Extreme Space Weather Impact on Critical Infrastructure

Gábor FACSKÓ[1,2], Gergely KOBÁN[1,3], Nikolett BIRÓ[1,3], Munkhjargal LKHAGVADORJ[4]

[1]Wigner Research Centre for Physics, Department of Space Physics and Space Technology, Budapest, Hungary

facsko.gabor@wigner.hu

[2]Milton Friedman University, Department of Informatics, Budapest, Hungary

[3]Eötvös Loránd University, Doctoral School of Physics, Budapest, Hungary

[4]Eötvös Loránd University, Faculty of Science, Budapest, Hungary

Security, Defence and Outer Space International Conference, Budapest, Hungary, May 9-10, 2023

Objectives

- Definitions and clarifications
- Introduction to space weather
  - Magnetic activity on our star
  - Flares and coronal mass ejections
  - Solar wind and solar wind streams
  - Terrestrial magnetosphere and aurora
- Extreme Space Weather impact on critical infrastructure
- Carrington Event
- Impact of a Carrington sized event nowadays
- Summary and TODO list

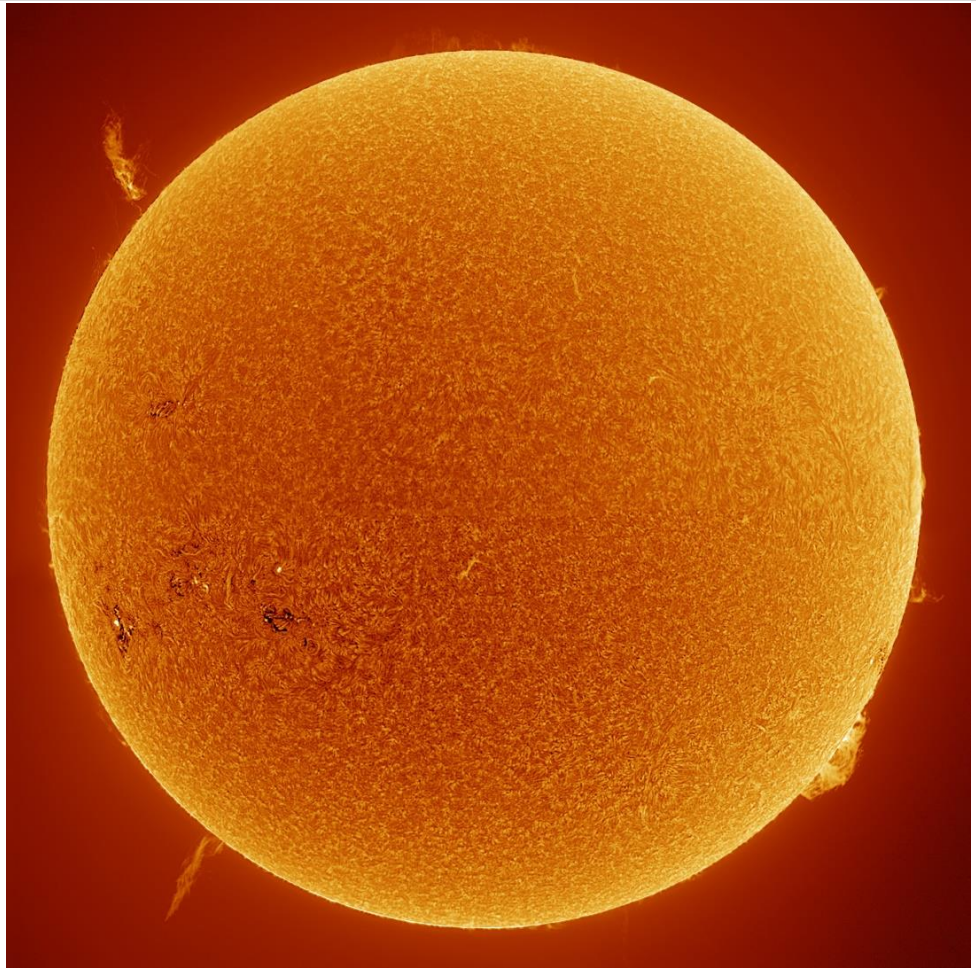
Definitions and Clarifications

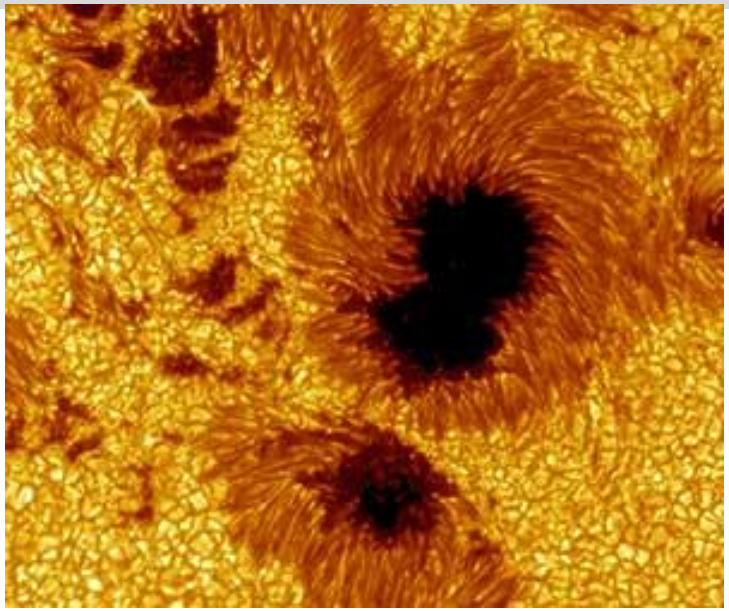
- Space Weather
  - A new(er) name of solar-terrestrial relationship
  - Predictions of the conditions of the near Earth cosmic enviroment
- Critical Infrastructure
  - Submarine internet cables
  - Gas pipelines
  - Transmission lines
  - Overhead wires
  - Transformers
  - GNSS navigation
  - Satellite telecommunication systems status
  - HF radio telecommunication systems

Long, conductive objects

Ionosphere (upper atmosphere)

Introduction to Space Weather

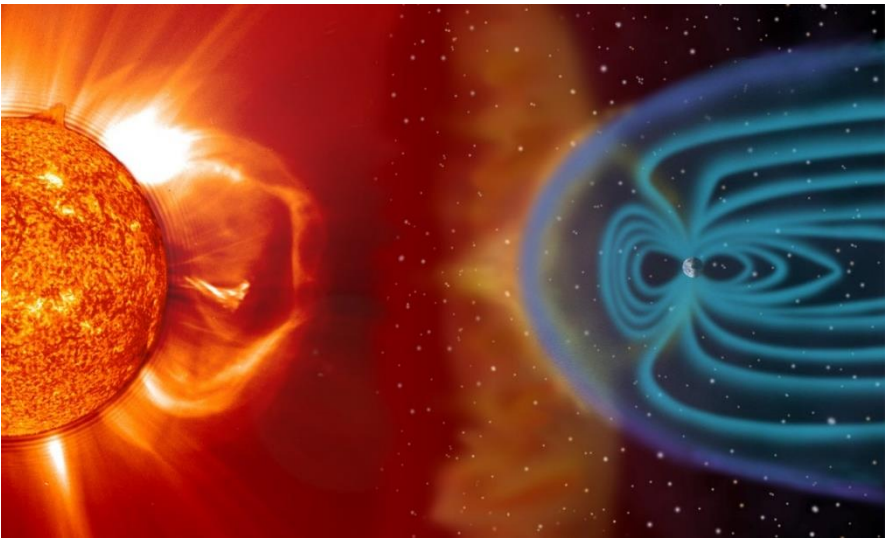


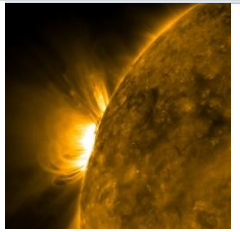


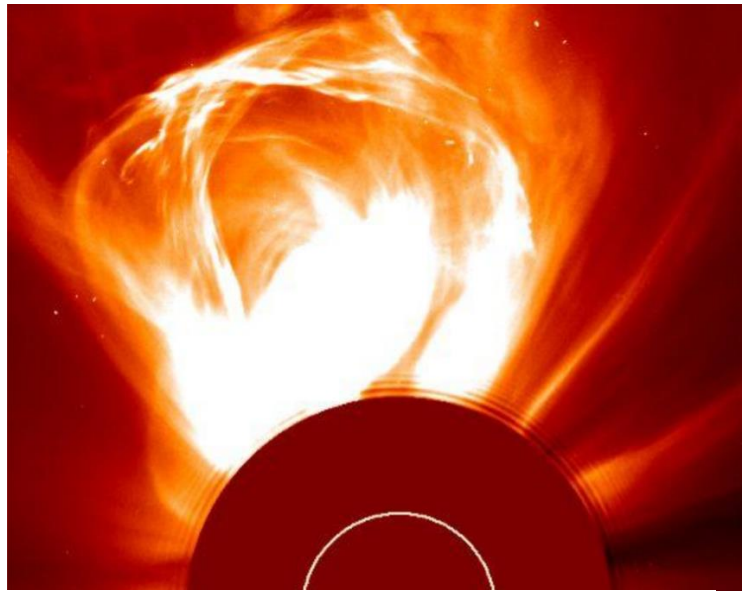
- We have an aggressive and dominant neighbor: the Sun
- Our star has magnetic activity and dominates the space nearby (solar wind)
- Its magnetic activity makes serious disturbances in the navigation and the communication

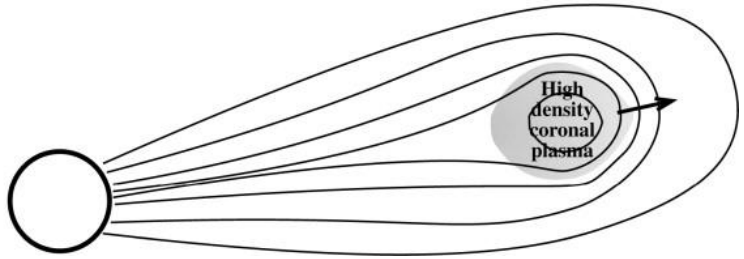
Credit:
https://www.timeanddate.com/eclipse/total-solar-eclipse.html, https://csillagtura.ro/.
https://tavcso.hu/galeria/1002555, http://csillagaszat.hu

Introduction to Space Weather – cont'd





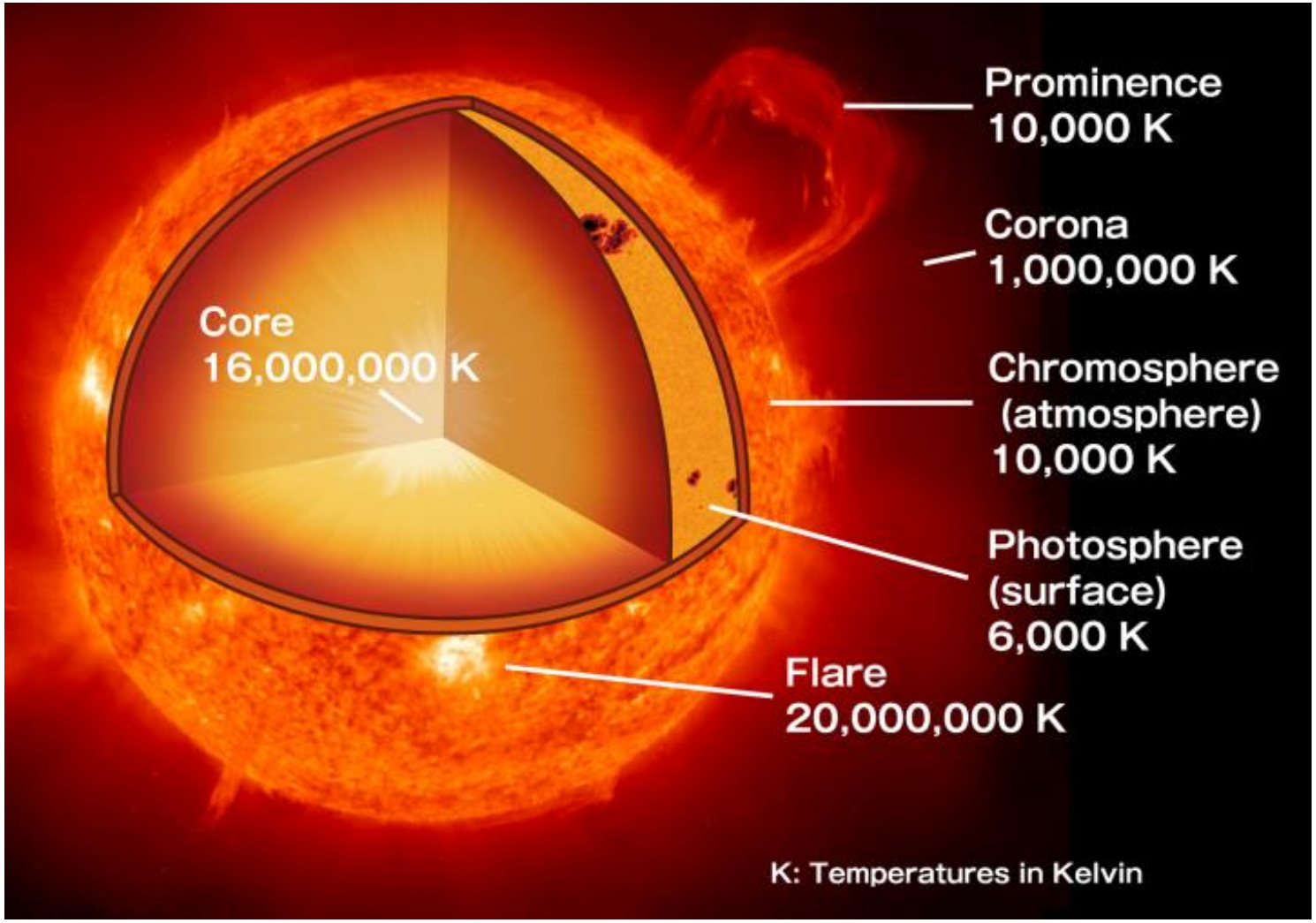


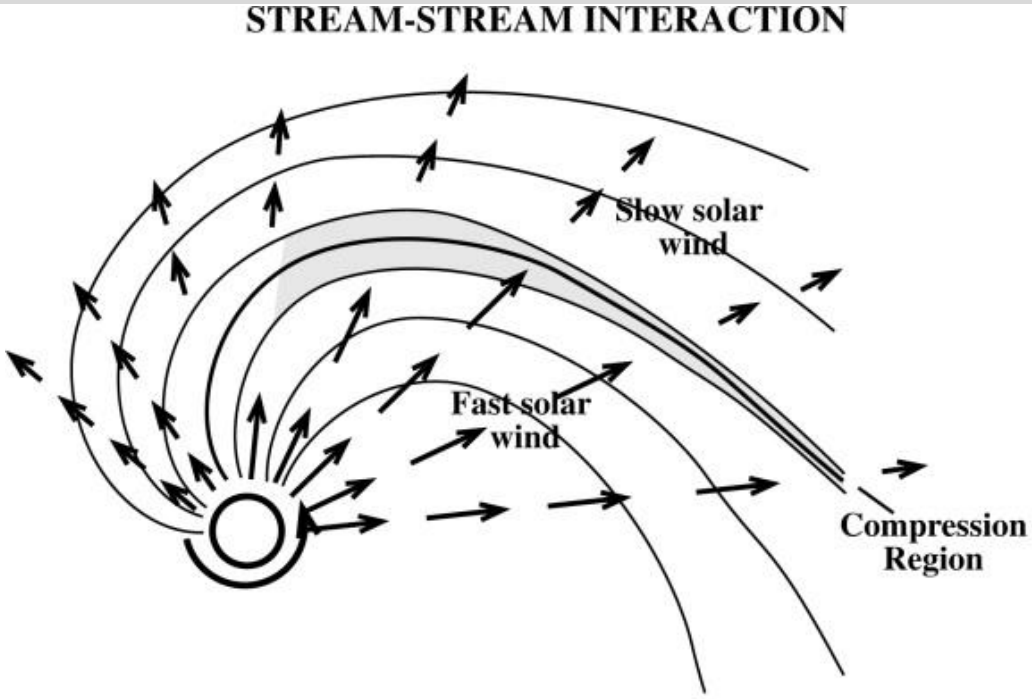


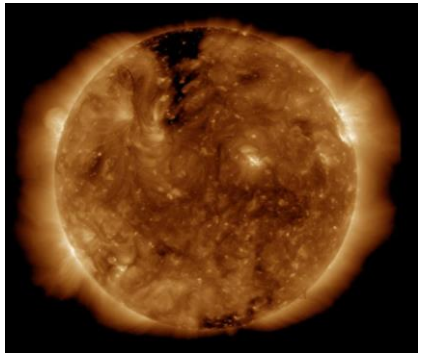
The magnetic activity of the Sun has an influence on the heliosphere.

Credit: csillagaszat.hu, ScienceDirect, NASA GSFC, ESA

Introduction to Space Weather – cont'd





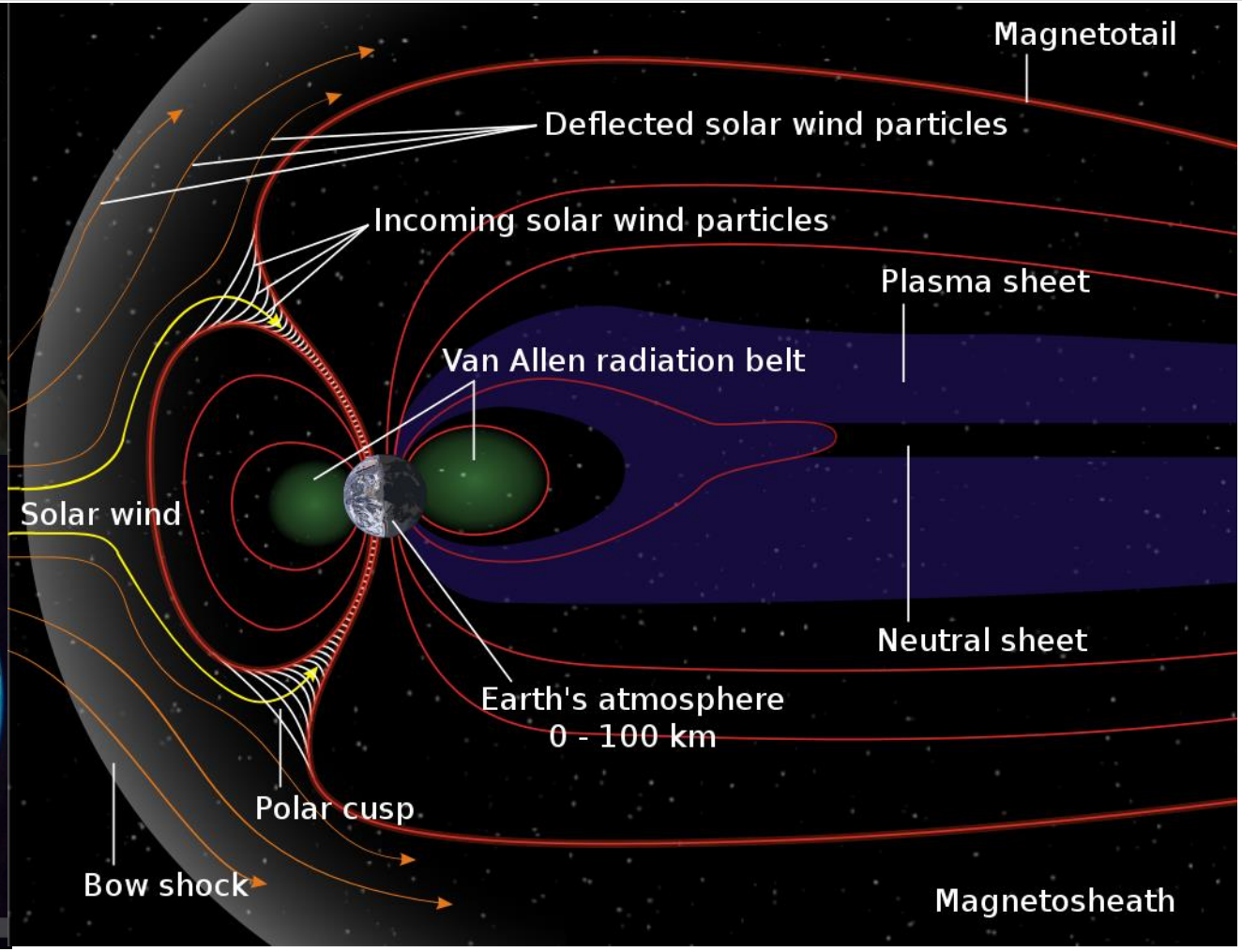


The reason of all troubles is the atmosphere of the Sun

Credit: ScienceDirect, NASA/SDO, ISAS/JAXA

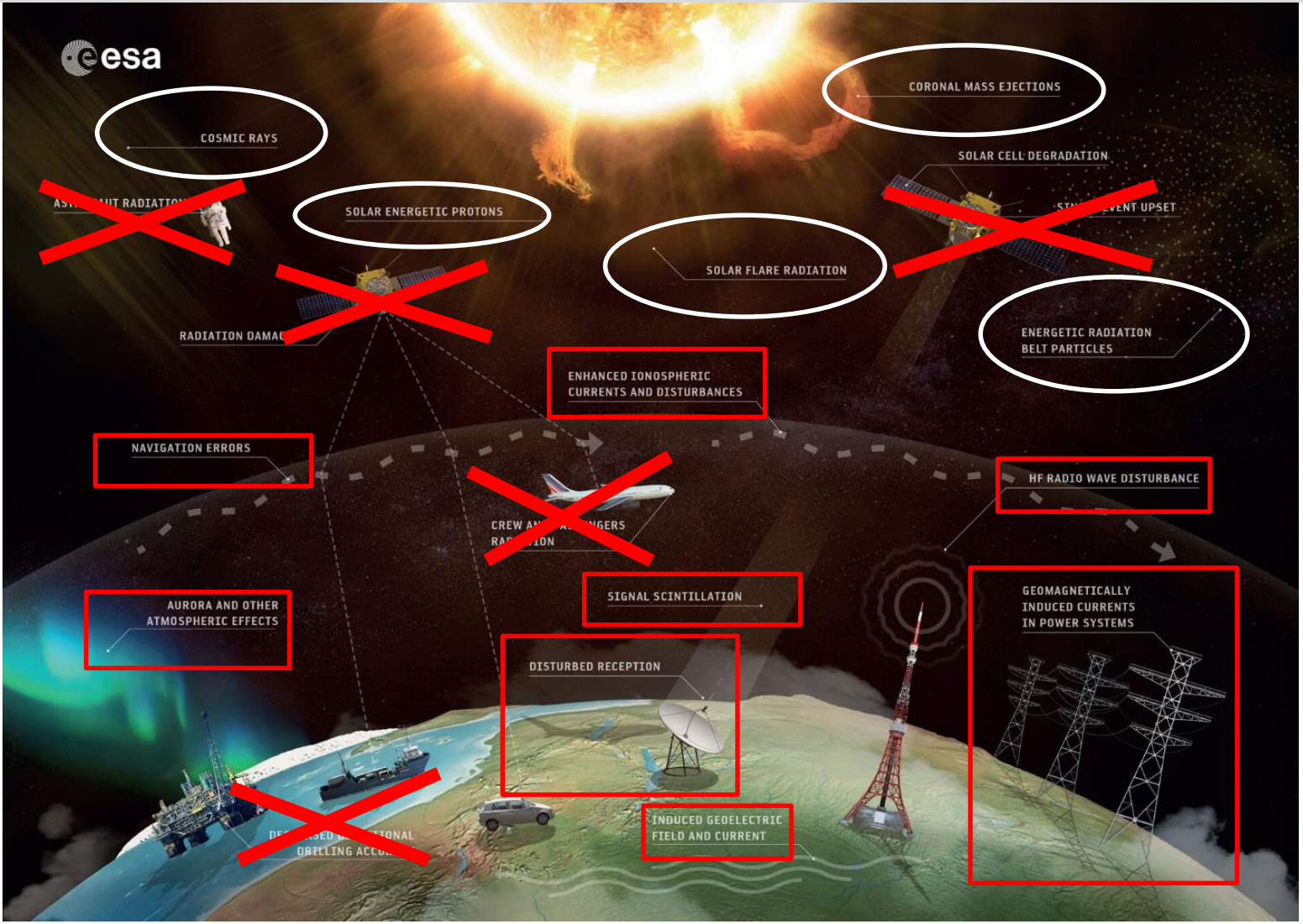
Introduction to Space Weather – cont'd

The solar wind enters to the terrestrial magnetosphere and creates aurora, magnetic disturbances, GICs and the radiation belts.



Credit: NASA GSFC, Amazing Sky Photography

Extreme Space Weather impact on Critical Infrastructure



- The sources of the radiation
  - Cosmic rays
  - Solar Energetic Particles (SEP)
  - Solar Flare Radiation
  - Solar Flare Radio Burst
  - Energetic Particle Belt Particles
  - Coronal Mass Ejections (CME)
- Damages and disturbances
  - Navigation errors
  - Signal scintillation
  - Disturbed reception
  - HF radio wave disturbances
  - Induced geoelectric field and current
  - Geomagentically induced currents in power systems, submarine cables, gaspipelines and overhead wires
- Aurora
  - Important indicator of the activity
  - Beautiful tourist attraction

Carrington Event

- The most intense observed geomagnetic storm
  - Its maxi-mum peaked from September 1 to 2, 1859
  - The solar storm associated with a very bright solar flare on September 1, 1859
  - The CME traveled 17.6 hours to the Earth and hit the magnetosphere
- The event causes strong aurora globally
  - From the poles to low latitude areas such as south-central Mexico, Queensland, Cuba, Hawaii, Japan, China, and Columbia
- Because of the GIC telegraph systems in Europe and North America failed, in some cases electrocuting their operators
  - Some telegraph stations sparked and even caught fire
  - Some operators could continue to send and receive messages after disconnecting their power supplies

Impact of a Carrington-size event nowadays

- Such strong flares and CME ejections are rare, however, they will happen again (2012 – STEREO event)
- The effects of such a solar storm look similar to a global thermonuclear bombardment exploding at high altitudes inside the magnetosphere using charges with improved microwave radiation capabilities
- Its impact would be catastrophic for our critical infrastructure
  - The geostationary and GNSS satellites would be damaged permanently. Therefore, communication and navigation would be impossible for a while
  - The transformer stations would be damaged and all computer systems, all elevators, all air conditioning, and all-electric equipment will be useless
  - The train, tram, and underground traffic would stop
  - The electric transfer systems would be useless
  - The gas pipelines would have to be shut down because of security reasons
- If Earth was hit by a Carrington event size CME the damage would range from $600 billion to $2.6 trillion in the US alone, which was 3.6 to 15.5 percent of annual GDP in 2013
- **Human civilization would be thrown back to the 19th century for months**
- These effects would be global, international communities could not rally and coordinate disaster response efforts, and every country would be left to deal with the damages alone
- The authorities must be prepared to recognize the effects of such a catastrophic event using national resources

Summary and TODO list

- The Sun dominates its neighborhood → The heliosphere is the region dominated by the Sun.
- The solar wind comes from the solar corona. It interacts with the objects in the heliosphere.
- The energy produced by fusion flows outward and creates magnetic activity. The magnetic field creates solar spots, protuberances, filaments, and flares.
- The magnetic reconnections produce an incredible amount of energy. In this flash, the flare ejects particles to the interplanetary space and the solar atmosphere. The flash could reach 20 MK and launch a coronal mass ejection (CME).
- The CMEs are material ejections to the interplanetary space. Their size could be much larger than the diameter of the Sun. If the CMEs reach the Earth they could create **magnetic disturbances**, **aurora**, **geomagnetically induced currents** in the pipelines. They may **ruin the communication equipment and electronic devices on the orbit of the Earth**. These events **cut the short wave communication** by changing the conductivity of the ionosphere however they can **disturb the satellite communication and navigation systems.**
- The aurora is the consequence of the phenomena above. The aurora activity is permanent under the aurora oval. **The intensity of the aurora is proportional to the bandwidth of the radio communication through the ionosphere.**
- These events can be predicted and the critical infrastructure can be prepared. The satellite systems can be switched off before the solar storm arrives.

- The occurrence of a catastrophic space weather event is imminent. Therefore we must train the authorities to recognize them and prepare a scenario to reduce their effect on our civilization.

Acknowledgements

The End

Thank you for your attention!

Acknowledgements This work was partially financed by the National Research, Development, and Innovation Office (NKFIH) FK128548 grant and the Stipendium Hungaricum Scholarship.