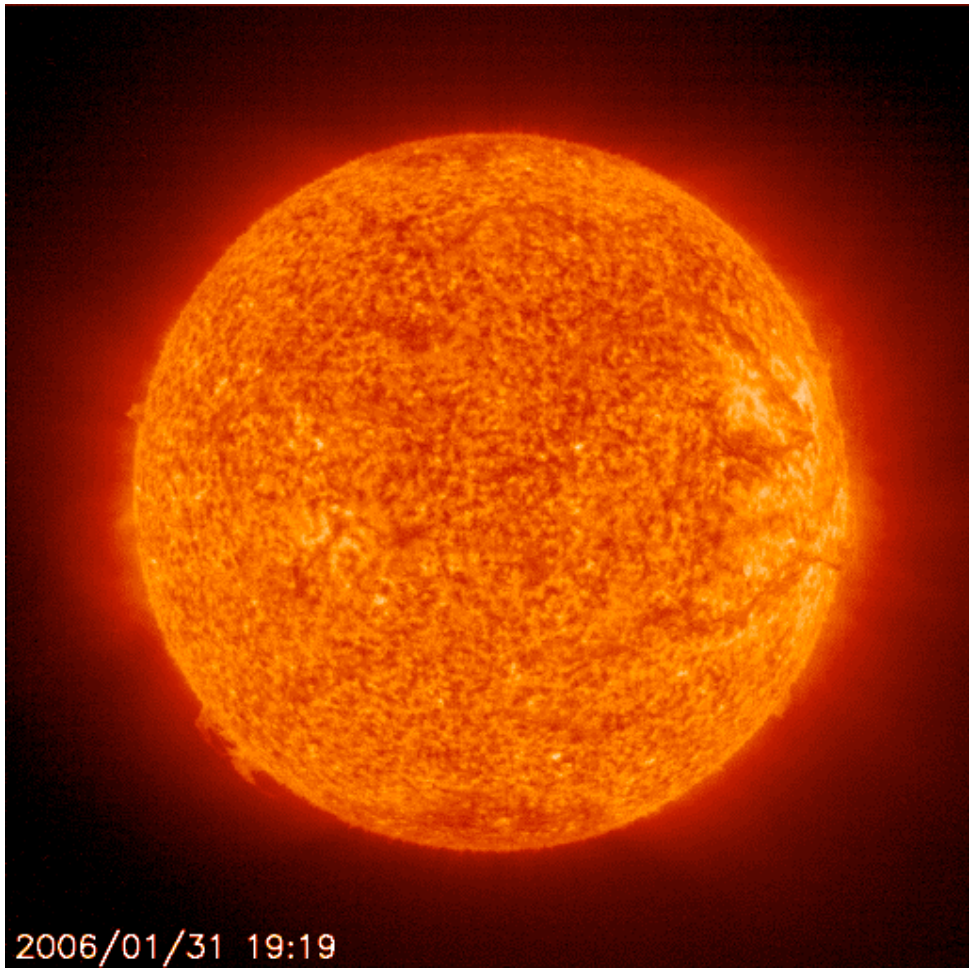
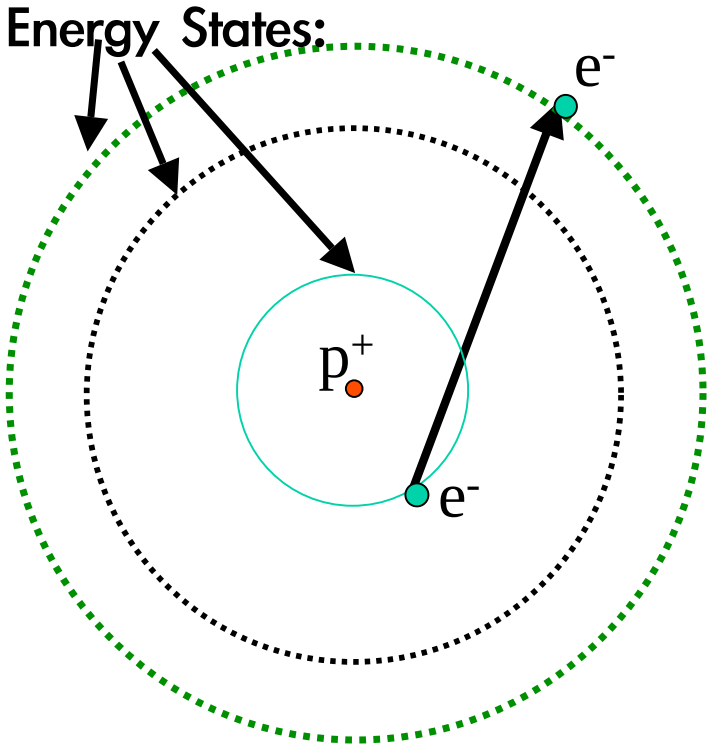
The Magnetic Sun



Zeeman Effect:

The Zeeman Effect is a product of the fact that electric fields and magnetic fields interaction.



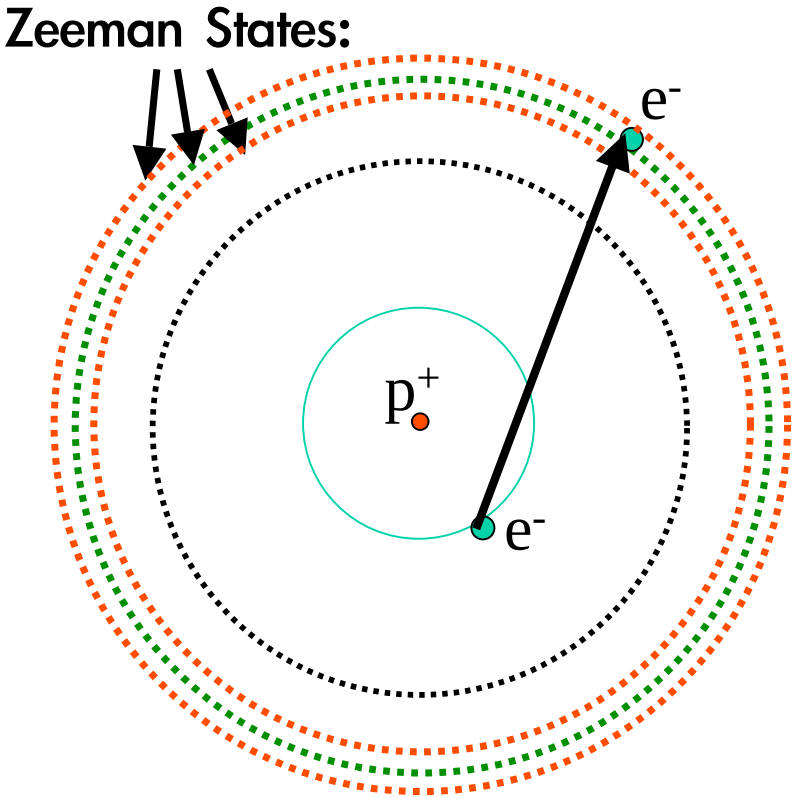
- Recall the idea of how an atom transitions from one *energy state* to another.

- The *restoring force*, or what encourages an electron to come back down is the electric attraction to the nucleus.

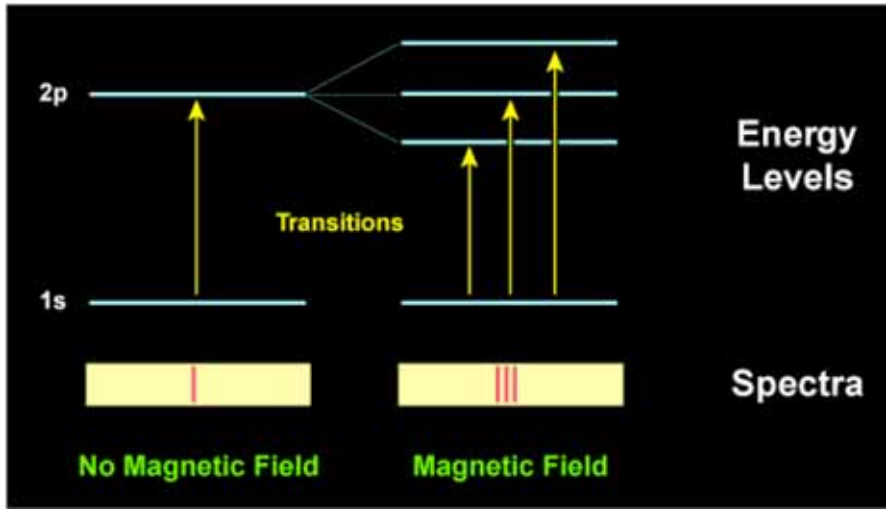
- However, if a magnetic field is present, it interacts with the energy level transition, such that one transition…..

Zeeman Effect:

Becomes THREE states!



- Since all three states are very close in energy (the spacing is directly related to magnetic field), the can all be triggered by a similar process.



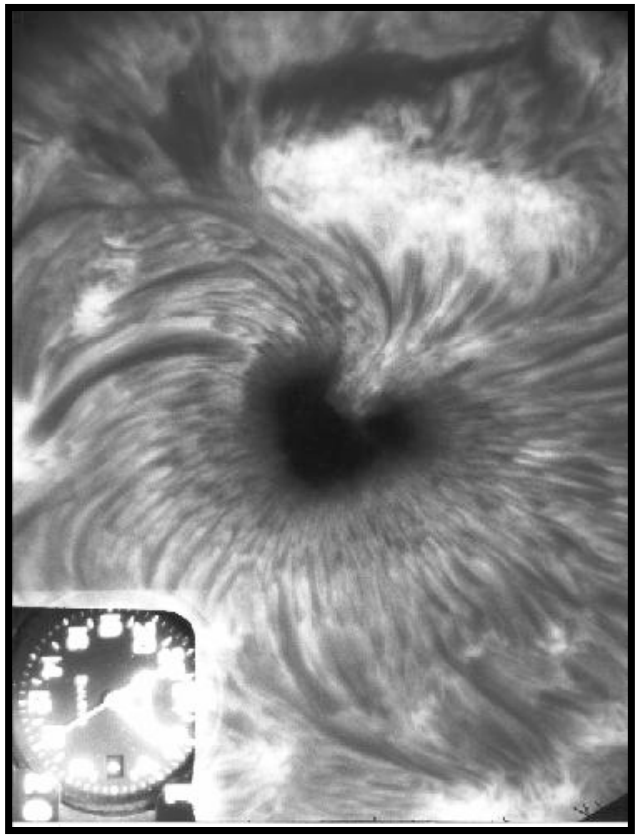
- So, with the Zeeman effect, you can measure the strength and direction (from scattered light polarization) of a magnetic field!

George Hale:

- 1908: George Hale used the Zeeman effect to determine that sunspots had a strong (10000x the Earth's) magnetic field!

- This was the first discovery of a magnetic field anywhere beyond the Earth.

- So what was going on in the Sun spots?



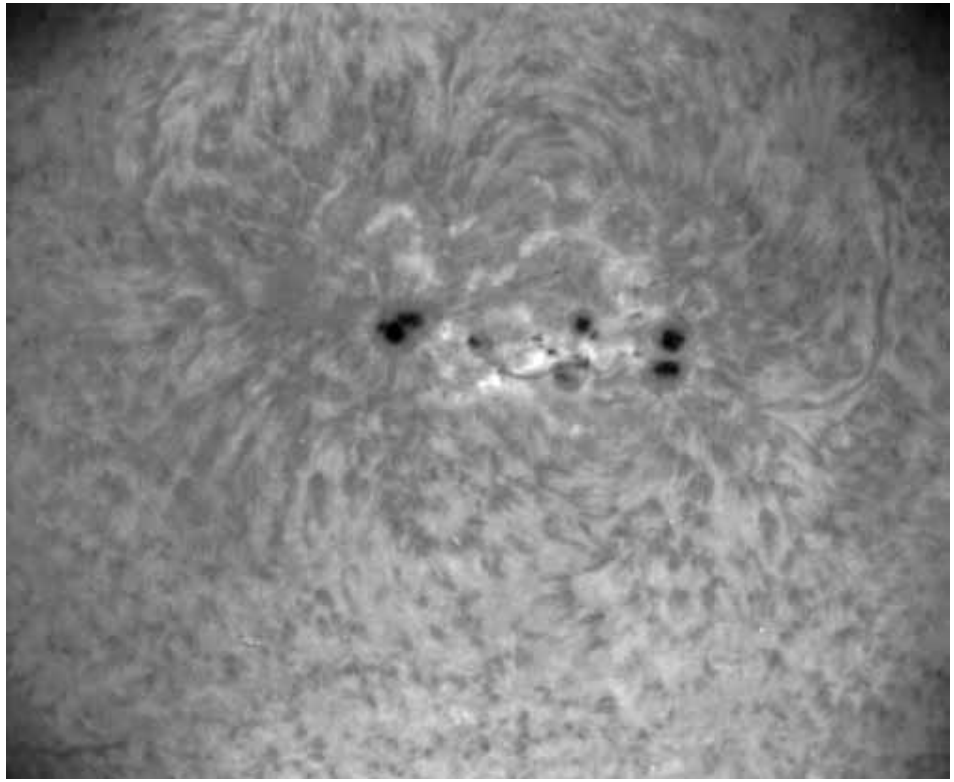
Sunspot Characteristics:

- Sunspots are strange objects given the seemingly unchanging nature of the Sun.

- Sunspots are typically paired on the surface of the Sun.

- They are often seen connected to filaments on the surface.

- They are clustered near the middle regions of the Sun and rotate with it.

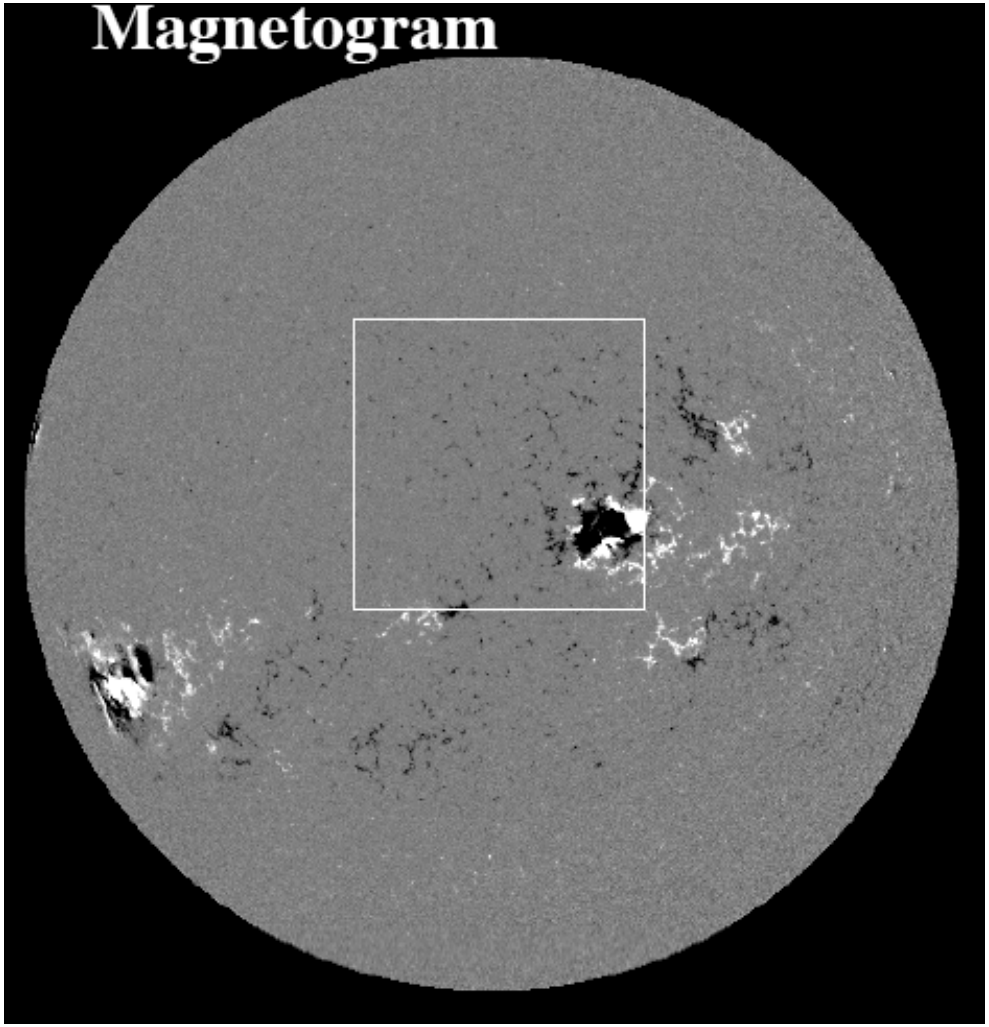


Sunspot Characteristics:

- Magnetograms of Sunspots show that they have regions of N-S and S-N magnetic field.

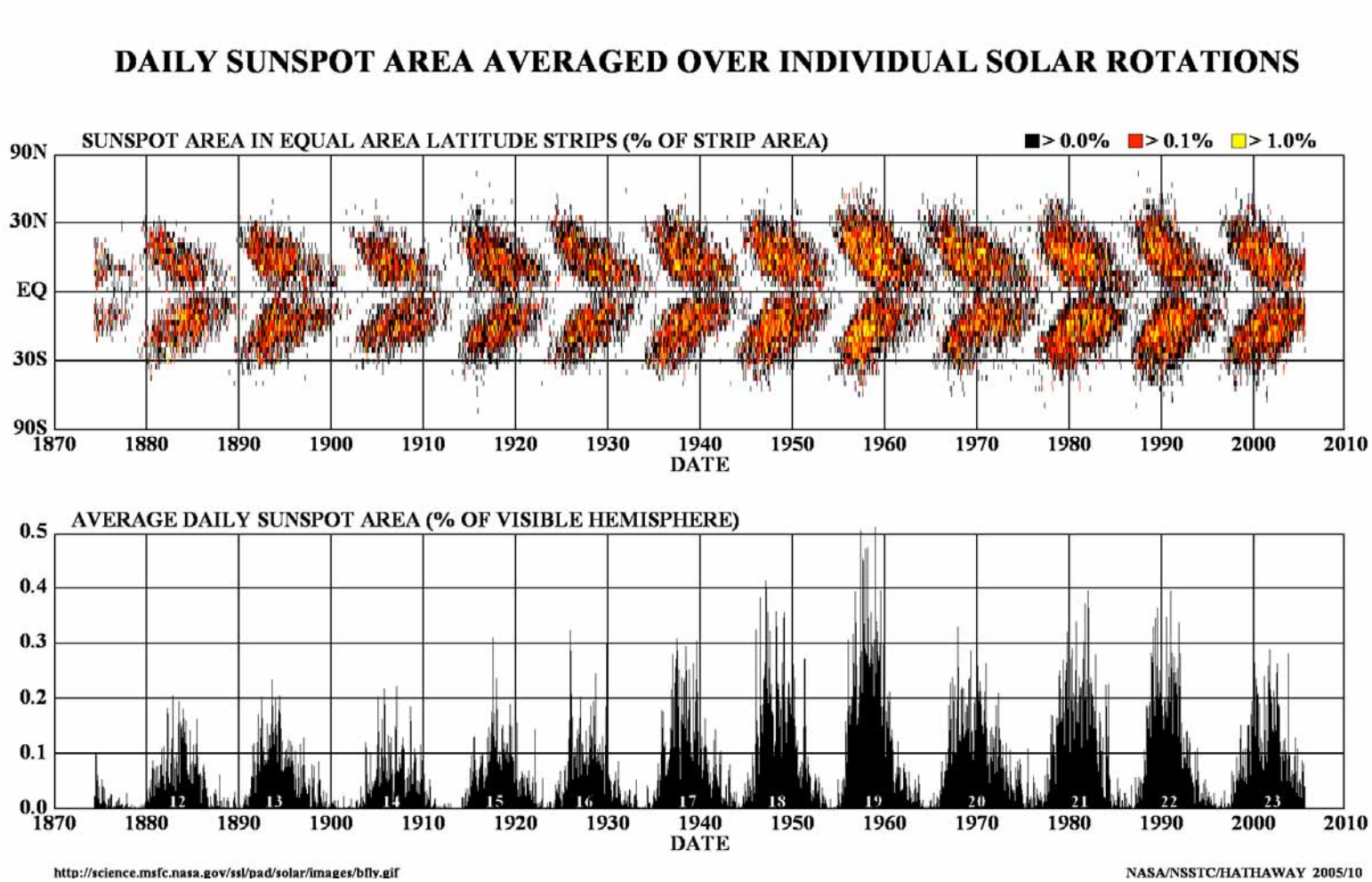
- One spot is ALWAYS N-S, while the other is S-N.

- At any given time the direction of the N-S to S-N arragement is the same for ALL sunspots.



Sunspot Characteristics:

- The number of sunspots waxes and wanes on an 11 year cycle, while the orientation of the spots (N-S ➔ S-N vs. S-N ➔ N-S) changes every 22 years.

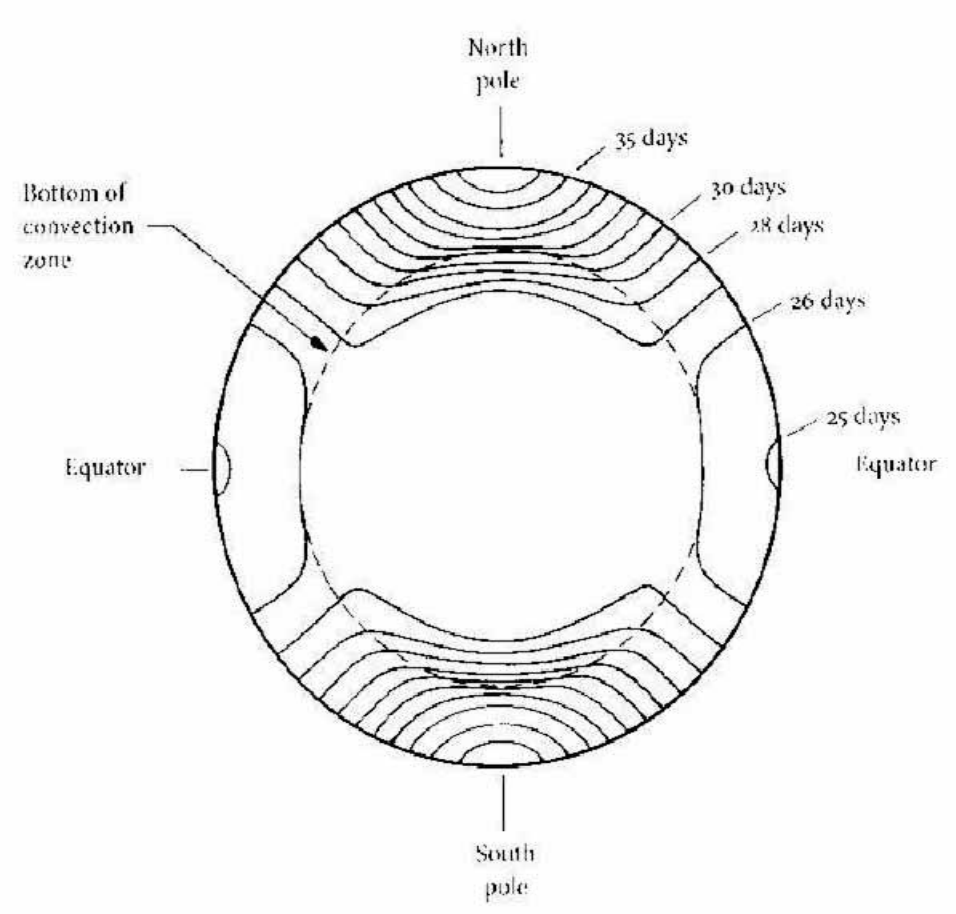


Differential Rotation:

- Recall that the Sun is rotating differentially.

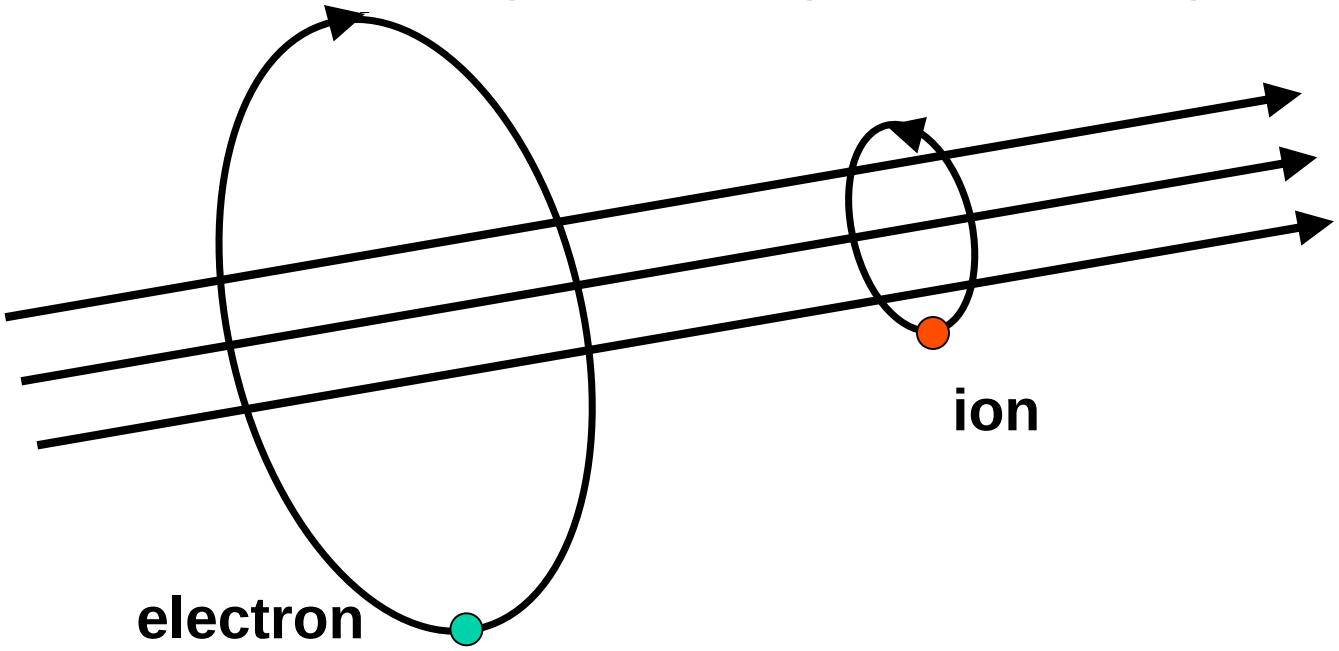
- Furthermore, there is an engine (or dynamo) of moving plasma in the convection zone that is generating a global magnetic field.

- This combination produces an amazing effect in the Sun.



When Plasma meets Magnetic Fields

- James Maxwell's equations showed that charged particles would become bound to a magnetic field (and vice versa).

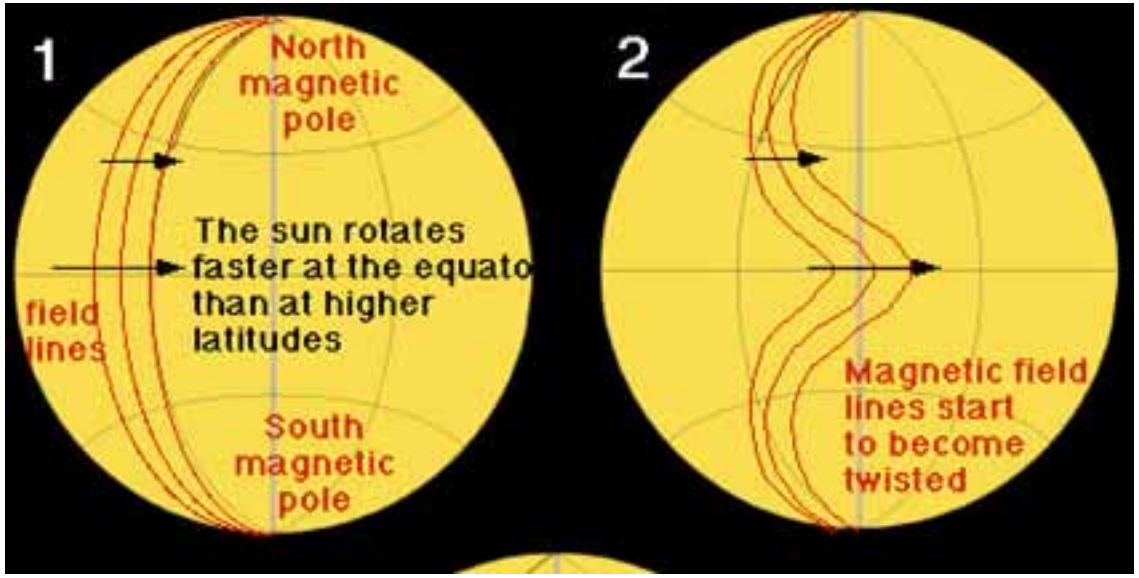


- Charged particles can move *along* a magnetic field, but they can't move away to a region with more or less magnetic strength.

- Likewise, a magnetic field is bound to the plasma. If the plasma is forced to move, then the magnetic field *must* follow!

Differential Magnetic Field.

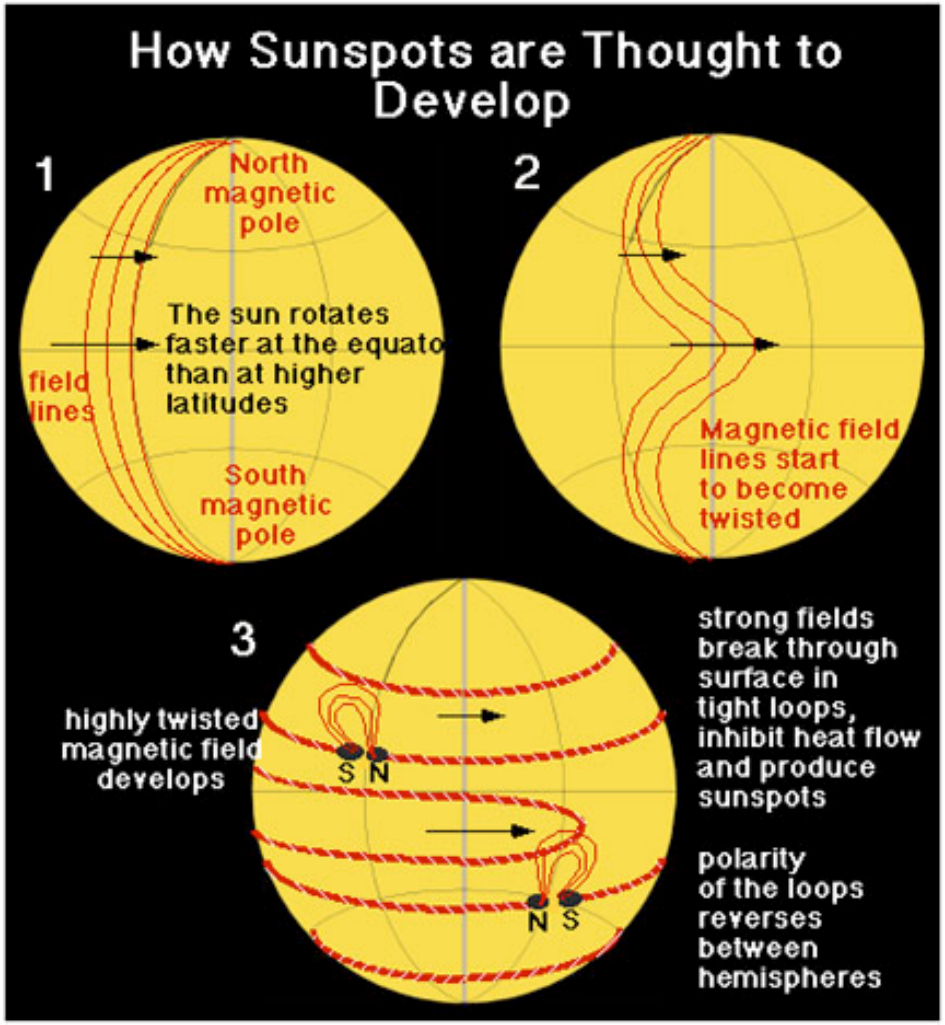
- Because the plasma inside the Sun is bound to the rotation of the neutral convection zone, the magnetic field is going to be stretched out by the differential rotation of the *neutral* Sun!



- This process takes some time, but eventually the field gets wrapped up, just like a tether ball. And just like a tether ball, the Sun's magnetic field bounces back! **What is the most obvious result?**

Solar Activity:

- This magnetic cycle is the reason why the Sun appears active and it sets the table for ALL space weather.



- Sunspots are the most common result of this, but not the most energetic.
- The occur where the magnetic field bursts out from the twisted lines of the field.
- Every 11 years the field ‘snaps back’ and the process starts again.
- However, the ‘new’ field has changed sign!

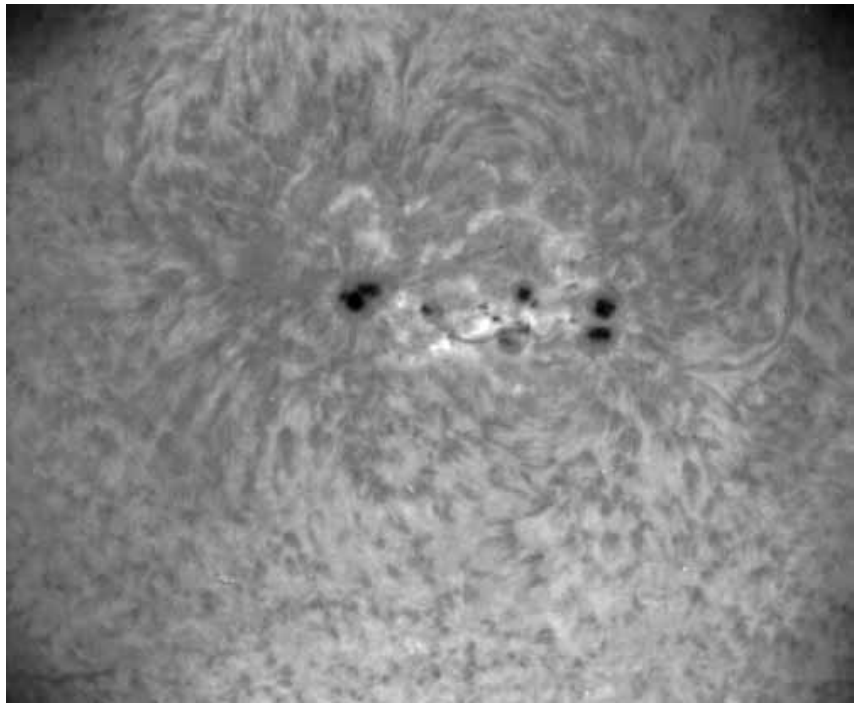
Sunspots Revealed:

- Sunspot characteristics make a lot of sense when we consider the magnetic Sun….

- Sunspot number is tied to how wrapped up the field is by differential rotation.

- The region where sunspots form is where the field gets the most wrapped up.

- The orientation of the N-S pairs is due to the orientation of the solar field and how it changes with cycle.

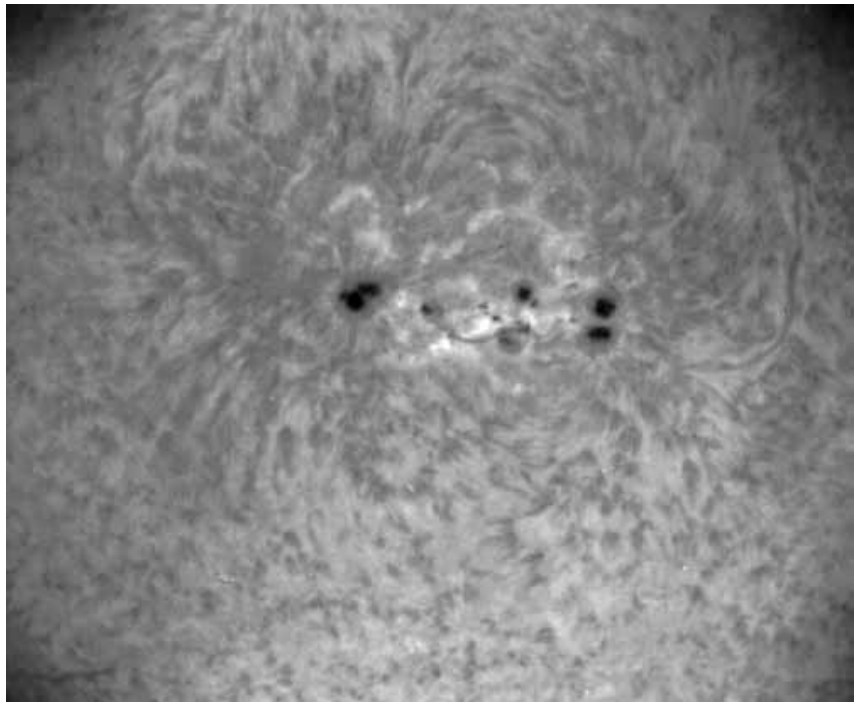


Not So Dark….

- None of this explains why sunspots are dark however…

- That goes back to the plasma-field relationship.

- Sunspots have strong fields that contain lots of plasma that doesn't want to move.



- This would be ok, except that the Sun's convection zone would like to move neutral material to the surface.

- The 'magnetic bubble' around the sunspot prevents convection from being as efficient. So less energy is delivered to the surface, and the gas is cooler there (*only 3000K*).

Other Types of Solar Activity:

Sunspots are the most obvious, but not the only manifestations of solar magnetic activity.

- We can break these down into two broad areas.

1) **Quiescent Features** (fairly static features that are long lived)

2) **Active Features** (energetic events that happen quickly)

- In these two areas are types of structures called filiments and prominences. For the most part they are 'connected' to the Sun in that they are bound either by gravity or a magnetic field.

Quiescent Features:

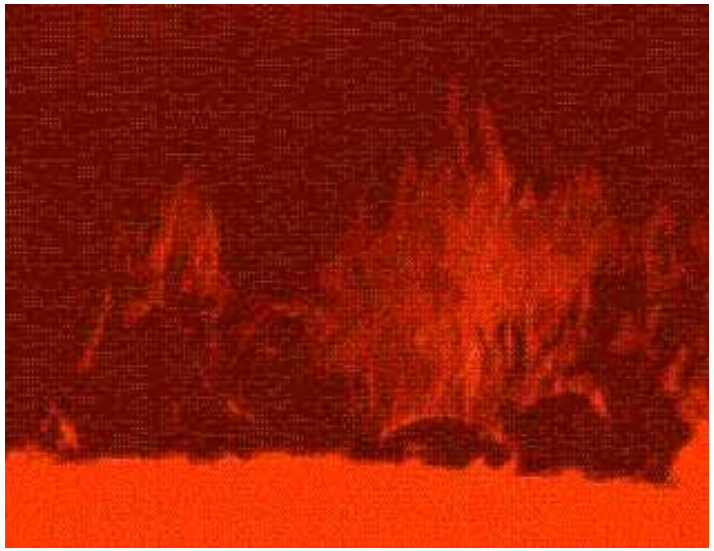
Quiescent Features (fairly static features that are long lived)

- Sunspots are clearly quiescent features in that they live a long time and stay where they are….

- There are three kinds of QF filaments/prominences.

1) *Quiet Region Filament/Prominece (QRF):*
2) *Ascending Promimences:*
3) *Active Region Filament/Prominence (ARF):*

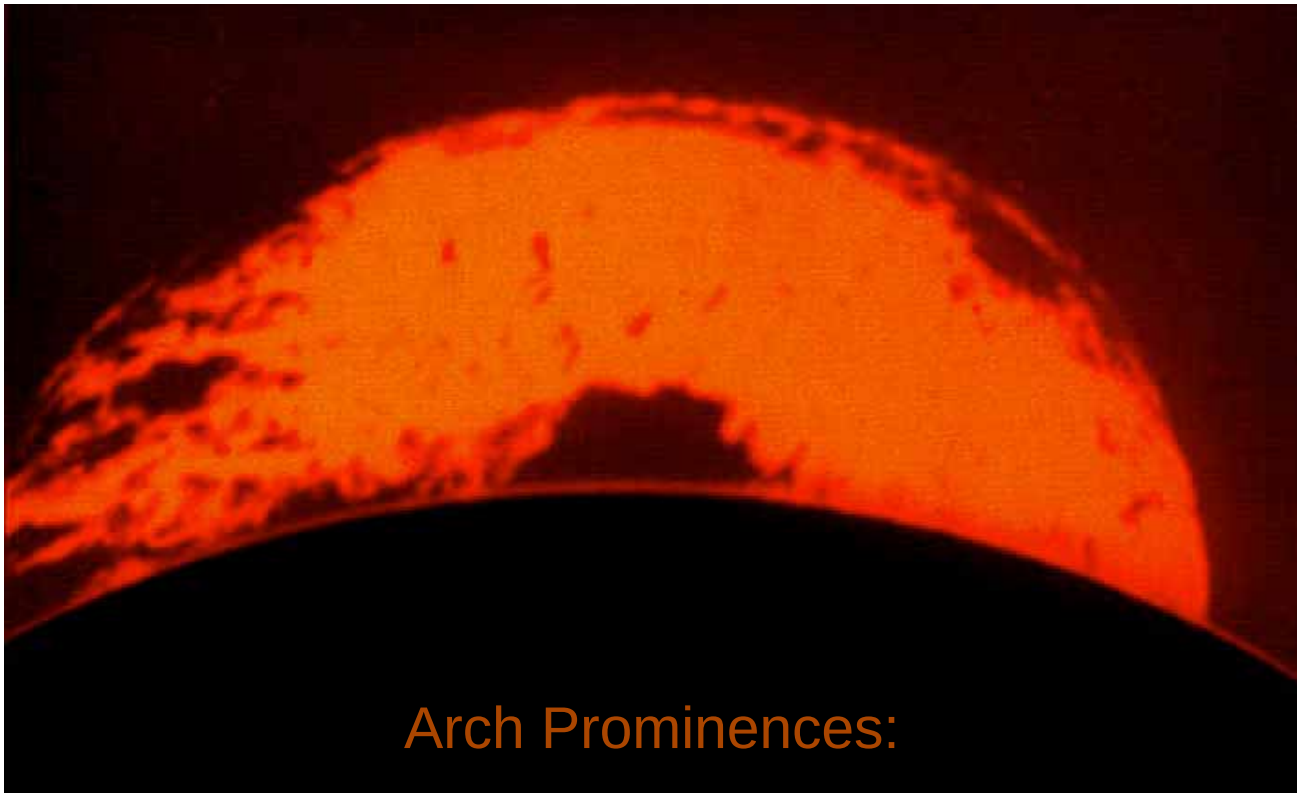
QRF Structures:



Hedgerow Prominences:

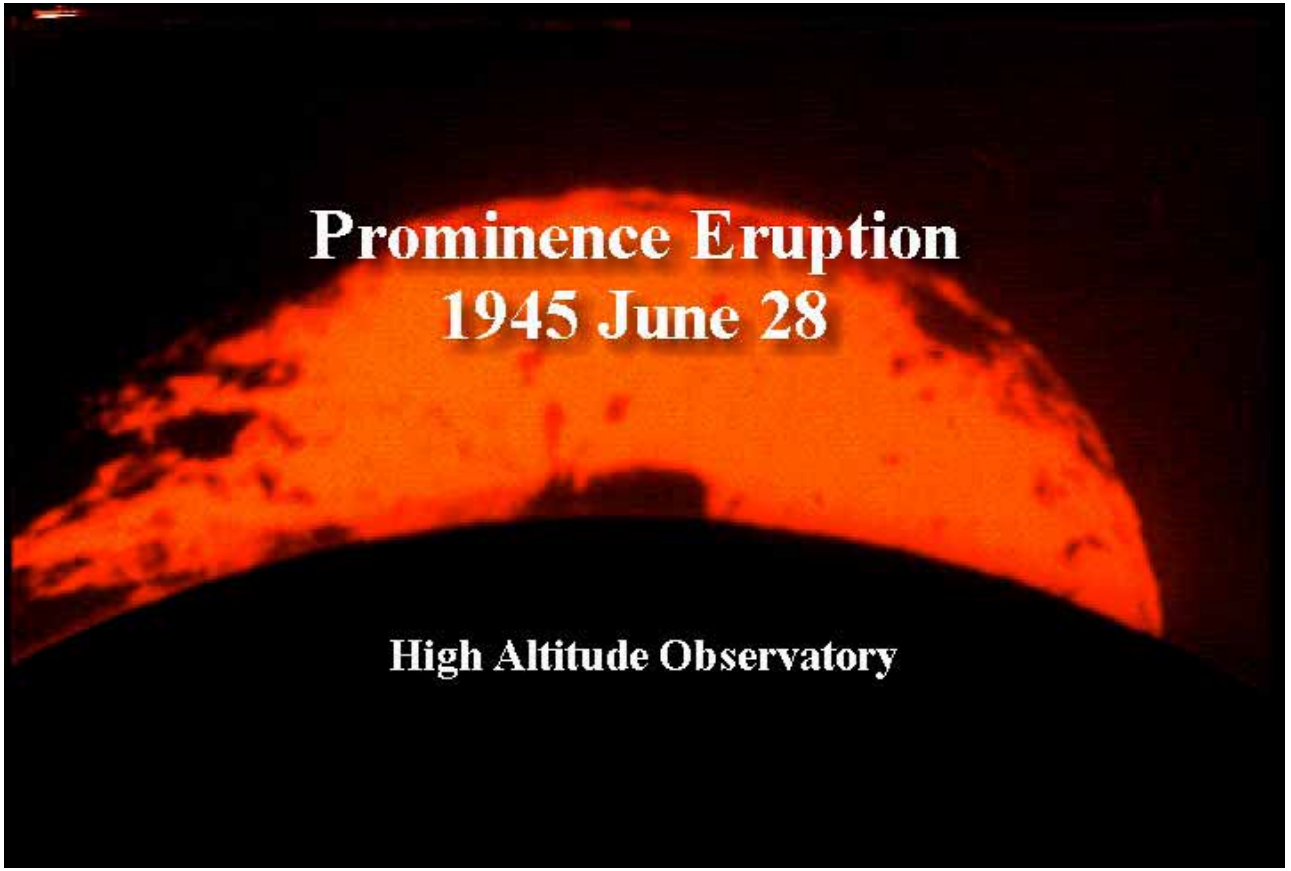
- Hedgerow prominences are suspended plasma above the Sun's surface. They are large in extent and tend to cluster toward the 'crown' (high latitude) of the Sun.

QRF/ARF Structures:



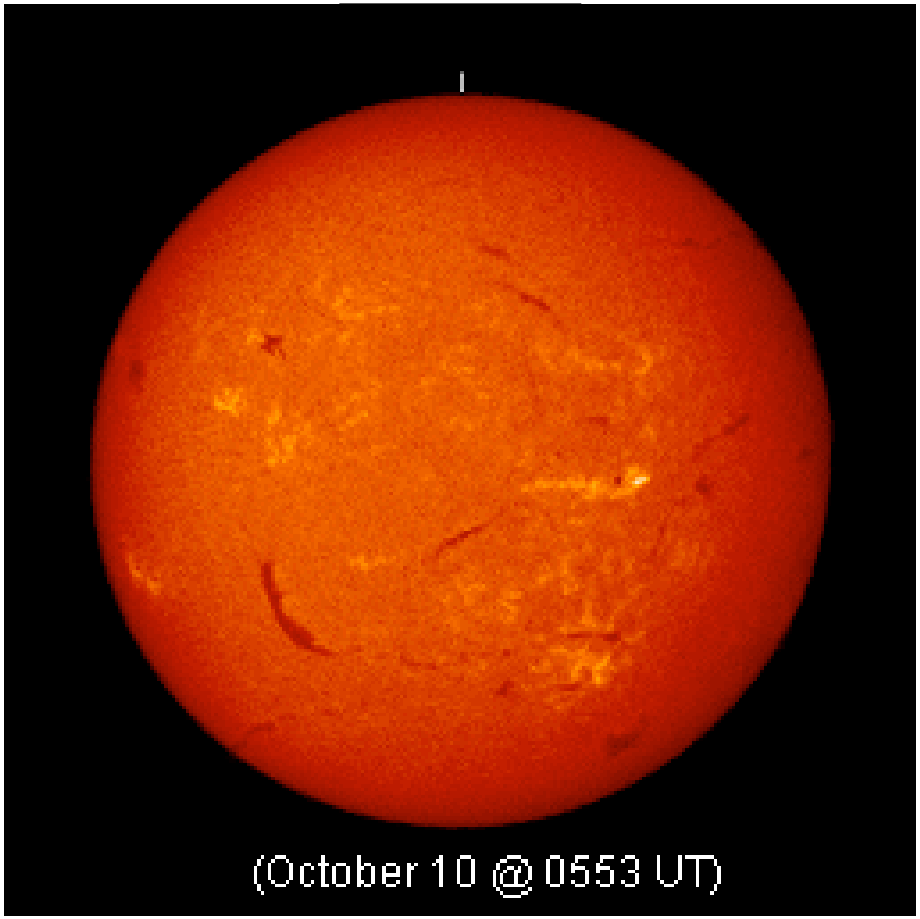
- Arch prominences are held in a more arch like form that follows field lines that go between regions on the Sun's surface.

QRF/ARF Structures:



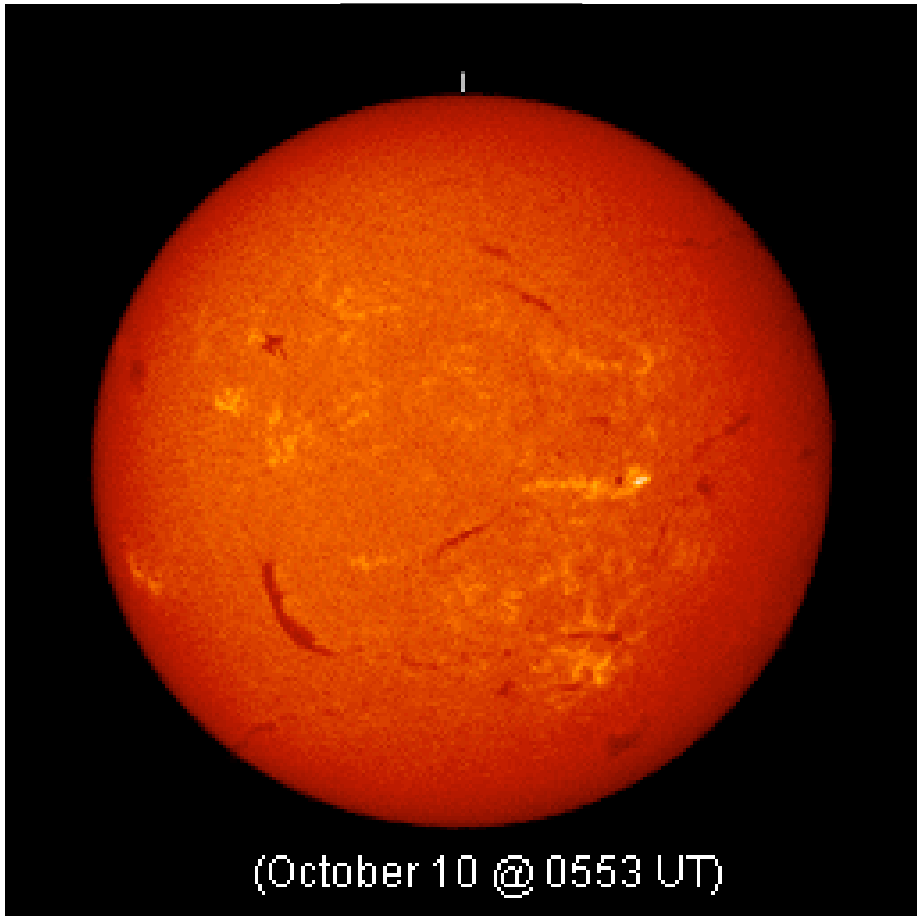
- Occasionally these features become detached from the Sun's surface. The plasma carries away the magnetic field into space.

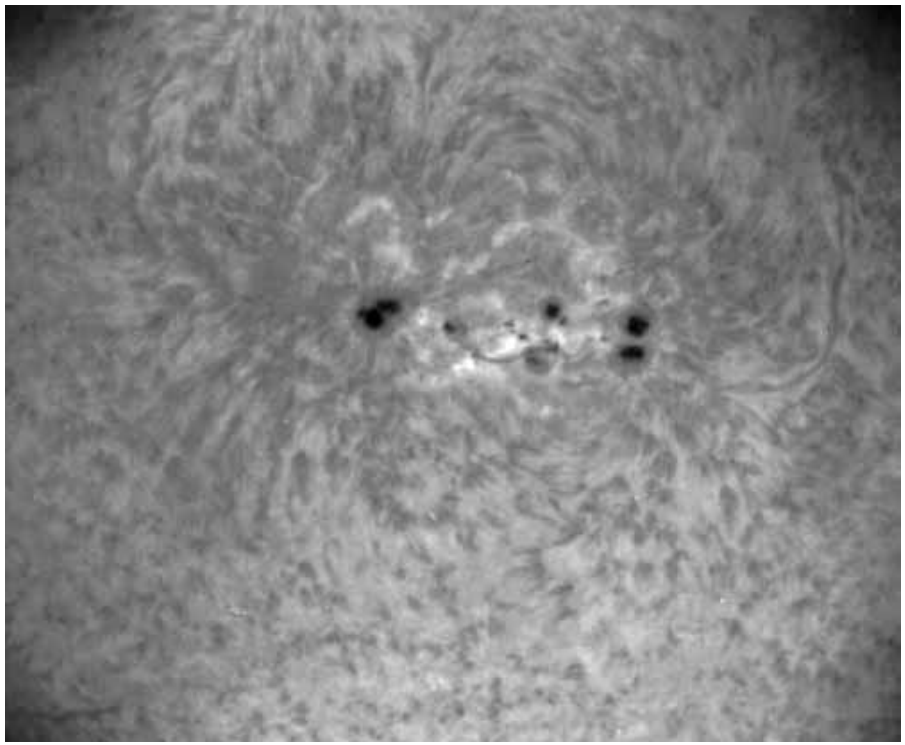
So what are filaments?



- Filaments are just the prominences viewed against the Sun!
- As you can see, they are cooler, just like the Sunspots.

Active vs. Quiet?





- The only difference is that the active filaments and prominences are attached to Sunspots and other regions of intense surface activity.

Active Features and the Solar Wind:

Quiescent Features generally stay bound to the Sun. The **Active Features** can affect us at the Earth!