Gemini 8 Meter Telescopes Performance Estimates Update

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ABSTRACT

The Gemini 8 Meter Telescopes performance with active and adaptive optics as a system is given. The telescopes are being designed to deliver near diffraction limited images at infrared wavelengths to the focal plane. This will be achieved with a combination of innovative telescope design, a fully active control system and a natural guide star adaptive optics (AO) system for the Mauna Kea Telescope. The predicted delivered performance while under full active control is given at 2.2 microns. The top level AO system error budget is presented including the effects of instrumentation.

The Gemini Telescopes have been designed from the outset to be fully active; from control of the primary mirror surfaces and positioning of the secondary to ventilation of the enclosure by control over the ventilation gates. Descriptions of the concepts used in the various subsystems have been published previously[1,2]. Here, we will emphasize the system level interactions between the Gemini Adaptive Optics System and the telescope and instruments. This includes a performance summary of how the telescope operates with and without AO.

First, the current system concept is outlined, which includes wavefront sensors/guiders in the following areas:

Acquisition and Guiding System :	Peripheral Wavefront Sensors
Scientific Instruments:	On Instrument Wavefront Sensors
Adaptive Optics System:	Facility Wavefront Sensor

The system performance depends upon the interactions of these three key sensor areas. For non-AO use, both peripheral and on instrument wavefront sensors may be used to support fast and slow guiding and active control of the telescope alignment and wavefront. For AO use, combinations of all three types of wavefront sensors may be used for adaptive atmospheric compensation in addition to the functions listed above. The system is designed to quickly change between modes of operation (AO to non-AO and back) under remote control.

Keywords: Acitve optics, adaptive optics, error budget, wavefront sensing.

2. GEMINI NON-AO PERFORMANCE ESTIMATES

In past presentations, many of Gemini's performance estimates concentrated on the telescope contributions to image degradation. This is summarized with the top priority 2.2 micron, 50% encircled energy error budget of 0.1 arc sec (including diffraction!). Here the performance estimates at 2.2 microns are given with the predicted error bars along with how these would translate into delivered images including the instruments. The quality of the delivered images on axis is also a function of how the atmosphere behaves.

Figure 1 shows the expected performance of the Gemini telescopes when operated under full active control. As guiding is performed with guide stars off axis, a gradual degradation occurs on axis due to atmospheric effects. The error bars on the estimates are also shown. One of the largest uncertainties in the predictions is self induced seeing effects from the mirrors, telescope, dome and slit. For guiding on an off axis guide star within about 1.5 arc minutes of the on axis science object, tilt and focus sensors on-board the science instruments are used for both slow and fast tip/tilt corrections (On Instrument WaveFront Sensors - OIWFS). For guiding with our peripheral WFS in the acquisition and guiding system, guide stars 4 to 7 arc minutes off axis are used. These peripheral WFS's must remain outside a 4 arc minute radius to prevent vignetting of the 3 arc minute science field (for the infrared instruments). A slight improvement is seen at the transition to the peripheral sensors as they typically have a much brighter guide star (14.5 magnitude for 99% sky coverage) than is available to the OIWFS (18.5 magnitude for 90% sky coverage).
Figure 2 shows these same estimates, but with the addition of the atmosphere and a small allocation for science instruments (the amount for science instruments is consistent with the near-IR imager requirements and represents about 2% of the total).

The 10th percentile 'best' seeing at Mauna Kea is used in this figure (with no additional error bars). Figure 3 shows the same but under median seeing.

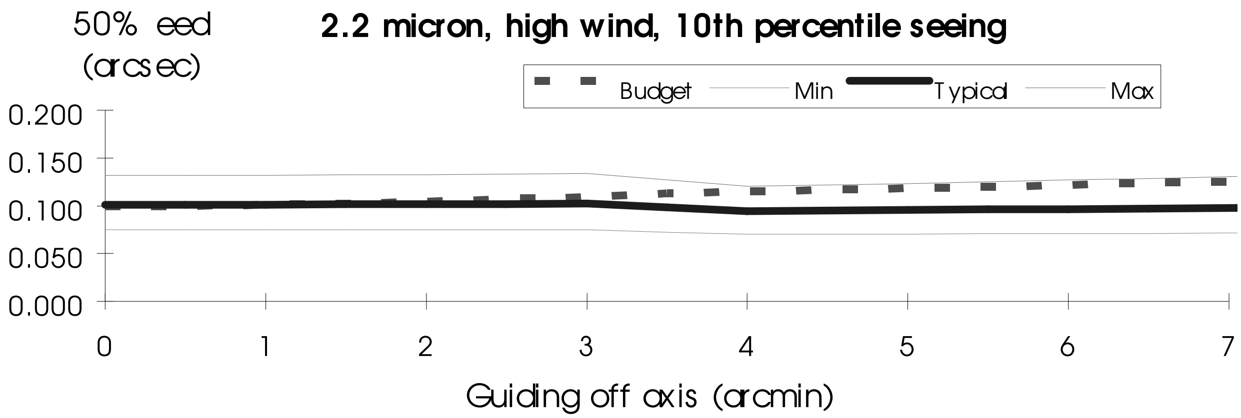


Figure 1. Telescope performance without atmosphere and instruments (includes diffraction)

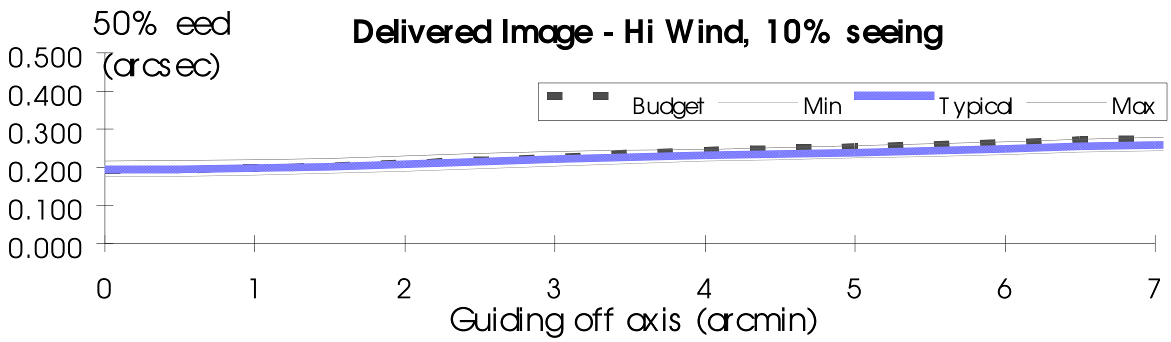


Figure 2. Performance with 10th percentile best seeing

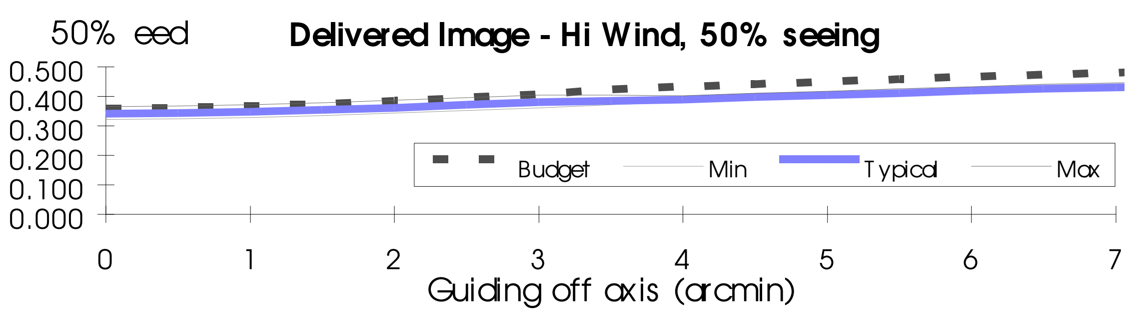


Figure 3. Performance under median seeing conditions

The small allocation for the near-IR imager seems to be very small at first glance. The rest of the paper shows that when using this instrument with Adaptive Optics, the performance of the instrument is a major consideration (at finest plate scale use). In fact, our estimate for AO performance leaves almost 1/3 of the error budget to the near-IR imager. For simple science instruments, designed specifically for AO use, this could be improved upon.

3. GEMINI AO SYSTEM ERROR BUDGET

The Gemini 8 meter telescopes, when using adaptive optics, are to deliver superb images under median seeing conditions. The specification for performance is given in the Gemini Science Requirements Document and is interpreted as delivered image quality. It is widely understood that use of AO will also correct for some of the telescope system imperfections. It cannot be assumed that all errors will be corrected. To this end, the Gemini telescopes have been designed to deliver superb image quality without AO and have made a concerted attempt where practical, to consider AO needs in specifying critical components such as the primary mirror polishing specifications. The goal is to build the best possible telescope, without any assumptions for correction of errors by AO. For AO use, we still must consider these residual aberrations and the effects of the optical quality of the scientific instruments using AO upon the final delivered images. This is what directly effects the science to be attained. As will be shown, an additional 'margin' or degradation due to the telescope and instruments will be in the 20-30% range and must be accounted for in a complete systems error budget.

Error Budget Considerations

When considering the addition of an adaptive optics system, one must still consider the telescope aberrations and the effect the AO system will have on them and the final scientific instrument errors, most of which will not be effected by the AO system. As shown later, we begin by developing an overall error budget consisting of three main items:

3.1 Telescope System
3.2 Scientific Instruments
3.3 Adaptive Optics System

The following is a discussion in each of these areas giving some level of background and details where possible on how the error budget items given later were derived. This represents a first cut at a system level AO error budget with some estimates of bottoms up performance included. The derivation of errors will be in terms of time varying rms tilt for any tracking errors and rms wavefront errors (spatially) for any higher order terms. These are converted to phase variance values which are related to strehl ratio by the following approximation:

$$StrehlRatio = e^{-\delta^2}$$

where: δ^2 = phase variance = $(2\pi\sigma/\lambda)^2$ for higher order spatial wavefront variations
σ = rms wavefront error in nm
λ = wavelength of interest

This relationship is widely used and considered to be valid for strehl ratios in excess of about 0.2.

Strehls given are given at 1.6 microns. Strehls at other wavelengths are given in the error budget listing for the complete system. Many of the errors are derived from the Gemini Systems Error Budget Plan, version 2.1. Specifically, the 2.2 micron, 50% encircled energy error budget is used as a starting point to derive various telescope errors. Only on axis correction at zenith is considered at this time.

3.1 Telescope System Errors

As will be done for all three areas, the errors of tilt and higher order effects are considered separately. First, we consider the tilt error contributions of the telescope.

When operating as a system, the tilt errors are measured by the AO Facility Wavefront Sensor (AO FWFS) or the On Instrument Wavefront Sensor (OIWFS) and feed back to a fast tilt mirror (and/or M2) for correction of tilt errors from any source within the system. The only exception is that there will be some slow flexure type errors which occur between the OIWFS (sensing slow variations) and the actual science focal plane of interest. For error budgeting purposes here, we will consider the major sources of tilt error from the telescope in this category, not including atmospheric tilt, measurement error, servo response (within the AO subsystem error budget allocation) and flexure between the OIWFS and science focal plane (within the science instrument focal plane). These will be considered in the AO subsystem error budget with the exception of flexure, which is accounted for in the scientific instrument error section.

The major source of tilt error in the telescope system that may not be negligible is residual windshake under median to 70th percentile winds. All gravity sag effects, misalignments causing tilt, and such will be negligible after AO correction and are assumed to be zero for this purpose. The detailed analysis of the residual wind shake error source has been analyzed for the non-AO case where the WFS's are used at up to 200 Hz to correct the tilt errors induced by windshake (could be OIWFS or PWFS for correction of wind shake). This analysis was done for 70th percentile winds at MK (11 m/s). For AO use, this may not be adequate. For a start, we approximate the residual error by assuming a 1000 Hz sampling (roughly 4 times the expected sampling needed for atmospheric tilt correction - based upon modeling by Brent Ellerbroek to date) as a starting guess. Since the measurement errors are considered separately, we will assume a very high signal to noise and no latency other than that inherent to the integration time consistent with the sampling rate. Under median wind conditions, this effect would be further reduced.

The estimate of this is scaled from a wind shake prediction at 200 Hz sampling of 0.034 arc sec 50% encircled energy. When scaled to 1000 Hz sampling, this amount is roughly reduced by the percentage increase in sampling rate, giving 0.0068 arc sec 50% encircled energy residual. In terms of rms wavefront variation, this is equivalent to 34 nm rms.

For higher order effects, the following higher level items are considered from the nominal Gemini Systems Error Budget:

Primary Mirror Surface Errors
Secondary Mirror Surface Errors
Alignment Errors
Self Induced Seeing Errors
A&G : AO fold and Science Fold Errors

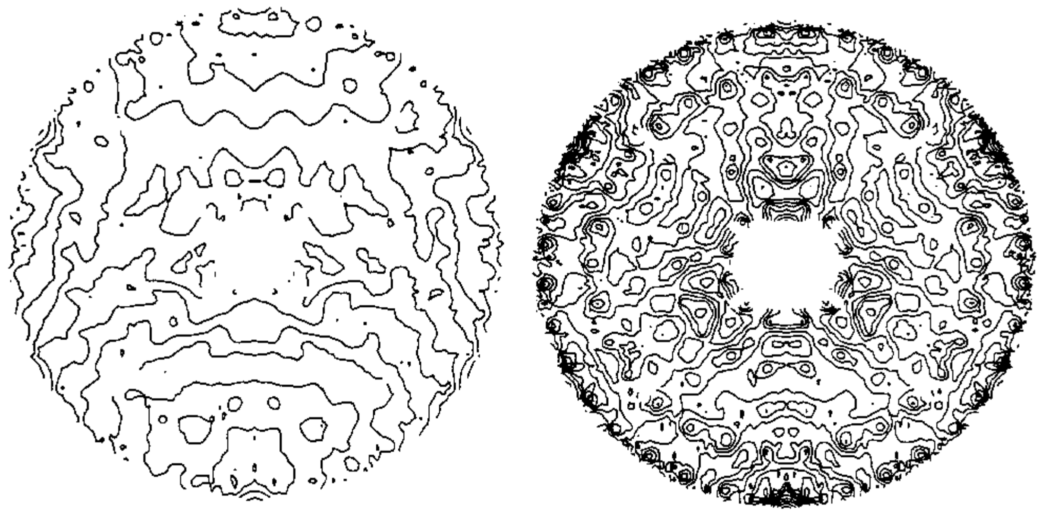
There are many more detailed items in the nominal Gemini error budget for the telescope, but they are either considered negligible for this purpose (a small contingency category should be considered for these) or are considered as a subset of the items listed above.

3.1.1 Primary Mirror Surface Errors

First, we will walk through a description of the detailed analysis which exists for the primary mirror surface errors to determine its contributions to the AO system error budget. This will be used as the basis for estimation of the secondary mirror contribution.

From the Gemini System Error Budget Plan[4], we can use the allocations given as the basis of the system performance without AO correction. For the primary mirror surface errors, we have an allocation of 0.036 arc sec, 50% encircled energy at 2.2 microns. Analysis to date shows slightly better performance predicted. Following the primary mirror PDR, several cases of surface error performance were modeled in detail. The cases modeled in detail each had about 20 specific detailed error sources including simulated polishing errors, many types of support system errors (axial and lateral), and thermal effects. For these cases, secondary mirror gravity sag was also included, but it did not effect the results after active optics correction. The results of one of these cases is shown in Figure 4.

The 3D plot on the left is before closed loop active optics correction (but with look-up table correction). It has a value of about 130 nm rms surface error. After aO correction, the plot on the right shows a residual surface error of 21 nm rms. This is the fitting error after correction with a 10 x 10 SH and correcting 15 to 20 mirror modes, using a support system consisting of 120 active elements. There is little difference in correcting more modes as the residual shown is simply the simulated high spatial frequency polishing errors used on the input file This holds true for correction of up to 80 modes of correction. An adaptive optics system of low to medium order will also not be able to reduce this error source any further. It would take a high order system, capable of correcting on small spatial scales. We have made no assumptions of scaling of the residuals versus number of actuators, based upon our aO analysis referred to above. If high order systems are envisioned, this should be revisited. We can expect other error sources which produce low spatial frequency errors such as those corrected well with the aO system to be very well corrected by the faster AO system. This would cover error budget items such as "dynamic image quality" listed in the Gemini Systems Error Budget Plan which produce small amounts of time varying coma. These



Surface RMS = 127 nm
Before aO correction

Surface RMS = 21 nm
After aO correction

Figure 4. Example of aO correction analysis performed by IGPO optics group and Brent Ellerbroek of SOR. Contour levels were adjusted between plots.

items, on axis would essentially be zero for operation with bright guide stars. We leave a small amount under the “alignment” section here to cover the small residuals (20nm rms which gives a strehl of 0.99).

Now that we have determined that high spatial frequency polishing errors will not be corrected (especially for low to medium order systems), we can use this to determine an AO allocation for the primary mirror surface allocations. It should be noted that the simulated polishing errors used here came from scaling actual surface measurements attained on the WIYN mirror. We may get better (or worse) results than this in the end, but we will not know until final polishing and testing of our first mirror. For error budgeting purposes, we will scale these to the limit allowed by our polishing specifications with REOSC. The case run in the analysis shown above was a point about half way between our requirement and a goal specified. The value to use to just meet our specification is about 30 nm rms.

For the error budget entry, this value is doubled to 60 nm rms to represent the effect of the surface figure on the reflected wavefront (defects on the surface effect the reflected wavefront a factor of two larger than the defect as the light travels through this ‘defect’ twice). This corresponds to a strehl of 0.95.

3.1.2 Secondary Mirror Surface Errors

For the secondary mirror, we have not simulated polishing errors. We have modeled a similar level of support, gravity and thermal error sources. All of these lead to fairly low order effects which are corrected well with either aO or AO. As noted above, secondary gravity sag was included in the modeling performed. For purposes here, we have essentially the same limits and specification as on the primary mirror polishing. Experience with polishing of convex secondary mirrors suggest that it is not unreasonable to expect high spatial frequency zonal errors (especially for large, steep aspheric mirrors). For this reason, we will allocate the same value of 60 nms rms wavefront to the AO error contribution of the secondary mirror.

3.1.3 Alignment Errors

For alignment effects (and dynamic image quality referred to earlier) we expect that, on axis, the residual errors to be very small. In the non-AO error budget, 0.026 arc sec, 50% ee @ 2.2 microns is allocated[4]. This corresponds to an rms wavefront error of about 130 nm rms (approximation of 0.01 arc sec equals 50 nm rms wavefront). Though all of this is very low order, we want to keep a small residual error here of 20 nm rms when operating with AO. This is an 85% reduction of these errors and represents a strehl of 0.99 as stated above (at 1.6 microns).

3.1.4 Self Induced Seeing Errors

Self induced seeing is much harder to quantify. We do not have accurate models of the spatial content of this effect. The amount of correction, even if the effect is of low spatial order, will vary as one tracks off-axis if conjugating to altitude. For limiting purposes here, we are assuming tracking and correcting on the object of interest and assume that the AO system will correct some level of this self induced seeing.

To start out with, we will take the non-AO case of self induced seeing as a starting point. From the Gemini System Error Budget Plan[4], the self-induced seeing error allocation for high wind is 0.035 arc sec 50% encircled energy at 2.2 microns. This corresponds to about 175 nm rms wavefront error. Without spatial frequency information, we can only guess as to the amount of correction on axis. As one goes off axis, less and less of this will be corrected if conjugating to altitude. Our "guess" is 50 nm rms residual error.

3.1.5 A&G : AO fold and Science Fold Errors:

Residual errors within the A&G system when using AO also fall with in the two categories of tilt and higher order effects. The tilt terms associated with ISS flexure and fold mirror flexure are considered as a negligible contribution since they are slow and within the system 'loop' which takes out these effects very well. For this reason, only the higher order effects are covered here. These come from the optical quality of the upper AO fold mirror and the science fold flat.

Some detailed analysis of these mirrors was performed as part of the A&G PDR and in subsequent designs by RGO , the project office, and in one case for the science fold, Eastman Kodak. These did not include any assumptions for polishing errors.

For the AO fold mirror, which sends the telescope science beam into the AO subsystem, low order effects due to gravity sag (for example) will be well corrected when guiding on axis. The residual error is also assumed here to be higher order polishing errors. Since in the loop, the estimate for the residual higher order effects is about 1/40th wave rms in the visible (considered a very good mirror by commercial standards). Remember that this level of correction is only valid on axis if conjugating to altitude. The wavefront effect is double this to 1/20th wave rms (not exactly doubled since at 45 degree, but close enough and on the conservative side for error budgeting purposes). This gives about 30 nm rms wavefront error. Given the small contribution of this error component, a more detailed calculation, though possible, is not warranted.

For the science fold flat, the considerations are a bit different. The mirror is after the higher order correction loop and hence should not be considered as correctable by AO. The surface quality of this mirror is therefore extremely important. Having higher order wavefront sensing after this mirror (i.e. in the instruments) would help here, but when one considers all of the elements before the final science detector plane which also cannot be corrected in the AO loop, this is still a small effect. The specification for the science fold called out is a 0.01 arc sec degradation at 2.2 microns, 50% encircled energy. This came directly from AO considerations and represents about a 50 nm rms wavefront (strehl of 0.96 @ 1.6 microns).

3.2 Scientific Instrument Errors

Differences exist here for each instrument. Spectrographs with minimal optics before the slit focal plane may perform a bit better than imagers with a relatively large number of elements before the final imaging focal plane. For now, we have chosen the case of the 1-5 micron imager to derive an AO allocation. This is a preliminary analysis. Once a complete tolerance analysis is performed on the instrument (using realizable manufacturing tolerances) this will be updated. Most lens design software such as ZEMAX and CodeV calculates the rms wavefront performance (with a given probability) for the design. The user must take care to put reasonable or typical manufacturing tolerances for this to be representative. For now, we estimate manufacturing tolerances from our experience. In practice, several errors due to directly and easily measured errors such as center thickness variation, centering data, etc. can be compensated for by re-running the optical design code with the numbers to re-adjust final element spacing and location to minimize wavefront error. For the best performance, some vendors will measure the quality of a system as it goes together in terms of measured wavefront quality (interferometrically) and adjust the figure on the later elements to compensate. This is a very time consuming and expensive process not typically done on these types of systems. Estimates here are based upon experience using simple compensators such as focus adjustments during the assembly.

To build this estimate (prior to any tolerance analysis), consider transmissive elements separately from reflective elements. For reflective elements, consider similar specifications as given for the science fold, but scaled down somewhat due to the smaller sizes of elements used. Here, if the average element is in the range of 2 inch-4 inches, a very good mirror would be

1/40th wave rms surface in the visible. Thus use 1/20th wave rms wavefront, visible (30 nm rms). This is about twice as good as the large science fold mirror. None of these errors are considered correctable by AO.

For transmissive elements, things get a bit easier for most. A typical high quality optic will have an rms wavefront quality (not including the basic design wavefront) in the neighbor hood of 1/50th wave in the visible for one element (12 nm rms). This is also for optics in the range of up to a few inches. Some elements will be better (such as filters), some are likely to be a bit worse (such as the larger field lens and LiF type materials). For material such as LiF (one in the current design), we estimate 1/10th wave rms transmitted wavefront quality. For the entire optical system, the basic designed wavefront quality is added to this for actual performance.

For the 1-5 micron imager, the following make up the optical path for the fine plate scale case:

Number of reflections:	7 (6 mirrors, 1 dichroic beamsplitter)
Number of transmissive elements:	9 (7 powered elements, 2 filters)

- Window, field lens, collimator, final imaging path for 0.02 arc sec plate scale, filters (2)

In addition to the contributions from manufacturing of individual elements, how well they are aligned as a sub system is to be considered. Our estimate for this is roughly 1/10th wave in the visible, rms (60nm rms).

From the number of elements and flats given above, the estimates of performance on a per element basis, and alignment considerations, the following performance is estimated (individual contributions are rss'd):

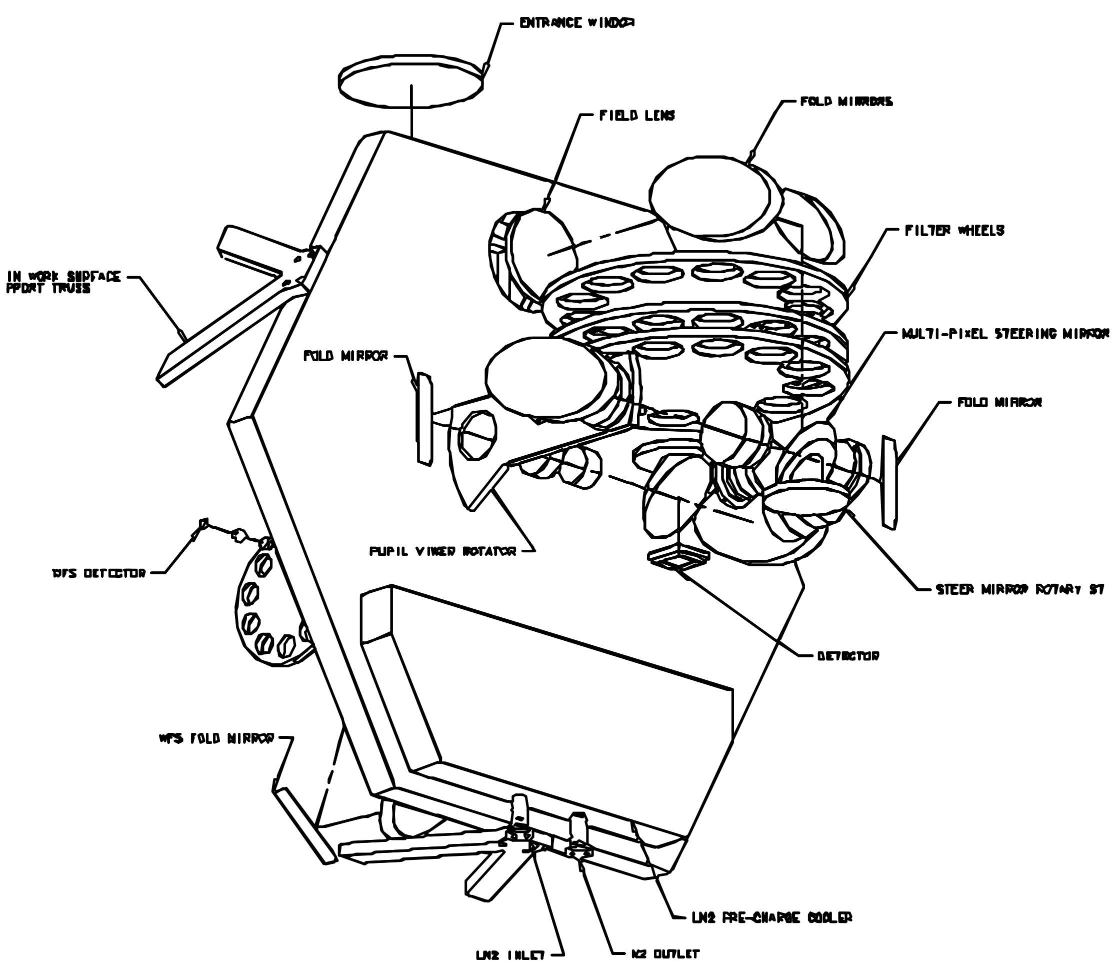


Figure 5. Near IR Imager Preliminary Design Layout.

Reflective elements:	79.4 nm rms

Transmissive elements (normal):	33.9 nm rms
LiF transmissive element (one element):	60 nm rms
Alignment of instrument:	60 nm rms
Total	*121.1 nm rms (strehl of 0.80 @ 1.6 microns)*

None of this is to be considered as corrected with the AO system. Again, complete tolerancing should be done to update these numbers. For now, consider it a reasonable starting point.

There is also one specific tilt term to consider here. Any relative flexure between the OIWFS and the science plane of interest, will 'smear' the image over long integration times. Great effort is being spent to insure that this motion is small. As a rough estimate, most instrument builders are trying to maintain focal plane stability on the order of a few microns over an hour. Taking this as a very rough estimate of achievable flexure between the guide probe and the focal plane, a smearing of 0.005 arc sec is obtained. The averaged strehl may be somewhat better, but for now, we will use the equivalent wavefront error that would give such a degradation in image quality. This is 25 nm rms (strehl of 0.99 @ 1.6 microns). This assumes an effective 6 micron smear (trying to be reasonable but conservative) with a focal plane scale of 1200 microns per arc sec (fine plate scale), over one hour.

3.3 AO Subsystem Errors

The AO subsystem error contributions are broken down into the following categories. This is not a detailed and exhaustive list. The details within this breakdown are the responsibility of the AO team. Hence, little explanation of the numbers presented are given at this time. The total effect of this category must be consistent with the telescope and instrument categories discussed earlier so that the desired delivered quality is attained. It should be noted that some choices here will effect the achievable contributions in the other areas (specifically telescope contributions). Examples are the choice of order of correction (thus correcting more or less telescope aberrations) and tilt loop sampling and latency, effecting the amount of tilt correction from sources such as telescope wind shake.

Fitting error (DM/WFS to atmosphere)	Servo response errors (bandwidth limitations)
Tilt response	Uncorrected internal optical errors
High order WFS measurement error	Calibration errors

3.3.1 Fitting error (DM/WFS to atmosphere)

For this exercise, the rms wavefront error allowed to still produce the desired strehl ratio is input. It is the last number to be filled in for this first cut. The combination of this and the seeing conditions will determine the order of correction needed (or number of actuators).

Tilt response: For tilt response, we consider the residual tilt performance assuming no additional lag time in the servo. From the Keck document[3], a 12th magnitude star would give roughly a 5 nRad rms tilt error. This is 1 milliarcsec or about 10 nms rms.

3.3.2 High order WFS measurement error:

High order measurement error comes from a Keck[3] estimate, dominated by photon noise. The value they assign is 30 nm rms.

3.3.3 Servo response errors:

Servo response error also comes from a Keck[3] estimate. The value here is 18 nm rms for their assumptions.

3.3.4 Uncorrected internal optical errors:

Uncorrected optical errors are estimated as a series of reflective optics with similar correctable errors as used for the AO fold mirror in the A&G. Seven reflective surfaces, each contribute 1/20th wave rms at 0.6 microns to the wavefront after AO correction (1/40th wave rms surface. The DM is considered to be one of these 7 elements. The rss'd total is 79 nm rms (strehl contribution of 0.92 @ 1.6 microns). A full tolerance analysis may help here, but the AO correctable portion may be hard to predict. It will be much more difficult to predict off axis, but that is to be considered at a later time.

3.3.5 Calibration errors:

Calibration errors are estimated to be 1/20th wave rms in the optical (0.6 microns). This is the same estimate made by Keck[3]. This is 30 nm rms or a strehl of 0.986 at 1.6 microns.

4. ERROR BUDGET PRODUCING 0.5 STREHL AT 1.6 MICRONS

Adaptive Optics Error Budget

Errors allocated in terms of rms wavefront error (or surface if noted)
Rms errors added in quadrature
Strehls calculated from following approximation: Strehl = S = exp[-2*PI*fractional rms
(considered good for strehls above 0.2)

		AO on axis rms wavefront (nm)
1.0 Telescope Limitations		121.1
	Strehl @ 1.6 microns:	0.80
Tilt/image smear effects		
Tilt loop performance		34
Higher order image quality effects		
Primary mirror		60
Secondary mirror		60
Alignment		20
Self induced seeing		50
A&G		58.30952
AO fold		*30*
Science fold (uncorrected)		*50*
2.0 Instrument Limitations		123.7
	Strehl @ 1.6 microns:	0.79
Tilt/image smear effects		
Flexure relative to OIWFS		25
Higher order image quality effects		121.1
3.0 AO System		122.5
	Strehl @ 1.6 microns:	0.79
Fitting errors (DM/WFS to atmosphere)		80.9
- Strehl @ 1.6 microns from atm. fitting:	0.86	
Tilt response		10
High order WFS measurement error		30.00
Servo response errors (bandwidth limitations)		18
Uncorrected internal optics		79
Calibration errors		30
Totals:		210.1148

	Strehl	Wavelength (microns)
Strehl Totals:	0.03	0.7
	0.17	1
	0.29	1.2
	0.50	1.6
	0.69	2.2

4.1 Derivation of required degrees of freedom

From the error budget item labeled “Fitting Errors (DM/WFS to atmosphere), we next derive the required number of degrees of freedom to achieve this residual error (for given atmospheric assumptions, to be stated below). Taken from “Adaptive

Optics for Keck" [3], the following is a relationship for atmospheric variance and number of degrees of freedom for a DM (and WFS). The equation is their number 4.3-13.

$$\delta_{dm}^{\ 2} = \mu_N (D / \sqrt{N_{dof}}\, r_0)^{5/3}$$

Where D = 8 meters
r_0 = 25 cm for median seeing in the visible, 41 cm for 10% best seeing
μ_N = 0.221 for continuous facesheet DM
δ_{dm} = phase variance = 2π rms σ/λ
σ = wavefront in nm rms
λ = 0.5 microns (or same as used in r_0 above)

Reworking this equation to solve for the number of degrees of freedom needed to attain a certain residual variance gives:

$$N_{dof} = \left[\frac{D / r_0}{\left(\delta^2 / \mu_N\right)^{3/5}} \right]^2$$

For the median seeing (r_0 = 0.25 m) and a desired residual of 80.9 nm rms wavefront, this leads to a variance of 1.034 and 160 degrees of freedom needed on the DM (and wavefront sensor).

For best seeing (r_0 = 0.41 m) and the above conditions, 60 degrees of freedom are needed. To show more of the range of possibilities, the following graph plots required number of degrees of freedom versus rms wavefront error (in nm rms).

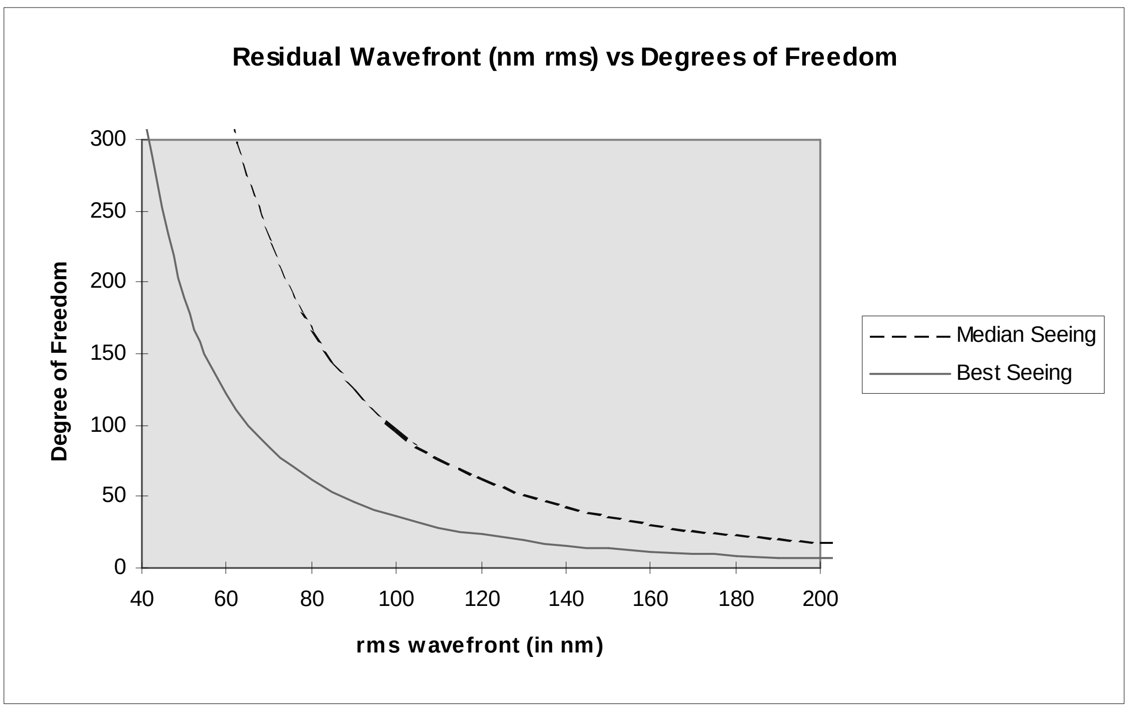


Figure 6. Deformable mirror atmospheric fitting error for a continuous face sheet DM

5. SUMMARY AND FUTURE WORK

This represents a first cut estimate of telescope, instrument, and AO subsystem contribution to delivered AO performance. Some areas are fairly well defined at this time (such as primary and secondary mirror contributions). Others may change quite a bit. The key feature derived from this is what type of margin one must design for in the AO system to achieve delivered images of a given quality. The example shown suggests as much as a 30% margin is to be allowed for items not directly under the AO subsystem control. If one looks carefully at the numbers and rationale, one will quickly see that under the most optimistic conditions, this margin will not be substantially reduced without major and costly impacts upon the rest of the telescope system. We should all work to reduce this margin as much as reasonable, but we must be practical as some areas will cost quite a bit to improve substantially over the levels estimated here. Also, substantial improvements are possible with simple instruments, designed specifically for AO use with a minimum of elements involved.

Specific cases of analysis were described in the discussions presented. They include:

Tolerance analysis of instrumentation (including surface quality effects)
Tilt loop performance in the presence of wind (70th percentile wind was used and roughly scaled)
AO subsystem optical tolerance analysis including correctable errors

These are only a few current examples. Also, as actual performance of various key items becomes available, this breakdown can be modified (and should!). For now, we can only estimate the effects based upon analysis done to date and some judgment. This will have to form the basis of any near term decisions to be made regarding AO subsystem implementation (along with any cost trades!).

6. ACKNOWLEDGMENTS

The performance analysis results presented here include input from many people. In particular, some of the key active optical analysis was performed by individuals in the Gemini Optics Group, headed by Larry Step along with Brent Ellerbroek of Starfire Optical Range. Much of the non-AO system performance analysis was pulled together by Rick McGonegal and the Gemini Controls Group.

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