Intro to Solar Weather & Radio Wave Propagation

By: Desiree Baccus, N3DEZ

WØTLM Amateur Radio Club

ARRL The national association for AMATEUR RADIO

WØTLM Tech Day
Saturday, October 7th, 2023

Introduction to Space Weather & Radio Wave Propagation

- ❖ Ionosphere
  - Where is it?
  - What is it?
  - Why is it important?
- ❖ Earth’s Magnetic Field
  - What is it?
- ❖ Space Weather
  - What is it?
  - Why does it matter?
- ❖ Radio Wave Propagation
  - Solar storms and communication disruptions
    - What we can do to mitigate the risks

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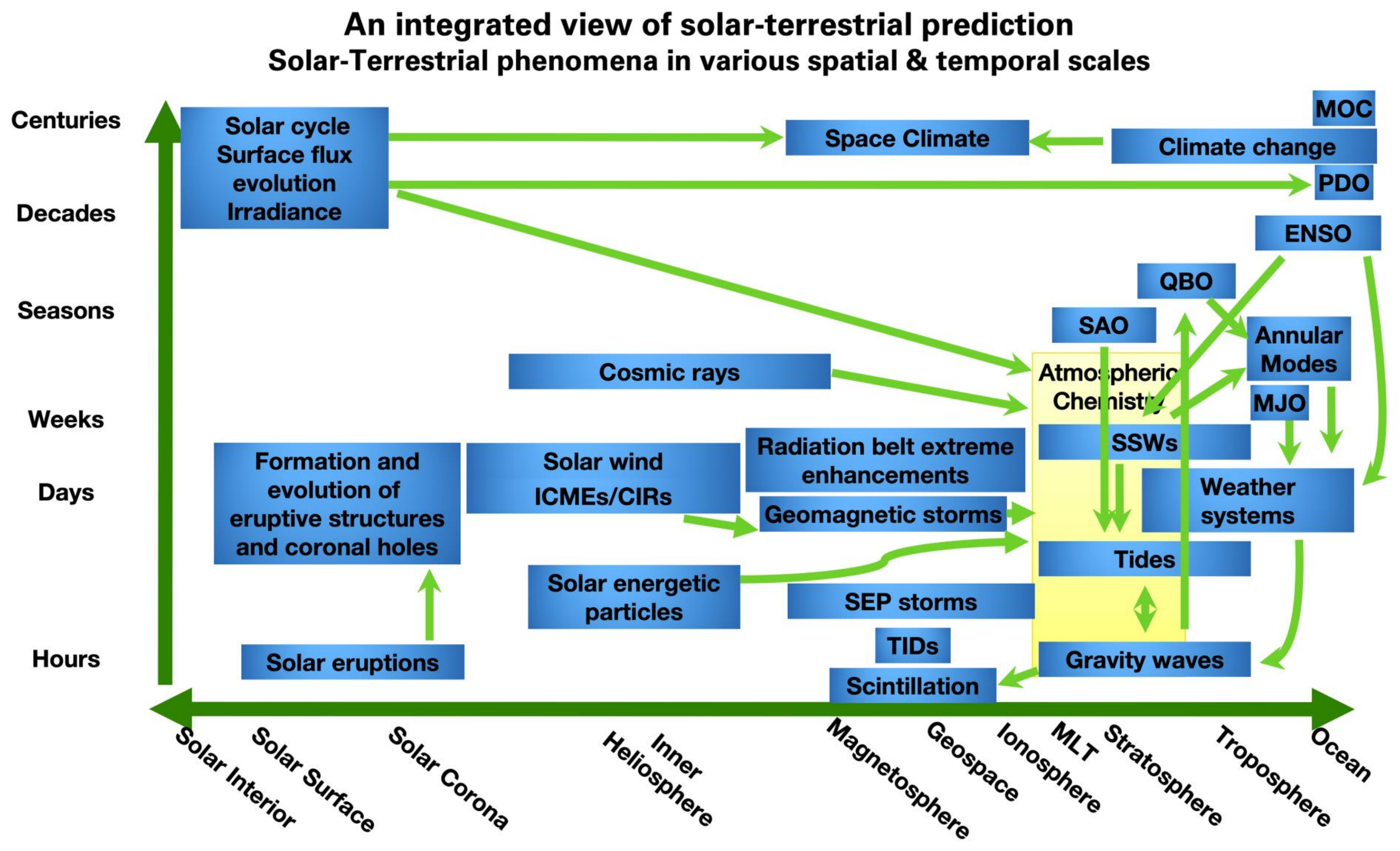
Space Weather is Intense!



This presentation will not be!

It is all about the relationship between the Sun and the Earth

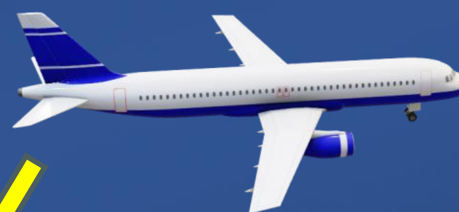
- ✓ Amateur Radio Operators have been sending and receiving radio signals around the Earth for over a century. Such communication is possible due to interactions between our Sun and the ionosphere.

Upper Atmosphere

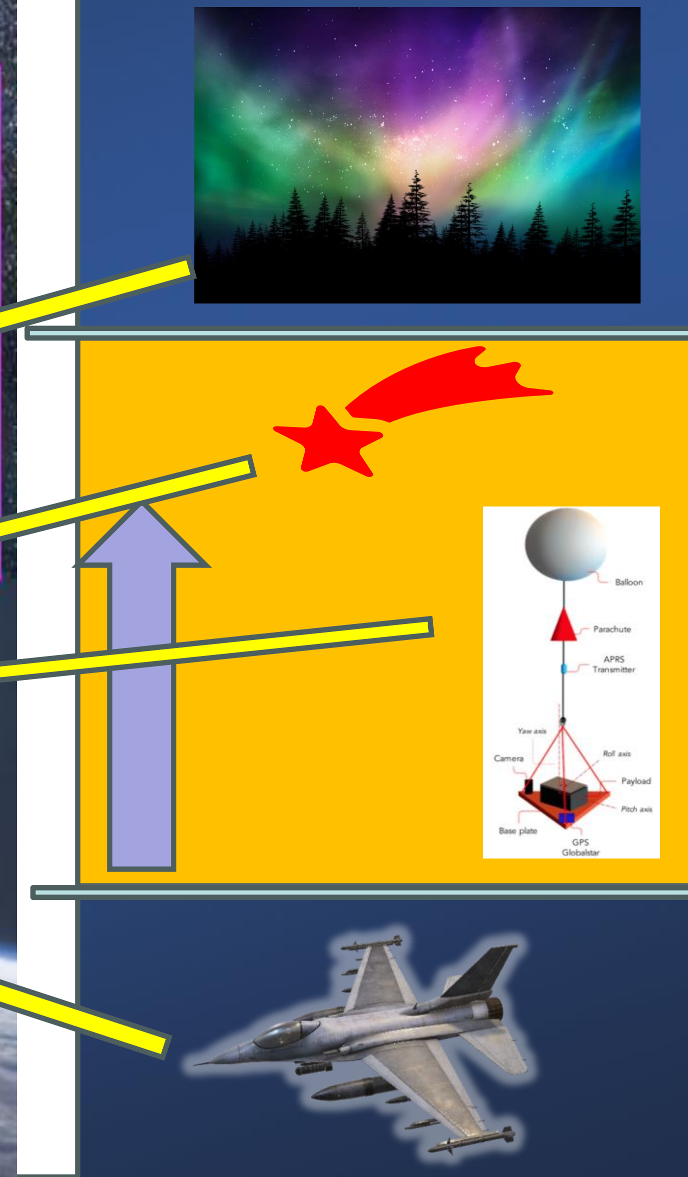
Middle Atmosphere

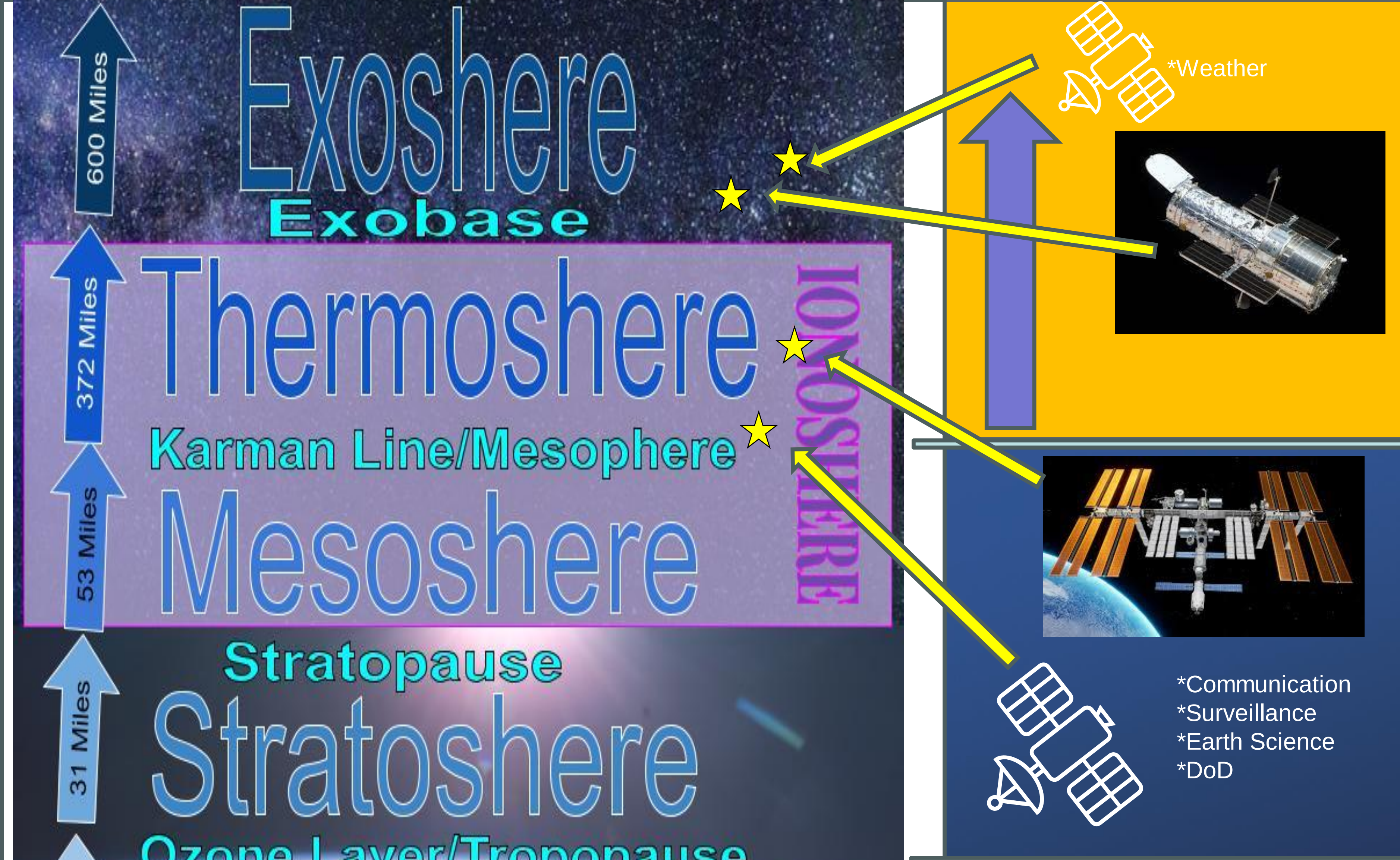
Lower Atmosphere

Lower Atmosphere

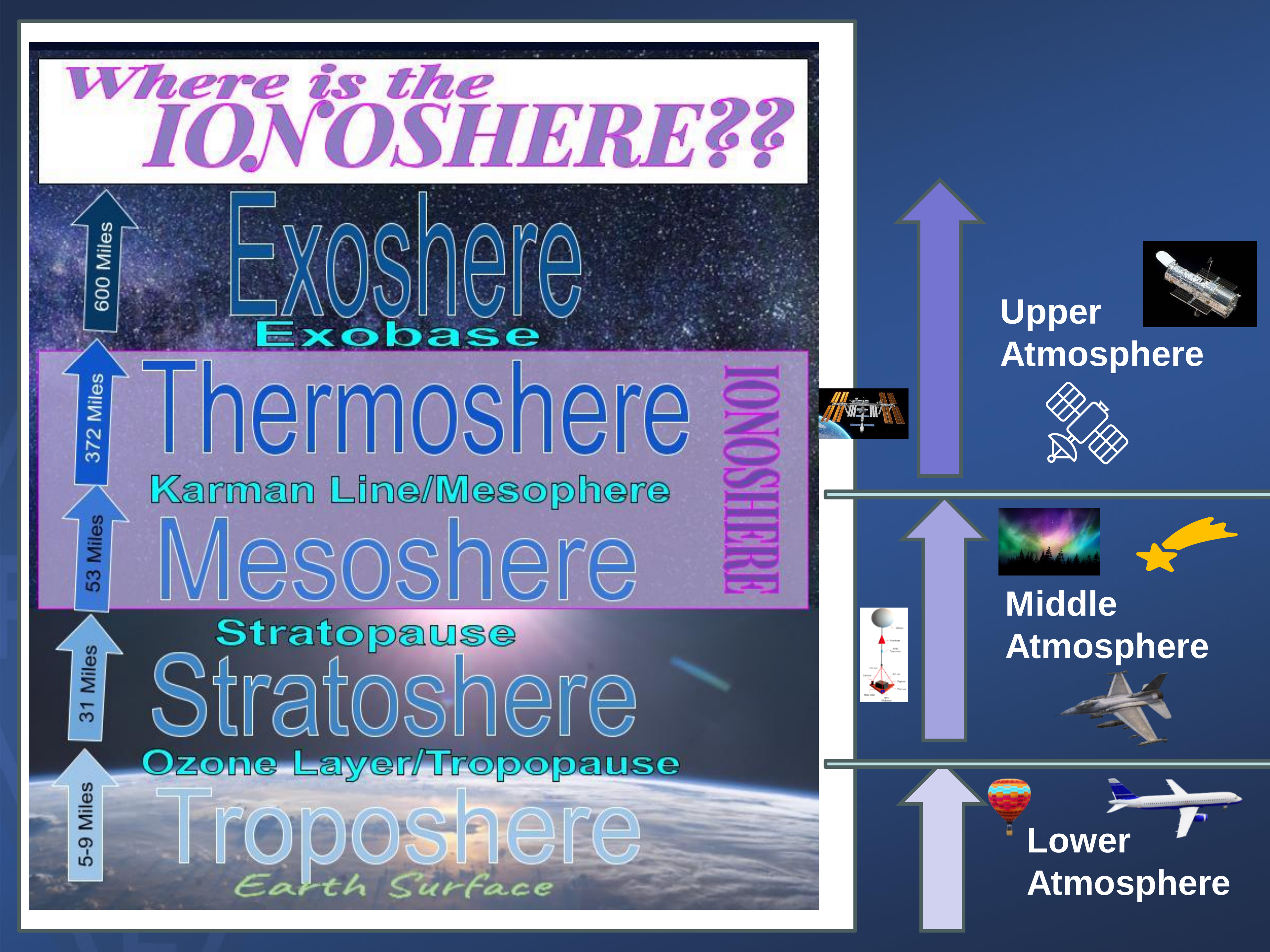


Middle Atmosphere

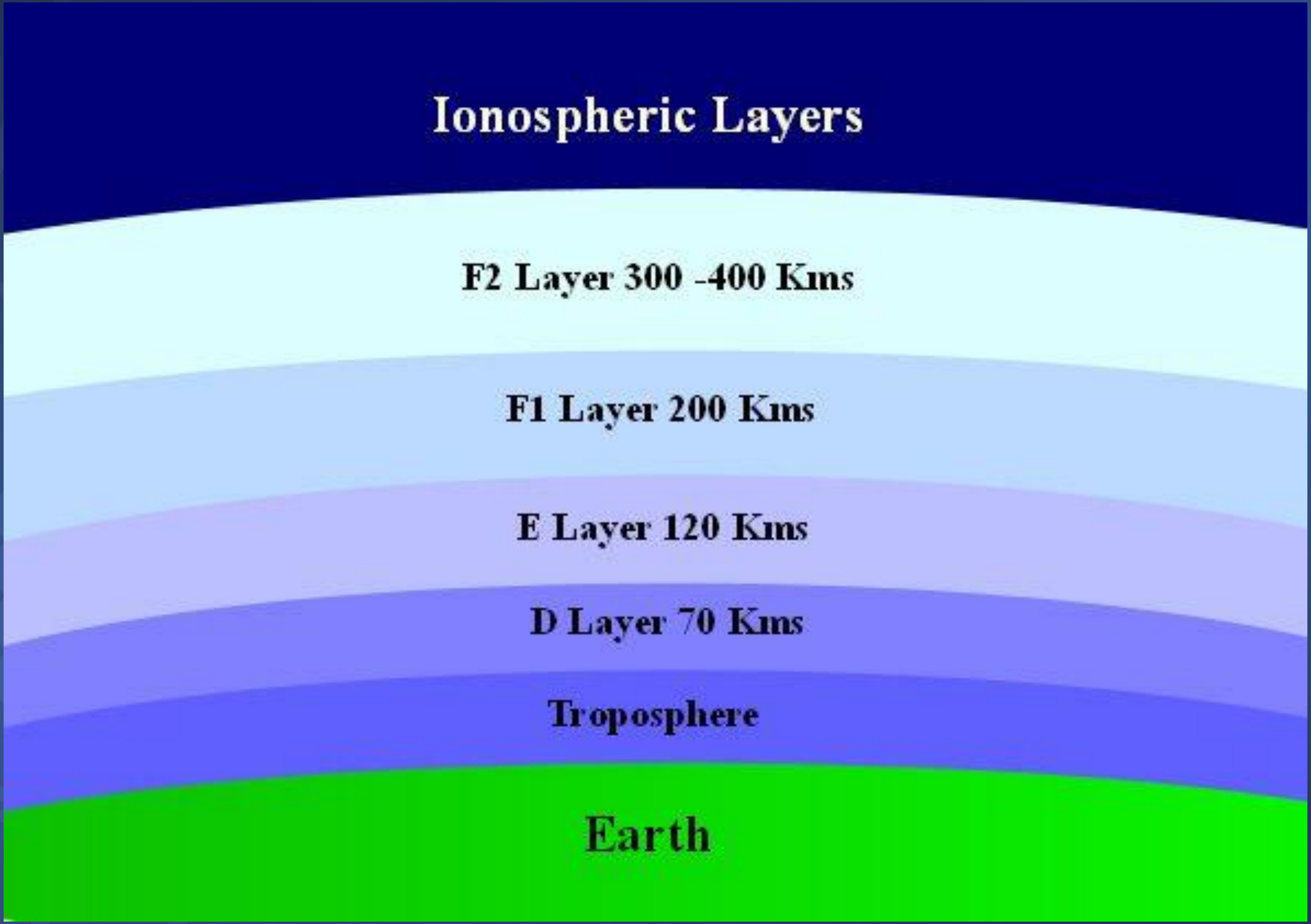




Upper Atmosphere


Where is the IONOSHERE??
600 Miles
Exoshere
Exobase
372 Miles
Thermoshere
Karman Line/Mesophere
53 Miles
Mesoshere
IONOSHERE
Stratopause
31 Miles
Stratoshere
Ozone Layer/Tropopause
5-9 Miles
Troposhere
Earth Surface
Upper Atmosphere
Middle Atmosphere
Lower Atmosphere

The Ionosphere Layers



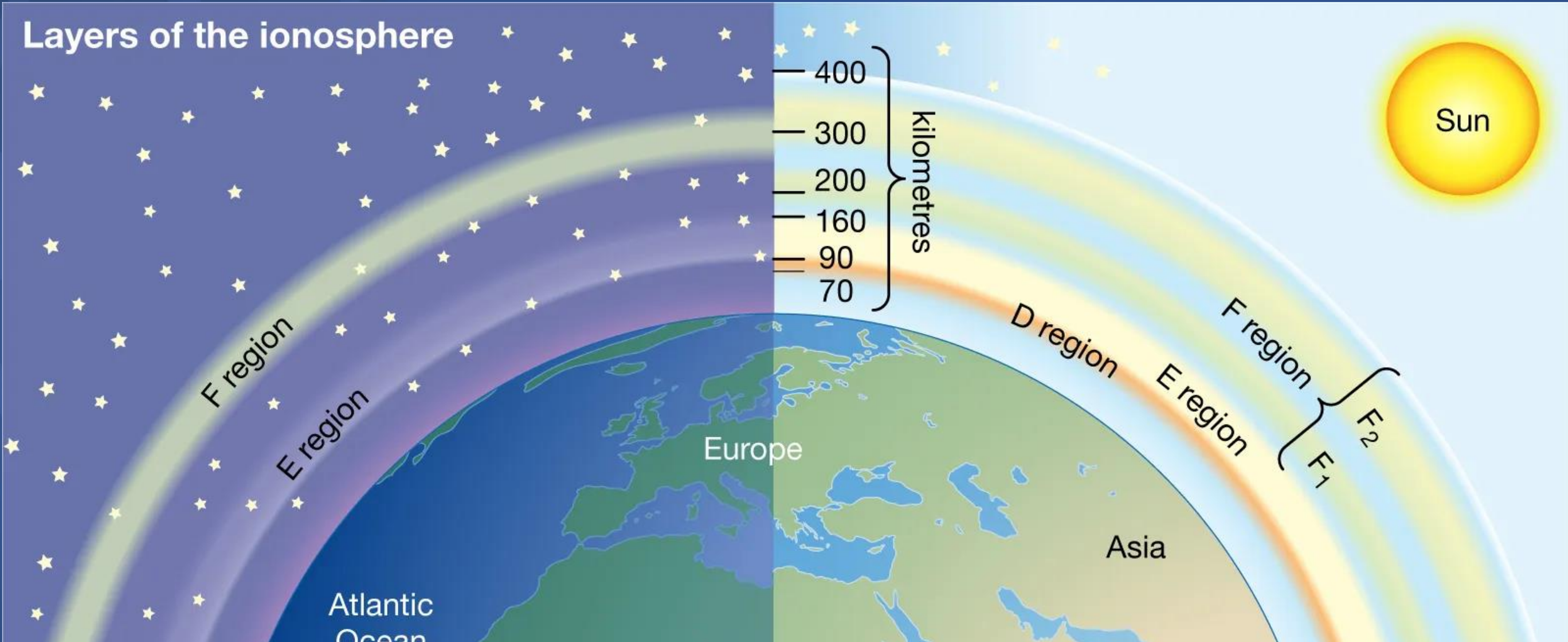
Ionosphere Levels

The Sun emits electromagnetic radiation due to its nuclear fusion process.

F Region: Electromagnetic radiation ionizes at wavelengths of 100 to 1000 Angstroms (ultraviolet)

E Region: Electromagnetic radiation ionizes at 10 to 100 Angstroms (soft X-rays)

D Region: Electromagnetic radiation ionizes at 1 to 10 Angstroms (hard X- rays)



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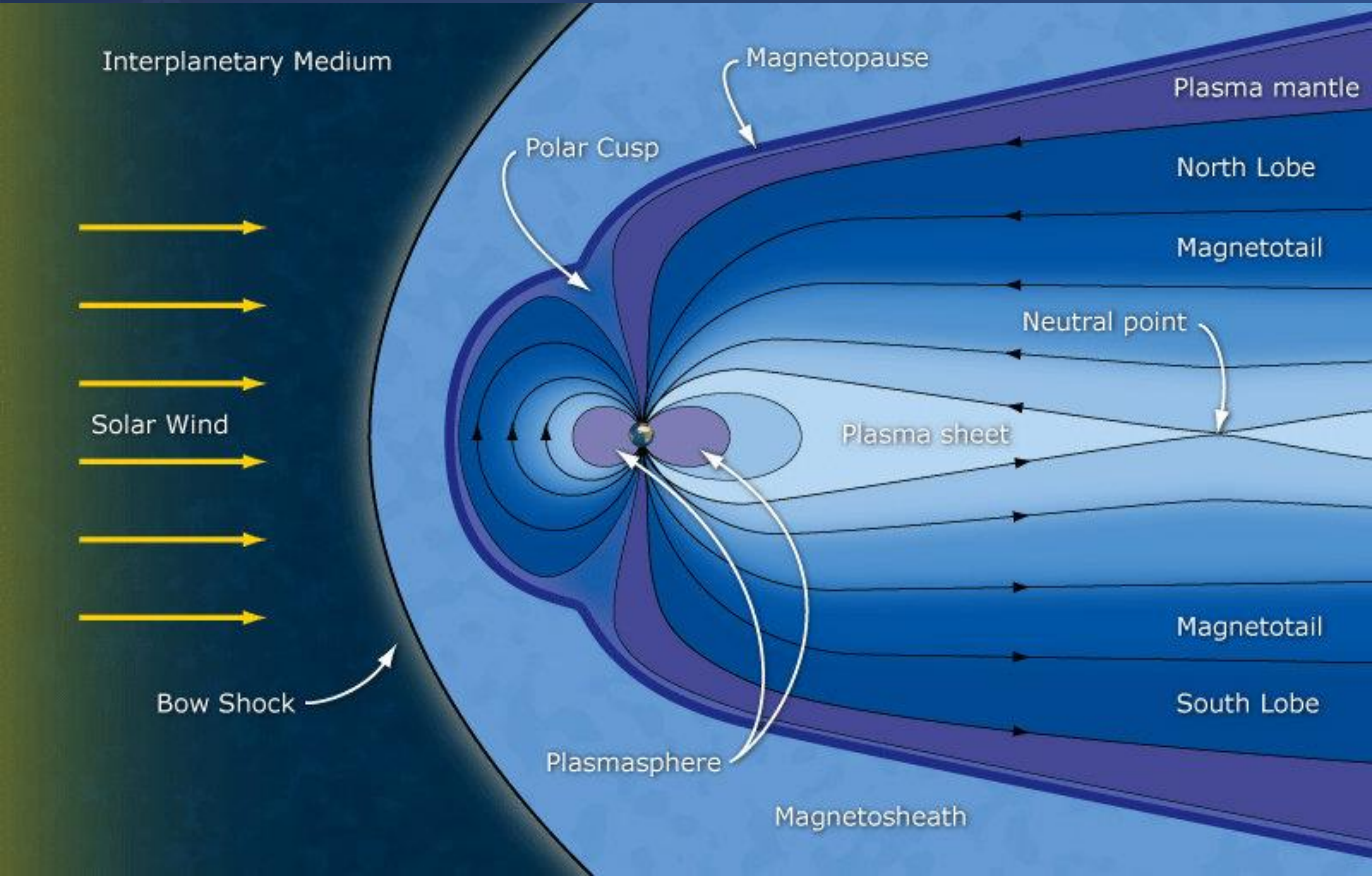
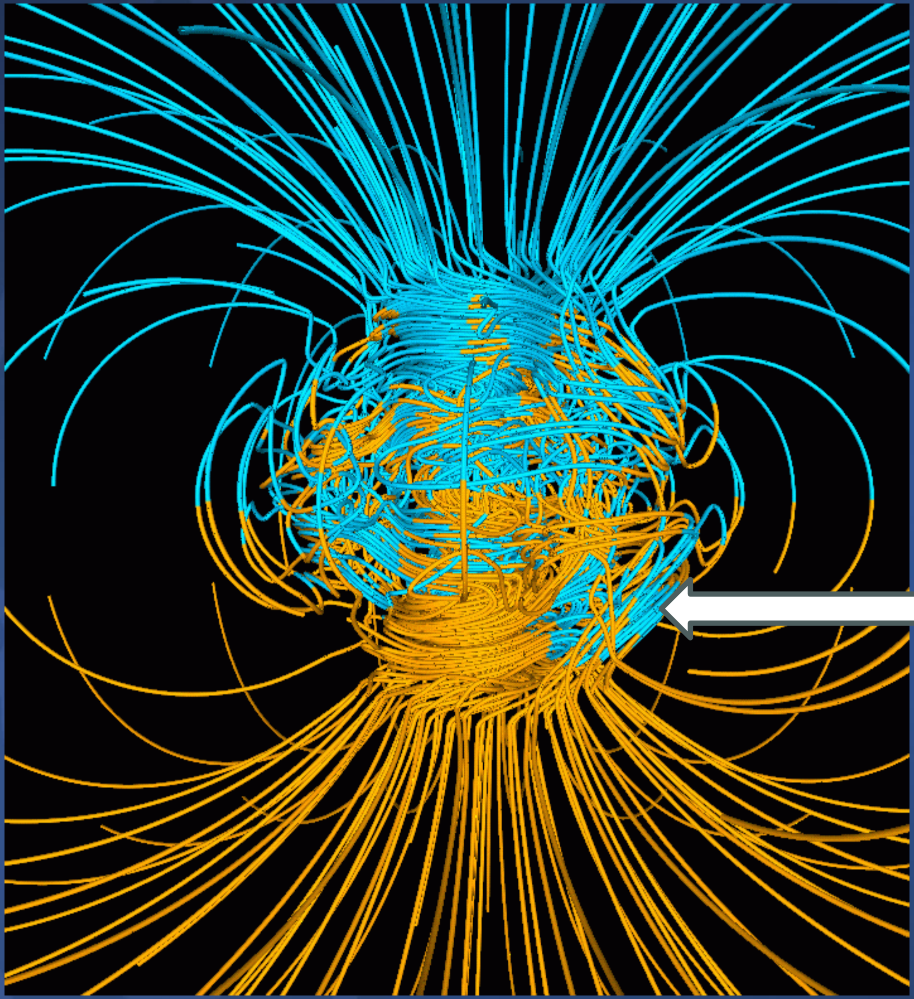
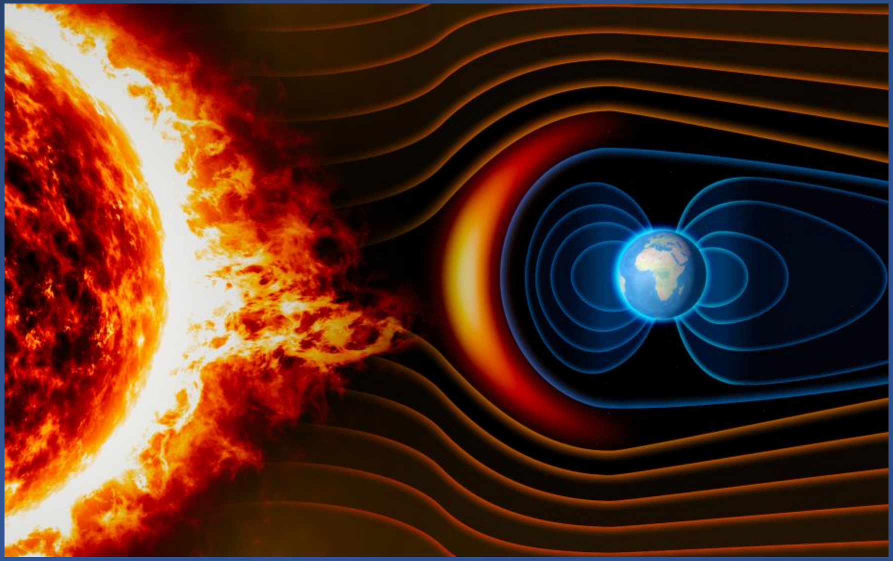
Earth's Geomagnetic Field = Magnetosphere



Earth’s Magnetic Field





Computer simulation of Earth’s Magnetic Field. The lines represent magnetic field lines, blue when the field points towards the center and yellow when away. With the dense cluster at its core.

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Understanding Space Weather

Space weather is the variations in the space environment between the surface of the sun and the surface of the Earth which describes the phenomena that impact systems and technologies in orbit and on Earth including amateur radio.

The Sun & The Solar Activity

- ✓ As a space weather storm leaves the sun, it passes through the corona and into the solar wind.
- ✓ When it reaches Earth, it energizes Earth's magnetosphere and accelerates electrons and protons down to Earth's magnetic field lines where they collide with the atmosphere and ionosphere, particularly at high latitudes.
- ✓ Each component of space weather impacts a different technology.

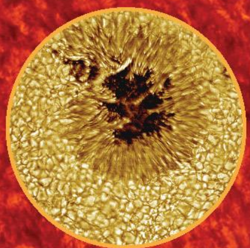
The Sun & The Solar Activity

Space Weather

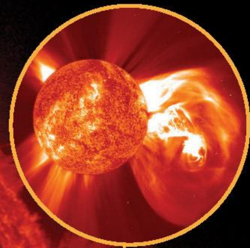
Space weather refers to the variable conditions on the Sun and in the space environment that can influence the performance and reliability of space-based and ground-based technological systems, as well as endanger life or health. Just like weather on Earth, space weather has its seasons, with solar activity rising and falling over an approximate 11 year cycle.

Sunspots

Sunspots are comparatively cool areas at up to 7,700° F and show the location of strong magnetic fields protruding through what we would see as the Sun's surface. Large, complex sunspot groups are generally the source of significant space weather.



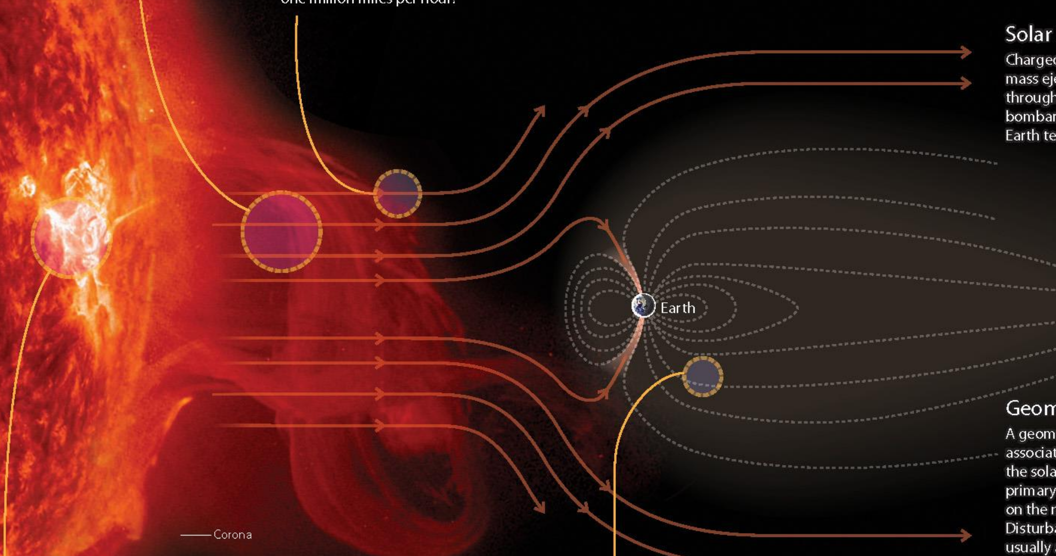
Coronal Mass Ejections (CMEs)



Large portions of the corona, or outer atmosphere of the Sun, can be explosively blown into space, sending billions of tons of plasma, or superheated gas, Earth's direction. These CMEs have their own magnetic field and can slam into and interact with Earth's magnetic field, resulting in geomagnetic storms. The fastest of these CMEs can reach Earth in under a day, with the slowest taking 4 or 5 days to reach Earth.

Solar Wind

The solar wind is a constant outflow of electrons and protons from the Sun, always present and buffeting Earth's magnetic field. The background solar wind flows at approximately one million miles per hour!

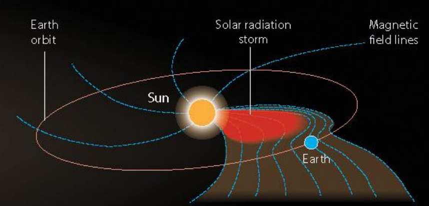


Sun's Magnetic Field

Strong and ever-changing magnetic fields drive the life of the Sun and underlie sunspots. These strong magnetic fields are the energy source for space weather and their twisting, shearing, and reconnection lead to solar flares.

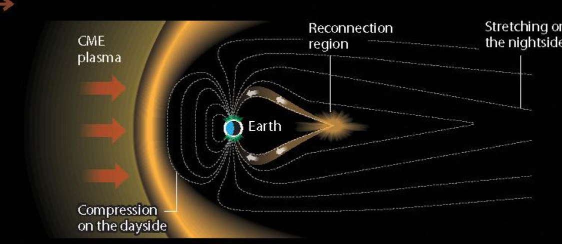
Solar Radiation Storms

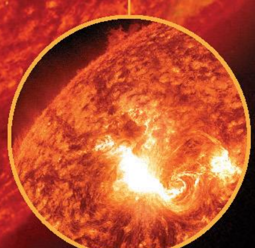
Charged particles, including electrons and protons, can be accelerated by coronal mass ejections and solar flares. These particles bounce and gyrate their way through space, roughly following the magnetic field lines and ultimately bombarding Earth from every direction. The fastest of these particles can affect Earth tens of minutes after a solar flare.



Geomagnetic Storms

A geomagnetic storm is a temporary disturbance of Earth's magnetic field typically associated with enhancements in the solar wind. These storms are created when the solar wind and its magnetic field interacts with Earth's magnetic field. The primary source of geomagnetic storms is CMEs which stretch the magnetosphere on the nightside causing it to release energy through magnetic reconnection. Disturbances in the ionosphere (a region of Earth's upper atomosphere) are usually associated with geomagnetic storms.





Solar Flares

Reconnection of the magnetic fields on the surface of the Sun drive the biggest explosions in our solar system. These solar flares release immense amounts of energy and result in electromagnetic emissions spanning the spectrum from gamma rays to radio waves. Traveling at the speed of light, these emissions make the 93 million mile trip to Earth in just 8 minutes.

Earth's Magnetic Field

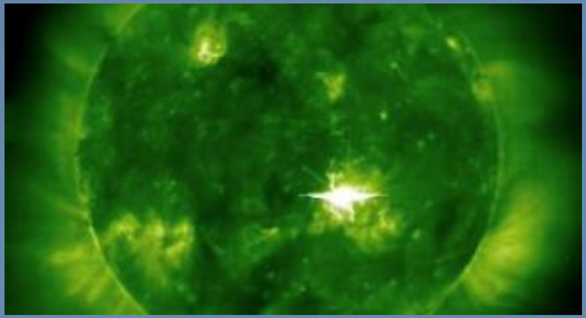
Earth's magnetic field, largely like that of a bar magnet, gives the Earth some protection from the effects of the Sun. Earth's magnetic field is constantly compressed on the day side and stretched on the night side by the ever-present solar wind. During geomagnetic storms, the disturbances to Earth's magnetic field can become extreme. In addition to some buffering by the atmosphere, this field also offers some shielding from the charged particles of a radiation storm.

NOAA Space Weather Prediction Center – www.spaceweather.gov

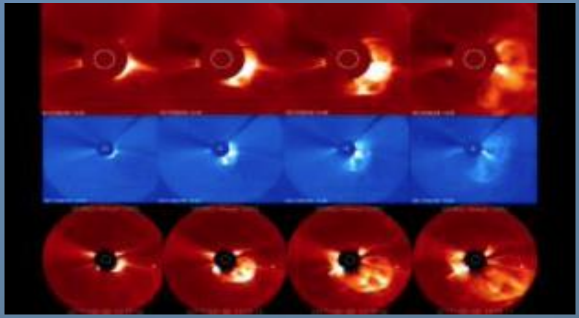
Source images: NASA, NOAA.

Solar Flares & Coronal Mass Ejections (CMEs)

- ✓ Solar Flares are an intense burst of electromagnetic radiation from the release of magnetic energy from the Sun that can last minutes to hours and are associated with sunspots.

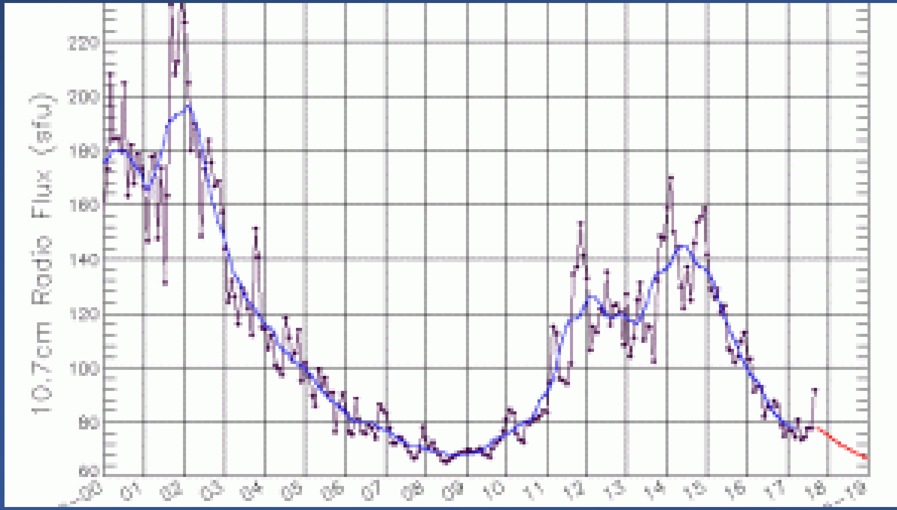


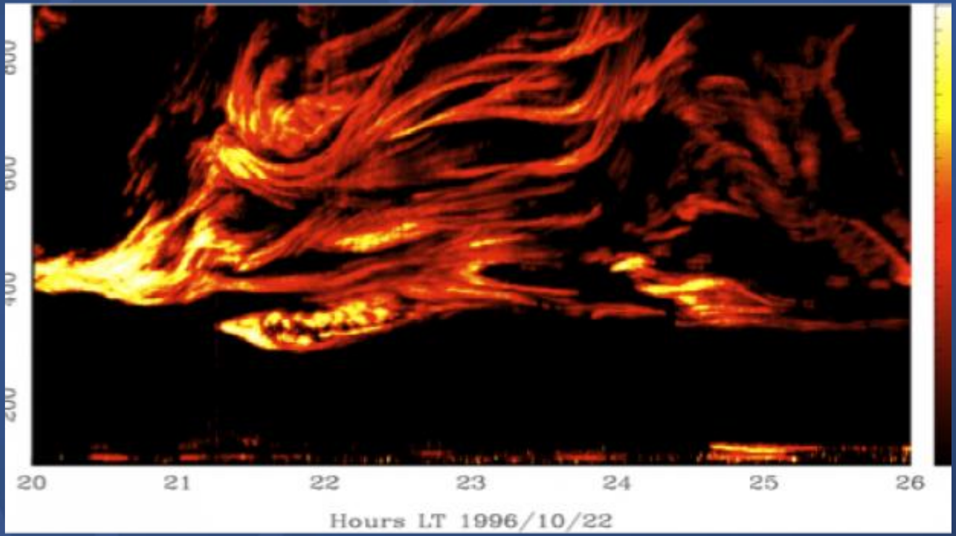
- ✓ CMEs are large explosions of plasma and magnetic field from the Sun's corona.



F10.7 CM Radio Emissions & Ionospheric Scintillation

The solar radio flux at 10.7 cm (2800 MHz) is an excellent indicator of solar activity.





Ionospheric scintillation is the rapid modification of radio waves caused by small scale structures in the ionosphere.

Sunspots/Solar Cycle

- ✓ Sunspots are dark areas that become apparent at the Sun’s photosphere because of intense magnetic flux pushing up from further within the solar interior.

- ✓ The solar cycle, also known as the solar magnetic activity cycle, sunspot cycle, or Schwabe cycle, is an approximate 11-year cycle of solar activity driven by the Sun’s magnetic field and indicated by the frequency and intensity of sunspots visible on the surface. Can be as short as 8 years or as long as 14 years.

Solar Cycle 25

- ✓ The current cycle began in December 2019.
- ✓ Solar activity is expected to ramp up until the predicted solar maximum as early as 2024.
- ✓ Heightened solar activity poses a risk to satellites, spacecraft and even spacewalking astronauts due to increased radiation exposure.
- ✓ On Earth, the large geomagnetic storms that solar activity triggers can interfere with high-frequency (HF) radio communications and Global Positioning Systems (GPS)

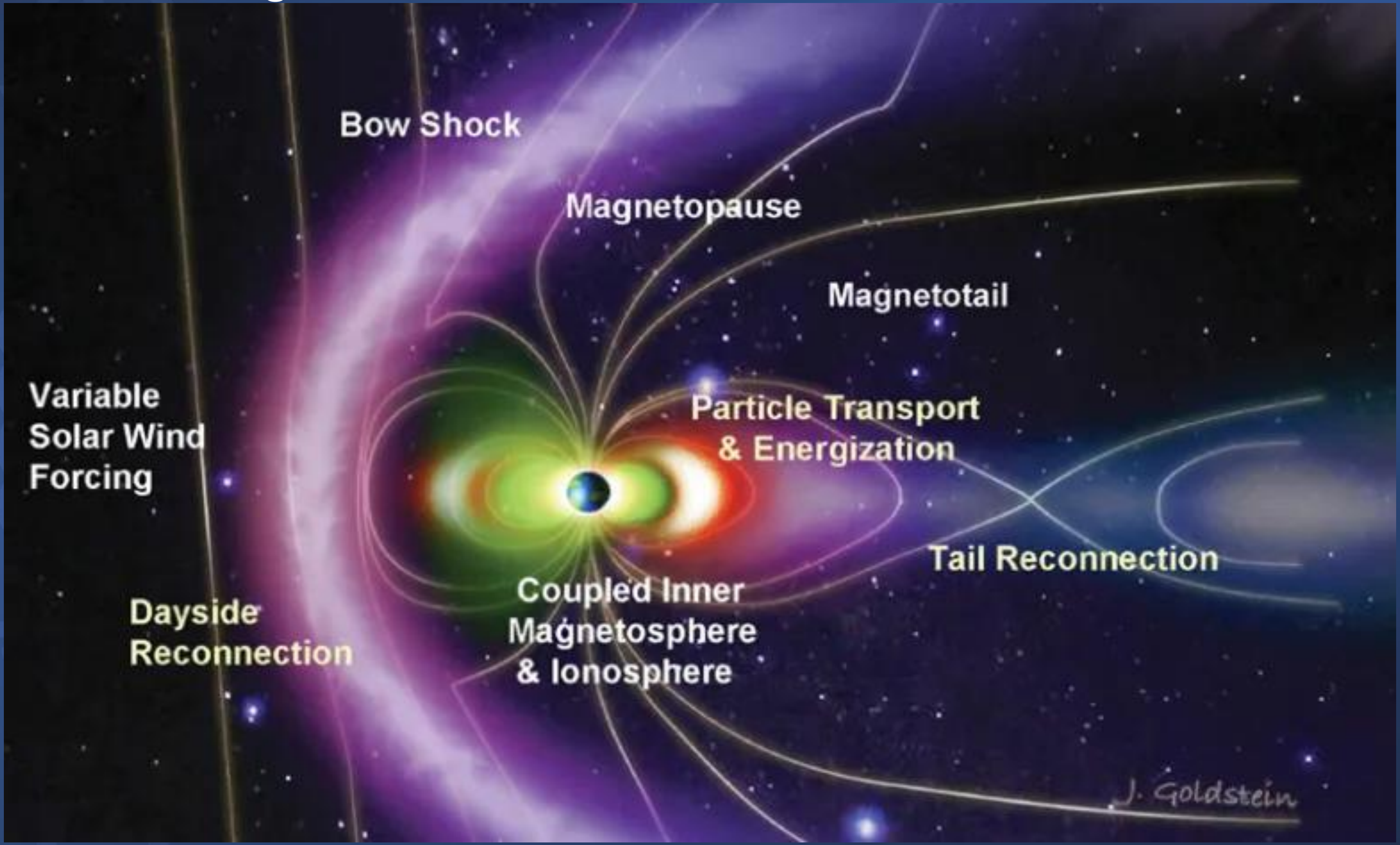
Solar Wind & Geomagnetic Storms

- ✓ Solar Wind continuously flows outward from the Sun and consists mainly of protons and electrons in a plasma state.
- ✓ Geomagnetic storms are fluctuations in the Earth's magnetic field that are caused by changes in the solar wind and interplanetary magnetic field.

The Aurora Borealis or "Northern Lights"
& the
Aurora Australis or "Southern Lights"
occur during geomagnetic storms
when charged particles impact the
Earth's upper atmosphere.

Earth's Magnetic Field

- ✓ If the solar wind is weak, the magnetosphere expands; while if it is strong, it compresses the magnetosphere and more of it gets in.



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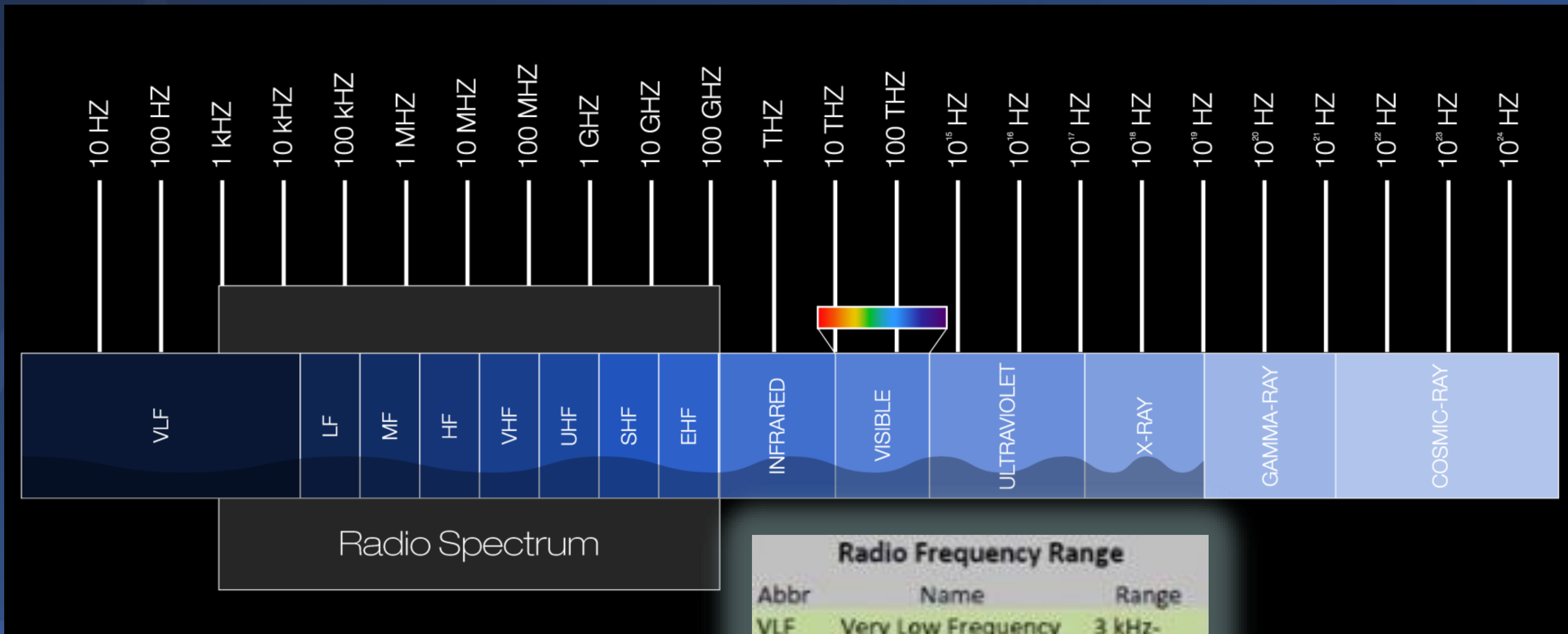
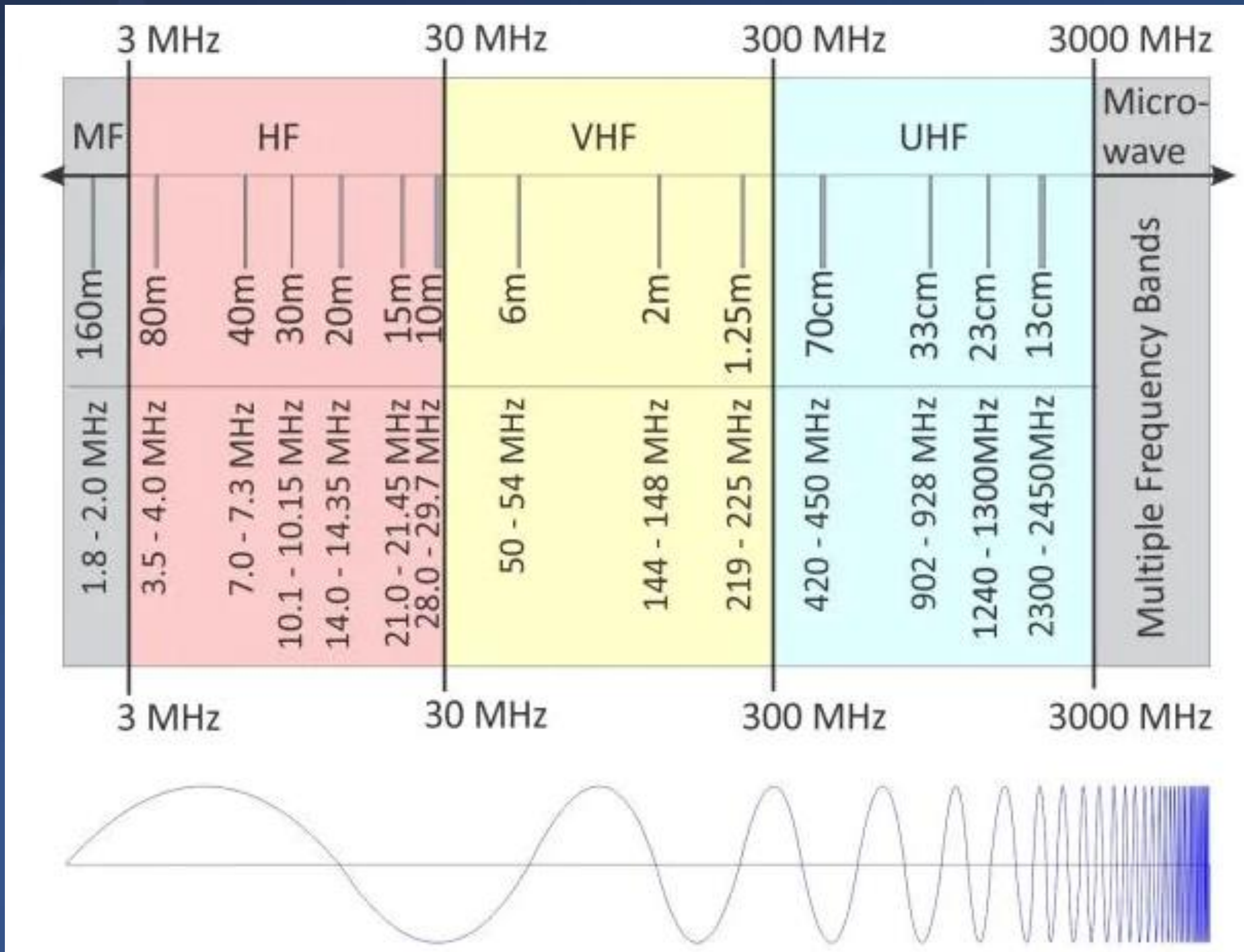
The Electromagnetic Spectrum



Radio Frequency Range

Abbr	Name	Range
VLF	Very Low Frequency	3 kHz-30 kHz
LF	Low Frequency	30 kHz-300 kHz
MF	Medium Frequency	300 kHz-3 MHz
HF	High Frequency	3 MHz-30 MHz
VHF	Very High Frequency	30 MHz-300 MHz
UHF	Ultra High Frequency	300 MHz-3 GHz
SHF	Super High Frequency	3 GHz-30 GHz
EHF	Extremely High Frequency	30 GHz-300 GHz

Amateur Radio HF, VHF, & UHF

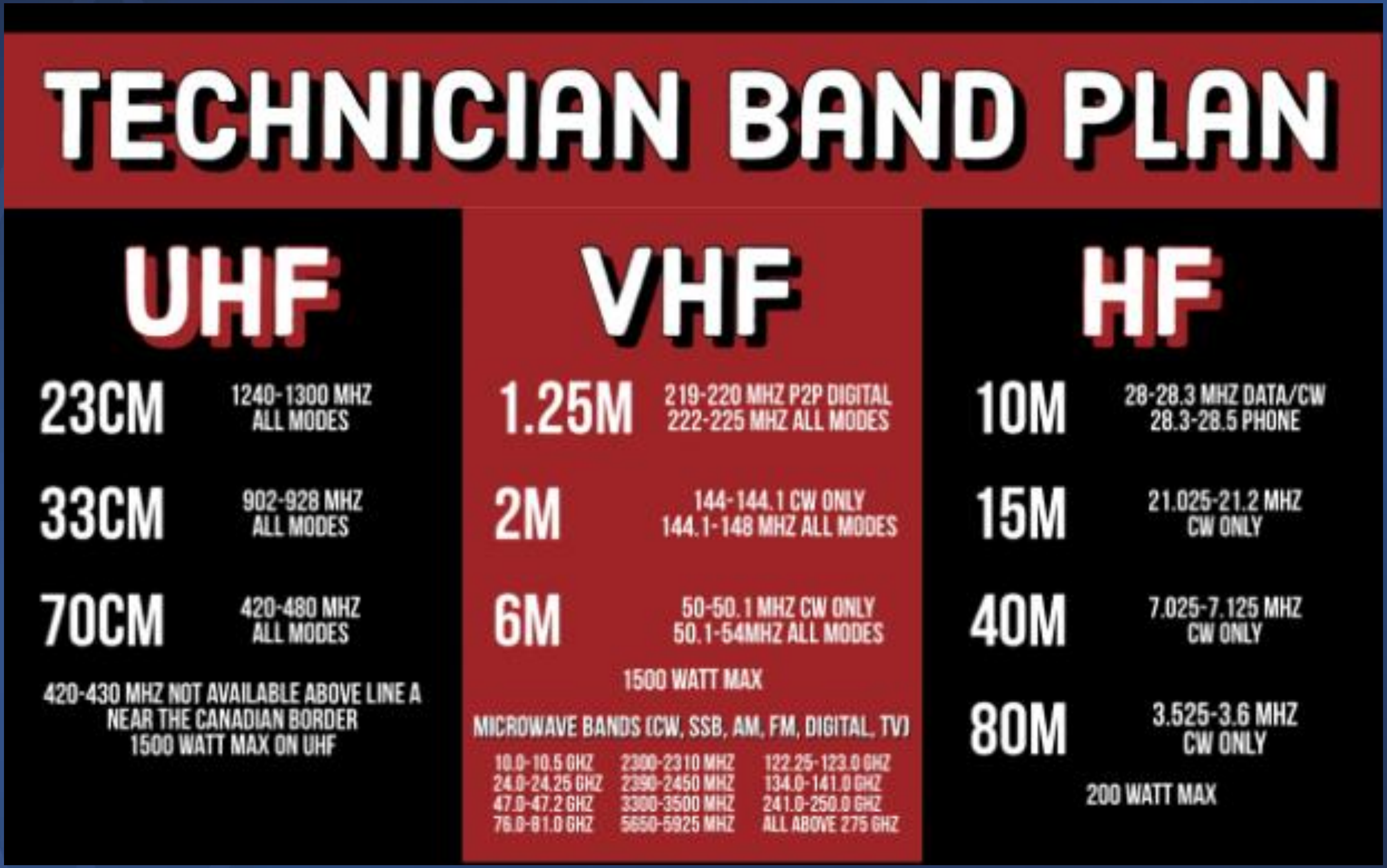


Amateur Radio Bands

Wavelength (meters)		Frequency (MHz)
160	HF	1.8
80		3.5
60		5.3
40		7
30		10.1
20		14
17		18
15		21
12		24
10		28
6	VHF	50
2		144
1.25		222
70cm	UHF	420
33cm		902
23cm		1240

HF = 10m, 12m, 15m, 17m, 20m, 30m, 40m, 60m, 80m
VHF = 1.25m, 2m, 6m
UHF = 13cm, 23cm, 33cm, and 70cm

Technician Class License



General Class License

GENERAL CLASS

10M	DATA: 28.000–28.300 PHONE: 28.300–29.700	20M	DATA: 14.025–14.150 PHONE: 14.225–14.350
12M	DATA: 24.890–24.930 PHONE: 24.930–24.990	30M	DATA: 10.100–10.150 DATA ONLY 200W
15M	DATA: 21.025–21.200 PHONE: 21.225–21.450	40M	DATA: 7.025–7.125 PHONE: 7.175–7.300
17M	DATA: 18.068–18.110 PHONE: 18.110–18.168	80M	DATA: 3.525–3.600 PHONE: 3.800–4.00

Extra Class License

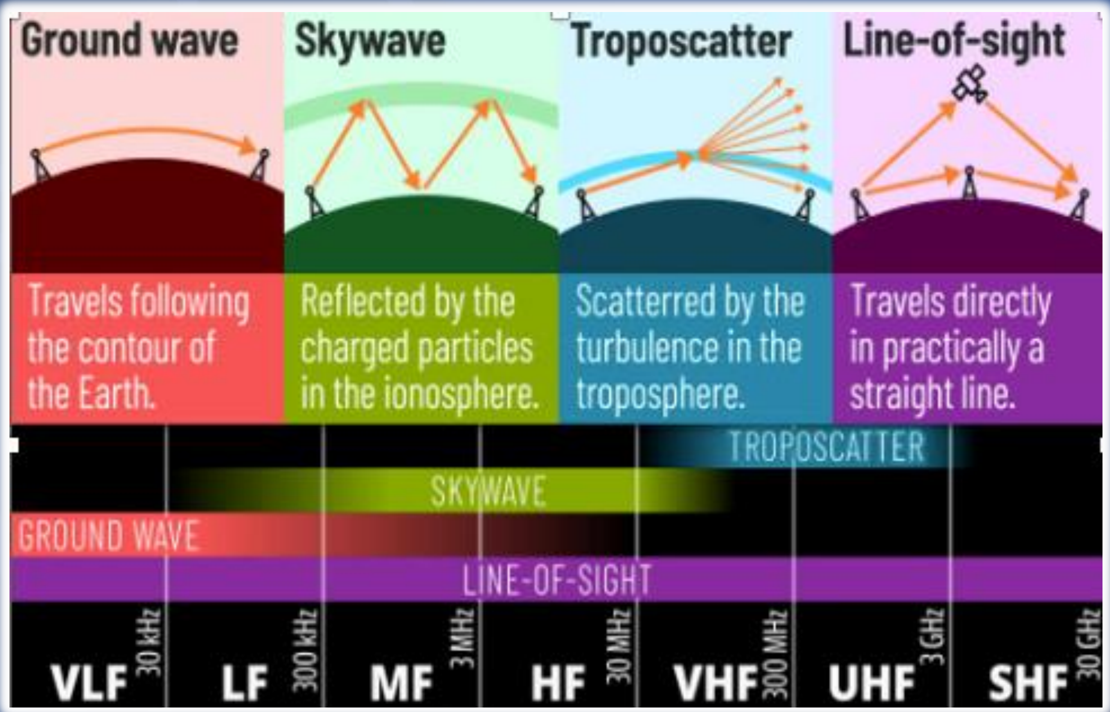
EXTRA CLASS

	Data	Phone
10M	28.000 - 28.300	28.300 - 29.700
20M	14.000 - 14.150	14.150 - 14.350
12M	24.890 - 24.930	24.930 - 24.990
30M	10.100 - 10.150 200 WATT MAX	
15M	21.000 - 21.200	21.200 - 21.450
40M	7.000 - 7.125	7.125 - 7.300
17M	18.068 - 18.110	18.110 - 18.168
80M	3.500 - 3.600	3.600 - 4.000

HF/VHF/UHF Radio Propagation

Radio Wave Propagation is the behavior or path of radio waves as they travel.

HF = Sky Wave
VHF = Space Wave/Troposcatter
UHF = Space Wave/Troposcatter



HF = Long Range, best for ground operators and base stations for worldwide communication, extremely reliable at night.

VHF = Long Range, best outdoors, works well on open sites like farms or constructions sites, requires large antennas to operate

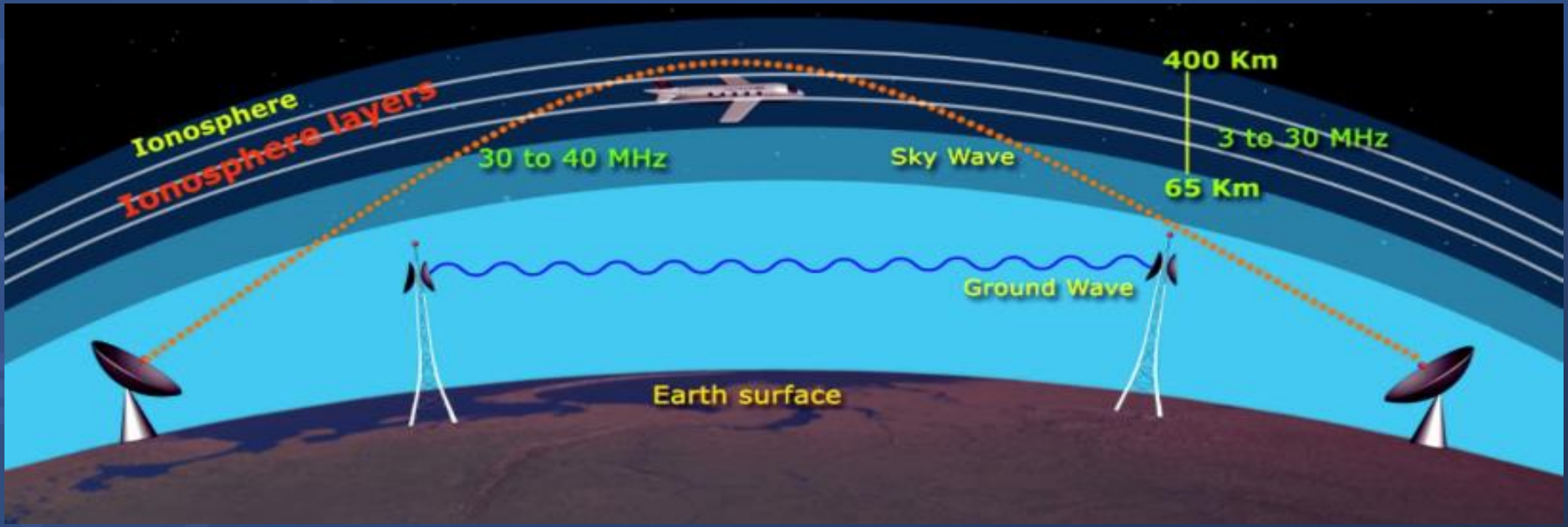
UHF = Short Range, best indoors, works well in buildings or in urban spaces, requires a lot of power to operate

VHF and UHF bands normally provide local or regional communication (repeaters & handhelds)

Impact on Radio Communications

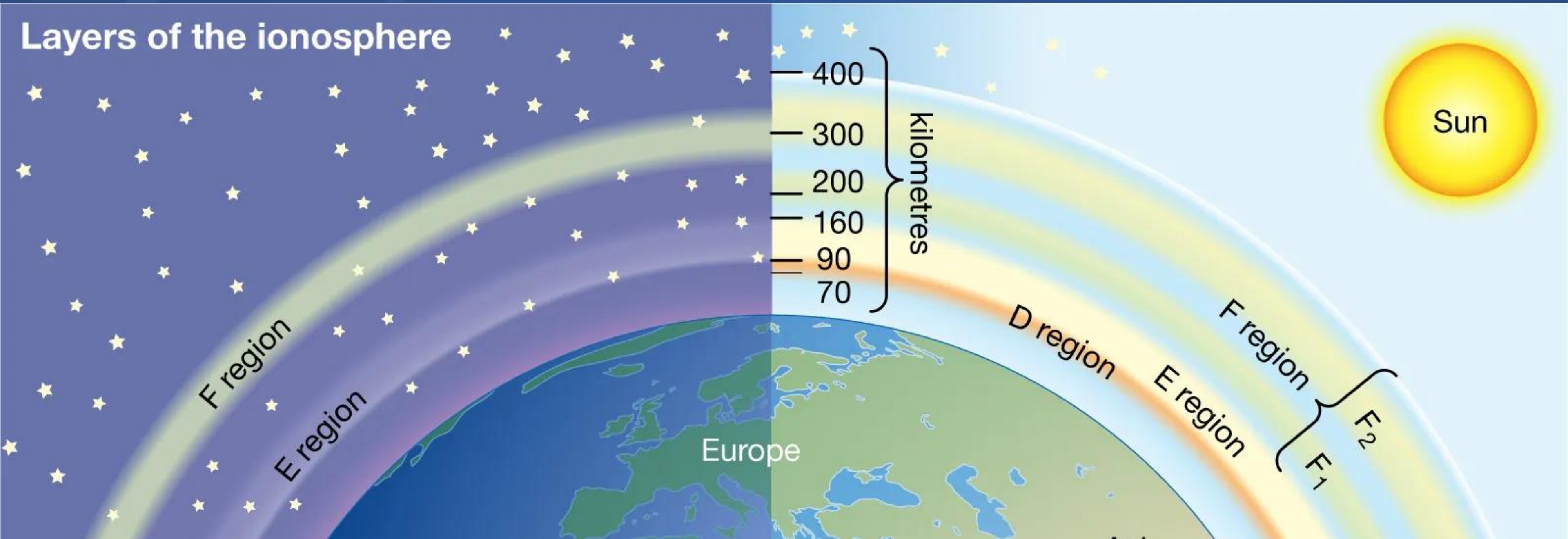
In solar geomagnetic storms, solar flares cause damage to amateur radio communication transmissions.

During these events HF radio frequencies are severely degraded or altogether absorbed. This results in what we call a blackout or the absence of HF communications in the 3 – 30 MHz band.

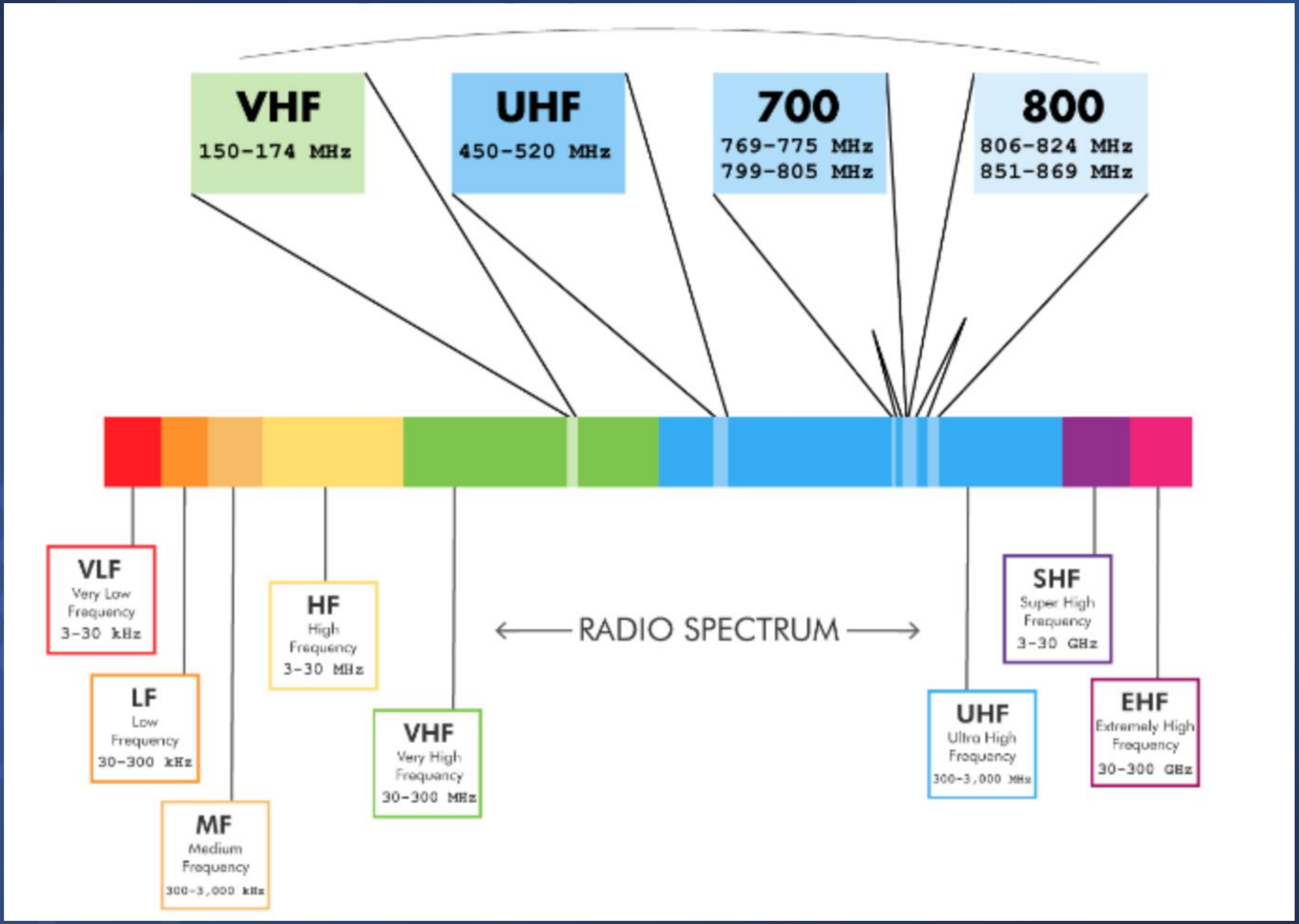


What Happens?

- ✓ During a solar storm from solar flares, the solar x-rays from the sun penetrate to the bottom of the ionosphere (to around 80 km).
- ✓ There the x-ray photons ionize the atmosphere and create an enhancement or thickening of the D layer of the ionosphere.
- ✓ This enhanced (dense) D-layer acts both as a reflector of radio waves and an absorber of waves at different frequencies.
- ✓ The Radio Blackout associated with solar flares occurs on the dayside region of Earth and is most intense when the sun is directly overhead.



Public Safety Bands



Mitigating Solar Weather Effects

- ✓ Ham radio operators can mitigate the effects of solar flares by switching to higher frequencies during the day and using lower frequencies at night, where solar flares have less impact.
- ✓ Stay Informed! Monitor space weather forecasts from agencies like NOAA's Space Weather Prediction Center or my personal favorite "Space Weather Woman" Dr. Tamitha Skov
- ✓ Well-designed antennas and robust grounding can help mitigate signal degradation and maximize signal strength during solar weather events.
- ✓ Consider using digital modes like FT8 or PSK31 that are more resilient to signal fading and noise compared to traditional voice modes.
- ✓ Ensure you have backup power sources in case of power outages caused by solar weather events.
- ✓ Share information about propagation conditions and best practices during solar weather events.

Do you want to help further the Science of Solar Propagation?

NASA

NSF National Science Foundation

ARDC
AMATEUR RADIO DIGITAL COMMUNICATIONS

MIT
HAYSTACK OBSERVATORY

In ONE WEEK, on Saturday October 14, 2023, from 1200-2200 UTC, during the annular solar eclipse we need you on the air!

This celestial event will be followed widely by hams because of the sudden and dynamic changes that occur in the ionosphere during an eclipse. While much is known about ionospheric propagation, much is still to be learned. Ham Radio Science Citizen Investigation encourages YOU to get on the air and operate as part of the The HamSCI Festivals of Eclipse Ionospheric Science.

Propagation experiments will include the Solar Eclipse QSO Party using CW, FT4/8, SSB and other digital modes and The Gladstone Signal Spotting Challenge (GSSC) using CW, WSPR and FST4W modes. Operators may operate on any band and any mode from 6-160 meters (except the WARC bands).

All the details may be found at www.hamsci.org/eclipse.

If you have any questions or know of a club that would be interested in having a presentation to learn more about the science around this and the April 8, 2024, total solar eclipse please contact:

HamSCI Ham Radio Science Citizen Investigation

HamSCI Public Relations Officer, Ed Efchak, WX2R
pressrelations@hamsci.org.

Save the dates…get on the air…and send in a log.

Random Trivia

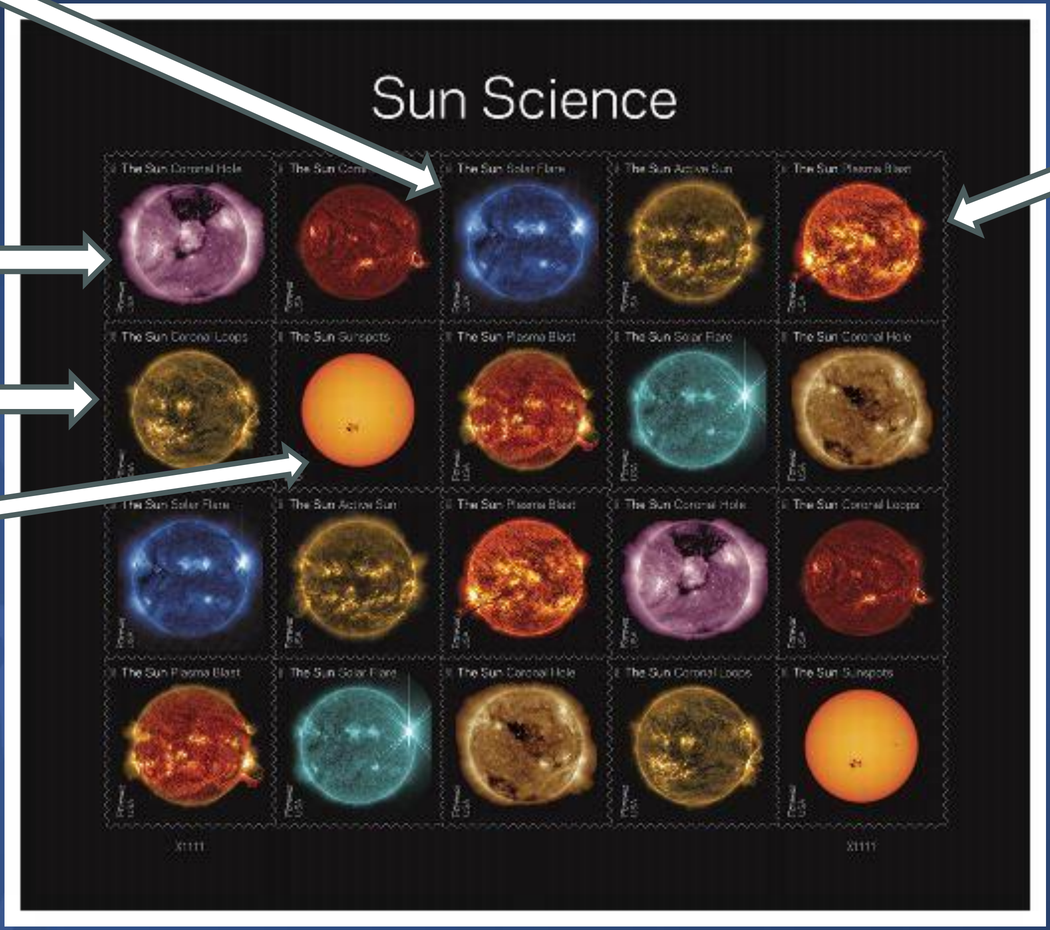
Solar Flare

Coronal Hole

Coronal Loops

Sunspots

Plasma Blast



June 18th, 2021, THE USPS issued Forever Sun Science Stamps
Images were colorized by NASA according to different wavelengths that reveal or highlight specific features of the Sun's activity.

Space Weather Impact Historical Examples

- **1859 (Late August-early September):** The Carrington Event, named for astronomer Richard Carrington who observed the solar flare preceding an historic geomagnetic storm. The storm disrupted telegraph communications around the world and produced aurora seen as far south as Hawaii and Central America.
- **1989 (March):** Quebec plunged into darkness for 9 hours as power grid overwhelmed by geomagnetic storm.
- **2003 (October):** “Halloween Storms” resulted in a 30-hour outage of the Federal Aviation Administration’s Wide Area Augmentation System (WAAS), which provides GPS navigation support to aircraft.
- **2005 (January):** United Airlines diverted 26 flights from polar routes to avoid radio blackout potential.
- **2013 (March):** Three separate CME arrivals in March resulted in three separate satellite outages lasting from hours to days.

Thank You

Desiree M. Baccus, N3DEZ

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References

- NOAA Solar Cycle 25 Video https://youtu.be/71we0DQSPjA
- NOAA Space Weather Prediction Center https://www.swpc.noaa.gov/products/report-and-forecast-solar-and-geophysical-activity
- NASA https://www.nasa.gov/news-release/solar-cycle-25-is-here-nasa-noaa-scientists-explain-what-that-means/
- Encyclopedia Britannica https://www.britannica.com/story/how-much-does-earths-atmosphere-weigh#:~:text=While%20mass%20and%20weight%20are,one%20millionth%20of%20Earth%27s%20mass
- HamSCI https://hamsci.org
- USPS https://about.usps.com/postal-bulletin/2021/pb22572/html/info_004.htm
- Space Weather Woman https://www.spaceweatherwoman.com

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