Giant Segmented Mirror Telescope: a point design based on science drivers

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ABSTRACT

We describe a 'point design' for a 30m Giant Segmented Mirror Telescope (GSMT) aimed at meeting a set of initial science goals developed over a period of two years by working groups comprised of more than 60 astronomers. The paper summarizes these goals briefly, captures the top-level performance requirements that follow from them, and describes a plausible, first-cut technical solution developed as part of an overall systems-level analysis. The key features of the point design are: (1) a fast (f/1) primary; (2) an adaptive secondary that serves both to compensate for the effects of wind buffeting and as the first stage of three adaptive optics systems: (i) multi-conjugate AO; (ii) high-performance on-axis AO; (iii) ground-level seeing compensation; (3) a radio telescope structure; (4) multiple instrument ports (prime focus; Nasmyth foci; direct Cass); (5) an hierarchical control system comprising multiple active and adaptive elements.
Keywords: Giant Segmented Mirror Telescope, conceptual design

1. INTRODUCTION

Najita and Strom[1] summarize the science enabled by the enormous gains in sensitivity and angular resolution afforded by a 30-m class telescope. Among the key programs described therein are:

- Quantifying the distribution of gas and galaxies at redshifts $z > 3$ in order to understand the link between emerging large-scale structure and the observed fluctuations in the cosmic microwave background;
- Measuring chemical abundances, star formation rates and kinematics of pre-galactic fragments and distant, young galaxies as a first step toward an empirical understanding of the initial phases of galaxy assembly;
- Quantifying the ages and chemical compositions of the stellar populations comprising galaxies as distant as 5 Mpc, as an essential complementary step toward a complete understanding of how galaxies of different morphologies form and evolve;
- Detecting the kinematic signatures of planets forming during the disk accretion phase in order to understand where, when and how frequently, giant planets form;
- Imaging extrasolar planets and characterizing their atmospheric structure and chemistry spectroscopically.

2. TOP LEVEL SYSTEMS REQUIREMENTS

To carry out these science programs requires a ~30-meter GSMT and an instrument package that provides:

- A wide (~20’), native-seeing-limited, field of view sampled by a kilo-slit or kilo-fiber multi-object optical spectrograph (essential for large-scale structure surveys)
- A moderate (~2’) adaptively-corrected field of view providing Strehl ratio ~ 0.6 at 1.2 microns, feeding an imager and integral field units (essential for stellar population and galaxy assembly studies)
- A narrow (~ few arc second) adaptively-corrected field of view providing Strehl ratio ~ 0.8 at 2 microns, and feeding (1) a high-resolution infrared spectrograph; and (2) an infrared coronagraphic imager and spectrograph

(essential for direct observation and analysis of mature extrasolar planets, and indirect detection of forming planets).

Table 1 abstracts the observing requirements on a 30-m GSMT for the programs described.

Table 1. GSMT performance requirements: (basic parameters).

	FOV [arcmin]	Spatial Resolution [arcsec]	Spectral Resolution	Lambda [microns]	Observation	Target density	Special Requirements
Galaxy survey $z > 3$	20	0.5	1000-5000	optical	galaxy redshifts	50,000 /sq. deg.	Wide-field, multi-object
IGM survey $z > 3$	20	0.5	5000-20000	optical	absorption lines	5000/sq. deg.	
Galaxy Formation							
Galaxies: integrated properties	20	0.5	1000-5000	optical	various	TBD	Wide-field, multi-object
First Luminous objects	2	0.1	3,000	1-2.5	redshift	TBD	IFU, wide field
Spatially resolved properties	2	0.01-0.1	2,000	1-2.5	spatial structure	10/ sq arcmin	IFU, deployable
Planet Formation Environments							
Probing accretion disks	< 5 arcsec	< 0.1 arcsec	100,000	2-20	proto-planetary disks	small	single object, diffraction-limited
Resolved Stellar Populations							
Stars in external galaxies	2	0.01-0.1	5-100	1-2.5	photometry	> 10^3/sq. deg.	uniform PSFs over field
High Dynamic-Range Science							
Detection of planets	< 2 arcsec	~ 0.01	5-100	1-2.5	reflected stellar light	1 per field	single object, diffraction limited coronagrapic capability
Detection of planets	< 2 arcsec	~ 0.01	5-100	> 2.5	thermal emission	1 per field	

3. A POINT DESIGN FOR A GSMT

Section 4 describes the development of a telescope design aimed at providing performance matched to these basic requirements. At this early stage, we have not yet iterated the design to optimize its performance. Rather, we regard the concept described here as a “point design” whose primary raison d’etre is to identify technical challenges or showstoppers, and areas of significant risk or cost. Our goal in this phase of our design work is to contribute to the understanding of the common issues faced by all extremely large telescope (ELT) projects.

We have adopted the philosophy that the design of a next generation telescope is above all a systems challenge, requiring an integrated approach that takes into account a whole range of issues: site characteristics, enclosure design and structural design; orchestrating the active and adaptive elements with a sophisticated control system; fabricating, polishing, controlling, and maintaining the segmented primary mirror surface; and instrumentation. Our approach is informed by the belief that it is no longer possible (as one example) to think of instruments as independent entities, uncoupled from the approach to Adaptive Optics (AO) systems, or, given their enormous scale, separate from the fundamental mechanical design of the telescope. Rather, the performance-cost-risk “sweet spots” can only be identified through a multi-dimensional set of systems trades.

4. EVOLUTION OF THE POINT DESIGN CONCEPT

In the conceptual design process, certain fundamental decisions must be made about the system archite[illegible] The following sections describe the key architectural features chosen for the point design and explain the reasons they were chosen.

4.1 Optics

30-m Filled Aperture: As a starting point, we have adopted a 30-m filled aperture telescope. We believe that this choice is consistent with achieving the above science goals, and with having a powerful next generation telescope available to the community during the prime operating phases of NGST and ALMA – a key recommendation of the recently completed NRC Decadal Survey[2].

Aspherical Primary Mirror: A second key decision was whether to use a spherical primary mirror, or to use an optical design requiring an aspheric primary. Several proposed concepts for ELTs use spherical primaries because spherical segments are easier to fabricate.[3,4,5] However, to achieve good performance over a reasonable field of view (FOV), a telescope with a spherical primary needs at least two aspheric corrector mirrors; many designs use four-element correctors. The designs that have been proposed use correctors made of pairs of opposed concave mirrors in a "clamshell" arrangement, where the light must come to a reasonably good focus to pass through a small hole in the center of each corrector mirror. However, with a fast spherical primary mirror, the circle of least confusion becomes large. The problem is exacerbated by the use of laser beacons that are not confocal with the science targets. These focus effects combined with the need for a significant field of view preclude the use of a small hole. Thus, there is an important cost in through[illegible] with this arrangement.

Moreover, for mid-IR instruments, the number of warm reflections should be kept to a minimum to control the effective emissivity of the telescope, thus making a two-reflection Cassegrain design preferable to a six-mirror design.

For these reasons, the point design incorporates an aspherical primary mirror.

Segmented Primary Mirror: In the current generation of large telescopes, three concepts for lightweight primary mirrors have been pursued:

- Thin, meniscus, solid mirrors made of zero-expansion glass or glass-ceramic
- Borosilicate honeycomb mirrors
- Segmented mirrors (composed of hexagonal, solid, zero-expansion meniscus segments)

Other lightweight mirror concepts are possible, but have not been developed either because they offered no real advantages (for example, thin meniscus mirrors of non-zero-expansion materials) or because they were significantly more expensive (for example, large structured ULE^{TM} mirrors, or segmented mirrors composed of lightweight structured segments).

The largest single-piece telescope mirrors are the 8.4-m diameter primary mirrors being made for the Large Binocular Telescope Project. Although somewhat larger single-piece mirrors could be made, relative costs would rise rapidly with increasing size, particularly the cost of the blank fabrication facility, polishing and testing facilities, transportation, handling equipment, and coating chambers. At the 30-m size, single-piece mirrors are unaffordable. Therefore, the only lightweight mirror approach that can be extended to this size involves the use of a segmented primary.

We believe that a segmented primary approach builds on the considerable heritage of current generation telescopes and represents a natural, extensible way forward toward 30+ meter telescopes: it is our choice for this Point Design.

Fast Primary Focal Ratio: The current generation of large telescopes uses primary mirror focal ratios between f/1 and f/2. Going to a relatively faster focal ratio has the following advantages and disadvantages, as shown in Table 2:

Table 2. Advantages and disadvantages of a faster primary mirror focal ratio.

Advantages	Disadvantages
Shorter telescope will have smaller gravity deflections.	Tighter tolerances for alignment between primary and secondary.
Shorter telescope will have smaller moving mass, less thermal inertia.	Greater segment asphericity for a given segment size.
Shorter telescope will have higher resonant frequencies.	Tighter tolerances for translation and clocking of segments.
Enclosure can be smaller.	Increased field curvature.
Smaller secondary mirror for same focal ratio and image position.	Increased aberrations for same angular field, particularly at prime focus.

The advantages of a faster focal ratio are mostly structural, and the disadvantages are mostly optical. In this case, the point design has favored structural considerations and the primary focal ratio was chosen to be f/1.

Hexagonal Segments: Two types of segment geometries have been considered seriously: (1) quasi-hexagonal segments, as used in the Keck, Hobby-Eberly, and GTC telescopes; and (2) petal or sector-shaped segments, as used in some Department of Defense segmented-mirror prototypes. Figure 1 shows notional geometries for these two types of segments used in an ELT.

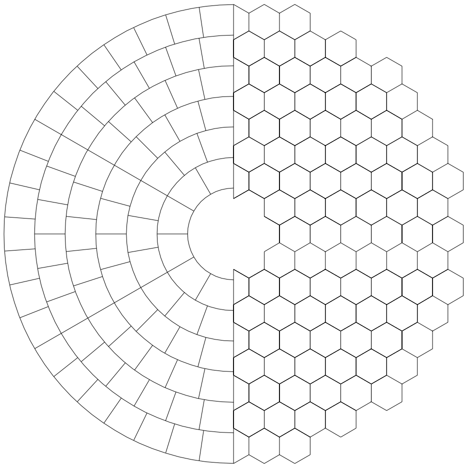

Figure 1. Notional geometries for a large telescope primary mirror, composed of hexagonal segments or sector-shaped segments.

Hexagonal segments have the advantages and disadvantages, as shown in Table 3. Sector-shaped segments have the advantages and disadvantages shown in Table 4.

The most important consideration seems to be the added difficulty of calculating and controlling the positions of sector-shaped segments, because the edge sensors would have to be at different locations on individual segments, even within a single ring. For the point design, we chose hexagonal segments whose position sensing and control are better understood. This decision is also partly driven by the choice of segment size, because this would be less of a problem if there were only 2-3 rings of sector-shaped segments.

Table 3. Advantages and disadvantages of hexagonal mirror segments.

Advantages	Disadvantages
Shape close to circular, which facilitates polishing and decreases required size of blanks.	Large number of segment types—only six copies of each type—complicates testing and accounting.
Edge sensor positions are the same for each segment.	Inner and outer edges of aperture are non-circular.
All segments can use same support geometry.	

Table 4. Advantages and disadvantages of sector-shaped mirror segments.

Advantages	Disadvantages
All petals in each ring are identical, which minimizes number of different optical test setups.	Segment shape not circular, which increases polishing difficulty and required size of blanks.
Inner and outer edges of aperture are circular.	Edge sensor positions vary from one segment to another.
Fewer different types of spare segments are required.	Simple edge sensors are not effective at lined-up radial joints.
	Segment support geometry must be customized for each ring.

Segment Size: The choice of segment size is another key decision, because the range of possible sizes is large. At this stage, we don't believe it essential to optimize the size within a few percent; however, the size should be set within about a factor of two.

The largest practical segment would be the size of the largest affordable single mirrors, about 8 meters across. At this size, only 19 segments would be required to make a 30-m telescope. At the other extreme, segments could be arbitrarily small, but at some point the number of sensors and actuators would become prohibitive. Table 5 lists advantages and disadvantages of reducing the size of the segments.

Table 5. Advantages and disadvantages of making aspheric segments smaller.

Advantages	Disadvantages
Reduced cost of optical fabrication and test equipment	Increased number of rigid attachment points on telescope structure
Reduced transportation cost	Increased number of position actuators
Reduced cost of coating chamber	Increased number of position sensors
Reduced asphericity in a single segment	Increased computational requirements in control system
Reduced effect of "in plane" position errors	Increased error propagation from edge sensor noise
Reduced support complexity for given thickness	Increased number of segment types

The size chosen for the point design segments is 1.15 meters across flats.

Aperture Stop Located at Secondary Mirror: The aperture stop is located at the secondary mirror, as is the choice for most telescopes optimized for infrared observations. The primary mirror is slightly oversized to allow chopping at the secondary mirror for background subtraction and to mitigate the difficulties resulting from the irregular shape of the edge of the segmented primary mirror.

Convex Secondary Mirror: A fundamental decision for the telescope design is whether the secondary mirror should be convex, flat, or concave. A flat mirror would introduce an unacceptably large central obscuration. A concave (Gregorian) secondary mirror would be easier to test, but at the size chosen for the point design, it will also be possible to test a convex secondary by conventional means. A Gregorian secondary mirror is in a favorable location to use as an adaptive mirror, because it will be conjugate to an altitude a few hundred meters above the primary mirror. However, a Gregorian secondary must be larger for a given final focal ratio and image position, which not only produces a larger central obscuration, but also increases the difficulty of making the mirror deformable. A Gregorian secondary also requires a significantly longer telescope structure, which in turn increases the size of the enclosure. The larger size and weight of a Gregorian secondary, combined with a longer telescope structure, tend to produce larger gravity deflections and lower resonant frequencies. These factors are summarized in Table 6.

Table 6. Advantages of convex and concave secondary mirrors.

Advantages of Convex Secondary Mirror	Advantages of Concave Secondary Mirror
Smaller obscuration for given focal ratio and image position	Optical testing easier and less expensive
Shorter telescope structure; smaller enclosure	Better positioned for adaptive correction, conjugate to atmospheric layer above primary mirror
	Produces real image of primary mirror
	Field curvature concave to instrument (easier to cancel in instrument design)

Among these factors we consider the size of the telescope structure and enclosure to be most important, so we have chosen a convex secondary mirror for the point design.

Size of Secondary Mirror: There are several reasons to minimize the size of the secondary mirror:

- To minimize the central obscuration
- To reduce the difficulty of optical testing
- To minimize the mass that must be carried at the top end of the telescope
- To minimize the cross-sectional area at the top of the telescope that is exposed to the wind
- To reduce the difficulty of making the secondary an adaptive, deformable mirror

However, as the size of the secondary is reduced, the focal ratio required to place the Cassegrain focus at a convenient position behind the primary mirror increases, as does the image scale. This means, for example, that elements in the higher-order AO systems will get larger. As the size of the secondary mirror is decreased, the amount of astigmatism increases for a given field angle, and the entrance pupil moves farther behind the primary mirror, which increases the primary mirror diameter required to avoid vignetting.

The size chosen for the secondary mirror is 2 meters diameter, and the delivered focal ratio is f/18.75.

Adaptive Secondary Mirror: Conventional AO systems have placed the adaptive components far down in the system to keep the adaptive components small. For example, in the Gemini Altair AO system, the first deformable mirror is M6. However, if the issues involved in producing a large deformable mirror can be successfully addressed, there are several advantages to using the secondary mirror as an adaptive mirror.

The GSMT point design incorporates an adaptive secondary mirror to serve the following needs:

- Correction of telescope wind-buffeting effects, including distortion of the primary mirror at frequencies higher than the bandwidth of the segment positioning system
- Adaptive Optics correction to high Strehl ratios in the mid-infrared with no further deformable elements
- Partial atmospheric correction in the visible and near-infrared, improving energy concentration even though the Strehl ratio is still low
- First stage in higher-order AO systems

4.2 Telescope Structural Design

The point design telescope structure is patterned after a radio telescope design. The telescope is a lightweight steel truss structure on an alt-azimuth mounting. The secondary mirror is relatively small, and is mounted on a tripod supported directly off the primary backing structure rather than on spider vanes supported off a tube-like structure. The primary mirror is several meters above the elevation axis.

A radio telescope type of structure has several advantages. By locating the primary mirror above the elevation axis, the elevation bearings can be moved inwards behind the primary. This decreases the span between the bearings and provides a more direct load path from the main concentration of telescope mass down into the pier, resulting in a more efficient structure with less mass and higher resonant frequencies. Moving the elevation bearings inward also makes it possible to provide large Nasmyth platforms without increasing the width of the telescope beyond that of the primary mirror. This helps reduce the size and weight of the telescope structure, and reduces the width of enclosure required if the enclosure is co-rotating.

In a more traditional design with the elevation axis above the primary mirror, the use of Nasmyth foci requires a large tertiary mirror to fold the beam along the elevation axis. The optical path distance from the secondary mirror to the focus is quite long, approximately equal to the primary mirror focal length plus half the primary mirror diameter. For a given final focal ratio, this requires a relatively large secondary mirror.

Figure 2. The current configuration of the point design telescope structure.

In contrast, in the GSMT point design the beam to the Nasmyth focus is relayed by an optical train located behind the primary mirror. The optical path distance from the secondary mirror to the first focus is just slightly more than the primary mirror focal length. For a given focal ratio, this allows use of a relatively small secondary mirror and simplifies the support of the tertiary mirror.

The point design also allows room for stationary laboratory space between the elevation bearings, where instruments can be located.

A radio telescope type of design has a few disadvantages, however. It requires a counterweight to balance the telescope and a greater front-to-back depth of the enclosure for a given primary mirror focal ratio. For the point design, we believe the advantages of this type of structure outweigh the disadvantages.

The advantages and disadvantages are summarized in Table 7:

Table 7. Advantages and disadvantages of a radio telescope type of structure.

Advantages	Disadvantages
Tripod M2 support has lower mass and thermal inertia.	Required counterweight raises total moving mass.
Elevation bearings are under the telescope structure, providing a more direct load path.	Telescope needs greater front-to-back depth of enclosure.
Nasmyth platforms fit within width of primary mirror, allowing narrower enclosure.	
Allows Nasmyth relay optics behind the primary, eliminating large tertiary mirror above primary.	
Shorter back focal length allows smaller secondary mirror.	

4.3 Instrument Locations and Mounting Requirements

The point design follows the philosophy that the optical design must be driven by the requirements of the science instruments. It should be possible to have more than one large instrument mounted and ready for use, and a range of different foci should be provided to accommodate the needs of different science instruments and observing programs. These needs include:

- Focal ratio/image scale
- Field of view
- Image quality (AO corrected, if necessary)
- Physical size of required instruments
- Instrument locations that maintain constant orientation relative to the telescope (minimizing IR background)
- Locations that do not tilt with the telescope (minimizing flexure)
- Foci that require minimal emissivity

The instrument locations incorporated in the point design include the following.

Prime Focus: Adaptive corrections may not be feasible for a significant fraction (> 20%) of the available time. It is thus important to provide the capability for frontier science observations that exploit these conditions, e.g., the observations of emerging large-scale structure summarized in the introduction and discussed more extensively in Najita and Strom.

However, for seeing-limited observations over a wide field, the image scale at the Cassegrain focus is inconveniently large. At f/18.75, one arcsecond is 2.7 mm wide, and a 20 arcminute field is 3.27 meters across. A more convenient image scale is available at the f/1 prime focus—6.9 arcseconds per millimeter. At prime focus, a 20 arcminute field is 175 mm across.

A prime focus corrector is necessary to provide good image quality over a wide field. This corrector is integrated into the key instrument we envision at prime focus: a multi-object fiber-fed spectrograph.

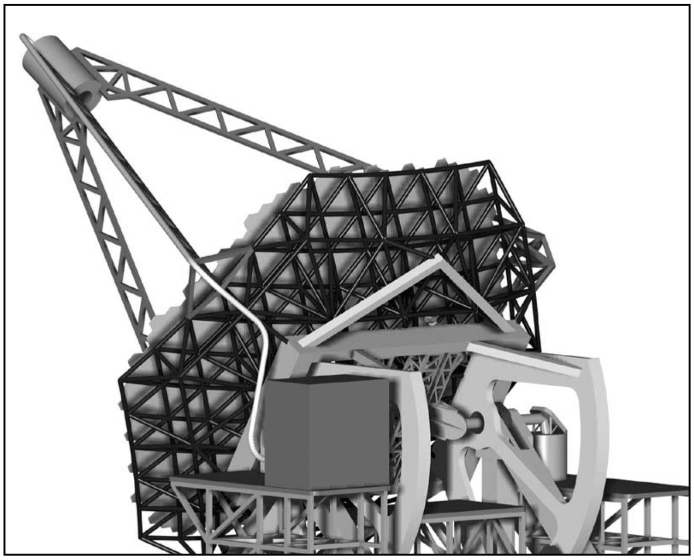

Figure 3. View of the prime focus instrument with a fiber-optic cable feeding light to spectrographs housed on the Nasmyth platform.

The prime focus instrument must be interchangeable with the secondary mirror assembly and should be relatively small (no more than about 3 meters in diameter).

Co-Moving Cassegrain focus: Instruments can be mounted directly at the Cassegrain focus, where they will move with the elevation structure. This is useful for infrared instruments, because they can be fed with only two warm reflections. It is also useful for instruments with second-stage AO, because it preserves a fixed orientation between the adaptive secondary and the wavefront sensor and deformable mirror. This simplifies control and improves performance.

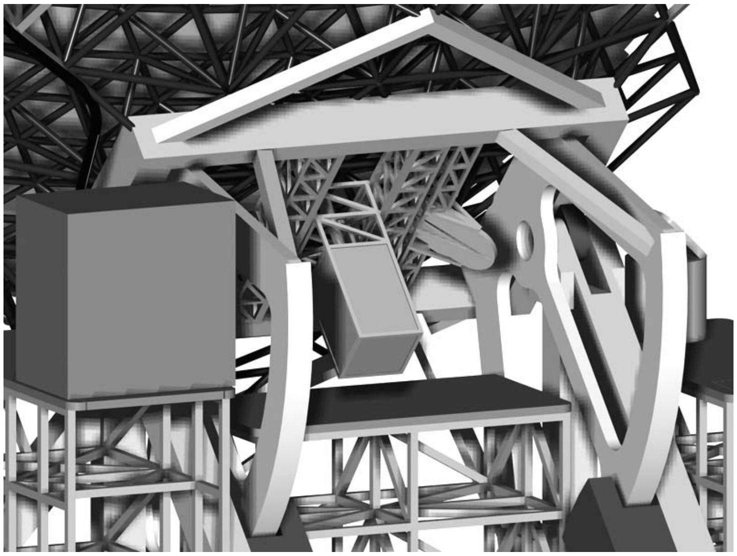

Figure 4. View showing a notional instrument at the co-moving Cassegrain focus

Gravity-Invariant Cassegrain focus: It is possible to locate an instrument in the laboratory space between the elevation bearings, with the beam fed in by means of two flat mirrors: one to direct the beam along the elevation axis, and another to direct the beam downwards into the instrument. An upward-looking instrument can be rotated in this position on a turntable to compensate for field rotation. This provides a fixed gravity environment for alignment-sensitive instruments.

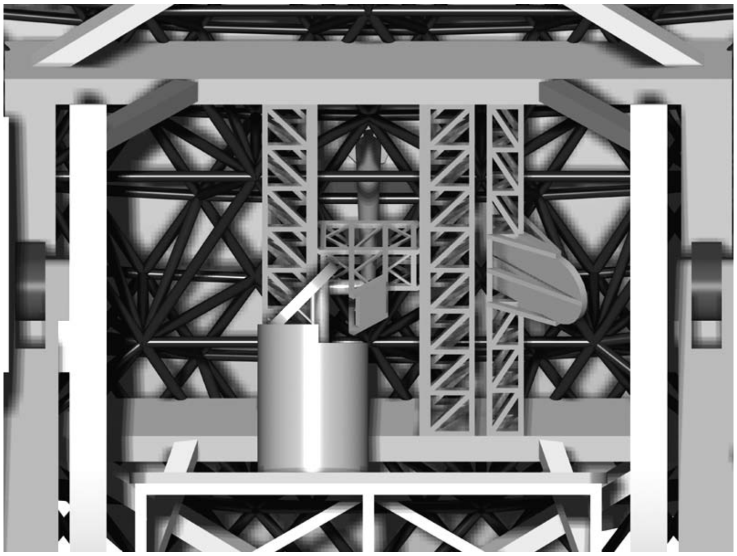

Figure 5. The instrument inside the cylinder would rotate on a turntable to compensate for field rotation, fed by a Cassegrain beam folded along the elevation axis by two flat mirrors.

MCAO-Corrected Nasmyth focus: The point design includes a multi-conjugate adaptive optics (MCAO) system, located behind the primary mirror and co-rotating with it. This system is designed to convert the Cassegrain beam to f/38 and feed it through one of the elevation bearings to instruments mounted on a Nasmyth platform. It would be possible to mount the instrument upward-looking on a turntable to compensate for image rotation, while maintaining a constant gravity orientation

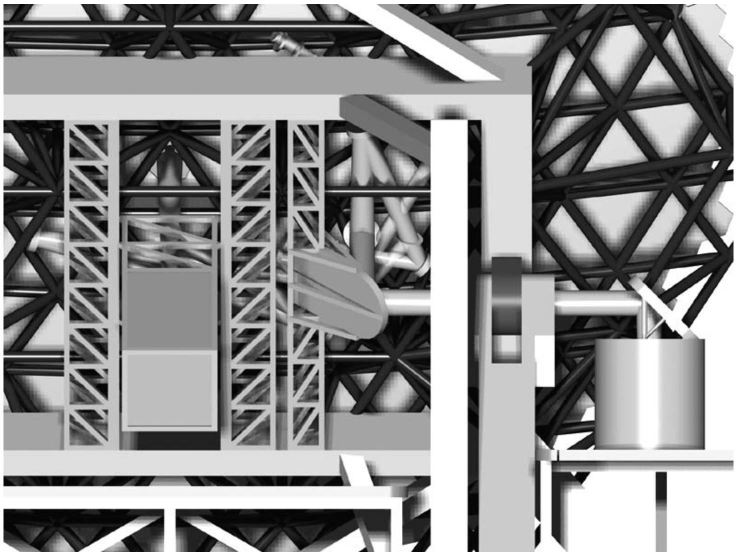

Figure 6. The instrument on the Nasmyth platform is fed by the output beam from the MCAO system.

Table 8. Characteristics of the instrument locations provided in the point design.

	Instrument Locations			
	Prime Focus	Co-moving Cassegrain	Gravity-invariant Cassegrain	MCAO-corrected Nasmyth
Focal ratio	1	18.75	18.75	38
Image scale (arcsec/mm)	6.9	0.37	0.37	0.18
Field of view (arcmin)	20	5.3	5.3	2
Field diameter (meter)	0.175	0.867	0.867	0.663
Image quality goal				
FWHM (arcsec)	0.5	0.012	0.035	0.012
Strehl Ratio	<0.1	0.9	0.9	0.4
at λ =	0.55 μm	2.2 μm	5 μm	1.6 μm
With:	Optical fiber feed to spectrometer	High-order AO coronagraph	High resolution IR spectrograph	MCAO Imager
Other possible instruments		Optical IFU, Optical spectrograph		Deployable IFU spectrograph

4.4 Four adaptive optics modes based on instrument requirements

Prime Focus AO: The instrument proposed for prime focus is a seeing-limited multi-object multi-fiber optical spectrograph. The natural guide star AO system proposed for prime focus has as its priority function correction for wind-buffeting disturbances of the primary mirror. We also believe it will be possible to use this system to compensate for ground-level seeing disturbances, and produce thereby images 20-40% smaller than 'natural seeing' images. Because it will use natural guide stars, the prime focus system will be able to exploit conditions (i.e., thin cirrus) that may not be suitable for MCAO.

Direct Cassegrain Focus AO: The direct Cassegrain focus can be used for infrared instruments to minimize the number of warm reflections. By having an adaptive secondary mirror, it should be possible to provide nearly diffraction-limited images in the infrared, with relatively high Strehl ratios. The adaptive secondary mirror can also compensate for wind-[illegible]ting disturbances of the primary mirror and correct dynamic alignment errors.

Narrow Field High-Order AO: The diffraction-limited coronagraph will include a high-order AO system to provide high Strehl ratios in the near infrared. This high-order corrective element will likely have limited dynamic range, so it will depend on the adaptive secondary mirror to serve as a first stage to compensate for larger amplitude aberrations.

Multi-Conjugate AO: Similarly, the MCAO system will use the secondary mirror as a coarse stage. Like the diffraction-limited coronagraph, the MCAO system will extend the focal ratio to about f/38 to provide a better match between the diffraction-limited resolution and detector pixel sizes.

All four proposed AO modes are directly based on the requirements of anticipated instruments. In two of these modes, prime focus AO and narrow field high-order AO, a deformable mirror will be incorporated into the instrument. In all of these modes, on-instrument guiding/wavefront sensors will be needed.

5. IMPLICATIONS OF DESIGN CONCEPT ON CONTROL SYSTEM

At the 30-m scale, glass and steel alone can't deliver diffraction-limited images at optical/IR wavelengths without extensive active and adaptive systems to correct internal inaccuracies and compensate for external disturbances. Our point design control system concepts are based on a hierarchical approach, where active and adaptive elements make corrections over a range of spatial and temporal frequencies. Some of these corrections are described below and summarized in Table 7.

Figure errors in individual primary mirror segments will be corrected by the segment active optics (warping) systems. Alignment and co-phasing of the primary mirror segments will be accomplished by the segment positioners and will be maintained using feedback from edge sensors and wavefront sensors.

Tracking errors and atmospheric image motion will be corrected on short time scales by fast tip-tilt of the secondary mirror; over longer time scales consistent with the response bandwidth of the mount structure, tracking errors will be corrected by the main drives and instrument rotators. For diffraction-limited observations at shorter wavelengths, image motion will be further corrected in the AO system.

Gravity sag and thermal expansion of the telescope structure will be corrected by repositioning the primary mirror segments and the secondary mirror. It may also be necessary to include active elements in the telescope structure. Gravity sag and thermal warping of the primary mirror segments will be corrected by the segment active optics systems.

Wind buffeting of the primary mirror will be corrected on short time scales by the deformable secondary mirror or the deformable mirror in the prime focus corrector. On longer time scales consistent with the response bandwidth of the segment positioning system, quasi-static wind loading will be compensated by moving the primary mirror segments.

Atmospheric seeing effects, including local “dome” seeing, will be compensated to the extent possible by the AO systems.

The control of these active and adaptive systems will be complex, requiring integrated hierarchical control systems layered by subsystem bandwidth.

Table 7. Summary of active and adaptive systems anticipated for GSMT. Bandwidth as used here is defined as the -3dB point of the closed loop error rejection function.

	Bandwidth (Hz)	**No. of Degrees of Freedom**	**Purpose**
Active Elements			
M1 segment warping	0.1	15	Control segment figure
M1 segment position	0.5	3	Keep M1 phased
M2 position control	5-10	5	Maintain alignment; stabilize image
Active structural members	TBD	TBD	Maintain alignment; damp vibrations
Adaptive Elements			
Prime focus corrector DM	15	2400	Compensate for M1; improve seeing
Adaptive secondary Mirror	15	2400	High Strehl in IR; first stage for higher-order AO systems at shorter wavelengths
Narrow-field high-order AO system	40	17,000	High Strehl in near IR
Multi-Conjugate AO	35	15,000	Wide field, good Strehl in near IR

6. SUMMARY OF POINT DESIGN FEATURES

The features that have been chosen for the fundamental system architecture of the GSMT point design are:

- Filled aperture
- Aspherical, segmented, f/1primary mirror
- Hexagonal segments—1.2 meters across flats
- Aperture stop located at secondary mirror
- Convex, adaptive secondary mirror
    - 2 meters diameter

- Radio telescope type of structural design
- Four instrument locations:
    - Prime focus
    - Co-moving Cassegrain focus
    - Gravity-invariant Cassegrain focus
    - MCAO-corrected Nasmyth focus
- Four AO modes based on instrument requirements:
    - Prime focus corrector
    - Adaptive secondary
    - Narrow field high-order AO
    - Multi-conjugate AO
- Hierarchical control system

Our initial telescope design represents the outcome of a systems approach: starting from community-based science goals, and developing a solution that integrates optics, structure, controls, and instrument concepts. We reiterate that the resulting 'point design' is just that – a design aimed at demonstrating *a* possible solution rather than *the* solution. NIO will continue to work with the community over the next year to further refine and weight science goals, evolve instrument concepts and evaluate sites: critical next steps in NIO's mission to provide access to a GSMT early in the ALMA/NGST era.

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