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Research Article

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Alternative design for extremely large telescopes and options to use the VATT for ELT design demonstration

Abstract: A variety of optical designs for extremely large telescopes (ELTs) can be found throughout the technical literature. Most feature very fast primary mirrors of either conic or spherical figure. For those designs with conic primary mirrors, many of the optical approaches tend to be derivatives of either the aplanatic Cassegrain or Gregorian systems. The Cassegrain approach is more common as it results in a shorter optical system, but it requires a large convex aspheric secondary mirror, which is extremely difficult and expensive to test. The Gregorian approach is physically longer and suffers from greater field curvature. In some design variations, additional mirrors are added to reimage and possibly flatten a Cassegrain focus. An interesting alternative ELT design uses a small Cassegrain system to image the collimated output of a Gregorian-Mersenne concentrator. Another alternative approach, currently in favor for use on the European ELT, uses three powered mirrors and two flat mirrors to reimage a Cassegrain focus out the side similar to a Nasmyth system. A preliminary examination suggests that a small, fast primary mirror, such as that used on the VATT, might be used for a subscale prototype of current ELT optical design options.

Keywords: extremely large telescopes; optical design; telescope.

OCIS classifications codes: 110.6770; 350.1260; 220.0220.

1 Introduction

The current generation of first-tier astronomical telescopes includes those in the 8- to 10-m class, collectively known as “large telescopes.” With the ever-present advance in technology and the desire of astronomers to observe ever more faint objects, the current generation of telescopes will eventually yield to the next generation of even larger systems, currently known as the “extremely large telescopes” (ELTs).

As telescopes get larger, they also become more expensive. At present, there are relatively few large telescopes, and it is thought that very few ELTs will ever be built. Observing time on these giants will be highly sought after, and astronomers will demand the utmost in image quality to match the supreme light grasp of these systems. The demand for high image quality will necessarily require careful attention be paid to optical design, site selection, alignment metrology, and instrumentation. The optical designs will prove to be critical as they will directly impact cost, manufacturability, maintainability, image quality, and the range of instruments that can be adapted to the optical assembly.

In this paper, we present a new optical design for an ELT with a fast, conic primary mirror along with a previously published design and examine the potential for a subscale demonstration of these optical systems using a small, fast primary, such as that present on the Vatican Advanced Technology Telescope (VATT). The new design features mostly concave surfaces and is specifically designed to produce high image quality, a relatively wide field-of-view, and a flat image plane. After introducing the design, we discuss how the VATT could be adapted as a pathfinder or demonstrator for the new optical design or the previously published E-ELT design.

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2 The current generation: large telescopes

The path to the current generation of large telescopes was not a direct one. Following completion of the 5-m Hale telescope in 1948, the great reflector at the Mount Palomar observatory remained the largest optical telescope in the world for more than two decades and was only bested in 1975 by the 6-m Bolshoi telescope [1] undertaken as a national effort by the former Soviet Union. Both of these telescopes helped to convince telescope designers and fabricators that massive, solid, monolithic mirrors had reached their limit. To go larger would require a new approach. The multiple-mirror telescope [2] was to be the first telescope employing a new approach. It succeeded in combining the images from six relatively moderate focal ratio (f/2.7) 1.8-m mirrors to function as a single larger telescope. The resulting field-of-view was, however, necessarily narrow. The monolithic mirror telescope (MMT) also demonstrated a new approach to telescope enclosure. While the altitude-azimuth (Alt-Az) mount had previously been demonstrated on the Bolshoi telescope, the relative inaccessibility of that telescope to western scientists resulted in it having a more limited impact. The MMT combined the Alt-Az mount with a rotating structure, thereby, helping to initiate a new era in observatory design. The MMT was sufficiently successful that it spawned one of the first proposals for a large (borderline extremely large) telescope, the 15-m National New Technology Telescope (NNTT) [3]. The plan was to combine the light from four mirrors of 7.5 m aperture, much the same as the MMT had combined the light from six smaller mirrors. In the end, both the MMT and the NNTT died as new mirror technologies made larger monolithic, lightweight mirrors possible. The NNTT has been retired to a footnote in telescope history, while the MMT was replaced with a single 6.5-m lightweight monolithic primary, making it the MMT [4].

The new mirror technologies include the spin cast technique, pioneered by the University of Arizona Steward Observatory Mirror Laboratory [5], and thin meniscus mirrors formed by slumping a large, thin blank over an approximate-shape form. The meniscus mirrors usually require active mirror cells to achieve and maintain proper figure.

At present, the largest spin cast monolithic telescope mirror is 8.4 m in diameter. A total of four such mirrors have been produced as of June 2009. Two mirrors with f/1.14 parabolic figures were made for the large binocular telescope (LBT) [6]. One mirror was fashioned as an off-axis portion of an f/0.7 elliptical mirror for the Giant Magellan Telescope (GMT) [7]. The final 8.4-m mirror is to be the primary mirror for the large synoptic survey telescope (LSST) [8]. Other large spin-cast mirrors have been made with various diameters, such as the twin 6.5-m mirrors for the Magellan telescopes [9].

Other large telescopes with monolithic primary mirrors use the thin meniscus approach. Telescopes of this type have apertures up to 8.3 m in diameter. Examples include Gemini North and Gemini South (8.1 m) [10], the four telescopes of the very large telescope (VLT) of the European Southern Observatory (ESO) (8.2 m) [11], and the Subaru Telescope (8.3 m) [12]. Neither large mirror technique is suitable for apertures much greater than those already in service. The reasons for this include both manufacturability and practicality of transport and installation.

To go larger, it is, at present, thought necessary to segment the primary mirror. Several schemes for such segmentation have emerged, including the use of many small hexagonal segments, segments, which are portions of an annular ring, and very large segments, more commonly called petals. Several examples of large telescopes with segmented primary mirrors already exist. These include the two Keck telescopes (10 m) [13], the Hobby-Eberly Telescope (HET – 9.2-m aperture, but with an 11-m diameter mirror) [14], the South African Large Telescope (SALT – 11 m) [15], and the Gran Telescopio Canarias (GTC – 10.4 m) [16].

Viewed as a whole, the collection of large telescopes shows considerable experimentation with optical configuration, primary mirror figure, and overall system fabrication technology. Best represented is the aplanatic Cassegrain design, but the classical Cassegrain and Gregorian are also seen in use. Spherical primary systems are limited to the HET and SALT, which is unfortunate as the spherical primary has multiple advantages for an ELT due to the ease of manufacture and the greatly reduced number of spare segments required. Noticeably absent from the list of designs is an aplanatic Gregorian. The Gregorian, in general, has never been an overly popular optical design, but it has experienced a considerable resurgence in recent years on telescopes such as the Magellan twins, the VATT, and for at least one set of foci on the LBT.

3 The next generation: extremely large telescopes

The next frontier for optical astronomy is the extremely large telescope (ELT). Plans for ELTs were in the works before construction of the first large telescope project had commenced. For years, a relatively large number of ELT projects have been active in the study and planning stages. Over time, some of these studies simply die, while others merge and evolve. At the present time, a modest number of proposals continue to be developed, some in great detail. Most feature primary mirrors made from a large number of relatively small hexagonal segments, while one concept is moving forward with a small number of large petals.

Currently, among concepts with smaller hexagonal segments, the 42-m European Extremely Large Telescope (E-ELT) [17] and the Thirty Meter Telescope (TMT) [18] are the only projects likely to see hardware within the next decade. Both projects are progressing, but the E-ELT was reduced slightly to 39-m equivalent diameter. The GMT [7] is actually underway at this time having one of its seven 8.4-m petals completed and another in process.

Both the TMT and E-ELT projects are planning to use a hyperbolic primary mirror, and each has settled on a basic aplanatic Cassegrain configuration. The E-ELT baseline design is a five-mirror system, using a reimaging mirror and two flat fold mirrors [17]. The design sounds quite complex but is actually rather simple. The flat fold mirrors are used to move the image to a more useful location. The basic optical layout is shown in Figure 1. This approach provides high image quality and can be optimized to produce a flat image field.

The TMT is, at present, a strict Ritchey-Chrétien with a single Nasmyth fold mirror. The design is not unlike that of the 3.5-m WIYN telescope located on Kitt Peak in Arizona.

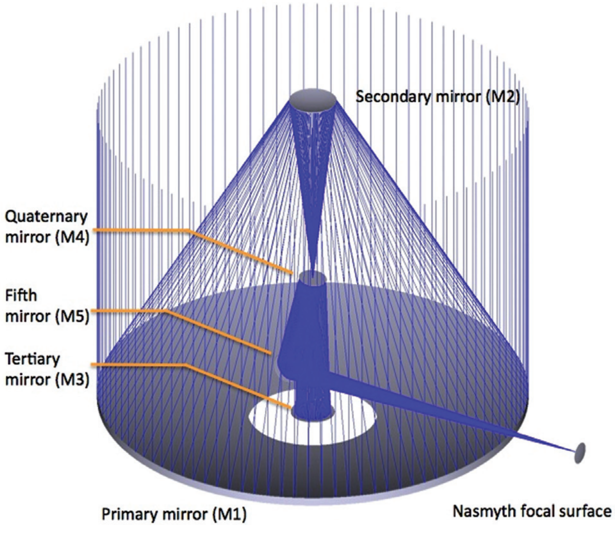


Figure 1 Five-mirror layout for E-ELT [19].

Primary mirrors for both the E=ELT and TMT will be composed of hexagonal segments. The segments are sorted into groups. Within each group, all segments are identical and can be ground, figured, and tested the same. Different groups, however, require different fabrication and testing. The use of a conic primary mirror has advantages that include reduced system complexity and improved image quality, but clearly has disadvantages in fabrication, testing alignment, and maintenance. In addition to all the unique mirror segments, each must be installed with only one orientation relative to the telescopes optical axis, and each group requires its own spare segment.

The GMT is the only ELT system currently in the hardware phase, although large-scale construction of the telescope really has not begun. The primary mirror is envisioned to consist of seven petals of 8.4 m in diameter each. Six segments are off-axis sections, while the seventh is axially symmetric. The seven petals fit together to result in an f/0.7 primary with an elliptical figure. Overall, the GMT will feature an aplanatic Gregorian configuration.

A problem with both the GMT and TMT is that the optical systems result in a curved focal surface. While the telescopes will have relatively narrow fields-of-view (10–20 arc min), given their size, field curvature will still be an issue. Owing to the size of the telescopes, the focal planes will also be large making refractive corrective optics either difficult or impossible. Alternate designs, such as the reimaged RC proposed for the E-ELT can flatten the image surface using only mirrors.

While there are advantages to the basic Cassegrain configuration, such as reduced overall length, a significant disadvantage is that they require a large, convex secondary mirror. Testing of these mirrors can range from difficult to nearly impossible. One option is for the secondary mirror to be tested as part of the full optical system. While this approach is possible, it is somewhat impractical as the fabrication facility will likely be distant from the observatory. Gregorian optical systems are slightly longer, but have the advantage of a concave secondary mirror, which can more easily be figured and tested.

One issue facing ELTs is that of the overall length of the optical assembly. To reduce wind loading and keep fabrication costs of the structure and enclosure reasonable, short telescopes are preferred to longer telescopes. This necessarily requires faster primary mirrors. Most current ELT plans call for primary mirrors with focal ratios on the order of f/1.0 or less. The primary mirrors for both the E-ELT and TMT operate at roughly f/1.0. The faster mirrors introduce greater aberrations, thereby, necessitating more complicated corrective optics.

4 The modified Gregorian-Mersenne ELT

An alternative approach to the GMT, E-ELT, and TMT ELT designs, relies on four mirrors in a combined Gregorian-type Mersenne [20] configuration followed by aplanatic Cassegrain reimaging optics. The system is not easily classified by any of the known classic names and is, here, referred to as a modified Gregorian-Mersenne (MGM). The basic configuration is shown in Figure 2. It starts with a fast concave primary mirror of elliptical figure. The primary brings the light to an initial focus that is followed by a small concave conic secondary mirror, much as in a classic aplanatic Gregorian. The difference between this design and a classic Gregorian is that the secondary mirror recollimates the light and directs it toward a small tertiary mirror. The tertiary is again a concave conic, which causes the light to concentrate as it moves toward the quaternary mirror. The final mirror is a small convex conic, which slows the beam and directs it toward the final focus.

The advantages of the MGM ELT configuration are that the secondary and tertiary mirrors are concave conics, while only the quaternary is a convex conic and the smallest of the four mirrors. The system also features a flat focal surface. Locating baffles in the MGM design can present a bit of a challenge. Baffle tubes extending forward of the Cassegrain corrector system formed by mirrors three and four as well as a tube extending back from mirror two help eliminate paths for stray light. Careful analysis for specific designs will be required. One option that provides some relief is to locate mirror four at the vertex of the primary and mirror three behind the primary, and then add baffle tubes as necessary. The MGM approach appears adaptable to any of the current ELT designs.

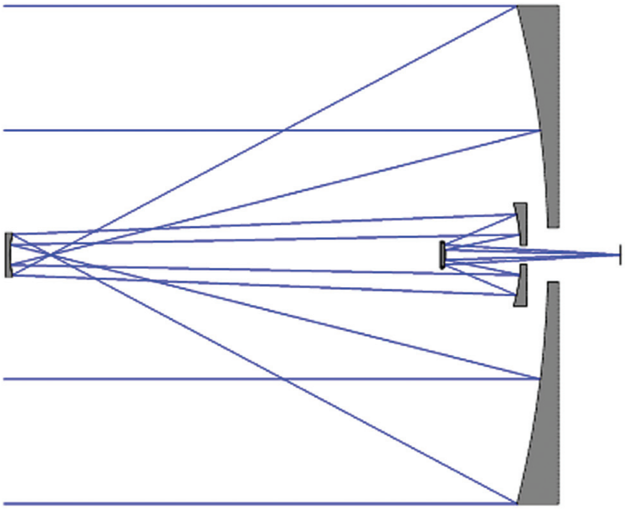


Figure 2 Modified Gregorian-Mersenne optical system.

The MGM optical configuration resulted from a design study looking at improving image quality in extremely large telescopes using only four mirrors. One goal of the study was to minimize the size of corrector mirrors, in general, and to minimize the size of convex aspheric mirrors, in particular. The details of the study are beyond the intended purpose of this paper, but a brief synopsis will be given.

When designing an aperture-efficient, axially symmetric four-mirror system, the first mirror is obviously concave. For the secondary mirror, one has the choice of Cassegrain or Gregorian configuration. A Couder or Schwarzschild configuration is also possible, but these choices lead to unworkable solutions and are not pursued here.

Once the secondary mirror configuration is identified, the next choice is whether to have an internal focus or not. With an internal focus, the light usually passes through the center of the quaternary mirror. Without an internal focus, the light will pass around the quaternary mirror.

For the last two mirrors, there are four choices, concave-concave (clamshell arrangement), convex-concave (Cassegrain configuration), concave-convex (inverted Cassegrain or INCA), or convex-convex. Clearly, the last choice leads to unworkable systems and is discarded. It is also possible to have an internal focus between the tertiary and quaternary mirrors. This generally only works well if there is no focus in between the secondary and tertiary mirrors.

When combining the choices and discarding ones that will obviously fail, one finds a total of 12 system layouts that must be developed and optimized. Briefly, there are two choices for the secondary, two choices for internal focus, and three choices for the aft two corrector mirrors. All 12 approaches were developed and evaluated. The MGM approach defined by a Gregorian secondary, no internal focus, and a Cassegrain aft section was found to offer the optimum combination of performance and simplicity, requiring only conic surfaces and a very small convex mirror.

In the technical literature, one finds a number of examples of four-mirror systems. Of the axially symmetric systems, some are uniaxial and others are biaxial, but can still be considered symmetric other than the fold mirror. Wilson publishes brief details of a small number of such designs, but all are of the Cassegrain type with an internal focus, followed by a clamshell, Cassegrain or INCA-type corrector [20]. Korsch publishes one basic example that is similar to one of Wilson's designs having an initial Cassegrain configuration with an internal focus, followed by a

Cassegrain corrector [21–23]. Sasian has looked at similar concepts but prefers to use a clamshell configuration for his corrector mirrors [24].

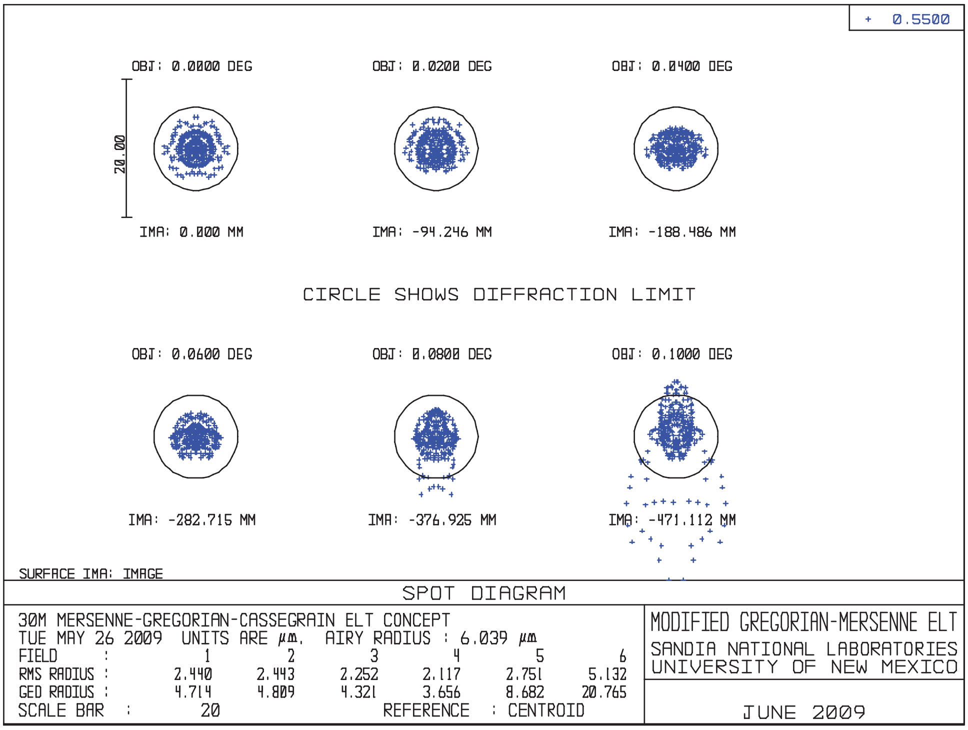
Much less common in the literature are four-mirror design examples where the light from the initial two mirrors passes back to the tertiary without an internal focus. Rakich has published such designs where the corrector is again of Cassegrain configuration. This type of telescope could be thought of as a double Cassegrain [25]. Another Rakich design uses an INCA-type corrector [26].

While some of the known designs in the literature perform well, they all suffer from a large convex secondary mirror. One goal of the design study was to eliminate large convex secondary mirrors. Four-mirror configurations where the initial two mirrors form a Gregorian system are essentially unknown, but have the advantage of using a concave secondary mirror. When comparing the MGM approach to the Cassegrain configurations, the Gregorian approach was found to give equal image quality with less complex mirror surfaces.

To compare the performance of the MGM system to other ELT approaches, we need to scale all systems to a common aperture. Here, we simply use a 30-m aperture similar to the TMT, even though the MGM approach easily scales to larger apertures, such as 39 m as proposed for the E-ELT. The MGM approach also works for the GMT, but with its faster primary mirror, the resulting system is a bit more difficult to optimize and is not explored further at this time. The MGM approach could be considered as an alternative to the current five-mirror E-ELT design. The MGM requires one less mirror, but the E-ELT design has slightly higher image quality. Both approaches result in a flat focal plane.

The optical layout for a 30-m MGM ELT is the same as that shown in Figure 2. Image performance is represented by the spot diagrams seen in Figure 3. The optical prescription is given in Table 1.

For comparison purposes, we have scaled the five-mirror design for the 39-m E-ELT to a 30-m aperture. The RMS spot diameter for the two designs is shown graphically in Figure 4. The ray-trace spots for both designs easily exceed the diffraction limit at λ=550 nm, but the five-mirror E-ELT approach does perform better. It is, however, necessary to note that the five-mirror E-ELT design (as scaled to 30 m) requires a 5.1-m diameter convex conic secondary mirror, and the 4-m diameter concave tertiary is a more complex general asphere. The larger secondary allows for better correction than the smaller secondary of the MGM approach. The 5.1-m diameter secondary will be challenging to test and might require the full optical system for a complete evaluation. When the overall system is scaled up to 39-m diameter, the problem becomes all the more



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30M MERSENNE-GREGORIAN-CASSEGRAIN ELT CONCEPT
TUE MAY 26 2009  UNITS ARE µm.  AIRY RADIUS : 6.039 µm
FIELD      :       1       2       3       4       5       6
RMS RADIUS :   2.440   2.443   2.252   2.117   2.751   5.132
GEO RADIUS :   4.714   4.809   4.321   3.656   8.682  20.765
SCALE BAR  :      20              REFERENCE  : CENTROID
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Figure 3 Spot diagram for 30-m MGM-based TMT.

Table 1 Optical data for 30-m MGM-based TMT.

#	Type	Comment	Radius of curvature	Thickness	Glass	Diameter	Conic
0	Standard		Infinity			0.0000	0
1	Standard		Infinity	35,000.0000		0.0000	0
2	Standard	M1	-60,000.0000	-33,796.9664	Mirror	30,000.0000	-0.991
3	Standard	M2	7994.4856	32,371.9664	Mirror	3945.3375	-1.307951
4	Standard	M3	-17,514.8003	-7503.2084	Mirror	6117.4647	-0.650429
5	Standard	M4	-5035.3585	7503.2084	Mirror	1455.1186	-1.68743
6	Standard		Infinity	2865.0838		1083.2372	0
7	Standard	Image	Infinity	0.0000		942.2704	0

difficult. The tertiary is also difficult to test being significantly aspheric, most likely requiring a computer-generated hologram. The MGM-TMT approach does not have as much design margin as the E-ELT five-mirror concept, but it is still diffraction limited, and the optics are all conics. The only convex optic is mirror number four, which is only 1.455 m in diameter and a mild conic. This mirror can be independently tested using existing technology and test hardware. Overall, the MGM-TMT approach would be easier to manufacture and test.

While the spot diagram for the 30-m MGM ELT appears impressive, many astronomers will chose to use the telescope in modes where the quality of the optical wavefront is more important than the image resolution. Spectrometers, for example, are sensitive to the quality of the optical wavefront. When a system is diffraction limited as depicted by the spot diagram seen in Figure 3, the wavefront will necessarily be of very high quality, resulting in a system Strehl ratio value of near one. The 30-m MGM as shown above results in an as-designed Strehl ratio in excess of 0.9 across the inner 80% of the field, falling to 0.8 at the edge of the field. Wavefront mapping in the center of the field shows a peak to valley range of 0.0834 waves at λ=400 nm in the center of the field, degrading to a peak to valley range of 0.54 waves at the edge of the field. This design was, however, optimized for spot size image quality. If optimized for wavefront error, the variation of wavefront across the field will be significantly reduced.

5 VATT as an ELT pathfinder

Even though the GMT project has already completed one of their seven primary mirror petals, and is in the process of finishing the second, the first light for any of the ELT projects is at least 5 years off, if not, a full decade. Until then, ELT optical concepts will remain design exercises, unless subscale prototype systems are built. Subscale systems could be used to demonstrate the basic optical approach and learn what unique challenges each design presents in

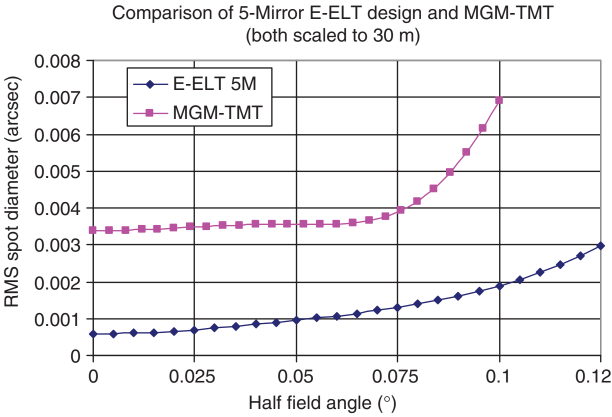


Figure 4 Comparison of E-ELT five-mirror and MTM-TMT four-mirror designs, both scaled to 30-m aperture.

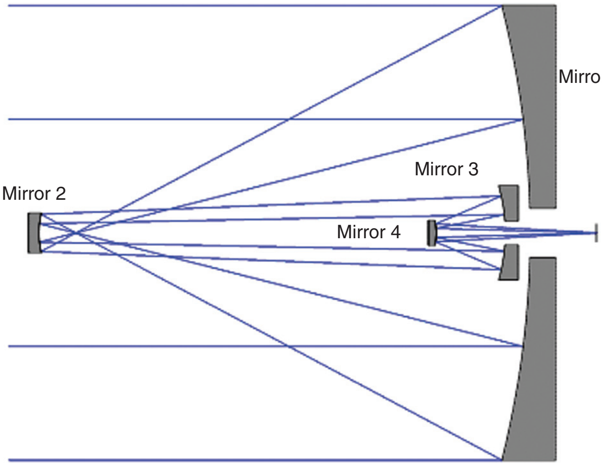
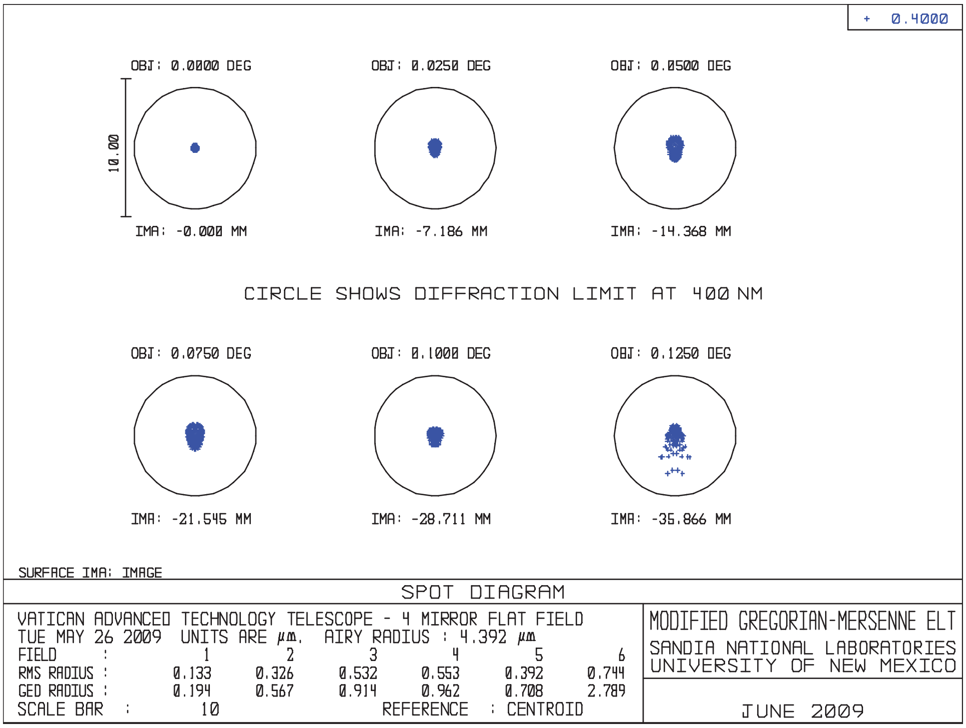


Figure 5 Optical layout of MGM-VATT.



VATICAN ADVANCED TECHNOLOGY TELESCOPE - 4 MIRROR FLAT FIELD
TUE MAY 26 2009 UNITS ARE µm. AIRY RADIUS : 4.392 µm

FIELD :	1	2	3	4	5	6
RMS RADIUS :	0.133	0.326	0.532	0.553	0.392	0.744
GEO RADIUS :	0.194	0.567	0.914	0.962	0.708	2.789

SCALE BAR : 10 REFERENCE : CENTROID

Figure 6 Optical performance of MGM-VATT.

the form of alignment and focus as the telescope moves across the sky, and the mirrors experience different gravitational loading. Large complex telescopes, such as any of the proposed ELT designs, will necessarily use some form of active mirror positioning and primary mirror figure control. It is possible that a subscale system could be used to demonstrate the various hardware and software elements necessary to sense and maintain alignment of the individual mirrors. While such development could be done on the full-scale system, the learning potential of a subscale demonstrator would likely accelerate final ELT assembly and alignment, potentially saving months of time at a very expensive, large facility. It is not the purpose of this paper to propose any specific demonstration and test program; the only intent is to introduce the potential for such activities.

One interesting possibility for demonstration of proposed ELT optical designs is provided by the VATT [27]. The VATT was built as a 1.8-m aplanatic Gregorian with a very fast, f/1.0 primary mirror. The conic constant is -0.9958 making it very similar to that specified for some of the former 30-m class aplanatic Gregorian designs.

The VATT was originally built for single point photometry and attempts to use it for imaging clearly show the impact of field curvature as image quality degrades rapidly with field angle. It is possible to correct the field with refractive components, but a more interesting alternative would be to modify the VATT into an MGM-ELT prototype

Table 2 Optical prescription for MGM-VATT.

#	Type	Comment	Radius of curvature	Thickness	Glass	Diameter	Conic
0	Standard		Infinity			0.0000	0
1	Standard		Infinity	2,100.0000		0.0000	0
Stop	Standard	Existing VATT M1	-3,660.0000	-1,978.9137	Mirror	1830.0000	-0.9958
3	Standard	New M2	323.4324	1878.9137	Mirror	159.2035	-1.443818
4	Standard	Existing VATT M2	-671.0600	-279.7267	Mirror	377.0000	-0.655
5	Standard	New M4	-205.6355	279.7267	Mirror	99.9923	-1.588412
6	Standard		Infinity	365.1738		0.0000	0
7	Standard	Image	Infinity	0.0000		71.7372	0

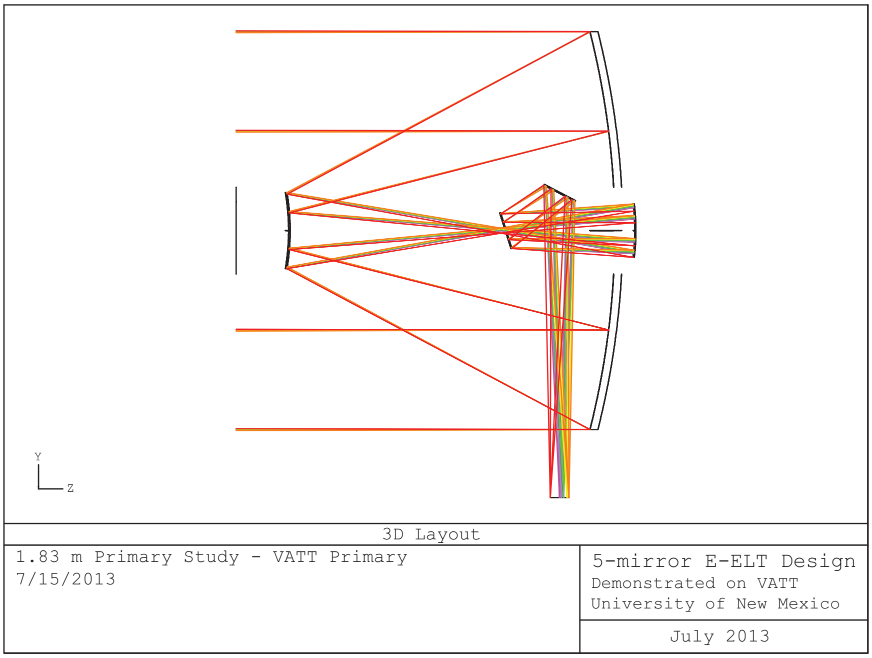
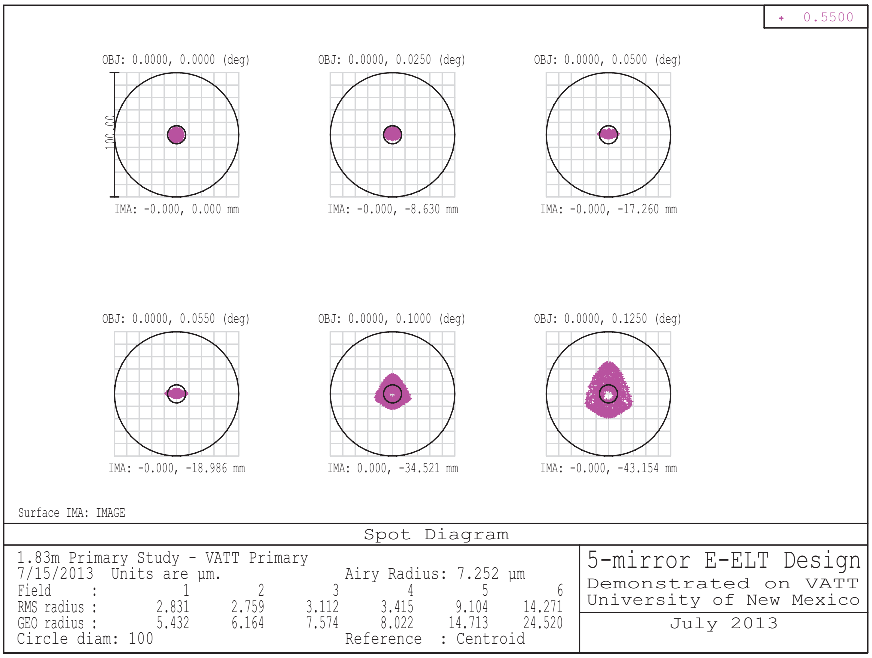


Figure 7 Optical layout of E-ELT demonstrator using VATT primary.

or an E-ELT five-mirror prototype. This would widen the useful field and result in a working optical model providing insight into the potential functioning of either ELT design. What is more interesting about the VATT is that it appears possible to use the current VATT secondary mirror as the tertiary for an MGM-based VATT. This is quite fortuitous as the only optics required for the MGM-VATT would be a small concave conic secondary and a small convex conic quaternary. The current VATT secondary is known to have a central perforation. The size of this perforation is not published, and it is not known for certain if the secondary could serve as the tertiary, but the possibility is intriguing.



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1.83m Primary Study - VATT Primary
7/15/2013  Units are µm.                Airy Radius: 7.252 µm
Field      :        1        2        3        4        5        6
RMS radius :    2.831    2.759    3.112    3.415    9.104   14.271
GEO radius :    5.432    6.164    7.574    8.022   14.713   24.520
Circle diam: 100                        Reference  : Centroid
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Figure 8 Optical performance of the E-ELT demonstrator using VATT primary.

The optical layout for an MGM-VATT is shown in Figure 5. This design was optimized to retain the f/9.0 final focus of the current VATT. Other focal ratios are possible within reason. Mirror number one and mirror number three are the original primary and secondary mirrors from the current VATT optical system. Optical performance is shown in Figure 6. The spot diagrams show the diffraction limit at λ=400 nm. This design is clearly diffraction limited and has substantial design margin, which should help reduce manufacturing and alignment tolerances. The optical prescription is given in Table 2.

The VATT could also be modified to serve as a demonstration telescope for the E-ELT five-mirror design. The conic constant of the primary is incorrect, but only slightly. The difference is really insignificant and can be compensated with slight changes in mirrors two and three. An adaptation of the five-mirror E-ELT design to a VATT-sized telescope is shown in Figure 7, and the ray-traced spot diagram is shown in Figure 8.

Comparing Figures 6 and 8, we quickly see that the MGM-VATT design performs much better than the five-mirror E-ELT demonstrator using the VATT primary. The fault here is not with the five-mirror design, but with the VATT primary. The existing VATT primary has the optimum shape for the MGM demonstrator but is not quite optimum for the five-mirror design. Nonetheless, the five-mirror VATT demonstrator appears to perform well suggesting that the VATT, or a similar small, fast primary mirror could serve as a system demonstrator for one of the ELT designs currently under consideration.

6 Summary and recommendations

The MGM optical design introduces an interesting alternative for ELTs with fast conic primary mirrors. The design has the significant advantage of not requiring a large convex conic mirror as used in aplanatic Cassegrain designs. The secondary and tertiary mirrors are concave, while only the small quaternary mirror is a convex conic. The design performs extremely well and is easily scaled to ELTs in the 30- to 40-m class. Image performance is exceptional, and the design results in a flat focal surface.

As a pathfinder for an MGM-based ELT, it appears possible to modify the current VATT into an MGM-based system, reusing both the VATT primary and secondary mirrors. A prototype of the MGM optical system with the VATT provides the opportunity to explore the limits and performance of the MGM design and will result in a VATT system optimized for imaging.

As the optical design for the 39-m E-ELT is already well developed, it is unlikely that project would switch to the MGM design, even if it was easier to fabricate and align. The VATT, however, also provides an opportunity for demonstration of the five-mirror E-ELT optical design. The ability to work with the functional design years in advance of first light for the E-ELT could prove to be of significant advantage, giving insight into operating characteristics and peculiarities of the optical system.

Received July 16, 2013; accepted August 29, 2013; previously published online September 27, 2013

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