Mientras que el Sol y el espacio entre nosotros puede ser visto como algo agradable y tranquilo desde nuestra perspectiva.

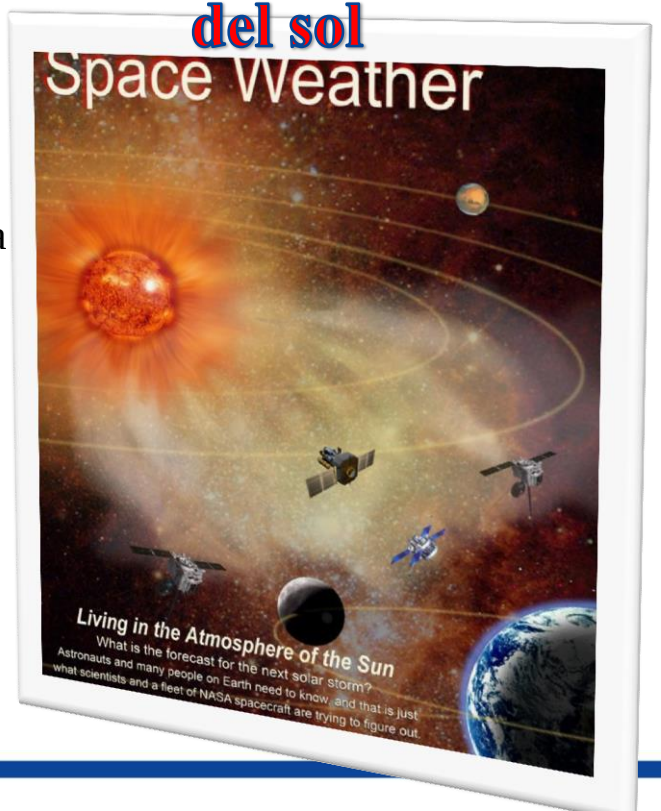
Es todo menos pacífico!

Which Weather? ¿Qué clima?

Vivir en la atmósfera de la tierra

Si el espacio cerca de la Tierra importa, queremos tener una predicción del tiempo. Sin embargo, si hablamos de comunicaciones y posicionamiento con la nueva tecnología estamos hablando del tiempo espacial.

Vivir en la atmósfera del sol



The Sun that we know

El sol en la luz blanca muestra manchas oscuras.

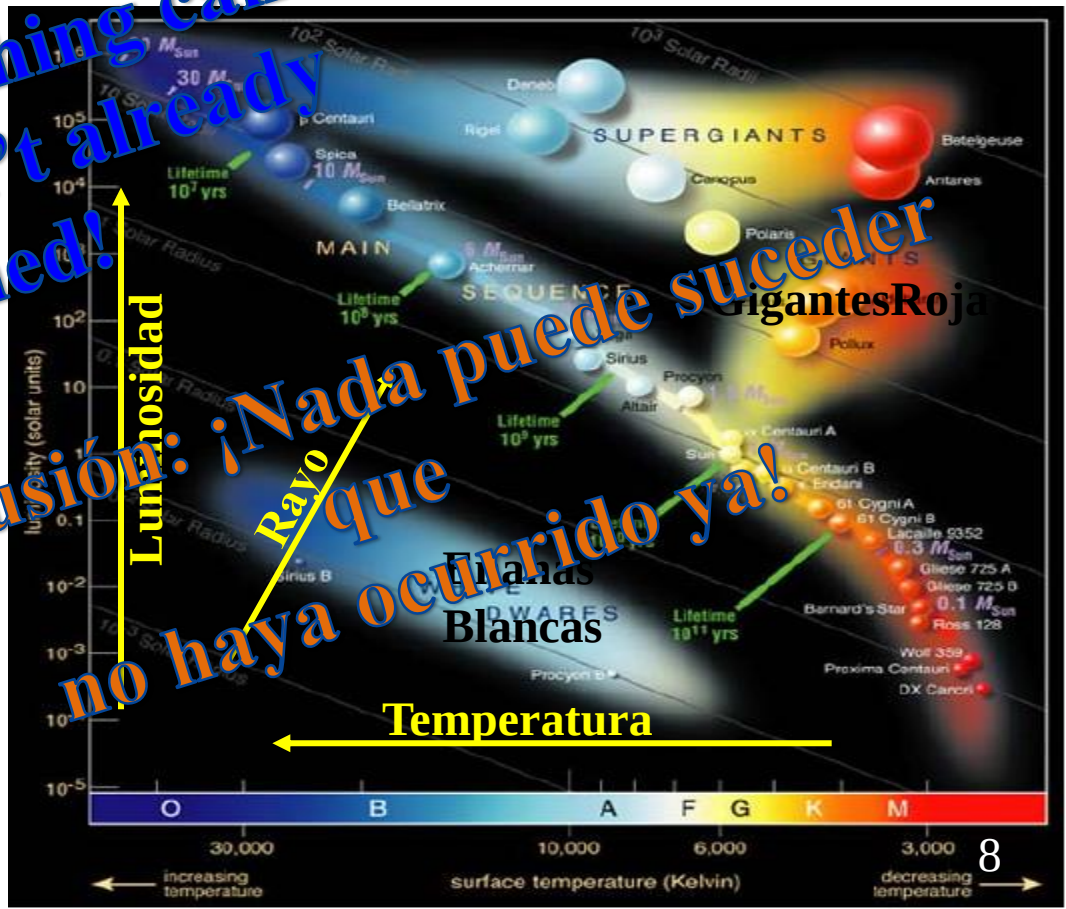
Estas manchas son conocidas desde hace al menos cuatro milenios.

Hoy sabemos que son regiones donde el campo magnético solar es muy intenso.

El sol tiene una rotación variada dependiendo de la latitud. En promedio da una rotación en 27 días.

The Hertzprung-Russel diagram

- El Sol se mantuvo estable en los últimos 4.500 millones de años.
- Va a tener otros 4.500 millones de años para vivir.
- Esta vida fue suficiente para garantizar que nada malo puede suceder a la Tierra.



We should not worry

No deberíamos preocuparnos

The Sun is a stable Star

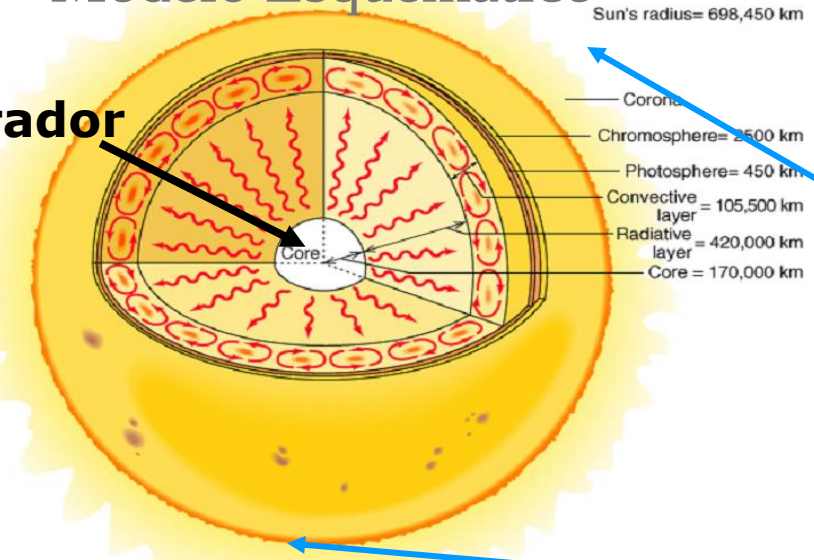
El sol es una estrella estable

In equilibrium, but Active.

Equilibrado, pero ... altamente dinámico en toda su estructura interior y exterior.

Composición del sol

Modelo Esquemático



Generador

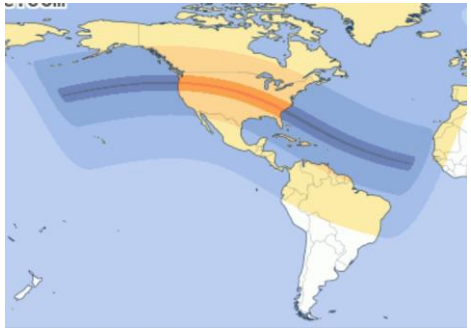
La energía se libera en el núcleo cuando el hidrógeno se funde en helio. Esta energía fluye como radiación, y luego como la ebullición (convección), y de nuevo como radiación fuera de la fotosfera, que es la porción del Sol que vemos.

The Sun has atmosphere
El sol tiene atmósfera

Proeminencias solares

Corona

ECLIPSE
21 August 2017
United States



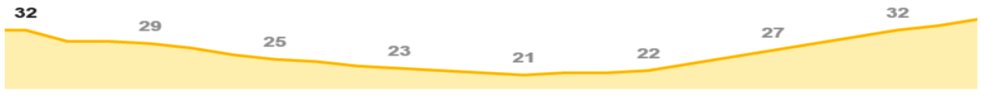
Forecasting what?

Jardim da Granja, São José dos Campos - SP
sexta-feira, 16:00
Nuvens esparsas

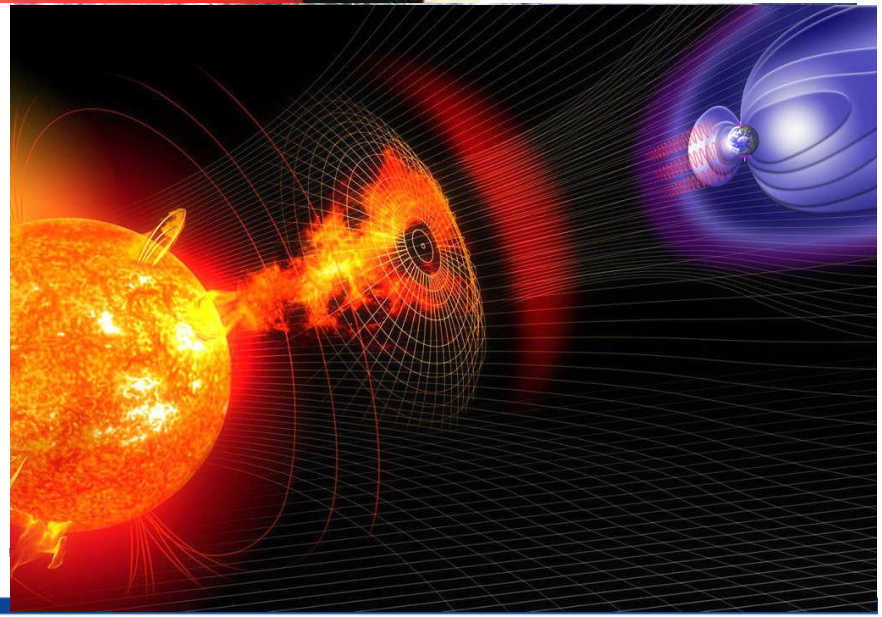
32 °C | °F

Chuva: 50%
Umidade: 33%
Vento: 19 km/h

Temperatura | Chuva | Vento



sex	sáb	dom	seg	ter	qua	qui	sex
33° 21°	36° 21°	32° 21°	30° 21°	32° 21°	28° 20°	29° 19°	33° 20°

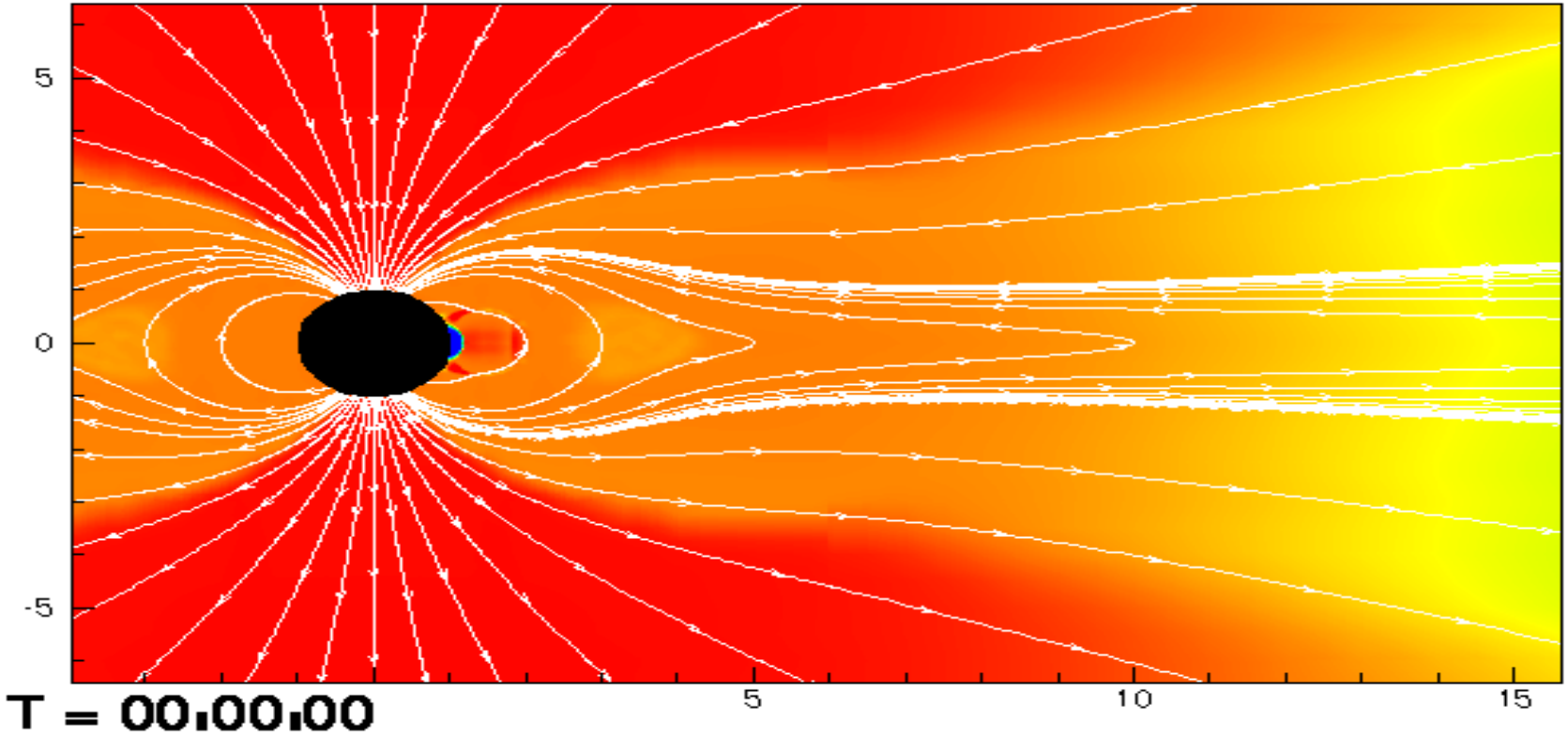


Important Features of Solar Observables

Características de Solar Observables.

How big is the problem?

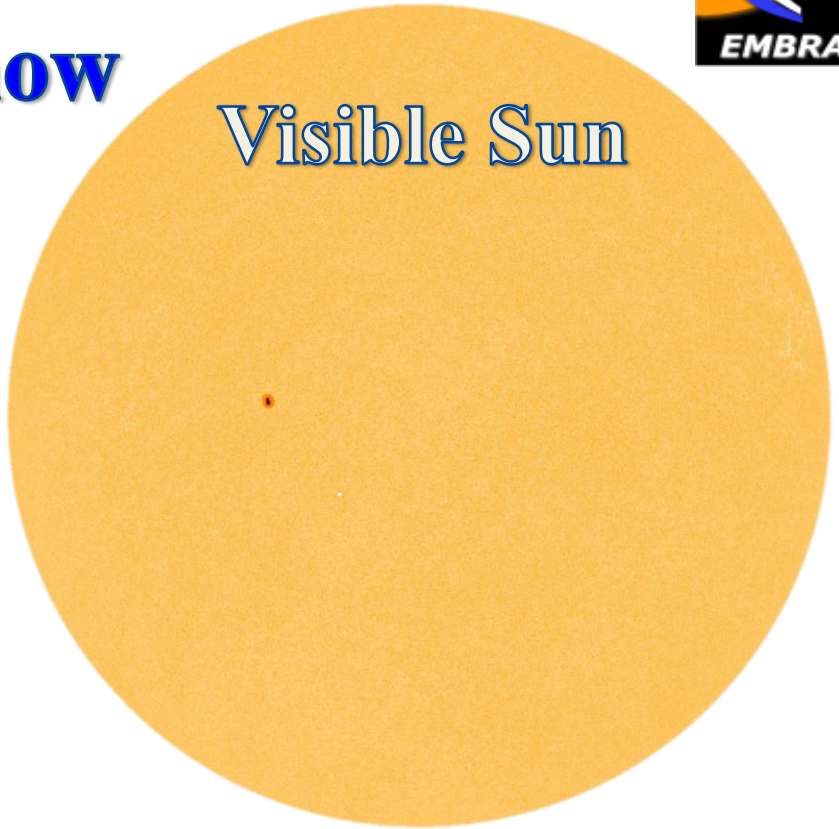
Center for Space Environment Modeling
University of Michigan



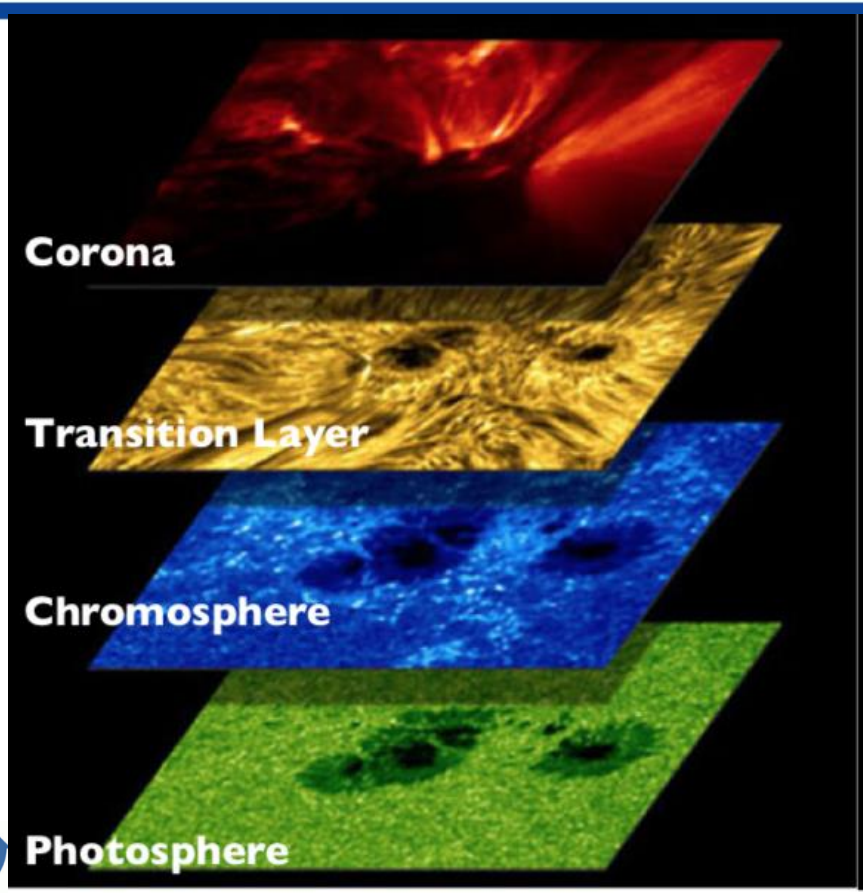
CME Simulation - University of Michigan

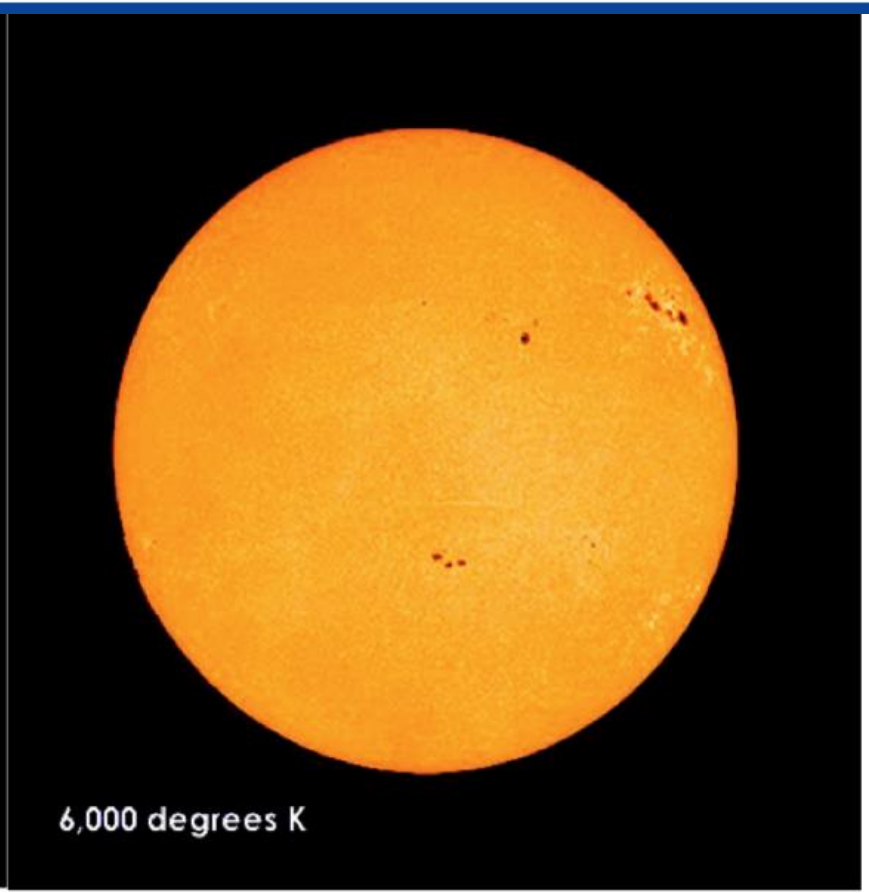
Wouldn't you like to know the sun that you don’t see?

No le gustaría conocer el sol que no ves?

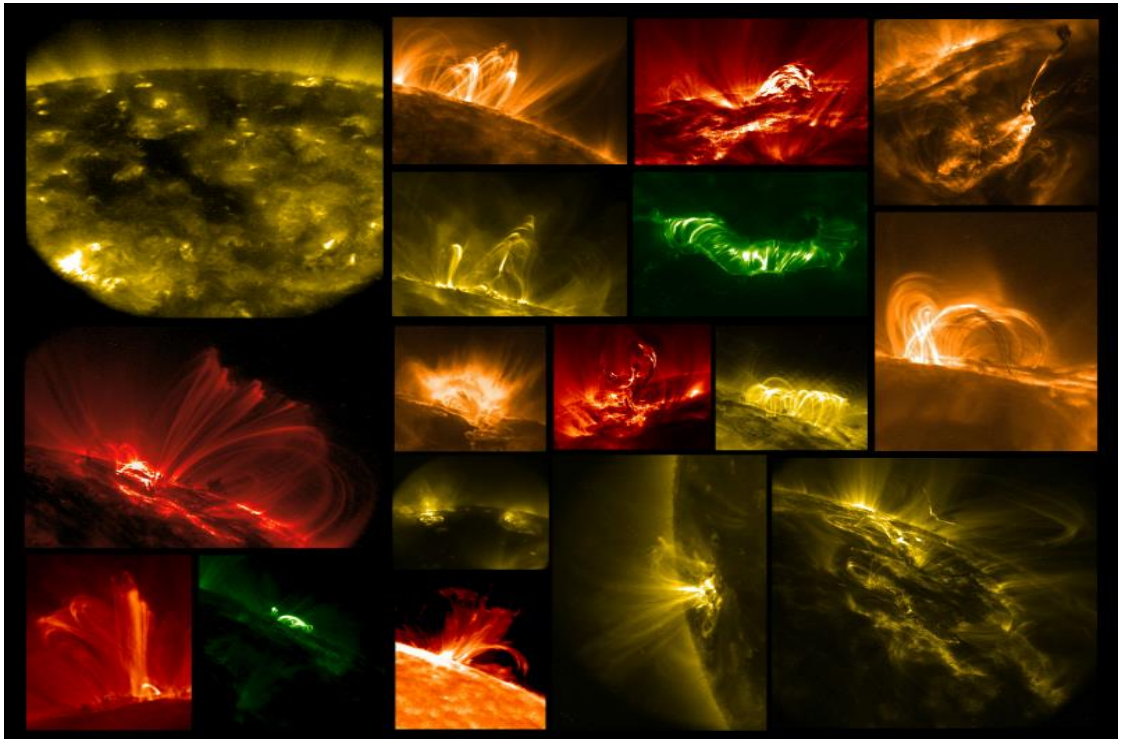


Solar Atmosphere and Radiation





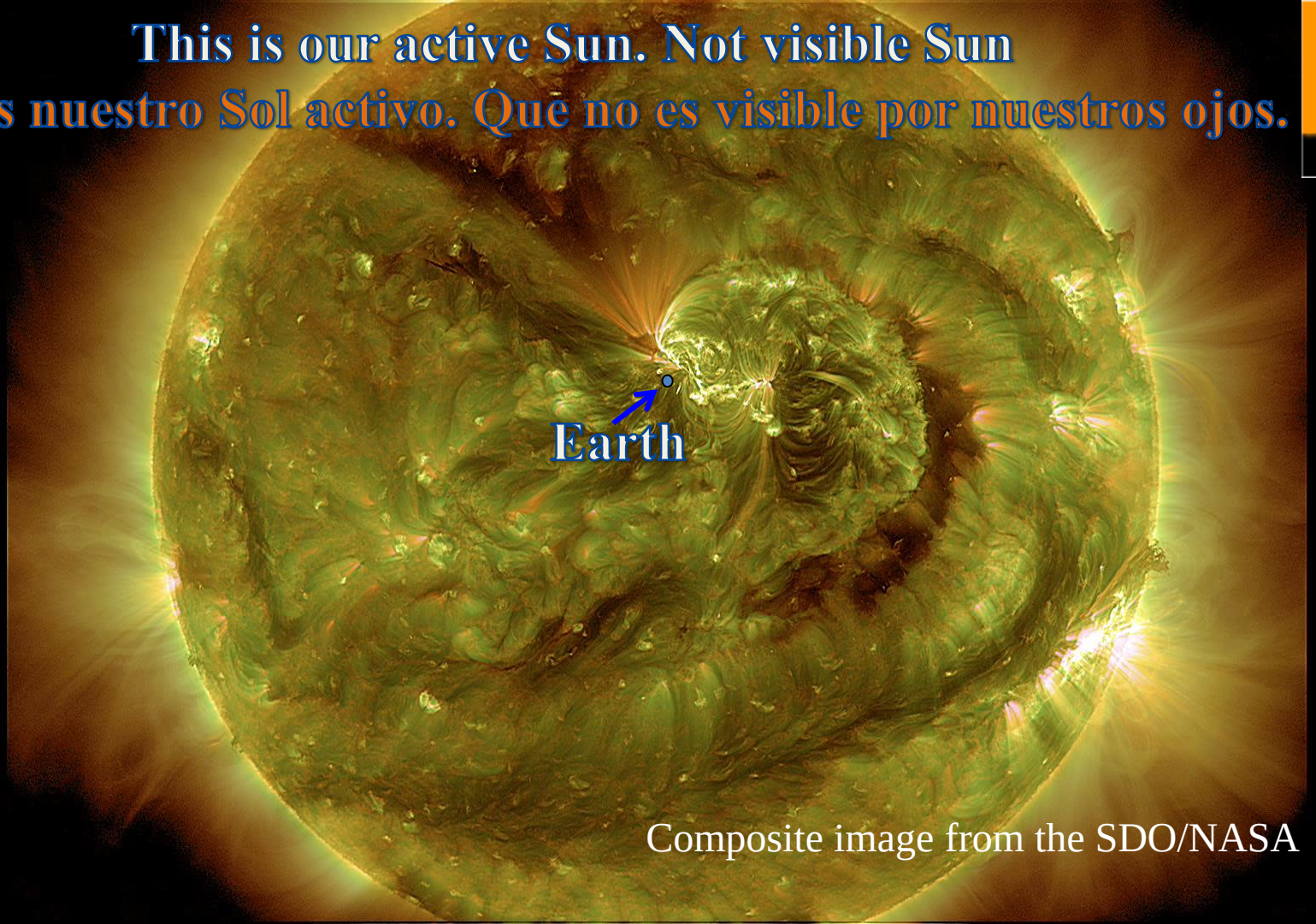
Show Magnetic Fields



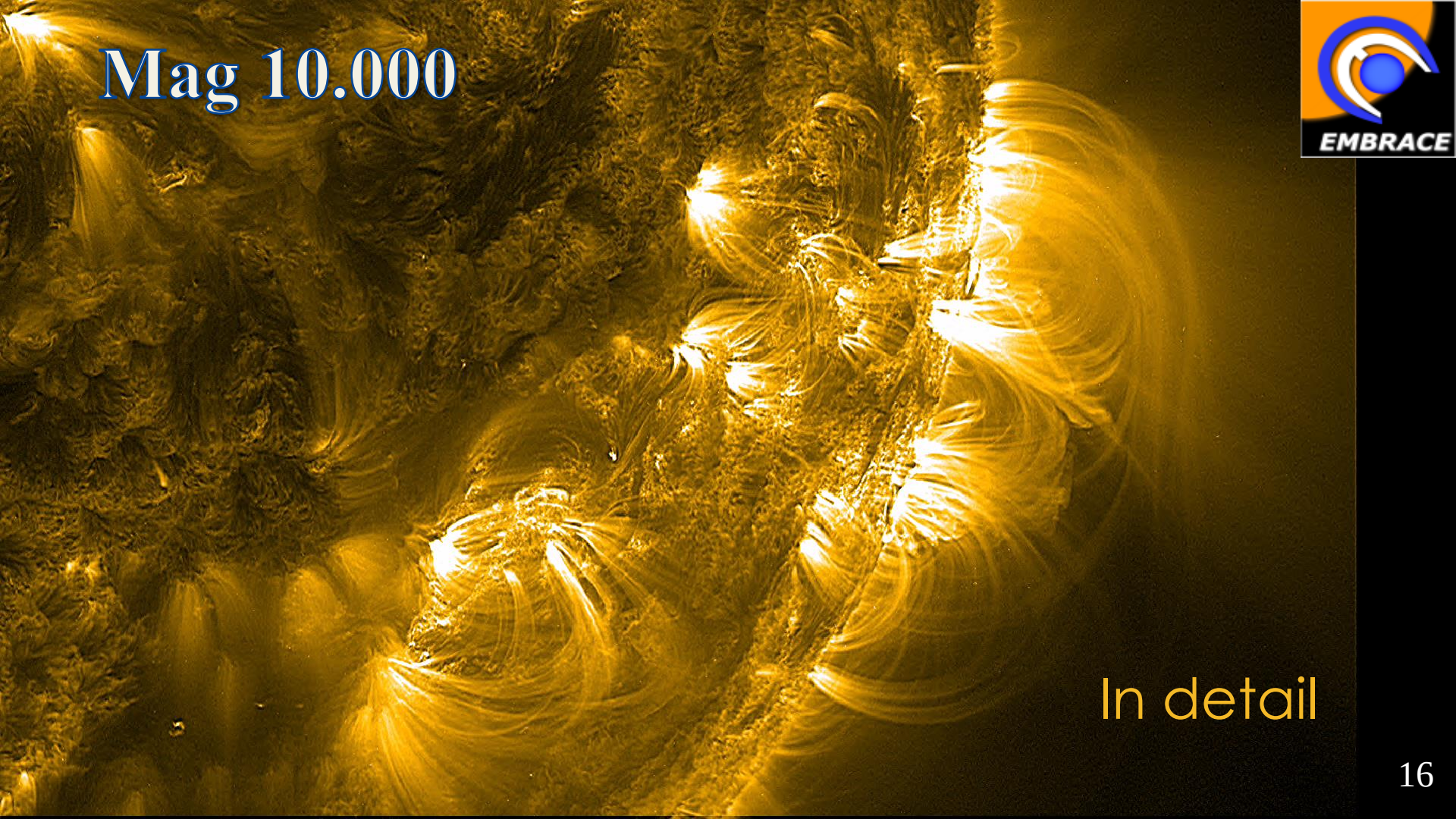
a 2.1 - Mosaico de imagens obtidas pelo instrumento TRACE na faixa espectral do ultravioleta extremo, nos comprimentos de onda de 171 Å, 195 Å e 284 Å. Fonte: NASA/Lockheed Martin.

This is our active Sun. Not visible Sun

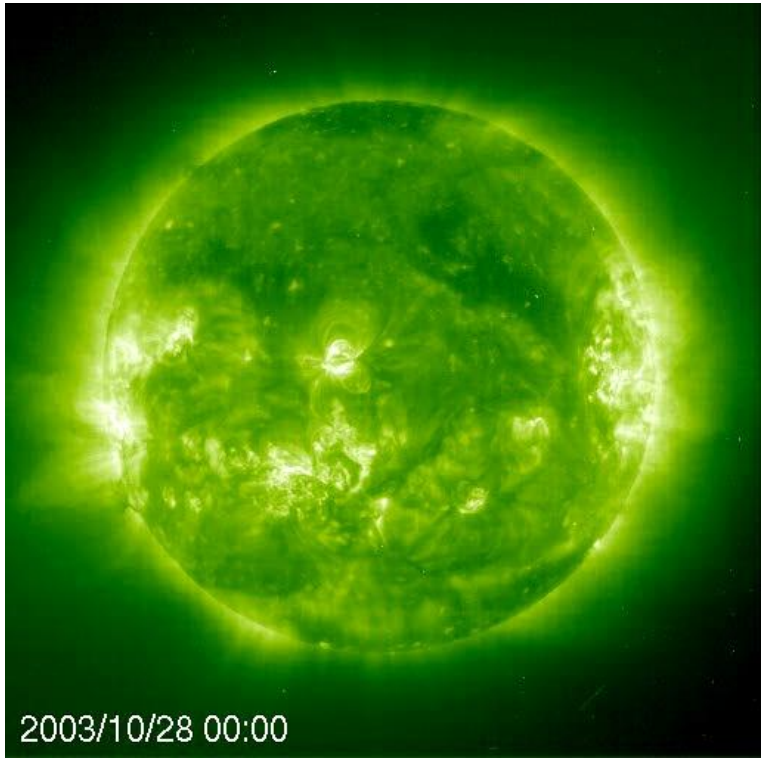
Este es nuestro Sol activo. Que no es visible por nuestros ojos.

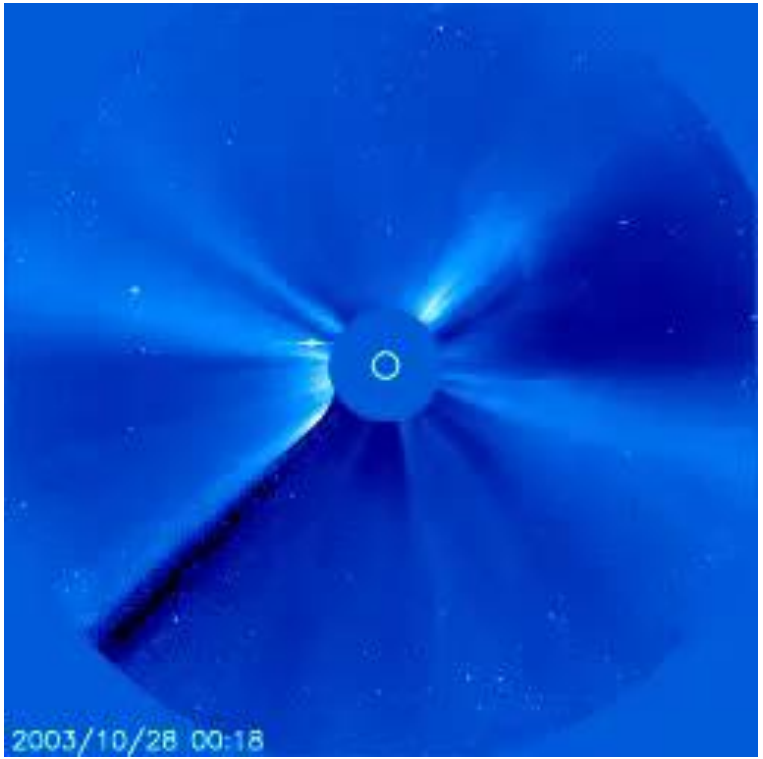


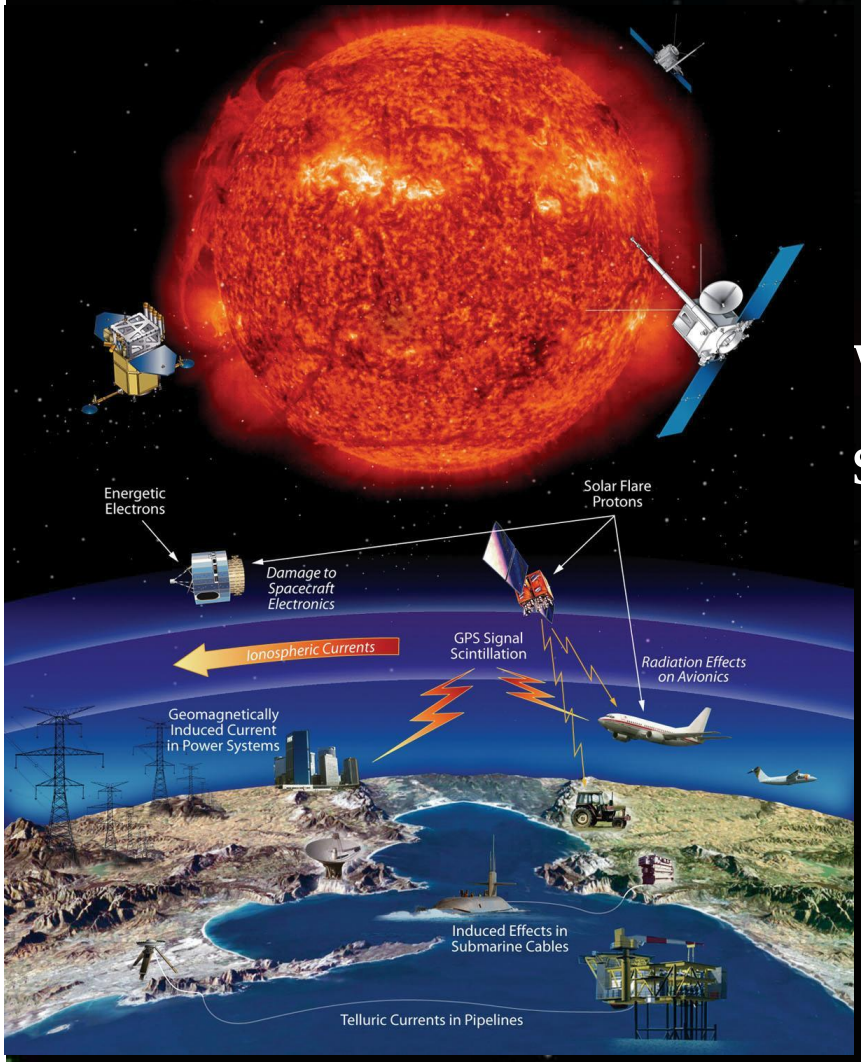
Composite image from the SDO/NASA


Mag 10.000
EMBRACE
In detail

Flares and CME's





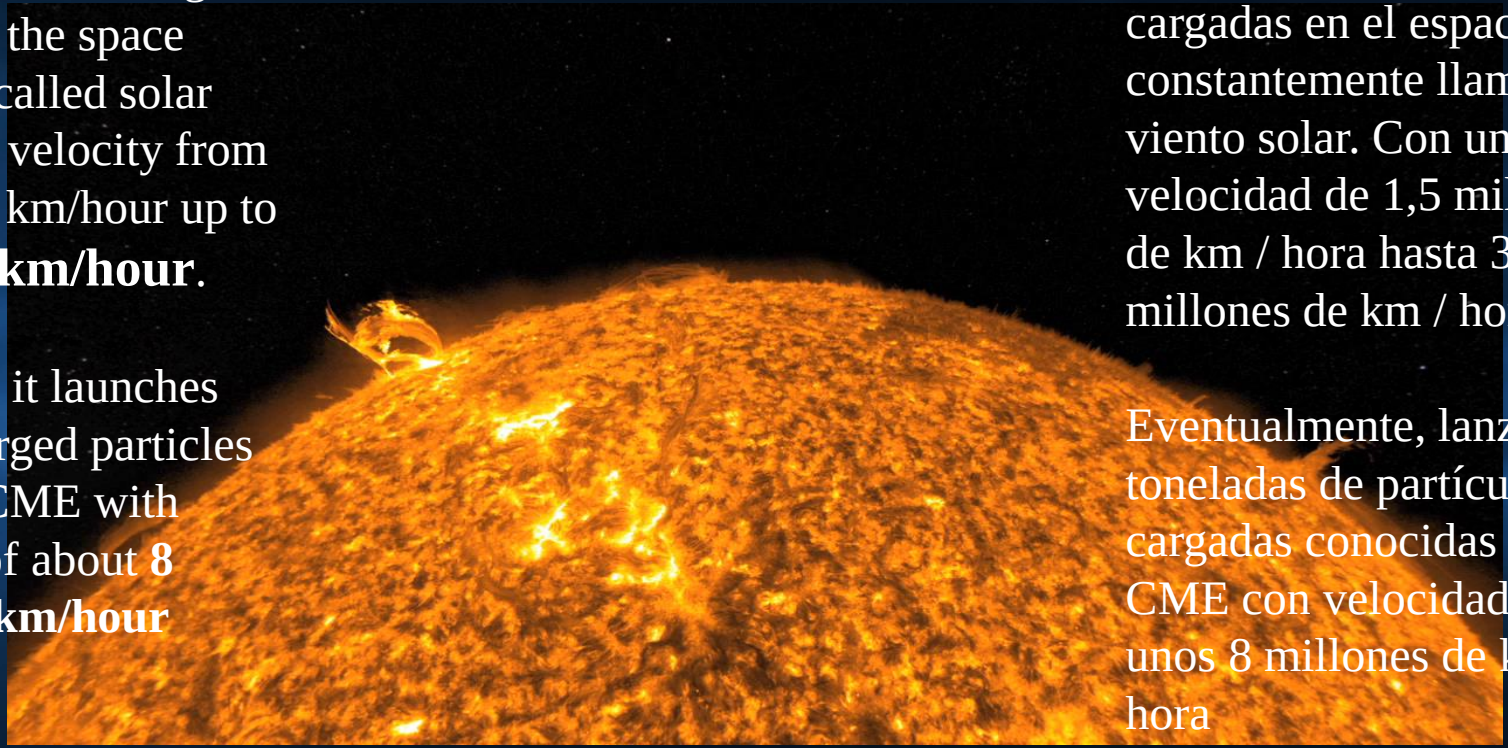


Why is this almost empty space important to us?

Connection: Sun - Earth

The Sun release charged particles in the space constantly called solar wind. With velocity from 1.5 million km/hour up to **3 million km/hour**.

Eventually, it launches tons of charged particles known as CME with velocities of about **8 million of km/hour**



El sol libera partículas cargadas en el espacio constantemente llamado viento solar. Con una velocidad de 1,5 millones de km / hora hasta 3 millones de km / hora.

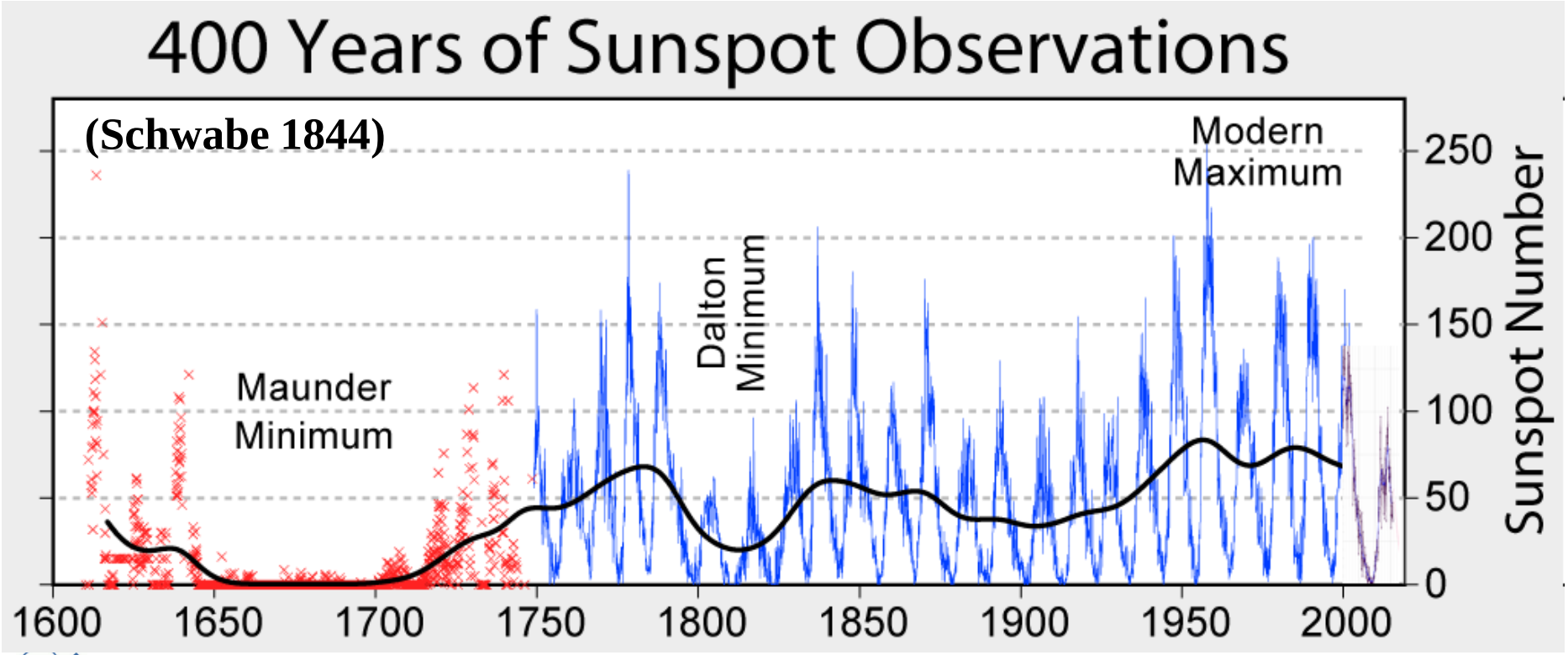
Eventualmente, lanza toneladas de partículas cargadas conocidas como CME con velocidades de unos 8 millones de km / hora

magnetosphere

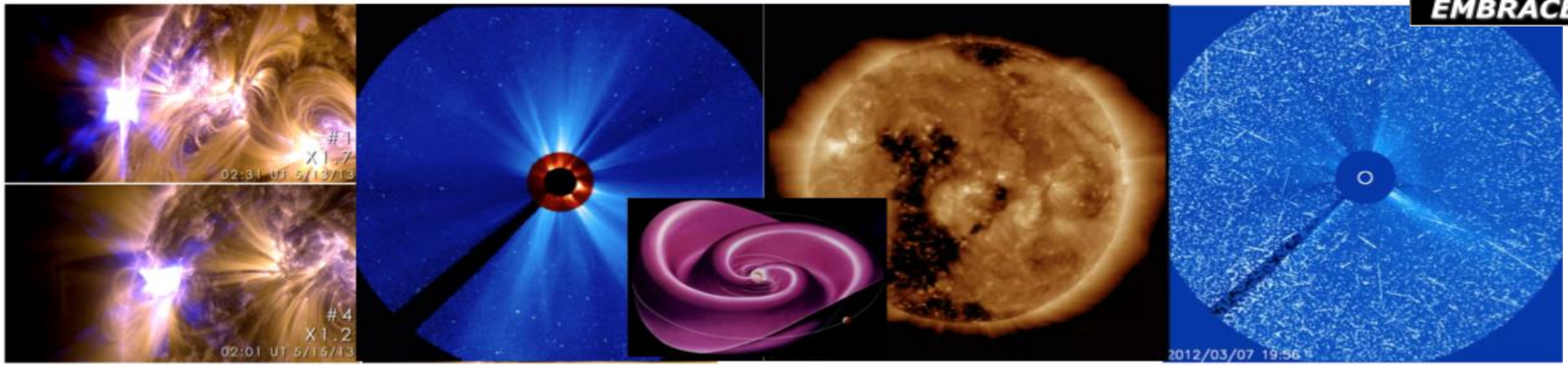
The solar Cycle

El ciclo solar

Sunspots and the Solar Cycle



Space of *Space Weather* Agents



- Flare (excess of rad.)
- Filament disruption
- SEP
- Solar Wind

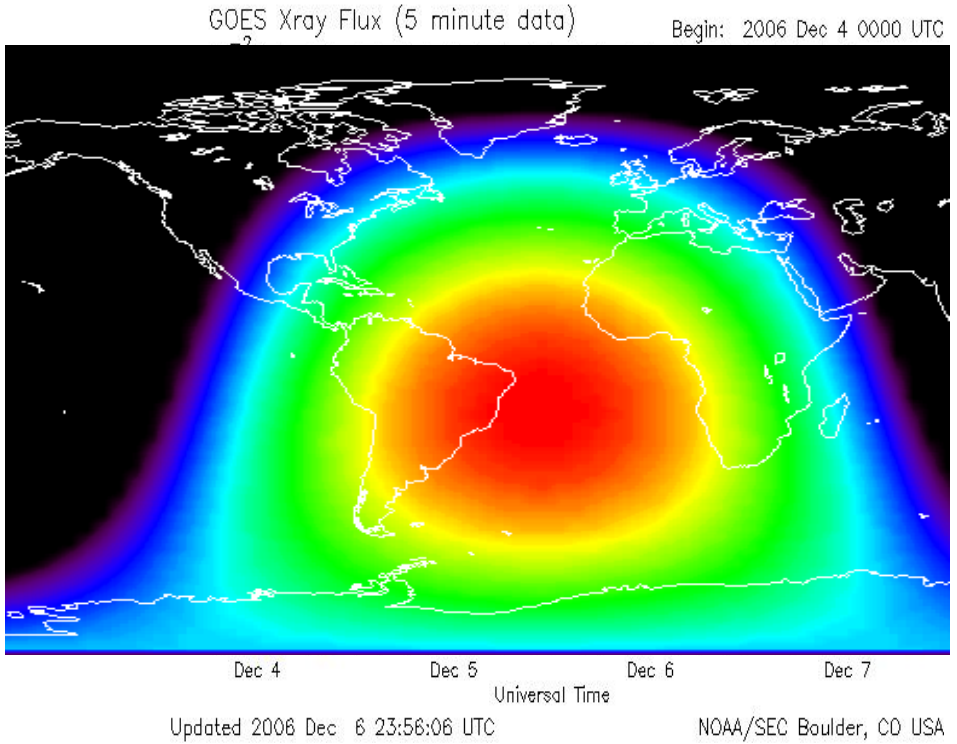
- CME or Magnetic Cloud
- Coronal Hole -> HSS
- Sector change
- CIR
- SEP

- SEP at near Earth

1-Type Storm: Radio Blackouts

1.Radio Blackouts

- Solar Flares send out x-rays
- Arrive at Earth in 8 minutes
- Modify the ionosphere
- Disrupt HF radio communication
- Impacts:
  - Airline communication
  - HF radio operators
  - Defense Communications
  - Satellite Communications

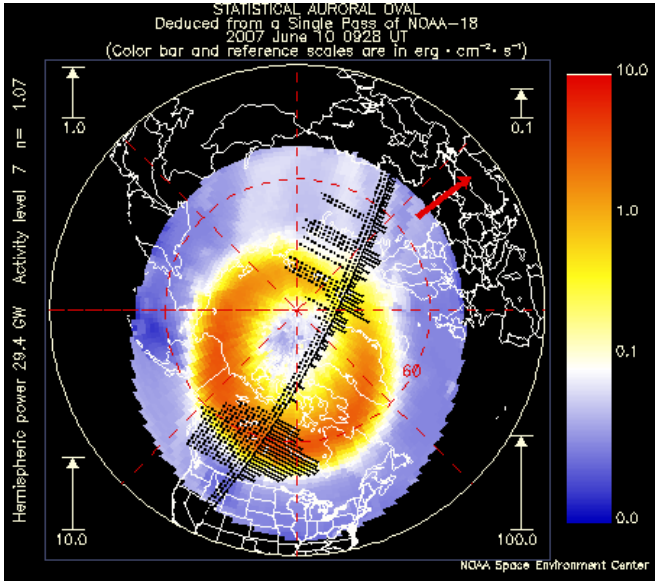


2-Type Storm: Radiation Storm

2.Radiation Storms

- Solar Flares and Coronal Mass Ejections (CMEs) send out Energetic Particles
- Arrive at Earth in 15 minutes to 24 hours
- Modify the high latitude ionosphere
- Disrupt HF radio communication
- Impacts:
  - Airline communication
  - HF radio operators
  - Defense Communications
- Ionizing radiation penetrates into the atmosphere
- Impacts:
  - Astronauts (radiation)
  - Satellite failures

3-Type Storm: Geomagnetic Storm

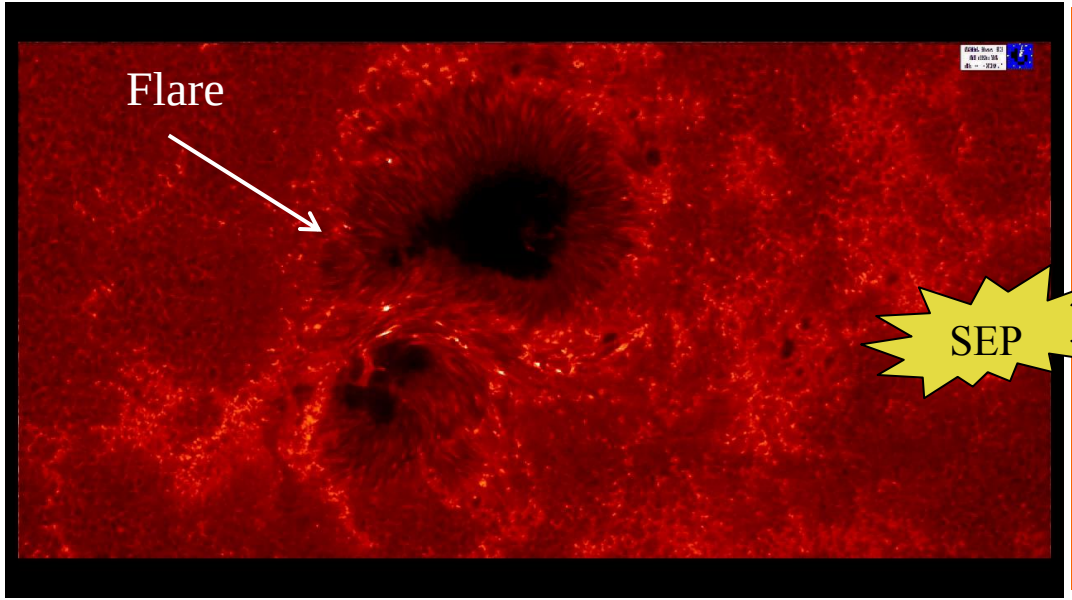


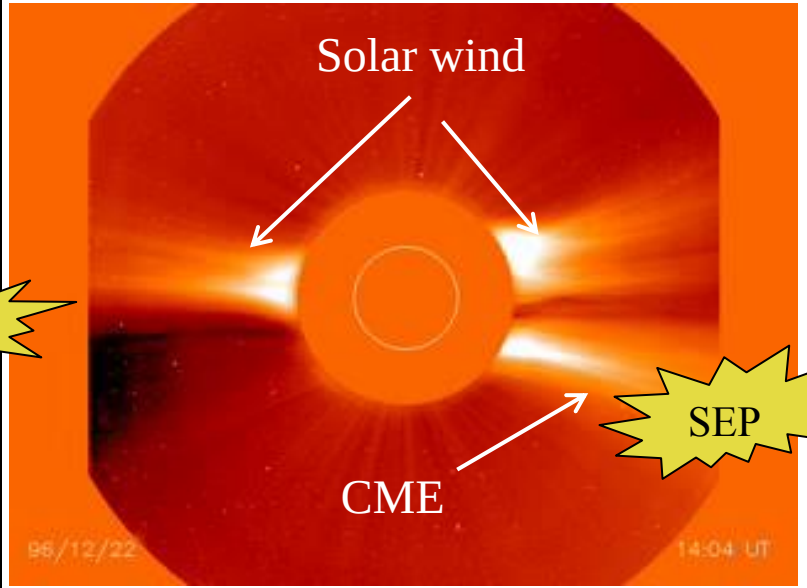
3.Geomagnetic Storms

- Coronal Mass Ejections (CMEs) send out Magnetic Clouds
- Arrive at Earth in 1-4 days
- Accelerate particles within the magnetosphere and into the ionosphere
- Impacts:
  - HF radio communication
  - Radio Navigation (GPS)
  - Electric Power Grids
  - Increased Satellite Drag
  - Aurora

Phenomena: Flare, Wind, CME, SEP

Fenómenos: Flare, Wind, CME, SEP

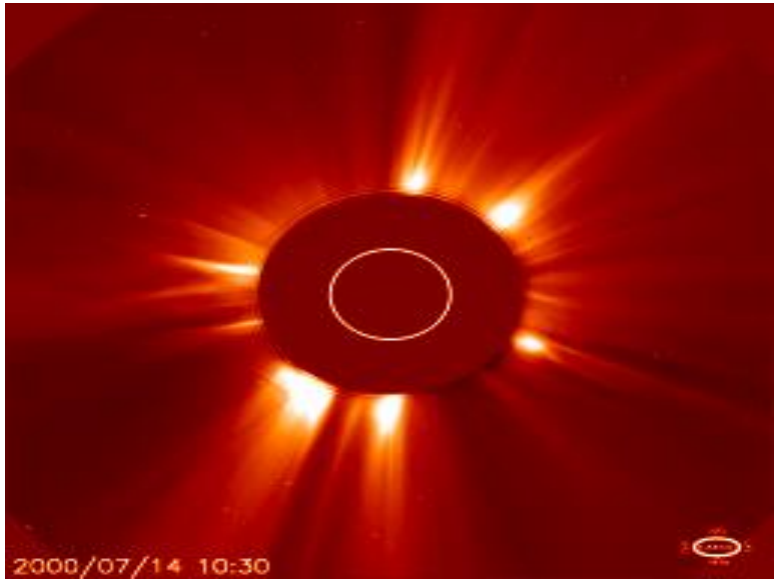


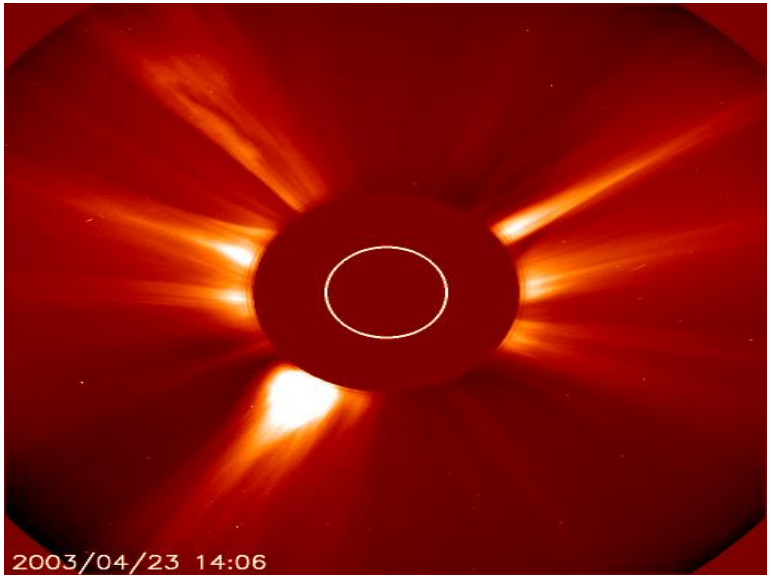


Bastille Solar Event

Example of High Radiation Background anomaly

July 14, 2000- A powerful X class flare erupted from sunspot region 9077 at approximately 10:24- it was accompanied by a full halo coronal mass ejection that is Earth directed.

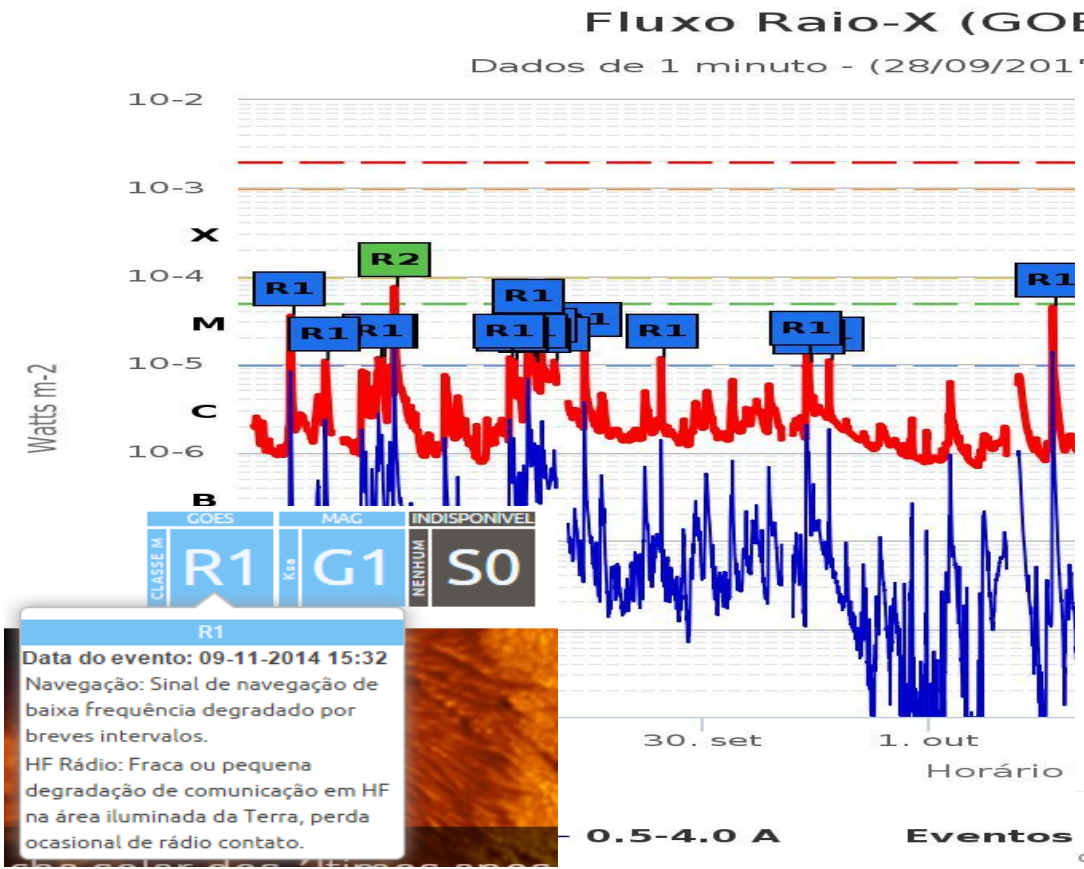




SOHO LASCO C2 Images

Source: Florian Nichitiu - Department of Physics, University of Toronto, Canada, *July 2004-Frascati*

Solar Flares

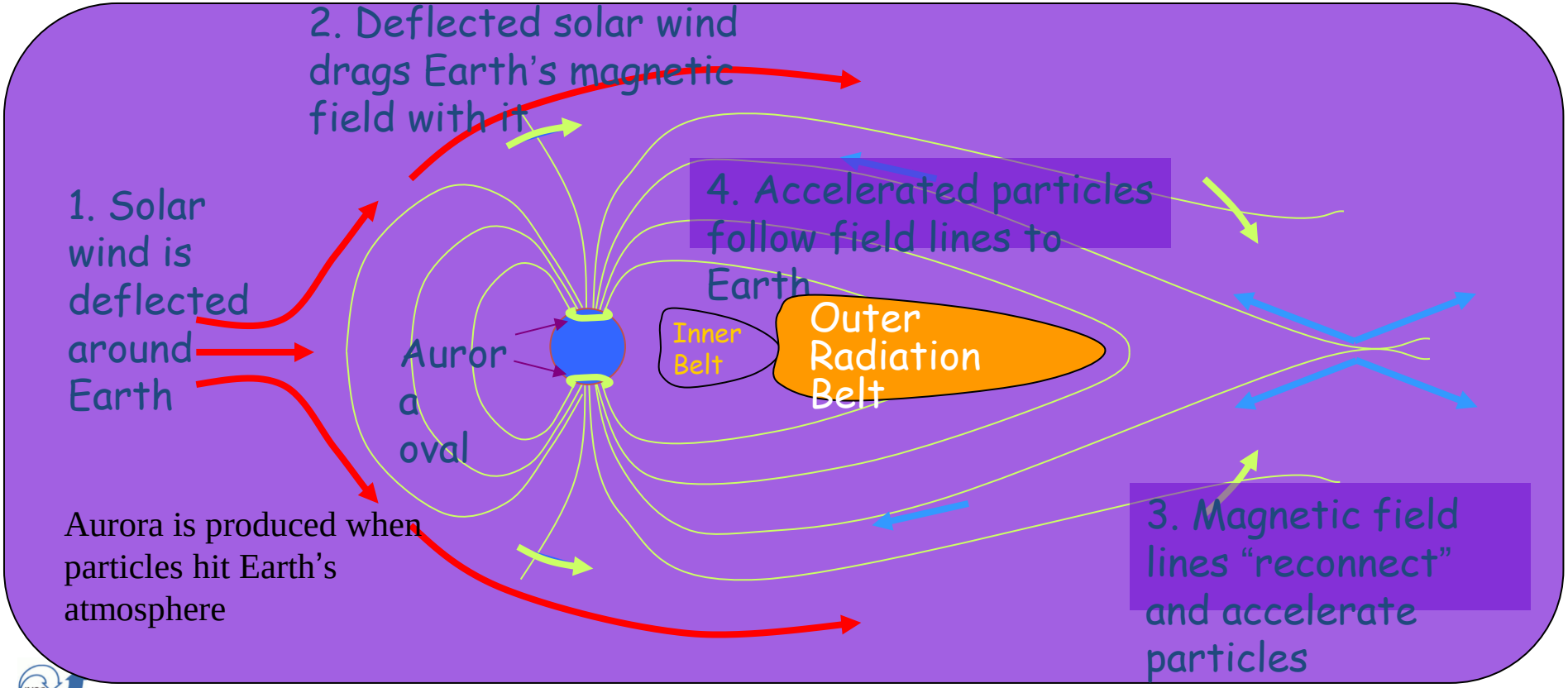


Flare Size Nomenclature

Class	Peak 1–8 Å Flux (W/m²)
A	$10^{-8} \leq \mathcal{F} < 10^{-7}$
B	$10^{-7} \leq \mathcal{F} < 10^{-6}$
C	$10^{-6} \leq \mathcal{F} < 10^{-5}$
M	$10^{-5} \leq \mathcal{F} < 10^{-4}$
X	$\mathcal{F} \geq 10^{-4}$

Eventos EMBRACE Eventos NOAA*

Magnetosphere (Wind and CME forming AURORA)



Geo-magnetic storm from Space

Aurora vista del espacio.

Geo-magnetic storm from Earth

Aurora vista de la Tierra.

Space Weather Important Terms

- **Solar Flare:** An eruption on the sun that emits light (UV, x-rays, radio) and often particles (electrons and protons).
- **CME (Coronal Mass Ejection):** A disturbance in the solar wind caused by an eruption on the sun.
- **Solar Wind:** The outward flow of electrons, protons, and magnetic field from the sun.
- **Energetic Particles:** electrons and protons that have been accelerated to high speeds in the sun and in the I.M.
- **Geomagnetic Storm:** The disturbance in the near-Earth particles and magnetic fields that can upset technological systems and creates aurora. **The G-Scale (from G1-G5)**
- **Radiation Storm:** A large flux of solar energetic protons as measured near Earth. **The S-Scale (from S1-S5)**
- **Radio Blackout:** An enhancement in the lower ionosphere as a result of large x-ray flares. **The R-Scale (from R1-R5)**

Indicators of Solar activity

Solar and geomagnetic indices describes the activity levels of the Sun and the disturbance of the geomagnetic field.

- **Sun Spot Number (SSN)**
- **Solar Radio emissions : Flux of 10.7 cm (Ottawa index). Are essential measurements of the total amount of thermal emissions from chromosphere and lower corona.The F10.7 index gives a good measure of the UV radiation output (new E107).**

  There are suggestions that 10.7 cm flux is also an excellent indicator of magnetic activity on the Sun.
- **UV flux, irradiance.**
- **Magnetic indices (aa, Ap, Kp, Dst, etc..).Geomagnetic indices typically describe the variations of the geomagnetic field over a certain time period. They provide a measure of the disturbance of the magnetosphere which has direct consequences for the charged particle space environment.**
- **Trapped proton and electron fluxes Creates radiation belts (Van Allen belts).**
- **Galactic Cosmic Rays, protons of very high energy and neutrons fluxes. Flux periodicity correlated with IMF and erosion effect of Earth atmosphere via Solar activity.**

Source: Florian Nichitiu - **Department of Physics, University of Toronto, Canada**, *July 2004-Frascati*

Energy in Space Radiation Environment

Electrons, protons and ions

→**Trapped by the Earth's magnetic field** :

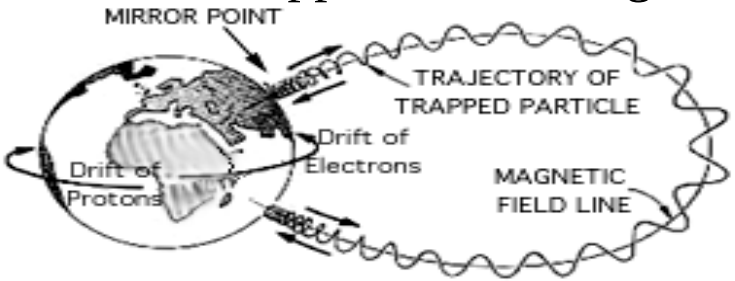
Radiation Belts (Van Allen Belts) e E< 2-3 MeV;
p E< 200-300 MeV

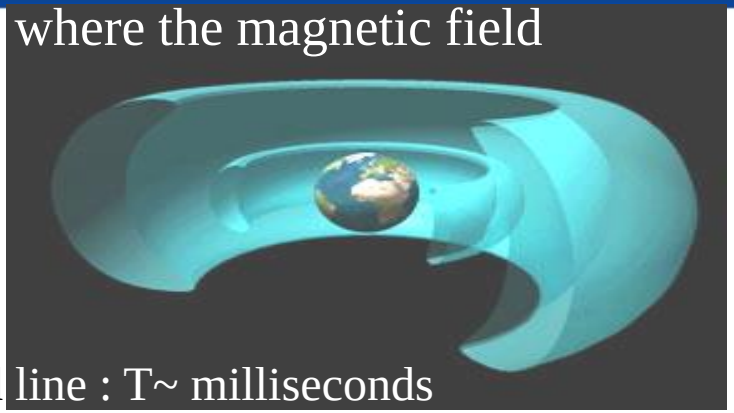
→**Passing through the solar system** :

Solar Wind (e, p He4) E< 100 KeV
Solar Particle Events mainly protons E = 1 - >100 MeV
Galactic Cosmic Rays E up to TeV

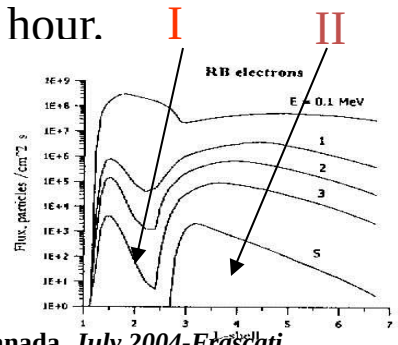
The Geo-Space: Inner & outer belts

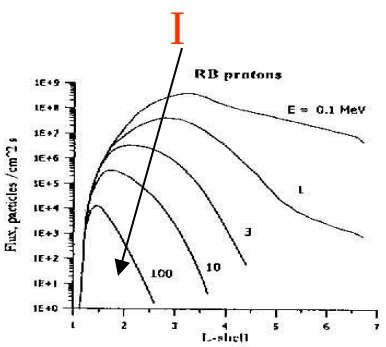
A charged particle became trapped in those regions where the magnetic field lines are closed





1) **Circular motions** with gyro-radius about the field line : T~ milliseconds
2) **Bounce back and forth along a field line**. Reversing direction at a mirror point: T~ seconds.
3) **Drift of particles around the Earth**: T~ one hour. Electrons drift to east, protons drift to west





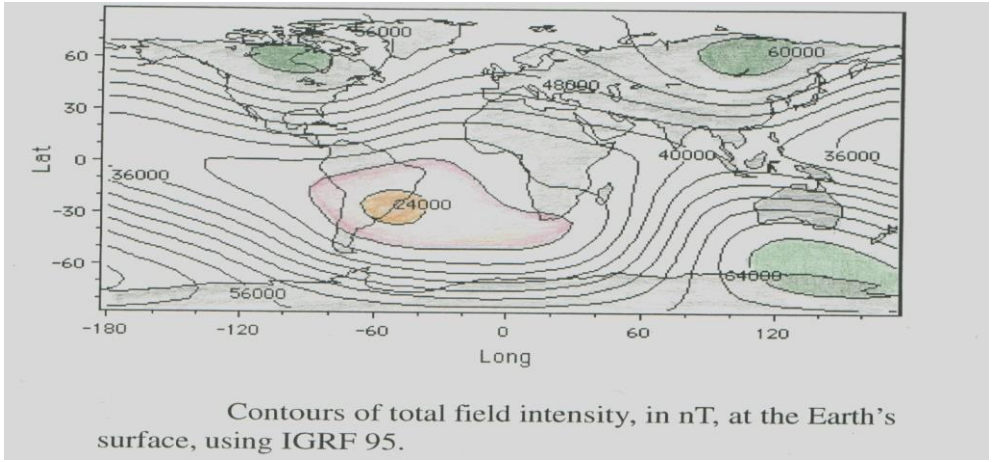
There are two main belts:

I- **inner belt** : e and p (up to 2.4 Re)

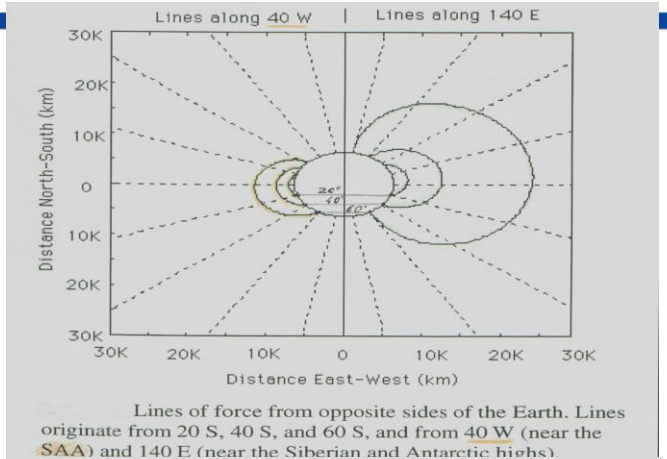
II- **outer belt** : e (2.8 – 12 Re)

Source: Florian Nichitiu - **Department of Physics, University of Toronto, Canada**, *July 2004-Frascati*

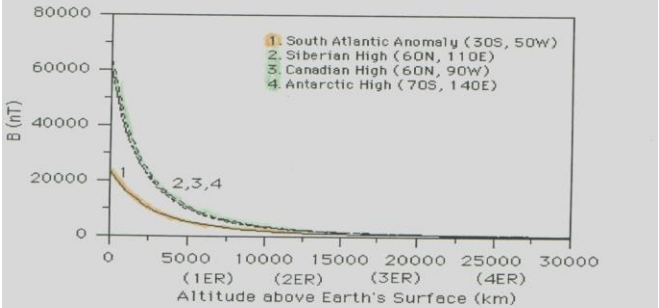
The Earth's magnetic field is not symmetric



Contours of total field intensity, in nT, at the Earth's surface, using IGRF 95.



Lines of force from opposite sides of the Earth. Lines originate from 20 S, 40 S, and 60 S, and from 40 W (near the SAA) and 140 E (near the Siberian and Antarctic highs).

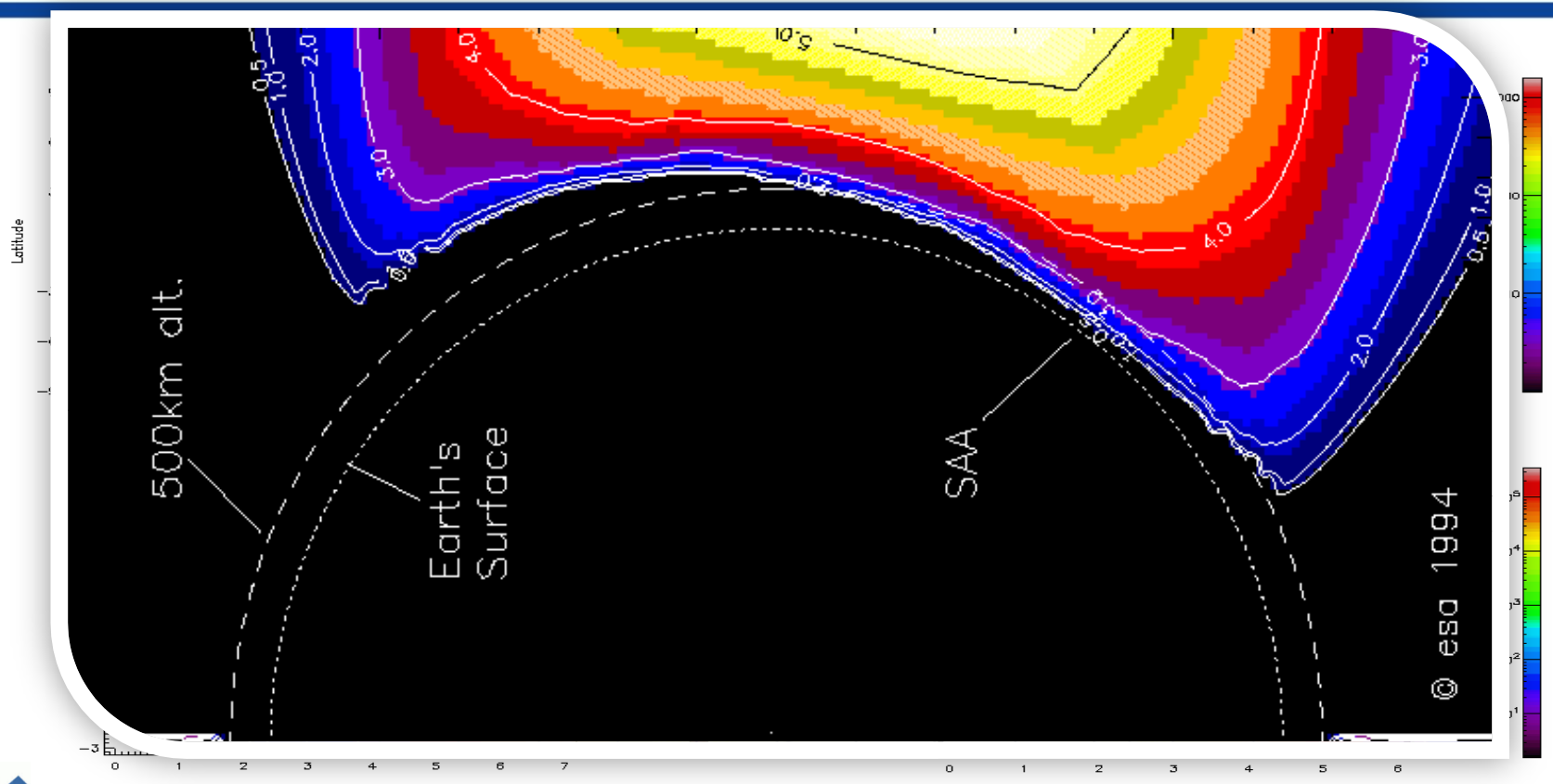


Field strength as function of altitude above four anomalous areas of the Earth's surface.

South Atlantic Anomaly (also called Brazilian Anomaly or South America Anomaly) is a lowest magnetic field region located at 26S, 53W.

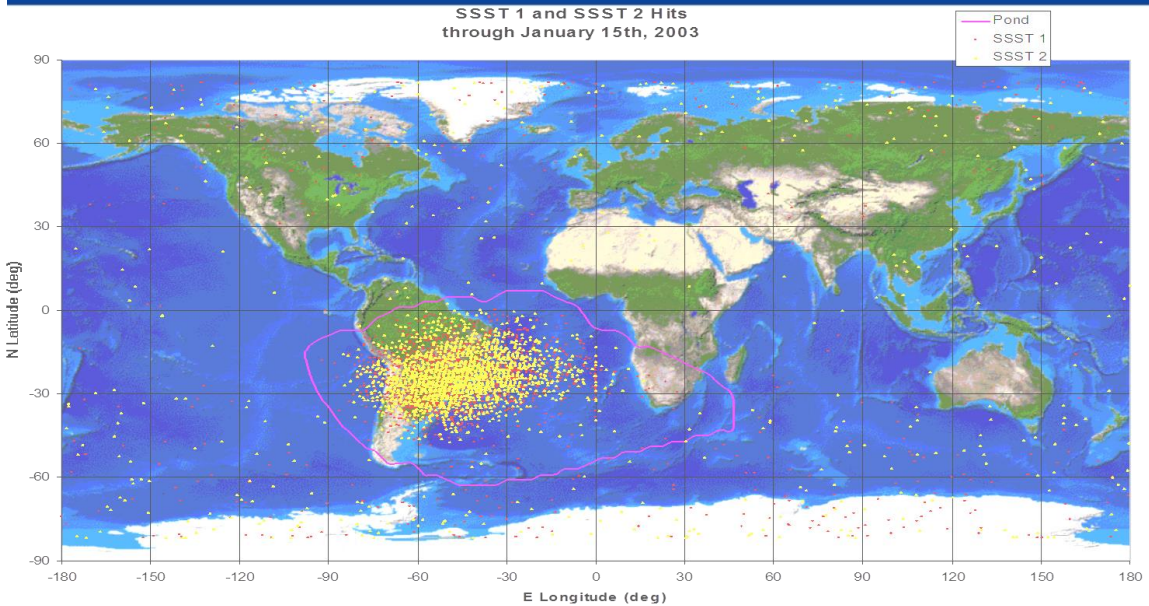
Source: Florian Nichitiu* - Department of Physics, University of Toronto, Canada, *July 2004-Frascati

Radiation Belt Models

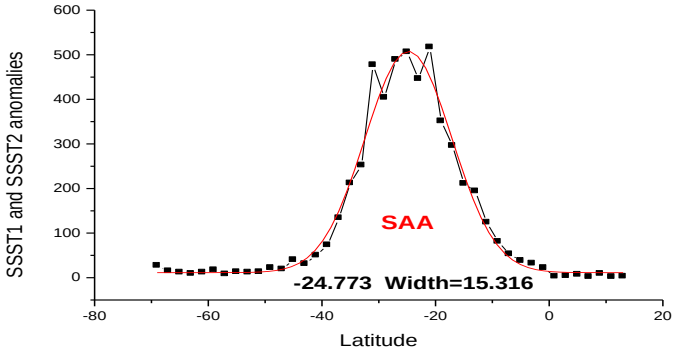


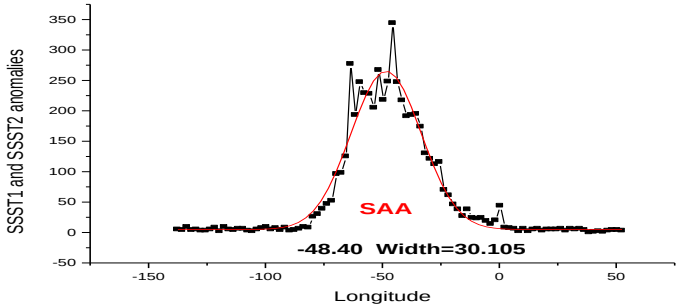
Source: Florian Nichitiu - **Department of Physics, University of Toronto, Canada**, *July 2004-Frascati*

TERRA - Solid State Star Tracker



Anomalies
High Background





Source: Florian Nichitiu - **Department of Physics, University of Toronto, Canada**, *July 2004-Frascati*

Solar Energetic Particles

SEP or SPE (Solar Proton Events)

(Solar Cosmic Rays)

Origin: **Solar flares** and **Coronal Mass Ejections** (CME)

p, e & **He** emitted by the sun in burst during **'solar storms'**

-energies > 10 MeV/nucleon

-access to open magnetic fields of polar cap.

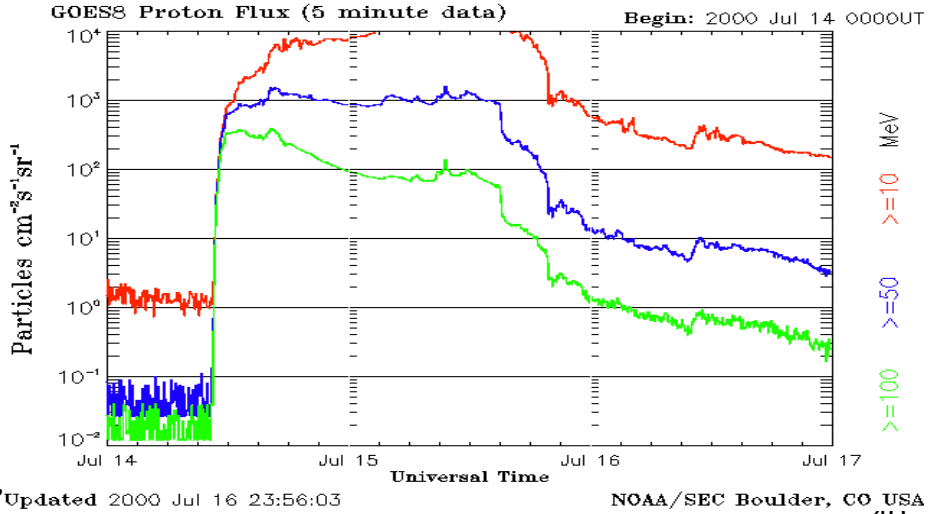
Produce also : X-rays; gamma-rays, UV light burst and verv fast wind flow which can inject protons into the trapping region (even create 'second proton belt')

Fluence: from 10^5 to 10^{11} part/cm^2

Duration of event: from one to several days

"Bastilia" Solar Event →

14 July 2000

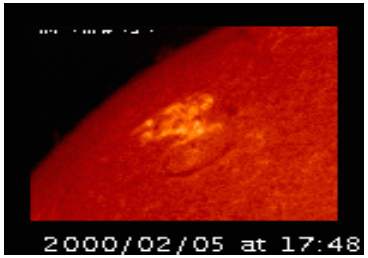


Source: Florian Nichitiu - **Department of Physics, University of Toronto, Canada**, *July 2004-Frascati*

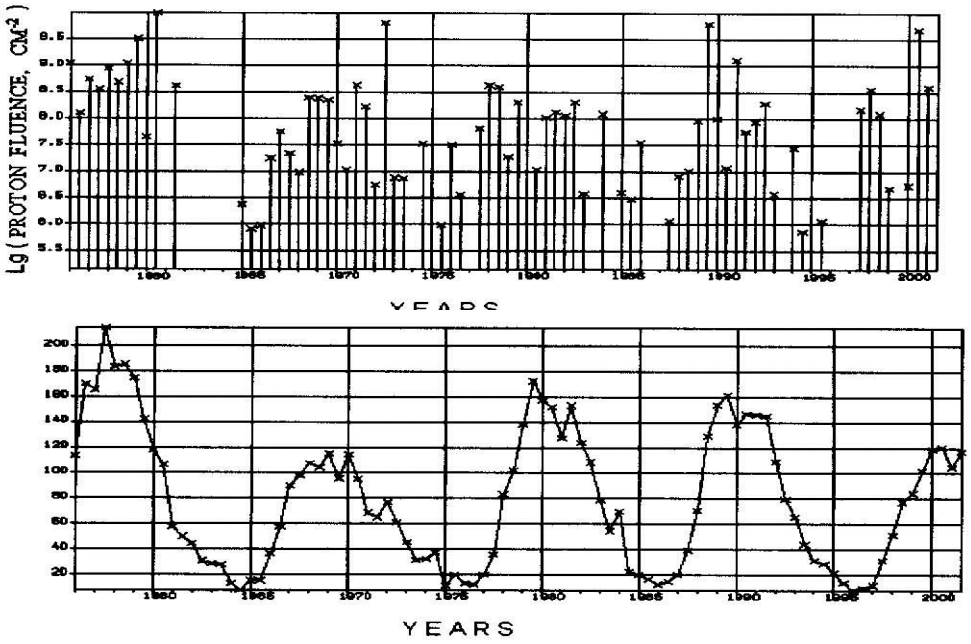
SPE Periodicity

Frequency spectra of solar proton fluence
of Energy > 30 MeV → periods of ~ 11 years and 3-4 years.
Not predictable yet.

-greater occurrence frequency
during **maximum** solar activity
- and **during decline** of cycle



NASA SOHO Image Solar Flare



Source: Florian Nichitiu - **Department of Physics, University of Toronto, Canada**, *July 2004-Frascati*

Cosmic Rays

Galactic Cosmic Rays:

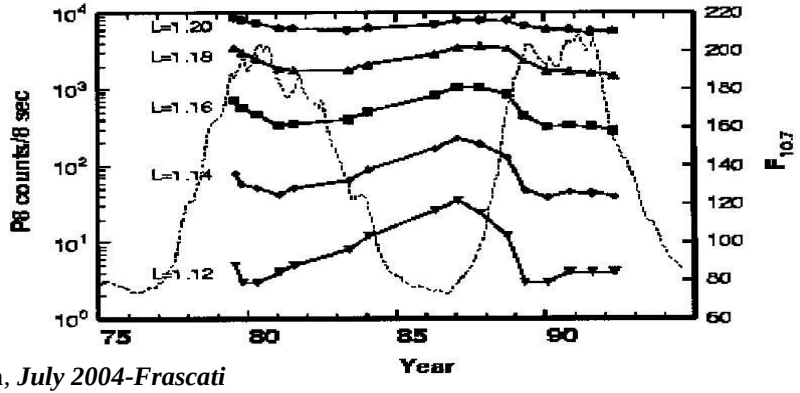
fully ionized particles of all stable elements (90% p ~7% He)

Origin: galactic and extragalactic; Energies up to TeV

Energy spectrum max at 0.3-1 GeV/nucleon

The incoming charged particles are '**modulated**' by the **solar wind** and **IMF** which decelerates and **partially excludes the lower energy** GCR from the inner solar system. There is a significant **anticorrelation** between solar activity and the intensity of the CR with E< 10 GeV.

Variations of proton counts
E=80-215 MeV of MEPED detector
aboard the TIROS/NOAA spacecraft



Source: Florian Nichitiu - **Department of Physics, University of Toronto, Canada**, *July 2004-Frascati*

Natural Albedo Radiation

Is in fact the **secondary radiation** generated in the inner magnetosphere due to:

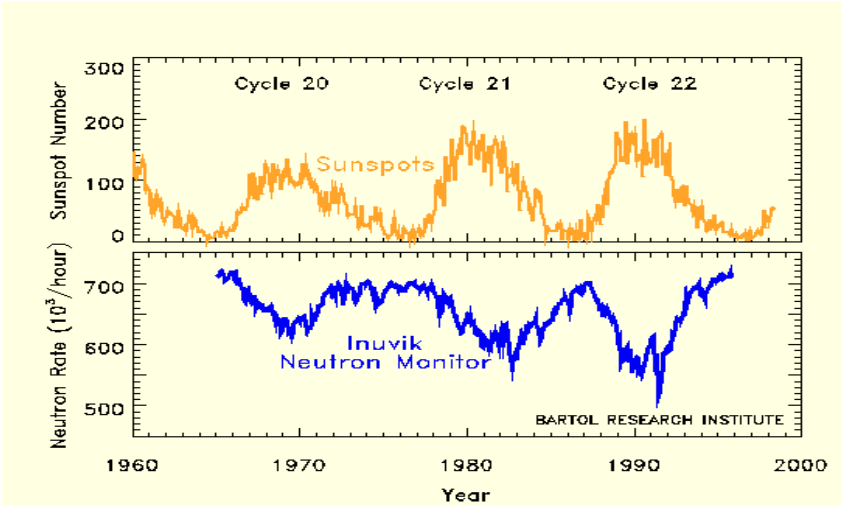
-**nuclear reactions** by GCR and SPE interactions with :

- protons of the inner belt
- and atoms of the atmosphere

-**secondary CR decay** (pions, muons..)

This radiation component consists mostly of:

- neutrons
- e- and e+
- protons (and antiprotons) , nuclei

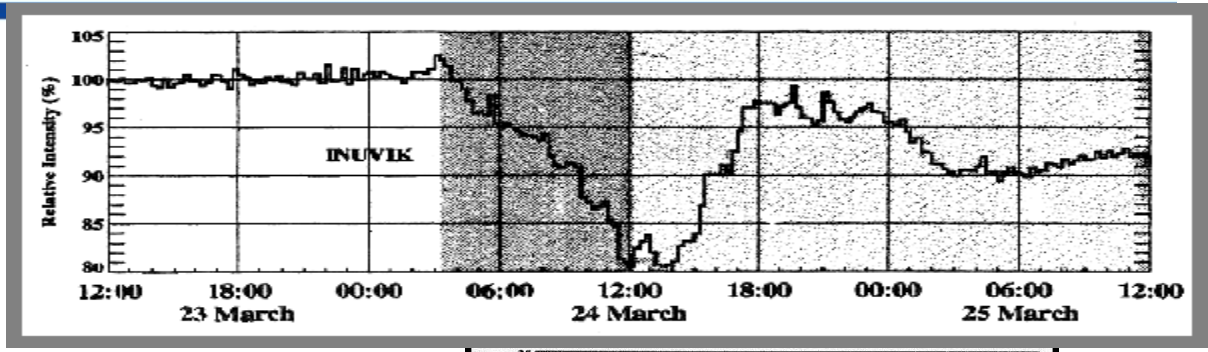


There is also an **anticorrelation** between solar activity and the intensity of secondary radiation as a result of **atmosphere expanding** (and increasing of **nuclear interaction rate**) during high solar activity.

Source: Florian Nichitiu* - Department of Physics, University of Toronto, Canada, *July 2004-Frascati

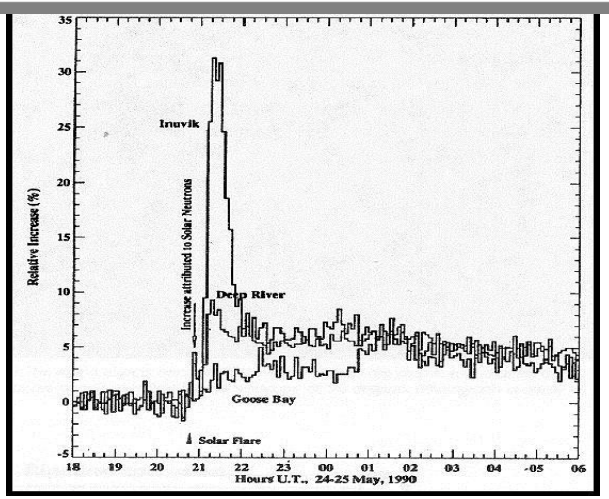
Variations of Albedo Radiation

-When the Sun releases a large burst of matter and magnetic disturbance→ a magnetic storm which prevent many cosmic rays from entering the atmosphere. Forbush decrease detected by the Inuvik neutron monitor at 23 Mar 1991.



"**Solar cosmic rays**" produced by a **solar flare** are recorded as a sharp increase in secondary neutrons flux.

The event of May 24, 1990 seen by Inuvik, Deep River and Goose Bay neutron monitors.

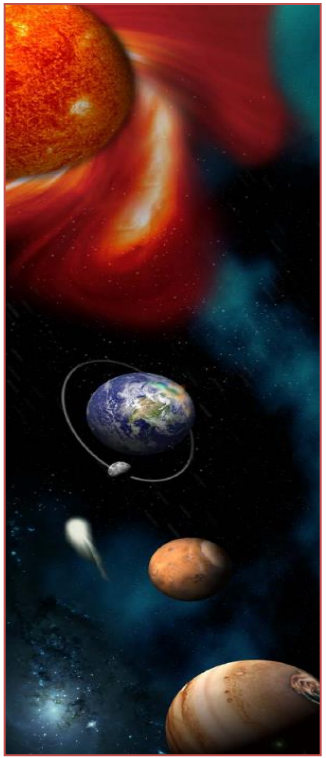


Source: Florian Nichitiu **- Department of Physics, University of Toronto, Canada,** ***July 2004-Frascati***

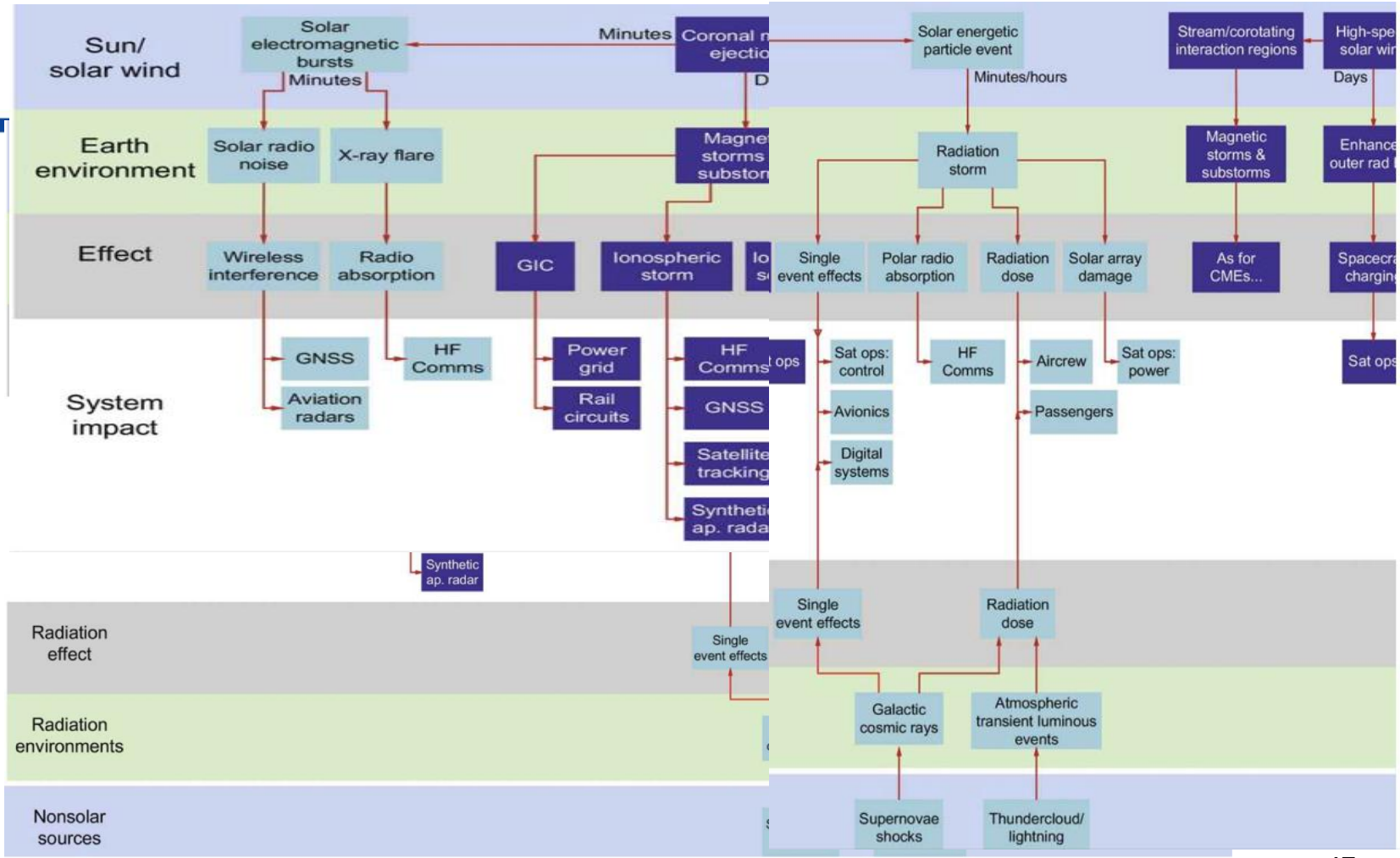
Time to arrive at Earth

- Radiation takes 8 minutes
- Slow solar wind takes 5-6 days
- Fast solar wind takes 3-4 days
- CME takes 2-3 days
- SEP takes 20-40 minutes

SPACE WEATHER IMPACTS



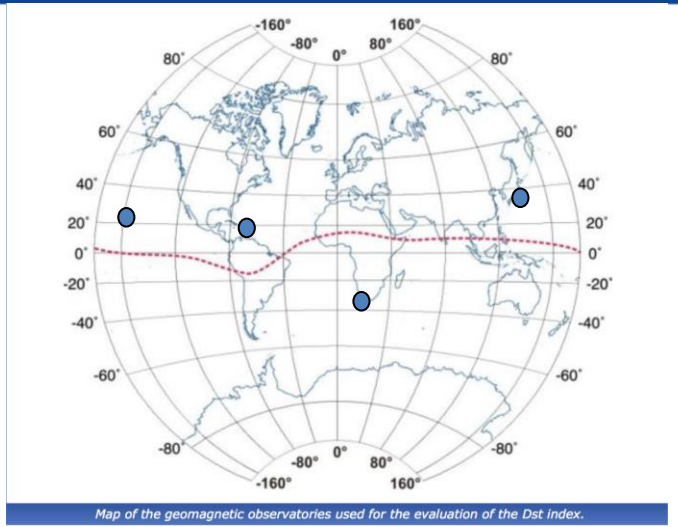
- ***Electric Power***
- ***Aviation***
- ***GNSS Applications***
- ***Satellite Operations***
- ***Deep Space Missions***
- ***Manned Space Flight***



Source: Extreme Events in Geospace: Origins, Predictability, and Consequences. Elsevier Science 2018. ISBN:978-0-12-812700-1.

Dst Index

Storm type	Minimum Dst below
Weak storm	−30 nT
Moderate storm	−50 nT
Strong storm	−100 nT
Severe storm	−200 nT
Great storm	−350 nT



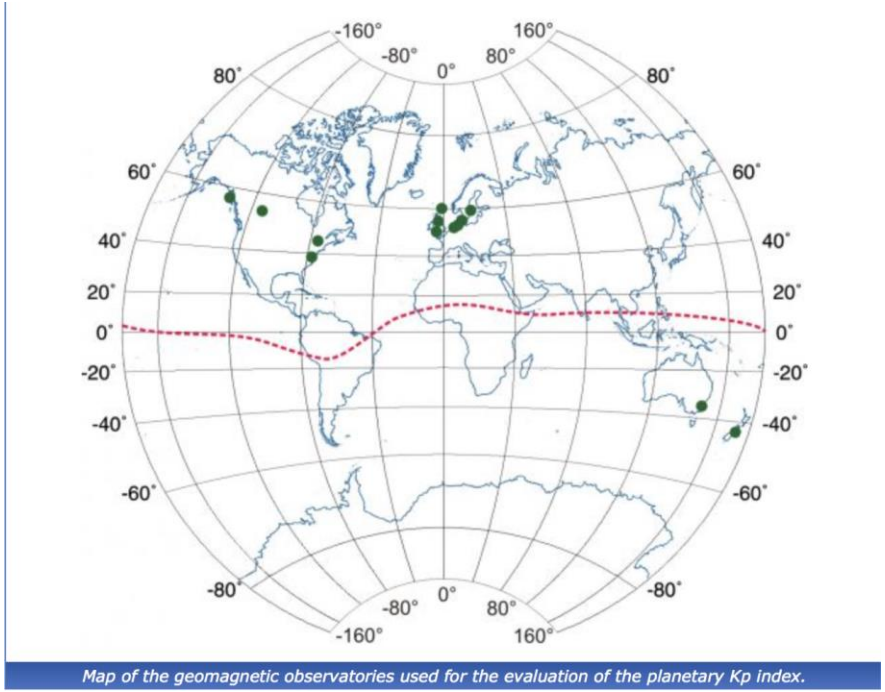
Map of the geomagnetic observatories used for the evaluation of the Dst index.

The **Dst** index (Disturbance storm time). Four geomagnetic observatories, Hermanus, Kakioka, Honolulu and San Juan are used, shown on the map. They are distributed as evenly as possible in longitude, and are at the same time sufficiently distant from both the auroral and equatorial electrojets so that they are not significantly influenced by either.

Dst index is the deviation of the horizontal components H of the magnetic field from the baseline. The baseline is calculated separately for each observatory and year. The ”five quietest days” for each month form the database for the baseline.

Kp

K index is derived for each observatory by determining the maximum deviation δmax for each component of the magnetic field.
An indication of the level of geomagnetic perturbation on planetary scale is given by Kp index.
Kp is estimated as the average among K index values provided by 13 reference observatories.
It is measured every 3 hours since 1932.

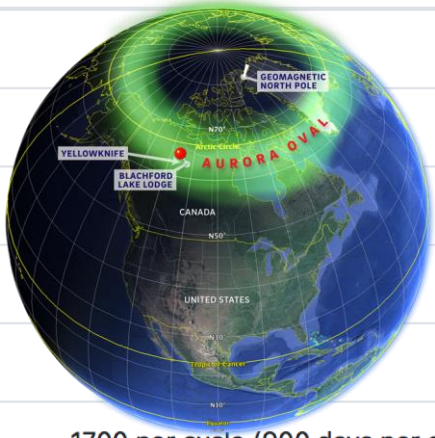


Map of the geomagnetic observatories used for the evaluation of the planetary Kp index.

Kp index – related to G-scale

- The table shows the Kp-index scale.
- 10 values and G-scale.
- Each Kp-value represents, the boundary of the auroral oval at local midnight.

Kp	G-scale	Geomagnetic latitude	Auroral activity	Average frequency
0	G0	66.5° or higher	Quiet	
1	G0	64.5°	Quiet	
2	G0	62.4°	Quiet	
3	G0	60.4°	Unsettled	
4	G0	58.3°	Active	
5	G1	56.3°	Minor storm	1700 per cycle (900 days per cycle)
6	G2	54.2°	Moderate storm	600 per cycle (360 days per cycle)
7	G3	52.2°	Strong storm	200 per cycle (130 days per cycle)
8	G4	50.1°	Severe storm	100 per cycle (60 days per cycle)
9	G5	48.1° or lower	Extreme storm	4 per cycle (4 days per cycle)



Regional Warning Centers (EMBRACE)

- Investigación
- Recoger información en el terreno y en el espacio
- Analizar y hacer predicciones
- Alerta para la mitigación

Thank you

Gracias

http://www.inpe.br/climaespacial

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