Auroras: A Users' Guide

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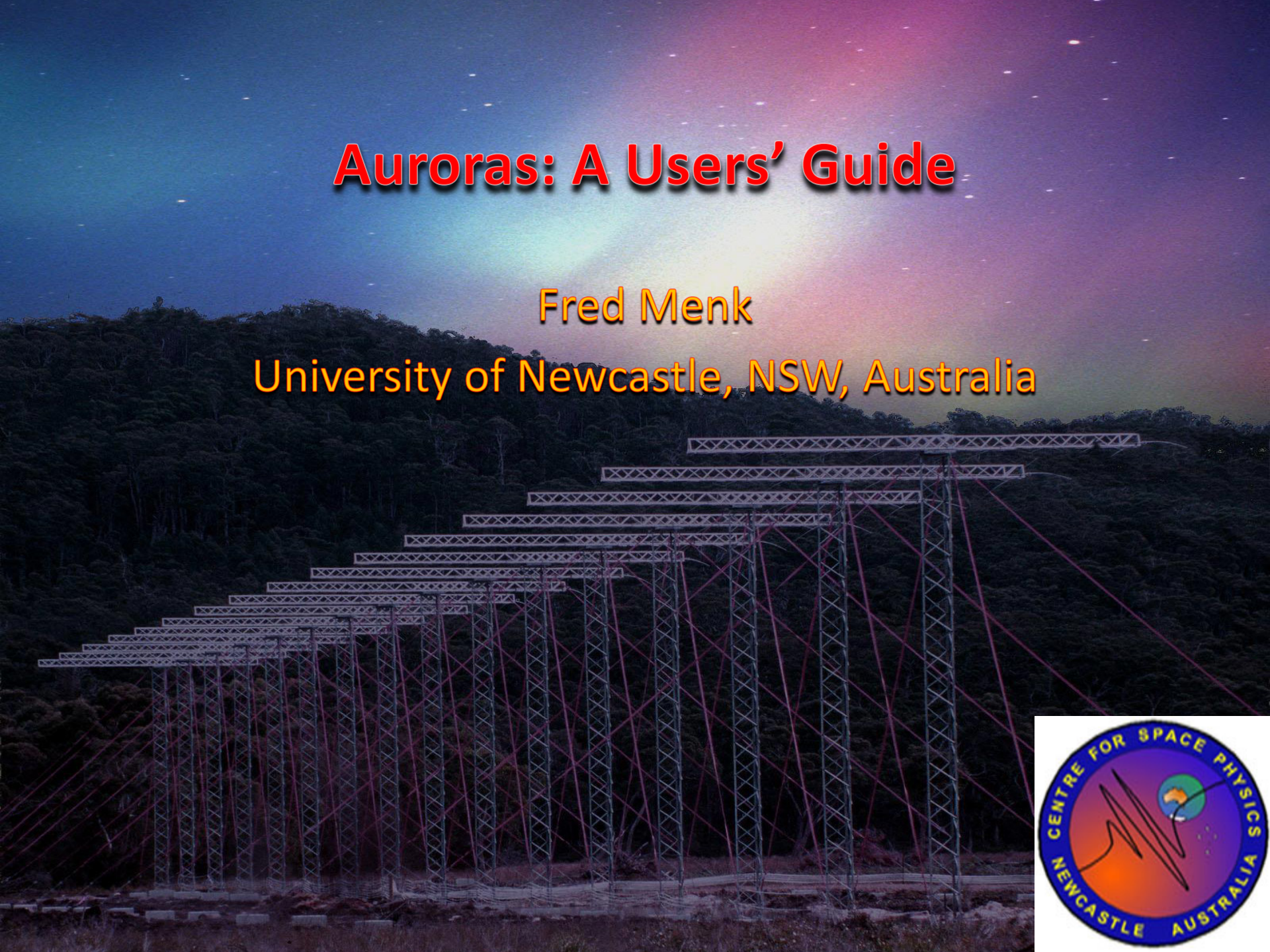


Aurora: What is it?

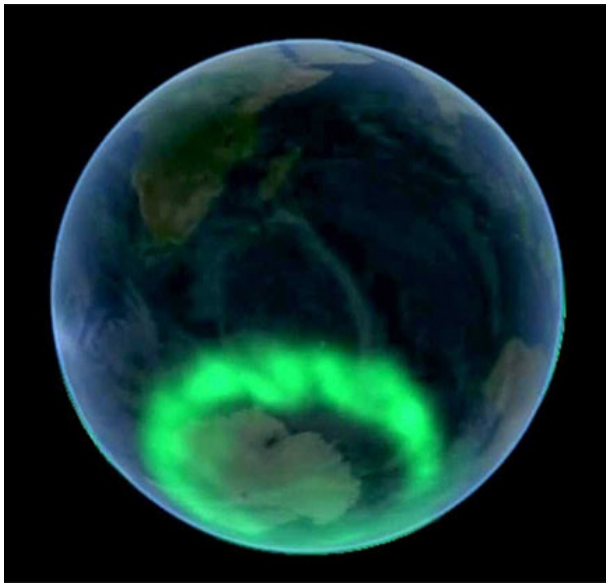
https://www.youtube.com/watch?v=mWRnvzodCO0

http://www.abc.net.au/news/2017-09-25/the-aurora-borealis-as-seen-from-the-iss/8980768

We see that auroras:

- Occur in both hemispheres
- Can take quiet (diffuse) or very active forms
- Quiet forms look like east-west arcs or bands
- Active forms look like curtains and rays pointing up magnetic field lines
- Can be bright (~ full moon)
- Colours vary with altitude
- Can pulsate rapidly
- Appear to extend into dayside

Auroral forms tend to be aligned east-west and occur over an oval-shaped region centred on the magnetic pole – the **auroral oval**.



Southern auroral oval [NASA]

THE SOUTHERN AURORAL OVAL

By F. R. Bond* and I. L. Thomas†

Aust. J. Phys., 1971, **24**, 97–102

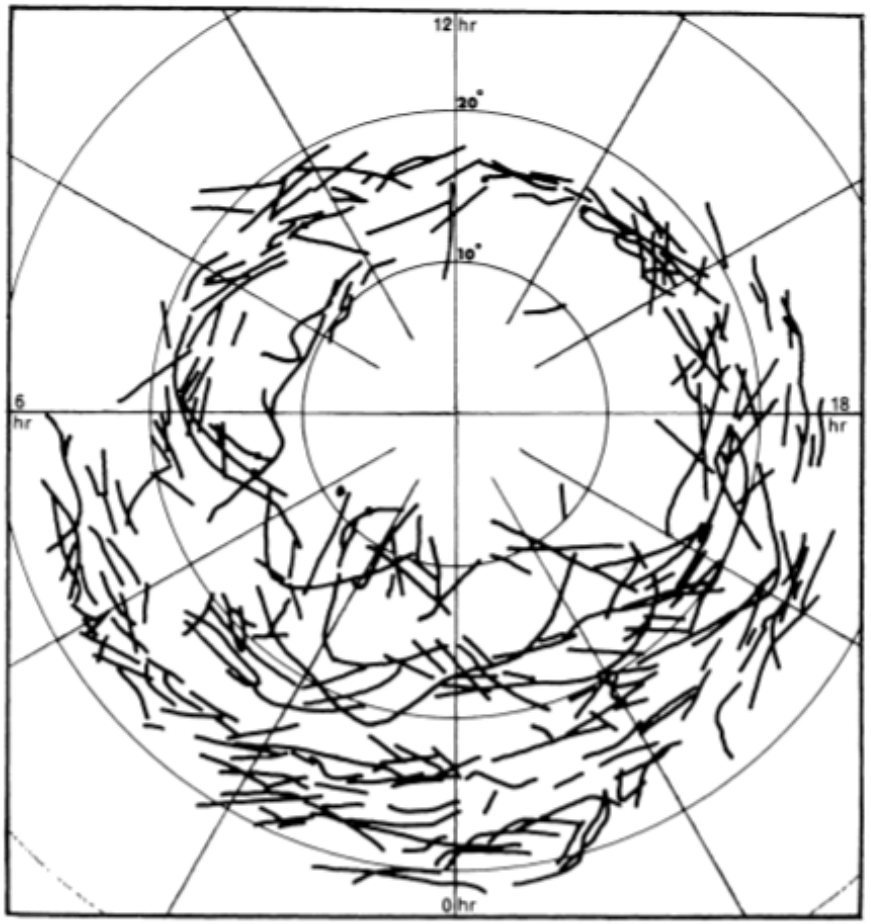
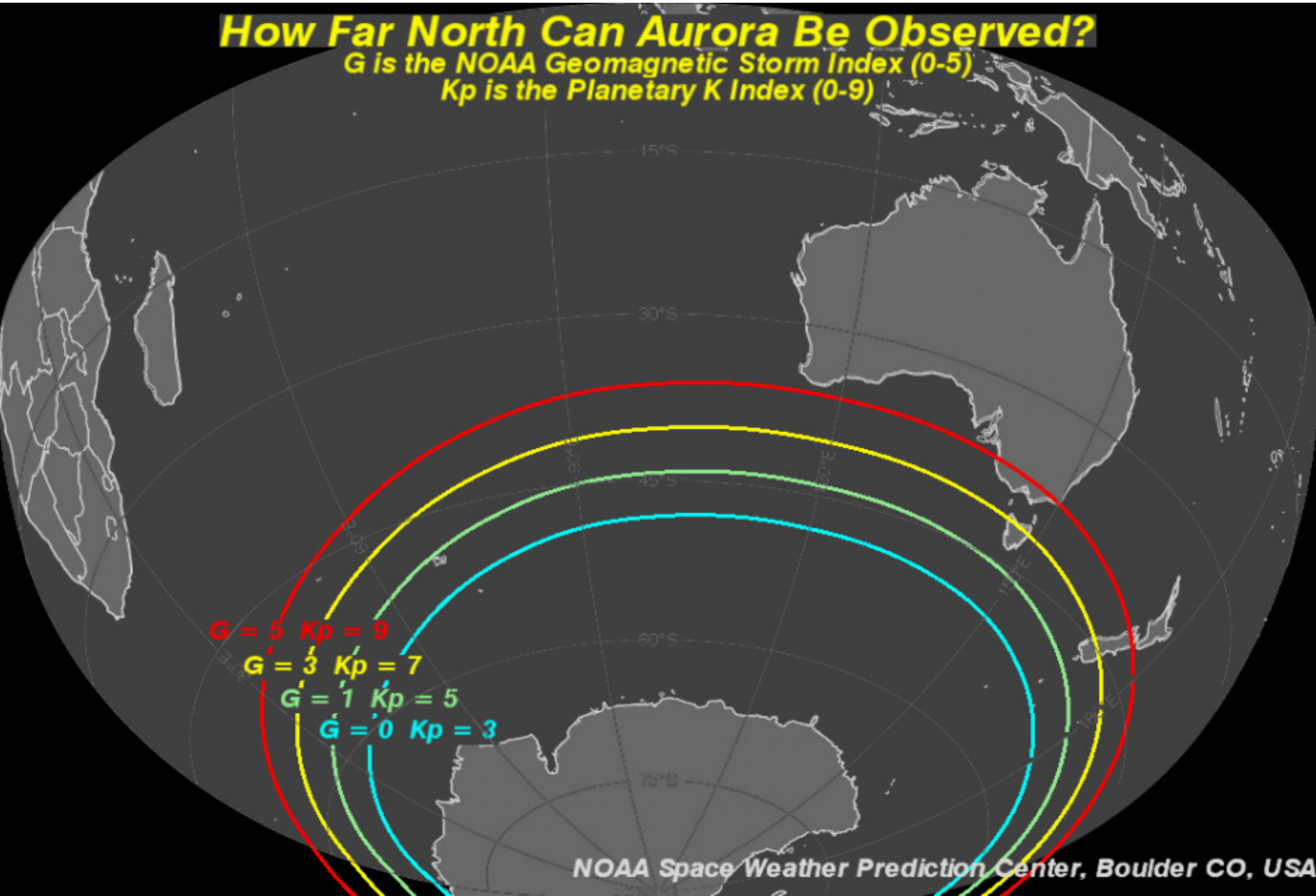
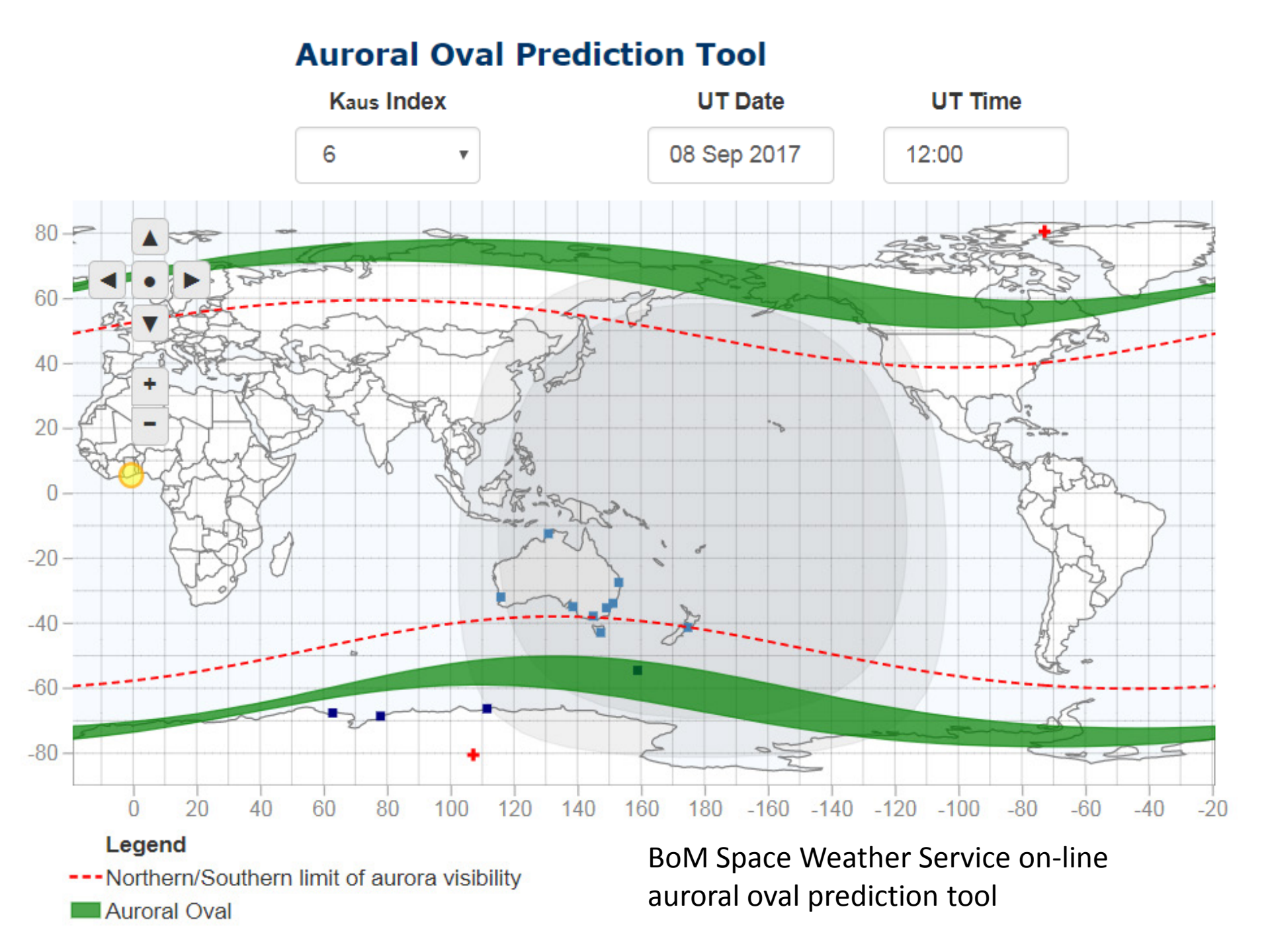


Fig. 2.—Mass plot of auroral forms for intervals when $K_p = 4$ on a polar coordinate representation of the θ_4, ϕ_4' colatitude : time-longitude system.

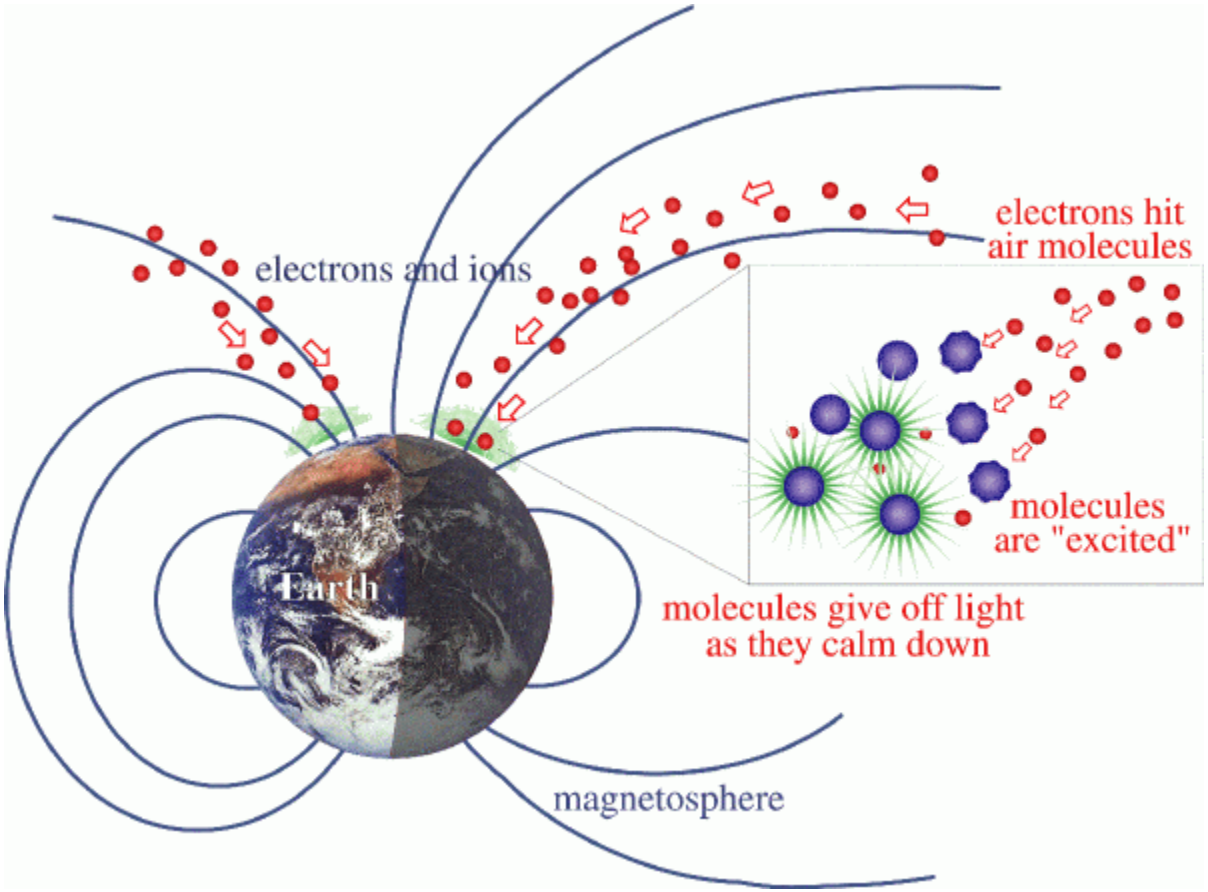
The latitudinal extent of auroras depends on magnetic activity





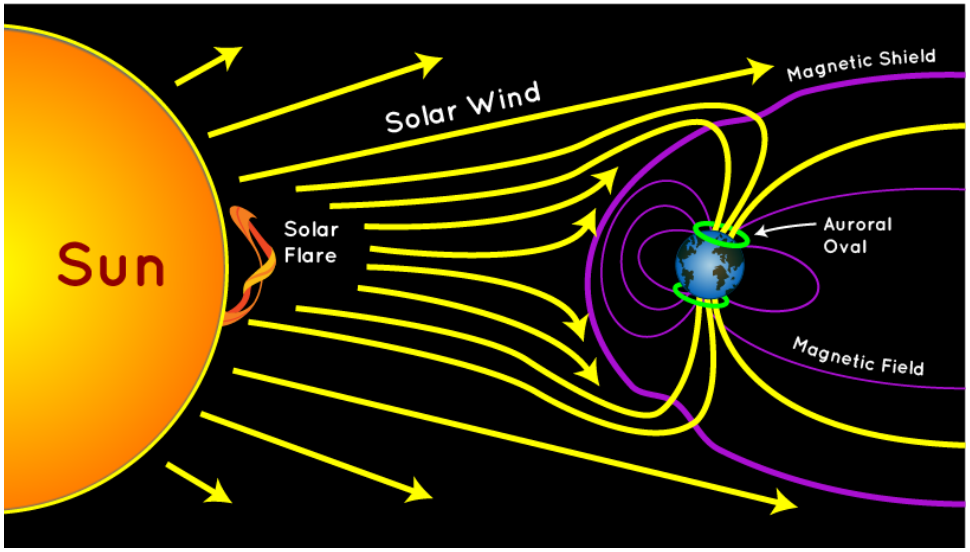
BoM Space Weather Service on-line auroral oval prediction tool

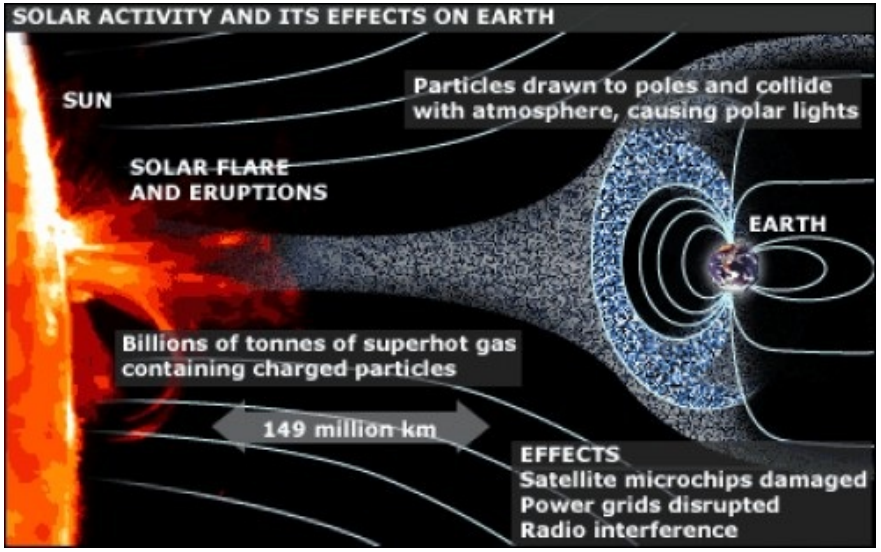
Aurora: What causes it?

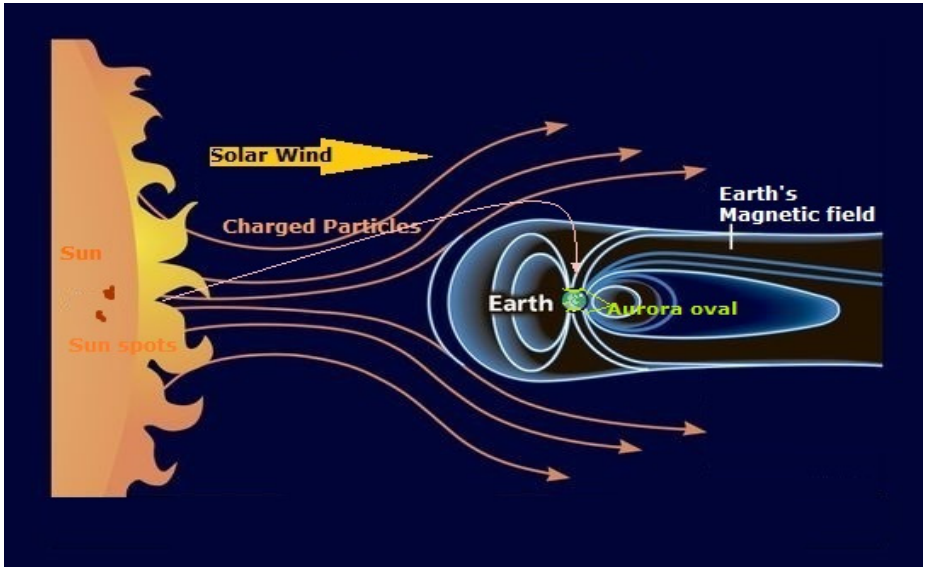


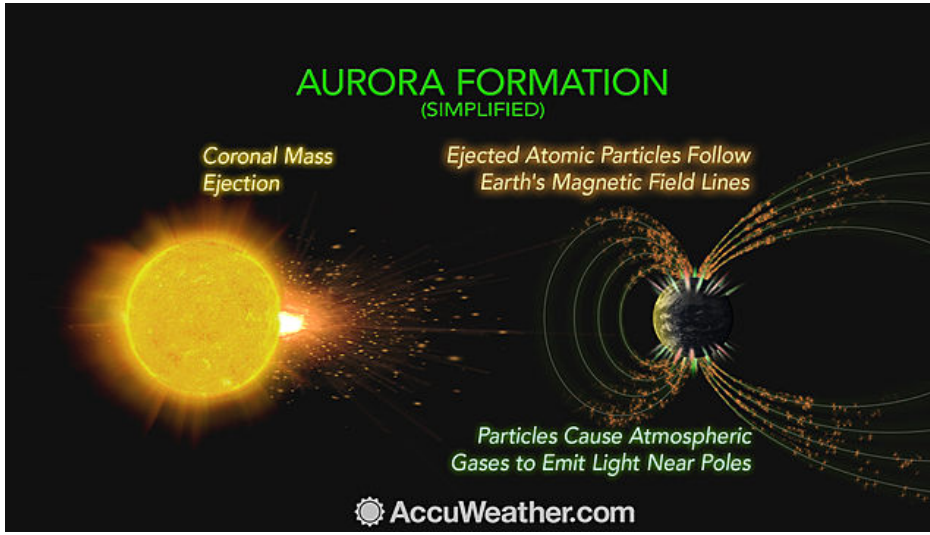
Source: NASA

Sources of the electrons and ions





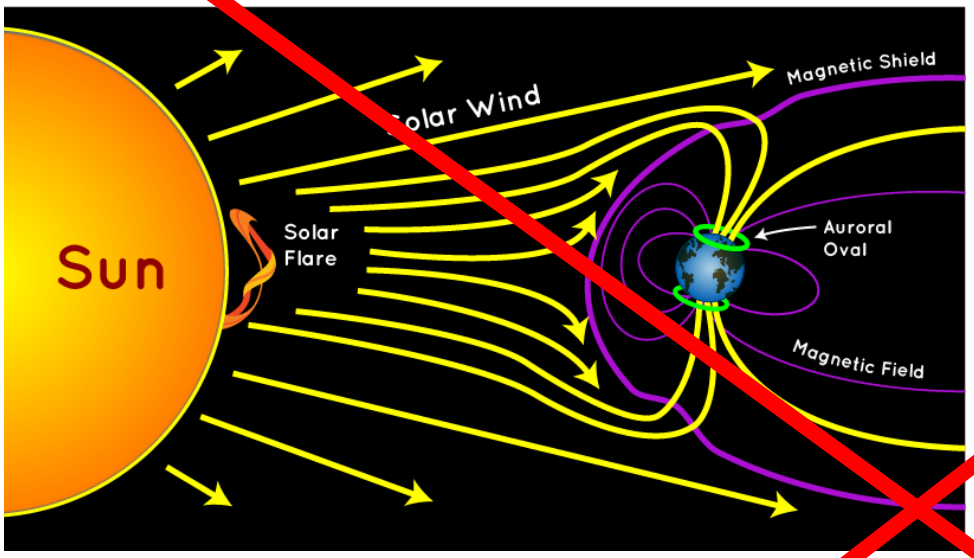


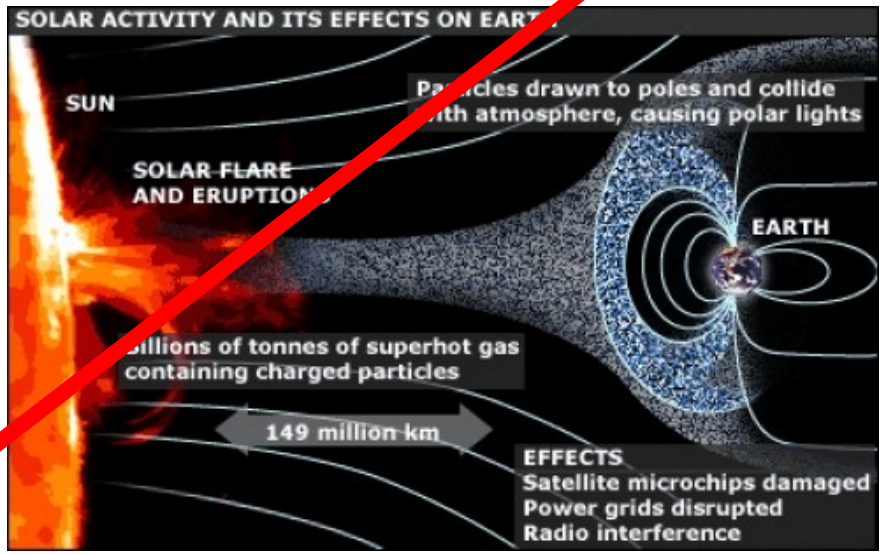


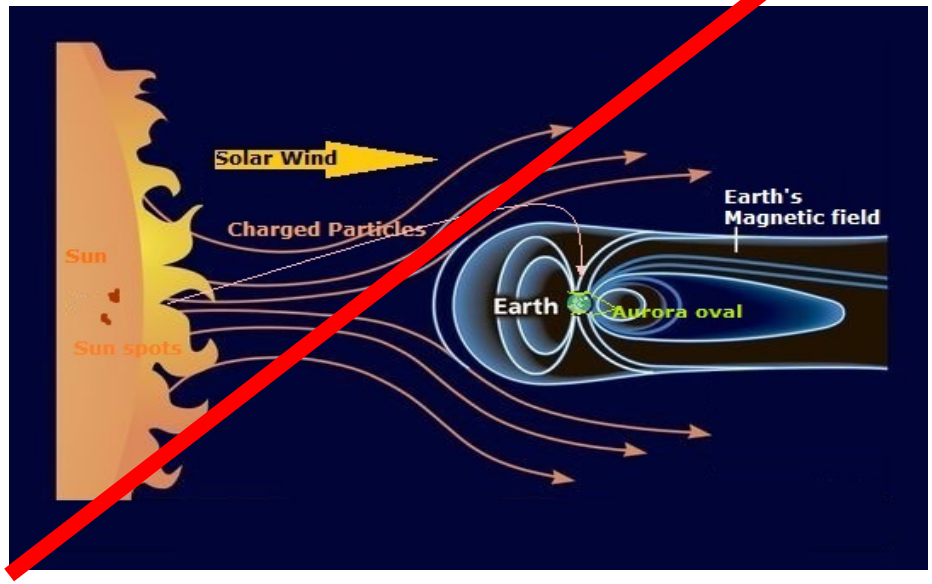
Quiet, diffuse and subvisual aurora are due to particles from the solar wind raining down on the ionosphere.

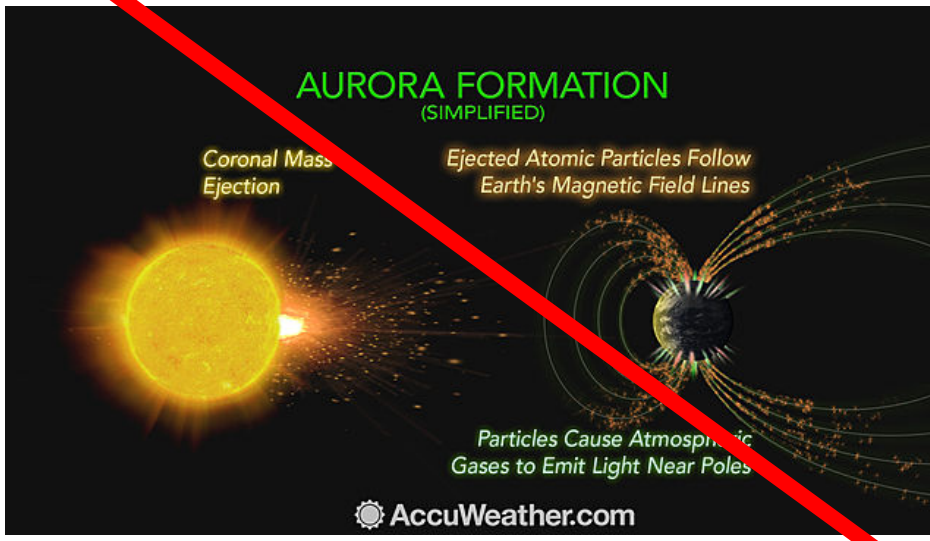
Diffuse aurora seen over Minnesota in July 2013 [Bob King, universetoday.com]

This does not explain active auroral displays

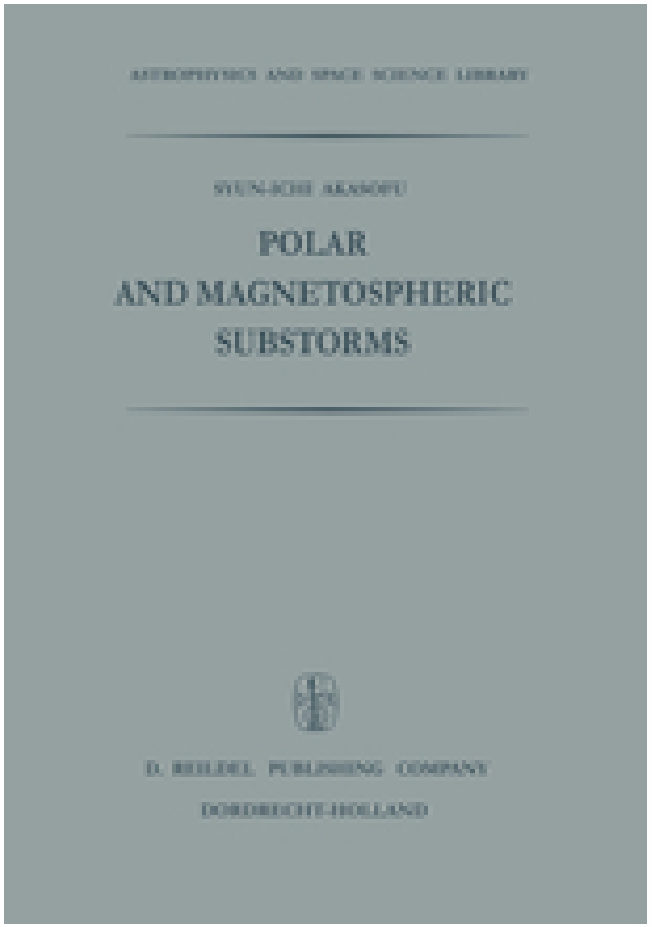








Active auroras are a manifestation of substorms and storms



1.1. Polar Upper Atmosphere and the Outer Magnetosphere

The polar upper atmosphere is unique in that it is connected to the outer magnetosphere by geomagnetic field lines. The magnetosphere may be divided into two parts: the inner magnetosphere, where energetic charged particles are temporarily trapped, and the outer magnetosphere.

There appears to be an almost continuous acceleration of charged particles near the boundary of the inner magnetosphere and the outer magnetosphere. Some of the accelerated particles are able to penetrate deep into the polar upper atmosphere, being guided by the geomagnetic field lines which lie near the boundary, and interact with atoms and molecules there. The interaction manifests itself in various phenomena

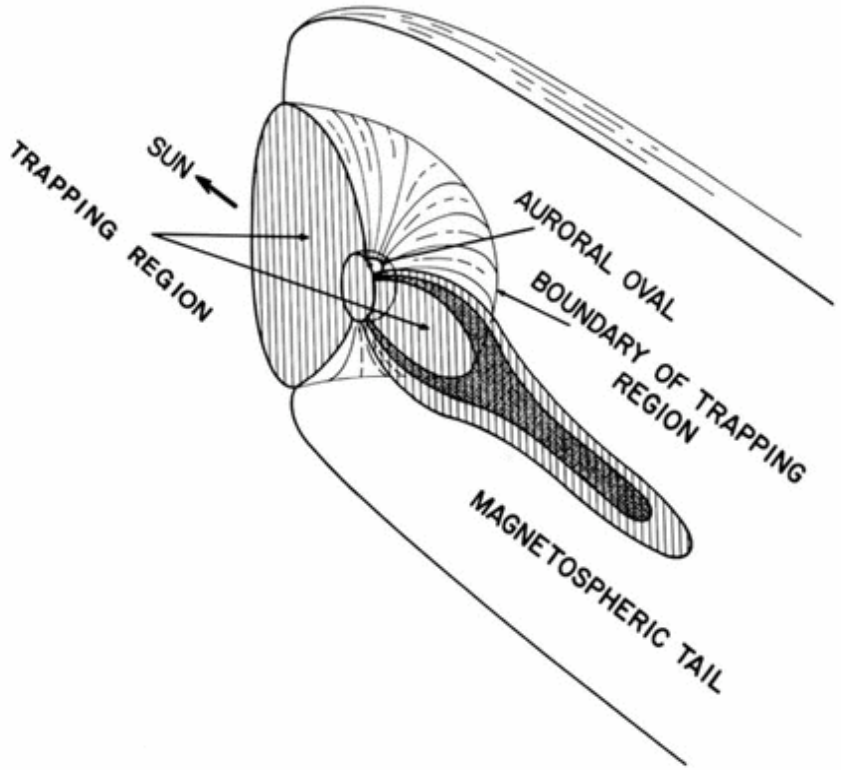


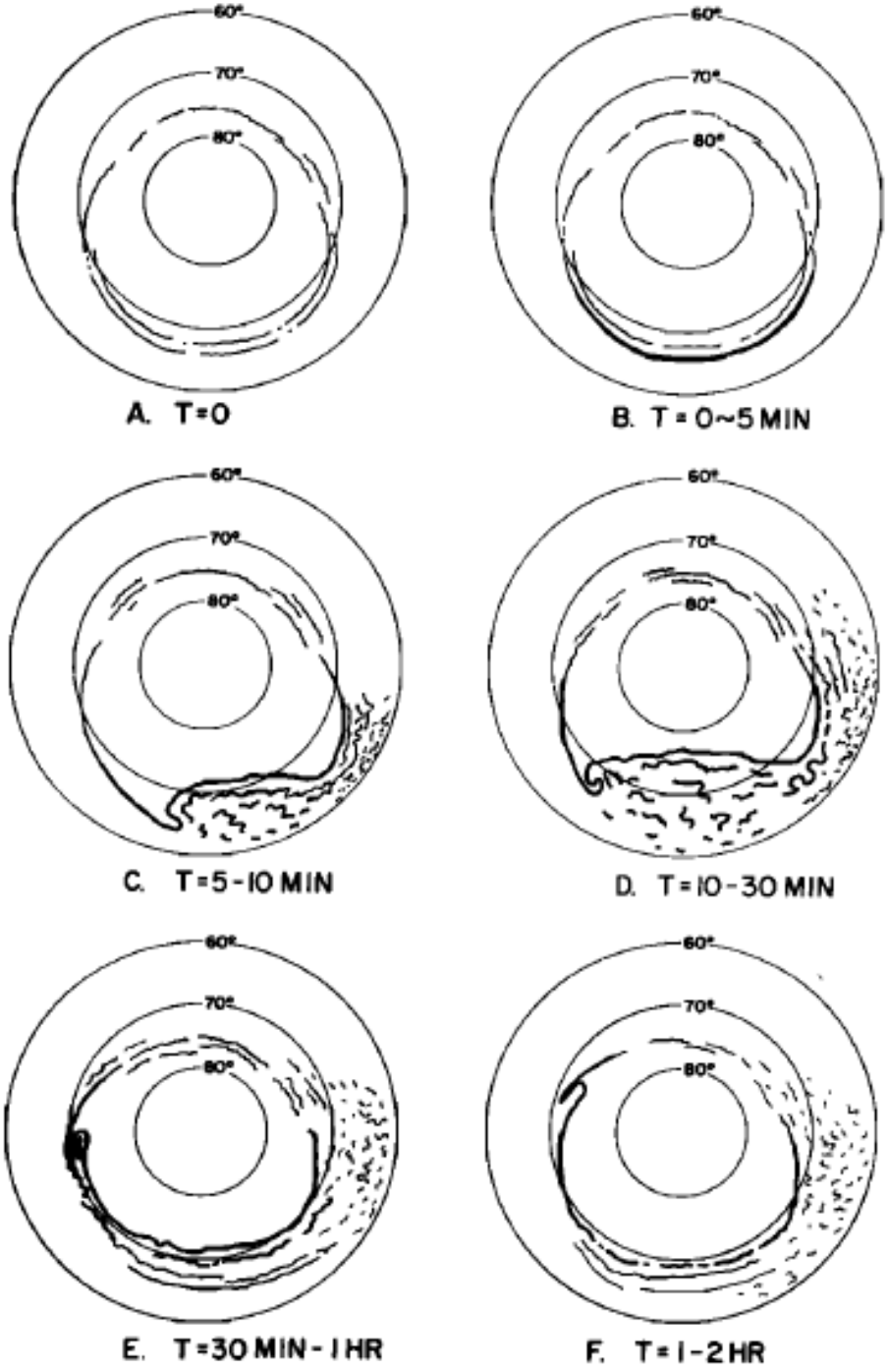
Fig. 1. Noon-midnight cross-section of the magnetosphere showing the structure of the magnetosphere and its relation to the auroral oval. The auroral oval delineates the projection of the boundary of the trapping region and the outer magnetosphere onto the polar atmosphere.

Auroral substorms evolve in a defined manner:

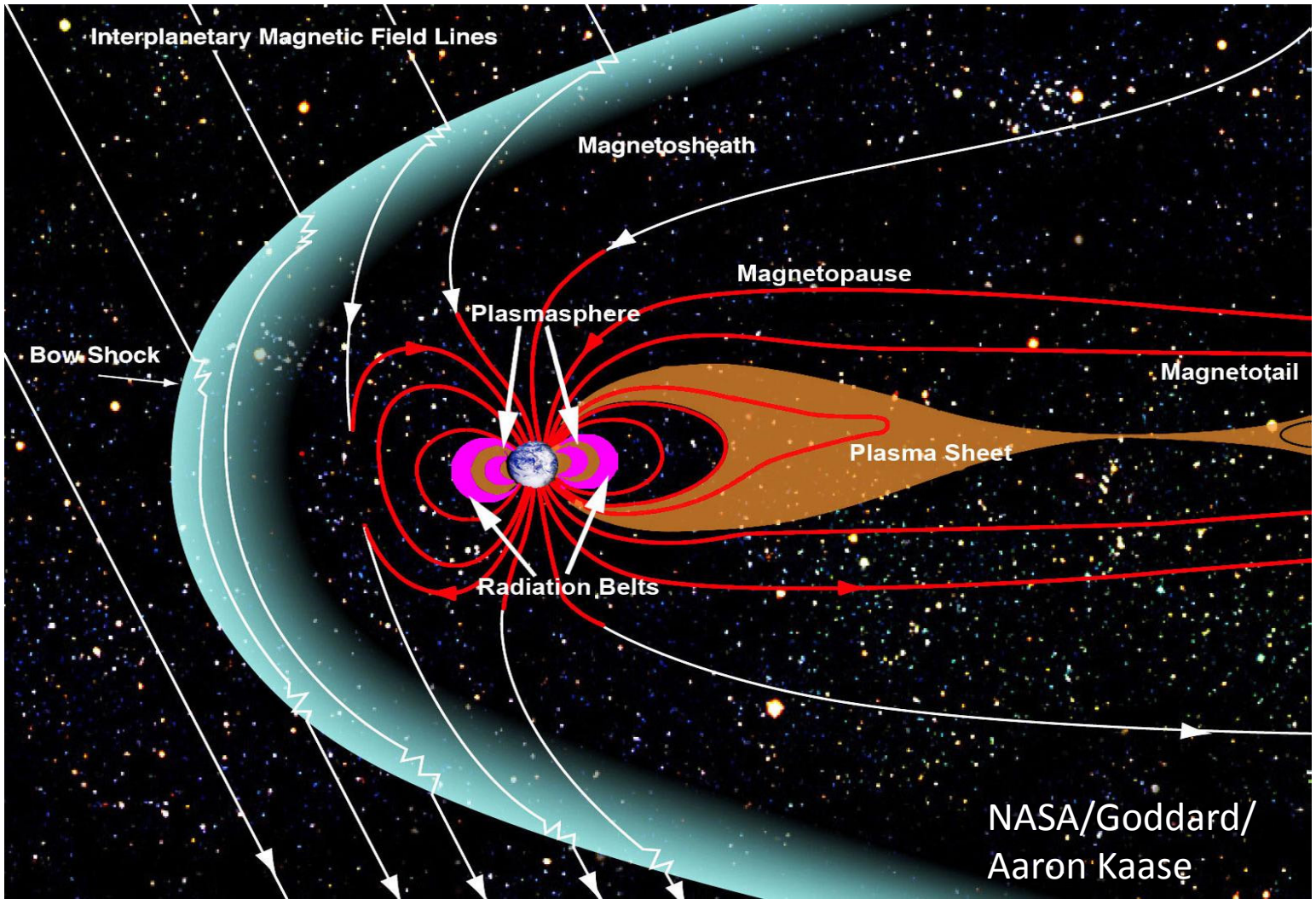
- Quiet arcs
- Expansion phase with
- westward travelling surge
- followed by rapidly moving forms and
- ending with breakup into pulsating patches.

Substorms accompany magnetic storms.

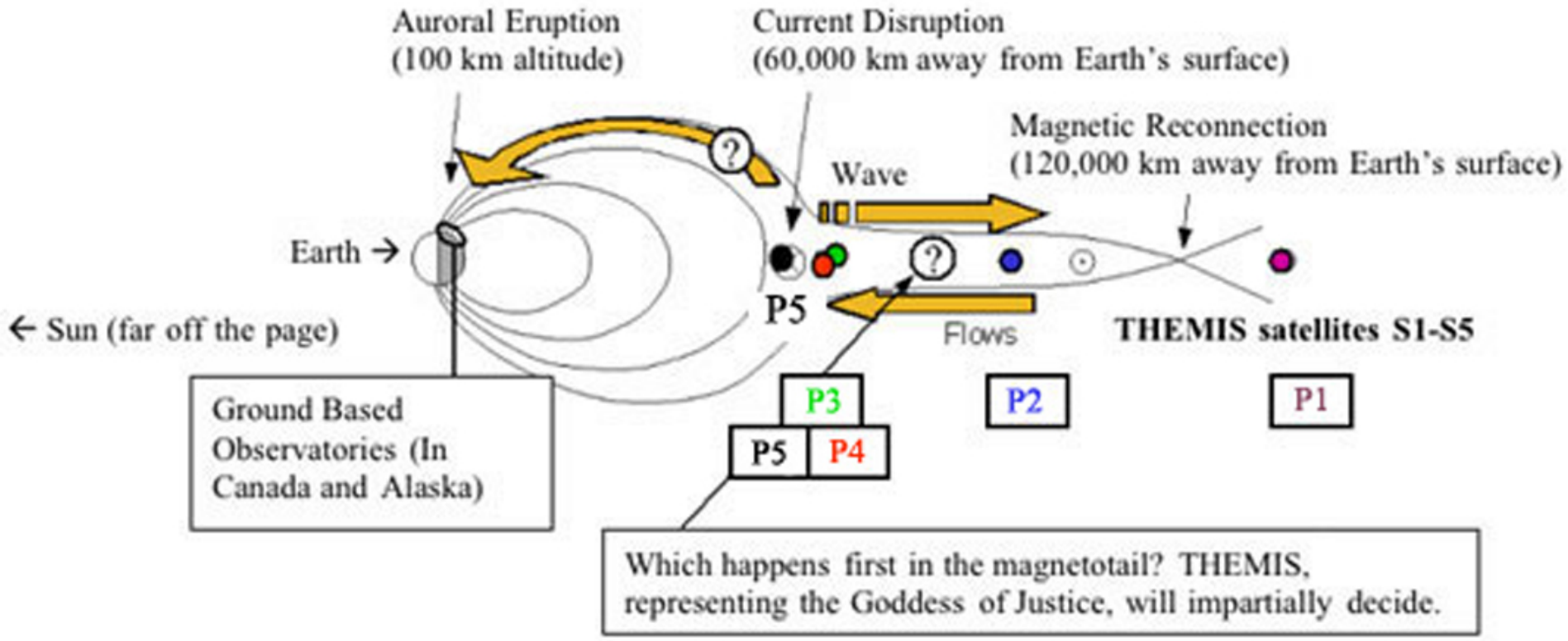
S-I Akasofu, Planet. Space Sci., **12**, *4*, 1964



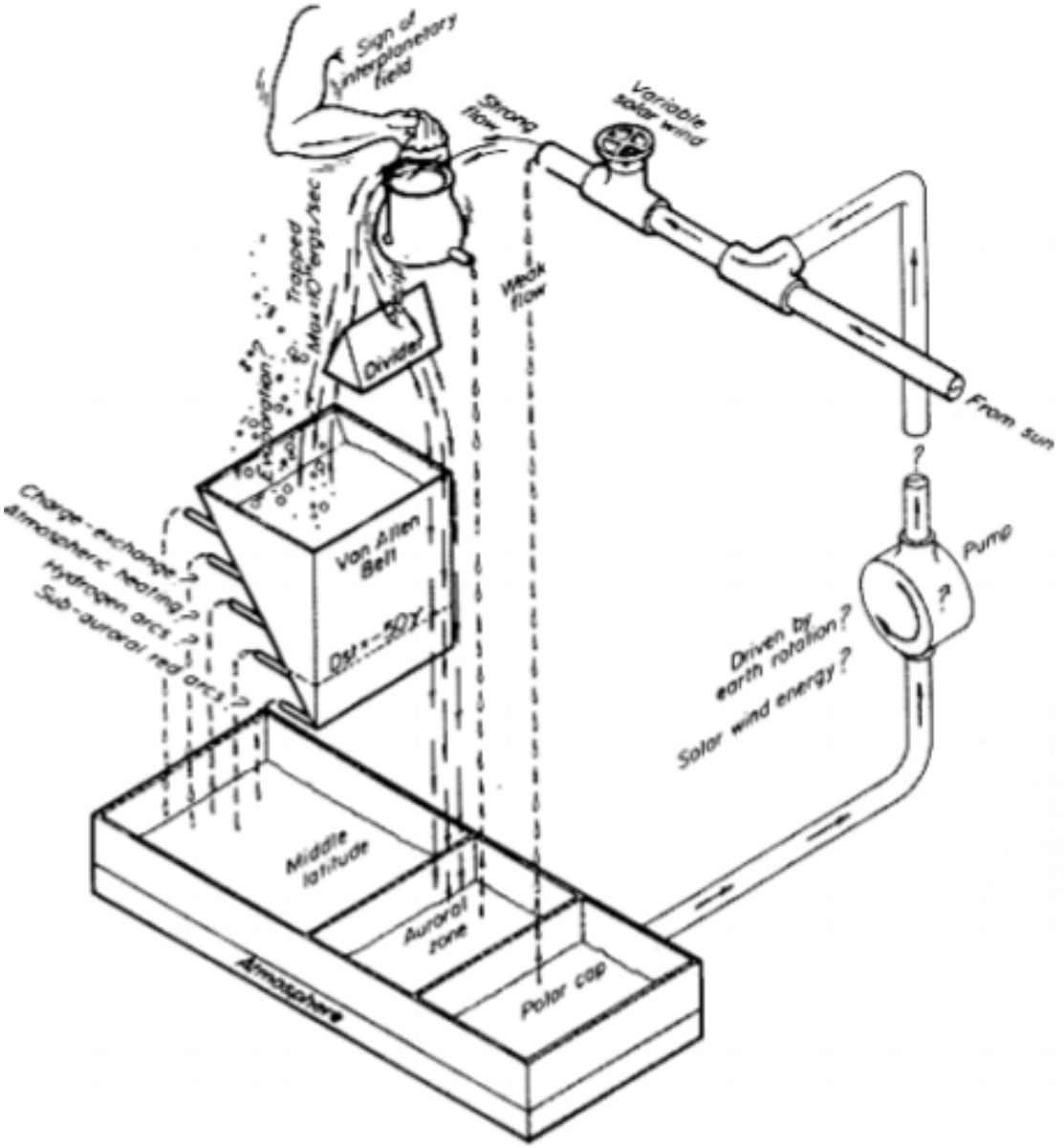
The energy for substorms comes from accumulation of magnetic flux in the tail due to reconnection from the streaming solar wind. Particles in the tail region come from the solar wind or the underlying ionosphere, forming a plasmasheet and tail current.



Sudden disruption of the tail current, or reconnection in the distant tail, releases this magnetic tension (i.e. 'shorts out' the plasma sheet current), causing dipolarisation of stretched field lines. The released energy accelerates charged particles along magnetic field lines. Plasma waves likely also play a role.



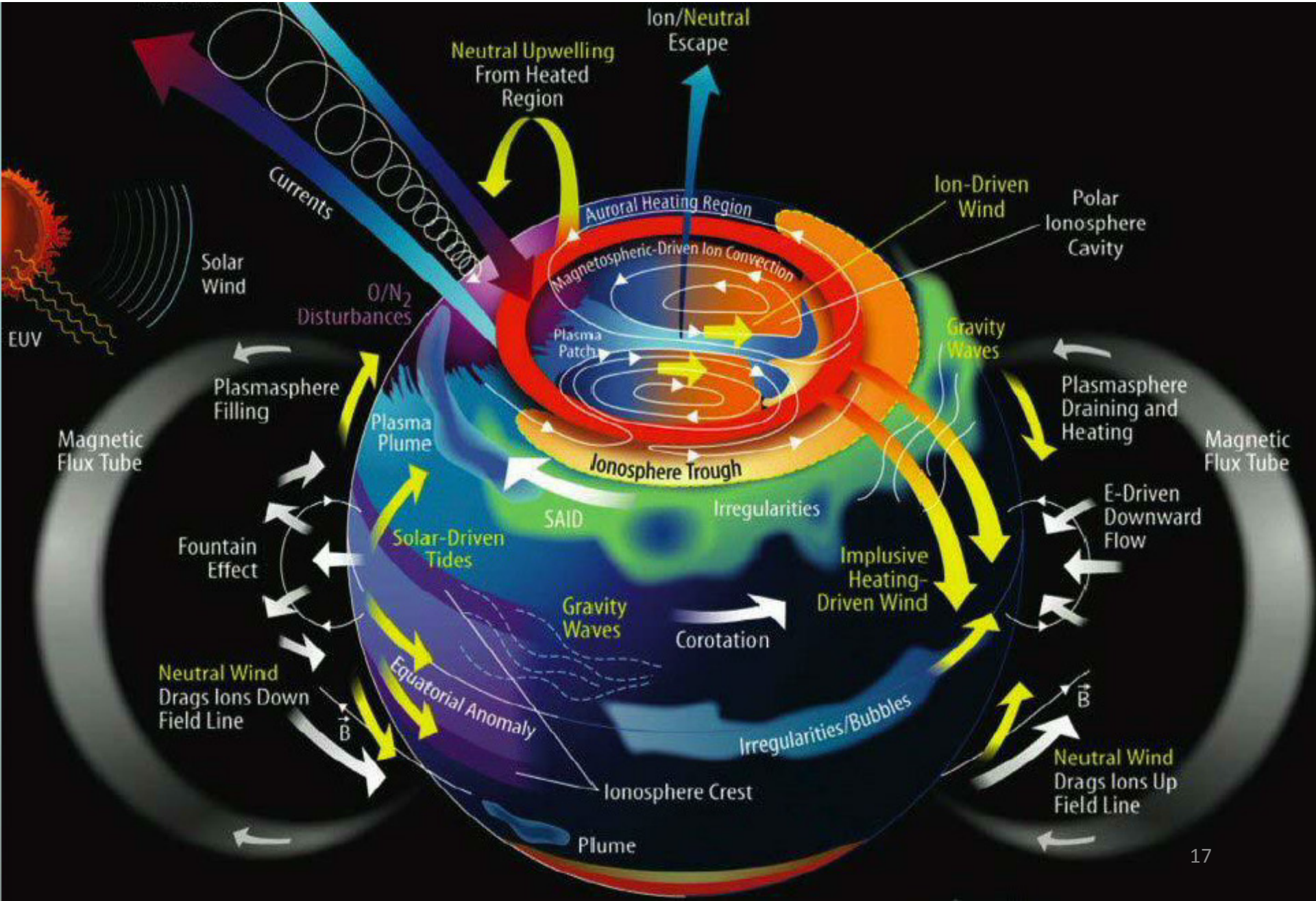
Expandable Tippy Thundermug analogy for substorm behaviour [Davis, 1970]. Particles are trapped in the Van Allen radiation belts and substorm occurs ('bucket dumps') when the interplanetary magnetic field turns southward.



Davis, 1970, from Russell, C.T., Solar wind and magnetospheric dynamics, 1974

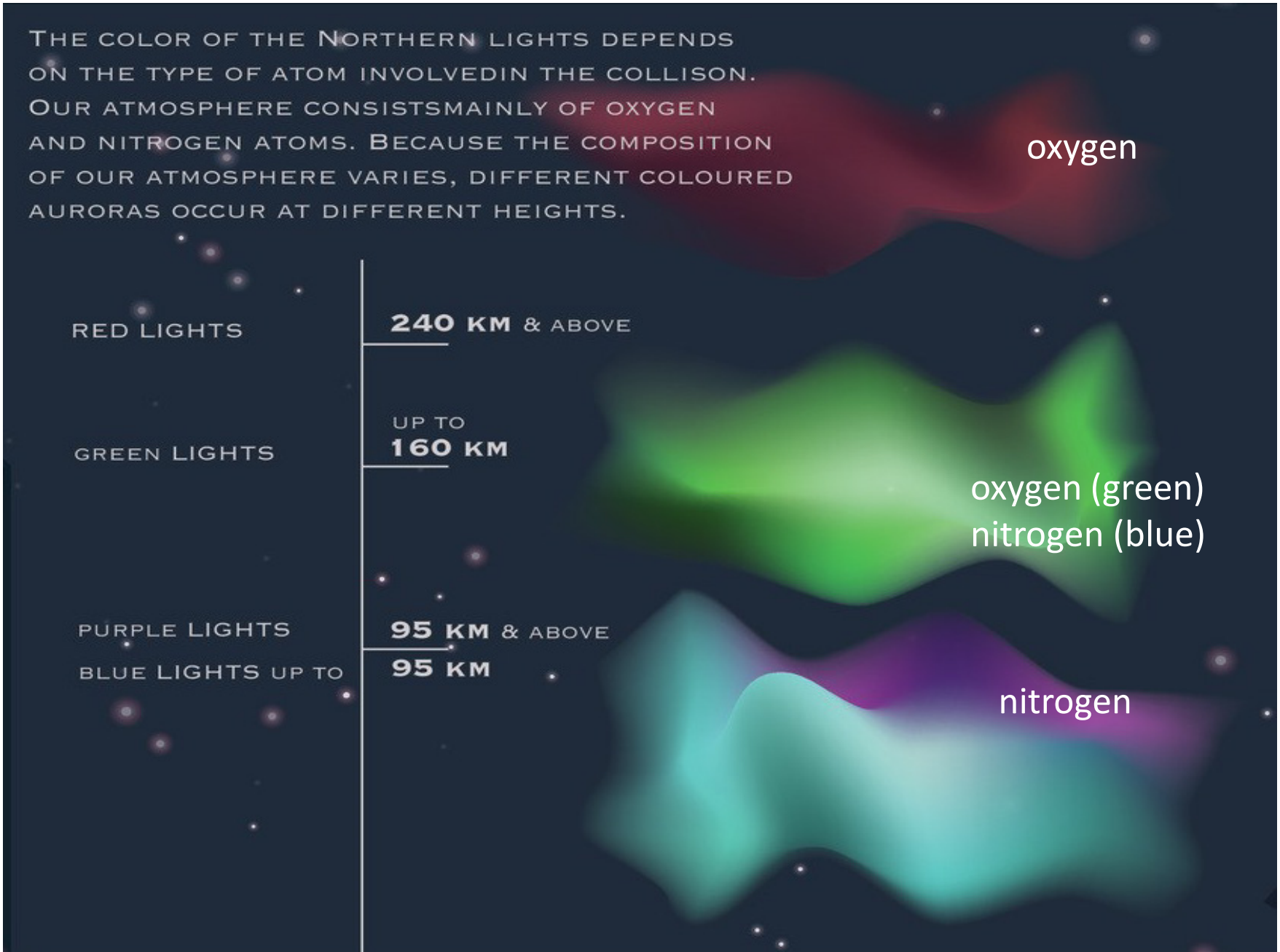
Aurora: What are its effects?

Auroras are part of a complex, interacting system



- Energetic particle precipitation into ionosphere → optical emission
- Ionospheric substorm → enhanced density, absorption, heating, generation of irregularities
- HF radar returns
- Field aligned currents (FACs)
- Auroral electrojet & GICs
- Auroral heating and generation of TIDs

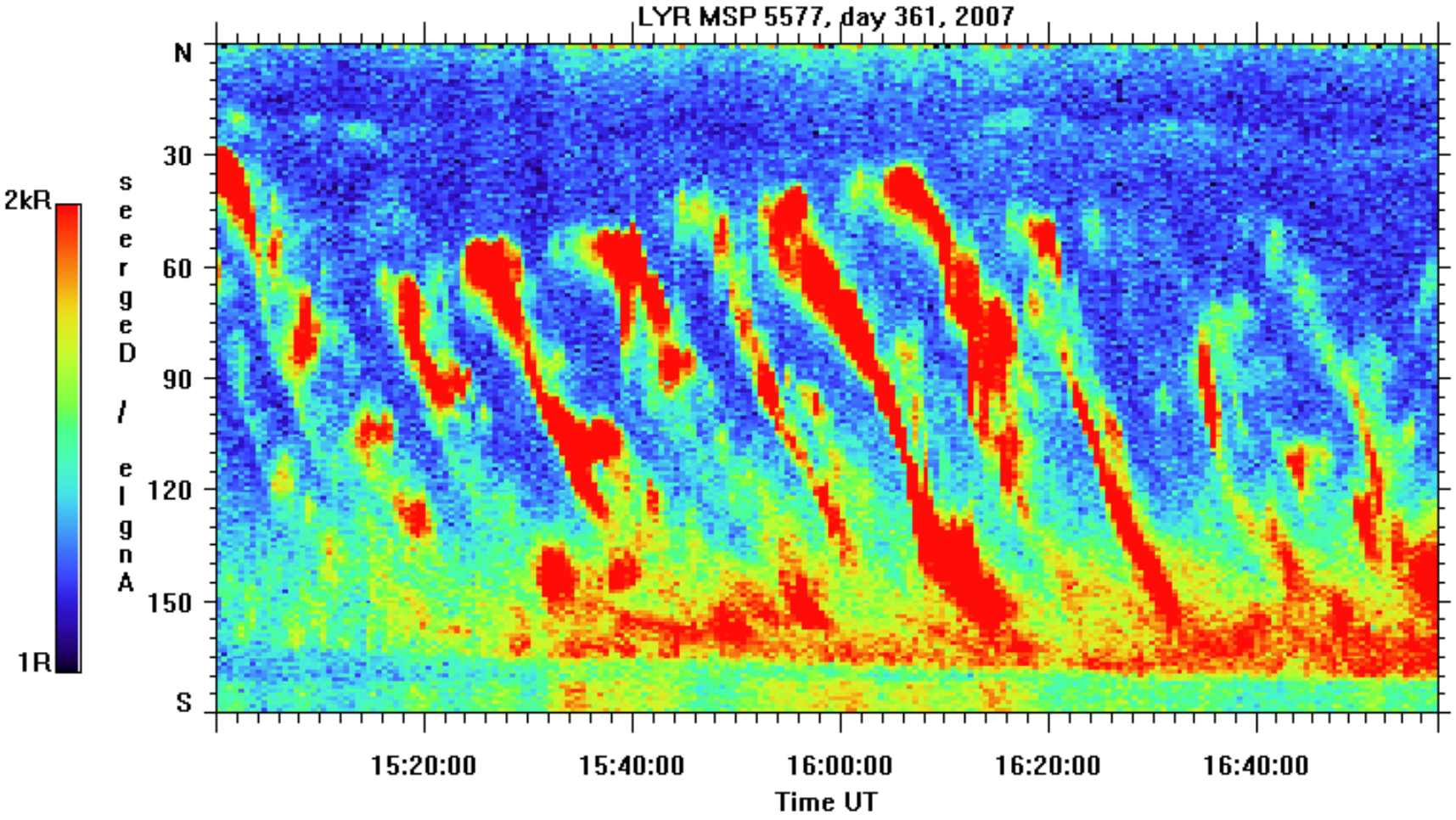
Precipitation and generation of optical emissions



Sub-visual stable auroral red (SAR) arcs and airglow occur at lower latitudes (e.g. Melbourne)

Image: Yuri Beletsky, EarthSky, Dec 2015

Particles causing auroras are moved by electric fields. Meridian scanning photometer observations show active auroral forms are modulated by ultra-low frequency plasma waves.



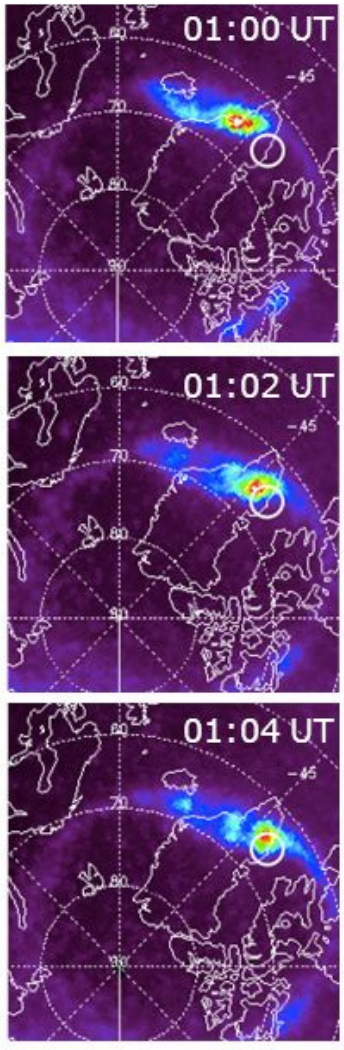
www.unis.no/research/arctic-geophysics/awat/

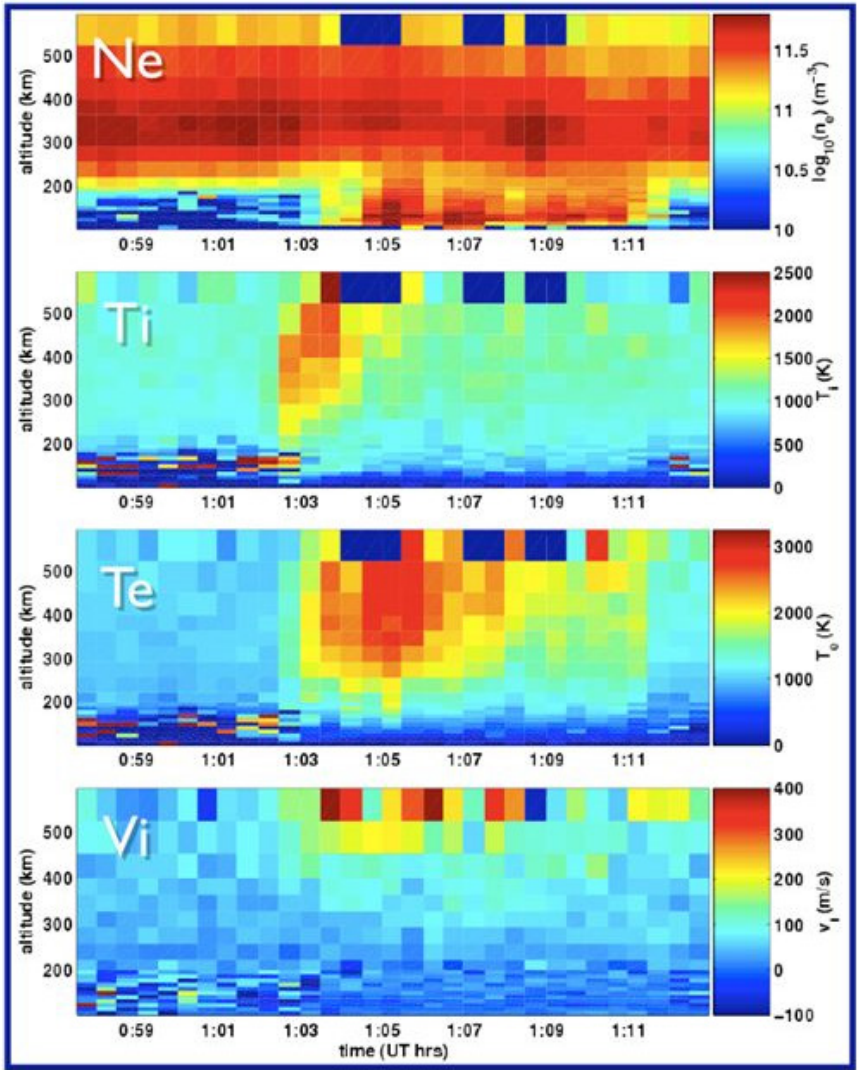
Sounding rockets release vapour to study such auroral convection

Shortly after 4am on Thursday, June 29, after numerous delays and scrubs, NASA's Wallops Flight Facility has a successful rocket launch which triggered colorful, glowing clouds for many to see over the Mid Atlantic.

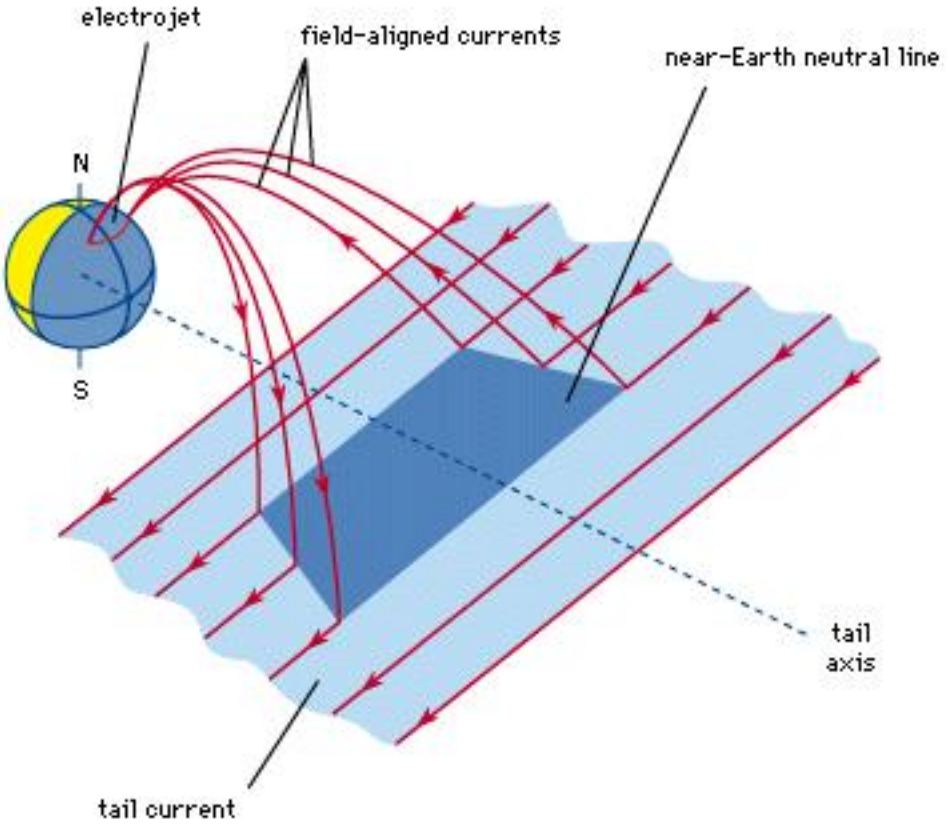
The NASA Terrier-Improved Malemute sounding rocket brought a payload of canisters more than 90 miles above the Earth's surface; these canisters deployed various substances to trigger the glowing clouds high in the sky. The Ampoule Test Launch is designed to support science around the study of aurora. The vapor tracers are formed through the interaction of barium, strontium, and cupric-oxide. Because these tracers are released at altitudes of 96-124 miles high, NASA says they "pose absolutely no hazard to residents along the Mid-Atlantic coast."

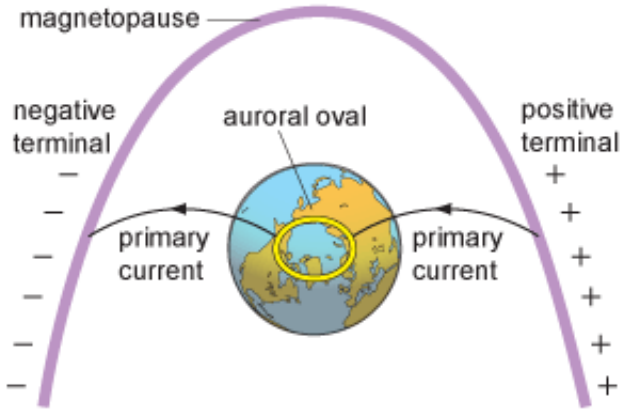
Ionospheric effects: changes in electron density, ion and electron temperatures and flow speeds → irregularities



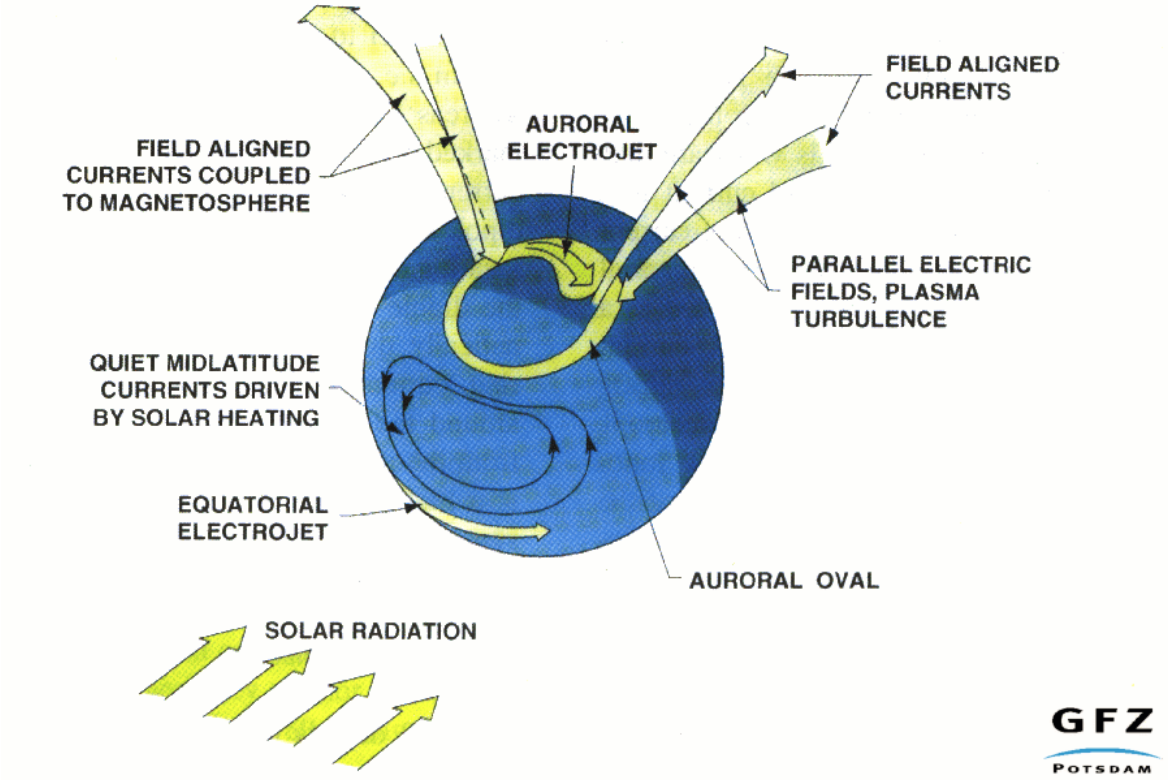


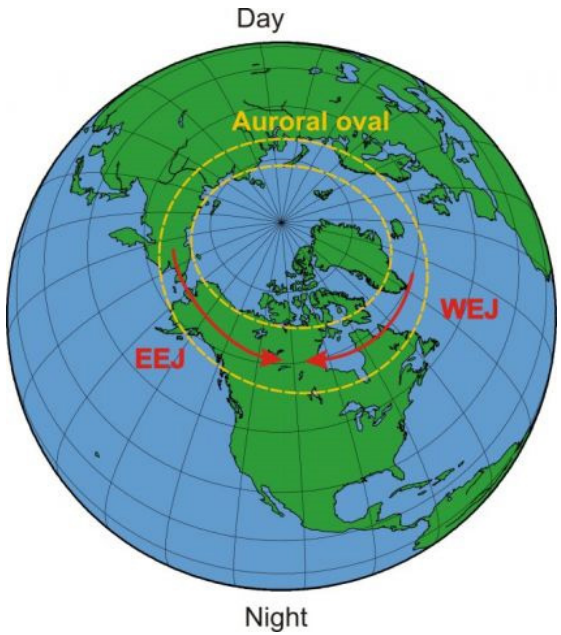
Substorm particle precipitation causes field aligned currents which flow from the magnetosphere into, through and return out of the ionosphere. The ionospheric conductivity is associated with a cross-cap potential difference of 10s kV.



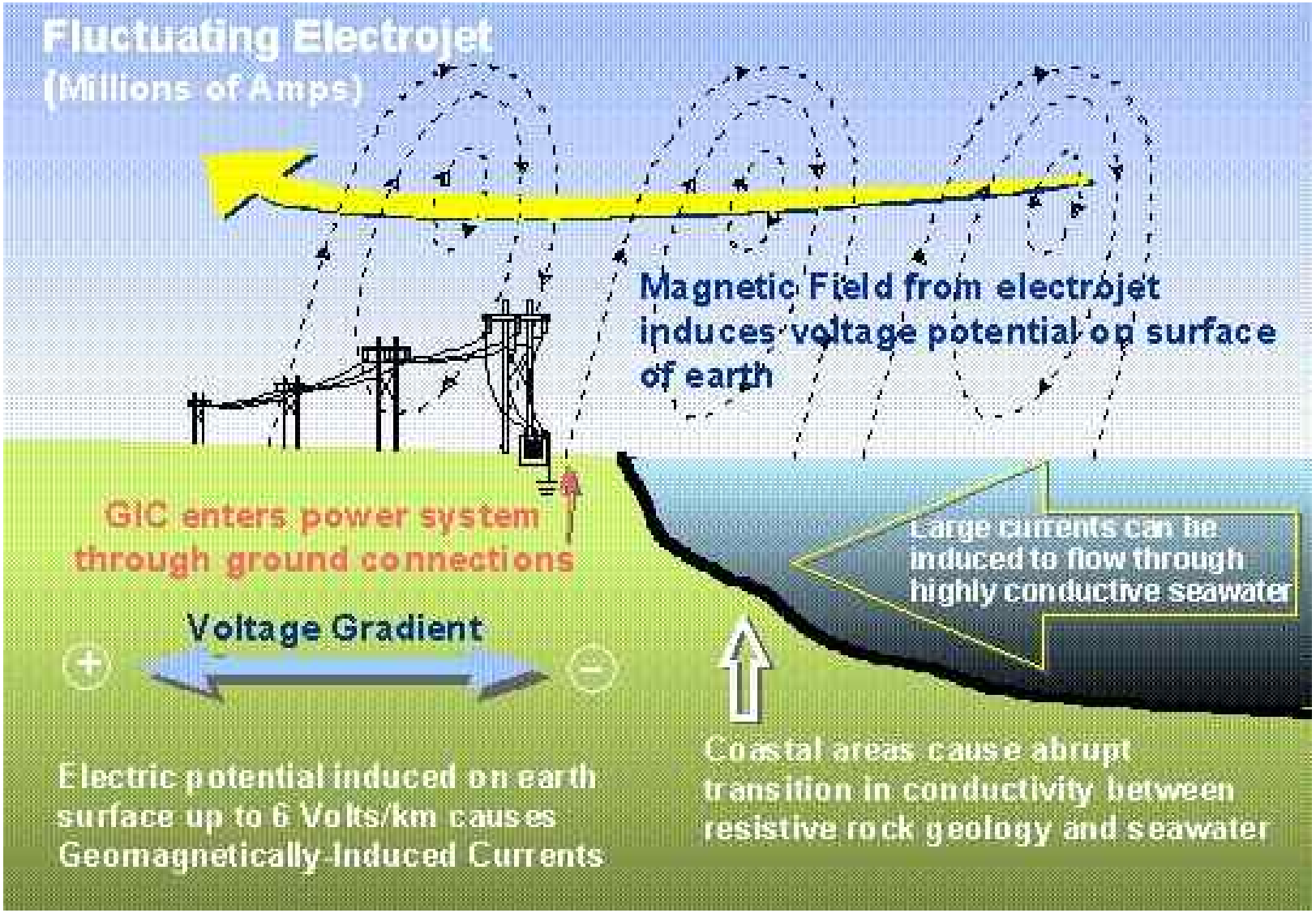


The auroral electrojets are mega-Amp currents which connect the field-aligned currents via the ionospheric E region (~110 km altitude).

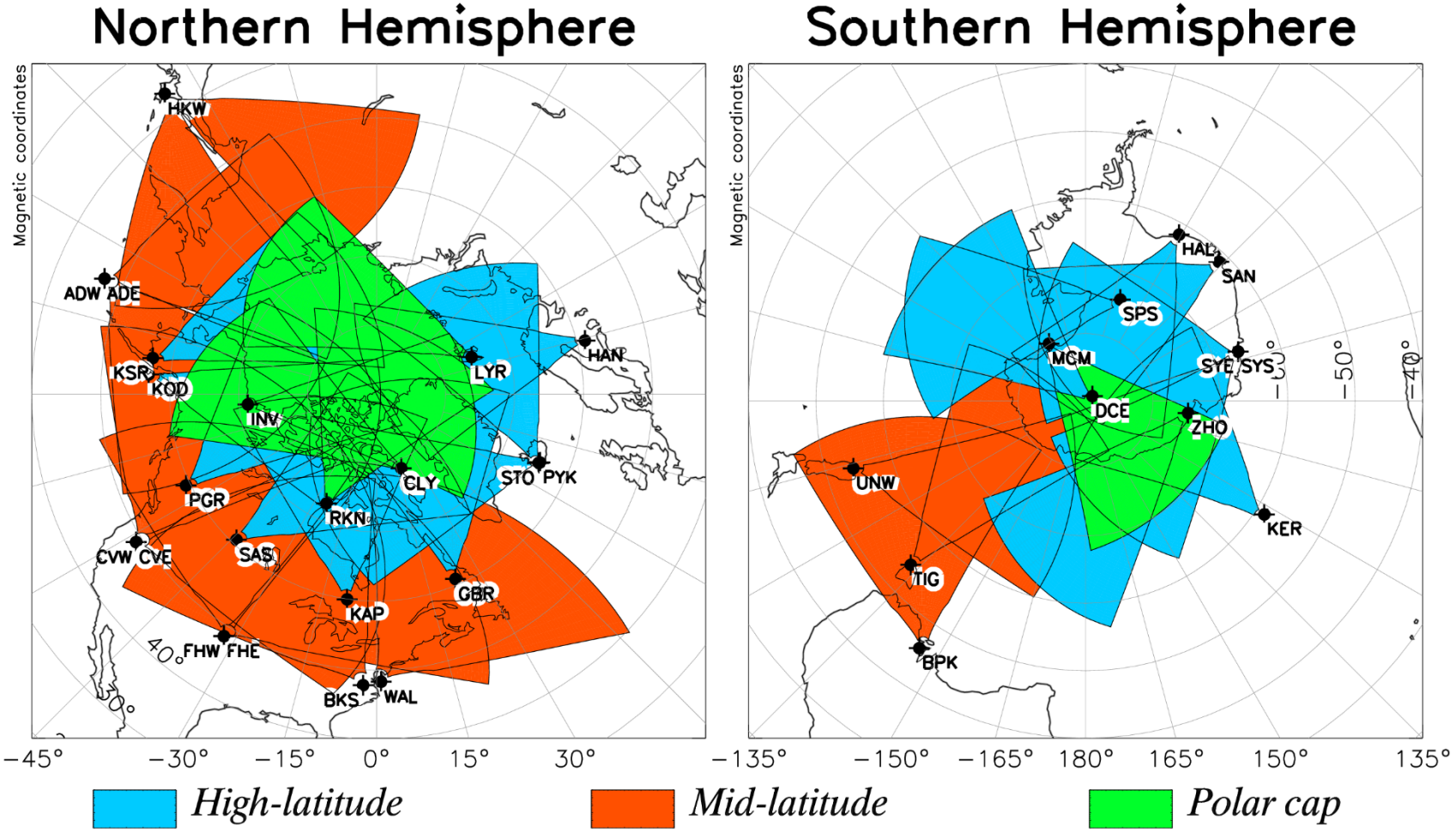




The electrojets produce geomagnetic induced currents (GICs) in pipelines and power grids.

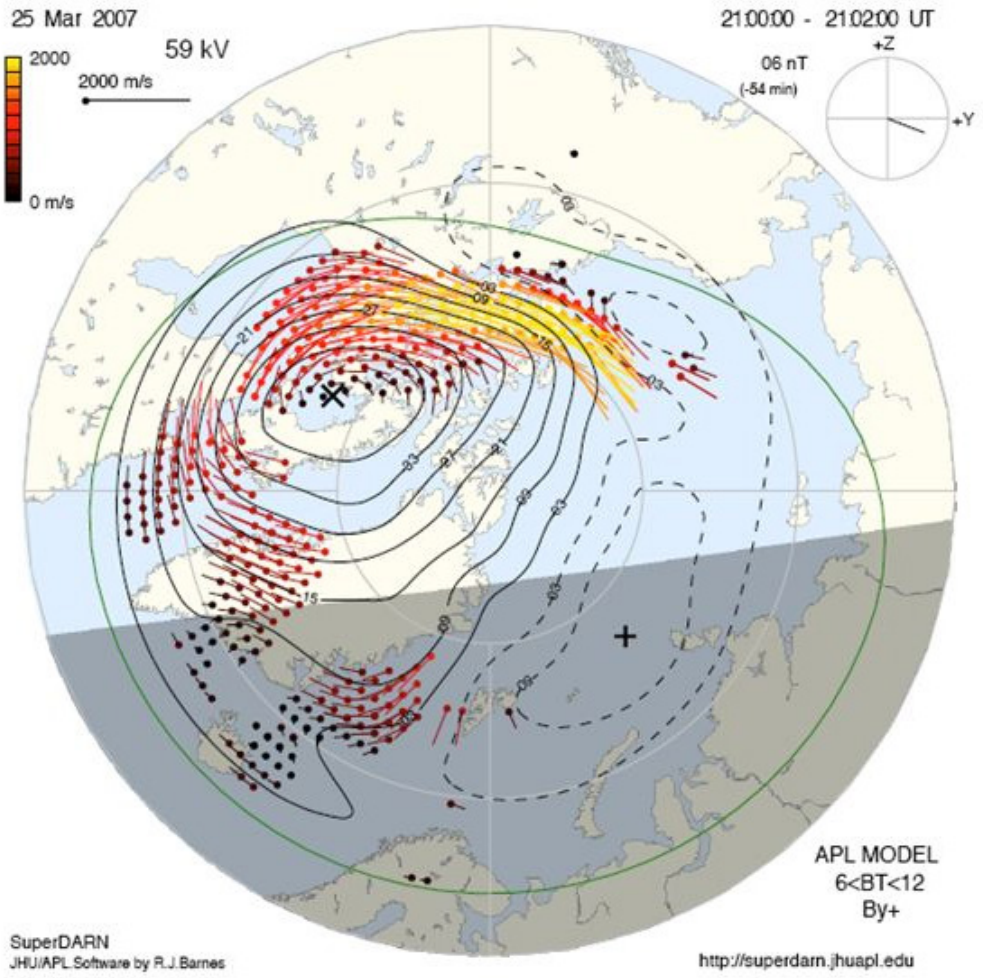


Field-aligned irregularities form in the ionosphere and return signals from HF radars. A multinational consortium, SuperDARN, operates a global network of such research radars.



The radars measure ionospheric flows (convection) and the cross-polar cap potential.

Example of SuperDARN "Disturbed" Geomagnetic Activity



The radars also detect ionospheric disturbances caused (in part) by heat energy deposited into the auroral region.

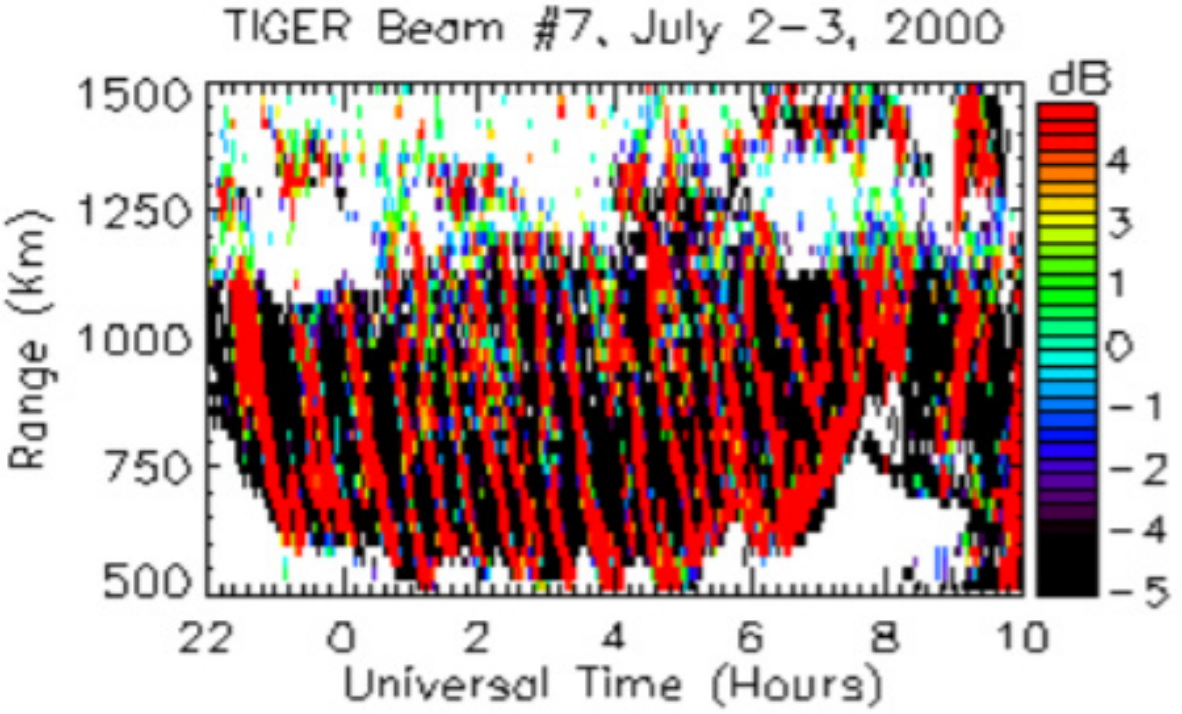
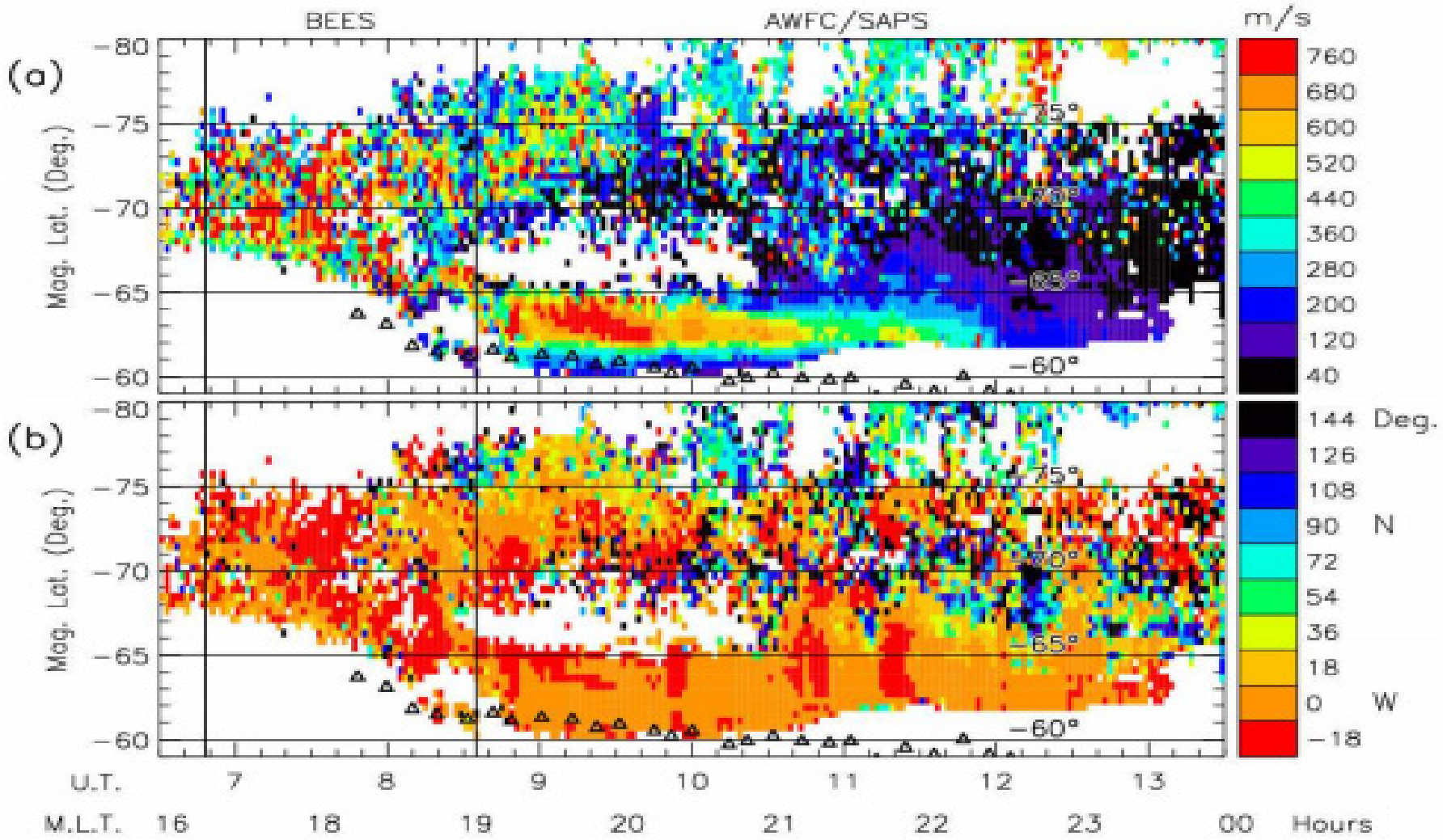


Fig. 1. Range-time plot of sea-echo power recorded using TIGER beam 7 from 2200 UT on 2nd July to 1000 UT on 3rd July, 2000. The powers were band-pass filtered over the period range 10 to 100 min. Magnetic latitudes of 60°, 65°, and 70°S correspond to ranges 486, 1041, and 1581 km, respectively. An HF propagation factor, $r = 0.5$, was used in all of the calculations in this paper.

He and Dyson, Proc. Workshop on Applications of Radio Science (WARS02), 2002

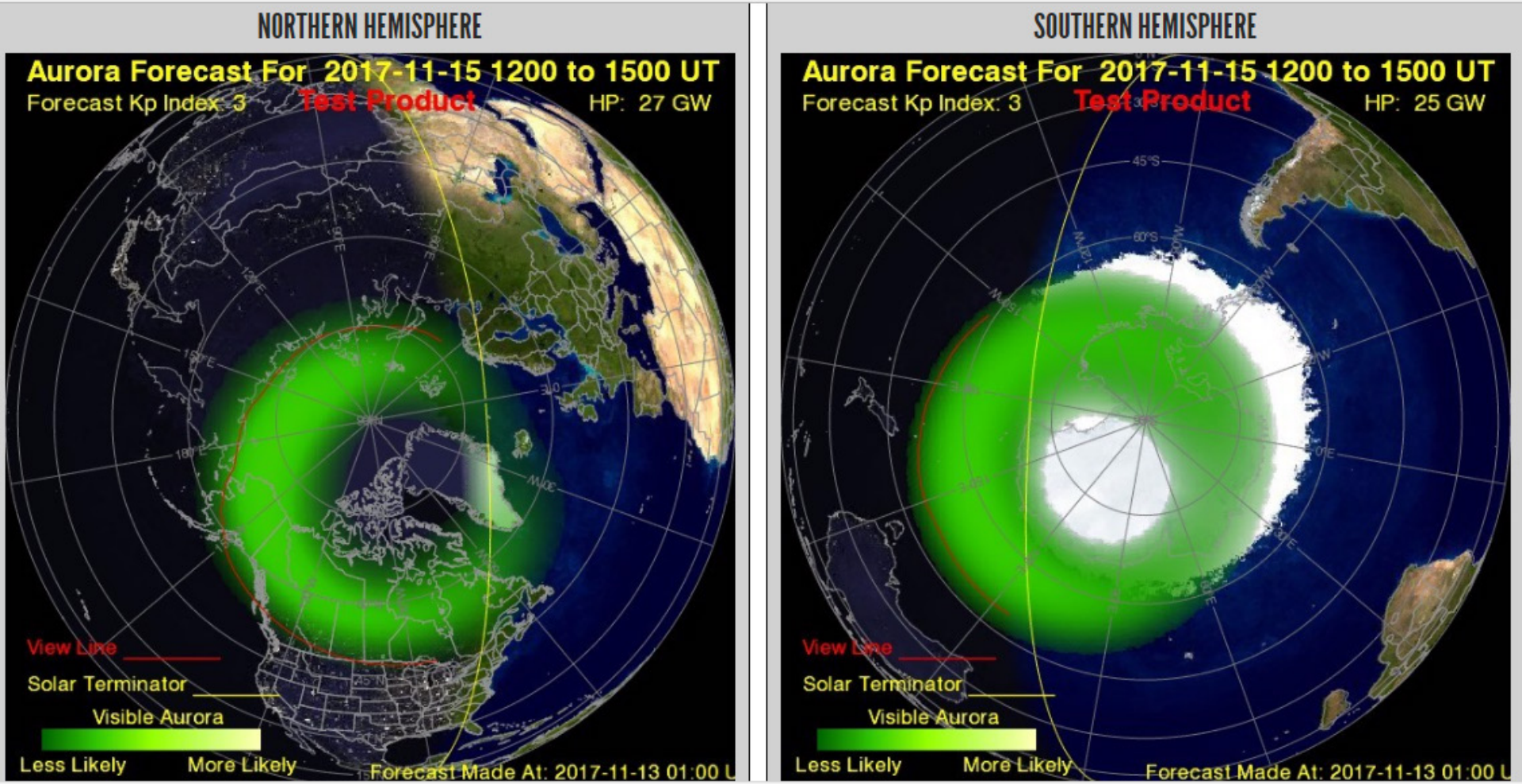
Westward flows occur in the F-region near the auroral oval.



Flow speed (top) and direction (bottom) for TIGER beam 4 on 7 April 2001. Triangles represent plasmapause locations.

Parkinson et al., Annales Geophys, 2007.

Models using all available data sets (optical, satellite particle and imaging, HF radars) are used to predict the location and intensity of auroral activity ~1 day in advance.



Preliminary 3-day auroral forecasting tool: swpc.noaa.gov/products/aurora-3-day-forecast


Questions?