Introduction to Space Weather and its Impact on our Daily Lives?

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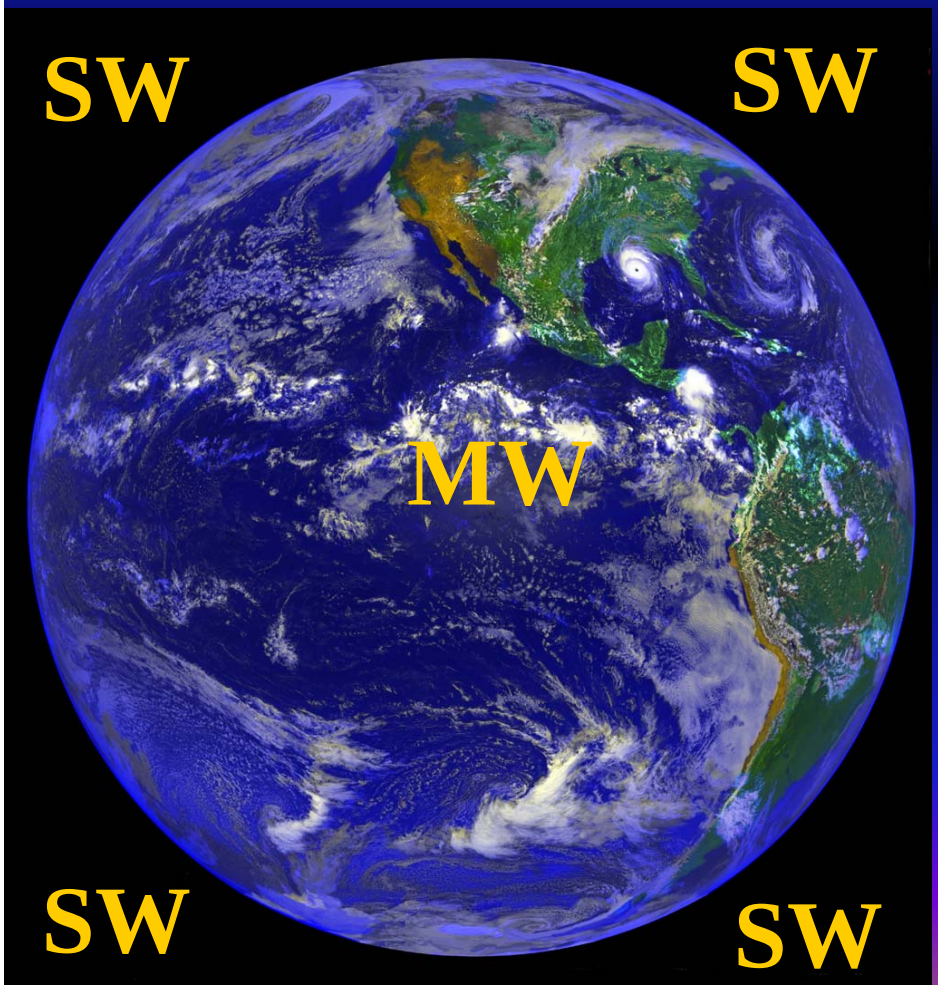
Boston College

Outline

- Introduction and history of space weather
- Why we are interested in space weather?
- How does space weather impact come to us? MI-coupling
- How do magnetosphere and ionosphere communicate each other?
- Economic and Health impact of Space weather
- Why do we care so much for ionosphere, and how it responds to Space weather impacts?
- Suitable instruments to monitor Space weather impacts
- Space weather impact summary in pictures

What is Space Weather?

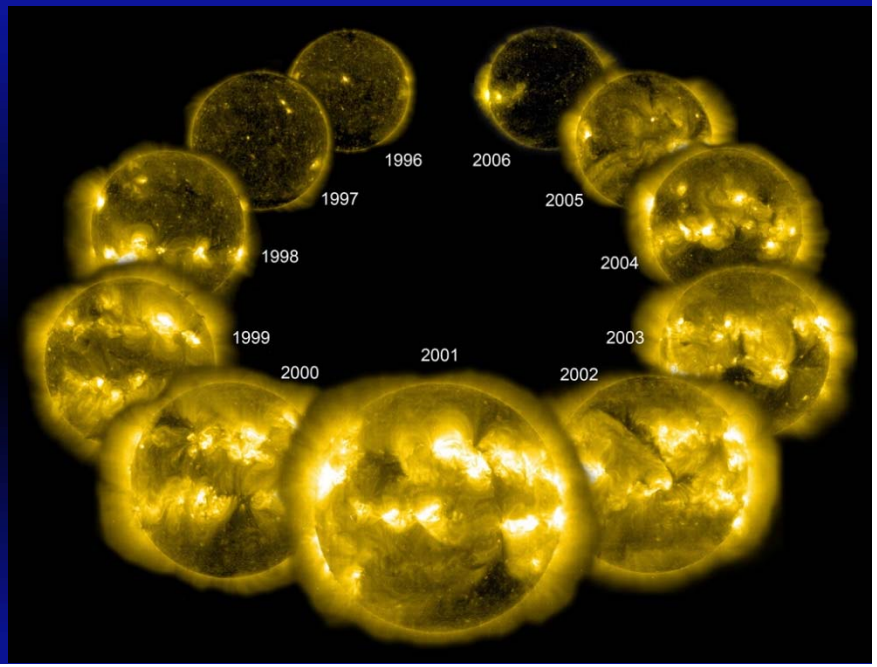
Why should we care about space weather?



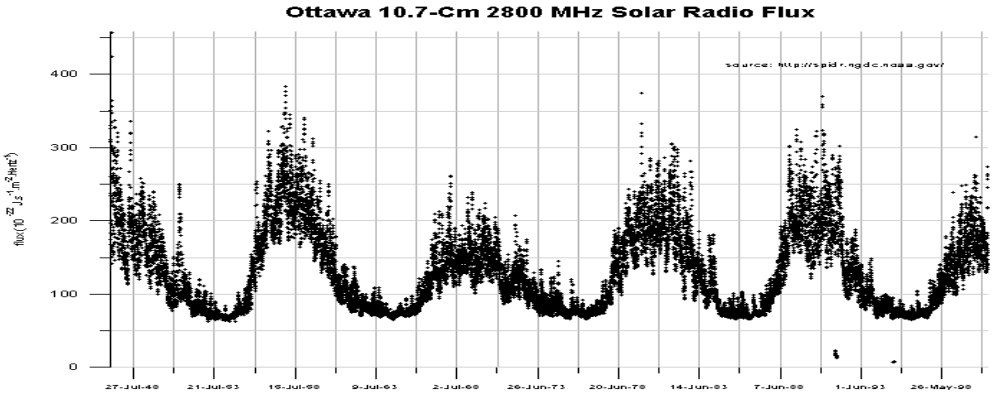
- In short, space weather impacts have the ability to damage modern space-age technology (communication, navigation, power distribution, Oil pipelines, money transaction etc) and significantly set us back from modern civilization

Who do we blame for the source of space weather problems?

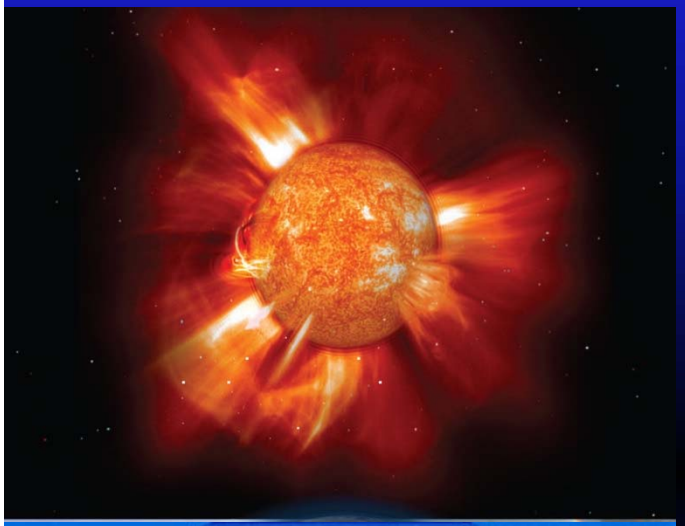
The SUN of course!



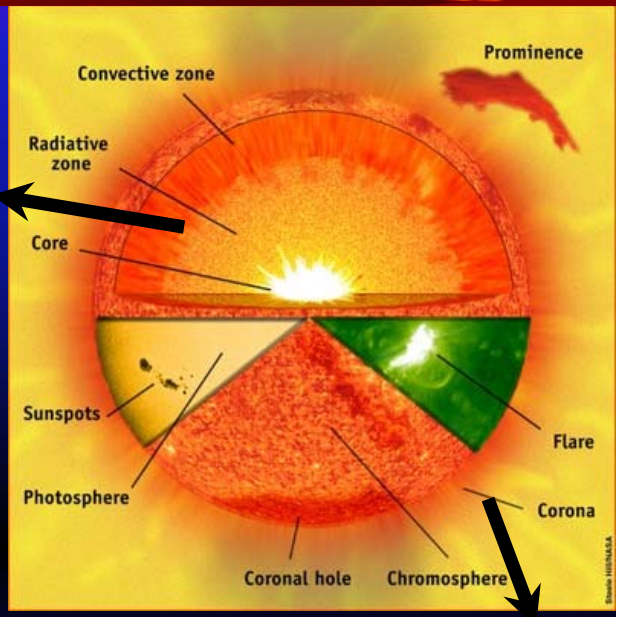
It can unleash the energy of 100 billion atomic bombs



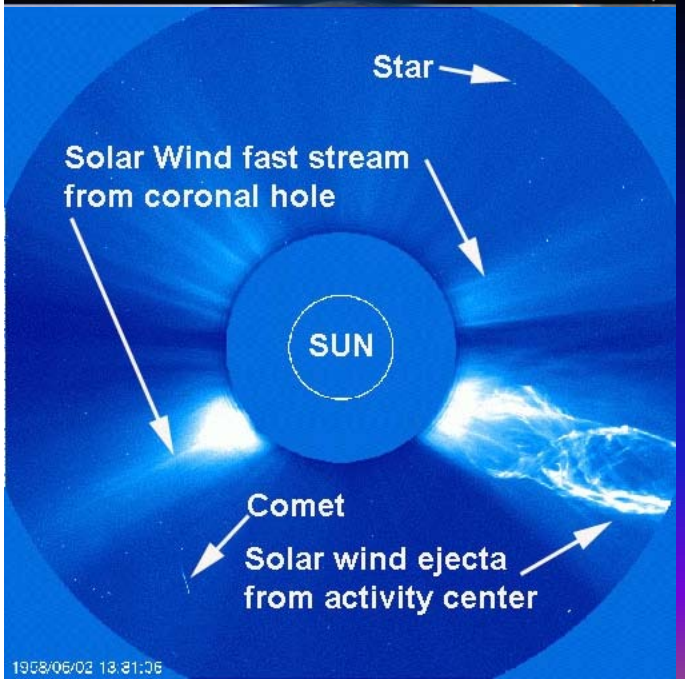
What is the Solar mysteries?



6000 ˚K



Millions of ˚C



Current Speculation: powerful MHD waves (specifically Alfven waves) propagating along magnetic field-lines from the solar interior to the corona, interacting with the plasma and heating it to astonishing temperatures

NASA plan to solve the mysteries and decided to send Solar Probe Plus deep into corona in 2018

History of Space Weather!

September 1, 1859 - Carrington observed a "**solar flare**" and two days later Magnetic disturbances in London.

"**One swallow does not make a summer.**"

November 30, 1892 - Royal Society Presidential Address

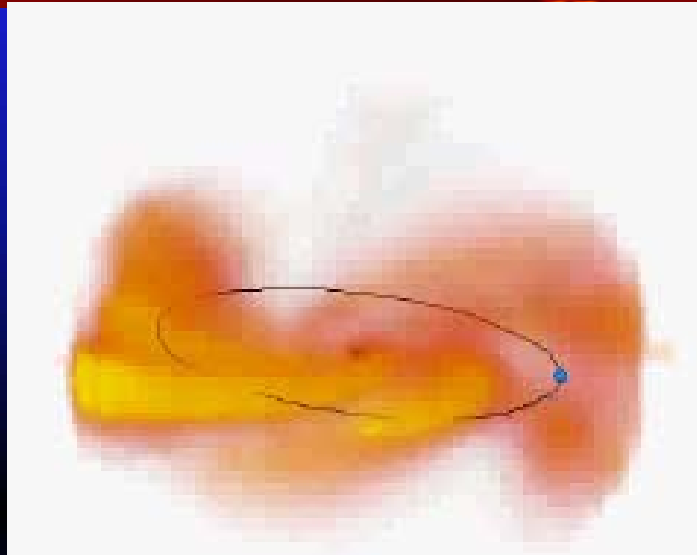
"It seems as if we may also be forced to conclude that the supposed connexion* between magnetic storms and sunspots is unreal, and that the seeming agreement between periods has been a mere coincidence." **Lord Kelvin (*"old" British spelling)**

November, 1905 - Monthly Notices of the Royal Astronomical Society "The origin of our magnetic disturbances lies in the Sun" **Prof. Maunder**

Outstanding Question: What kind of stuff from the Sun Causes Magnetic Storms and Aurora?

What Causes Storms?

- CME
- Shocks
- High Speed Streams (CIR storms)
- Flares are important for impulsive events, but are not the cause of most major storms

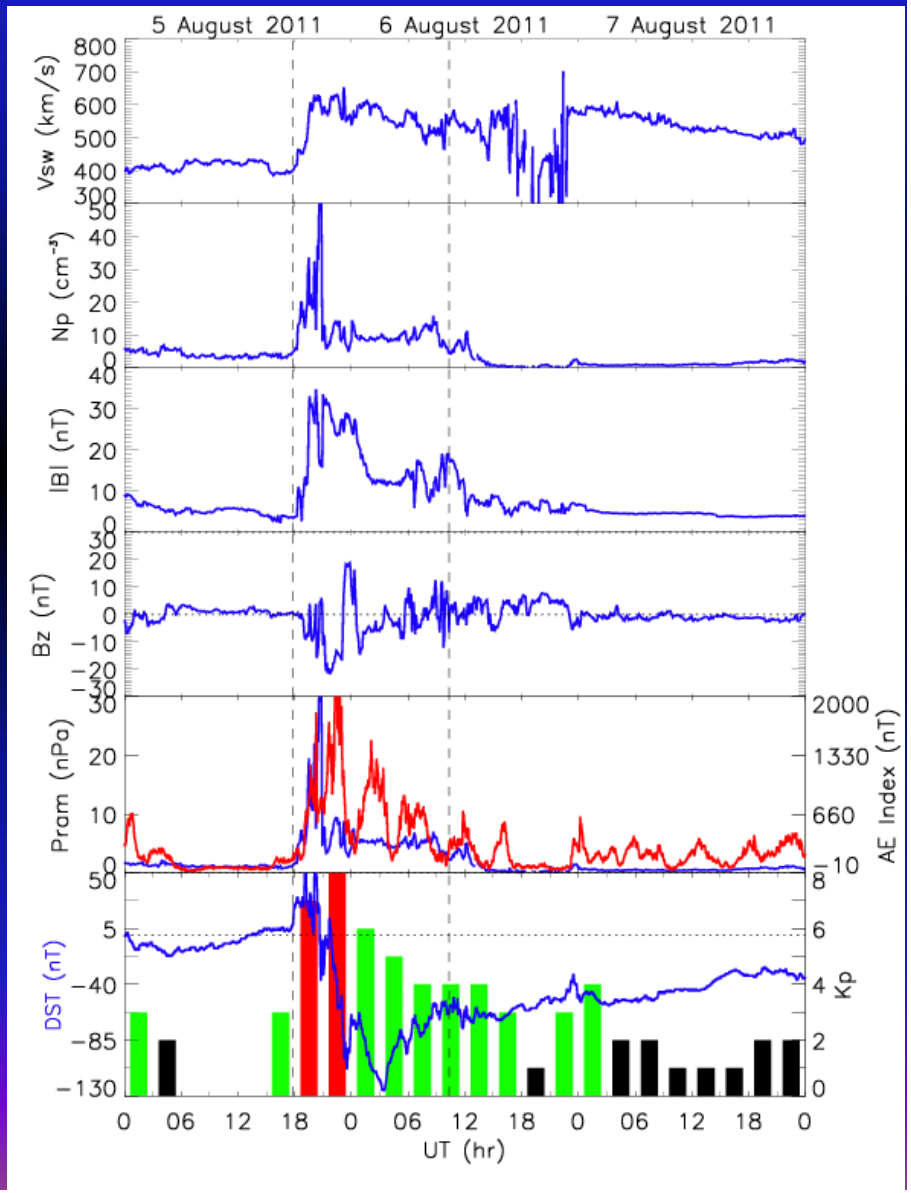


How do we know this?

- Ground observations of aurora and magnetic field
- Satellite observations of radiation, plasma, and electric and magnetic fields

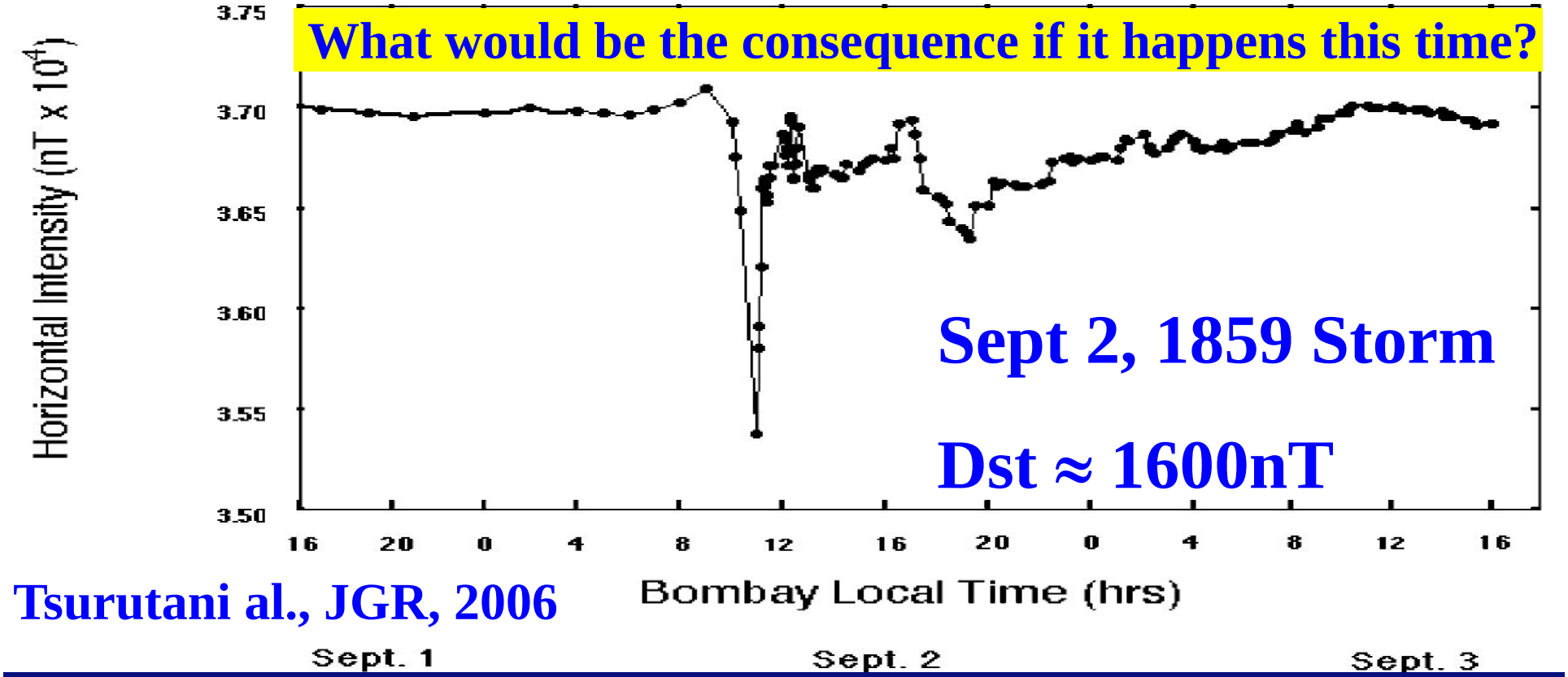
How do we measure space weather storms?

- Indices (like Richter Scale - earthquakes, Saffir-Simpson-hurricanes) - Kp, Dst for space weather storms
- **Kp** - planetary magnetic field disturbance index (logarithmic from 0 to 9)
- **Dst** - disturbed stormtime index - also a magnetic index that examines the strength of the ring current.



The most severe storm ever recorded

What would be the consequence if it happens this time?



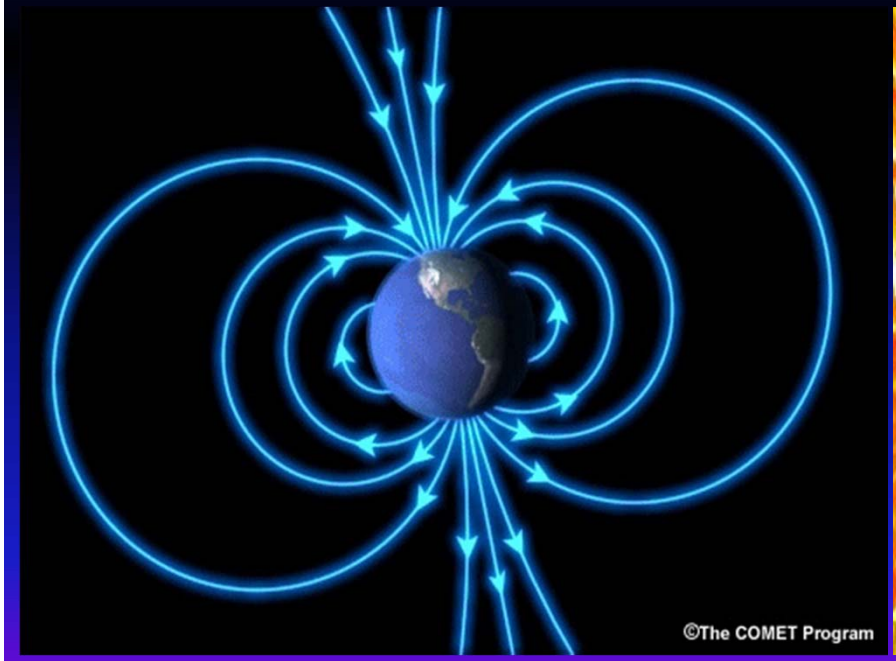
Tsurutani al., JGR, 2006

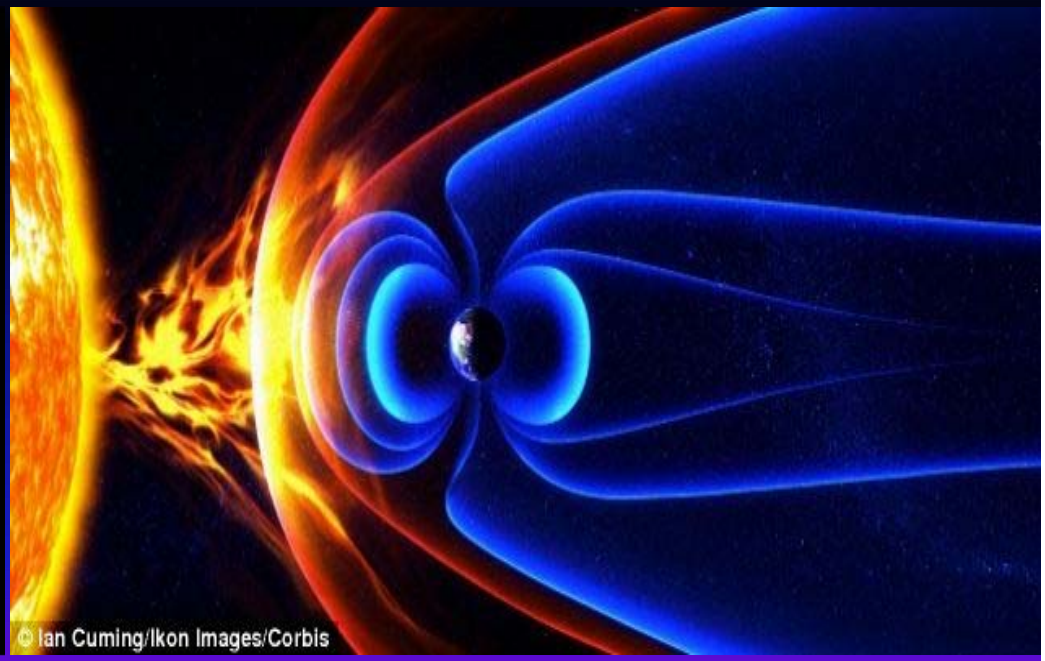
The 2008 US National Research Council report estimated the cost if a September 1859 sized CME hit us;

"First it could take us 10 years to recover, and the cost could be between $1 and $2 trillion (in the first year alone) to repair the damage." *BBC News, 2012*

How does space weather impact from the Sun communicate with Earth atmosphere?

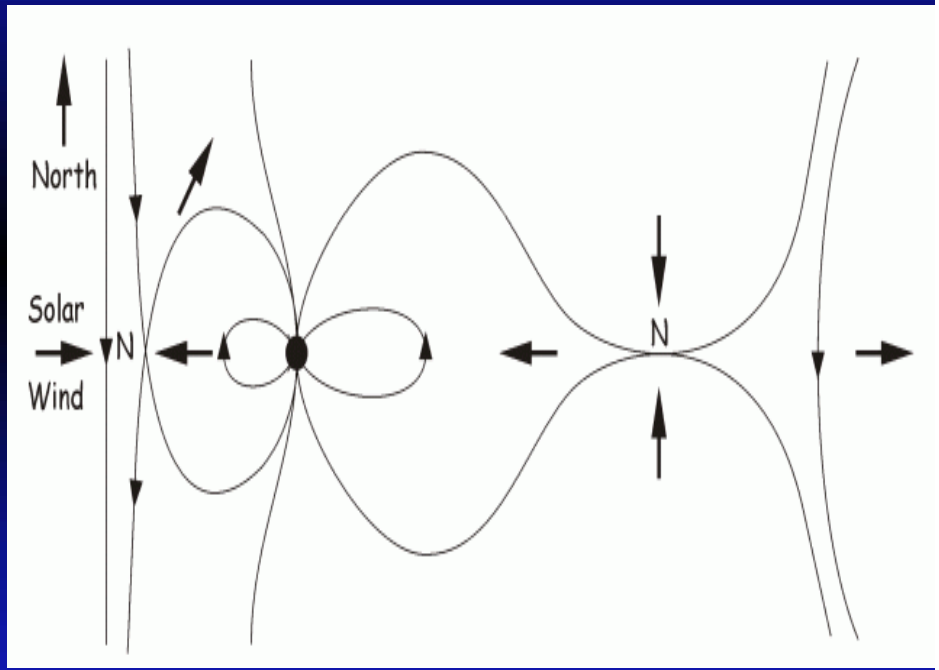
Through open field line!





How the stuff from the Sun reach to us?

Some space weather impacts take from minutes to days to reach to Earth and disrupt our navigation, communication as well as impose health problem due to high Radiation exposure for air travellers



CMEs are bubbles of plasma wrapped in a magnetic field, and if Bz turns south this magnetic bubble can penetrate into our magnetosphere and inject high energy particles (mainly protons) deep into the Earth's atmosphere.

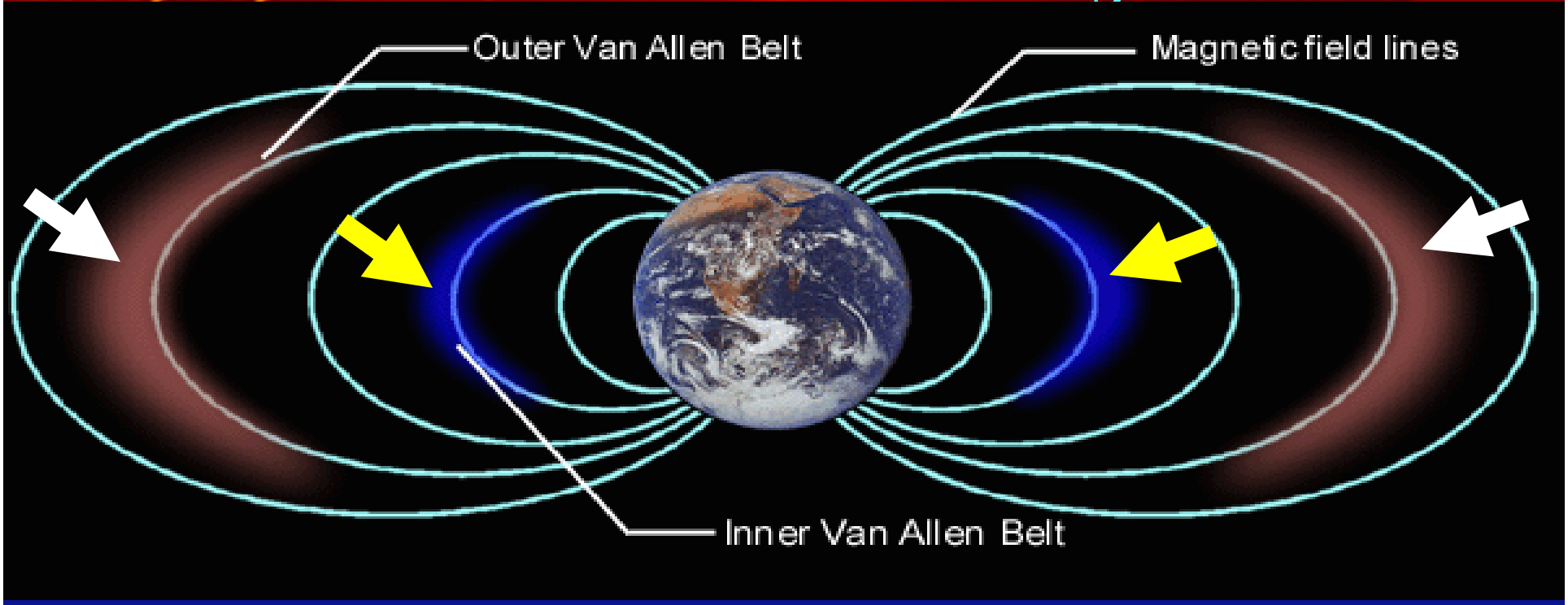
Space weather and Magnetosphere?

"Forget global warming, worry about the MAGNETOSPHERE: Earth's magnetic field is collapsing and it could affect the climate and wipe out power grids"

- **Earth's magnetic field has weakened by 15 per cent over the last 200 years and could be a sign that the planet's north and south poles are about to flip**
- **If this happens, solar winds could punch holes into the Earth's ozone layer**
- **This could damage power grids, affect weather and increase cancer rates**
- **As the magnetic shield weakens, the spectacle of an aurora would be visible every night all over the Earth**

The British Mail Newspaper, 27 January 2014

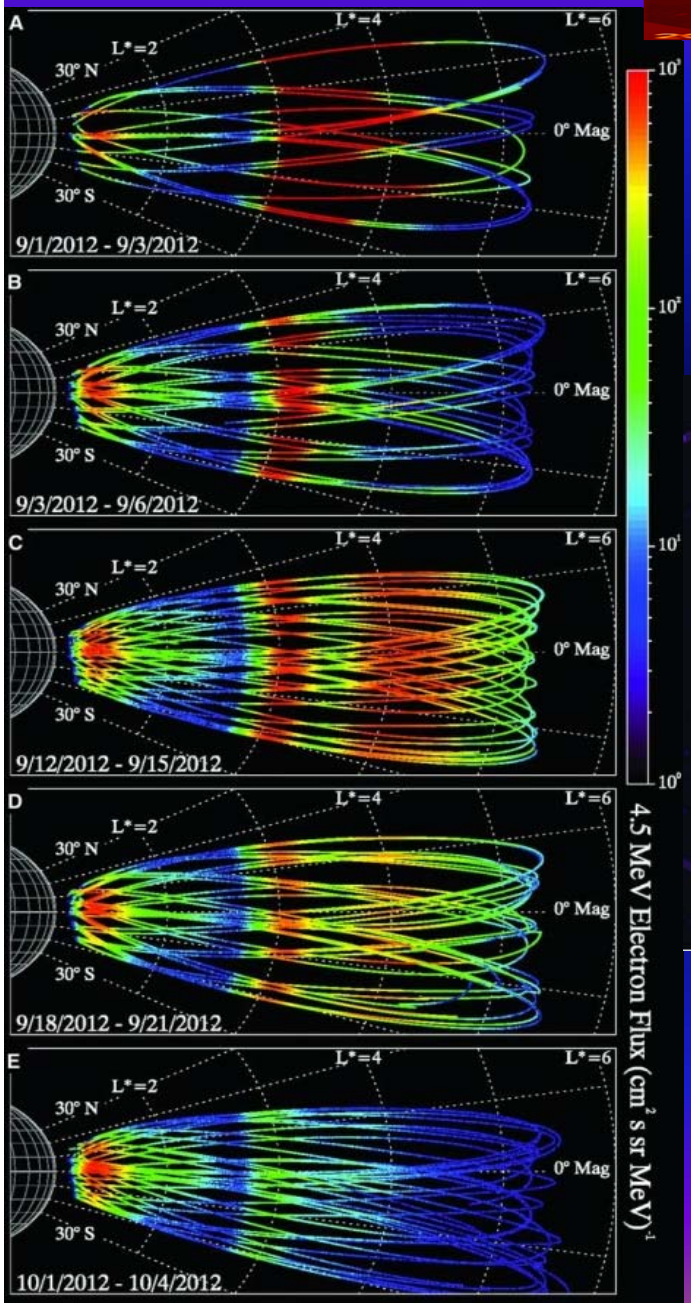
What does the magnetosphere contains mainly?



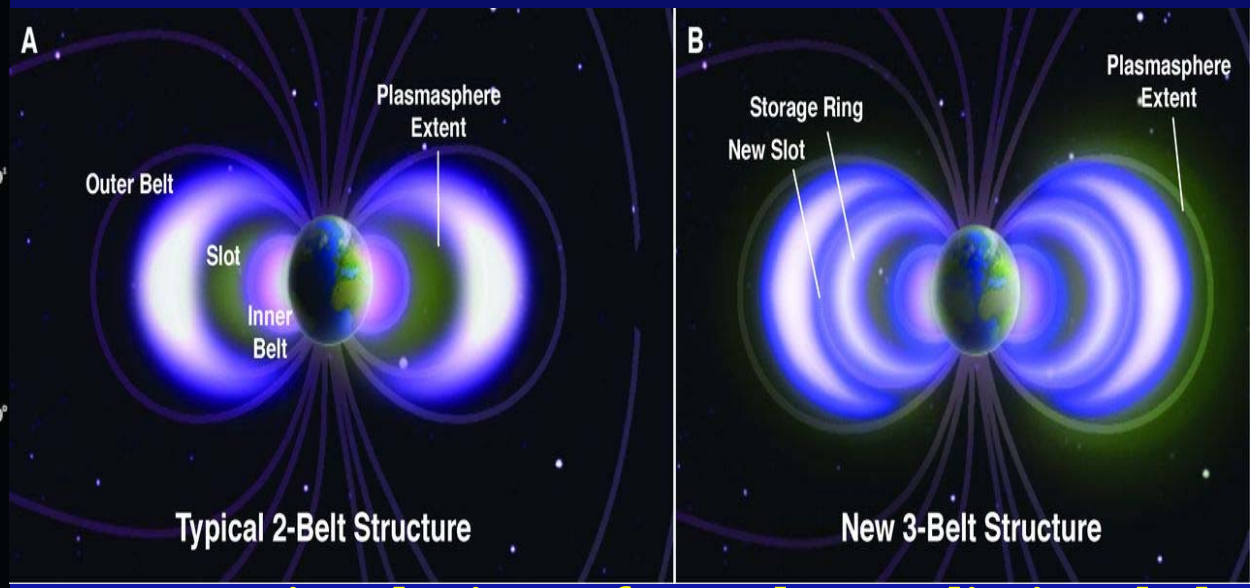
- **Protons with 10-100 MeV at 1.5 R_E, attributed to albedo neutron decay and cosmic radiation interaction with the upper atmosphere.**
- **population of trapped ions and electrons with the energy of ~1MeV at 2.5–8 R_E.** **(1e produce ~ 1.6 x 10E-11 J)**

Baker et al., 2013

Recent breakthrough observation with new NASA mission (RBSP)



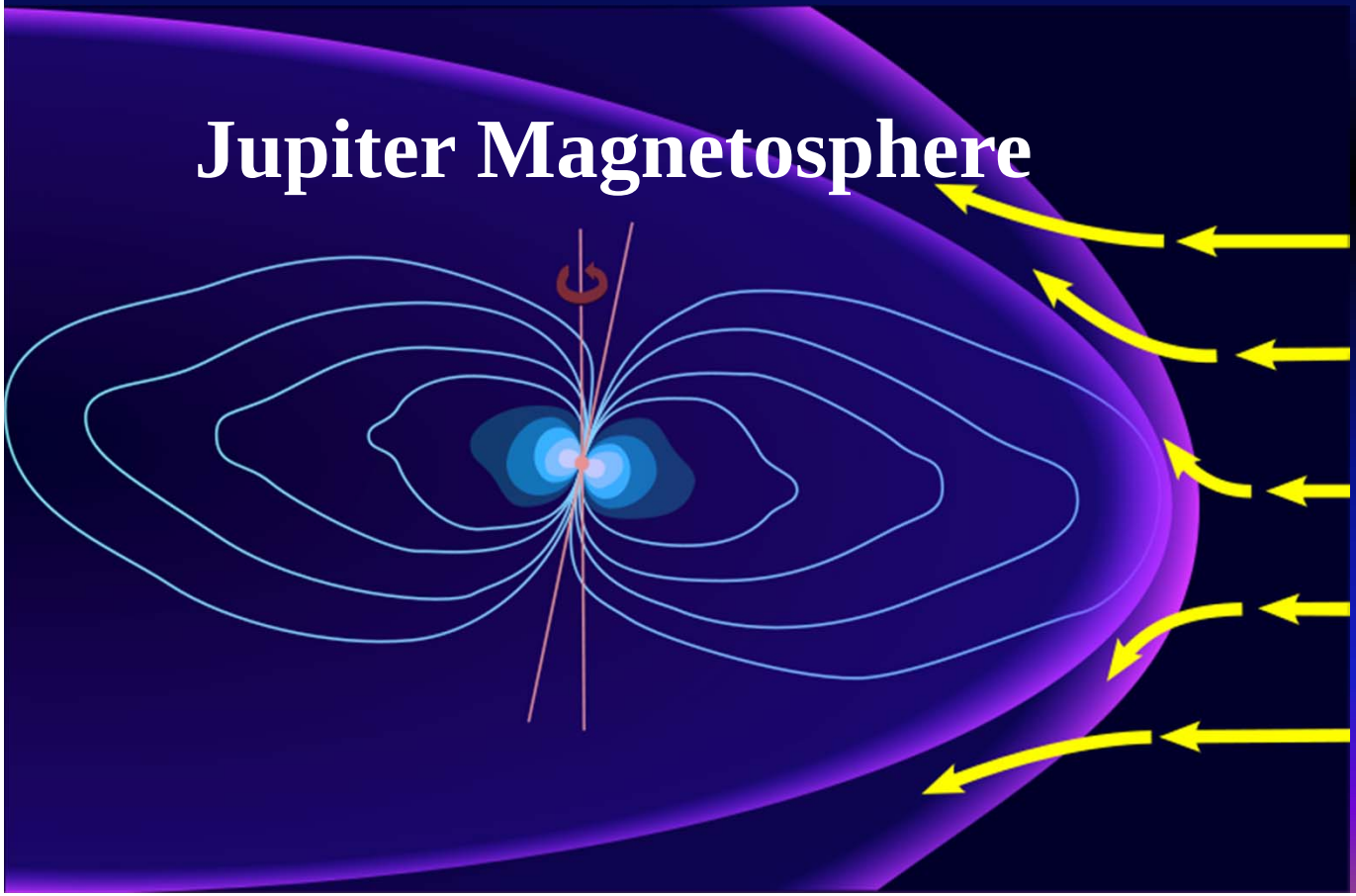
Meridional plane projections of the Relative Electron-Proton Telescope (REPT)-A and REPT-B electron flux (4.0 to 5.0 MeV) values as shown magnetic latitude L* coordinate system.



Cross-sectional view of Earth's radiation belt structure with normal plasmasphere location (left panel), and more highly distended plasmasphere and unexpected triple radiation belt (right panel).

Are we alone or is there any other planets that have magnetosphere?

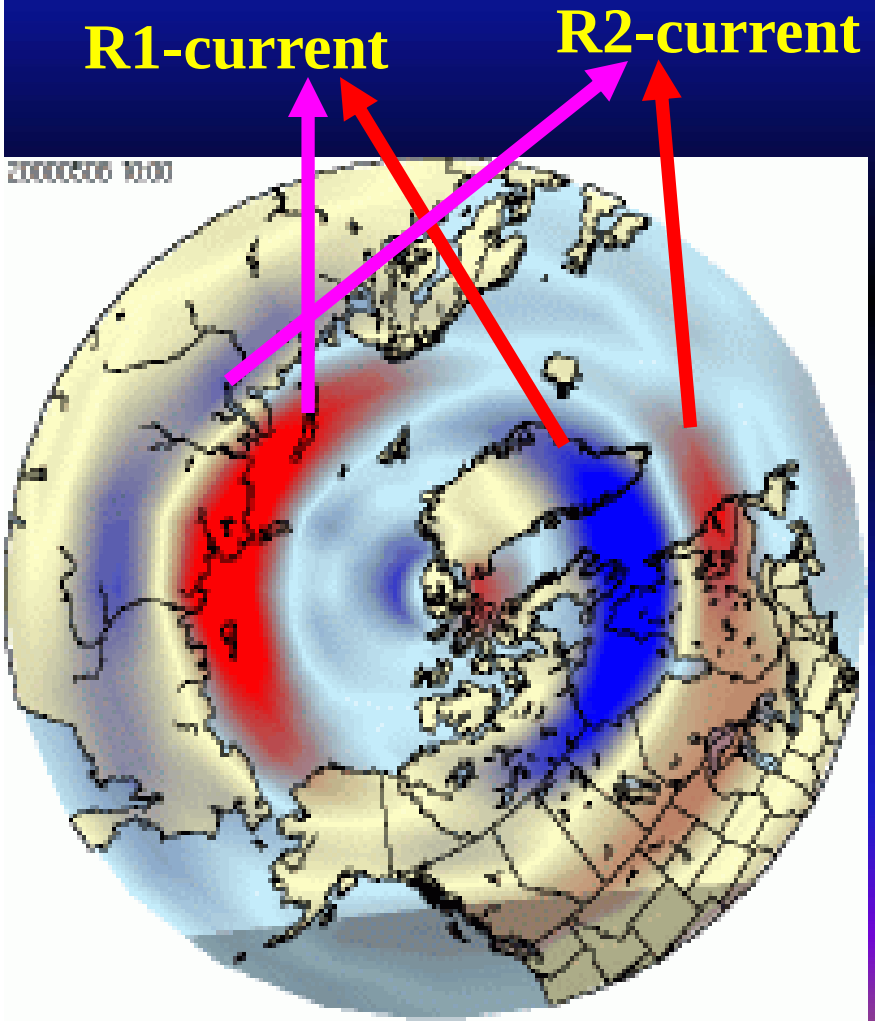
Mercury, Earth, Jupiter (Ganymede), Saturn, Uranus, and Neptune have magnetic fields

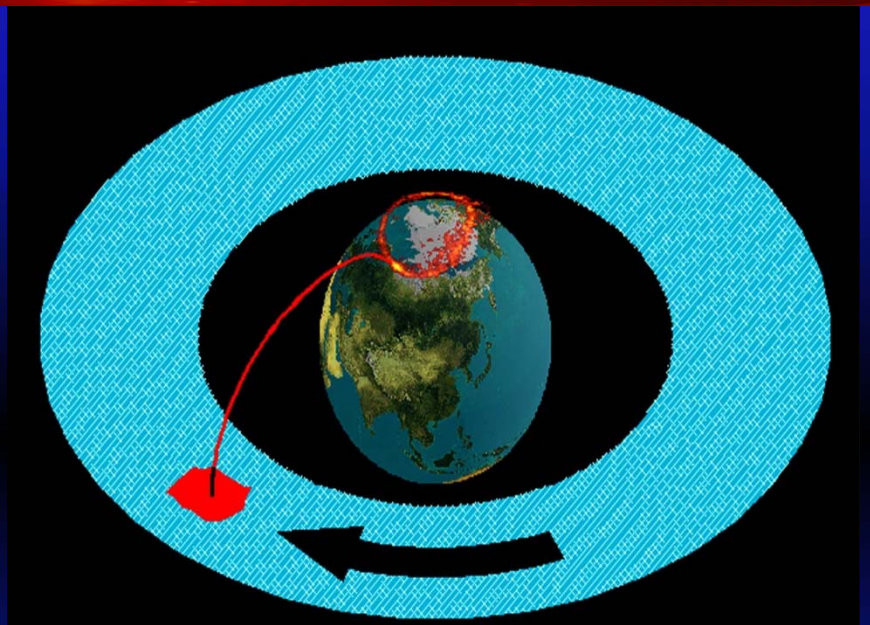


- Wider and flatter
- The biggest magnetosphere in the solar system
- MPP ~ 50 -100R_J
- MTL ~ 7000R_J
- R_J ~ 71,500km

How does magnetosphere and ionosphere communicate?

Through Current



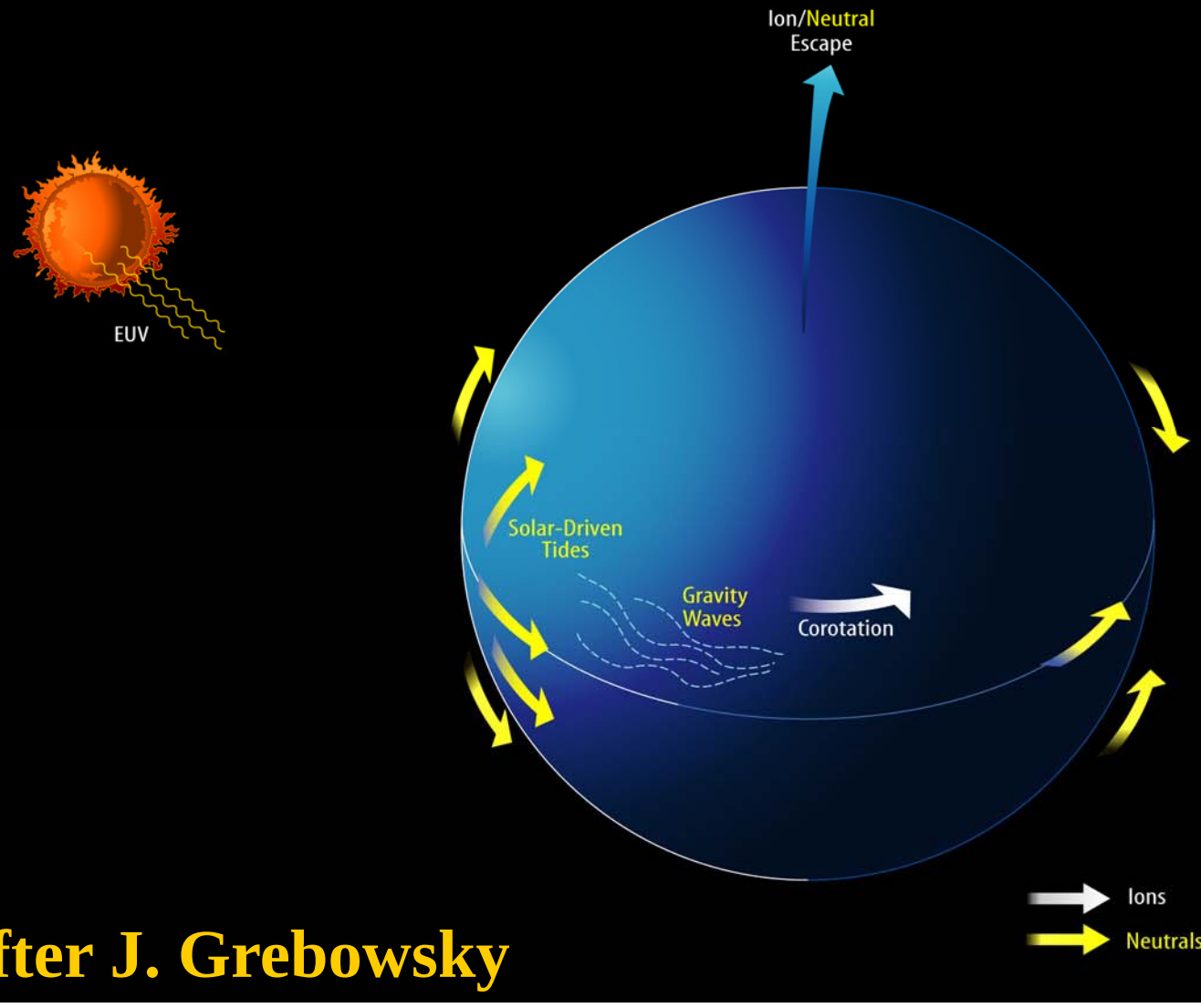


What are ionospheric current?

- Connect the magnetosphere to the ionosphere
- Can flow along the magnetic field (FAC)
- Can perturb power grids

M-I coupling gets messy

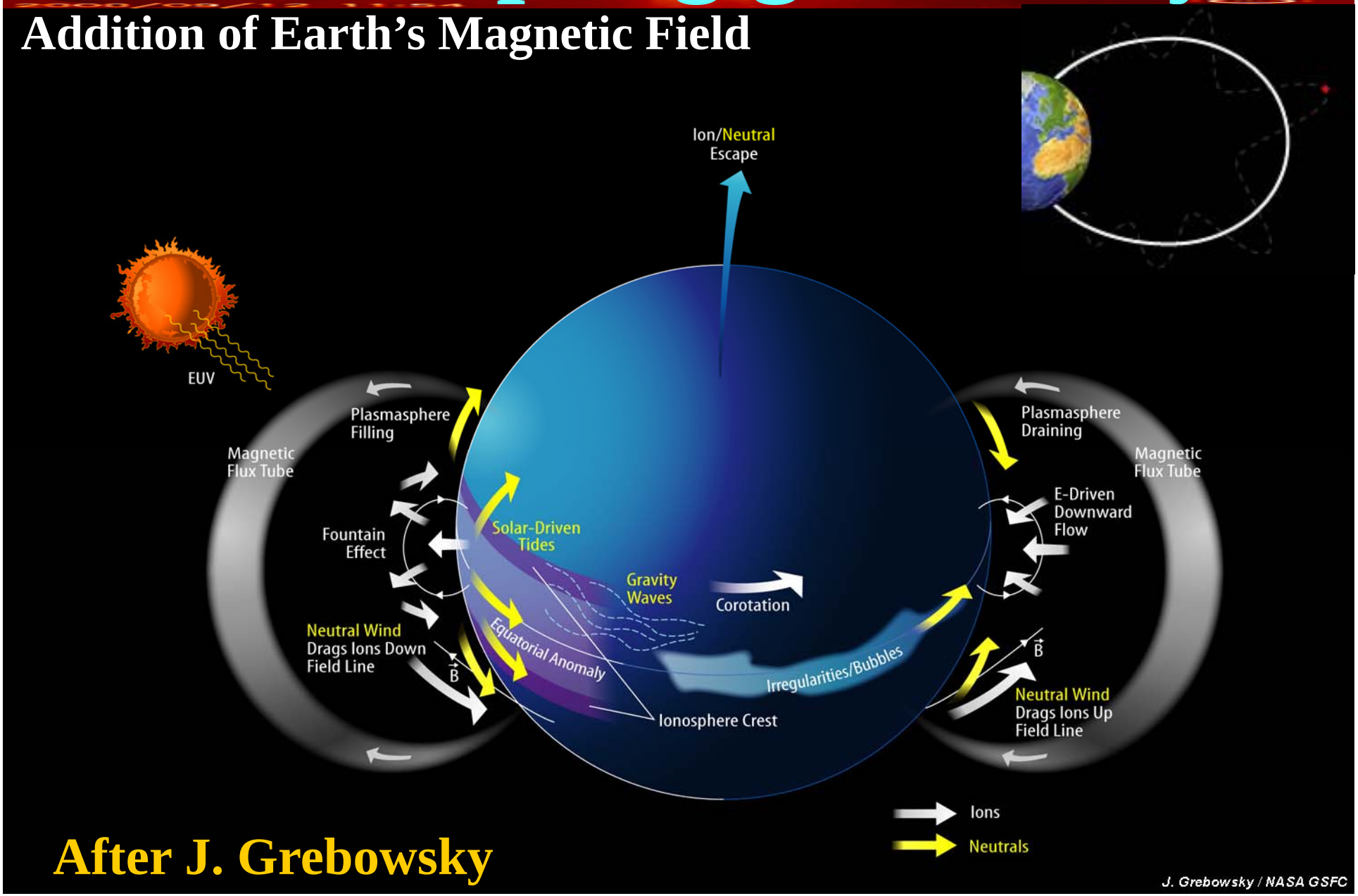
Solar EUV Effects: No Magnetic Fields



After J. Grebowsky

M-I coupling gets messy

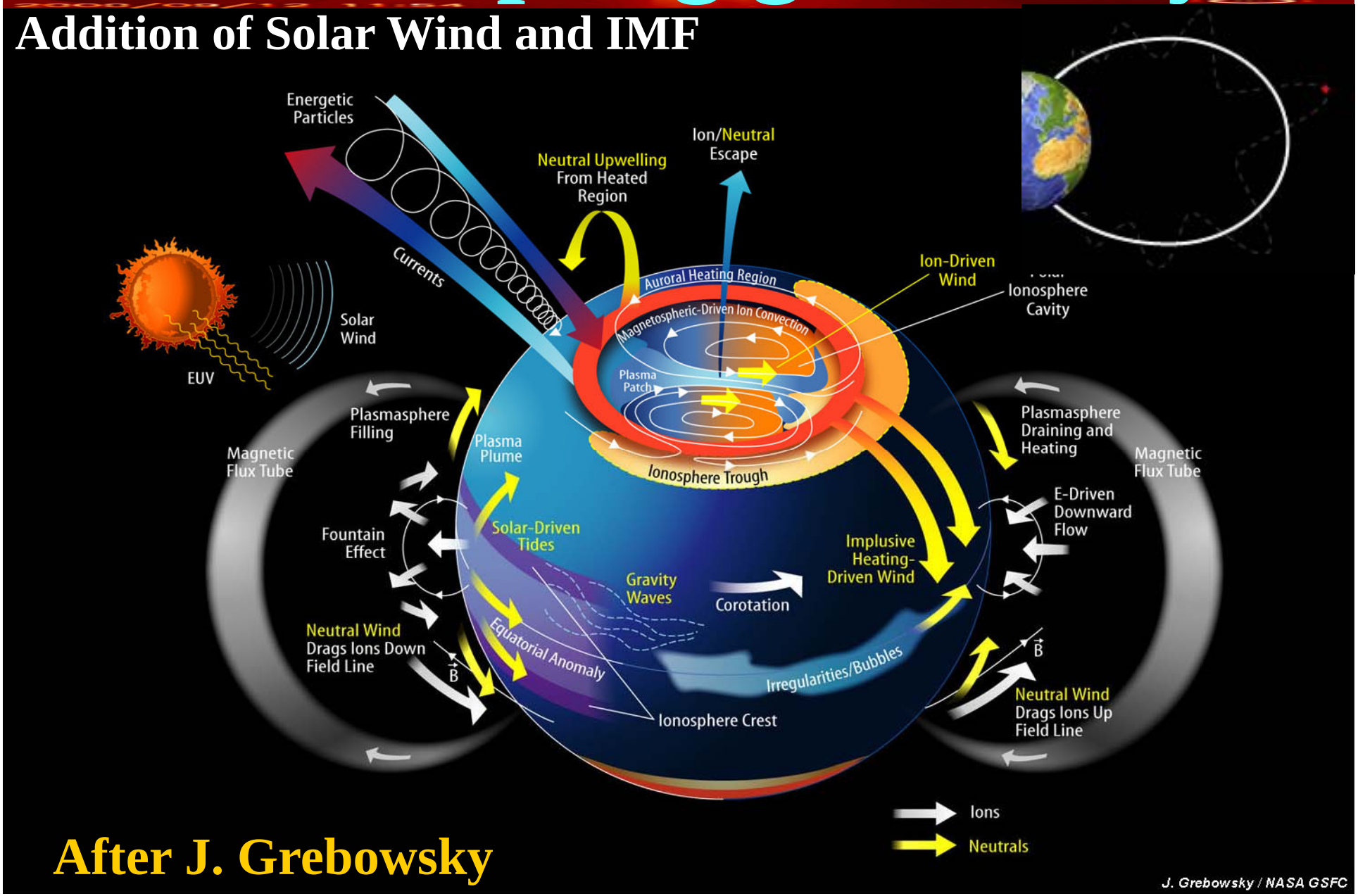
Addition of Earth's Magnetic Field



After J. Grebowsky

M-I coupling gets messy

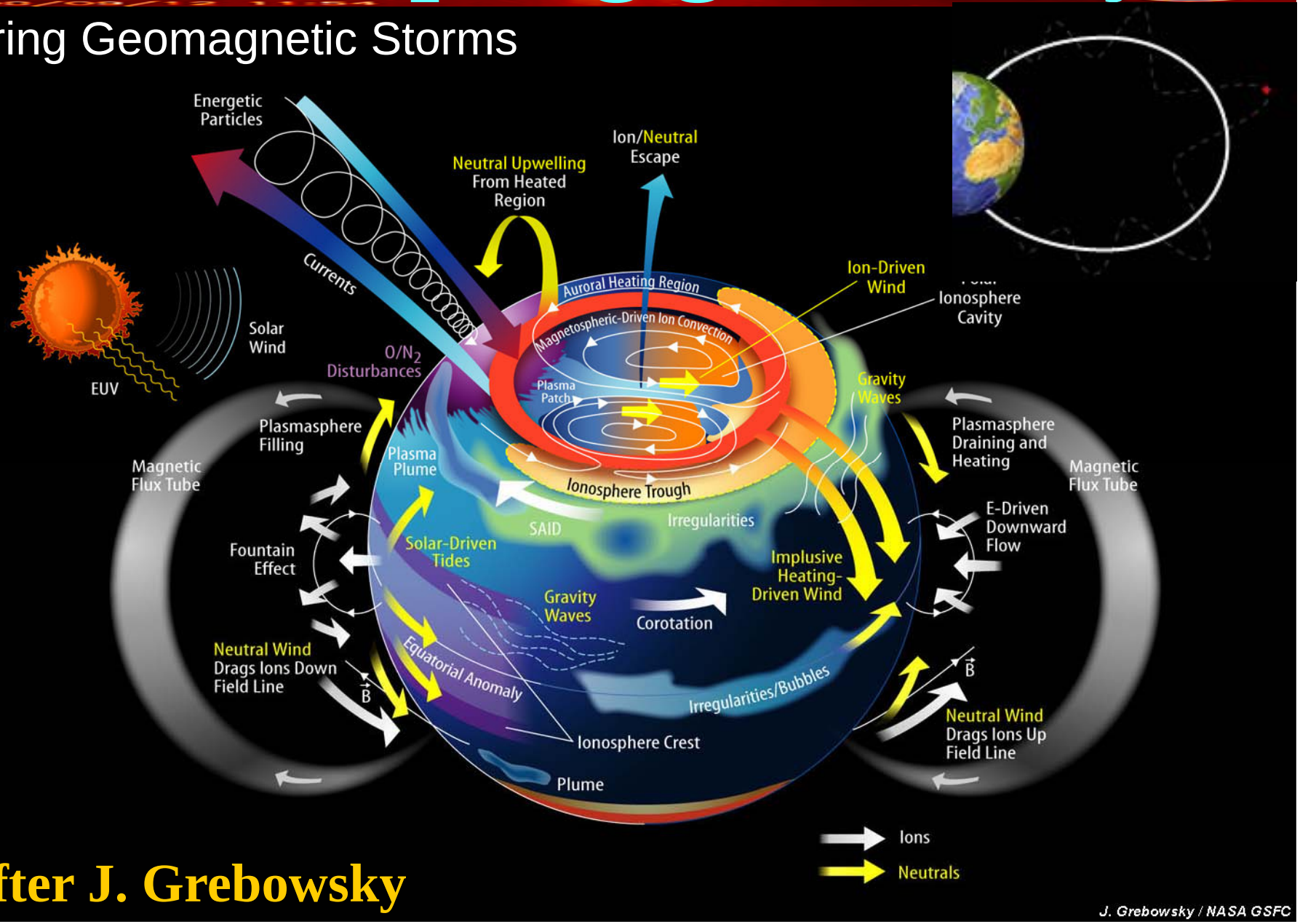
Addition of Solar Wind and IMF



After J. Grebowsky

M-I coupling gets messy

During Geomagnetic Storms



After J. Grebowsky

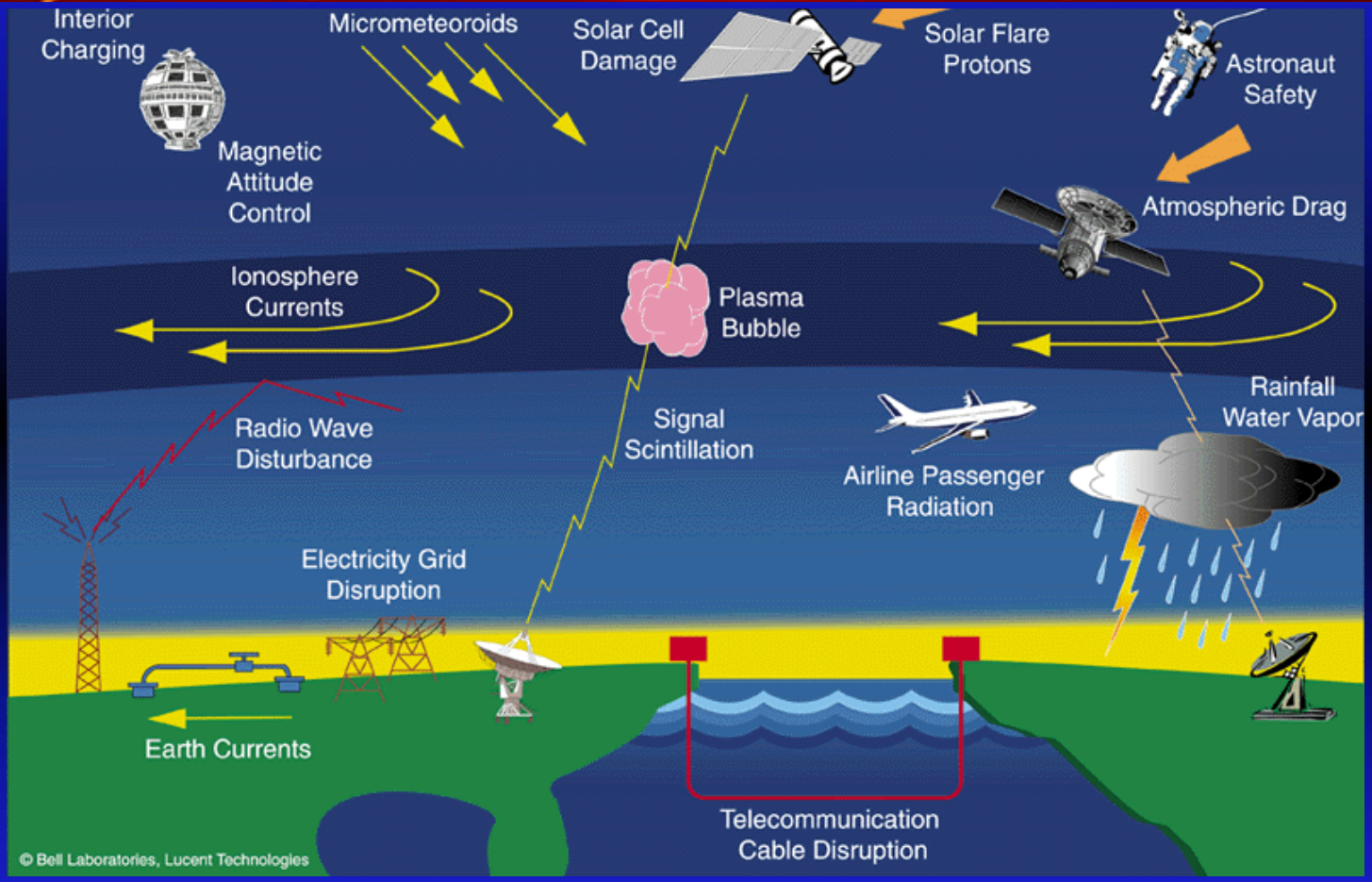
Why should every society, including Rwanda, be interested in Space Weather?

- Do you watch TV? Do you listen to radio?
- Do you own a cell phone? Do you imagine life without cell phone (just for one day)?
- Have you flown on an airplane?
- Do you need electricity for your apartment, home or office?

Well! all of these activities can be impacted by Space Weather!

Here are some specific examples!

How wide variety of technologies are depend on space weather impacts



All these instruments are in trouble during geomagnetic storm time

Could Space Weather cause an Economic depression as well as health problem?

- What are the economic impacts of space weather?
- What is the worst case scenario?
- What is the probability of the worst case scenario?
- What type of health issue we fear from space weather impacts?

Here are some example how?

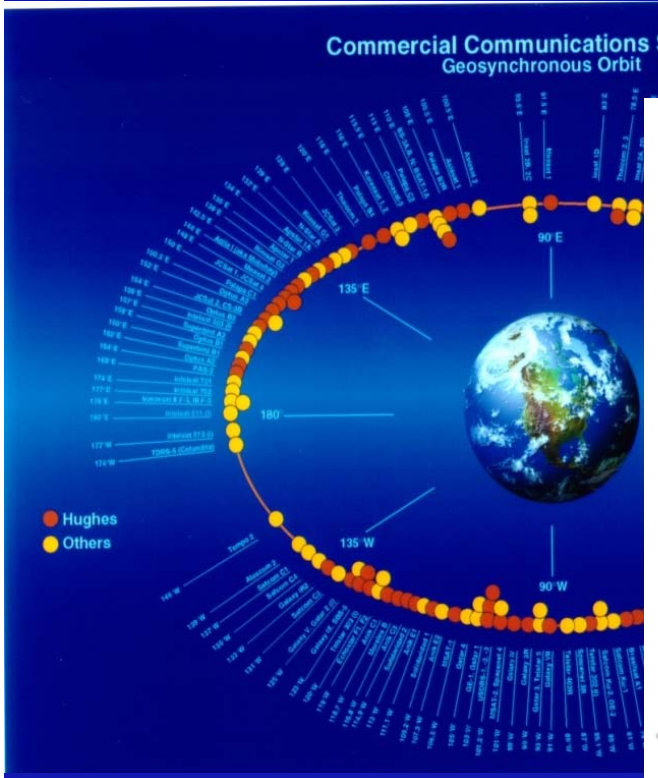
GIC induction on long conducting cable

Power losses increased in the transformers Saturation

Since many African countries are located at the geomagnetic equator, where space induced currents (equatorial electrojet) are too high, such power plant damage is a real threat for the country

Space weather impacts on our space-based technologies

Due to SEP



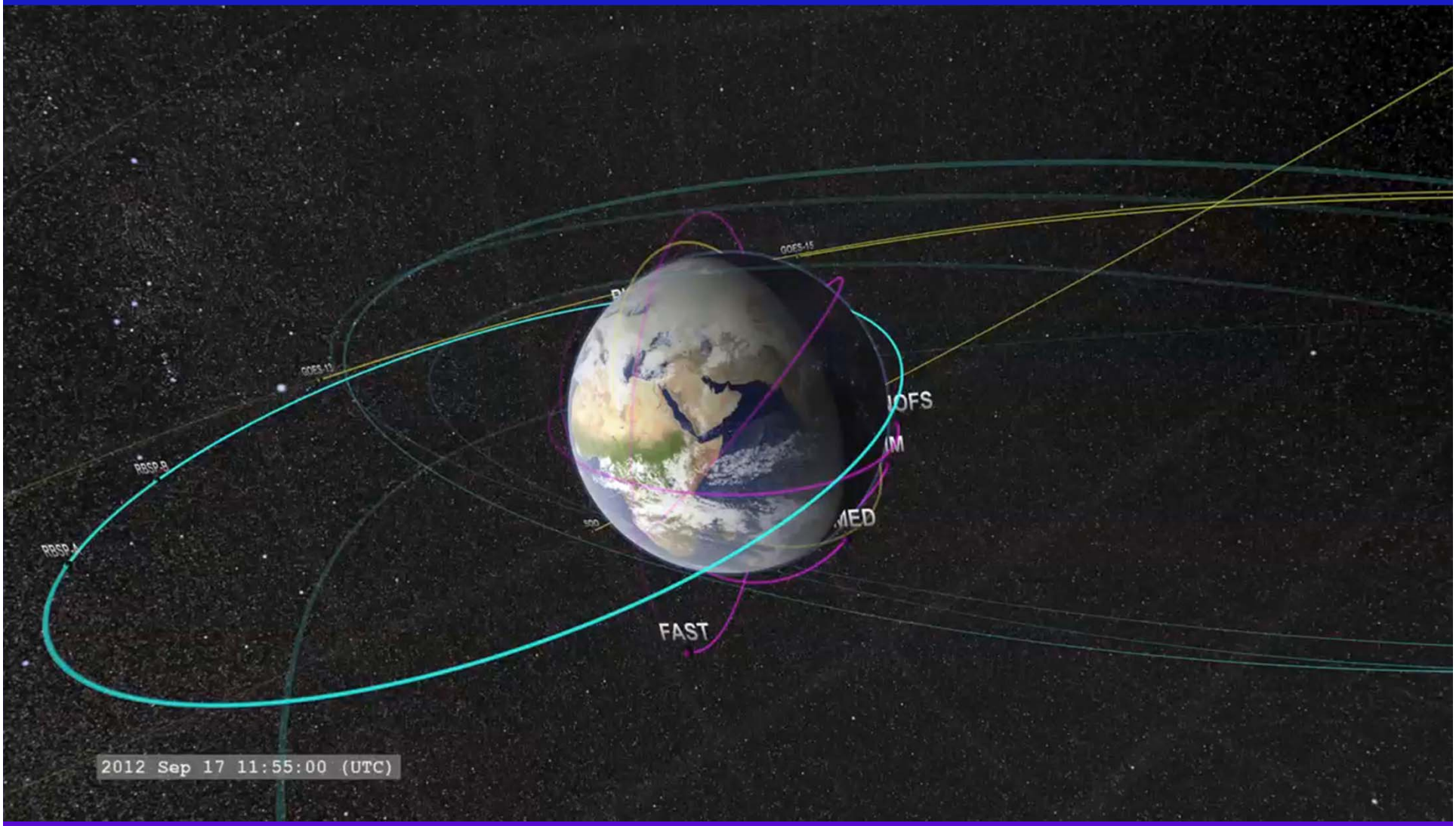
If one of the satelli

storm, then Rwanc

TVs, radios), banki

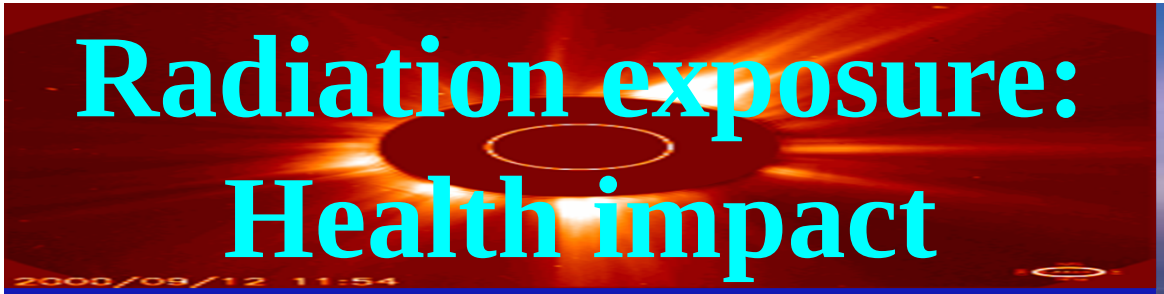
Image Credit: L. J. Lanzerotti, Bell Laboratories, Lecent Technologies, Inc.

Some of our Space-based laboratories



Courtesy of NASA

Radiation exposure: Health impact



15 000 m

12 500 m

10 000 m

RISK/ RISQUE

Technological development

Comparison with other large economic events

- San Francisco Earthquake ….. 1906 ……..$ 500B
- Hurricane Katrina …….... 2005 ……..$ 120B
- Annual loss from Electric interruption ……..$ 80B
- North American Power Grid Blackout ……..$ 30B/day
- GEO satellite revenue loss ……> $25B
- GEO satellite revenue loss ……..$ >25B
- Blackout of East Coast ……... 1955 ……..$ 10B
- Mt Lassen Volcanic Eruption .. 1915 ……$ 5B
- Quebec Blackout …….. 1906 ……..$ 2B

Baker et al.

Other space weather impacts on our daily life

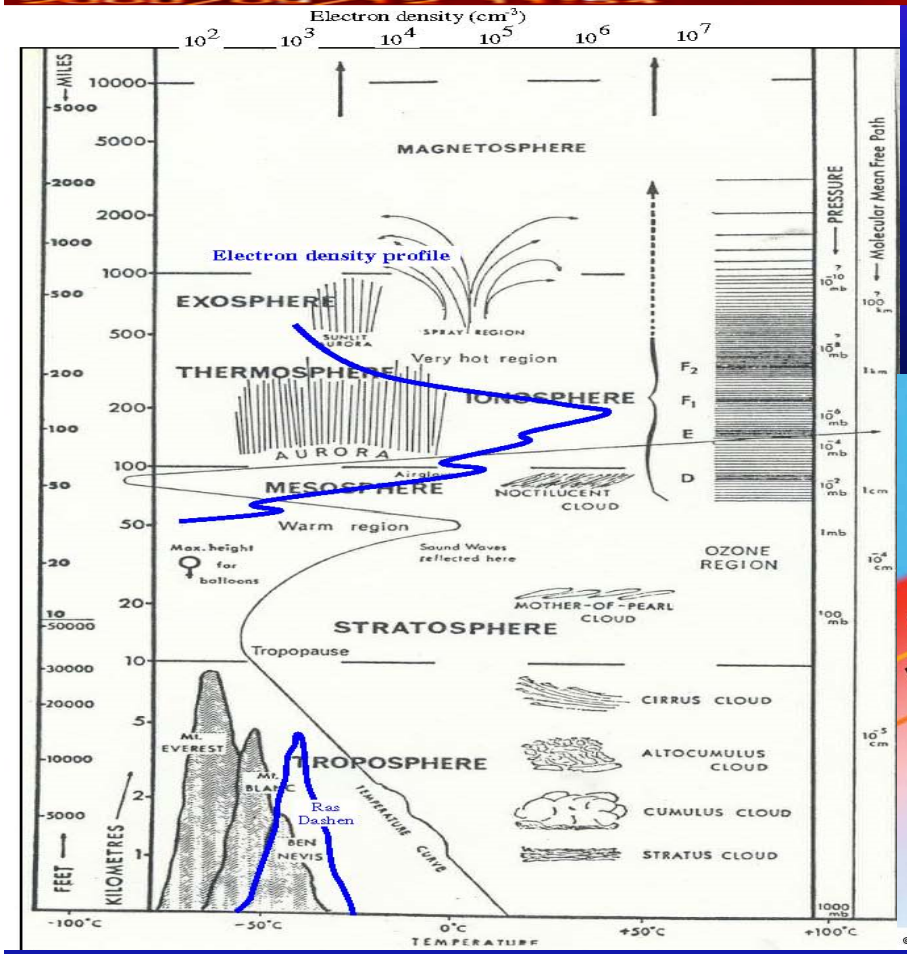
Communication

- The main factor that affect the navigation and communication system is the dynamic variability of plasma in our atmosphere.

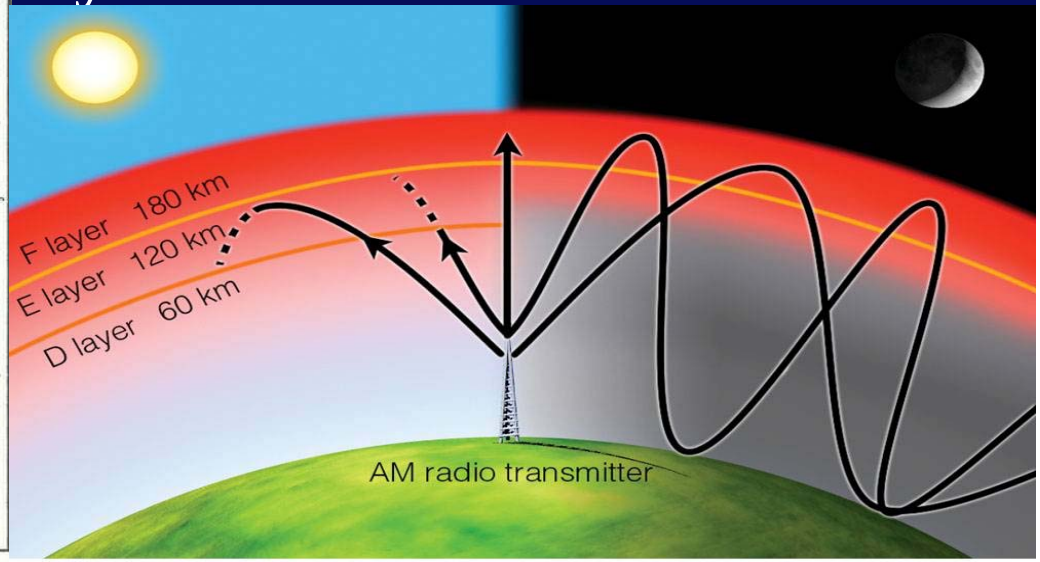
How and where, and why the densities are variable?

Navigation

Atmospheric region of interest



Ionosphere, is both important and trouble making region for our technological systems.



If so how does these ions/electrons act differently?

Production: due to Solar photons and electron precipitation

Transport: due to Electrodynamics

So what? Why do we care about ionospheric dynamics?

Electronic Communication

How does ionospheric dynamics in particular and space weather in general impact it?

Well! How do we get information or how do we communicate with the rest of the world?

Radio wave!

How does the ionosphere interacts with Radio Waves?

- **Can refract it:**
  - **Slows down waves and leads to dispersion**
- **Can reflect it:**
  - **Allows us to have OTH radio communication**
- **Can Scatter it:**
  - **Causes signal degradation and loss**
- **Can Absorb it:**
  - **Causes HF radio blackout**

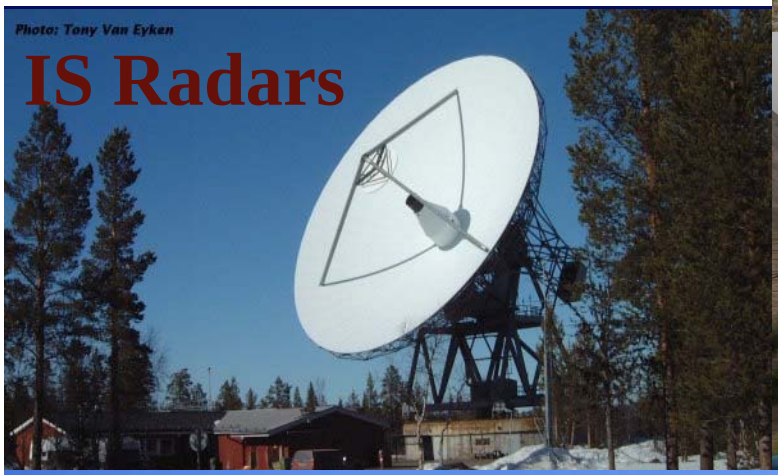
How do we monitor the condition of the ionosphere and its drivers?

Ground-based Instrumentations

VLF receiver

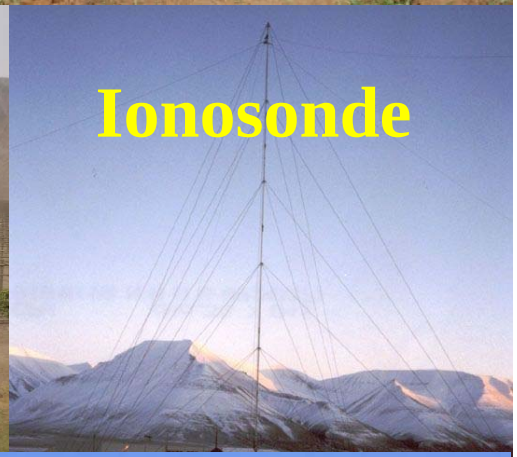

UHF receiver


Magnetometer



IS Radars

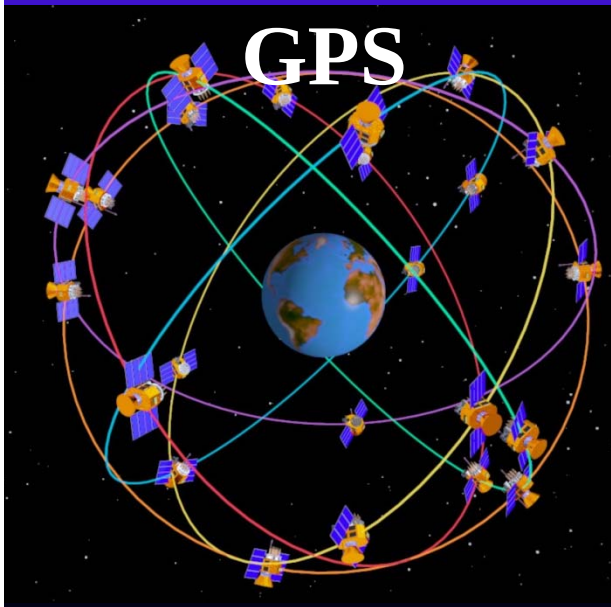

VHF Backscatter


Ionosonde


SuperDARN Radars

GNSS Constellations

GPS

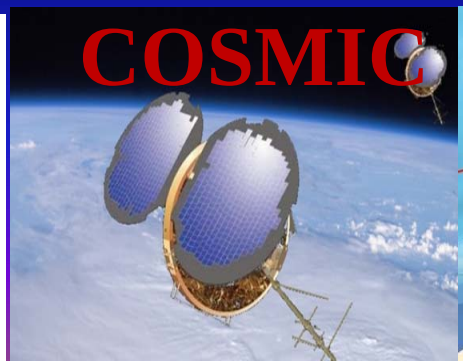


GLONASS

GALILEO

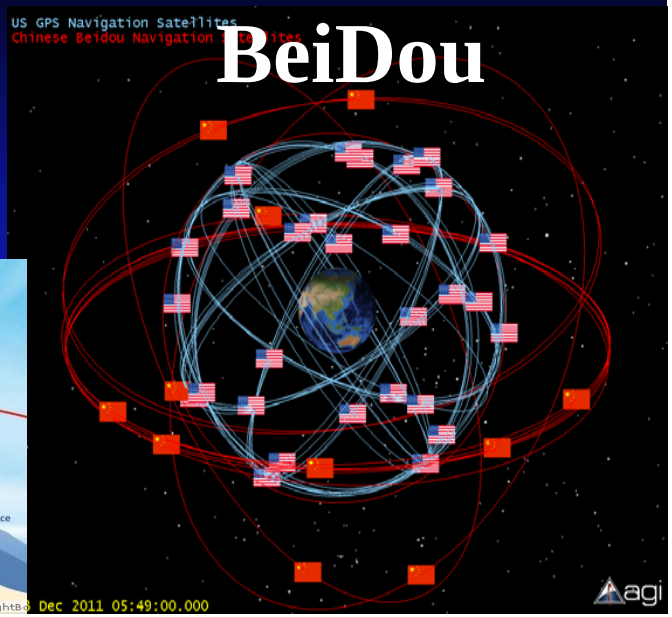
The signals can be listened by receivers on the ground and onboard LEO satellites

COSMIC

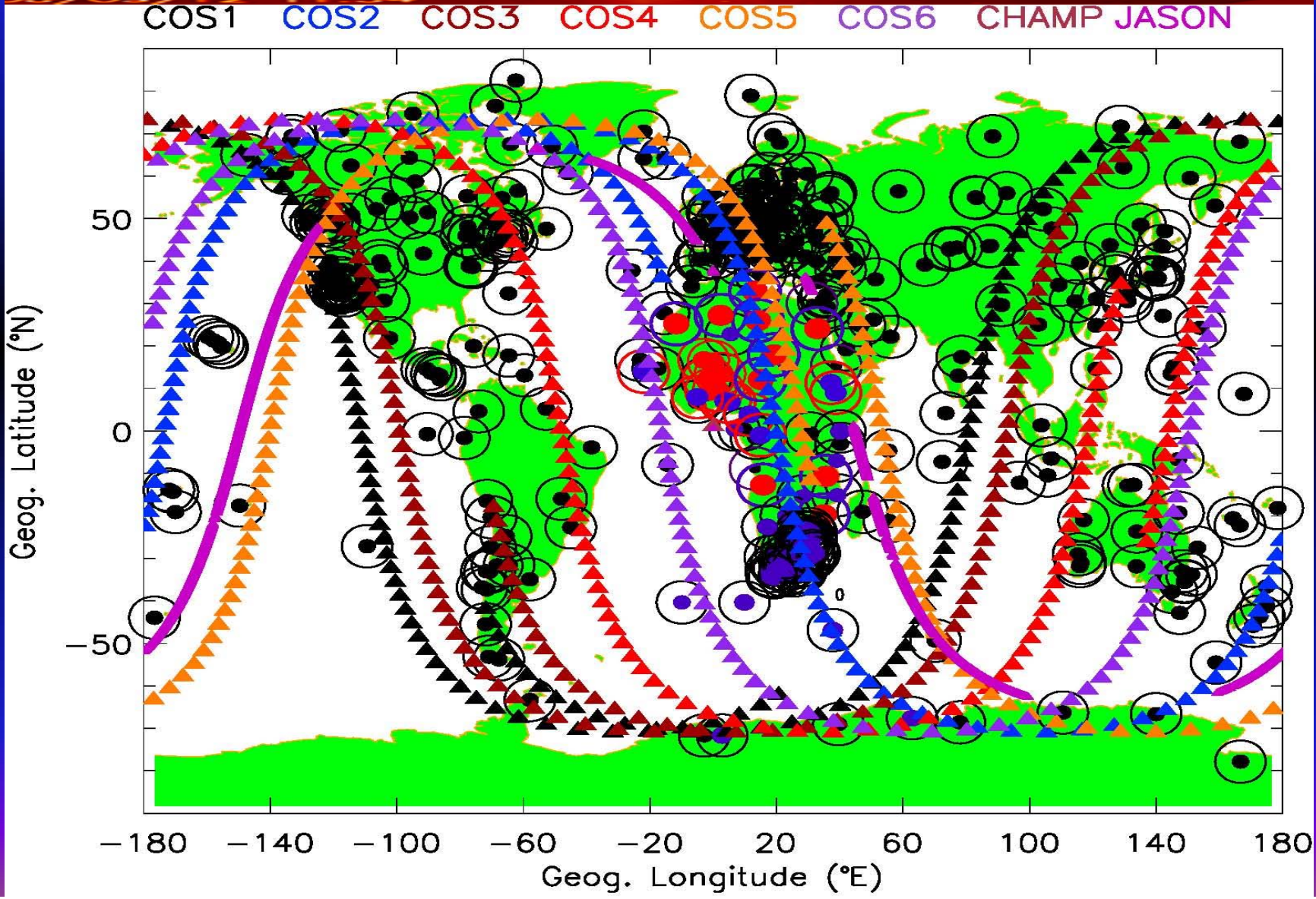


JASON

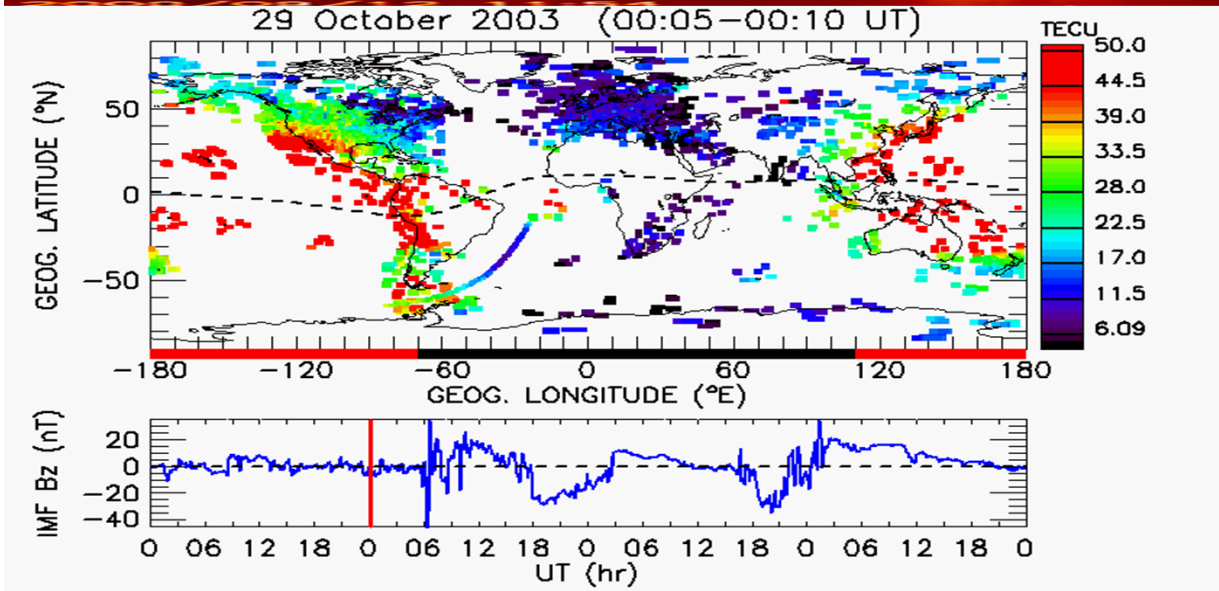
BeiDou

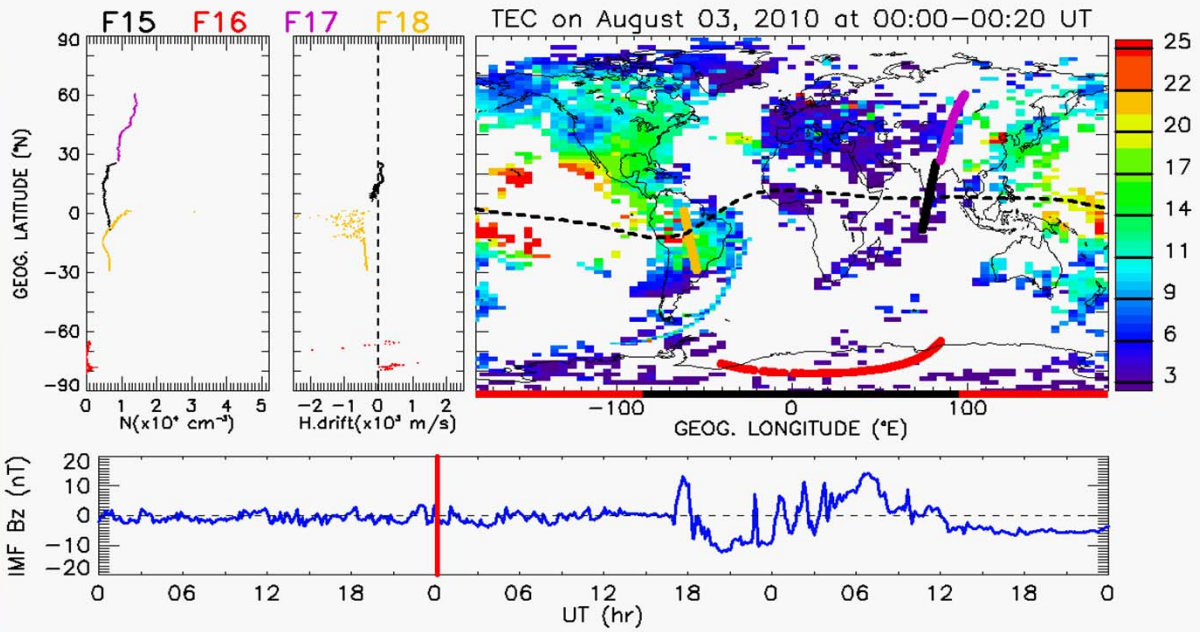


GNNS signals receivers: ground- and space-based



Ionosphere is boiling like ---?



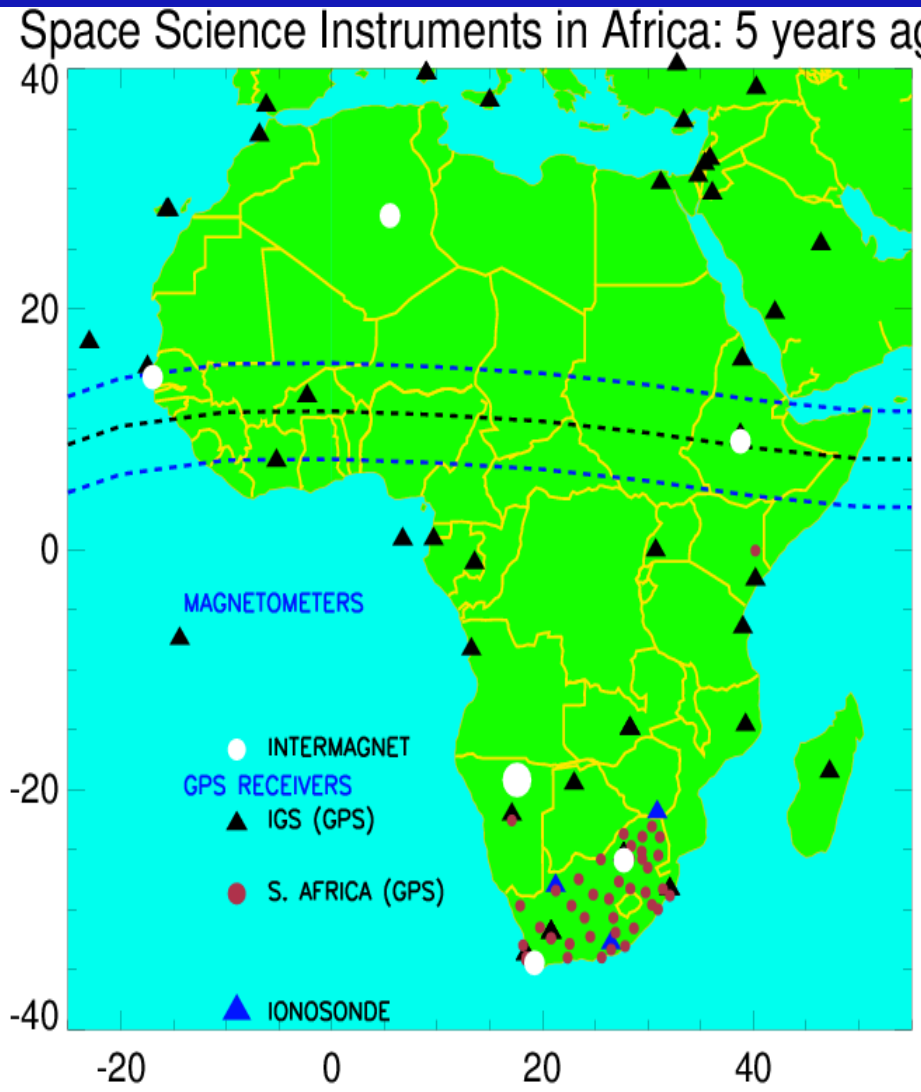


GNSS and LEO coverage: a decade ago

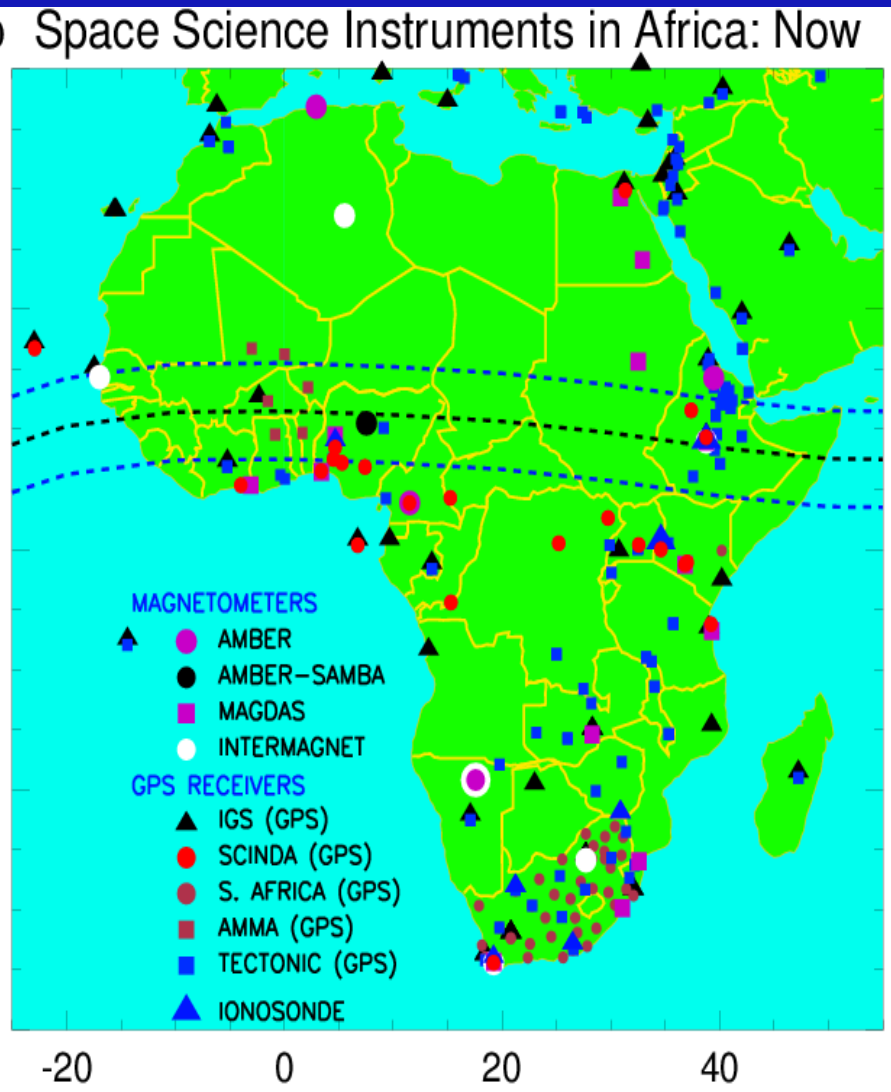
GNSS and LEO coverage: three years ago

General Instrumentation in Africa

Six Years ago



One Year ago

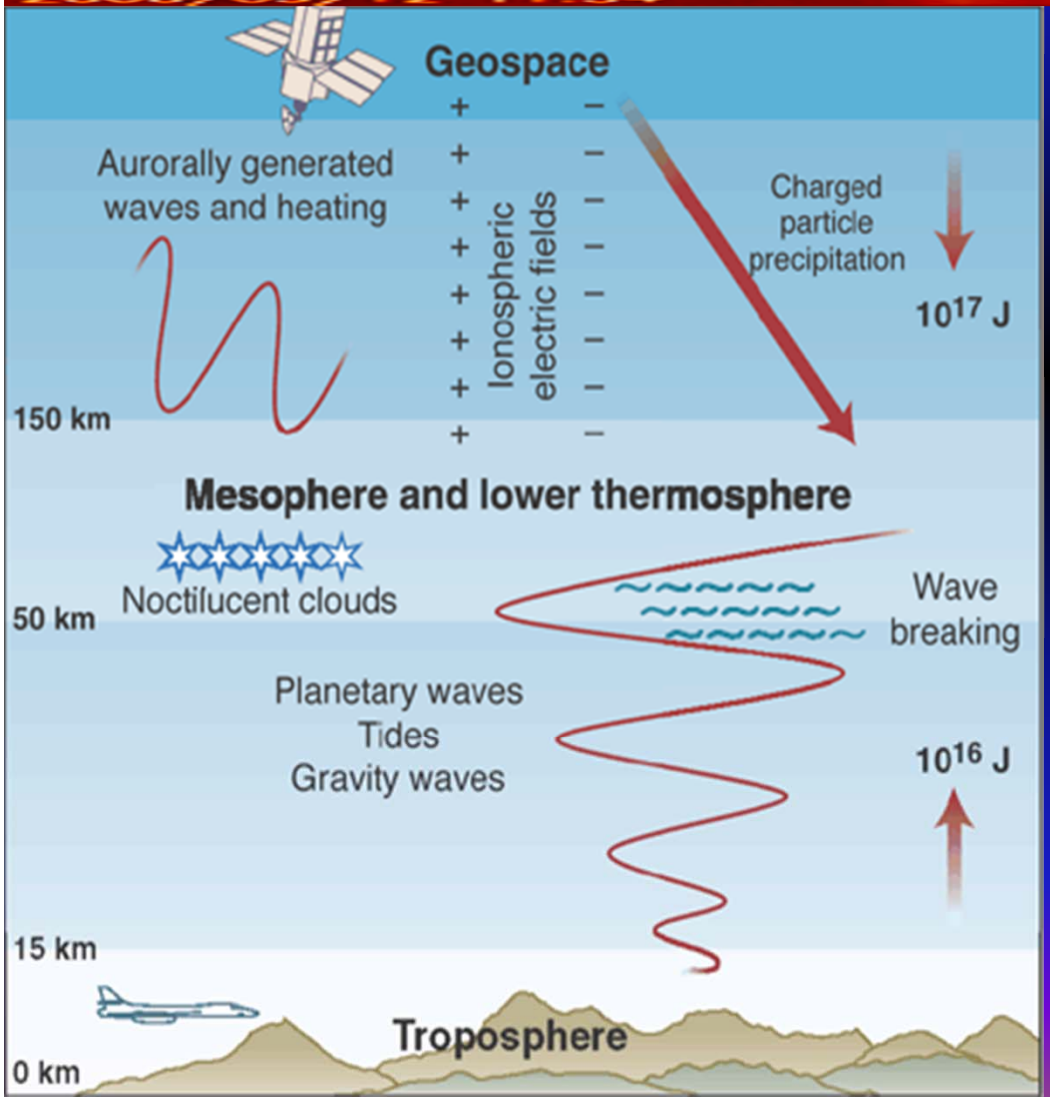


What does these instruments, deployed in Africa, do?

- First it trains and exposes young Africans to science & technology
- It monitors the space weather impacts in the African sector and provide advice to stake holder authorities, which is important to the African socio economic developments.
- It opens opportunities for African scientists to participate in the global space weather research activities

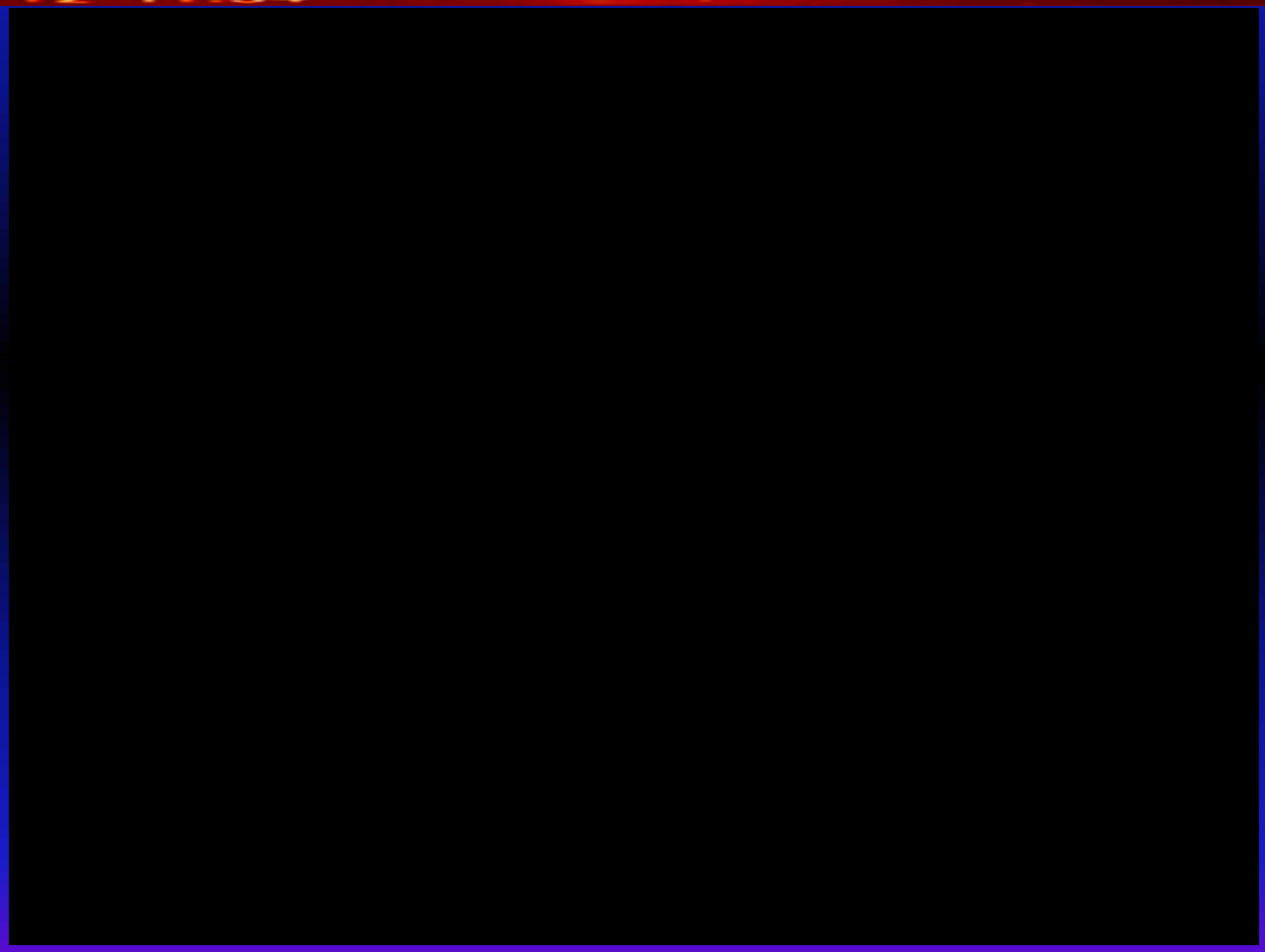
✈ **The TWO prominent challenges:** Frequent Power outage and Internet Connectivity

Space weather impact from the lower atmosphere



- Gravity waves can propagate upward and produce density irregularities
- Tsunami and earthquake can generate strong gravity wave
- Thermospheric tides also modulate the equatorial electrodynamics and thus the longitudinal density distribution

Tsunami and Earthquake impact on ionospheric density



Courtesy to David Galvan

How can such impact be reduced?

- Provide advice to the power station crew to reduce the output current in advance by looking at the Sun
- However, experienced space weather expert is required to provide such advice.
- For Africa, encouraging the next generation of African scientists to become inspired by space science is important.
- One way to do this is creating opportunities for Africans to make interaction with international scientists.
- The instrument deployment in Africa through IHY & ISWI program significantly spark interest in space science education and research throughout Africa.
- A follow-up training workshop, like GNSS workshop, is highly essential to produce more young well trained fellows.

In 2012 the British government declare that space weather is one of the greatest threats to the country

"Severe space weather can cause disruption to a range of technologies and infrastructure, including communications systems, electronic circuits and power grids."

Cabinet Office's National Risk of Civil Emergencies report

The 2008 US National Research Council estimated the cost if a September 1859 sized CME hit us.

"First it could take us 10 years to recover, and cost could be between $1 trillion and $2 trillion (in the first year alone) to repair the damage"

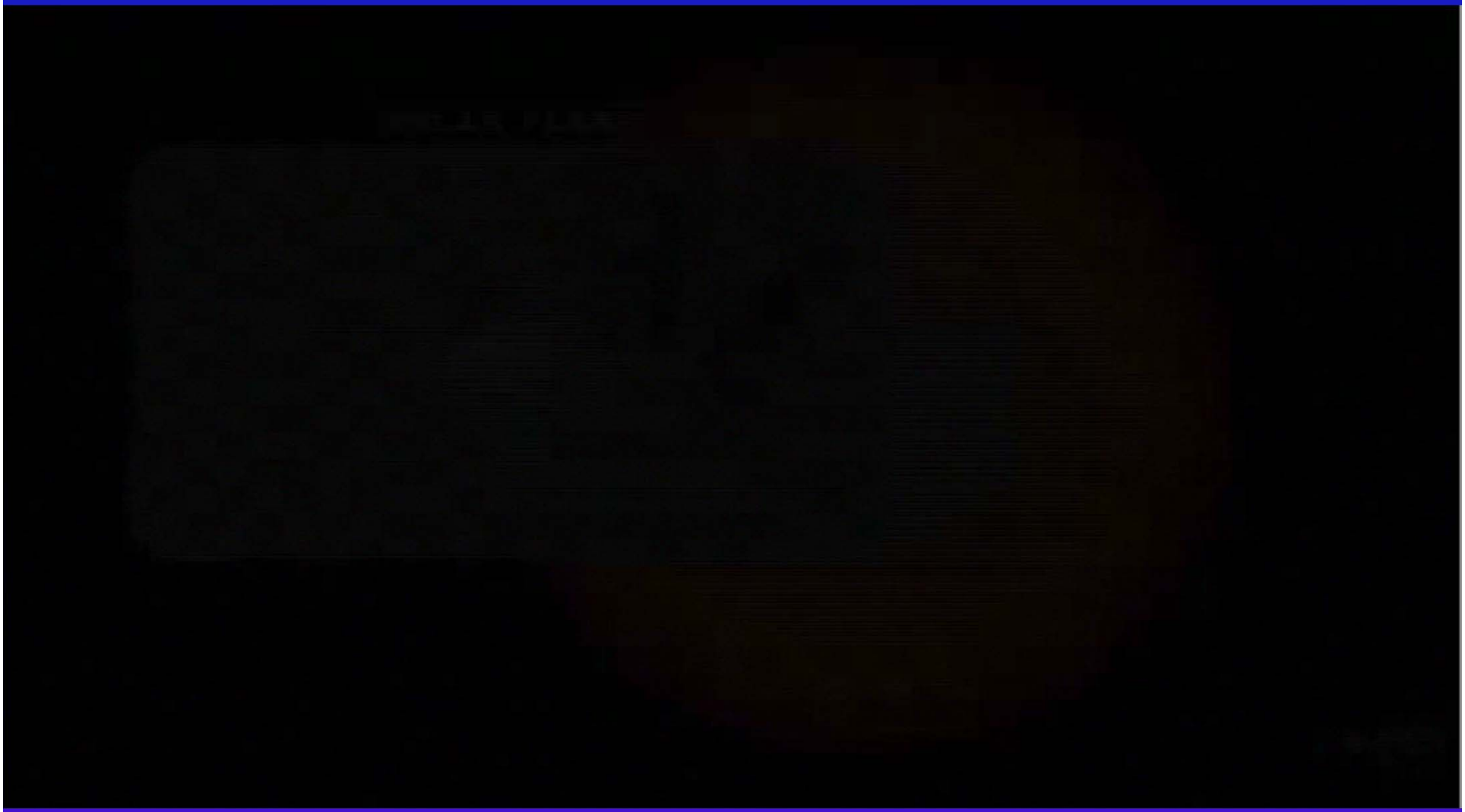
The 2008 US National Research Council report

New Theory of Climate Change and Sun!

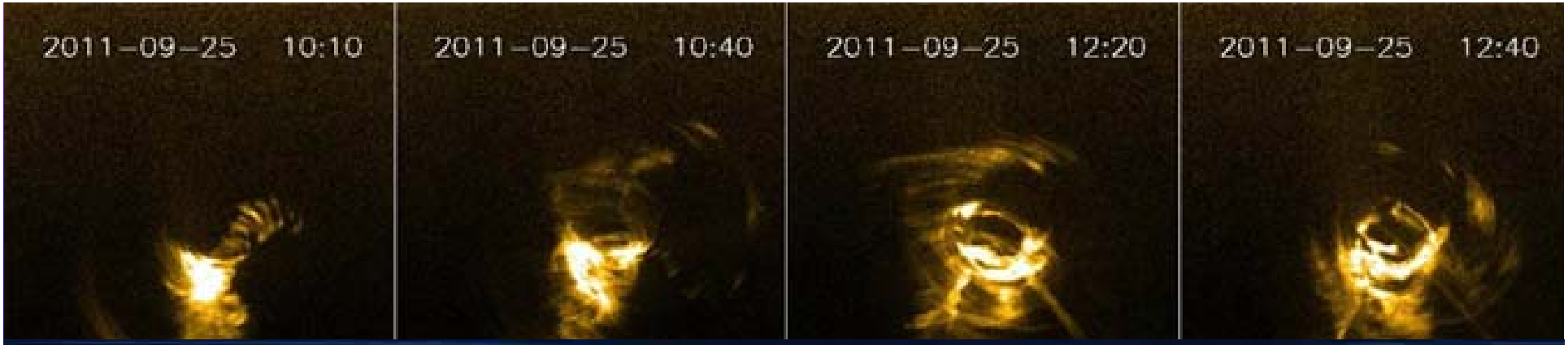
"global warming is directly related to the magnetic field change rather than CO2 emissions. They claimed that fluctuations in the number of cosmic rays hitting the atmosphere directly alter the amount of cloud covering the planet."

Danish National Space Center report

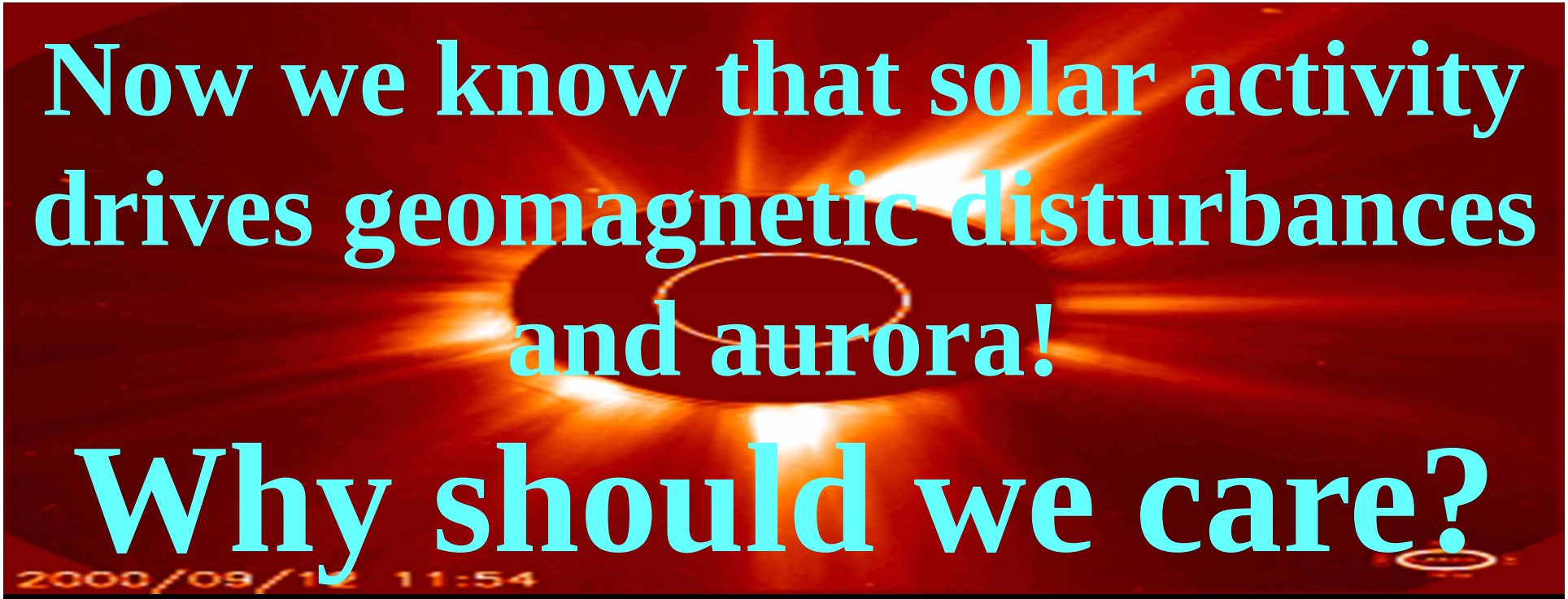
Pictorial Summary!



Courtesy of NASA



Thank you for having us here in Kigali, and hope we'll have a productive workshop at the end!



Now we know that solar activity drives geomagnetic disturbances and aurora!

Why should we care?

- **Geomagnetic disturbances and aurora are signatures of space weather.**
- **Space weather storms now have the ability to damage modern space-age technology (communication, navigation and power distribution) and significantly impact civilization**