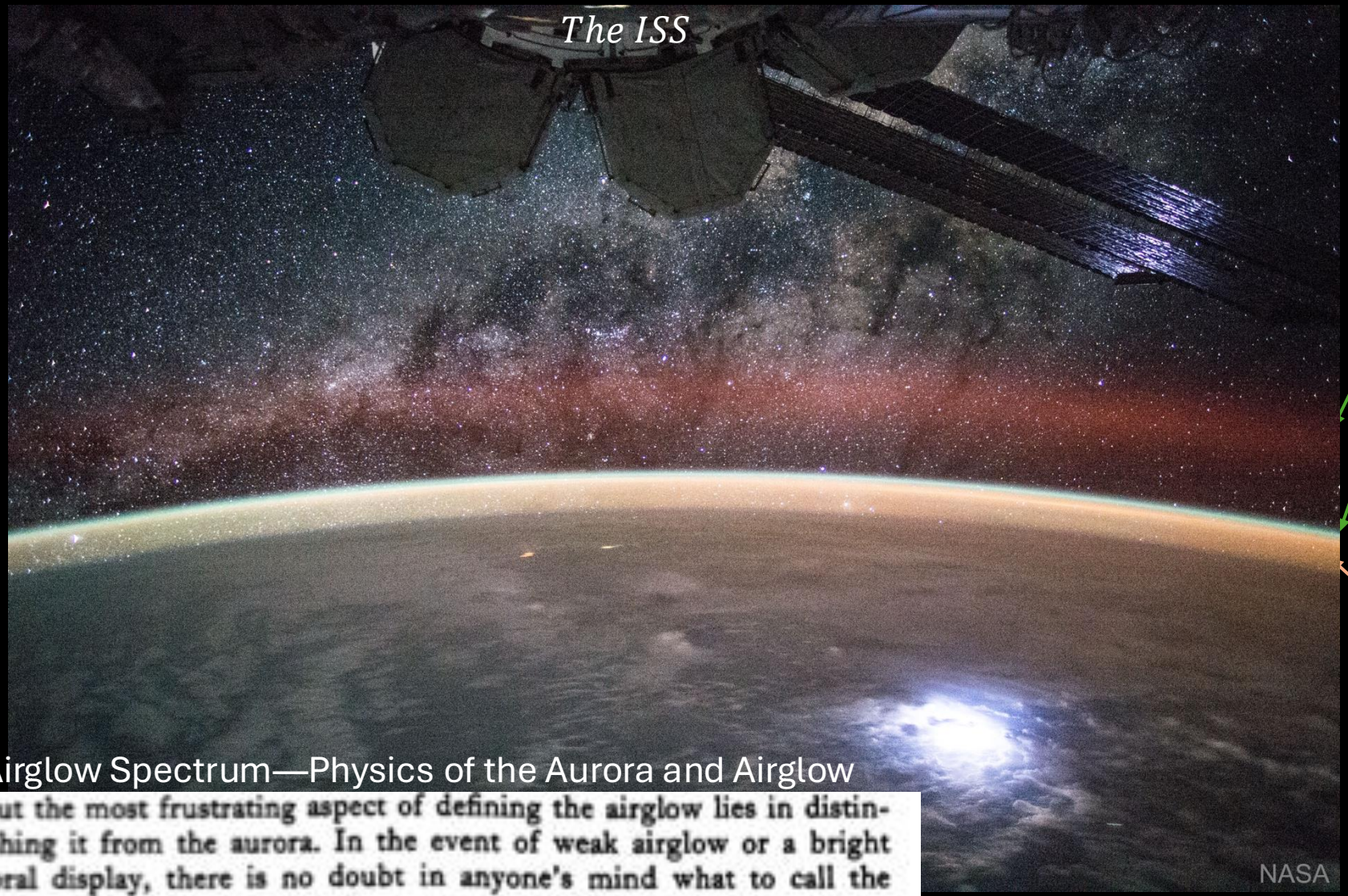
Atmospheric Emissions at Earth: What Should PUNCH Observe?



Aurora

Emission produced by magnetospheric electrons and ions precipitating into earth atmosphere

Airglow/ Nightglow

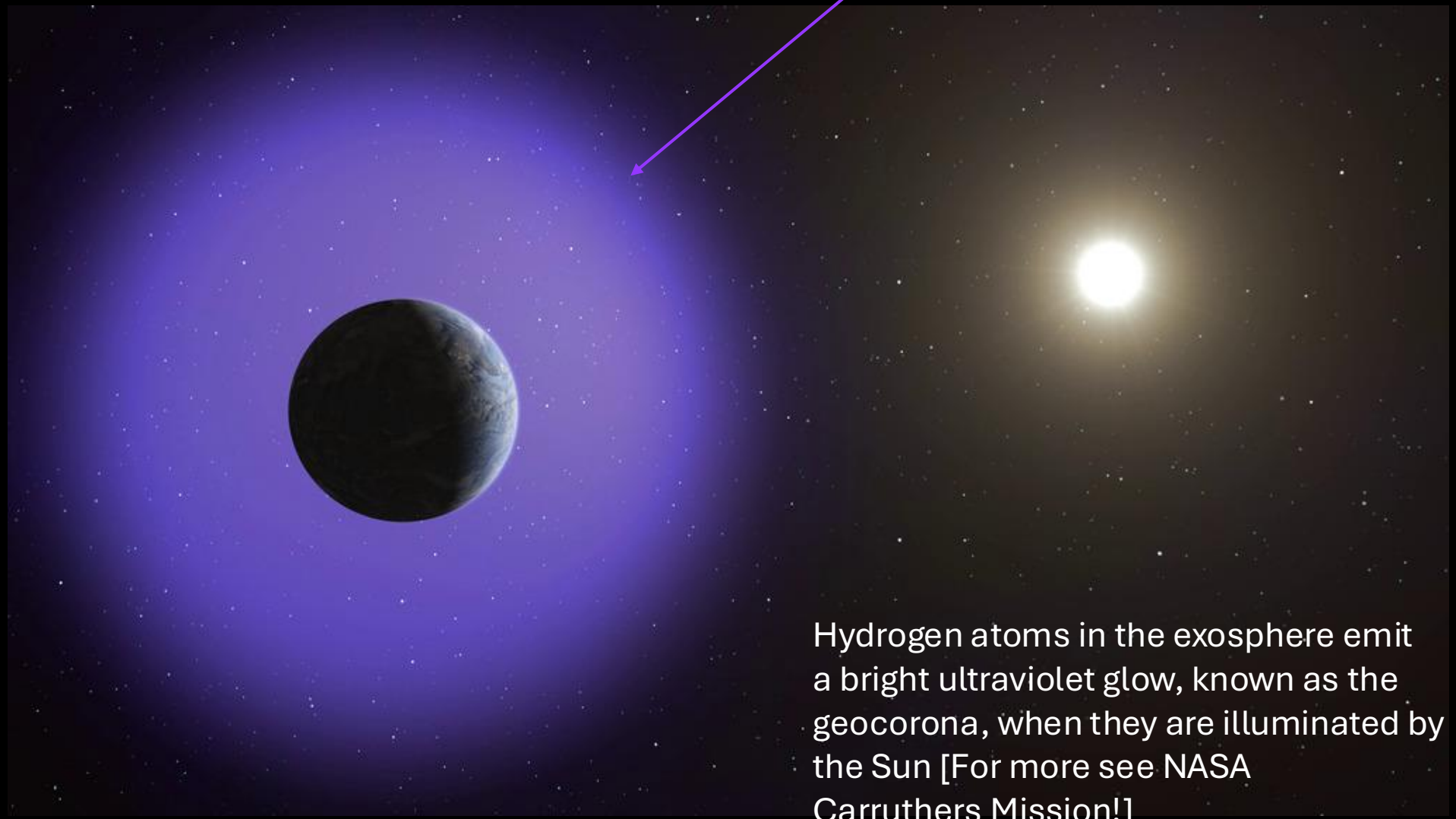
Quiescent terrestrial glow, dayglow and nightglow

The Airglow Spectrum—Physics of the Aurora and Airglow

But the most frustrating aspect of defining the airglow lies in distinguishing it from the aurora. In the event of weak airglow or a bright auroral display, there is no doubt in anyone's mind what to call the phenomenon; for the borderline cases of a bright airglow or faint aurora, however, there is considerable doubt! Generally one distin-

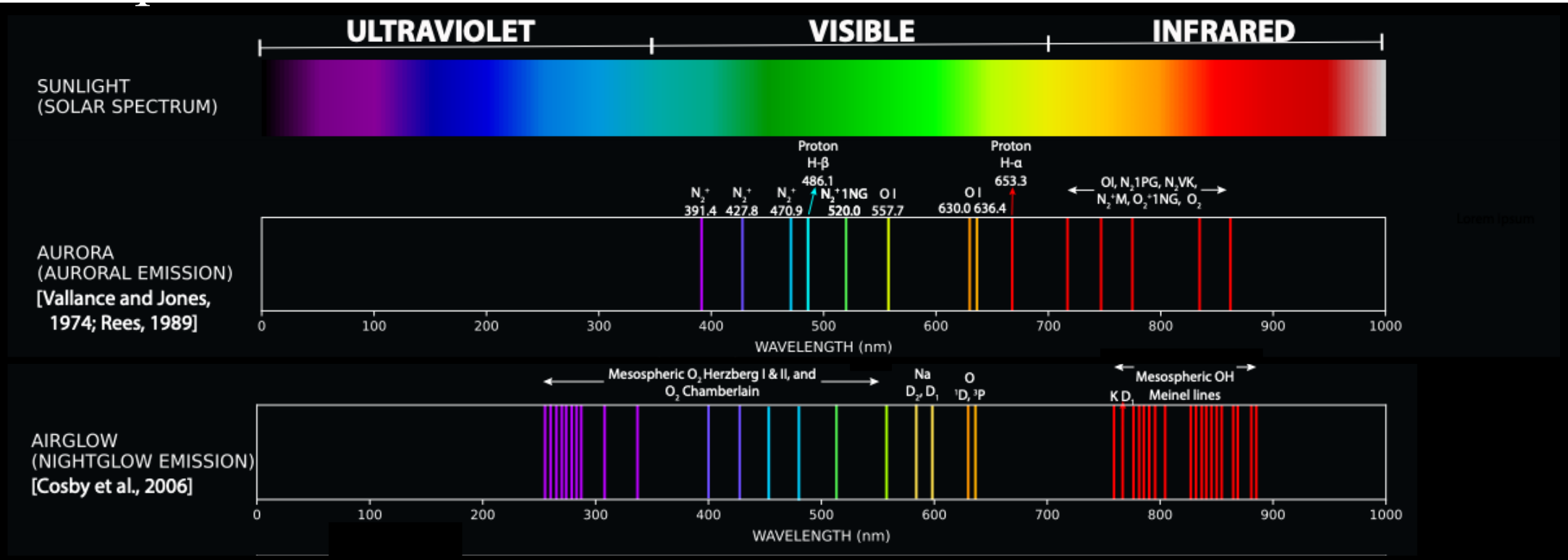
Atmospheric Emissions at Earth: What Should PUNCH Observe?

Geocorona



Hydrogen atoms in the exosphere emit a bright ultraviolet glow, known as the geocorona, when they are illuminated by the Sun [For more see NASA Carruthers Mission!]

Atmospheric Emissions at Earth: What Should PUNCH Observe?



Nightglow exhibits numerous emission lines; however, most of these originate in the mesosphere (~50–90 km altitude), well below the observational range relevant for PUNCH.

Atmospheric Emissions at Earth: What Should PUNCH Observe?