Appendix A

Astronomical Calibration Mission Study

A.1 Engineering Drawing of Integrating Sphere

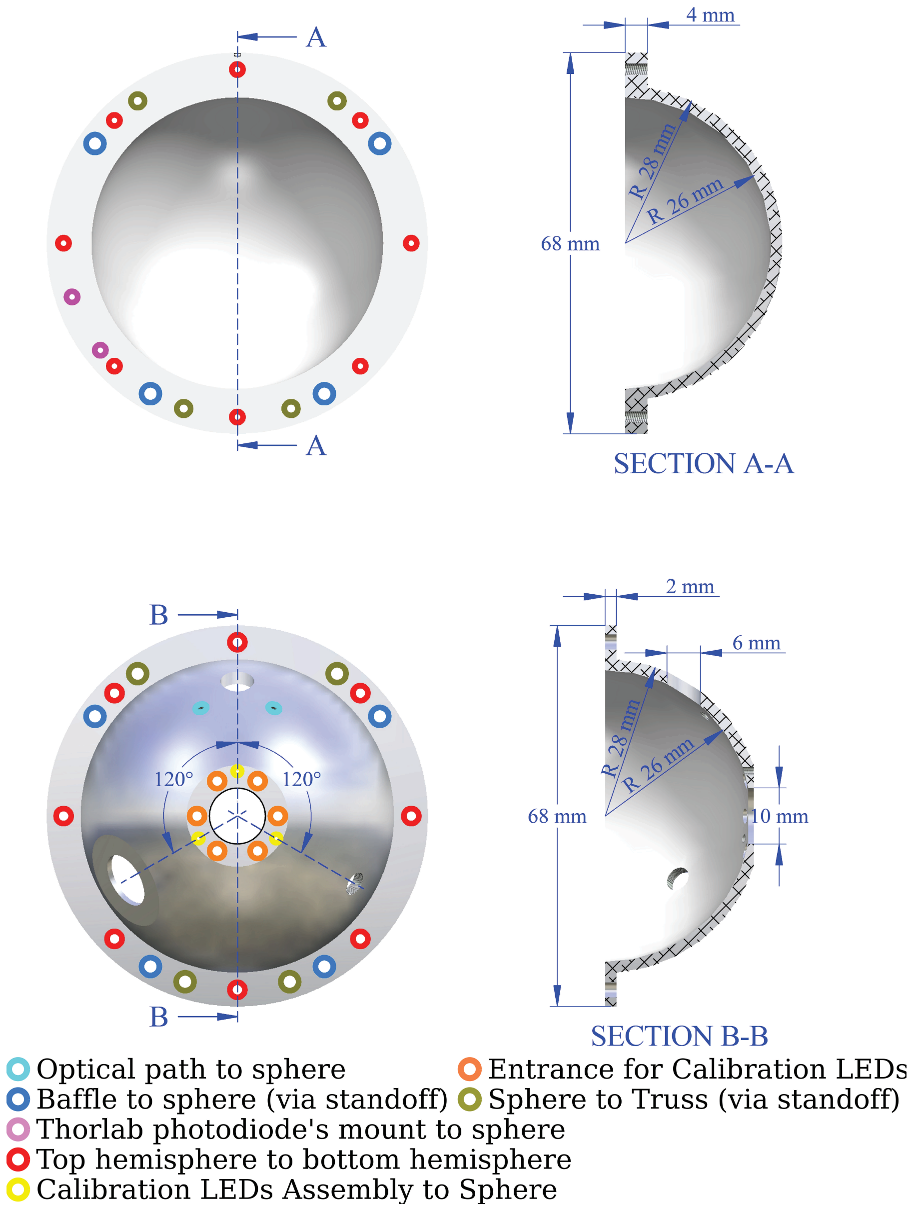
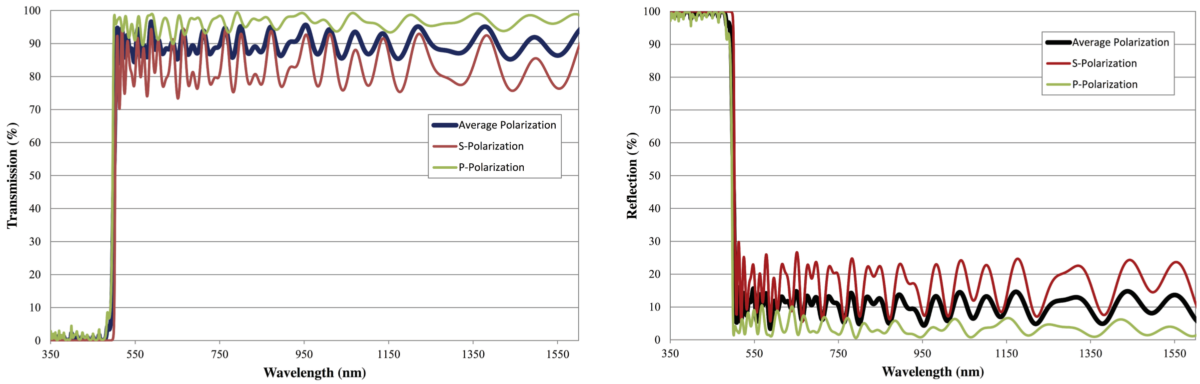
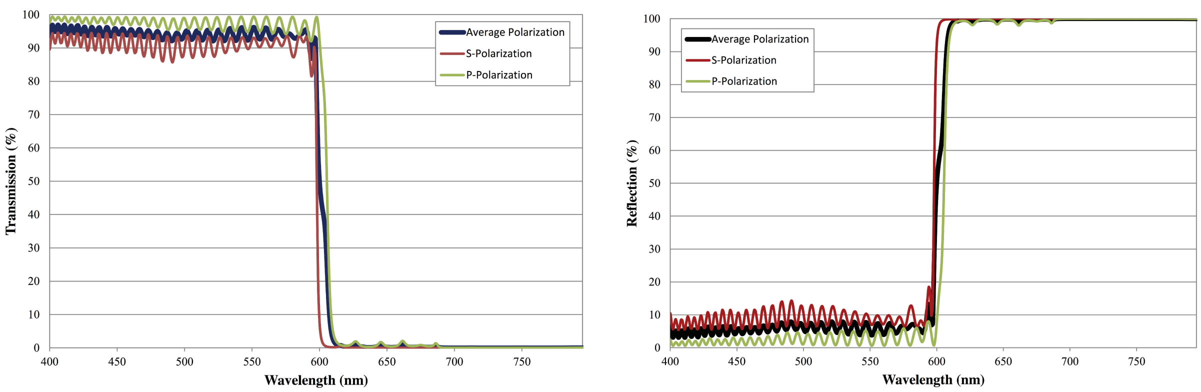


Figure A.1: Engineering drawing of the integrating sphere designed at SFL.

A.2 Sample Graphs of Dichroic Mirrors



(a) Graphs of DM1 - a longpass dichroic mirror with cut-on wavelength of 500 nm. Right: transmission graph; left: reflection graph [30].



(b) Graphs of a DM2 - a shortpass dichroic mirror with cut-off wavelength of 600 nm. Right: transmission graph; left: reflection graph [31].

Figure A.2: Sample graphs for two types of dichroic mirrors: longpass (top) and shortpass (bottom).

A.3 Adjustment of Dichroic Mirrors in Wedge Units

In a wedge unit, the angle at which the dichroic mirror is mounted to the wedge-shaped central part, can be adjusted by tightening or loosening three screws, labeled A, B and C In Fig. A.3. A hypothetical triangle $\triangle ABC$ can be formed which has its vertices at the centers of these "adjustment screws", with dimensions as summarized in Table A.1.

Table A.1: Lengths of the sides and the heights of the triangle △ABC in Fig. A.3

Description	Length (mm)
Distances between vertices A and B	10.0
Distances between vertices B and C	19.65
Distances between vertices A and C	19.65
Height from vertex A	9.67
Height from vertex B	9.67
Height from vertex C	19.0

Given the pitch of a screw, it is possible to calculate the vertical distance that the screw travels (denoted by x in mm) after certain amount of rotation (denoted by ϕ in degrees) from the following equation:

$$x = \frac{\phi \times p}{360^\circ} \tag{A.1}$$

where p is the pitch of the screw in mm. Given the pitch of adjustment screws in wedge units is 0.4 mm and assuming that the they can be rotated in 5-degree steps (i.e. $\phi = 5^\circ$, the vertical translation of an adjustment screw after a step of rotation is calculated to be 0.006 mm. As a result of this vertical adjustment, the angle of the dichroic mirror's surface (denoted by θ, in degrees) will also change, which can be calculated as follows:

$$\theta = \arctan\left(\frac{x}{y}\right) \tag{A.2}$$

where y is the normal distance from an adjustment screw to the line connecting the center of two other adjustment holes (i.e., y is the length of the height). Therefore, based on the geometry of the dichroic mirror holder and the distance between the adjustment screws (summarized in Table A.1), rotating screw A, B, or C changes the angle by about 0.016°, 0.033°, 0.033° respectively. It should be noted that since screw A is located at the farthest distance, finer adjustment can be achieved by this screw.

In order to run the analysis for the worst case of divergence, it will be assumed that in a wedge unit, the amount of angular divergence caused to the laser beam will be 0.033°

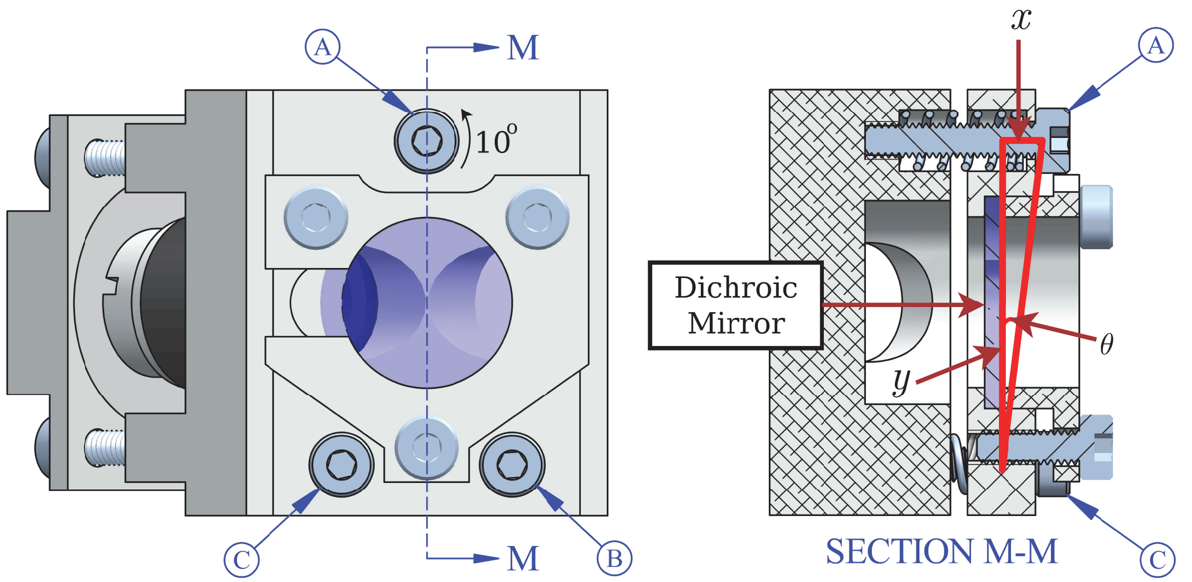


Figure A.3: Dichroic mirror's spring-loaded surface-angle adjustment mechanism. Rotating each of the screws A, B or C changes the angle of dichroic mirror's surface with respect to the incident laser beam.

caused when the beam passes through or gets reflected by the dichroic mirror.

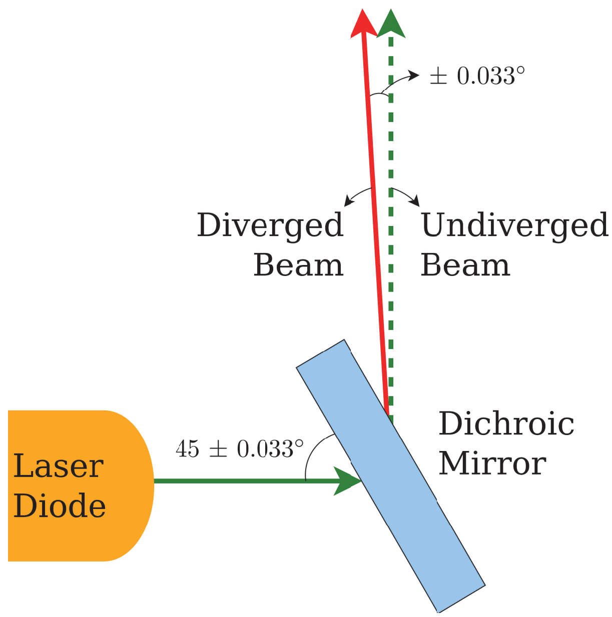


Figure A.4: Dichroic mirror's spring-loaded surface-angle adjustment mechanism. Rotating each of the screws A, B or C changes the angle of dichroic mirror's surface with respect to the incident laser beam.

A.4 Adjustment of Small Mirrors in Optical Path

Small mirrors in the optical path are aligned by their flanges that presumably sit flush to the interior surfaces of the parts that make up the optical path. However, in reality, due to inaccuracies in of small mirrors as well as other components of the optical path, there will be misalignments between the pieces (e.g., between flange of small mirrors and optical path structure).

If the machining precision tolerance is assumed to be no greater than ±0.005 inches, it is possible to calculate how much the small mirrors will be misaligned. In "DETAIL A" view Fig. A.5, x is the maximum tolerance value (i.e. 0.005 inches, or equivalently 0.127 mm), y is the length of the side of the flange which supposedly sits flush with the optical path's surface (6 mm by design). The misalignment angle θ is calculated as blow:

$$\theta = \arctan\left(\frac{x}{y}\right)$$

Therefore, θ is calculated to be ca. 1.2°. This is the angle the diverged laser beam makes with its original path.

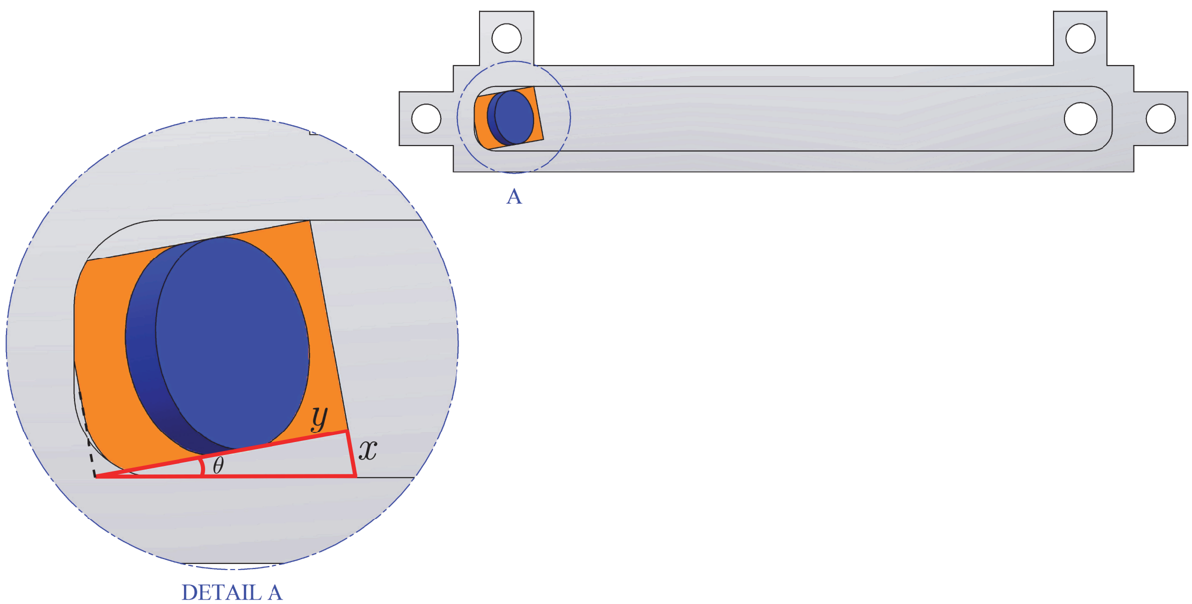


Figure A.5: Alignment of small mirrors in the optical path module suffers from the 5 thou machining error.

A.5 Payloads Subsystem Mass Budget

A detailed breakdown of AstroCal payload subsystem is presented in Table 1.6.2.

Table A.2: Selected laser diodes for multicolor laser module in AstroCal mission study.

Component	Status	Per Unit Masses (g)			AstroCal Mission		
		Estimated	Contingency	Total	Number	Contingency	Mass (g)
Multicolor laser module						**25.3**	**399.6**
Thermoelectric Cooler	M1	2.8	0.1	2.9	4	0.6	11.8
Diode Holder	M1	0.6	0.0	0.6	4	0.1	2.3
Laser Diode (9 mm)	M1	1.4	0.1	1.5	4	0.3	5.9
Collimating Lens	M1	0.3	0	0.3	4	0.1	1.1
Collimator Tube	M1	1.2	0.1	1.3	4	0.2	5.1
Lens Holder (Top)	M1	3.2	0.2	3.3	4	0.6	13.4
Lens Holder (Bottom)	M1	1.1	0.0	1.0	4	0.2	4.1
Dichroic Mirror	M1	6.8	0.3	7.1	4	1.4	28.6
Spring J-80	E	0.1	0.0	0.1	12	0.2	1.2
Back plate	M1	1.6	0.1	1.6	4	0.3	6.6
Wedge piece	M1	10.1	0.5	10.6	4	2.0	42.4
Top Plate	M1	43.1	2.2	45.2	1	2.2	45.2
Main Housing	M1	165.7	8.3	174	1	8.3	174.0
Laser Standoff	M1	4.2	0.2	4.4	4	0.8	17.6
Micro-D Connector	E	5.7	1.4	7.1	1	1.4	7.1
Screw M2-0.4 [6.0 mm]	E	0.2	0.1	0.3	12	0.6	3.2
Screw M2-0.4 [10.0 mm]	E	0.3	0.1	0.4	28	2.1	10.3
Screw M2.5-0.45 [8.0 mm]	E	0.5	0.1	0.6	14	1.7	8.5
Screw M3-0.5	E	2.2	0.6	2.8	4	2.2	11.0
Optical Path						**3.6**	**42.4**
MCL Attachment	M1	6.4	0.3	6.7	1	0.3	6.7
Short C-channel	M1	4.7	0.2	4.9	1	0.2	4.9
Short Flat Gasket	M1	0.8	0.0	0.9	1	0.0	0.9
Long C-channel	M1	8.9	0.4	9.3	1	0.4	9.3
Long Flat Gasket	M1	3.1	0.2	3.3	1	0.2	3.3
Gasket (Integ. Sphere)	M1	5.7	0.3	6.0	1	0.3	6.0
Small Mirror	E	0.3	0.1	0.4	3	0.3	1.3
Screw M2-0.5 [8.0 mm]	E	0.5	0.1	0.6	4	0.5	2.4
Screw M2.5-0.45 [6.0 mm]	E	0.4	0.1	0.6	2	0.2	2.4
Screw M3-0.5 [6.0 mm]	E	0.7	0.2	0.9	2	0.4	1.8
Nut M3-0.5	E	1.0	0.3	1.3	3	0.8	3.7

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Component	Status	Per Unit Masses (g) Estimated	Contingency	Total	AstroCal Mission Number	Contingency	Mass (g)
Integrating Sphere						**16.1**	**200.6**
Top Hemisphere	M1	36.8	1.8	38.7	1	1.8	38.7
Bottom Hemisphere	M1	28.8	1.4	30.2	1	1.4	30.2
Baffle	M1	29.4	1.5	30.8	1	1.5	30.8
Hamamatsu Photo Diode	M1	22.3	1.1	23.4	1	1.1	23.4
PD Mount Hamamatsu	M1	5.1	0.3	5.3	1	0.3	5.3
BNC Connector	E	14.1	3.5	17.6	1	3.5	17.6
Thorlab Photo Diode	M1	18.1	0.9	19.1	1	0.9	19.1
PD Mount Thorlab	M1	1.8	0.1	1.9	1	0.1	1.9
SMA Connector	M1	3.9	0.2	4.1	1	0.2	4.1
Integ. Sphere Standoff	M1	0.5	0.0	0.5	4	0.1	2.1
Baffle Standoff	M1	0.5	0.0	0.5	4	0.1	2.1
Screw M2-0.4 [5.0 mm] BH	E	0.2	0.0	0.2	3	0.1	0.7
Screw M2-0.4 [6.0 mm]	E	0.2	0.1	0.3	10	0.5	2.7
Screw M3-0.5 [35.0 mm]	E	2.2	0.6	2.8	8	4.4	22.0
Microwave Source						**16.5**	**105.1**
Source	E	50.0	12.5	62.5	1	12.5	62.5
MCX Connector	E	3.0	0.8	3.8	1	0.8	3.8
Filter Holder	M1	26.6	1.3	28.0	1	0.8	28.0
Filter Gasket	M1	1.7	0.1	1.8	1	0.1	1.8
Filter	E	1.0	0.3	1.3	1	0.3	1.3
Screw M2-0.4 [8.0 mm]	E	0.3	0.1	0.3	4	0.3	1.3
Screw M2.5-0.45 [10 mm]	E	0.5	0.1	0.7	4	1.3	2.6
Screw M3-0.5 [8 mm]	E	0.8	0.2	1.0	4	0.8	4.0
Payload OBC						**25.4**	**127.4**
Computer	E	100.0	25.0	125.0	1	25.0	125.0
OBC Standoff	M1	0.1	0.0	0.1	4	0.0	0.6
Screw M2-0.4 [12.0 mm]	E	0.4	0.1	0.4	4	0.4	1.8
Wiring Harness						**25.0**	**125.0**
Wiring Harness	E	100.0	25.0	125.0	1	25.0	125
Total						**111.9**	**999.0**
Total (without contingency)							887.2
Target							1,000.0
Margin							1.0