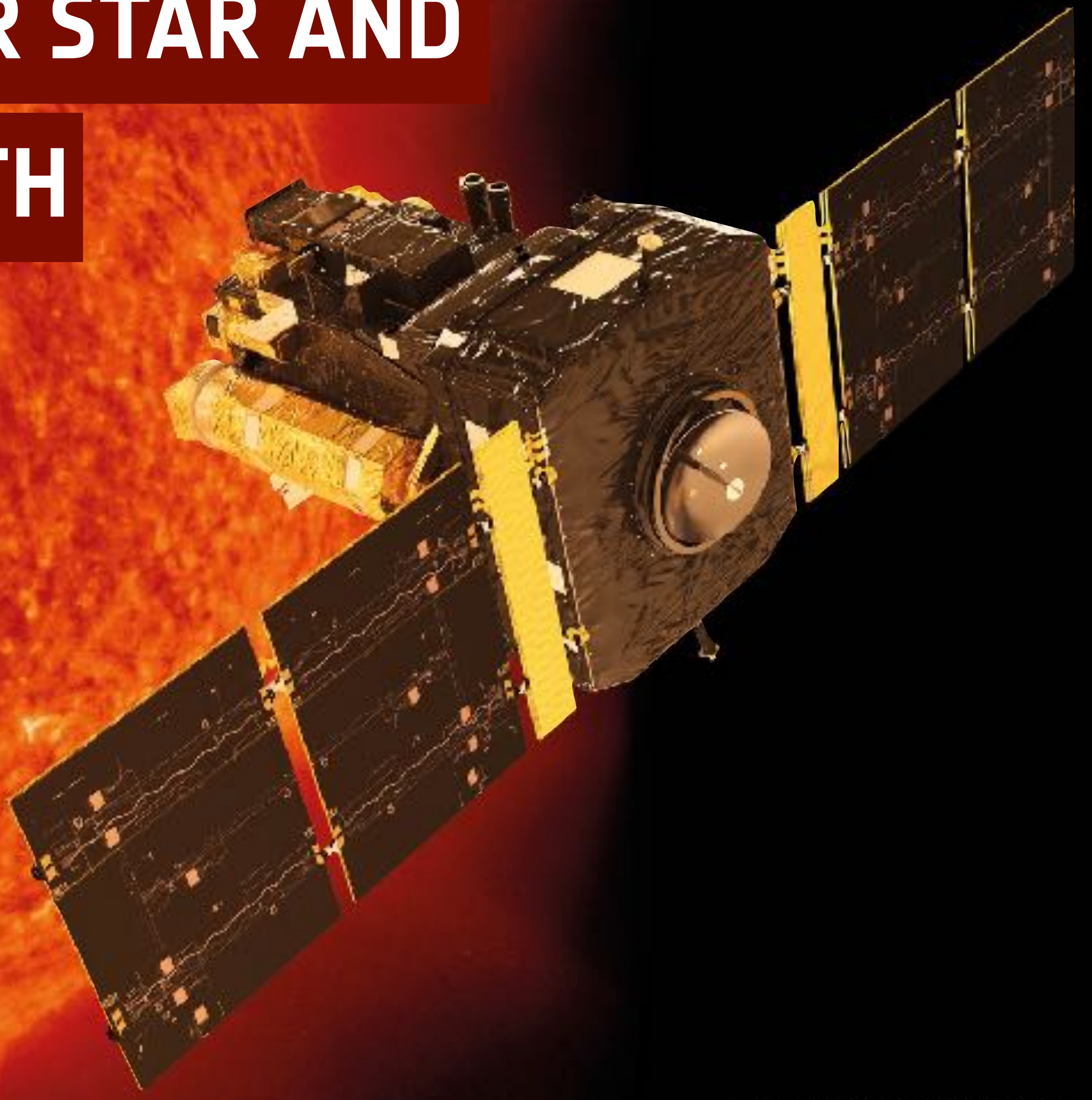
soho

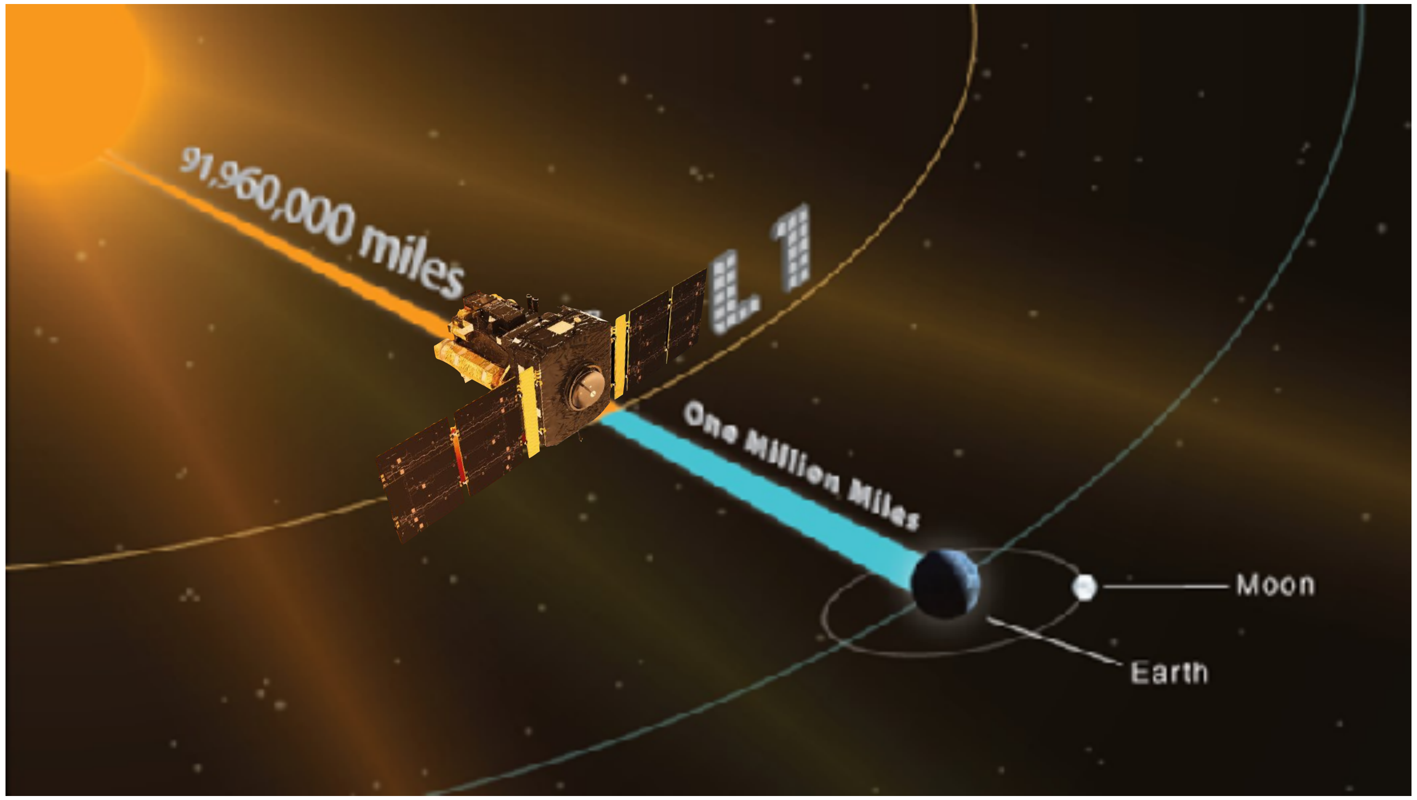
# → UNDERSTANDING OUR STAR AND ITS INFLUENCE ON EARTH WITH SOHO



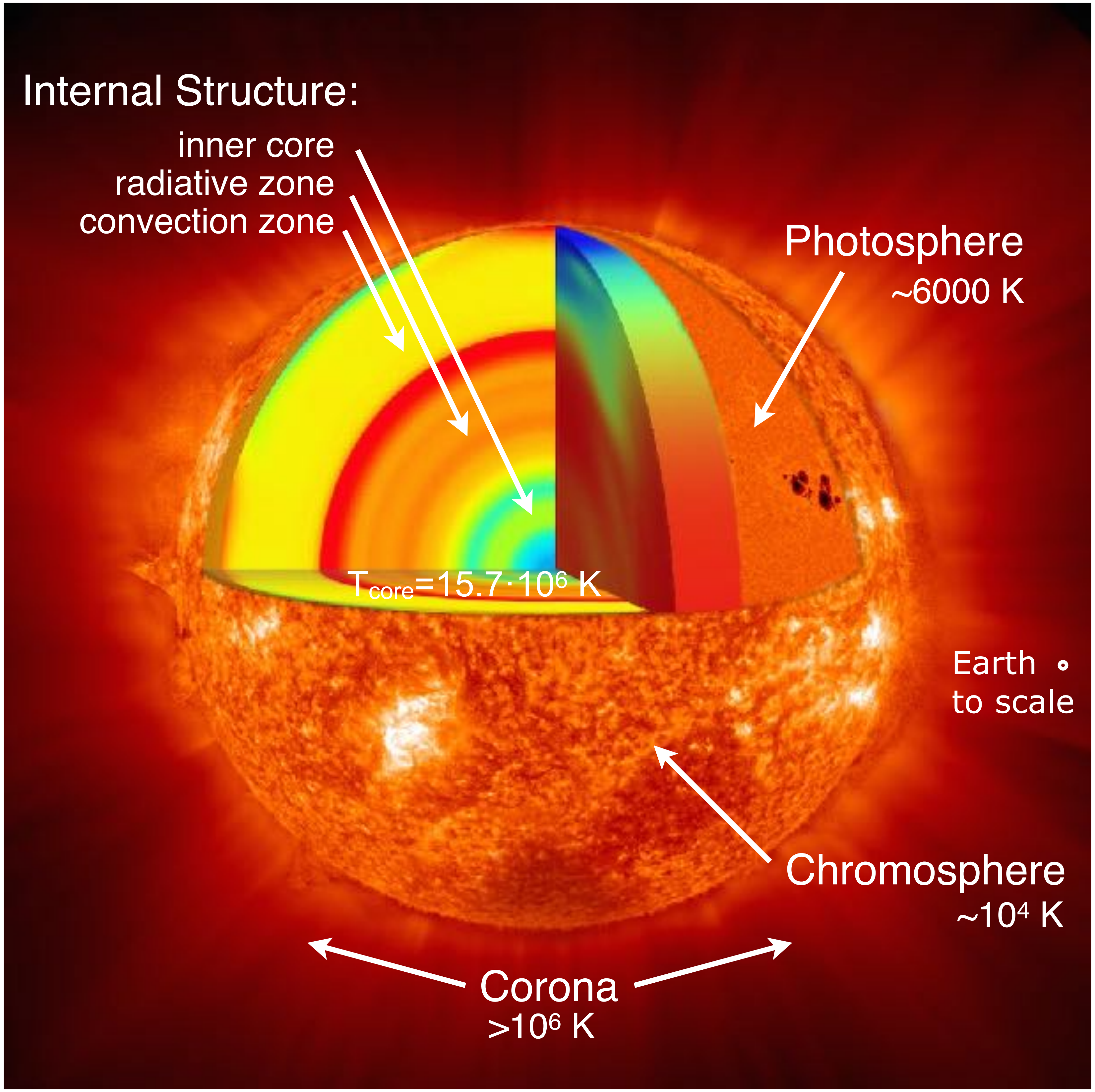
Daniel Müller
Solar Orbiter Project Scientist

# SOHO - Quick Facts

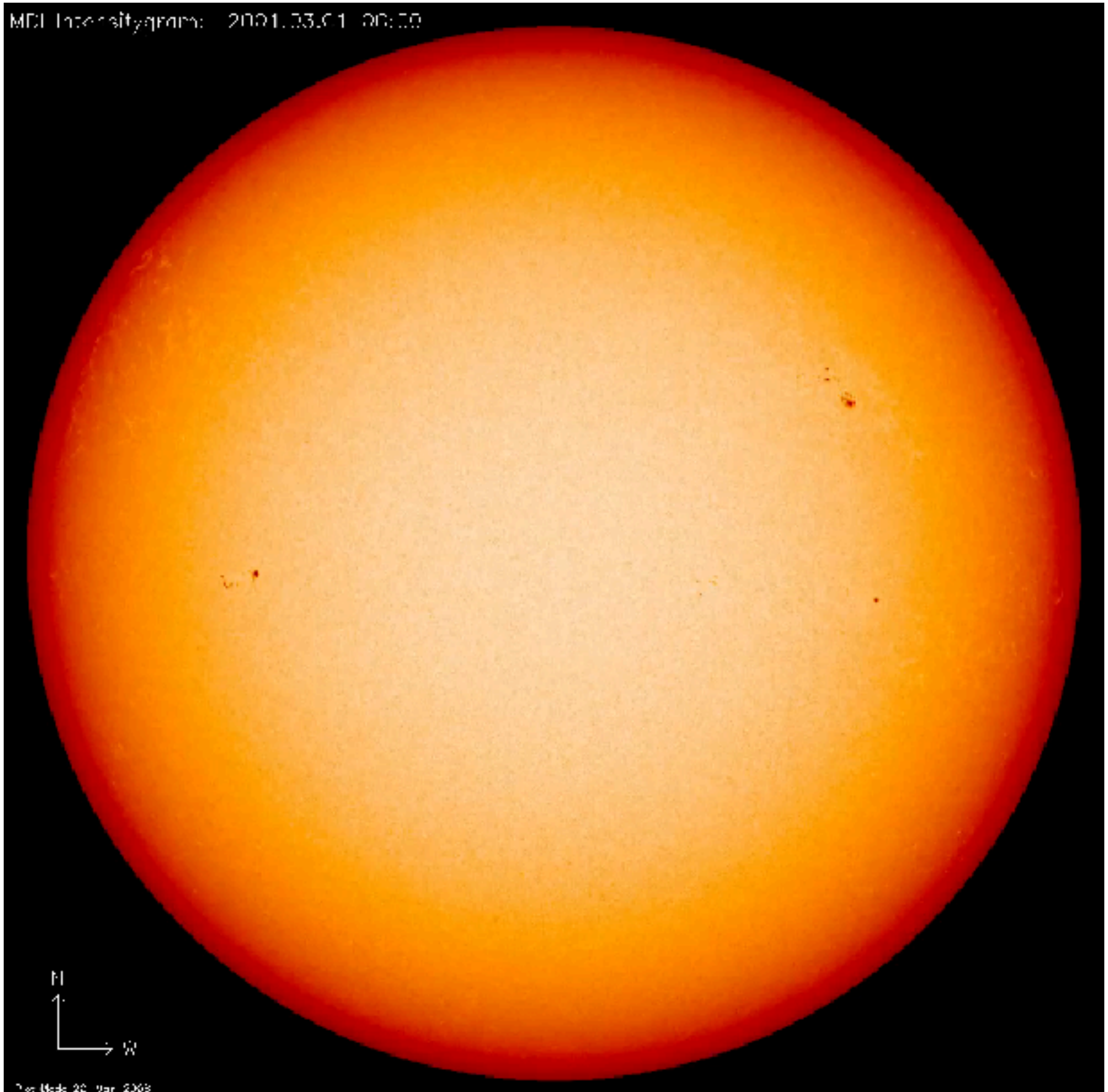
- Joint ESA/NASA project
- Built in Europe, launched by NASA (2 Dec 1995)
- Orbits around Lagrangian point L1
- 8 of the 12 instruments on SOHO still operational, providing
  - critically important white-light coronagraph observations from Sun-Earth line
  - total solar irradiance
  - low frequency global oscillations
  - integrated EUV solar output
  - energetic particles and solar wind plasma parameters
  - unique long-term data record over full 22-year magnetic cycle

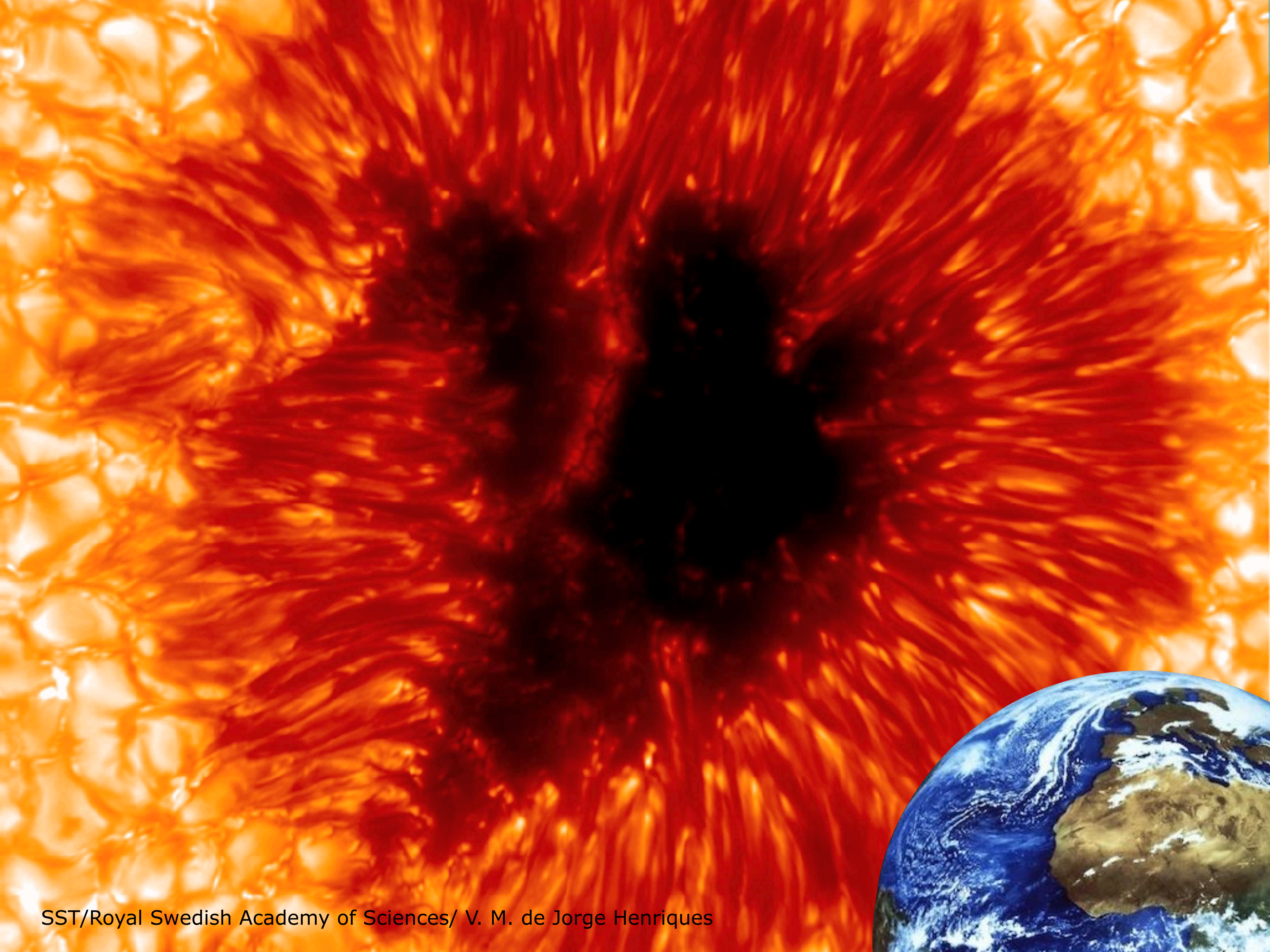


# The Sun in a Nutshell



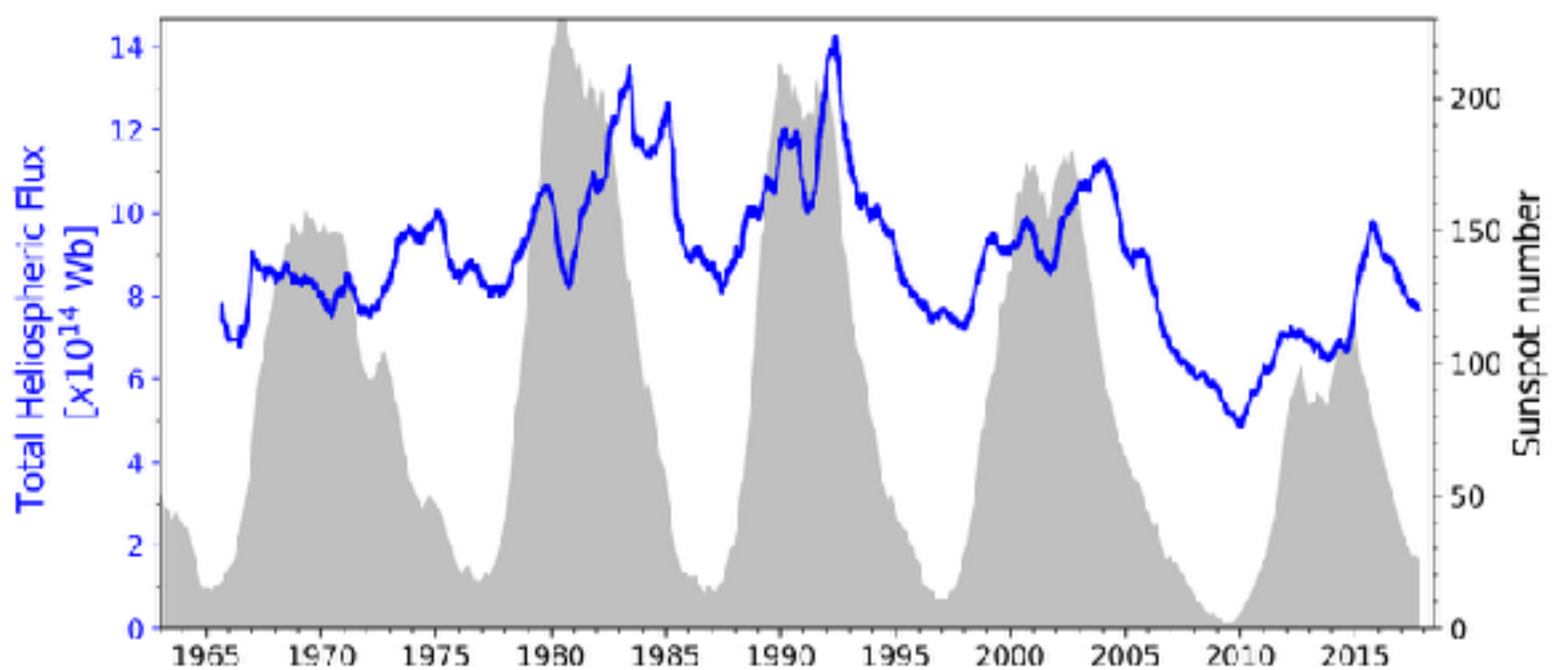
# Sunspots



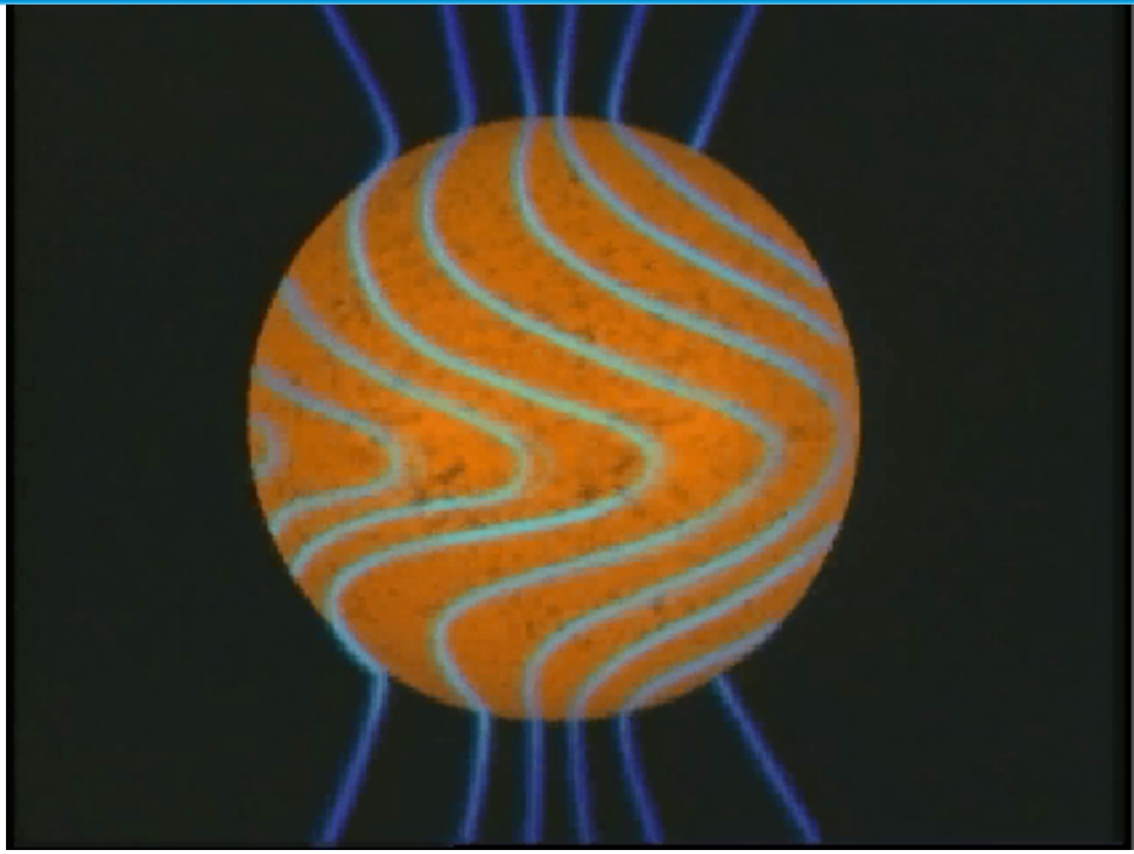

SST/Royal Swedish Academy of Sciences/ V. M. de Jorge Henriques

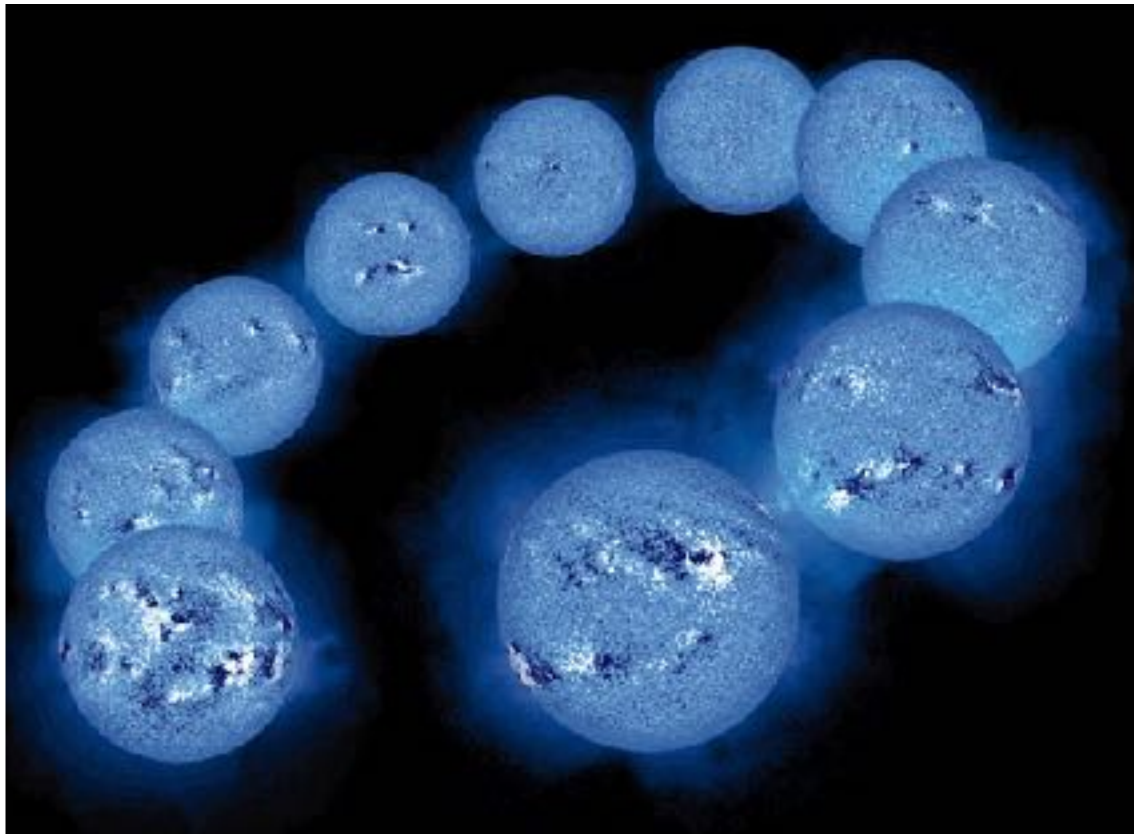
# The Sun is a magnetically variable star

- Inside the Sun, moving charges generate magnetic field
- Solar Dynamo:Field amplification at the base of the convection zone
- Bundles of intense magnetic field rise to the Sun's surface due to magnetic buoyancy → Sunspots
- Sunspot Cycle: Period of ~11 years - but why?



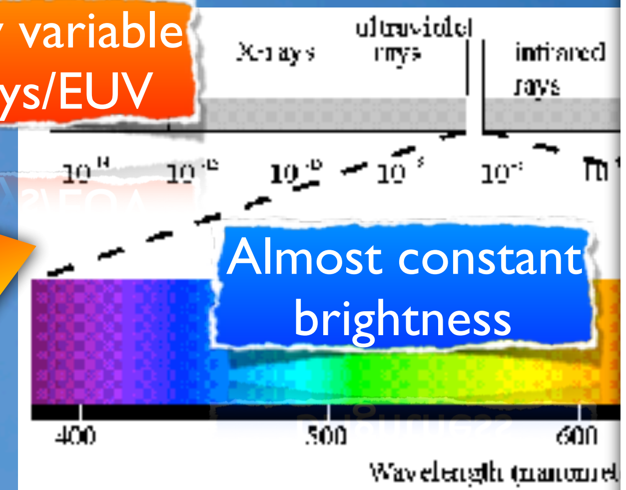

*M. Owens, University of Reading*





# What the Sun sends our way

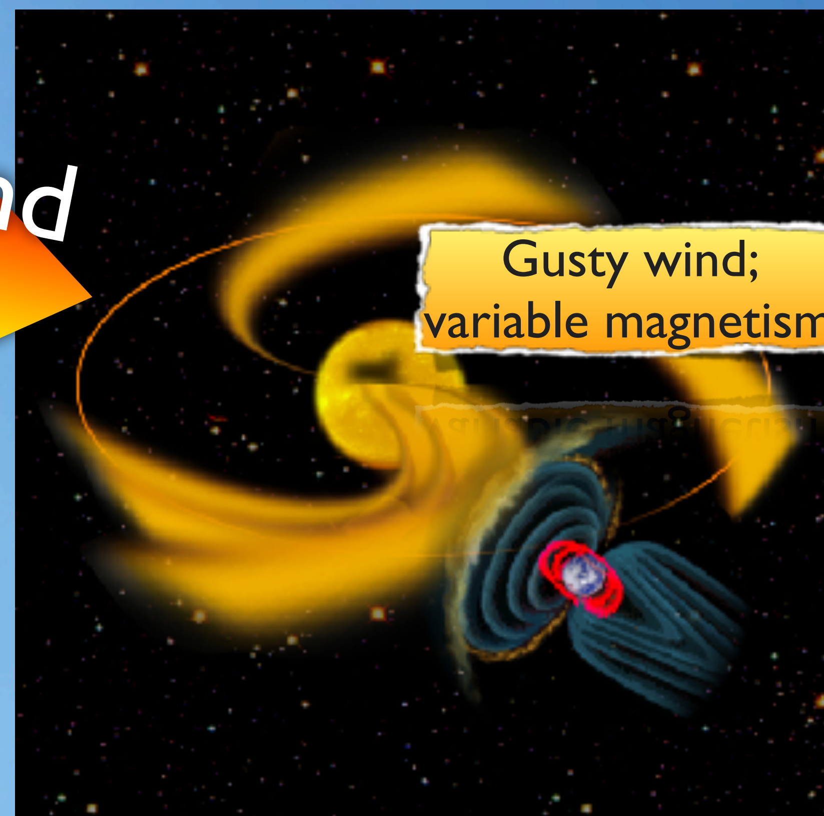
Highly variable X-rays/EUV




Almost constant brightness

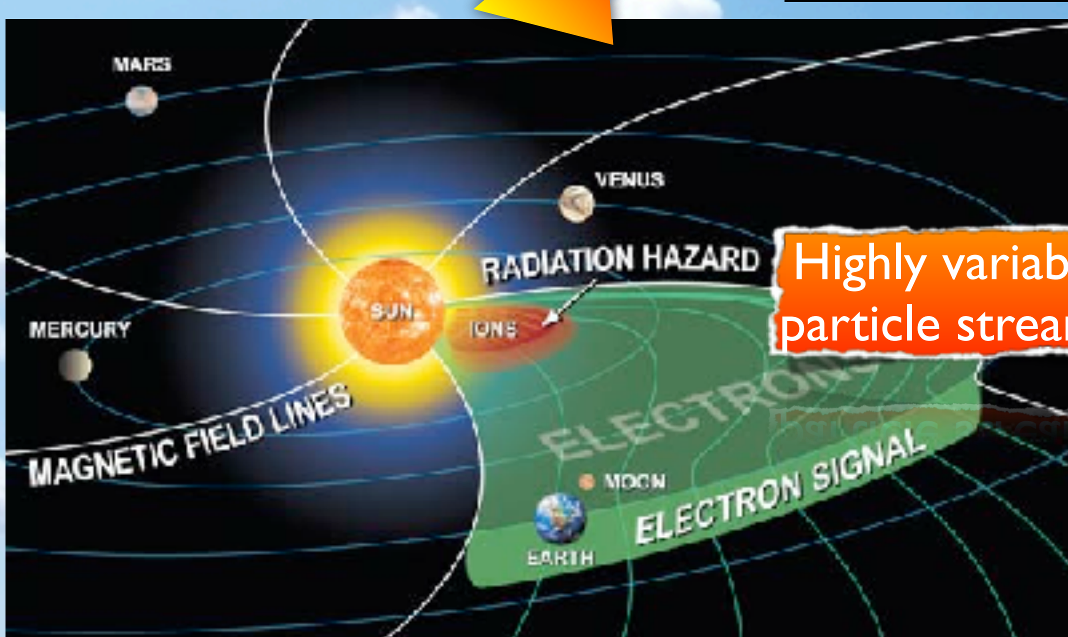
Light (X-ray to radio)

Magnetized wind



Gusty wind; variable magnetism

Particle radiation




Highly variable particle streams

Courtesy C. Schrijver

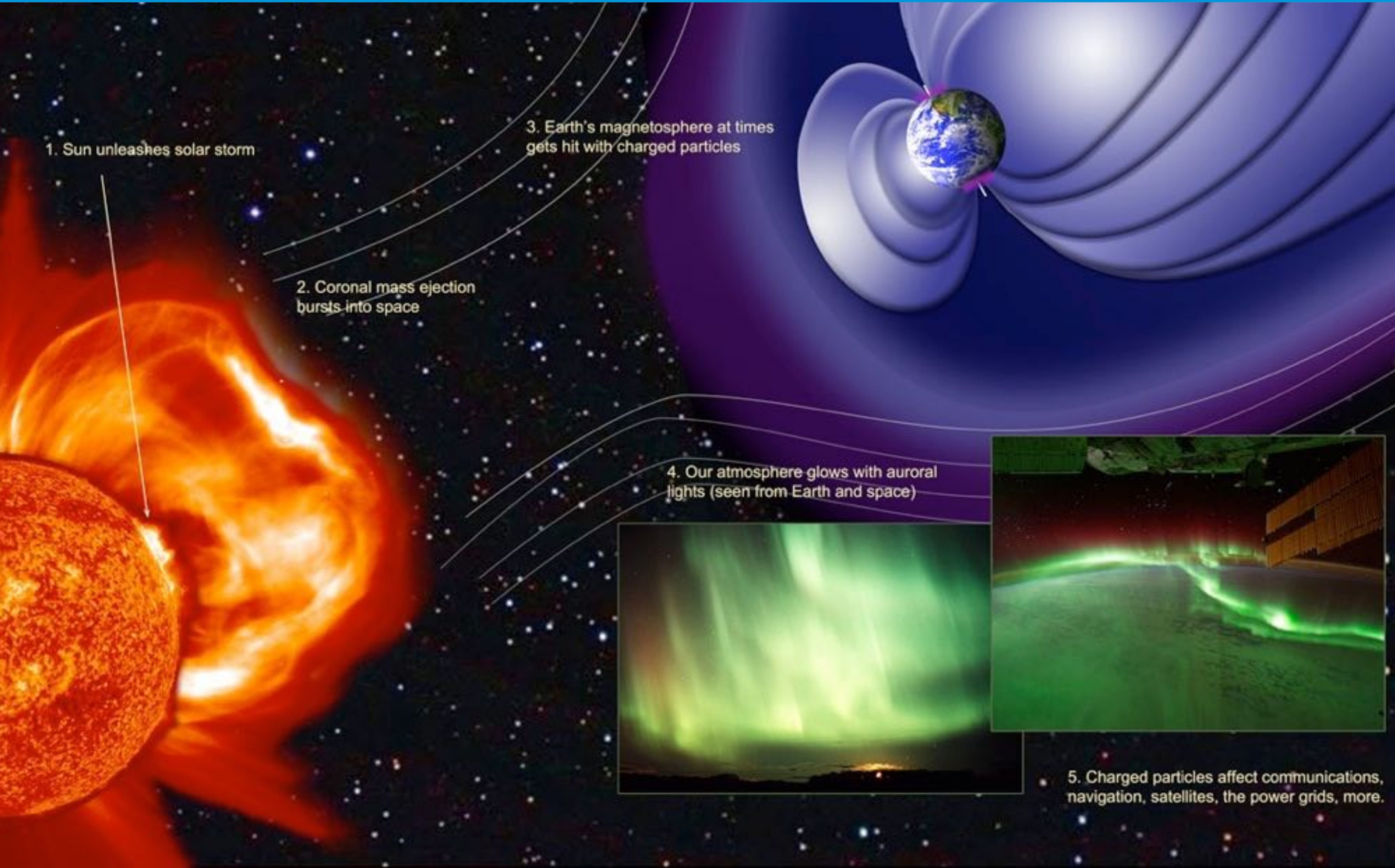
## *Examples of space weather*

Geomagnetic storms: couple into power grids, cause ionospheric disturbances affecting satellite-based navigation. Aurorae

Radiation storms: hazard to astronaut health and satellite function; affects high-latitude radio comm.; position errors on navigation.

Radio blackouts. Satellite drag affecting orbits and re-entry.

# Coronal Mass Ejections (CMEs) can cause geomagnetic storms



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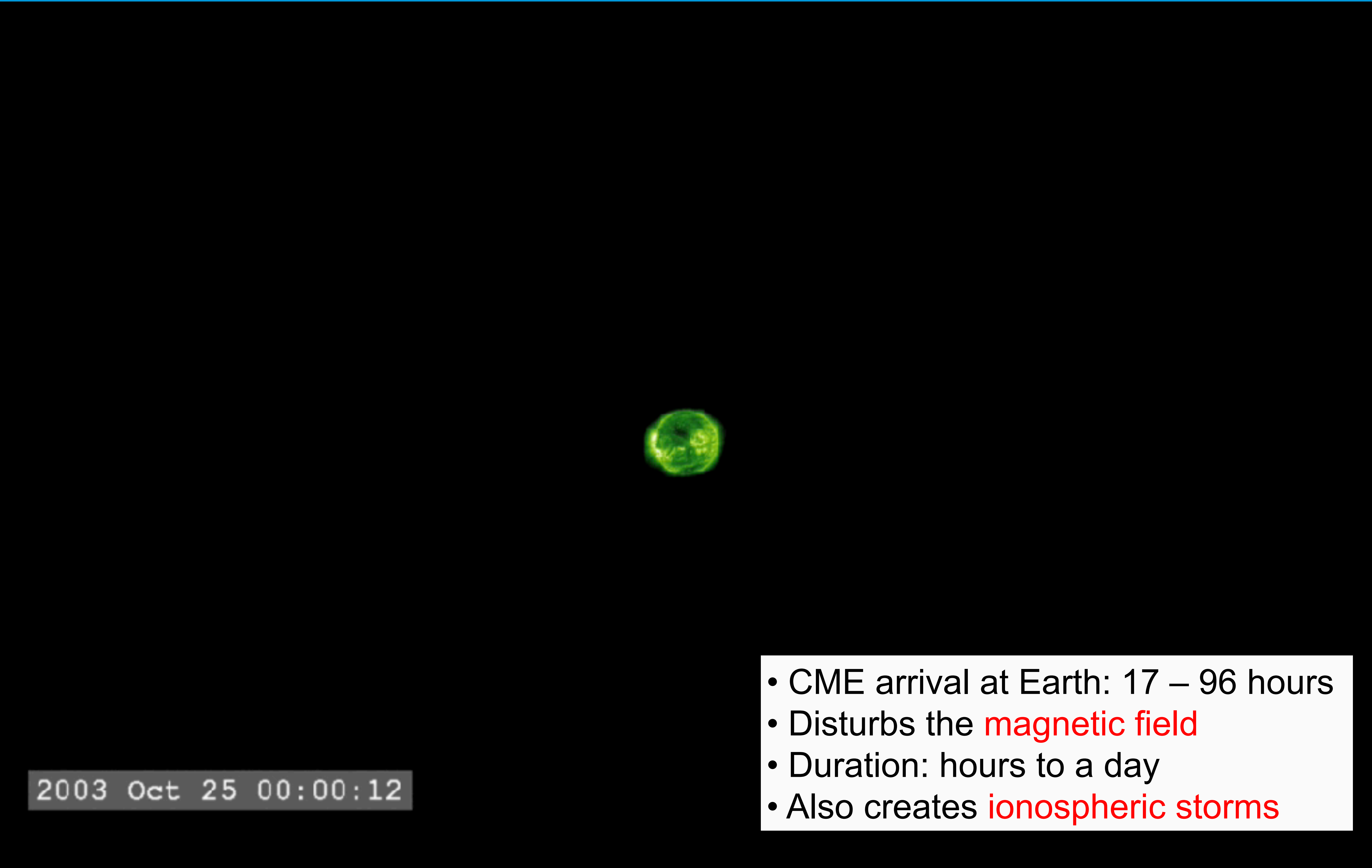



- CME arrival at Earth: 17 – 96 hours
- Disturbs the magnetic field
- Duration: hours to a day
- Also creates ionospheric storms

# Geomagnetic Storm Impacts

Impacts from geomagnetic storms are wide-ranging with potentially significant consequences.

**Satellite Operations**

Loss of  mission, reduction in capability

**Manned Spaceflight**

Increased radiation risk

**GPS**

Precision Agriculture, Surveying, Drilling, Military

**Power Grid Operations**

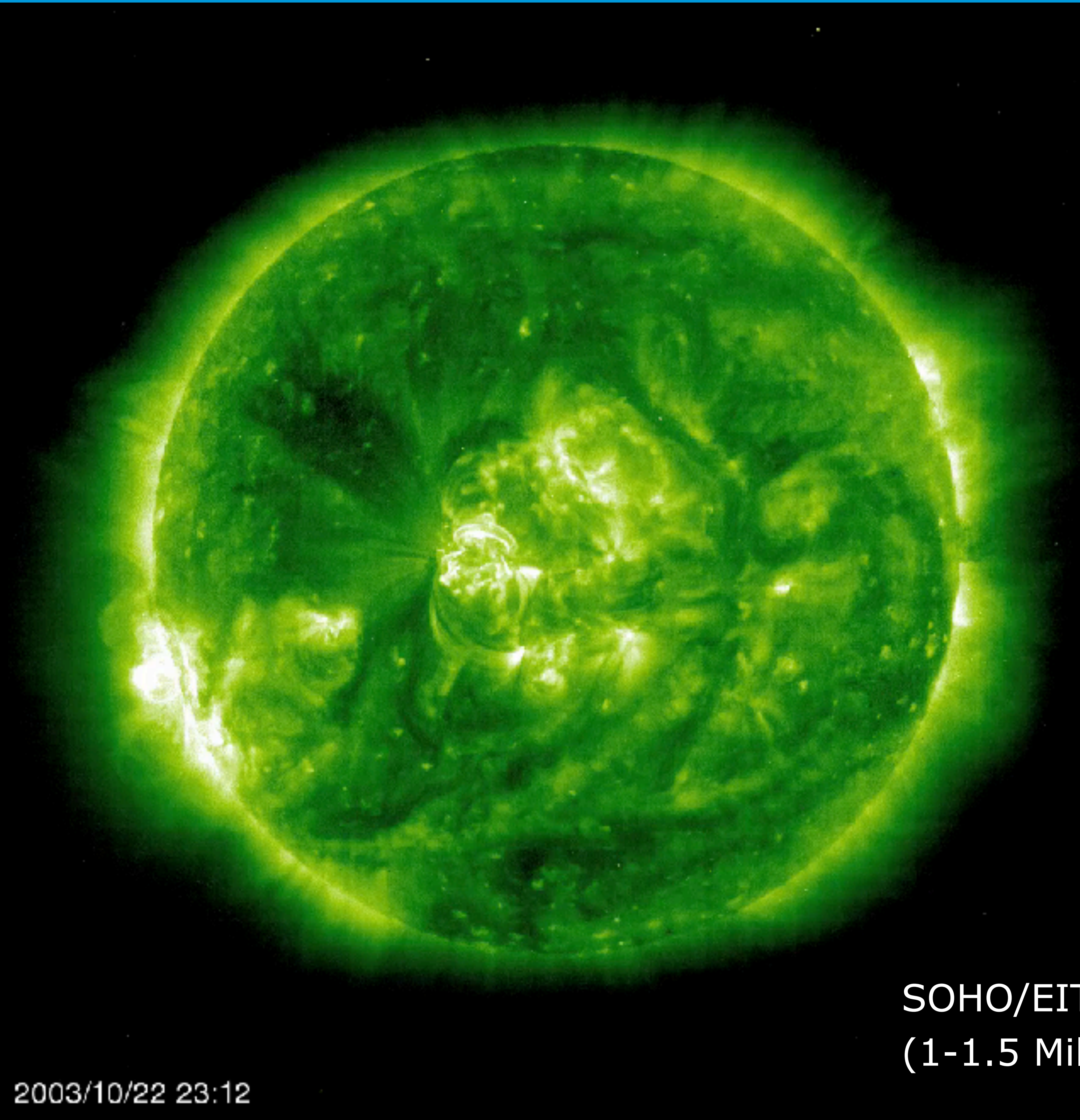
Grid failure, Grid capacity, Component Failure, GPS Timing

**Aircraft Operations**

Polar Flights, WAAS, NextGen, Airline Communication

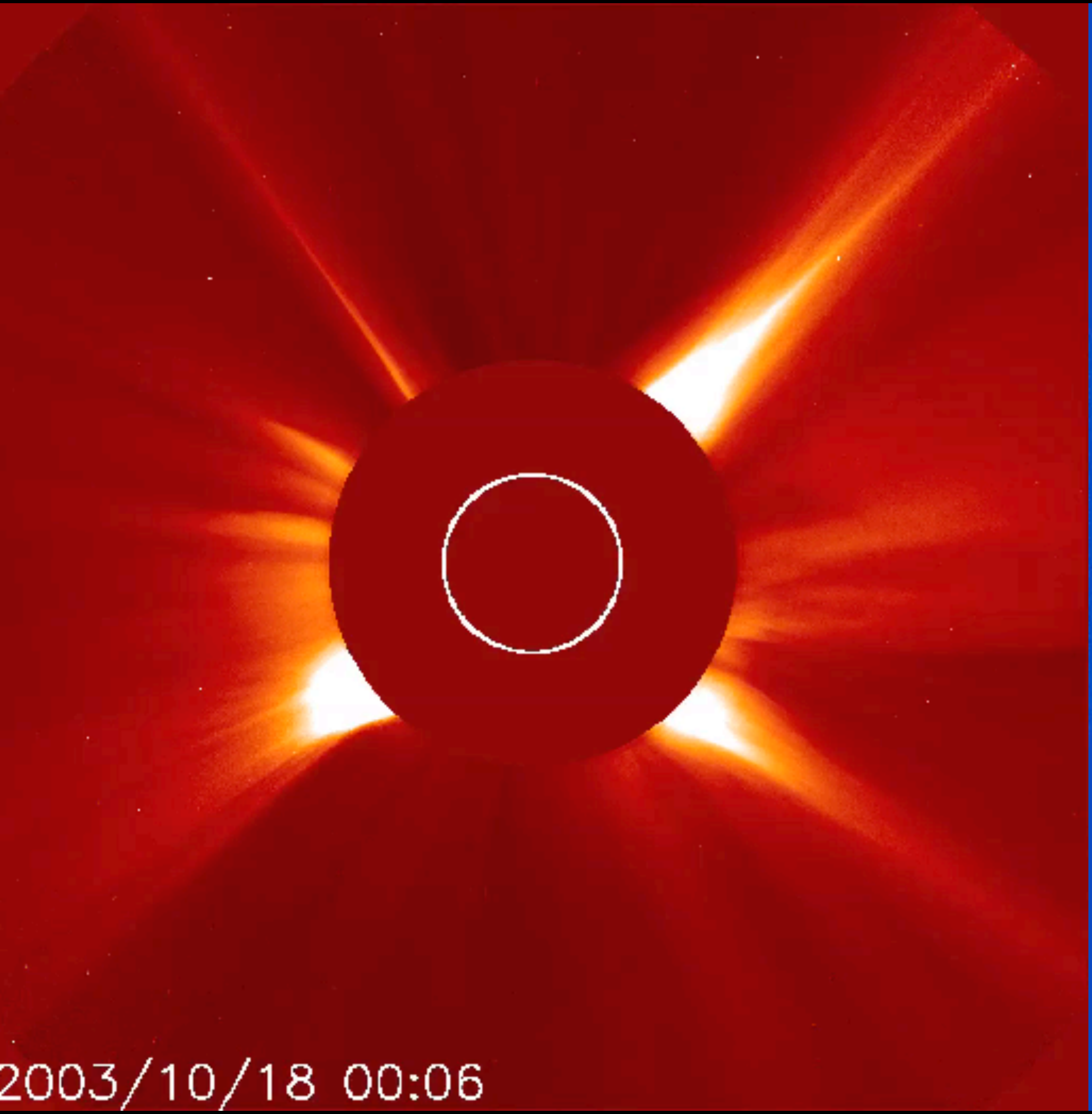
Courtesy D. Biesecker/NOAA     https://cpaess.ucar.edu/heliophysics/resources-textbook-2

# Halloween Storms 2003: CMEs & X-flares

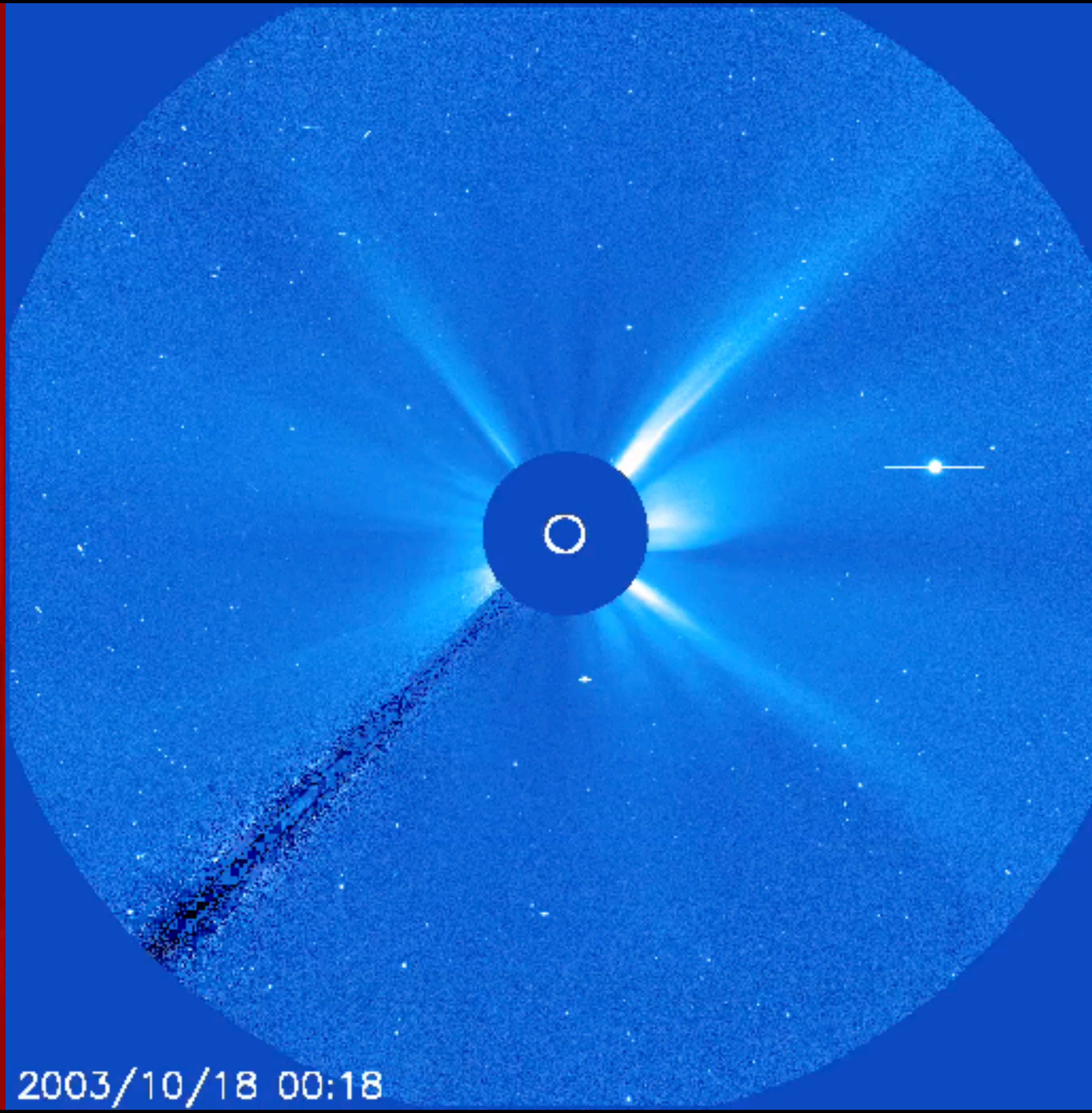



SOHO/EIT Fe IX/X 195 Å
(1-1.5 Million Kelvin)

# Halloween Storms 2003: CMEs & X-flares



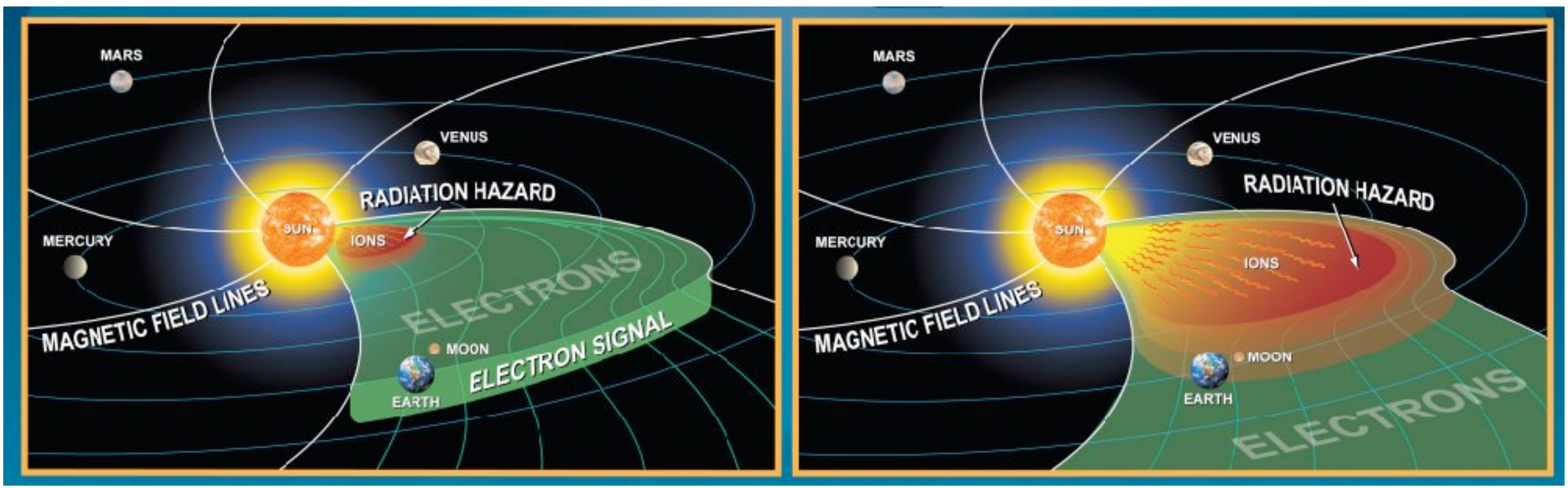

LASCO C2 coronagraph




LASCO C3 coronagraph

# Radiation Storms

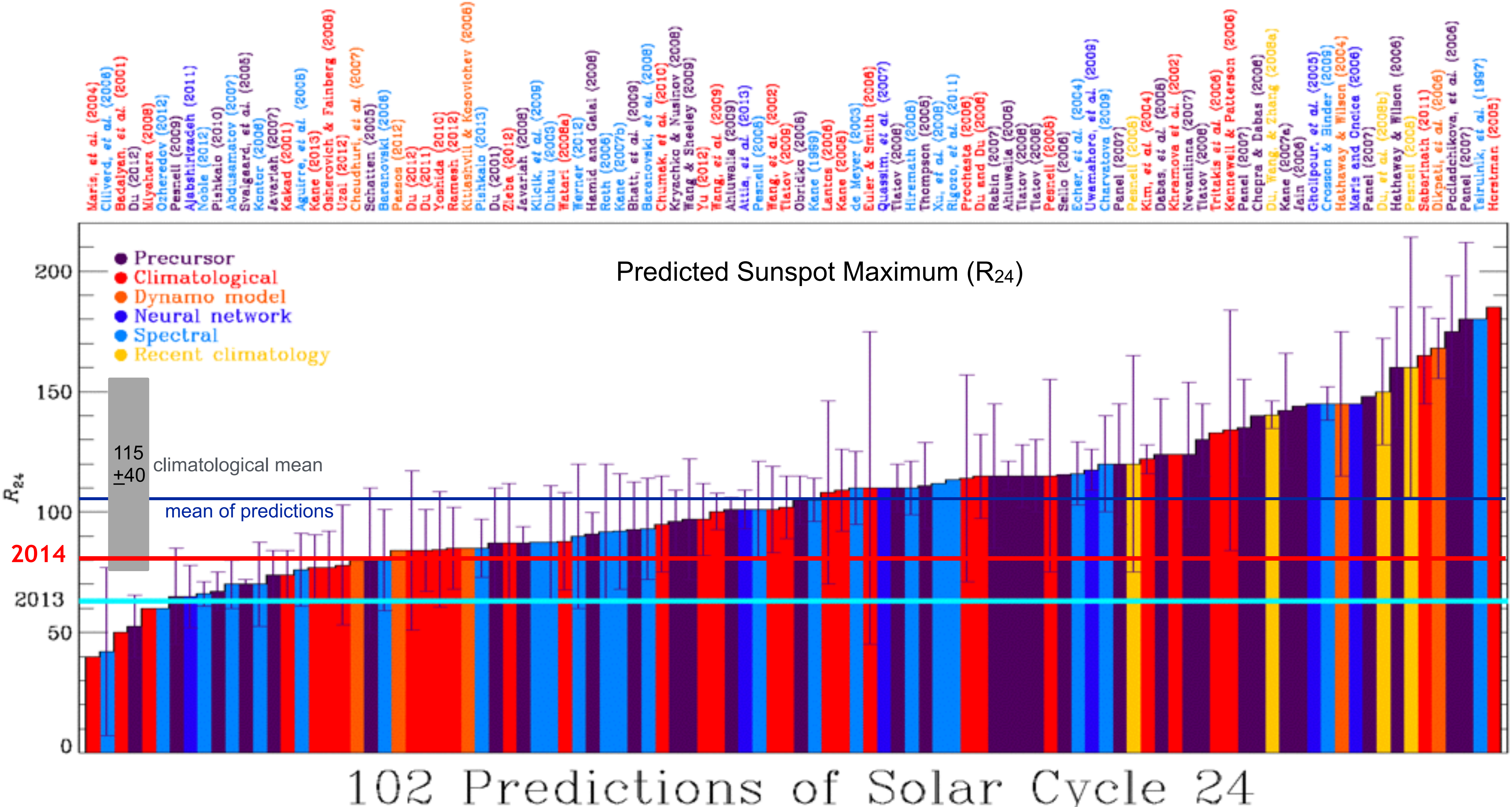
- Radiation storm = mix of electrons, protons, ions
- Electrons travel faster than protons
- COSTEP $e^-$ data → forecast matrix → up to 1h advance warning
- Used by Johnson Space Center to ensure astronaut safety




Posner et al., 2007 AGU

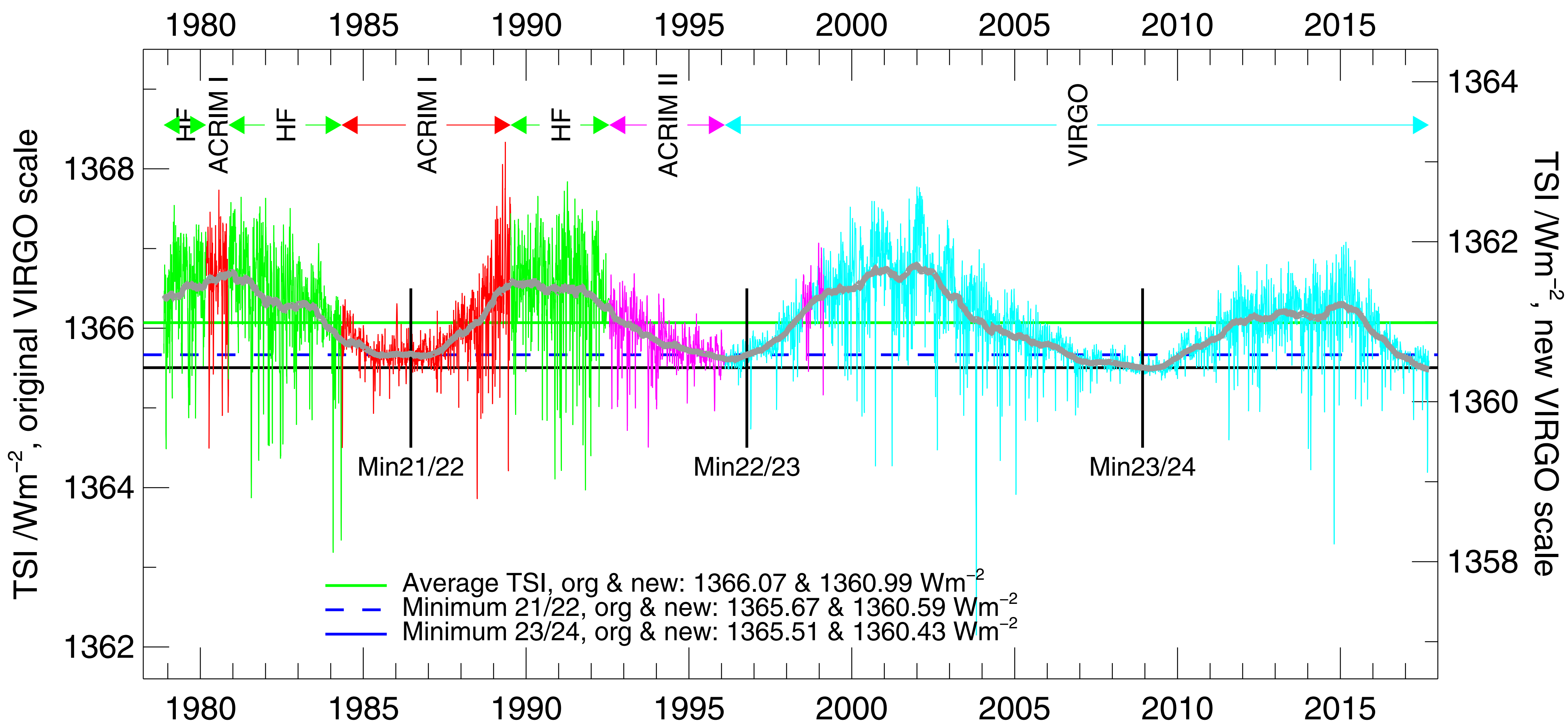
# How Well Can We Predict the Solar Activity Cycle?

# How Well Can We Predict the Solar Activity Cycle? [Not very well…]




Pesnell, *Space Weather* 2016

# Total Solar Irradiance (TSI)




*e.g. Foukal et al., Nature 2006, Fröhlich & Lean, A&ARv 2004*

- Almost 4 solar cycles of TSI measurements
- Solar cycle variation: 0.90±0.02 W/m$^2$, i.e. ≈ 0.06 %
- No non-zero trend at 3σ level
  → unlikely that Sun had significant influence on global warming since 17th century
- However, UV/solar wind forcing cannot be ruled out

# December 2015: 20 Years of SOHO

- > 5000 refereed papers by > 3500 scientists
- > 250 Ph.D. theses
- > 3000 comets
- > 3 million command blocks sent to the spacecraft
- > 1 million exposures by LASCO
- > 1.6 PB of data served by SOHO web servers
- > 5.5 billion web page requests served
- > 5000 meetings
- 0 gyros, but

**One amazing spacecraft!**

# Looking ahead: Solar Orbiter
# Exploring the Sun-Heliosphere Connection

*Mission overview: Müller et al., Solar Physics **285** (2013)*

## Solar Orbiter will approach the Sun to 0.28 AU and for the first time image its polar regions

| Value for Sun-Earth science (examples): | What Solar Orbiter will provide: |
|---|---|
| Link Sun to Heliosphere | Combination of RS & IS observations to identify solar origin of solar wind & IMF |
| Radial evolution of CMEs | Combination of RS & IS observations |
| Particle transport | Radial evolution of key properties, IS coordinated burst mode |
| Magnetic field evolution | Magnetograms not visible from Earth/L5 |