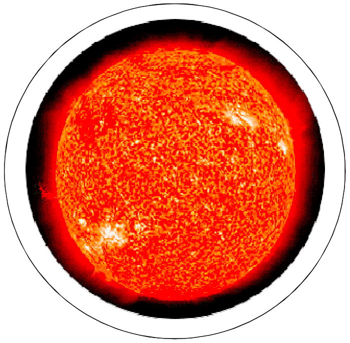
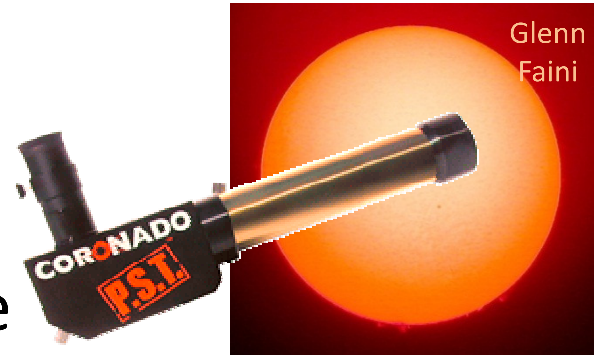


# Filters and Coatings for Visual Astronomy

*by*

**Michael W. Masters**

# *Introduction*



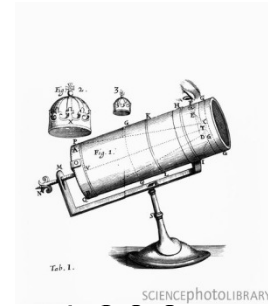

- The initial inspiration for this talk was RAC's H-alpha Personal Solar Telescope
  - I liked it so well I bought a **Lunt Solar** 60mm double stack!
  - Being ever the curious soul, I had to find out how it worked!
  - Also, I thought we should have an answer for the ***skeptical mothers*** at outreach events who keep demanding to know, ***"Why should I let my child look through that thing?!"***
- But, H-alpha scopes alone weren't enough for a talk

- From a previous talk, "How We See the Sky", I had material on filters, anti-reflection lens coatings and mirror coatings
  - That content was a bit skimpy and required filling out
  - Content grew and grew! So, some slides are reference
- Talk covers **visual** use only – not photography

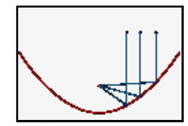
# *Outline*

- ***Mirror coatings***
- Lens coatings
- Color filters
- Nebula filters
- Solar filters

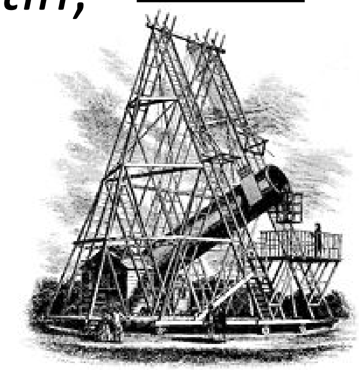
# *Early Telescope Mirrors*



- The ability of a curved mirror to form an image may have been theorized from the time of Euclid
- Galileo and many others wrote of the possibility in the 1600s
- In 1666, Isaac Newton produced the first working reflecting telescope, the design that bears his name today



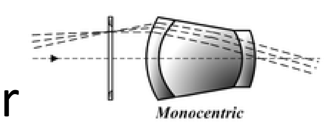
- The mirror was made from an alloy of *copper* and *tin*, an alloy called *speculum metal* (2:1 ratio)
- Speculum metal was used for nearly 200 years as the basis for reflecting telescope primary mirrors
  - Enormous mirrors were made, e.g. Herschel's 49.5"!



- Limited by its reflectivity, at ~66% when fresh
  - Tarnished quickly, requiring removal, polishing & refiguring

Many had two mirrors!

- In 1856-57, Karl August von Steinheil and Leon Foucault developed a process for depositing a thin layer of *silver* on the first surface of glass mirrors
  - Reflected 90% of incident light and tarnished much slower
  - Did not require refiguring when silver coating was removed



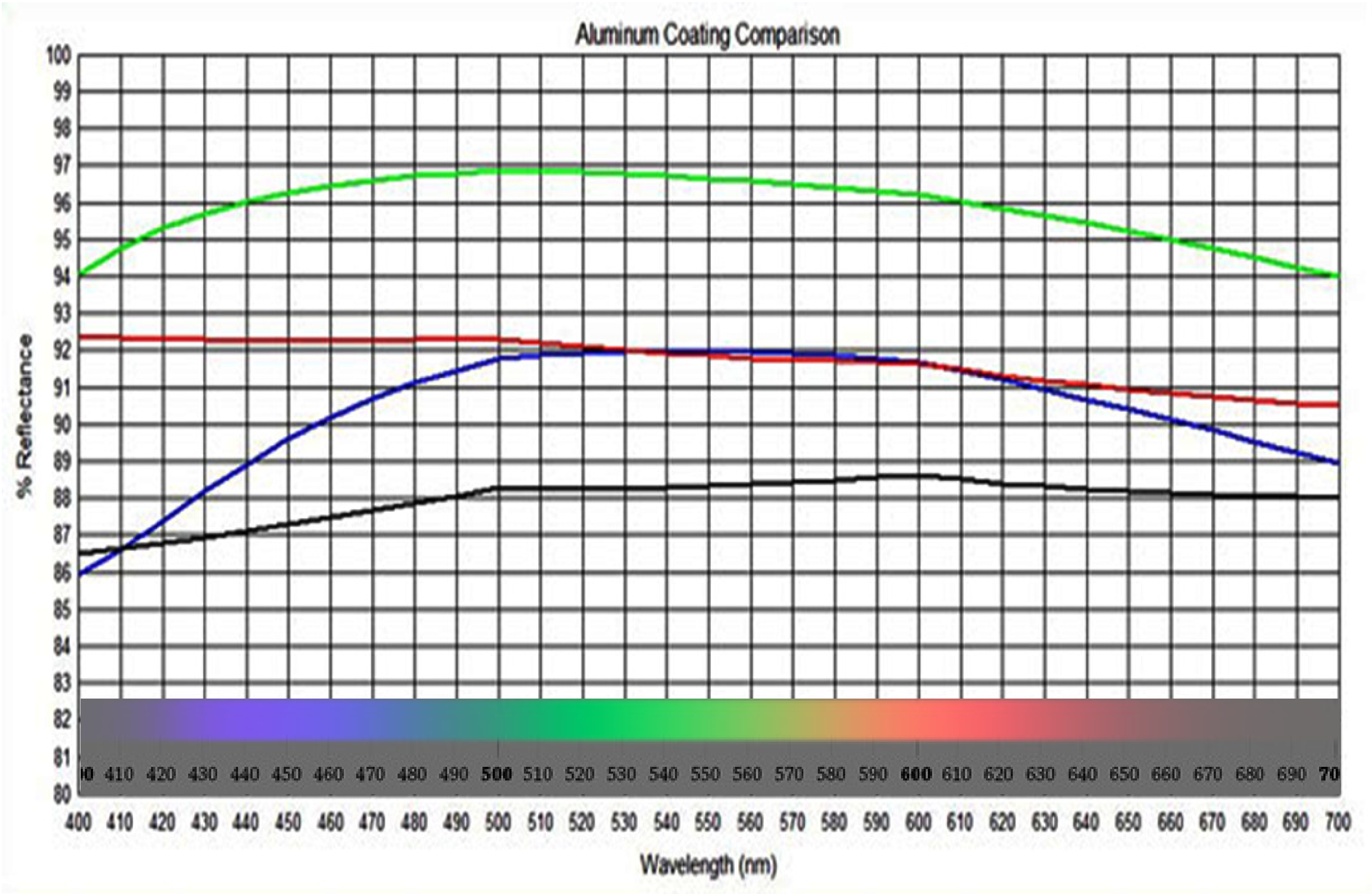

Steinheil Eyepiece by Adolf Steinheil, son of Karl Steinheil

Source: http://en.wikipedia.org/wiki/History_of_the_telescope & http://en.wikipedia.org/wiki/Speculum_metal

# *Aluminized Mirror Coatings*

- Silvered mirrors still had the problem of tarnishing
  - Had to be re-silvered every few months
- In 1932, John Donavan Strong of the California Institute of Technology developed a technique for coating a mirror with a long-lasting film of aluminum
- The process was called ***thermal vacuum evaporation,*** and it became known as "aluminization"
  - Today alternative processes are often used, e.g. sputtering and chemical vapor deposition
- Today's mirrors are overcoated with thin films such as silicon dioxide (SiO2), quartz, titanium dioxide (TiO2), and various rare earth oxides
  - Increases reflectivity and durability of base aluminum coating

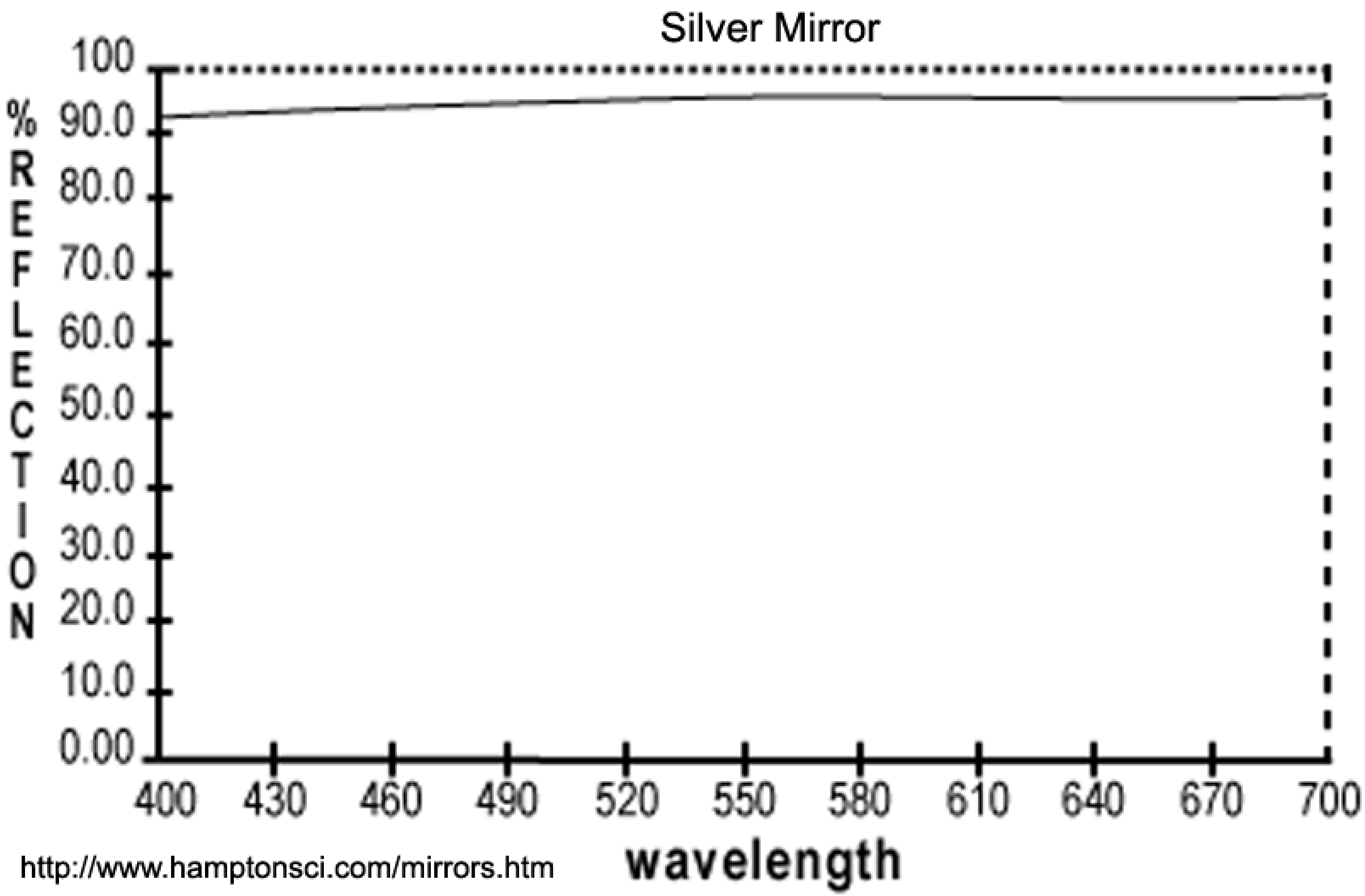
Source: http://en.wikipedia.org/wiki/History_of_the_telescope & http://www.spectrum-coatings.com/coatings.htm




| Bare Aluminum Coating | Protective SiO2 Layer | ½ Wave SiO2 Protective Layer * | Enhanced w/Ta2O5 + SiO2 Layer † |
|---|---|---|---|
| | | | |

* ½ wave maximizes reflectivity
† Ta = Tantalum AN 73

— Source: Optical Mechanics, Inc. (opticalmechanics.com)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# *Outline*

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- ***Lens coatings***
- Color filters
- Nebula filters
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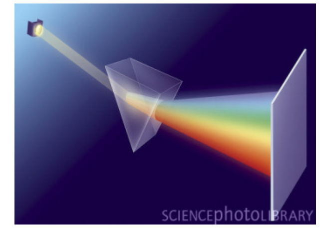
# *Early Lens-Based Telescopes*




- Simple lenses made from rock crystal had been know from before recorded history
- Ptolemy's 2nd century work, ***Optics***, described the properties of light, including ***reflection***, ***refraction*** & ***color***
- The earliest known telescopes appeared in 1608
  - Credited to Hans Lippershey, but also claimed by Zacharias Janssen Middelburg and Jacob Metius
- These refracting telescopes consisted of a convex objective lens and a concave eyepiece
  - By 1655 Christian Huygens and others were building scopes with compound eyepieces
- The achromatic (two element) objective lens was introduced by Chester Moore Hall in 1733
  - John Dollond independently developed and produced achromats in commercial quantities starting in 1758

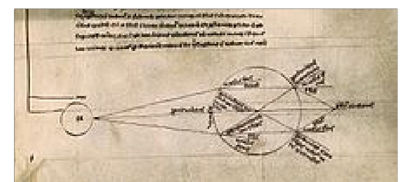
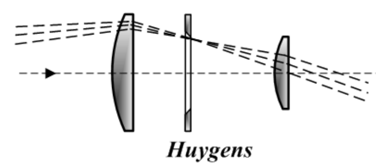
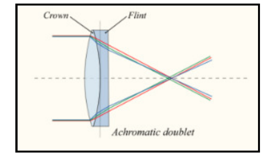


**Diagram of light refracted through a glass containing water, by Roger Bacon**



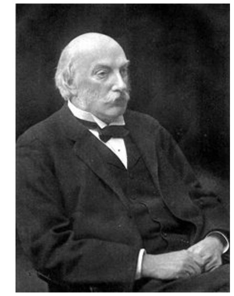

Source: http://en.wikipedia.org/wiki/History_of_the_telescope

# Problems with Lenses



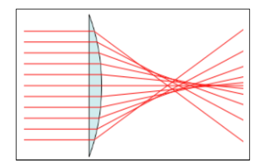
Chromatic aberration

- Just as early mirrors had problems with low reflectivity & tarnishing, early lenses did not transmit 100% of incident light
  - About **4%** of incident light is reflected at each glass surface; thus for a single lens, a total of ~**8%** is reflected and only **92%** is transmitted
- Single lens objectives and eyepieces are subject to many optical **aberrations**, which must be corrected by adding additional lens elements, thus compounding the problem
  - The scattering of light caused by all these internal reflections severely compromised the image quality of early refractors


John William Strutt
3rd Baron Rayleigh

- In 1886, Lord Rayleigh tested samples of old, tarnished glass and was surprised to discover that they transmitted more light than new glass
  - Strength of reflection is a function of the **difference** in the **refractive indexes** between two mediums
  - Because tarnish has a refractive index intermediate between that of glass and air, each interface exhibited less reflection than glass alone
  - Reflection had been mathematically described by **Fresnel*** in 1818


Augustin-Jean Fresnel *


Spherical aberration


Fresnel Lighthouse Lens

***Lord Rayleigh had discovered anti-reflection coatings!***

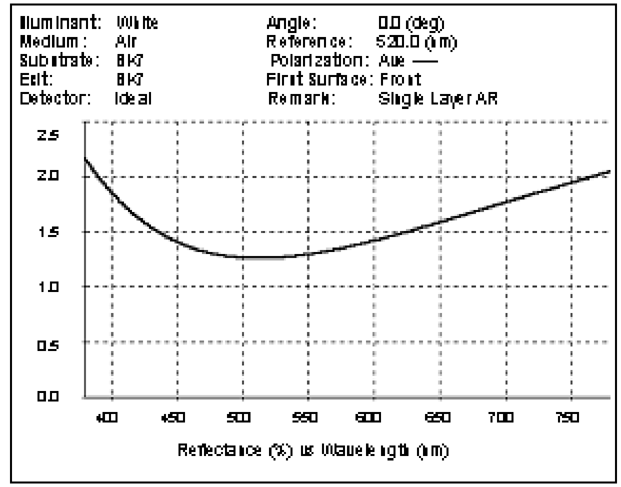
  - It would be another 50 years before a commercial AR process emerged

* **Augustin-Jean Fresnel, 1788 – 1827, Inventor of Fresnel lens**

Source: http://en.wikipedia.org/wiki/Anti-reflective_coating

# Commercial AR Coatings

- In 1935, Ukrainian born Alexander Smakula, working at Carl Zeiss AG in Jena Germany, invented and patented the first commercial anti-reflective coating process for lenses
- The process was first kept a military secret
  - Captured Carl Zeiss binoculars were prized by allied soldiers during World War II for their anti-reflection characteristics




Source: L&L Optical Services
www.llopt.com/ar.html

- In 1938, Katharine Burr Blodgett of GE and Irving Langmuir* devised a method to put monomolecular coatings on metal and glass only a few nanometers thick
  - Glass coated with the Langmuir-Blodgett process was > **99%** transmissive and was called "invisible glass"
  - Used in the making of *Gone with the Wind!*

* 1932 Nobel Prize in Chemistry: theory, chemistry of oil films
http://en.wikipedia.org/wiki/Irving_Langmuir


Lamont Cranston, the *Invisible Man!*


- At first, a single layer of magnesium fluoride was used
  - This reduced reflectivity to the **~1%** range
- Modern multilayer coatings perform much better, transmitting **~99.9%**

Source: http://en.wikipedia.org/wiki/Alexander_Smakula & http://en.wikipedia.org/wiki/Katharine_B._Blodgett & http://www.smecc.org/ziess.htm

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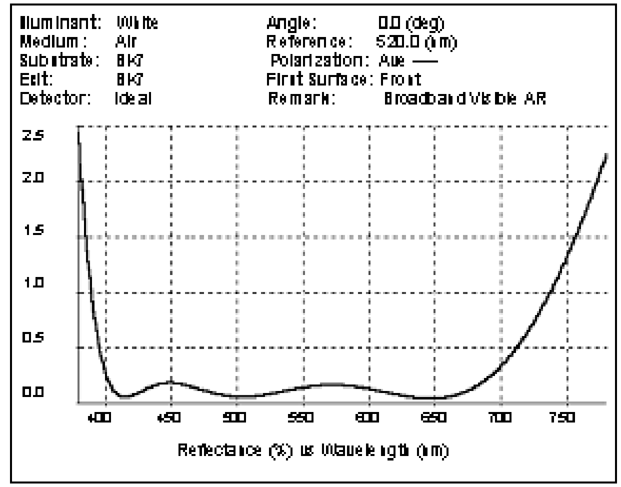


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# *How Do AR Coatings Work?*

- There are two separate causes of optical effects due to coatings, often called ***thick film*** and ***thin film*** effects

## ***Thick Film (Reflection Based)***

- Thick film effects arise because of differences in the index of refraction between the layers above and below the coatings
- **Layers are typically air, coatings, and glass**
- Thick films do not depend on film thickness so long as it is ***greater than a wavelength of light***

## ***Thin Film (Interference Based)***

- Thin film effects arise when the thickness of the coating is approximately ***one quarter wavelength of light***
- Reflections can be made to add destructively and hence cancel each other out
- Thin films effects depend on wavelength of light and angle of incidence

Source: http://en.wikipedia.org/wiki/Anti-reflective_coating

# Reflection Based Coatings

- When light enters glass, some portion of the light is reflected
- The strength of the reflection, **R ***, depends on the refractive indices, **n**, of the two media as well as the angle of the beam
- Ignoring absorption and scattering, light **transmitted** is equal to **incident (1)** minus **reflected** ***T = 1 – R***
  - For air to glass, **R ≈ 4%**
- The real situation is far more complex because glass has two surfaces and optical systems have many components

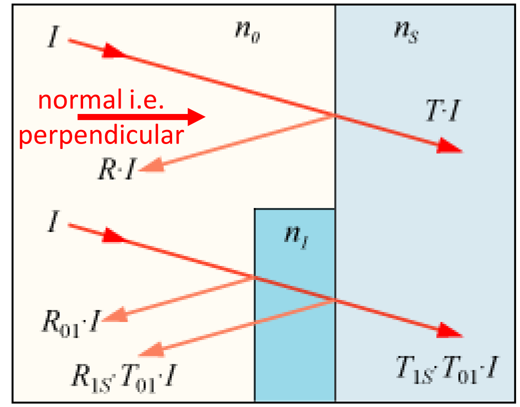
*** R derived by Augustin-Jean Fresnel in 1818**
**http://en.wikipedia.org/wiki/Fresnel_equations**

**For normal incidence**

$$R = \left(\frac{n_0 - n_S}{n_0 + n_S}\right)^2$$

**Reflectance coefficient R is usually quoted as a percentage, 0% to 100%**

**Bare glass transmits 96% of incident light *at each surface!***




- For a Rayleigh coating, $n_1$, the light reflects twice
  - Air to $n_1$ and $n_1$ to $n_S$

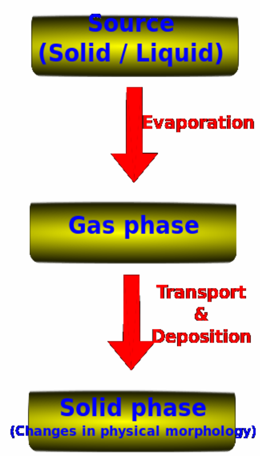
**$n_0 \approx 1.0$**
**$n_S \approx 1.5$**
**$n_1 \approx 1.225$**

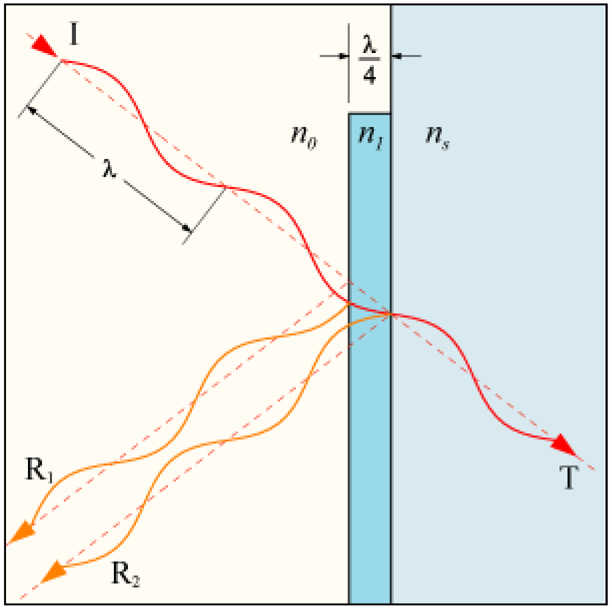
- Transmission at each interface is
  - $T_{01} = 1 – R_{01}$ & $T_{1S} = 1 – R_{1S}$
  - Total Transmittance is $T_{1S}T_{01}$
- Through optimum choice of $n_1$, transmission can be maximized
  - $n_1 = \sqrt{n_0 n_S}$ **Reflection loss ≈ 1%**

Source: http://en.wikipedia.org/wiki/Anti-reflective_coating

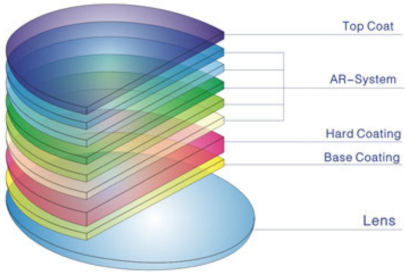
# Interference Based Coatings

- Some light, $R_1$ is reflected by the coating and some, $R_2$ is reflected by the glass behind the coating
- If the coating is exactly ¼ wave thick, the $R_2$ reflection will be exactly ½ wave out of phase with the $R_1$ reflection at the $n_0\ n_1$ interface, and will cancel $R_1$
- Real coatings do not reach perfect performance since
  - Thickness of coating can vary
  - Light has multiple frequencies
  - Absorption will cause $R_2 < R_1$
- Magnesium fluoride was long used as single layer coating
  - Vapor deposition process
  - Coated, fully-coated, multicoated …
- As with mirrors, many exotic materials are used today




- Further reduction is possible by using **multiple coating layers**, designed such that reflections undergo maximum destructive interference
  - **Today's multi-coated lenses achieve 99.9% transmission**




mingyuanoptics.com

Source: http://en.wikipedia.org/wiki/Anti-reflective_coating & http://en.wikipedia.org/wiki/File:PVD_process.svg

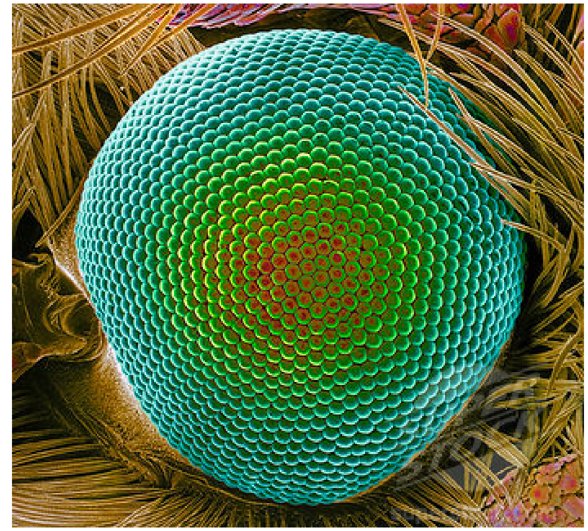
# *Modern Multicoating*

Source: Nikon Inc.

- The photographic industry is a leader in developing commercial multicoatings
  - Sales volume
- Unfortunately, camera makers – and most other optical firms – treat their coatings as **highly proprietary** and do not make details public
- **So I can't give specifics about how a particular product is coated**

Source: Canon Inc.

Source: http://en.wikipedia.org/wiki/Anti-reflective_coating

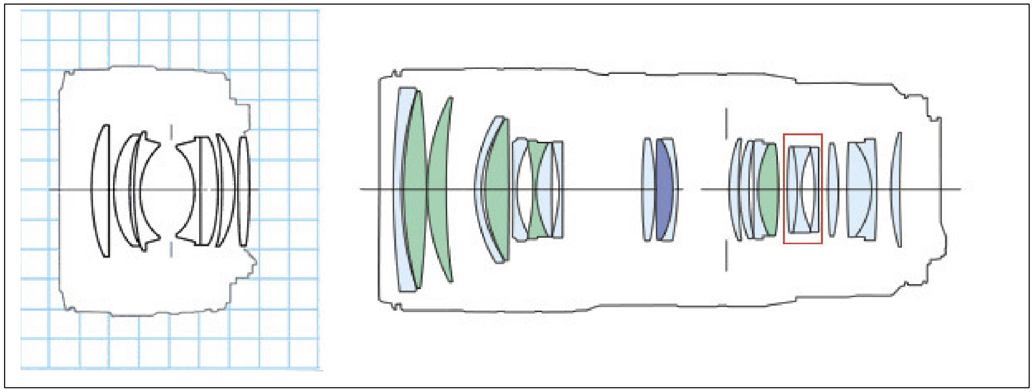


Source: superstock.co.uk

- **Nanocoatings**: the future?
  - Based on moths' eyes; a natural nanostructure of hexagonal pattern of bumps, each 200 nm high, spaced on 300 nm centers
  - Smaller than the wavelength of visible light, with a continuous refractive index gradient which effectively eliminates the air-lens interface

# How Important are AR Coatings?

Effects of AR coating on light transmission in photographic lenses



| % of Incident Light Transmitted by Lens | Simple Fixed Focal Length Lens | Complex Modern Telephoto Zoom |
|---|---|---|
| **Air-to-glass interfaces** | **12** | **32** |
| **Lens w/o Coatings**<br>4% reflected per surface | **62%** | **30%** |
| **1935-era Single Layer**<br>1% reflected per surface | **88%** | **73%** |
| **Modern Multi-coating**<br>0.1% reflected per surface | **98%** | **97%** |

http://www.lensrentals.com/blog/2011/12/reflections-on-reflections-the-most-important-part-of-your-lens

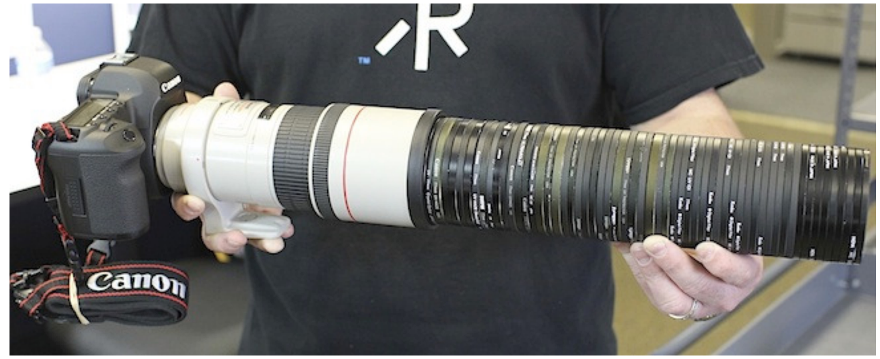
# LensRentals.com Has Fun With Filters

***With apologies to Hamlet. . .***
***To filter or not to filter, <u>that</u> is the question!***

- Most pros do not use filters
  - Claim it affects image quality
- Are they right? It depends
  - Sun behind: No. . .
  - Into the Sun: Yes!
- Use the best!


Before and after: no surprises here!

Five good filters. . .
And five not so good!




50 UV filters on a Canon 5D Mk II and 300 mm f4 lens!

- What about protection?
  - Most Internet examples cite dropped lenses saved by filters
  - A lens hood provides better protection than a filter
- Best use of filters is to preserve front element in hostile environments
  - Nevertheless, lens coatings are pretty tough these days
- One can always remove filter when not needed

Source: http://www.lensrentals.com/blog/2011/06/good-times-with-bad-filters

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**For a high quality filter, the small impact on image quality will be below the resolution of today's digital sensors – and thus undetectable**

**Resolution will be unaffected, but the Sun's presence in or near the frame will increase flare if a filter is present**

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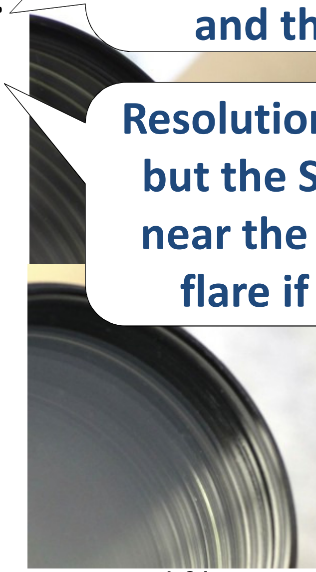

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# *Outline*

- Mirror coatings
- Lens coatings
- ***Color filters***
- Nebula filters
- Solar filters

# *Color Filters*

- Colored eyepiece filters are used to aid in ***lunar*** and ***planetary*** observing
  - Includes colored, neutral density and polarizing filters
  - **Increases contrast by selective filtering**
  - Increases definition and (apparent) resolution
  - **Reduces glare and light scattering**
  - Reduces irradiation and **lessens eye fatigue**

Meade.com

- Most eyepieces are threaded to accept filters
- Filter effectiveness depends on several factors
  - Scope aperture and focal length
  - Magnification used
  - Seeing conditions
- Minus violet filters are used to remove fringing in achromatic refractor

— Source: Celestron.com

# Color Filter Uses

| | Moon | Venus | Mars | Jupiter | Saturn | Uranus | Neptune |
|---|---|---|---|---|---|---|---|
| Yellow † | Enhances features | Increases contrast | Darken maria, etc. | Enhances belts | Improve blue band detail | Improve detail* | Improve detail* |
| Orange | Greatly enhances | Daytime observing | Darken maria, etc. | Enhances belts | Improve blue band detail | – | – |
| Red | Improves features | Daytime observing | Polar caps Dust storms | Bluer clouds | Improve blue band detail | – | – |
| Blue † | Enhances detail | Cloud shading | Polar caps Dust storms | Great Red Spot | Improve low contrast areas | – | – |
| Green † | Enhances features | Cloud shading | Polar caps Dust storms | Great Red Spot | Enhance white areas | – | – |
| Violet † | – | Cloud shading | Clouds & polar haze | – | Ring structure | – | – |
| ND | Reduces glare | Stack w/ color filter | Stack w/ color filter | Stack w/ color filter | Stack w/ color filter | – | – |
| Polarize | Reduces glare | Reduces glare | Reduces glare | Reduces glare | Reduces glare | | |

* 11" and larger scopes
† improves comet views

Note: Several colors come in multiple strengths
For full discussion of uses, see link below

**Color filters are not a panacea – expect effects to be subtle at best**

Source: http://www.**celestron**.com/c3/support3/index.php?_m=knowledgebase&_a=viewarticle&nav=0&kbarticleid=1881

# Filter Colours and Uses

### # 15 Deep Yellow

- Contrast of lunar surface
- Polar caps & orange desert regions on Mars
- Orange and red features on Saturn and Jupiter

### #25 Red

- Martian surface detail in larger scopes
- Contrast of Mercury against blue sky
- contrast and cloud definition of Venus
- Bluish clouds of Saturn and Jupiter

### #58 Green

- Lunar surface detail
- Contrast of red spot on Jupiter
- Contrast of subtle red and blue hues
- Melt lines around polar caps on Mars

### #80A Medium Blue

- Contrast of comet tails
- lunar surface detail (significantly)
- Martian polar caps and high clouds

### # 11 Yellow-Green

- Contrast of Martain maria and polar caps
- Orange and red features on Saturn and Jupiter

### # 21 Orange

- Contrast of Mercury and Venus in daylight
- Bands and festoons on Jupiter and Saturn

### # 47 Violet

- Contrast of Venus, reducing glare and twinkling
- Surface detail on Mercury and Venus
- Ring structure of Saturn

### # 82A Pale Blue

- Orange and purple cloud belts of Saturn and Jupiter
- Comet tails
- Suppresses chromatic aberation in refractors

### # 23A Light Red

- Maria on Mars
- Comet Dust tail and coma
- Orang and red belts on Jupiter and Saturn

### # 38A Deep Blue

- Dust storms on Mars
- Subtle details in Saturn cloud belts
- Bright comet gas tails

### # 56 Light Green

- Martain polar caps and low clouds
- Low-contrast blue and red hues of Jupiter
- Surface contrast of Saturn

### # 8 Light Yellow

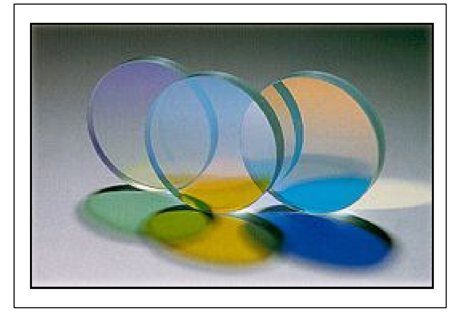
- Maria on Mars
- Comet dust ail and coma
- orange and red belts on Jupiter and Saturn

At one time, Sirius also made a line of neodymium metal coated filters suitable for Mars observation. They are not currently listed for sale, possibly because Mars is not at present in a very close opposition, as it was in 2003.

— Source: **Sirius-Optics**.com.au/filters.htm

Dave Knisely Sirius NPC Neodymium filter review: http://www.cloudynights.com/item.php?item_id=41

# *Outline*



- Mirror coatings
- Lens coatings
- Color filters
- ***Nebula filters***
- Solar filters

# *Filters for Deep Sky Objects*

- Amateurs use a variety of filters to improve views of deep sky objects
  - Increase object contrast against sky background
  - Minimize sky glow and light pollution impact
  - Limit bandpass to selected frequencies, admitting light from desired objects and blocking unwanted frequencies
- These filters are used on diffuse and planetary nebulae and supernova remnants – but not star clusters
- Hence, such filters are often called ***nebula filters***
  - Deep Sky (light pollution) — Broadband
  - Ultra high contrast (UHC) — Narrowband
  - Oxygen III (OIII) — Single line bandpass
  - Hydrogen Beta (H-beta) — Single line bandpass

# *Nebula Filters*

Carina Nebula
Source:
NASA/Hubble

- Nebula filters limit admitted light to a selected range of frequencies
- They reduce the amount of transmitted light and thus the brightness of the target object
- However, they increase object visibility by darkening sky background more than the objects for which they are designed, **thus increasing contrast and therefore visibility**
  - **Faint objects are usually best seen with *averted vision***
- Maximum eye pupil – 7mm for young, ~5mm for older people

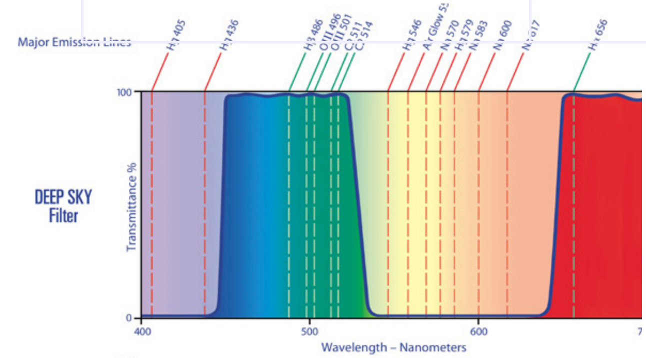

| Optimum Eyepiece Exit Pupil for Nebula Filters | | | | |
|---|---|---|---|---|
| **Filter Type** | **Deep Sky** | **UHC** | **OIII** | **H-Beta** |
| **Bandpass** | 90nm | 22-26nm | 10-12nm | 8-10nm |
| Light-polluted sky | 0.5-2mm | 1-4mm | 2-5mm | 3-7mm |
| Dark sky | 1-4mm | 2-6mm | 3-7mm | 4-7mm |

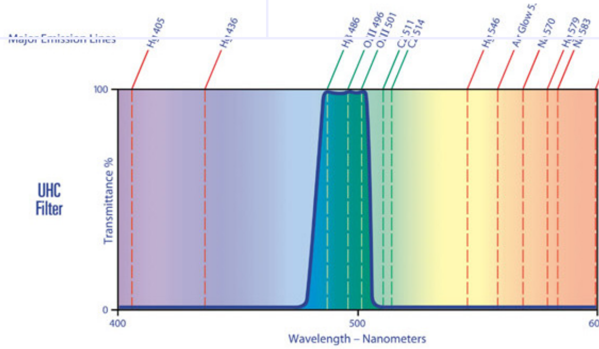
— Source: Lumicon.com

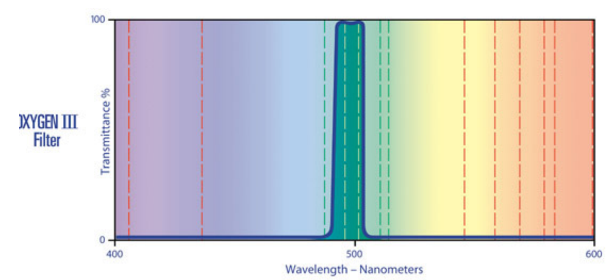
# Nebula Filter Characteristics

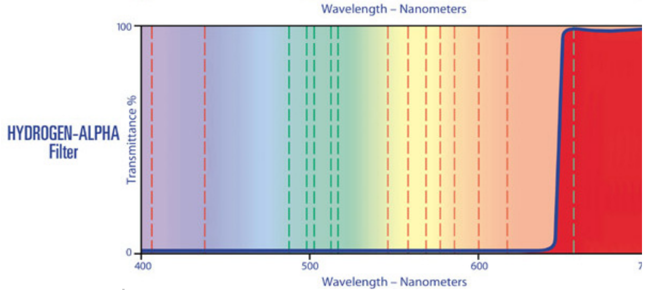
| Objects | Examples | Best Filter for Viewing | Best Filter for Photography |
|---|---|---|---|
| Stars & Star Clusters | M13, M11 | None | Deep Sky |
| Diffuse Nebulae | Lagoon, Swan | OIII (light polluted sky) Deep Sky, UHC (dark sky) | Deep Sky |
| Planetary Nebulae | Dumbbell, Ring | OIII (light polluted sky) Deep Sky, UHC (dark sky) | Deep Sky |
| Faint Planetary Nebulae | NGC 7293, Abell 33 | OIII | Deep Sky |
| Reflection Nebulae | Pleiades, Trifid | Deep Sky | Deep Sky |
| Spiral Galaxies | M33, M101 | None | Deep Sky |
| Faint Nebulae | Veil, Rosette, N. American, Pelican | OIII (light polluted sky) Deep Sky, UHC (dark sky) | Deep Sky |
| Extremely Faint Nebulae | California, Horsehead | H-Beta | Night-Sky H-Alpha Deep Sky |

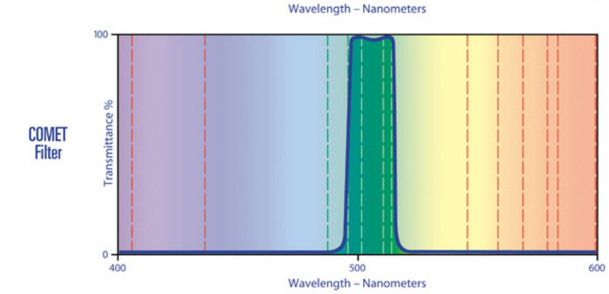
— Source: Lumicon.com

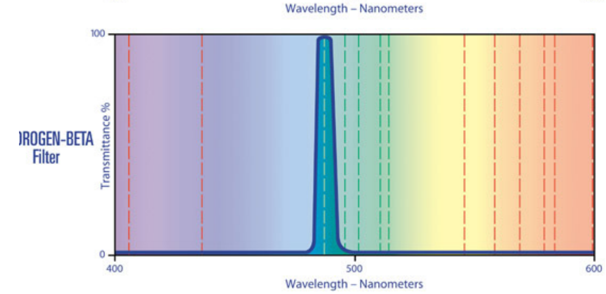


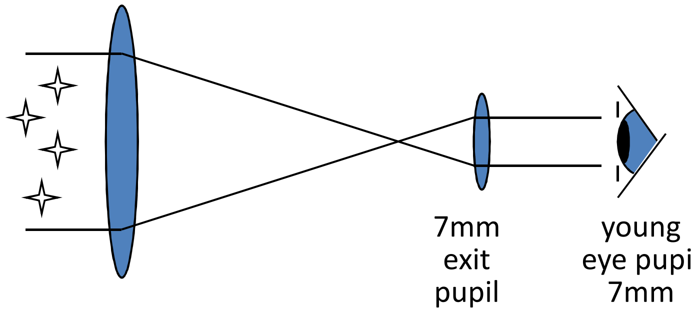



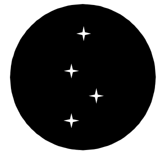



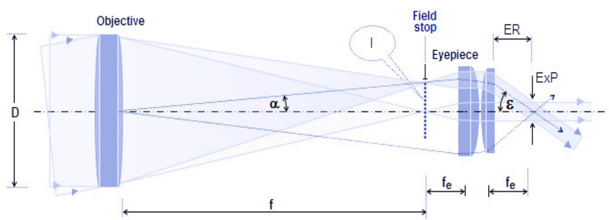



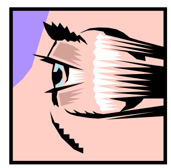
# Eyepiece Exit Pupil & Eye Entrance Pupil



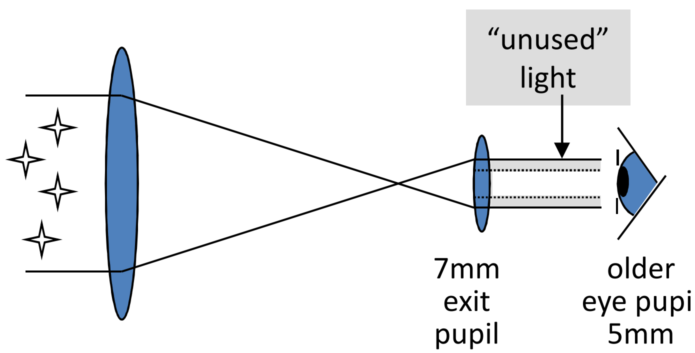



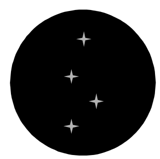
Eyepiece exit Pupil and eye entrance pupil same size → All light collected by objective is captured by eye



| **Exit pupil = fe ÷ F ratio** |
|---|
| *Example*<br>Light from objective is reduced by ratio of pupil radii squared<br>$r^2_{eye} / r^2_{eyepiece} = 51\%$<br>In this example, a 7” scope would deliver only as much light as a 5” scope |



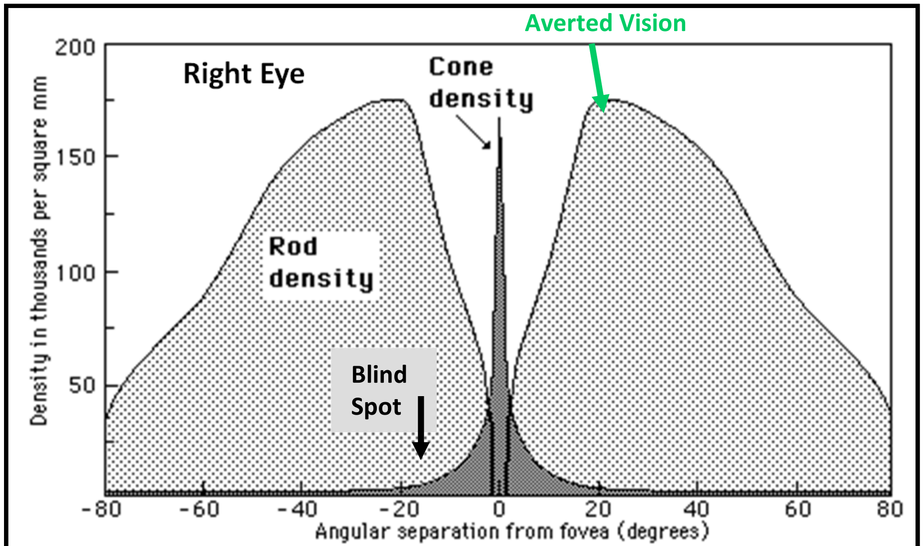
Eyepiece exit pupil larger than eye entrance pupil → Smaller eye pupil excludes some light collected by objective

Objective D = 100mm, f = 700mm => F7 ratio
Eyepiece $f_e$ = 50mm (typical 2” Plossl)
**Exit pupil = 50mm / F7 = 7.1mm**

**One may still want an eyepiece with a large exit pupil for the wider true field it provides – even though some light will be lost.**

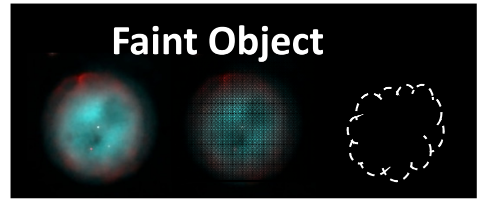
# Averted Vision

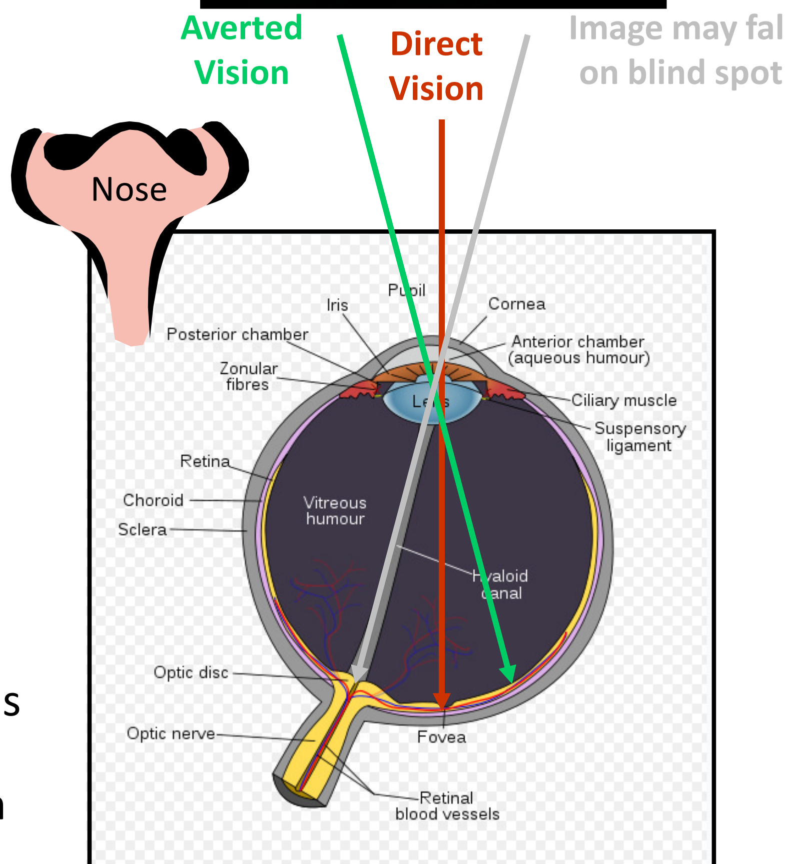
**Note: small amateur scopes do not collect enough light to stimulate color vision**




Rod and cone density on retina

— Source: Georgia State University HyperPhysics Dept.




Schematic diagram of right eye

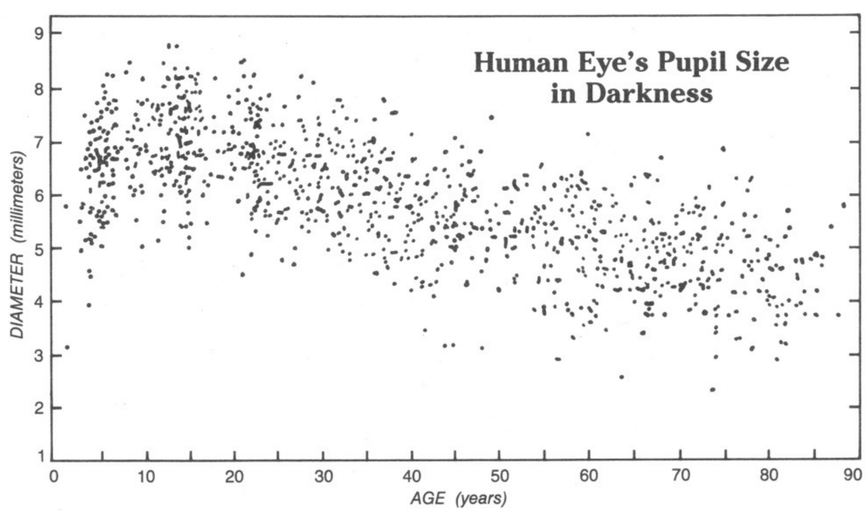
— Source: Wikipedia

- Averted vision places faint objects at peak density of dark-adapted rods
  - ~15-20 deg from center of vision
  - Allow light to build up for 5-10 seconds
- Rod neural paths are "bundled," which increases sensitivity compared to cones
- Place faint object on the nasal side of the eye in order to avoid the retina blind spot
- Averted vision works better for faint extended objects than for bright point sources

— Source: Orion-XT10.com

— Owl Nebula Photo Credit: Robert J. Vanderbei, Wikipedia

# Eye Pupil, Age and Magnification



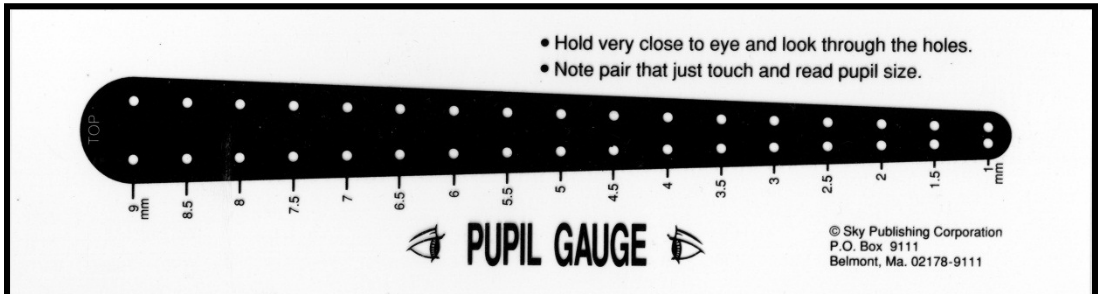

Over 1,200 people had their eyes measured to create this graph of pupil diameter versus age. Clearly, the conventional wisdom that the human eye opens to 7 millimeters in darkness is only a very rough average even for young people. Over age 50, a more realistic average is 5 mm. Which of these points would represent you? From a study by I. E. Loewenfeld published in *Night Vision* (National Academy Press, 1987).

— Source: Sky & Telescope, May 1992

**Age vs. Pupil Size and Lowest Magnification**
**(Low power eyepieces have large exit pupils)**

| Approx. Age | Avg. Pupil Size | Lowest Effective Magnification per inch of Aperture | Lowest Effective Magnification per cm of Aperture |
|---|---|---|---|
| < 25 | 7 | 3.5 | 1.4 |
| 30 | 6.5 | 3.8 | 1.5 |
| 35 | 6 | 4.1 | 1.6 |
| 45 | 5.5 | 4.5 | 1.8 |
| 60 | 5 | 4.9 | 2 |
| 80 | 4.5 | 5.4 | 2.2 |

— Source: Event Horizon Newsletter, April 1996, Hamilton Amateur Astronomers




Any eyepiece/telescope combo with a larger exit pupil than the eye's entrance pupil excludes some light from the objective. The eye pupil declines with age.

# *"Filter Performance Comparison for Some Common Nebulae"*

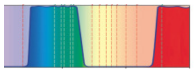
- Comparison test performed by Dave Knisely of Prairie Astronomy Club
  - Reported on Cloudy Nights.com
  - http://www.cloudynights.com/item.php?item_id=1520
  - Visual performance comparing of emission nebulae for various filters
  - Telescopic observation of 93 objects in 2006
  - A few unaided-eye observations were made using the filters hand-held and looking up at the sky
    - **Rosette, North America, California Nebula, and Barnard's Loop**
- Instruments used
  - 10" f/5.6 Newtonian at 52X, 59X, 70X, 141X
  - 9.25 inch SCT at 59X, 98X
  - 80mm f/5 refractor at 15X
  - 100mm f/6 refractor at 22X

Telescopes for illustration only; not necessarily used in study

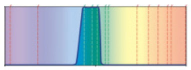
Source: Dave Kinsely on cloudynights.com

# Dave Kinsely Filter Comparison

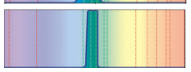
- Filters used (Lumicon)



  – DEEP-SKY (broadband)
    - **Light pollution**



  – UHC (narrowband)



  – OIII (line)

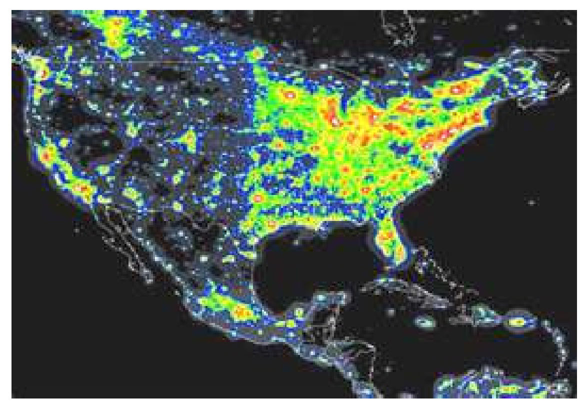
  – H-BETA (line) **Limited use**

| Optimum Exit Pupil for Nebula Filters | | | | |
|---|---|---|---|---|
| **Filter Type** | **Deep Sky** | **UHC** | **OIII** | **H-Beta** |
| **Bandpass** | 90nm | 22-26nm | 10-12nm | 8-10nm |
| Light-polluted | 0.5-2mm | 1-4mm | 2-5mm | 3-7mm |
| Dark sky | 1-4mm | 2-6mm | 3-7mm | 4-7mm |
| Power | Mid-High | Low-Hi | Low-Mid | Lo-Mid |

- Eyepiece recommendations

  – OIII & H-Beta: low to mid power
    - **Low to mid power 2” eyepieces appropriate**
  - UHC and Deep Sky: mid to high power (UHC low power under dark skies)
    - **Mid to high power 1.25” eyepieces appropriate** (and 2” for UHC)
- Usually filters were mounted in a modified Lumicon Multi-filter Selector

  – Allowed rapid comparisons, avoiding problems caused by time spent changing filters
- Observing was done from a dark-sky site (visual naked-eye limit 6.5 to 7.0)



Source: Dave Kinsely cloudynights.com

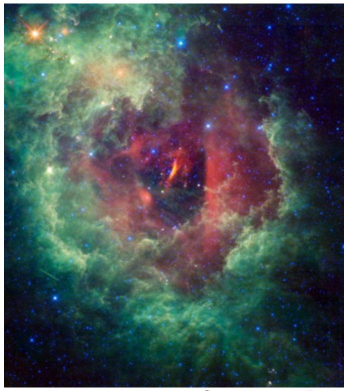
# *Filter Comparison Method One*

- **Each filter was given a 0-5 point score for each object observed**
  - Overall surface brightness, area of nebulosity observed, contrast of detail, etc. used to judge how well a filter improved the view


California Nebula
Source: bf-astro.com


North America & Pelican Nebulae
Source: flickr.com

- **Scoring Legend**
  0. **Much worse than no filter**
  1. **No improvement or slightly fainter**
  2. **Slight Improvement over no filter**
  3. **Moderate improvement over no filter**
  4. **Large improvement over no filter**
  5. ***Very large improvement over no filter***


Rosette Nebula
Source: wired.com


Barnard's Loop
Source: seds.org

- "Since this judgment contains some of the observer's personal preferences, exact results may be somewhat subjective"

Source: Dave Kinsely cloudynights.com

# *Filter Comparison Method Two*

- Method Two was a somewhat subjective recommendation of the **best filter to use on a given object**
  - Based on personal judgment

Carina Nebula

Source: NASA/Hubble

Veil Nebula

Source: NASA/Hubble

- Factors taken into consideration
  - Nebular brightness
  - Total area shown
  - Contrast of detail
  - Overall view

- "When objects were best seen in two filters, both filters were recommended for the object, **<u>as first and close second</u>**"

Orion Nebula detail

Source: NASA/Hubble

Source: Dave Kinsely cloudynights.com

# *Filter Performance Results*

## *Method One (Scoring)*

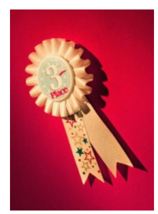
1. **UHC – 330 points**
   – **Average rating 3.55**
2. **OIII – 297 points**
   – **Average rating 3.19**
3. **Deep-Sky – 205 points**
   – **Average rating 2.20**
4. **H-Beta – 134 points**
   – **Average rating 1.44**

*UHC*

*OIII*

***H-Beta***

***Deep-Sky***



- **UHC & OIII are filters of choice for nebulae**
- They perform best at **3.5x to 10x per inch**

## *Method Two (Ranking)*

1. UHC best on 41 nebulae, close 2nd on 46
   **TOTAL 1st and 2nd recommendations for UHC: 87 objects**
2. OIII best on 33 nebulae (helped by the inclusion of some planetary nebulae), Close 2nd on 23, not recommended on 6
   **TOTAL 1st and 2nd recommendations for OIII: 56 objects**
3. H-BETA best on 14 nebulae, 2nd best on 2
   ***Not recommended on 39!***
   **TOTAL 1st and 2nd recommendations for H-Beta: 16 objects**
4. DEEP-SKY best on 7 nebulae, 2nd best on 3
   **Provided at least slight improvement for all nebulae surveyed (light pollution filter)**
   **TOTAL 1st and 2nd recommendations for DEEP-SKY: 10 objects**

**H-BETA: California, Cocoon, Horsehead**

Source: Dave Kinsely cloudynights.com

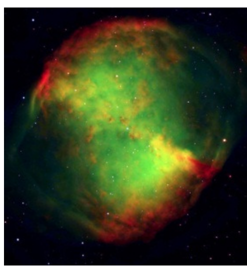
# *UHC and OIII Best Overall*

- The **UHC** and **OIII** are the **filters of choice for viewing nebulae**
- These filters perform best from **3.5x per inch to 10x per inch of aperture** (low to mid power)

Source: TeleVue

  - The **UHC** tended to reveal a slightly **larger and/or brighter area of nebulosity**, while the **OIII** often yielded **more contrast & dark detail**
  - **OIII** filter gives **outstanding low power views** with 2" eyepieces

Veil Nebula
Source: NASA/Hubble



Dumbell Nebula
Source: ESO

Ghost of Jupiter
Source: NASA

  - The **OIII** tended to be better than the **UHC** for locating small planetary nebulae in rich star fields **using the "blinking" technique**

- The **H-Beta** filter tended to be most useful on a more limited number of objects (about 15% of the 93 objects surveyed) than either the UHC or the OIII **(e.g. California, Cocoon, Horsehead)**
- The **Deep-Sky** filter **produced a modest gain in contrast** for nearly every object observed

Horsehead Nebula
Source: NASA/Hubble

Source: Dave Kinsely cloudynights.com

# *Veil Nebula & OIII Filter*

***The best view I've ever had of the Veil Nebula was a view seen through my 16" Starmaster Dob with TeleVue 31mm Nagler and 2" Lumicon OIII filter***

**Suprisingly, neither the seeing nor the transparency seemed exceptional that night – but the view was spectacular!**

Source: panther-observatory.com

# Outline

- Mirror coatings
- Lens coatings
- Color filters
- Nebula filters
- ***Solar filters***

***Big thanks to SunGazer.net!***

# *Safe Solar Observing*

- How the eye is damaged
  - Lifetime solar radiation contributes to aging of the eye and development of cataracts
  - Immediate damage takes place when observing the sun without adequate protection
    - **Exposing the retina to high-intensity visible light triggers a series of complex chemical reactions that can impair, damage or even destroy rods and cones**
    - **Infrared wavelengths literally cook and blind exposed photoreceptor cells**
- Both types of damage cause no pain
  - Visual effects may not show up right away, making prolonged exposure likely

*Sky & Telescope* staff members demonstrate different ways of safely studying the Sun

- Safe non-telescopic solar filters are rated with a number called a shade factor
- **A shade 14 filter is safe for solar observing & is recommended**

http://www.skyandtelescope.com/observing/objects/sun/3304056.html?page=1&c=y

# *Background*

- For a long time, the affordable choices available to amateurs for solar observation were technologically limited
  - Filtered direct observation
  - Eyepiece projection
  - Solar eyepieces
  - White light solar filters

- Views were less than fully satisfying
  - White light only
  - Only sunspots visible
  - No prominences, granulations, plages or other phenomena

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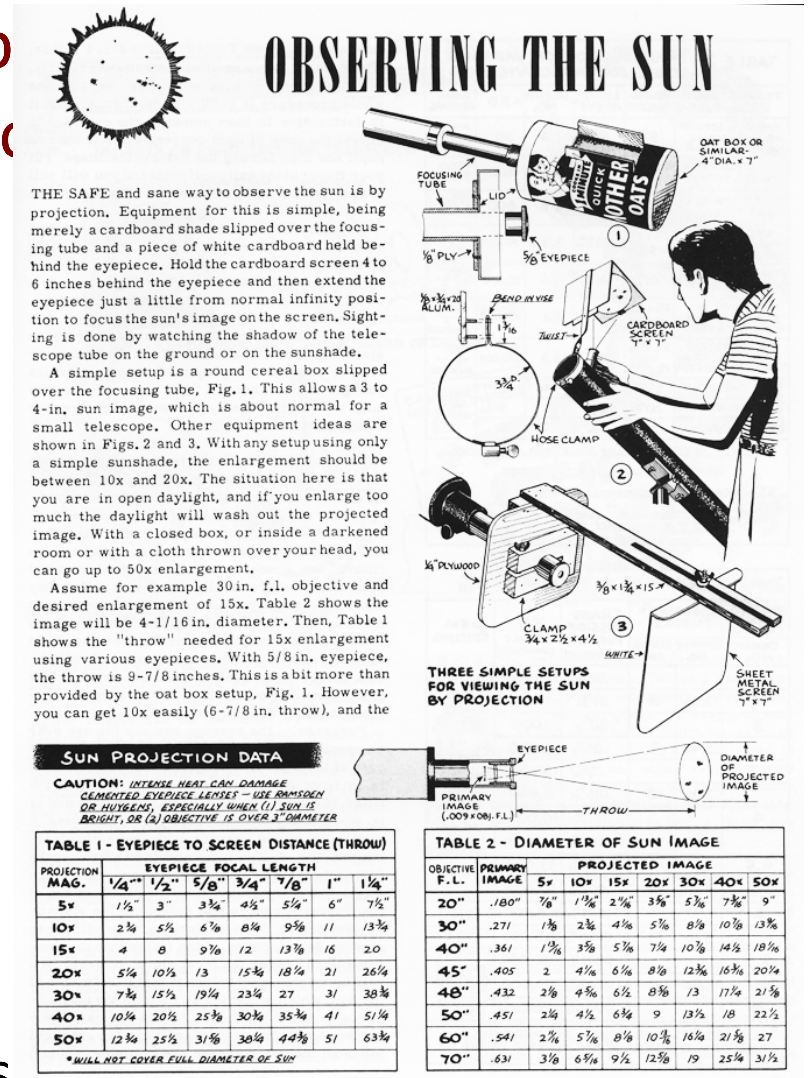

# OBSERVING THE SUN

THE SAFE and sane way to observe the sun is by projection. Equipment for this is simple, being merely a cardboard shade slipped over the focusing tube and a piece of white cardboard held behind the eyepiece. Hold the cardboard screen 4 to 6 inches behind the eyepiece and then extend the eyepiece just a little from normal infinity position to focus the sun's image on the screen. Sighting is done by watching the shadow of the telescope tube on the ground or on the sunshade.

A simple setup is a round cereal box slipped over the focusing tube, Fig. 1. This allows a 3 to 4-in. sun image, which is about normal for a small telescope. Other equipment ideas are shown in Figs. 2 and 3. With any setup using only a simple sunshade, the enlargement should be between 10x and 20x. The situation here is that you are in open daylight, and if you enlarge too much the daylight will wash out the projected image. With a closed box, or inside a darkened room or with a cloth thrown over your head, you can go up to 50x enlargement.

Assume for example 30 in. f.l. objective and desired enlargement of 15x. Table 2 shows the image will be 4-1/16 in. diameter. Then, Table 1 shows the "throw" needed for 15x enlargement using various eyepieces. With 5/8 in. eyepiece, the throw is 9-7/8 inches. This is a bit more than provided by the oat box setup, Fig. 1. However, you can get 10x easily (6-7/8 in. throw), and the



## SUN PROJECTION DATA

CAUTION: INTENSE HEAT CAN DAMAGE CEMENTED EYEPIECE LENSES — USE RAMSDEN OR HUYGENS, ESPECIALLY WHEN (1) SUN IS BRIGHT, OR (2) OBJECTIVE IS OVER 3" DIAMETER

TABLE 1 - EYEPIECE TO SCREEN DISTANCE (THROW)

| PROJECTION MAG. | EYEPIECE FOCAL LENGTH 1/4"* | 1/2" | 5/8" | 3/4" | 7/8" | 1" | 1 1/4" |
|---|---|---|---|---|---|---|---|
| 5x | 1 1/2" | 3" | 3 3/4" | 4 1/2" | 5 1/4" | 6" | 7 1/2" |
| 10x | 2 3/4 | 5 1/2 | 6 7/8 | 8 1/4 | 9 5/8 | 11 | 13 3/4 |
| 15x | 4 | 8 | 9 7/8 | 12 | 13 7/8 | 16 | 20 |
| 20x | 5 1/4 | 10 1/2 | 13 | 15 3/4 | 18 1/4 | 21 | 26 1/4 |
| 30x | 7 3/4 | 15 1/2 | 19 1/4 | 23 1/4 | 27 | 31 | 38 3/4 |
| 40x | 10 1/4 | 20 1/2 | 25 3/8 | 30 3/4 | 35 3/4 | 41 | 51 1/4 |
| 50x | 12 3/4 | 25 1/2 | 31 5/8 | 38 1/4 | 44 3/8 | 51 | 63 3/4 |

*WILL NOT COVER FULL DIAMETER OF SUN

TABLE 2 - DIAMETER OF SUN IMAGE

| OBJECTIVE F.L. | PRIMARY IMAGE | PROJECTED IMAGE 5x | 10x | 15x | 20x | 30x | 40x | 50x |
|---|---|---|---|---|---|---|---|---|
| 20" | .180" | 7/8" | 1 13/16" | 2 11/16" | 3 5/8" | 5 7/16" | 7 3/16" | 9" |
| 30" | .271 | 1 3/8 | 2 3/4 | 4 1/16 | 5 7/16 | 8 1/8 | 10 7/8 | 13 9/16 |
| 40" | .361 | 1 13/16 | 3 5/8 | 5 7/16 | 7 1/4 | 10 7/8 | 14 1/2 | 18 1/16 |
| 45" | .405 | 2 | 4 1/16 | 6 1/16 | 8 1/8 | 12 3/16 | 16 3/16 | 20 1/4 |
| 48" | .432 | 2 1/8 | 4 5/16 | 6 1/2 | 8 5/8 | 13 | 17 1/4 | 21 5/8 |
| 50" | .451 | 2 1/4 | 4 1/2 | 6 3/4 | 9 | 13 1/2 | 18 | 22 1/2 |
| 60" | .541 | 2 11/16 | 5 7/16 | 8 1/8 | 10 13/16 | 16 1/4 | 21 5/8 | 27 |
| 70" | .631 | 3 1/8 | 6 5/16 | 9 1/2 | 12 5/8 | 19 | 25 1/4 | 31 1/2 |

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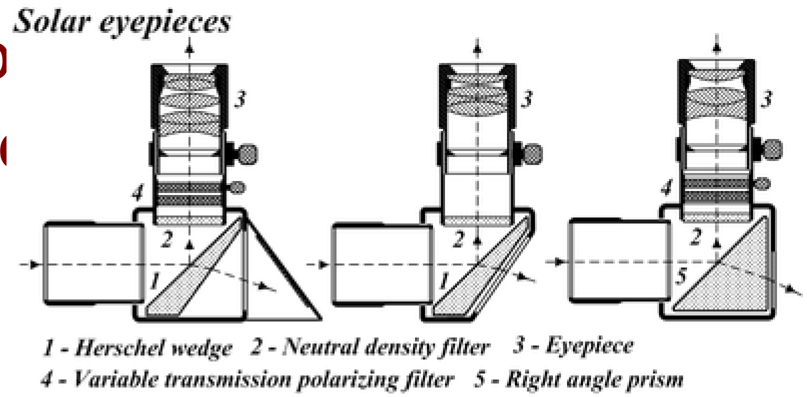
*All about Telescopes*, Sam Brown, 1967, Edmund Scientifics

# *Background*

- For a long time, the affordab amateurs for solar observati limited
  - Filtered direct observation
  - Eyepiece projection
  - Solar eyepieces
  - White light solar filters
- Views were less than fully satisfying
  - White light only
  - Only sunspots visible
  - No prominences, granulations, plages or other phenomena




Glass Solar Filter


Mylar White Light Solar Filter

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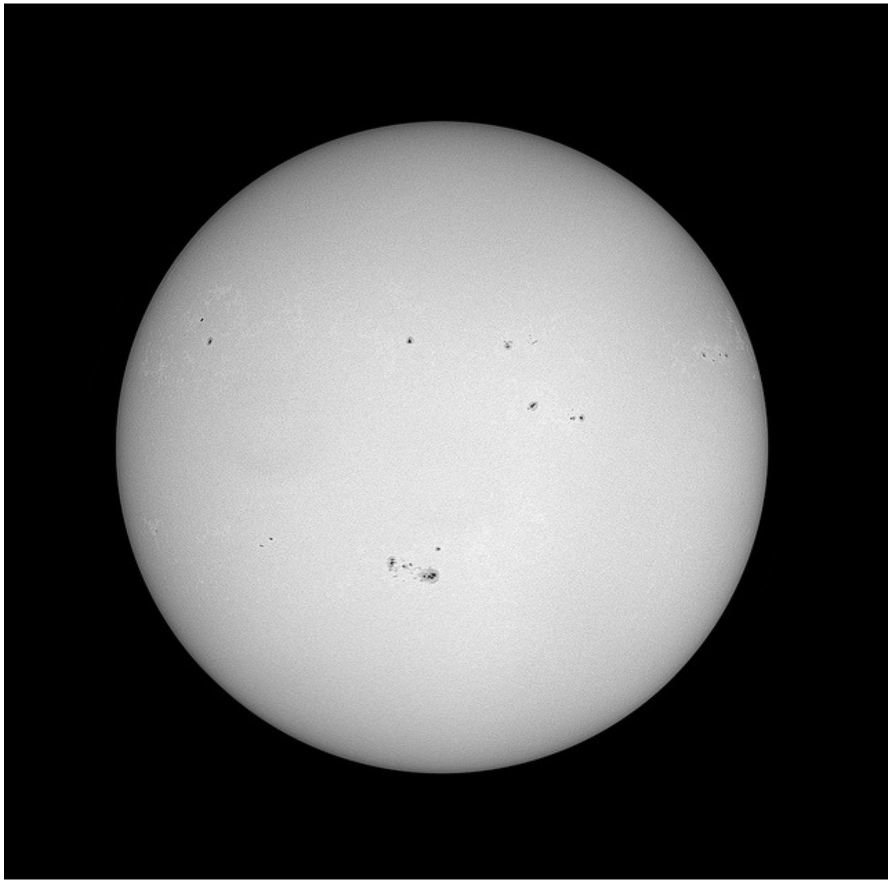
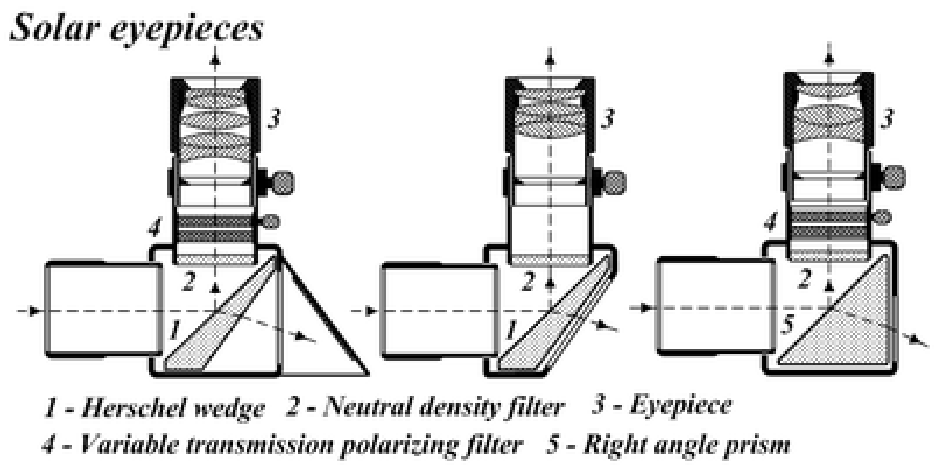


# Herschel Wedge

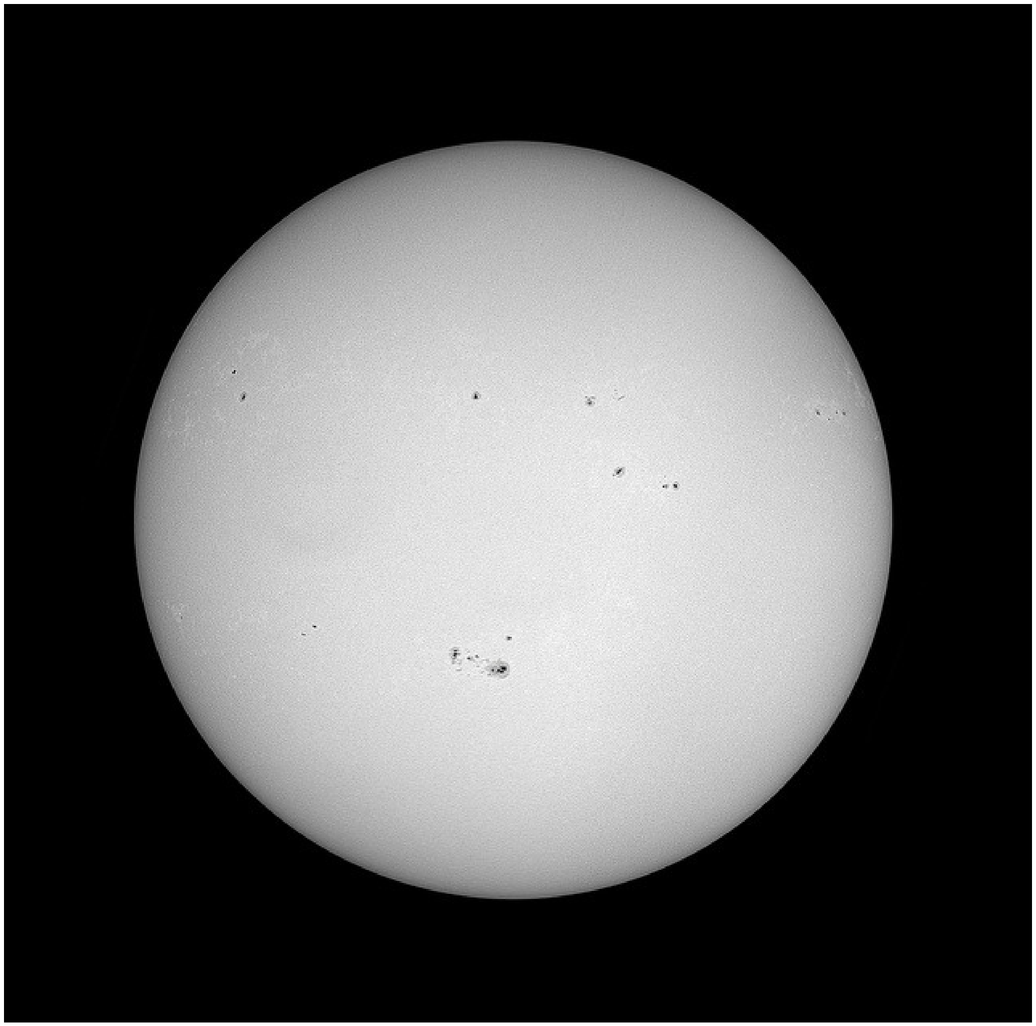
- Herschel wedge is a prism used for solar observation
  - Refracts most light out of the optical path, allowing safe visual observation
  - Surface acts as a diagonal mirror, reflecting about 5% of light to the eyepiece
  - The remaining 95% excess light & heat is dispensed through the back of the diagonal
- Does not affect visible spectra
  - Provides alternative to "white light" filters, which do block certain frequencies




- Limitations
  - Even at 5%, sunlight is still too strong and must be filtered
  - Cannot be used with reflecting telescopes
    - Reflectors concentrate UV & IR, which will crack optical elements
  - Not widely used today

Source: http://en.wikipedia.org/wiki/Herschel_Wedge

# *Our view of the Sun once looked like this*



Source: http://sungazer.net/ha/ha3.html

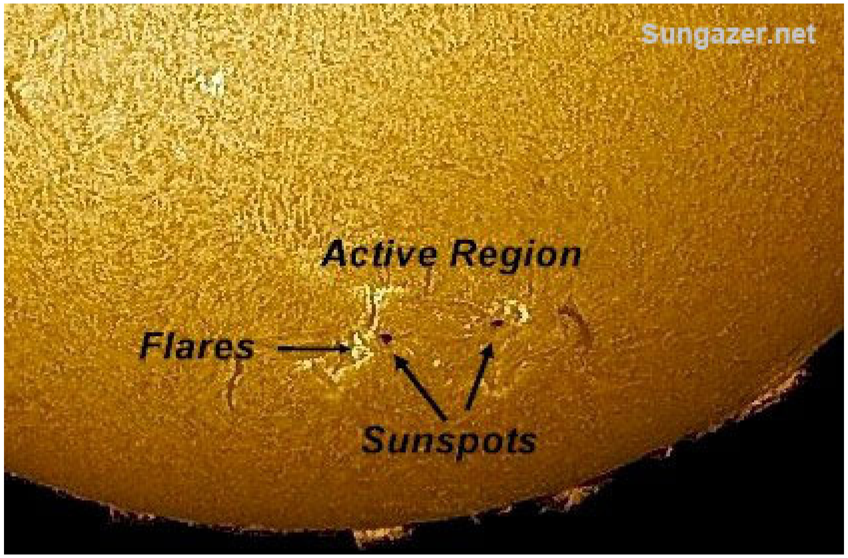
# *A Hundred Year Old Technology* ***Reapplied***

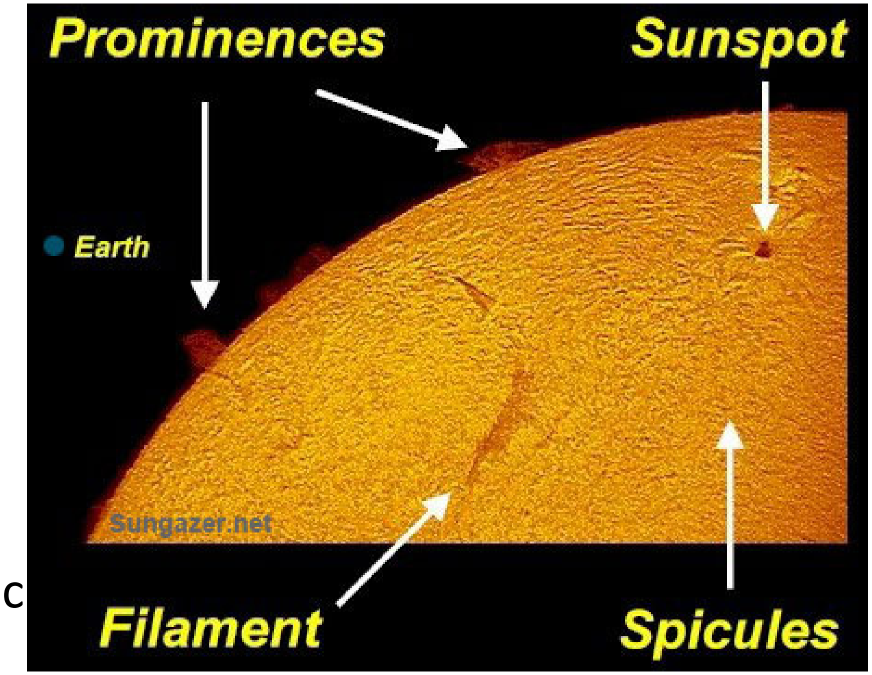
**The advent of reasonably priced tunable *Hydrogen alpha etalons* based on the Fabry-Pérot interferometer changed all that!**

Source: Meade.com

Source: LuntSolarSystems.com

# A Hundred Year Old Technology Reapplied



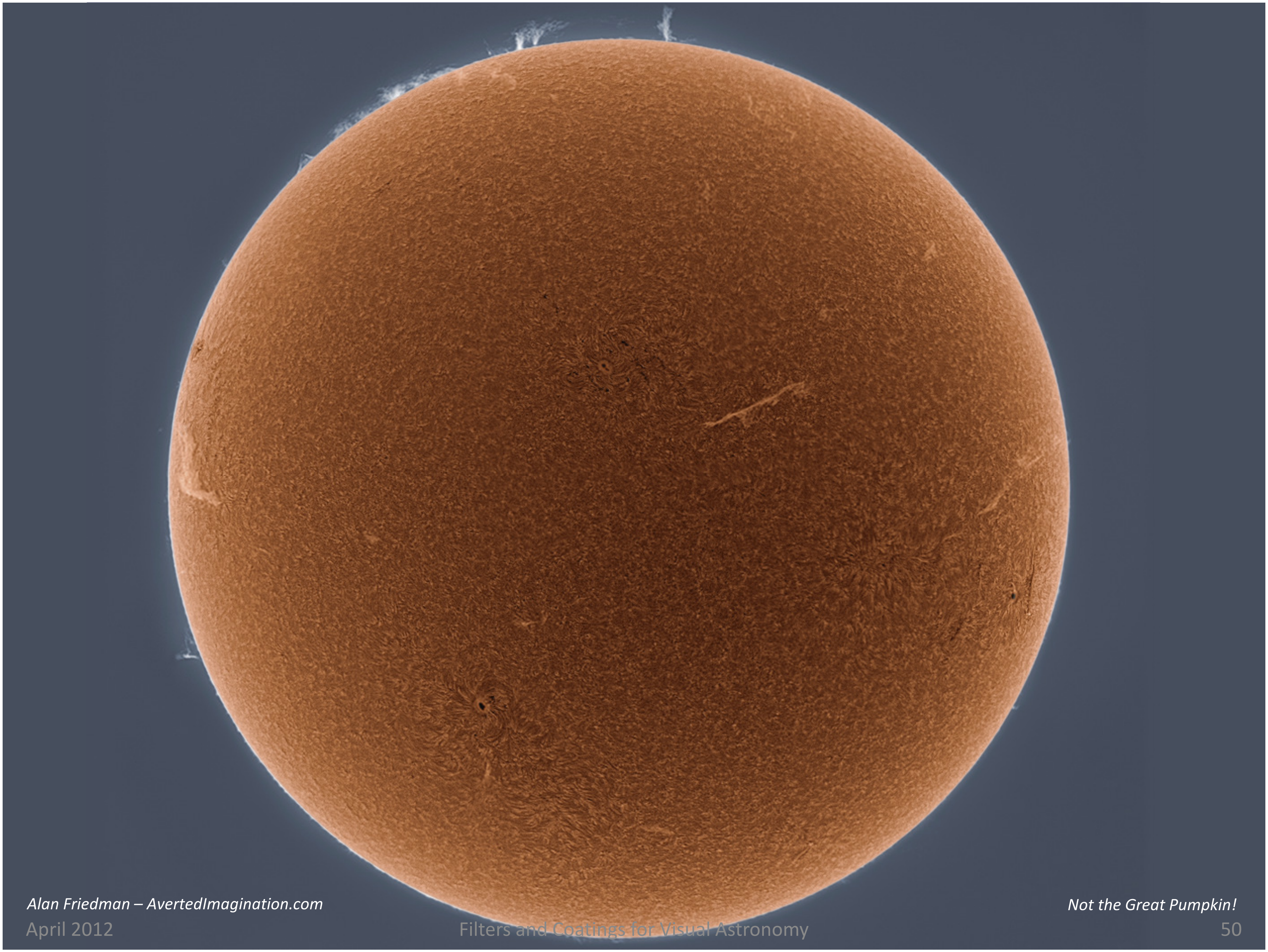

- **Sunspots** – Locus of intense magnetic activity that inhibits convection
- **Prominences** – Clouds of ionized gas
- **Filaments**– prominences seen from above
- **Active Regions** – wide areas of noticeable solar magnetic activity
- **Flares** – Violent releases of energy
- **Plages** – Bright features near sunspots
- **Surges** – Vertical ejection during flare
- **Sprays** – Explosive ejection during flare
- **Granules** – Plasma convection currents

Source: http://sungazer.net/ha/ha3.html

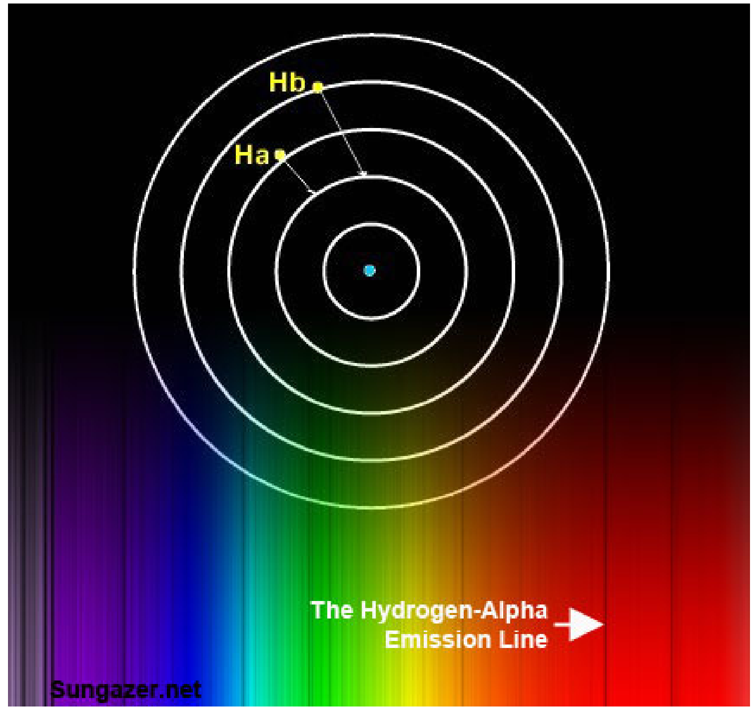

Source: LuntSolarSystems.com


*Alan Friedman – AvertedImagination.com*

*Not the Great Pumpkin!*


Alan Friedman – AvertedImagination.com
Not the Great Pumpkin!

# *Hydrogen Alpha Emissions*




- The Sun's chromosphere is red because hydrogen atoms emit energy in the red portion of the visual spectrum
- When a hydrogen nucleus emits energy, the electron moves downward and produces an emission line
- Electrons jumping from the 3rd to the 2nd orbit produce the Hydrogen alpha emission line at 656.3 nanometers; **hydrogen-alpha etalons let us see that light**
  - Electrons jumping from the 4th to the 2nd orbit produce the **Hydrogen beta** (**Hb**) emission line at 486.1 nanometers (cyan)
  - The **Horsehead Nebula** in Orion, the **Cocoon Nebula** in Cygnus, and the **California Nebula** in Perseus are best seen with **Hb** filters

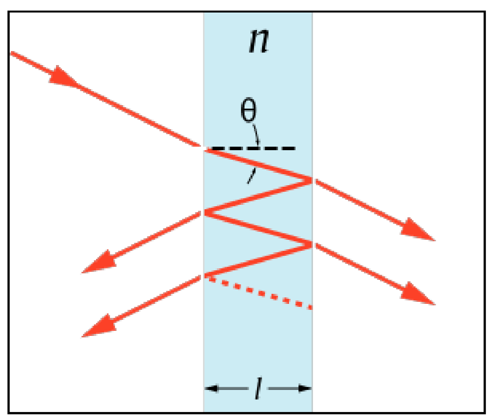
Source: sungazer.net

# *Fabry – Pérot Interferometer*

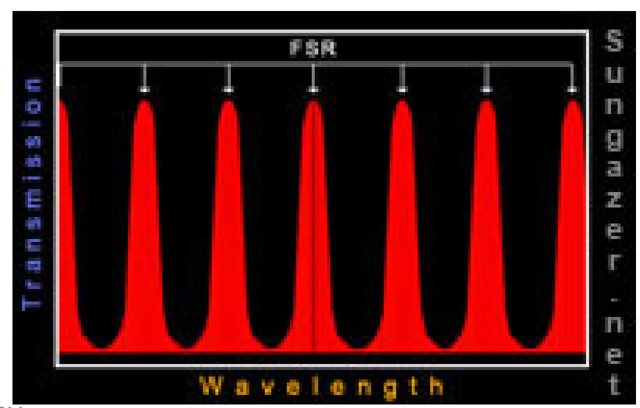
- The Fabry-Pérot interferometer, based on Charles Fabry's theory of multi-beam interference, was constructed by Fabry and Alfred Pérot in 1897-99
- The device consisted of two parallel glass plates, coated on their facing surfaces with thin silver films
  - A light beam passing through the first plate was trapped between the plates and reflected back & forth many times
  - At each reflection, a small fraction of the incident beam escaped through the $2^{nd}$ plate
  - For rays that were in phase, constructive interference caused a transmission peak to be formed
  - If out of phase, a null was formed
  - Created a "comb" of frequencies

Charles Fabry　　Alfred Pérot

- Whether the transmitted rays are in or out of phase depends on wavelength, angle of entry, etalon thickness, and refractive index of the separating material




Fabry–Pérot Etalon




Source: CloudyNights.com & http://en.wikipedia.org/wiki/Etalon

# *Charles Fabry*

- Born in Marseille, France
  - Educated at Ecole Polytechnique in Paris
- Interest in astronomy acquired while observing the night sky with his two brothers
- Doctoral dissertation on the theory of multibeam interference phenomena
  - Treated as early as 1831 by George Airy of Airy disk fame (stellar diffraction disk)
- Served as foundation for later development of Fabry – Pérot Interferometer
- **Charles Fabry is not as well known today as he deserves to be**
  - Fabry published 197 scientific papers, 14 books, and 100+ other articles
  - He received the Rumford Medal from the Royal Society of London in 1918
  - He received the Henry Draper Medal from the National Academy of Science in 1919 and the Benjamin Franklin Medal from the Franklin Institute in 1921
  - In 1927 he was elected to the French Academy of Sciences

Charles Fabry
1867 - 1945

Source: http://www.neafsolar.com/bb/etalon.html

# *Alfred Pérot*

- Born in Metz, France
  - Educated at Lycee, Nancy & Ecole Polytechnique
  - Doctorate, University of Paris
- Early research in electromagnetic theory
- Their interferometer became the first of several collaborations with Fabry
  - Fabry handled theory, planning, and calculations
  - Pérot provided design & construction of the device and instrumentation
- **Pérot's design skills were crucial to success of the interferometer device**
- Pérot later succeeded Henri Becquerel at the Meudon Obervatory near Versailles
  - He devoted much of his career to solar physics and use of the interferometer in study of astrophysics
  - Attempted to verify the gravitational redshift predicted by relativity but was not successful

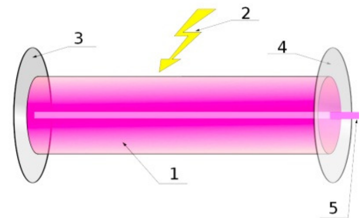
Alfred Perot
1863 - 1925

- Pérot made contributions to the triode vacuum tube & telegraphy

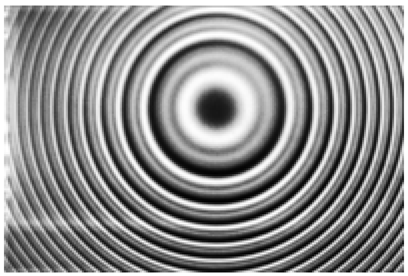
Source: http://www.neafsolar.com/bb/etalon.html

# *Uses of Fabry – Pérot Interferometers*

- Today, etalons are widely used in telecommunications, lasers, and spectroscopy to control and measure wavelengths of light
  - “Etalon” is taken from the French *etalon*, meaning “measuring gauge” or “standard”
  - “Etalon” and “interferometer” are used somewhat interchangeably



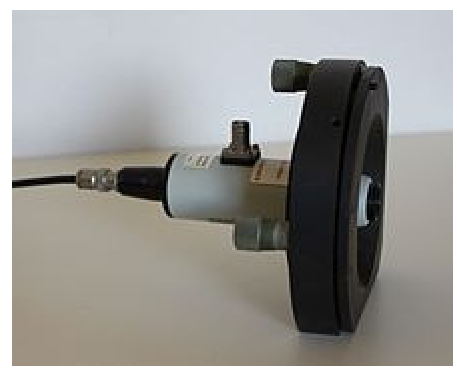

*__Laser components:__*
1. Gain medium
2. Laser pumping energy
3. High reflector
4. Output coupler
5. Laser beam



Interference fringes from a Fabry–Pérot etalon

- Etalons contain a semi-transparent solid plate with two reflecting surfaces (e) or two mirrors (i) that exhibit multiple peaks of transmission corresponding to the resonance of the etalon

- Advances in fabrication methods have enabled affordable production of very precisely ***__tunable__*** Fabry–Pérot etalons that pass the *hydrogen alpha* frequency

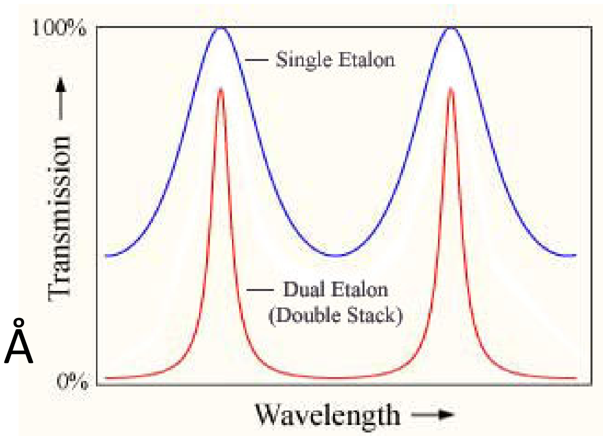


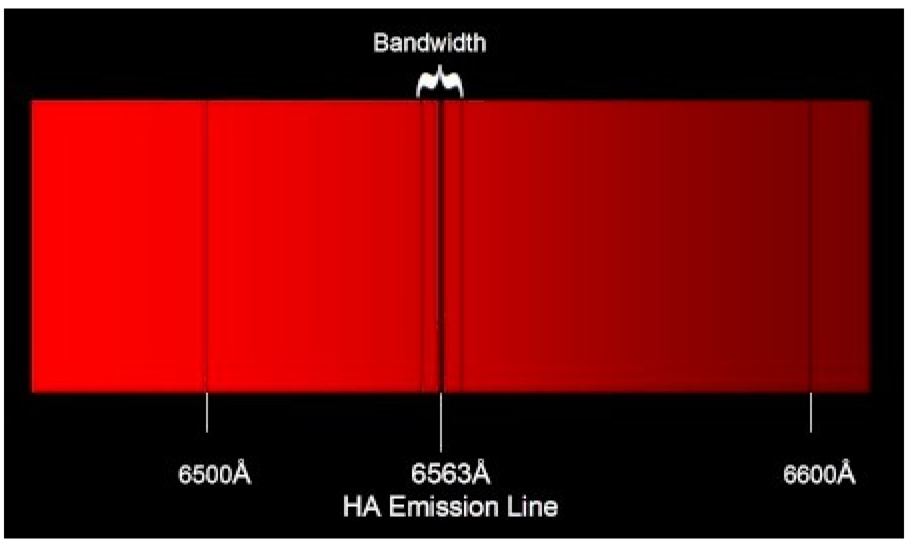
Commercial Fabry-Pérot Device

Source: Wikipedia.com

# Hydrogen Alpha Filters

- Ha filters are rated by their **bandwidth**, or how much of the spectrum they cover of the Hydrogen alpha emission line
- A filter with a bandwidth of 2Å may only show prominences but a 1Å filter (which is considered narrowband) will show prominences and surface detail
- The narrower the bandwidth, the greater the contrast and the more detail visible, but the higher the price.
  - Typical Ha scopes have a bandwidth of ~.7Å
  - Double stack etalons reduce bandwidth to ~.5Å



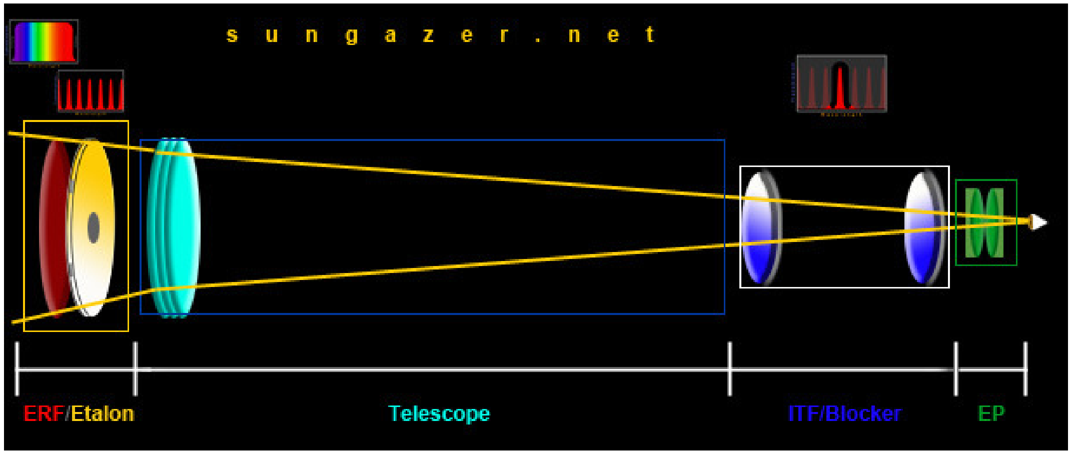

- Different solar features, such as prominences, granulations and sunspots, have slightly different ***Doppler shifts***; therefore the etalon must be **tuned** to make them visible

Source: SunGazer.net/ha/ha1.html

# H-alpha Solar Scope Component

- Hydrogen alpha telescopes consist of several components
  - **Energy rejection filter**
    - Rejects IR and UV
  - **Etalon**
  - Objective lens
    - Achromatic objective not necessary since single Ha frequency is sought
  - **Telecentric component**
    - If etalon is rear-mounted *
  - **Induced Trans. Filter & final ER blocker filter**
    - Allows only Ha to pass
  - Diagonal
    - Optional
  - Eyepiece
    - Custom eyepiece not needed

- The etalon may be either **front-mounted** or **rear-mounted**
  - * If the etalon is rear-mounted, a **telecentric component** is required to "straighten" the light beam coming from the objective lens



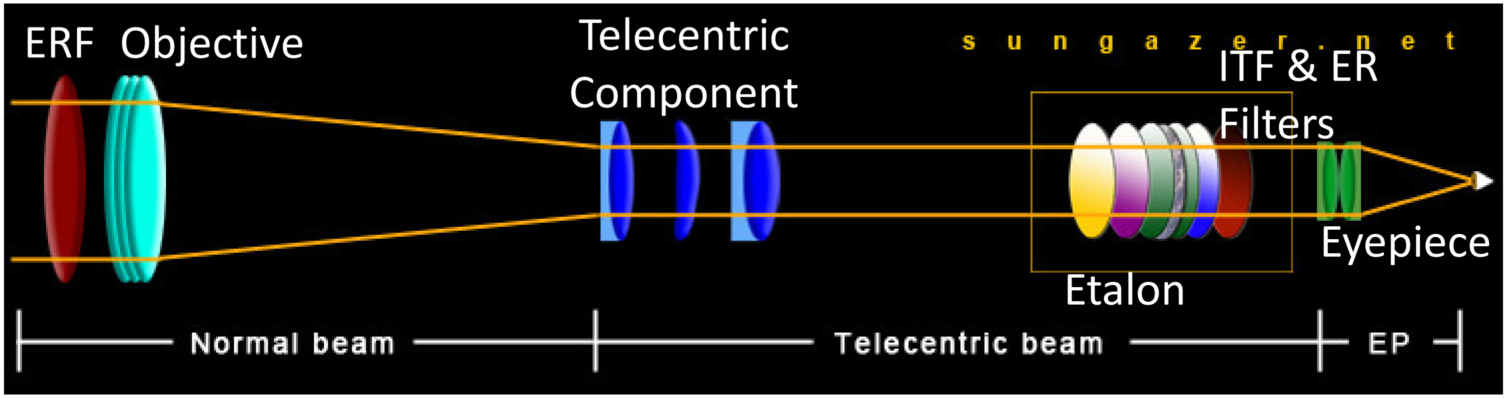

**Front-mounted etalon**

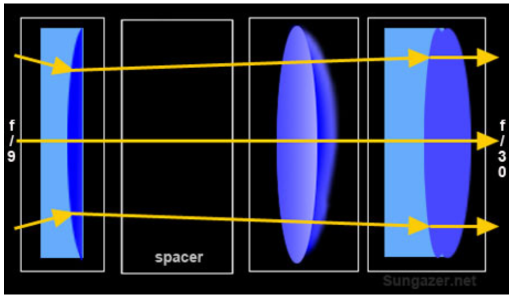
Components in **red** reduce solar radiation reaching observer's eye


Source: SunGazer.net/ha/ha1.html

# *H-alpha Solar Scope Components*

- The first thing a light ray hits in an Ha system is an **Energy Rejection Filter** or ERF.
- ERF's are usually made of red glass that is polished optically flat.
- The ERF blocks unwanted ultraviolet and infrared wavelengths.
- The ERF protects the **etalon filter** from deteriorating and stops heat buildup from knocking the etalon off band.
- The diagram below illustrates a **rear-mounted etalon** design

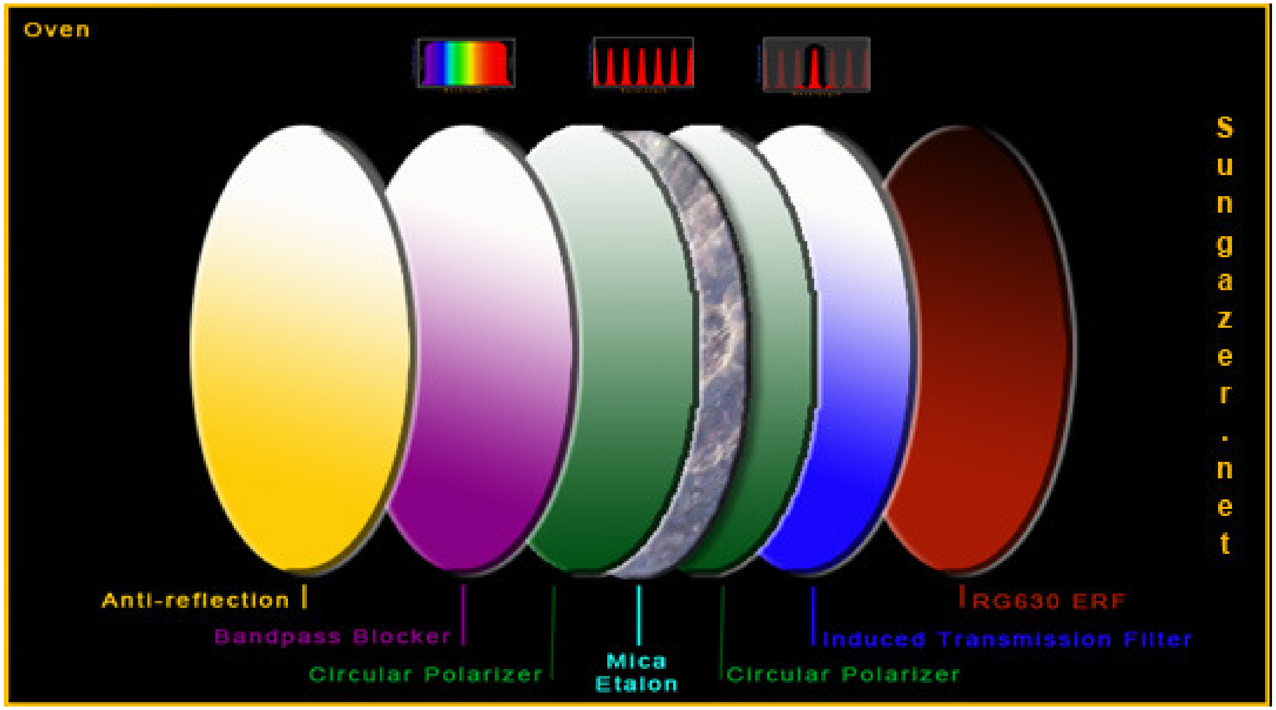



- Light must strike the etalon at a perpendicular or normal angle of incidence for the etalon to work properly.
- In a rear-mounted design, a combination of lenses in the ***telecentric position*** is used to straighten the rays.

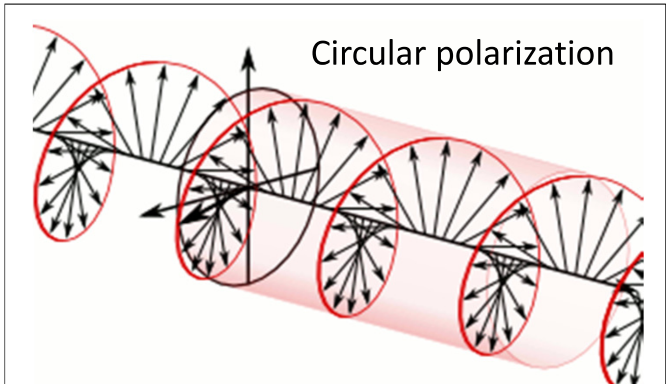

Source: SunGazer.net/ha/ha1.html

# Etalon Components




According to Sungazer.net, this diagram is a representation of a DayStar H-alpha etalon

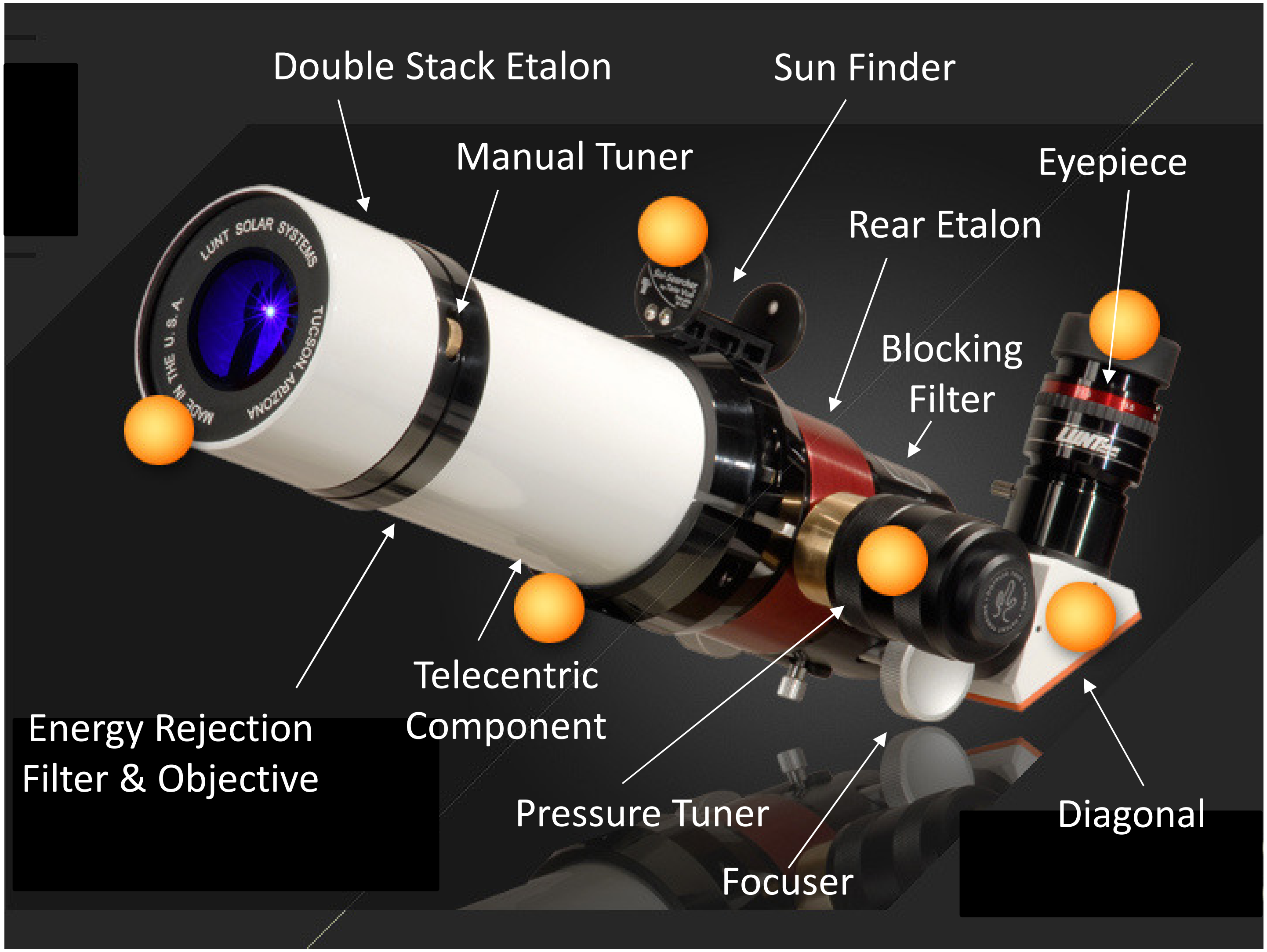
- Anti-reflection filter
- Bandpass blocker
- Circular polarizer
- Etalon (in this case, mica)
- Circular polarizer
- Induced transmisssion filter
- RG630 Energy rejection filter




Polarization sharpens transmission peaks

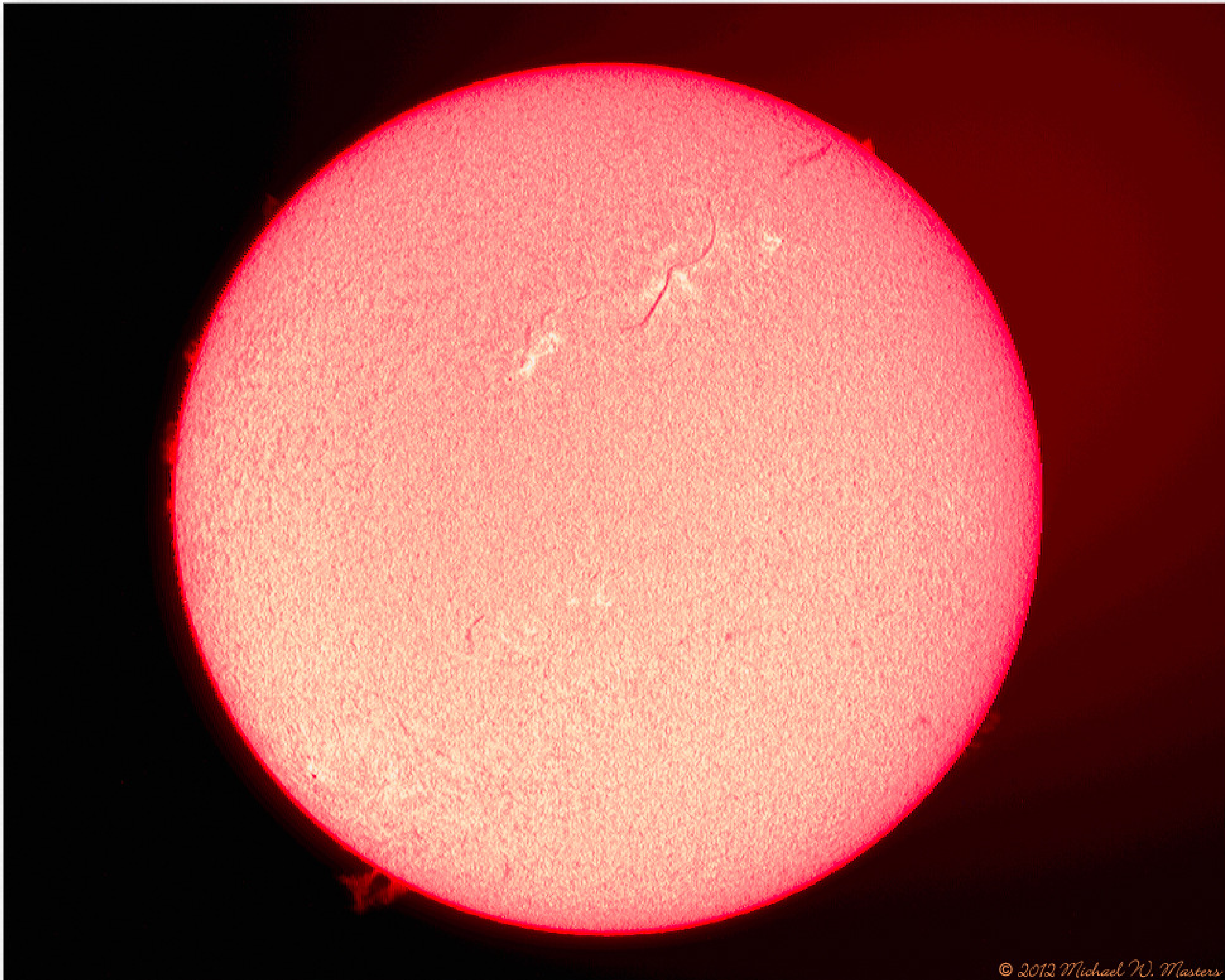
Source: SunGazer.net, DayStar Filters & http://en.wikipedia.org/wiki/Polarizer

# *Anatomy of a Solar Scope*




Orange balloons are Lunt feature mouse-overs

Source: LuntSolarSystems.com



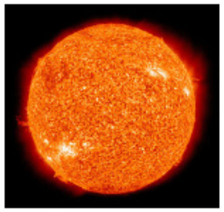
# Fact sheet for RAC outreach solar programs

**http://raclub.org/ Documents/Papers/ Fun Sun Facts.pdf**

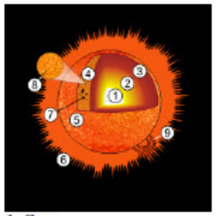
**Page 1 of 2**

## Fun Sun Facts!

Facts and Figures



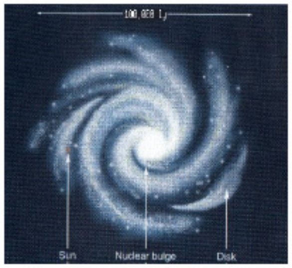
- Diameter: 865,000 miles (109 times diameter of the Earth).
- Mass: 330,000 times mass of Earth (99.86% of the mass of the solar system).
- The Sun rotates in 25.6 days at the equator and 33.5 days at the poles.
- Earth-Sun distance: 93,000,000 miles (also called one astronomical unit).
  - Earth-Sun distance was first estimated by Aristarchus of Samos, 310-230 BC!
- The Sun does not have a solid surface but is composed of hot gas and plasma.
- The Sun's surface temperature is 9940° F.
- About 3/4 of the Sun's mass is hydrogen and most of the rest is helium; less than 2% is heavier elements.
- The Sun generates energy by fusing hydrogen nuclei into helium.
  - Equivalent of 4.3 million tons mass-energy are produced each second – $9.1x10^{10}$ megatons of TNT!
- The Sun is composed of many layers: core, radiative zone, convective zone, photosphere, chromosphere, corona, magnetic field.



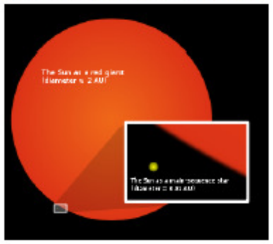
**1. Core**
**2. Radiative zone**
**3. Convective zone**
**4. Photosphere**
**5. Chromosphere**
**6. Corona**
**7. Sunspot**
**8. Granules**
**9. Prominence**

The Sun's Place

- The Sun is a type-G (yellow-white) main sequence star and, while not large, is brighter than 85% of the stars in the Milky Way, most of which are red dwarfs.




- The Sun is located 25,000-28,000 light years from the center of the Milky Way, which is 100,000 light years in diameter.
- The Sun was formed about 4.57 billion years ago when a hydrogen molecular cloud collapsed, possibly due to a nearby supernova explosion.
- The Sun is a Population I or metal-rich star, meaning that the Sun formed from a nebular cloud rich in heavy elements produced by early supernovae, elements needed for the formation of planetary systems.
- The Sun is in the galactic habitable zone: close enough to the center to be rich in heavy elements and far away enough to avoid high-frequency radiation from the central super massive black hole.



- The Sun is not massive enough to collapse at the end of its life and explode as a supernova. Instead, in about 5 billion years it will end as a white dwarf.
  - First, the Sun will enter a red giant phase. As the hydrogen in the core is consumed, the core will contract and heat up and helium fusion will begin, producing carbon. As a result, the outer layers will expand, forming a red giant.

- Eventually the Sun's outer atmosphere may reach beyond Earth's orbit. Internal thermal instability and pulsations will cause the Sun to throw off its outer layers, forming a planetary nebula and exposing the central hot core.
- The remnant hot core will no longer be able to support nuclear fusion and will slowly cool and fade over many billion years, leaving a white dwarf composed largely of carbon.

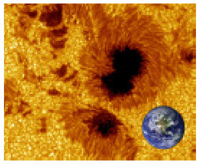
Source: Wikipedia.com

# Fact sheet for RAC outreach solar programs

**http://raclub.org/Documents/Papers/Fun Sun Facts.pdf**

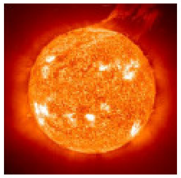
**Page 2 of 2**

**NEVER OBSERVE THE SUN WITHOUT PROPER EQUIPMENT AND SUPERVISION BY AN EXPERIENCED OBSERVER. FAILURE TO USE SUITABLE EQUIPMENT WILL RESULT IN IMMEDIATE AND IRREVERSIBLE EYE DAMAGE.**

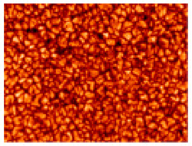


Observable Solar Phenomena

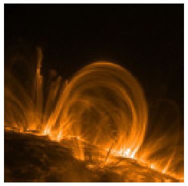
- **Sunspots & Plages** – Sunspots are relatively cool regions of intense magnetic activity, visible as dark spots compared to nearby regions of the Sun. They are cooler because the magnetic activity inhibits convective activity near the sunspot. Conversely, bright high temperature regions are called plages. Sunspots can be as large as 50,000 miles across, and can sometimes be seen with the naked eye if the Sun's light is attenuated by heavy haze, especially near sunrise or sunset. Sunspot minimums and maximums follow an 11 year cycle. The earliest surviving record of sunspot observation dates from 364 BC, by the Chinese astronomer Gan De.



- **Prominences** – Prominences are large, bright features extending outward from the Sun's photosphere in the shape of giant flares or coronal loops. A typical prominence extends over many thousands of miles and may appear to detach from the photosphere and hover above the Sun.
- **Granulations** – Solar granulations are caused by convection currents (i.e. thermal columns) of hot plasma within the Sun's convective zone. The grainy, boiling appearance of the solar photosphere is produced by the tops of these convective cells. A typical granule has a diameter of 500 miles or more and lasts 8 to 20 minutes. Some can be up to 15,000 miles in diameter and last for 24 hours.



Hydrogen Alpha Solar Telescopes



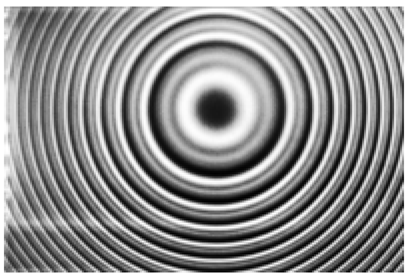
- The Sun may be safely observed through specially built solar telescopes that transmit a single frequency of light, the hydrogen alpha line at 6562.8 angstroms, visible in the red part of the spectrum.
  - This frequency is a primary emission source for the Sun, and many of the Sun's features – such as sunspots, prominences and granulations – are visible in the H-alpha frequency.
- Solar telescopes employ a **Fabry–Pérot etalon**, a technology invented in 1899. The etalon drastically attenuates solar energy by a process called interference. The etalon is augmented by an energy rejection filter that removes harmful UV and IR frequencies. Finally, a blocking filter built into the right angle diagonal allows only the single H-alpha wavelength to pass through the telescope, rendering the view through the solar telescope safe for human observation. The bandpass of these telescopes is approximately 0.7A. For a good tutorial, visit: http://www.sungazer.net/ha/ha1.html.


- Several companies manufacture solar telescopes based on the Fabry–Pérot etalon technology. Since the underlying technology is similar, no brand is recommended over any other, and a decision to purchase can be based on cost, convenience, ease of use, build quality, accessories, features, etc.
  - Before purchase, consult with any of the many reputable merchants who specialize in quality astronomy gear. For more information, contact your local astronomy club.
- **A solar telescope should never be used without ALL of its components since each component is an essential part of the observing protection that the telescope provides.**
- **A solar telescope should never be disassembled or repaired by the owner. All repairs and upgrades should be performed by a qualified factory technician and with factory specified parts; else the telescope will no longer perform as it was designed to do.**

Sources: Wikipedia.com
SunGazer.net

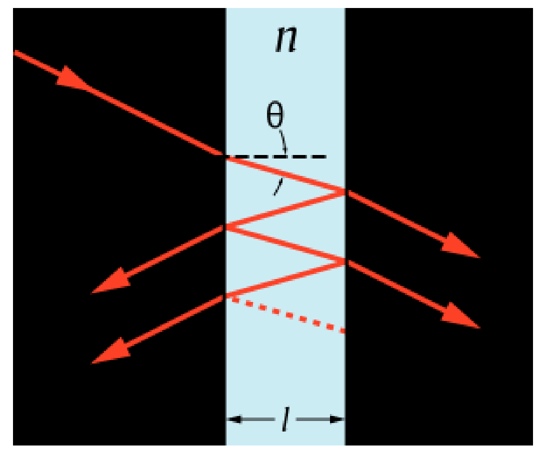
# Hydrogen Alpha Solar Filters

- The Fabry-Pérot etalon used in today's Hydrogen Alpha solar scopes was invented in 1899 by Charles Fabry and Alfred Pérot
  - "Etalon" is taken from the French *etalon*, meaning "measuring gauge" or "standard"



Interference fringes from a Fabry–Pérot etalon

- Typically the etalon consists of a transparent plate structure with two reflecting surfaces that exhibit multiple peaks of transmission corresponding to the resonance of the etalon




A Fabry–Pérot etalon. Light enters the etalon and undergoes multiple internal reflections.

- Etalons are used in lasers, spectroscopy and telecommunications to control and measure the wavelengths of light
- Recent advances in fabrication techniques have enabled the creation of very precise ***tunable*** Fabry–Pérot etalons

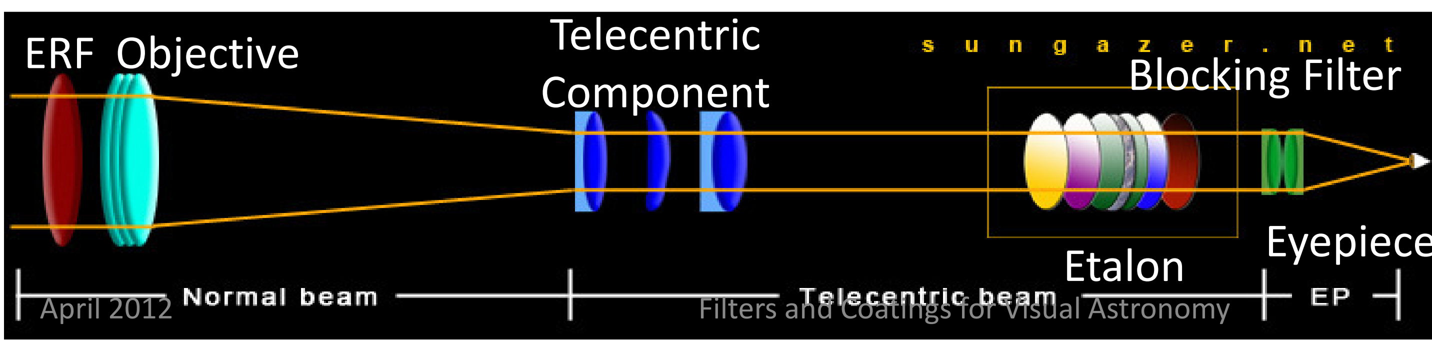
Tutorial for RAC solar programs – http://raclub.org/Documents/Papers/How Ha Solar Telescopes Work.pdf

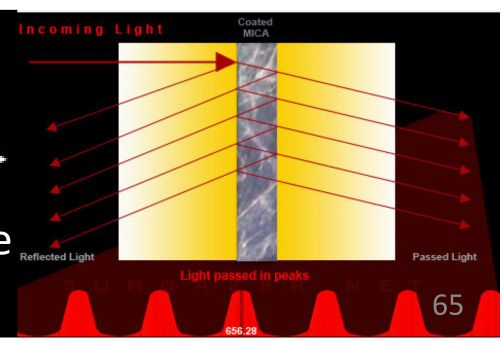
Source: Wikipedia.com

# *Hydrogen Alpha Telescope Components*

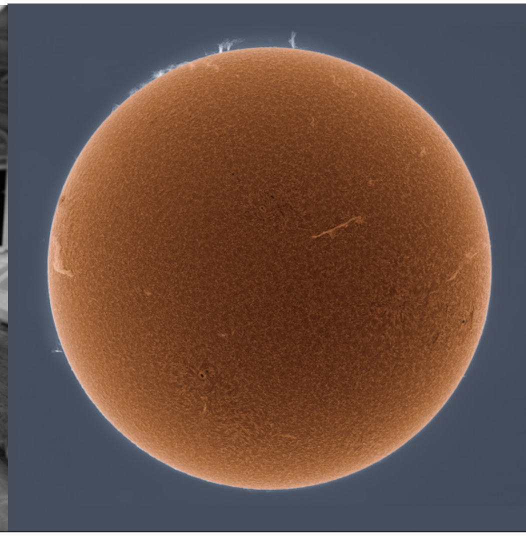
- The first thing a light ray encounters in a Hydrogen Alpha solar telescope is an **energy rejection filter** or **ERF**
  - **The ERF blocks unwanted ultraviolet and infrared wavelengths**
- The next component, the **telescope objective**, focuses the Sun's light
- After light passes through the telescope in a rear mounted design, it must be straightened prior to striking the etalon by a **telecentric** component, which acts like a Barlow lens
- The key component, the **etalon** produces a "comb-like" filtering effect on the incoming light, allowing only multiples of a certain frequency to pass
- The etalon has a **tuning mechanism** to allow slight frequency shifts
- A final **blocking filter** removes all of the remaining frequency peaks except the desired Ha frequency
  - The blocking filter also attenuates incoming amplitude
- As with all telescopes, the **eyepiece** magnifies the solar image
  - Contrary to advertising claims, special eyepieces are not needed!

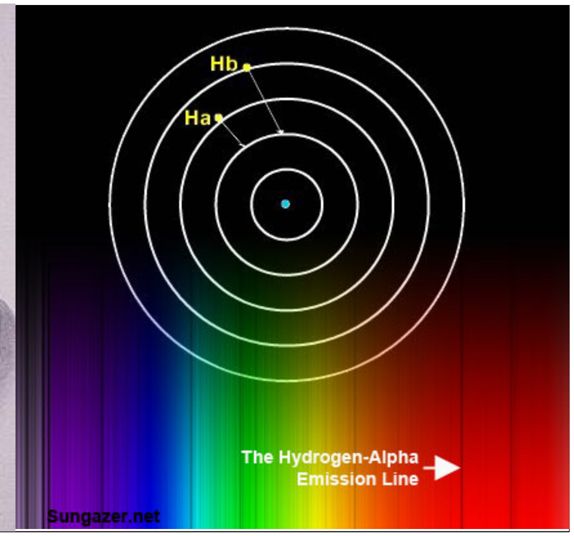
Source: SunGazer.net



# *Questions & Answers*

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[Reference: http://www.copyright.gov/fls/fl102.html, May 2009]

**Never point a telescope at the sun**
**– unless it's a solar telescope, of course!!**
**. . .and don't look into the laser pointer either!!**

# References


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- http://en.wikipedia.org/wiki/Astronomical_filter
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