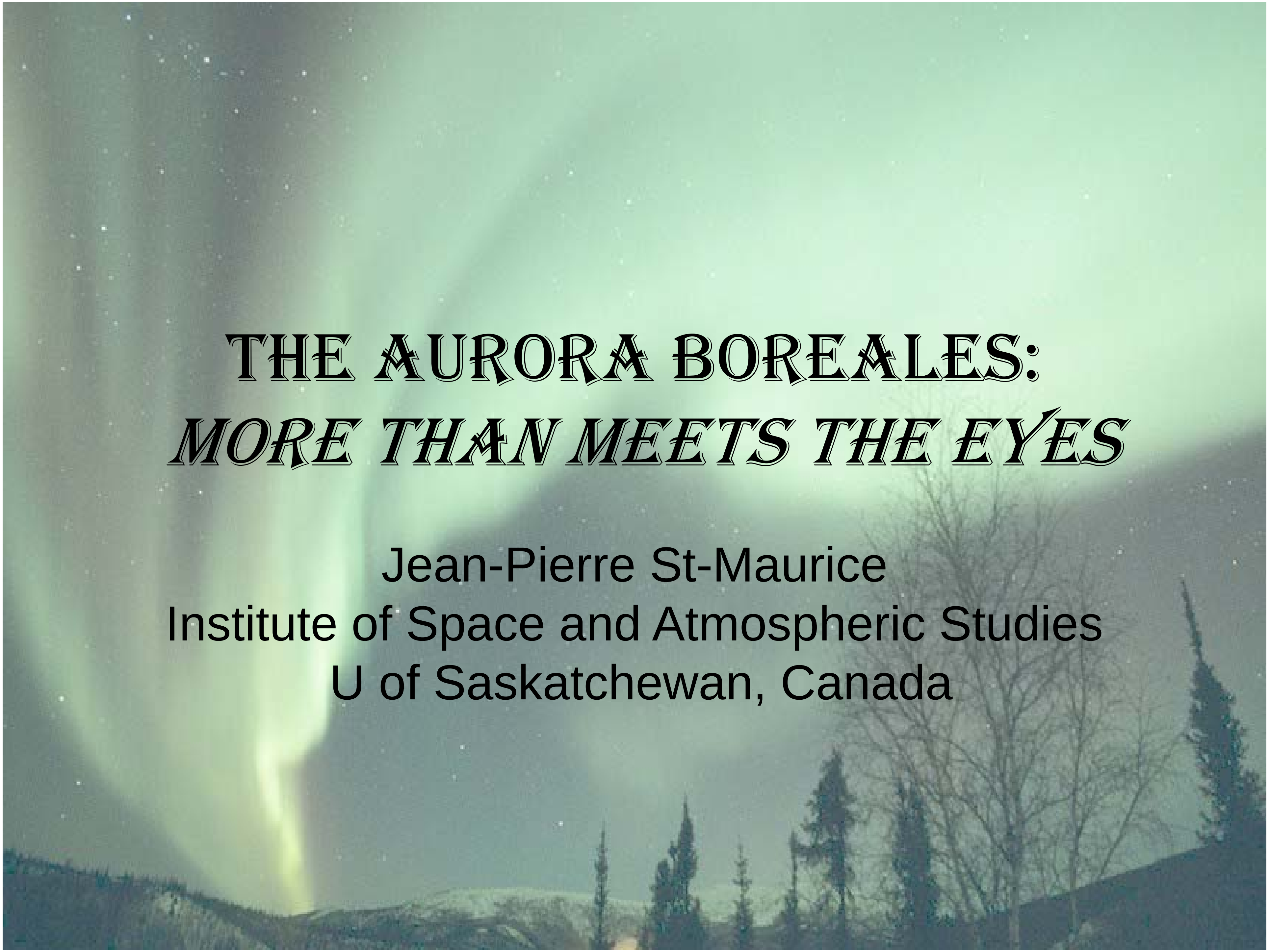
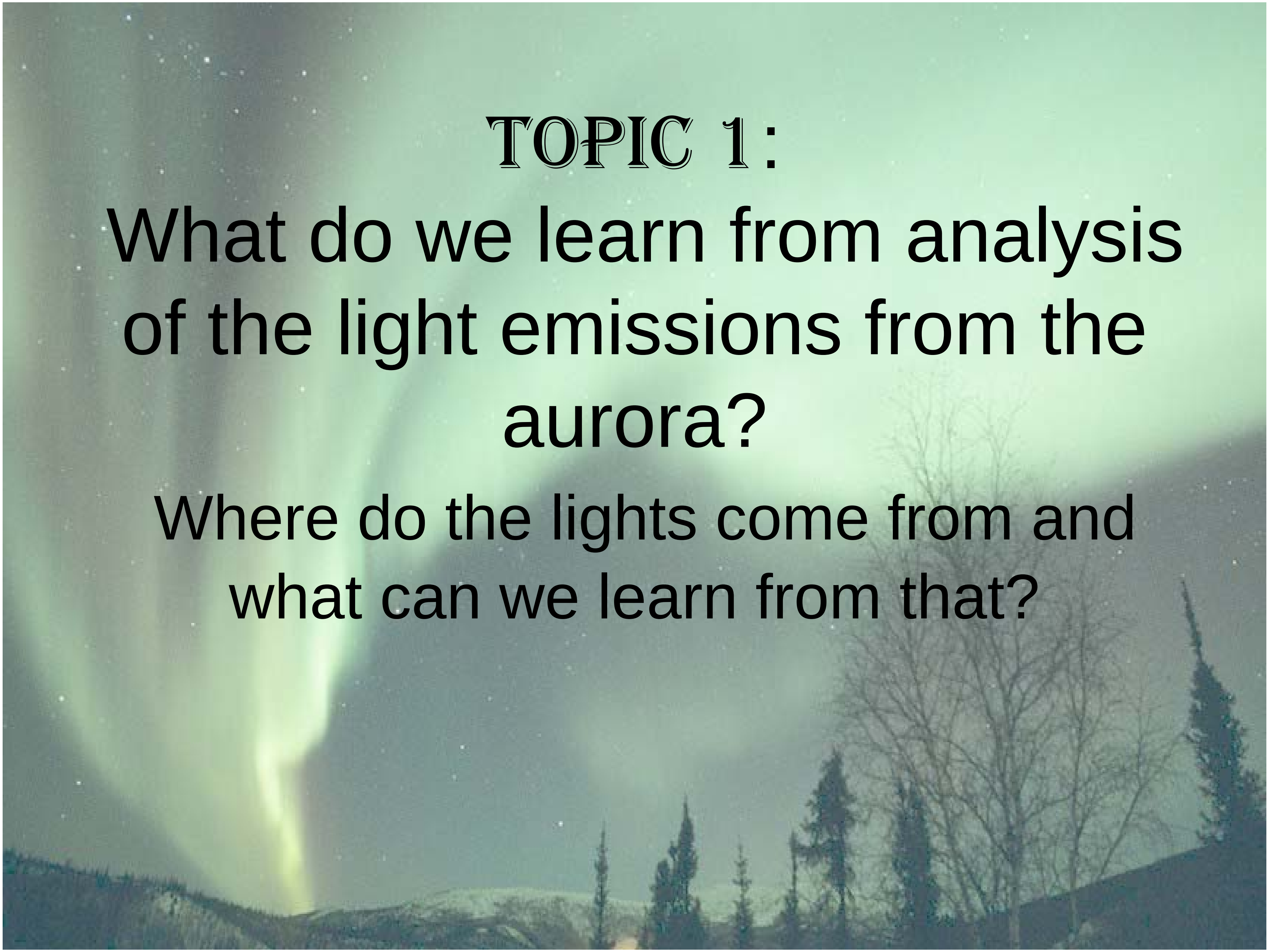

The Aurora Boreales:
More than meets the eyes
Jean-Pierre St-Maurice
Institute of Space and Atmospheric Studies
U of Saskatchewan, Canada

More Than Meets the Eyes!

1. What do we learn from analysis of the light emissions from the aurora?
2. Is the aurora involved in electrical currents? If so, what is the current system like?
3. The fly in the ointment: could the aurora be a tad turbulent? If so, what does it mean for us, students of the aurora?


TOPIC 1:
What do we learn from analysis of the light emissions from the aurora?
Where do the lights come from and what can we learn from that?

First things first: *What is the color of the aurora?*

- White? Green? Blue? Red? Yellow? Gray? Black?
  - Answer: green blue red (and white as a result).
  - But, surprise, it can also be black!

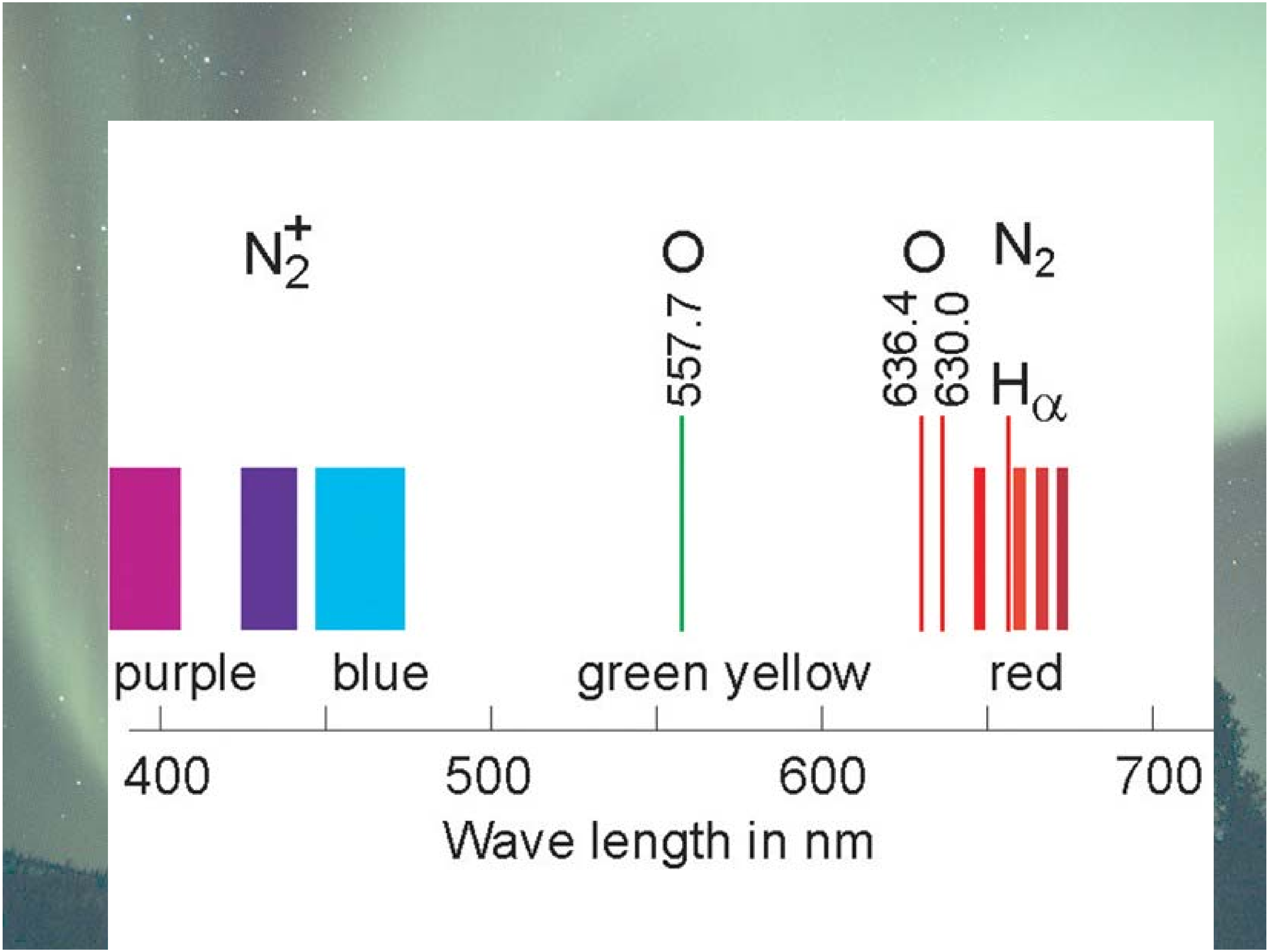
Sometimes, it’s all red.

The Romans thought it was blood in the sky. Bad omen!

There can be green below the red, with withish in between.

How are the colors produced? Where do they come from?

- Answer: excited atomic states of the constituents known to exist in the upper atmosphere, except for black, which is an absence of aurora in the middle of an auroral patch



N_2^+
O
O
N_2
557.7
636.4
630.0
H_α
purple
blue
green yellow
red
400
500
600
700
Wave length in nm

Just how are the atoms and molecules excited electronically? What is the “hammer” that hits them?

- Clue: the presence of the striations, which are along the magnetic field lines.
  - Magnetic fields do not affect neutral particles but do affect charged particles, which find it very difficult to move across magnetic field lines.
- Conclusion: we indeed have charged particles falling from the sky: electrons and protons.

All good, but why is red sitting on top of green?

- CLUE 1: red and green are both from excited stated of O
- CLUE 2: red and green are both "forbidden emissions". Green takes 1 s to emit and red takes 100 s
- CLUE 3: collisions with other atoms or molecules will get rid of the excited state.
- CLUE 4: the collision time is 1 s at 120 km and 100 s at 200 km altitude

How do we know that protons, not just electons are also falling from the sky?

ANSWER

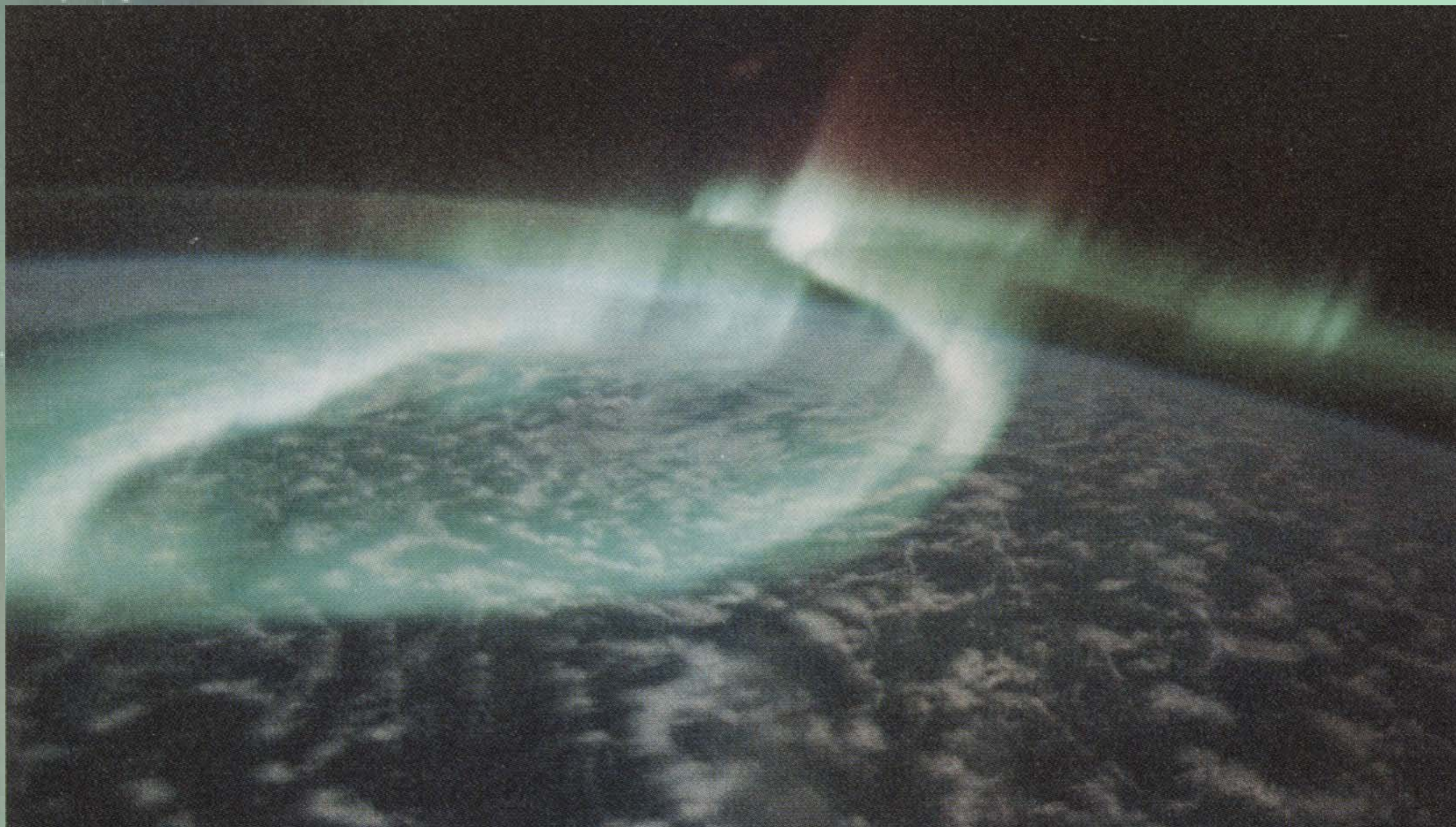
- Hydrogen emissions are sometimes part of the aurora and there is basically no Hydrogen in the lower ionosphere.
- But H is not H+. Does that mean that H is falling from the sky?

How is the altitude of the aurora used to infer the energy of the charged particles that excite the aurora?

- Clue: the higher we go the less dense the atmosphere is
- Answer:
  - The lower the altitude is, the more energy it takes for the charged particles to penetrate the atmosphere.

Question:
How high up in the sky is the aurora?

- Answer:
  - 100 to 250 km, mostly
- Question: how do we figure this out?
  - “Triangulation”
  - Look at a picture taken from the space shuttle (200 km altitude)
- Food for thought:
  - Ever seen an aurora when the sky is cloudy?
  - If you think it comes down near the ground you’re in good company. In earlier days, the scientists would go to the top of mountains to get really close… only to find that the aurora was still not reachable.



- Aurora as seen from the shuttle, 200 km above the ground.

Calculating the energy of the charged particles that produce the aurora.

- From fairly straightforward calculations we know that electrons require 10 keV of energy to reach down to 100-110 km altitudes.
  - To produce aurora at 250 km requires much less, more like 50 eV.
  - However, the temperature is like 0.1 eV and less, so even 50 eV is a lot more than is found in the ionosphere below 5000 km altitude.

Summary: what we learn from an analysis of the auroral lights themselves

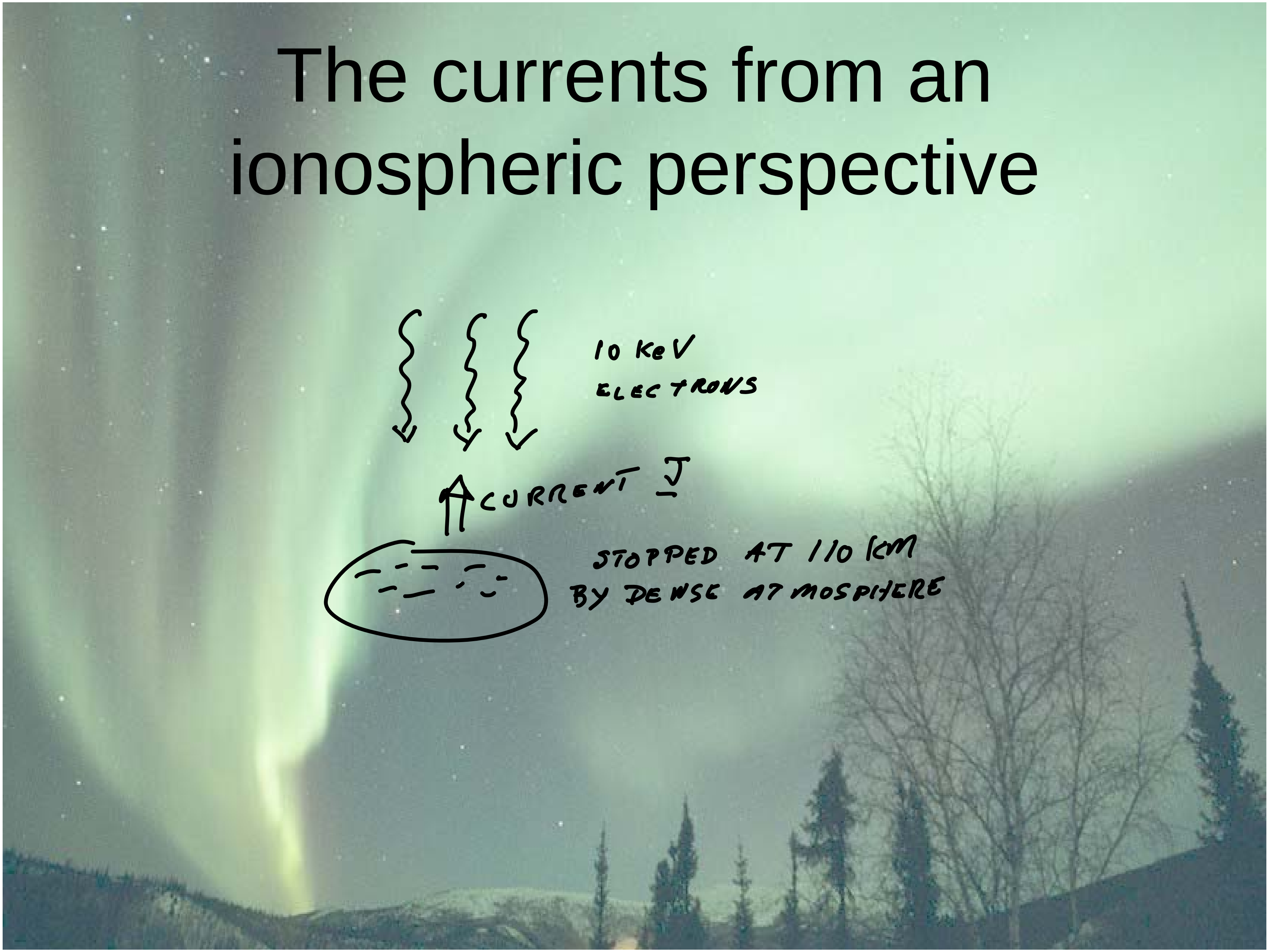
- The light comes from electronically excited atoms and molecules (O, N_2 and their ions) in the upper atmosphere.
- The particles that collide with the atmosphere are charged: electrons and protons
- The energy of the charged particles that are coming in is 500 to 100,000 more than the energy of the particles normally found below 5000 km altitude.
  - We have to deduce that they must have been accelerated by an electric field well above 1000 km altitude

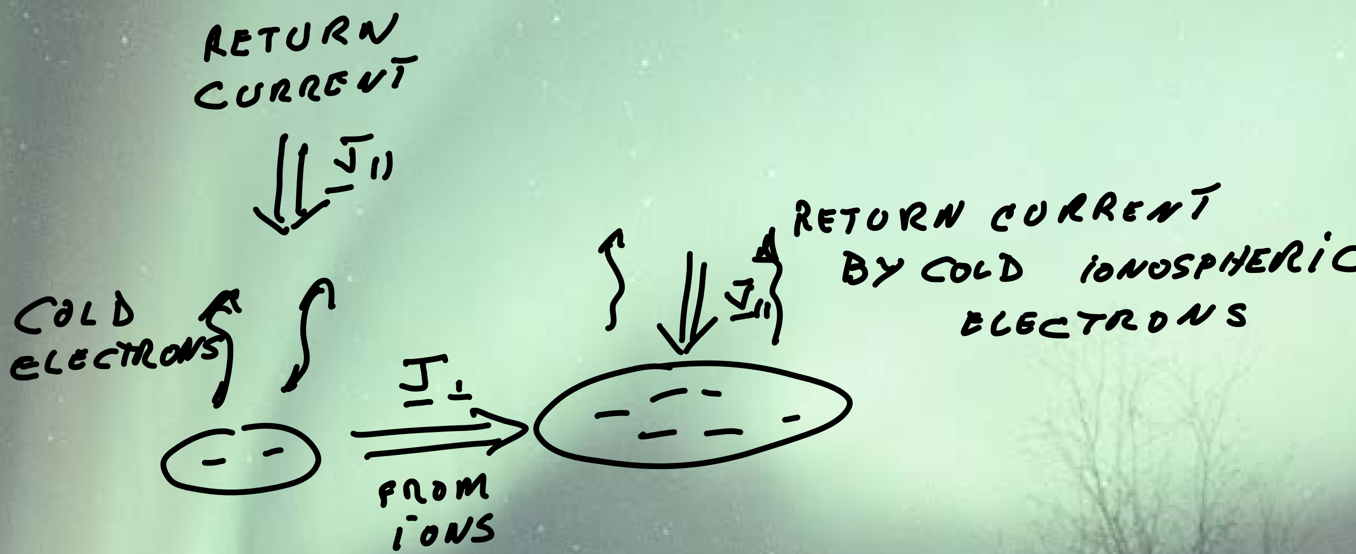

TOPIC 2
Aurora and electrical currents and electric fields

Are the electrons that are falling from the sky creating currents?

- ANSWER:
- YES, of course
- BUT not necessarily: plentiful cold electrons coming up from the ionosphere are perfectly able to cancel the incoming energetic electron flux.
- But, yes: the precipitating electrons are part of an intricate current system in the end. Local cancelling is not 100% effective

The currents from an ionospheric perspective

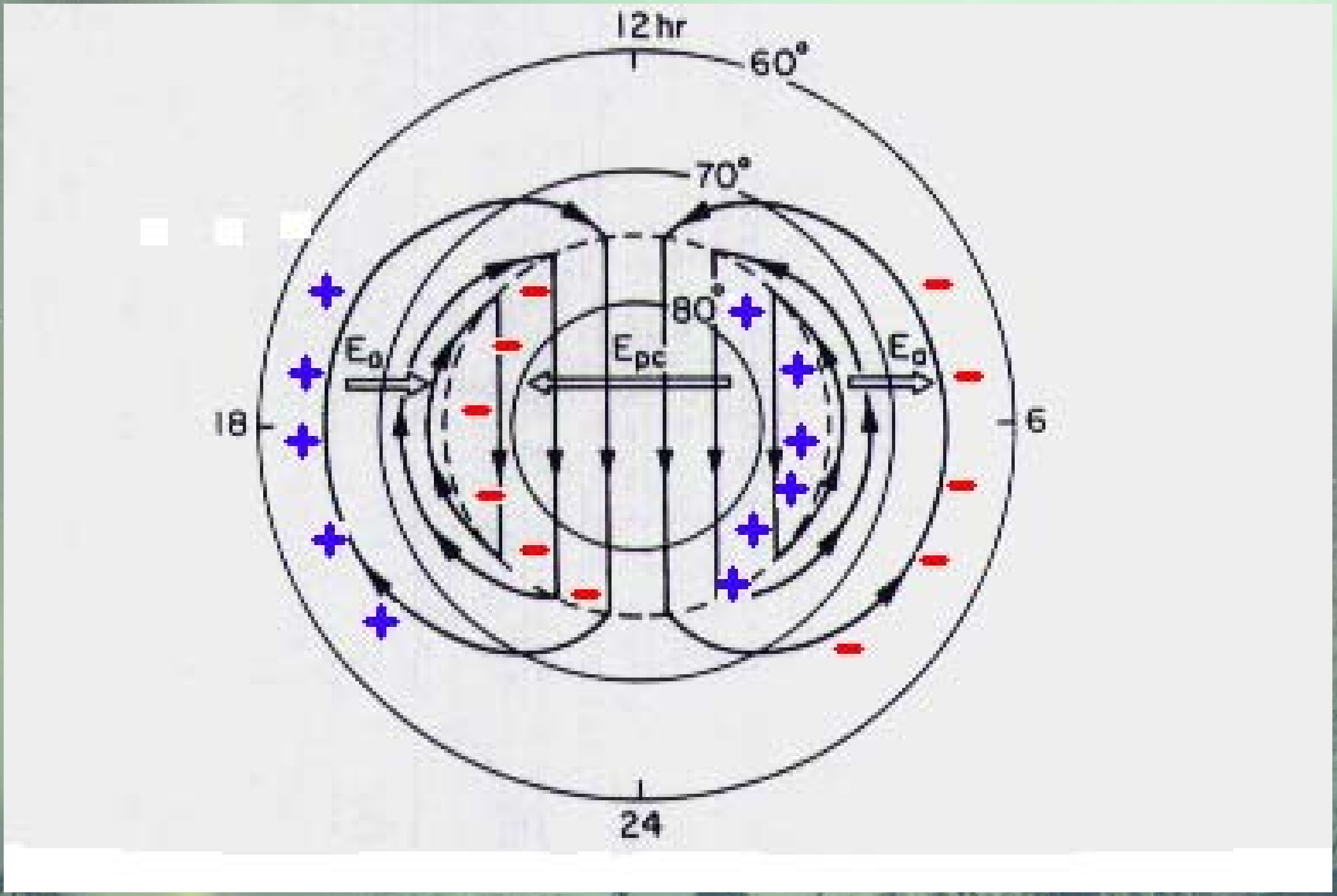




Electrons are highly mobile along B, but not perpendicular to B. It's the opposite for the ions, particularly below 200 km.

This picture could be applied to a single magnetic field line but it actually is something that is elongated along circles of latitude

The big picture of auroral currents: it's a global circuit!



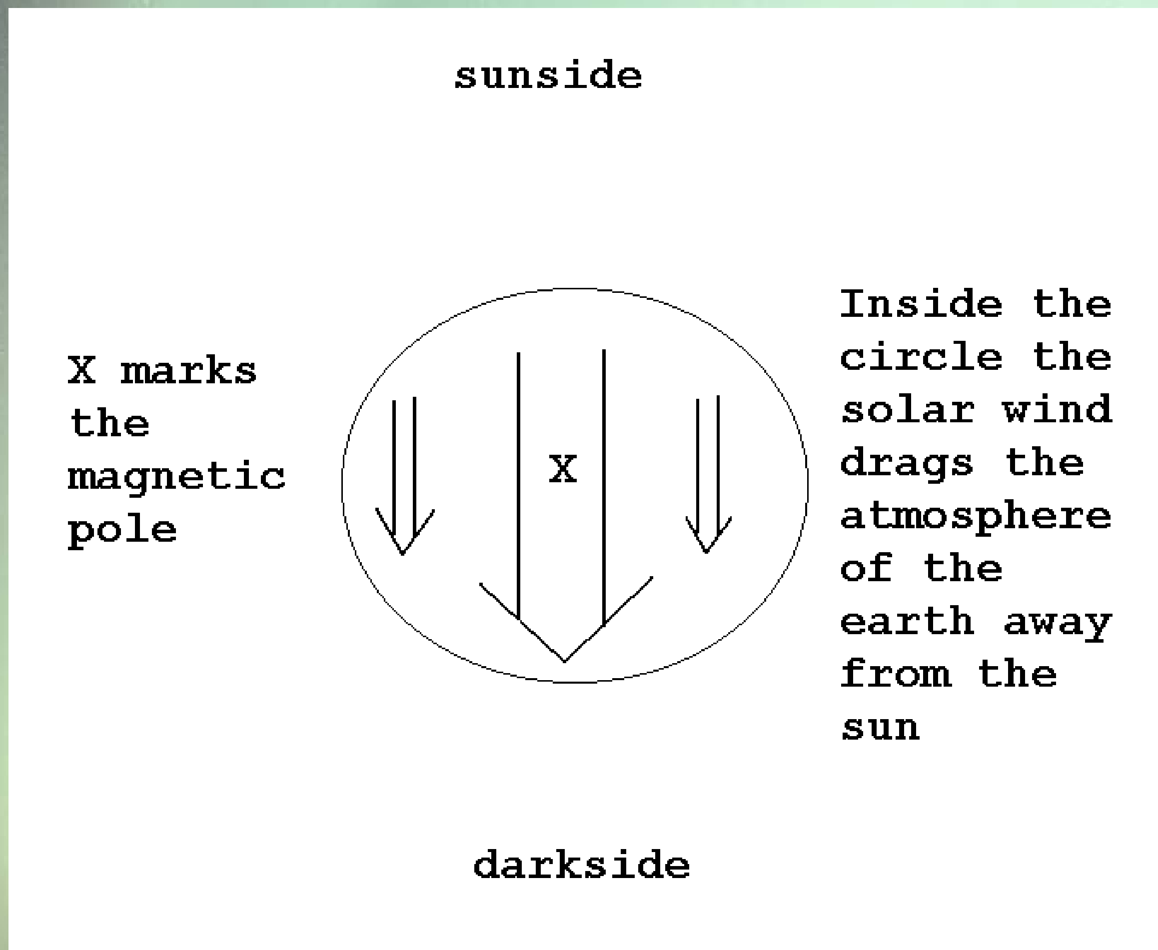
The chicken or the egg: which comes first: currents or E fields?

- The electric fields allow the plasma to move in the “ExB” direction everywhere above 150 km.
- The push over the polar cap is from the solar wind. In that sense the electric field is more important than the currents.
- But then again, the solar wind could be a current rather than voltage generator!

The sequence of events

1. The plasma is pushed away from the sun in the polar cap region
2. The plasma returns towards the sun at lower latitudes
3. The returning plasma flows towards the sun around the polar cap region
4. An electric field is produced by the charge separation created when the returning particles encounter an increasingly strong magnetic field
5. The electric field is from the charged magnetic field lines. The charges run away from each other, getting accelerated in the process and leading to the aurora
6. The magnetic field tubes of returning plasma are charged positively on dusk side, negatively on dawn side

Step 1


sunside
X marks the magnetic pole
X
Inside the circle the solar wind drags the atmosphere of the earth away from the sun
darkside

Step 2

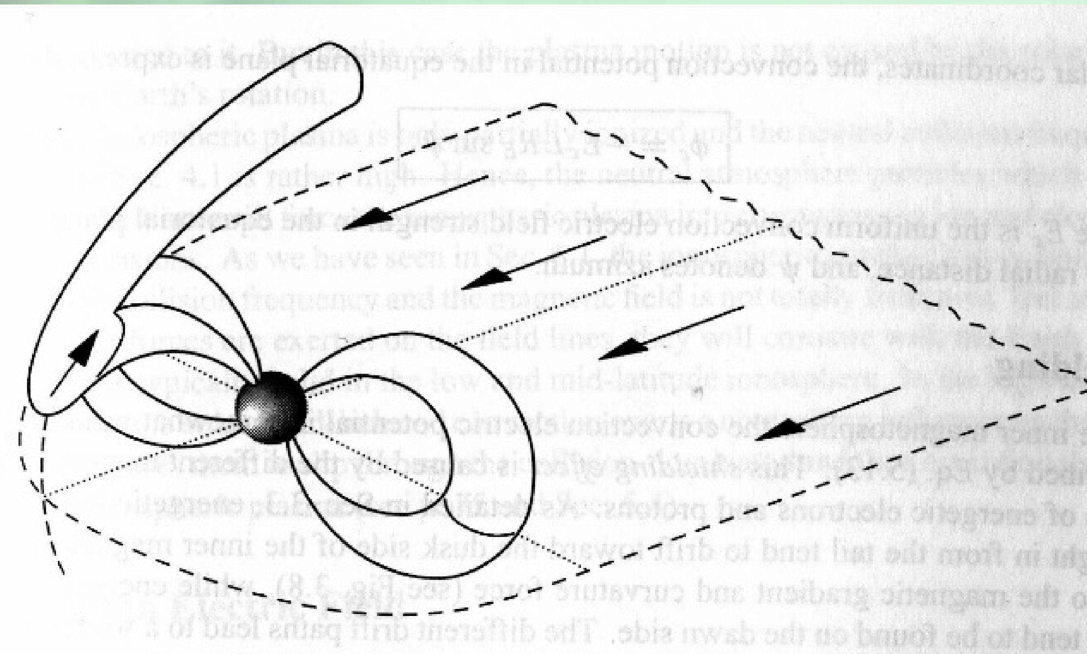
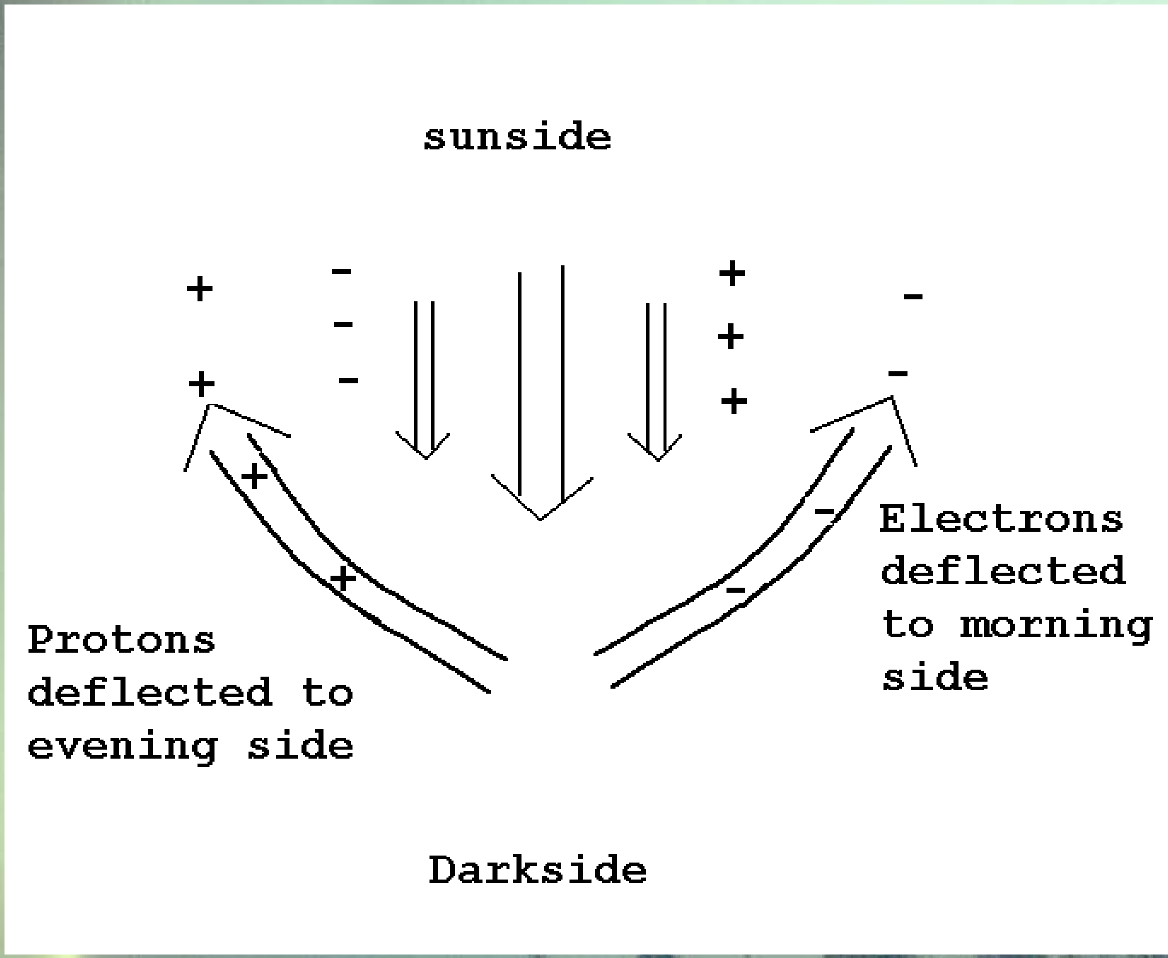


Fig. 5.5. Flux tube and plasma convection caused by magnetic merging.

Steps 3 and 4


sunside
Electrons deflected to morning side
Protons deflected to evening side
Darkside

Step 5

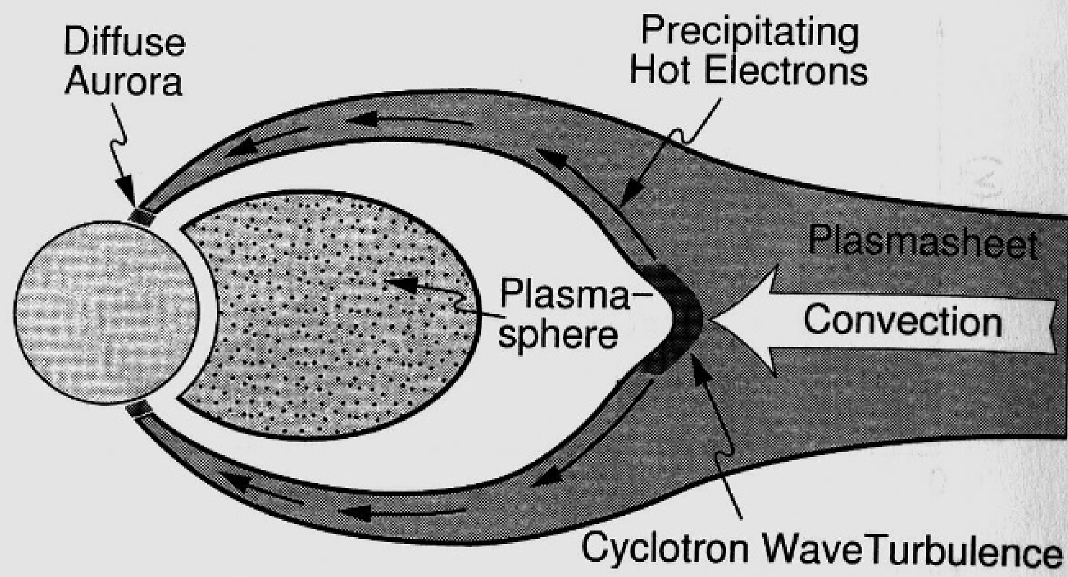
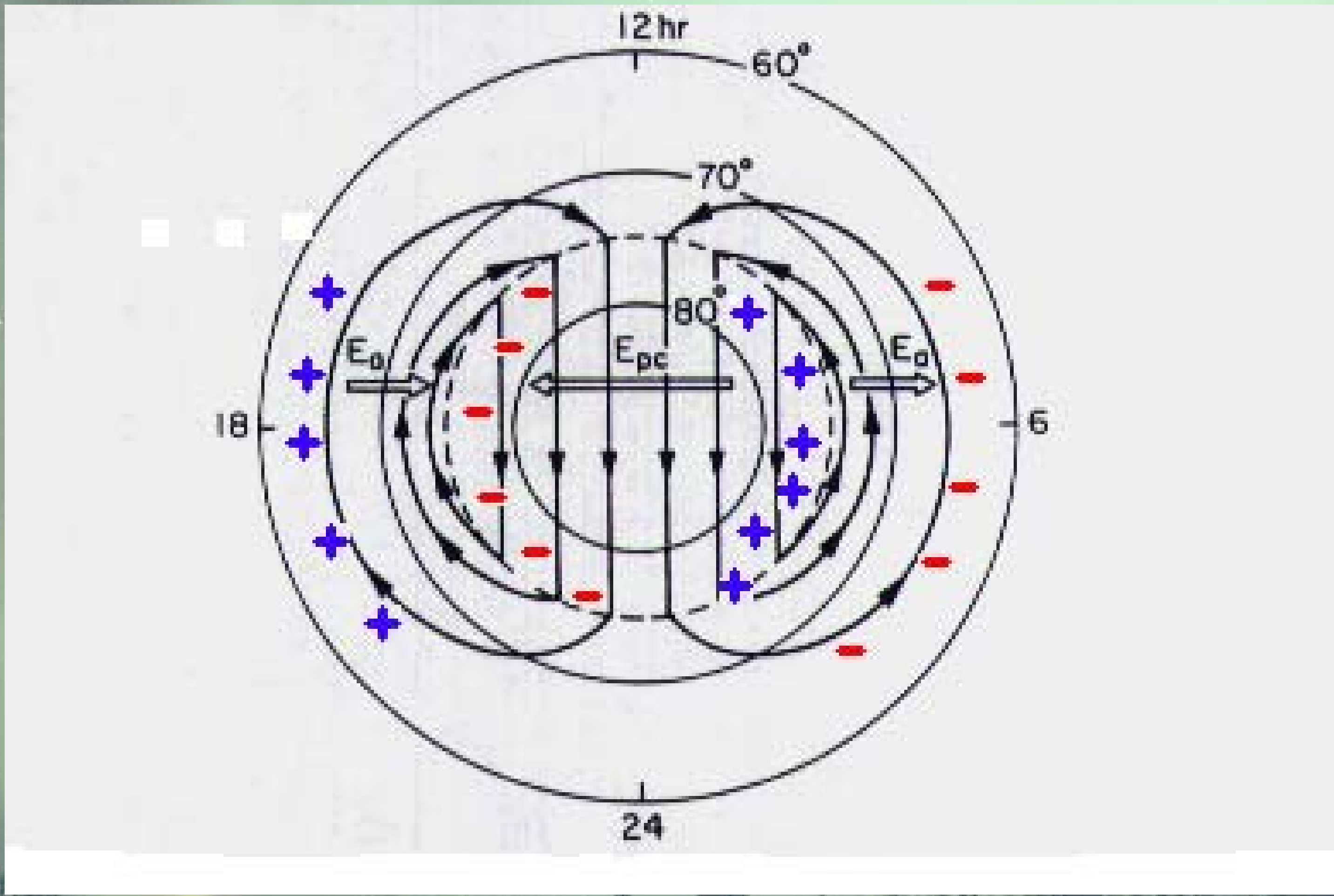


Fig. 4.16. Ring current particle precipitation due to electrostatic cyclotron waves.

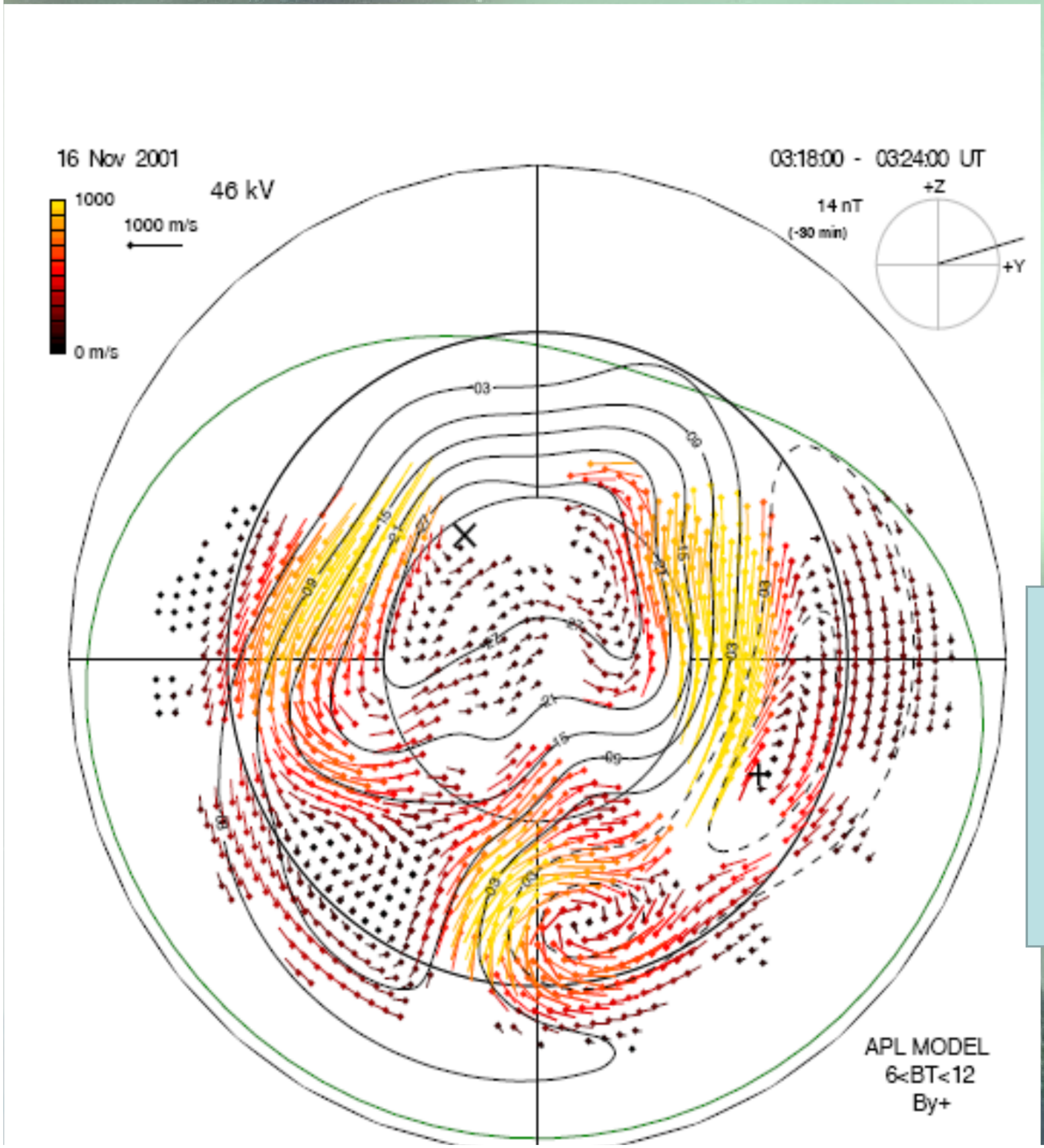
Step 6



3. How Good Is Our Nice Static Picture of the Electric Fields and the Aurora?

Let’s have a look!

Example of global radar map of the plasma circulation

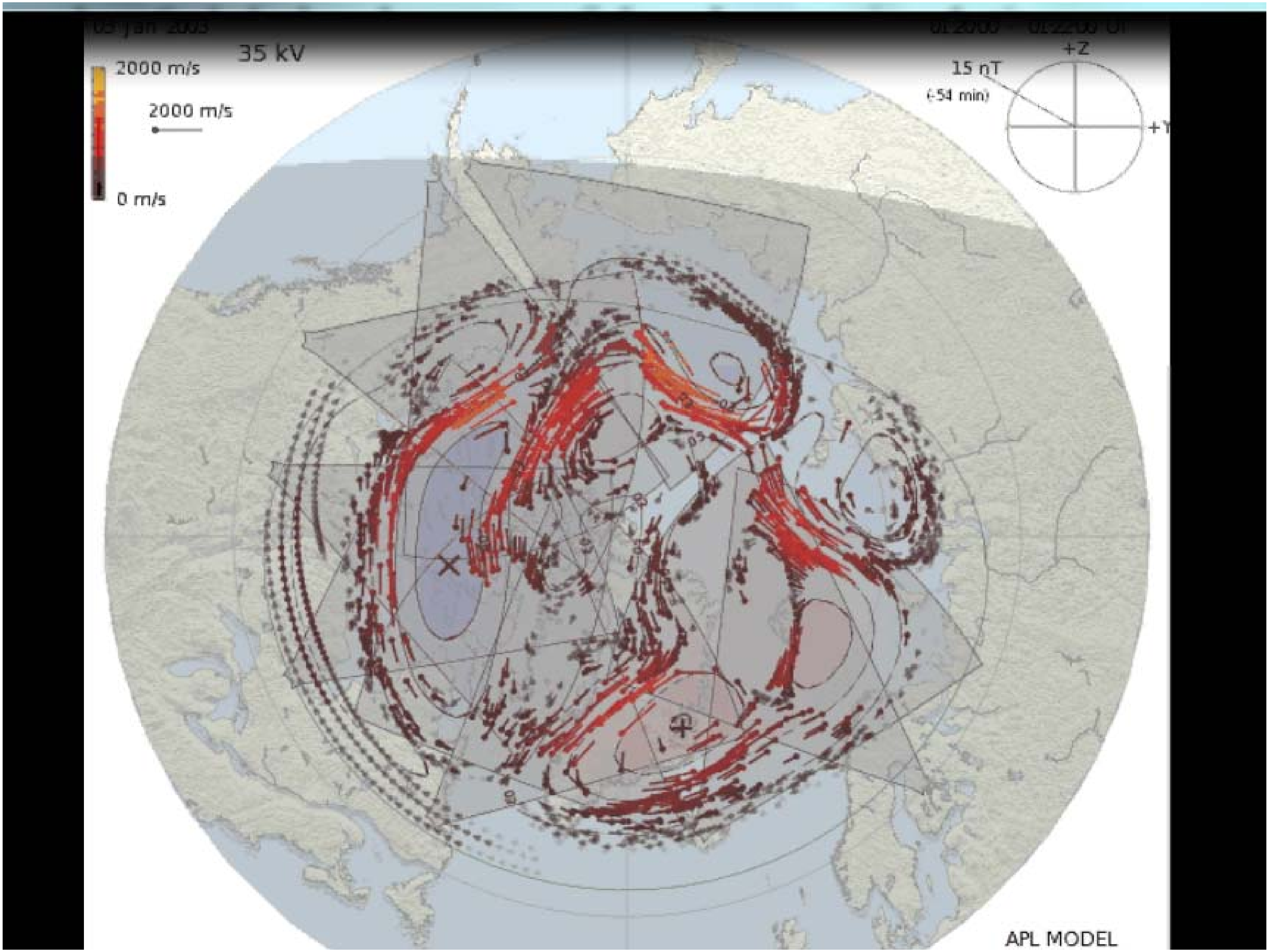


Example of an animation from successive radar maps

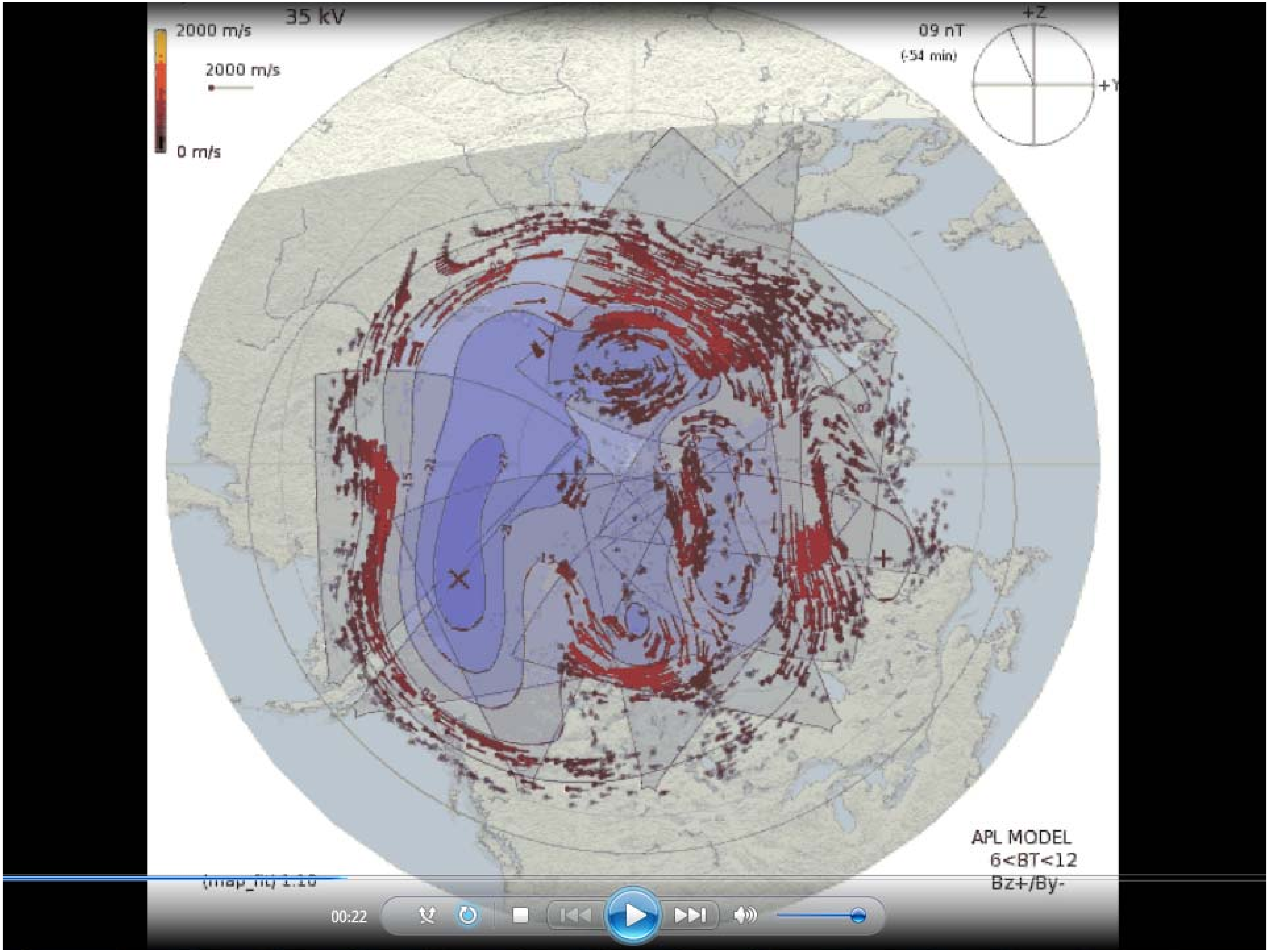
The funny thing about this is that if we average over long enough time, we get the simple 2 cell convection pattern shown in previous cartoons.

Variability, chaos, turbulence

- The next 2 slides show how disorganized the circulation pattern can be if the solar Interplanetary Magnetic Field is northward. The slides are taken from a more continuous animation.
- They are based on SuperDARN data and show the flow through tracers, not just flow vectors.
- They show turbulence on a scale of 1000’s of km

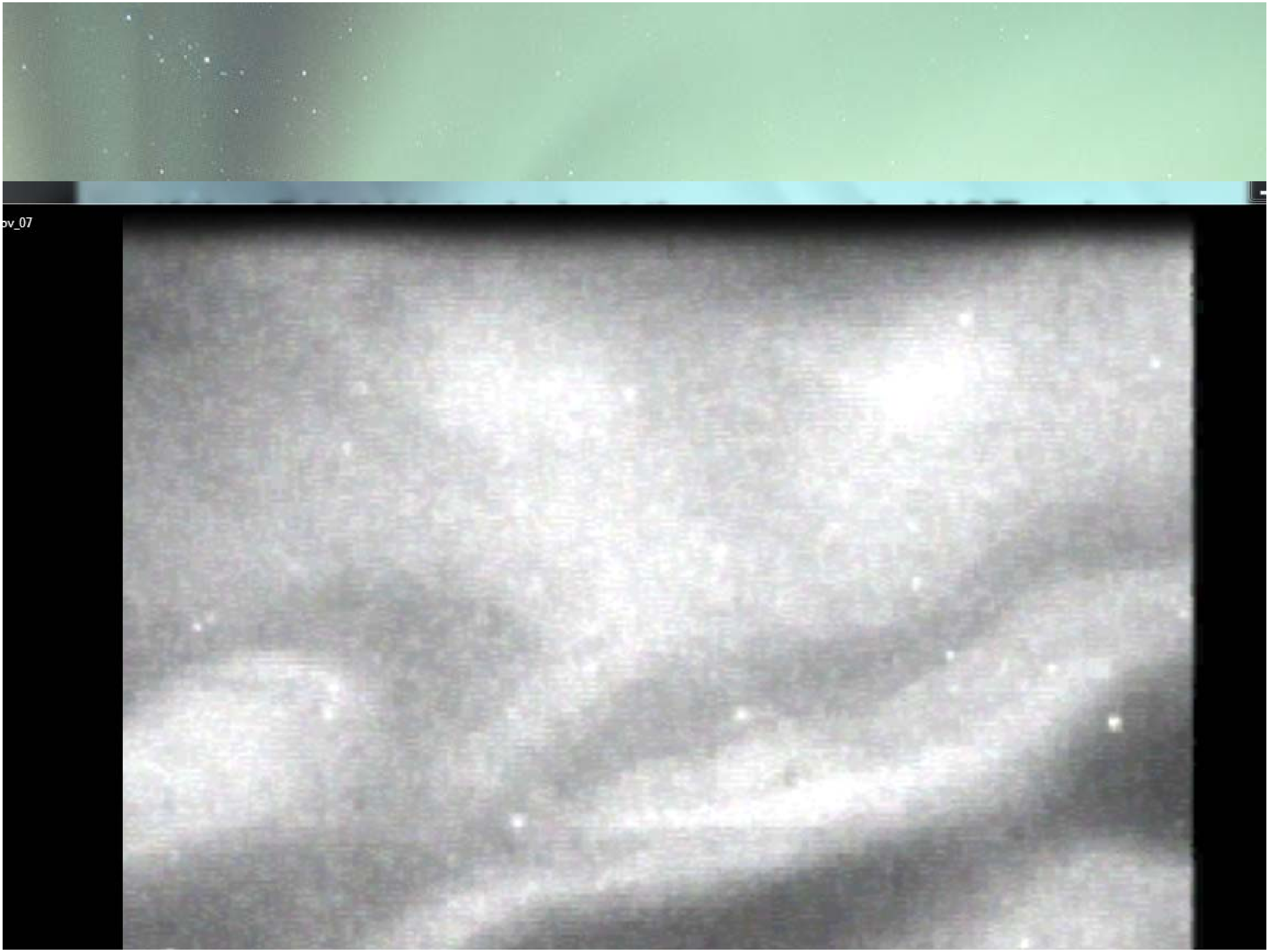


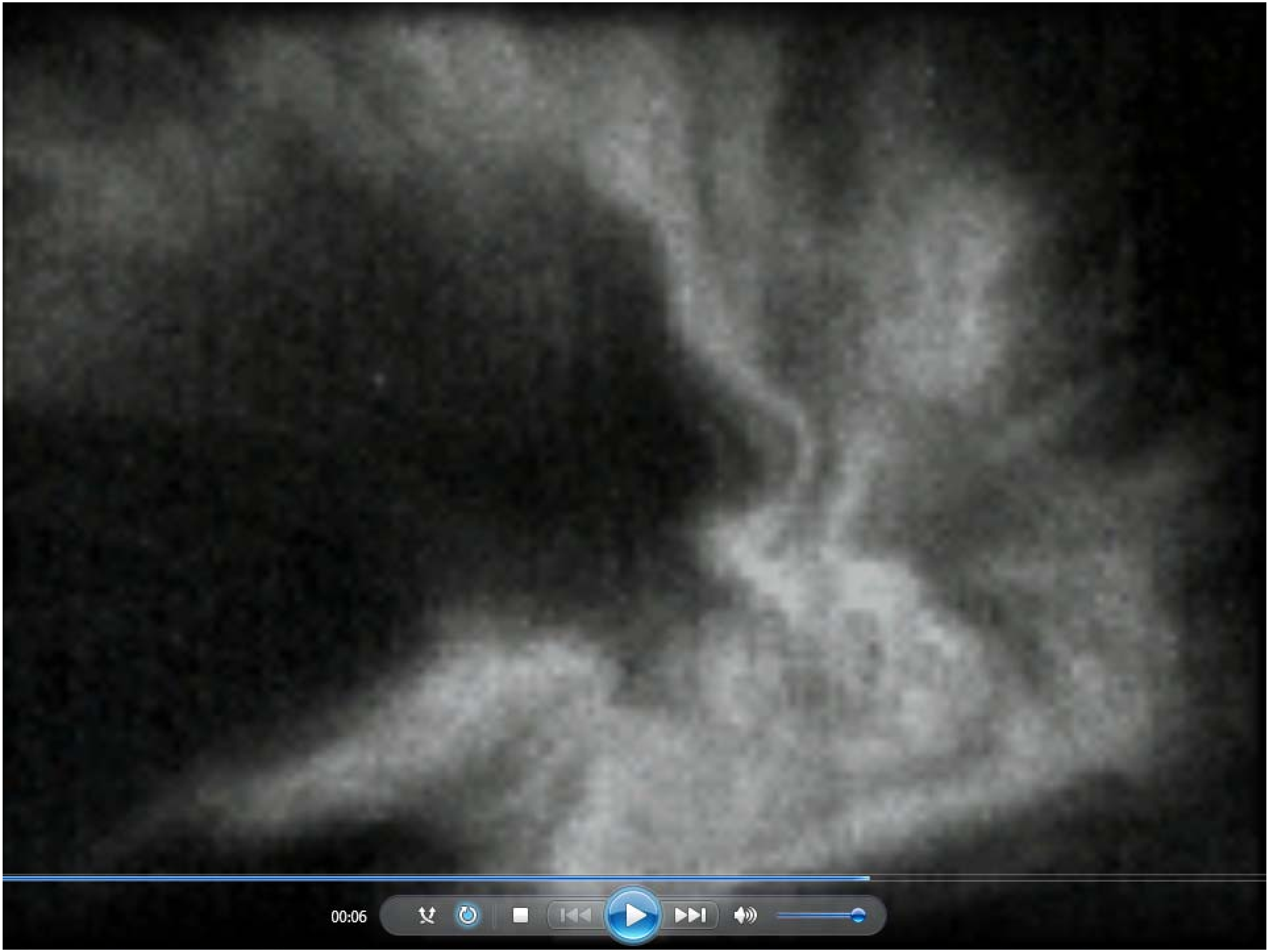
35 kV
2000 m/s
2000 m/s
0 m/s
+Z
15 nT
(-54 min)
+Y
APL MODEL


35 kV
2000 m/s
2000 m/s
0 m/s
09 nT
(-54 min)
+Z
+Y
APL MODEL
6<BT<12
Bz+/By-
00:22

Small scale turbulence

- The next 2 slides show turbulence on a much smaller scale. The FOV is 10 km by 12 km and the resolution is 30 m. The movie is based on 30 frames per second (courtesy, Trond Trondsen, u of Calgary)
- This kind of thing is seen inside quiet arcs
- It's based on prompt auroral emissions. Note that conductivity depends on the precipitation averaged over a few s or longer. So, it's not too hopeless for ionospheric electrodynamical calculations


ov_07


00:06

Other Complications

- When the E field is very strong, the ions become supersonic and are strongly heated by friction.
  - Their velocity distribution is affected by this
  - For strong E fields, this affects the analysis of ISR data as well as in-situ satellite observations
- The neutral atmosphere gets heated as well: instead of getting hot, it moves upward. Lots of complications with that:
  - Example: Ions are expelled from the hot regions. Are the resulting upflows significant? Do they lead to outflows?
- Instabilities of all sorts…It’s a doggie’s breakfast

Summary Points

1. The aurora is created by energetic electrons and protons falling towards the earth along the magnetic field lines.
2. The light is from ambient excited atoms and ions excited electronically when they are hit. Hydrogen emissions are from neutralized protons.
3. The precipitating charged particles carry currents along the magnetic field lines

4. Once they are stopped by the atmosphere the charged particles produce electric fields.

5. The electric fields are stronger if the electrical conductivity (ionospheric density) is smaller. Currents have to close no matter how large or small the E field is.

6. The whole thing starts with the solar wind pushing the plasma over the polar cap in the antisunward direction

7. The average picture is nice and tidy but actually it’s pretty much all turbulence and chaos out there.


Any *questions*?