DESIGN OF THE SCHMIDT-CASSEGRAIN

by Dick Suiter

(orig May 2005, revised Dec 2017)

Now, let's examine the design of Schmidt-Cass catadioptrics (we shall leave Schmidt cameras to the photographers). A family of designs are possible, just as in the all-mirror Cassegrains, ranging from the Dall-Kirkham (ellipsoidal primary/spherical secondary) to the classical Cass[§] (paraboloidal primary/ hyperboloidal secondary) to the Ritchey-Chrétien (hyperboloidal primary/strong hyperboloidal secondary). What is the design that is most likely to be produced? Optimum would be a Ritchey-Chrétien analogue – the R-C design is used in nearly all observatories – but this choice is not preferred because it involves shaping a convex aspherical secondary mirror, and that would require artisan workers again. The most likely choice for the majority of S-C's is the Dall-Kirkham analogue, which has the worst off-axis coma but is the easiest to make. A weak Schmidt corrector allows both mirrors to be spherical.

An 8-inch *f*/2 spherical mirror was arranged having a corrector plate somewhat inside its focus and a spherical secondary was put somewhat inside of the corrector. Focus was demanded 6 inches behind the primary and the focal length was forced to be 80 inches. Variables were the curvature of the secondary, the mirror spacing, and the 2nd and 4th-order powers on the Schmidt surface of the corrector. Wavelengths were set at 510, 550, and 610 nanometers (green, yellow-green, and orange) with equal weights on each.[*] The solution was found in the ray-trace program ZEMAX with nearly the entire weight on the center of the field-of-view and the optimization occurring on the wavefront. It appears below in millimeter units. Looking at the layout diagram in the first figure, we can talk through the elements one at a time. First comes the Schmidt corrector, which has a thickness of 5 mm (the thickness matters little. We'll talk about the curve ground into it after we go through the rest of the instrument.) After the Schmidt corrector we move rightward 320 mm (~13 inches) until we encounter the main mirror, which has a radius of -812.8 mm. The light reflects and strikes the secondary about 312.62 mm to the left; the secondary has a convex radius of –231.07 mm and a diameter of 66 mm (the precision in the table is not necessary). We next go through the main mirror again and focus is found 150 mm beyond that. The image surface bows back toward the telescope with radius of about 200 mm. Total length of the instrument, including back focus, is about 490 mm. The gaps in the layout (Figure 1) are where baffles can go.

Table 1. A design that is very close to most S-C telescopes

SURFACE DATA SUMMARY: all spherical mirrors, units are mm.

203.2 mm (8 inch) *f*/10 ====Schmidt coefficients====

Surf	Radius	Thickness	Glass	Diameter	$A(r^2)$	$B(r^4)$
OBSTRUCT				67.6		
1[†]		5	BK7	203.2	7.8053e-6	-6.69807e-10
2		320				
4	-812.8	-312.62177	MIRROR	203.2		
5	-231.06678	312.62177	MIRROR	66		
6		150.0				
IMA	-208					

[†] aperture stop = diameter of corrector plate

Recall from last time that the corrector surface is in the form: $z = Ar^2 + Br^4 + Cr^6 + ...$

Plotting the values of *A* and *B* appearing in the lens description versus the radius, we see the behavior in the sag profile figure. Amplitude is less than 0.02 mm, or a quarter the thickness of a sheet of typing paper. Terms higher than B are hard to make and neglected.

[§] The "classical cass" eerily reminds me of a popular 1960s guitar solo. But I digress.

[*] Bruce H. Walker, *Optical Design of Visual Systems*, Vol TT45, SPIE Press, 2000. Walker favors a similar placement for visual instruments, which is different from the usual C-F correction curve.

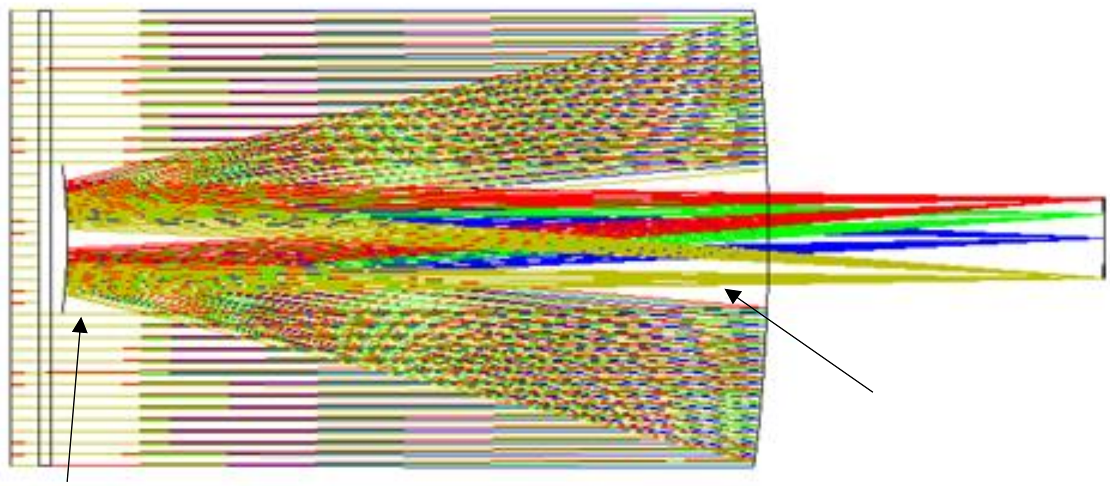
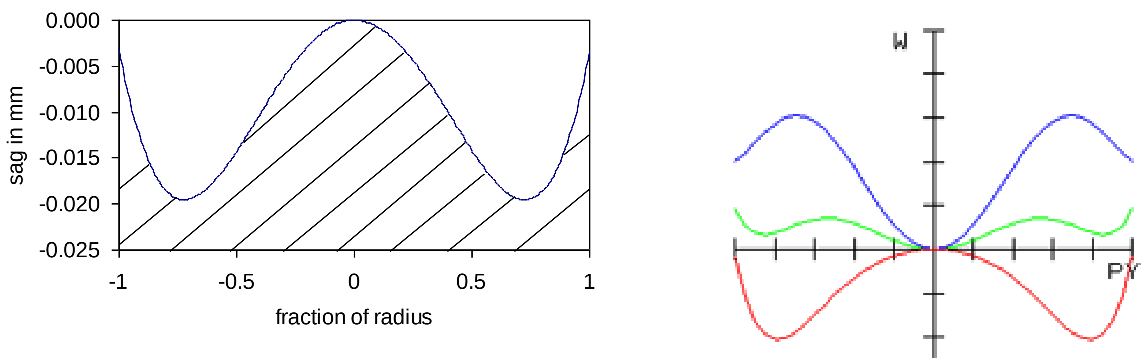


Figure 1. Layout. Baffles may be placed on narrow gaps indicated by arrows.

The flat point of this theoretical curve is about 75% of the way toward the outside. Whether this is case in real instruments is not known to me. In any case, it can vary between 60 and 90 percent without any significant change. Most probably it is put at a position where the plate naturally bends anyway, and nominal coefficients A, B, and C are adjusted for minimum wavefront.

In the next figure is shown the on-axis wavefront. Even though the defocus coefficient is carefully counterbalancing the primary spherical aberration coefficient at 550 nm (the green curve), leaving only a residual 6th-order wiggle, it is slightly out of focus at 510 and 610 nm.[‡] Still, it is within 0.2 wavelength. We can see the chief sin of the all-spherical design in the matrix spot diagram figure. Off-axis as little as 0.15 degree the image is plagued by coma. Of course, images at 0.15 degree would only be viewed with a medium-power eyepiece. What we have designed is a very serviceable instrument.



Corrector sag profile

On-axis wavefront (full scale = 1/5 wavelength)

Figure 2. Front surface cross-section and wavefront of generic S-C

The way commercial Schmidt Cassegrains focus is by changing the distance between the main mirror and the secondary. The final focus changes by the separation change times the secondary magnification squared. Thus, if the separation changes 1 mm, the focus changes by 25 mm. (These are *f*/2 primary *f*/10 overall with a secondary magnification of 5.) How does this affect the wavefront? If we move the focus 2

‡ By the way, that 6th-order wiggle would have changed to a much smaller 8th-order curve if we had found a way of including a coefficient C.

inches behind the nominal 6 inches behind the primary, such as by including a diagonal in the optical path, or compensating for the depth of a camera, we get the wavefront in Figure 4. The main effect is to change the spherical aberration correction slightly, but we see that 2 inches won't change it enough to damage the optics. Now the wavelength 610 nm is well-corrected instead of 550 nm.

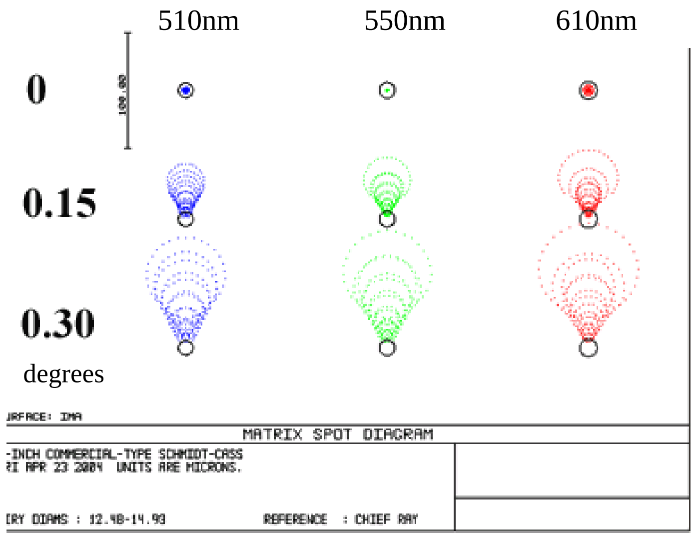


Figure 3. Spot diagram - circles are ideal Airy disks. Scale bar is 100 μm.

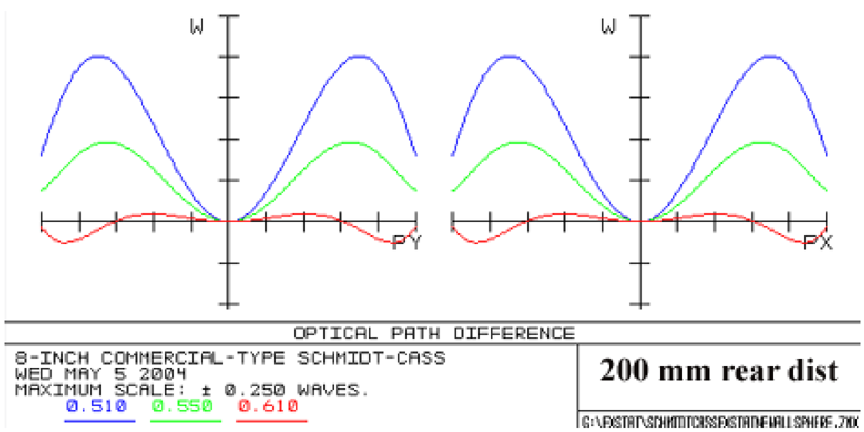


Figure 4. Wavefront of the simple Schmidt-Cassegrain, focus-shifted 50 mm farther back.
(Full-scale is 1 wavelength.)

The final question is how well can the Schmidt-Cassegrain function if we pull out all the stops and aspherize the secondary. (The first such analysis appeared in the book *Telescope Optics* by Rutten and van Venrooij, Willmann-Bell 1988.) The answer is very well indeed; we can get all the way to an aplanatic (i.e., coma-free) condition. Below is a spot diagram of an *f*/8 Ritchey-Chrétien analogue. The curvatures, spacings, and Schmidt coefficients differ slightly but the main difference is that the secondary mirror is a prolate spheroid roughly 3/4 of the way to the paraboloid. The other chief difference is that the instrument has stronger field curvature. Figure 5 has a field with radius -164 mm (or away from the observer). If this is compensated-for by a good field-flattener, the ray still basically arrives on a flat focal plane inside the Airy disk a full 0.5 degrees away, or a Moon diameter!

So why aren't these superior telescopes not the default choice for all Schmidt-Cassegrains?

It all boils down to the perception and needs of the typical observer, as well as what most people are prepared to pay. The spherical-mirror S-Cs have an excellent on-axis image and few visual observers will ever detect the difference. Most people are not set up to take care of the field-curvature anyway (typical eyepieces have field curvatures going the other way). A smooth spherical surface often gives a darker background than a knobby aspheric one. Finally, we must not forget the purpose of making Schmidt-Cassegrain telescopes to begin with. The manufacturers want to reduce the making from an art form to a cost-predictable technical process.

[Since this article was written in 2005, the big manufacturers are making aplanatic Schmidt-Cassegrains alongside their usual types, and charging a high price. These are often directed toward photography and hence are made with lower aperture ratio. The optical design they use is unknown to me – HRS 2017.]

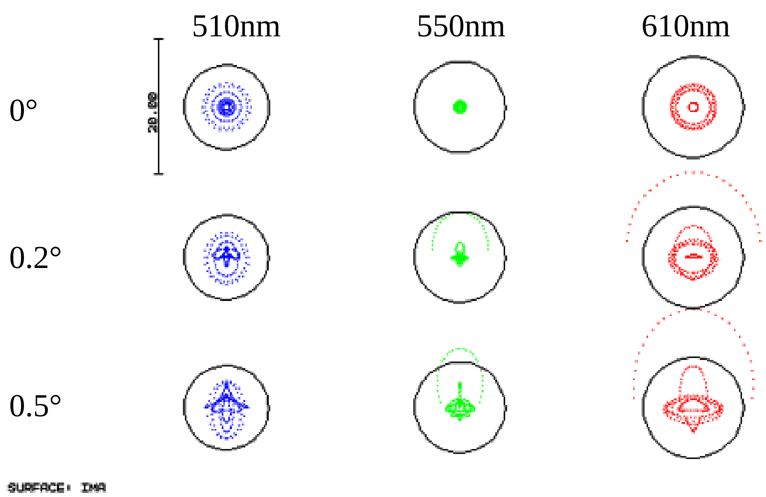


Figure 5. Spot diagram of an optimized (aplanatic) S-C catadioptric along a curved field -- circles are Airy disks. Scale bar is 20 μm long.

Table 2. The design of a theoretical 200 mm *f*/8 R-C analogue.

#	Type	Radius	Thickness	Glass	Semi-Diameter	Conic	Coeff (r^2)	Coeff (r^4)
0	Object		Inf		0			
1	Even Asphere (Stop)		5	BK7	100		7.80E-06	-7.80E-10
2			302.10		100			
3		-800	-293.04	MIRROR	102.85			
4		-281.71	293.04	MIRROR	35	-1.16		
5	Back focus		130.02		18.81			
6	Image	-164			50			