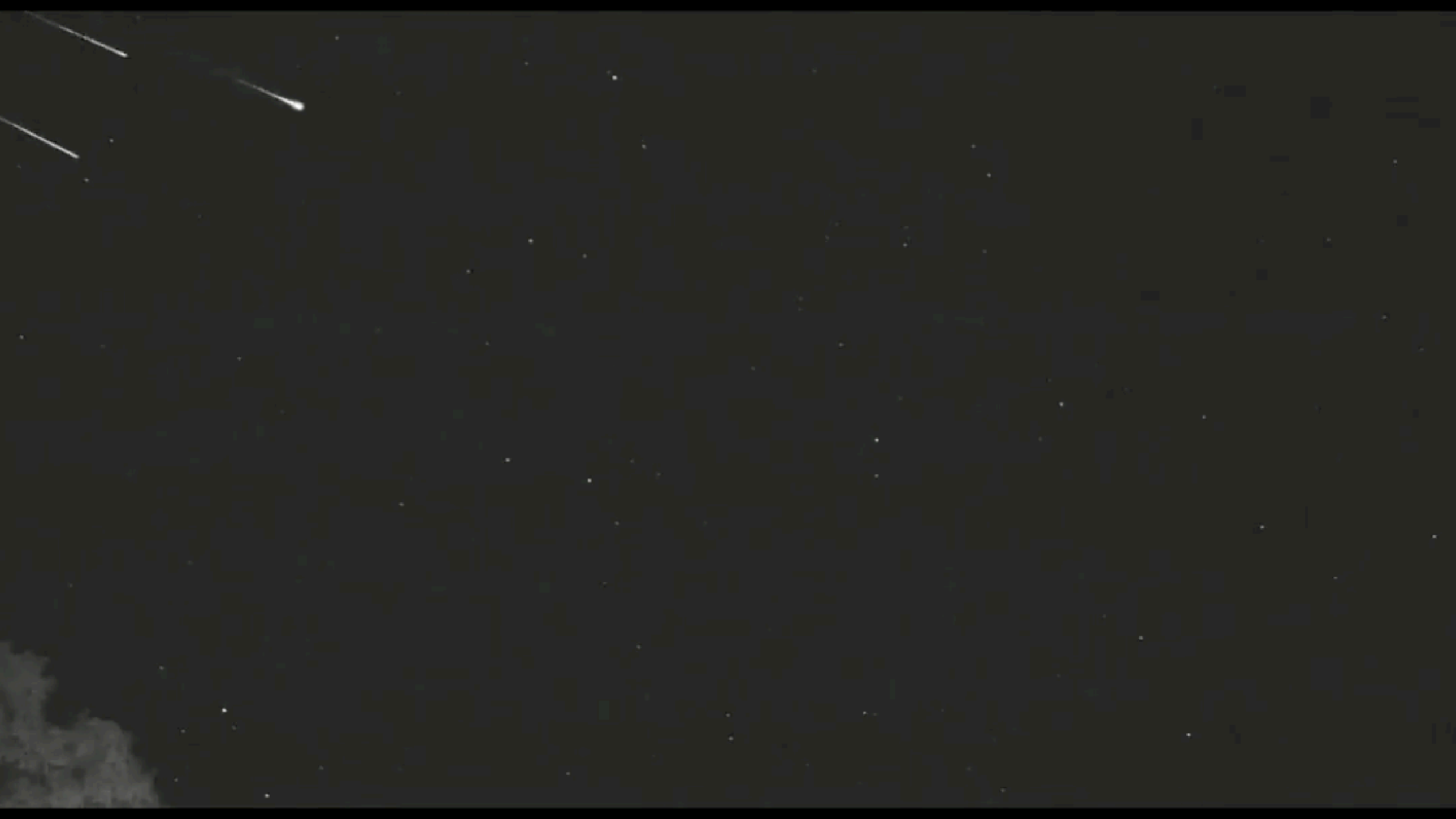
03/02/2022


Video courtesy of SpaceX
SPEED
0
KM/H
ALTITUDE
-0.0
KM
STAGE 1 TELEMETRY
STRONGBACK RETRACT
STARTUP
LIFTOFF
MAX-Q
MECO
FAIRING
T - 00:00:03
STARLINK



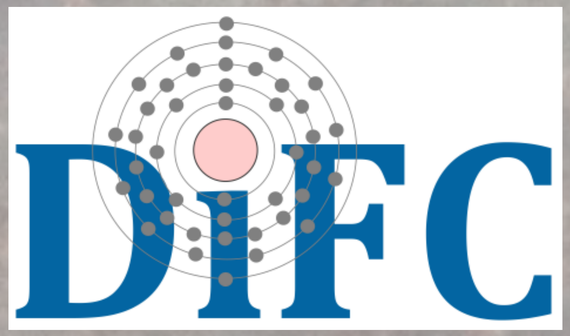
qualche giorno prima…

Space Weather

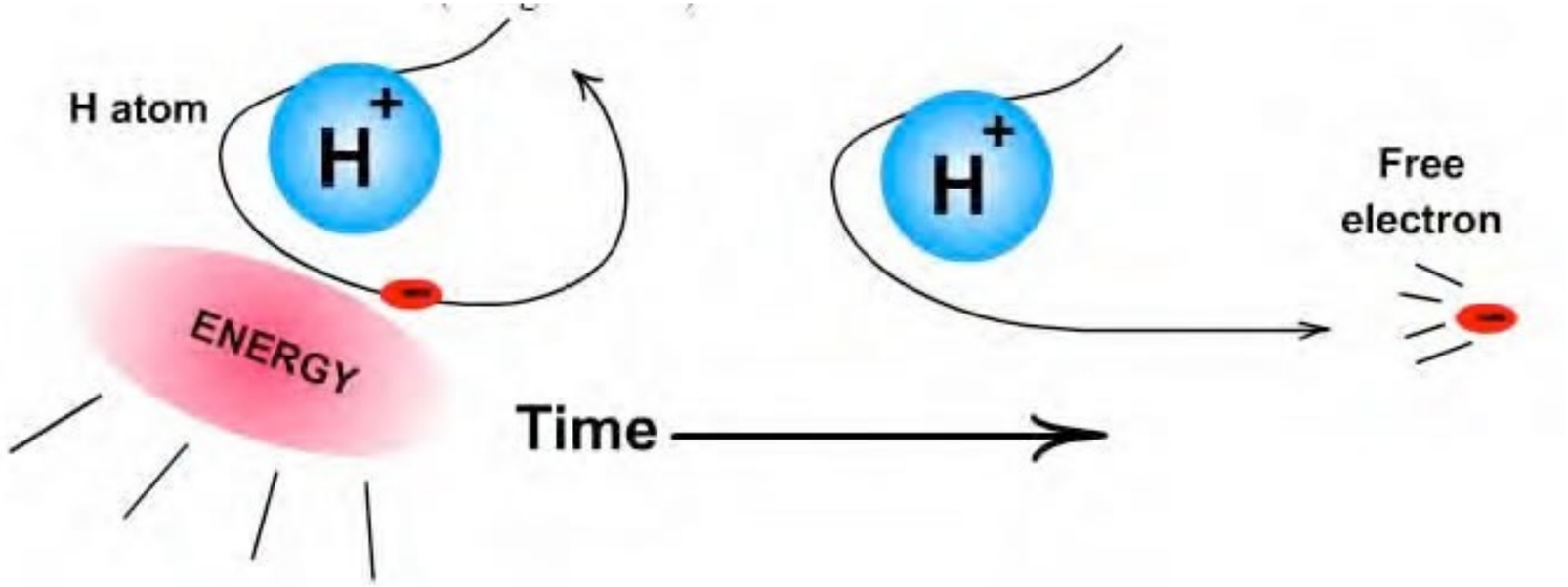
Academy of Distinction
Astrophysics
March, 21st 2024

Università degli Studi di Palermo

Paolo Pagano



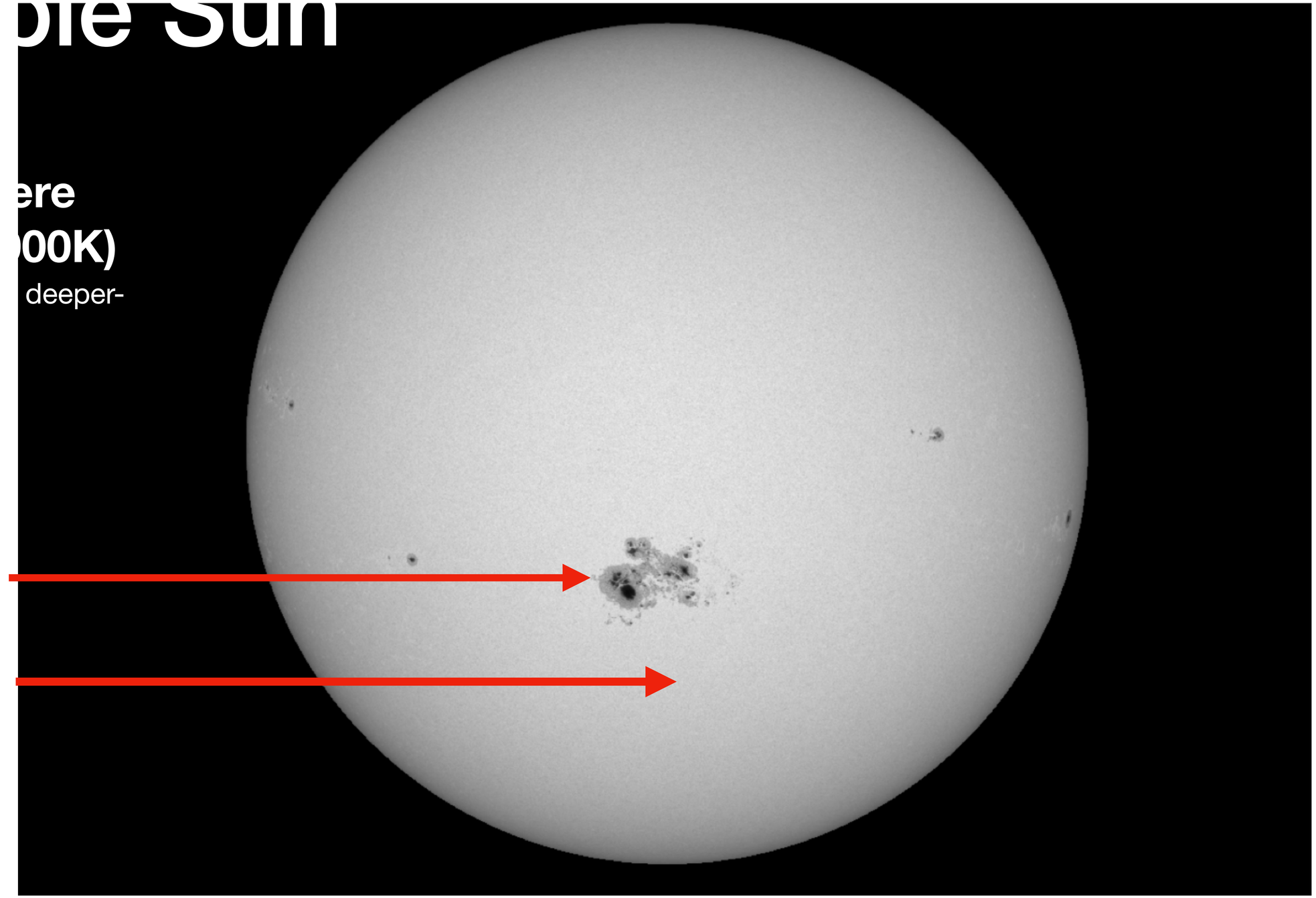
“The Sun is made of ionised Hydrogen, that is the most abundant element in the universe”
Cecilia Payne, 1925

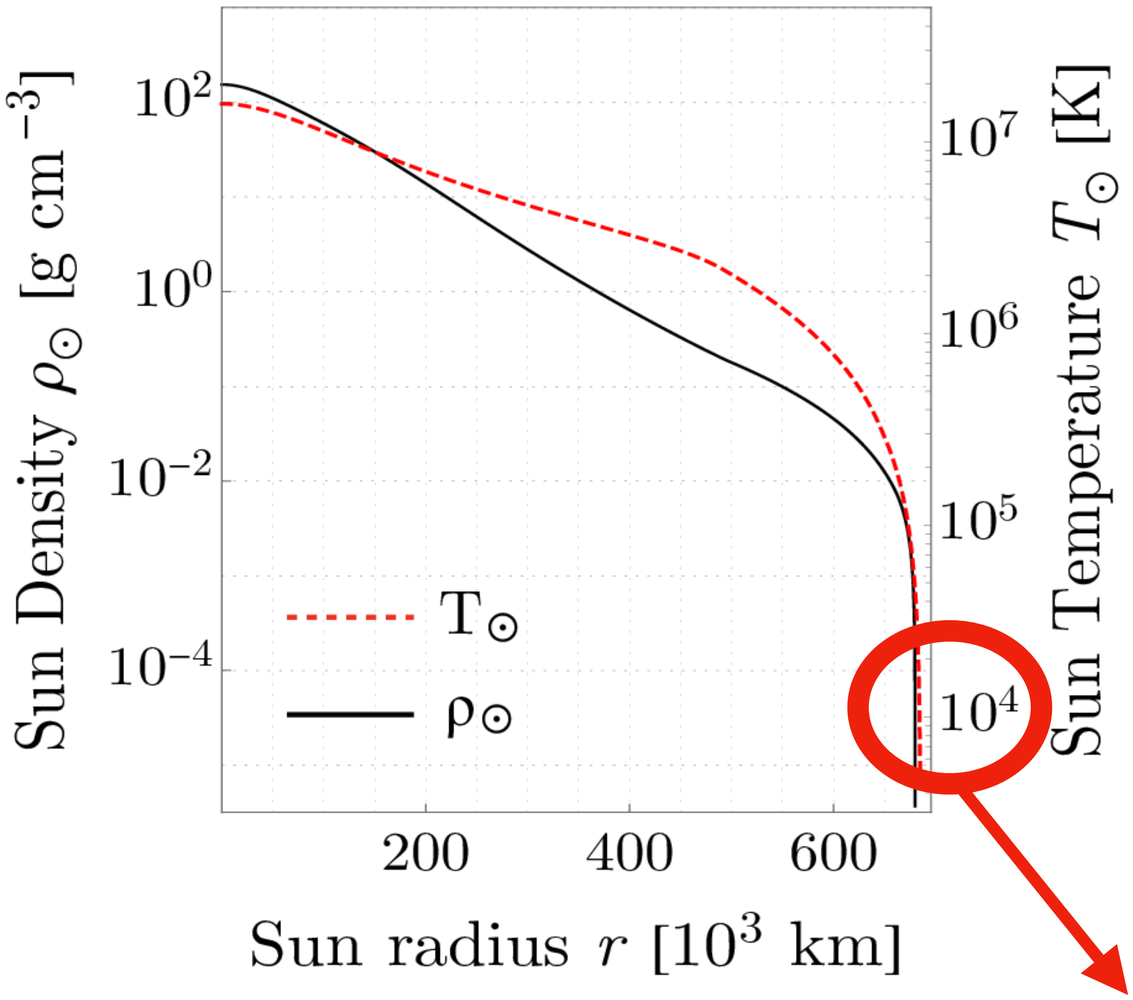


$$\frac{n_{i+1}}{n_i} \propto e^{-\frac{E_{i+1}-E_i}{k_b T}}$$

ble Sun

ere
00K)
deeper-

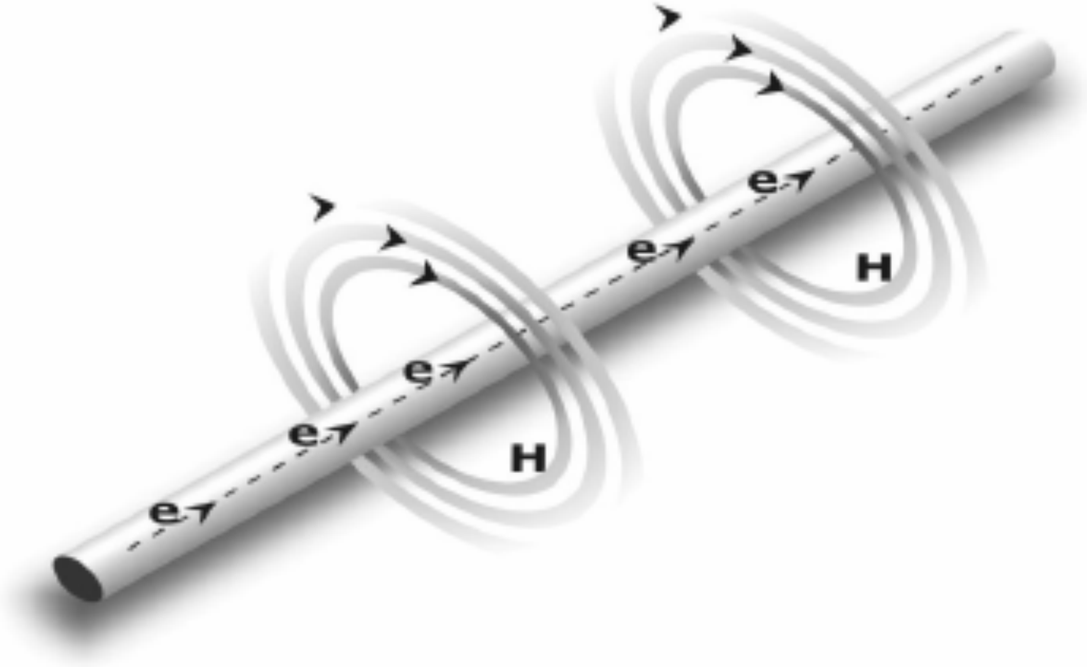


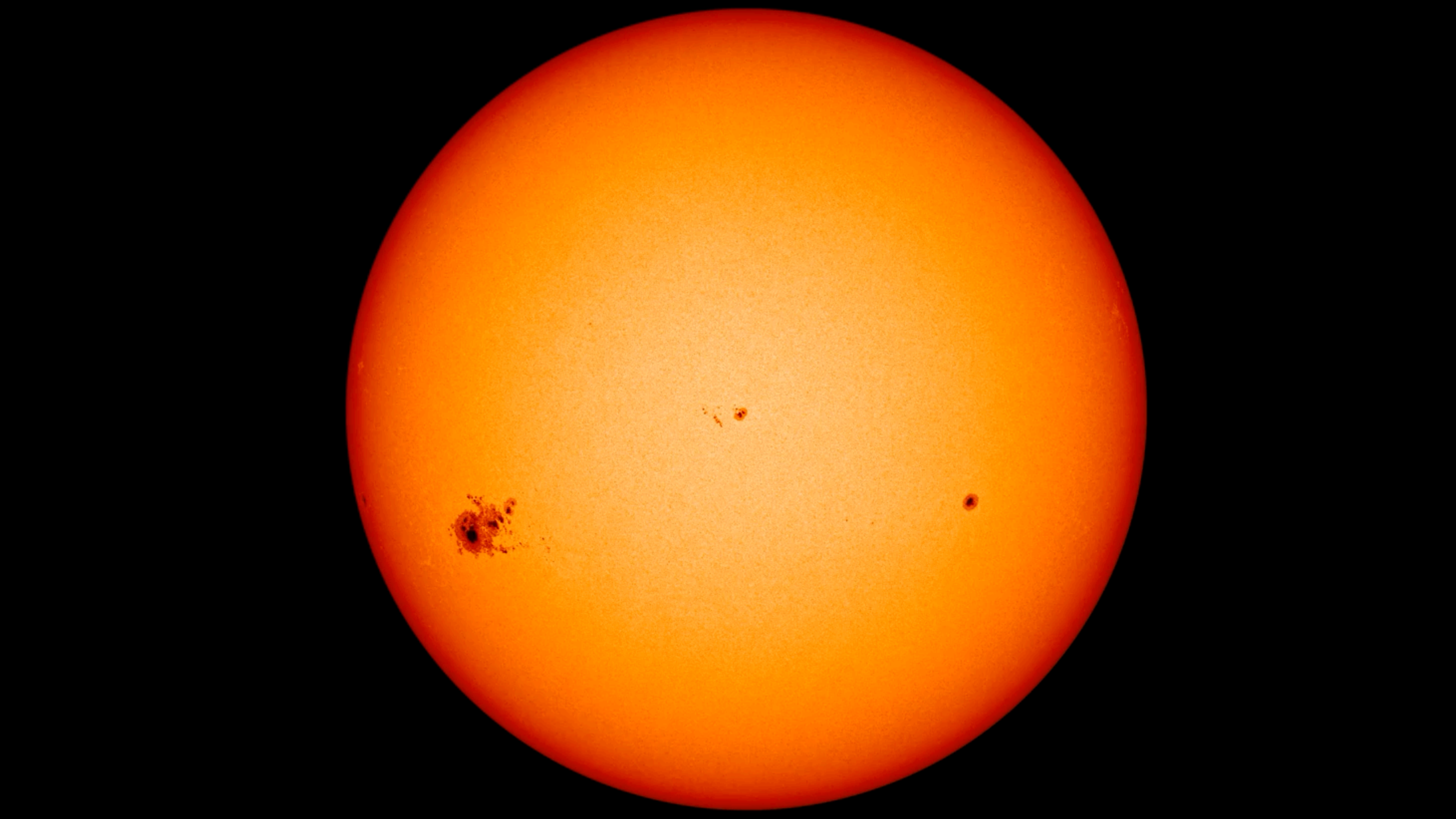


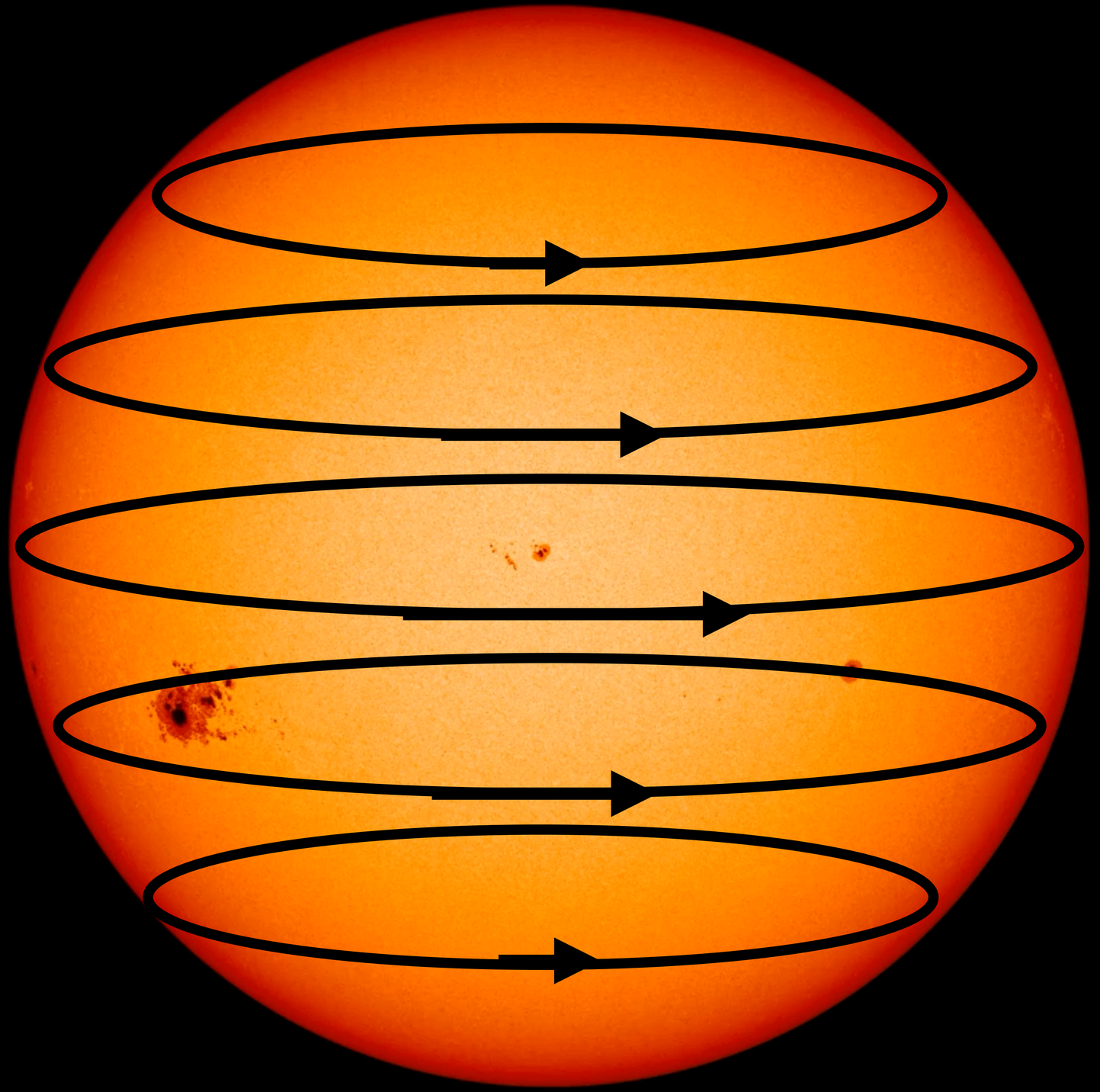
H ionisation temperature

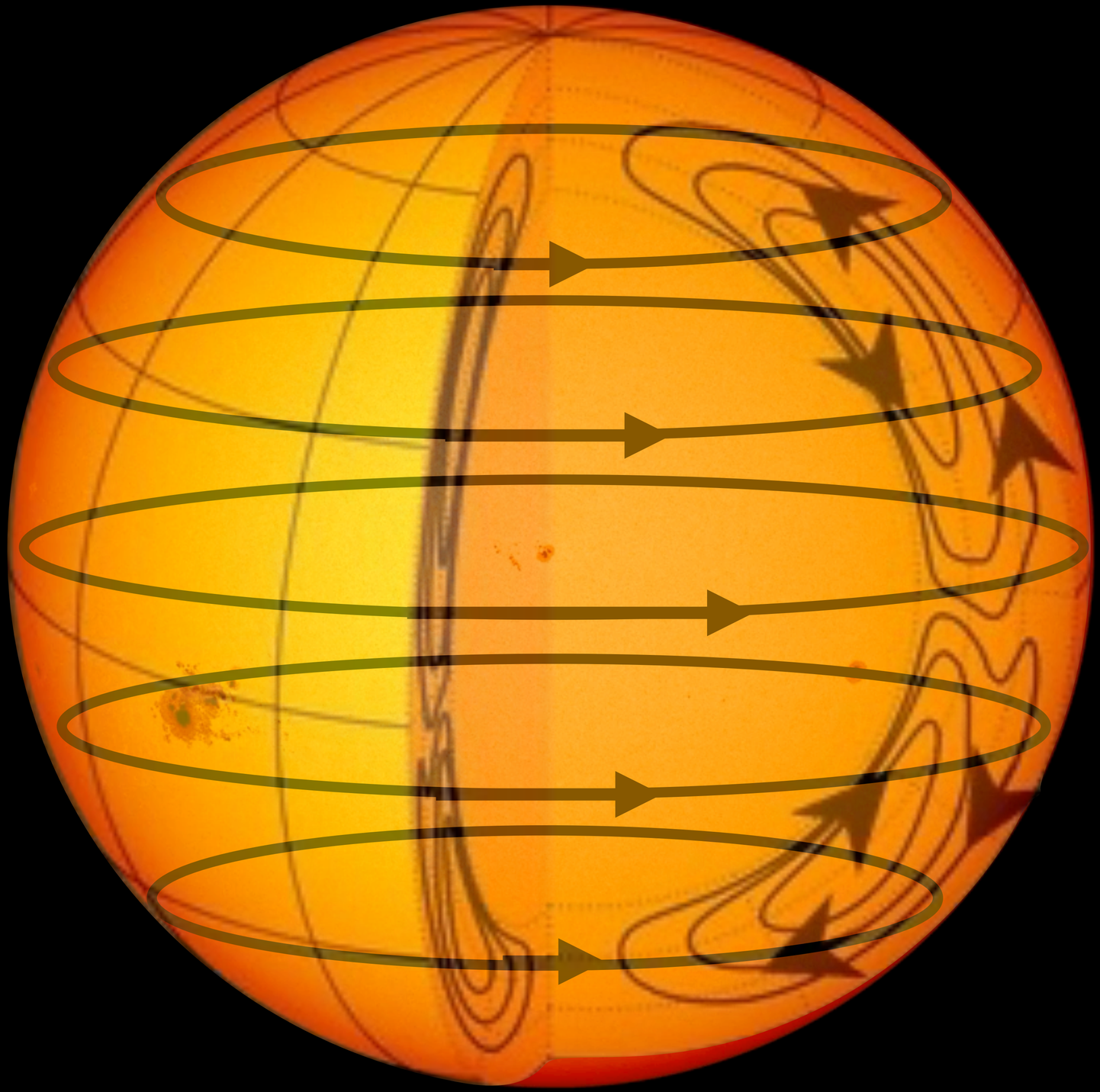
$$\vec{j} = en_e\vec{v}$$

$$\nabla \times \vec{B} = \mu_0\left(\vec{j} + \epsilon_0\frac{\partial \vec{E}}{\partial t}\right)$$

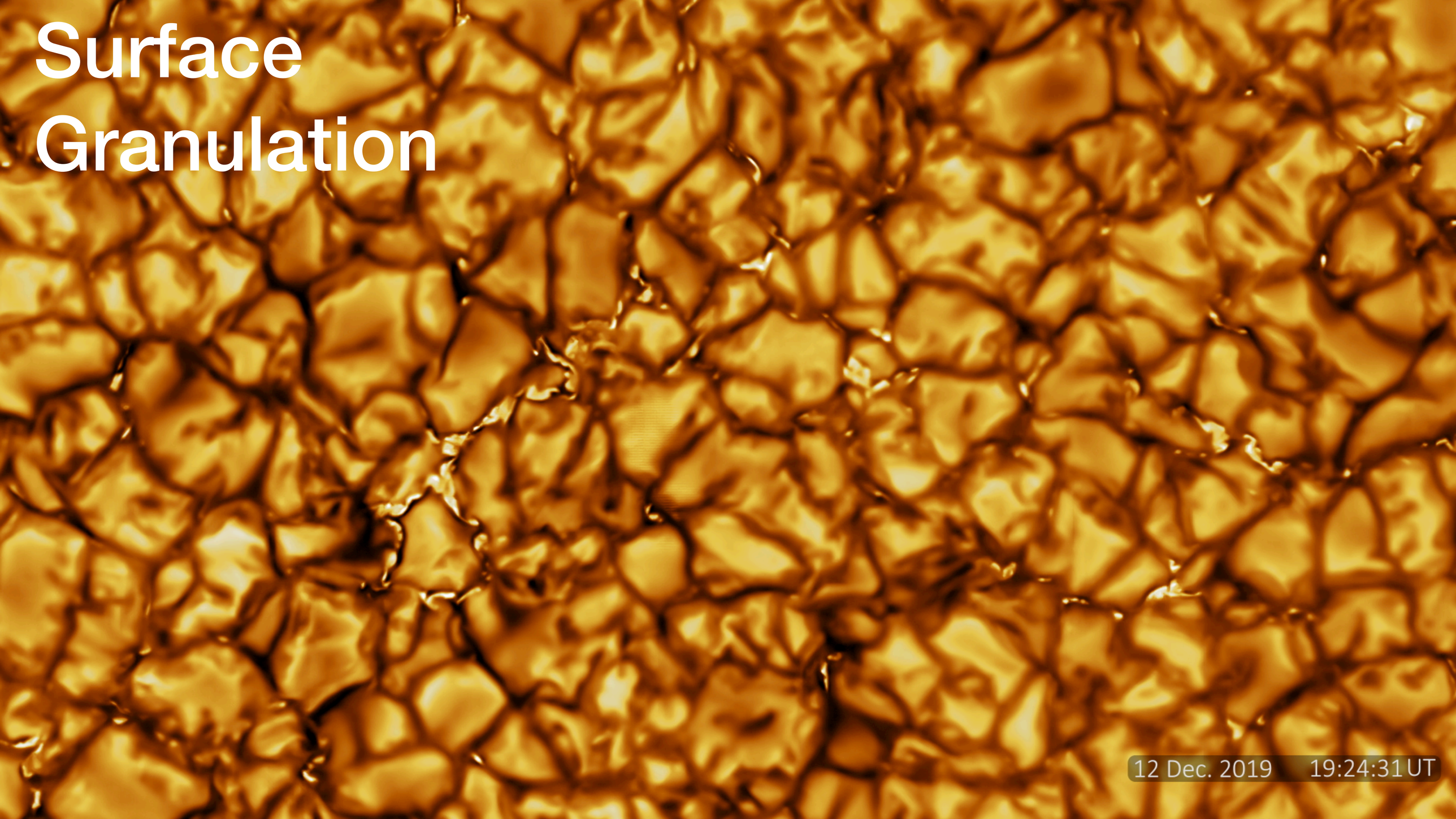








Surface Granulation



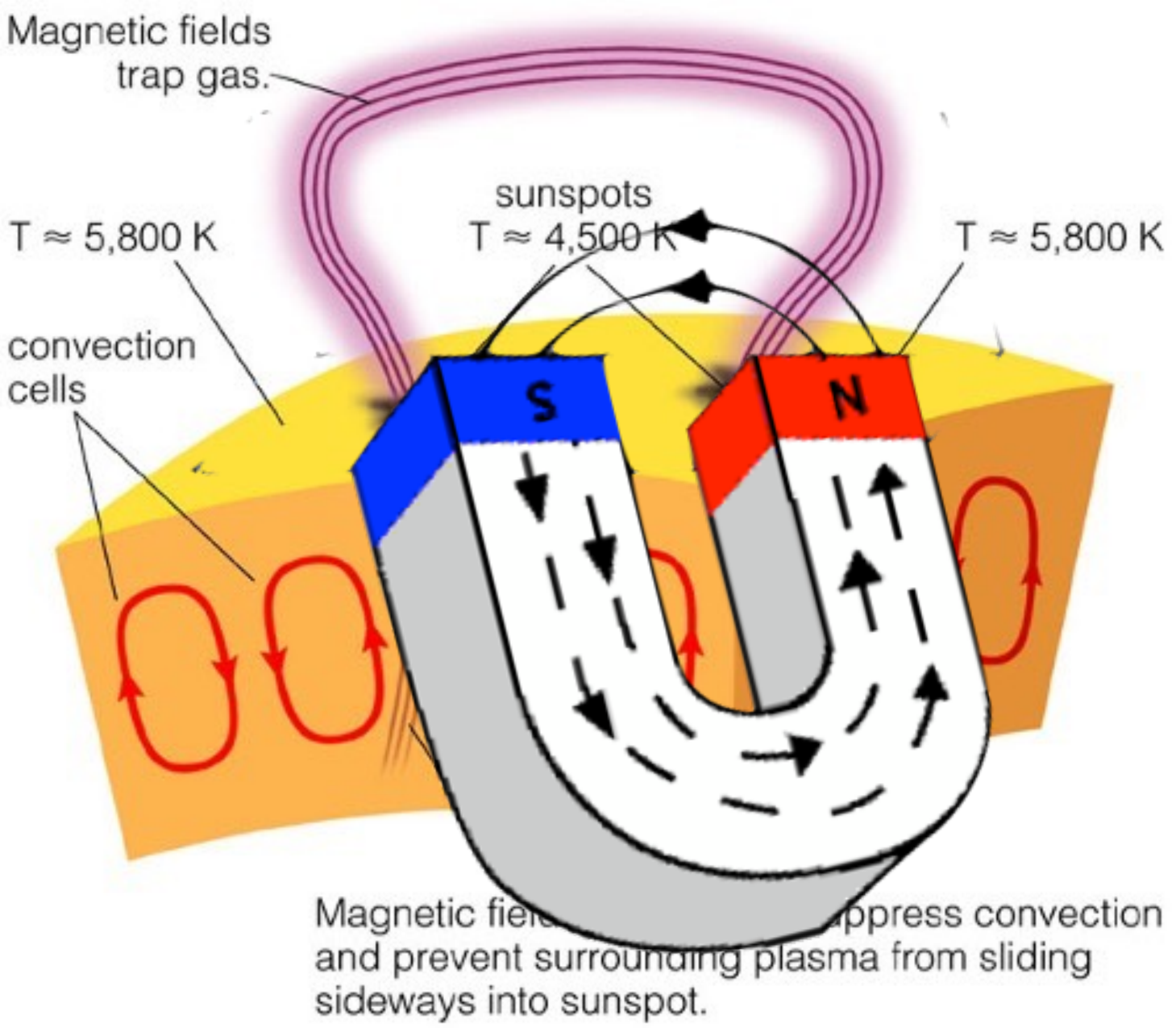
$$\frac{\partial \vec{B}}{\partial t} = \nabla \times \left(\vec{v} \times \vec{B} \right)$$

12 Dec. 2019 19:24:31UT

Atmosphere

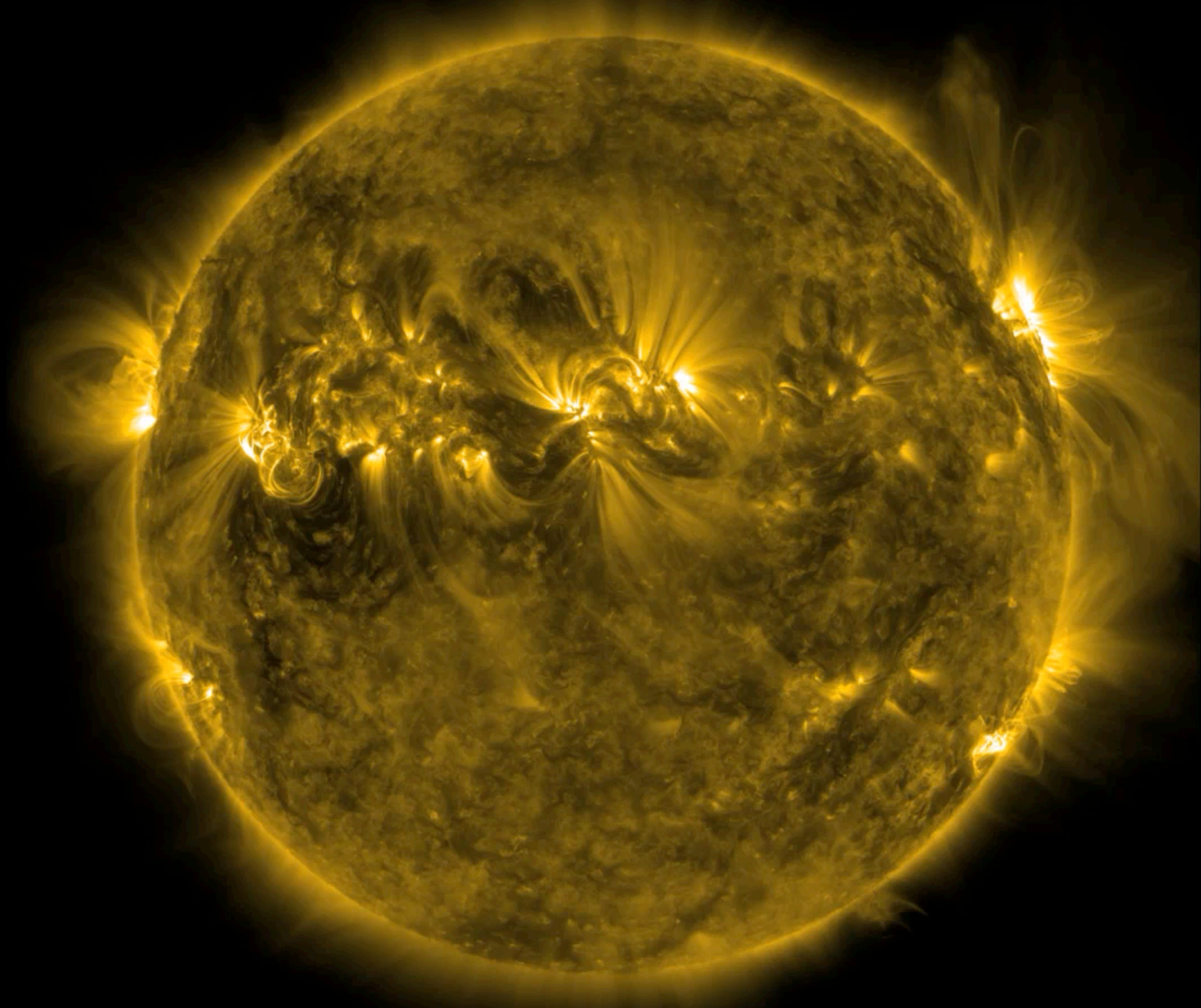
Photosphere

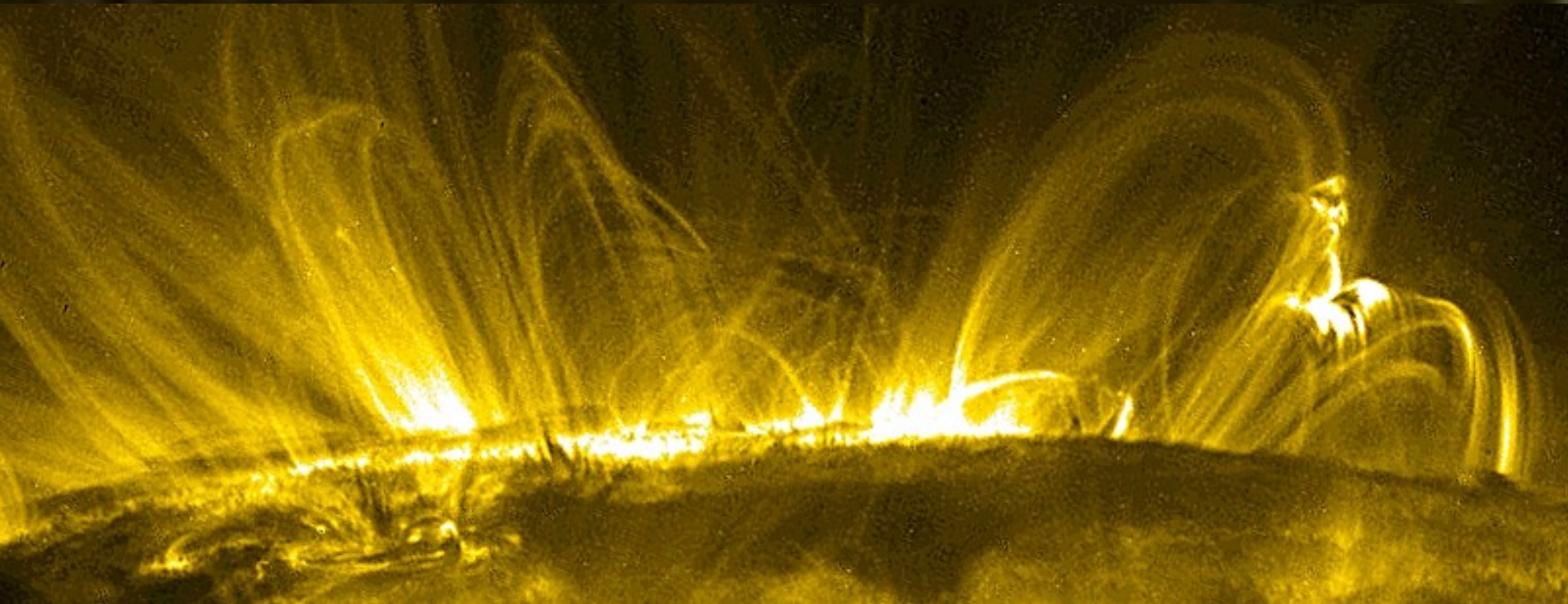
Interior

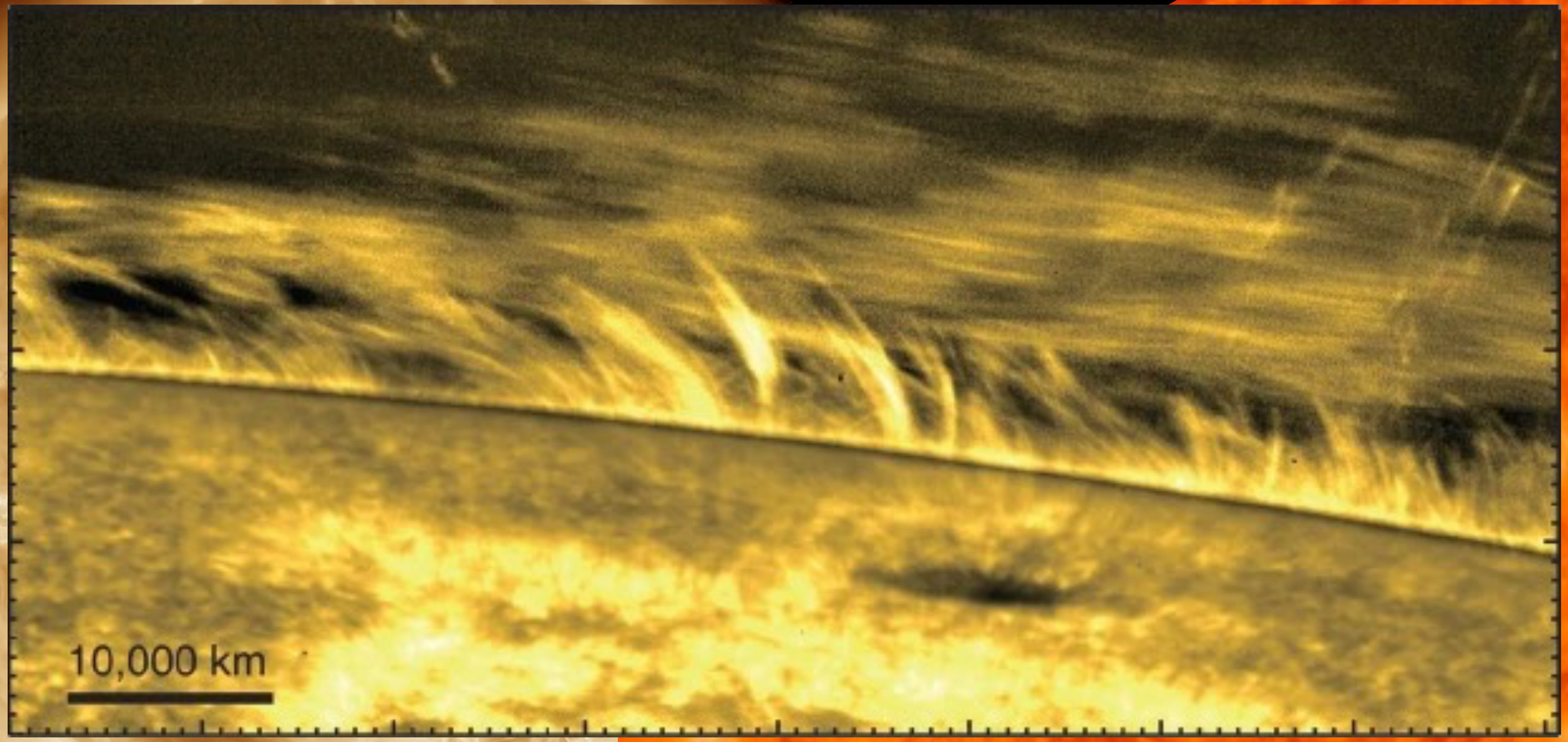


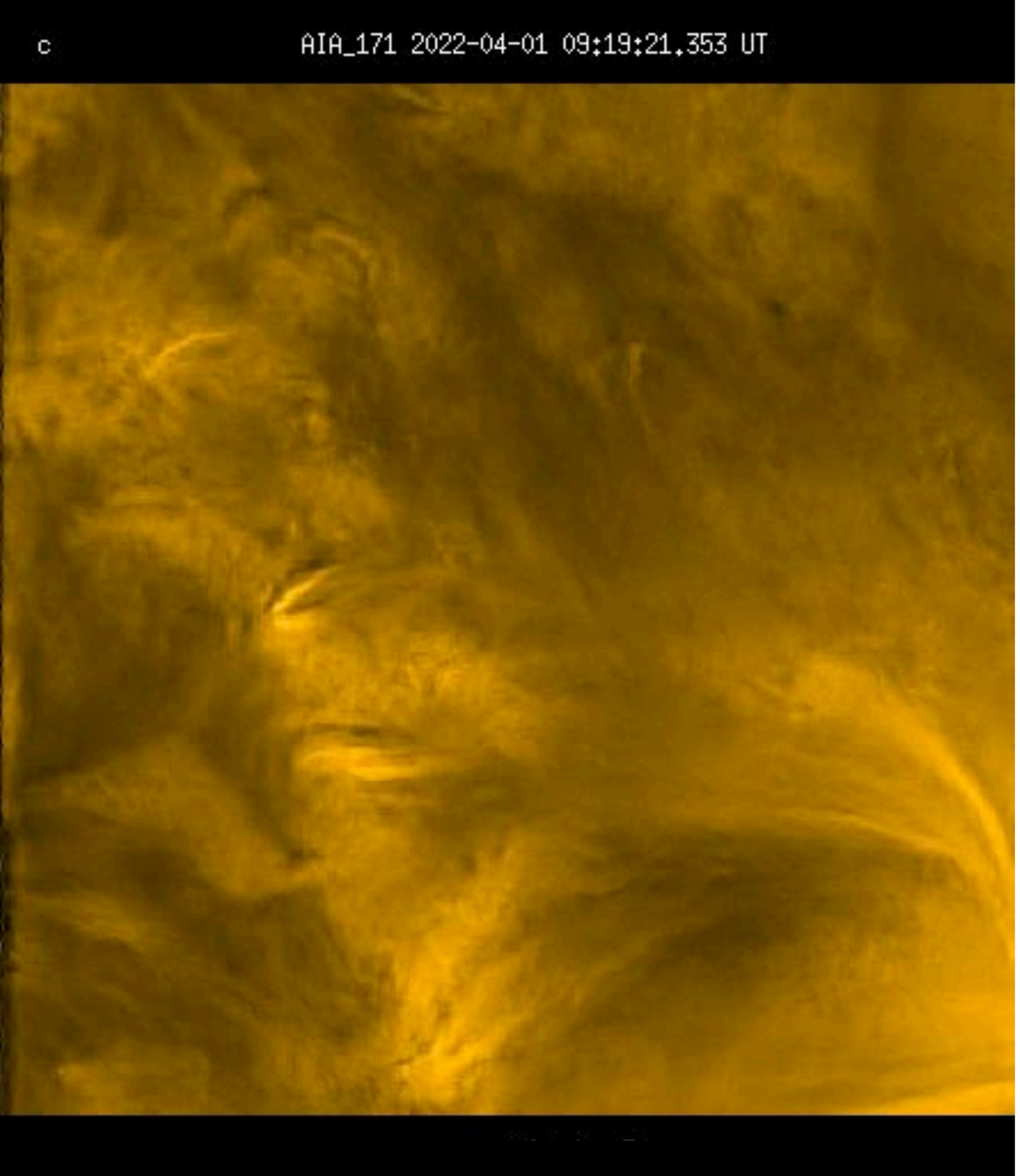

USA 2017

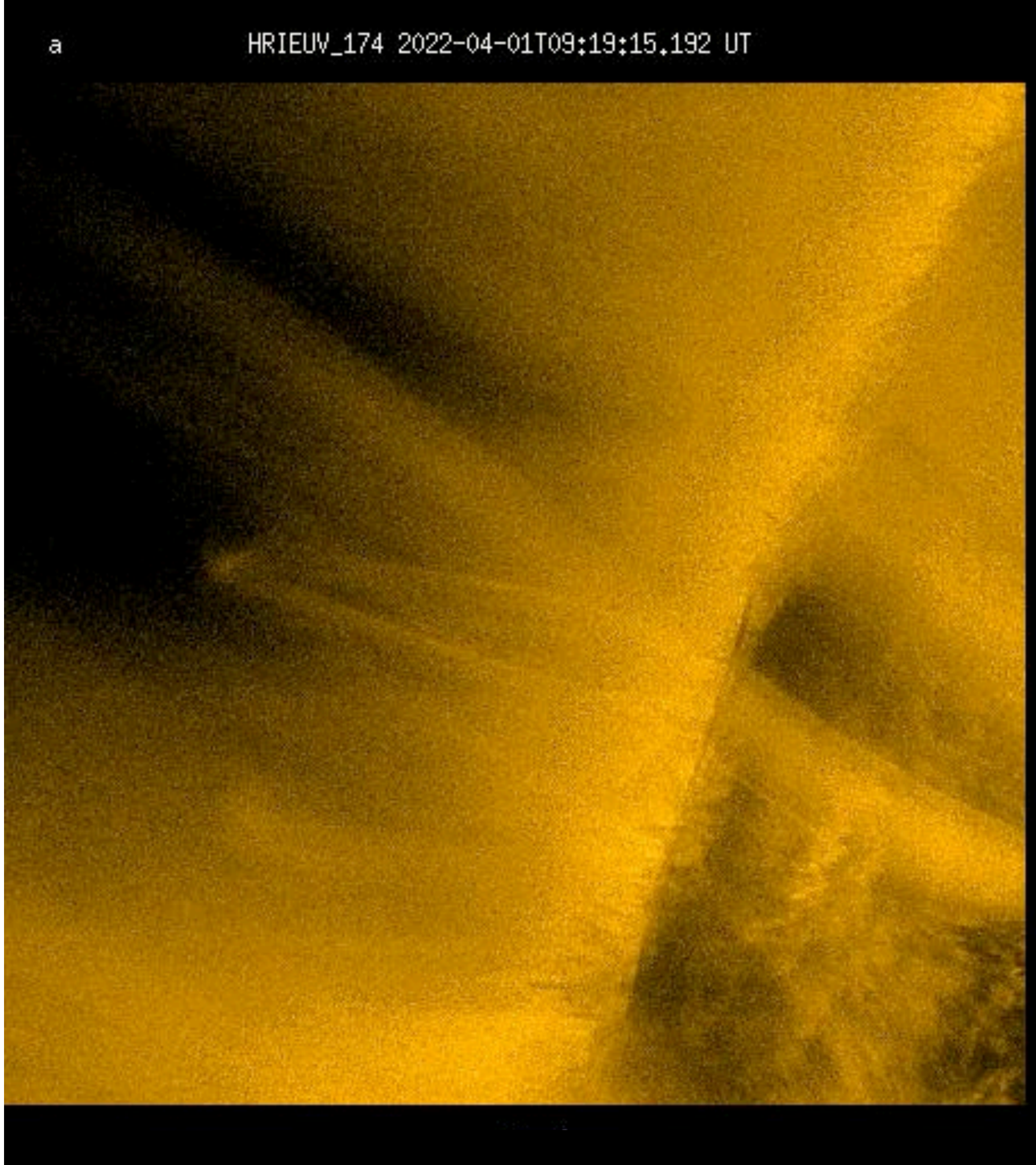
Fe IX

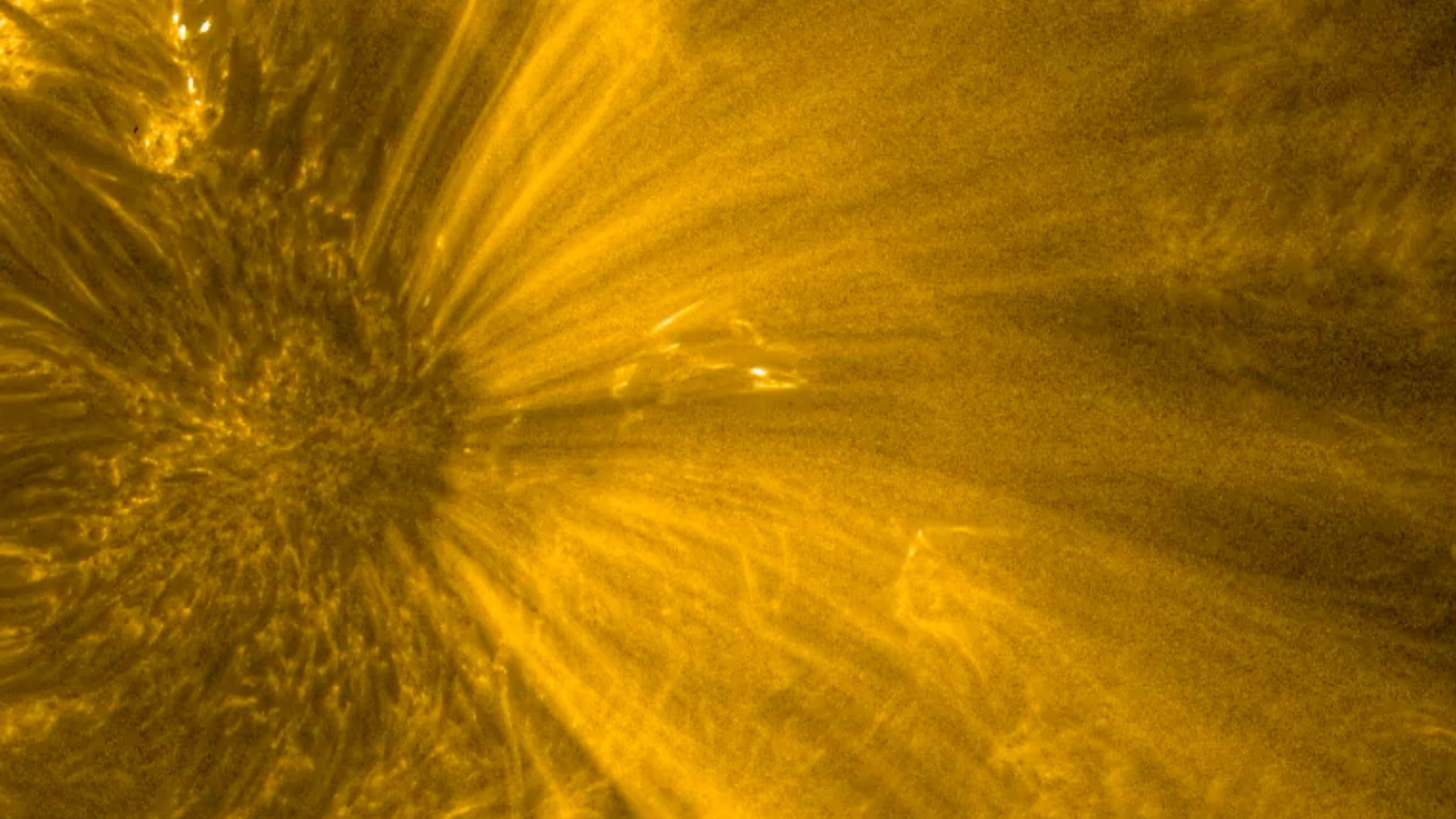




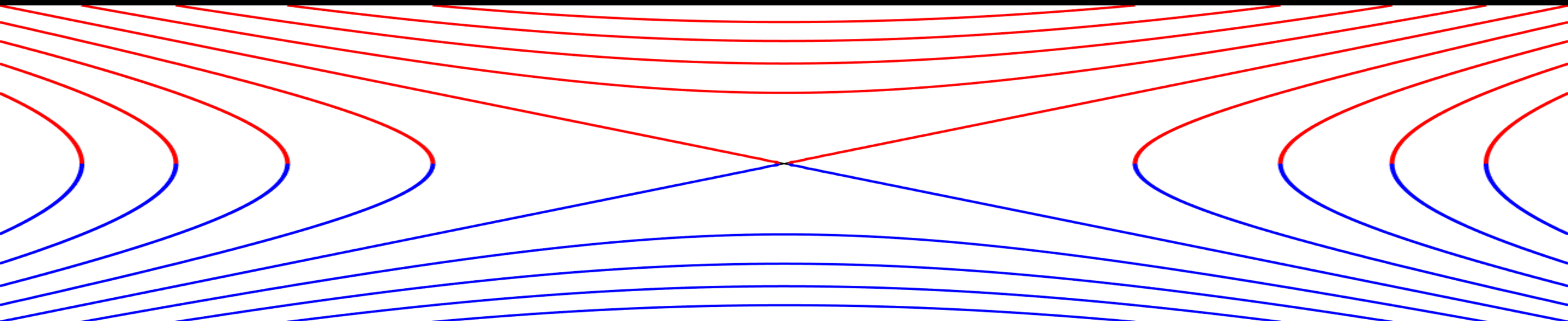

10,000 km

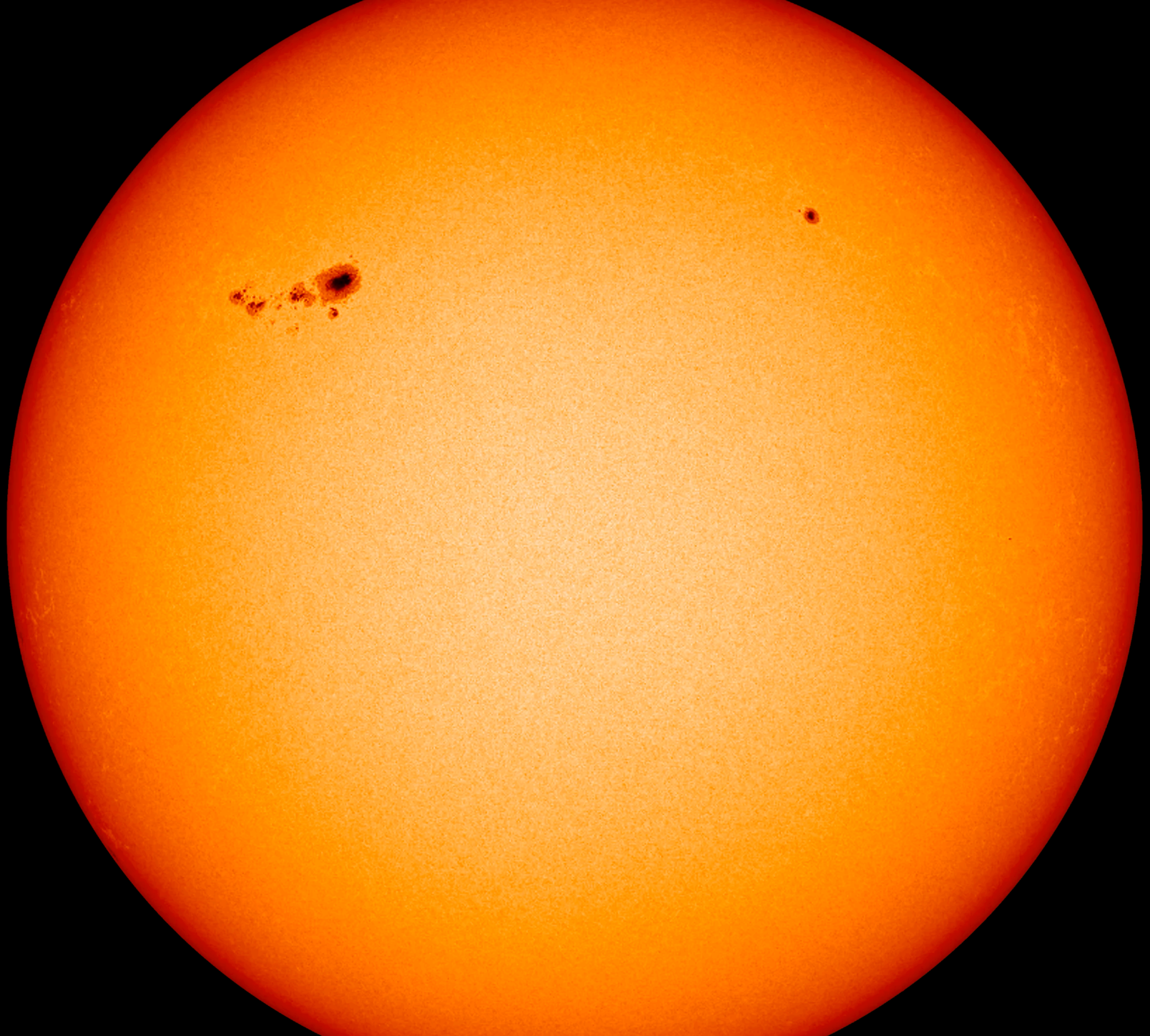

c
AIA_171 2022-04-01 09:19:21.353 UT

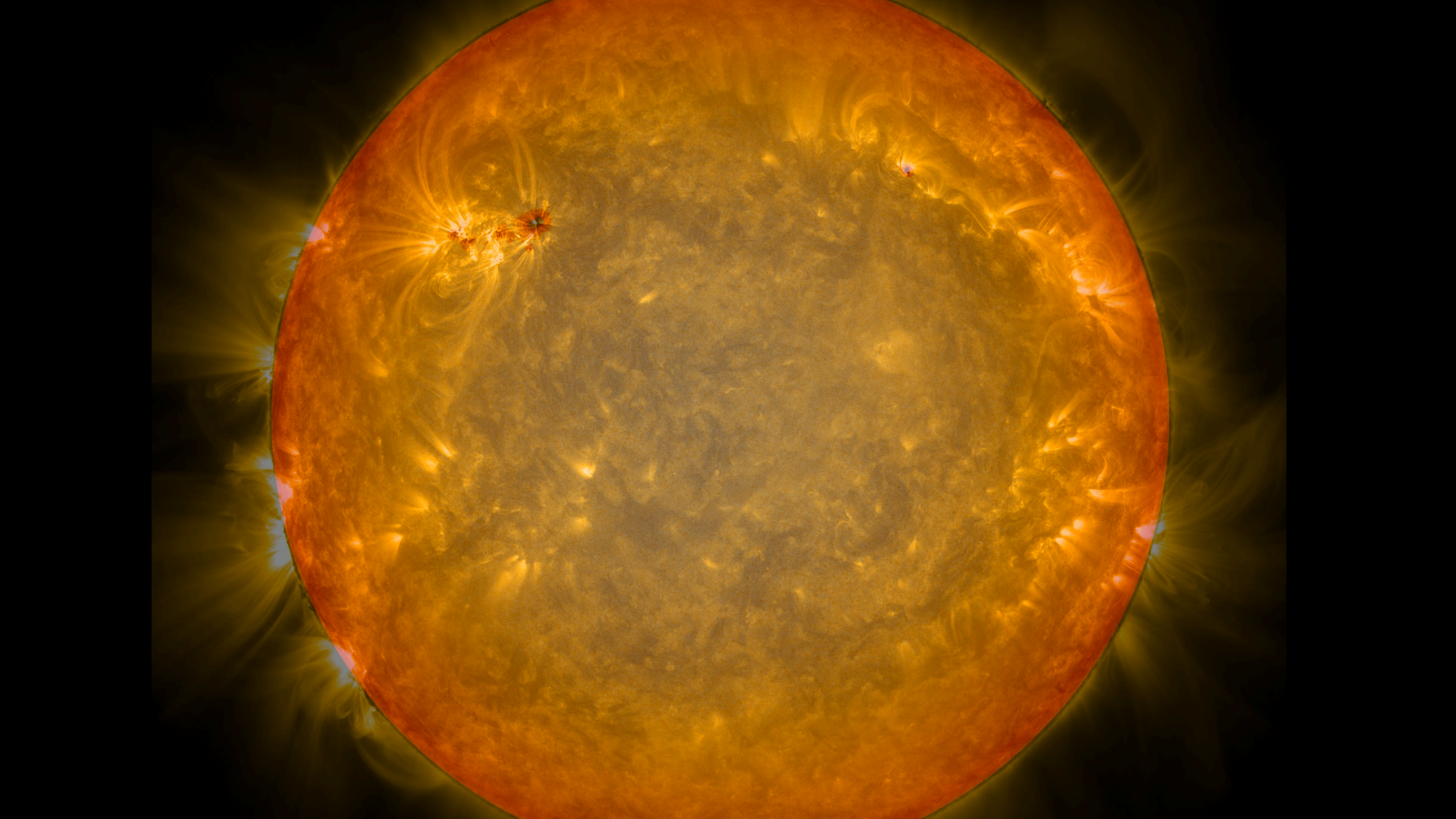

a
HRIEUV_174 2022-04-01T09:19:15.192 UT

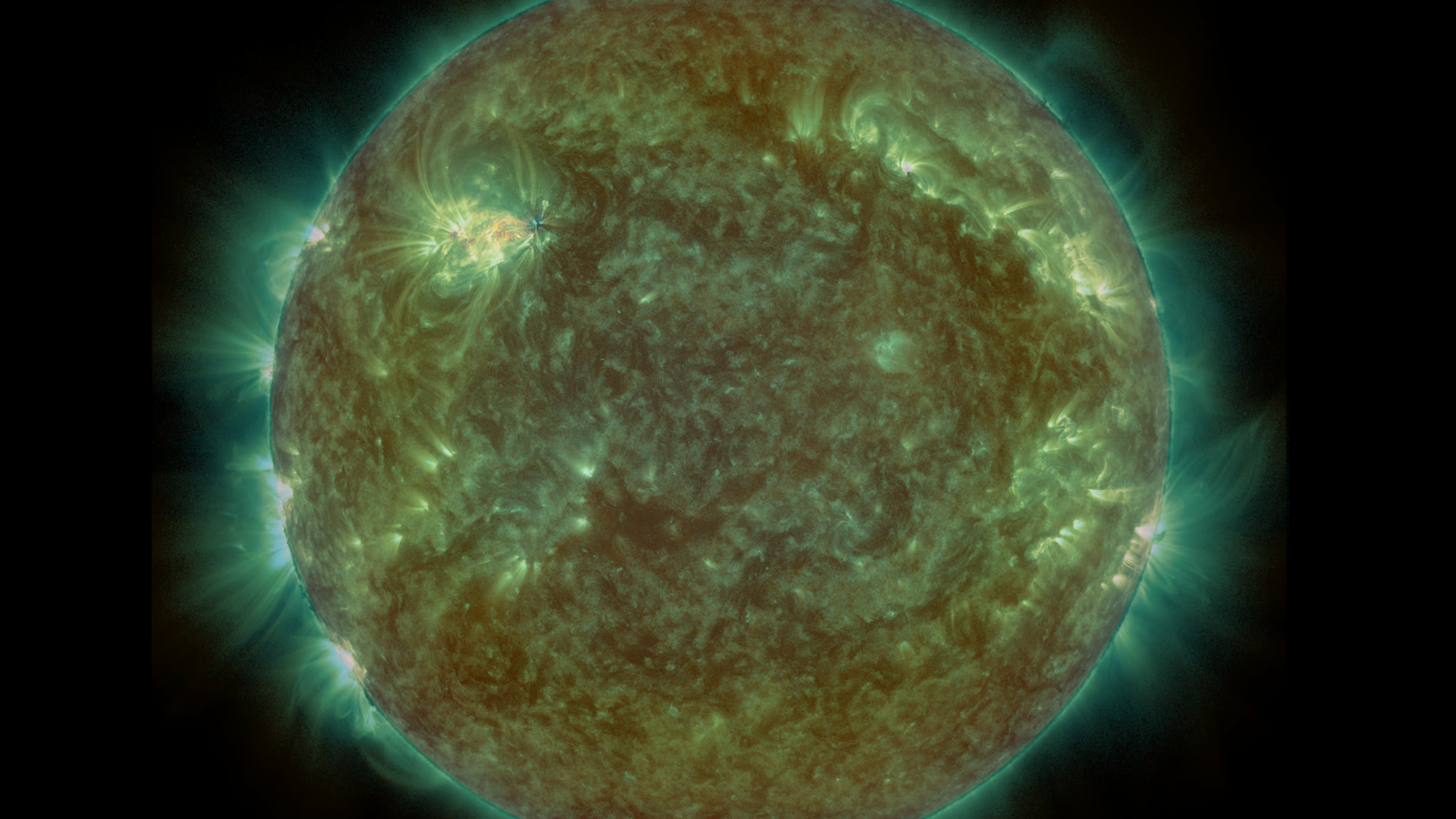


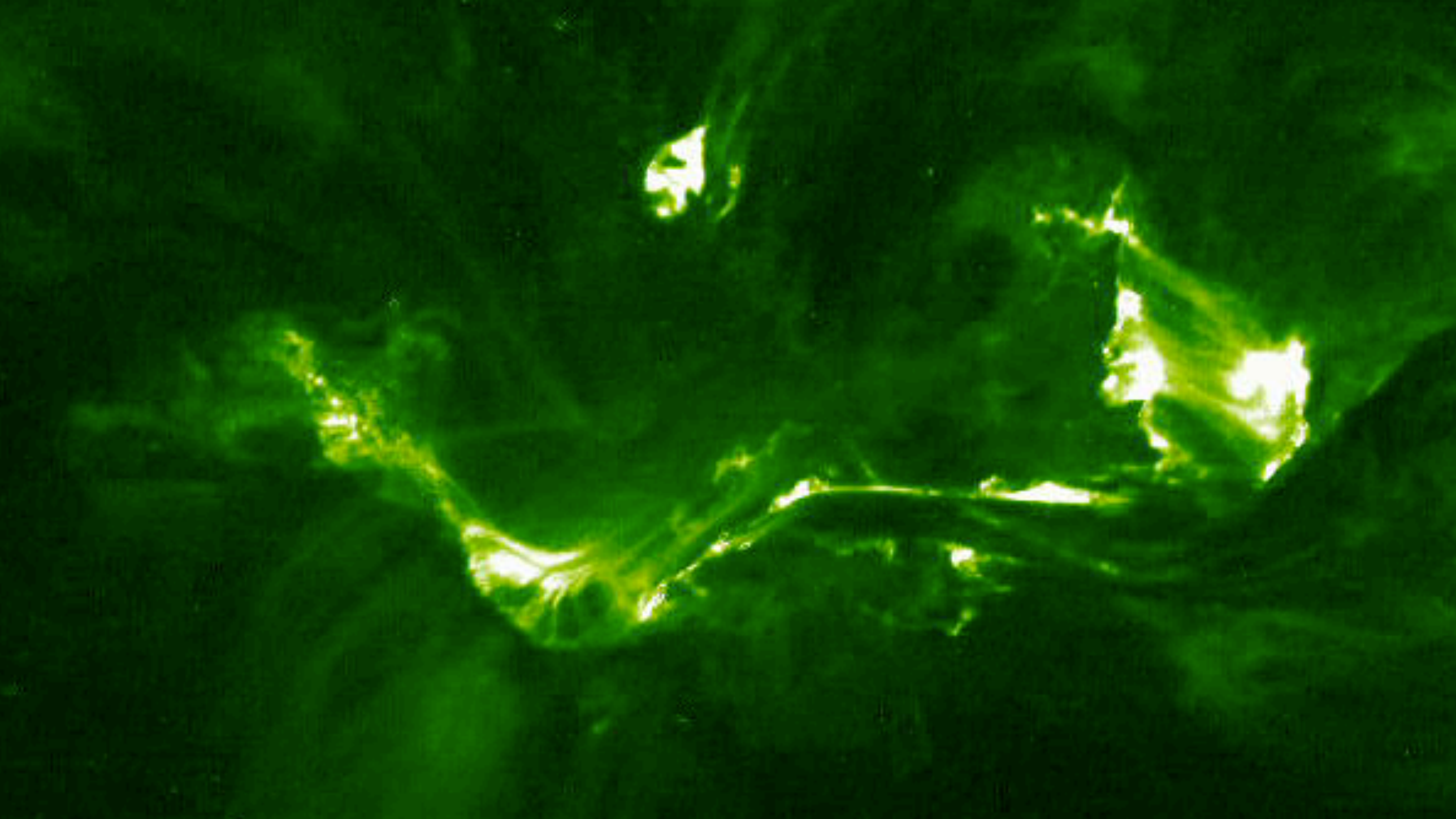
$$\frac{\partial \vec{B}}{\partial t} = \eta \nabla^2 \vec{B}$$

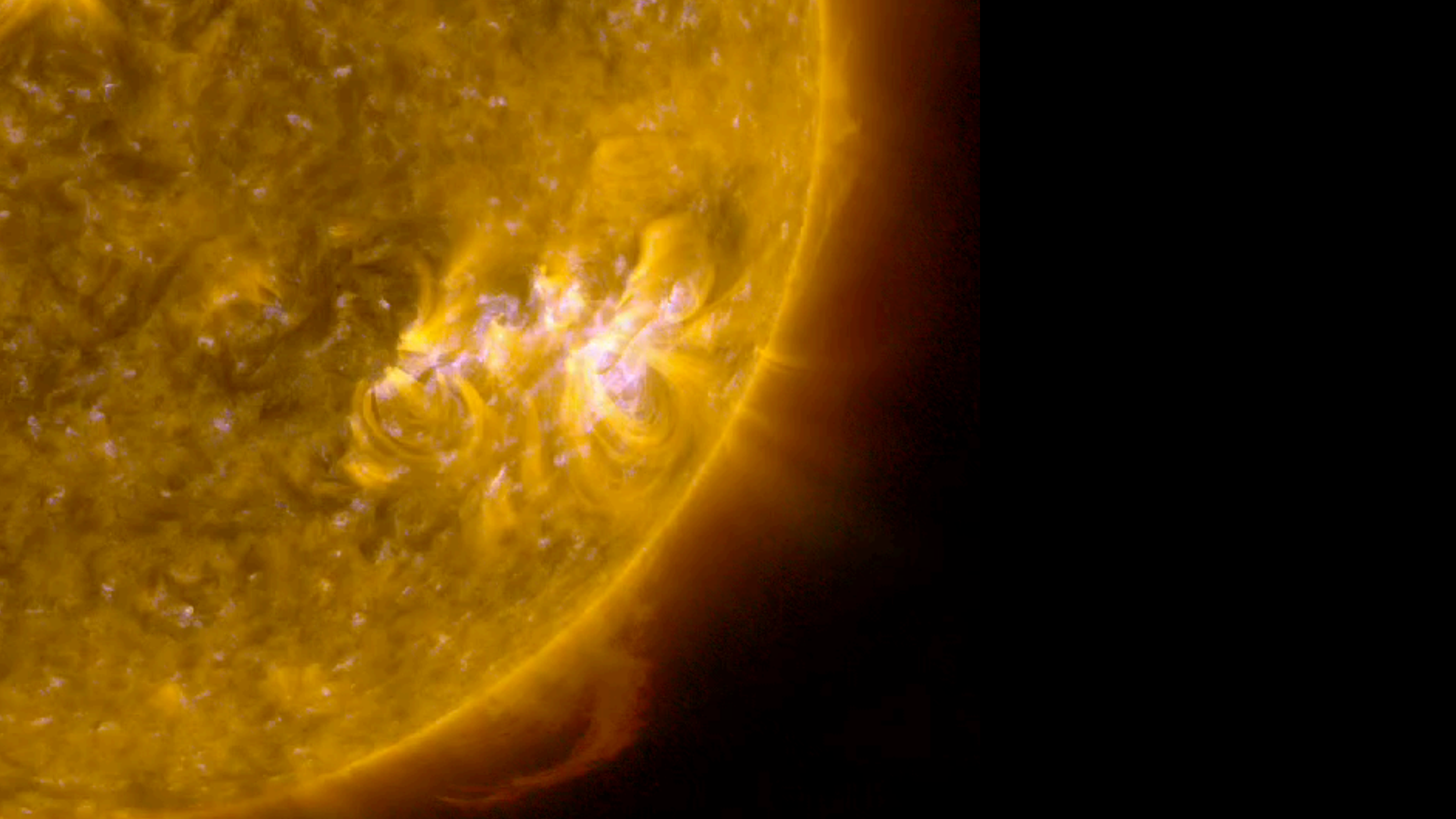


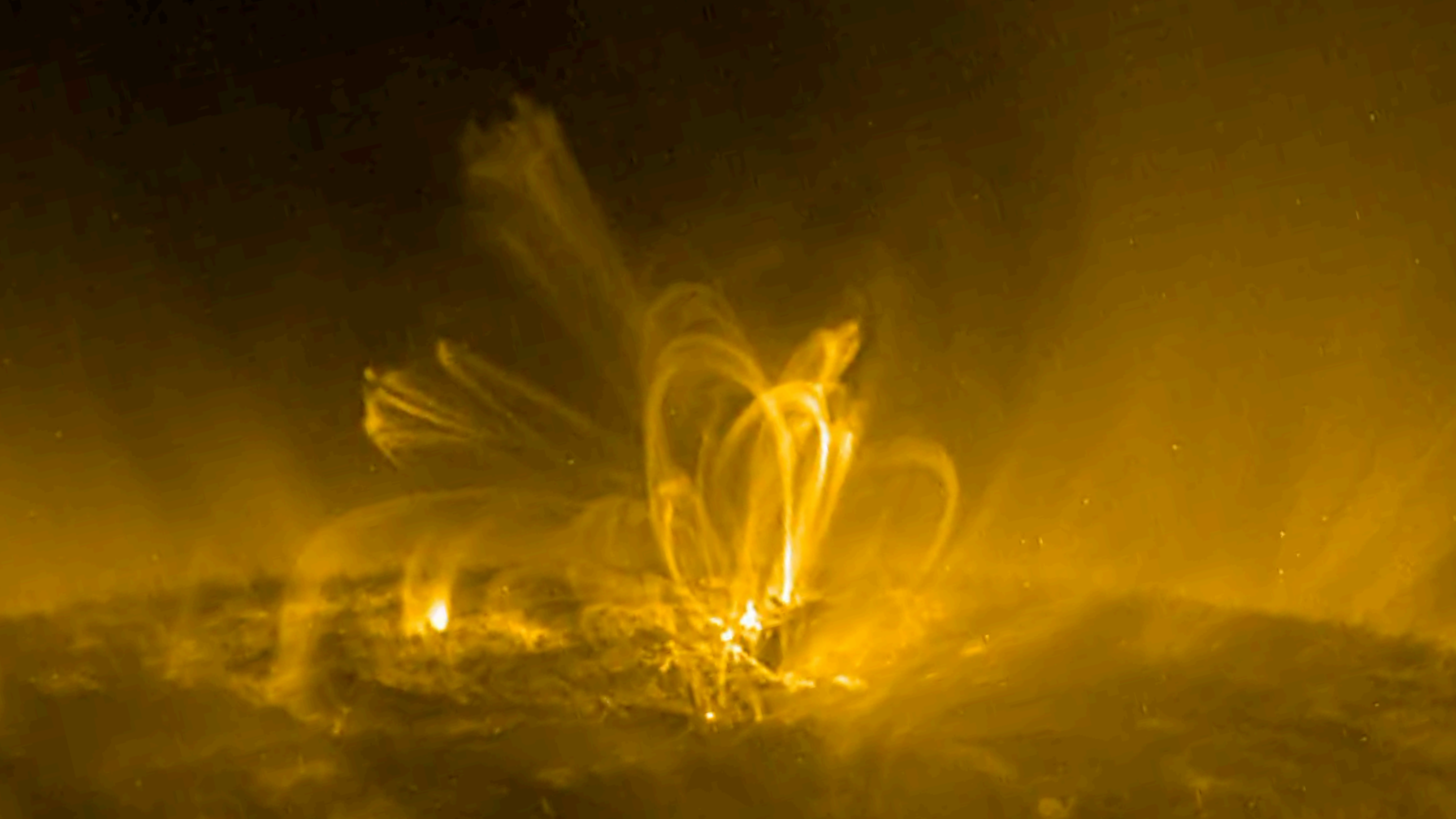


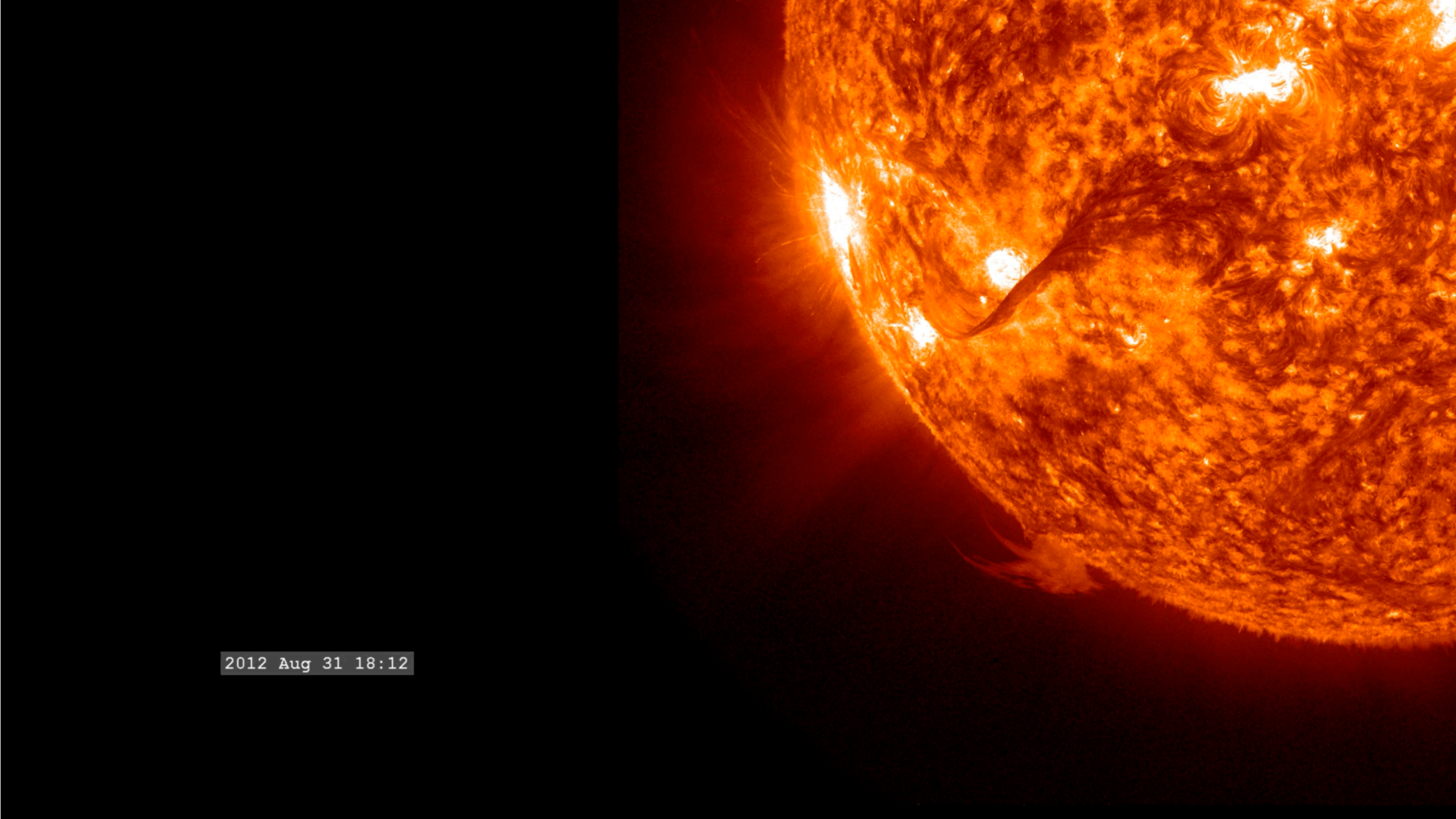


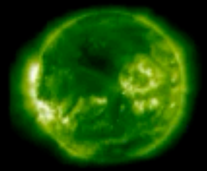






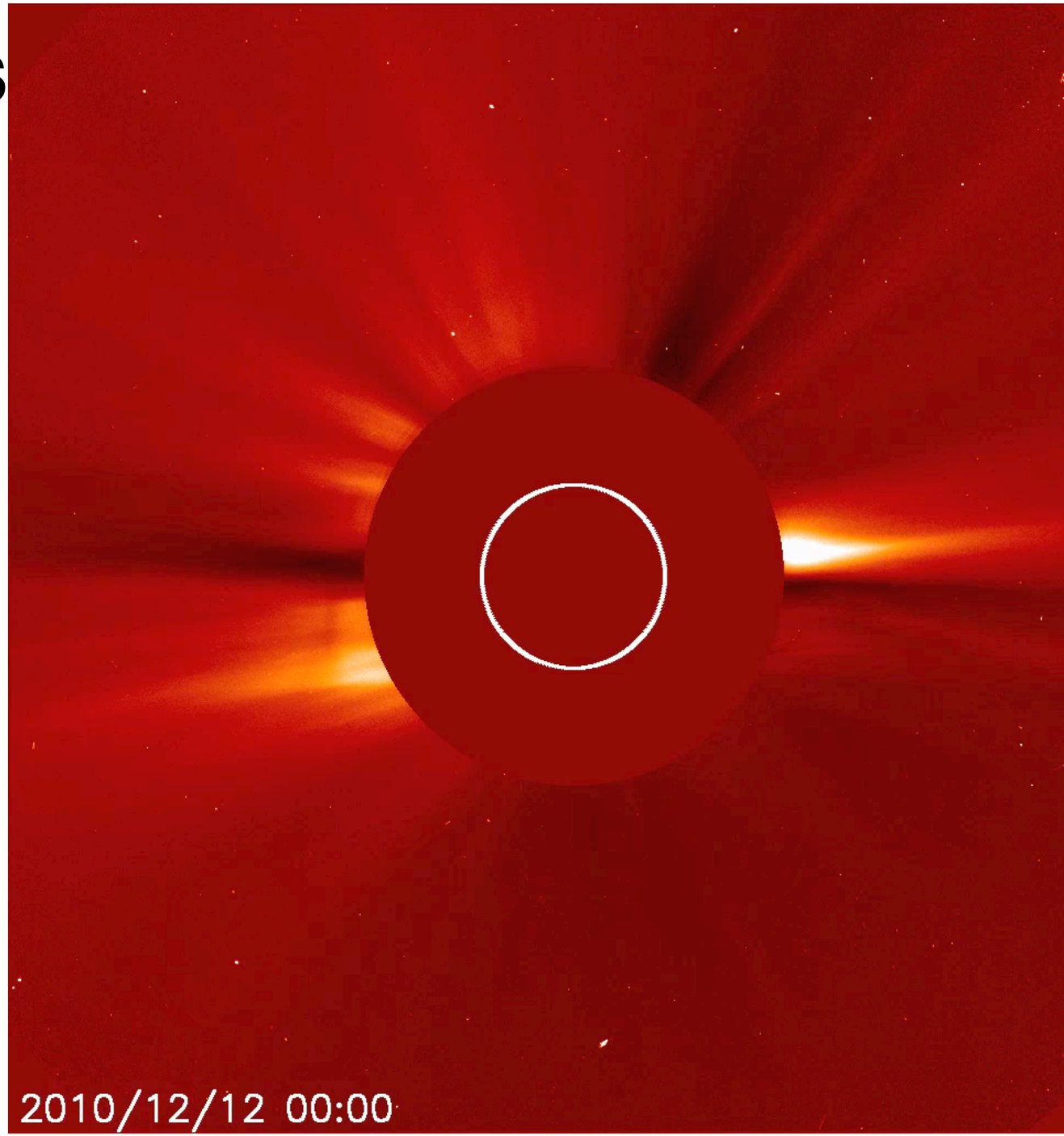



2012 Aug 31 18:12

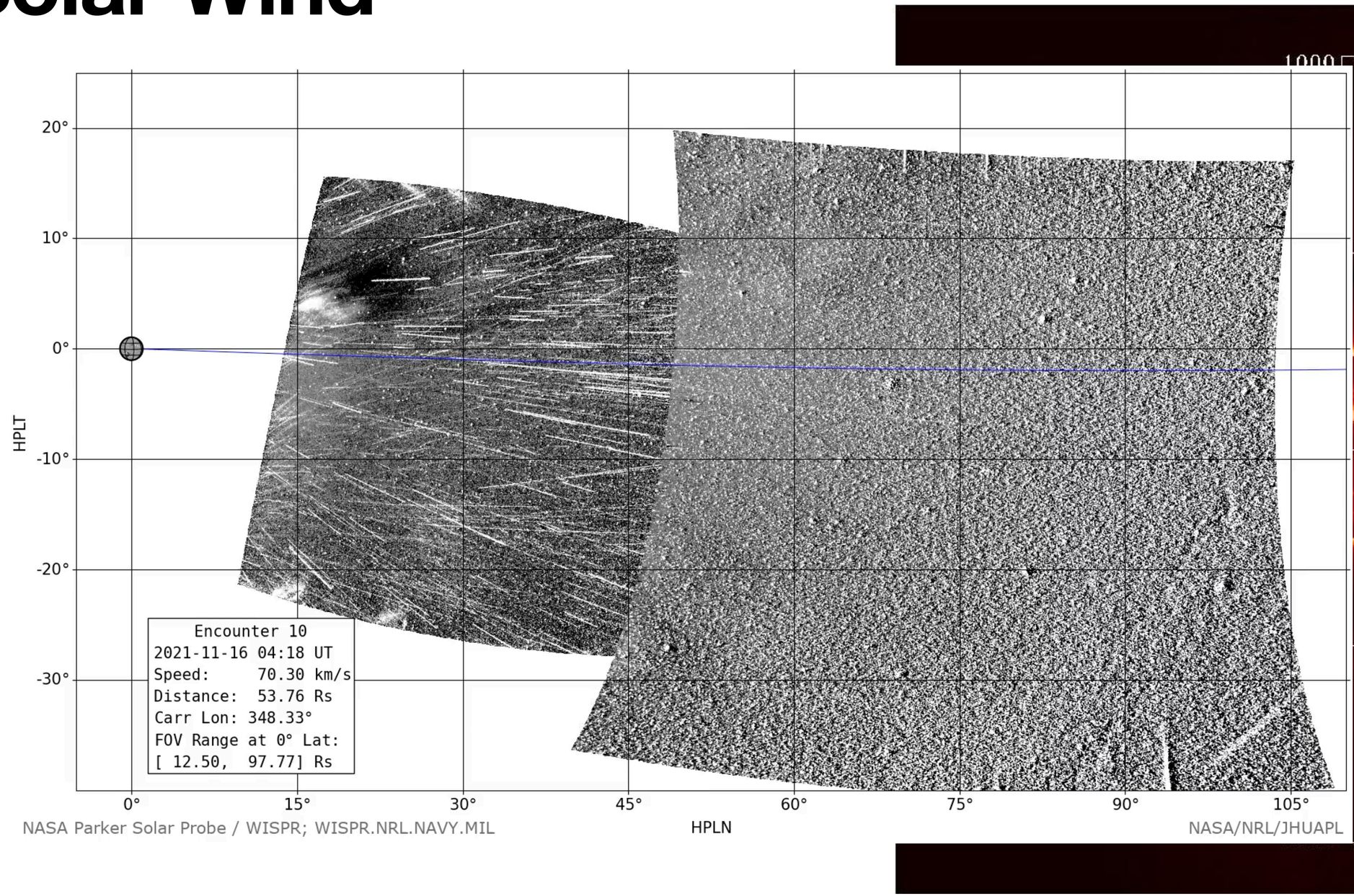


Coronal Mass Ejections

- 500 - 2000 km/s
- Dense front and core
- Expand as propagate
- Couple to the solar wind at 4 $R_{\odot}$
- Magnetic flux and plasma



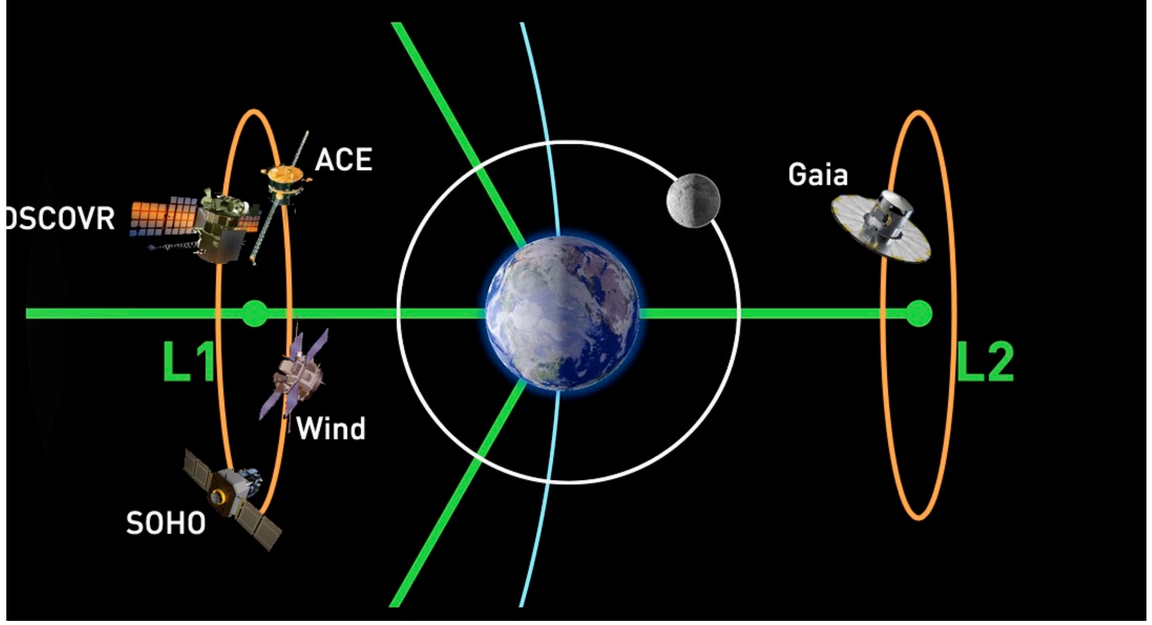
Solar Wind

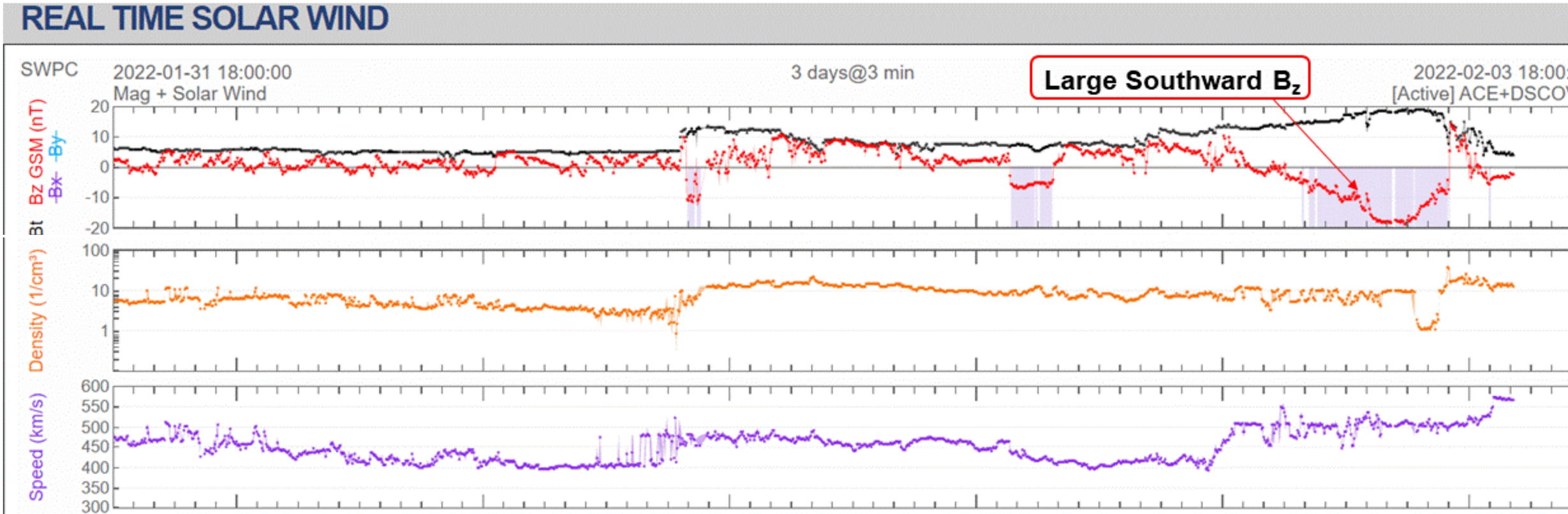

20°
10°
0°
-10°
-20°
-30°
HPLT
0°
15°
30°
45°
60°
75°
90°
105°
HPLN
Encounter 10
2021-11-16 04:18 UT
Speed: 70.30 km/s
Distance: 53.76 Rs
Carr Lon: 348.33°
FOV Range at 0° Lat:
[12.50, 97.77] Rs
NASA Parker Solar Probe / WISPR; WISPR.NRL.NAVY.MIL
NASA/NRL/JHUAPL

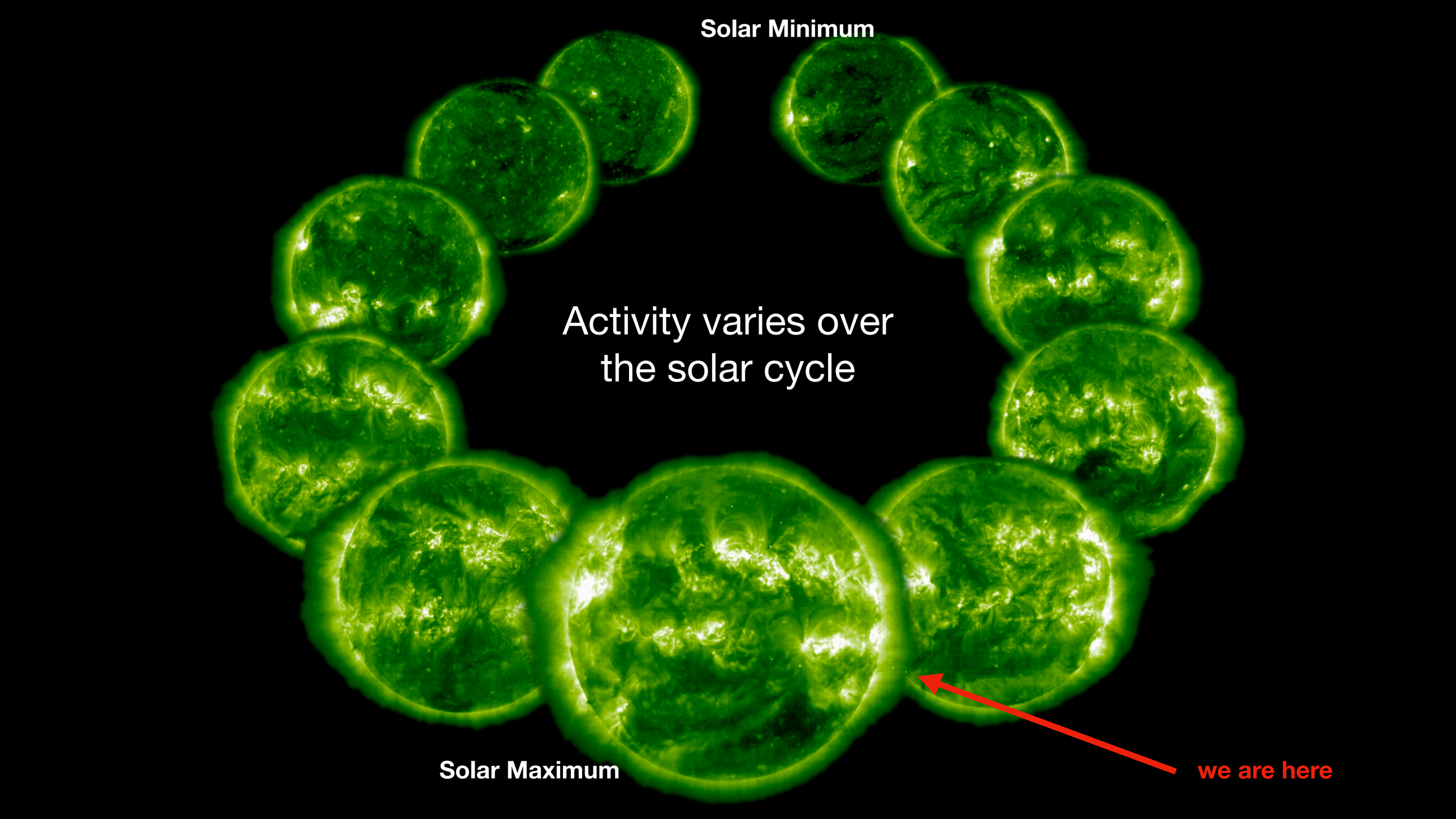
Speed (km s^{-1})
1000
1000
EIT (NASA/GSFC)
Mauna Loa MK3 (HAO)
LASCO C2 (NRL)

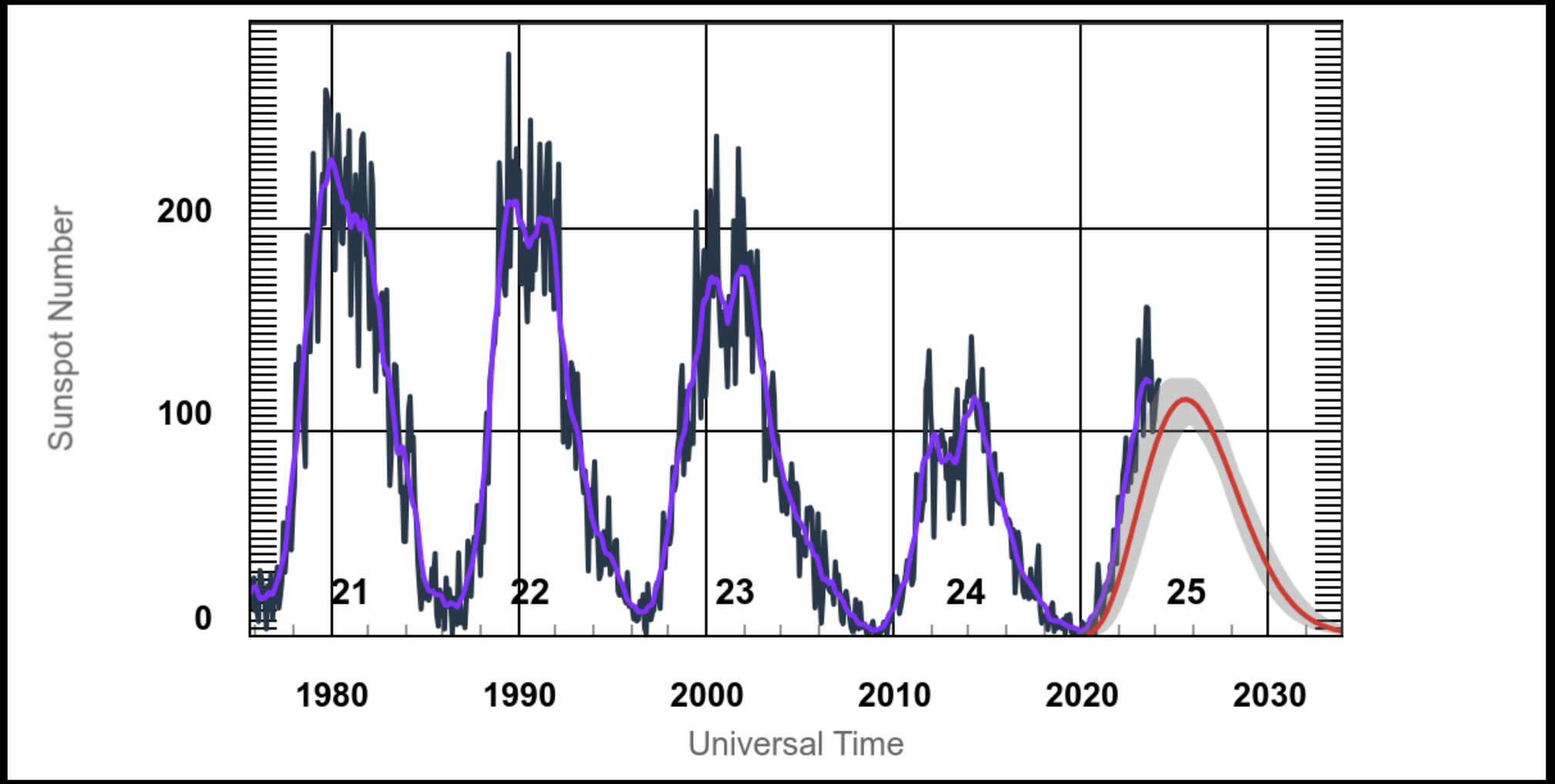
Coronal Mass Ejections

CME magnetic flux perturbs magnetosphere

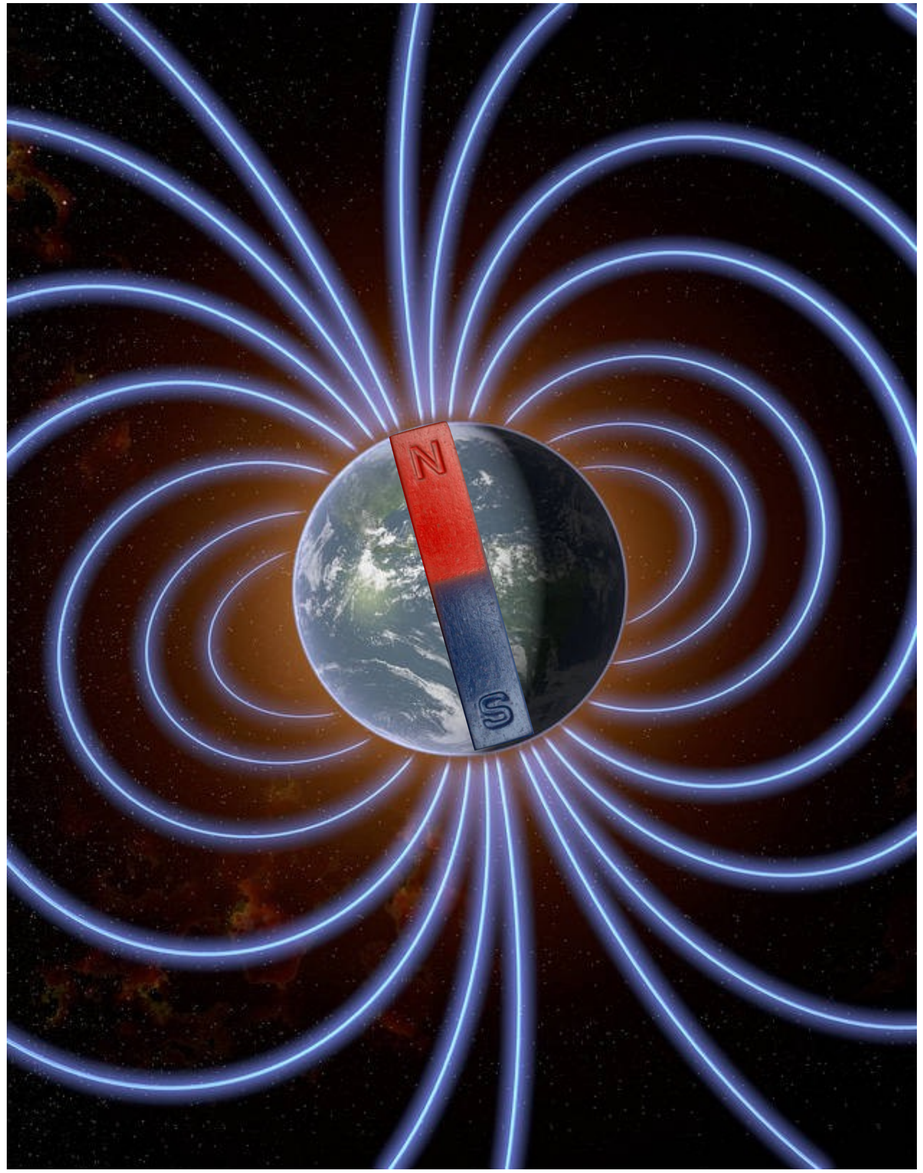





Solar Minimum
Activity varies over
the solar cycle
Solar Maximum
we are here


Sunspot Number
200
100
0
21
22
23
24
25
1980
1990
2000
2010
2020
2030
Universal Time

Earth magnetic field



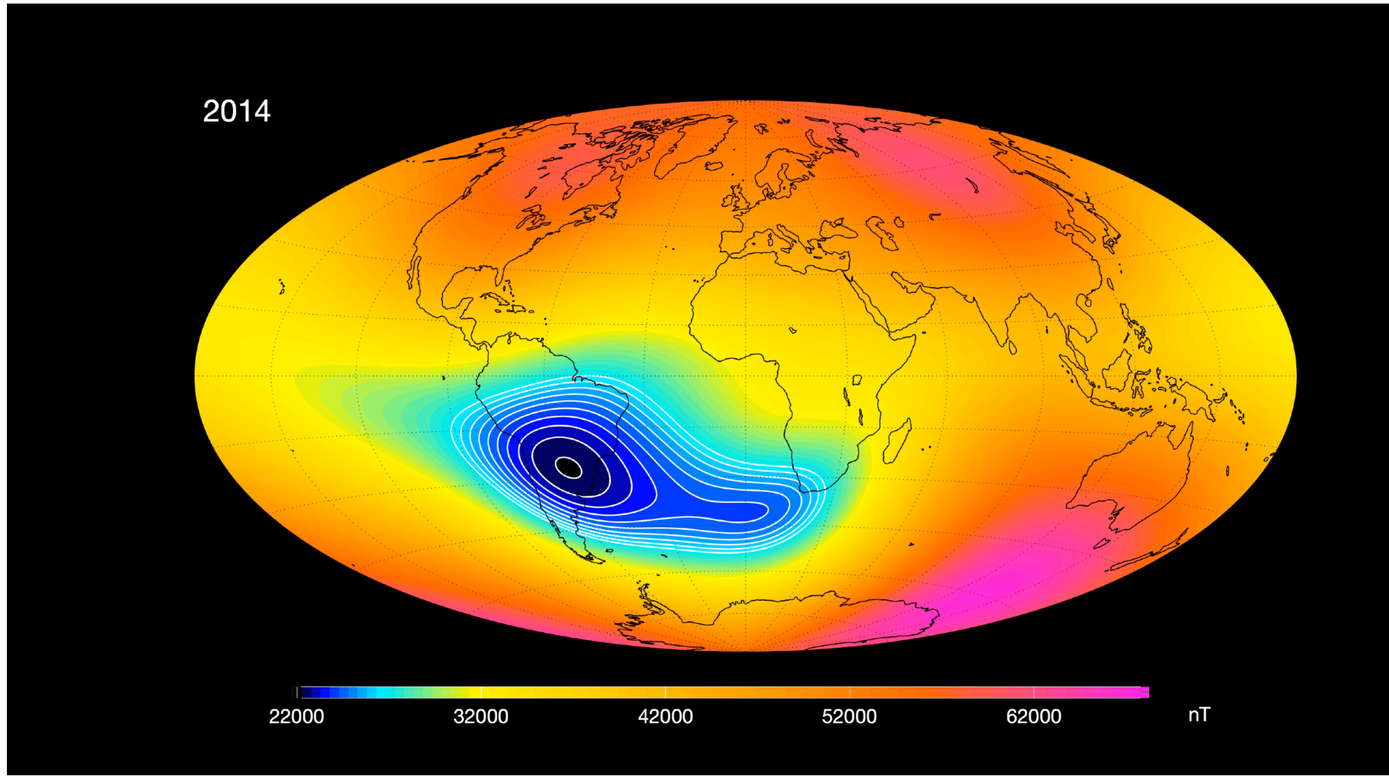
Dipolar field ($30\ 000\ nT$)

Currents generated by earth core ($1\ 220\ Km$)
$20\,\%\ R_E$ made of NiFe, as hot as the Sun

Earth dynamo
Convection of the outer core

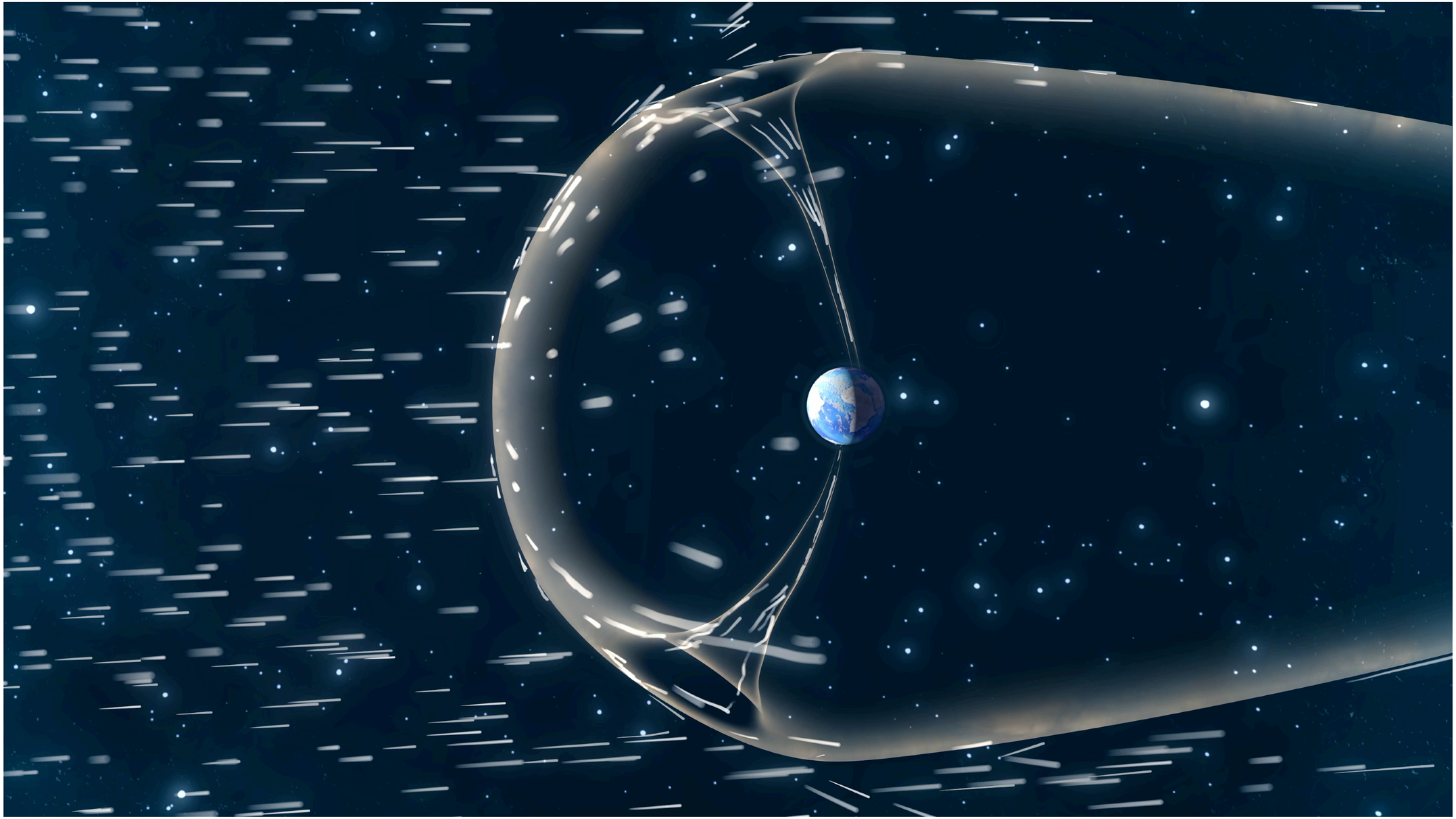
Deflects charged particles (makes life possible)

Inhomogeneities lead to South Atlantic anomaly



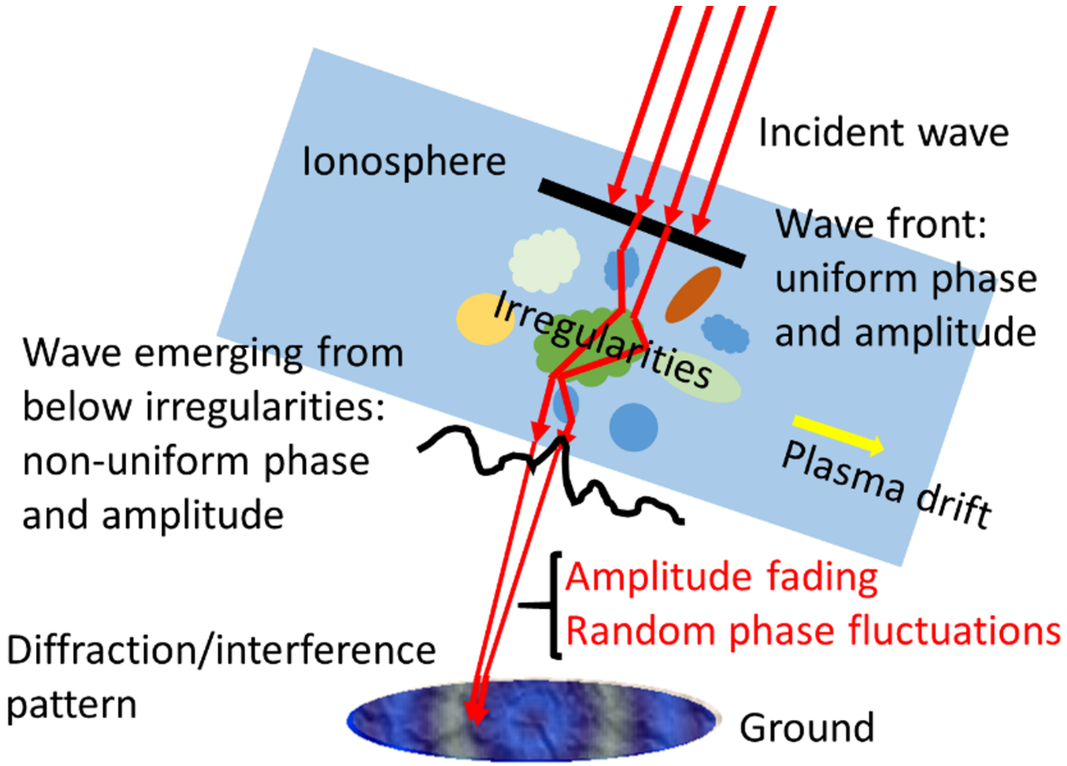
Solar Wind

$$\vec{F} = q\left(\vec{E} + \vec{v} \times \vec{B}\right)$$



Ionospheric scintillation

Analogously to what is observed on the brightness of the stars in the optical band, ionospheric scintillation is defined as a rapid and random fluctuation in the received amplitude and/or phase of radio waves passing through an electron density irregularity.



REFRACTION

Is a **deterministic process,** such scintillations can be corrected using multi-frequency measurements

Typically produced by ionospheric irregularities at small wave numbers, induces mainly phase fluctuations.
The received phase changes because the electromagnetic wave enters a medium of either increased or decreased phase velocity.

DIFFRACTION

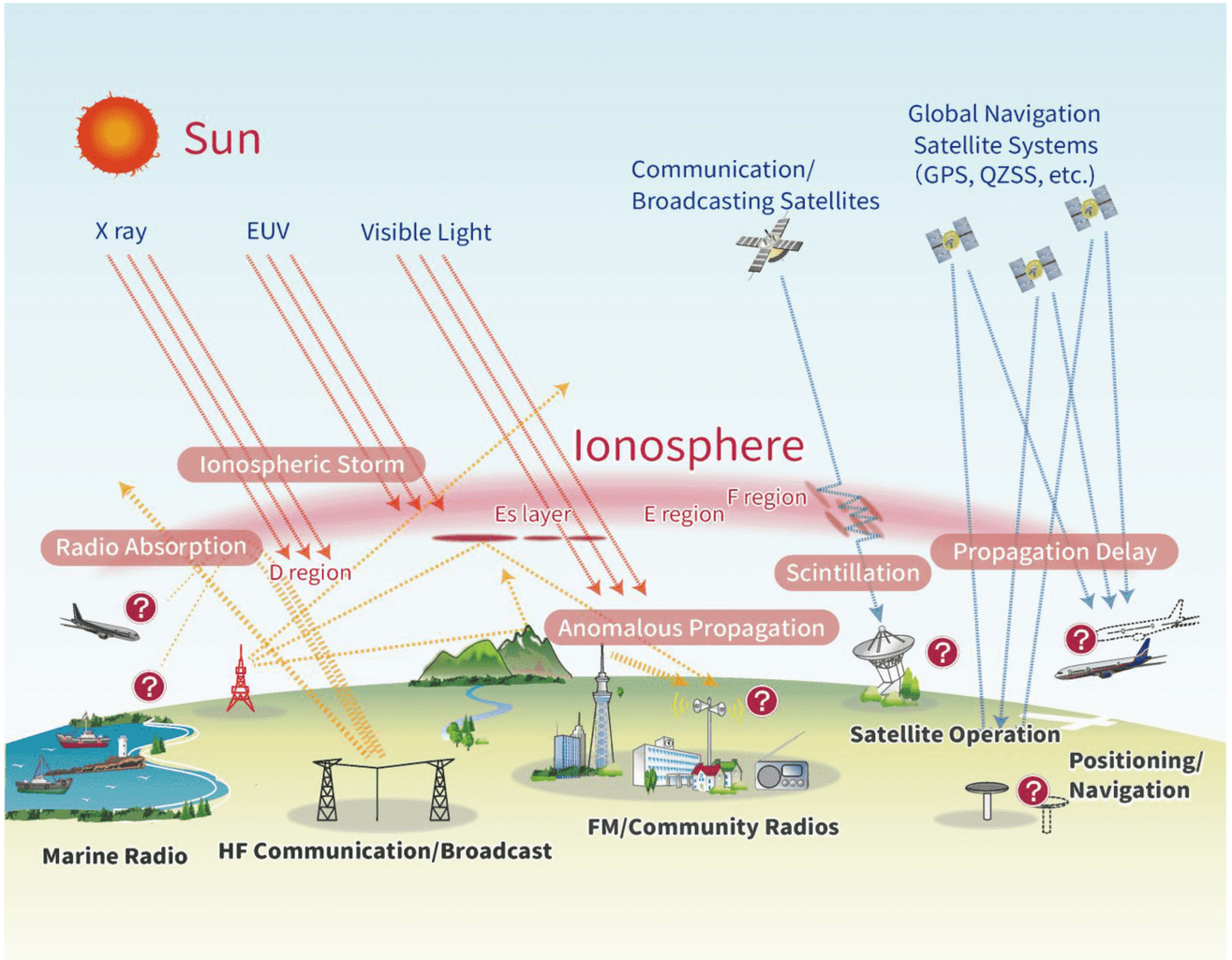
Is a **stochastic process**, such scintillations cannot be corrected

Produced by ionospheric irregularities near the first Fresnel radius (up to hundreds meters for GNSS signal transmitted at L1 = 1575.42 MHz), induces amplitude fading and random phase fluctuations.
The impinging electromagnetic wave enters the ionosphere with a spatially uniform phase and amplitude and exits the ionosphere with a spatially irregular phase and amplitude.

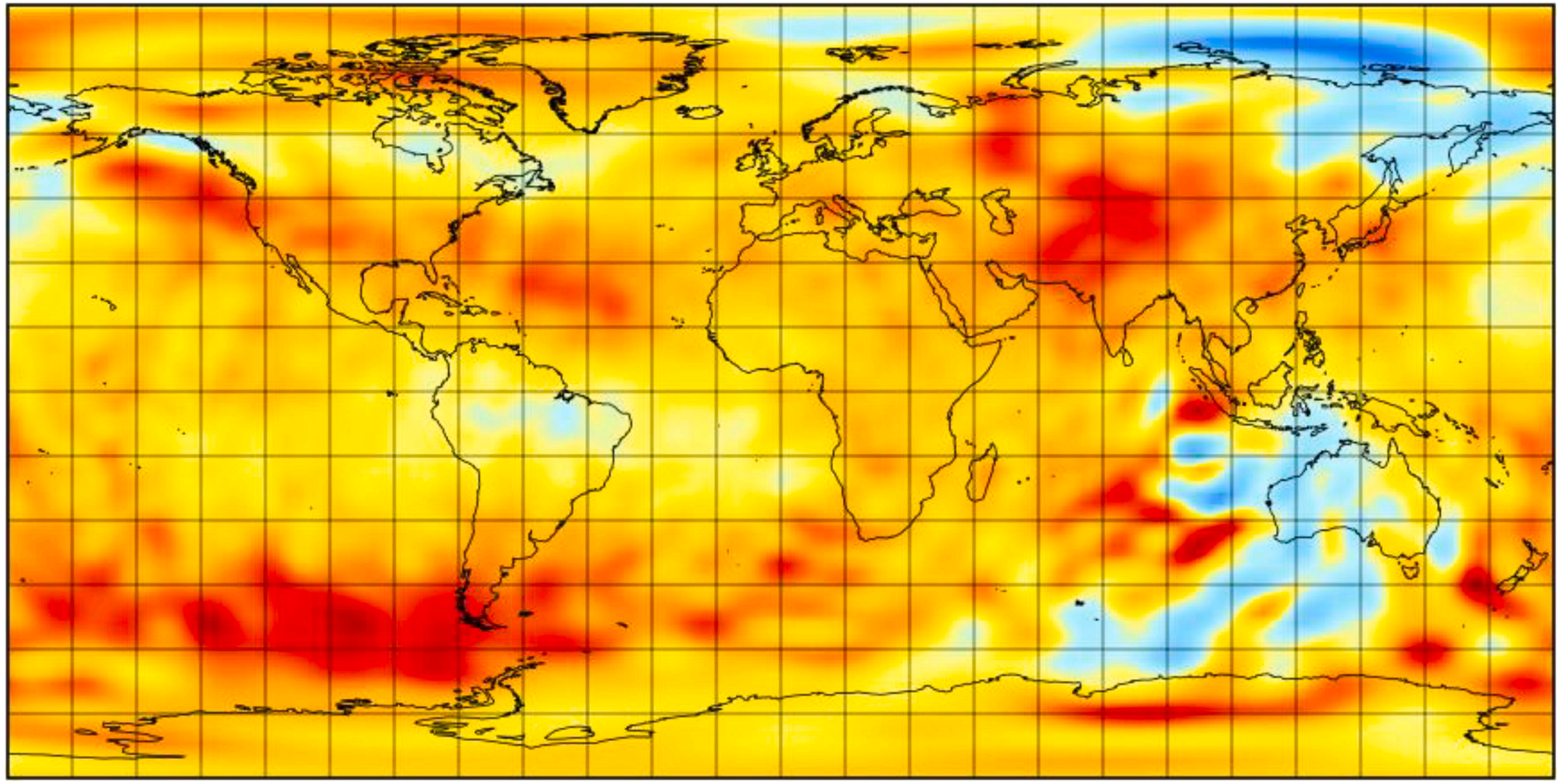
Ionospheric effects on radio propagation

Irregularities generate fluctuations in the ionospheric refractive index having significant effects on radio waves.

Giving rise to refraction, reflection, absorption, time delay phenomena as well as Doppler sudden shifts, and randomly, amplitude and/or phase changes of the radio waves passing through the ionosphere, they can degrade trans-atmospheric signals on which some technological systems relay on.



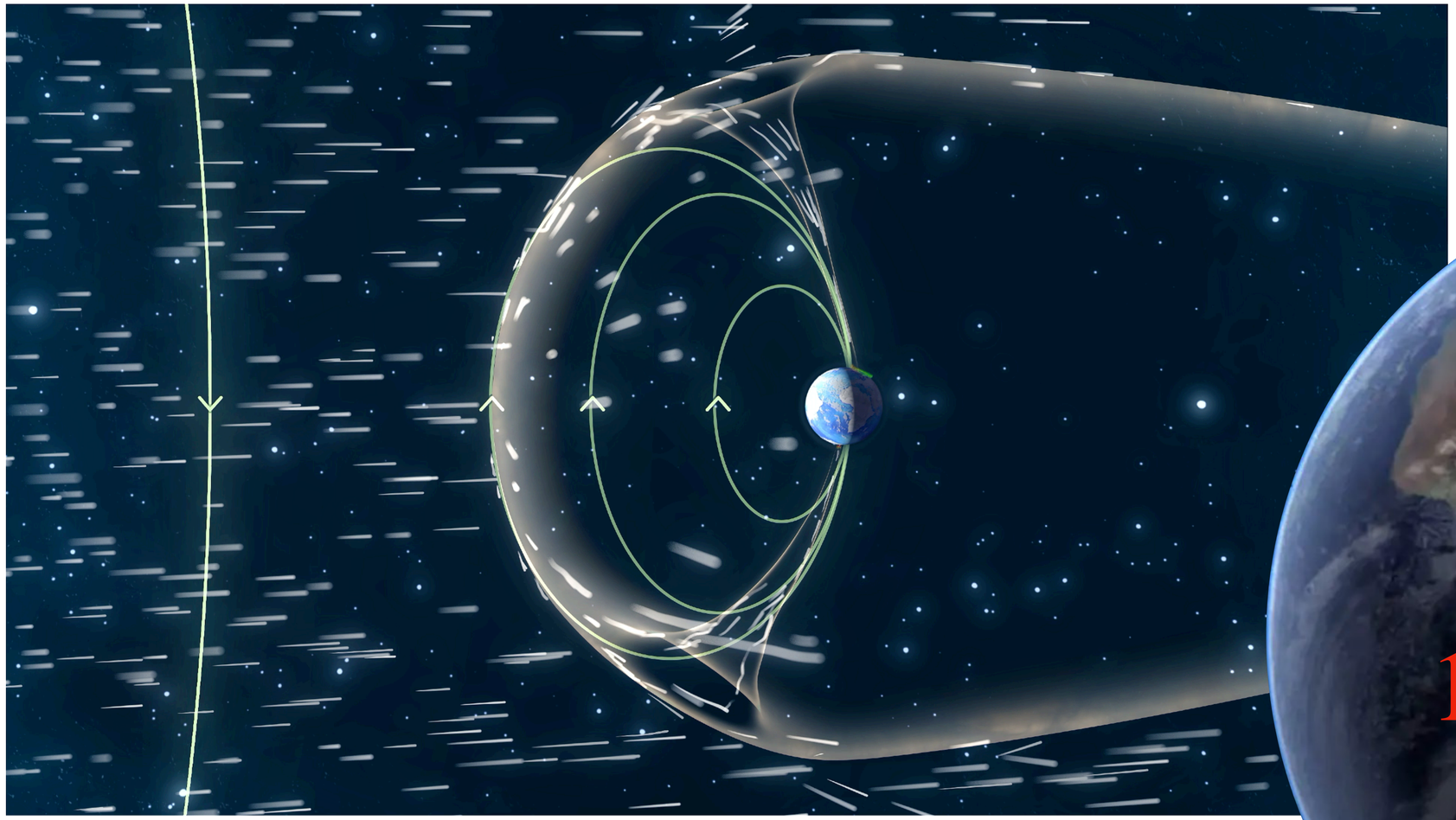
Neutral Mass Density at 400km Height (2022/2/4 21:00UT)

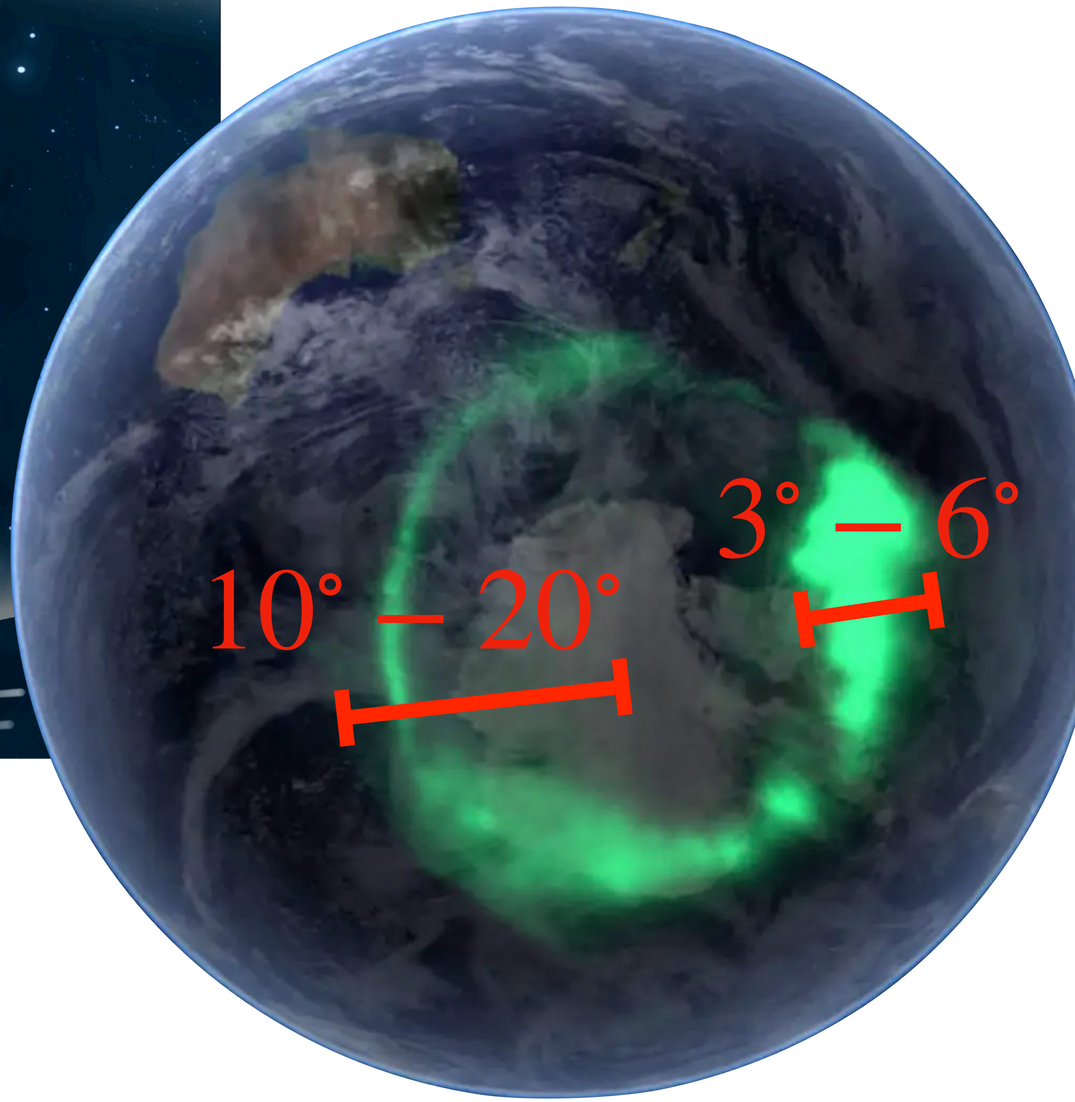


(Storm - Quiet) / Quiet [%]

-50.0 -30.0 -10.0 10.0 30.0 50.0

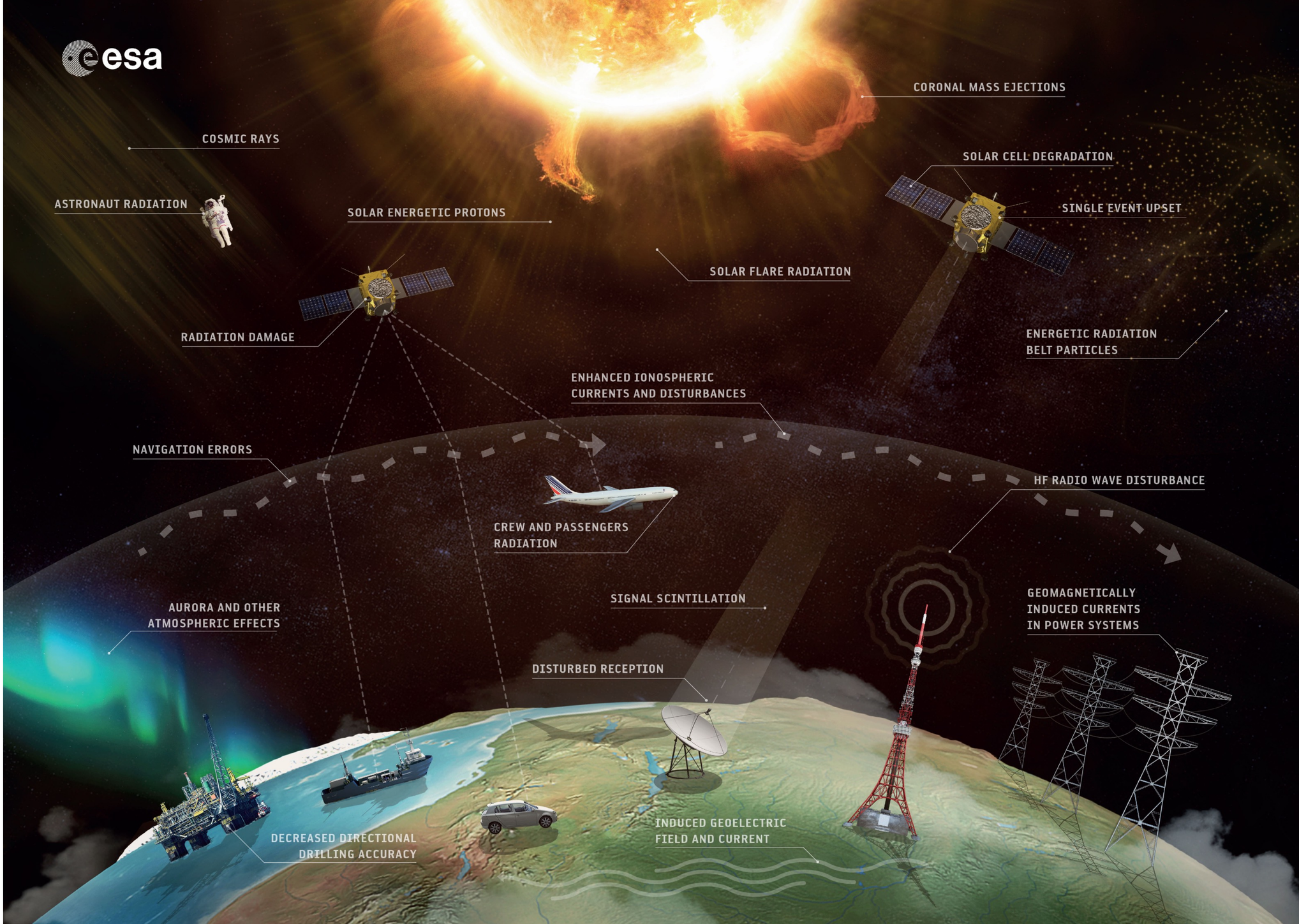
Aurora





- Above 80 km
- Recombination of ionised nitrogen.
- Transition to ground state of oxygen and nitrogen molecules

Space Weather in one slide



Telecommunications

20m

Corey McKay
@CMcKayFL

40m condx really deteriorating. KD4UYR, net control for #HurricaneWatchNet, not able to be heard via SDRs in Miami, Key West, or Dominican Republic. Only picking up via SDR in Maryland.

5:33 PM · Sep 1, 2019 · Twitter for Android

60m???

Aviation

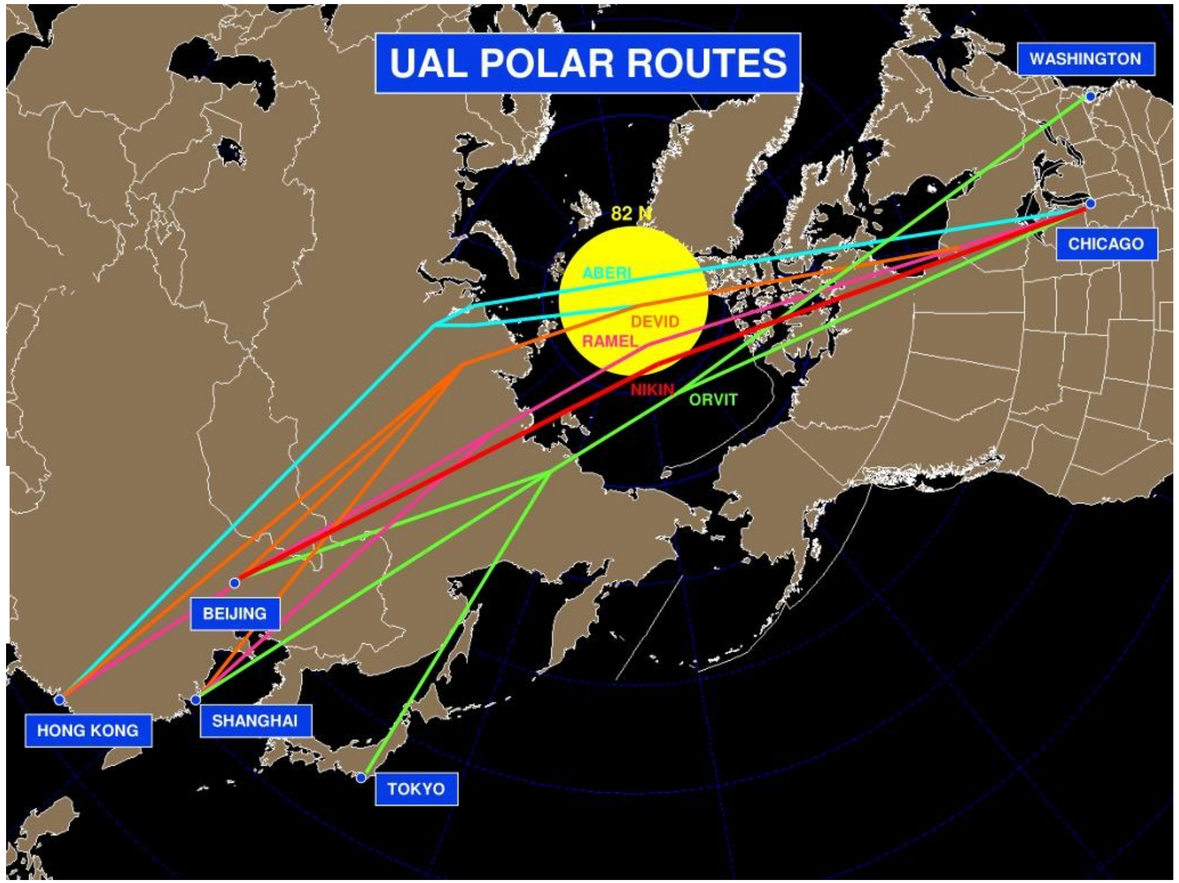
CBC | NEWS

Science

Solar storm knocks out flight control systems in Sweden, grounds planes

Agency spokesman Per Froberg said flights disappeared from radar screens in Swedish air traffic control towers during the blackout, which lasted about an hour until 5:30 p.m. local time (11:30 a.m. ET). Froberg said it was unclear why the impact was so severe, adding the last time something similar happened in Sweden was in 1999.

Save about 3 tons of fuel

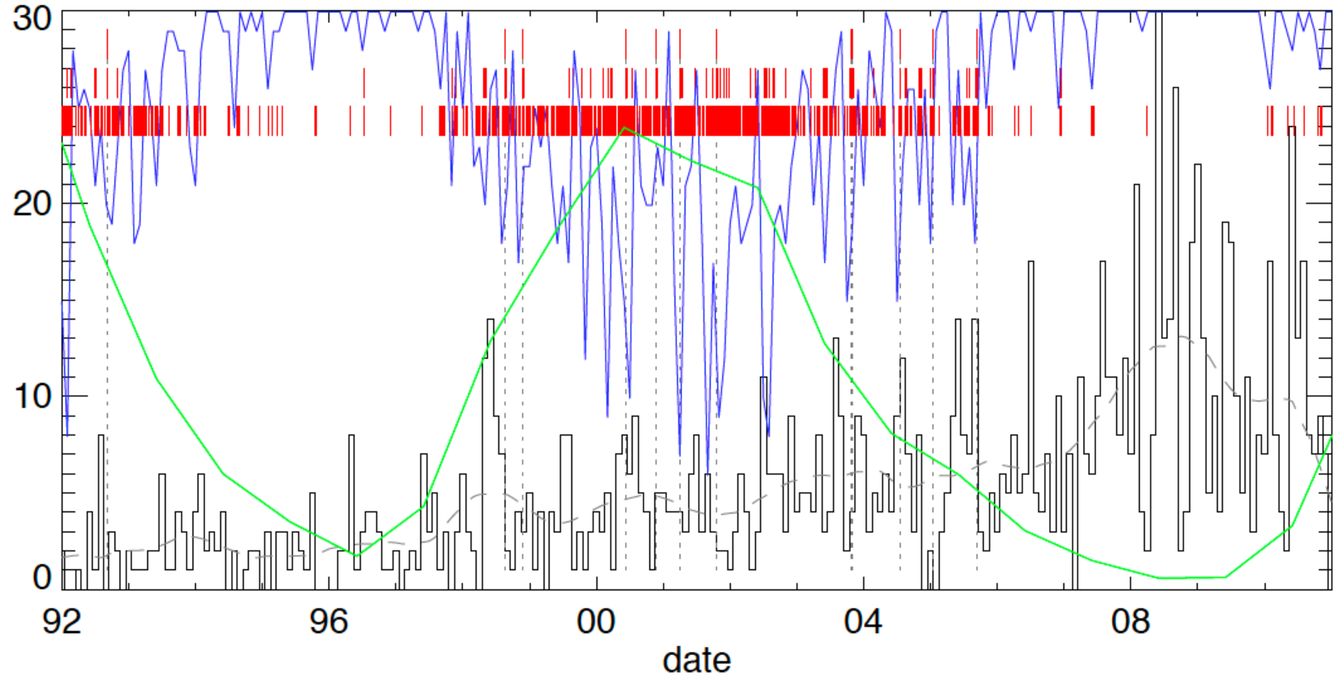


Now relevant also for Europe-Asia flights

Power grids

does not break the grids,

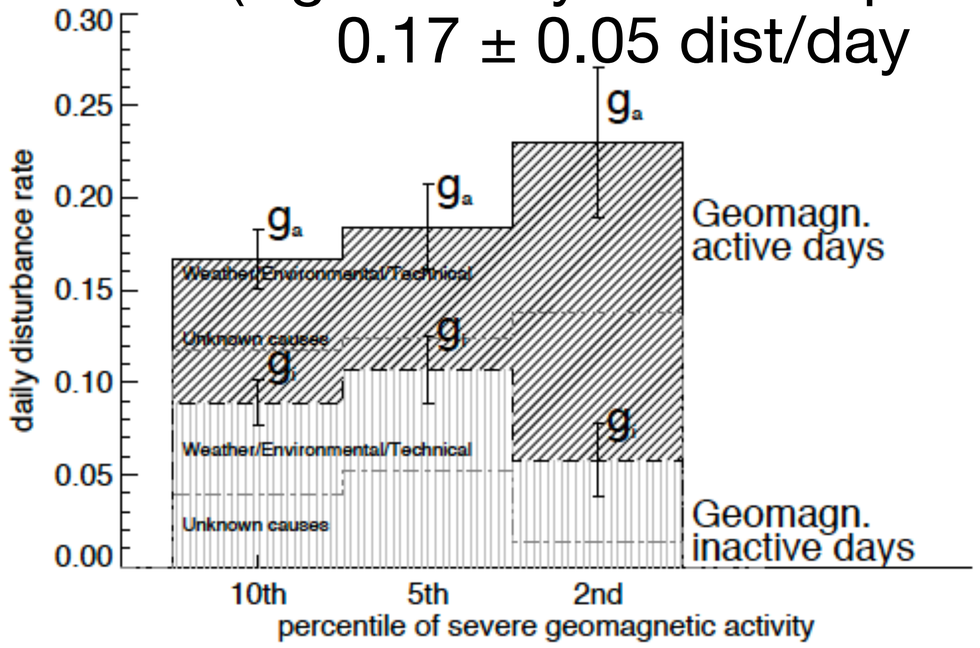
(peaks do not align)



but it contributes to their stress

(significantly more frequent)

0.17 ± 0.05 dist/day



Schrijver & Mitchell, 2013

Trees

Article | OPEN | Published: 28 August 2018

Solar superstorm of AD 774 recorded subannually by Arctic tree rings

J. Uusitalo, L. Arppe, T. Hackman, S. Helama, G. Kovaltsov, K. Mielikäinen, H. Mäkinen, P. Nöjd, V. Palonen, I. Usoskin & M. Oinonen

Nature Communications **9**, Article number: 3495 (2018) | Download Citation

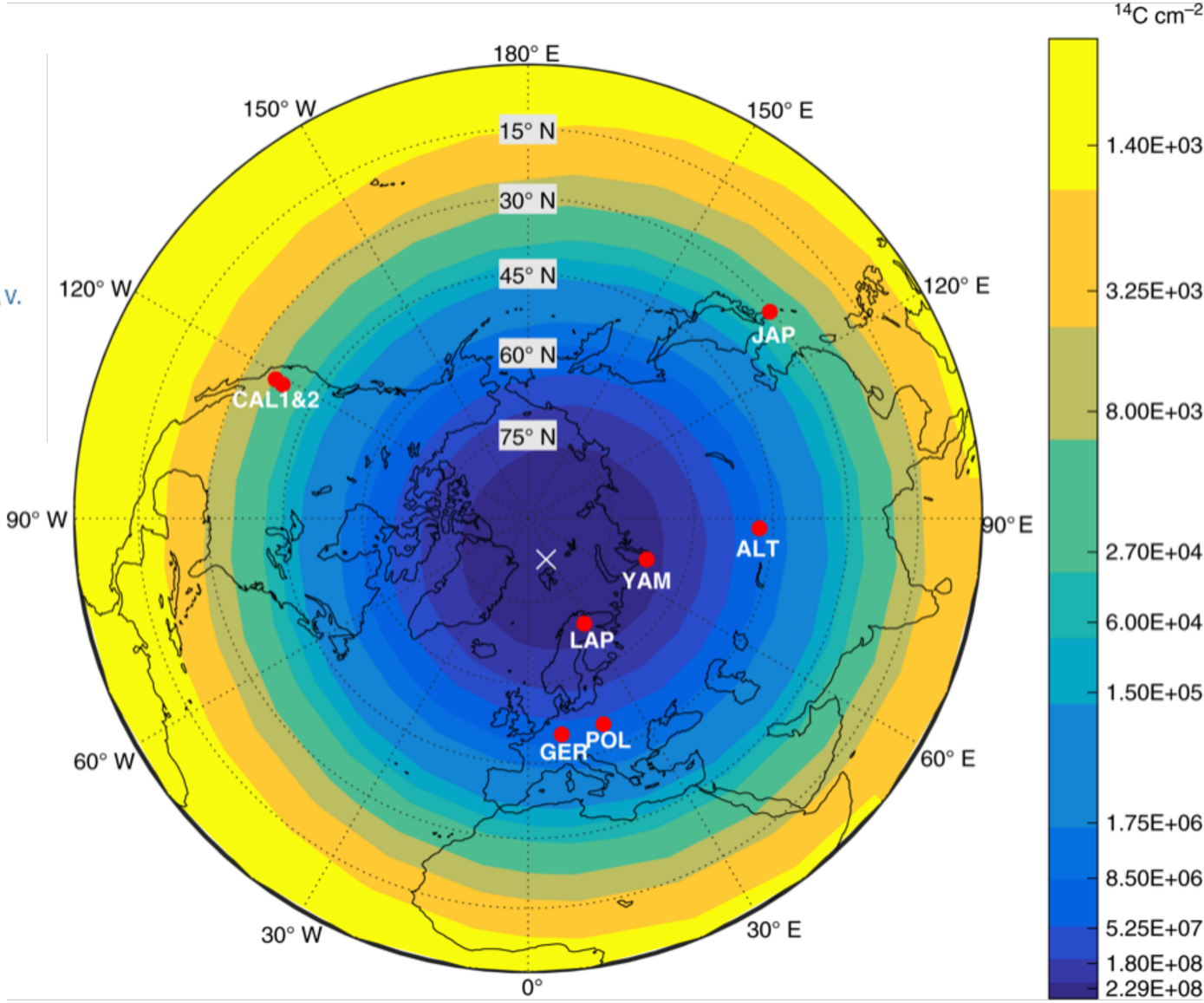
Shanxi Province, China in AD770 (twice), AD773, and AD775.

England "red cross" in the sky dated AD773/774 in different manuscripts of the Anglo-Saxon Chronicle

Germany "inflamed shields" in the sky, AD776

Ireland "fire from heaven", AD772

Germany apparition interpreted by Christians as riders on white horses AD773

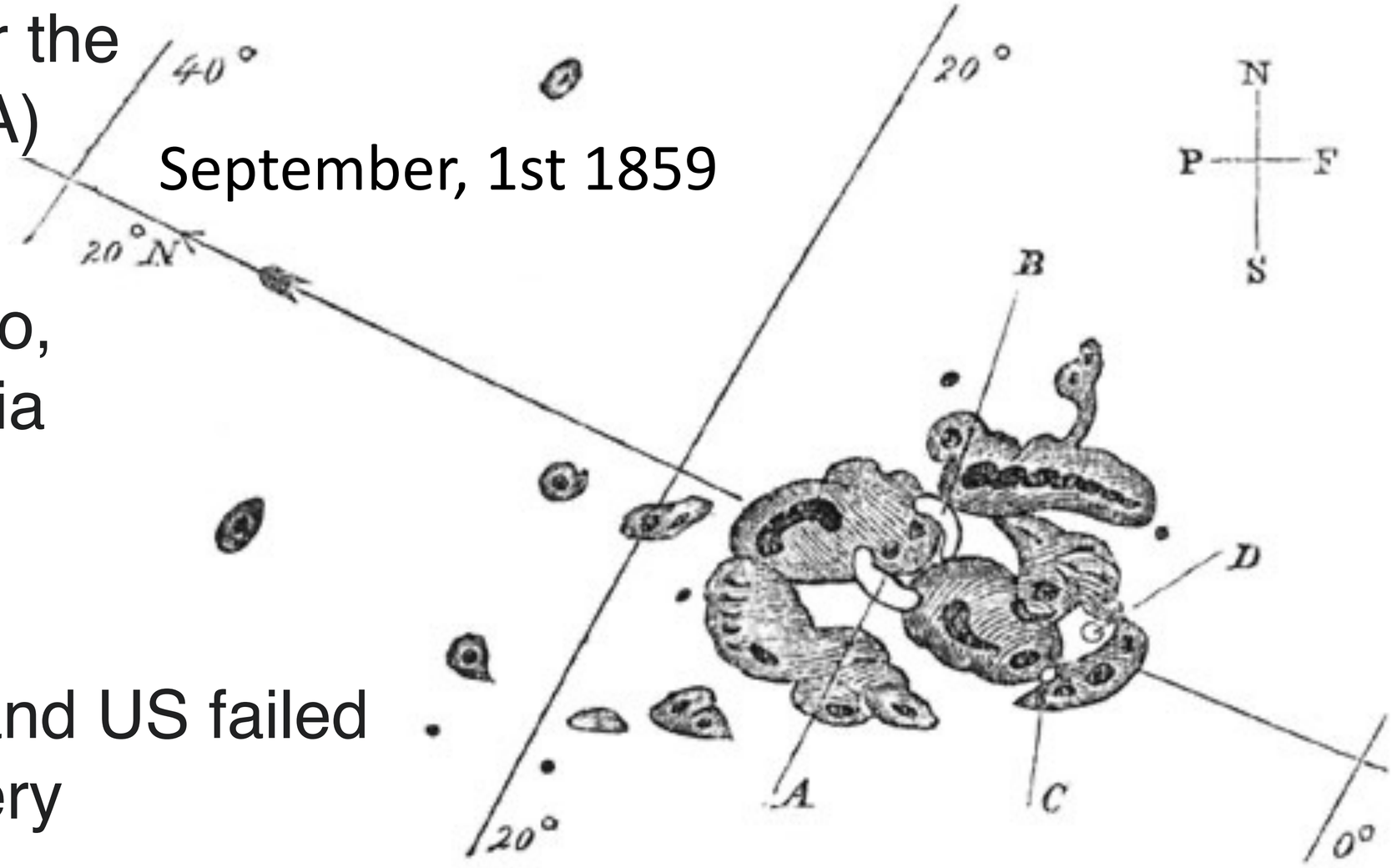


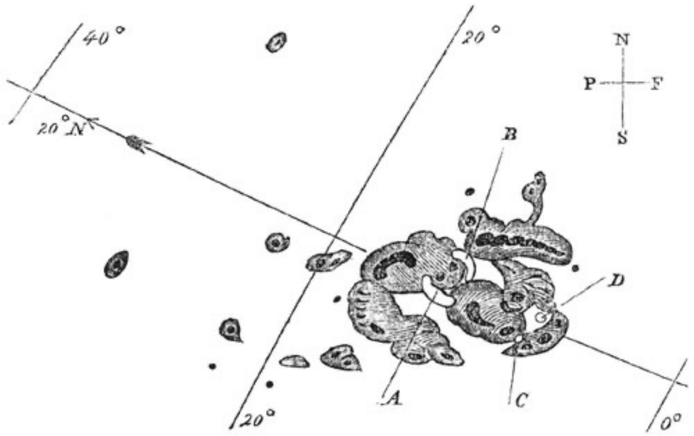
Carrington Event

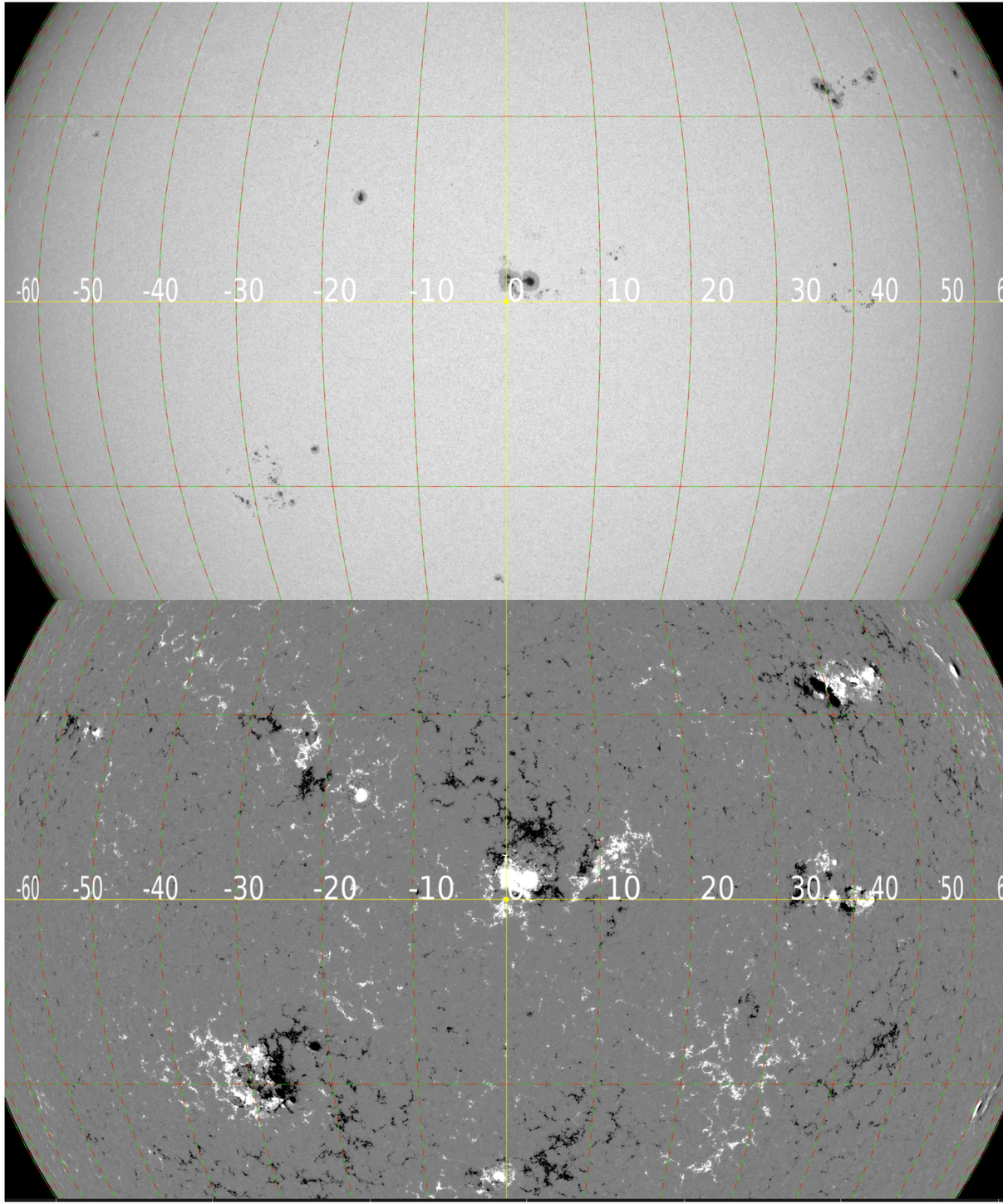
Very bright aurora over the Rocky Mountains (USA)

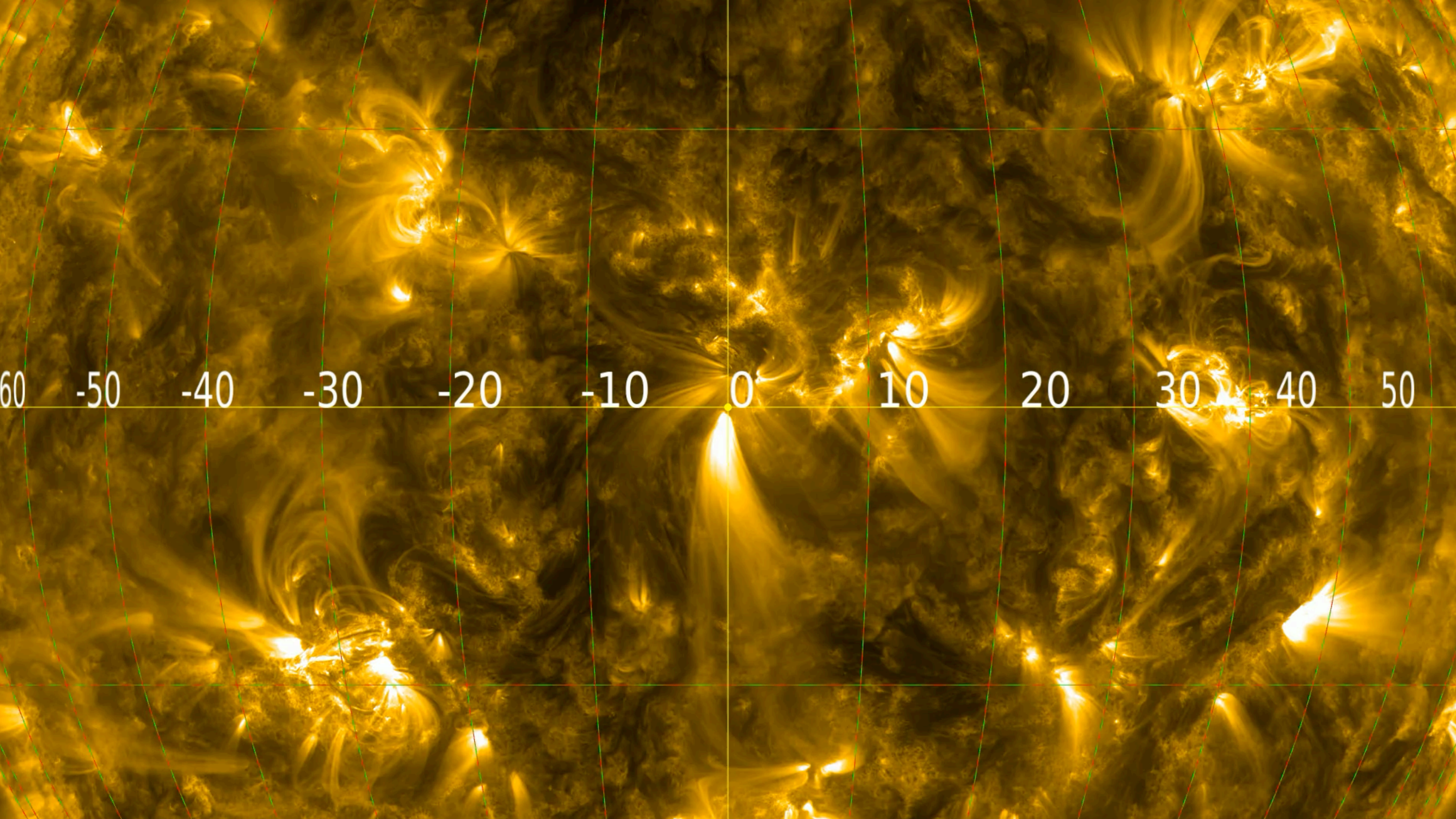
Aurora visible in Mexico, Cuba, Hawaii, Colombia

Telegraphs in Europe and US failed or worked without battery




40°
20°
20° N
N
P
F
S
B
D
A
C
20°
0°


-60 -50 -40 -30 -20 -10 0 10 20 30 40 50
-60 -50 -40 -30 -20 -10 0 10 20 30 40 50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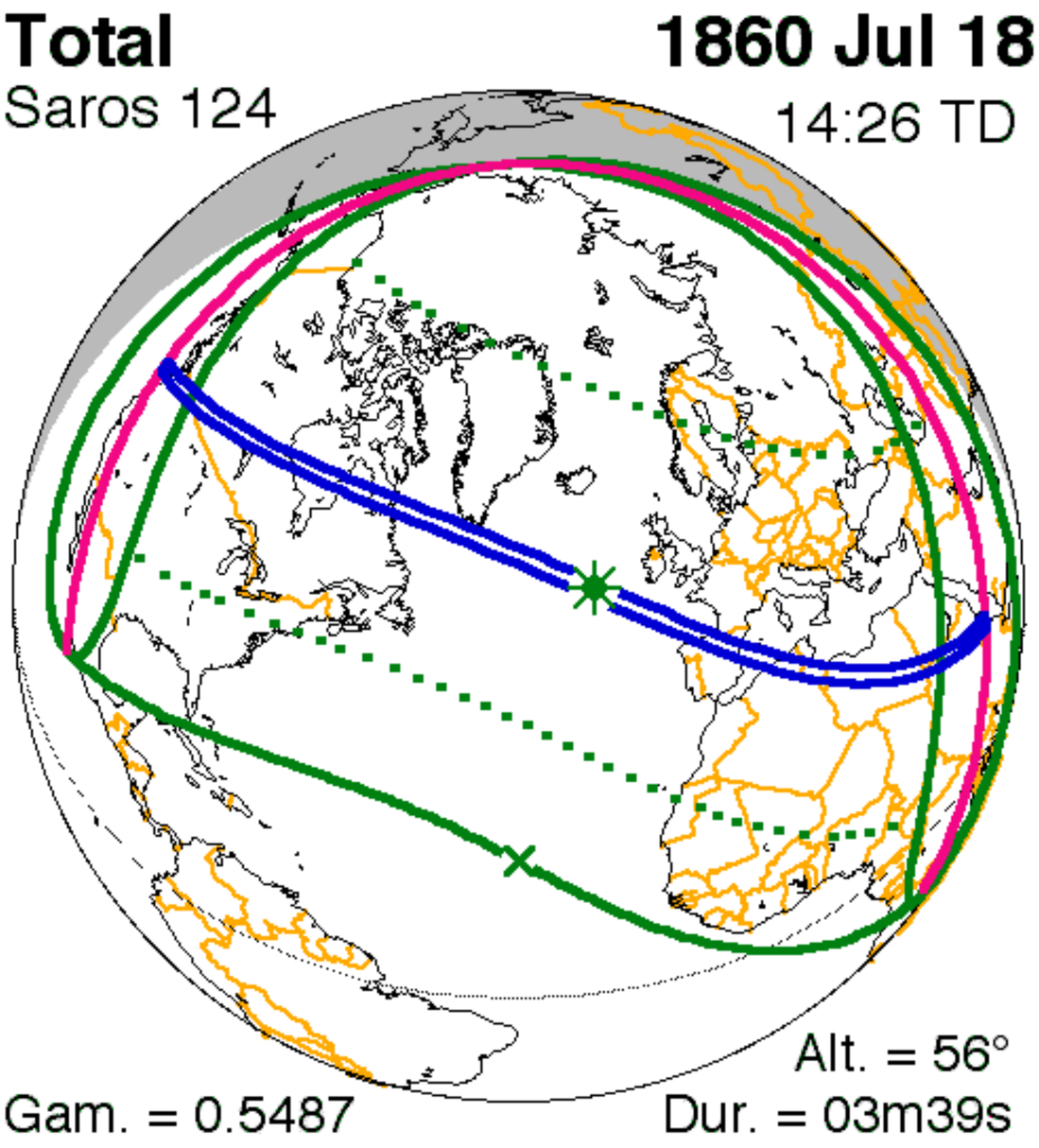
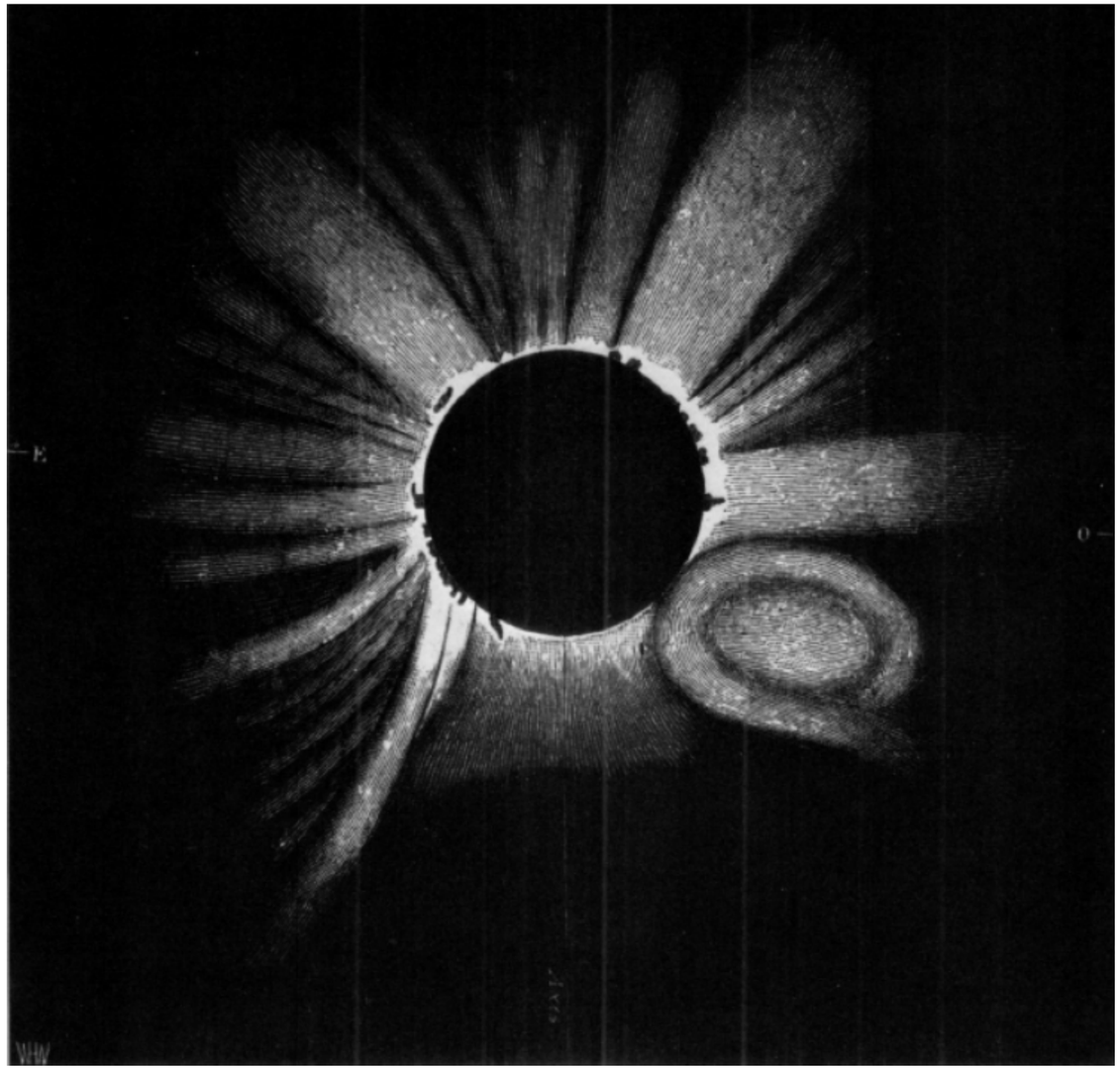
First observations of a CME 18 July 1860





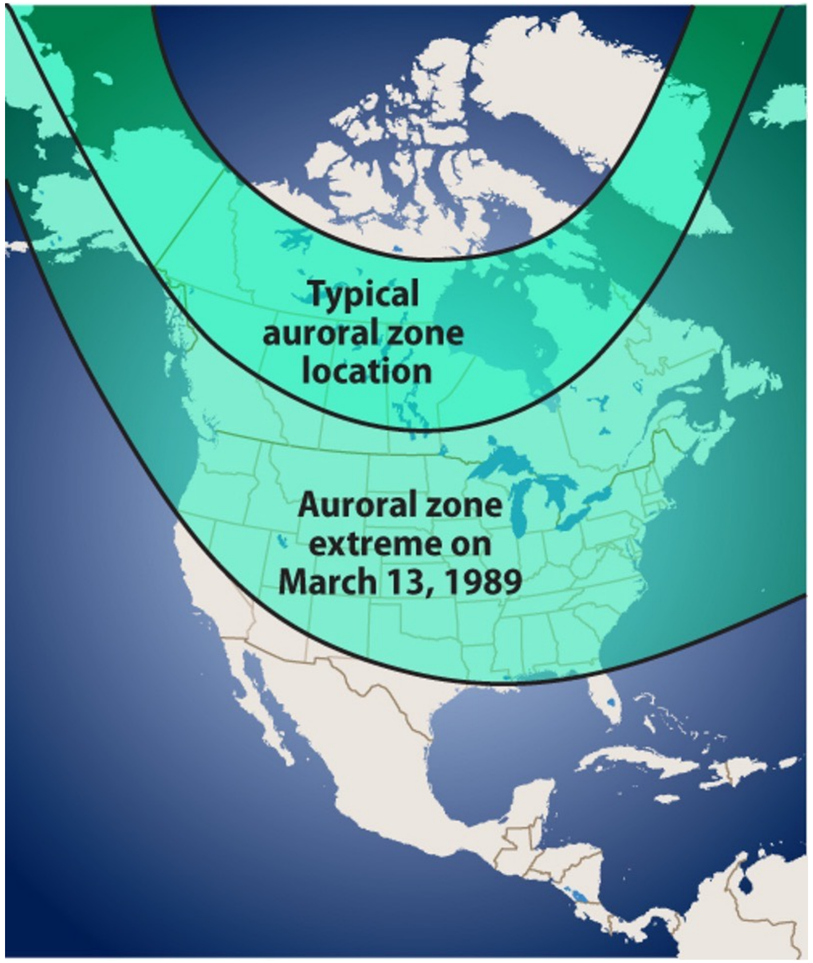
Quebec 1989

March, 10th and 12th CMEs

Electricity power grid failure (9 hours blackout)

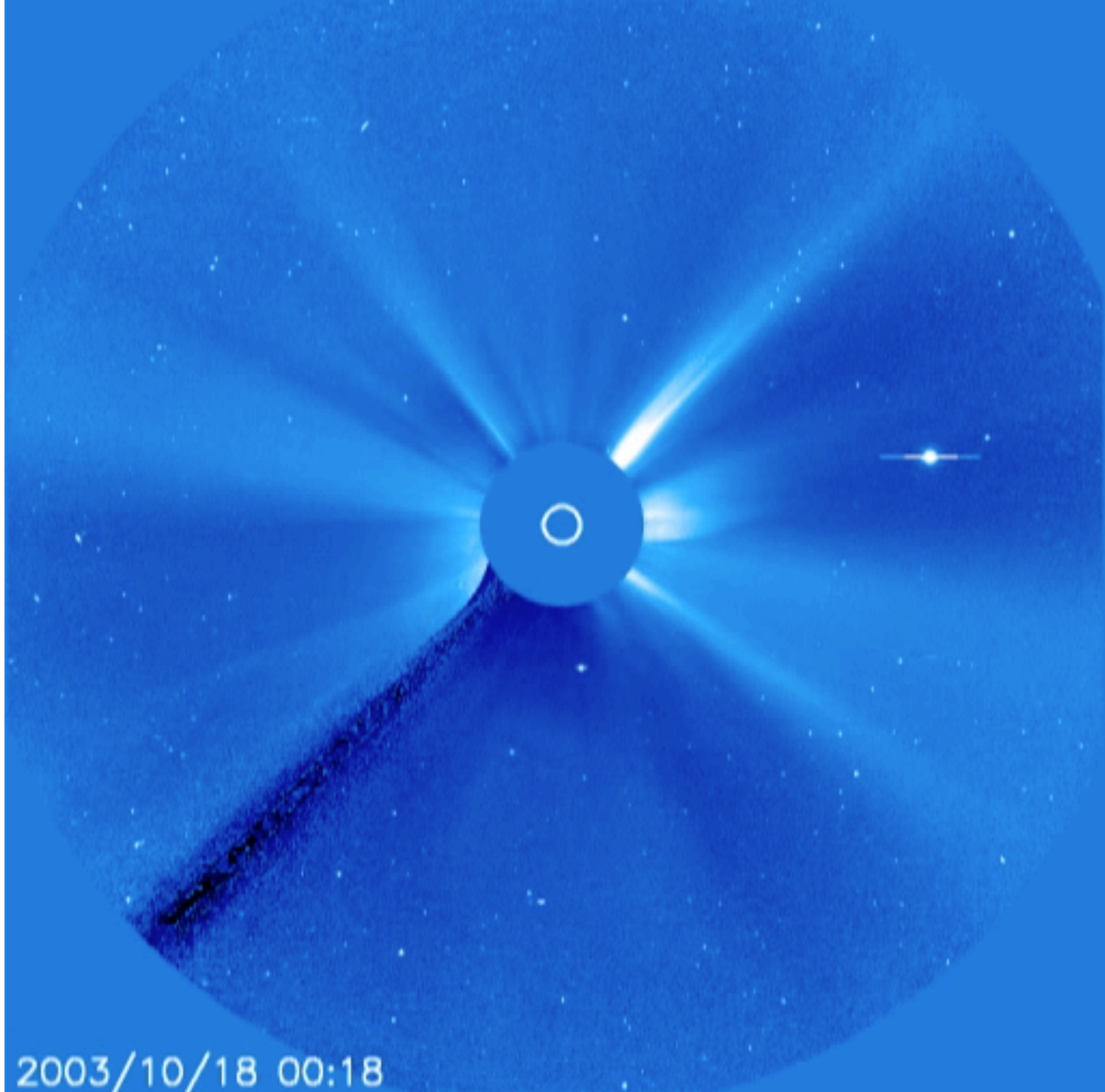
Aurora in Florida

Communications Blackout



Halloween Event 2003

17 flares in 2 weeks



Halloween Event 2003

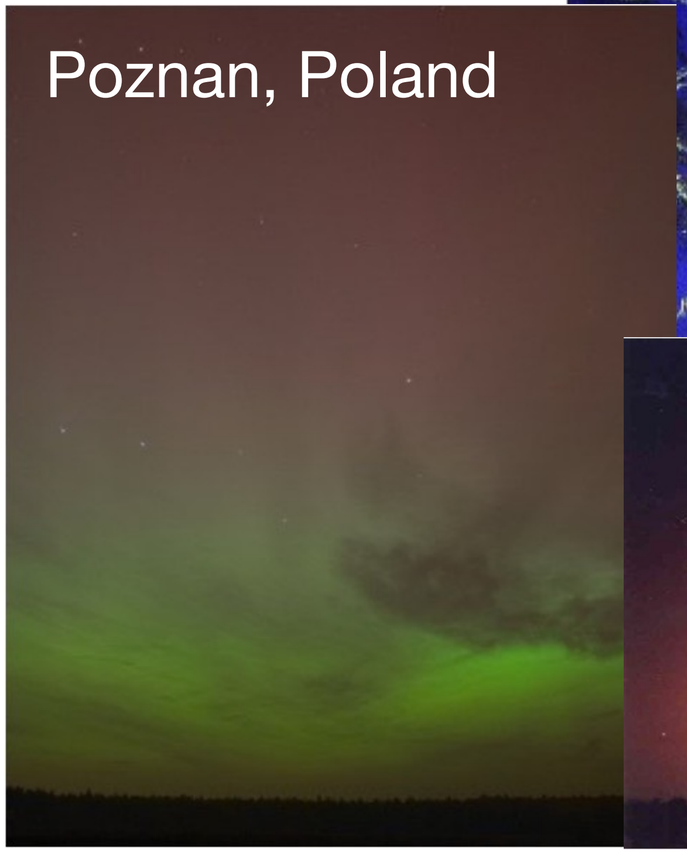
Ulysses at Jupiter and *Cassini at* Saturn detected emissions

Damages to South Africa's power supply (15 large transformers)

Two transformers in England

Power outage in Sweden for one hour

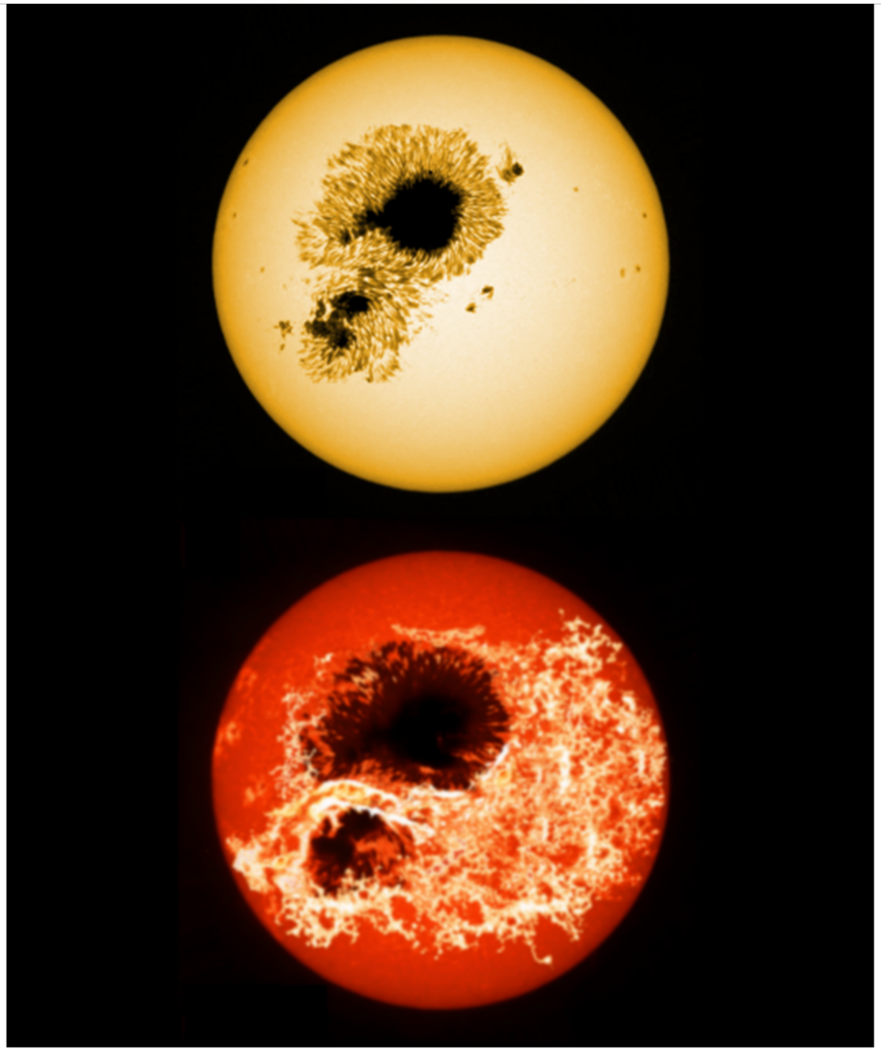
Aircrafts re-routed

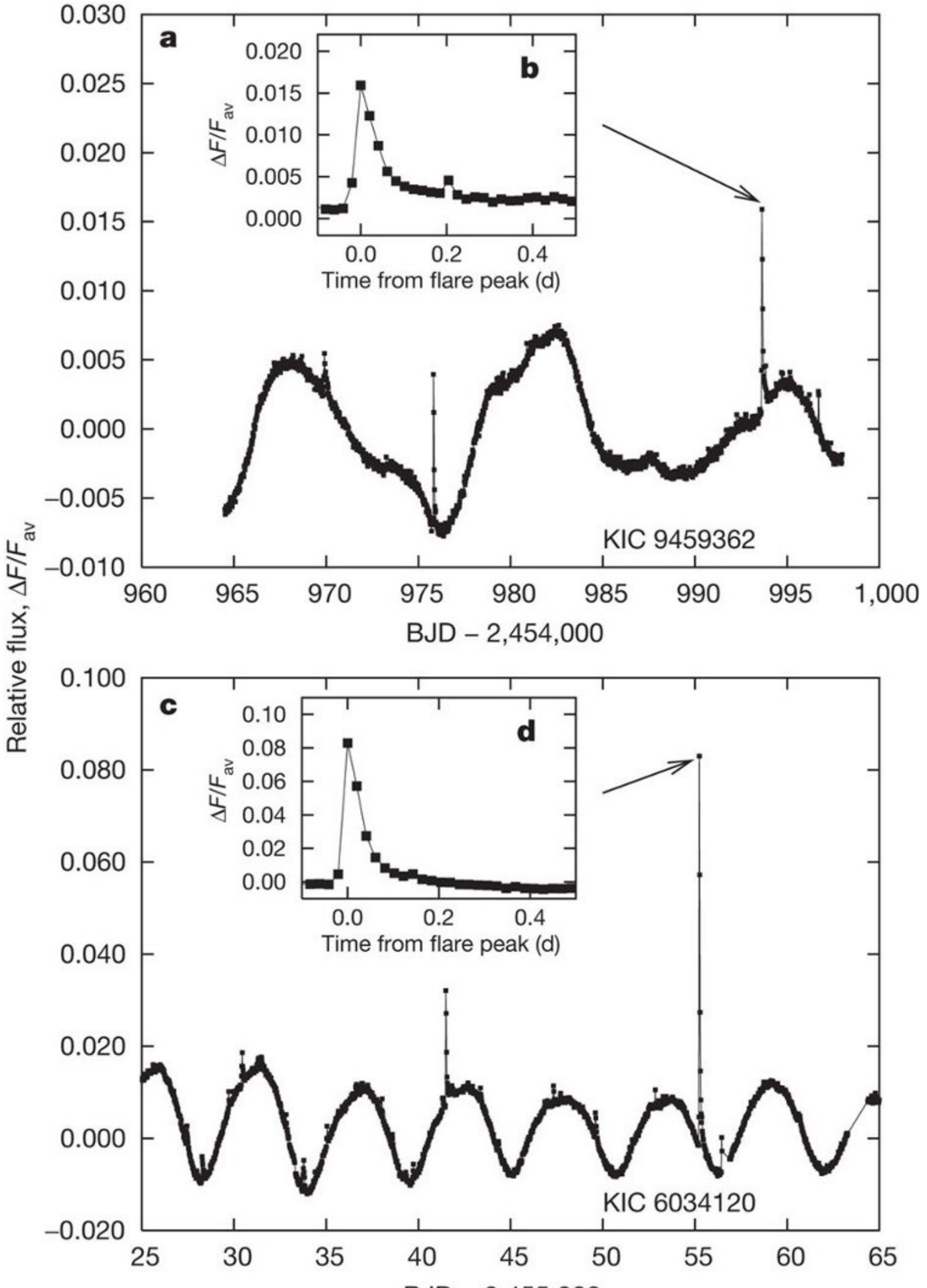


Superflares on solar-type stars

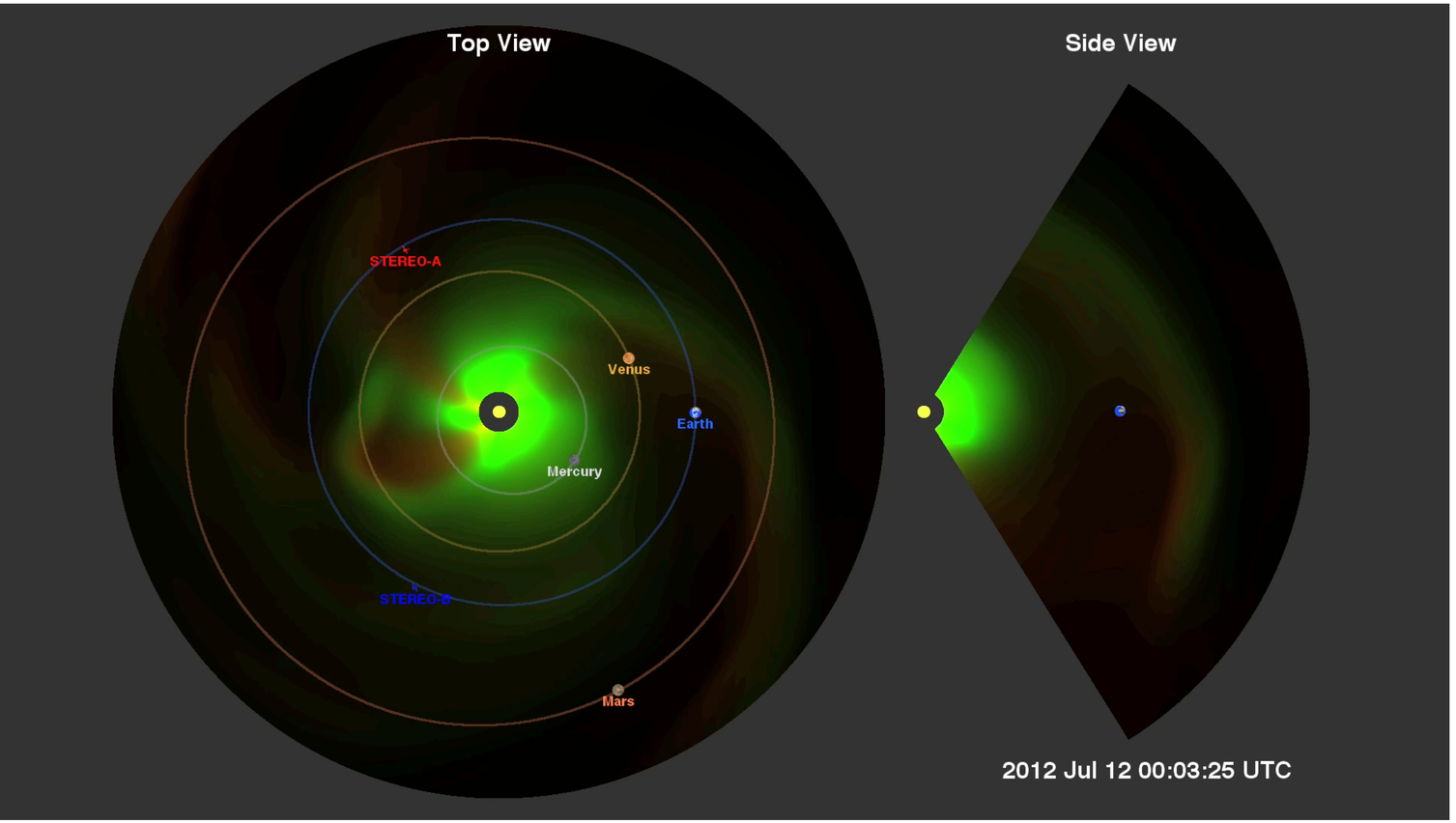
Hiroyuki Maehara ✉, Takuya Shibayama, Shota Notsu, Yuta Notsu, Takashi Nagao, Satoshi Kusaba, Satoshi Honda, Daisaku Nogami & Kazunari Shibata

Nature **485**, 478–481 (24 May 2012) | Download Citation ⬇





Space Weather forecasting



Space Weather News (Dr Tamitha Skov)