



# The Historical Development of Solar-Terrestrial Relations

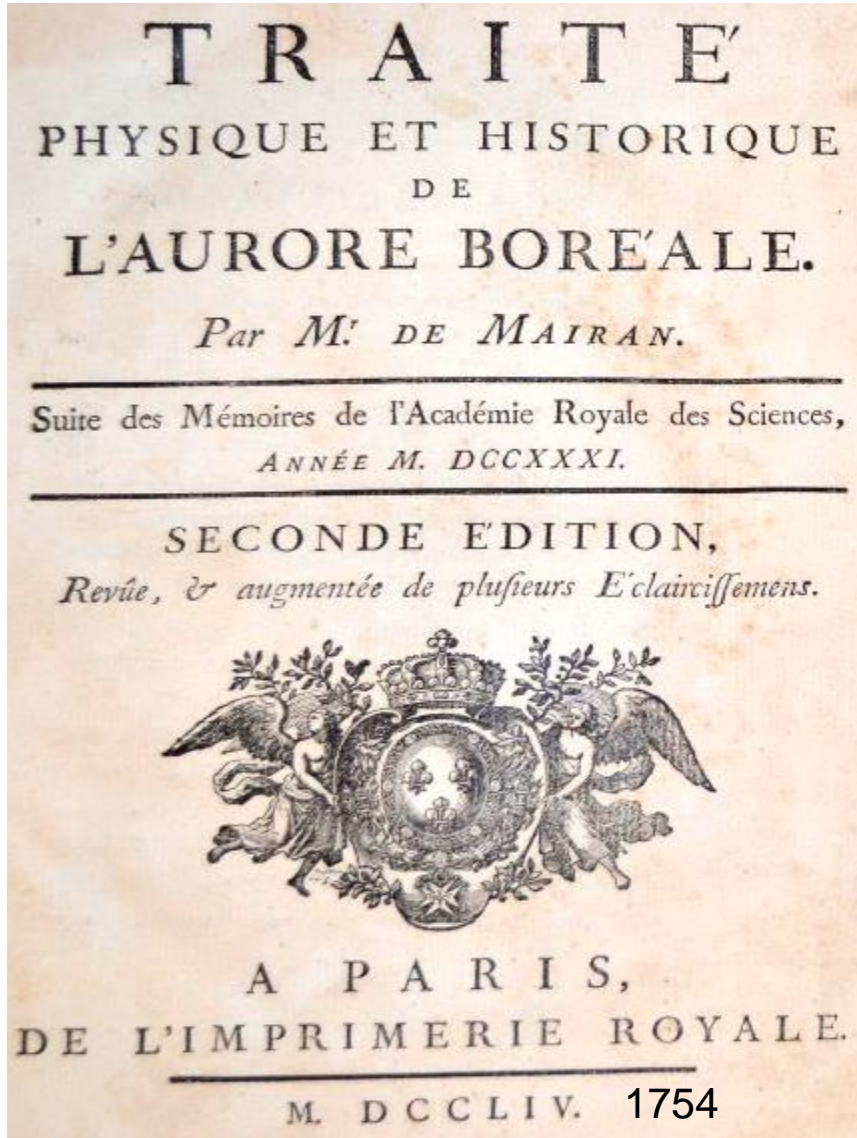
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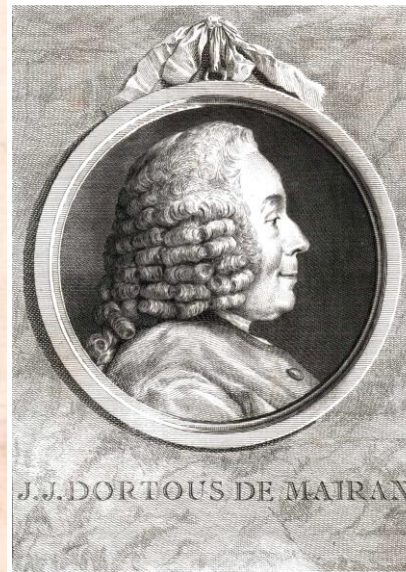
IAGA-2017, Cape Town, ZA

A42-1220 (Invited), Aug. 31, 2017

# The Science of Solar-Terrestrial Relations Began With Mairan's 1733 Book on the Aurora



The extraordinary Auroral Display observed in much of Europe [but not in cloudy Paris] on 6 March 1716 was considered by E. Halley to be a purely Terrestrial phenomenon of “Magnetic Vapors” rising from the polar regions into the sky.



1678-1771

Following a similar strong display in 1726 that caused great panic in France, the French Government charged J.-J. Dortous de Mairan to provide a scientific explanation for the display just like the Royal Soc. had asked Halley to give ten years earlier.

# Mairan's Speculation About a Solar-Terrestrial Relationship

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Supposé que la matière de l'Atmosphère Solaire ne soit ni lumineuse ni enflammée par elle-même & dans sa source, ne peut-il point arriver, 1.<sup>o</sup> Qu'elle devienne l'un & l'autre, en tout ou en partie, & plus ou moins vite, en tombant dans les couches les plus élevées de l'Atmosphère Terrestre, de la même manière que certains Phosphores s'allument étant exposés à l'air, ou mêlés avec certaines liqueurs?

*Sur les modifications que la matière de l'Atmosphère Solaire peut recevoir, en se mêlant avec l'Atmosphère Terrestre.*

*Sur les Taches du Soleil.*

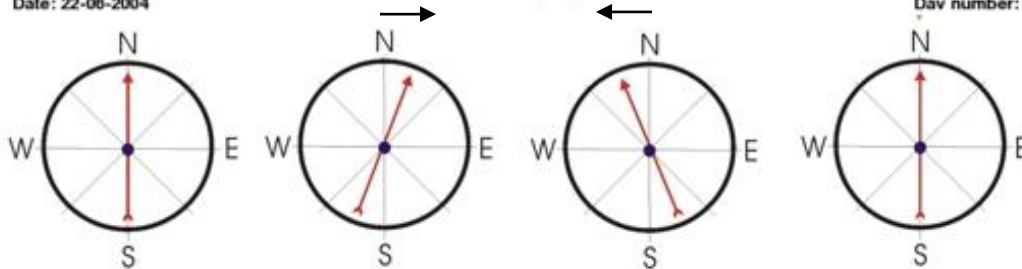
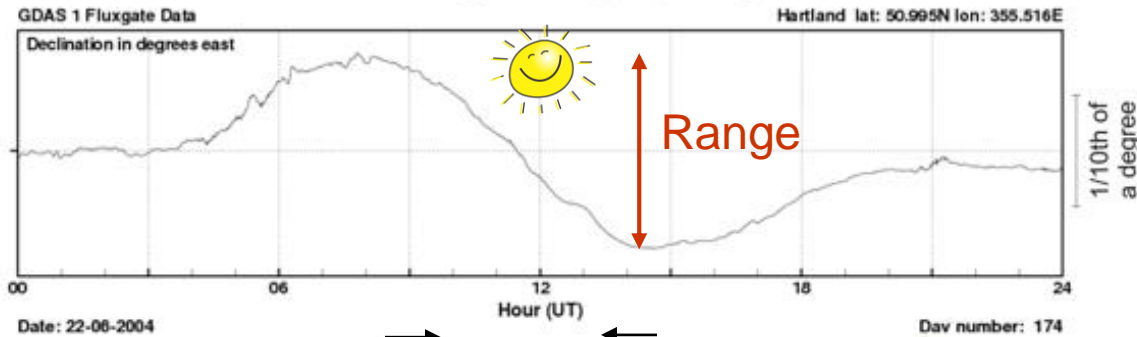
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Ne seroit-ce point à quelque semblable précipitation de parties de l'Atmosphère du Soleil, que seroient dûes les Taches qu'on voit si souvent sur la surface de son Globe? Et ne pourroit-on point découvrir quelque analogie entre la fréquence, les cessations & les retours de ces Taches, & les apparitions, les retours & les cessations de la Lumière Zodiacale?

Mairan speculated that the Aurora is due to the interaction of a material solar atmosphere [extending out past the orbit of the Earth] and visible during total eclipses and at other times as the Zodiacal Light. He raised the question whether the variation of the number of sunspots were also related to variations of the solar atmosphere.

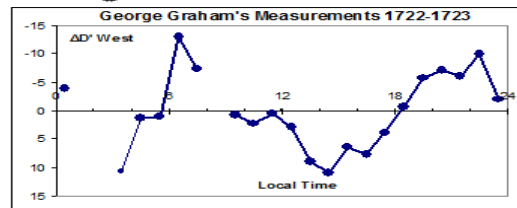
# The Diurnal Variation of the Direction of the Magnetic Needle

National Geomagnetic Service, BGS, Edinburgh



IV. *An Account of Observations made of the Variation of the Horizontal Needle at London, in the latter Part of the Year 1722, and beginning of 1723. By Mr. George Graham, Watchmaker, F. R. S.*

Made ~1000 observations

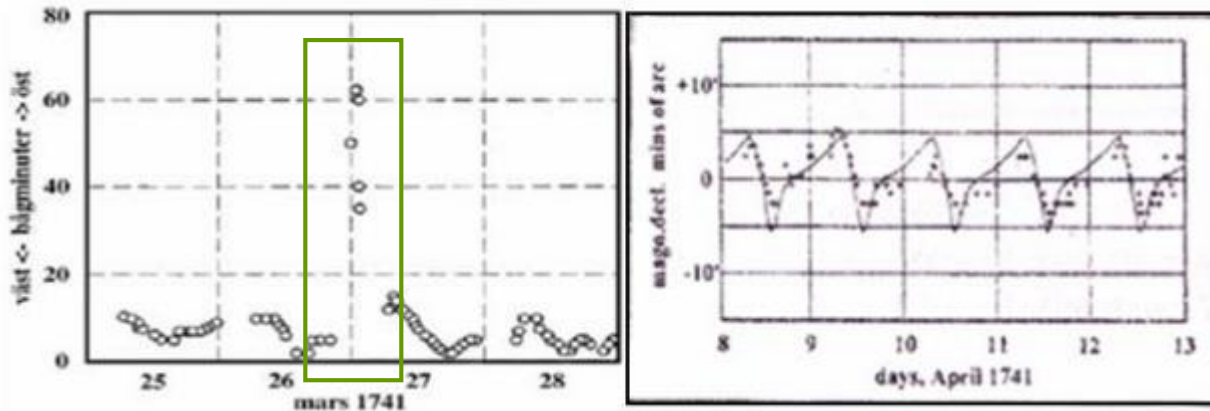


George Graham [London] discovered [1722] that the geomagnetic field varied during the day in a regular manner.



# Observations in the 1740s

**Olof Petrus Hjorter** was married to Anders Celsius' sister and made more than 10,000 observations of the magnetic declination in the 1740s.

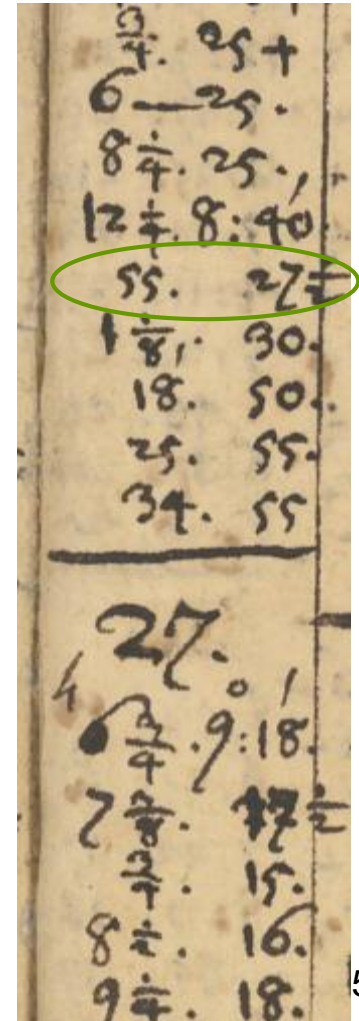


Right: Hjorter's measurements of the magnetic declination at Uppsala during April 8-12, 1741 (old style). The curve shows the average variation of the magnetic declination during April 1997 at nearby Lovö (Sweden).

Left: Variation during strong Northern Light on March 27<sup>th</sup>. Also observed by Graham in London, showing that the aurorae and magnetic field are connected on a large scale and not just local meteorological phenomena.

Note there are really **two** phenomena going on, regular daily variation and sporadic, large aurora-related excursion...

This is from Hjorter's original notebook for that day. Observations were made with an instrument constructed by Graham.



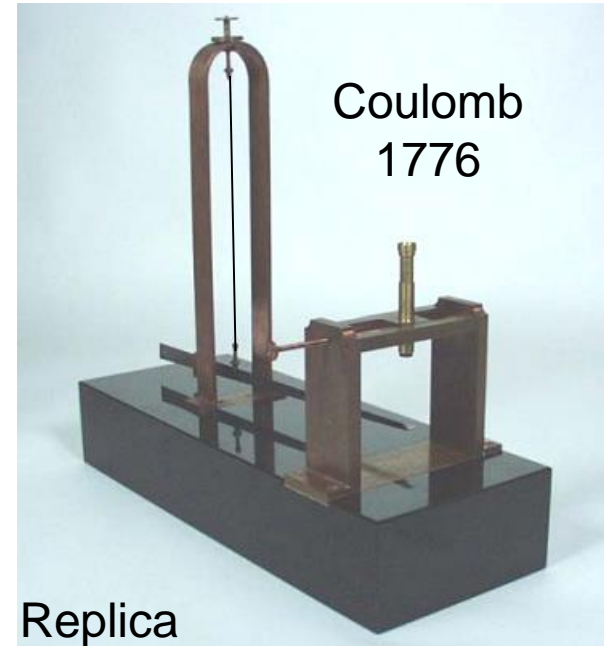
# Even Rather Simple Instruments Could Readily Show the Variation



John Canton  
[1759] made  
more than 4000  
observations of  
the Declination  
on 603 days in  
London

and noted that 574 of these days showed a 'regular' variation, while the remainder (on which aurorae were 'always' seen) had an 'irregular' diurnal variation.

**“Regular Irregularity and  
Irregular Regularity”**



Canton's theory was that Temperature was controlling the magnet, and he thought that the daily and [predicted] seasonal variations were proof of that. Correct application of The Scientific Method, but nevertheless wrong.

# There Must be More than One Cause

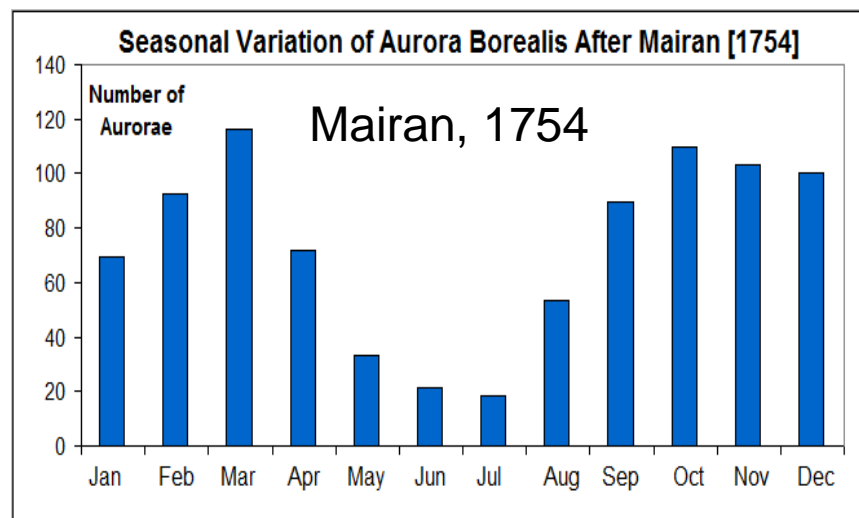
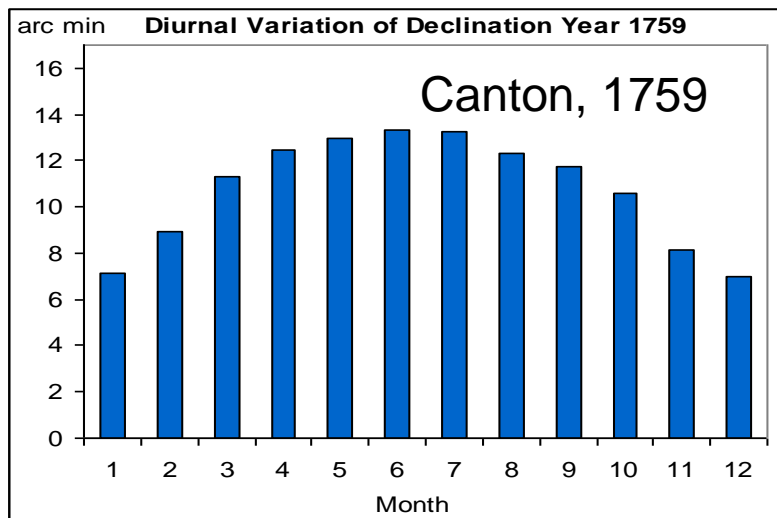
Canton concluded that “*The irregular diurnal variation must arise from some other cause than that of heat communicated by the sun*”.

This was also evident from the association of days of irregular variation with the presence of aurorae.

The different seasonal variations are important clues to the physical processes at work:

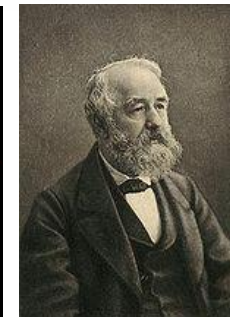
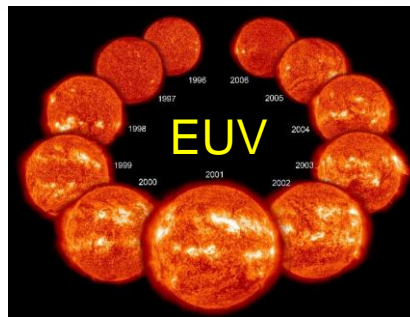
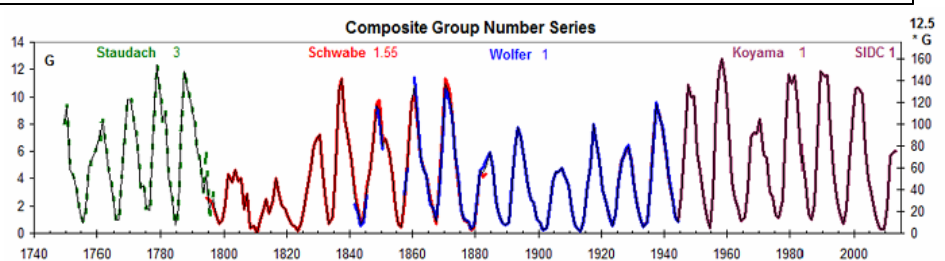
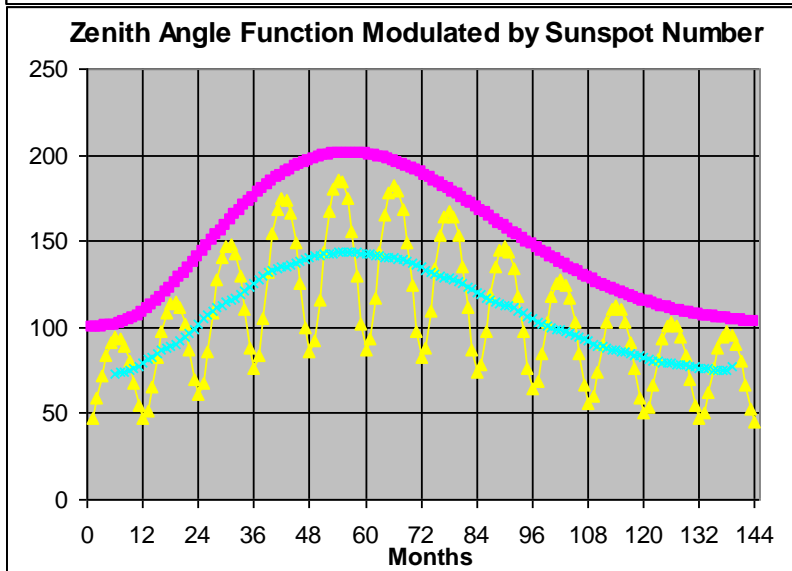
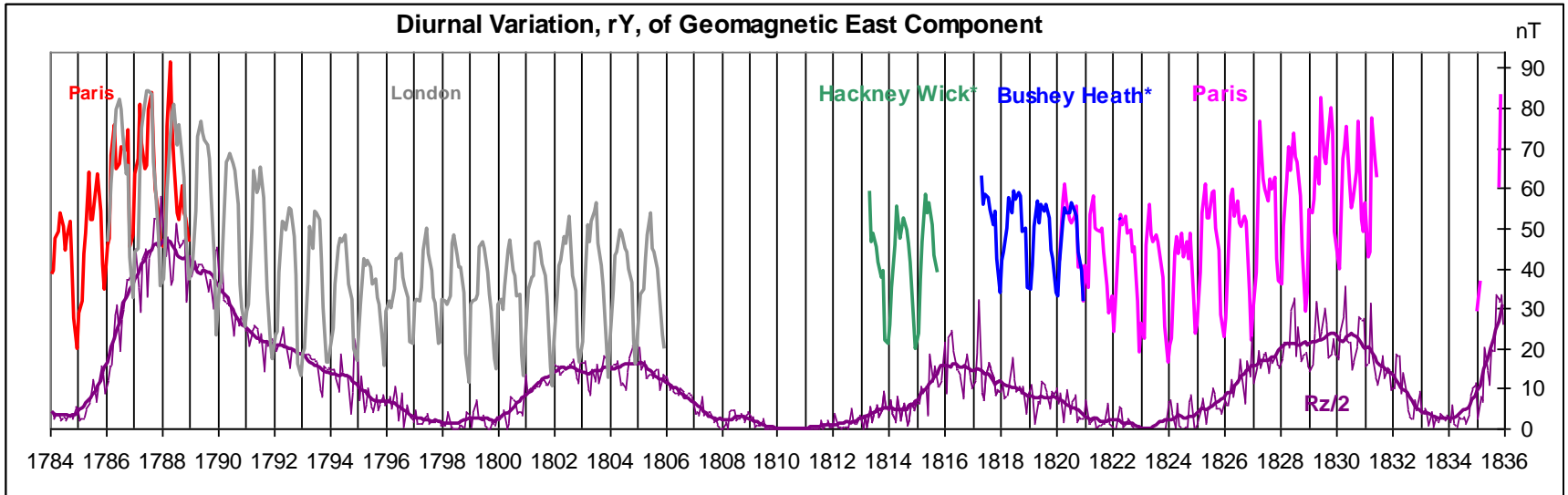
Solar ‘Rays’ dependence on Zenith Angle

Solar ‘Matter’ Semiannual variation



But a century would now pass before further progress could be made ...

# Solar Cycle and Zenith Angle Control of the Solar 'Rays'



**Rudolf Wolf**

1852: “who would have thought that one could compute a terrestrial effect from observations of sunspots” 8



# We all Know about Marconi's Long-Distance Radio Transmissions



## Guglielmo Marconi sends message from England to Newfoundland

Dec 12. The Italian physicist Guglielmo Marconi, who sent wireless telegraphic messages across the English Channel from Dover, England, to Boulogne, France, on March 29, 1899, repeated his experiment today over the Atlantic Ocean, a distance of 2,232 miles.

In order to carry out this experiment, Marconi set up a 164-foot-



*Guglielmo Marconi and his first wireless.*

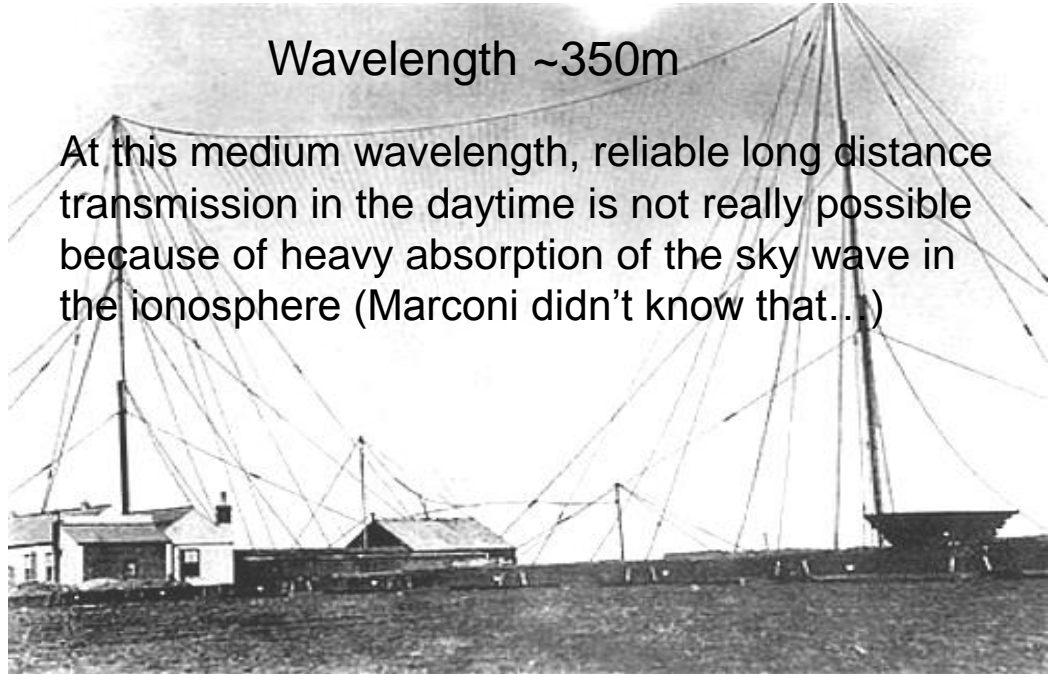
high antenna in Poldhu, Cornwall, England. Then, he erected a receiver in St. John's, Newfoundland, Canada. In spite of the earth's curvature, he received a Morse signal corresponding to the letter "S" from the Poldhu station across the ocean.

When Marconi realized the importance of his first discoveries in 1895, he asked the Italian Minister of Telecommunication to help him. But the minister found that Marconi's experiments were too extravagant. That's why Marconi went to England, where he won the support of Sir William Peace, the Postmaster General, who immediately understood the significance of the young Marconi's work. Thanks to Peace's perspicacity and the help of Professor Adolf Slaby, Marconi could hit his target today (→ 2/22/03).

Dec. 12, 1901

Wavelength ~350m

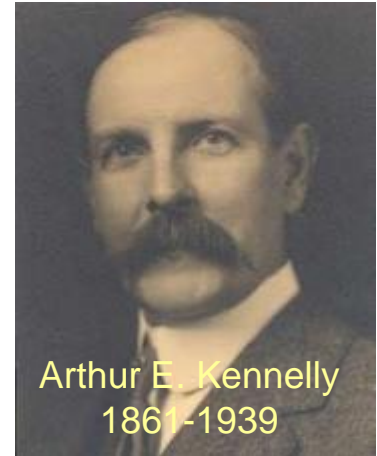
At this medium wavelength, reliable long distance transmission in the daytime is not really possible because of heavy absorption of the sky wave in the ionosphere (Marconi didn't know that...)



# Kennelly Suggested a Wave Guide

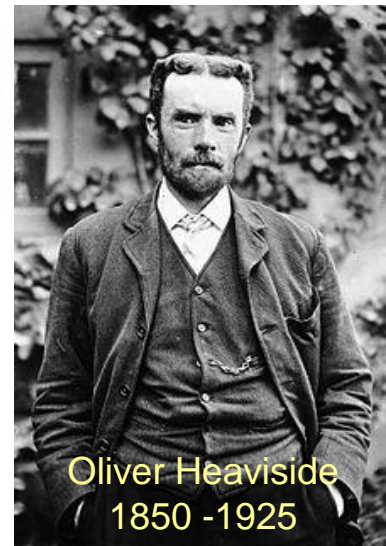
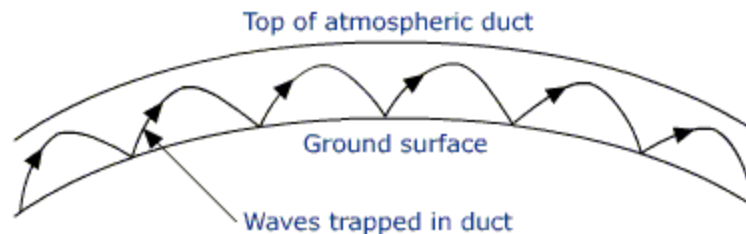
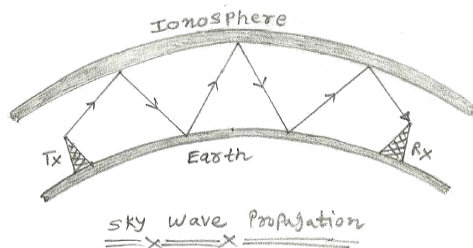
On the Elevation of the Electrically-Conducting Strata  
of the Earth's Atmosphere. 1902

and also upwards, until the conducting strata of the atmosphere are encountered, after which the waves will move horizontally outwards, in a 50-mile layer between the electrically-reflecting surface of the ocean beneath, and an electrically-reflecting surface, or successive series of surfaces, in the rarefied air above.

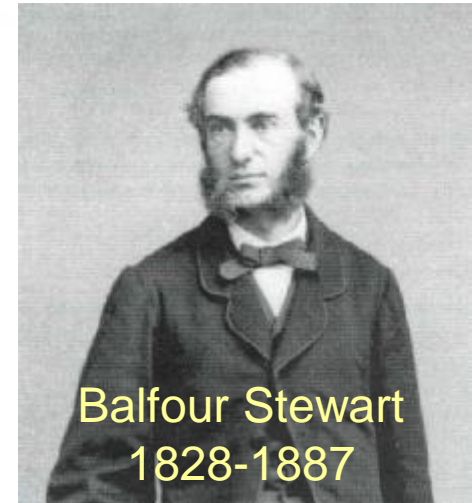
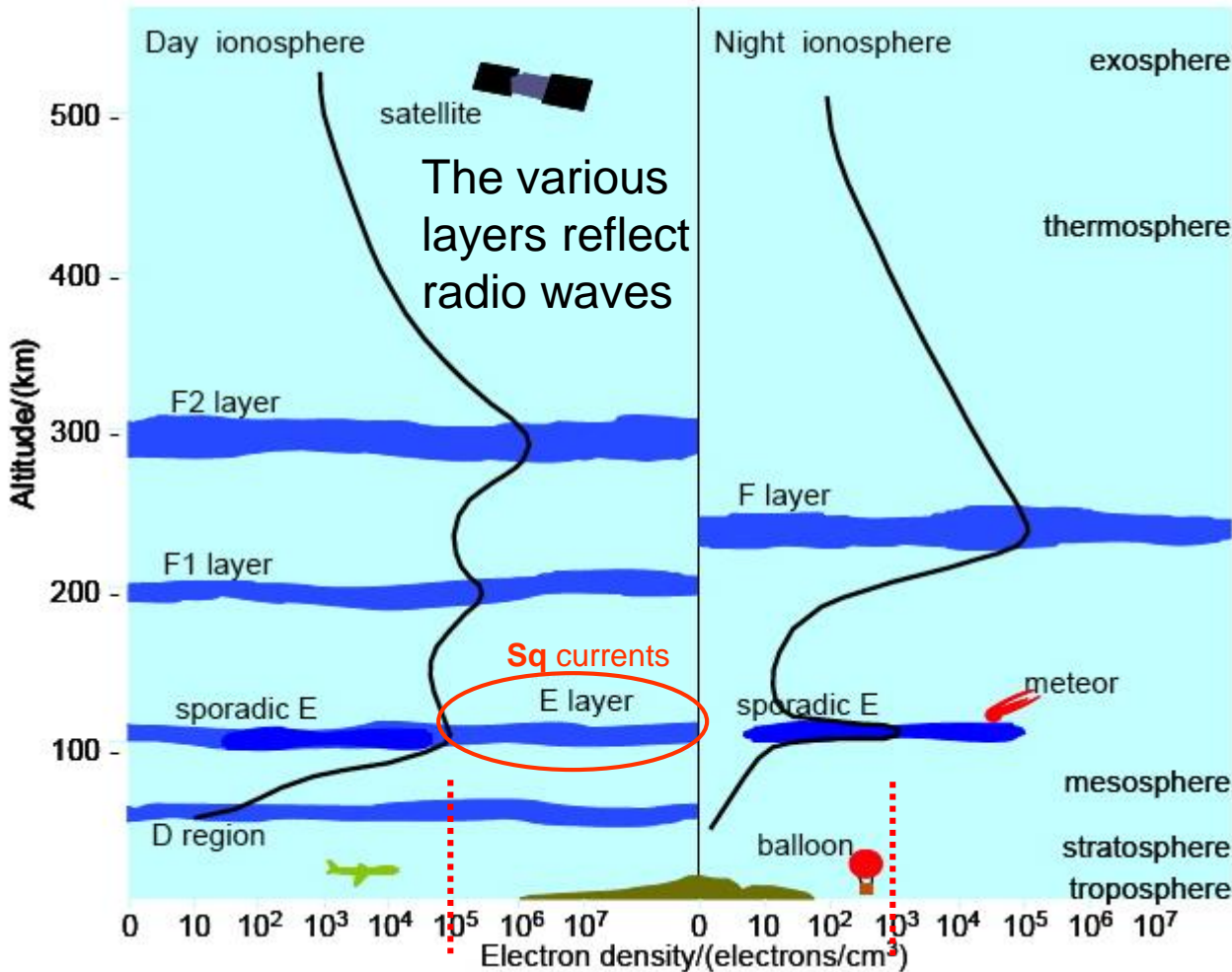


# Oliver Heaviside Got the Same Idea

And then comes the *most* famous part of the article. "There is another consideration. There may possibly be a sufficiently conducting layer in the upper air. If so, the waves will, so to speak, catch on to it more or less. Then the guidance will be by the sea on one side and the upper layer on the other." 10<sup>th</sup> ed. of Encyclopaedia Britannica



# Ionospheric Conducting Layers

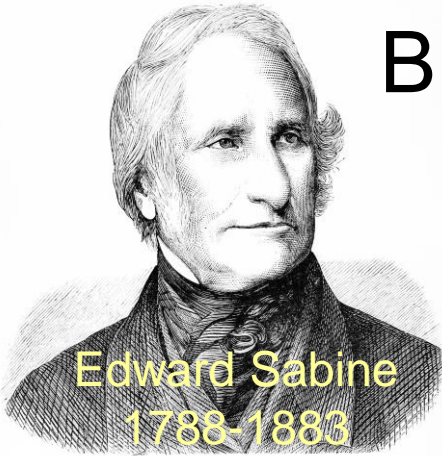


1882, Encyclopedia Britannica, 9th Ed.:

“there seems to be grounds for imagining that their **conductivity may be much greater than has hitherto been supposed.**”

Winds moving the charges across the magnetic field creates a dynamo current, whose magnetic effect we can observe at the surface as Graham discovered



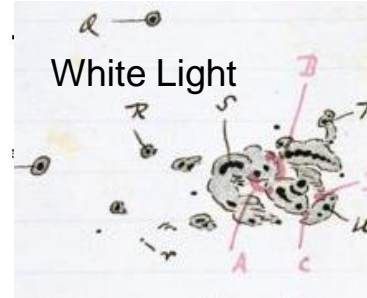


# But the Aurorae are Due to that “Other Cause” (The Solar Atmosphere)

As are also the great magnetic disturbances associated with them.

Sabine (1852) noted that magnetic perturbations superimposed on the daily variation also varied in phase with the newly discovered Sunspot Cycle.

## Solar Observations of Flares

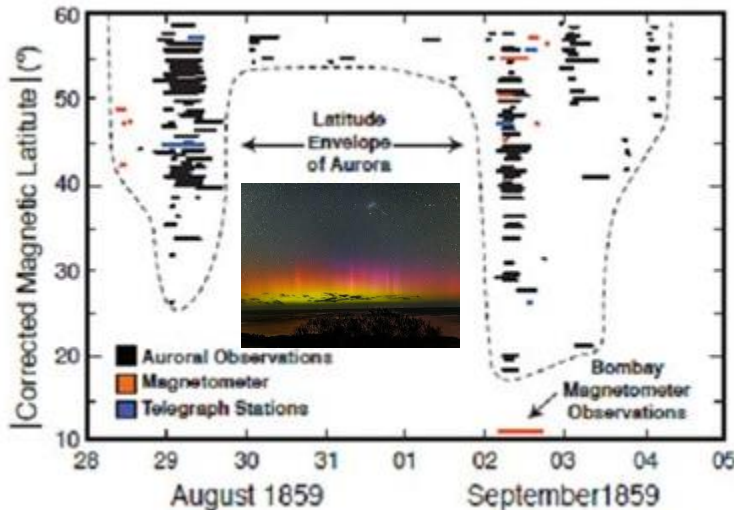


Carrington Event, Sept. 1859



Halloween Event, Oct. 2003

## Low Latitude Aurorae



Major flares were followed by strong geomagnetic storms, e.g. after the Carrington flare in 1859, generating strong aurorae

Solar Rays

September 2nd

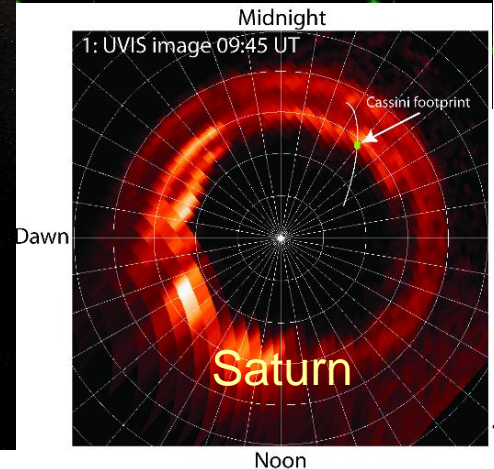
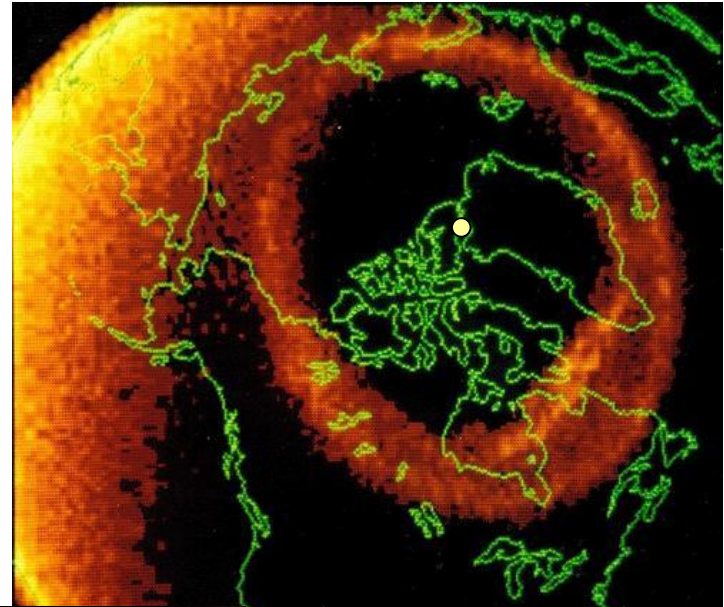
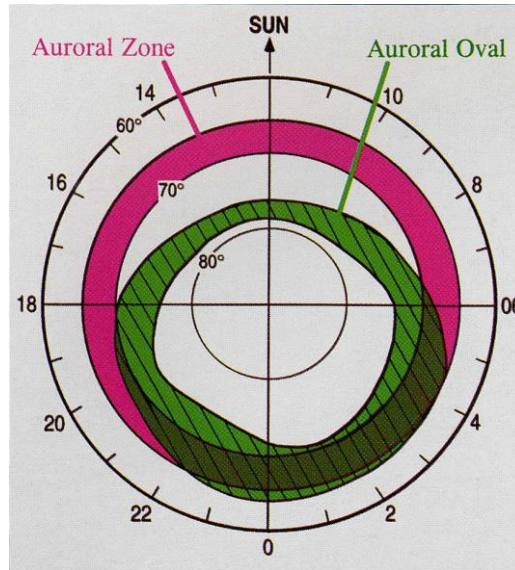
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# During the Very Successful IGY We Discovered the Auroral Oval



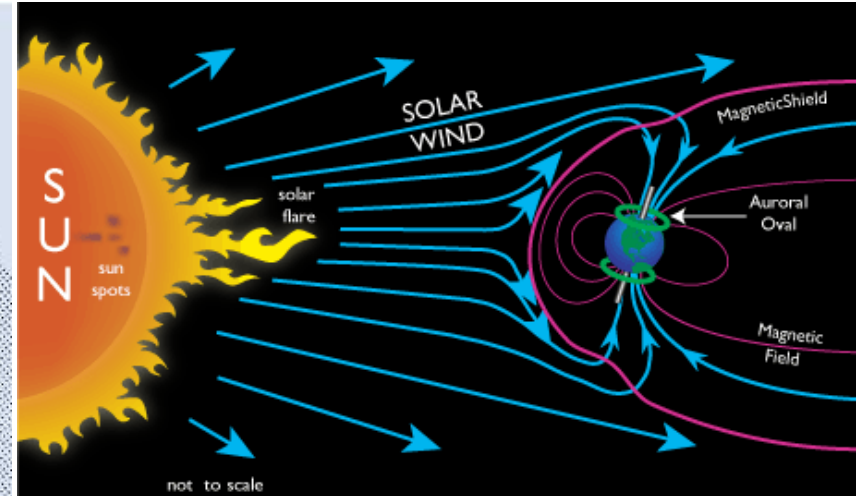
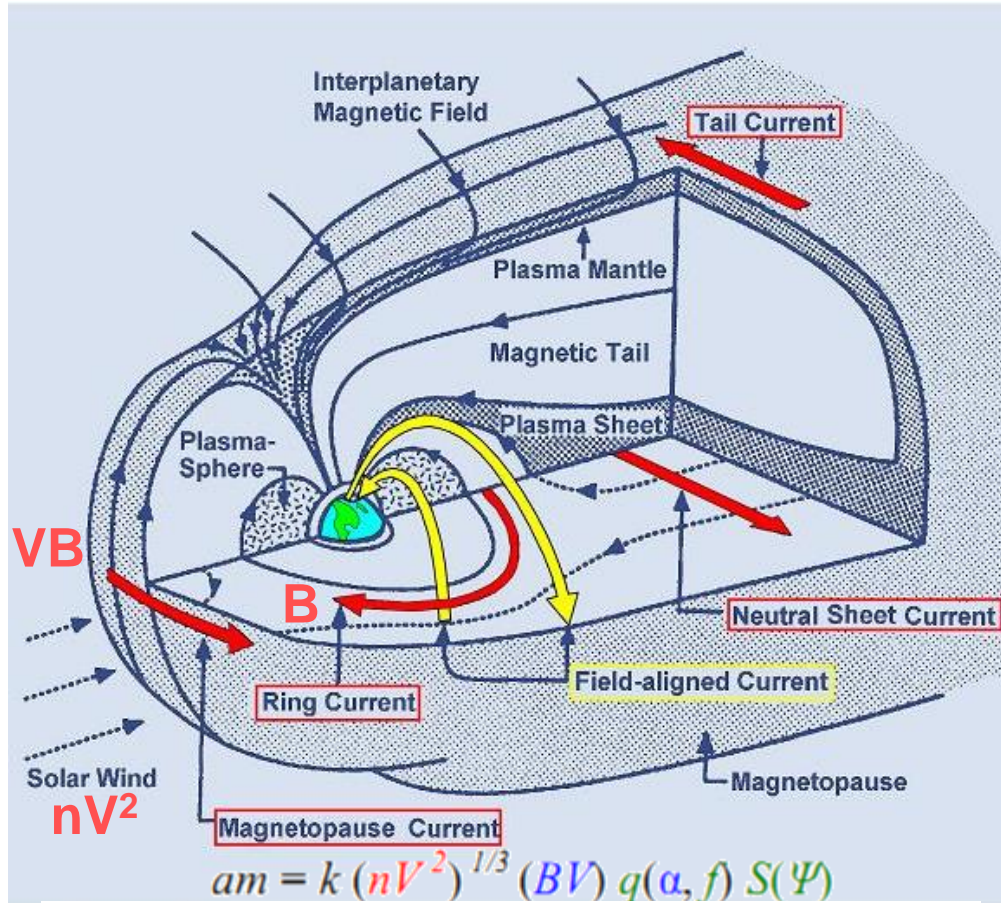
Deduced [1962]  
the ever-present  
oval from All-Sky  
camera images  
of the aurorae.

Other planets with a  
magnetic field have  
auroral ovals, too

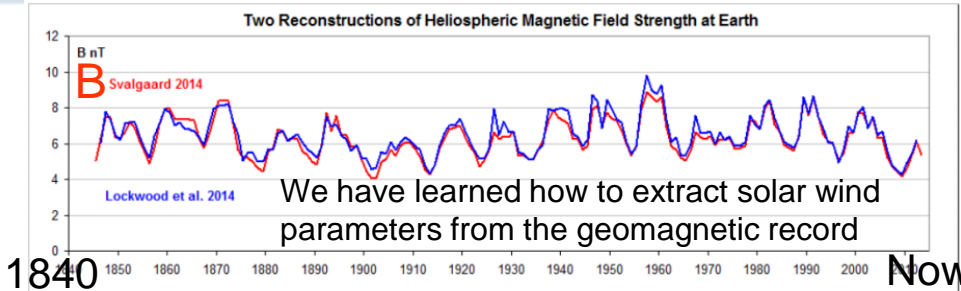




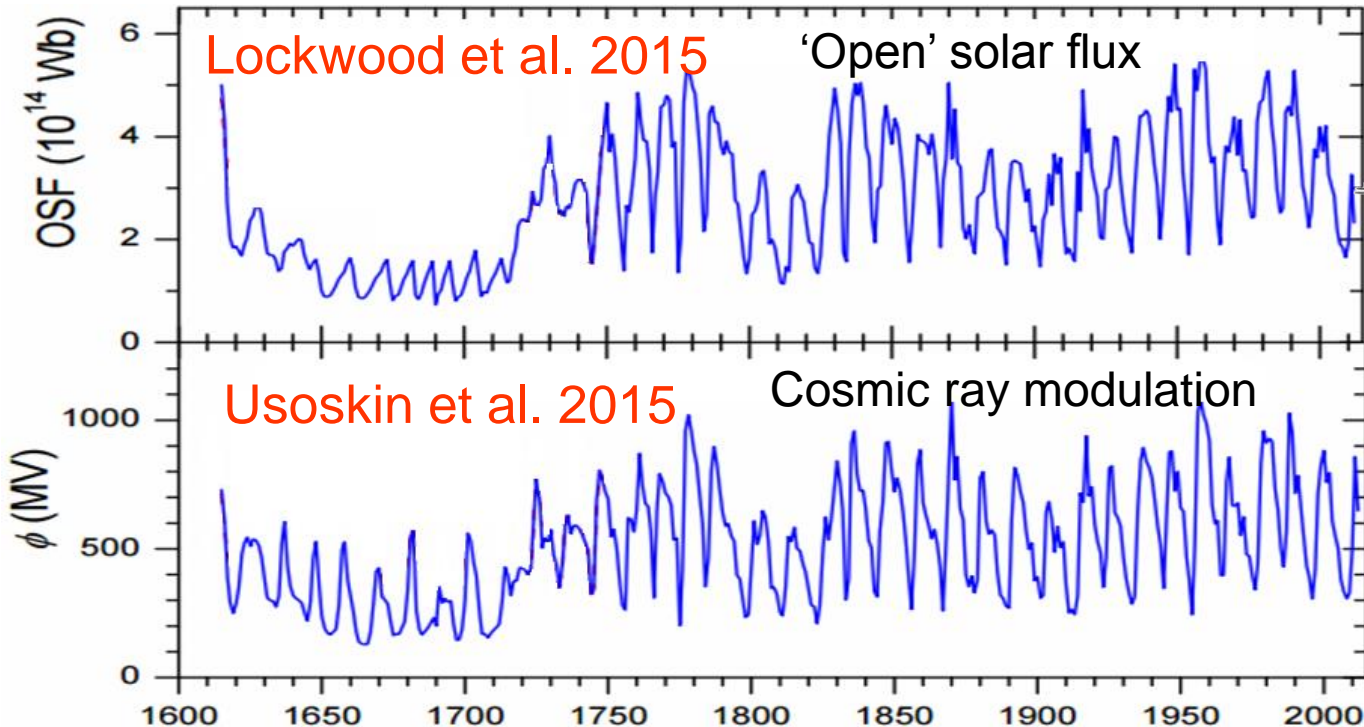
# Electric Current Systems in Geospace



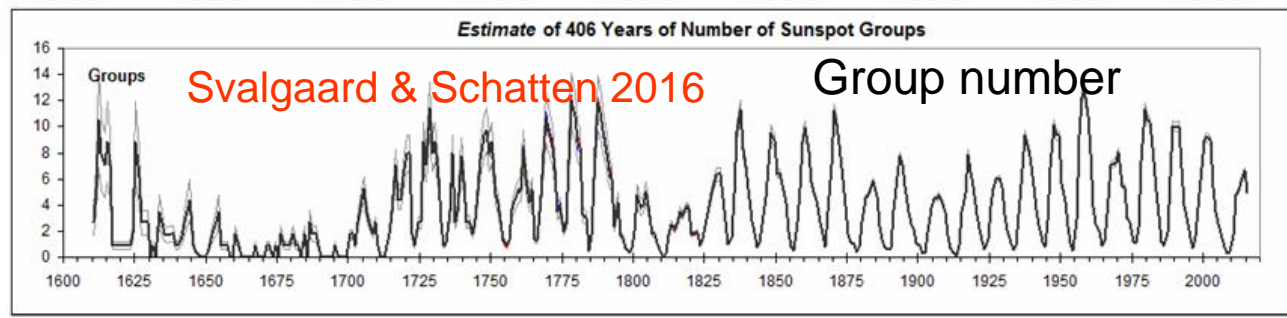
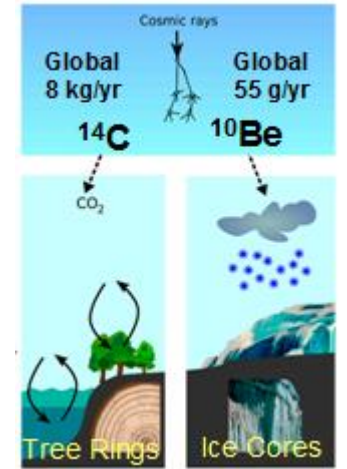
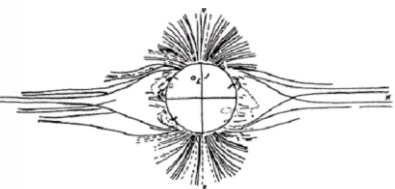
The material [and magnetized] solar atmosphere extending past the orbit of the Earth [the 'Solar Wind'] interacts with the magnetic field of the Earth to create a system of electric currents and plasma regimes around the Earth from where charged particles are accelerated along magnetic field lines towards the Earth to make the atmosphere glow with auroral displays along ovals around the poles, extending to lower latitudes during solar storms.



# Revised Solar Activity Records



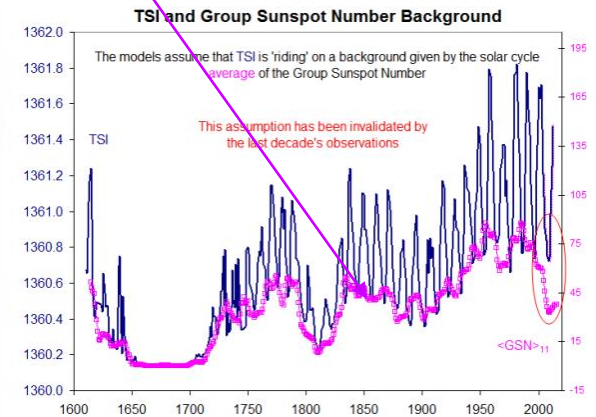
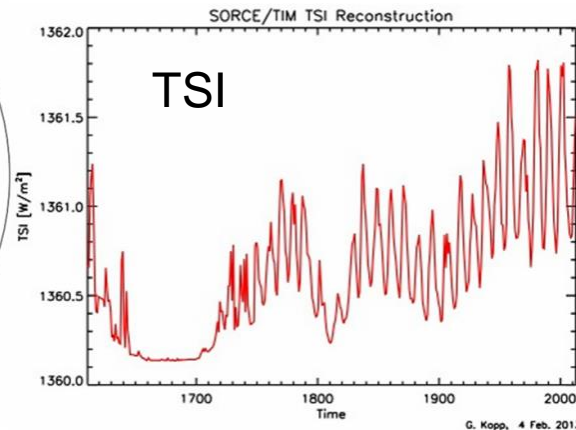
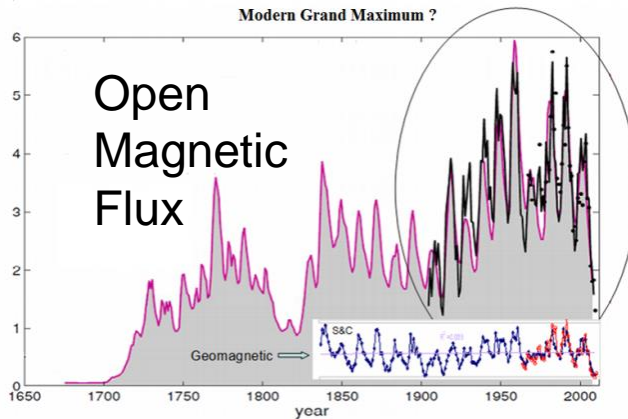
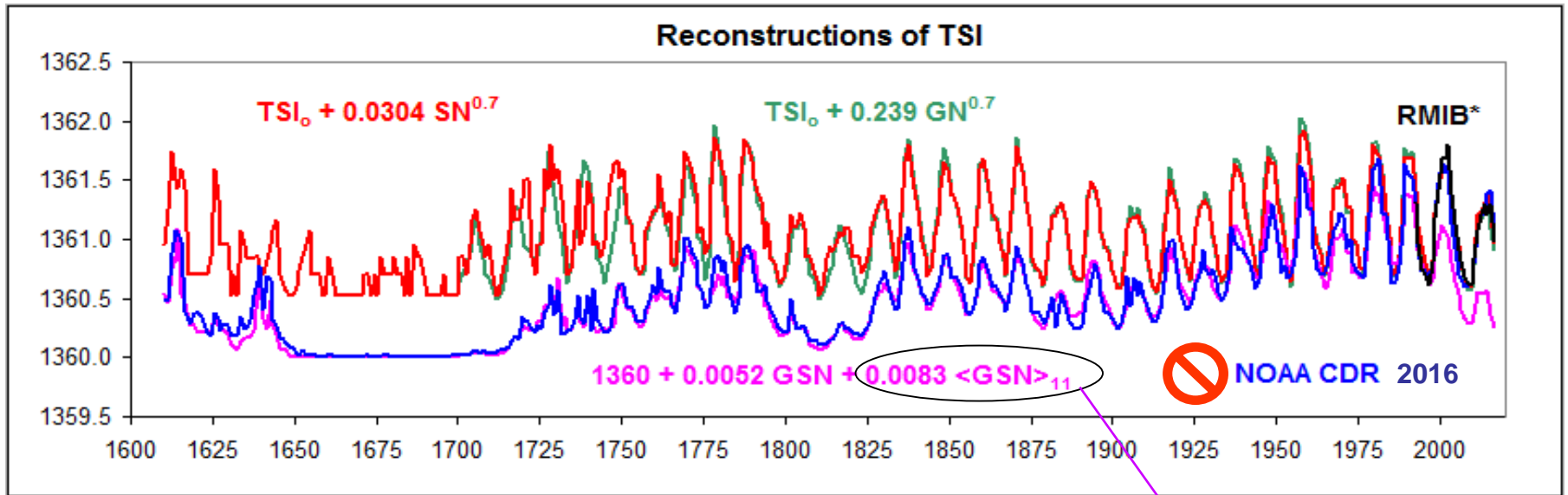
Solar Eclipse 1954



Very good agreement between different reconstructions.

Full Disclosure: There is still a rear-guard debate about the early record

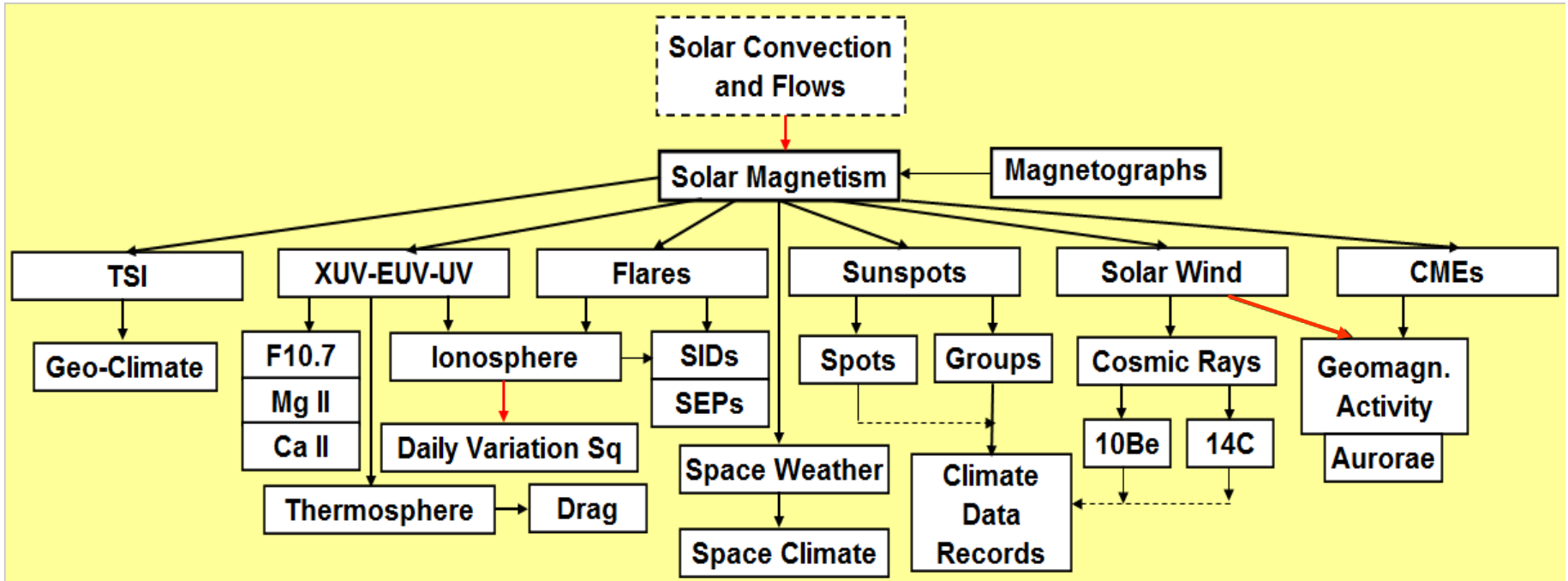
# Long-term Variation of Total Solar Irradiance



There is no slowly varying Background acting as Climate Forcing...



# The Great System of Which We Make a Portion



Faraday wrote to R. Wolf on 27th August, 1852: “I am greatly obliged and delighted by your kindness in speaking to me of your most remarkable enquiry, regarding the **relation existing between the condition of the Sun and the condition of the Earths magnetism.** The discovery of periods and the observation of their accordance in different parts of **the great system, of which we make a portion**, seem to be one of the most promising methods of touching the great subject of terrestrial magnetism...

# Abstract

We discuss the historical development of our understanding of the influence of solar activity on geospace; from the first glimmer of awareness to today's practical applications of hard-won knowledge gained over several centuries. Faraday's words in a letter [1852] to Rudolf Wolf: "The discovery of periods and the observation of their accordance in different parts of the great system, of which we make a portion" underscores the notion of being part of a System. Many cause and effect interactions work together to modulate and drive each other. Our modern technological civilization depends in ever-increasing ways on the behaviour of that Great System; for better and for worse. Great advances in data collection and international cooperation [e.g. the IGY] have from time to time spurred on and deepened our understanding. To tell that story is a privilege. The lesson to be extracted is that unselfish cooperation and sharing form the bedrock on which future progress must be build.