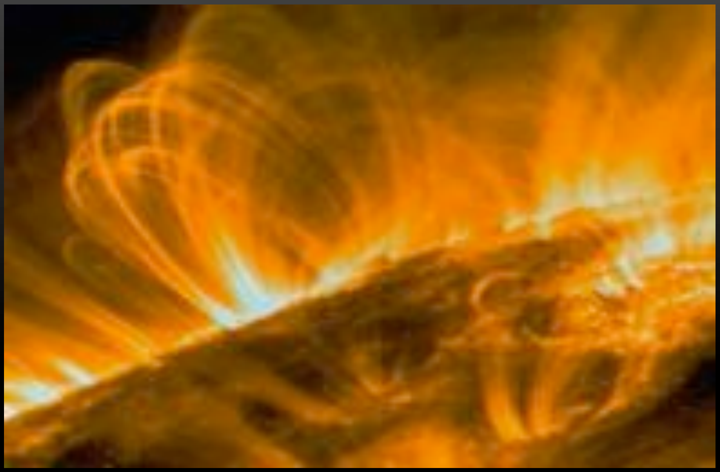

AUTOMATIC PREDICTION OF SOLAR FLARES USING A NEURAL NETWORK

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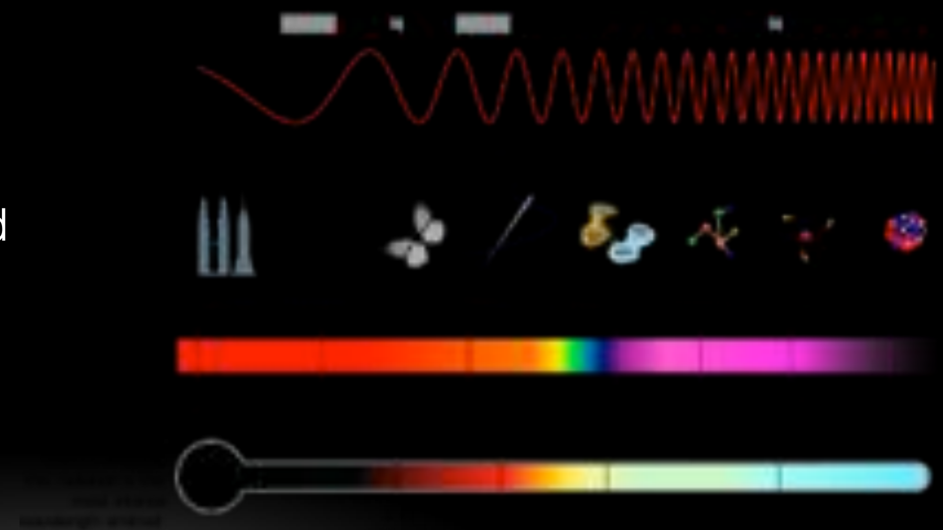
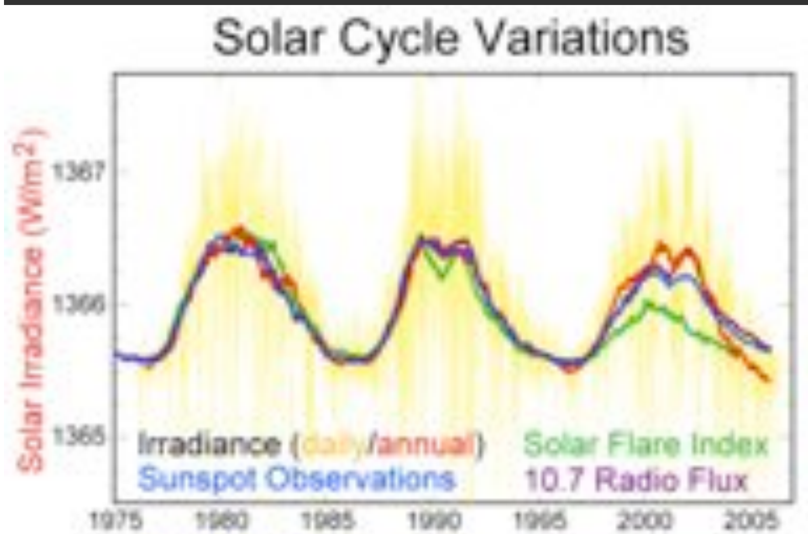
LASP

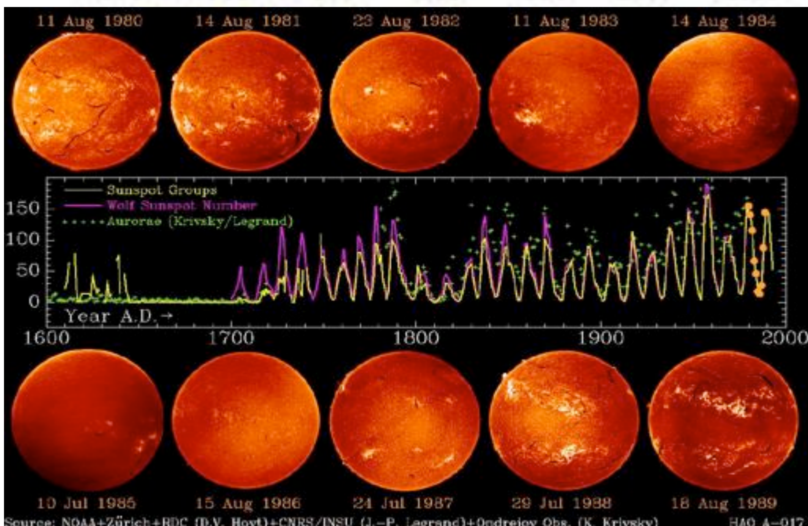
SOLAR FLARE

- A flare is defined as a sudden, rapid, and intense variation in brightness.
- A solar flare occurs when magnetic energy that has built up in the solar atmosphere is suddenly released. Radiation is emitted across virtually the entire electromagnetic spectrum, from radio waves at long wavelength end, through optical emission to x-rays and gamma rays at the short wavelength end.
- The first flare recorded in astronomical literature was on September 1, 1859.
- Occurred when two scientists observed sunspots.



SOLAR CYCLE



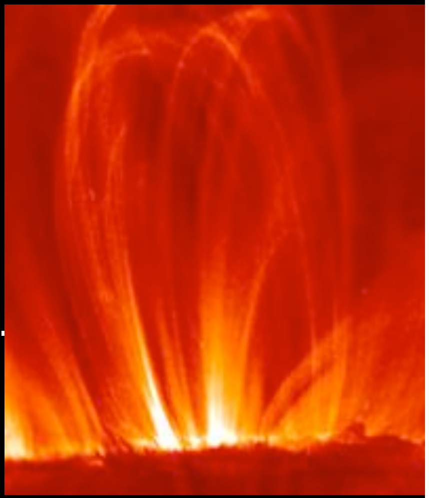


- The solar cycle has a period of about 11 years. It is inferred by scientists through the frequency and location of sunspots visible on the Sun.
- Ultimately, the Solar cycle is due to the eventual reversal of the polarity on the Sun.
- As a consequence of solar cycles, there is a periodic change in the amount of irradiation from the Sun that is experienced on earth.
- Consequently during solar maximums, the frequency of solar flares and coronal mass ejections rises.
- This is so because the Sun’s magnetic field structures its atmosphere and outer layers all the way through the corona and into the solar wind.
- The magnetic field is dictated by turbulent convection caused by the differential rotation of the Sun.
- Thus disconnection of magnetic field lines can give rise to a flare.

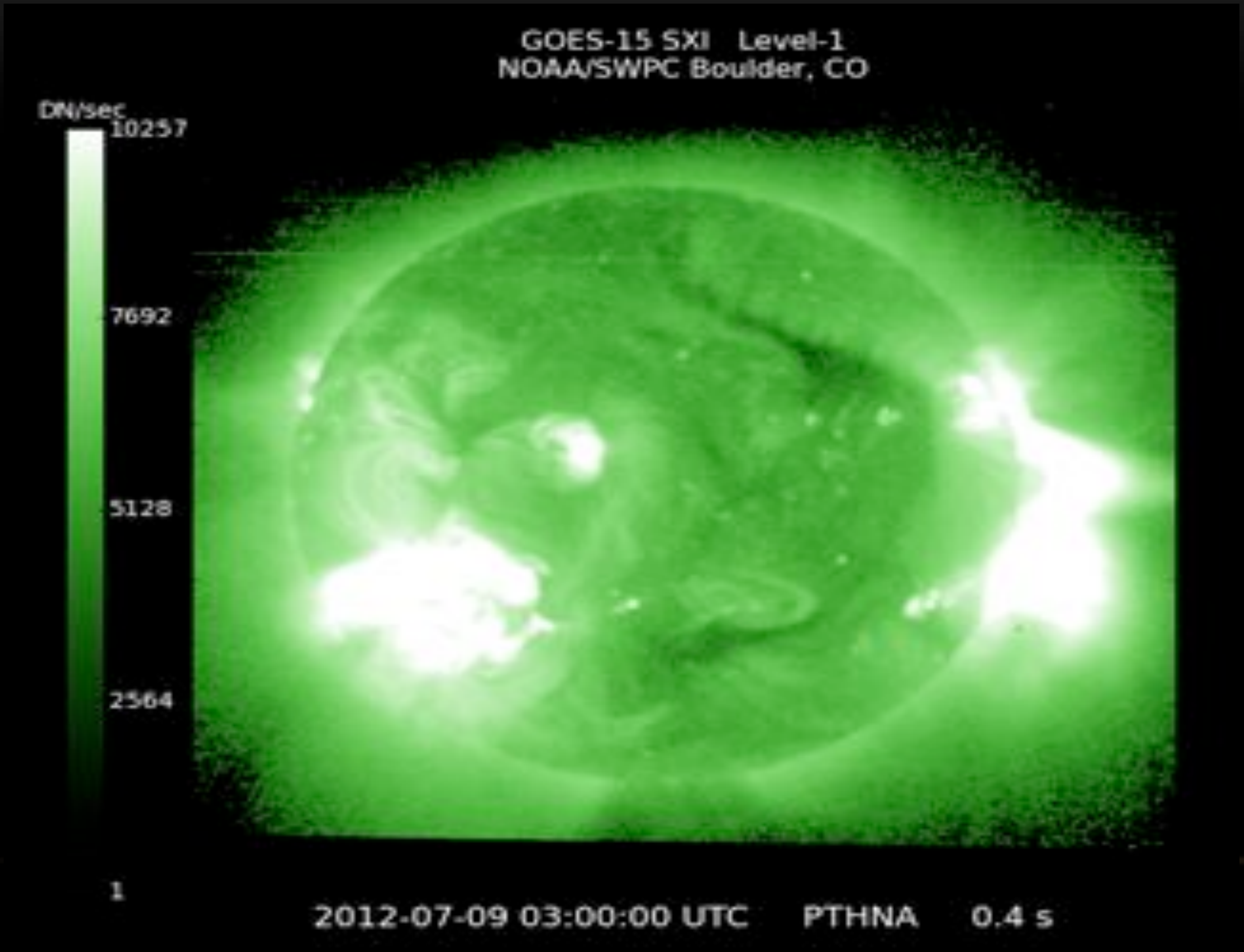
STAGES OF A FLARE

- There are usually three phases of a solar flare: the precursor stage, the impulsive stage, and the decay stage. These stages can be as short as a few seconds or as long as an hour.
- 1) Precursor stage: the release of magnetic energy is triggered. Soft X-Ray emission is detected in this stage.
- 2) Impulsive stage: protons and electrons are accelerated to energies exceeding 1 Mev. During this stage, radio waves, hard x-rays, and gamma rays are emitted.
- 3) Decay stage: the gradual build up and decay of soft x-rays.
- Throughout these stages, solar flares extend out to the corona.
- This is the outermost atmosphere of the Sun, consisting of highly rarefied

  gas. This gas normally has the temperature of a few million degree Kelvin.
- Inside a flare, the temperature usually reaches 10 or 20 million degree Kelvin.



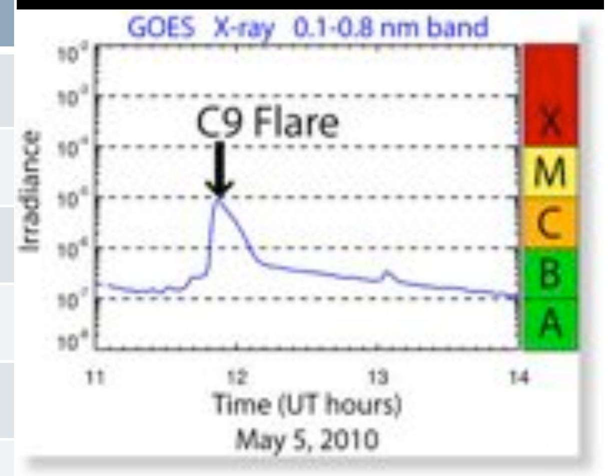
X-RAY IMAGE OF SOLAR FLARE



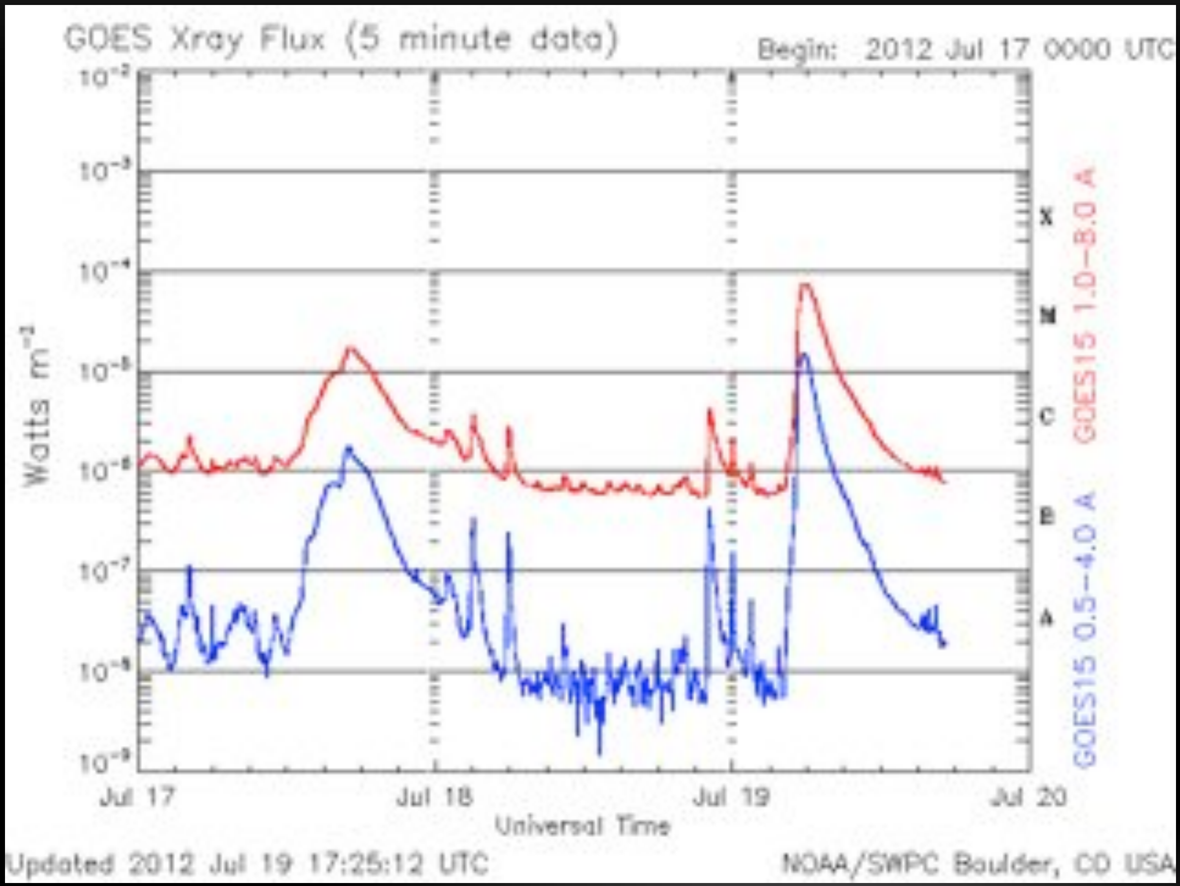
SOLAR CLASS

- Solar flares are classified A, B, C, M, or X according to peak flux in watts per square meter, W/m^2.

Classification	Watts/ Square Meter
A	<10^(-7)
B	10^(-7) – 10^(-6)
C	10^(-6) – 10^(-5)
M	10^(-5) – 10^(-4)
X	>10^(-4)



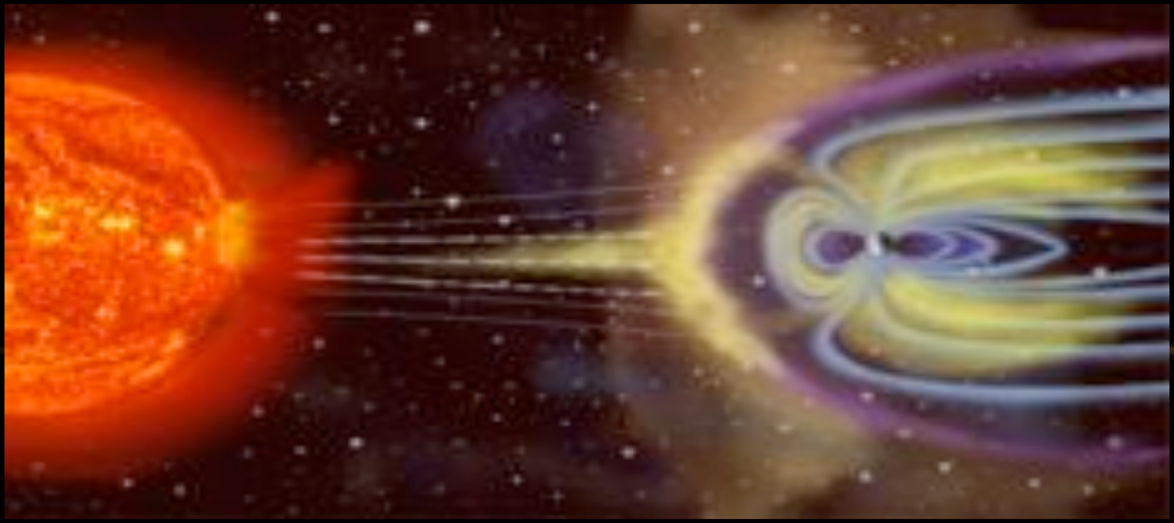
FLARE DATA



From this graph, we can infer solar irradiance, class of flare, and the time series for solar activity.

SOLAR FLARE EFFECTS ON EARTH

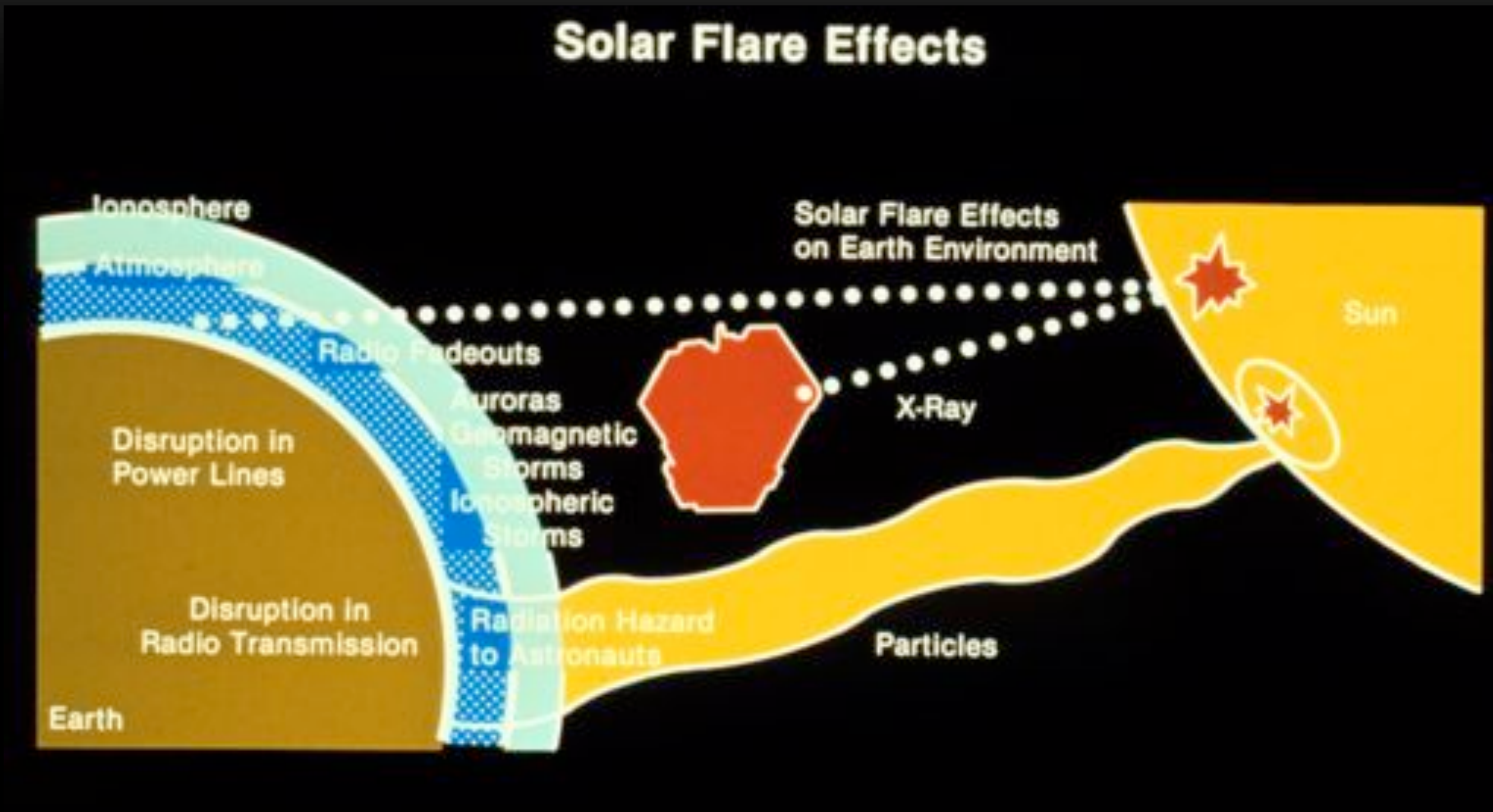
- Solar Flares can have an energy release up to 6 x 10^(25) Joules of Energy.
- X-Rays and UV radiation emitted buy these flares can affect the ionosphere of the earth and can create geomagnetic storms.
- When the plasma in the sun is heated to tens of millions of kelvins, electrons, protons, and heavier ions are accelerated to near the speed of light towards earth.
- This solar radiation is visible through the Aurora that occur near the poles.
- These storms of solar radiation interacting with our atmosphere can disrupt satellite communication, resource information, electrical power, and radar.



SOLAR FLARE EFFECTS EXTEND PAST TERRESTRIAL IMPACTS

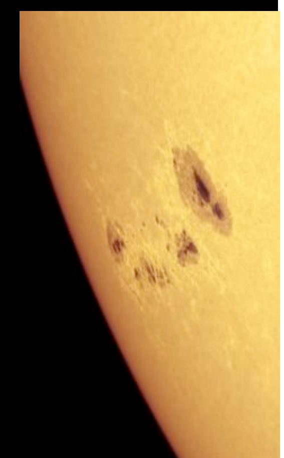
- Soft X-ray flux from X class flares can increase ionization of the upper atmosphere, which can interfere with short wave radio communication and add heat to the outer atmosphere. This can cause orbital decay, where a drag is increased on low orbiting satellites.
- Energy in the form of hard x-rays can also damage space craft electronics.
- Astronauts on missions to mars, the moon, and satellites around earth can also face the potential threat of energetic protons passing through the human body, causing biochemical damage.

HUMAN IMPACT



ACTIVE REGIONS

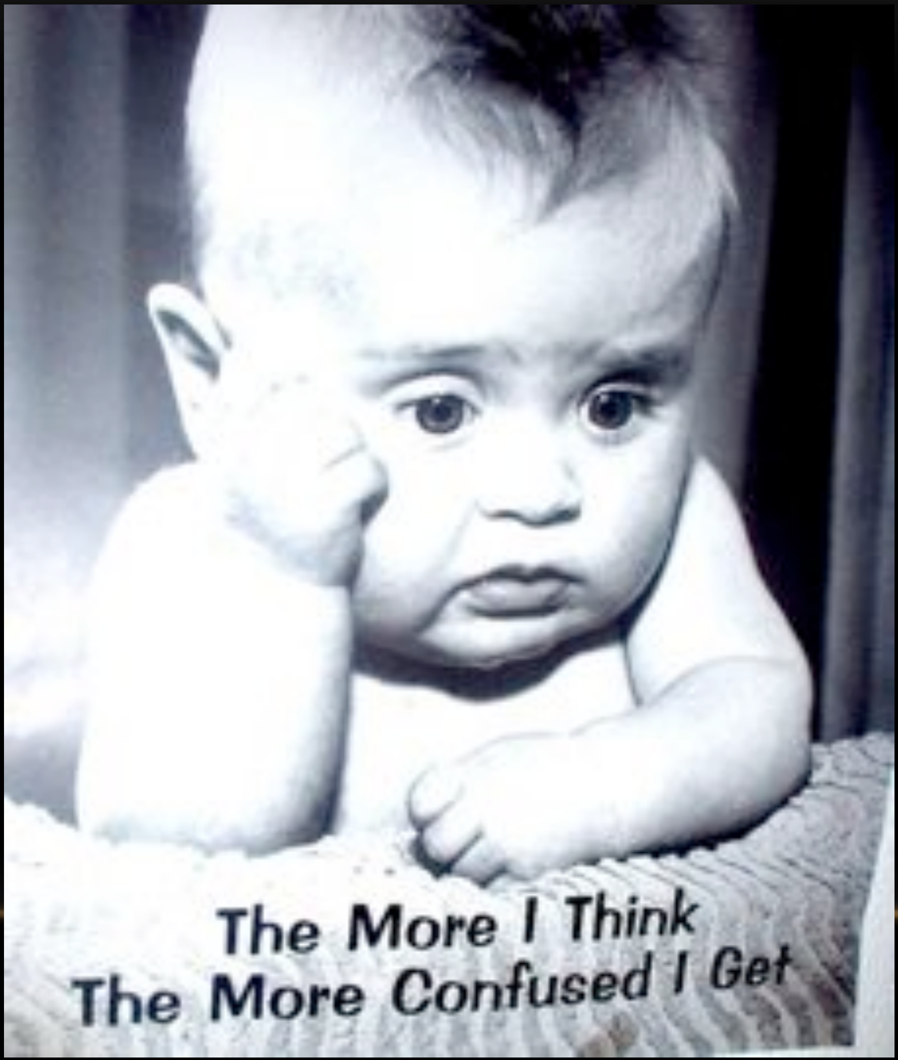
- During quiet sun phases of the solar cycle, solar flare activity is reduced
- While in the active phase, magnetic activity is at it's peak. During this abundance of magnetic activity, and due to the differential rotation of the sun, 'active regions' surface on the sun.
- As a result, sunspots appear that correspond to concentrated magnetic activity. From these regions of high magnetic activity, where intense magnetic fields penetrate the photosphere to link the corona to the solar interior, solar flares are birthed. The reconnection and eventual release of this magnetic field stored in the corona eventually produce these solar flares and eject them radially outward from the sun.



SPACECRAFT MISSIONS THAT MONITOR SOLAR ACTIVITY

- WIND- Global Geospace Science WIND satellite. Low frequency spectrometer to study solar winds and flares.
- **GOES- Geostationary Operational Environmental Satellite. Measures soft X-ray flux and classifies flares.**
- RHESSI- Reuvan Ramaty High Energy Solar Spectral Imager. Image solar flares in energetic photons from soft X-rays to gamma rays.
- SOHO- Solar and Heliospheric Observatory. Images in extreme UV.
- TRACE- Transition Region and Coronal Explorer. Images the solar corona and transition region at high angular and temporal resolution.
- **SDO- Solar Dynamics Observatory. Uses the Helioseismic and Magnetic Imager (HMI), the Atmospheric Imaging Assembly (AIA), and the Extreme Ultraviolet Variability Experiment (EVE).**
- HINODE- Launched by the Japan Aerospace Exploration Agency. Focuses on magnetic fields thought to be the source of solar flares.

SO WHERE DOES THAT LEAVE US IN TERMS OF PREDICTING SOLAR FLARES?



TECHNOLOGY HOLDS OUR ANSWERS

- Through the use of IDL (Interactive Data Language), Neuroph Studios (software that allows the user to create a neural network), and data from space crafts currently taking solar data we can harness the ability to automatically predict solar flares! (or at least try to)

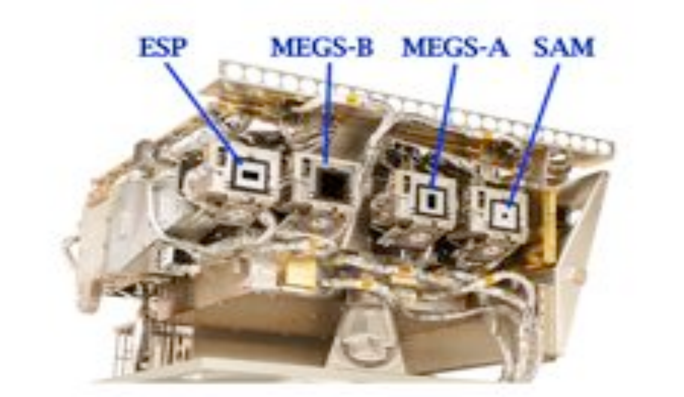
SO WHICH SATELLITES DO WE USE?

- In order to help us automatically predict solar flares, we will be using data from the GOES satellite and from SDO.
- GOES will provide us data pertaining to the magnetic activity and X-ray flux of the Sun.
- Specifically, the SDO instrument we will be using is the Extreme Ultraviolet Variability Experiment (EVE).
- Eve is designed to measure EUV irradiance. The EUV radiation includes the .1nm-105nm range, which provides the majority of the energy for heating Earth's thermosphere and creating Earth's ionosphere.
- On EVE are subsystems: MEGS and ESP. Megs is a multiple Euv Grating Spectrograph. MEGS-A: grazing incidence grating spectrograph from 5nm-37nm range.

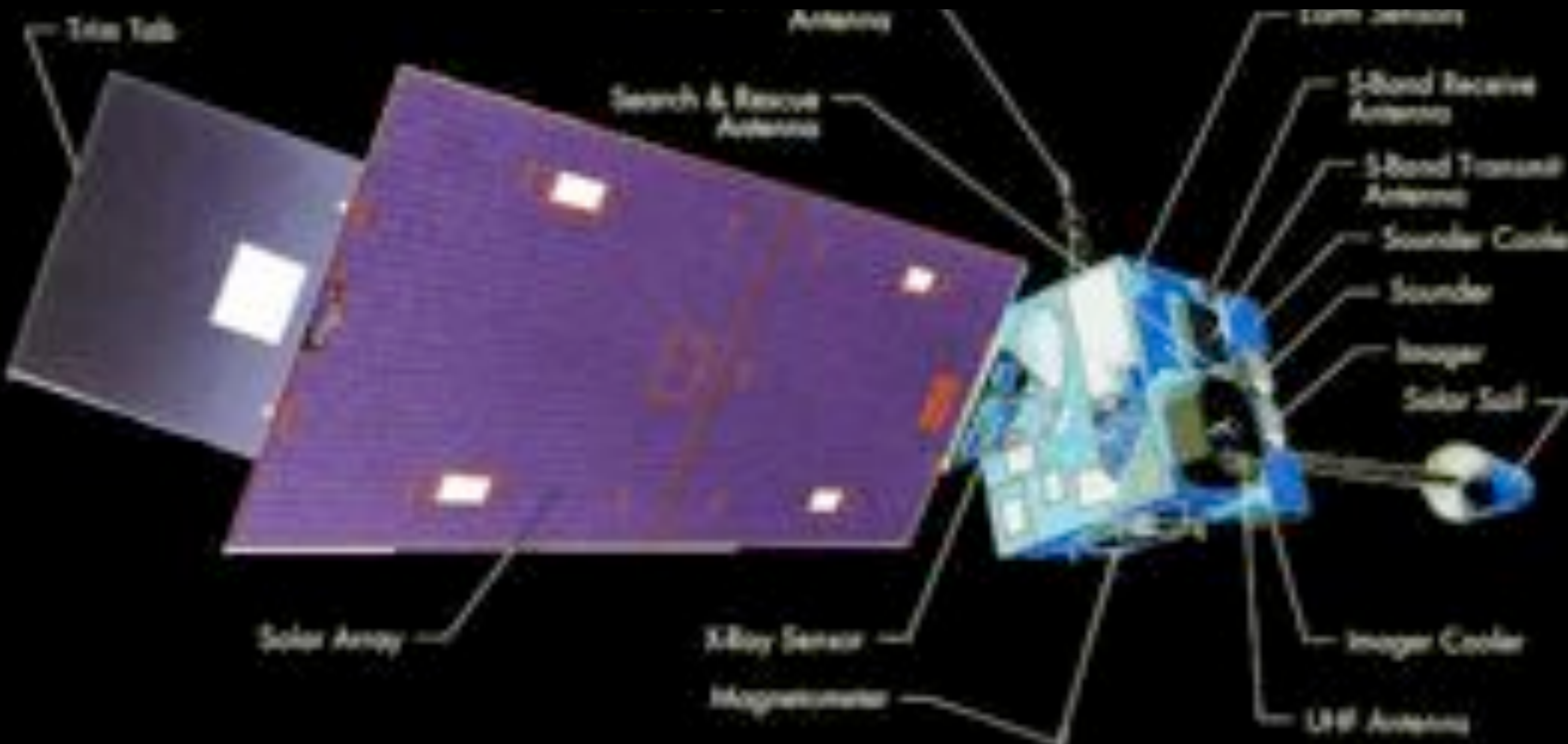
MEGS-B: double normal-incidence grating spectrograph for 35nm-105nm.

MEGS-SAM: pinhole camera used with MEGS-A CCD to measure individual X-Ray photons in .1nm-7nm range.

ESP- Euv SpectroPhotometer: transmission grating spectrograph that measures 4 bands in the 17-38nm range and also .1-7nm in zeroth order.



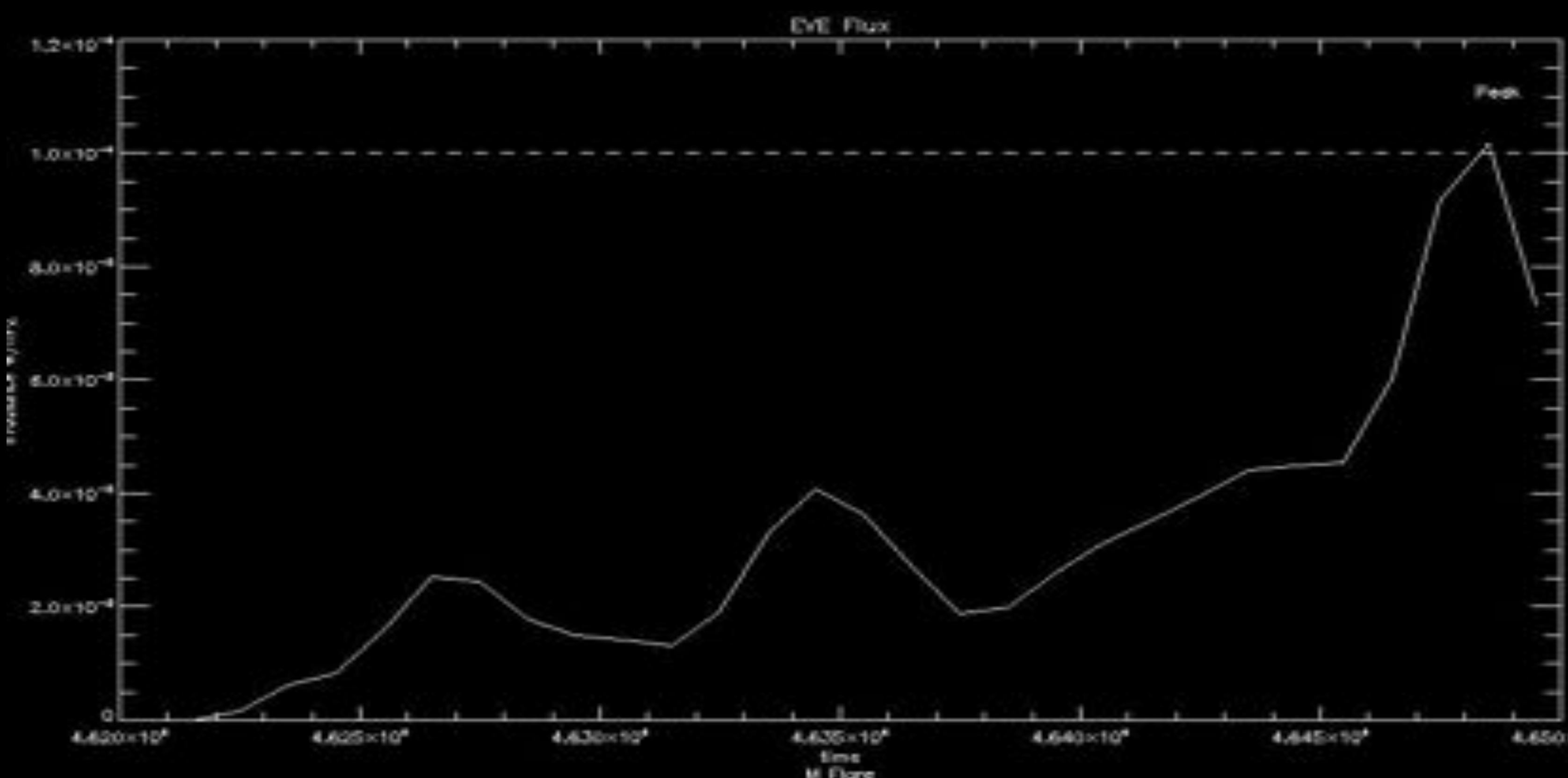
GOES

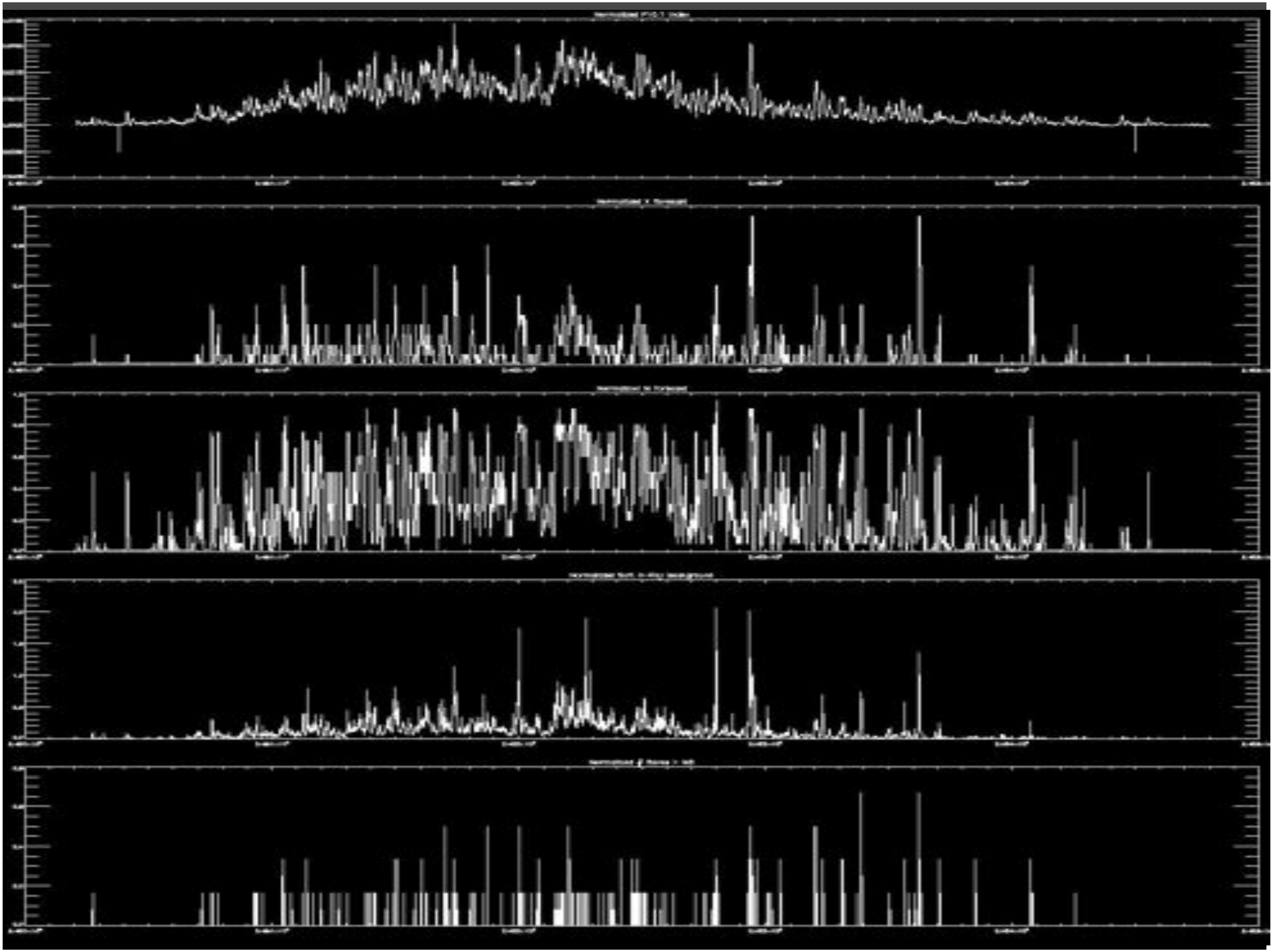

Trim Tab
Search & Rescue Antenna
S-Band Receive Antenna
S-Band Transmit Antenna
Sounder Cooler
Sounder
Imager
Solar Sail
Solar Array
X-Ray Sensor
Magnetometer
Imager Cooler
UHF Antenna

IDL

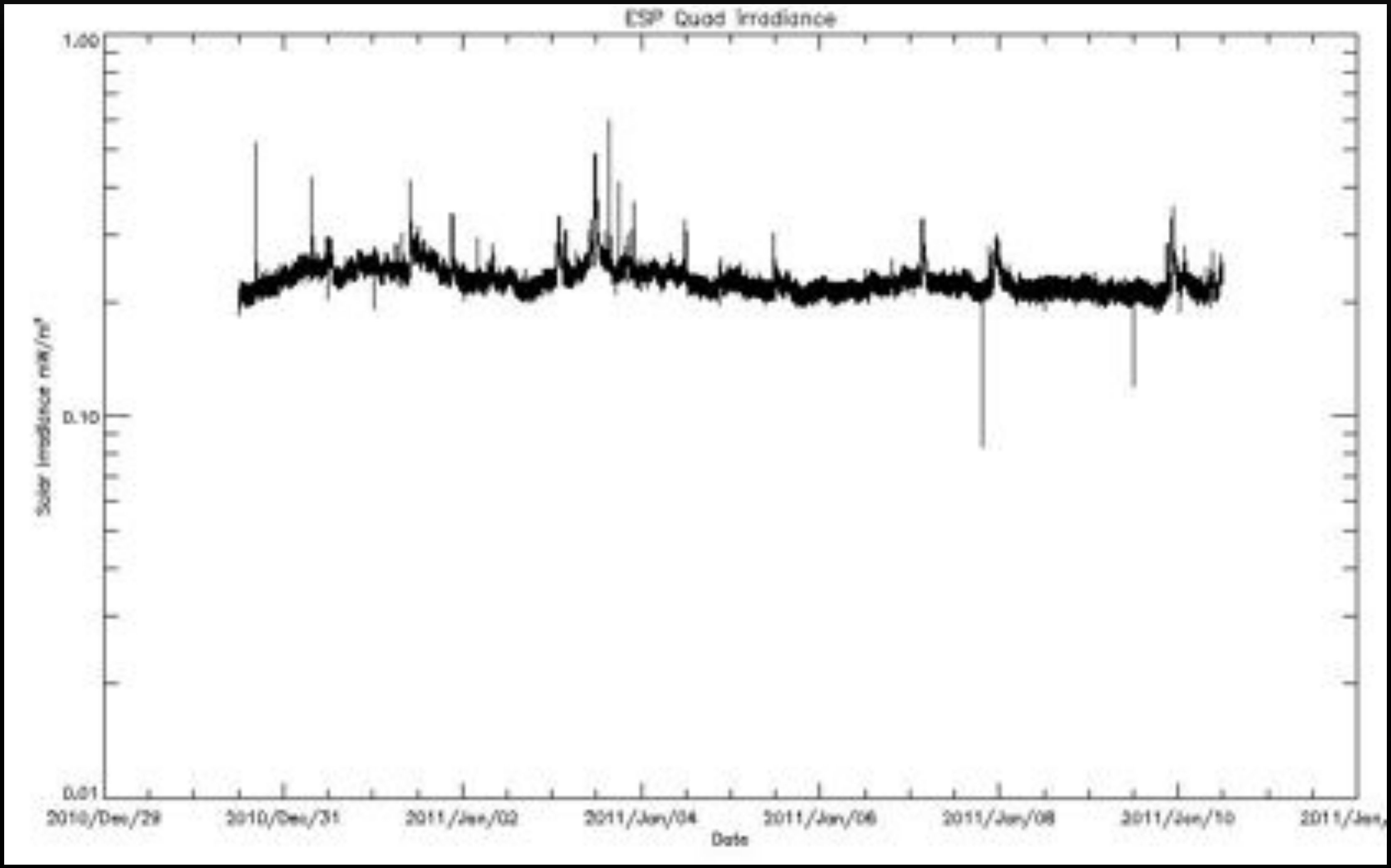
- IDL can offer valuable tools when classifying, analyzing, and presenting solar data.
- Being directly connected to the EVE and GOES data hub enabled efficient readings of daily solar data that could be later used within Neuroph Studios.

July 17, 2012

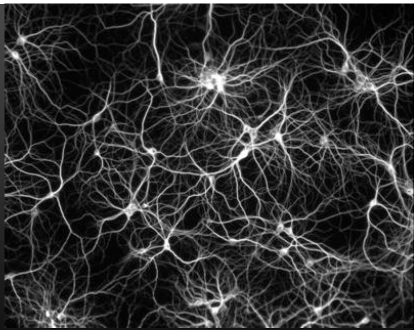




ESP QUAD IRRADIANCE



NEURAL NETWORK: WHAT IS IT?

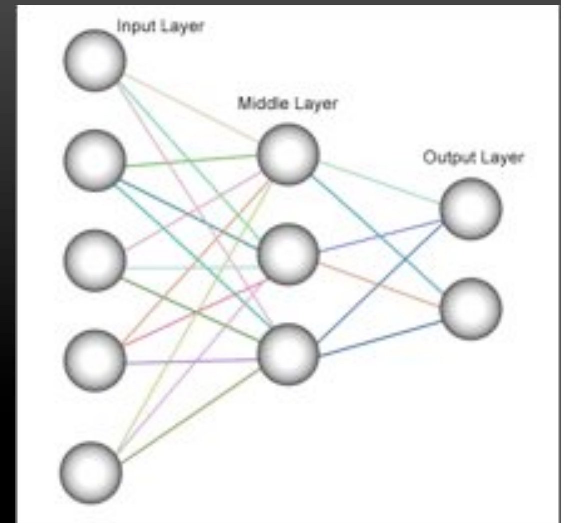


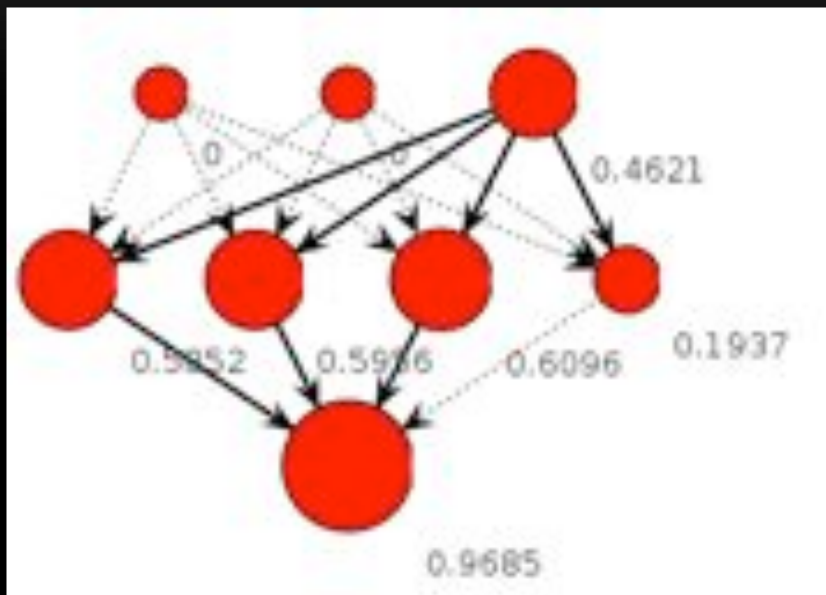
- Dr. Robert Hecht Nielsen, inventor of one of the first supercomputers, defines it as “ a computing system made up of a number of simple, highly interconnected processing elements, which process information by their dynamic state response to external inputs”.
- An Artificial Neural Network is a mathematical model that is inspired by the structure and functional aspects of biological neurons.
- There exists an interconnected group of artificial neurons, that process information through a connected series of computations.
- They are modeled by complex relationships between inputs and outputs to find patterns in data.
- An example system has three layers. The first layer has input neurons, which send data via synapses to the second ‘hidden’ layer of neurons, and then via more synapses to the third output layer of neurons. The synapses store parameters called ‘weights’ that manipulate the data in the calculations.
- Typically defined by 3 parameters: 1) The interconnection pattern between different layers of neurons, 2) The learning process for updating weights and interconnections, and 3) The activation function that converts a neuron’s weighted input to its output activation.
- IBM software engineers reference that “ it may be the future of computing”.

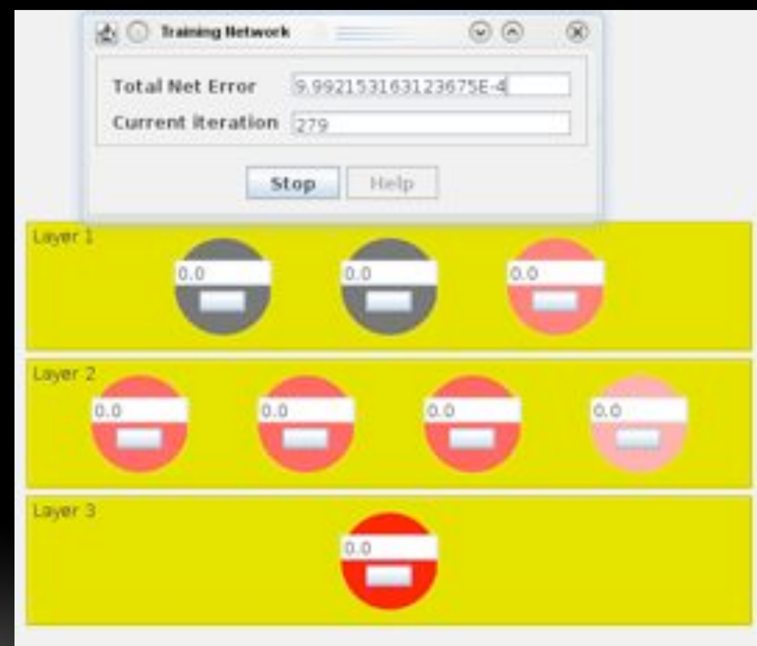
SAY WHAT?

- According to a simplified account, the human brain consists of 10 billion neurons. And a neuron, on average, is connected to several thousand other neurons.
- By way of these connections, neurons both send and receive varying quantities of energy. Yet, they don't instantly react to this flux of energy.
- Rather, they sum their received energies, and send their own quantities of energy to other neurons only when this sum has reached a certain critical threshold.
- The brain learns by adjusting the number and strength of these connections.
- This is a simple representation of biological occurrences, yet is powerful in modeling the artificial neural network.

NEURAL NETWORK!

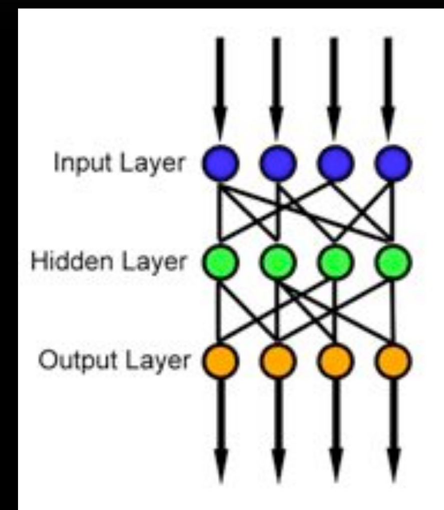


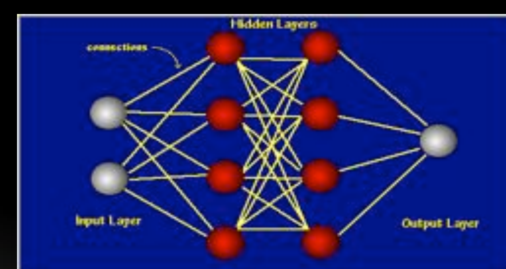




WHAT TYPE OF NEURAL NETWORK IS IDEAL FOR PREDICTIONS OF SOLAR FLARES?

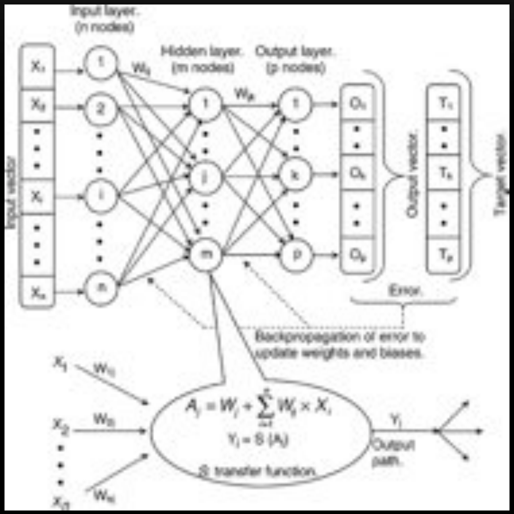
- Initially considered for this model was a feed forward neural network. Essentially, this means connections between units do not form a directed cycle.
- Back-propagation is more useful in our case. With back propagation, the input data is repeatedly presented to the neural network. With each presentation the output of the neural network is compared to the desired output and an error is computed. This error is then fed back (back propagated) to the neural network and used to adjust the weights such that the error decreases with each iteration and the neural mode gets closer and closer to producing the desired out put. This process is known as “training”.
- Essentially, it simply requires a data set of the desired output for many inputs, making up a training set. Within the training set, a learning rule updates the weights of the artificial neurons.

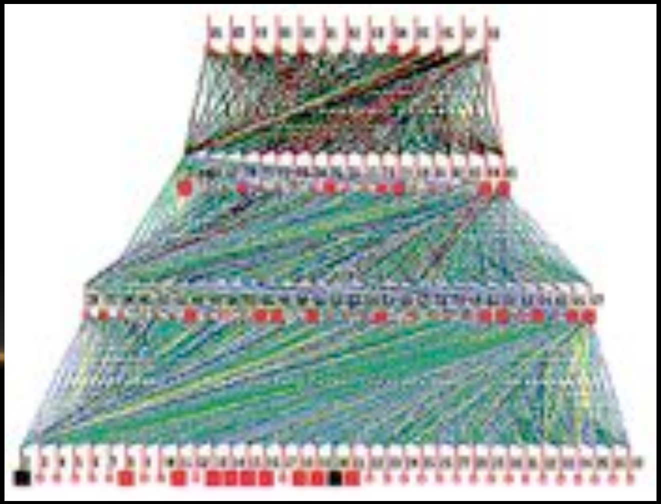




ADDITIONAL ARCHITECTURAL WORK

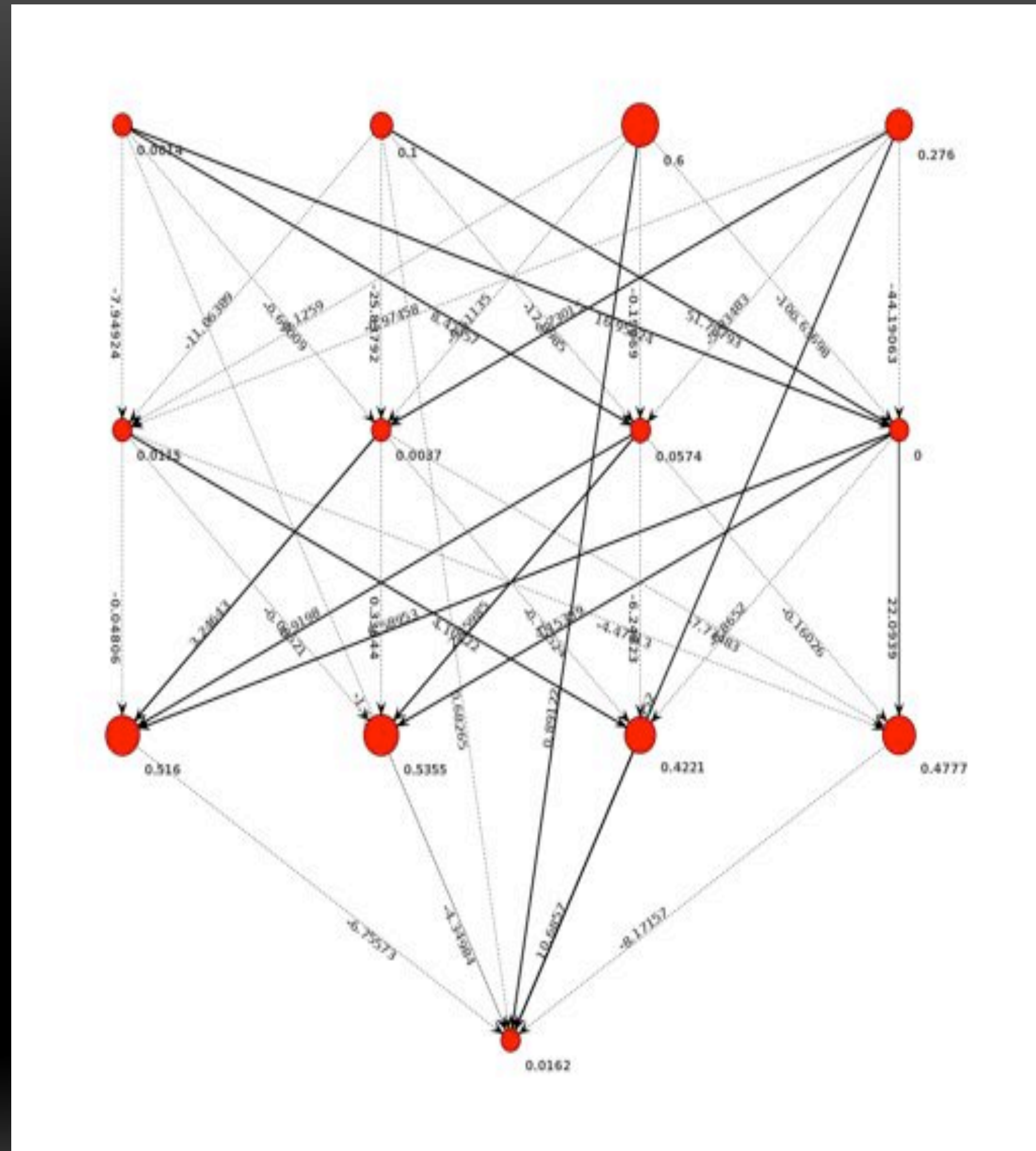
- The learning rate is one of the parameters that governs how fast a neural network learns and how effective the training is. Essentially it is the “size” of the steps the algorithm will take when minimizing the error function in an iterative process.
- “Weights” are used to change the parameters of the throughput and the carrying connections to the neurons.





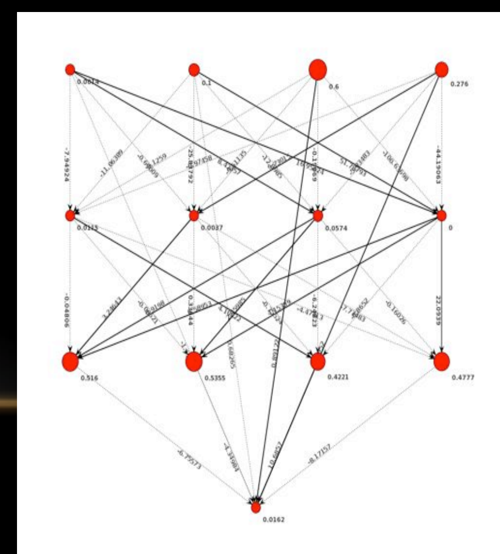
ACTUAL NETWORK

- This was an actual Neural Network trained with data from GOES.
- Training for flares greater than M5
- Supervised learning was used, which just means that each neuron consists of an input object and a desired output value. This learning algorithm, analyzes data and produces an inferred functioned, called a classifier.
- The data inputs were F-10.7 Radio Flux, X-forecast, M-forecast, and soft X-ray background (in that order), from May, 5th, 1996 to Jan 1st, 2008.
- The Data values for the inputs were normalized within IDL because the network only accepted values between 0 and 1.
- This was done by finding minimum and maximum values of the array (getting the minimum to zero and the maximum to 1).

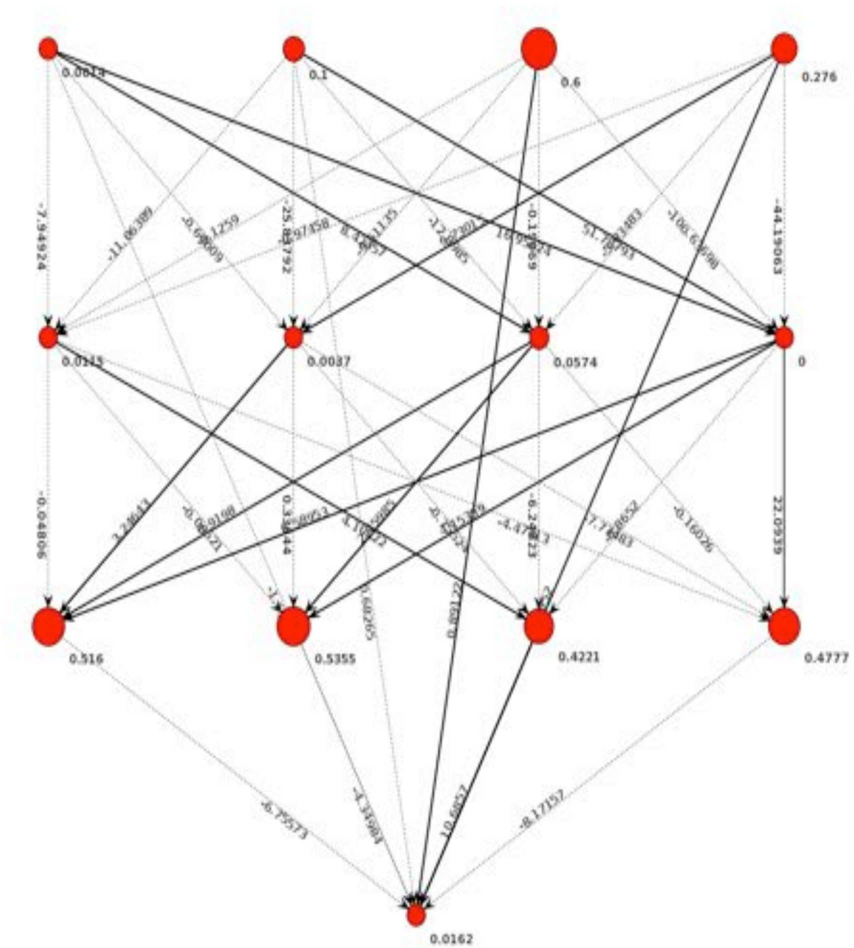


ACTUAL NETWORK PART 2

- The simplest way to describe this system: The inputs are fed into the input layer and get multiplied by interconnection weights as they are passed from the input layer to the first hidden layer. Within the first hidden later, they get summed then processed by a nonlinear function (Sigmoid function in our case but it can be a hyperbolic tangent). Sigmoid functions are ideal for making sure signals remain within a specified range.
- As the processed data leaves the first hidden later, again it gets multiplied by interconnection weights, then summed and processed by the second hidden higher layer.
- Finally the data is multiplied by interconnection weights then processed one last time within the output later to produce the neural network output.



ACTUAL NETWORK PART 3

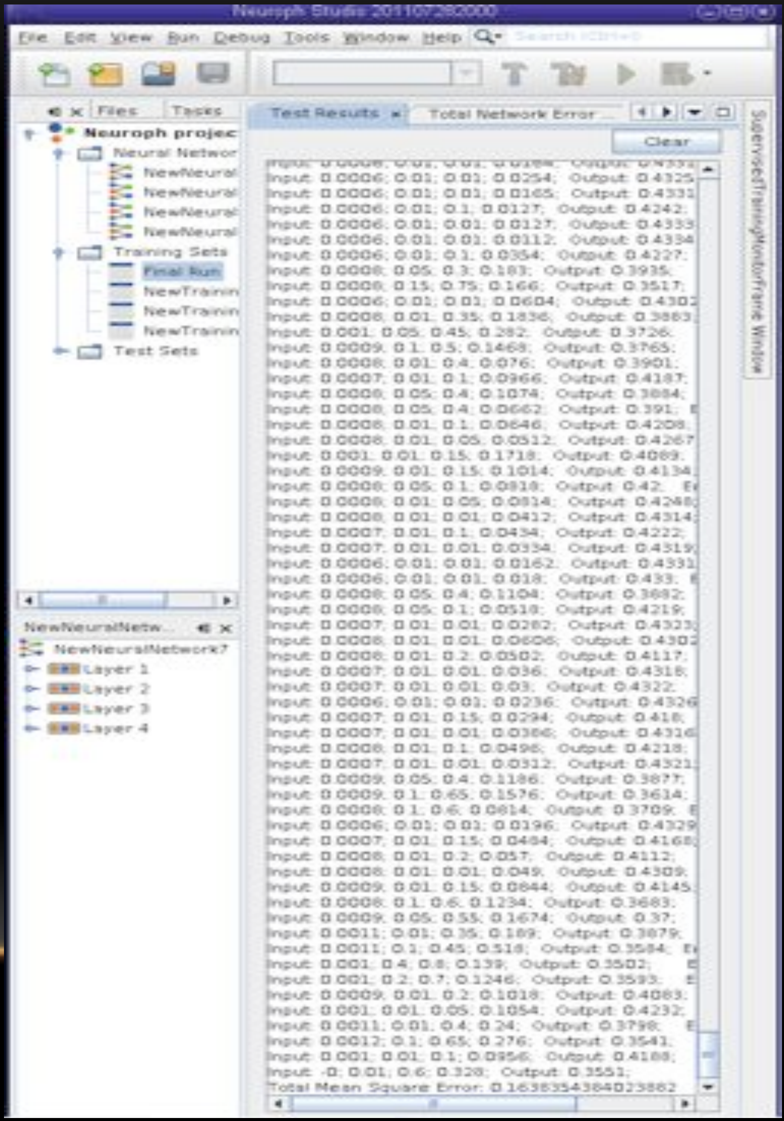


- There were roughly 5,647 data points.
- The addition of a second hidden layer allows more connections.
- This improved correlation of input combinations and allowed the network to be trained easier.
- The output value is the trained value, the number we are training to.
- .008 was the max error chosen.
- This means that the permit table error for the trained values is .08%, yet almost all flare values we were training were near zero for normalization.
- Improvements will be considered later on.

TEST

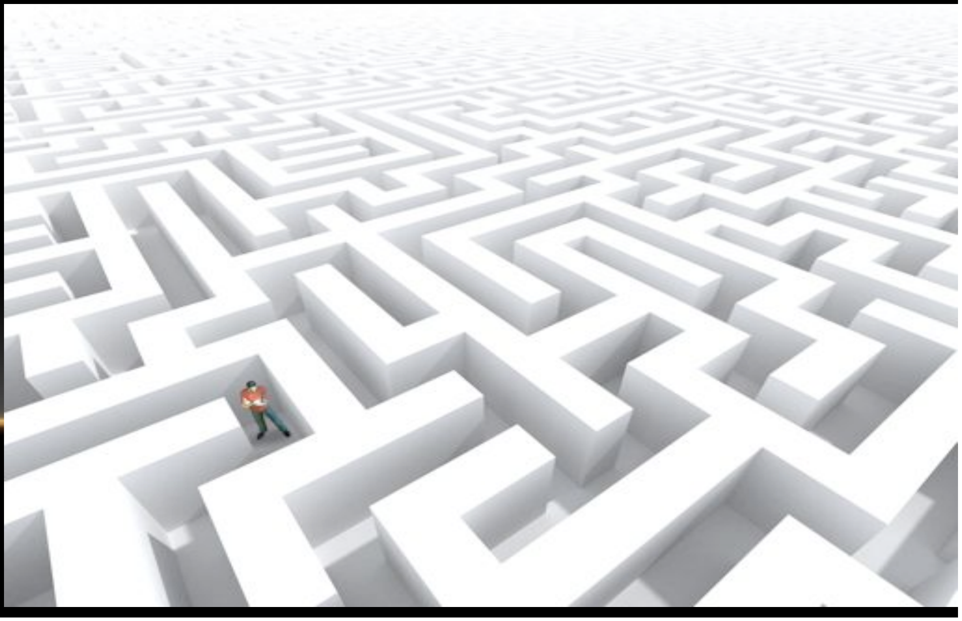
- Small snippet of the data shows how immense The calculations are when actually running the Network through a simulation.

- The connection weights are also modified every time the network doesn't show the desired behavior.



LIMITATIONS?

- In reference to back-propagational networks there are some specific issues to be aware of:
- These neural networks are sometimes seen as black boxes. Aside from defining general architecture of the network and initially seeding it with random sets of data, the user has no other role than to feed it input and to watch it train and await the output.
- Many online references state in relation to back-propogation that, “you almost don’t know what you’re doing”. The learning itself progresses on it’s own.
- The final product of this process is a trained network that provides no equations or coefficients or pretty plots defining a relationship beyond its’ own internal mathematics. The network IS the final equation in the system.



WAIT, MORE COMPLICATIONS??

- Back-propogational networks also tend to be slower than other types of networks and can often require thousands of steps.
- If being run on a truly parallel computing system (ie. supercomputers that may run many calculations simultaneously) then running the network is not really a problem.
- However, when using standard serial machines (Macs and PCS) training may take quite a while. This is due to the fact that the machines CPU must complete each function of each node and connection separately, which can be problematic in massive networks with an abundance of data. This can be a problem if we want to feed the network every minute or so to predict flares.

HOPE IS NOT LOST

- Artificial Neural Networks can provide an analytical alternative to standard techniques which are usually inhibited by strict assumptions of normality, linearity, and variable dependence.
- Because ANN can take in many kinds of relationships it allows user to model, relatively easily, phenomena which otherwise may have been very difficult or impossible to explain otherwise.
- Can be used for: character recognition,

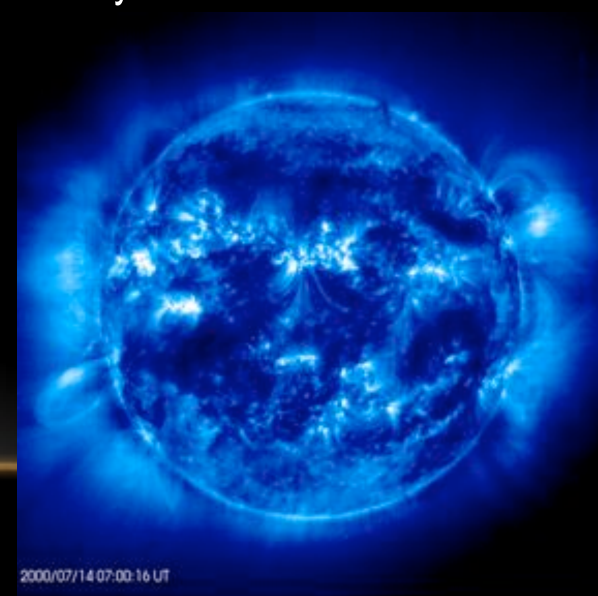
breast cancer categorization,

stock market prediction,

etc…

CONCLUSIONS

- The Artificial Network constructed is a starting step towards a much larger project.
- Training methods may need to be further optimized to more accurately filter out data that not be useful to the network.
- We could possibly utilize image processing to characterize active regions, which can reveal concentration of magnetic activity. As a result, the network may be able to perform ‘local’ forecasting about the possibilities of an individual or group of regions producing large flares.
- A larger training set may be more ideal
- Other factors, such as temperature, spectral range, and magneto-grams may be used to further the parameters that characterize a solar flare.
- These may assist in the accuracy and efficiency of predicting flares.




THE END

SOURCES

- http://www.swpc.noaa.gov/SWN/index.html
- http://hesperia.gsfc.nasa.gov/sftheory/flare.htm
- http://en.wikipedia.org/wiki/Solar_flare
- http://lasp.colorado.edu/home/eve/science/instrument/
- http://en.wikipedia.org/wiki/Artificial_neural_network
- http://en.wikipedia.org/wiki/Solar_cycle
- http://www.astropa.unipa.it/~orlando/INTRO_SUN/slide17.html
- http://pages.cs.wisc.edu/~bolo/shipyard/neural/local.html
- http://www.ibm.com/developerworks/library/l-neural/
- Neuroph.sourceforge.net
- http://www.nd.com/neurosolutions/products/ns/whatisNN.html