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Phase Change References for In-flight Recalibration of Orbital Thermometry

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Need for Orbital Temperature Reference

- Phase transition cells for absolute temperature reference are key components of any future climate monitoring mission.
- Mission requires:

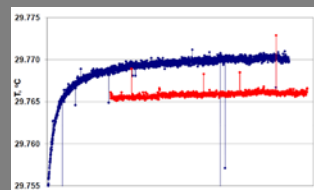
  "…an SI-traceable standard for absolute spectrally resolved radiance in the infrared with high accuracy (0.1K 3σ brightness temperature… Each of the interferometers carry, on-orbit, phase transition cells for absolute temperature,… with SI traceability [1]."

- Because the temperature uncertainty will only be one of the contributors to the 0.1K requirement absolute temperature uncertainty will need to be lower, on the order of 0.01 K or better.

Program History

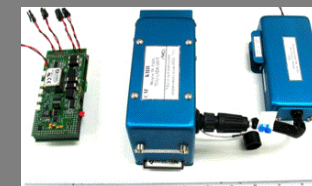
VEGA Intl. approached to collaborate on gallium eutectic work

Vega Results show Ga eutectics as viable PCMs for calibrations



ESTO office begins funding support to speed development to benefit CLARREO with space qualification results

Launch opportunities delayed by Russian Calibration Institute approvals with ties to VEGA



Hardware returned on Soyuz to IBMP and then to SDL

2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014

FY1 FY2 FY3 FY4

SDL IR&D program

(2004) Initial internal studies of potential for NPOESS started

(2006) SDL approached IBMP to provide ISS testing of PCM cells.

SDL starts IR&D program to get ISS tests with PCM cells and patent technology

Hardware Launched on Soyuz,
ISS experiments conducted

ISS Based Microgravity Testing with PCM Cells

- Institute for Biomedical Problems Moscow
- 20+ yr. collaboration with SDL on ISS experiments
- Joint interest in improving temperature sensors to support space science.

- Effort to test space-based implementations of fixed-points

International Program Cooperation

Energia provides: Hardware launch and station resources.

NASA provides: research funding, hardware/plant tissue return, hardware design input.

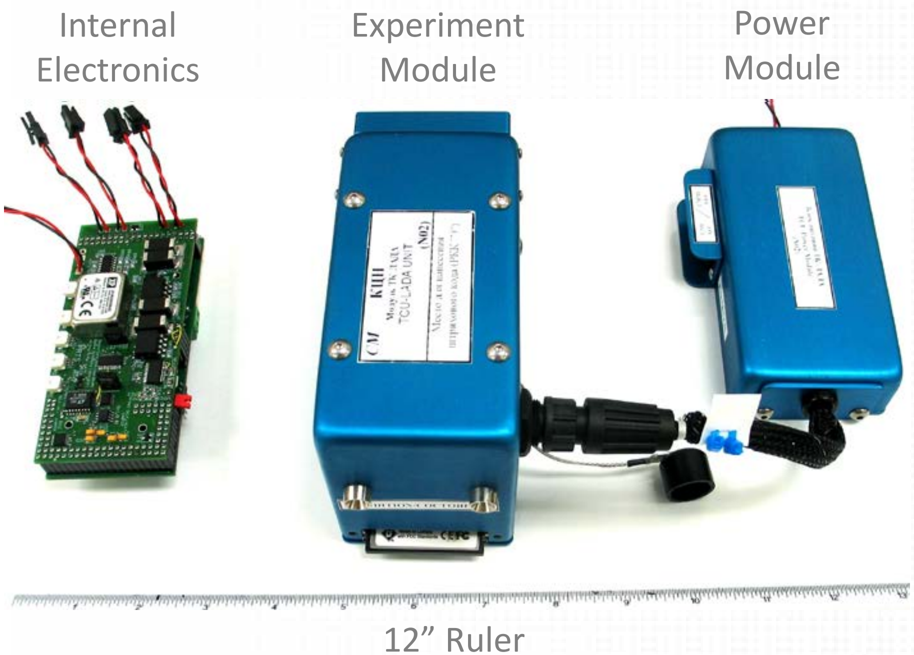
-Data is shared by all participants.
-Hardware and tissue samples are returned by Shuttles and Soyuz.

Intl. Cooperative Agreement

IBMP provides: Hardware qualification, station flight support for experiments, data analysis, internal research funding

SDL provides: Internal research funding, hardware construction, data analysis, program management

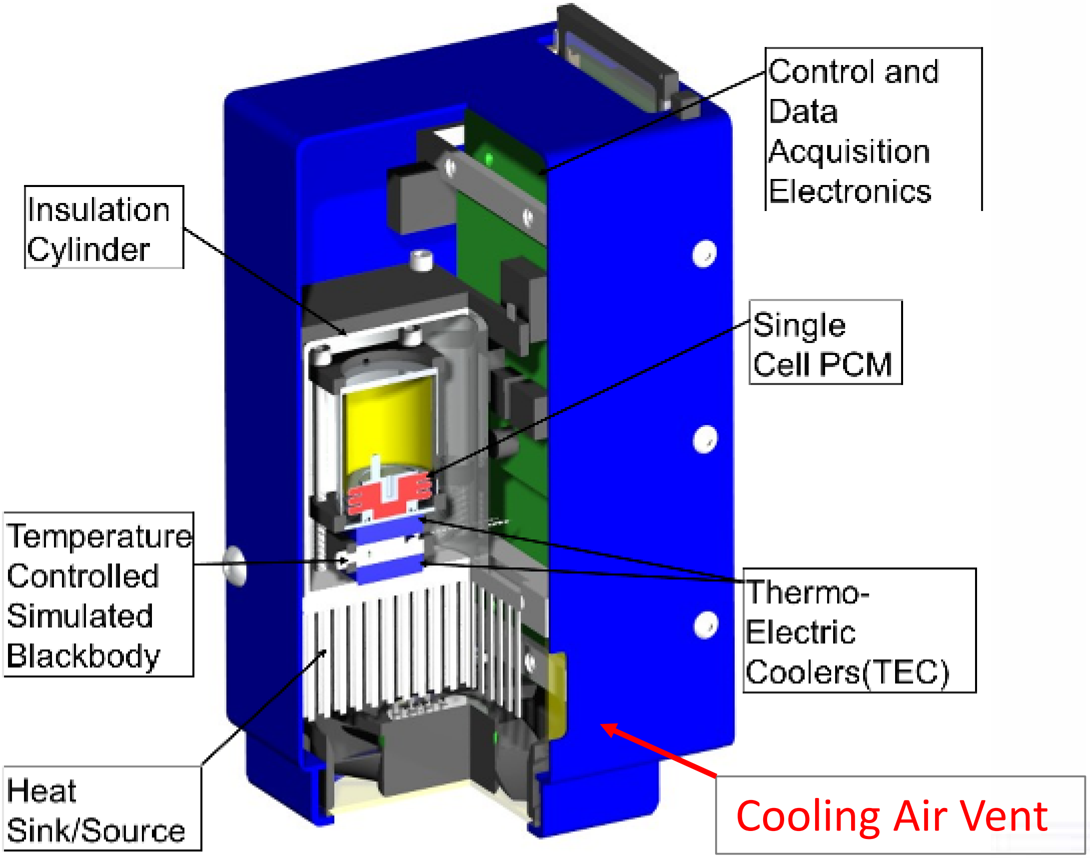
ISS Experiment Package



- Experiment module capable of thermal control and measurements of different cell designs.
- Experiment is automated by a Tern embedded computer and electronics.
- Experiment module is returnable on Soyuz.

ISS MOTR Flight 1, Ga System Layout

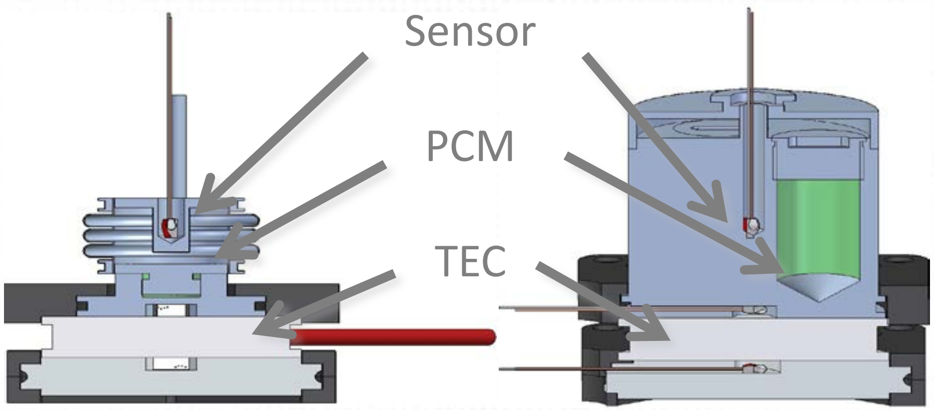
- PCM temperature controlled by 2 TECs and a temperature controlled heater enclosure.
- Heat exhausted to cabin through forced ventilation.
- 2 LED indicators display experiment status.
- Automated experiment data stored on CF card, removable only on ground.

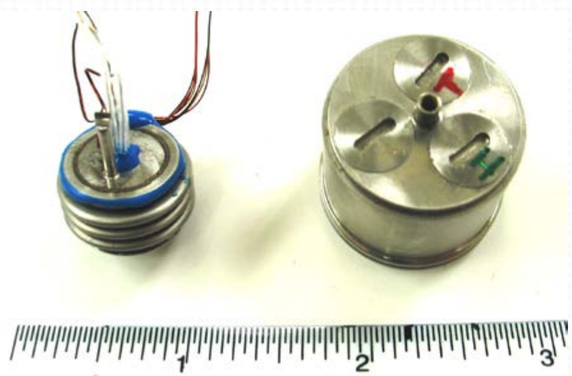


Flight Cell Designs for Two Flight Experiments

1st experiment:

- Single PCM Gallium
- sealed SS container
- Container allows for PCM expansion.
- Reentrant well for sensor in PCM
- PCM volume ~1mL
- TEC allows heating and cooling of PCM.





2nd experiment:

- 3 PCM Gallium, Gallium-Tin eutectic, and water
- sealed SS container
- Compressible trapped gas allows for PCM expansion.
- Sensor in container adjacent to PCM
- PCM volume ~0.75mL (each)
- TEC heats and cools PCM.

Launch & Delivery of Flight Unit Hardware

- **Flight units both delivered to Moscow:**
  - Flight 1 (Dec. ‘10)
  - Flight 2 (Feb. ‘11)
- **Experiments initially manifest on expeditions 33 & 34 to ISS for fall of 2012. Multiple slips occurred.**
- **Actual launch (Oct. ’13).**
- **ISS experiment conducted (Jan. ’14).**
- **Hardware and flight data returned to IBMP in Moscow (Apr. ’14).**
- **Hardware returned to SDL in Utah (Jun, ’14)**
- **SDL ground recalibration (Sep. ‘14)**

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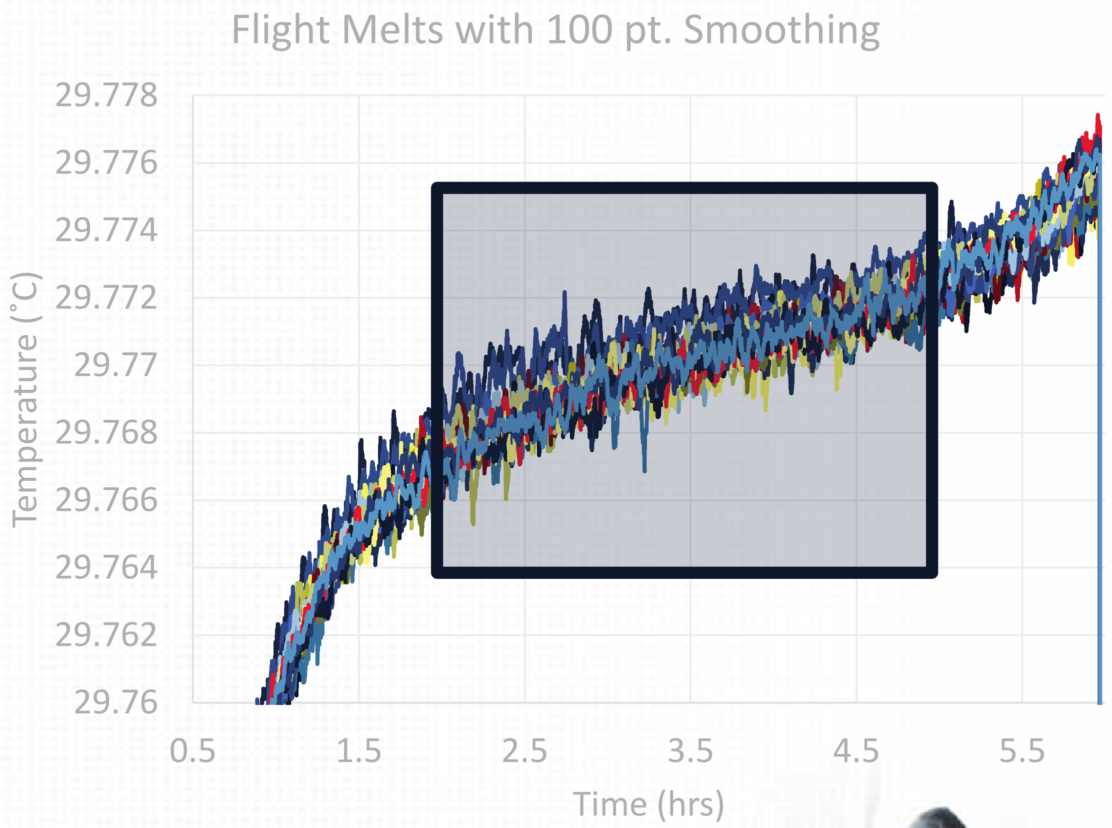
Flight Successes and Failures

- **Both Flight units initially resetting during freeze stages on ISS due to PCB over temperature faults.**
- **Energia safety requirement: software to shut down all electronics if over temperature occurs, wait to cool down, then restart.**
- **Over temperature determined to be the result of absence of natural convection on orbit.**
- **1^{st} flight unit recovered after 22 unsuccessful attempts to freeze the Ga and collected data from 21 successful freeze/melt cycles.**
- **2^{nd} flight unit never successfully froze water.**
    - Some observable passive melts and freezes of GaSn eutectic are visible in 2^{nd} unit flight data but not analyzed yet for repeatability.

Flight 1 Experiment Data Analysis

- Data quality screening
- Bath calibration correction
- Drift resistor correction
- Melt window average
- Small heater power effect correction



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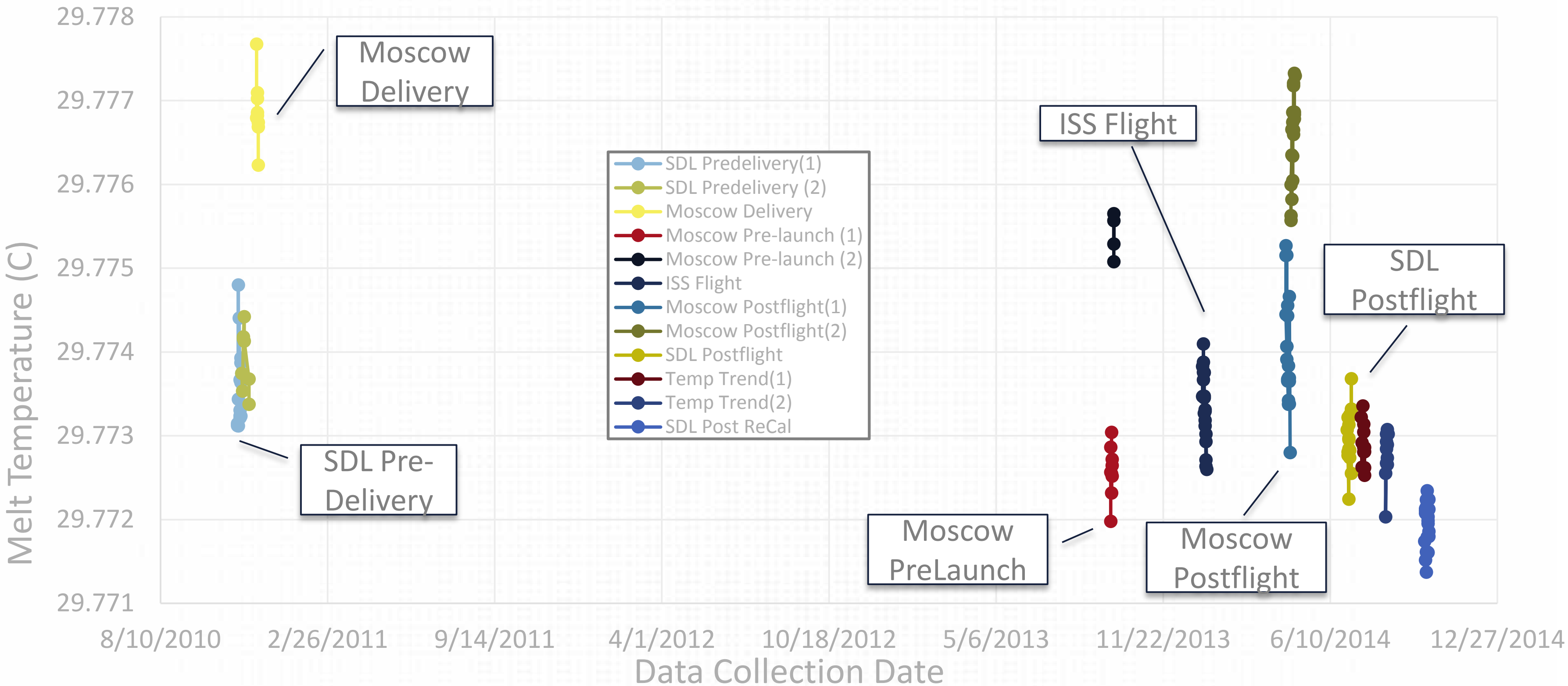
Data Collection Timeline



No continual drift trends observed over 4 years of melt data, indicates PCM contamination not a factor

Moscow Data Sets are generally noisier, less repeatable, and higher.

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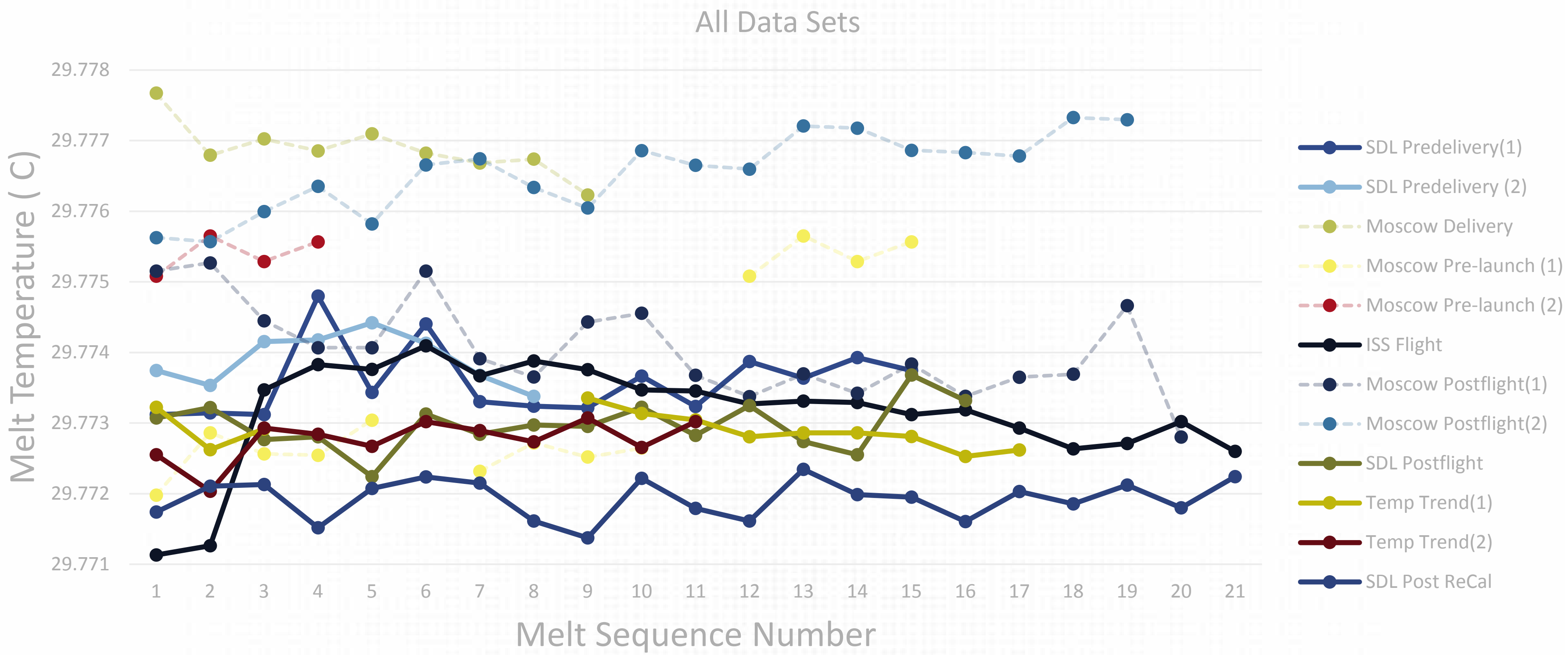
Summary of All Data Sets

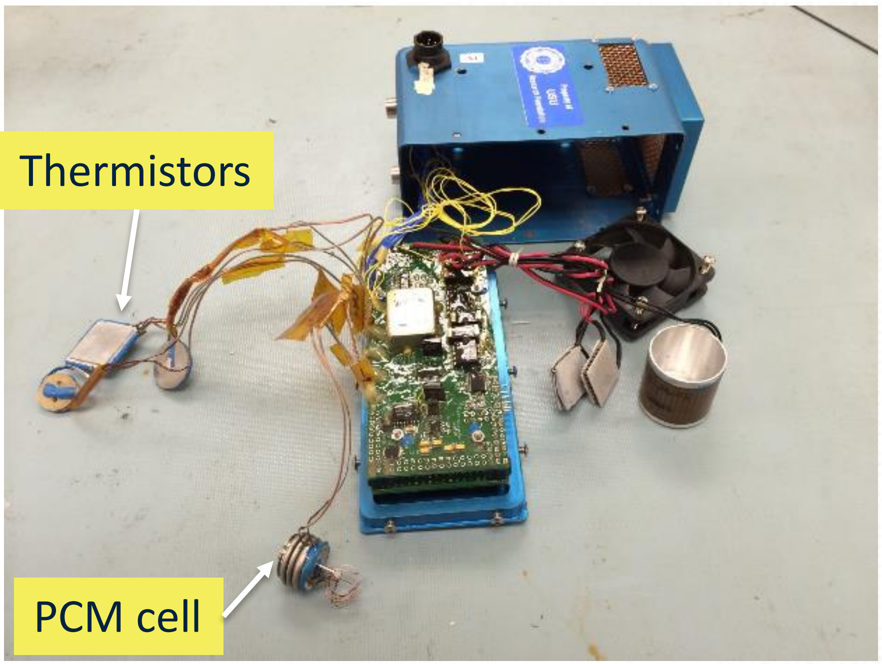


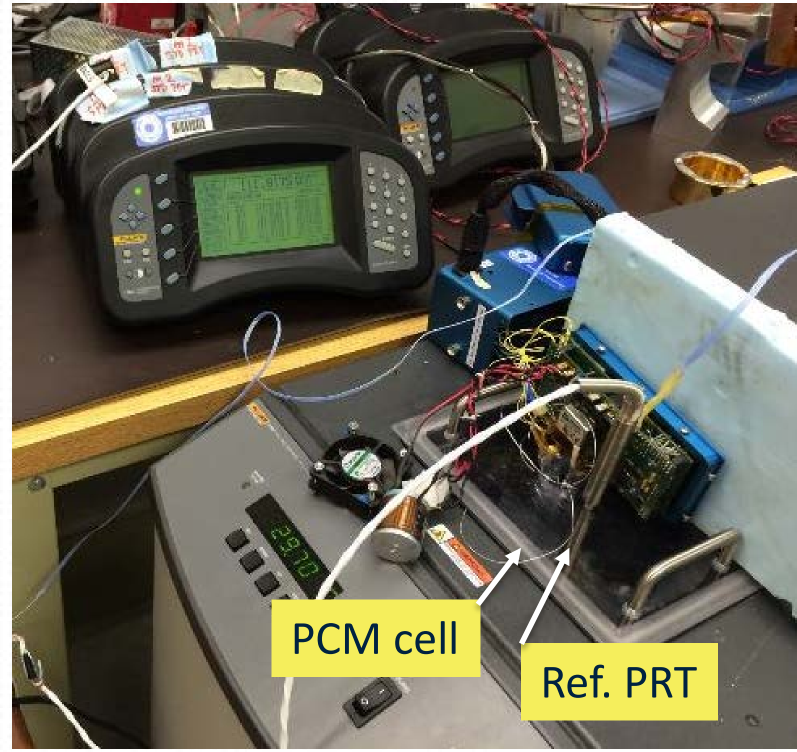
All Data: *Average Melt Temperature =* ***29.77417 C,*** *Standard Deviation =* ***1.77 mK,*** *Range* ***±4 mK***

ISS & SDL Data Only: *Average Melt Temperature =* ***29.77285 C,*** *Standard Deviation* ***0.928 mK,*** *Range* ***±2 mK***

Post Flight Ground Recalibration

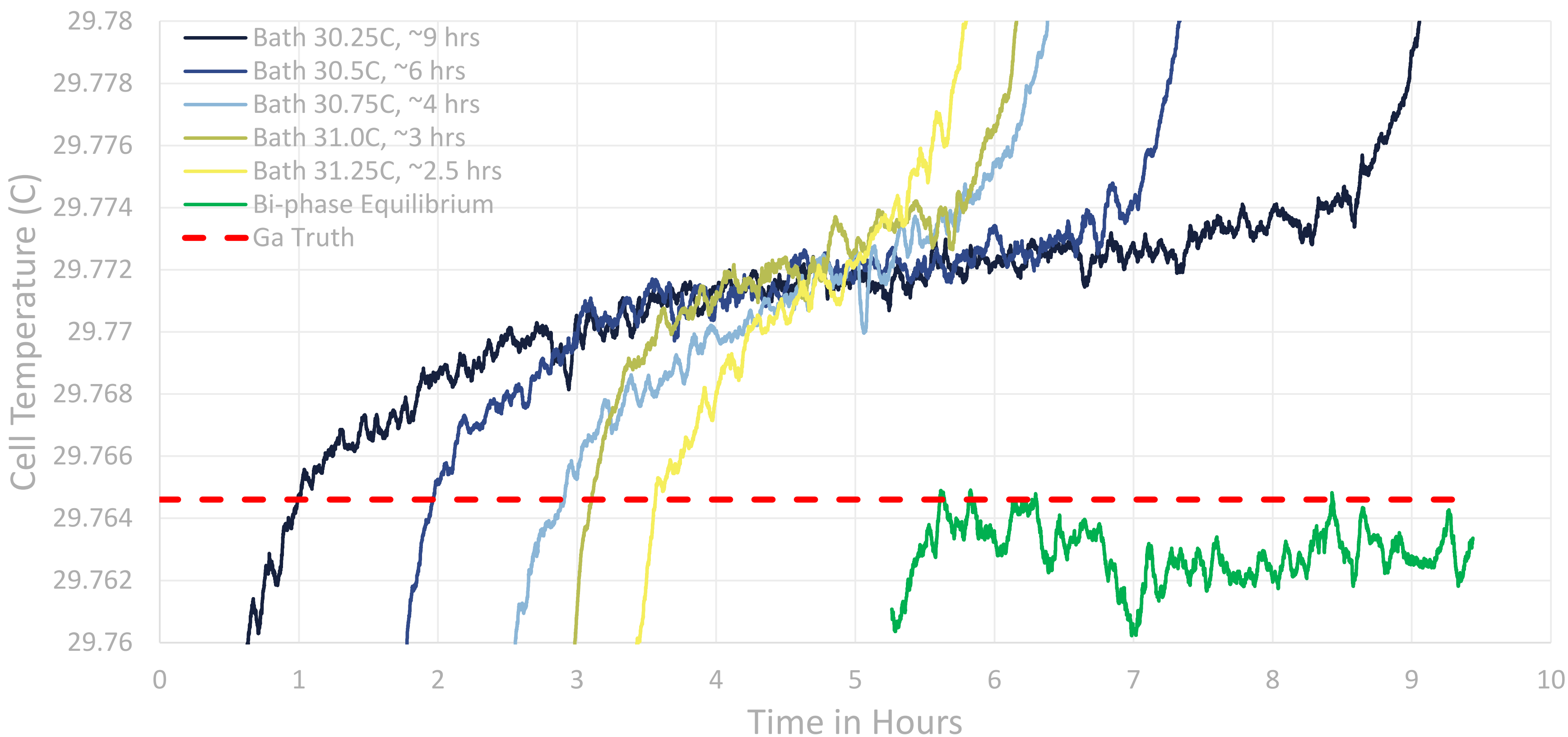
- **Temperature sensor were disassembled and place in a temperature controlled bath of Isopropanol to compare to a NIST traceable reference standard PRT.**





- **PCM was melted in bath also to verify melt temperature.**

Post-flight Bath Tests



Ga melt point = **29.7646 C**

Bath Biphase Equilibrium point T_0 **= 29.763 C** *(-1.6 mK)*

Bath melts Averaged Center Point = **29.772 C** *(+7 mK)*

Hardware melts averaged **= 29.77285 C** *(+8 mK)*

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Preliminary Conclusions

- **Absolute accuracy of melt data is within the absolute uncertainty of calibration equipment (±10mK)**
- **Within the repeatability of the instrumentation (±2 mK), there was no observable affect on Ga melt temperatures due to:**
  - the microgravity environment
  - PCM contamination or containment issues or
  - thermistor sensor drift
- **PCM fixed points are a viable method for extending the calibration accuracy and stability of orbital temperature measurements.**

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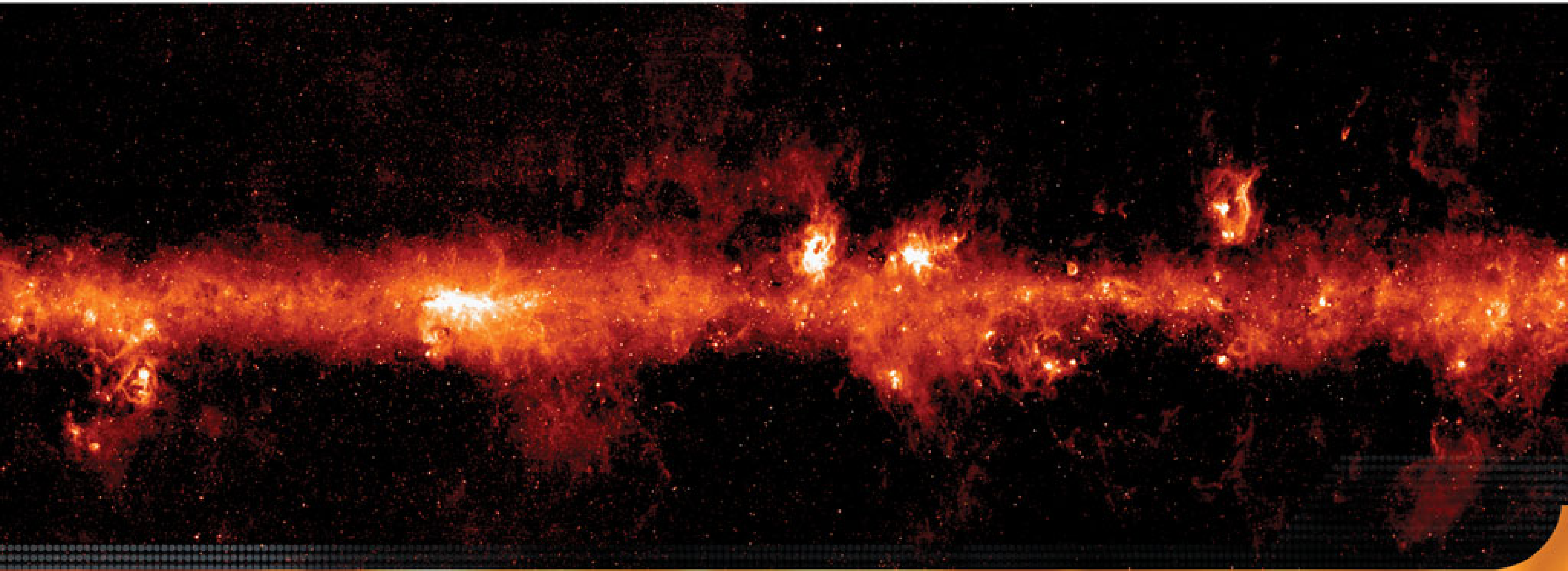

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-NASA Langley’s CLARREO team for CORSAIR work

Questions?

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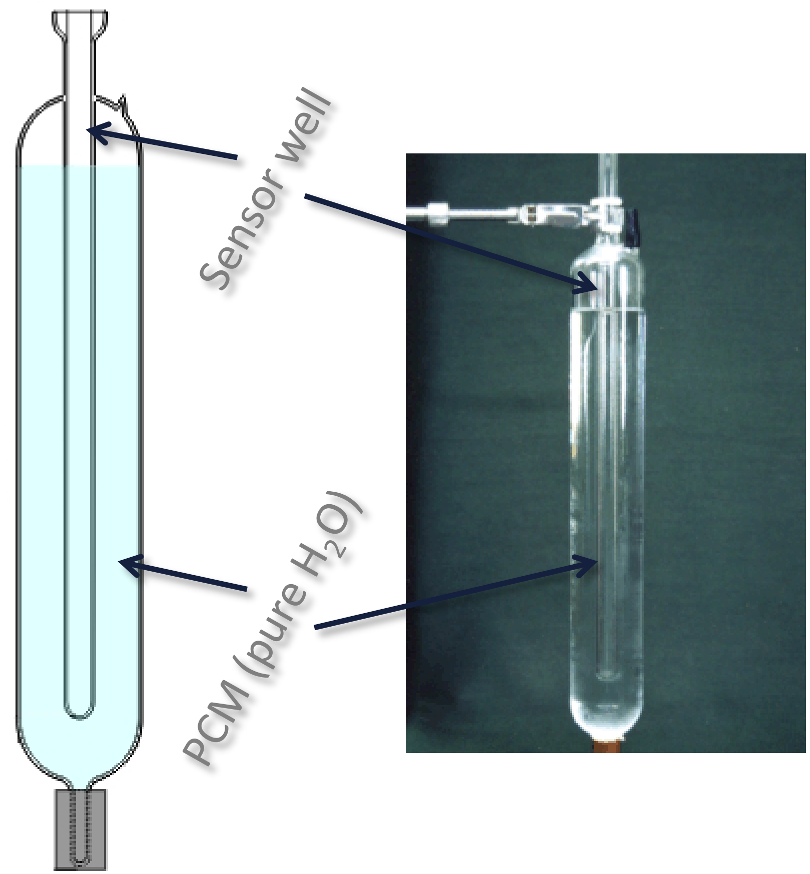
Additional Slides

Phase Transitions as References

Traditional Triple Point of Water Cell.

- Large volume of PCM
- Long melt times
- Deep reentrant
- No in situ sensor calibration
- Fragile container
- Detailed manual heating and cooling procedures

Practical absolute uncertainty, 0.1 mK or better [2,3]

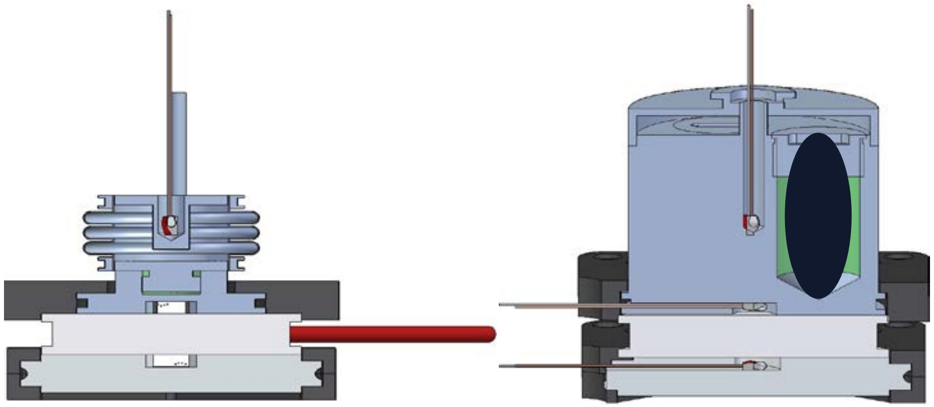


Sealed Cells vs. Pressure Dependence of Fixed-Point

- **For contamination issues PCM containers must be sealed.**
- **1 atm pressure changes melt temperature of water by 10 mK [3].**
- **Container must allow PCM expansion without changing fixed-point temperature.**

Flexible container:

-No internal voids
-PCM can expand container
-PCM vacuum filled
-complex filling
-complex container
-moving parts



Rigid container:

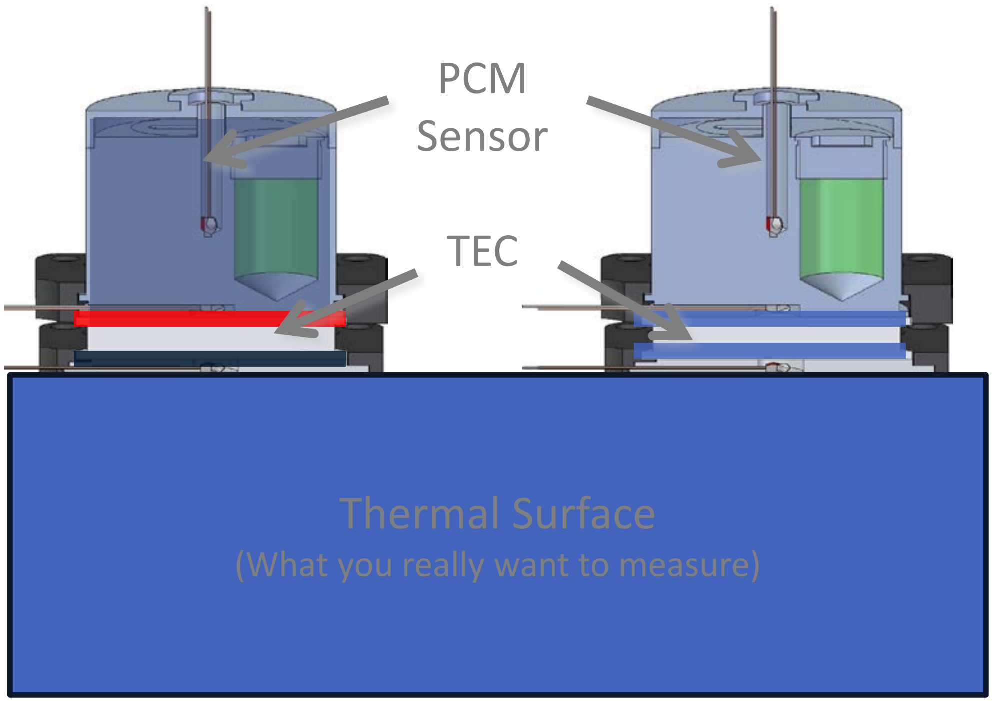
-PCM filled at 1 atm
-Internal gas voids compress as PCM expands.
-location of voids in space?

Transfer of Calibration

Calibration:

During a recalibration the TEC is powered and the PCM is controlled to a different temperature than the thermal surface to melt the PCM.

Temperature data collected during the melt allows recalibration of the PCM sensor.



Transfer:

When the TEC is not powered it acts as a thermal link to the thermal surface.

If adequately insulated it will come to equilibrium with the thermal surface.

The PCM sensor can be compared to thermal surface sensors' readings.

SDL Temperature Sensor Testing

- **Heraeus PRT and GE thermistor excellent size and long term stability [6,7].**
- **GE Thermistors tracked standards PRT ±3mK, with calibration improvement to ~1mK.**
- **Heraeus PRTs tracked ±10-15mK (worse than larger wire PRTs).**
- **Heraeus shock resistance 40g at 10-2kHz**