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TECHNICAL REPORT

Active and Passive Temperature Compensation for the ESI Camera

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§1 INTRODUCTION

This technical report describes various active and passive methods of thermal compensation for the ESI camera. Changes in temperature during operation of the ESI camera will, if uncompensated, cause unacceptable changes in both the focus and plate scale of the instrument. Three different methods of thermal compensation are proposed.

The effects taken into account were change of refractive index of all of the optical materials, and the coefficient of thermal expansion (CTE) of all of the optical materials and the cell material. The thermal changes were computed from 2.0 degrees C to 5.0 degrees C. The cell was made completely from Aluminum, with an assumed CTE of 24.0 ppm/C. The multiplets were referenced to the cell at the edge of the front (prism-side) of the multiplet, and the remaining elements were held forward by springs.

The camera was raytraced by using the imaging pupil of the camera, apodized appropriately for the Keck telescope. Motion of the collimator was simulated by using a converging or diverging beam. The position of the focus was found by finding the best focus for 10 colors over the entire field, and then averaging over wavelength. The plate scale was found by using the centroids of 10 field positions at a wavelength of 0.5 microns.

§2 RESULTS

Table 1 shows the results of all of the effects considered. The column 'Axial Image Defocus' is the motion axially along the camera that the detector must move in order to restore the best focus. The column 'Lateral Image Motion' is the motion radially along the chip for the centroid of a spot at the corner of the CCD detector. The first line describes the full model of the camera, with all of the effects included. The second line includes only the thermal effects of the change in indices of refraction. The third line is the complete model, but with the Aluminum cell replaced with Invar, a material with a virtually zero CTE. The second and third lines are included only to show the comparative sizes of the various effects.

The fourth line shows the effect of moving the collimator through a distance of 0.05 inches. The remaining lines show the effects of adding an extra 0.001 inches to any of the 4 air gaps in the camera.

Table 2 shows what happens when a single adjustment is made to thermally compensate the camera. Either the focus was corrected, or the plate scale. The 'Motion' columns are the distance per degree C through which the adjustment must move to correct the thermal effect in question. For the air gaps, this distance is in addition to the thermal expansion of the Aluminum cell. For each air-gap, a gap size for a spacer was assumed, and this value was used to derive a CTE required to give the required motion, assuming a single material is used across the entire gap. The CTE values assume that the previous Aluminum spacer is replaced with a new material with the given CTE. The 'Lateral' column was the image motion resulting from the change in plate scale after the focus was corrected, and the 'Axial' column was the resulting change in focus when the plate scale was corrected.

Table 3 shows what happens when two adjustments are used simultaneously. The 'CTE' column uses the gap sizes given in Table 2.

§3 CONCLUSIONS

Inspection of the Tables reveals that there are three viable options for thermal compensation:

1) passive compensation of the triplet-triplet air gap for focus. This method requires a 'low' CTE spacer of only 176.1 ppm/C, which would be relatively simple to design and manufacture. The maximum image motion due to change in plate scale would be 0.18 pixels per C, better than most astronomical instruments.

2) passive compensation of the triplet-triplet air gap and active compensation of the collimator. This method requires a 'moderate' CTE spacer of 358.7 ppm/C, which might not be much more difficult to design and manufacture than the previous spacer. Both the focus and plate scale would be completely compensated, but the the

temperature would have to be continually monitored, and the collimator controlled to compensate.

3) passive compensation of both the triplet-triplet air gap and the doublet-singlet air gap. This method requires a 'low' CTE spacer of 212.3 ppm/C, and a 'high' CTE spacer of -1013.6 ppm/C. This high-CTE spacer could be made from a sandwich of, for example, Invar and Delrin, and the resulting spacer would have to fit into the cell without vignetting. Both the focus and plate scale would be completely compensated, with no active control required.

The analysis given here assumed that the entire camera was in thermal equilibrium, which would almost never be true following a change in ambient temperature. Since the basic premise of the thermal compensation schemes given here is incorrect, the final choice of compensation scheme should not be over-engineered to correct thermal effects to a much higher degree than the accuracy of the analysis, or to a higher degree than would be noticed by most users. Secondly, the more complex spacers are more likely to be out of thermal equilibrium with the rest of the camera, and are thus might make the thermal effects worse. With these caveats in mind, the first scheme, with a single spacer, would be the most simple, most reliable to implement, and most likely to perform adequately.

Thermal Changes in the ESI Camera		
Perturbation	Axial Image Defocus	Lateral Image Motion
	[μ]	[μ]
Indices + Aluminum Cell + CTE's / C	13.0457	-4.8581
Indices Only / C	14.4548	-4.5474
Indices + Invar Cell + CTE's / C	18.9162	-5.6732
Collimator Focus / 0.05"	23.0506	0.0119
Doublet-Singlet Gap / 0.001"	-0.3994	-0.2736
Singlet-Triplet Gap / 0.001"	-10.8252	1.3167
Triplet-Triplet Gap / 0.001"	-21.4452	3.6228
Triplet-Dewar Window Gap / 0.001"	-27.9609	3.5886

Table 1

Thermal Correction with a Single Adjustment							
Adjustment	Gap Size	Focus Correction			Scale Correction		
		Motion	CTE	Lateral	Motion	CTE	Axial
	[inches]	[inches/C]	[ppm/C]	[μ/C]	[inches/C]	[ppm/C]	[μ/C]
Doublet-Singlet	7.5	0.03266	4379.10	-13.7948	-0.01776	-2343.50	20.1375
Singlet-Triplet	3.0	0.00121	425.71	-3.2713	0.00369	1253.87	-26.8950
Triplet-Triplet	4.0	0.00061	176.08	-2.6543	0.00134	359.24	-15.7119
Triplet-Window	0.5	0.00047	957.14	-3.1838	0.00135	2731.52	-24.8066
Collimator		-0.02830		-4.8648	20.41218		9423.3079

Table 2

Thermal Correction with Two Adjustments					
First Adjustment			Second Adjustment		
	Motion	CTE		Motion	CTE
	[inches/C]	[ppm/C]		[inches/C]	[ppm/C]
Triplet-Triplet	0.00134	358.69	Collimator	0.03398	
Triplet-Triplet	0.00075	212.32	Doublet-Singlet	-0.00778	-1013.61
Triplet-Triplet	0.00323	830.25	Singlet-Triplet	-0.00518	-1703.92
Triplet-Triplet	0.00366	938.41	Triplet-Window	-0.00234	-4653.44
Collimator	-0.04371		Doublet-Singlet	-0.01779	-2348.57
Collimator	0.05809		Singlet-Triplet	0.00368	1250.37
Collimator	0.05359		Triplet-Window	0.00135	2724.41
Doublet-Singlet	-0.01015	-1329.82	Singlet-Triplet	0.00158	550.58
Doublet-Singlet	-0.00980	-1282.72	Triplet-Window	0.00061	1237.12
Singlet-Triplet	-0.04383	-14584.97	Triplet-Window	0.01743	34892.75

Table 3