TILTED COMPONENT TELESCOPES PART I by Dick Suiter

Tilted-component telescopes (TCTs) have been known since William Herschel found that he could get a brighter image if he canted his long-focus Newtonian mirror far enough over that his head would not get in the way, thus eliminating the diagonal mirror (the metal mirrors then in use only reflected about 50 percent, so eliminating one mirror represented a real savings). The image from such an out-of-alignment telescope would be awful, but he employed this telescope at low-power to look for faint nebulae and galaxies. He was willing to make the trade for the extra light . The first figure is a spot diagram of a 10-inch f/20 with the focus diverted so that it is about 3 inches outside the entering beam, with the little circle being the Airy disk. It has aberrations amounting to several wavelengths, mostly astigmatism and coma.

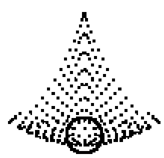

Figure 1: On-axis Herschelian spot.

The reason that this is still an interesting topic is not the obvious one. Most people would think that getting the diagonal mirror out of the optical path would be sufficient justification, but it is not. It can be shown that the diagonal mirror is not a significant contributor to errors in the image in obstructions less than 20 percent, and it is just too easy to make the aperture of your scope a little bigger to completely counterbalance this problem. Getting rid of secondary obstruction is a non-issue of TCTs as far as I am concerned.

The primary reason TCTs are interesting is more subtle. The on-axis reflector can be made in variations of only a couple of forms, with the primary focusing power being contained in only one or two mirrors. Curvature of field in the popular Cassegrainian form of the two mirrors is strong and completely uncontrolled. The Newtonian is so simple that correction of any off-axis aberration is difficult. Sure, coma correctors exist, but they trade off lateral color and spherical correction, Wright-Newtonians and Lurie-Houghtons have flat fields, but they need full-aperture correctors. The most important reason that TCTs are interesting is that additional degrees of freedom are opened up by the addition of elements and tilt angles. More degrees of freedom imply a greater capability toward finding solutions to correct more aberrations. Arthur Leonard, inventor of the Yolo discussed in Part II, made the point about degrees-of-freedom again and again in the *Maksutov Club Circulars*, but I don't think that anyone paid attention to him. Everyone kept on droning the mantra about "getting rid of the diagonal." [By the way, the best of the *Circulars* were republished in the a two-volume book *Advanced Telescope Making Techniques*, where I saw it.]

Reason why good refractors are superior to most reflectors:

1) Indifferent or non-existent baffling of reflector
2) Poor alignment of reflectors (refractors tend to hold their alignment).
3) Open tubes invite thermal troubles
4) Refractors have higher focal ratio:
- *easier for eyepieces*
- *darker apparent field in same eyepiece*
- *easier to figure main optical element*

5) Refractor makers generally know what they're doing (unlike all reflector makers)

Another good property of TCTs, one that depends less on details of their optical performance than on external factors, is that they are a counterexample to the supposed perfection of refractors vs. reflectors. Refractor fanatics come up with all sorts of illusory reasons that refractors are superior to reflectors, including micro-roughness, the diagonal again, and spider diffraction. There is no argument from me that most premium (i.e., non-department store) refractors are superior to most reflectors, but the reasons the refractor fans give are wrong. The true reasons are in the sidebar.

It is clear that something must be done to rectify problems in the image before we can tilt it with impunity. The simplest to imagine, if not to perform, is to just suppose that the telescope is cut out of a large centered telescope. Such telescopes are not really off axis, its just that some of the optical paths are missing.

The trouble with such a procedure is that it requires figuring to an odd shape. It is difficult, to say the least, to figure a mirror to a paraboloid that starts somewhere off the edge of your mirror. Wouldn't it be nice, some people reasoned, if spherical surfaces could be made, and the tilts chosen to counteract aberrations?

The Schiefspiegler

In the 1950s a German optical designer, Anton Kutter (first syllable pronounced as in "cookie"), came up with a series of TCTs that were the first to really do this well. He started with an imagined Cassegrain, blocked off most of the mirror with an off-axis mask, and then tilted the elements to angles where the whole Cassegrain would not have worked, but the subaperture worked better. Most of these are theoretical devices, too cumbersome to make unless you are a specialized optical hobbyist, but one of them, the 110-mm f/26 anastigmat schiefspiegler, was actually made by a significant number of amateurs, with the end view of not just having fun making it, but actually deriving better images. The term "anastigmat" means "without astigmatism," and schiefspiegler is German for "tilted mirror" or better, "oblique mirror." It is not corrected for coma, although at this long aperture ratio, coma is acceptable. I have a 3D diagram of the "schief" in Figure 2.

In the figure, light enters from the left through an empty circle that defines an imagined portal, then it goes to the rear of the telescope at the right and is focused on a smaller mirror above the entrance portal, and then it is diverted at a greater angle and returned toward the rear side again, where it is imaged. The inset depicts a peculiarity of the focal plane, in that it is tilted. The amount of tilt at the edge of the field is very near the depth-of-focus, so it is probably safe to ignore it. Real optical fanatics will want to carry the eyepiece in a skewed adapter, however. [The particular starting design I input before optimization (from *Telescope Optics*, by Rutten and van Venrooij) was f/25, so this probably differs from Kutter's original in trifling ways.]

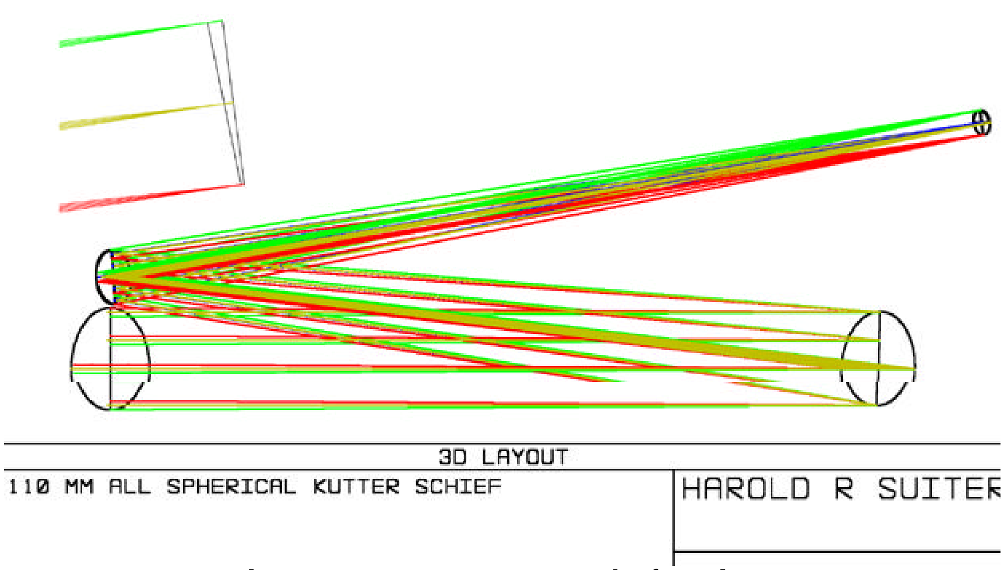

Figure 2: The 2-mirror, 110-mm Kutter schiefspiegler anastigmat

The actual tube of the 110-mm schief doesn't include much of the part up to the entrance portal (I used this "virtual" surface to check that my secondary mirror did not intrude inside the entering beam). Most of the tube encloses that long skinny portion leading back to focus. Where the beam enters the side of this tube is found an elliptical cutout. The primary mirror is usually surrounded by a stubby larger tube (a coffee can has been used) and the stubby tube and the long, narrow tube are connected by a wood piece called a saddle. When it is actually mounted and used, the entering beam usually comes in at the top, so this figure is really upside-down. The correction is given by the relative angles, so the saddle must be made accurately.

The two mirrors in the schief are made together with the same curvature, one convex and one concave. Since they must start the process the same size, the smaller mirror is then "biscuit cut" out of the center of the convex blank. Testing these shallow surfaces is hard. Their radius of curvature is 3240 mm. The Foucault tester is 3.2 m from the concave 110-mm mirror. The convex mirror is tested by interference with the concave mirror, once you are satisfied with its sphericity. Of course, you only need pay attention to the inner 2.1 inches in the case of the convex element. You'll chop away the outer part when you biscuit-cut it.

Another difficult thing is alignment. This is best done by making a bulls-eye cover for the main mirror (to align the secondary) and a hanging target at the virtual entrance port (for aligning the primary). Fine alignment is done using the star test. I once saw a person aligning one of these and the image passed from an oval image through a round image to an oval image on the other side of alignment. As with other reflectors, you align it from the eyepiece end. He was doing the final star-test tweak at the secondary end, but I don't know if this is universal.

As badly comatic as the on-axis image looks, it will be blurred by diffraction to resemble a good normal image. The Strehl ratio is a respectable 0.9, comparing to about 1/6th wave of spherical aberration. The field of view is 0.5 degree, the angular size of the moon. The moon is painted at the focal plane with a 24-mm diameter, filling the field stop of a low-power 1 1/4-inch eyepiece. The number of eyepieces that are consistent with the long focal ratio is limiting. A two-inch, 50-mm focal length has an exit pupil of only 2 mm at 55 power. That's the realistic low end. A 6-mm eyepiece gives the distant end of 450 power. Clearly, high-power eyepieces are more available than low-power ones. On the other hand, complicated eyepieces are a waste of time. At f/25, even homemade eyepieces work fine.

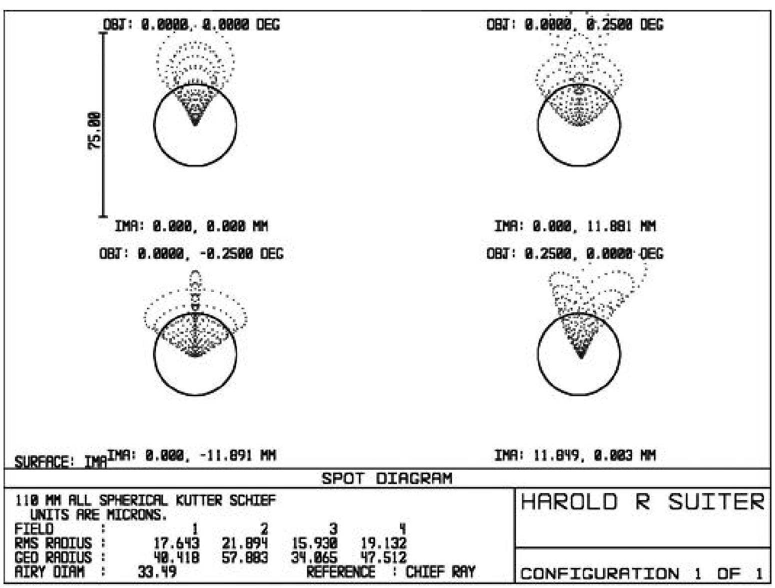

Figure 3: Spot diagram of 2-mirror, 110-mm Kutter schief

[Next month. The Yolo.]