

# Thermal reflector to reduce thermal radiation in the entrance of cryogenic Instruments

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## ABSTRACT

The entrance of a cryogenic instrument is often a major heat load, since the opening in the cold instrument has a large solid angle. We present a novel thermal reflector that, placed between two openings, reduces the load by reflecting radiation emitted in the hot opening and not directed toward the cold opening. In the Spartan IR Camera, this thermal reflector, placed between the vacuum window and the field stop, reduces the load by a factor of 2.5, which is 1.5 times the limit defined by the size of the field stop, the minimum window size, and the separation between the two.

**Keywords:** Thermal radiation, heat load, cryogenic, emissivity

## 1. INTRODUCTION

The Spartan Infrared Camera<sup>1</sup> for the SOAR Telescope has a rather large entrance opening in the cryogenic box to admit the light for four 38-mm square detectors. The thermal radiation through the entrance opening is substantial. We present a thermal reflector that reduces the radiation through the opening.

The calculated total heat load of the Spartan Camera would increase by 65% without the thermal reflector. The designed total load is 6.0 W. See Table 1. The radiation through the 120×120 mm entrance opening is 6.5 W without the thermal reflector and 2.6 W with the reflector. The net radiation on the walls of the cryogenic enclosure (0.74×1.01×0.43m, 3.0m<sup>2</sup>) is 1.3 W, having been reduced by a factor of 1000 by a 10-layer aluminized PET blanket. The conduction through eight G10 struts (four 38×13×352mm and four 8×8×352mm) is 1.3 W. The conduction through cables and nitrogen fill and vent tubes is 0.75 W.

The measured heat load is within 20% of calculation.

We have measured the heat load with a less-than-ideal blanket to be 10 W, where the calculated load is 8.4 W. The measurements are the flow rate of nitrogen gas and the total hold time of a 7.5-L filling of the reservoir for liquid nitrogen.

Table 1 Heat load of the Spartan Camera

Source	Load [W]		
	(1)	(2)	(3)
Walls, 3.0 m <sup>2</sup>	R	3.4	1.3
Opening, 12x12cm, w/ reflector	R	2.6	2.6
Opening, 12x12cm, w/o reflector	R		6.5
Struts to outside	C	1.7	1.3
Detector Cable	C	0.35	0.35
Motor Cable	C	0.26	0.26
Nitrogen tubes	C	0.14	0.14
Total		8.4	6.0
Measured		10.0	

1. R=radiation; C=conduction
2. Calculated load for test.
3. Design goal

## 2. THEORY & RESULTS OF MONTE CARLO MODEL

The thermal radiator has two reflecting parts, a hemisphere and a plane, with openings in both to admit light. The thermal reflector is placed at the opening of the instrument. See Figure 1. The purpose of the hemispherical part is to reflect thermal light rays back out through the entrance opening and thus reduce the heat load. Only light rays from the center of the hemisphere reflect back to the entrance position and exit; other rays may exit through another part of the entrance opening or they may miss the opening. The rays that miss the opening reflect off the plane. The plane and hemisphere function as a corner reflector to redirect rays in approximately the reverse direction.

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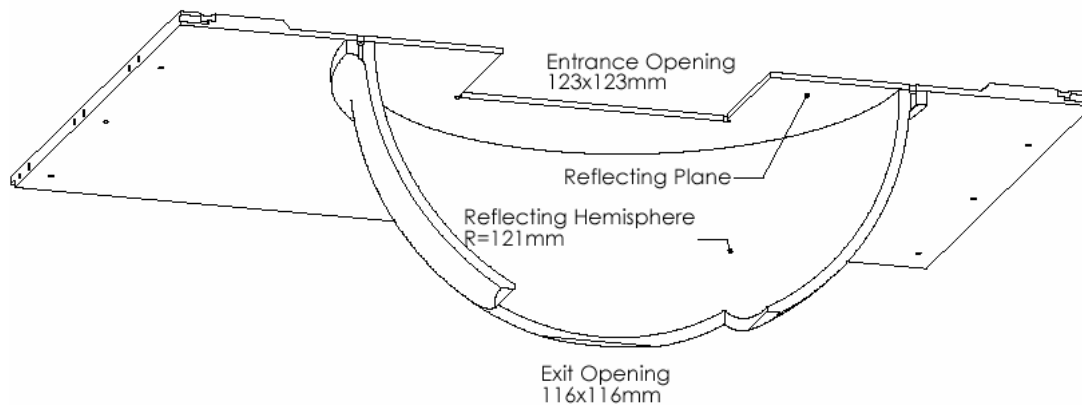


Figure 1 Section view (half is cut away) of the thermal reflector

We have created a Monte Carlo program with Mathematica (wolfram.com) to compute the emissivity of the entrance opening. The ray positions and directions are generated by random numbers. The model has two idealizations. (1) Reflection is specular. (2) Absorption is independent of the angle of incidence. The thermal reflector is cold: absorption on it contributes to the heat load, and its radiation is negligible.

A light ray from the entrance opening may take one of many possible paths. The paths for the thermal reflector used in the Spartan Camera are shown in Figure 2. The entrance opening is a 123-mm square; the exit in the hemisphere is a 116-mm square. The radius of the hemisphere is 121 mm. (a) The light ray reflects off the hemisphere and exits the entrance opening. This case occurs for 38% of the rays. (b) The light ray reflects off the hemisphere, off the plane, off the hemisphere twice, and exits the entrance opening. This case occurs for 25% of the rays. (c) The light ray reflects off the hemisphere twice and exits the entrance opening. (e) The light ray goes directly to the exit opening. (f) In all cases except for (e), some of the light ray is absorbed in the thermal reflector, and contributes to the heat load. For each ray, the fraction of energy absorbed is  $1 - r'^n r^n$ , where  $r$  and  $r'$  are the reflectivity of the plane and hemisphere, and  $n$  and  $n'$  are the number of reflections off of each.

For the Spartan Camera, the emissivity of the plane is 2% in the thermal infrared, and that of the hemisphere is 5% (§3).

Table 2 Summary of contributions to the emissivity of the thermal reflector for the Spartan Camera.

Outcome: Ray leaves through	Occurance	Emissivity
Exit (in hemisphere) w/o reflection	22.8%	22.8%
Exit (in hemisphere) w/ reflection	4.3%	4.3%
Entrance (in plane)	72.8%	7.3%
		<u>34.5%</u>

With the thermal reflector, the emissivity of entrance opening is 35%. Of course, without the thermal reflector, the emissivity would be 100%. The contributions to the emissivity are shown in Table 2. All of the rays traced to leave through the exit contribute to the emissivity, since they are absorbed either in the cold thermal reflector or the cold instrument. The rays traced to leave through the entrance opening contribute to the emissivity (7.3% in Table 2).

The floor for the emissivity of the thermal reflector is set by the rays that go directly from the entrance opening to the exit opening. For the Spartan Camera, the size of the field determines the entrance and exit openings; the exit opening is very close to the image of the telescope. The distance between the vacuum window and the telescope image determines the radius of the thermal reflector. If the exit open were farther away, the emissivity of the thermal reflector would be lower.

The emissivity floor is 23%, and the actual emissivity is 35% or 1.5 that of the floor. If the thermal reflector were made of a perfectly reflecting material, the emissivity would be 27% or 1.2 that of the floor.

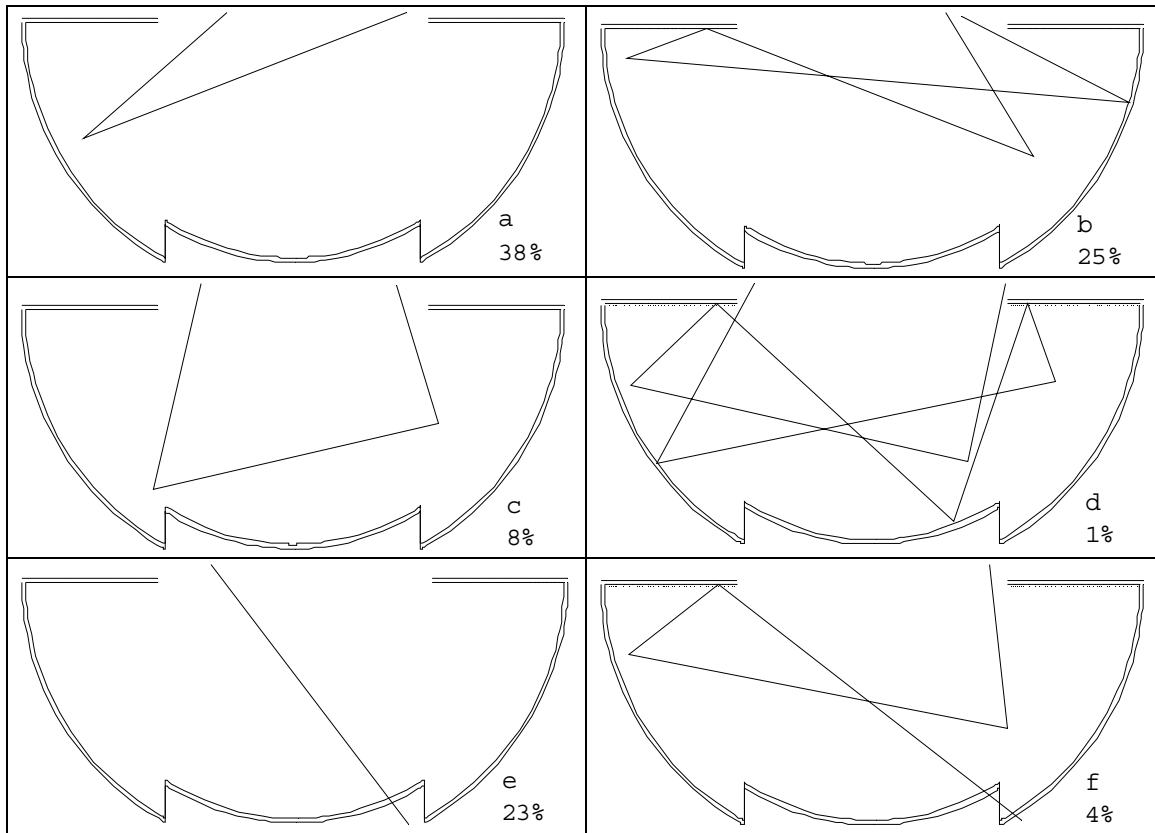


Figure 2 Raytrace for the six most common cases for the thermal reflector in the Spartan Camera. Light enters from the top and returns through the entrance in cases a–d, thereby not heating the instrument. In cases e and f, the light exits through the opening in the hemisphere and heats the instrument. The percentage is the occurrence of each case. The occurrence of the cases not shown is 1.6%.

The performance of the thermal reflector depends on the emissivity of the surface of the hemisphere and the plane. Since a highly reflective plane is easily obtained, we consider the emissivity of the hemisphere. See Figure 3. The fit of emissivity  $\epsilon$  of the entrance opening to the Monte Carlo data is  $\epsilon = 0.283 + 1.32 \epsilon_{hs} - 0.7 \epsilon_{hs}^2$ , where  $\epsilon_{hs}$  is the emissivity of the hemisphere.

### 2.1. Fabrication

MC Molds of Williamston, MI, machined the hemispherical part and then polished it with #9 diamond lapping compound, for which the particle size is 8–12  $\mu\text{m}$ . The measured reflectivity of a flat sample is 95%.<sup>2</sup> They used an Amber Sentinel thermal infrared camera, which is sensitive to wavelength range 8–12 $\mu\text{m}$ , and imaged a heated resistor and its reflection.

The plane part is made of Sheldahl 146458 film (Sheldahl.com), which has 100-nm thick aluminum layers on both sides of a 25- $\mu\text{m}$  thick polyethylene terephthalate film (PET), stretched over an aluminum piece. The measured reflectivity of the aluminized PET is 98%.<sup>2</sup>

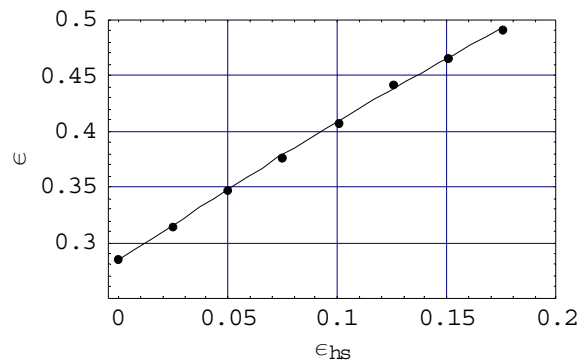


Figure 3 Emissivity of the entrance opening vs. emissivity of the hemisphere. Each point has 30,000 rays.

### 3. CONCLUSIONS

We have demonstrated a thermal reflector that reduces the thermal radiation in the entrance opening (123mm square) by a factor of 2.5 (from 6.5 W to 2.6 W). For the Spartan Camera, this reduces the total heat load by a factor of 1.6. Such a thermal reflector will be useful for instruments for large telescopes, where the entrance opening is necessarily large.

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### REFERENCES

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