



The Sun and space weather

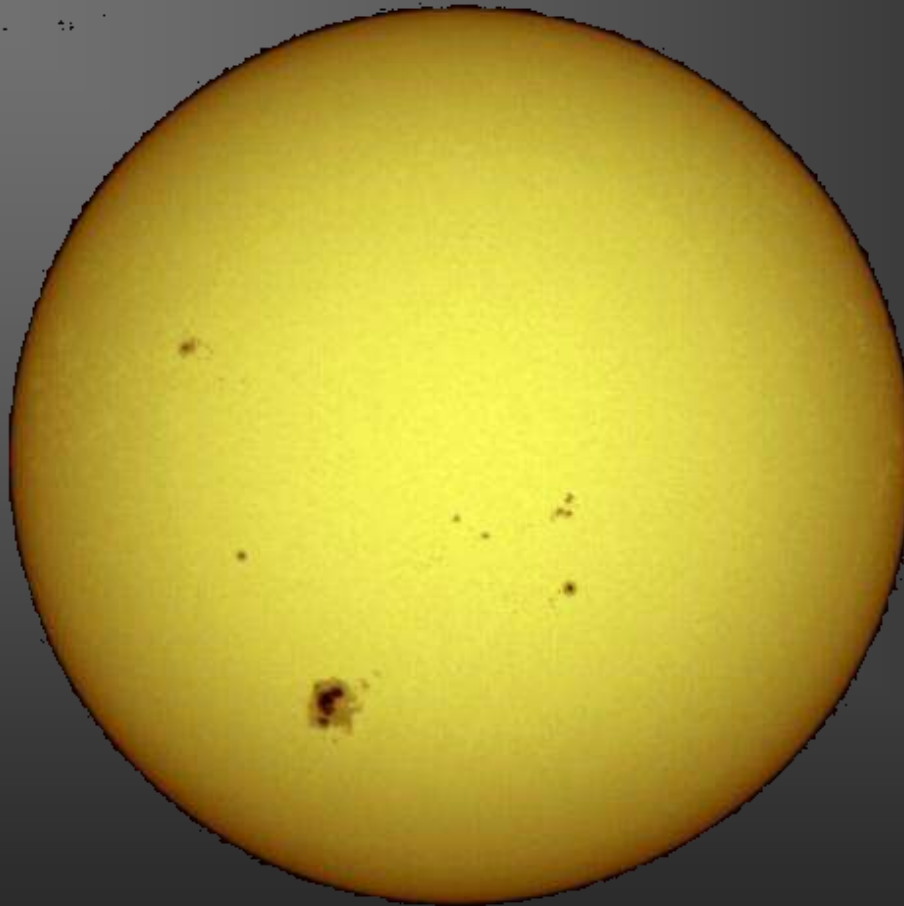
Panagiotis Evangelopoulos
IA - FORTH



Co-funded by the
Erasmus+ Programme
of the European Union



The Sun: the closest star



The Moon has
a radius 400
times smaller
and is 400
times closer
than the Sun

Photo on the
visible part of
spectrum -
sunspots

The Sun: the closest star

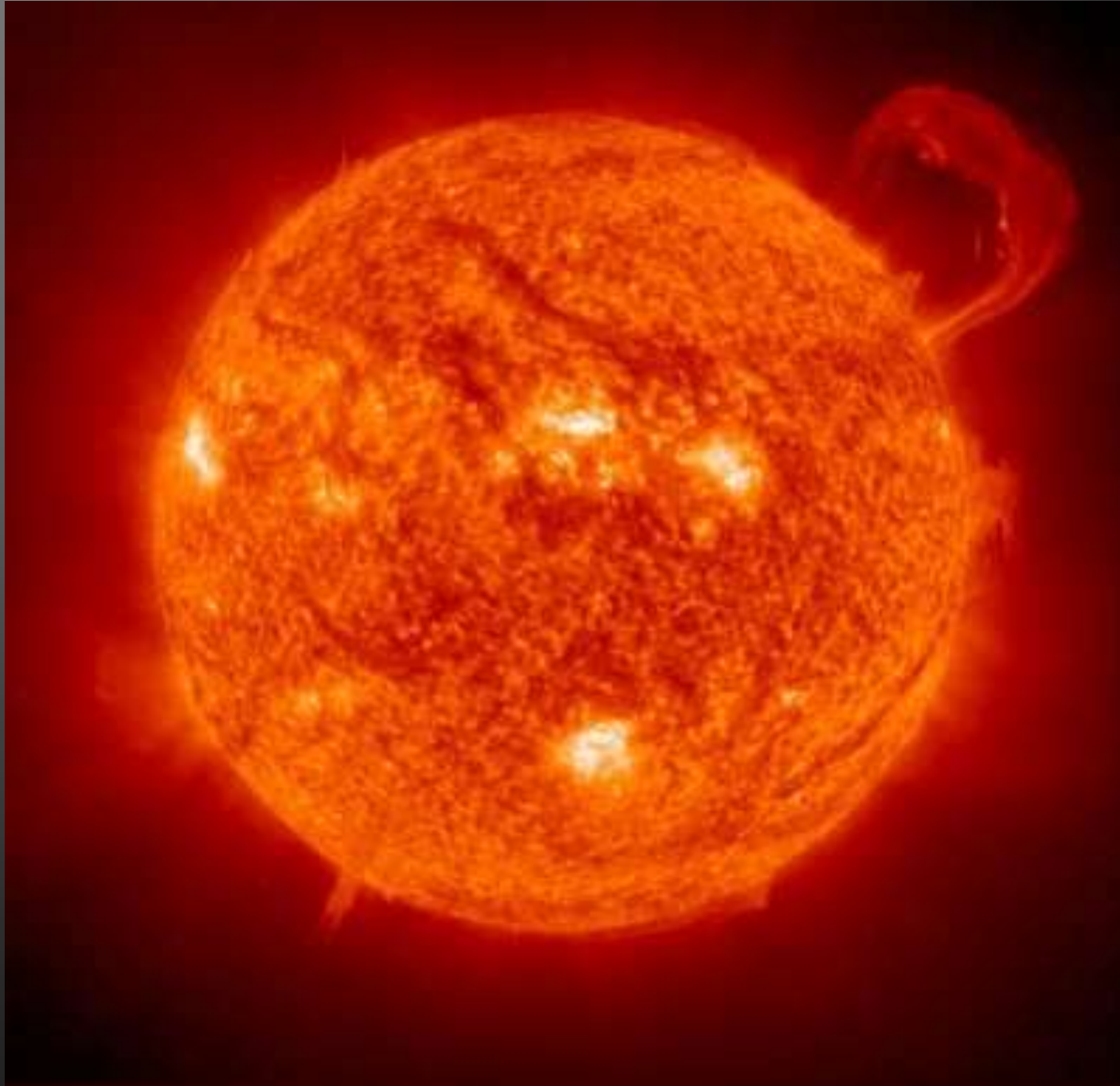


Photo on the
ultraviolet -
prominences

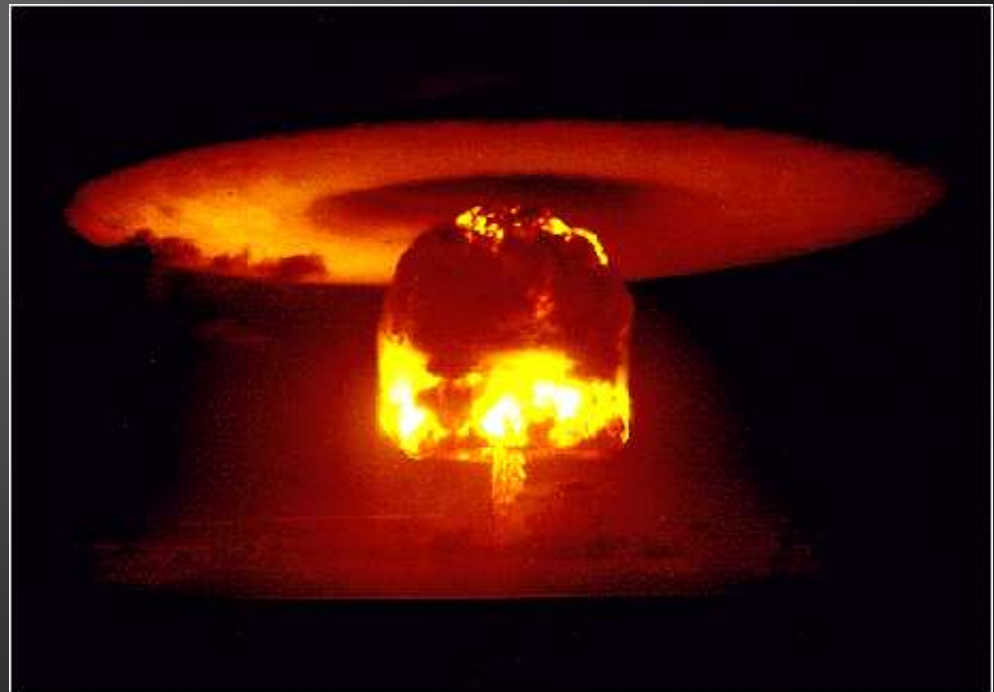
The Sun temperature

Surface: ~6000 degrees



Twice the temperature of a light bulb filament

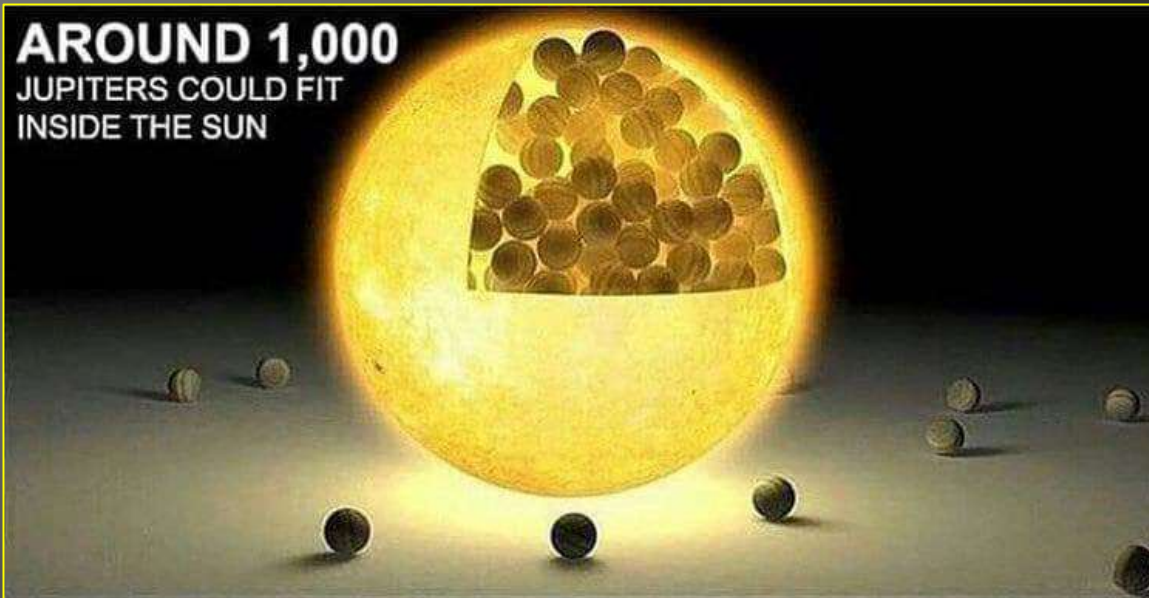
Core: ~15 million degrees



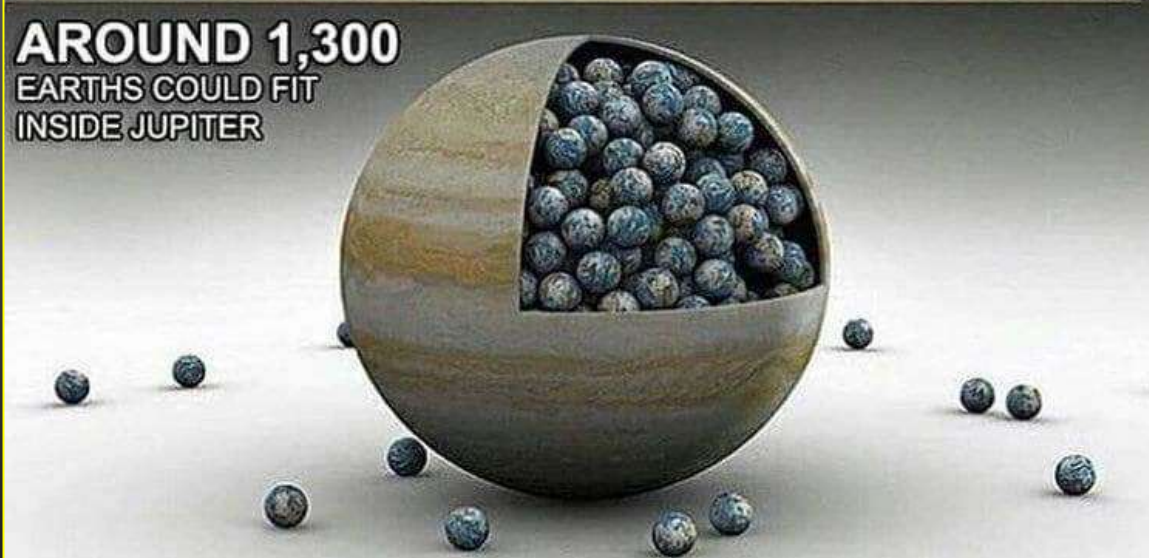
Capable of nuclear reactions
(Hydrogen bomb: 1952 USA)

Sun – Jupiter - Earth

AROUND 1,000
JUPITERS COULD FIT
INSIDE THE SUN



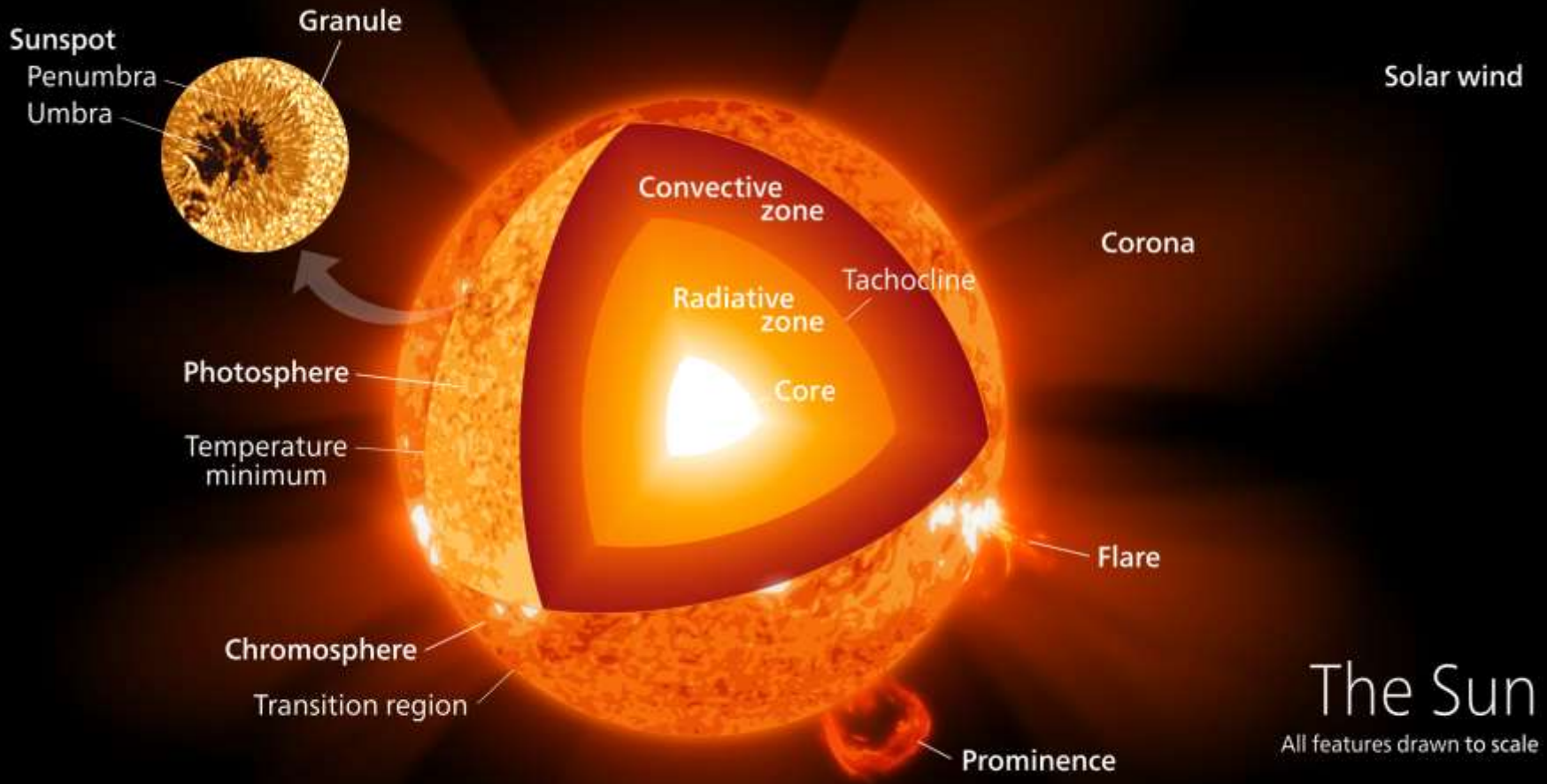
AROUND 1,300
EARTHS COULD FIT
INSIDE JUPITER



How the Sun was born

- Initial cloud mostly of hydrogen
 - Initial size~150 light years (ly)
 - Initial mass~ 10,000 solar masses
- The cloud due to gravity "shrank" and "broke" into small denser clouds
 - One of these clouds has a size of 0.5 ly~300,000 AU (AU is the mean distance between the Sun and the Earth)
 - Mass ~50 solar masses
- The cloud rotates so it becomes more flattened
- At its center, density increases => pressure & temperature increase
- Nuclear reactions begin (10^7 degrees) => The Sun is born
- The Solar "wind" clears the cloud, leaves the planets

Solar structure



The Sun

All features drawn to scale

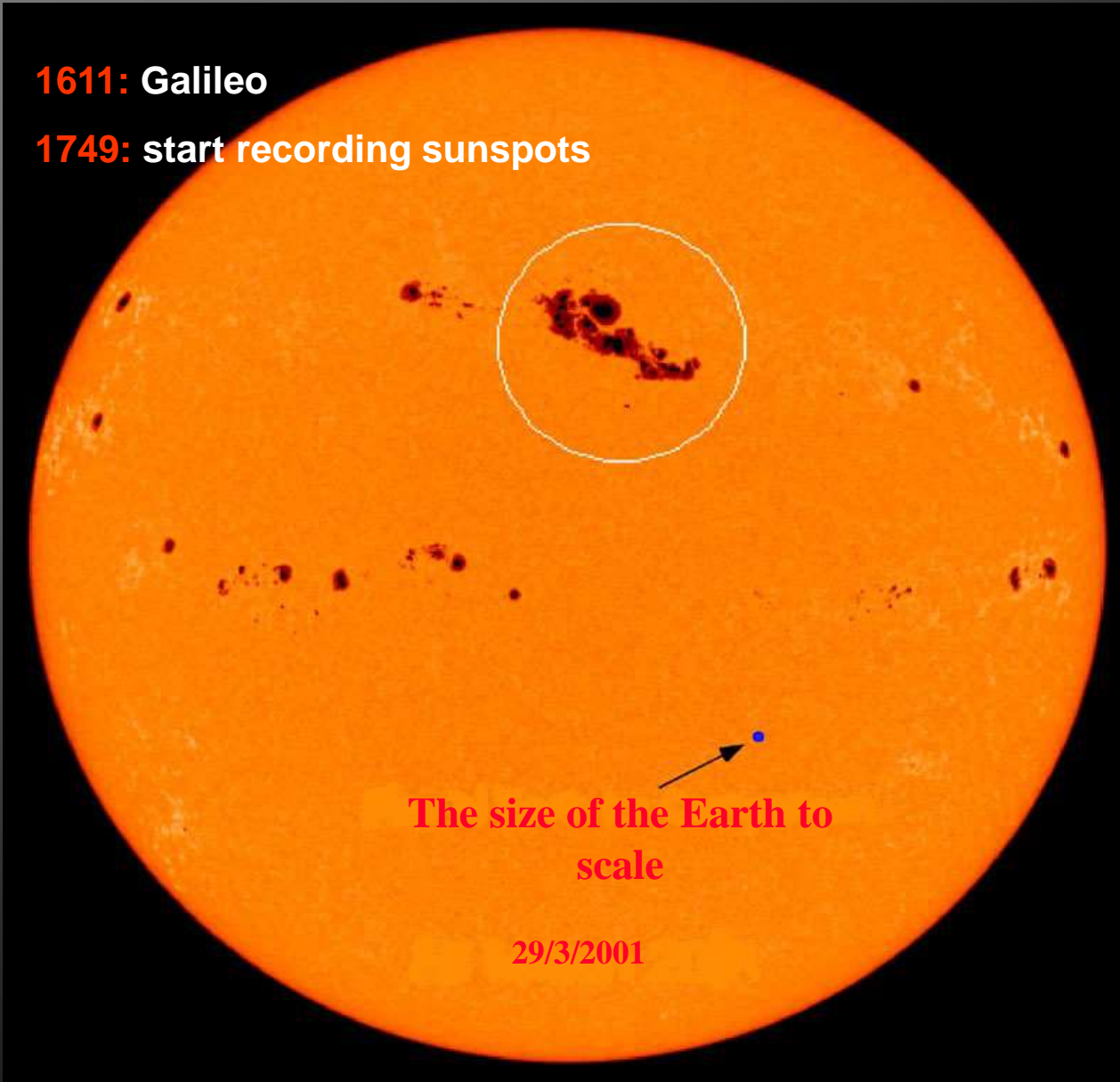
Solar corona



Sunspots

1611: Galileo

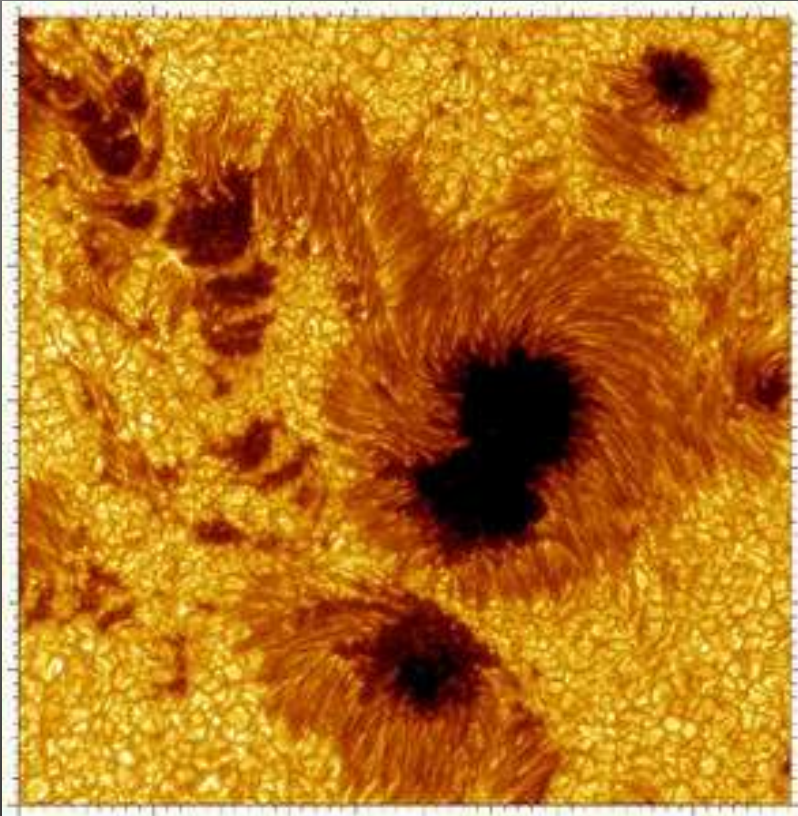
1749: start recording sunspots



**The size of the Earth to
scale**

29/3/2001

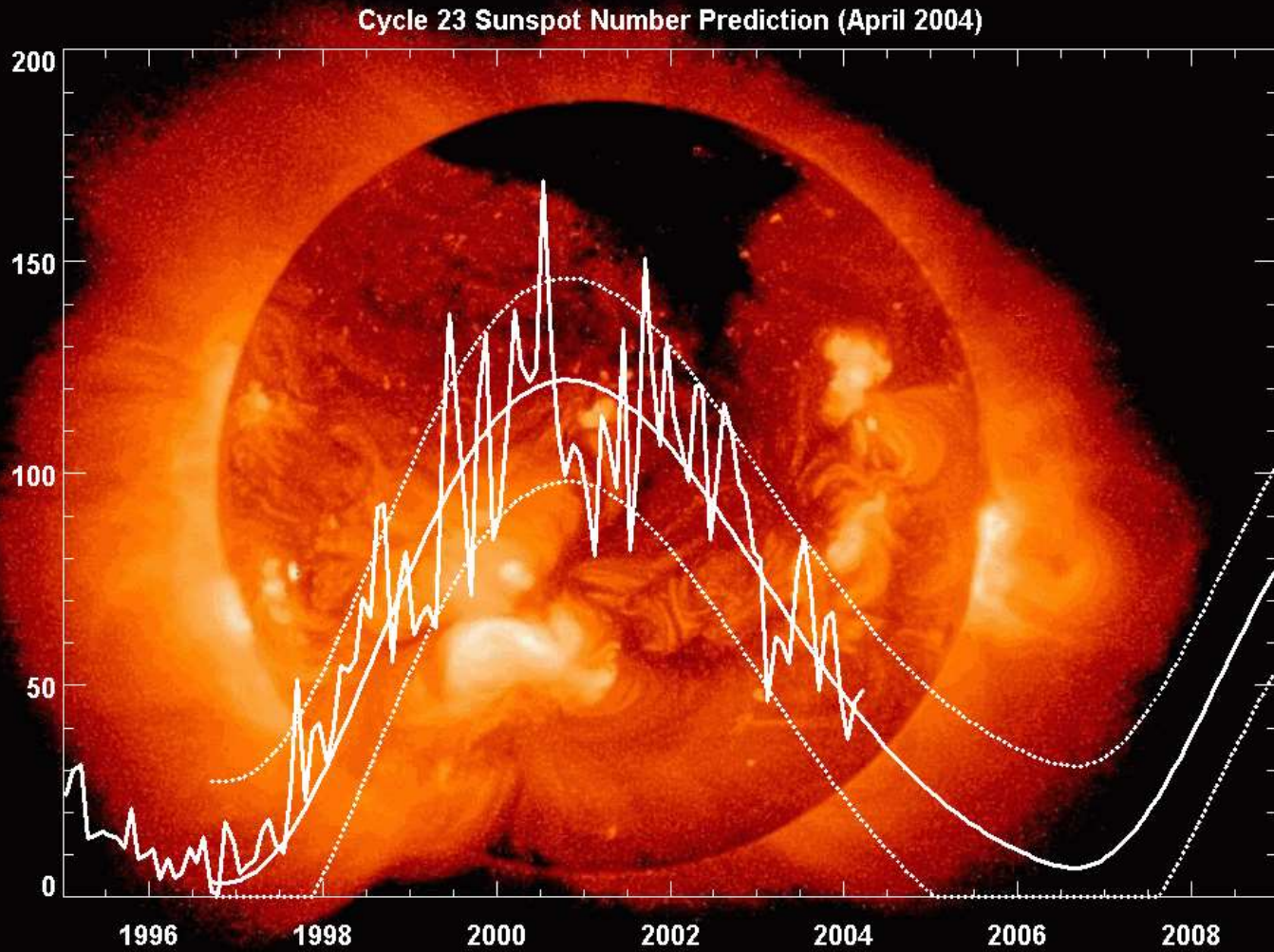
The sunspots up close

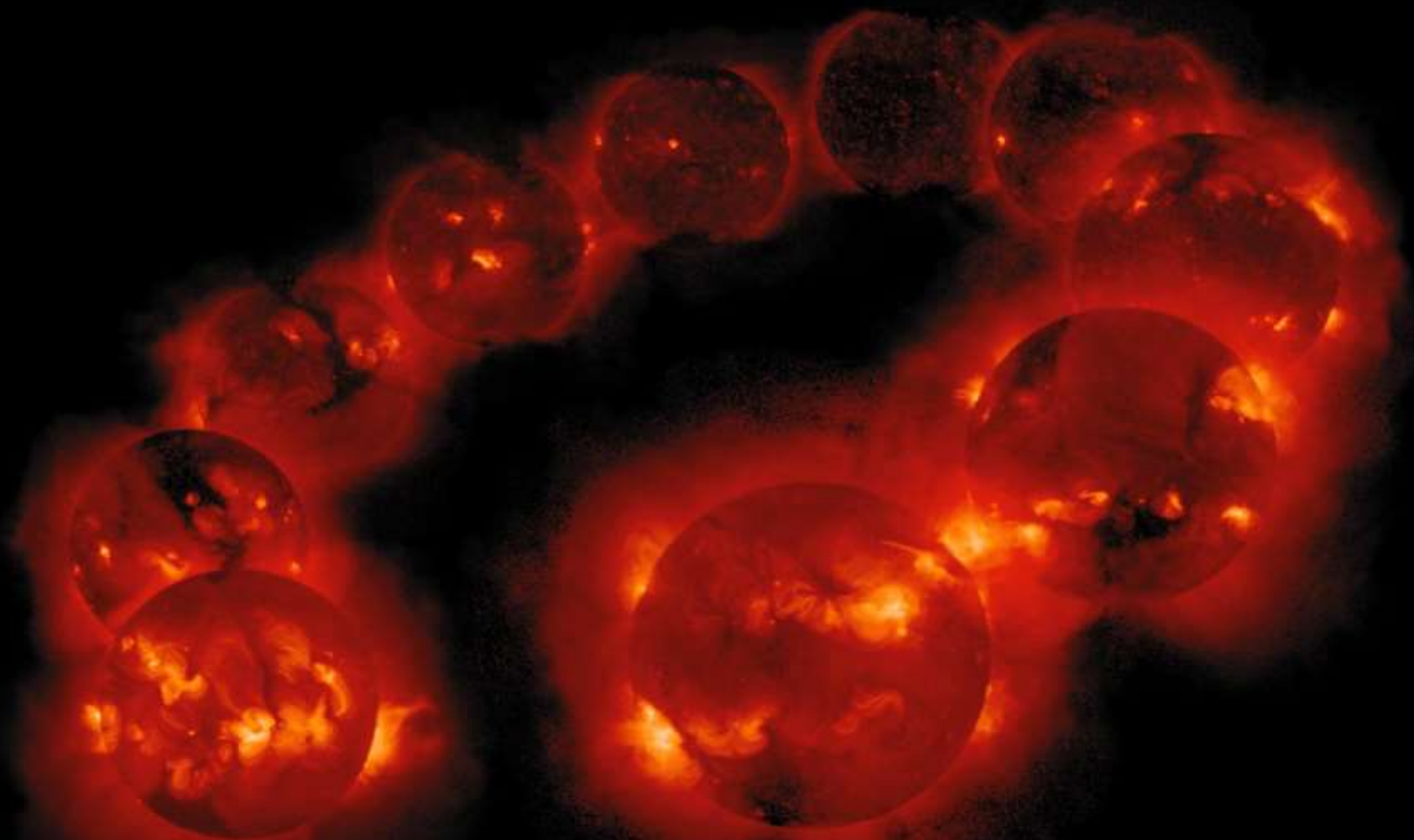


The sunspots are colder regions than the surrounding photosphere, hence they appear darker. Due to their very strong magnetic field, hot plasma is transported to the surrounding area.

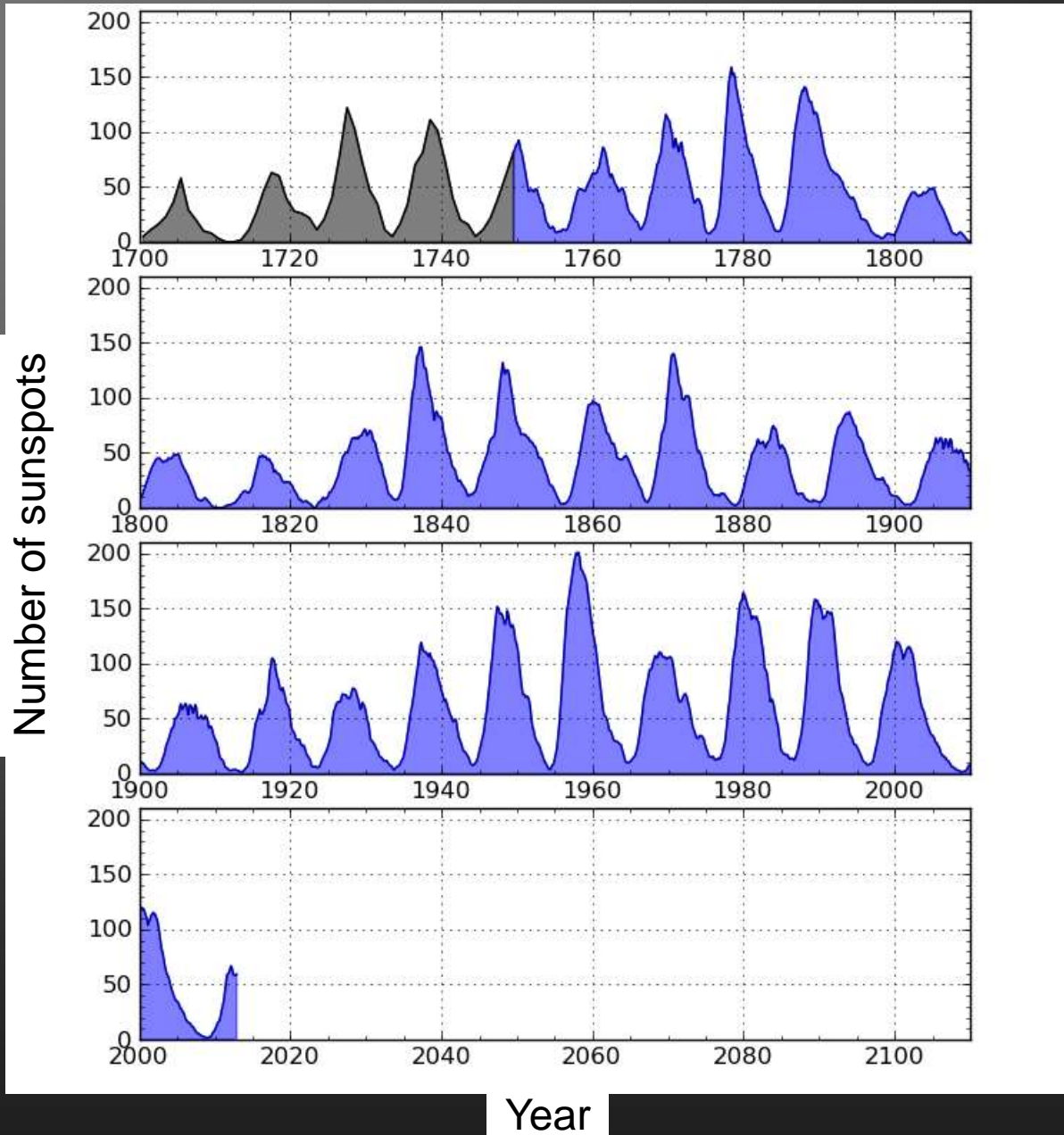


11-year solar cycle

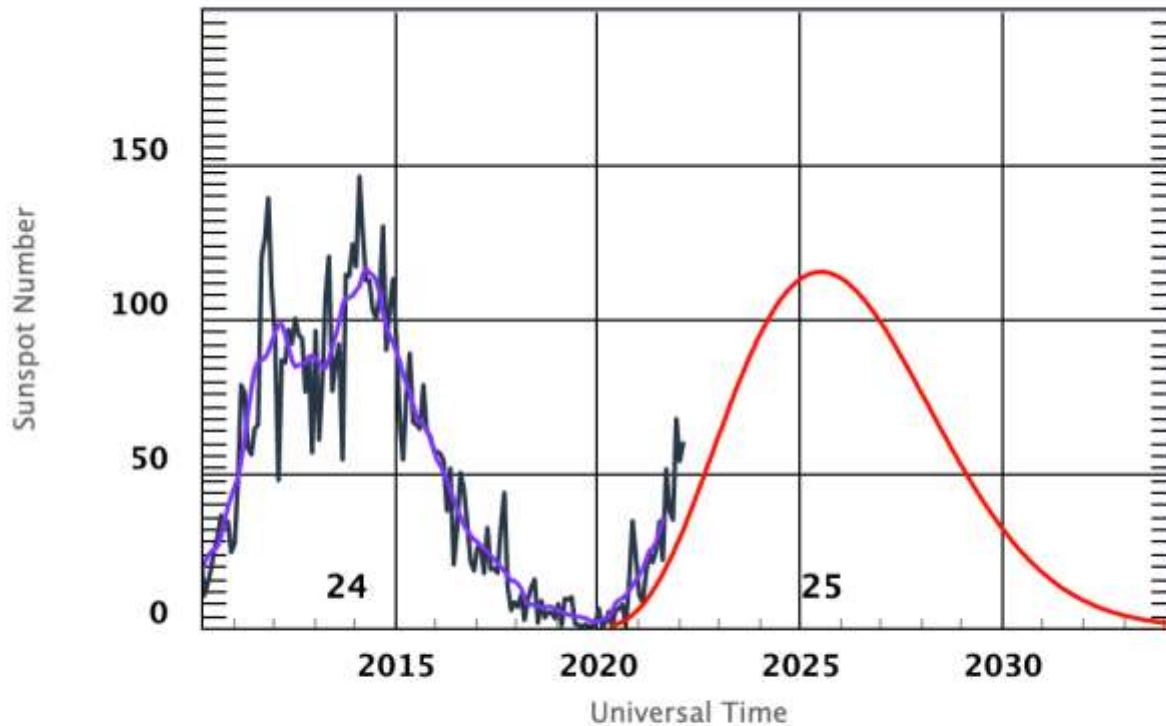




Variation in the number of sunspots



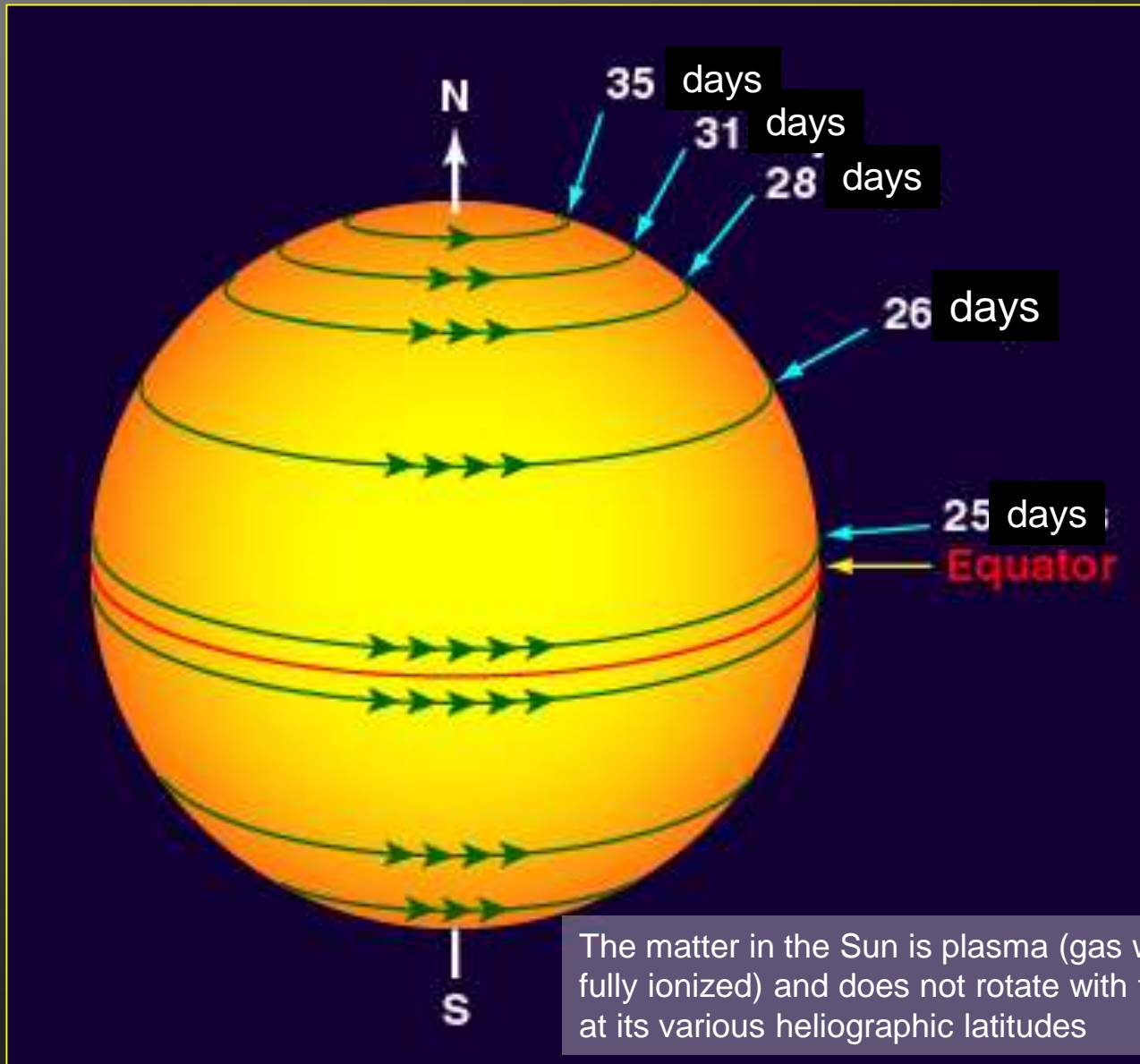
ISES Solar Cycle Sunspot Number Progression



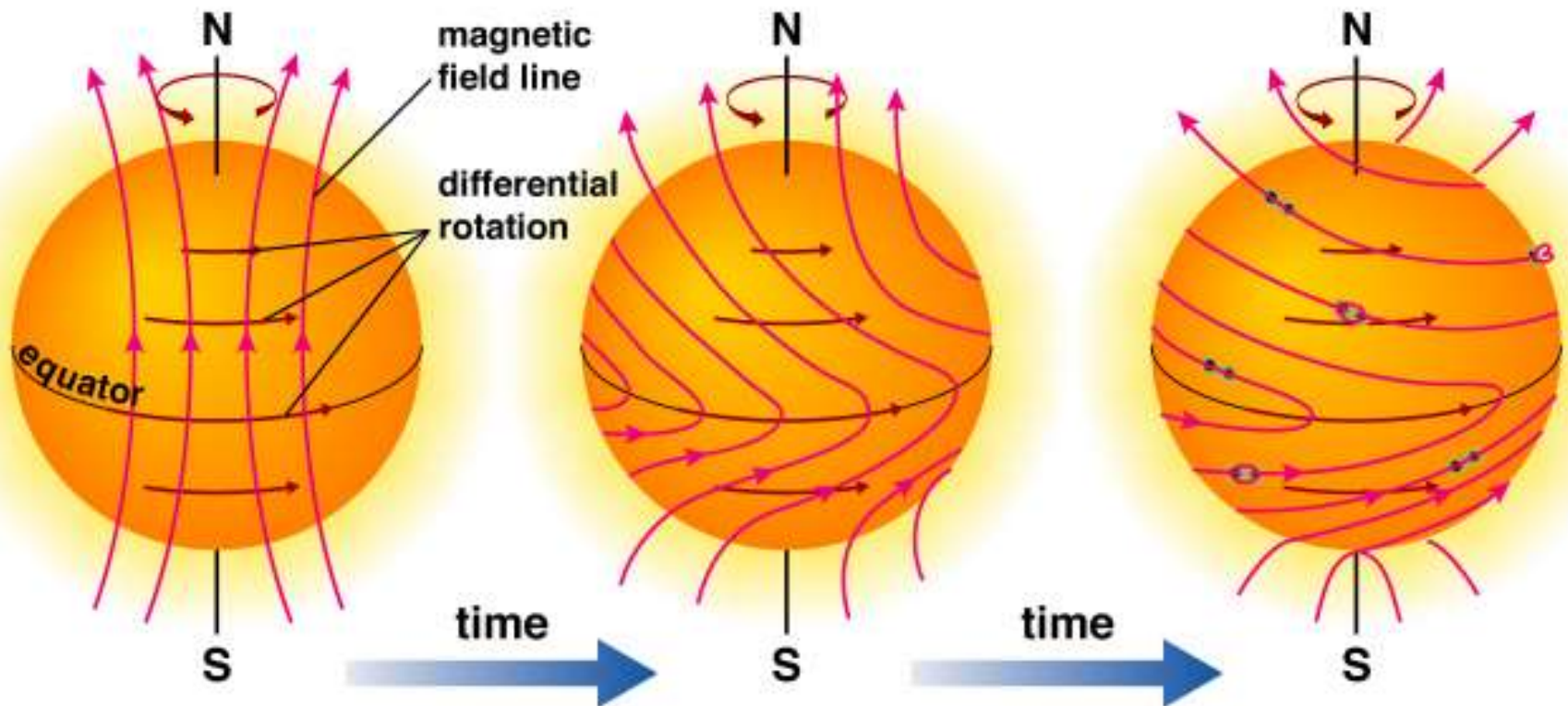
◆ Monthly Values — Smoothed Monthly Values — Predicted Values

Space Weather Prediction Center

How the sunspots form



How the sunspots form



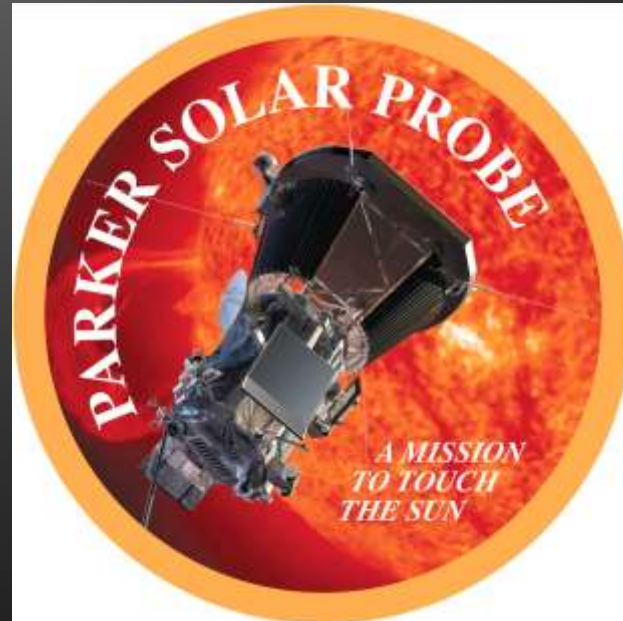


Solar wind

- ❑ Electrically neutral mixture of ions and electrons
(plasma: H^+ , ${}^4He^{++}$, e^-)
- ❑ temperature: 100.000 K
- ❑ speed: 400-800 km/sec
- ❑ density: 5 particles/cm³
- ❑ It needs 2 to 4 days to reach the Earth

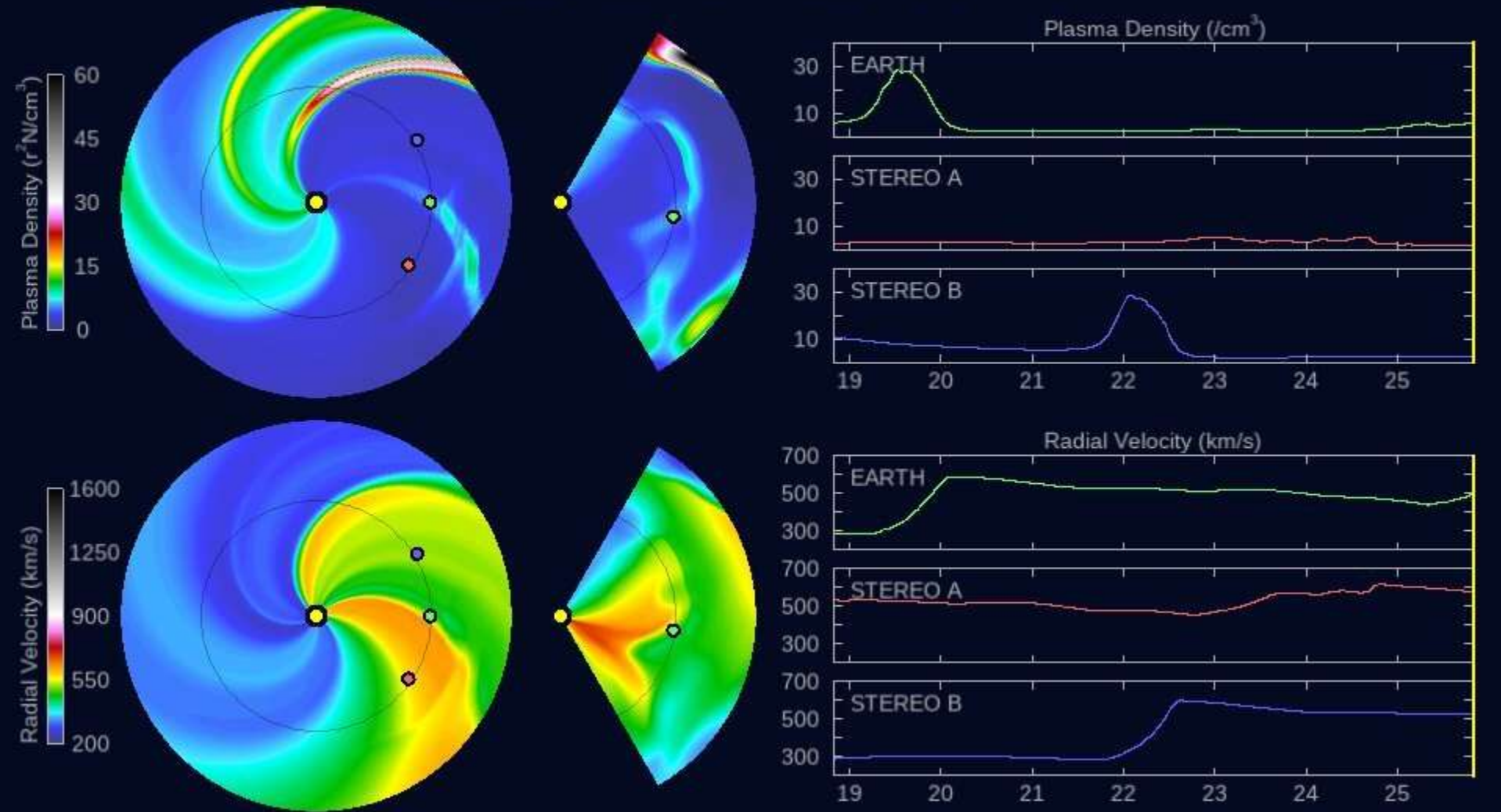


Eugene Parker (1927-2022)





2022-03-25 20:00:00



Space Weather Prediction Center

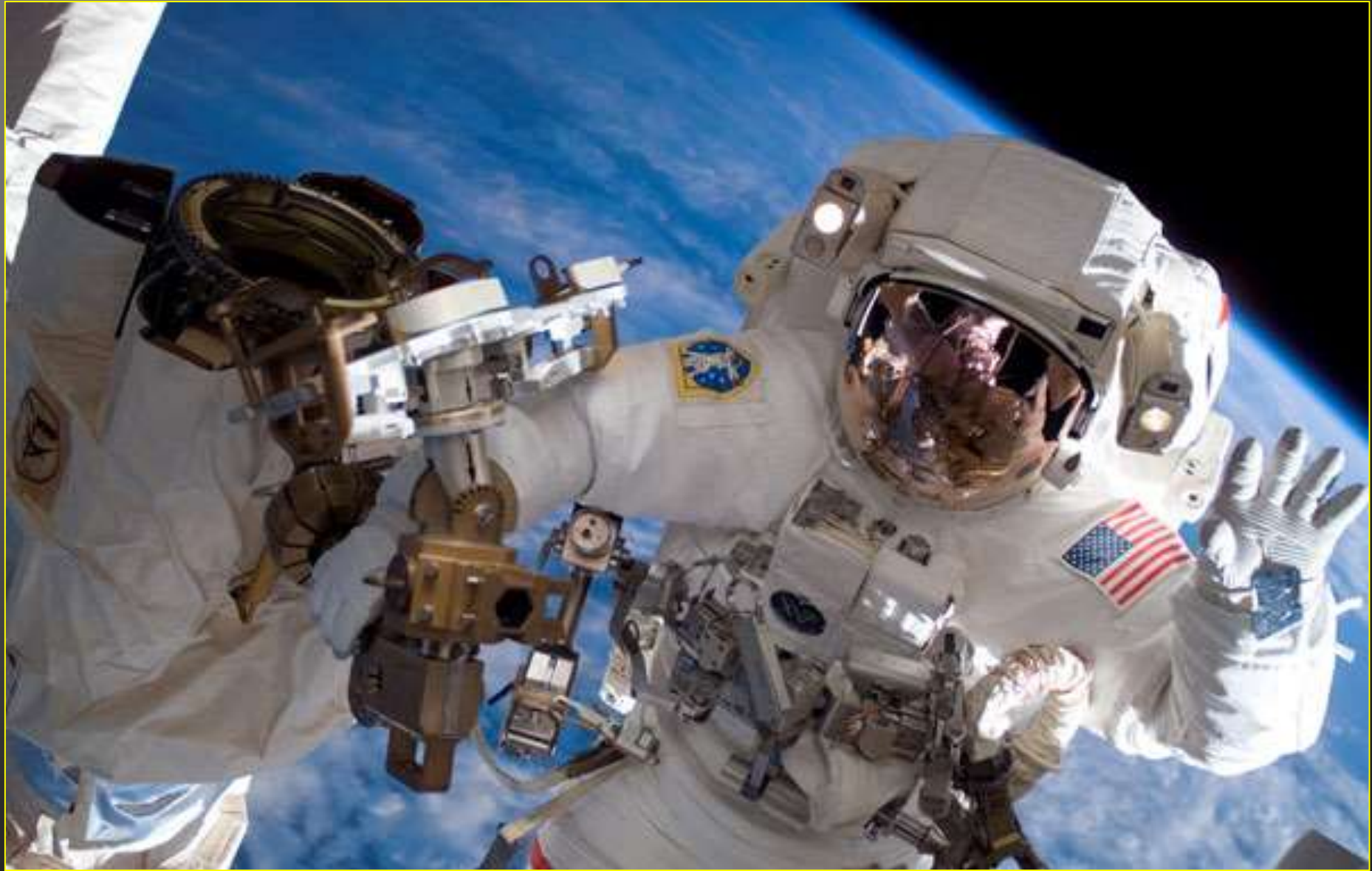
Run Time: 2022-03-20 20:00 UT Mode: CME

Image Created: 2022-03-20 21:27 UT

Πηγή: <https://www.swpc.noaa.gov/products/wsa-enlil-solar-wind-prediction>

Space weather

It's all the changes in the plasma, the magnetic field and the electromagnetic radiation in the space environment which now affects the technological systems in space and on Earth and possibly also the living beings.



Solar flare

Abrupt and rapid increase in the intensity of electromagnetic radiation at many wavelengths

Energy release: 10^{22} - 10^{25} Joule

Hydrogen bomb: 10^{17} Joule





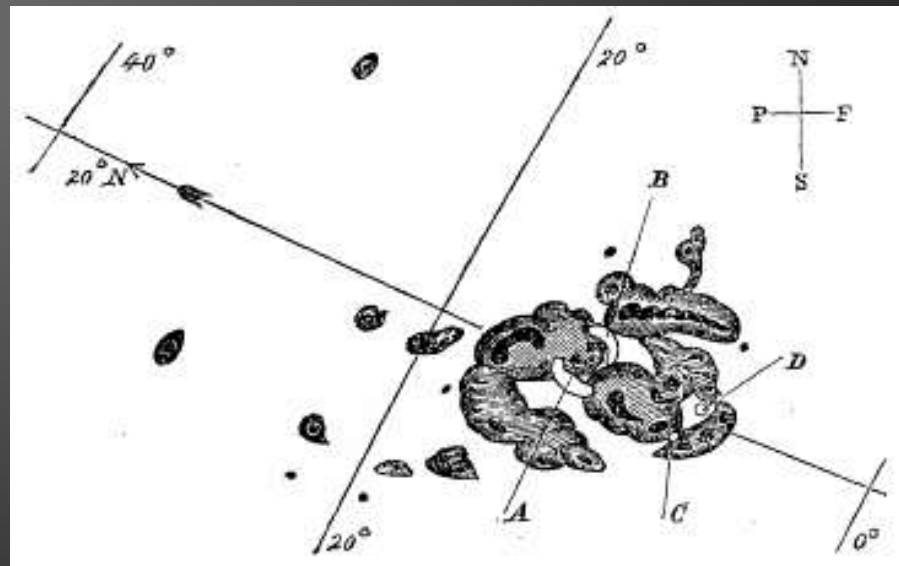
2003/11/04 19:48



Aurora borealis from Athens
(November 2003)
Credit: Antonis Agiomamitis

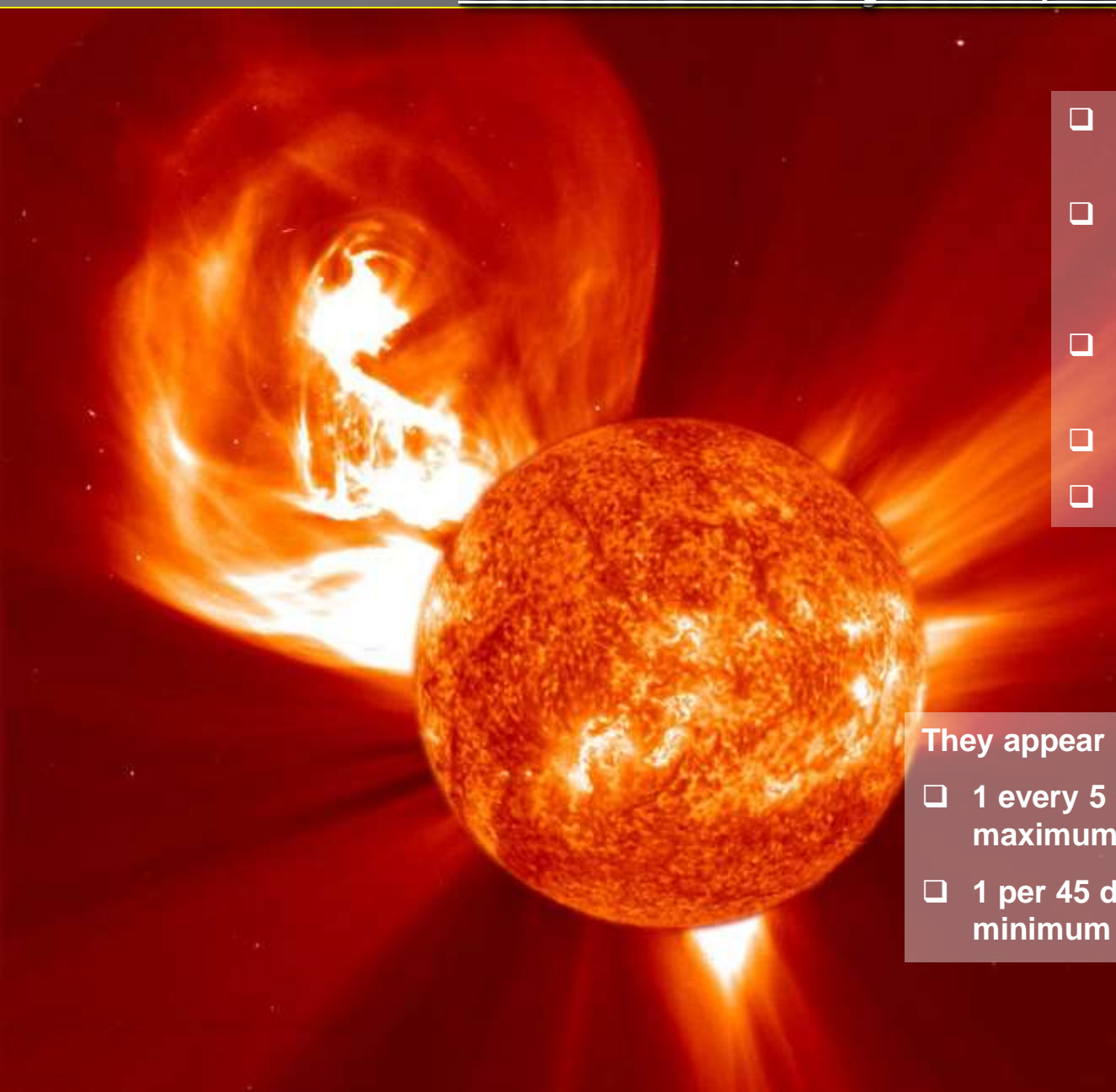
The “mother” of all flares (1/9/1859)

It was accompanied by an intense magnetic storm the next day



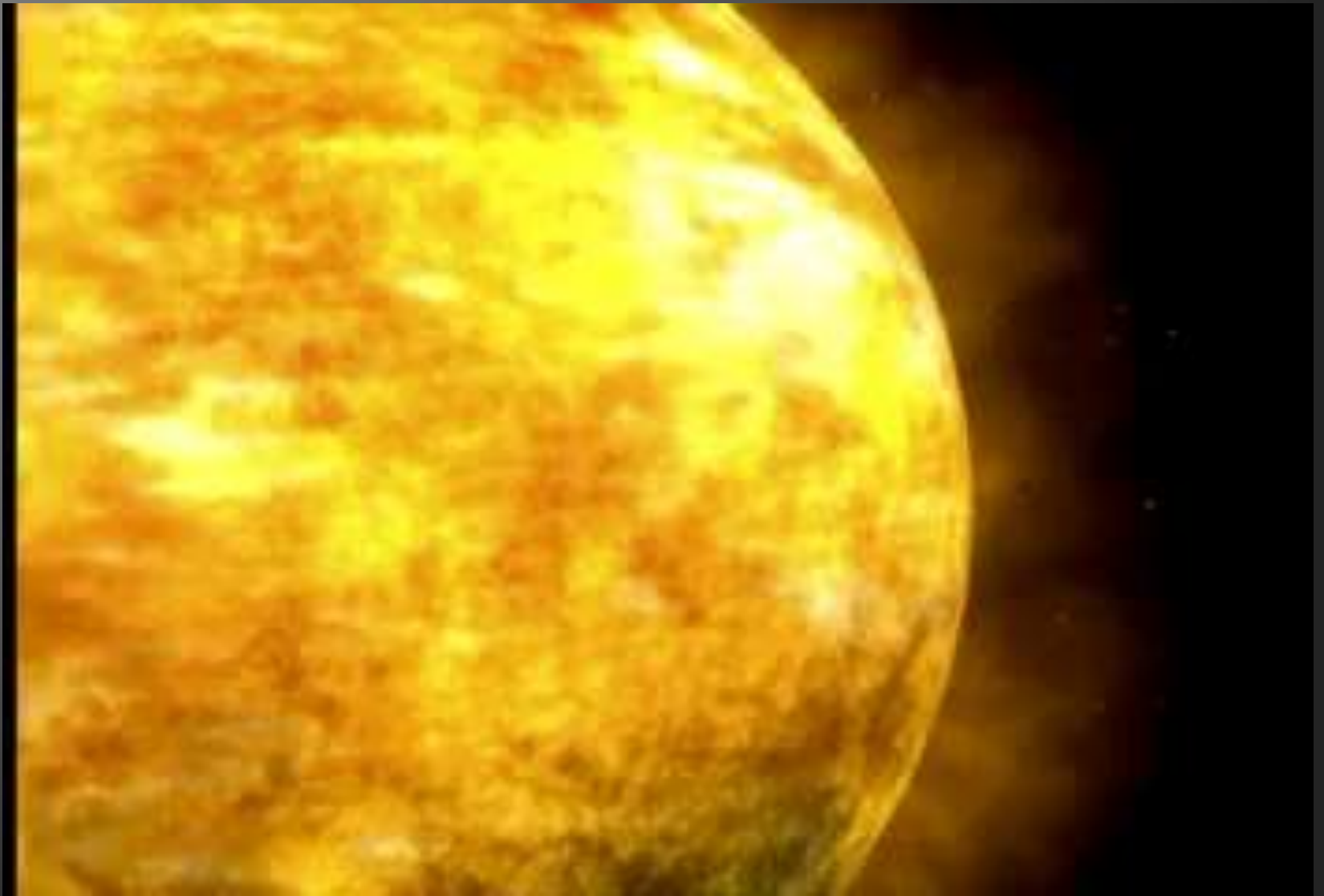
Carrington's design

Coronal Mass Ejection, CME

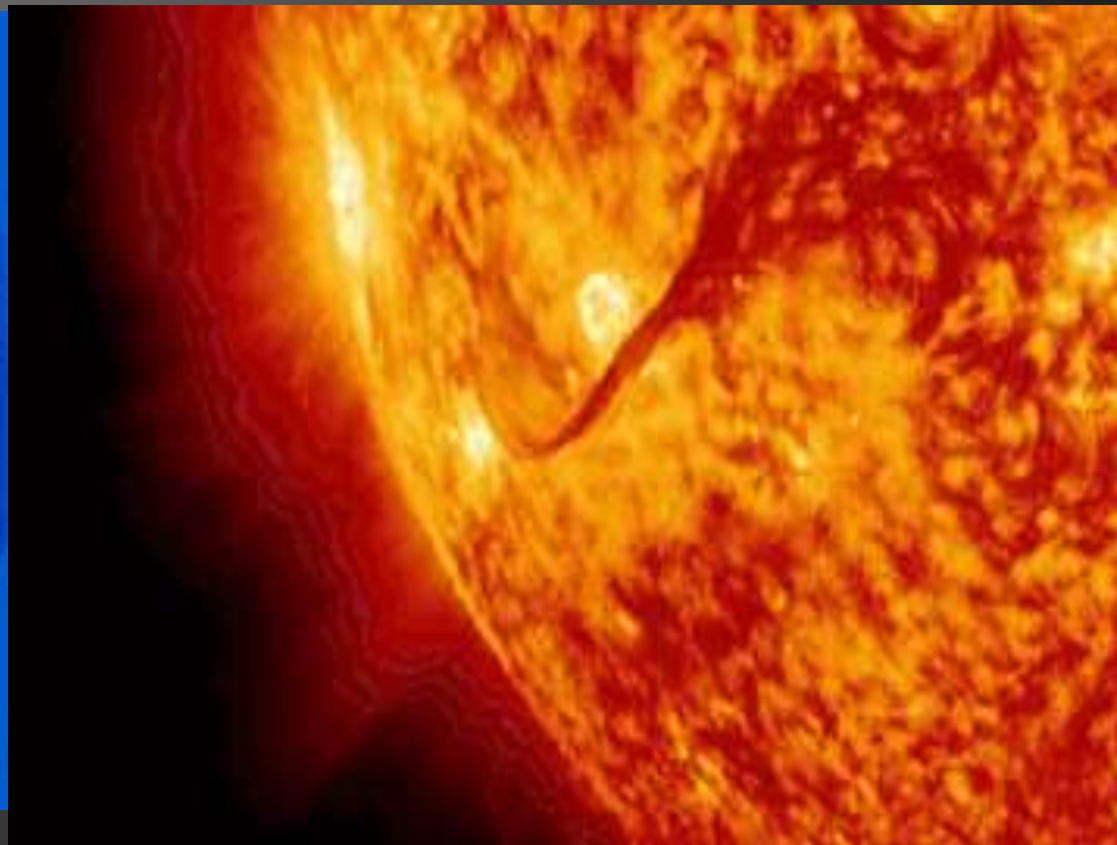
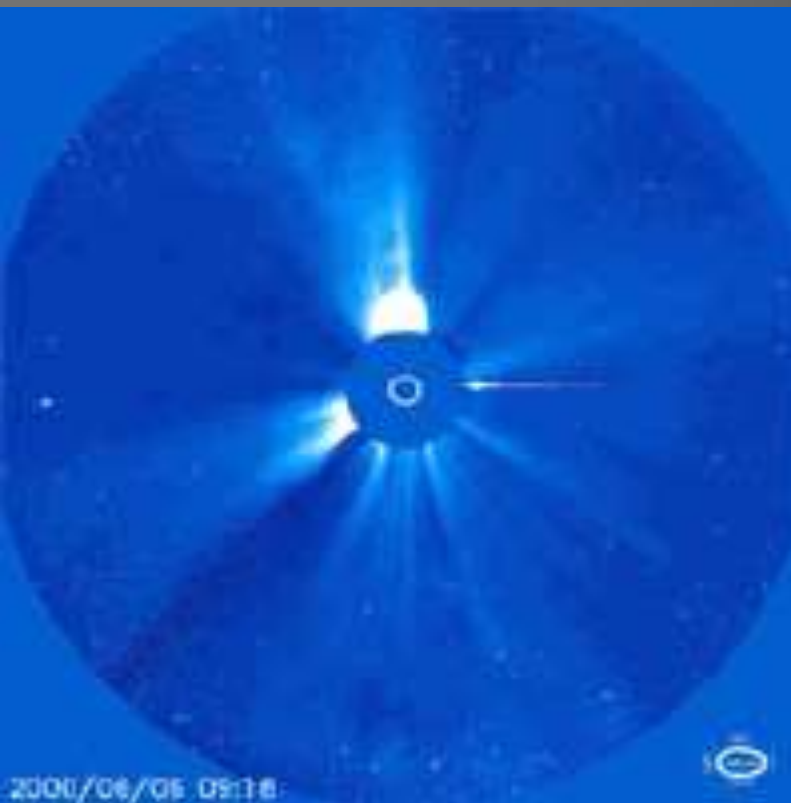
- 
- ❑ They are sometimes associated with flares
 - ❑ They travel at 3 times the speed of the solar wind (~1,500 km/s)
 - ❑ They contain protons, e- and strong magnetic fields
 - ❑ Size: ~50 Sun Rays
 - ❑ They create a shock wave

They appear

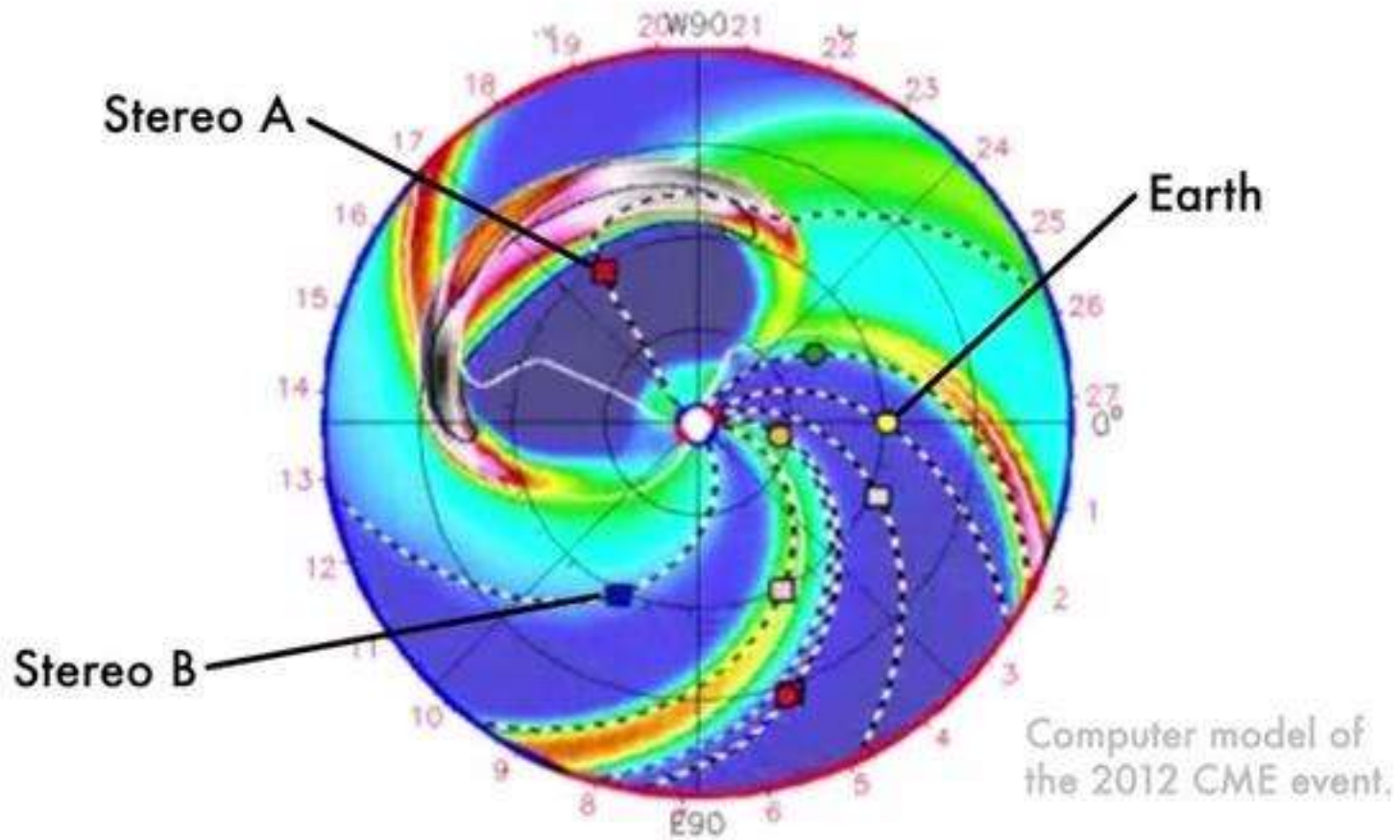
- ❑ 1 every 5 days during periods of solar maximum
- ❑ 1 per 45 days during periods of solar minimum



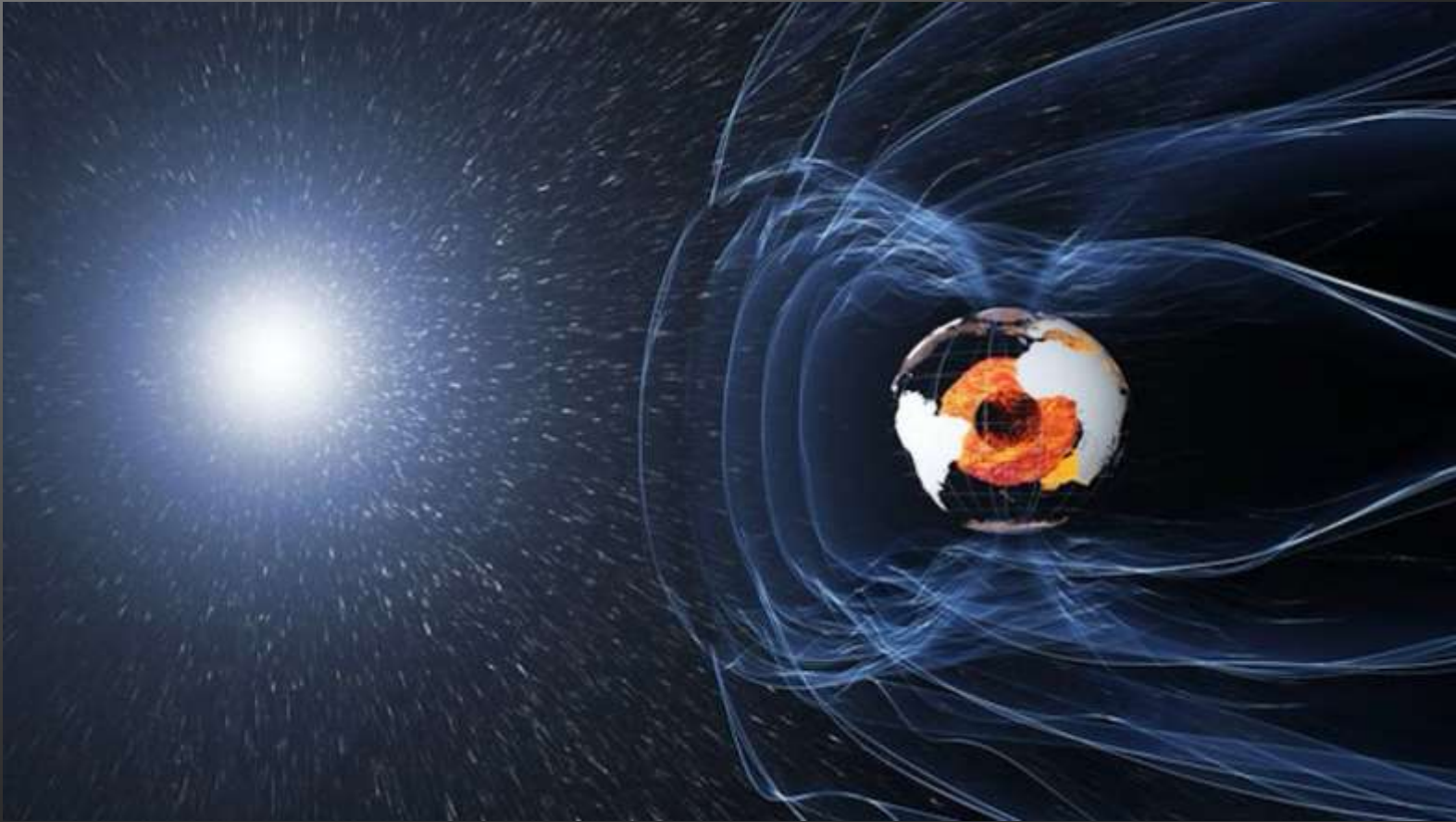
Credit: NASA/Walt Feimer



Πηγή: *science.nasa.gov*



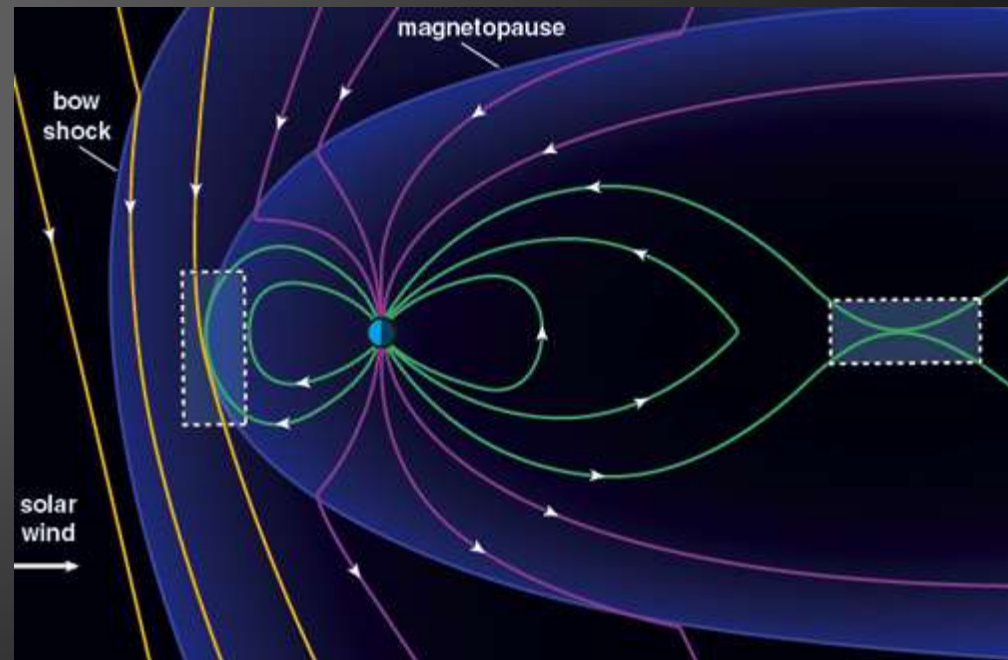
Geomagnetic field

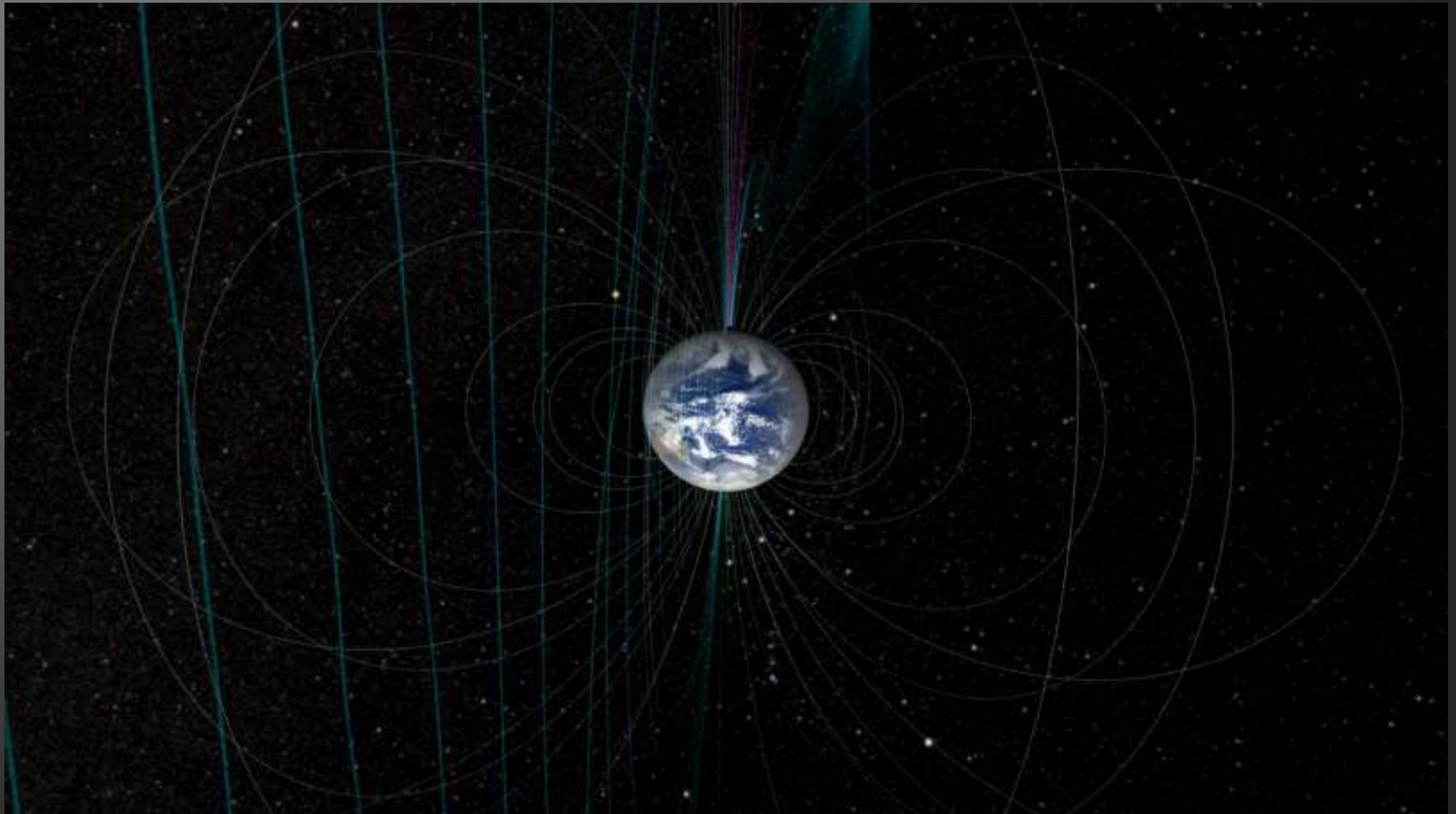


Credit: ESA and AOES medialab

Conjunction of Sun and Earth

Input of large amounts of energy from the solar wind.





*Credits: NASA's Scientific Visualization
Studio*

Aurora borealis

- ❑ Conjunction of the solar wind with the atmosphere





"Bad" Space weather [NOAA]

- **Radio blackouts [source: flares]** -> sharp increase in intensity mainly in X-rays

They affect telecommunications and satellite navigation

- **Solar radiation storms [source: flares, CMEs]** -> caused by a flow of energetic ions

They affect the operation of satellite and biological systems

- **Geomagnetic storms [source: CMEs]** -> global decrease in the intensity of the geomagnetic field

They affect the operation of various technological systems more broadly

Technological effects



Communications

Intelsat V
Intelsat k

GOES East
(75 W Long)

Weather

NOAA-11
DMSP

Navigation

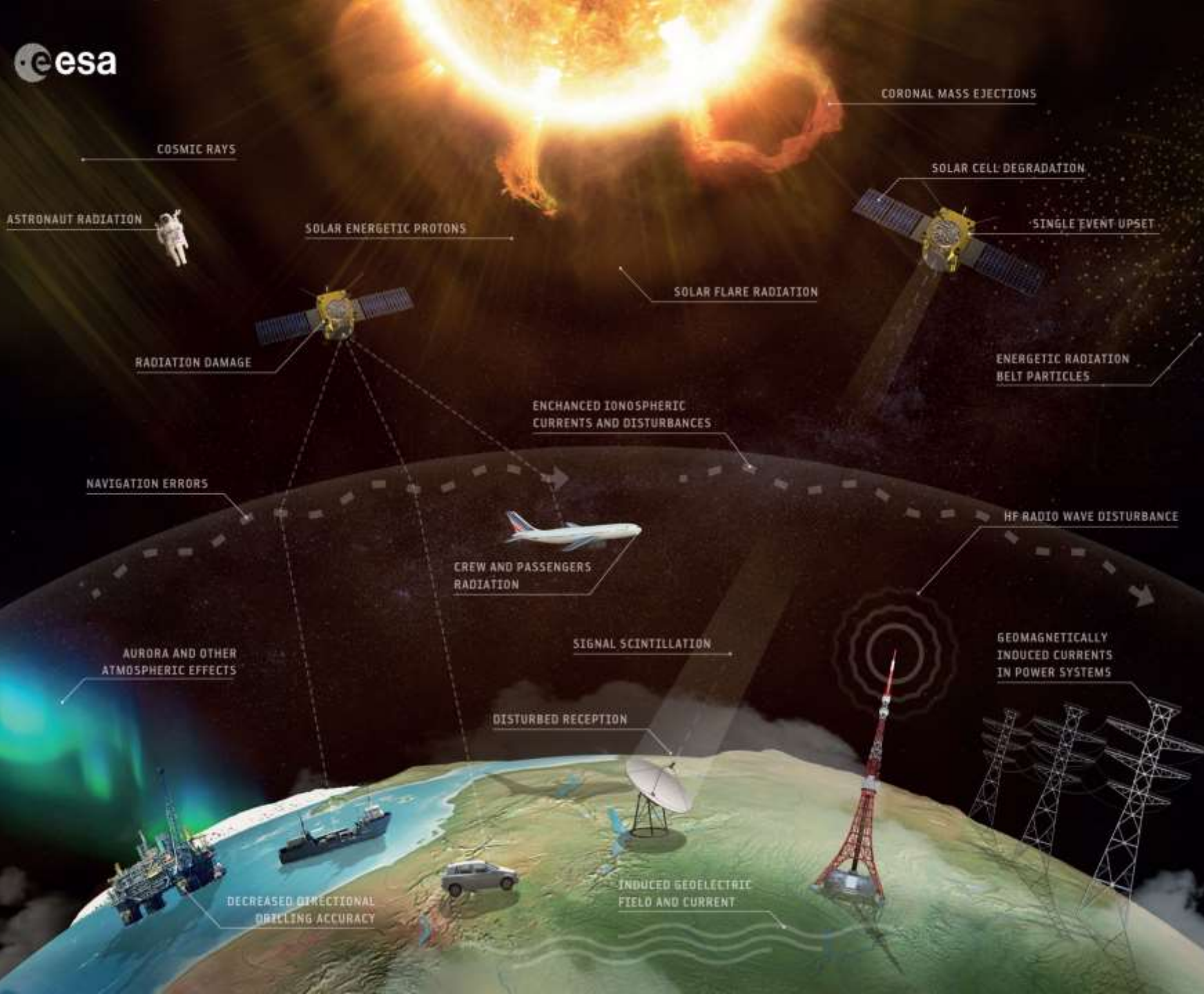
GPS

Scientific Research

SOHO
SAMPX

Remote Sensing

Landsat



COSMIC RAYS

ASTRONAUT RADIATION

SOLAR ENERGETIC PROTONS

SOLAR FLARE RADIATION

CORONAL MASS EJECTIONS

SOLAR CELL DEGRADATION

SINGLE EVENT UPSET

RADIATION DAMAGE

ENERGETIC RADIATION
BELT PARTICLES

ENHANCED IONOSPHERIC
CURRENTS AND DISTURBANCES

NAVIGATION ERRORS

HF RADIO WAVE DISTURBANCE

CREW AND PASSENGERS
RADIATION

AURORA AND OTHER
ATMOSPHERIC EFFECTS

SIGNAL SCINTILLATION

GEOMAGNETICALLY
INDUCED CURRENTS
IN POWER SYSTEMS

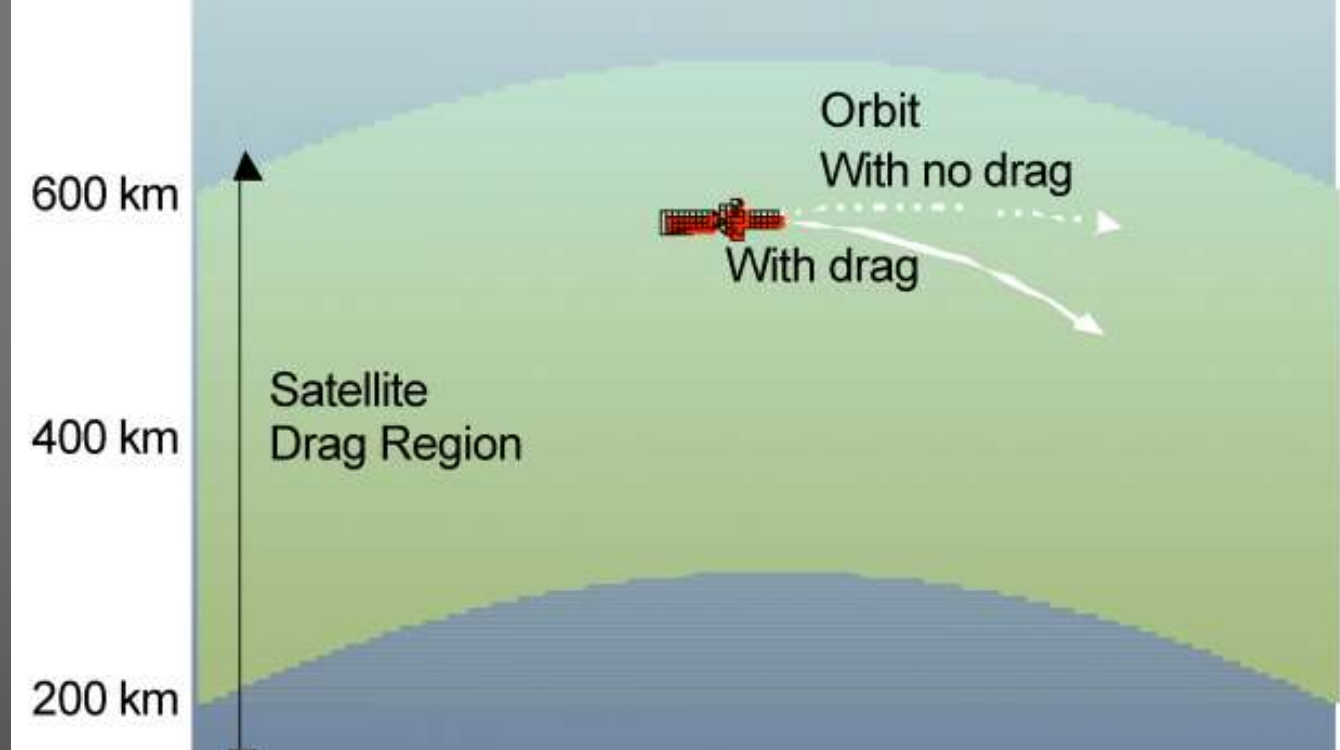
DISTURBED RECEPTION

DECREASED DIRECTIONAL
DRIFTING ACCURACY

INDUCED GEOELECTRIC
FIELD AND CURRENT

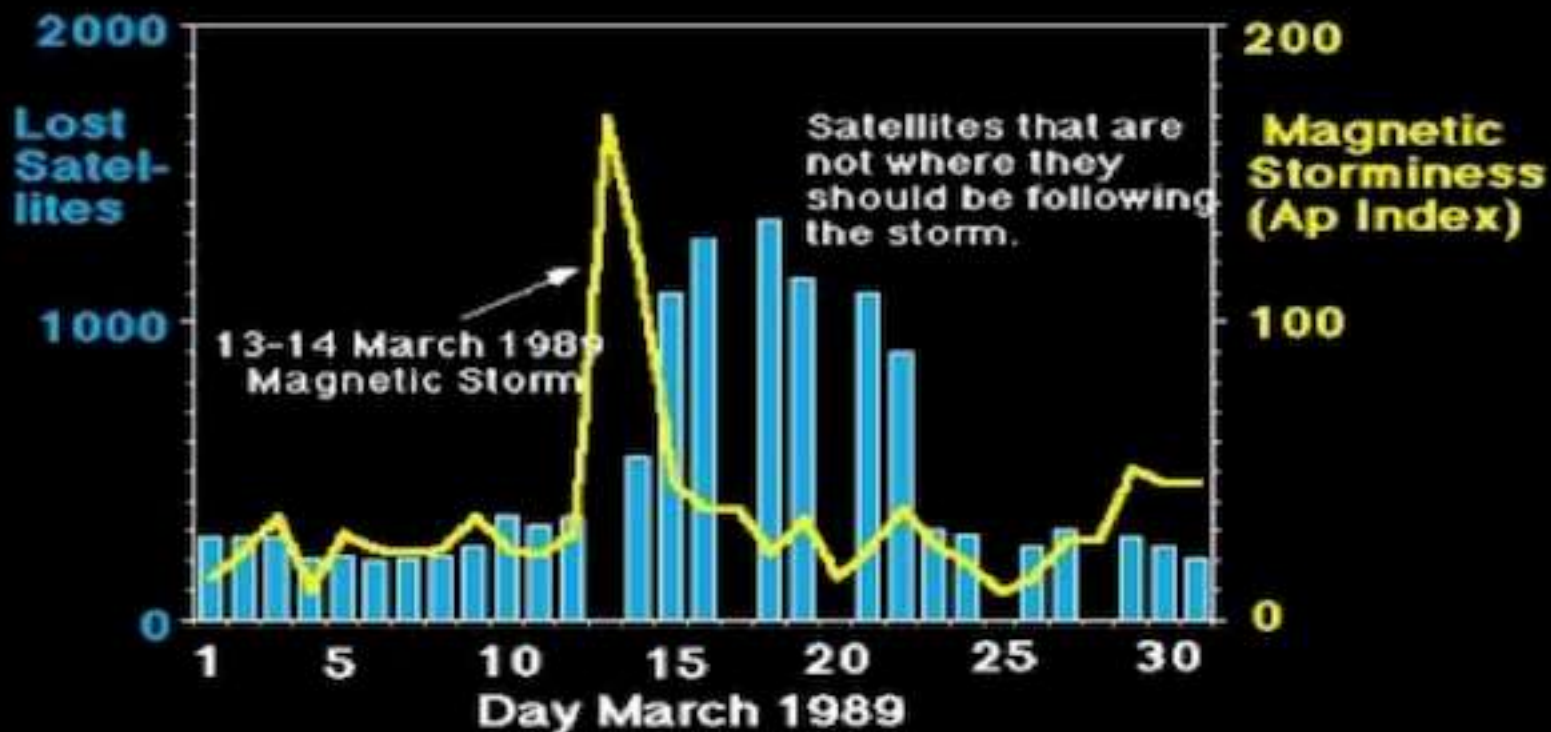
- Complete lack of communication with the satellite
- Damage to the surface part of the satellite from UV, X-rays (stress of the thermal control material, damage to the solar panels, etc.)
- Problems due to high-energy particles (instrument read error, satellite computer processor stuck)





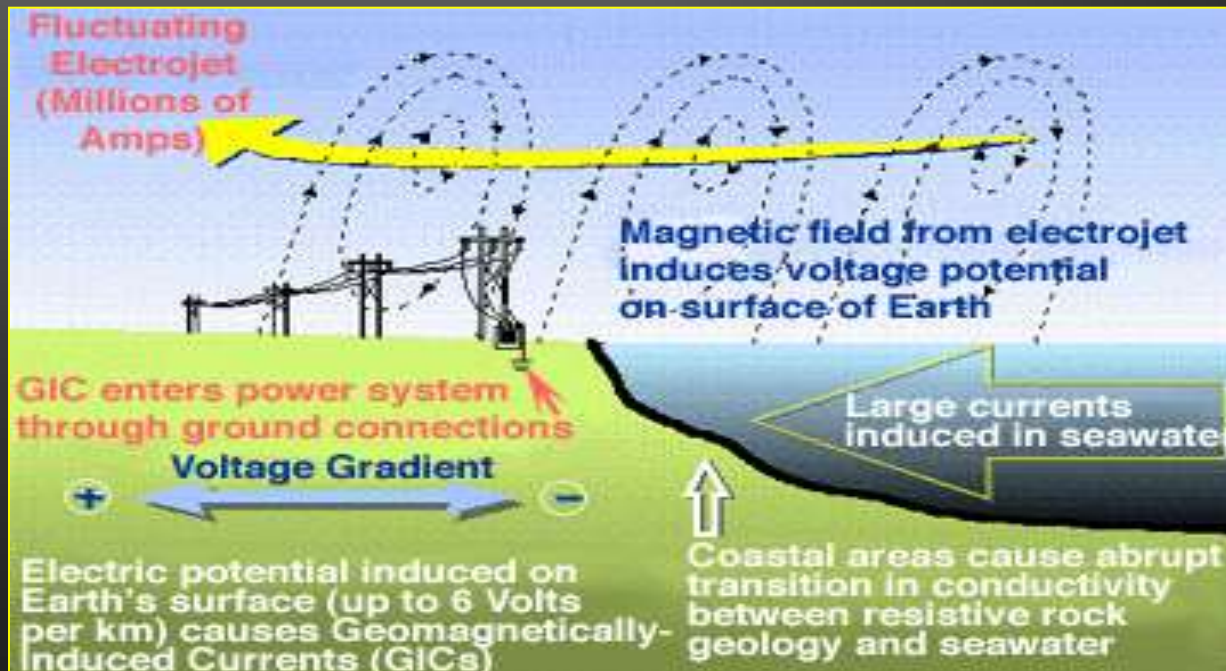
(Image credit: Eddie Irizarry/Sociedad de Astronomía del Caribe (SAC))

Satellite Tracking Problems After March 13-14, 1989 Storm





- ✓ 1847-1859: destruction of telegraph cables in England
- ✓ Ιούλιος 1982: railway breakdowns in Sweden
- ✓ 13 Μαρτίου 1989: the power grid collapsed in Quebec, Canada, for 9 hours.



Biological effects

Biological effects (ICRP, 1991)

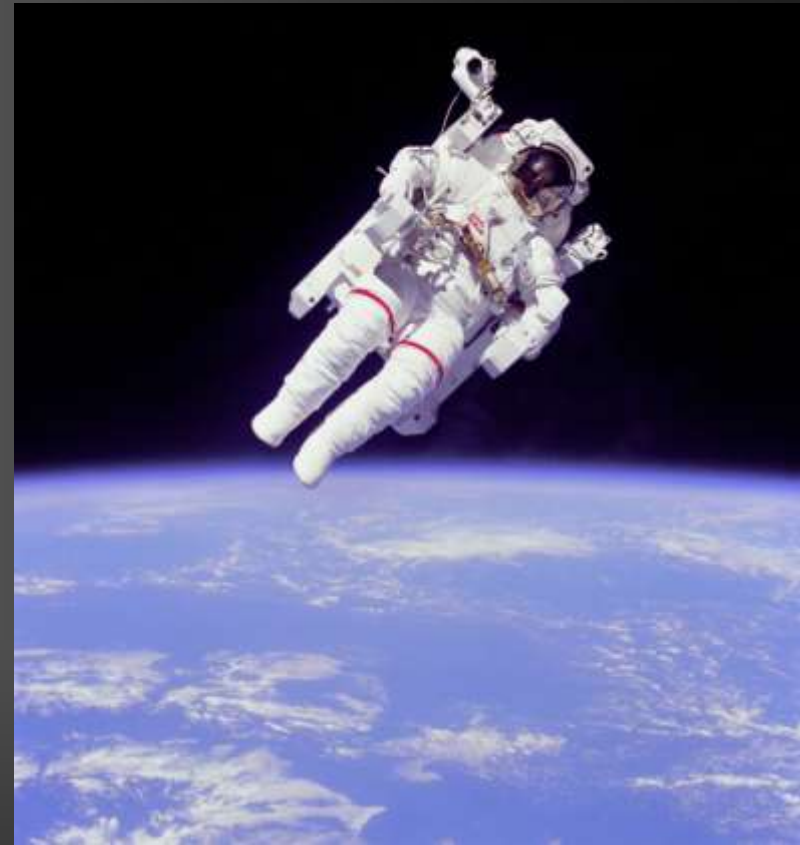
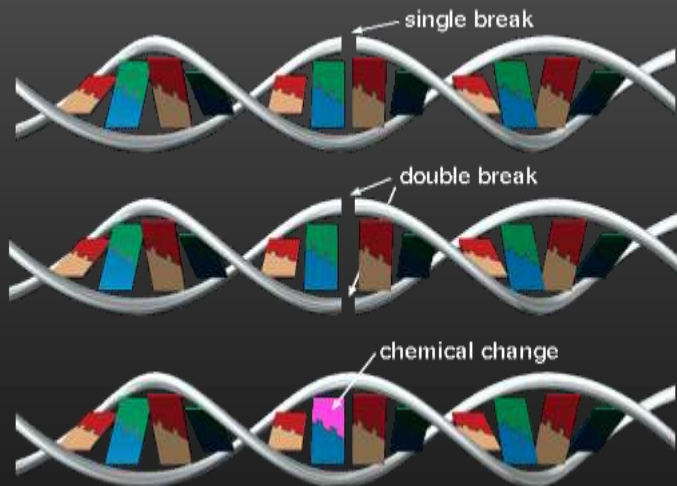
– *Acute effects (Malfunctions of organs, eye cataracts, etc).*

Deterministic, threshold doses

– *Late effects (DNA damage, mutations, cancer)*

Stochastic, no threshold doses

Accumulated dose from GCR is a serious problem for long voyage scenarios (Mars), even at solar maximum



Bruce McCandless

Astronauts and flight crew passengers at high latitudes are most exposed



Astronauts have about 20 minutes to enter the ISS after a high-energy particle event warning

Here
comes
the sun.

-The Beatles



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