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KAON XXX: Background and transmission budgets for the Keck NGAO system

Document owner: Antonin Bouchez

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Revision Sheet

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Rev. 0.1	8/2/07	Initial draft released

Contents

1 GENERAL INFORMATION

1.1 Purpose

This note describes thermal and optical background and transmission budgets for the Keck Observatory Next Generation Adaptive Optics (NGAO) system. Background and transmission budgets are computed for several notional optical designs, for light transmission to science instruments and wavefront sensors.

1.2 Acronyms and Abbreviations

AO	Adaptive Optics
IRTT WFS	Infrared Tip/Tilt Wavefront Sensor
TWFS	Truth wavefront sensor
HOWFS	High-order wavefront sensor
LOWFS	Low-order wavefront sensor
LGS	Laser guide star
NGAO	The Keck Observatory's next generation adaptive optics system
NGS	Natural guide star
PALM-3000	A 3000+ actuator upgrade to the Palomar AO system

1.3 Related Documents

1.4 Point of Contact

Antonin Bouchez
Email: abouchez@astro.caltech.edu
Tel: (626) 395-8915

2 BACKGROUND AND TRANSMISSION MODEL

2.1 Description of background and transmission model

The background and transmission model of the Keck NGAO system is based on that described by Herriot *et al.*[1] for the TMT NFIRAOS instrument. We begin with emission and transmission models of the night sky at high spectral resolution, tabulated for Mauna Kea from several sources[2] on the Gemini Observatory web site. We then numerically propagate this spectrum through the telescope and AO system, multiplying the emission and transmission spectra by the reflectivity or transmission of each optical surface, and adding to the emission spectrum the thermal contribution of each surface.

Reflectivity and transmission spectra for standard optical materials were gathered from several sources, including the web sites of Denton Corp., and general references[3]. In cases where spectrally resolved data were not available, a scalar reflectivity and emissivity were used. All surfaces were initially assumed to be "clean", though this assumption is revisited in section 2.2.

The telescope and AO system were divided into three temperature zones. The first zone, whose temperature was assumed to be a constant 275.6 K (the annual average summit temperature[4]), includes the telescope optics, and a window into the AO system enclosure. The second zone, whose temperature can be varied, includes all AO optics and wavefront sensors, and the entrance window to the science instrument. The third temperature zone encompasses all instrument optics inside a cryostat window.

It is important to note that this model predicts the performance of an optical system with no off-axis thermal contributions (eg. pupil stops exclude all warm surfaces such as secondary spiders and optics mounts).

2.2 Model validation and adjustment

Before evaluating the thermal background of candidate NGAO architectures, we attempted to validate the model against measurements with the current Keck 2 LGS-AO system and NIRC2, and found the need for some adjustments. The science path of the "K2AO" architecture consists of three aluminized telescope mirrors, a K-mirror rotator, a 4-mirror AO relay, and a dichroic which transmits the infrared beam to the science camera entrance window (see Appendix A for the optical prescription used).

Transmission and background models for the K2AO architecture, with an AO enclosure temperature of 278.0 K, are shown in Figures 1 and 2. The sky brightness predicted by the "clean optics" model, in magnitudes per square arcsecond over standard filter bandpasses[5], is compared to measured NIRC2 values in Table 1. The predicted background is consistently ~1.0 magnitudes higher (darker) than that measured with NIRC2 in all but the H band, indicating an error in either the assumed temperature of the telescope and AO system or their emissivity.

An unrealistically high AO enclosure temperature (>293 K) would be required to match the observed background with the initially assumed clean optical surfaces. We therefore choose instead to adjust the emissivity to match the observed background. We find a very close match to the measured H, K, L', and M_s background values by adding 2.0% to the emissivity for each surface in the AO lab, and adding 4.0% to the three telescope mirrors (and reducing their reflectivity/transmission by the same amount). While a reduction of 2% transmission for each surface seems greater than expected for optics in a cleanroom environment, the total emissivity is in fact constrained by NIRC2 measurements, and the partitioning between AO system and telescope chosen here seems reasonable. We therefore chose to carry this

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[1] Herriot, G. *et al.* 2005, "NFIRAOS: Emissivity as a function of temperature & number of surfaces". TMT publication: TMT.AOS.TEC.05.012.REL02.

[2] Krisciunas 1997, "Optical night-sky brightness at Mauna Ka over the course of a complete sunspot cycle", PASP 109, 1181-1188.

[3] Klocek, P. 1991, Handbook of Infrared Optical Materials (New York: Dekker).

[4] "Keck Telescope and Facility Instrument Guide", August 2002, http://www2.keck.hawaii.edu/observing/obswmkpl.html.

[5] We used NIRC2 filter curves where available, otherwise the curves for NIRI filters measured by Gemini Observatory at http://www.gemini.edu/sciops/instruments/niri/NIRIFilterList.html.

"real-world" adjustment forward to the NGAO thermal models, under the assumption that optics in the NGAO era are unlikely to remain significantly cleaner than those in the current K2AO system. Finaly, we note here that the average transmission of the telescope plus K2AO system across the infrared implied by the NIRC2 background measurements (and reproduced by the adjusted model) is 56% ± 1%.

Filter	Average sky brightness (mag. arcsec^{-2})	Initial Model background (mag. arcsec^{-2})	NIRC2 measured background (mag. arcsec^{-2})	Adjusted model background (mag. arcsec^{-2})
J	16.01	15.98	*14.9*	15.93
H	13.78	13.75	13.6	13.70
K	14.91	13.62	12.6	12.67
L'	5.00	3.90	2.91	2.97
M_s	1.61	0.81	-0.12	-0.02

Table 1: Comparison of the Mauna Kea sky brightness, initial ("clean") model background at the science instrument focus, background measured with NIRC2, and adjusted ("real-world") model background, for standard infrared filters. The adjustment required increasing emissivity of AO optics by 2% and telescope optics by 4%. The discrepant measured background value in the J band is unexplained.

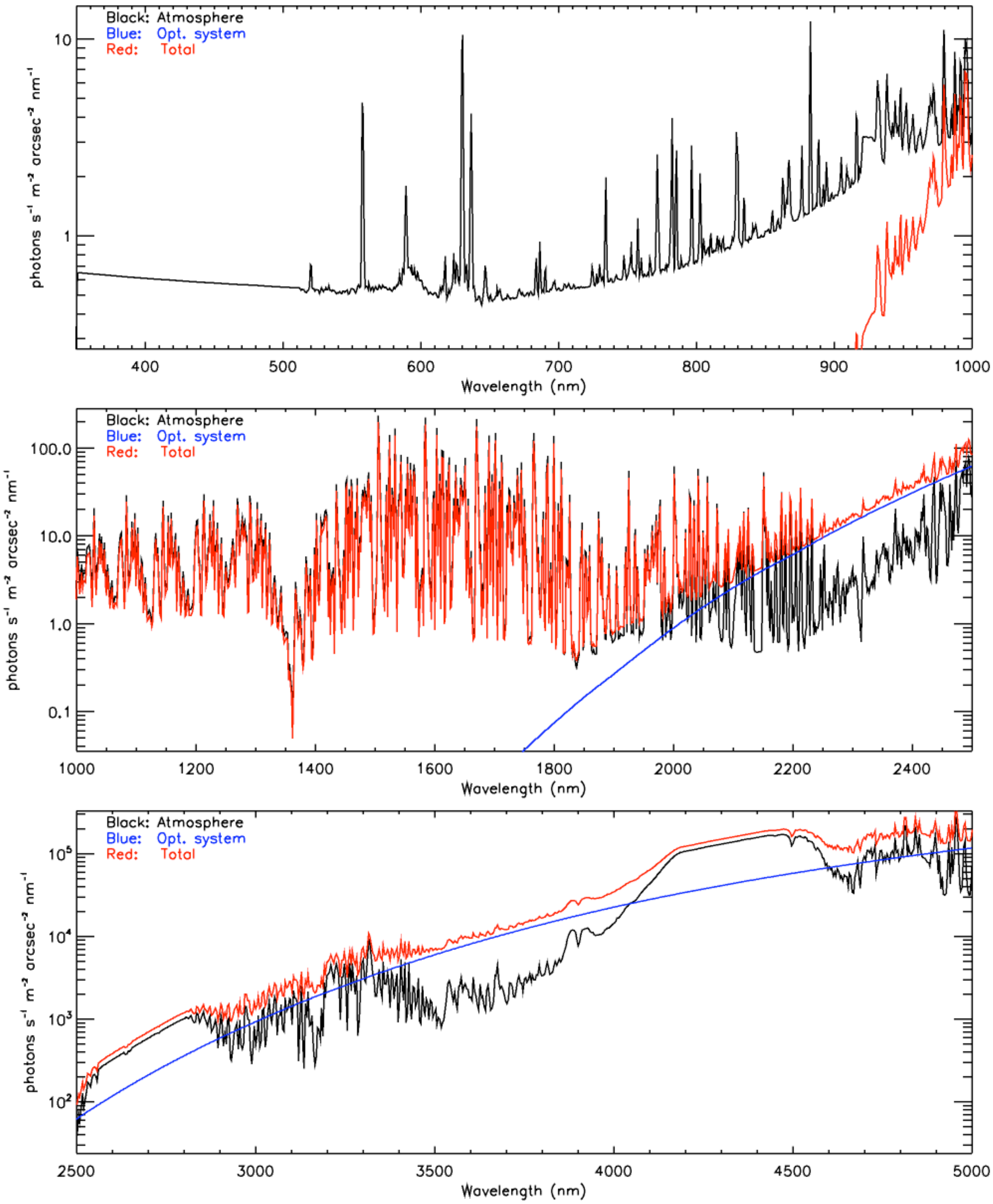
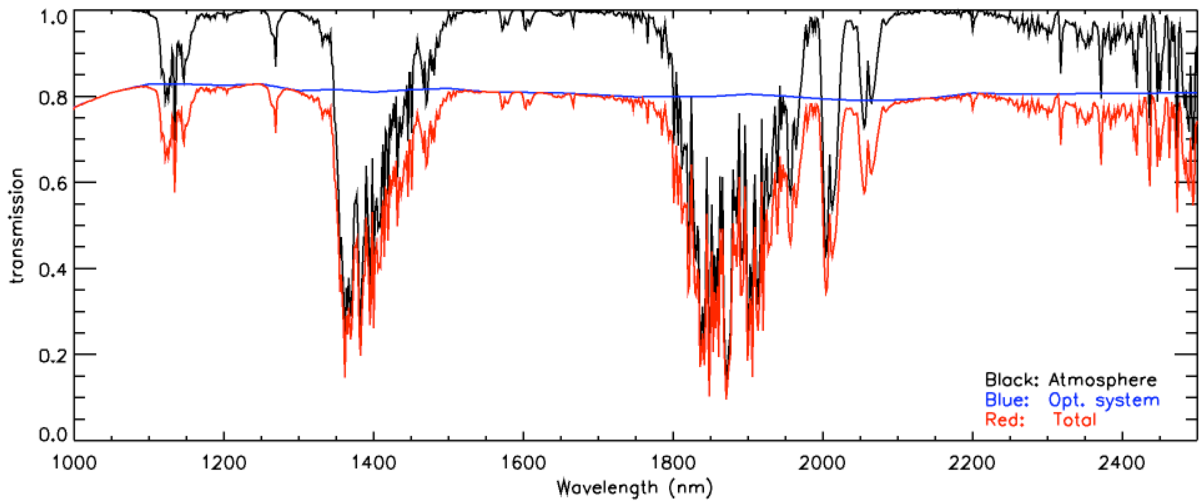


Figure 1: Background model for the science path of the Keck 2 AO system from 0.35 to 5 μm wavelength, at a spectral resolution of $\lambda/\Delta\lambda$=1000. The background due to the atmosphere is shown in black, that due only to the telescope and AO system in blue, and the sum at the science focal plane in red.



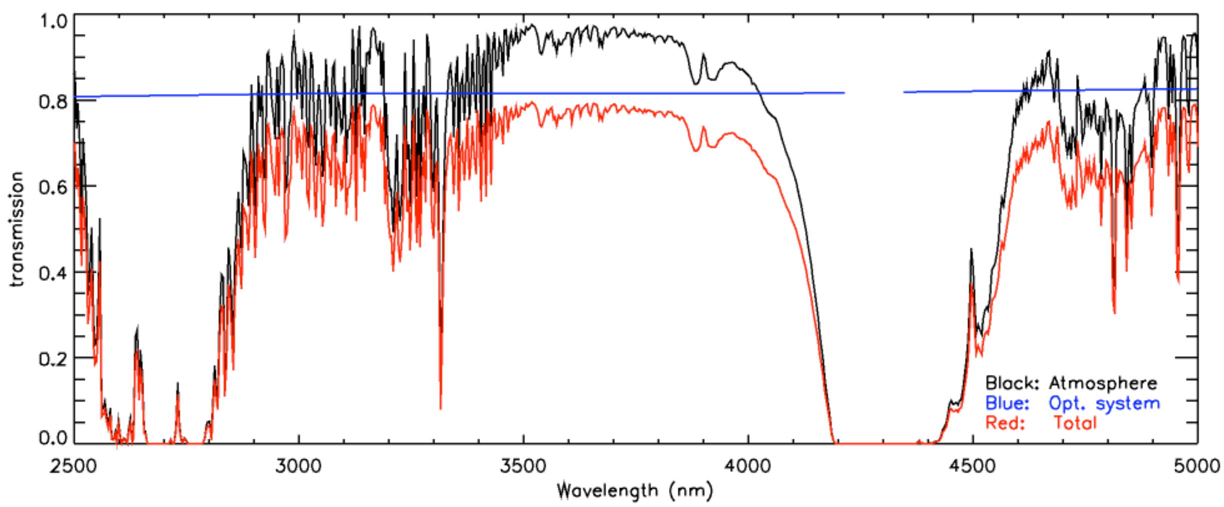


Figure 2: Transmission model for the science path of the Keck 2 AO system from 1 to 5 μm wavelength, displayed at a spectral resolution of $\lambda/\Delta\lambda$=1000. The transmission of the atmosphere alone is shown in black, that due only to the telescope and AO system in blue, and their product in red.

2.3 Background requirements

Choosing the correct metric for evaluating thermal models of candidate AO architectures is somewhat subtle. A requirement such as "the AO system shall contribute <30% of the total background", as currently stated in the NGAO instrument requirements, in fact leads to the perverse result that AO systems with the highest emissivity and lowest transmission must be cooled the least. This is because the background from the sky and telescope are viewed through the AO system, whose imperfect transmission (and colder temperature) in fact reduce this background with each optical surface. Thus it would be far preferable to specify the AO system background as a fraction of the *unattenuated* sky plus telescope background.

I will therefore interpret the instrument requirement as follows: "The AO system shall contribute less than 30% of the unattenuated sky plus telescope background at 2.360 μm and at a spectral resolution $\Delta\lambda/\lambda$ = 4000." This wavelength was chosen to be between atmospheric emission lines, at the long-wavelength lend of the d-IFU and NIRI passbands, the most difficult case. Note that the thermal background contributed by an outer AO window is in this document included in the sky+telescope sum, and not in the AO system tally, since its temperature is that of the dome.

3 RESULTS FOR NGAO ARCHITECTURES

Results of thermal models for various NGAO architectures[6] are shown in Table 2, and discussed in more detail in the remainder of this section.

Architecture	Near-IR avg. transmission	AO background / sky + telescope	
		0.30	0.50
Split relay, d-IFU	0.62	264 K	270 K
Split relay, NIRI	0.45	255 K	261 K
AM2, d-IFU	0.67	270 K	276 K
AM2, NIRI	0.57	261 K	267 K
Large relay, d-IFU	0.45	255 K	261 K
Large relay, NIRI	0.41	254 K	260 K
K1 upgrade, d-IFU	0.49	256 K	262 K
K1 upgrade, NIRI	0.43	255 K	261 K
Cascade, d-IFU	0.56	260 K	266 K
Cascade, NIRI	0.46	256 K	262 K

Table 2: Predicted near-IR average transmission of the each AO system architecture, and maximum AO enclosure temperatures which would meet 30% and 50% of sky+telescope background requirements over the entire d-IFU and NIRI passbands.

4 IMPLICATIONS FOR TELESCOPE MIRROR COATINGS

While the contribution of the AO system to near-infrared science instrument backgrounds can be limited to a small fraction of the total by cooling the AO enclosure to between 254 and 270 K, the total background emission is nevertheless elevated above the sky-only background by a factor of >10 across most of the K band. Since cooling the telescope below the ambient temperature does not appear to be a viable option, we consider here the possibly benefits of lower emissivity telescope mirror coatings. Figure 3 (top) displays the background and transmission in the K band for the Split relay, NIRI case, with the AO enclosure at 255 K and *clean* aluminum-coated telescope mirrors. The bottom two panels show the same case with *clean* protected silver coatings on the telescope mirrors. The background across the K band is reduced from 5.5 to 4.6 times the natural sky background, a small improvement.

[6] Velur, Viswa, 2007, "Surface counts for the five NGAO architectures", version 0.6.

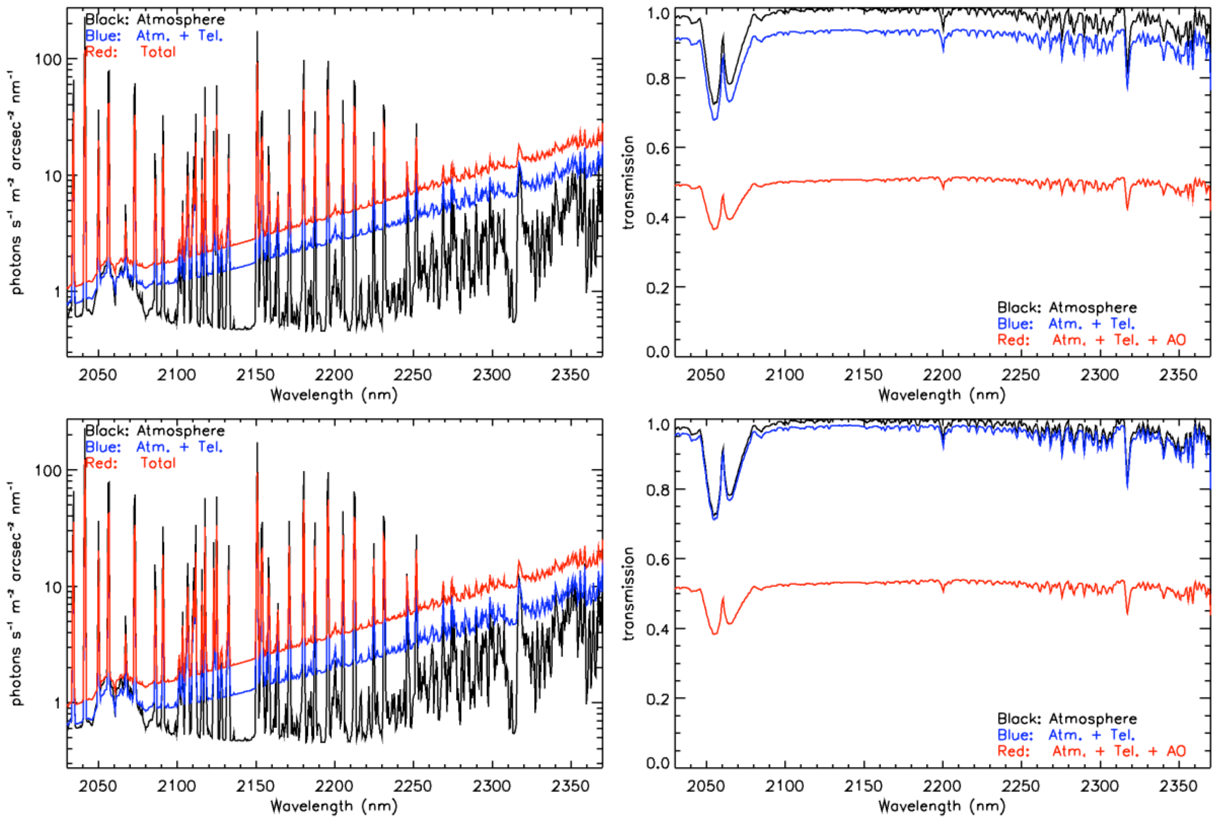


Figure 3: Comparison of *clean* aluminum (top) and protected silver (bottom) coatings on telescope mirrors, for the Split relay, NIRI architecture with the AO enclosure at 255 K.

5 CONCLUSIONS

6 APPENDIX: NGAO CANDIDATE ARCHITECTURES