

Máster Universitario en Ingeniería Aeronáutica

The Space Environment

The radiation environment.



POLITÉCNICA

UPM PlasmaLab

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Based on the work by Luis Conde

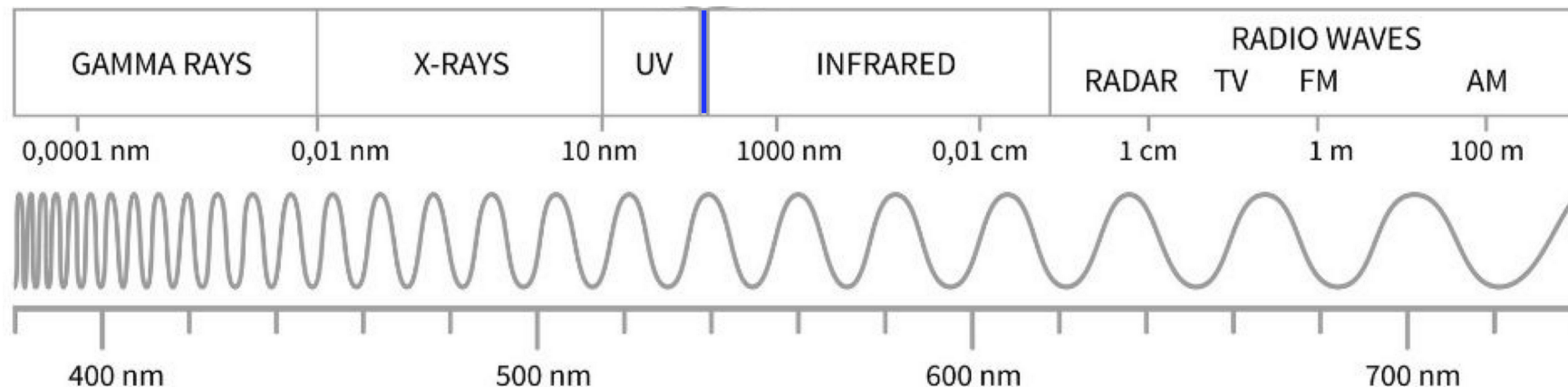
Personal website: <http://plasmalab.aero.upm.es/~lcl/>

Departamento de Física Aplicada

Radiation sources in space

Radiation environment in space concerns to the interaction with matter of *high-energy particles* (corpuscular) and *electromagnetic radiation* (photons).

- **Corpuscular radiation:** The fluxes of electrons with $E_e > 100$ keV and protons with $E_p > 1$ MeV from,
 - Van Allen belts of trapped particles (inner 1.000-12.000 km and outer 13.000-60.000 km)
 - Equivalent to Galactic cosmic rays (protons and ionized heavy nuclei)
 - Solar flares/events highly time dependent (protons/heavy nuclei)
- **Electromagnetic radiation:** From different sources, mainly of solar origin the frequency ranges of interest are,
 - Radio and microwave frequencies from DC to 300 GHz (GHz: gigahertz, 10^9 Hz)
 - IR, visible and UV light from 300 GHz to 750 THz (THz: terahertz, 10^{12} Hz)
 - Extreme EV and X-rays from 750 THz to 30 EHz (EHz: exahertz, 10^{18} Hz)



The small portion of visible light in the EM spectrum schematic is indicated by the blue block

Radiation by trapped particles

The Van Allen belts have a torus shape and are originated by charged particles mainly from the solar wind that are trapped by the geomagnetic field; electrons, protons and a lesser percentage of heavy ions. Today explored by NASA Van Allen probe mission (<https://science.nasa.gov/mission/van-allen-probes/>) with ESA collaboration along 2012-2030.



W. Picketing, J. Van Allen and W Von Braun satellite on January 31, 1958, with a model of the Explorer 1 of 2 meters long.

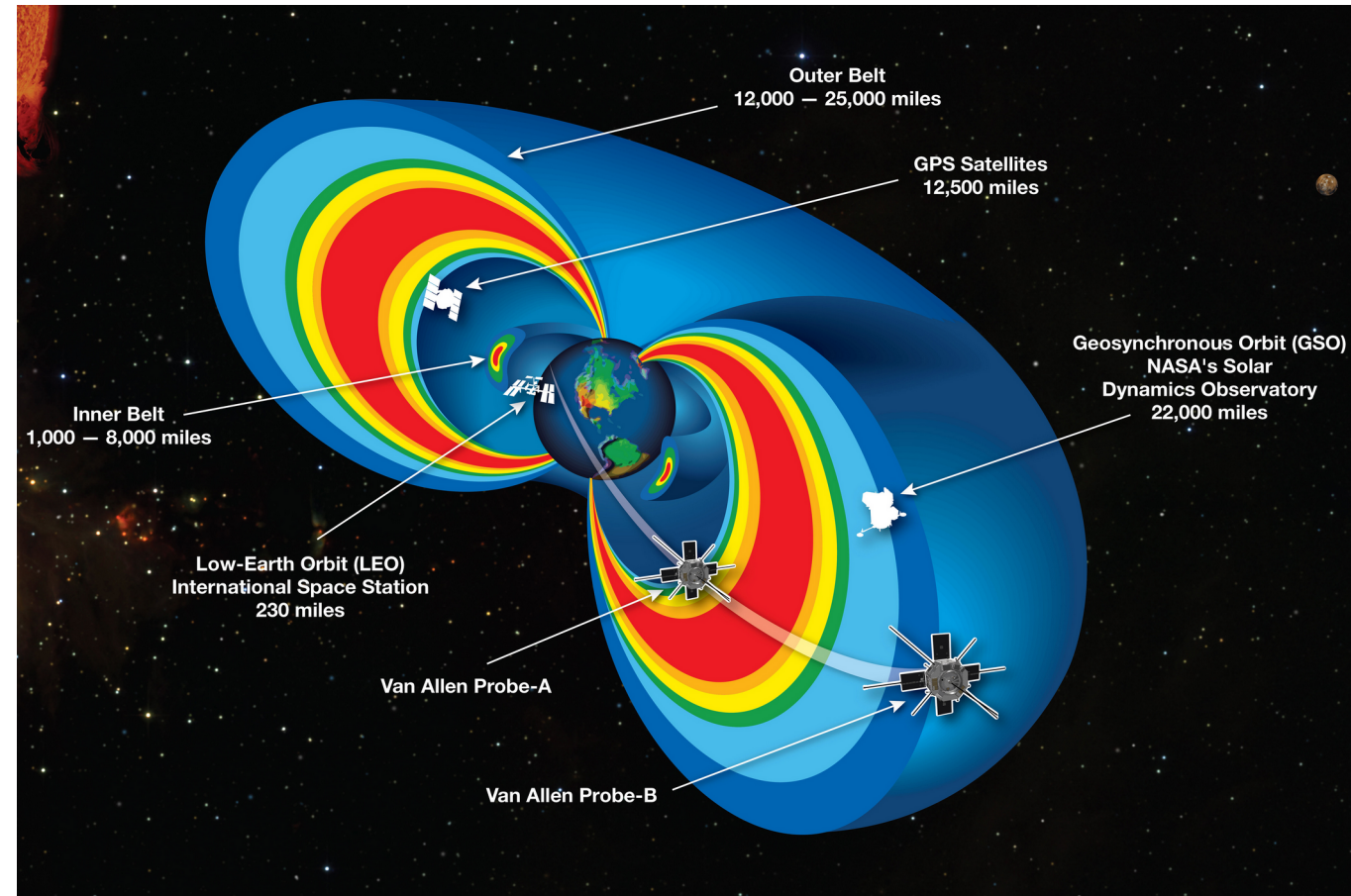


Figure from the cited link to NASA probe mission website.

Trapped particles radiation

The different belts areas with a high density of charged particles separated by an abrupt decrease in densities.

- Inner belt:

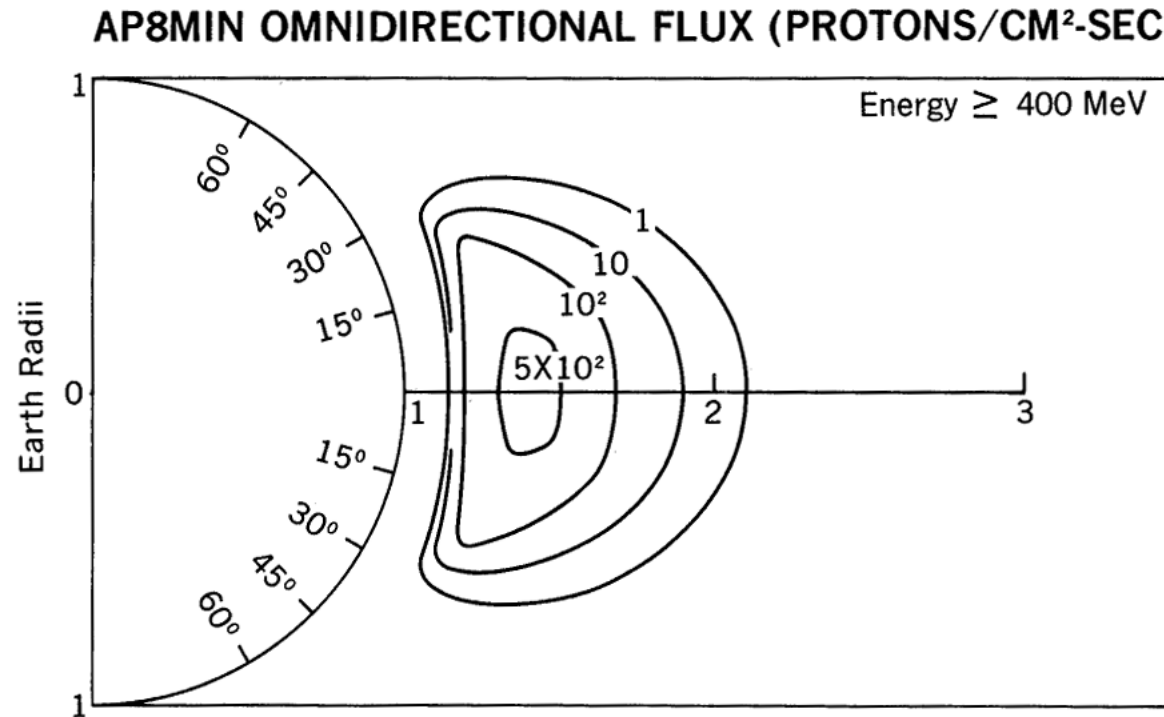
- Located at $0.2 - 2.0 R_E$ (equivalent to 1.000 – 12.000 km) inner boundary can be as low as 200 km height over the Earth's surface at the South Atlantic Anomaly
- High-energy protons with energies exceeding ~ 100 MeV
- High concentration of electrons with energies of ~ 100 keV
- The electron concentrations shows a factor 3 closely correlated with geomagnetic storms.

- Outer belt:

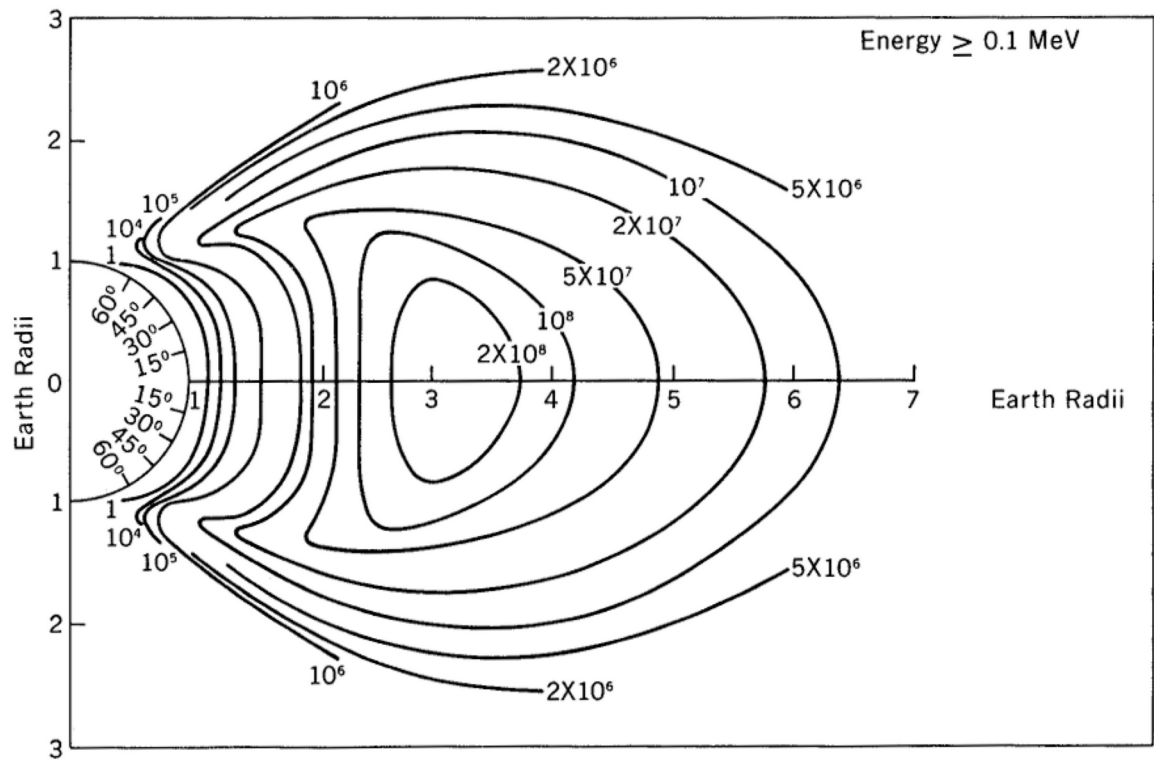
- Located at $3 - 10 R_E$ (equivalent to 13.000 – 60.000 km) is strongly influenced by the solar activity.
- High energy electrons with energies of $0.1 - 10$ MeV
- Electron concentrations can experience a factor 10^3 temporal fluctuations.

- A third radiation belt was reported to be discovered in 2023 composed of high-energy ultrarelativistic charged particles originated from coronal mass ejections from the Sun.

- Calculation of radiation exposure is based on computer models based on observations from many different satellites.
 - Models AP8 and AE8 (P protons and E is for electrons are available in the NASA website
 - <https://ccmc.gsfc.nasa.gov/modelweb/models/trap.php>
- provide the omnidirectional flux of charges for the magnetic coordinates (B, L).

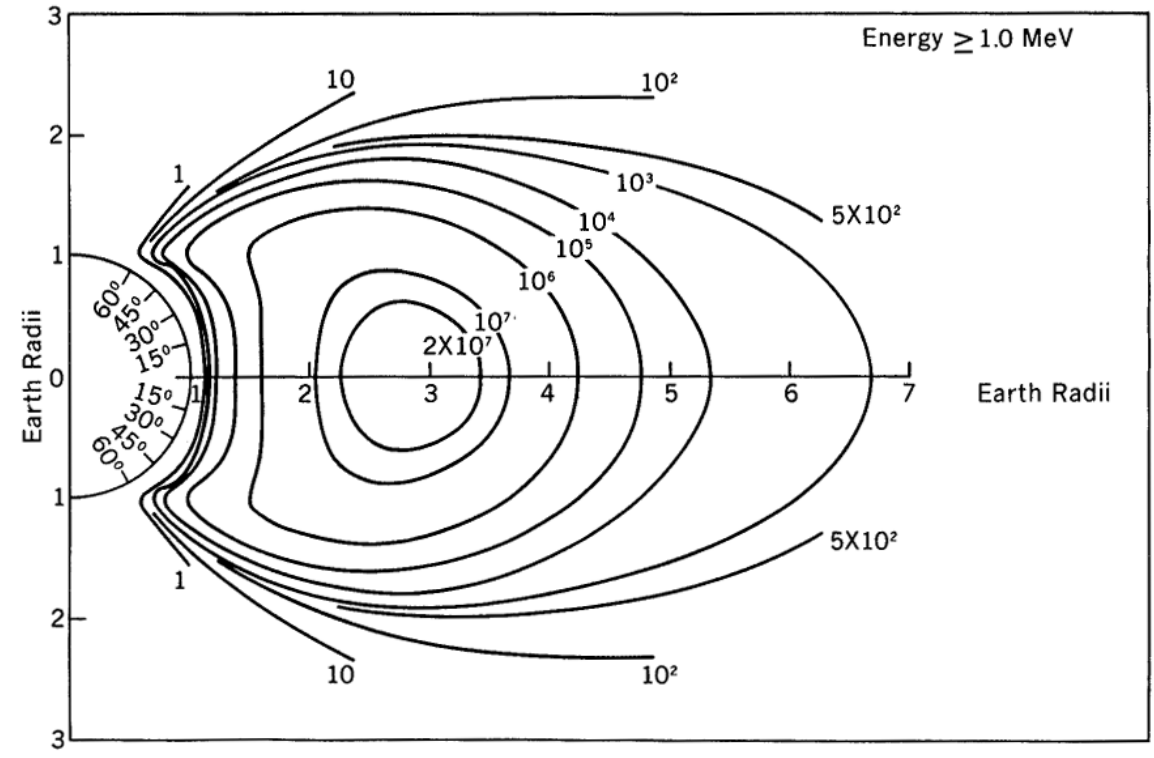


AP8MIN OMNIDIRECTIONAL FLUX (PROTONS/CM²-SEC)



Maximum worst case for protons with $E > 0.1$ MeV and given conditions.

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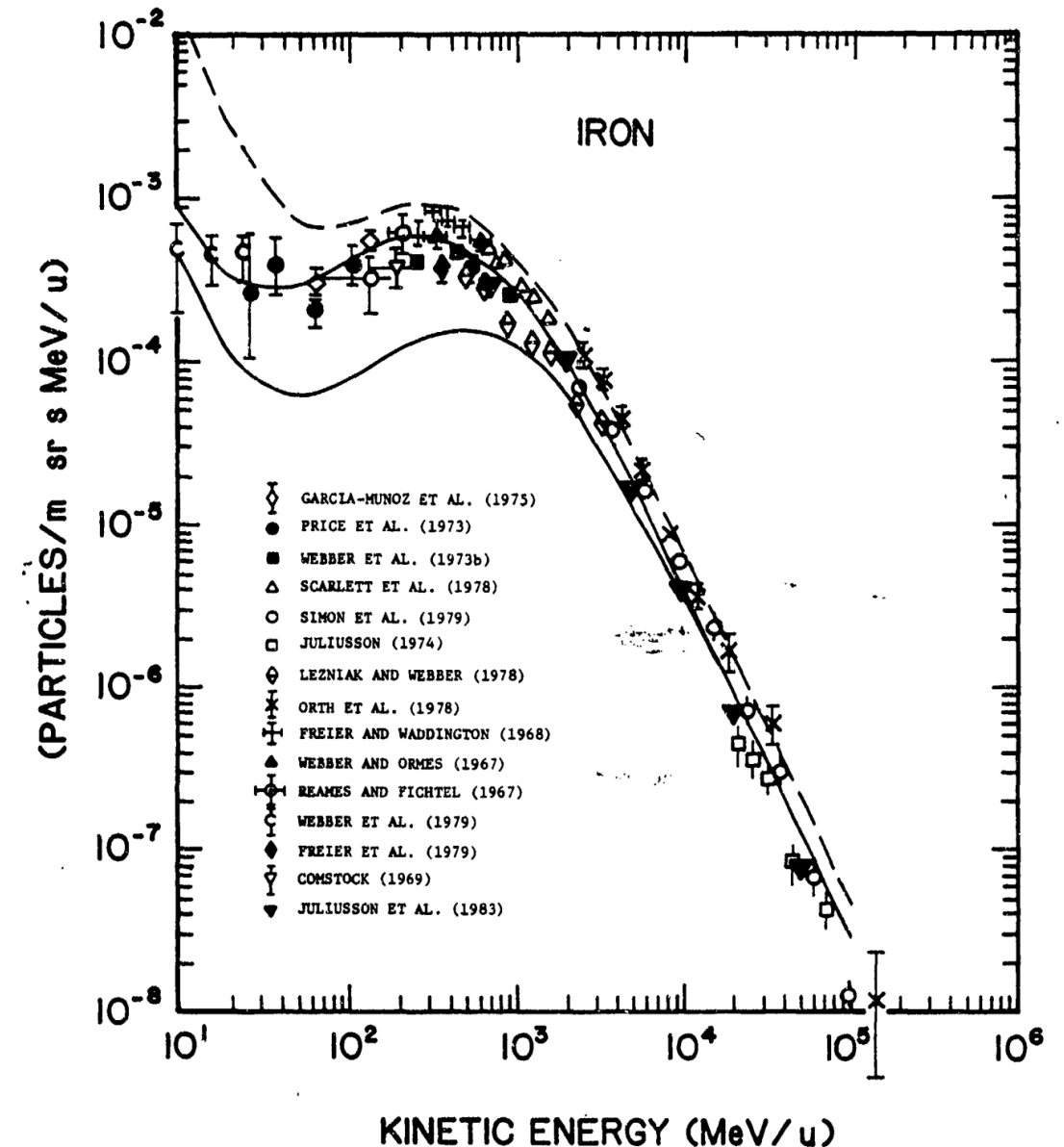
Galactic cosmic rays.

- Protons and ionized heavy nuclei with typical energies of 10^{10} eV/nucleon.
- Outside the magnetosphere is a uniform isotropic background for all ranges of energies.
- In LEO geomagnetic field deflects low energy particles and are guided in PEO orbits.

Solar proton events.

- Solar flares are associated with intense fluxes of solar proton events associated to SEU and malfunction in electronics.
- Protons and heavy nuclei are ejected with energies from 1 MeV/nucleon to 10 GeV/nucleon.
- Are orders of magnitude higher than GCR fluxes.
- Difficult to predict.

NOTE: Acronym SEU/SEE means Single Event Upset/Single Event Error a change of state caused by one single ionized particle striking a sensitive node of a microelectronic device.



Flux of ion ions outside the magnetic field of the Earth critical for SEU. From Cosmic ray effects on microelectronics. Part IV. NRL report 5901 (1986).

EM wave environment

- EM wave environment in space covers a wide range of frequency range of solar and human origin.
- The currently accepted division of the electromagnetic spectrum is in the table below.
- The hazards increase with the photon energy $E = hf = \hbar \omega$ or equivalently with the frequency (ω, f) of the wave.

| | | |
|-------|--------------|-----------|
| 1 MHz | 10^6 Hz | Megahertz |
| 1 GHz | 10^9 Hz | Gigahertz |
| 1 THz | 10^{12} Hz | Terahertz |
| 1 PHz | 10^{15} Hz | Petahertz |
| 1 EHz | 10^{18} Hz | Exahertz |

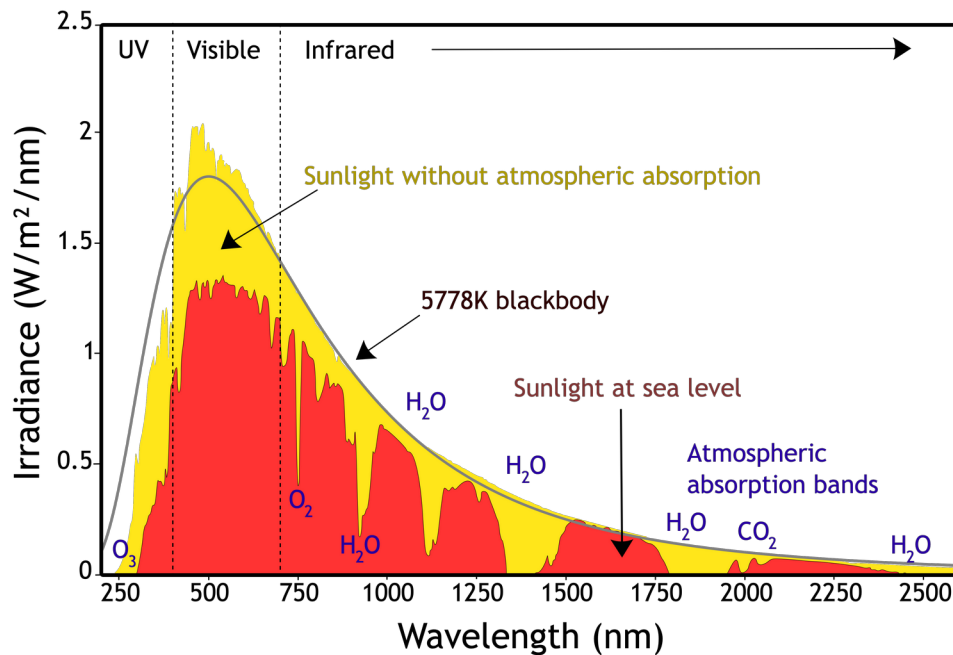
| Electromagnetic spectrum | | | | |
|--------------------------|---------------|----------------------|-------------------|--------------------------|
| | Name | Wavelength λ | Frequency f | Photon energy $E = hf$ |
| RF | Radio | ≥ 1 m | ≤ 300 MHz | ≤ 1.24 μ eV |
| MW | Microwave | 1 m – 1 mm | 300 MHz – 300 GHz | 1.24 μ eV – 1.24 meV |
| IR | Infrared | 1 mm – 750 nm | 300 GHz – 400 THz | 1.24 meV – 1.7 eV |
| | Visible light | 750 nm – 400 nm | 400 THz – 750 THz | 1.7 eV – 3 eV |
| UV | Ultraviolet | 400 nm – 124 nm | 750 THz – 3 PHz | 3 eV – 10 eV |
| EUV | Extreme UV | 124 nm – 10 nm | 3 PHz – 30 PHz | 10 eV – 124 eV |
| | X-rays | 10 nm – 0.01 nm | 30 PHz – 30 EHz | 124 eV – 124 keV |
| | Gamma rays | < 0.01 nm | > 30 EHz | > 124 keV |

General: EM emissions at frequencies ω below the plasma frequency $\omega < \omega_{pe}$ are severely damped, as $\omega_{pe} \sim \sqrt{n_e}$ attenuation depends on the electron density n_e of local plasma. For the Earth's ionosphere, frequencies typically below 10 MHz are reflected by the F-peak.

○ **Radiation at RF/MW frequencies.**

- Radio noise at frequencies above 1 – 10 MHz range are due to galactic EM radiation. This background is broadband contrary to narrowband terrestrial sources.
- RF/MW solar emissions are divided in different categories and are quite variable with intense burst associated to solar flares and solar events.
- It is not possible to predict the magnitude and occurrence of large solar RF/MF flares.

Spectrum of Solar Radiation (Earth)

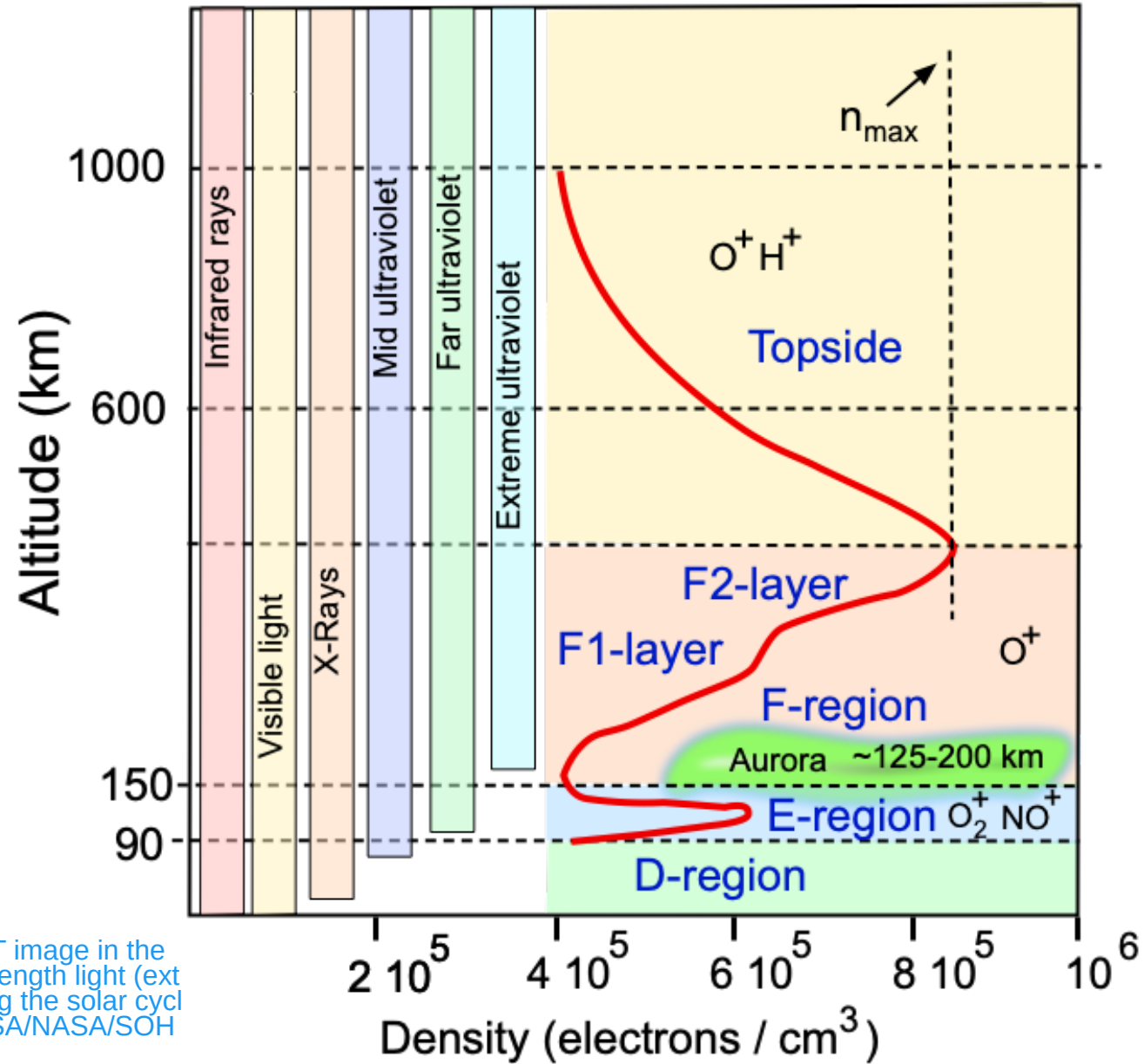


○ **IR radiation and visible light.**

- Visible light is Earth's orbits is dominated by the solar flux and peaks around $\lambda \sim 500$ nm
- Solar energy flux outside the atmosphere is currently estimated as 1.370 W/m^2 .
- Additional sources of IR/visible are light reflected by the Moon, atmospheric glow, Earth emission and the light from the aurora.
- The IR albedo from the Earth contributes to the thermal balance of spacecrafts in LEO orbit.

o IR UV, EUV and X-rays.

- Solar radiation is the main source of these high frequency energy fluxes outside the atmosphere that are affected by the solar cycle.
- Spacecraft materials exposed to UV, EUV and X-rays experience surface changes and/or photoelectron emission.
- Energetic components are mainly absorbed in the ionosphere and stratosphere and contribute to the dynamics and production charged species.
- X-rays contribute to the ionization in the E-region.
- EUV produce the photoionization of O_2 , N_2 and atomic oxygen in the ionosphere and produce thermosphere heating.



The SOHO EIT image in the 28.4 nm wavelength light (extreme UV) along the solar cycle. Courtesy ESA/NASA/SOHO

