ESS 7
Lecture 17
May 14, 2010

The Aurora
Aurora – Amazing Light Show

Andrew Keen, Inari, Finland 18 Feb 2010
-31º C
spaceweather.com
Athabasca Aurora Oct 3 2003

Courtesy Mikko Syrjäsuo
There is a Long Record of Auroral Observations

- The record of auroral observations dates back thousands of years to Greek and Chinese documents.
- The name aurora borealis (Latin for northern dawn) was coined in 1621 by P. Gassendi during a spectacular event observed in southern France.
What are Aurorae*?

- The aurora is mainly caused by excitation due to precipitating electrons and ions. Auroras typically are found at high geomagnetic latitudes where magnetospheric and solar wind electrons can readily access the upper atmosphere.

- Typically $10^{11}$ Js$^{-1}$ is required to maintain auroral emissions – this is about twice the maximum generating capacity of California. A Js$^{-1}$ or joule/second is a watt (W). This power of the aurora is thus 100,000 MW.

*Aurorae=plural; often also “auroras”
Auroral Light

• Auroral emissions are primarily due to a two-step process in which precipitating energetic auroral particles collide with the atoms and molecules of the Earth’s upper atmosphere.

• Part of the particles kinetic energy is converted into energy stored in the chemically excited states of atmospheric species.

• The excited states relax giving off photons.

• The brightest visible feature of the aurora, the green line at 557.7nm is due to the transition of an electron from $^1S$ excited state to the $^1D$ state of atomic oxygen.
Chemically Excited States

• Another commonly observed line particularly in the polar cusp and cap is the red line at 639 nm. This occurs as the $^1D$ state relaxes to the ground state ($^3P_2$):

$$O(^3P) + e \rightarrow O(^1S) + e'$$

followed by

or

$$O(^1S) \rightarrow O(^1D) + h\nu \ (557.7\text{nm})$$

For the red doublet

$$O(^3P) + e \rightarrow O(^1D) + e'$$

followed by

$$O(^1D) \rightarrow O(^3P) + h\nu \ (630 / 636.4\text{nm})$$

(e’ has less energy than e)

• If the $O(^1S)$-state electron gives up its full energy in a single step, instead of two, it emits a 297.2 nm photon.
Auroral Spectra Contain Lines from Many Transitions

- It is sometimes easier to see the transitions by looking at a chart showing the different levels.

- The line at 557.7 nm is called a forbidden line.
  - Allowed transitions occur much more rapidly (10^-7s) than forbidden transitions (0.8s in this case).
  - Forbidden transitions occur at high altitudes (>200km) since at lower altitudes they have a good chance of being knocked out of the state before they can emit.

- There are many permitted oxygen and nitrogen lines from higher excited states.
The Colors of the Aurora

• The 630nm emission forms the diffuse background radiation in which the discrete arcs are embedded.

• “Blood-red” auroras are produced by low-energy electrons (<<1 keV) they are found at high altitudes (>200km)

• “Red lower borders” indicate the presence of energetic particles (>10keV).

• Most auroras are yellow-green but sometimes appear gray (because our eyes are insufficiently sensitive)

• Magenta predominates below 100 km and is a combination of N² and O⁺₂ emissions near 600nm and N⁺₂ violet
The Shapes of Auroras

• There are four forms of aurora.
  – Quiet homogeneous arcs stretching in an east-west direction across the sky.
  – Auroral rays.
  – Diffuse auroral clouds.
  – Spirals and curls.
Shapes and Colors

Diffuse aurora
Arcs

Curtain, Drapes
Rays
Arcs and Rays

Courtesy Jan Curtis
Diffuse and Discrete Aurora

• In addition to discrete auroral structures seen in the images there is a background aurora called diffuse aurora.

• The discrete aurora can be seen as peaks in the radiance curve at the right.

• The discrete aurora rise out of the diffuse aurora which extends over a much wider range of latitude.

• A typical auroral arc receives about $10^6$ kW – a large power plant.

Note: logarithmic scale. The eye detects on a logarithmic scale. Only in this way can we see at night and also during the day! A camera needs many changes of setting for night/day; we don’t!
The Particles that Excite the Aurora

- **Aureol-3** (French for aurora) observations of electrons and ions precipitating into the nightside ionosphere.
  - Middle panel shows average energy
  - Bottom panel shows the energy flux to the ionosphere.

- Ion signature around 2124 UT is a velocity dispersed ion structure thought to be the signature of the PSBL.
Particles Making Discrete and Diffuse Aurora

- Red electron fluxes equatorward are “inverted V” events associated with discrete aurora.
- Precipitating particles equatorward of 68.5° produce the diffuse aurora.
The Auroral Oval

- The aurora are found in rings about the north and south poles.
- These are magnetically connected to the equatorial magnetosphere.
- The sketches on the right are based on observations and show the regions with aurora for quiet and disturbed times.
Polar Cap Sun-Aligned Aurora

- Disturbed auroral oval occurs for southward IMF during storms and substorms.

- When the magnetosphere is quiet and the IMF is northward polar-cap sun aligned arcs oriented from midnight to noon can occur.

- They occur about 50% of the time when the IMF is northward.
Image of “theta aurora” during the passage of a magnetic cloud past the Earth.
Assignment

- Read Chapter 6
- Problems 5.1, 5.2, and 5.3
- Due May 21, 2010