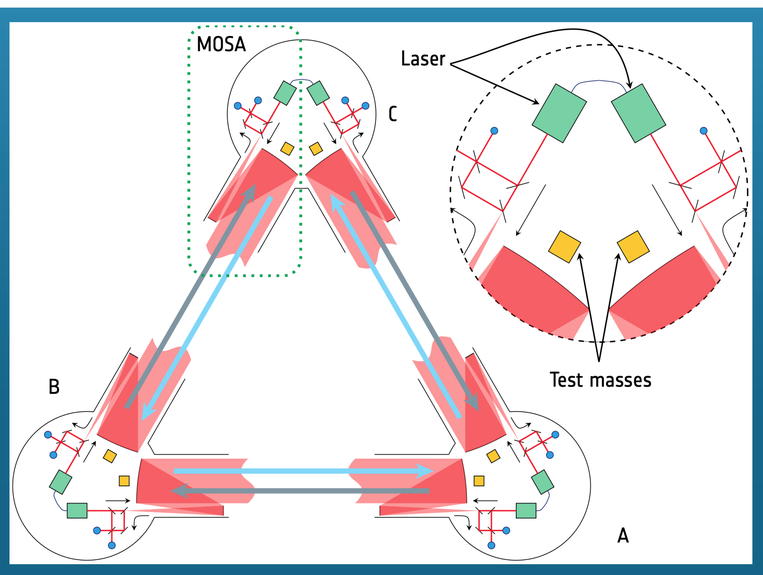
Application of Systems Engineering to LISA Laser System

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15th International LISA Symposium 2024

1. LISA Constellation[1]



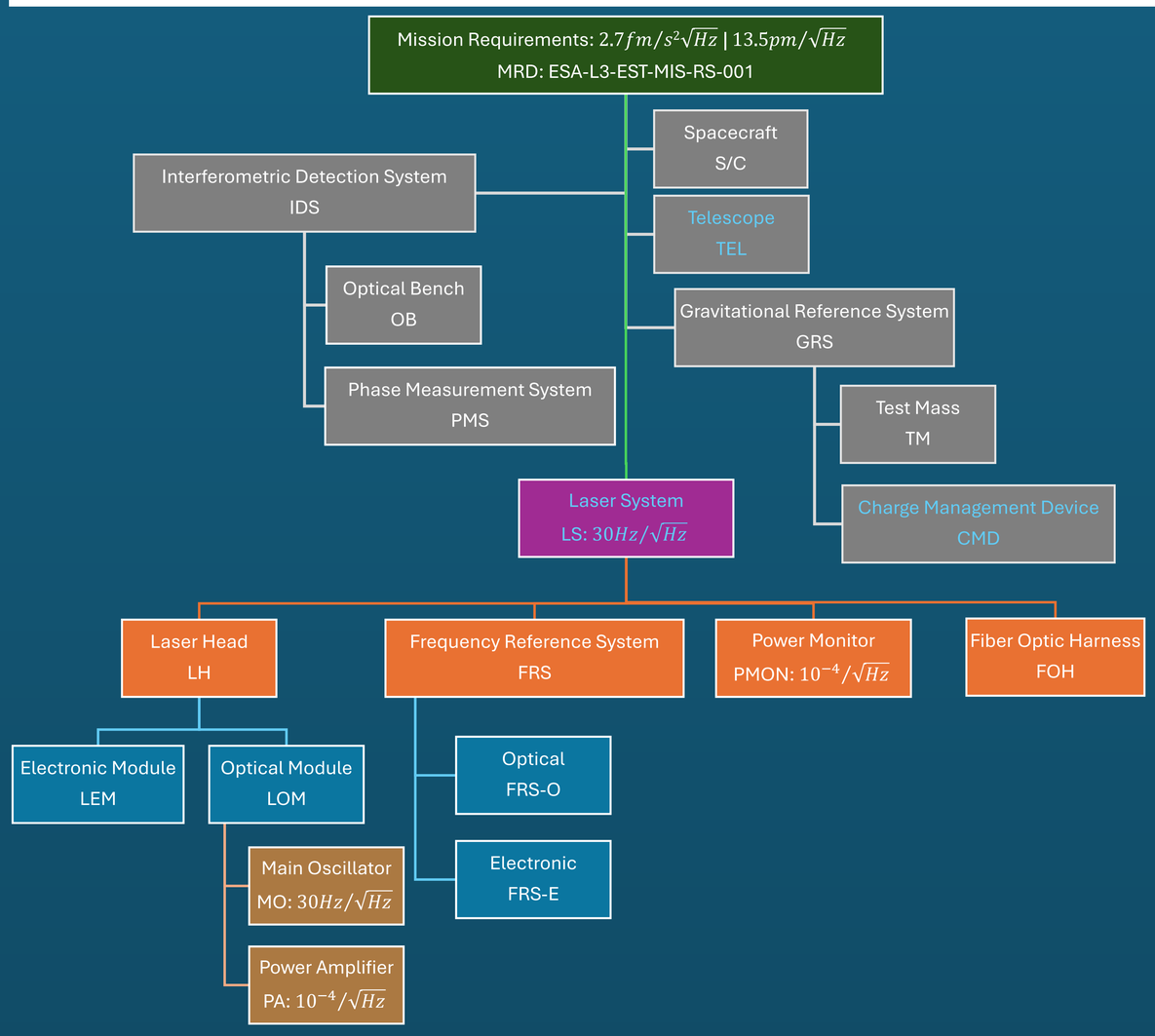
Schematic view of the LISA constellation and the S/C-S/C measurement

2. Mission Level Targets[1,2]

SciRD	$Acceleration\ Noise:\ 3fm/s^2\sqrt{Hz} \oplus Displacement\ Noise:\ 15pm/\sqrt{Hz}$
MRD	$Acceleration\ Noise:\ 2.7fm/s^2\sqrt{Hz} \oplus Displacement\ Noise:\ 13.5pm/\sqrt{Hz}$
Systems	Time Delay Interferometry; Optical Metrology Noise; Test Mass Acceleration

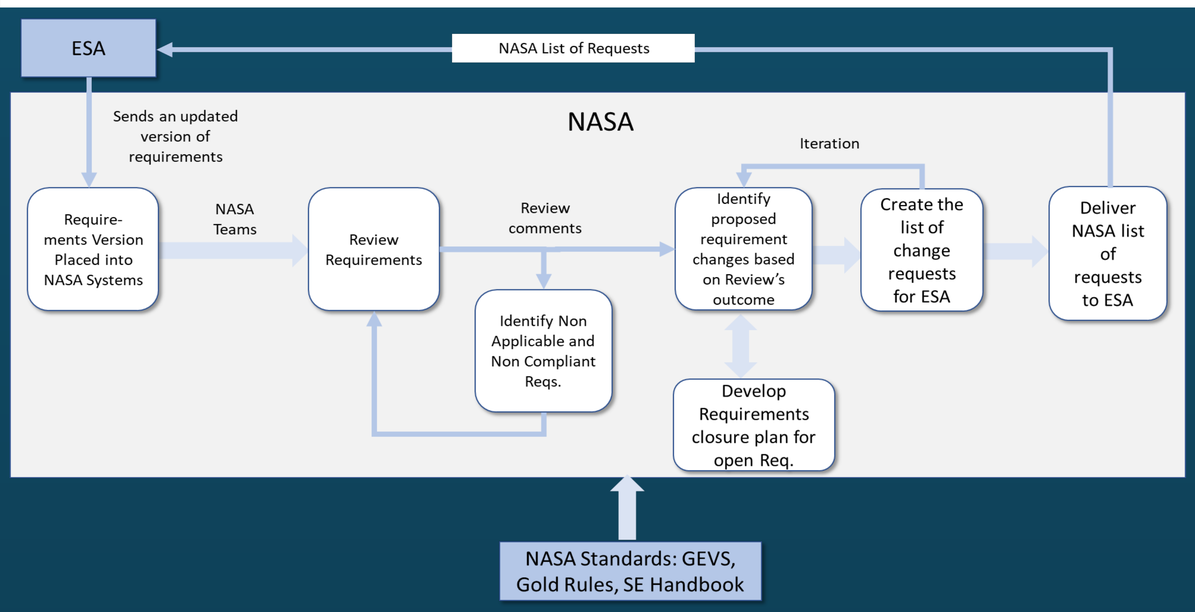
Propagation of Science to Mission to Systems Level Requirements

3. LISA Subsystems[2]



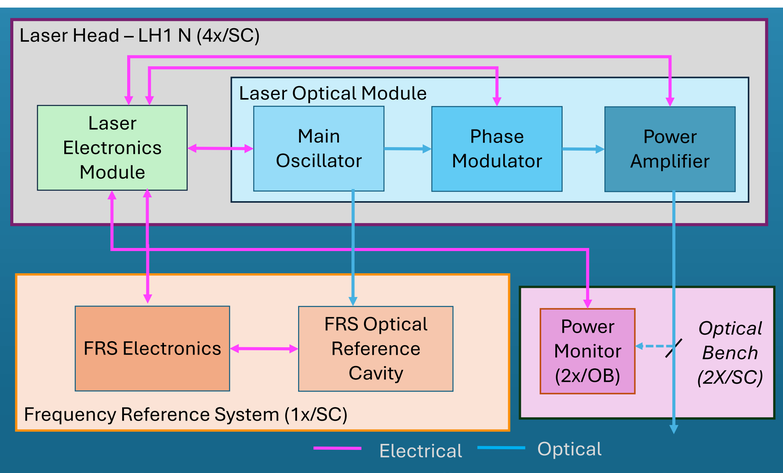
The interfaces and relationships for the Laser Subsystems

4. NASA ESA Requirements Feedback Loop



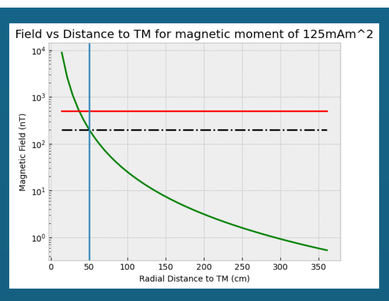
NASA-ESA Approach for reviewing requirements

5. Instrument & Subsystems

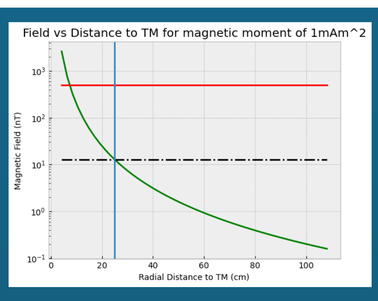


Block diagram for the Laser Subsystems and Interface

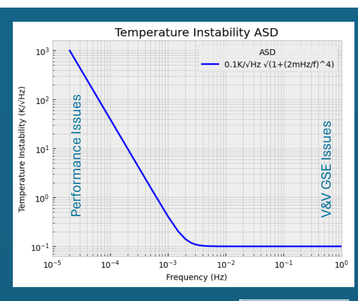
6. Environmental Considerations[2]



Magnetic Field at 50cm = 200 nT
Magnetic Field at 1m = 25 nT



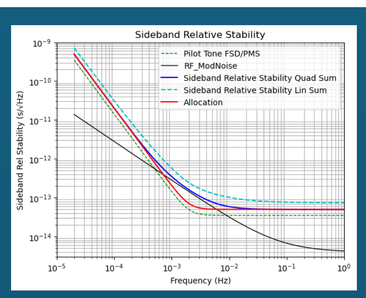
Magnetic Field at 25cm = 12.8 nT
Magnetic Field at 50cm = 1.6 nT



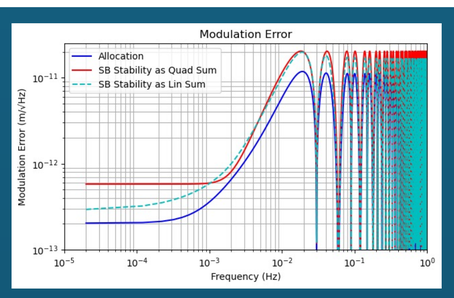
$$Temp\ Instability = \frac{0.1K}{\sqrt{Hz}}\sqrt{1+\left(\frac{2mHz}{f}\right)^4}$$

Magnetic and Thermal environments are critical to LISA system and subsystem performance

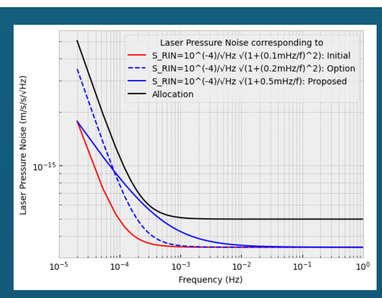
7. Nature of Noise (based on Study Phase Performance Model)[2]



SB Stability as Quadratic (uncorrelated) vs Linear (Correlated) Sum



Modulation Error as Quadratic (uncorrelated) vs Linear (Correlated) SB Stability Sum



Compare Laser Pressure Noise from:
$S_{RIN}^{1/2} = \frac{10^{-4}}{\sqrt{Hz}}\sqrt{1+\left(\frac{0.1mHz}{f}\right)^2}$ and $S_{RIN}^{1/2} = \frac{10^{-4}}{\sqrt{Hz}}\sqrt{1+\frac{0.5mHz}{f}}$

Environments can perturb the nature of noise dependencies and thereby the budget allocations

8. Systems Challenges

- Thermal Stability Requirements
- EMC Requirements verification
- Magnetic Requirement verification
- Temperature to Phase Coupling
- Examining Jitter Effects
- Constellation Acquisition Actuators
- Ground and Storage Lifetime
- Turn On Temperatures
- Trade Studies
- Resolving TBC/TBDs before RFPs
- Intensity to Phase Coupling
- Quantum Noise Assessment
- Mechanical Vibrations
- Extended Mission Lifetime

9. Conclusions

- Implications of Lisa Pathfinder S/C Temperature instability to be absorbed
- Temperature fluctuations may change noise propagation behavior
- Trade Studies to ease analogue signal noise underway
- EMC requirements and their verification are difficult but necessary
  - Cross Calibration of EMC V&V equipment between ESA and NASA, and plan warranted
- End-to-end verification of certain subsystems requires coupling with PMS/OB
  - RF & PRN related Test As You Fly (TAYF) test with PMS
  - Absolute Laser output calibration through OB elements
  - PMON environmental TAYF tests potentially requiring OB coupling
- Coupling of temperature and intensity noise into phase noise to be assessed

10. References

1. Red Book : ESA-SCI-DIR-RP-002 : https://arxiv.org/abs/2402.07571
2. Performance Model : https://perf-lisa.in2p3.fr/ , Plots from: https://github.com/raidurgesh
3. NASA SE Handbook : SP-6105 : https://www.nasa.gov/wp-content/uploads/2018/09/nasa_systems_engineering_handbook_0.pdf

11. Acknowledgement

DKR, DDP and BJS would like to thank Martin Hewitson for the discussions and inputs on the presentation.