The Sun and Eclipses: Will the Dragon Devour our Star?

Mitzi Adams, Solar Scientist, NASA/MSFC ZP13

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The Sun Itself

Never Look at the Sun Without Proper Protection!!!

Eclipse Glasses
Number 14 Welder's Glass
Appropriately Manufactured Filters for the Front of Telescopes

The Sun: a Few Numbers

Mass = 1.99 x 10^{30} kg (= 1 $M_{\odot}$)
333,000 times Earth's Mass

Average density = 1.4 g/cm^3
Air/5000

Luminosity = 3.84 x 10^{26} W (= 1 $L_{\odot}$)

Effective temperature = 5777 K (G2 V)
9930 degrees F

Core temperature = 15 x 10^6 K
28 million degrees F

Surface gravitational acceleration g = 274 m/s^2

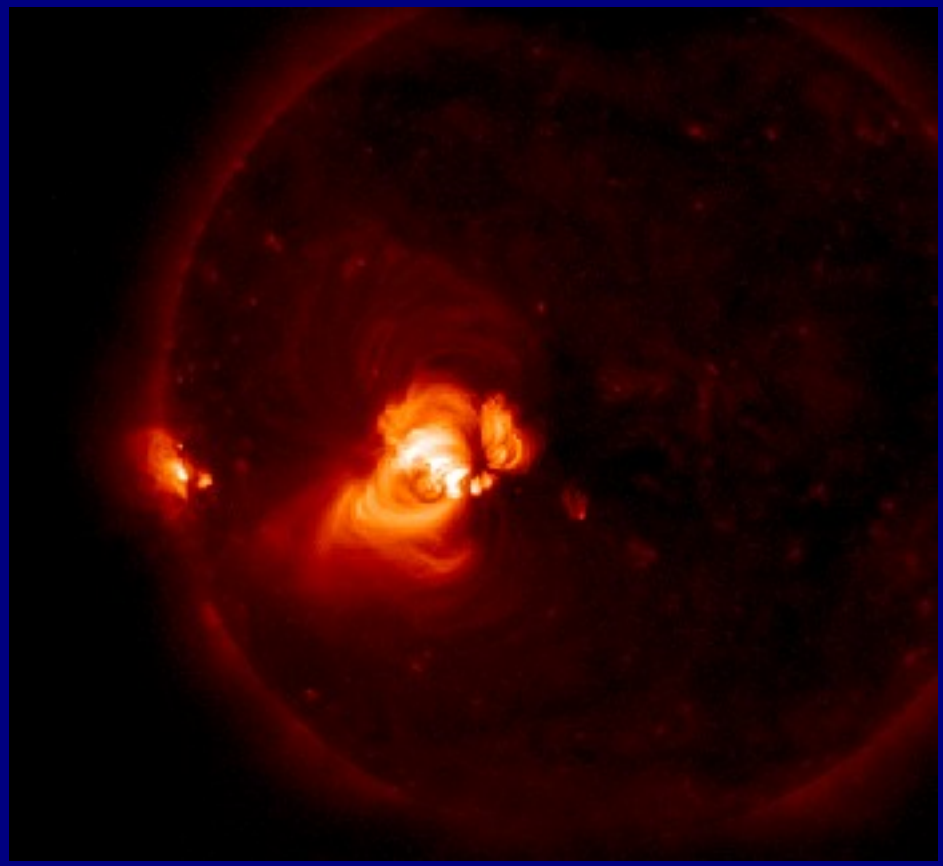
Age = 4.55 x 10^9 years (from meteorite isotopes)

Radius = 6.96 x 10^5 km

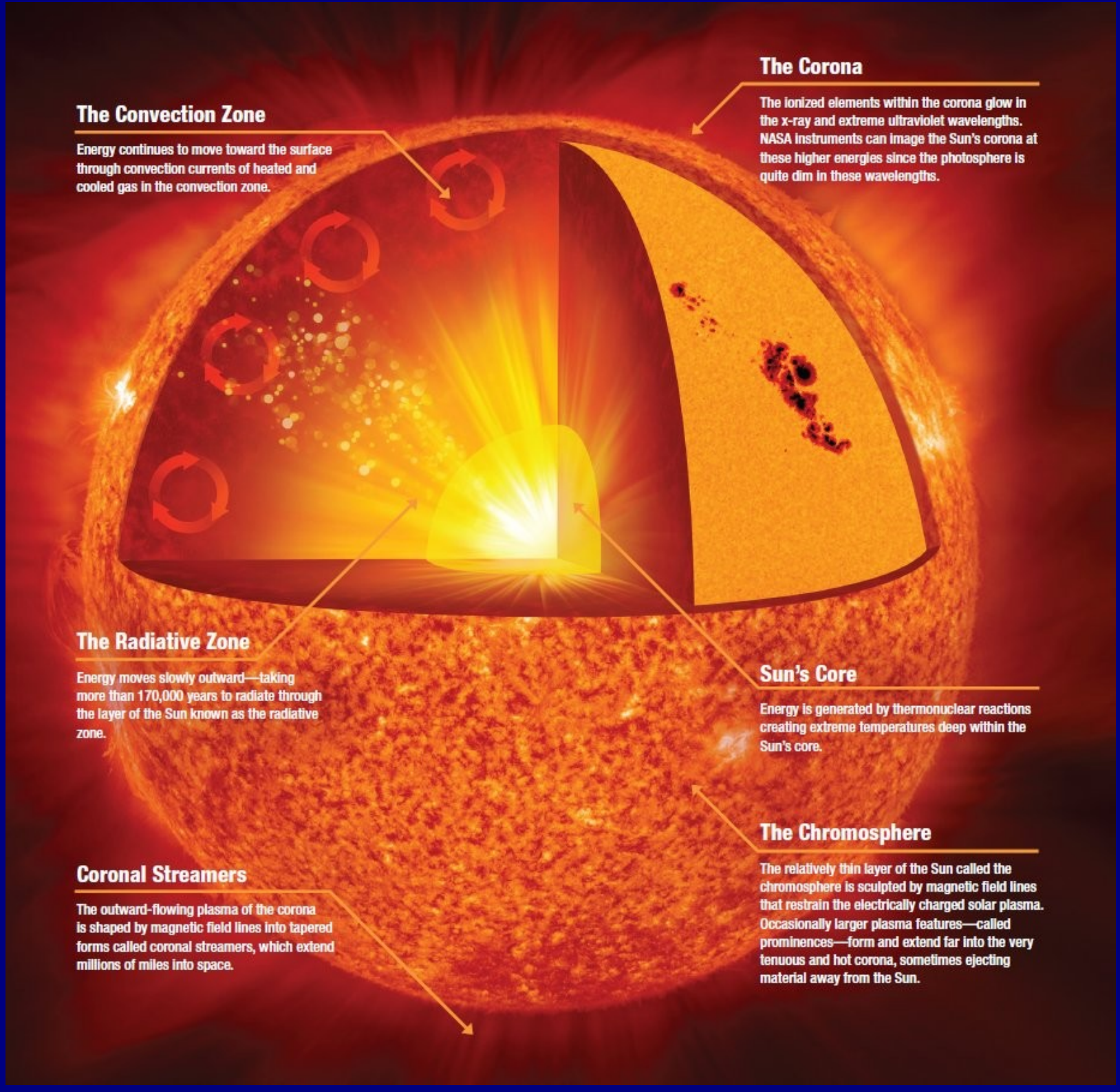
Distance = 1 AU = 1.496 (+/-0.025) 10^8 km

1 arc sec = 722±12 km on solar surface (elliptical Earth orbit)

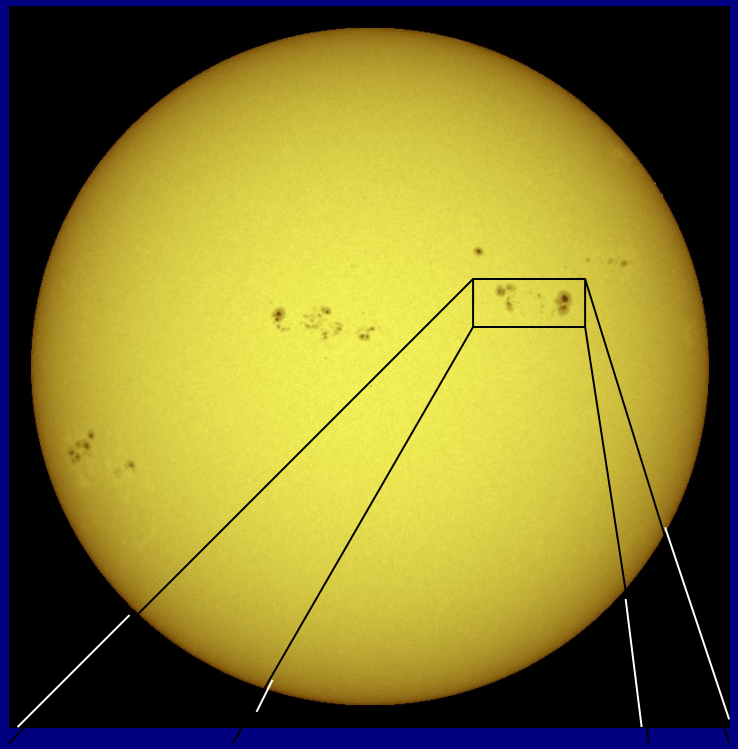
Rotation period = 27 days at equator (sidereal, i.e. as seen from Earth; Carrington rotation)

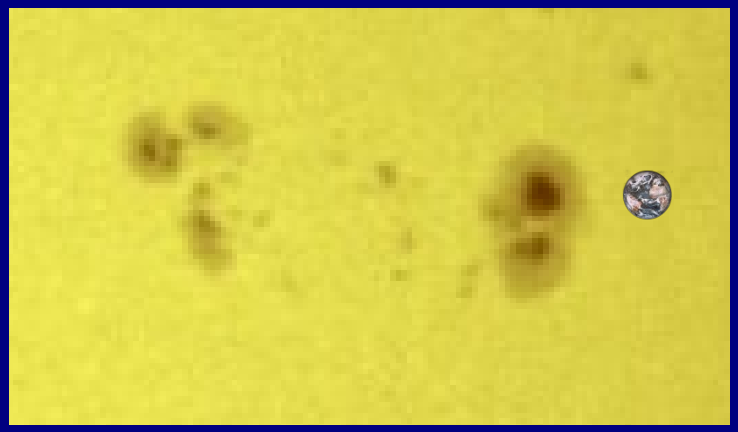


Composition: 70% H
28% He
2% C, N, O...


The Corona
The ionized elements within the corona glow in the x-ray and extreme ultraviolet wavelengths. NASA instruments can image the Sun's corona at these higher energies since the photosphere is quite dim in these wavelengths.
The Convection Zone
Energy continues to move toward the surface through convection currents of heated and cooled gas in the convection zone.
The Radiative Zone
Energy moves slowly outward—taking more than 170,000 years to radiate through the layer of the Sun known as the radiative zone.
Sun's Core
Energy is generated by thermonuclear reactions creating extreme temperatures deep within the Sun's core.
The Chromosphere
The relatively thin layer of the Sun called the chromosphere is sculpted by magnetic field lines that restrain the electrically charged solar plasma. Occasionally larger plasma features—called prominences—form and extend far into the very tenuous and hot corona, sometimes ejecting material away from the Sun.
Coronal Streamers
The outward-flowing plasma of the corona is shaped by magnetic field lines into tapered forms called coronal streamers, which extend millions of miles into space.

Sunspots

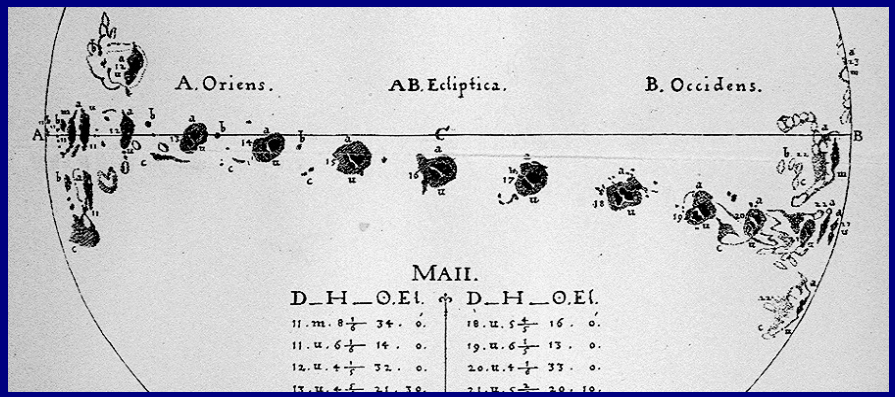


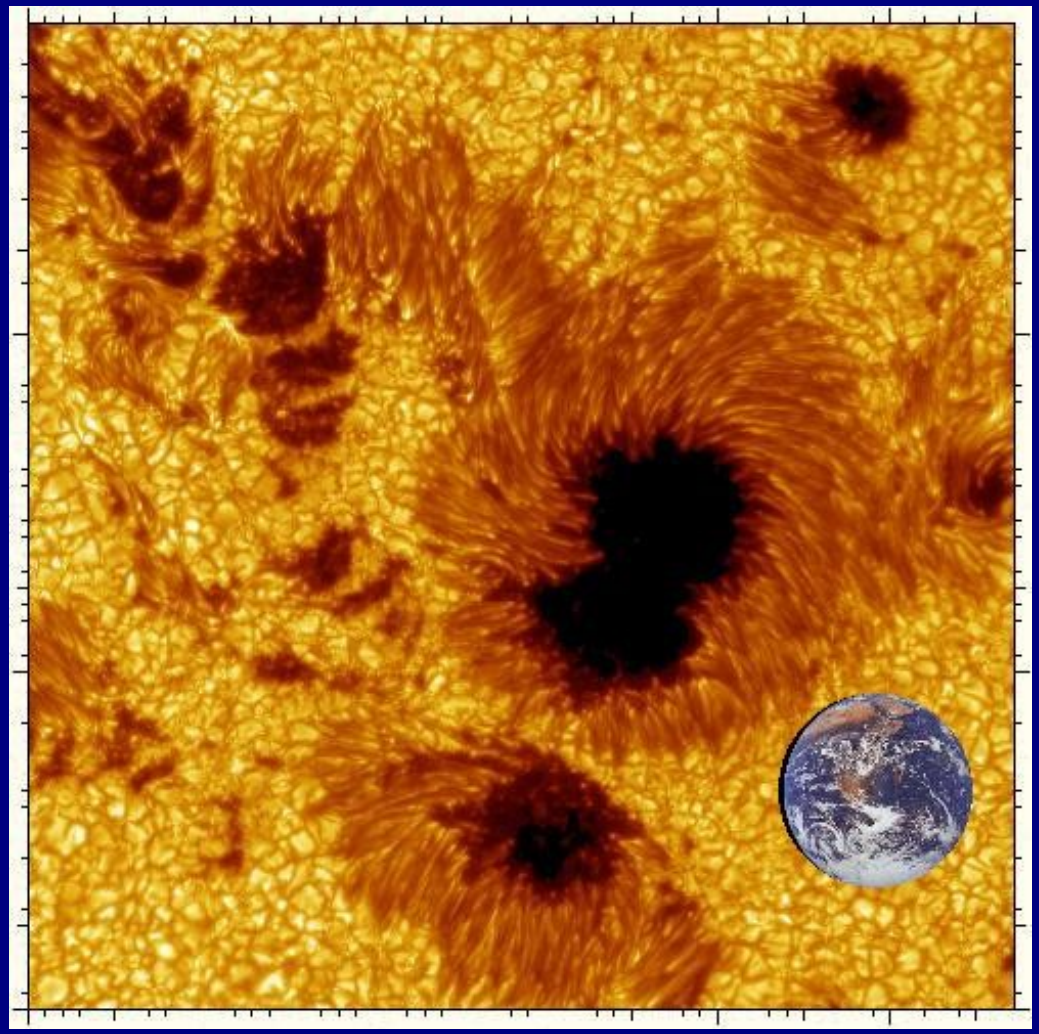


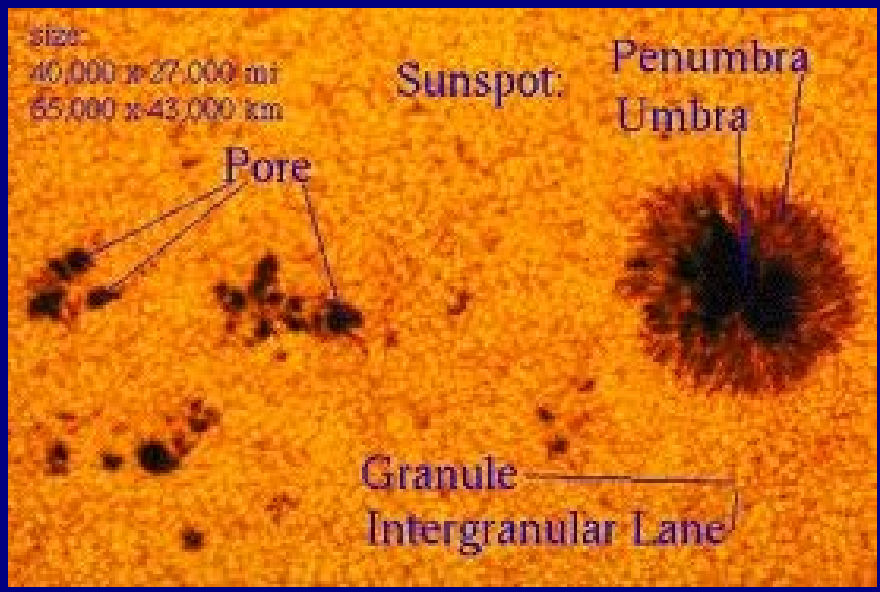
Sunspots are dark (and cooler) regions on the surface of the Sun. They have a darker inner region (the Umbra) surrounded by a lighter ring (the Penumbra).

Sunspots usually appear in groups that form over hours or days and last for days or weeks.

The earliest sunspot observations (c. 1609) indicated that the Sun rotates once in about 27 days.

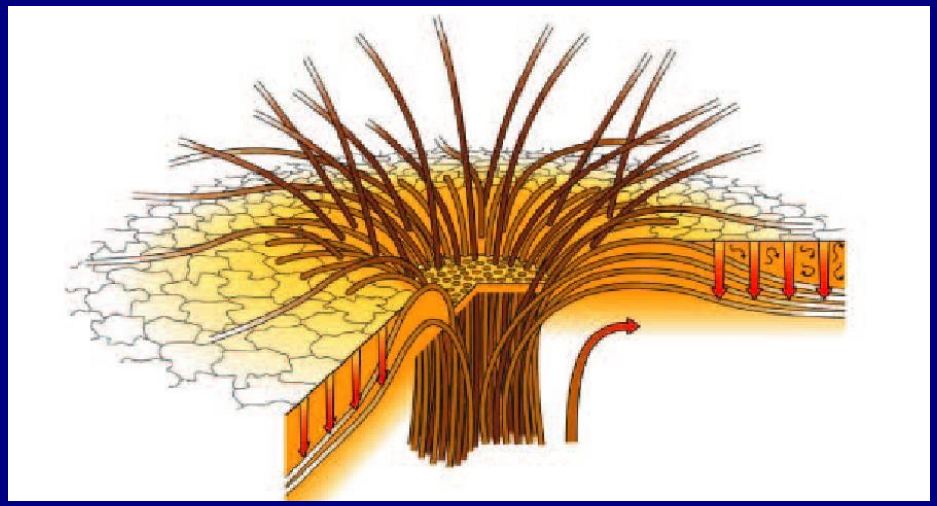


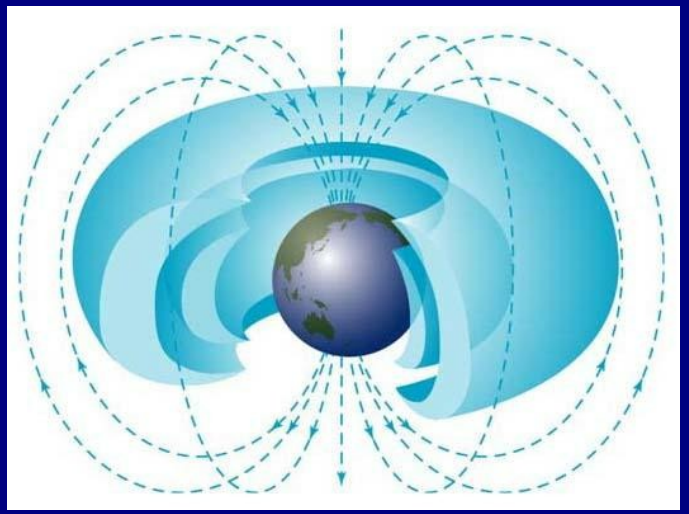



size:
40,000 x 27,000 mi
65,000 x 43,000 km
Sunspot:
Penumbra
Umbra
Pore
Granule
Intergranular Lane

Sunspot Structure

Sunspots are regions where intense magnetic fields break through the surface of the Sun. The magnetic field strengths are typically about 6000 times stronger than the Earth's magnetic field.





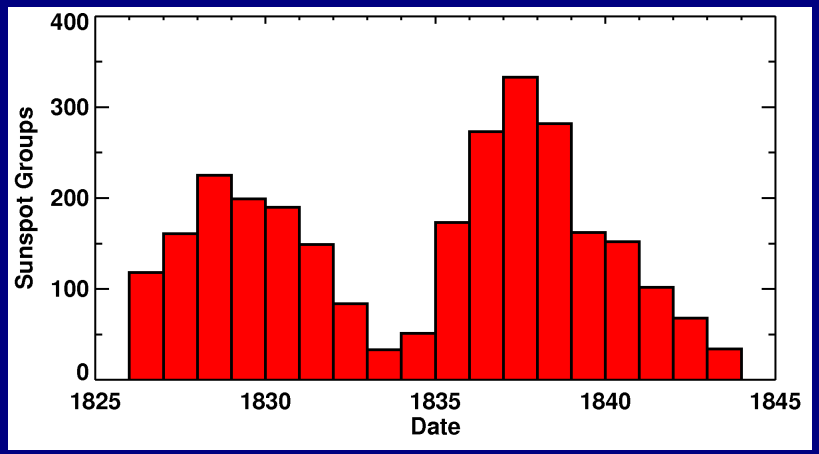
Magnetic fields and the ionized gases within the Sun are intimately tied together. Where magnetic pressure dominates – the gas follows the magnetic field. Where gas pressure dominates – the magnetic field follows the gas. In sunspots the magnetic pressure dominates – this inhibits the convective transport of heat and makes sunspots cooler.

The Solar Cycle

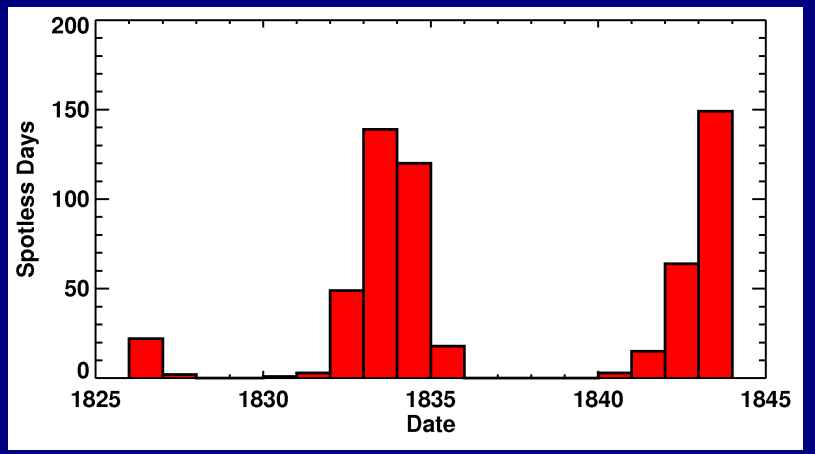
Sunspot Cycle Discovery

Astronomers had been observing sunspots for over 230 years before Heinrich Schwabe, an amateur astronomer in Dessau, Germany, discovered in 1844 that the number of sunspot groups and the number of days without sunspots increased and decreased in cycles of about 10-years.

Schwabe's data for 1826 to 1843

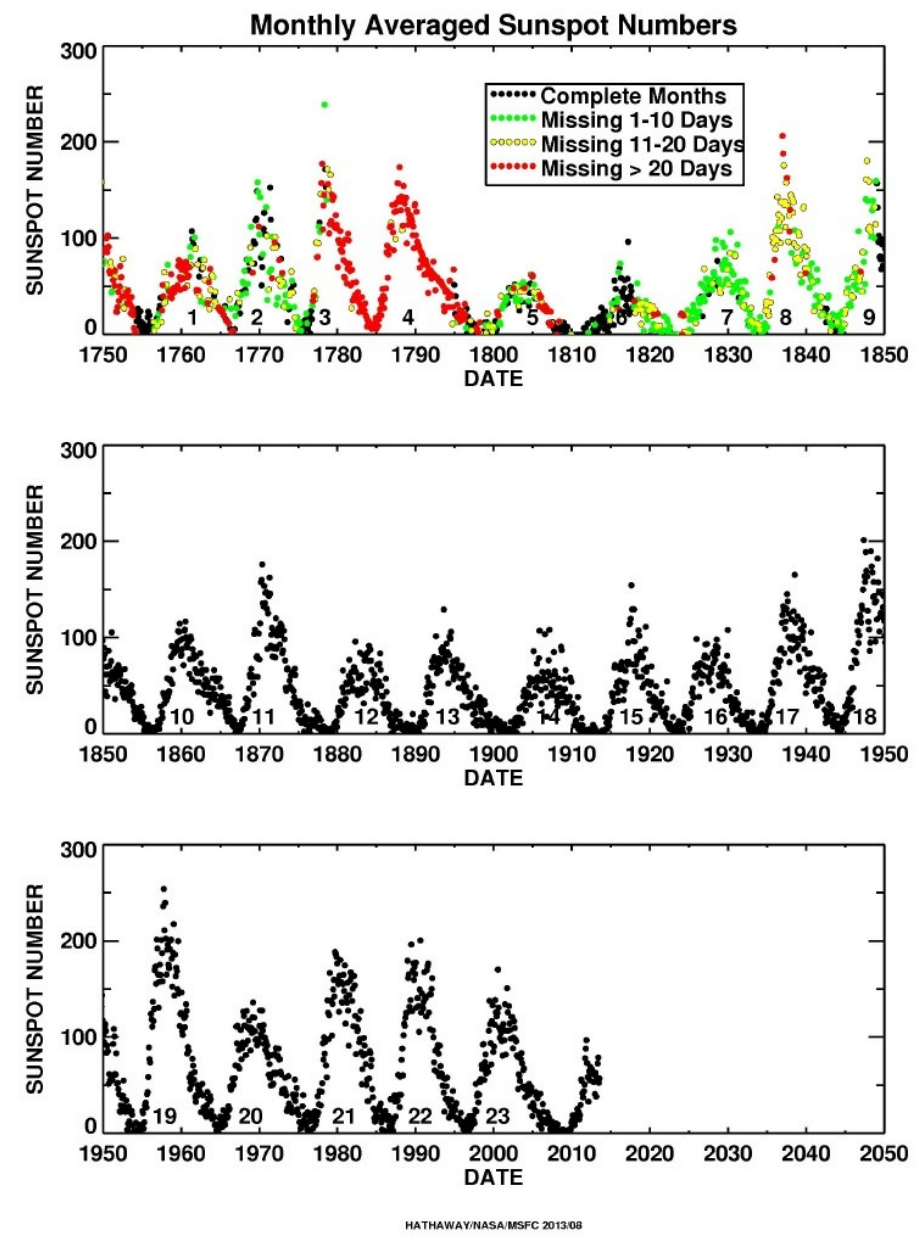


Number of Sunspot Groups per Year



Number of Spotless Days

23 Full Cycles



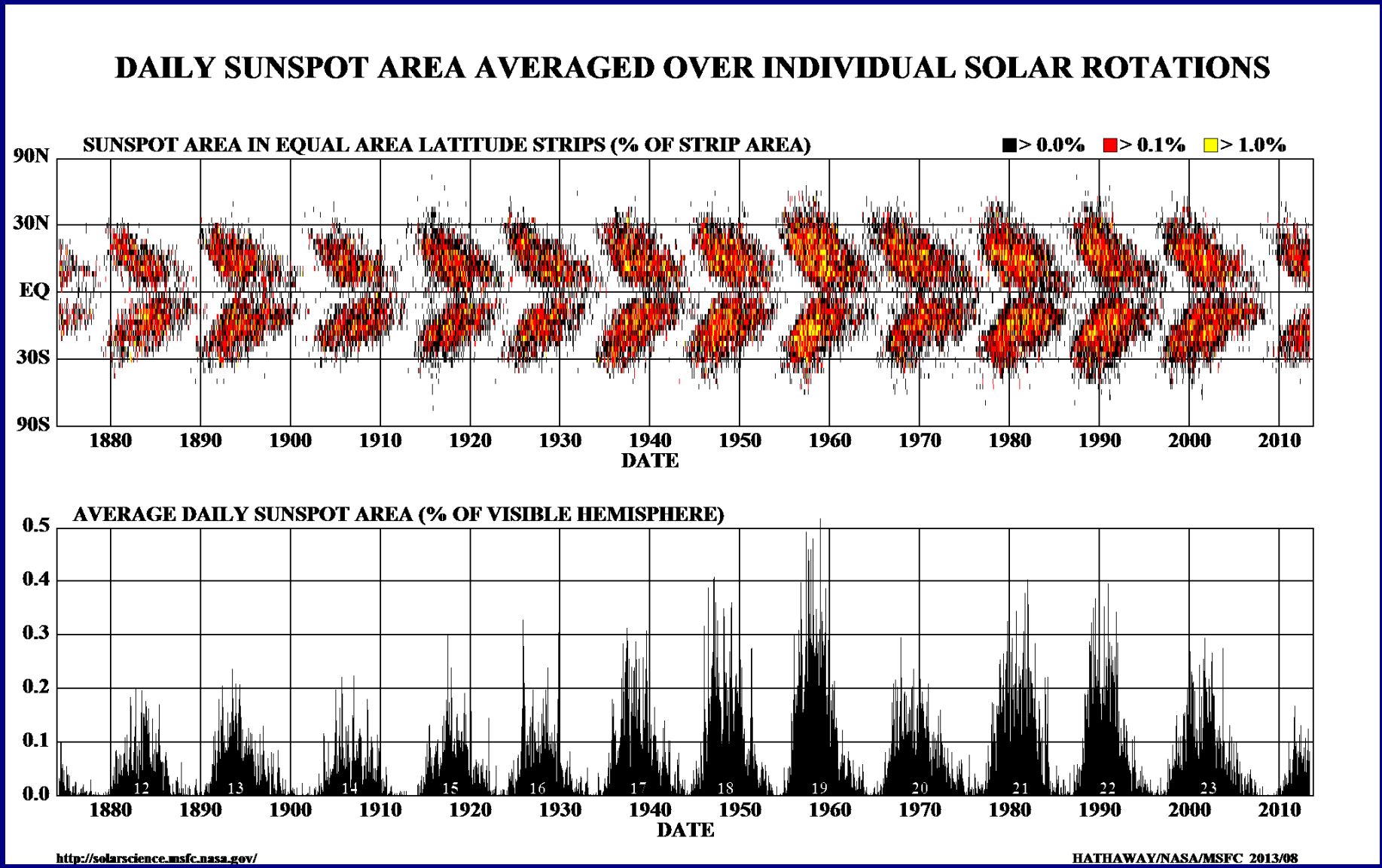
Shortly after Schawbe discovery Rudolf Wolf proposed using a "Relative" Sunspot Number count. While there were many days without observations prior to 1849, sunspots have been counted on every day since. To this day we continue to use Wolf's Relative Sunspot Number and his cycle numbering.

The average cycle lasts about 11 years, but with a range from 9 to 14.

The average amplitude is about 100, but with a range from 50 to 200.

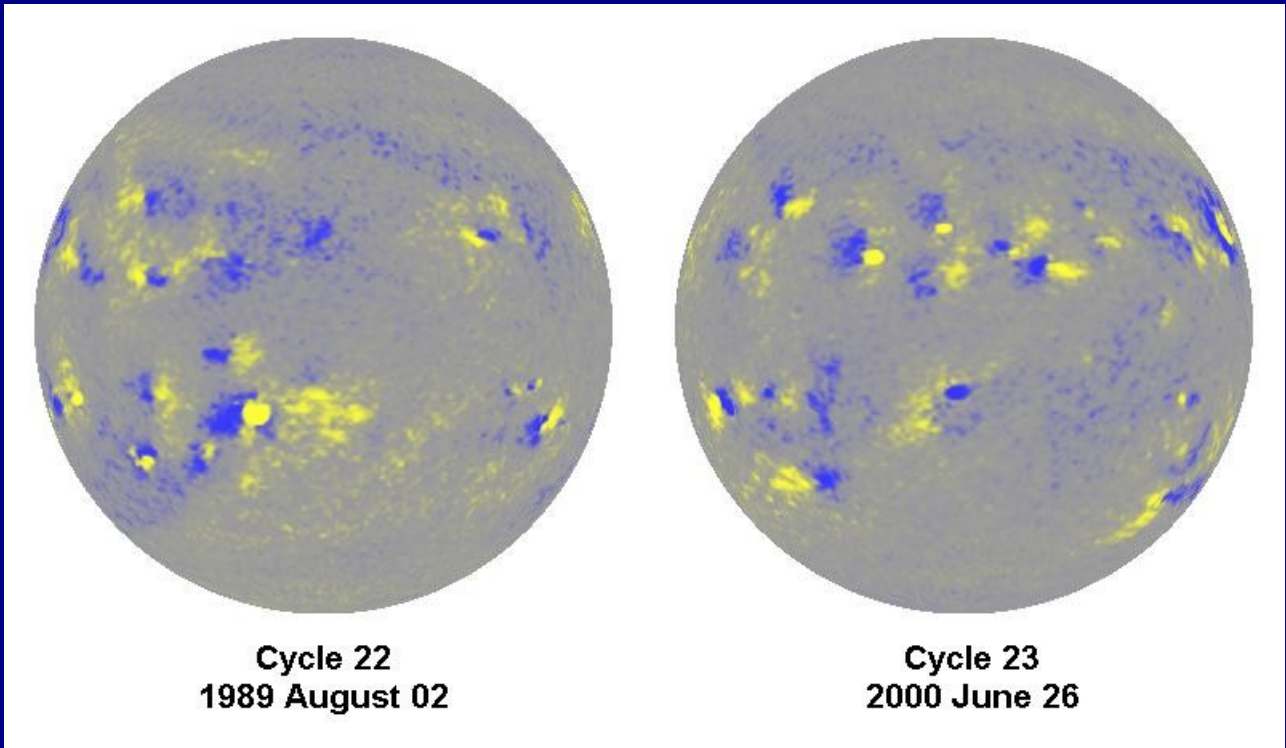
Sunspot Latitudes

Sunspots appear in two bands on either side of the equator. These bands drift toward the equator as the cycle progresses. Big cycles have wider bands that extend to higher latitudes. Cycles overlap by 2-3 years.



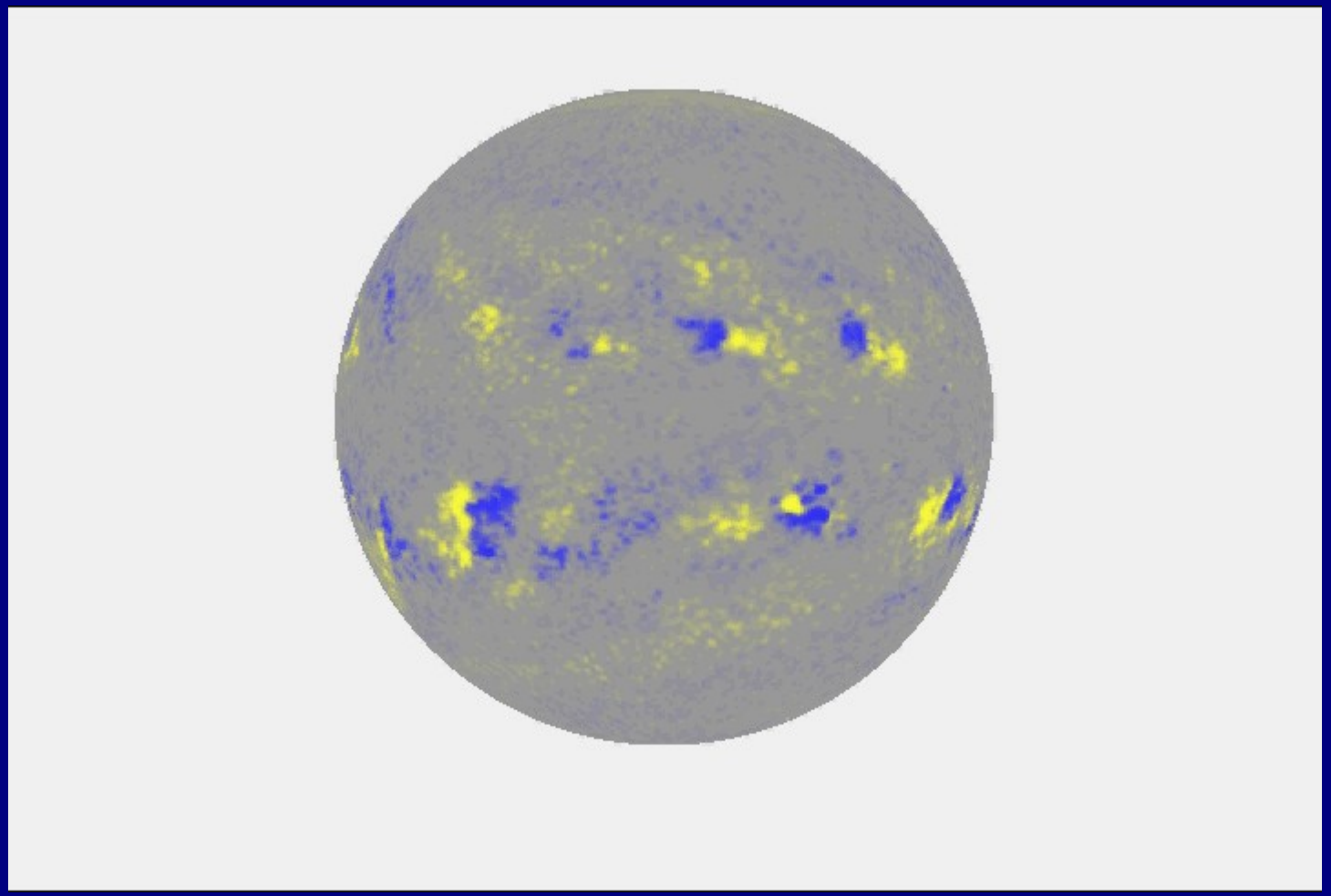
Hale's Magnetic Polarity Law

In 1919 Hale (along with Ellerman, Nicholson, and Joy) found that the magnetic field in sunspots followed a definite law, "Hale's Law" such that: *"…the preceding and following spots … are of opposite polarity, and that the corresponding spots of such groups in the Northern and Southern hemispheres are also opposite in sign. Furthermore, the spots of the present cycle are opposite in polarity to those of the last cycle".*



Three Solar Cycles in 3D

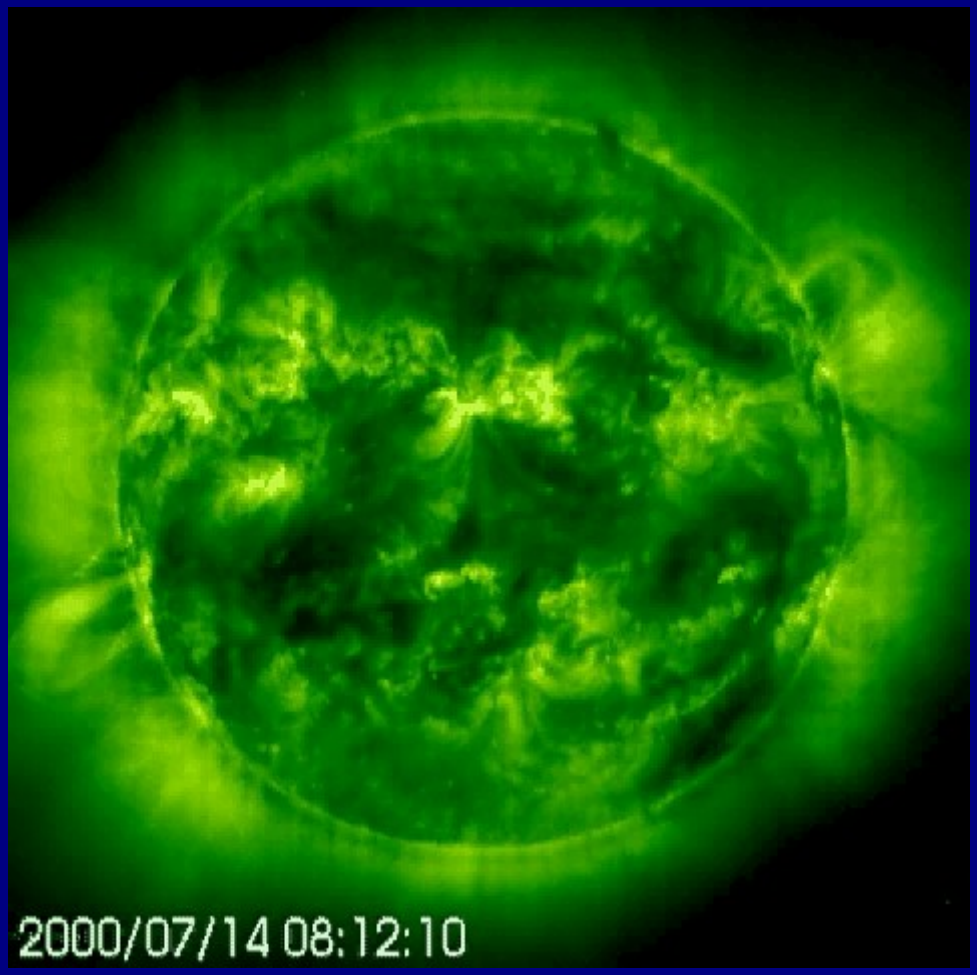
In addition to these magnetic polarity changes and the equatorward drift of the sunspot latitudes, there are important flows on the surface and within the Sun: *Differential Rotation* – faster at the equator, slower near the poles; and *Meridional Flow* – flow from the equator toward the poles along the surface.



Effects of the Sunspot Cycle

Explosive Events

- Solar flares – 10-1000X excess in X-rays and Extreme Ultraviolet (EUV)
- Coronal Mass Ejections (CMEs) – magnetic clouds blasted off the Sun
- Solar Energetic Particles – relativistic particles from flares and CMEs



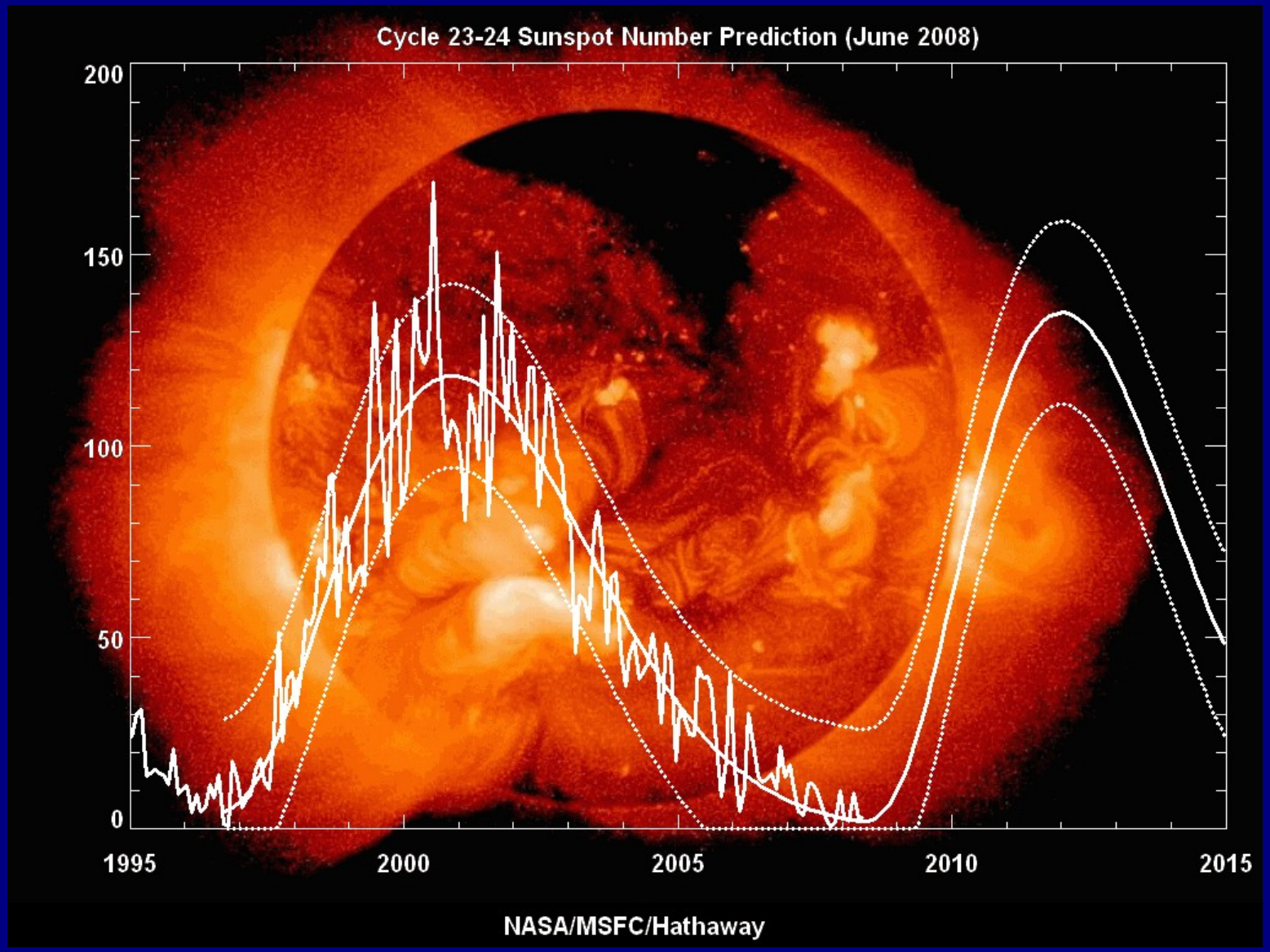
CME Impact on Earth

Magnetized clouds of plasma blasted off of the Sun as CMEs can impact the Earth's environment – distorting the magnetic field surrounding the Earth and producing energetic particles that stream into the Earth's atmosphere to create aurorae.

Space Weather

Solar Cycle Predictions

The Deep Solar Minimum Following Cycle 23



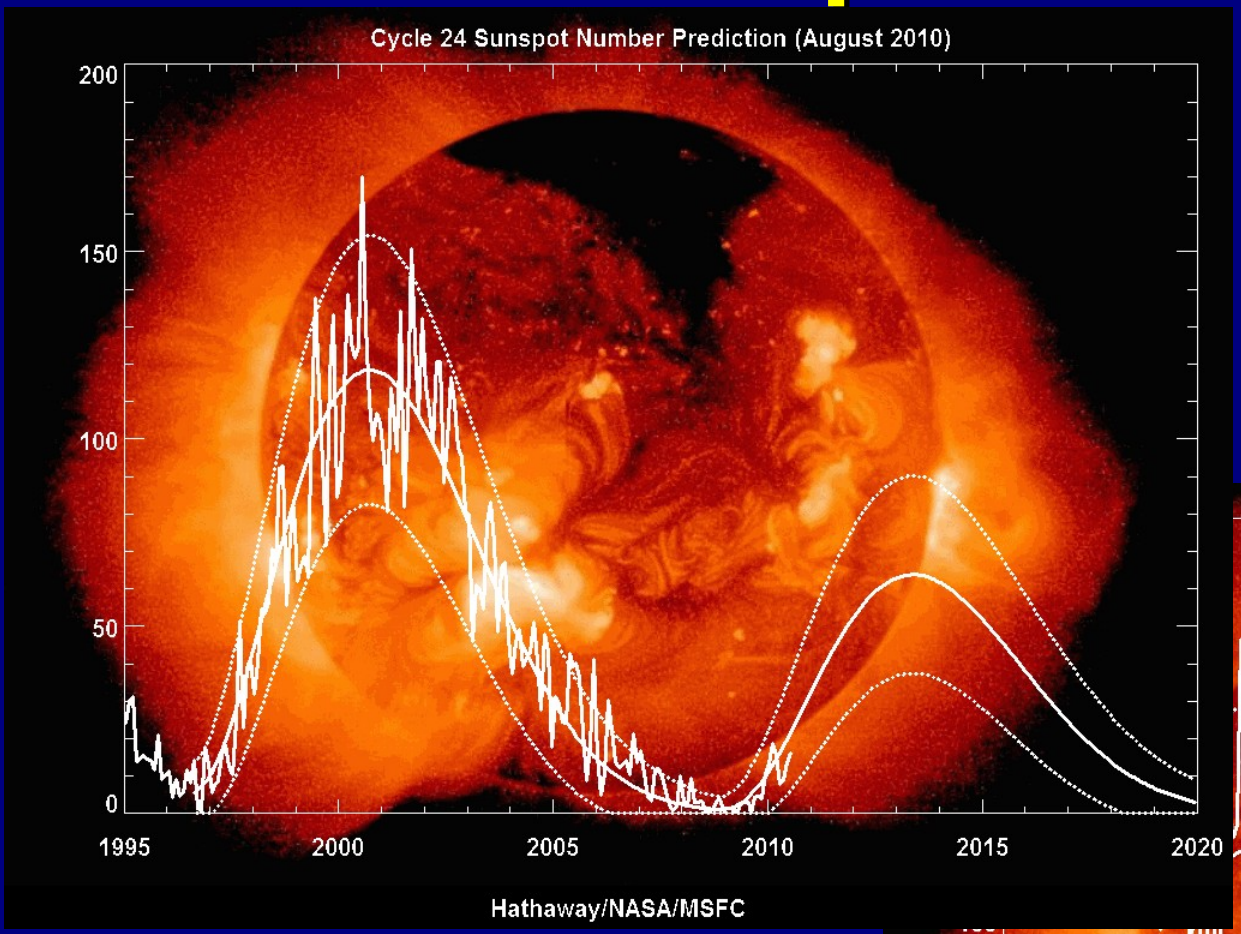
Spotless Days:
311 in 1913
250 in 1912

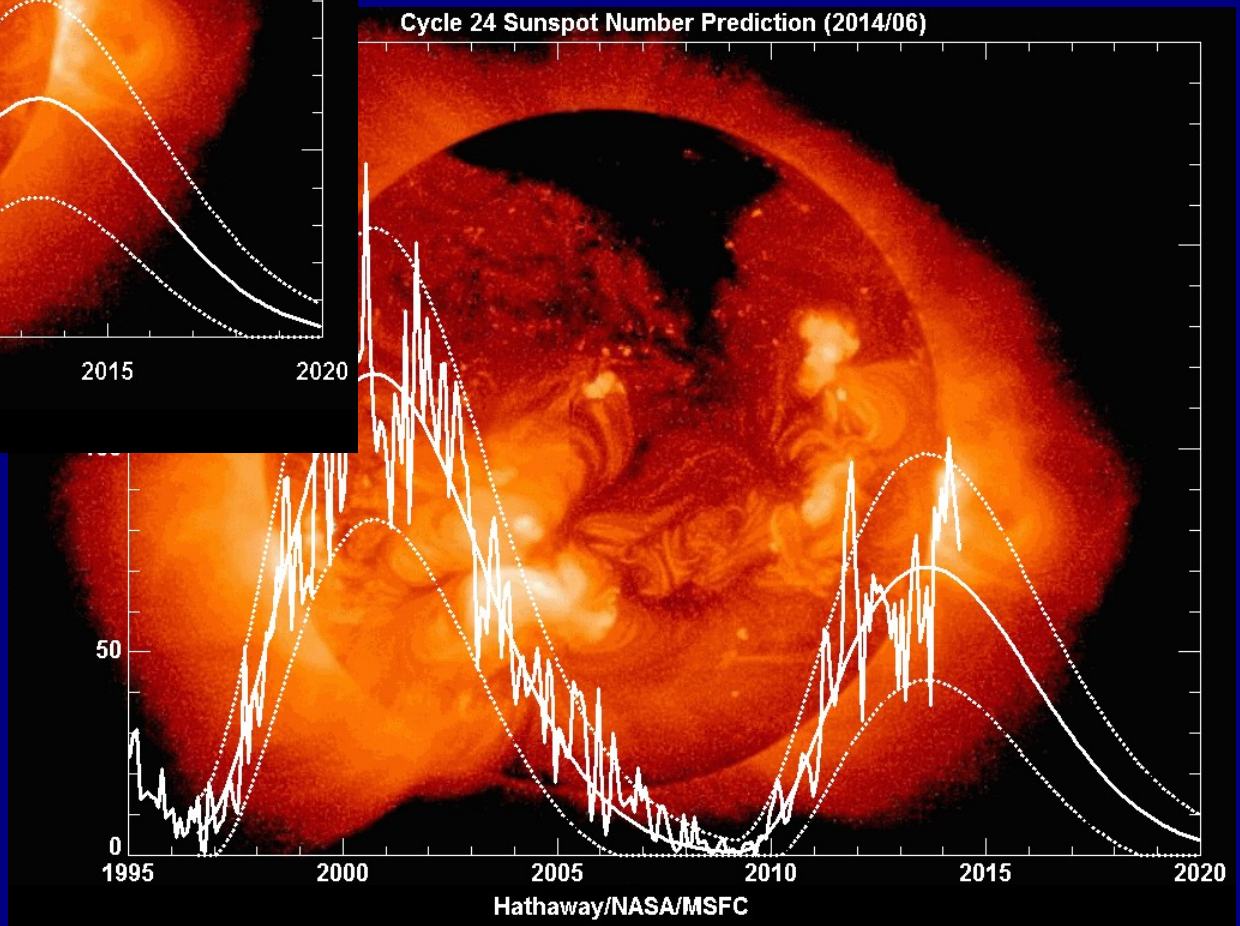
274 in 2009
266 In 2008

Length of cycle:
Cycle 23 – 12.6 yrs
Cycle 22 – 9.7 yrs
Cycle 21 – 10.3 yrs
Cycle 20 --11.7 yrs

Cycle 13 – 11.9 yrs
1890-1902
Cycle 14 --11.5 yrs
1902-1913
Cycle 15 – 10 yrs
1913-1923

2010 Compared to This Year





Summary So Far

Through the use of observations, mathematics,mathematical tools (such as graphs), inference, testing, and prediction we have gathered evidence that there are sunspots, a solar cycle, and have begun to understand more about our star, the Sun.

We are making progress in understanding the cause of the solar cycle.

Solar cycle 24 has peaked

Cycle 24 will be the smallest cycle in 100 years.

Even so, there may still be large flares/CMEs in this part of the cycle.

Solar Eclipses

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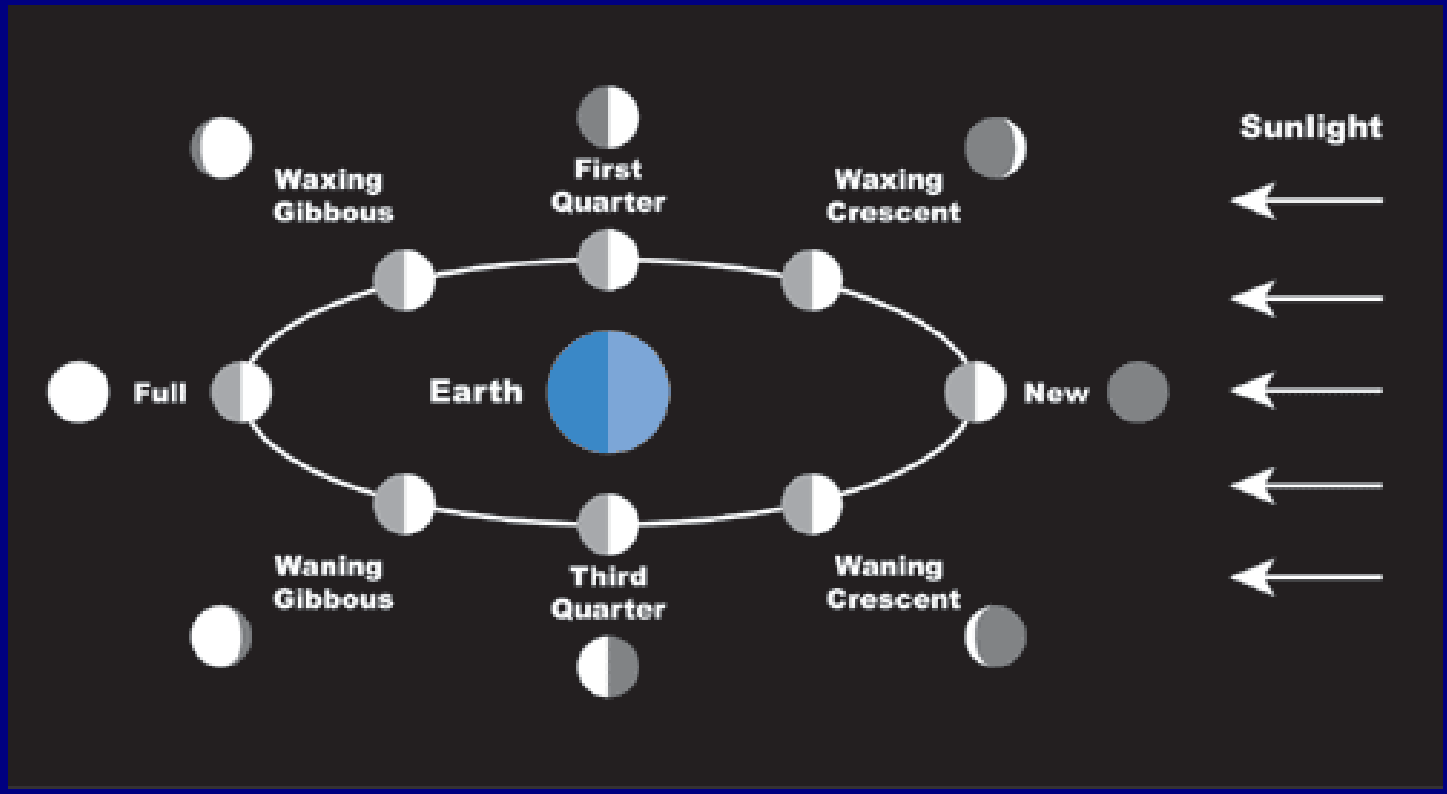
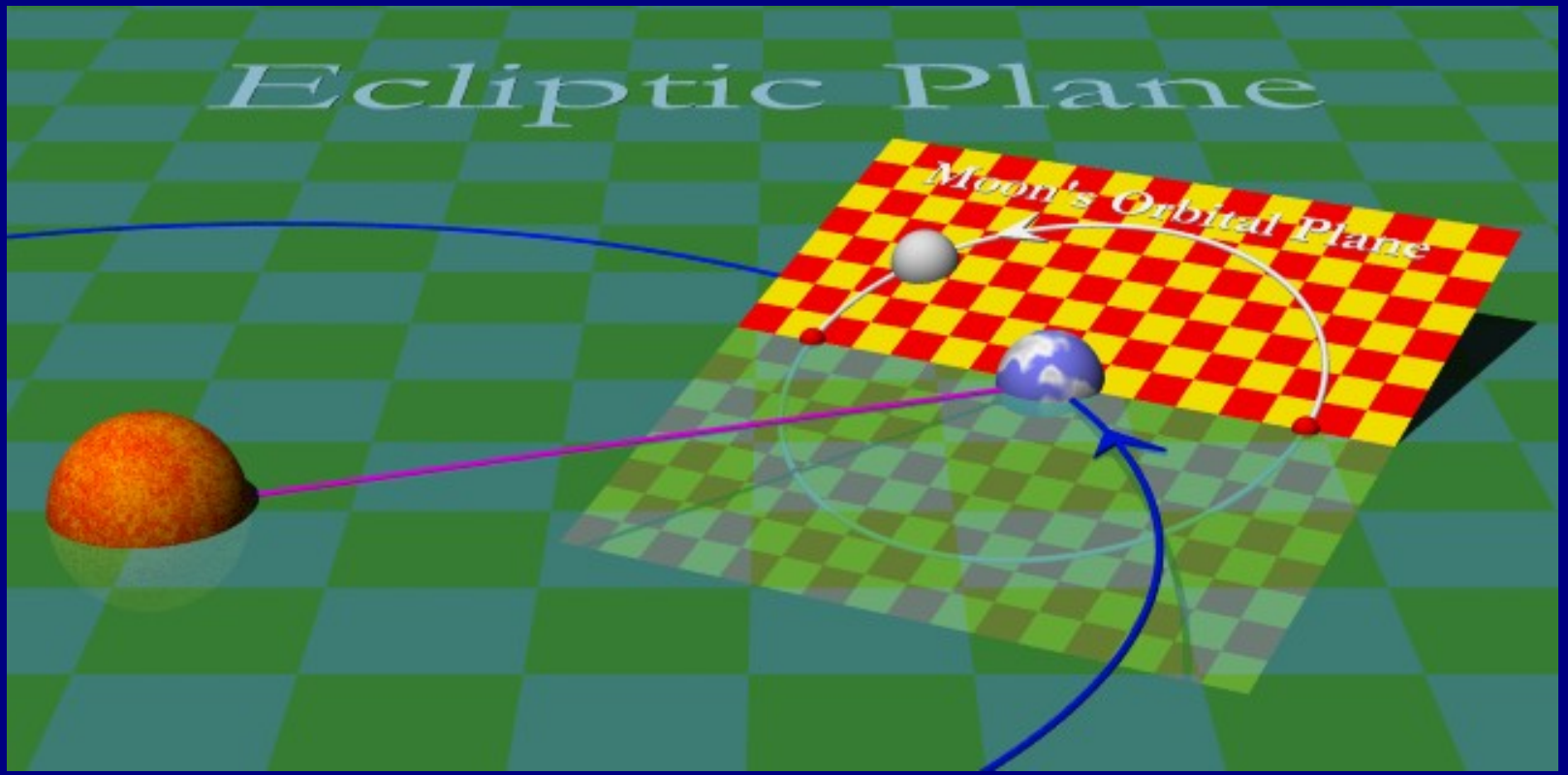
Solar Eclipse Geometry

Phases of the Moon



Solar Eclipse Geometry

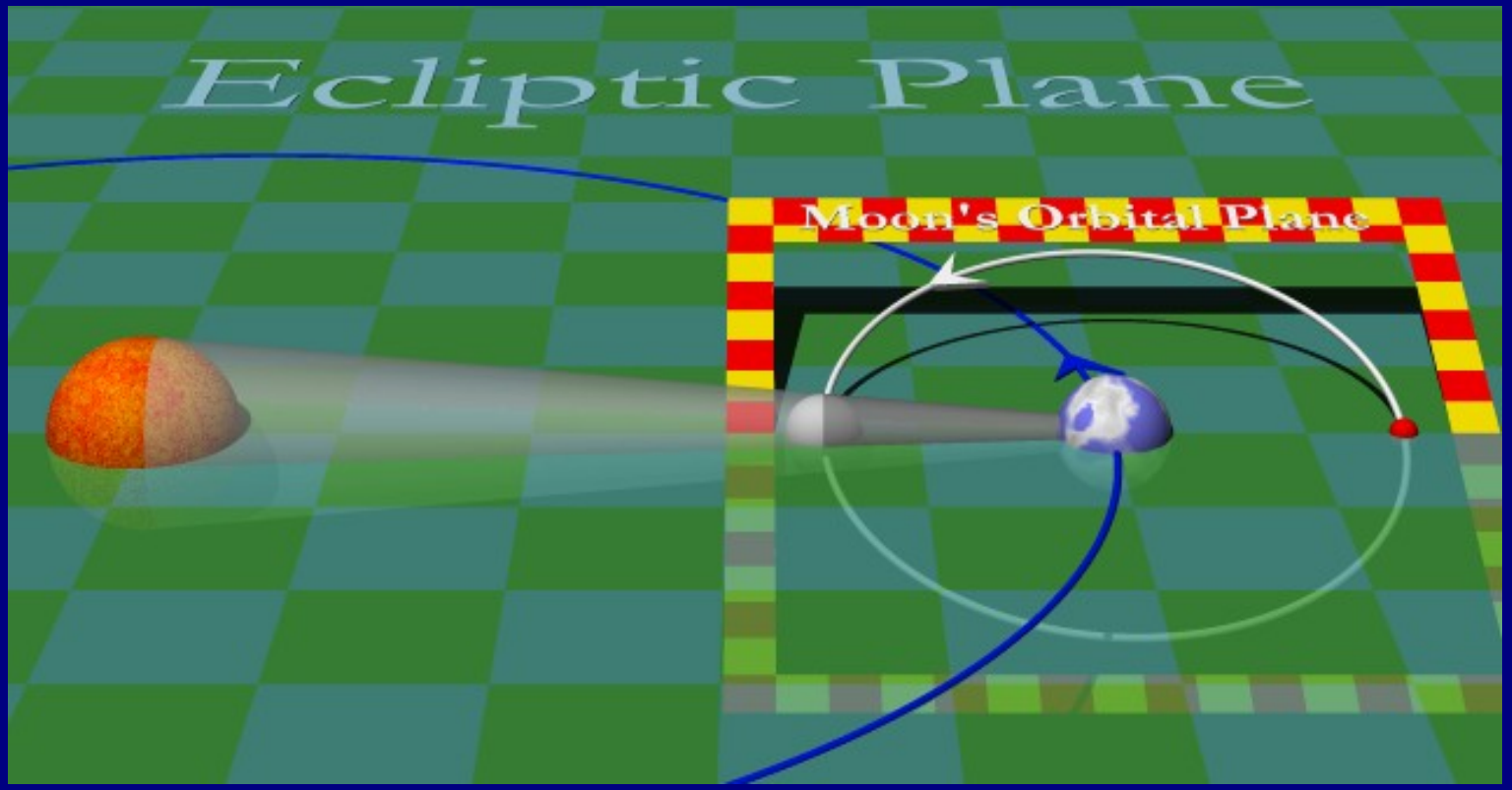
Orbital Nodes



(From: http://moonblink.info)

Solar Eclipse Geometry

An eclipse will happen



(From: http://moonblink.info)

Solar Eclipse Geometry

An eclipse in Progress

Solar Eclipse Observations

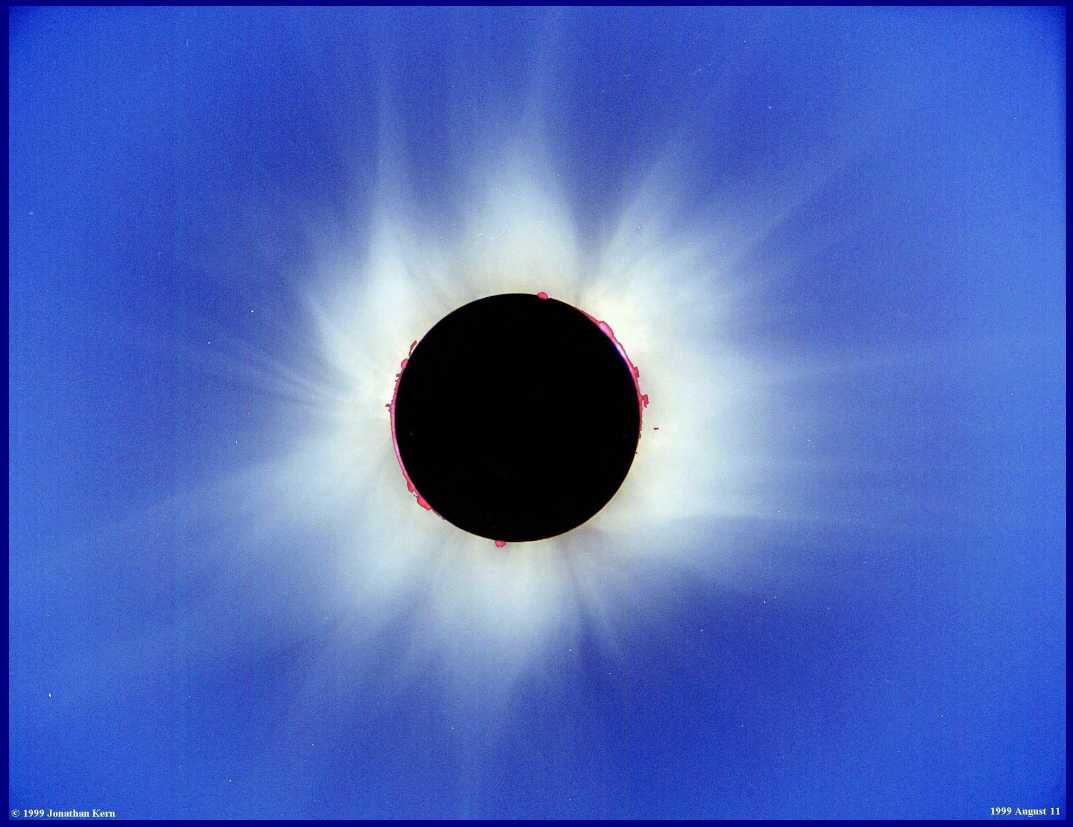
Corona at Sunspot Minimum and Maximum

October 1995, northern India
near solar minimum

August 1999, Rimnicu-Vilcea, Romania
near solar maximum

Solar Eclipse Observations

Features – Solar Prominences

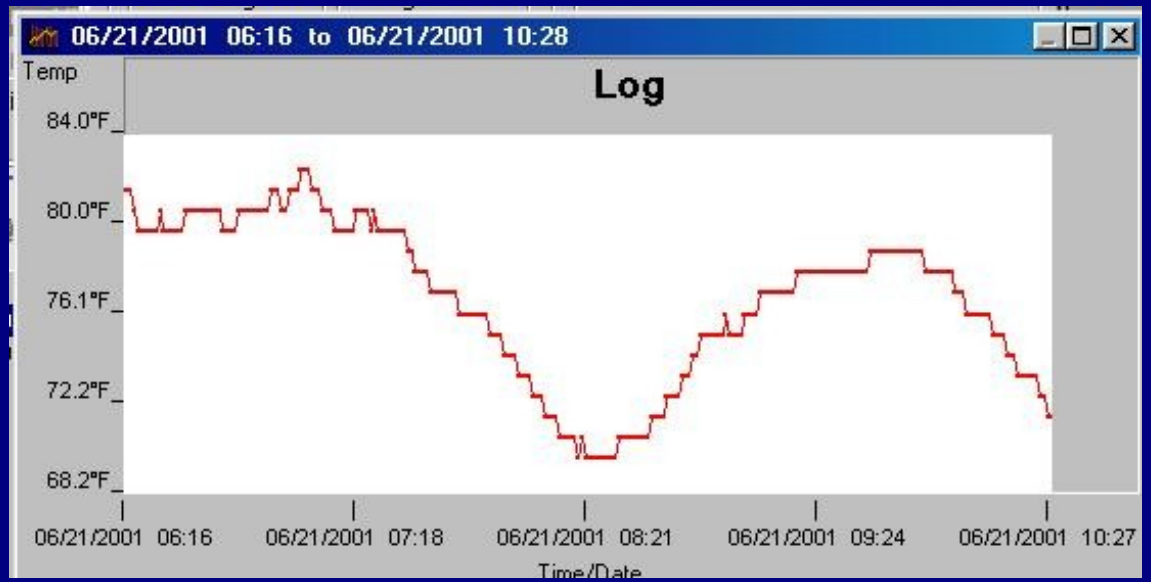


1999 Eclipse from Romania, a composite photo – Jonathan Kern's corona with Mitzi Adams' prominences.

1999 eclipse as seen from around Yvetot, France. Photo by Gordon Laing.

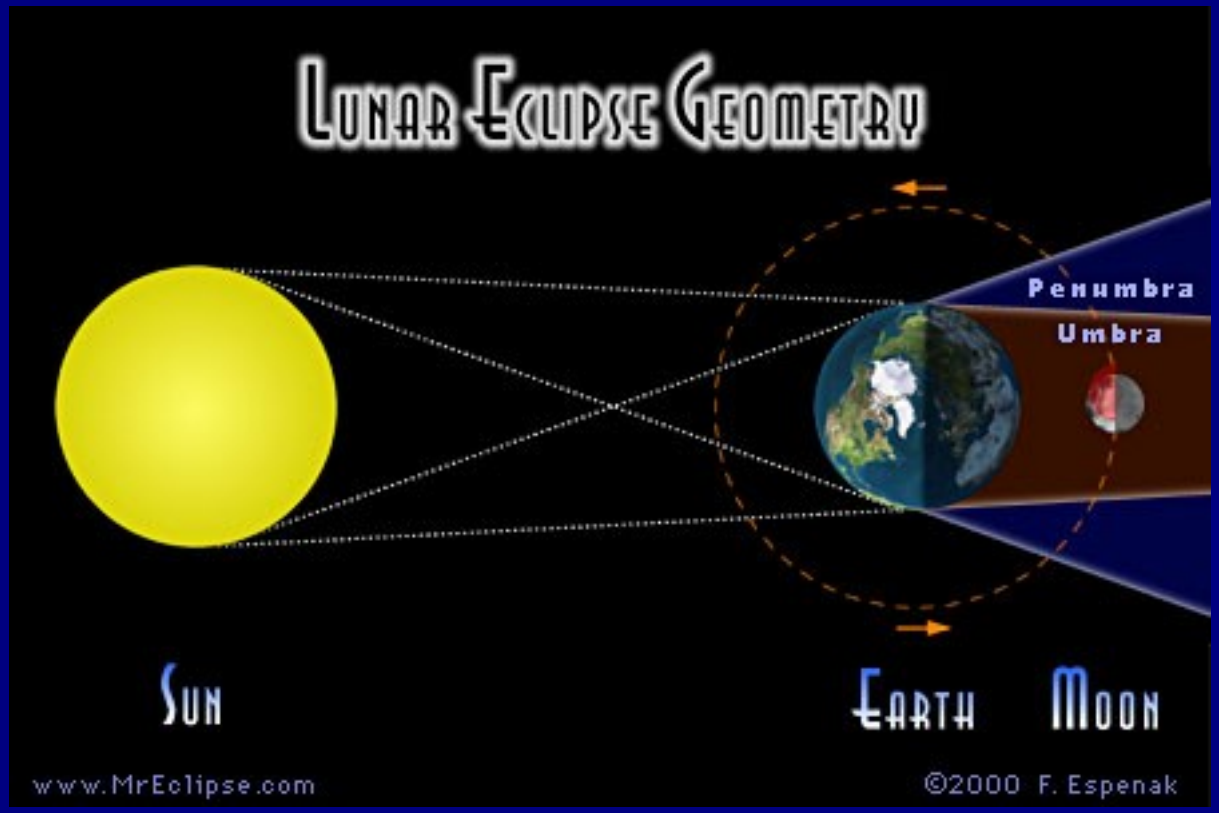
Solar Eclipse Observations

Partial Phases, Temperature, Planets



Lunar Eclipses

Lunar Eclipse Geometry



Lunar Eclipse Observations

Entire Moon in Penumbral Shadow

~70% of the Moon in the umbral shadow

Eclipses in the Near Future
Visible From Here

October 23, 2014	Partial Solar Eclipse
April 4, 2015	Total Lunar Eclipse
September 28, 2015	Total Lunar Eclipse
August 21, 2017	Total Solar Eclipse

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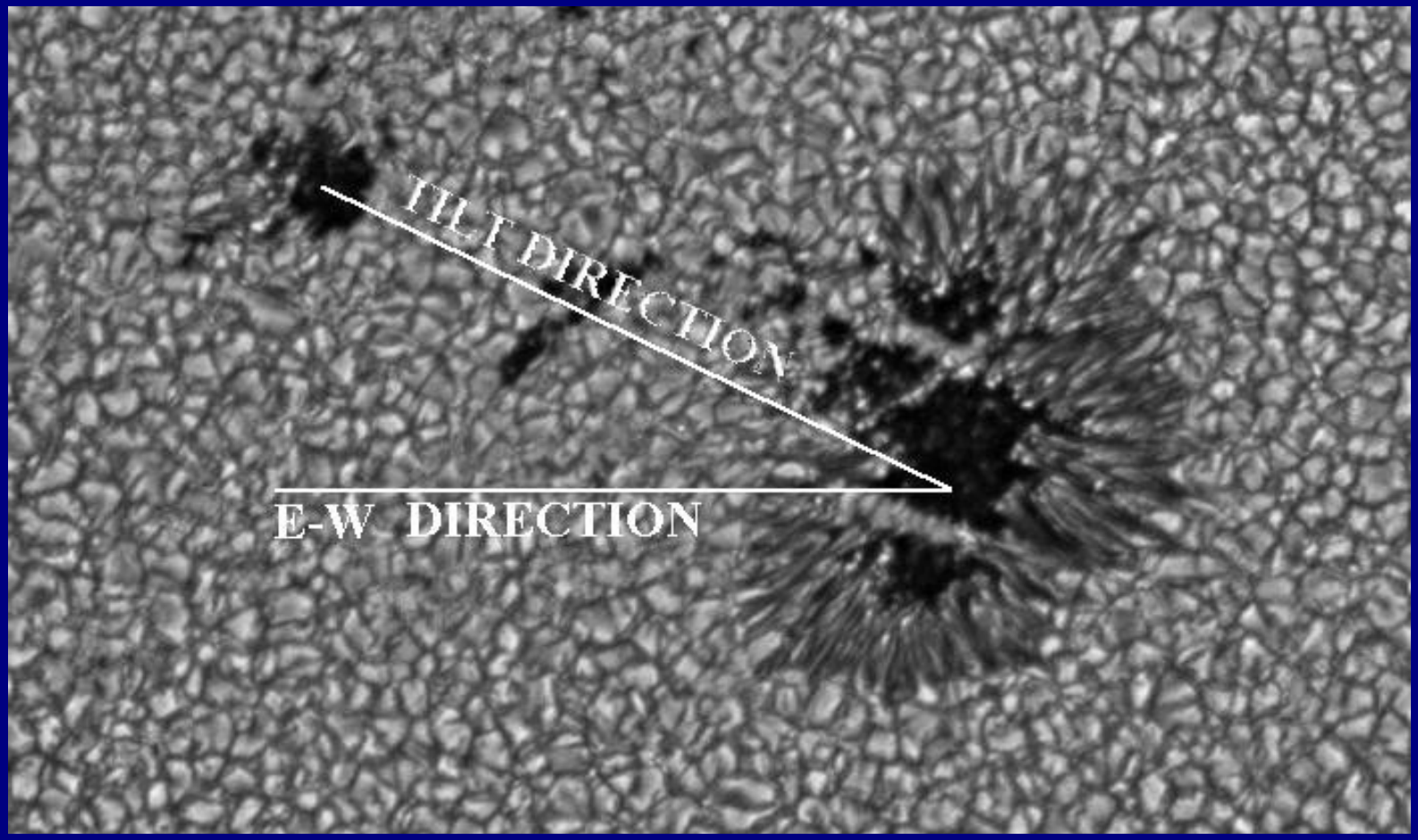
Extra Slides

Active Region Tilt- Joy's Law

In that same 1919 paper Joy noted that sunspot groups are tilted with the leading spots closer to the equator than the following spots. This tilt increases with latitude.



Polar Field Reversals

In 1959 Babcock noted that the magnetic polarities of the Sun's weak polar fields also reverse from one cycle to the next, and that this reversal happens at about the time of sunspot cycle maximum.

– The Sun's northern polar field changed polarity in June 2012, the southern reversed in July 2013.