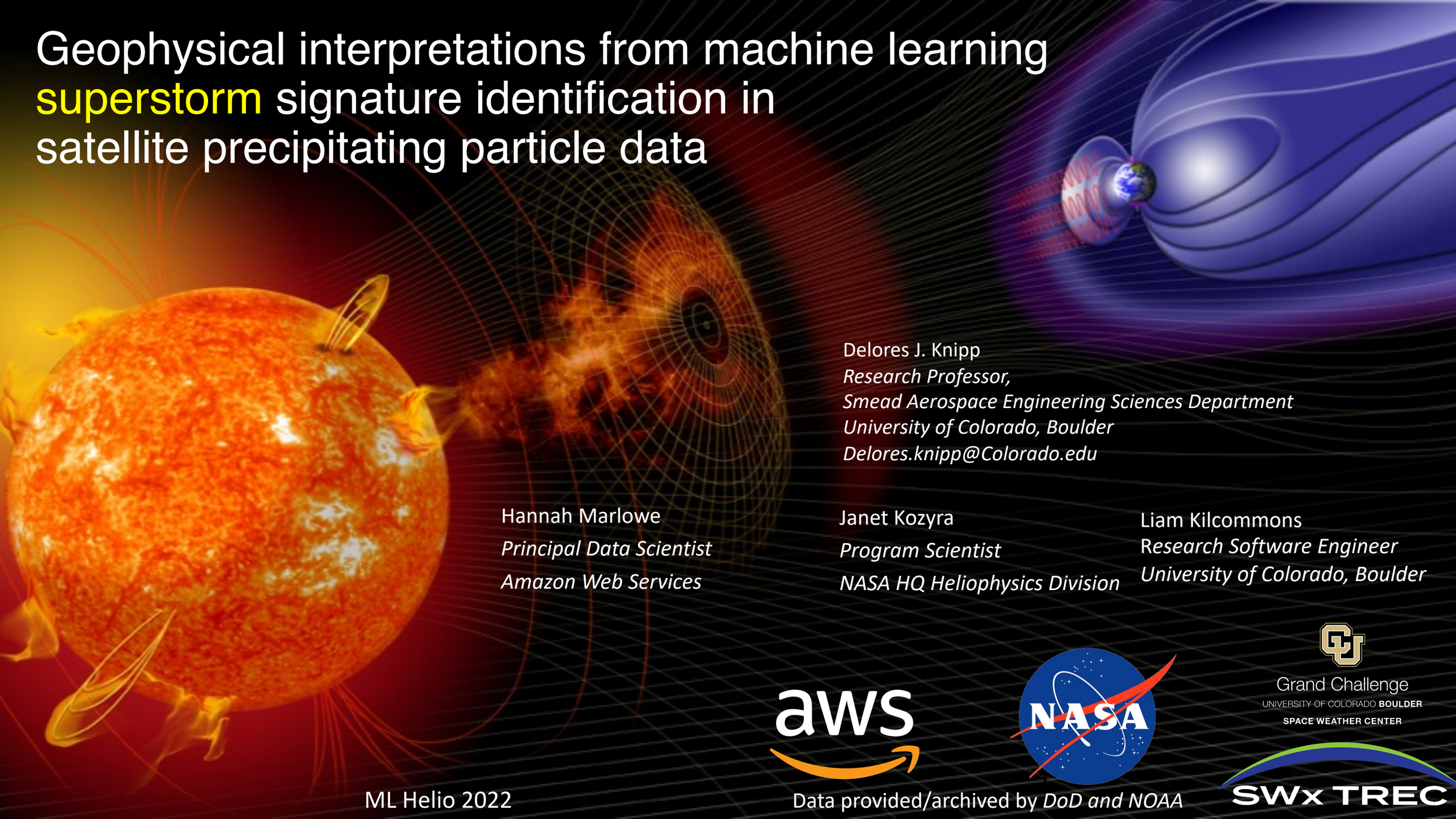
Geophysical interpretations from machine learning superstorm signature identification in satellite precipitating particle data



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Grand Challenge
UNIVERSITY OF COLORADO **BOULDER**
SPACE WEATHER CENTER

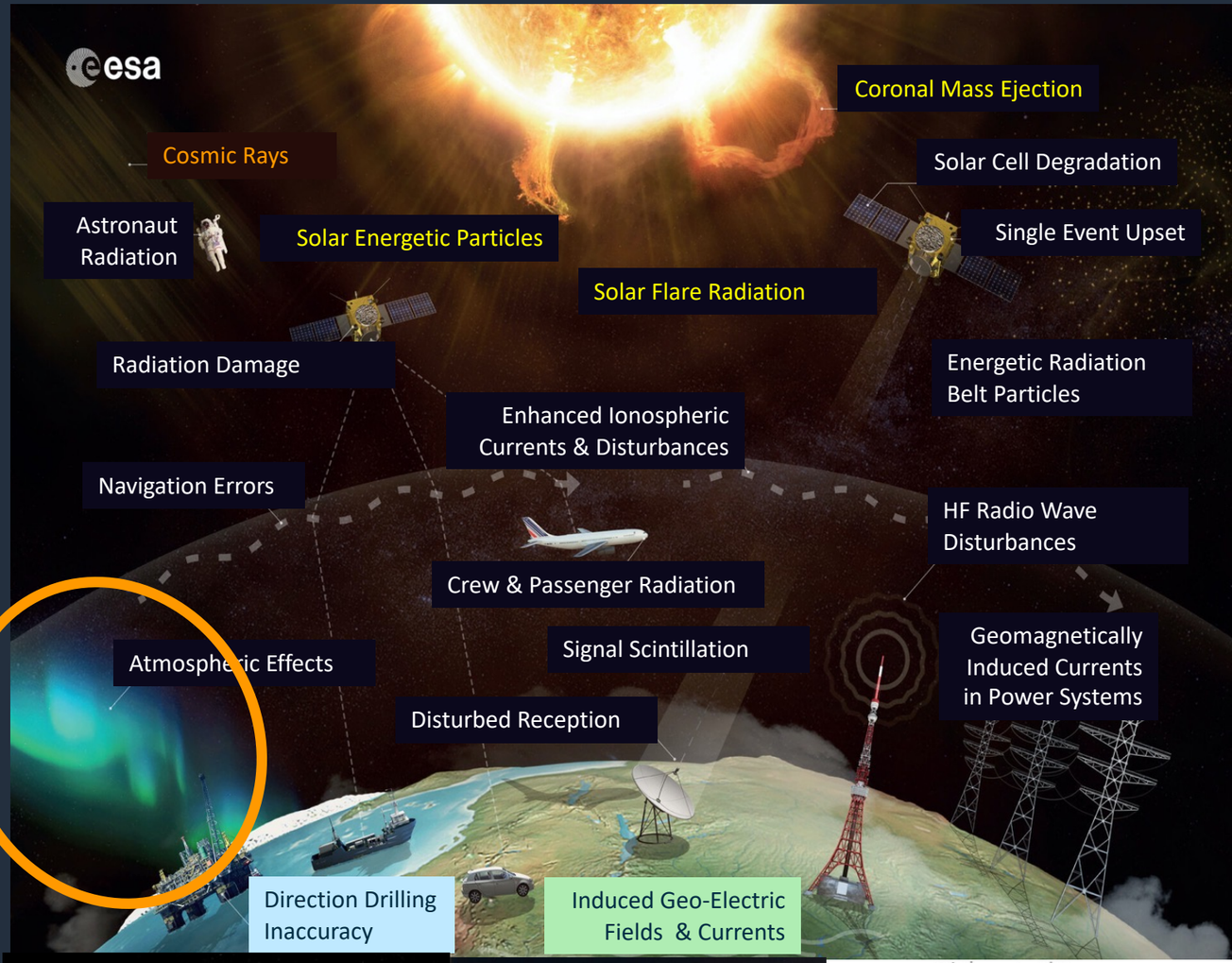
SWx TREC

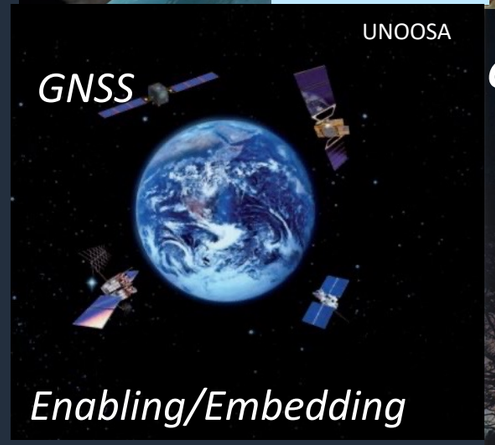
ML Helio 2022

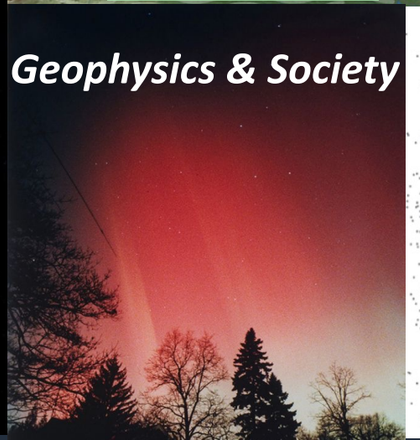
Data provided/archived by *DoD and NOAA*

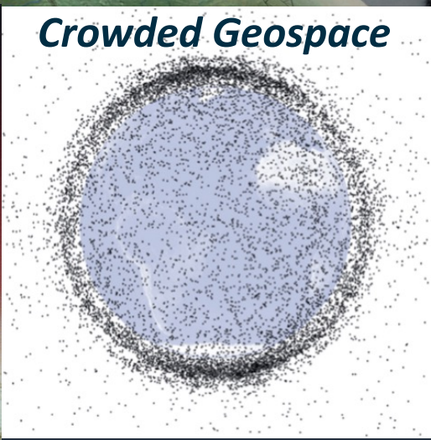
Motivation

- Identify Superstorm Characteristics
  - Anomaly Detection
  - LEO Particle Observations
- Geophysical & Data Overview
  - Why these data?
  - Processed in this way?
- New Insights/New Questions
  - Formulate Questions for Models
  - Suggest Alternate/New Observations



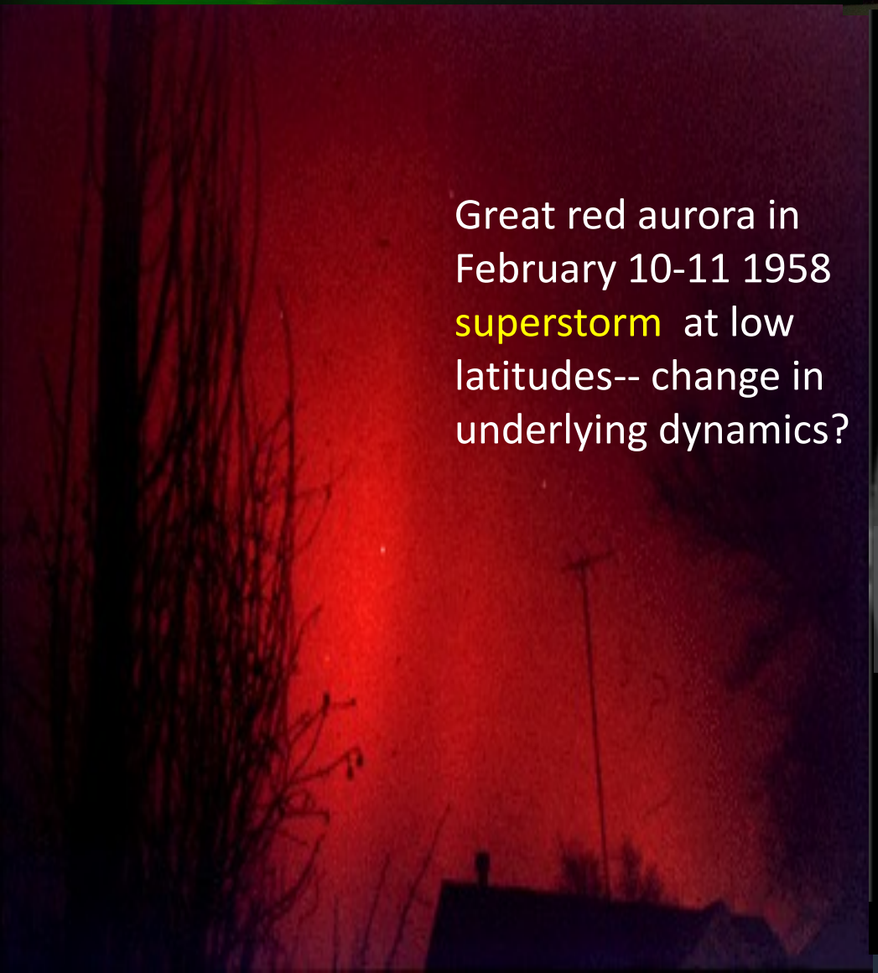




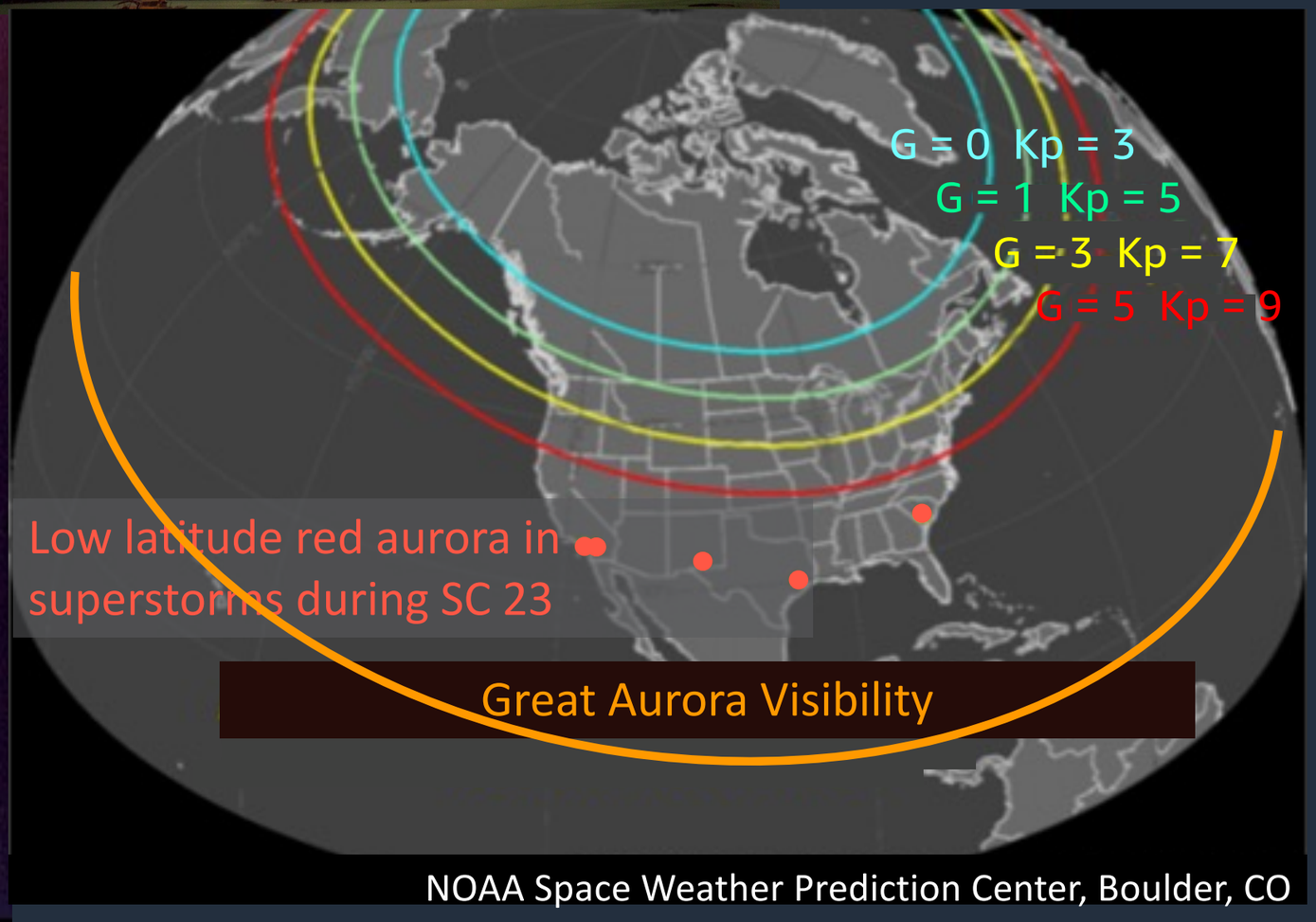


Typical Aurora vs Anomalous Features of Superstorms

Most common auroral emission is green & at high latitudes



Great red aurora in February 10-11 1958 superstorm at low latitudes-- change in underlying dynamics?



NOAA Space Weather Prediction Center, Boulder, CO

~Every 50 Years

Anomalous ‘Particle’ Behavior During Superstorms

Great red auroras occur only during extreme magnetic activity.

- Features:
  - Red auroral displays of unusual brightness
    - (> 100 kR of 630 nm light)
    - May extend to exceptionally low MLATs;
    - Cover up to 95% of the sky in places

[c.f. Vallence-Jones, 1992]:

USGS

For reasons not understood:

- Observations suggest these aurora are produced by
  - 10-20 min bursts of large fluxes of soft electrons (10s to 100s eV)

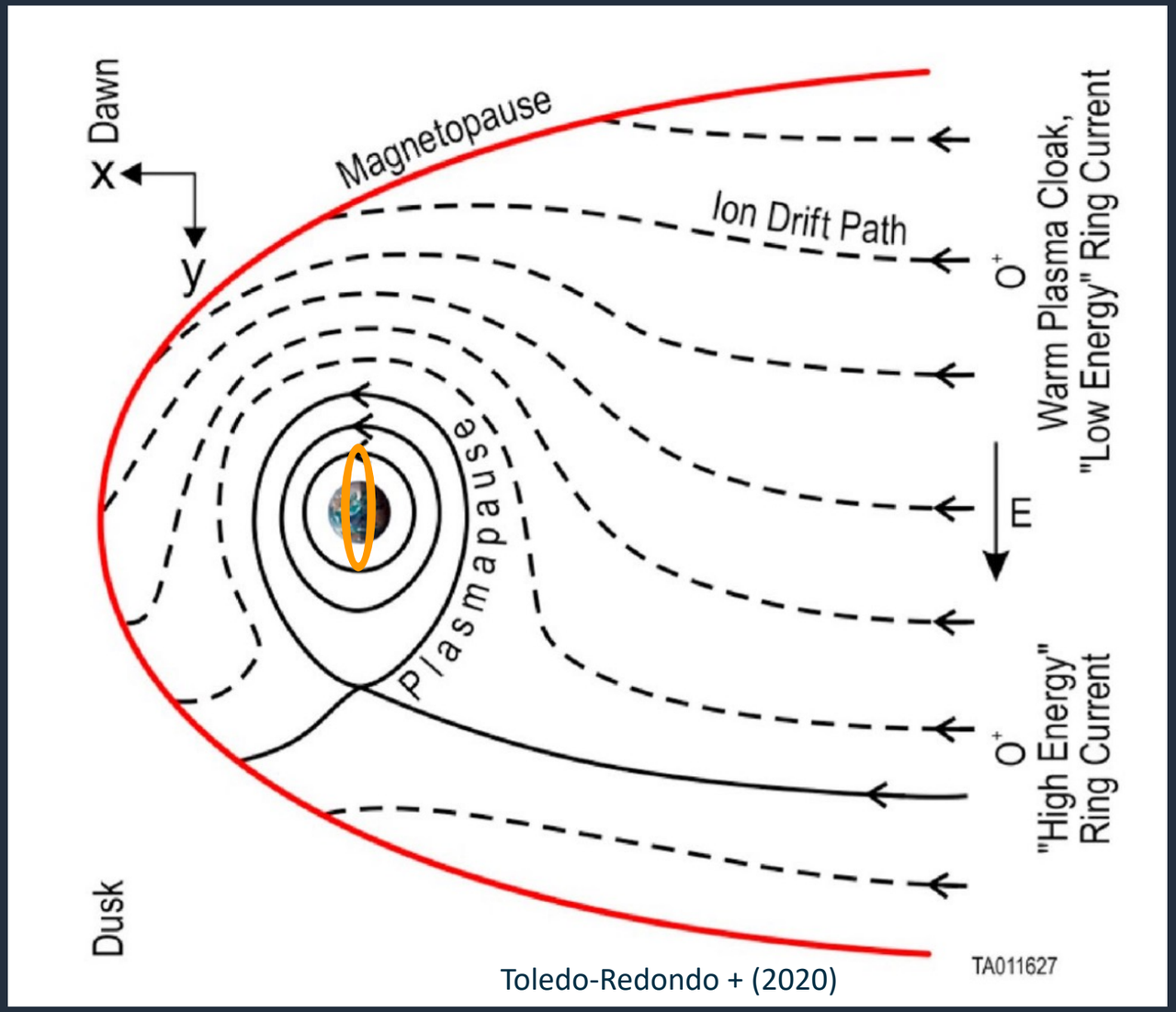
[c.f., Robinson et al., 1985; Shiokawa et al., 1997]

  - Source unknown with some preference for dawn sector
- Auroral precipitation softens in energy during intense storms

[c.f., Hecht et al.,2008]

Courtesy Janet Kozyra, 2010

Geospace “Tutorial”



Toledo-Redondo + (2020)

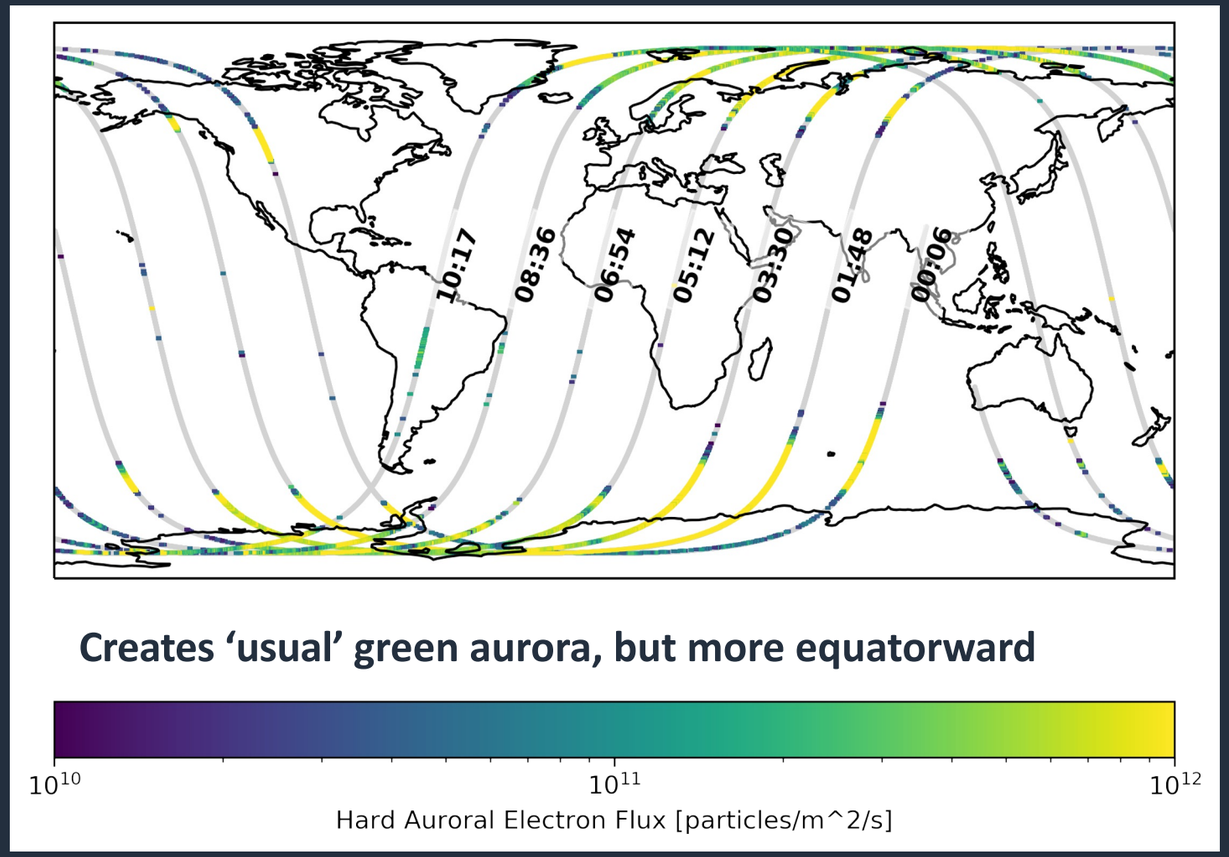
Equatorial cut of Earth’s magnetosphere

Particles drift sunward

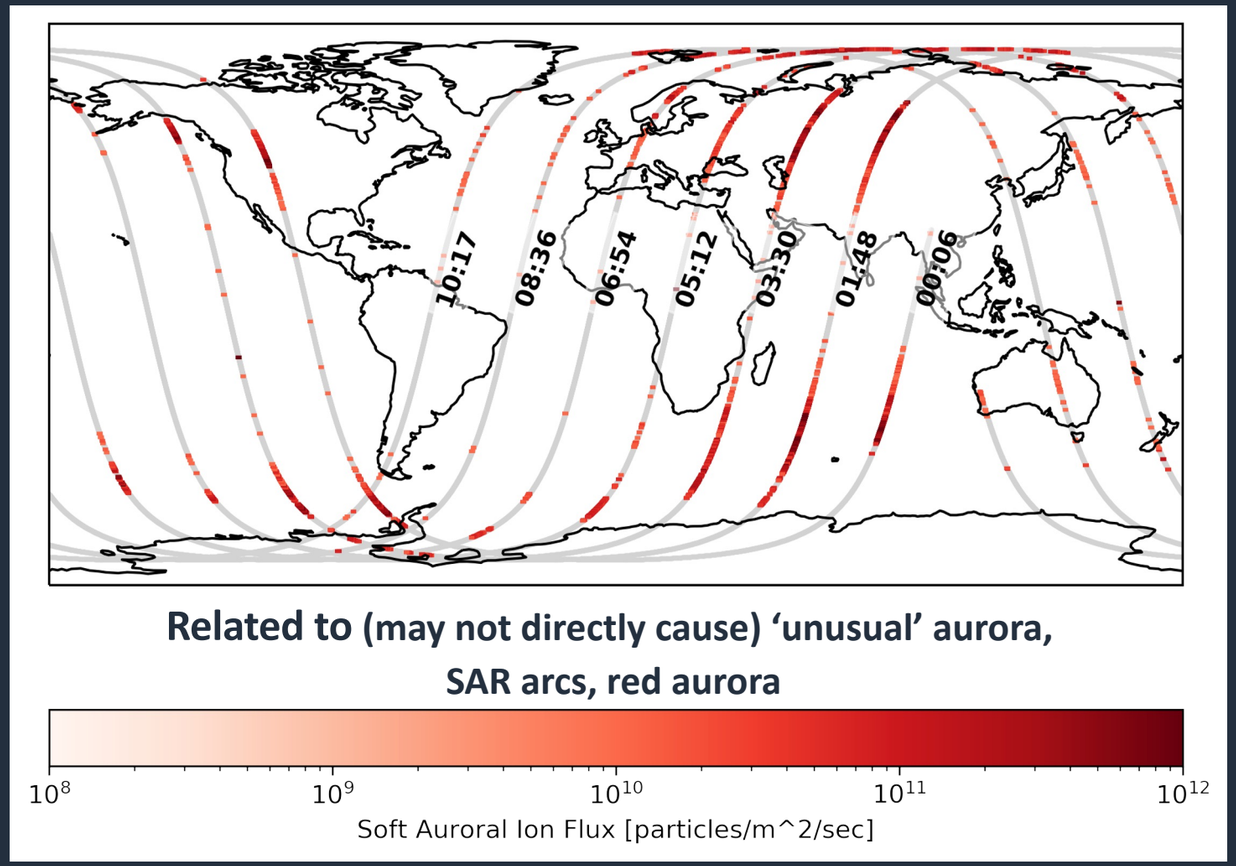
- Convection
- In geomagnetic field
  - Changes shape
- Cool to warm ions & e- :
  - Drift together
- Medium-Hot particles drift & produce charge separation and ring current
- Hottest particles trapped in radiation belts
- Drifting particles generally shielded from low latitudes
- Except……

Particle Precipitation During a Superstorm:

Electron precipitation at higher latitudes than Ion precipitation



Creates ‘usual’ green aurora, but more equatorward



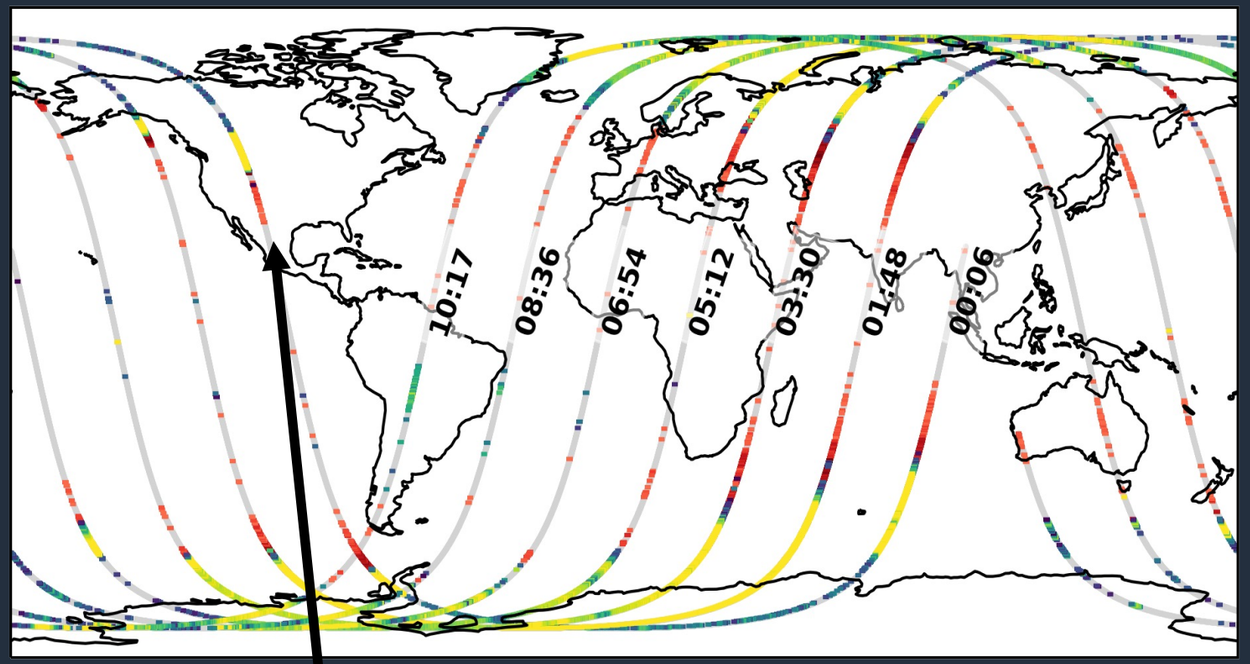
Related to (may not directly cause) ‘unusual’ aurora, SAR arcs, red aurora

DMSP F13 2003-10-30

- Specifically look at **hard electrons** and **soft ions**

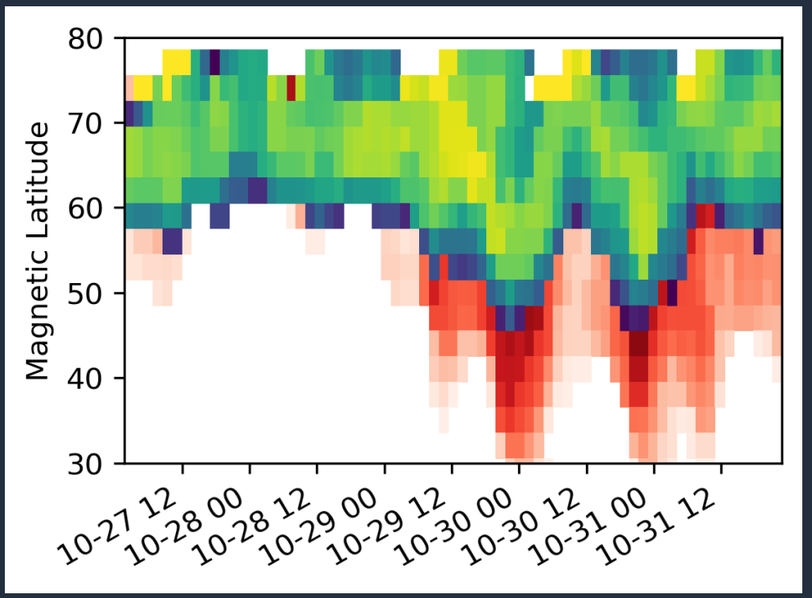
Ion precipitation reaches lower latitudes than Electron precipitation during **superstorms**

October 2003

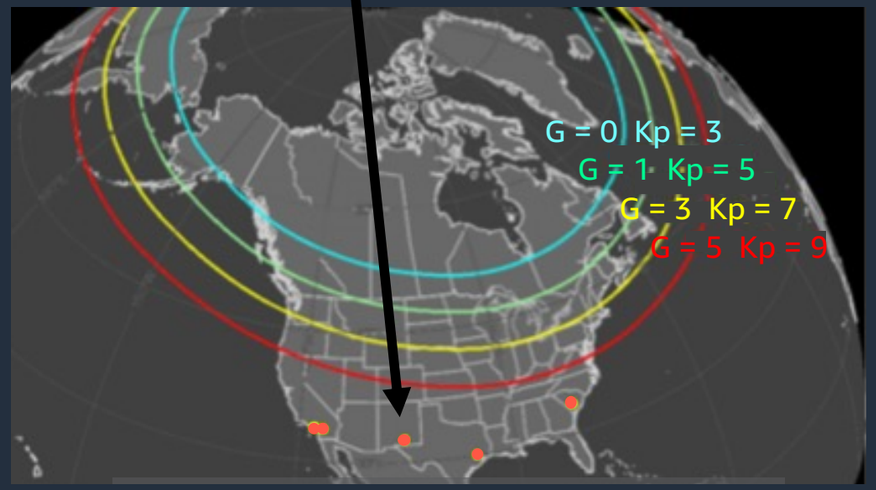


19 channels, of ions and electrons per second (millions / day)

Each orbit becomes one time step



NH dawnside particle overlay

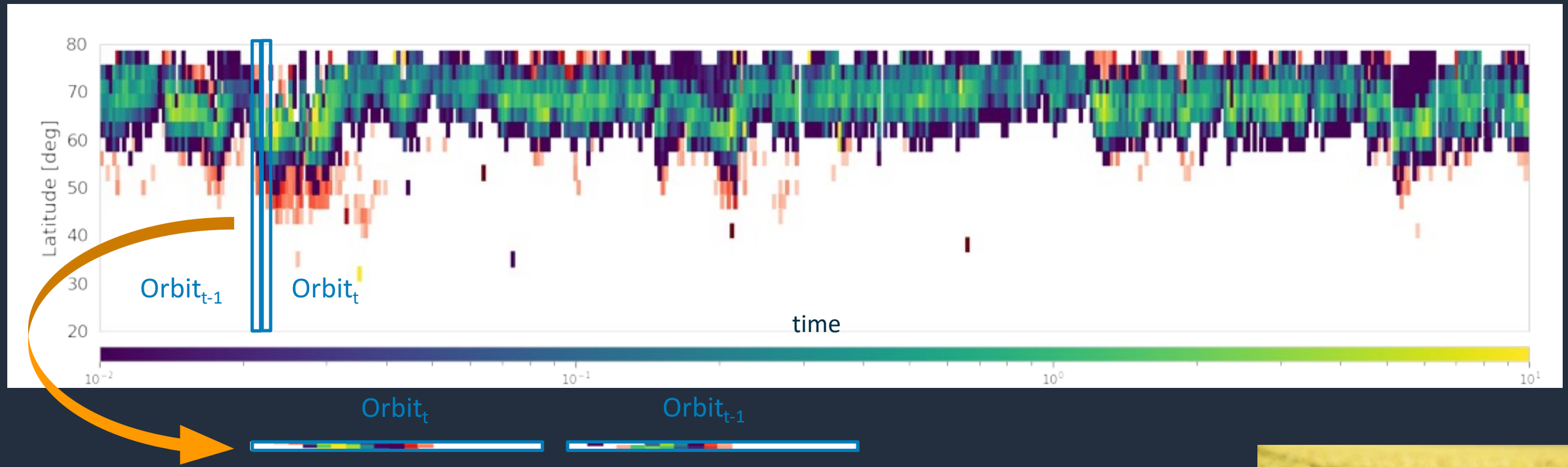


Ion precipitation reaches as far south as red aurora observations (red dots)

- **Need ML-ready data**
  - Impractical to use full data stream
  - Remove detector anomalies and nuisance signals—median filtering
  - Careful data reduction (averaging/filtering) to preserve signals of interest

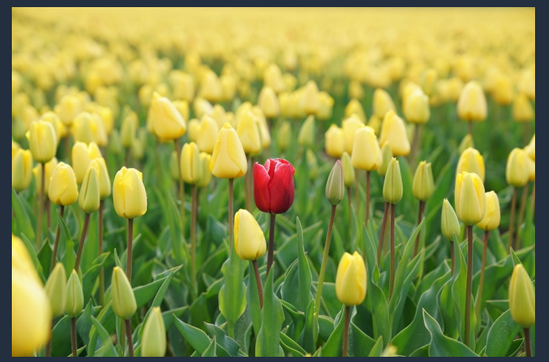
Pre-model Data Prep; Then Categorize Storms

- Shingling DMSP data
  - Feed multiple past orbits into the model to reduce small-scale sensitivity
- Remove residual noise with median filter (~35,000 DMSP orbits 2000-2006)



Model

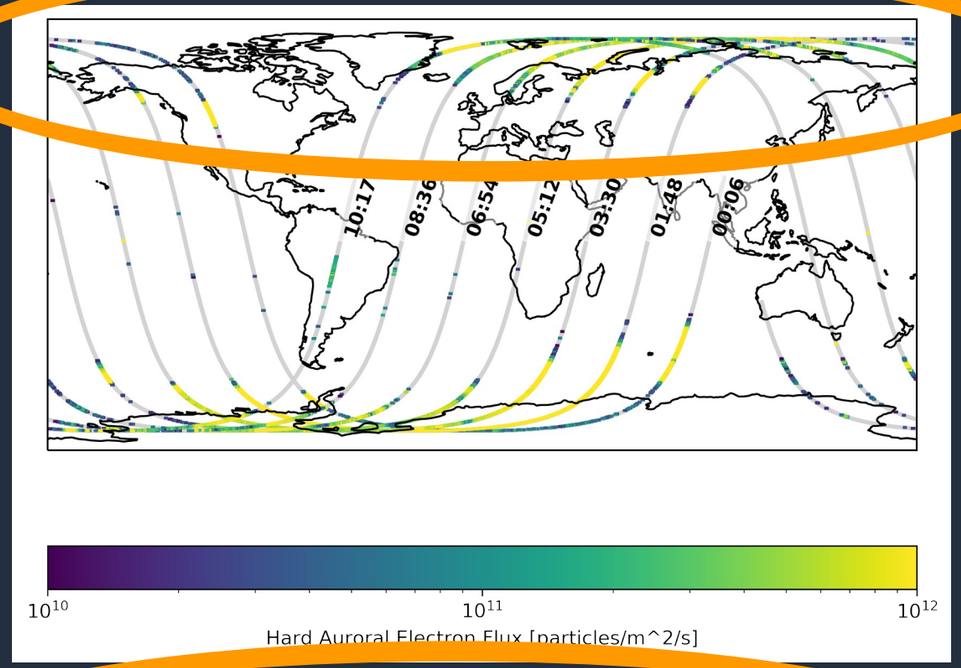
- Model to Categorize storms
  - Unsupervised anomaly detection
  - Random Cut Forest

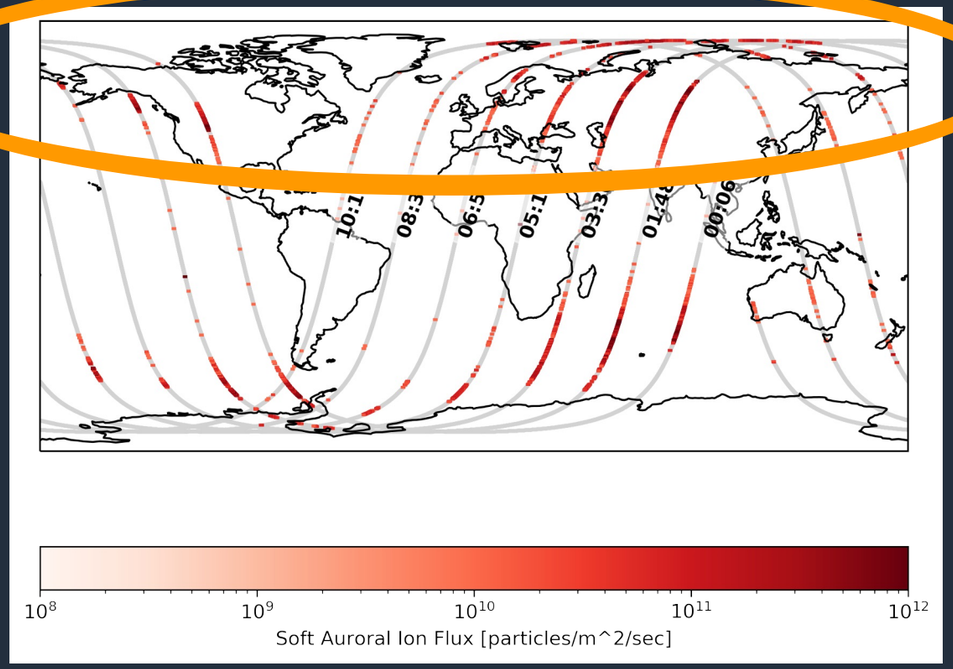


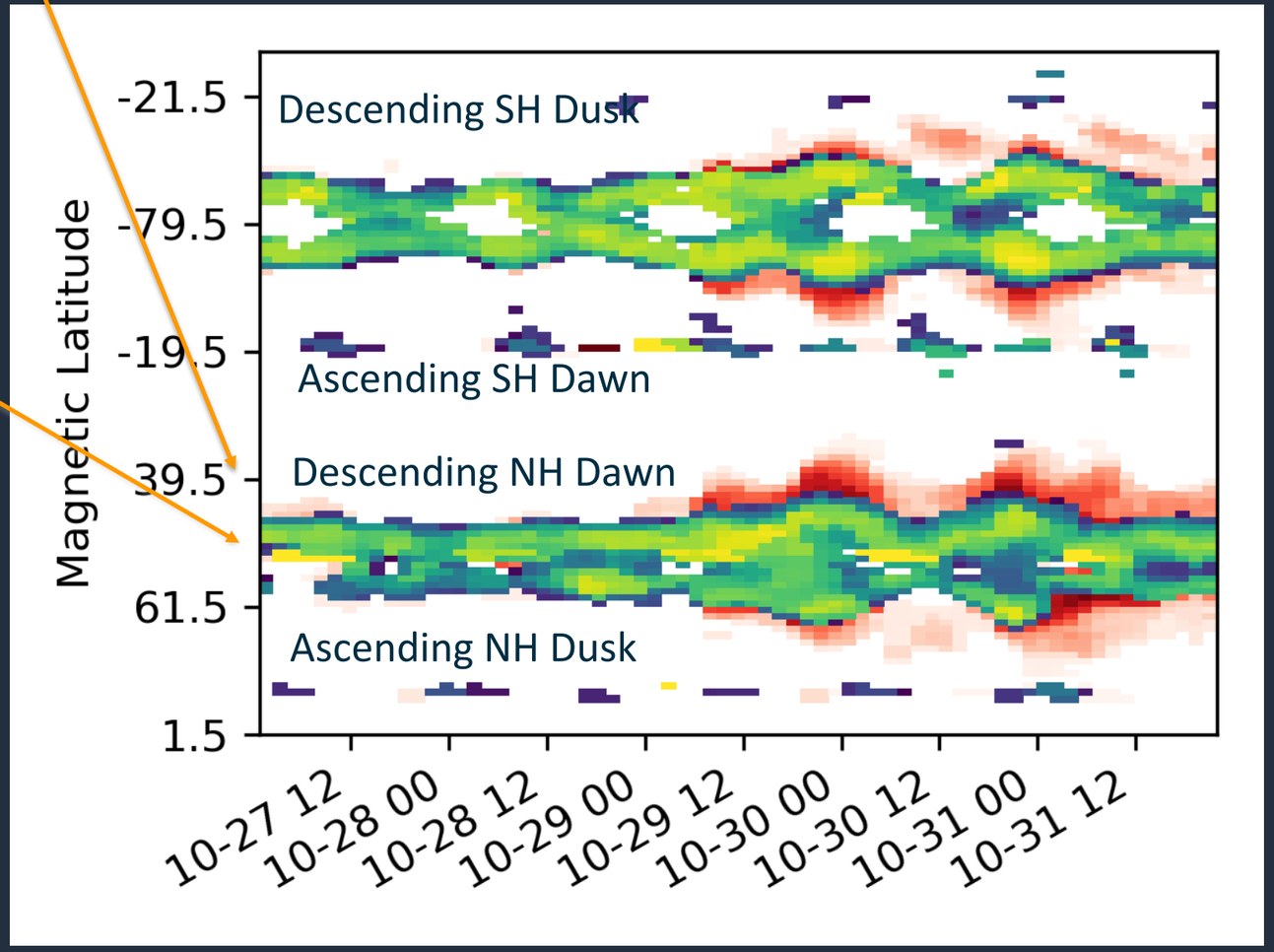
Start with Ground track--geographic

Collapse to one orbit per time step

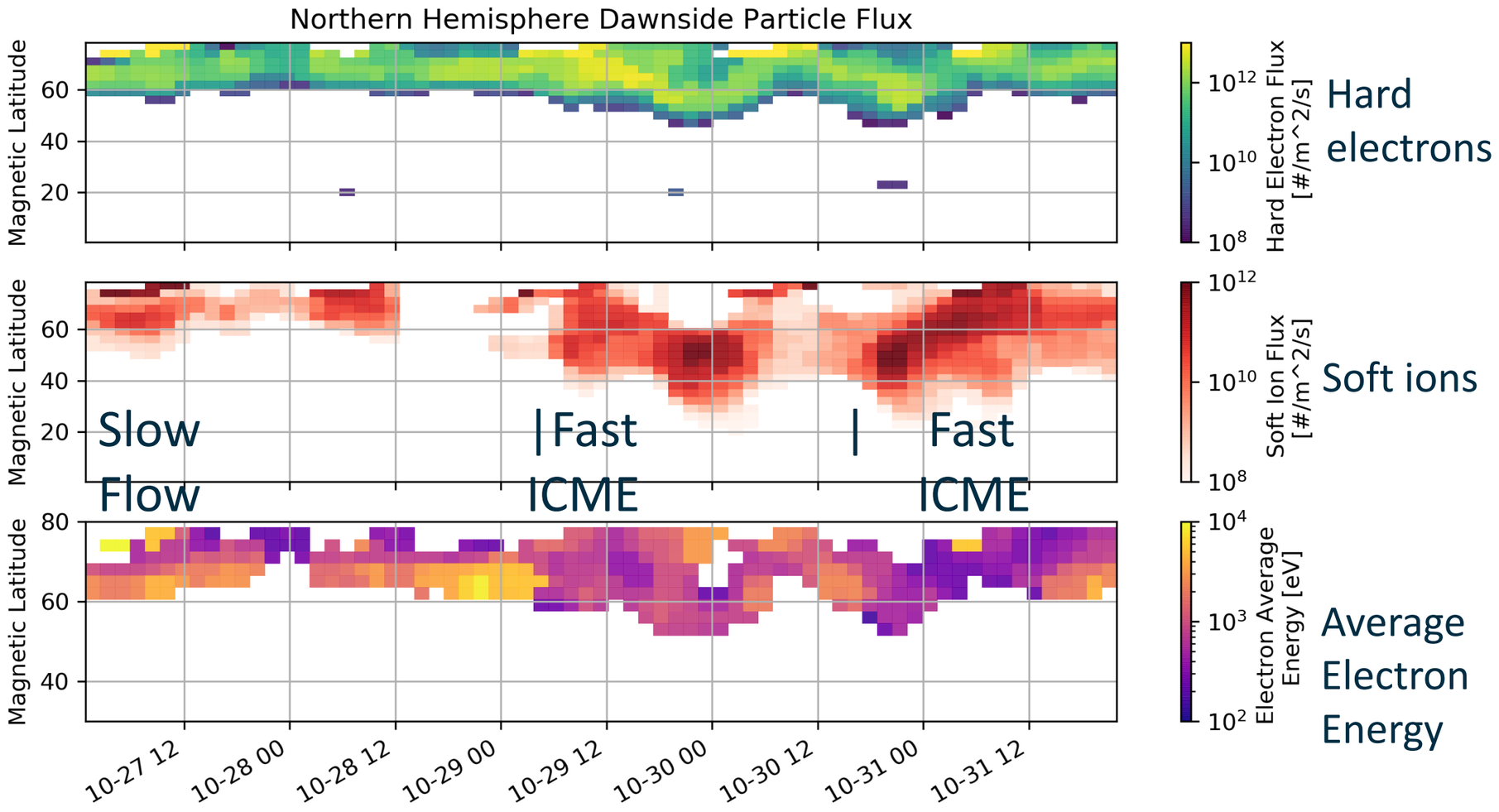
Convert to Geomagnetic both poles







DMSP ML-ready inputs October 27-November 1 2003 & Results:



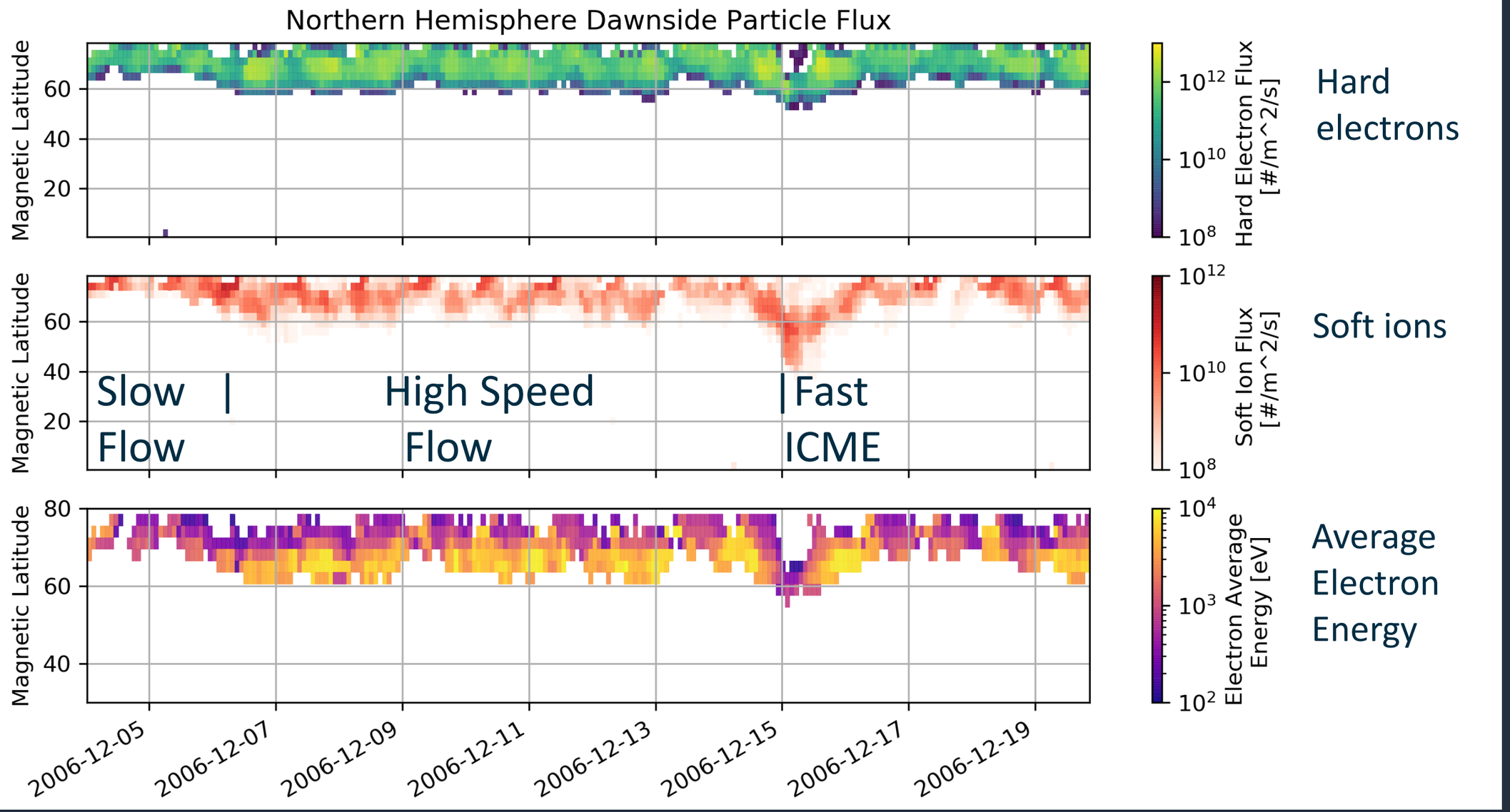
Anomaly Score:
1.17
~ 24 hr

SymH
-420

Kp
9

Expanded auroral zone; Intense soft ion flux @ low latitudes; Electron Avg energy decreases

DMSP ML-ready inputs December 4-19 2006 & Results :



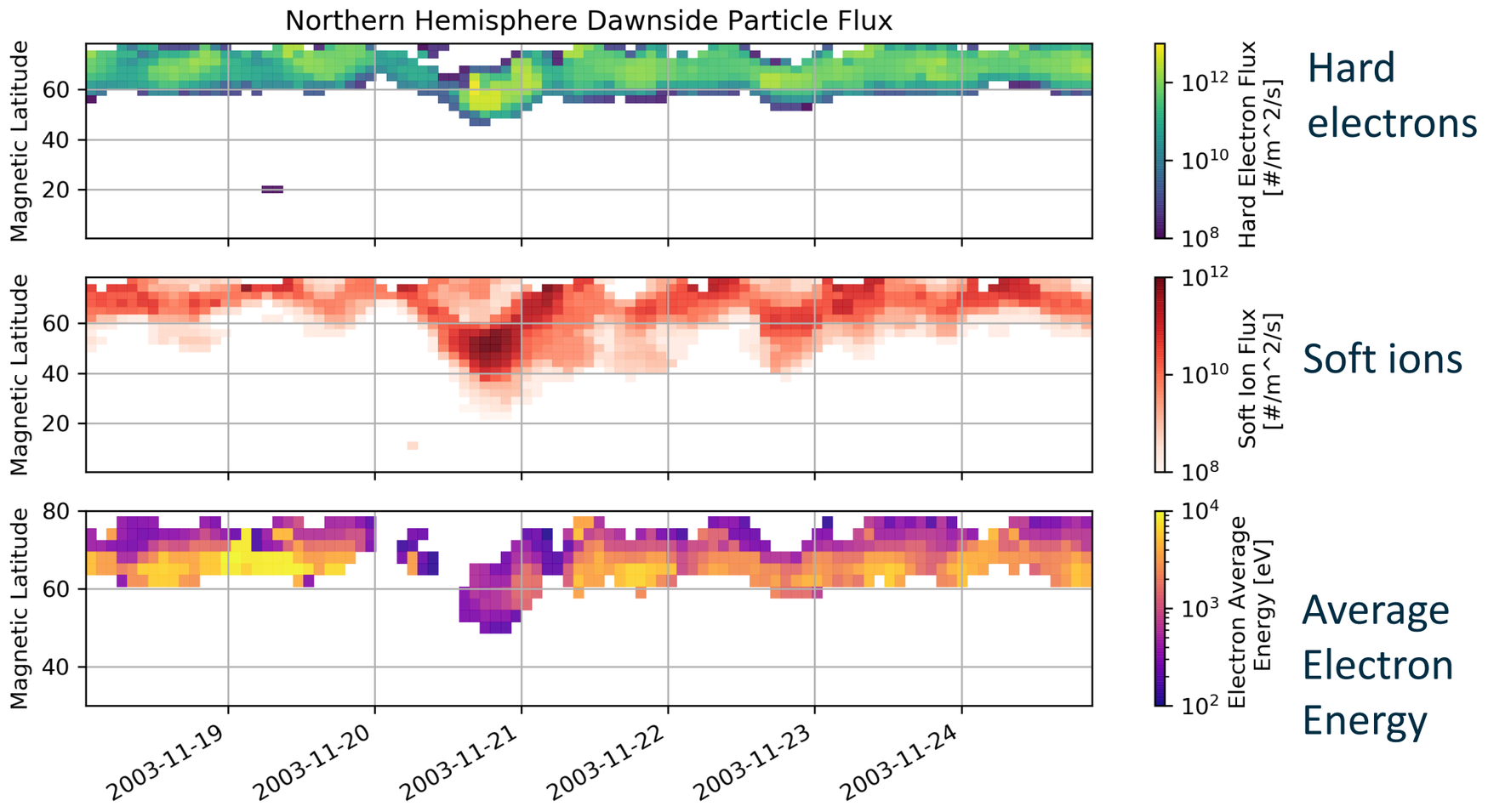
Anomaly Score:
1.2
Single Peak

Sym-H
-210 nT

Kp
8+

Expanded auroral zone; Intense soft ion flux @ low latitudes; Electron Avg energy decreases

DMSP ML-ready inputs November 18-24 2003 & Results :



Hard electrons

Soft ions

Average Electron Energy

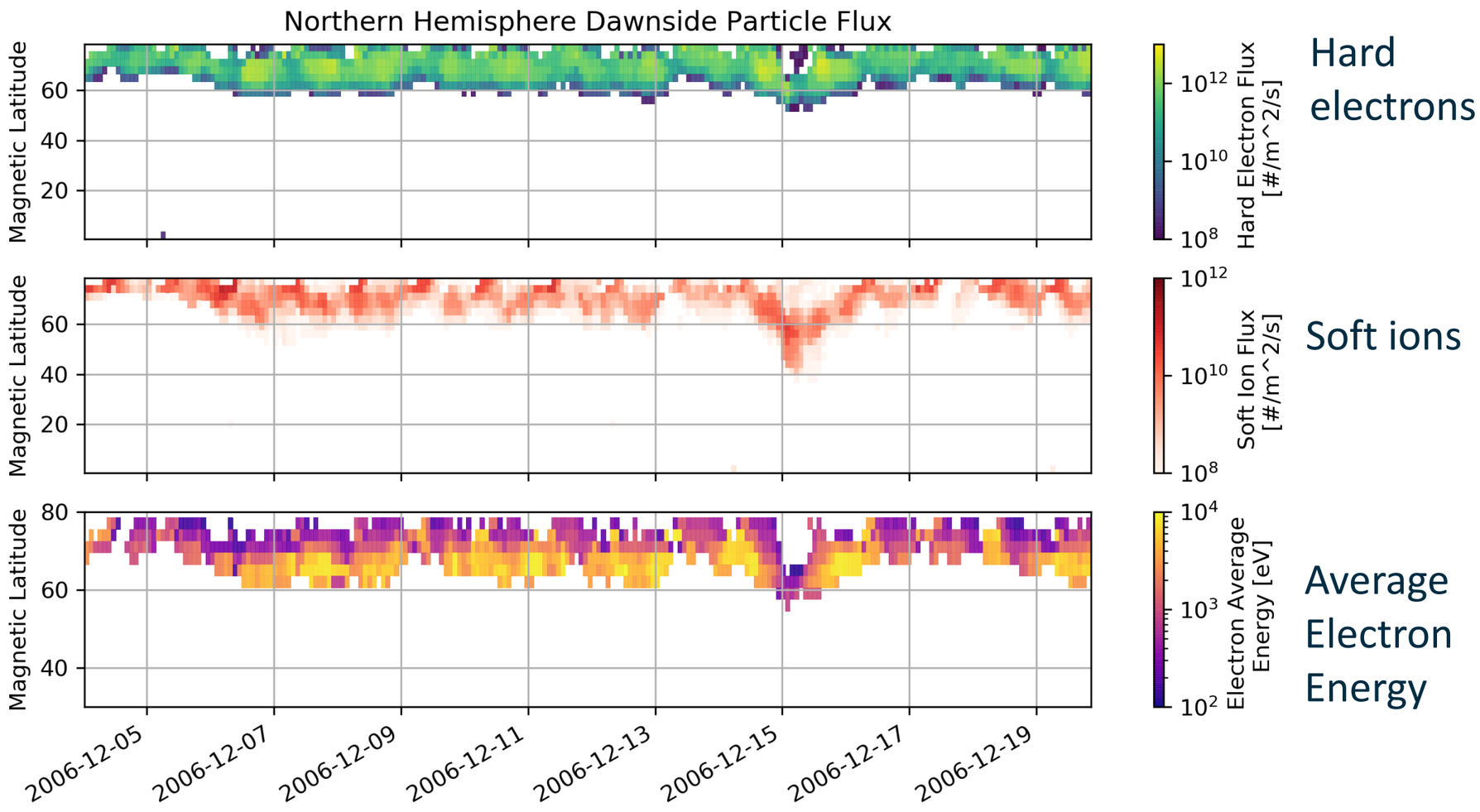
Anomaly Score:
1.18
Multi-day
Multi-peak

SymH
-480 nT

Kp
9

Expanded auroral zone; Intense soft ion flux @ low latitudes; Electron Avg energy decreases

DMSP ML-ready inputs January 15-26 2005 & Results :



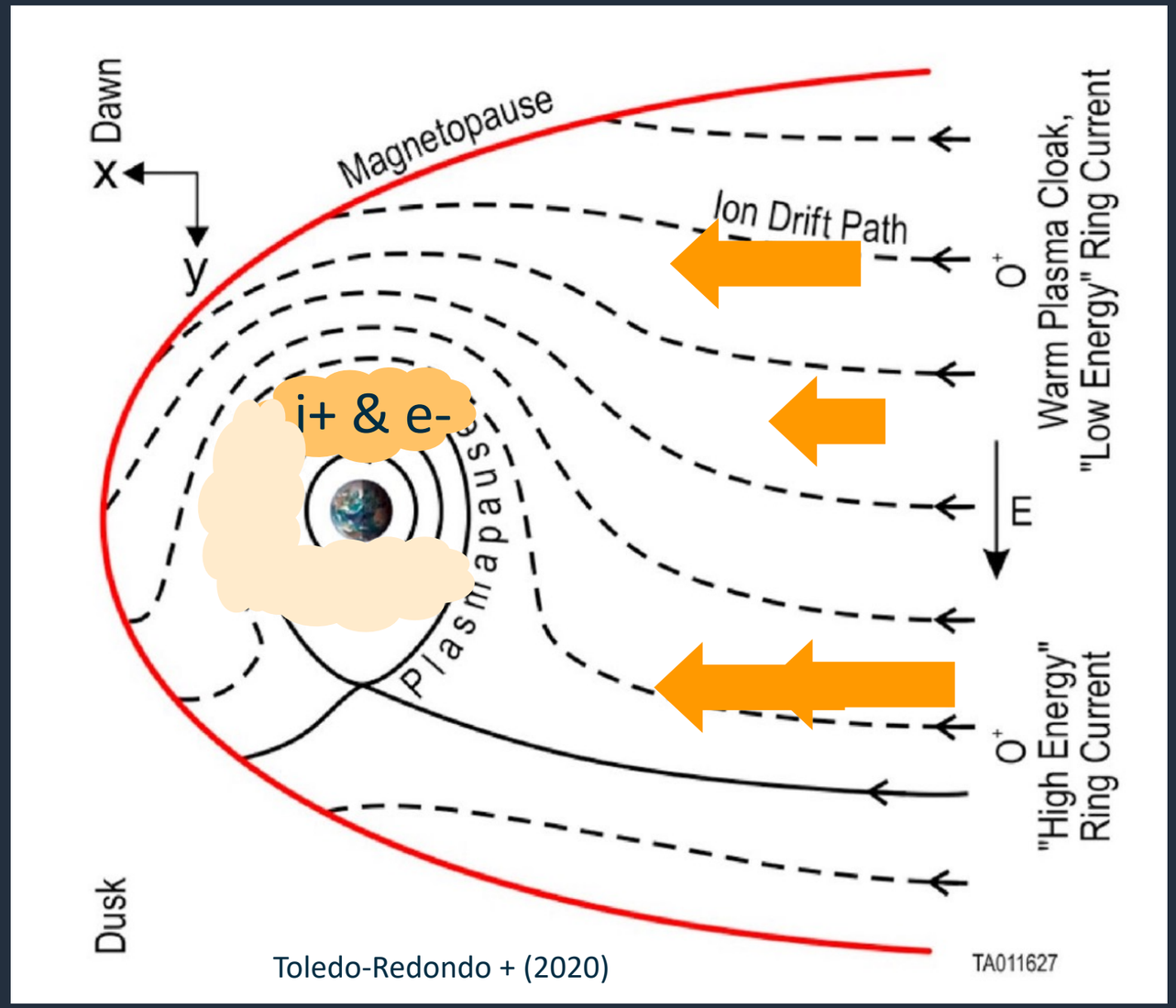
Anomaly Score:
1.1
Two Peaks

SymH
-105 nT

Kp
8

Expanded auroral zone; Intense soft ion flux @ low latitudes; Electron Avg energy decreases

Questions for Modelers:



Toledo-Redondo + (2020)

Source of low energy ions and electrons with access to

- Dawnside
- Low latitudes

- Why intense storm preference?

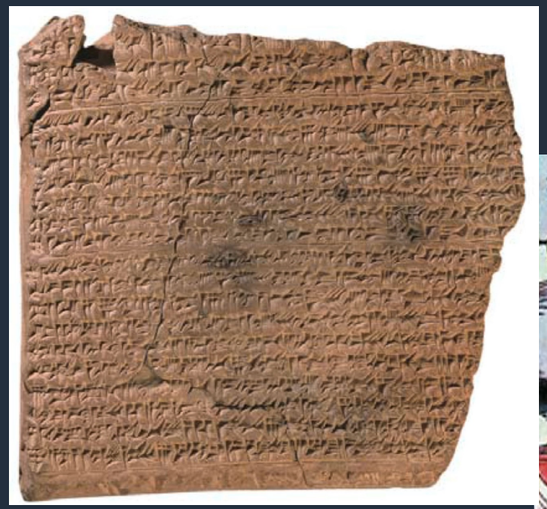
- How do these particles get to low latitudes?

- Role of SW density?
- Role of unsteady penetration electric field?

Red Aurora & Superstorms

Society Impacts ➡Machine Learning

Clay tablet 10.9 cm by 10.6 cm.



"Night of the 29th, red glow flared up in the west …" at Babylon

37th year of King Nebuchadnezzar II,

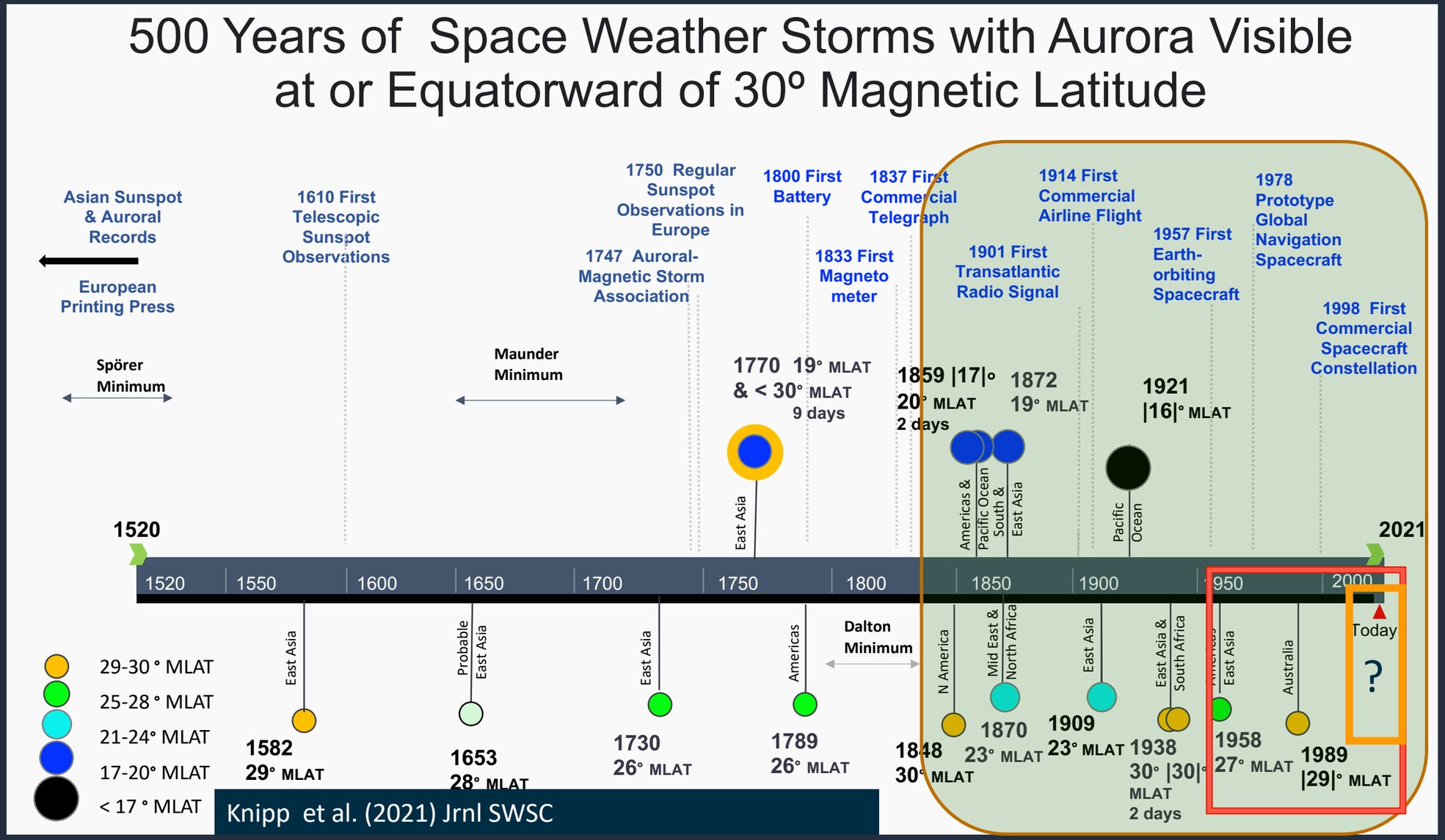
12-13 March 567 BCE (~41 MLAT that epoch)

Stephenson et al. (2004)

Daglis & Akasofu (2004)

Bert Vorchheimer, Feb 10 1958

Superstorms: Machine Learning ➡ Society Impacts



14 Visual 'Great' Events in 500 Years

- All since 1859 disrupted conducting technologies: telephones, submarine cables, power grids via magnetic perturbations
- Latest in 1989
  - -HydroQuebec grid collapse
  - -2000 'lost' objects from space catalogue had to be 're-acquired'; weeks of effort

SWx TREC

Thank You

Questions/Comments?