Keck Deployable Tertiary: comments on requirements

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1 Introduction

In order to minimize costs we want to make the requirements as loose as possible while meeting all necessary needs. The deployable tertiary must serve 6 focal stations and when not in use, not interfere with instruments at the cassegrain focus. It must provide a high quality beam to HIRES on one Nasmyth platform, and also feed an AO instrument on the other Nasmyth platform. One major function of the tertiary is to quickly move the light beam for short observations at one instrument, then returning the light to the original instrument.

The basic optics of Keck has the entrance pupil the circle that circumscribes the primary, with a diameter 10.949m. The exit pupil is 1.460m in diameter and is 17.45m from the primary vertex, which puts it 2.053m behind the secondary. The tertiary is 4.000m in front of the primary, while the f/15 focus is 2.5m behind the primary.

The f/15 plate scale is 727μm/arcsec.

Rotation of the tertiary about the y-axis (while pointing to a Nasmyth platform) causes image motion of 63μm/arcsec or 0.0867 arcsec/arcsec, while rotation of the tertiary about the z-axis causes half that, 0.0433 arcsec/arcsec. The x-axis connects the Nasmyth platforms, while the z-axis goes towards the secondary mirror.

The exit pupil is reflected by the tertiary and appears to be 13.45m from (behind) the tertiary, on the opposite side Nasmyth platform. A rotation of the tertiary about the y-axis (tertiary semi-minor axis) causes the exit pupil to move 130.4μm/arcsec, or about 8.93e-5 of the exit pupil diameter/arcsec. We will call this tilt and rotation about the z-axis tip (following the convention already set up).

At the tertiary the projected beam diameter is 0.476m for a single star, while the projected diameter for a 5 arcmin field of view is 0.623m and for the 20 arcmin field it is 1.064m.

2 Draft Requirements

Version2 of the requirements runs an amazing 70 pages, but here we discuss only a few.

From Table 8

Field of view	5 arcmin
Optical flatness	0.25 fringe
Rms flatness	0.125 fringe

Table 9

Module defining error y-axis	2.88 arcsec
Module defining error z-axis	2.88 arcsec
In-beam positioning accuracy	2.88 arcsec
In-beam tip-tilt repeatability	2.88 arcsec
Retracted rotation about optical axis	1 arcsec

3 Comments

3.1 Optical quality

Regarding optical flatness, I don't understand what “fringe” means.

Since this mirror will be the only tertiary for Keck 1, it should be flat and smooth enough for all seeing-limited and AO uses. One might write a spec on its impact on the wavefront, rather than on the surface itself. If we ask that the Strehl contribution be 0.9 or greater at 1µm (the shortest wavelength we might use AO) we require that the rms wavefront error is < 52nm. If we assume the mirror is smooth, then a slope requirement is appropriate for seeing-limited performance.

The original Keck specification for the tertiary allows only 0.054 arcsec (80% enclosed energy). For a Gaussian EE80=3.59σ, so the rms wavefront slope error is σ=7.3e-8 radians on the sky. If we ask what wavefront slope is allowed at the tertiary, it is 23x larger (the ratio of 10.949/0.476) or 1.68e-6 radians. Ignoring tilt, if we assume the entire error is quadratic, we can obtain an upper bound on the amplitude of the wavefront error,

$z = C_{20}(2\rho^2 - 1)$ (wavefront error)

$s_x = \frac{4C_{20}}{a^2}x$ (x slope) (a= 0.238m)

rms slope = $\sqrt{\frac{1}{A}\int s_x^2\,dA} = \frac{2C_{20}}{a}$

wavefront rms $= \frac{C_{20}}{\sqrt{3}}$

Now we must consider the fact that this error is really over a 10m aperture (image blur measured on the sky), so we should be using a =5.474m instead of a=0.238m. So if we allow σ=7.3e-8 radians, we obtain C_{20}=200nm and an rms wavefront error of 115nm. This is only 2x looser than the Strehl requirement gave us.

Given that any AO system will automatically remove low order aberrations in the tertiary, we think that a slope specification on the projected wavefront of 7.3e-8 radians is sufficient. One must ask over what spatial scales this should be applied. At the tertiary, a wavefront slope error of 1.68e-6 radians reaches a height difference of 4nm over a lateral distance of 2.4mm. Noise may prevent measurement of such slopes on this spatial scale.

We suggest that projected wavefront errors be under 4nm on all scales<10mm (this should be easy for polishing a flat) and on scales larger than this the rms slope errors be < 1.68e-6 radians. 4nm rms wavefront errors gives a Strehl at 1µm of 0.9994 and 0.9975 at 500 nm wavelength, so scattered light should be small.

3.2 Pointing and image location

The Keck telescope points to about 5 arcsec rms, so there is little loss if the tertiary only repeats the image location to 1 arcsec. Even allowing for future possible improvements in the Keck pointing, a spec of 1 arcsec rms is adequate.

One critical use of this tertiary is to briefly stop an observation with one instrument, make an observation with another instrument, then return to the original observation. Since all instruments have autoguiders repeatability only has to be within the capture range of the guider in order to return the science target rapidly to its original position. Thus we expect repeatability (on the sky) of 1 arcsec rms should be sufficient.

Given the conversion to tertiary motion, we think that repeatability of the tilt to 11 arcsec rms and 22 arcsec in tip is sufficient as a requirement. One might want to have a goal as well, perhaps 3 arcsec rms.

3.3 Pupil stability and repeatability

Particularly for adaptive optics applications, one wants the pupil (the image of the primary) to be repositioned to a small fraction of the sampling subaperture. Current Keck AO systems sample the pupil about 20 times across its diameter. Future AO systems might sample more densely, perhaps 100 times across the diameter. If we allow alignment variations 10% of a subaperture then we want the pupil location to repeat to 0.001 of the pupil diameter. This requires that the tertiary tilt be repeatable to 11 arcsec and tip to 22 arcsec. We should ask whether this is rms, or not to exceed. I think rms is adequate.

It is probably most important to know where the pupil is. This can be easily measured by monitoring the flux in the AO subapertures; those at the edge are sensitive to the exact pupil location. This is routinely done at PCS where pupil location is particularly important. If pupil location becomes important for some future AO instrument, the instrument will probably have its internal way to adjust the pupil location; this is done by PCS.

3.4 Comments on listed requirements

As can be seen by the technical discussion, I see no reason why the tertiary accuracy or repeatability should be anything close to 2.88 arcsec peak. These seem to be a factor ~10 too tight. They also do not distinguish between tilt and tip. Clearly some discussion with the Keck staff is needed.