US NAVAL OBSERVATORY 1.3 M TELESCOPE IS OPERATIONAL!!!

DFM Engineering, Inc. has completed the installation of the new 1.3 meter aperture F/4 very wide field telescope at the US Naval Observatory Flagstaff Observing Station. Dr. Frank Melsheimer presented a poster paper at the SPIE Munich meeting describing the telescope including the design and manufacturing of the optics. First light images were also displayed.

Additional images of the telescope are located at:
http://www.astro.lsa.umich.edu/users/seitzer/debris

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A VERY WIDE FIELD, VERY FAST TELESCOPE

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ABSTRACT

A 1.3 meter aperture Cassegrain telescope with a very wide flat field has been completed and is now producing images. The field of view is a stunning 1.7 degrees while the focal ratio is a very fast F/4. The telescope is located at the United States Naval Observatory Flagstaff Station in Arizona, USA.

The authors discussed the concept of a fast, very wide flat field optical system years ago, but no system was built. Now the system has been realized using only primary and secondary mirrors with a small fourth order (Schmidt plate) corrector. The mirrors form a modified Ritchey Cretien' system but are significantly more aspheric-especially the secondary mirror. The corrector was made using the vacuum technique invented by Bernard Schmidt. The resulting optical system is unique.

The design performance, optical fabrication techniques, and optical test results are discussed. Images taken with the system are also displayed.

Keywords: "Very Wide Field", "Fast", "Unique"

1. INTRODUCTION

The United States Naval Observatory desired a very wide field reflecting telescope to perform astrometry using a mosaic CCD camera. The observatory staff has considerable experience with a 1.6 meter folded prime focus telescope first using traditional photographic plates and now using a CCD. The plate scale of the 1.6 meter telescope limited the field based upon the size of CCDs. The new telescope will provide a very wide field using a realizable mosaic CCD camera with 15 micron square pixels. The plate scale of the telescope is 25 microns per arc second.

2. OPTICAL DESIGN

A more traditional Ritchey-Cretien' design with field corrector/flattener was investigated by the Observatory staff and it was shown that such a design was viable. The authors investigated the concept of using two mirrors and a small, thin fourth order field corrector and determined that such a system could produce the desired results at a lower cost and provide better performance.

The detailed optical design included the effects of the filter wheel glass and the CCD vacuum window glass. Also, the optical testing of the primary and of the system was performed at a slightly different optical spacing to account for not having these additional two optical elements in the testing path.

The optical layout of the system is shown in Figure 1. The additional elements near the focal plane allow for the filter and the CCD vacuum window. These elements are plano-plano pieces of glass of the required thickness for their function.

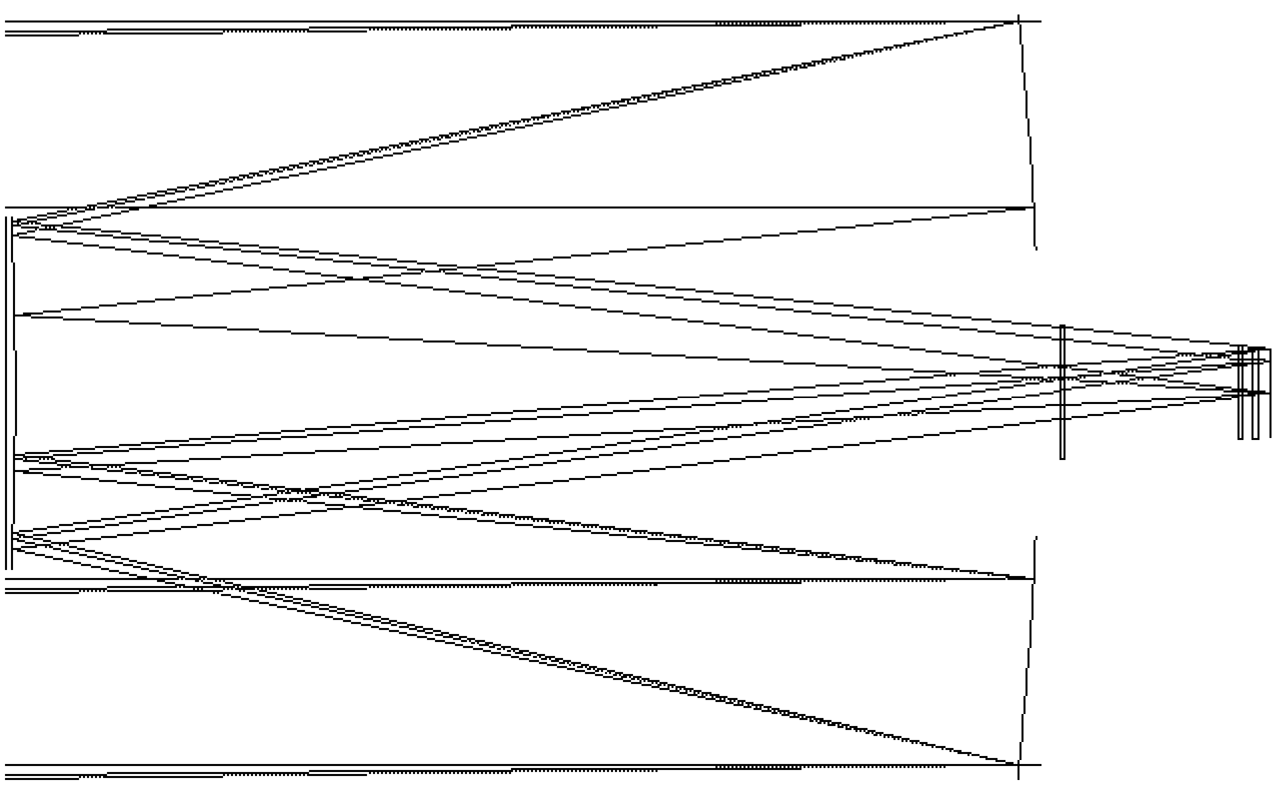

Figure 1. Optical system layout.

Figure 2 shows the diffraction encircled energy taking into account the central obscuration caused by the light baffles and for polychromatic light. Even at 0.85 degrees off axis, the design shows the system to be nearly diffraction limited-the difference being a small fraction of the pixel size.

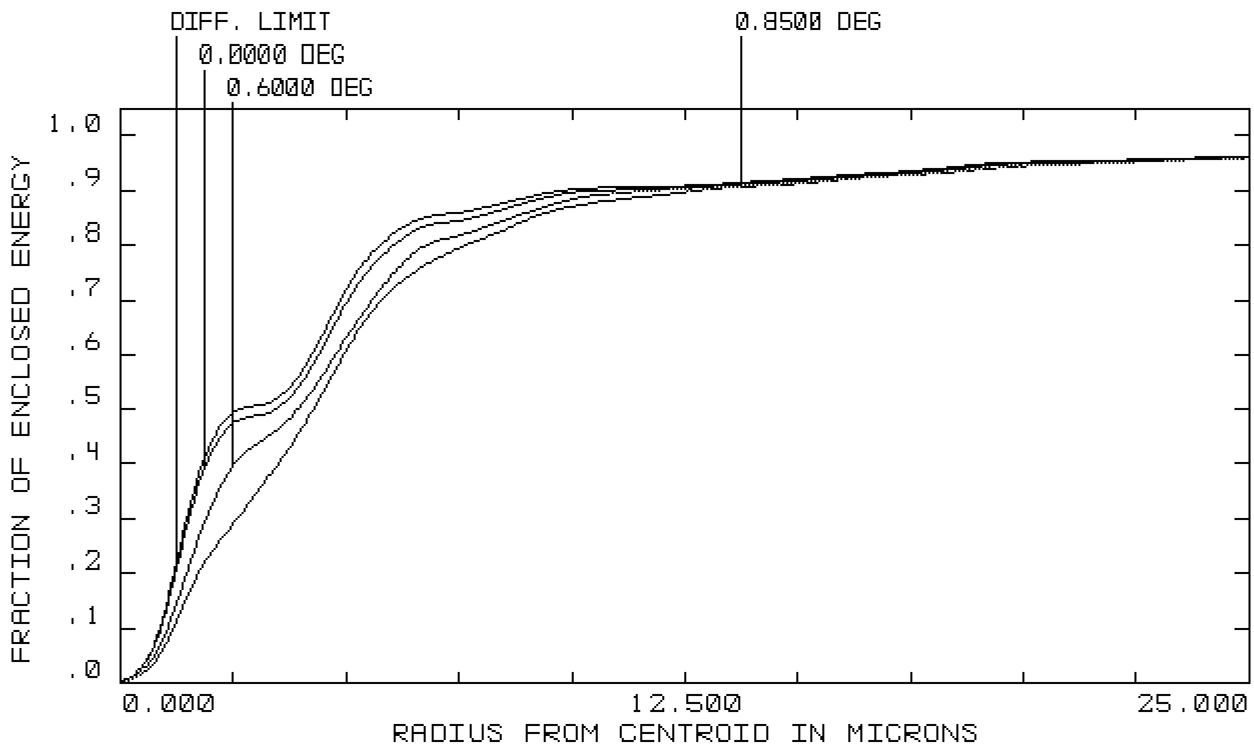

Figure 2. Diffraction encircled energy. (12.5 microns radius is equivalent to 1 arc second in diameter).

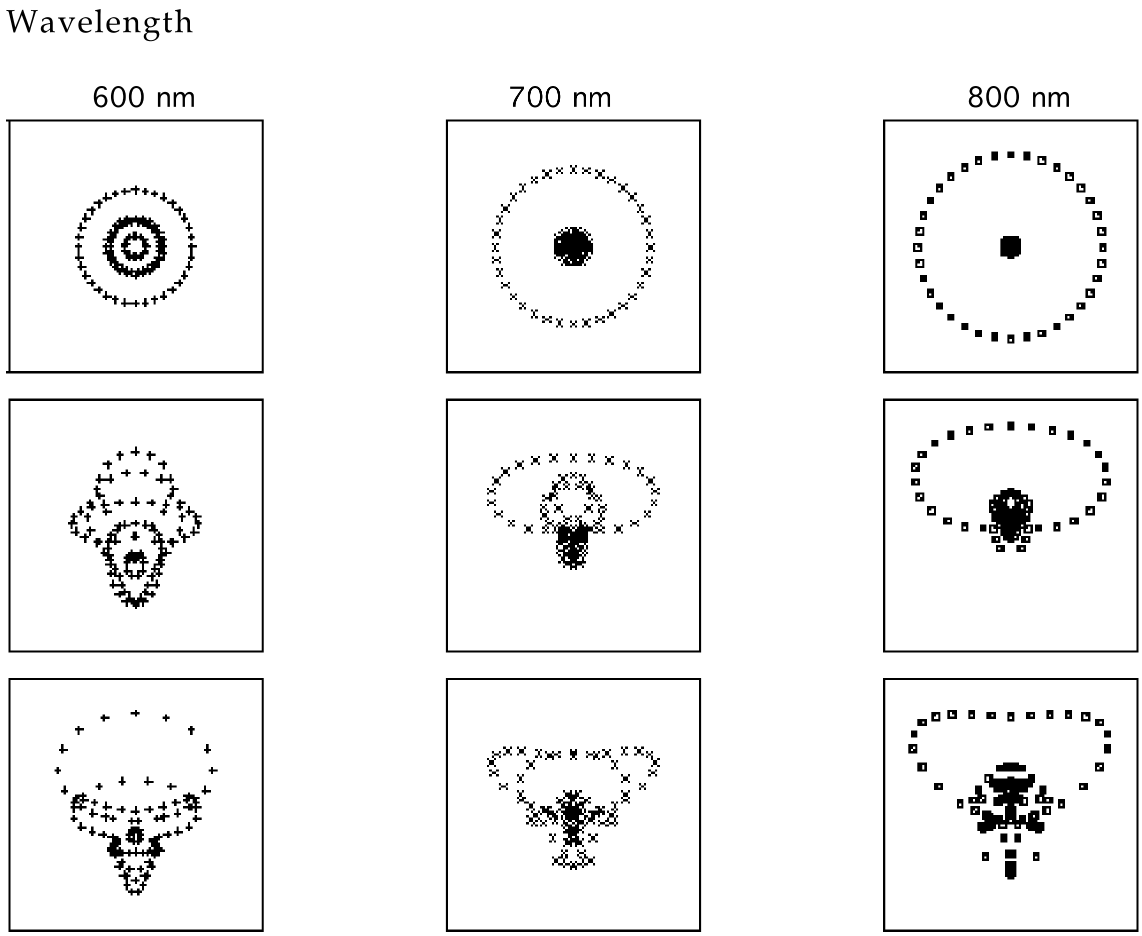

Figure 3.
Spot diagrams for (Top) on axis, (Middle) 0.6 degrees off axis, and (Bottom) 0.85 degrees off axis. The boxes are 1 arc second square.

These spot diagrams show that the image is always smaller than 1 arcsecond.

3. OPTICAL FABRICATION

The optical fabrication for the primary and secondary mirrors was contracted to Kodak because of their ability to perform an all up system test in autocollimation using a full sized optical flat. The fourth order field corrector was fabricated by DFM Engineering.

The primary mirror was processed using a combination of pitch polishing and ion milling. Some edge roughness consisting of up-down-up-down zones was hand worked using a pitch "T" lap as the spacing of the features was too close together to reduce with ion milling. The hand polishing required less than 60 minutes. The substrate material is Corning ULE.

The secondary mirror was shaped by Kodak and then subcontracted to The Optical Corporation of America as they have perfected a method to "stitch" together interferograms taken of a secondary mirror using an undersized Hindle sphere. We investigated the availability of a full size Hindle sphere within the United States, and found no suitable Hindle sphere for this large secondary mirror (64 cm diameter). The substrate material is Corning ULE.

The fourth order corrector plate (diameter 230 mm) was fabricated by DFM Engineering using the vacuum technique invented by Bernard Schmidt. The corrector blank is supported by a narrow ledge located just inside of the anti-chip bevel. The blank is then deformed a calculated amount and the first surface is ground and polished to a calculated long radius sphere. The second surface is then worked in a similar manner.

It is generally accepted that the vacuum technique works well for corrector plates that fully correct a sphere of F ratio slower than about F/2.5. The limiting factor is the stress induced in the glass when the blank is deformed under vacuum. This corrector is faster than F/2. The vacuum technique was successfully used because the corrector was made from fused silica which is considerably stronger than crown, the correction was divided between the two sides, and special procedures were incorporated in the processing of the blank.

The corrector blank was ground to the desired mechanical thickness using loose abrasives with a total 0f 0.7 mm removed from each side. One side was then polished to a long radius convex spherical surface. The polished surface was placed in tension in the vacuum chuck while the other surface was fine ground and polished. The corrector was then reversed and the second side ground and polished under the vacuum induced deformation. In this manner, a ground surface was never placed in tension. The corrector plate was also thinner than normally used to reduce the stress in the material when deformed under the vacuum and to allow deforming the corrector plate sufficiently with the atmospheric pressure available here in Colorado (1530 meters altitude)!

The vacuum technique typically allows a very smooth surface to be polished as the polishing is performed with a full sized lap. We have found that some control over the pitch is necessary to provide the proper figure. Usually the central part of the aperture needs to be raised. This was polished in using a ring lap. The total final grinding, polishing, and figuring time was less than 40 hours for the corrector plate.

4. OPTICAL TESTING

The primary mirror was interferometrically tested using an Offner type null lens. The secondary mirror was interferometrically tested using a sub aperture technique with an undersized Hindle sphere. The secondary mirror individual Interferograms were then "stitched" together.

The corrector plate was null tested in double pass by placing the corrector very close to an accurate concave spherical mirror. The test would have required testing at two widely different conjugate foci similar to testing an ellipse, but we chose to use the spherical mirror and a null lens. The null lens allowed the test to be performed at the equivalent center of curvature of the system. The testing was performed at an equivalent focal ratio of about F/1.

The corrector plate was tested using a knife edge and Ronchi grating. The diameter of the corrector plate was 230 mm, but the beam size is only 50 mm in diameter. The corrector plate is close to the focus requiring a smooth figure, but the overall correction is not very critical. The double pass through the corrector plate allowed Ronchi testing to provide sufficient accuracy. A small CCD camera was used to view the Ronchi bands and knife edge cutoff.

The overall system was interferometrically tested in double pass autocollimation. The focal plane was moved slightly to account for not testing with the filter glass or vacuum window. All three optical elements were polished by different optical shops, but when the system test was performed, no additional correction was required to meet the specifications.

5. TELESCOPE

The telescope mount is an equatorial fork mount with friction drives on both axes. The primary and secondary mirrors are spaced with Invar rods to minimize focus shift with temperature. Additionally there are bimetallic temperature compensation rods within the focus housing to further temperature compensate the optical spacing. For a slowly changing temperature, the optical tube assembly has an essentially zero temperature coefficient.

The tracking performance of the telescope is excellent. Open loop tracking with a total error of less than 1 arc second in 20 minutes was demonstrated. Particular care was exercised to accurately align the telescope on the refracted celestial pole to minimize field rotation.

1.3 Meter Telescope by DFM Engineering, Inc. for U.S. Naval Observatory

For more information on the equatorial fork mount features and benefits, please visit our web site.
www.dfmengineering.com

6. FIRST LIGHT IMAGES

Figure 4 shows a 17 by 17 arc minute field of view image recorded using a 1K by 1K CCD camera with 24 micron square pixels. The seeing was about 1.8 arc seconds FWHM. Since the first light images, additional images have been taken using a camera containing one of the 2K by 4K CCD chips that will be expanded into the mosaic camera. The single chip camera provides a field 20 by 40 arc minutes.

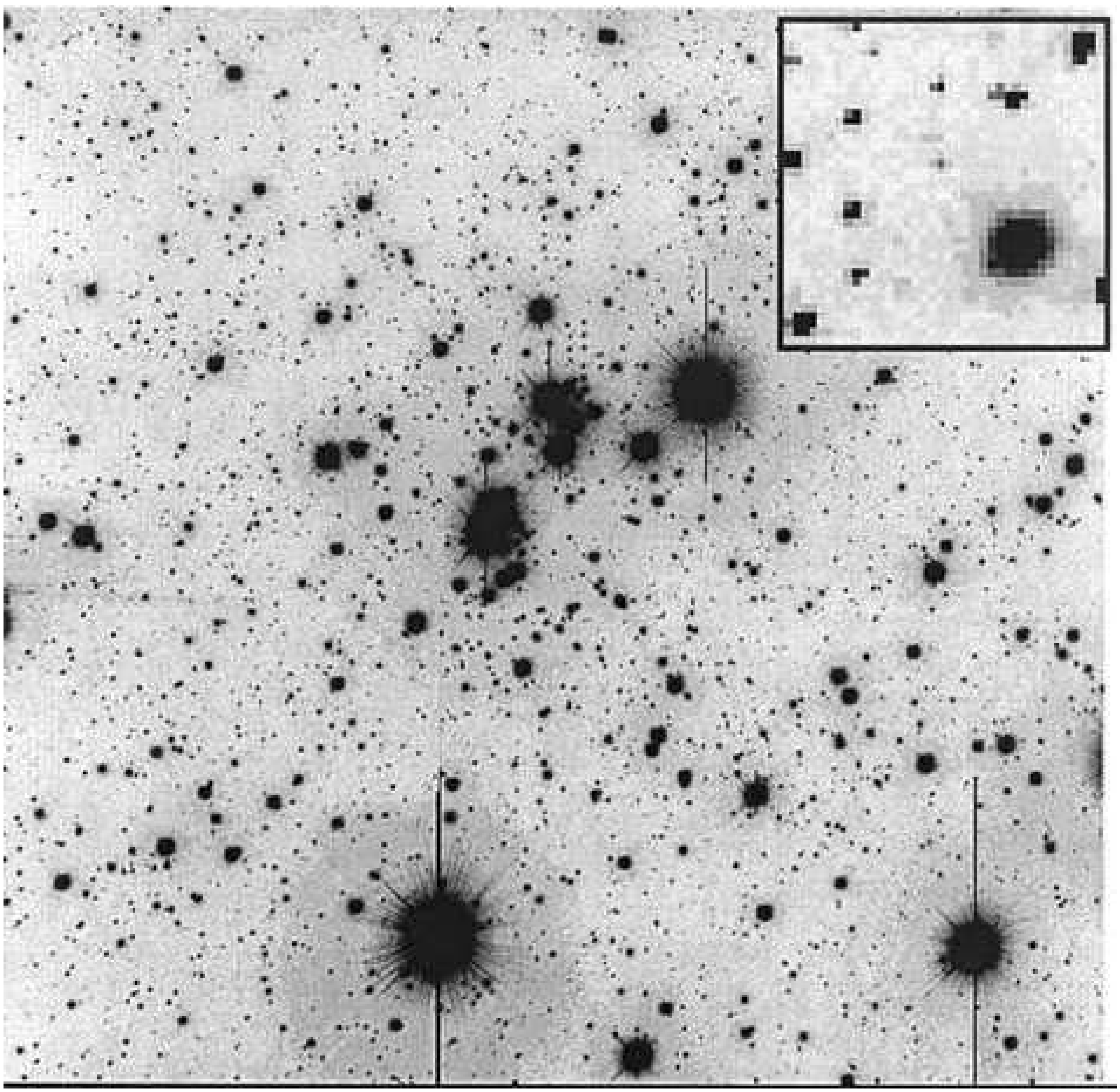

Figure 4. A first light 17 arc minute by 17 arc minute image of Chi Perseus.

Figure 5. The Orion Nebula taken with the 1 K by 1 K CCD camera.

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