LISA

Beyond Einstein: From the Big Bang to Black Holes

LISA Thermal Design

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July 15, 2004

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Outline

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- Thermal Design (Disturbance Reduction)
- Thermal Design (Heat Rejection)
- Evaluation of Thermal Design
- Thermal Modeling Challenges
- Rapid Analysis Model Results
- Summary and Future Work

Thermal Requirements

Qualitative Requirements

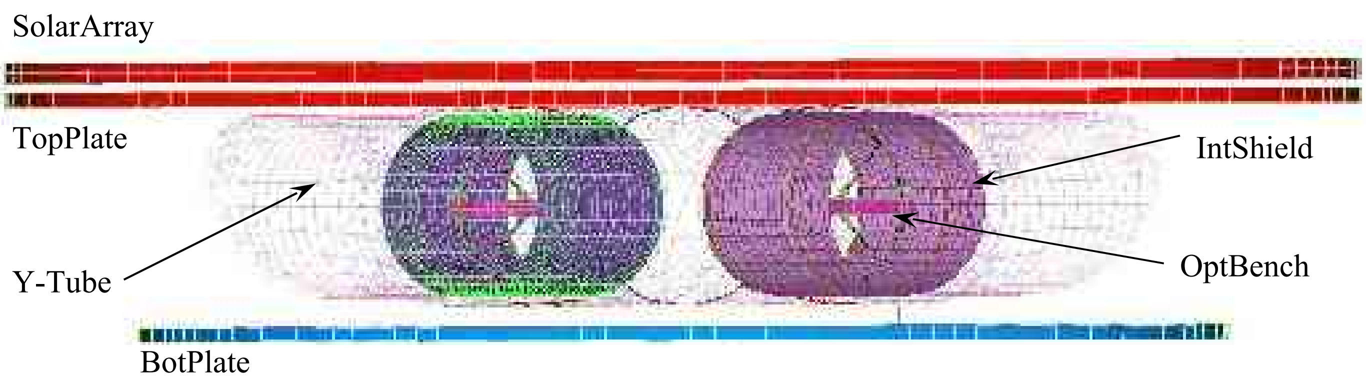
- Minimize Disturbances on Proof Mass
  - Self Gravity changes with Thermal Distortion
  - Gas Pressure Effect
  - Radiation Pressure Effect
  - Outgassing Effect
- Minimize Thermal Distortions on Optical Bench and Components (Alignment)
- Identify Potential Thermal Disturbances
  - Variations in Solar Flux
  - Variations in Power Dissipations

Quantitative Requirements

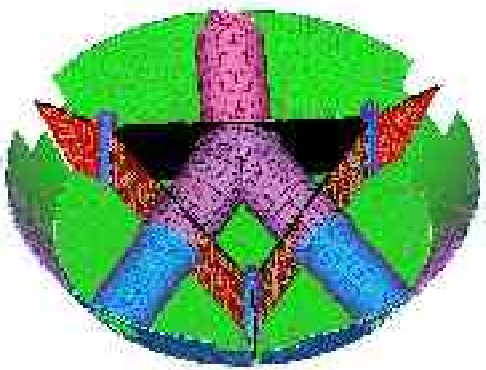
- Maximum temperature gradient fluctuations across the GRS reference housing = 60 $\mu K/\sqrt{Hz}$ at 0.1 mHz.
- Maximum temperature fluctuation of the laser stabilization cavity = 10 $\mu K/\sqrt{Hz}$ at 1 mHz

Thermal Design (Disturbance Reduction)

- Thermally stable environment (Constant orientation to sun, Zero Earth/Albedo)
- Power Stabilized electrical components (constant dissipation)
- Descending layers of thermal isolation (both conductive and radiative) to minimize effect of disturbances. Three "zones" of isolation are identified:
  - ***Through the Solar Array:*** The SolarArray Panel is made up of two layers of honeycomb with top layer cells filled with low conductivity foam. The SolarArray is also isolated from the TopPlate by low conductivity standoffs
  - ***Through the Y-Tube:*** The Y-Tube is coated with a highly specular, goldized coating to minimize the radiative heat transfer path. The Y-Tube is also isolated with three low conductivity standoffs from the BotPlate to minimize the conduction path
  - ***Through the Internal Shield:*** The IntShield is coated with a highly specular, goldized coating to minimize the radiative heat transfer path and low conductivity pivots to minimize the conduction path from the Y-Tube



Radiator, Walls, Tubes Not Shown



SolarArray, TopPlate Not Shown

Thermal Design (Heat Rejection)

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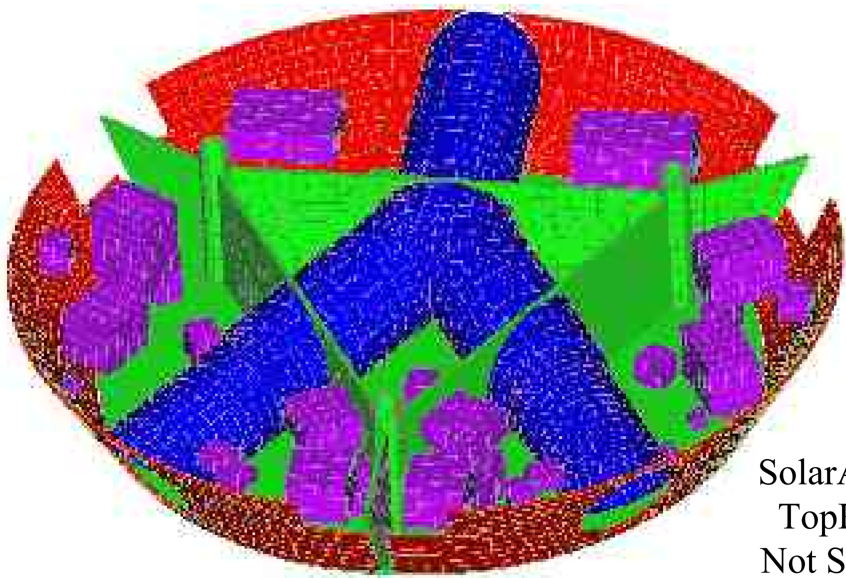
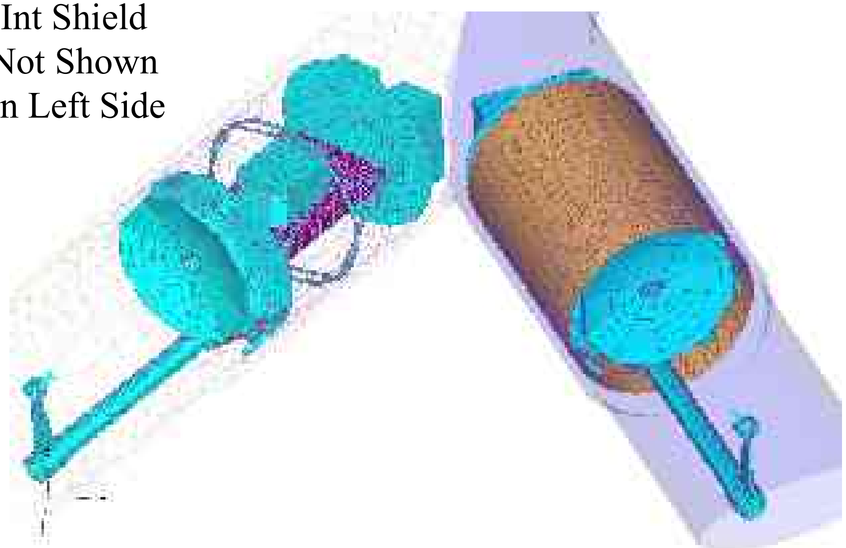
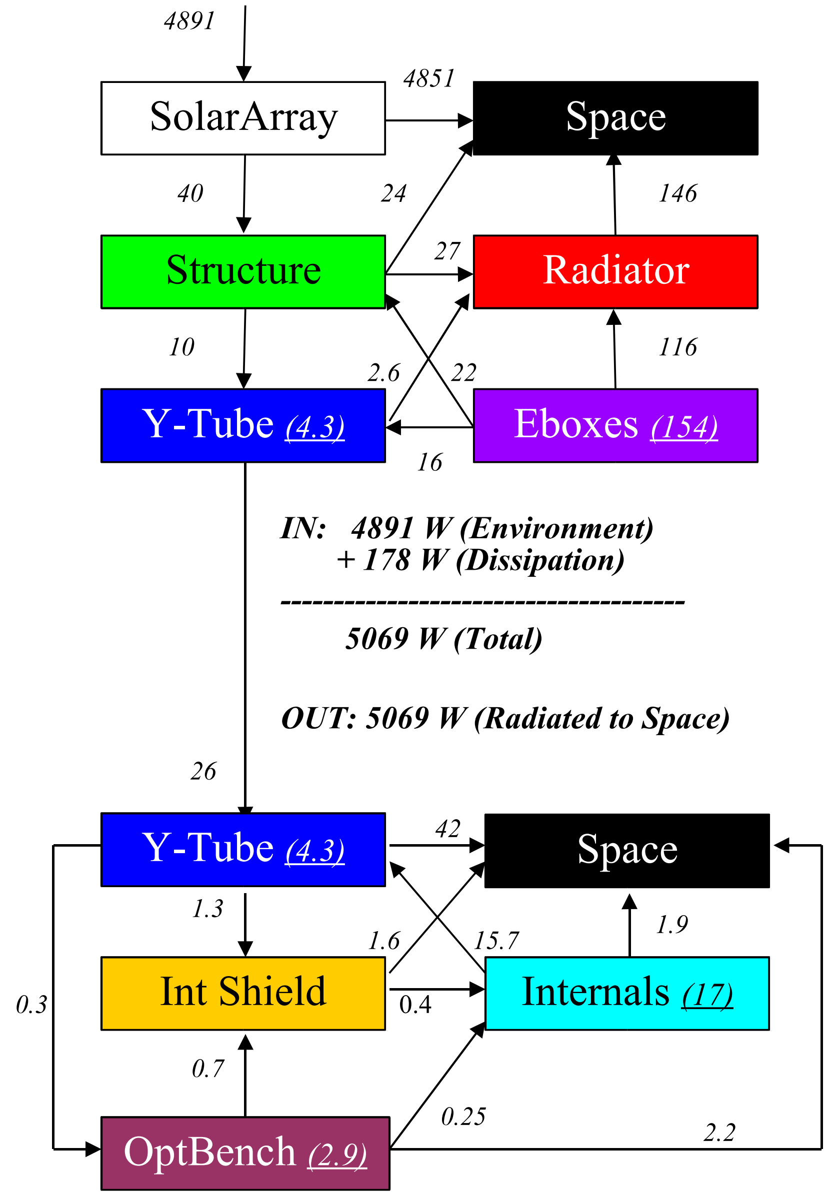


SolarArray, TopPlate Not Shown

Int Shield Not Shown on Left Side

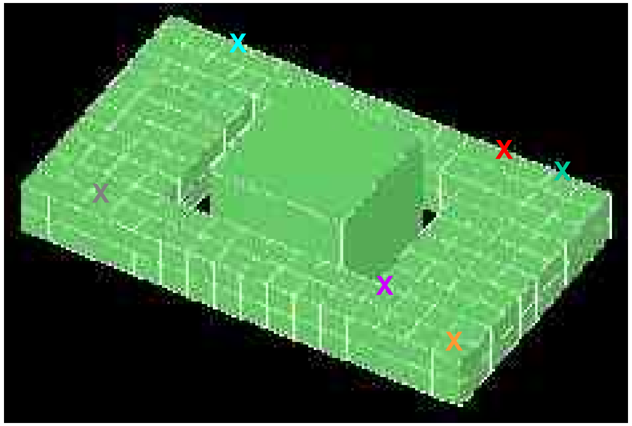




Evaluation of Thermal Design

- Difficult to ground test (End-to-End)
  - Self-Gravity/Radiation Pressure effects cannot be demonstrated in a 1g environment
  - Difficult to simulate minor solar variations in testing environment
- LISA will rely strongly upon modeling for design validation
  - High accuracy needed to satisfy requirements
- Numerous STOP-G (Structural-Thermal-OPtics-self Gravity) FEM analyses
  - Necessary to identify and minimize any sources of error
  - Single mesh used to eliminate temperature mapping errors
  - Highly detailed mesh needed for Structural and Self-Gravity
- Rapid Analysis model used for trade studies (Surface Based/Finite Difference)
  - Effect of local component heating on optical bench
  - Temporal response/thermal lag to sine inputs
  - Test case for Backload-Interface Solution method

Component	Abbr	Power
Quadrant Photodiode 1	qp1	1.1457
Photodiode	p1	0.2601
Charged-Coupling Device	CCD	0.024
Photodiode	p3	0.0162
Fiber Positioner	FP	0.01
Photodiode	p2	0.0007



Thermal Modeling Challenges

- Current models represent TRIP Report design; used to test modeling practices, software capabilities, and data exchange
- Finite Element Models (FEM) not typically used for Thermal Analysis
  - Thermal software traditionally does not interface well to FEM
  - Thermal Detail << Mechanical/Self-Gravity Detail
- Thermal Software Evaluation (codes that work well with FEM)
  - ***TMG:*** Element temperatures solved; extrapolate to get node temperatures
  - ***ThermalDesktop:*** Node temperatures solved, no extrapolation needed
  - Simplified FEM (~10000 nodes) used in each code for evaluation purposes
- Use of a single mesh to eliminate mapping errors leads to…
  - Very large thermal model (generating too many radiation terms for current OS)
  - Potential errors associated with filtering small radiation terms
  - Long solution times
- High accuracy requirements also increase solution times (more iterations needed)
- Propose to solve the Internal and External models independently
  - More radiation terms included in solution
  - Backload / Temperature at Y-Tube interface

Rapid Analysis Model Results

Spatial Temperature Differences

	15.018	14.738	14.109	13.355	12.622	12.105	11.812	11.607	11.487	**11.547**
	16.553	15.758	14.742	13.79	12.994	12.398	11.987	11.705	11.508	11.372
	20.008	17.721	15.721	14.324	13.328	12.628	12.151	11.836	11.596	11.405
qp1	**29.98**	20.723	16.609	14.731	13.55	12.772	12.274	12.019	**11.771**	11.5
	20.022	17.778							11.782	11.623
	17.767	16.965							11.733	11.658
	15.888	15.805							11.796	11.756
	14.846	14.894							11.951	11.923
	14.193	14.252			To Telescope ↑				12.177	12.15
	13.774	13.825							12.471	12.43
	13.515	13.56							12.852	12.749
	13.365	13.421							13.403	13.045
	13.26	13.27	13.325	13.409	13.524	13.679	13.877	14.115	14.516	15.337
	13.24	13.256	13.31	13.393	13.509	13.67	13.898	14.259	14.998	**17.363** p1
	13.21	13.235	13.289	13.371	13.484	13.638	13.849	14.143	14.567	15.138
	13.178	13.214	13.269	13.349	13.457	13.601	13.786	14.012	14.259	14.439

Temperatures across Optical Bench (29.98-11.37°C)

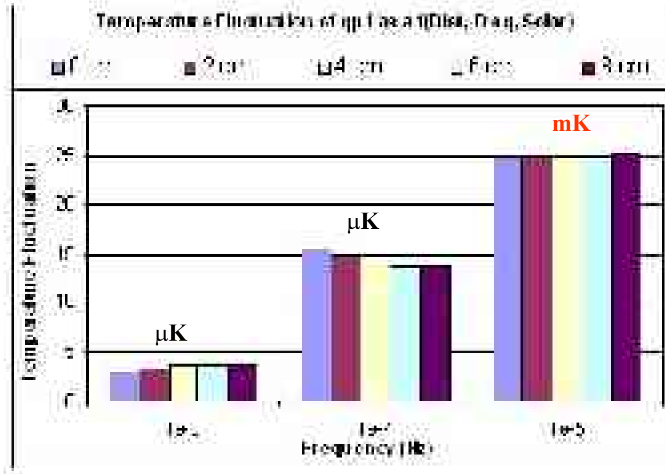
Temporal Temperature Fluctuations with respect to:

- Solar Variation *(1%)*
- External Electronics Box Variation *(1%)*
- Optical Component (qp1 and p1) Variation *(1%)*

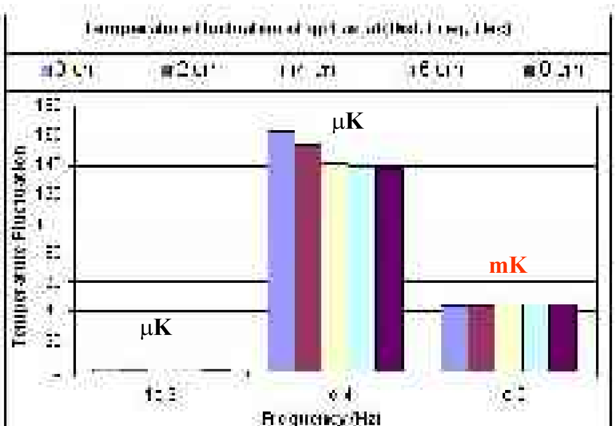
Expected Solar Variation as a function of Frequency

Freq	Solar
1e-3	0.13%
1e-4	0.28%
1e-5	0.60%

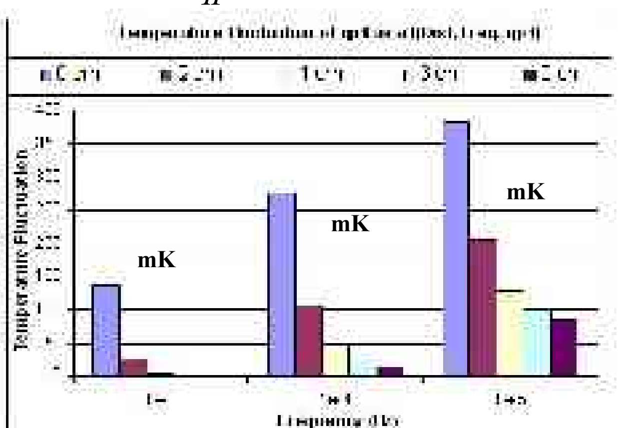
Solar Variation



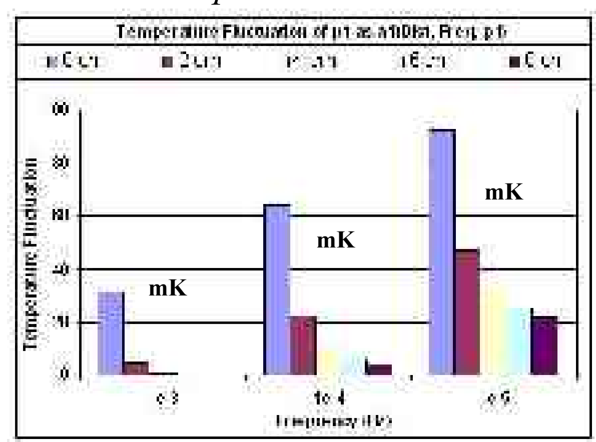
Electronics Variation



qp1 Variation



p1 Variation



Summary and Future Work

- Layers of thermal isolation in the thermal design effectively filter disturbances in important frequency ranges (1 Hz to 0.1 mHz)
  - Majority of Solar environment is re-radiated to space due to low conductivity foam
  - Y-Tube and Internal Shield help to further reduce disturbances
- Critical to minimize electronic dissipation disturbances
- Accurate modeling will be very important to LISA
- Rapid Analysis model used to investigate sensitivities and trade studies
  - Much faster turnaround of results than FEM
  - Effect of local optical component variations diminishes rapidly with distance
- Future Work
  - Currently evaluating STOPG FEM for Self-Gravity effects
  - Run STOPG FEM with more radiation terms
  - Further investigation of TMG and ThermalDesktop accuracy
  - Design modifications to baseline configuration