Tertiary Mirror size, shape and Location

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1 Introduction

The tertiary mirror is sized and positioned to deliver an unvignetted beam to some focus. The beam is defined by the pupil at one end and the focal region at the other. In general this frustum is axisymmetric around the z or optical axis. The tertiary mirror intersects this at 45 degrees, to send the light to the focus. The intersection of a plane with a cone is an ellipse, but in general it is not centered on the optical axis.

It is a useful approximation to assess the size of the tertiary mirror by examining the light cone in a plane normal to the optical axis, and to assume the ellipse is simply an ellipse with e=1/sqrt(2), but this is only approximate unless the cone of light is a cylinder. Here we work out the exact formulation of the ellipse.

2 Details

The cone can be written as

$$x^2 + y^2 = \tan^2\theta (z - z_0)^2$$

and the plane as

x=z

where the origin of the coordinate system is the intersection of the optical axis (z), with the elevation axis (x) and z_0 is the coordinate of the apex of the cone, and depends on the selected field of view.

$\tan\theta = \dfrac{D_p - D_f}{2(z_p - z_f)}$ the cone half opening angle where D_p is the diameter of the exit pupil

D_f is the diameter of the unvignetted focal plane

z_p is the z coordinate of the exit pupil

z_f is the z coordinate of the focal plane

and

$$z_0 = z_p - \frac{D_p}{2\tan\theta}$$

Now for an ellipse

$$\frac{(u-u_o)^2}{a^2} + \frac{v^2}{b^2} = 1$$

and the eccentricity is defined by $e^2 = 1 - \frac{b^2}{a^2}$

Now it is known from projective geometry that $e = \frac{\sin\phi}{\cos\theta}$ where ϕ is the angle of the plane (45 deg in our case).

It is easy to show (by computing the locations of the two end points) that the major axis of the ellipse is given by

$$d_1 = -\sqrt{2} z_0 \frac{\tan\theta}{1+\tan\theta}$$

$$d_2 = -\sqrt{2} z_0 \frac{\tan\theta}{1-\tan\theta}$$

$$\text{major axis} = 2a = d_1 + d_2 = 2\sqrt{2} z_0 \frac{\tan\theta}{\tan^2\theta - 1}$$

and the offset of the center of the tertiary (in the plane of the tertiary) is given by

$$u_0 = a - d_1 = \frac{d_2 - d_1}{2} = \sqrt{2} z_0 \frac{\tan^2\theta}{1-\tan^2\theta}$$

It is perhaps worth noting that z_0 is negative and θ is small for our situation.

3 Examples

3.1 For the Keck deployable tertiary

D_p	1.460m
D_f	0.2176m (for a 5 arcmin field of view)
z_p	13.448m
z_f	-6.500m

2a	0.881m
2b	0.623m
u_0	0.0137m

3.2 For the full Keck tertiary

D_p	1.460m
D_f	0.8702m (for a 20 arcmin field of view)
z_p	13.448m
z_f	-6.500m
2a	1.503m
2b	1.063m
u_0	0.0111m

3.3 For the TMT tertiary

D_p	3.092m
D_f	1.309m (for a 15 arcmin field of view)
z_p	26.387m
z_f	-20.000m
2a	3.465m
2b	2.450m
u_0	0.0211m