SIMG-503

Senior Research

Focal Reducer/Wide-Field Corrector for the C. E. Kenneth Mees Telescope

Final Report

Laurie Tuttle

Center for Imaging Science

Rochester Institute of Technology

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Laurie Tuttle

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Title Page

Focal Reducer/Wide-Field Corrector for the C.E. Kenneth Mees Telescope

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Abstract

Introduction of CCD astronomical imaging has had a tremendous impact on the astrophysical community. The greatest advantage to CCD astronomical imaging is the phenomenal increase in efficiency when compared to photographic plate imaging. Images which previously required exposure times in the range of several hours can be captured in a matter of seconds using a CCD astronomical imaging system. The disadvantage to using a CCD for astronomical imaging is the loss of information capture due to the change in size of the detector area. Originally equipped with a Boller and Chivens 3" x 5" photographic plate, the Mees telescope provided a 0.4 degree full-field angle.

The purpose of the research was to design a focal reducer to reduce the focal ratio of the telescope system from f/13.5 to f/4.5 to enable a larger field of view to be imaged onto the smaller CCD detector area with a 9-um pixel size. Optics Software for Layout and Optimization(OSLO), lens design software was implemented for designing the system. The original goal to design the system using only readily available lens components from the OSLO database eliminates the need for expensive special order optics components.

Several focal reducer/wide-field corrector designs were configured using OSLO. None of the designs using only readily available lens database components met the design criterion. Determination has been made to abandon the restriction to the lens database components in favor of a customized focal reducer/wide-field corrector design. Preliminary research suggests two possible design configurations for the customized focal reducer/wide-field corrector. The first design would consist of a 6" diameter, f/2 collimating lens located at the telescope mounting flange followed by a f/4.5 fully corrected camera system. A second design would consist of a symmetrical Biotar focal reducer design. The Biotar design would require extensive optimization using OSLO. Preliminary research suggests the Biotar design might provide a more fully corrected system.

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Center for Imaging Science
Rochester Institute of Technology
Rochester, NY 14623-5604

This report is accepted in partial fulfillment of the requirements of the course SIMG-503 Senior Research.

Title: Focal Reducer/Wide-Field Corrector for the C.E. Kenneth Mees Telescope
Author: Laurie Tuttle
Project Advisor: Zoran Ninkov
SIMG 503 Instructor: Joseph P. Hornak

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Focal Reducer/Wide-Field Corrector for the C.E. Kenneth Mees Telescope

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Focal Reducer/Wide-Field Corrector for the C. E. Kenneth Mees Telescope

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Introduction

For centuries astronomers have been gathering information on celestial objects to uncover the secrets of our Universe. For the last several decades, astronomical photographic plate photography has been instrumental in the acquisition of celestial research data. Astrophotography using long exposure times has allowed astronomers to record "unseeable" faint stars.

Introduction of the Charge Coupled Device (CCD) image detector in 1970 has revolutionized Astrophotography. The major advantage to CCD astronomical imaging is the phenomenal increase in efficiency when compared to photographic plate imaging. The increase in efficiency has led to CCD astronomical imaging being adopted throughout the global astrophysical community for a majority of astrophotographic imaging applications.

The inherent problem in using CCD astronomical imaging with a telescope system that was designed for photographic plate photography is the loss of information capture due to the change in size of the detector area. The goal of the research was to eliminate this problem for the Mees telescope, CCD imaging system by designing a focal reducer/wide-field corrector. The focal reducer/wide-field corrector would be used in conjunction with the Mees telescope, CCD imaging system to increase the field of view being imaged onto the smaller CCD detector area. The increased field angle of the telescope, CCD imaging system would allow information capture over the same area as the photographic plate imaging system.

Background

The C. E. Kenneth Mees telescope is housed in the C. E. Kenneth Mees Observatory in Bristol, New York. Owned by the University of Rochester, the Mees Observatory is used by faculty and students pursuing research in physics and astronomy [1].
The C. E. Kenneth Mees telescope was constructed in 1964. The design is a 24" Boller and Chivens classical Cassegrain reflecting telescope. The system is a f/13.5 with a full-field angle of 0.4 degrees. It was originally equipped with a Boller and Chivens 3" x 5" photographic plate for astronomical imaging.

Figure 1: Boller and Chivens 24" Reflecting Telescope

Despite vast improvements in photographic emulsions the efficiency of a photographic plate is still only 3 to 4% at best. This means that for every 100 photons that strike the photographic plate only 3 or 4 react with the silver in the film's emulsion to produce an image. The efficiency of the front side illuminated CCD camera is 50% or more. Compared to the photographic plate this represents a phenomenal increase in sensitivity.

The increase in sensitivity relates to an overall shortening of exposure times that is astounding. Using the CCD camera the exposure time required to capture the same information as an hour-long exposure using a photographic plate can now be captured in as little as a few seconds. The exposure times for imaging the faintest celestial objects using a CCD camera may still be measured in terms of one or two hours. This time is relatively short when compared to the twenty or more hours that would be required to gather enough information to record the same image with a photographic plate. In addition, there is no reciprocity failure as encountered in long duration astrophotography due to the CCD response which is a linear function of incident flux and exposure time [2].

Perhaps the most exciting revolution in CCD imaging is the ability of the CCD camera to be able to capture the results of an exposure and immediately have them displayed on a computer screen where they can be visually inspected. This gives the astronomer convenient access to determine if a problem with the exposure might exist and presents the option to readily capture a new image of the celestial object. This offers a significant advantage over a process that may have spanned over a number of days with photographic plate exposures. Previous to CCD astronomical imaging the astronomer would not be certain of the quality of his images prior to development of the photographic plate at which time the celestial positioning or the atmospheric conditions may not prove conducive for re-imaging.

The CCD provides for a simpler and more effective way to obtain scientifically valuable results when compared to photographic imaging techniques. A major advantage over photographic plate photography is that CCD imaging allows for precise measurements of celestial object parameters such as brightness, position, and dimensional analysis that photographic images do not readily contain.

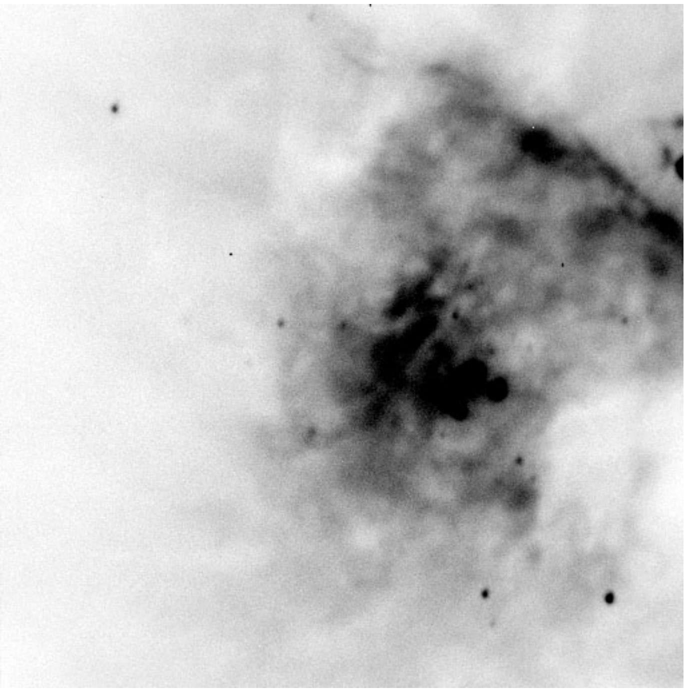
The data collected using CCD astronomical imaging will provide scientists and research students using the Mees Observatory with a compendium of information. The large database of astronomical images available due to the Mees telescope, CCD imaging system will enhance their investigation and ability to gain insight into the astronomical and physical aspects of our universe.

Currently the Mees telescope is used in conjunction with a Kodak PXL CCD camera. The detector area of the CCD array of the camera is 36-mm x 36-mm with a 9-um pixel size. The size of the CCD array is ultimately the limiting factor for the field of view of the CCD camera. In addition, the size of the CCD array is the limiting factor for the field of view for the telescope/CCD camera system. Comparison of photographic plate size to CCD detector array size would indicate that there is an approximate 7.5 times larger plate size for the 3" x 5" photographic plate over the 36-mm x 36-mm CCD array size. This corresponds to a larger field at the Cassegrain focus for the photographic plate than for the CCD detector. The larger photographic plate size provides for an image that captures a larger field of view of the object as compared to the imaged field that can be captured using the CCD camera.

The purpose of the focal reducer/wide-field corrector is to reduce the focal ratio of the 24" reflecting telescope system by a factor of three, from f/13.5 to f/4.5.to enable a larger field of view to be imaged onto the smaller detector area. This will create a correspondingly larger field of view for the telescope/focal reducer/wide-field corrector system that in turn could be imaged onto the fixed field of the CCD camera. The focal reducer/wide-field corrector will increase the scale on the CCD from its current plate scale of 0.2-arcseconds/ 9-um pixel to 0.6-arcseconds/ 9-um pixel.

The image of the Orion Nebula captured with the Mees telescope using a back thinned CCD and tunable filter is evidence of the need for the wide-field corrector for the Mees, CCD imaging system. With seeing at approximately 2.5-arcseconds half-width full maximum this image is representative of the over-sampling for the Mees, CCD imaging system.

Figure 2:
Oversampling: Orion Nubula Imaged with the Mees Telescope using a Back Thinned (512 x 512) CCD with 24-um pixels and Tunable Filter.



Over sampling with the Mees telescope/CCD system. Full-width at half-maximum 12.5 pixel coverage.

Mees telescope full-width at half-maximum 2 pixel coverage.

Technical papers presented in recent years demonstrate an increasing need for customized focal reducer/wide-field corrector designs for use with existing telescopic imaging systems. Research of focal reducer designs provided several preliminary design configurations for use with the Mees focal reducer/wide-field corrector. The most widely used design configuration in the literature consisted of a combination of a collimating lens and a symmetrical achromatic camera system 3.
This design provided the starting point for the Mees focal reducer/wide-field corrector.

A focal reducer is used to increase the speed of slow systems in order to obtain shorter exposure times for astrophotography or to increase the angular field of the system. A focal reducer is a positive system of lenses, which is placed in the converging beam of the objective with the aim of decreasing the focal length of the objective 4. The focal reducer by nature of being a positive lens system has the tendency to produce a focal surface that is more strongly curved than the surface of the telescope objective it replaces. To correct for this it is necessary to design the focal reducer to be overcorrected for astigmatism.

To effectively bypass this situation a focal reducer/wide-field corrector design that consists of achromatized lenses should be used to effectively reduce the focal length to provide a wider field for the system. When an achromat is used as a focal reducer with positive power the positive lens should be composed of crown glass, while the negative lens is a flint glass. The powers of the positive and negative lens components for a wide-field corrector will follow the thin lens achromatization formula quite closely 5. According to the achromatization formula the focal lengths of the positive and negative lens components of an achromat doublet are inversely proportional to the Abbe numbers of the glasses of the lens components. The wide-field corrector would use a symmetrical set of achromatized doublets to reduce aberrations to a minimum.

Optics Software for Layout and Optimization (OSLO) lens design software was implemented for designing the focal reducer/wide-field corrector. The original goal was to design the system using only readily available lens components from the OSLO database.

The first step in the design was to characterize the current overall capabilities of the Mees telescope system. This was done using OSLO analysis routines generated over a range of wavelengths from 400-nm through 900-nm. The extension from the visual range of wavelengths into the near infrared region corresponds to the spectral sensitivity of the CCD camera.

Ray trace analysis provides information on the lens system design in regards to the geometrical optics associated with the system such as astigmatism, longitudinal spherical aberration, and distortion. In addition the ray trace analysis provides information on the input lens design in terms of the propagation of wavefronts through the optical system such as wavefront analysis, spot diagrams and modulation transfer functions 6.

A complete geometrical analysis including aberrations, ray trace and spot diagrams were generated with OSLO routines to characterize the performance of the model for the Mees telescope design. The geometric analysis was constructed using a range of off-axis ray traces through the system. A complete physical optical analysis including wavefront, MTF, and spread functions were generated with OSLO routines to characterize the performance of the model for the Mees telescope design.

Ray tracing with OSLO gives exact results for the particular rays traced. The basic concept used in ray tracing with OSLO is that light energy flows along rays, so that by determining the trajectory of a ray through an optical system, you can find paths along which the energy flows through the system. This provides an excellent characterization of the system performance of the model for the Mees telescope to the extent that the traced rays are representative of the other rays that traverse the telescope system.

Paraxial ray trace analysis using OSLO was used to find reference values for a given lens design system by computing the Gaussian constants that provide a first order description of the optical system. In addition to the paraxial ray trace analysis the exact ray calculation analysis for rays near the edge of the pupils and for off-axis object points provides essential information for analyzing system performance. The differences between the paraxial ray analysis values and the exact ray analysis values computed with OSLO provide a measure of the performance of the optical design system.

These differences describe the aberrations in the optical system design. It is the goal of the design process to make aberrated rays coincide with the paraxial rays for optimization of the system. A thorough description of aberrations in telescope designs, including extensive equations for calculating aberrations for different telescope systems can be found in either of the following references; Advanced Telescope Making Techniques; Volume 1, Optics 7. or Astronomical Optics 8.

OSLO computes three groups of aberrations. These groups are the chromatic aberration, the Seidel, and fifth-order aberrations. When a concave, focusing mirror is used as the objective as in the case of the Mees telescope there is no chromatic aberration due to the fact that there is no refraction associated with the primary mirror. The Seidel aberrations are composed of the third-order spherical aberration, coma, astigmatism, field curvature and distortion.

OSLO provides the resultant coefficients of the various aberrations as a result of the paraxial and exact ray trace analysis. In addition, this information can be displayed as a function of axial performance, or in the case of distortion, as a percentage.

OSLO uses spot diagram analysis to trace a large number of rays from a single point through several aperture coordinates of the lens design system. The data for any particular ray can be treated statistically if enough rays are traced through the aperture coordinates. The information from the spot diagram analysis provides more detailed information about the quality of the image of the lens design system. The spot diagram serves as a basis for a variety of image evaluations, including wavefront analysis. The wavefront analysis can be used as a measure of the diffraction associated with the lens design system. This serves as an aid in determining the resolution of the lens design system.

Methods

Mees Model

The Mees telescope model was constructed using the Boller and Chivens optical diagram for the Mees telescope with OSLO.The system analysis of the model for the Mees telescope, designed using OSLO was implemented to determine the basis for design optimization for the proposed wide-field corrector design system. The optimal wide-field corrector design for the Boller and Chivens 24" Cassegrain reflecting telescope will limit any deviation from the existing performance parameters of the current Mees telescope design to a minimum.

By comparison of the analysis performed on the model for the Mees telescope using OSLO ray tracing routines and analysis of the Mees model telescope/focal reducer/wide-field corrector combination the focal reducer/wide-field corrector design will be optimized. Optimization will result in performance parameters being as close to the performance parameters of the Mees telescope as possible to avoid introduction of any additional aberrations to the system.

Ray trace analysis for the model of the Mees telescope design was performed using OSLO lens design and optimization routines. The ray trace analysis was performed using wavelength parameters of 0.400-um, 0.600-um, and 0.900-um. The wavelengths represent the accommodation of the range of wavelengths for use with the focal reducer/wide-field corrector/Mees telescope/CCD astronomical imaging system.

Spot diagram analysis for the Mees model telescope design was performed using OSLO lens design and optimization routines. The spot diagram analysis was performed using wavelength parameters of 0.400-um, 0.600-um, and 0.900-um.

Focal Reducer/Wide-Field Corrector

The focal reducer/wide-field corrector design parameters were calculated using the focal length design equation for a focal reducer 9.

Equation 1:
The Focal Reducer Equation for Calculating the Focal Length Combination for the Focal Reducer/Wide-Field Corrector System.

$$Fcomb. = \frac{Fo + Fr}{Fr + d}$$

Where:

Fcomb = focal length combination for the wide-field corrector/Mees telescope

Fo = focal length of the Mees telescope

Fr = focal length of the focal reducer/wide-field corrector

d = the distance inside the Cassegrain focal plane

Preliminary calculations suggested a focal length for the reducer/corrector ranging from 750-mm to 3000-mm for the available distance inside the Cassegrain focal plane for the system. The Mees telescope model was implemented to configure the wide-field corrector using the OSLO lens component database. The OSLO lens component database consists of a variety of singlet and doublet lens components in addition to a select group of special optics gradient and aspheric components from a number of major manufactures including Melles Griot, Spindler and Hoyer, and Edmund Scientific.

Using the OSLO lens database proved to be ineffective for the original collimator/camera lens configuration. The problem was introduced as a result of the 150-mm large diameter optics needed for the telescope/focal reducer/wide-field corrector system. The OSLO lens database offered a handful of achromats in the range of 900-mm to 1000-mm. The largest lens diameter offered in this range was 100-mm. The effective focal lengths in the range of 1500-mm to 2000-mm were offered in the 150-mm diameter.

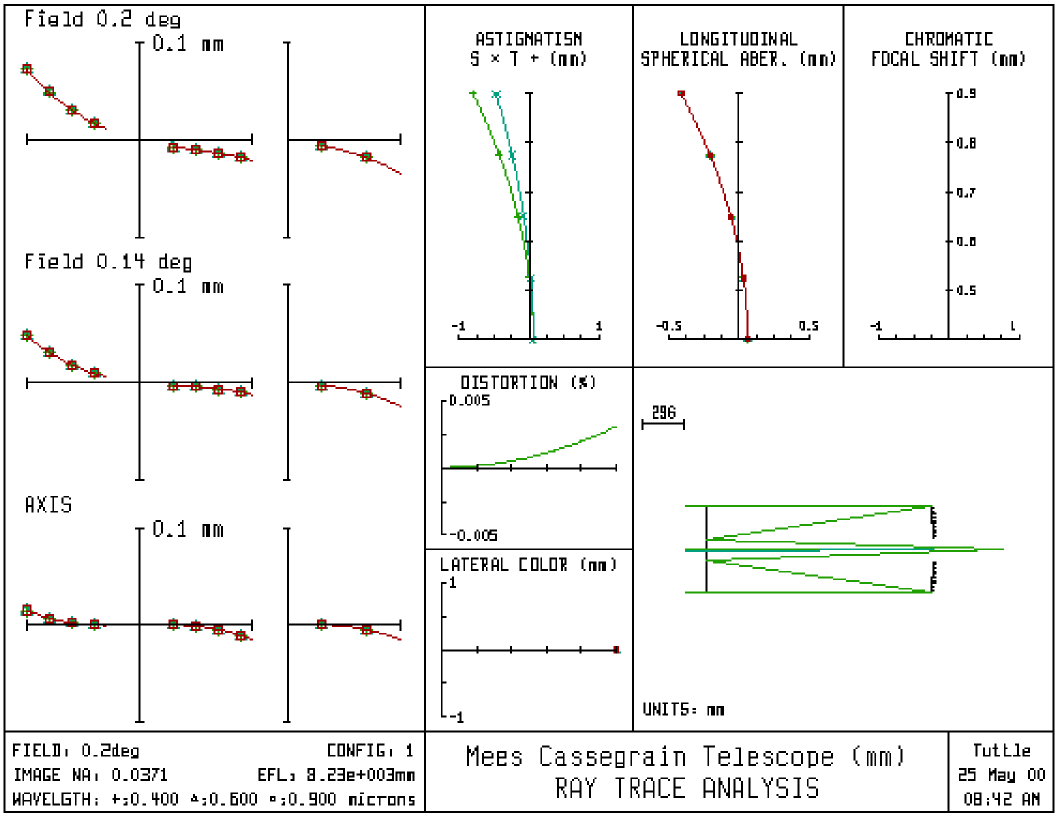
The second method used to configure the focal reducer/wide-field corrector using only lens database components was to set the desired 0.6 degree half-field angle of the system as a constrained design parameter prior to adding any lenses to the Mees model. This method produced several wide-field corrector designs using OSLO with the spot size as the optimizing design parameter.

Results

Mees Model Telescope

The ray-trace analysis for the model of the Mees telescope design was performed using OSLO lens design and optimization routines. The ray trace analysis was performed using wavelength parameters of 0.400-um, 0.600-um, and 0.900-um. The wavelengths represent the accommodation of the range of wavelengths for use with the focal reducer/wide-field corrector/Mees telescope/CCD astronomical imaging system.

Figure 3: C.E. Kenneth Mees Telescope Ray-Trace Analysis for 0.600-um.



Astigmatism occurs in the reflecting optical system when an object point lies some distance from the axis of the mirror. The incident rays make an appreciable angle with the mirror axis resulting in an image of two mutually perpendicular lines being formed as the ray strikes the mirror asymmetrically 10. The astigmatism for the Mees model telescope with a wavelength of 0.600-um is 62.5-um on axis covering approximately 7 pixels. The astigmatism is within 1000-um for the tangential and sagital planes at the edge of the field Mees model telescope.

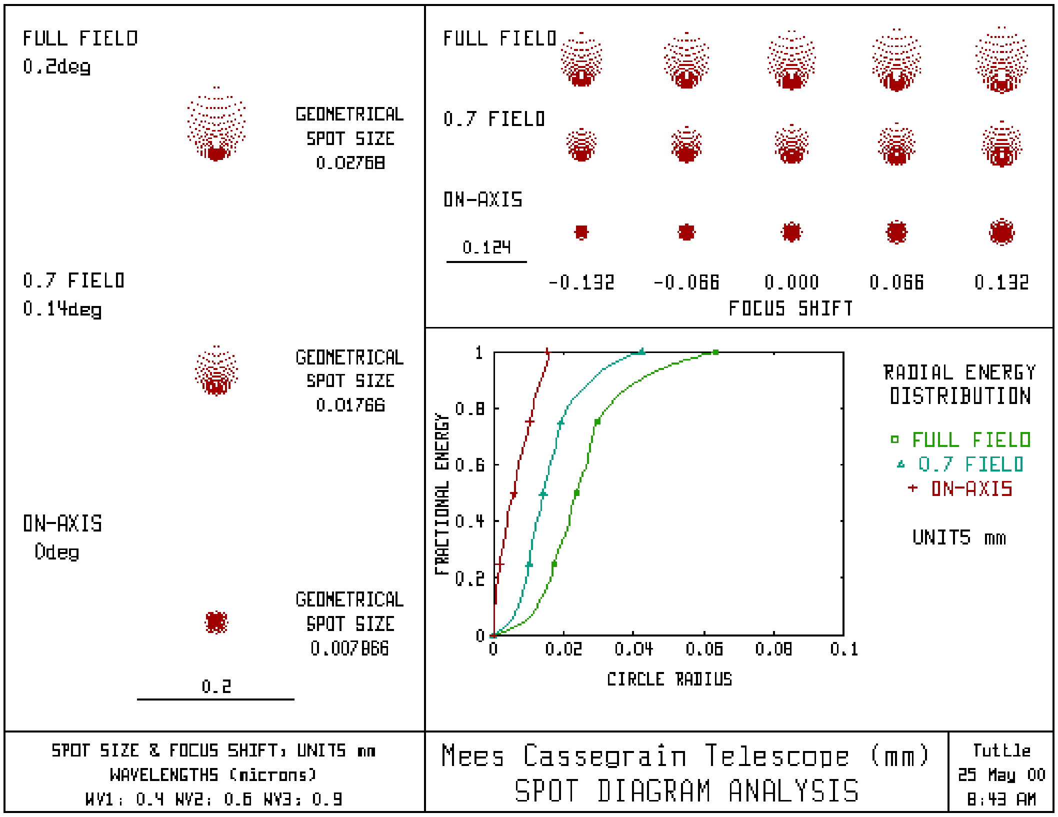
The longitudinal spherical aberration is the distance between the axial intersection of a ray and the first order focus. Spherical aberration results from the fact that when light is not confined to the paraxial region rays from an object point do not come to focus at a common point in the image plane11. The longitudinal spherical aberration for the Mees model telescope with a wavelength of 0.600-um is 62.5-um on axis covering approximately 7 pixels and within 500-um at the edge of the field.

The chromatic focal shift for the Mees model telescope is 0 as would be expected for a reflecting optical system.

To be free from distortion a system must have uniform lateral magnification over the entire field. The distortion for the Mees model telescope with a wavelength of 0.600-um is 0 % on axis and within 0.0025 % at the edge of the field.

Spot diagram analysis for the Mees model telescope design was performed using OSLO lens design and optimization routines. The spot diagram analysis was performed using wavelength parameters of 0.400-um, 0.600-um, and 0.900-um.

Figure 4: C.E. Kenneth Mees Telescope Spot Diagram Analysis for 0.600-um.



The aberration coma is due to the fact that the principal planes can actually only be treated as planes in the paraxial region. The principal planes are principal-curved surfaces. Coma is caused by the change in magnification off-axis due to the principal curved surfaces.

The on-axis spot size for the Mees model telescope is 7.866-um. The full-field spot size is 27.7-um due to the appreciable off-axis coma.

The radial energy distribution for the Mees model telescope with a wavelength of 0.600-um suggests that 80 % of the fractional energy is contained within 15-um. This corresponds to 80 % of the fractional energy on axis being confined to a 2 pixel plate-scale. The radial energy distribution for 80 % of the fractional energy for seven-tenths of the field is within 20-um or just over 2 pixels.

Included for discussion are two of several design configurations generated using OSLO optimization routines. They are presented as focal reducer/wide-field corrector designs for the C.E. Kenneth Mees telescope. The first design was able to meet the original design criterion of producing a f/4.5 focal reducer/wide-field corrector/telescope system. Evidenced from the ray-trace analysis for the system it is a completely unacceptable design for producing quality imaging.

F/4.5 Focal Reducer/Wide-Field Corrector Design

The f/4.5 wide-field corrector design is a three component lens system. The first lens component of the system is a 150-mm diameter, 15.00-mm thick, 503.851-mm effective focal length Spindler and Hoyer plano-convex singlet lens located 490-mm inside the Cassegrain focus. The first component is followed by a 98.988-mm diameter, 22.085-mm thick, 1001.760-mm effective focal length Spindler and Hoyer air-spaced achromat lens component at a distance of 39.00-mm from the first lens component. The third component is an 80-mm diameter, 29.400-mm thick, 310.015-mm effective focal length Spindler and Hoyer air-spaced achromat component located 65.67-mm from the wide-field corrector imaging plane.

Figure 5: F/4.5 Focal Reducer/Wide-Field Corrector Design.

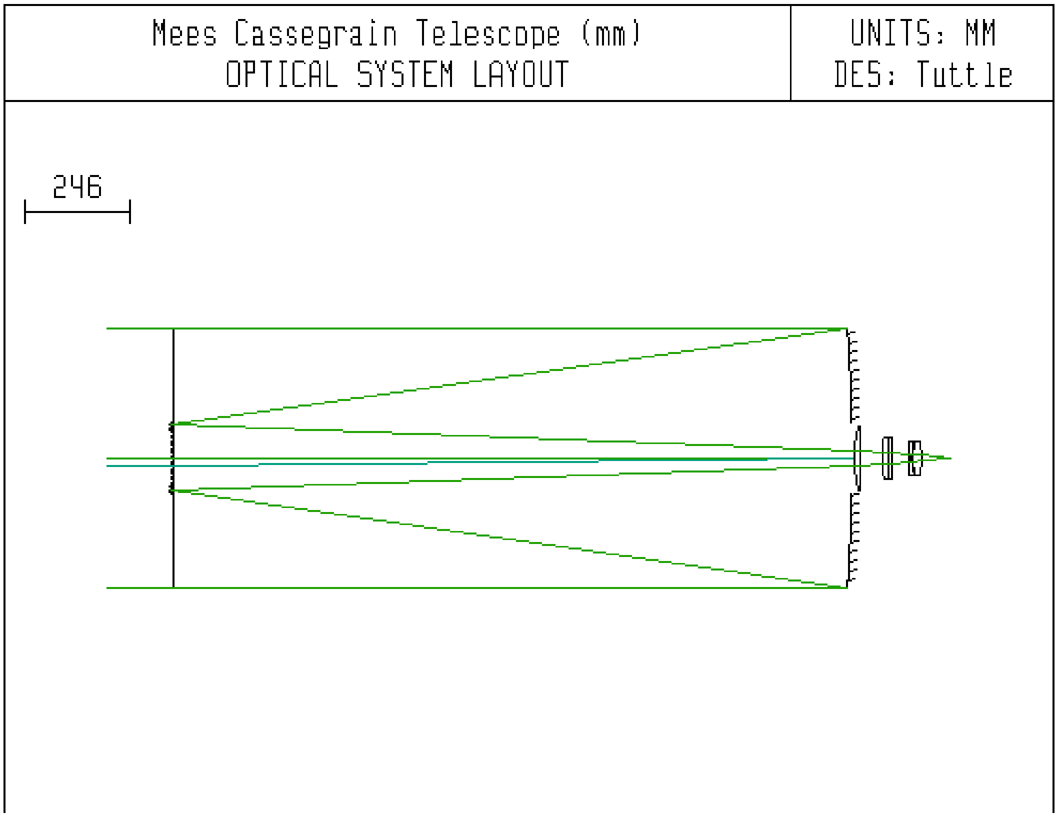
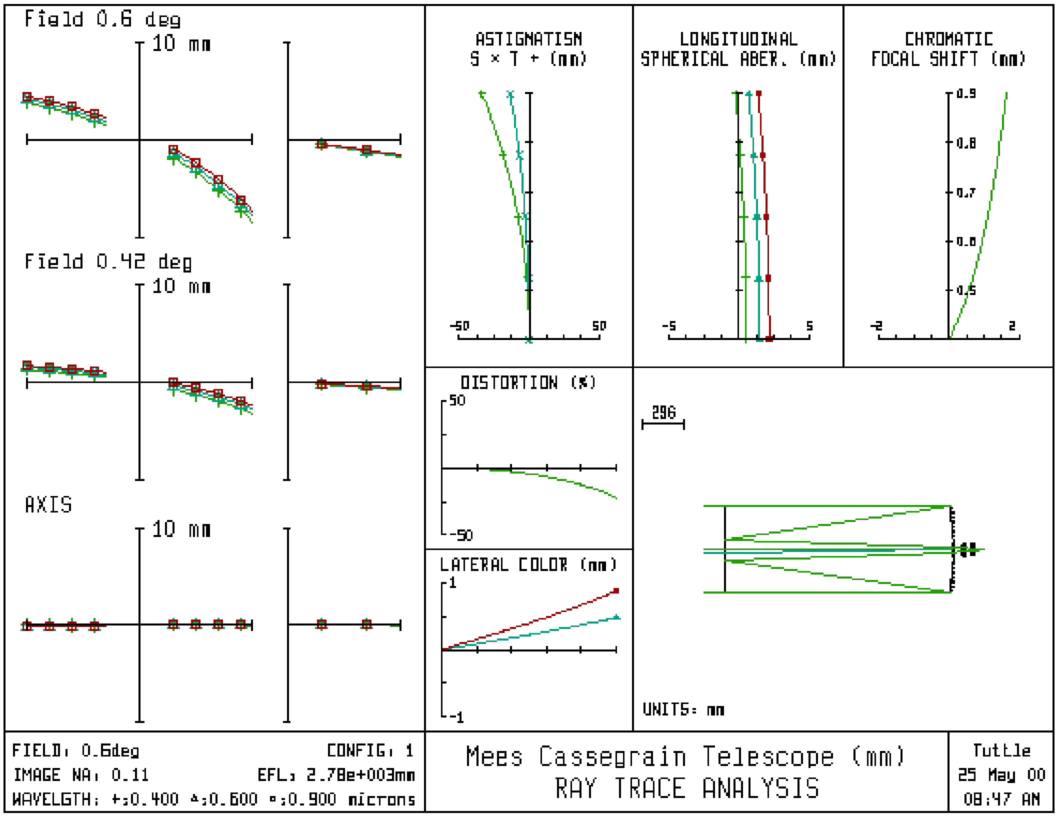
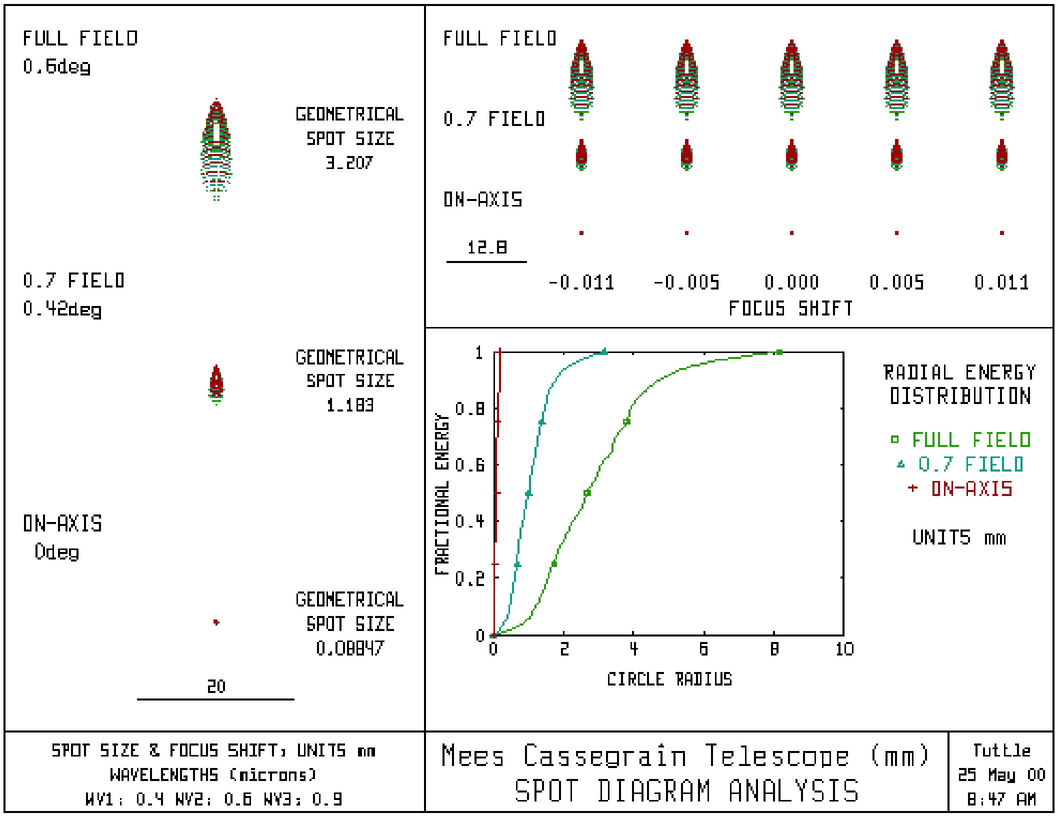


Figure 6: Focal Reducer/Wide-Field Corrector Telescope f/4.5 System Ray-Trace Analysis for 0.600-um.



The spot diagram analysis for the f/4.5 focal reducer/wide-field corrector telescope system design confirms the poor quality of the design.

Figure 7: Focal Reducer/Wide-Field Corrector Telescope f/4.5 System Spot Diagram Analysis for 0.600-um.



The second focal reducer/wide-field corrector design is a f/9.29 system. This design provides a system that will produce a much better image than the design that met the required f/4.5 system requirement. This design will not provide the angular coverage required for the wide-field corrector/ telescope system.

F/9.29 Focal Reducer/Wide-Field Corrector Design

The f/9.29 focal reducer/wide-field corrector design is a single achromatic lens component system. The achromatic lens component is a 150-mm diameter, 24.630-mm thick, 1000.200-mm effective focal length MG precision optical achromat lens located 475-mm inside the Cassegrain focus.

Figure 8: F/9.29 Focal Reducer/Wide-Field Corrector Design.

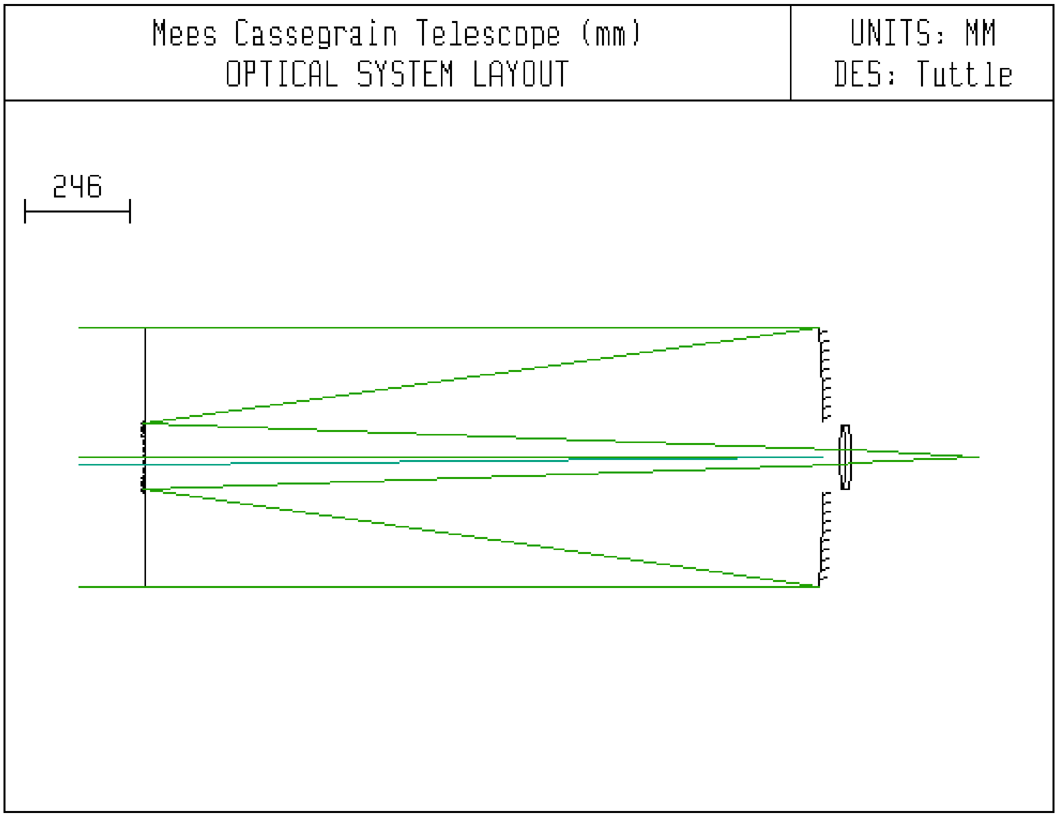


Figure 9: Focal Reducer/Wide-Field Corrector Telescope f/9.29 System Ray-Trace Analysis.

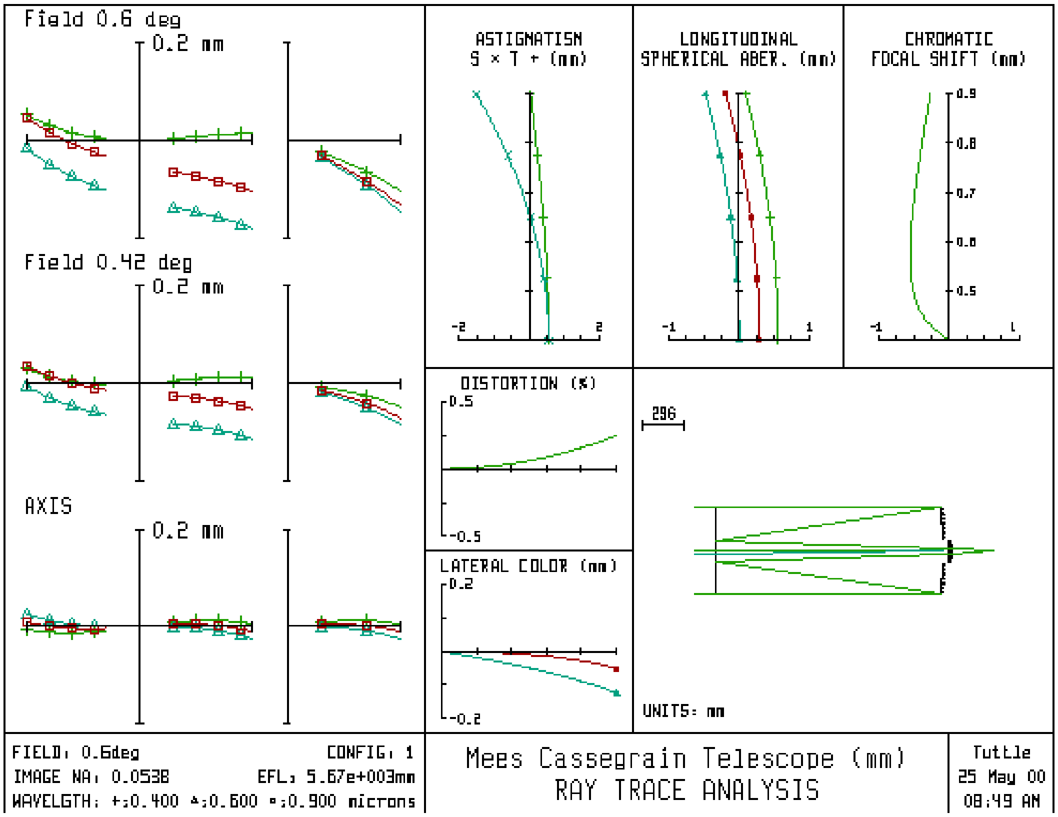


Figure 10: Focal Reducer/Wide-Field Corrector Telescope f/9.29 System Spot Diagram Analysis.

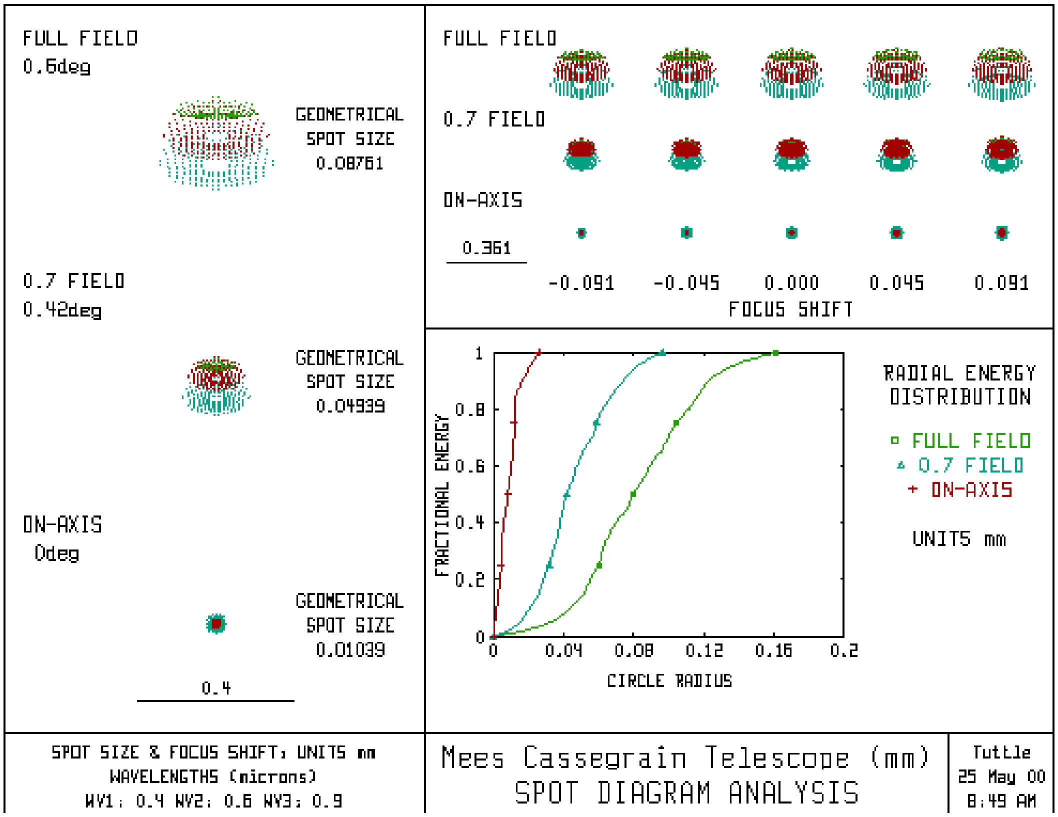


Table 1 is the tabulated results of the design parameters for the Mees model telescope, the f/4.5 focal reducer/wide-field corrector design, and the f/9.29 focal reducer/wide-field corrector design.

Table 1: Mees Model Telescope/Focal Reducer/Wide-Field Corrector Design Parameters.

System	Astigmatism-um	Longitudinal Spherical Aberration-um	Distortion-%	Geometrical Spot Size-um	Focus Shift-um	80% Fractional Radial Energy Distribution-um
Mees Model						
On-Axis	62.5	62.5	0	7.866	0	10.4
7/10 Field	-375.0	187.5	0.001501	17.66	99	20.0
Full Field	-812.5	-406.25	0.003064	27.68	197	31.9
F/4.5						
On-Axis	0	2.08 x 10	0	88.47	0	80.0

7/10 Field	16.7 x 10	1.67 x 10	-9.330496	118.3	5	1.36 x 10
Full Field	31.3 x 10	1.25 x 10	-22.19437	3207.0	11	3.84 x 10
F/9.29						
On-Axis	560.0	560.0	0	10.39	0	11.8
7/10 Field	-560.0	320.0	0.118784	49.39	45	43.9
Full Field	1520.0	-480.0	0.247280	87.61	91	111.5

Discussion

The Mees model telescope ray-trace analysis and spot diagram analysis serve to characterize the optical performance of the C. E. Kenneth Mees telescope. They were used to optimize the focal reducer/wide-field corrector system to ensure that the focal reducer/wide-field corrector introduced minimal aberrations into the system. For a complete discussion of OSLO ray trace techniques including ray-trace analysis, and spot diagram analysis refer to OSLO Version 5 Optics Reference 12.

Results of the ray-trace analysis for the f/4.5 focal reducer/wide-field corrector/telescope system provide evidence that the system is a completely unacceptable design for producing quality imaging. The distortion introduced into the system increased from 0.003064 % for the Mees model to 22.19437 % for the focal reducer/wide-field corrector. Longitudinal spherical aberration increased from 62.5-um on-axis for the Mees model to 2080- um for the focal reducer/wide-field corrector.

The spot diagram analysis for the f/4.5 focal reducer/wide-field corrector/telescope system confirms the unacceptable image quality for the design. The geometrical spot size on-axis went from 7.866-um for the Mees model to 88.47-um on-axis for the focal reducer/wide-field corrector system.

Results of the ray-trace analysis for the f/9.29 focal reducer/wide-field corrector/telescope system provided results that are significantly closer to the optimized Mees model telescope. The distortion introduced into the system increased from 0.003064 % for the Mees model to 0.247280 % for the focal reducer/wide-field corrector. Longitudinal spherical aberration increased from less than 62.5-um on-axis for the Mees model to 560-um for the focal reducer/wide-field corrector.

The spot diagram analysis for the f/9.29 focal reducer/wide-field corrector/telescope system provided a geometrical spot size on-axis went from 7.866-um to10.39-um for the focal reducer/wide-field corrector system. This represents an approximate 32.09 % geometrical spot size increase for the focal reducer/wide-field corrector system over the 7.866-um geometrical spot size for the Mees telescope model. The on-axis radial distance for the 80% radial energy distribution for the f/9.29 focal reducer/wide-field corrector/ telescope system increased by approximately 14 % over the on-axis radial distance for the 80% radial energy distribution of the Mees telescope model. The significant increase in on-axis radial distance for the 80% fractional energy, coupled with the addition of aberrations introduced as a result of the refracting lens components suggests a more suitable wide-field corrector design should be considered.

Trial and error methods for designing the focal reducer/wide-field corrector for the Mees telescope within the constrained lens database proved to be a tedious procedure. Consultation with an optical engineering consultant validated the results and confirmed the need for a customized focal reducer/wide-field corrector system for the C. E.

Kenneth Mees telescope.

Conclusions

Several focal reducer/wide-field corrector designs were configured using the OSLO lens database components. None of these designs were able to meet the design criterion using only the readily available lens database components. Determination has been made to abandon the restriction to the lens database components in favor of a customized focal reducer/wide-field corrector design. Preliminary research suggests two possible design configurations for the customized focal reducer/wide-field corrector. The first design would consist of a 6" diameter; f/2-collimating lens located at the telescope mounting flange followed by a f/4.5 fully corrected camera system. A second design would consist of a symmetrical Biotar focal reducer/wide-field corrector design. This design would require extensive optimization using OSLO. Preliminary research suggests the Biotar design might provide a more fully corrected system.

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Focal Reducer/Wide-Field Corrector for the C. E. Kenneth Mees Telescope

Laurie Tuttle

List of Symbols

Symbol	Definition
CCD	Charge Coupled Device
OSLO	Optics Software for Layout and Optimization
nm	nanometers
mm	millimeters
um	micrometers

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