

Brief historical remarks concerning one type of wide-field catadioptric telescopes

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Recently, the Telescope Engineering Company (www.telescopengineering.com) has presented a wide-field telescope TEC-VT 300mm/7deg at the North-East Astronomy Forum (NEAF, April 28th-29th, 2012; see Fig. 1).

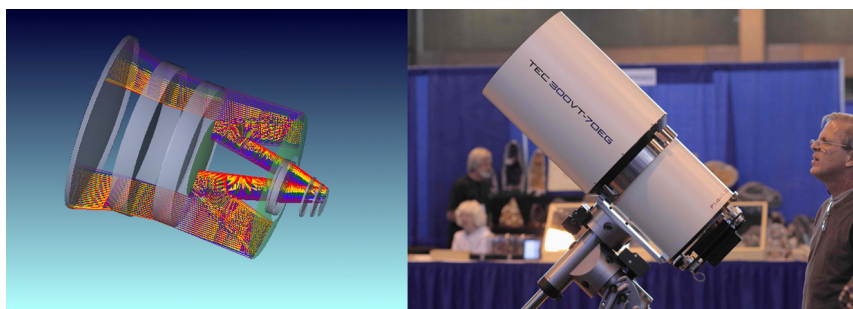


Fig. 1. Optical layout of TEC-VT, and the telescope representation at the NEAF

As it is clear from its name, the telescope has 300-mm aperture and 7° (52.1 mm) field of view. The optical layout of the $f/1.44$ telescope consists of a three-lens front corrector, two mirrors, and a two-lens rear corrector. All surfaces are spherical nevertheless the design yields sharp images: the RMS spot diameter is less than $4\text{ }\mu\text{m}$ ($1''.9$) in the integral light $0.42 - 0.84\text{ }\mu\text{m}$. The diameter of the flat field corresponds well to a diagonal of commonly available CCDs.

In this connection, the TEC and author of the optical design have obtained a number of requests concerning historical roots of the optical scheme. The following short remarks do not claim to be an exhaustive review of this extensive topic; the only goal was in noting some important steps which have led to the creation of a three-lens corrector to a spherical mirror. Undoubtedly, this cursory glance on such an extensive topic requires further development and specification.

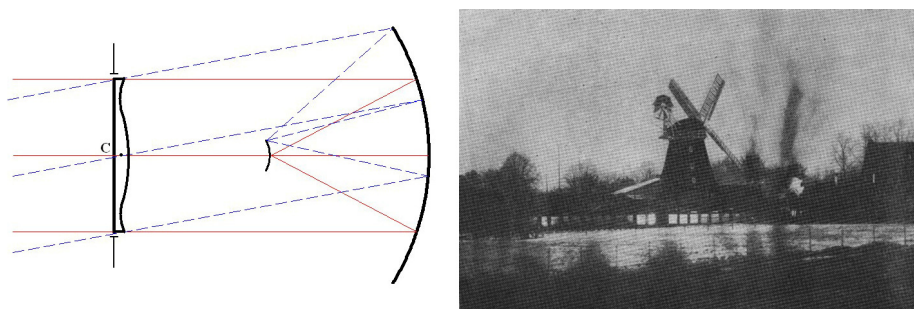


Fig. 2. Layout of Schmidt telescope, and the test photo taken with the first such camera

Unlike many other directions of optics which were formed gradually, in area considered here there is the definite date designating radical expansion of a telescope field of view. Bernhard Schmidt had proposed in 1930 a new optical layout (Fig. 2), and he made its prototype by himself having applied the utterly original method of manufacturing aspheric surfaces. The first Schmidt's $f/1.74$ camera had the 36-cm aperture; it provided the unvignetted field of view nearly 4° in diameter; moreover, it showed feasible images even at the edge of the 16° field!

It was the great breakthrough, as a classical telescope of Laurent Cassegrain yields the field only a few minutes of arc in diameter.

The native of the small Estonian island Naissaar, Schmidt was the self-educated person. Nevertheless, he not only possessed appropriate theoretical knowledge in optics but also was a master of manufacturing objectives large for those times. The latter is especially amazing as far back as in childhood Schmidt had lost his right hand, while he ignored polishing with application of machine tools. Karl Schwarzschild named Schmidt “The artist of his trade.”

Such a wide field is provided in the Schmidt camera by proper placement of only two optical elements: the glass entrance corrector and the spherical mirror of a somewhat larger diameter. The main difficulties in manufacturing and in operation of a Schmidt camera are caused by complexity of the corrector’s surface (at minimum, it is a 4th-order aspheric), curvature of the field and large tube length (see, e.g., Ingalls [1996]).

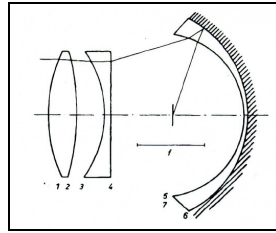


Fig. 3. Sonnefeld camera $f/0.6$

Naturally, the Schmidt followers have tried first of all to replace an aspheric corrector with one spherical lens, as it made Dmitry Maksutov [1944], or with two such lenses, according to August Sonnefeld [1936]. The meniscus lens in Maksutov system possesses appreciable optical power, so to avoid chromatism we can’t step aside far from its achromatic version, while the latter is not quite optimum for correction of other aberrations. The additional degrees of freedom appear at use of two-lens corrector to a spherical mirror. Since the purpose of Sonnefeld was manufacturing a spectrograph, he has achieved very high speed, $f/0.6$, which required applying a Mangin-type mirror (Fig. 3). A successful Cassegrain version of the Sonnefeld’s camera with the $6^\circ.5$ -field was built by Amon, Rosin and Jackson [1971].

It is worth mentioning that utilizing of a back-covered mirror for correcting chromatism goes back to Isaac Newton (Turnbull [1959], Whiteside [1969]) and to W.F.Hamilton [1814]. Modern development of such systems has been discussed in a recent paper of Terebizh [2011], so this subject will not be discussed herein.

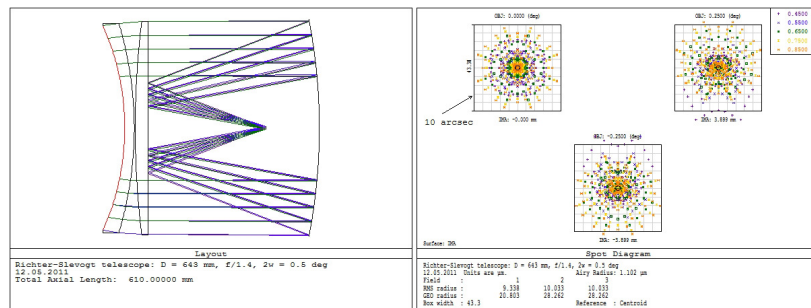


Fig. 4. Richter-Slevogt $f/1.4$ telescope of diameter 64 cm located in the Crimean Observatory. Spot diagram in the field $0^\circ.5$ corresponds to waveband $0.45\text{--}0.85\text{ }\mu\text{m}$; box width is $43.3\text{ }\mu\text{m}$ ($10''$)

Robert Richter and Hermann Slevogt [1941] did not aspire to reach such high speed. The optical power of the RS-system (Fig. 4) is provided by usual spherical mirror, whereas optical power of the corrector made of positive and negative lenses is close to zero. Evidently, choosing one type of glass for both lenses removes the chromatism, as in a plane-parallel plate, whereas the spherical aberration and coma of a mirror can be corrected appreciably. The fact that corrector is nearly afocal results in remarkable property of RS-designs: the exclusive softness of a system’s tolerances at diffraction-limited image quality.

The first Richter-Slevogt telescopes were made in the early 1940's. In the end of the Second World War one of them has been removed to the Crimean Observatory at Ukraine; it is intensively used to this day. Modern development of the RS-systems has allowed increasing field of view more than at order of value (see Terebizh [2011]).

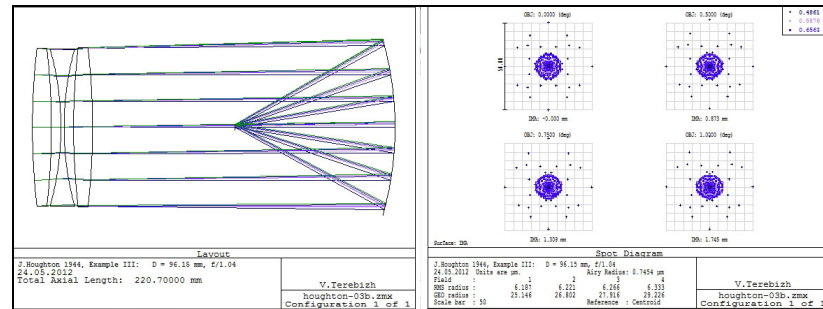


Fig. 5. Houghton [1944] three-lens $f/1.04$ camera of diameter 96 mm.
Spot diagram corresponds to waveband 0.486-0.656 μm ; scale bar is 50 μm (103")

Before long, the system similar to the Richter-Slevogt telescope has been proposed by James Houghton [1942, 1944]. However, Houghton did not confine himself by two-lens front corrector but considered also a few versions of a three-lens all-spherical system. An Example III of the original patent by Houghton (Fig. 5) provides the RMS spot diameter about 27" in a 2° field (we have optimized the back focus). In spite of poor images, this system by Houghton should be considered as generic for many subsequent wide-angle telescopes, in particular, the Hawkins-Linfoot camera (Hawkins and Linfoot [1945]) and the known Baker-Nunn system (Henize [1957], Baker [1962]). As Buchroeder [1971] notes, "The use of a three-element corrector is a fundamental advance in the art of catadioptric design that we utilize in modern optical designs."

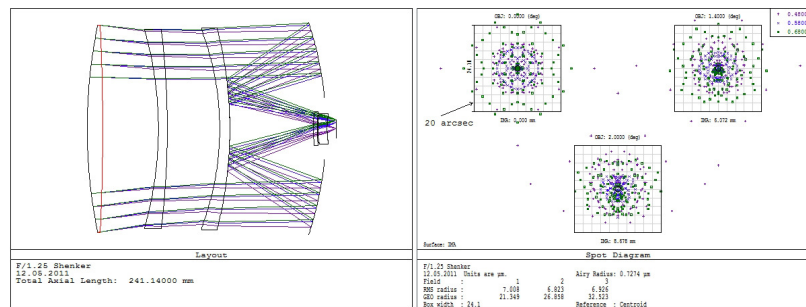


Fig. 6. Shenker $f/1.24$ telescope of diameter 200 mm and field of view 4° .
Spot diagram corresponds to waveband 0.48-0.68 μm ; box width is 24 μm (20")

In the mentioned above Hawkins-Linfoot and Baker-Nunn cameras, all or the majority of optical surfaces of lenses are high-order aspheres. This way has allowed reaching the field width in tens degrees, however the spectral range remained narrow, the focal surface has been located inside a telescope and strongly bent, and images of stars on this surface were insufficiently sharp, an order of tens angular seconds.

Some better quality of images – at a much smaller field of view – has been reached in the systems which have kept all-spherical optics. Fig. 6 depicts the best system of Shenker [1966]. It yields a field of a feasible size, 4° in diameter, though, the system has a very short back focal length, and the main thing, the RMS image spot diameter in a narrow waveband is about 12".

After Houghton and Shenker's work, a few investigations of the all-spherical systems were made, in particular, by Maxwell [1972] and Laikin [1995]. The latter author enlarged the

flat field up to 9° . His $f/1.2$ design of 206.5 mm aperture yields the RMS spot diameter $15 - 35 \mu\text{m}$ ($12'' - 28''$) in the wavelengths range $0.486 - 0.656 \mu\text{m}$.

It is very likely that the apparent lack of interest in three-lens all-spherical systems over the years resulted from their low, in modern conception, image quality, which is essentially inferior to that provided by Schmidt telescope of the same field. Nevertheless, it is possible to achieve the desired image quality while retaining all the advantages of the system even broadening the waveband and increasing the aperture, back focal length and field of view.

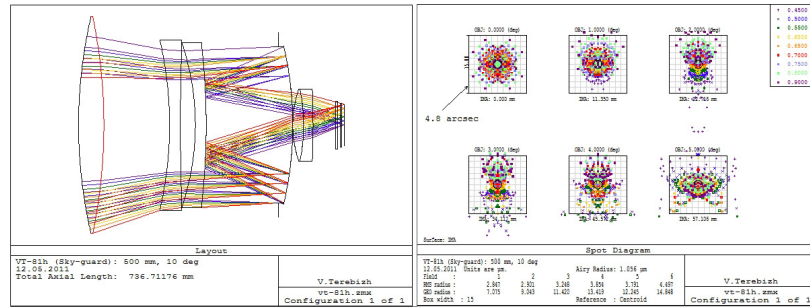


Fig. 7. VT-81h design $f/1.3$ of diameter 0.5 m and field of view 10° . Spot diagram corresponds to waveband $0.45-0.90 \mu\text{m}$; box width is $15 \mu\text{m}$ ($4''.8$)

Fig. 7 shows one of our designs with a 10° field made of all-spherical optics (Terebizh [2007, 2011]). The RMS spot diameter in polychromatic waveband $0.45 - 0.90 \mu\text{m}$ varies from $5.7 \mu\text{m}$ in the center of the field up to $9.0 \mu\text{m}$ at its edge ($1''.8 - 2''.8$). All lenses can be made of one simple glass; the use of more expensive glass types in the two-lens exit corrector gives slightly better images. As one can see from Figs. 6 and 7, the VT-81h design has 2.5 times larger aperture in comparison with the Shenker's system, 2.5 times wider field of view, 2.25 times broader waveband, an essentially longer back focus but more than twice the image sharpness.

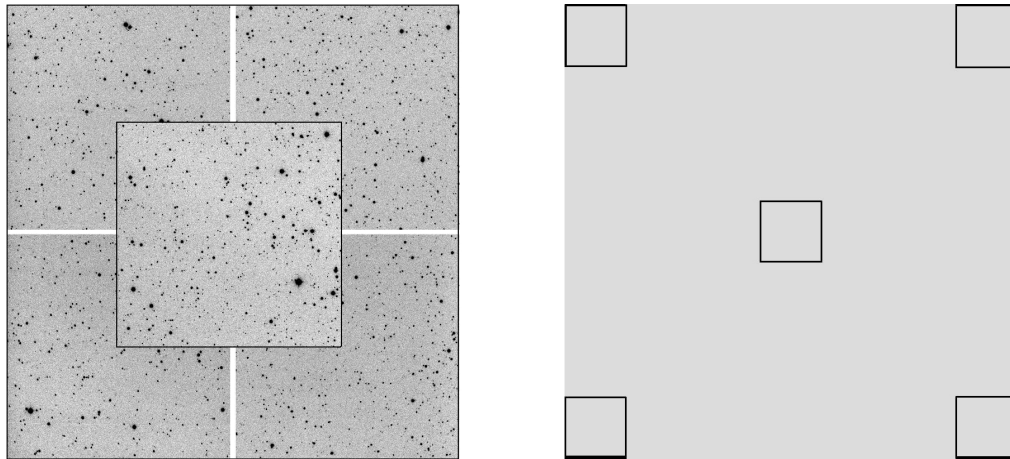


Fig. 8. Fragments $\sim 1^\circ \times 1^\circ$ of a picture of an open star cluster M44 taken with the VT-78a camera (at left). Positions of the fragments in a full frame of $7^\circ \times 7^\circ$ are shown at right

Prototype of this system with the aperture diameter 192 mm, VT-78a, has been made by G.Borisov in the Crimea. Fig. 8 shows fragments of a test picture obtained with the VT-78a; one can find the original $7^\circ \times 7^\circ$ images of the sky at the <http://terebizh.ru/V.Yu.T/pictures/vt-78a/>. The image detector was FLI ML9000 camera with 3056×3056 pixels of $12 \mu\text{m}$ ($8''.4$) size. The star images across the original full-frame picture are of one pixel size all over the field, so the lesser pixels of $9\text{-}\mu\text{m}$ size are now in use.

We would like to stress once more that the all-spherical telescopes have mild tolerances in comparison with their aspheric counterparts, so they are much more stable in operation.

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