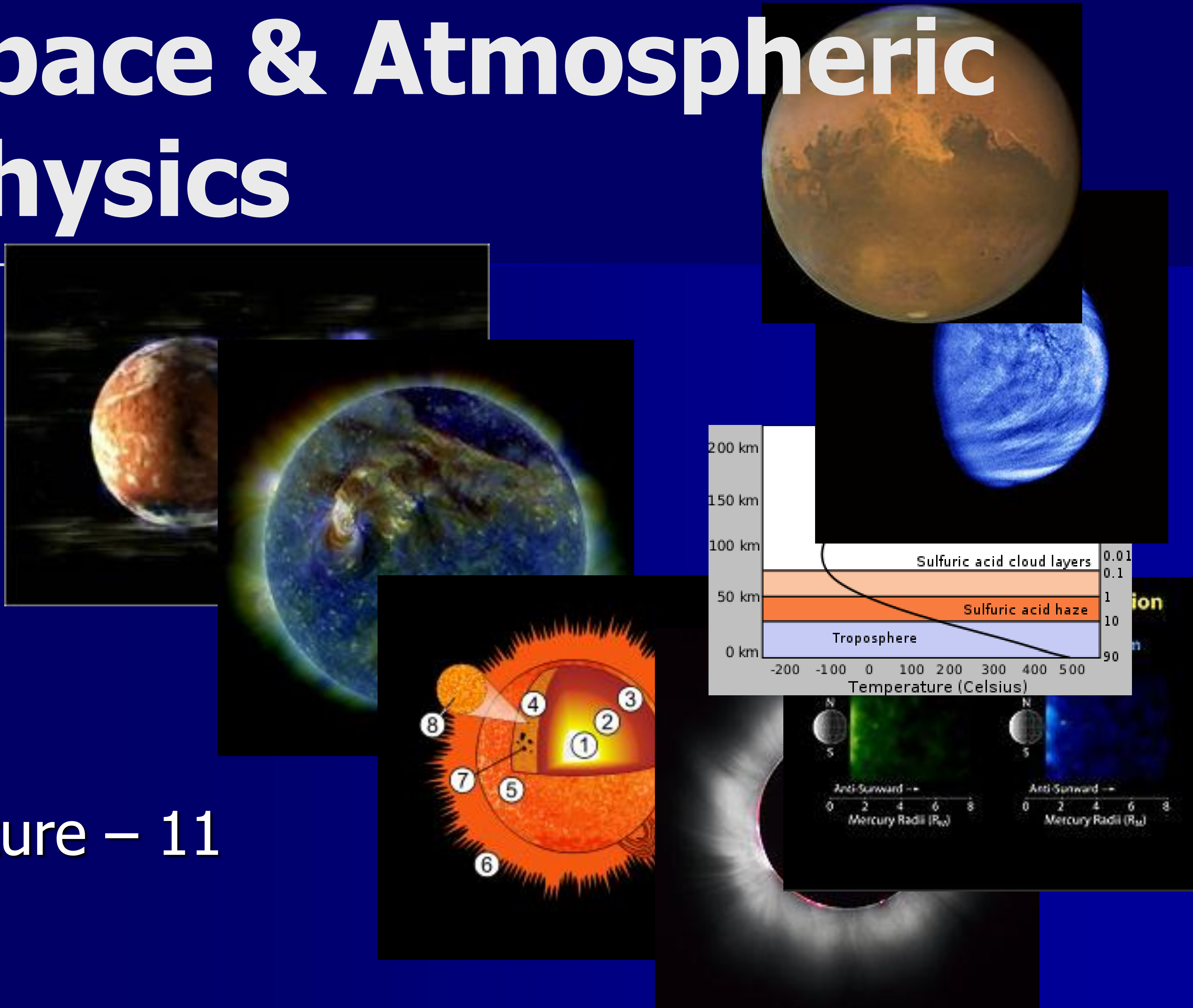
Space Physics

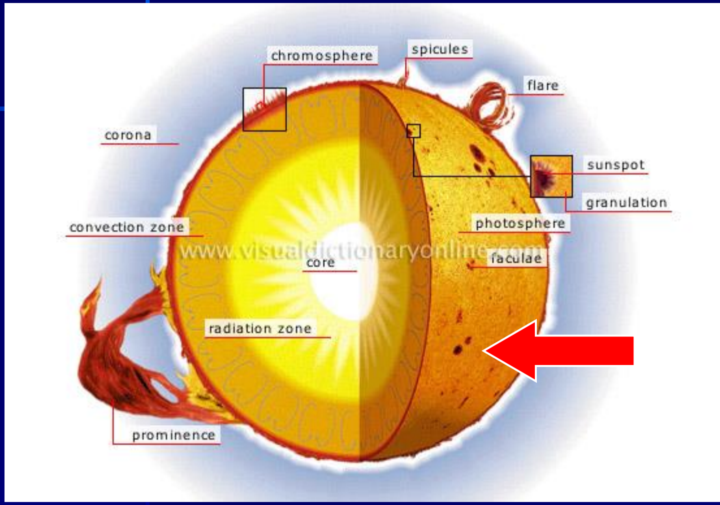
Space & Atmospheric Physics



Lecture – 11

The Structure of the Sun

The photosphere



The photosphere is the layer of the Sun from which we receive practically all of the **optical emission**. One can think of it as a luminous shell at a glowing temperature of nearly 6000 K. The width of the solar photosphere is determined not by any physical boundaries, but by the degree to which each layer of the solar atmosphere is transparent or opaque to the optical rays.

The region above the photosphere is practically transparent to the optical rays which originate in the photosphere. **On the contrary** (against) **the layers below the photosphere are opaque and therefore not accessible to optical observations**.

The thickness of the solar photosphere in white light is only of the **order of several hundred kilometers**, i.e. less than 0.1% of the radius of the Sun. Hence the photosphere, which emits practically **all of the visible solar radiation**, is an **extremely thin layer of the Sun**.

The Structure of the Sun

The photosphere

The energy emitted by the photosphere is produced in the core of the Sun through the conversion of hydrogen to helium and is transferred to the bottom of the photosphere by convection. Inside the photosphere, the energy passes from layer to layer in the form of radiation (radiative transfer) which at the temperature and density of the photosphere in a mush more effective process than convective transfer.

The relation, which describes this entire process is called the **equation of radioactive transfer**. In the solar photosphere, most of energy absorbed in the optical domain is used for freeing electrons which are attached to neutral hydrogen atoms. This is called **negative ion absorption**,

$$H^- + hf = H + e^-$$

and the corresponding absorption coefficient $\varkappa_f$ varies by less than a factor of 2 over the entire optical region of the spectrum where most of the solar radiation is emitted.

The Structure of the Sun

The photosphere

It is also justified to assume that the solar photosphere is in both local thermodynamic equilibrium and radiative equilibrium so that the solution of the equation of radiative transfer is given by the **Eddington approximation**,

$$I(\theta, 0) = \frac{\sigma T_e^4}{2\pi}\left(1 + \frac{3}{2}\cos\theta\right)$$

Where $I(\theta,0)$ is the intensity of the solar radiation emited from the top of the photosphere ($\tau=0$) at an angle θ to the verticle. T_e is the effective temperature of the Sun. **Above equation shows that $I(\theta,0)$ will decrease as θ varies from 0° to 90°**. (Because $\cos\theta$ is decreasing when θ is increasing from **0° to 90°**)

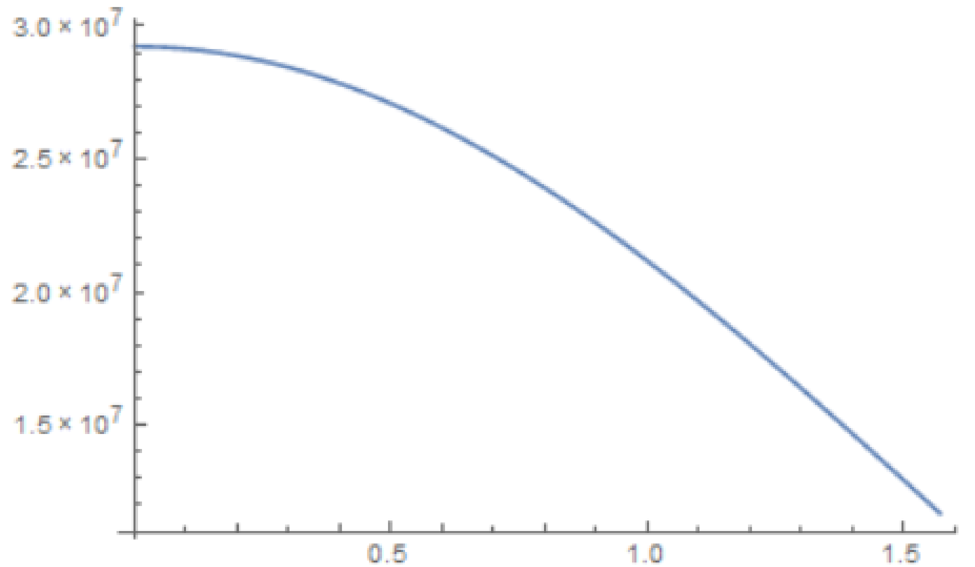
P. T. O.

The Structure of the Sun

```
In[15]:= sig = 5.6704×10^-8;
         te = 6000;
         it = ((sig*(te)^4)/(2*Pi))*(1+(3/2)*Cos[t])
         Plot[it, {t, 0, Pi/2}]
```

Out[17]= $1.1696\times10^{7}\left(1+\frac{3\,\mathrm{Cos}[t]}{2}\right)$

Out[18]=



The relative magnitude of $I(\theta,0)$ with respect to the intensity at the center of the Solar disk $I(0,0)$ is given by,

$$\frac{I(\theta,0)}{I(0,0)}=\frac{\frac{\sigma\,T_e^4}{2\,\pi}\left(1+\frac{3}{2}\cos\theta\right)}{\frac{\sigma\,T_e^4}{2\,\pi}\left(1+\frac{3}{2}\cos 0\right)}$$

The Structure of the Sun

The photosphere

The relative magnitude of $I(\theta,0)$ with respect to the intensity at the center of the Solar disk $I(0,0)$ is given by,

$$\frac{I(\theta,0)}{I(0,0)} = \frac{\frac{\sigma T_e^4}{2\pi}\left(1+\frac{3}{2}\cos\theta\right)}{\frac{\sigma T_e^4}{2\pi}\left(1+\frac{3}{2}\cos 0\right)}$$

$$\frac{I(\theta,0)}{I(0,0)} = \frac{2}{5}+\frac{3}{5}\cos\theta$$

$$\frac{I(\theta,0)}{I(0,0)} = 1-\frac{3}{5}+\frac{3}{5}\cos\theta$$

$u = \frac{3}{5}$ =0.6

$$\frac{I(\theta,0)}{I(0,0)} = 1-u+u\cos\theta$$

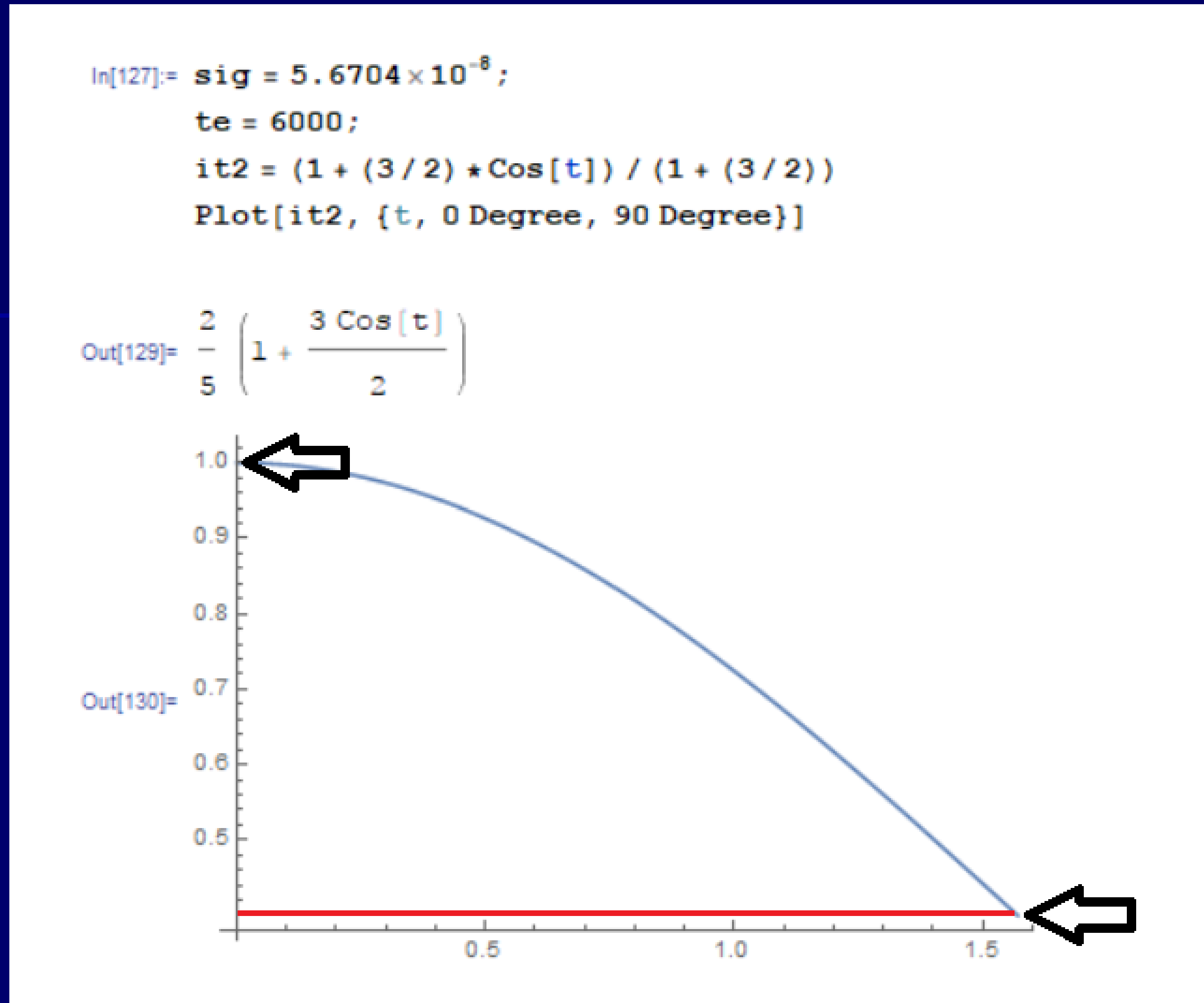
If $\theta = 0$, then $$\frac{I(\theta,0)}{I(0,0)} = 1-u+u\cos 0$$

$$\frac{I(\theta,0)}{I(0,0)} = 1$$

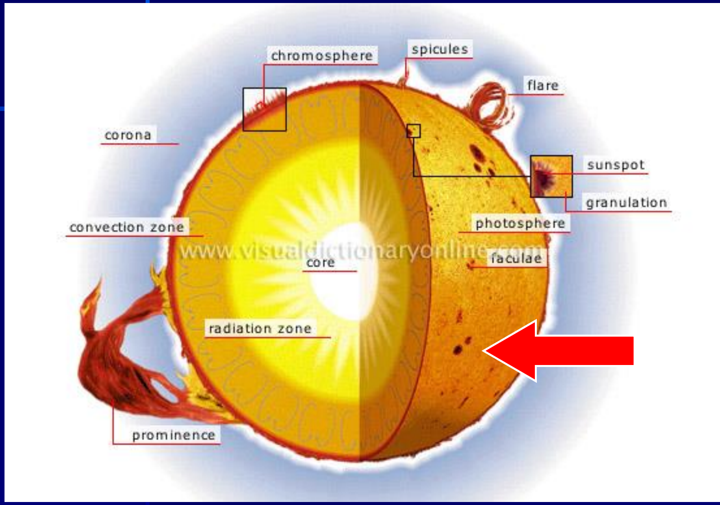
If $\theta = 90°$, then $$\frac{I(\theta,0)}{I(0,0)} = 1-u+u\cos 90°$$

$$\frac{I(\theta,0)}{I(0,0)} = 1-u = 0.4$$

The Structure of the Sun



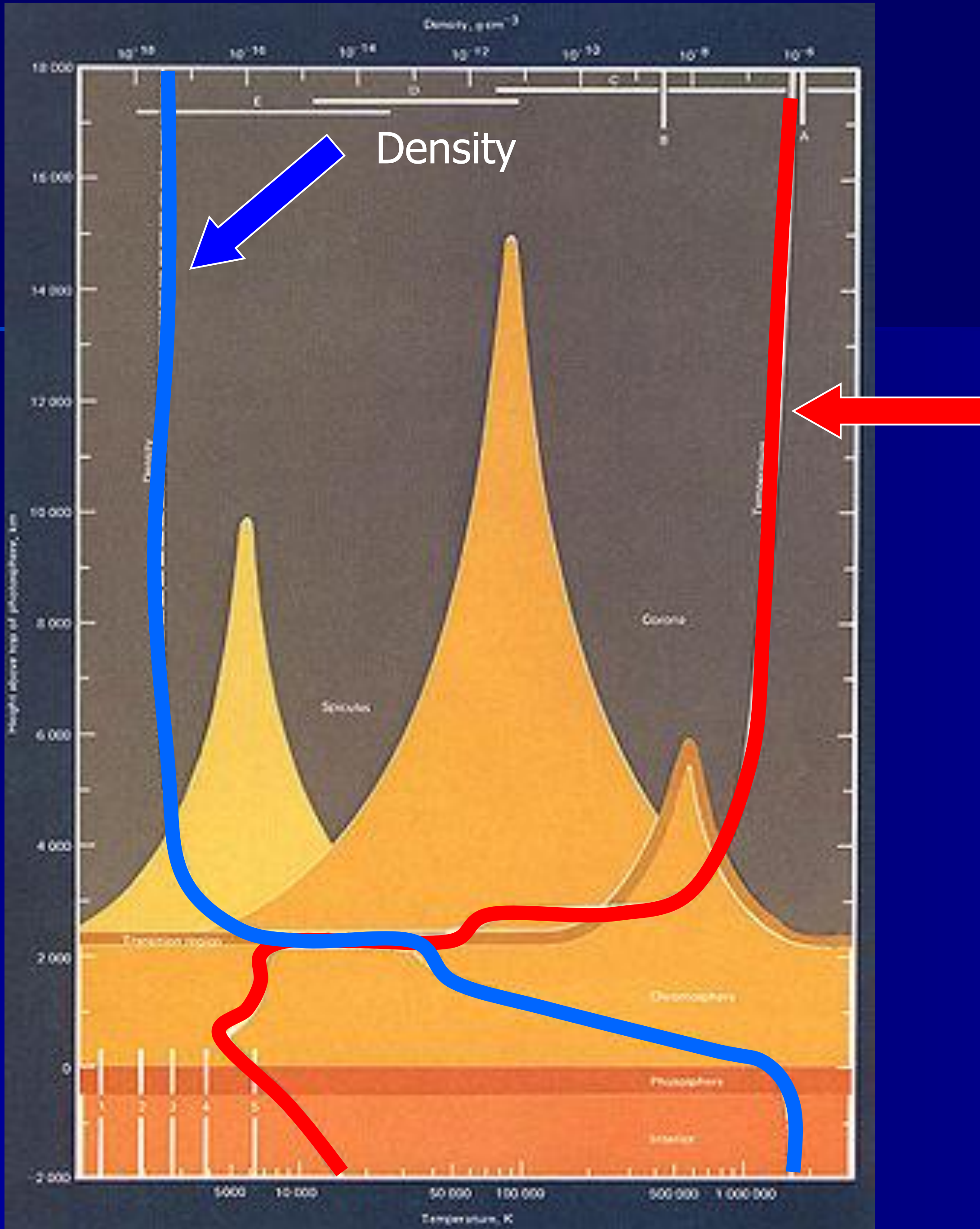
The above equation says that, the **Sun is brighter at the center of the disk** (θ=0°) **than at the limb** (θ=90°) **where it loses more than half of its brightness.** This phenomenon is called **"limb darking"**.



Photospheric composition (by mass)

Hydrogen	73.46%
Helium	24.85%
Oxygen	0.77%
Carbon	0.29%
Iron	0.16%
Sulfur	0.12%
Neon	0.12%
Nitrogen	0.09%
Silicon	0.07%
Magnesium	0.05%

Temperature and density of the Sun's atmosphere

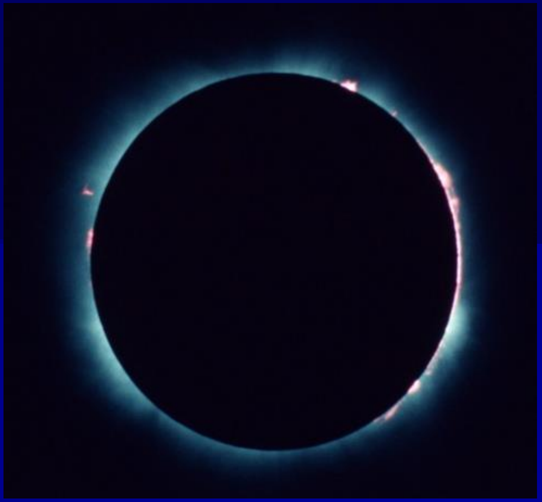


The Structure of the Sun

The Chromosphere and the Corona

The Structure of the Sun

The Chromosphere and the Corona



The region above the photosphere is called the chromosphere, which in Greek means the "**color-sphere**". This name comes from the **Red color** of the chromosphere which is due to the predominance (sight strongly) of **H–alpha line of hydrogen** (The first Balmer line at 6563 Å). The chromosphere is approximately 10000 km thick and **becomes visible only a few moments before totality during a total eclipse of the Sun**. As we have seen, the **effective temperature of the Sun (5750 K) occurs at r=2/3, i.e. approximately 100km below the surface of the photosphere**. At the top of the photosphere, the temperature drops to about 5000 K and continues to decrease to about 4500 K in the first few hundred kilometers of the chromosphere.

The Structure of the Sun

The Chromosphere and the Corona

Beyond this minimum the temperature begins to increase, slowly at first and then more rapidly. It reaches values in the 10,000 K to 50,000 K to range in the first few thousand kilometers and then the transition zone occurs, where the temperature rises steeply (more sloping) from 50,000 K to 500,000 K in probably less than a thousand kilometers. This sharp increase in temperature represents on of the most complex and most intriguing (fantastic) problems of **solar physics**.

Above this region the temperature continues to increase but at a much slower rate reaching finally at an altitude of 10,000 to 20,000 km a temperature of about 1.5×10^6 K which is the nearly constant temperature of the **solar corona**.

During a total Solar eclipse, the solar corona can be seen with the naked eye during the brief period of totality.

The Structure of the Sun

The Chromosphere and the Corona

The first 1000 km of the chromosphere are a fairly uniform layer, but above this height the chromosphere become a very in-homogeneous region because it consist of many small jets shooting out into the corona. These projections are called "**spicules**" and in general have the shape of a rather long **cylindrical cone** approximately **1000 km thick** and about **5000 km tall**. **The spicules continuously rise and fall and their average life time is close to 5 minutes**.

The solar corona begins essentially in the region between the spicules and extends outwards merging ultimately with the interplanetary medium. The temperature of the corona is approximately **1.5×10^6 K** and changes very slowly with the distance from the Sun. The **coronal gas at this high temperature is fully ionized** and consists essentially of **electrons** and **protons**.

The Structure of the Sun

The Chromosphere and the Corona

An empirical expression which is often used for the electron density profile of the quiet corona is the **Baumback-Allen Formula**,

$$N_e = 10^8 \left(1.55\, \rho^{-6} + 2.99\, \rho^{-16}\right) \quad e^n/cm^3$$

In which $\rho = r/R_0$ is the ratio of the radial distance r from the center of the Sun to the **radius R_0 of the photosphere**.

The **electron density of the corona over an active region has approximately the same profile but multiplied by a factor of 10 or 20**. The Baumback-Allen formula applies only to **values of ρ less than about 5**, because at larger distances, the density of the solar corona falls of very nearly like the square of the distance, i.e. like ρ^{-2}.

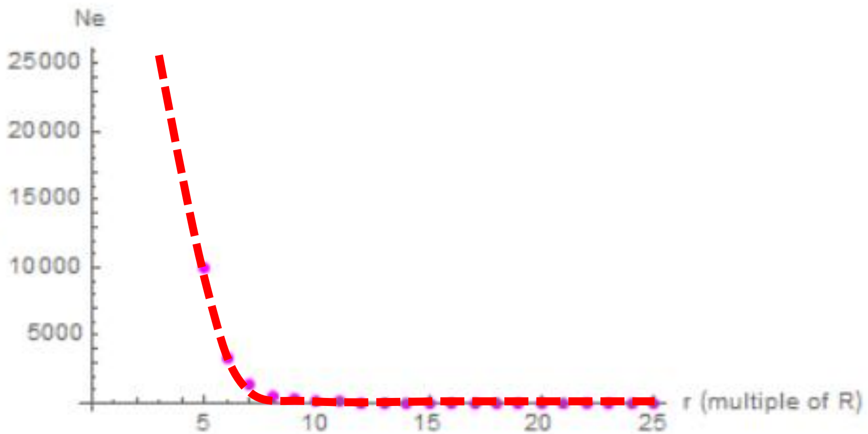
Elec Num Density of the Suns Atmosphere.nb * - Wolfram Mathematica 10.0

File Edit Insert Format Cell Graphics Evaluation Palettes Window Help

```
In[48]:= r = Table[R * i, {i, 1, 25}];
         (* R = Radius of the Sun *)
         rho = r / R;
         (* r = Radial Distance from the  center of the Sun*)
         ne = 10^8 * (1.55 * (rho^(-6)) + 2.99 * (rho^(-16)));
         (* electrons per cubic meter *)
         nevsr = Transpose[{r / R, ne}]
         ListPlot[nevsr, PlotStyle → {Magenta, PointSize[0.02]},
          AxesLabel → {"r (multiple of R)", "Ne"}]
```

Out[51]= {{1, 4.54×10^8}, {2, 2.42644×10^6}, {3, 212627.}, {4, 37841.9}, {5, 9920.}, {6, 3322.19}, {7, 1317.48}, {8, 591.278}, {9, 291.66}, {10, 155.}, {11, 87.4935}, {12, 51.9092}, {13, 32.1123}, {14, 20.5856}, {15, 13.6077}, {16, 9.23872}, {17, 6.42152}, {18, 4.55719}, {19, 3.29466}, {20, 2.42188}, {21, 1.80724}, {22, 1.36709}, {23, 1.04704}, {24, 0.811081}, {25, 0.63488}}

Out[52]=



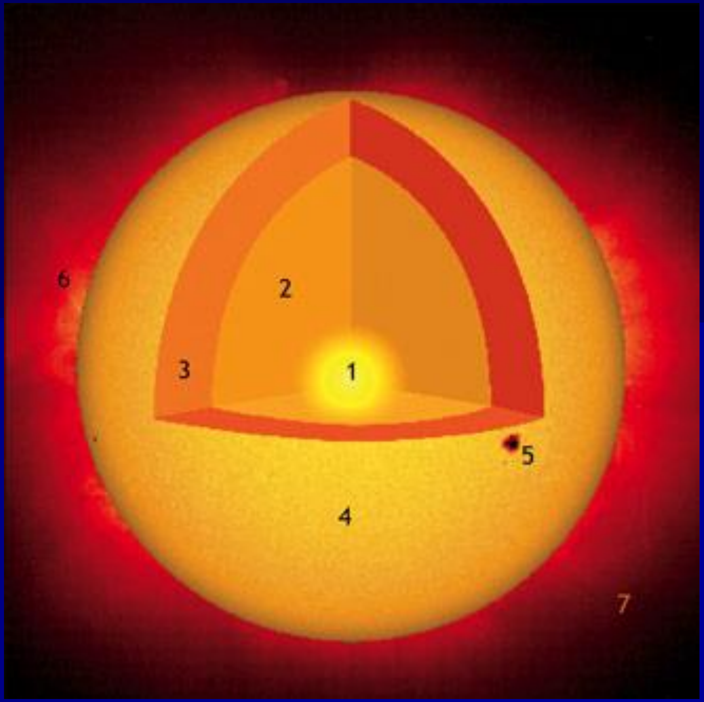
The Structure of the Sun

The Chromosphere and the Corona

The sharp rise of the temperature in the transition zone and the heating of the **corona** to temperatures several hundred times higher than the effective temperature of the Sun, represent a very difficult problem which has not been worked out yet in its full complexity. The basic process, can be described in the following simple terms.

Sound (acoustic) **waves** are generated by turbulence and convection below the photosphere and they start moving up carrying only about 1% of the total energy flux.

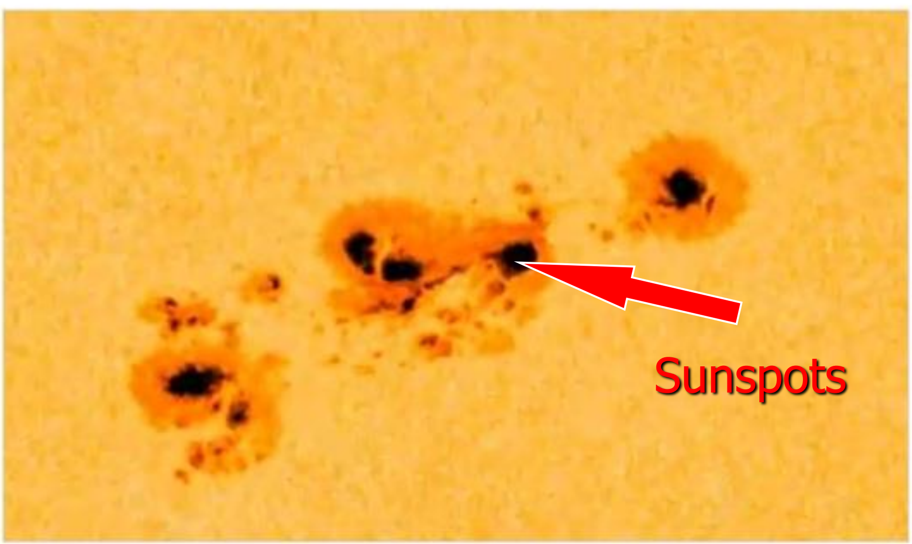
The Active Sun



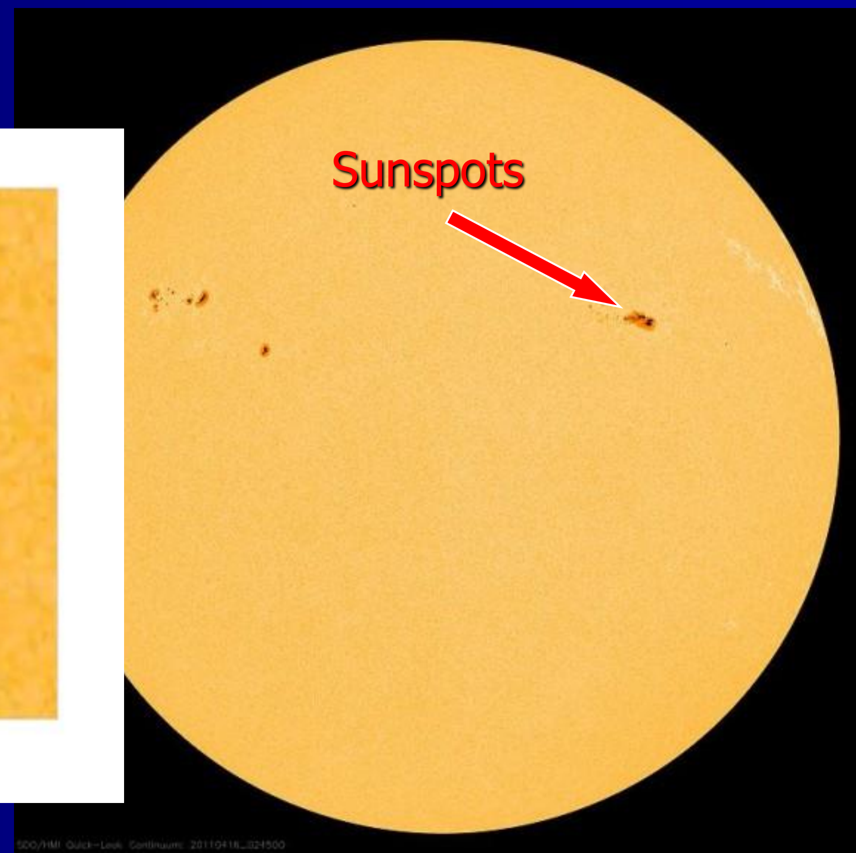
The Sun and Stars
Introduction of the Active Sun
The Photosphere
The Chromosphere and the Corona
Sunspots and the Solar Cycle
Faculae, Flares and Prominences
Radio and X-ray Bursts from the Sun
The Development of an Active Region on the Sun
Effect of the Solar Cycle
Life Cycle of the Sun

Sunspots & the Solar Cycle

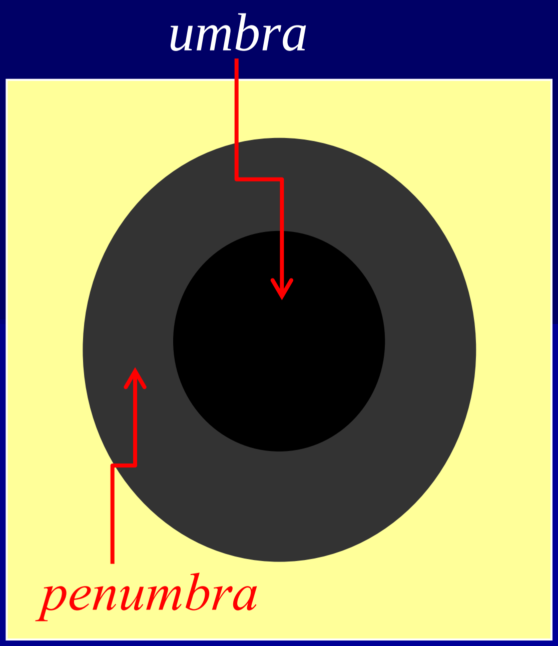
Sunspots are small, dark, transient (changeable) spots on the surface of the Sun. They can easily be seen with naked eye by projecting the image of the Sun on a white surface. It is believed that Theophrastus of Athens, a pupil of Aristotle, was the first one to observe the Sunspots around 300 BC. The Chinese complied many naked-eye records of sunspots from the 1st to 17th century.



Sunspots *NASA/SDO*



Sunspots & the Solar Cycle



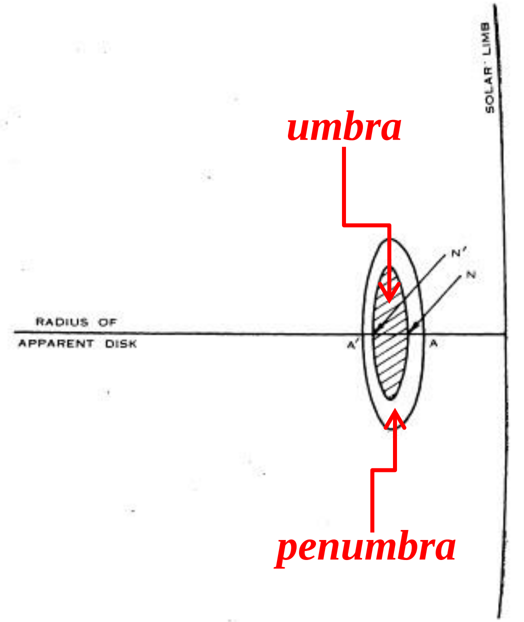
Sunspots were observed for first time through a telescope in year 1611 by several people, including Galileo, in three different countries. Sunspots have a central dark region which is called the **umbra** (total image), and a less dark region which surrounds the umbra and it called the **penumbra** (sub image).

The umbra is nearly featureless but the penumbra consists of many radial filaments which are believed to be due to roll convection of photospheric matter along the radial magnetic field lines of the sunspot.

A significant contribution in the study of the sunspots and in general of the solar atmosphere, was the discovery of the **Wilson Effect** by Alexander Wilson in 1976. **Wilson observed that while the sunspots have an essentially symmetric penumbra when they are near the center of the Solar Disk, they develop an asymmetric penumbra as they move closer to the limb** (edge of something) **with the narrower side of the penumbra further away from the limb**.

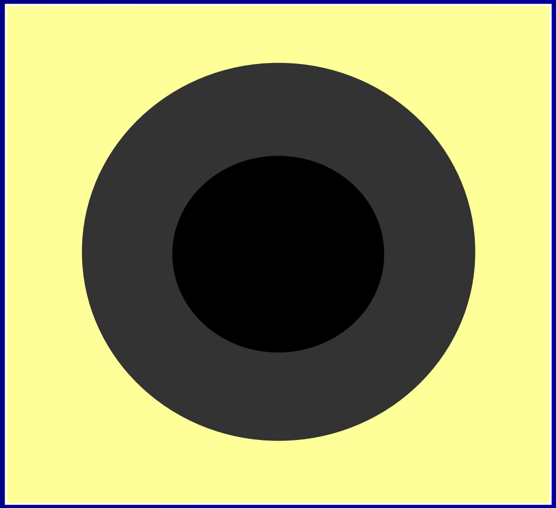
Sunspots & the Solar Cycle

This is shown diagrammatically in the following figure.

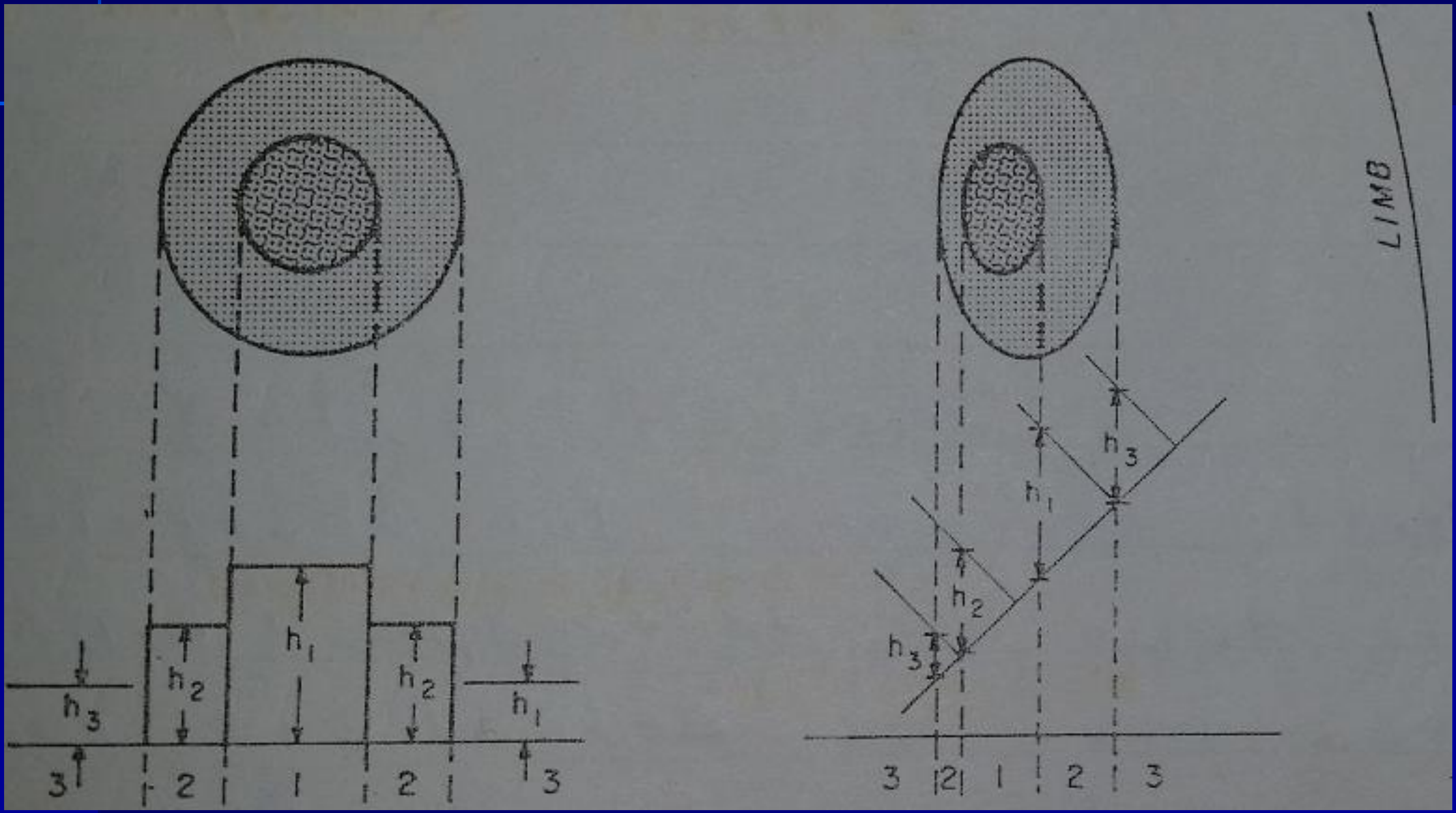


AA′ is the arc intercepted by the spot on the great circle whose plane contains the solar radius and the line-of-sight to the centre of the spot. *AN* and *A′N′* are the apparent widths of the penumbra on the sides of the spot towards and remote from the solar limb respectively.

Wilson himself offered a geometric explanation for this effect by suggesting that sunspots are **saucer-shaped** depression on the surface of the Sun.

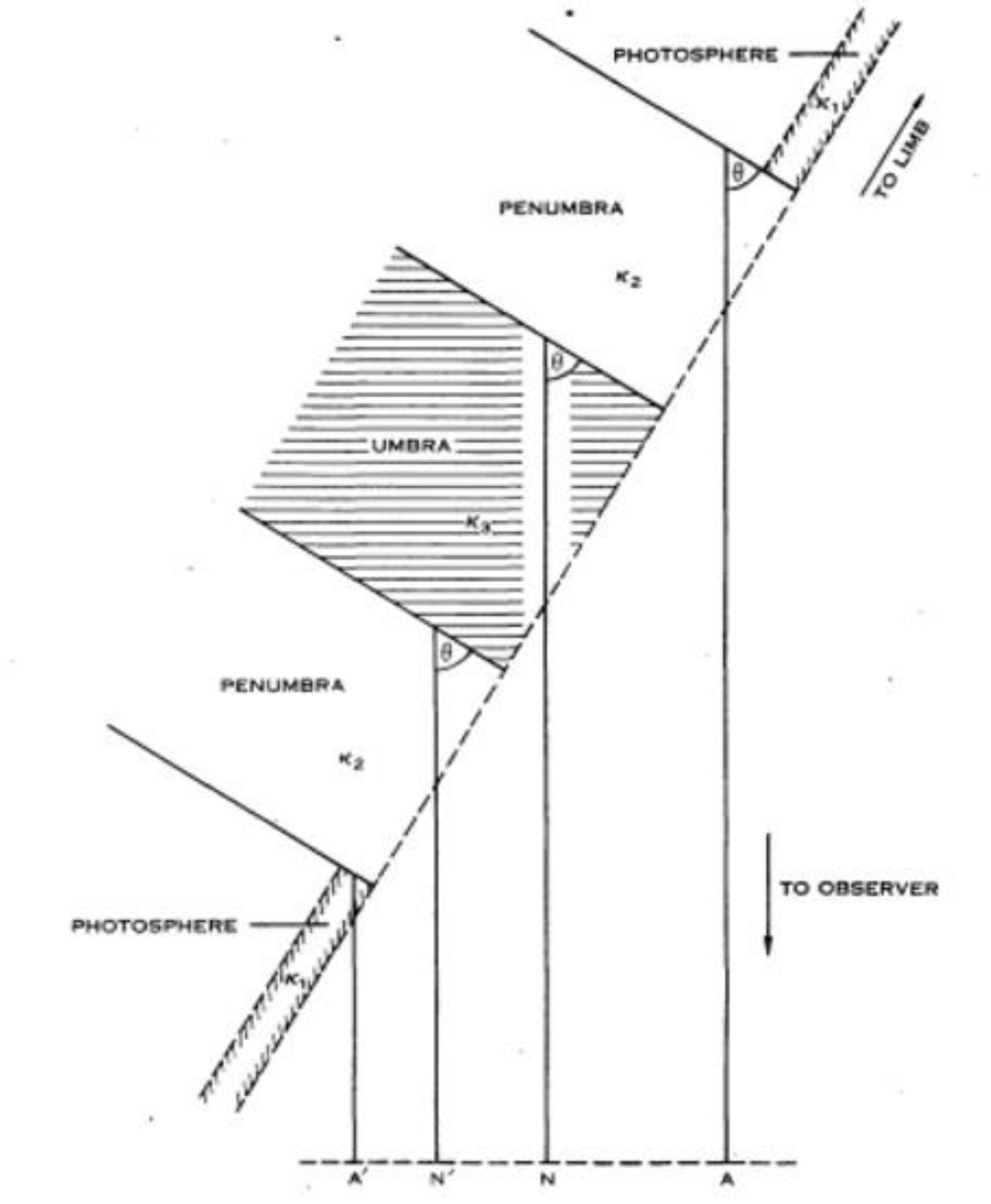


Sunspots & the Solar Cycle



The Wilson effect of the sunspots as they approach the limb of the solar disk.

Sunspots & the Solar Cycle



A simple model of a sunspot. The figure shows a section of the spot by the plane of the grate circle containing the solar radius and the line of sight to the spot.

The Wilson Effect in Sunspots - Loughhead, R. E. & Bray, R. J. (Australian Journal of Physics,vol. 11, p.177)

Sunspots & the Solar Cycle

It was not until 1843 that **Heinrich Schwabe** announced in Germany that his long sunspot observations had shown that the average number of sunspots on the Sun varies with a **period of approximately 10 years**.

Further studies in past records by **Rudolf Wolf** confirmed the existence of an **11 year sunspot cycle** and in 1851, Wolf introduced his relative sunspot number R which is given in the relation,

Calibration Factor

Relative Sunspot Number

$$R = k\,[10\,g + f\,]$$

Number of individual sunspots on the disk of the Sun

Number of sunspot groups on the disk of the Sun

Where, **k** is a coefficient assigned to each observing station to assure uniformity in the R numbers obtained by the different stations. This k is called "**Calibration Factor**" of the equation.

Relative Sunspot Number, R

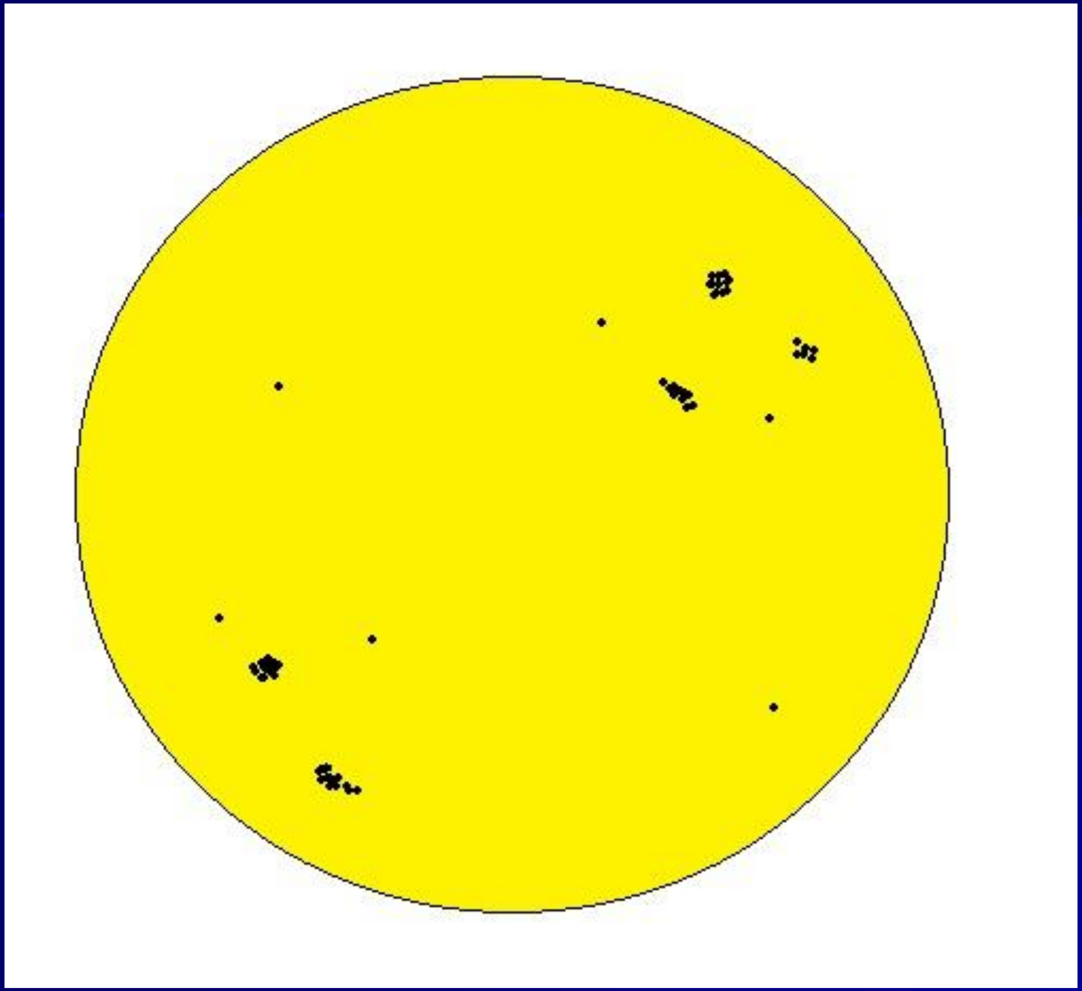
$$R = k\,[10\,g + f\,]$$

In 1855 Wolf become the director of the new Zurich Observatory and established there a Long Tradition of Solar Observations. For this reason **R** is also called **Wolf sunspot number** or **Zurich sunspot number**.

Coefficient k :

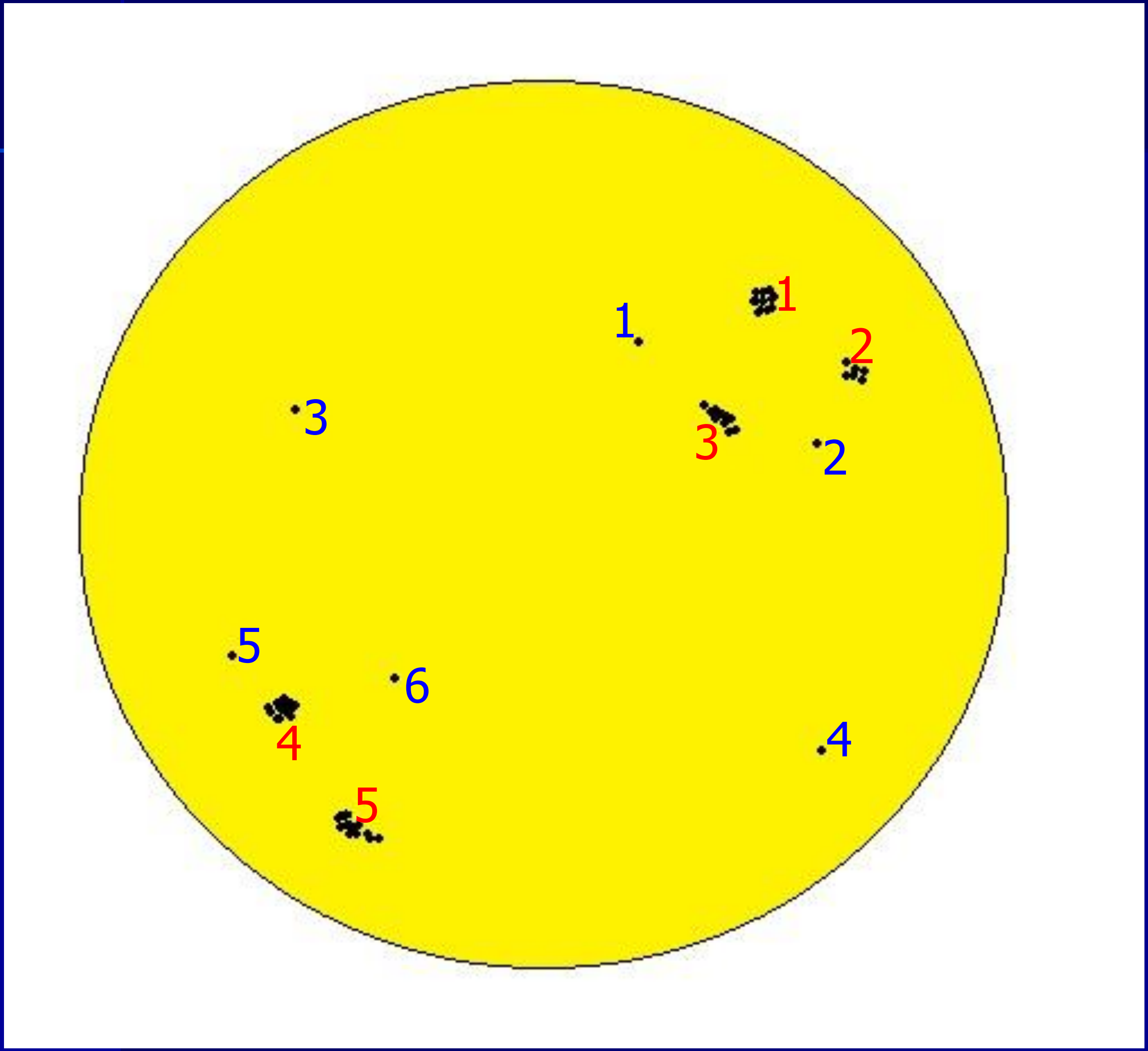
This k is **variable scaling factor** (Usually $k < 1$) **that accounts for observing conditions** and **the type of telescope** (binoculars, Space Telescope, …). Scientists combine data from lots of observations – each with its own k factor to arrive at a daily value!

Sunspots & the Solar Cycle



Eg: The above figure shows the telescopic image of the Sun and the value of the variable scaling factor based on the telescope 0.45. Find the value of the sunspot number.

Sunspots & the Solar Cycle



Number of sunspot groups on the disk of the Sun

g = 5

Number of individual sunspots on the disk of the Sun

f = 6

Relative Sunspot Number,

$$R = k\,[10\,g + f]$$

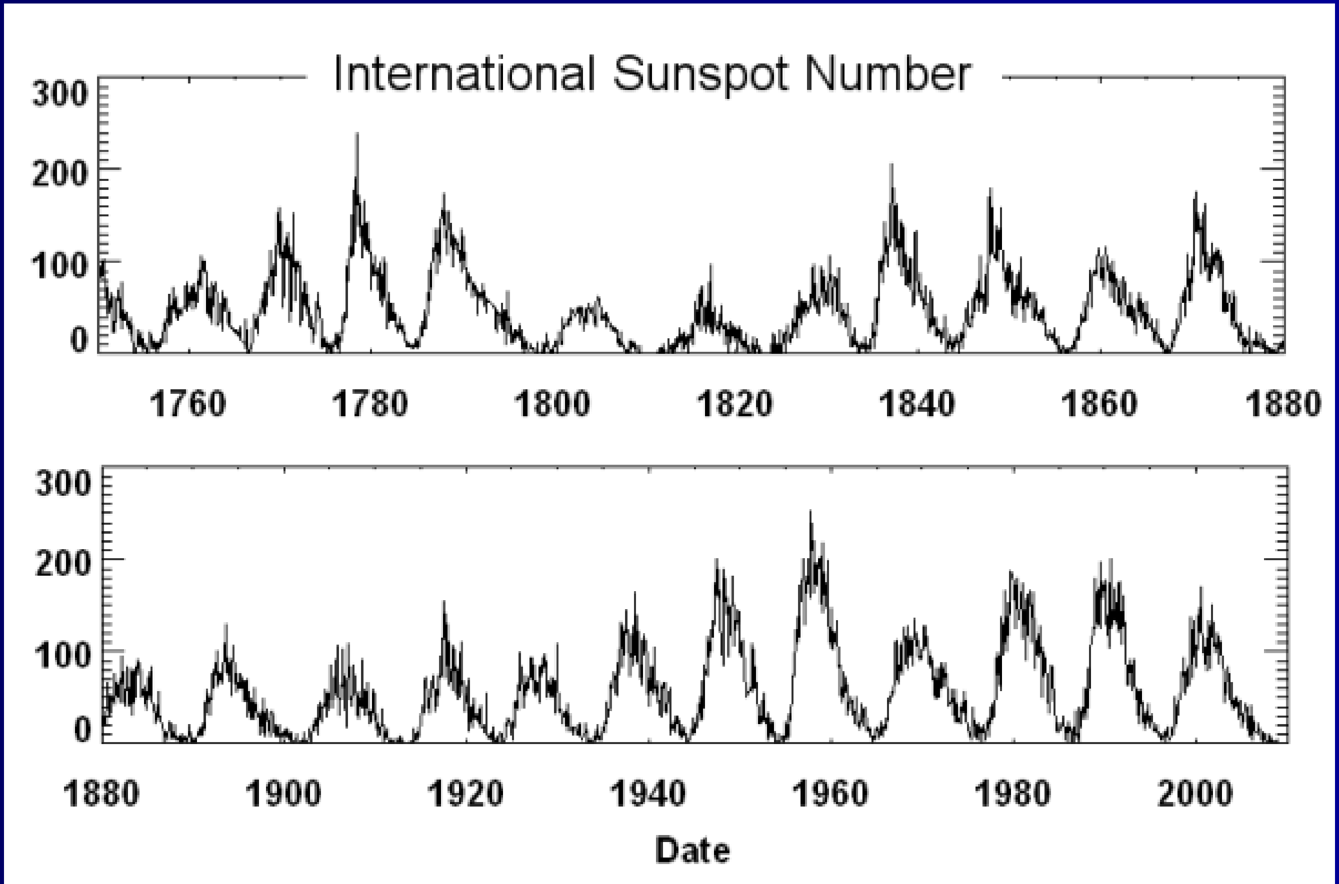
$$R = k[10 \times 5 + 6]$$

If k = 0.45

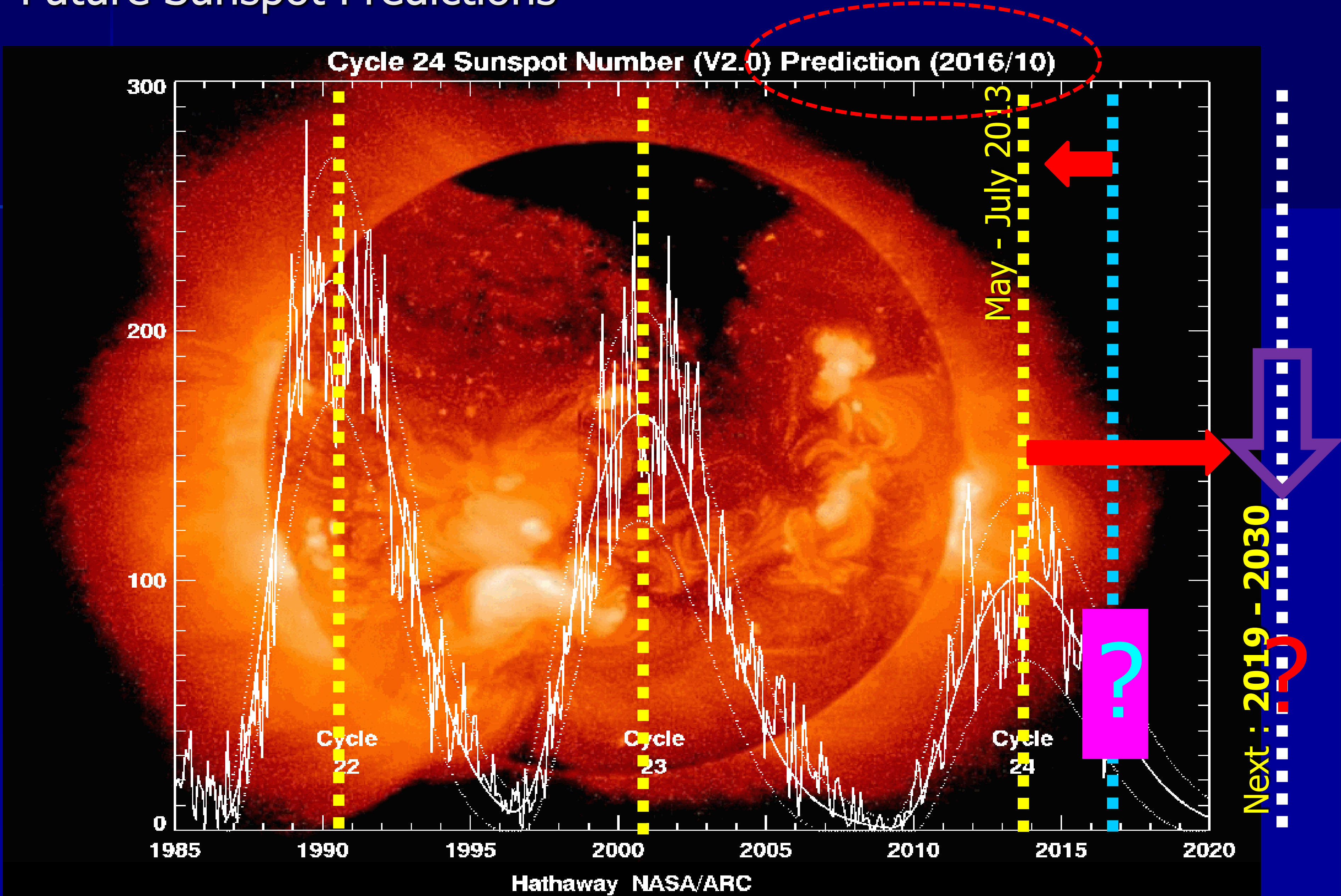
$$R = 25.2$$

International sunspot numbers from 1745 to the present

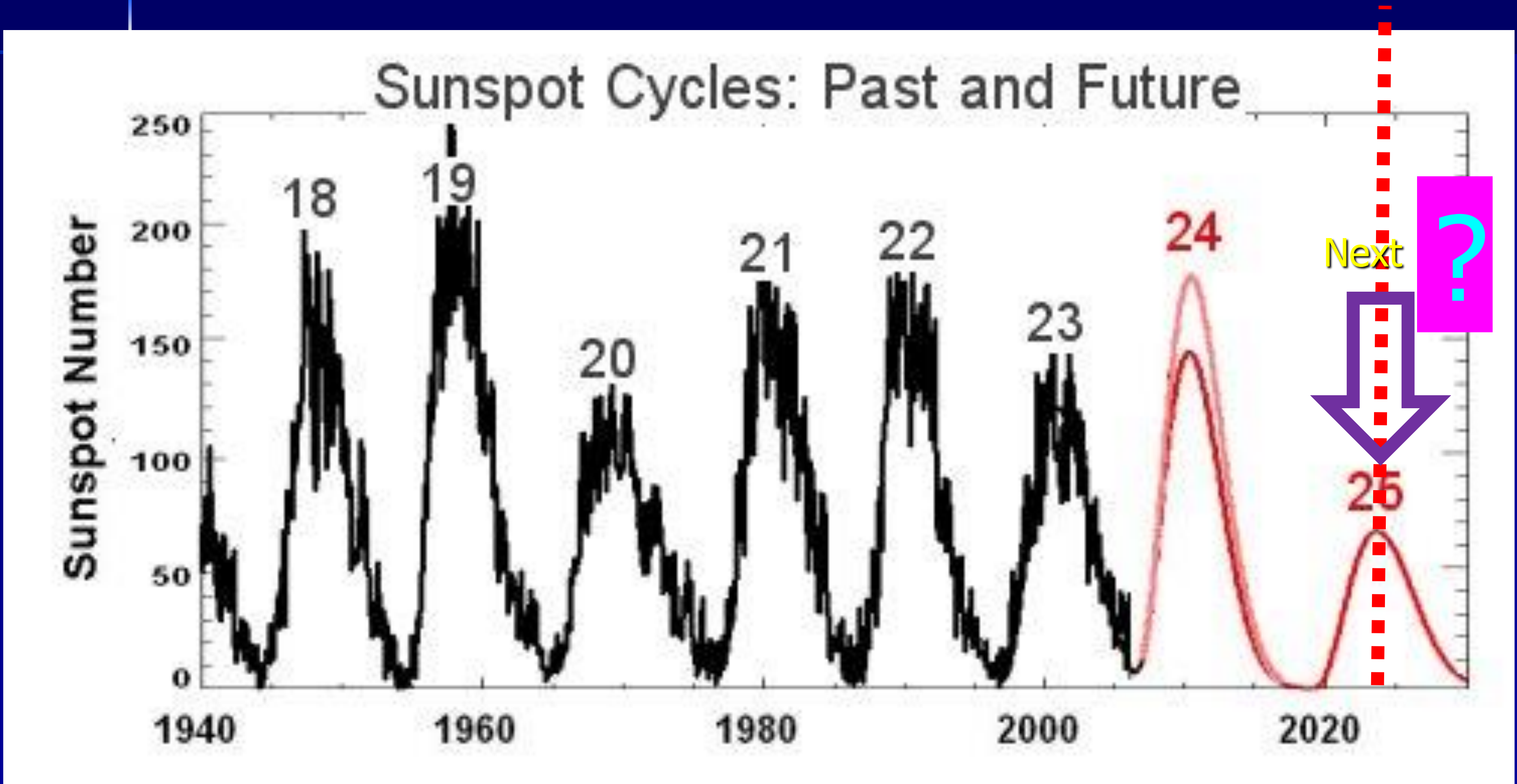
The following figure shows the variation of the yearly average of the sunspot number since 1745 to the present. Data for the first hundred years were reconstructed from old records by **Wolf**.



Future Sunspot Predictions



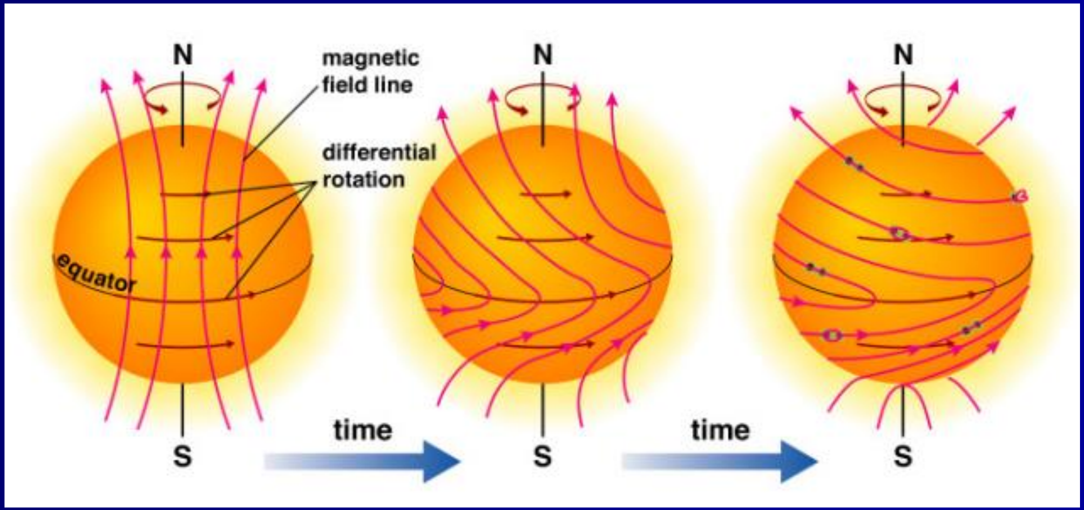
Future Sunspot Predictions :



In more recent years it has been found that all other manifestations of solar activity follow essentially the same **11 year cycle**. It should be mentioned that the cycle of the various indices show considerable differences over the 11 year cycle and their maxima might differ by a year or more.

It is probably more accurate to speak of a 22 years solar cycle which includes two 11 years sub cycle !

In 1908 **George Ellery Hale**'s observations revealed that the Solar Cycle is a **magnetic cycle with an average duration of 22 years**. However, because very nearly all manifestations of the solar cycle are insensitive to magnetic polarity, it remains common usage to speak of the " **11 years solar cycle** ".



The Solar Cycle

Solar Cycles						
Cycle	Started	Finished	Duration (years)	Maximum (monthly SSN (Smoothed Sunspot Number))[4]	Minimum (monthly SSN; end of cycle)[5][6]	Spotless Days (end of cycle)[7][8][9]
Solar cycle 1	March 1755	June 1766	11.3	86.5	11.2	
Solar cycle 2	June 1766	June 1775	9.0	115.8	7.2	
Solar cycle 3	June 1775	September 1784	9.3	158.5	9.5	
Solar cycle 4	September 1784	May 1798	13.7	141.1	3.2	
Solar cycle 5	May 1798	December 1810	12.6	49.2	0.0	
Solar cycle 6	December 1810	May 1823	12.4	48.7	0.1	
Solar cycle 7	May 1823	November 1833	10.5	71.5	7.3	
Solar cycle 8	November 1833	July 1843	9.8	146.9	10.6	
Solar cycle 9	July 1843	December 1855	12.4	131.9	3.2	~654
Solar cycle 10	December 1855	March 1867	11.3	97.3	5.2	~406
Solar cycle 11	March 1867	December 1878	11.8	140.3	2.2	~1028
Solar cycle 12	December 1878	March 1890	11.3	74.6	5.0	~736
Solar cycle 13	March 1890	February 1902	11.9	87.9 (Jan 1894)	2.7	~938
Solar cycle 14	February 1902	August 1913	11.5	64.2 (Feb 1906)	1.5	~1019
Solar cycle 15	August 1913	August 1923	10.0	105.4 (Aug 1917)	5.6	534
Solar cycle 16	August 1923	September 1933	10.1	78.1 (Apr 1928)	3.5	568
Solar cycle 17	September 1933	February 1944	10.4	119.2 (Apr 1937)	7.7	269
Solar cycle 18	February 1944	April 1954	10.2	151.8 (May 1947)	3.4	446
Solar cycle 19	April 1954	October 1964	10.5	201.3 (Mar 1958)	9.6	227
Solar cycle 20	October 1964	June 1976	11.7	110.6 (Nov 1968)	12.2	272
Solar cycle 21	June 1976	September 1986	10.3	164.5 (Dec 1979)	12.3	273
Solar cycle 22	September 1986	May 1996	9.7	158.5 (Jul 1989)	8.0	309
Solar cycle 23	May 1996	December 2008 [10]	12.6	120.8 (Mar 2000)	1.7	820 (through Jan 15, 2011) [11]
Solar cycle 24	December 2008 [10]					
Mean			11.1	114.1	5.8	

Find Nest Solar Maxima.nb * - Wolfram Mathematica 10.0

File Edit Insert Format Cell Graphics Evaluation Palettes Window Help

```
lastsmax = 2009 ; (* December = 12/12 *)
tim = Table[i, {i, 1, 23}];
scdura = {11.3, 9.0, 9.3, 13.7, 12.6, 12.4, 10.5,
   9.8, 12.4, 11.3, 11.8, 11.3, 11.9, 11.5, 10.0,
   10.1, 10.4, 10.2, 10.5, 11.7, 10.3, 9.7, 12.6};
scmean = Total[scdura] / Length[scdura];
Print["Mean value is : ", scmean]
Print["Next Maxima is : ", 2009 + scmean]

tsc = Transpose[{tim, scdura}];
g1 = ListPlot[tsc,
   PlotStyle → {Blue, Pointsize[0.02]}];
mm = 10 ; (* no of polynomials *)
mod = Table[Table[t^n, {n, 0, m}], {m, 1, mm}];
ff = Table[Fit[tsc, mod[[i]], t], {i, 1, Length[mod]}];
ss = ff /. t → Length[tim] + 1
Print["Next Maxima is : ", 2009 + ss]
g2 = Table[Plot[ff[[i]], {t, First[tim], Last[tim]},
    PlotStyle → Hue[1 / i]], {i, 1, Length[mod]}];
Show[{g1, g2}]
```

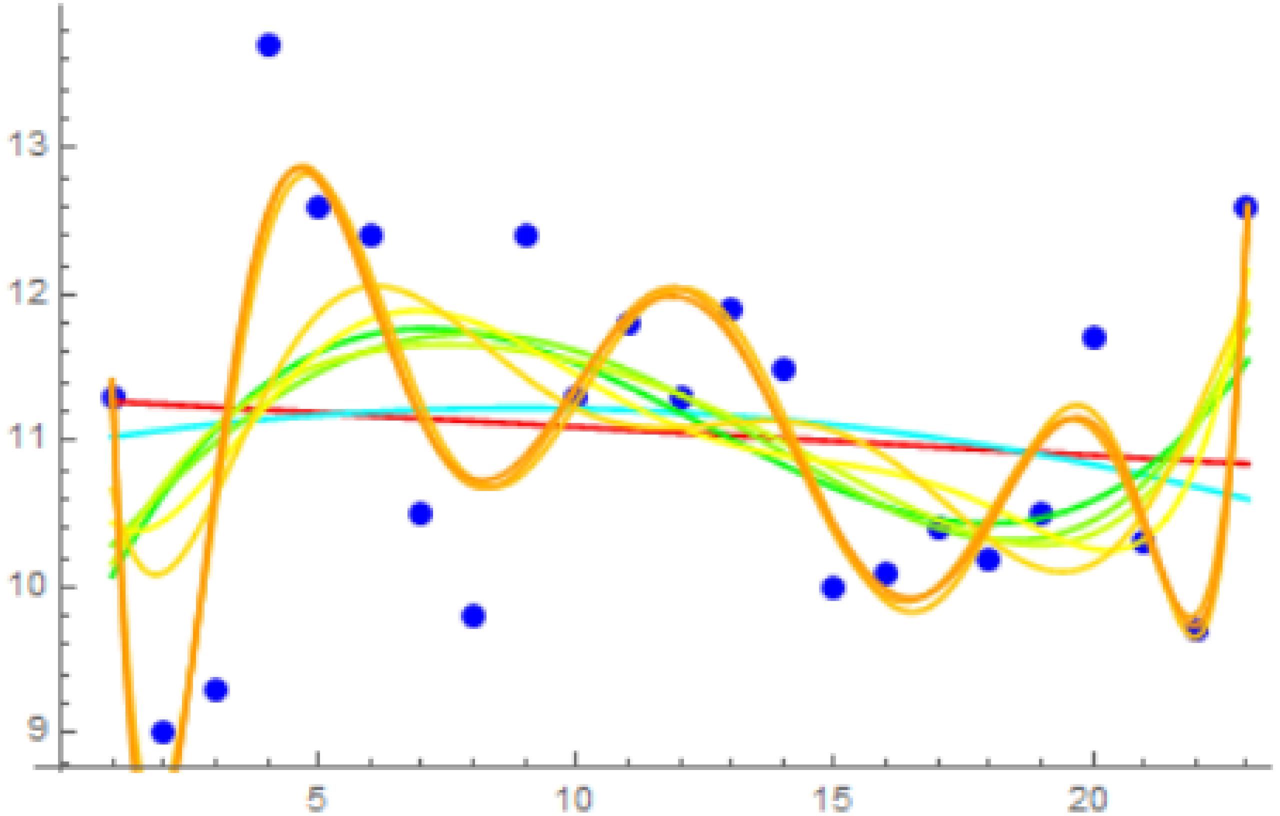
```
Mean value is : 11.0565

Next Maxima is : 2020.06

Out[70]= {10.8241, 10.5102, 12.1121, 12.6148, 13.0931,
  14.8751, 12.1354, 28.7872, 25.9803, 28.5978}

Next Maxima is : {2019.82, 2019.51, 2021.11, 2021.61,
  2022.09, 2023.88, 2021.14, 2037.79, 2034.98, 2037.6}
```

Out[73]=



Find Nest Solar Maxima.nb * - Wolfram Mathematica 10.0

File Edit Insert Format Cell Graphics Evaluation Palettes Window Help

```
lastsmax = 2009 ; (* December = 12/12 *)
tim = Table[i, {i, 1, 23}];
scdura = {11.3, 9.0, 9.3, 13.7, 12.6, 12.4, 10.5,
   9.8, 12.4, 11.3, 11.8, 11.3, 11.9, 11.5, 10.0,
   10.1, 10.4, 10.2, 10.5, 11.7, 10.3, 9.7, 12.6};
scmean = Total[scdura] / Length[scdura];
Print["Mean value is : ", scmean]
Print["Next Maxima is : ", 2009 + scmean]

tsc = Transpose[{tim
g1 = ListPlot[tsc,
   PlotStyle → {Blu
mm = 10 ; (* no of p
mod = Table[Table[t
ff = Table[Fit[tsc, mod[[i]], t], {i, 1, Length[mod]}];
ss = ff /. t → Length[tim] + 1
Print["Next Maxima is : ", 2009 + ss]
g2 = Table[Plot[ff[[i]], {t, First[tim], Last[tim]},
    PlotStyle → Hue[1 / i]], {i, 1, Length[mod]}];
Show[{g1, g2}]
```

```
Mean value is : 11.0565
Next Maxima is : 2020.06
```

Find Nest Solar Maxima.nb * - Wolfram Mathematica 10.0

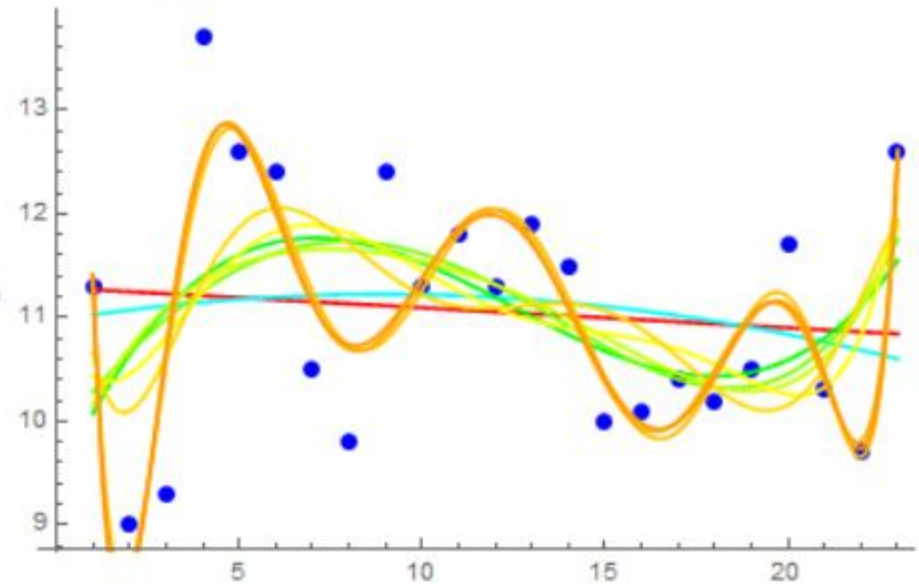
File Edit Insert Format Cell Graphics

```
lastsmax = 2009 ; (* Dece
tim = Table[i, {i, 1, 23}
scdura = {11.3, 9.0, 9.3,
    9.8, 12.4, 11.3, 11.8
    10.1, 10.4, 10.2, 10.
scmean = Total[scdura] /
Print["Mean value is :
Print["Next Maxima is :
```

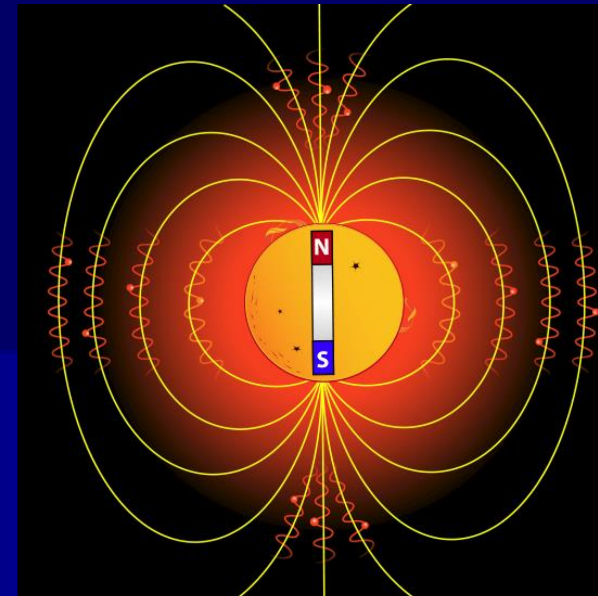
```
tsc = Transpose[{tim, sc
g1 = ListPlot[tsc,
    PlotStyle → {Blue, P
mm = 10 ; (* no of polynomials *)
mod = Table[Table[t^n, {n, 0, m}], {m, 1, mm}];
ff = Table[Fit[tsc, mod[[i]], t], {i, 1, Length[mod]}];
ss = ff /. t → Length[tim] + 1
Print["Next Maxima is : ", 2009 + ss]
g2 = Table[Plot[ff[[i]], {t, First[tim], Last[tim]},
     PlotStyle → Hue[1 / i]], {i, 1, Length[mod]}];
Show[{g1, g2}]
```

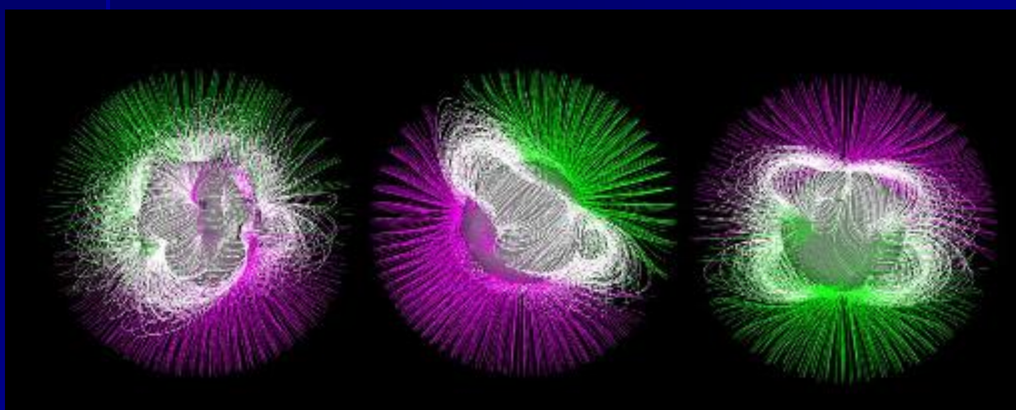
Next Maxima is : {2019.82, 2019.51, 2021.11, 2021.61, 2022.09, 2023.88, 2021.14, 2037.79, 2034.98, 2037.6}

Out[73]=

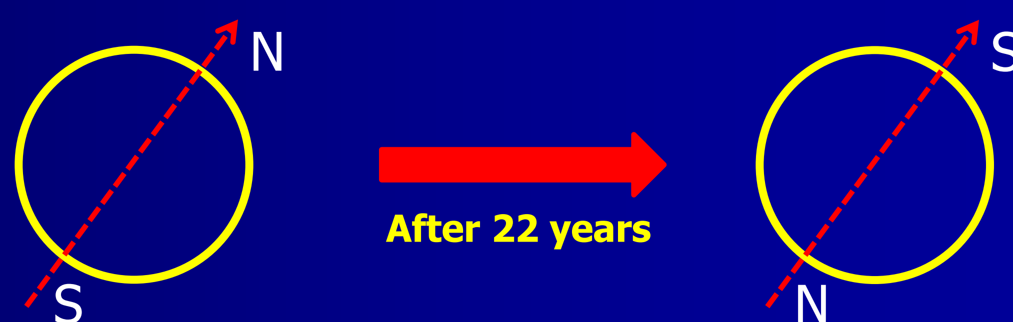


Half a century later, Harold Babcock and Horace Babcock (father and son) showed that the solar surface is magnetized even outside of the sunspots; that this **weaker magnetic field** is to first order a dipole; and that this dipole also undergoes polarity reversals with the same period (22 years) as the sunspot cycle.

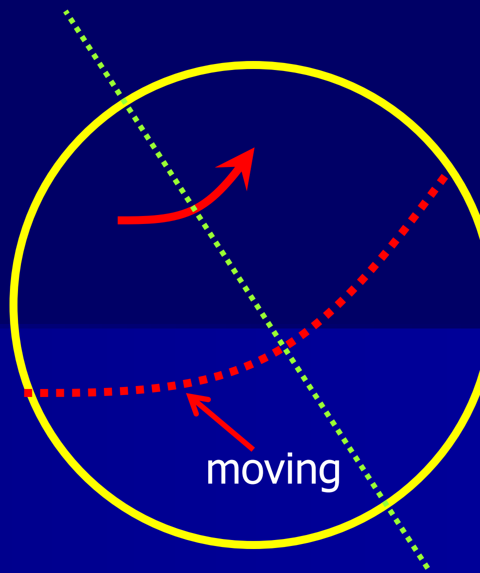


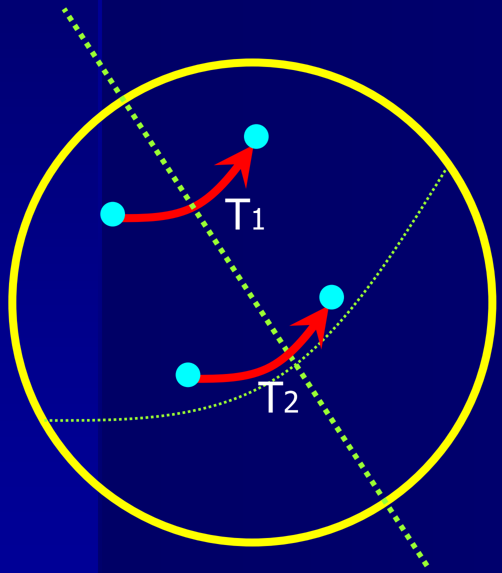


Sun's Magnetic Field



If the Sun is rotating, the sunspots are also rotating. **If we analyzed the two sunspots, the gap between those two sunspots are changing due to the Sun's rotating**. Because the surface of the Sun is not a solid sphere.

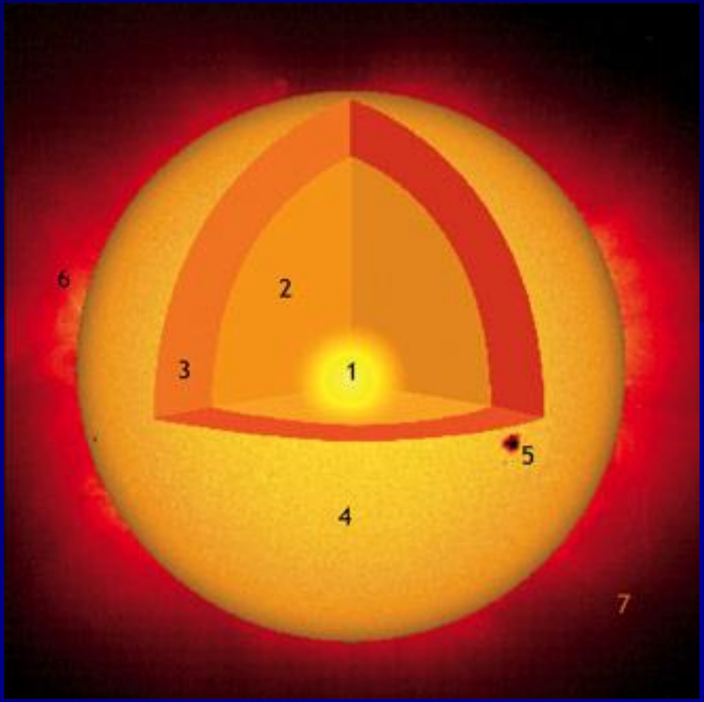




$T_1 \neq T_2$

Also the other thing is the velocities of two sunspots, one on the equator and the other one near the poles are not the same values. That means rotating velocities of the Sun's equator and the poles are different to each other.

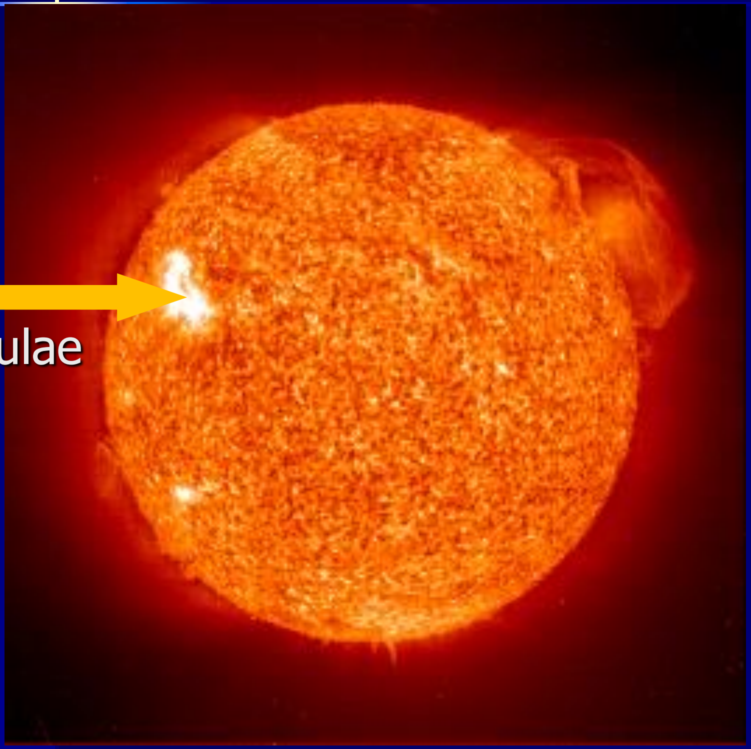
The Active Sun



The Sun and Stars
Introduction of the Active Sun
The Photosphere
The Chromosphere and the Corona
Sunspots and the Solar Cycle
Faculae, Flares and Prominences
Radio and X-ray Bursts from the Sun
The Development of an Active Region on the Sun
Effect of the Solar Cycle
Life Cycle of the Sun

Faculae (දීදුල) , Flares & Prominences

In this section we will discuss the different **optical manifestations of the active Sun**.

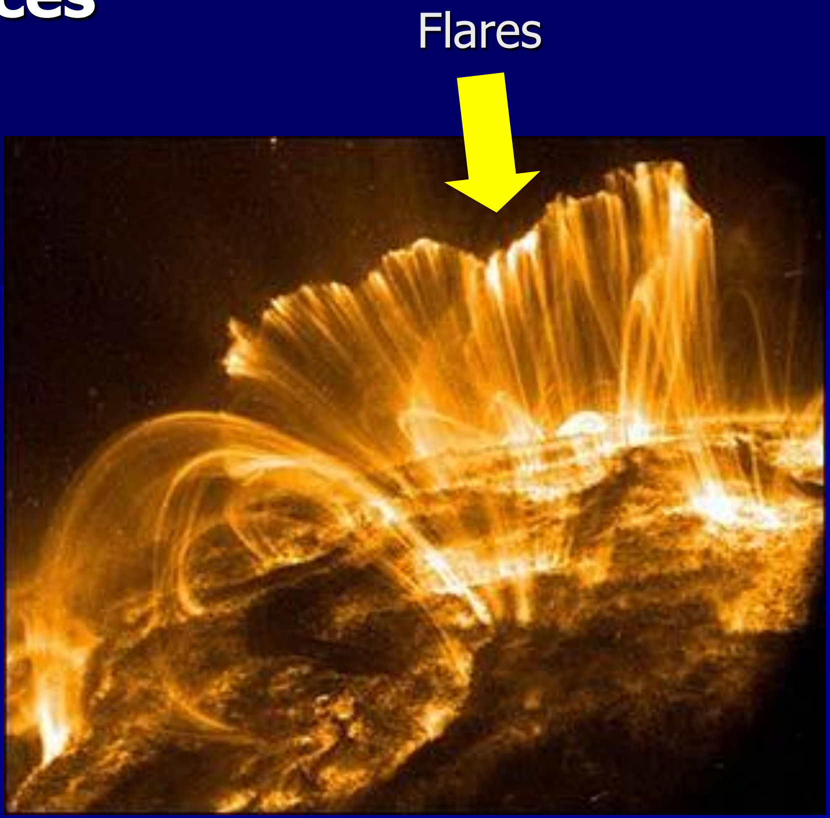


The first sign of solar activity is the appearance of a bright area which, when near the limb of the Sun, is brighter than the photosphere even in white light. These bright areas are called "**Faculae**", or more precisely "**Photospheric Faculae**"

Faculae usually engulf (ගිලදමනවා) a sunspot group, but they become noticeable before the appearance of the sunspots and often survive them by a month or two.

Faculae , Flares & Prominences

A **flare** is a sudden local increase in the brightness of the solar surface which lasts for nearly one hour. **Flares appear in an active region**, i.e.; a pelage (birth) area with sunspots the eruption (very fast explosion) of a **Solar Flare** is the culmination (get a peak) of the activity that has been mounting up in the sunspot region.

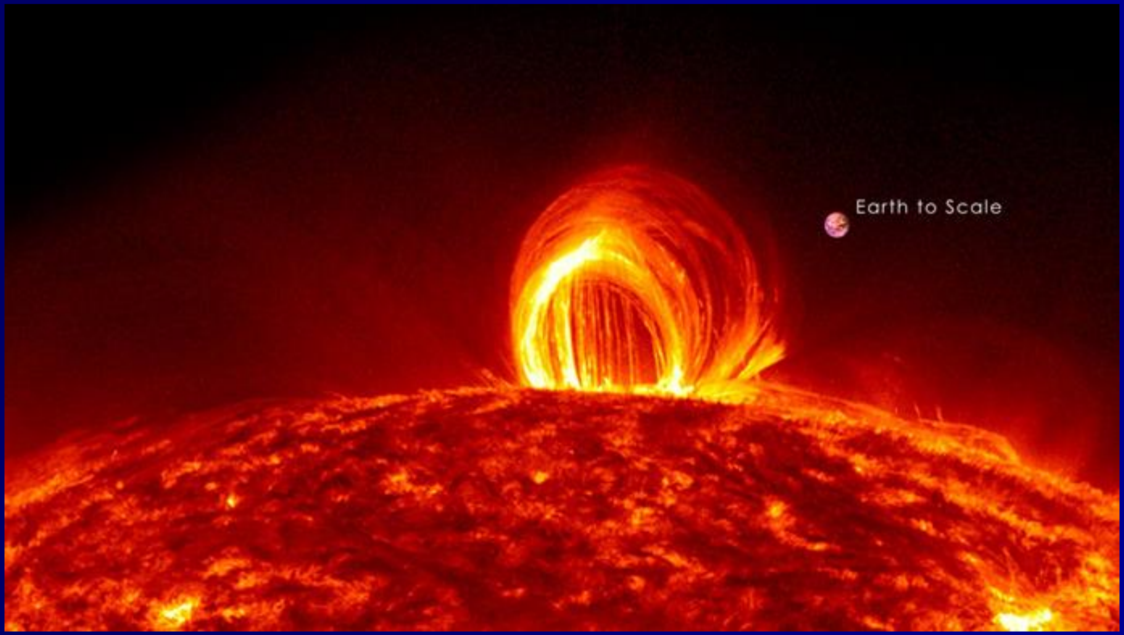


A flare is the optical effect produced by the sudden release of tremendous (very large) amount of energy ($6x10^{25}$ J/s) in the upper chromosphere or the lower corona. This explosion, which probably takes place above the layers where the optical flare appears, produces also a strong outburst (blast to the outside) of X-ray and Radio Emission which we will discuss in the next section.

Faculae , Flares & Prominences

When seen in projection at the limb of the Sun, flares appear to have different shapes…

Mounds (ගල්ගොඩ), **Spikes** (කූරු), **Cones** (කේතු), **Loops** (වළලු), **…. ect,**



that start chromosphere and extend into the lower corona. Typical heights range between 3000 km and 20,000 km. **Large Flares** can be seen in the **white light**, but **flares are usually observed in the H-alpha line** where they can be seen much better.

Solar Activity & Solar Flares

The incidence of solar flares is another measure of solar activity and is related to the sunspot number by,

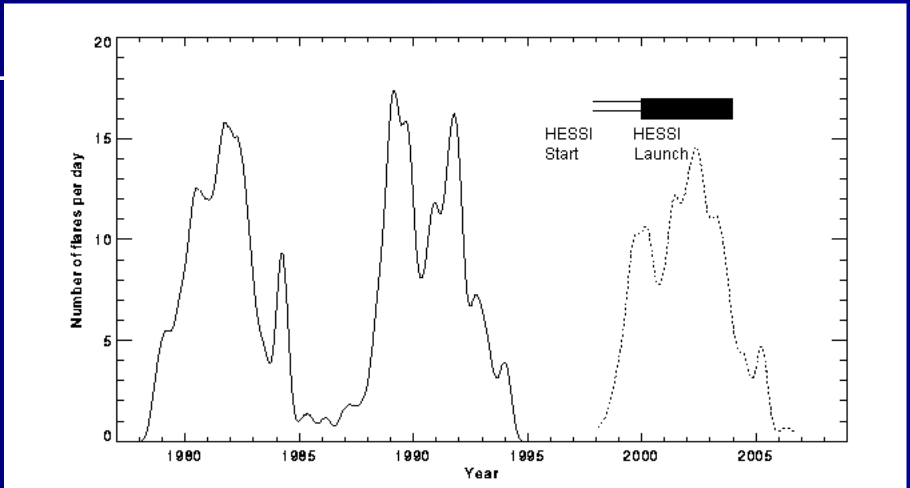
Number of Solar Flares observed → N_t

Mean Sunspot Number → $\bar{R}$

$$N_t = \alpha \left[\bar{R} - 10\right]$$

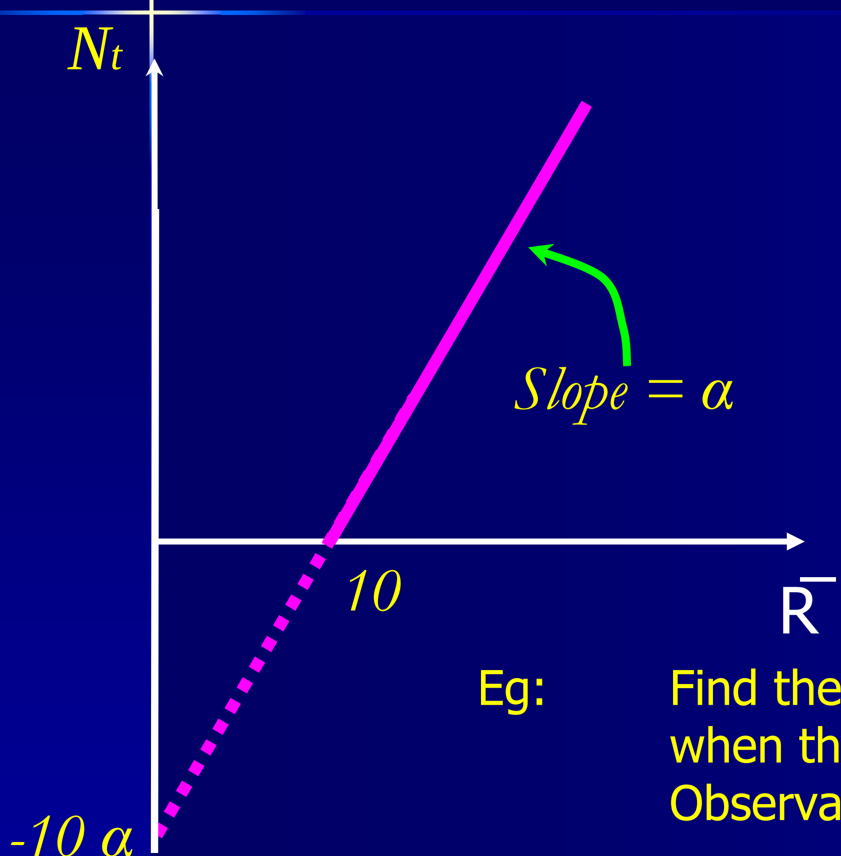
α: *Observatory Constant ~ 1.5 – 2.0*

Where, N_t is **Number of Solar Flares observed during one solar rotation**, $\bar{R}$ is the **Mean Sunspot Number** and α (alpha) is an **Observatory Constant** of value between ~1.5 – 2.0.



Solar Activity & Solar Flares

The graph of Number of solar flares observed per solar rotation verse mean sunspot number :



$$N_t = \alpha \left[\bar{R} - 10\right]$$

$$N_t = \alpha \bar{R} - 10\alpha$$

y (N_t), m (α), x ($\bar{R}$), - c (10α)

If, $N_t = 0 \rightarrow \bar{R} = 10$

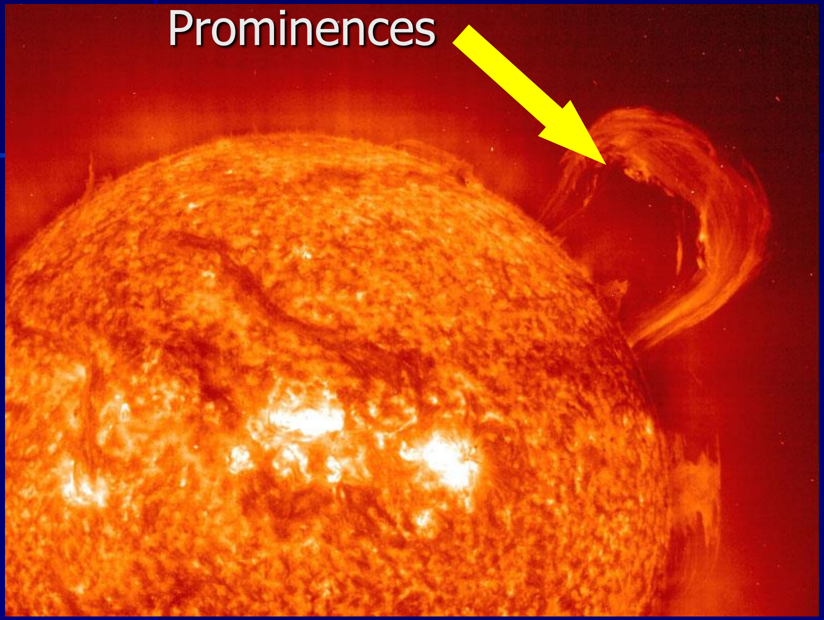
If, $\bar{R} = 0 \rightarrow N_t = -10\alpha$

Eg: Find the number of solar flares per solar rotation when the mean sunspot number is 25 and Observatory Constant 1.6.

$$N_t = \alpha \left[\bar{R} - 10\right] \Rightarrow N_t = 1.6\left[25 - 10\right]$$

$$\Rightarrow N_t = 24$$

Faculae , Flares & Prominences (නෙරුම)

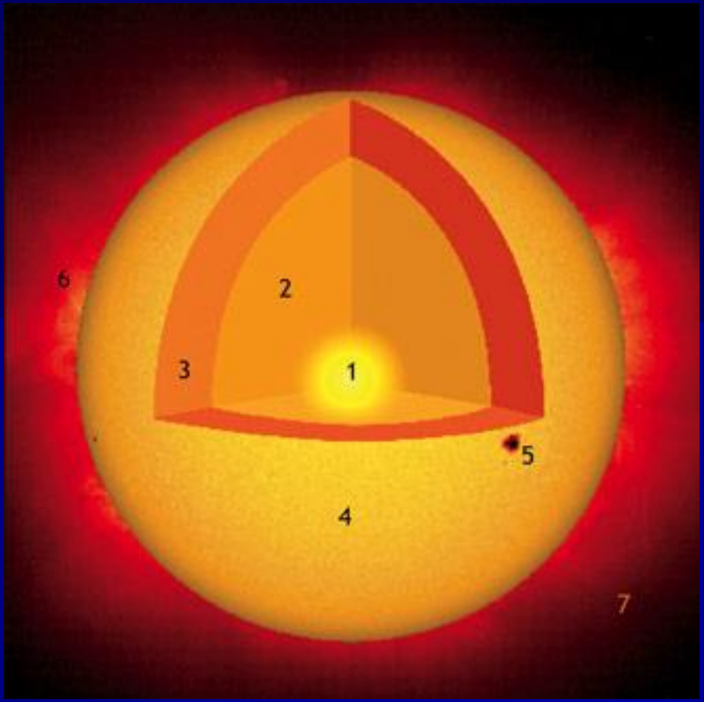


Solar **prominence** (**more gases emitted place**) have been recorded in same very impressive sequences with time-lapse photography. When seen at the limb of the Sun, prominence appear as luminous arch-like structures with continuous internal motion. These arches are about 200,000 km long but only a few thousand kilometers thick.

When they are projected on the luminous disk of the Sun they simply appear as **long dark filaments**.

The **active prominences** which appear over a sunspot group and for this reason they are called **sunspot prominences**, and the **quiescent** (very calm) **prominences** which are associated with peculiar (own) regions without sunspots or with sunspot groups in their decaying stage.

The Active Sun



The Sun and Stars
Introduction of the Active Sun
The Photosphere
The Chromosphere and the Corona
Sunspots and the Solar Cycle
Faculae, Flares and Prominences
Radio and X-ray Bursts from the Sun
The Development of an Active Region on the Sun
Effect of the Solar Cycle
Life Cycle of the Sun

Radio & X-ray Bursts from the Sun

In the specific meaning of the term, a solar flare is the sudden brightening of a small region of the solar disc. More generally it is an explosive event in the atmosphere of the Sun which produces not only optical effect but also radio, X-ray and corpuscular radiation (ළවක විකිරණය).

While the **optical flux from the Sun never varies by more than 1%,** the enhancement in the X-ray region and in the radio domain during a flare event can exceed the respective flux from the quiet Sun by several orders of magnitude. X-ray bursts from the Sun can be detected either directly with special instruments flown on rockets and satellites, or indirectly from the ground by the effects which they produce in the terrestrial ionosphere. **Solar radio bursts are observed directly from the ground through the radio window of the terrestrial atmosphere.**

When a flare event is triggered in an active region on the Sun, it produces a sharp burst of energetic electrons and protons which stream **with velocities** of the order of $v \sim 10^8$ m/s both **outwards towards the corona and inwards towards the chromosphere.**

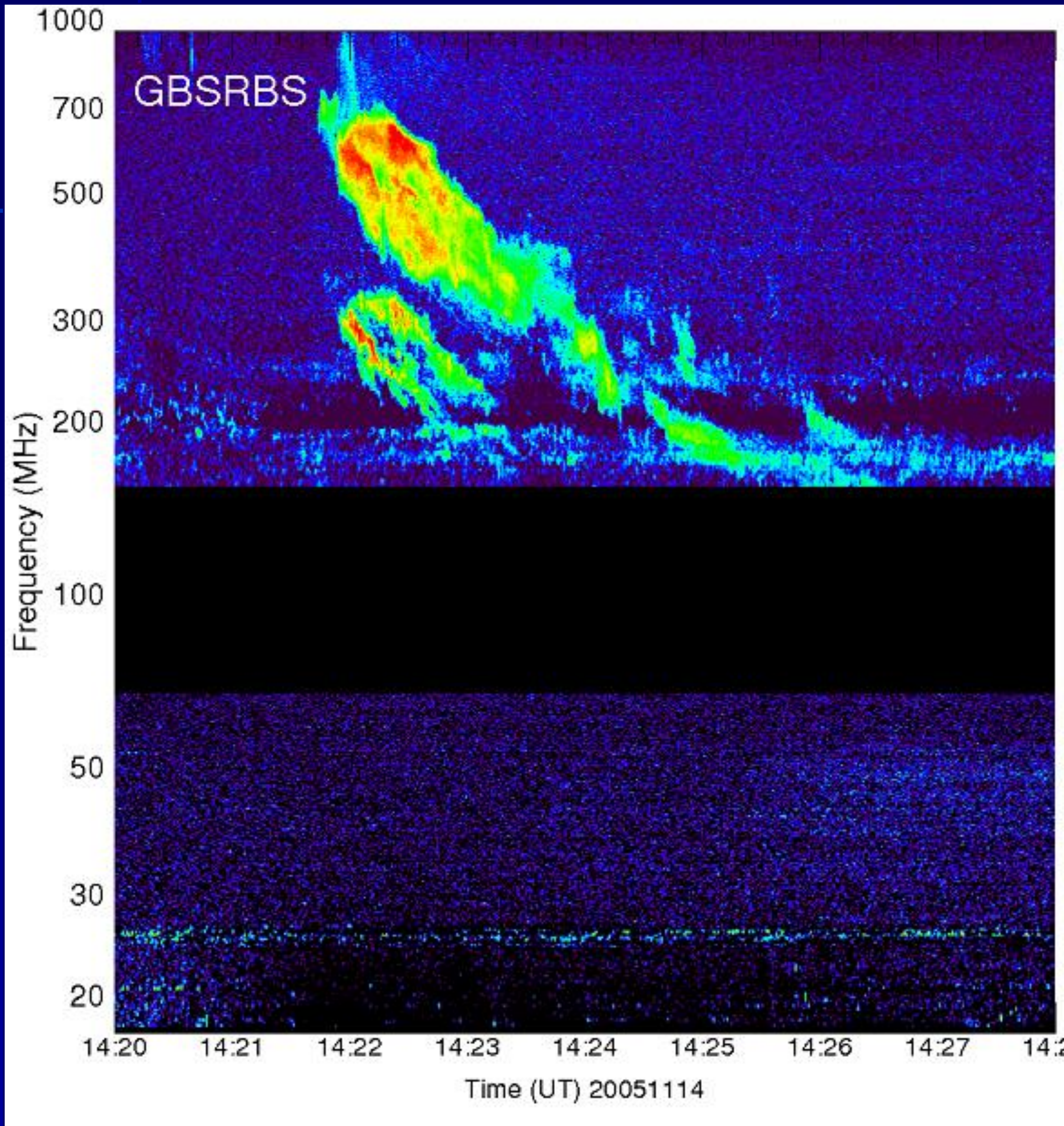
Radio & X-ray Bursts from the Sun

The downward stream of the relativistic electrons produces immediately a **burst of hard X-rays** through collisions with ions in the **corona** or with neutral hydrogen atoms in the **chromosphere.**

Besides the downward burst of high energy electrons, there is usually also an upward burst of energetic particles which speed through the solar corona exciting plasma waves. These compression waves of the coronal plasma use part of their energy to generate radio waves at the local plasma frequency **f_p.**

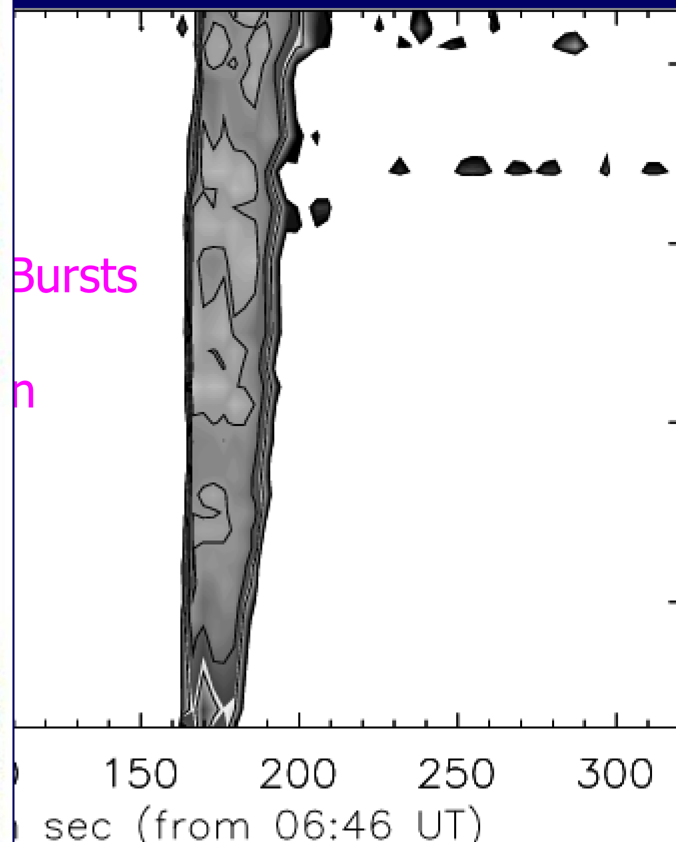
As these energetic particles move with high velocities ($v \sim 10^8$ m/s) outwards through layers of continuously lower electron density, the peak frequency of the radio burst drifts rapidly toward lower values.

Radio & X-ray Bursts (පැල්ම) from the Sun



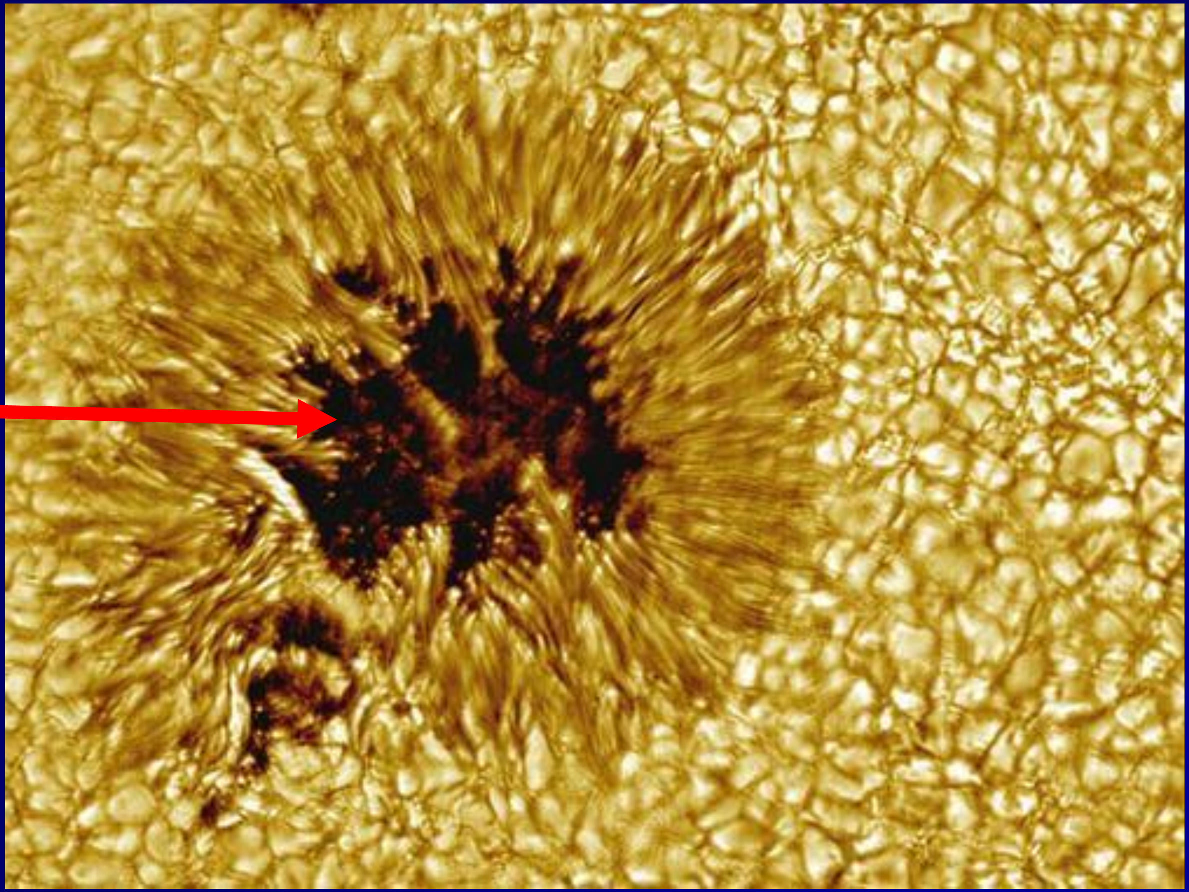
Bursts

n

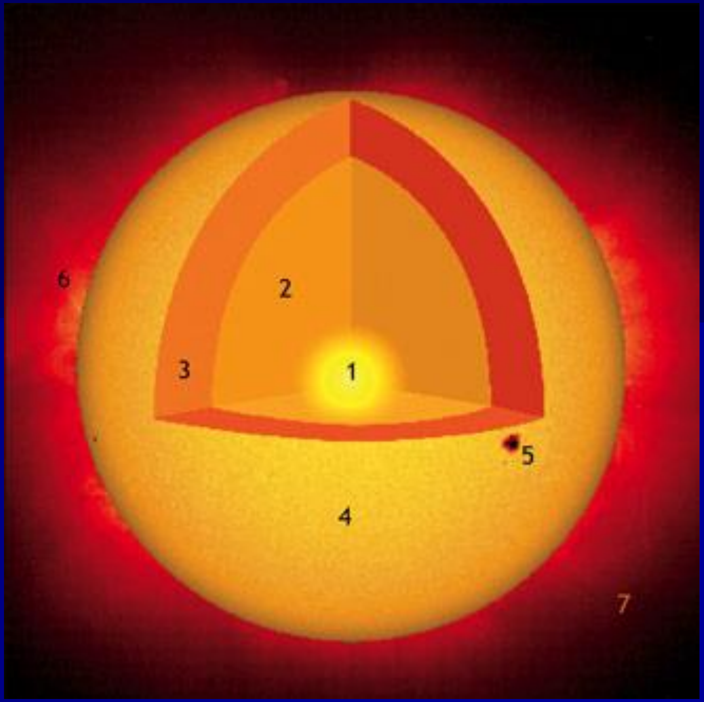


Radio & X-ray Bursts from the Sun

X ray Bursts
of
the Sun



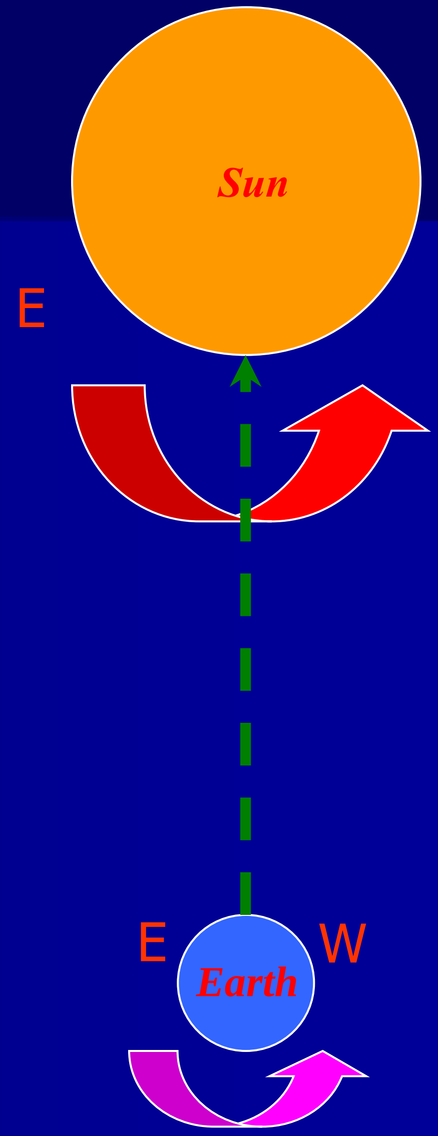
The Active Sun



The Sun and Stars
Introduction of the Active Sun
The Photosphere
The Chromosphere and the Corona
Sunspots and the Solar Cycle
Faculae, Flares and Prominences
Radio and X-ray Bursts from the Sun
The Development of an Active Region on the Sun
Effect of the Solar Cycle
Life Cycle of the Sun

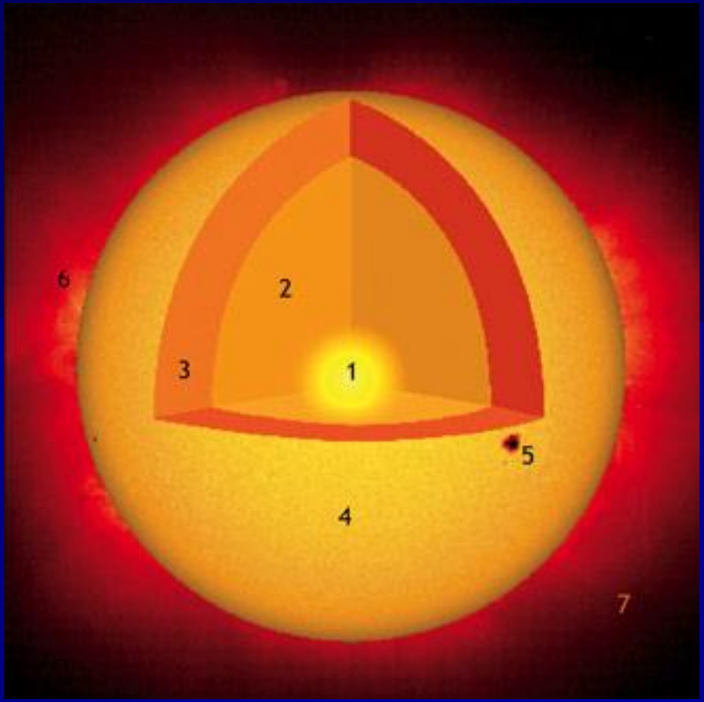
The Development of an Active Region on the Sun

Now that we have studies all the different manifestation of the solar activity, we must try to tie tem together into a chronological (time base) sequence of events. For this reason we will summarize in this section the life history of an active region of the Sun. Note that according to an established convention that Sun rotates from the east limb to the west limb. As seen from the following figure, a terrestrial observer of the Sun from a position on the noon meridian has west to his right both for the Earth and the Sun.



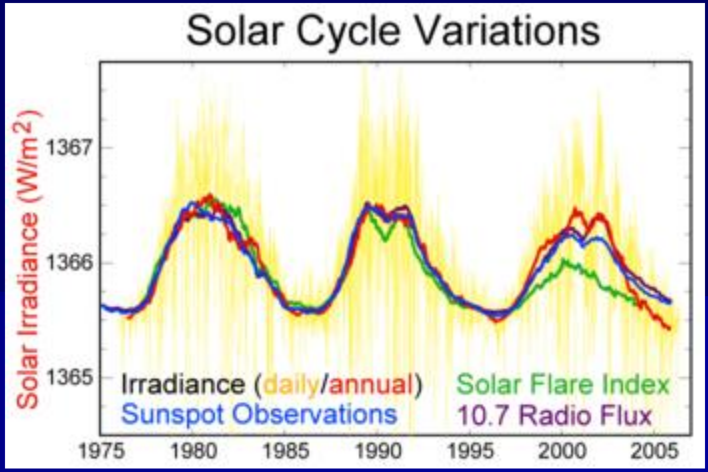
The first sign usually is the appearance of a small bright speck (dot) which is the beginning of the facular region. If this region is located near the limb it might be visible in **white light**, but at any rate it will always be visible in the H-alpha line of Hydrogen or K-line of Calcium. The magnetic field of the region increases rapidly to 100 Gauss or more and a few hours later the first dark pores (very tiny hole) appear.

The Active Sun



The Sun and Stars
Introduction of the Active Sun
The Photosphere
The Chromosphere and the Corona
Sunspots and the Solar Cycle
Faculae, Flares and Prominences
Radio and X-ray Bursts from the Sun
The Development of an Active Region on the Sun
Effect of the Solar Cycle
Life Cycle of the Sun

Effects of the Solar Cycle :



The Suns magnetic field structures its atmosphere and outer layers all the way through the corona and into the solar wind. Its spatiotemporal variations lead to a host of phenomena collectively known as solar activity. All of solar activity is strongly modulated by the solar magnetic cycle.

- Surface Magnetism
  Sunspots may exist anywhere from a few days to a few months, but they eventually decay, and this releases magnetic flux in the solar photosphere.

- Solar Irradiance (shinning)
  The total solar irradiance is the amount of solar radiative energy incident on the Earth's upper atmosphere.

Effects of the Solar Cycle :

- Short-wavelength Radiation
  With a temperature of 5870 K, the photosphere of the Sun emits very little short wavelength radiation, such as extreme UV and X-rays. The solar UV, EUV, and X-ray varies markedly in the course of the solar cycle.

- Solar Radio Flux
  Emission from the Sun at centi-metric (radio) wavelength is due to primarily to coronal plasma trapped in the magnetic fields overlying active regions.

Sunspot activity has a major effect on long distance radio communication particularly on the shortwave bands although medium wave and low VHF frequencies are also affected.

High levels of sunspot activity lead to improved signal propagation on higher frequency bands, although they also increase the level of solar noise and ionospheric disturbances. These effects are caused by impact of the increased level of solar radiation on the ionosphere.

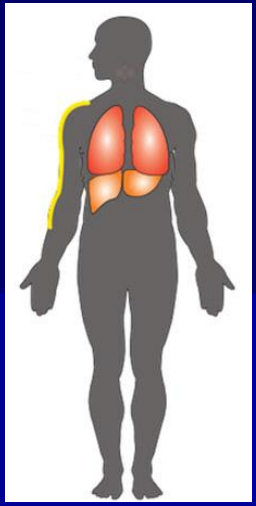
Effects of the Solar Cycle :

- Geo-effective eruptive (breaking) phenomena
  Complex coronal magnetic field structures evolve in response to fluid motions at the solar surface, and emergence of magnetic flux produced by dynamo action in the solar interior. Sometimes, these structures lose stability, leading to **coronal mass ejections** into interplanetary space. Or flares caused by sudden localized release of magnetic energy driving copious (huge) emission of **UV** and X-ray radiation as well as energetic particles.

- Cosmic Ray Flux
  The outward expansion of solar ejecta into interplanetary space provides over densities of plasma that are efficient at scattering high energy cosmic rays entering the solar system from elsewhere in galaxy.

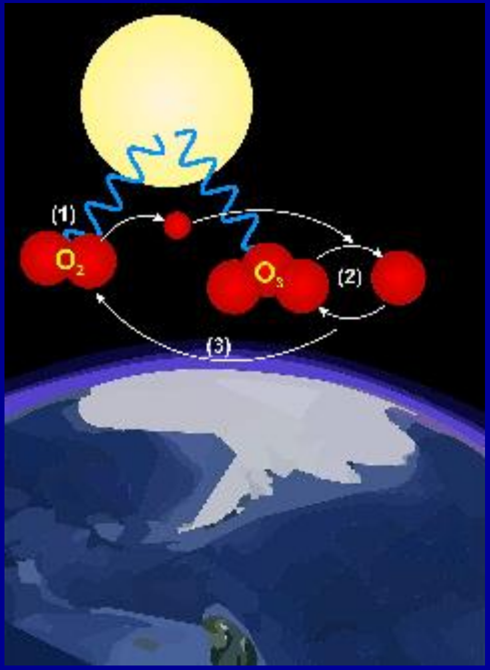
  Some high energy cosmic rays entering Earth's atmosphere collide hard enough with molecular atmospheric constituents to cause occasionally nuclear **spallation reactions**.

The Solar Cycle, Effects on Earth



- The impact of Solar cycle on living organisms has been investigated (see chronobiology). Some researchers claim to have found connections with human health.

- The amount of UV-B light at 300 nm reaching the Earth varies by as much as 400% over the solar cycle due to variations in the protective Ozone Layer. In the stratosphere, ozone is continuously regenerated by the splitting of O_2 molecules by ultraviolet light. During a solar minimum, the decrease in ultraviolet light received from the Sun leads to a decrease in the concentration of ozone, allowing increased UV-B to penetrate to the Earth's surface.

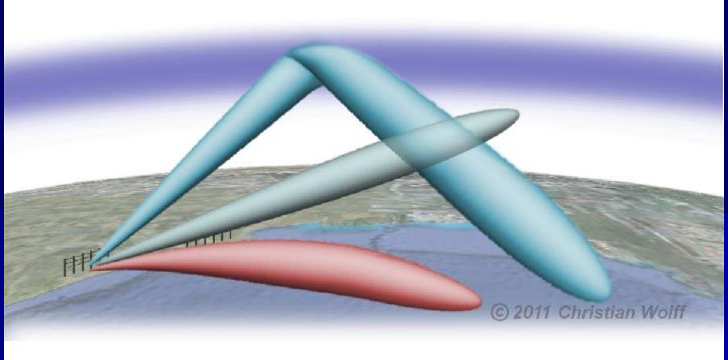


The Solar Cycle, Effects on Earth

- The sunspot cycle has been implicated in having effects on climate, and may play a part in determining global temperature.

The Solar Cycle, Effects on Earth

- Sky-wave modes of radio communication operate by bending (reflecting) radio waves (electro-magnetic radiation) off of the Ionosphere.



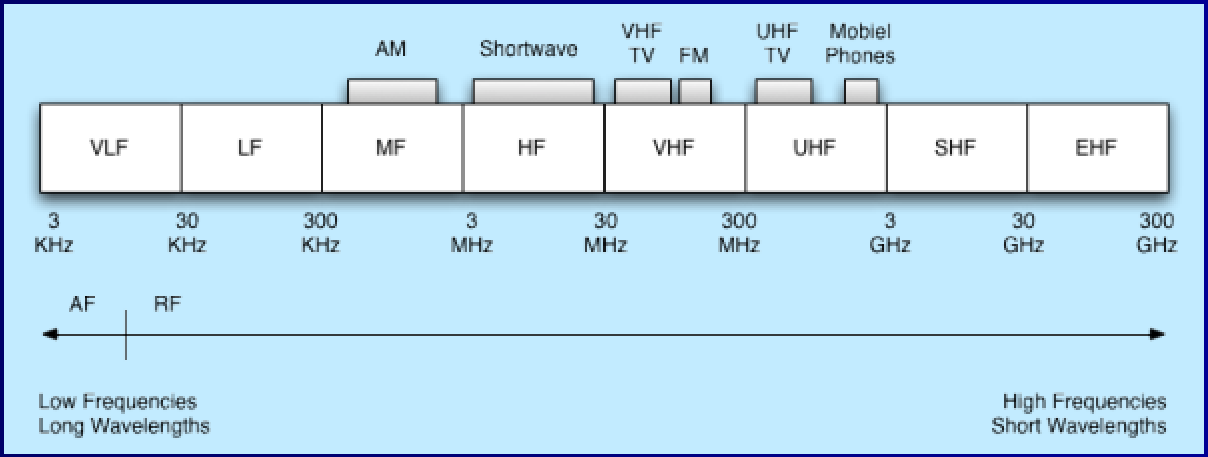
During the "peaks" of the solar cycle, the ionosphere becomes ionized by solar photons and cosmic rays.

This affects the path (propagation) of the radio wave in complex ways which can both facilitate (easy) or hinder (blocked) local and long distance communications.

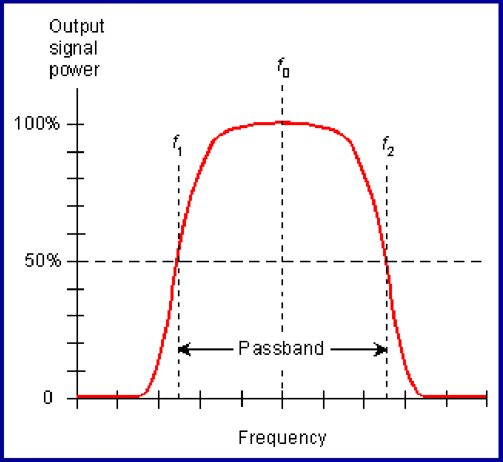
Forecasting of sky-wave modes is of considerable interest to commercial marine and aircraft communication, amateur radio operators, and short wave broad casters.

The Solar Cycle, Effects on Earth

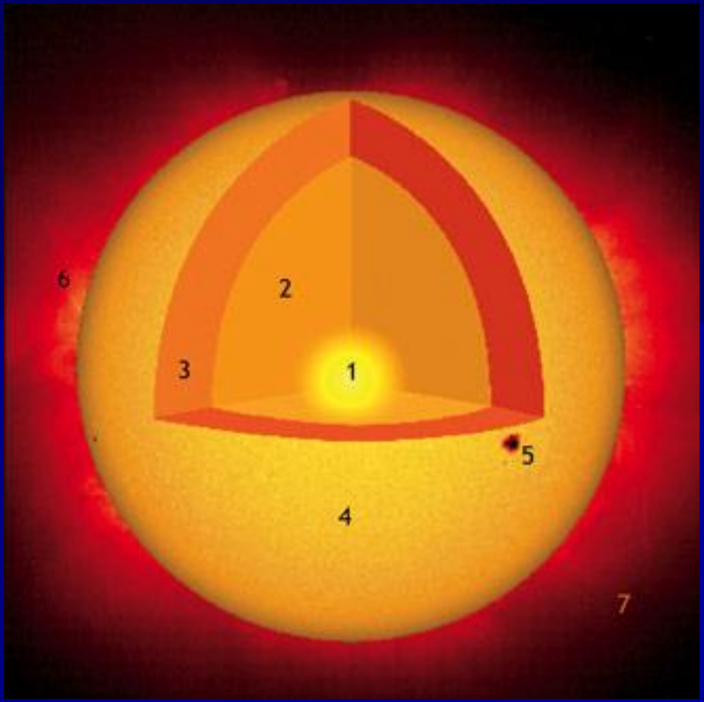
- These users utilize frequencies within the high-frequency or 'HF' radio spectrum which are most **affected by these solar and ionospheric variance**s.



- Changes in solar output affect the maximum usable frequency, a limit on the highest frequency usable for communications.

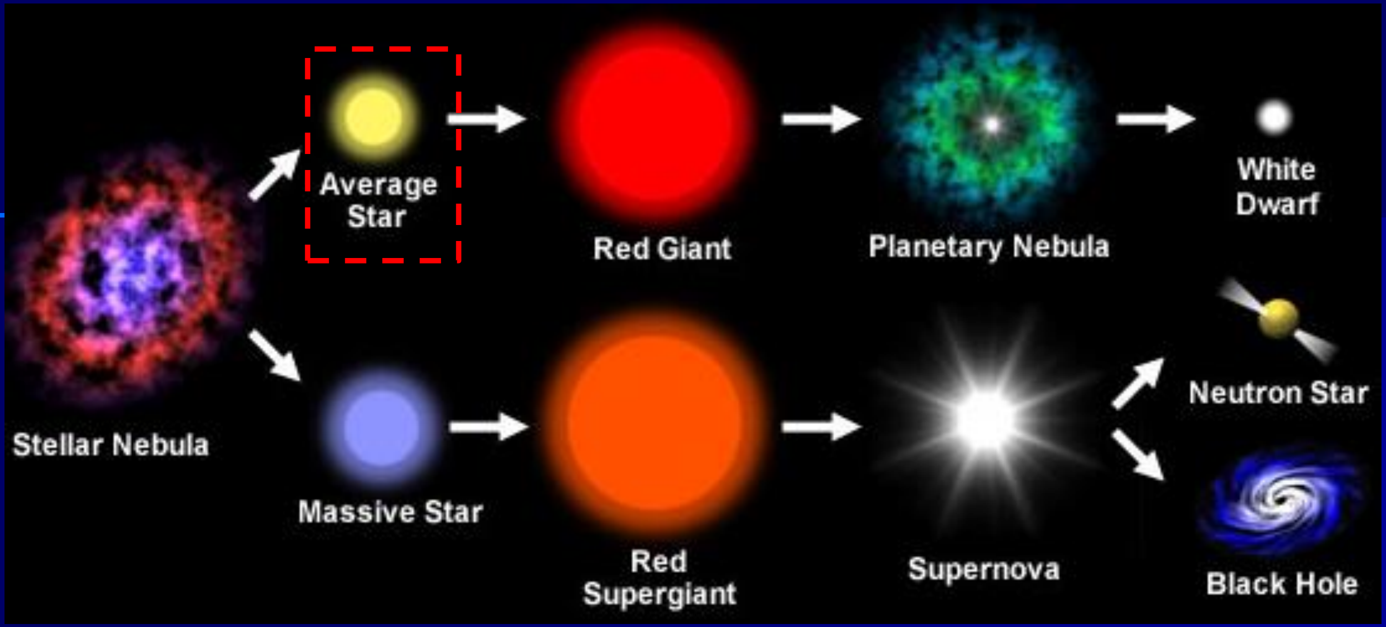


The Active Sun



The Sun and Stars
Introduction of the Active Sun
The Photosphere
The Chromosphere and the Corona
Sunspots and the Solar Cycle
Faculae, Flares and Prominences
Radio and X-ray Bursts from the Sun
The Development of an Active Region on the Sun
Effect of the Solar Cycle
Life Cycle of the Sun

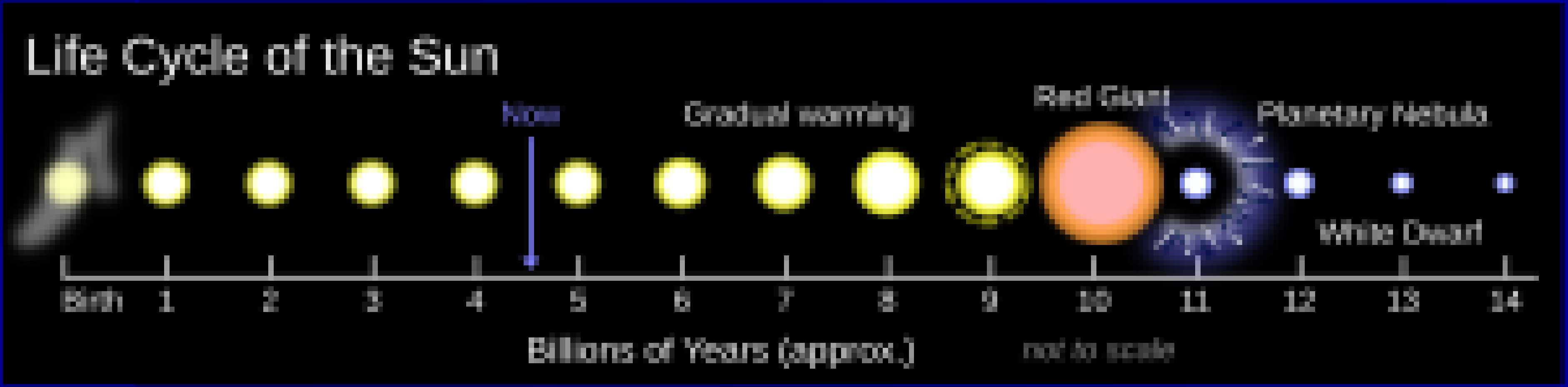
Life cycle of the Sun



The Sun was formed about **5 billion years ago** (4.57), when a hydrogen molecular cloud collapsed. The Sun is about halfway through its main-sequence evolution, during which nuclear fusion reactions in its core fuse **hydrogen into helium**. Each second, more than four million metric tons of matter are converted into energy within the Sun's core producing neutrinos and solar radiation. At this rate the Sun has so far converted around 100 Earth masses of matter into energy. The Sun will spend a total of approximately **10 billion years** as a main sequence star.

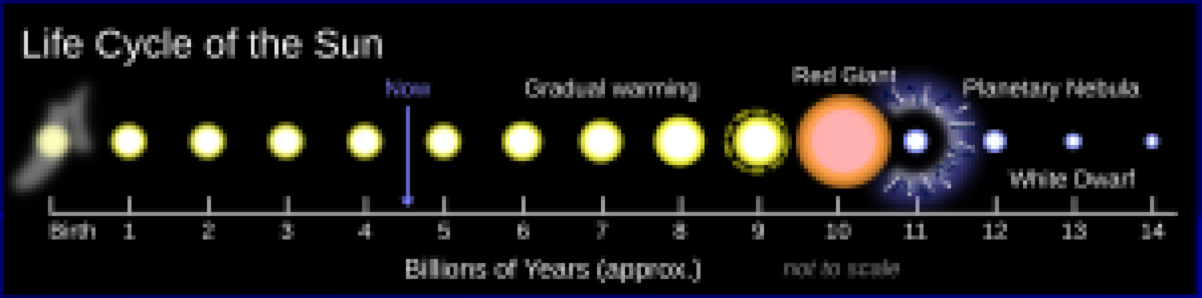
Life cycle of the Sun

The Sun does not have enough mass to explode as a supernova. Instead, in about 5 billion years, it will enter a red giant phase, its outer layers expanding as the hydrogen fuel in the core is consumed and the core contracts and heats up. **Helium fusion** will begin when the core temperature reaches around 100 million Kelvins and will produce Carbon, enterning the asympotic giant branch phase.



Life-cycle of the Sun; sizes are not drawn to scale.

Life cycle of the Sun

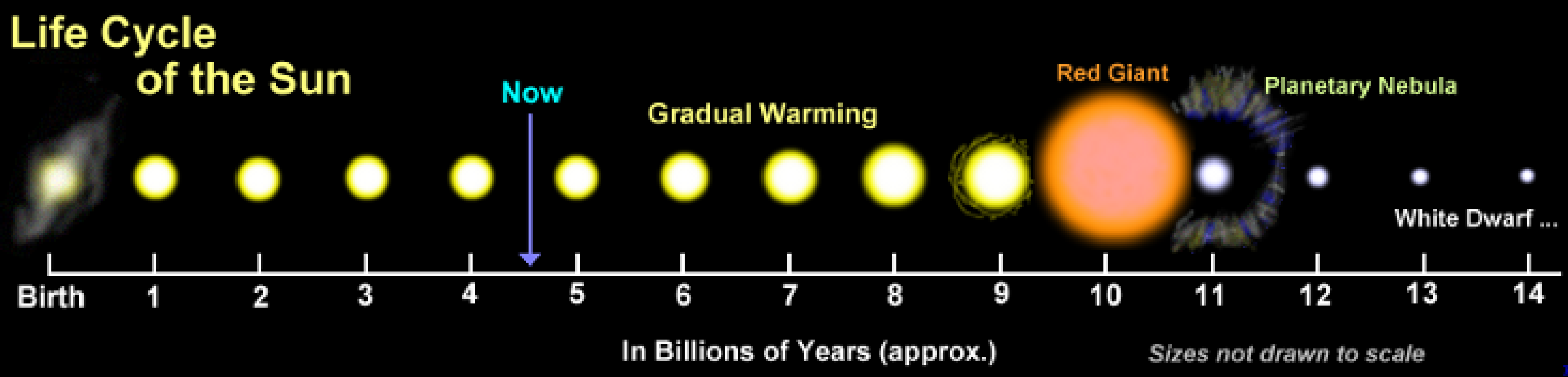


Earth's fate is precarious (can not predicted). **As a red giant, the Sun will have a maximum radius beyond the Earth's current orbit, 1 AU (~1.5×10^{11} m), 250 times the present radius of the Sun**.

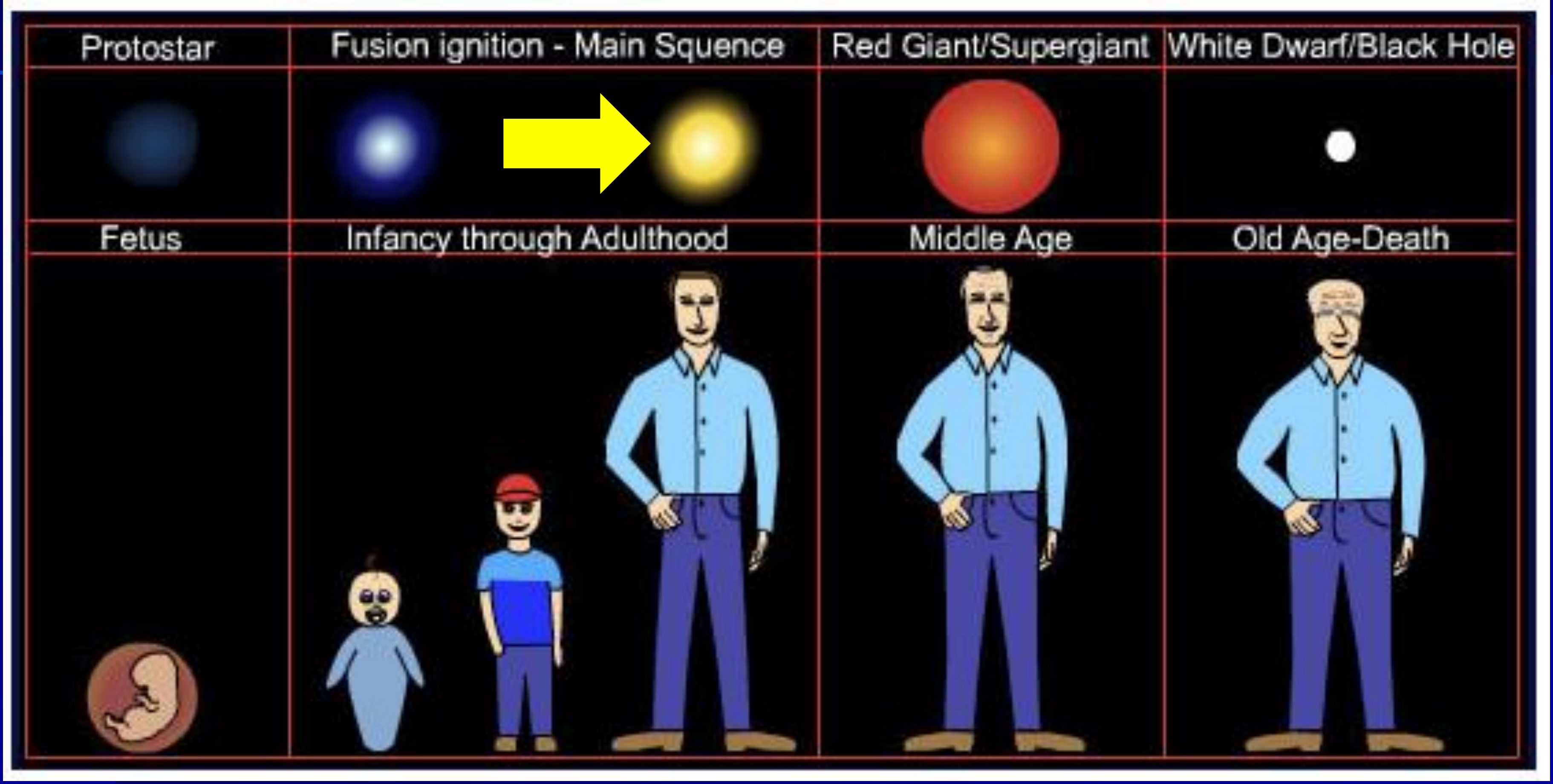
Even during its current life in the main sequence, the Sun is gradually becoming more **luminous** (about 10% every 1 billion years), and its surface temperature is **slowly rising**.

Following the red giant phase, intense thermal pulsations will cause the Sun to throw off its outer layers, forming a planetary nebula. The only object that will remain after the outer layers are ejected is the extremely hot stellar core, which will slowly cool and fade as a white dwarf over many billions of years. This **stellar** (about the planets) **evolution** scenario is typical of low-to medium mass stars.

Life cycle of the Sun



Life cycle of the Sun



Thank You !