SPECTROHELIOSCOPE DESIGNS

Fredrick N. Veio, 2001

Introduction

A variety of technical facts will be discussed in order to understand how to build a spectroheliosсope (SHS). This is a condensation of my book of 119 pages, some of which are mentioned in these pages. It is not necessary to have high precision parts. There are tolerances in many dimensions and in many optical adjustments. Do not be obsessed with exactly this or exactly that. All major events on the solar disk are easily studied. Read these pages very slowly; there is much meaning in them.

Prototype: The writer made a successful prototype in 1964. It was published in Sky and Telescope magazine, January of 1969. It was low cost, portable and compact. The telescope was 2.7 meters f.l., and the spectroscope was 1.9 meters f.l. The lenses were made by the writer. It was later realized that long focal length concave mirrors and commercial achromats can be used instead of lenses. Apogee and Sky Instrument (USA) sell such reasonably priced achromats.

Mutual F-ratios: A grating of 90% theoretical resolution with a ruled area of 32x30mm has a diagonal about 42mm. The spectroscope lens or mirror should be about 50mm diameter. The F-ratio is 42mm divided into 1.9 meters f.l., or about F:44. The F-ratio of the telescope and the spectrscope must be about the same so that the ruled area of the grating will be filled 100% with sun light in order that the full resolving power of the grating be utilitzed, namely get about 0.2A. But a grating about 90% illuminated will work very good. It is not critical for H alpha work with a passband of 0.6A. A telescope of 2.7 meters fl. will produce a 25mm diameter sun image at the entrance slit.

SHS Designs

The following designs use concave mirrors of spherical shape, also other optics. Assume 1/8 wave on the wave front correction for spherical aberration at infinity focus. This is equal to 1/15 wave at the ROC.

Design A:

<u>Telescope</u>: one concave mirror of about 76mm diameter, 2.7 meters f.l. approximately, used slight off-axis (Hershel telescope design).

<u>Spectroscope</u>: two concave mirrors 62 to 76mm diameter, 1.9 meters f.l. approx., both do not have to be exactly the same focal length.

<u>Grating</u>: 50mm blank with 32x30mm ruled area, 1200gr/mm, 5000A (green) or 6000A (orange-red) blazed wavelength in the first order. Heliostat: diagonal with minor axis about 76mm, 1/8 wave flat. Young solar image synthesizer (page 108 to 109), knodding diagonals with minor axis about 25mm, 1/8 wave flat. In the spectroheliosсope mode, equivalent eyepower is about 22X, barely see 5 arc/sec solar disk detail in H alpha light. Entrance slit about 125 microns for 0.5A passband.

Design B:

Telescope: about 80/1300 to 90/1300mm achromat, used with a 2X Barlow (-250mm f.l., or more so). Even an 80/1000mm achromat with an adjusted 2.5X Barlow is workable.

Spectroscope: two concave mirrors 62 to 76mm diameter, 1.9 meters fl.

Grating: 32x30mm ruled area, 1200 gr/mm. Heliostat: 80 to 90mm minor axis diagonal. Young synthesizer. SHS mode, about 22X eyepiece, 5 arc/sec detail. Slits 125 microns.

Design C:

Telescope: about 80/1300mm achromat with 2X Barlow.

Spectrosocpe: one single concave mirror, spherical shape, about 150 to 160mm diameter, about 1.9 meters f.l.(Ebert design). Young synthesizer. SHS mode, 22X, 5 arc/sec detail. Slits 125 microns. Other optical variations are possible too. Keep the focal lengths as long as possible.

Notes:

1. Concave mirrors about F:25, used slightly off-axis, will give a sharp image. Reference: *Sky and Telescope* magazine, September, 1958. As long as the off-axis aberrations are within the Airy disk itself, this gives the almost equivalent of using the concave mirror on-axis.
2. All concave mirrors and achromats should be evaluated using a Ronchi test to be sure that spherical aberration is 1/8 wave or better. Willmann-Bell sells Ronchi rulings on stiff film, 50x50mm, three spacings (65, 85, 133 lines per 25mm). Each is $3.50. Mount it on a piece of good quality optical window glass about 50x50mm, flat about 99% is all right with tape. Three dark bands across the full diameter of the optics is 1/8 wave, which is excellent. If the ends of the bands are hooked (turned edge), just stop down the optic a bit, not critical. Edmund Scientific sells glass Ronchi rulings but they are more expensive.

Design Factors

Eyepieces: Regular telescope eyepieces will not be necessary, namely about 6mm to 25mm f.l., give much too much power, washing out any solar disk detail in a SHS mode. Short f.l. achromats or single element lenses will be quite satisfactory. For the SHS mode, use about 112mm to 135mm fl. A telescope of 2.7 meters f.l. divided by 125mm f.l. eyepiece gives 22X eyepiece for the solar disk. Shorter f.l. eyepieces, say about 50mm f.l., give too much power, washing out the solar disk detail by lowering the contrast too much. For the spectroscope mode, use about 45 to 60mm f.l., eyepiece. The solar spectrum will be seen visually in very fine detail in the first order. Tilt the grating to the second order and finer detail will be seen easily. Small achromats are favored over single element lenses because the quality is usually better, no scratches or chips, whatever. A diameter about 25mm is sufficient. The low cost achromats do not have to be tested for spherical aberration in most cases because narrow solar beams of sunlight pass through them to the eye. Short fl. achromats have about one wave of spherical aberration across the full diameter of the optic (page 83).

Resolution on the Solar Disk Detail depends upon the diameter of the solar image on the entrance slit and on the width of the entrance slit. Using a 2.7 meter fl (giving a 25mm sun image) and an entrance slit of 125 microns:

Average Resolution = slit width/ sun image x 1900 arcsec

= 0.125mm slit/ 25mm sun x 1900 arcsec

= 10 arcsec

The true resolved solar disk detail depends also upon the shape and the brightness or darkness (flare or filament) of the detail in H alpha light. Expect about 5 arcsec for conspicuous detail and about 10 arcsec for fainter detail.

Field of view: The field of view of a SHS for the solar disk is limited by the mechanical and optical design of the solar image synthesizer. For example, a sun image of 25mm (30 arc/min) with an entrance slit of 25mm length and the up/down motion of the sun image by the Young synthesizer of about 12mm gives a field of view of 30 arc/min by 15 arc/min of the sun. The whole sun will not be seen at one time with a SHS in most cases. Must keep the up/down motion to a minimum to avoid a vibration problem. Do not directly compare a SHS with other solar H alpha filter systems.

Seeing: The atmosphere seeing averages about one arc/sec. The visual SHS shows about 5 arc/sec for the solar disk. This is why a compact SHS works good most of the time. Also why other H alplha filters perform good too. Seeing scale from Sky and Telescope about 40 years ago: excellent, 1/4 arc/sec; good, 1/2 arc/sec; average, one arc/sec; fair, 2 to 3 arc/sec; bad, 5 arc/sec or worse.

Heliostat: A single flat mirror for the reflection system will need a RA total gear reduction about 2100:1 with a one revolution per minute motor. Latitude about 38 degrees. A two mirror coelostat mirror system will need 2880:1 gear ratio (page 95).

Dawe's limit: Dawe's limit, D = 4.54/aperture in inches, is for two close stars barely resolved. For sun spots Dawe's should be modified to about D s = 2.2/aperture, barely solved spot detail. For easily resolved spot detail, D s = 4.4/aperture. That is why small to medium sized telescopes give good, or better, views of the sun spots in average seeing.
Read chapter in the book Amateur Astronomers Handbook by J. Sidgwick.

Sources for gratings: Excellent gratings of 90% theoretical resolution can be obtained from Richardson Grating Laboratory and Diffraction Products, Inc., both in the USA, and also from Jobin-Yvon of France. The latter company has offices in Germany, Italy, the Netherlands, Great Britain, USA and Japan. Diffraction Products is about 10% less expensive. A few companies sell gratings of 45% theoretical resolution. They are not recommended for a SHS. They are acceptable for a small to medium spectroscope.

For example, with a 32x30mm ruled area grating, 1200 gr/mm and 90% theoretical resolution, get about 0.2A resolved in the first order. With a grating same size and 45% theoretical resolution, get about 0.4A resolved. The H alpha line has a dark core of 0.6A for a desired passband of 0.6A, and the grating should resolve about two to three times better than that, namely about 0.2A. The red of the first order over laps the violet of the second order. And the red of the second order over laps the violet of the third order. The over lapping of the orders prevents visually using the H alpha line in the second order in an efficient manner.

Grating resolution: The resolving power of a grating depends upon the width of the ruled area, grooves/mm and the order. So a 32mm ruled width x 1200 gr/mm x first order equals about 38,000 total lines. Divide the H alpha line (6563A wavelength) by 38,000 lines gives about 0.2A resolved spectral detail in the first order, or about 0.1A in the second order. You want the grating to have about three times better resolution than the passband employed. A grating 32x30mm ruled area costs about $350; 50x50mm area, about $500 or more.

Linear dispersion: The linear dispersion of a grating defines how long the solar spectrum is stretched. Examples from the violet to the red in the first order as follows. Grating 1200gr/mm.

Spectrometer Focal Length *(meters)*	**Linear Dispersion** *(A/mm)*	**Spectrum Length** *(meters)*	**H alpha 0.6A Pass** *(microns)*	**Na, He, 0.1A Pass** *(microns)*
1.9	4	1.0	150	25
1.0	8	0.50	75	12
0.5	16	0.25	37	6

In the second order (green) the linear dispersion is about 2.5 times higher, and the solar spectrum is about 2.5 times longer. The dispersion is not linear at higher orders.

A spectroscope with high linear dispersion (4A/mm) is needed to measure visually the dark core width of the spectral lines. Second order is used too. The passband to have good contrast on the solar disk: H alpha, 0.6A; green Mg, yellow Na and He, 0.1A; violet H and K lines, 3A. The human eye has poor sensitivity to violet light; must use photography or CCD. The cones of the retina are about 1.5 to 2.0 microns diameter. Film resolves about 5 micron lines. CCD pixels have about 10 microns square. The human eye works very good.

Synthesizer and Spectroscope: There are many solar image synthesizers, and each has various advantages. They can be classified into two groups: fixed slits and moving slits. With fixed slits you can use almost any optics in the spectroscope. With moving slits you must in most cases use a positive meniscus lens shape for the spectroscope in order to remove scatter light off of the lens surfaces. Sometimes a plano-convex lens is good. Just tilt the lens to the side to throw the scattered light to the side. Pick the wrong synthesizer with the wrong optics, and you will not have a properly functioning SHS. For the sake of simplicity, the Young synthesizer is recommended in the discussed SHS designs. The synthesizer mounting floats on three thin rubber pads. Also the moving parts are balanced to remove vibrations. The Young synthesizer properly made will work excellent.

Grating mounting: Some basic shop tools are needed to make all the parts for the SHS. Use common materials as wood, plastic, nuts and bolts, pieces of metal, lots of common sense. The grating mount does not require precision parts. The surface of the grating does not have to be exactly in line with the up/down axis of movement. The orientation of the grooves does not have to be exactly horizontal to the ground. Grooves of the grating and the slits do not have to be exactly parallel to each other. Not that critical at all. The grating must be tilted with a lever system, or a worm and gear, because tilting by manual means is too delicate.

Never touch the bare surface of the grating. Never clean it. Never breathe on it to remove dust. Have the grating surface mounted downward so that dust will not settle on the surface. Rarely let others handle the grating. Almost always the owner of the grating holds it, snugly with the fingers - never too tight, or too soft, lest the grating slip to the ground.

Spectroscope Slits: Do not try to make the slits for the spectroscope. You can use blades from a pencil sharpener, about 20mm long. Single edge razor blades are good. The edge of the slits do not have to be perfectly straight. The slits do not have to be exactly parallel to each other. For example, one end of the entrance slit can be about 120 microns wide and the other can be about 130 microns wide. Not critical at all. For the H alpha passband, you do not need exactly 0.5A. A tiny bit more or less will cause no problem. The slits do not have to be sharp, can be dull sharp.

To adjust the slits, have one blade fixed. The other blade is moveable with finger pressure. Firstly close the two blades a bit tight. Hold the mounted slits up to a light bulb. Look through the closed slits towards the light. Adjust one blade until it barely lets the light through the slit. This is about 10 microns in width. Move the blade a bit more so that the light comes through easily. This will be about 25 microns width. The 10 microns is best for the spectroscope mode. For wider slit widths, use metal shims, whatever, to get about 125 microns for H alpha at about 0.5A passband. The entrance and the exit slits do not have to be exactly the same. They also do not have to exactly in line with each other.

Vibrations: If the Young synthesizer vibrates about 10 microns and the slits are about 125 microns wide, you do not have a problem. If the synthesizer mount vibrates about 50 microns, the solar image will be slightly blurred. So just get rid of the vibration about 99%.

Air-Current Wall: The wall can be made of thick paper, thin metal or thin wood. It has two openings to let the sun light pass to and from the grating. Each opening has a thin optical window over it. Distance of the wall from the synthesizer is not critical. About 100mm is good. The wall prevents weak air currents to move inside the spectroscope box. The weak air currents can move the H alpha line at the exit slit and give an uneven appearance of the solar disk in H alpha light. Window glass can be flat to about two waves, about 2 to 3 mm thick, about 30mm diameter. Dimensions are not critical. The synthesizer slightly moves up and down, but the movement is enough to stir up currents in the front of the spectroscope box. Must use a wall.

Passband and focal length. For a given focal length of the spectroscope lens, there is a needed slit width in order to pass about 0.5A. A passband of 0.7A will have a bit lower contrast to solar details in H alpha light, and a passband of 0.8A a bit lower still. It is desired to have about 0.5A to 0.6A passband to maximum contrast to the solar details. This makes it easier to adjust the entrance and exit slits. Any slight variation of the slits will still even out the passband. It is not necessary to have exactly this or that passband.

Always use the first order of the grating for the H alpha line with the solar disk. The sun will be reasonably bright. Do not use the second order. Red and blue filters must be used to remove overlapping orders so selected. But the filter will diminish the light into the eye, resulting in a much less bright solar disk in H alpha light.Solar detail will be seen with difficutly or not at all.

Having the H alpha line pass exactly through the exit slit is not easy. You must use a lever system. But you can move the solar spectrum 99% with a lever system near the exit slit, and the last 1% with the line shifter as the H alpha tuner. Quite easy to do.

For a 1200 gr/mm grating, here is the equivalent passband and slit widths.

Spectroscope Focal Length *(meters)*	**Exit Slit Width** *(microns)*	**H Alpha Passband** *(Angstroms)*
1.90	200 175 150 125	0.8 0.7 0.6 0.5
0.85	100 88 75 62	0.8 0.7 0.6 0.5

Other values can be interpolated for various focal lengths. An 1800 gr/mm grating will have the H alpha line 1.5 times wider. Therefore, the exit slits above will be 1.5 times wider for the same passband. It is obvious that a slight change of 25 microns can easily change the passband. So try to adjust with a passband about 0.5A to 0.6A range comprise, making it easier on your patience and nerves.

Barlow lens: The positon of the Barlow is easy to locate at the 2X position. Assume -500mm f.l. Find the exact focus of the primary mirror or achromat. Put the Barlow inward of the focus by 250mm.The Barlow will project the sun image 250mm beyond the primary focus, namely 500mm from the Barlow itself.

References and Order Addresses:

The Spectrohelioscope, book by Veio.
It is free on the Internet at:
sunmil1.uml.edu/eyes/veio

Caution, one (1) after sunmil. Click on book.

www2s.biglobe.ne.jp/~t-oni/shs
Look at the upper right corner of home page.
Click on spectrohelioscope.

Diffraction Products: All gratings in a catalog are listed with the blazed wavelength in the first order. For almost all SHS designs, you need a grating with 5000A or 6000A blazed wavelength for the first order.

Diffracton Products, Inc.
P. O. Box 645
Woodstock, IL 60098, USA

Jobin-Yvon: Home office and other details at

Jobin-Yvon
16 - 18, rue du canal
91165 Longjumeau cedex, France

http:// www.isainc.com
email: isajyoem@aol.com

Offices in Germany, Italy, the Netherlands, Great Britain, USA and Japan.

Newport Corporation: The company makes an excellent Barlow lens with surfaces better than 1/4 wave spheroid for the full diameter. Two diameters are 25mm, about $35, and 50mm, about $80. Shipping costs are extra. Use a long negative focal length, about -250 to -500mm. An F:44 SHS has a beam of light about half or less of the full diameter of the Barlow, so this is equal to about 1/8 wave on the wavefront, excellent. (Plano-convave lens, BK-7, grade A, AR coating, order no. KPC064, -500mm fl, 50mm diameter)

The company has many outlets in the world.

Newport Corporation
1791 Deere Ave
Irvine,CA 92606, USA
