Appendix C

Experience of High Accuracy Thermal Modelling from the LISA Pathfinder Thermal Noise Analysis

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Abstract

The increasing accuracies of the thermal stability of space science missions requires that thermal models of the instrument payloads need to have higher stability requirements. The Lisa Pathfinder technology demonstration mission for detecting gravity waves is one such sensitive mission with changes in temperature of 10^{-6} K being significant to the payload. Following on from the work by Ulrich Rauscher on Guidelines for High Accuracy Thermal Modelling (presented at the 21st Workshop last year) the implementation of Double Precision values in ESATAN has been investigated with Lisa Pathfinder. The study of the variations on temperature convergence and the Power Spectral Density analysis of the identified Thermal Noise sources on the mission have shown that the payload meets the temperature requirements of 10^{-3} K $Hz^{-1/2}$.

Experience of High Accuracy Thermal Modelling from Lisa Pathfinder Thermal Noise Analysis

By Nick Fishwick, Simon Barraclough, 2008

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- Heat Imbalance Errors in ESATAN
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- Noise PSD Results for Lisa Pathfinder
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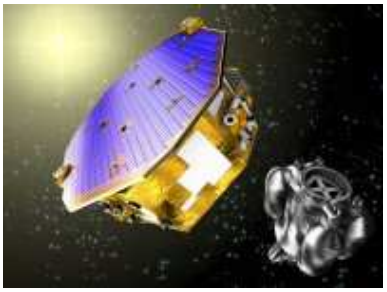
Lisa Pathfinder - Mission

- Technology Demonstration Mission for LISA
- Searching for Gravity Waves
- Lissajous Orbit at Lagrange L1
- NASA / ESA Co-op Program
- Test Lisa Technology Package (LTP) and Micro-Propulsion



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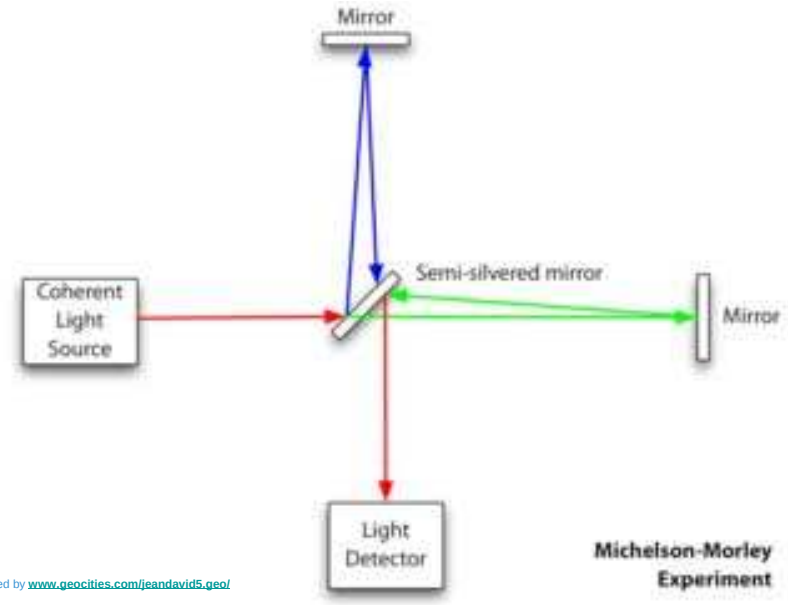
Lisa Pathfinder - Interferometer



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Michelson-Morley Experiment

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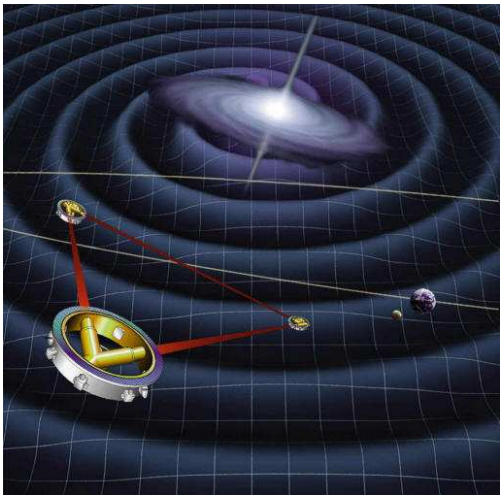
Lisa - Interferometer



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Distance between each spacecraft ≈ 5 million km

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Lisa Pathfinder – Interferometer Requirements

- Objective: "Free-Floating" Test Mass
- Very Sensitive: 10^{-12} m (atom = 10^{-10} m)
- Temperature Stability: 10^{-3} K / √Hz
  from 0.001 to 0.1 Hz

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Inaccuracies in Thermal Modelling

- ESATAN can be accurate to temperatures of order **10^{-6} K**
  (Ulrich Rauscher, 21st European Workshop on Thermal and ECLS Software)
- **Inaccurate modelling of the system is caused by:**
  - Discretization errors
  - Material data inaccuracy
  - Boundary conditions, dissipation assumptions
  - Human error from hand calculations and model definition
  - Simplified radiative modelling.
- ***Inaccuracy in the solving process***
  - *Heat imbalance errors (Model Convergence)*
  - *Influence of different solvers on the iteration process*
  - *Truncation and rounding errors in the calculation process*

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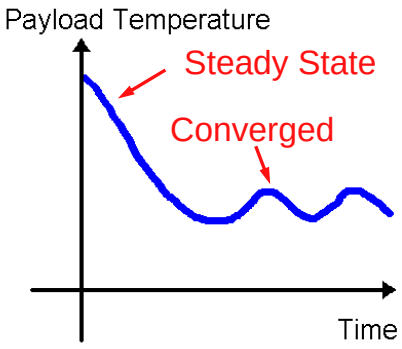
ESATAN Model Convergence

- Model needs to converge to order 10^{-6} K accuracy
- Major Sources of Thermal Noise Identified:
  - Solar Flux
  - Thruster Power Supplies
  - Power Control and Distribution Unit (PCDU)
  - Computer (OBC)
- Noise Profiles Generated
  - Determined from Solar Flux Measurements
  - Worst case where one thruster has failed
  - White Noise at 0.5% of Total Unit Dissipation
- Due to addition of Noise Profiles (external heat flux variation) during Transient calculation, there is a drift in the overall temperature level
  - Needs a Steady State pre-calculation with a very low heat imbalance to minimise temperature drift
  - Need to run the Transient Analysis until convergence



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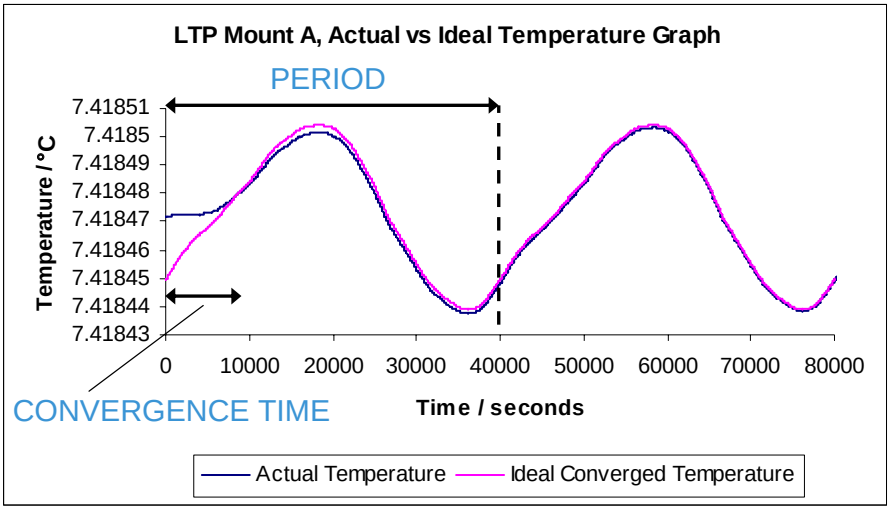
ESATAN Convergence Results



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ESATAN Model Settings

- Steady State Relaxation Convergence Criterion (RELXCA) = 10^{-10}
- Transient Relaxation Convergence Criterion (RELXCA) = 10^{-6}
- Node starting temperatures = 10.0 ºC
- Solvers used = SOLVIT
  = SLCRNC
- Output Interval = 5.0 seconds
- Most other settings at default values
  (e.g. Temperature Damping (DAMPT) = 1.0)
- Noise Profiles with no discontinuities over repeated cycles
- Real computational time takes six hours every Noise Period

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Double Precision in ESATAN

- Every value can be declared at double precision in ESATAN
- However the variable precision is changed in ESATAN from input file to executable file
  (Ulrich Rauscher, 21st European Workshop on Thermal and ECLS Software)
- For certain data blocks, the pre-processor truncates the variables down to single precision and then extends them back to double precision in the executable program file:
  - $NODES - Truncated and Extended
  - $CONDUCTORS - Truncated and Extended
  - $CONSTANTS - Truncated and Extended
  - $ARRAY - Truncated and Extended
  - $INITIAL - Remains at Double Precision

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Double Precision Workaround in ESATAN

- Declare all data in $DATA blocks as normal (initialise)
- Declare all data again in the $INITIAL block to Double Precision as Subroutines

- Problem: Limited Number of Subroutines due to Memory
  - Solution: Use ESATAN v10.2
- Problem: Limit on Size of Very Large Subroutines
  - Solution: Split up the Large Subroutines into Little Ones
- Problem: Double Precision Workaround does not allow for two separate coupling references to the same pair of nodes
  - Solution: Rewrite all multiple coupling references into one reference

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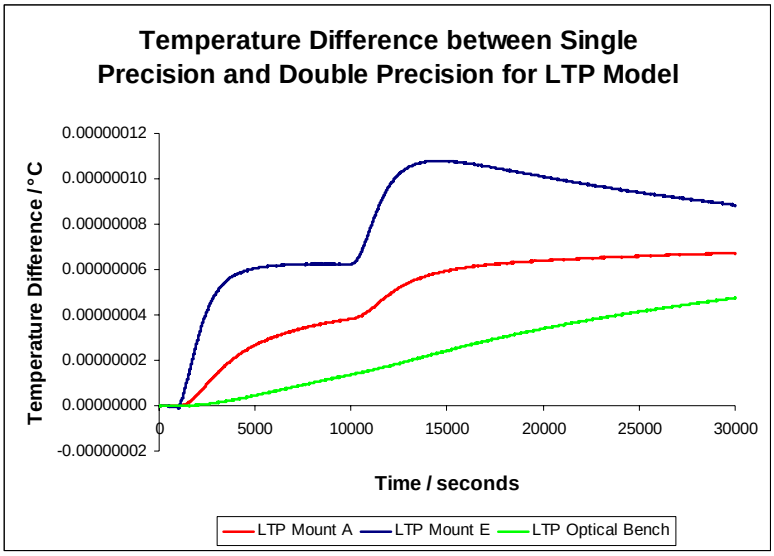
Double Precision Results



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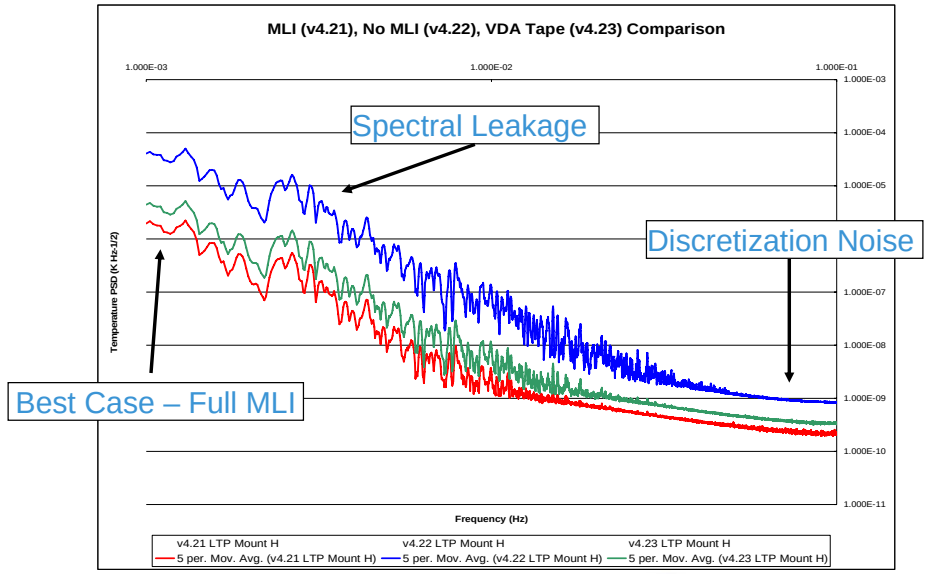
PSD Results



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Conclusion

- LTP Thermal Model meets the Requirements
- LTP Model converges to within 10^{-5} K within 1st Period
- ESATAN Double Precision Workaround Possible
- PSD Analysis Works

- Suggestions on ESATAN Improvements:
  - Make sure that data blocks in ESATAN are kept as double precision during the Pre-processor stage
  - Increase the model maximum node number capacity for the ESATAN Frequency Response Transfer Function (SLFRTF) [from 1,500 nodes to greater than 6,000 nodes]
- Next Steps:
  - Investigate Improved Noise Profiles
  - Review Alternative Transfer Functions

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Any Questions?

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