K1DM3 Design Note

Coordinate Systems for the K1DM3 Project

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I. Introduction

The Keck I Deployable Tertiary Mirror (K1DM3) will replace the existing Keck I tertiary mirror. To facilitate its design, fabrication, commissioning, and fabrication we have generated this document to specify the coordinate systems to be used within the project.

II. Coordinate Systems

All told we have generated four coordinate systems (CSs) for the K1DM3 project. The following text, equations, and diagrams describe each of these.

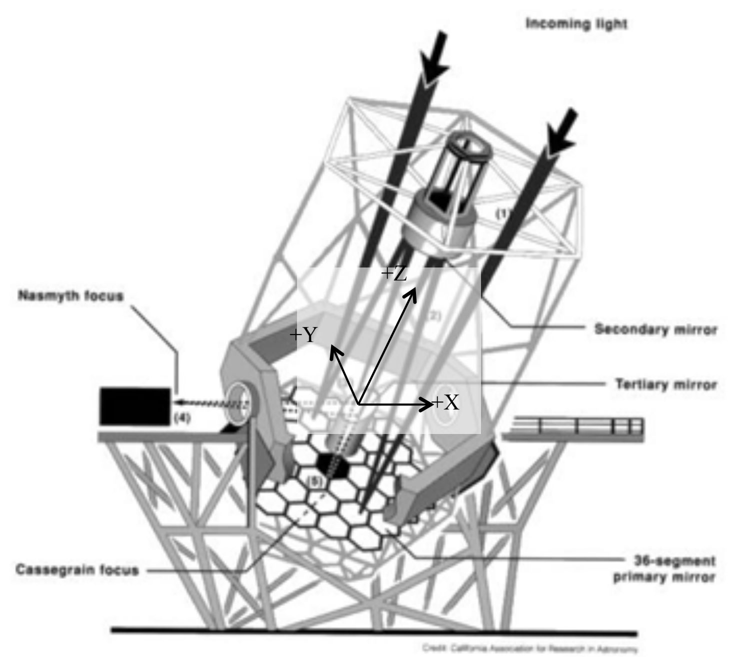

Fig. 1.— Telescope coordinate system

Telescope Coordinate System (C1)

This coordinate system matches the conventions used by WMKO for the Keck telescope (Figure 1). We summarize the zero-point (ZP) and axes of this CS as follows:

- The zero-point (ZP) of this coordinate system is the center of the primary mirror.
- The z-axis (Z1) corresponds to the telescope optical axis. Positive is defined as towards the sky (i.e. away from the reflective side of the mirror).
- The x-axis (X1) is parallel to the telescope elevation axis (horizontal). We define positive to be towards the HIRES instrument on the Nasmyth platform.
- The y-axis (Y1) is defined by the right-hand rule. It points up to the sky when the telescope is pointing along the horizon.

Tertiary coordinate system (C3)

The tertiary mirror folds the light from the secondary into the telescope XY1 plane, centering the optical axis on the center of the opening in the elevation bearing where it then forms the Nasmyth focus as shown in Figure 1. Not shown in Figure 1 are the four bent Cassegrain (BC) focal stations. There are four on one side of the elevation ring (the side on top when the telescope is pointed at the horizon).

We define the tertiary coordinate system as the Euclidean frame fixed to the tertiary module. It is identical to the C1 coordinate system at one rotation angle $\phi = 0$ degrees and shares the same zero point. [Check: In practice, the rotation axis of the module will not be identical to the Z1/Z3 axis.] Explicitly,

- $ZP_3 = ZP_1$
- Z3 is identical to Z1.
- X3 points to one of the ideal Nasmyth or bent-Cassengrain foci.
- Y3 is defined by the right-hand rule.

Mirror coordinate system (CM)

We define the mirror coordinate system as the Euclidean frame tied to the tertiary mirror (i.e. the glass and moveable support attached to it; Figure 2). The ZP is the center of the ellipsoidal mirror. The ZM axis is oriented normal to the surface and points away from the reflective side. When deployed, this axis is at 45 degrees from the Z3 axis and approximately parallel to the X3 axis when retracted. The XM axis runs along the major axis of the ellipsoid such that the XZM plane is ideally within the XZ3 plane. When stowed, this implies the XM axis runs towards the primary mirror. This places the YM axis along the minor axis of the ellipsoid. Summarizing

- ZP_M is the center of the reflecting surface of the ellipsoidal mirror.
- ZM is normal to the mirror and points away from the reflective surface.
- XM lies along the major axis. Positive is towards the focus of interest.
- Y3 lies along the minor axis and is defined by the right-hand rule.

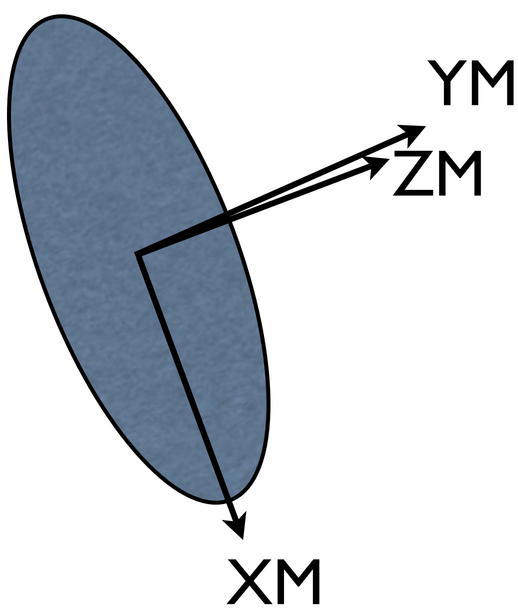

Fig. 2.— Mirror coordinate system (CM).

Telescope Focus (CF)

This system is fixed with respect to the telescope structure at each focal station. It facilitates interfacing with the instruments. It is defined as:

- ZP_F is at focus of the telescope, on the ideal optical axis (generally the optical and rotation axes of the instrument).
- ZF points into the instrument. It is identical to the X3 axis of the tertiary coordinate system (C3).
- XF points parallel to Z1/Z3, i.e. towards the sky.
- YF is defined by the right-hand rule.

III. Transformations

It will often be necessary to transform from one coordinate system to another. The following notes and equations describe those transformations. Note that thus far these are all simple rotations and translations.

Telescope-Tertiary (C1-C3)

These coordinate systems have a common ZP and share the z-axis. Therefore, the z-transformation is trivial

$$z_1 = z_3 \tag{1}$$

The only degree-of-freedom is the rotation angle of the module ϕ. Let $\phi = 0$ degrees be the ideal configuration to send light to HIRES on the Nasmyth platform. Then

$$x_1 = x_3 \cos\phi - y_3 \sin\phi \tag{2}$$

$$y_1 = y_3 \cos\phi + x_3 \sin\phi \tag{3}$$

Tertiary-Mirror (C3-CM)

The Tertiary Mirror Document describes the size, shape, and location of the tertiary mirror for the Keck telescope based on the desired field-of-view (FOV). The following assumes a $5'$ FOV and should be revised if this requirement is modified. Also, these transformations only apply to when the tertiary mirror is deployed at its ideal angle of 45 degrees (see Figure 3).

Because the mirror rotates with the tertiary module, the relative orientation of the axes are fixed, as described by the figure. As defined, the XZM plane coincides with the XZ3 plane and the y-axes are parallel. The center of the mirror is ideally offset from the Z3 axis, specifically by $\mu_0 = 0.0137\,\mathrm{m}$ in the negative XM direction. With the elevation axis 4.000m above the primary, the zero-point of the mirror ZP^M in the C3 coordinate frame is:

$$ZP_3^M = \left(-\frac{\mu_0}{\sqrt{2}}, 0, \frac{\mu_0}{\sqrt{2}} + 4.000\mathrm{m}\right) \cdot \left(\widehat{X3}, \widehat{Y3}, \widehat{Z3}\right) \tag{4}$$

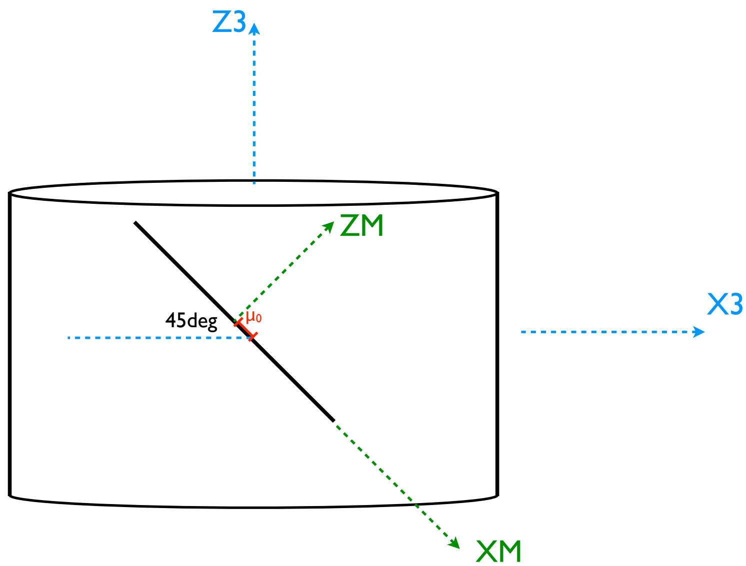

Fig. 3.— Mirror in the module, defining the relative orientations of the C3 and CM coordinate systems.

The remainder of the transformation simply takes into account the 45° tilt of the mirror, and we have:

$$x_3 = \frac{\left(x_M - \mu_0/\sqrt{2}\right)}{\sqrt{2}} + \frac{z_M}{\sqrt{2}} \tag{5}$$

$$y_3 = y_M \tag{6}$$

$$z_3 = \frac{\left(z_M + \mu_0/\sqrt{2} + 4.000\mathrm{m}\right)}{\sqrt{2}} + \frac{\left(x_M - \mu_0/\sqrt{2}\right)}{\sqrt{2}} \tag{7}$$

IV. Optical Effects of Misalignment

There are six degrees of freedom for the mirror, three translation and 3 rotations. They are best considered in the CM system:

1. CM-trans-X no effect on image. Vignetting if beams falls off edge.
2. CM-trans-Y no effect on image. Vignetting if beams falls off edge.
3. CM-trans-Z image motion (ΔXF) and defocus (ΔZF). No field rotation (Vignetting if beams falls off edge, same magnitude as CM-trans-X)
4. CM-rot-X image motion (ΔYF) and field rotation (θ_{ZF}). No defocus (to first order).
5. CM-rot-Y image motion (ΔXF), no defocus (to first order). No field rotation.
6. CM-rot-Z no effect on image. Vignetting if beams falls off edge.

Notes:

1. Items 3 and 5 can be combined to produce no image motion, and yet there can be a displacement of the pupil image.
2. No defocus assumes a focal plane, whereas the focal surface is slightly curved; thus, there will be negligible second-order defocus.

3. Wherever image motion occurs, there are negligible effects due to field distortions.