NIRCam thermal subsystem

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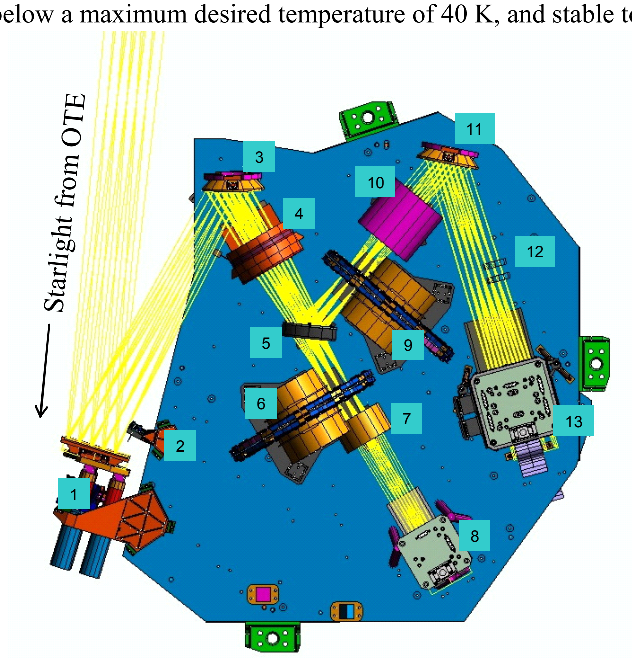
ABSTRACT

The Near Infrared Camera (NIRCam) instrument for NASA's James Webb Space Telescope (JWST) is one of the four science instruments to be installed into the Integrated Science Instrument Module (ISIM) on JWST. NIRCam's requirements include operation at 37 Kelvin to produce high resolution images in two wave bands encompassing the range from 0.6 microns to 5 microns. In addition, NIRCam is to be used as a metrology instrument during the JWST observatory commissioning on orbit, during the precise alignment of the observatory's multiple-segment primary mirror. This paper will describe the NIRCam Thermal subsystem design for stable operation at 37 Kelvin.

Keywords: NIRCam, Thermal, Cryogenic

1. INTRODUCTION

The NIRCam instrument is located in 2 thermal regions on JWST, Region 1 and Region 2. Region 1, operating between 32 and 37K, contains the heart of the NIRCam instrument – an approximately 1 meter x 1 meter optical bench containing the optics, detectors, mechanisms, and calibration sources (see Figure 1). The NIRCam instrument is mounted in an ISIM enclosure with the three other JWST science instruments. Region 2, operating between 273 and 313 K, contains the electronics needed to operate the instrument. Between Region 1 and Region 2 is a network of 4 to 6 meter length cables, designed to be as thermally & electrically resistive as operationally possible. NIRCam's Region 1 temperature, attained through the JWST thermal design, thermally straps the optical bench to a large passive radiator. The radiator is designed to accommodate a maximum heatload from NIRCam of 165.5 mW, one of NIRCam's key thermal requirements, to include heat dissipation from the mechanisms, calibration sources, focal planes, as well as parasitic heat leaks from the cables from Region 2. Another thermal challenge for NIRCam is to maintain the focal planes below a maximum desired temperature of 40 K, and stable to 0.1 K over an integration period of 4,000 seconds.



1	Pick-Off Mirror Assembly
2	Coronagraph
3	First Fold Mirror
4	Collimator Lens Group
5	Dichroic Beamsplitter
6	Long Wave Filter Wheel Assembly
7	Long Wave Camera Lens Group
8	Long Wave Focal Plane Housing
9	Short Wave Filter Wheel Assembly
10	Short Wave Camera Lens Group
11	Short Wave Fold Mirror
12	Pupil Imaging Lens
13	Short Wave Focal Plane Housing
14	ICE Interface Panel
15	FPE Interface Panel

Figure 1: NIRCam Instrument in Region 1

2. METHODOLOGY

The Region 1 NIRCam thermal math model was created using IDEAS/TMG, and is depicted in Figure 2. The model contains a total of about 29,000 elements, 12,000 of which are the NIRCam Region 1 instrument hardware and 17,000 of which are the instrument control electronics (ICE) and the focal plane electronics (FPE) cables. The thermal model is used to calculate the long-term average heat load flowing through the thermal interface to the radiator, to predict the impact on the detector stability due to mechanism operations and thermal interface instability, and to perform thermal analyses on heater sizing, surface treatments, and other system level design trades.

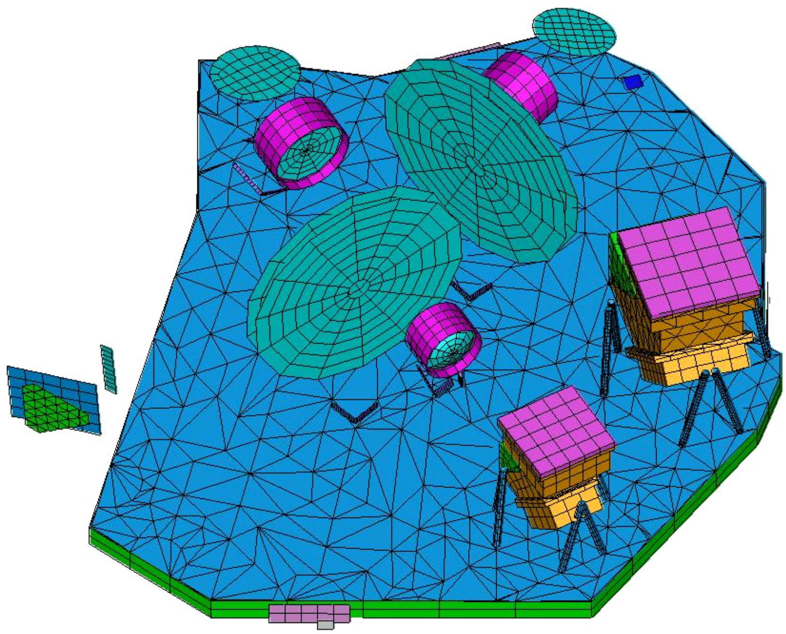


Figure 2: NIRCam Region 1 Thermal Model

3. DATA

The NIRCam long-term average thermal heat load in Region 1 is a combination of operational thermal dissipation from mechanisms, calibration sources, heaters, and detectors as well as from parasitic heat leaks from the cables coming from the room temperature electronics. Operational thermal dissipation in Region 1 is listed in Table 1. The cable definition and the parasitic heat leak into Region 1 are listed in Table 2.

The JWST-provided thermal strap interface to the radiator and ISIM radiative enclosure are boundary requirements provided to us in the NIRCam Instrument Specification. The thermal strap interface is defined in the thermal model as a boundary, between 32 and 37K, with a short-term maximum temperature variation of 0.5K over 10,000 seconds, and long-term temperature variation of 1K over 24 hours. The radiative enclosure is also set as a boundary, between 32K and 40K, with an emissivity of 0.7.

					FLIGHT AVG		FLIGHT MAX	
Assembly	Component	Peak Power (mW), PER item at 35K	Average Duty Cycle	Calculated Power, mW	Average Power per Bench, mW	Contin-gency, %	Predicted Power per Bench, mW Per Item	Per S/S
FPA	SCAs (1 LW/4 SW)	3.4	100%	3.4	17.0	25	21.3	27.4
	SW FP Heater	2.7	100%	2.7	2.7	25	3.3	
	LW FP Heater	2.2	100%	2.2	2.2	25	2.8	
FWA	Filter Wheel Motor	35.8	0.4%	0.1	0.3	50	0.4	0.5
	Pupil Wheel Motor	35.8	0.1%	0.0	0.1	50	0.1	
FAM	FAM Actuator	20	16 sec ON/month	0.0	0.0	50	0.0	0.0
PIL	LAT	TBD	3010 sec ON/month	0.3	0.3	100	0.5	0.5
Calibration	Coronagraph Source	650	300 sec ON/year	0.0	0.0	50	0.0	1.7
	Flatfield Source	625	2400 sec ON/month	0.6	1.1	50	1.7	
Instrumentation	Temp Sensors	0.01	100%	0.0	0.378	50	0.567	0.6
				TOTAL PER Bench	24.0		30.7	
				TOTAL Both Benches	48.1		61.4	

Table 1: NIRCam Region 1 thermal dissipation

Cable	Assembly	Component	Peak Current (mA), PER item	Average Duty Cycle	Material	AWG	Parasitic heatleak PER bench calculated (mW)	Contingency, %	Parasitic heatleak Per Item	Per S/S
FPE	FPA	SCAs (1 LW/4 SW)	0.2	100%	Manganin	36	2.0	50	3.0	8.3
		SCA Shielding	0	0%	Aluminum		1.9	50	2.9	
		SW FP Heater	2	100%	Manganin	26	0.5	50	0.7	
		SW FP Heater Shielding	0	0%	Aluminum		0.2	50	0.3	
		LW FP Heater	2	100%	Manganin	26	0.5	50	0.7	
		LW FP Heater Shielding	0	0%	Aluminum		0.2	50	0.3	
		SW Cernox sensors	0.07	100%	Manganin	36	0.2	50	0.2	
		LW Cernox sensors	0.07	100%	Manganin	36	0.2	50	0.2	
ICE	FWA	Filter Wheel Motors	127	0.4046%	Phosphor-Bronze	25	4.2	50	6.3	13.4
		Pupil Wheel Motors	127	0.1306 %	Phosphor-Bronze	27	2.5	50	3.8	
		Filter Wheel Inductive Sensors	2	0.4046%	Stainless		0.9	50	1.3	
		Pupil Wheel Inductive Sensors	2	0.1306 %	Stainless		0.8	50	1.2	
		FWA Shielding	0	0	Aluminum		0.5	50	0.7	
	FAM	FAM Actuators	200	16 sec ON/month	Manganin	26	2.0	50	3.0	3.7
		FAM Inductive Sensors	2	16 sec ON/month	Stainless		0.3	50	0.4	
		FAM Shielding	0	0	Aluminum		0.2	50	0.2	
	PIL	LAT	120	3010 sec ON/month	Phosphor-Bronze	21	3.3	100	6.6	7.3
		Inductive Sensors	2	3010 sec ON/month	Stainless		0.2	100	0.4	
		PIL Shielding	0	0	Aluminum		0.1	100	0.2	
	Calibration	Coronagraph Source	130	300 sec ON/year	Manganin	22	1.6	50	2.4	5.1
		Flatfield Source	125	2400 sec ON/month	Manganin	22	1.6	50	2.4	
		Cal Shielding	0	0	Aluminum		0.1	50	0.2	
	Instrumentation	Temperature Sensors	0.01	100%	Manganin	36	0.5	50	0.7	0.9
		Temp Sensor Shielding	0	0%	Aluminum		0.2	50	0.2	
					TOTAL PER Bench		24.5		38.6	
					TOTAL Both Benches		49.0		77.1	

Table 2: NIRCam Region 1 parasitic heatleak from cables

4. RESULTS

The total long-term average heat load for NIRCam is listed in Table 3, and is the sum of Tables 1 & 2. These results show that we are maintaining the heat load below our allocation with 27mW of margin. Contingency values are used to reflect the maturity of the design at this phase in the program, with the Predicted value being what we would expect the final design to use.

			Basic Estimate, mW	Contin-gency, %	Predicted, mW
IN	FPA	FPA SCAs	34.0	25	**42.5**
		FPA heater	9.8	25	**12.2**
		FPE Cable	11.0	50	**16.5**
	FWA	FWA	0.7	50	**1.1**
		FWA Cable	17.8	50	**26.8**
	FAM	FAM	0.0	50	**0.0**
		FAM Cable	4.9	50	**7.3**
	PIL	PIL	0.5	100	**1.0**
		PIL Cable	7.3	100	**14.5**
	Calibration	Sources	2.3	50	**3.5**
		Cable	6.8	50	**10.1**
	Instrument	Temp Sensors	0.8	50	**1.1**
		Temp Sensors Cable	1.2	50	**1.9**
OUT	**ISIM**		97.0		**138.5**
				REQ	**165.3**
				MARGIN	**26.8**

Table 3: NIRCam Region 1 long-term average heatload

The average steady state temperature distribution across NIRCam is shown in Figures 3 & 4. This reflects a thermal strap interface boundary temperature of 35K, and a radiative enclosure of 35K. Figure 3 shows the full NIRCam optical assembly, with the maximum temperature of 37.59 K located at the short-wave detector. A profile of the optical bench only in Figure 4 shows the very uniform temperature distribution of within 70mK of the thermal interface temperature. The maximum steady state temperature distribution was also run in a separate analysis, with the resulting maximum detector temperature at 39.9K.

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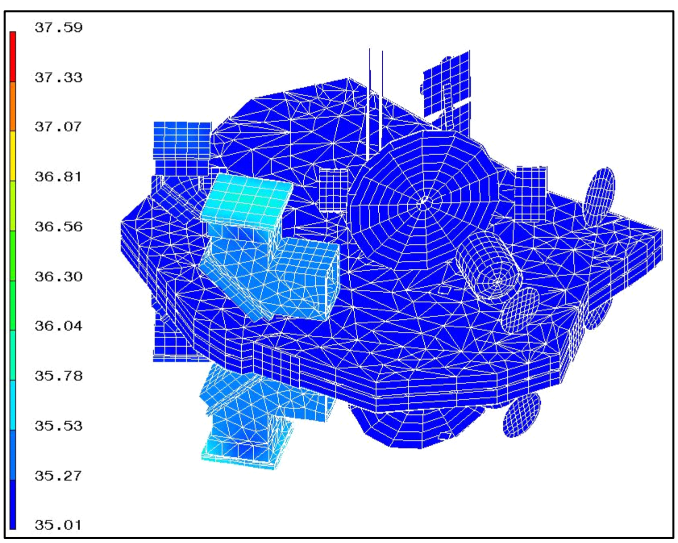

Figure 3: Steady state temperature profile of the optical assembly

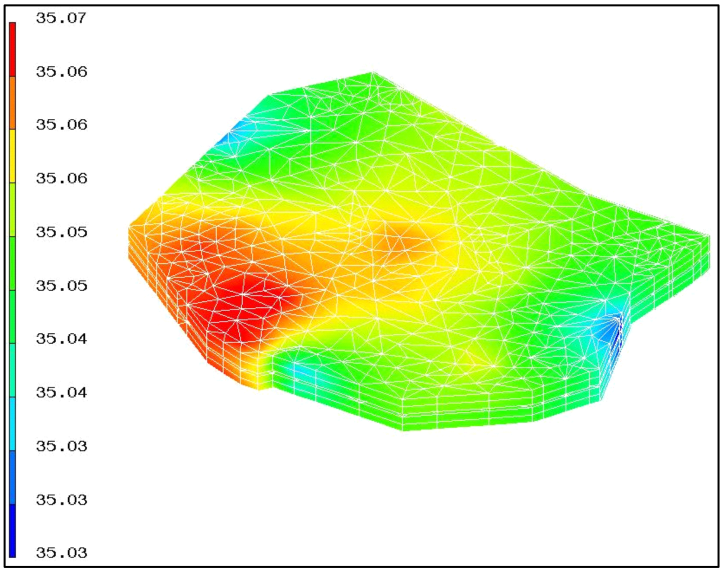

Figure 4: Steady state temperature profile of the optical bench only

The impact to the detector stability due to mechanism operations is shown in Figures 5, 6 & 7. Figure 5 shows the temperature response of the filter wheel assembly and optical bench from an imposed maximum filter wheel operational duty cycle. The maximum change in temperature of the bench from these operations is 28mK over 4,000 seconds. The resulting rate of change on the SW detector is shown in Figure 6 and is 6.5mK over 4,000 seconds. The LW detector impact is shown in Figure 7, and is 8.9mK over 4,000 seconds. These temperature variations are well within our stability requirement of 100mK over 4,000 seconds.

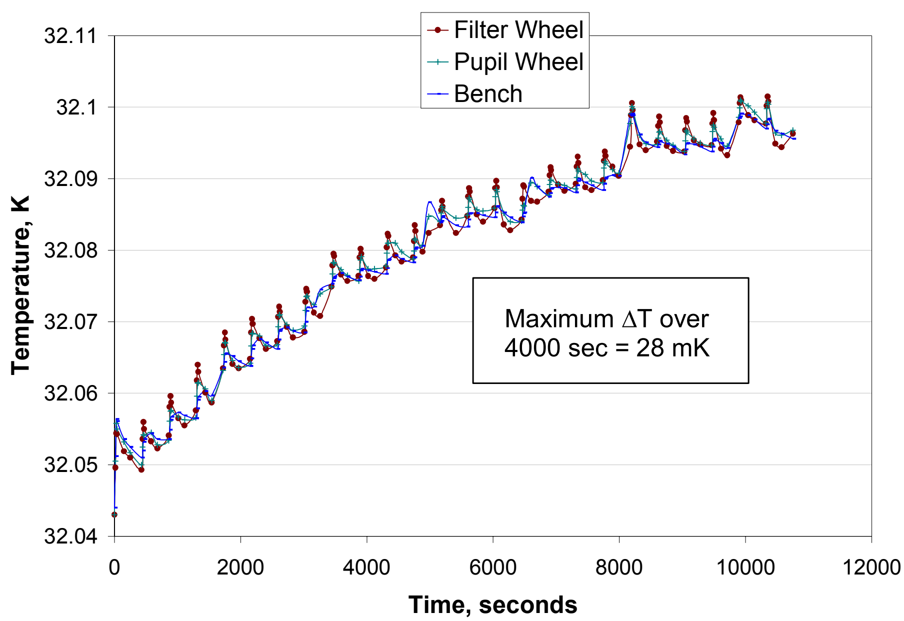

Figure 5: Temperature response of filter wheels and optical bench from maximum operational frequency

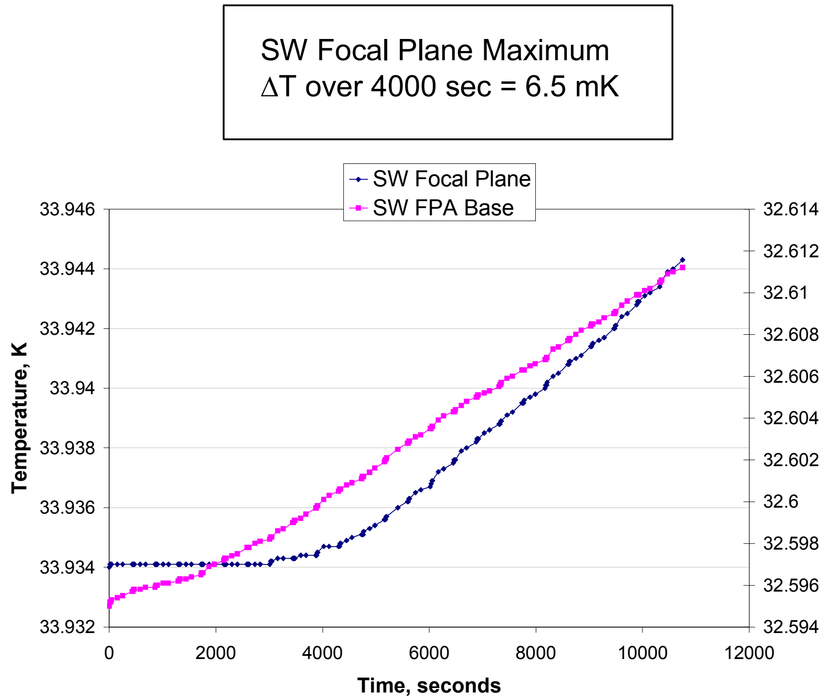

Figure 6: Temperature response of SW detector from mechanism operation

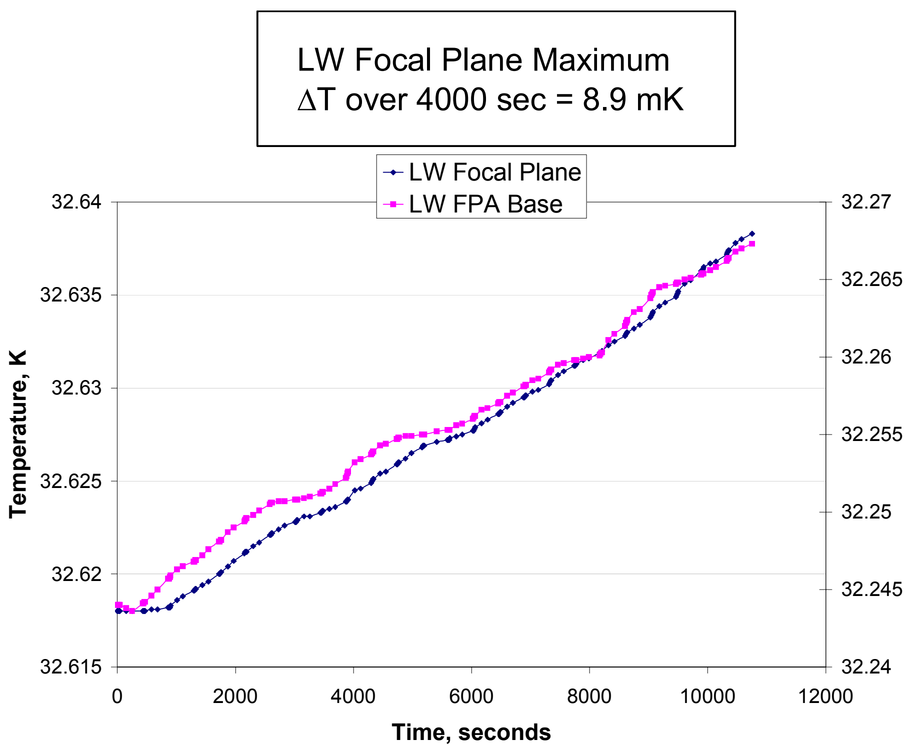

Figure 7: Temperature response of LW detector from mechanism operation

Imposing a maximum thermal strap interface temperature change of 0.5K over 10,000 seconds impacts the detector more than the mechanism operations, as shown in Figures 8 & 9. The resulting SW detector temperature change is 87K over 4,000 seconds, and the resulting LW detector temperature change is 140mK over 4,000 seconds. Although the LW detector rate of change exceeds the 100mK over 4,000 seconds maximum requirement, these results are encouraging, since they do not include the effect of having a thermal control heater installed on the detector mount plate. The heater control would mitigate this impact.

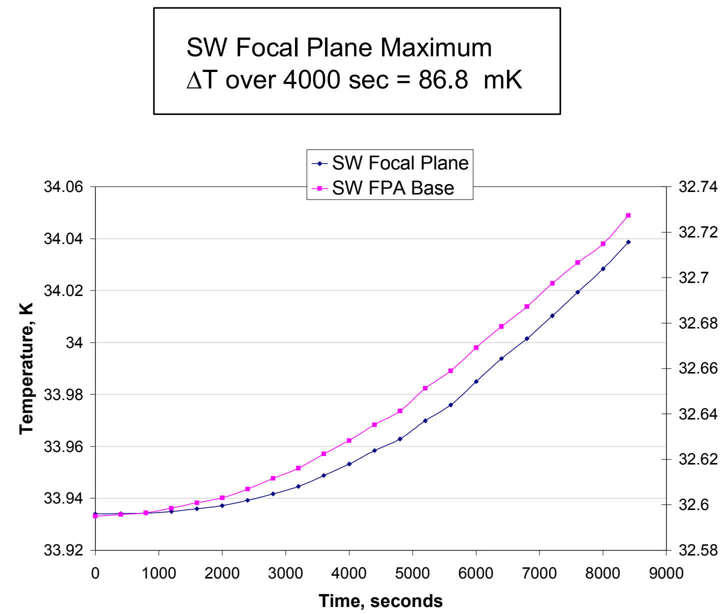

Figure 8: SW detector impact from thermal strap interface temperature change

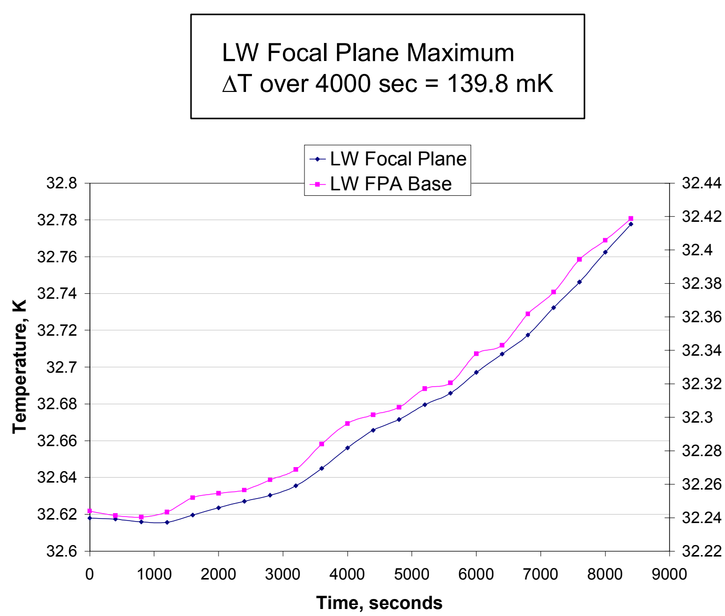

Figure 9: LW detector impact from thermal strap interface temperature change

5. CONCLUSIONS

The NIRCam Region 1 thermal design is well established. The three major thermal requirements, Region 1 long-term average heat load, maximum detector temperature, and maximum allowable detector instability, have been discussed. The results show that the design complies with all of the thermal requirements.

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