Space weather sensor systems using radio spectrum

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Content

1 Brief introduction of Space Weather phenomena

2 Societal impacts of Space Weather storms

3 Monitoring Space Weather with Radio

4 Conclusions

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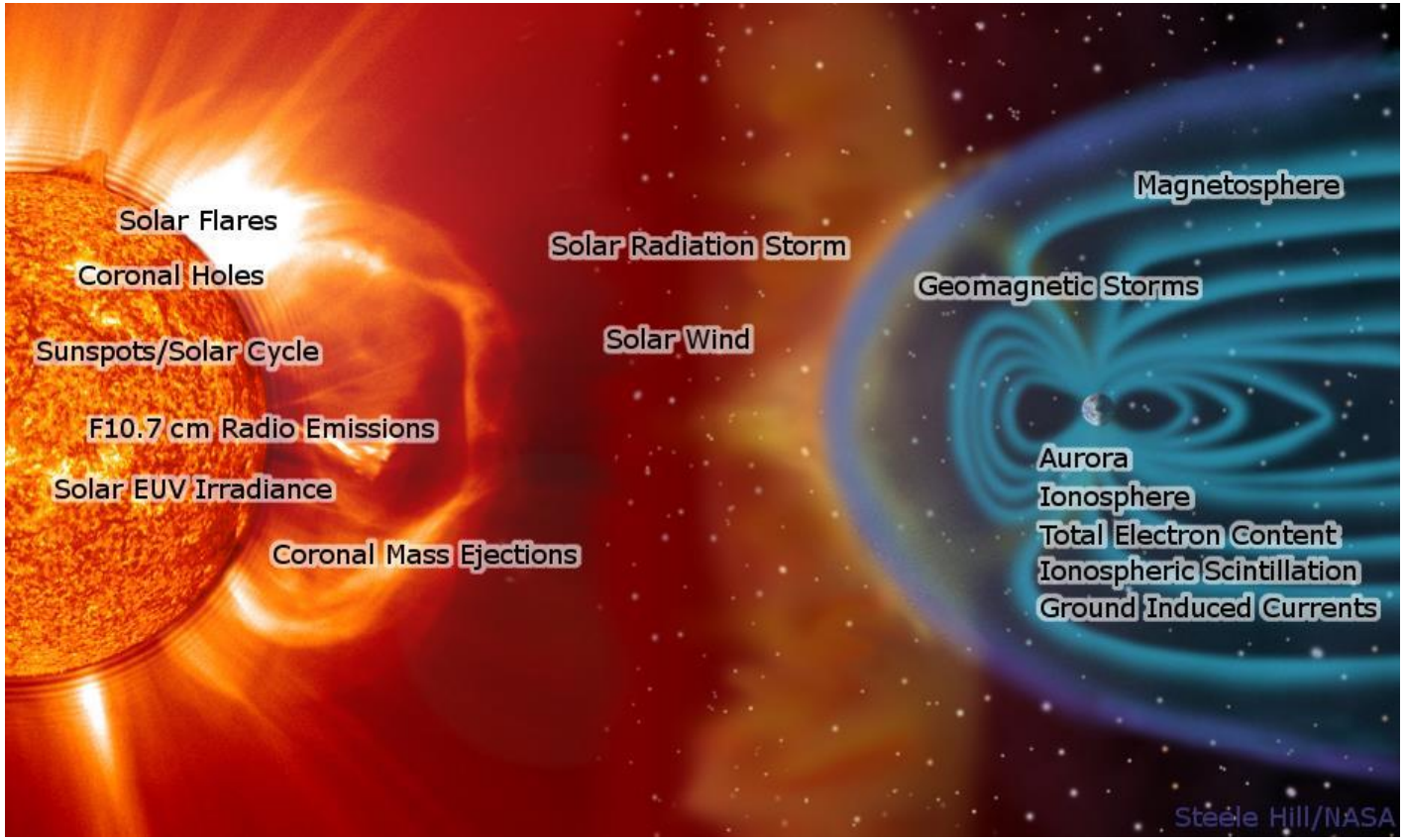
Space weather is a chain of events from Sun to Earth

Solar eruptions change the (near-Earth) plasma environment, including the ionosphere



Source: Report ITU-R RS.2456-1, Figure 1. Credit: Steele Hill/NASA

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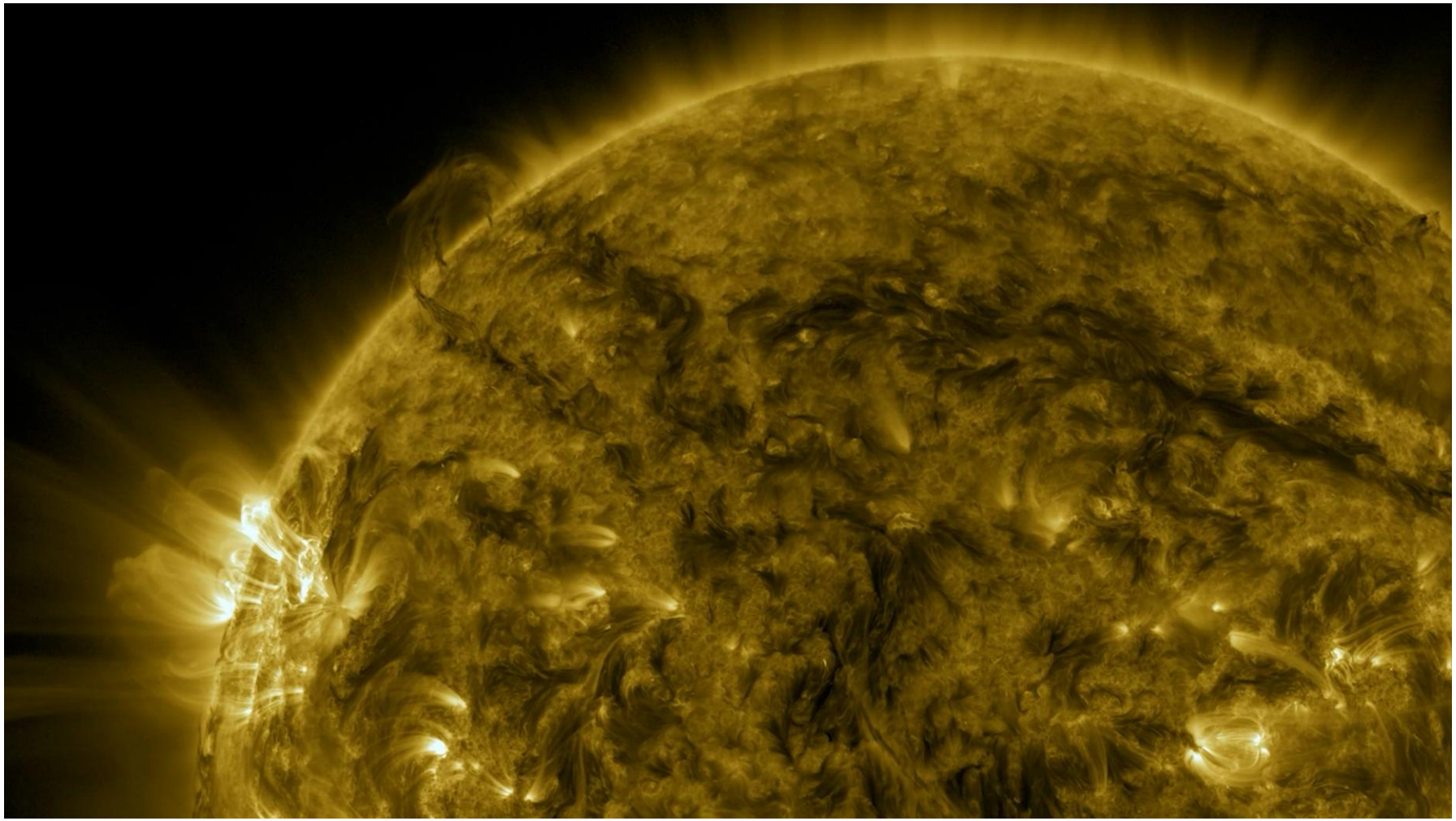
Space weather starts on the Sun



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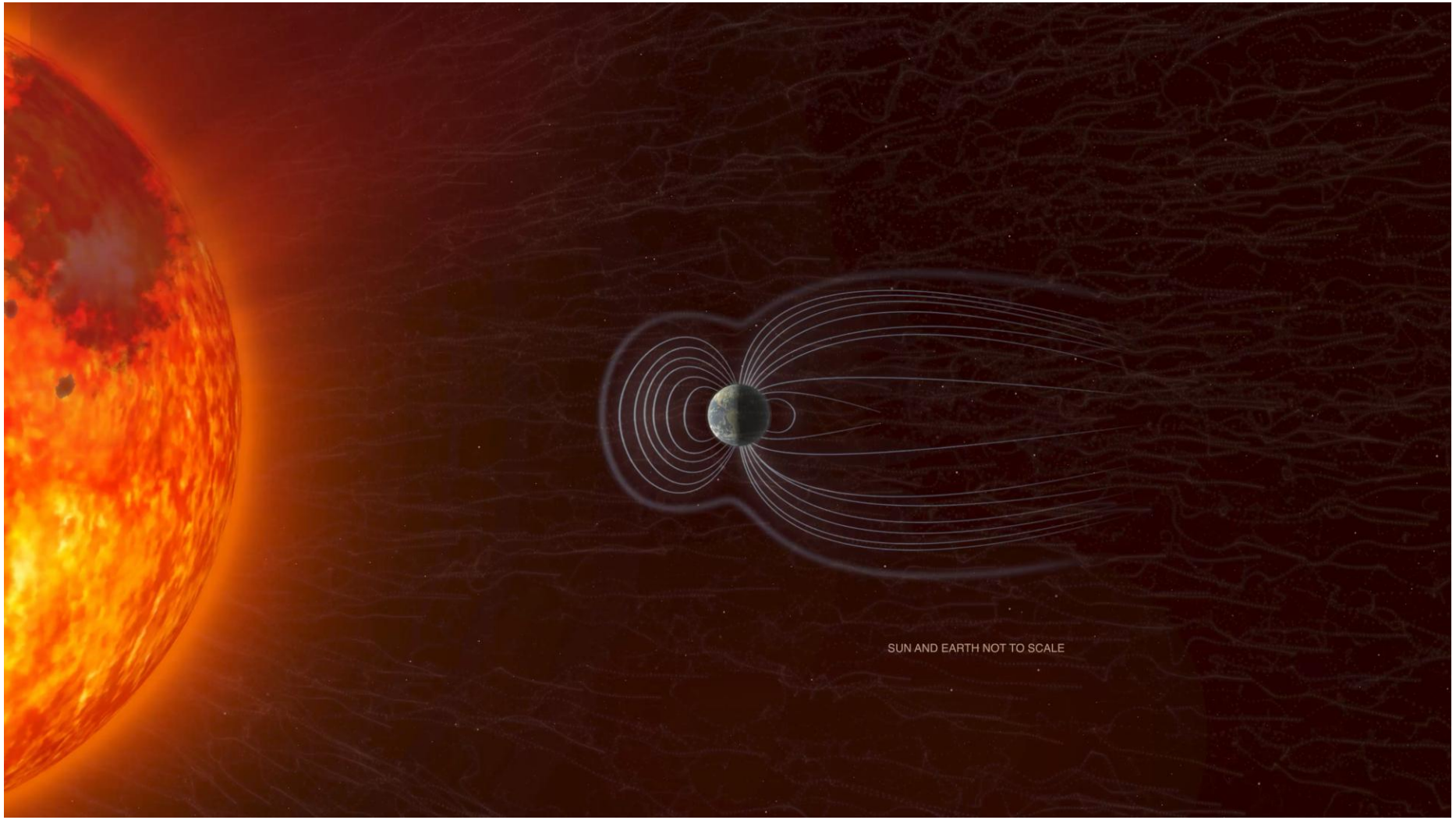
Source: NASA Goddard Space Flight Center

Solar activity affects the (near-Earth) plasma environment



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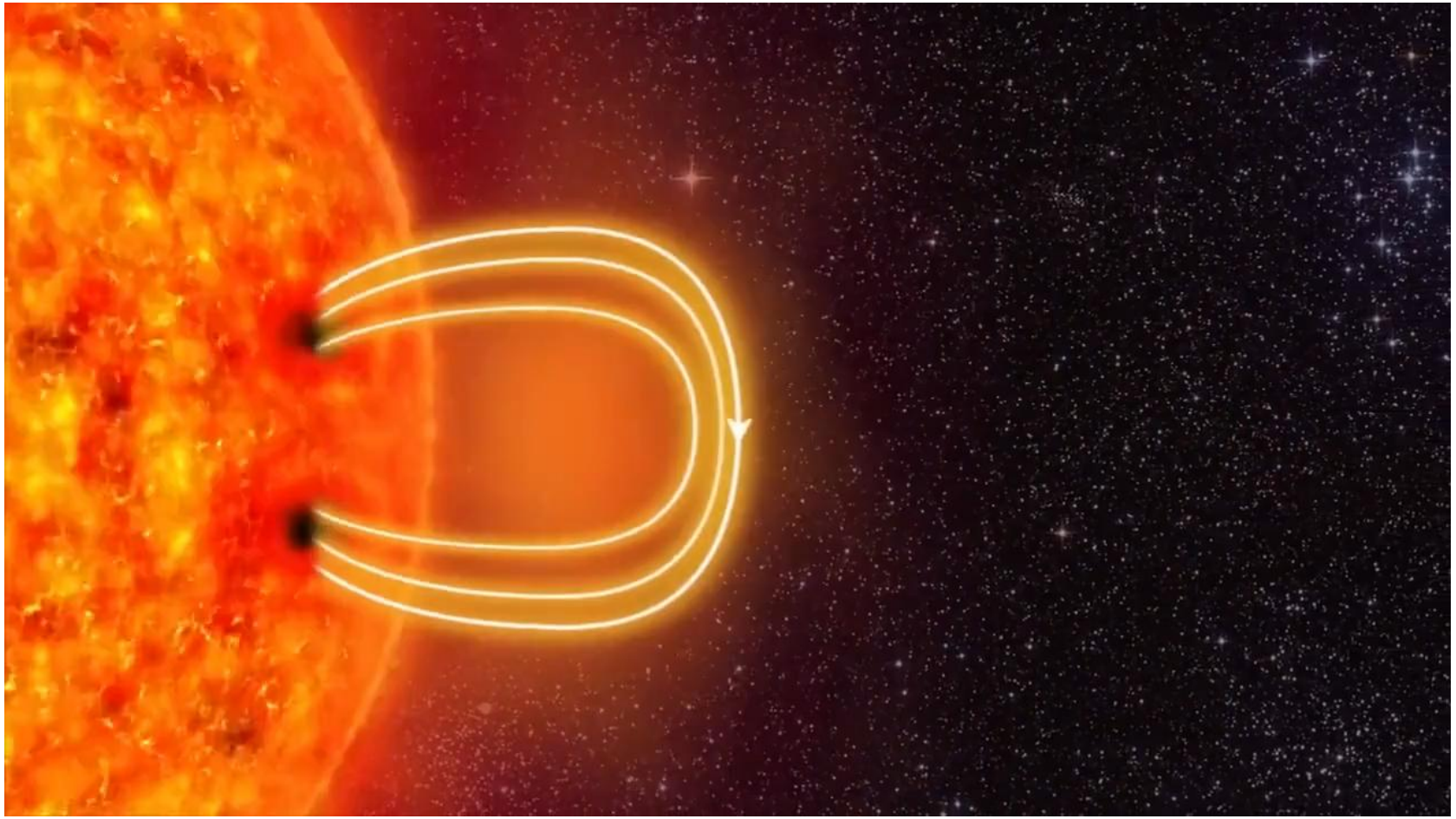
Source: NASA Goddard/CIL/Bailee DesRocher

Coronal mass ejections are the main drivers of severe geomagnetic storms



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Source: NASA Goddard/CIL/Bailee DesRocher

A sequence of events

ONE SOLAR ERUPTION, MULTIPLE EFFECTS AND TIMING

FLARE

X-ray emission

Sudden Ionospheric Disturbance/Communication Outages

FLARE AND CME

Solar radio bursts

Radio Frequency Interference

FLARE AND CME

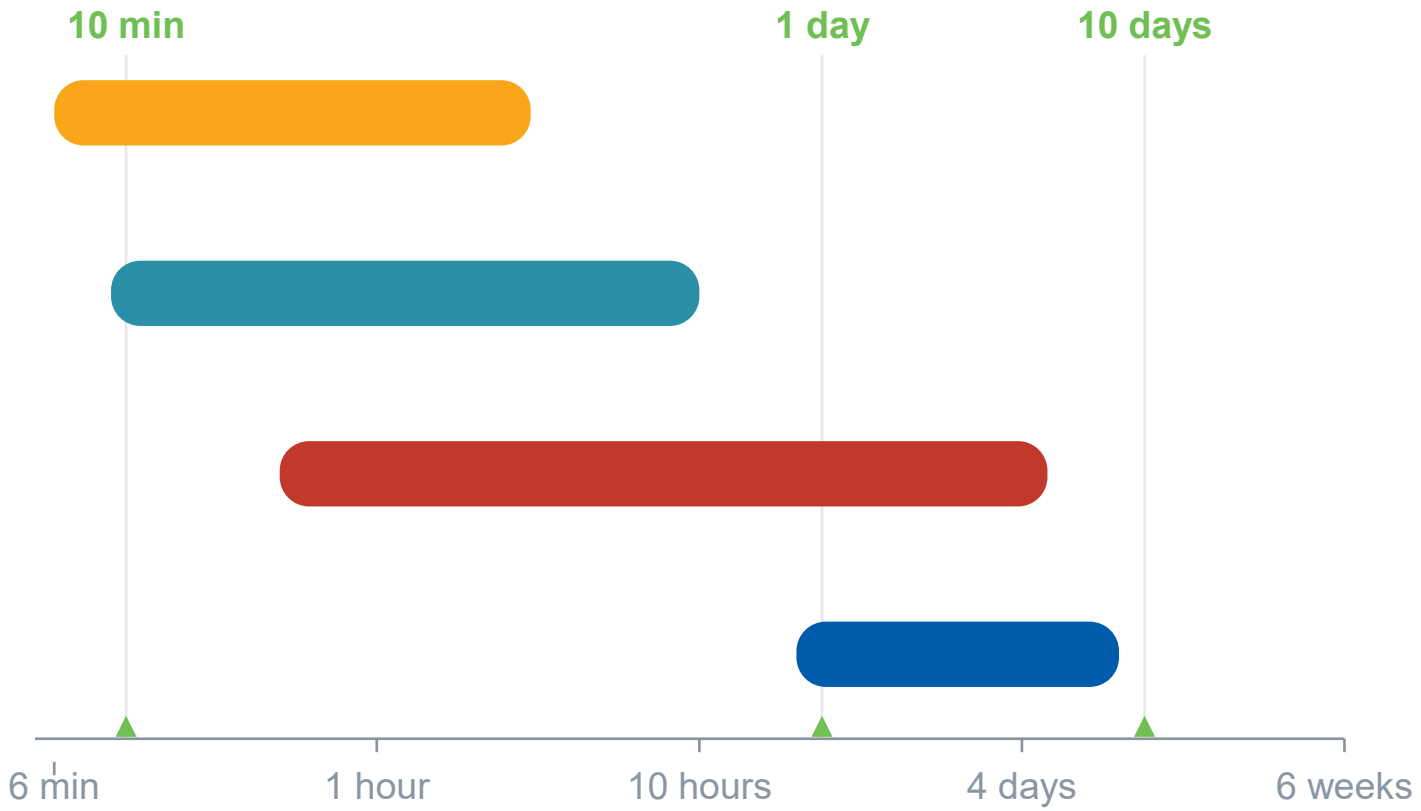
Solar proton event

Polar Cap Absorption/Communication Outages

CME

Geomagnetic and ionospheric storm

Communication Outages/Scintillations



time after the eruption, logarithmic scale

Adapted from Air Force Research Laboratory

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The effects of space weather

Satellites

CMES · PARTICLES

- Increased drag
- Radiation damages electronics

Navigation and timing

FLARES · CMES

- GNSS positions become less accurate
- Signal can temporarily be lost
- Timing services can be disrupted

Aviation

ALL THREE DRIVERS

- Radio communicaton can be lost
- Navigation becomes less reliable
- Higher radiation exposure on some routes

Radio communication

FLARES · PARTICLES

- Long-distance radio outage
- Disruptions lasting minutes to hours
- Polar regions can be affected for longer

Power grids

CMES

- Extra currents enter power networks
- Transformers can overheat
- In extreme cases: power outages

Pipelines and railways

CMES

- Corrosion in pipelines
- False signals on railways.

One storm, many different systems

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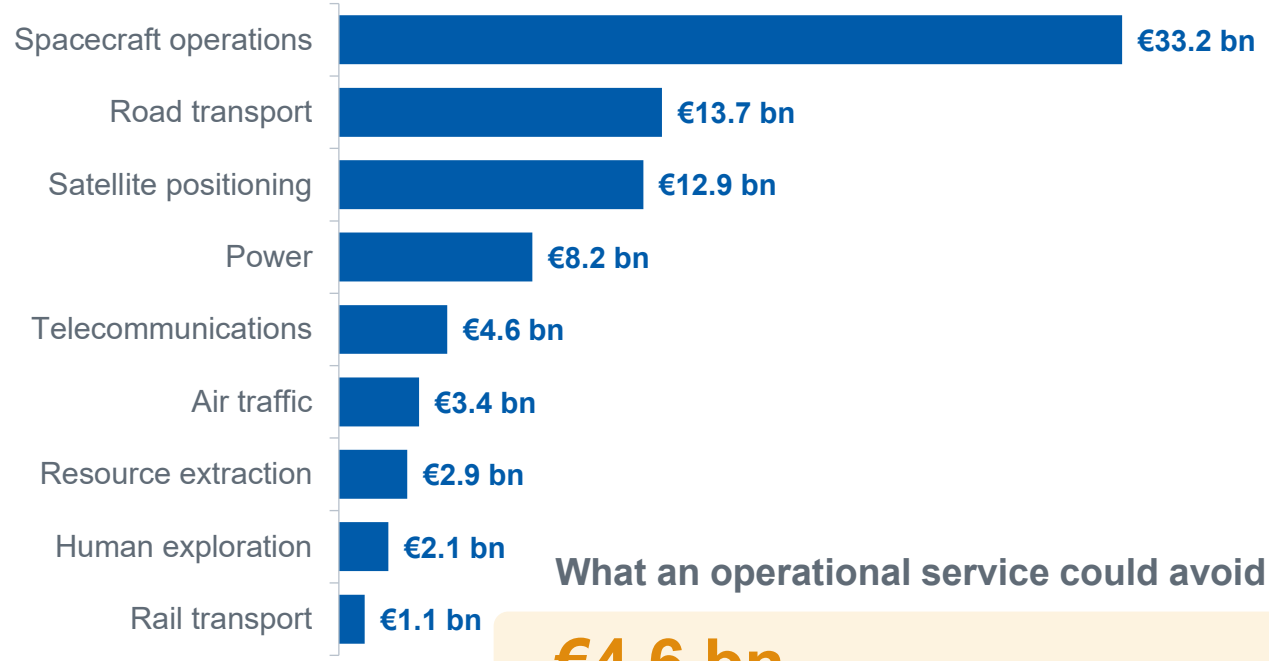
One extreme event (once-in-century): EU and US estimates

Modelled scenario: a single extreme solar storm affecting the EU, reference year 2040

What one extreme event could cost the EU



What an operational service could avoid

€4.6 bn	Power
€11.5 bn	Spacecraft operations
€10 bn	Satellite positioning

Modelled scenario: a single extreme solar storm affecting US, focus in power transmission

- 3.5 Million people and 91 000 businesses are predicted to lose power
- Daily economic losses 1.22 billion dollars →
- One week ~8.5 billion dollars

Sources: ESA and European Commission, "The Impact of Space Weather on the EU" (2026) & Sidder, A., (2026), The economic costs of solar storms, EOS, 107, https://doi.org/10.1029/2026EO260258

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Radio spectrum has two roles in space weather

WHAT SPACE WEATHER DISTURBS

- **HF radio**
  increased absorption or unexpected reflection in the ionosphere; long-distance and polar links fail
- **GNSS**
  signals are delayed and distorted; positioning degrades
- **Satellite links and radar**
  radio bursts can interfere with radio receivers

Radio is both affected by space weather and essential for observing it.

WHAT WE USE TO WATCH IT

At the Sun

Solar flux monitors – F10.7 and F30 indices of solar activity used in upper-atmosphere models

Solar radio spectrographs — detect radio bursts associated with solar activity and particle acceleration

Radioheliographs — image solar radio emission

Interplanetary scintillation — tracks solar wind disturbances

In the upper atmosphere

Riometers — monitor radio-wave absorption

Ionospheric tomography — 3D information of electron density

RNSS — total electron content and scintillation measurements

Ionosondes — monitor ionospheric conditions relevant to HF propagation

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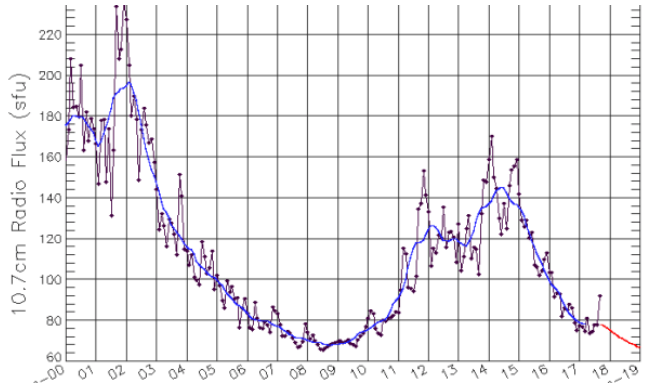
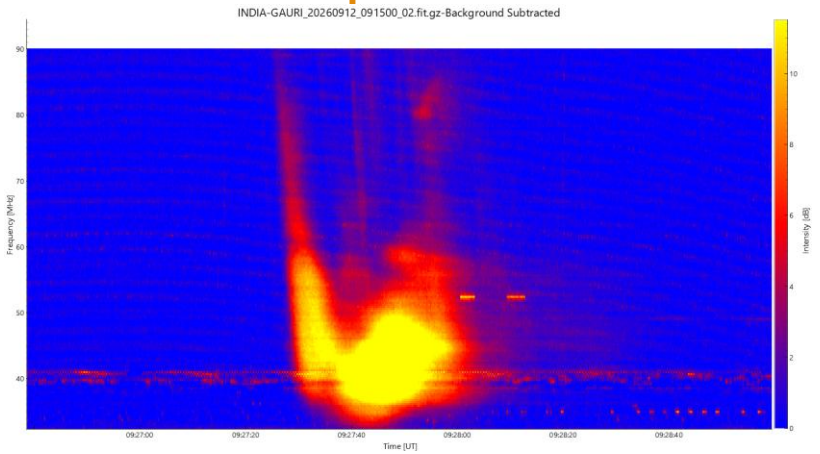
Radio observations of the Sun

Solar radio flux



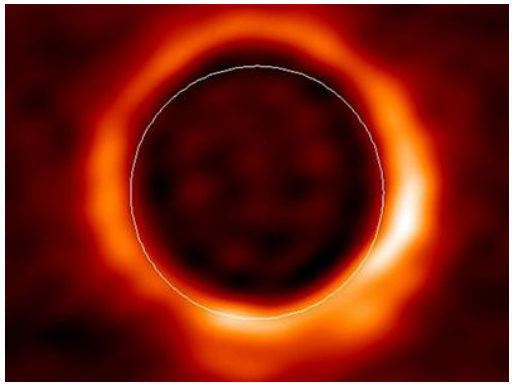
Dominion Radio Astrophysical Observatory
National Research Council Canada
Penticton, Canada

Solar radio spectrometers



E-Callisto network
India, Station Gauri, 20260912, 09:15 UT

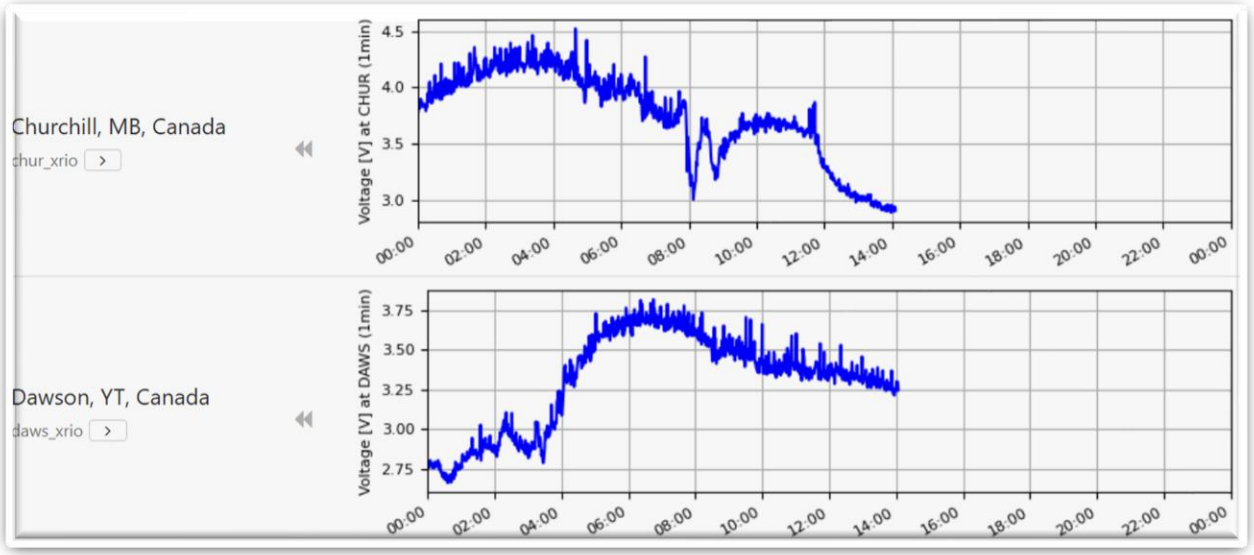
Radioheliograph



Nançay Radio Heliograph
Observatoire Radioastronomique de Nançay
Nançay, France

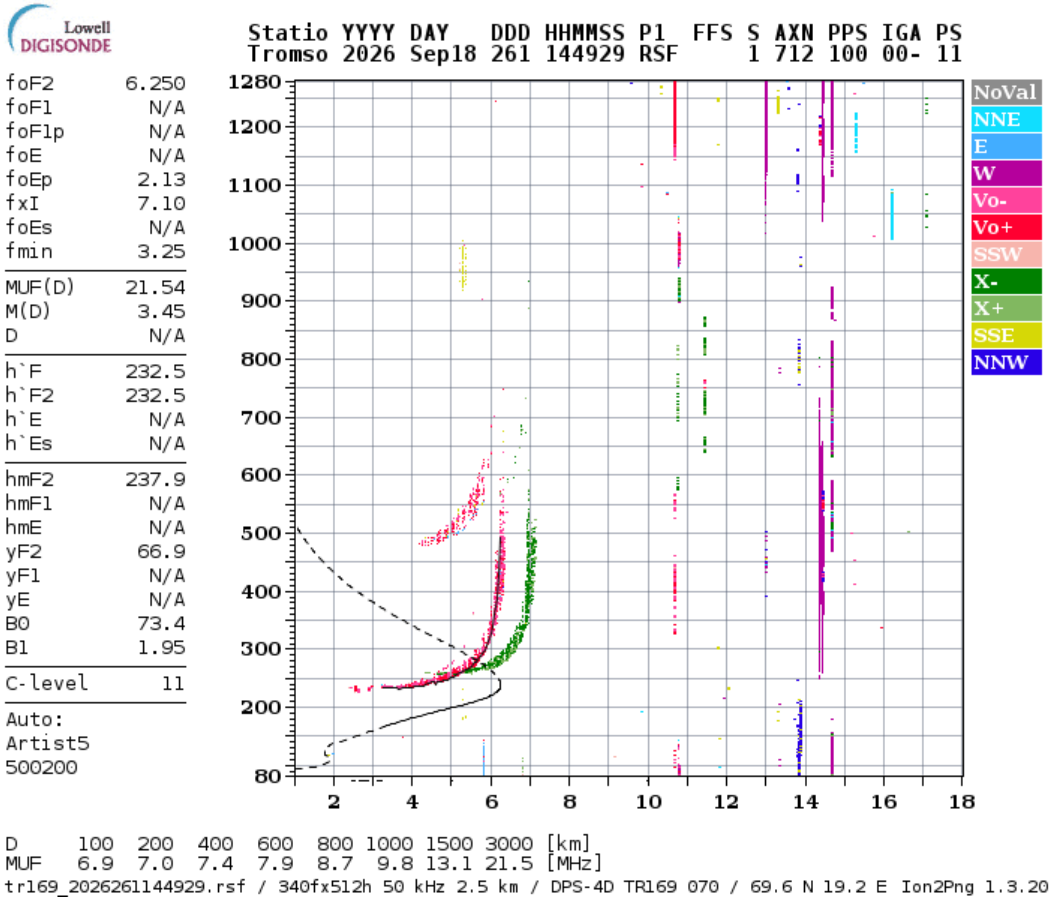
Radio observations of the upper atmosphere

Riometer



Data plots from the Canadian riometer network operated by Natural Resources Canada

Ionosonde



Ramfjordnorden ionosonde

Tromsö Geophysical Observatory, Norway

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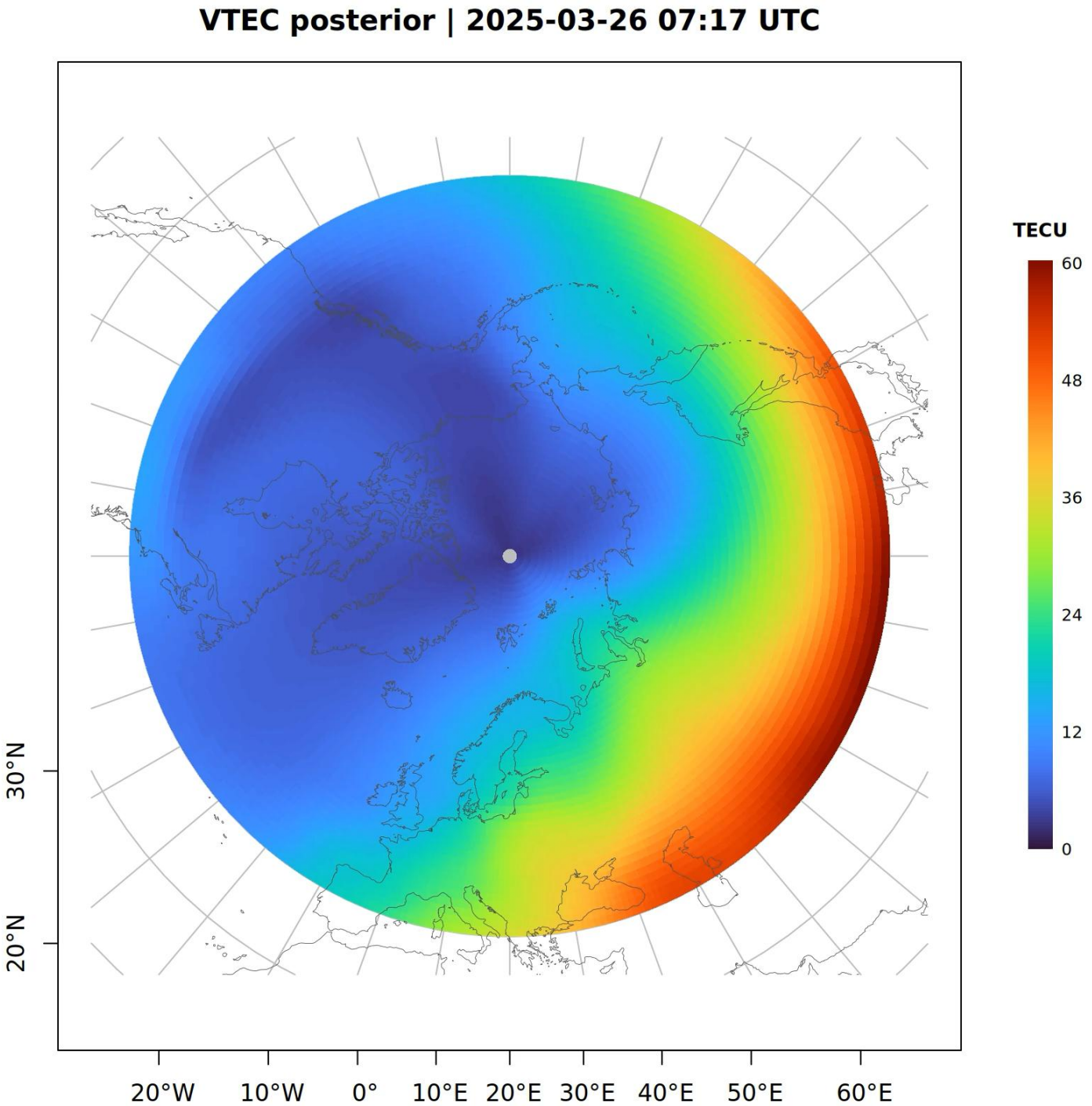
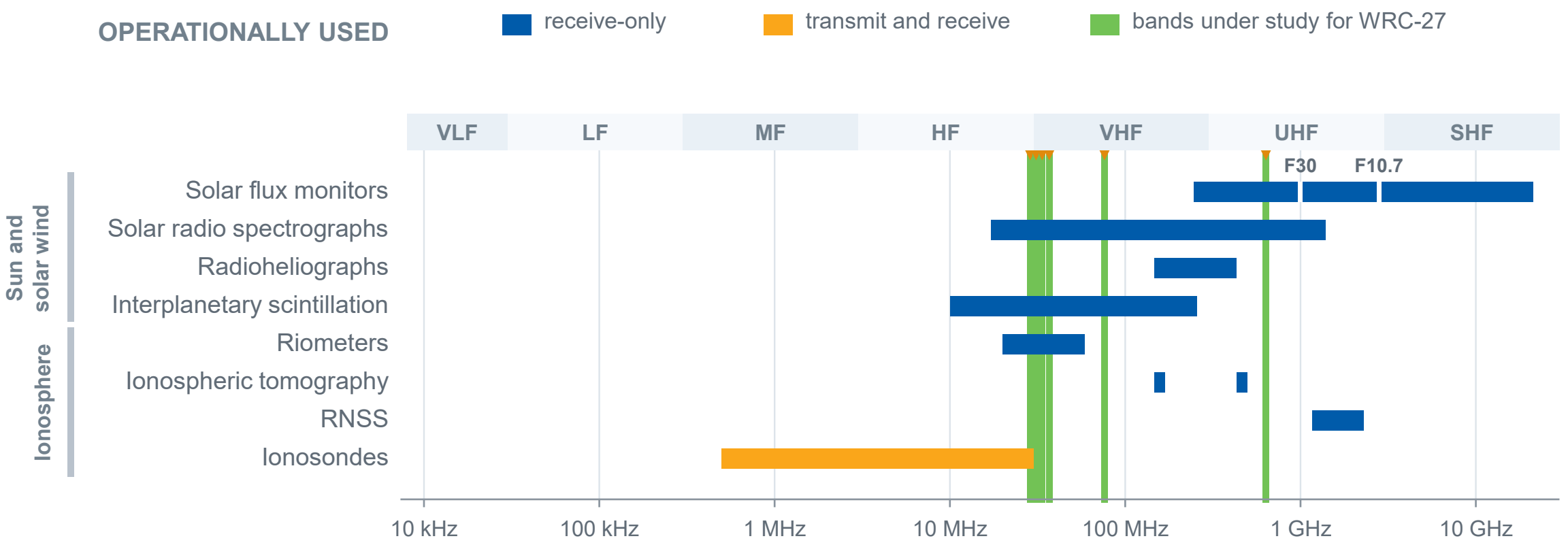
Probing ionosphere with the dense RNSS networks with some support by ionosondes



Animation: Johannes Norberg (Finnish Met Institute)
GNSS & Ionosonde data: Madrigal and GIRO services.

Space weather observation spans the spectrum



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Frequency ranges from Report ITU-R RS.2456-1; bands under study from Resolution 682 (WRC-23)

CALLISTO network: Solar radio spectrometers

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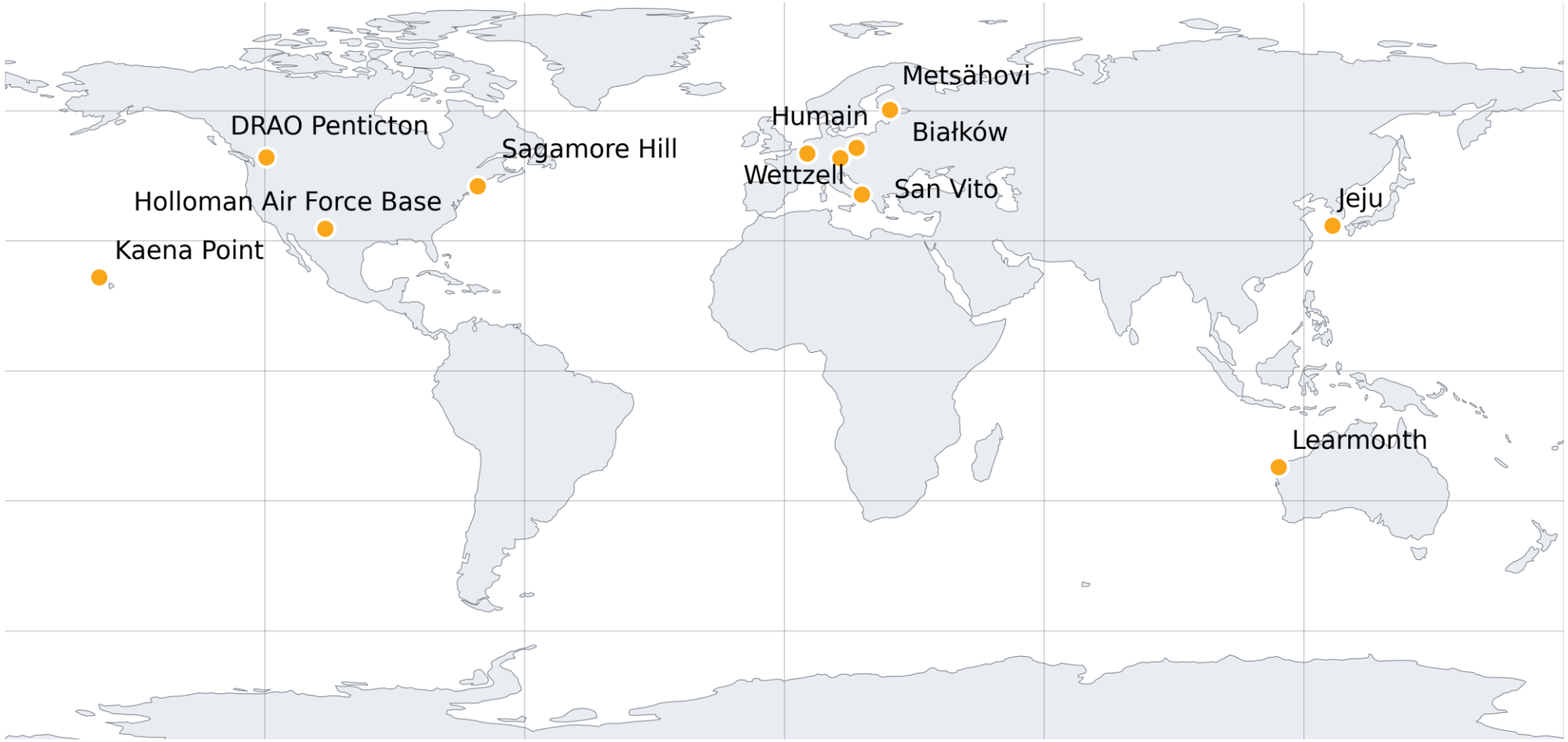
CALLISTO Data Status List, Version 10.5, 2026-08-26

Examples of 10.7 solar flux monitors



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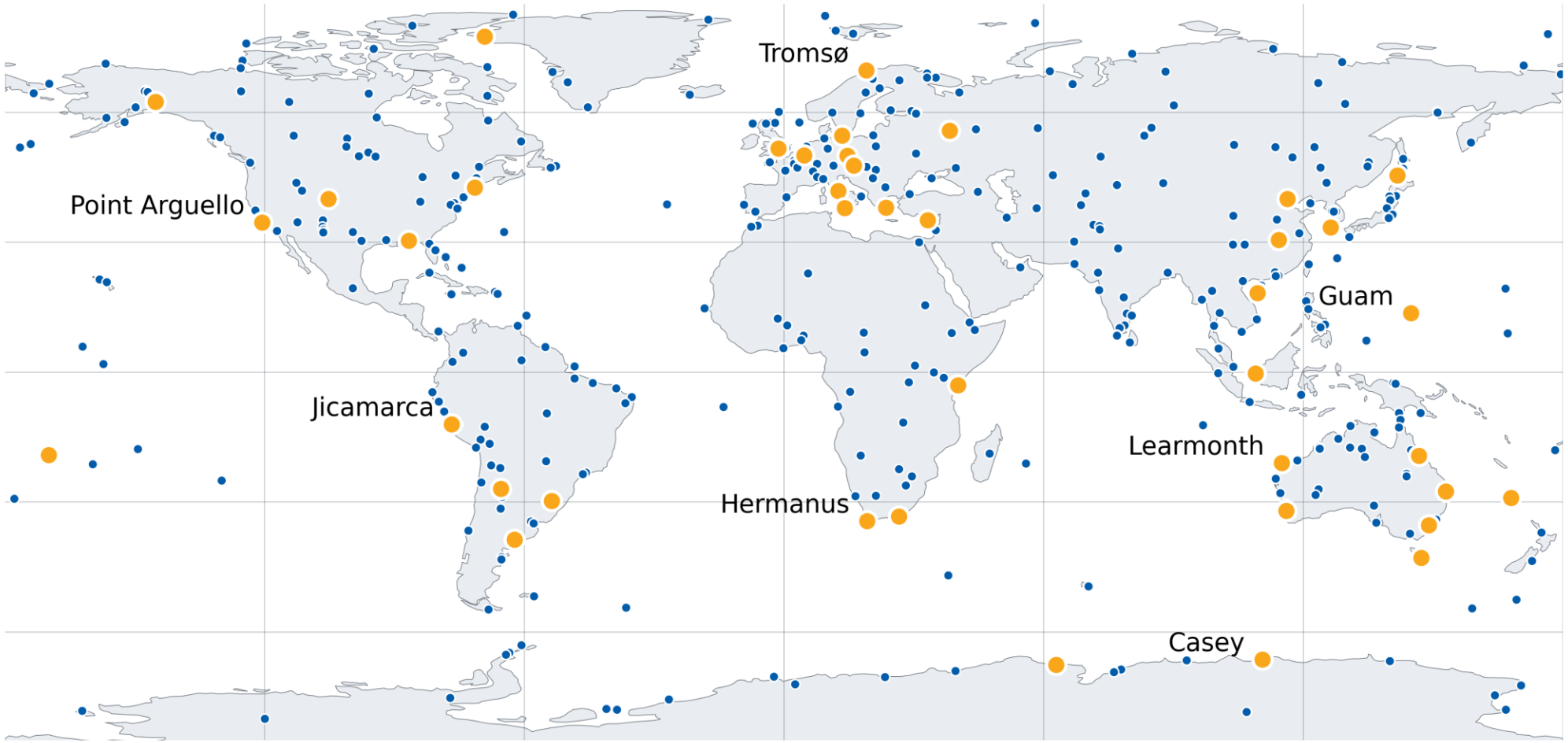
Indicative station locations, based on information given in the Report ITU-R RS 2456-1.
Missing from the map: The China Solar Radio Telescopes in Yunnan, Jiangsu, Shandong, Xinjiang and Beijing

Ionosonde locations



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Near-real-time stations (indicative list)

Other stations

Map based on the URSI codes of ionosondes (URSI = Internation Union of Radio Science)

Three things to take away

1

Space weather storms can harm modern society

- In extreme cases economic costs can be in the order of billions of euros

2

Space weather services harvest often research-oriented observation networks

- WMO is recognized as a key player in the efforts for improved coherence in data acquisition and dissemination

3

Space weather matters for radio and radio matters for space weather

- Space weather can disrupt HF communication, GNSS and other radio-based systems
- Operational services rely on radio observations from the Sun to the ionosphere

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Thank you.

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