The Unique Optical Design of the NESSI Survey Telescope

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Abstract

We present the optical design for the Near Earth Space Surveillance Initiative (NESSI) survey telescope. The telescope will be the second incarnation of the CCD Transit Instrument (CTI-2). Science objectives include precision astrometry and photometry of a 1.0deg wide strip of sky. Optically this translates into one quarter arc second images over a field 1.42deg wide with essentially zero distortion. The final optical design features a classical folded Cassegrain configuration with a five lens, all spherical refractive corrector and amazing image quality. Design exploration suggest the five lens approach can be adapted to other telescopes and observing programs.

1. Introduction

The original CCD Transit Instrument (CTI) was the first Paul-Baker design telescope of appreciable aperture (1.8m) ever fielded [1]. It operated as a transit instrument on Kitt Peak in Arizona for seven years during the 1980s. Now the CTI optics are being redesigned to support the Near Earth Space Surveillance Initiative (NESSI). In its new form, the telescope will be known as CTI-II (or CTI-2). It will be fielded at McDonald observatory in western Texas, and again operated in transit mode. It will provide a nightly deep survey of a 1deg wide strip of sky centered at 28deg N. Science objectives for the survey include precision astrometry and photometry.

Development of the final CTI-2 optical design has been a long and winding journey. As with any telescope, there are competing constraints, but the need to reuse the existing, unperforated f=2.2 parabolic primary significantly limited the available design space. Science objectives for the survey tended to force the design towards a field scale of 60μm/arcsec. With a 1.8m aperture, this required a focal length of 12.376 meters. As the primary radius of curvature was approximately 7.825m, achieving this plate scale necessitated abandoning the Paul optical system. While a number of different optical approaches were considered including a highly innovative modified Gregorian design [2], in the end, a bent Cassegrain configuration with a five lens corrector was selected.

This paper describes the design and performance of the five lens field corrector. As a literature search has failed to find previous instances of five lenses of spherical figure being used to correct a Cassegrain configuration telescope (including Ritchey-Chrétien systems), we believe the approach to be unique and therefore represent a new corrector design.

2. CTI-1 Background

The original CTI telescope served as a transit instrument providing a nightly survey of a narrow strip of sky at 28deg N latitude as seen from Kitt Peak in Arizona. The telescope was designed by Harland Epps and built and operated by John McGraw and Roger Angel [1].

The CTI primary mirror was the proof of concept mirror for the NASA space telescope project. The mirror was never intended to fly and was built sub-scale with an aperture of 1.8m. It featured an f=2.2 parabolic surface figure and had no central hole. For the original CTI team, the design solution was obvious - build a Paul-Baker system. The secondary and tertiary mirrors would be relatively simple and the system would be capable of high image quality over reasonably wide fields. The system was optimized for a 1.0deg field which might have been a problem as the classic Paul design requires a curved focal surface. In the end, the relatively small area CCDs available in the early 1980s limited the telescope to imaging a strip of sky only 8arcmin across so field curvature was not an issue. With two CCDs, the telescope could simultaneously operate in two color bands. In addition to the innovative optical design and the unique use of CCDs in drift-scan mode, the telescope featured an innovative passive thermally compensated structure.

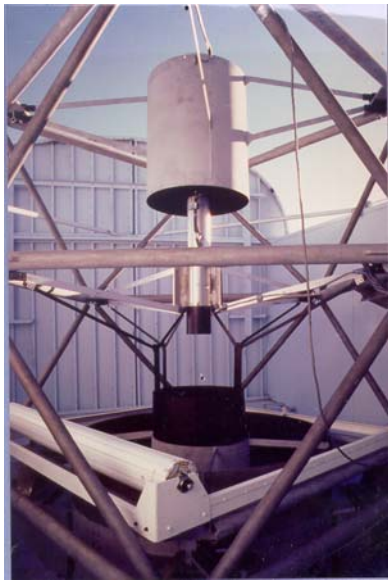


FIG 1. The original CTI telescope in
Paul-Baker configuration on Kitt Peak AZ.

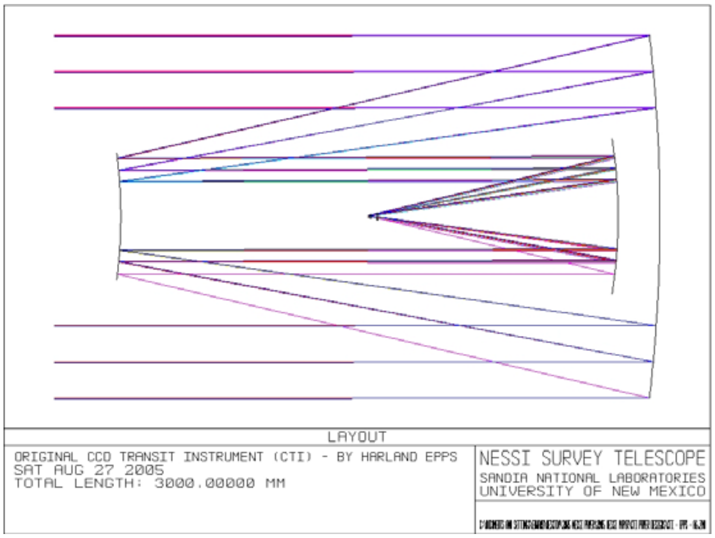


FIG 2. The Paul-Baker optical configuration of the original CTI telescope.

3. Development of the CTI-2 Optical Design

Specific details of the science goals for the NESSI survey have evolved over time with a back and forth negotiation between the science team and the telescope team. With each design iteration, the science team would ask for just a little more performance and each time they were told “NO” by the telescope team. Over time however, the design team would figure out how to accommodate the revised science requirements and deliver improved performance to the science team. Rather than saying “thank you” and being happy with their new design, this behavior only encouraged the science team to continue to ask for more.

3.1 Early Optical Designs

As the science requirements and the optical design progressed through thousands of iterations, we seriously considered a variety of optical approaches. The earliest designs considered were modifications of the existing Paul-Baker optics. As mentioned above, the classic Paul design results in a curved image surface. Lenses easily flatten the image but introduce lateral color, thereby requiring more lenses to correct the chromatic aberrations. We looked at a number of Paul configurations with three lens correctors and were able to achieve high image quality over fields ranging from 1.2 to 1.5deg, but the field scale was never sufficient for the anticipated science. An example of an early corrected Paul design is seen in figure 3.

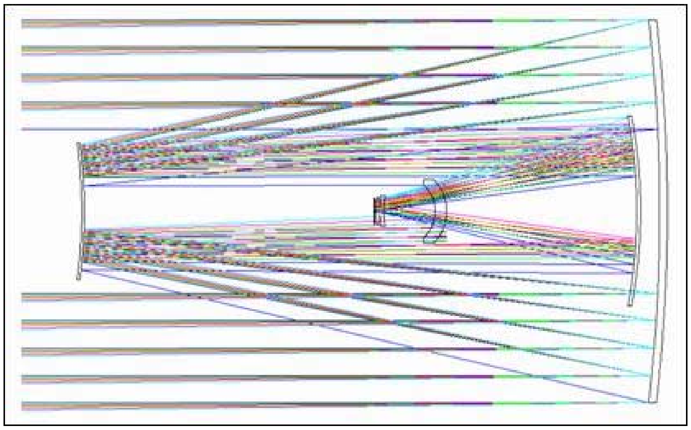


FIG 3. Paul design with three lens corrector.

In addition to Paul type systems, we considered prime focus correctors. These designs result in approximately the same field scale as the Paul, but with lower obscuration and potentially easier alignment. Correctors ranging from five to seven elements and providing fields as wide as 2.2deg were considered. An example of one such prime focus corrector is shown in figure 4. The prime focus correctors performed well but the field scale was again insufficient to support the evolving science objectives.

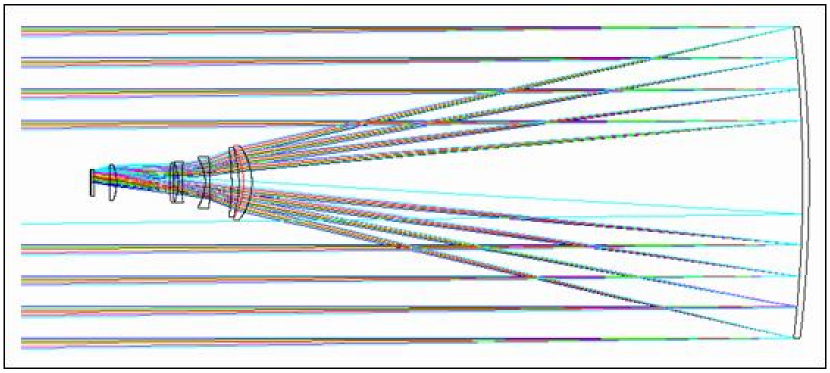


FIG 4. Seven element prime focus corrector design.

To increase the system field scale, designs other than the Paul and prime focus corrector were investigated. Three such options were considered at great length. The first was a modified Paul. This is a true two-mirror, three-reflection system where the primary is used twice. With a three lens corrector, this design provided high image quality over wide fields at a focal ratio nearly twice that of a simple Paul. The drawback of this design is the large perforated secondary. An example of this design is seen in figure 5.

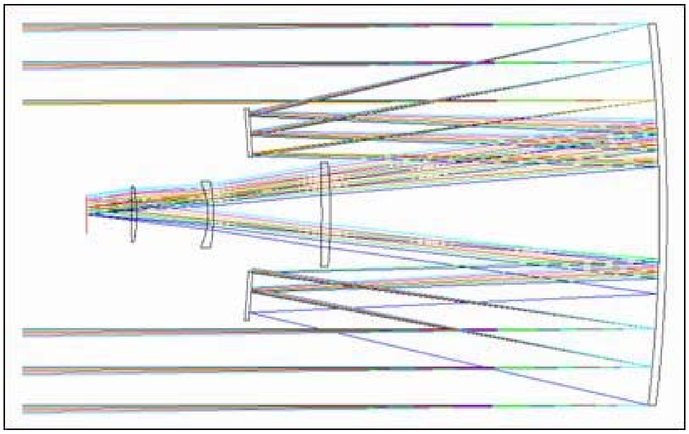


FIG 5. Optical design for a modified Paul system.
This represents a true two-mirror, three-reflection system.

Another option for increasing the field scale was the Gregorian design. Traditionally, no one ever mentions the words "Gregorian" and "wide-field" in the same sentence. The classic Gregorian design is known to suffer from coma and field curvature, both of which severely limit its useful field of view. The Aplanatic Gregorian somewhat relieves the coma problem but field curvature remains significant. Also, this was not an option for CTI-2 as our primary is parabolic. It is possible to design a Gregorian telescope with several lenses both near the internal focus and just prior to the final focus. Here this design is referred to as a modified Gregorian. This approach appears to have been independently developed at least three times now by the authors, by Peter Ceravolo [3], and by Dick Buchroeder [4]. The basic approach was successfully applied to CTI-2 resulting in an f=6 system with a near diffraction-limited, flat-field of 1.5deg. In the end however, the design was abandoned as it would have resulted in a much longer optical system than desired. The modified Gregorian design can be seen in figure 6.

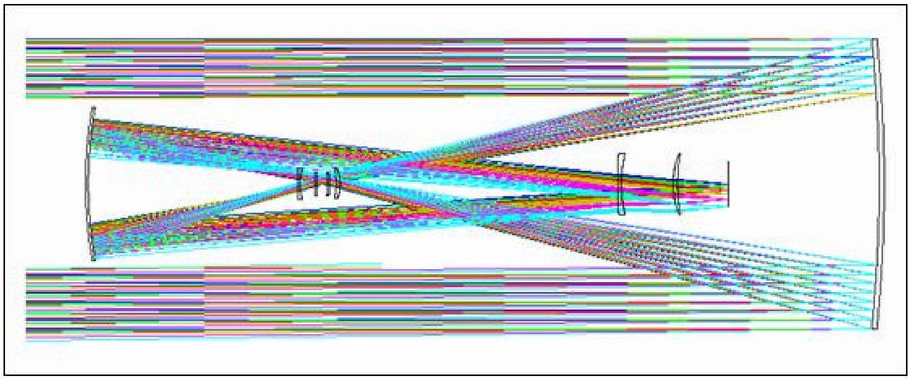


FIG 6. Modified Gregorian optical design.

The final choice for CTI-2 appeared to be the classic Cassegrain. It was capable of the longer focal lengths while maintaining a shorter optical assembly. Cassegrains however also feature significant coma and field curvature and are not known for being low in distortion. There was however a significant body of literature on Cassegrain approaches to wide-field imaging.

Unfortunately, none of the published approaches adapted well to our science requirements. An example of an early bent-Cassegrain design is shown in figure 7.

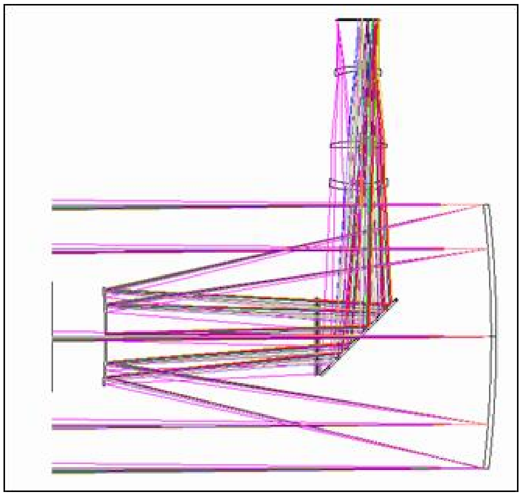


FIG 7. Example of a bent-Cassegrain design considered early in the project.

3.2 Later Optical Designs

As the optical design improved, the demands from the science team for even more performance grew. In the end, they asked for the near impossible. To help match pixels and the telescope to the anticipated 10% best seeing at McDonald observatory (about 0.6arcsec), the science team requested a field scale of 60mm/arcsec. The required one quarter arcsec images (80% encircled energy diameter) over a field 1.42deg wide. Initial designs performed well overall but were found to have some deficiencies in the details. For example, some designs appeared to have acceptable polychromatic averaged spot sizes but performance in specific color bands was not always acceptable. Finally the requirement for extremely low distortion proved to be the demise of many designs as it was necessary to trade some image quality for lower distortion.

3.2.2 The Three Lens Bent Cassegrain

Intending to minimize the number of air to glass interfaces, the design team seriously considered a bent Cassegrain with a three lens corrector. A corrector with all spherical surfaces was tried but performance was not as desired. Image quality did not meet science requirements and distortion was on the order of 1%. The corrector group for this design can be seen in figure 8 and the spot diagrams in figure 9.

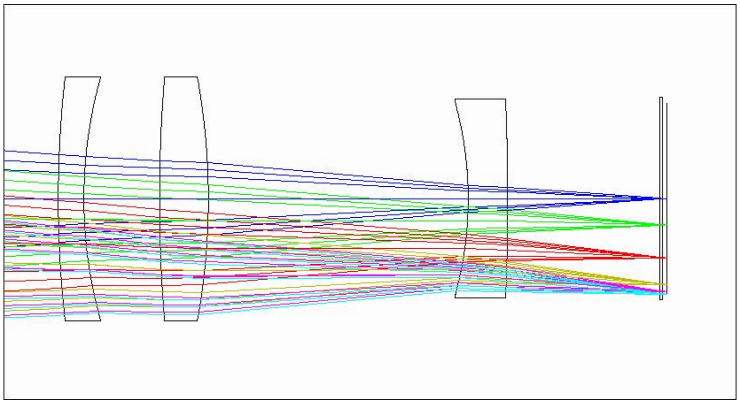


FIG 8. Three spherical lens corrector for bent Cassegrain.

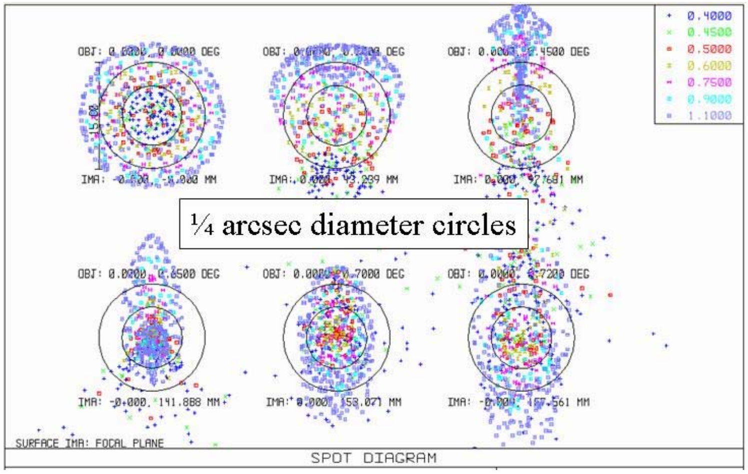


FIG 9. Ray-traced spot diagrams for spherical three lens corrector group. The inner circle represents the diffraction limit at λ=500nm.

To improve image quality and decrease distortion, the design was optimized to include a conic figure on the forward surface of lens three. Performance improves substantially and distortion was reduced to 0.001% which represents a total maximum chief-ray deviation of less than 2μm from the desired location. Details of this design can be seen in figures 10-13. Unfortunately, performance is still not as desired mostly due to lateral color as can be seen in figure 13. Also, the aspheric surface is very fast (roughly f=0.6) with a conic constant on the order of -1.9 thereby making it highly aspheric and expensive to produce.

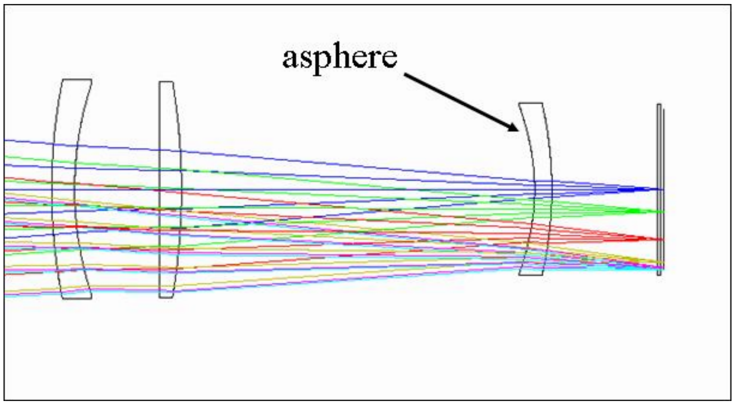


FIG 10. Three lens aspherical corrector for bent Cassegrain.

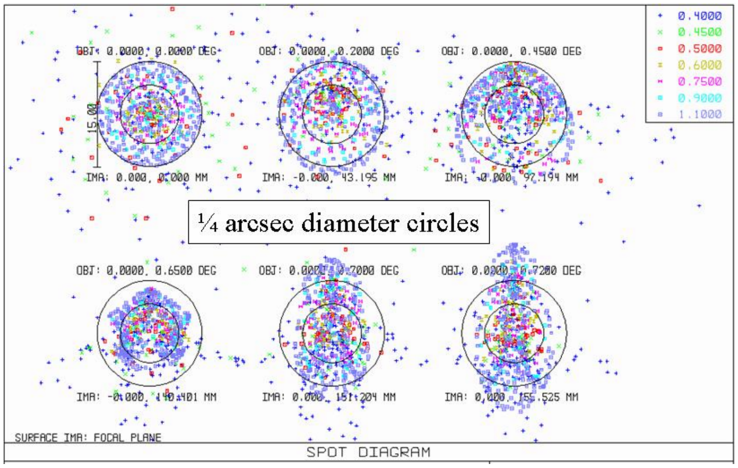


FIG 11. Ray-traced spot diagrams for aspherical three lens corrector group.

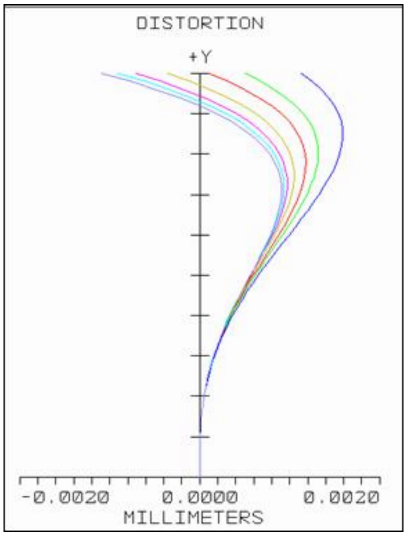


FIG 12. Maximum distortion of about 2μm for the three lens aspherical corrector

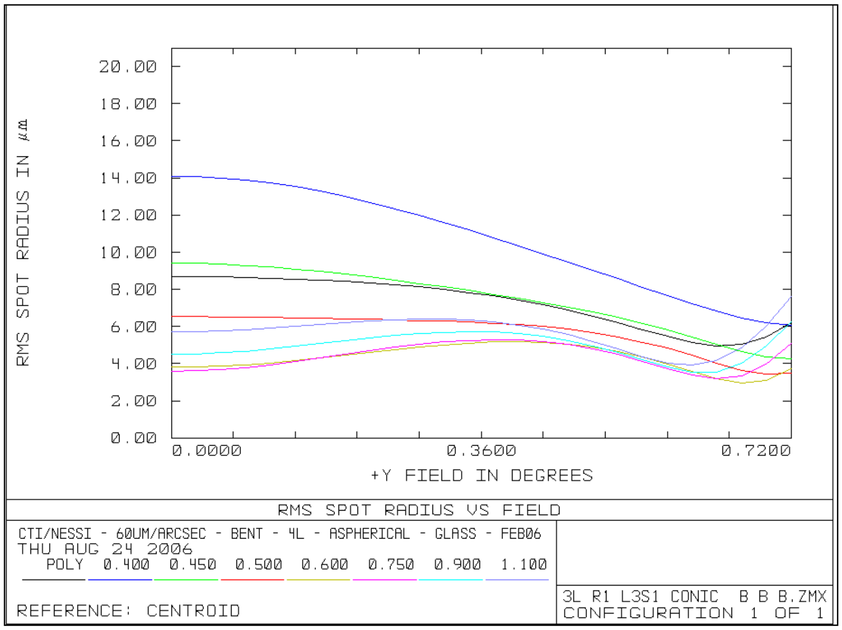


FIG 13. RMS spot radius for various wavelengths of the three lens aspheric corrector.

3.2.3 The Four Lens Bent Cassegrain

To improve the three lens corrector, a fourth lens was added. This particular design was probably explored in greater depth than any other potential CTI-2 optical design. Attempts were made with various combinations of glass, different lens spacing, different combinations of positive, negative and meniscus lenses and anywhere from zero to three aspheric surfaces. In the end, best performance was achieved by a relatively simple design made with all one glass type, either fused silica or N-BK7 glass. The design included a single concave asphere. While this surface was a perfect parabola, it was very fast at roughly f=0.6 and was therefore determined to be very costly to manufacture and test.

Presented below in figures 14-21 are examples of the four lens corrector in both all spherical form and with the single parabolic asphere. Note that the aspheric version of this corrector features near diffraction limited spots at all field angles and very well controlled lateral chromatic aberration.

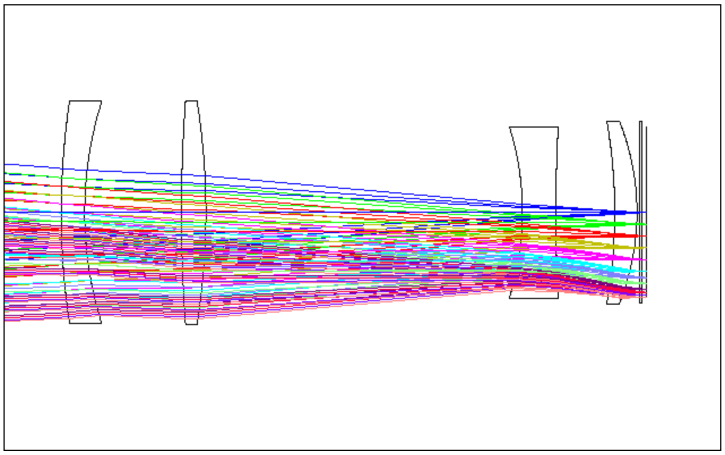


FIG 14. Four spherical lens corrector.

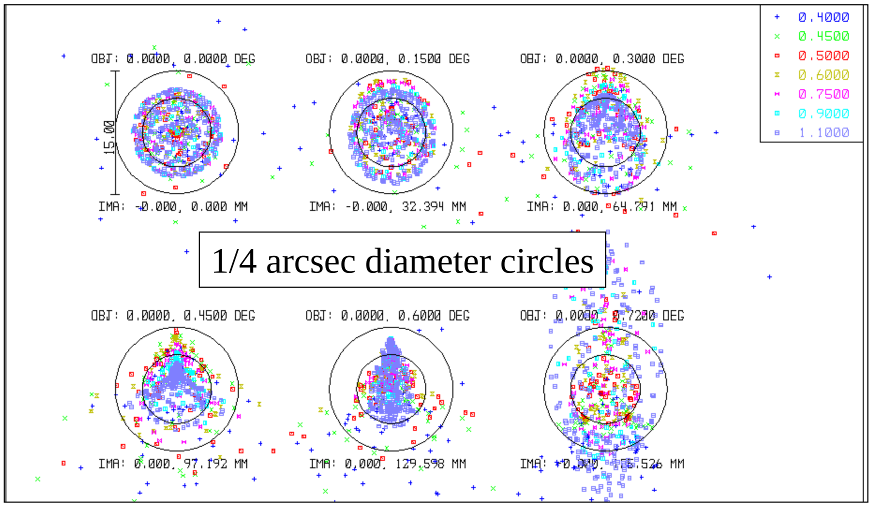


FIG 15. Spot diagrams for the four spherical lens corrector. The inner circle represents the diffraction limit at λ=500nm.

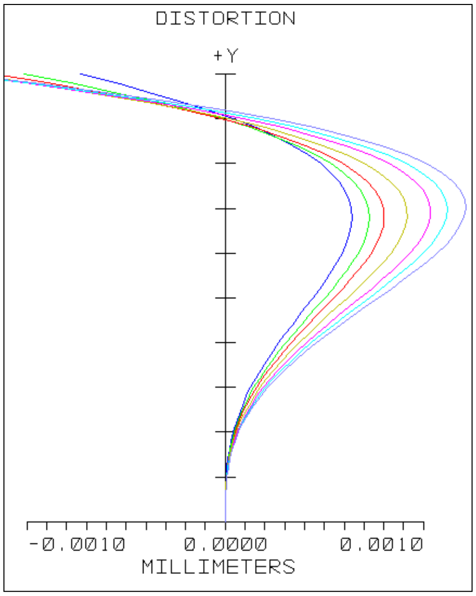


FIG 16. Distortion plot for the
four spherical lens corrector.

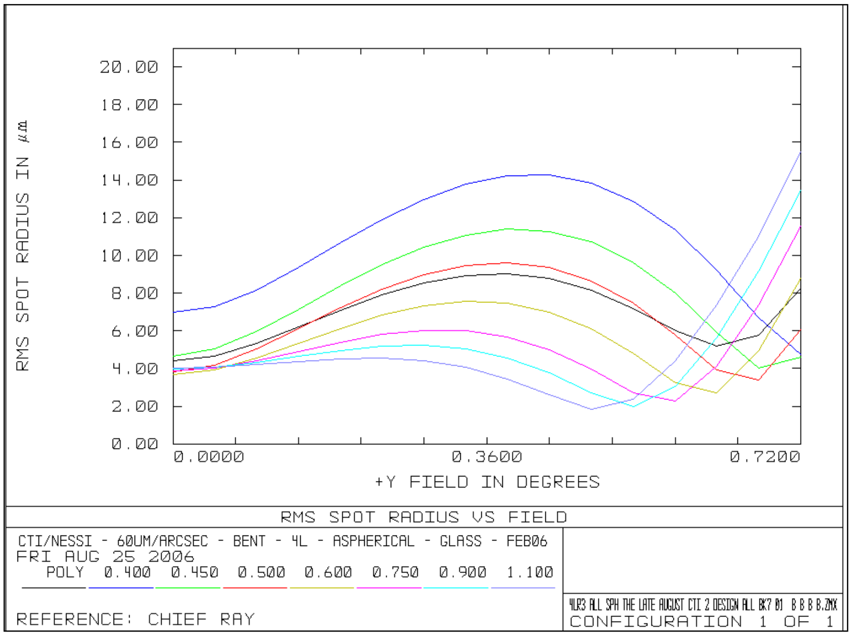


FIG 17. RMS spot radius for various wavelengths
of the four spherical lens corrector.

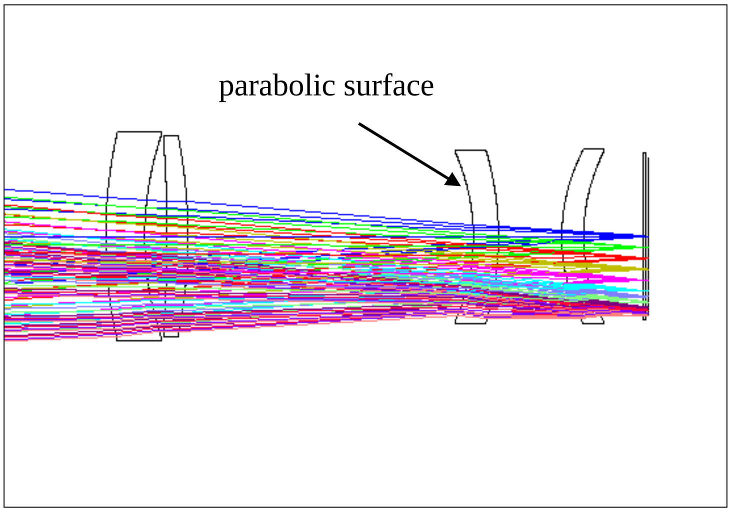


FIG 18. Four lens corrector with one aspheric surface.

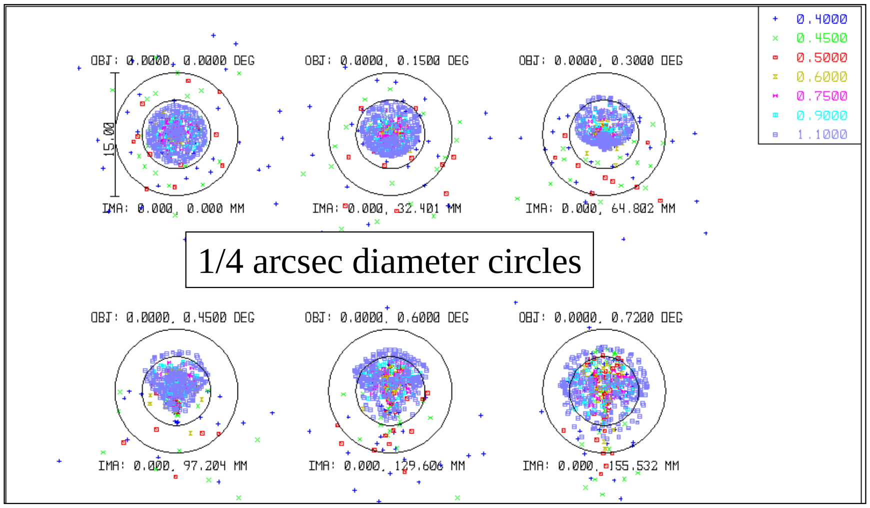


FIG 19. Spot diagrams for the four lens aspheric corrector.
The inner circle represents the diffraction limit at λ=500nm.

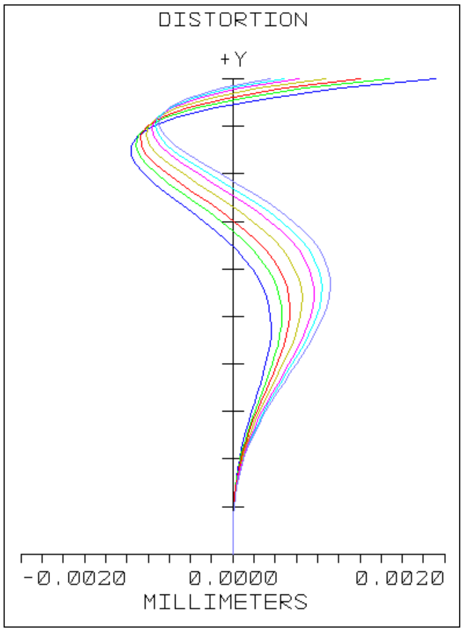


FIG 20. Distortion plot for the
four lens aspheric corrector.

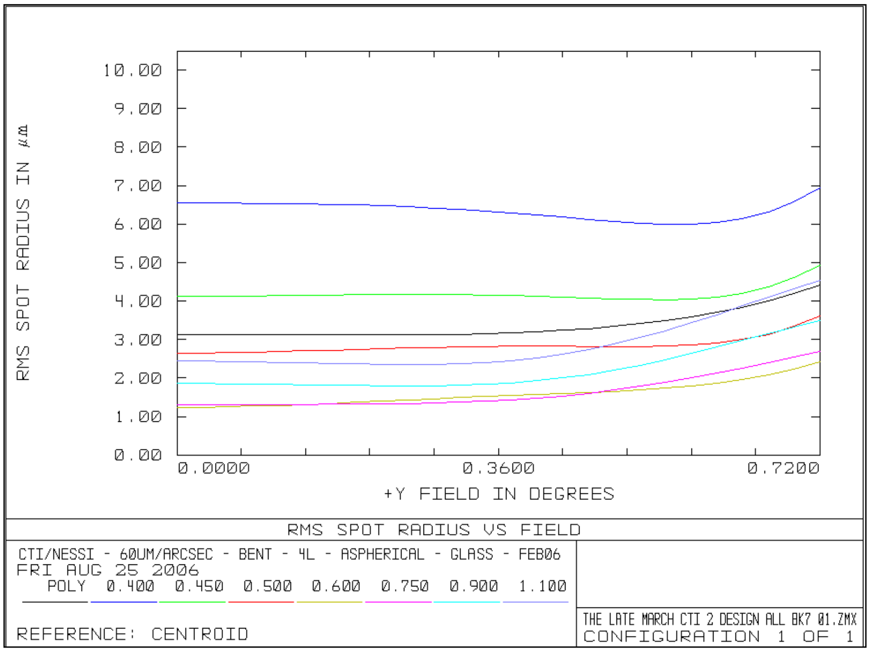


FIG 21. RMS spot radius for various wavelengths
of the four lens aspheric corrector.

3.2.4 The Five Lens Bent Cassegrain

Not satisfied with the performance of the all spherical, four lens corrector, and having been talked out of attempting the extremely fast parabolic surface required for the four lens aspheric corrector, the only logical paths to follow were to reduce the asphericity of the four lens design, or look towards five and six lens, all spherical correctors. All attempts to reduce the complexity of the four lens aspheric design resulted in significantly decreased performance for extremely small reductions in surface complexity. Designs with six spherical elements performed extremely well but appeared to have surfaces which contributed little to the overall corrector performance. This naturally led to a five lens corrector with all spherical surfaces.

The final optical design for the CTI-2 telescope will be a five lens corrector with all spherical surfaces. Some slight adjustment of the design is being accomplished at present but the final design will be nearly identical to that presented below. Our design is believed to be unique. We have extensively read available literature on correctors for Cassegrain type telescopes and found no serious mention of five lens designs.

For the CTI-2 science requirements, the five lens design appears to be very robust offering exceptional performance with relatively low sensitivity to manufacturing and alignment tolerances. The design is sufficiently flexible that we were able to achieve near diffraction limited performance over the entire 1.42deg field, with near zero distortion using only seven powered surfaces as the design includes three plano surfaces.

The design and relevant performance data are presented in figures 22-26. The most recent versions of this corrector (not shown here) feature thinner lenses, smaller spots and slightly less distortion. The corrector can be made from all fused silica or all N-BK7 type glass.

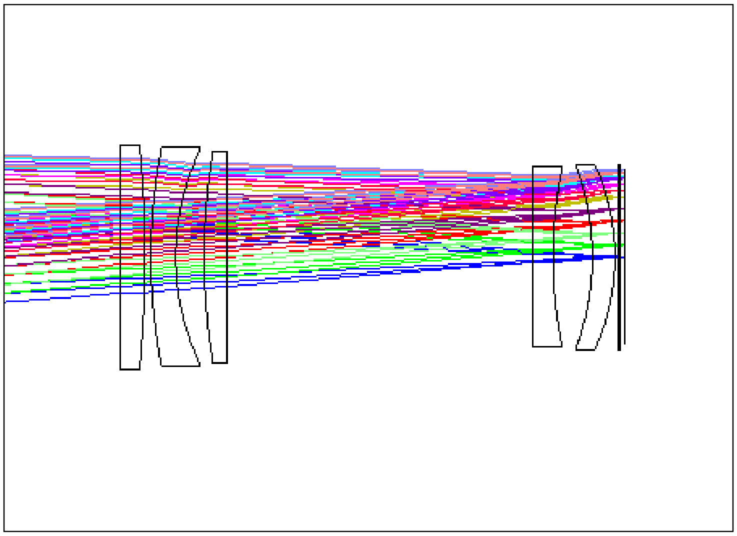


FIG 22. Five lens corrector with seven spherical and three plano surfaces.

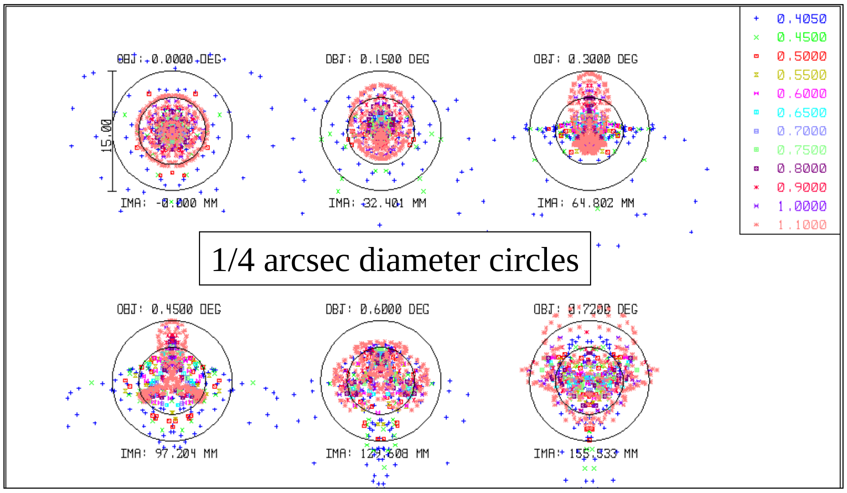


FIG 23. Spot diagrams for the five lens corrector.
The inner circle represents the diffraction limit at λ=500nm.

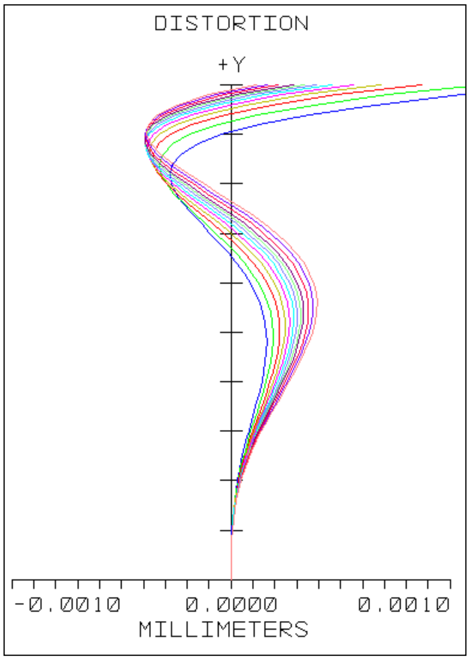


FIG 24. Distortion plot for the
five lens corrector.

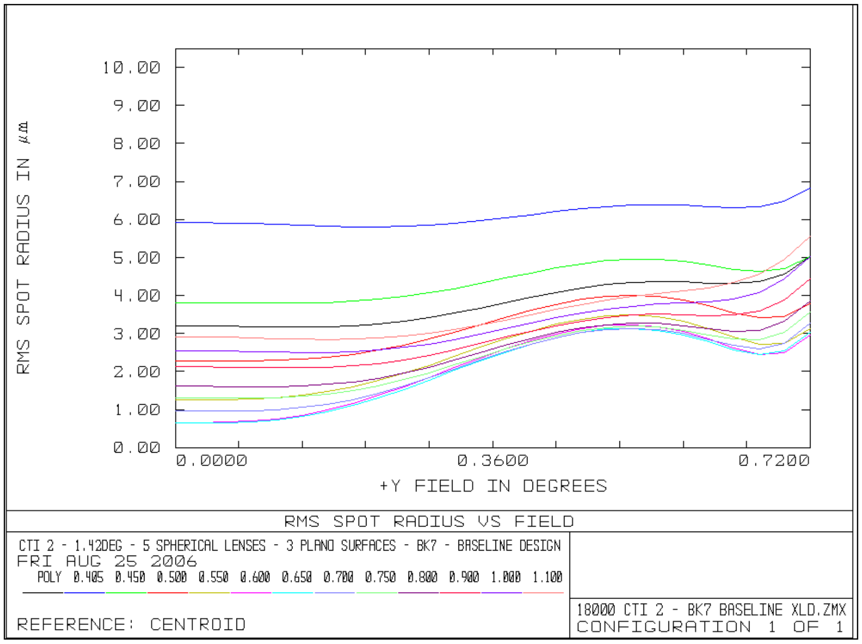


FIG 25. RMS spot radius for various wavelengths
of the five lens corrector.

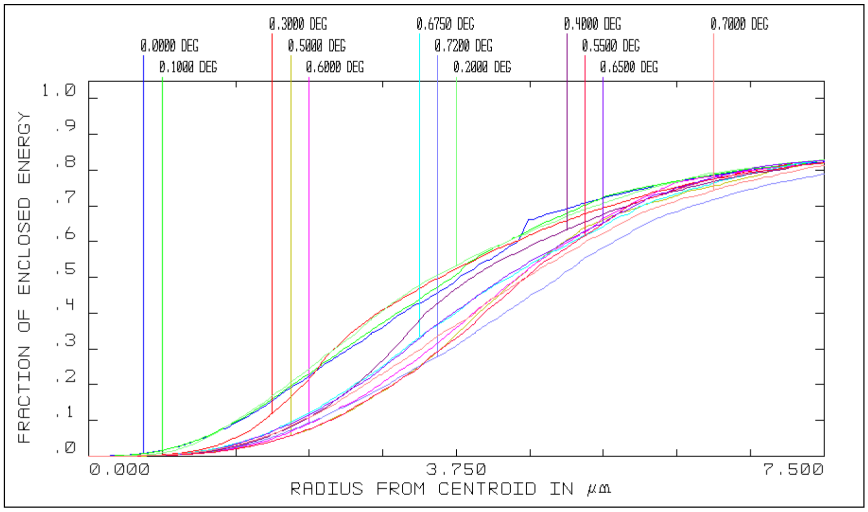


FIG 26. Encircled energy calculation for the five lens corrector.
The 7.5µm radius corresponds to ¼ arcsec diameter.

3.2.5 Comparing the 3, 4 and 5 Lens Designs

The three, four and five lens correctors each have their unique characteristics. The obvious advantage of the three lens design is that it only consists of three elements. The aspheric surface is however both fast and has a significant deviation from the best fitting sphere. Performance is actually very good, but not quite as desired for CTI-2 as lateral chromatic variation increases spot sizes at any single wavelength even though the polychromatic averaged spot sizes are small.

The four lens design has the best overall performance but not by much. The aspheric surface is again very fast and has significant deviation from the best fit sphere, but is perfectly parabolic. It was hoped that manufacturers would know how to grind and test even a fast parabola, but the asphericity is significant and the cost became an issue.

The five lens design is quite interesting in that it requires only seven powered surfaces and those are relatively easy to grind, polish and test. Performance is extremely high and features lower distortion than the four lens design but with slightly larger spots.

Figure 27 compares the RMS spot diameter as a function of field angle for the three designs.

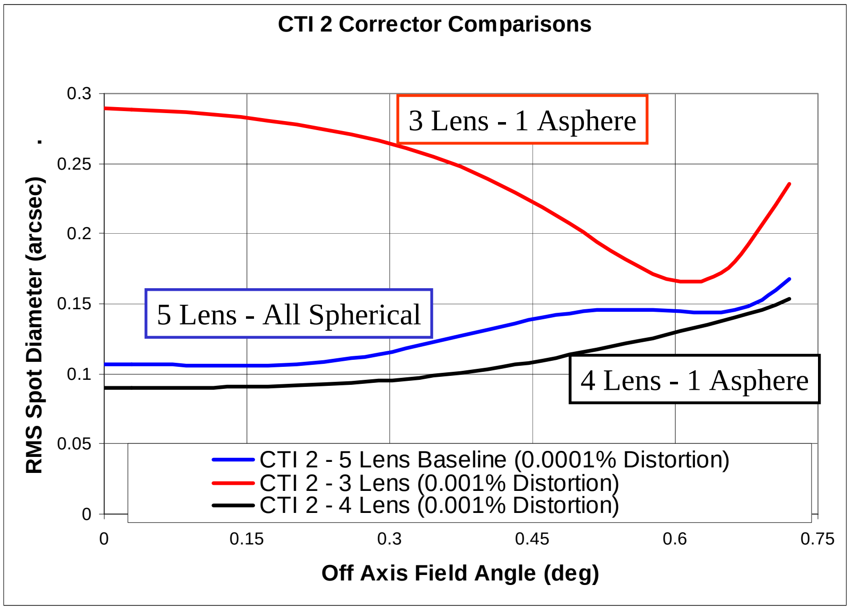


FIG 27. Comparing the RMS spot diameter
for the 3, 4 and 5 lens bent Cassegrain corrector.

3.2.6 Extending The Five Lens Bent Cassegrain Design

The CTI-2 five lens corrector turns out to be a rather robust design and is capable of being pushed to fields greater than 1.42deg. It is relatively easy to widen the design to a field of 1.60deg while retaining the same configuration with three plano surfaces. Performance for this design is shown in figures 28-30. Wider fields are possible but begin to require all ten surfaces being figured and performance does decrease. At full fields of 2.0deg, 80% encircled energy is attained with spots less than 0.40 arcsec diameter while maintaining maximum distortion of only 2μm. At full fields of 3.0deg, 80% encircled energy is attained with spots less than 0.84 arcsec diameter while maintaining maximum distortion of only 5μm. Note that all of these design excursions are for a parabolic primary. If the primary is allowed to take on a hyperbolic figure performance improves enormously.

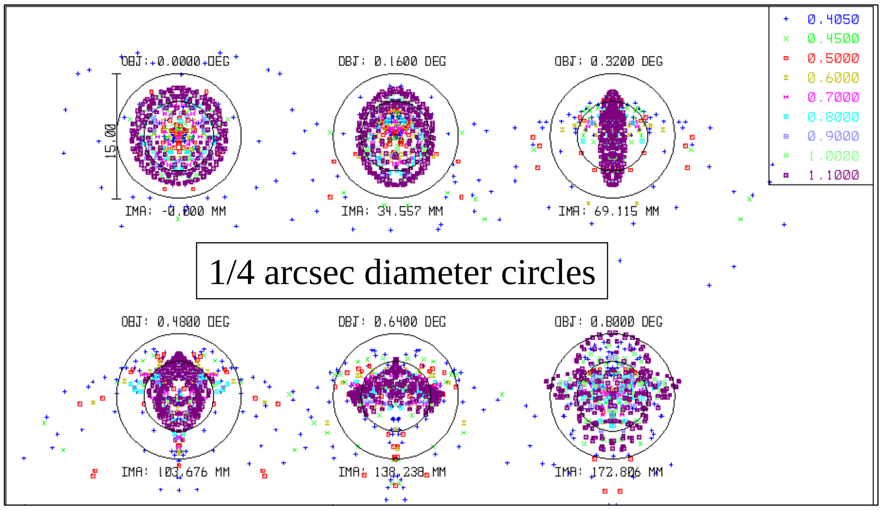


FIG 28. RMS spots for 1.60deg field CTI-2.
The inner circle represents the diffraction limit at λ=500nm.

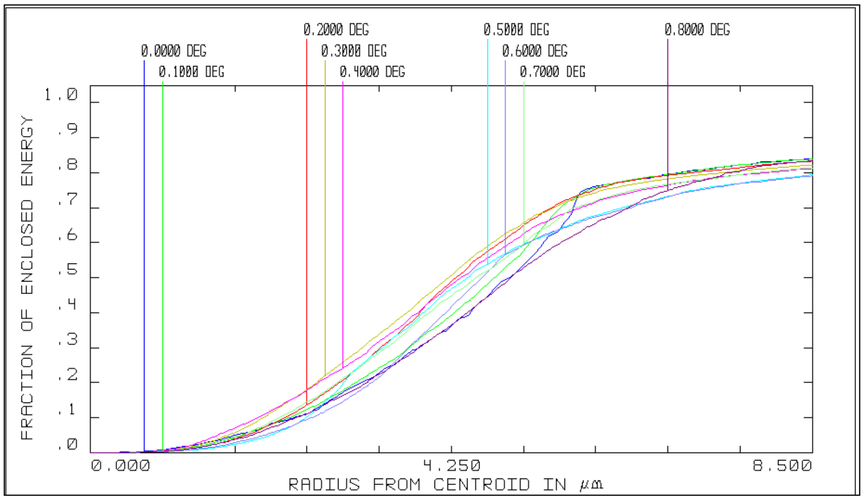


FIG 29. Encircled energy plot for 1.60deg CTI-2
showing spots of less than 0.40 arcsec.

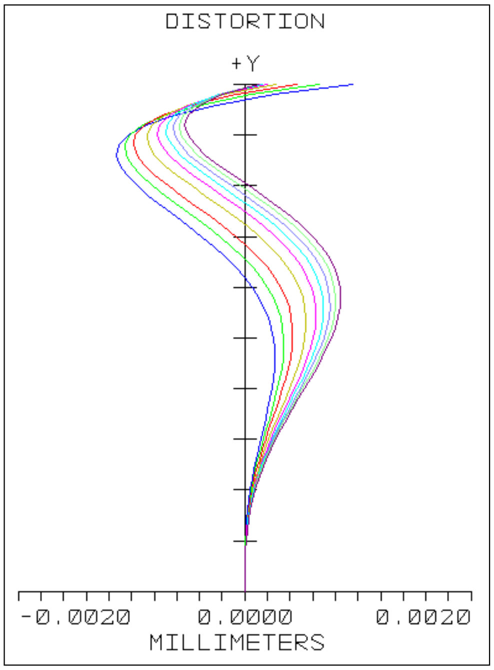


FIG 30. Distortion plot for 1.60deg CTI 2.

4. CTI-2 Attempts with Conventional Designs

In between development of the four and five lens correctors, a design consultant asked why we had not pursued more conventional corrector designs. He believed our design was unusual and unconventional. At his urging, we set out to review more conventional designs to see if they could be adapted to CTI-2 with its unusual design constraints. In the end, we considered six proven designs with mixed results, but none could match the performance of our design for both image quality and distortion.

4.1 SDSS-Based CTI-2

The telescope for the Sloan Digital Sky Survey (SDSS) is a 2.5m instrument used for both sky survey and spectroscopic studies. It features a 3.0deg field of view and is based on a simple Ritchey-Chrétien configuration with two Gascoigne type aspheric corrector plates. The basic SDSS approach was applied to the CTI-2 constraints and resulted in a design with surprisingly high image quality, but with unacceptably large distortion. Details of this design are shown in figure 31.

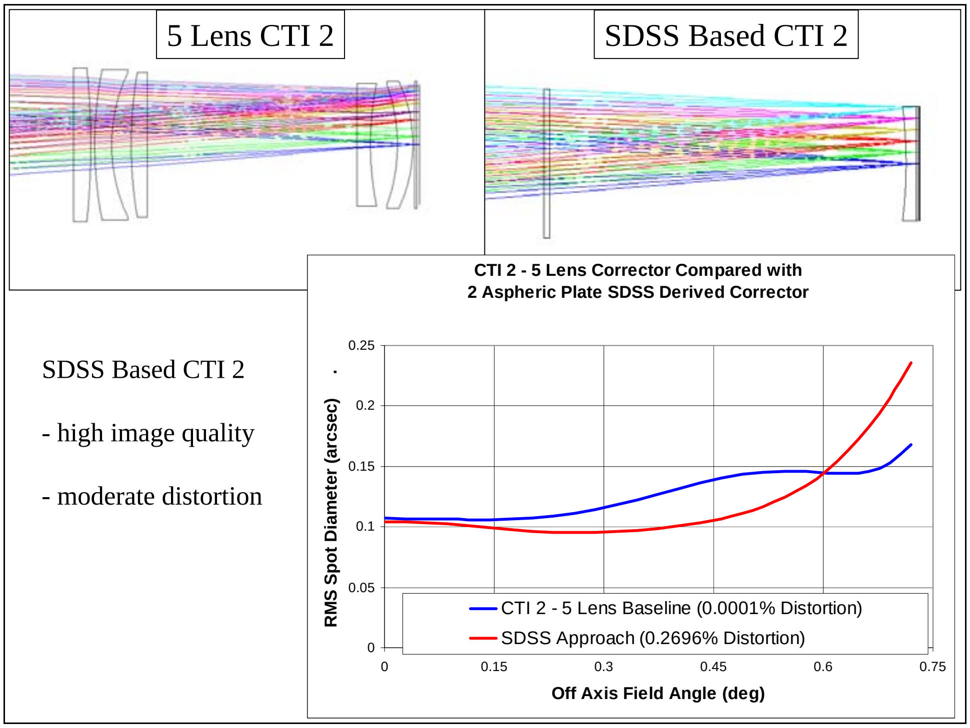


FIG 31. Comparison of 5 Lens CTI-2 design with SDSS derived CTI-2.

4.2 SkyMapper-Based CTI-2

SkyMapper is a 1.3m synoptic survey instrument coming online at Mt. Stromlo Observatory in Australia. The telescope features a 3.4deg field of view and an absolutely unique optical design based on a modified Ritchey-Chrétien with a three lens corrector. The first lens is an almost zero power meniscus with the concave side facing the secondary mirror. This surface has a very mild 6th order correction. The remaining two lenses are all spherical and form a corrector group much closer to the focal plane. Lens two is a biconcave element and lens three is biconvex. The design produces half arcsec spots which are perfect for the anticipated seeing and mission of the telescope.

The SkyMapper design has never been published but sufficient details are available for the basic approach to be explored [5]. We applied the SkyMapper design to the CTI-2 telescope and produced a high performing system but not quite up to the performance level set by the five lens corrector. As SkyMapper has a hyperbolic primary and CTI-2 a parabolic primary, it was necessary to include both 4th and 6th order terms on the aspheric meniscus. Details of this design are shown in figure 32.

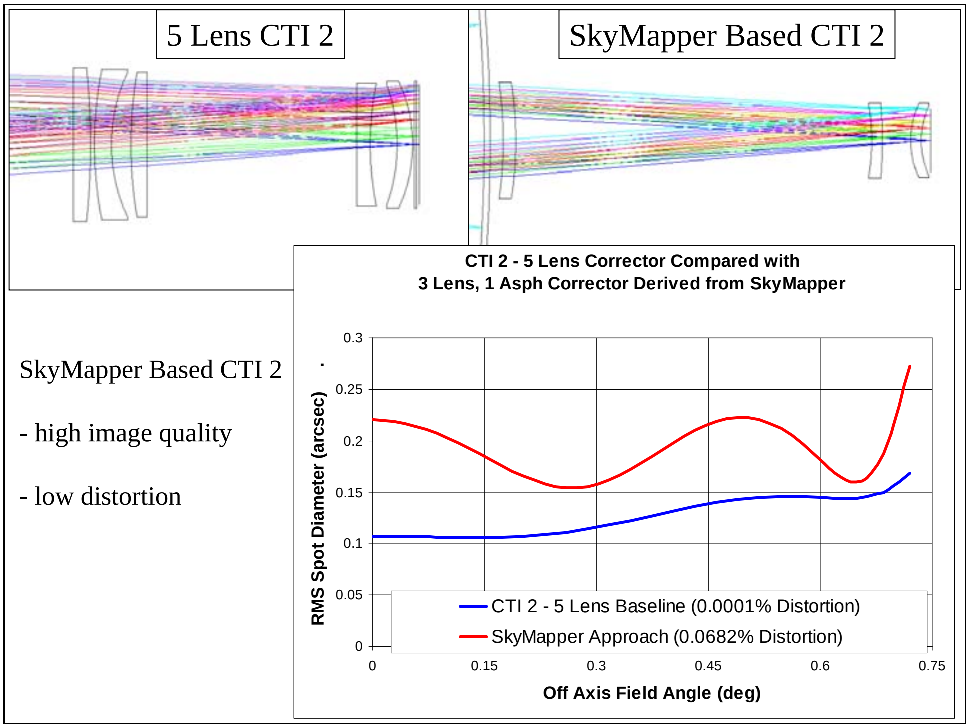


FIG 32. Comparison of 5 Lens CTI-2 design with SkyMapper derived CTI-2.

4.3 PanStarrs-Based CTI-2

The PanStarrs prototype telescope features a 1.8m aperture and a 3.0deg field of view. It is of the super Ritchey-Chrétien design (hyperbolic with higher order aspheric terms) and features a three lens corrector assembly with an additional aspheric surface. Earlier versions of the PanStarrs design did not include the atmospheric dispersion compensator (ADC). One of these earlier designs was used as the starting point for an attempt at producing a CTI-2 system [6].

The basic PanStarrs design is very robust and is capable of extremely high performance. With the more narrow CTI-2 field, the design performance is exceptional but degrades some when the primary mirror is switched to parabolic figure. In the end, the PanStarrs-based CTI-2 exhibited slightly better image quality than the five lens design, but with much higher distortion. All attempts to reduce the distortion resulted in significantly degraded image quality. Details of the design are shown in figure 33.

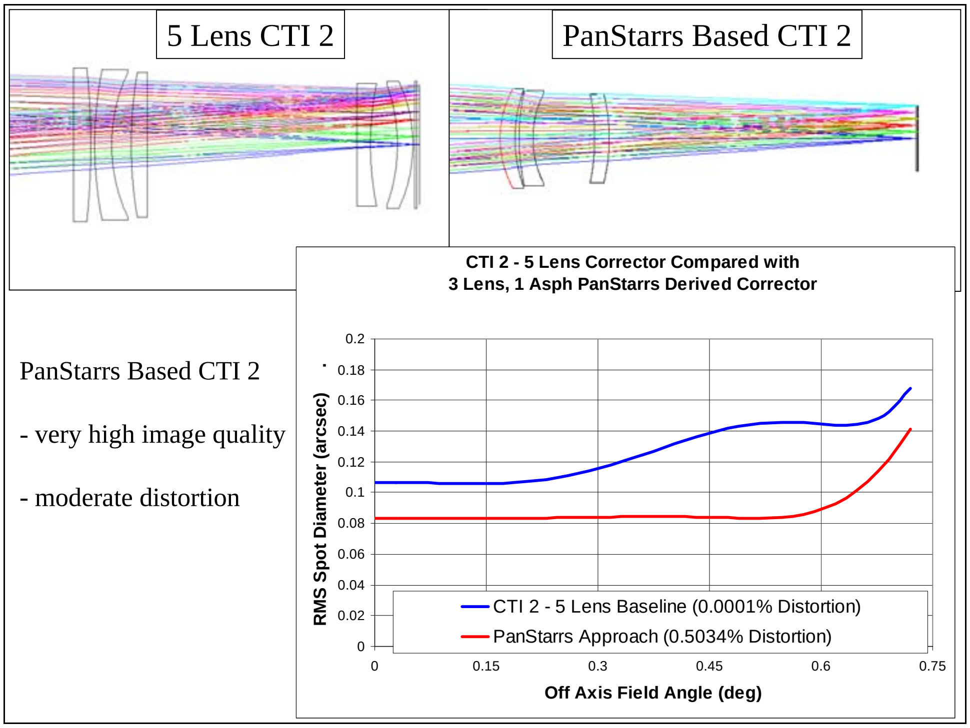


FIG 33. Comparison of 5 Lens CTI-2 design with PanStarrs derived CTI-2.

4.4 VST-Based CTI-2

VST is the 2.61m survey telescope for the Very Large Telescope (VLT) project of the European Southern Observatory [7]. VST is designed for a 1.5deg field of view and is based on a Ritchey-Chrétien system with a three lens corrector. Two different versions of the VST design have been published, one with an ADC and one without and the two designs are considerably different.

We applied the VST approach to the CTI-2 design constraints and produced a system with considerably lower image quality and higher distortion than our five lens design. Details of the design are shown in figure 34.

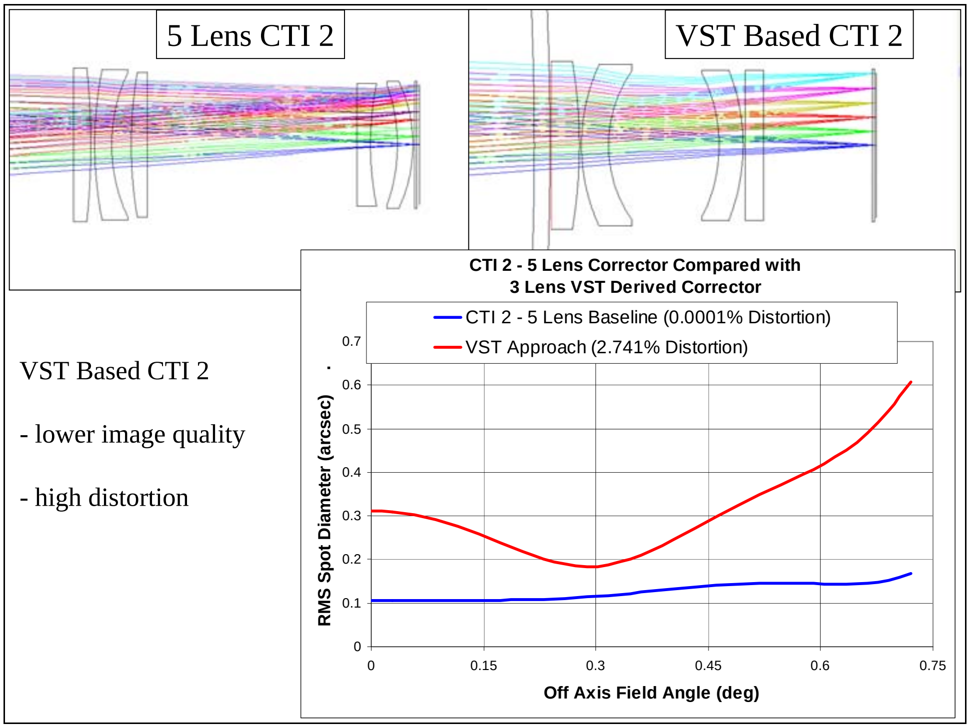


FIG 34. Comparison of 5 Lens CTI-2 design with VST derived CTI-2.

4.5 WIYN ODI-Based CTI-2

WIYN is a 3.5m Ritchey-Chrétien telescope. For wide-field imaging, it is fitted with a three lens corrector known as the One Degree Imager (ODI) [8]. This system is very much like CTI-2 in that it is optimized to produce a 1.42deg image circle and the focal plane array images a 1deg square inscribed within that image circle. The ODI can be used with or without an ADC.

We have adopted the ODI design approach to the CTI-2 constraints and replaced the ADC with a monolithic slab of similar optical properties. Results are not as hoped with image quality degrading steadily towards the edge of the field and relatively high distortion throughout. Details of the design are shown in figure 35.

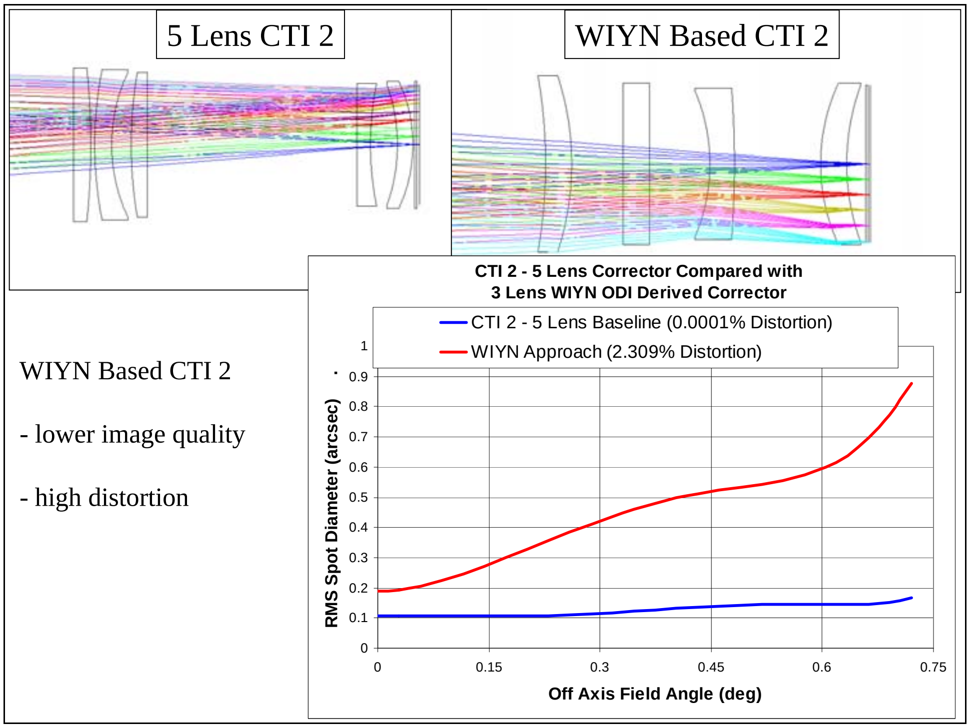


FIG 35. Comparison of 5 Lens CTI-2 design with WIYN-ODI derived CTI-2.

4.2 MMT-Based CTI-2

The final "conventional design" explored was that of the four lens corrector for the 6.5m MMT [9]. This corrector was designed to produce images over a 0.5deg flat field. We have applied that design approach to the CTI-2 constraints and optimized for the required 1.42deg field. Results are disappointing with only moderate image quality and high distortion. This should not be a surprise as the CTI-2 field covers nearly nine times the area of the MMT field. Details of this design are shown in figure 36.

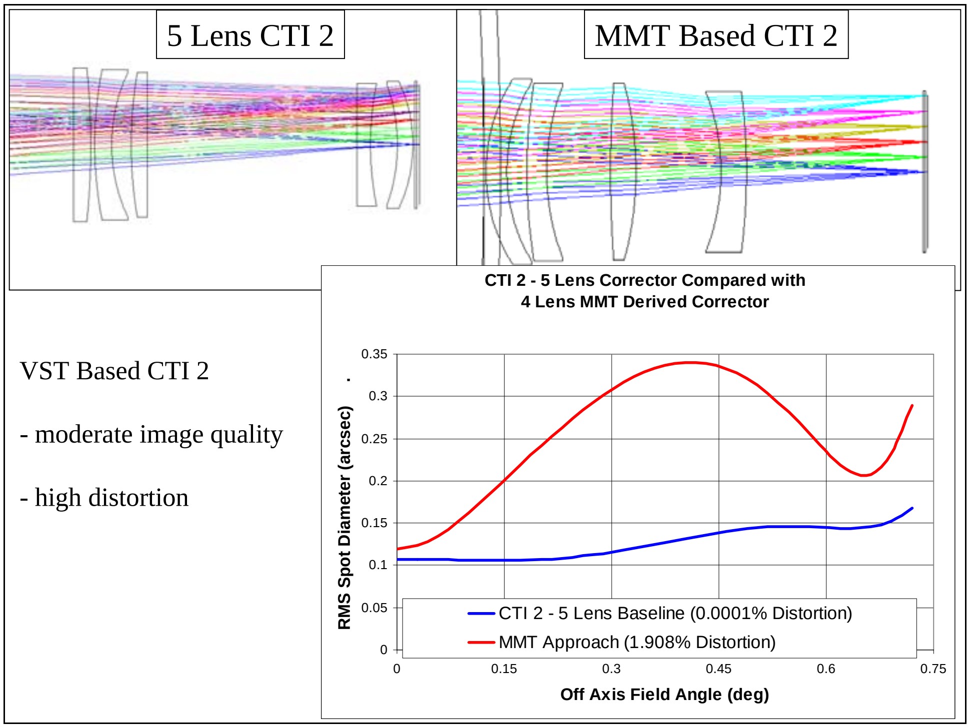


FIG 36. Comparison of 5 Lens CTI-2 design with MMT derived CTI-2.

5. Application of 5 Lens Corrector to Other Systems

As we had gone to great lengths to explore conventional corrector designs and attempt to apply them to the CTI-2 design constraints, we thought an interesting excursion would be to reverse that process and attempt to apply the 5 lens corrector concept to each of the other systems. The results were very interesting showing that the 5 lens approach is quite robust and adaptable to a multitude of other telescopes and science missions. One thing to note is that the five lens corrector appears to perform well with a smaller secondary mirror than many of the other designs.

5.1 5 Lens Corrector for SDSS

Performance of the published design for SDSS exhibits some problems with image quality, particularly out towards the edges of the field. It is not known is this is how the actual system performs but the same optical prescription has been published several times. We designed a five lens corrector to work with the existing SDSS mirrors. The resulting design has exceptional performance across the entire 3.0deg field as seen in figure 37. When the present Sloan survey is complete, this five lens design might be considered as the basis of a refurbished Sloan optical system.

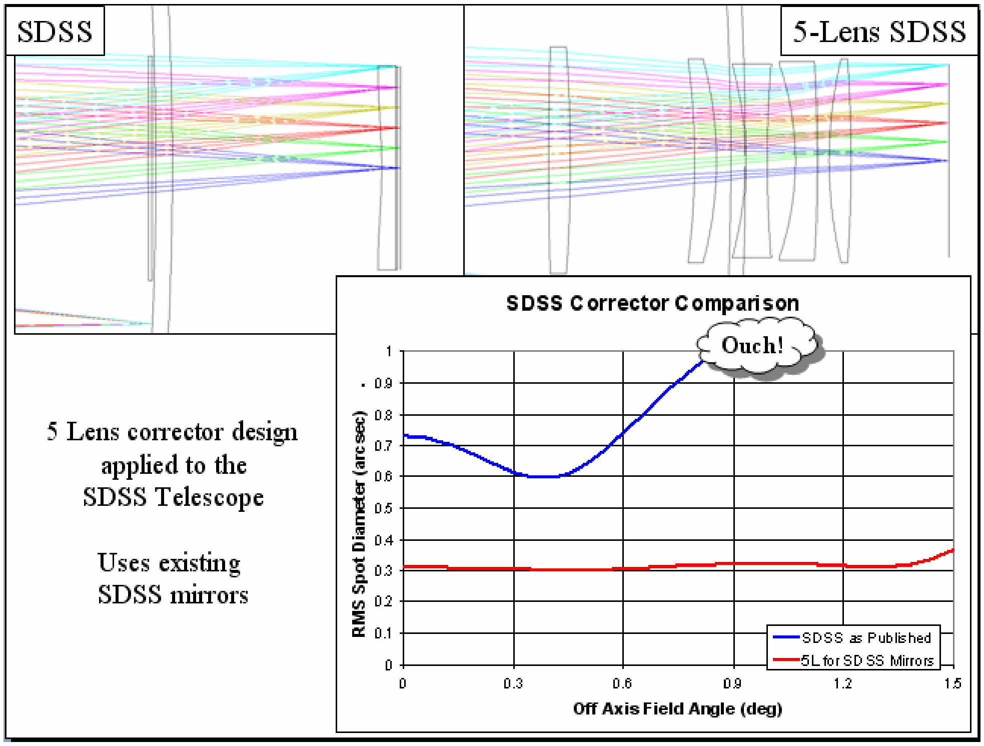


FIG 37. Application of the 5 lens corrector to the SDSS telescope.

5.2 5 Lens Corrector for SkyMapper

After reverse engineering the SkyMapper optical design, we attempted to replace the highly innovative aspheric three lens corrector with a five lens, all spherical corrector. The results, shown in figure 38, are very interesting. The SkyMapper telescope would appear to have nearly equal performance with either the three or five lens corrector. It was observed that the three lens SkyMapper design is somewhat sensitive to the size of the secondary mirror while the five lens corrector can tolerate a smaller diameter secondary. Also, it was observed that the five lens design could push out to wider fields with higher image quality than the three lens version. However, for the performance space addressed by the SkyMapper optical design, the five lens corrector offers no real improvement.

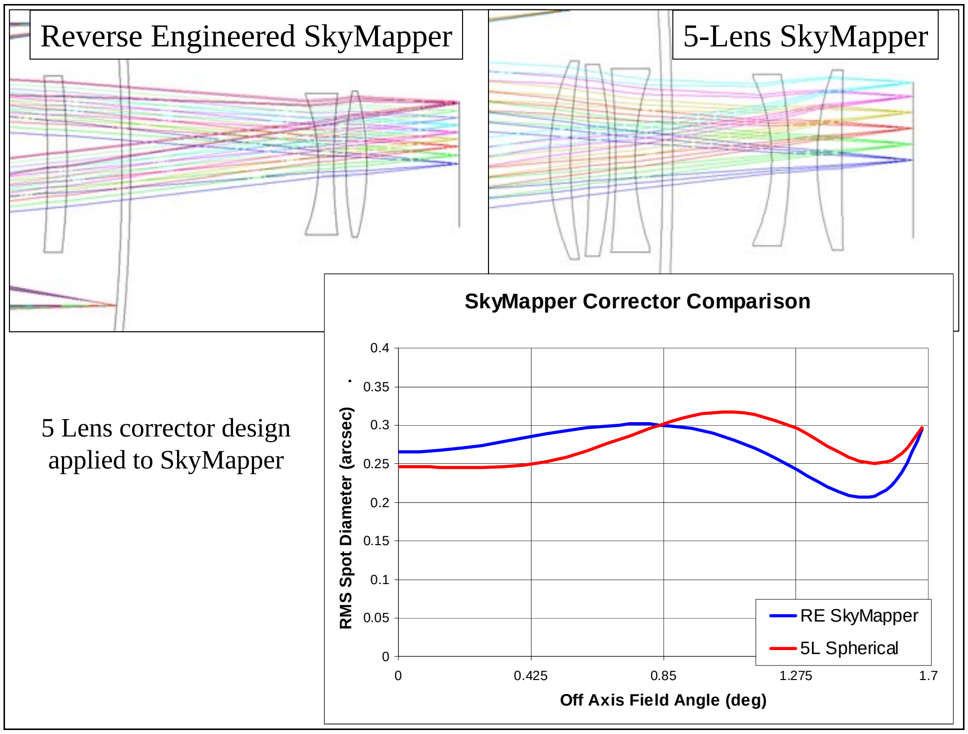


FIG 38. Application of the 5 lens corrector to the SkyMapper telescope.

5.3 5 Lens Corrector for PanStarrs

It was interesting to apply the five lens corrector concept to the PanStarrs telescope. Several comparisons were made, all using the existing PanStarrs primary and secondary mirror prescriptions (based on the PanStarrs preliminary design 4U). Some of the designs were forced to retain the 8000mm focal length while this constraint was relaxed in other designs. A subset of the results are shown in figure 39.

Overall the PanStarrs 4U design has excellent performance but does exhibit roughly 0.2% or about 400µm distortion. One five lens design achieved 0.00001% distortion for a maximum spot deviation of only 0.25µm. Image quality was slightly less than PanStarrs 4U. Another design exactly matched PanStarrs image quality but with 0.0025% distortion giving a maximum spot deviation of only 8µm. The final design features RMS spot diameters less than 0.15arcsec across the entire field.

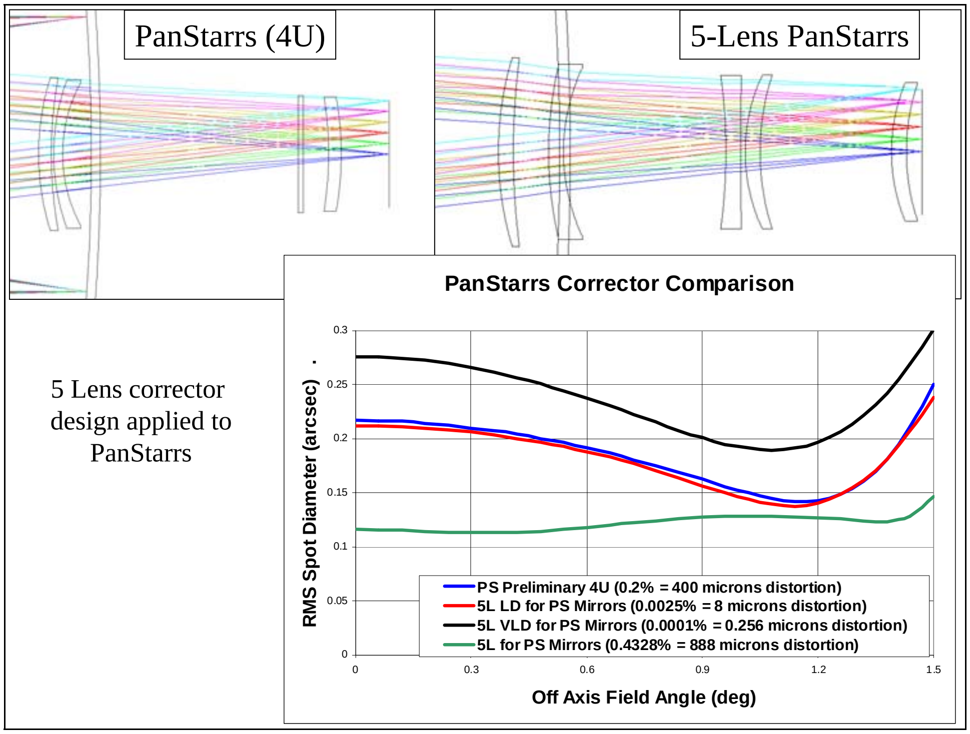


FIG 39. Application of the 5 lens corrector to the PanStarrs telescope.

5.4 5 Lens Corrector for VST

A five lens corrector was designed for the VST telescope using the existing VST mirrors. The new design features better image quality at all field angles as can be seen in figure 40.

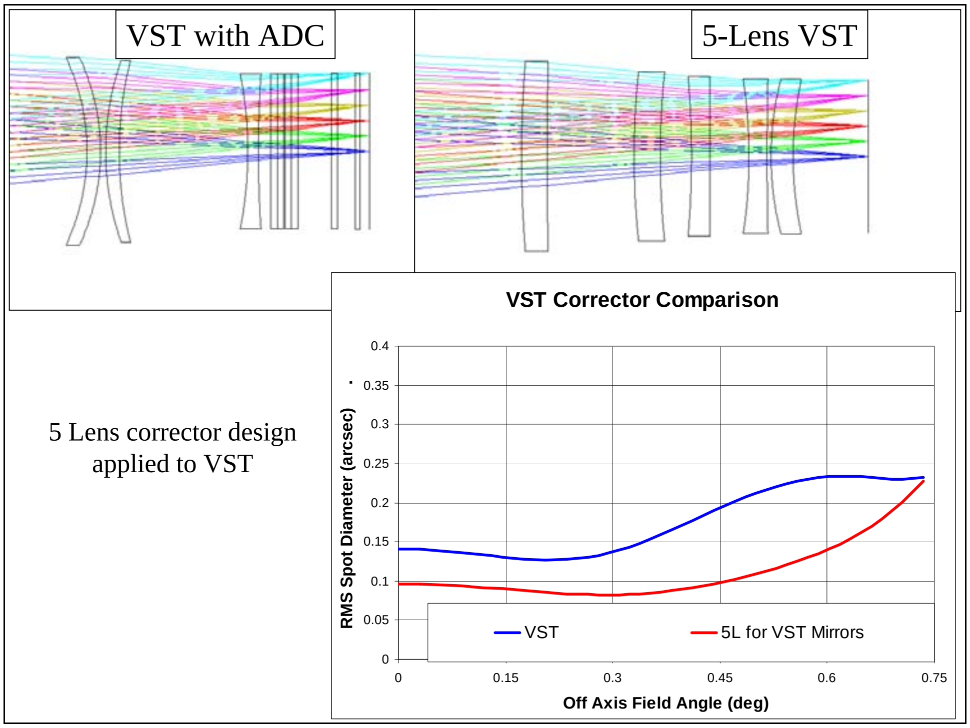


FIG 40. Application of the 5 lens corrector to the VST telescope.

5.5 5 Lens Corrector for WIYN-ODI

The five lens corrector design was applied to the one degree imager for the WIYN telescope. The results were spectacular. The five lens design exceeds the image quality of the ODI at all field angles and is much better behaved with a slight monotonic decrease in spot size as a function of field angle. In terms of distortion, the WIYN-ODI has maximum distortion of 3200μm (3.2mm). The five lens corrector has -0.0019% distortion for a maximum spot deviation of only 7 μm. The five lens WIYN design is shown in figure 41.

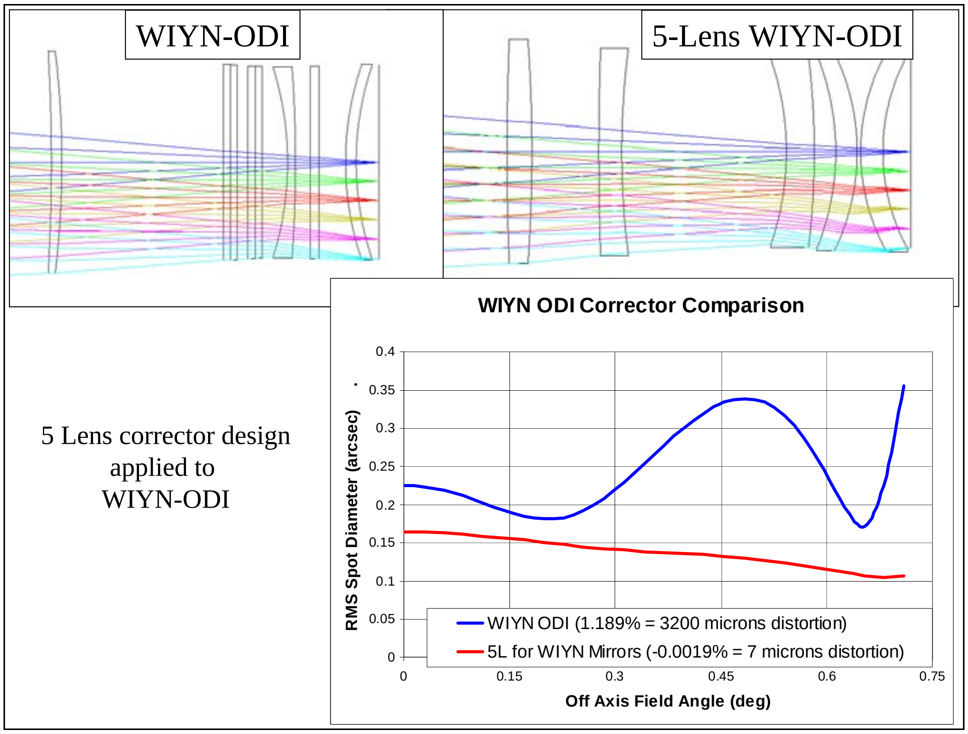
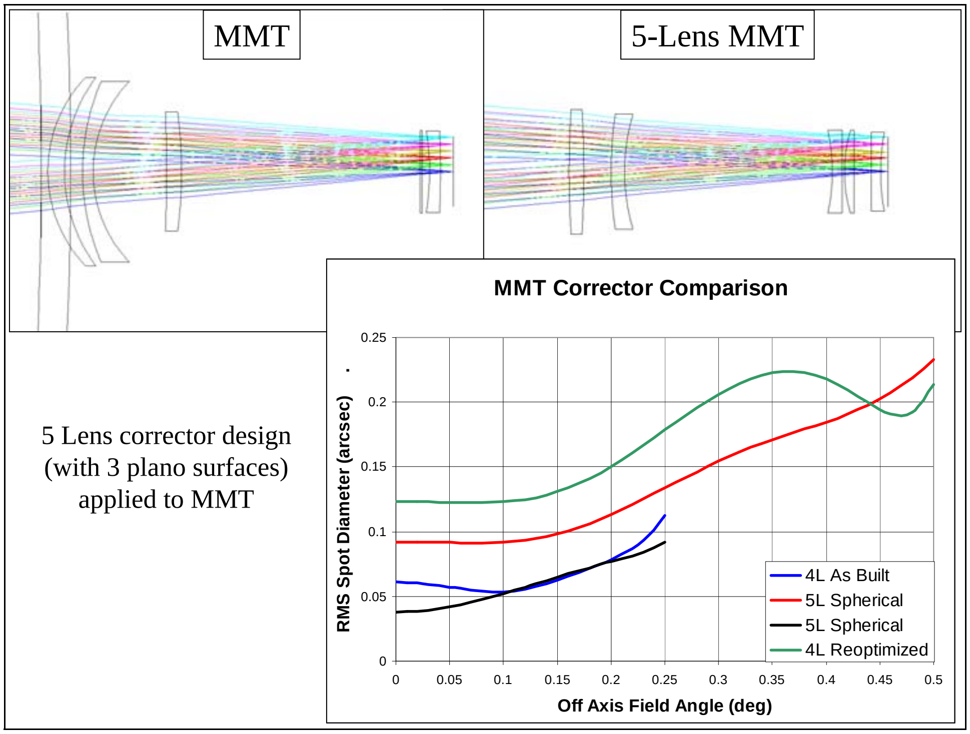


FIG 41. Application of the 5 lens corrector to the WIYN telescope with ODI.

5.6 5 Lens Corrector for MMT

The five lens corrector approach was applied to the MMT. Two designs are presented, one with a 0.5deg field and one with a 1.0deg field. Both produce high image quality. For the 0.5deg field design, performance exceeds the published MMT design, but not by much. However, it should be noted that the MMT design features eight powered surfaces while the five lens design requires only seven powered and three planar surfaces. For the 1.0deg field design, the comparison is less direct as the MMT corrector was not intended to produce flat images over this wide a field. Therefore, the 1.0deg MMT design presented here was developed by the authors by re-optimizing the published 0.5deg field design for a 1.0deg field. Then compared to a 1.0deg field five lens design, we see that the five lens system produces better image quality over almost the entire field. The designs are shown in figure 42.

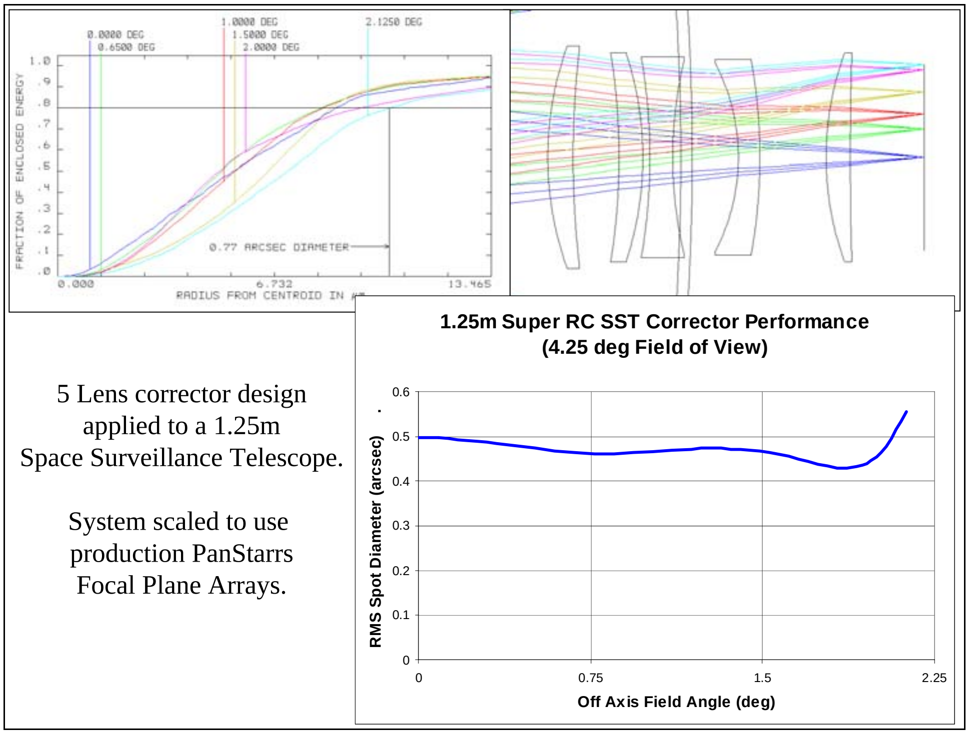


5 Lens corrector design
(with 3 plano surfaces)
applied to MMT

FIG 42. Application of the 5 lens corrector to the MMT.

5.7 1.25m, 4.25deg Field Survey Telescope with 5 Lens Corrector

As a final academic excursion, we attempted to design a small, compact telescope for sky survey or space surveillance using a five lens corrector. The final design pursued featured a 1.25m aperture and a 4.25deg field of view. The telescope was designed to use the existing production PanStarrs focal plane arrays. The resulting telescope is intended to be a competitor of PanStarrs. Rather, it was envisioned as a small, low-cost and transportable telescope the Air Force could use for space situational awareness. It could be deployed to any part of the world within a few days and would be small enough and cheap enough that multiple systems could be built. Image quality is suitable for space surveillance but is not up to the standards necessary for astronomical research. This design is shown in figure 43.



5 Lens corrector design
applied to a 1.25m
Space Surveillance Telescope.

System scaled to use
production PanStarrs
Focal Plane Arrays.

FIG 43. Application of the 5 lens corrector to a 1.25m, 4.25deg field sky survey telescope. Note: This optical system was scaled to use the production PanStarrs focal plane array.

6. Summary

In this paper we have presented details of the unique optical design developed for the NESSI survey telescope, also known as CTI-2. The design features five lenses with seven surfaces of spherical figure and three planar surfaces. Performance is exceptional with 80% of the polychromatic averaged encircled energy falling within a circle of ¼ arcsec diameter or less. Variations in image performance with wavelength are minimal and well behaved with only slight enlargement of spot sizes towards the blue wavelengths.

Attempts to apply more conventional corrector designs to the CTI-2 constraints produced results not meeting science requirements. Some of the designs gave respectable image quality but none could match the performance of the five lens corrector for both image quality and extremely low distortion.

Turning the problem around, we attempted to apply the five lens corrector approach to other telescopes and found the results very favorable. In general, the five lens approach was able to produce higher quality images with lower distortion than the designs used for other telescopes.

The five lens corrector design presented forms the basis of the final optical design for the CTI-2 telescope. From this point forward, only small adjustments will be made for ease of manufacture and alignment.

7. References

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