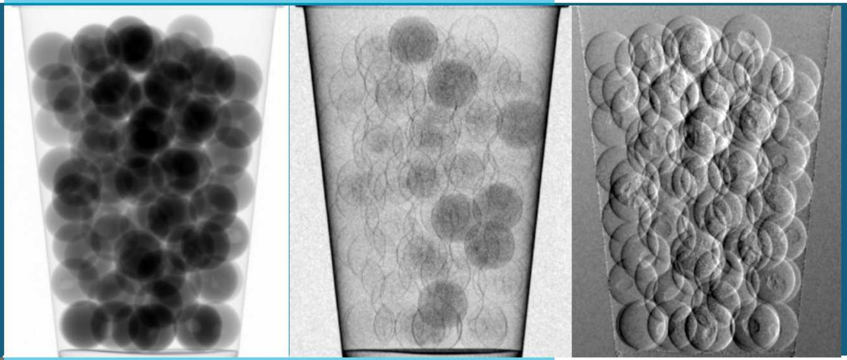
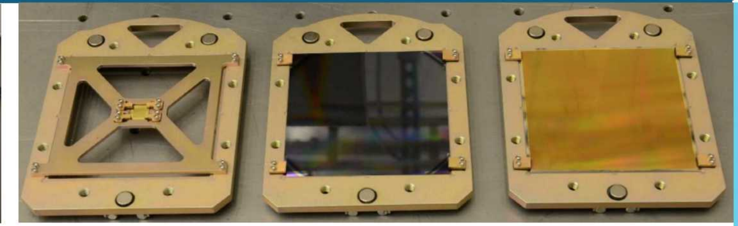
XNPIG 2019
Session VIII: Methods & Instrumentation V
Tuesday, October 22, 2019

SAND2019-12436C

The Effects of Thermal Expansion of Gratings in Talbot-Lau Lab-Based X-Ray Phase Contrast Imaging





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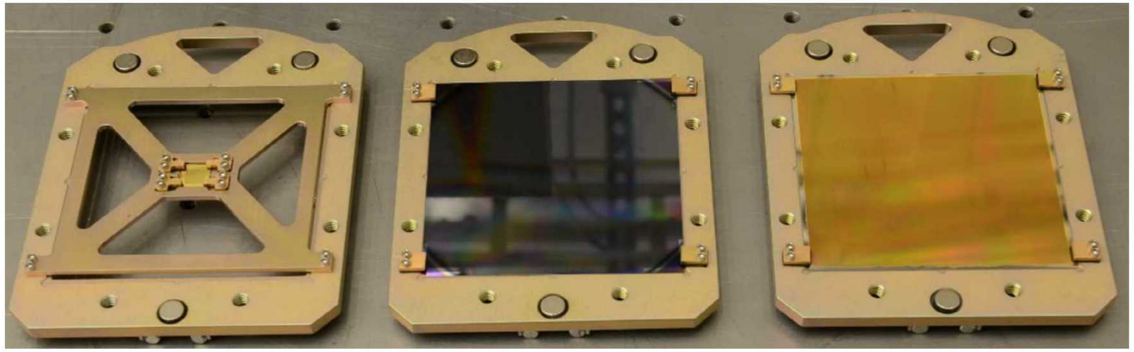
Hypothesis

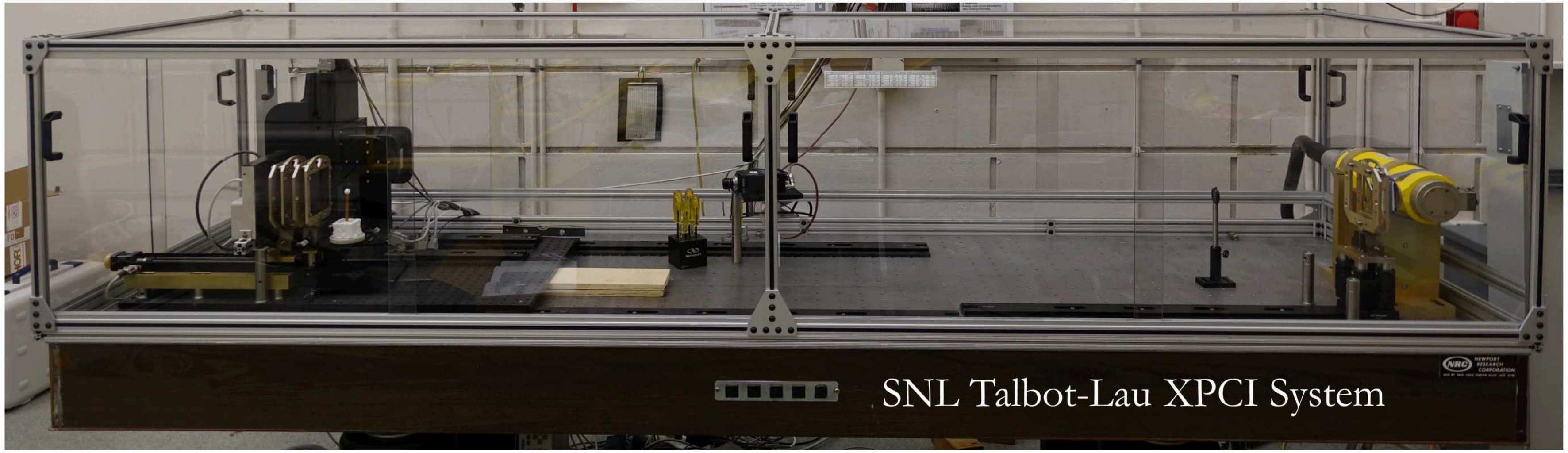
Grating-based XPCI systems can be tuned to, and operated at high-sensitivity to achieve high-contrast images. To do this requires quality system components and **control of the acquisition environment**.

Outline

1. **Overview of XPCI**
   a. Talbot-Lau Cone-Beam XPCI System Design
   b. Operating XPCI System at *High Sensitivity*
   c. Signal Model
2. **Thermal Expansion of Gratings**
   a. Sources of Heat
   b. Effect of Thermal Expansion on Signal Parameters
   c. Mitigation of Thermal Expansion
3. **Questions**



SNL large-area Talbot-Lau interferometer gratings



SNL Talbot-Lau XPCI System

Overview of XPCI

Talbot-Lau Cone-Beam XPCI System Design

1. A Talbot-Lau XPCI system[1,2] has three gratings: G_0, G_1, and G_2

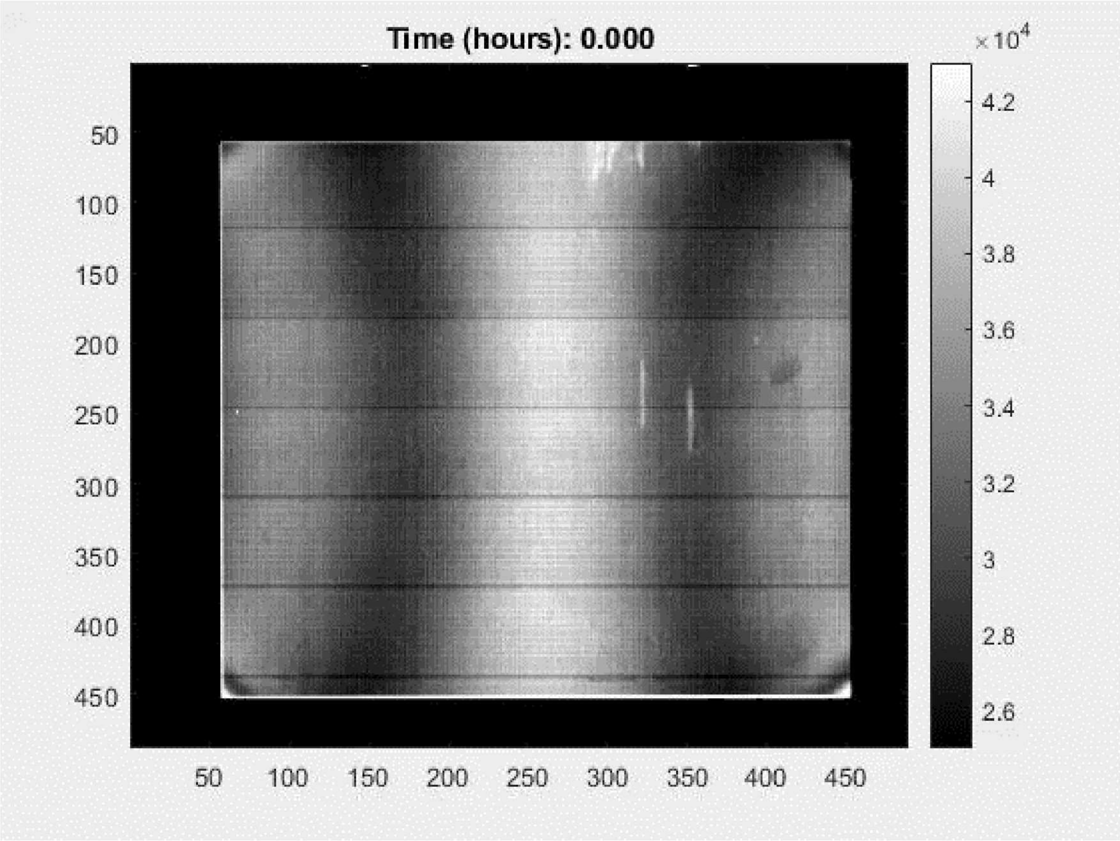
2. A ***High-sensitivity*** XPCI system has:
   - Matched set of gratings
   - Ideal *L* and *d* distances
   - Low fringe count
   - High Fringe Contrast/Visibility

3. Signal model for reference and sample data:[3-5]

$$f_M(x) = A_M \sin(\omega_M x(n) + \phi_M) + b_M, \quad \text{where } \omega = \frac{2\pi}{p_2}$$

Subscript *M* represents reference (R) and sample (S)

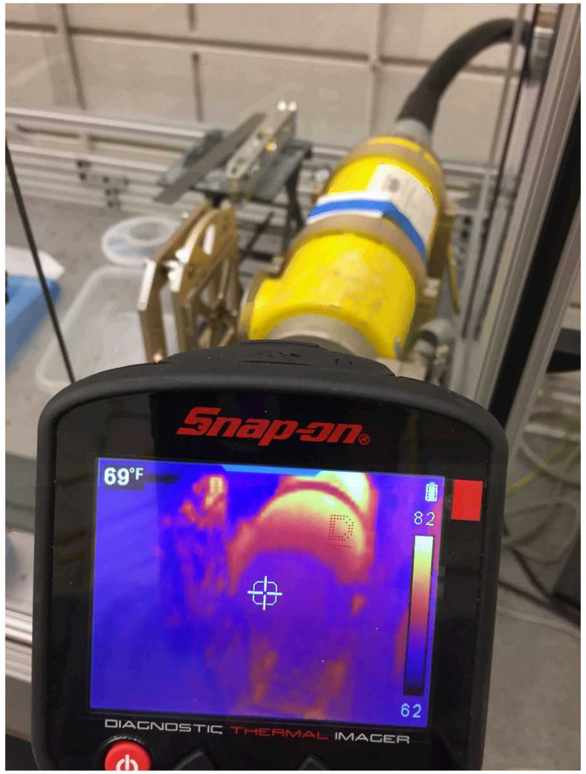
Video: Detector, no heat shield.

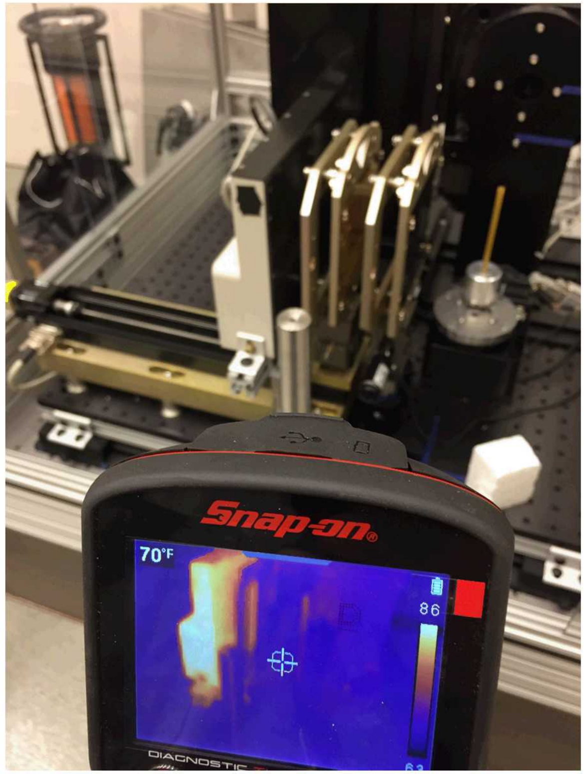


Thermal Expansion of Gratings

Temperature

1. Room temperature and heat from system electronics, such as the X-ray source and detector, can cause thermal expansion of the gratings
2. Thermal expansion changes the period and duty cycle of the gratings





Thermal Expansion of Gratings Effects the Moiré Frequency

1. The Moiré spatial frequency from a cone-beam XPCI system is related to the grating periods by,

$$f_{Moire} = \frac{p_0p_1 - 2p_0p_2 + p_1p_2}{p_1p_2(p_0+p_2)}.$$

2. Derivatives with respect to the grating periods are,

$$\frac{\partial f_{Moire}}{\partial p_0} = \frac{-2p_1p_2^3}{\left(p_1p_2(p_0+p_2)\right)^2},$$

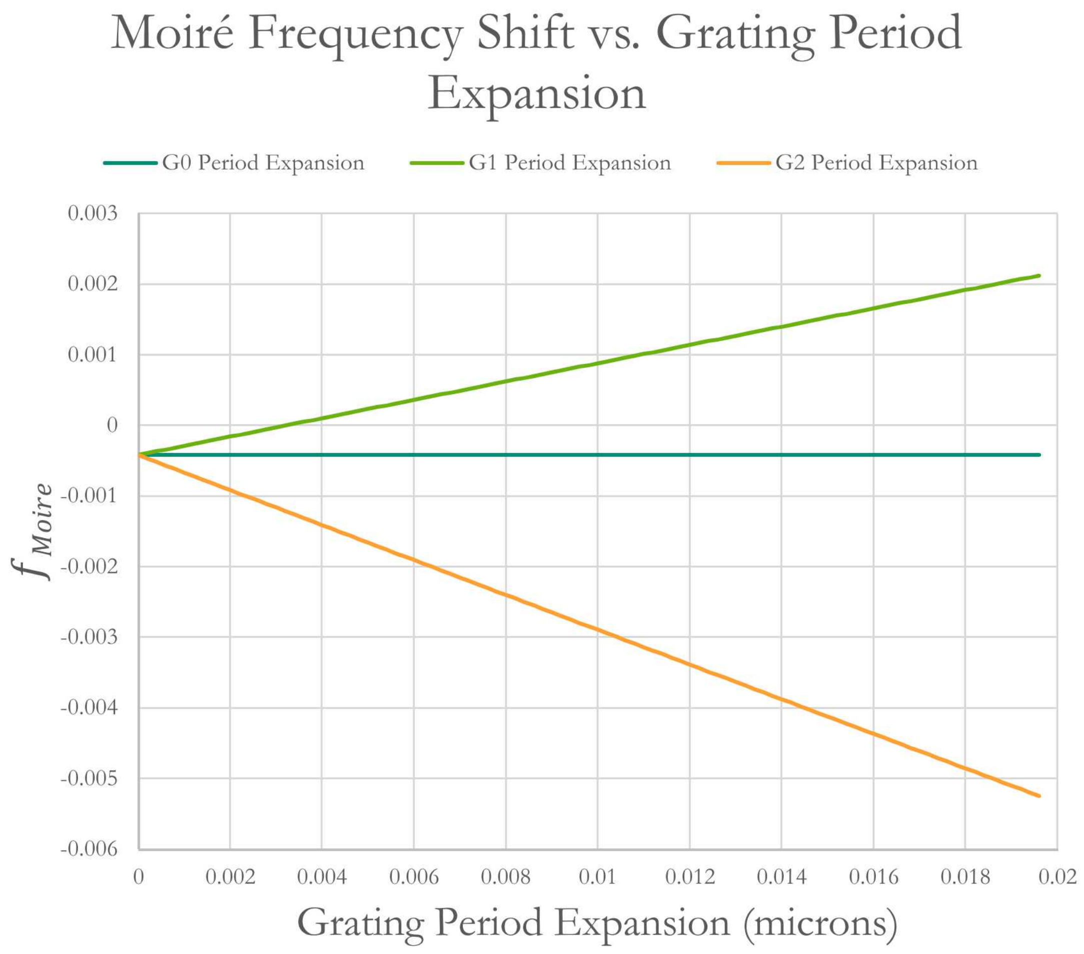
$$\frac{\partial f_{Moire}}{\partial p_1} = \frac{2p_0p_2^2(p_0+p_2)}{\left(p_1p_2(p_0+p_2)\right)^2},$$

$$\frac{\partial f_{Moire}}{\partial p_2} = \frac{-p_1^2(p_0+p_2)^2 + 2p_0p_1p_2^2}{\left(p_1p_2(p_0+p_2)\right)^2},$$

3. Thus, expansion of p_0 decreases the Moiré frequency while expansion of p_1 increases it.

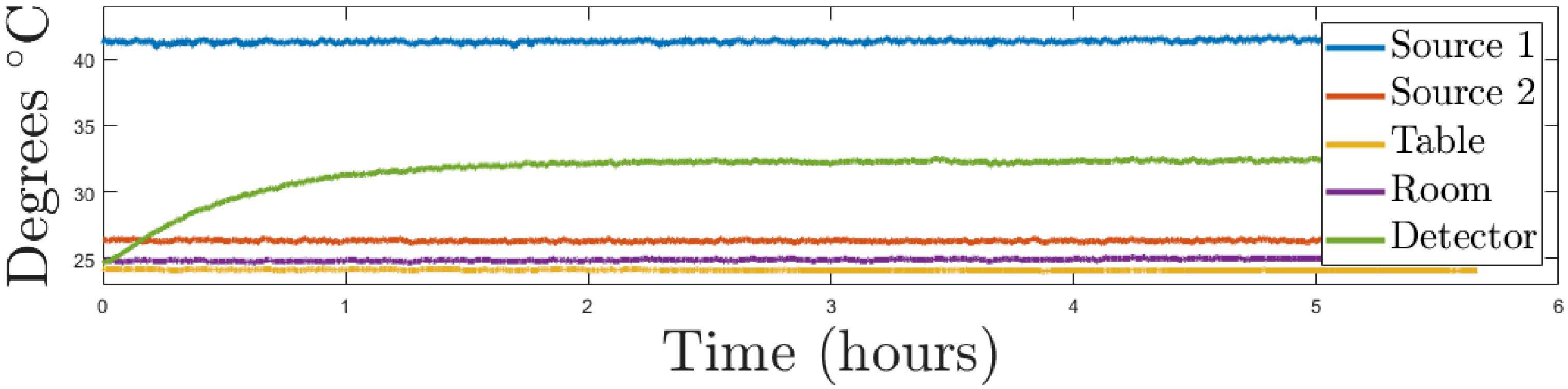
4. Expansion of p_2 is more complicated:

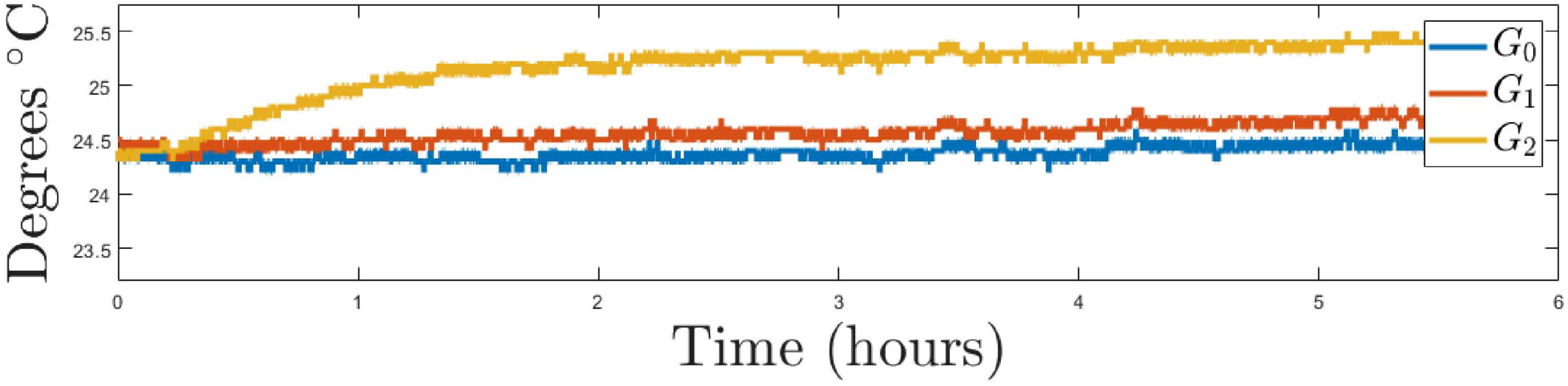
$$\frac{\partial f_{Moire}}{\partial p_2} < 0 \text{ if } \; p_1(p_0+p_2)^2 > 2p_0p_2^2$$



Thermal Measurements **Without** Heat Shield

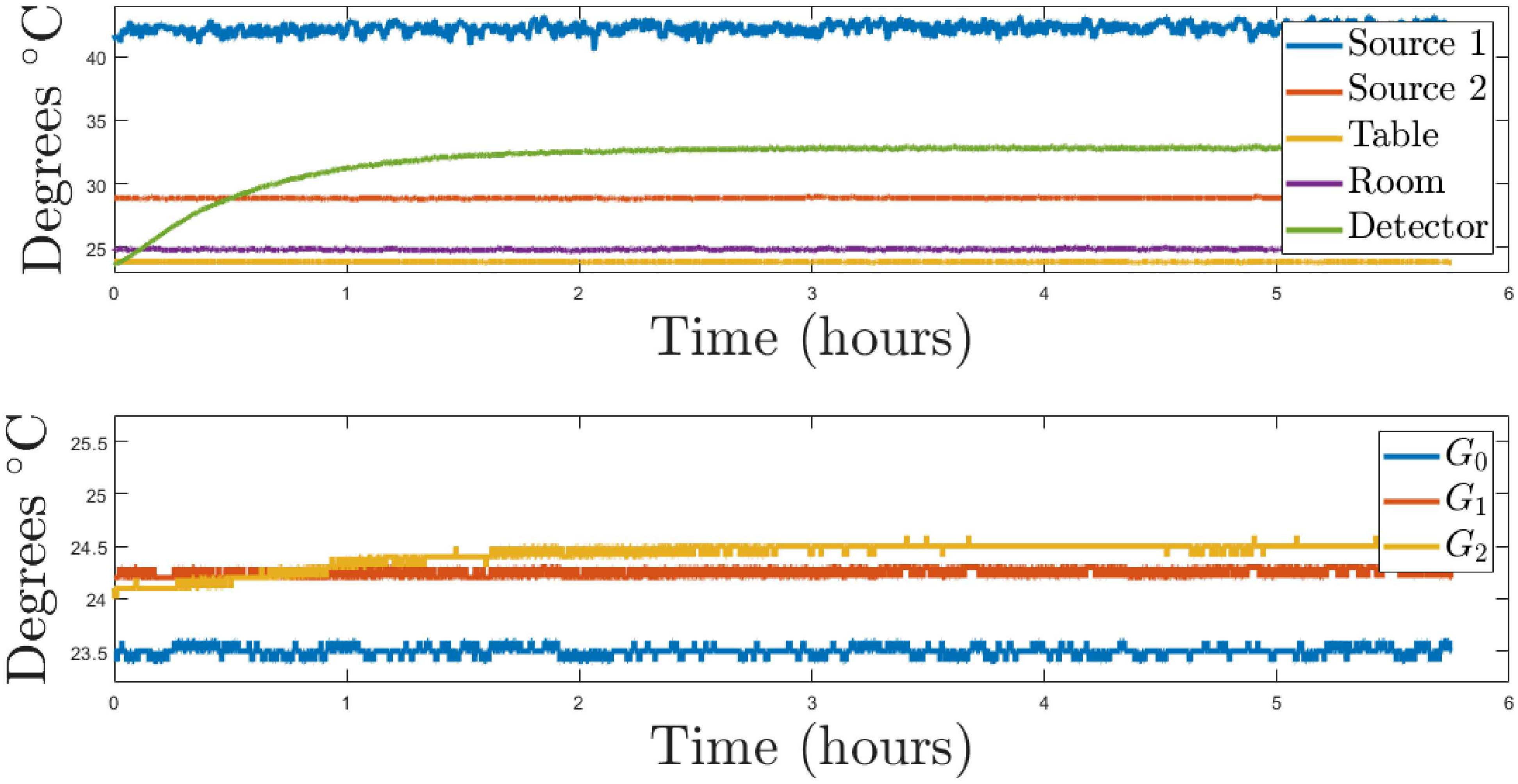
The source, G_0, room, and table are at thermal equilibrium before the detector is powered on. Powering the detector causes G_1 and G_2 to increase in temperature and also causes a slight temperature increase of G_0.





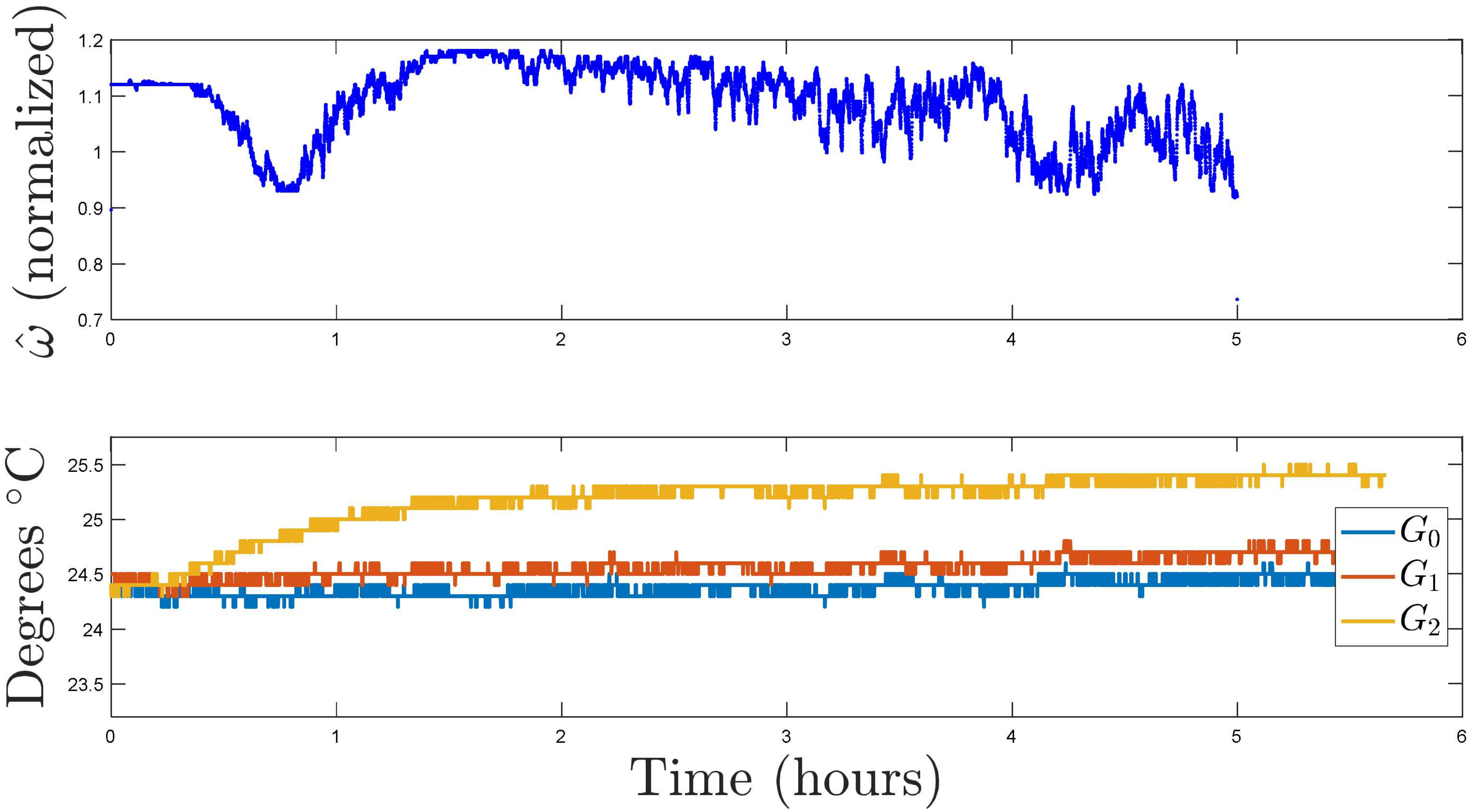
Thermal Measurements **With** Heat Shield

The source, G_0, room, and table are at thermal equilibrium before the detector is powered on. Powering the detector with the heat shield in place only causes a slight increase in the temperature of G_1 and G_2.



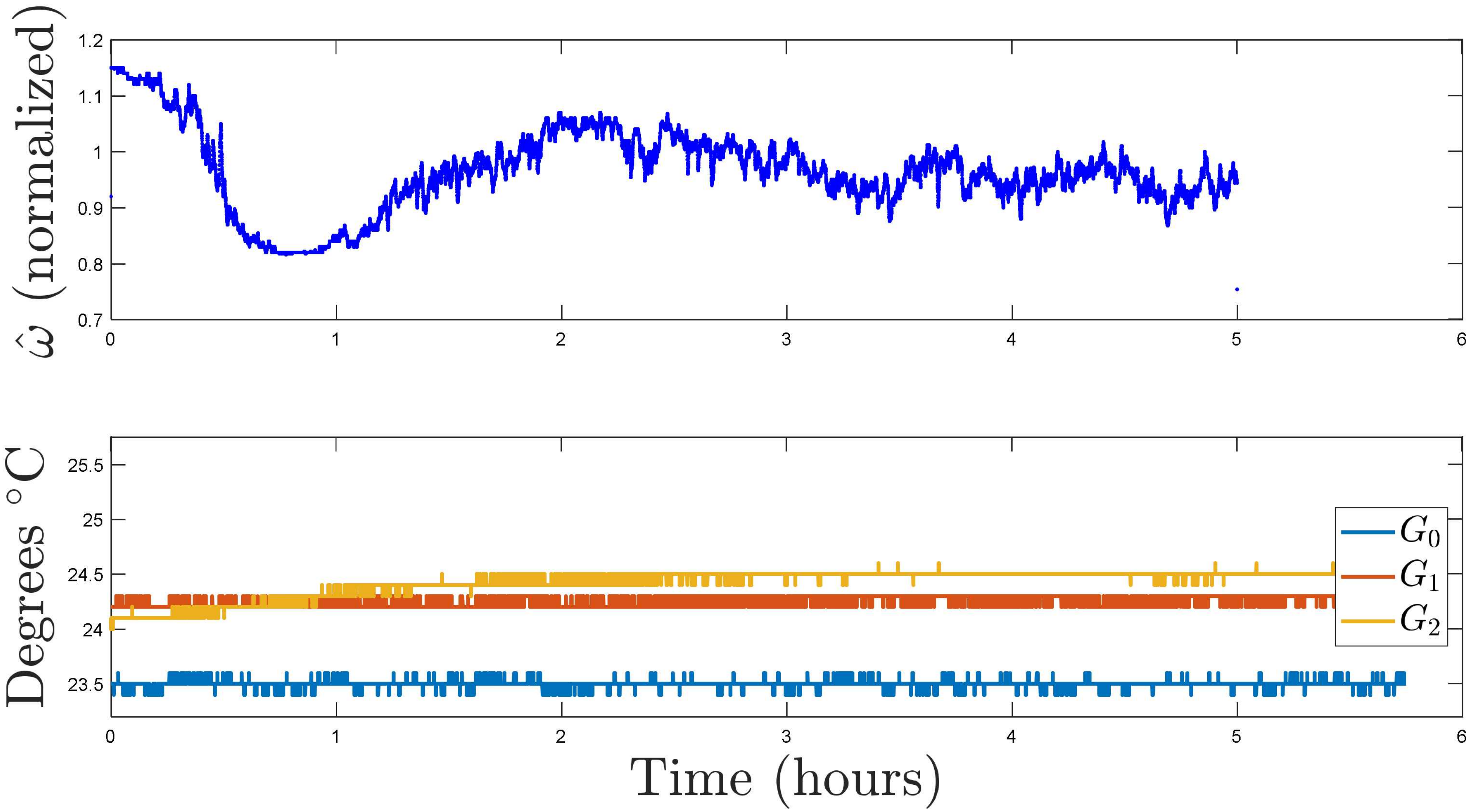
Moiré Frequency: **Without** Heat Shield

The interplay between grating expansions is complicated, but does affect the Moiré spatial frequency.



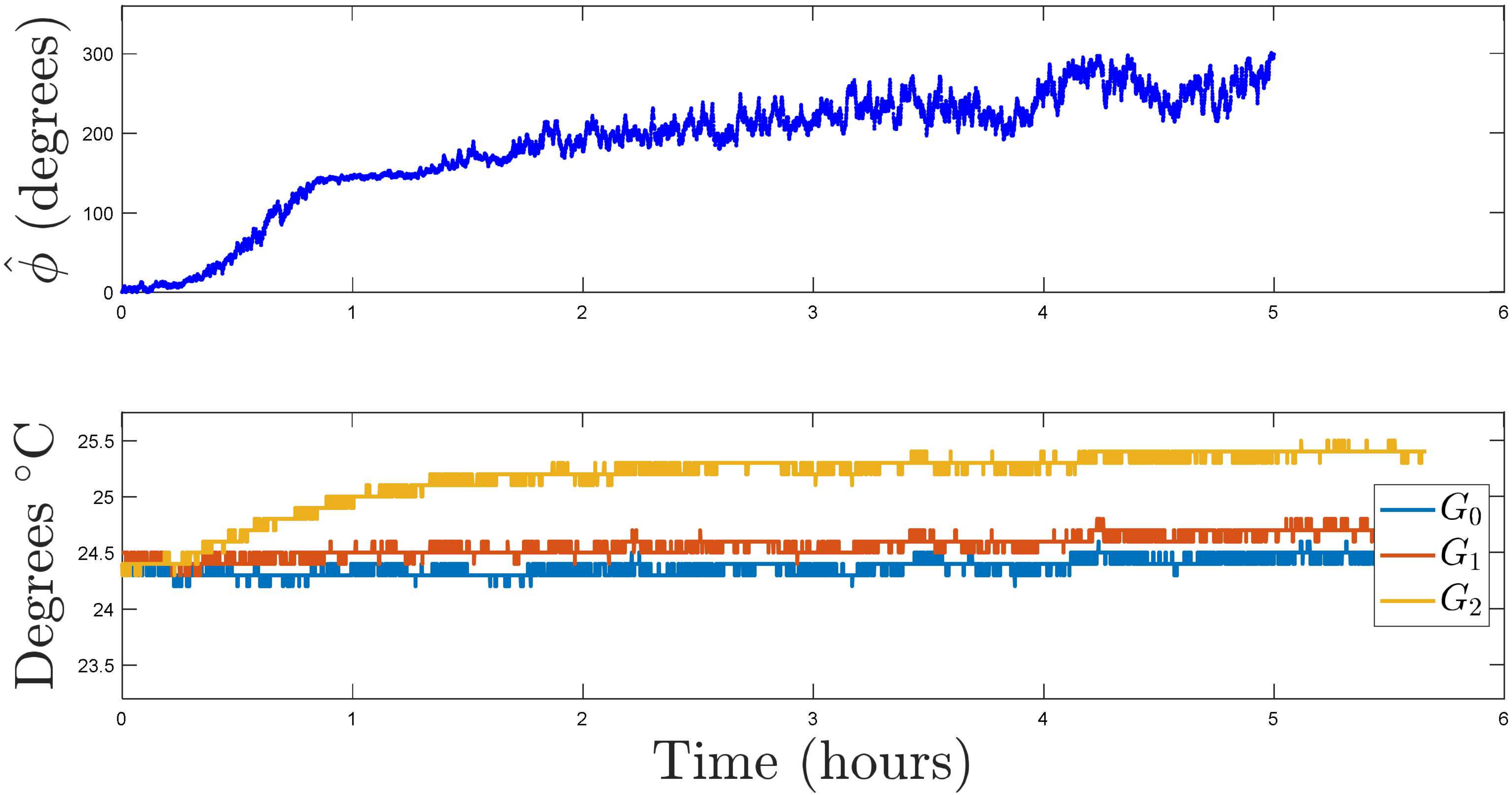
Moiré Frequency: **With** Heat Shield

With the heat shields, the Moiré frequency settles close to one, which is where it should be.



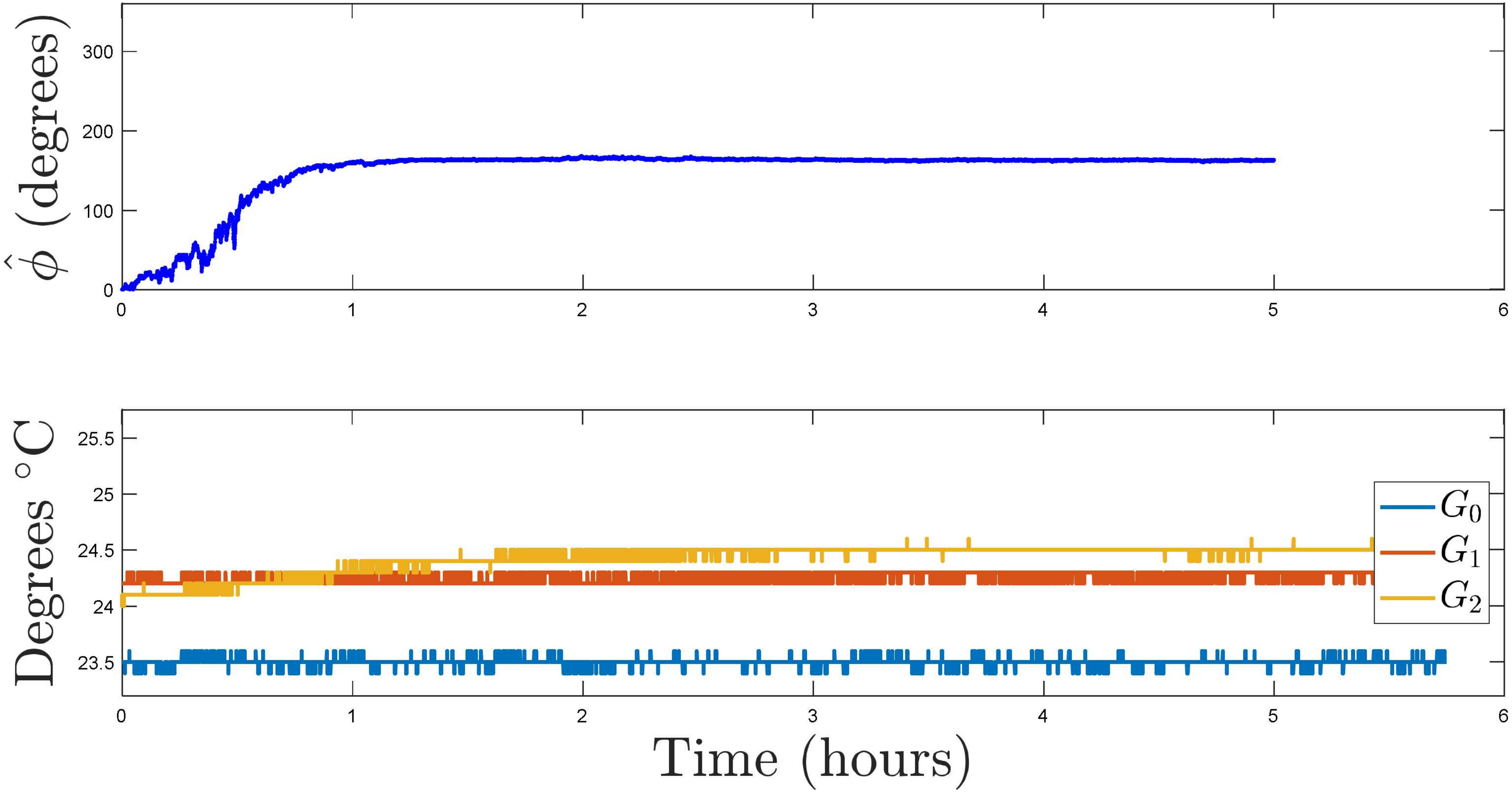
Moiré Phase: **Without** Heat Shield

The phase (normalized to start at zero) of the Moiré pattern shifts with the thermal expansion of the gratings.



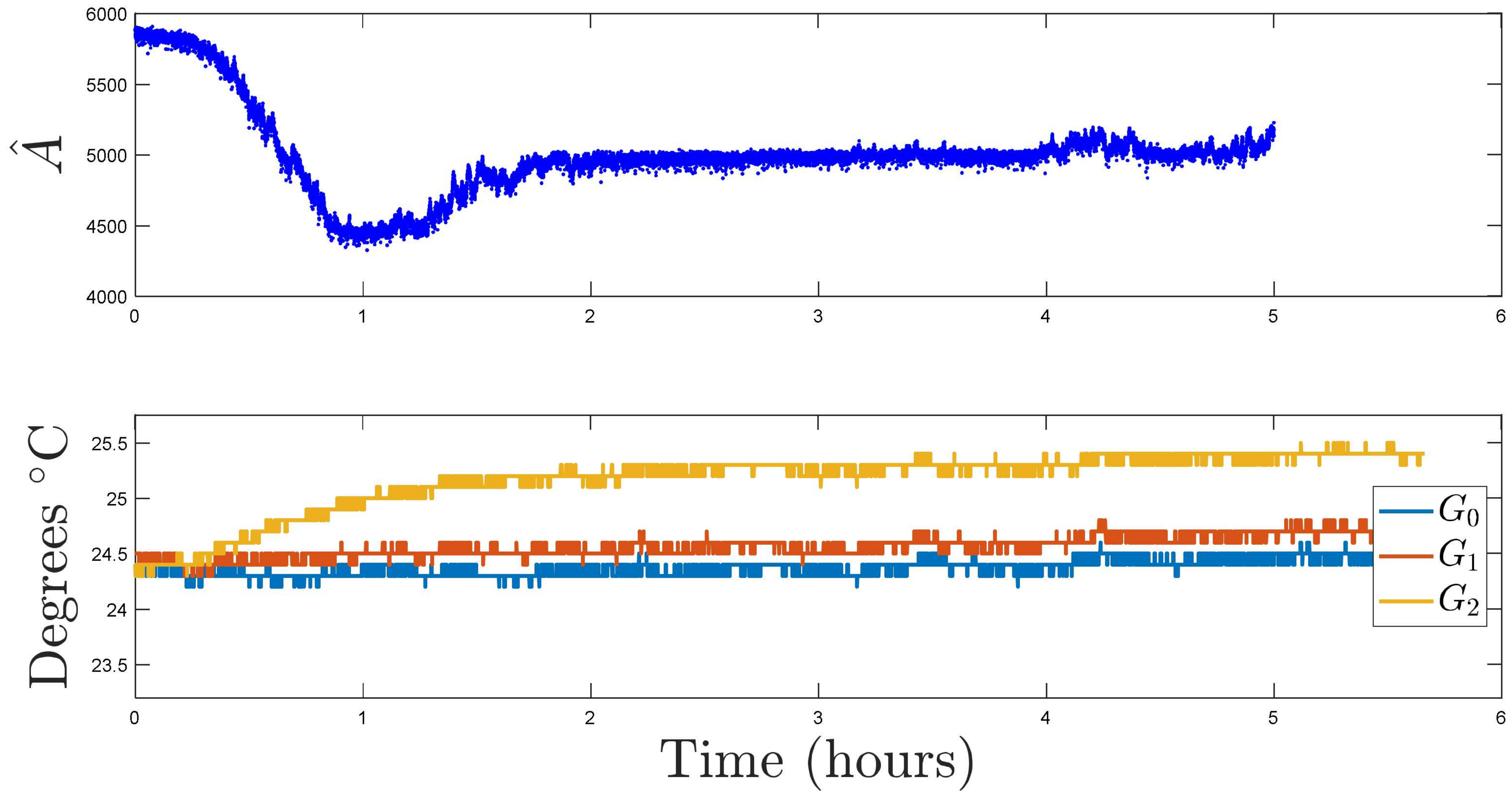
Moiré Phase: **With** Heat Shield

The phase stabilizes with the heat shield in place.



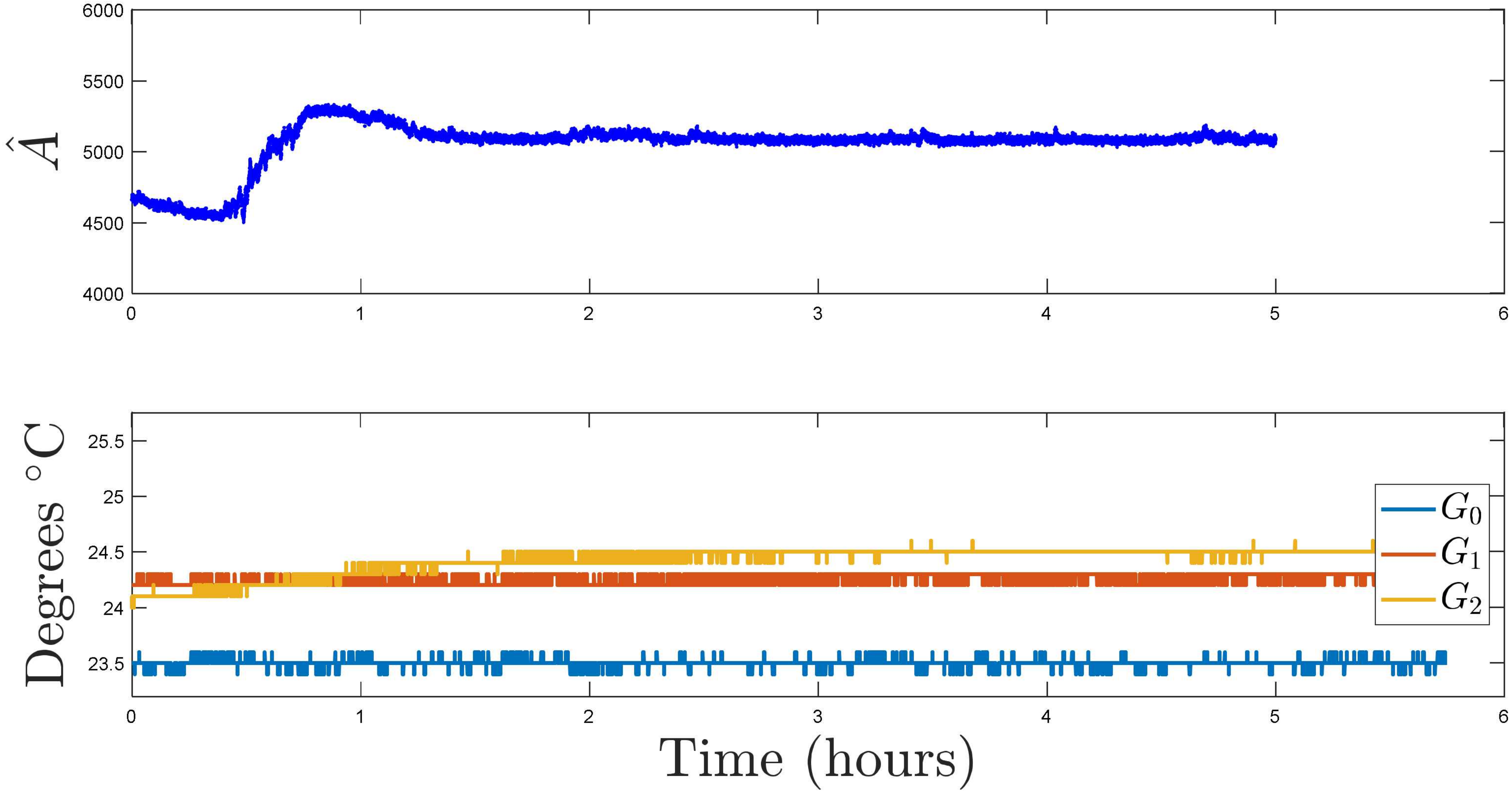
Moiré Amplitude: **Without** Heat Shield

The amplitude of the Moiré pattern stabilizes, but has variability about the operating point.



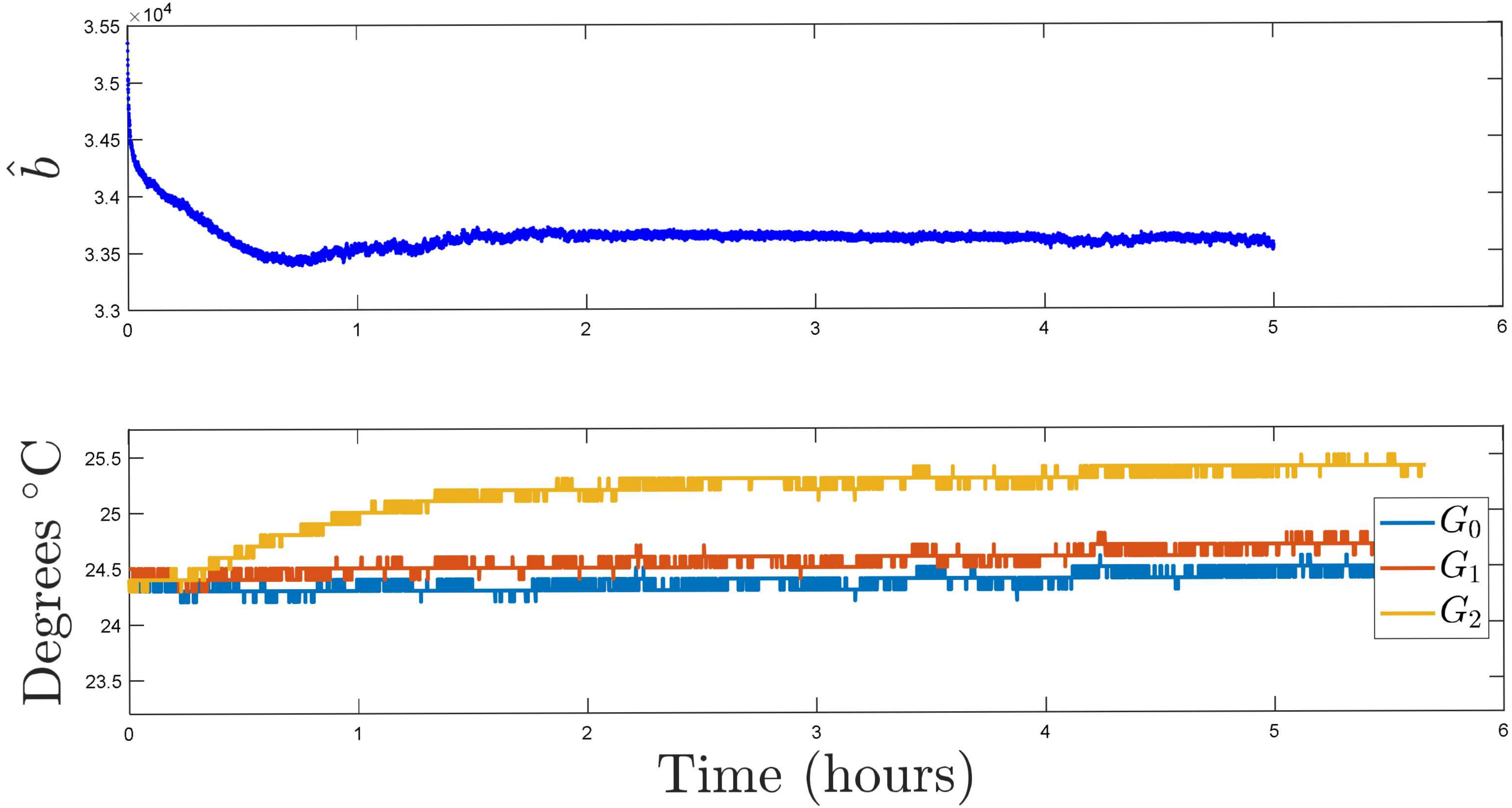
Moiré Amplitude: **With** Heat Shield

With the heat shield, the amplitude stabilizes and has less variability about the operating point.



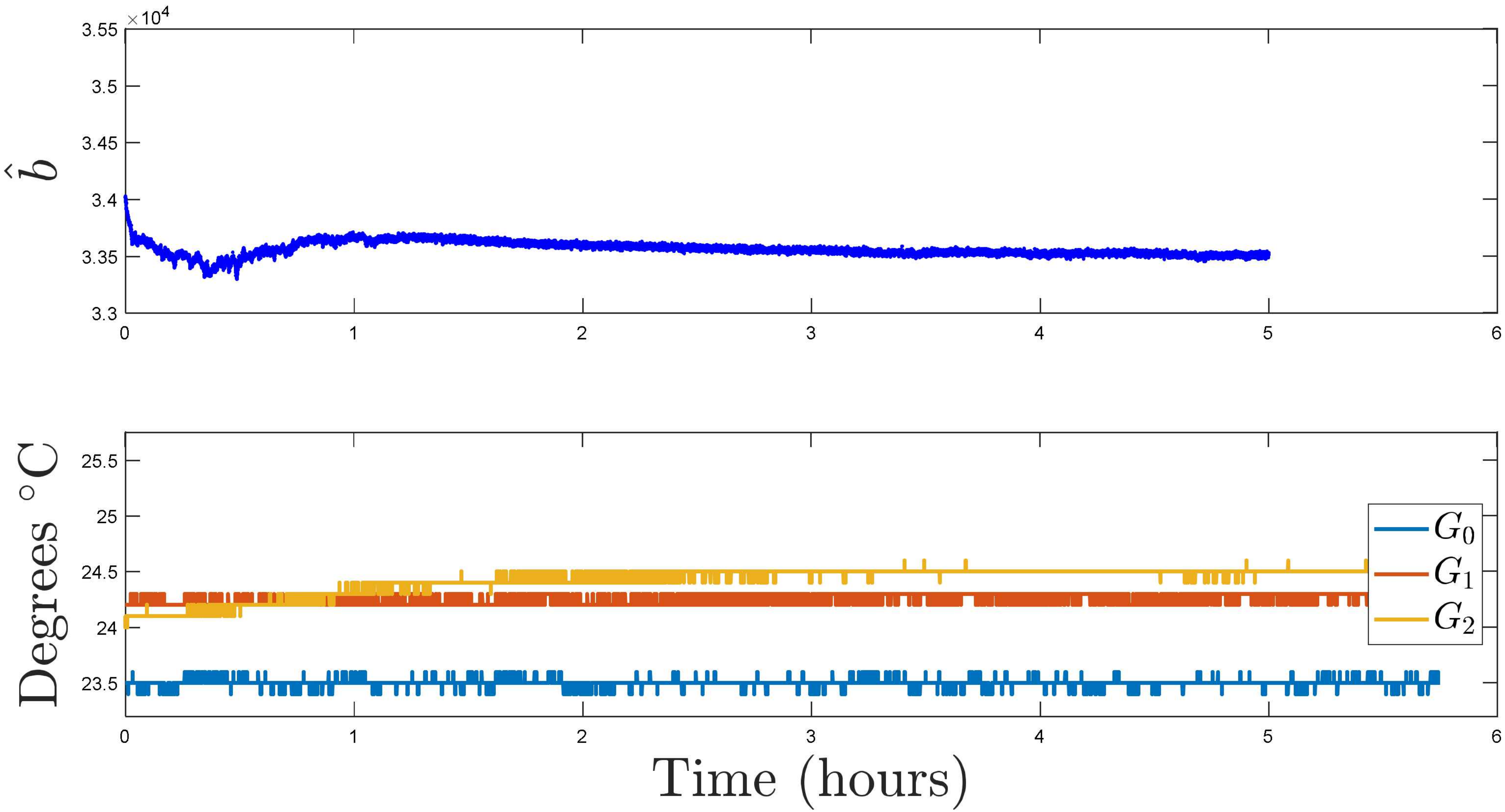
Moiré Bias: **Without** Heat Shield

The bias without the heat shields...



Moiré Bias: **With** Heat Shield

The bias is relatively unaffected by thermal expansion of the gratings.



Summary

- The signal model parameters most effected by thermal expansion of the gratings are the frequency and phase.
- The bias signal model parameter, which does not directly depend on the gratings, is the effected the least by thermal expansion
- Ideally the system should be thermally stable.
- Thermal changes will introduce changes in the system performance (i.e. change the fringe patterns).
- The XPCI system should be designed to minimize the influence of thermal sources.
- Component temperature monitoring may facilitate software corrections.
- Future work will explore the effect of variations in the x-ray source.

Questions?

References

[1]Pfeiffer, F., Weitkamp, T., Bunk, O., and David, C., "Phase retrieval and differential phase-contrast imaging with low-brilliance x-ray sources," Nature Physics 2 (Mar 2006).

[2]Kottler, C., Pfeiffer, F., Bunk, O., Grünzweig, C., Bruder, J., Kaufmann, R., Tlustos, L., Walt, H., Briod, I., Weitkamp, T., and David, C., "Phase contrast x-ray imaging of large samples using an incoherent laboratory source," physica status solidi (a) 204(8), 2728-2733 (2007).

[3]Pfeiffer, F., Bech, M., Bunk, O., Kraft, P., Eikenberry, E. F., Brönnimann, C., Grünzweig, C., and David, C., "Hard-x-ray dark-field imaging using a grating interferometer," Nature Materials 7 (Jan 2008).

[4]Pfeiffer, F., Bech, M., Bunk, O., Donath, T., Henrich, B., Kraft, P., and David, C., "X-ray dark-field and phase-contrast imaging using a grating interferometer," Journal of Applied Physics 105(10), 102006 (2009).

[5]Wang, Z., Huang, Z., Chen, Z., Zhang, L., Jiang, X., Kang, K., Yin, H., Wang, Z., and Stampanoni, M., "Low-dose multiple-information retrieval algorithm for x-ray grating-based imaging," Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 635(1), 103 - 107 (2011).