



Rightsizing LISA

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Everything should be made as simple as possible,
but not simpler.

-A. Einstein

OUTLINE

- ***Motivation***
- ***Saving on the baseline***
- ***De-scopes***
 - *Three scenarios*
 - *Science consequences*
- ***Concept changes***
- ***Science to Cost relationships***
- ***Summary***

Motivations

- ***We, the LISA community, want the most science from a mission concept that can be selected and flown.***
 - *The ‘selection process’ is complex and difficult to anticipate.*
 - *The formulation, implementation and operation phases of the mission demand a robust, buildable design.*
- ***There is - and will continue to be - pressure to reduce cost from agencies, reviewers, and the broader research community.***
- ***There have been - and will be more - opportunities to augment the scope of LISA science.***
- ***Exploring trade-offs between science and cost is an important part of mission formulation.***

Questions

The LISA science requirements and conceptual design have been very stable for over a decade.

- *Is the baseline design close to optimal?*
- *Can we reduce the cost of the baseline design?*
- *What can be saved through de-scopes?*

N.B. *There are no definitive answers to these questions, only strong suggestions from the work done to date. There's always room for an innovation.*

Boundary Conditions

- ***The science requirements set the scope of the mission.***
- ***The design must at least have the minimal equipment and capability to meet the requirements.***
- ***The architecture must meet the redundancy and probability of success requirements***
 - *The probability of success shall be 70% at the end of the required lifetime (1.5 yr transfer and checkout, 5 yr science operations).*
 - *There shall be no credible single point failures.*
- ***We can't change the LISA Pathfinder equipment (much).***

The hunt for savings

- **Architecture simplifications:**
 - *Eliminate nonessential subsystems*
- **Reduction of equipment/propellant**
 - *Eliminate nonessential components*
 - *Make parts and assemblies smaller, cheaper, more efficient*
 - *Smaller launch vehicle*
 - *Less propellant*
- **Reduce complexity**
 - *Simplify subsystems*
 - *Combine elements (e.g., combine two avionics boxes into one)*
- **Accept higher risk**
 - *Reduce redundancy (e.g., 'selective redundancy')*
 - *Use lower grade parts*
 - *Reduce testing*
- **Streamline activities**
 - *Concurrent/staggered designing, building and testing multiple units*
 - *Compress schedule*

Minimal Science Hardware - 1/2

- ***Fiducial points (test masses)***

- *One at each end of a measurement arm requires at least 3.*
- *Redundancy requires at least 4.*
- *The 4th must be positionable. Six is cheaper than a 4th spacecraft.*
- *Six active is easier than 3 active, 3 back-up.*
- *Residual acceleration requirements mandate drag-free flight, which leads to sensing, forcing, charge control, micronewton thrusters, caging and vacuum system.*

- ***Measurement arms***

- *Two to benefit from a generalized Michelson “white light fringe” (aka TDI). Means at least 3 spacecraft.*
- *Three for redundancy gives a second polarization free.*

Minimal Science Hardware - 2/2

- ***Science measurement***

- *1 laser beam, per direction per arm, with redundancy. Does this require 12 duplicate laser subsystems? Could it be 9?*
- *And so on for laser pre-stabilization subsystems, telescopes, ultra-stable oscillators, photoreceivers, phasemeter channels, pointing equipment, etc.*
- *Long and short arms for robustness and buildability.*

Minimal spacecraft, prop module & launch vehicle

Most of these subsystems use standard equipment.

- **Avionics**

- *Some comm, attitude control system, power handling, fault detection and handling functions can be integrated into the flight processor.*

- **Power subsystem: solar arrays, battery, and harnesses can be optimized.**

- **Thermal shielding, temperature measurement, heaters**

- **Structure and mechanisms**

- *More efficient structures through clever design, choice of materials*
- *Minimum number of lightweight, compact separation and launch-lock mechanisms*

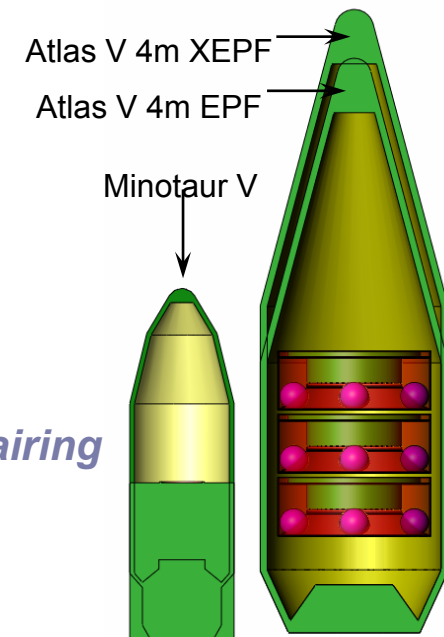
- **Comm system**

- *Multiple channels, antennas*

- **Propulsion**

- *Smaller engines*
- *Reduced propellant*
- *Optimized number and size of tanks*

- **Smaller launch vehicle, fewer solid strap-ons, smaller fairing**



Cost Savings in the Baseline

- ***The Project asked the Mission Design Lab to search for cost savings in the baseline, assuming:***
 - *The payload could not be changed.*
 - *Micro-newton thrusters not included.*
- ***Fully integrated avionics: Power Support Equipment moved to Computer & Data Handling subsystem***
- ***Elimination of rate gyros***
- ***Schedule compression of one year***
- ***Reduced quote (Δ =\$50M) for Atlas V (531) launch vehicle***

De-scopes

- ***After 15 years of study by the community and industry, the proposed architecture is the only one known that can detect gravitational waves with high certainty***
 - *3 spacecraft*
 - *Low disturbance proof masses*
 - *Interferometry*
- ***Parameters that can be traded include***
 - *Arm length*
 - *Mission life*
 - *Noise Level*
- ***Three scenarios have been studied to determine the relationship between science and cost***
 - *Baseline mission (spacecraft, prop module, launch vehicle, ground system)*
 - *De-scope-I (spacecraft, prop module, launch vehicle, ground system)*
 - *De-scope-II (delta-v, propellant changes only)*
- ***Preliminary assessment of these de-scope scenarios were presented to HQ in August 2007, based on parametric cost models and primitive science assessments (see K. Danzmann's talk).***

Three Concepts

Concept	Armlength	Noise (Position/Armlength) (Acceleration)	Science Ops Lifetime
Baseline	5 Gm	3.6×10^{-21} $3 \times 10^{-15} \text{m/ s}^2$	5 yrs
De-scope-I	2.5 Gm	7.2×10^{-21} $3 \times 10^{-15} \text{m/ s}^2$	3 yrs
De-scope-II	1 Gm	11×10^{-21} $3 \times 10^{-15} \text{m/ s}^2$	2 yrs

Relative Science Performance (1 of 2)

▪ Massive Black Hole Mergers

See C. Cutler's talk

- Number of mergers detectable with $SNR > 10$ (best estimates)
 - Baseline: 100-200
 - De-scope-I: 50-75
 - De-scope-II: 35-40
 - All configurations will be able to detect mergers, but with decreasing ability to measure scientifically important characteristics (see below).
- Number of mergers with useful distance determination ($\pm 10\%$)
 - Baseline: 43
 - De-scope-I: 16
 - De-scope-II: 5
 - Ability to understand black hole formation and evolution requires distances to better than $\pm 10\%$ ($\pm 1\sigma$). de-scope loses capability to make meaningful statements about formation and evolution, particularly if rates are lower than best estimates.
- Number of mergers with useful sky localization (10 deg^2 - LSST FOV)
 - Baseline: 14
 - De-scope-I: 5
 - De-scope-II: 1
 - Sky localization capability is required for determination of cosmological parameters and for correlating merger and host galaxy characteristics. Localization capability is lost for De-scope I and at risk for De-scope II if rates are lower than current best estimates.

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Relative Science Performance (2 of 2)

- **Extreme Mass Ratio Inspiral (EMRI) events**

- *Inspiral of white dwarves and stellar-mass neutron stars and black holes into massive black holes in galactic nuclei*
- *Science objectives: mass and spins of massive black holes in $z < 1$ universe; compact object population in galactic nuclei; precision tests of General Relativity; determination of Hubble constant*
- **Number of detectable events (best estimates, SNR>30 required)**
 - *Baseline:* 260
 - *De-scope-I:* 50
 - *De-scope-II:* 1
- *EMRI science (both physics and astrophysics) essentially lost for de-scope. EMRI science degraded for de-scope and put at risk if event rates are lower than current best estimate.*

Numbers could be a factor of x10 lower

- **Ultra-Compact Galactic Binaries**

- **Number of individual detectable binaries with SNR>10**
 - *Baseline:* 17,000
 - *De-scope-I:* 7,000
 - *De-scope-II:* 2,500
 - *All configurations can detect significant numbers of binaries, but with differing capability of determining scientific characteristics (see following example).*
- **Number of binaries for which both distance and sky location can be determined**
 - *Baseline:* 2,800
 - *De-scope-I:* 600
 - *De-scope-II:* 200
 - *Scientific return for ultra-compact binaries is significantly enhanced by the ability to determine the spatial distribution of binaries, particularly for rarer subclasses of binaries.*

Summary of Performance Relative to Baseline

▪ **De-scope-I**

- *Partial EMRI science (x 5 reduction in number of sources).*
- *Reduction in ability to perform precision test of GR (lower SNR).*
- *Significantly reduced number (x4) of Massive Black Hole Binary sources for which an electromagnetic counterpart could be determined. Reduction in the maximum SNR that will be observed by LISA thus limiting its ability to do precision measurements of these systems.*
- *Some loss of Galactic Binary science.*
- *Incurs additional science risk in several areas compared to baseline (e.g. could lose EMRI science and massive black hole localization capability if rates are lower than current best estimates).*

▪ **De-scope-II**

- *Lose all EMRI science including precision tests of GR and determination of mass and spin distribution of massive black holes in galaxies in the $z < 1$ Universe.*
- *Significant risk of not being able to determine electromagnetic counterparts for any massive black hole mergers.*
- *Loss of capability to study black hole formation and evolution (not enough sources with good distance determination).*
- *Significant (x10) loss of Galactic Binary science.*

Complete Studies

	<i>Baseline Case</i>	<i>Descope-I</i>	<i>Descope-II</i>
Armlength	5 Gm	2.5 Gm	1 Gm
Orbit	22° behind Earth	12° behind Earth	9° behind Earth
Mission lifetime	6.5 yrs nominal; 10 yrs goal	4.5 yrs nominal; 6.5 yrs goal	2 yrs nominal
Redundancy	Single-fault tolerant design	Selective redundancy	Selective redundancy
Mission Delta-V (including ACS tax & margins)	1130 m/s	517 m/s	333 m/s
Launch vehicle C3(km ² /sec ²): 0.5	ULA - ILS Atlas V (531), ~ 5165 kg	ULA - ILS Atlas V (431), ~ 4065 kg	ULA - ILS Atlas V (421), ~ 4065 kg

Highlights of Descope Changes

- **Integrated avionics:**
 - Generally redundant except for valve drive and deployment cards – justification: Propulsion Module (P/M) has an 18 month life
 - Includes Power System Electronics (PSE), which reduces total mass and volume
- **Power:**
 - Slightly smaller Solar Array area, 4.89 m² (previously 5.3 m²)
 - PSE incorporated in the Avionics unit
- **ACS:**
 - Eliminated sciencecraft gyros
 - Reduced Star Trackers to 2 from 3
- **Propulsion:**
 - MMH/NTO Four 5-lbf bipropellant axial thruster system, $\Delta V = 517$ m/s
 - Four tanks to keep Center of Gravity (CG) relatively constant
 - Mission life of 18 months allows elimination of redundant thruster string
 - ACS P/M requirements can tolerate loss of a single thruster
- **RF communications:**
 - Eliminated Ka band system, increased X-band power
 - Single 0.5-m High Gain Antenna (previously two 0.3-m HGAs)
 - Design is essentially redundant except for HGA
- **Launch vehicle Atlas V (431), 4 m fairing**

Mass Comparison

	Arch. Doc., 40 cm, 5 Gm	Baseline, 40 cm, 5 Gm	Descope I 25 cm, 2.5 GM	Descope II 25 cm, 1.0 GM	Baseline MDL Grass Roots	Descope MDL Grass Roots	MDL Delta Grass Roots
System	Mass (kg)	Mass (kg)	Mass (kg)	Mass (kg)	Mass (kg)	Mass (kg)	Mass (kg)
S/C Bus Mass	314	265	246	243	290	264	26
Microthrusters		45	41	37	45	45	0
Power/Solar Arrays		30	30	30	51	29	22
C&DH		25	28	28	28	28	0
ACS		10	9	9	5	3	2
Thermal		10	10	10	16	14	2
Comm		30	19	19	37	37	0
Structure/Mechanisms		90	85	85	108	108	0
Harness		25	25	25	0	0	0
Payload Mass	259	310	261	261	259	259	0
Prop Module Mass	259	270	256	256	320	293	27
Structure	110	110	141	141	203	203	0
Thermal	11	15	15	15	11	9	2
Separation System	24	25	7	7	24	24	0
Harness	6	10	10	10	6	6	0
Bi-Prop System (tanks/lines)	101	100	72	72	71	47	24
ACS	5	5	5	5	2	1	1
Comm	2	5	5	5	3	3	0
Dry S/C Flight Mass	832	845	763	760	869	816	53
30% Margin	250	254	229	228	261	245	16
Dry Flight Mass w/Margin	1082	1099	992	988	1130	1061	69
Delta-v (m/s)	1100	1100	605	370	1130	517	
Propellant		498	249	168			
ACS Propellant		30	15	10			
Total P/M Propellant		528	264	178			
Total P/M Prop + 2% residual	474	539	269	181	527	231	296
Wet S/C Flight Mass w/o Margi	1306	1384	1033	941	1396	1047	349
Wet S/C Flight Mass w/ Margi	1556	1637	1262	1169	1657	1292	365
3 S/C Wet Mass w/margin	4667	4911	3785	3507	4970	3875	1095
LV Adaptor	200	180	180	180	200	200	0
Total Launch Stack Mass	4867	5091	3965	3687	5170	4075	1095

Basis of Payload & S/C Cost Reductions

- ***Constellation closer to earth reduces the communications requirement***
 - *\$2M savings assuming a scaling factor relative to the baseline hardware cost*
- ***Reduced laser power for shorter arms***
 - *\$5M savings assumed by scaling baseline cost estimate*
- ***Reduced telescope diameter***
 - *\$2.5M assumed by scaling baseline cost estimate*
 - *Smaller telescope does not change the overall payload dimensions*
- ***A shorter mission life does not:***
 - *Justify LISA to be a single string design*
 - *Change the laser & thruster design*
- ***No savings in any other sub-systems were found***
- ***None of the parameters change the GRS design***
 - *GRS designed will be proven by LPF and should not be change anyway*

Systems - Schedule Comparison

	<i>Baseline Case</i>	<i>Descope Case</i>
<i>Phase A - Preliminary Analysis</i>	<i>12 months</i>	<i>12 months</i>
<i>Phase B - Definition</i>	<i>15 months</i>	<i>12 months</i>
<i>Phase C - Design</i>	<i>15 months</i>	<i>12 months</i>
<i>Phase D1 - Subsystem Development, S/C I&T</i>	<i>36 months</i>	<i>30 months</i>
<i>Phase D2 - Cruise and Commissioning</i>	<i>18 months</i>	<i>18 months</i>
<i>Phase E/F - Primary/ Extended Operations</i>	<i>60/42 months</i>	<i>36/24 months</i>

Cost reductions not taken

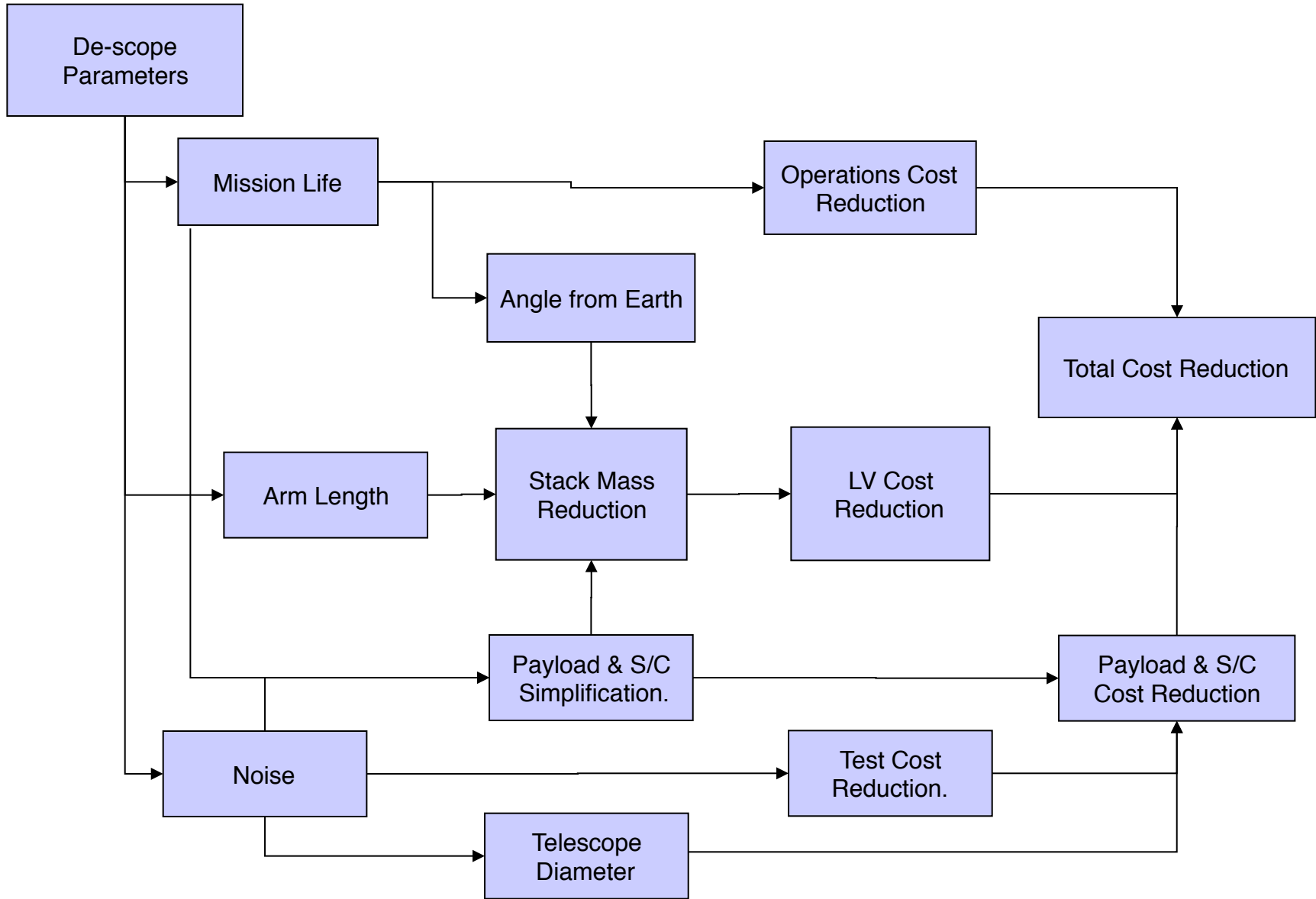
- ***Architecture simplifications: none found***
- ***Reduction of equipment:***
 - *X-band only comm not compatible with DSN plans in 2018*
- ***Single string, selective redundancy: additional savings not compatible with NPRs***
- ***Class C parts: unacceptable reliability***

De-Scope II Mission

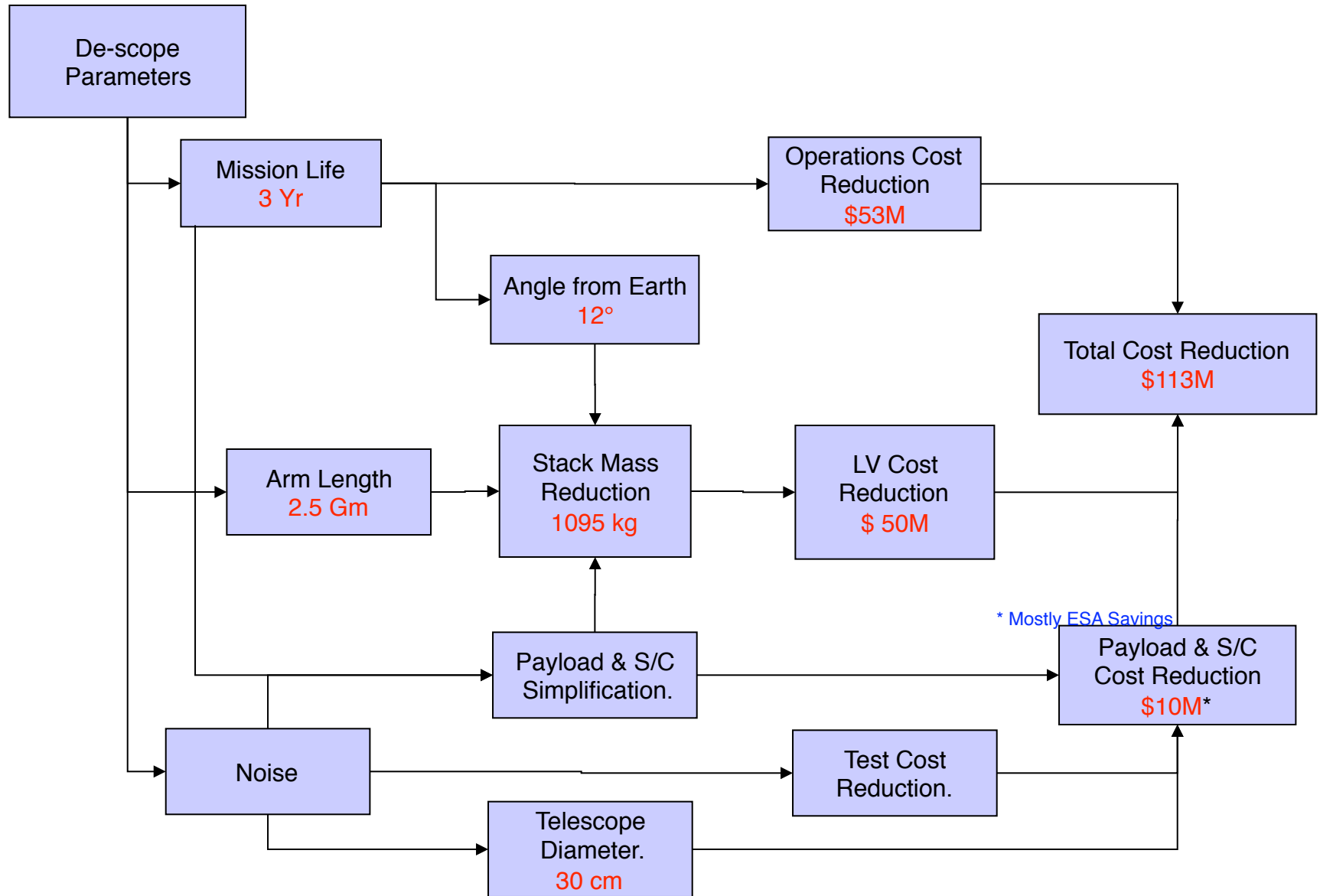
- *The only work done by the MDL was done by Propulsion to estimate the mass savings for a $\Delta_v = 333$ m/s*
- *The mass savings is 87 kg/vehicle.*
- *The De-scope II launch stack mass is 3804 kg.*
- *The cost savings comes only from launch vehicle savings.*
- *The scaling of launch vehicle costs from 401 to 431 is \$10M per solid rocket booster.*
- *The mass capabilities (not including KSC margin):*

<i>Launch Vehicle</i>	<i>Mass capability at C3 of 0.5 (km/sec)²</i>
<i>Atlas V (431)</i>	<i>5500 kg</i>
<i>Atlas V (421)</i>	<i>4600 kg</i>
<i>Atlas V (411)</i>	<i>3900 kg</i>
<i>Atlas V (401)</i>	<i>3415 kg</i>

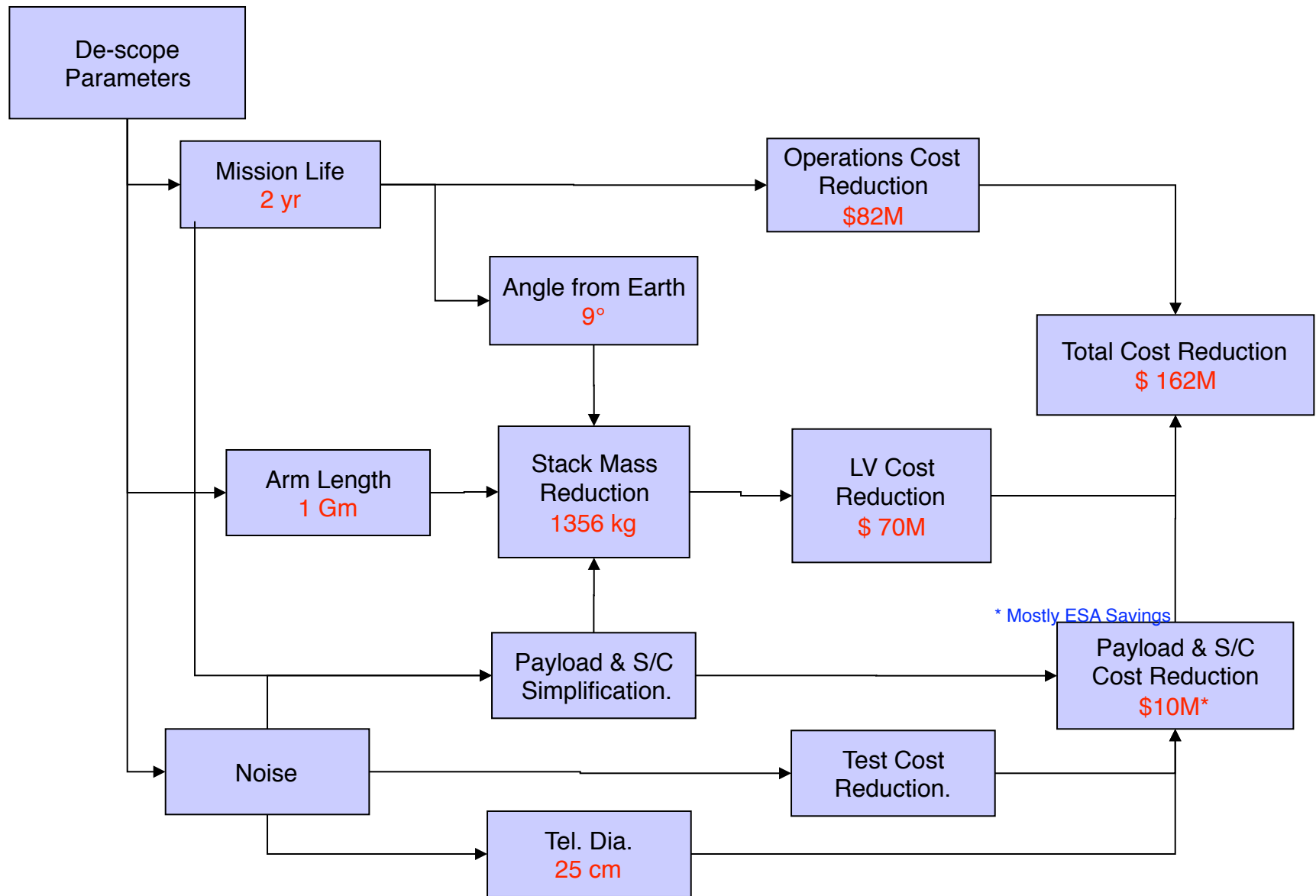
Science To Cost Relationships



De-scope-I



De-scope-II



* Mostly ESA Savings

Summary Of De-scoping Exercise

- ***The US science community has studied two de-scoped science scenarios***
 - *Developed to establish costing relationships*
 - *Have not been endorsed by the full LIST*
- ***Project has estimated cost savings resulting from the de-scopes***
- ***Mission complexity and cost changes very little with changes in science capability, even for extreme reductions in science capability***
- ***Neither de-scope allows the Project to fit within the NASA budget target***
- ***Major contributors to savings include***
 - *Smaller launch vehicle (Due to reduction in propellant requirements)*
 - *Reduced mission life time*

Conclusions

- *LISA is close to the “right” size.*
- *Give up more than half of the science, and save ~10%.*
- *However, cost is a critical issue.*
 - *Higher cost generally means starting later.*
 - *At the current cost, LISA may have to compete against the biggest missions - and win.*
 - *Finishing second in Astro2010 may well be fatal.*
- *There don't seem to be substantial additional savings to be had in the spacecraft and operations.*
- *A radical idea that confronts complexity and/or redundancy in the payload seems unlikely.*
- *Incremental growth is toxic.*