University of Colorado

Near Infrared Camera and Fabry-Perot Spectrometer (NIC-FPS)
Astrophysical Consortium 3.5 meter Telescope

Abstract

This report contains an analysis of the optical feasibility and limitations for a 0.38:1 (f/4) magnification reimaging camera. The camera will serve a dual purpose; it will be designed for a 2048 X 2048 HAWAII 2 HgCdTe (MCT) Mercury Cadmium Telluride array built by Rockwell International. However, a 1024 X 1024 HAWAII will be used initially. Due to the similar pixel pitches for these arrays, 18.0 and 18.5 μm respectively, the detector can be interchanged without any appreciable performance impact. Information about the telescope was provided by Mr. Stephane Beland from the University of Colorado. It is assumed that the telescope is optimized for viewing in the infrared. The telescope is a modified Richey-Chretien design with a 3.5 meter f/1.8 primary mirror and F/10 secondary Cassegrain. It is nominally f/10.3 with a [~5.9] arcsec/mm plate scale. The camera will be located at the Nasmyth port focus. It will operate at an ambient temperature of –20 °C to +20 °C.

The 0.38:1 f/4 Camera

This camera mode, see Figure 1, allows a reduced magnification to view a larger field of view. The f/4 camera consists of a total of seven elements: one for the window, three for the collimator, and three for the reimaging optics (See Figure 1). Four different materials were used to make the elements shown in Figure 1. They were chosen to balance chromatic dispersion and aberrations. Additionally, a field flattener lens will have to be used to reduce the Petzval field curvature at the telescope focus (See Figure 2).

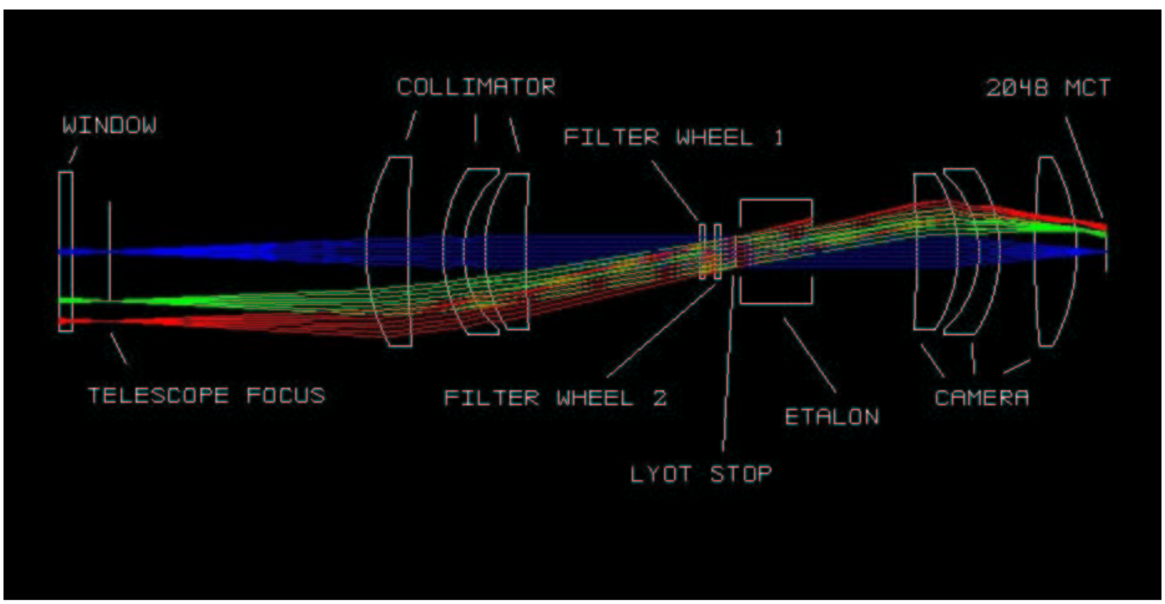

Figure 1: 3-D layout of the 0.38:1 f/4 optical design

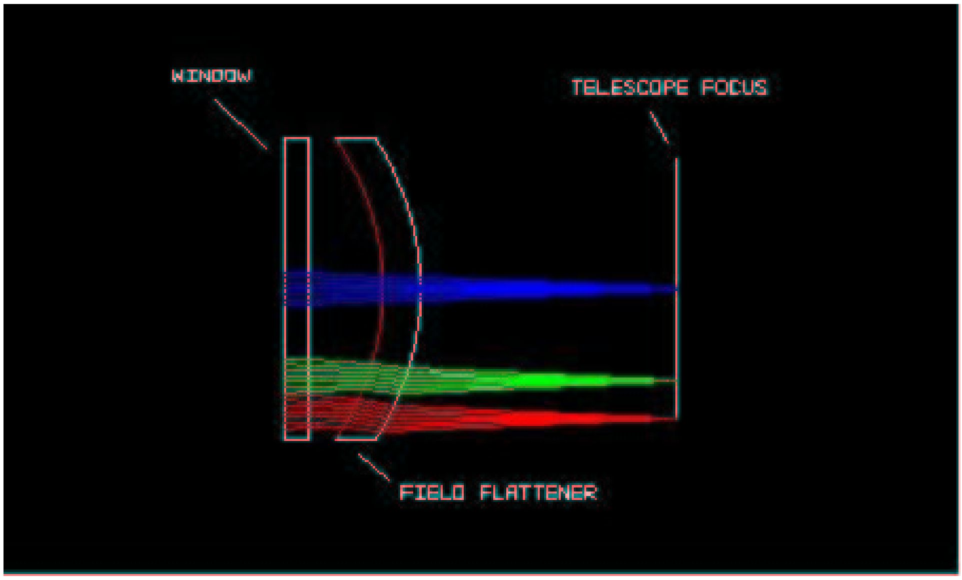

Figure 2: 3-D layout of the Field Flattener

The collimator triplet will be housed in an aluminum optical tube mounted directly to the cryogenic cold work surface. The interior surface of the tube will be black anodized. There will be aluminum, black anodized spacers between the lenses with threaded, aluminum, black anodized rings securing the ends. A wavy washer will be placed between two of the spacers to account for thermal contractions. Table 1 describes the characteristics for each lens of the collimator at room temperature (20 °C).

PARAMETER	LENS			TOLERANCE
Lens #	1	2	3	
Shape	Meniscus	Meniscus	Meniscus	
Material	BaF_2	Fused Silica	BaF_2	
Operating Temp.	77 K	77 K	77 K	
Radius 1 (mm)	-190.551001	-143.18381	-137.365985	+/- 0.1 %
Radius 2 (mm)	-931.22208	-100.223800	-1130.119789	+/- 0.1 %
Irregularity	1 fringe	1 fringe	1 fringe	
Center Thickness	39.776653	19.997934	39.776602	+/- 0.01
Diameter (>=)	180	160	150	+0.00/- 0.13
Clear Aperture	~ 163.1	~ 145.2	~ 132.1	
Surface Quality	40/20	40/20	40/20	
Quantity	1	1	1	

Table 1: Lens Parameters for Collimator Triplet @ 20 °C

The 0.38:1 camera optics are composed of three lenses, see Table 2. The same two materials used in the collimator were used for the reimaging lenses to balance chromatic dispersion and aberrations. In addition, ZnSe was used as a replacement for BaF_2 in the first lens to take advantage of its higher refractive index. It is a suitable material that compliments the other materials in dispersion. The radii are expressed at room temperature (20 °C).

PARAMETER	LENS			TOLERANCE
Lens #	1	2	3	
Shape	Meniscus	Meniscus	Bi-convex	
Material	ZnSe	Fused Silica	BaF_2	
Operating Temp.	77 K	77 K	77 K	
Radius 1 (mm)	1130.119789	100.000000	-931.222008	+/- 0.1 %
Radius 2 (mm)	137.365985	143.183381	190.551001	+/- 0.1 %
Irregularity	1 fringe	1 fringe	1 fringe	
Center Thickness	39.776602	19.997934	39.776653	+/- 0.01
Diameter (>=)	125	110	150	+0.00/- 0.13
Clear Aperture	~ 116.8	~ 99.2	~ 71.8	
Surface Quality	40/20	40/20	40/20	
Quantity	1	1	1	

Table 2: Lens Parameters for 0.38:1 Camera Triplet @ 20 °C

Because of the detector size and the field requirements, the primary focus (telescope focus) is quite large, ~94 x 94 mm. As a result, Petzval field curvature dominates the image quality. The addition of a field flattener will greatly improve the optical performance, as seen in Figure 2. The spot diagrams in Figure 3a and 3b show the RMS spot size for three different fields (corresponding to the center, edge, and corner of the 2048 array) across the full spectral band of 1.0 to 2.3 µm at the operating temperature of ~77 K. Notice that the spot size at full field has been reduced by a factor of four. On-axis performance is slightly worse, but well within the Airy disk size of 19.83 microns.

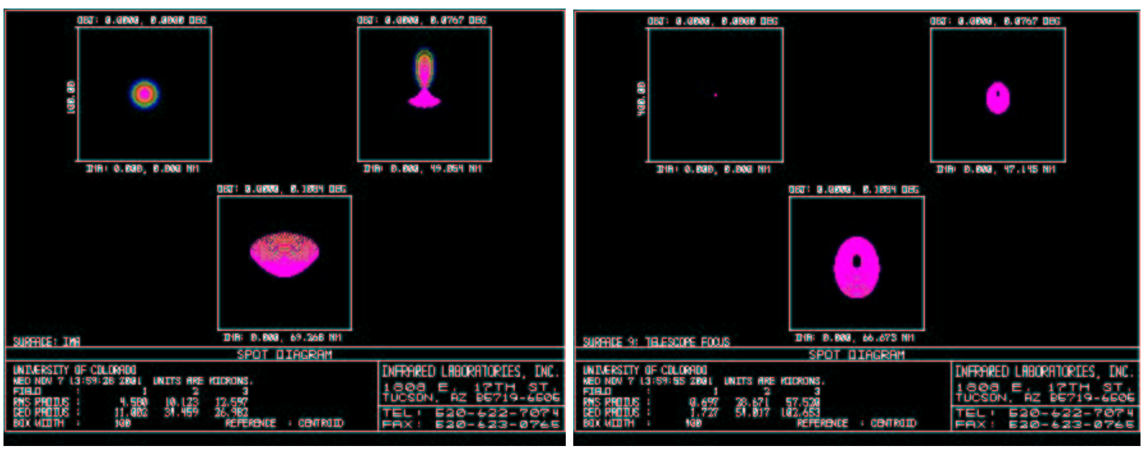

Figure 3a & 3b: Spot Diagram at Telescope Focus with and without Field Flattener

The design incorporates two filter wheels and a Lyot stop. The filters will have to be at least two (2) inches in diameter so that they do not vignette the collimated beam. A Fabry-Perot etalon, provided by [Rice University], will also be inserted into the collimated space. Due to its size constraints, it will be the limiting clear aperture and will vignette the beam. Approximately 20 percent of the beam will be vignetted by the etalon. Because the collimated beam is being vignetted and not the reimaging beam, the result will be a 20 percent decrease in intensity with no impact on image quality. This is the single biggest limitation of the optical design.

The optics necessary in this design are large and consequently will be expensive. Furthermore, availability of appropriately sized blanks will be limited. In particular, crystals like BaF_2 are difficult to grow in large diameters without inclusions or other defects in the crystal lattice. Table 3 gives a ballpark quotation for the optics in this design. Please note that these are only approximate figures and should not be used as final numbers.

OPTIC	MATERIAL	PRICE	COMMENTS
Window	BaF_2	$ 6,000.00	
Field Flattener	BaF_2	$ 22,000.00	
Collimator 1	BaF_2	$ 35,000.00	
Collimator 2	Fused Silica	$ 22,000.00	IR grade Fused Silica
Collimator 3	BaF_2	$ 33,000.00	
Camera 1	ZnSe	$ 38,000.00	6 months for material
Camera 2	Fused Silica	$ 22,000.00	IR grade Fused Silica
Camera 3	BaF_2	$ 25,000.00	

Table 3: Approximate quotation of the optics used in this design

Operating Temperature (77 K) vs. Room Temperature (20 °C)

Thermal contraction can alter an optical design considerably. Zemax has the ability to analyze the performance of a design given the temperature and pressure. There are two cases of interest: the Operating Condition and the Static Condition. The case of the Static Condition has been described and tabulated in the earlier sections. Optically, one is interested to understand how an optical design changes during the Operating Conditions. What aberrations are introduced from thermal contractions of the optics? This information can be ascertained by examining the Seidel and wavefront coefficients.

Due to the large size of the optics, it will be necessary to slowly cool the optics to prevent large temperature gradients within the materials that can cause stresses and possible fractures. Although a mechanical design has not been performed, IR Labs has experience with mounting and cooling large optics.

In order to best focus the camera as a function of wavelength, the detector and fanout board can be mounted on a Z-axis translation stage. Any chromatic focal shift can be eliminated by a small movement of the stage.

Summary

The optical design uses a collimating triplet and three lens reimaging camera optics. This allows a space between the two sets of optics to place filters, other optical elements (i.e. grisms, beamsplitters, polarizers, etc.), and the Fabry-Perot etalon that do not affect the optical quality. Additionally, it creates a well-defined Lyot stop to baffle all unwanted radiation. During the camera's initial use with a 1024^2 HAWAII 1 array, baffles can be placed throughout the optics path, although they are not necessary. The Lyot stop remains a fixed size for both detectors and consequently will baffle out all non-sequential off-axis rays.

The 0.38:1 camera compromises aberrations at full field. During this feasibility optical design study, the camera optics were not optimized and an analysis of the optical performance at the image plane was not done. However, it can be generalized that diffraction limited performance can be achieved on axis with increasing field curvature toward the corners of the array. Considering the large field and broad spectral band, image quality can be maintained over 80 percent of the field.

One of the requirements for the design is the ability to move a Fabry-Perot etalon in and out of the collimated beam space. Given the detector size and field specs, the beam will vignette as it passes through the etalon. The overall result is an approximate 20 percent loss in intensity.

Finally, due to the size of the optics, availability of satisfactory optical blanks may play a role in the leadtime. Typically, multiple blanks are purchased in the event that the optician must remake the optic. This will, of course, drive up the cost.