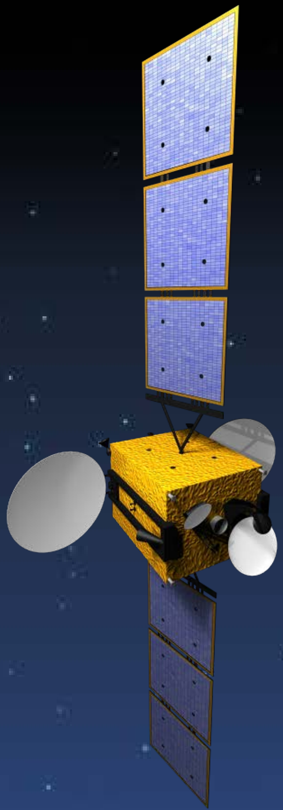

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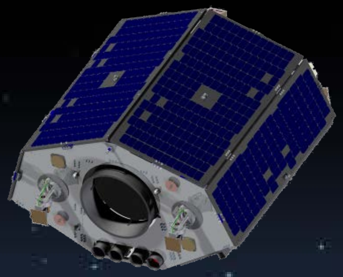
Changing the economics of space



Service Oriented Active Debris Removal

CleanSpace Event ESTEC 23rd May

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Introduction

- ESA funded GSP study (4000108122/13/NL/MV.0 *Service Oriented Approach to the Procurement and Development of an Active Debris Removal Mission*)
- Aim of the study was to make a preliminary investigation of the technical feasibility of actively removing a single large debris object from orbit, and to further investigate and analyse the possibility of providing this mission - and further missions - as commercial services rather than traditional procurements
- The study 'user case' was an Active Debris Removal (ADR) mission targeting >4000kg ESA-owned object via controlled re-entry into atmosphere. Four main tasks :
  - Preliminary mission design and spacecraft concept (at phase-0 level)
  - Definition of a business model for the mission
  - Market study and business study for future commercial ADR operations
  - Programmatic assessment of the Envisat mission
- Project Team:

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Objectives and Requirements

- Define and justify target and establish preliminary mission profile
- Undertake conceptual design of ADR spacecraft (the "Chaser") and trade-off of key sub-systems
- Rough Order of Magnitude cost and risk assessment
- Specify technology pre-developments
- ***Mission Objective: "Safely capture a large debris object in Sun Synchronous Orbit and perform a controlled re-entry over a specified part of the Earth"***
- Cost minimisation is the main driver

- ***MIS -010 The system shall be designed for compatibility with a launch using a launcher from the European launcher family***
- ***MIS -020 The system shall perform a rendezvous with the uncooperative target object***
- ***MIS -030 The system shall be compatible with targets, where no a-priori knowledge of the magnitude and orientation of the attitude motion vector is available***
- ***MIS -040 The target object shall be an ESA owned object (non-operational satellite) in the LEO region (e.g. SSO), heavier than 4 tonnes***
- ***MIS -050 The system shall be able to capture and manoeuvring the target satellite without generating any extra debris that do not decay in less than 25 years***
- ***MIS -060 The system shall perform a safe controlled re-entry, of itself and of the target, such that the impact foot-print can be ensured over an ocean area, with sufficient clearance of landmasses and traffic routes.***
- ***MIS -070 The mission shall comply to ESA space debris mitigation requirements***
- ***MIS -080 The mission shall be launched before 2022***

Target


Capture System

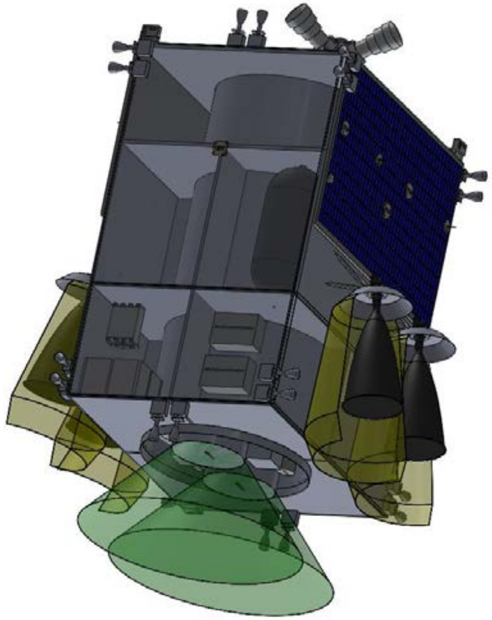
- The mechanism (or mechanisms) used to capture and control the debris is a critical mission decision, and has a strong influence on the overall system design and mission feasibility
- Detailed multi-parameter trade-off conducted on a range of capture systems including “flexible” types (net, harpoon, bags,…), “rigid” types (robot arms, tentacles), “exotic” types (glues, foams,…)

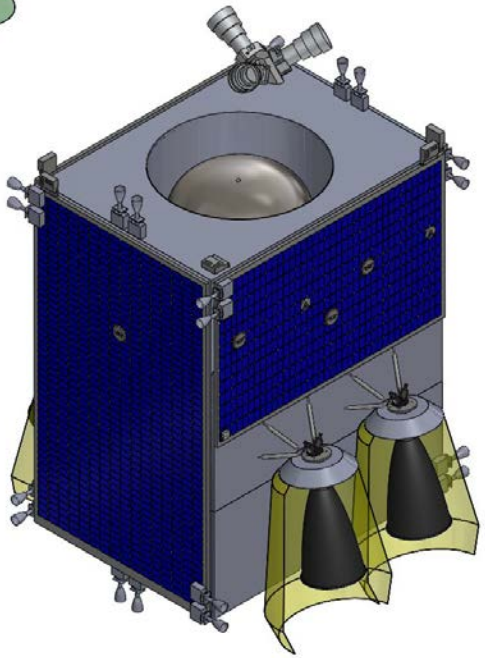
Nets and Tentacle based solutions are closely matched. Net chosen for this study (also good versatility for a wide range of target types for future mission applications)

	Priority	Robotic systems					Tethers-based concept			Inflatable systems	Glues or foams
		Tentacles with robotic arm (e.deorbit)	Tentacles without robotic arm (e.deorbit)	Tentacles with airbag (e.deorbit evolution)	Single robotic arm with tailored effector (VAC)	collapsible gate (HADR - IAC paper)	Fisherman-net (ROGER)	Butterfly net (HADR - IAC paper)	Harpoons	inflatable hand/ tentacles	Adoption of glues or foams for sticking on large debris
Mass and volume	4	3	4	4	2	2	5	4	5	4	2
Hazardousness	4	3	3	4	3	4	4	4	1	5	5
Control capability	4	4	3	4	3	5	2	2	2	3	2
Recurring cost (future missions)	5	3	4	3	3	2	5	4	4	3	2
Non recurring cost	4	3	4	3	3	3	4	3	3	3	2
Complexity of design	3	2	3	2	4	2	4	3	2	1	1
Reliability (1FT requirement)	5	4	4	4	2	3	3	4	4	4	3
Versatility	3	3	4	4	3	4	5	5	4	5	4
Technology availability (TRL)	4	4	4	4	4	4	3	3	3	2	2
System Integration level (IRL)	3	2	3	2	3	1	4	2	4	1	1
Abort Capability	3	4	5	5	5	5	1	2	1	3	3
Reusability	1	5	5	5	2	2	1	1	2	2	2
Resources needed	2	2	2	2	2	1	4	3	3	3	1
Innovation	1	4	3	4	2	3	3	4	3	3	5
Testability	2	4	4	4	5	3	3	3	5	3	2
Complexity of approach and capture	4	2	2	3	2	2	5	2	3	3	4
Residual tumbling after capture	2	3	3	4	3	3	3	4	2	3	2
Impact on chaser complexity	5	4	4	4	4	1	3	2	2	2	1
Total (unweighted)	59	59	64	65	55	50	62	55	53	53	44
Total (weighted)	-	191	211	211	182	165	213	183	176	178	142

Preliminary System Concept

- Net based capture system (ROGER, YES-2 heritage)
- Structure based on GMP-T carbon fibre thrust tube (937mm diameter) with aluminium closure and shear panels
- Bi-propellant propulsion system architecture based on GMP-T with 4 LAE in total (2 prime and 2 redundant) and 24 RCT (dual redundant)
- AOCS heritage equipment (star trackers, gyro, sun-sensors, reaction wheels)
- Body mounted solar panels & battery
- SSTL heritage S-band Tx/Rx for TT&C and data dumping, with commercial (Inmarsat) Inter-Satellite Link (low rate)
- OBC and OBDH architecture based on SSTL heritage equipment
- Titanium high temperature MLI thermal shields around each LAE
- Redundant pair of nets carried recessed in base of thrust tube
- Wide and Narrow angle cameras, and LIDAR for GNC payload
- Wet Mass at Launch = 1480kg (1.2% launcher margin on Vega)
- Dry Mass = 681.8kg (inc. 20% system margin)





Definition of Business Model

- One of the major activities for the study was to consider providing the mission as a service to ESA, rather than the more usual procurement route
- Active Debris Removal (ADR) against a target such as Envisat will always be a mission with a certain element of technical risk, and for a service model, also commercial and legal risk as well
- These need to be carefully traded by the "service provider" to assess if it is in the interest of their business to undertake the mission
- ESA must be satisfied that the service model does not present an unacceptable level of risk to them (as legal responsibility for Envisat will remain with ESA under current treaties)
- The best service models in space are a public private partnership (PPP) between agency and industry (e.g. NASA COTS and CRS), but the <u>success of these are critically dependent on the existence of market opportunities</u>

Definition of Business Model

- A number of different 'flavours' of PPP model exist
- Most are based on availability payments over a long period of time
  - Payment mechanisms can be suitably formulated (e.g. user charging through road tolls for transport PPP)
  - Dependent on the existence of a market which does not exist for ADR (currently)
- For an Envisat removal mission, there is a single 'binary event' (removal) rather than an on-going operations phase
- A true concession style PPP (as for Skynet 5) is not feasible
  - E.g. industry pays up front for capital expenditure and the customer pays later
  - Too much risk & uncertainty
  - If no promise of future missions or revenue streams then commercial investments will be made in other markets e.g. EO, Telecommunications
  - Concession probably not the best model for a binary mission

Other Constraints

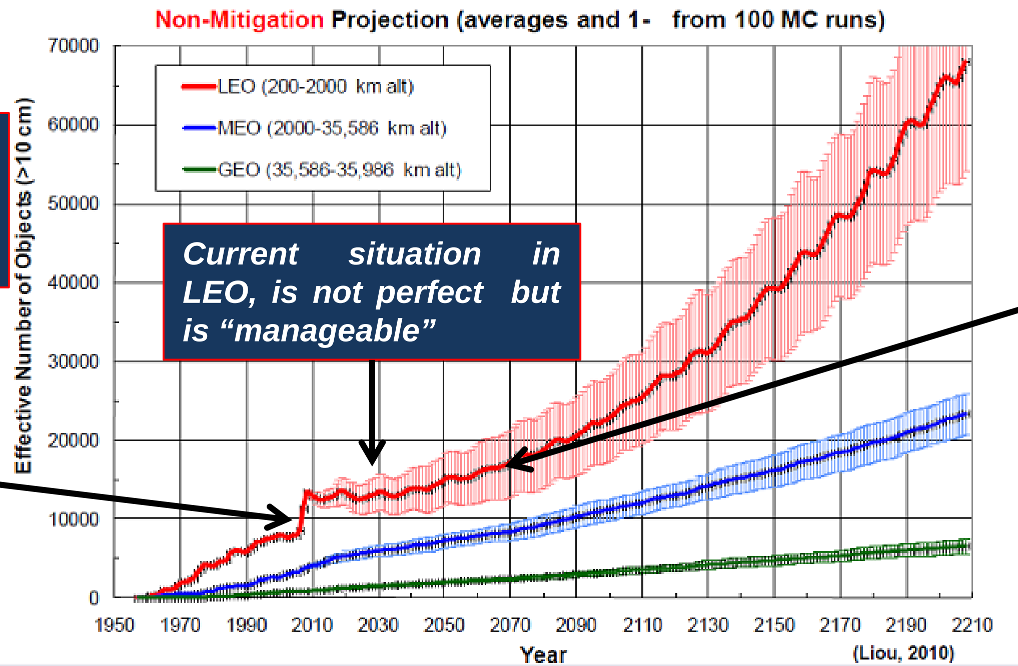
- Under current international legal conventions, ESA – as the launching state – will retain legal responsibility for Envisat even if a service model was adopted
  - Agreement will be needed from the ESA member states who contributed to the Envisat programme, as they ultimately hold liability for Envisat (shared in a pro-rata arrangement)
- It is still not clear how liabilities would be shared once Envisat is captured and the two spacecraft are connected
  - Under current law, both ESA and the UK (if SSTL is the service provider) would retain legal responsibility for each other's 'part' of the composite pair of objects
  - Complex hold harmless agreements would be needed between ESA and SSTL (and subcontractors) in the event of a service approach

Long-Term Commercial Aspects of ADR

- The fundamental underlying paradox at the heart of ADR is that unlike virtually all other space missions, despite costing money, it brings *no immediate value*
  - No data is collected, no communications traffic is transmitted, no images are acquired…

ADR will benefit everybody, so why should one individual pay to clean up space?

Should those that have "polluted the most" pay the most towards ADR?

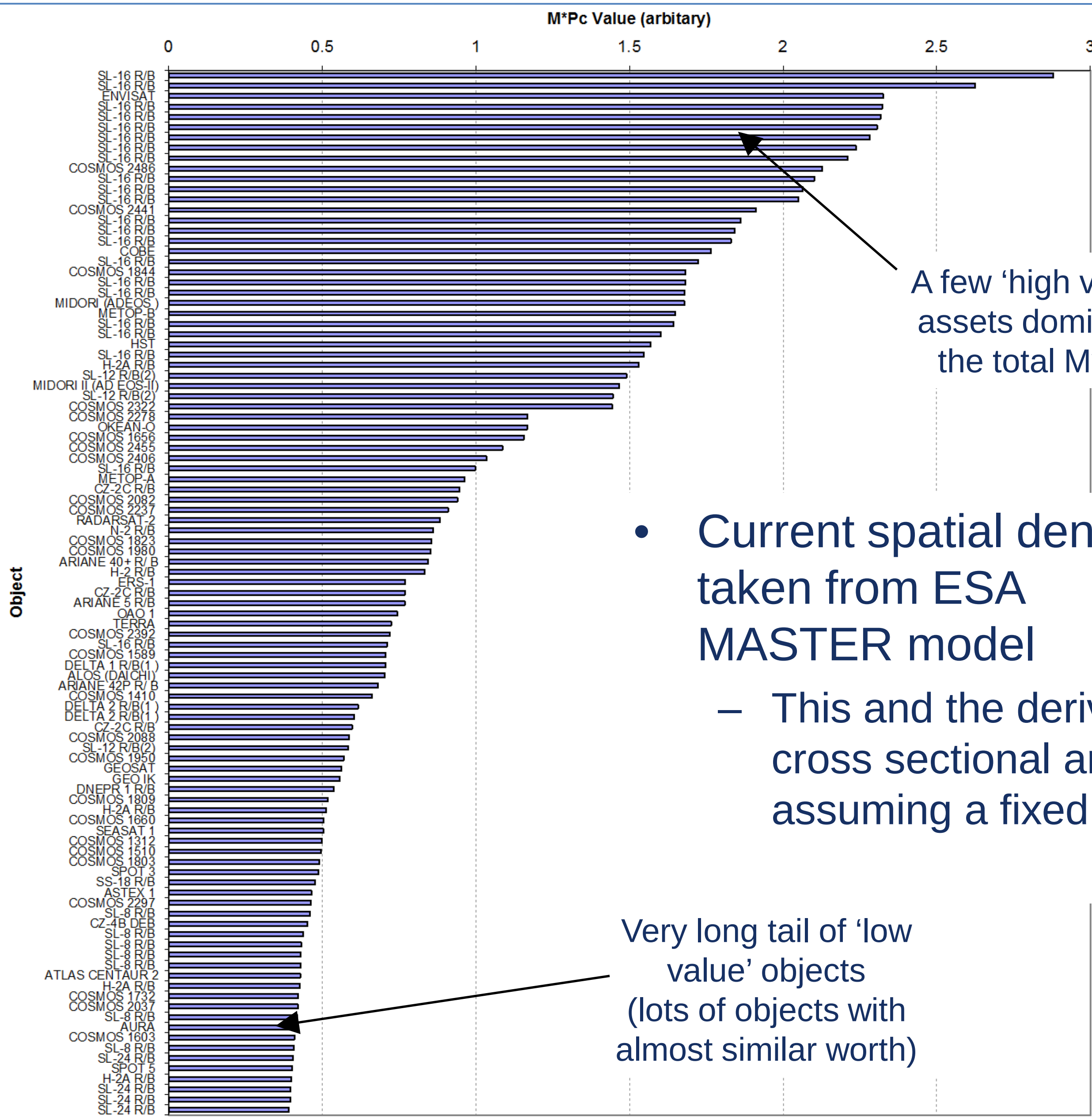


Population in LEO not expected to rise significantly for ~50 years. Should we pay for ADR now?

- To perform ADR will be difficult and expensive especially if a dedicated launch vehicle is needed for each mission and the Chaser is also removed along with the target
- Everything in space (debris or not) belongs to, and is the legal responsibility of, one or more nation states, and cannot be arbitrarily "disposed" by a 3rd party

What financial value do national governments, space agencies and the private commercial space sector place on the space activities they carry out and the benefits they derive from them? Furthermore, how much are they prepared to pay to ensure future availability?

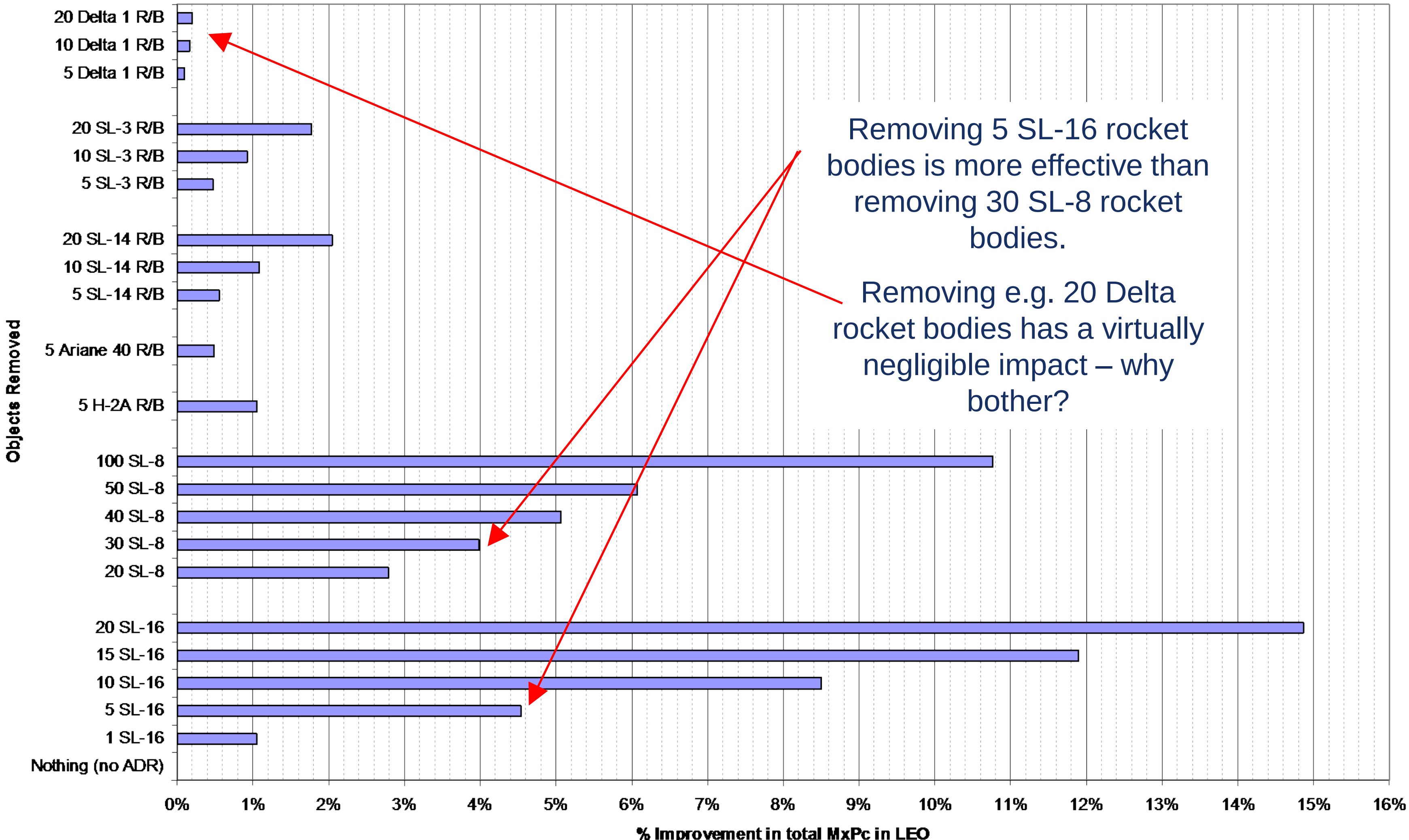
Value of Debris



- Current spatial density (5cm) taken from ESA MASTER model
  - This and the derived cross sectional area gives P_c assuming a fixed V_{rel}

Improvement in Risk

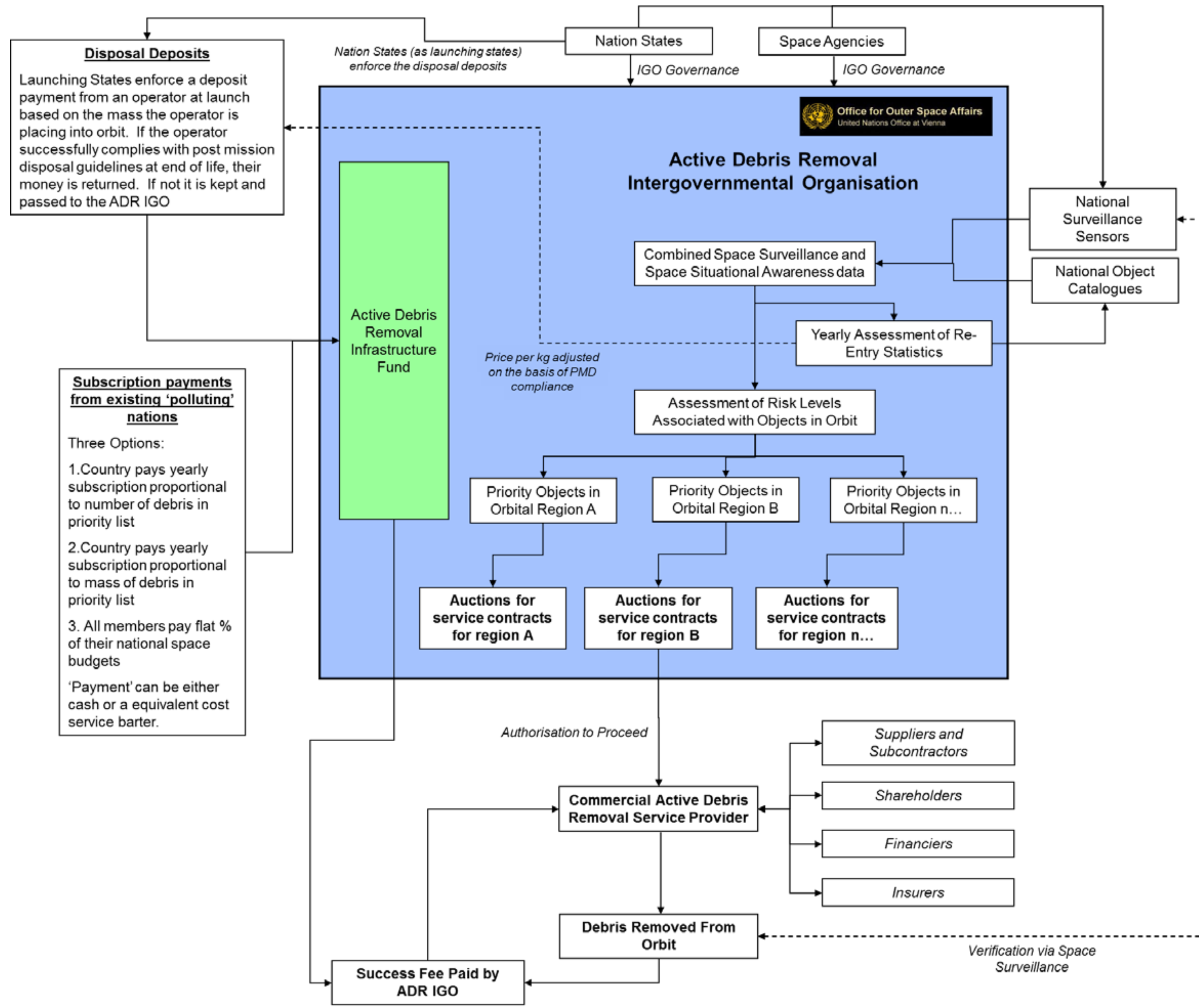
- Improvement in total $M \times P_c$ in LEO when removing certain objects



Business Architectures

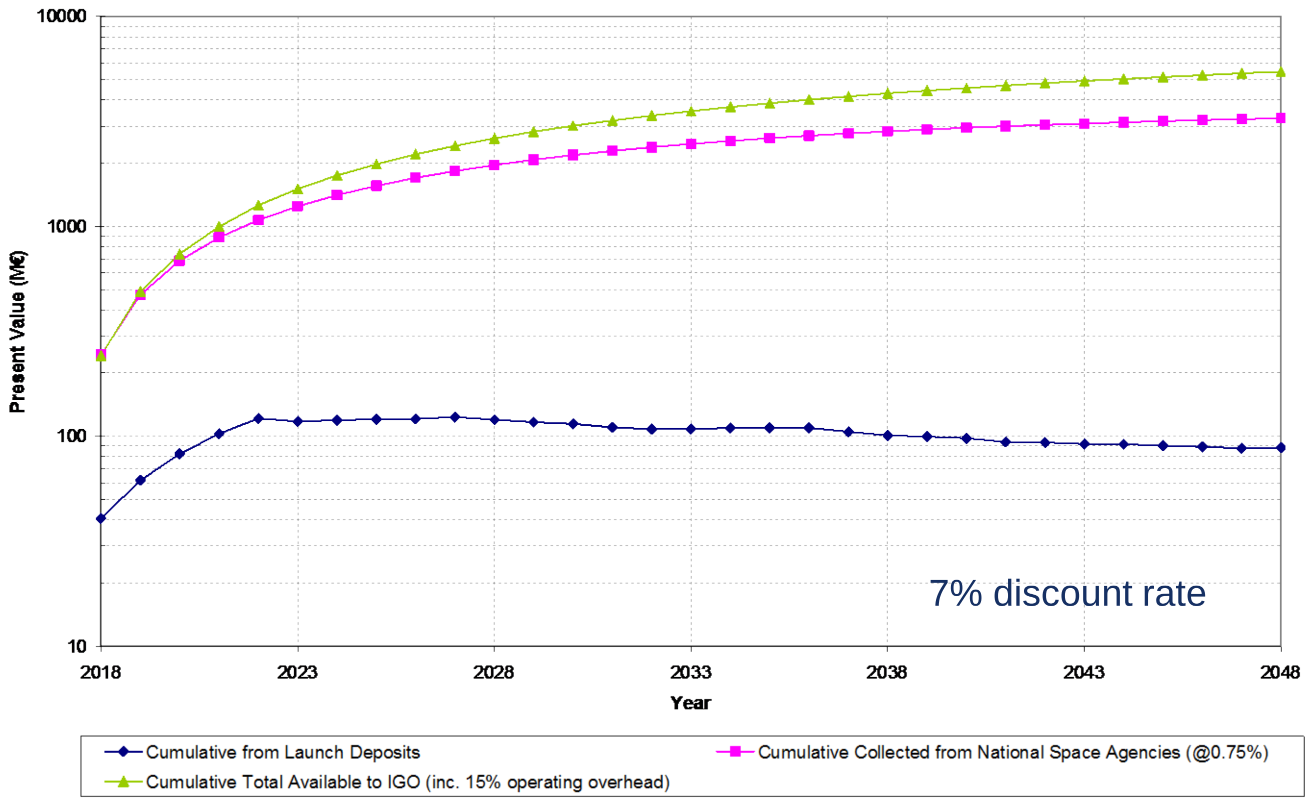
- Fundamental questions for any business operator in any field of operation:
  - 1.Is there a market into which to sell your product?
  - 2.Is your product something that anybody is willing to pay for?
  - 3.Is the price at which you sell your product compatible with the operating and overhead costs of the business?
- Requirement in statement of work was that ESA funding is limited to the first mission only
  - So who will pay and where is the market?
  - As a leading international space agency it is not realistic to think that ESA will have no contribution to any further ADR missions
  - Most space activities in Europe can be tied back to ESA or some form of institutional form of funding or co-funding, even if this is for seeding new technology developments
- However the debris population has been shown to be international with major contributors not coming from Europe
- Therefore some form of international authority and funding seems a pre-requisite for a business with ADR as its main focus
  - Alternative is be-spoke negotiations with each launching state for each object
- Some big assumptions were essential in defining the business plan!

An IGO for ADR



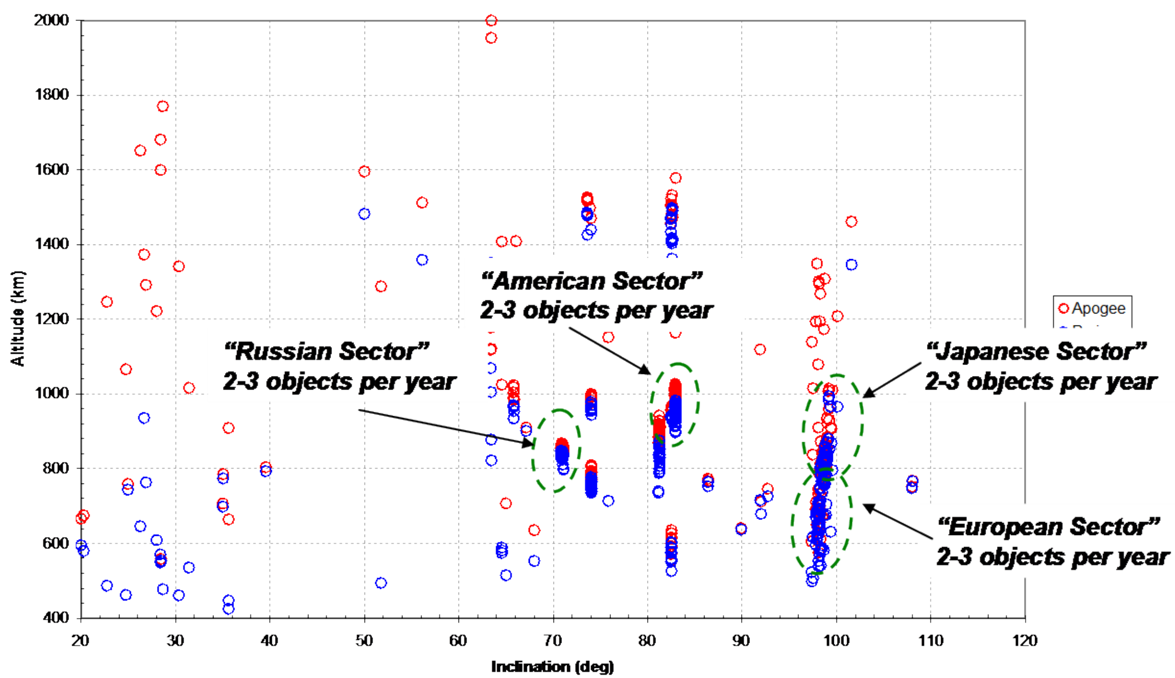
ADR IGO Funding

- The "polluter needs to pay" (which would imply Russia and USA primarily), but should Europe and ROW be able to exploit the resultant value in LEO without paying for ADR?
- The fairest route seems to be that each country pays the same percentage contribution of its national space budgets + IGO administers launch deposit scheme
  - Each country feels an equal amount of pain
  - Each country shares the global benefits which will accrue from performing ADR



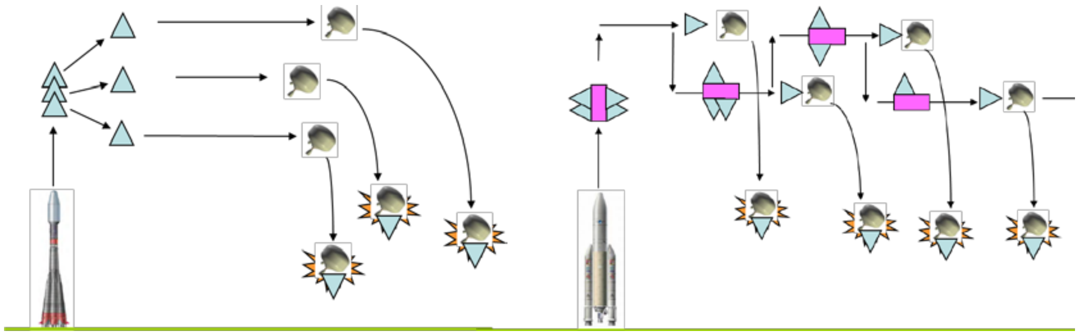
Constraints

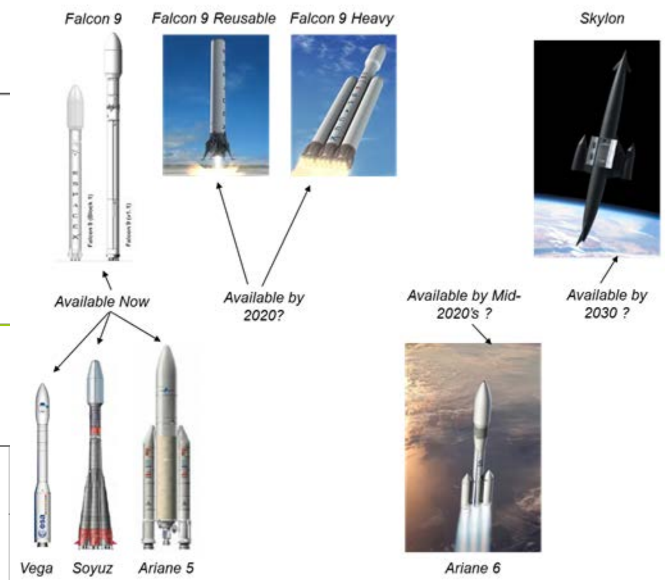
- ITAR and other national classification/technology transfer issues may be present for lots of objects in orbit (not just American)
- Payments from one country (ultimately from tax payers) may not be permitted to be spent on a service supplier from another country?
- IGO may have to implement a ‘sector’ based approach, whereby the global total of e.g. 10 objects removed each year, is split into several altitude-inclination sectors where a different service provider removes e.g. 2-3 objects per year
  - Allows multiple providers
  - Could have ‘American sector’, ‘Russian sector’, ‘European sector’ etc.
  - Debris needs to be removed concurrently from different regions anyway (for maximum benefit)

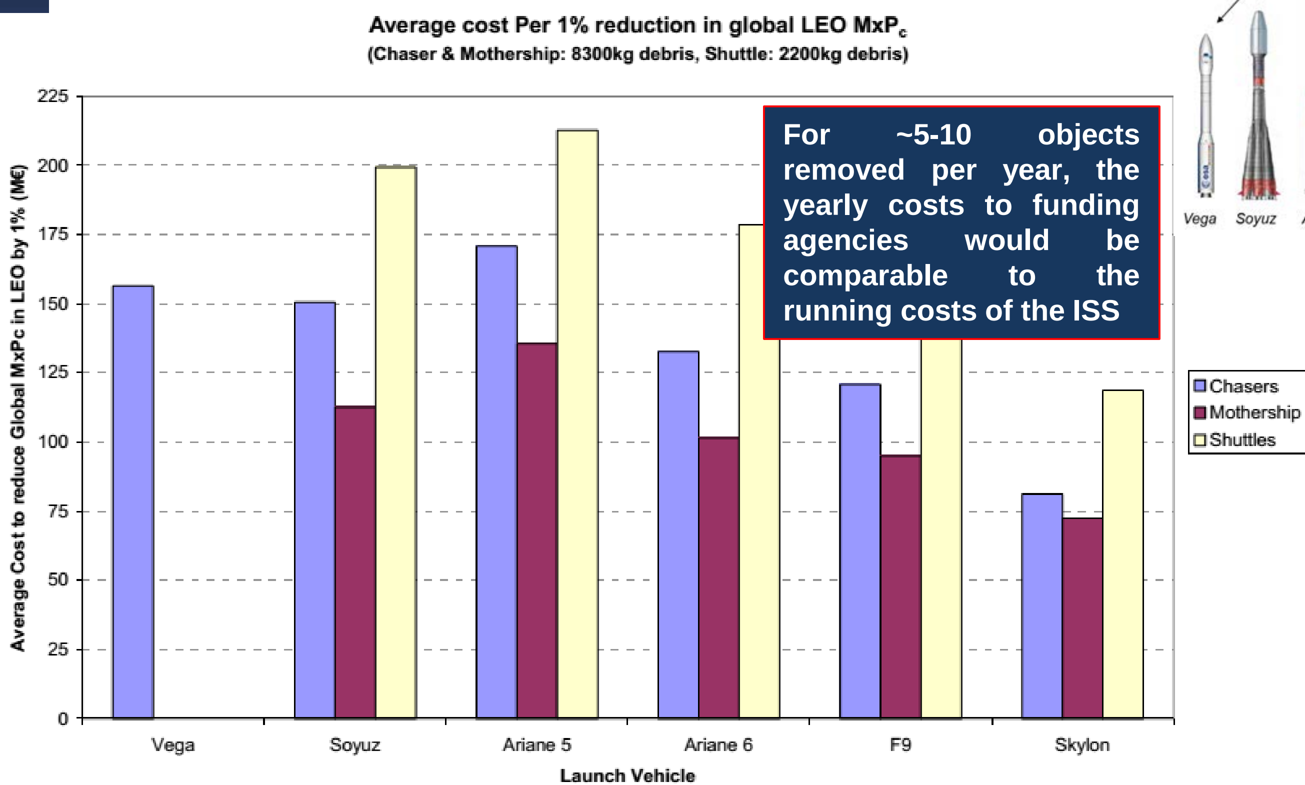


An ADR Business

- A number of different architectures have been explored to examine the financial viability of an ADR service provider, and to establish the likely costs and prices for long term operations







For ~5-10 objects removed per year, the yearly costs to funding agencies would be comparable to the running costs of the ISS

Critical aspects:

•A low recurring cost for the Chaser spacecraft

•Reusable launch vehicles that actually realise low kg-to-orbit costs

•Ability to remove multiple debris objects with a single ADR mission

Conclusions & Summary

- Study performed on Envisat removal as a dedicated mission, and long term ADR business architectures
- Preliminary system design for Envisat mission using Nets and launched on Vega
- Without further market opportunities, it does not seem feasible to envisage this mission as a true PPP
  - Complex mix of liability and legal responsibilities
  - High technology risk
  - No market
- Some form of international collaboration and ideally a dedicated Inter Governmental Organisation (IGO) dedicated to ADR needs to be established
  - Could be a highly complex and highly political endeavour!
  - IGO would auction service contracts for removal missions in dedicated orbital sectors
  - Funded by collected launch deposits based on PMD compliance, and flat rate (%) subscription from space agencies
- Some objects are a lot more 'valuable' than others in terms of reducing on-orbit risk (mass and collision probability), and these could attract a different price for removal
- A number of different architectures have been studied in terms of on-orbit operations and business structures
- To remove the recommended 5-10 objects per year, the total cost to the IGO is estimated as being comparable to the current yearly expenditure on the ISS
  - Will rely on international collaboration, trust, transparency and long-term commitment
- SSTL continues to explore ADR and its possibilities

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Thank You!

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