1223 BC – 1599 AD

- 1223 BC Oldest Solar Eclipse (Ugarit, Syria)
- ~800 BC First Sunspot Observation (China)
- 968 AD First Mention of Solar Corona (Turkey)
- 1128 AD First Drawing of Sunspots (England)
- 1185 AD First Mention of Solar Prominences (China)
17th Century

- 1610 First Telescopic Obs. of Sunspots (Harriot, Galileo, ...)
- 1645-1700 Sunspots seem to vanish (Maunder Minimum)

Sunspot Number = 10*groups + spots

Newton 1687: mass of the sun
18th Century, I

- 1769 Wilson Effect
- 1758-1796: Staudach made 1134 Drawings of Sunspots

Width of spot penumbra on disc center side reduces rapidly as it approaches the solar limb • Effect caused by sauce pan shape of depressed sunspot. Still being studied
18th Century, II

• Christian Horrebow, sunspot drawings 1761-1776
• Relationship between sun’s atmosphere and the aurorae (Mairan, 1754, 2nd ed.)

Speculated that there might be a periodicity in the number of spots
The Diurnal Variation of the Direction of the Magnetic Needle

Variation during strong Northern Light on March 27th. 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.

O.P. Hjorter, 1741
The Physics of the Relationships was too Complicated for the Age, so Progress was Slow (Understanding had to wait ~200 years)

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.

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

The different seasonal variations are important clues to the physical processes at work:
19\textsuperscript{th} Century: The Discovery of the Sunspot Cycle and More…

- 1800 The Sun’s Invisible Radiation (Infrared & UV)
- 1802–1817 Wollaston & Fraunhofer: Spectral Lines
- 1838 The Solar ‘Constant’ (Now called the Total Solar Irradiance = TSI)
- 1843 H. Schwabe discovered the Sunspot Cycle
- 1849 Rudolf Wolf Codified Solar Activity with his ‘Relative Sunspot Number’ and extended the Series back in time to 1700 AD
The Geomagnetic Daily Variation is Controlled by the Sun and Varies with the Cycle

Solar Cycle and Zenith Angle Control of the Solar ‘Rays’

A current system in the ionosphere is created and maintained by solar EUV radiation

The magnetic effect of this system was what George Graham discovered
The Physics of the Daily Variation

Ionospheric Conducting Layers

The various layers reflect radio waves.

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

1882, Encyclopedia Britannica, 9th Ed.:
“there seems to be grounds for imagining that their conductivit may be much greate than has hitherto been supposed.”

An effective dynamo process takes place in the dayside E-layer where the density, both of the neutral atmosphere and of the electrons are high enough.
The Source of the Ionization: EUV

Because the process is slow (the Zenith angle $\chi$ changes slowly) we have a quasi steady-state, in which there is no net electric charge. The conductivity thus varies with the square root of the zenith angle and of the overhead EUV flux.
The Many Links in the Effect

The EUV causes an observable variation of the geomagnetic field at the surface through a complex chain of physical connections.

The physics of each link in the chain is well-understood in quantitative detail and can be successfully modeled.

We’ll use this chain in reverse to deduce the EUV flux from the geomagnetic variation.
Geomagnetic Storms Caused by Sun

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.

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

PJM Public Service Step Up Transformer

Severe internal damage caused by the space storm of 13 March, 1989.
We are Beginning to Understand the Complicated Physics of the Solar System

A Systems Approach: Everything Must Fit

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...”

These are exciting times for Solar Physicists