Characterization of Small Industrial Temperature Sensors

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Motivation

- Space Dynamics Lab builds remote sensing instrumentation for ground, airborne, and space applications
  - Especially infrared
- Infrared instruments are calibrated using ground and on-board blackbodies
- Blackbodies accuracy limited by temperature sensor accuracy
- Blackbody temperature sensors must be small
  - Flight blackbody size must be limited
  - Ground blackbodies not compatible with large standard or secondary standard probes

Accuracy needs

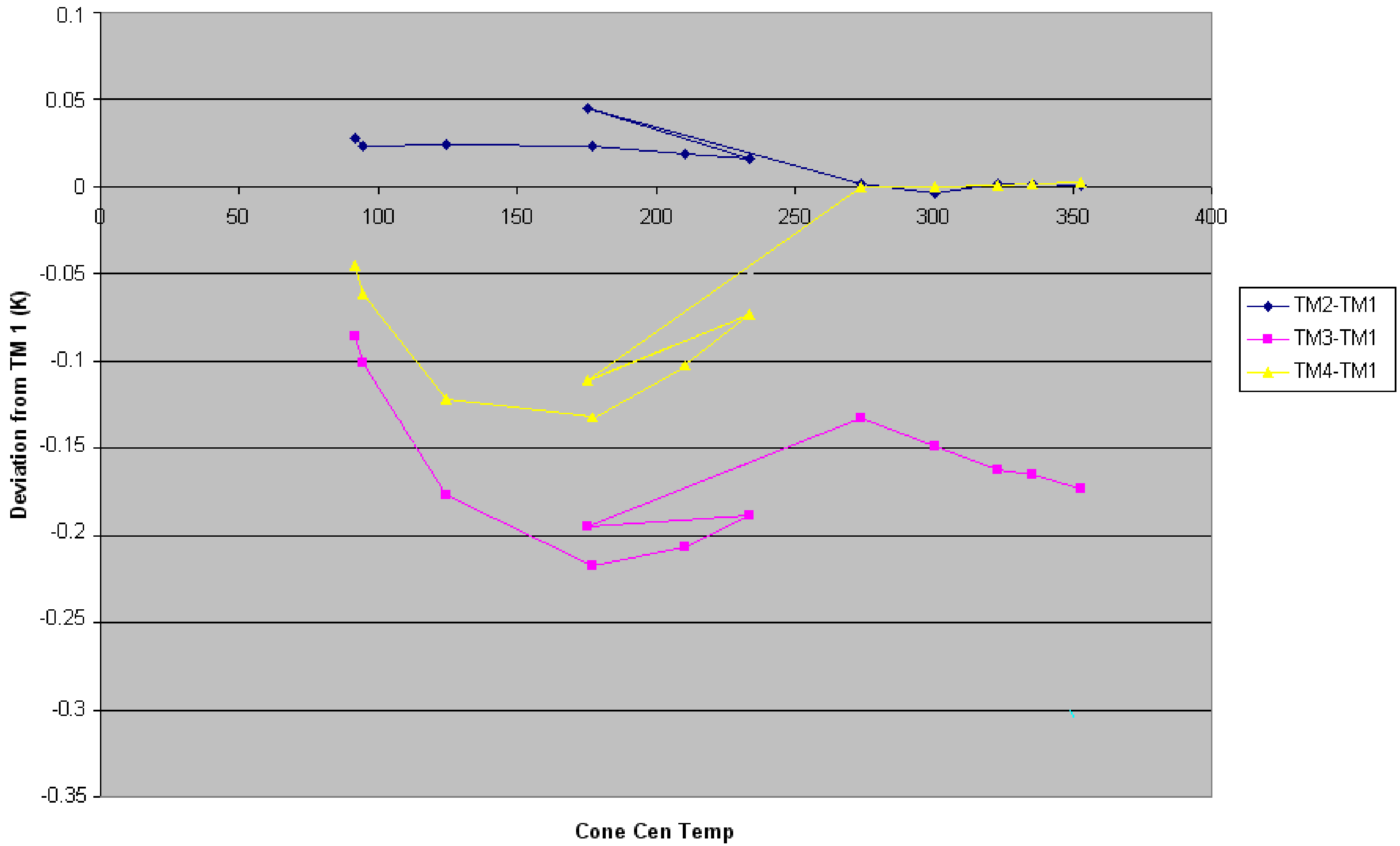
- Accuracy requirements
  - Better than 0.25 K usually desired at SDL
  - Earth observing / climate monitoring instruments need better
    - CLARREO needs 0.1 K accuracy (k=3) for 5 years on-orbit
- SDL and others have found that small industrial temperature sensors don't behave as well as expected
  - Inconsistent readings from co-located sensors
  - Significant hysteresis
  - Lack of repeatability at same temperature / drift over time

Observed variation

Data from 4 PRT sensors on part of a blackbody uniform to 5 mK

Sensors 1, 2, 4 were calibrated to ~10 mK prior to placement in blackbody

Up to 170 mK of deviation here

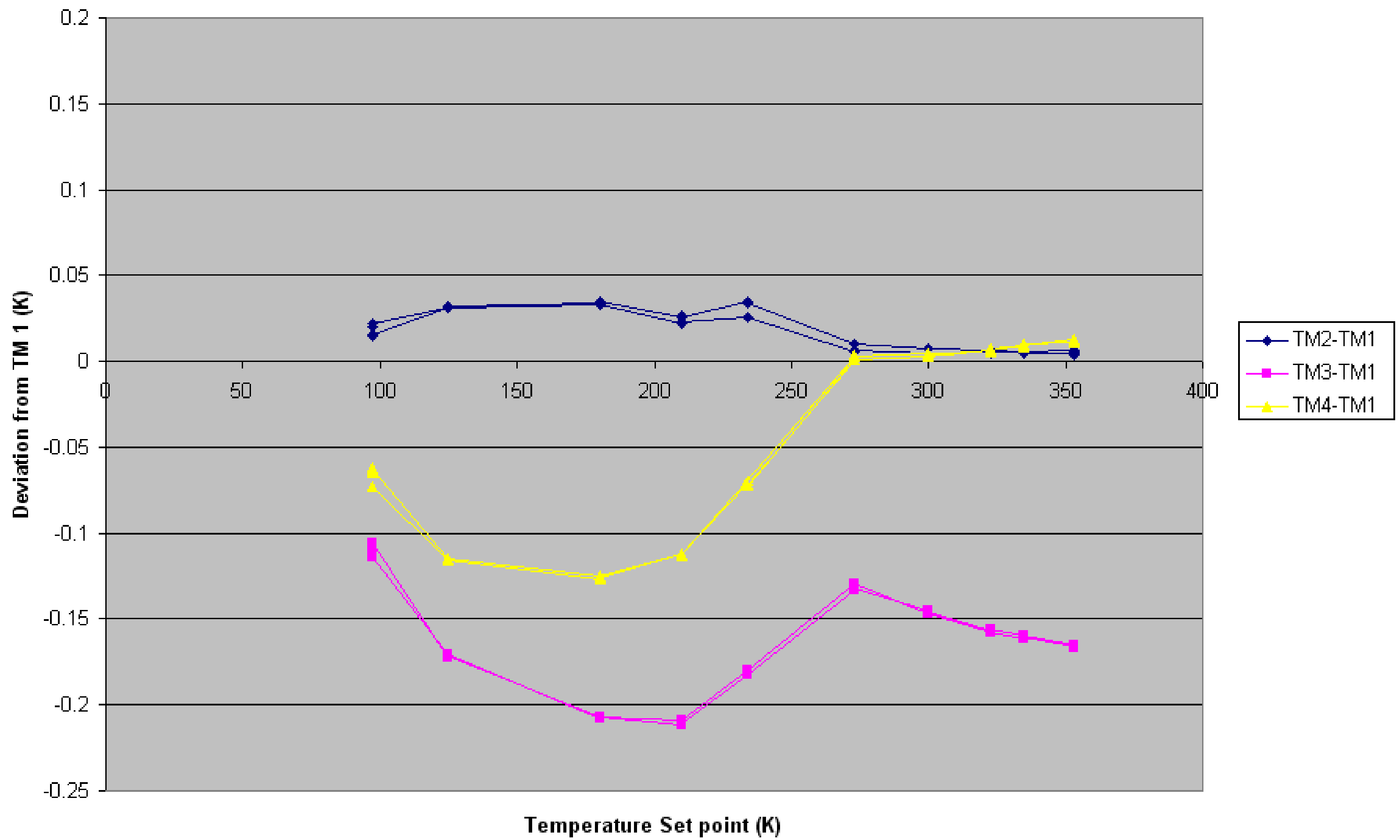


Difference between sensors 2, 3, 4 and sensor 1 vs. blackbody temperature

More observed variation

Same sensors, one year later

~10 mK changes from previous plot



Difference between sensors 2, 3, 4 and sensor 1 vs. blackbody temperature

Temperature sensor testing

- We tested temperature sensors to better understand behavior
- Tested PRTs and Thermistors
  - PRT can cover entire desired 80 to 350 K temperature range, while thermistors can cover a significant portion of it
  - Widely available, potentially high accuracy, relatively inexpensive
  - Used 100 Ω PRTs for these tests

- Main testing was cycling in a thermal bath
- Additional results observed when tested sensors placed into a blackbody

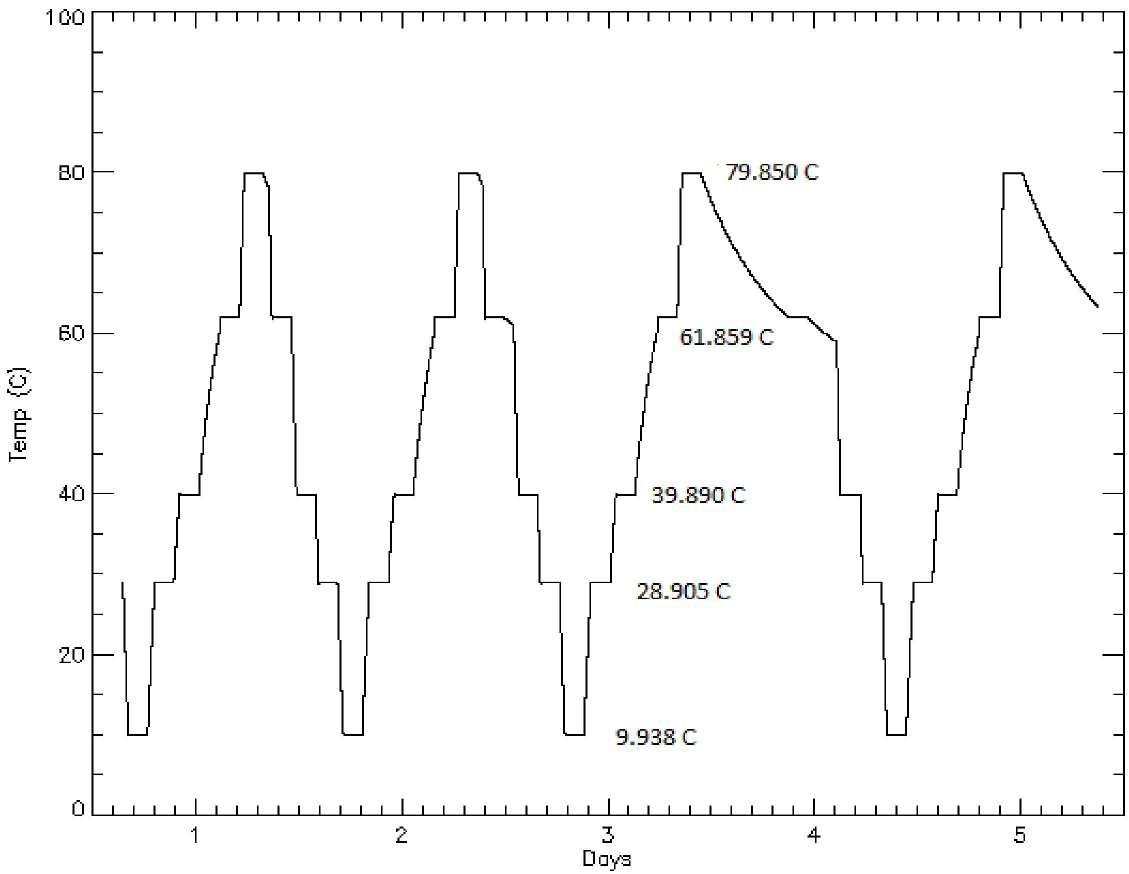
Thermal Bath setup

- Thermal bath range: -45 to 150 C
  - Used 10 to 80 C with water
  - Used -40 to 35 C with isopropanol
- Temperature standard: secondary standard PRT probe
  - Calibration absolute accuracy ~5 mK
  - Cycling to LN_2 and boiling water temps and testing in triple point of water cell shows no hysteresis and no drift over time
  - ~12” long
- Temp sensor readers:
  - Absolute accuracy 10 mK for PRTs over full resistance range, better for thermistors
  - Used precision resistor to monitor drifts, generally <1 mK effect
- Sensors under test in bath kept near calibrated probe
- Various methods used to keep sensors well coupled to bath

Temperature cycling tests

- Temperature cycle multiple sensors for several days in bath
  - Does not test longer-term behavior
- Go to 5-9 temperatures and hold for ~1 ½ hour at each
- Bath repeats to ~3 mK

- Calibrate sensors under test using their resistance vs. bath temperature on plateaus
  - 3 or 5 ITS-90 coefficients for PRTs
  - 3 Steinhart-Hart coefficients for Thermistors
- Use these to calculate temperature for each sensor under test

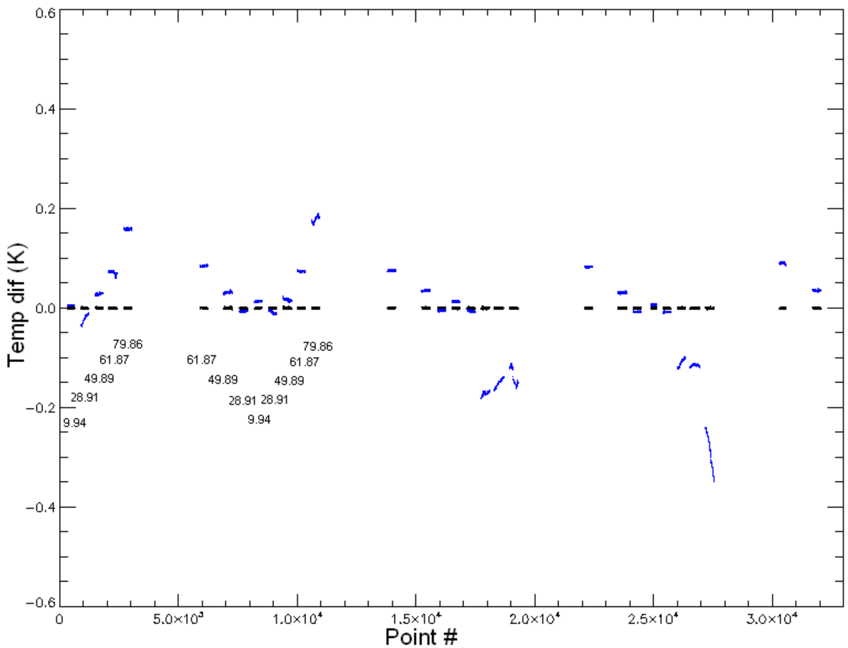


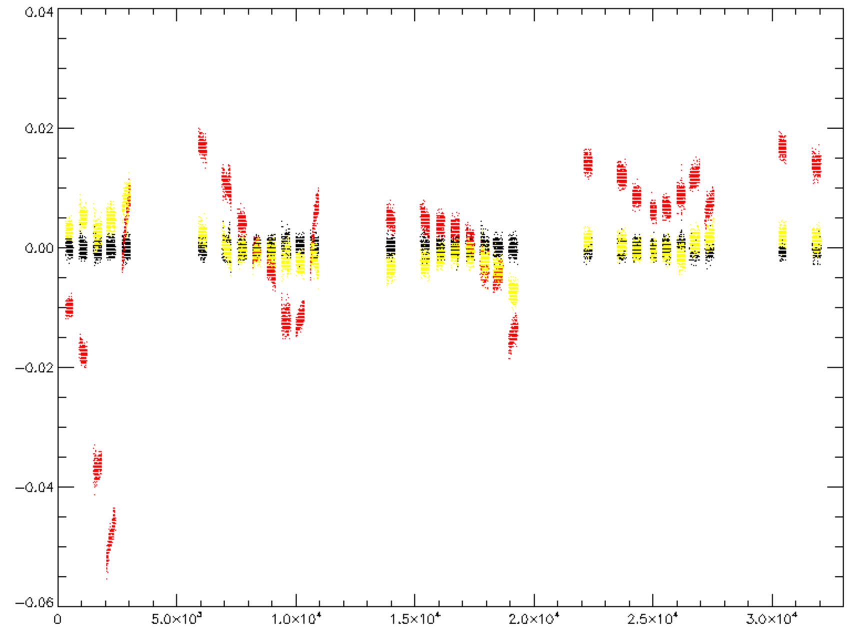
Bath Temperature as measured by Calibrated probe

Temp sensor testing

- Compare temperature on plateaus for sensors under test to average over plateau for calibrated probe
  - Black curve is calibrated probe in PRT plots

- These plots show PRTs that drift significantly over time





Temperature deviation (sensor temperature reading – average bath temperature on plateau) vs. time for several different PRTs (each one a separate color). The numbers show the approximate bath temperature on plateaus

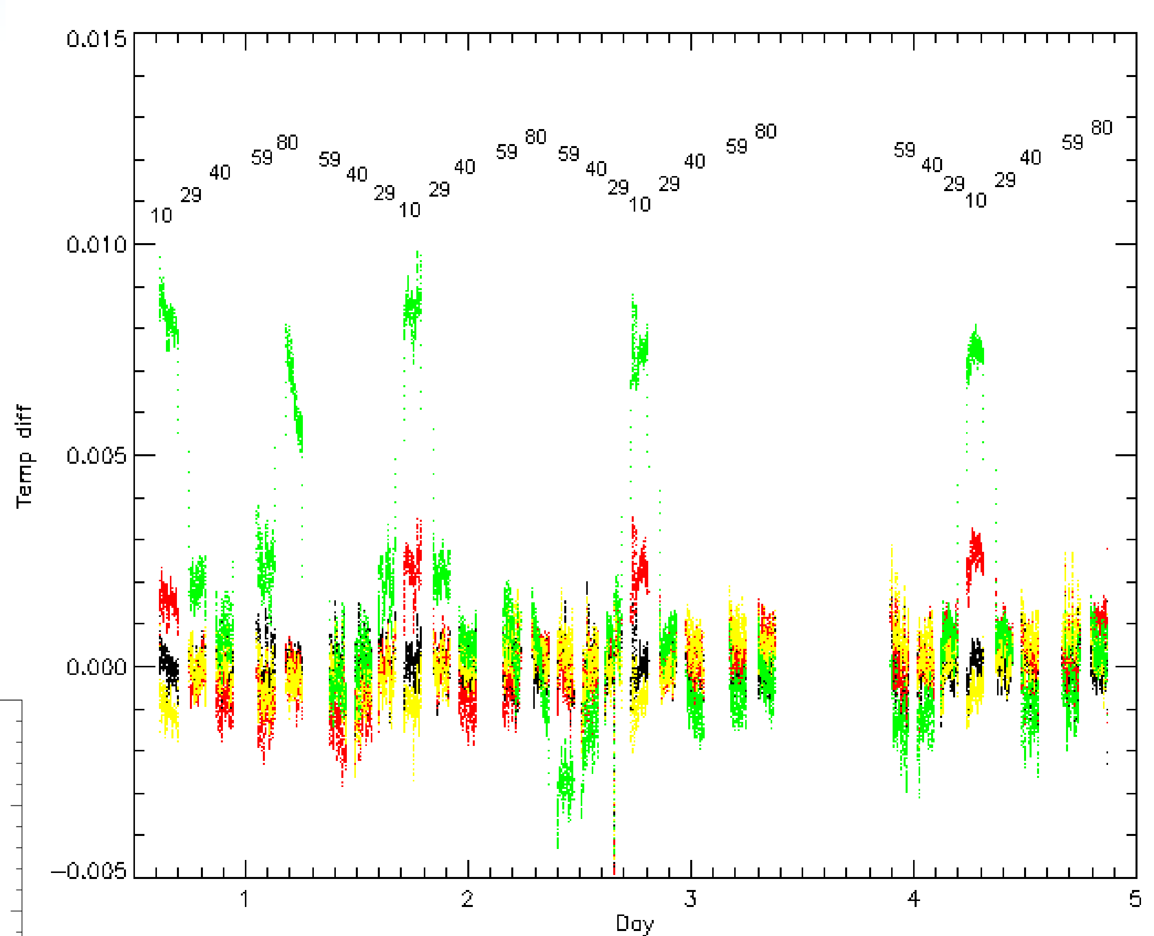
Bath testing results

- **Temperature sensors drift over time when the temperature is cycled**
  - The drift appears random over time
  - May exceed specifications for sensor accuracy
  - Behavior is same whether sensors are mounted in fixture or not
  - Some sensors much better than others
  - All units of one models usually have similar drift, but there are exceptions
- Long hold at constant temperature does not show drift
- Repeated cycling from liquid nitrogen to boiling water also produces drift, comparable to that in 70 C cycling
- Sensor self heating is generally a few mK in bath tests, not a concern
- Temperature sensors of type used in blackbody shown previously had 10-15 mK drifts

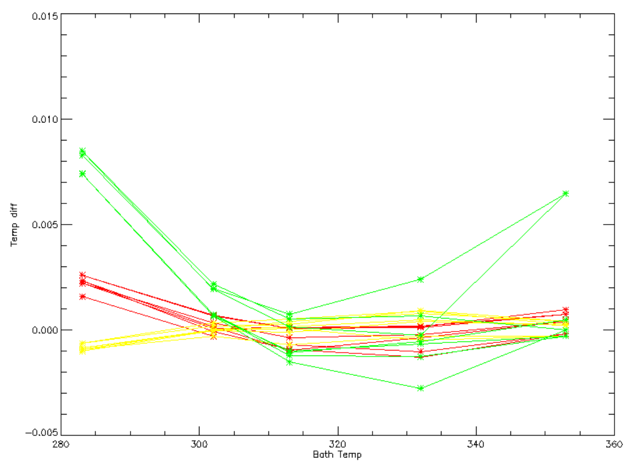
- Mounting in fixture observed to have ~10 mK affect on PRT and Thermistor
- Putting under vacuum and tightening fixture onto block showed no change

Low drift PRTs

- These 3 PRTs show <11 mK variation over time
- Yellow curve best, red not as good, green notably worse
- Some of the deviation is correlated with temperature
  - Too few coefficients in T(R)



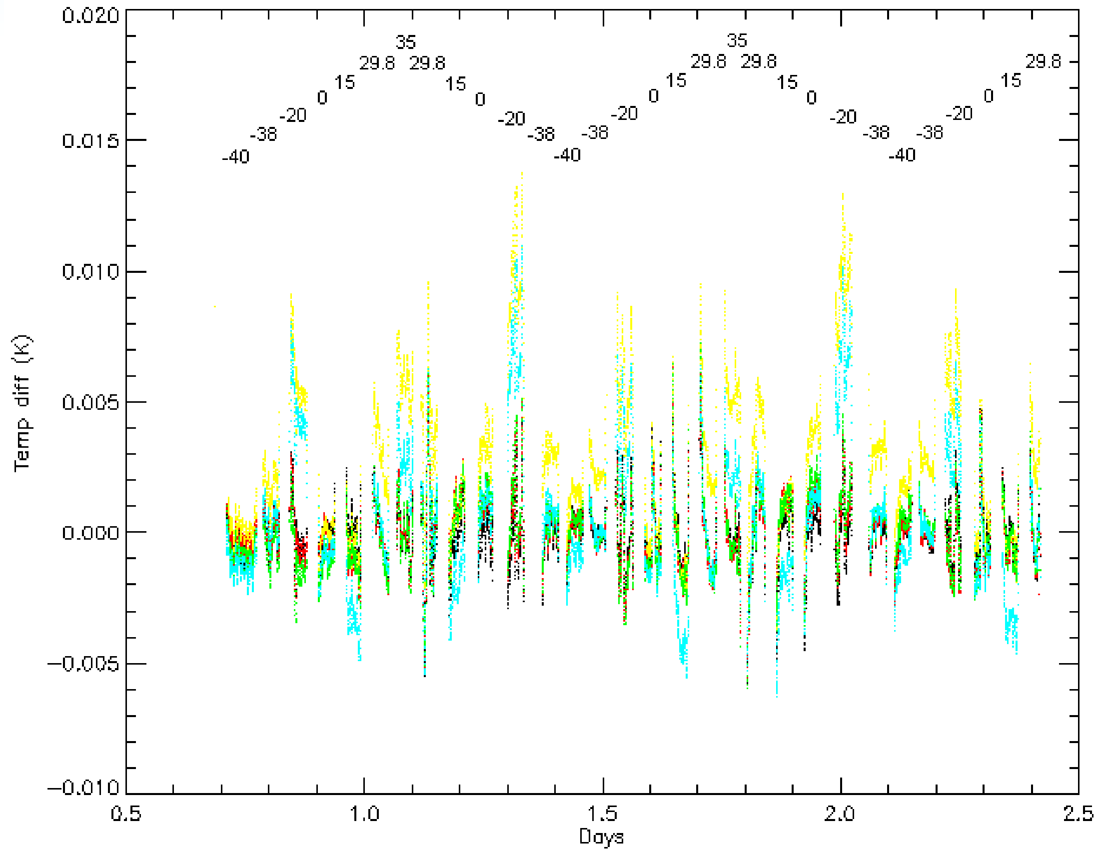
Deviation vs. time plot for 3 PRTs, all same model. Numbers are approximate bath temp on plateaus

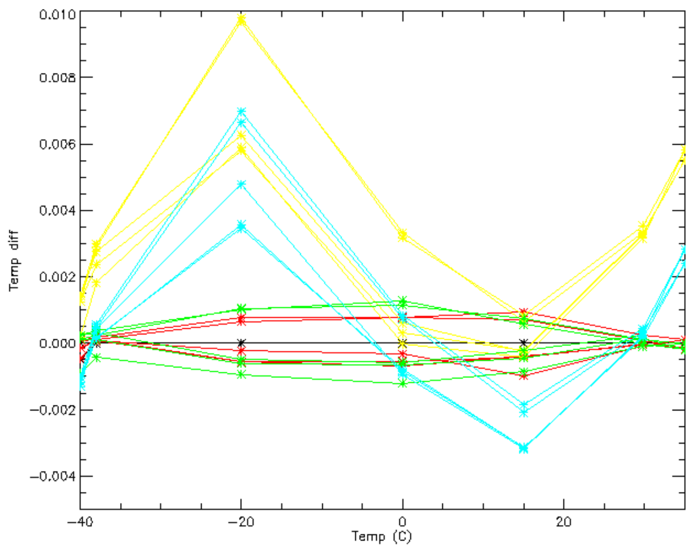


Average deviation on plateau vs. temp on plateau

Another low drift PRT

- Most deviation is from too few coefficients
- ~ 1mK drift
- Up to 4 mK hysteresis

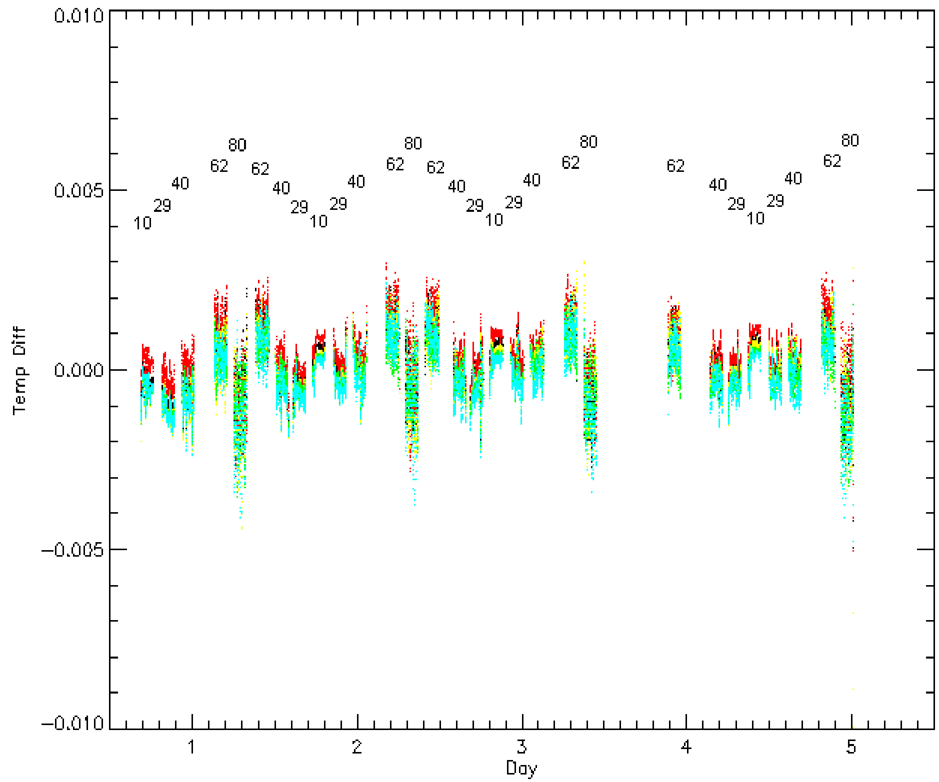




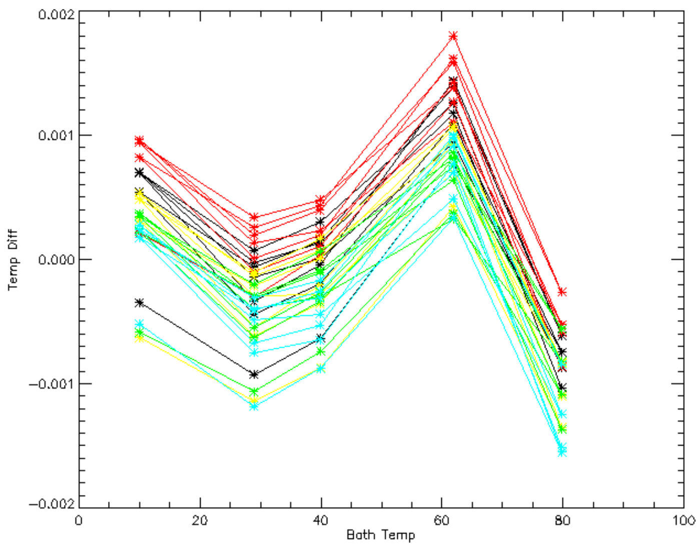
Deviation vs. time (above) and average deviation vs. temp (left) for 4 PRTS

Good Thermistors

- All sensors track calibrated probe to ~ 1 mK
- Variation partially correlated with bath temperature
  - Need more coefficients
  - Systematic errors in PRT reader

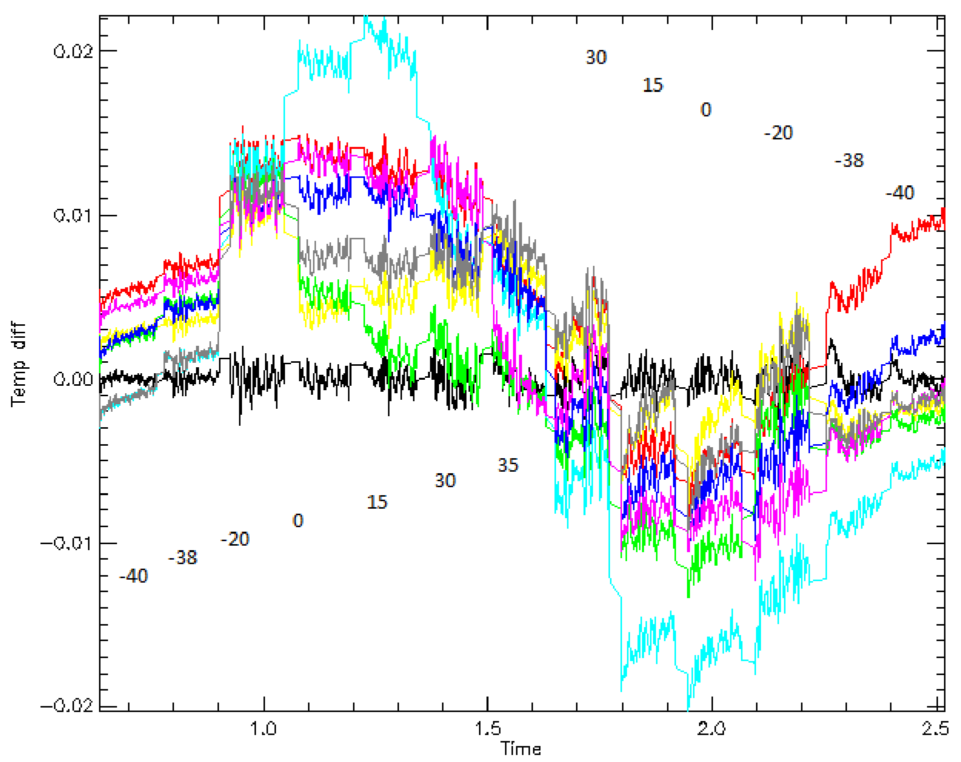


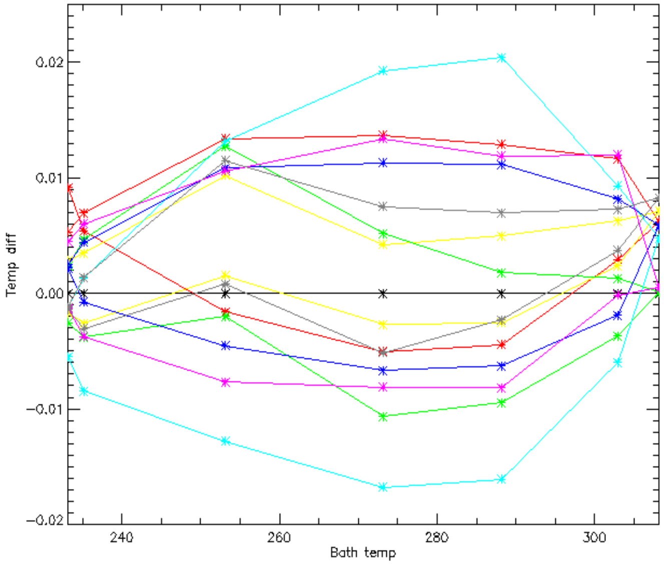
Deviation vs. time (above) and average deviation vs. temp (left) for 5 Thermistors



Inexpensive PRTs

- Inexpensive PRTs
  - We use for housekeeping sensors
- ~ 5 mK drift
- ~20 mK hysteresis





Deviation vs. time (above) and average deviation vs. temp (left) for 7 PRTs

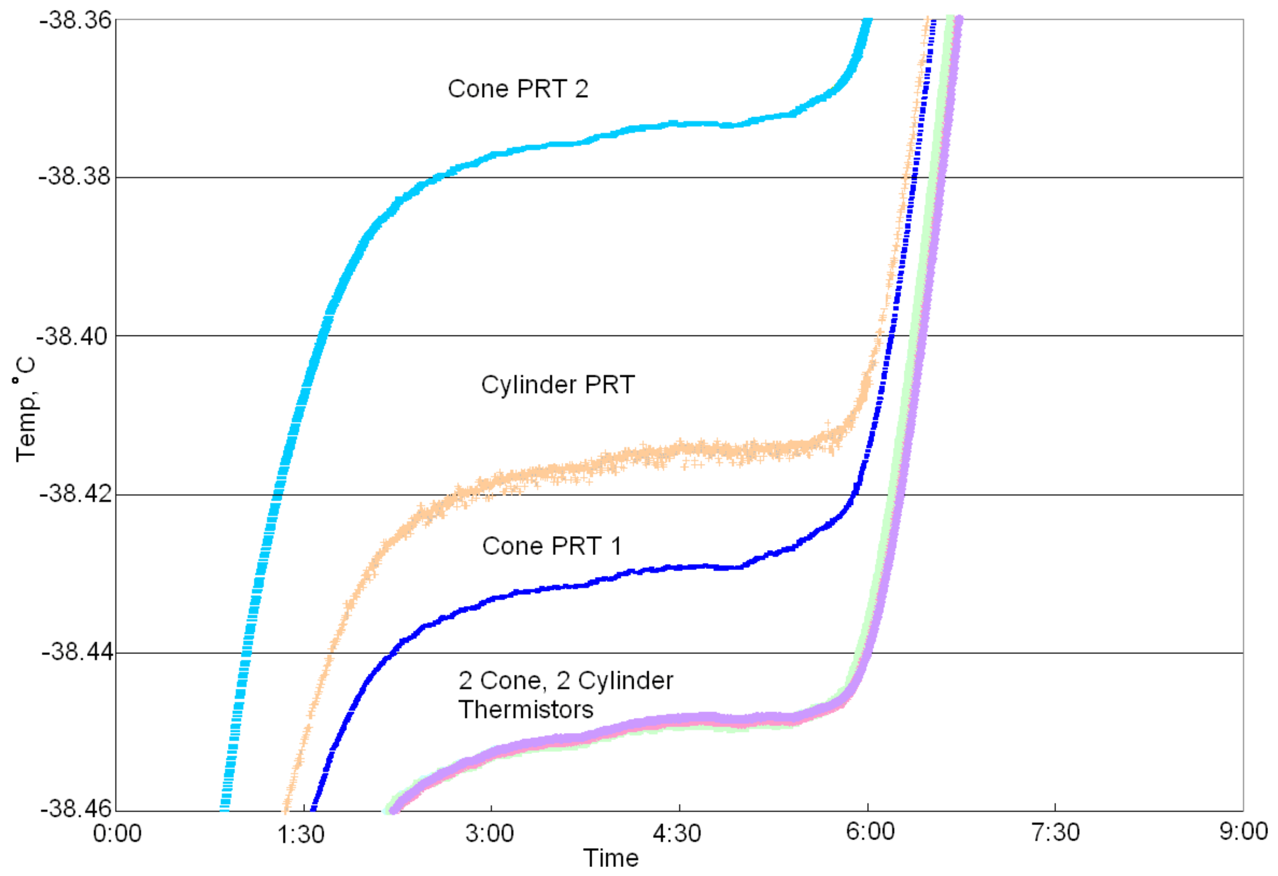
Blackbody results

- In the recently built CORSAIR blackbody we used
  - the first type of low-drift PRT
  - the thermistors
  - the inexpensive PRTs (for housekeeping)

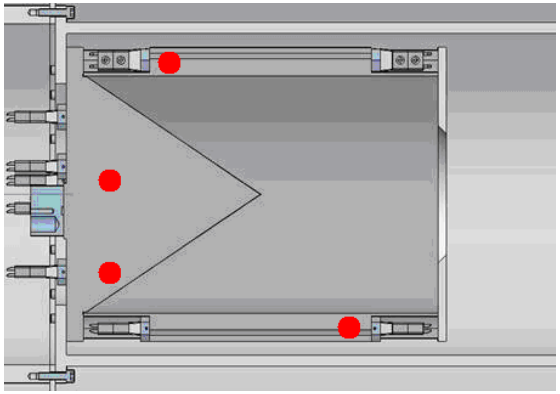
- Calibrated all from -40 to 35 C in bath prior to placement in blackbody
  - Absolute accuracy ~15 mK
  - Observed low drift PRTs change calibration by up to 20 mK if taken out of bath and retested
    - Very sensitive to minor handling?
  - Thermistors and housekeeping PRTs maintained calibration

Sensors in blackbody

- Plot for blackbody temperature held constant at -38.4 C
- From thermal models:
  - Cone isothermal to 3 mK
  - Cylinder 0 to 10's of mK from cone
- PRTs on cone differ 60 mK
  - Changed on insertion

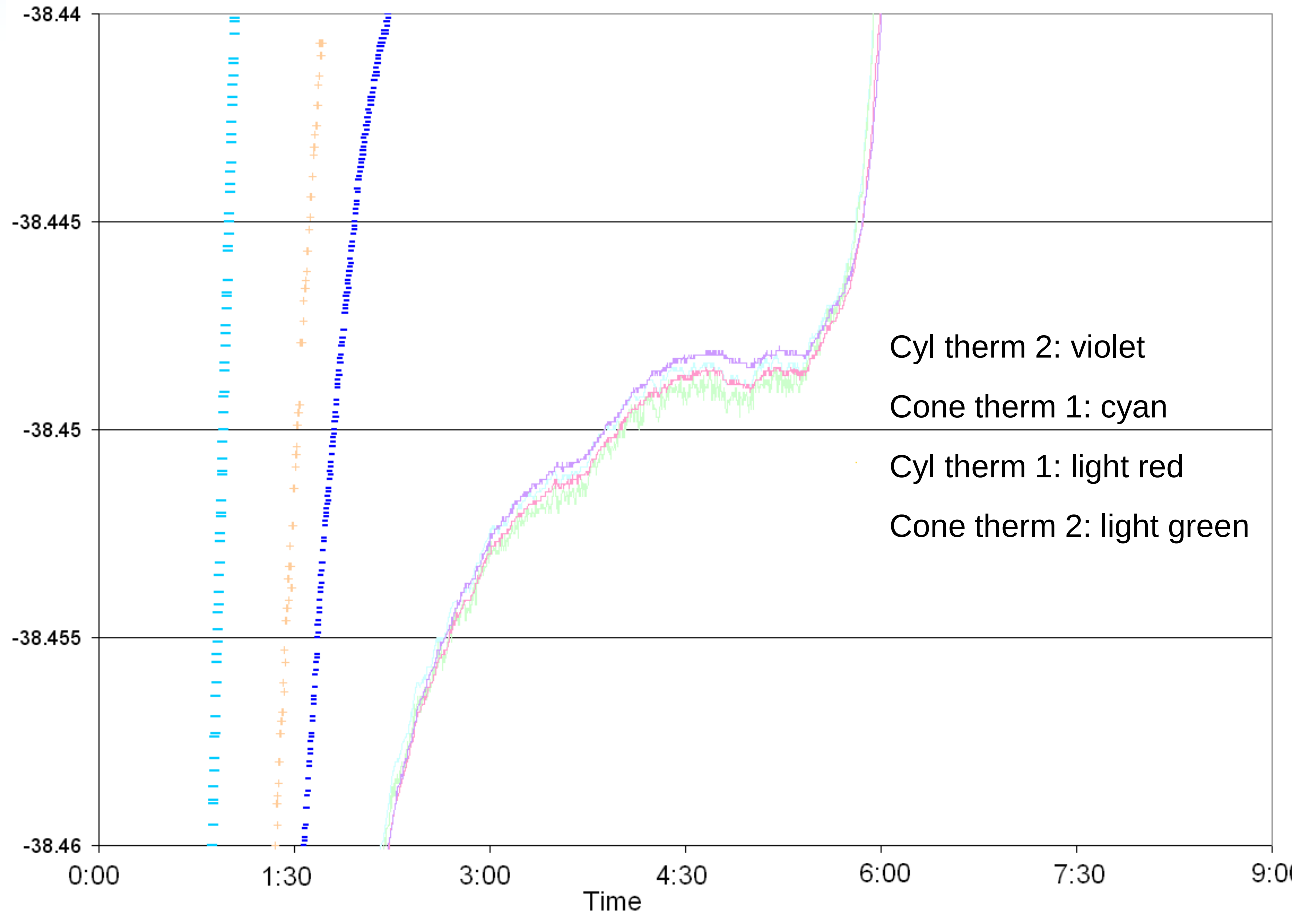


Blackbody temperature vs. time (above) as measured by 4 thermistors and 3 PRTs at locations shown (left)



Sensors in blackbody

- All thermistors within 1 mK
- When blackbody stable from -40 to 37 C, thermistors always within 4 mK
  - Thermistors maintained calibration
  - No gradient from blackbody cone to cylinder
- Phase change cell in blackbody:
  - a thermistor reads +5, -10, -17 mK from melt point of Hg, H_2O and Ga



Blackbody temperature as measured by 4 thermistors

Temperature Sensor Testing Summary

- Sensors drift when temperature is cycled
  - Some models are better than others
  - Screen sensors before using
  - Older sensors had worse drift, is drift a failure mode?
- Calibrate sensors after mounting in fixture
- Some PRTs are highly sensitive to handling
- One thermistor model provides very good performance