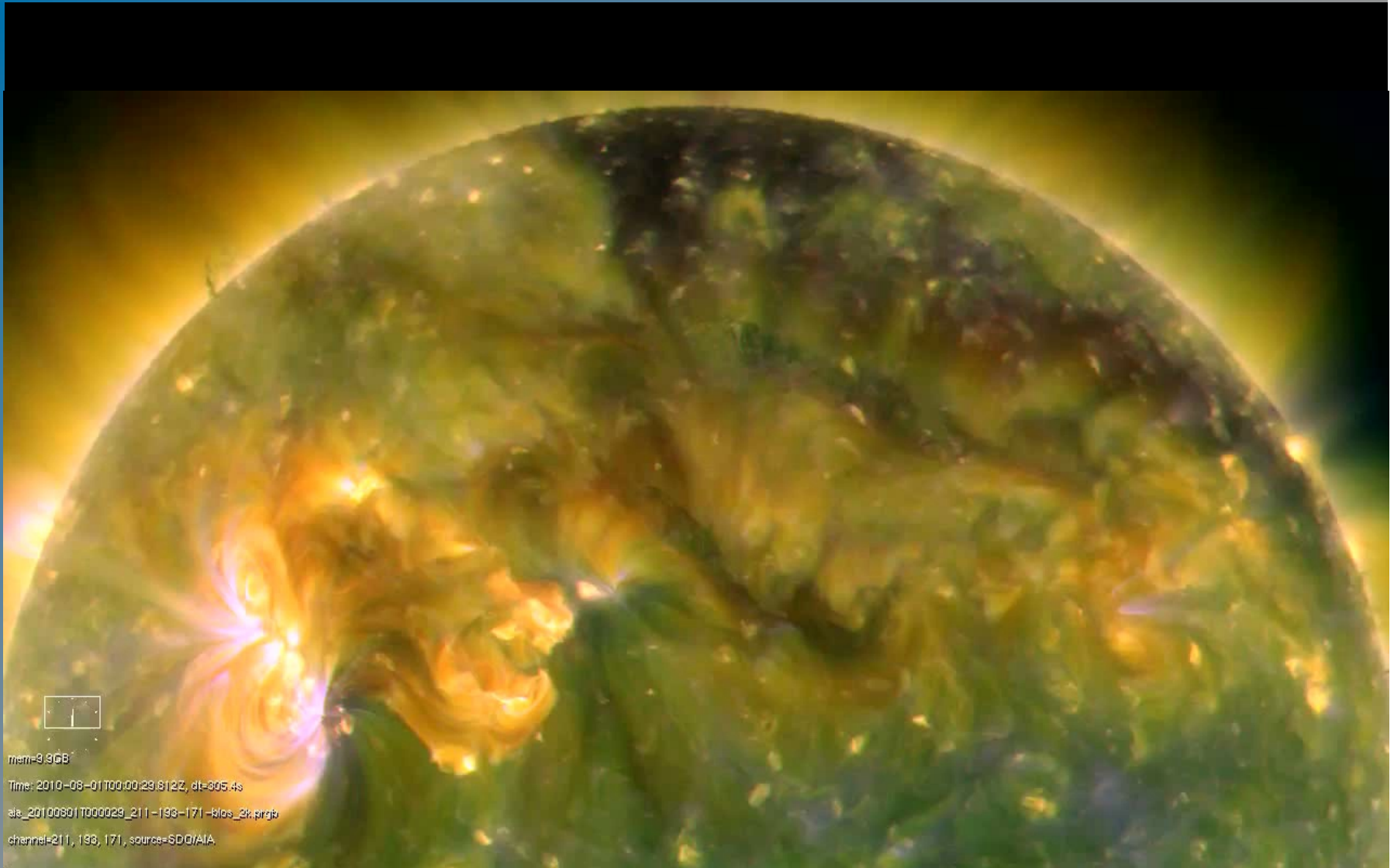


Aurora and the Earth's
Magnetotail

From Birkeland to THEMIS

The image is a composite of three parts. On the left, the Sun is shown as a bright orange sphere with solar flares. In the center, a view of Earth from space shows a colorful magnetotail structure extending from the planet. On the right, a photograph shows the aurora borealis as a green and purple light display in a dark sky over a forest of evergreen trees.

Aurora and the Earth's magnetotail





3rd August 2010

Aurora and the Earth's magnetotail



OAW

❖ History of Auroral Research

❖ The early years

❖ Anders Celcius (1741)

❖ Maximilian Hell (1777)

❖ The Sun Kings

❖ Kristian Birkeland (1867-1917)

❖ Modern Day Research

❖ In Situ Study of Auroras

❖ Birkeland's Victory

❖ Magnetotail Dynamics:

❖ Cluster

❖ Themis

HISTORY

MODERN



Let's Go to the Past With the Doctor

Aurora and the Earth's magnetotail



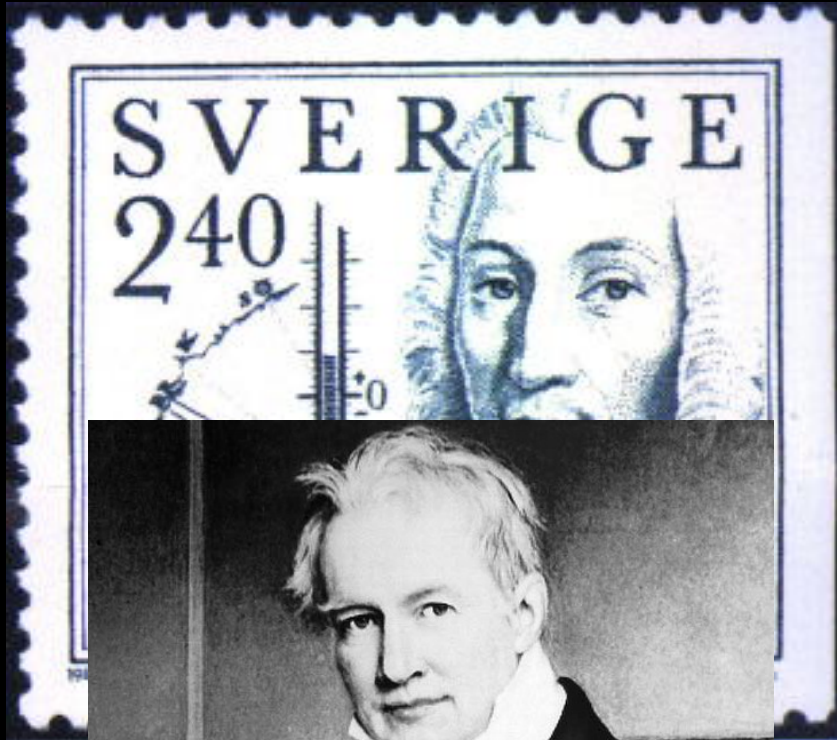
OAW

Aurora and the Earth's magnetotail



- ❖ In 1716 there was large scale auroral activity over Europe that fascinated Celcius
- ❖ In 1741 he and Hiorter marked a compass needle reading every hour for a whole year
- ❖ If there was aurora then the compass needle wiggled!





- ❖ The stronger the aurora, the more the compass needle moved
- ❖ Thus it was found that the aurora was „magnetic in nature“ but no model was given
- ❖ Alexander von Humboldt would later call this a „magnetic storm“

Austria's Attempt: Father Maximilian Hell

Aurora and the Earth's magnetotail

- ❖ Father Hell was the „director“ of the Wiener Universitätssternwarte
- ❖ Between 1767 and 1770 he moved to Vardö in the Barentsea
- ❖ He studied the northern lights, but he did not observe any motion of a compass needle he brought with him





... Stof des Nordlichts [ist] die Sonnenatmosphäre, die mit der Atmosphäre der Erde vermischt und durch eine dadurch entstandene gewisse Gaerung leuchtet

... die von den schweflichten und salpetrischen Ausduenstungen der Erde, die sich in der Atmosphäre befinden, und durch Gaehrung, Reibung, oder von den Sonnenstralen entzuetet leuchtete

... die Atmosphäre werde von jenem Schein erleuchtet, den das Eis von den Groenlandkuesten zurueckwirft,

... [das] durch taegliche Erfahrung belehrte Volke der kalten Zone behaupten: Der Stof des Nordlichts seien die in der Atmosphäre vereiseten Ausduenstungen

- ❖ In the end, Father Hell concluded that the aurora was created by the light of the sun and moon reflected and refracted by frozen water vapour in the atmosphere
- ❖ That creates nice effects like this „solar pillar“ but not aurora



Hurry up, please,
we are leaving!
Can't let the
Tardis wait.



The Doctor kindly requests
everyone to get into the
Tardis again

Aurora and the Earth's magnetotail





THE PENNY MAGAZINE

OF THE
Society for the Diffusion of Useful Knowledge.

110.]

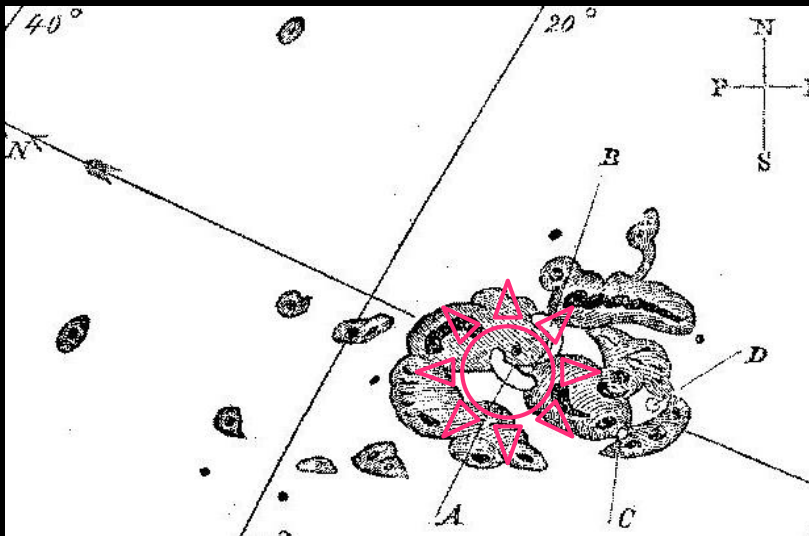
PUBLISHED EVERY SATURDAY.

[DECEMBER 21, 1833.]

THE AURORA BOREALIS.

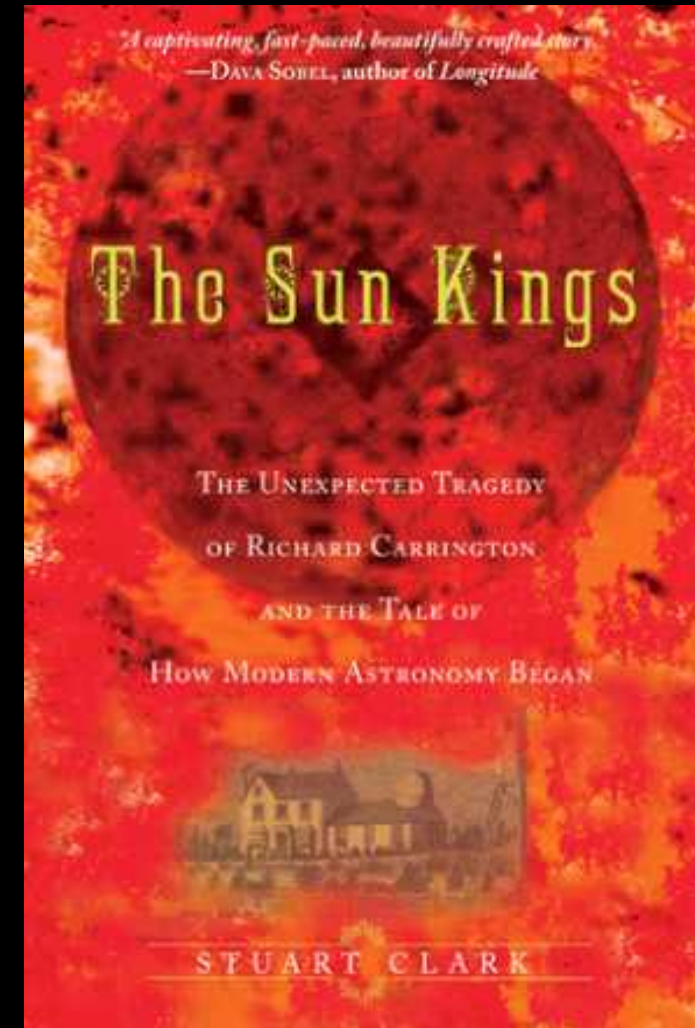


The Aurora Borealis is a beautifully luminous meteor, appearing in the form of streams of light, rays, arches and crowns.



- ❖ 1 September 1859
- ❖ Richard Christopher Carrington observed the Sun and drew the sunspots with bright spots, turning into a connecting bright ribbon
- ❖ Unfortunately there exists no picture of Richard Carrington

- ❖ The largest auroral activity in modern times
- ❖ The aurora went as far south as the Caribic!
- ❖ Telegraph lines stopped working and fires broke out in the stations
- ❖ And something had happened on the sun
- ❖ This event started the Sun-Earth connection studies



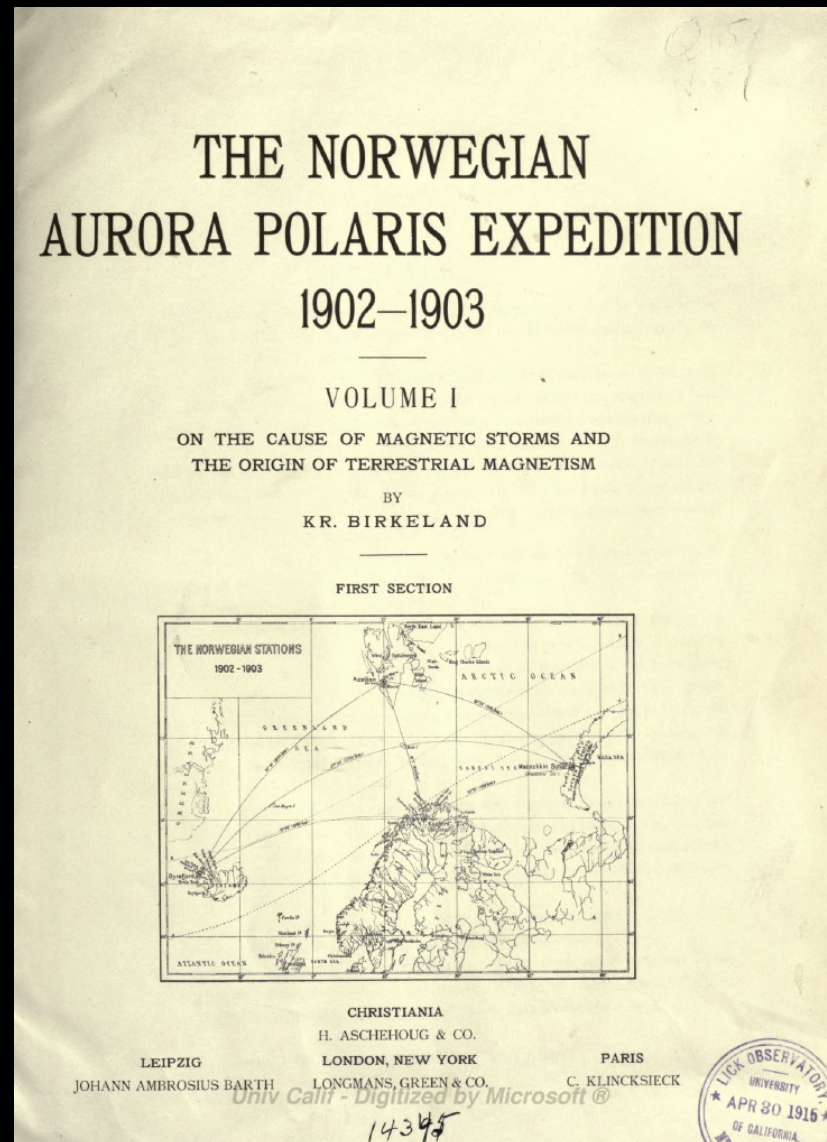
- ❖ Idea of something linking the Sun to the Earth was strange
- ❖ But somehow when something happened on the Sun the Earth's magnetic field responded
- ❖ Herschel showed that the magnetic disturbances walked in lockstep with the number of sunspots





- ❖ Professor Kristian Birkeland (1867-1917)
- ❖ Famous for inventing a method to produce salpeter and for building a hydroelectric plant
- ❖ This was all done with one goal in mind:
 - ❖ **Financing the study of the Aurora**

- ❖ Put magnetic field measurement tools at various locations
- ❖ Go onto “Arctic Expeditions”
- ❖ Have students and employees read the magnetic measurements during times of aurora
- ❖ But he was there himself too

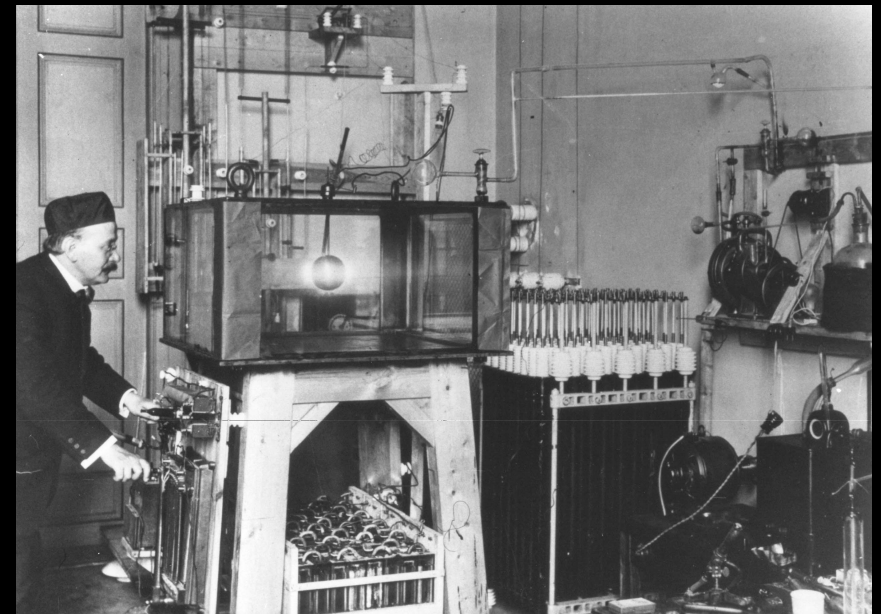
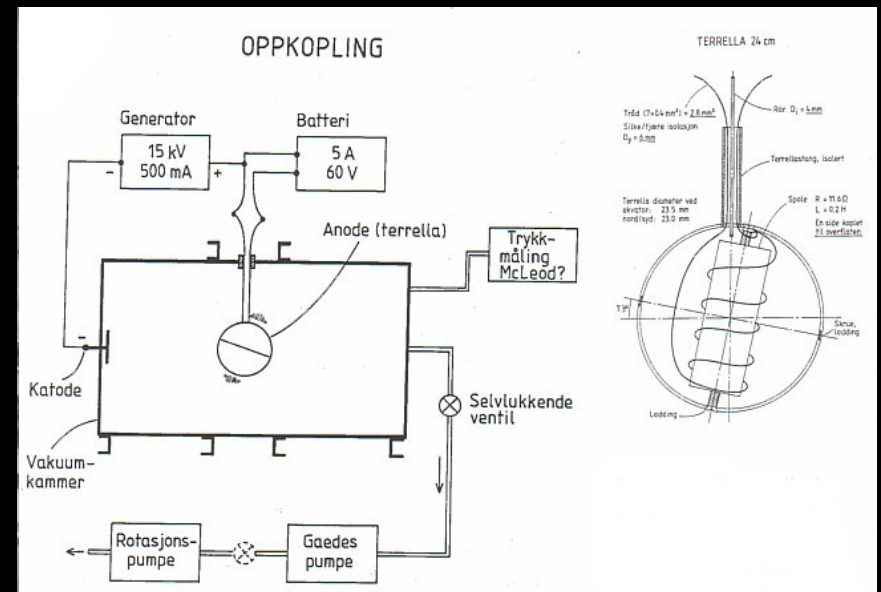


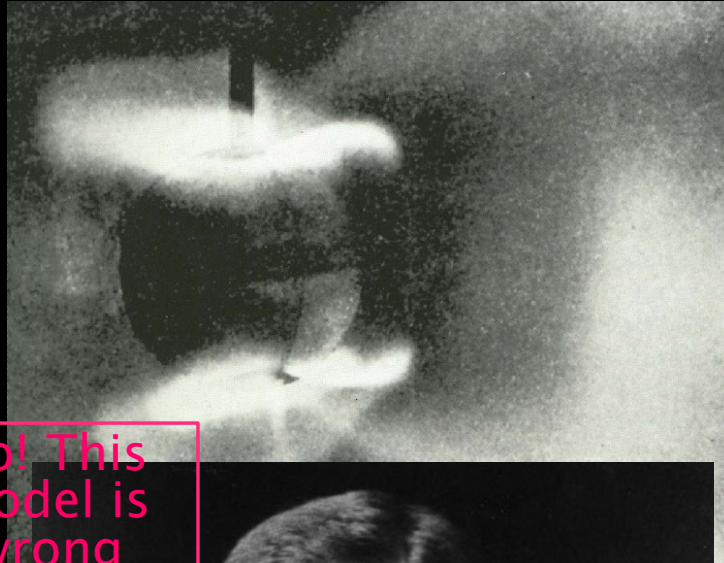


- ❖ Birkeland was well aware of Maxwell's theories
- ❖ Measured deviation in Earth's magnetic field must come from currents
- ❖ The Örsted experiment shows this rather well

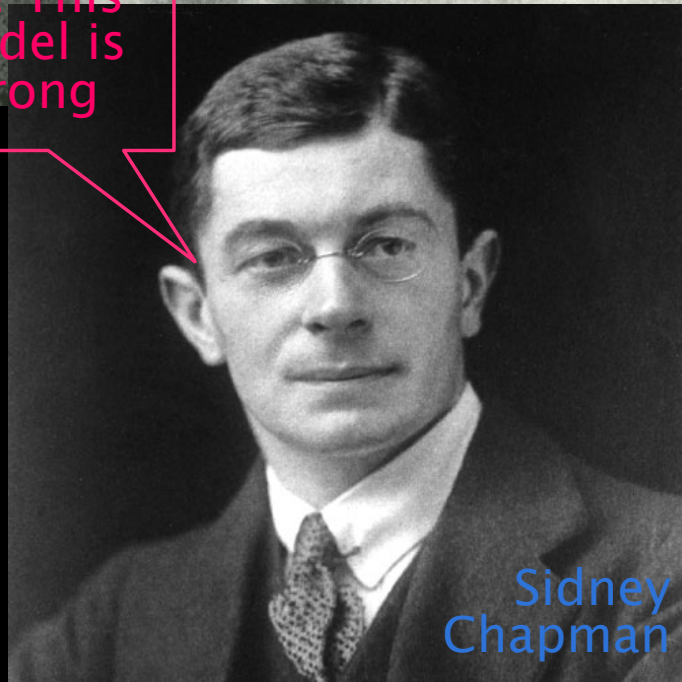
❖ A magnetized ball acting as an anode to which electrons from a cathode were released

❖ He build a “Terrella” (small Earth)





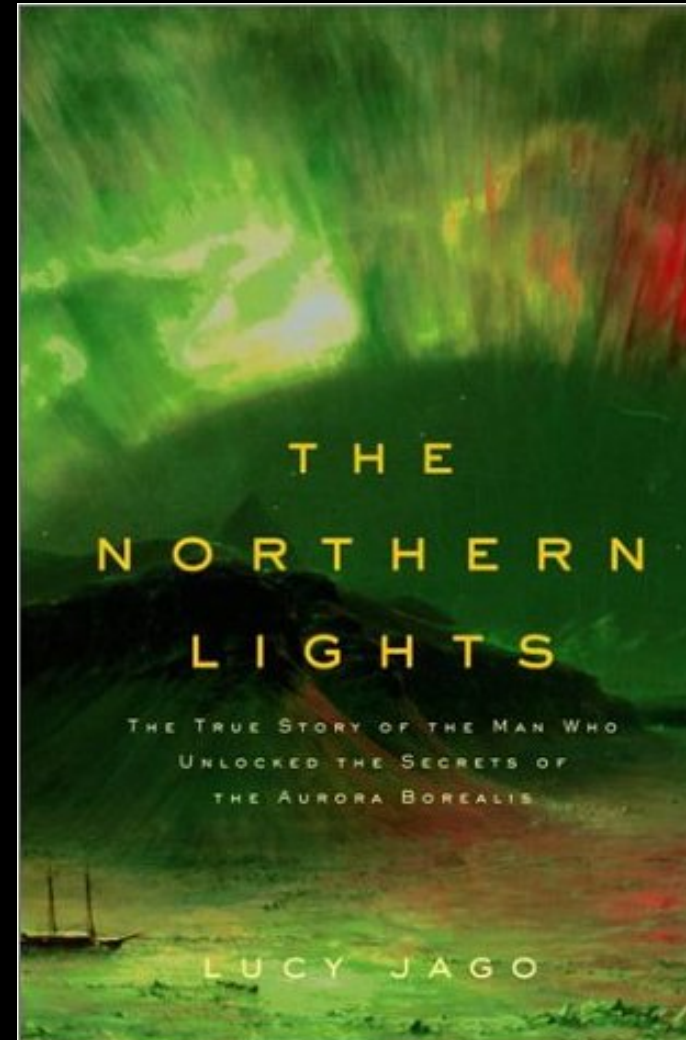
No! This model is wrong



Sidney Chapman

- ❖ Radiating rings around the magnetic poles appeared
- ❖ Indicating the “electric nature” of the Aurora
- ❖ From a physical point of view it is most probable that solar rays are neither exclusively negative nor positive rays, but of both kinds“
In other words, the Solar Wind consists of both negative electrons and positive ions.

- ❖ To read the whole story of Kristian Birkeland:
 - ❖ The Northern Lights
 - ❖ Lucy Jago
- How one man sacrificed love, happiness and sanity to unlock the secrets of space



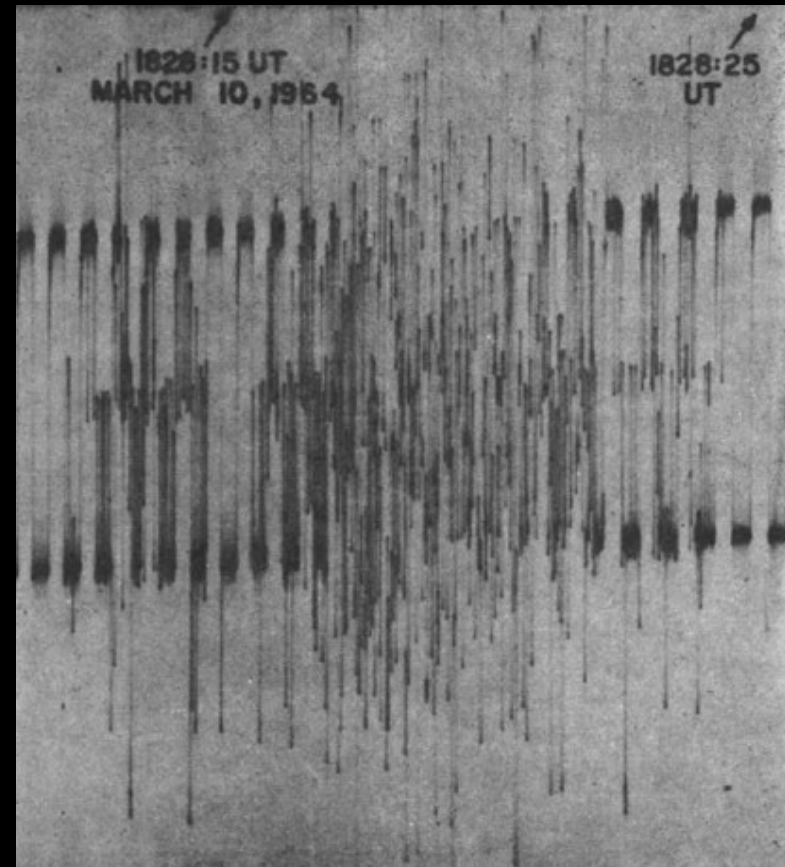
Aurora and the Earth's magnetotail

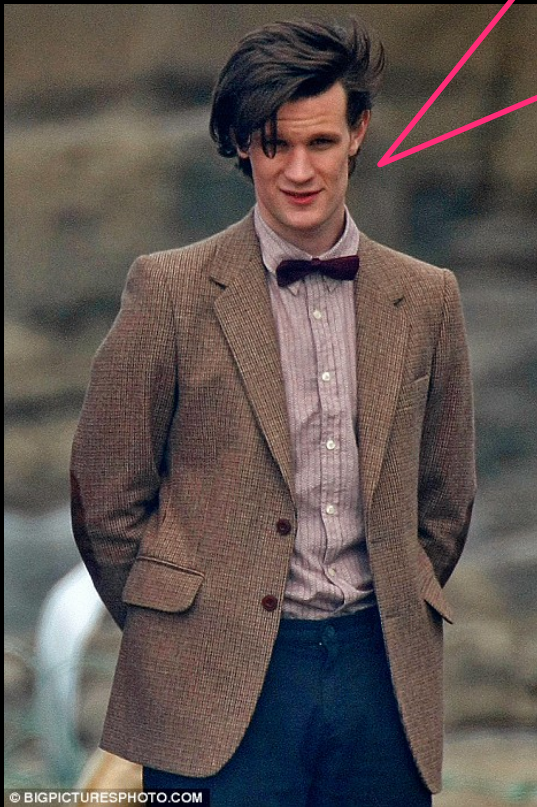


Okay! Time to move to 1966!



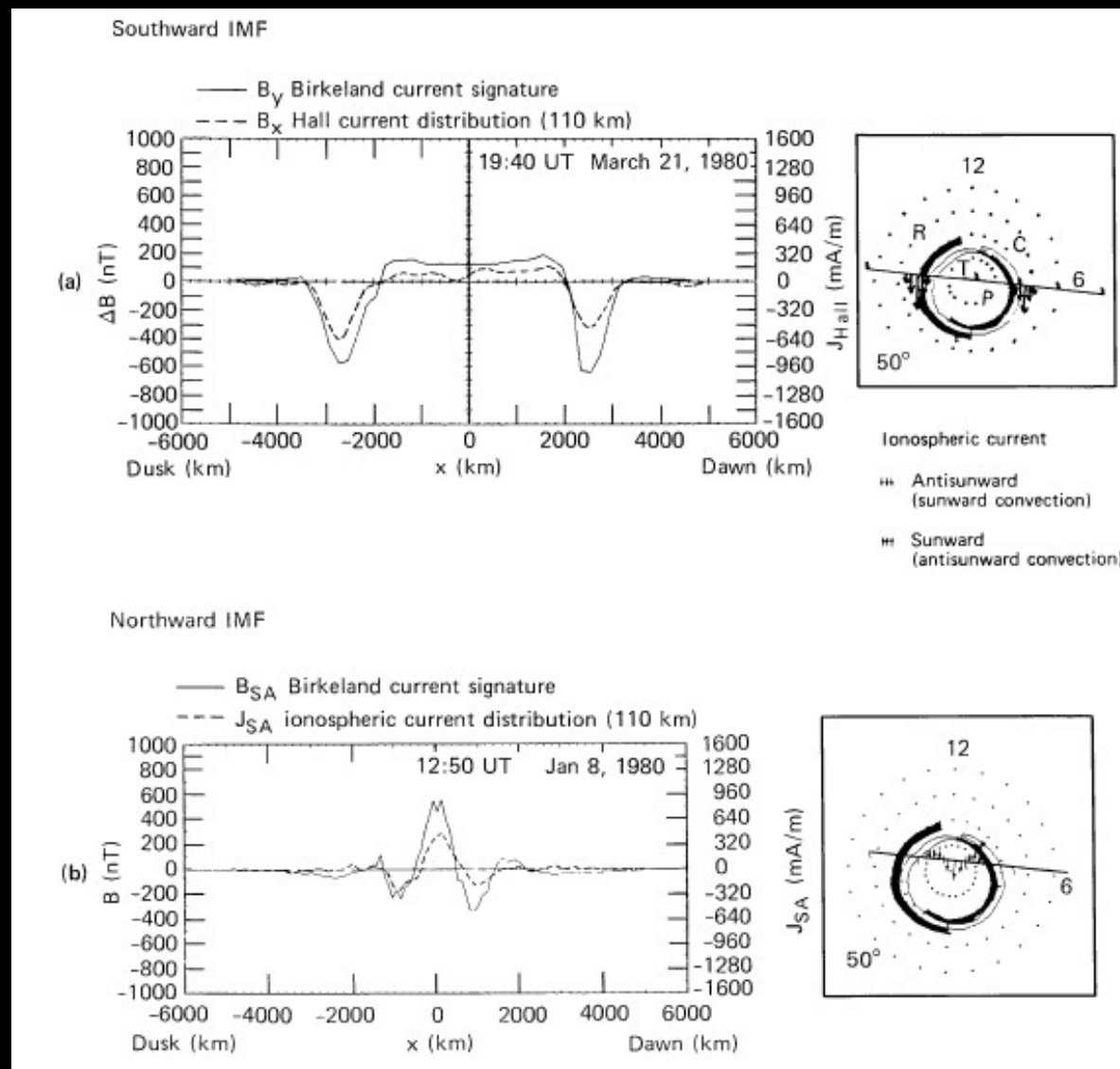
- ❖ 1963:
 - ❖ Launch of low altitude satellite 1963-38C
 - ❖ Equipped with magnetometers
 - ❖ When crossing the auroral region transverse magnetic field fluctuations were observed
 - ❖ No mention of Birkeland or field-aligned currents





GERONIMO



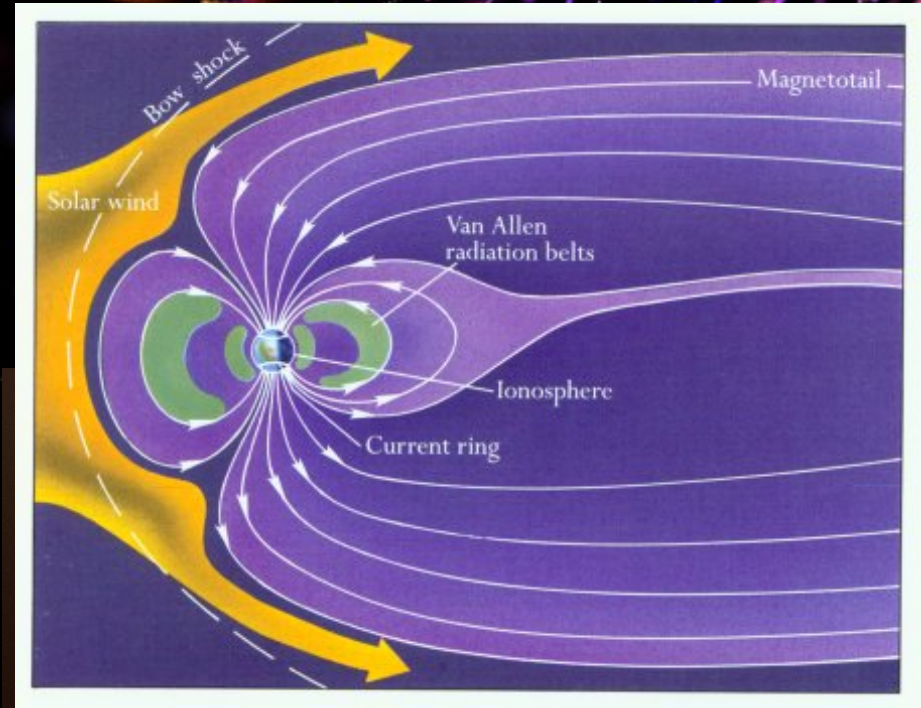


How does the Solar Wind Interact?

Solar wind is hot ionized gas (plasma) streaming from the Sun

Embedded with a magnetic field

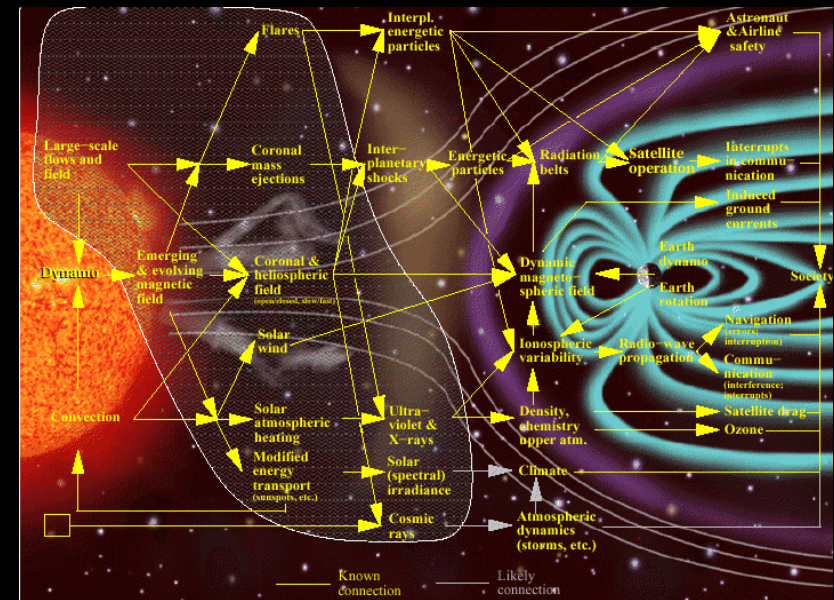
Interacts with the Earth's magnetic field



So What Happens?

Aurora and the Earth's magnetotail

- ❖ The aurora is related to the sun somehow
- ❖ The aurora is “electrical in nature” causing:
 - ❖ Light of three colours
 - ❖ Magnetic disturbances
- ❖ What is doing all that????
- ❖ Here is the solution



Too Difficult?
Let's look at this
movie.

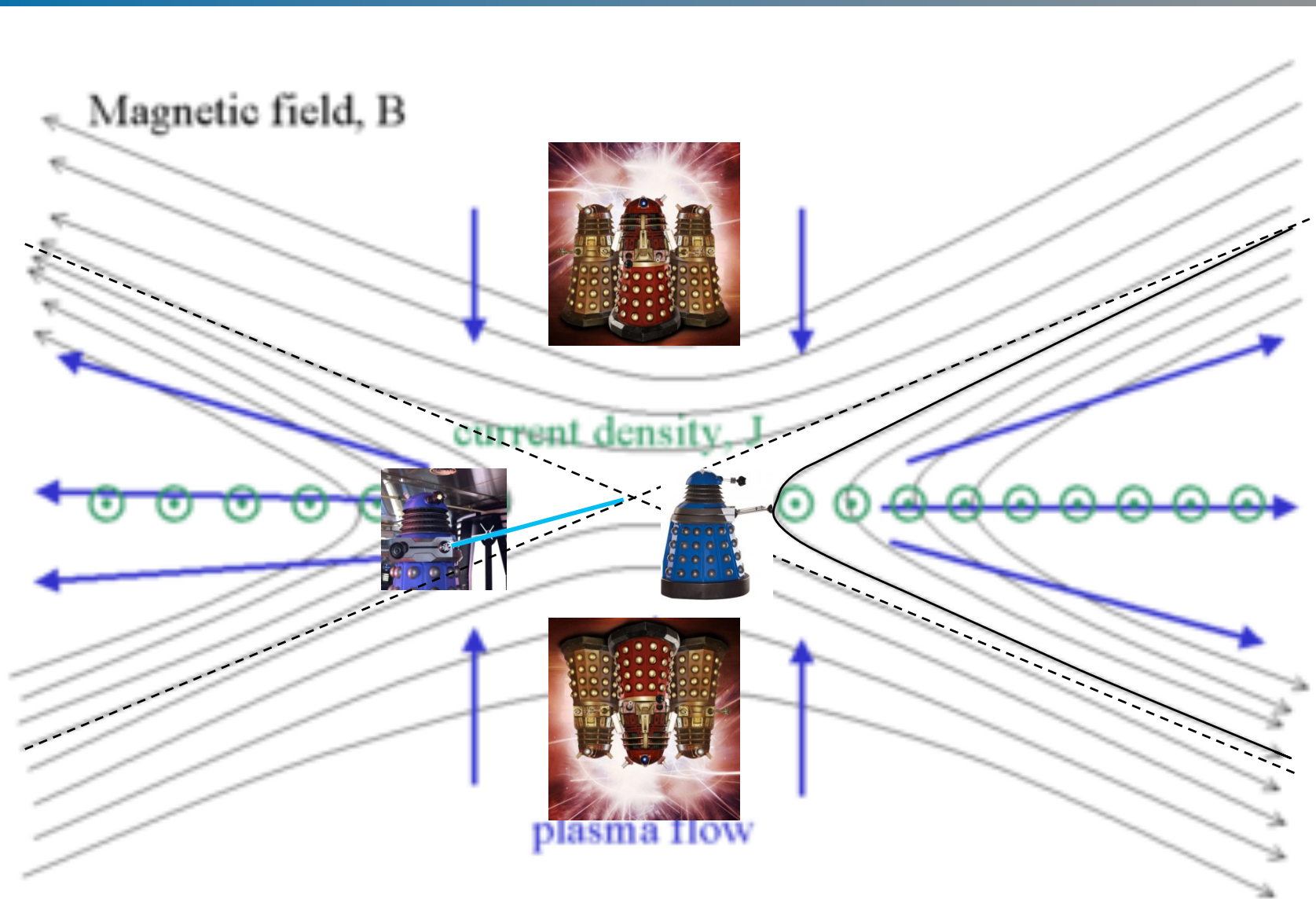


Kaboom!

Aurora and the Earth's magnetotail

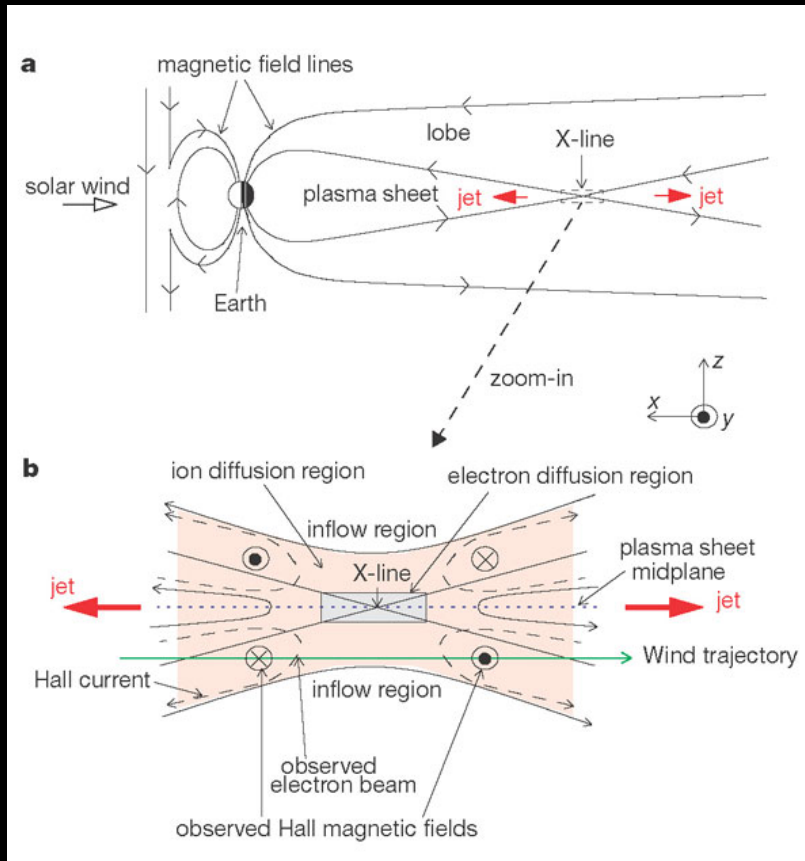


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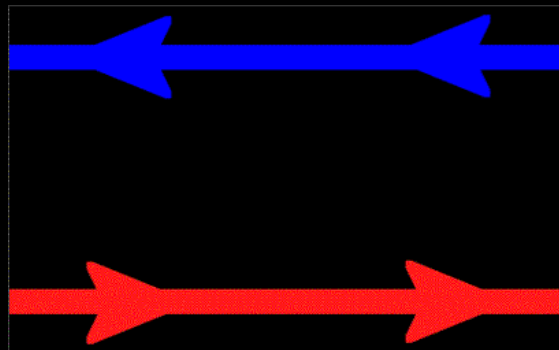


Magnetic Reconnection in the Tail

Aurora and the Earth's magnetotail

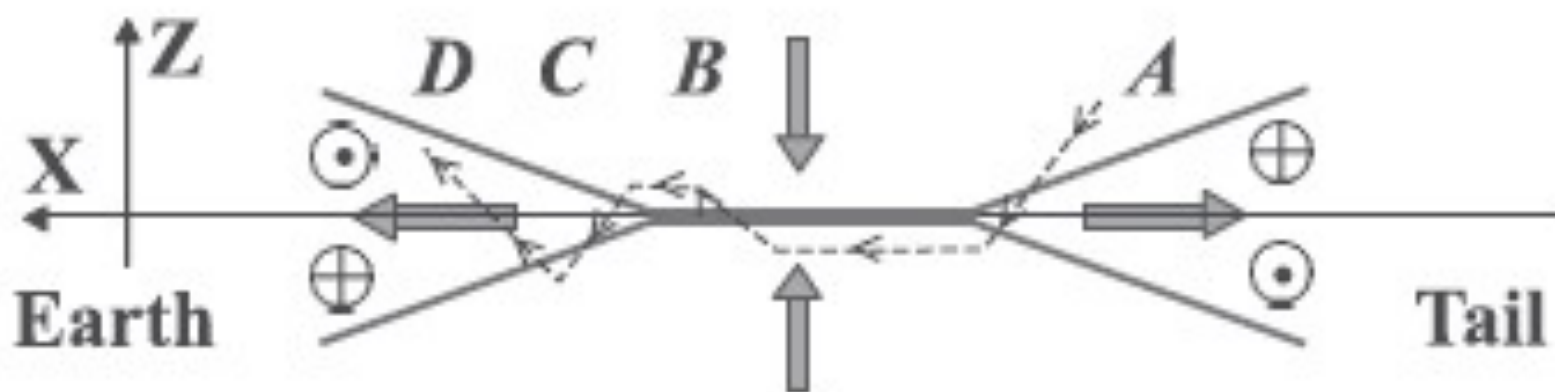
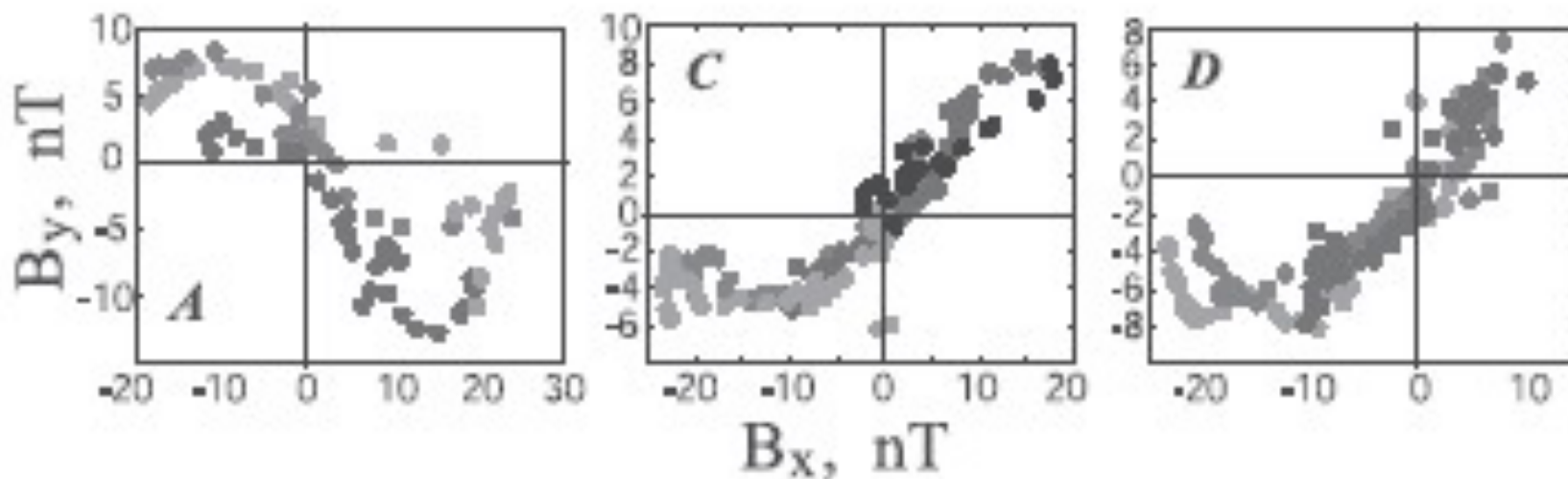


- ❖ Like a gummy band the magnetic field stretches
- ❖ Storing energy
- ❖ This gets released explosively
- ❖ Accelerating particles and setting up electric currents

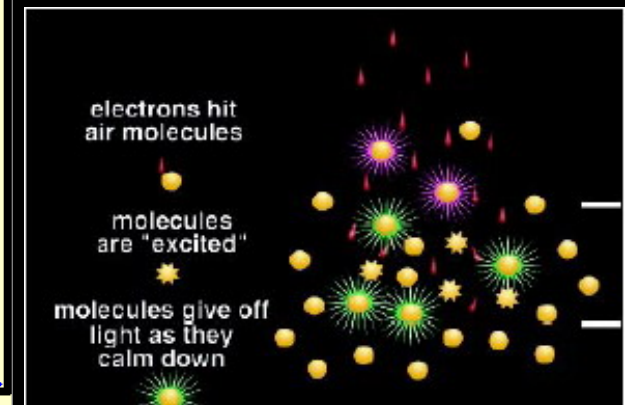
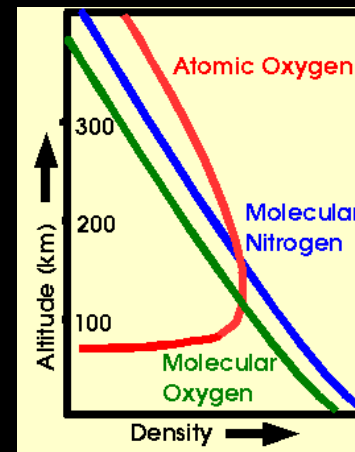
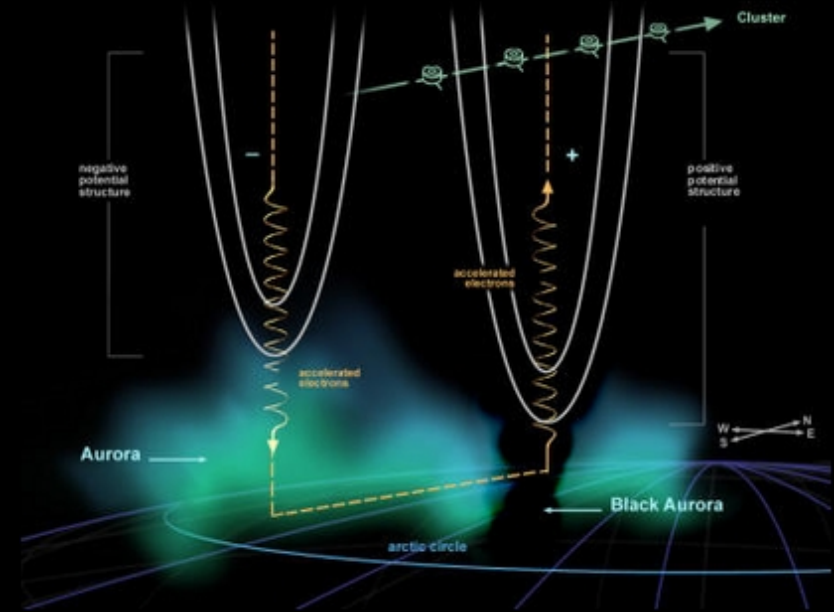


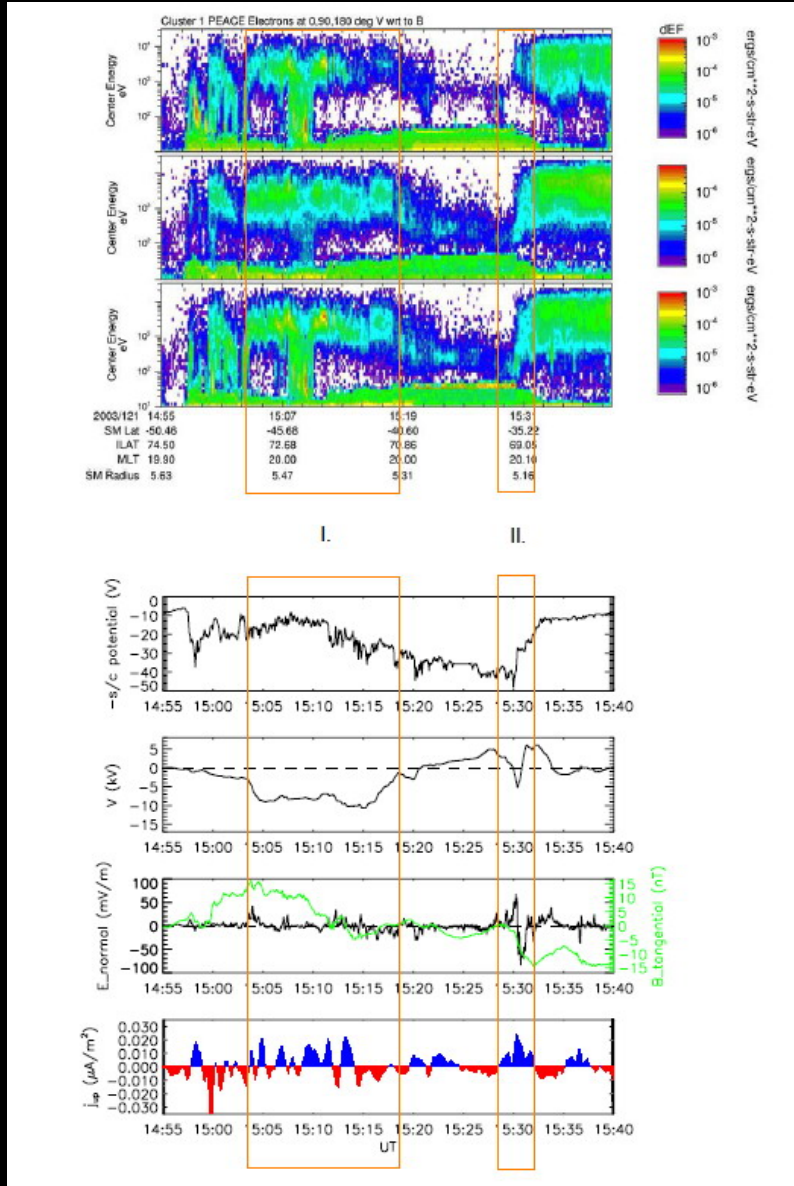


- ❖ A set of 4 equal spacecraft
- ❖ In polar orbit around Earth
- ❖ Tetrahedron configuration in interesting regions
- ❖ Measurements of particles and fields
- ❖ Gradients!



- ❖ Dynamics of magnetic field generates electric fields (dynamo)
- ❖ Concentrated over the Earth's poles
- ❖ Acceleration of electrons downward
- ❖ Generation of curtains of light, with colour depending on what is hit





- ❖ Cluster spacecraft flying over the auroral region
- ❖ Measurements of:
 - ❖ Energetic Electrons
 - ❖ Spacecraft Potential
 - ❖ Electric Field
 - ❖ Magnetic Field
- ❖ Derivation of:
 - ❖ Electric Currents
- ❖ They are filamented

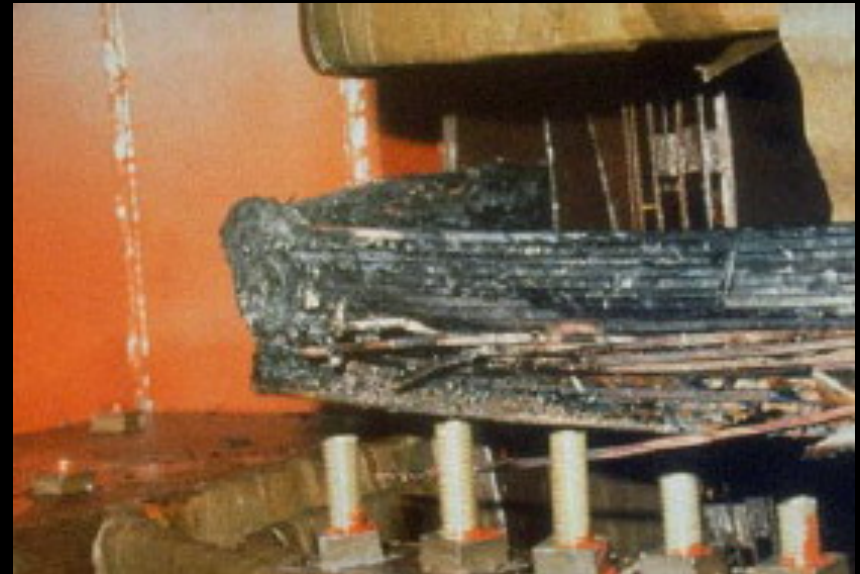


Every curtain has its own current system.

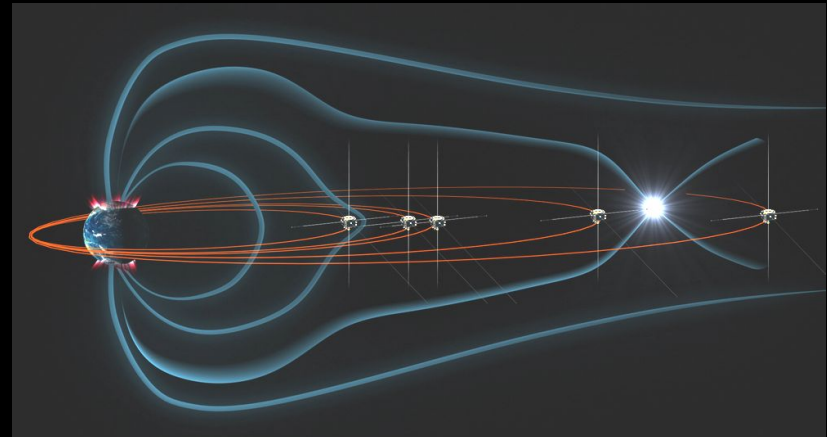
- ❖ The Aurora is created by electrodynamics
- ❖ Strong changes in magnetic field

$$\frac{\partial \mathbf{B}}{\partial t} \propto -\nabla \times \mathbf{E}$$

- ❖ $\mathbf{J} = \sigma \mathbf{E}$ currents can be induced creating great damage




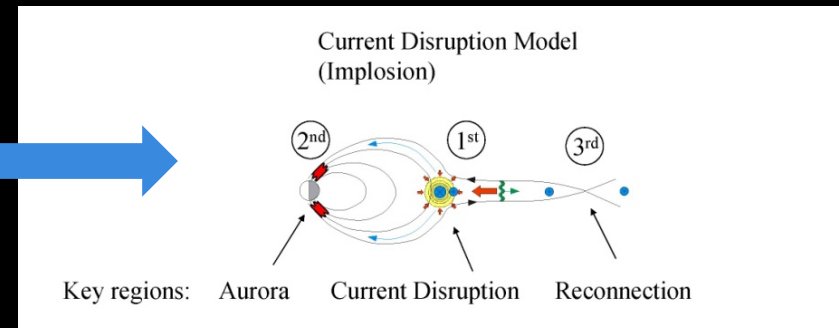
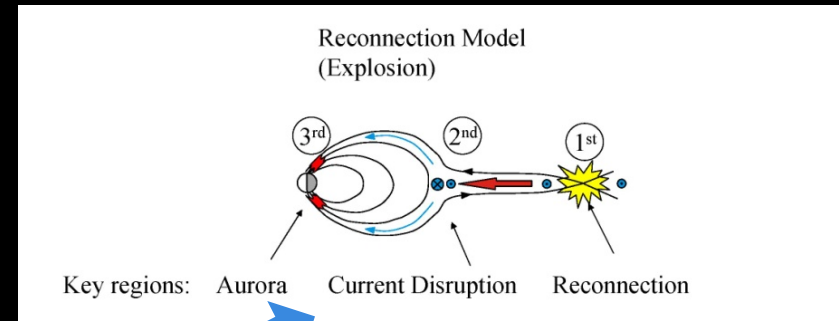
- ❖ Time History of Events and Macroscale Interactions during Substorms
- ❖ Measuring the processes in the tail along a string of satellites
- ❖ Now we can find out what happens in which order (maybe)



What comes first?

Aurora and the Earth's magnetotail

- ❖ Two models:
 - ❖ Reconnection
 - ❖ Current disruption
- ❖ Where should be:
 - ❖ Down the tail? 
 - ❖ In the middle?
- ❖ THEMIS may tell



- ❖ Change in magnetic field in P1 and P2 opposite in B_z
- ❖ 1.5 minutes later Aurora shows up
- ❖ Then something happens in the middle at P3
- ❖ Attentive listeners will have noticed this is neither model

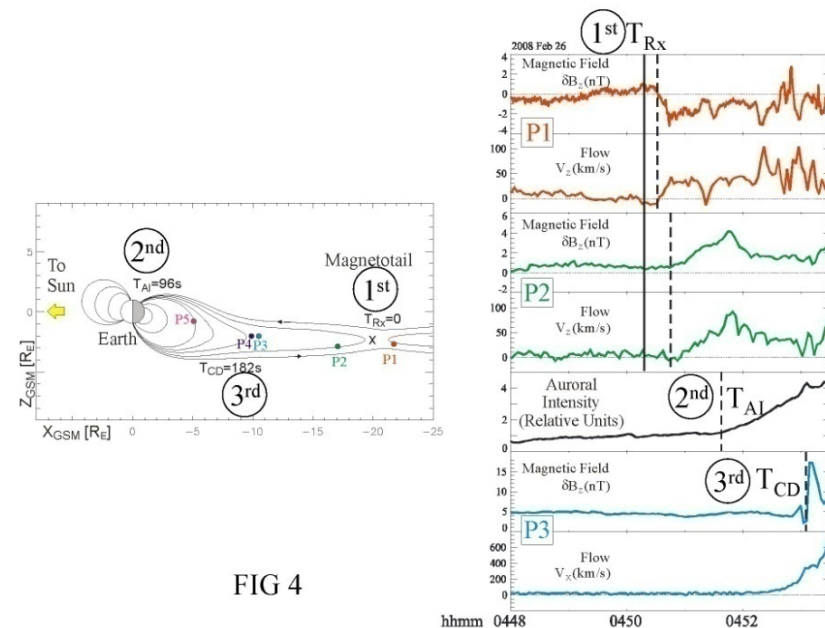
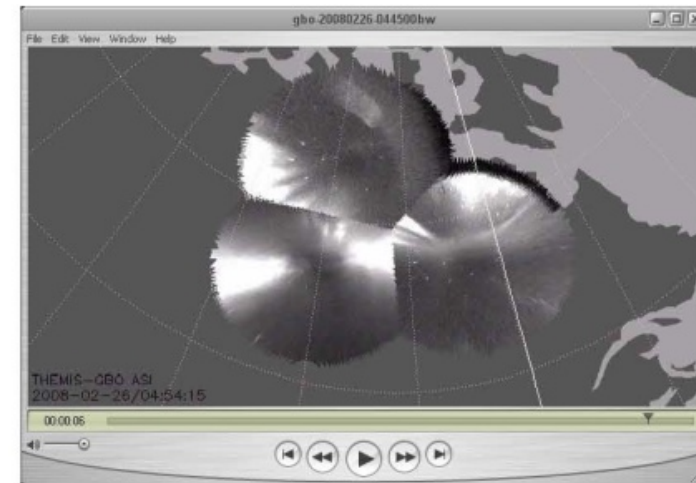
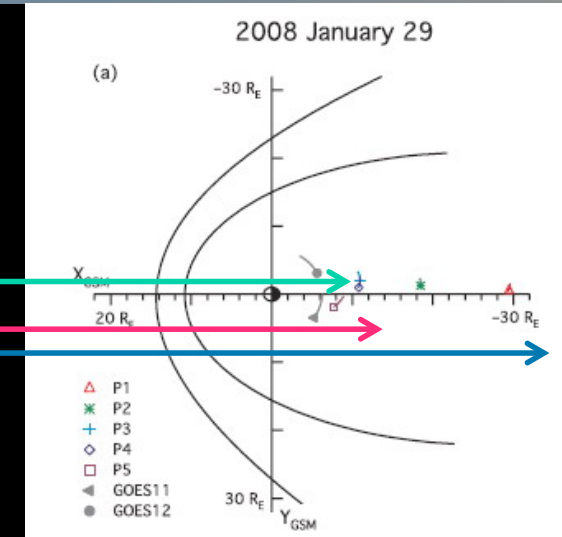
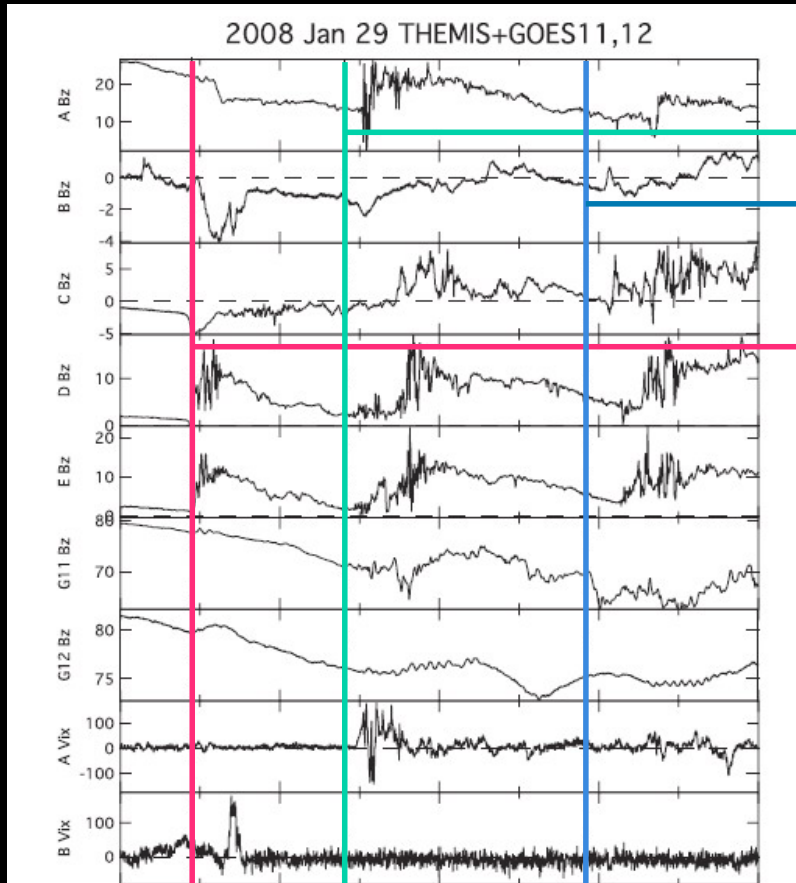


FIG 4



- ❖ ThD and C ($X -11$ to $-18 R_E$) for the first auroral activation
- ❖ ThA and D ($X -8$ to $-11 R_E$) for the second auroral activation
- ❖ tailward of ThB (at $X -30 R_E$) for the third auroral activation

So, no clear picture arises as to what model is correct

❖ Inside-out or Outside-in?????

Aurora and the Earth's magnetotail

