Lesson 6: Proton aurora, diffuse aurora and some specific phenomena

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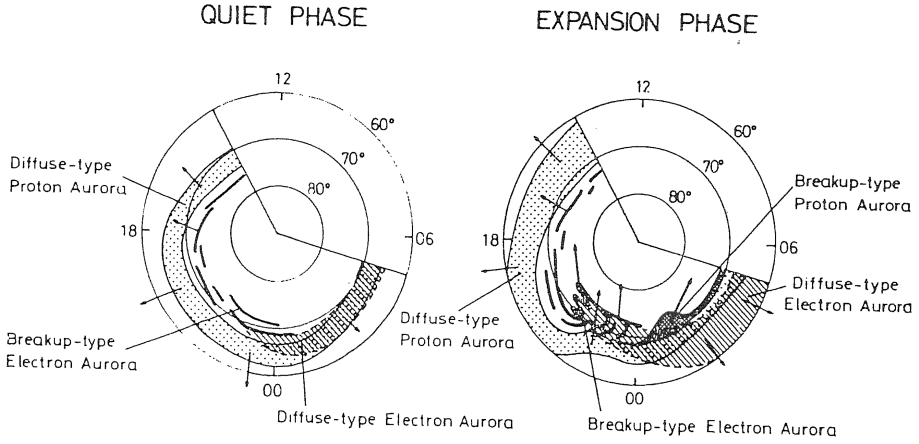
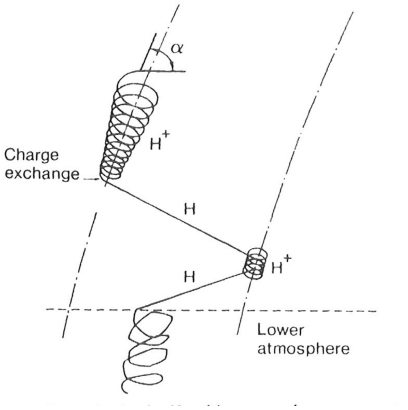
Proton aurora

Distribution of proton and electron aurora before and after substorm onset (Fukunishi, 1974). Proton aurora is very weak compared to electron aurora!



Proton aurora

H+ precipitation: charge-exchange with ionospheric H => **spreading of H+ aurora in the ionosphere**



H+ precipitation from the magnetosphere by pitch-angle diffusion due to

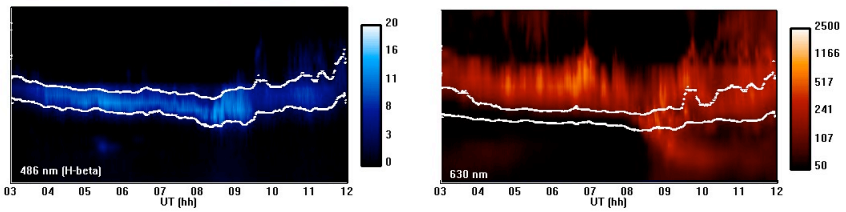
- tight field line curvature compared to ion gyroradius
- wave-particle interactions

Excited hydrogen atoms H* produce emissions Hα (656.3 nm) and Hβ (486.1 nm).

Proton aurora

Proton aurora (left) within the main oval before substorm onset (Donovan, 2011).

Proton Aurora vs. Electron Aurora



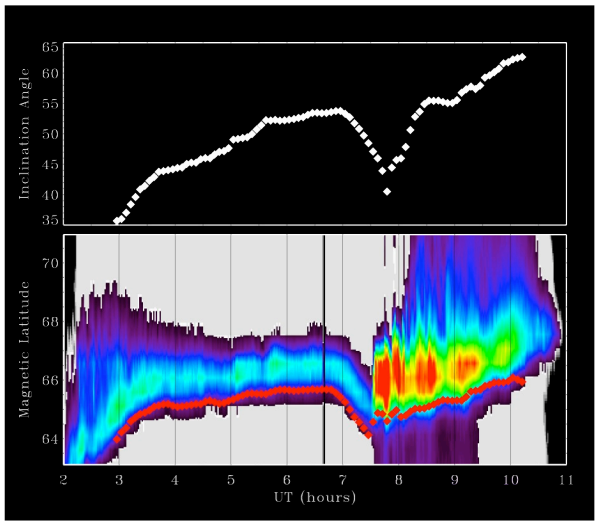
H+: Typically viewed from the ground via 486 nm "Balmer Beta" viewed via MSP; viewed from space via Lyman-Alpha, and from the ground through secondary electron emissions… big problem: paucity of data.

e-: Easily observed via imagers, MSPs, spectrographs, etc. Viewed in various emissions, and at different scales, all of which convey different information and bring different problems… big problems: complicated phenomena; M, I, or MI; cowboy tendencies of auroral observers ☺!

Proton aurora

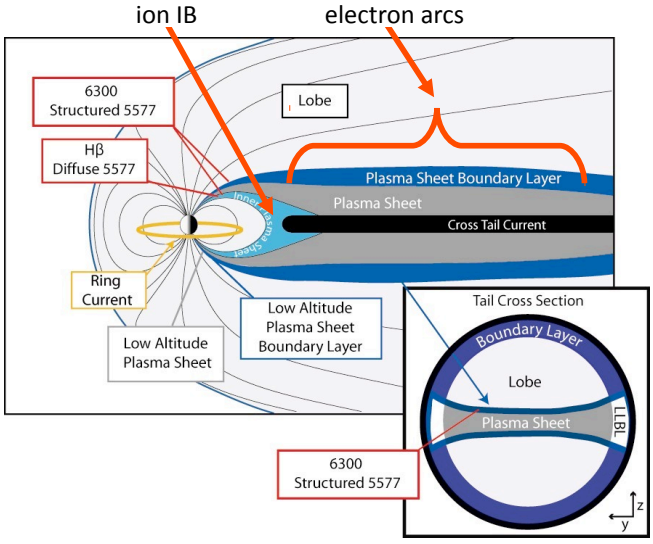
H+ aurora (bottom) follows the configurational changes of the magnetotail (top) (Donovan, 2011). When magnetotail stretches (incl. angle decreases), field lines map to lower latitudes and H+ aurora shifts equatorward.

We can use the H+ aurora to remote sense the magnetotail ((stretching, pressure, etc.



Proton aurora

H+ aurora from the cyan region and electron arcs poleward of the ion isotropic boundary (IB), which marks the region between dipolar and taillike field lines (Donovan, 2011).



Origin of diffuse aurora

- It has been believed that diffuse aurora is caused by pitch-angle scattering of CPS electrons (0.1–30-keV) into the loss cone, but the precise mechanism has been unclear.
- Two classes of magnetospheric plasma waves, electrostatic electron cyclotron harmonic (ECH) waves and whistler-mode chorus waves, could be responsible for wave-particle interactions that lead to P-A scattering:

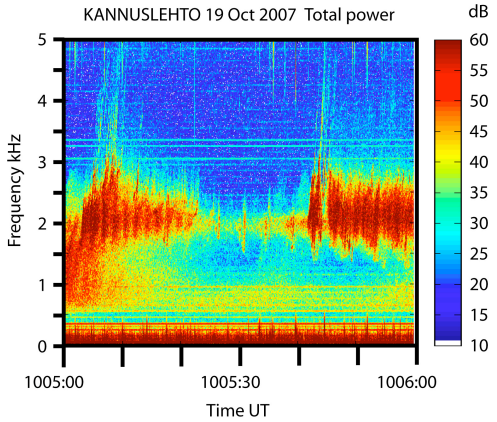
$$\omega - k_{||}v_{||} = n\Omega_{ec} / \gamma \ ,$$

where ω is the wave frequency, Doppler shifted to a multiple (n=0,±1,±2,...) of the relativistic electron gyrofrequency Ω_{ec} and $k_{||}$ and $v_{||}$ are parallel components of the wave vector and particle velocity (γ is the relativistic factor).

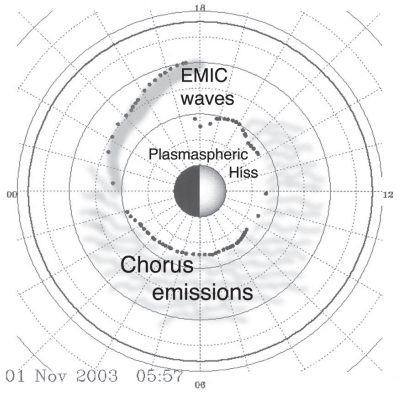
- Thorne et al. reported in Nature in 2010 that **scattering by whistler mode chorus waves ($f < f_{ec}$)** is the dominant cause of the most intense diffuse auroral precipitation.

Origin of diffuse aurora

Whistler mode chorus waves ($f < f_{ec}$) recorded on the ground (left) and expected distribution in space in a recovery phase of a storm (right).



(courtesy of J. Manninen)



(Thorne, 2005)

Statistics: Note polar cap arcs

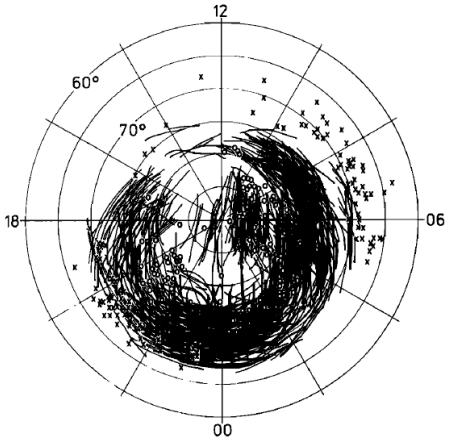
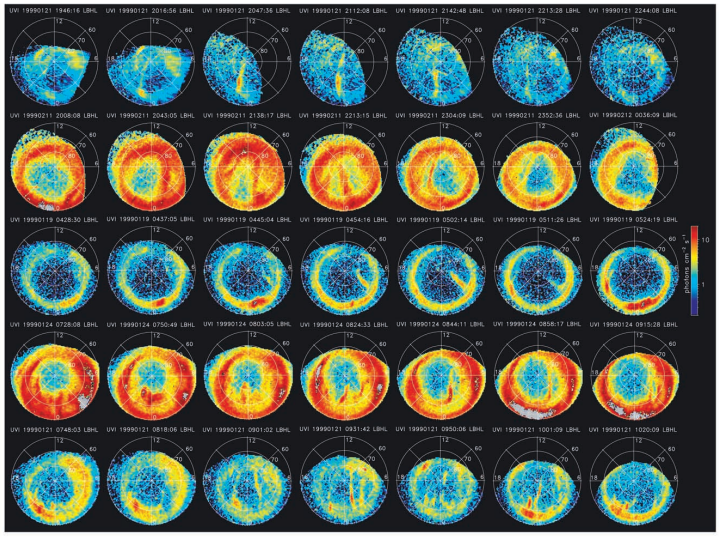


Fig. 7. Mass plot of discrete arcs for $AE = 41$–50 nT (from Figure 4) shown together with the equatorial (crosses) and poleward (circles) boundary points from Figures 6*a* and 6*c*.

[Lassen & Danielsen, JGR, 1989]

Polar cap arcs

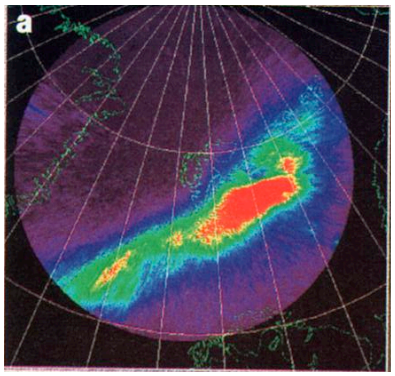


Polar UVI Lyman-Birge-Hopfield long (LBHl, 160-180 nm) filter: from N2 molecules, intensity depends on total energy flux of precipitating electrons.

Kullen et al., JGR (2002): during northward IMF (Bz<0), strong IMF magnitude, and high solar wind speed. Dependence on By.

Cusp aurora

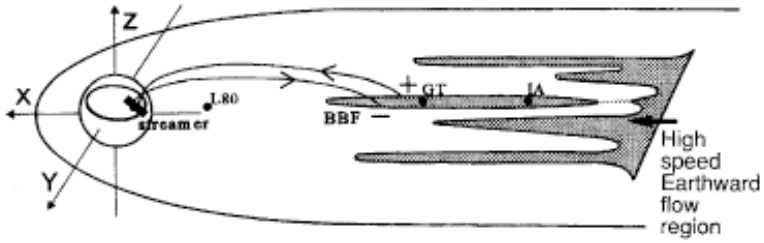
- Caused by precipitating magnetosheath electrons and ions
- Due to dayside reconnection (FTEs), also mixture of magnetospheric and magnetosheath plasma populations
- Relatively low energies of these particles means that the aurora is dominated by 630.0 and 636.4 nm (red line) emissions of atomic oxygen
- Since the radiative lifetime of the ^1D state is 110 s, the excited atomic oxygen moves with the thermospheric wind (e.g. for 500 m/s the distance traveled is about 55 km from the site of excitation).



630.0 nm emission measured by ASC at LYR at 07:34 UT and mapped to an altitude of 250 km. F-o-v corresponds to 80° zenith angle (Sandholt et al., JGR 2000).

North-south aurora and plasma bubbles

Bursty bulk flows (BBFs) in the magnetotail are transient high-speed ($v_x \geq$ 400 km/s) flows which contain depleted (low Ne) flux tubes.



Sergeev et al.. (2000)

North-south aurora and plasma bubbles

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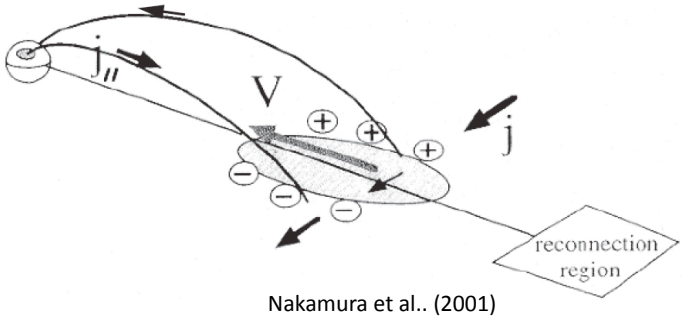
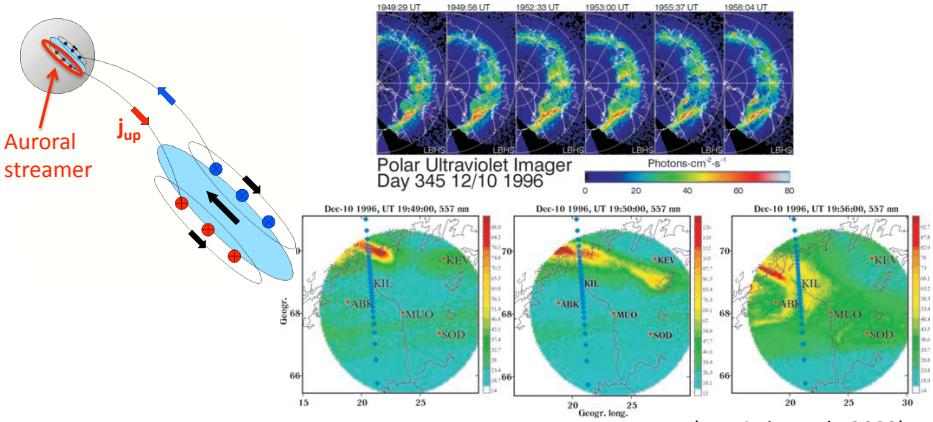


Nakamura et al.. (2001)

The main explanation for BBFs is **the plasma bubble model** by Pontius and Wolf (1990): The bubble moves earthward due to E_{pol} (interchange instability), and is associated with F-A currents.

North-south aurora and plasma bubbles

North-south aurora was suggested by Henderson et al. (1998) to be asociated with bursty bulk flows (BBFs) in the magnetotail. The bubble model is the most plausible model to explain BBFs and observations confirm that the upward FAC of the bubble is associated with N-S aurora (also called streamers) (e.g. Kauristie et al., 2003; Pitkänen et al., 2011).



(Kauristie et al., 2003)

Seasonal effects on energetic electron precipitation

Newell et al. published in 1996 in Nature an article:
"**Suppression of discrete aurorae by sunlight**"

They found that:

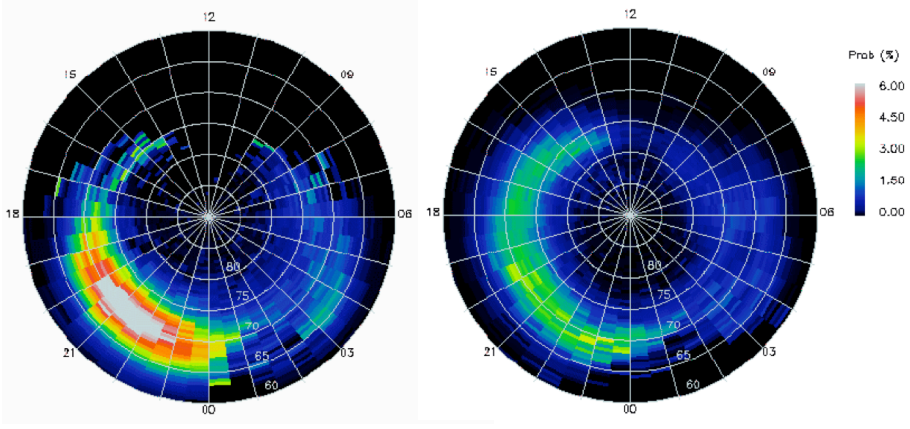
- the **beams of accelerated electrons** that cause intense discrete aurorae occur mainly in darkness: the **winter** hemisphere is favoured over the summer hemisphere, and **night** is favoured over day (by a factor of 3)
- discrete aurora rarely occur in the presence of diffuse aurora

Also, other phenomena related to electrostatic acceleration show the same seasonal variation:

- intense electric fields in auroral acceleration region (Marklund et al., 1994)
- upflowing ion beams (Collis et al., 1998)
- auroral kilometric radiation (Kumamota and Oya, 1998)

Seasonal effects on energetic electron precipitation

Probability of observing accelerated e^- (monoenergetic) aurora (for energy fluxes > 5 erg/cm^{2}s^{-1})



Darkness Sunlight

Newell et al. (1996)

Seasonal effects on auroral particle precipitation

Conclusion by Newell et al. (1996): **Ionospheric conductivity plays a role**, e.g. by the ionospheric feedback instability.

Another explanation suggested is that formation of parallel electric field requires **low background densities at high altitudes** (density cavities), which MIGHT form preferentially when ionospheric electron densities are low in the entire field line.