Recent Progress at NASA in LISA Formulation and Technology Development

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U.S. LISA Project Scientist

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Abstract

Over the last year, the NASA portion of the LISA team has been focused its effort on advancing the formulation of the mission and responding to a major National Academy review. This talk will describe advances in, and the current state of: the baseline mission architecture, the performance requirements, the technology development and plans for final integration and test. Interesting results stimulated by the NAS/NRC Beyond Einstein Program Assessment Review will also be described.

BEPAC - Overview and Documents

- ***The NASA Administrator requested a review of the Beyond Einstein Program (LISA, Constellation X, Black Hole Finder, Joint Dark Energy Mission, CMB Polarization), and a recommendation for which mission would start first.***
- ***The Beyond Einstein Program Assessment Committee (BEPAC) first met in November 2006, and will deliver their report in September 2007.***
- ***The LISA Project, particularly the NASA team, expended ~8 months of effort responding to the BEPAC.***
- ***The response included:***
  - *3 BEPAC meetings with two major presentations*
  - *4 Town Hall meetings*
  - *211 pages answering 71 questions*
  - *8 major documents totaling 656 pages*

Science Requirements

- ***There is a new "science case" document, available at http://www.lisa-science.org/resources/talks-articles/science/lisa_science_case.pdf***
- ***The science requirements document (ScRD) is the statement of the science that the project intends to perform.***
- ***The LISA International Science Team (LIST) is evolving the ScRD from SNR-based detection to uncertainty in estimation of source parameters from mission data.***
- ***Version 4 of the science requirements document is based on***
  - *Science Objectives*
  - *Science Investigations*
  - *Observational requirements*
  - *Instrument sensitivity model*
  - *Validation calculations*

Science Requirements

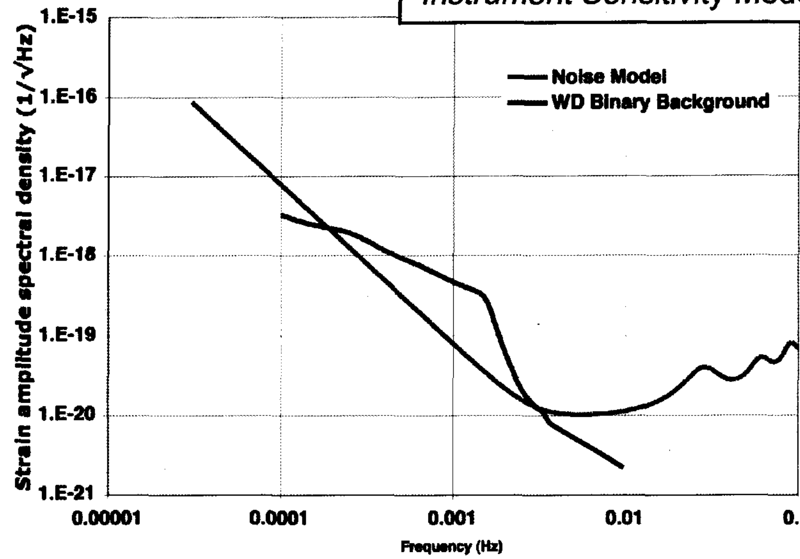
Science Investigation

4.2.1 Determine the relative importance of different black hole growth mechanisms as a function of redshift

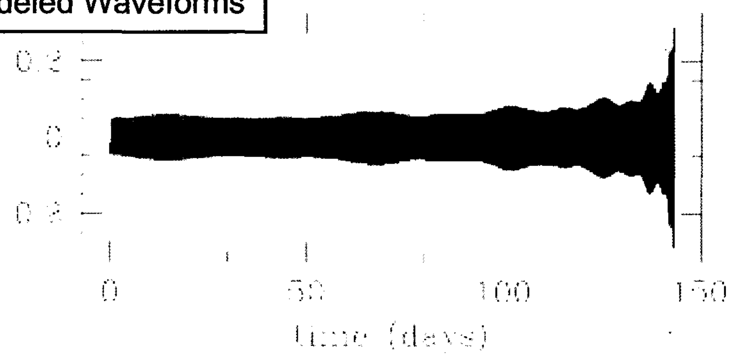
Observation Requirement

OR2.1: LISA shall have the capability to detect massive black hole binary mergers, with the larger mass in the range $3x10^4\ M_{\odot} < M_1 < 3x10^5\ M_{\odot}$, and a smaller mass in the range $10^3\ M_{\odot} < M_2 < 10^4\ M_{\odot}$, at $z = 10$, with fractional parameter uncertainties of 25% for luminosity distance, 10% for mass and 10% for spin parameter at maximal spin. LISA shall maintain this detection capability for five years to increase the number of observed events.

Instrument Sensitivity Model



Modeled Waveforms

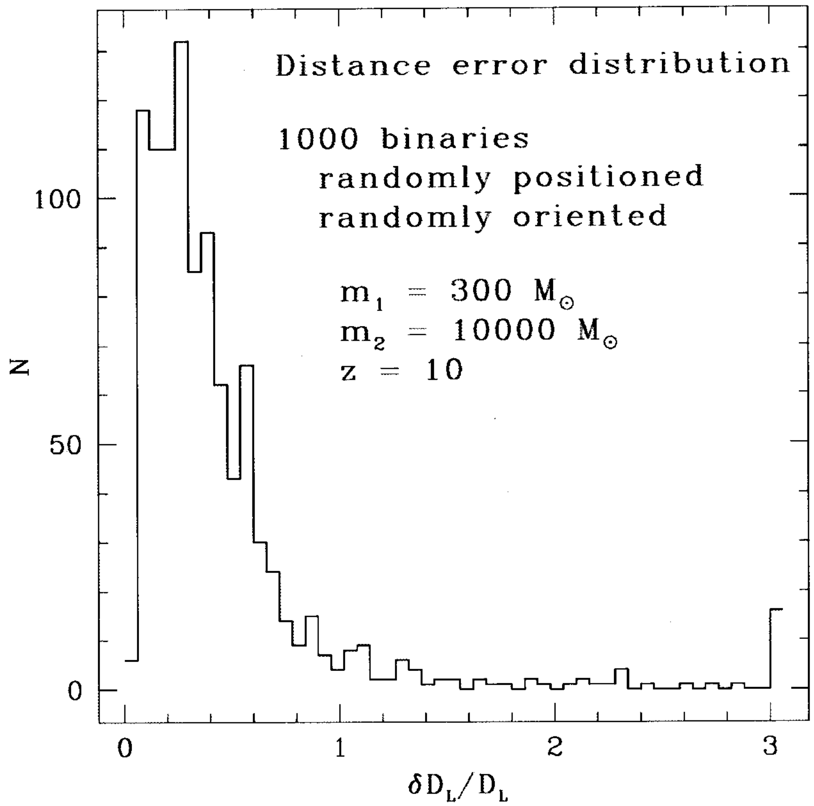


Parameter Uncertainties

M_1	M_2	D_L Uncertainty	Spin Uncertainty	SNR
1.00E+04	3.00E+02	31.90%	0.012	10.80
	1.00E+03	34.10%	0.029	18.50
	3.00E+03	43.20%	0.070	30.90
	1.00E+04	41.10%	0.115	47.90
3.00E+04	3.00E+02	28.50%	0.005	14.90
	1.00E+03	26.80%	0.008	26.40
	3.00E+03	25.00%	0.016	45.30
	1.00E+04	24.20%	0.041	79.50
1.00E+05	3.00E+02	31.70%	0.005	14.60
	1.00E+03	23.30%	0.006	27.80
	3.00E+03	20.20%	0.008	46.00
	1.00E+04	19.30%	0.020	75.00
3.00E+05	3.00E+03	22.50%	0.016	10.20

Lang & Hughes

- **Lang & Hughes calculation**
  - Full 2 PN waveform simulation
  - Sky and polarization averaged
  - 1 and 2 interferometers
  - Monte Carlo spins
  - Median performance



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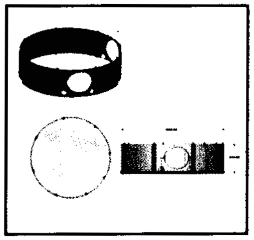
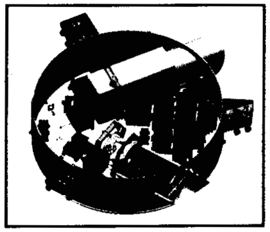
Mission Elements and Integration

Mission

Launch Segment (LS) | Flight Segment (FS) | Ground Segment (GS) | Science Data Processing Segment (SDPS)

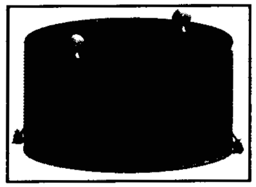




x3

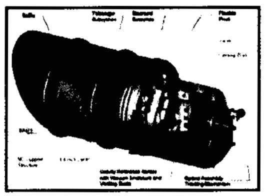
Bus

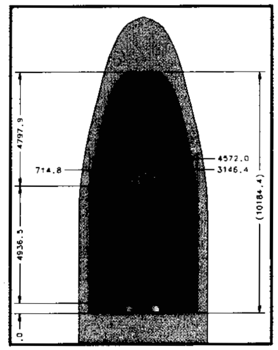
Scientific Complement/ Payload (PL)



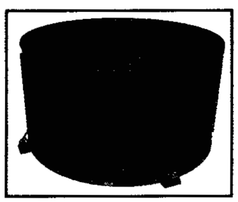
Sciencecraft

Propulsion Module (P/M)





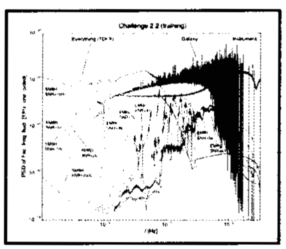
Spacecraft (S/C)

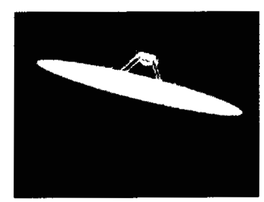


Stack

EELV

Launch/Cruise/Science





Science Operations Centers (SOCs)

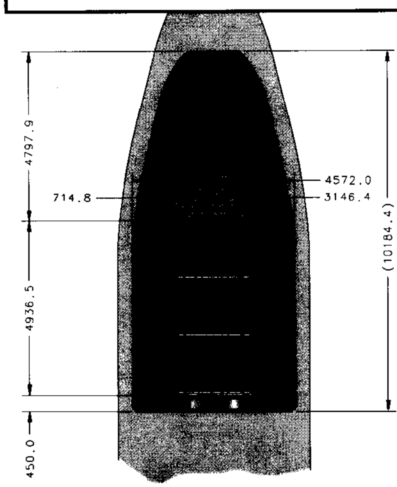
Mission Operations Center (MOC)

DSN

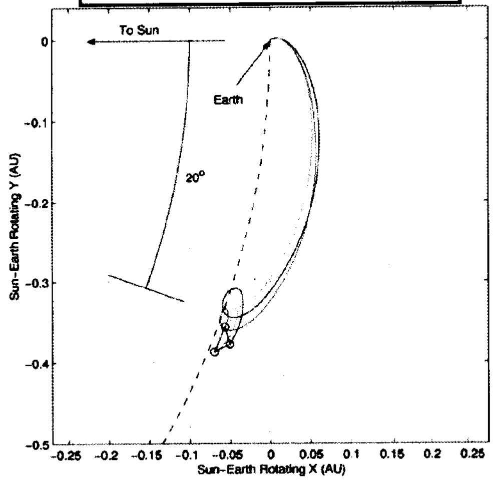
Mission Design

Atlas 531 EELV

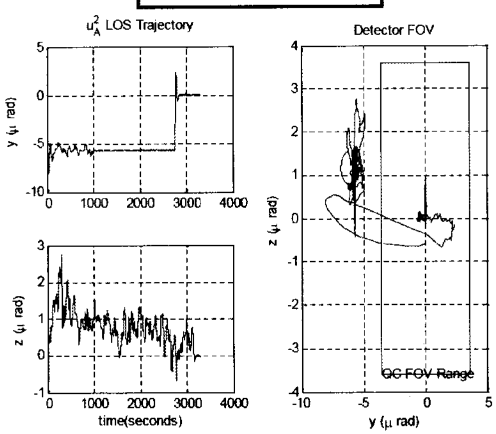
Stack in Atlas 5 m PLF



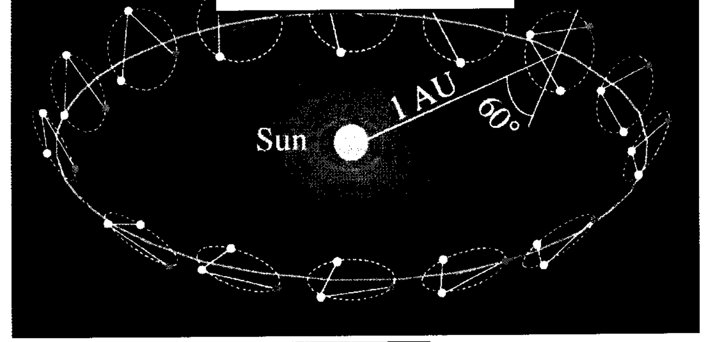
Cruise Trajectories



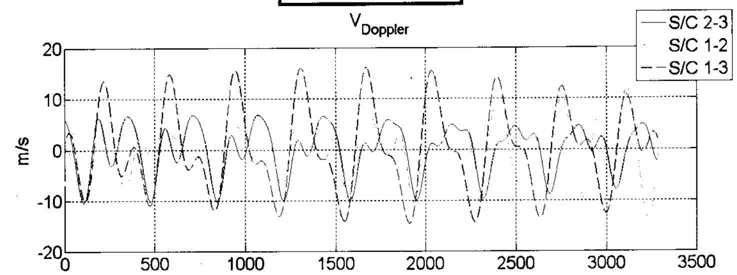
Acquisition

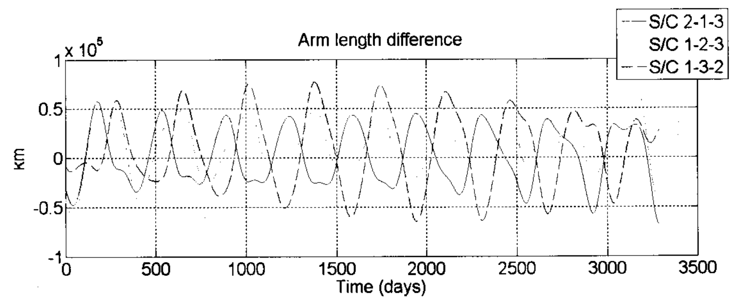


Science Orbits

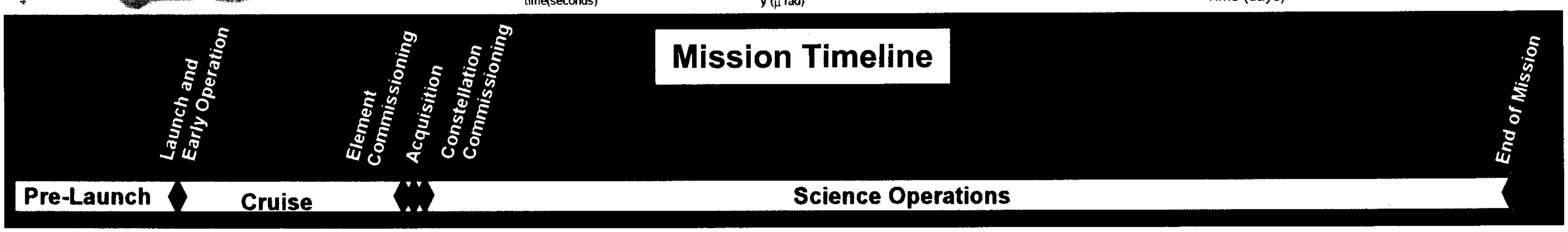


Doppler

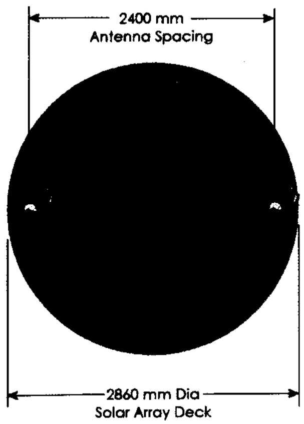


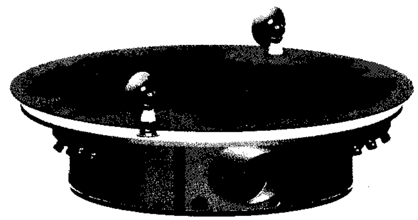


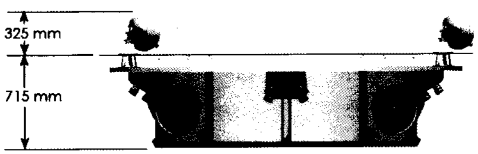
Mission Timeline

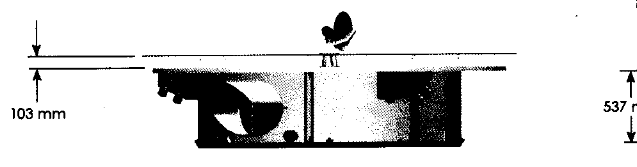


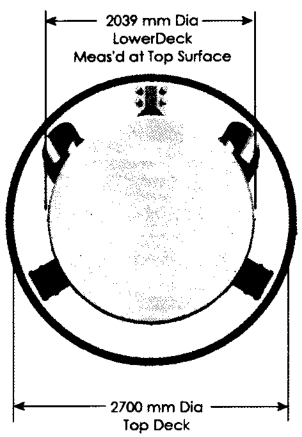
Bus – "Designed around the Science Complement"

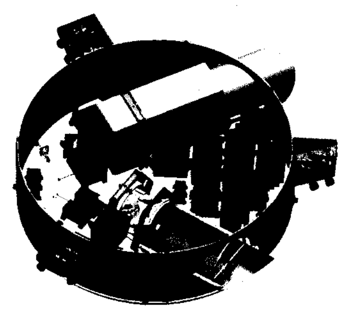








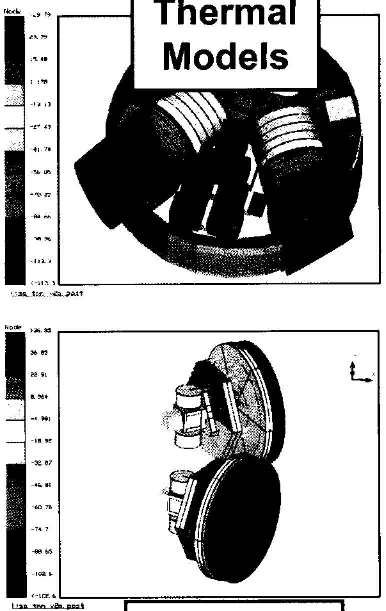




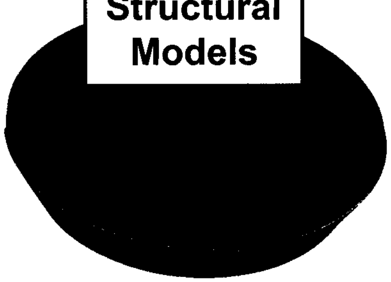
Propulsion	▪µN thrusters
ACS	▪Star Trackers ▪Sun Sensors ▪Gyros
Comm.	▪2 Ka-Band HGAs ▪4 X-Band Omni LGAs
C&DH	▪Flight Proven CPU ▪Standard Serial Bus
Thermal	▪Passive Design
Power	▪Triple junction GaAs fixed SA ▪Li-Ion Battery
Structures and Mechanisms	▪Aluminum Honeycomb Composite ▪2 mechanisms

Sciencecraft

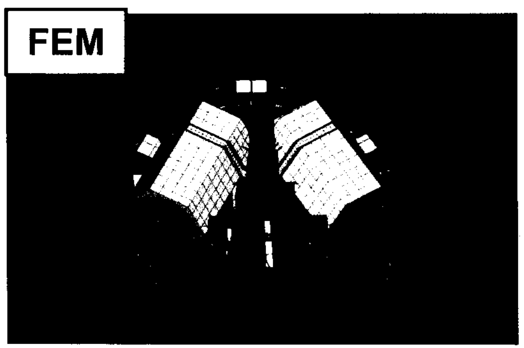
Thermal Models



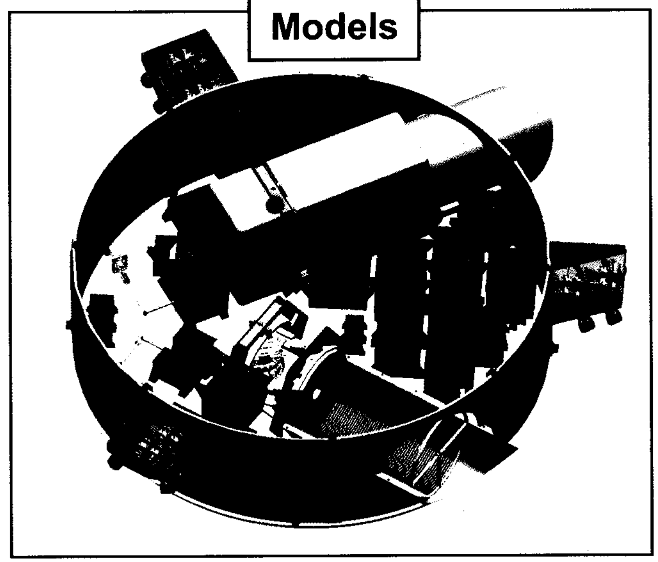
Structural Models



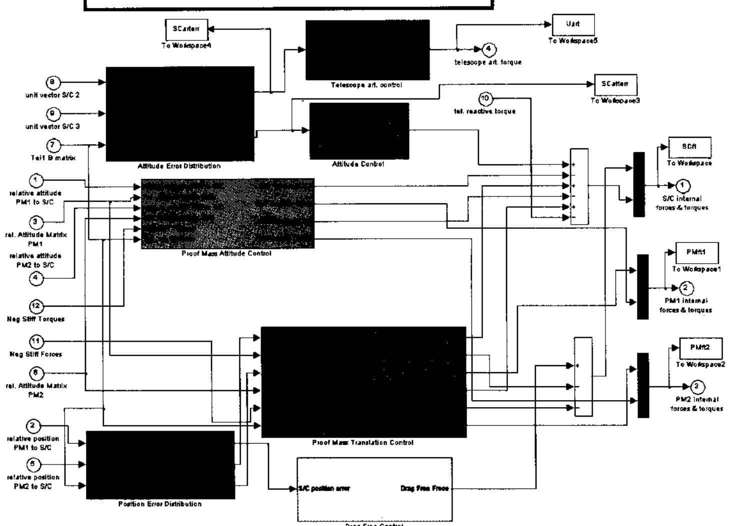
FEM



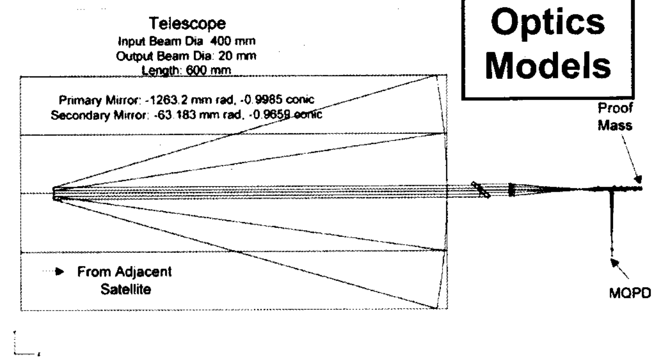
CAD Models



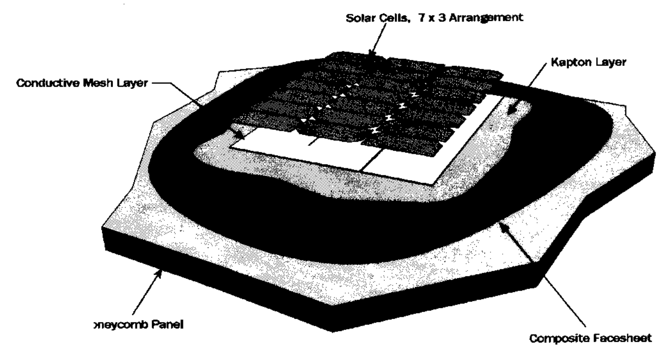
Simulink®/Stateflow® DRS Controls Model



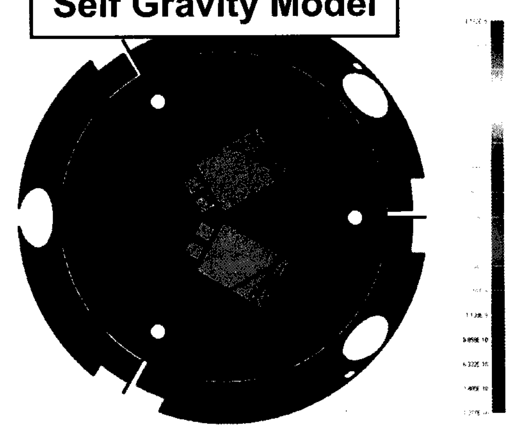
Optics Models



SA Assembly Magnetics

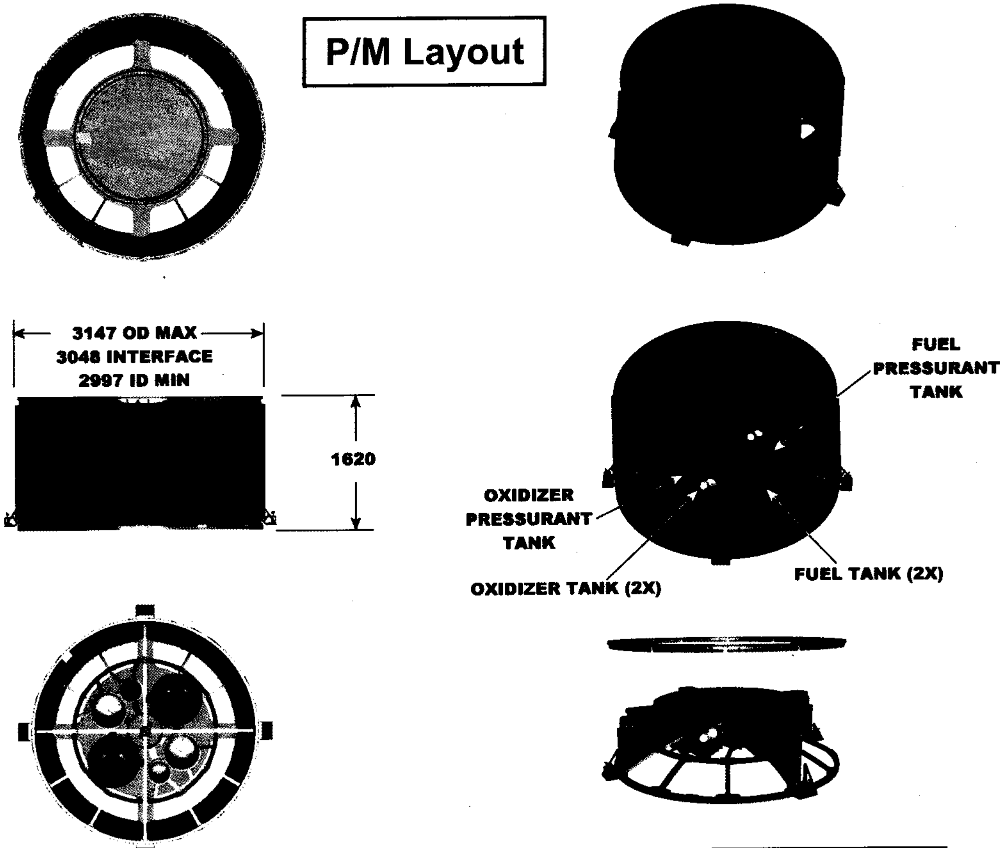


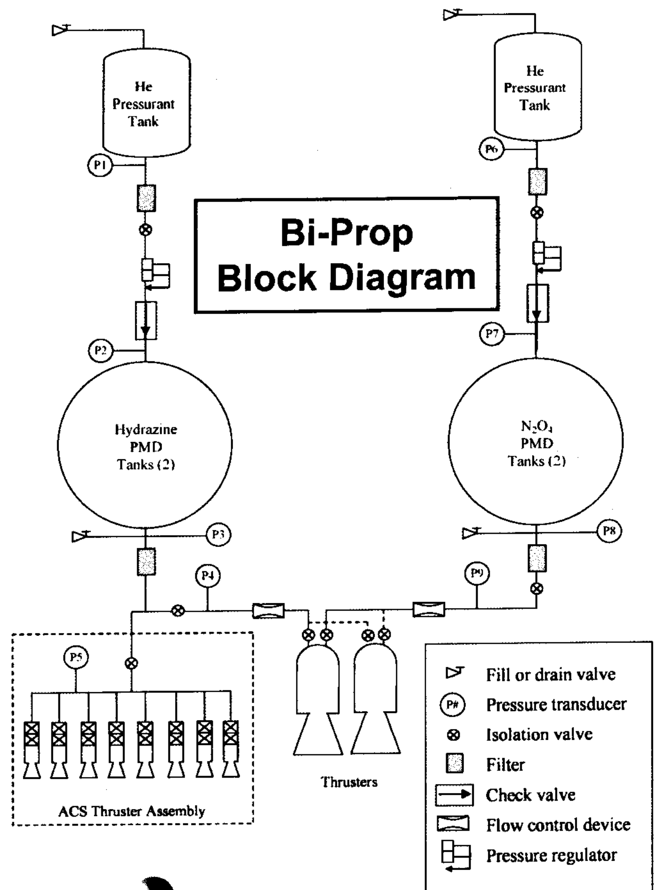
Self Gravity Model



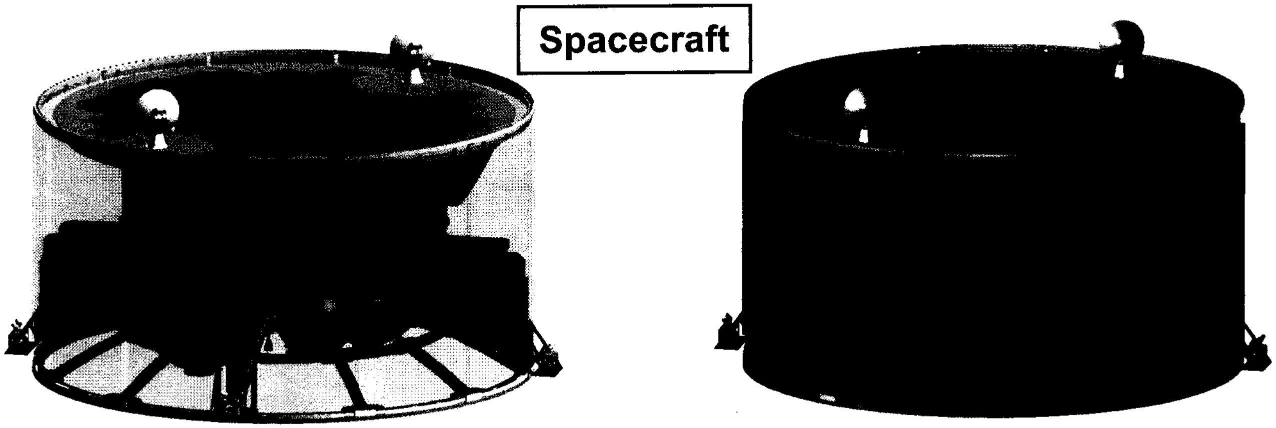
Propulsion Module (P/M) / Spacecraft (S/C)

P/M Layout



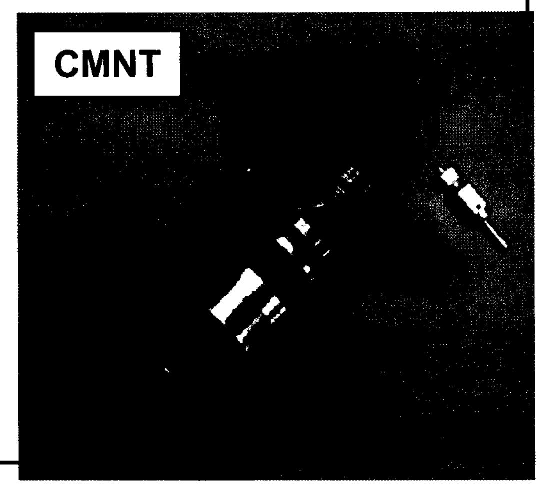


Spacecraft



Technologies – μN Thrusters

- ***Prototype thruster emitter testing continuing successfully***
  - *Emitter current stability improvement has been demonstrated, reducing thrust noise and overspray*
  - *Emitter design is compatible with ST7 thruster head to maximize heritage*
  - *We continue to prepare for our long duration test of emitter clogging (Starts in July-August)*
- ***Completed testing of first LISA Colloid Micro-Newton Thruster***
  - *Thruster purchased from Busek in Fall of 2005; testing was completed last month*
  - *Evidence for low-energy ion population in exhaust beam verified by independent measurements of beam energy*
  - *Results are critical to understanding accelerator overspray and beam / neutralizer / spacecraft interactions*
  - *Results will be presented at the 2006 Joint Propulsion Conference in July*
- ***Completed initial model of bubble formation and collapse in propellant feed system***
  - *Understanding bubble formation and collapse is critical to thruster performance and lifetime*



Trade Studies

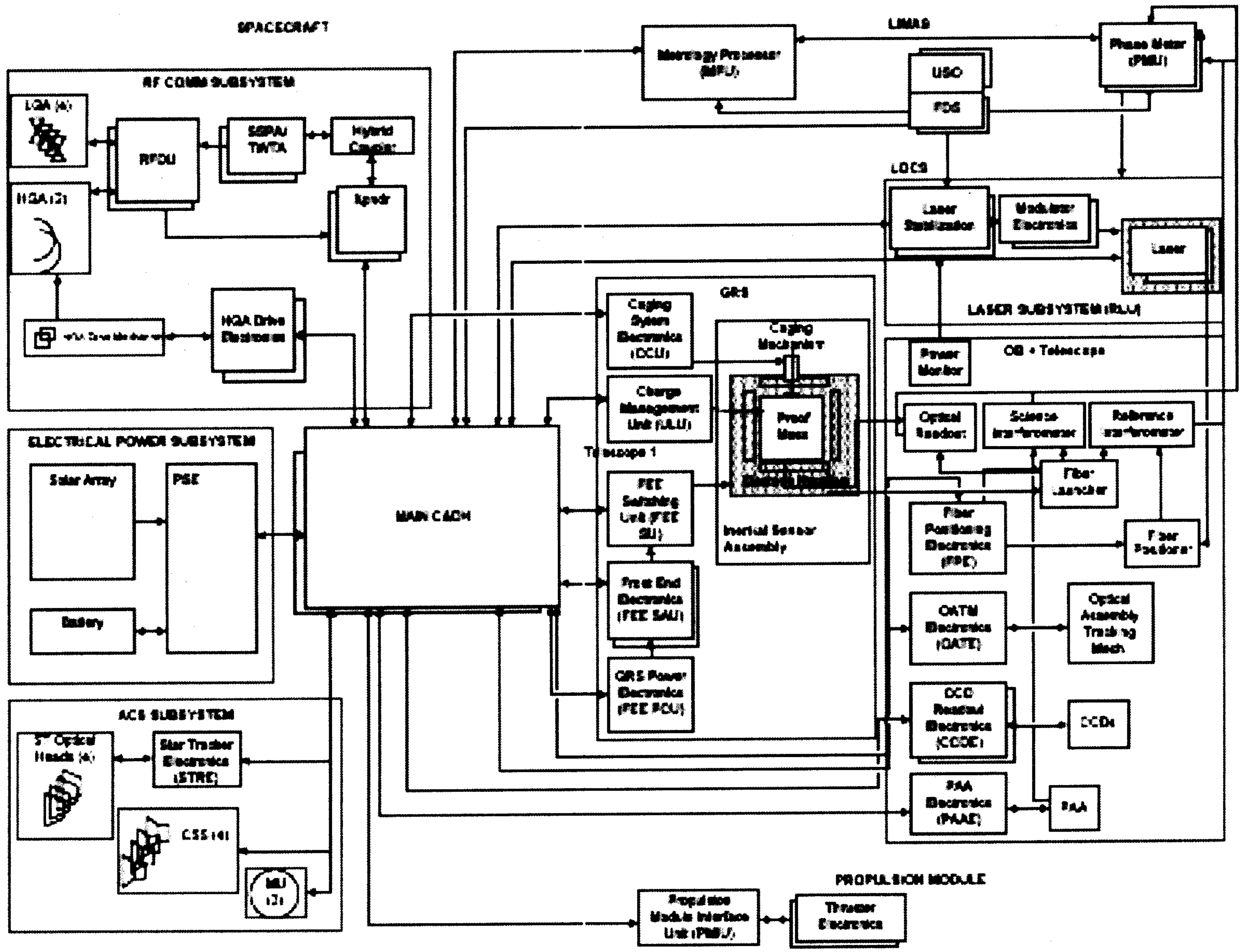
- √ *Propulsion Module And Launch Stack Configuration: External Structure (Options 1 or 2), Central Structure*
- √ *Getting to orbit: LV options and SEP vs. chemical*
- √ *Propulsion Module As Communication Relay: versus No Communication Relay*
- √ *Micro-Propulsion Subsystem: Accommodation to Generate Force-free Moments, Accommodation Using Solar Dynamic Pressure*
- √ *Star Tracker Re-use: Additional STR on Propulsion module, Use Science Spacecraft STR*
- √ *Separation Strategy From Propulsion Module: Separation with spinning SC/Propulsion Module, Non spinning separation*
- √ *Telescope design: Dall-Kirkham (FTR design modified to 40 cm aperture), Ritchey-Chretien, Symmetrized Korsch (Schiefspiegler), Cassegrain*
- √ *Vacuum Enclosure: Vacuum enclosure, getters, or vent to space*
- √ *Instrument Pointing: Optical assembly pointing, Telescope pointing, In-FOV pointing*
- √ *Point-ahead Angle Correction: PAA correction by PM actuation, PAA correction with actuator on Optical Bench, Optical Element(s) in the Science Beam, Optical Element(s) in the Local Oscillator Beam, Rotating the Main Beam Splitter,*
- √ *Point Ahead Actuator Trade-Off*
- √ *Optical Bench Layout: Number and location of optics, height of beam, "Frequency Swap" versus heterodyne with outgoing laser*
- – ***2 Mkm arm option with negation of Earth perturbation and in-field pointing, single optical bench***
- √ *Strap-down System Vs. Direct Proof Mass Reflection*: Proof Mass to Proof Mass measurement, Proof Mass versus Optical bench measurement*
- √ *Electrostatic Readout Vs. Optical Read-out (ORO)*: Optical readout only in sensitive axis, Optical readout also in non-sensitive axis*
- √ *Laser Frequency Stabilization: Free-running laser with cavity stabilization, Arm Locking, Higher order/extended arm locking*
- √ *Laser Beam Acquisition: Scanning, Defocusing, Super CCD star tracking*
- √ *Data Transmitted To Ground*: Classical approach, Sending one quadrant and difference to other quadrants*
- √ *Perform End-to-End Data Architecture Trade: Ka vs. X, contact time and frequency, power amp, antenna size,steerable dish vs. phased array and interSC comm,*
- √ *Define Strategy for Flat Spot Finding and Calibration at Far Spacecraft*
- √ ***Develop First Cut Avionics and FSW Architectures***
- – ***Define Thermal Stability Requirements and Architecture, define interface requirements***
- √ *Perform Self-Gravity Zone Definition*
- √ ***Magnetic Analysis Zone Definition***
- √ *Define detailed Arm-Locking requirements*
- √ *Document 40 cm Telescope Decision: ...to go to 40cm from 30cm*
- √ ***Define Top-Level On-Orbit Alignment Concept***
- √ *Define Pointing Mechanism Requirements and Concept (Constellation "Breathing Angle")*

Mass and Power Budgets

Element	Mass (kg)
S/C Bus	314
Payload Mass	259
Prop Module Mass	259
Dry Flight System Mass	832
30% Contingency	250
Dry Mass Total	1082
Spacecraft Propellant Mass and contingency	474
Wet Mass	1556
3 S/C Wet Mass	4668
LV Adaptor	200
Total Launch Mass	4868
Atlas 531 Launch capability to the required C3 = 0.5 km^2/s^2	5165
Excess lift capability	297

Spacecraft Bus		336.2
	Power	50.0
	Command & Data Handling	45.0
	Comm	61.0
	Attitude Control	18.0
	Micro-Newton Thrusters	127.2
	Thermal	35.0
Payload		252.7
	LOCS	173.0
	LIMAS	79.7
Sciencecraft Total (W)		588.9
Total (W)		588.9
Total with 30% Margin (W)		765.6

Electrical Block Diagram



Integration, Verification and Test Plan

- ***Every requirement must be shown to be met either by measurement, analysis, or "similarity."***
- ***Jeff Livas has developed an extensive plan for the integration and test of the LISA flight system***
- ***Goal: to assess the effects of architecture changes on one of the most challenging phases of the mission***
- ***Main components***
  - *List of tests*
    - *Environmental tests*
    - *Science payload tests*
    - *Constellation tests*
  - *Cost database*

Step #	IV&T flow step
1	Optical Bench Integration
1	Optical Bench Initial Testing
2a	GRS Integration
2a	GRS Testing
2b	GRS and OB Integration
2b	GRS and OB Testing
3a	Laser System Integration
3b	Laser and OB Testing
4	Telescope Integration
4	Telescope Testing
5	LOCS Integration
5	LOCS Testing
5	LOCS acceptance testing
6a	LIMAS Integration
6a	LIMAS Testing
6b	LOCS and LIMAS Integration
6b	LOCS and LIMAS Testing
6b	LOCS/LIMAS acceptance testing
7a	Spacecraft Bus Integration
7b	Sciencecraft Integration
7b	Sciencecraft Testing
8	Constellation Testing
9a	Propulsion Module (PM) Integation
9a	PM Testing
9a	PM acceptance testing
9b	Cruise Module Integration
9b	Cruise Module Testing
10	Launch Stack Integration
10	Launch Stack Testing
11	KSC acceptance testing
11	KSC Integration
11	KSC testing

Recent Work Reported in Other Talks

- ***Phase measurement - see presentation by Daniel Shaddock***
- ***Laser sideband locking - see poster by Ira Thorpe an Jeff Livas***
- ***Mock LISA Data Challenge - see presentation by Matt Benaquista***
- ***Numerical Relativity - see presentation by Bernard Kelly***

Summary

- ***The LISA Project has expended a substantial effort supporting the NRC's Beyond Einstein Program Assessment.***
- ***Technology development on micronewton thrusters, phase measurement system, laser stabilization, etc. continues.***
- ***The formulation effort has focused on trade studies and alternate payload architectures.***