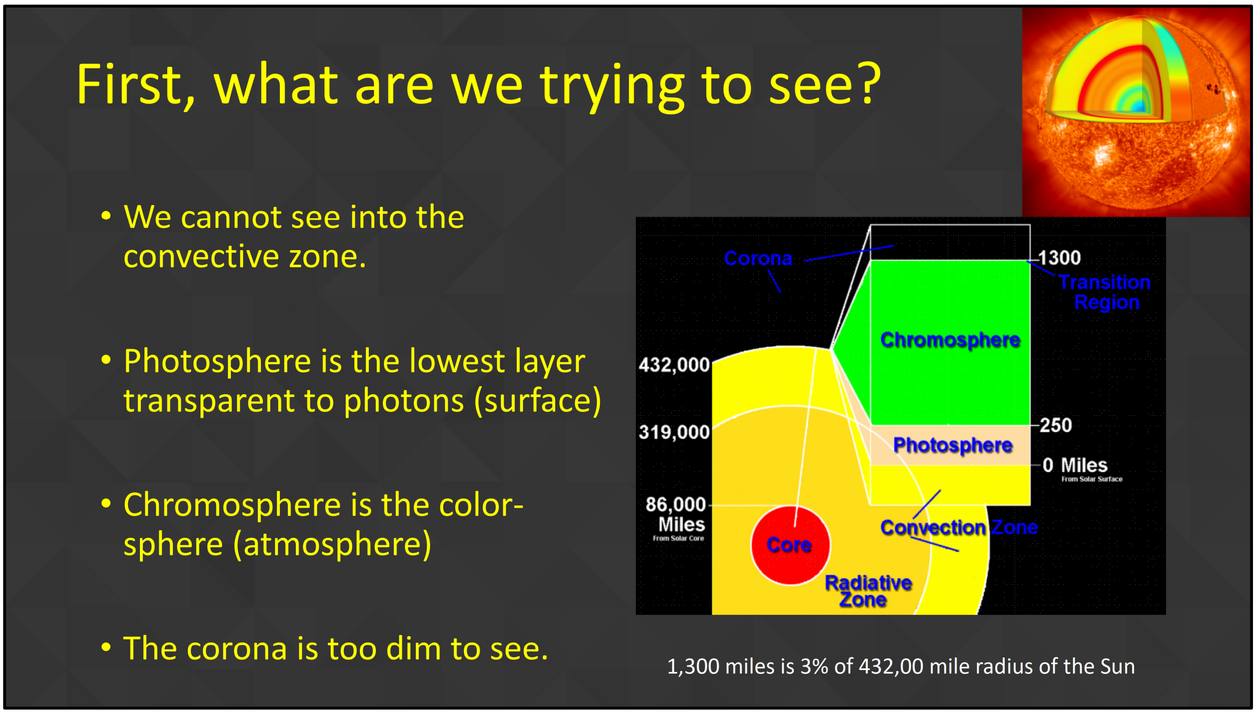
Unless otherwise noted, data and photos are from NASA.gov. Information on solar telescopes and filters is taken from the manufacturer mentioned. Any opinions expressed are mine. I try to be as accurate as possible with data and attribution, but if I'm wrong, please let me know.

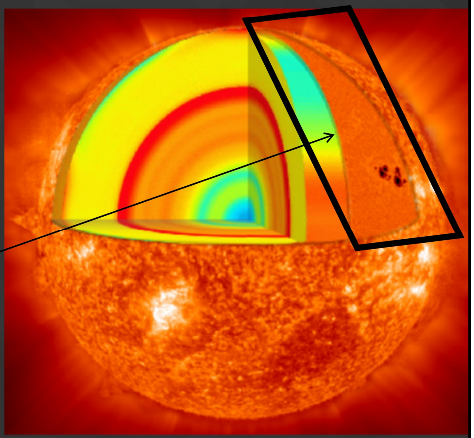


1,300 miles is 3% of 432,00 mile radius of the Sun -

The only layers normally visible to man are the photosphere and chromosphere. The corona is normally too dim to see, but a total eclipse allows us to see it for a few minutes. The convective zone below the photosphere blocks photons and is not visible to us.

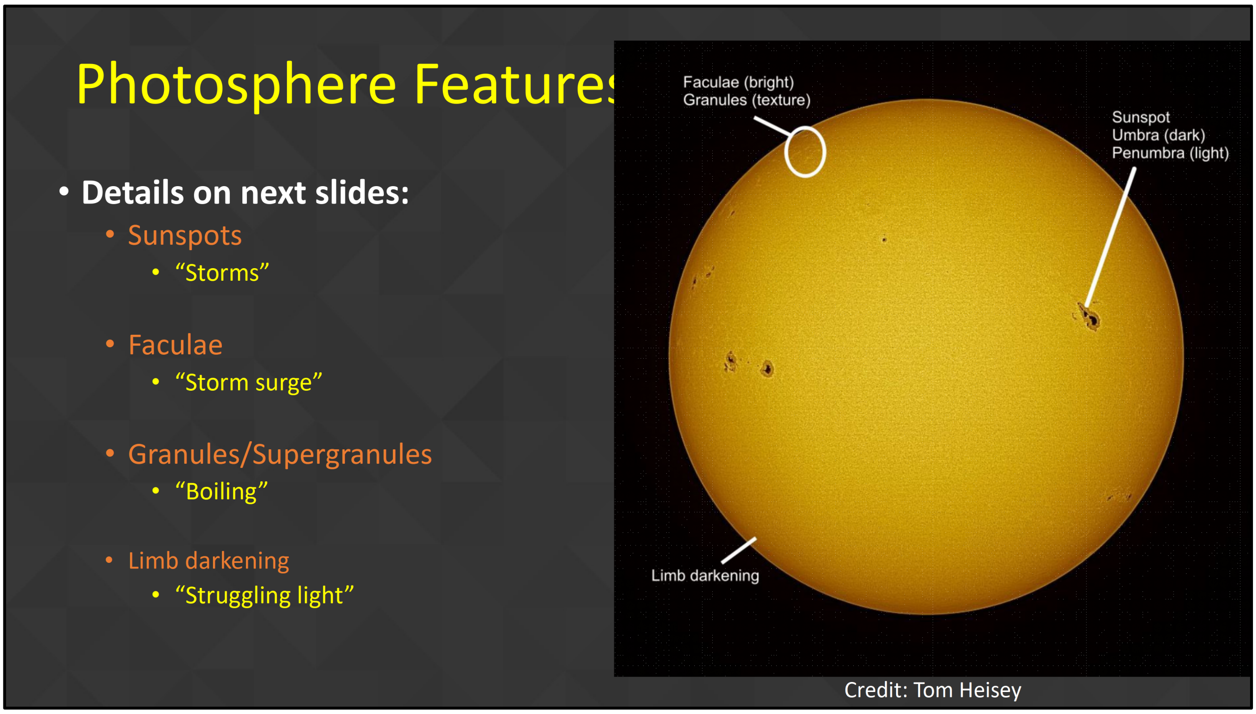
Photosphere

- Ancient Greek - ‘phos sphaira’ meaning ‘light sphere’
  - Deepest region of a star that is transparent to photons
  - Sun’s visual surface
  - White light
- “Surface” of the Sun
  - Plasma, not liquid or solid
  - Very thin compared to other layers
    - Just 250 miles thick vs. 435,000 mile radius of the Sun



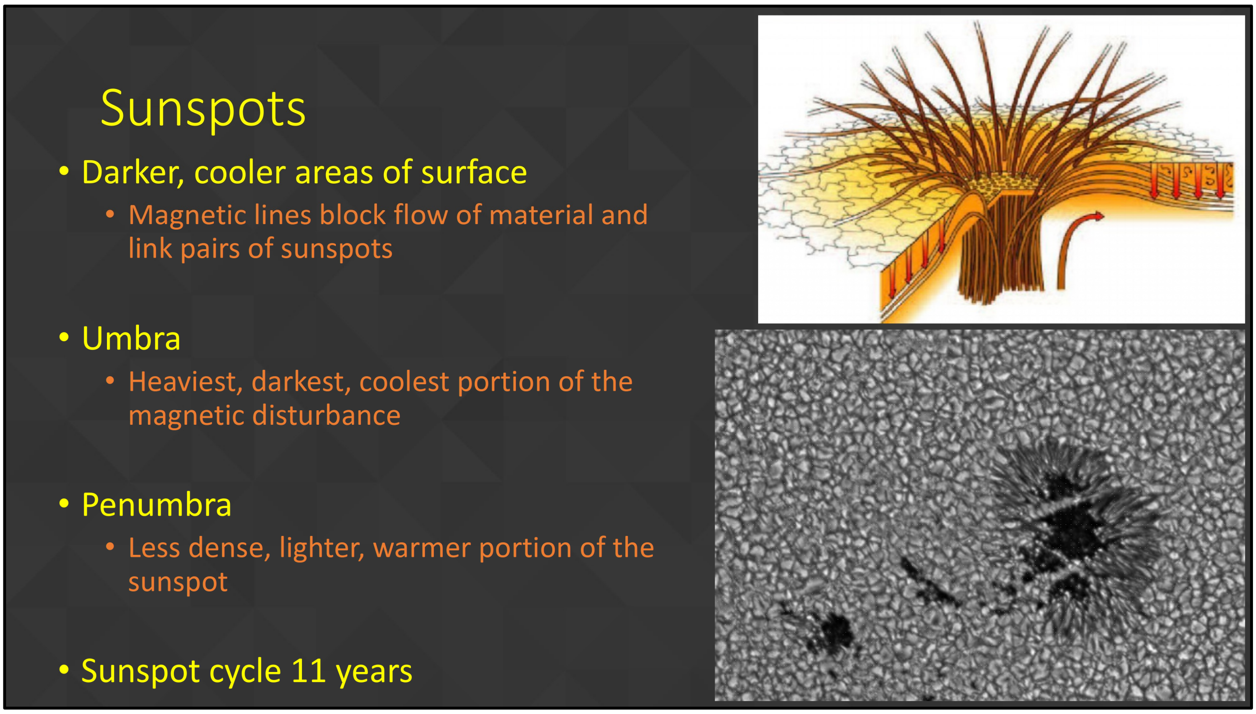
https://solarscience.msfc.nasa.gov/surface.shtml
https://en.wikipedia.org/wiki/Photosphere

The photosphere is the visible surface of the Sun that we are most familiar with. Since the Sun is a ball of gas, this is not a solid surface but is actually a very thin layer (very, very, thin compared to the 700,000 km radius of the Sun) that is transparent to photons. We cannot see below this layer.



https://solarscience.msfc.nasa.gov/feature1.shtml

Quick list of features - more about each in the following slides.

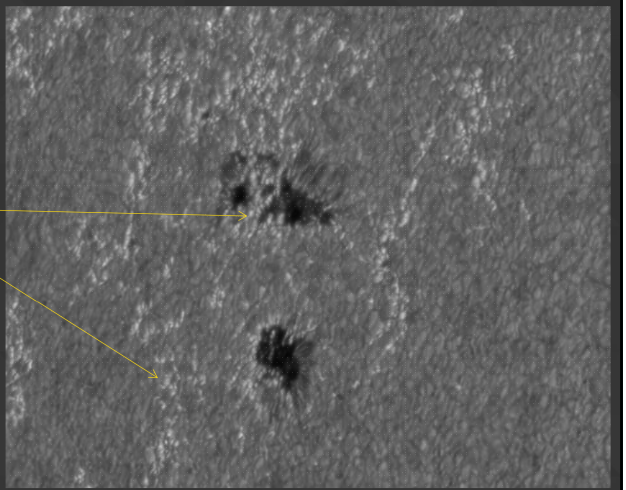


https://solarscience.msfc.nasa.gov/feature1.shtml

Sunspots appear as dark spots on the surface of the Sun. Temperatures in the dark centers of sunspots drop to about 3700 K (compared to 5700 K for the surrounding photosphere). They typically last for several days, although very large ones may live for several weeks. Sunspots are magnetic regions on the Sun with magnetic field strengths thousands of times stronger than the Earth's magnetic field. Sunspots usually come in groups with two sets of spots. One set will have positive or north magnetic field while the other set will have negative or south magnetic field. The field is strongest in the darker parts of the sunspots - the umbra. The field is weaker and more horizontal in the lighter part - the penumbra.

Faculae

- AKA active regions
- Concentrated magnetic field
  - Smaller bundles than sunspots
  - Can surround sunspots
  - Canyons between solar granules
- Hotter, brighter spots
  - Material brought to surface
  - During solar max, faculae make the Sun about 0.1% brighter
- Base of plage in chromosphere



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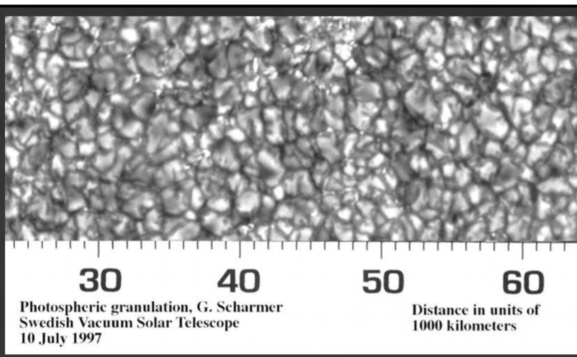
Faculae
Faculae are bright areas that are usually most easily seen near the limb, or edge, of the solar disk. These are also magnetic areas but the magnetic field is concentrated in much smaller bundles than in sunspots. While the sunspots tend to make the Sun look darker, the faculae make it look brighter. During a sunspot cycle the faculae actually win out over the sunspots and make the Sun appear slightly (about 0.1%) brighter at sunspot maximum that at sunspot minimum.

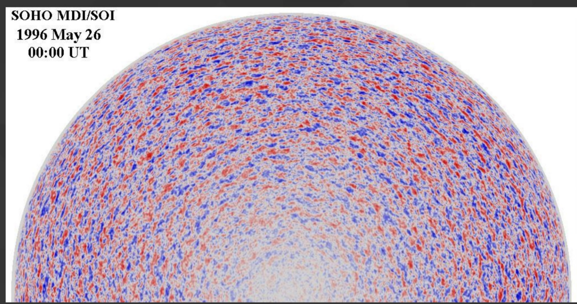
https://en.wikipedia.org/wiki/Facula

Solar faculae are bright spots in the photosphere that form in the canyons between solar granules, short-lived convection cells several thousand kilometers across that constantly form and dissipate over timescales of several minutes. Faculae are produced by concentrations of magnetic field lines. Strong concentrations of faculae appear in solar activity, with or without sunspots. The faculae and the sunspots contribute noticeably to variations in the "Solar constant". The chromospheric counterpart of a facular region is called a plage.

Granules/Supergranules

- Convection cells that cover the surface of the Sun
  - Except at sunspots
  - Hot fluid rising from interior (bright center), cools (dark ring) and sinks
- Sizes
  - Granules ~1,000 Km (621 mi.)
  - Supergranules ~35,000 km (21,700 mi.)
- Life Span
  - Granules ~20 minutes
  - Supergranules 1-2 days



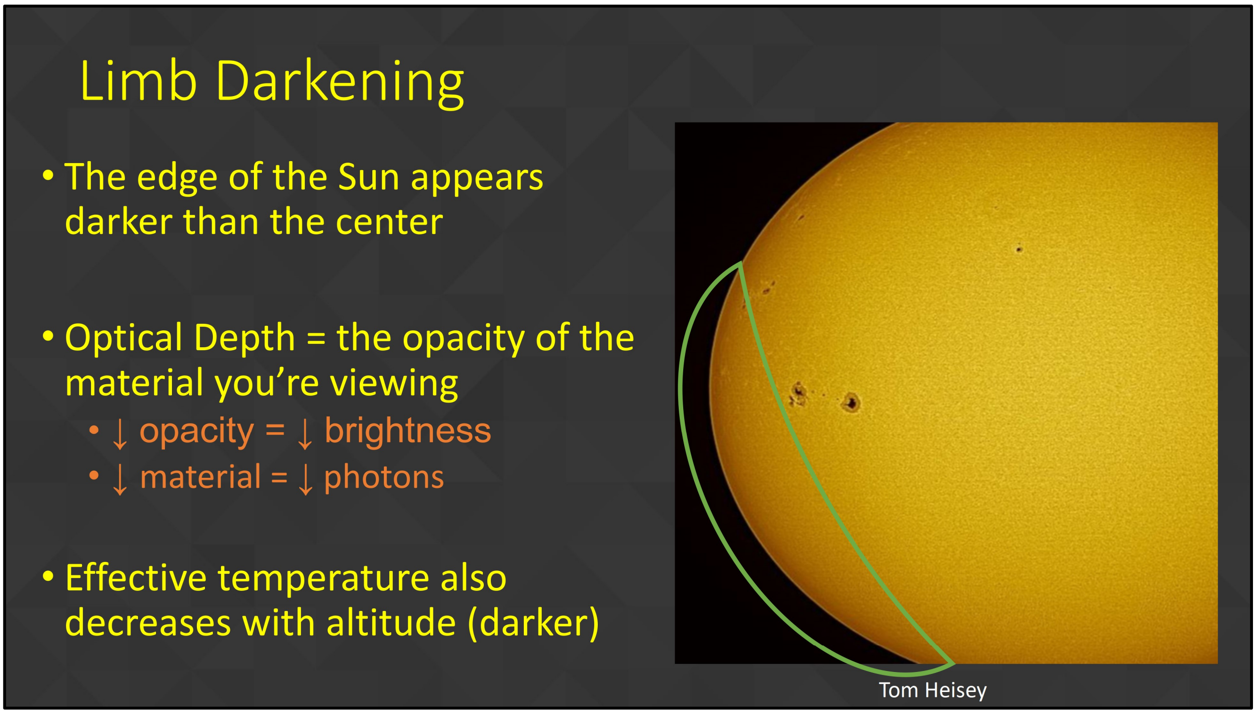


NASA/MSFC Hathaway

Texas = 800-1,000 miles N-S, Earth diameter 7,917.6 mi
https://solarscience.msfc.nasa.gov/feature1.shtml

Granules are small (about 1000 km across) cellular features that cover the entire Sun except for those areas covered by sunspots. These features are the tops of convection cells where hot fluid rises up from the interior in the bright areas, spreads out across the surface, cools and then sinks inward along the dark lanes. Individual granules last for only about 20 minutes. The granulation pattern is continually evolving as old granules are pushed aside by newly emerging ones (470 KB MPEG movie from the Swedish Vacuum Solar Telescope). The flow within the granules can reach supersonic speeds of more than 7 km/s (15,000 mph) and produce sonic "booms" and other noise that generates waves on the Sun's surface.

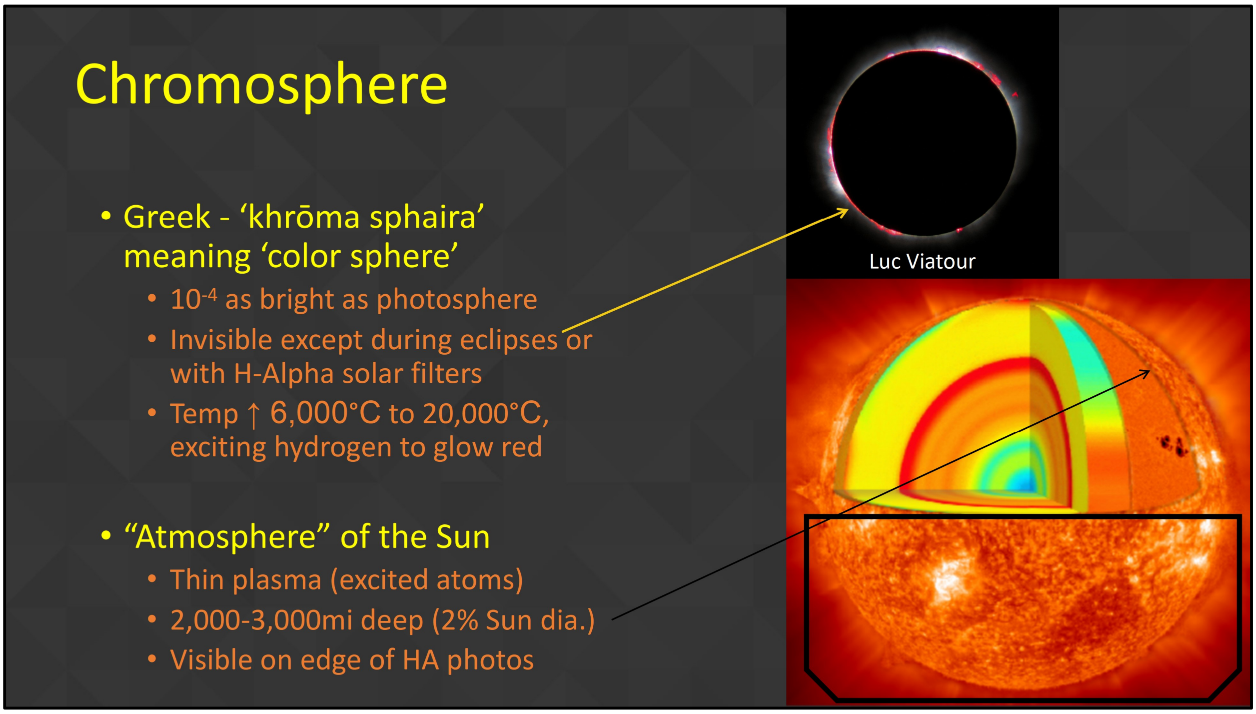
Supergranules are much larger versions of granules (about 35,000 km across) but are best seen in measurements of the "Doppler shift" where light from material moving toward us is shifted to the blue while light from material moving away from us is shifted to the red. These features also cover the entire Sun and are continually evolving. Individual supergranules last for a day or two and have flow speeds of about 0.5 km/s (1000 mph). The fluid flows observed in supergranules carry magnetic field bundles to the edges of the cells where they produce the chromospheric network.



https://en.wikipedia.org/wiki/Limb_darkening

Optical depth, a measure of the opacity of an object or part of an object, combines with effective temperature gradients inside the star to produce limb darkening. The light seen is approximately the integral of all emission along the line of sight modulated by the optical depth to the viewer (i.e. 1/e times the emission at 1 optical depth, 1/e2 times the emission at 2 optical depths, etc.). Near the center of the star, optical depth is effectively infinite, causing approximately constant brightness. However, the effective optical depth decreases with increasing radius due to lower gas density and a shorter line of sight distance through the star, producing a gradual dimming, until it becomes zero at the apparent edge of the star.

The effective temperature of the photosphere also decreases with increasing distance from the center of the star. The radiation emitted from a gas is approximately black-body radiation, the intensity of which is proportional to the fourth power of the temperature. Therefore, even in line of sight directions where the optical depth is effectively infinite, the emitted energy comes from cooler parts of the photosphere, resulting in less total energy reaching the viewer.



https://solarscience.msfc.nasa.gov/chromos.shtml
The chromosphere is an irregular layer above the photosphere where the temperature rises from 6000°C to about 20,000°C. At these higher temperatures hydrogen emits light that gives off a reddish color (H-alpha emission). This colorful emission can be seen in prominences that project above the limb of the sun during total solar eclipses. This is what gives the chromosphere its name (color-sphere).

https://en.wikipedia.org/wiki/Chromosphere

Chromospheres have also been observed on stars other than the Sun.[2] On large stars, chromospheres sometimes make up a significant proportion of the entire star. For example, the chromosphere of supergiant star Antares has been found to be about 2.5 times larger in thickness than the star's radius.[3]

By I, Luc Viatour, CC BY-SA 3.0,
https://commons.wikimedia.org/w/index.php?curid=60794

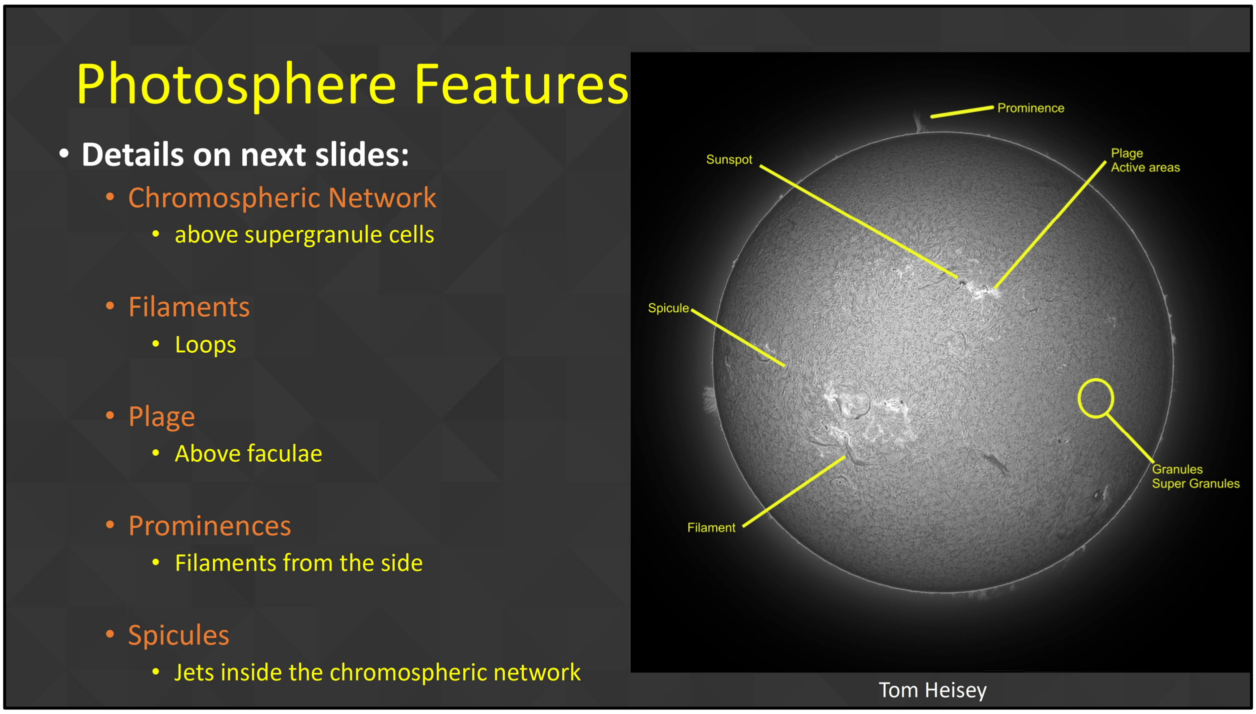


Photo by me, Tom Heisey

https://solarscience.msfc.nasa.gov/feature2.shtml

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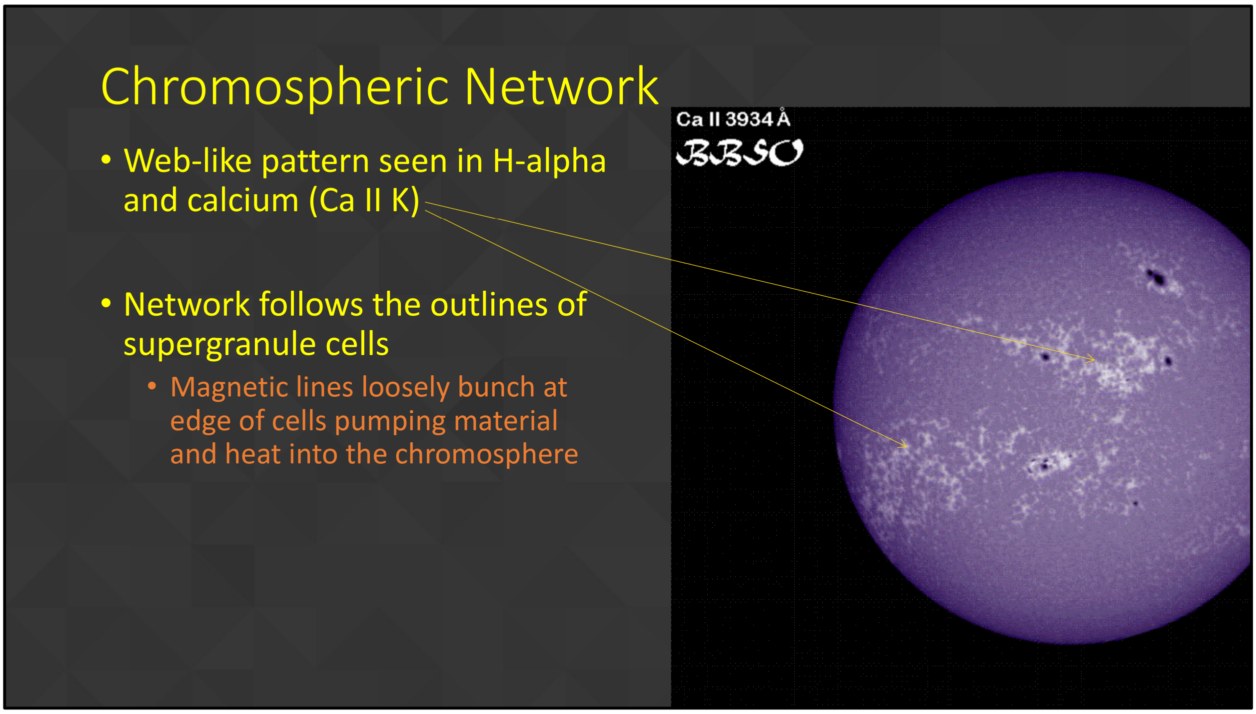

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Faculae are bright areas that are usually most easily seen near the limb, or edge, of the solar disk. These are also magnetic areas but the magnetic field is concentrated in much smaller bundles than in sunspots. While the sunspots tend to make the Sun look darker, the faculae make it look brighter. During a sunspot cycle the faculae actually win out over the sunspots and make the Sun appear slightly (about 0.1%) brighter at sunspot maximum that at sunspot minimum.

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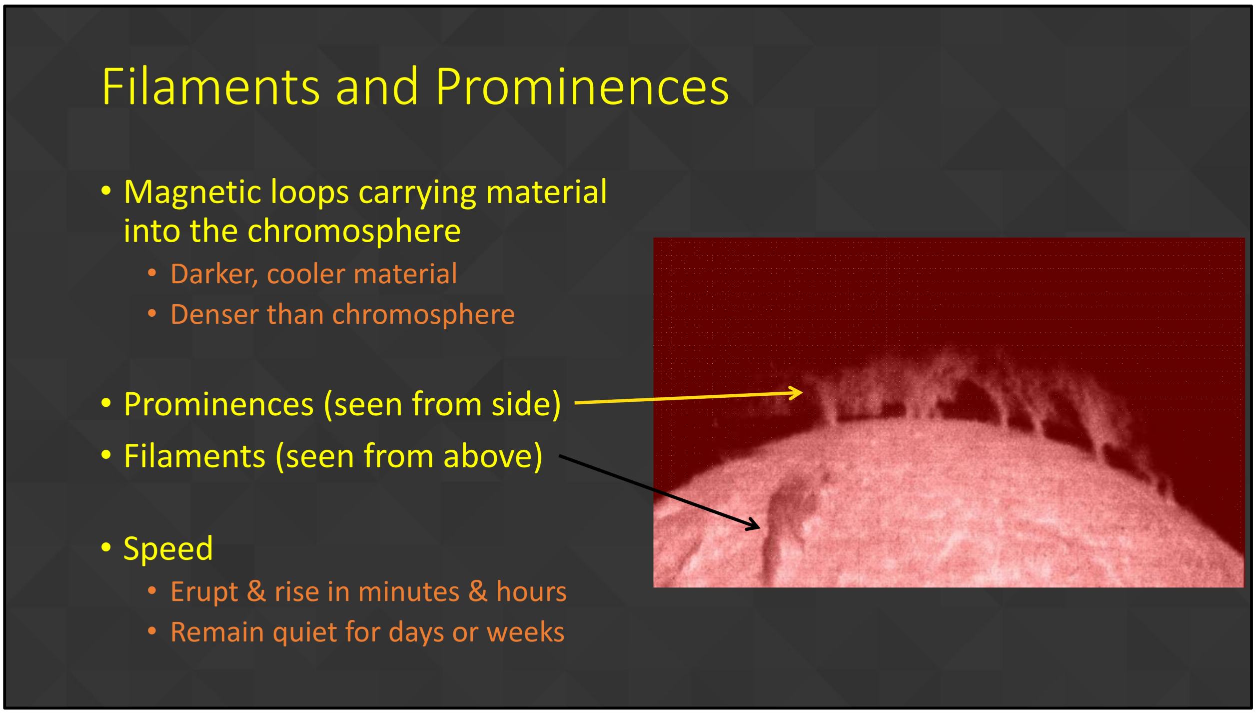


https://solarscience.msfc.nasa.gov/feature1.shtml

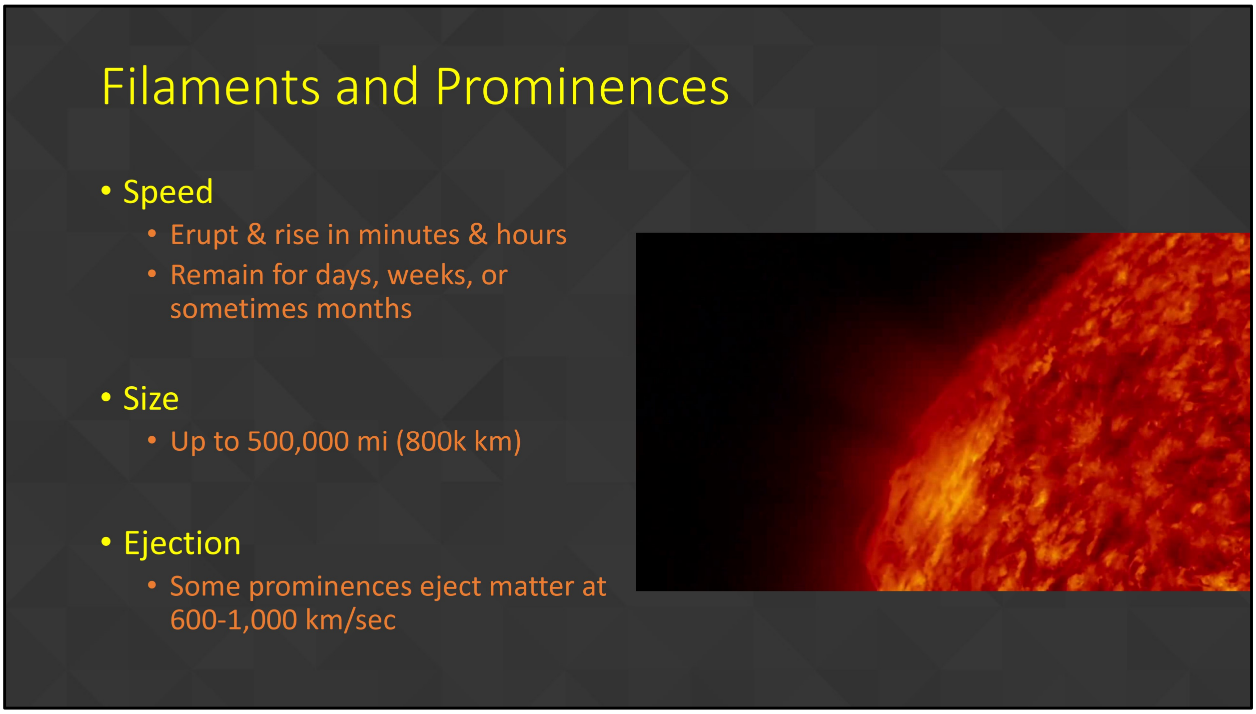
Filaments are dark, thread-like features seen in the red light of hydrogen (H-alpha). These are dense, somewhat cooler, clouds of material that are suspended above the solar surface by loops of magnetic field

Prominences are dense clouds of material suspended above the surface of the Sun by loops of magnetic field. Prominences and filaments are actually the same things except that prominences are seen projecting out above the limb, or edge, of the Sun. Both filaments and prominences can remain in a quiet or quiescent state for days or weeks. However, as the magnetic loops that support them slowly change, filaments and prominences can erupt and rise off of the Sun over the course of a few minutes or hours

https://en.wikipedia.org/wiki/Solar_phenomena
Prominence plasma is typically a hundred times cooler and denser than coronal plasma. A prominence forms over timescales of about an earthly day and may persist for weeks or months. Some prominences break apart and form CMEs.

A typical prominence extends over many thousands of kilometers; the largest on record was estimated at over 800,000 kilometers (500,000 mi) long [26] – roughly the solar radius.

When a prominence is viewed against the Sun instead of space, it appears darker than the background. This formation is called a solar filament.[26] It is possible for a projection to be both a filament and a prominence. Some prominences are so



https://solarscience.msfc.nasa.gov/feature1.shtml

https://en.wikipedia.org/wiki/Solar_phenomena
A prominence is a large, bright, gaseous feature extending outward from the Sun's surface, often in the shape of a loop. Prominences are anchored to the Sun's surface in the photosphere and extend outwards into the corona. While the corona consists of high temperature plasma, which does not emit much visible light, prominences contain much cooler plasma, similar in composition to that of the chromosphere.

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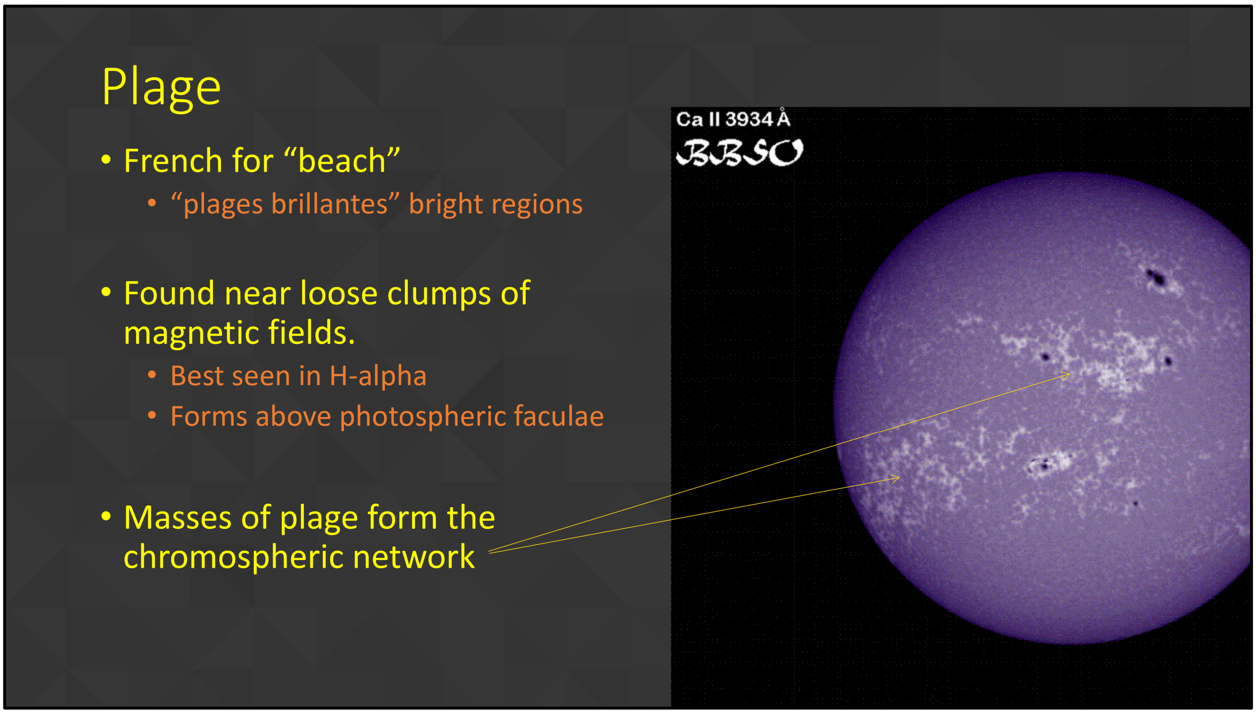
When a prominence is viewed against the Sun instead of space, it appears darker than the background. This formation is called a solar filament.[26] It is possible for a projection to be both a filament and a prominence. Some prominences are so powerful that they eject matter at speeds ranging from 600 km/s to more than 1000 km/s. Other prominences form huge loops or arching columns of glowing gases over sunspots that can reach heights of hundreds of thousands of kilometers.[27]

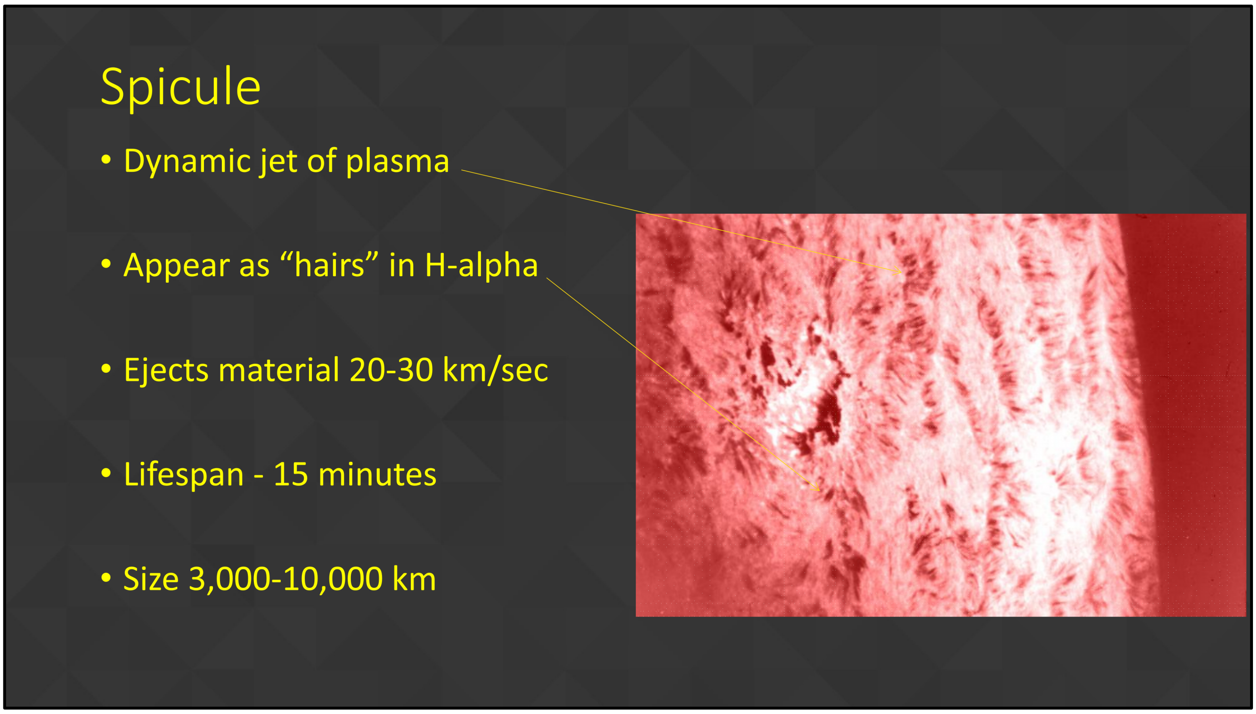


https://solarscience.msfc.nasa.gov/feature2.shtml

Plage, the French word for beach, are bright patches surrounding sunspots that are best seen in H-alpha. Plage are also associated with concentrations of magnetic fields and form a part of the network of bright emissions that characterize the chromosphere.

https://en.wikipedia.org/wiki/Solar_plage
A plage /pleɪdʒ/ is a bright region in the Sun's chromosphere, typically found in and around active regions. Historically, they have been referred to as bright flocculi, in contrast to dark flocculi, and as chromospheric faculae, in contrast to photospheric faculae.

Classically plage have been defined as regions that are bright in Hα and other chromospheric emission lines. but nowadays most researchers identify plage based on the photospheric magnetic field concentration of the faculae below.



https://solarscience.msfc.nasa.gov/feature2.shtml

Spicules are small, jet-like eruptions seen throughout the chromospheric network. They appear as short dark streaks in the H-alpha image to the left (National Solar Observatory/Sacramento Peak). They last but a few minutes but in the process eject material off of the surface and outward into the hot corona at speeds of 20 to 30 km/s.

https://en.wikipedia.org/wiki/Solar_spicule
In solar physics, a spicule, also known as a fibril or mottle,[a] is a dynamic jet of plasma in the Sun's chromosphere about 300 km in diameter.

Spicules last for about 15 minutes;[2] at the solar limb they appear elongated (if seen on the disk, they are known as "mottles" or "fibrils"). They are usually associated with regions of high magnetic flux; their mass flux is about 100 times that of the solar wind. They rise at a rate of 20 km/s (or 72,000 km/h) and can reach several thousand kilometers in height before collapsing and fading away.

Prevalence
There are about 3,000,000 active spicules at any one time on the Sun's chromosphere.[2] An individual spicule typically reaches 3,000–10,000 km altitude above the photosphere.[3]

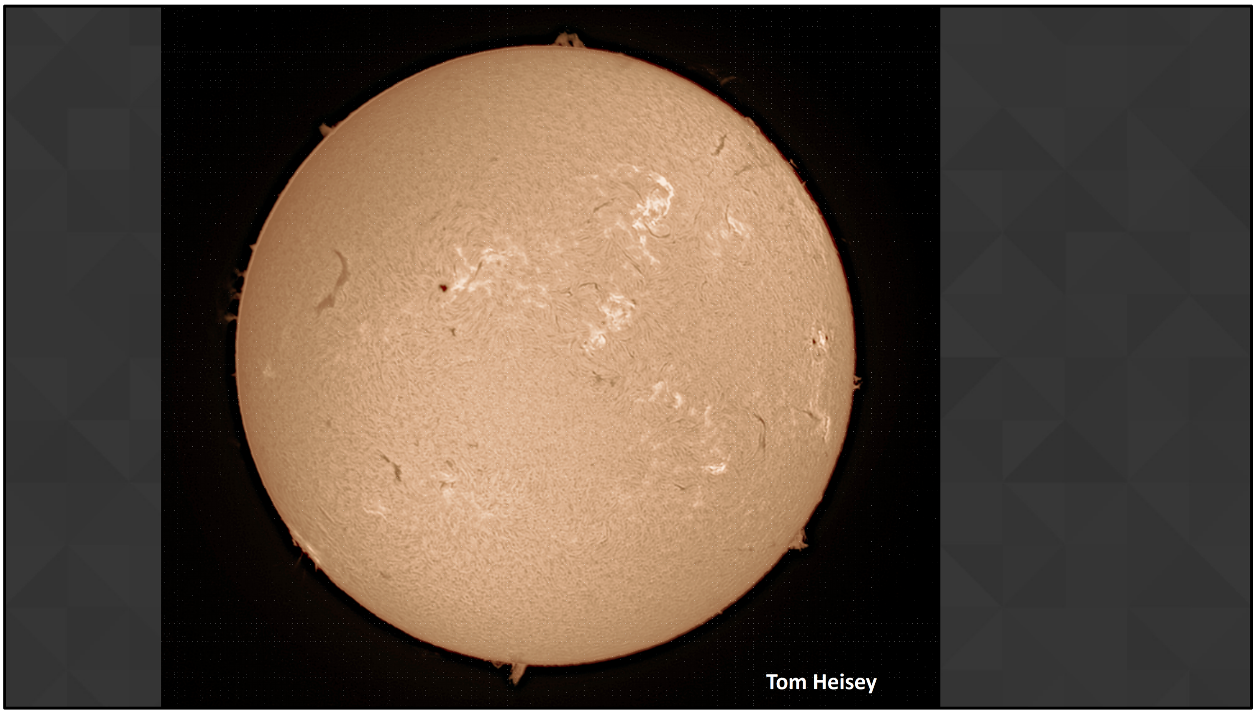
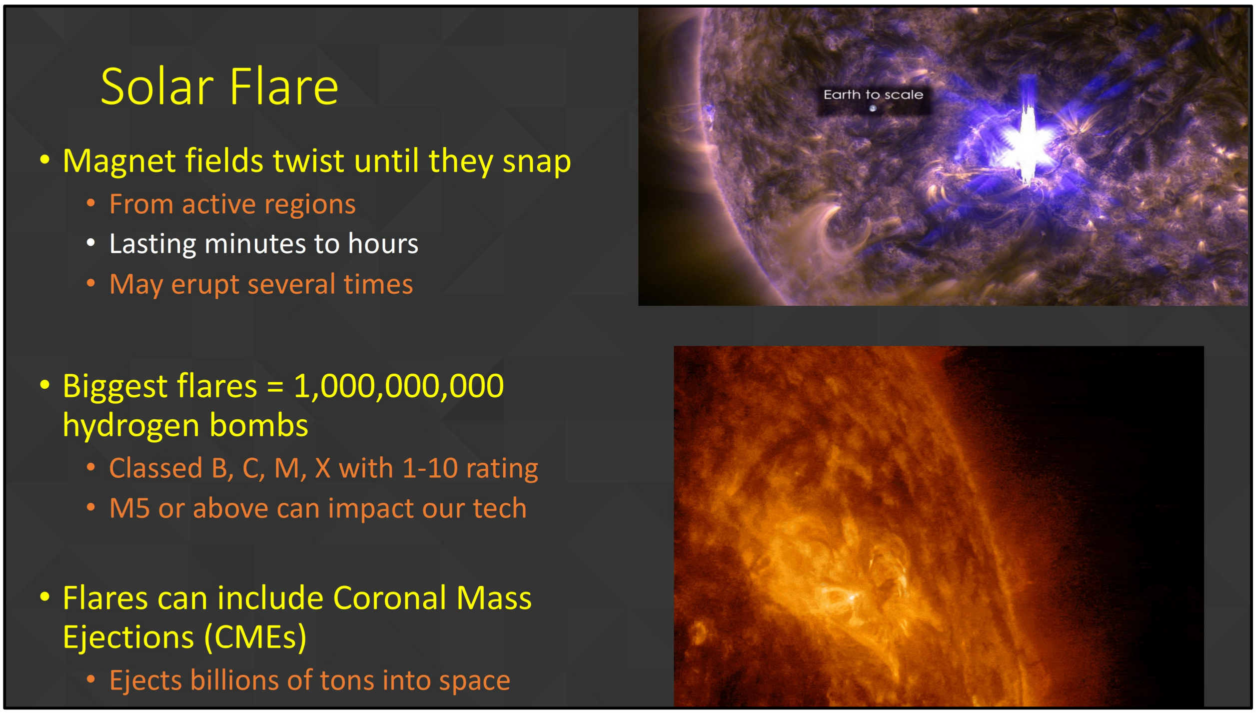


Photo by me, Tom Heisey
This was my first photo through my Lunt 60mm double stacked H-alpha telescope.
(It's not my first solar image. Before this shot, I had practiced on a friend's scope.)



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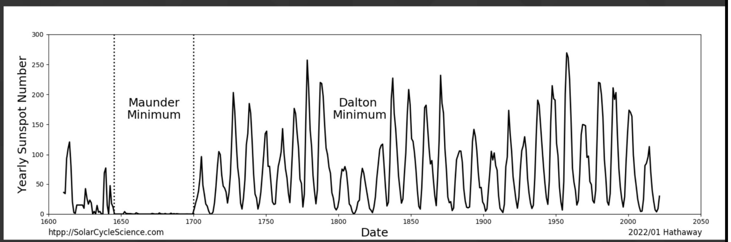
Solar Cycle

- Solar activity slowly varies over an average of 11 years
  - Tracking sunspot numbers
  - Recorded since 1600
- Not well understood
  - Differential rotation twists magnetic fields
  - Magnetic polarity switch
  - Surface flows carry polarity to north and south poles



http://solarcyclescience.com/solarcycle.html

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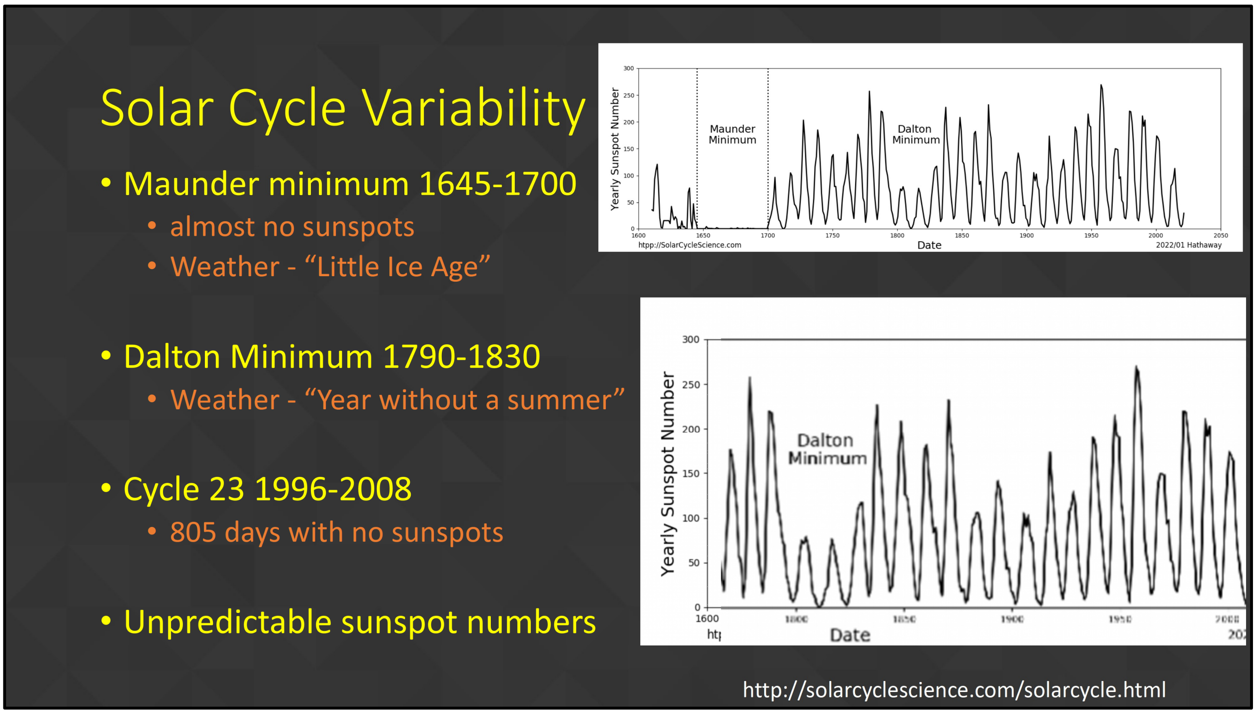
Obtaining a good understanding of the solar cycle and its variability is the oldest and most significant problem in solar physics. H.W. Babcock (1961) proposed the first complete (phenomenological rather than numerical) Dynamo Model to explain the magnetic properties that were observed on the Sun. This model progresses in four stages:
Solar Minimum. An axisymmetric dipole (poloidal) field exists. Field lines emerge at high latitudes and thread through the convection zone to the opposite hemisphere.
Differential Rotation causes the submerged magnetic field to stretch in the toroidal direction (wrapping around the Sun). The field is strengthened by this stretching.
The toroidal field become buoyant and causes sunspots to emerge with Joy's Tilt and Hale's Polarity (polarity of leading spots matches the polarity of the polar field at minimum).
Magnetic flux is shredded off of the sunspots. The leading polarity fields cancel across the equator. The surface flows transport the following polarity to the poles. The following polarity cancels the old polar field and creates a new poloidal field with opposite polarity.
missing
While Babcock's model is widely accepted as the underlying mechanism behind the solar cycle, the finer details are still not well understood. Given this (and many more recent dynamo models), most solar physicists agree that the polar fields at solar minimum are the seeds to the next solar cycle.



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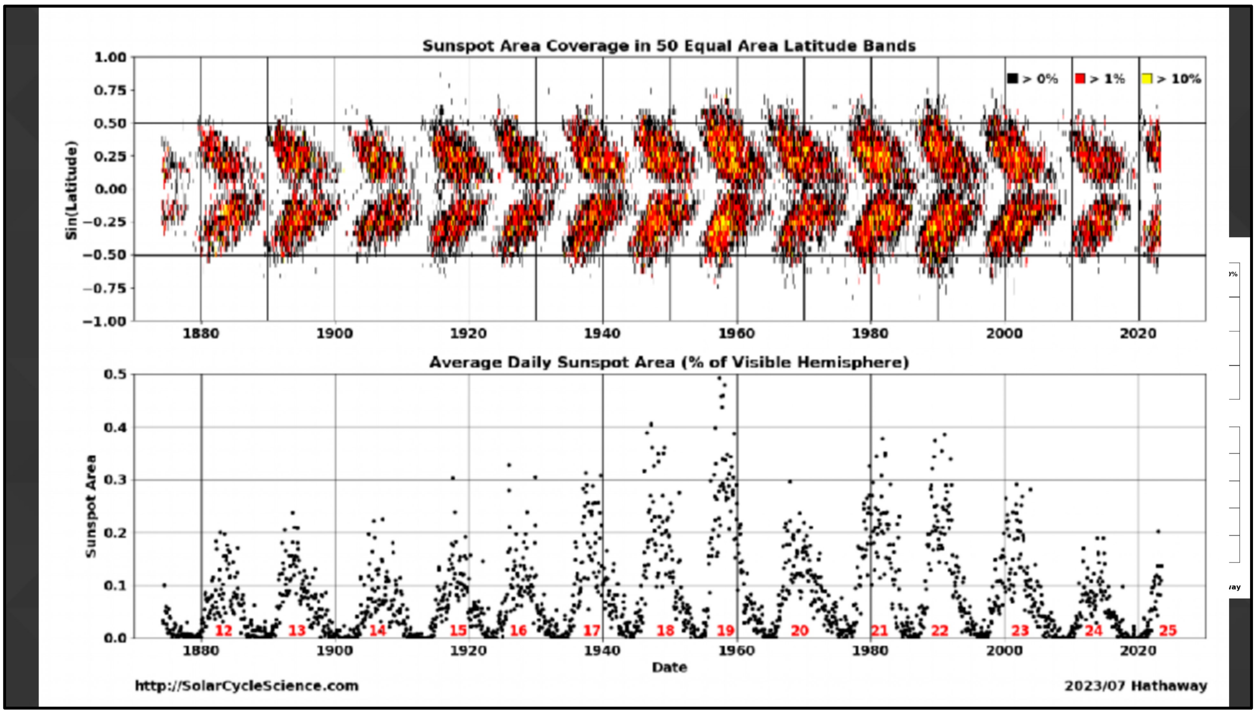
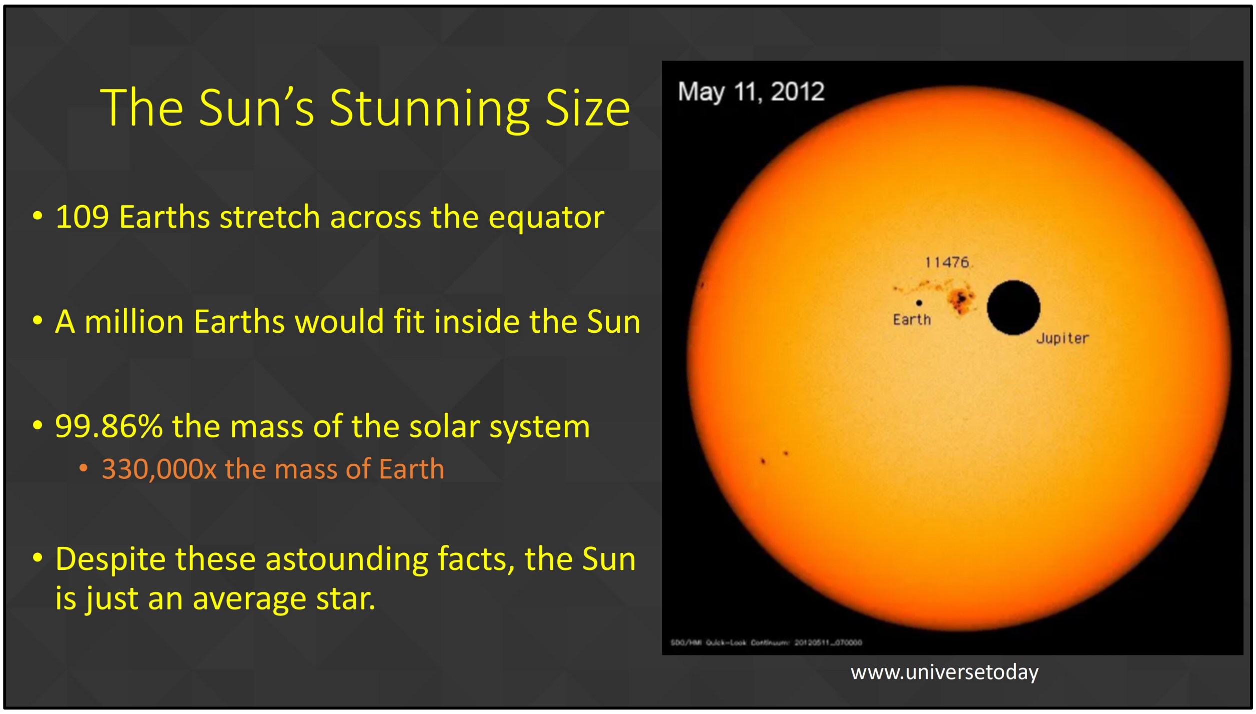
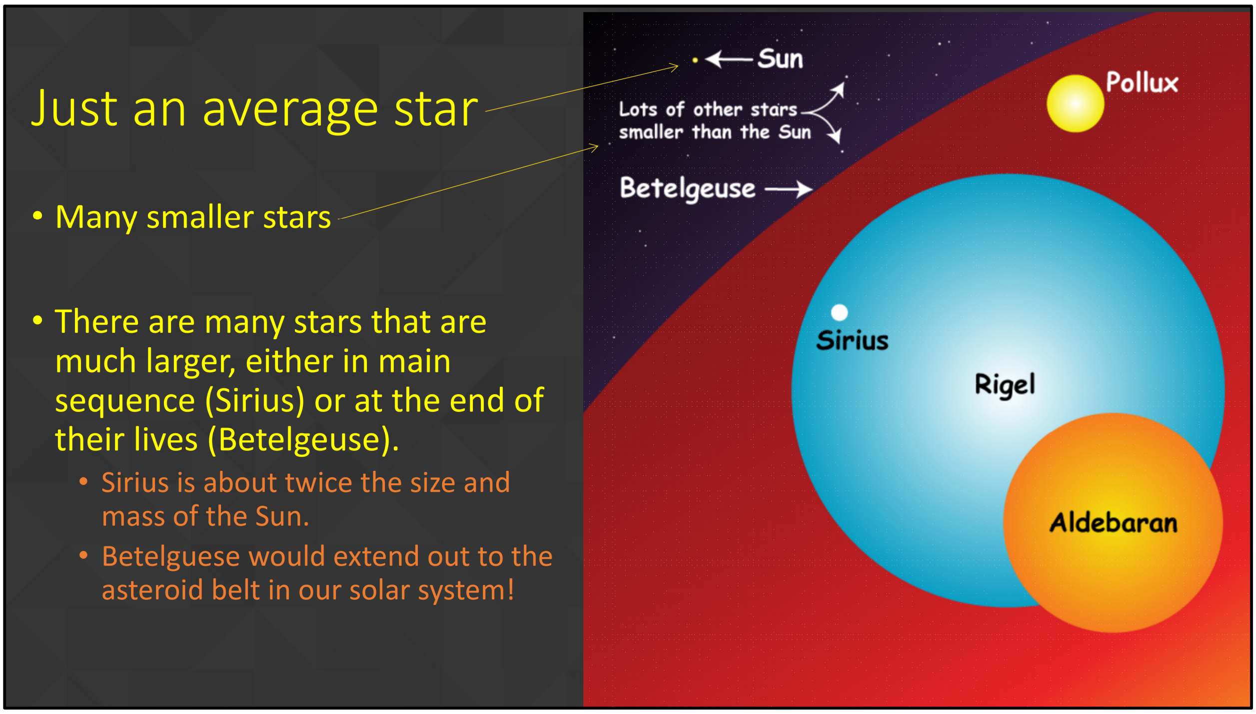


http://SolarCycleScience.com
Butterfly Diagrams illustrate how the distribution of sunspots and magnetic flux are distributed on the Sun and how they change over time. Sunspots appear in bands on either side of the equator. Cycles typically overlap by 2-3 years. At the beginning of each cycle, the active regions emerge at latitudes of about 30 degrees [Sin(Latitude)=0.50]. As the cycle progresses, the active regions emerge closer and closer to the equator, an effect known as Sporer's Law. Cancellation of magnetic polarity at each latitude and across the equator leaves behind an excess of following polarity that is transported to the poles. The north and south poles have opposite polarities that reverse from cycle to cycle. The timing of this polar field reversal is near the time of the solar cycle maximum.



https://en.wikipedia.org/wiki/Sun

- Ball of hot plasma,heated to incandescence by nuclear fusion reactions in its core.
- Radiates this energy mainly as light, ultraviolet, and infrared radiation, and is the most important source of energy for life on Earth.
- Radius is about 695,000 kilometers (432,000 miles), or 109 times that of Earth.
- Mass is about 330,000 times that of Earth, comprising about 99.86% of the total mass of the Solar System.
- Roughly three-quarters of the Sun's mass consists of hydrogen (~73%); the rest is mostly helium (~25%), with much smaller quantities of heavier elements, including oxygen, carbon, neon, and iron.[21]
- G-type main-sequence star (G2V), informally called a yellow dwarf, though its light is actually white.
- Formed approximately 4.6 billion years ago
- Core fuses about 600 million tons of hydrogen into helium each second, and in the process converts 4 million tons of matter into energy.
- This energy can take between 10,000 and 170,000 years to escape the core
- Eventually transform into the Sun into a red giant. It is calculated that the Sun will become sufficiently large to engulf the current orbits of Mercury and Venus, and render Earth uninhabitable in five billion years. After this, it will shed its outer layers and become a dense type of cooling star known as a white dwarf, and no longer produce energy by fusion, but still glow and give off heat from its previous fusion.



data from wikipedia.org:

Name	Distance	Mass	Radius
Sol -	93,000,000mi	1 M*	1 R*
Sirius -	8.7 ly	2.063 M*	1.711 R*
Pollux -	33.78 ly	1.91 M*	9.06 R*
Aldebaran -	65.3 ly	1.16 M*	45.1 R*
Rigel -	863 ly	21 M*	78.9 R*
Betelgeuse+ -	584 ly	15.6-19 M*	764-1,021 R*

M* = Solar masses R* = Solar radius

+ Combining these data with historical distance estimates of 180 to 815 ly yields a projected radius of the stellar disk of anywhere from 1.2 to 8.9 AU. Using the Solar System for comparison, the orbit of Mars is about 1.5 AU, Ceres in the asteroid belt 2.7 AU, Jupiter 5.5 AU—so, assuming Betelgeuse occupying the place of the Sun, its photosphere might extend beyond the Jovian orbit, not quite reaching Saturn at 9.5 AU.

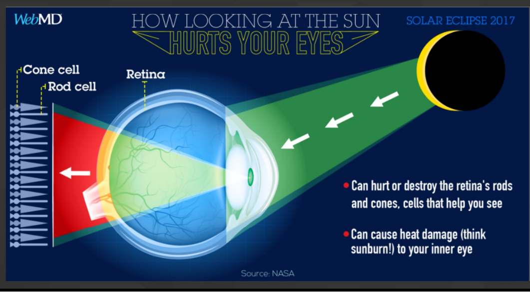
The precise diameter has been hard to define for several reasons:

1. Betelgeuse is a pulsating star, so its diameter changes with time;
2. The star has no definable "edge" as limb darkening causes the optical emissions to vary in color and decrease the farther one extends out from the center;
3. Betelgeuse is surrounded by a circumstellar envelope composed of matter ejected from the star—matter which absorbs and emits light—making it difficult to define the photosphere of the star;[58]

https://en.wikipedia.org/wiki/Betelgeuse

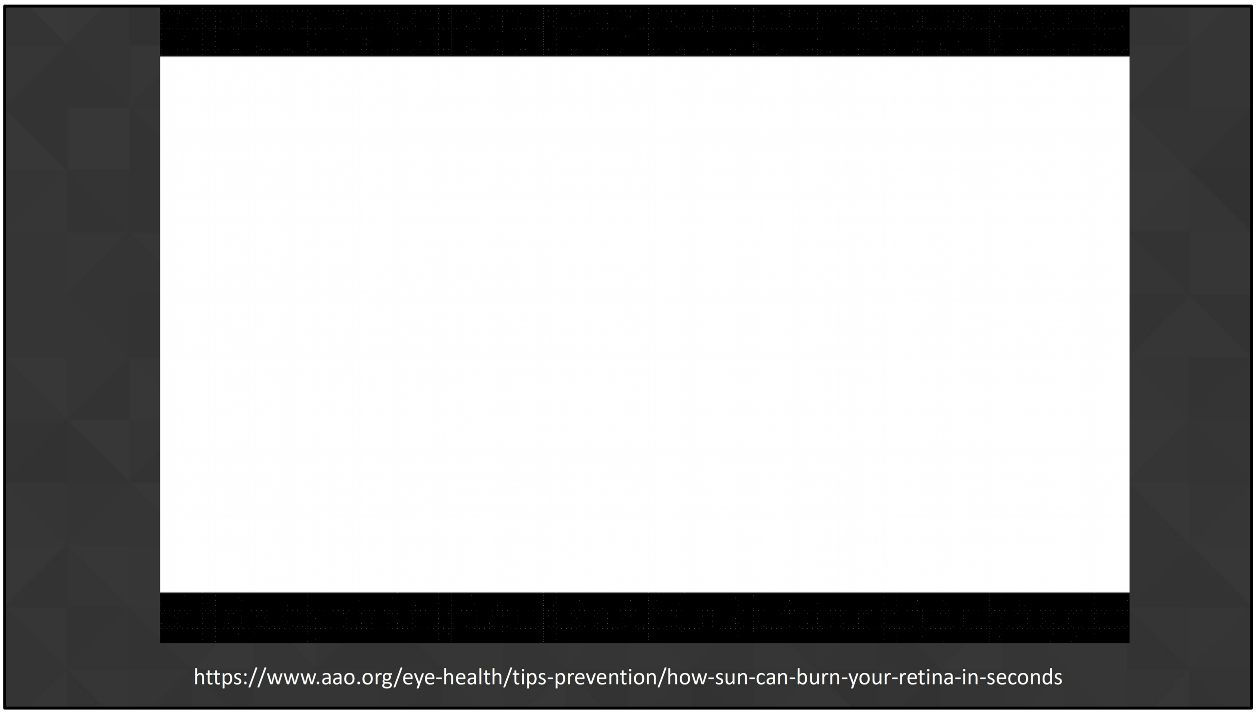
Safety, Safety, Safety

- Staring at the sun any time is dangerous
  - Dilated eyes are particularly dangerous
  - Permanent damage can happen quickly
- Eclipses are particularly dangerous
  - Light level is low (dilation)
  - UV light is at dangerous levels until totality
  - Annular eclipses are never safe
- You will not feel pain while your retina fries - there are no pain receptors.



Looking directly at the Sun is dangerous, even for short periods.

https://www.nasa.gov/content/eye-safety-during-a-total-solar-eclipse/
https://solarsystem.nasa.gov/eclipses/safety/
https://www.aao.org/eye-health/tips-prevention/solar-eclipse-eye-safety
https://www.space.com/35555-total-solar-eclipse-safety-tips.html
https://www.webmd.com/eye-health/what-to-know-solar-eclipse-glasses

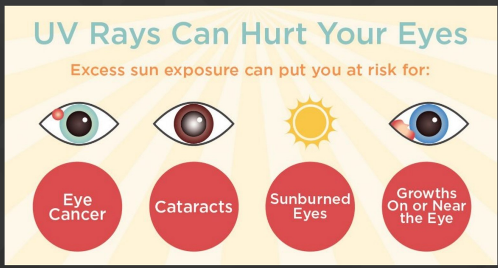


Short video from American Academy of Ophthamology on how the Sun can burn your retina.

https://www.aao.org/eye-health/tips-prevention/how-sun-can-burn-your-retina-in-seconds

How do we safely look at the sun?

- Projection
  - Pinhole
  - Telescope or bino
- White Light Filters
  - Glasses
  - #14 welder's glass
  - Telescope
  - Camera
- H-Alpha Filter
  - Telescope



https://www.nasa.gov/content/eye-safety-during-a-total-solar-eclipse/
https://solarsystem.nasa.gov/eclipses/safety/
https://www.aao.org/eye-health/tips-prevention/solar-eclipse-eye-safety
https://www.space.com/35555-total-solar-eclipse-safety-tips.html
https://www.webmd.com/eye-health/what-to-know-solar-eclipse-glasses

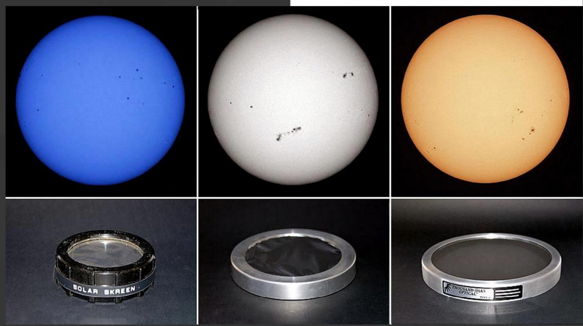
Unsafe "solutions"

- Eyepiece "solar filters"
  - Glass filters can crack without warning
- Telescope or camera with solar filter over your eyes
  - The glasses are not safe for the additional light from your scope or cam
- Ordinary sunglasses, even ones that block UVA and UVB
  - The UV will overwhelm the glasses and harm your dilated eyes quickly.
- Home-brew filters
  - 35mm film
  - CD/DVD
  - Mylar balloons
  - Chip bags

https://eclipse.aas.org/eye-safety
https://www.space.com/35555-total-solar-eclipse-safety-tips.html
https://www.nsc.org/community-safety/safety-topics/seasonal-safety/how-to-watch-a-solar-eclipse
https://eclipse.gsfc.nasa.gov/SEhelp/safety2.html
https://www.exploratorium.edu/eclipse/how-to-view-eclipse

Mylar and Glass White Light Filters

- Glass filters
  - Filter mixed into the glass $$$$ or
  - 2 layers of glass surrounding aluminum
  - Welder's glass (green) mixed into glass
- Mylar filters
  - Aluminized polyester (blue)
  - Black polymer (yellow/orange)
  - NOTE: can come in various densities for visual, camera, and telescope brightness

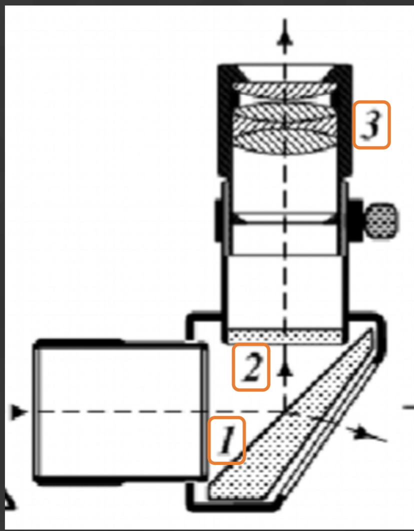


www.cloudynights.com

https://astronomyconnect.com/forums/articles/3-a-guide-to-white-light-solar-filters.23/
https://www.astronomy.com/astronomy-for-beginners/solar-filters-for-observing-the-sun/
https://www.cloudynights.com/topic/694511-do-all-white-solar-filters-look-the-same/
https://www.baader-planetarium.com/en/solar/whitelight.html

Herschel Wedge

1. Trapezoidal or triangular prism
   - Refracts ~95.4% of light and heat away from eyepiece
   - Absorbs UV/IR light
2. Polarizer or ND filter
   - Even 4.6% of sunlight will cause eye damage!
3. Safe levels transmitted to the eyepiece.



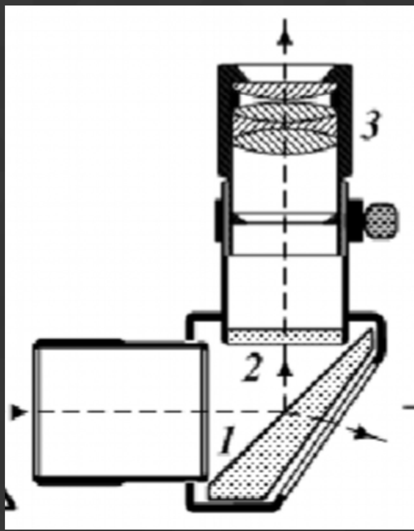
Tamasflex - wikipedia.org

https://en.wikipedia.org/wiki/Herschel_wedge

The prism in a Herschel wedge has a trapezoidal cross section. The surface of the prism facing the light acts as a standard diagonal mirror, reflecting a small portion of the incoming light at 90 degrees into the eyepiece. The trapezoidal prism shape refracts the remainder of the light gathered by the telescope's objective away at an angle. The Herschel wedge reflects about 4.6% of the light that passes through one of the prism faces that is flat to 1/10 of the wavelength of the light. The remaining ~95.4% of the light and heat goes into the prism and exits through the other face and out the back door of the housing; thus, the excess light and heat is disposed of and not used for observing.[1] While they decrease the intensity of the light, they do not affect the visible spectra, resulting in a more accurate spectral profile, which can be filtered to bring out certain details. They are an alternative to white light filters, which, despite their name, inherently must block certain visible spectra.[further explanation needed]

Herschel Wedge Notes

- Sized for small (↓4-6") refractors
  - 4" is roughly the sweet spot for
- Not suitable for reflectors
  - Larger objectives sends unsafe levels of energy to the eyepiece
  - potential damage to the secondary and/or the wedge itself
- Does not change visible spectra unlike Mylar & glass filters



wikipedia.org

By Tamasflex - Own work, CC BY-SA 3.0,
https://commons.wikimedia.org/w/index.php?curid=15720703
https://en.wikipedia.org/wiki/Herschel_wedge

Information from https://luntsolarsystems.com/viewing-with-white-light-telescopes/

In the meeting, I stated that a polarizer filter is required on eyepiece. That is incorrect - I had misunderstood the directions. The required filter is actually in the wedge itself, so it is always present unless you take it apart. The polarizer or neutral density filter on the eyepiece just reduces the light levels for comfort.

Old vs. New Style Herschel Wedge

Old, open style (heat hazard)

stargazerslounge.com

Lunt’s Heat Sink Herschel Wedge

luntsolarsystems.com

https://stargazerslounge.com/topic/356455-which-herschel-wedge/

Old wedges simply dumped the 95.4% of incoming sunlight below the eyepiece, which created a burn hazard if you’re not careful. Since the wedge is (1.25” or) 2” square, any scope larger than 6” concentrated enough light to cause a serious hazard to the observer’s body, clothing, and eye.

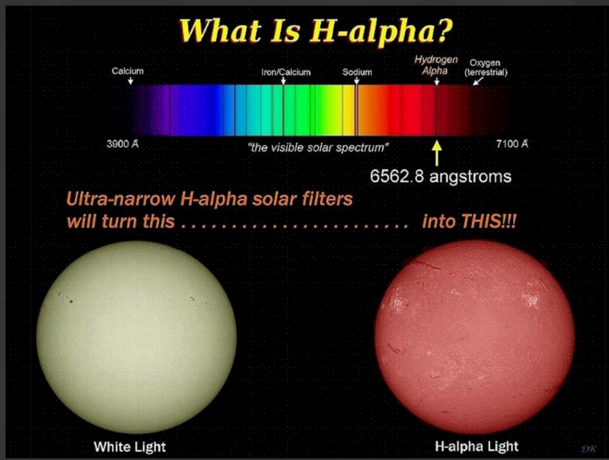
Newer wedges have a metal or ceramic heat sink (red button) to absorb and discharge the heat in a safer manner. In my 70mm or 80mm refractors, the Lunt wedge’s heat sink gets just a little uncomfortably warm to the touch after an hour or more. It’s a bit like black magic, but you still need to let it cool before tossing it in the case or you may melt the foam if air can’t circulate.

H-Alpha Solar Filter

- Filters out all light except 656.28 nm
  - Alpha Balmer line of excited hydrogen

- Bandpass rules -
  - 1-0.7nm - PST, etc.
  - 0.7nm - Lunt, Coronado
  - 0.6-0.5 - Double stack

- Requires 2 glass plates that are optically flat and parallel to a small fraction of wavelength $$$$



luntsolarsystems.com

Taken from Lunt Solar Systems, Daystar Filters, Coronado Solar filters, and Wikipedia. The bandpass for telescope models can vary over time based on QA, manufacturing methods, and the like.

The bandpasses listed above are general guides. The PST is a mass-produced scope with a wider bandpass than most, resulting in a less than stellar image, but it can produce fantastic images when double-stacked. Most larger solar scopes will have a bandpass around .7 nm and double stack can decrease that to .5-.6 mn. That's not to knock any of these scopes because even the PST opens up a whole new world to the observer in an affordable way.

Bandpass - (simplified) The wavelength width of light allowed through a filter.

Main Manufacturers

- Coronado
  - https://www.meade.com/solar-telescopes/

- Lunt
  - https://luntsolarsystems.com/

- Daystar
  - http://www.daystarfilters.com/

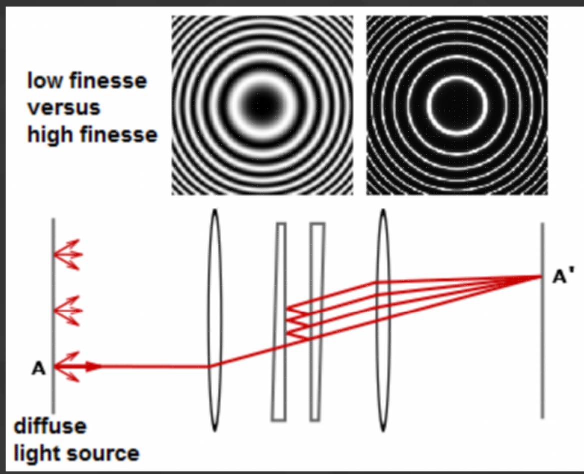
General observations/opinons:
Older Coronado scopes were some of the best. Meade bought Coronado and reputation for quality has declined. (Online articles, reviews, and forums.) However, the PST remains popular. They use tilt tuning, which may not have an even field if all of the materials are not exactly matched. They also use a center "foot" to space the etalon plates. They can be temperature sensitive and may require tuning while observing..

Lunt is relatively new and has an reputation for quality. My sample is certainly good. The etalons are pressure tuned, which ensures an flat field and temperature independence. They pride themselves on quality and go extra steps to ensure it.

Daystar had a good reputation, but it seems to have reduced lately. (Judging by online forums and reviews.) They use eyepiece units with a long Barlow (4x) that are tuned for either proms or surface. However, you can get a system with 0.3 nm, the tightest available for amateurs.

Etalons - The heart of the system

- Partially reflective glass plates
  - tilted or wedge shaped
  - Distance tuned to wavelength 100nm!
  - Collimating lenses either side
- Internal or External
  - External - large, expensive, allows night and day use.
  - Internal - smaller, dedicated, less $$$$
- Tuning - tilt, pressure, heat
  - Plates must move to tune the wavelength for surface or prominences

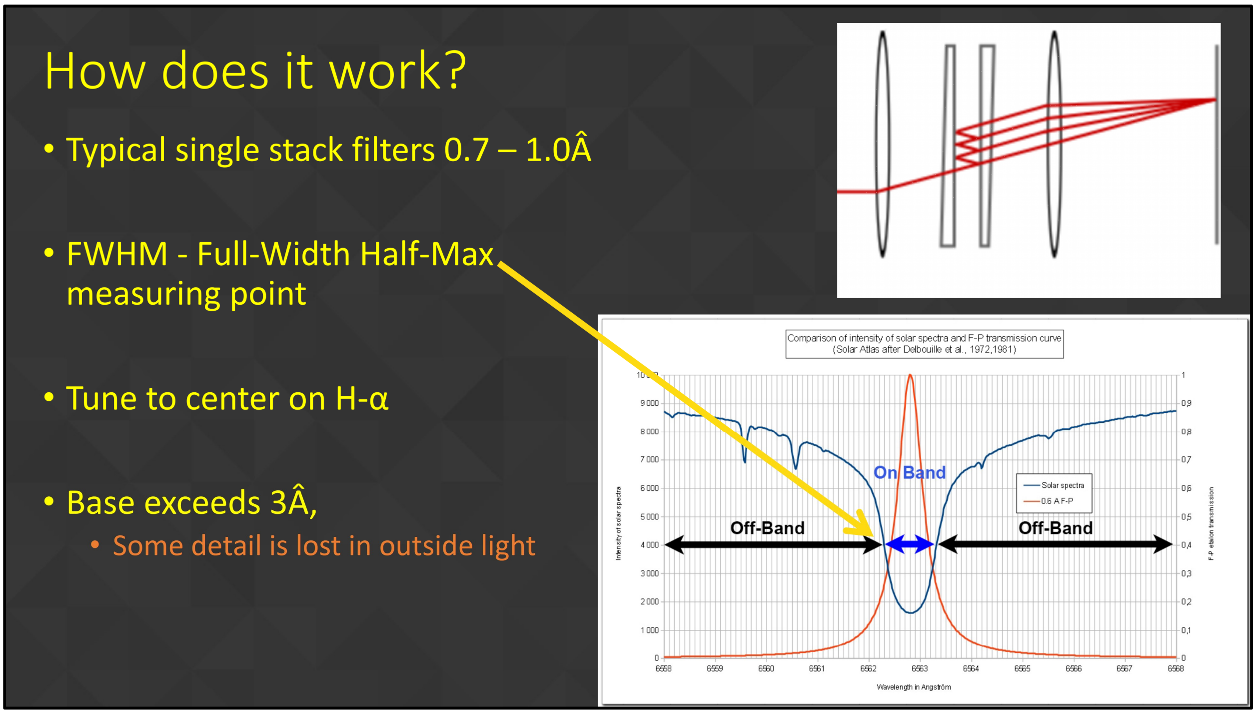


Stigmatella aurantiaca

https://en.wikipedia.org/wiki/Fabry%E2%80%93P%C3%A9rot_interferometer

In optics, a Fabry–Pérot interferometer (FPI) or etalon is an optical cavity made from two parallel reflecting surfaces (i.e.: thin mirrors). Optical waves can pass through the optical cavity only when they are in resonance with it. It is named after Charles Fabry and Alfred Perot, who developed the instrument in 1899.[1][2][3] Etalon is from the French étalon, meaning "measuring gauge" or "standard"...

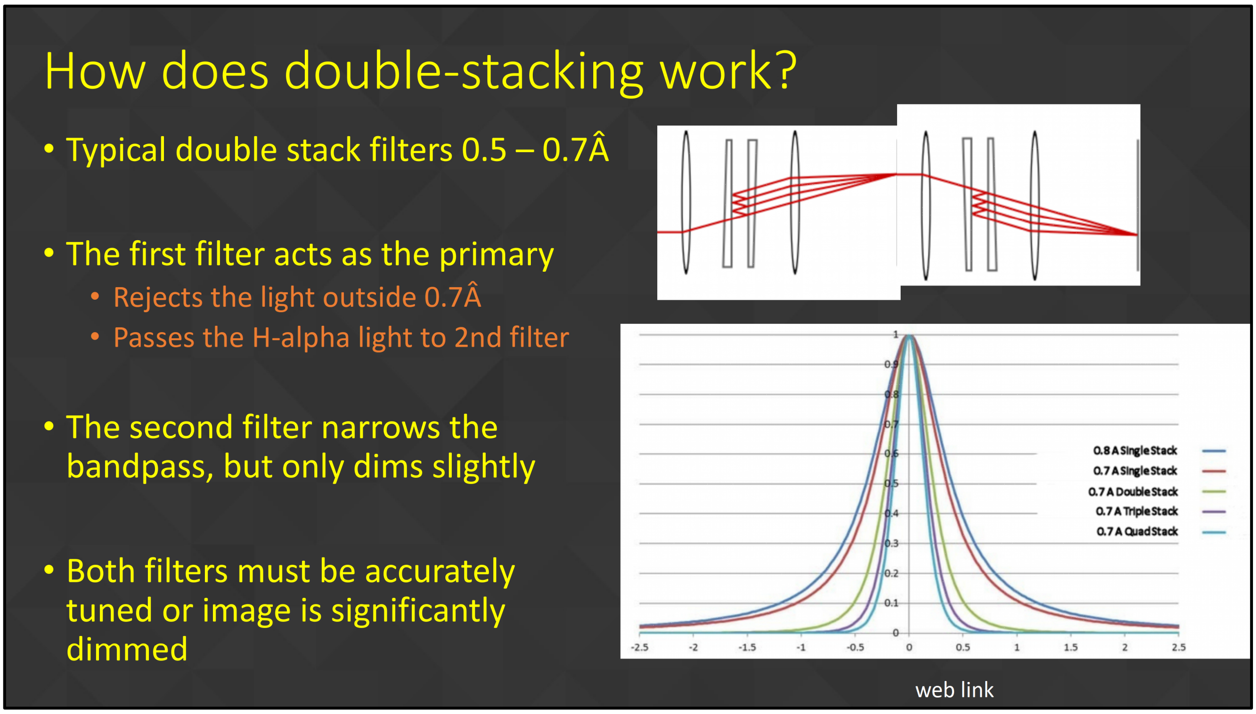
In a typical system, illumination is provided by a diffuse source set at the focal plane of a collimating lens. A focusing lens after the pair of flats would produce an inverted image of the source if the flats were not present; all light emitted from a point on the source is focused to a single point in the system's image plane. In the accompanying illustration, only one ray emitted from point A on the source is traced. As the ray passes through the paired flats, it is multiply reflected to produce multiple transmitted rays which are collected by the focusing lens and brought to point A' on the screen. The complete interference pattern takes the appearance of a set of concentric rings. The sharpness of the rings depends on the reflectivity of the flats. If the reflectivity is high, resulting in a high Q factor, monochromatic light produces a set of narrow bright rings against a dark background. A Fabry–Pérot interferometer with high Q is said to have high finesse.



The whole idea of an etalon is to reject all light except the very narrow band of light you want. With the sun, it's like trying to see the pattern on the front of a headlight - the pattern is lost in the glare of the light. An etalon narrows down on the light band of excited hydrogen, so you're seeing details lost in the glare.

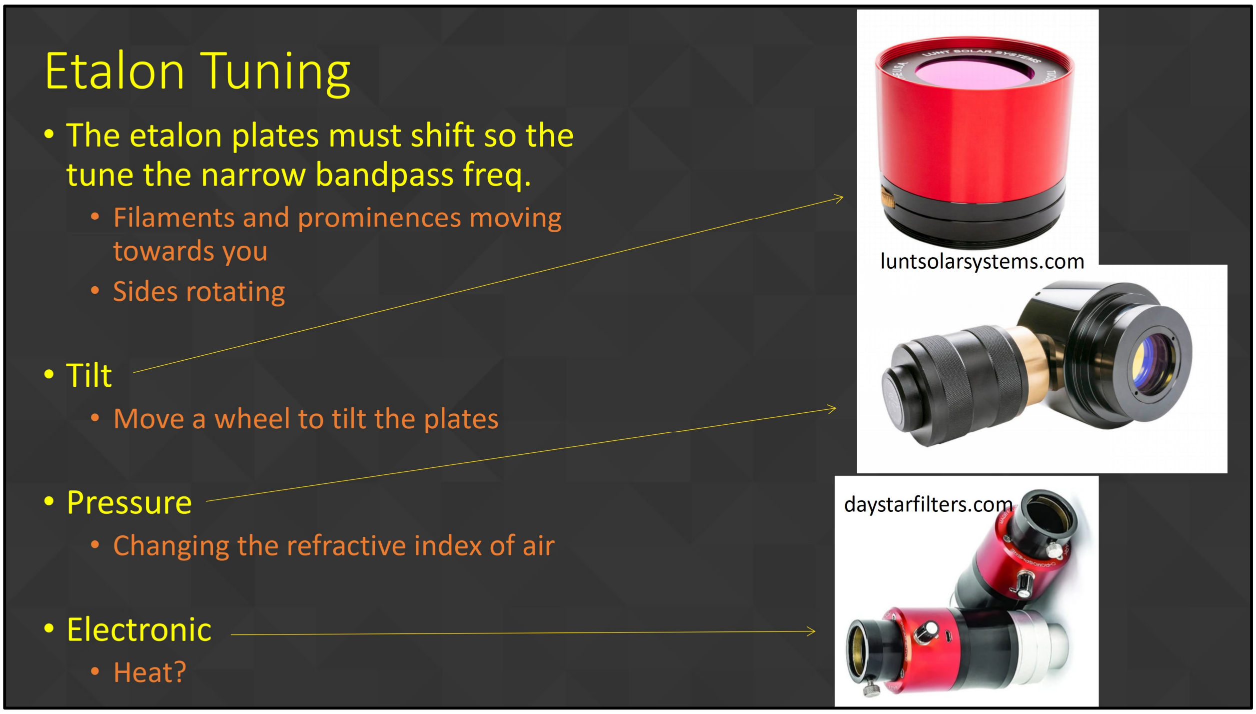
FWHM - a standard measuring point in optics and elsewhere. It's just halfway up the height and full width.

The closer you get to 656.2 nm, the clearer your image will be. Details will jump out when you hit the center. The narrower the band, the less stray light overwhelms details.



Double stacking is simply adding a second (expensive) etalon to the system, most commonly on the objective. This has the effect of narrowing your peak, increasing detail, and slightly dimming the image. For an internal etalon system like mine, the 2nd etalon on the objective is the one that rejects the sun's energy and the the internal one just refines the bandpass.

The graph shows the diminishing returns of adding a triple or quad stack to the system.

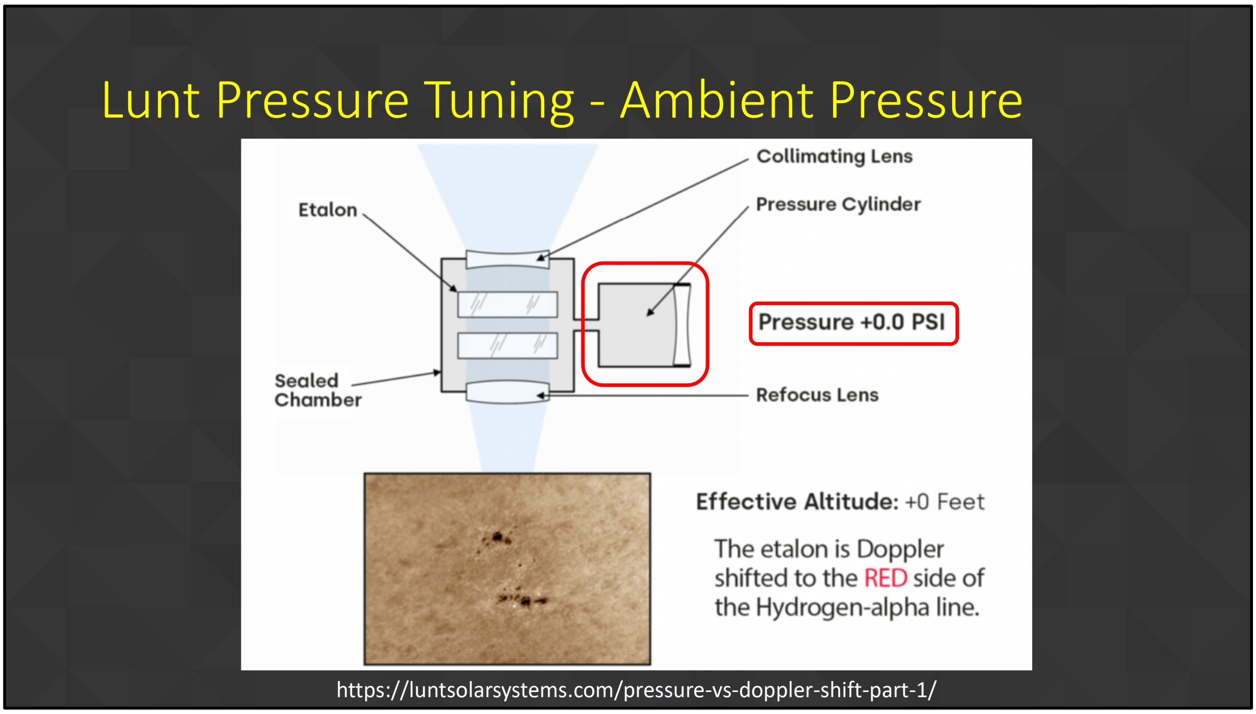


https://www.ianmorison.com/h-alpha-solar-telescopes-an-in-depth-discussion-and-survey/
The effective separation of the etalons internal surfaces and hence the precise wavelengths passed, depends on the refractive index of the air between them. This will depend both on height and atmospheric pressure so the effective spacing must be adjusted to compensate.

One method – the tilt method – is to vary the angle of the etalon to the incoming light so that it takes a slightly longer path to pass between them (like crossing a road at different angles). This method is used by Solarscope in their Solarview series and also found in some of the Lunt H-alpha telescopes. The full aperture Lunt double stacking etalons (see below) are also tilt tuned.

A second method, employed in the Coronado H-alpha telescopes, and called ‘Rich View’, is, I believe, to apply pressure to the etalon (there is a pad at the centre of the etalon) and so alter the separation of the two glass sheets.

A third method, used now in many of the Lunt telescopes, is to alter the air pressure within the etalon to provide a tuning range of +/- 0.4 Ångströms. Thus the etalon always remains perfectly at right angles to the light path, so this highly elegant system is theoretically the best method of etalon tuning. The chosen wavelength may also need to be altered to see the filaments lying above the surface or solar prominences at their best as Doppler shifts affect their observed wavelengths.



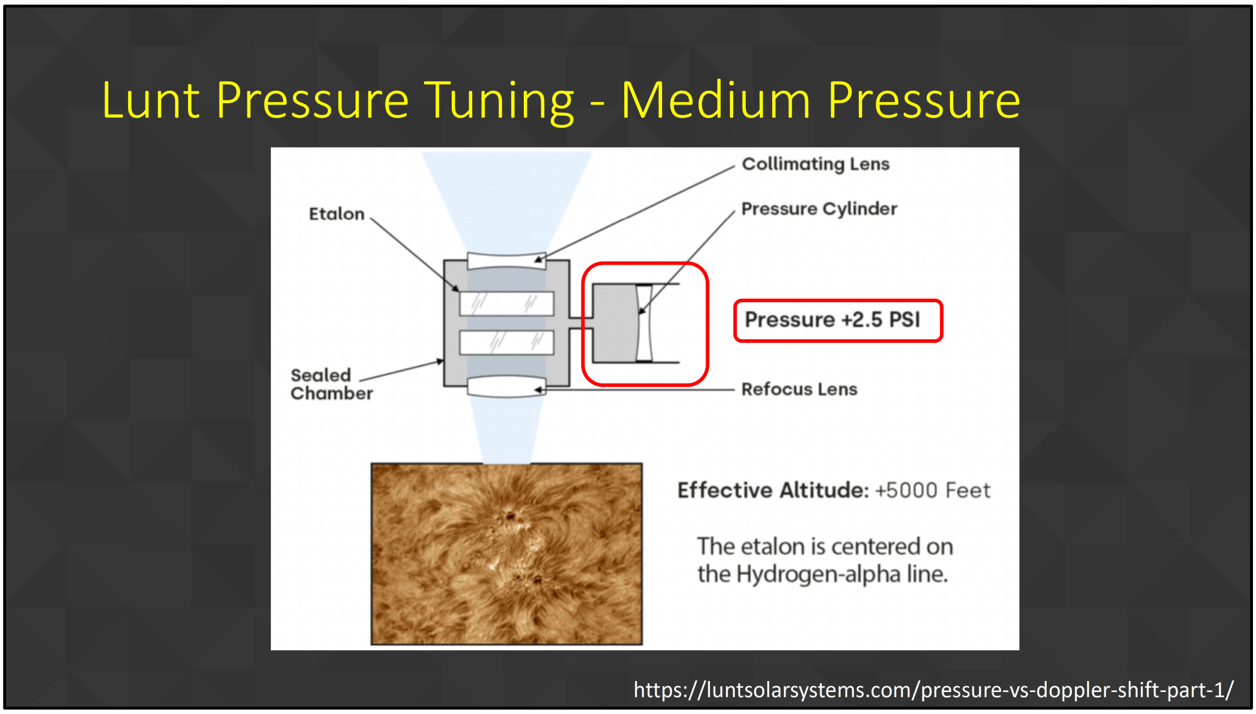
The system works because the etalons used in the current Lunt designs are air spaced. These air spaced etalons have been typically tuned to the Hydrogen-alpha line via several mechanisms.

The first is the spacing of the air gap between the high reflective surfaces of the ultra flat plates. By changing the spacing, you change the CWL. The distance of this spacing is generally held constant because the refractive index of the medium between the plates (air) is relatively stable at ~1.

The center wavelength can be manipulated from there by slight tilting of the etalon. This changes the angle of the light at the interface of the high reflector/air layer, having the effect of moving the center wavelength toward the blue.

Slight changes in barometric pressure and/or a change in altitude will effect the CWL due to the change in refractive index of the spacer layer.

These changes can be compensated for by additional tilting provided that the etalon is tuned to accommodate those changes.



The diagram shown above indicates that the air pressure inside the sealed chamber has been increased. At this point the CWL of the bandpass is at 656.28nm. At this position we are looking at the Hydrogen-alpha line and the energy associated with that wavelength.

The sealing of the cavity is done via the collimating and refocus lens so that the etalon itself is isolated from differential pressure.

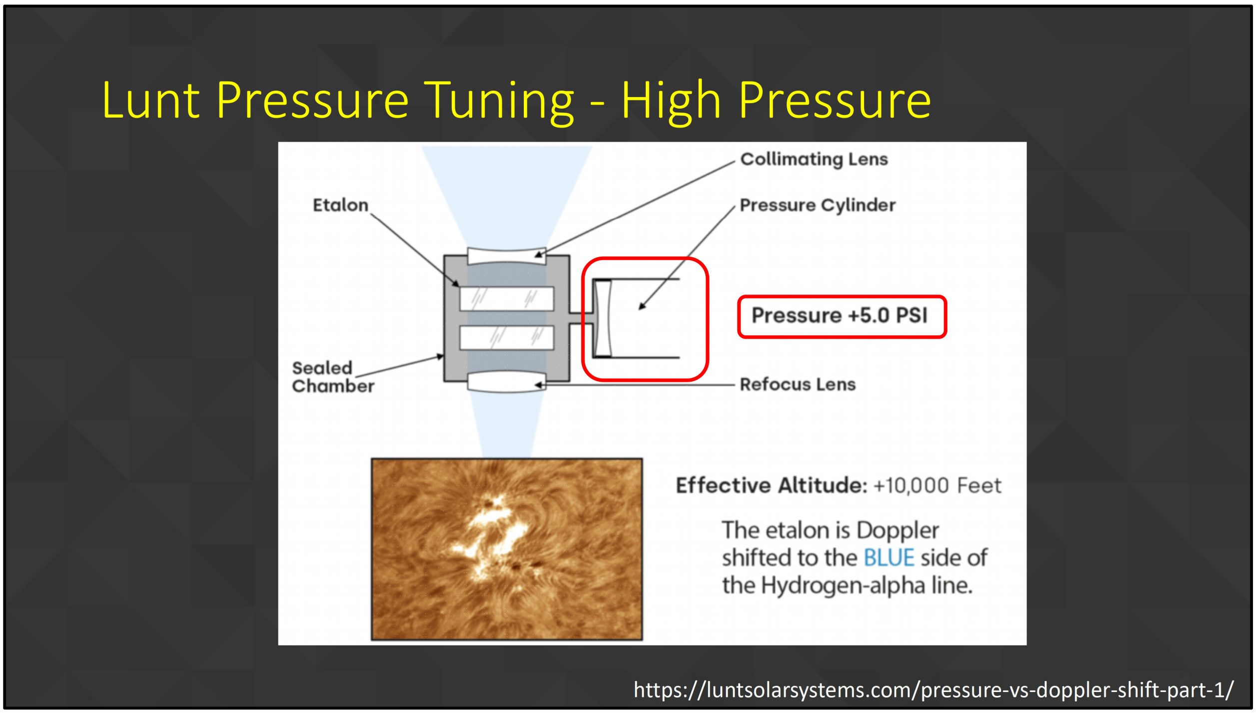
The piston applies from zero to a pressure that is equivalent to taking an etalon from -500ft to +12,000ft above sea level.

This has the added benefit of making the etalon system altitude insensitive.

In addition the etalon can be used from -50 to +200 degrees Celsius due to the fact that the tuning can compensate for the very small changes that heat would have on the “feet” of the etalon.

I have gone into great detail in prior posts regarding the compromises of tilting internal to a telescope. Only very small adjustments to the tilt of an etalon can be done otherwise the etalon system will begin to suffer from the off axis rays of the re-collimated beam.

People have noted that in internal tilt systems the CWL is very sensitive to even small adjustments of the tilt wheel.



The diagram above shows the system has been fully pressurized. This pressure is equivalent to about a 10,000 ft altitude change.

The air inside the sealed chamber has been compressed due to the reduced volume. As a result the refractive index of the air has increased and caused the CWL of the etalon to move to the blue or high energy side of the Hydrogen wavelength.

Due to the fact that there is no tilt involved, the image field remains flat and very precise.

Traditional tilting allows the Doppler shifting across the field in a plane perpendicular to the axis of light. The user can see a change to the image that allows for the viewing of proms and then filaments. The optimum position is when the proms and surface are both fairly detailed. Overtilting will tighten the bandpass but will also produce a banding effect. The resolution under the band is higher, but at the expense of the entire field of view.

People often feel that the entire field should be as good as the area created under the band. If this were possible, the systems would be spec'd at a much lower bandpass. If a band occurs, the system has probably been over attenuated.

True Doppler Tuning allows for a shift into and away from the user. Adding a 3D component to the viewing experience.

While it has minimal effect on proms due to their being at the edge of the disk, it does have an effect on filaments and active regions

Internal Vs. External Etalon

- Internal
  - + Smaller, less expensive
  - + Integrated into the telescope
  - - Dedicated to only solar observing

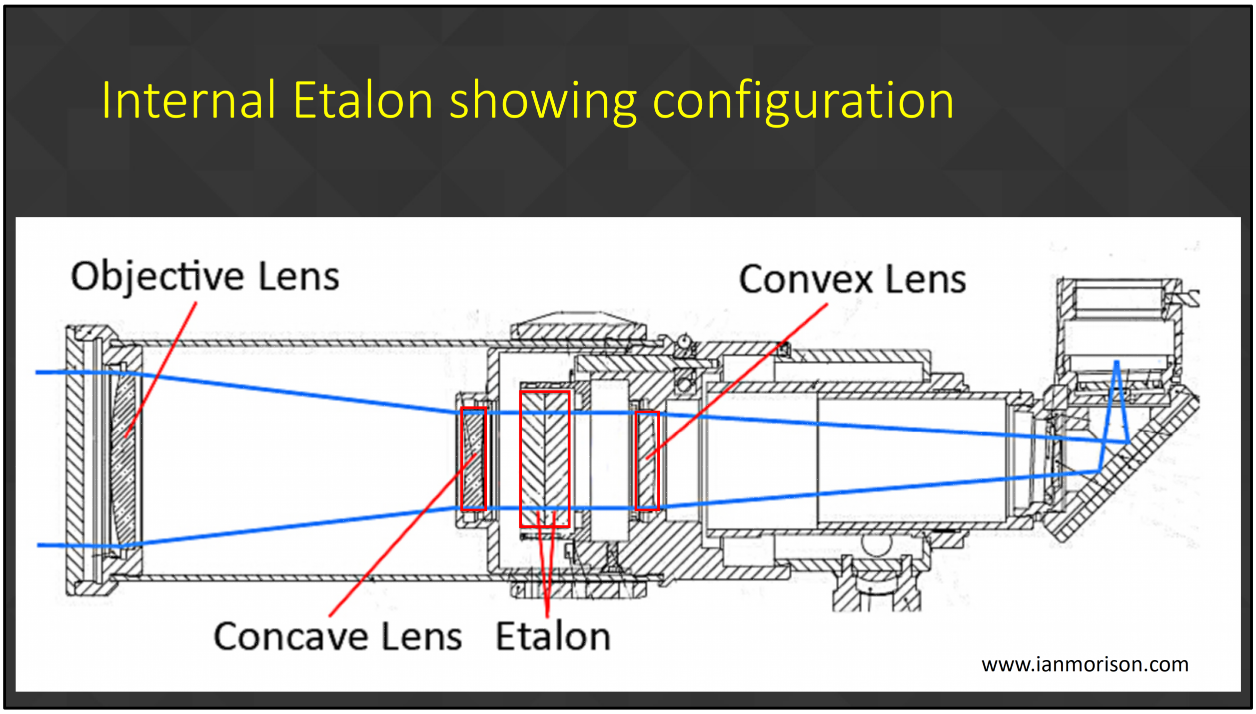
luntsolarsystems.com

- External
  - - Larger, much more expensive
  - + Separate from the scope
  - + Allows day and night use

Internal and external etalons each have pros and cons. Note that Daystar filters are like Barlows that insert into the diagonal. (The energy rejection filter replaces the diagonal or attaches to the objective.)

Internal etalons are integrated into the scope, making them easier to handle but dedicates the scope to solar only (most of the time). I find them easier to handle, since they're already installed. The etalon can be smaller, since the sunlight can be concentrated down from the size of the objective, reducing cost.

External etalons are larger, matched to a specific objective size (or reduces objective size like above) and requires a threaded adapter to attach firmly to the scope. However, these etalons tend to be much larger, harder to produce in quality, and much more expensive than internal etalons. The pro is that you don't need to purchase the scope and can use that scope for other purchases.



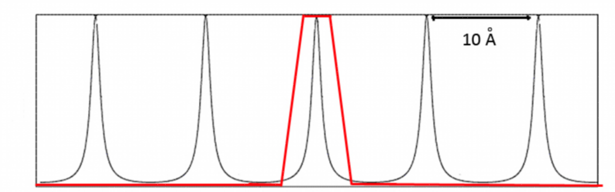
https://www.ianmorison.com/h-alpha-solar-telescopes-an-in-depth-discussion-and-survey/

The Lunt internal etalon follows this model - there are two lenses before and after the etalon that bend the light parallel for the trip through the etalon, then refocus the beams on the other side. The diagonal is the energy rejection filter. The Objective focuses the full power of the sun falling on its surface.

External etalons attach to the front of the scope, covering the objective. The etalon rejects filters the light that

Blocking Filters

- Etalon output includes other peaks
- The blocking filter blocks harmful and unwanted light.
- You cannot safely use an etalon without the blocking filter.



The blocking filter selects the appropriate narrowband

www.ianmorison.com

Lunt Solar Systems

https://www.ianmorison.com/h-alpha-solar-telescopes-an-in-depth-discussion-and-survey/

How do they isolate the H-alpha spectral line?

To reveal this wonderful view of the Sun an hydrogen-alpha (H-alpha) filter must be designed to produce a very narrow pass band around the wavelength of 6,562.8 Ångströms and the way that this is usually achieved in a two stage process that is somewhat more complicated than many imagine. At some point either within the telescope tube or in front of the objective lens is located a Fabry-Perot etalon composed of two sheets of glass in very close proximity. They produce a comb of very narrow pass bands (~0.7 angstroms wide) spaced about 10 angstroms apart across the whole of the visible spectrum. The etalon will reject ~90% of the total sunlight but this is not sufficient to provide a safe viewing level so that there will also be an energy rejection filter to bring the light level down to a suitable level. This will also block all the infra-red light which is most damaging to our eyes. Following a further filter to reduce the light intensity placed at the front of the diagonal there is a final ‘blocking filter’ at the exit of the diagonal which selects only the narrow band centered on the H-alpha line so removing all but the H-alpha emission.

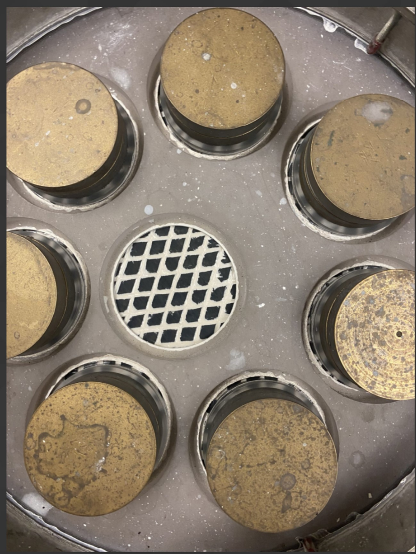
How Lunt Makes Etalons

- Purchased precision cut UV grade Fused Silica blanks
  - Highest grade possible
  - no bubbles or striae
- Bevel edges and grind flat both sides
- Polishing
  - 8 hours to four days depending on size
  - 35mm to 140mm in size
  - **Standard 1/40th wave or better within a % of the edge**
  - The edge is where the feet sit

https://luntsolarsystems.com/how-a-lunt-etalon-is-made/

Definition of Striae
An important property of processed optical glass is the excellent spatial homogeneity of the
refractive index of the material. In general, one can distinguish between global or long range
homogeneity of refractive index in the material and short range deviations from glass homogeneity. Striae are spatially short range variations of the homogeneity in a glass. Short
range variations are variations over a distance of about 0.1 mm up to 2 mm, whereas the
spatially long range global homogeneity of refractive index ranges covers the complete glass
piece (see TIE-26/2003 for more information on homogeneity).
https://wp.optics.arizona.edu/optomech/wp-content/uploads/sites/53/2016/10/tie-25_striae_in_optical_glass_us.pdf

Polishing machine - 3’ across, granite base



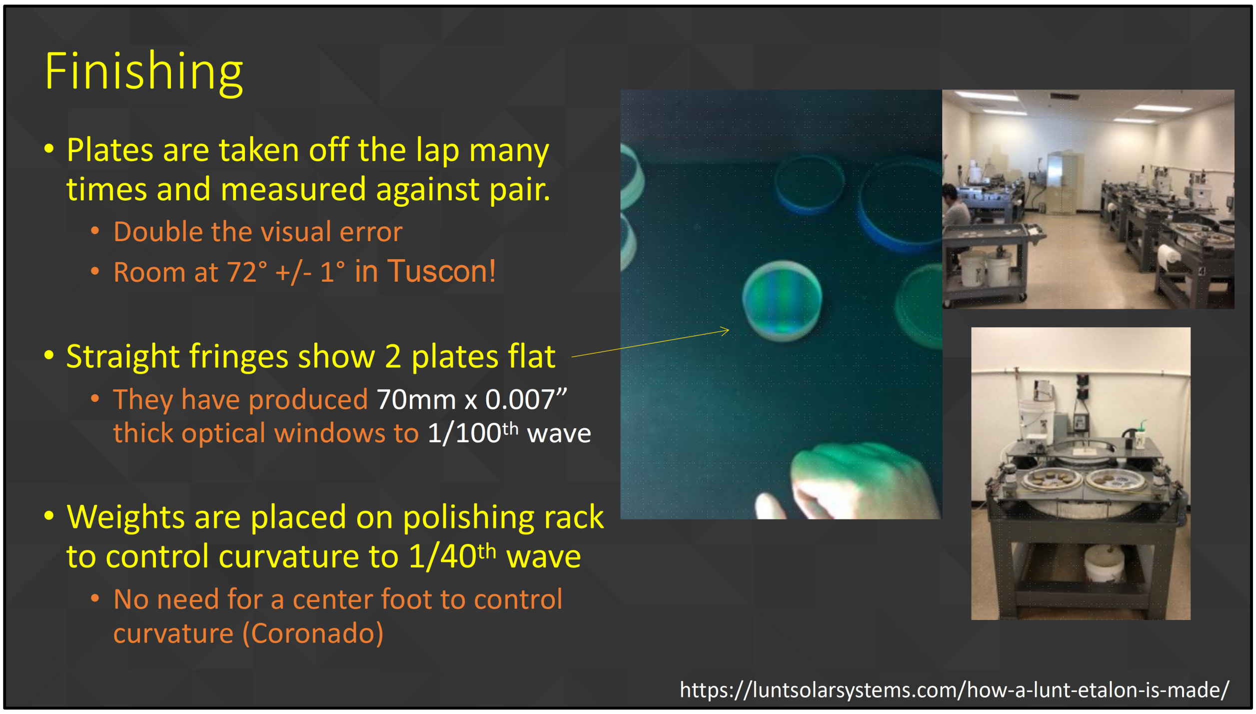
https://luntsolarsystems.com/the-lunt-optics-polishing-process/

We use a thick (6”) solid granite backing plate to act as a rigid structure for the lap. Granite is used in the manufacture of large precision tables due to its thermal stability and is a good choice for our laps.

The Magic:
Given that the lap is 36” in diameter and moved through a few fringes each way, we are able to place smaller etalon plates (1” – 6”) on the lap to polish. The plate takes on the shape of the lap. However, 1 fringe over 36” is a small fraction of a wave over the 4” plate. The key to making the world’s most precise flats is to catch the plates when the 36” lap passes through the “flat” timeframe when going from Concave to Convex or Convex to Concave. Obviously. It is never quite that simple but the process for the various sizes of plates is predictable given the rate of change of the counterweight and the size of the plates.

It takes several days for a new lap to reach equilibrium. Turning off a lap means that the continuous shaping of the lap via the counterweight has stopped. Lunt run our continuous polishers 24 hours a day, 7 days a week for most of the year. We start the “rough” polishing process overnight and finish the surface figuring process during the day.

The process of pitch polishing is time consuming and labor intensive. However, it results in the highest quality, lowest surface roughness (laser quality), and flattest profile that make up the heart of the Lunt etalon systems.

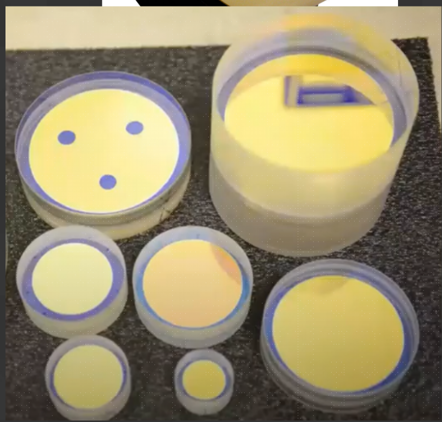


Throughout the blog, Lunt talks about the care and quality assurance they give their products. I've been most impressed with the discussions I've had with Lunt personnel vs. inquiries to the other companies. This shows in the blog where they talk about the incredible lengths they go through to ensure high quality etalons.

Etalon construction

- Etalon is simple - 2 parallel plates - but requires extreme precision

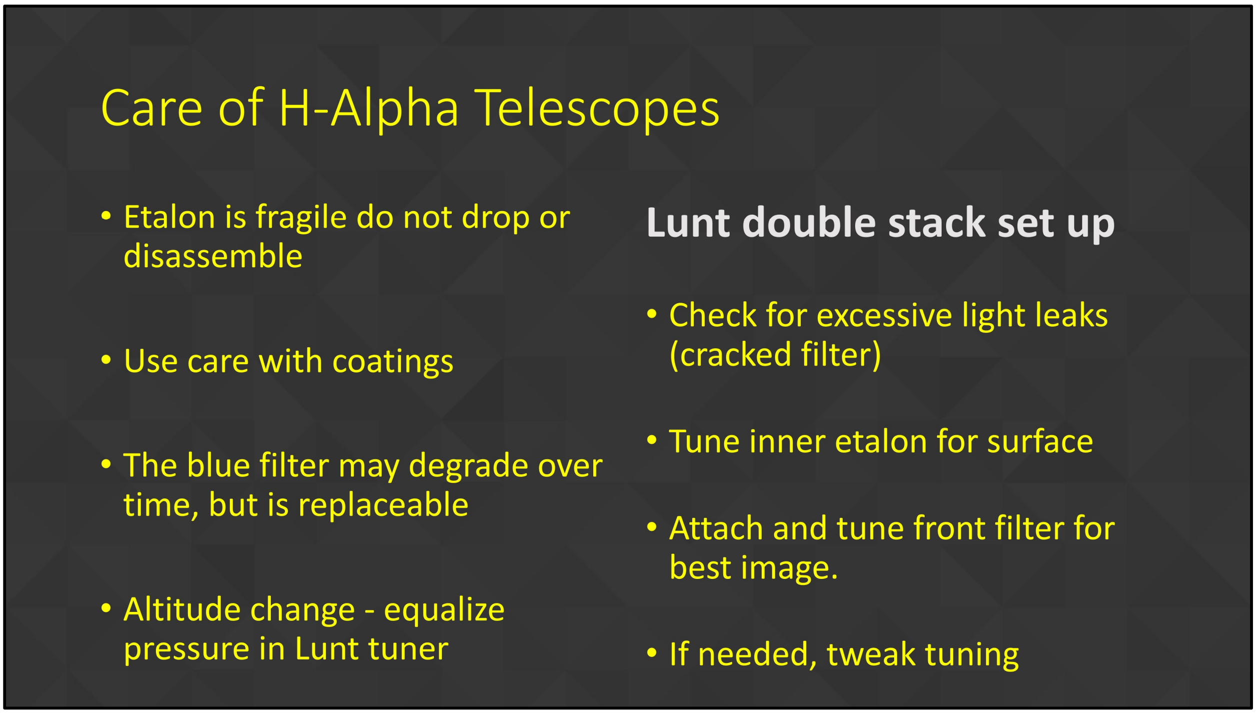
- Lunt polishes plates to fine precision
  - Spacers between plates tuned for H-Alpha 656.3 nm
  - No need for central obstruction like Coronado and others



https://luntsolarsystems.com/sun-filter/

https://luntsolarsystems.com/what-60-mm-lunt-telescopes-can-do/

An etalon is comprised of 2 flat and parallel optical surfaces that have been optically coated with a highly reflective dielectric layer, with the high reflector layer peaking at the desired bandpass point for best results. These optical surfaces are separated by a gap. This gap can be either air or a solid material. The light resonates in the gap by internal reflection off the highly reflective layers on the surfaces. Through interference at this gap, only light meeting the correct angle of incidence to the surface is not “interfered with” and can pass; all other light is lost.



Care of an etalon is much like care for any fragile optical component. Keep it from shock, water, finger prints, excessive heat & cold, etc. In addition, do not disassemble the etalon as the spacing is critical and down to nanometers.

Solar Links

- solarscience.msfc.nasa.gov/
- solarcyclescience.com/solarcycle.html
- nso.edu/for-public/
- mreclipse.com/Totality3/TotalityCh11.html

Solar Telescope Manufacturers

- Coronado - https://www.meade.com/solar-telescopes/
- Daystar - http://www.daystarfilters.com/
- Lunt - https://luntsolarsystems.com/
  - https://luntsolarsystems.com/category/technical-articles/
  - https://luntsolarsystems.com/what-60-mm-lunt-telescopes-can-do/

So What's the cost?

- Mylar or Glass filter - $50 and up
  - Sheets for homemade much cheaper
- Herschel Wedge - $300-$500

60mm H-Alpha Costs

- Daystar, f/15, prom or chrom, requires power, 0.7 A - $1,595
- Coronado, f/6.6, wide tilt tune, 0.7 A - $1,999
- Lunt, f/7, wide pressure tune, 0.65 A (0.45 A double stack) - $2,600

Information taken from manufacturer's web sites.