Sunspots

A Discussion for Radio Amateurs

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Version 2

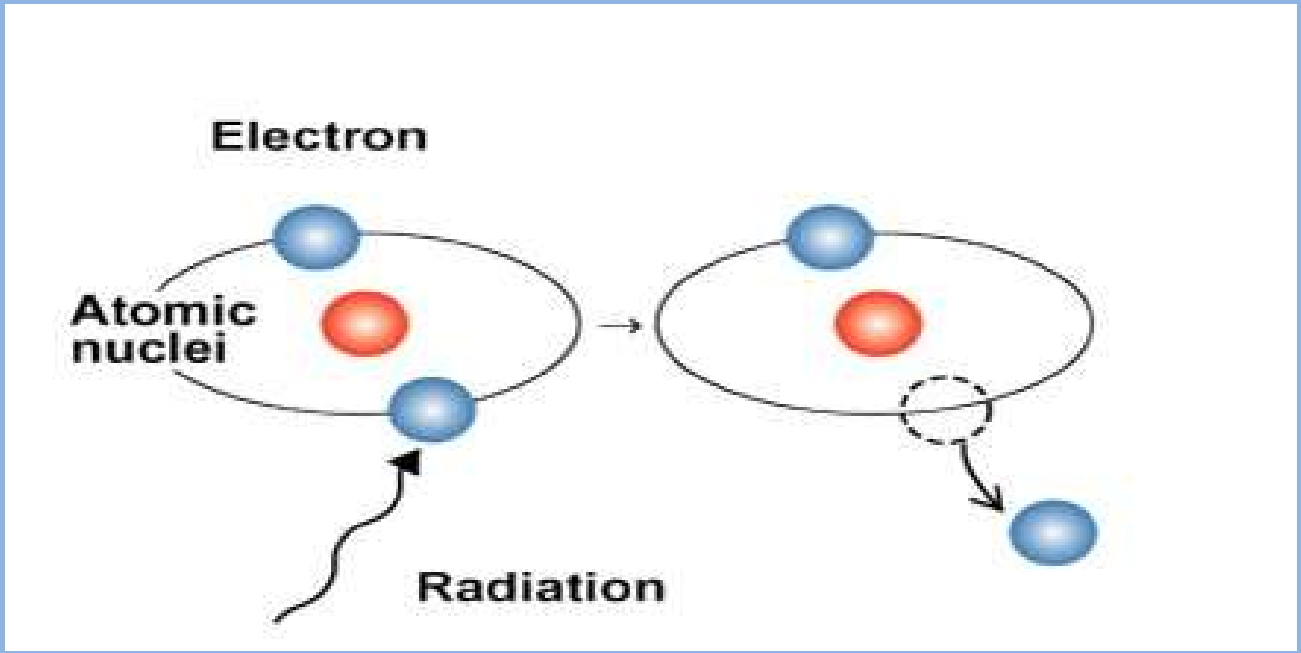
Why Sunspots Matter

- Amateur radio operators depend on sunspot-induced physical phenomena for communication beyond the line of sight
- Energy from sunspots interacts with the earth's environment to allow radio waves to cover earth-spanning distances
- More sunspots at a given time yields enhanced opportunity for long-distance communication

How Does Propagation Work

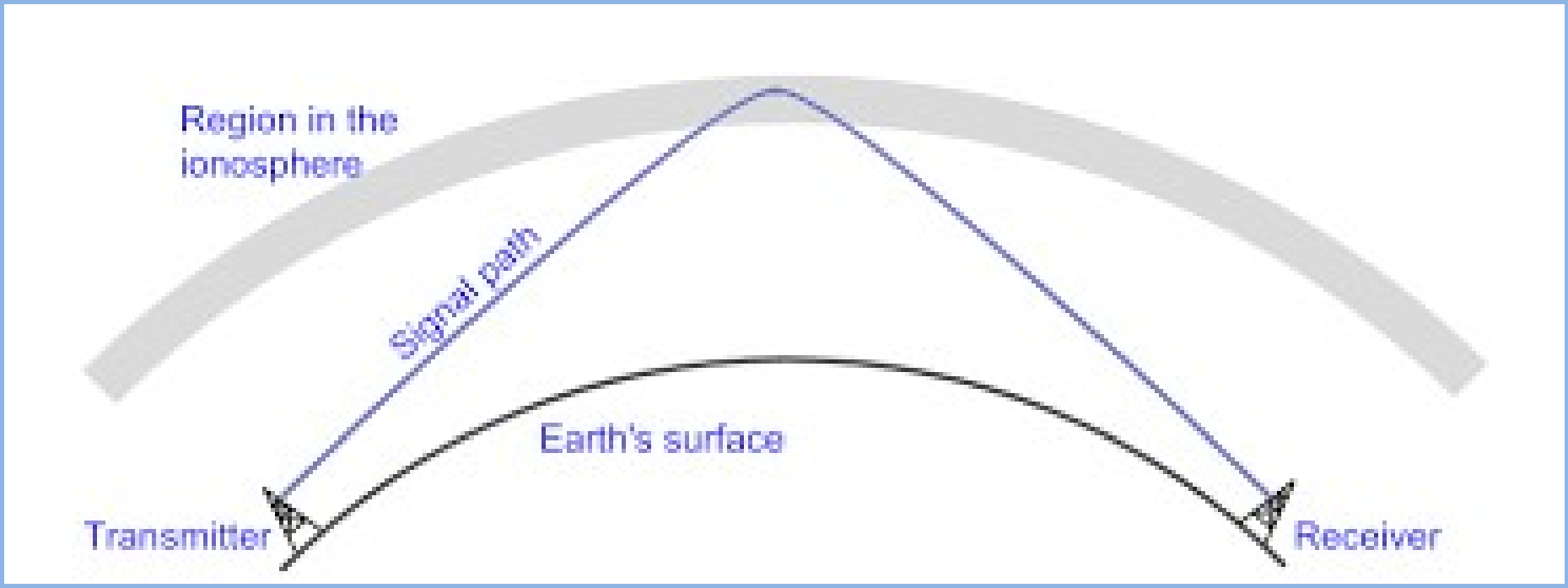
- When 'ionized,' specific layers of a portion of the upper atmosphere can permit incident radio waves to be reflected downward and be received thousands of miles away
- Ionization involves a photon, a particle of electromagnetic radiation, ejecting an electron from a neutral atom producing a charged atom
- $X + \Upsilon \rightarrow X^{+} + e^{-}$
  - such as $H + \Upsilon \rightarrow H^{+} + e^{-}$

Ionization



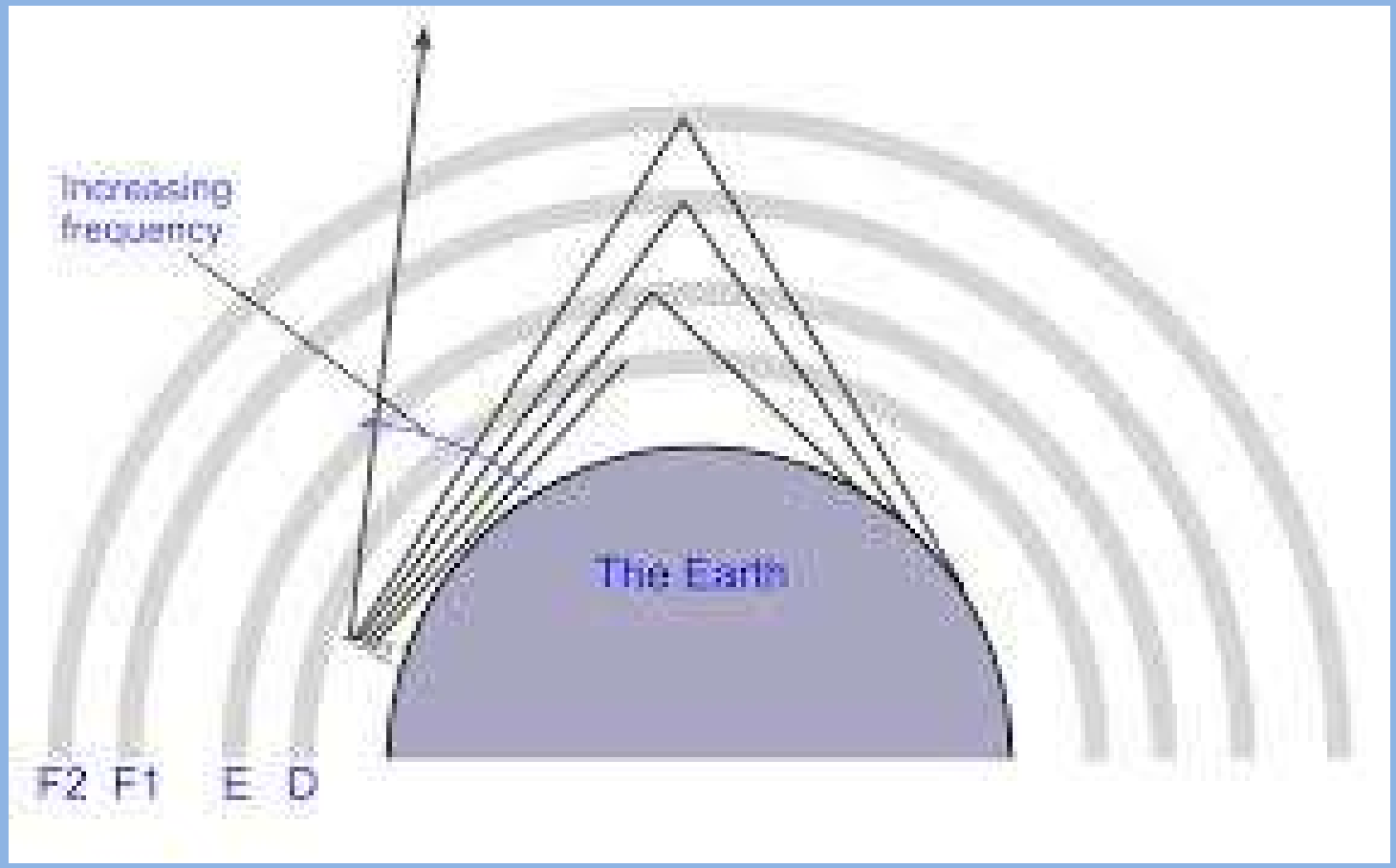
Credit: ionizationpandai.blogspot.com

Ionosphere



Credit: electronic-notes.com

Ionosphere Propagation for Hams



Credit: electronic-notes.com

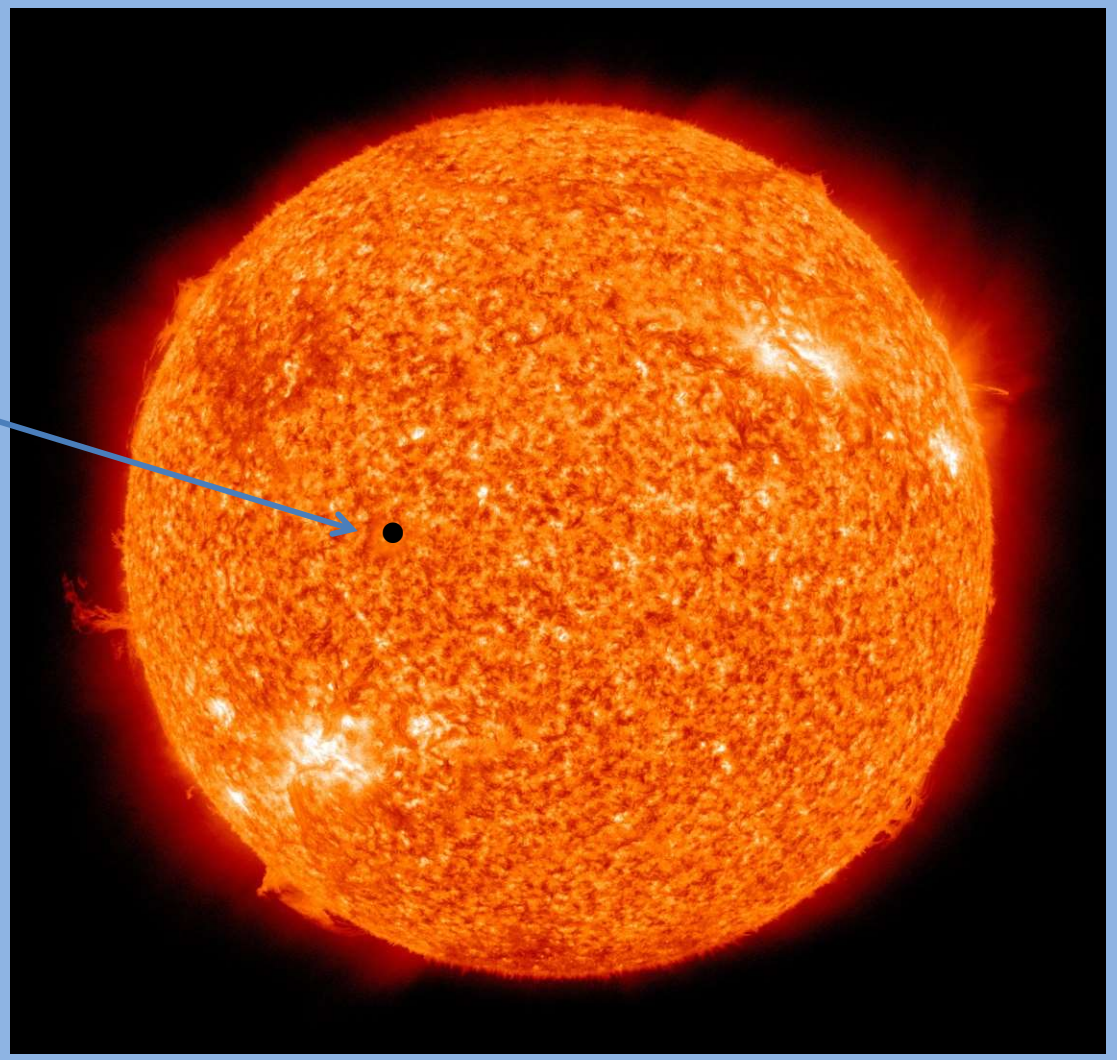
Let's Talk about the Sun

- The sun is a spectral class 'G' yellow dwarf star
- The sun is approximately 4.6B years old
  - Formed in the Orion Spur of the Milky Way galaxy
  - It is probably a third-generation star, formed from the remains of earlier first- and second-generation stars
  - The sun is comprised of ~74% hydrogen and ~25% helium with the remaining ~1% small amounts of oxygen, carbon, neon, and iron

The Sun Is Big and a Busy Place

- Its diameter is about 864,000 miles
  - 109 times that of earth
  - 1,000,000 earths would fit in the sun
- The mass is about 330,000 times that of earth
- The sun is comprised of plasma, the fourth state of matter, like a gas, where atoms are disassociated into protons + neutrons (atomic nucleus), and electrons
- The sun is rotating but, not being a solid, the sun rotates faster at its equator than at its poles
  - At its equator, the sun rotates approximately every 27 days; at its poles, it rotates roughly every 36 days

The Sun Is Big and a Busy Place

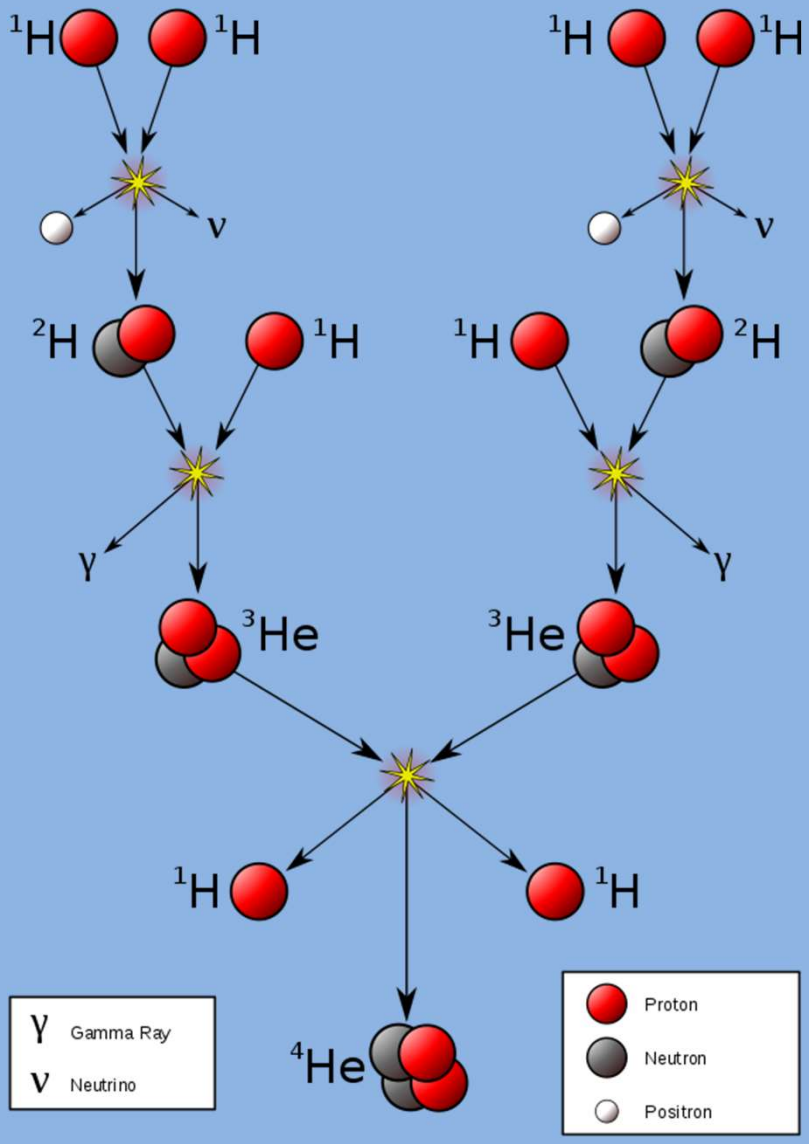


Credit: NASA Solar Dynamics Observatory

The Sun Is a Hydrogen Bomb That Has Been Operating for 4.6B Years

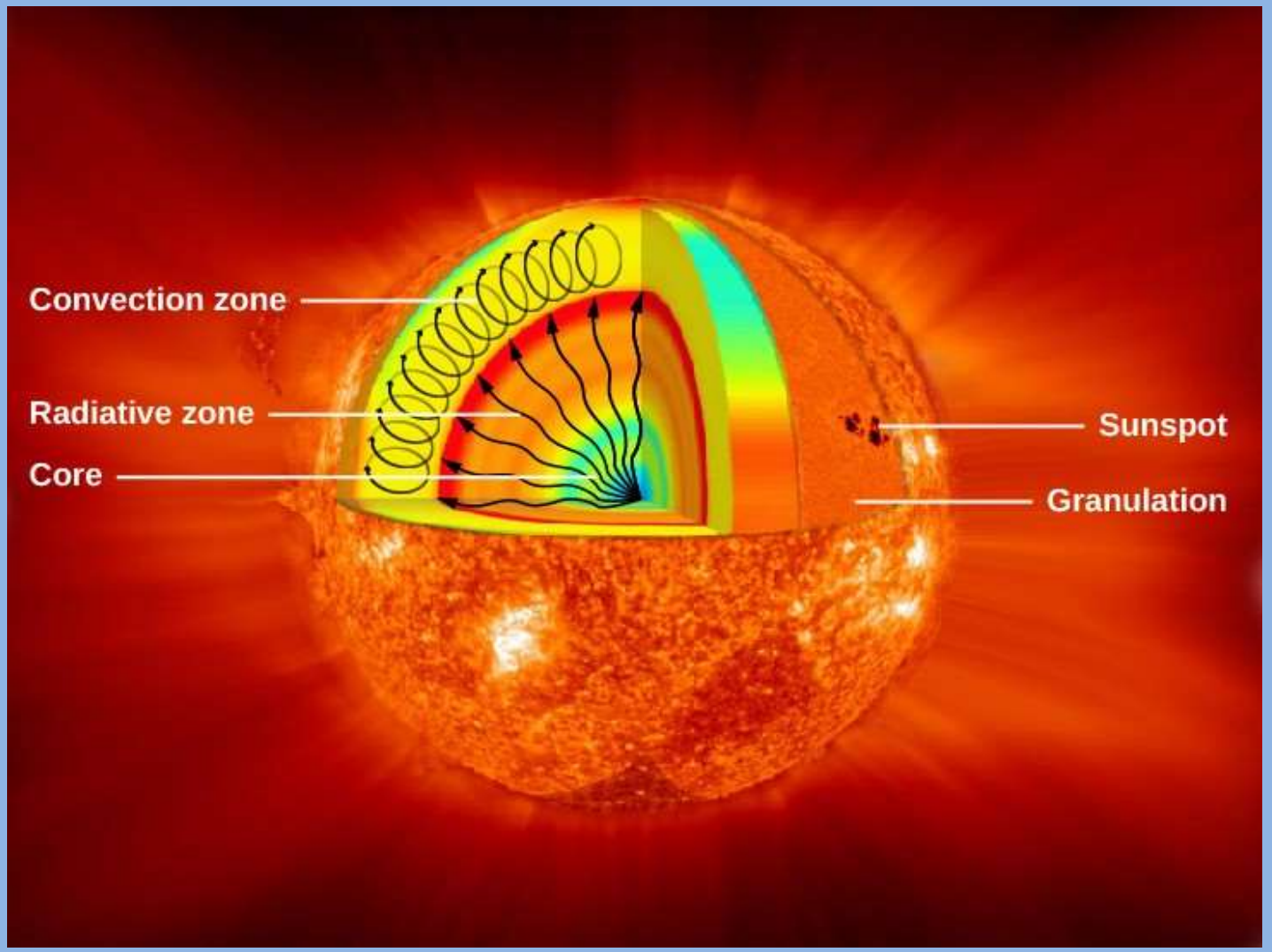
- The sun fuses about 600 million tons of hydrogen into about 596 million tons of helium every second, converting 4 million tons of matter into energy every second as a result of $E = mc^2$
- Output of the reaction
  - Two gamma ray photons (Υ) in the mid-cosmic-ray energy range
  - Two neutrinos (ν)
  - Two positrons (e^+)
  - Two neutral hydrogen atoms (H)

Proton-Proton Reaction



Credit: Sarang - Own work, Public Domain

Cross-Section of the Sun

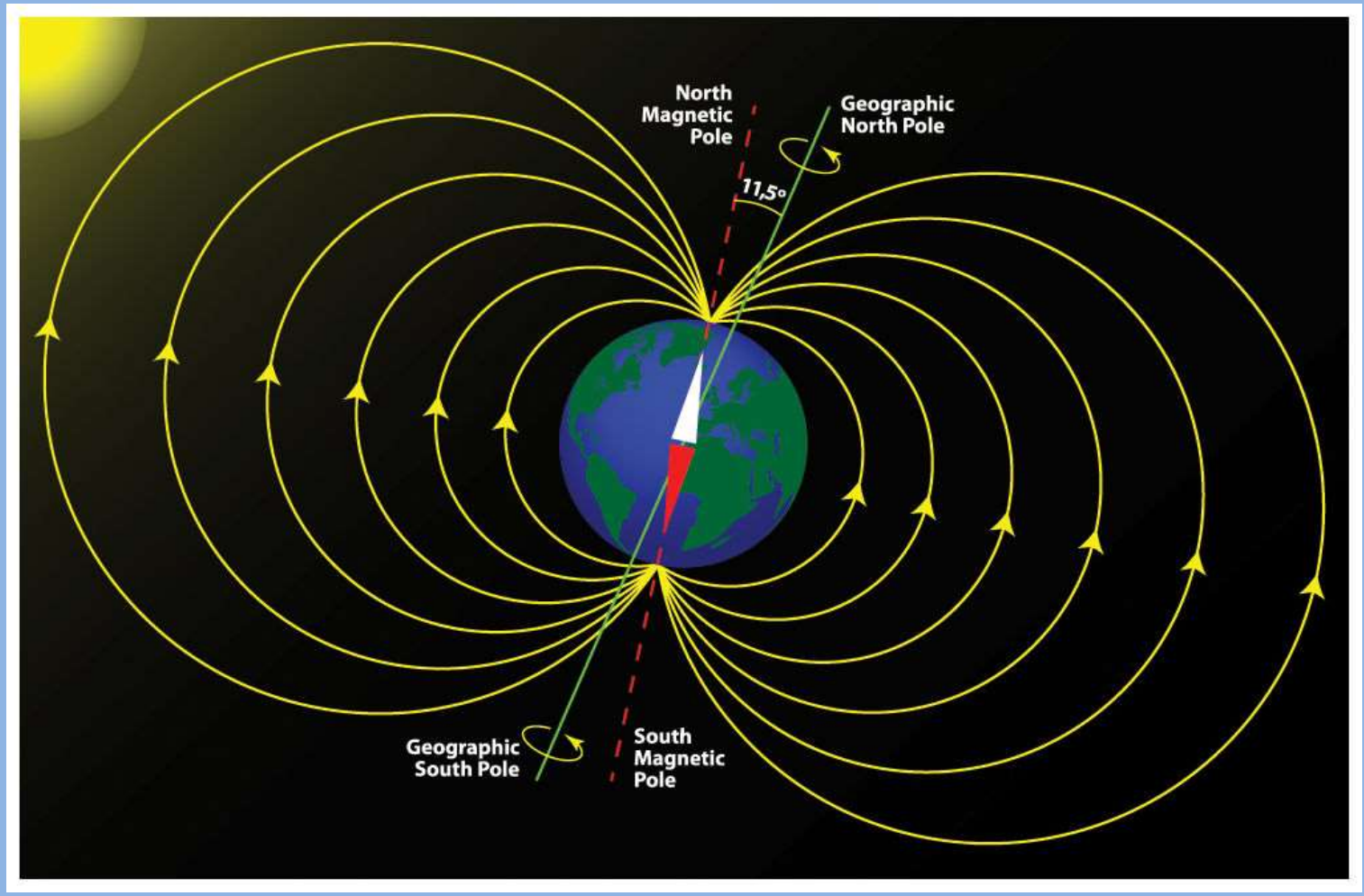


Credit: Lumen - Astronomy: The Sky and the Solar System

The Sun Has a Very Strong Magnetic Field

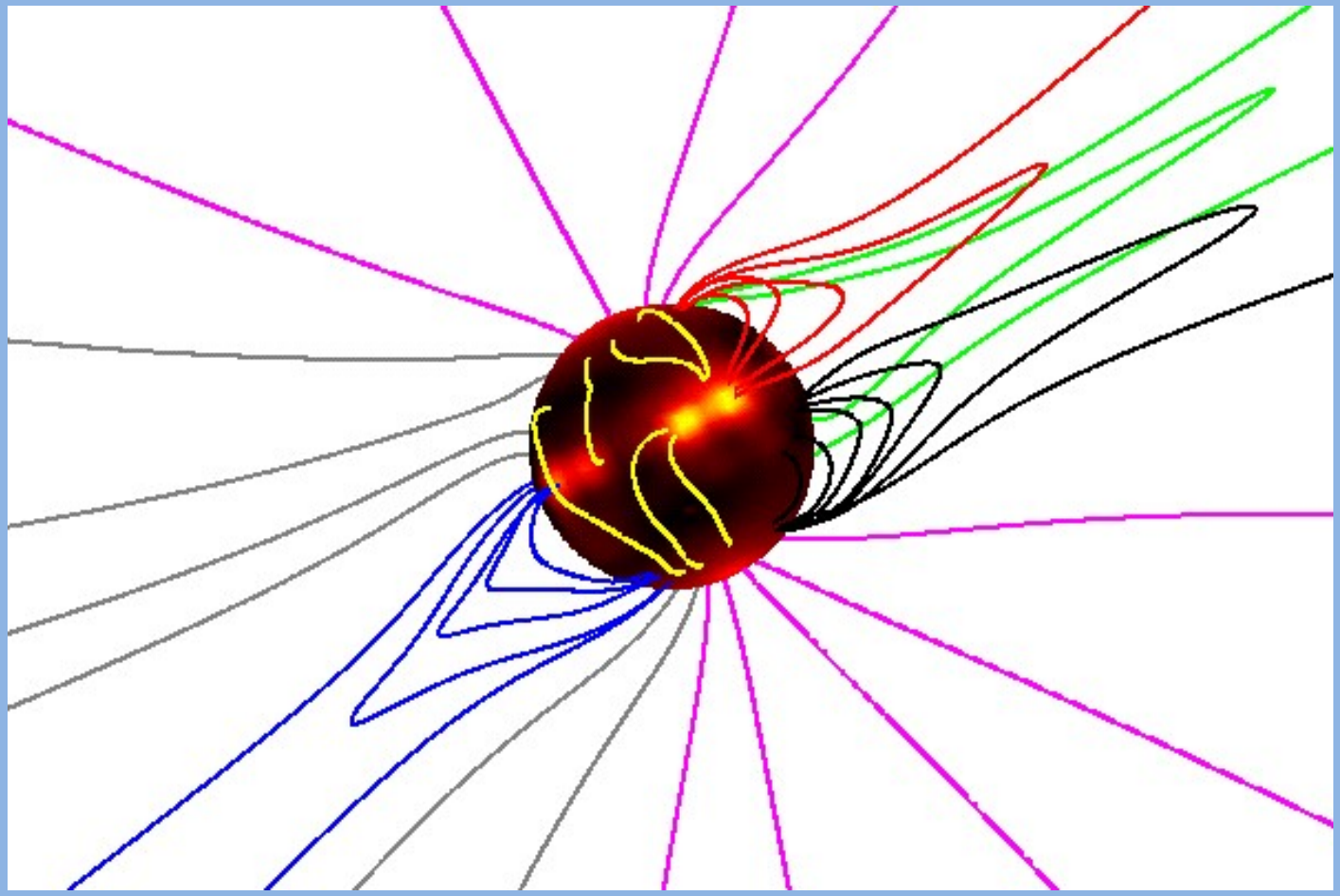
- Electrons, disassociated from atoms, circulate in the convective zone
  - Michael Faraday proved that moving electric charges (electrons) generate a magnetic field
  - Sun's magnetic field at the surface is about 1.0 Gauss
    - Earth's magnetic field at the surface is about 0.5 Gauss
    - A typical refrigerator magnet is about 100 Gauss
- Sun's surface is 12,000 times as large as earth's surface => magnetic field is 24,000 times greater than earth's

Earth Has a Very Structured Magnetic Field



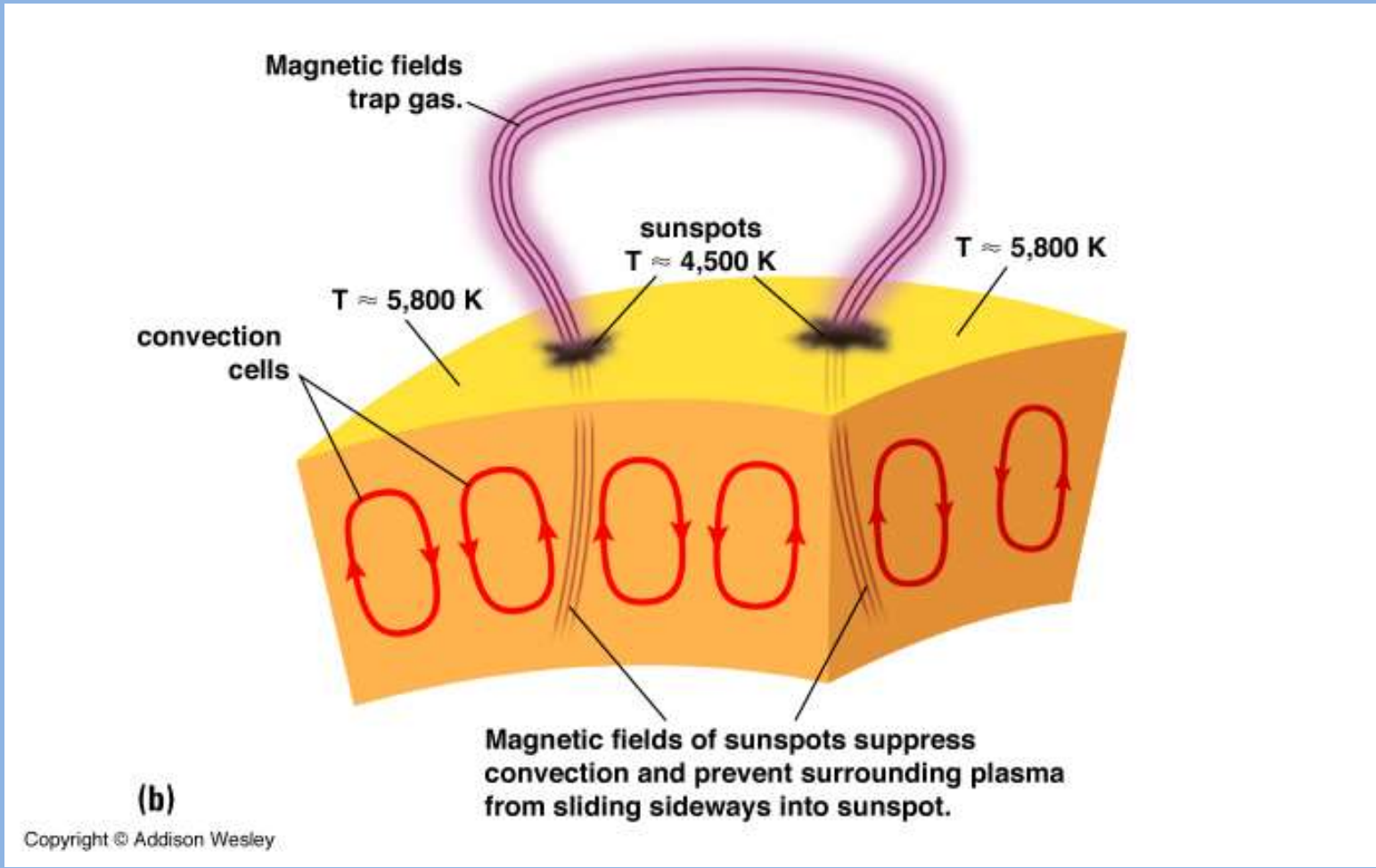
Credit: sott.net – Science and Technology

The Sun Has a More-Complex Magnetic Field



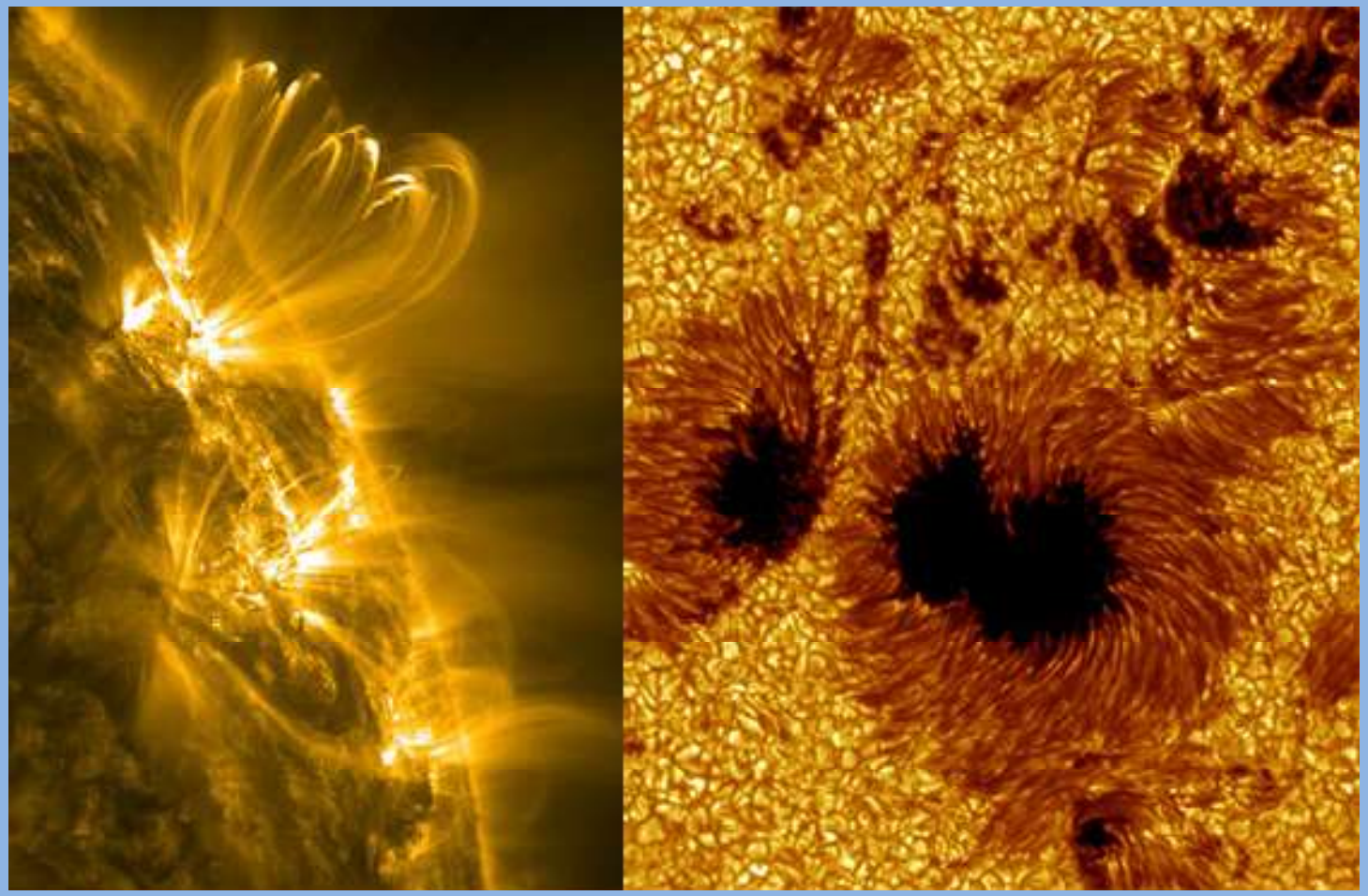
Credit: Windows to the Universe – The Sun's Magnetic Field

Sometimes There Are Loops of Magnetic Energy Forming Sunspots



Credit: © Addison Wesley

Sunspots Are Often in Groups



Credit: Royal Swedish Academy of Sciences - Göran Scharmer and Mats Löfdahl (sunspots) and NASA/SDO and the AIA, EVE, and HMI science teams (coronal loops).

Sunspots Are Formed by Motions Inside the Sun

- An active region on the sun is an area with an especially strong magnetic field
- Active regions are most common during the peak of the sunspot cycle when the sun's magnetic field is highly disturbed
- Active regions appear bright in X-ray and ultraviolet images of the sun. The powerful magnetic fields around active regions release intense bursts of energy, which often take the form of high-energy X-ray and UV photons

Sunspot Cycles

- The duration of the sunspot cycle is, on average, around eleven years
  - Between 1700 and the present, the sunspot cycle has varied in length from as short as nine years to as long as fourteen years
  - Of the 26 solar cycles during that three-century span, 21 had a length between ten and twelve years.

Sunspot Cycles

- The 11-year sunspot cycle is actually half of a longer, 22-year cycle of solar activity
  - Each time the sunspot count rises and falls, the magnetic field of the sun associated with sunspots reverses polarity; the orientation of magnetic fields in the sun's northern and southern hemispheres switches
  - In terms of magnetic fields, the solar cycle is only complete (with the fields back the way they were at the start of the cycle) after two 11-year sunspot cycles. This solar cycle is, on average, about 22 years long—twice the duration of the sunspot cycle

Longer Sunspot Cycles

- There is evidence for other, longer-period variations in the sunspot and solar cycles
  - Besides these regular cycles, the sun has exhibited periods of very unusual sunspot counts. Most notably, from about 1645 to 1715 there were very few sunspots—in some years none at all were observed
  - This period, now called the Maunder Minimum (after E.W. Maunder, who did important pioneering work related to this phenomenon), corresponded to an extremely cold spell in Europe known as the Little Ice Age

Maunder Minimum

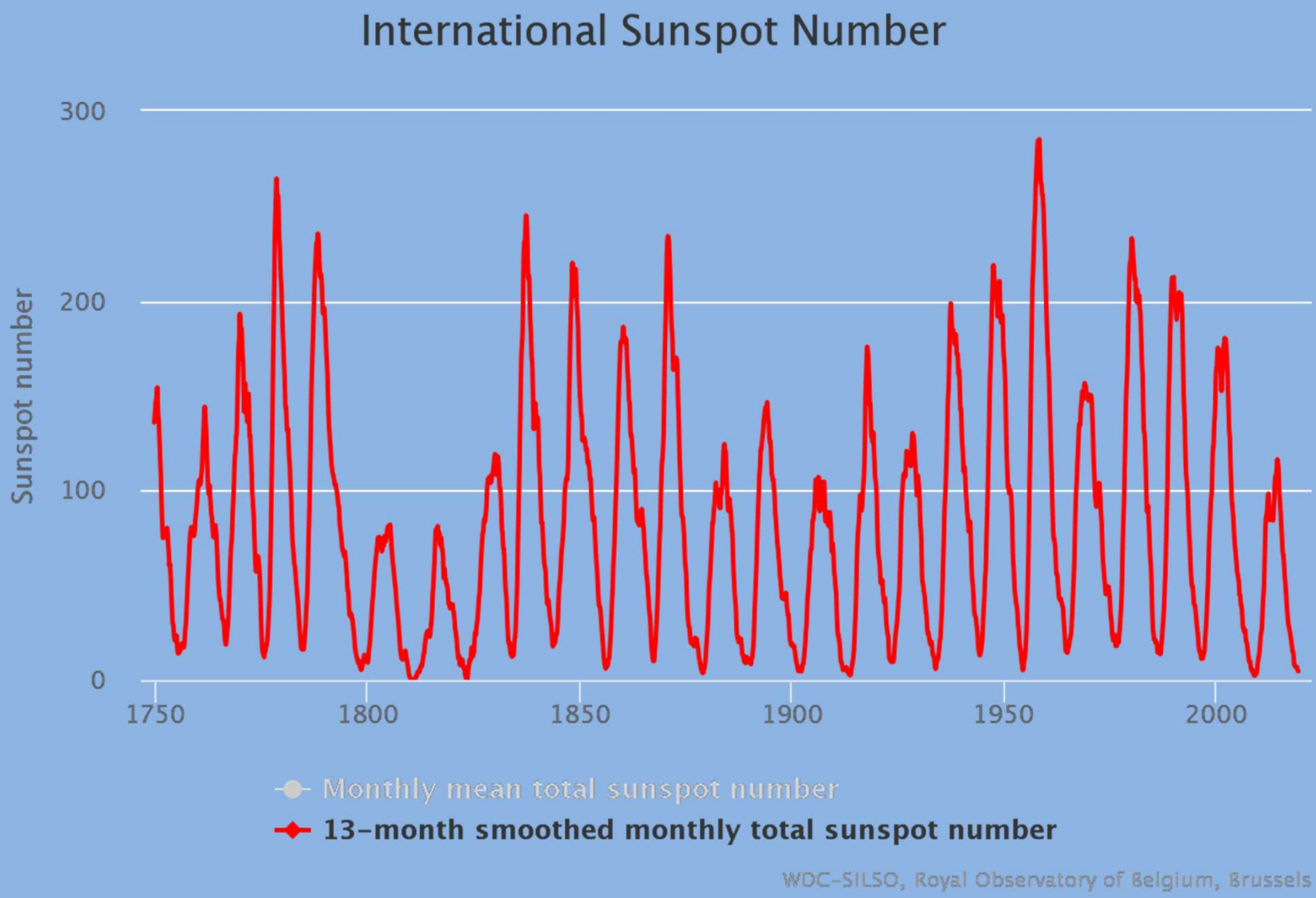
Pieter Bruegel the Elder – Winter Landscape with Skaters and Bird Traps

Longer Sunspot Cycles

- "The resulting summary curve, which is linked to the solar activity curve defined by the averaged sunspot numbers, restored backward for 3000 years, shows about 9 grand cycles of 350–400 years, with the times of their grand minima having remarkable resemblance to those reported from the sunspot and terrestrial activity in the past millennia"
  - Maunder (grand) Minimum (1645–1715)
  - Wolf grand minimum (1200)
  - Oort grand minimum (1010–1050)
  - Homer grand minimum (800–900 BCE)
- Combined with the warming periods:
  - Medieval (900–1200)
  - Roman (400–10 BCE)
  - "And other ones occurred between the grand minima"

Credit: www.nature.com/scientificreports: Oscillations of the baseline of solar magnetic field and solar irradiance on a millennial timescale

Longer Sunspot Cycles



Longer Sunspot Cycles

- One theory suggests these ‘grand solar cycles’ are the result of a ‘dual dynamo’ in the sun
  - Electric charges at two or more different depths in the sun are moving at different speeds and/or in different directions
  - Observational evidence is probably impossible to obtain, so modeling is difficult or impossible
  - Models of this complexity involve differential equations ☹

Credit: www.nature.com/scientificreports: Oscillations of the baseline of solar magnetic field and solar irradiance on a millennial timescale

Are We in a Low Sunspot Cycle?

- Forecasts are as numerous as there are forecasters
  - "Researchers are still learning to predict the ebb and flow of solar activity. Forecasting techniques range from physical models of the sun's inner magnetic dynamo to statistical methods akin to those used by stock market analysts"

Credit: spaceweatherarchive.com: Experts Predict a Long, Deep Solar Minimum

Are We in a Low Sunspot Cycle?

- “We assessed ~61 predictions in the following categories: Climatology, Dynamo, Machine Learning/Neural Networks, Precursor Methods, Spectral/Statistical Methods, Surface Flux Transport, and Other,” says Upton. “The majority agreed that Solar Cycle 25 would be very similar to Solar Cycle 24.”

Credit: spaceweatherarchive.com: Experts Predict a Long, Deep Solar Minimum

Are We in a Low Sunspot Cycle?

- "As you can see–we haven't quite reached the lowest levels of the last cycle–where we experienced several consecutive months with no sunspots. However, the panel expects that we should reach those levels [between now and the end of 2020]."

Credit: spaceweatherarchive.com: Experts Predict a Long, Deep Solar Minimum

Others Focus on the Long-Term Cycles

- “We calculated the double dynamo summary curve of magnetic field variations backward one hundred thousand years allowing us to confirm strong oscillations of solar activity in regular (11 year) and recently reported grand (350–400 year) solar cycles caused by actions of the double solar dynamo.”
- “In addition, oscillations of the baseline (zero-line) of magnetic field with a period of 1950 ± 95 years (a super-grand cycle) are discovered by applying a running averaging filter to suppress large-scale oscillations of 11 year cycles.”

Credit: www.nature.com/scientificreports: Oscillations of the baseline of solar magnetic field and solar irradiance on a millennial timescale

Others Focus on the Long-Term Cycles

- “Latest minimum of the baseline oscillations is found to coincide with the grand solar minimum (the Maunder minimum) occurred before the current super-grand cycle start.”

Credit: www.nature.com/scientificreports: Oscillations of the baseline of solar magnetic field and solar irradiance on a millennial timescale

Longer Sunspot Cycles

"This approach allowed us to predict the modern grand solar minimum (GSM) approaching the sun in 2020–2055"

Credit: www.nature.com/scientificreports: Oscillations of the baseline of solar magnetic field and solar irradiance on a millennial timescale

What Are We to Do?

What Are We to Do?

FT8

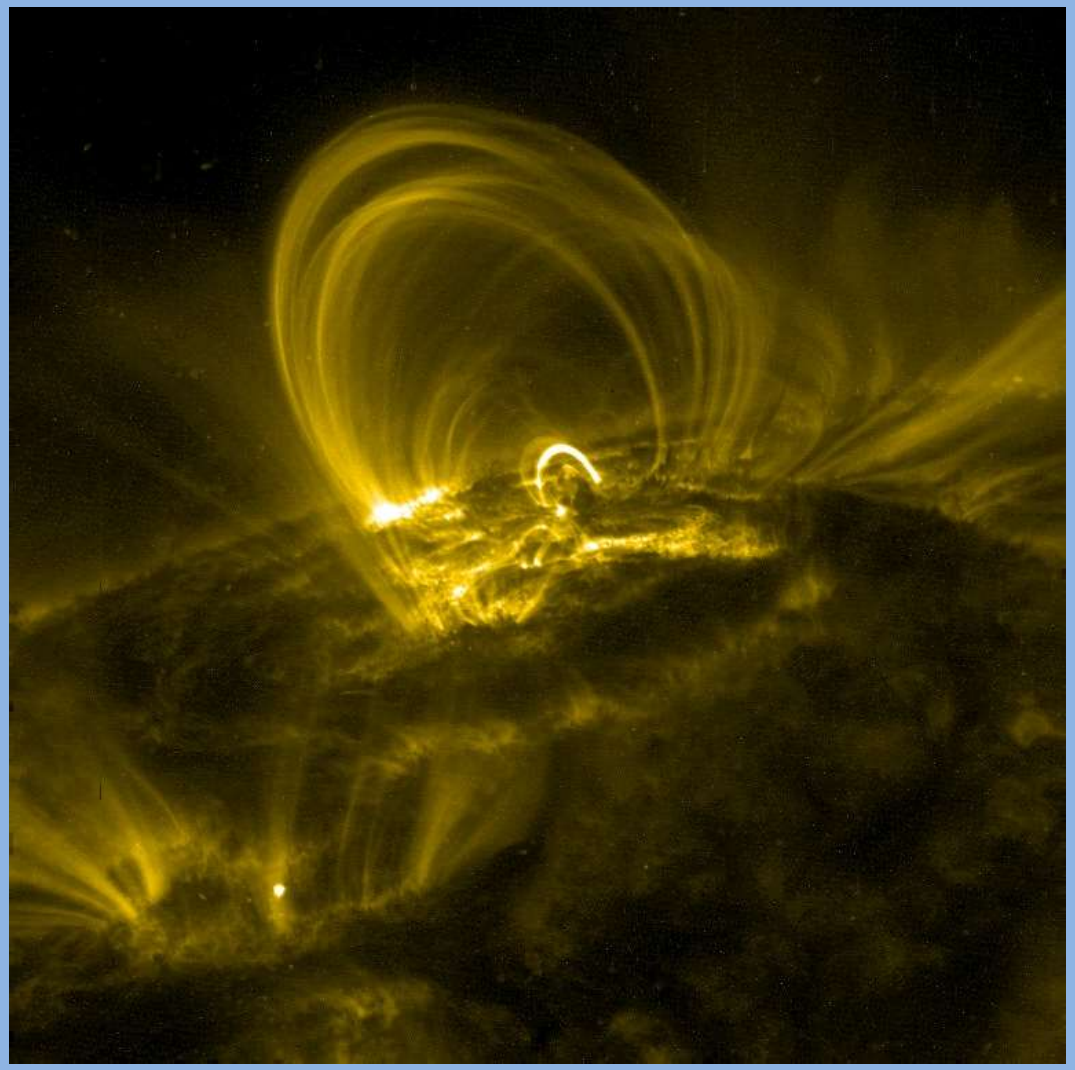
Good Sun, Bad Sun

- An active sun with lots of sunspots is beneficial for HF communication
- An active sun can also generate effects that are bad both for HF communication and for our modern infrastructure
  - Solar flares/failed solar prominences
    - The magnetic field lines near sunspots often tangle, cross, and reorganize. This can cause a sudden explosion of energy called a solar flare
    - Can wipe out HF communication by energizing the D-layer of the ionosphere

Good Sun, Bad Sun

- An active sun can also generate effects that are bad both for HF communication and for our modern infrastructure
  - Coronal Mass Ejections (CMEs)
    - CMEs are huge bubbles of radiation and particles from the sun. They explode into space at very high speed when the sun's magnetic field lines suddenly reorganize
    - Can wipe out HF communication by energizing the D-layer of the ionosphere
    - If severe, can damage electrical equipment and well as the electricity grid itself

Magnetic Loops – Solar Prominences



Credit: By NASA - http://trace.lmsal.com/POD/TRACEpodarchive24.html (direct link), Public Domain, https://commons.wikimedia.org/w/index.php?curid=3961471

Solar Flares

- Generally occur when magnetic loops twist beyond their strength and fail, producing tremendous explosions on the surface of the sun
  - In a matter of just a few minutes they heat material to many millions of degrees and release as much energy as a gigaton of TNT. They occur near sunspots, usually along the dividing line (neutral line) between areas of oppositely directed magnetic fields

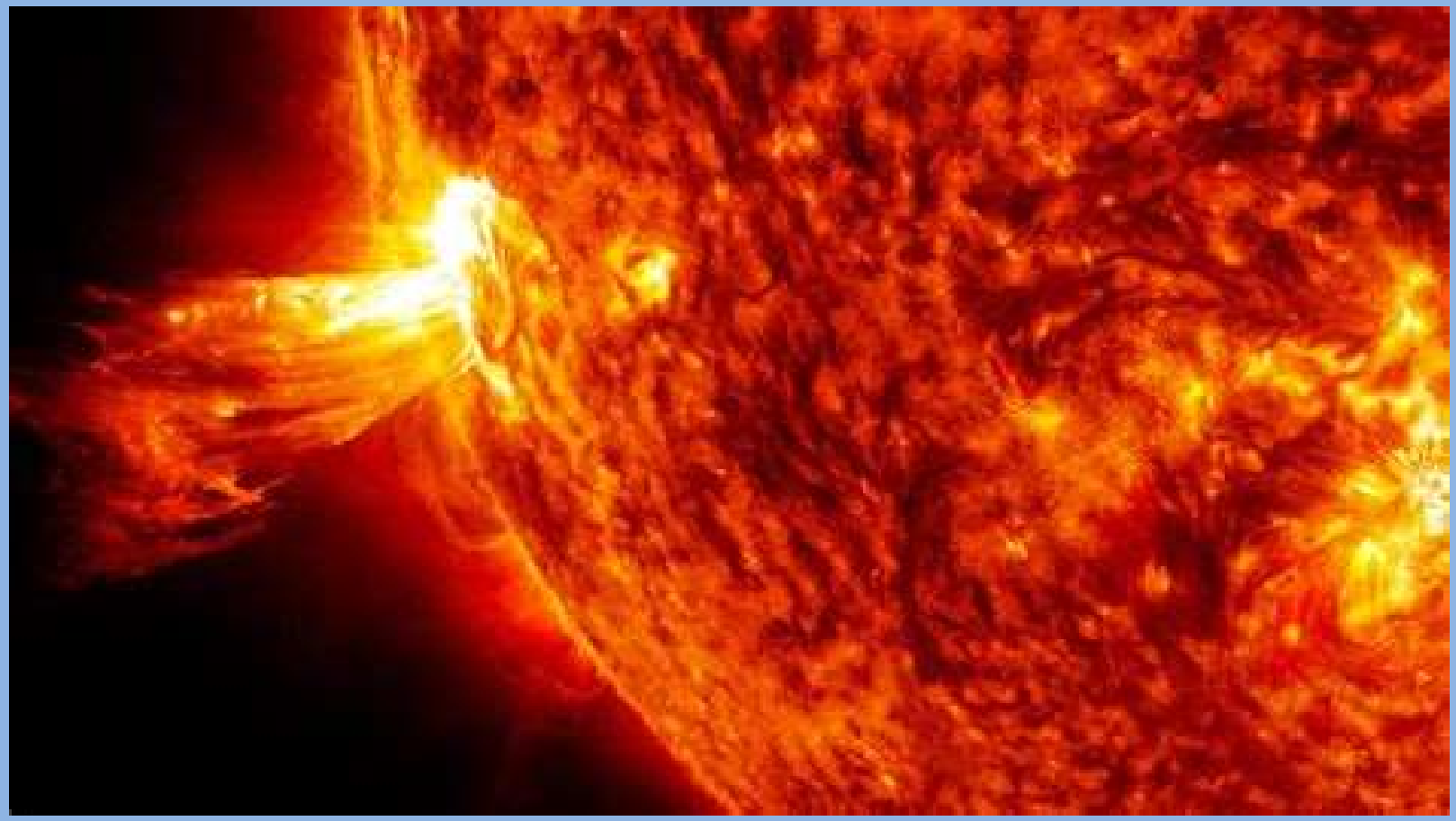
Credit: NASA Marshall Space Field Center – Solar Flares

Solar Flares

- Flares release energy in many forms
  - Electro-magnetic (gamma rays and X-rays)
  - Energetic particles (protons and electrons)
  - Mass flows
- Flares are characterized by their brightness in X-rays (X-Ray flux).
  - The biggest flares are X-Class flares
  - M-Class flares have a tenth the energy seen in X-Class flares
  - C-Class flares have a tenth the energy seen in M-Class flares

Credit: NASA Marshall Space Field Center – Solar Flares

Coronal Mass Ejections (CMEs)



Credit: EurekAlert! Science News

Coronal Mass Ejections (CMEs)

- CMEs usually are associated with solar flares
  - Coronal mass ejections release large quantities of matter and electromagnetic radiation into space above the sun's surface
  - The ejected material is a magnetized plasma consisting primarily of electrons and protons
    - While the terrestrial effects of solar flares are very fast (limited by the speed of light), CMEs are relatively slow, perhaps a million MPH
    - Takes perhaps 90-100 hours to arrive

https: //en.wikipedia.org/wiki/Coronal_mass_ejection

Coronal Mass Ejections (CMEs)

- When the ejection is directed towards earth and reaches it, the shock wave of traveling mass causes a geomagnetic storm that may disrupt earth's magnetosphere, compressing it on the day side and extending the night-side magnetic tail. When the magnetosphere reconnects on the night-side, it releases power on the order of terawatt scale, which is directed back toward earth's upper atmosphere

https: //en.wikipedia.org/wiki/Coronal_mass_ejection

Coronal Mass Ejections (CMEs)

- Coronal mass ejections can disrupt radio transmissions and cause damage to satellites and electrical transmission line facilities, resulting in potentially massive and long-lasting power outages
- Energetic protons released by a CME can cause an increase in the number of free electrons in the ionosphere. The increase in free electrons can enhance radio wave absorption, especially within the D-region of the ionosphere

https: //en.wikipedia.org/wiki/Coronal_mass_ejection

Solar Storm of 1859: The Carrington Event

- On September 1–2, 1859, one of the largest recorded geomagnetic storms (as recorded by ground-based magnetometers) occurred
  - Auroras were seen around the world, those in the northern hemisphere as far south as the Caribbean
  - Telegraph systems all over Europe and North America failed, in some cases giving telegraph operators electric shocks

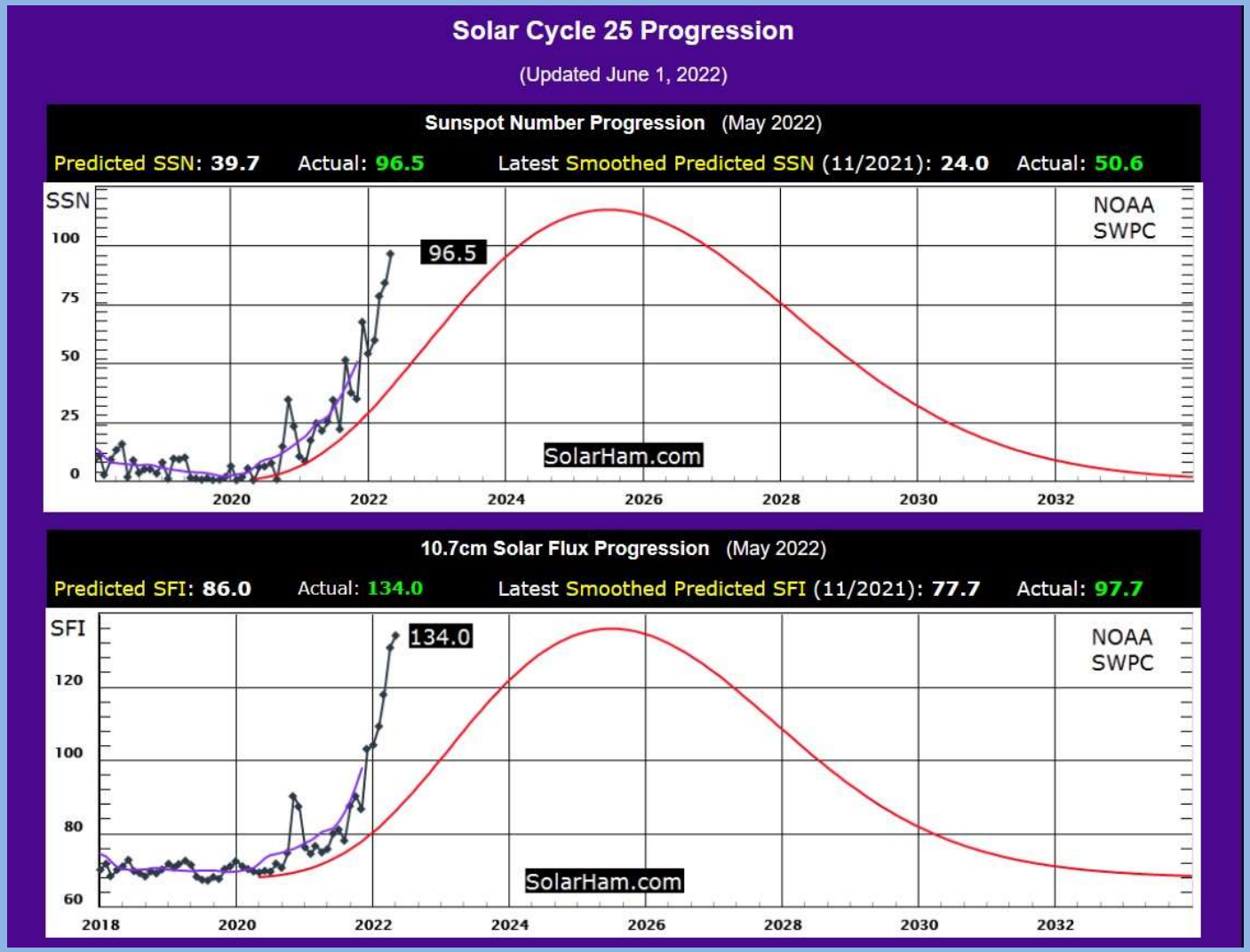
https://en.wikipedia.org/wiki/Solar_storm_of_1859

Solar Storm of 1859: The Carrington Event

- On September 1–2, 1859, one of the largest recorded geomagnetic storms (as recorded by ground-based magnetometers) occurred
  - Telegraph pylons threw sparks
  - Some telegraph operators could continue to send and receive messages despite having disconnected their power supplies
  - In June 2013, a joint venture from researchers at Lloyd's of London and Atmospheric and Environmental Research (AER) in the United States used data from the Carrington Event to estimate the current cost of a similar event to the U.S. alone at $0.6–2.6 trillion

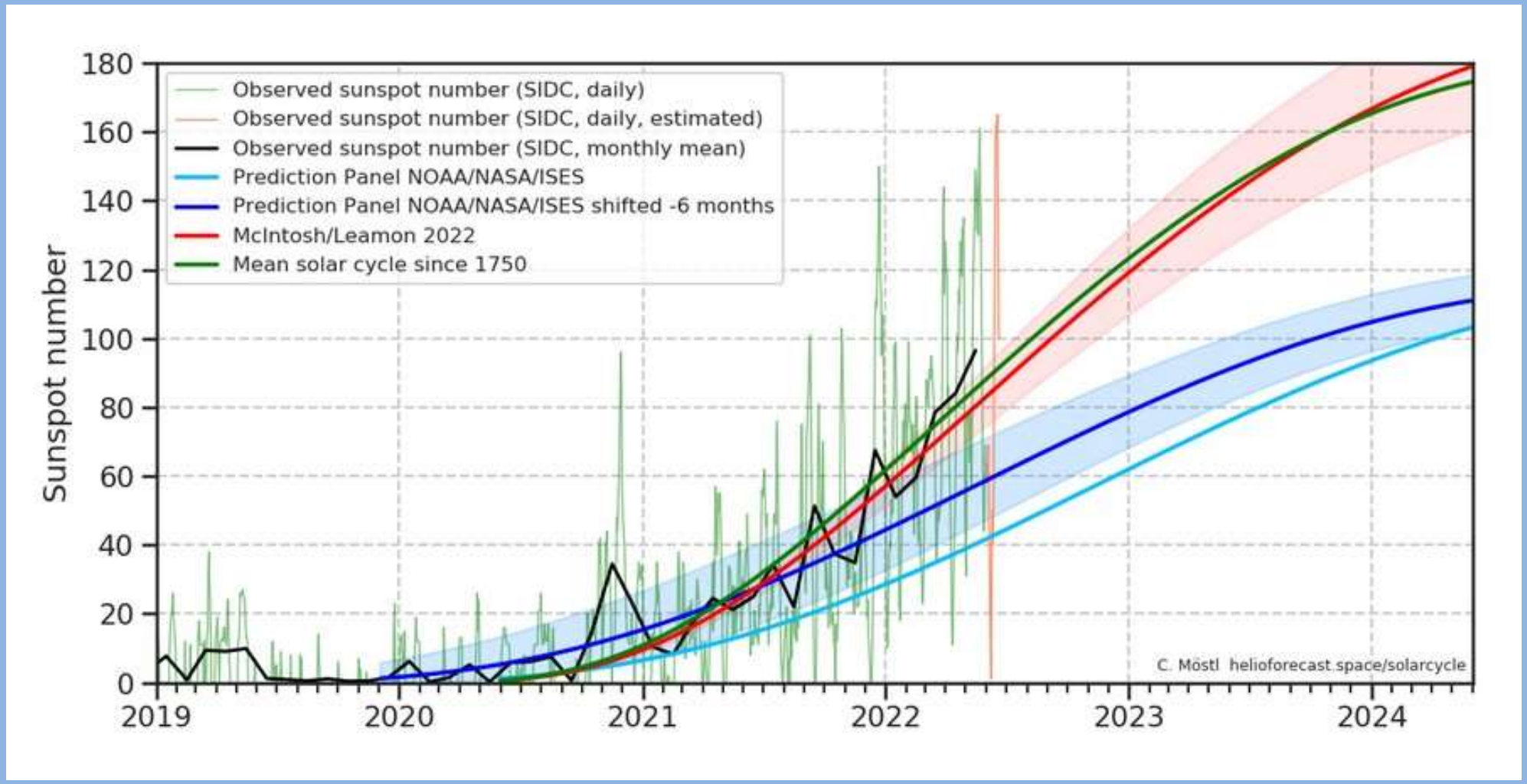
https://en.wikipedia.org/wiki/Solar_storm_of_1859

What if Cycle 25 Is Stronger than Expected?



Source: Solarham.com

Forecast from NCAR Scientist Scott McIntosh



Source: https://helioforecast.space/solarcycle

What if Cycle 25 Is Stronger than Expected?

- That's terrific, right!!!
  - Great DXing
  - QRP DXCC
  - ATNOs for many very rare entities
- Yeah, but CMEs increase in frequency and magnitude on an active Sun
  - Well, how bad can it get?
  - …Really, really BAD

The Carrington Event Is not the Largest in History

- A similar-size event in Cycle 15 called the 'New York Railroad Storm' occurred in May 1921
- In earlier times, there were much larger CME events
  - A 'Super Flare CME' struck the Earth in 775 CE
    - Flare was **more than 100 times** the power of Carrington Event
    - Identified by Professor Fusa Miyake of Nagoya University using Beryllium 10 spikes in ice cores
    - Others identified in 5259 BCE and 7176 BCE
      - Dates established using tree rings

Twenty-First Century Infrastructure Is Sensitive to Induced Currents

- Passing electric and magnetic fields from CMEs will induce currents of varying voltages and frequencies in any conductor
- Voltages can be very high, enough to destroy electronic components
- Breakdown voltages for semiconductors including integrated circuits are very low
  - Ever seen ‘magic smoke’ from a 3.3vdc device receiving 5.0vdc?

Transformers Are the Most-Vulnerable Element of 21st-Century Infrastructure

- There are hundreds of thousands of transformers in North America
- They come in various sizes, capacities, and voltage transformations
  - Some are customized
- This issue is so obvious that the U.S. Department of Homeland Security is starting to stockpile transformers

Transformers Are the Most-Vulnerable Element of 21st-Century Infrastructure

- Random AC frequencies varying only small amounts from 60Hz (North America) or 50Hz (Europe/Japan) will explode transformers
  - Transformers include two (or more) inductors that are frequency sensitive
- Induced DC is also a problem as utility transformers get saturated and lose their ability to transform the AC portion of the wave since it gets offset upwards with the superimposed DC component.
  - Transformers need DC blocking capacitors across the leads.
    - Utilities are slow in installing the needed capacitors.

There Is Even A Dramatization of This Happening

- Season one of the British TV series 'COBRA' dramatized the engineering and political impact of a modest solar flare event in the UK
  - Broadcast on PBS in the US in 2020
  - 'COBRA' is not one of those dramatic/exciting acronyms for the British crisis management group. It stands for the Cabinet Office Conference Room 'A'
- "A massive solar flare strikes Europe, blowing the electric grid and navigational systems, leaving much of Britain without power and creating social and political chaos. As a result, the Prime Minister must decide how and where to distribute a limited number of relief generators to provide power"

Quote Source: Wikipedia

Another Super Flare in CME
in Cycle 25?

A World Without Electricity – Living Again in 775 CE

n.b.: The Dark Ages…again


That's all Folks!

Access to Information

- Today's Slides
  - www.terryadennison.com/Sunspots.htm

- Science Article - *Oscillations of the baseline of solar magnetic field and solar irradiance on a millennial timescale*
  - https://doi.org/10.1038/s41598-019-45584-3

Access to Information

- Article Discussing Implications of a Carrington-Level Event – Royal Academy of Engineering Report (2013)
  - https://www.raeng.org.uk/publications/reports/space-weather-summary-report
- Article Discussing Implications of Voltage Levels and Frequencies (sic) Variation (2014)
  - https://pdhonline.com/courses/e437/e437content.pdf