



# Wholesale LEO Debris Removal for Safe Space Operations

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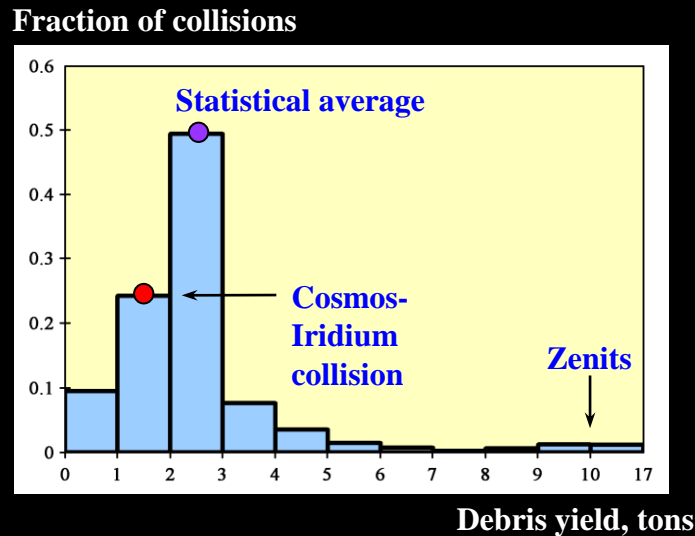
Star Technology and Research, Inc.  
[www.star-tech-inc.com](http://www.star-tech-inc.com)

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[www.tetherapplications.com](http://www.tetherapplications.com)

# Next Catastrophic Collision

- Statistically, like 2007 ASAT and Cosmos-Iridium combined
- Could produce ~500,000 untracked but potentially lethal fragments in the centimeter range (“shrapnel”)

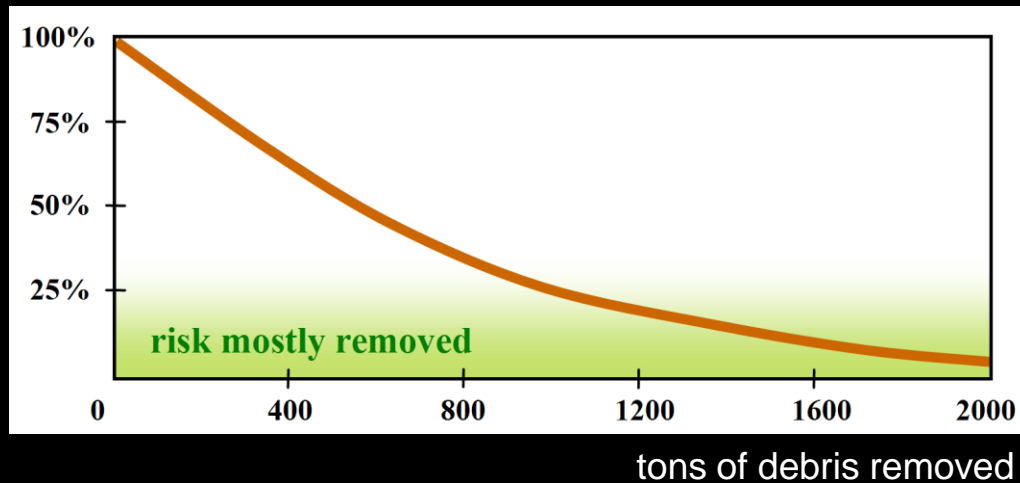


- Must remove large debris objects, the primary source of “shrapnel”

# How Much to Remove

- Statistical yield of fragments:  $R = \sum M_n \cdot P_n$

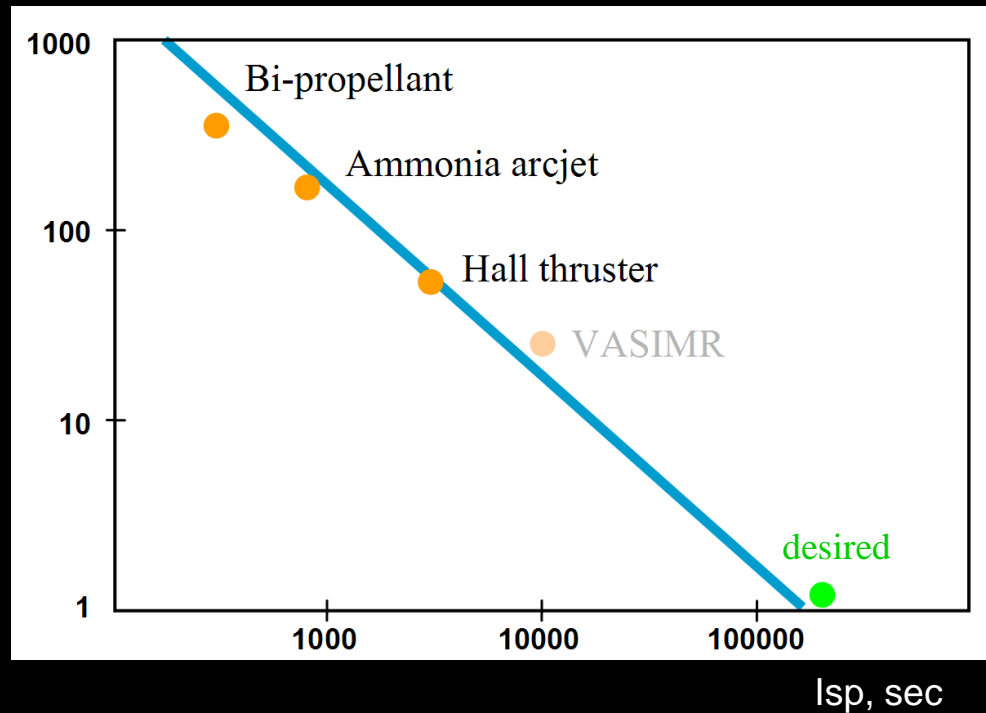
Debris generation potential



- Small-scale removal won't make a difference
- We need wholesale debris removal

# How Much to Launch

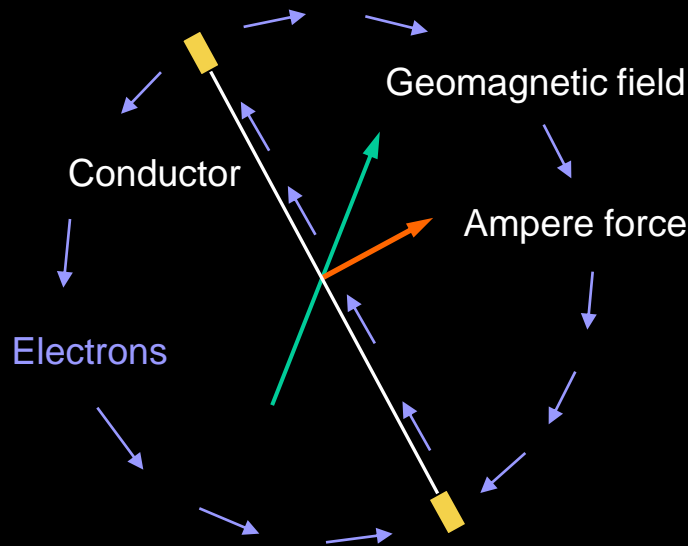
Estimated mass to launch, tons



- 2200 dead satellites and spent stages all over LEO, 2000 tons total
- Too demanding for rockets

# Electrodynamic Propulsion

- Propellantless, electrical, solar powered



Electron emitter



Hollow cathode

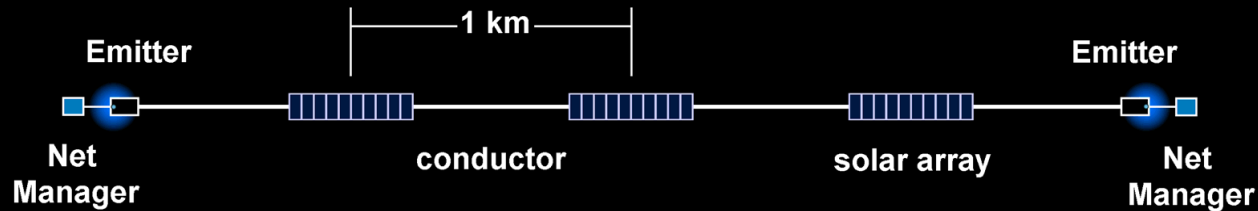
Electron collector



Aluminum tape

- Operation demonstrated in orbit by Plasma Motor Generator in 1993 and Shuttle Tethered Satellite System, TSS-1R, in 1996

# EDDE: The LEO “Garbage Truck”



- ElectroDynamic Debris Eliminator (EDDE)
- Only 100 kg—two fit into one ESPA secondary payload slot
- Nano-satellites “taped” together, but can move tons in LEO

ESPA ring



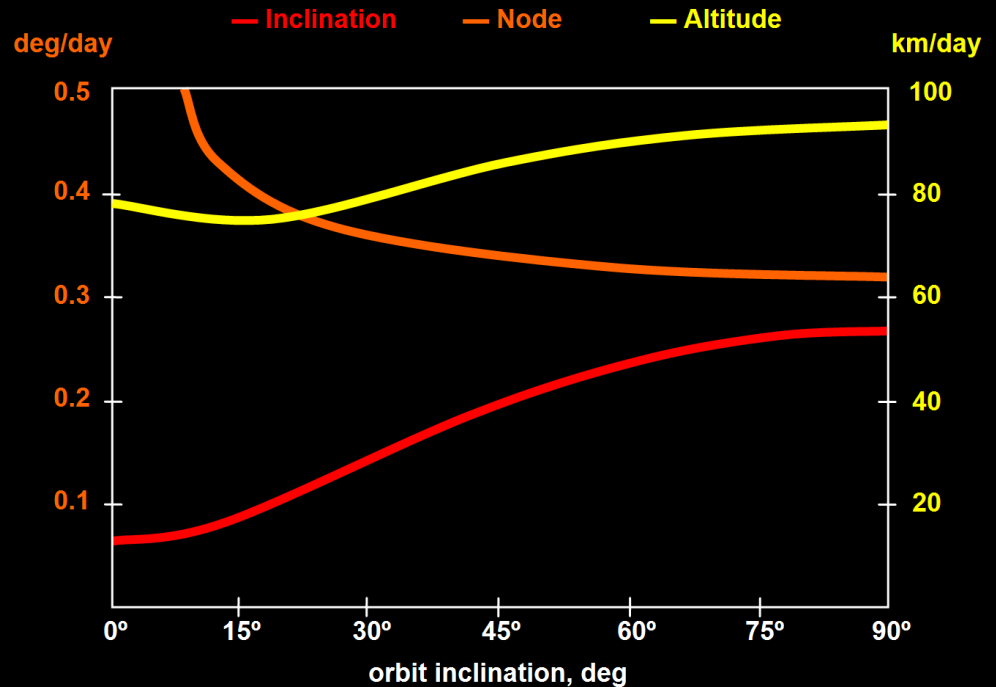
[www.csaengineering.com](http://www.csaengineering.com)

# How to Think About It

- EDDE sails in the magnetic field like a sailboat in the wind
- Changing electric current with conductor rotation allows EDDE to move rapidly to any orbit in LEO



Key West, 2006

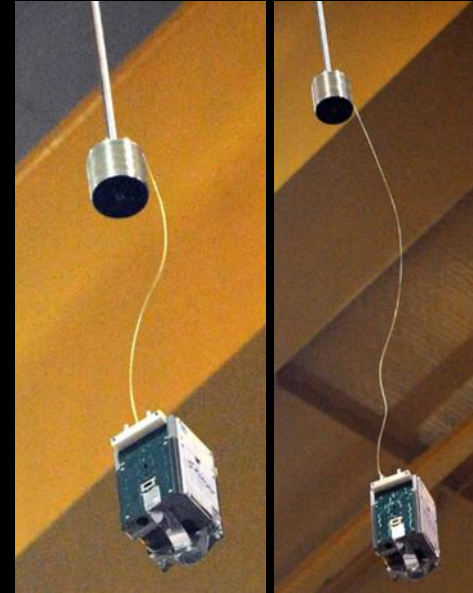
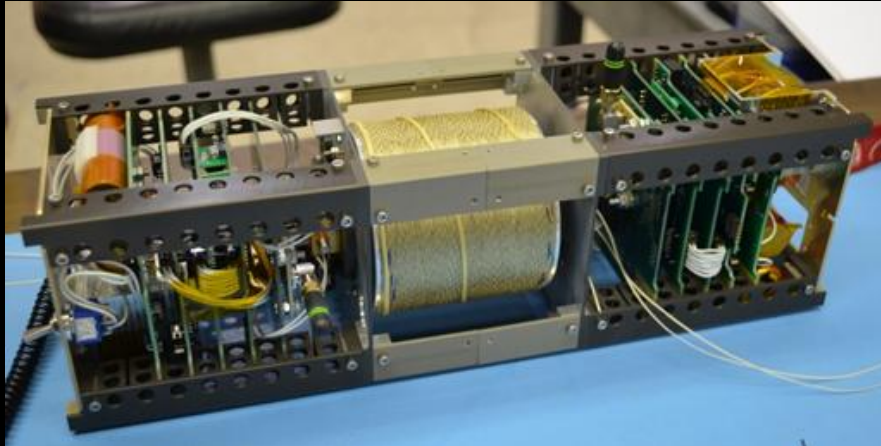


Orbit changes with 1-ton payload



# Electrodynamic Propulsion Flight Tests

- NRL Tether Electrodynamic Propulsion Experiment (TEPCE)



- Next step is Mini-EDDE flight test

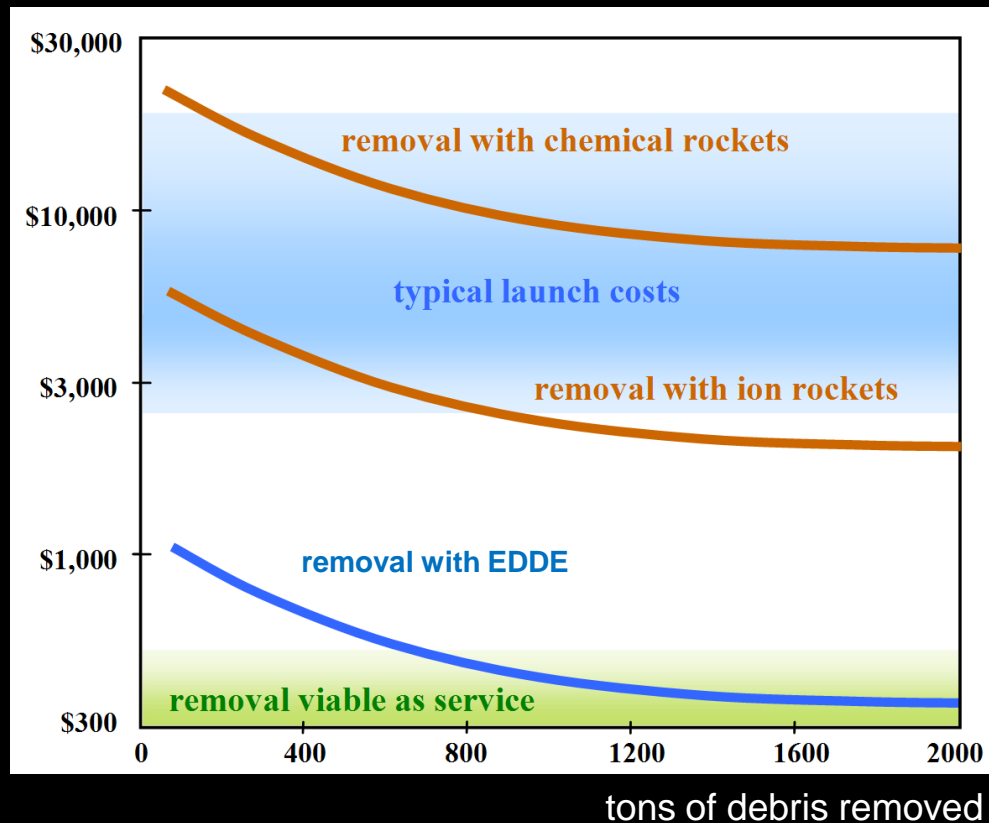
# EDDE Development Status

Technology	TRL now	After TEPCE	After Tech. Maturation	After Mini-EDDE
Electrodynamic thrust	6	7	7	8
HV electron collection	6	7	7	8
Bare tape collector	5	7	7	8
High-voltage solar arrays	6	6	6	8
High voltage electronics	5	6	7	8
Hollow cathodes	9	9	9	9
Hot-wire electron emitters	6	7	7	8
End-body yaw control	5	7	7	8
Single axis array steering	2	2	6	8
Born-spinning deployment	4	4	6	8
GPS, sensors, electronics	5	6	7	8
Optimum orbit transfers	3	5	6	8
Control algorithms and software	3	5	5	8
Navigation w/avoidance	3	6	7	8
Tracking; orbit prediction	4	7	7	8
Rotating tip rendezvous	2	2	5	8

# Commercial Service

- Removal should cost much less than launch to make economic sense

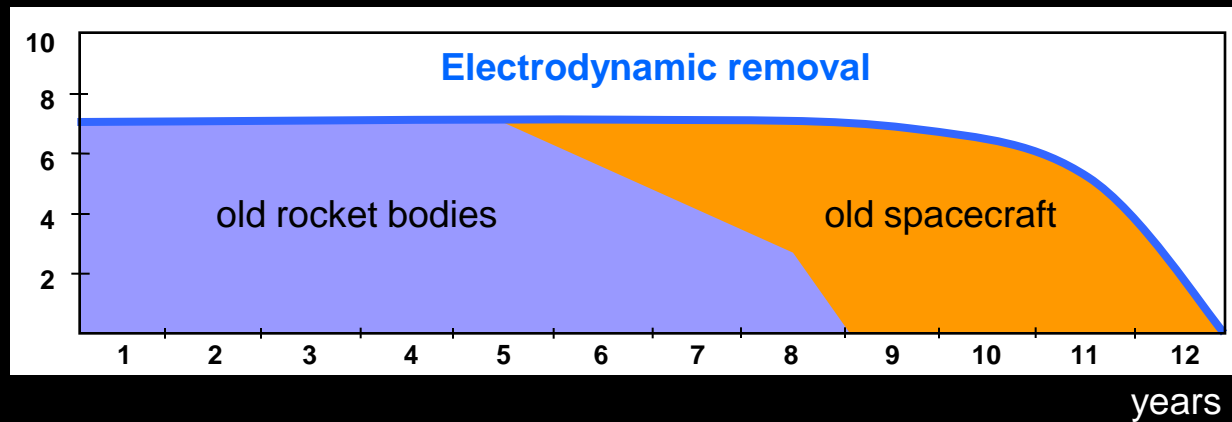
Cost per kg of debris removed



# Wholesale Removal Campaign

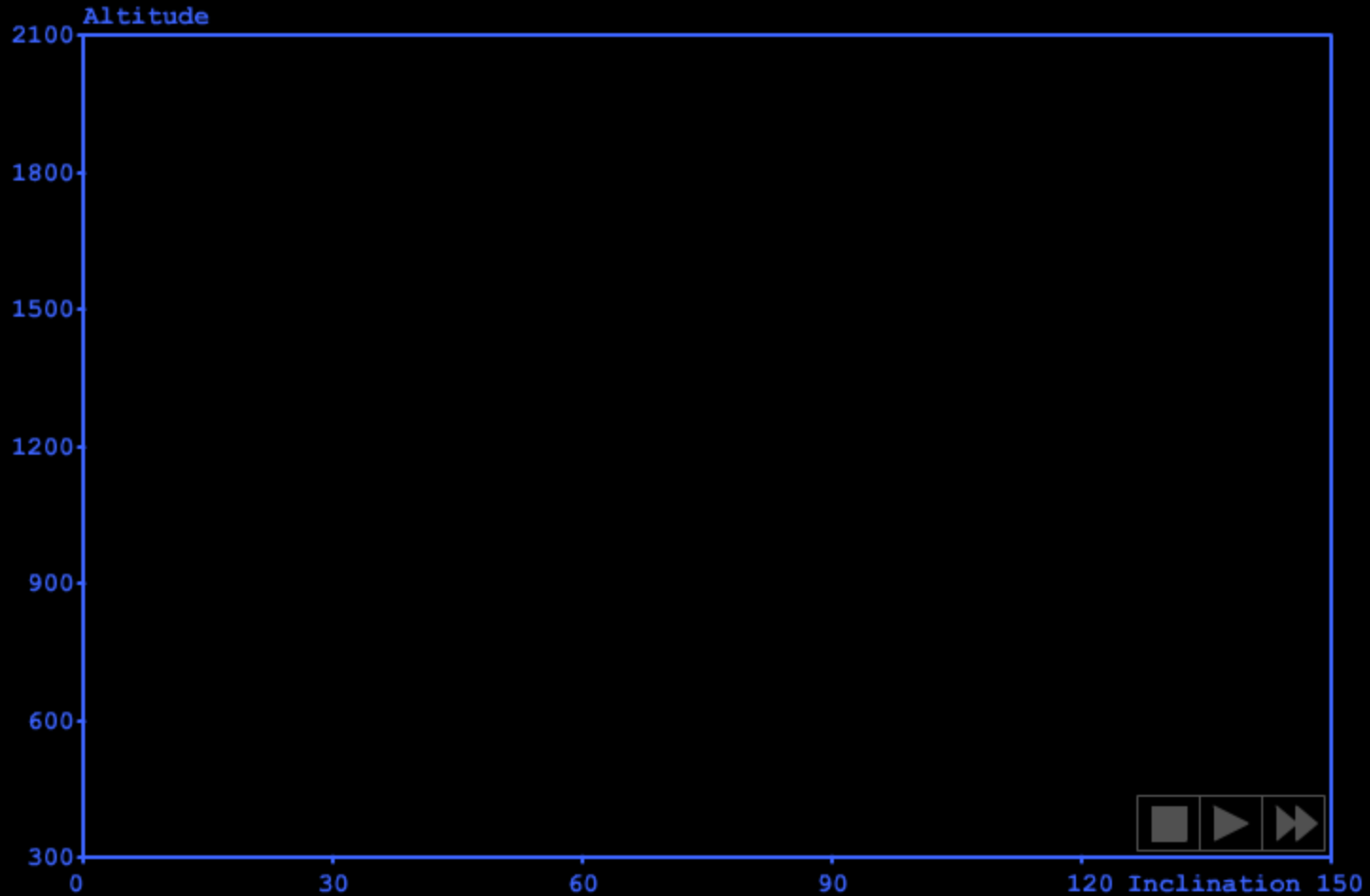
- If the IADC member agencies decide to share the expense

\$M per agency per year



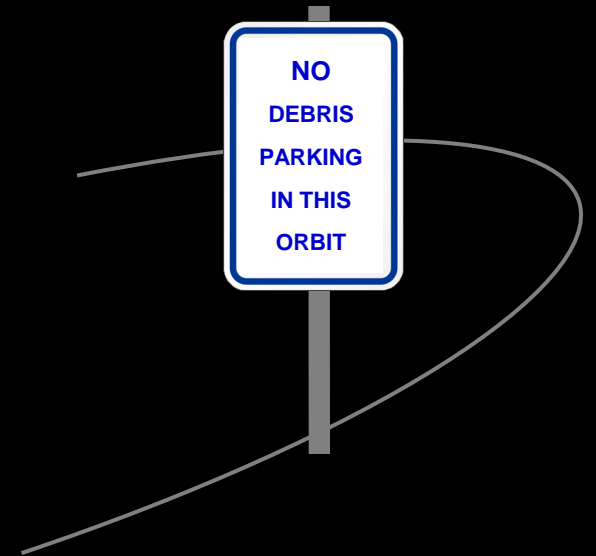
- Could use competitive bidding from service providers

# Wholesale Debris Removal



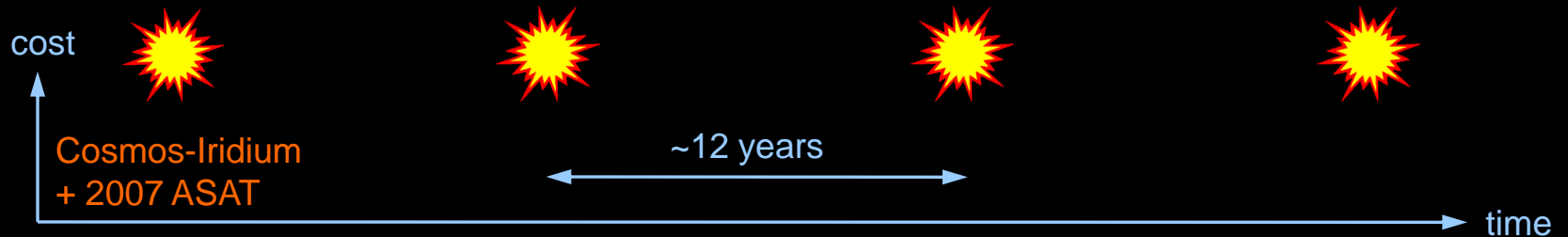
# New Rules

- Legacy debris: states paying for its removal set rules going forward
- New debris: should remove spent stages and failed satellites promptly
- Prototype: 25-year rule in U.S., but need a much shorter grace period
- Enforcement: participating states supervise their subjects
- Core group: states represented in IADC
- Enabler: affordable debris removal service
- Mechanism: salvage contract for each object



# Three Scenarios for LEO

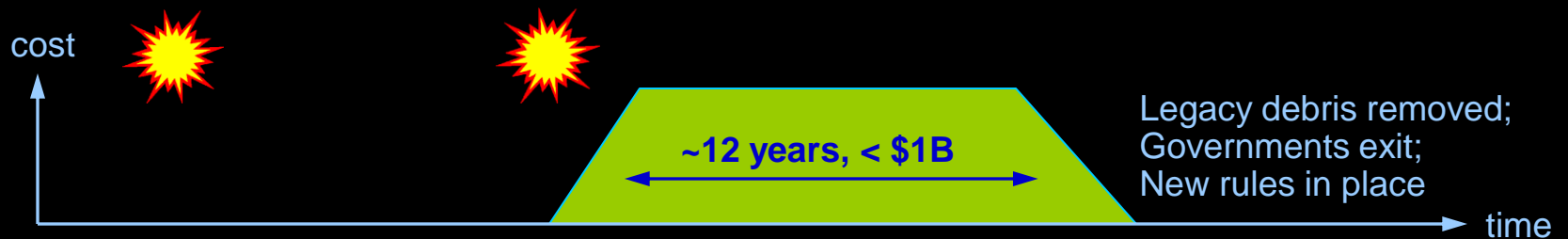
## 1. Doing nothing



## 2. Selective removal with rockets

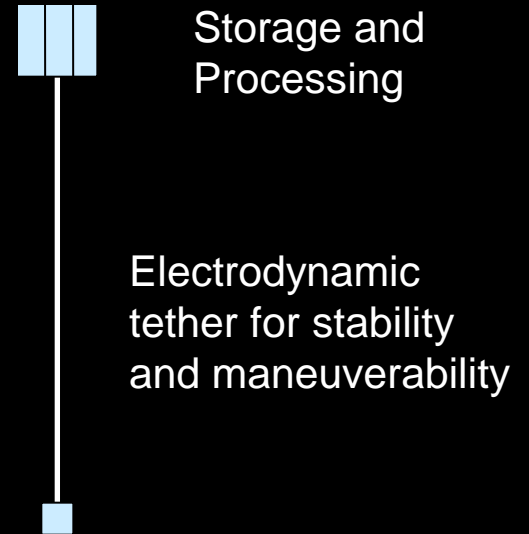
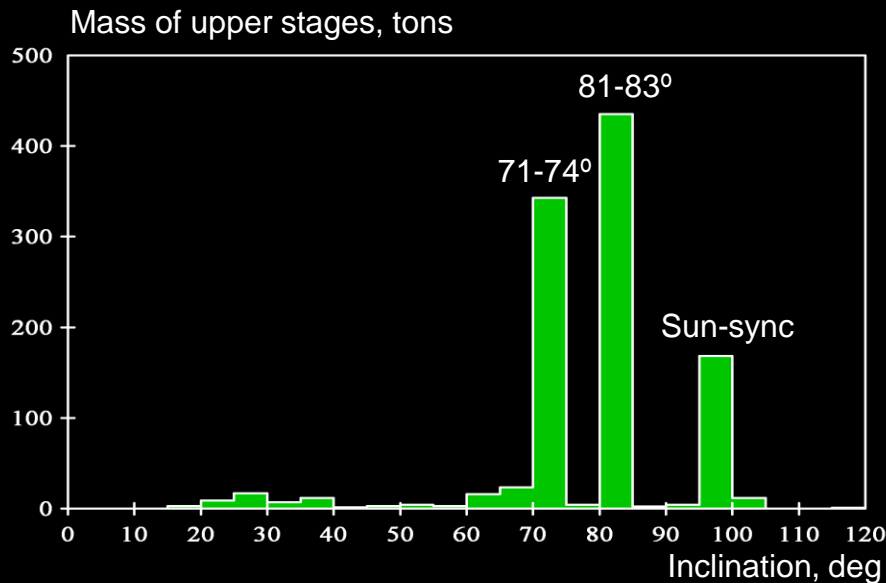


## 3. Wholesale removal with EDDE vehicles



# Debris Collection

- Avoid mass reentry
- Can use 1000 tons of mostly aluminum in upper stages





# Wholesale Debris Removal

- Implications for FAA:
  - Need for space traffic control
  - Need to integrate roving vehicle operations with other spacecraft
- Implications for commercial space:
  - Safer commercial space operations
  - New markets for end-of-life disposal and orbit clearing
- Implications for space situational awareness:
  - Need for improved tracking of non-Keplerian objects
  - Need for safe navigation of roving vehicles