All-Spherical Catadioptric Gregorian Optical Designs for Meter Class Telescopes

Peter Ceravolo
Ceravolo Optical Systems
www.ceravolo.com

Abstract

Two all-spherical catadioptric Gregorian telescope designs suitable for meter class telescopes are described. Common to both designs are a group of small, conventional lenses placed at the intermediate focus of the Gregorian system to correct the aberrations of the high-speed (f/1.5) spherical primary mirror and spherical secondary mirror. In the first design, a classic Gregorian configuration, the secondary mirror amplifies the focal length of the primary to yield a typical f/8 beam. A second configuration is illustrated that has the secondary mirror reducing the primary's focal length resulting in a higher-speed, (f/1) imaging system.

Introduction

Prior to the development of computer-aided optics fabrication, the elimination of aspheric surfaces in reflective telescope optics was desirable. The imperfect imaging properties of spherical mirrors are best corrected with lenses at the system's pupil or, in other words, the use of full aperture correctors as in the classic Schmidt telescope. But the massive lenses required become optically, mechanically and thermally impractical when the system's aperture exceeds 0.5 m. While the aspheric surfaces typically found on large telescope mirrors are no longer the headache they once were to fabricate, exploring design forms that eliminate the use of aspherics is still a worthwhile exercise.

The idea of using a group of relatively small lenses at the intermediate focus of a classic Gregorian telescope (parabolic primary, elliptical secondary and focal plane behind primary) has been used to improve field correction at the final focus. This paper demonstrates that it is possible to use similar corrective lenses at the same location to compensate for the massive spherical aberration of an all-spherical Gregorian mirror system. The second example of the all-spherical Gregorian design has the secondary mirror acting as a focal reducer, increasing the speed of the f/1.5 primary to f/1.

The principal limitation of the all-spherical classic Gregorian design form is the restricted field of view caused by the location of the corrective lenses within the centrally obscured region of the converging cone of light. The field of view of the high-speed variant is hampered by the non-optimal position of the focal plane, within the centrally obscured beam, resulting in the need for a compact detector package.

Design Approach

The challenge of eliminating a fast spherical primary mirror's considerable spherical aberration at the infinity focus with a small, simple lens system seems daunting, but the correction of large amounts of spherical aberration is accomplished regularly in optical shops when null test techniques are applied to aspheric mirrors at the center of curvature. The Offner null test, Figure 1, corrects the spherical aberration of a mirror at the center of curvature with two small, simple lenses. One relay lens corrects the primary spherical aberration while the second lens corrects the higher order spherical aberration residuals. The all-spherical catadioptric Gregorian design was conceived by applying Offner's spherical aberration correction technique to a telescope mirror at its infinity focus.

Null tests are performed using a monochromatic light source; consequently the large chromatic aberration in the Offner null system is not an issue. Adapting the null lens concept to a panchromatic imaging system necessitates replacing the positive relay lens with a concave mirror to avoid overwhelming color dispersion. The secondary mirror's image conjugates are chosen to place the focal plane at an easily accessible point behind the primary mirror. The resultant optical system now resembles the Gregorian configuration with a field lens at the intermediate focus. In practice more than one lens is required at the intermediate focus to achieve the desired aberration correction.

The initial design of the system, once the basic approach was conceived, was surprisingly easy: A Gregorian mirror system was laid out and four zero power meniscus lenses were placed symmetrically around the intermediate focus. A simple merit function was constructed to constrain the size of the corrective lenses to fit within the obscured portion of the beam. After several trials the design quickly converged toward a practical system that provided reasonable images.

Ideal performance can be achieved with as few as four small lenses of conventional glass types, figure 2. Allowing the elements to be very thick, figure 9, with an aspect ratio of 1:1 or greater serves to reduce the number of corrector lenses but at the expense of bulk scatter within the substrate. Other design forms have been explored that use only one glass type (silica) for the corrective lenses for enhanced UV transmission. While this option was not explored, it should be possible to design a system with lens substrates suitable for the IR. Smaller aperture designs have been formulated; it was found that a mangin secondary, figure 9, was required to yield the desired performance.

Practical Issues

A simple visual examination of the ray paths, figure 3, around the corrector group suggests that the steep incident angles will pose some challenges during construction and alignment of this system. The lenses themselves do a significant amount of ‘work’ to compensate for the mirror’s aberrations and therefore will be sensitive to manufacturing and mounting errors. The first and last surfaces of the corrector group in the example illustrated below are the most sensitive as they do the most of the work to correct the large spherical aberration of the mirror combination. Aligning the spherical primary with the secondary/corrector lens subassembly is a straightforward tip/tilt task, as the primary has no discrete optical axis. However, the primary’s radius of curvature must be controlled to within 0.05% or less since a small variation will result in a significant change in its spherical aberration contribution.

1Meter All Spherical Gregorian Telescope

The 1-meter aperture f/8.5 design, figure 2, is diffraction limited in the central visual part of the spectrum using only four corrective lenses of conventional glass types with the largest lens being only 80 mm diameter. The spot diagrams, figure 4, illustrate the performance of the system over a 1k square CCD array of 24 micron (0.55 arc second) pixels. The image size over the broad spectral range of 360 nm to 1 micron is no larger than 1 arc second (corresponding to a 2x2 array of 24 micron pixels) across much of the central area of the detector's field, with degradation occurring in off axis images only at the extreme ends of the spectrum.

Prescription Data

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Title: 1 Meter All Spherical Catadioptric Gregorian Telescope
All dimensions in millimeters

Entrance Pupil Diameter :           1060
Effective Focal Length  :           9000
Image Space F/#         :       8.490566
Total length            :       2946.298
```

SURFACE DATA SUMMARY:

Surf	Type	Radius	Thickness	Glass	Diameter
OBJ	STANDARD	Infinity	Infinity		0
1	STANDARD	Infinity	2300		0
STO	STANDARD	-3256.573	-1505.802	MIRROR	1060.167
3	STANDARD	118.6191	-10.30369	BAK4	78.95786
4	STANDARD	-244.7791	-1.000114		76.64665
5	STANDARD	-98.83866	-22.97498	SK18A	76.67311
6	STANDARD	602.551	-192.429		72.03239
7	STANDARD	1276.971	-17.90319	SK16	69.32805
8	STANDARD	98.83866	-0.9999581		73.86686
9	STANDARD	-1443.362	-6.369977	SK4	75.42739
10	STANDARD	-121.0674	-456.9428		76.55445
11	STANDARD	951.5192	2861.024	MIRROR	339.0405
IMA	STANDARD	Infinity			34.74072

High Speed 1M All Spherical Gregorian Telescope

The all-spherical classic Gregorian configuration's long physical length and the efficiencies of modern aspheric fabrication techniques make the design interesting but of little practical value, even in small meter class telescopes. However, a high-speed variant of the design, figure 5, has been explored that may have applications in very low light level, long range imaging applications.

The high speed configuration is realized when the all spherical Gregorian's concave secondary mirror is increased in curvature and moved further away from the primary forcing it to act as a focal reducer. In practice the system can be folded to realize a more compact system. The principal limitations of the design are the non-optimal position of the focal plane, the limited field of view and overall length. A more compact layout can be realized by folding the optical path with a large plane mirror, figure 7.

Prescription Data

```
Title: Fast 1 Meter All Spherical Catadioptric Gregorian telescope
All dimensions in millimeters

Entrance Pupil Diameter :            1060
Effective Focal Length  :            1000
Image Space F/#         :            0.94
```

SURFACE DATA SUMMARY:

Surf	Type	Radius	Thickness	Glass	Diameter
OBJ	STANDARD	Infinity	Infinity		0
1	STANDARD	Infinity	2800		0
STO	STANDARD	-3259.334	-1513.231	MIRROR	1060.606
3	STANDARD	90.99614	-12.7	BK7	95.82692
4	STANDARD	1366.806	-8.018109		97.34539
5	STANDARD	156.0036	-16.88789	BK7	97.40354
6	STANDARD	92.46479	-94.35924		99.99994
7	STANDARD	-1865.508	-18.70669	BK7	68.50178
8	STANDARD	149.6235	-189.7256		65.54982
9	STANDARD	817.1522	-19.97027	BK7	96.89738
10	STANDARD	115.2804	-12.37665		100.0004
11	STANDARD	-140.5739	-10.92559	BK7	99.62861
12	STANDARD	-84.21605	-830.6091		95.32266
13	STANDARD	672.1069	461.7981	MIRROR	500.0001
14	STANDARD	55.45514	13.80078	SILICA	54.74105
15	STANDARD	260.0548	19.99998		46.49624
IMA	STANDARD	Infinity	14.29529		

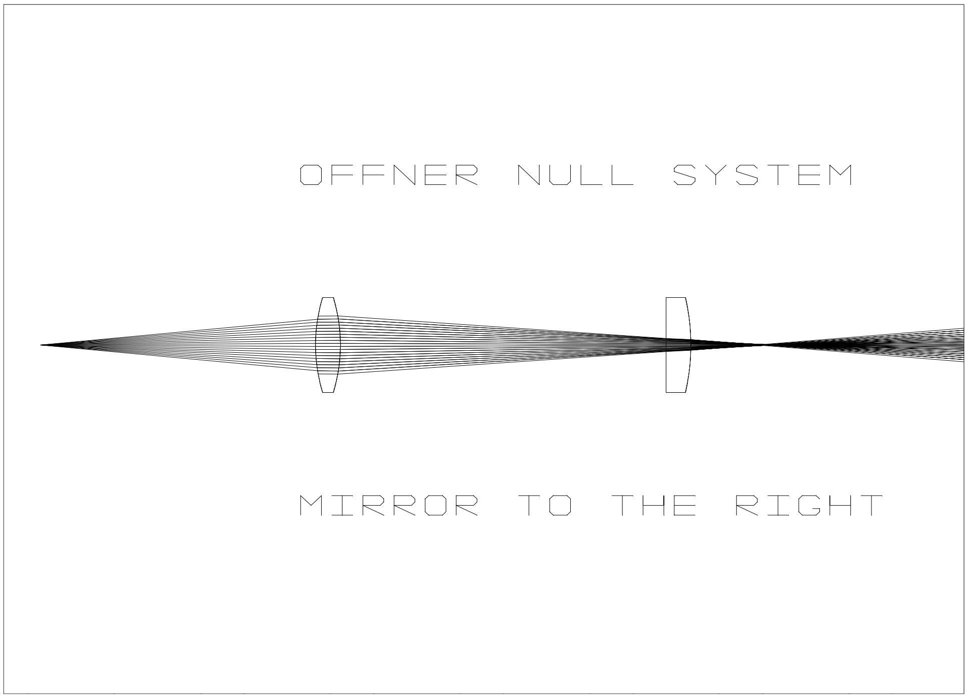

Figure 1. Offner null test

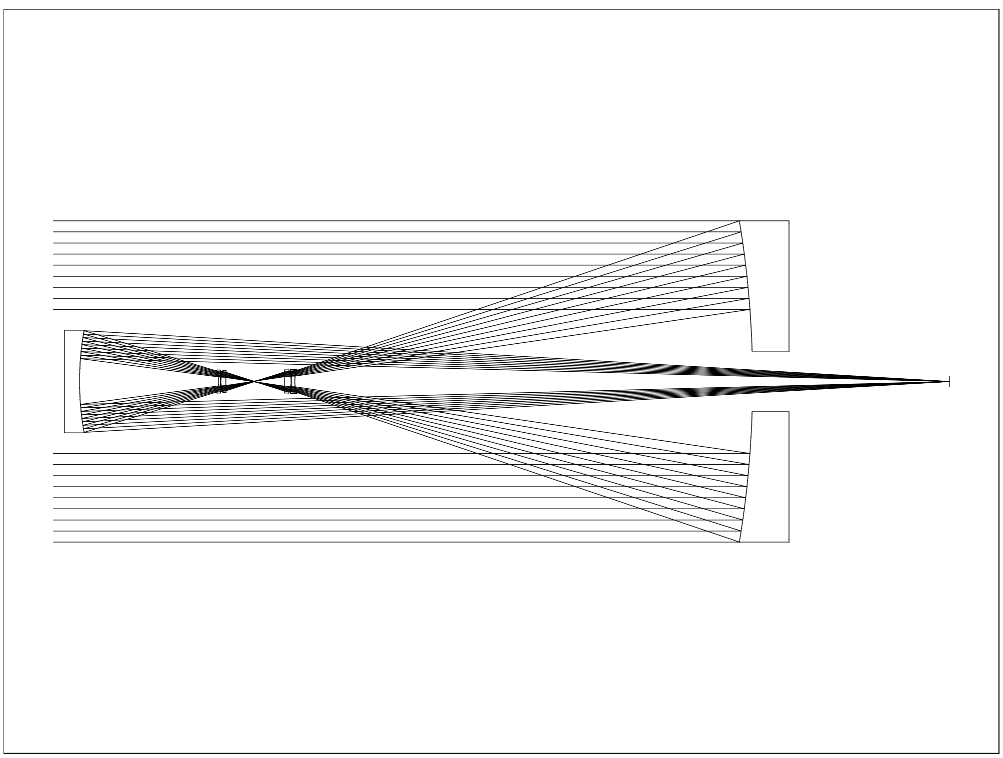

Figure 2. All spherical catadioptric Gregorian telescope

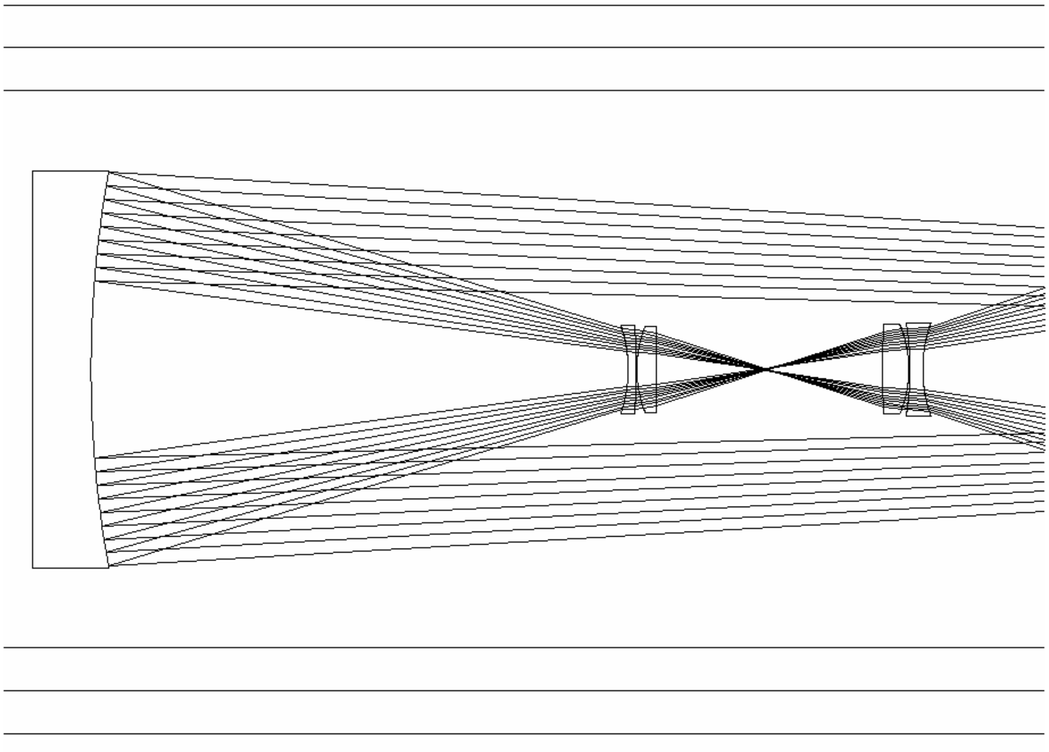

Figure 3. All–spherical Gregorian corrector

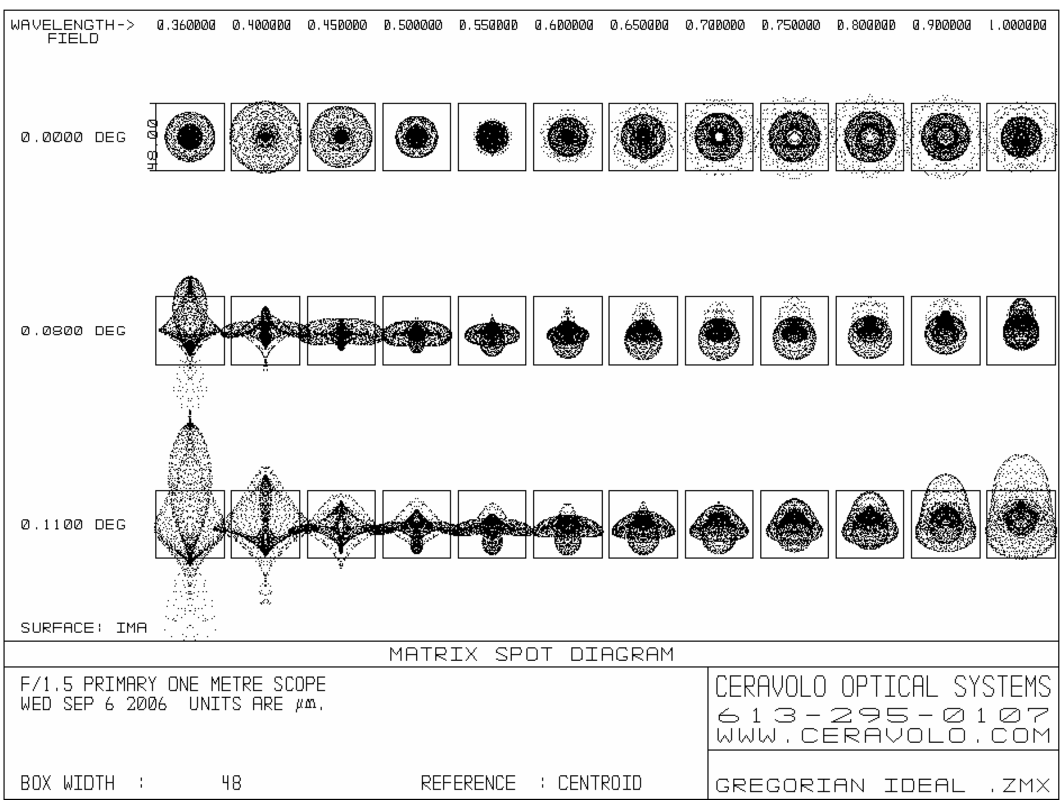

Figure 4. Performance of 1M F/8.5 all-spherical Gregorian

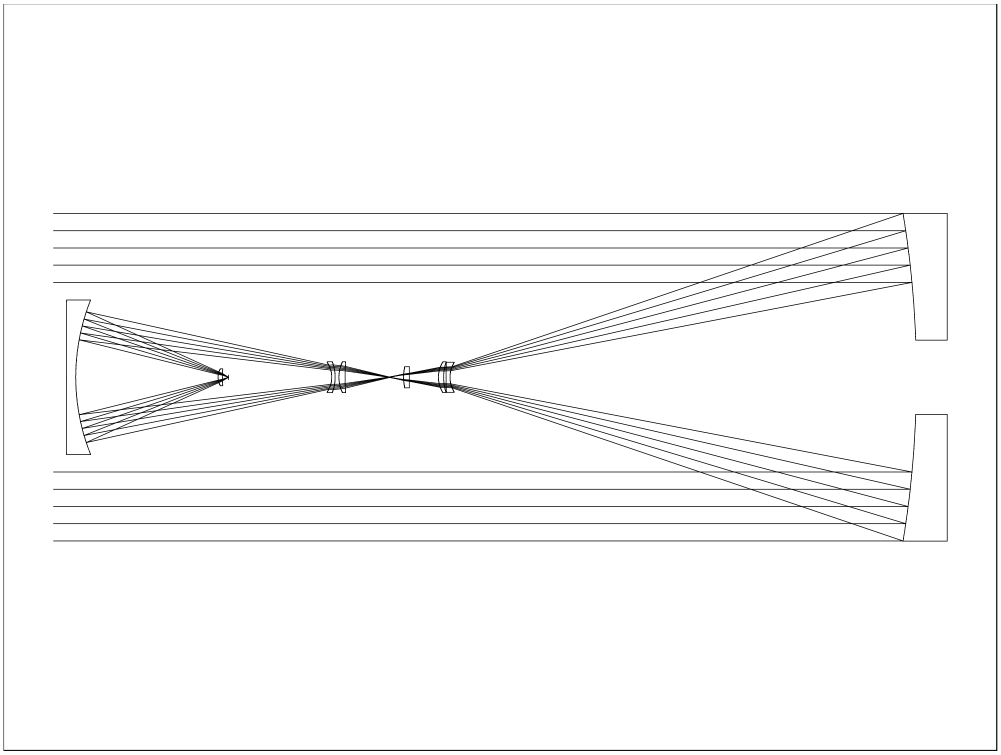

Figure 5. High-speed all spherical Gregorian

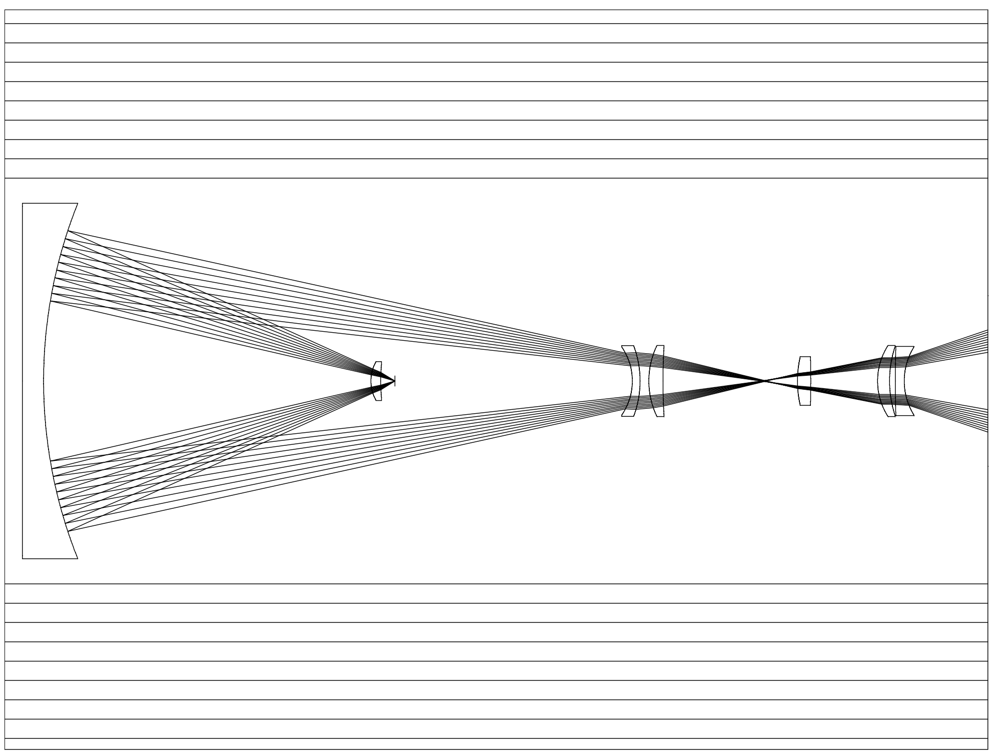

Figure 6. High speed all-spherical Gregorian corrector lens layout

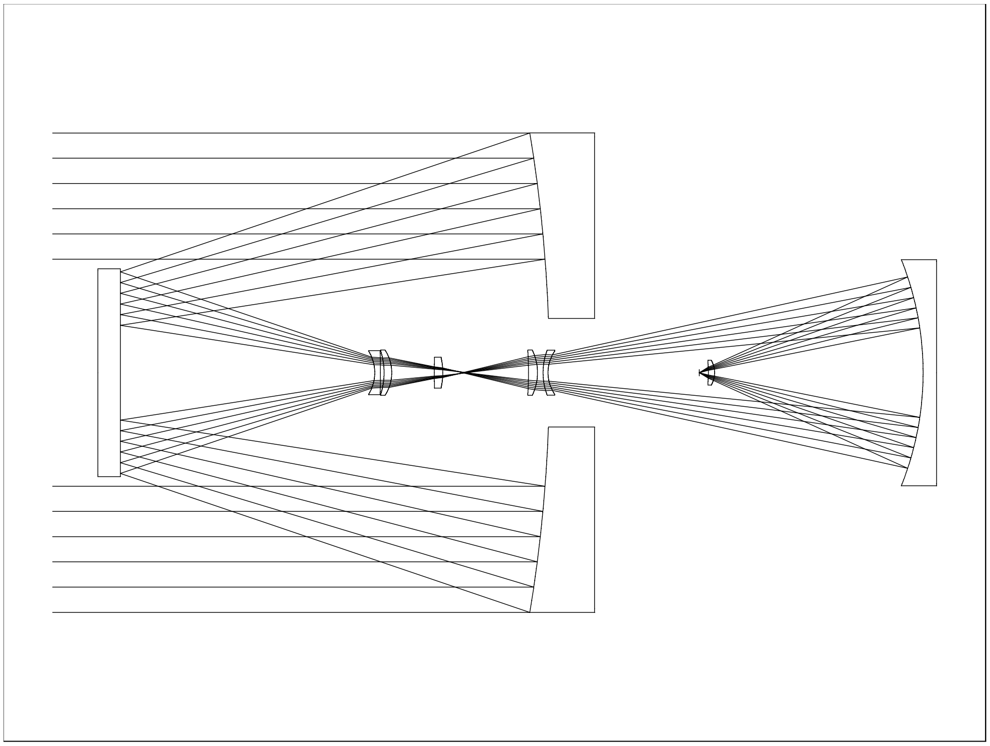

Figure 7. Folded all spherical high speed all-spherical Gregorian

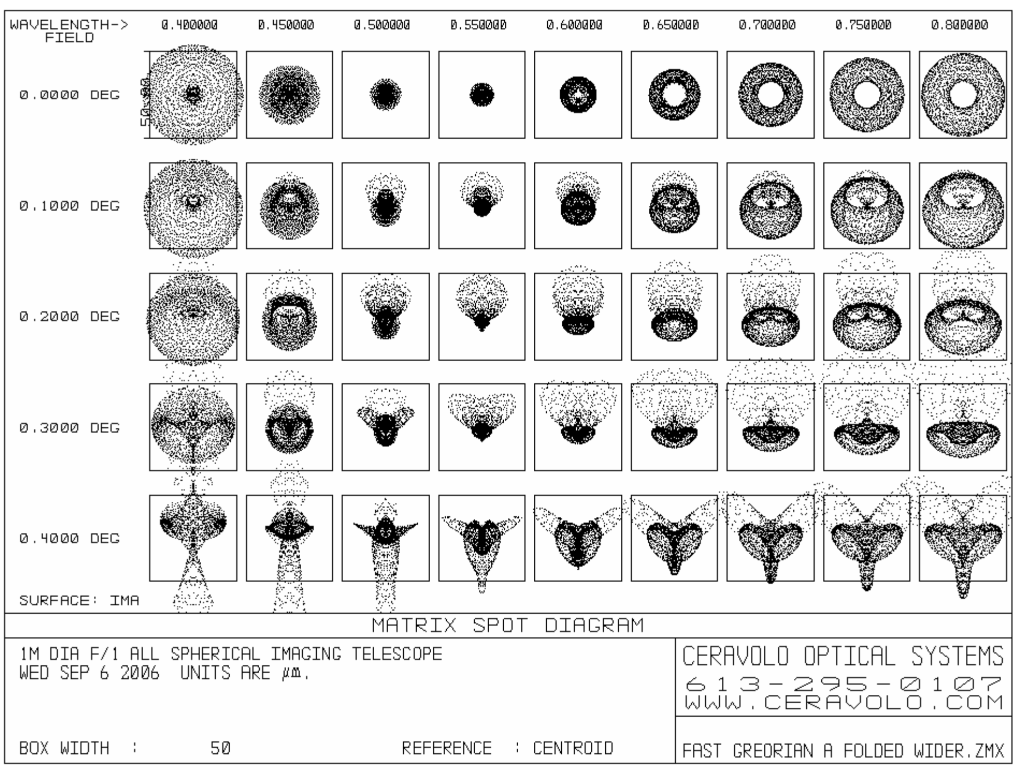

Fig 8. All spherical high speed Gregorian performance

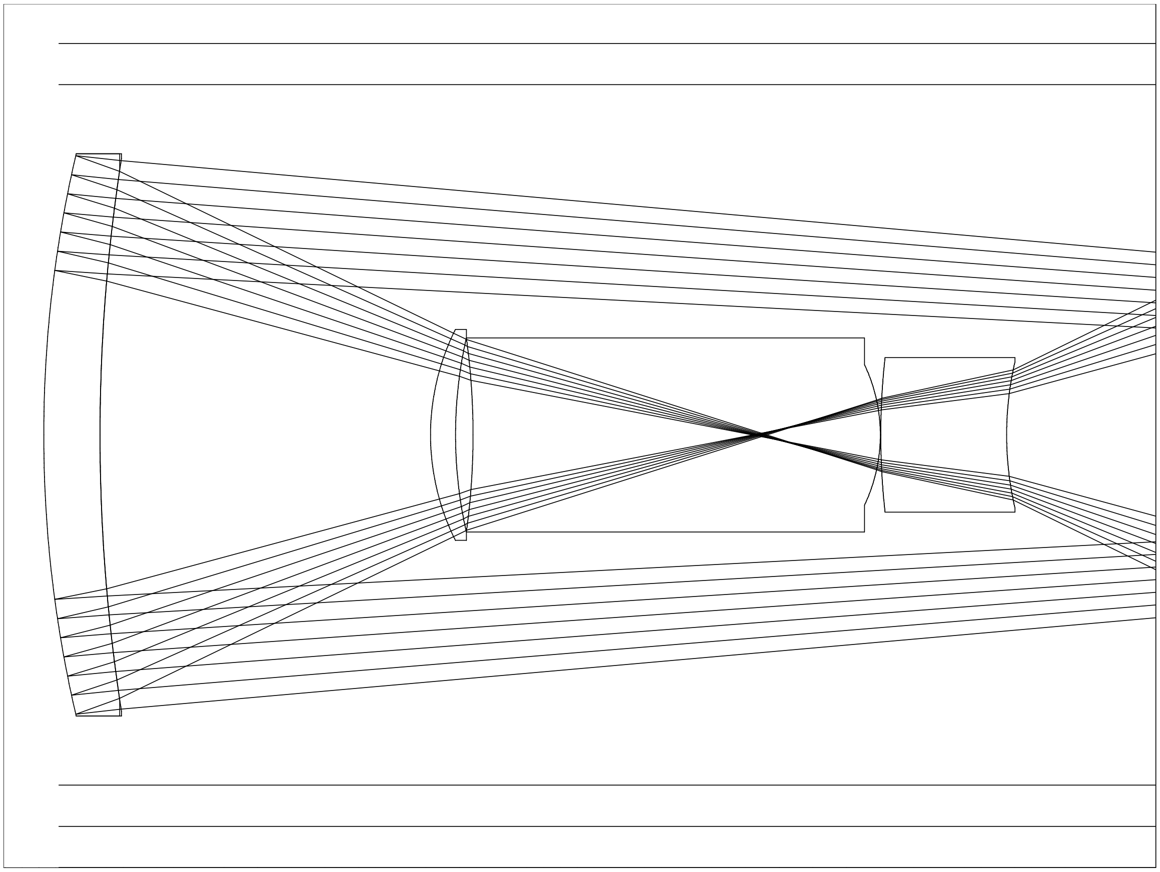

Figure 9. Design using Mangin secondary and thick lenses