Resonant Spaces
Part 1: An Introduction to Air Spaced Etalons and Solar Telescope Technology
by Colin Kaminski

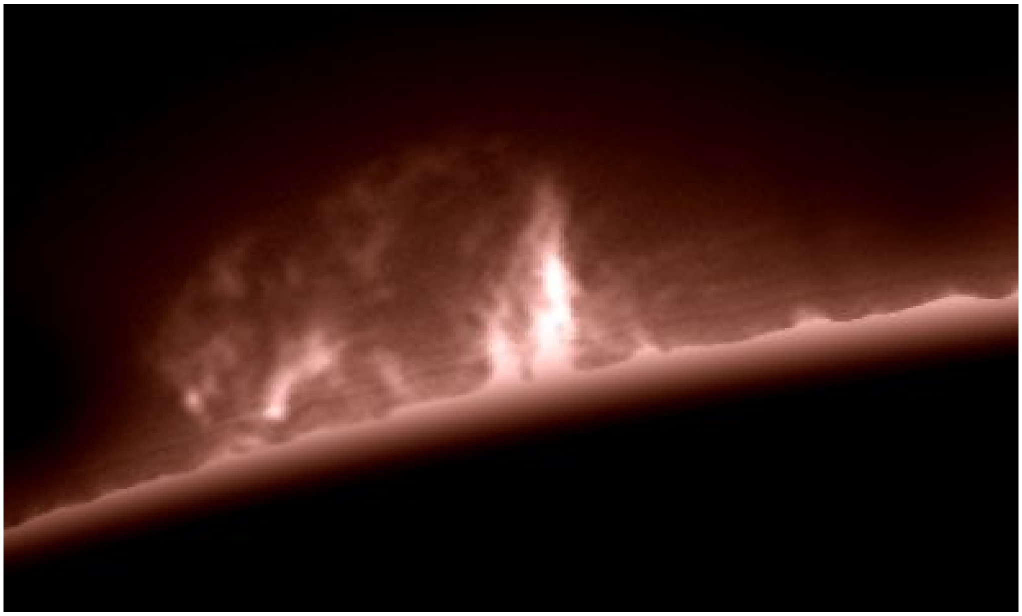

Fig. 1
H-alpha prominence by Nick Howes using a
80mm H-Alpha Internal Mounted Air Spaced Etalon Photographic System
at 0.7A (f/40)

Introduction

One sunny day I was on my way to judge some holograms for an amateur holography contest. I was meeting up with another holographer who has more technical knowledge than I and the goal was he would judge the technical aspects and I was going to judge the artistic aspects of the holograms.

When I arrived at his house he was sitting in his yard looking at the sun through a Hydrogen–alpha (H-alpha) filter. His telescope was quite refined and had some very interesting features. I quickly looked at the telescope as he offered me the eyepiece. I paused for 5 seconds for a safety check; the wheels started turning in my mind. What are the dangers, how does this scope work, who is offering me the eyepiece? I quickly decided that if anyone knew enough about optics to make the contraption I was standing in front of it was Bob. This scope was 75mm in aperture, had the optical axis aligned with the north pole and was using a motor driven diagonal from a Newtonian to direct sun light into the objective (heliostat).

I sat down at the chair and was treated to a full disk view of the sun in H-alpha. The first thing I noticed was this telescope did not jiggle at all. The mounting was perfection. The next thing I noticed was my first prominence. I spent about 30 seconds at the eye piece and then talked with Bob a little about the telescope.

I took one more view at the eyepiece before I was convinced that I was going to have to acquire one of these things. Within a week I had my first h-alpha scope, a Coronado PST, and was completely fascinated by the technology. I have been designing optical setups and lasers for holography for more than 10 years and I was happy to find that much of my experience was useful in understanding the H-alpha telescope.

Warnings

Don't ever look directly at the sun without a filter. Don't ever use a filter that is home made such as, but not limited to photographic negatives, trash bags, CDs, Mylar bags, smoked glass, or welding filters except a shade 14. Perform a safety check before each use of a solar telescope. Make sure no part has been damaged in storage. Make sure there is no way for parts to fall off or be removed by children. Don't forget your finder scope! It needs to have a filter or be blocked. Don't modify a solar telescope unless you are an engineer and have researched the risks. Don't repair a solar telescope, send it to the manufacturer, only they fully understand the design. Don't leave your solar telescope unattended. Don't use your telescope for at least one hour after you have eaten. Ok, I made that one up.

Design Overview

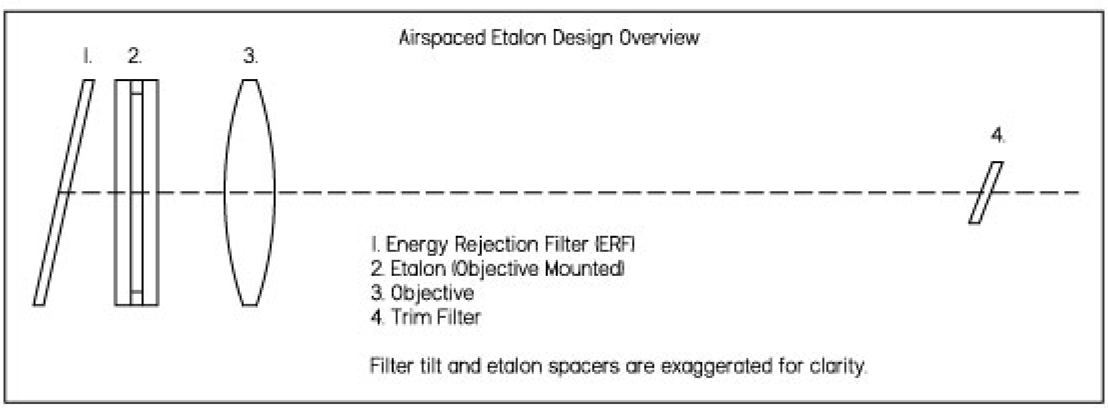

Fig. 2

A solar H-alpha telescope consists of a small number of optics that have been re-oriented by designers over the years. It will be helpful for us to simplify it and look at each component. In Fig. 2 we have a sketch of an objective mounted etalon design. Light first hits an energy rejection filter (ERF). This filter is mainly to remove unwanted heat and damaging UV from the system and can even be coated on the front surface of the etalon. Then we have the etalon and objective. Having the etalon in front of the objective makes sure that the light is parallel going through the etalon. Finally we have a trim filter that only passes a single line from the etalon. The largest commercially available front mounted etalon is 100 mm although there are plans (Lunt Solar Systems) to produce a 160 mm etalon in the near future.

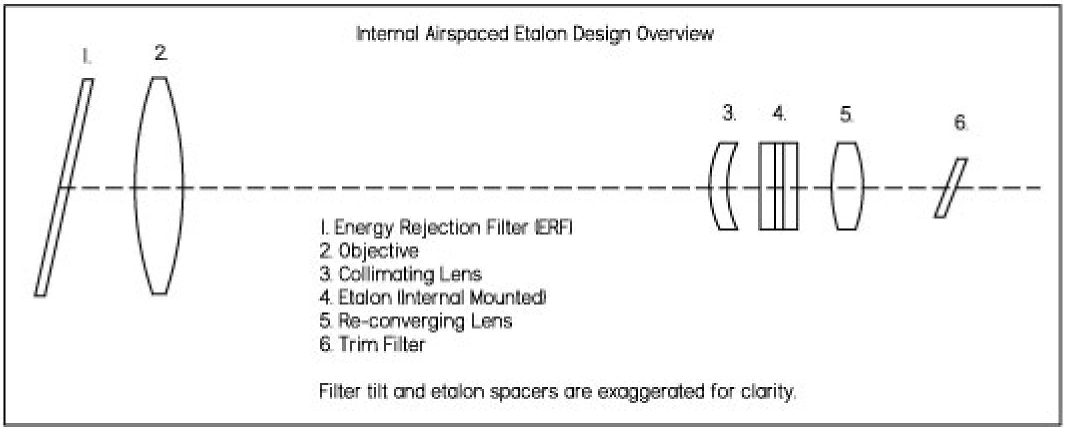

Fig. 3

Another common arrangement is to have the etalon internally mounted. Fig. 3 shows the same optics with the addition to a lens pair that makes sure the light is collimated through the etalon. This has the advantage of lowering the cost by making the etalon smaller but some observers claim the view is better in the full aperture models. It also has the further advantage of allowing larger apertures.

The light coming to us from the sun at the H-alpha frequency (6563 Angstroms) is coming from a rarified layer of hydrogen gas slightly above the surface of the sun (photosphere) called the solar chromosphere. It is more sensitive to the effects of solar activity than the photosphere because its structure is dominated more by magnetic effects than the temperature and pressure effects that control the photosphere. More often than not one can see filaments above the surface of the sun and prominences on the limb with even a small h-alpha telescope.

Theory

The heart of an H-alpha telescope is an etalon. More precisely it is called a Fabry-Perot etalon. This article is restricted to the discussion of air-spaced etalons but there are solid etalons as well. We are going to start with some theory (not too much) as it will help us learn why H-alpha telescopes have different qualities and prices.

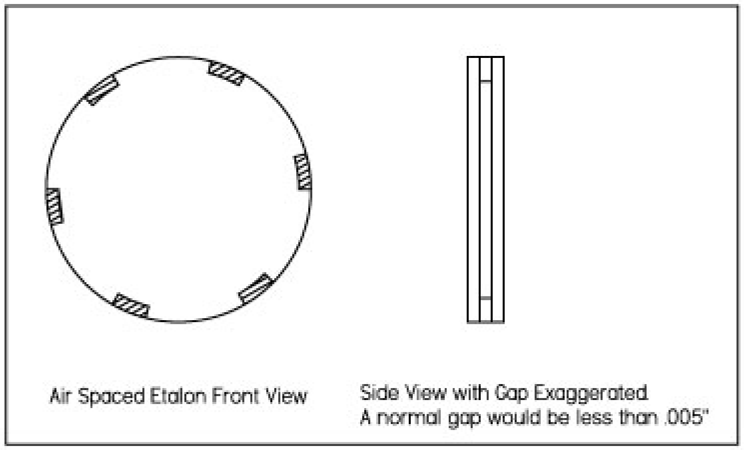

Fig. 4

An etalon is a resonant structure. It works by bouncing light back and forth between two partially reflective mirrors. When the cavity width is an integer multiple of half of the wavelength it will transmit light. Light not satisfying this criterion is reflected.

There are two very important measurements of quality in an etalon. Finesse and Free Spectral Range (FSR). It is much easier to show a graph than to workout the math involved. If you need to do the calculations yourself see the references at the end of this article.

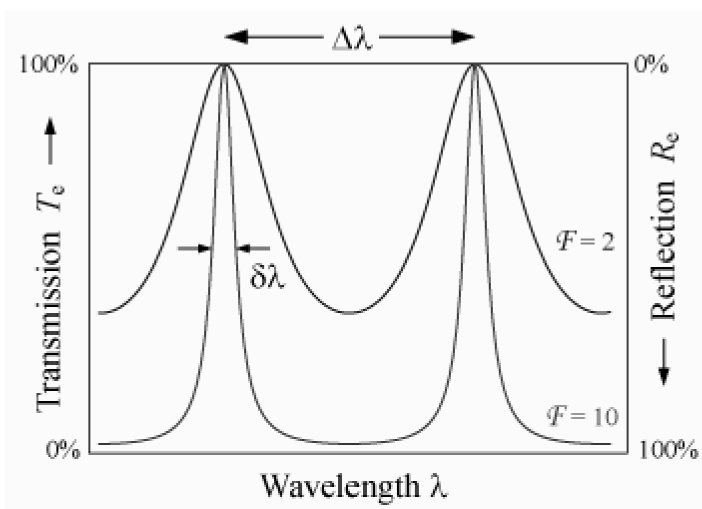

Fig 5.

This graph shows the difference between two etalons that have the same FSR (marked Δλ) and different Finesse (marked δλ). The finesse directly affects the bandwidth. In solar telescope terminology we measure the bandwidth by Full Width Half Maximum (FWHM). To measure FWHM we measure the width at half the height of the peak in Angstroms. This does not tell us the full story as it is possible to design an optic that has steeper sides on the graph or with more flair at the bottom but to compare one air spaced etalon to another it is adequate. A typical air spaced etalon has a bandwidth of .7

Angstroms, which is a very high finesse indeed (around 15 or so). With a narrow bandwidth you will see more contrast on the solar disk through the eyepiece. While deep space observers get “aperture fever” solar astronomers get “bandwidth fever” and seek the lowest bandwidths.

In order to achieve a very high finesse the manufacturer needs to control many factors. Reflectivity, parallelism, surface quality, surface flatness and tilt need to be very tightly controlled. The most expensive factor here is surface quality and flatness and the difficulty increases at more than the square of aperture making large etalons quite expensive. Even if you are able to polish the plates to 1/100 wave your coating has to be dead on to keep it.

The FSR defines the distance between the peaks and is controlled by the mirror spacing (less than .1mm). An etalon is a “comb filter”. It will have hundreds of peaks ranging from IR to UV, limited only by the qualities of the glass and reflection coatings used for the mirrors and the resulting graph looks like a comb. These other lines need to be blocked by other filters to make a useful H-alpha telescope system. The higher the FSR is the easier it is to design and manufacture the blocking filter and at some point the designer must make a compromise.

Since an etalon is only a comb filter we need to use other filters to remove unwanted bands. The traditional way is to use a full aperture filter that blocks UV and IR, often called an Energy Rejection Filter (ERF). Then after the etalon and close to the focal point add a “trim filter” or “blocking filter”. (These terms are used loosely in the industry as there are many ways to eliminate all of the unwanted light.)

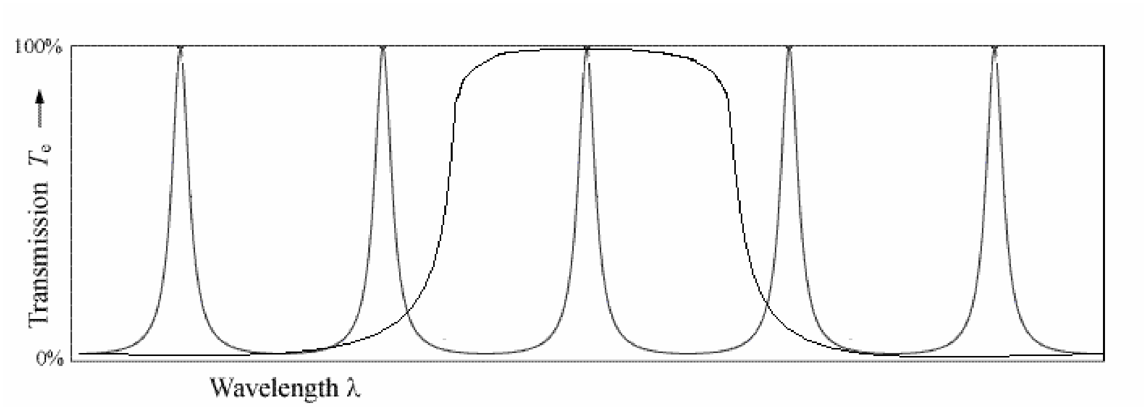

Fig. 6

Fig. 6 shows how adding blocking filter trims the unwanted bands from the etalon. The blocking filter is very expensive and is placed near the focal point of the objective in order to keep the size very small and lower the cost. Depending on the FSR of the etalon, bandwidths of 1 to 5 nm are used (10 to 50 Angstroms). This filter has to remove much of the energy of the system and its design is critical to the success of an H-alpha telescope.

Since the trim filter takes the brunt of the energy load over a very small area its life is limited. A common repair in solar telescopes is to have the trim filter replaced.

Blocking filters are offered by the different manufactures in different apertures. Choosing the proper aperture is a matter of calculating the size of the sun at the point where the blocking filter will be placed. This size is only dependent on the focal length of the telescope and the filters are rated for focal length. (ie B600 is for telescopes with a focal length shorter than 600mm.)

Tilt tuning

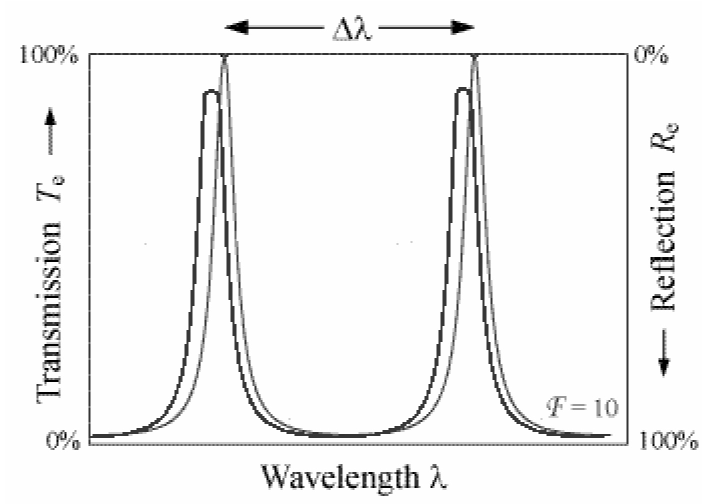

Fig. 7

Tilting an etalon has the effect of as raising the bandpass frequency (blue shifting) as well as slightly lowering the finesse. The tilted etalon is shown in the graph above with the non-tilted etalon. In a perfect world you want your etalon on band with no tilting. This is not practical in a manufacturing environment because it requires spacers that are made to an exact thickness within a few wavelengths of light. Also the refractive index of air changes with altitude making a tilting mechanism a necessity. So, air spaced etalons for solar telescopes are tilted up to .5 degrees to tune on band. It is not economical to temperature tune an air spaced etalon because the index of refraction of air changes slowly with temperature.

Double stacking

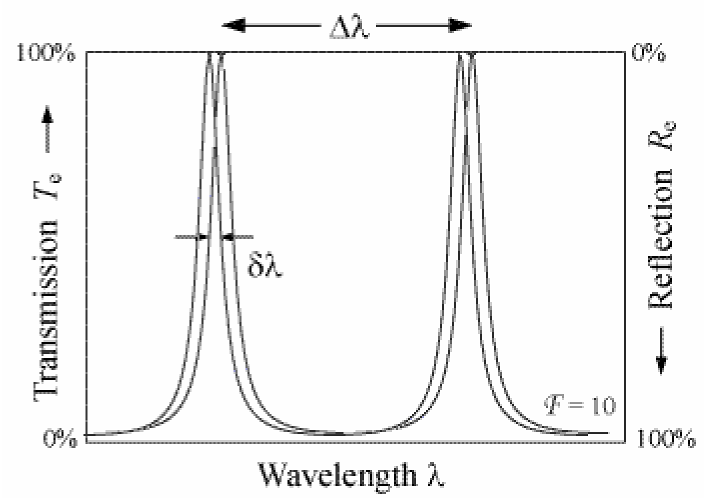

Fig. 8

The bandpass of an air spaced etalon is limited to around .7 Angstroms due to the difficulty with polishing and coating glass to the required tolerances. In order to get a tighter resolution you need to add another etalon. This has been termed double stacking. One etalon is tuned to a slightly different frequency than the other. This causes the transmission curves to overlap. As can be seen in Fig. 8 this lowers the light throughput as well as narrowing the bandwidth. A typical double stacked air spaced etalon will have a bandwidth of .5 Angstroms. It has the side effect of dimming the image slightly but most users prefer it over the wider band. The ideal two etalons will have different tilts to bring them on band. This helps eliminate ghosting of the image.

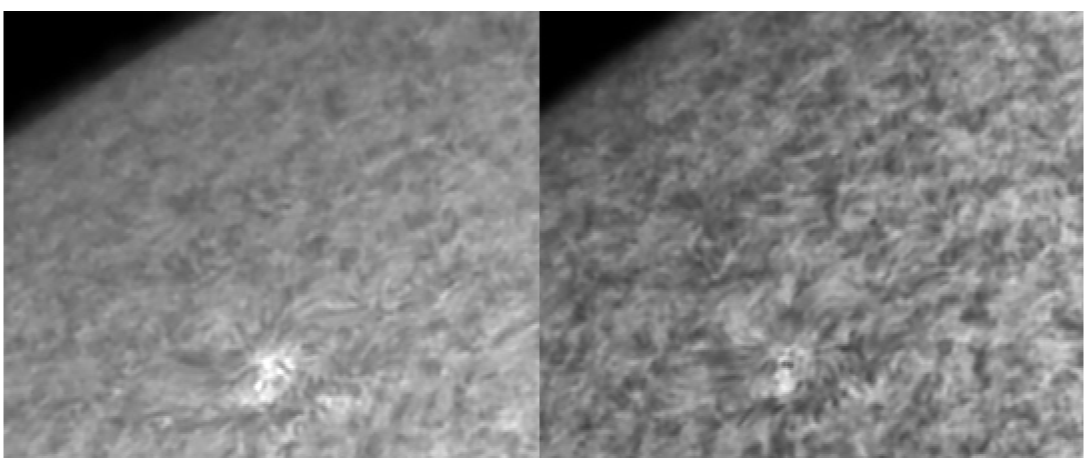

Fig. 9
By Pete Lawrence with a SolarScope 70mm filter
Single Stacked Image on Left and Double Stacked Image on Right.

A very interesting side note to etalons is that they provide evidence for the wave nature of light. Imagine if you will, a photon traveling through space and it encounters an etalon.

The first surface of the glass is AR coated so it passes without any problems. The next surface is coated to 85% reflectivity. The photon rolls the dice and 85% of the time it is reflected back. But if we then place another partially mirrored surface slightly behind the first one, the photon (if it has the right frequency) will transmit 95% of the time! How does this photon know that there is a mirror right behind the first one?

Installation

Installation of an aperture mounted air-spaced etalon can not be easier. You may or may not need an adaptor. If you do the cost for an adaptor is a small fraction of the cost of the filter and they are available for most every telescope. Since the etalon is fragile use both hands when attaching the etalon to the telescope. Make sure to install the blocking filter at the eyepiece end. This is often contained in a diagonal.

Tuning

When tuning a single stacked filter you simply focus till the limb of the sun is sharp starting from outside of focus and going towards inside of focus (make the telescope shorter). When the limb is sharp you adjust the tilt of the solar filter until surface detail is most prominent. Then you can start to scan the limb for prominences. A few iterations of this procedure will have the filter quickly tuned to perfection.

Tuning a double stack is very similar except there are two filters that must be aligned very close to the desired band. However, once at the eyepiece a little practice is worth 1000 words of instruction.

Solarscope

Fig. 10
Courtesy of Solarscope

A traditional air spaced etalon is made from two plates of glass with a thickness 1/6th of the diameter that are polished flat to better than 1/20 of a wave and the irregularities are lapped together to within 1/100 of a wave! This remarkable achievement is quite time consuming and expensive.

Solarscope founded in 1973 in the Isle of Mann makes traditional air spaced etalons although their exact polishing specifications are proprietary. There is a ring of spacers around the outside holding the plates in alignment with no central obstructions. The precision and quality of the filters is admirable and they have been aptly described as the Rolls Royce of solar filters. They make filters in 50, 60, 70 and 100 mm aperture versions and offer complete solar telescopes.

Coronado

Fig. 11
SM-90 and BF-30 by Mike Taormina

Coronado started making etalons for the amateur astronomer in 1997. David Lunt patented many ideas to reduce the cost of and improve air spaced etalons. One however became the defining feature of Coronado telescopes. Patent 6181726 specifies that instead of polishing the etalons to extremely high tolerances he could polish large thin pieces of glass with standard production techniques and cut out the best parts of the plate to make an etalon. Then to make them even more accurate they would make very large spacers around the edges or even add one to the middle called a "foot" (although the patent does not require it). These large spacers cover more than 25% of the etalon making the outer diameter larger than a traditional etalon (The patent does require more than 25% of the surface area be used for spacers). The spacers are made to a very high tolerance by very carefully selecting areas of normally polished plates. This forces the plates into a tighter tolerance by straining the plates into alignment during contacting (gluing).

The next way Coronado lowered the cost of etalons was to make smaller etalons and place them inside the telescope. This was an idea from the long established solid etalon industry. Without additional optics this is not possible because the light cone is converging and the conditions of resonance are not met for light coming from the edges of the objective. This problem is enhanced by low index of refraction gaps and since air has an index close to 1 beam angles need to be controlled more tightly than in a solid etalon. Coronado reduced this problem by placing a negative lens ahead of the etalon expanding the light rays to a nearly parallel bundle before passing through the etalon. Then after the etalon they placed a second lens to re-converge the light. (See Fig. 2) This design was used in many of the Lunt scopes including the PST which has a 40 mm aperture and a 20 mm etalon and drove the cost down to where almost anyone could own an H-alpha telescope.

Coronado was acquired by Meade and continues to make the product line. Coronado makes 40, 60 and 90 mm aperture etalons as well as complete telescopes.

Lunt Solar Systems

Fig. 12
Courtesy of Lunt Solar Systems

The newest player on the air spaced etalon scene is Lunt Solar Systems formed in 2007. It was started by David Lunt's son, Andy Lunt. Lunt Solar Systems is designing both air spaced and solid etalons. Only the air spaced designs will be considered here.

Andy Lunt has worked on optical design and fabrication for the aerospace industries and is hoping to bring some of the technology to H-alpha solar telescopes. Lunt Solar Systems has a patent pending status on their new air spaced etalon used on their largest aperture etalons. The patent is not public yet, but according to Andy Lunt one of the claims in the patent is the new "Root 3" system.

The "Root 3" etalons use a traditional sized spacer with highly polished flats. The spacers are arranged in a circle around the outside of the etalon allowing about 95% of the aperture. There is a second circle of spacers placed approximately at 1/1.73 (1/square root of 3) of the diameter of the etalon in the field of view. This is intended to make the etalon glass stiffer as well as give the etalon more contacting area to avoid the problem of de-contacting with rough handling.

As of this writing Lunt Solar Systems has not started delivering etalons yet. They are currently in production and should be on the store shelves this summer. They are taking pre-orders on 50, 75, 100 and 160mm etalons as well as complete telescopes.

Conclusion

The last 20 years has seen a great amount of innovation in air spaced etalon design for H-alpha telescopes. We have seen the apertures increase and the cost decrease as new ideas and manufacturers have entered the market. What was once a very specialized instrument is now common place. If you have not yet viewed through one please try to get to a local astronomical meeting and take a peek. You will not be disappointed.

Further Reading

Wikipedia - http://en.wikipedia.org/wiki/Etalon
Etalon Designer Applet - http://www.lightmachinery.com/etalon-designer-r6.php
Solarscope - http://www.solarscope.co.uk/
Coronado Website - http://www.coronadofilters.com/
Lunt Europe Website - http://www.luntsolarsystems-europe.com/

Fundamentals of Solar Astronomy, Bhatnagar and Livingston
Optics, Hecht
Cambridge Encyclopedia of the Sun, Lang

Patent 06181726
Patent 06215802
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