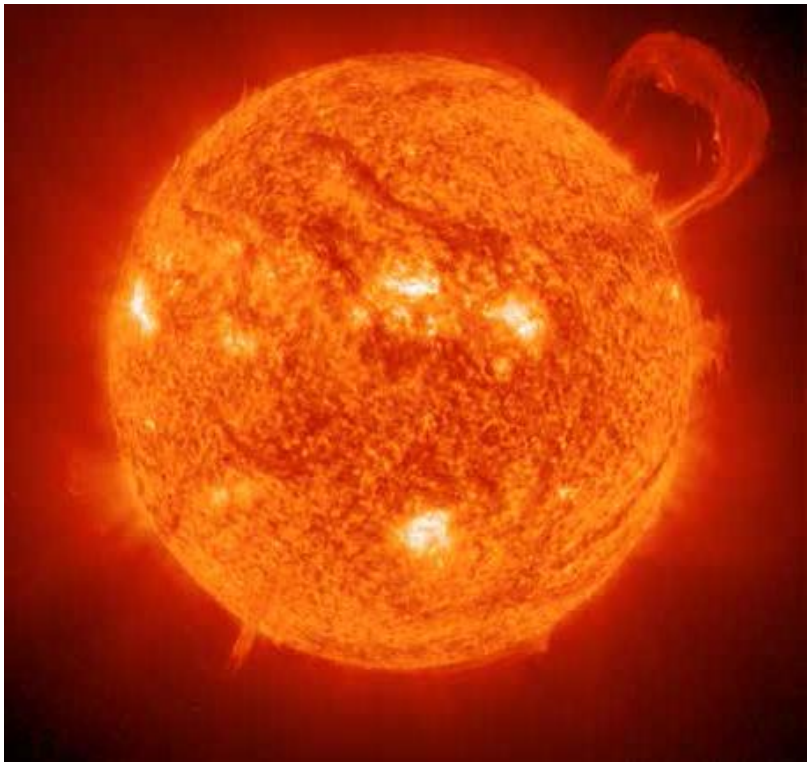
Ministerie van Infrastructuur en Milieu



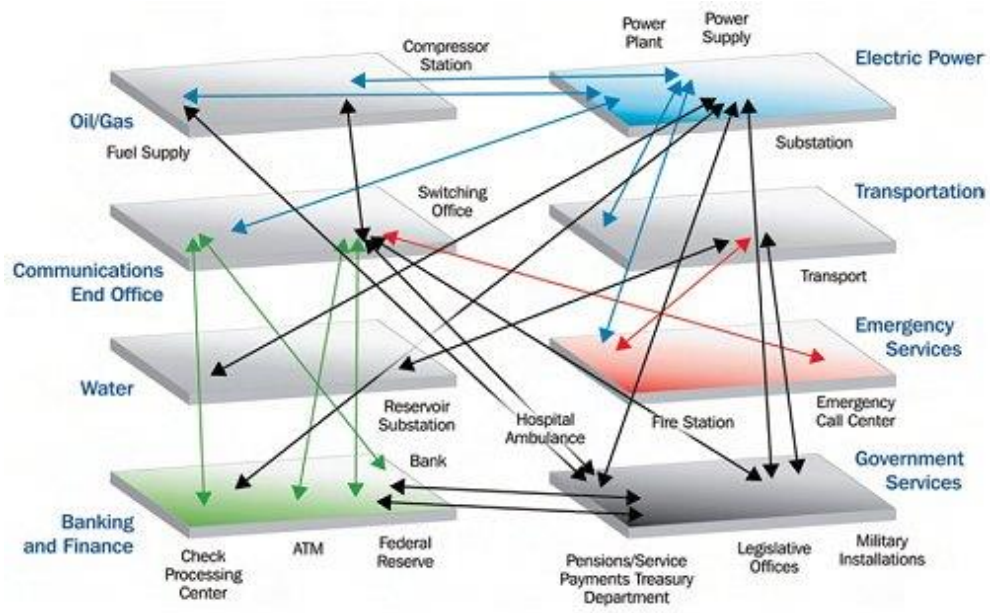
# Resilience against solar activity: what if the Sun turns off the light

## Connecting space weather and radio astronomy

Bert van den Oord - KNMI

# Critical Infrastructure Resilience

- 2011 National Risk Analyses
- 2015 Reevaluation
  - Category A
  - Category B
  - Non-vital




Criteria:

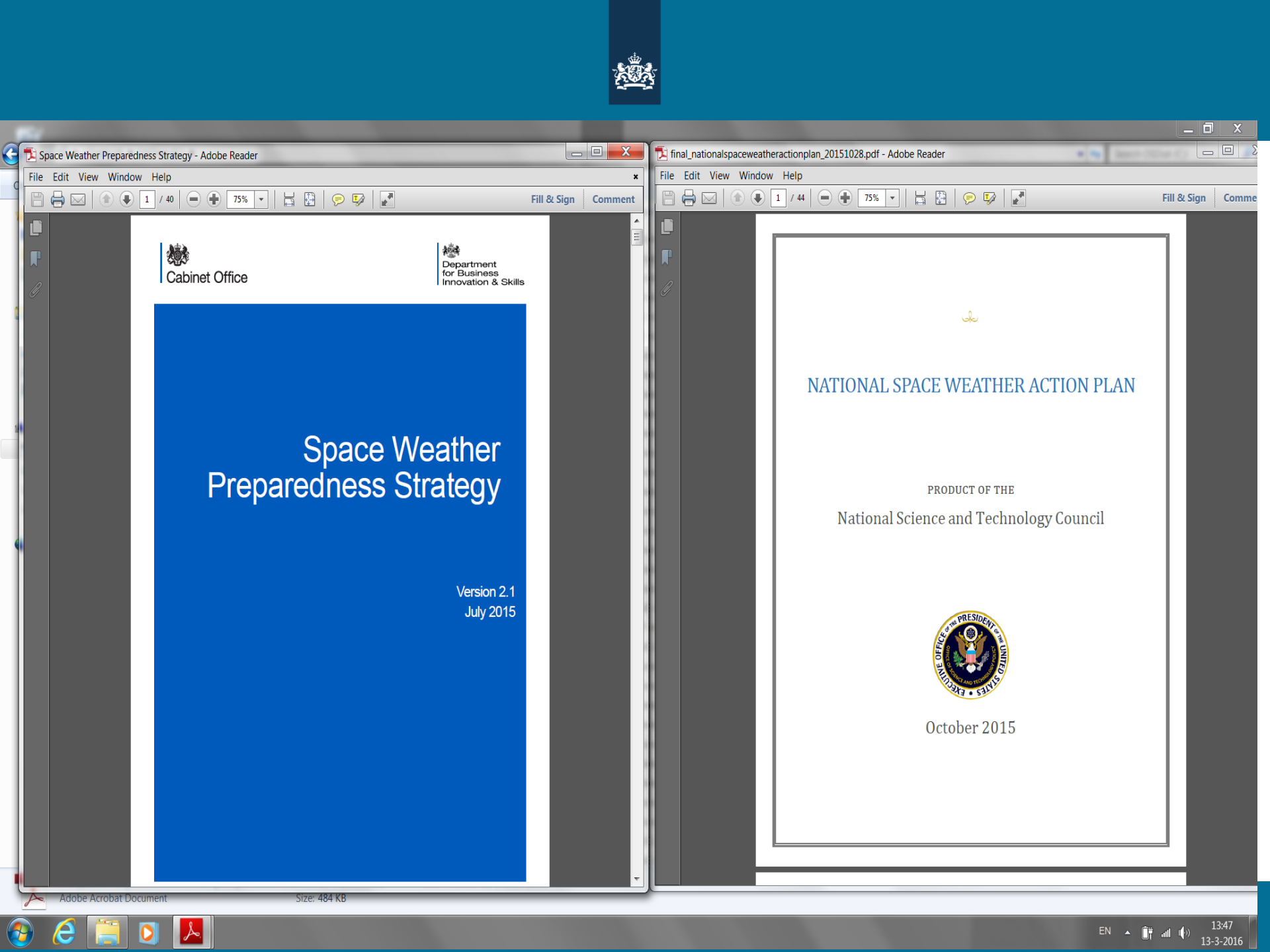
- Damage: >50/5 billion€
- Casualities: >10.000/1000 persons
- Disruption: $10^6$ /$10^5$ persons

Chain effects: e.g. financial sector (Category B) is through chain effects coupled with Category A (electric power, communication)

# Vital sectors

| CATEGORIE A |
| --- |
| Landelijk transport en distributie elektriciteit |
| Gasproductie, landelijk transport en distributie |
| Olievoorziening |
| Drinkwatervoorziening |
| Keren en beheren waterkwantiteit |
| Opslag, productie en verwerking nucleair materiaal |
| Internetdienstverlening *<br>Mobiele telefonie *<br>Satelliet *<br>Radio *<br>Vaste telefonie * |

| CATEGORIE B |
| --- |
| Regionale distributie elektriciteit |
| Regionale distributie gas |
| Vlucht- en vliegtuigafhandeling |
| Scheepvaartafwikkeling |
| Grootschalige productie, verwerking, opslag (petro)chemische stoffen |
| Toonbankbetalingsverkeer |
| Massaal giraal betalingsverkeer |
| Hoogwaardig betalingsverkeer tussen banken |
| Effectenverkeer |
| Communicatie met en tussen hulpdiensten via 112 en C2000 |
| Inzet politie |
| Betrouwbare basisinformatie digitale overheid |


Space Weather Preparedness Strategy - Adobe Reader
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Cabinet Office
Department for Business Innovation & Skills
Space Weather Preparedness Strategy
Version 2.1
July 2015
final_nationalspaceweatheractionplan_20151028.pdf - Adobe Reader
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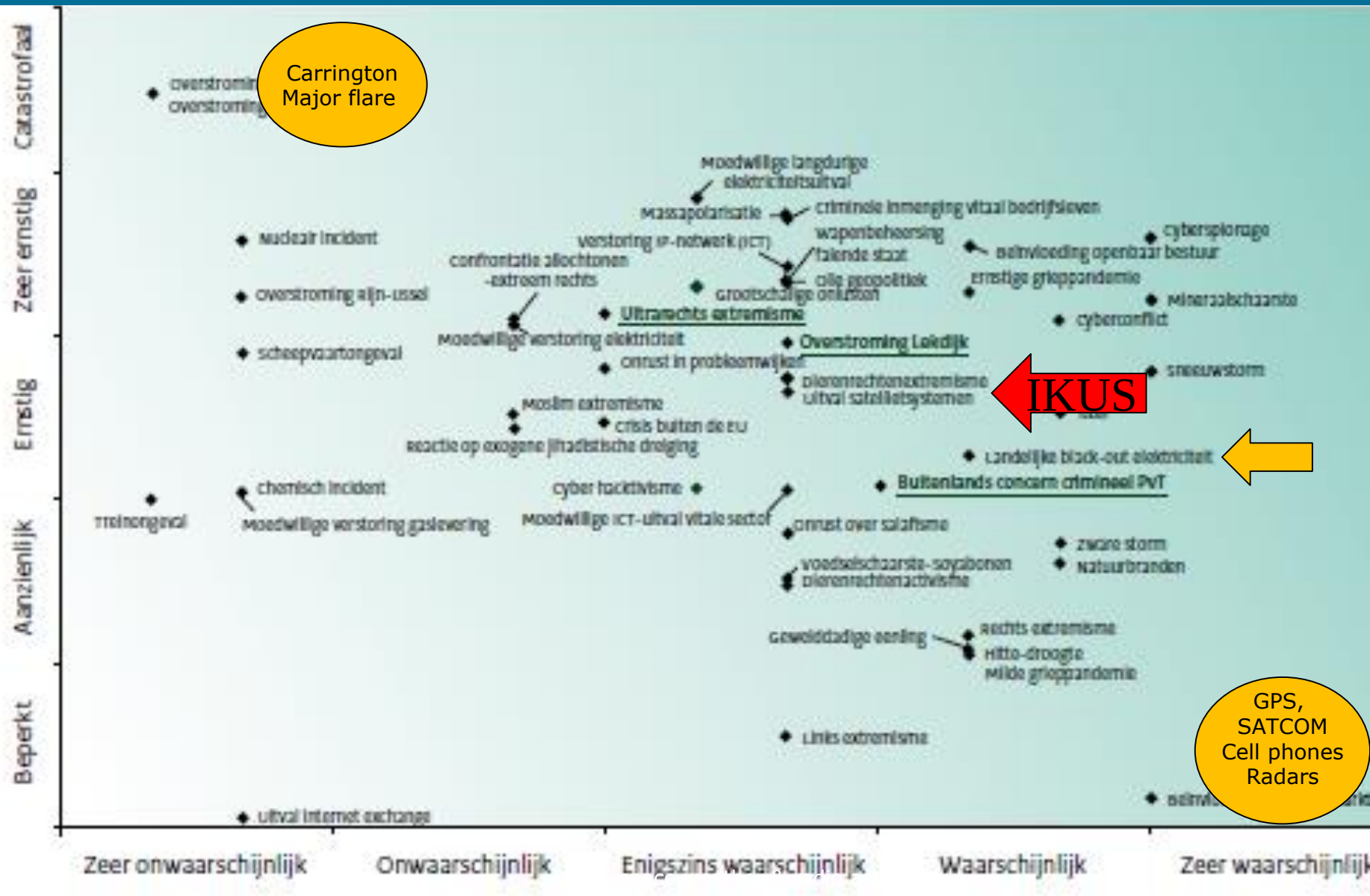
NATIONAL SPACE WEATHER ACTION PLAN
PRODUCT OF THE
National Science and Technology Council
October 2015
Adobe Acrobat Document
Size: 484 KB
EN
13:47
13-3-2016

# Risk analyses vital sectors 2011: context space weather



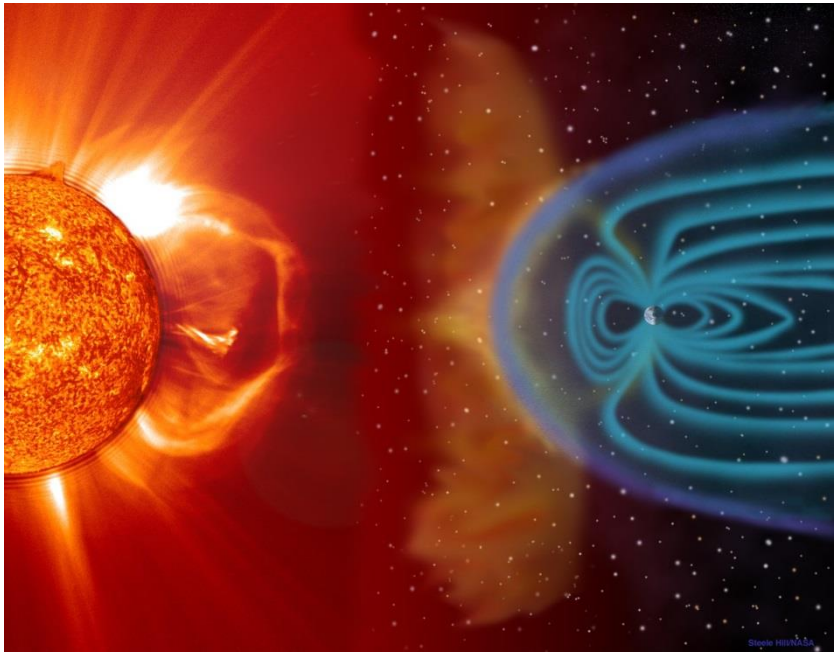
# Vulnerability for space weather

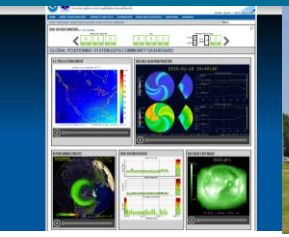
- Insurance
  - US 2000-2010 power grid related payments: 119-188 M$/yr (10% space weather)
  - Most extreme case 1 trillion $ i.c.o. Carrington event (GNP 2015 18 trillion $)

INFRASTRUCTURE/OPERATIONS:

- Power grids, trans-atlantic internet (geophysically induced currents)
- Direct impact on satellites (direct damage)
- Direct impact on radar (ATC), communication systems by radio flares
- Impact on ionosphere that affects
  - SatCom
  - GPS
    - Timing information (GNSS)
      - Synchronizing networks (telecom, power,…..)
      - Time stamping financial transactions

# Sun- Earth System: **Space** Weather Alert

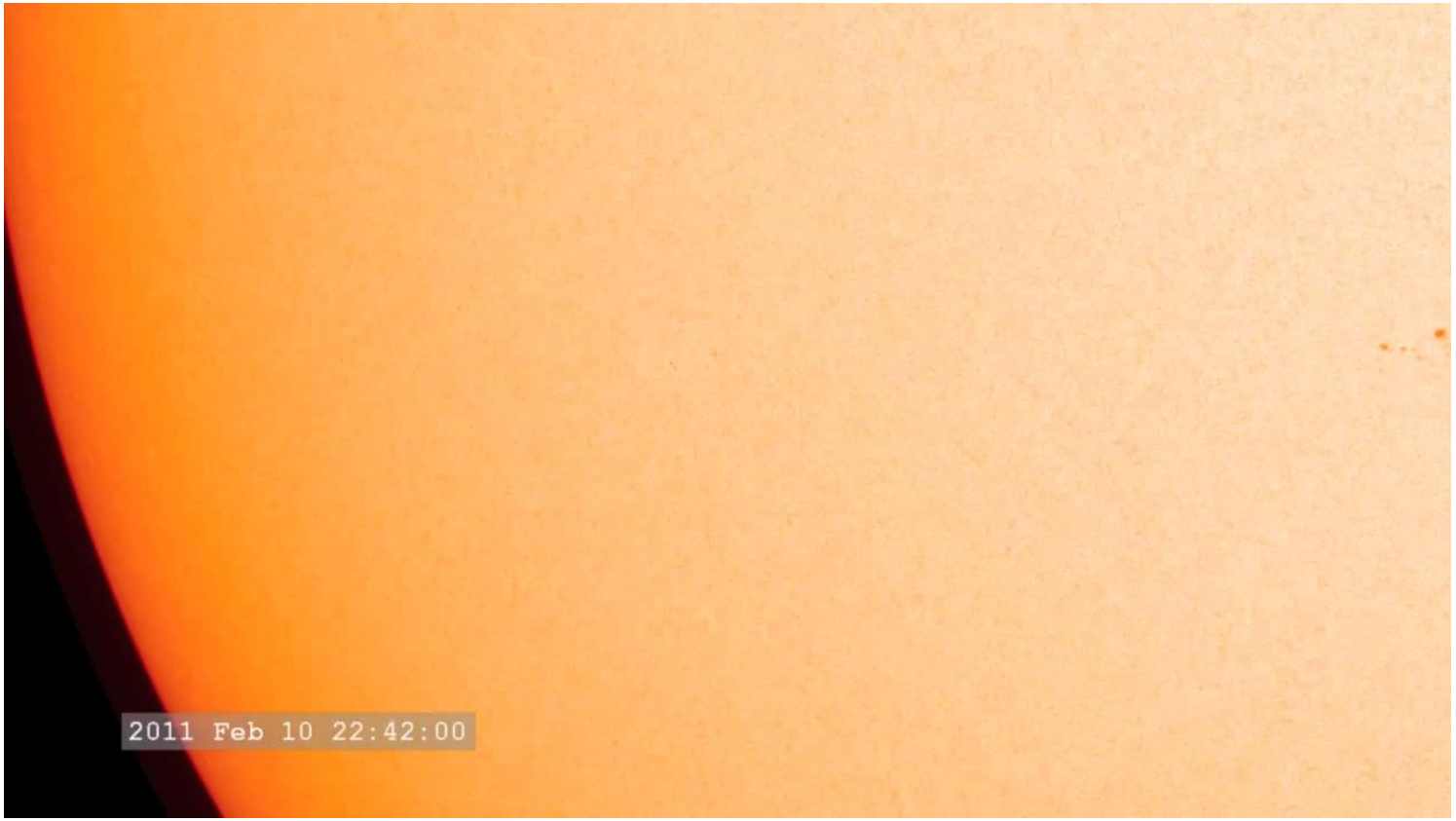


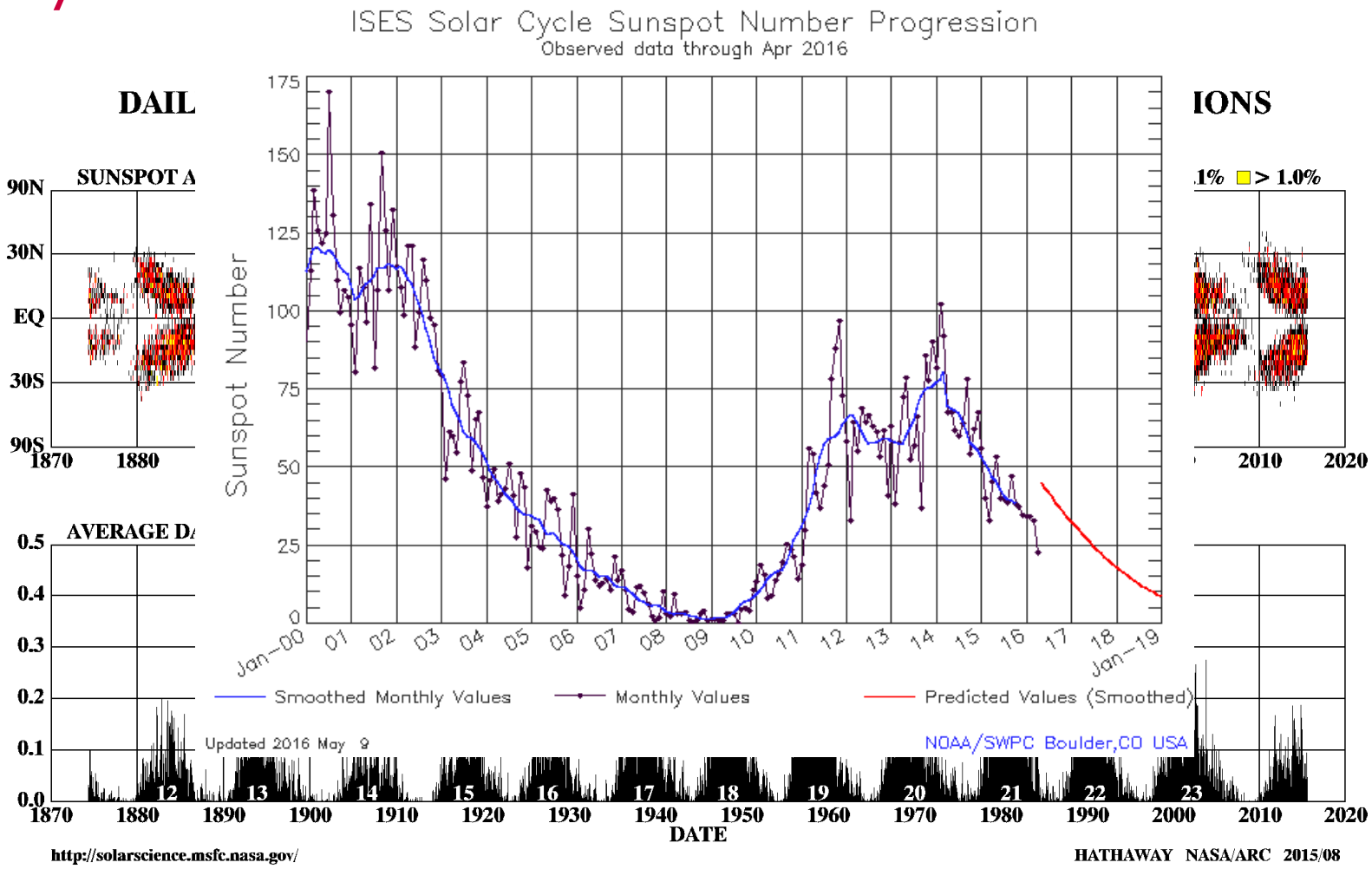

# Activities

- KNMI will provide an **alerting service for vital sectors** by the end of 2016
  - Joint back office with the air force
  - Two front offices: civilian & military
  - Research network
  - Experiments (Mali, Lauwersmeer, Fugro, Kadaster, Internet,…. )
  - Active role within WMO, IAU, ICAO
- Requires collaboration with vital sectors (+NCTV,NCSC,LOCC,VR, NCC,DCCs,….):
  - Assess the vulnerability of critical infrastructure systems
  - Develop a real-time infrastructure assessment and reporting capability (situational awareness)
  - Translate model forecasts into impact effects on infrastructures
  - Improve forecasting and communications (specific for NL)
- Report on annual basis to Parliament via ministry VenJ

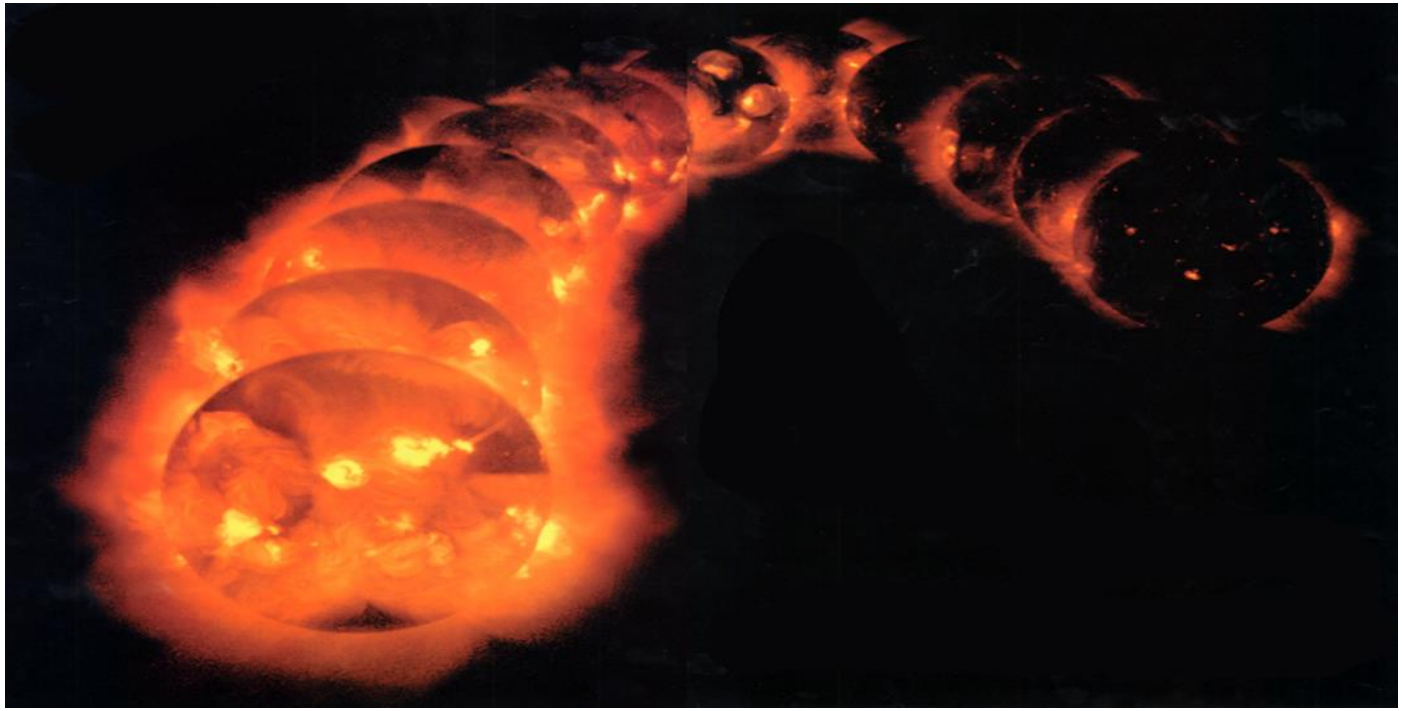
# Development active region



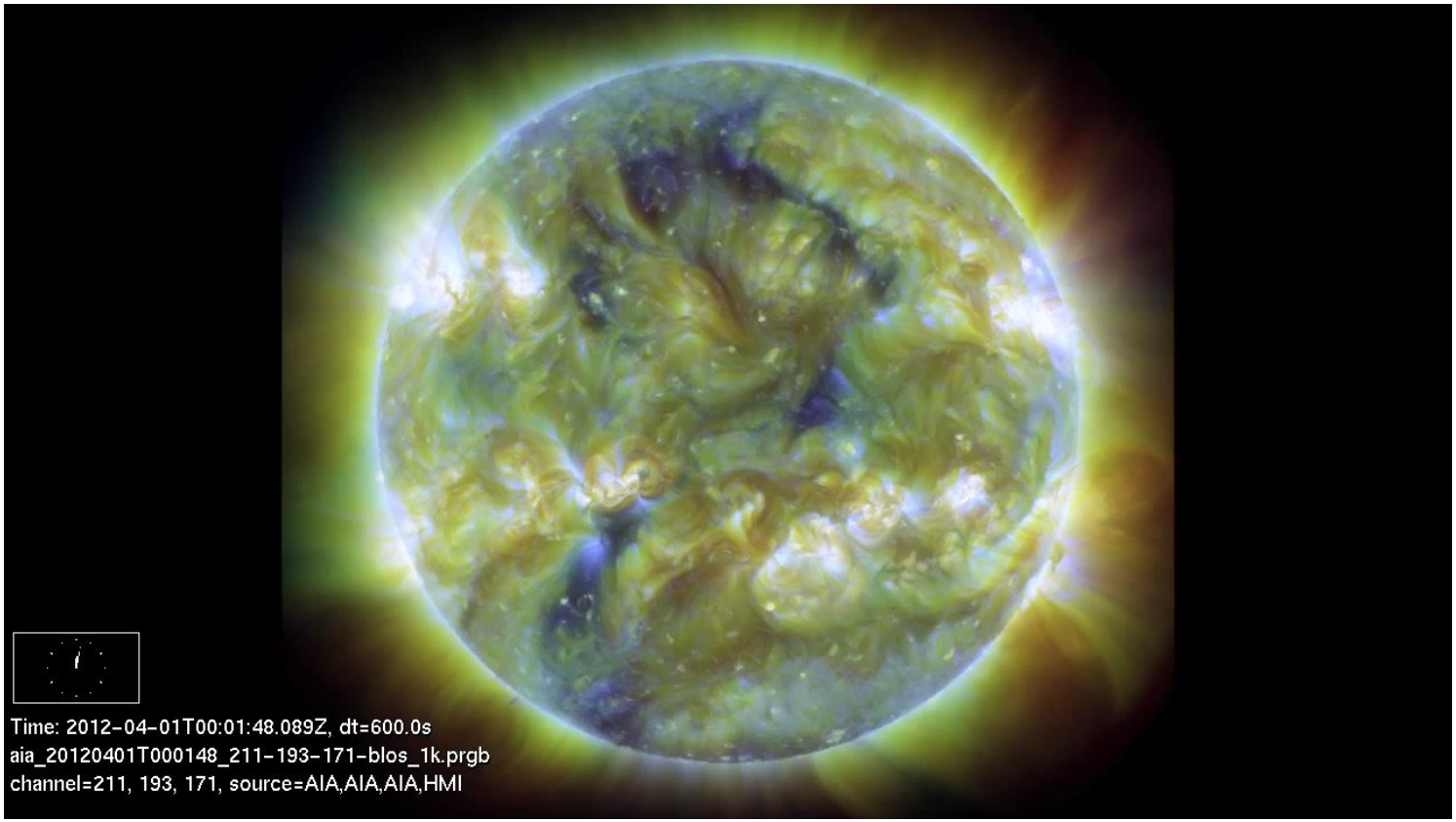
# 11 year sunspot cyclus



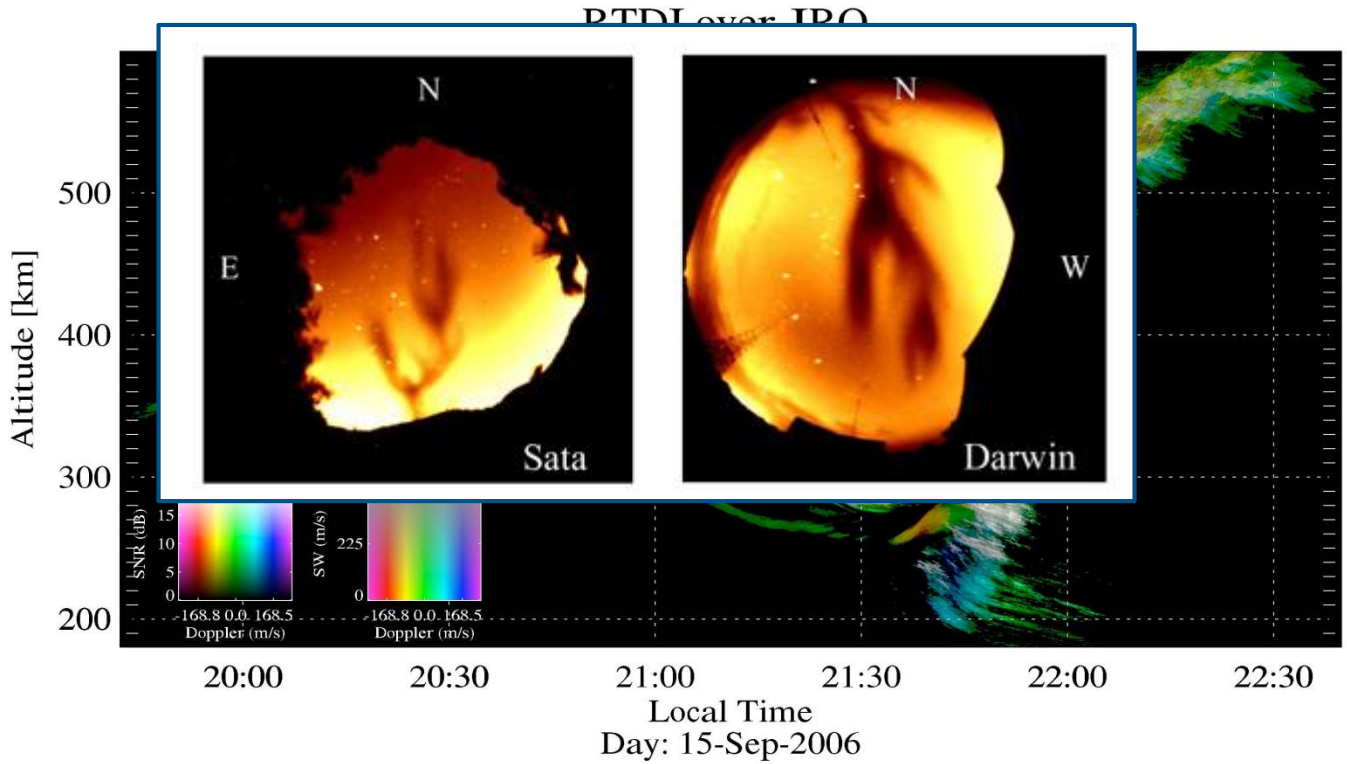
# 14 years the Sun in X-rays: modulation SW



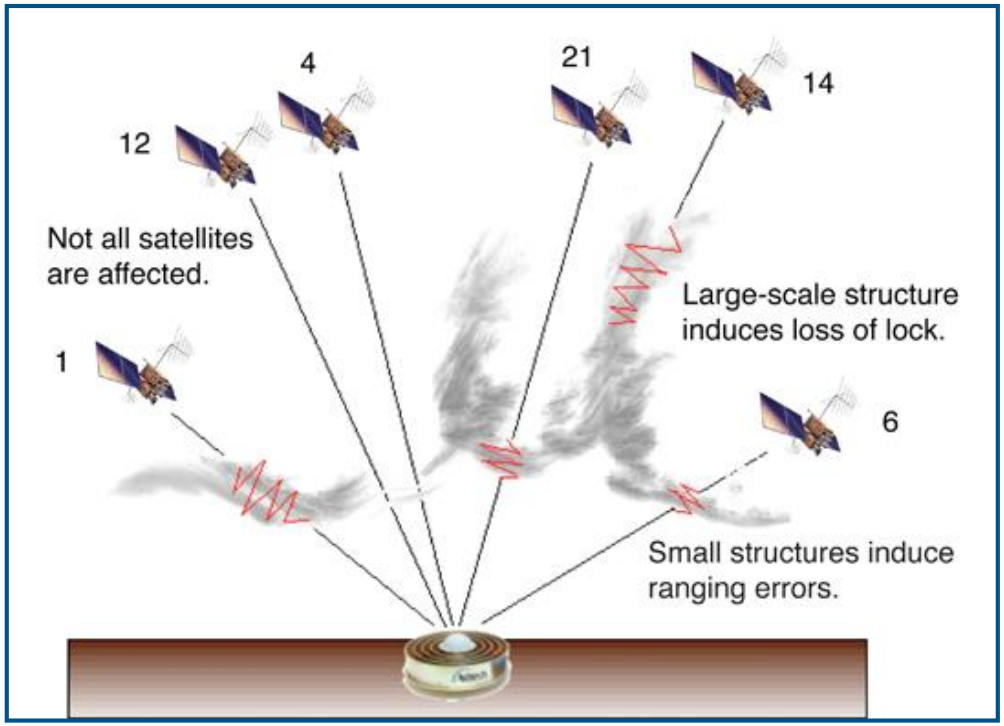
# Solar corona: loops and holes

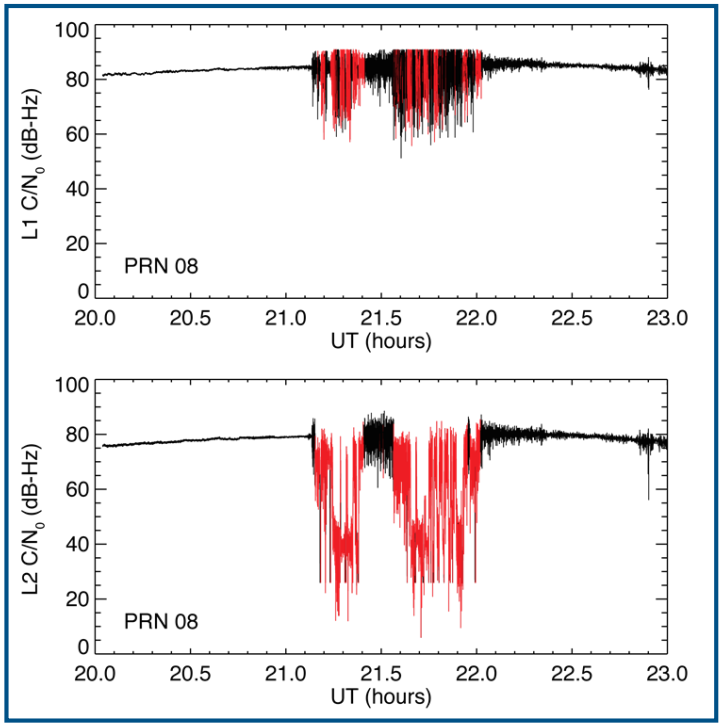


# Effect of X-ray and UV on GPS and SATCOM



# The effect of bubbles on GPS...



# … and on UHF SATCOM

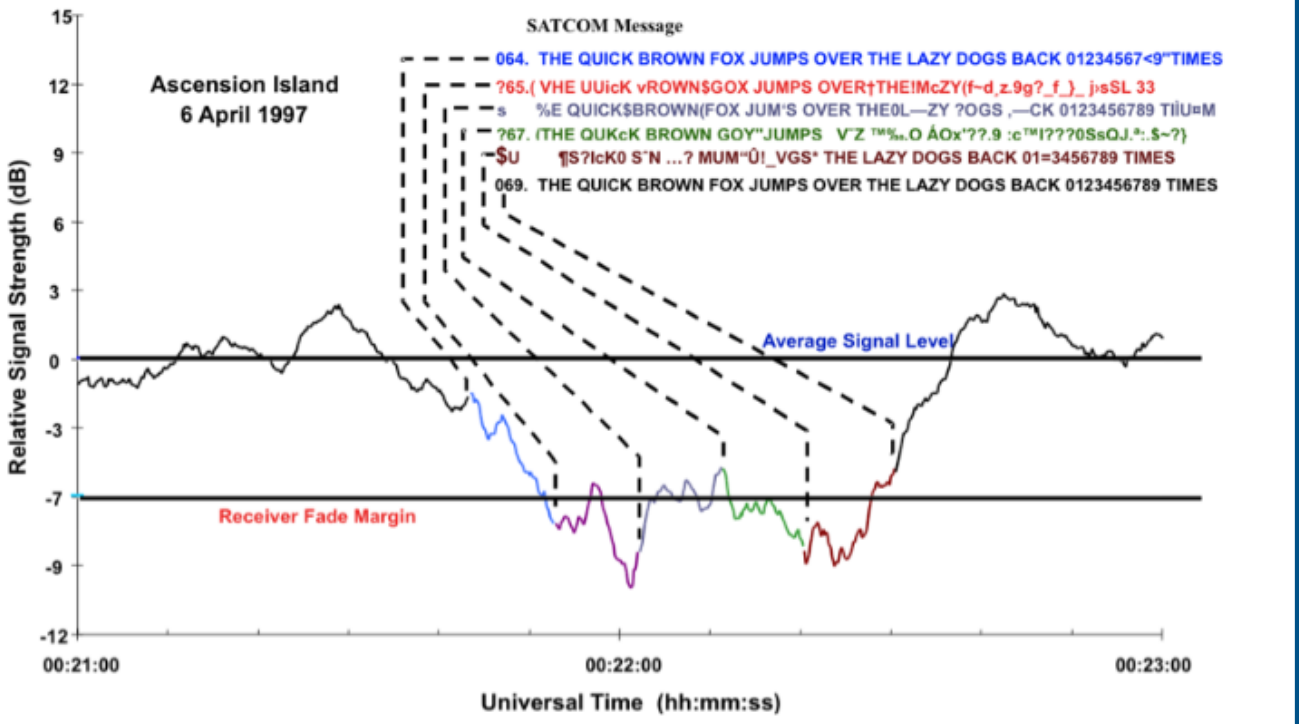
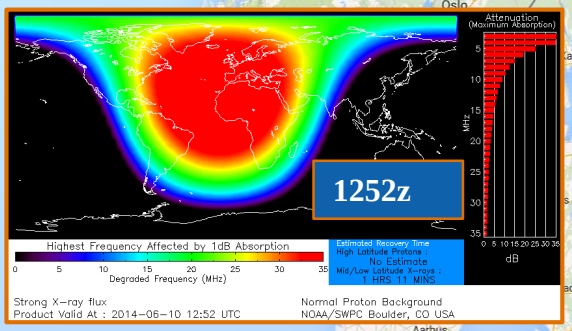
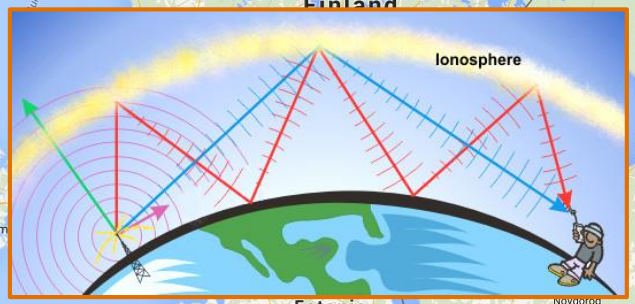



*Figure 1: A real-world example of SATCOM effects from an AFRL campaign in 1997. During periods of scintillation, the received message at Ascension Island was garbled.*

# Navigation, communication and detection

# Praktijkvoorbeeld 2: Zr. Ms. Mercuur



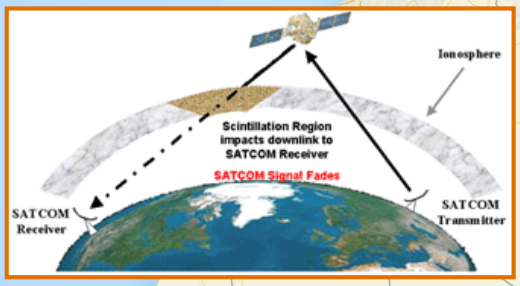



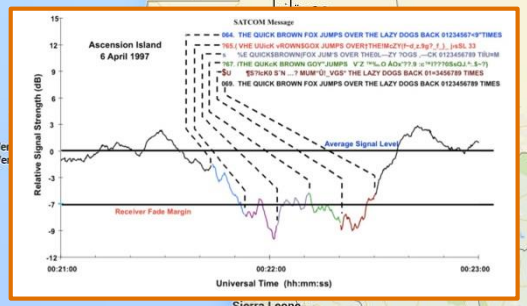

Feedback Zr. Ms. Mercuur

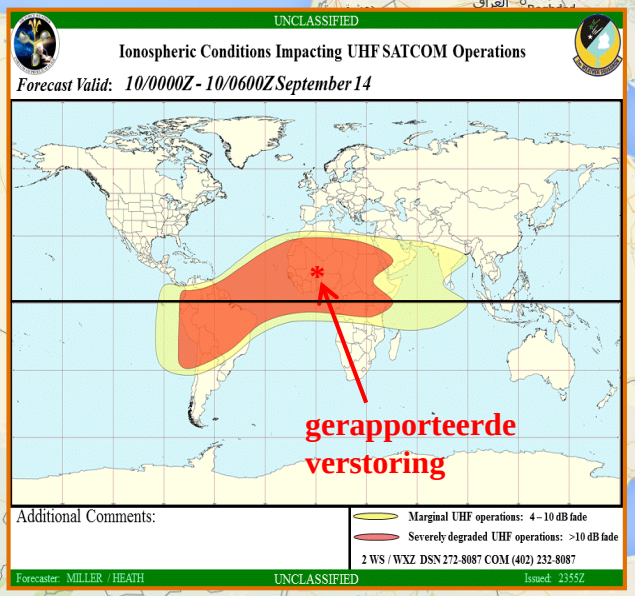
"De hele nacht en ochtend hebben we een goede ontvangst gehad. Hierna zijn we overgegaan op frequenties in het skywave gebied (4-12MHz). We hebben een erg slechte ontvangst gehad in deze banden."

DTGR : 10**1320z** jun 14
FM : NAVCOMMCEN DEU
TO : all units copying bcst X21D
BCST interference
Due to high solar activity (Moegel dellinger effect) temporal poor reception of all deu bcst possible

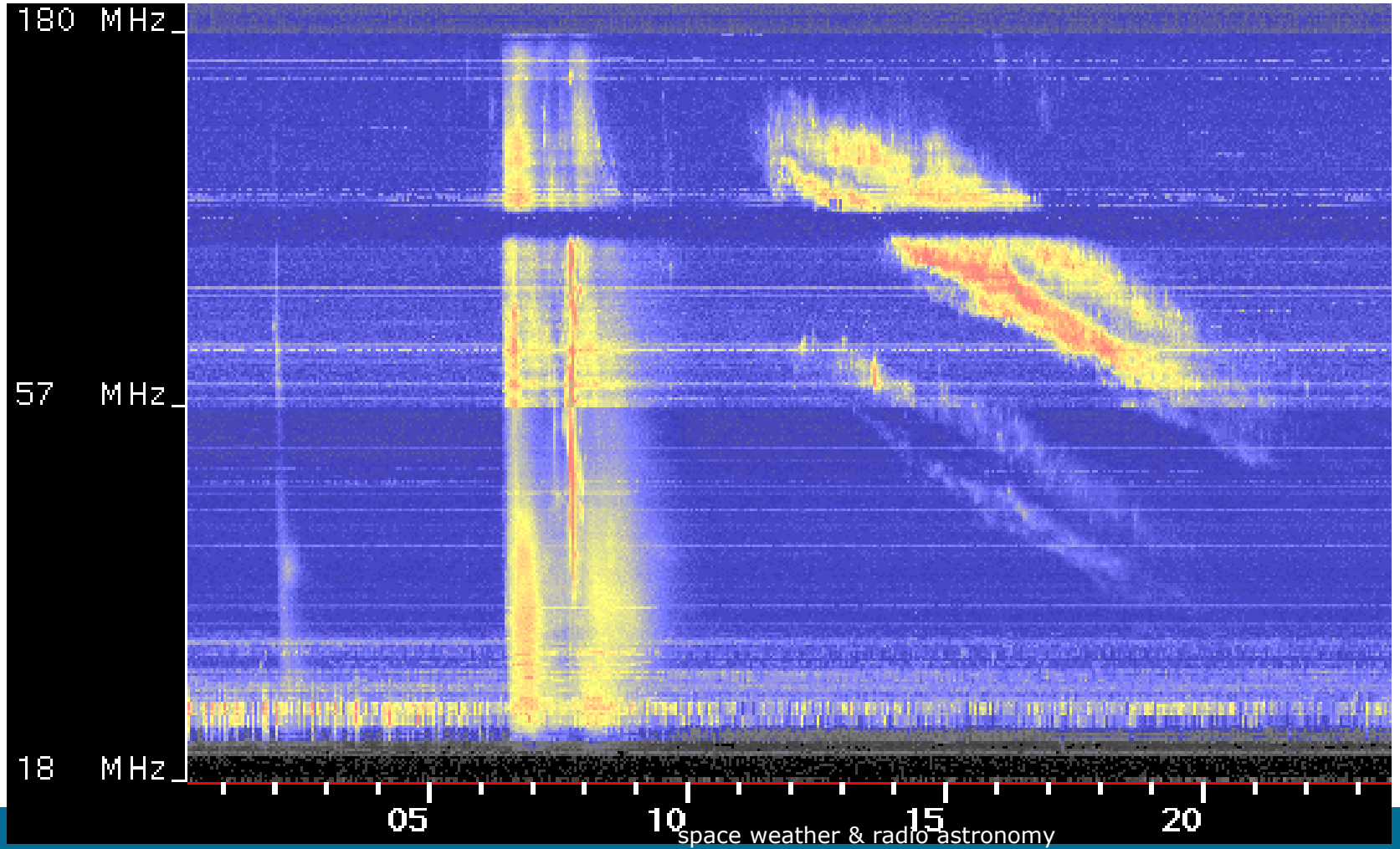
# Praktijkvoorbeeld 3: MINUSMA



# Radioflares



# Summary magnetic fields

- Solar dynamo transforms kinetic energy into magnetic energy
- Magnetic flux tube become buoyant and emerge at surface
- Permanent motions result in heating of gases (solar corona has temperature of million degrees -> X-rays) and particles acceleration (radio flares)
- Solar wind from coronal holes 400 km/s & 700- 900 km/s
- Flares $10^{25\text{-}27}$ Joule (quarter million hurricanes during a week)
- **Coronal mass ejections: $10^{12\text{-}13}$ kg (Mount Everest); energy $10^{24\text{-}25}$ Joule (5000 atomic bombs); velocity 450-2000 km/s.**
- Ionosphere protects against radiation and terrestrial magnetic field against fast particles and CMEs.
- But at the expense of disturbances and strong induced currents.

# Mayor League solar flares: Coronal mass eruptions Carrington event



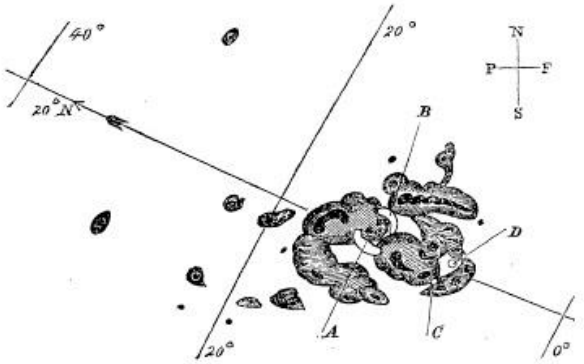
bination with the ancient measures, to a new computation by M. Oom, of the Royal Observatory of Lisbon, at present living at Pulkowa. The results of his computation have entirely confirmed my father's conclusions, that the changes observed in the course of 28 years in the relative positions of the two stars find a complete explanation in the proper motion of the principal star, but the new formula does but very little diminish the discordance of the results obtained in 1823 by transit observations.

*Pulkowa, October, 1859.*

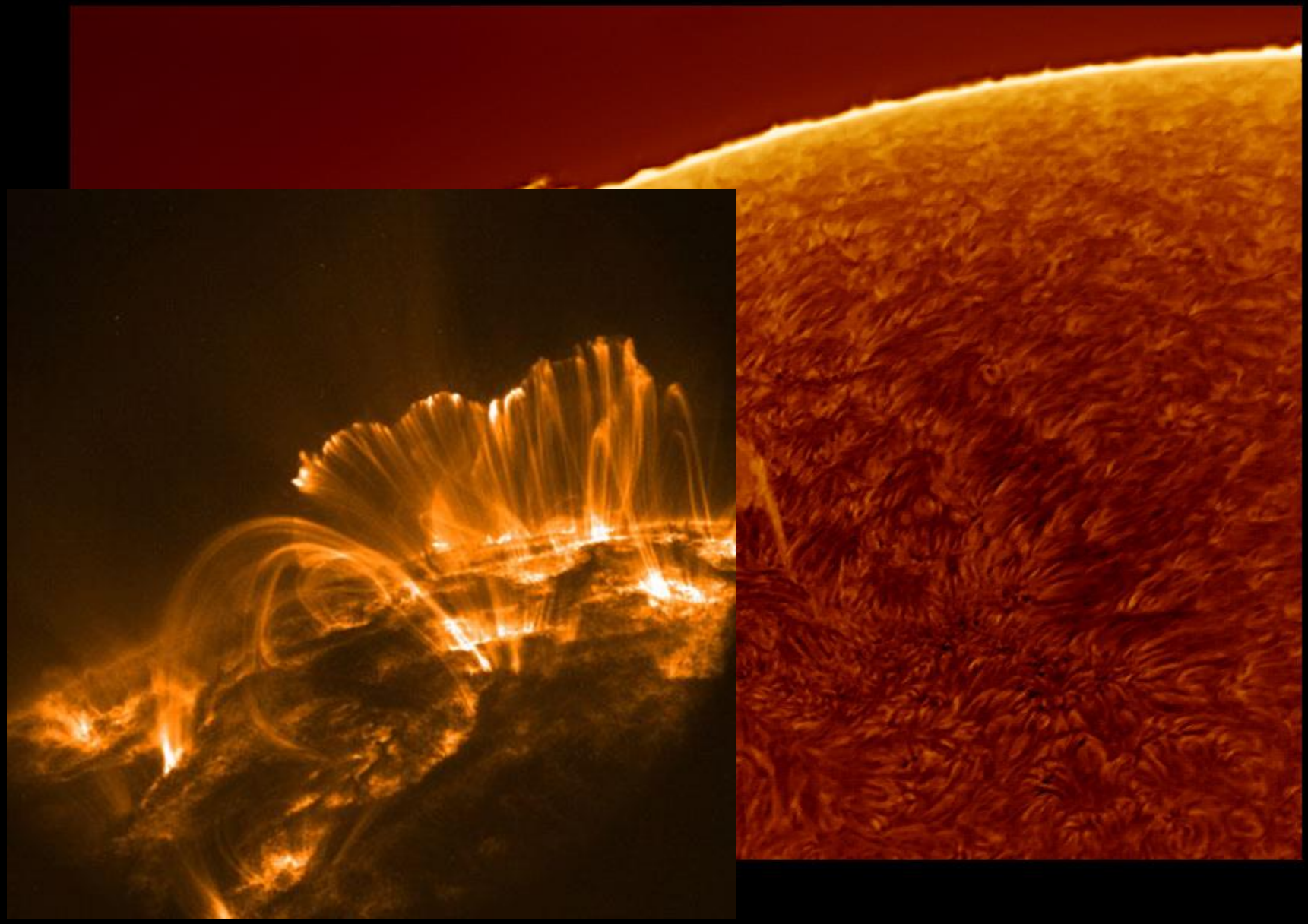
---

*Description of a Singular Appearance seen in the Sun on September 1, 1859.* By R. C. Carrington, Esq.

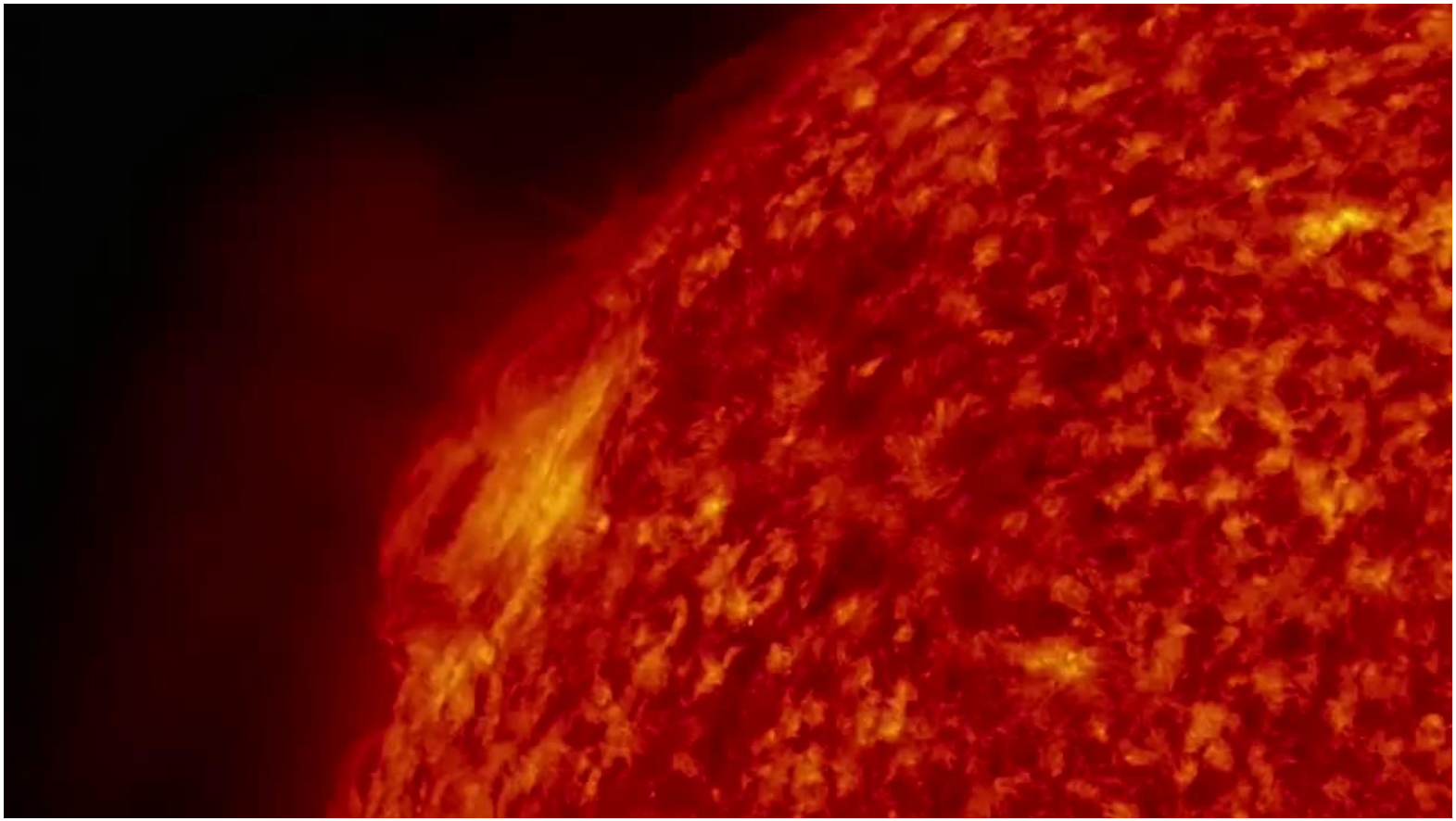
While engaged in the forenoon of Thursday, Sept. 1, in taking my customary observation of the forms and positions of the solar spots, an appearance was witnessed which I believe to be exceedingly rare. The image of the sun's disk was, as usual with me, projected on to a plate of glass coated with distemper of a pale straw colour, and at a distance and under a power which presented a picture of about 11 inches diameter. I had secured diagrams of all the groups and detached spots, and was engaged at the time in counting from a chronometer and recording the contacts of the spots with the cross-wires used in the observation, when within the area of the great north group (the size of which had previously excited general remark), two patches of intensely bright and white light broke out, in the positions indicated in the appended diagram by the letters A and B, and of the forms of the spaces left white. My



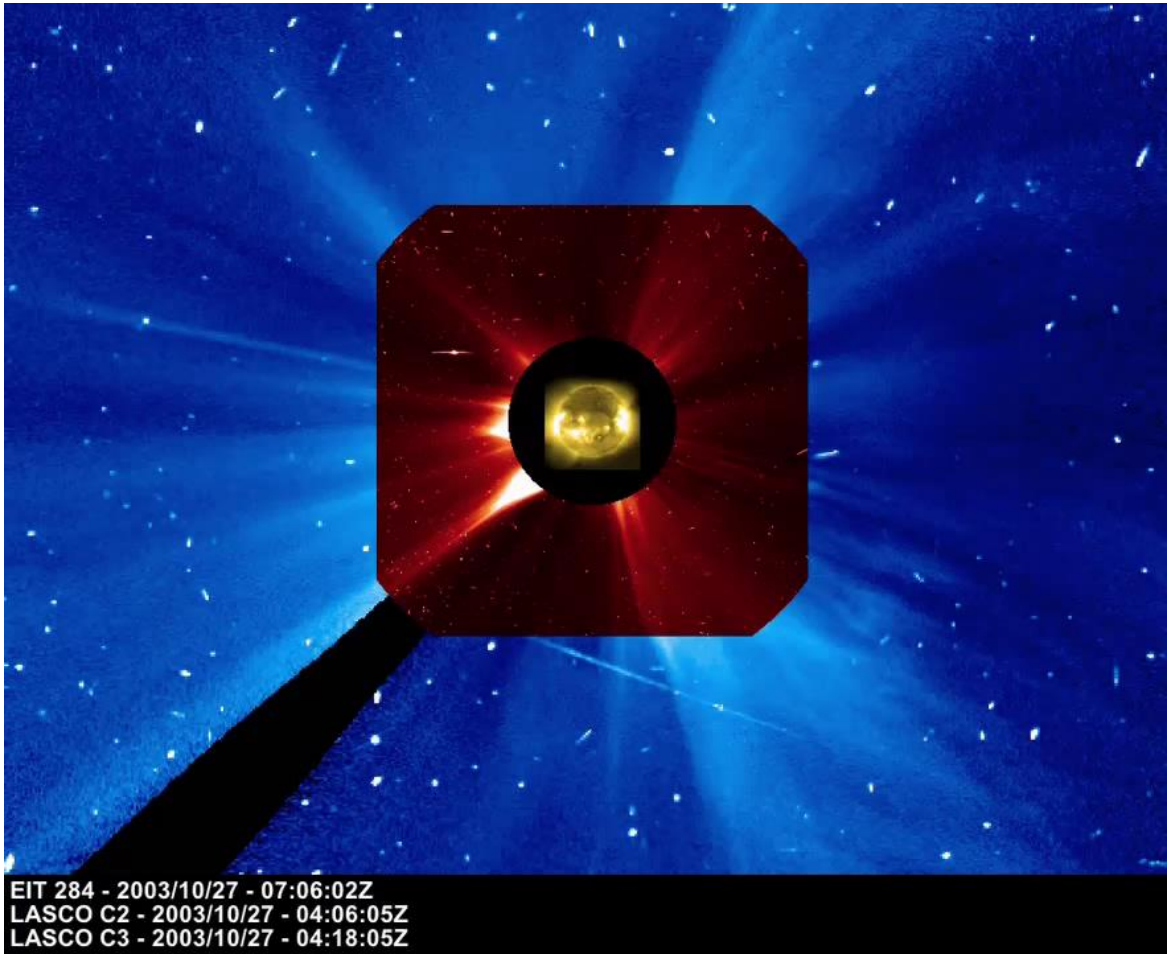

first impression was that by some chance a ray of light had penetrated a hole in the screen attached to the object-glass, by



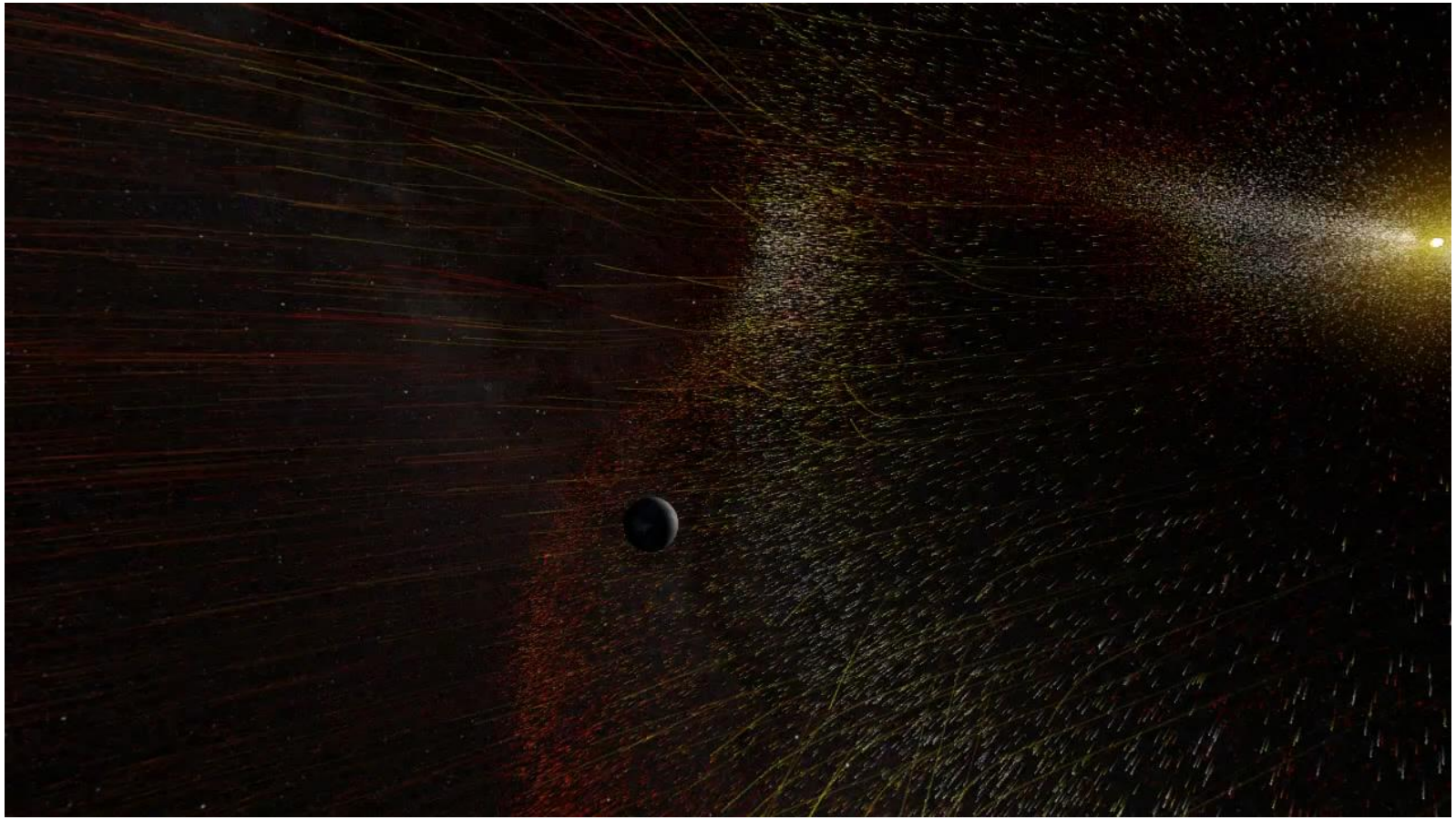
# Coronale massa uitstoting



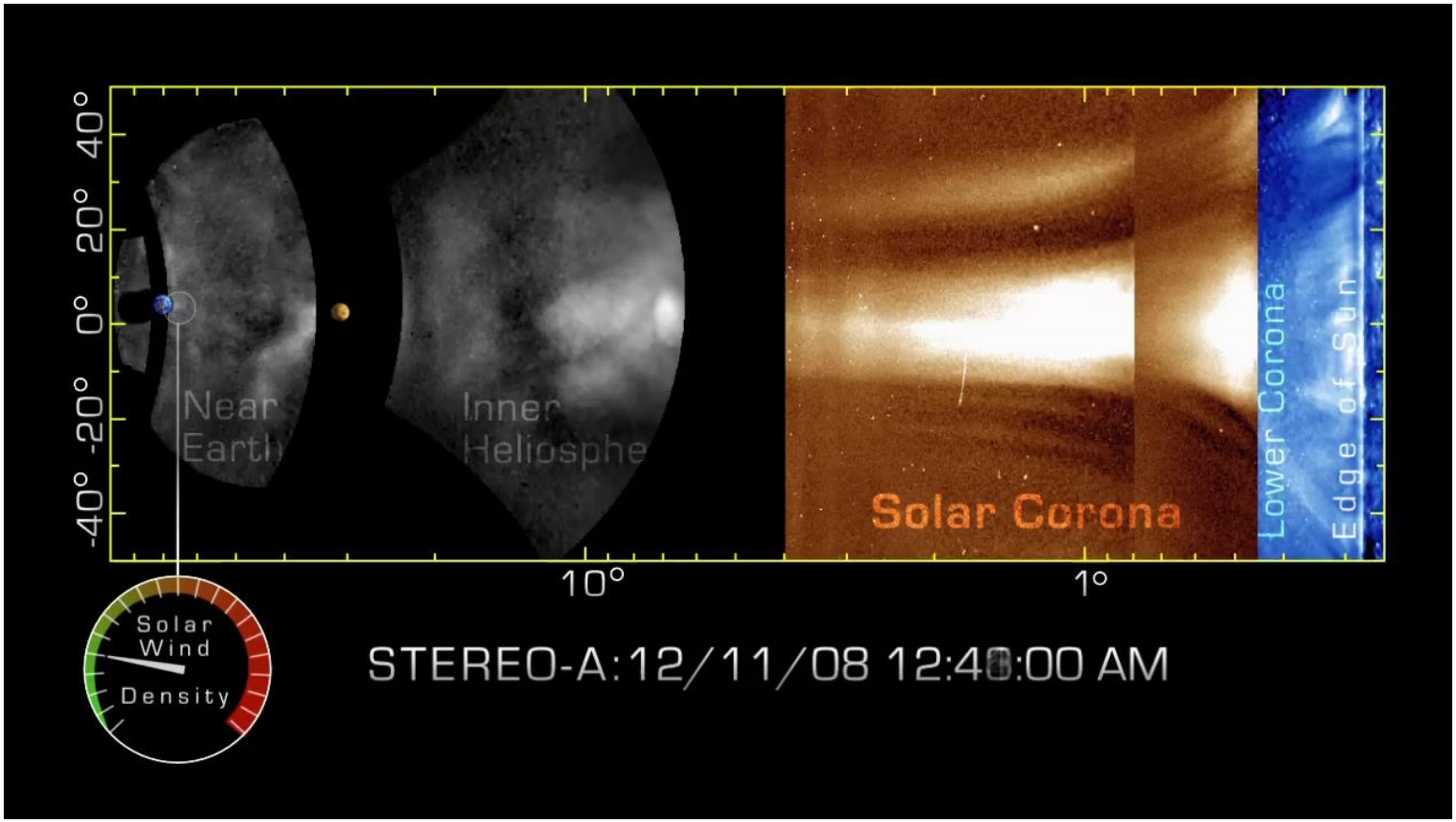
# Coronal mass ejection: effect on satellite



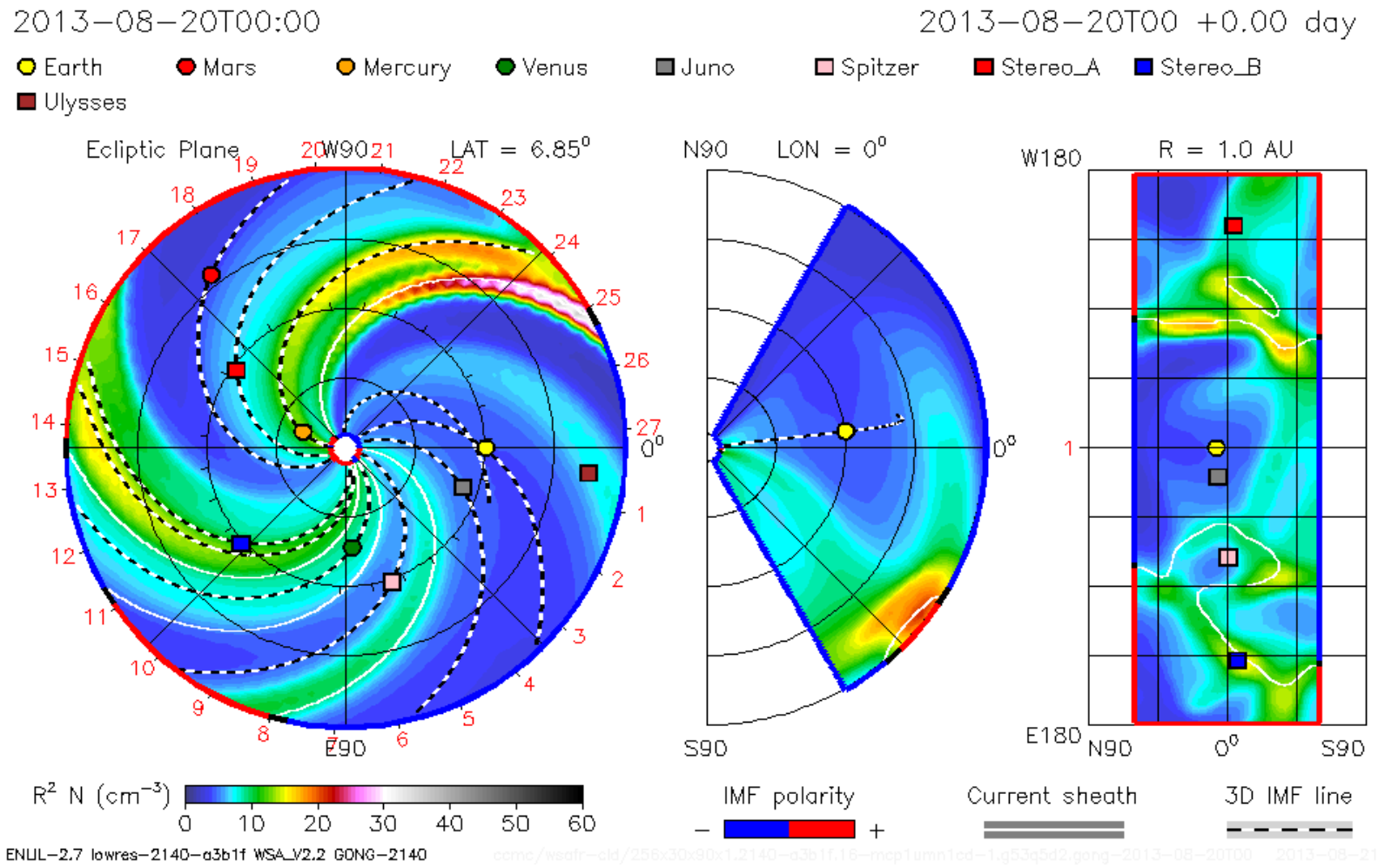
# Space weather



# CME: from the Sun to the Earth

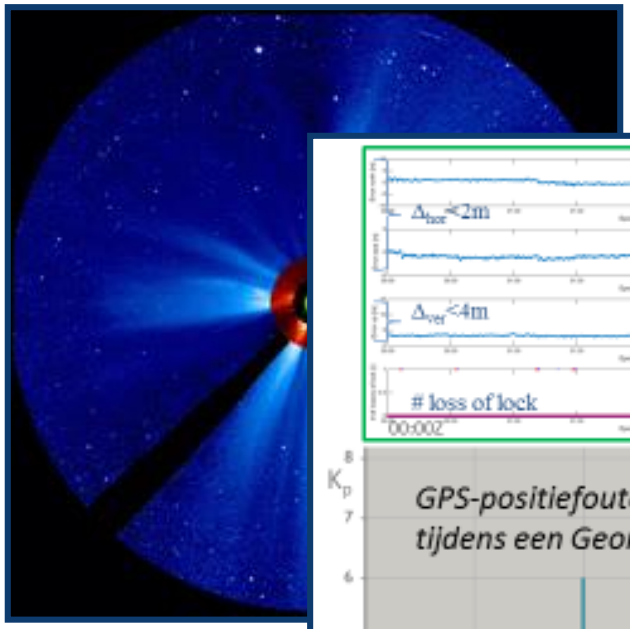


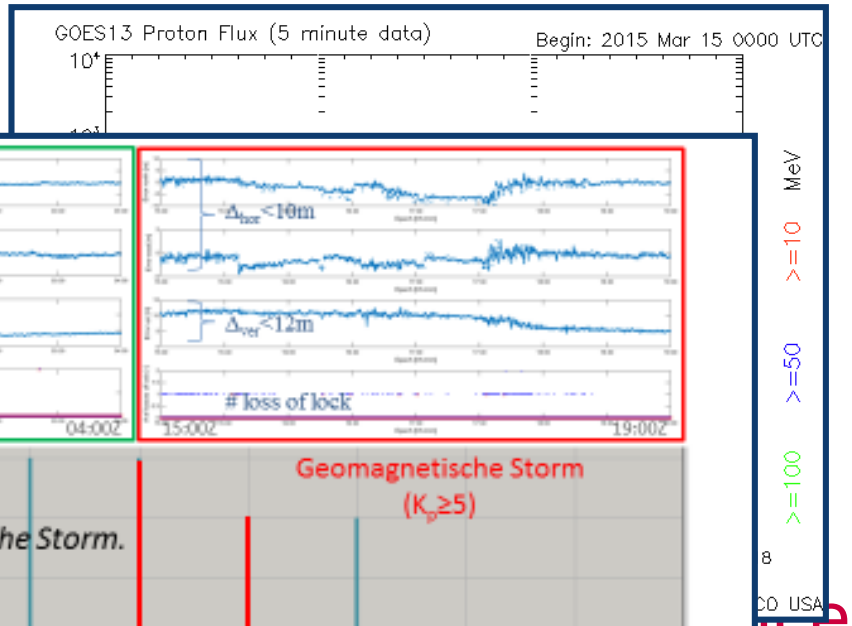
# WSA-ENLIL Model




Sodankylä, Finland,
23 Nov 2010

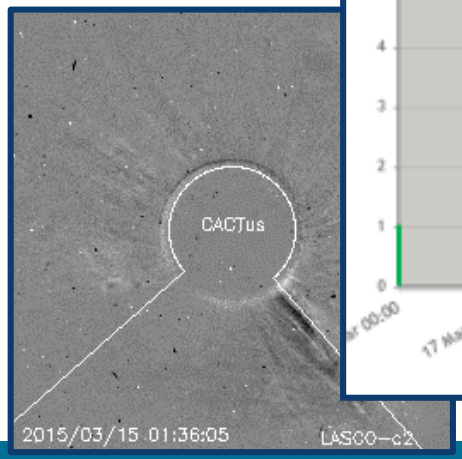
# Geomagnetic Storm & GPS 17 March 2015 Delft









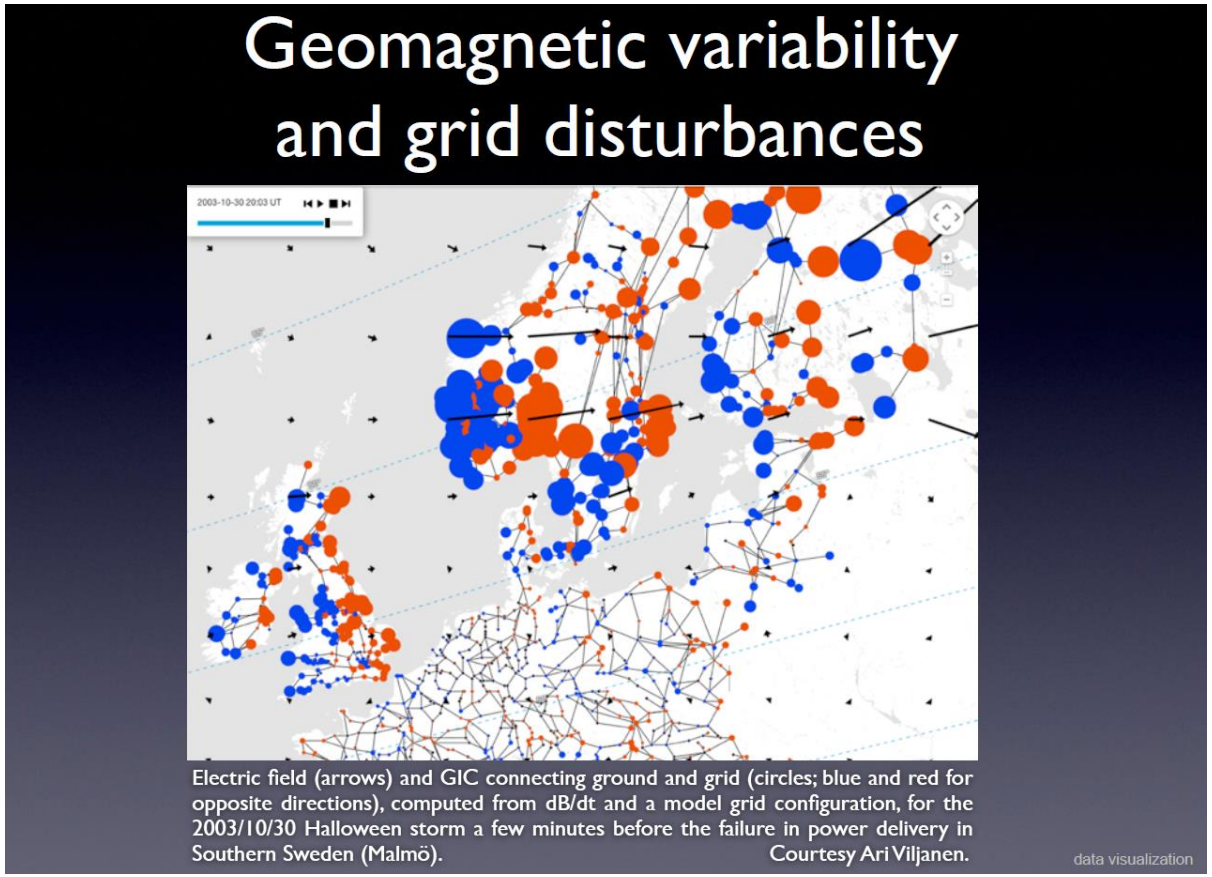




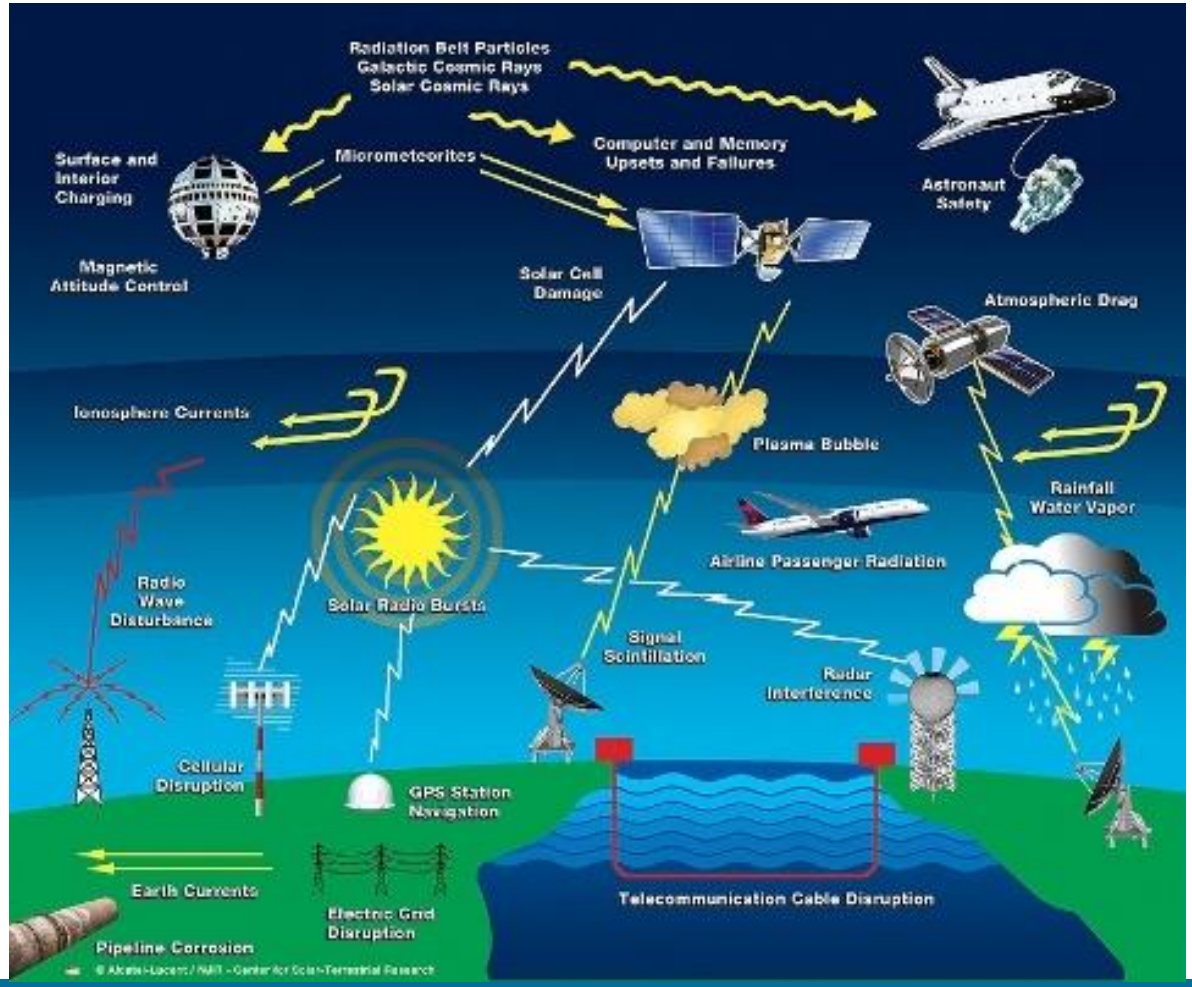
ices in
erlands:
2015

Credit: Barend Lubbers, Faculteit Militaire Wetenschappen

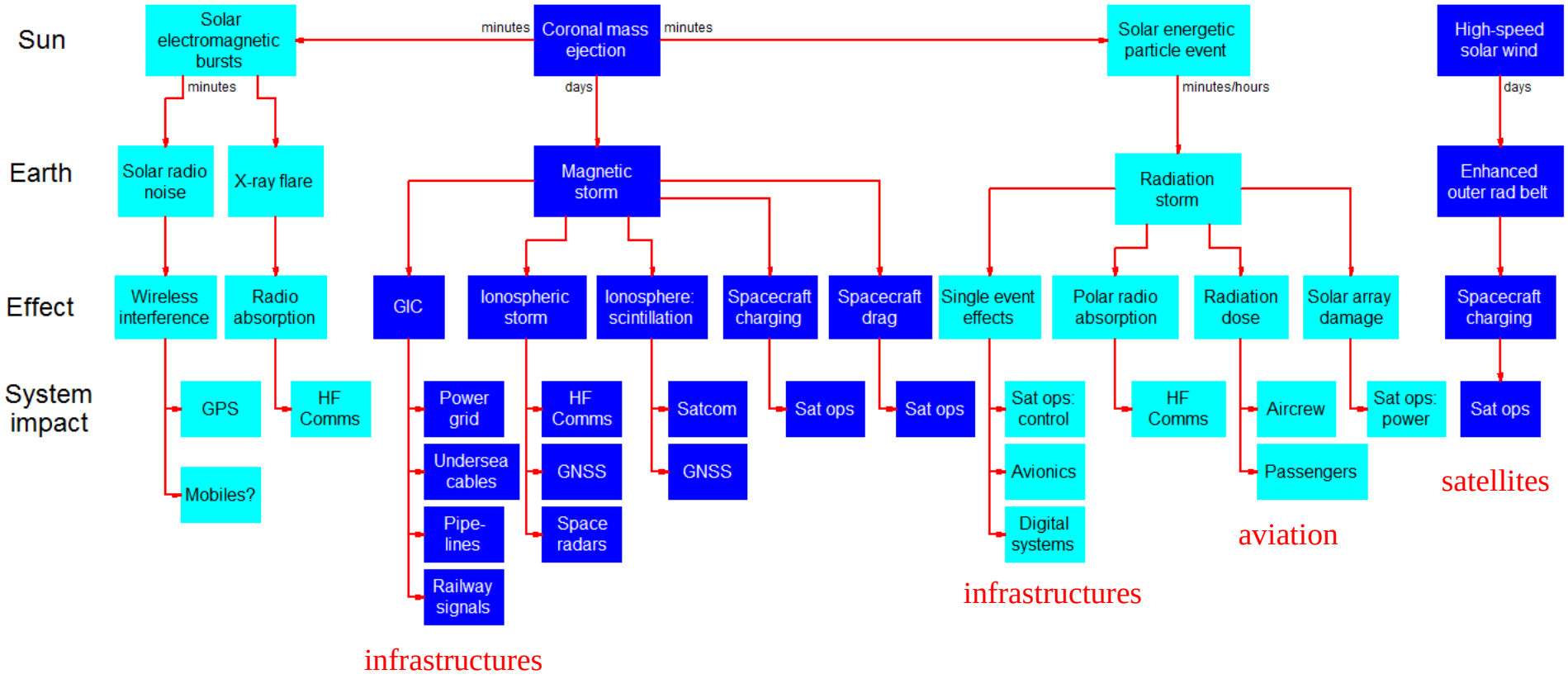
# Power grid breakdown 30-10-2003 (Malmő)



# Vulnerabilities



# Cause–effect diagram (without scintillation)



# Space weather infrastructure


UV, röntgen, ϒ

radio

visible

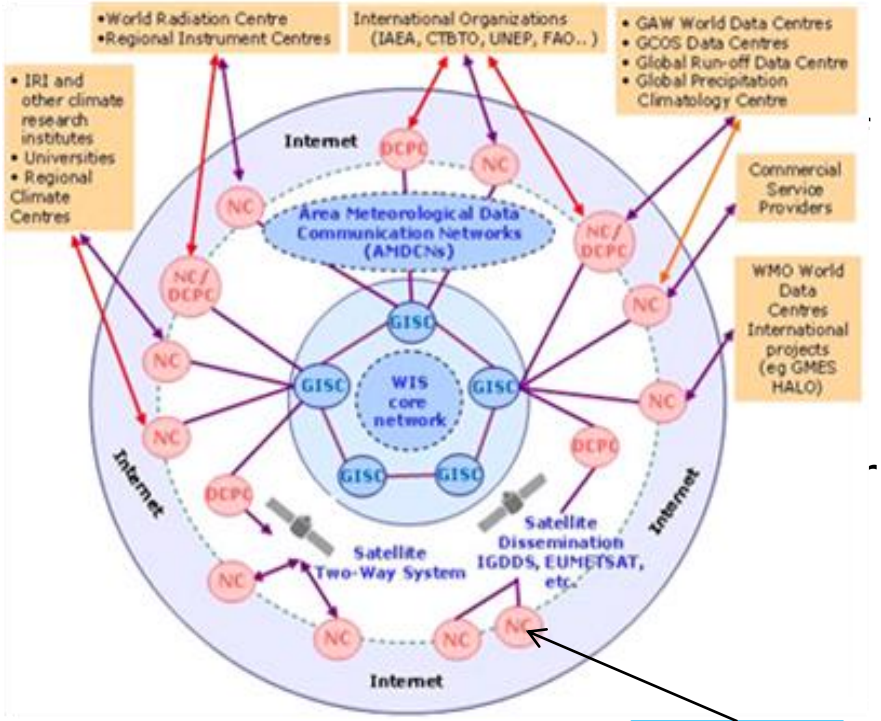
Models and observations

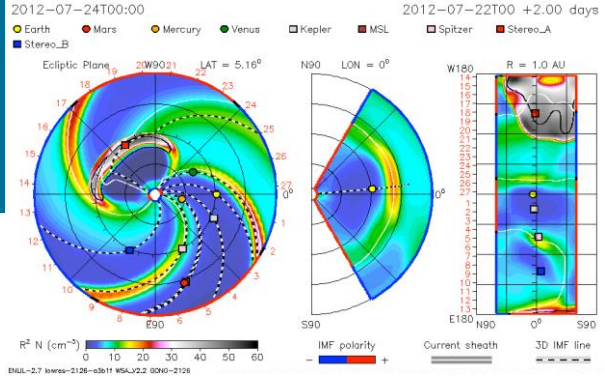
# Who is who

## Services

- NOAA Space Weather Prediction Center
- ISES International Space Environment Services
  - 15 members + ESA +Toulouse


- And many others……






# Importance of radio astronomy

- Detection radio flares
- Knowledge/models for ionospheric scintillation
- **Improving forecasting models by providing information about interplanetary density and magnetic field**
- Help developing the research component in NL (solar physics virtually non-existent): observations, modelling, technical knowledge infrastructures

(Inter)national partners: WMO, IAU, NOAA, ISES, SIDC, ESA

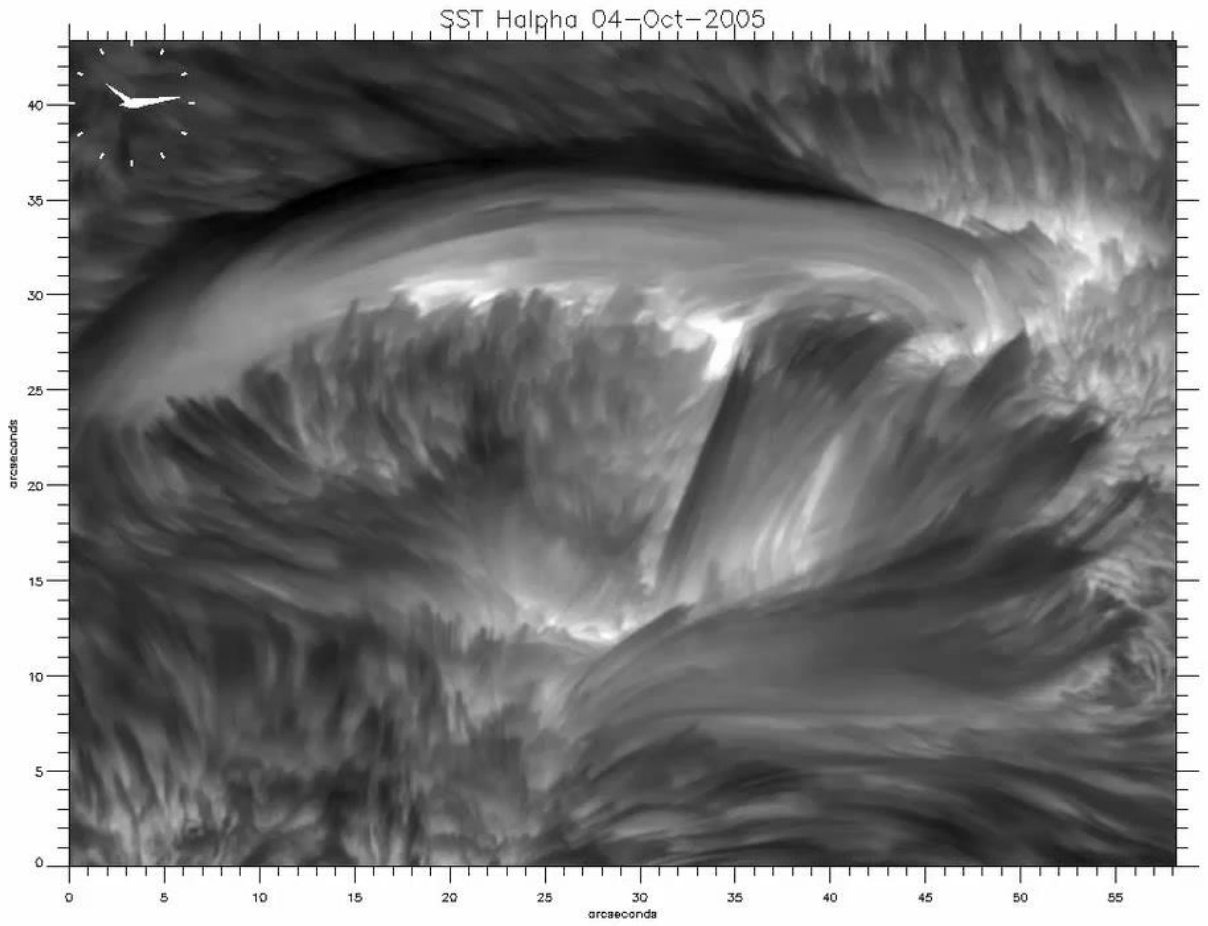
BACK OFFICE: research, product development, observations

Front office Military

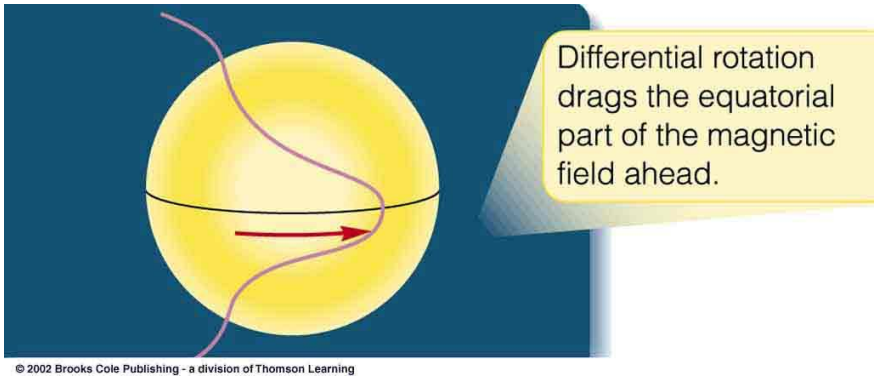
Front office Civil

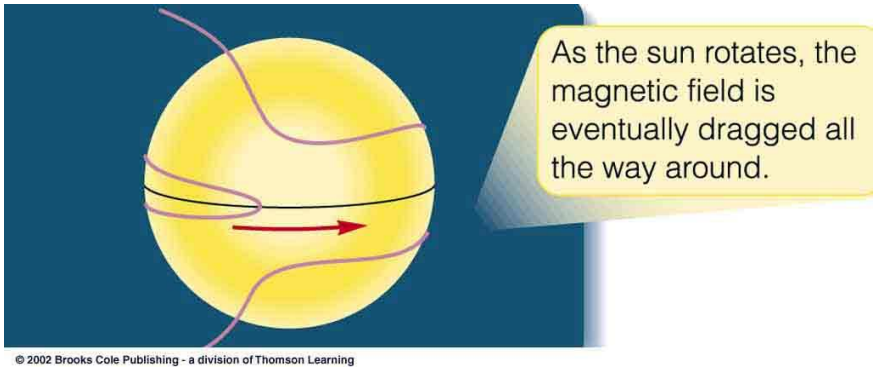
# BACK-UP SLIDES

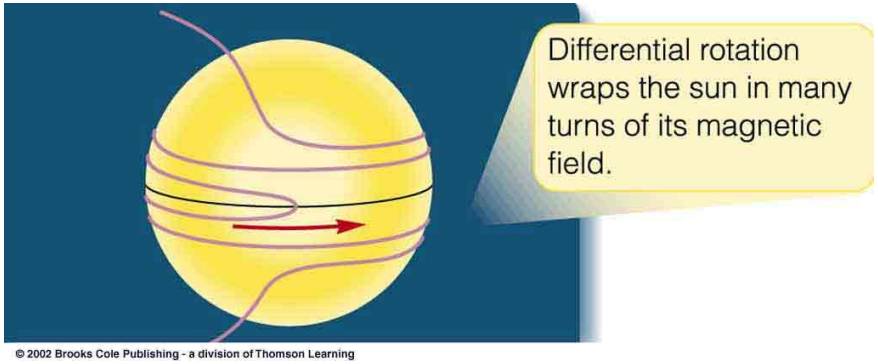
# Sun  spot – high resolution

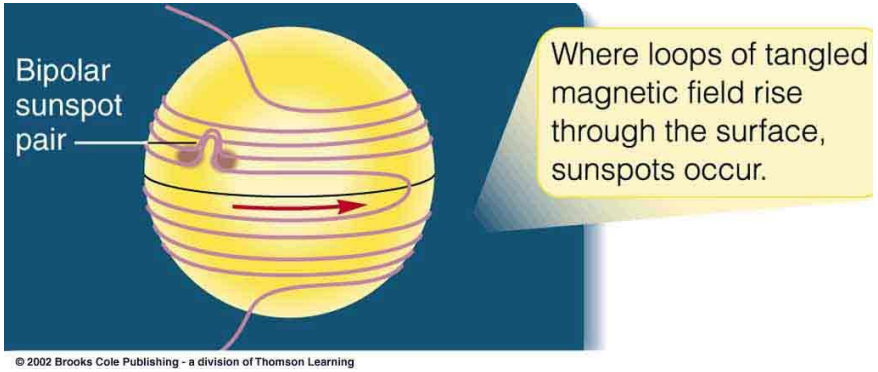


# Solar dynamo: 11-22 space weather cycle

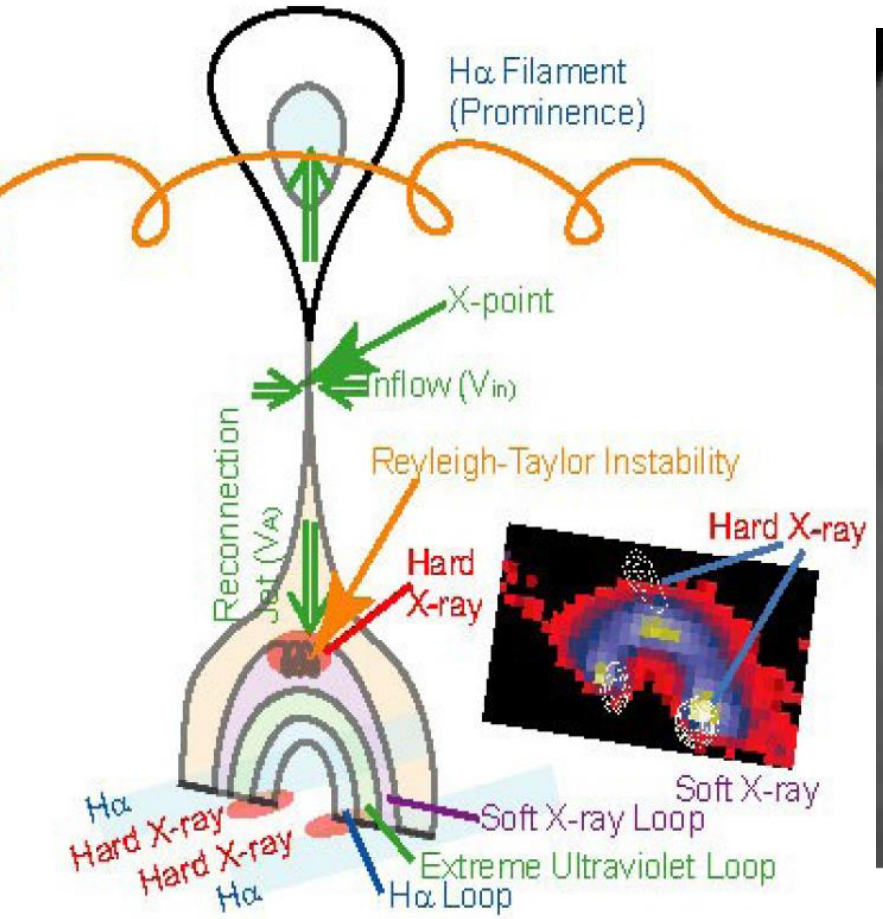


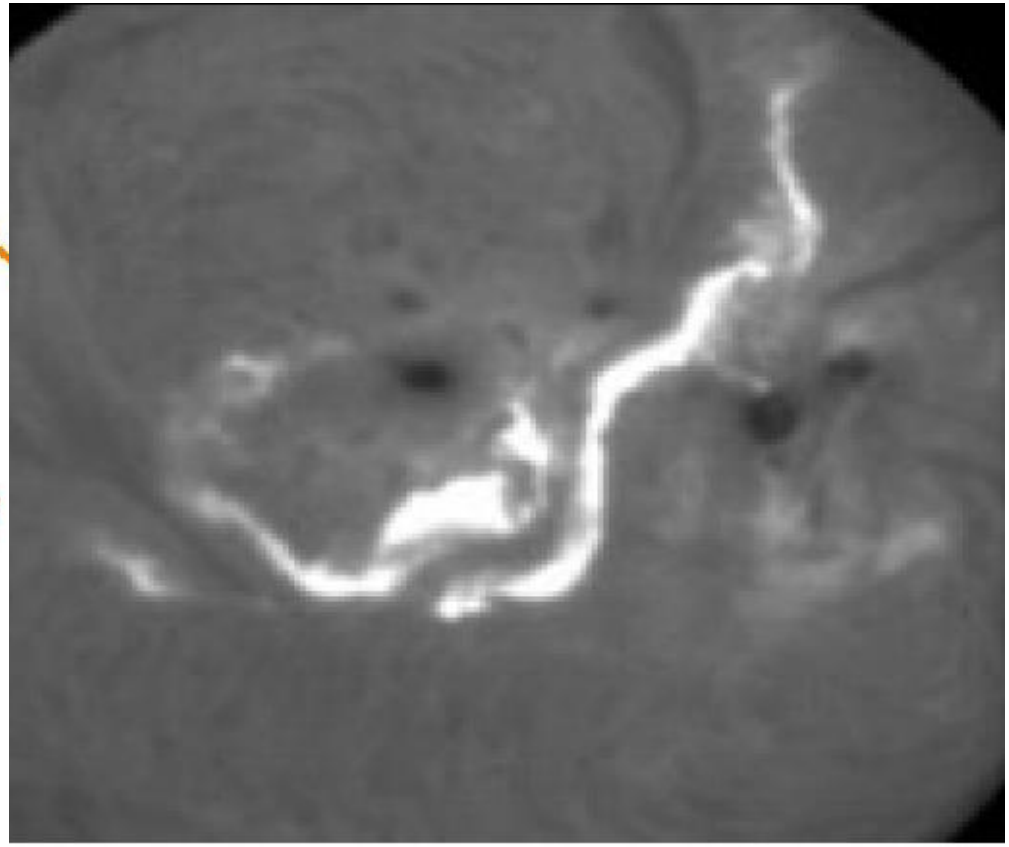



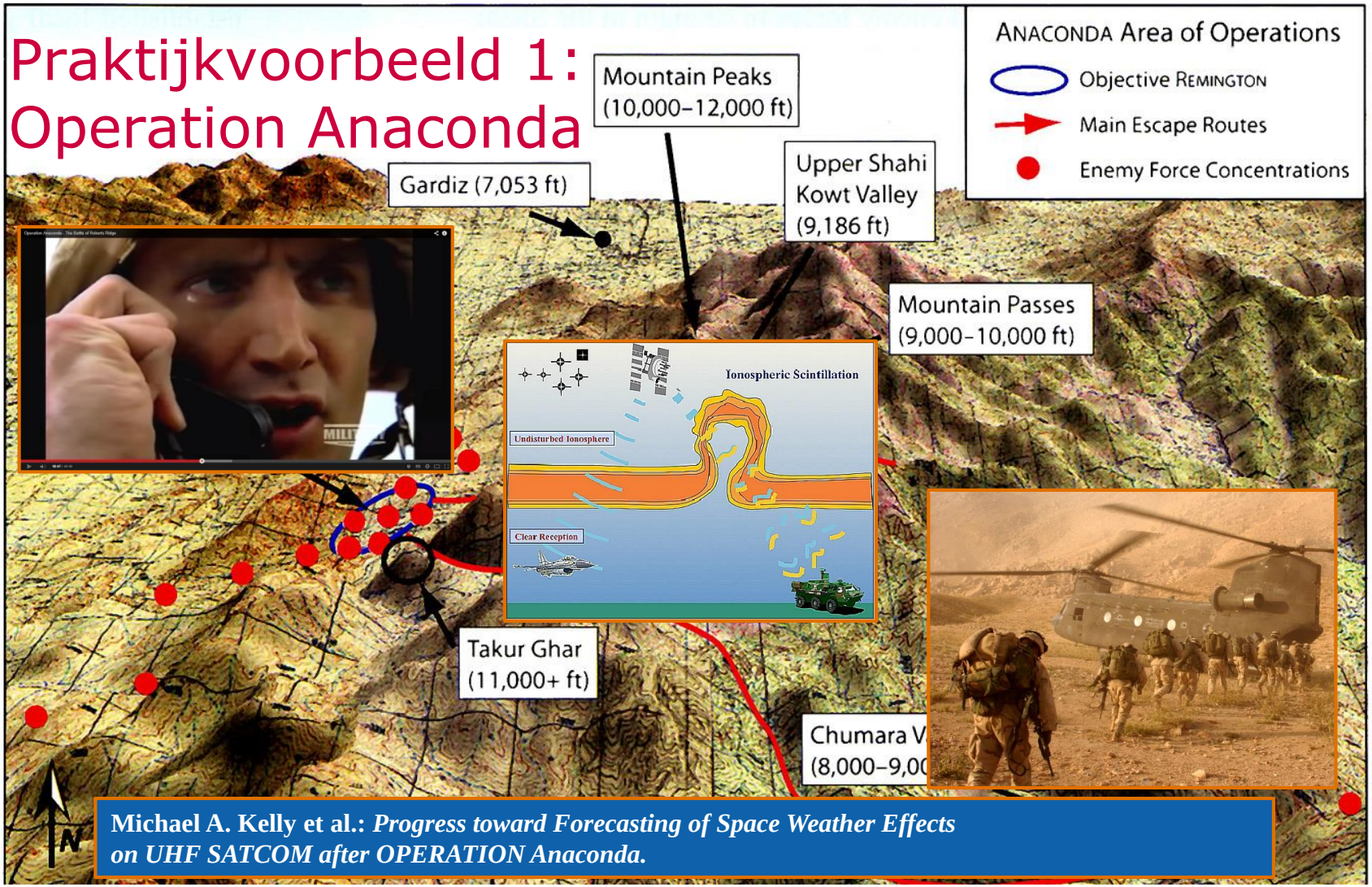
# Two ribbon flare



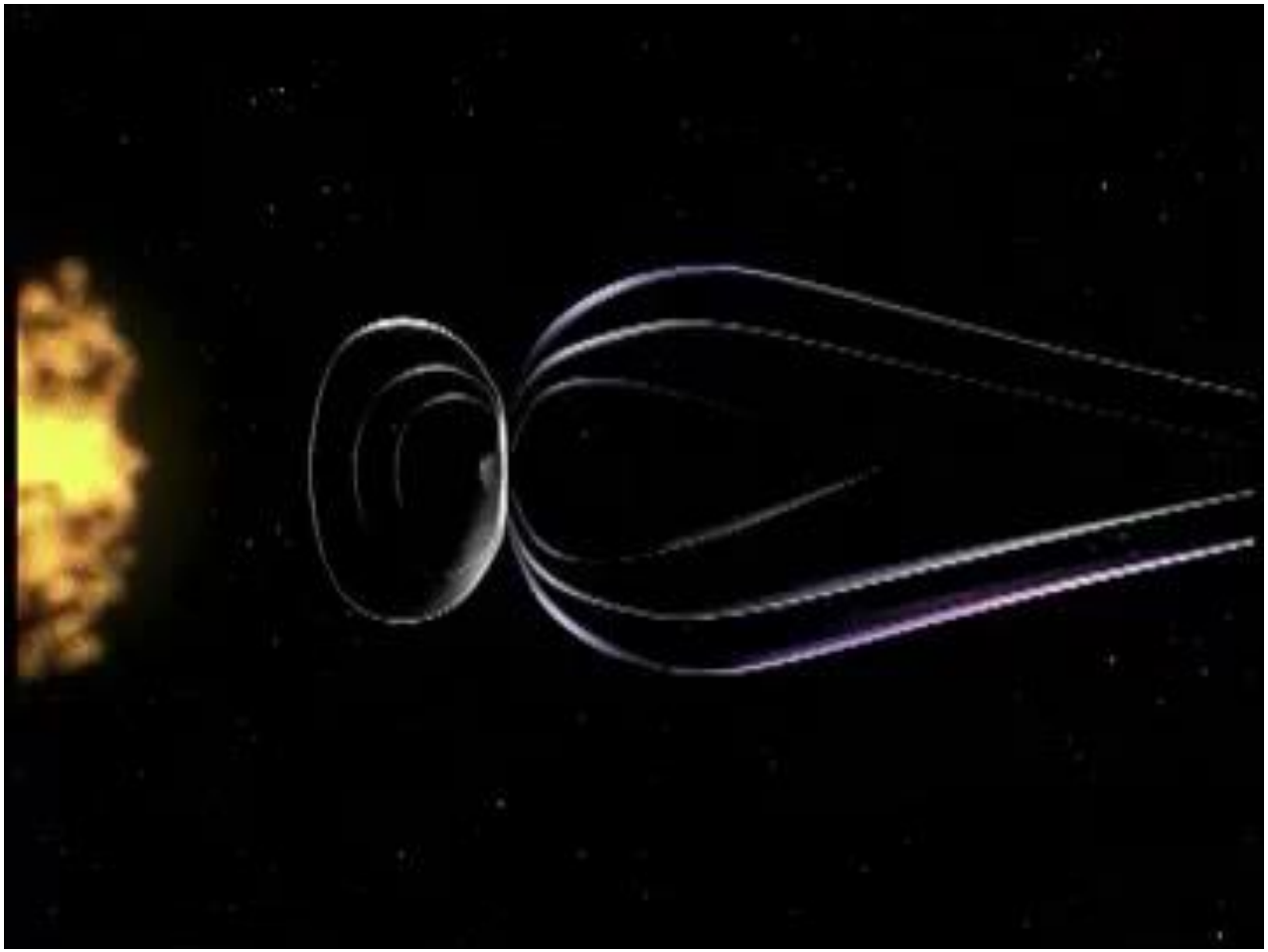
(Ribbon Flare)

# Praktijkvoorbeeld 1: Operation Anaconda

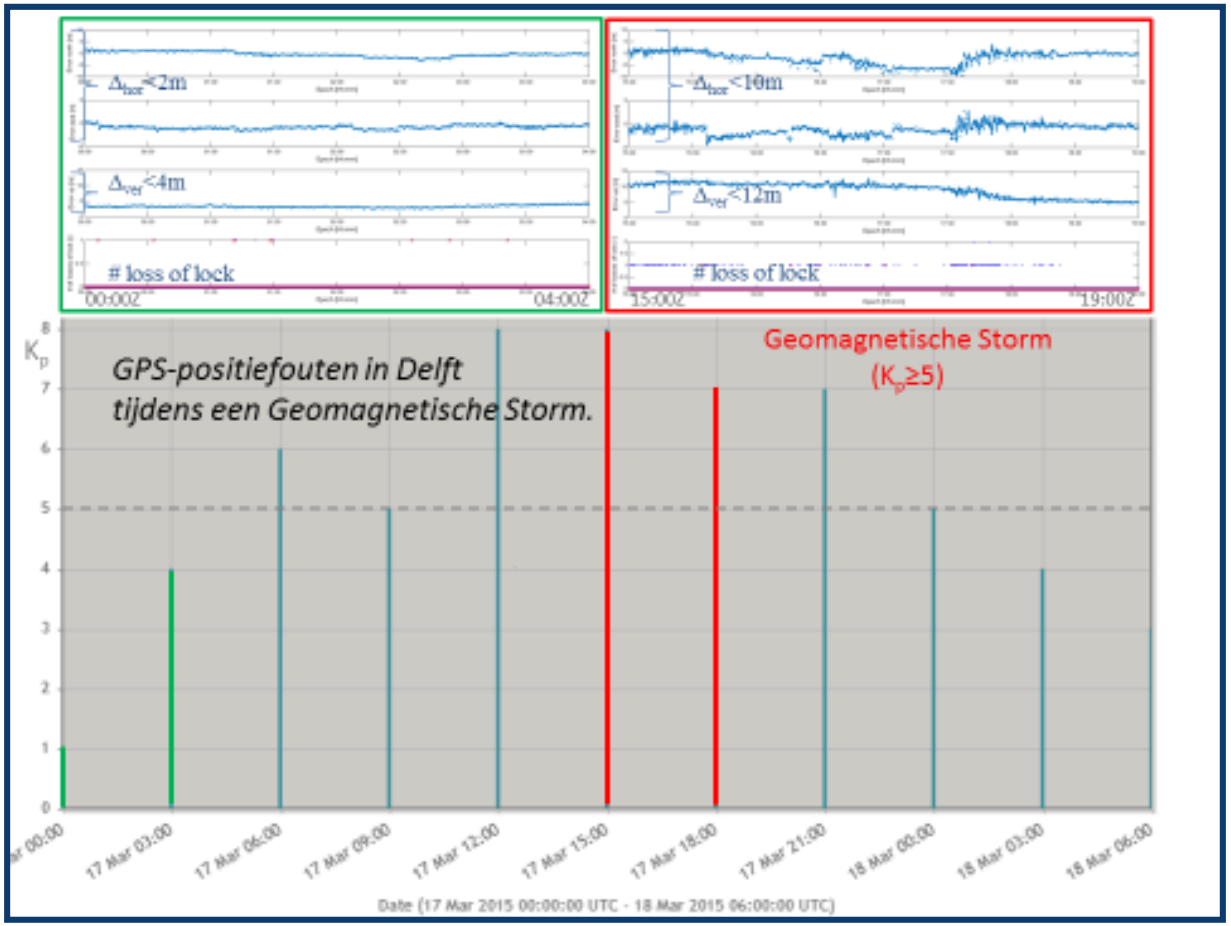



**Michael A. Kelly et al.:** ***Progress toward Forecasting of Space Weather Effects on UHF SATCOM after OPERATION Anaconda.***

# Aurora



# Geomagnetic Storm & GPS 17 March 2015 Delft

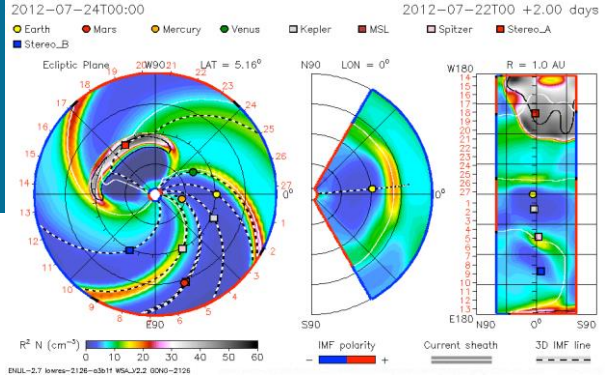



Credit: Barend Lubbers, Faculteit Militaire Wetenschappen

# July 23, 2012 event

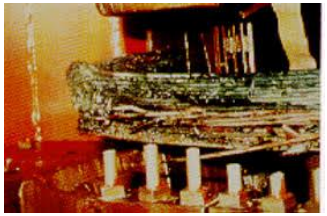
- If the huge solar eruption in 2012 had hit the Earth, the effects would have been so devastating that we'd still be recovering two years later, scientists working on several new studies conclude.
- A huge coronal mass ejection — a large cloud of hot plasma sent into space — erupted from the sun on July 23, 2012. The CME went through Earth's orbit, and had it happened only one week earlier, our planet would have been in the way and faced severe technological consequences.
- There would have been three waves of damage associated with the extreme solar storm. First, X-rays and ultraviolet radiation from the solar flare would have produced radio blackouts and GPS navigation errors. The second part would have seen satellites fried by energetic particles like electrons and protons, which arrived only minutes to hours later
- Finally, magnetized plasma from the CME would have struck our planet within the next day. Power blackouts could have been devastating
- - See more at: http://www.space.com/26669-huge-solar-storm-2012-destruction.html#sthash.8hsMYoVV.dpuf

# ESA simulation




## 23 July 2012 event reaches Earth scenario

- Day 0: detection active region
- Day 2-5: small disturbances in GPS, SATCOM, mobile communications
- Day 6:
  - disturbances mobile communication in direction of Sun
  - 11.13 UT GLE alert: Increased energetic particle levels (affecting IT systems)
  - 16:00 CME detected: forecast available at 19:00 UT: expected time of arrival 6:00 UT
  - disturbances in GPS, SATCOM, mobile communications
- Day 7:
  - Power outages, transformers smelt down/fire
  - all communication satellites in safe mode
  - extreme disturbances trans-Atlantic internet traffic for 48 hours
  - GPS services and SATCOM not available for 48 hours
- Day 8:
  - Power systems: High-latitude power systems may experience voltage alarms, long duration storms may cause transformer damage.
  - Spacecraft operations: all services affected by recovery/mitigation actions
  - Other systems: HF radio propagation can fade at higher latitudes, aurora observed throughout Scandinavia.



# User frequency NOAA services

SCHRIJVER AND RABANAL: SPACE WEATHER CUSTOMER SURVEY

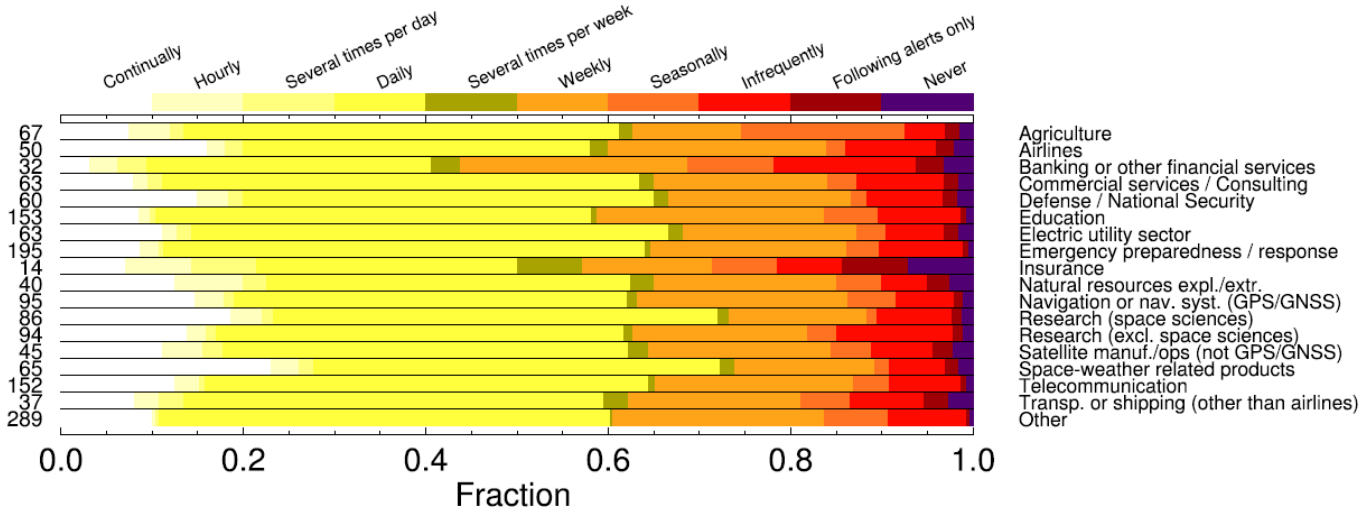
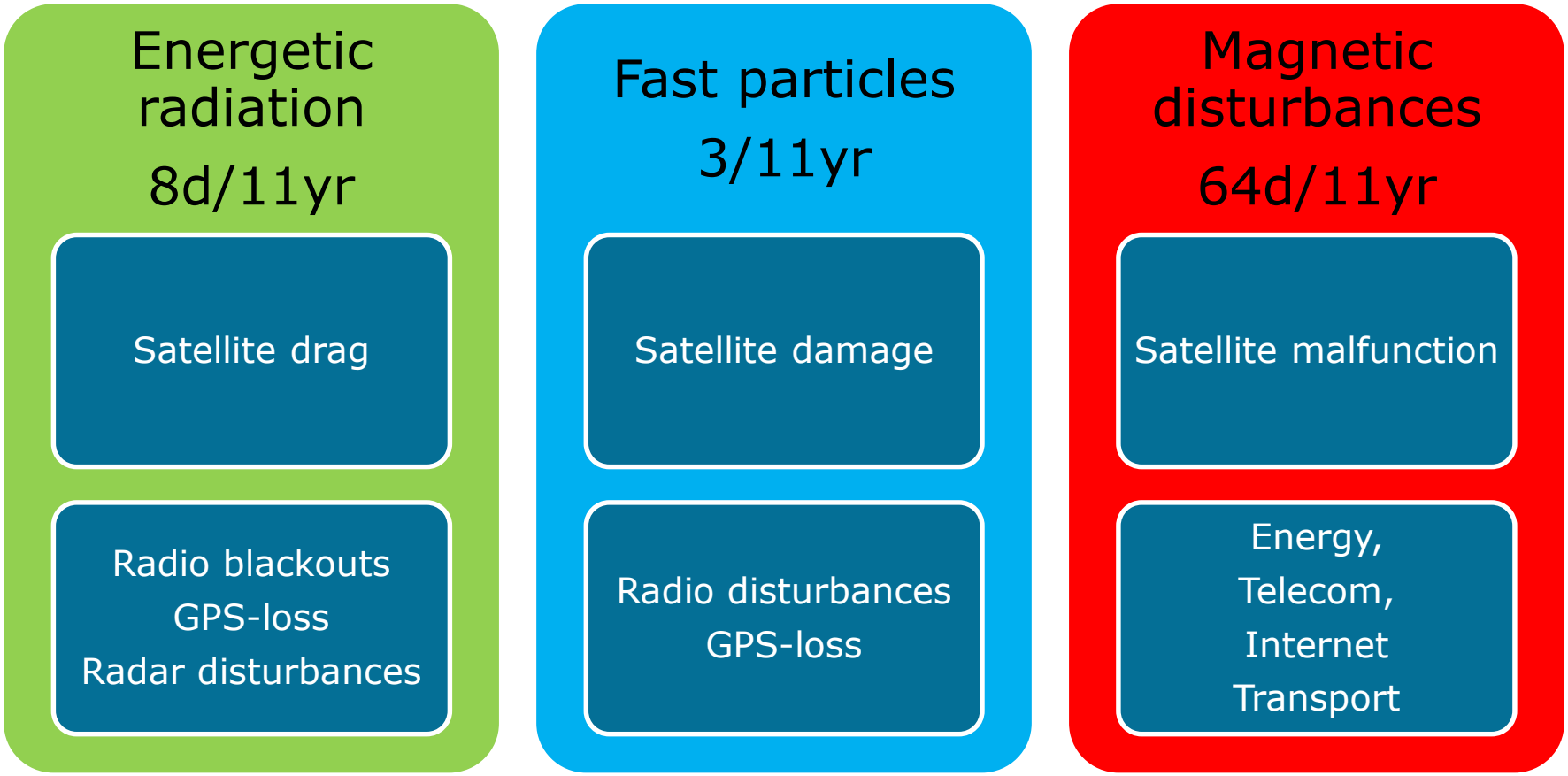
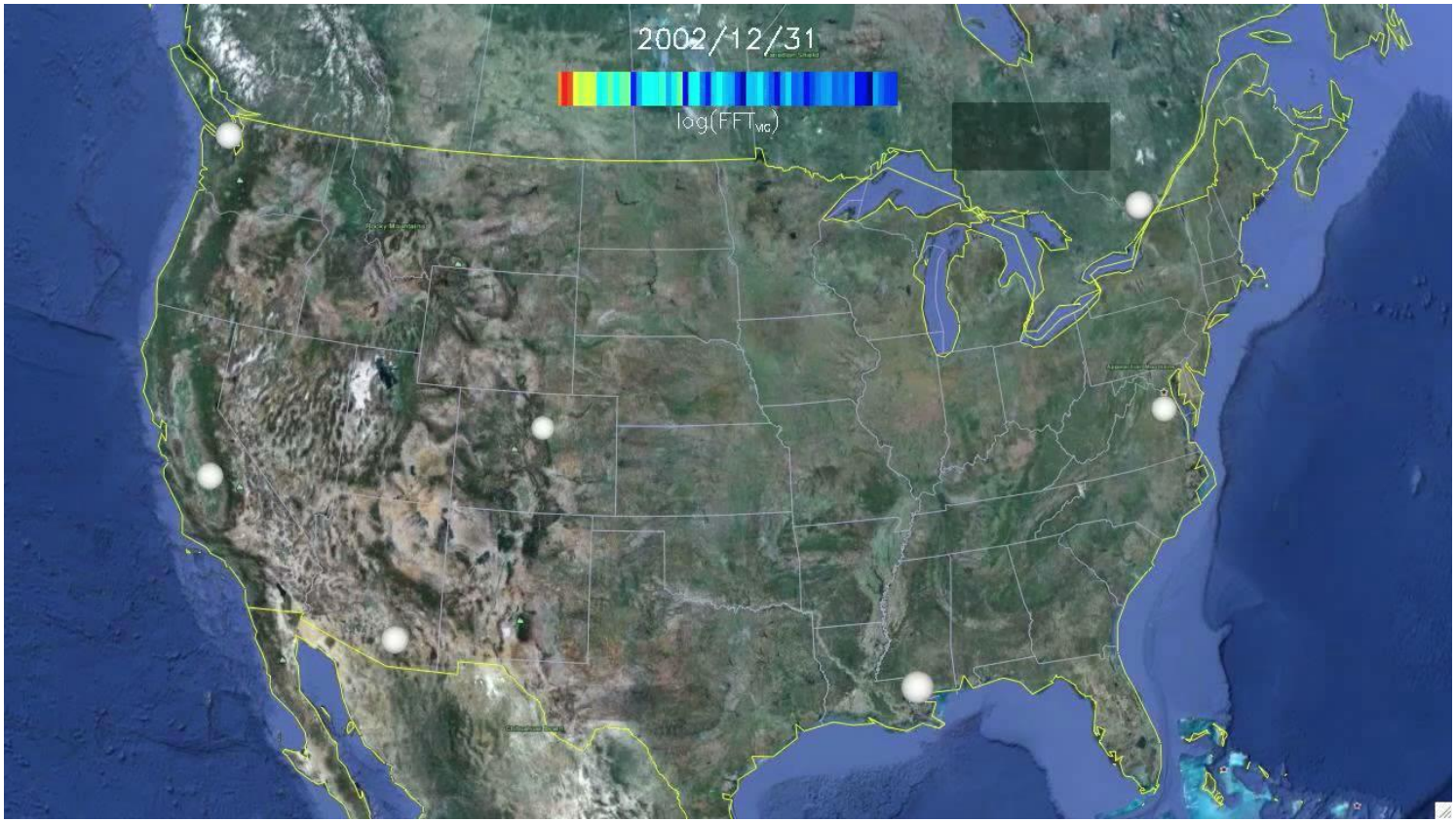



**Figure 5.** Monitoring frequency of space weather resources by societal sector.

# What sends the Sun towards us? (severe & extreme occurrences)

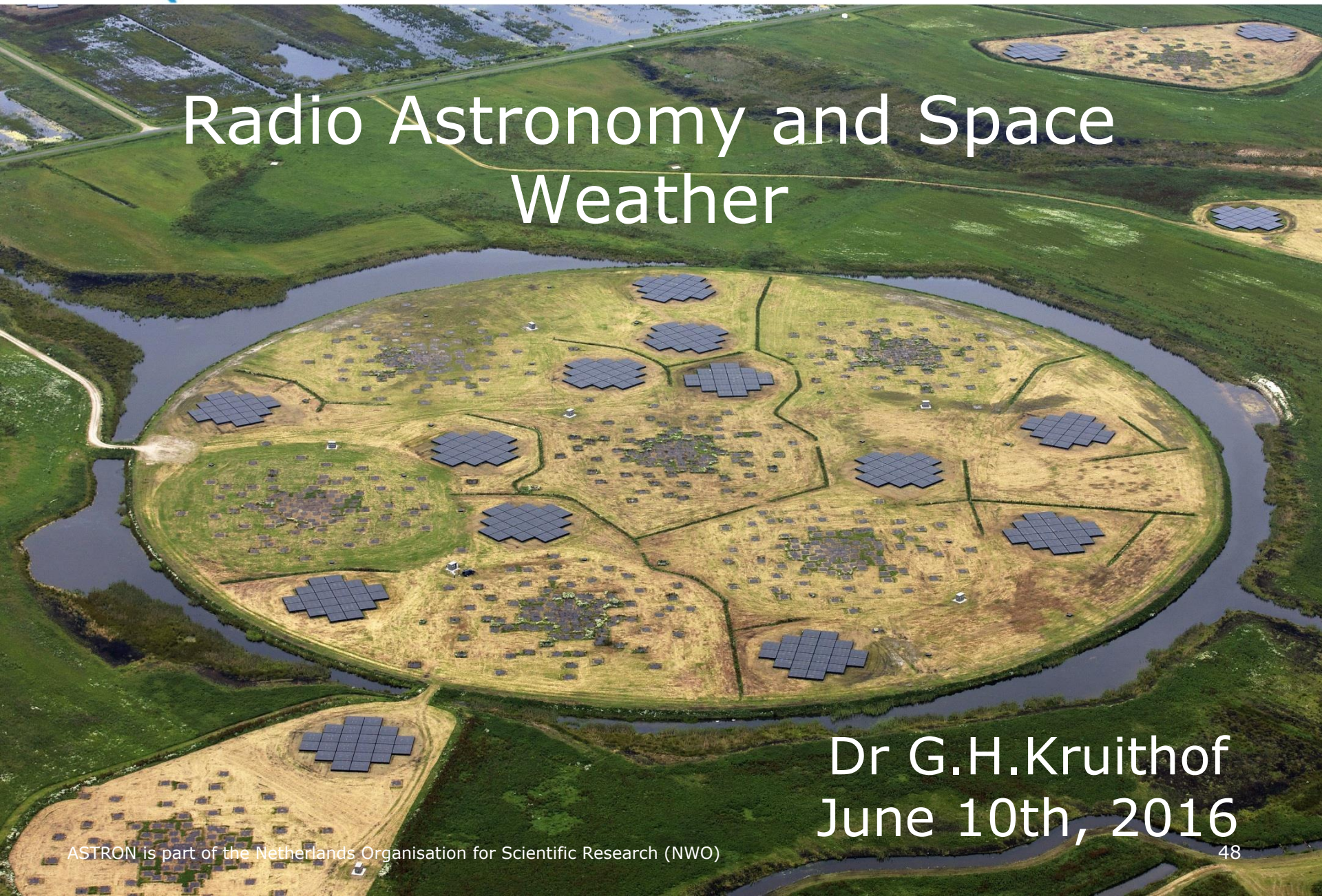


# Powergrid disurbances due to space weather 2013



ASTRON Netherlands Institute for Radio Astronomy

# Radio Astronomy and Space Weather



Dr G.H.Kruithof

June 10th, 2016

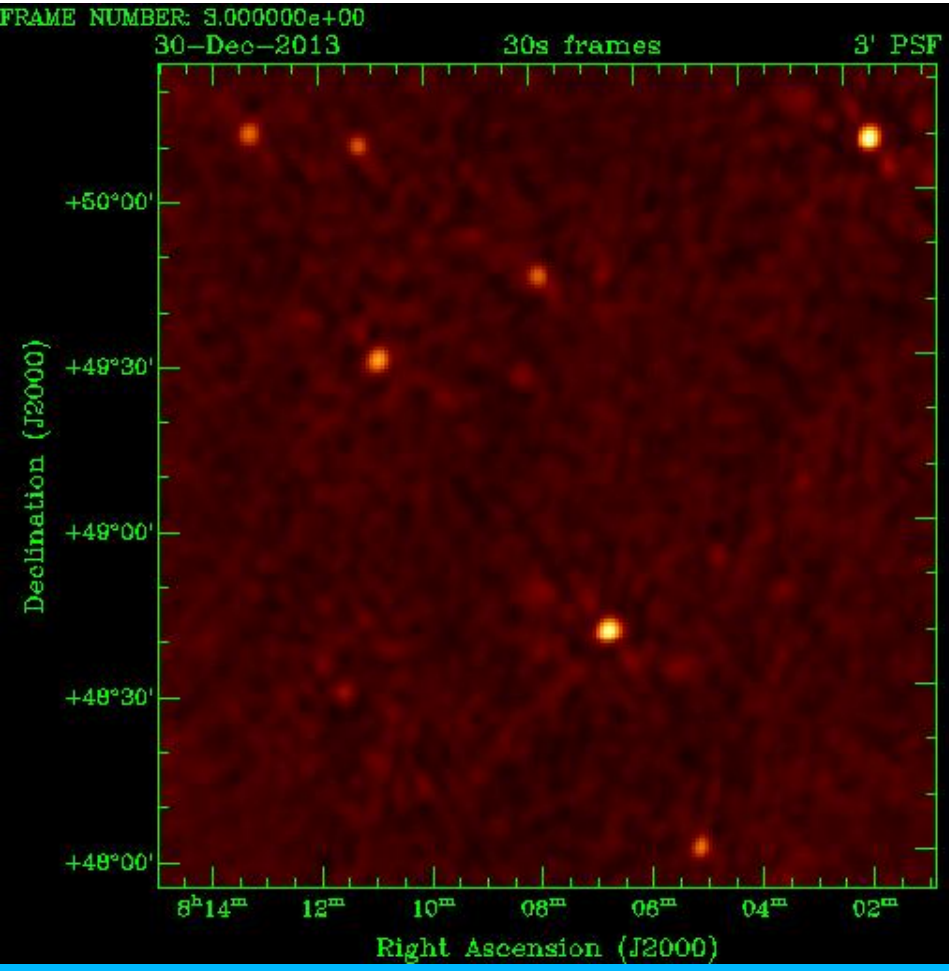
# Two interesting regions

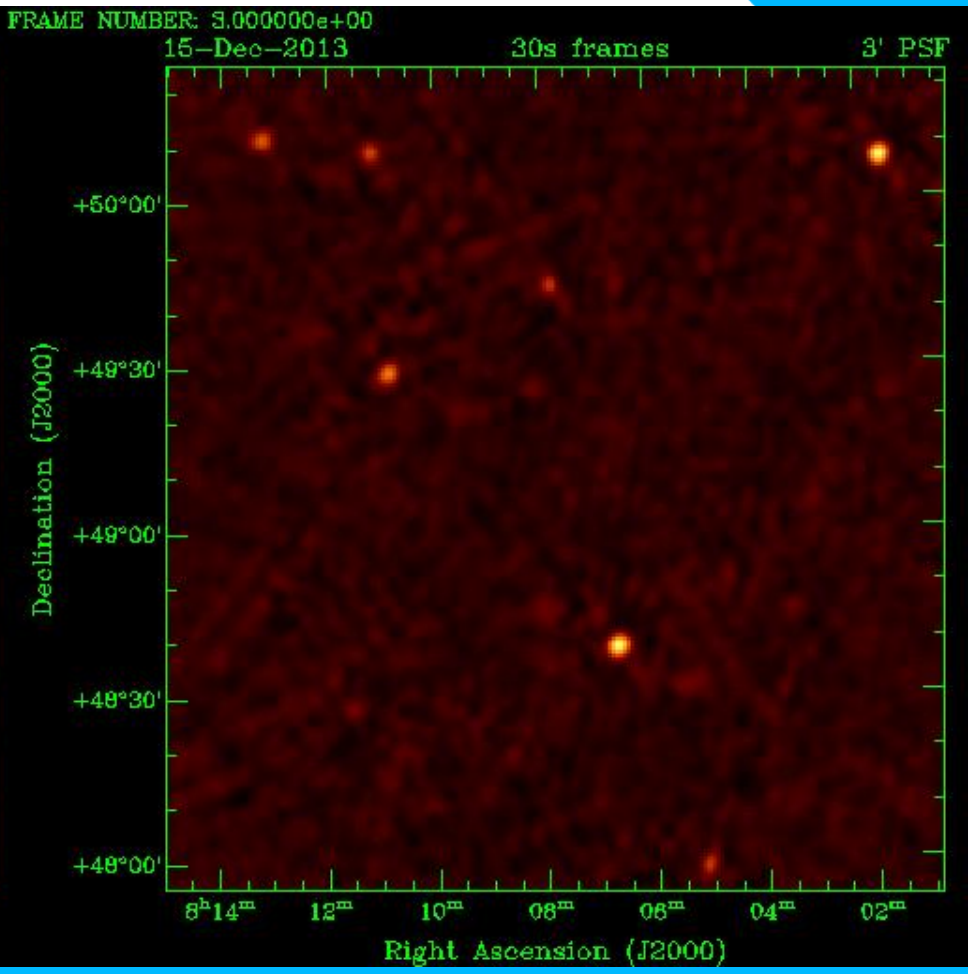
Ionosphere

Interplanetary Space

# On a very hot day

# Ionosphere on 2 different nights




"Quiet" ionosphere

Active ionosphere

# Ionosphere above Australia

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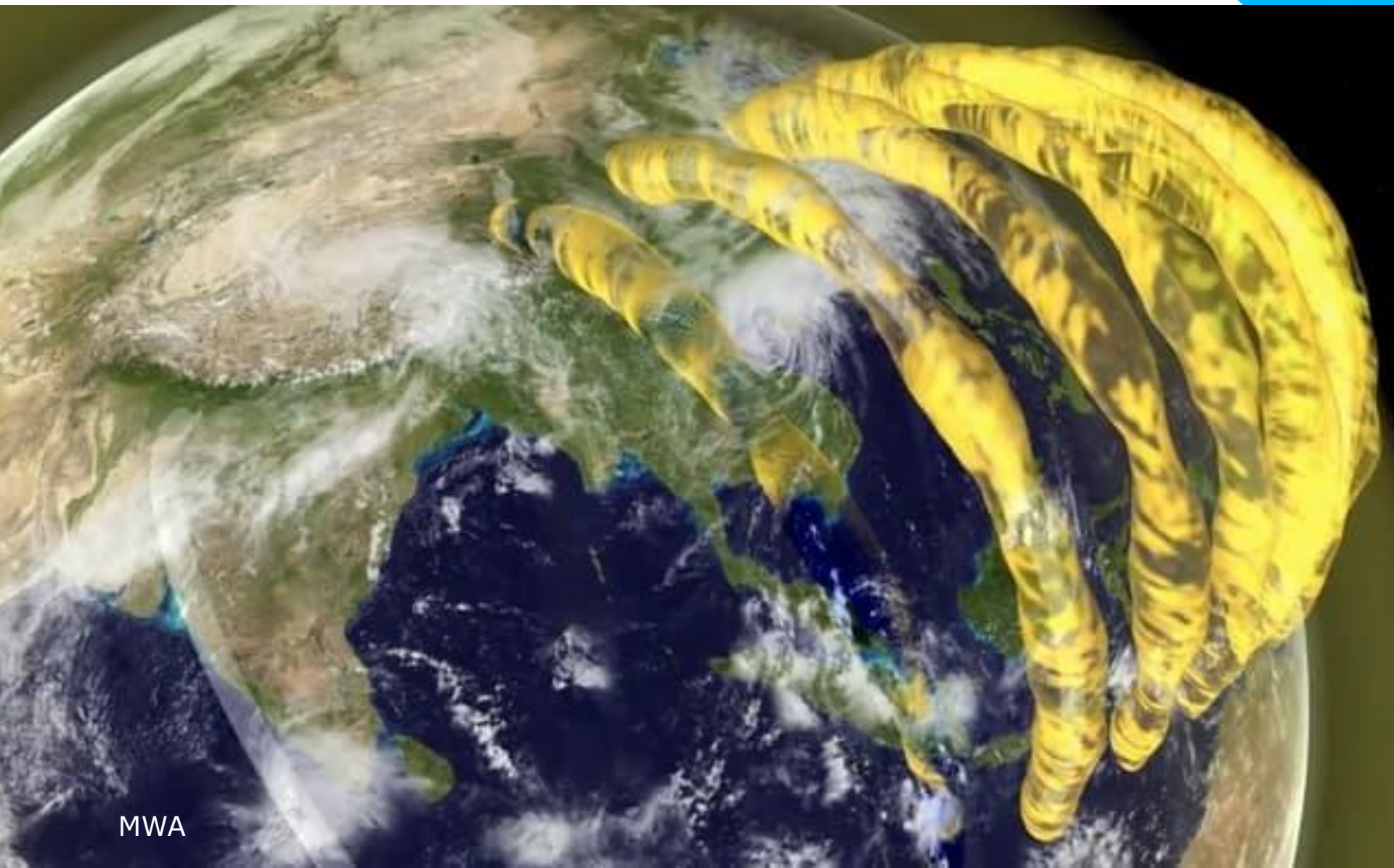
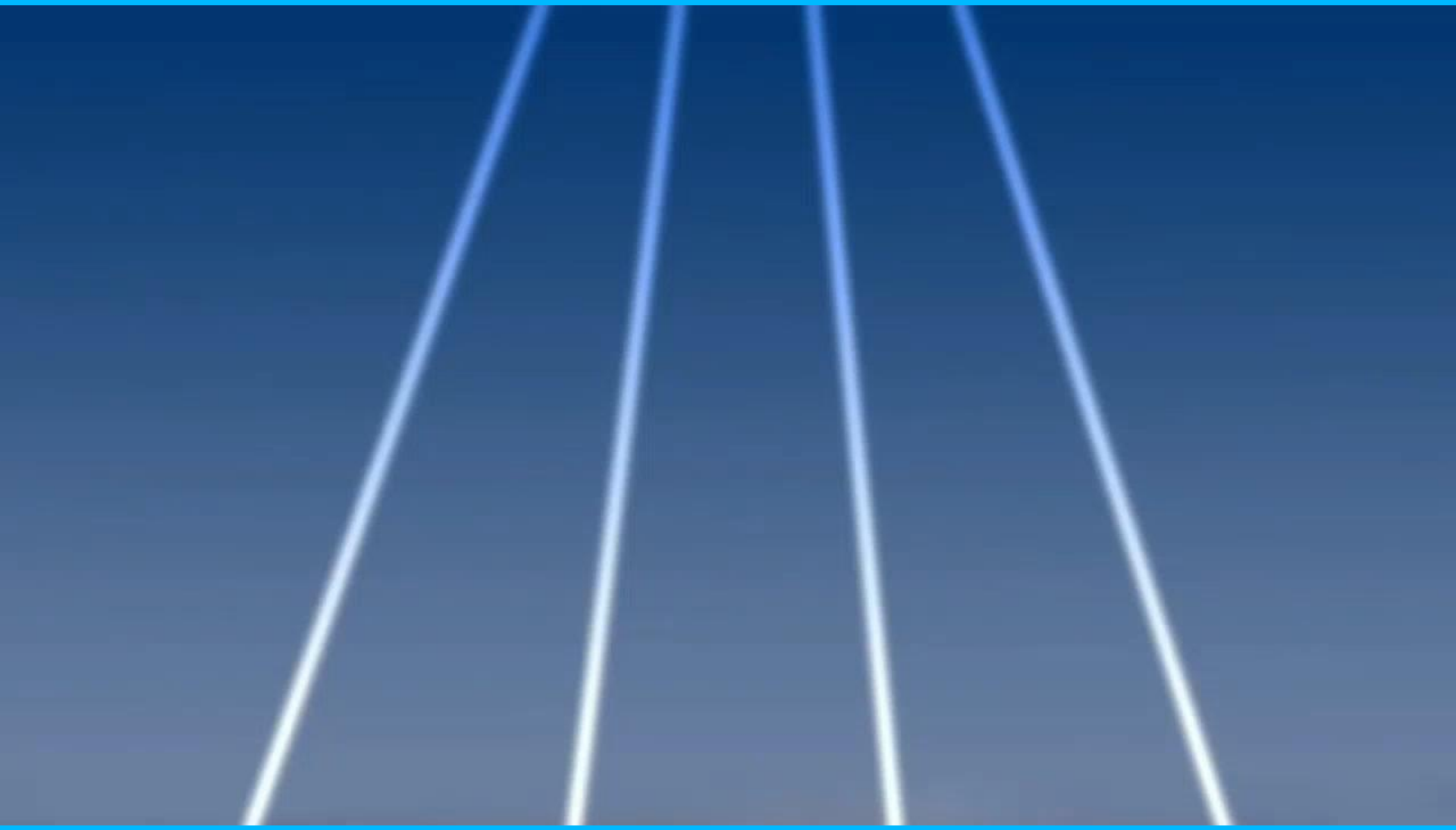
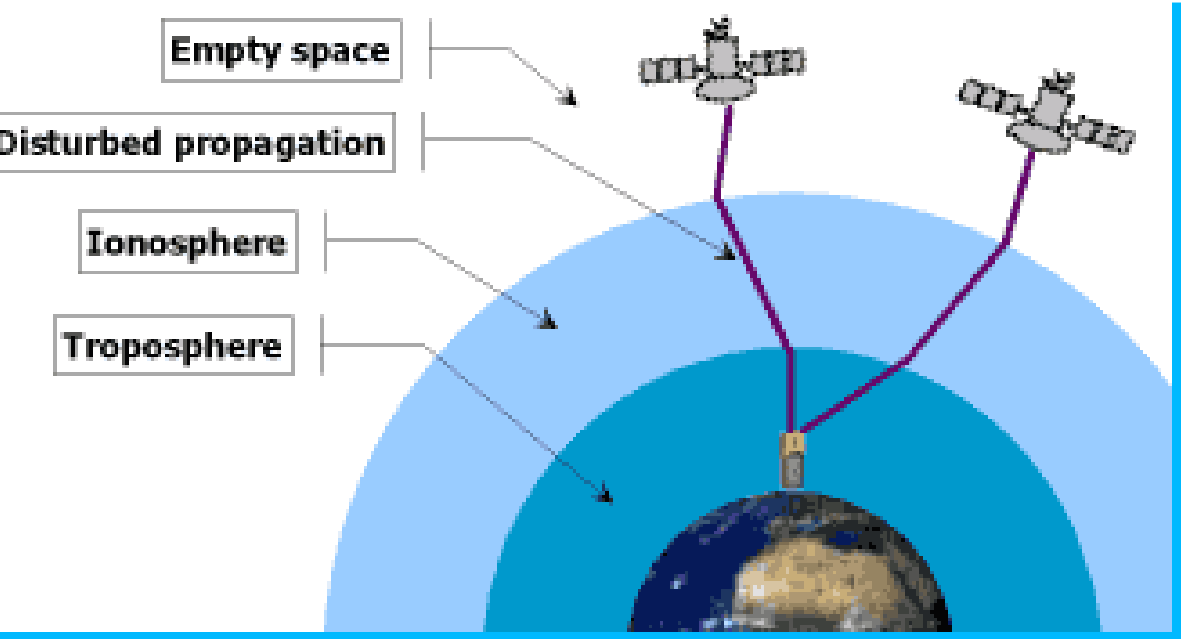


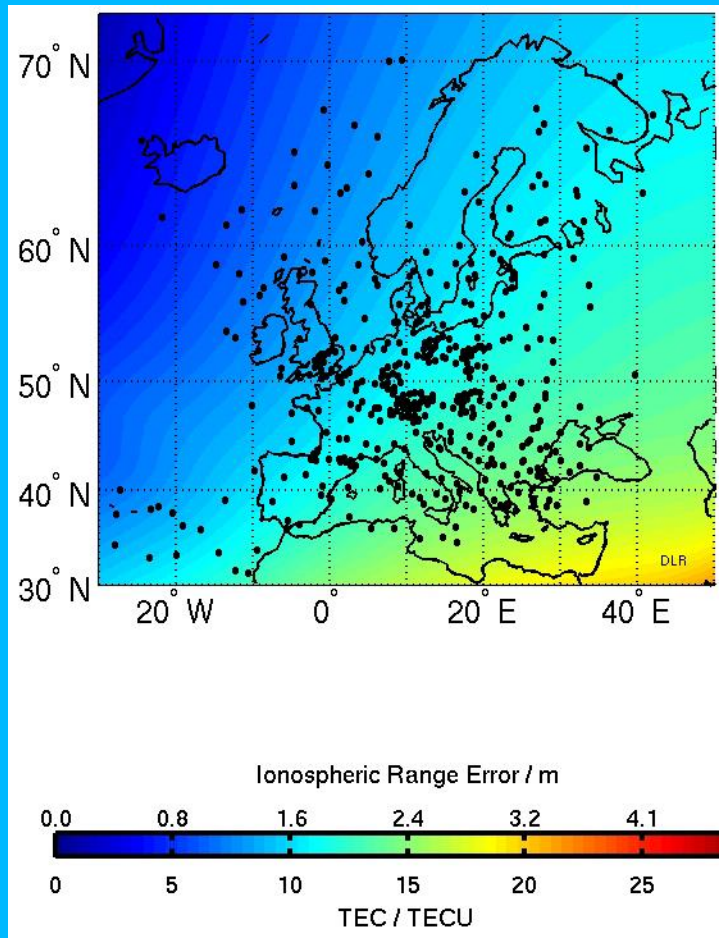


# Navigation errors




Object is apparently
on a different position

## Positioning errors



# Using LOFAR Calibration:
## Ionospheric correction for each “patch”

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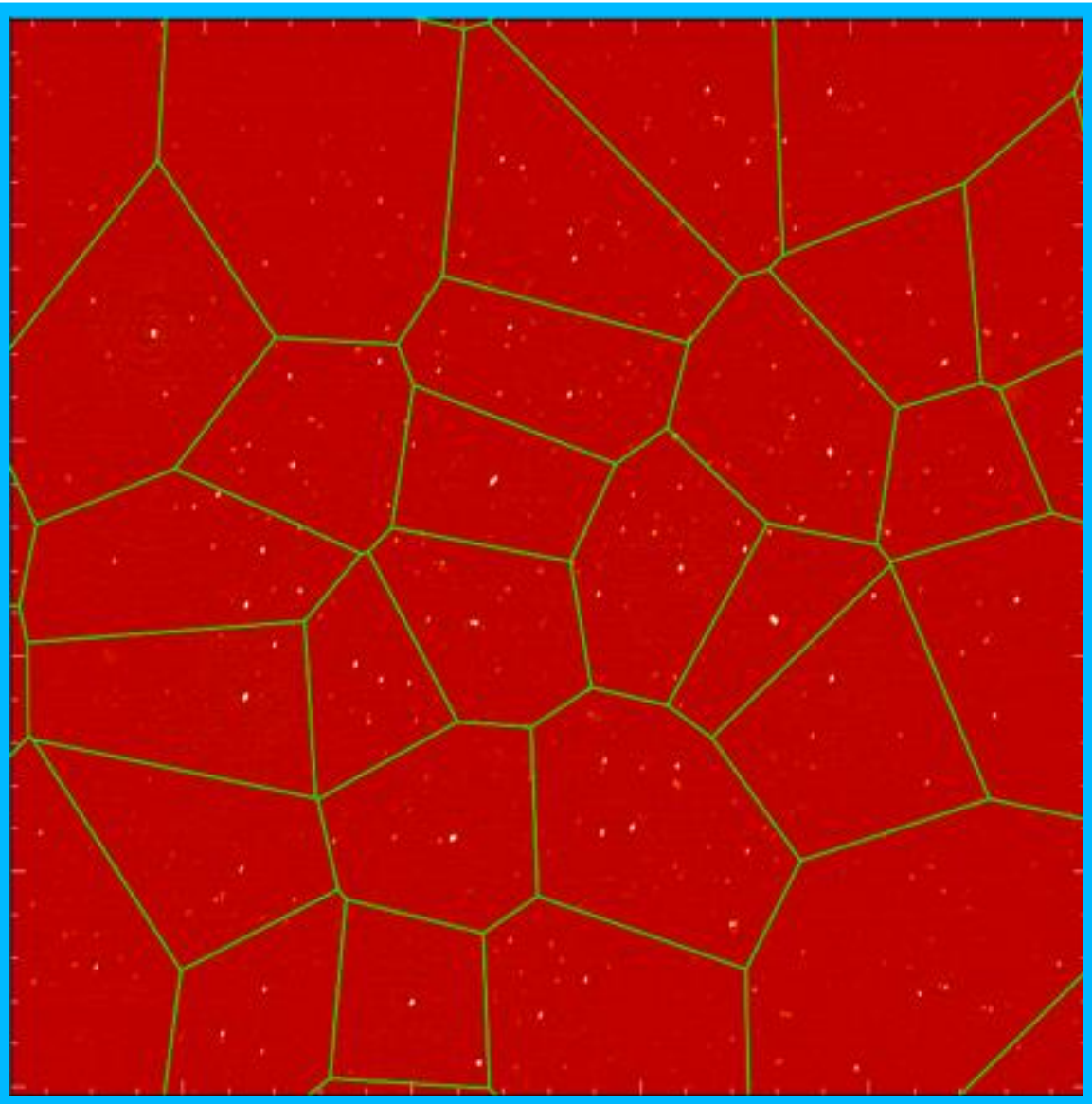


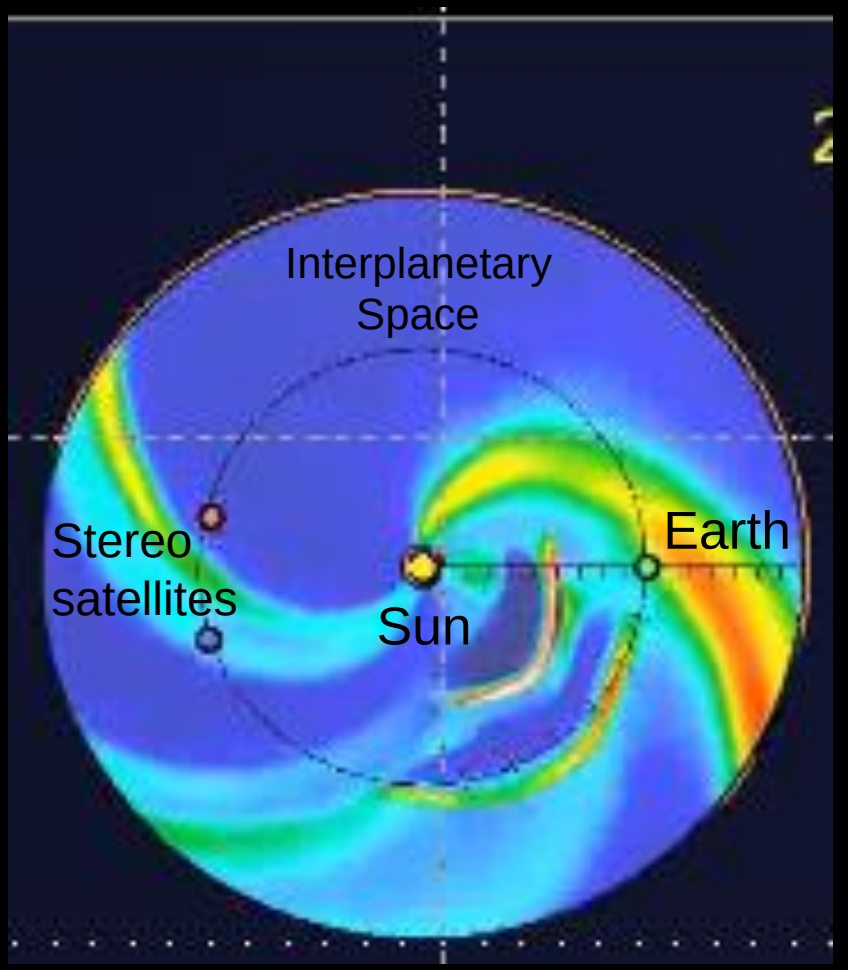
⇒ Ionospheric Models

# Solar Weather

Accurate **observation** and modelling of **solar wind** and **magnetic field** essential to forecasting impact on geospace environment.

# State of the art in Space Weather prediction

- Only data from solar surface
- No data from Interplanetary Space
- Propagation is only a model
- Prediction times:
  ~1 – 3 days +/- 6 hours



# Solar Weather with LOFAR

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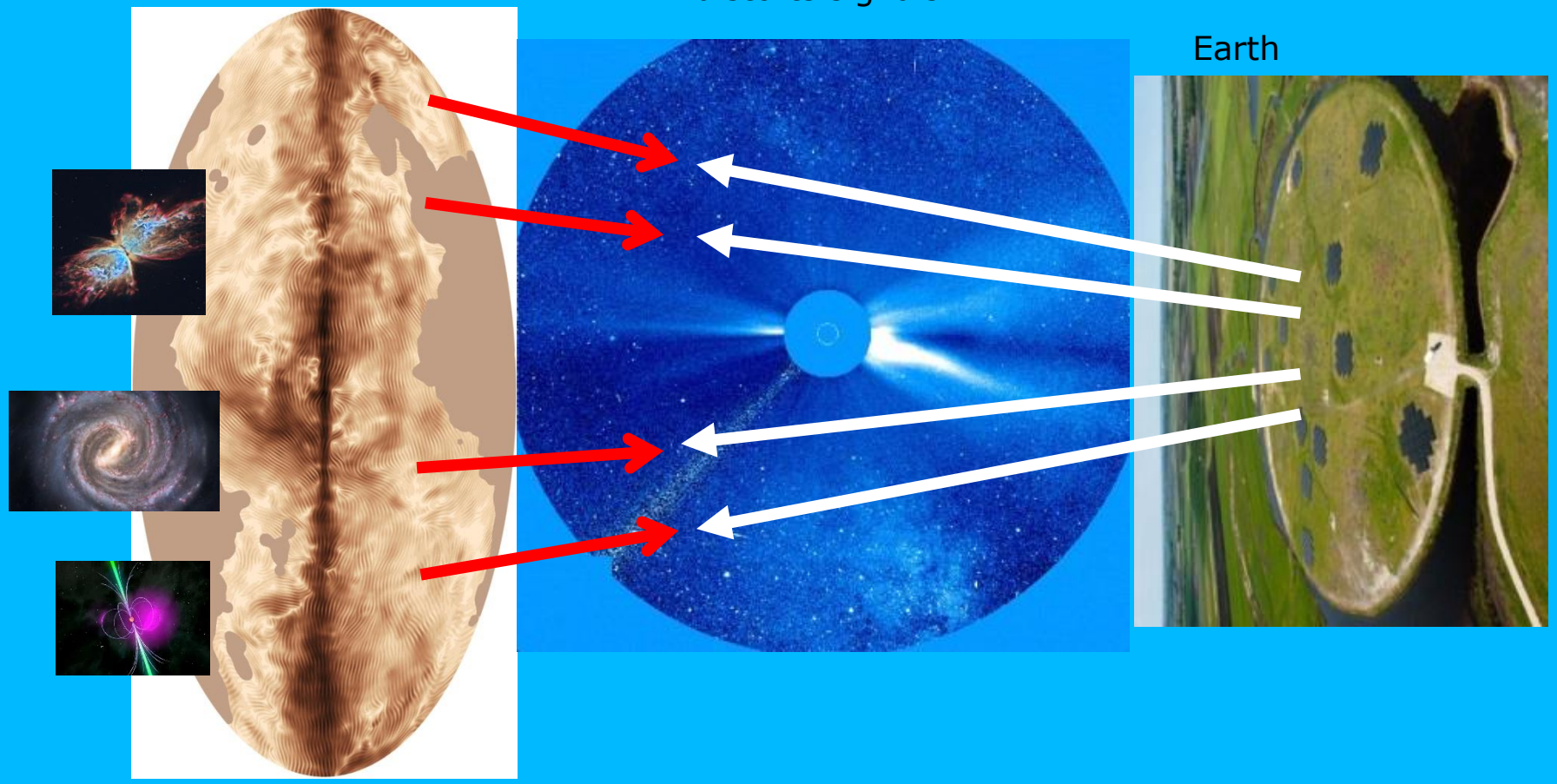
Milky Way
Nebulae
Pulsars

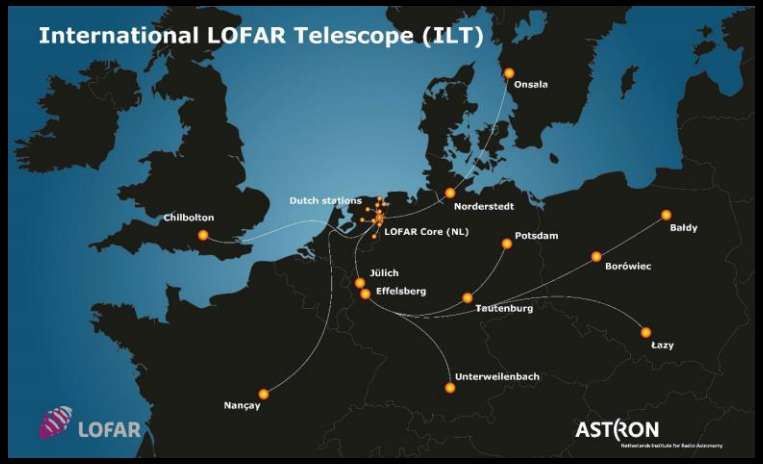
Solar wind
distorts signals

Earth



# Why LOFAR?

- Low-Frequency (100 – 300 MHz)
- Scintillation: Baselines of hundreds of kms.
- Faraday rotation: large collecting area
- Multibeaming
- Only one instrument in the world: LOFAR
- 90% in Netherlands, operated by ASTRON
- Space Weather and Radio Astronomy synergistic



# Radio Observations – Observing the Solar Wind to Earth-Orbit

Solar wind velocity

Solar wind density

# Space Weather:

ASTRON

- Very important for society and economy
- Many opportunities for industry
- NL has a very powerful combination in KNMI, ASTRON and NLR
- Working on Dutch subscription on ESA SSA program
- Focus on national organization, services, instrumentation
- Space weather combines civil and military needs