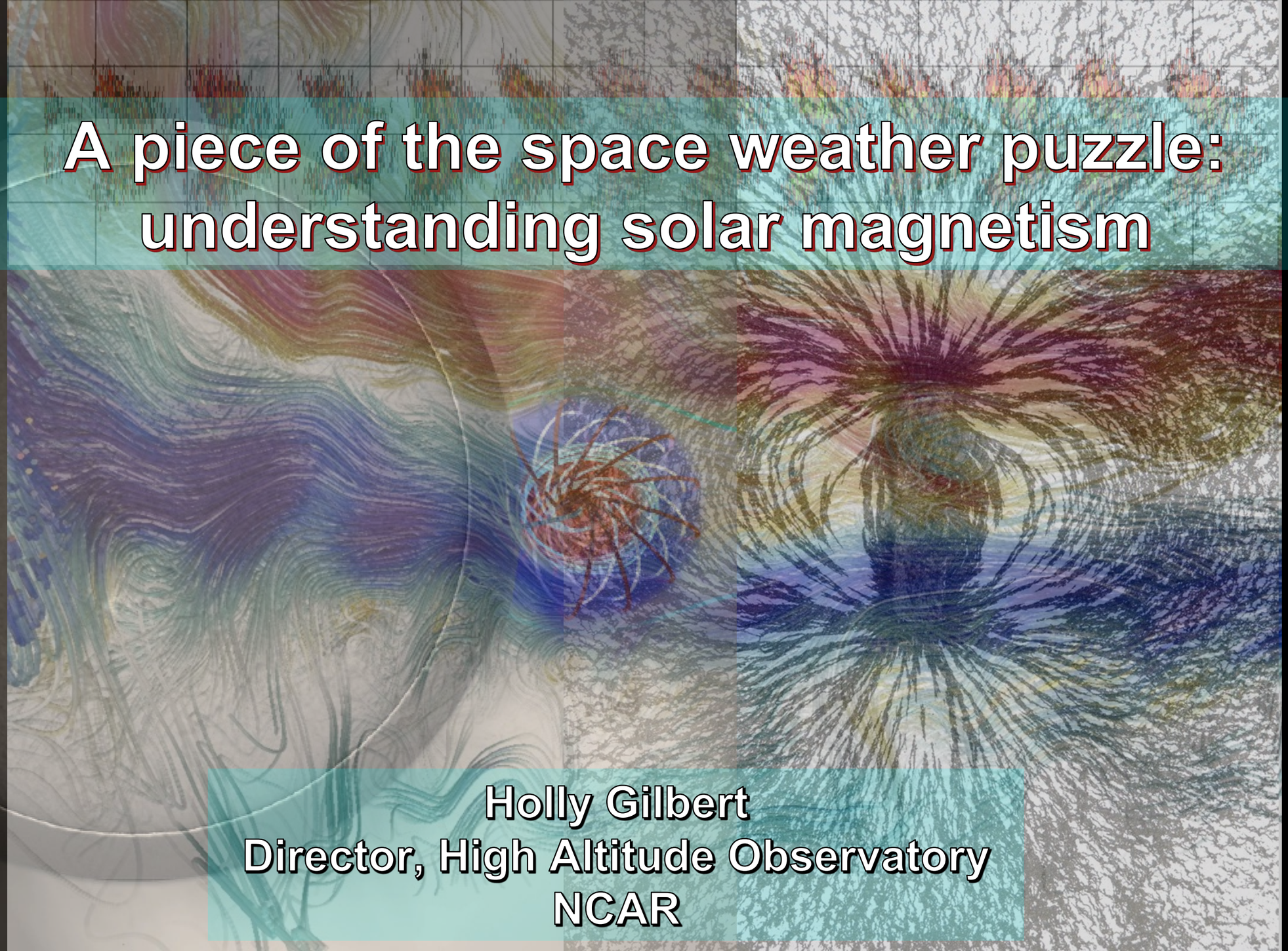
A piece of the space weather puzzle: understanding solar magnetism

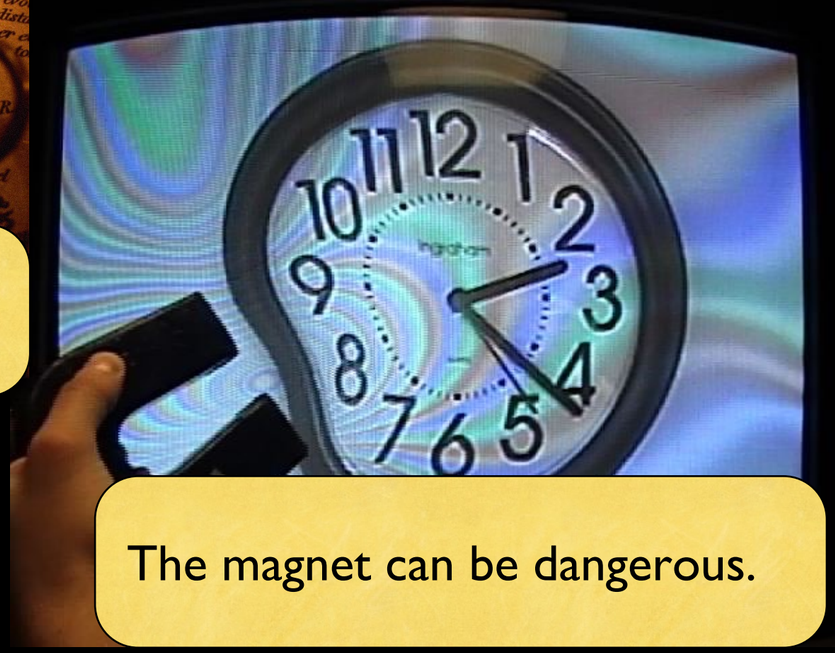


Holly Gilbert
Director, High Altitude Observatory
NCAR

Magnetism at home

The magnet is alive!

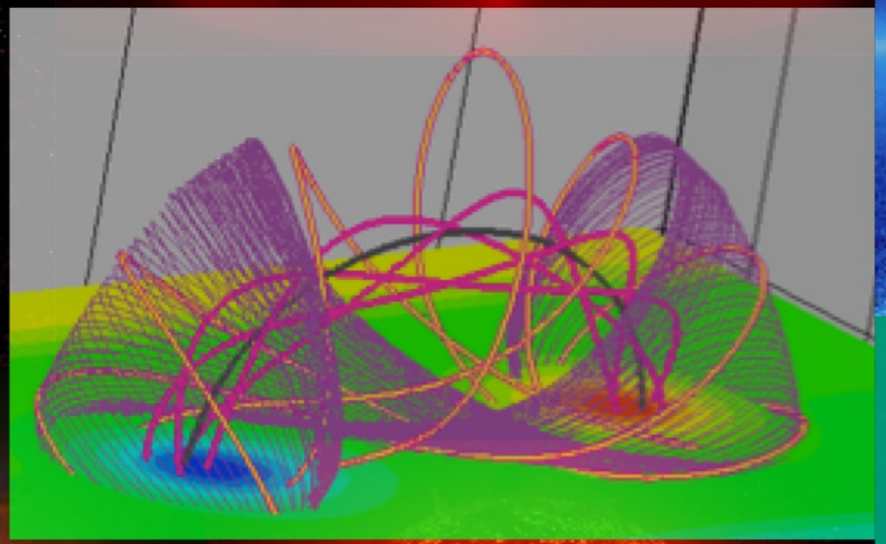
The magnet is useful…

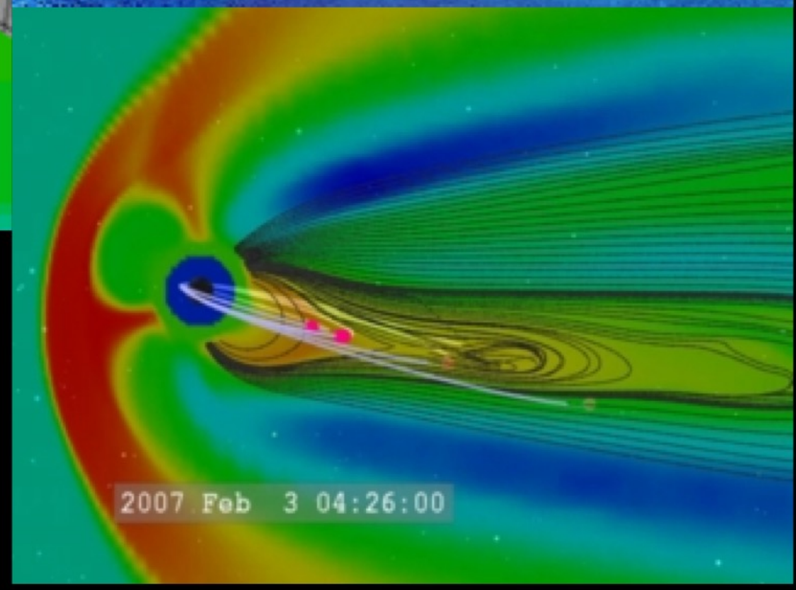


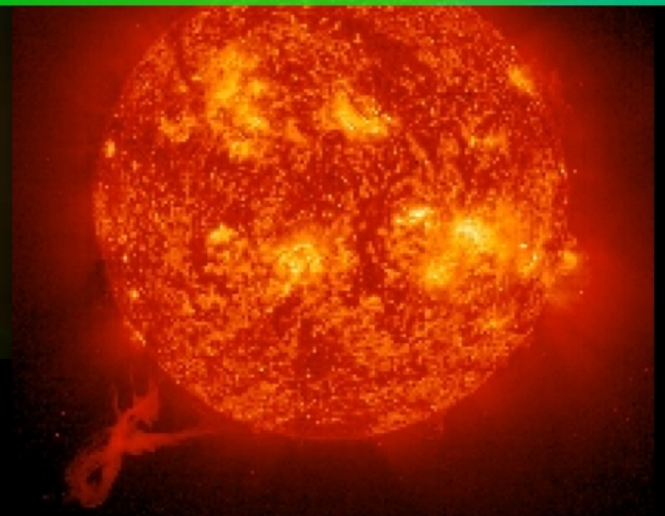
The magnet can be dangerous.

Magnetism across the Universe

Storage and release of magnetic energy



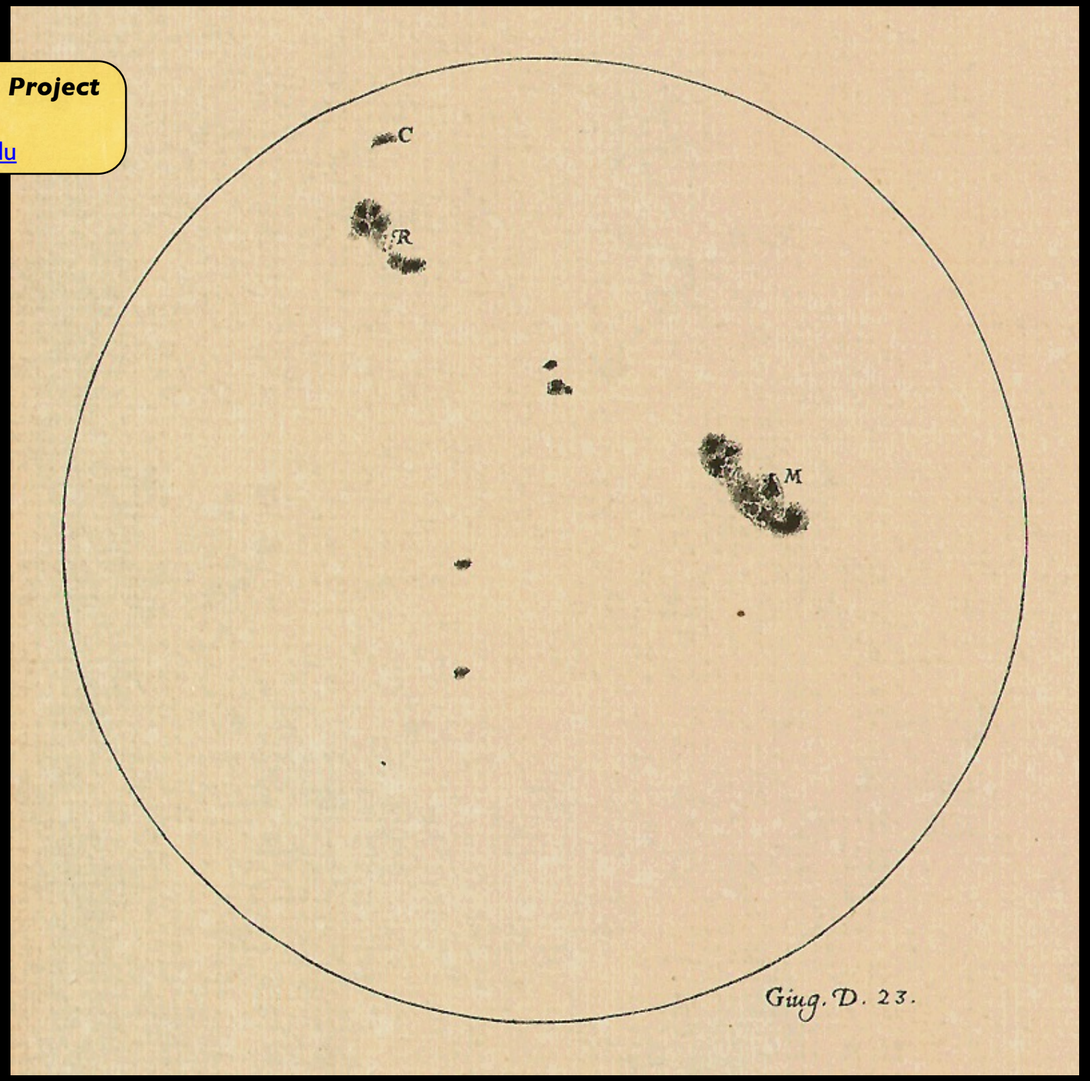




Magnetism across time

Galileo Galilei (1564-1642)

Courtesy of ***The Galileo Project***
Rice University
http://galileo.rice.edu



Sunspots

28 BC: First seen by Chinese Astronomers
1610-1612: Telescopic Observations by Thomas Harriot, Johannes & David Fabricus, Galileo Galilei, Christoph Scheiner
1826-1843: Heinrich Schwabe discovers 11-year sunspot cycle
1850's: Richard Carrington determines that the Sun's equator spins faster than its poles by observing sunspots
1908-1909: George Ellery Hale detects magnetic fields in sunspots 1000 times stronger than those at the surface of the Earth

Magnetism across time

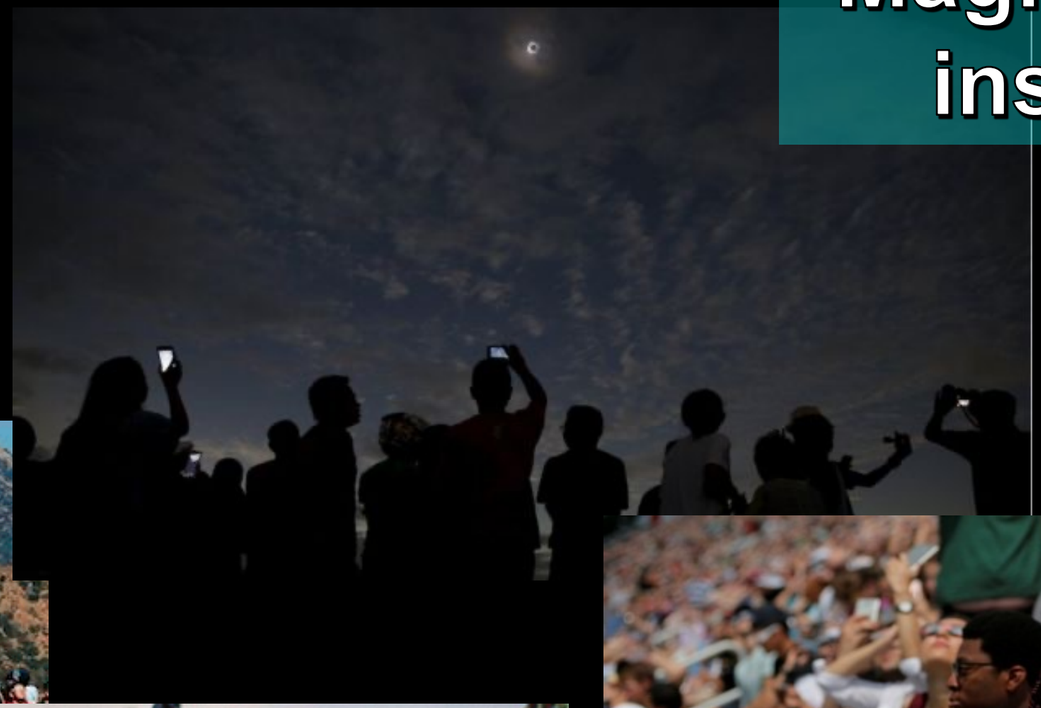
The mysterious corona

Antoine Caron's Painting "Astronomers Studying an Eclipse”, 1571

Early astronomers took advantage of solar eclipses, those rare moments when the moon blocks the Sun in the sky, to catch glimpses of the atmosphere of the Sun

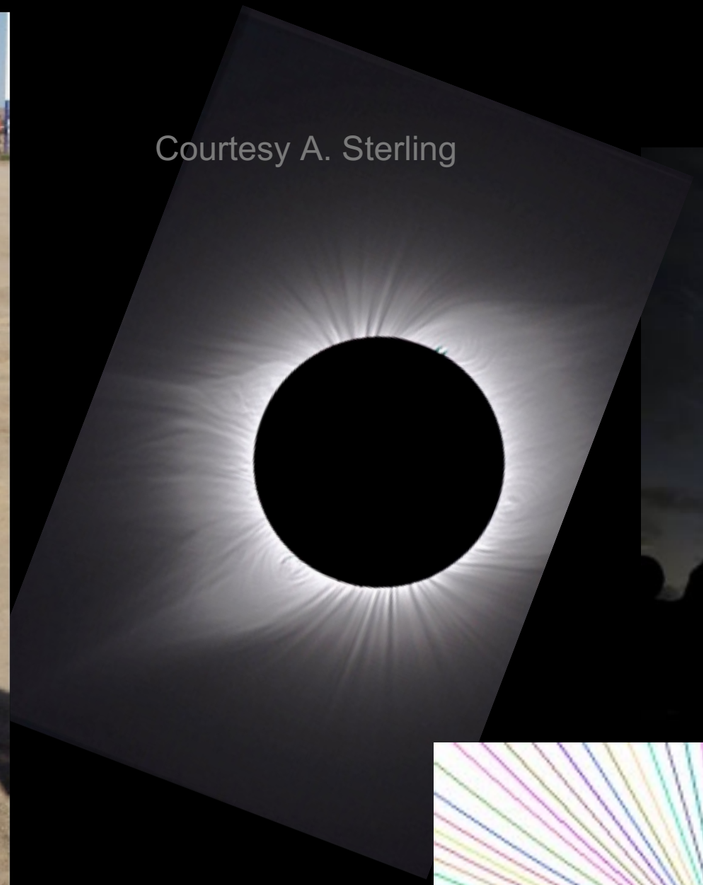
As the human eye adapts to the artificial night, faint wisps of material surrounding the Sun emerge. We called these wisps the corona, Latin for crown

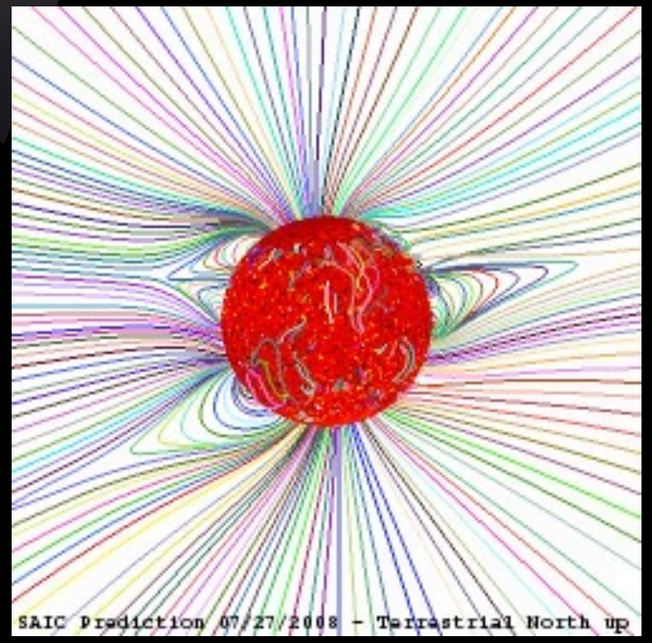
Magnetism is inspiring



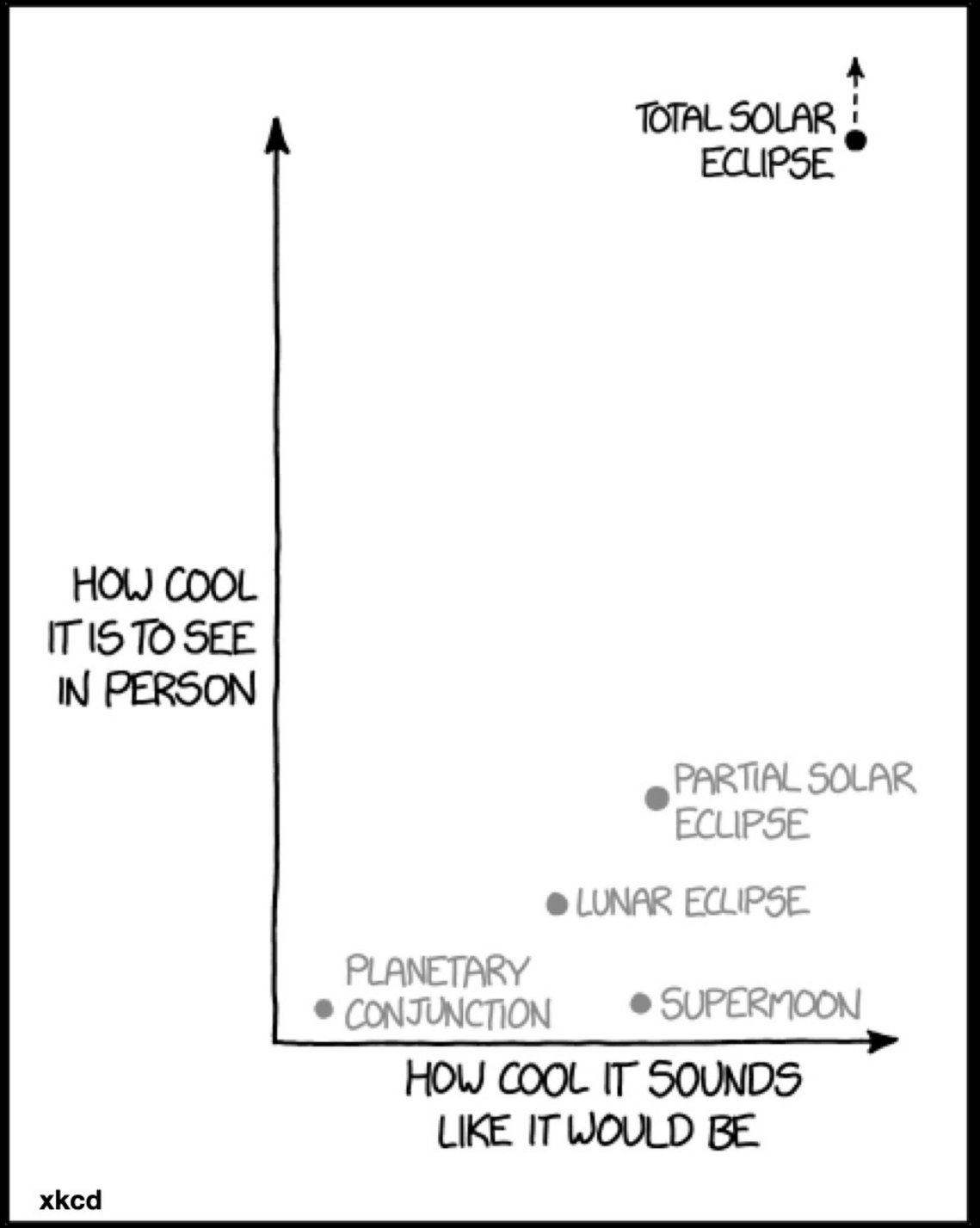
Magnetism is inspiring

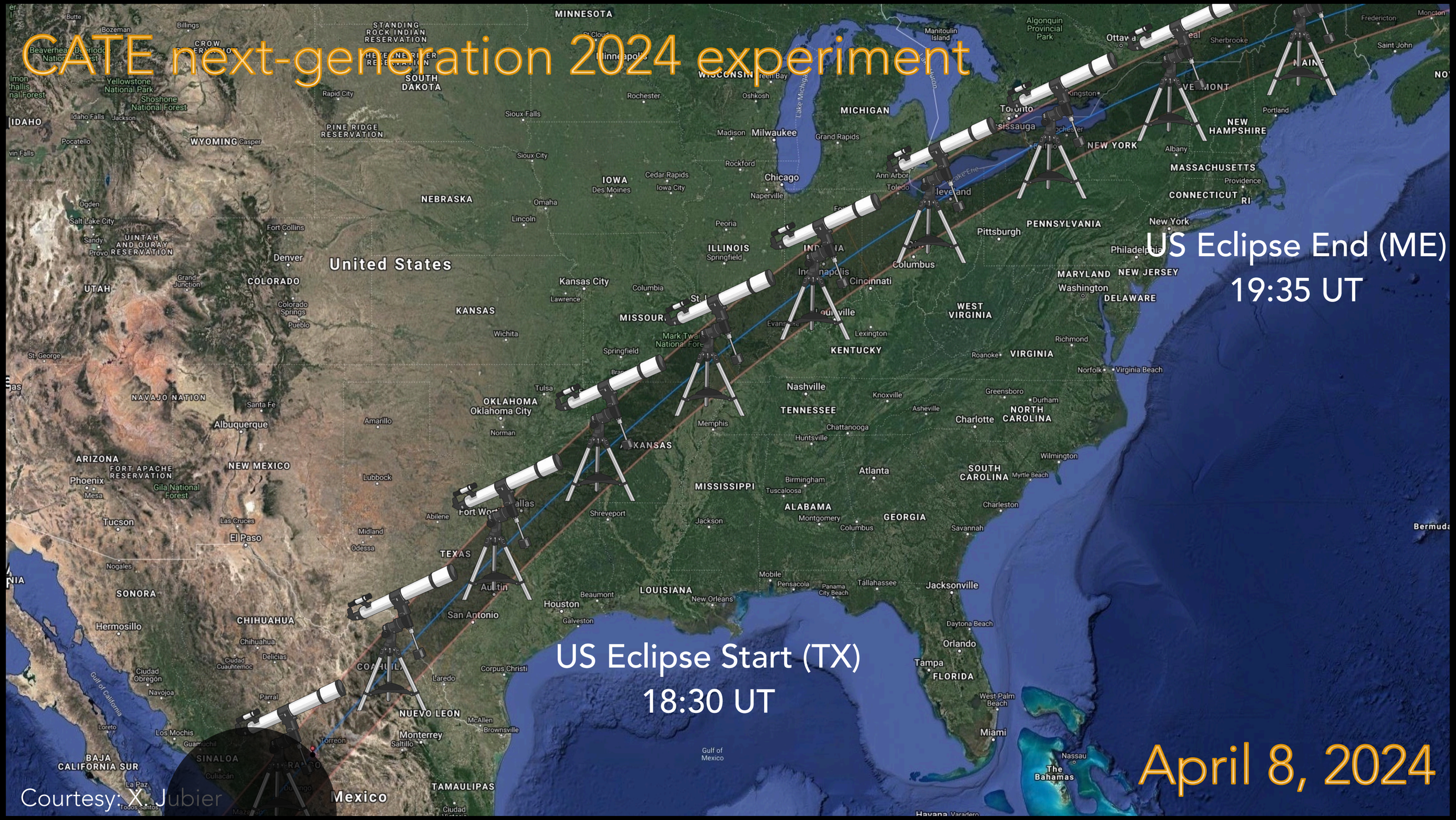
Courtesy A. Sterling





Humans have been "seeing" solar magnetic fields for a long time…


TOTAL SOLAR ECLIPSE
HOW COOL IT IS TO SEE IN PERSON
PARTIAL SOLAR ECLIPSE
LUNAR ECLIPSE
PLANETARY CONJUNCTION
SUPERMOON
HOW COOL IT SOUNDS LIKE IT WOULD BE
xkcd


CATE next-generation 2024 experiment
US Eclipse End (ME)
19:35 UT
US Eclipse Start (TX)
18:30 UT
April 8, 2024
Courtesy: X. Jubier

CATE 2024 will deploy 35+ identical stations run by community participants to capture a 60-minute movie of the inner solar corona in polarized light

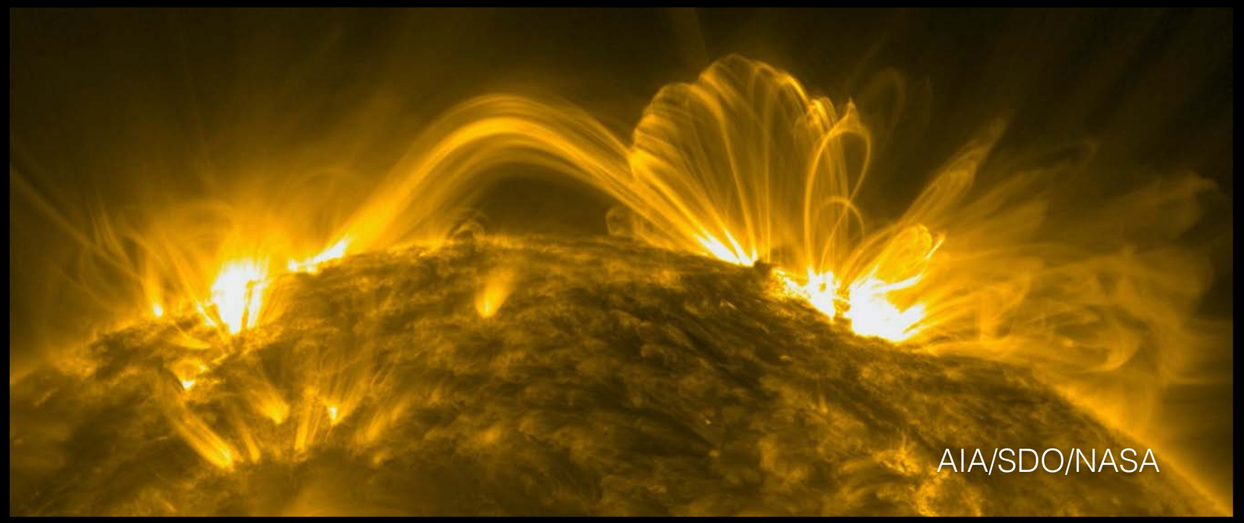
Participant communities keep their telescope setups after the eclipse!

@citizenCATE2024

cate@boulder.swri.edu

Diagnosing the magnetic field

The origins of space weather can be traced back to magnetic fields on the Sun



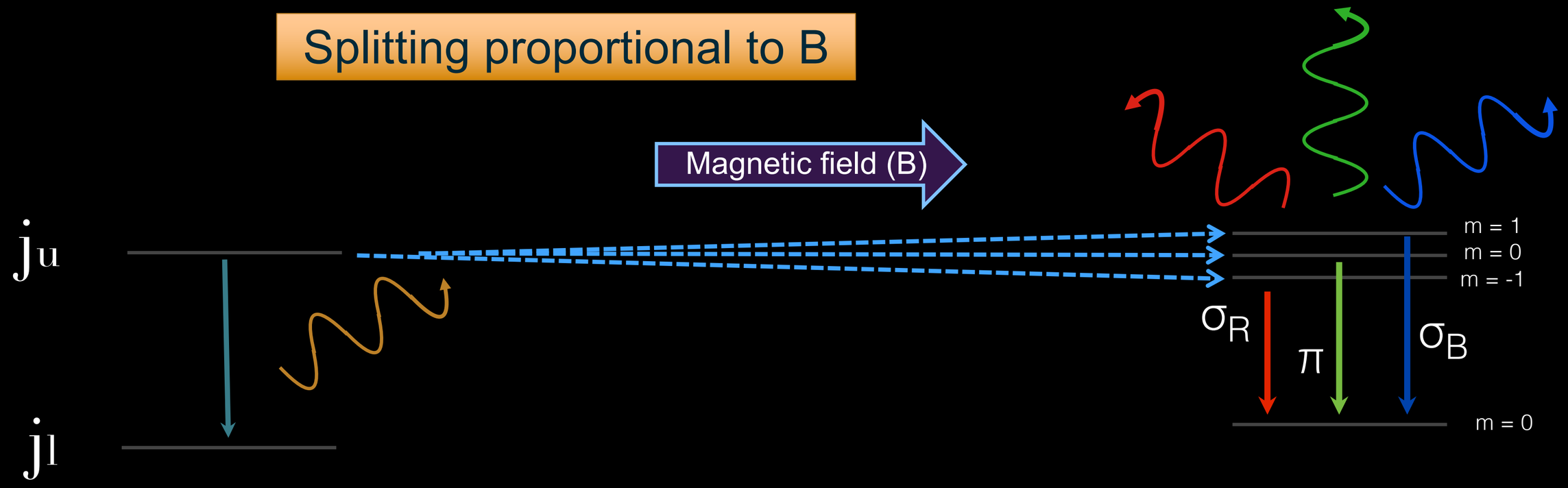
- Magnetic fields leave an imprint on the polarized spectrum of the Sun
- Observations are interpreted through complex models of polarized radiative transfer

Two-pronged approach to study the magnetic origins of space weather

- High-resolution observations to study small-scale magnetic processes
- Large-scale synoptic observations of the Sun as a whole to enable forecasts

Diagnosing the magnetic field- the Zeeman Effect

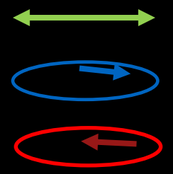
Splitting proportional to B



π-transitions: absorb/emit **linearly polarized** light ∥ B

σ_B-transitions: absorb/emit **right-handed circularly** polarized light ⊥ B

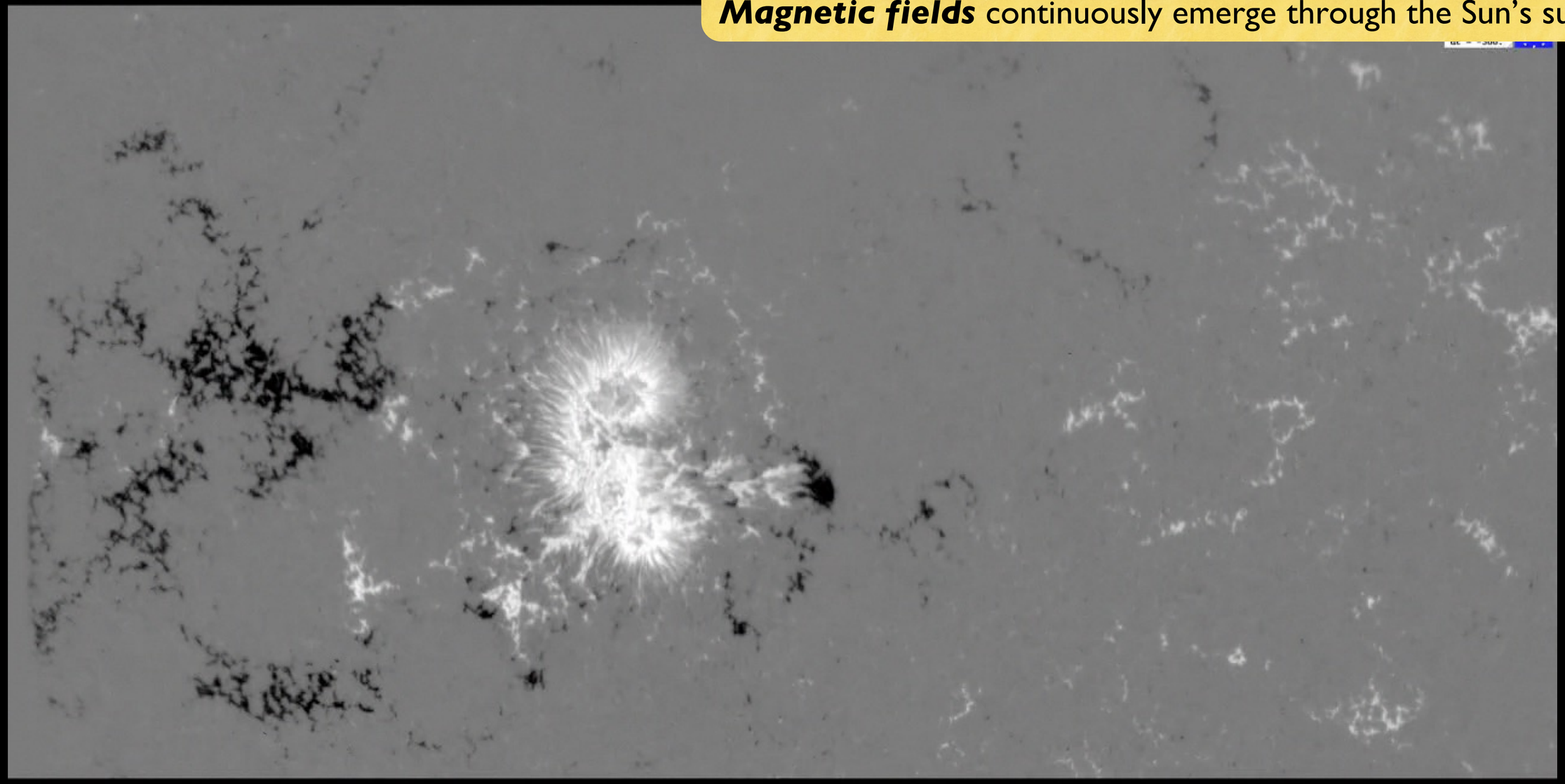
σ_R-transitions: absorb/emit **left-handed circularly** polarized light ⊥ B



The different transitions have different polarizations

Magnetic field in the photosphere

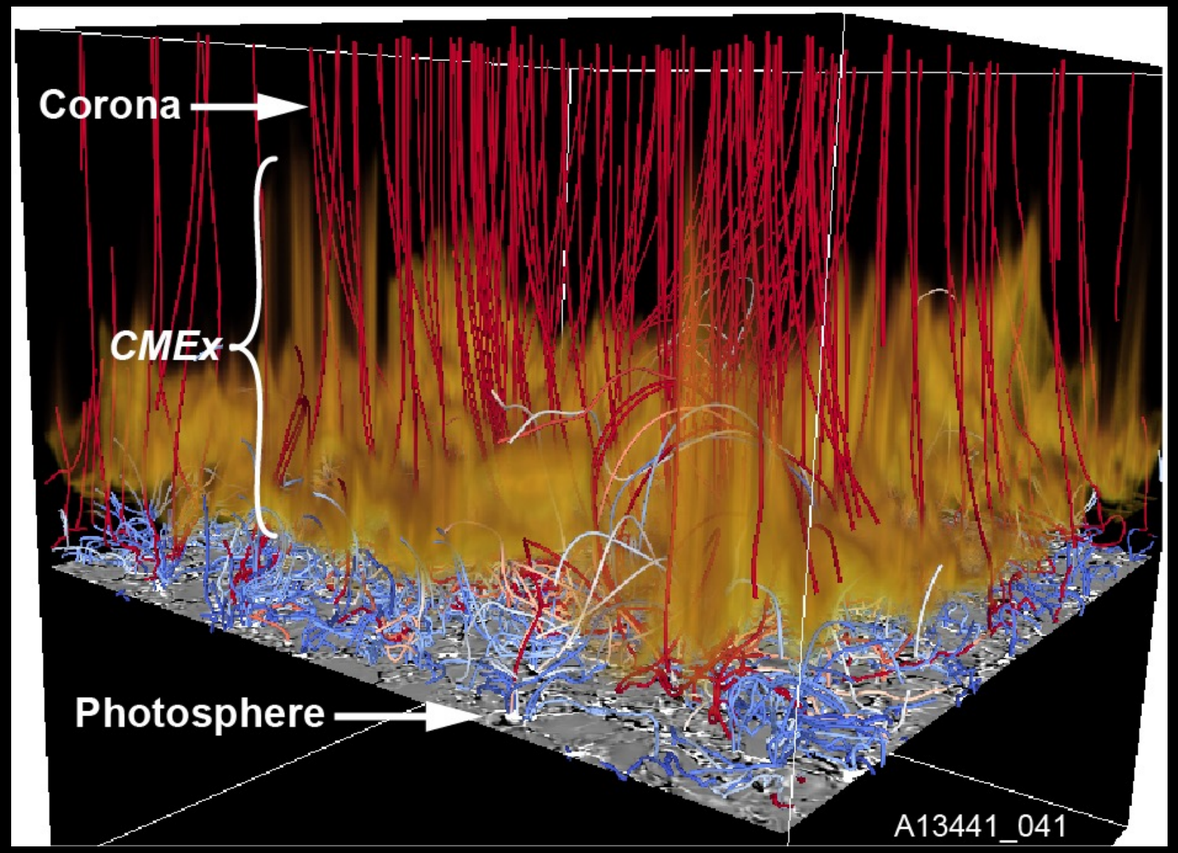
Magnetic fields continuously emerge through the Sun's surface



Measuring the magnetic field in the chromosphere

The Chromospheric Magnetism Explorer

- Photospheric magnetic fields are routinely measured from space.
- But inferring coronal fields from these results in large uncertainties.
- To accurately predict eruptive events, we need measurements of the magnetic field in the upper atmosphere.



MHD simulation shows the changing complexity of the magnetic field between the photosphere and corona

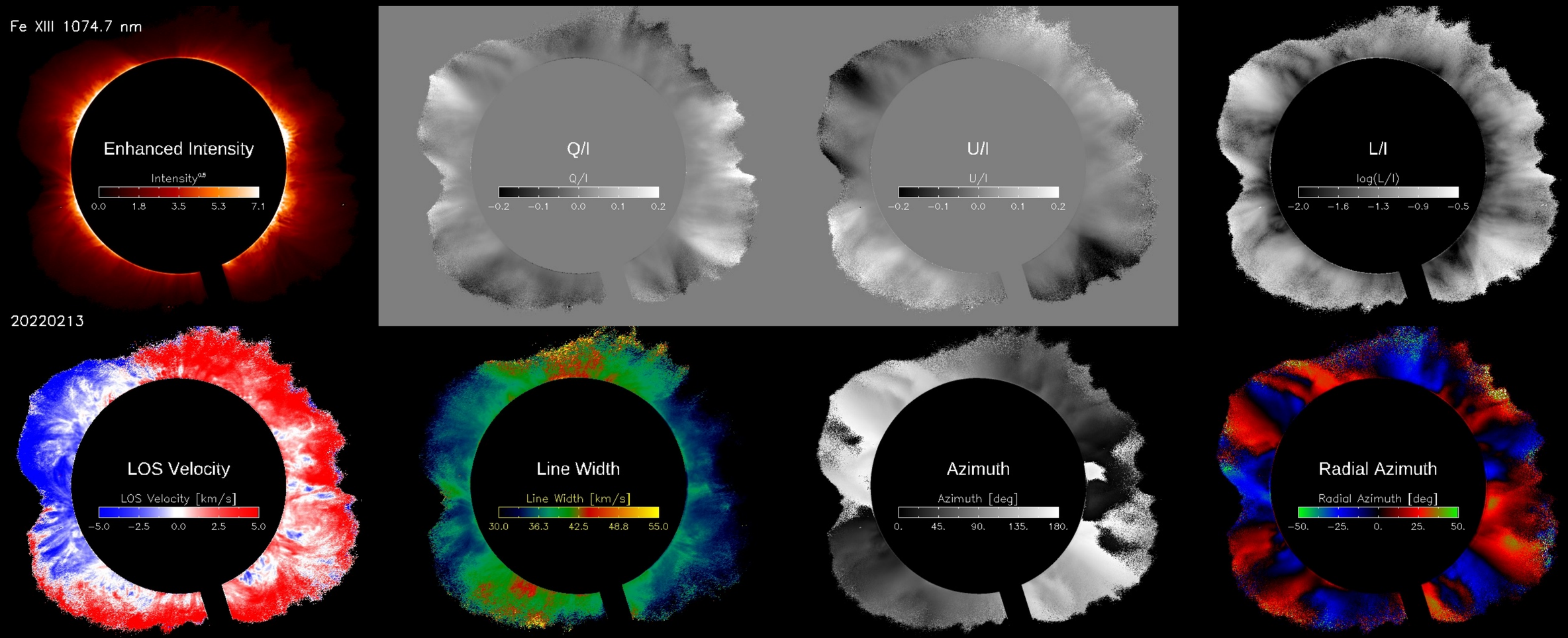
Ground-based instruments can measure these to some extent BUT

1. Have a very limited duty cycle
2. Are blind to the UV

Measuring the magnetic field in the corona

Mauna Loa Solar Observatory's

Upgraded Coronal Multichannel Polarimeter (UCoMP)



It's a team effort!

Working together to study the Sun

SOLAR ORBITER

Space-based
Observing Mechanism: Remote photons, in-situ particles
Orbit: Will fly within 0.28 AU of the Sun
The European Space Agency and NASA's *Solar Orbiter* will examine how the Sun creates the vast bubble of charged particles blown by the solar wind into the interstellar medium, known as the heliosphere.

PARKER SOLAR PROBE

Space-based
Observing Mechanism: In-situ particles
Orbit: Will fly within 0.04 AU of the Sun
NASA's *Parker Solar Probe* will provide a statistical survey of the Sun's outer corona, tracing the flow of energy and exploring what accelerates and heats the solar wind.

DKI SOLAR TELESCOPE

Earth-based
Observing Mechanism: Remote photons
Orbit: 1 AU
The NSF's *Daniel K. Inouye Solar Telescope*, the world's largest solar telescope, indirectly measures the magnetic fields to create a synoptic map of the corona and better understand how and why the corona heats up so dramatically.

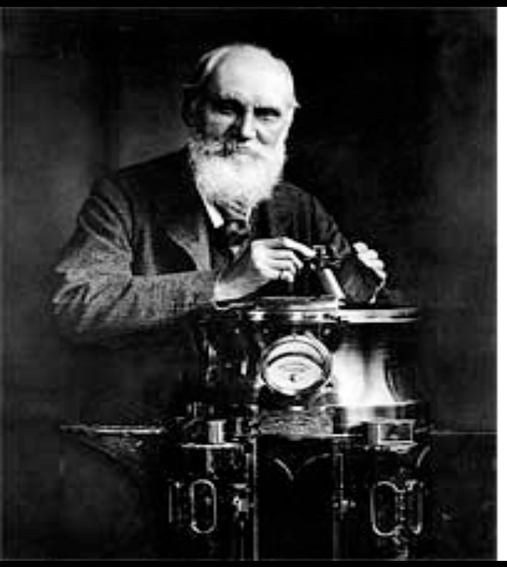
1 AU ~ 150,000,000 km (~93,000,000 mi)

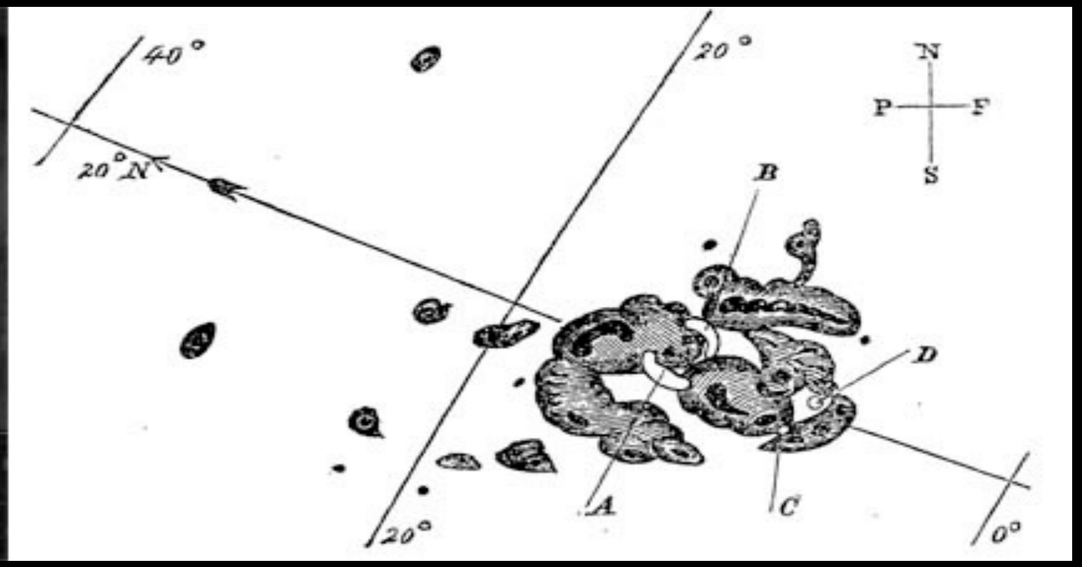
NSO NSF

THE CORONAL SOLAR MAGNETISM OBSERVATORY

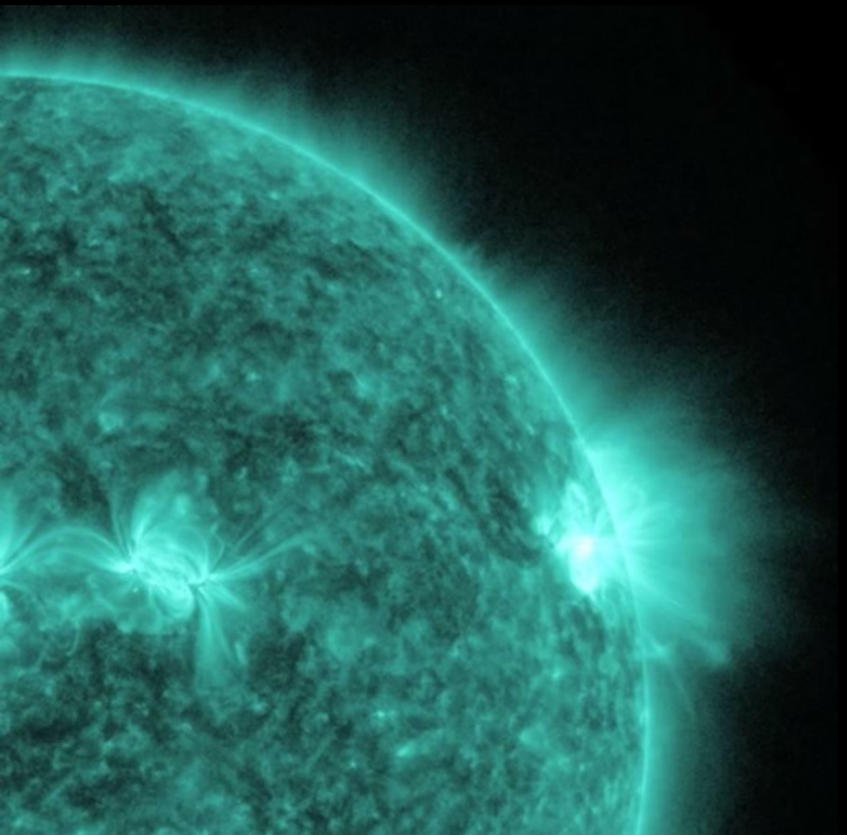
NSF's Daniel K Inouye Solar Telescope

COSMO



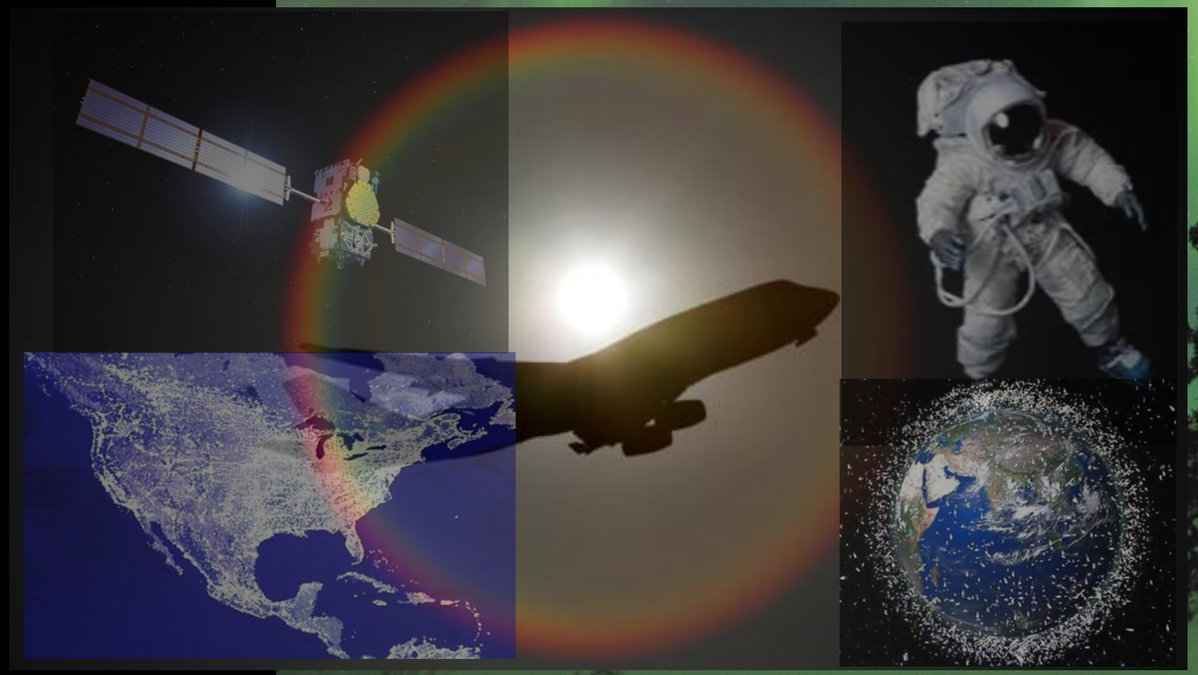


Our violent Sun



Magnetism and space weather

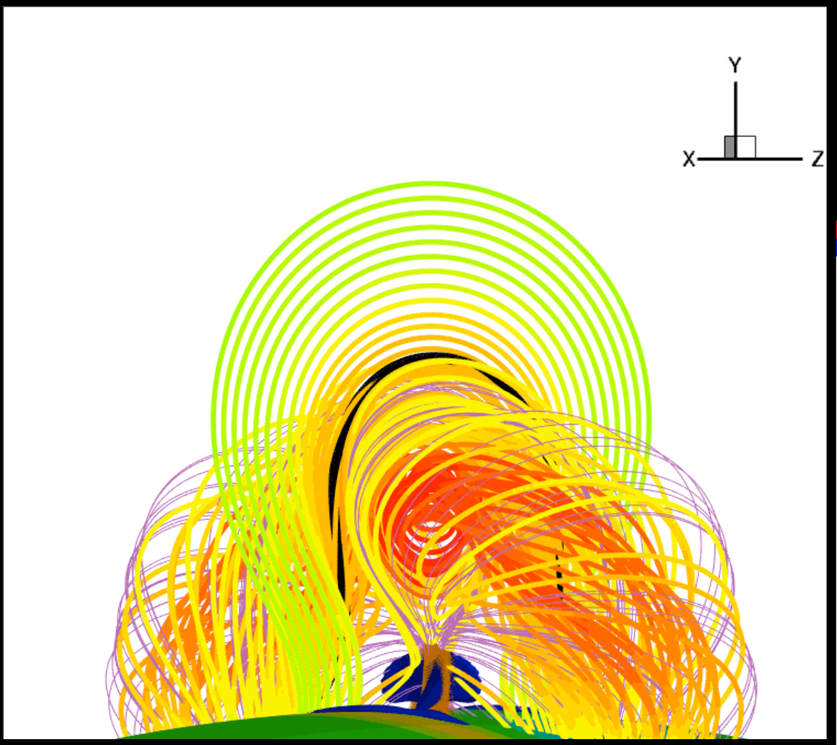
Always had potential for beauty…



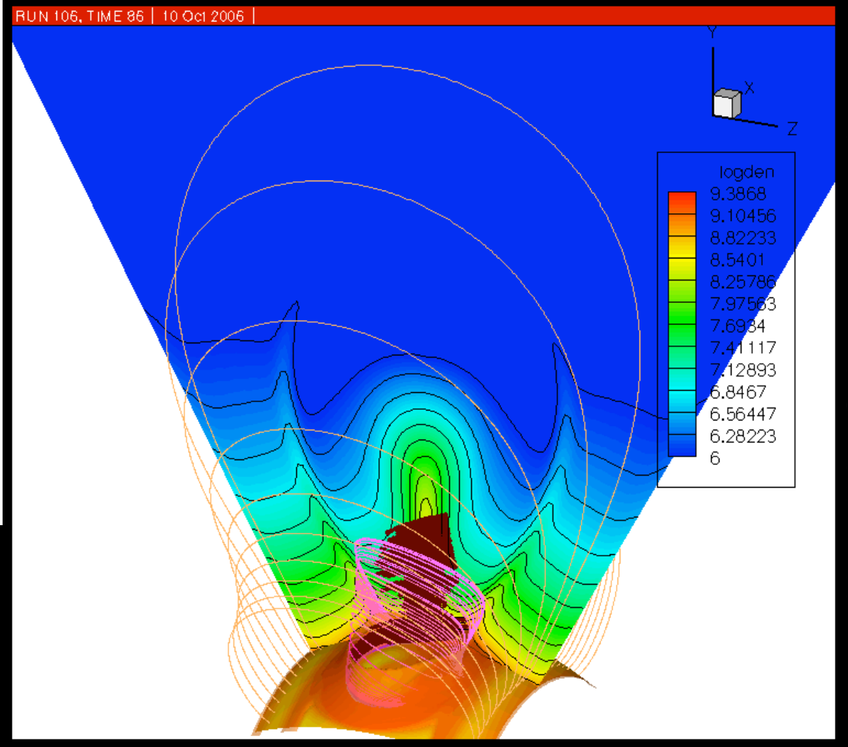
…now has potential for danger

Magnetism and space weather

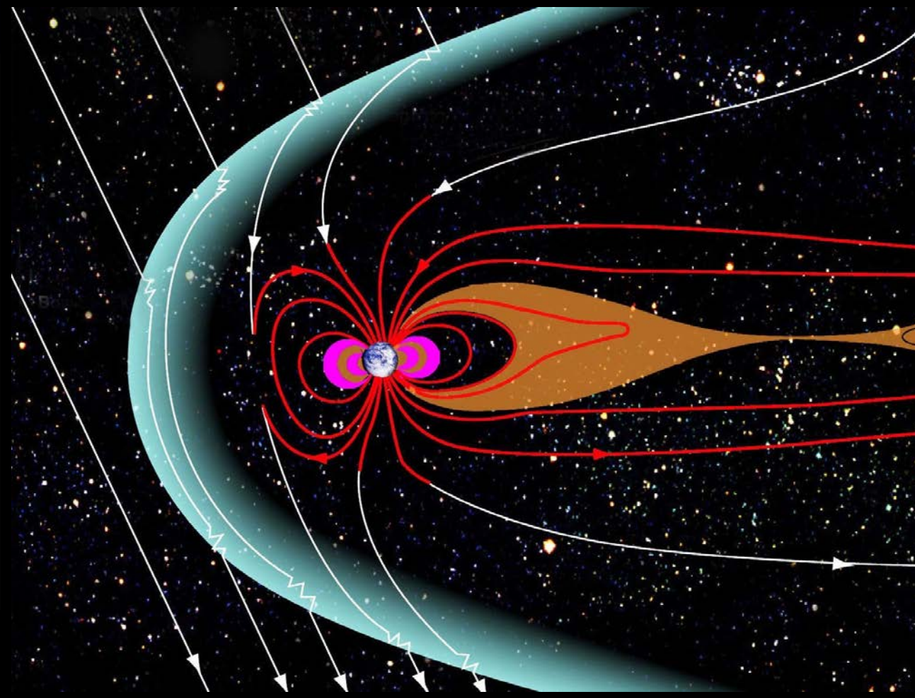
Magnetic energy stored in twisted magnetic field



Released through solar eruption



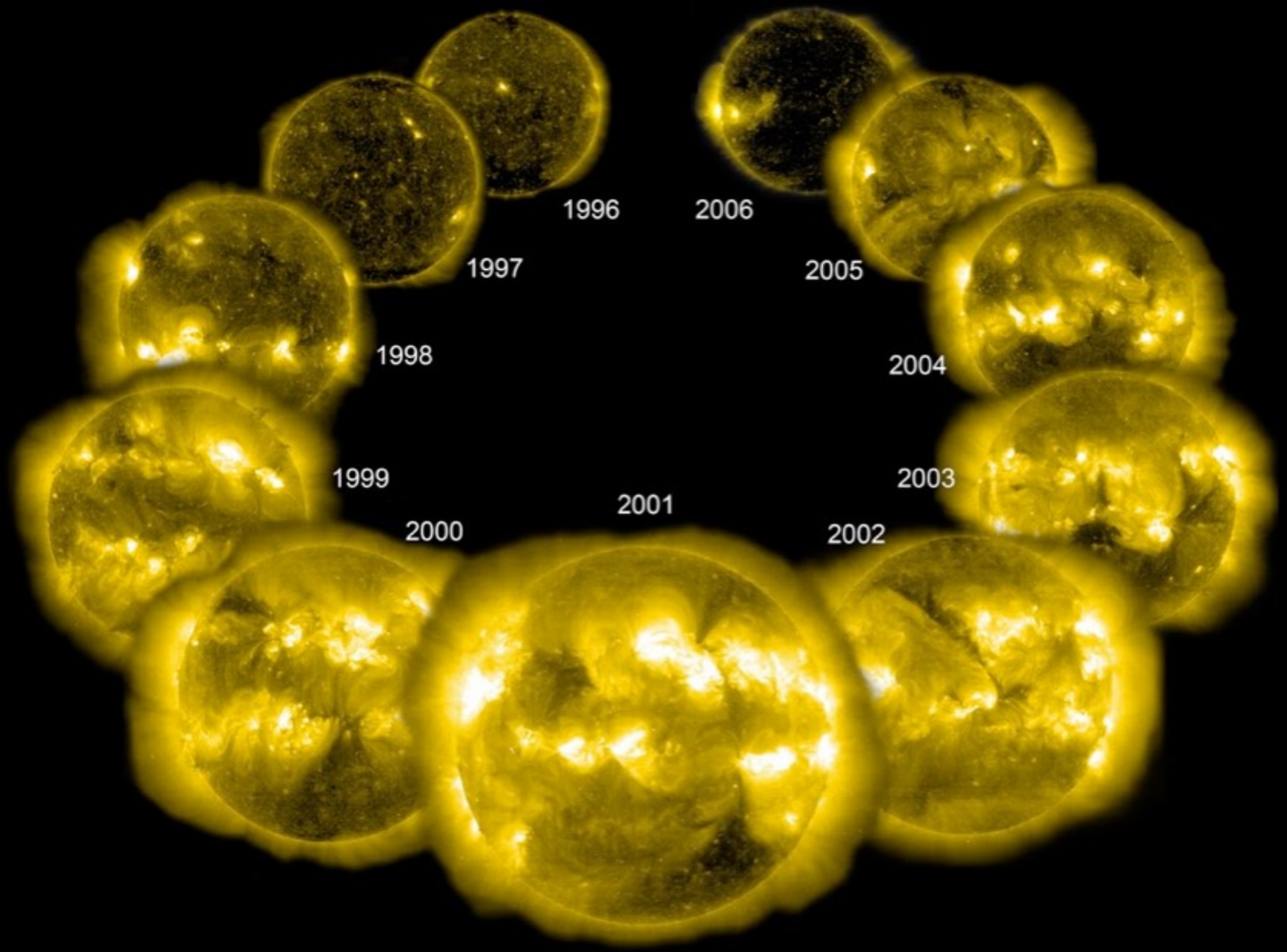
Impacts the Earth



Magnetism and space climate

Space weather varies with the solar cycle

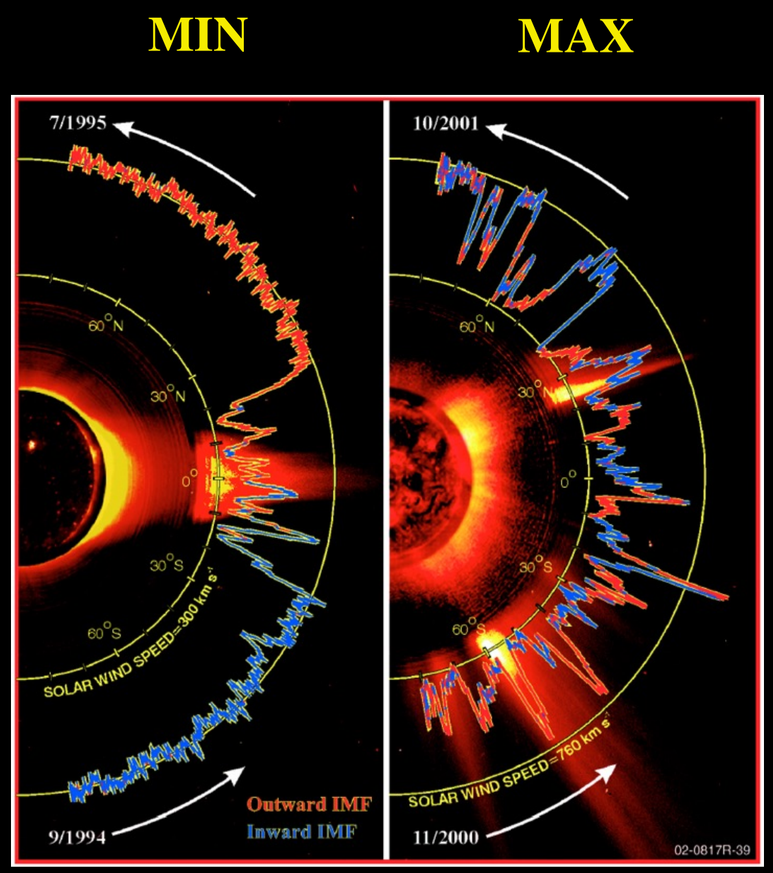
From the Sun…

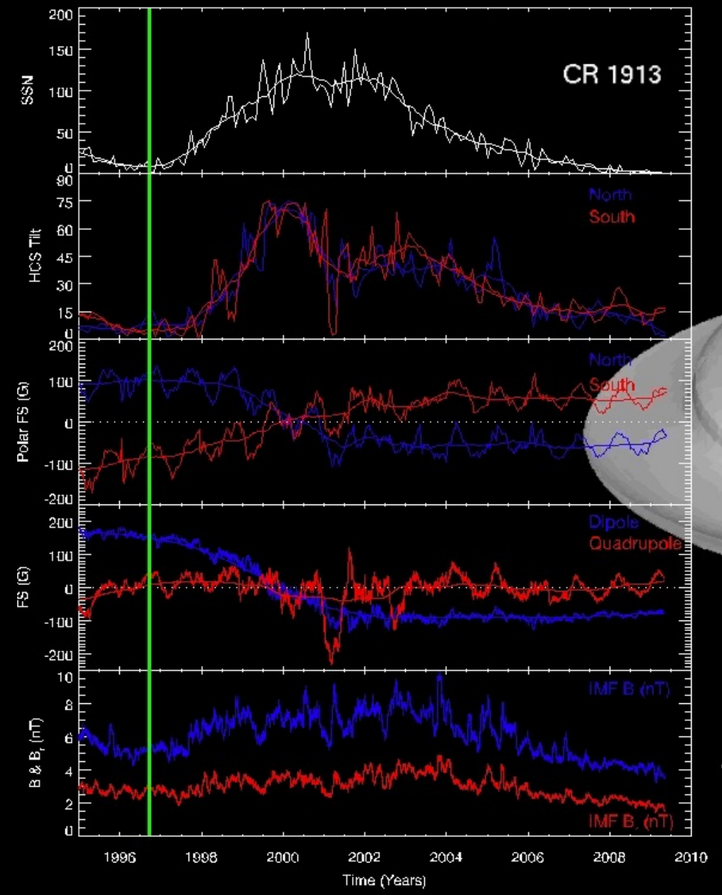


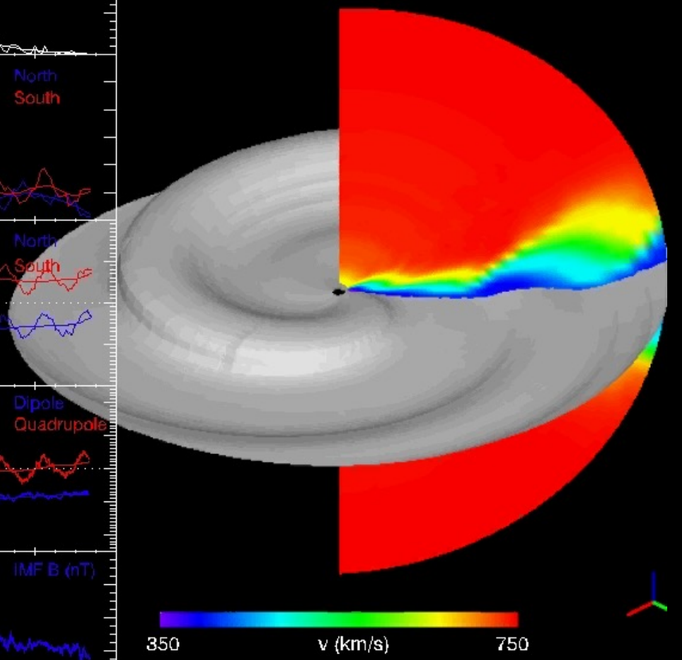
Magnetism and space climate

Space weather varies with the solar cycle

Through the Solar Wind…





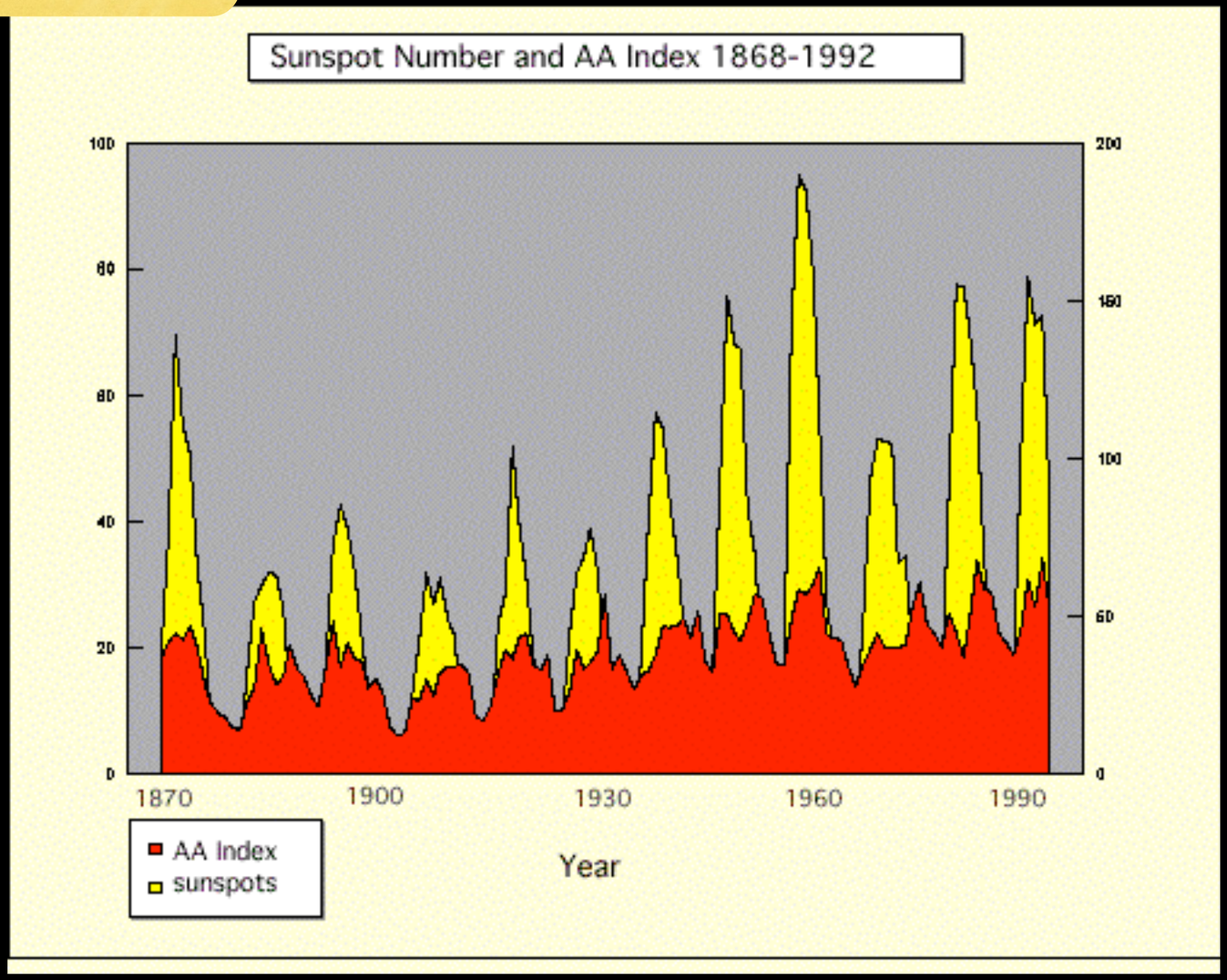


Magnetism and space climate

Space weather varies with the solar cycle

Geomagnetic Activity

To the Earth



Conclusions

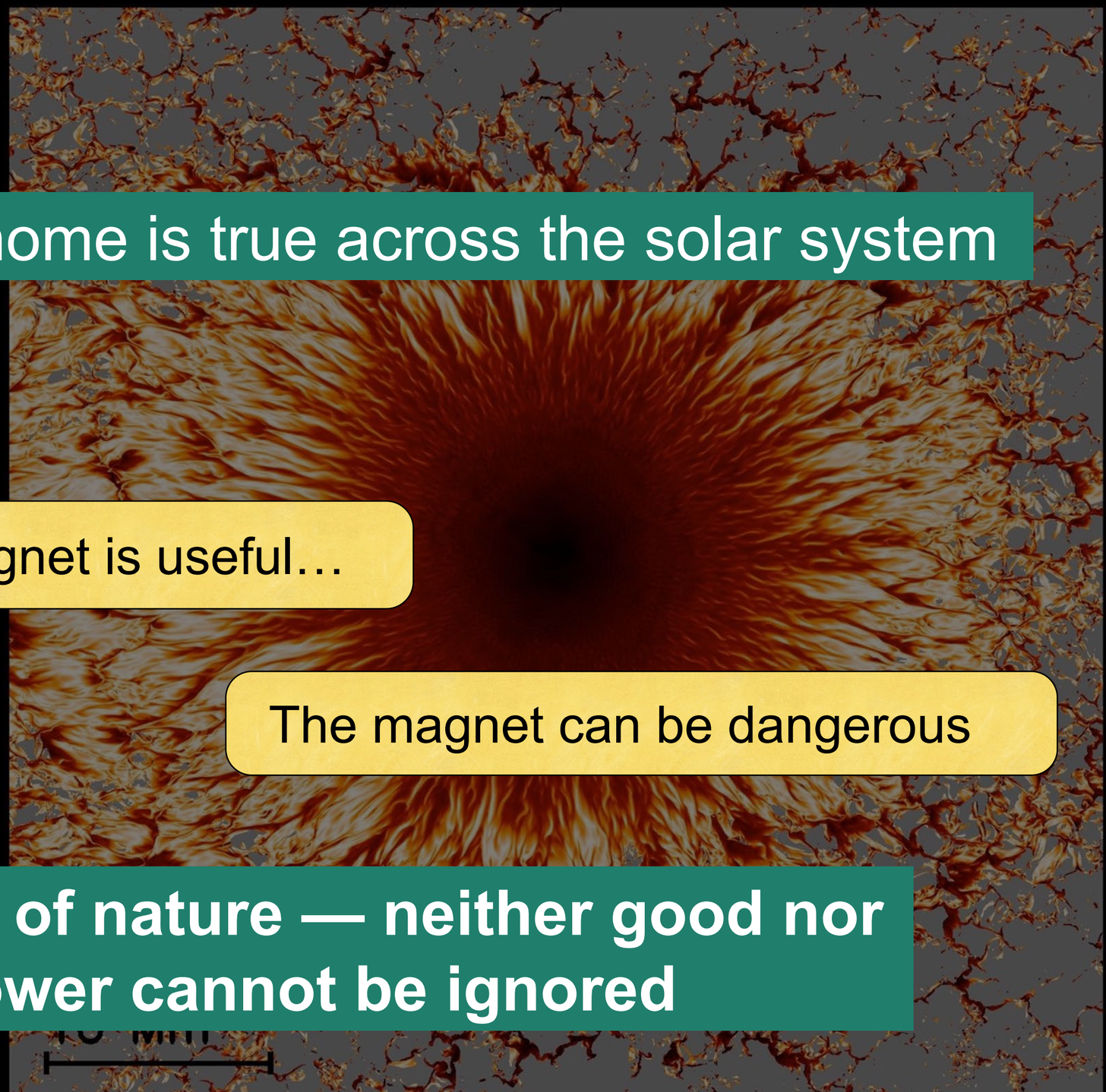
What's true at home is true across the solar system

The magnet is alive!

The magnet is useful…

The magnet can be dangerous

Magnetism is a force of nature — neither good nor evil, but its power cannot be ignored



Backup

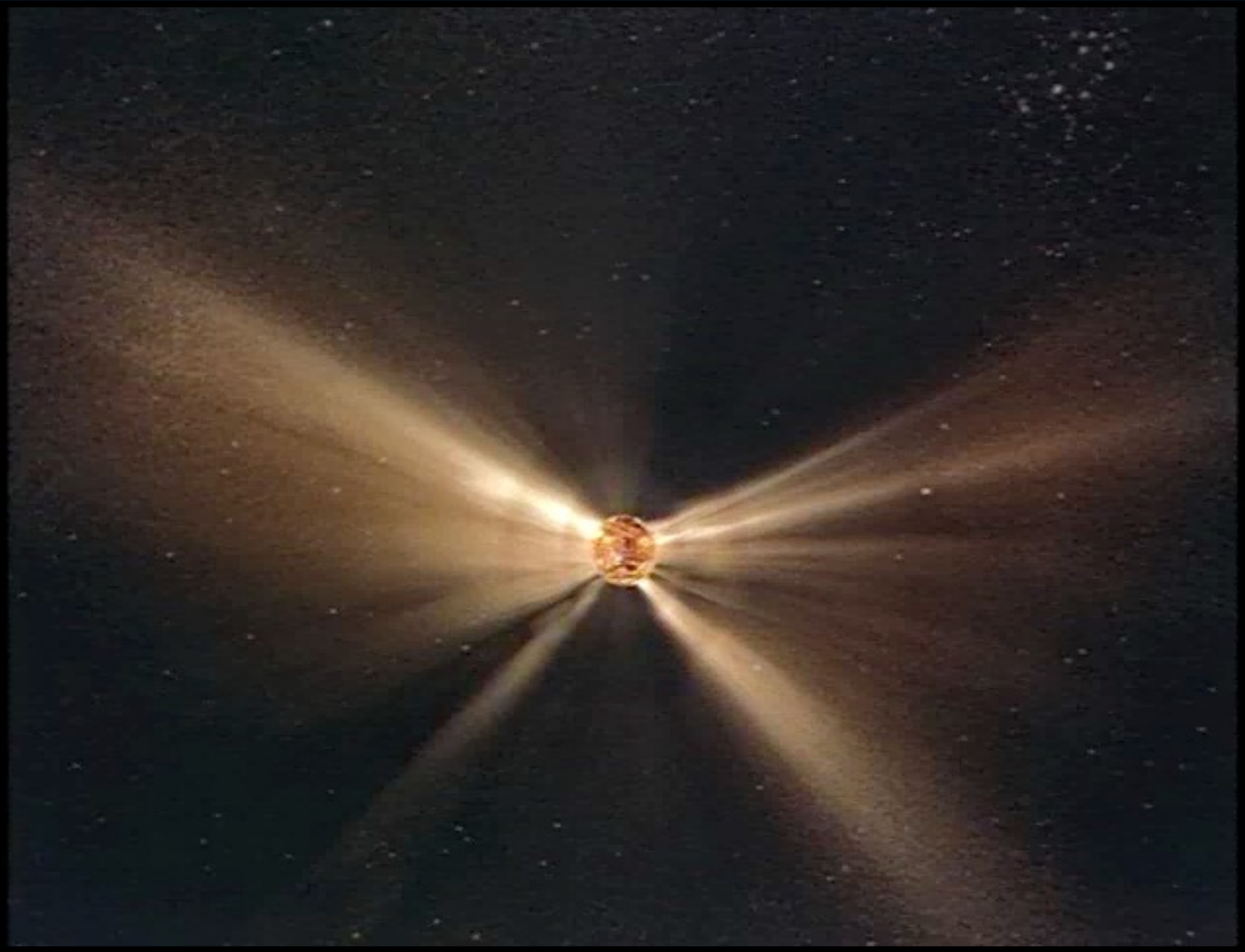
Begin at the Earth: Space Weather

Ordinary….

Earth Science and Remote Sensing Unit, NASA-Johnson Space Center. "The Gateway to Astronaut Photography of Earth." <http://eol.jsc.nasa.gov/videos/crewearthobservationsvideos/videos_aurora.htm>

…and Extraordinary

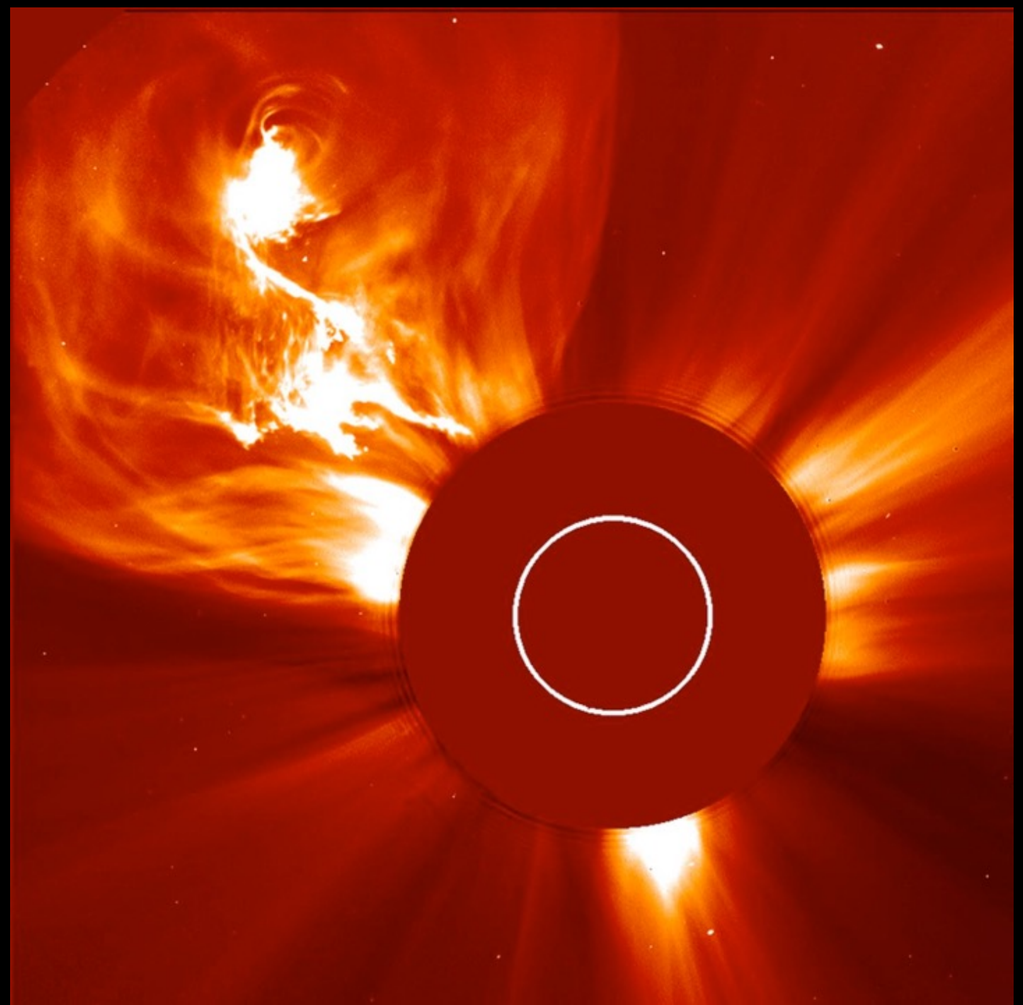
Back to the Sun: Magnetic Origins

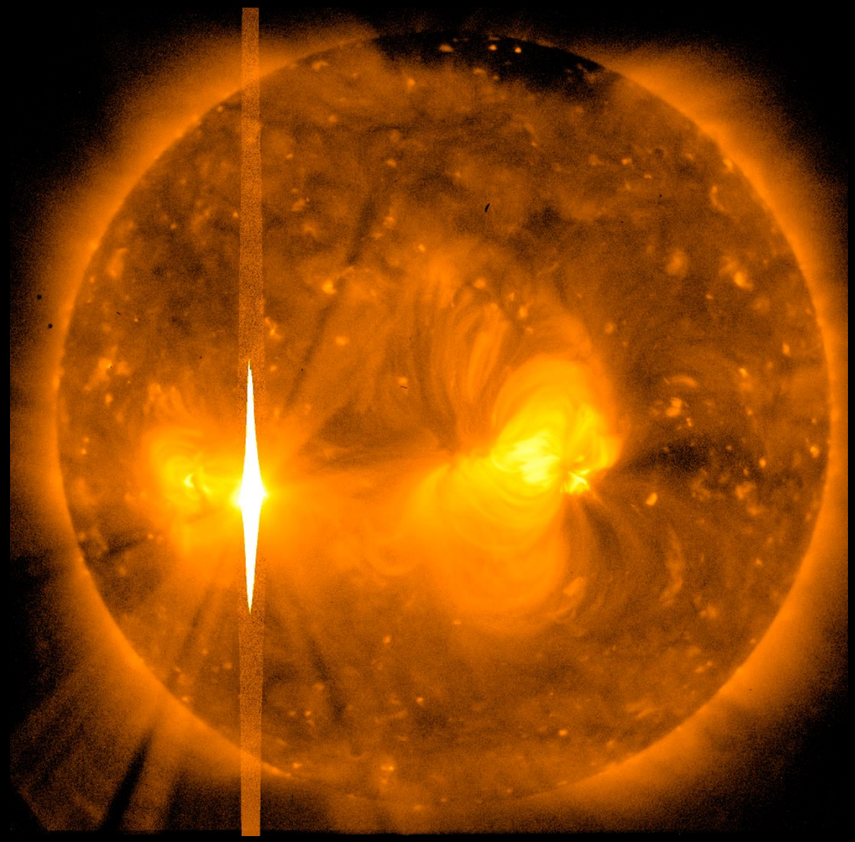


Solar Storms

Back to the Sun: Magnetic Origins

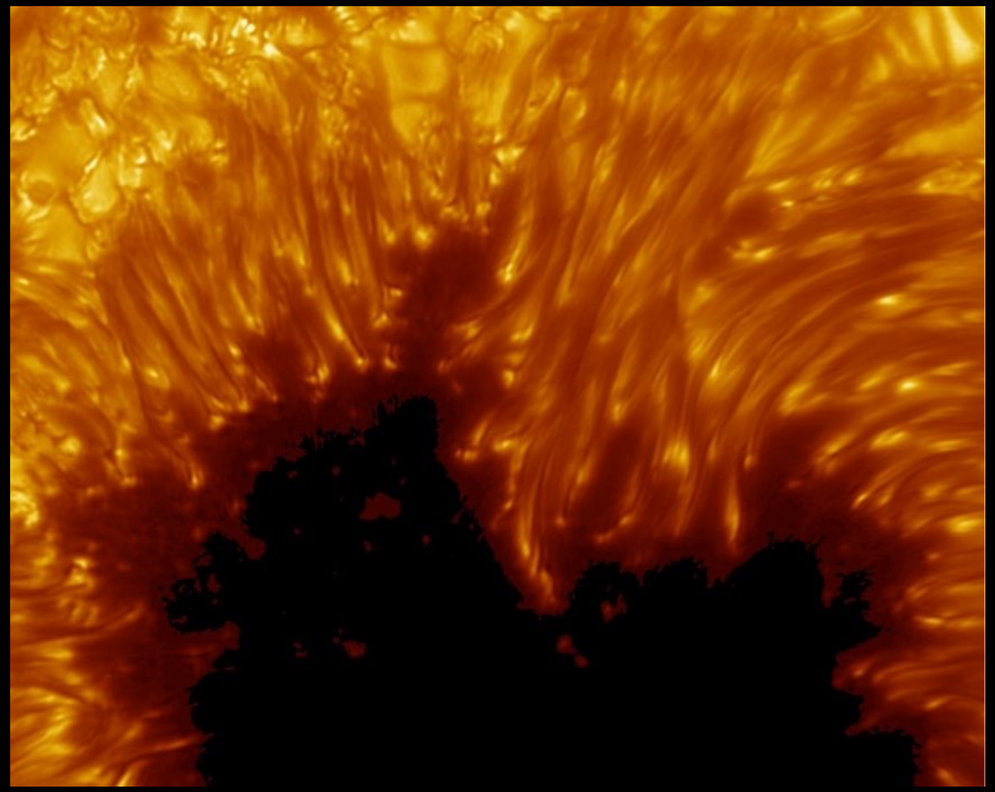
Coronal Mass Ejections (CMEs) and Flares

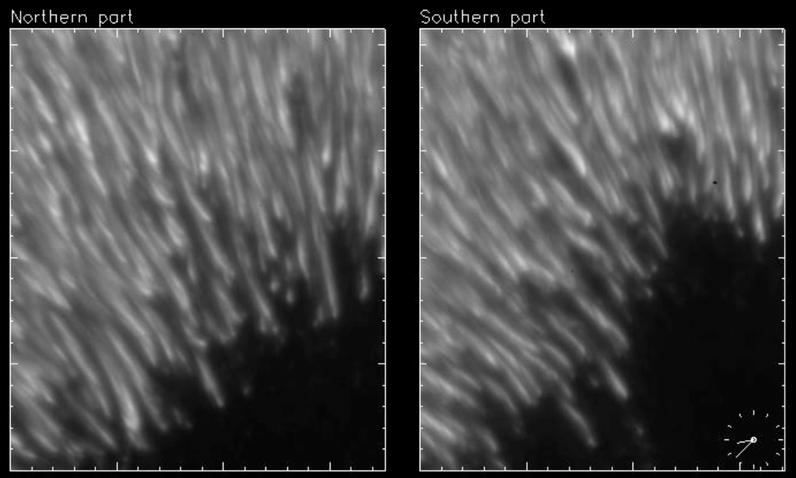




Together, they represent a release of magnetic energy

Back to the Sun: Magnetic Origins

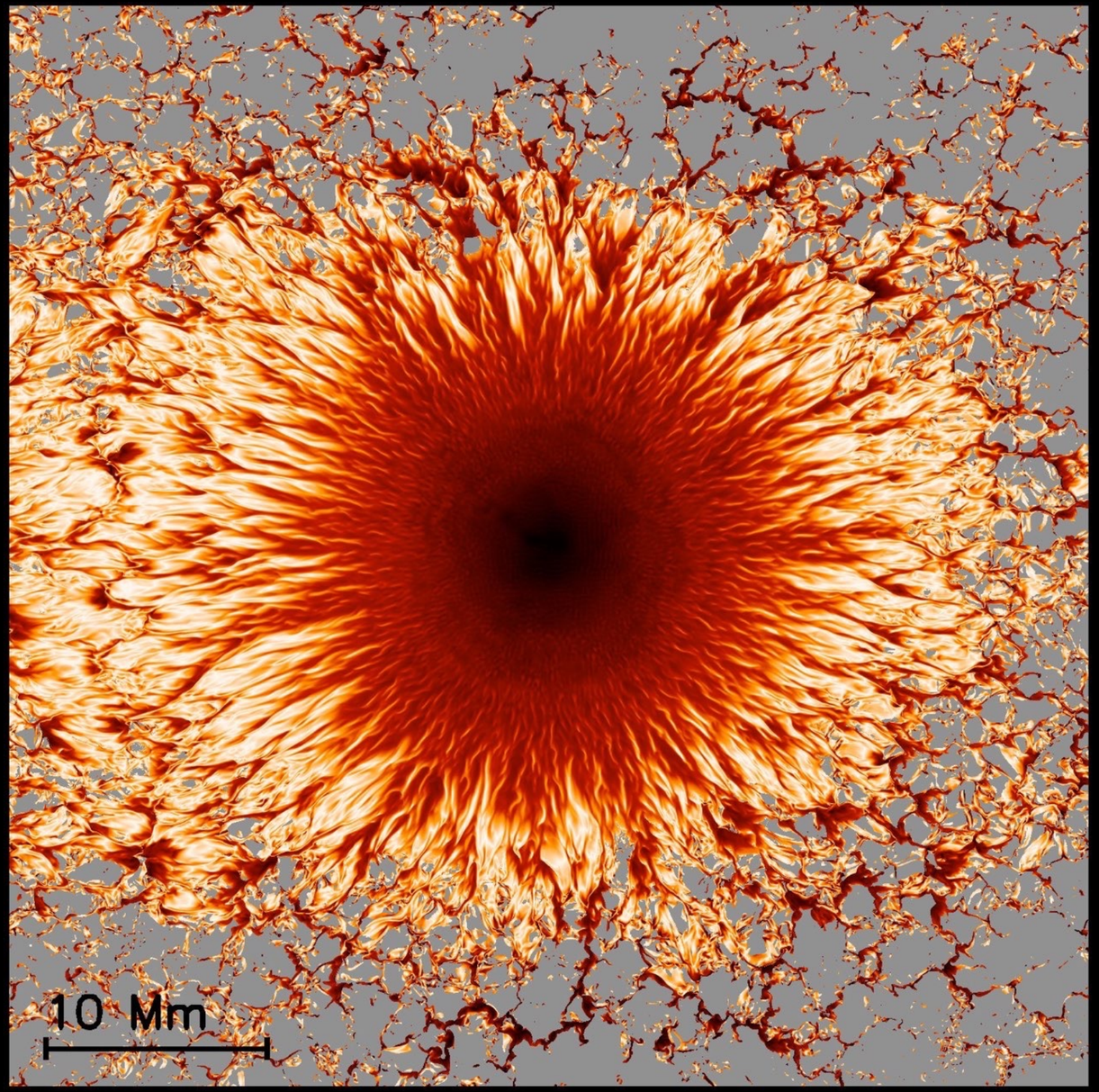




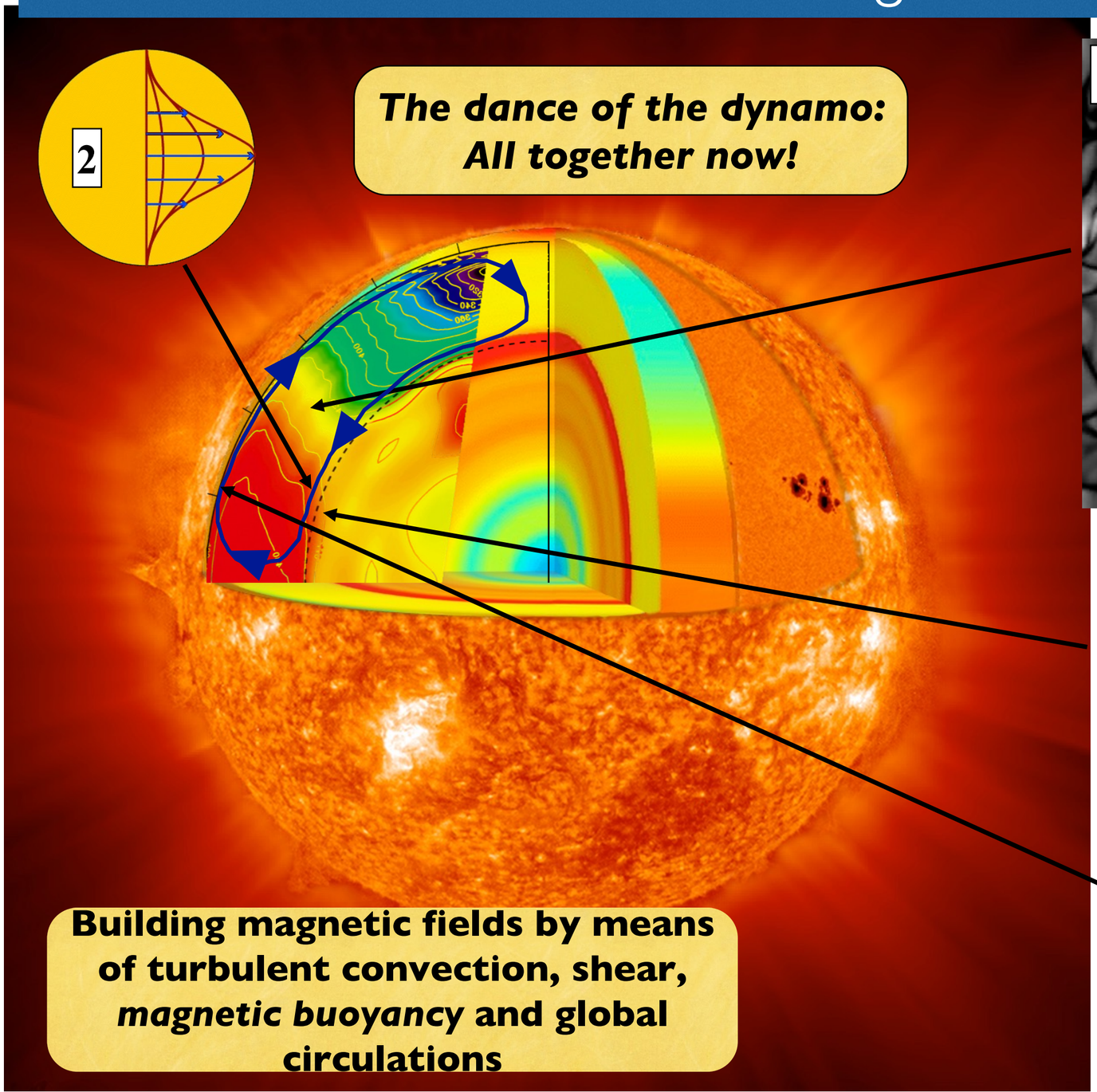
"...near the spots the changes are often so rapid and extreme as to puzzle even a skilled draughtsman to keep up with them."

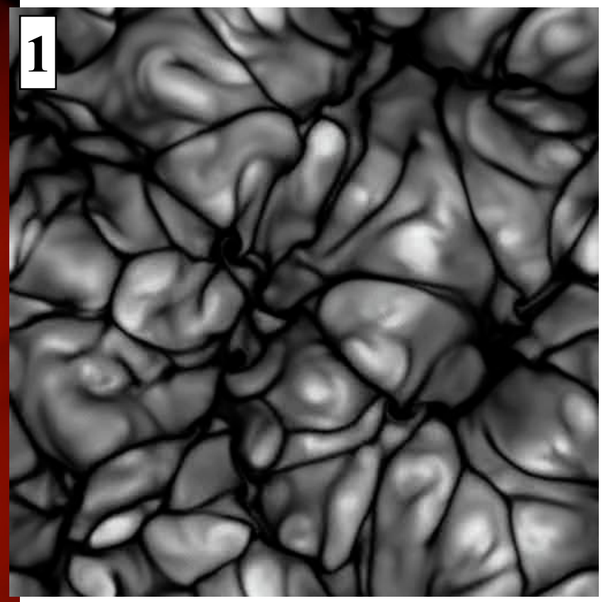
*in **The Sun** (1895) by Charles Augustus Young*

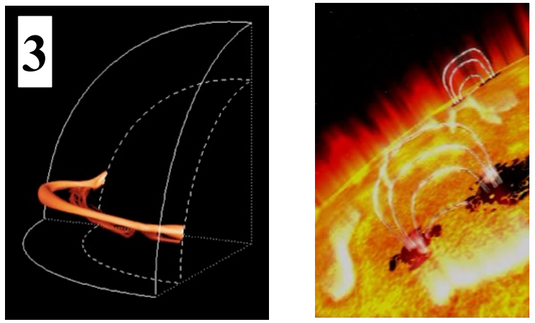
Back to the Sun: Magnetic Origins

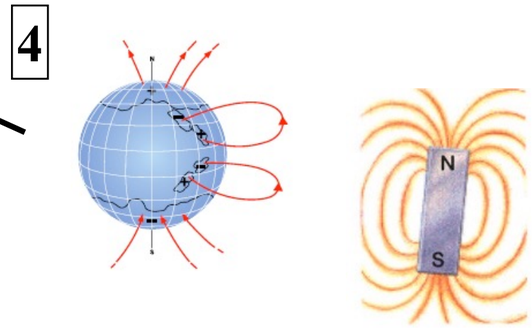


Back to the Sun: Magnetic Origins



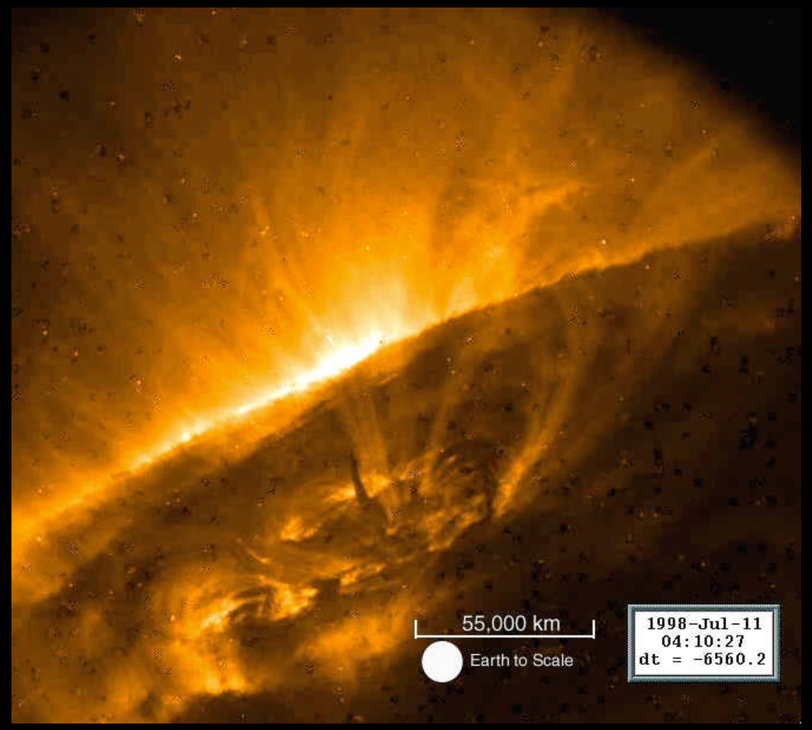


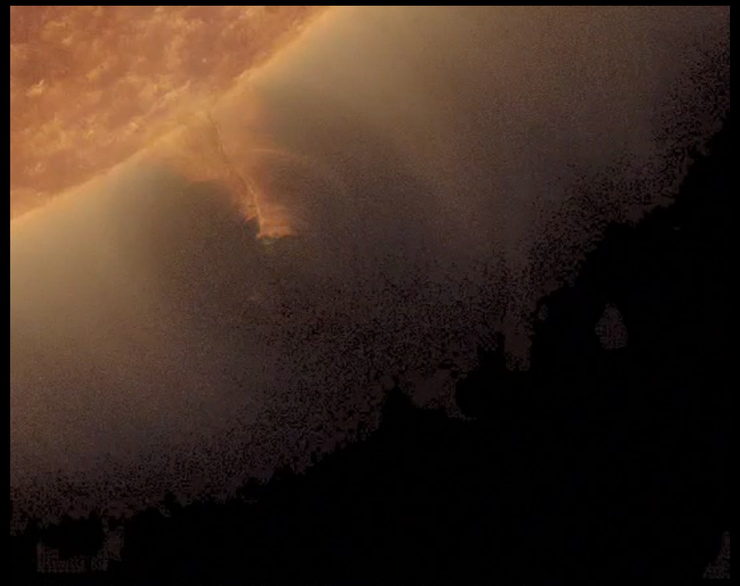




Back to the Sun: Magnetic Origins

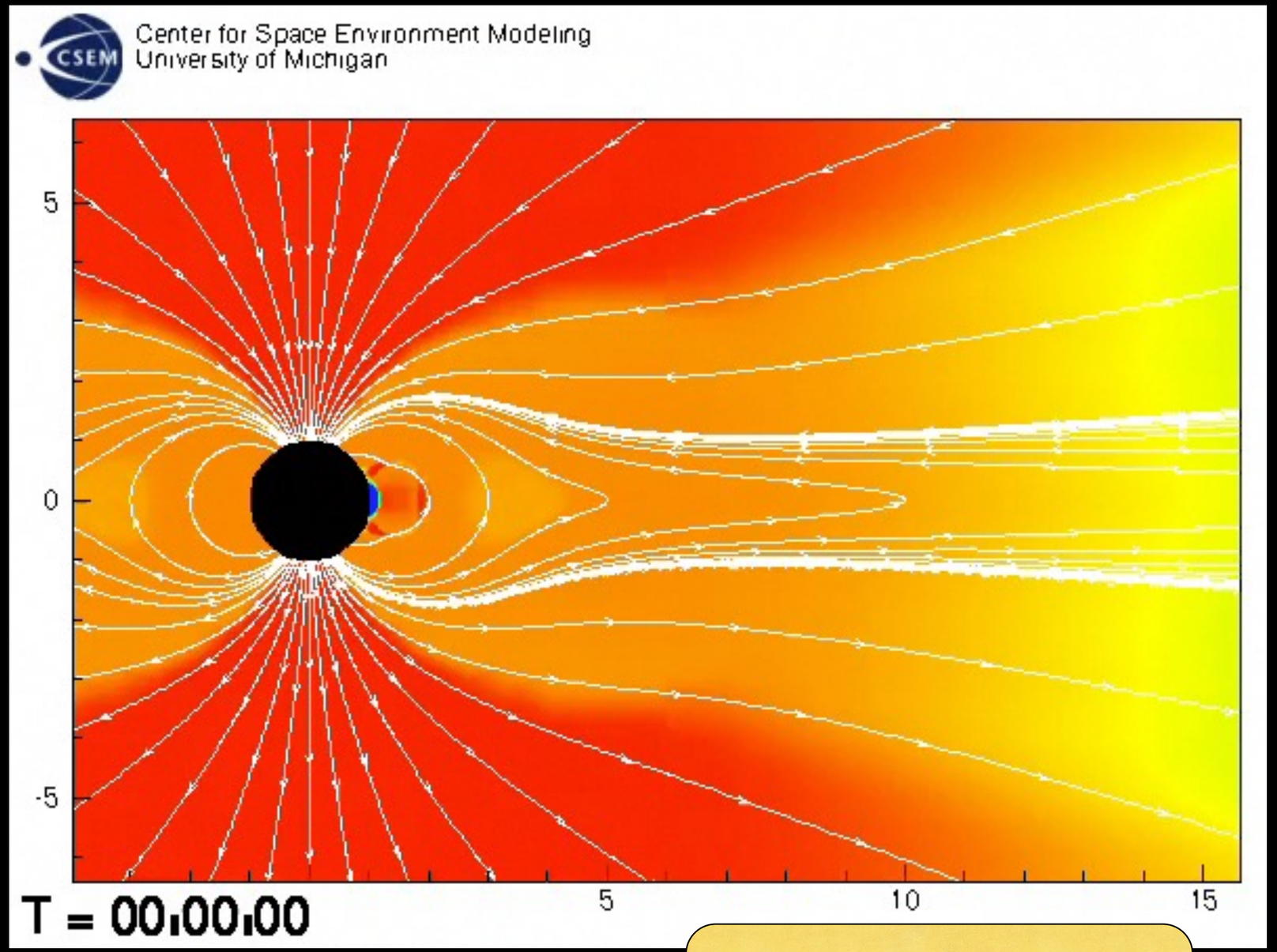
3D and Twisted





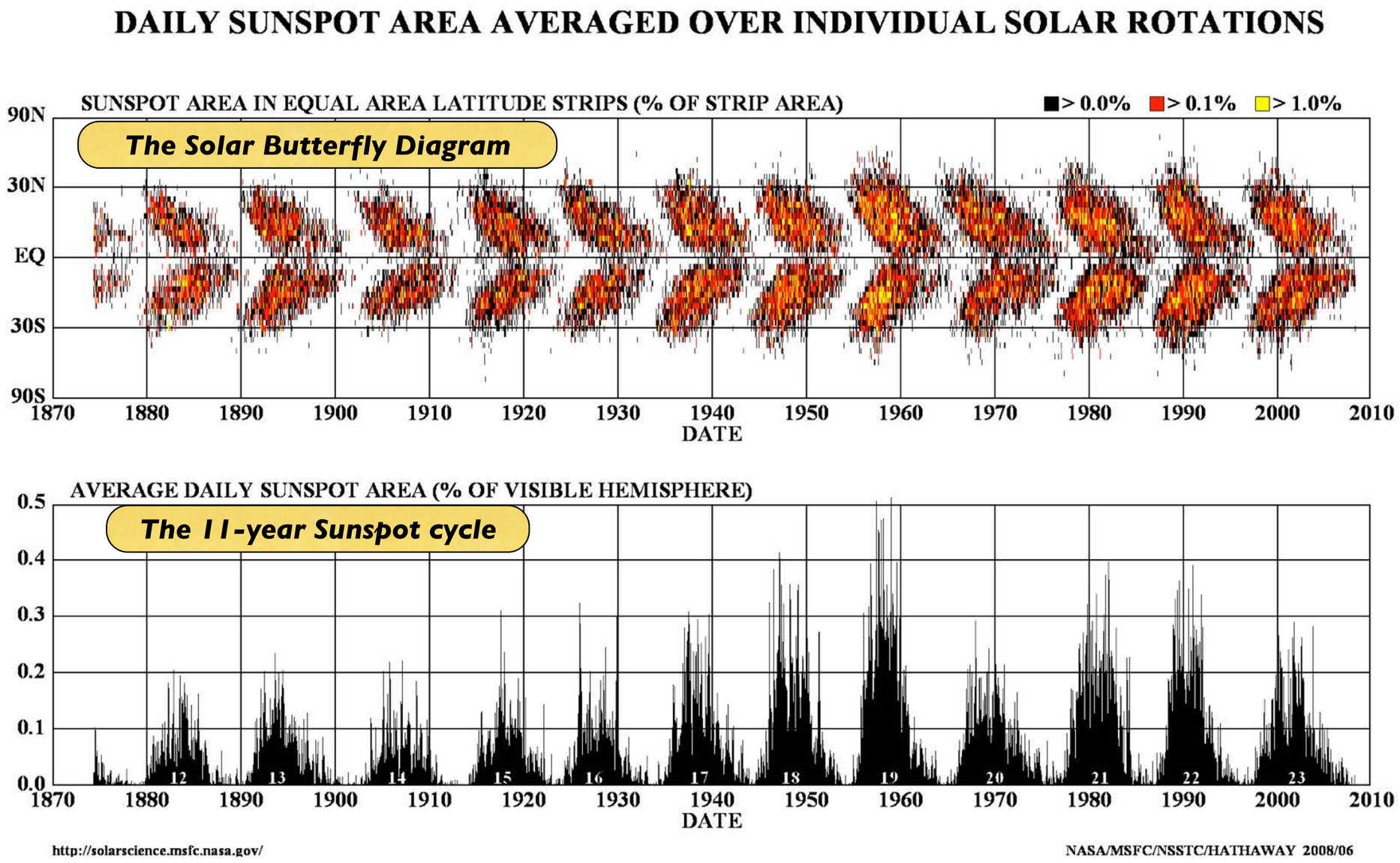
AIA 304 - 2011/09/25 - 10:00:08Z
AIA 171 - 2011/09/25 - 10:00:00Z
AIA 211 - 2011/09/25 - 10:00:00Z
AIA 193 - 2011/09/25 - 10:00:09Z

Magnetism and Space Weather

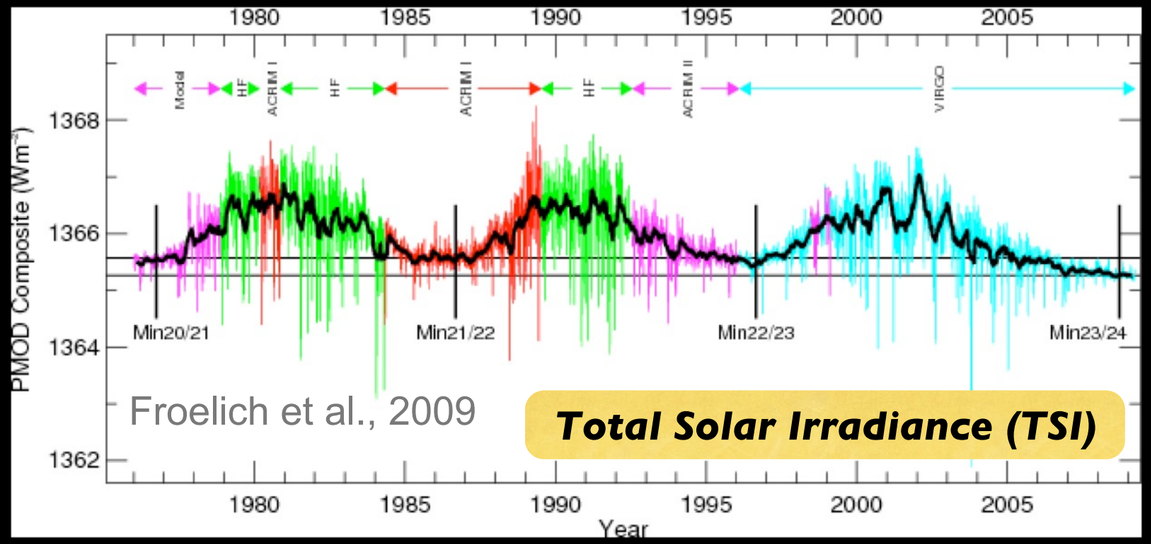


Putting it into context...

Magnetism and Space Climate



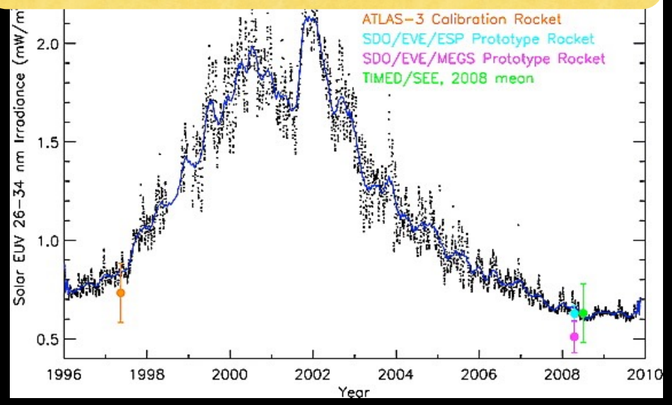
Magnetism and Space Climate

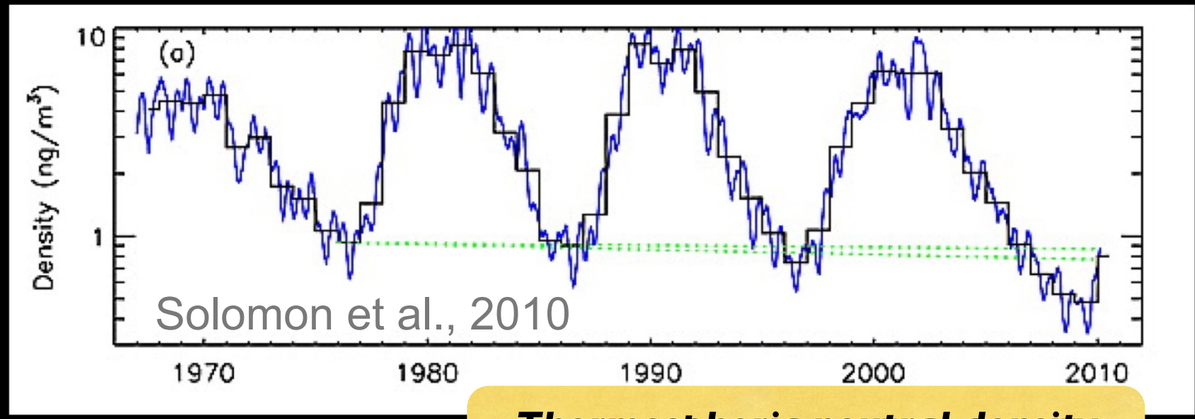


Total Solar Irradiance (TSI)

What about radiation?

Short wavelength radiation (EUV)

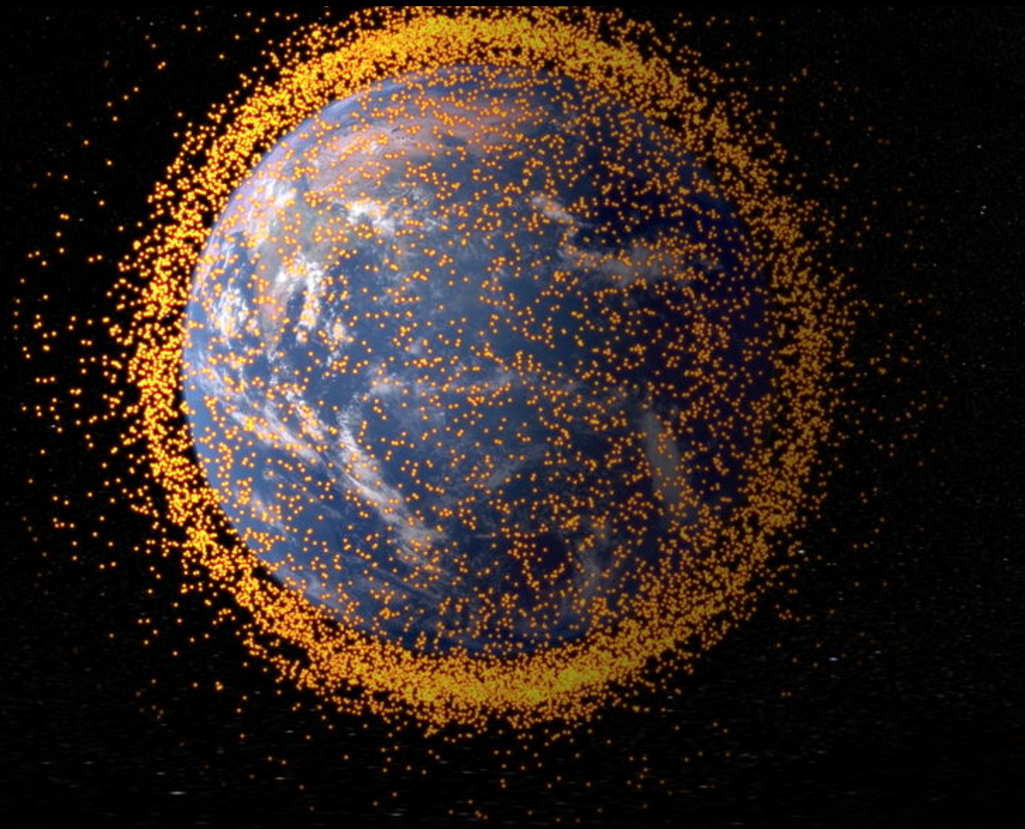




Thermospheric neutral density

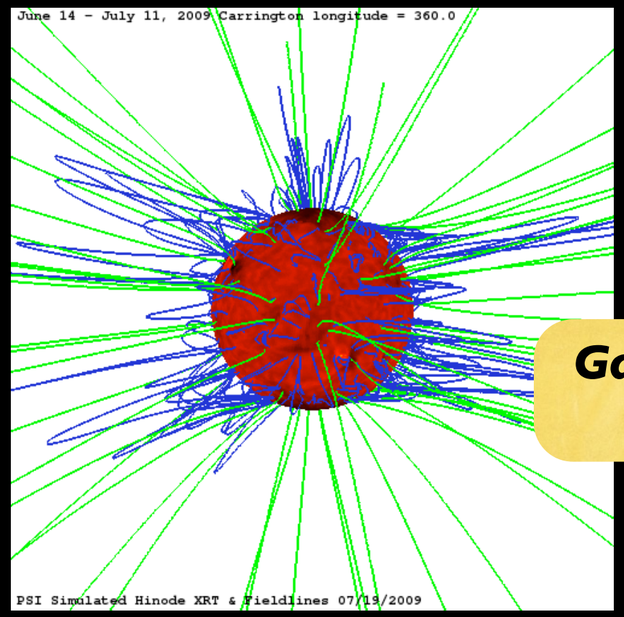
Recent solar minimum was unusually deep

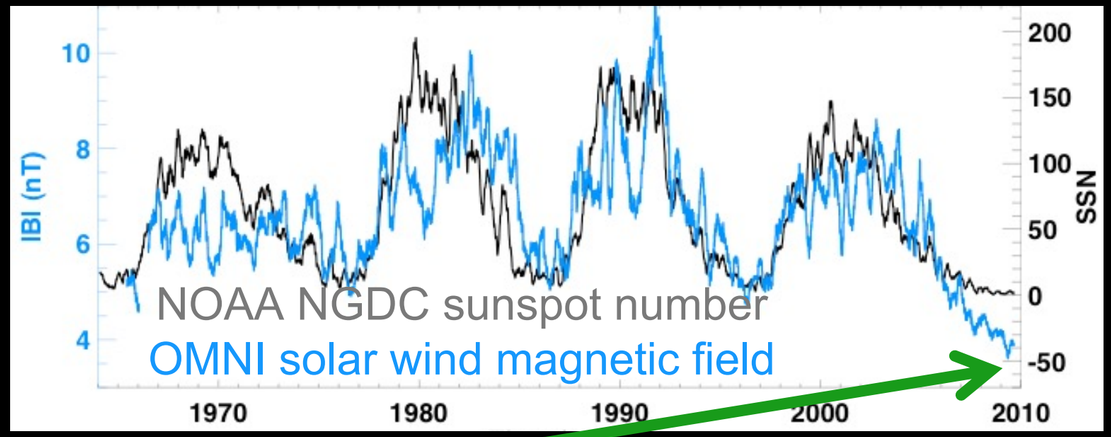
Magnetism and Space Climate



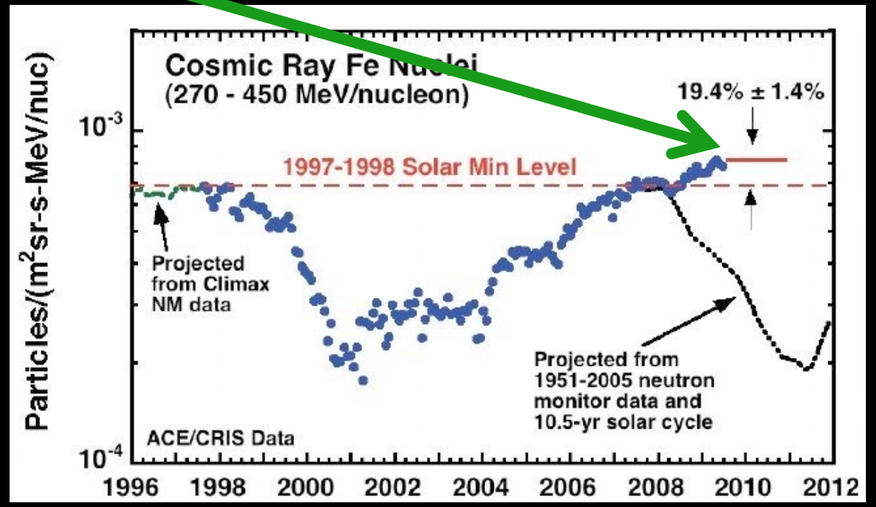
Killer Space Junk

A Deep Solar Minimum



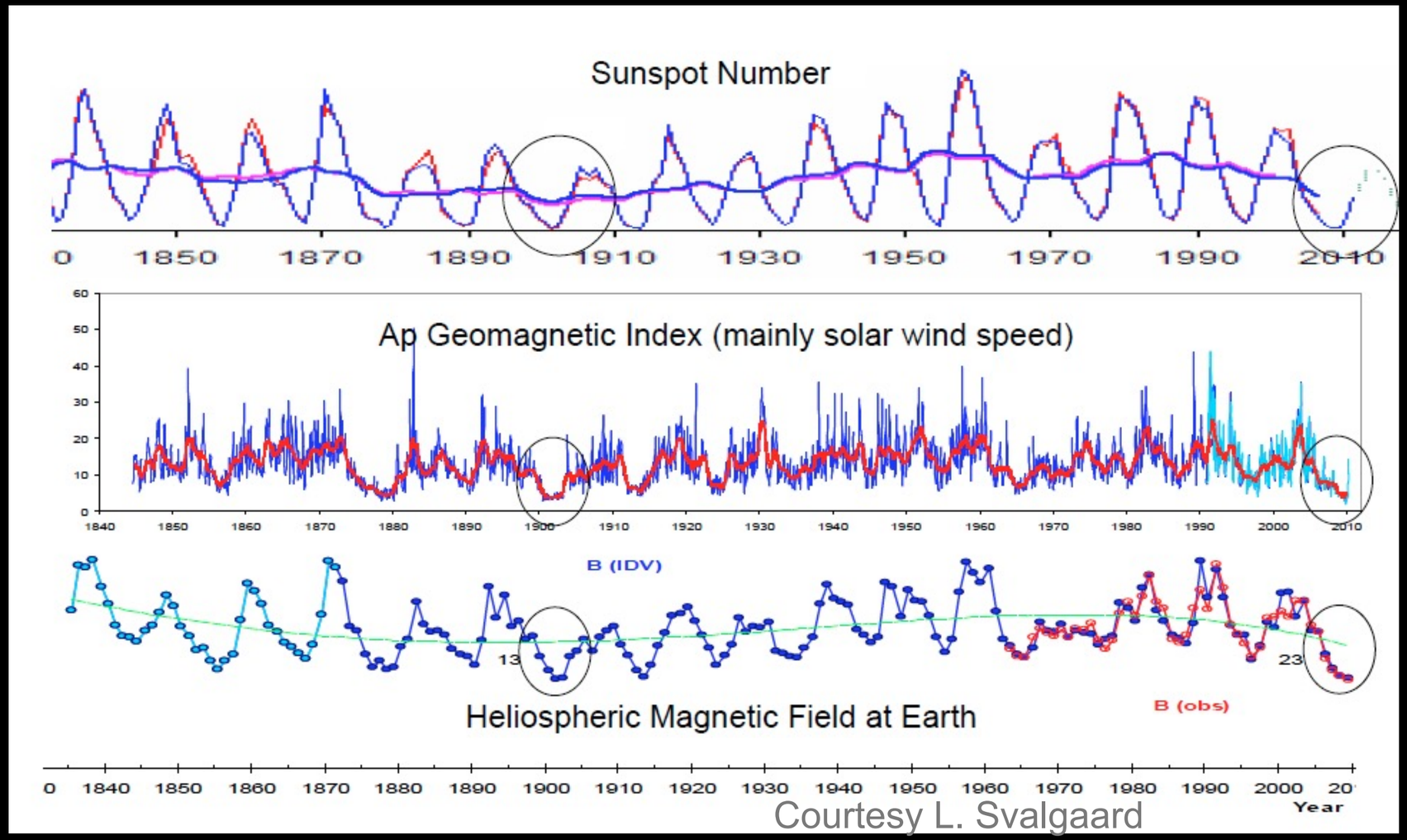


Galactic cosmic rays reached space-age high, in a magnetically weak and quiet heliosphere



A Deep Solar Minimum

Weird for the Century…

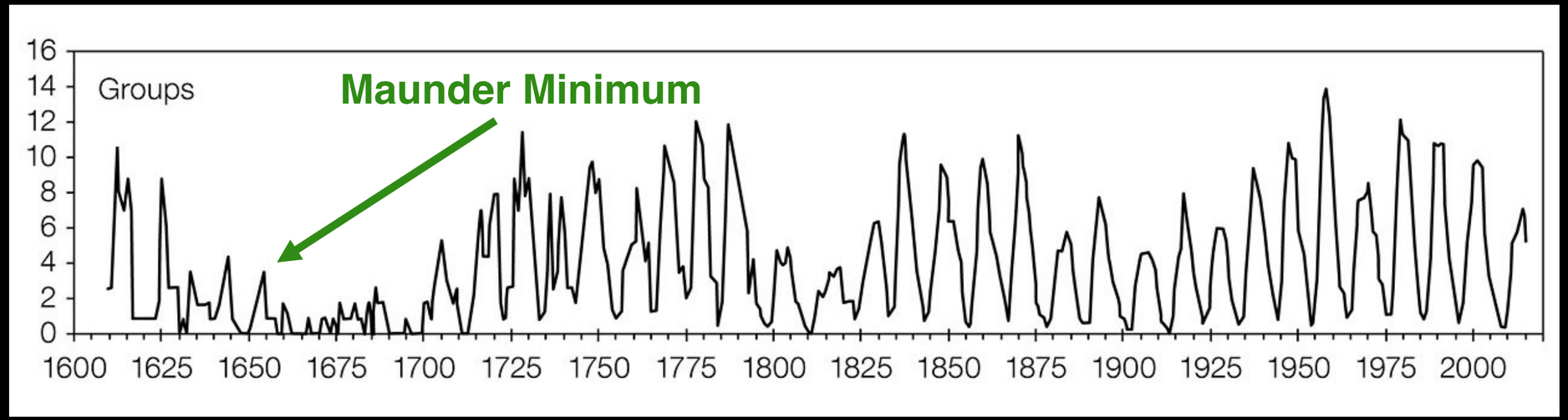


Courtesy L. Svalgaard

A Deep Solar Minimum

Not this Weird.

Yearly averaged sunspot numbers 1610-2015



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