**Wolfgang Busch, "Astropraxis," *Sterne und Weltraum* (10/1977), pp. 338-341, trans. R. Ceragioli**

## For Experienced Mirror Makers

### Production of a nearly apochromatic telescope objective from prefabricated parts.

In close collaboration with the firm of Heinrich Reichmann (Brokdorf, Germany), the author has in the last few years developed a high-performance objective for visual and photographic observation, which any amateur who has ever ground and polished a telescope mirror can finish. No additional know how or equipment is needed to do the work or testing. A construction kit composed of prefabricated parts requires nothing besides the operations which have to be mastered in the production of mirrors. The prototype--after a continuous two-year exposure to the climate of Hamburg, Germany (!) --was shown at the 1976 "Photokina" in Cologne. Discussions with interested parties from at home and abroad led to the completion of the kits.

### Development of the System

The starting point was this: all "open"--that is to say, uncemented--telescope objectives have a difficulty hard to overcome for the amateur, namely the sensitivity to decentration occurring in the very thin, meniscus-shaped "air lens" which exits between the neighboring glass elements. In the case of half- or full-apochromats, this sensitivity is even many times larger than with the usual Fraunhofer objective, on account of the stronger curvature of the inner surfaces. Thus, according to its 1964 Catalog of Instruments, "The B-Objective, produced for about 50 years by the Firm of Carl Zeiss, is no longer made due to its high sensitivity to decentration." Its successor, the F-Objective--likewise a triplet apochromat--consists of dense flint glasses, and achieves comparable performance using far weaker curves.

It follows from the above that only an objective whose component lenses are in optical contact with one another can be securely made in the workshop of an amateur.

As a cement, common Canada balsam has the disadvantage that it can be applied only at a rather high temperature, which always means great danger in the case of large lenses. Synthetic cements can indeed cold-harden, but then require *very* high temperatures to soften again, which in case of a mistake during cementing would quite probably lead to damage.

For this reason we decided on a special oil, since it fulfills all our demands: like a kind of "fluid glass" it forms an optical bridge between the crown and the flint elements; it is applied cold (if necessary it is easily changed out); and it "goes along" when the lenses change shape during temperature variations. Moreover, the oil-solution ("immersion principle") eases several other important problems:

1)  The central [flint] lens is now united to both of the [exterior] crown glass elements by means of an oil layer about 0.01mm thick, although sideways displacements as occur during grinding and polishing are possible.  To meet this, we were easily able to construct a cell in which the middle, somewhat smaller lens element is adjustable (relative to the other two [outer] lenses) using four plastic screws.  This removes the centering problem, and even lenses with obvious wedge error can be used.

2)  Atmospheric dispersion, which so seriously impairs planetary observation near the horizon, can be removed by a small intentionally applied decentration.

3)  The four inner surfaces no longer demand any special precision.  Therefore, one can now feel certain during testing that a zonal error, for example, can only have arisen on an exterior surface.

4)  The indices of the glasses and oil are so similar that one can now completely dispense with polishing the four inner surfaces [cf. photo 1, p. 338].  We have made measurements showing that the brightening of the background remains restricted to a value 1/100,000th that of the object under consideration, corresponding to 12.5 mag. dimmer.

5)  Because of the similarity of the indices, these surfaces form no reflections.  Light is transmitted free of loss to the other glass types.  But there are also no internal reflections, and so for this triplet system no anti-reflective coating is necessary.  The two external surfaces (each with a 4.5% reflection) can only introduce a secondary light-path [ghost] into the telescope whose focus point lies quite close behind the objective.  In a Fraunhofer objective, there are already six such light-paths [ghost reflections], and in an uncemented triplet there are actually fifteen!

6)  In polishing the exterior surfaces, it has proved best to support each of the lenses being worked across its entire surface, by layering it on top of the other two lenses in the final lens cell.  The feared distortion from warm cement is then out of the question (as well as many other [problematic] construction steps).

7)  The disadvantage that with a cemented system one cannot correct spherical aberration as much as one likes, must be compensated by slightly exaggerating the curvature of the entrance surface [r1] at its periphery.  Otherwise, the back focal length of the edge rays remains too long by about 1/1000th part of the [paraxial] value.  A method which on the one hand utilizes the increasing elasticity of the convex lens up to its edge, and on the other the ground-in support bed of the next lens surface [r3], has already shown faultless results on initial trial.

Glasses with lower refractive indices bring several additional conveniences:

--they weigh relatively little
--they absorb hardly any light (on average 1%/cm)
--their transparency extends into the UV

--the crown glasses are extraordinarily stable chemically and mechanically very hard, so that they can be polished out rather quickly.

## Optical Performance

Secondary spectrum is notably smaller than with the usual half-apochromats: longitudinal [chromatic] aberration for the region from red (C-line) to blue (F-line) is smaller than 0.0002f; with the Fraunhofer it is 0.00057f. The difference from the d-line (green) up to the g-line (violet) amounts to 0.0006f; with the Fraunhofer it is 0.0025f [see lower right figure, p. 338]. Spherochromatism (the chromatic difference of spherical aberration) is as small as with the most modern doublet half-apochromats. Offense against the Sine Condition [OSC] amounts to only 0.0002f, assuming the usual construction with a flat exit surface, and disappears in the residual color error. Therefore it does not pay to give up the advantage of a flat surface.

The costs for the complete construction kit amount to about 1/3 that of a finished objective of comparable performance. All [design] quantities have been exactly maintained, so that the amateur's work commences with fine grinding (400 carbo). Our intention is to assist lovers of the stars in obtaining a refractor of the highest performance, without also getting them too deeply into the red.
----------------------------------------

## Text of the Captions, p. 338:

1) Photograph (center): "The inner surfaces are ground only with 400 carbo. Yet already the immersion oil provides for very high contrast transfer."

2) Lens cell drawing (lower left): "Cross-section through the system plus cell. One can see the possibility of working the outer surface of a lens without removing it from the cell."

3) Aberration graph (lower right): "Axial correction of the HAB 130mm/1900mm *Immersion Objective* (ditto for the HAB 150mm/2250mm). Upsilon = entrance pupil height in mm."