<u>IIT INDORE ONLINE INTERNSHIP REPORT</u>

ON

SPACE WEATHER PREDICTION USING MACHINE LEARNING

SUBMITTED BY

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Total duration of internship- 1 month (From 5th June 2021 to 5th July 2021)

--Timeline of internship--

06 June 2021-14 June 2021

Accumulated knowledge regarding factors affecting space weather from the book “Physics of the space environment”.

15 June 2021 -20 June 2021

Acquired knowledge about the access and use of data from SDO and AIA.

21 June 2021- 29 June 2021

Used Astrometrica and SAOimageDS9 to view fits file from the SDO and AIA website and perform certain actions like slicing images with RGB etc.

30June 2021-5July 2021

Analyzed few research papers that helped us to be a bit clearer about the importance of SDO/AIA website in the field of space weather prediction and how it is practically occurring.

- ❖ **<u>The Sun-</u>**

<u>The core.</u> -This is the high density, high temperature region at the center of the Sun, where thermonuclear energy production takes place. The core extends from the center to about Ro/4 (1/64-th of the Sun's volume), but it contains about half of the solar mass. Practically all of the Sun's energy production takes place in this region.

<u>The radiative zone.</u> -The energy produced in the core is transported through the core and the radiative zone by gamma ray diffusion. The gamma rays are scattered, absorbed, and reemitted many times before they reach the outer edge of the radiative zone.

<u>The convection zone.</u> This zone is located in the uppermost 30% of the solar interior. In this region the solar material is convectively unstable, because the radial temperature gradients are large. When a blob of plasma (with a typical size of ~ 1,000 km near the solar surface) is displaced upward from its equilibrium location, it enters into a colder and consequently higher density region.

The buoyancy force pushes the blob even further upward. The resulting granulation covers the solar surface. The colder material "sinks" downward near the dark edges of the granules.

The solar atmosphere consists of four layers. The lowest is the thin and dense photosphere that emits most of the sunlight. The equivalent blackbody temperature of the photosphere is 5,770 K.

The next layer is the chromosphere where the temperature increases from 4,200 K to 10^4K. The chromosphere is the source region of several transition lines (such as H-a and some UV lines) that are very important in the terrestrial upper atmosphere. The chromosphere is followed by a very narrow transition layer where the temperature increases from ~ 10^4K to ~ 10^6 K. This transition layer is one of the most interesting and least understood layers of the solar atmosphere. The uppermost layer of the solar atmosphere is the solar corona. This region extends into the interplanetary space where it becomes the solar wind. The density in chromosphere is even lower than the photosphere. The net energy produced by this "hydrogen cycle" is 26.73 MeV, which is the equivalent of the mass difference between four hydrogen nuclei and a helium nucleus (0.029 atomic mass units). It is this energy that fuels the Sun, sustains life, and drives most physical processes in the solar system.

- ❖ **<u>Coronal holes-</u>**

- Regions of open magnetic field lines contain low density plasma, therefore look dark, these regions are also called coronal holes.
- Near solar minimum coronal holes cover 20 percentage of the sun surface.
- **Polar coronal holes**- essentially permanent.
- **Lower latitude holes**- only last for several solar rotations, usually connected to polar coronal holes.
- The interplay between inward pointing gravity and outward pointing pressure gradient force results in a rapid outward expansion of the coronal plasma along the open magnetic field lines.

❖ **<u>Solar wind Stream-</u>**

- Near the ecliptic lane the solar wind tends to organized into alternating streams of slow-fast streams.
- These winds are tending to be encountered by earth on several solar rotation.
- Fast stream—600km/s, typically unipolar
- Slow stream- 350m/s, sharp and long-lived reversals in magnetic field polarity occur at low-speed close to the leading edges of the high-speed streams.

  Long lived, high speed streams- originates in coronal hole
    - -large and nearly unipolar region in the solar atmosphere.
    - associated with open magnetic field lines.
    - the solar wind expansion is unrestricted by the solar atmosphere.
- Low speed flows-originate in the enter regions of coronal streamers
    - -studle regions of magnetic polarity reversals
    - -related to complicated open mag field line topologies in the coronal streamer hole.

❖ **<u>The Heliosphere-</u>**

- Regions of space influenced by the sun, its corona and the solar wind.
- The pressure of the expanding coronal bubble asymptotically approaches zero as the heliocentric distances goes to infinity.
- If there is a finite pressure in the interstellar medium, the coronal expansion must eventually stop at a point and the solar wind pressure becomes smaller than the interstellar pressure.
- Interstellar charged particles are prevented to enter the heliosphere by <u>plasma physical process.</u>

The sun is a point source of supersonic magnetized plasma that radially expands into a low-pressure external medium.

An immediate consequence of the supersonic motion of the heliosphere in the interstellar plasma is the formation of an upstream low shock, which decelerates and deflects the interstellar charged particles.

<u>Heliopause</u>-flow lines of the interstellar plasma don't penetrate into the regions dominated by the solar wind but flow around a contact surface also called heliopause.

<u>Helioseismology</u>- it is the study of solar oscillation which is possible due to the wave motion in the sun.

❖ **<u>Corona-</u>**

- the outermost terminal region of the solar atmosphere extending to large distances and essentially becoming the solar wind.

- Characterized by very high temp and by the presence of low density fully ionized plasma.
- Much more research is going on the heating effects of corona.

- **<u>Helmet streamers-</u>**
- The most common coronal structures seen on eclipse photographs are helmet streamers.
- Bright elongated structure
- Fairly wide near the solar surface
- Narrow spiked
- Base contain dark cavity
- Appear brighter than the rest of the corona and the reason is they are high density regions, also scattering of solar radiation is enhanced.

Near the poles the coronal intensity is generally depressed, particularly around solar maximum.

- **<u>The sun spot-</u>**

Sunspots first appear as small dark pores, which over a day or so gradually grow bigger and develop into sunspots. The effective temperature of the umbra is a few thousand kelvins lower than the blackbody temperature of the photosphere. Because of its lower effective temperature. a sunspot emits much fewer photons than the surrounding areas and therefore appears much darker. The lower effective temperature of sunspots is associated with strong local magnetic fields.

Sunspots are usually associated with strong local magnetic fields. Usually each sunspot (or sunspot group) is associated with a single magnetic polarity. These unipolar spots are accompanied by another sunspot or sunspot group of opposite polarity. These groups together form a bipolar sunspot group. Observations show that during any given solar cycle the polarity of the leading and trailing sunspots in a bipolar sunspot group is usually the same for a hemisphere. For instance, during solar cycle 21 the leading and trailing spots in the northern solar hemisphere were predominantly of north and south polarity, respectively. During the same solar cycle, the leading spots were predominantly of south polarity in the southern hemisphere. The sunspot groups in the next solar cycle are of opposite polarities: In solar cycle 22 the leading spots of northern hemisphere bipolar groups were of south polarity. This 11-year reversal of sunspot group polarities defines a 22-year magnetic solar oscillation.

Sun spot index-R=k(10g+f)

F= no of individual sunspots

g= no of recognizable sunspot groups

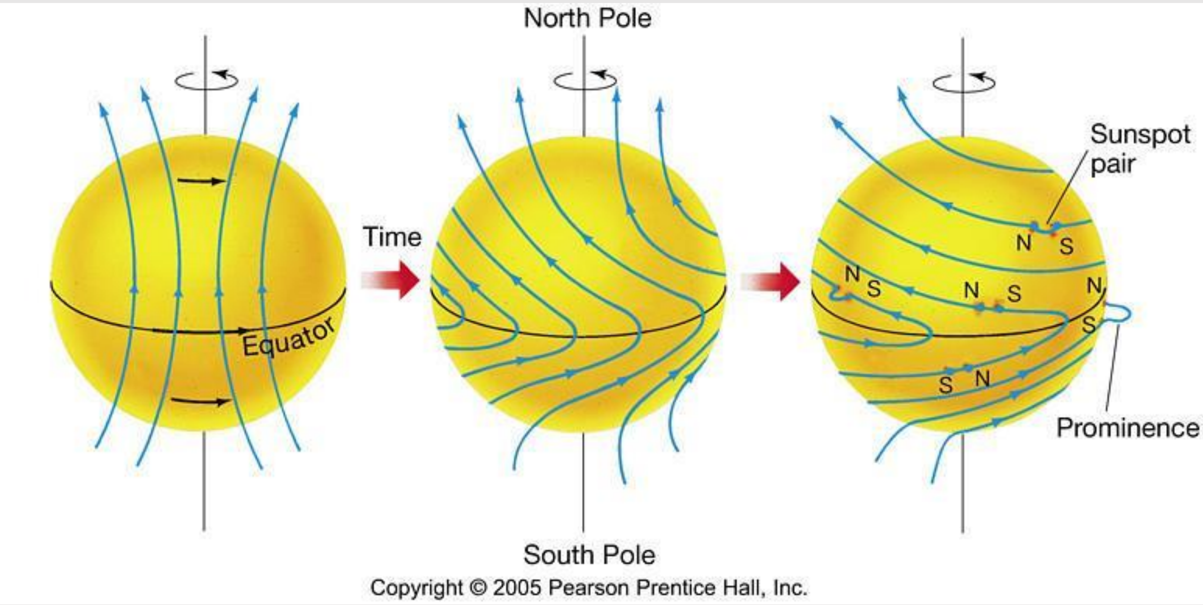
K= conversion factor

- **<u>Babcock Model-</u>**

Babcock was able to show that the time required to achieve a given level of field intensification increased toward the equator. When a certain level of intensification is achieved the field penetrates into the photosphere where the field line footpoints appear as sunspots with strong magnetic field (about 1 kg.). Naturally, each emerging magnetic field line returns to the solar interior through a second sunspot. The letters “f” and “p” denote magnetic polarities following and preceding the direction of solar rotation. The emergence of the magnetic field through the photosphere is the third stage of the solar cycle.

In the fourth stage the Sun’s poloidal field is neutralized and reversed. The “f” portions of the active regions tend to move toward higher latitudes, while the “p” regions migrate toward the equator. Eventually the “f” polarities of the active regions neutralize the existing poloidal field, while the “p” regions originating at the two hemispheres merge near the solar equator where their magnetic fields cancel each other. Further poleward migration of the “f” regions replaces the old poloidal field with a new one with opposite magnetic polarity.

Finally, in stage five we find a reversed weak axisymmetric poloidal field about 11 years after the beginning of phase one.



- ❖ **<u>Solar flare-</u>**
  - It is a localized explosive release of energy that appears as a sudden, short-lived brightening of an area in the chromosphere.
  - Releases their energy mainly in the form of electromagnetic radiation and energy particles.
  - Solar flares are classified according to their radiative energy release.
  - Brilliance of flare measured by 2 frequencies-optical and x ray.
  - Total energy ranges 10^{21}J to 10^{25}J
  - Mostly occur in closed field line regions.

- **CME**-
  - large amount of mass sporadically ejected into the interstellar medium, such transient ejection of mass called CME.
  - Material ejected with a speed of 50km/s to 2000km/s.
  - Most CMEs occur in closed mag field regions in the corona where the mag field is strong enough to constrain the plasma from expanding outward.
  - CMEs are not generated by the solar flares.
  - CMEs are associated with long duration x ray events.
  - Flares are essentially photon output while CMEs produce plasma.

- **Airglow and Aurora-**

  Both are formed due to the excitation of the atmospheric species followed by subsequent radiation of photons.

Airglow is mainly caused by

- direct scattering of sunlight,
- emission associated with ionization,
- recombination and radiation associated with neutral photoemission.

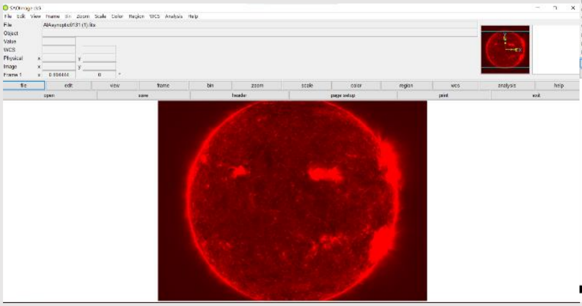
Whereas aurora is mainly caused by dissipation of energy carried by precipitating energetic particles (mostly Kev electrons). The main principal sources are absorption of electromagnetic radiation and chemical reaction. Earth's night air glow is dominated by the green and red forbidden lines of neutral atomic oxygen and by the yellow resonance doublet of sodium, NaI.

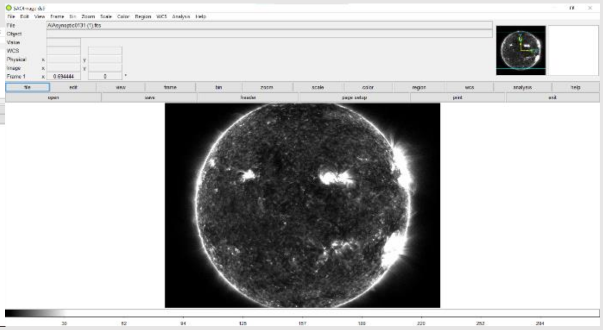
- **Auroral Electrons-**

Most bright auroras are generated by precipitating energetic electrons mainly downward along open geomagnetic field lines. The energetic primary auroral electrons ionize the gasses into the upper atmosphere and produce secondary electrons. Electrons are also produced in the atmosphere by photoionization electrons created inside the atmosphere are generally referred as photoelectrons or supra thermal electrons.

❖ Data Analysis

I have used the SAO image DS9 to view the fits datasets from SDO/AIA website where I have sliced the images in RGB colour format in order to observe the origin of solar flare, CMEs and Sunspots etc. By observing these files for a period of time I got to know about how these processes occur in various regions of sun, their changes according to time and how they are affecting the space weather of Earth.





Research Paper Analysis

❖ FLARECAST

In this section I am going to describe how this FLARECAST system works by using SDO/AIA datasets and machine learning algorithms.

Mostly there are some energetic events like CME and solar flare that affects the space telecommunication system, network agencies, power grids of some countries and satellite operations.

FLARECAST workflow divided into 4 steps i.e.-

- imports data from the archive of SDO/HMI (although other remote archives can be used, such as the one at the NOAA Space Weather Prediction Centre).
- Extracts features from the loaded data.
- Models the data features by means of machine learning methods.
- Validates the results from the previous step.

So FLARECAST has 2 types of machine learning systems that are supervised and unsupervised.

In case of unsupervised algorithms pure data observation occur without using any historical dataset whereas in supervised algorithms historical datasets are used to train the prediction when unlabeled data arrive for analysis.

Advanced machine learning methods are used in FLARECAST in order to fulfill objectives specific kind of applications like loss function in regularization networks, penalty terms tailored to feature selection arguments, more automatic and more general approaches to unsupervised applications finally, innovative approaches that have been formulated within the project framework and that are applied here for the first time against a real-world use-case.

Solar flares are explosive events in which massive amounts of energy stored in Coronal Magnetic fields are released thus triggering secondary effects like the emission of electromagnetic radiation, coronal materials and energetic particles, so these solar flare regions are called active regions (AR).

In FLARECAST the extraction algorithms extract up to 171 features including geometrical and physical features associated with each AR. While the supervised kind of algorithms started analyzing them by extracting 66% AR from the overall set to check the intensity of the AR regions for the possible situations of solar storms and other emissions.

- ## Halo CMEs: -

Halo CMEs are responsible for the most severe geomagnetic storms. Hence predicting their effectiveness and travel time to Earth will be crucial for space weather. The assumptions of the cone model are such as the shape of HCMEs is an asymmetric cone and they propagate with constant angular widths and speeds, at least in their early phase. In an asymmetric cone model, the shape of CMEs is a cone but the cone cross section is an ellipse. The limb HCMEs appear as halo events only due to compression of pre-existing coronal plasma. Geo effectiveness of HCMEs depends not only on HCMEs speeds but also the direction of their propagation. The magnetic field direction at the front of the magnetic cloud determines to a large degree the geo effectiveness of events.

- ## Variation of Solar Corona Rotation: -

Coronal rotation has a different nature during the solar magnetic cycle as that of its neighbouring lower atmosphere layers; however, it is almost independent of the phases of the Solar magnetic cycle. Latitude dependent coronal rotation profiles with respect to increasing temperature or height, have no symmetric variation as observed in the case of solar interior. The chromosphere rotates 8% faster than the photosphere. Thus, the rotation rate increases with increasing temperature from photosphere to chromosphere. Considerable decreasing trend of average rotation rate from interior of the sun to outward photosphere. In this case the temperature decreases from solar interior to upward in the photosphere. Such observations are made by using the image datasets of SDO and AIA website.

- ## The Wave properties of Coronal Bright Fronts (CBFs) observed using SDO/AIA

CBF are large wavefronts that propagates through solar corona. These are first observed using the 195A^0 passband at a temp 1.2MK and heights above 70-90 Mm above the photosphere. CBFs remain an enigma with many competing theories attempting to explain this phenomenon. They have been interpreted MHD waves. Traditional analysis of CBFs has produced kinematics that are inconsistent with MHD wave theory.

But later the observation of deep learning CBFs combined with effects of low observing cadence suggest that this might not be the case. Also there has been indications of CBF dispersion with propagation. The Data volume produced by SDO/AIA is 1.5 tb /day which has made semi-automated and automated CBF detection and tracking algorithms essential.

- **Pulse broadening**

The temporal variation in full width at half maximum FWHM was examined for evidence of pulse broadening. The general expansion rate in each case is positive within error, which implies significant pulse broadening. Hence CBFs are dispersive pulse.

- **Temperature dependence**

The variation in initial velocity and acceleration of pulse was studied by making comparison with t peak (peak emission temperature) of different AIA passbands and it was found that CBF kinematics and tpeak for each passband are inversely related. Hence in cooler and denser plasma the CBF has a higher velocity, which makes CBF a compressive pulse and combined with dispersion and deceleration we can consider CBF to be a MHD wave.

- **Coronal seismology**

The pulse morphology is very much influenced by the plasma through which it propagates. On examining the effects of plasma on kinematics for each passband, it is possible to probe the physical characteristics of quiet coronal plasma through which the pulse propagates.

- *References-*

Babcock model Image -
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