The Geo-Response to Extreme Solar Events: How Bad Can it Get?

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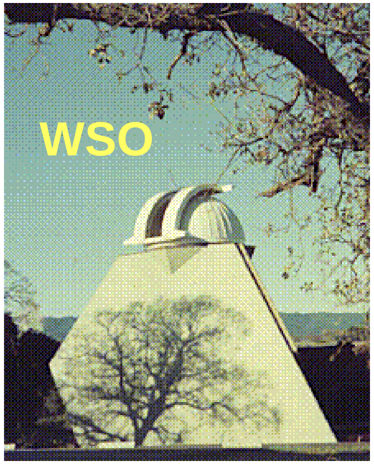
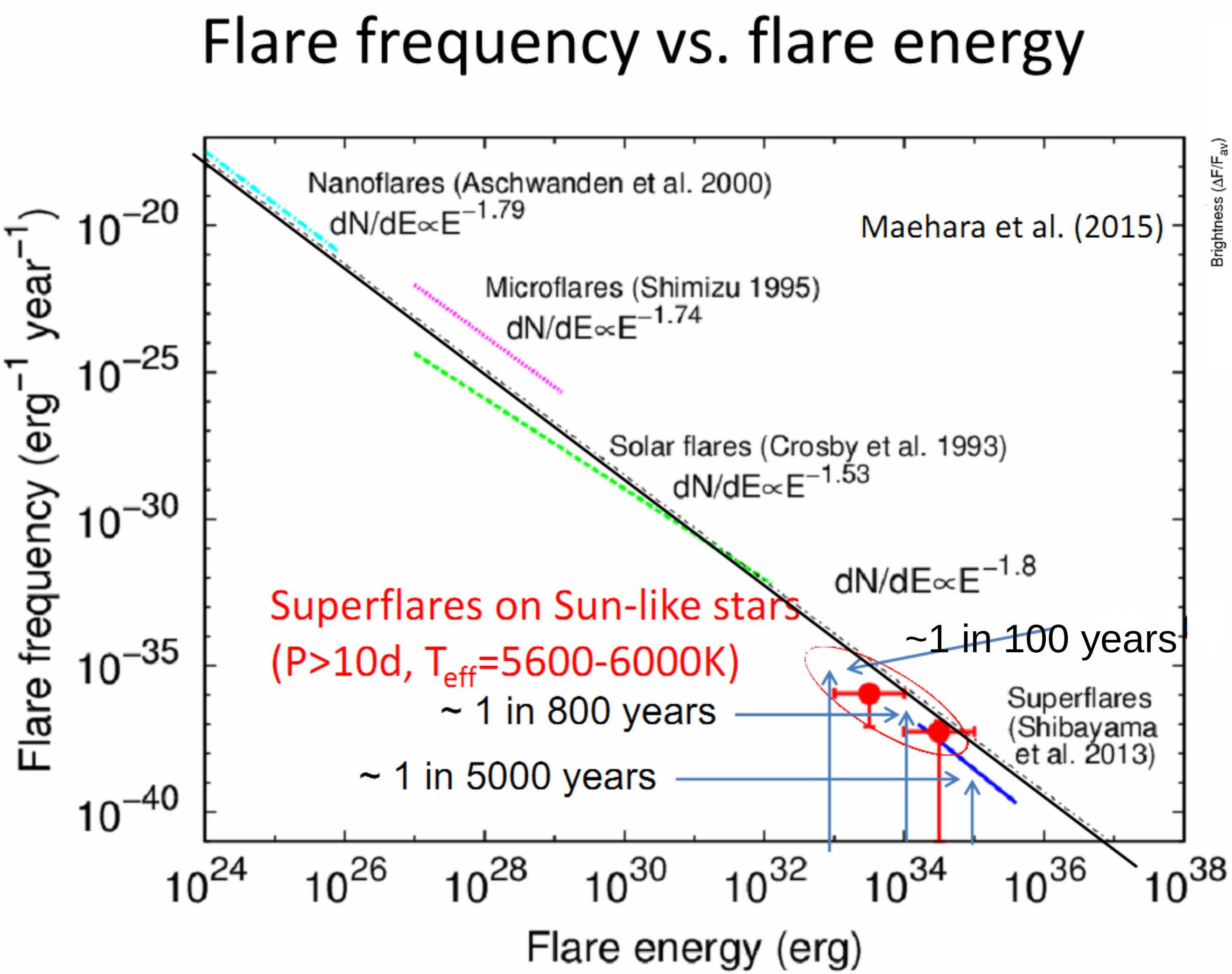
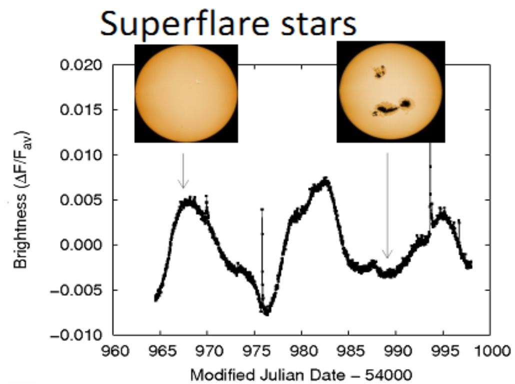
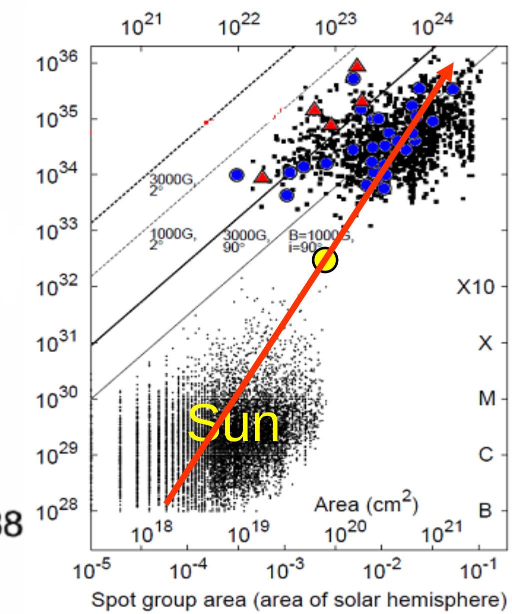
AOGS, Singapore, August 2015



Superflares May Just be Rare

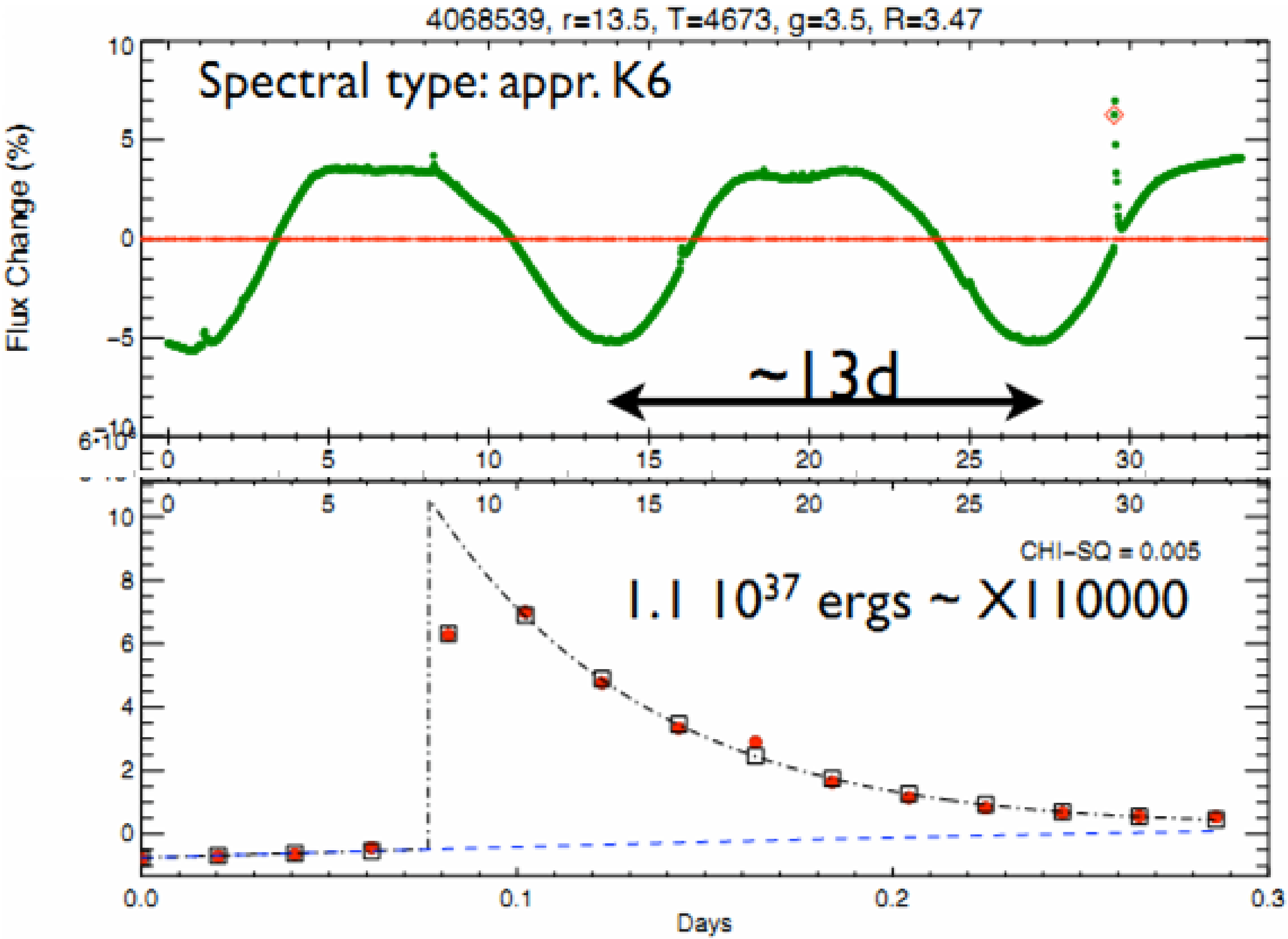




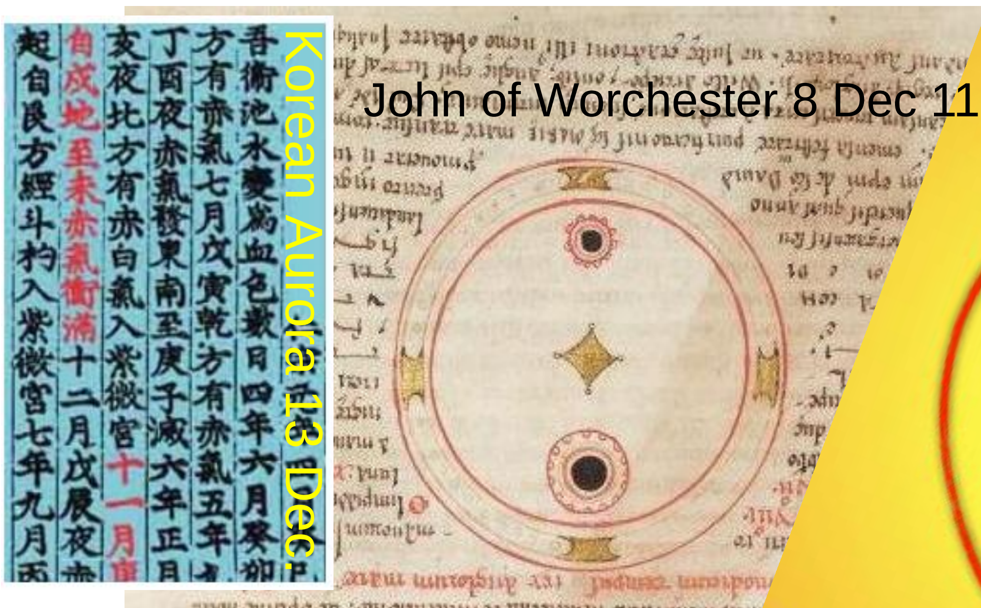


Kepler

An X110,000 Flare…

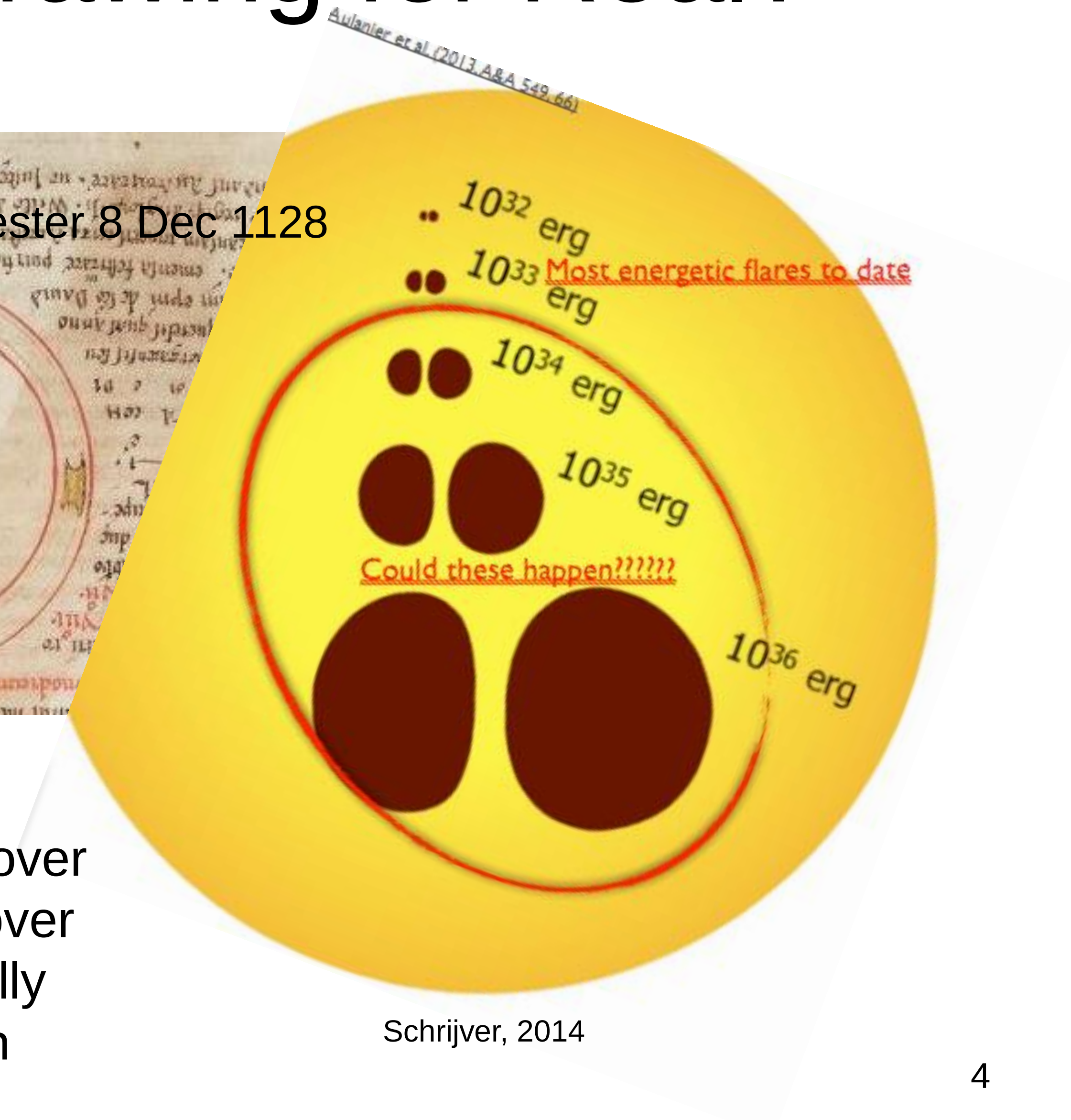


Is This Drawing for Real?



Korean Aurora 13 Dec.

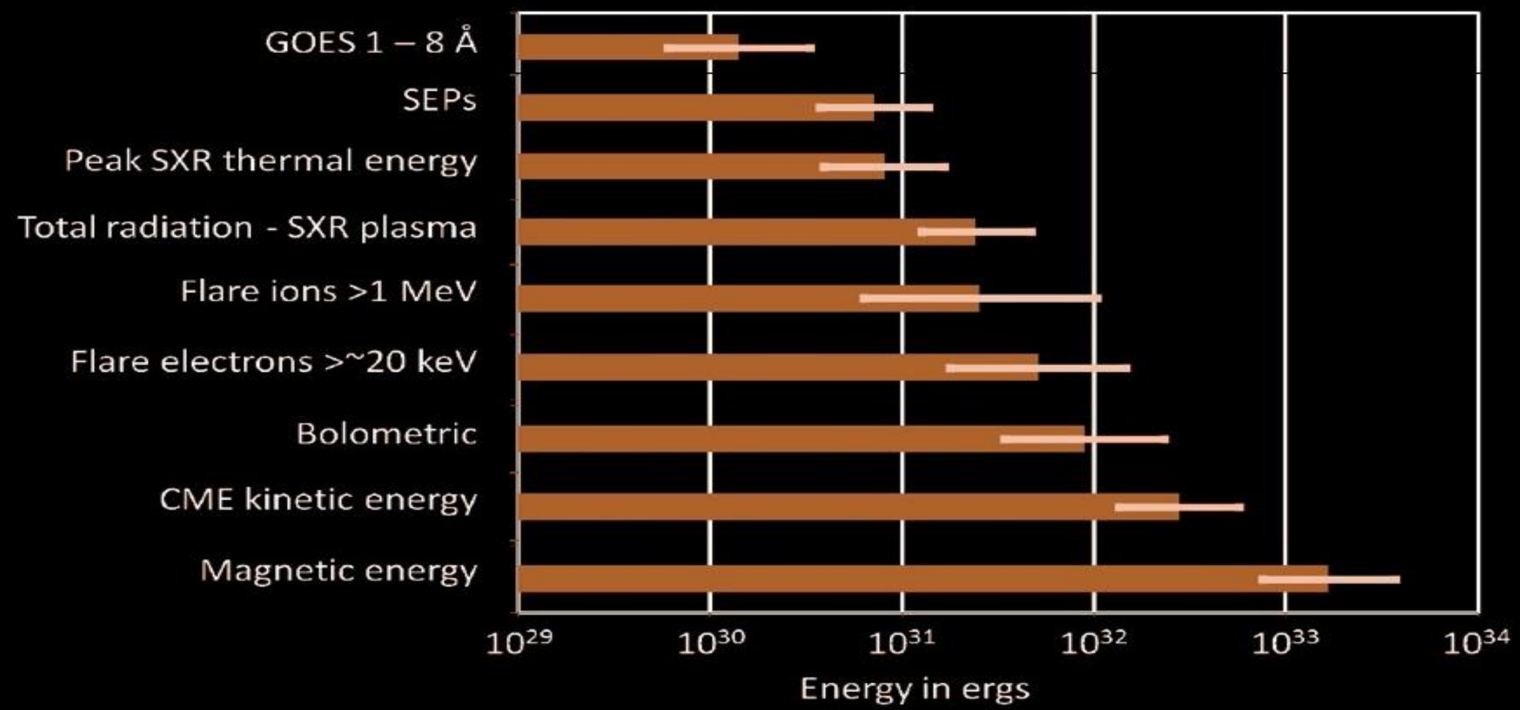
John of Worchester 8 Dec 1128



Schrijver, 2014

Knowing the worst case over millennia requires data over that long, which we really don’t have for the Sun

Solar Flare Energy: Mostly White-Light and Kinetic/Magnetic

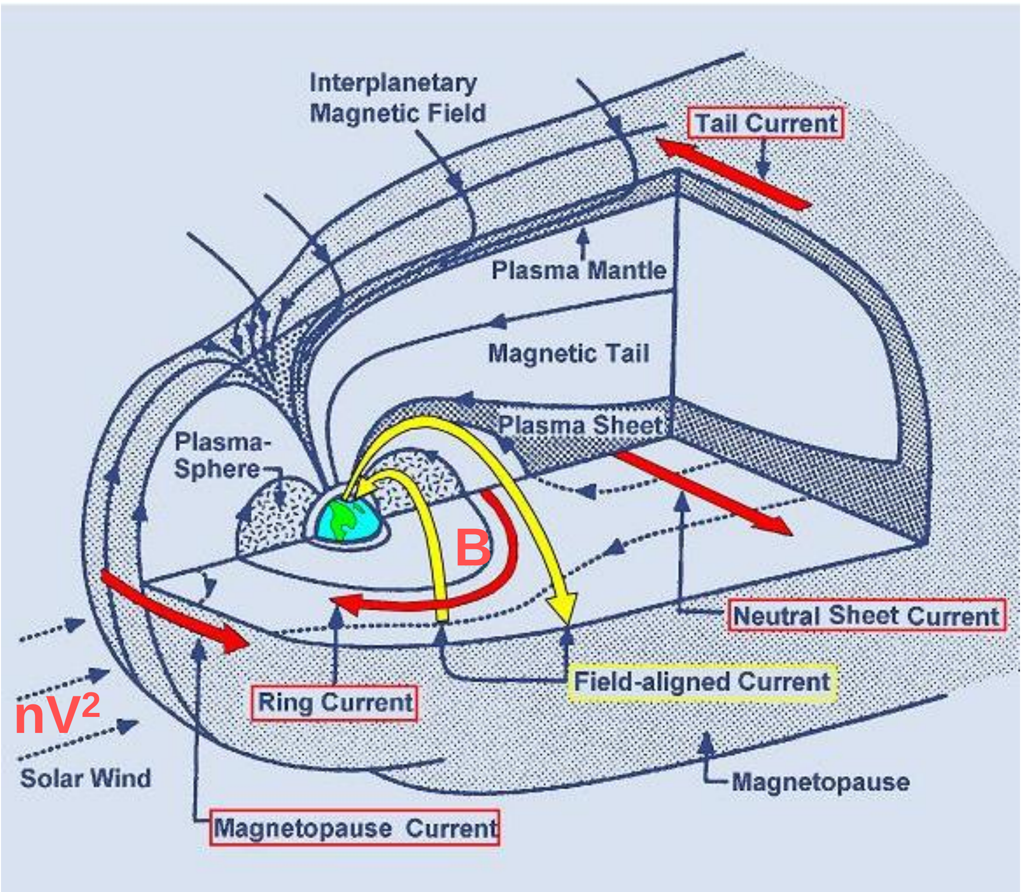


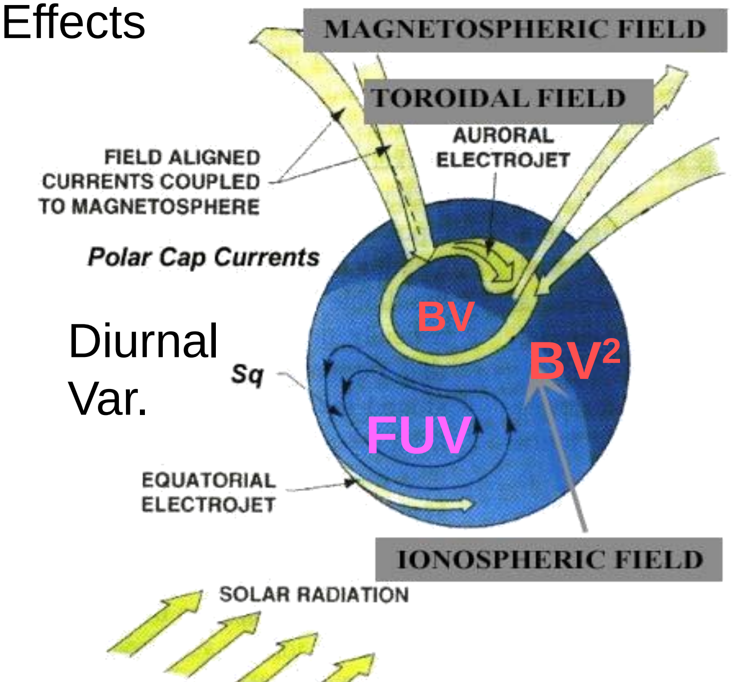
Modified after Emslie et al. (2012): values for X3, X3, X4, X7, X8, X10 flares.

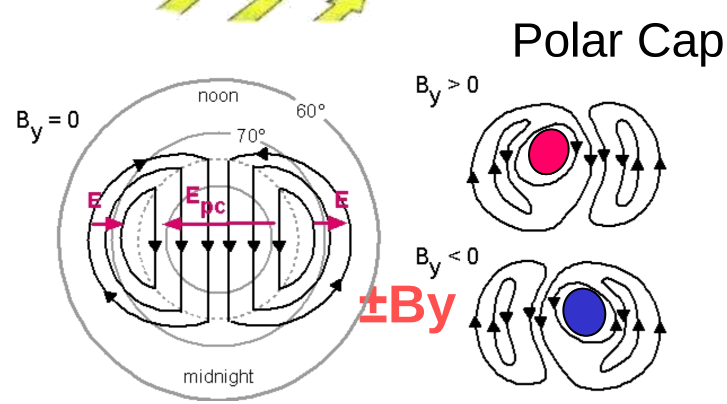
Schrijver, 2014

Electric Current Systems in Geospace

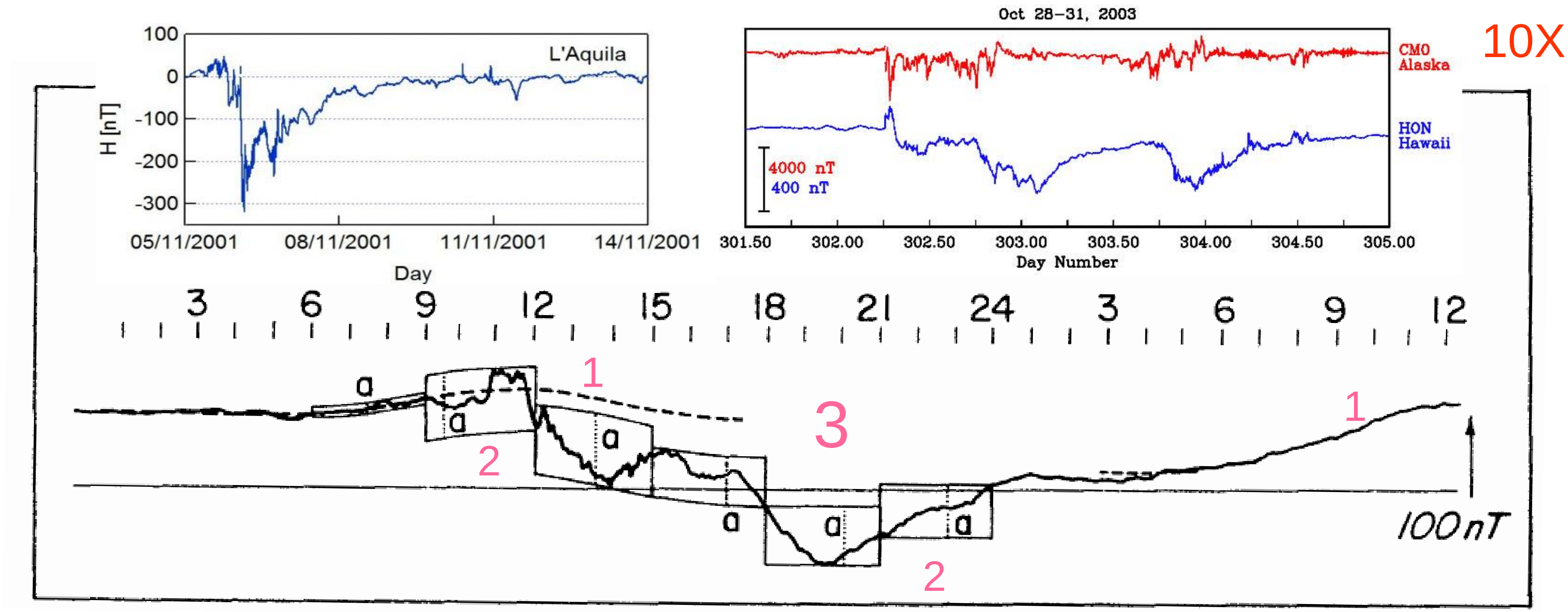
Different Current Systems ⇄ Different Magnetic Effects







Typical Recording over 36 Hours



Three simultaneous features:

1: A Regular Daily Variation [it took ~200 years to figure out the cause]

2: Shorter-term [~3 hour] fluctuations ['substorms' recognized in 1960s]

3: Large disturbances ['geomagnetic storms' explained in the 1930-1960s]

The complicated, simultaneous effects withstood understanding for a long time

Vasyliũnas, JASTP, *73*, 2011

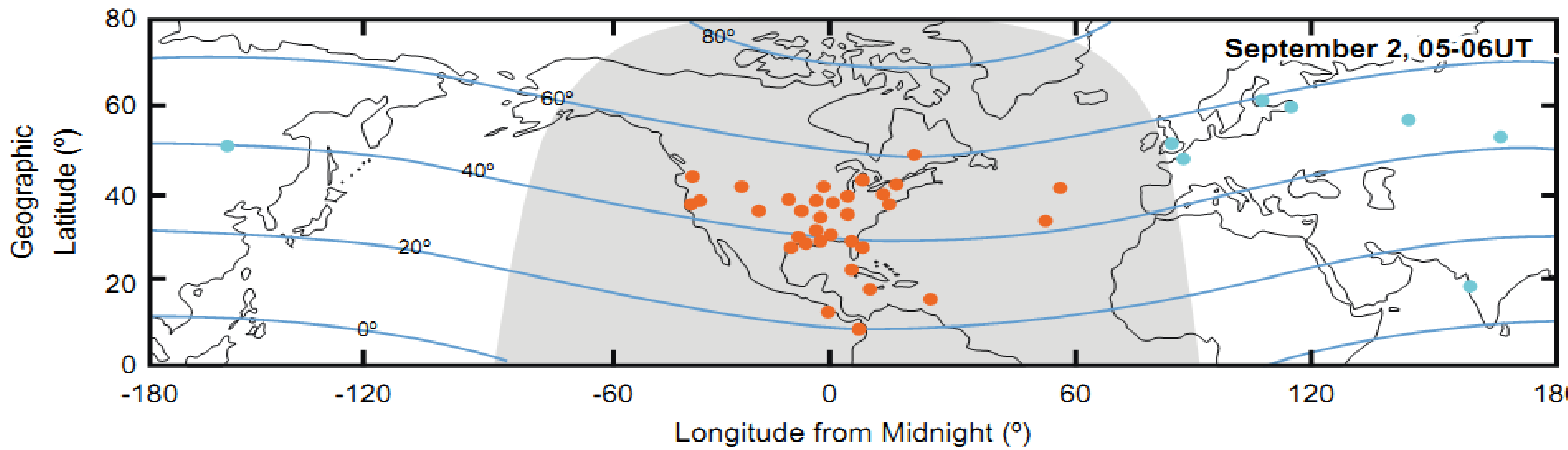
“The largest imaginable magnetic storm”

The size of a magnetic storm is measured by the maximum depression (Dst) of the horizontal magnetic field at the Earth’s equator. The largest depression that could possibly occur can be estimated by noting that the geomagnetic field is inflated by plasma pressure in the magnetosphere

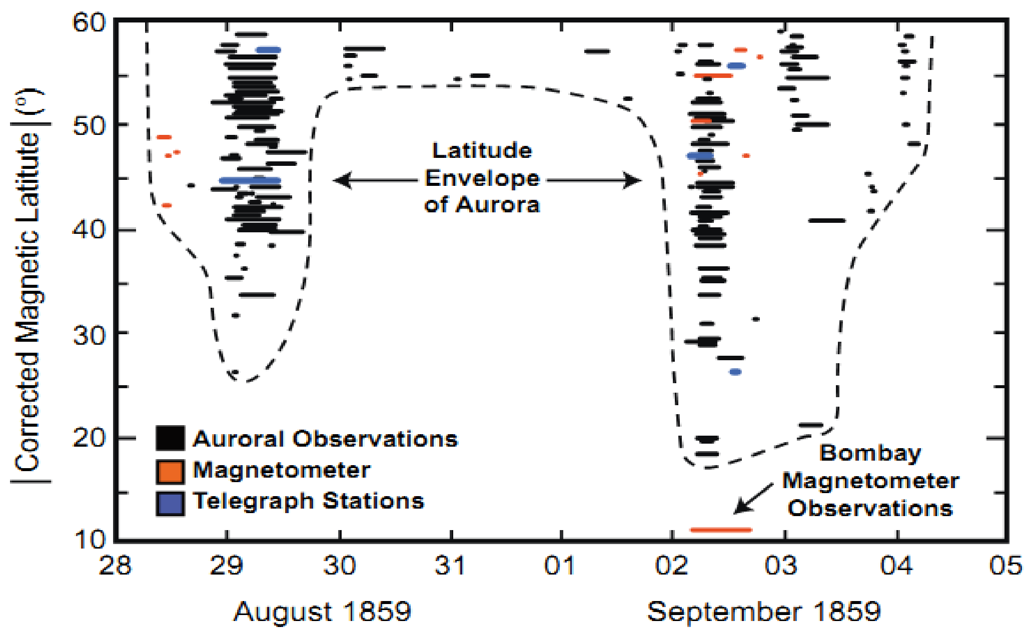
A rough but reasonable upper limit can then be estimated by setting the effective plasma pressure equal to the magnetic pressure of the dipole field at the equator of each flux tube, and applying the Dessler–Parker–Sckopke theorem*. The upper limit thus obtained for the value of the Dst index is Dst ~ –2500 nT.

This is about twice as large as observed until now

*gives the magnetic field perturbation at the Earth due to plasma trapped in the terrestrial dipole magnetic field



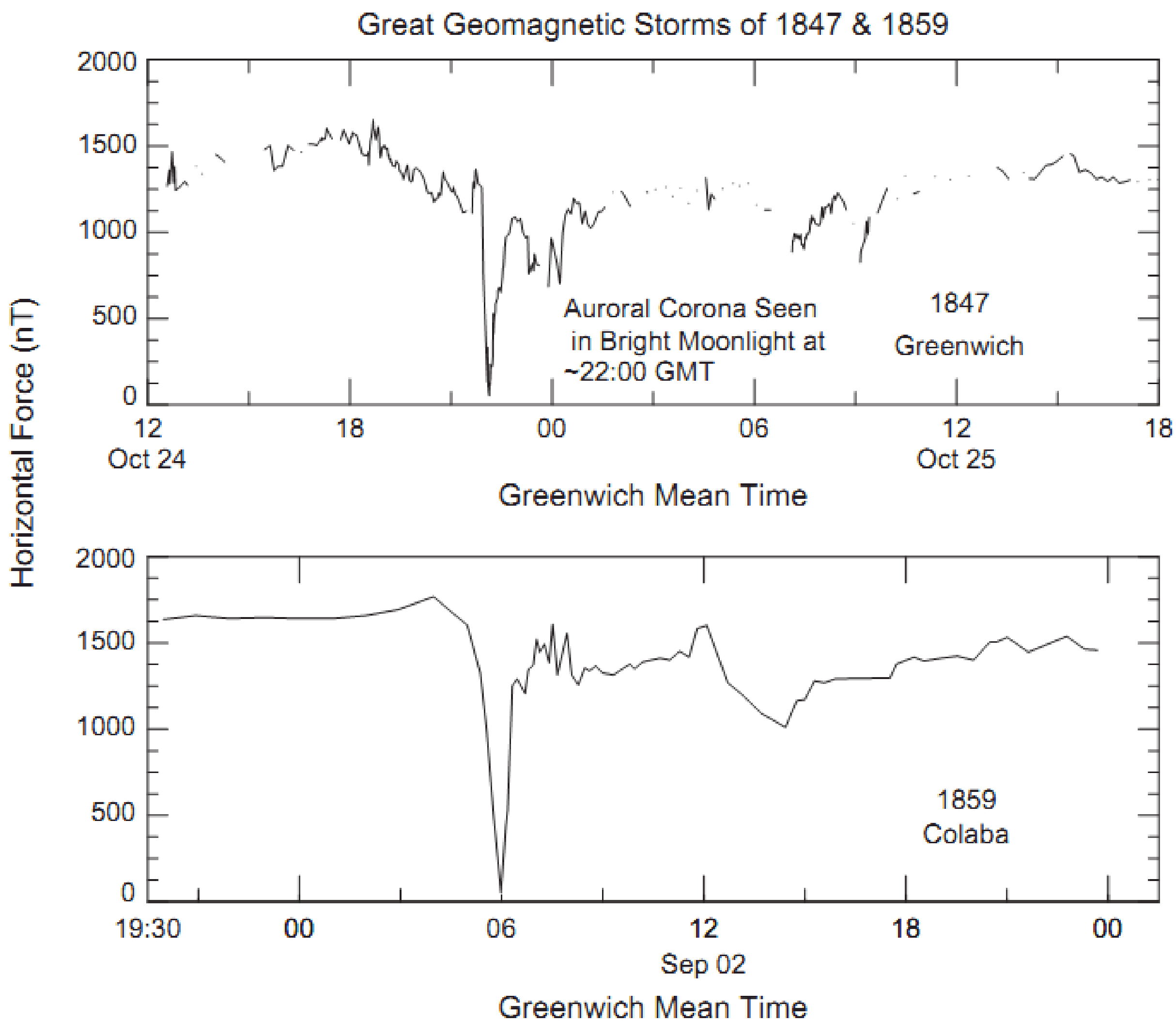
At Rome (geomagnetic latitude = 38.8N), Secchi (1859) observed a decrease of ~3000 nT in H.



The Auroral Oval can hardly get any bigger…

The 1859 Carrington/Hodgson Event

D_{st} is not everything



The phenomenon of geomagnetic induced currents was first noticed in 1847 with the telegraph.

As a student (at solar maximum in 1967) I was an observer in Greenland and saw a 6000 nT substorm

How Big can the aa-index be?

$aa = 7\ q(f,\alpha)[BV_o/21][nV_o^2/105]^{1/3}$

where V_o = V/100 km/s, B nT, n protons/cc

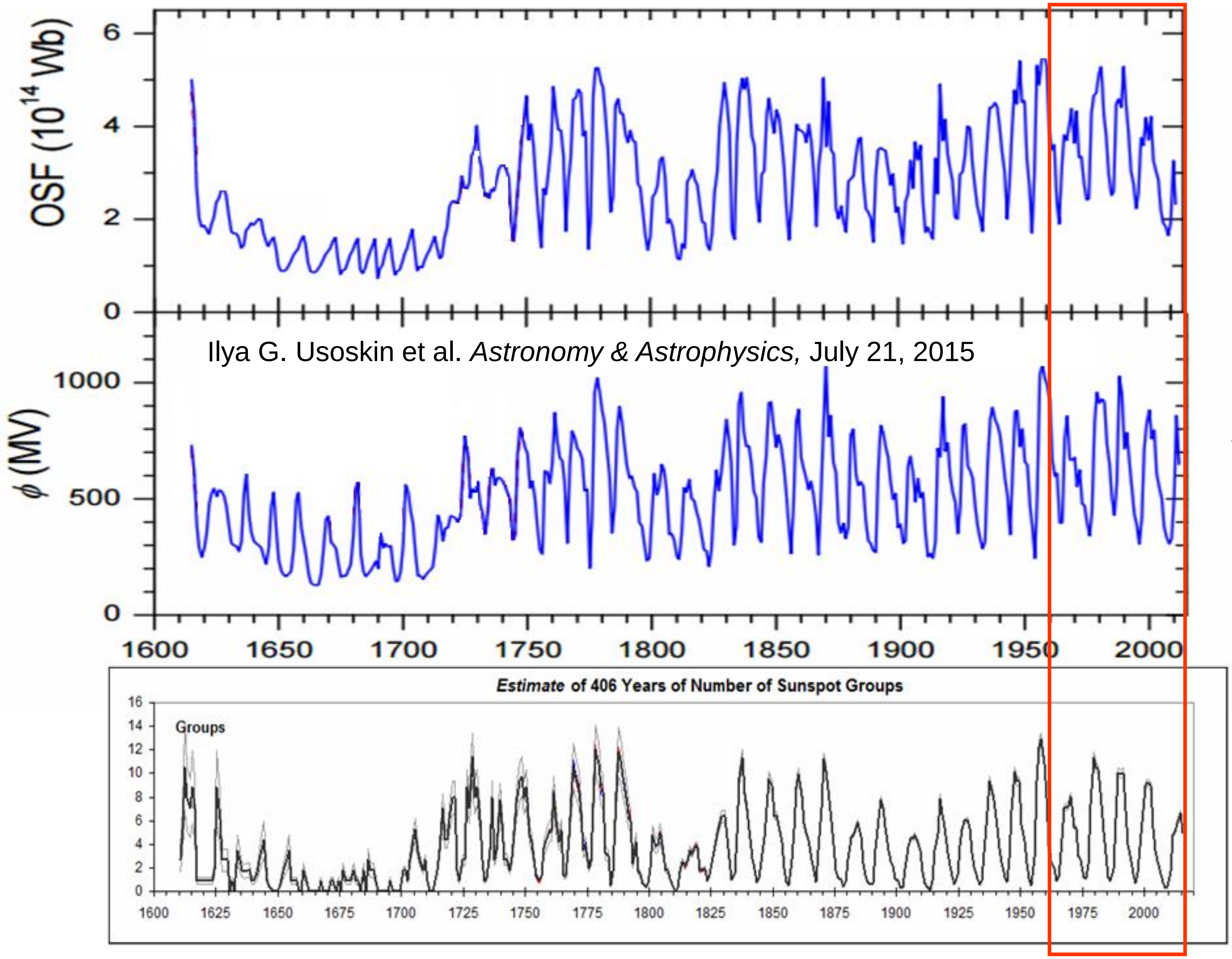
Approx. $aa = k/6\ BV_o^2$

where k varies from 0.5 to 2

k = 1

B nT	500	750	1000	1500	2000	2500	<= V
5	21	47	83	188	333	521	
10	42	94	167	375	667	1042	
20	83	188	333	750	1333	2083	
40	167	375	667	1500	2667	4167	
80	333	750	1333	3000	5333	8333	
100	417	938	1667	3750	6667	10417	

aa is the fluctuation in nT over a 3-hour period



The open solar magnetic flux (OSF) is the main heliospheric parameter driving the modulation of cosmic rays.

The OSF has been modeled by quantifying the occurrence rate and magnetic flux content of coronal mass ejections fitted to geomagnetic data.

The OSF and the cycle-variable geometry of the heliospheric current sheet allows reconstruction of the cosmic ray modulation potential, φ.

The ‘Space-Age’ has been rather typical of the last 300 years

Newly Revised Reconstructions of Solar Activity

ST21-32-D3-AM1-323-006

There is Awareness of the Problem

"[...] an estimate of $1 trillion to $2 trillion during the first year alone was given for the societal and economic costs of a "severe geomagnetic storm scenario" with recovery times of 4 to 10 years."

SEVERE SPACE WEATHER EVENTS—
UNDERSTANDING SOCIETAL AND ECONOMIC IMPACTS

A WORKSHOP REPORT

Committee on the Societal and Economic Impacts of Severe Space Weather Events: A Workshop

Space Studies Board

Division on Engineering and Physical Sciences

NATIONAL RESEARCH COUNCIL OF THE NATIONAL ACADEMIES (2008)

How Severe Can Space Weather be?

- Observations of Sun-like stars suggest that flares can reach energies 100-300 times those observed during the space- age
- Ice and rocks from Earth and Moon show that energetic solar particles may saturate at a ‘few’ times the space-age maximum
- Theory of geomagnetic storms suggests that they may not exceed about twice the 1859 Carrington Event
- Recent 2012/7/23 storm that missed the Earth suggests that these strong storms may not be so rare as thought
- In any event, such extremes exceed the levels to which our modern technological infrastructure has been exposed