DESIGN OF THE MAKSUTOV-CASSEGRAIN

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We had a figure in the April issue that looked like the top one to the right. Note that the focus isn't good. What if we allow the curved arc to be filled with glass instead of air?

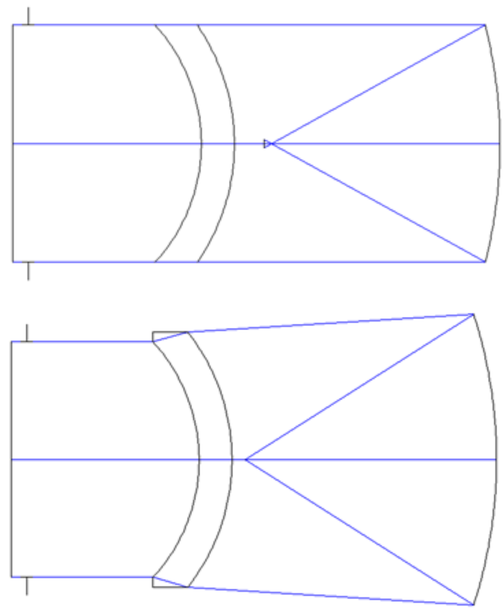

Figure 1. The Maksutov idea

We get Figure 1 on the bottom, which is the usual form of the Maksutov camera. The reason that the Mak system works is that the longitudinal spherical aberration (or the amount that the rays are "sideshifted") is proportional to the square of the radius from the center. We will leave the design of Mak cameras or Mak Newtonians to the minority who is interested in such a thing and concentrate on the Mak Cass.

The design of a Maksutov-Cassegrain is usually limited by the secondary mirror being the same as the back of the corrector. This design was popularized in the 1950's by John Gregory, and is similar to the Orion Maks and the old 90mm Meade ETX. But there is no reason that the secondary mirror must be an aluminized spot located on the corrector. It is merely easier that way because the designer need not come up with a separate secondary mirror support. Also, it is not a source of spider diffraction. See layout in Figure 2.

The design is done for three colors, 510 nm, 560nm, and 610nm, equally weighted. The largest residual on-axis aberration is a non-negligible balanced 5th-order transverse spherical aberration (6th order on the wavefront), in Figure 3. It is roughly 0.15 wave peak to valley. The merit function (i.e., a goodness-of-fit maximization function) has a fixed focal length. There is also no choice on the material the corrector is made of (Schott BK7). The merit function is heavily weighted on the center of the field.

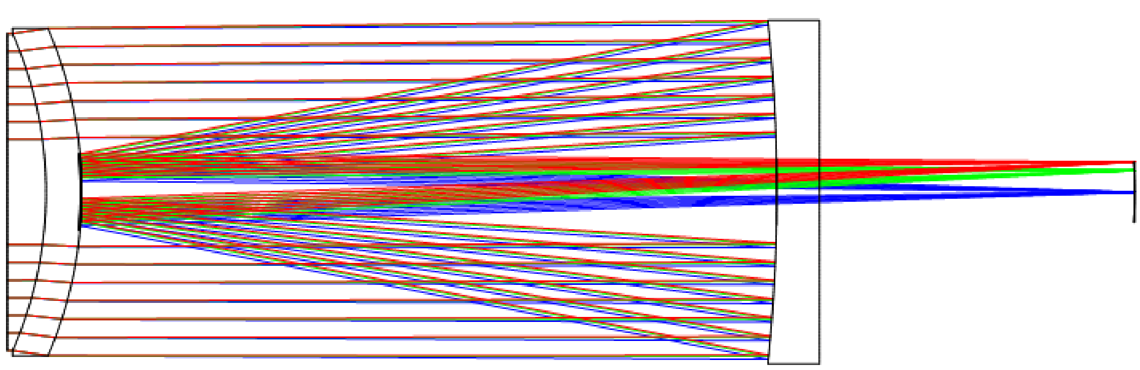

Figure 2. My guess on a certain mirror-on-corrector Maksutov-Cassegrain of high quality (wink-wink).
89 mm *f*/16 having total folded length 315 mm. Focal length is 1400 mm.

The prescription is in Table 1.

Table 1. Prescription data for small Mak with a moderate refractor-like speed.

Surf	Radius	Thickness	Glass	Diameter
OBJ		infinity		
STO 1	Infinity	10.80		89.0
2	-112.82	10.82	BK7	89.0
3	-119.18	196.42		92.2
4	-480.57	-196.42	MIRR	96.7
5	-119.18	196.42	MIRR	21.7
6		100.00		18.6
IMA 7	-114.71			17.0

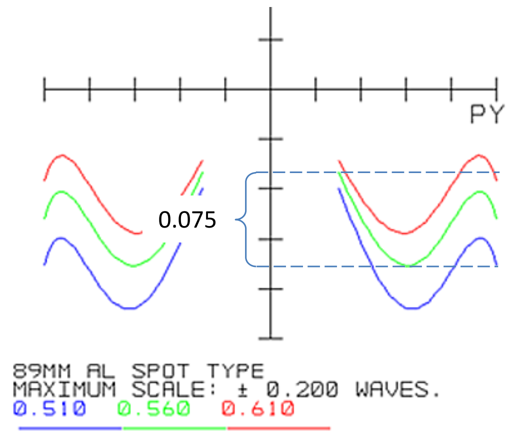

Figure 3. Residual on-axis optical path difference of 89-mm f/16 depicted in Figure 2. Strehl ratio of this objective is 0.98. Full scale = 0.2 wavelengths.

Reading from the top, the object is at infinity, and the 89-mm diameter stop is placed on the first surface. The corrector is 10.82 mm thick at the center. It has a -112.82-mm radius, i.e., cupped toward the object. Its inside surface is cupped the same way and has the shallower radius of -119.18 mm. This slightly different radius corrects a large fraction of the induced chromatic aberration of the single piece of glass that makes up the corrector. Then the main mirror is found 196.42 mm down the tube and has a radius of curvature of -480.57 mm, again cupped toward the front. If we traverse the -196.42 mm up the tube again, we find the secondary mirror, and it has the identical curvature of the rear of the corrector, or -119.18 mm. It is 20 mm in diameter, but needs to be 21.7 mm for 100% illumination, so it will vignette a small amount at the edge. We break up the optical path into two pieces: one is the 196.42 mm to get back to the main mirror, and two is the 100 mm back focus. The Strehl ratio is 0.98 at the center. Other than the 22% obstruction, it is essentially perfect.

Yet the tiny 0.075 wave aberration of Figure 3 is detectable in the star test, if it not used in the correct way.

Some people claim the star test doesn't work for complex systems. They make this statement because their expensive Maksutovs don’t seem to star test perfectly yet work fine. In fact, the star test works for all systems. If it did not, most optical physics would have to be rewritten. Once the wavefront is decoupled from the glass it is just light propagating in free space.

The critics of the star test choose their highest-power eyepiece and defocus it only slightly, and then complain about what they see. Just because the star test is most sensitive at very high powers with small defocus doesn’t mean that users should always test that way. Welford says that the star test used in such a manner can detect small zones of only 1/60th of a wavelength and slowly varying errors of 1/20th wavelength.[1] Why, then are they surprised that it can detect 0.1 to 0.15 wavelength residual aberration. But *detection* is not *failure*.

Moderation is the key in this as in all things. Choose a moderate-to-high power eyepiece (giving a roughly 1 mm exit pupil) and defocus it a bit **more** than 8 to 12 wavelengths, which reduces sensitivity to acceptable levels. Serious difficulty is still visible but you won't blow up insignificant residual aberrations. Following is an example star test diagram, with outside focus depicted at the left. Differences are subtle, especially as you view them one after another instead of side-by-side as you do here.

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[1] D. Malacara and W.T. Welford, *Optical Shop Tests, 3rd Ed.*, Ch. 11, p. 409, Wiley-Interscience 2007. (quotes JOSA, v. 50, 21, 1960)

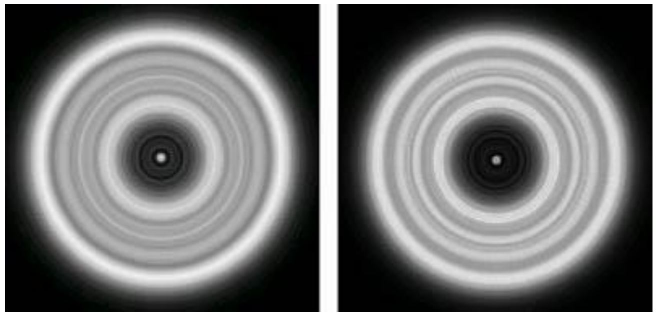

Figure 4. Calculated star test of a good Maksutov telescope, showing subtle difference that would likely go unnoticed when viewed serially.

It is said that one manufacturer of Maksutov-Cassegrains breaks the rules a little by figuring an aspheric surface into the system. I don't know if that is true, but it does lead to less 5th order residual aberration. See the wavefront of Figure 5. It doesn't seem to make sense in the viewpoint of repeatable fabrication, but maybe the goal here is finer on-axis performance. Note that full scale is only 0.1 wavelength.

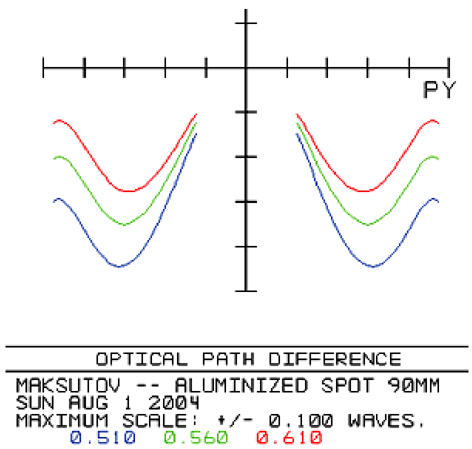

Figure 5

The aluminized spot limits the design freedom of a Mak-Cass. The net effect is that we can't really allow the telescope design to get too large. If we open up the design by allowing the secondary to have a different spacing and curvature than the rear of the corrector, we obtain the true excellence of the form in large apertures.

Below is the design in a 10-in *f*/15 configuration. All measurements are in millimeters. There are no aspheres. It is the result of a ZEMAX optimization. The spot diagram is on the next page.

Table 3. SURFACE DATA SUMMARY:

Surf	Radius	Thickness	Glass	Diameter
STO	Infinity	25		254
2	-394.252	20	BK7	256
3	-405.7704	814.0225		270
4	-2050	-791.0225	MIRROR	272.9954
5	-679.7866	791.0225	MIRROR	70
6	Infinity	150		54.07248
IMA		-625		50.02356

The Strehl ratio is over 0.996 and the optics are good even off-axis. Peak to valley aberration is about 1/20th wavelength and the 5th-order residual is miniscule. Note the corrector is thin at 20mm. If we tried to scale up the earlier 90-mm aluminized spot Mak-Cass, we'd get an expensive thick corrector as well as mediocre optics.

Is all the mystique about the Mak-Cass justified? Certainly it can be designed with excellent optics, but design and execution are two separate things. If a great deal of care (read "expense") is taken with its manufacture, it can provide outstanding images with all spherical surfaces. However, if you buy a $250 Mak from the shelves at your mega-store, you are not likely to get the best. That deep meniscus is challenging to make.

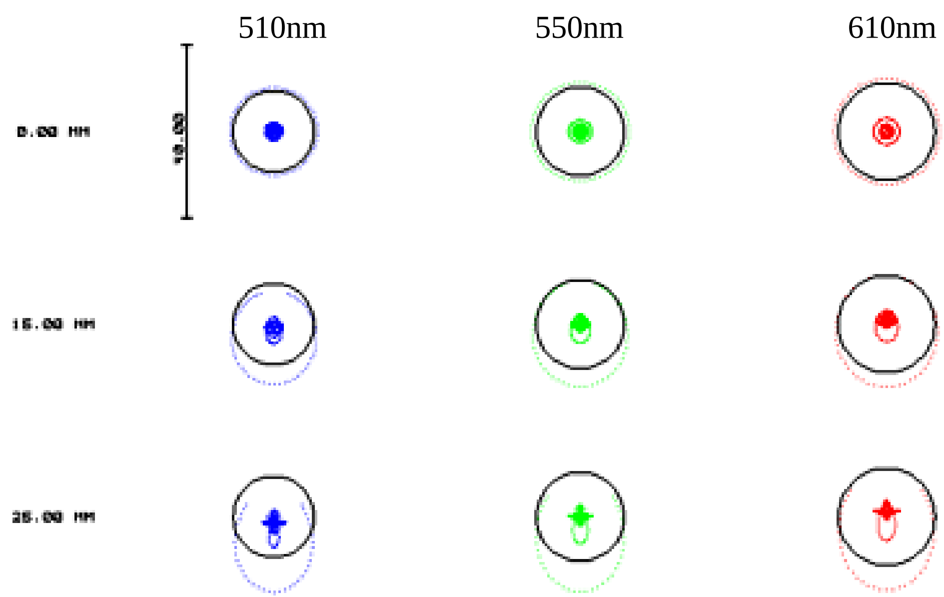

Figure 6. Spot diagram of big separated secondary Mak-Cass.