MEMORANDUM
To: Dan Fabricant
From: Warren Brown
Date: 23 May 2002
Subject: Binospec Thermal Analysis III: Baseline Model Results

1. INTRODUCTION

This is the third in a series of memos concluding the Binospec thermal analysis: this memo presents the results of the general Binospec model. The construction of the Binospec model is described in the "Description of the Thermal Model" memo. Here, I present the results for "baseline" parameters, and describe how the results vary for different conditions. Results for the collimator and camera optics are detailed in the Optics memo.

2. BASELINE BINOSPEC MODEL

The baseline Binospec model assumes 1) 3 inch thick urethane foam surrounding Binospec, 2) an exterior convection coefficient of $h = 18$ W m^{-2} K^{-1}, 3) an interior convection coefficient $h = 2$ W m^{-2} K^{-1} (for still air in an enclosed space), and 4) no active motors. The baseline Binospec model uses "typical" MMT dome temperatures (which have $\pm 3^\circ$ C variations over 24 hour periods) for its boundary condition.

2.1. Heat Exchange

The temperatures in the Binospec model come from heat transfer calculations, and so I begin by summarizing the overall heat exchange of the baseline model with the environment. Because the average heat exchange with the environment must be zero, I present the *peak* heat flowing into or out of the spectrograph in Table 1. The peak heat exchange with the environment occurs on a daily cycle.

TABLE 1
Peak Binospec $\leftrightarrow$ Environment Heat Exchange

Component	Q (Watts)
Bottom insulation	4
Side insulation	12
Top insulation and window	6
Mounting flange struts	8
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Total:	30

When I use the "extreme" MMT dome temperatures (that have ±10° C variations over 8 hour periods) as the boundary condition, the peak heat exchange doubles.

2.2. Temperature Gradients

A primary goal of the heat transfer analysis is to understand the temperature gradients in Binospec. Temperature gradients lead to bending and poor optical performance; the Optics memo looks in detail at temperature gradients in the collimator and camera optics. Here I review the temperature differences found in the baseline Binospec model. Table 2 summarizes the results for "typical" MMT temperatures.

What is important to note in Figures 1 through 5 is the *range* of temperature gradients. The exact shape of the curves is unimportant; the shapes results from the MMT dome temperatures I chose as the boundary condition. In the following paragraphs I summarize the range of temperature gradients for the baseline Binospec model.

The **optical bench** experiences ±0.075° C axial and ±0.4° C radial temperature gradients, shown in Figures 1 and 2. The axial gradient is induced in part by the ±0.5° temperature difference between the **air** above and below the optical bench (Figure 1). Approximately 0.1°, or 25%, of the radial gradient is caused by conduction from the telescope via the **mounting flange struts** which vary ±0.75° with respect to the optical bench (Figure 2). The remainder of the radial gradient is caused by conduction through the **foam insulation**; Figure 3 shows ±3.5° temperature differences between the spectrograph and environment.

Figure 4 shows ±0.3° C temperature differences between the fold mirror and the **fold mirror structure**, which in turn has ±0.05° C temperature differences with respect to the inner support plate it attached to. Flexures conductively insulate the fold mirrors throughout Binospec; convective heat flow is twice as large as conduction on the fold mirrors.

TABLE 2
Temperature Gradients: Baseline Binospec Model

Objects	ΔT (±° C)
Environment – Spectrograph	3.5
Mounting Struts – Optical Bench	0.75
Optical Bench: edge – center	0.4
Optical Bench: top – bottom	0.075
Air: above – below Optical Bench	0.5
Fold Mirror – Fold Mirror Structure	0.3
Fold Mirror Structure – Inner Support Plate	0.05
Inner Support Plate – Support Ring	0.06
Camera Base – Optical Bench	0.2
Entrance Window – Surrounding Insulation	0.5

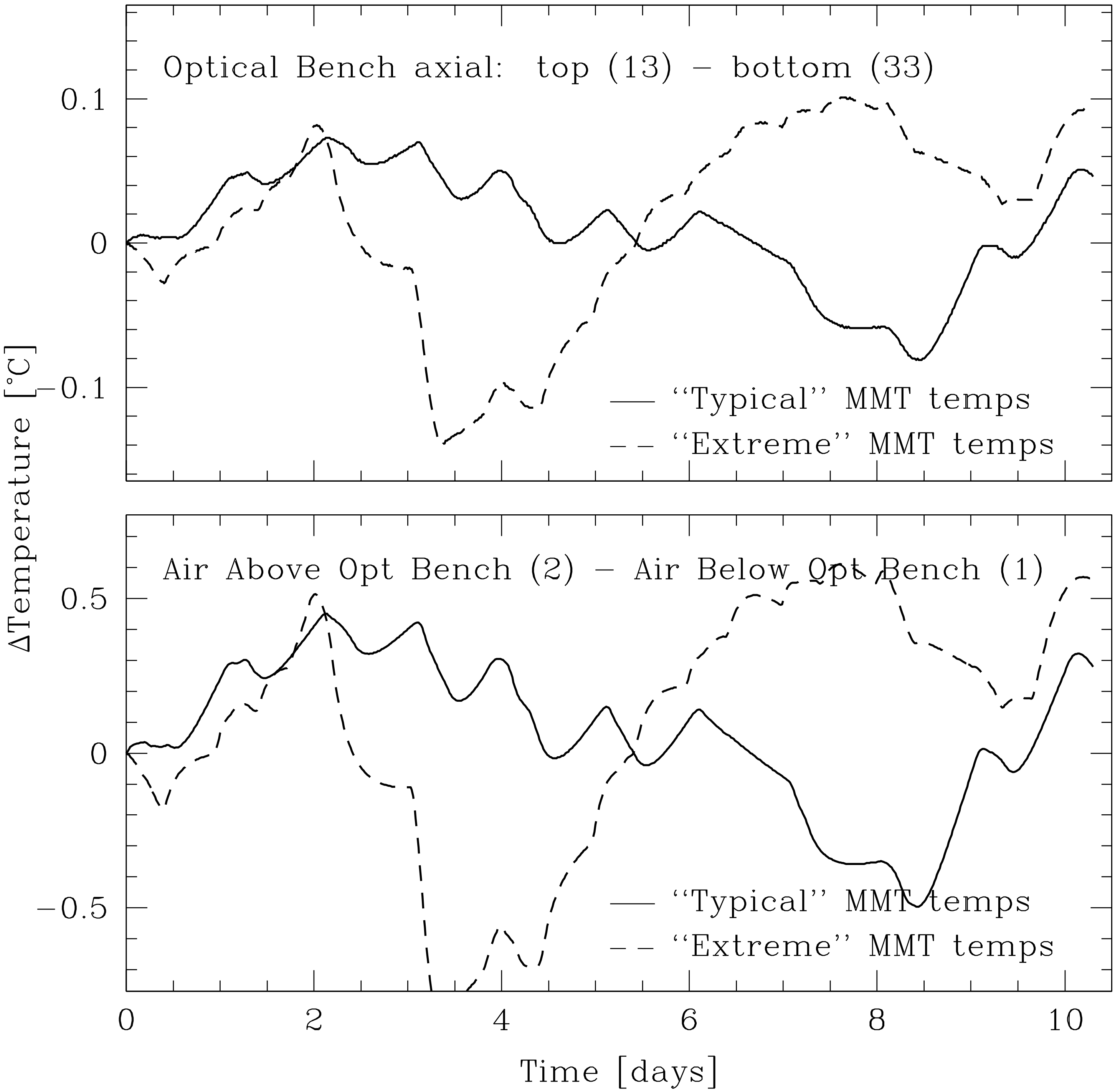

Fig. 1.— Temperature gradients.

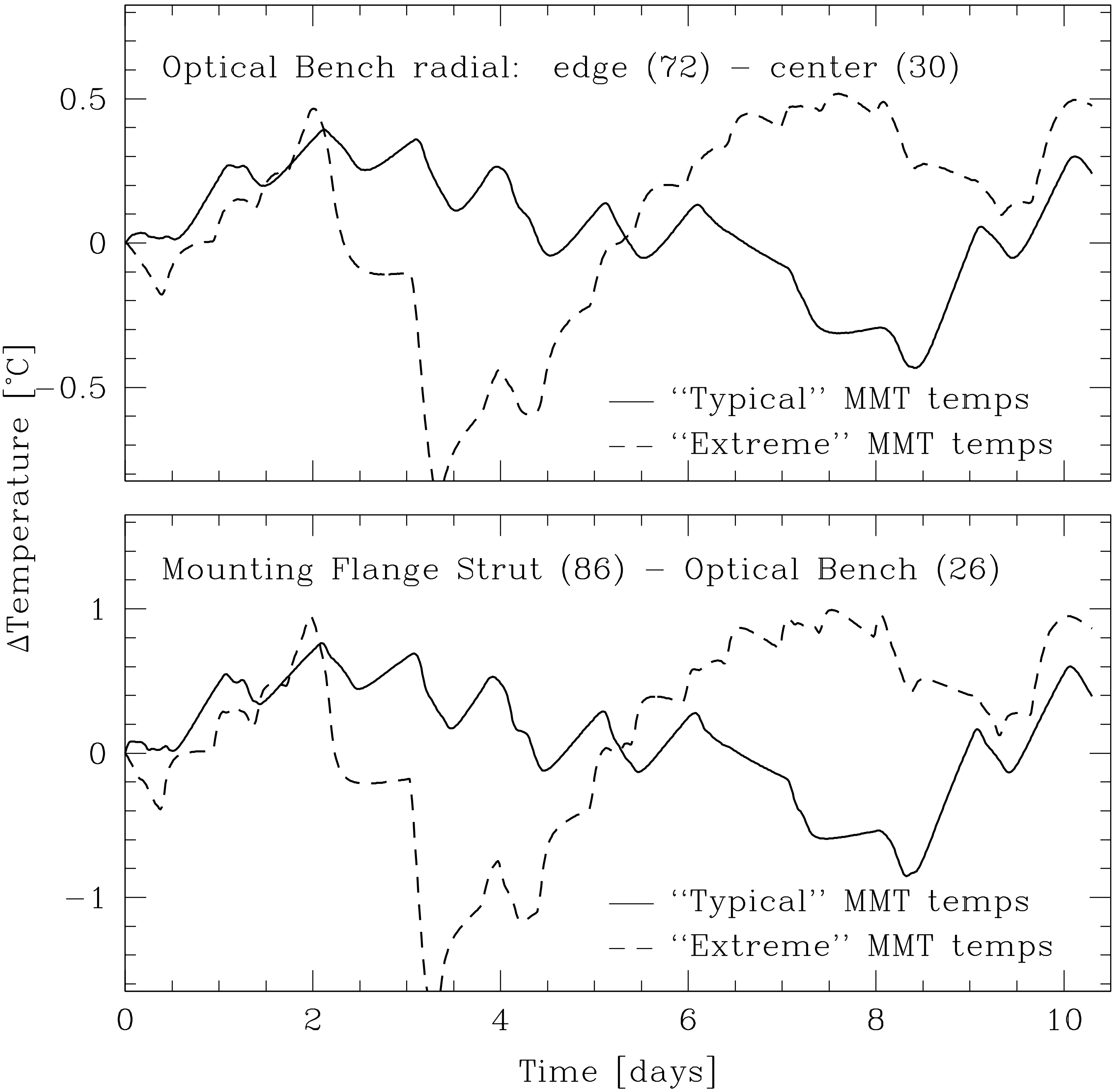

Fig. 2.— Temperature gradients.

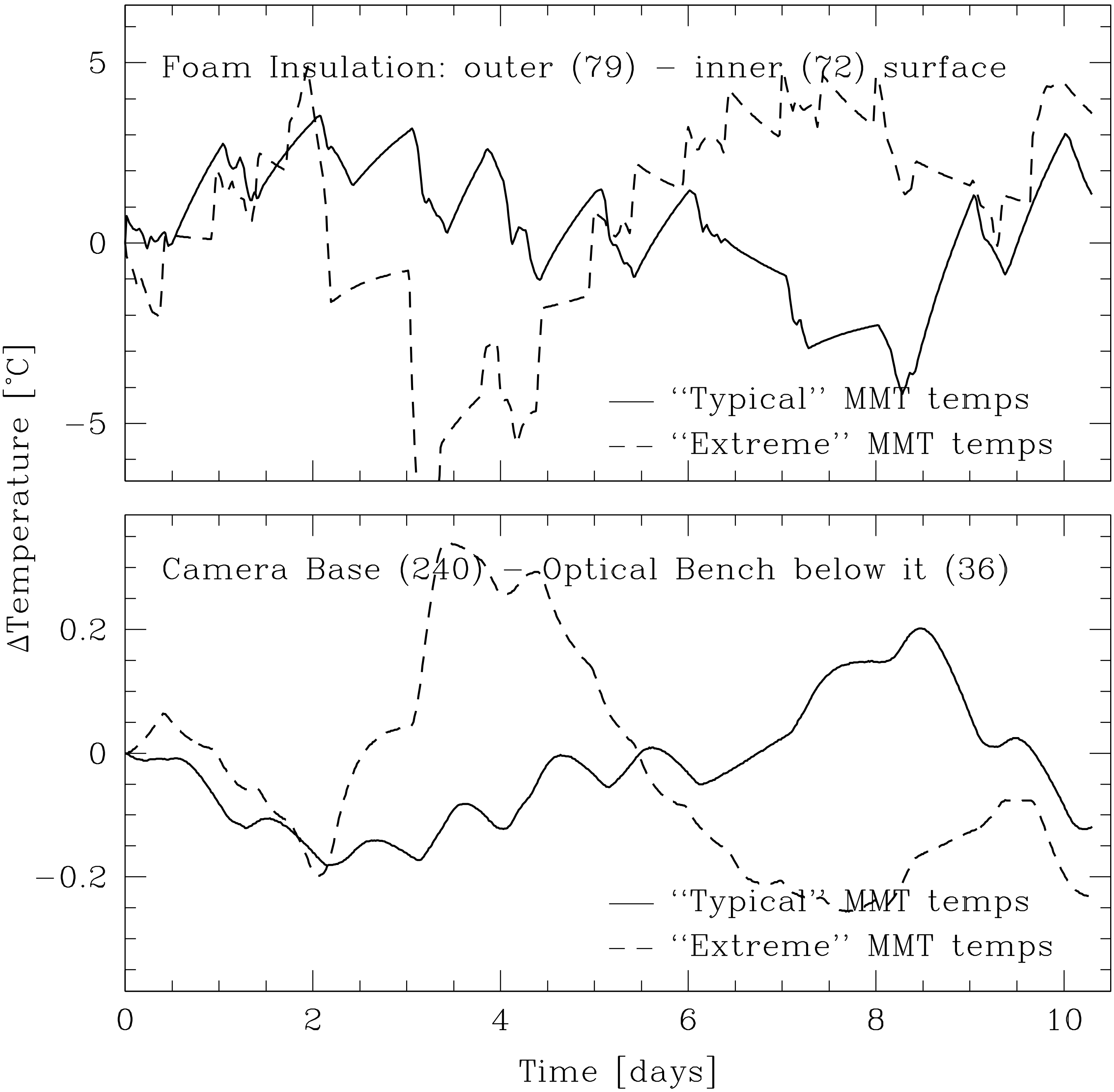

Fig. 3.— Temperature gradients.

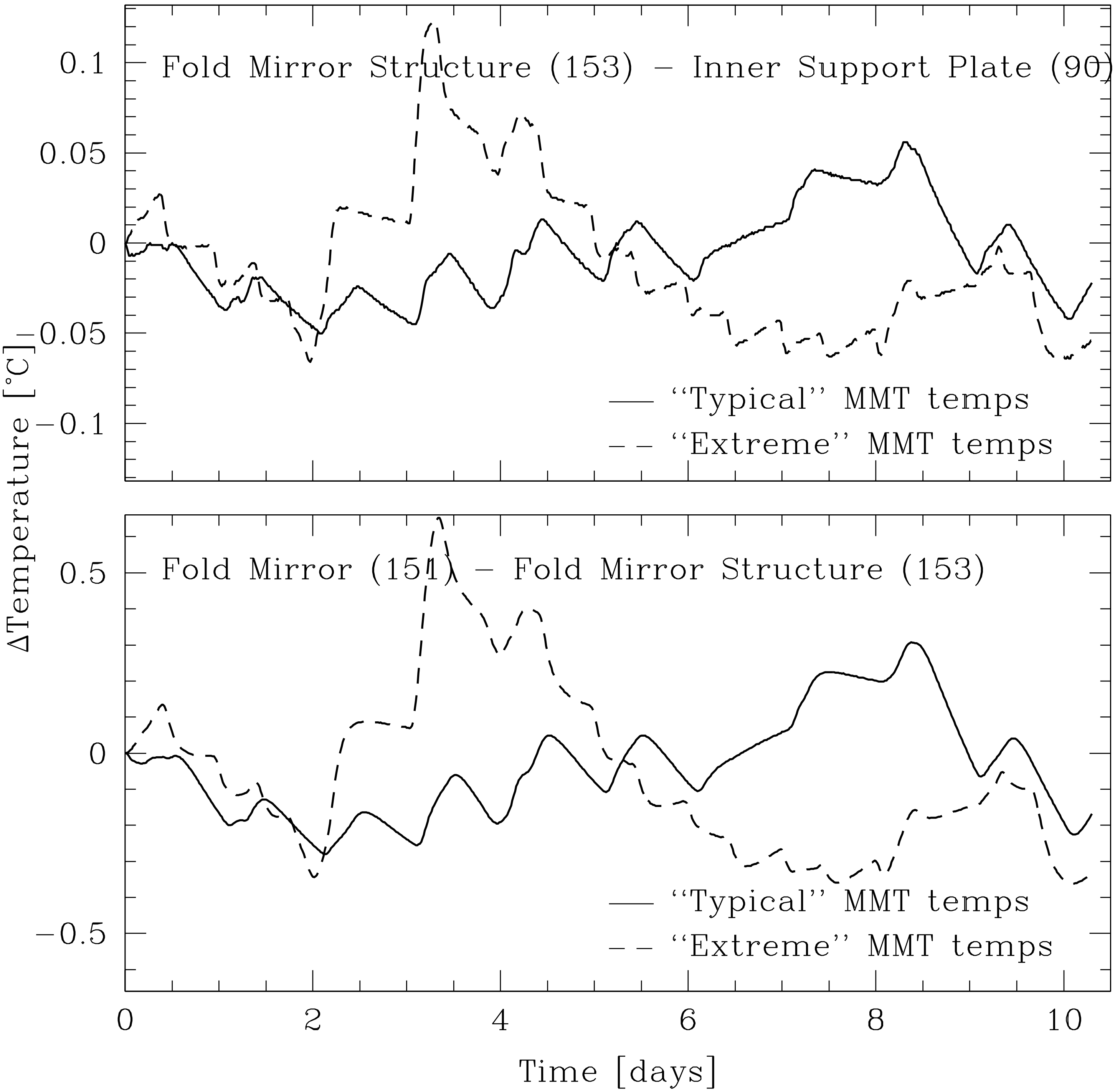

Fig. 4.— Temperature gradients.

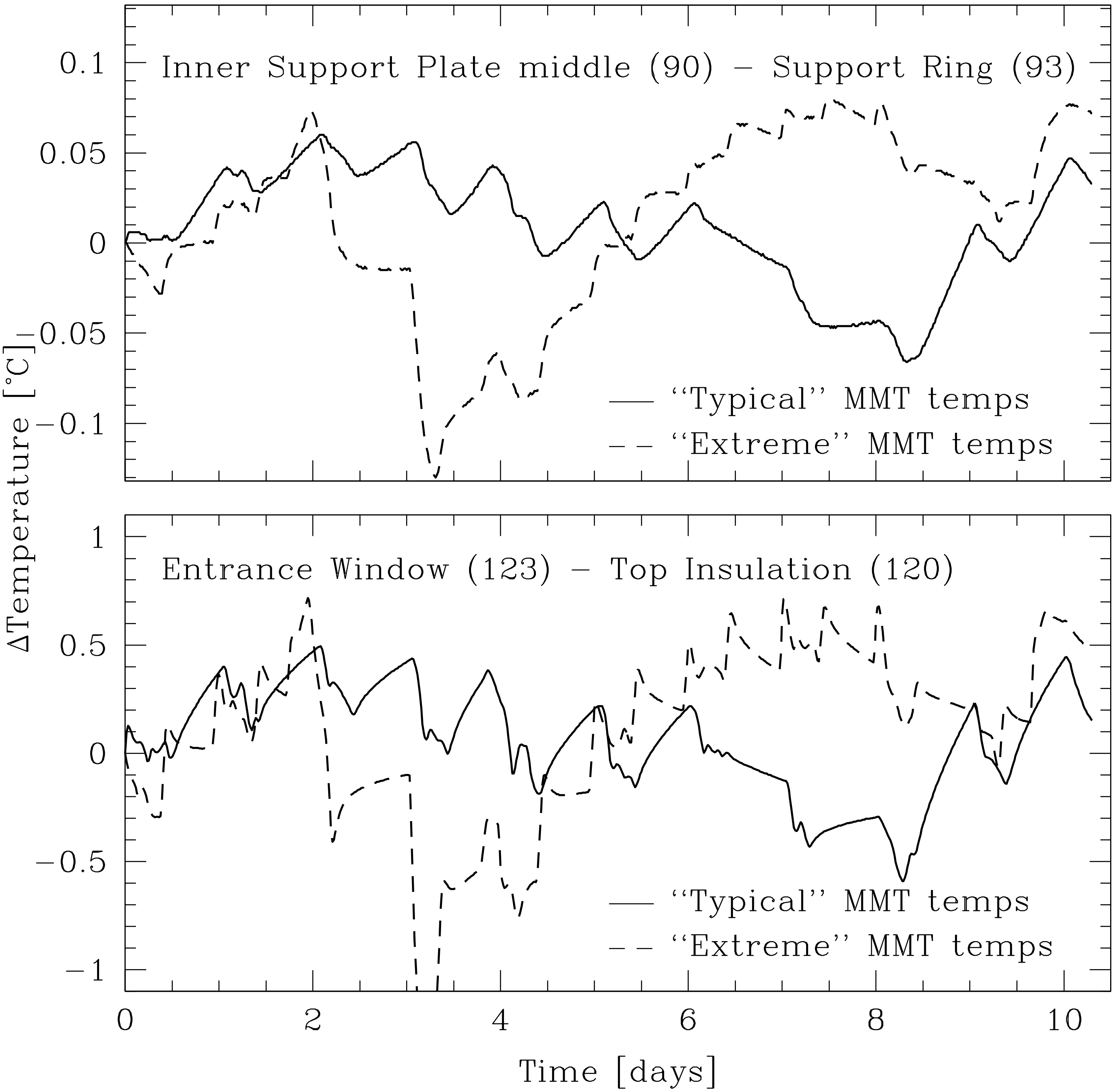

Fig. 5.— Temperature gradients.

The **inner support plate** has $\pm 0.06°$ C temperature differences with respect to the support ring it rests on (Figure 5). Other components that may bow due to temperature differences include the camera base, which has $\pm 0.2°$ temperature differences with the optical bench (Figure 3), and the entrance window, which has $\pm 0.5°$ temperature differences with the surrounding insulation (Figure 5).

2.3. Time Constants

Table 3 lists the e-folding time constants associated with the temperature gradients in Table 2. The time constants are calculated by starting Binospec at a uniform temperature 10°C above the environment and finding how long it takes each node to equilibrate. Where adjacent nodes have different time constants, such as the edge, mid-section, and center of the optical bench, temperature gradients will arise.

TABLE 3
Time Constants: Baseline Binospec Model

Object (node)	τ (hours)
Insulation, bottom (70)	34
Entrance window (125)	19
Mounting flange strut (86)	27
Air, below optical bench (1)	37
Air, above optical bench (2)	31
Air, above inner support plate (3)	28
Optical Bench edge (42)	35
Optical Bench mid-section (33)	37
Optical Bench center (30)	39
Inner support plate (90)	30
Inner support plate Support Ring (93)	31
Fold Mirror (151)	34
Fold Mirror Structure (153)	31
Collimator lens group 2 bezel (158)	43
Collimator lens group 3 bezel (161)	40
Grating (202)	53
Grating holder (201)	38
Grating turret (200)	37
Camera base (240)	40
Camera lens group 1 bezel (241)	46
Camera lens group 2 bezel (242)	50
Camera lens group 3 bezel (243)	41

3. MODEL VARIATIONS

This section outlines how the Binospec model results *change* for a given change to the baseline model. I summarize these results in a handy table.

Table 5 is categorized by whether temperature gradients are made worse, are unchanged, or made better. The worst case temperature gradients in the optics are listed for each case: ΔT_{lenses} the temperature difference between collimator lens group 1 and 2, $\Delta T_{radial\ lens}$ the radial temperature gradient in collimator lens group 2, and $\Delta T_{axial\ lens}$ the axial temperature gradient in camera lens group 3. The values of these optics temperature gradients should be compared to baseline values (0.6° C, 0.12° C, 0.08° C).

3.1. Operating Motors

Table 5 summarizes the effects of operating motors in Binospec. "Imaging mode" assumes a filter change every 5 minutes, while "spectrograph mode" assumes a grating and slit mask change every 1 hour. Typical heat exchange with the environment ranges 14 - 28 Watts; the motor heat flux averaged over time is 2.6 Watts in "imaging mode" and 0.3 Watts in "spectrograph mode." Thus temperature gradients caused by the motors are small compared to those caused by environmental changes. However, the motors heat up and affect Binospec locally. For example, collimator lens group 1 is heated by 0.04°C and the optical bench top is heated by 0.01°C in imaging mode.

Table 4 gives baseline model temperatures for motors operating in imaging and spectrograph mode.

Table 4
Motor temperatures — baseline Binospec model

Motor	$\Delta T_{imaging\ mode}$ (° C)	$\Delta T_{spectrograph\ mode}$ (° C)
Guide probe	0.2	
Slit mask rail	0.2	
Filter rail	2	
Filter housing	1.2	
Filter gripper	0.8	
Grating turret		0.04
Grating housing		0.03
Grating gripper		0.25
Camera focus	0.1	

TABLE 5

Variations on the Baseline Binospec Model

Change to Baseline Model	$(\Delta T_{lenses},\ \Delta T_{radial\ lens},\ \Delta T_{axial\ lens}) = (0.6°, 0.12°, 0.08°)$ Result
BAD CHANGES	
No entrance window	(1.0°, 0.2°, 0.12°)
	Temperature gradients in optics 67% greater
	Inner support plate has ±2.5° (5× greater) temperature swings with respect to the optical bench
	Optical bench axial gradient 0.15°, $\tau = 26$ hrs (30% faster)
"Extreme" MMT dome temperatures (±10° C variations during 8 hour periods)	(0.9°, 0.18°, 0.12°)
	Temperature gradients in optics 50% greater
	Optical bench has 0.75° radial, 0.13° axial gradients
Insulation foam 1 inch thick	(0.8°, 0.16°, 0.10°)
	Temperature gradients 30% greater
	Optical bench has ±1.2° greater temperature swings
Graphite epoxy conductivity 3× greater	(0.7°, 0.15°, 0.10°)
	Lens group gradients are 10% greater
	Optical bench ±0.1° axial and ±0.5° radial gradients are 25% greater than baseline case
	Heat flux from mounting flange increased by 3×
Change gratings (set gratings, holders, air +10°C)	(0.63°, 0.20°, 0.12°)
	Temperature gradients in optics are +0.10° larger
	Spectrograph heated ∼ 0.5°C
Change filters (set filters, air +10°C)	(0.72°, 0.14°, 0.09°)
	Collimator lens group 1 heated 0.15°C
	0.3° (200% increase) optical bench axial gradient
	Spectrograph heated ∼ 0.1°C
Change slit masks (set slit masks, air +10°C)	(0.66°, 0.12°, 0.08°)
	Collimator lens group 1 heated 0.06°C,
	Col lens group 1 axial gradient peaks 4-5 hrs after change
Motors in "imaging mode" (change filter every 5 minutes)	(0.6°, 0.12°, 0.08°)
	0.18° (10% greater) axial gradient, col lens group 1
	Filter rail motor heated ∼ 2°C
	Average 2.6 Watt heat flux
	Spectrograph heated by 0.1°C in 12 hours

Change to Baseline Model	Result
MIXED CHANGES	
Thermal stand-offs on filter motors (in imaging mode)	(0.6°, 0.12°, 0.08°) – no significant change Motors get $\sim 3\times$ hotter Filter rails are not significantly heated
Motors in “spectrograph mode” (change grating & slit mask every hour)	(0.6°, 0.12°, 0.08°) – no significant change Average 0.3 Watt heat flux
Decrease exterior convection coefficient to 6 (equivalent to a 5 mph air flow)	(0.6°, 0.12°, 0.08°) – no significant change
Increase interior convection coefficient to 6	(0.6°, 0.10°, 0.05°) Lens group gradients 10-30% smaller 0.1° (25% greater) optical bench axial gradient 0.3° (25% smaller) optical bench radial gradient
Add 2in spacers between insulation and optical bench	(0.6°, 0.12°, 0.08°) – no significant change Optical bench radial gradient 0.36° (10% smaller) Optical bench time constant longer
GOOD CHANGES	
Connect air above and below optical bench	(0.45°, 0.12°, 0.08°) 25% smaller col lens group 1 - 2 temp difference 0.04° (50% decrease) optical bench axial gradient
Stand-offs on graphite epoxy struts	(0.5°, 0.11°, 0.07°) Temperature gradients in optics 10% smaller Peak heat flux from mounting flange reduced by $4\times$ to 2 W; Struts account for $\sim 10\%$ heat exchange with environment
Remove camera barrel; add convection to lens group surfaces	(0.6°, 0.12°, 0.08°) 0.4° (20% decrease) camera lens group 2 - 3 temp difference

3.2. Changing Slit Masks

Changing the slit masks, filters, and gratings may potentially provide the greatest thermal shock to the spectrograph optics. I model a slit mask change by setting the slit masks and the air above the inner support plate a pessimistic 10°C above an otherwise uniform temperature Binospec. The basic results are summarized in Table 5; the Optics Memo describes the effect on the optics.

A slit mask change primarily affects collimator lens group 1, via heat flow through the inner support plate and fold mirror assembly. The inner support plate is heated by 0.3°C. The heat from the inner support plate radiates, convects, and conducts through the graphite epoxy struts to the optical bench with a time constant of $\sim$ 2 hours. The optical bench experiences a 0.05° axial gradient as the result of a slit mask change.

A filter change will heat the entire spectrograph by $\sim$ 0.1°C and immediately affect the optical bench and collimator lens 1. The optical bench experiences a 0.1° axial and 0.1° radial gradient with a time constant of $\sim$ 20 minutes. There is a 0.05° axial gradient in collimator lens group 1 also with a time constant of $\sim$ 20 minutes.

A grating change will heat the entire spectrograph by $\sim$ 0.5°C and dramatically affect the optics. The gratings are radiatively (and convectively) connected to collimator lens group 3 and camera lens group 1 and induce 0.1° axial gradients in them. Because of the longer $\sim$ 3 hour time constant of the grating change, the optical bench only experiences 0.03° axial and 0.05° radial gradients. The collimator lens group 1, however, has a peak radial gradient of 0.15° 4 hours after the grating change.