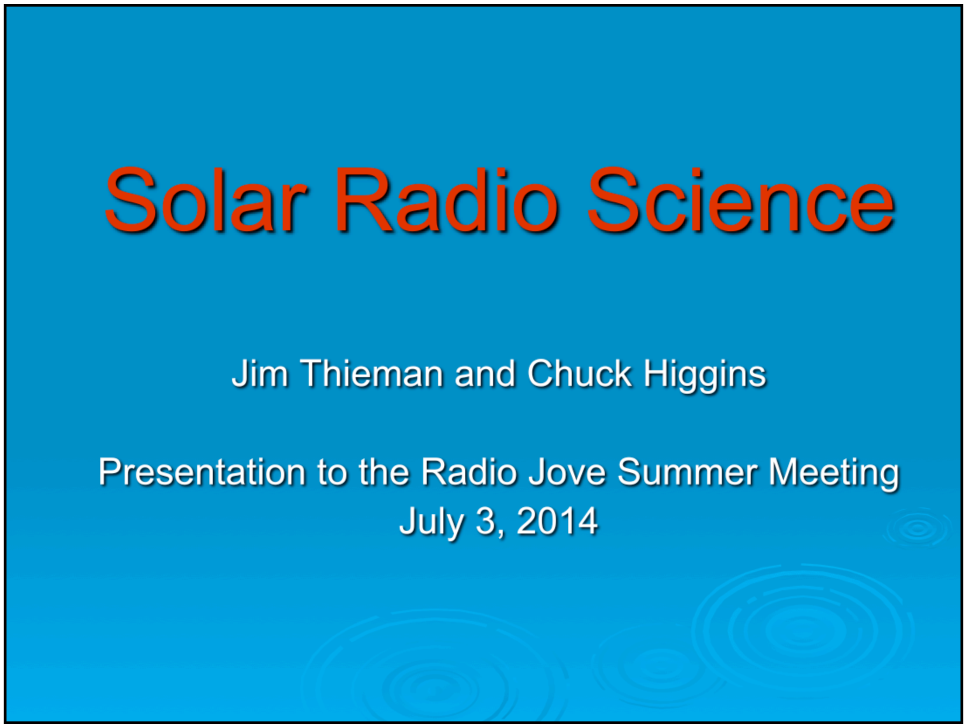
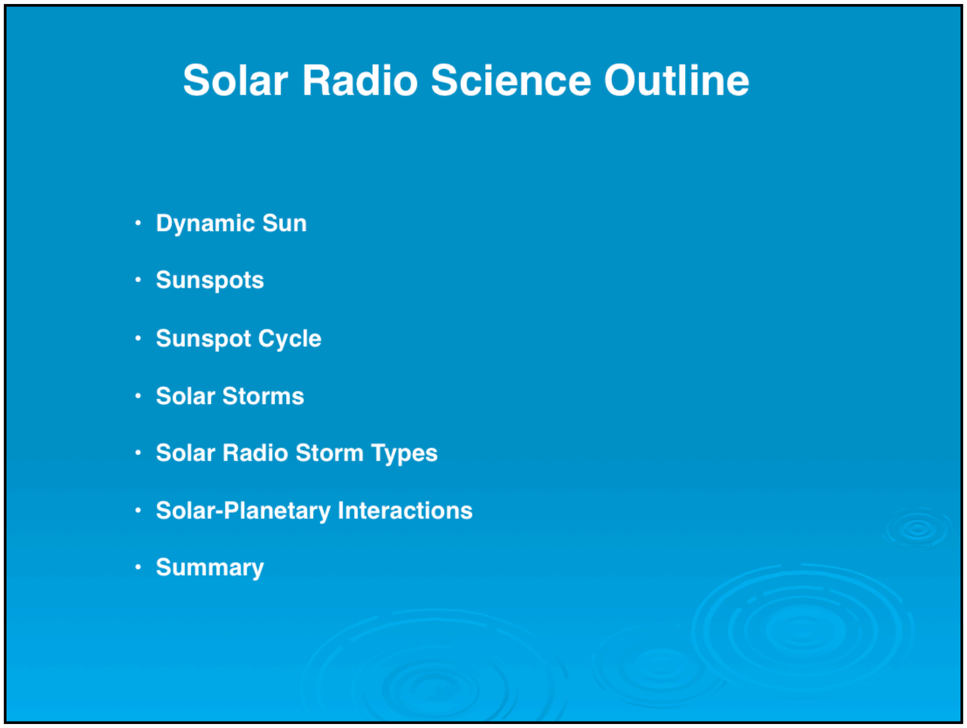
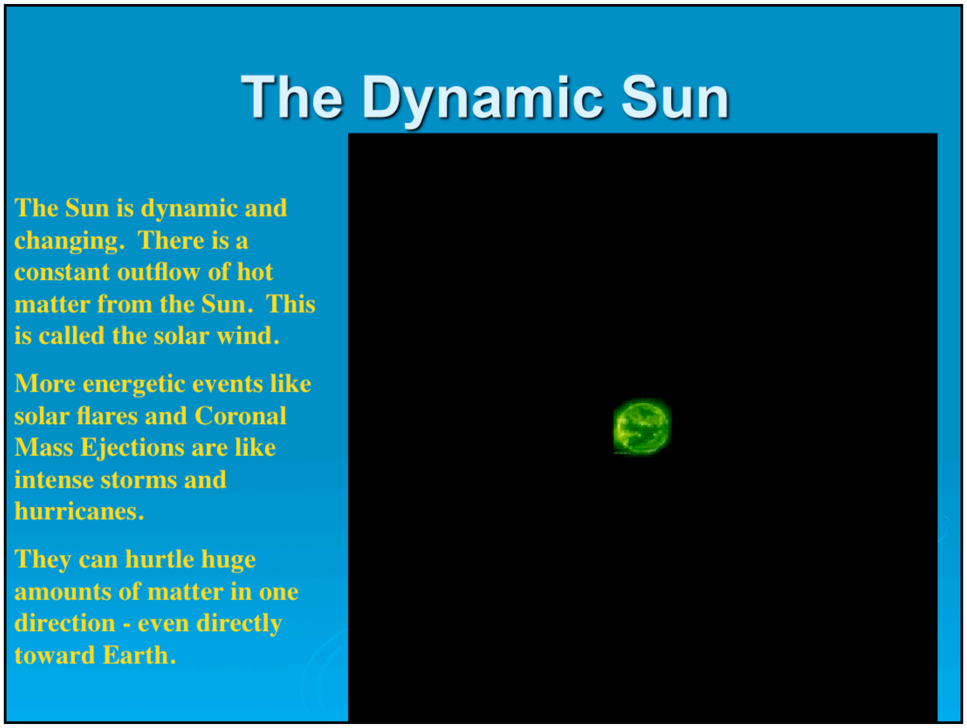

Solar Radio Science
Jim Thieman and Chuck Higgins
Presentation to the Radio Jove Summer Meeting
July 3, 2014

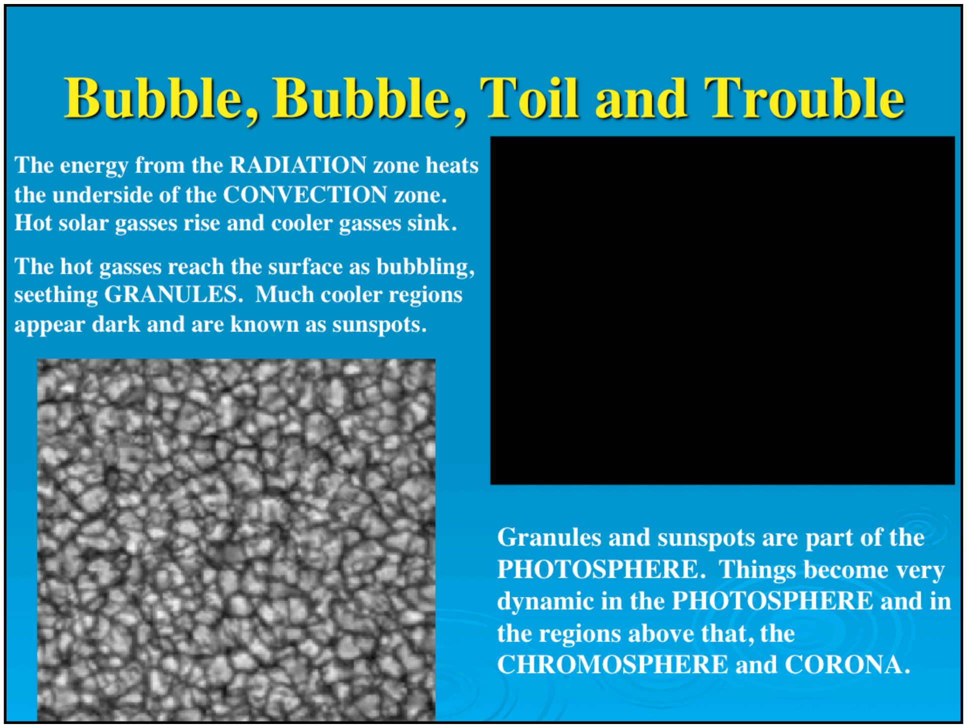



The presentation begins with the exhibition of the dynamism of the Sun as evidenced by solar phenomena such as granules, solar wind, sunspots and solar storms. The sunspots come and go in a regular rhythm called the sunspot cycle. Sunspots are in turn closely related to the solar storms that are revealed by studying the Sun not only in radio wavelengths but all across the electromagnetic spectrum. The storms in the radio regime have been traditionally classified into a set of "storm types" which are used by both amateurs and professionals to describe what appears in radio spectrographs. Particularly strong solar storms can greatly affect the surrounding solar system and this is becoming more of a threat in our dependence on modern space technology. In summary the study of the Sun through radio waves gives an appreciation for how much our lives can be affected by the vagaries of the Sun.

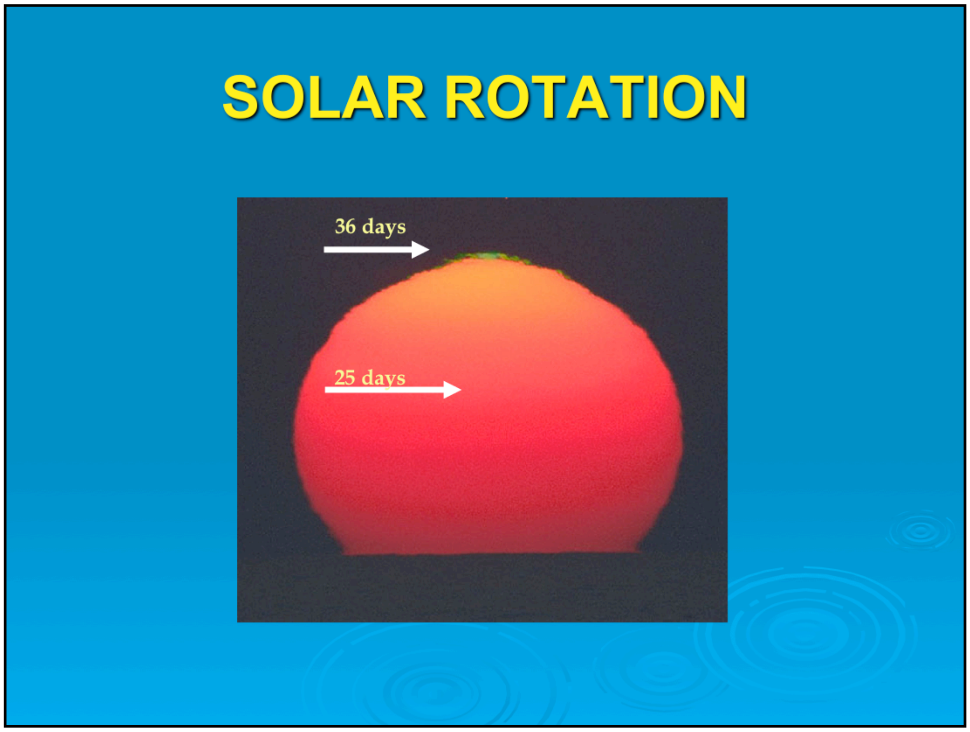

The Sun is much more than a steady source of heat and light. There is constant turmoil on the Sun that is easy to observe through our Radio Jove equipment. Indeed there is turmoil that can be detected across the electromagnetic spectrum.



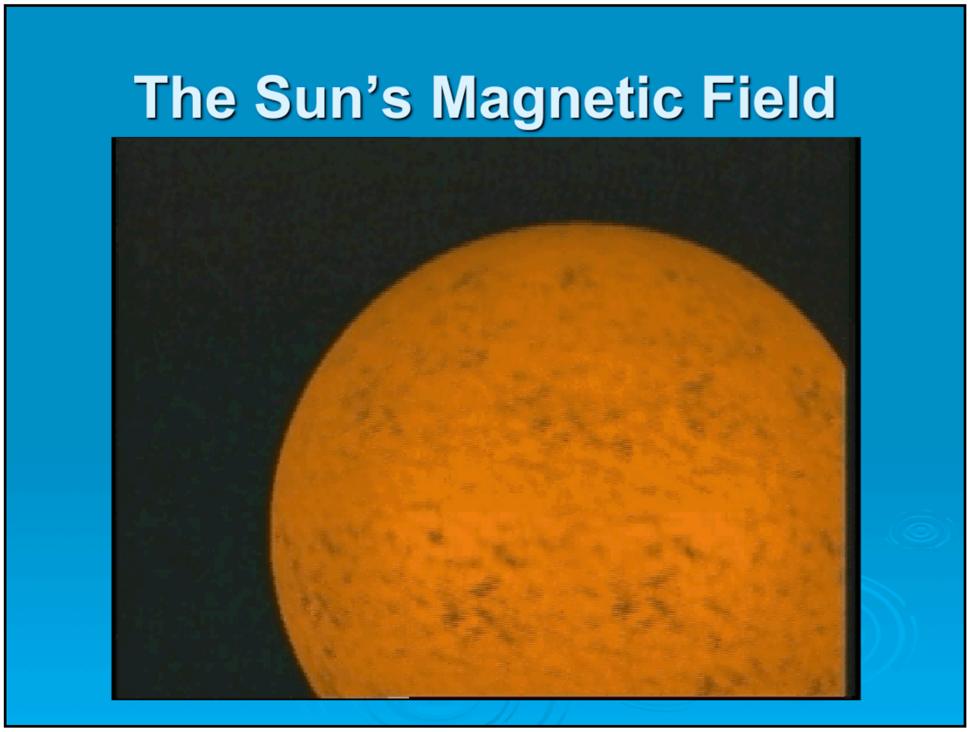

. The Sun is much more than a steady source of heat and light. There is constant turmoil on the Sun that is apparent when we look closely through the instruments sensitive to different portions of the spectrum.



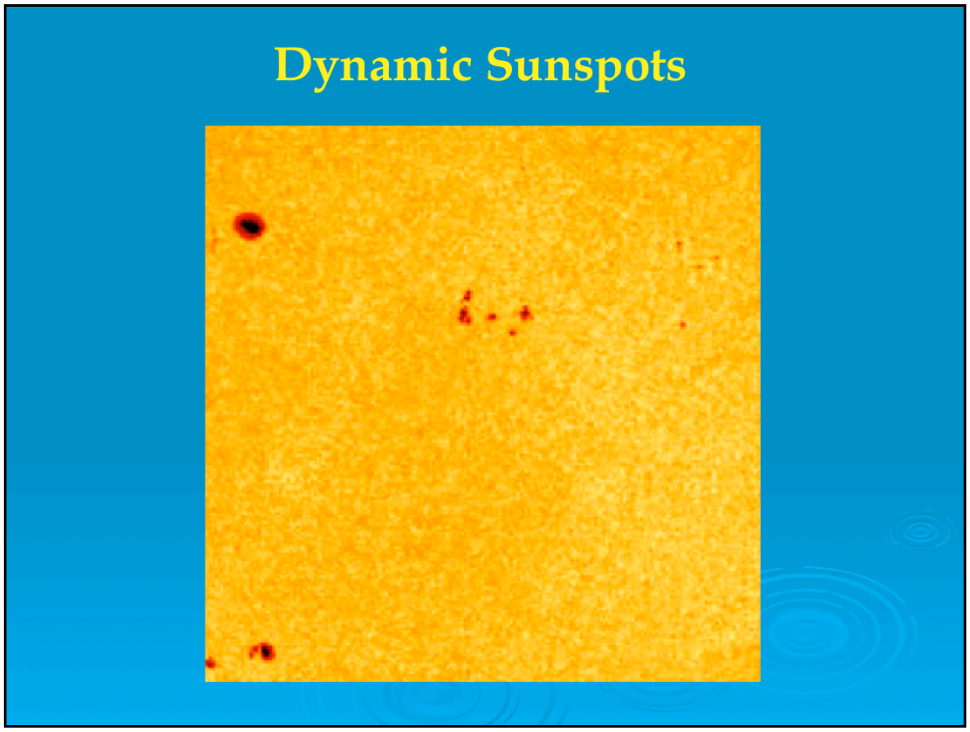

A closeup of the Sun's surface shows a boiling seething caldron of granules the size of the state of Texas which are just the outermost vestige of the convection at the Sun's surface driven by the Sun's fusion engine at its core.



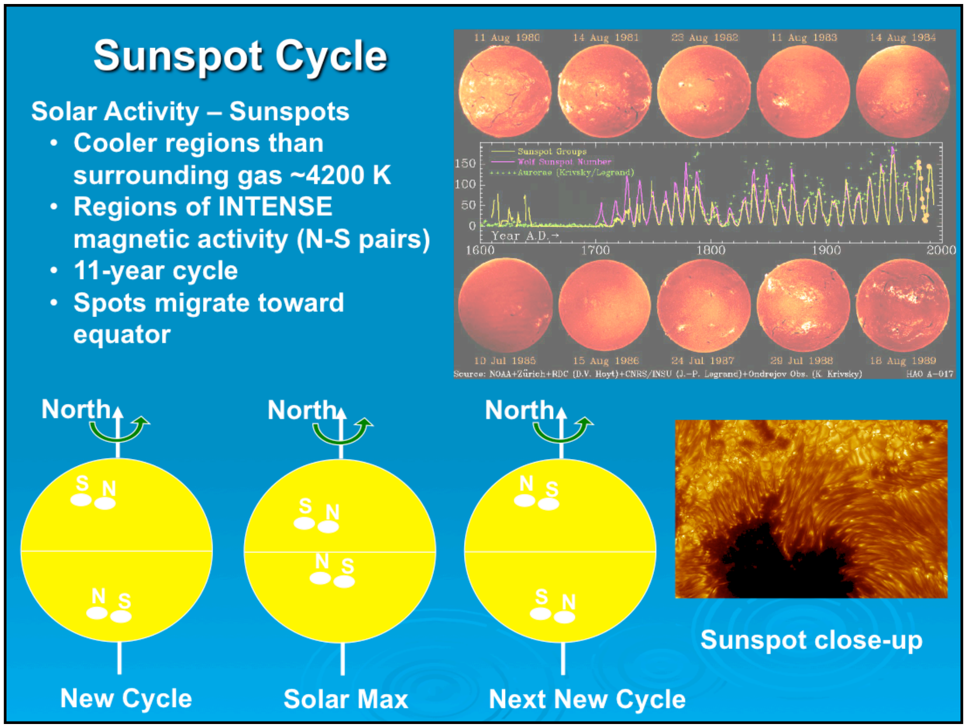

Close observation of the surface of the Sun reveals that this sphere of incandescent gas actually rotates at different rates depending on solar latitude. The gas near the Sun’s equator rotates slower than that near the Sun’s poles or rotational axis.



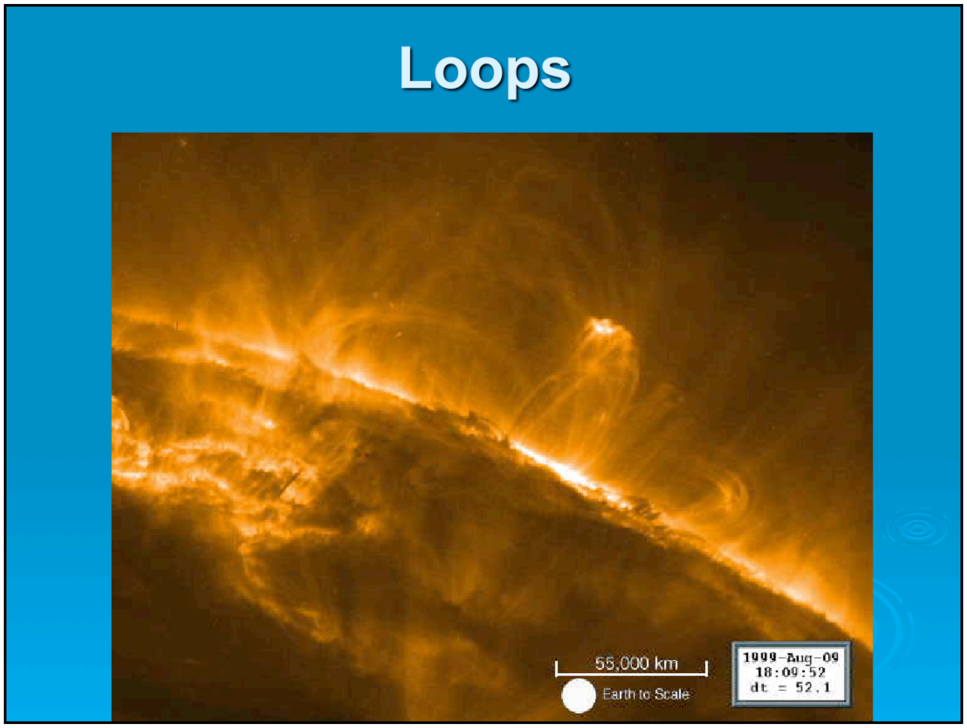

The Sun is nearly all plasma or very hot charged particles and, these particles are in rapid motion as we saw in previous slides. Moving charged particles create magnetic fields and the magnetic fields that are generated by one particle will affect the motion of other charged particles. Magnetic fields of the planets are usually fairly simple and orderly since the charged particles that create the fields are in simple and orderly motion. Any regularity to the Sun's magnetic field is quickly disrupted as the differential rotation and general heat-driven motion of the charged particles makes the magnetic field quite complex.



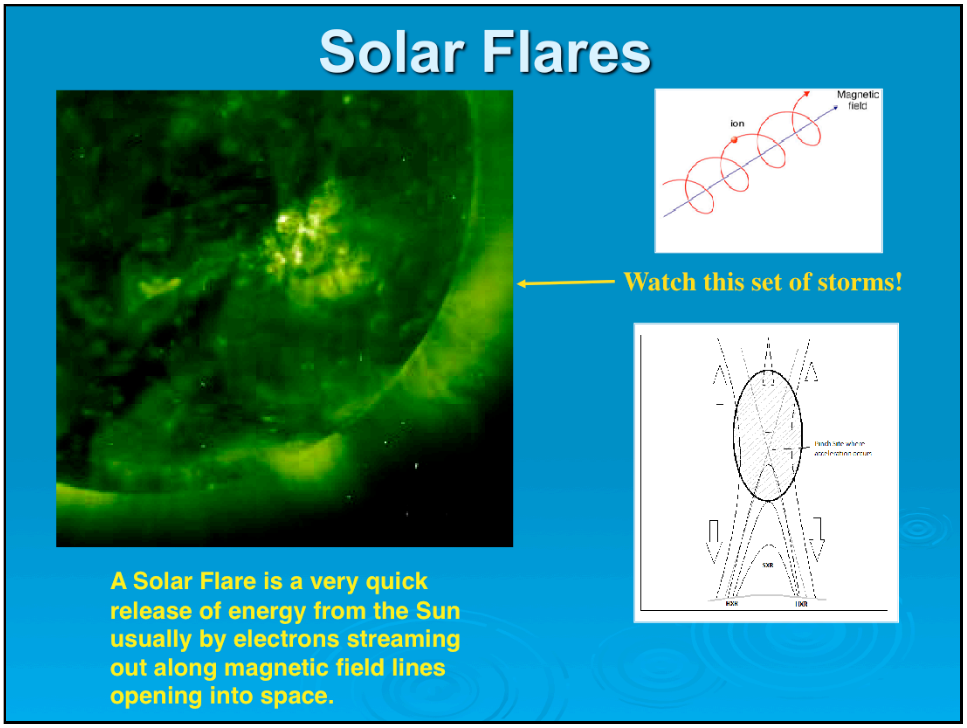

In places where the complex magnetic field is concentrated at the surface of the Sun, the motion of the plasma is constrained and the particles are forced to be cooler than the surrounding plasma. The areas of cooler plasma appear to be darker than the surrounding plasma and we call these darker regions sunspots. The concentration of magnetic field can trap and channel enormous amounts of energy. We can see the effects by observing the Sun in various wavelengths of electromagnetic radiation.



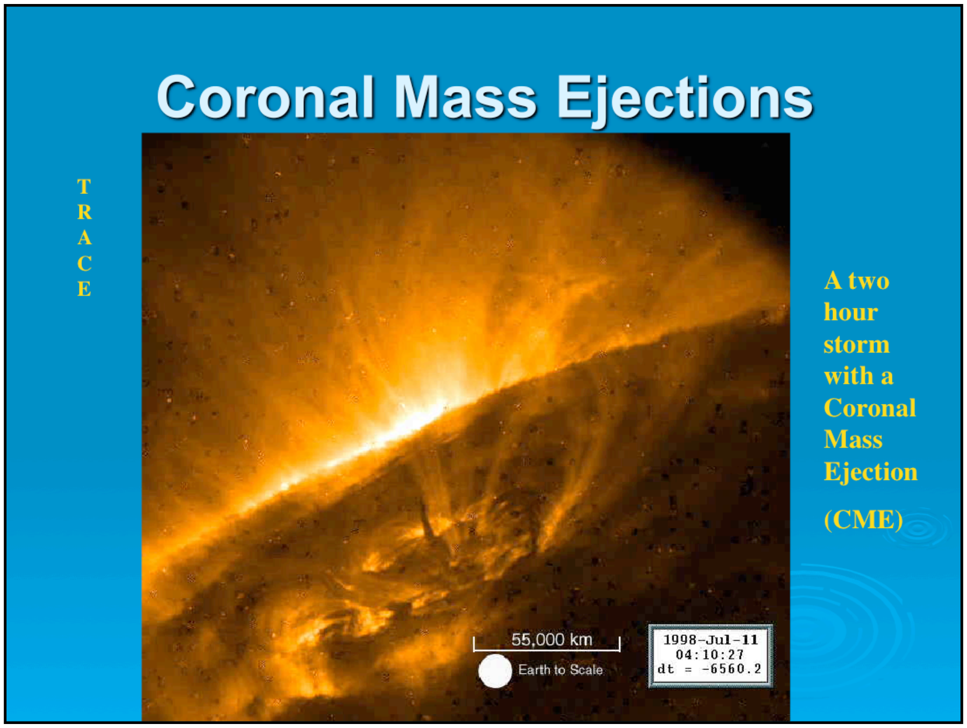

Sunspots have an interesting periodicity to them since the number of sunspots increases and decreases with an approximately eleven year cycle. Plots of the counts of the number of sunspots vs. time shows this eleven year cycle although it also shows variations in the heights and depths of the peaks and valleys of the cycles. In the late 1600's there was a complete lack of sunspots for several decades and the Earth experienced unusually cold weather during that time. Actually, the eleven year sunspot cycle is a 22-year cycle if we consider that sunspots usually come in pairs with magnetic field lines coming out of the Sun in one part of the pair and the lines usually form an arch leading to the second part of the pair in which the lines go back into the Sun. So the pairs of sunspots act like Northern and Southern poles of magnets. At any particular time as the Sun rotates the sunspot pairs in the Sun's northern hemisphere will mostly be have northern magnetic field sunspots leading the pairs followed by the southern magnetic field spot whereas in the southern hemisphere the reverse is true. In the next eleven year cycle the reverse is usually true. Also, as a solar cycle builds from a low sunspot count to the peak of the count the sunspots usually appear at high latitudes and then appear at lower and lower latitudes as the cycle progresses. This is the general rule, but realize this is an oversimplification and there are exceptions to these rules that often occur. All part of the mysteries of the Sun.



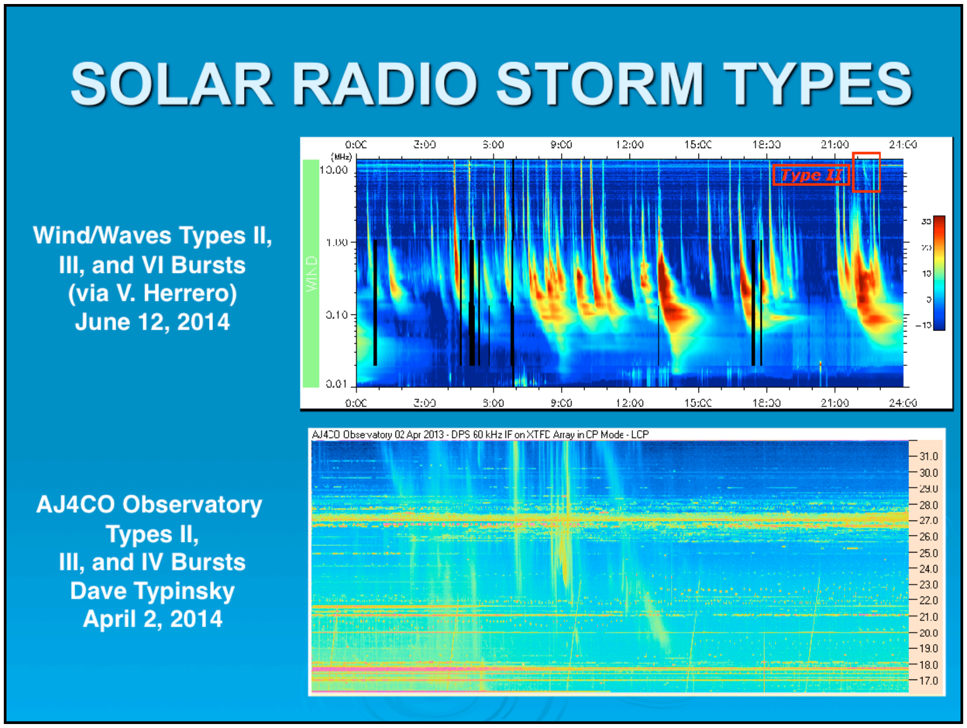

These loops of solar magnetic field lines can appear all over the Sun in very complex patterns, but they are usually concentrated around sunspots. Sometimes the dynamics of the Sun cause these loops to interact, break, and reconnect and this can result in the sudden release of electromagnetic energy sort of like a rubber band suddenly breaking.




The release of energy often results in a solar flare. This is the breaking of a magnetic field line such that it is no longer anchored in the Sun but releases the electrons it has trapped out into space. The electrons give off electromagnetic energy as they spiral around the field lines on their outward journey through the Sun’s decreasing density regions. As the density decreases the frequency of the radiation decreases. Since these are electrons they move rapidly through these regions and the result is a Type III radio burst.




Sometimes the breakage and reconnection of the magnetic field and interaction with the plasma results in the acceleration and release of a large amount of plasma in what is called a Coronal Mass Ejection. This involves not just electrons, but the heavier plasma particles such as ionized hydrogen, helium, etc. atoms. These heavier particles cannot move as quickly from the higher to lower density layers of the Sun as they travel outward so the radiation they emit as they escape drifts more slowly to lower frequencies and results in what are called Type II radio storms.




Here are examples of solar storms of types II, III, IV, and VI as they appear on spectrograms taken by the Waves instrument on the Wind spacecraft and by the AJ4CO spectrograph operated by Dave Typinsky.

# SOLAR RADIO STORM TYPES

**NOAA Solar Event Reports - http://www.swpc.noaa.gov/ftpmenu/indices/events.html**
**June 12, 2014**

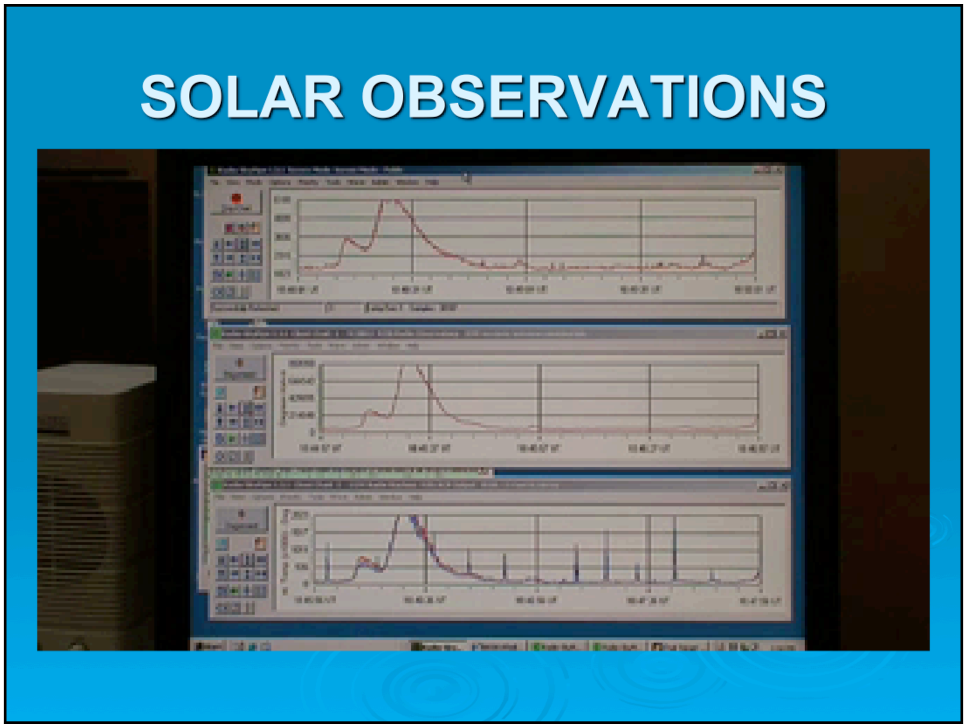
| #Event | Begin | Max | End | Obs | Q | Type | Loc/Frq | Particulars | Reg# |
|---|---|---|---|---|---|---|---|---|---|
| 3580 + | 2204 | 2204 | 2205 | PAL | G | RBR | 245 | 340 | |
| 3600 | 2213 | //// | 2223 | CUL | C | RSP | 020-040 | II/3 | 2085 |
| 3620 | 2241 | 2242 | 2320 | HOL | 3 | FLA | S18E45 | SF ERU | 2087 |
| 3620 | 2318 | //// | 2336 | LEA | C | RSP | 048-180 | IV/1 | 2087 |

**Type/Intensity**

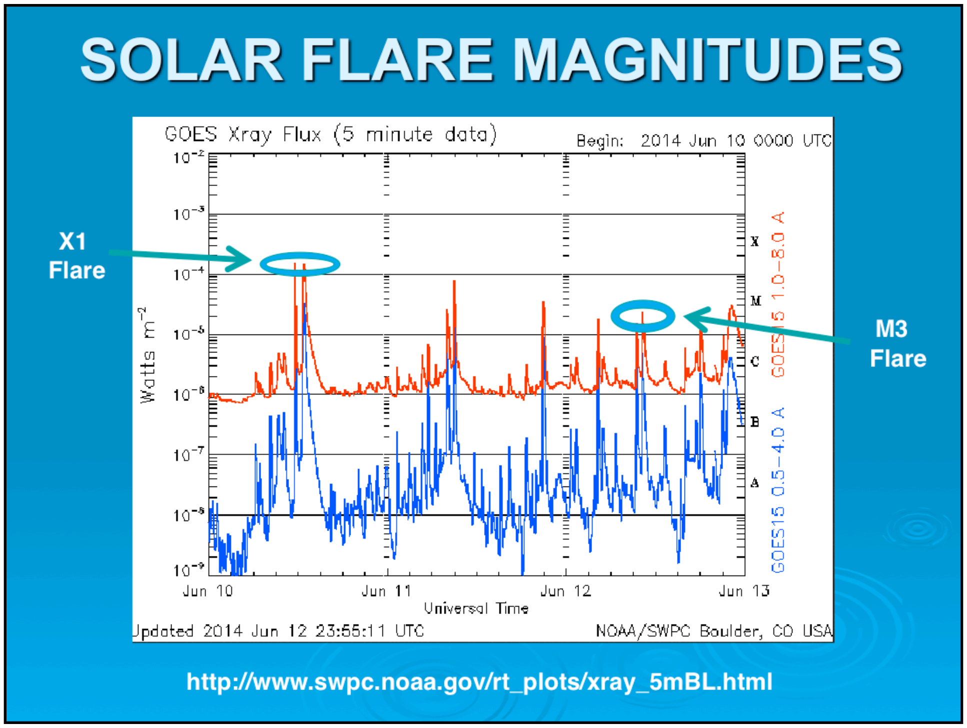
- **Type I: Narrowband non-drifting bursts of short duration (D. Gary)**
- **Type II: Slow drift burst**
- **Type III: Fast drift burst**
- **Type IV: Broadband smooth continuum burst**
- **Type V: Brief continuum burst, generally associated with Type III bursts**
- **Type VI: Series of Type III bursts over a period of 10 minutes or more, with no period longer than 30 minutes without activity**
- **Type VII: Series of Type III and Type V bursts over a period of 10 minutes or more, with no period longer than 30 minutes without activity**
- **Type CTM: Broadband, long-lived, dekametric continuum**

**Intensity is a relative scale 1=Minor, 2=Significant, 3=Major**

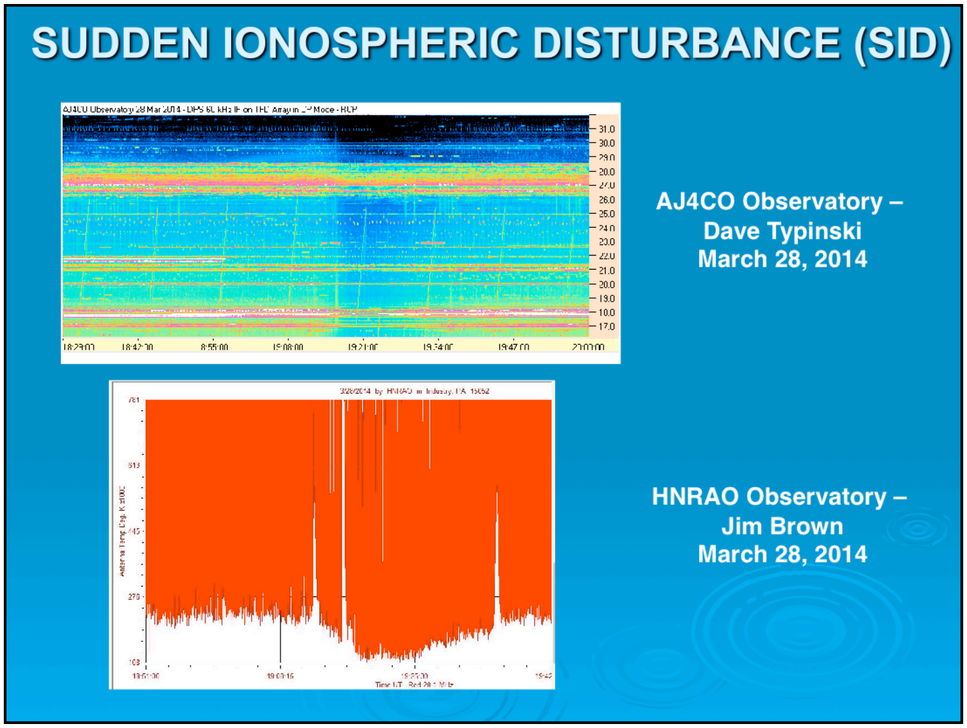
Besides Type II and III solar storms there are other types defined from Type I to Type VII. NOAA regularly observes the Sun from a number of radio telescopes around the Earth and reports daily on the findings. These can be found in the NOAA Solar Event Reports at the URL indicated above. Note that they explain the shorthand documentation they use for these reports in the same general area. It is interesting that their definition of Type shows storms of Types II through VII, but no Type I. The definition of a Type I solar storm according to Dr. Dale Gary has been added to the list in red lettering.



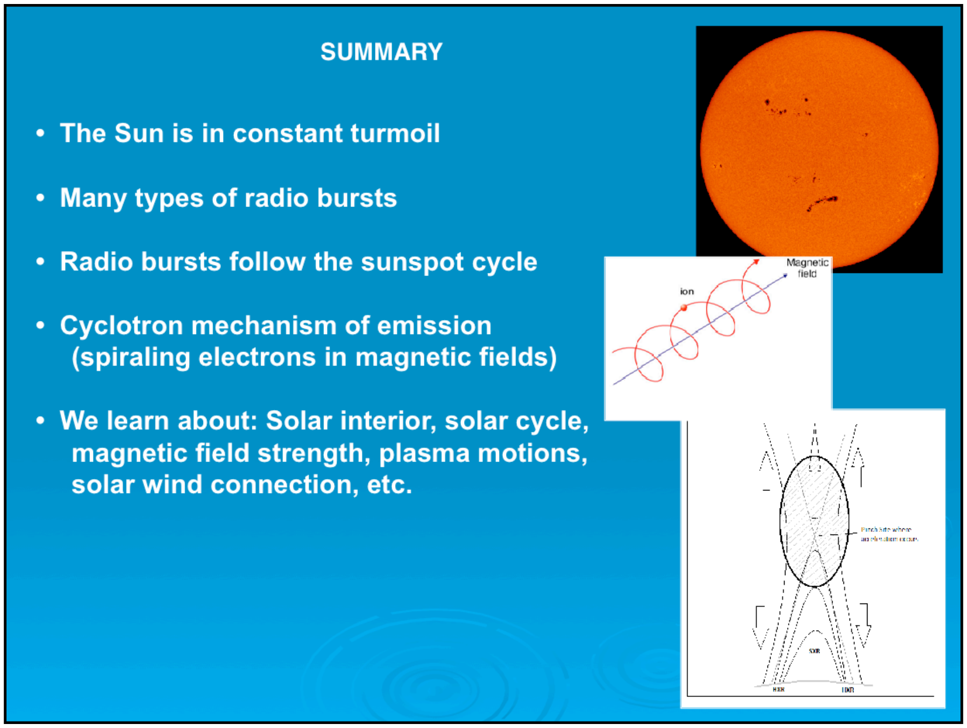

In the single frequency radio observations made with Radio Jove equipment a solar storm (Type III) is usually strong enough to appear very similar even on widely-spaced radio telescopes. This video clip shows a solar storm being received simultaneously on three different telescopes. The shark fin type of shape of the peak and the characteristic sound are useful to become familiar with as indicators of a solar storm.



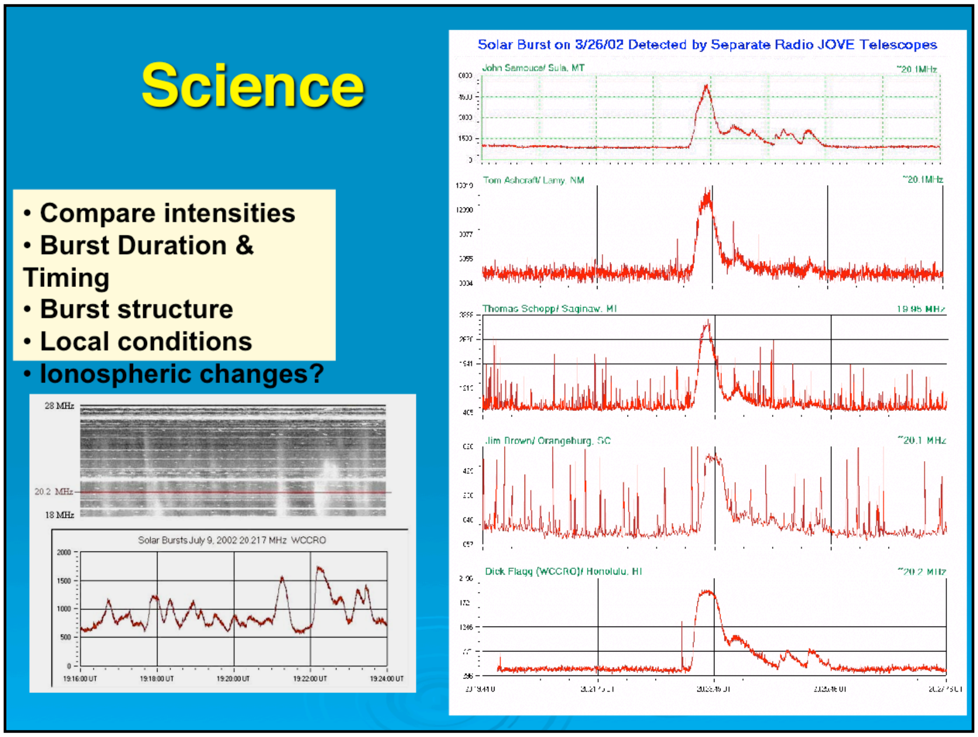

NOAA also observes and reports on the magnitude of solar storms so that we often hear this was an M1.1 magnitude storm or a C6. These classifications are based on the GOES Xray Flux measurements. These graphs can be found at the URL indicated on the bottom of this slide. Solar storms will cause a sudden spike in the Xray flux. The maximum value of the peak of the spike in Watts/meter-squared indicates the strength of the storm. Note the logarithmic scale of the left hand vertical axis. Rather than use a numeric value of Watts/meter-squared the increasingly higher logarithmic values of the scale were given letter designations of A, B, C, M, and X as indicated on the right side. So, for example, the circled peaks would be called X1 and M3 flares.




A solar flare can generate a Sudden Ionospheric Disturbance (SID) that causes the ionospheric electron density to increase due to arrival of intense ultraviolet or x-ray radiation from the flare. (Eight minutes after it occurs on the Sun). The increased electron density absorbs the radio waves in the frequency range monitored by Radio Jove equipment. Note the sudden decrease and gradual recovery in the 20.1 MHz baseline observed by HNRAO at 20.1 MHz and at multiple frequencies by the AJ4CO spectrograph.




In summary the Sun is a very interesting yet generally unpredictable target for Radio Jove observations.




Here's another example of a solar storm being simultaneously received by five different widely-scattered Radio Jove sites. They have different types of interference for the rest of their recordings but the solar storms are quite similar.