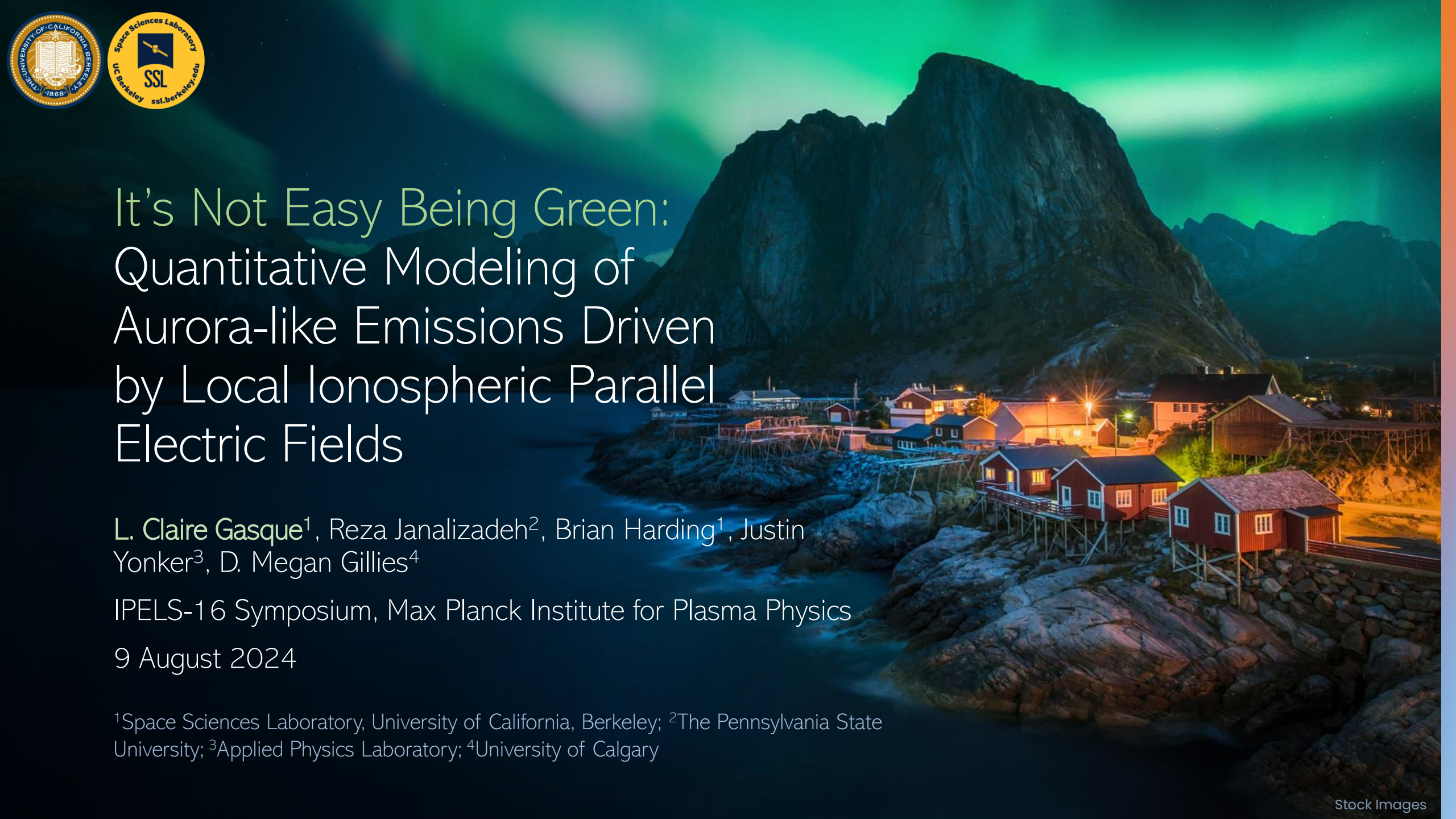


It's Not Easy Being Green: Quantitative Modeling of Aurora-like Emissions Driven by Local Ionospheric Parallel Electric Fields

L. Claire Gasque[1], Reza Janalizadeh[2], Brian Harding[1], Justin Yonker[3], D. Megan Gillies[4]

IPELS-16 Symposium, Max Planck Institute for Plasma Physics

9 August 2024

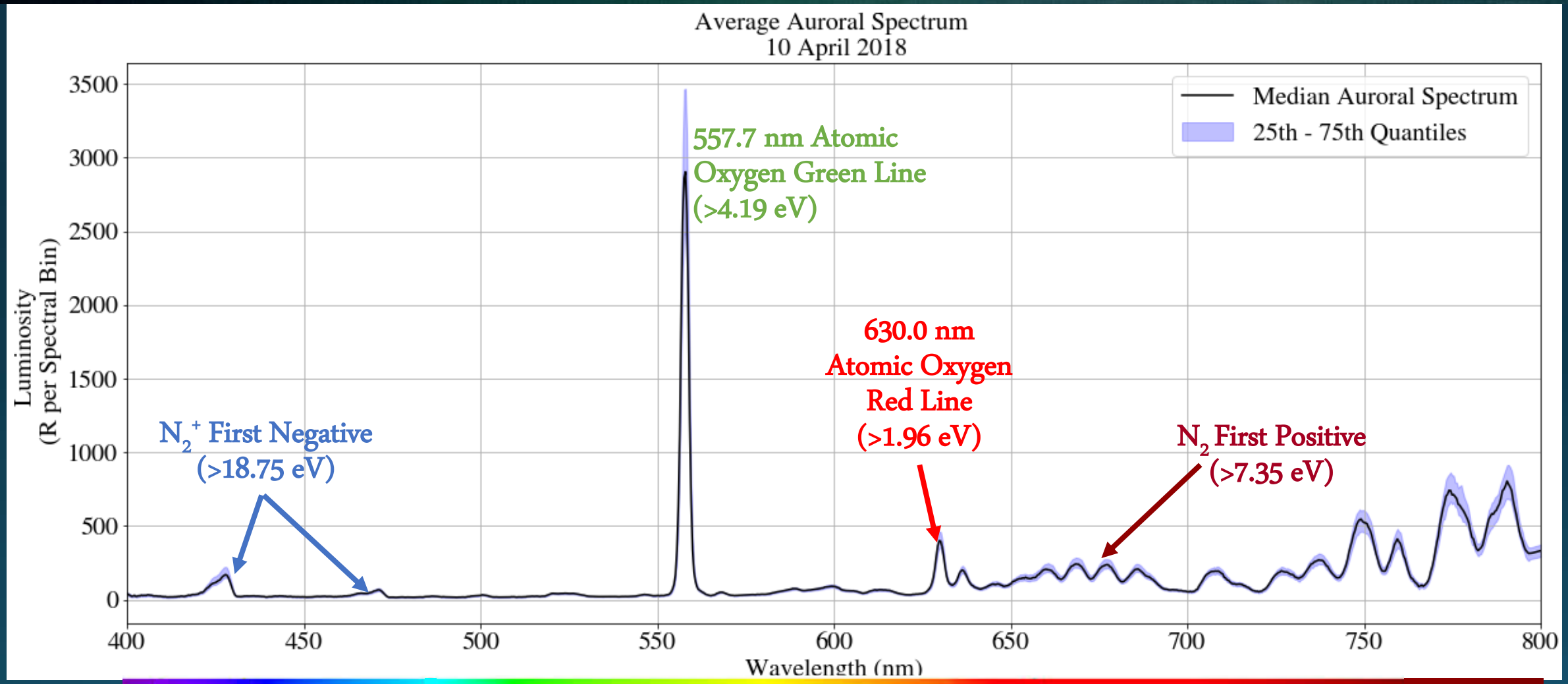
[1]Space Sciences Laboratory, University of California, Berkeley; [2]The Pennsylvania State University; [3]Applied Physics Laboratory; [4]University of Calgary

Stock Images

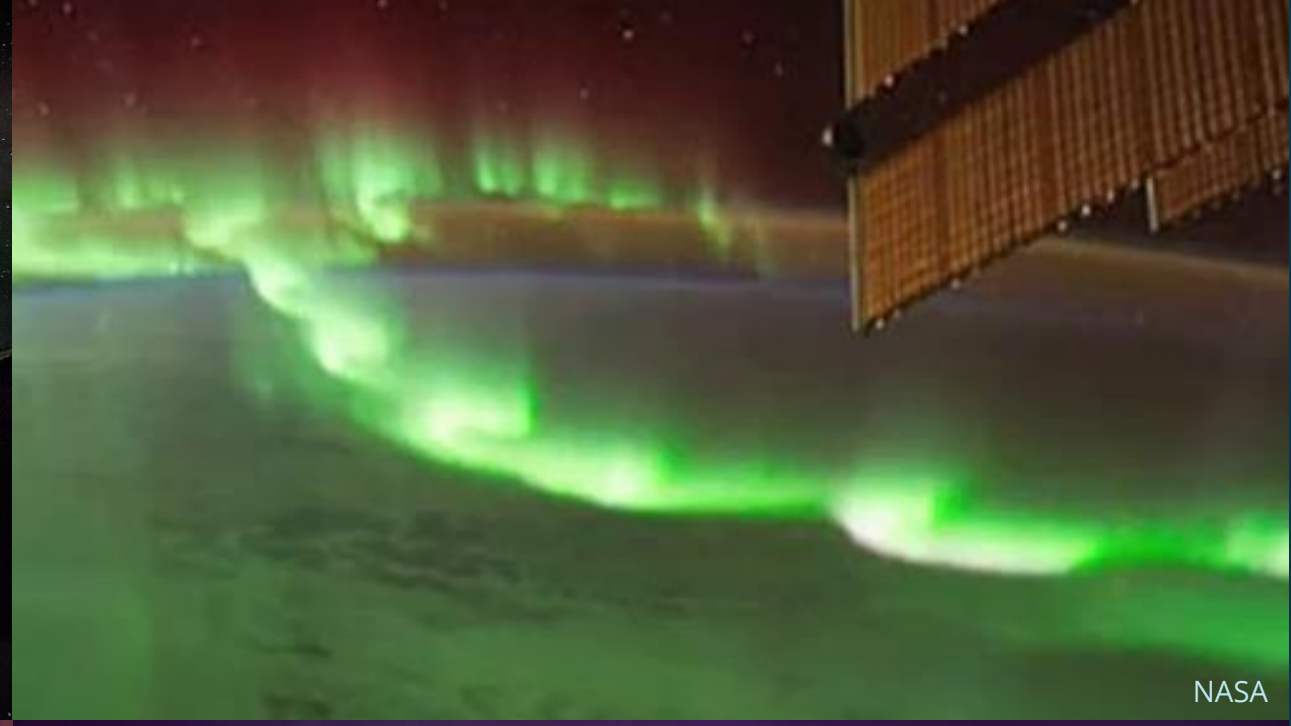
NASA (ISS)

Typical Green Auroral Spectrum

Andrea Klaussner



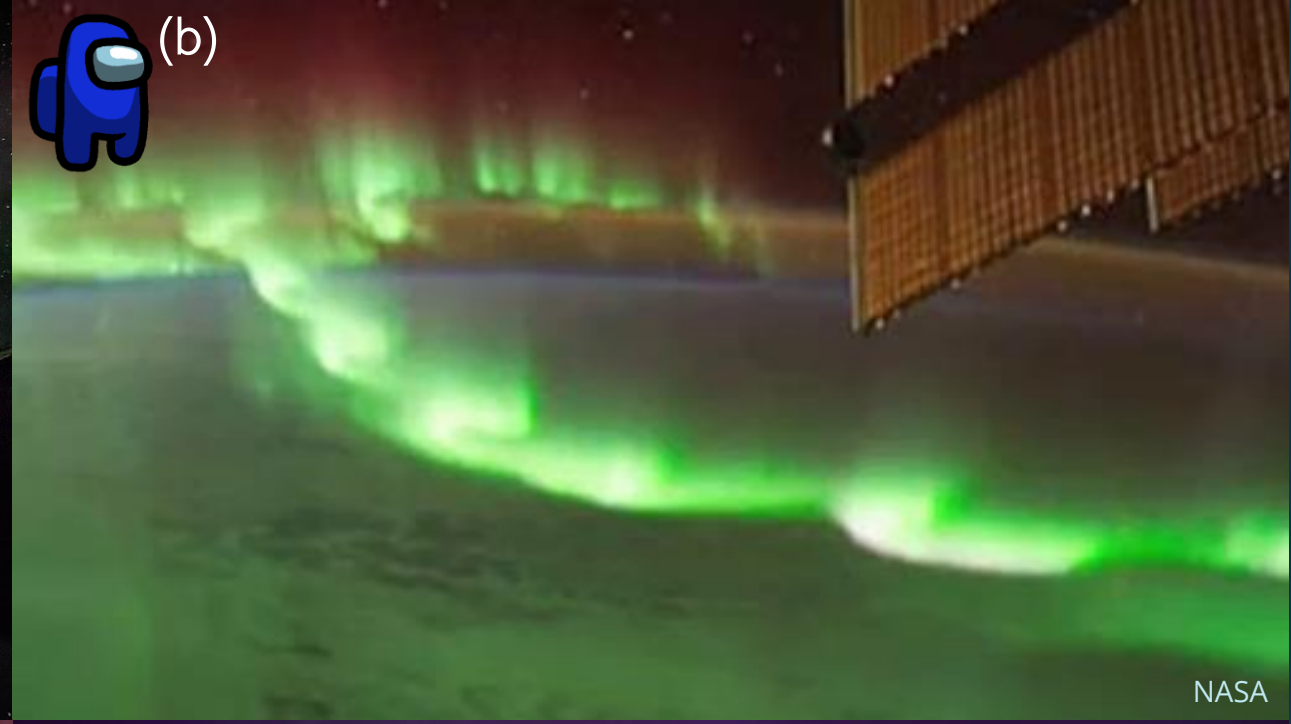

Robert Downie Photography


NASA


Allison Jaynes


Bert Thiessen

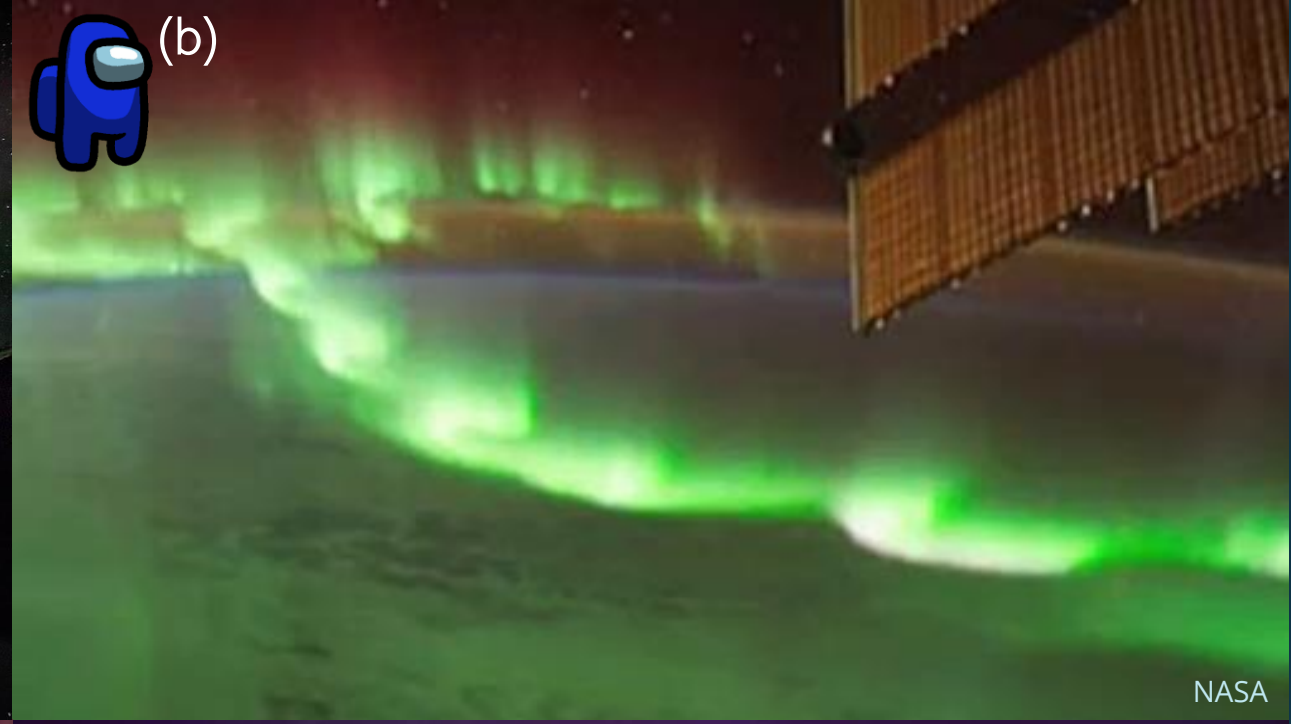

(a)
Robert Downie Photography


(b)
NASA


(c)
Allison Jaynes


(d)
Bert Thiessen


(a)
Robert Downie Photography


(b)
NASA


(c)
Allison Jaynes


(d)
Bert Thiessen


(a)
Steve
Picket Fence
Robert Downie Photography

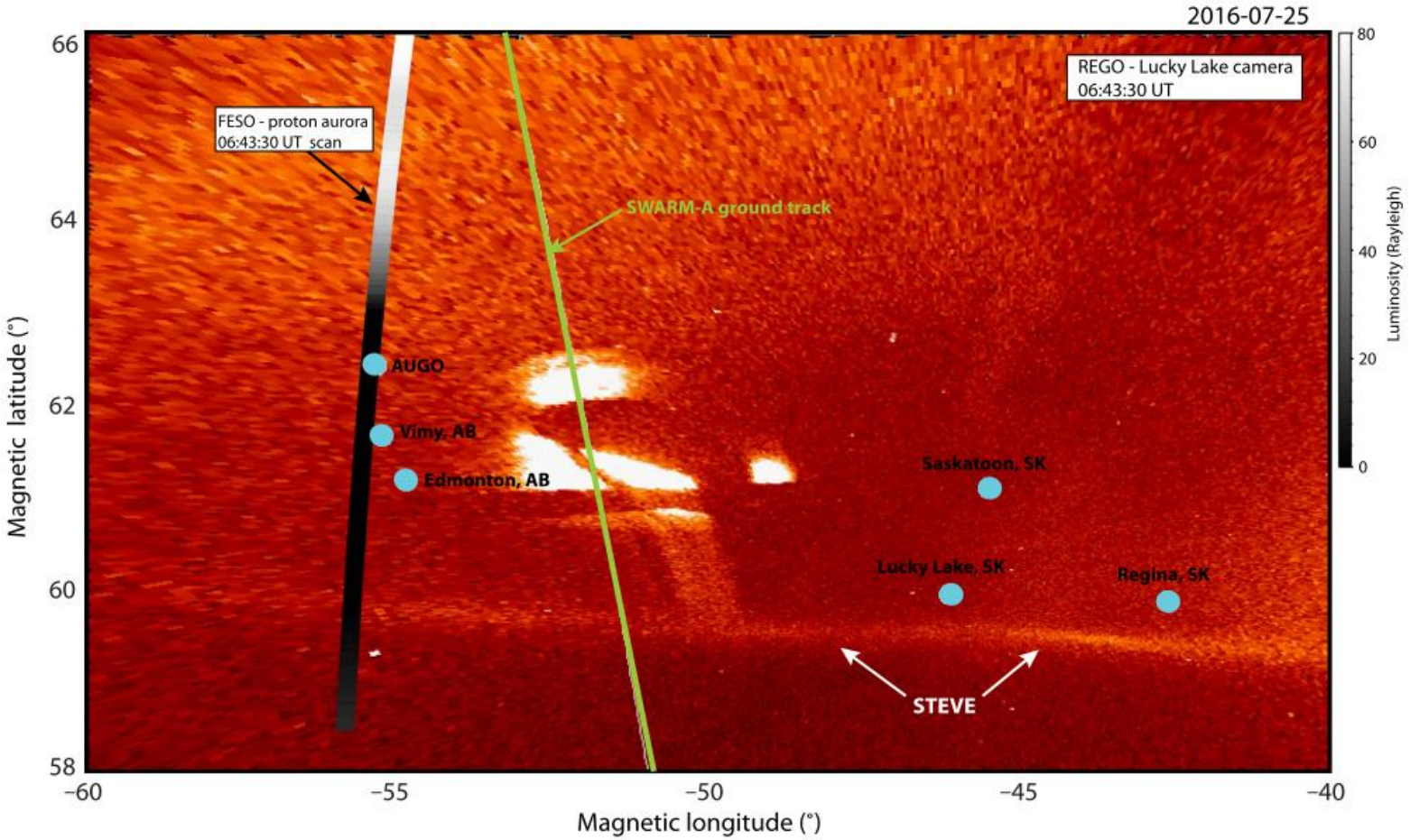
(Dreamworks Animation)

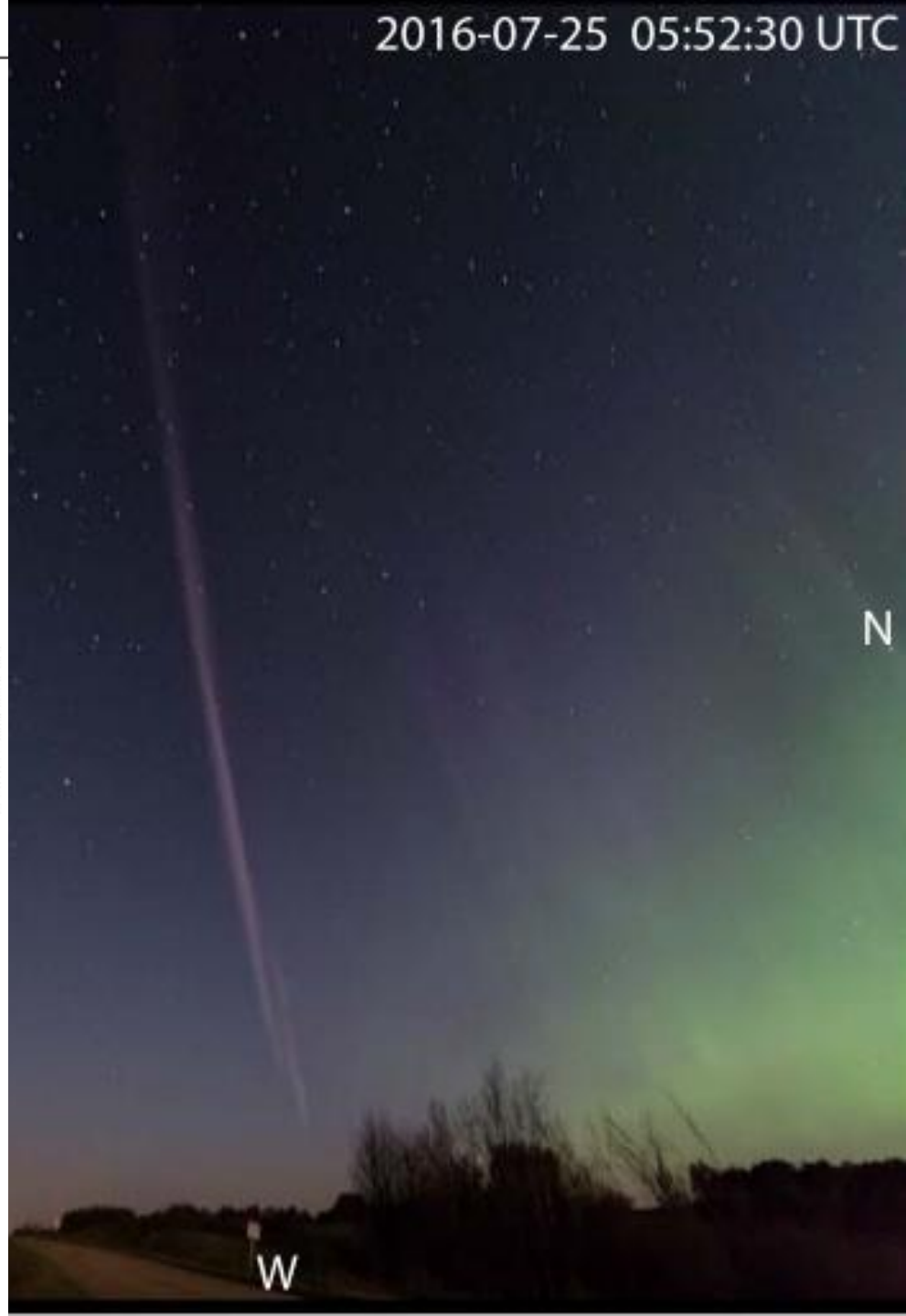
Robert Downie Photography

SPACE SCIENCES

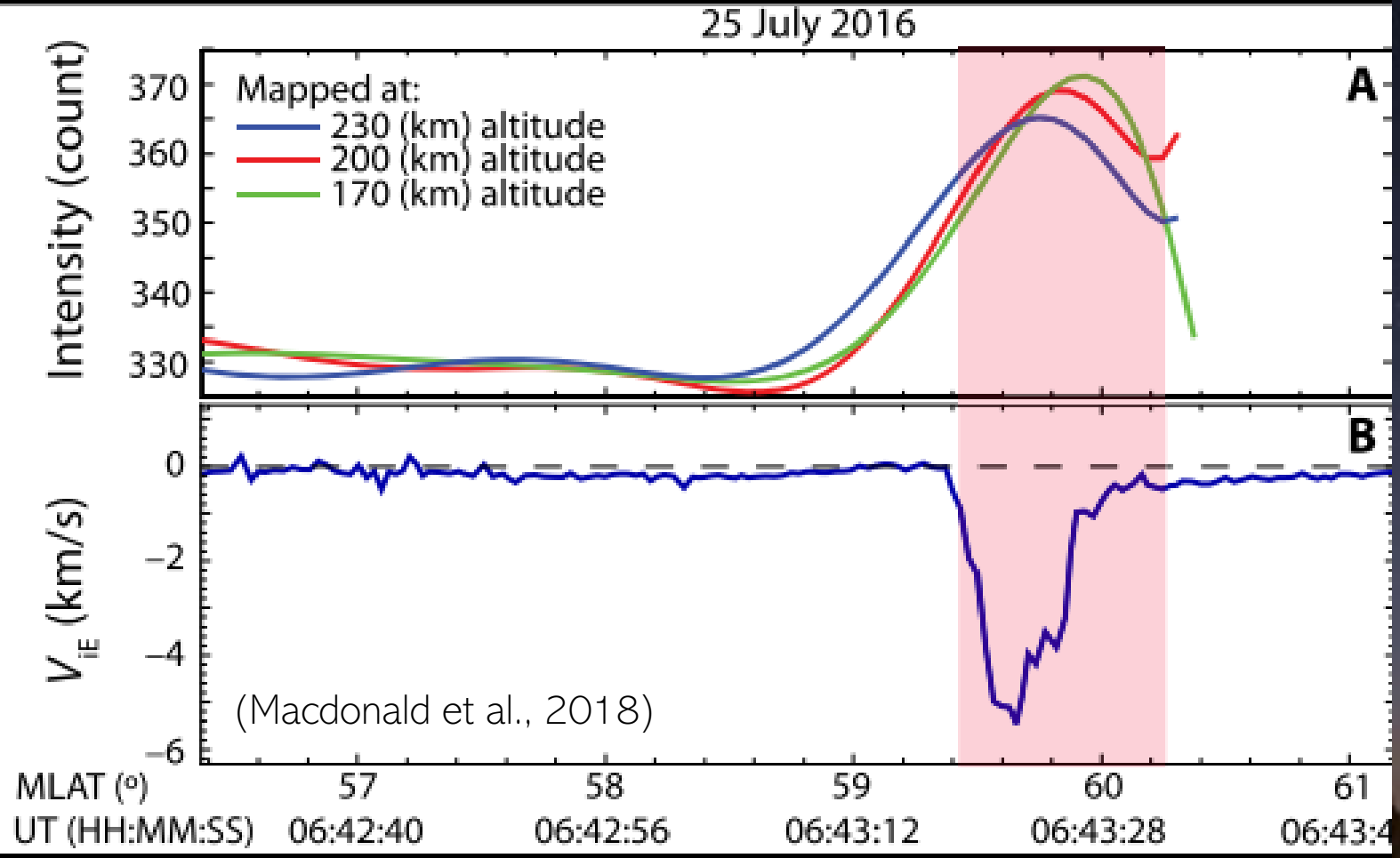
New science in plain sight: Citizen scientists lead to the discovery of optical structure in the upper atmosphere

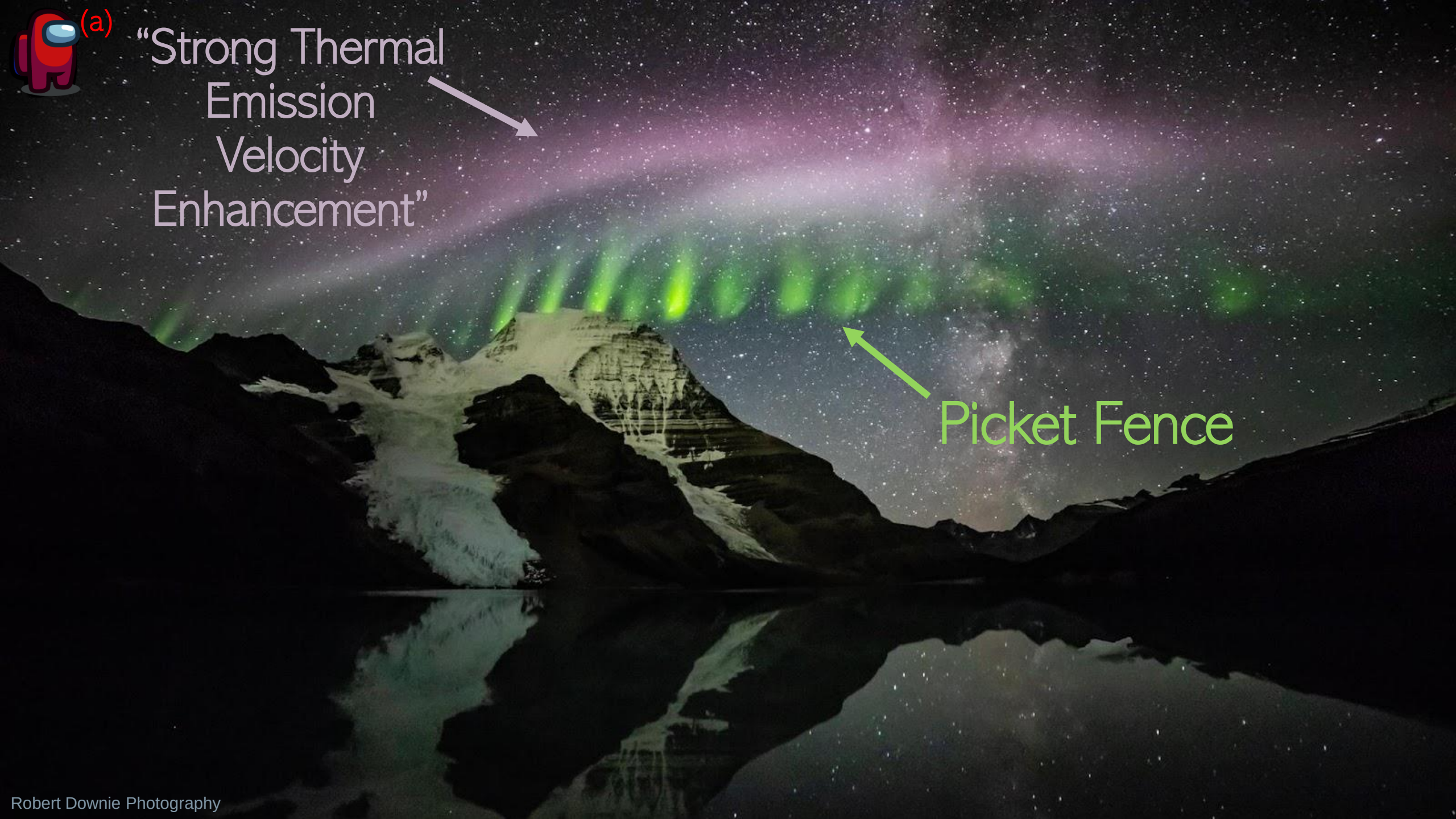
Elizabeth A. MacDonald,[1,2]* Eric Donovan,[3] Yukitoshi Nishimura,[4,5] Nathan A. Case,[6] D. Megan Gillies,[3] Bea Gallardo-Lacourt,[3,5] William E. Archer,[3†] Emma L. Spanswick,[3] Notanee Bourassa,[7] Martin Connors,[3,8,9] Matthew Heavner,[2,10] Brian Jackel,[3] Burcu Kosar,[1,2] David J. Knudsen,[3] Chris Ratzlaff,[7] Ian Schofield[8]





Steve (and the picket fence) are associated with extremely fast (>5 km/s) plasma flows in the ionosphere, called Sub-Auroral Ion Drifts (SAIDs).




(a)
“Strong Thermal Emission Velocity Enhancement”
Picket Fence
Robert Downie Photography


(a)
STEVE
Picket Fence
Robert Downie Photography

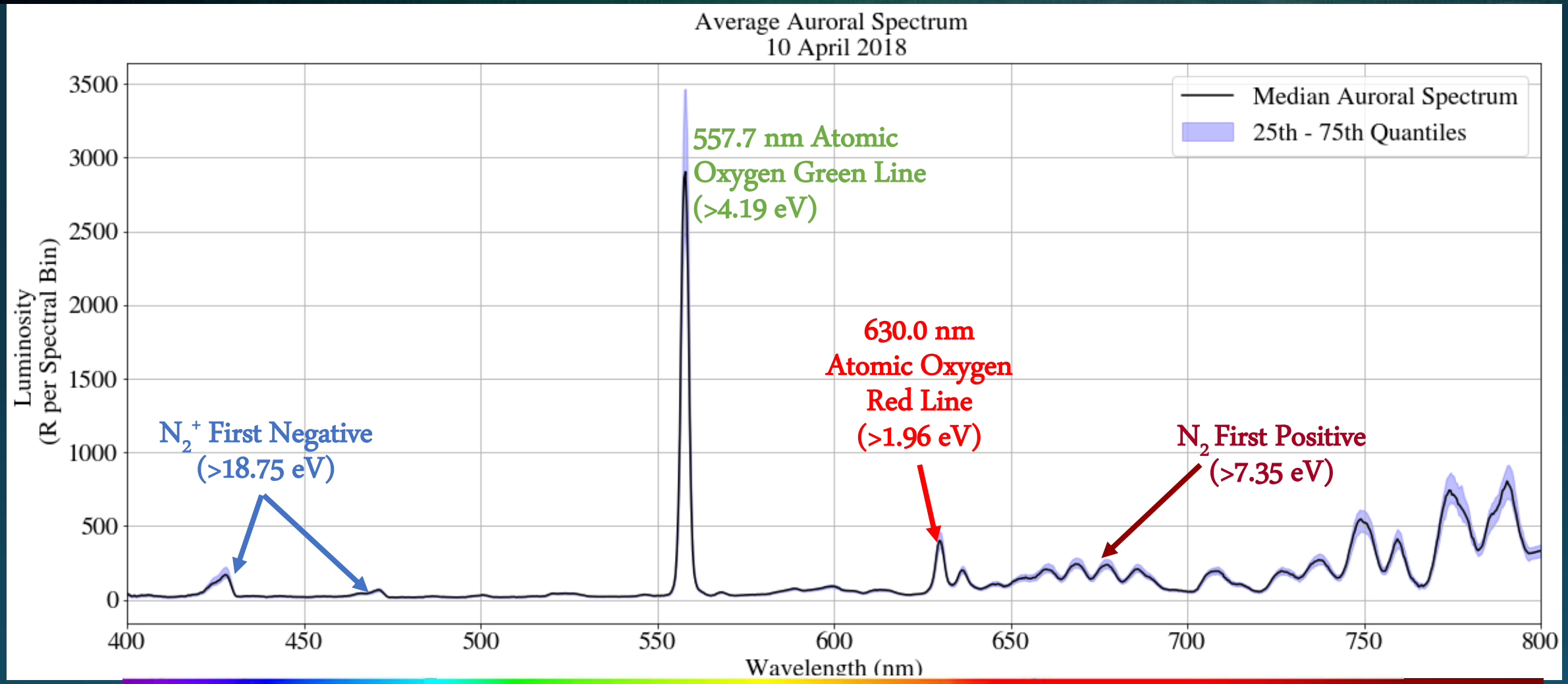
Sherri Grant

Matt Quiring

Matt Quiring

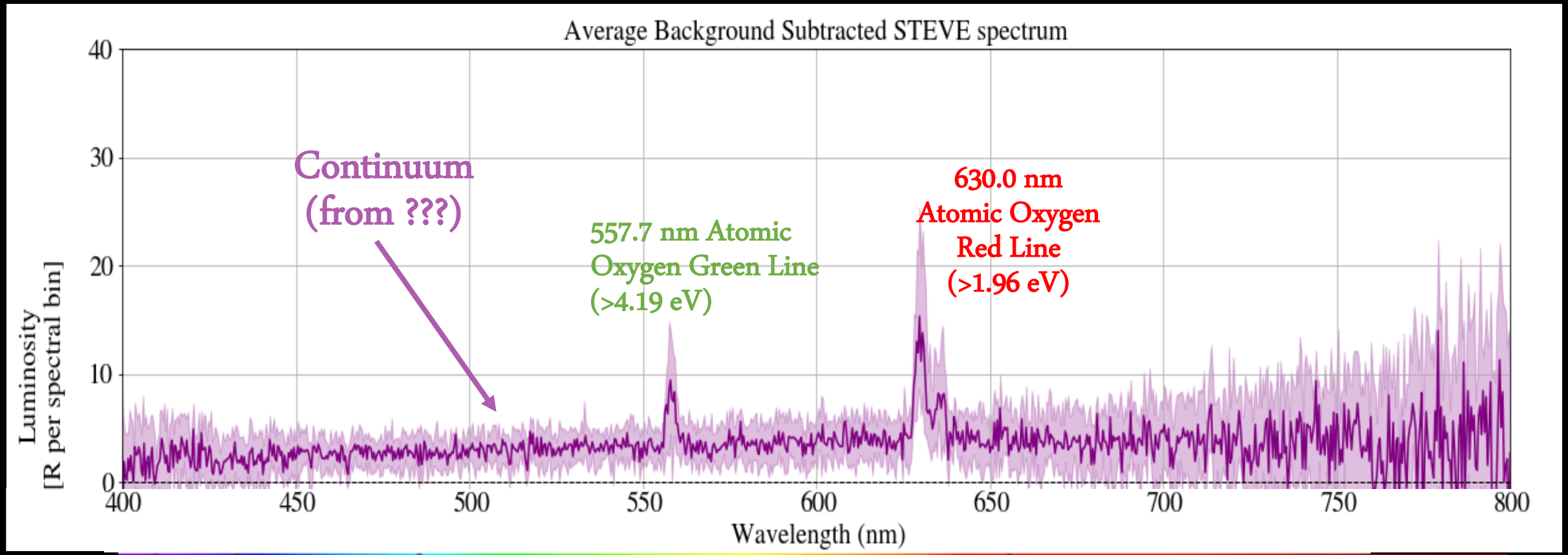
Typical Green Auroral Spectrum

Andrea Klaussner



STEVE Spectrum

Robert Downie



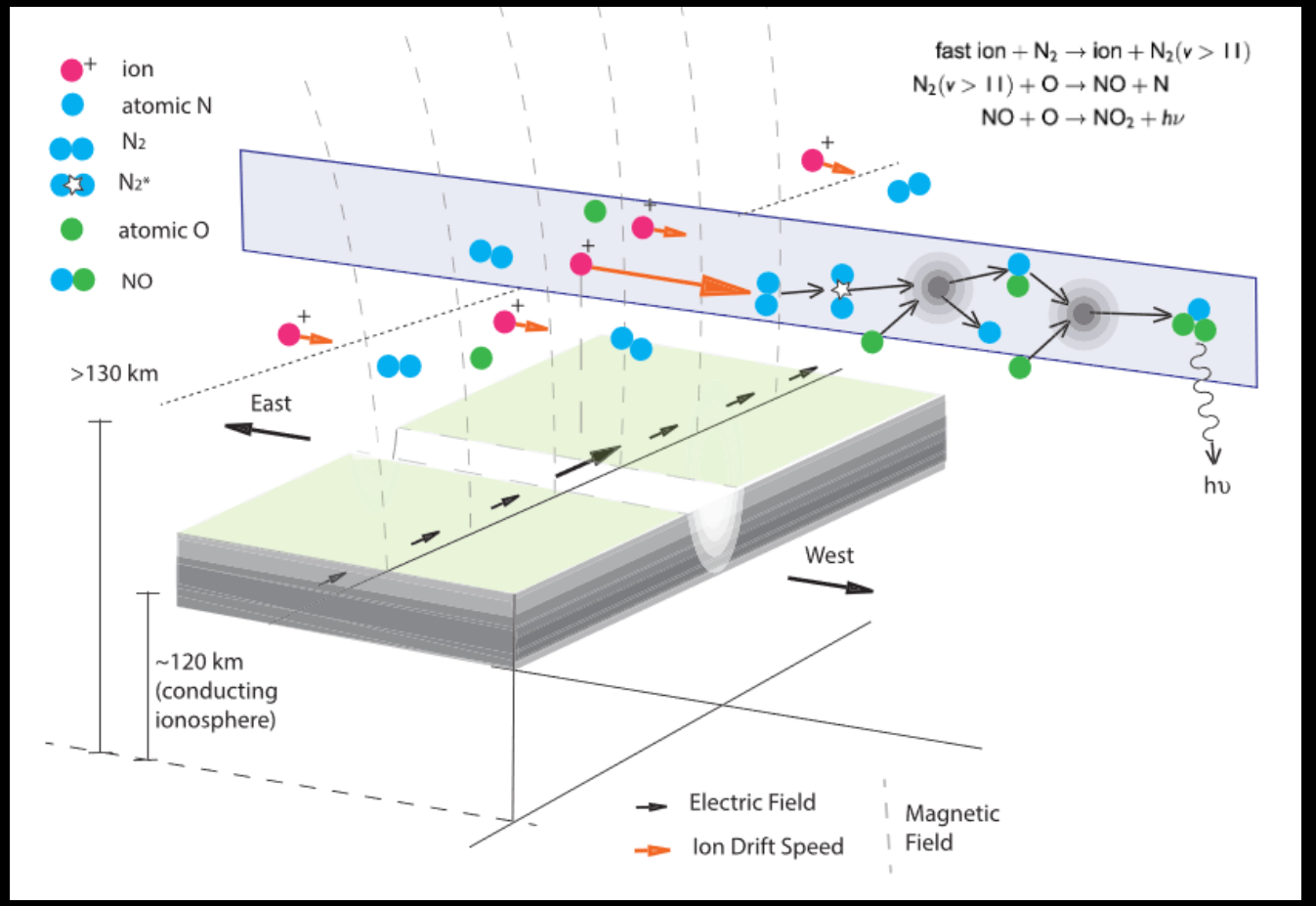
The Only Current Theory for STEVE's Continuum Emission

A Mechanism for the STEVE Continuum Emission

Brian J. Harding[1], Stephen B. Mende[1], Colin C. Triplett[1], and Yen-Jung Joanne Wu[1]

Harding et al. (2020)

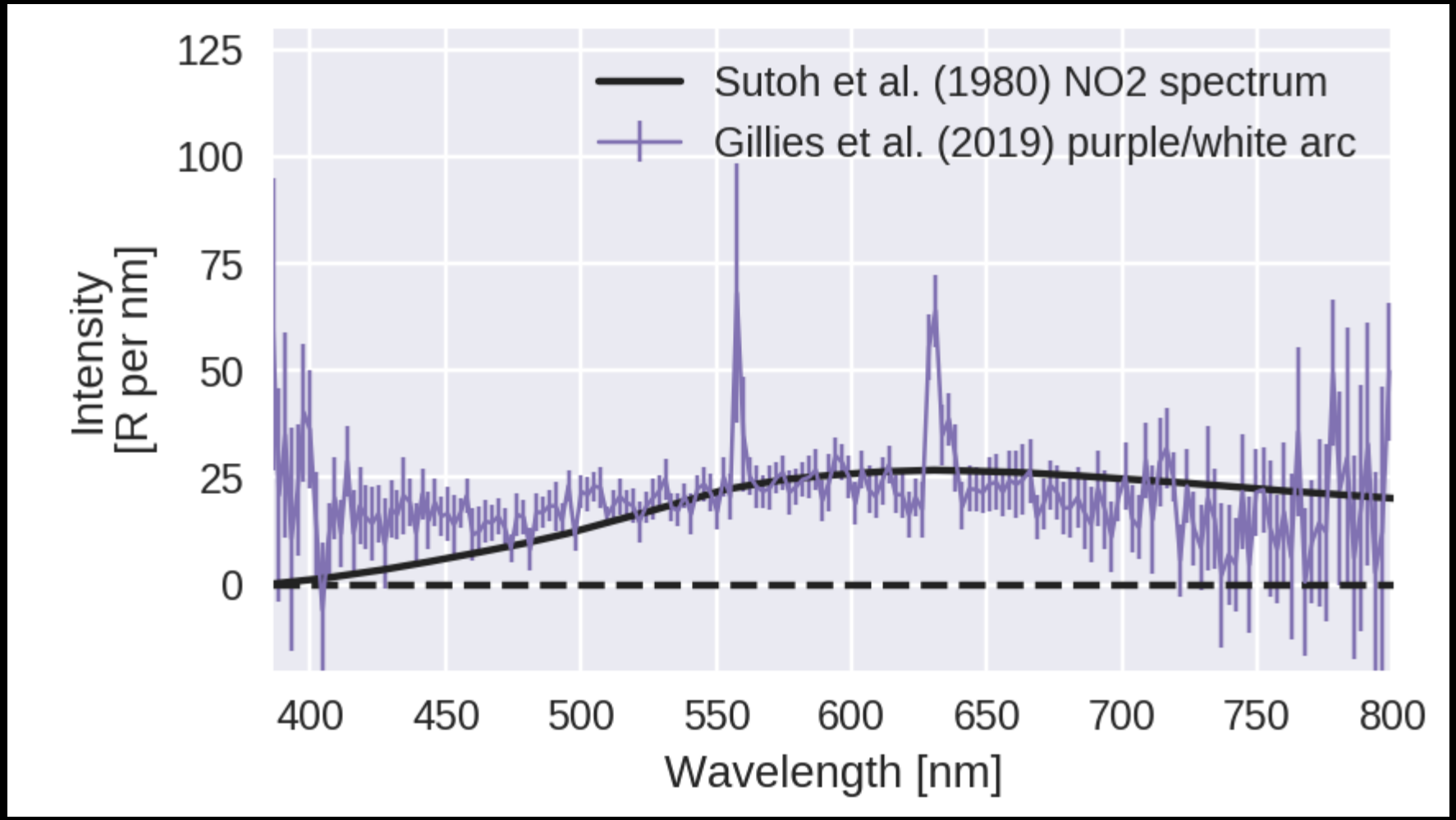
Fast-flowing ions flows in SAID channels collide with and vibrationally excite N_2, overcoming the activation energy of the $N_2 + O \rightarrow NO + N$ reaction. The resulting NO combines with ambient O, producing NO_2 and spectrally broad light.



But this theory doesn't explain everything…

Courtesy of Brian Harding

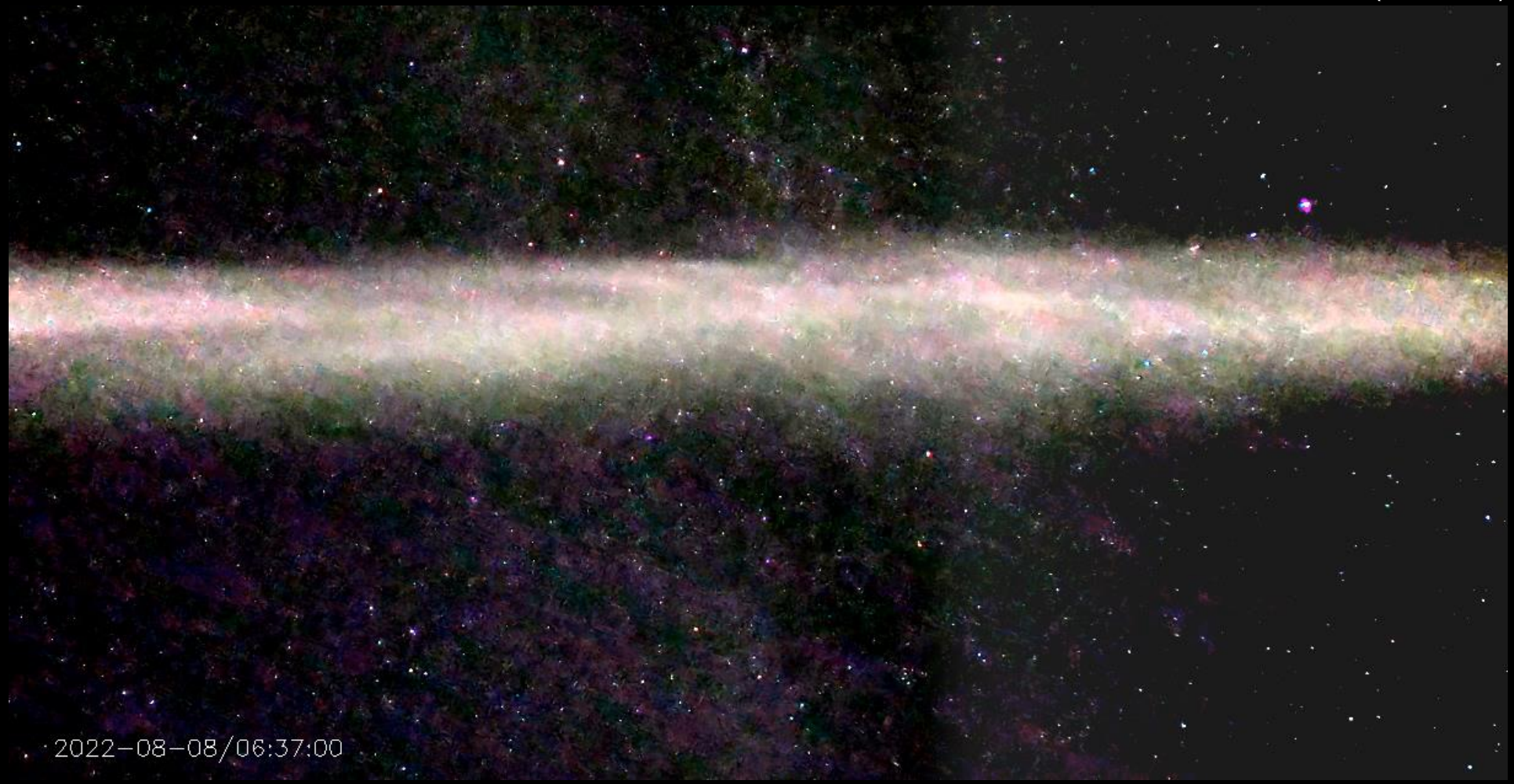
NO_2 laboratory spectrum does not match observations at blue end



But this theory doesn't explain everything…

Nishimura et al. (2023)

Emission timescales predict that STEVE should be a smooth arc, but high-resolution imaging reveals substructure which this theory cannot explain.



…so the excitation mechanism remains an open question.

STEVE emissions are not thought to be due to precipitation, but the specific generation mechanism remains a mystery.

What about the picket fence?

Early observations suggested that picket fence emissions may be driven by electron precipitation, just like the aurora

Magnetospheric Signatures of STEVE: Implications for the Magnetospheric Energy Source and Interhemispheric Conjugacy

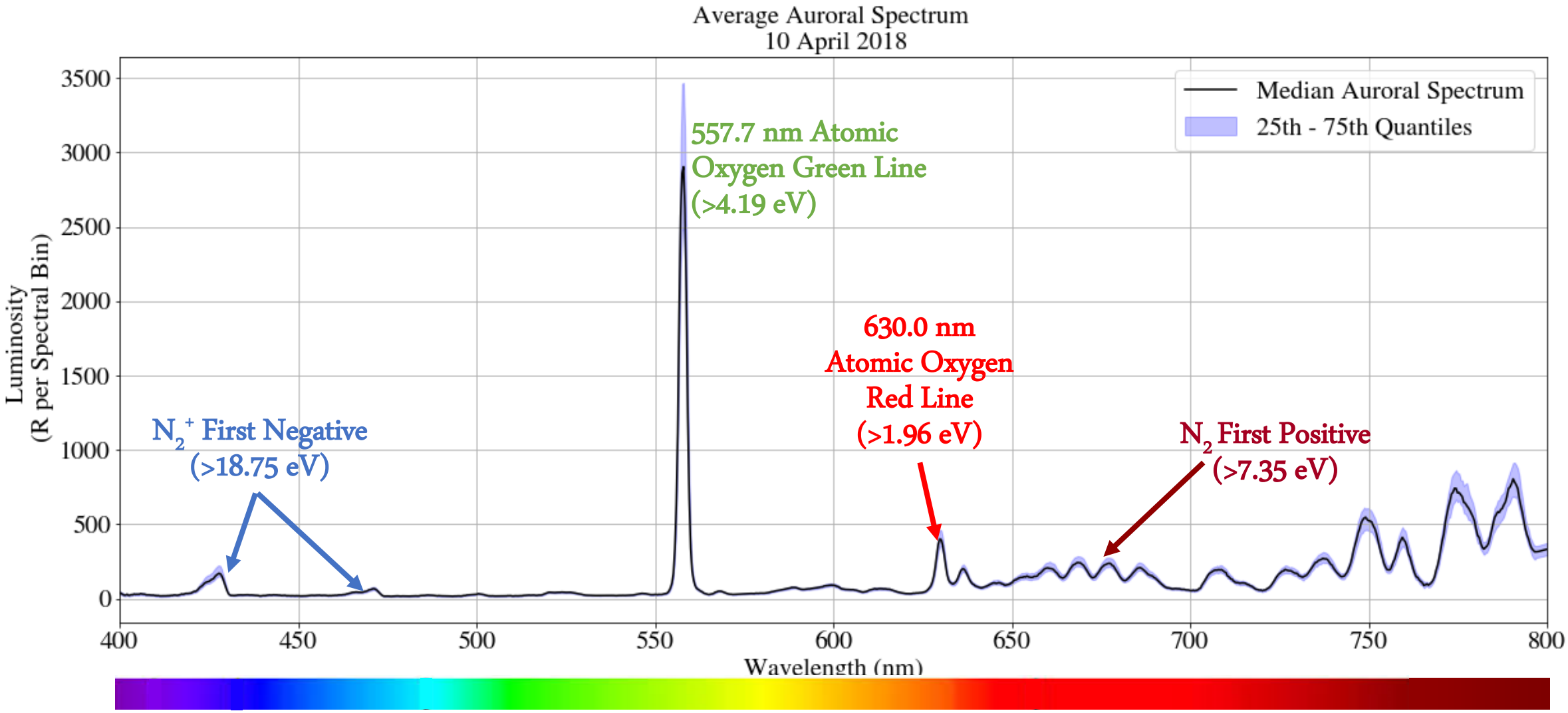
Y. Nishimura[1,2], B. Gallardo-Lacourt[3], Y. Zou[4,5], E. Mishin[6], D. J. Knudsen[3], E. F. Donovan[3], V. Angelopoulos[7], and R. Raybell[8]

Abstract We present three STEVE (strong thermal emission velocity enhancement) events in conjunction with Time History of Events and Macroscale Interactions (THEMIS) in the magnetosphere and Defense Meteorological Satellite Program (DMSP) and Swarm in the ionosphere, for determining equatorial and interhemispheric signatures of the STEVE purple/mauve arc and picket fence. Both types of STEVE emissions are associated with subauroral ion drifts (SAID), electron heating, and plasma waves. The magnetosphere observations show structured electrons and flows and waves (likely kinetic Alfven, magnetosonic, or lower-hybrid waves) just outside the plasmasphere. Interestingly, the event with the picket fence had a >~1 keV electron structure detached from the electron plasma sheet, upward field-aligned currents (FACs), and ultraviolet emissions in the conjugate hemisphere, while the event with only the mauve arc did not have precipitation or ultraviolet emission. We suggest that the electron precipitation drives the picket fence, and heating drives the mauve as thermal emission.

(Nishimura et al., 2019)

Typical Green Auroral Spectrum

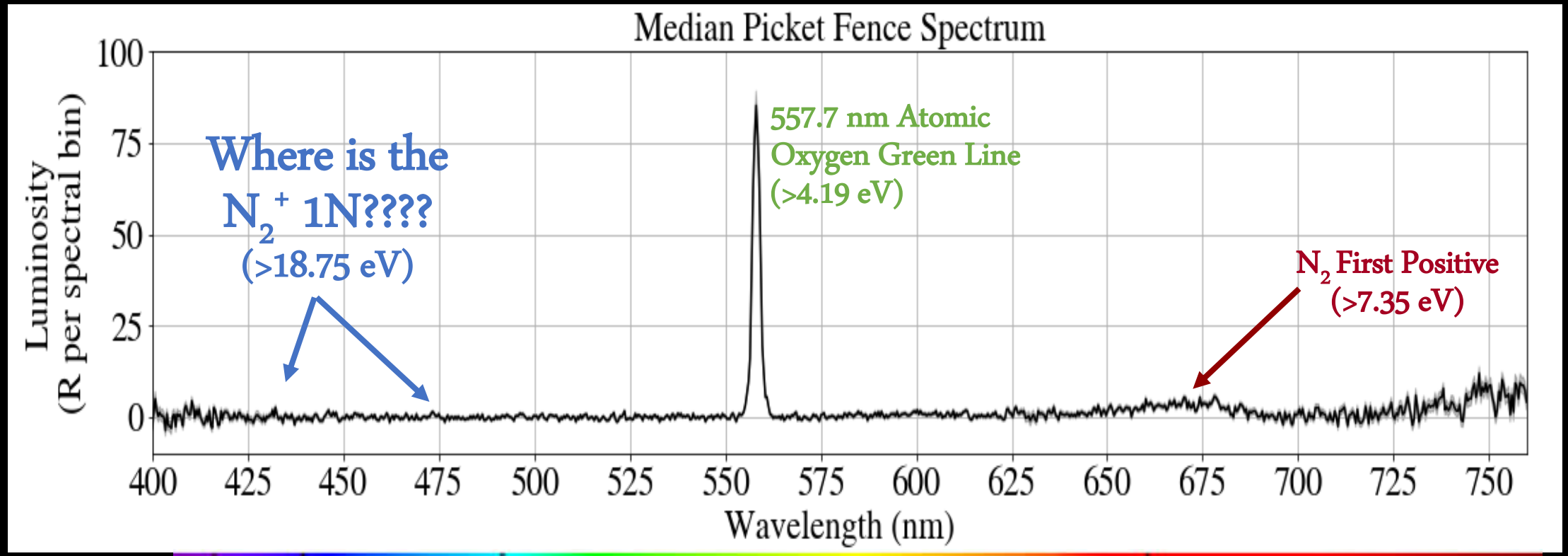
Andrea Klaussner



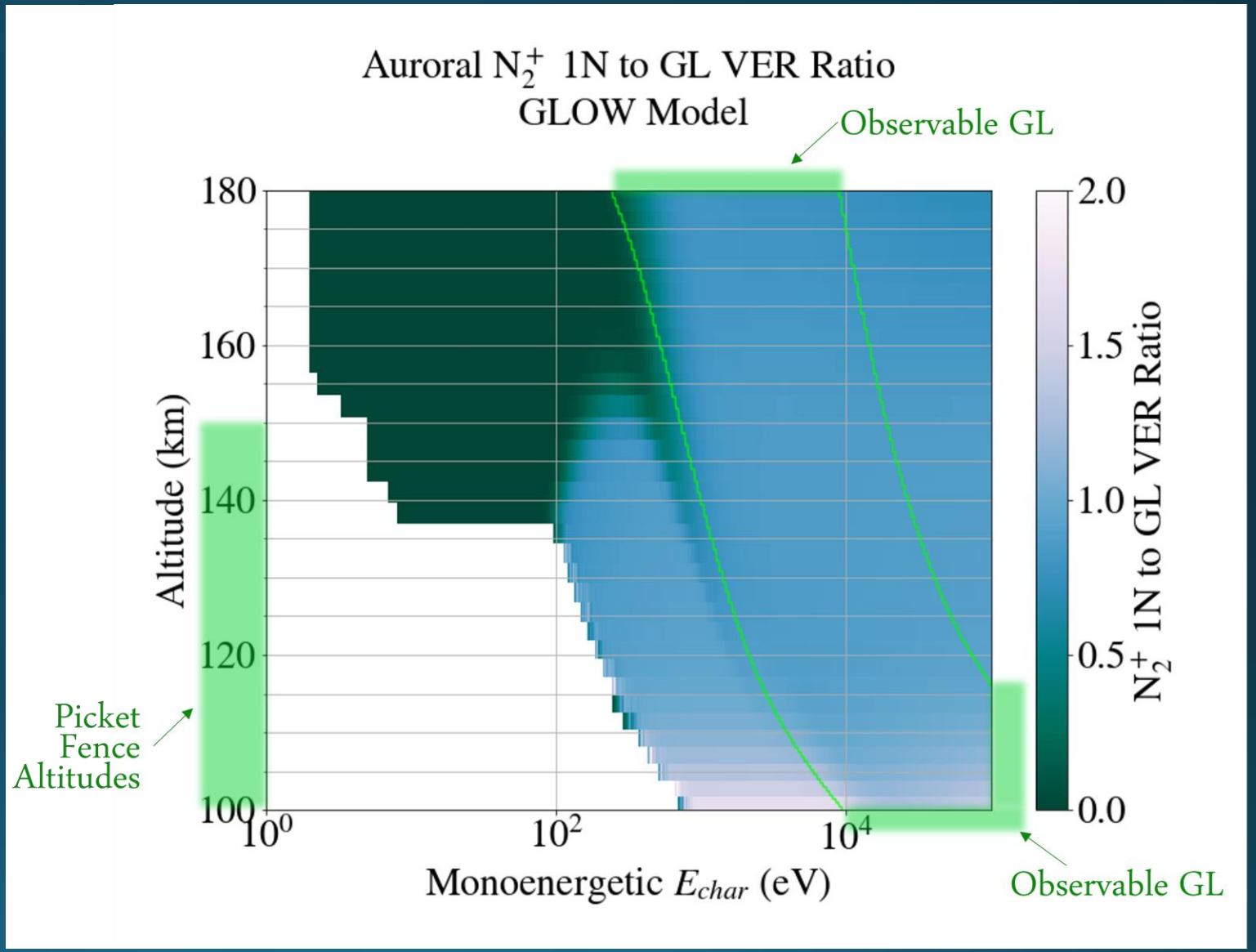
Picket Fence Spectrum

Robert Downie

Gillies et al., (2019)
Mende et al., (2019)



Electron transport models predict that N_2^+ 1N emissions should be ubiquitous in aurora produced by particle precipitation

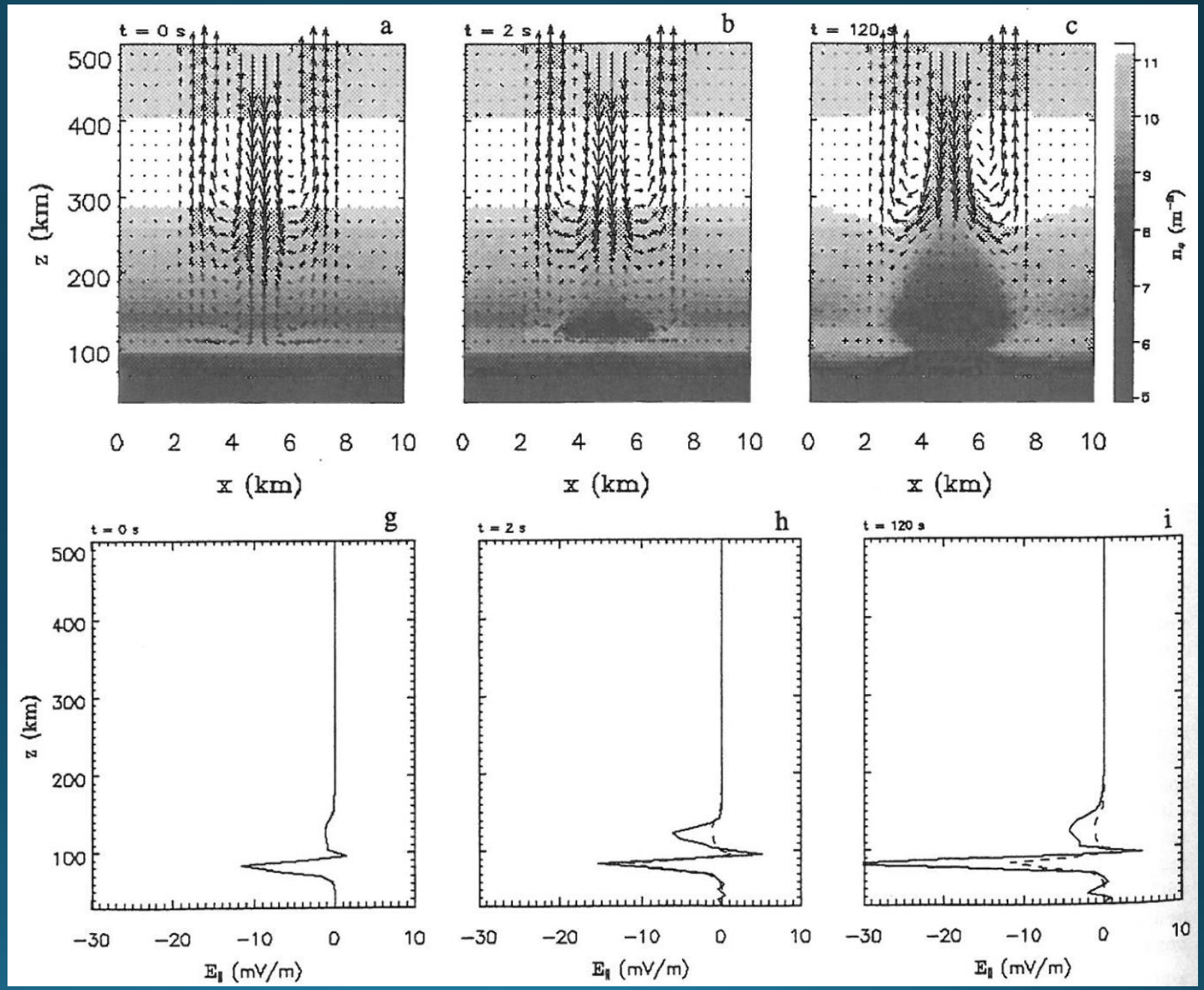


Particle precipitation → Ionizes nitrogen and generates N_2^+ 1N emissions

No N_2^+ 1N emissions → NOT generated by particle precipitation → Imposter aurora!

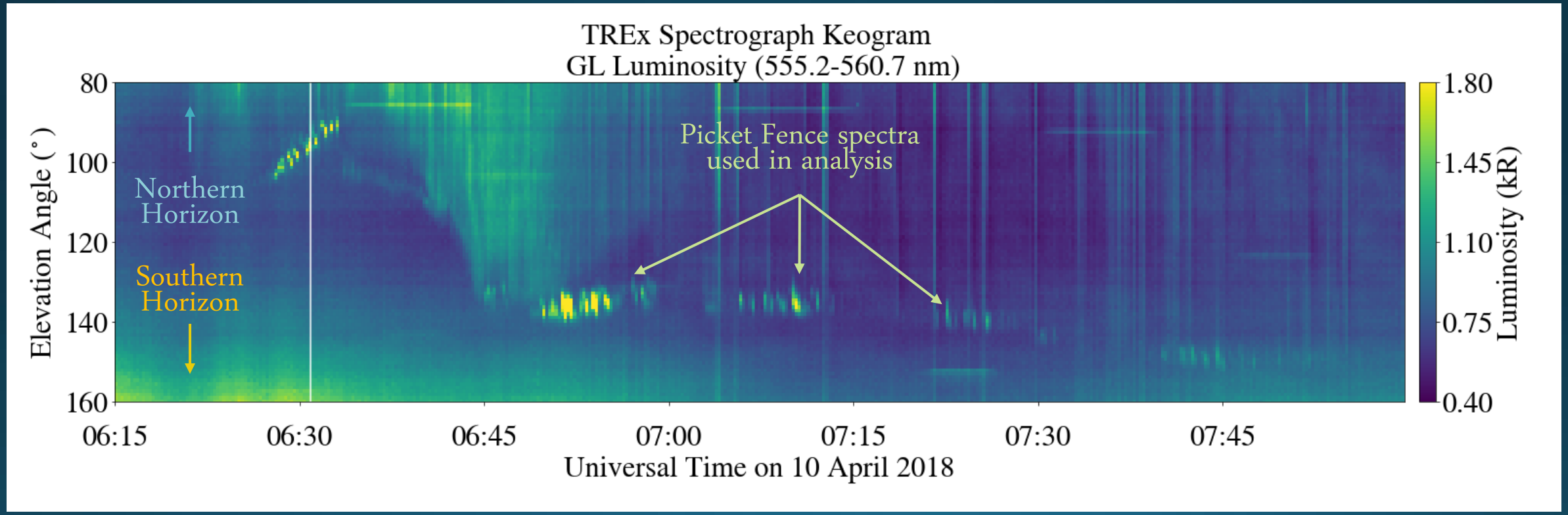
What might energize the superthermal electron population that drives the picket fence?

Hypothesis: Electric fields parallel to the magnetic field in the collisional base of the ionosphere



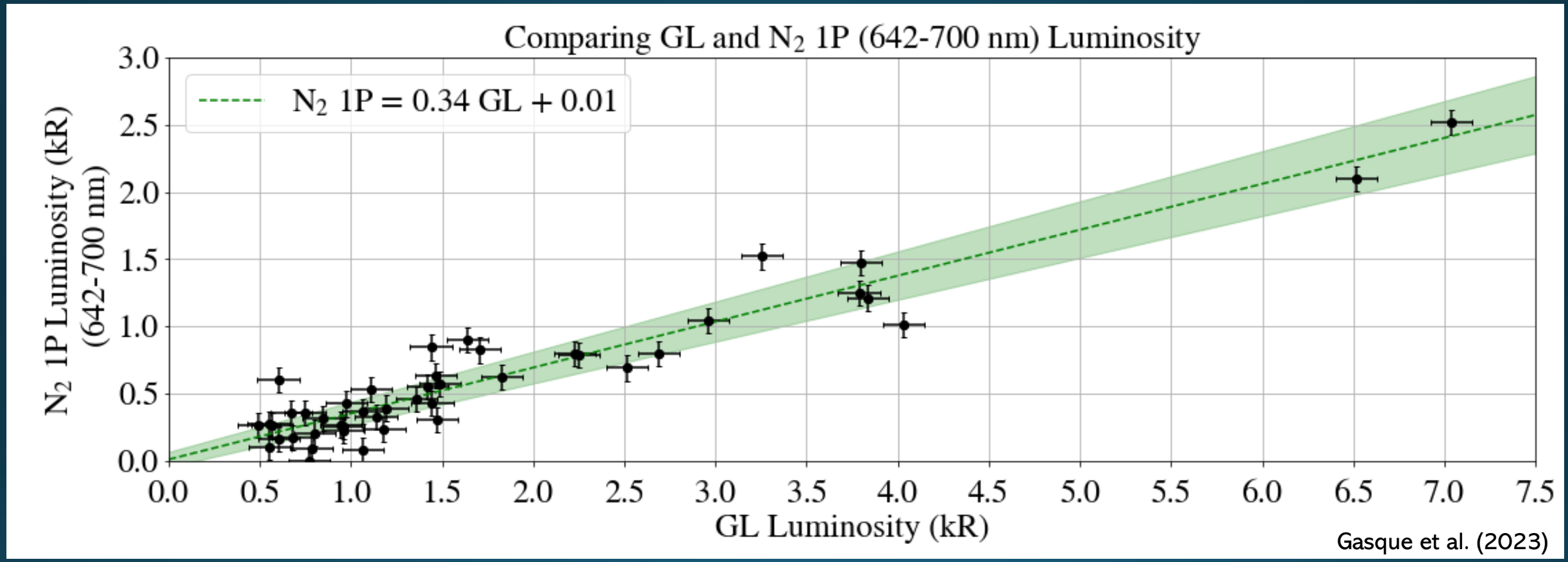
Karlsson + Marklund (1998)

Using spectral observations from the picket fence, we constrained the expected ratio between the oxygen green line and N_2 1P red emissions.



Gasque et al., (2023)

Observations: The TREx Spectrograph



Gasque et al. (2023)

Can a model driven by parallel electric fields replicate the observed ratio between GL and N_2 1P while also NOT producing N_2^+ 1N emissions?

Kinetic Modeling

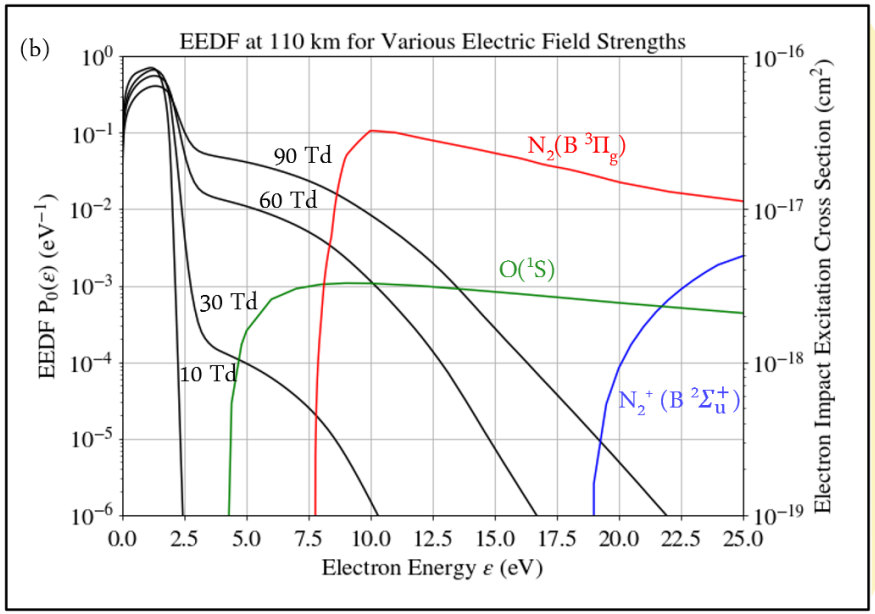
In a realistic neutral atmosphere, we model changes in the electron energy distribution function (EEDF) under the influence of parallel electric fields.

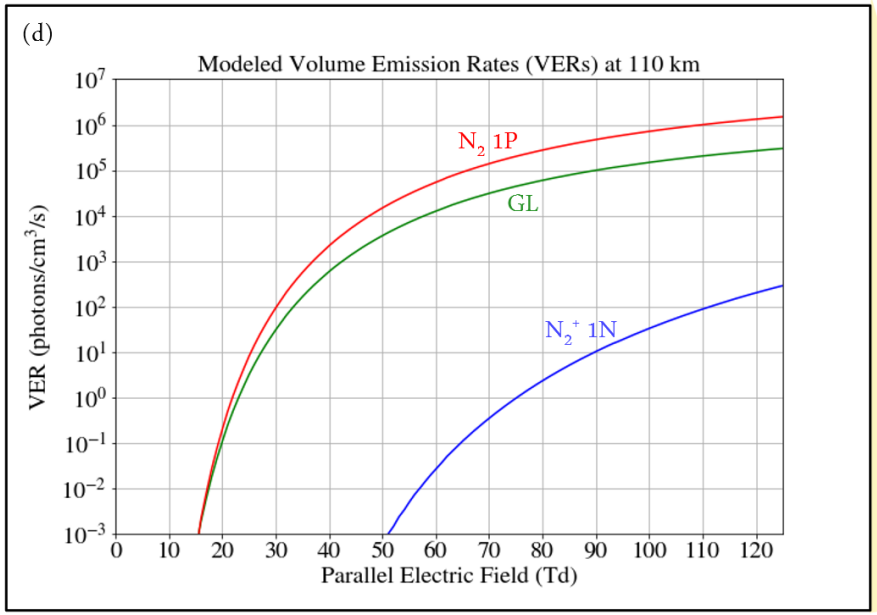
From the EEDFs and electron impact excitation cross sections, we obtain electron impact excitation rates.

Additional steady-state modeling applies the effects of quenching and cascade from higher energy states, allowing us to calculate volume emission rates (VERs) as a function of altitude and electric field strength.

Gasque et al., (2023)

Picket Fence Modeling Flowchart





MSIS, IRI, IGRF

(a) Input Atmospheric and Ionospheric Profiles

BOLSIG+

(b) EEDF: $P_0(\varepsilon)$

Average Electron Impact Excitation Rate Coefficients over EEDF

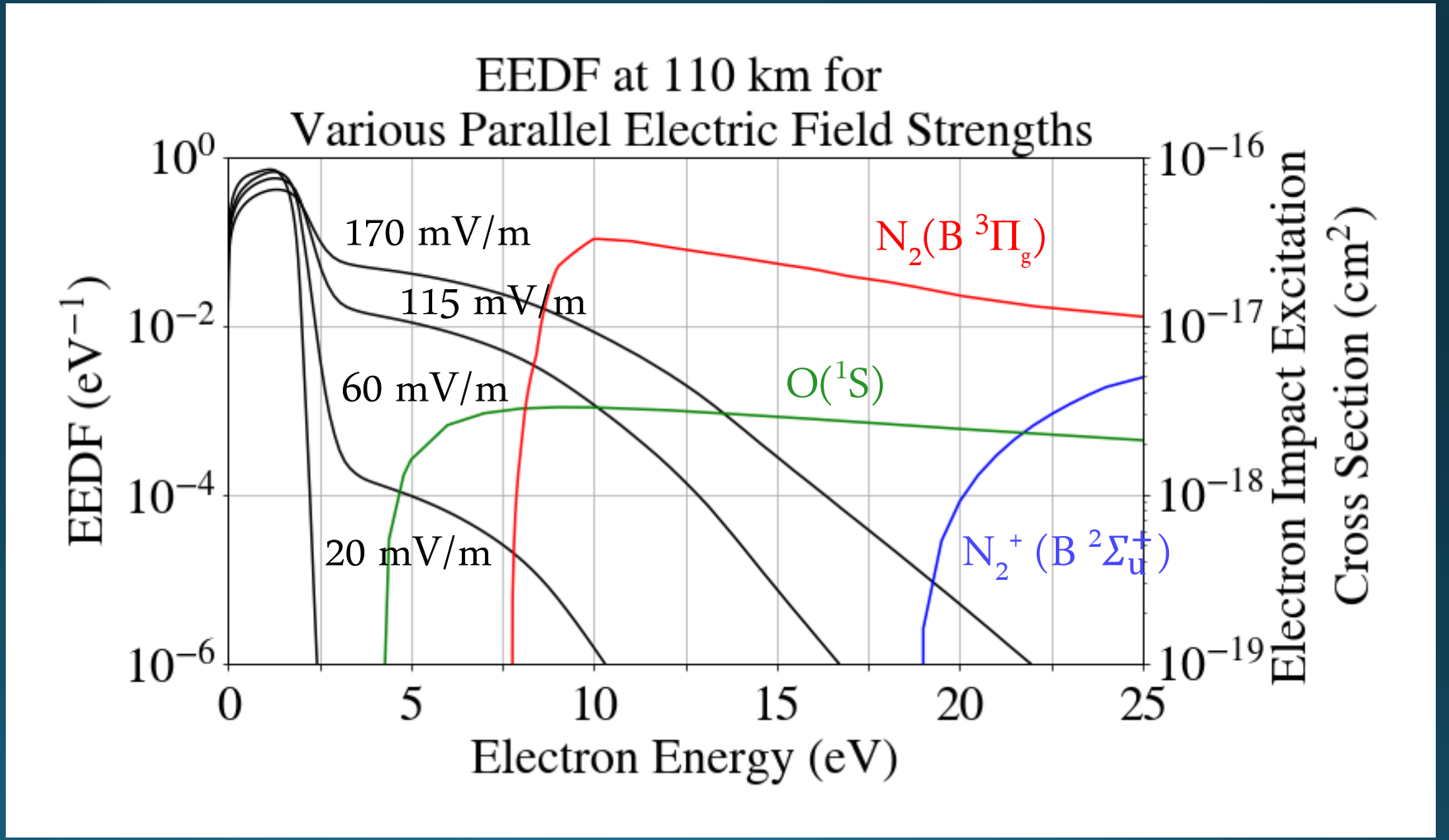
(c) Electron Impact Excitation Rates

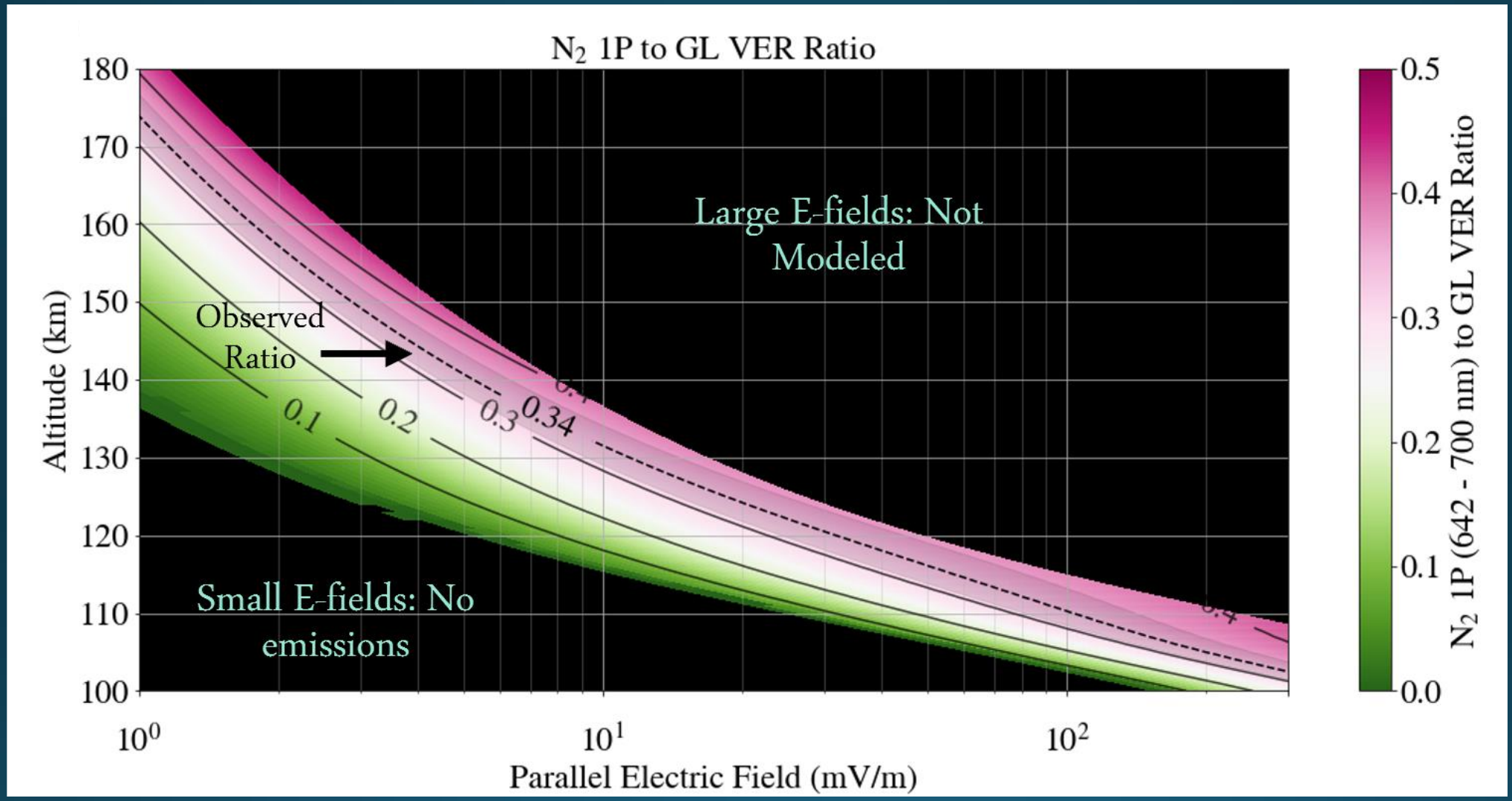
Steady State Kinetic Model

(d) Volume Emission Rates

Kinetic Modeling: Effect of Parallel Electric Fields on EEDF

Increasing the applied parallel electric field strength stretches the tail of the electron energy distribution function to higher energies





Results: The specific emission ratio observed in the picket fence can be produced by ~80–150 mV/m parallel electric fields at 110 km

…so the parallel electric fields hypothesis is viable…

Other Picket Fence-like Emissions

- Fragmented Aurora-like Emissions (Dreyer et al., 2021)

Dreyer et al. (2021)

Other Picket Fence-like Emissions

- Fragmented Aurora-like Emissions (Dreyer et al., 2021)

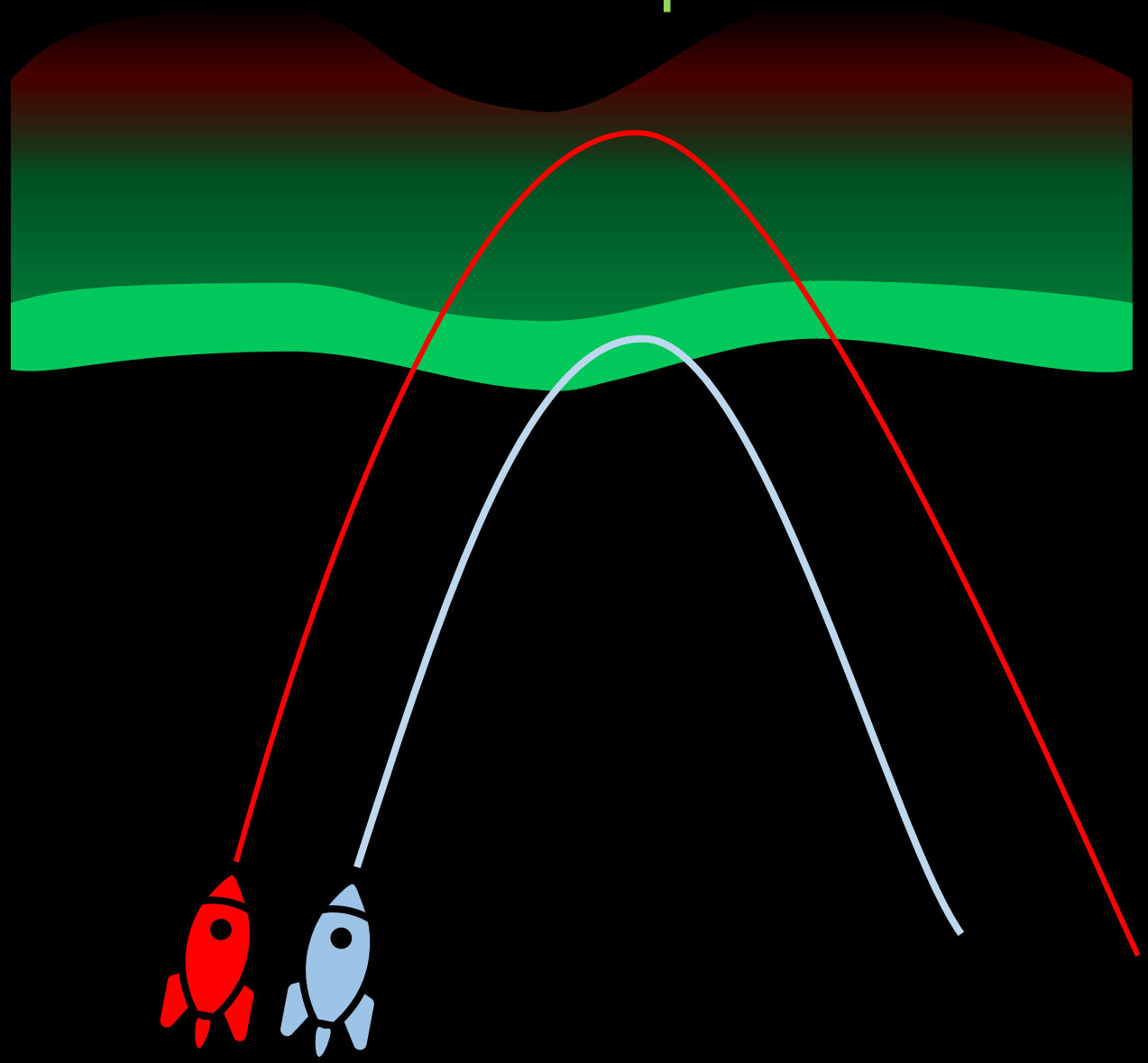
- Enhanced Aurora (Hallinen et al., 1985)
  - Modeling (Karlsson et al., 2005) suggests these could be generated by parallel electric fields in the downward current region.
  - May occur as often as 50% of the time that the aurora is visible

"Regular" Aurora

Enhanced Aurora

Credit: Vincent Ledvina, theauroraguy.com

Next Step: Submitted Rocket Mission Proposal



Proposed to send a rocket through the enhanced aurora to measure the theorized parallel electric fields for the first time.

This is a pathway mission for a STEVE/picket fence rocket.

Summary: *It's Not Easy Being Green*

- Observations of picket fence spectra differ quantitatively from green aurora spectral observations, suggesting different origins.
- Kinetic modeling driven by local parallel electric fields replicates picket fence spectra without requiring particle precipitation.
- At 110 km, parallel electric fields between 40 and 70 Townsend (~80 to 150 mV/m at 110 km) reproduce observed picket fence spectra.
- Enhanced aurora may also be produced locally by a parallel electric field – we've submitted a rocket proposal to attempt to measure these fields.

Want more information? Check out the paper!

Thank you for your attention!
Any questions?

Email me:
lcgasque@berkeley.edu