# Cost Benefit Analysis of Space Debris Remediation

Tom Colvin, Ph.D.
John Karcz, Ph.D.
Grace Wusk, Ph.D.
Office of Technology, Policy, and Strategy (OTPS)

Office of Technology, Policy, and Strategy

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Reviewers
- Patrick Besha, OTPS
- Bo Naasz, STMD

# Nov 2021 Genesis of OTPS

In his letter to the Chair of the Congressional Committees on Appropriations requesting the creation of the office, Administrator Bill Nelson wrote that

- "Establishment of OTPS within the Office of the Administrator …will enable a more focused leadership on technology, strategy, and policy."
- OTPS will "serve as the NASA Administrator's advisor on strategic engagement in key areas to align Mission and Agency-level activities, supported by assessments to inform NASA senior leadership."
- OTPS will "continue to serve as the NASA Administrator's principal advisor and advocate on matters concerning Agency-wide technology policy and programs, including advocacy for NASA research and technology programs through communication and integration with technology efforts being conducted by other Federal agencies."

National Aeronautics and Space Administration

Office of the Administrator
Washington, DC 20546-0001

October 12, 2021

The Honorable Jeanne Shaheen
Chairwoman
Subcommittee on Commerce, Justice,
Science, and Related Agencies
Committee on Appropriations
United States Senate
Washington, DC 20510

Dear Madam Chair:

The purpose of this letter is to notify the Committee of a reprogramming action, in compliance with Section 505 of Division B of the FY 2021 Consolidated Appropriations Act (P.L. 116-260), involving a reorganization of Agency offices.

Specifically, I have determined that it is in the Agency's interest to establish an Office of Technology, Policy and Strategy (OTPS) within the Office of the Administrator. OTPS will consolidate the previous Office of the Chief Technologist and the previous Office of Strategic Engagements and Assessments into a single office, perform the functions of those previous offices, and incorporate the staff of those previous small offices.

Establishment of OTPS within the Office of the Administrator recognizes the importance of technology as a key driver of sound policy and strategy to guide NASA's current and future missions, and will enable a more focused leadership on technology, strategy, and policy. I appreciate the strong support of the Committees on Appropriations for NASA. I look forward to working with you to implement this reorganization expeditiously.

Sincerely,

Bill Nelson
Administrator

Enclosure

# OTPS Vision

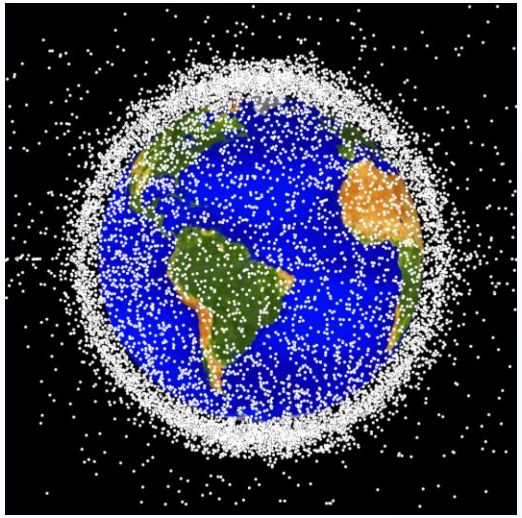
Working transparently and in collaboration across NASA and with the broader space community...

...OTPS research and analysis informs NASA's most consequential decisions about its future

"The greatest deception men suffer is from their own opinion."
-Leonardo da Vinci, c. 1500

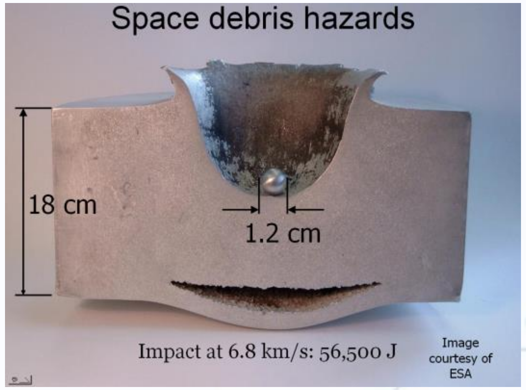
# Risks From Orbital Debris are Growing

- Orbital debris is "any human-made space object orbiting Earth that no longer serves any useful purpose"
- Risk is probability times consequence:
  - Probability increasing
  - Consequence of debris strike increasing
- Consequences are costs to:
  - Assess risk exposure
  - Maneuver to avoid tracked debris
  - Collision with untracked debris



Defunct upper stages with masses up to 9,000 kg

Failed satellites from large constellations




Debris below 10cm is not currently tracked

# NASA is Working to Reduce Risks Across the Debris Lifecycle

## Space Sustainability

- International Leadership
  - United Nations
  - IADC
- Domestic Leadership
  - White House Policy Development
  - ODMSP

## Mitigate

- Low TRL Development
  - Resilient Materials
  - Autonomous navigation
  - Collision avoidance
- Modeling
  - Collisions with debris
  - Mitigation options
- Standards Review

## Track and Characterize

- Measurement
  - Debris environment
- Modeling
  - Evolution of debris
- Conjunction Assessment
  - Robotic spacecraft
  - ISS and visiting vehicles

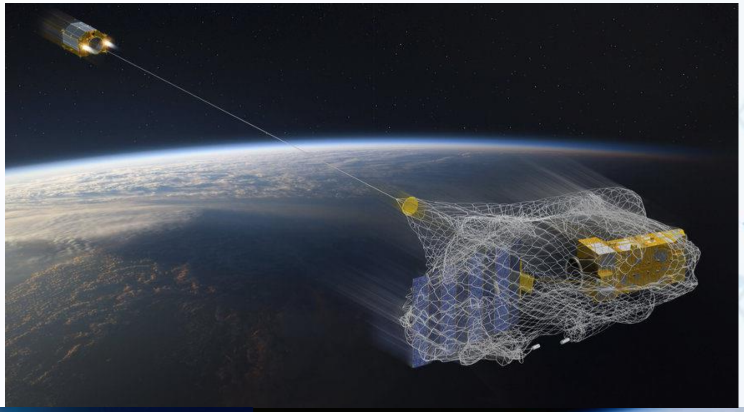
## Remediate

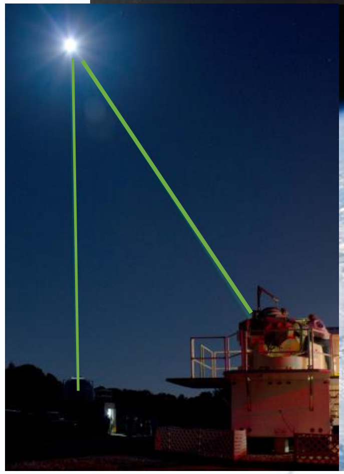
- Low TRL Development
  - Related ISAM capabilities
  - Commercial Services
- Cost Benefit Analysis

# Problem: The Utility of Debris Remediation is Uncertain

- Remediation is any action performed on debris to reduce risk
- Benefits usually discussed on long time scales
    - Hard to incentivize near-term action
- Hard to know which methods to prioritize
    - Many types of debris
    - Many cleanup methods
- Much of the uncertainty is economic
    - What is the cost to remediate?
    - How much is a piece of debris worth?
    - Who should pay?

**Remove**





**Move**

**Reuse**

# Goal and Methodology

**Goal:** A landscape-level view of various remediation methods, including their costs and near-term benefits, that can inform technology and policy development

**Approach:**

- Modeled the costs imposed by debris on satellite operators
- Quantified benefits of various remediation concepts in dollars
- Estimated costs to develop and operate various remediation concepts
- Identified the remediation concepts with most favorable cost-benefit ratios
- Held discussions with 35 organizations that have relevant expertise

# Two Remediation Scenarios

## Scenario 1: Remediate Top 50 Derelicts

- McKnight et al. (2021)
- Mass of objects ranges from 800 kg to 9,000 kg
- Orbits from 625 km to 1175 km
  - 25 objects clustered at 825 km
- $3.5M benefit in first year*
  - Benefits compound annually

## Scenario 2: Remediate 100K Small Debris

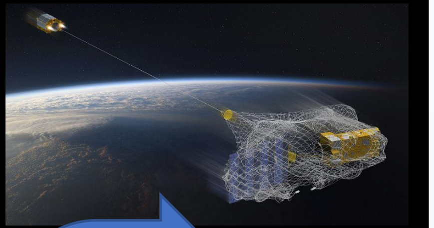
- 1-10 cm in diameter
- Orbits from 450-850 km
- Chosen to maximize benefit
- Debris removed in uniform proportion from each orbit
- $23M benefit in first year*+
  - Benefits compound annually

* Calculated from annual risk model
+Caution: does not mean that small debris is more valuable than large debris.

# Remediation Methods Considered

## Tug to Controlled Reentry

**Remove:** Chemical propulsion guides debris into ocean



(Credit ESA)

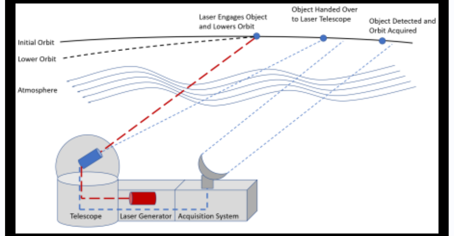
## Tug to Uncontrolled Reentry

**Remove:** Tug or drag device accelerates the uncontrolled reentry

(Credit ESA)

## Lasers for Nudging Debris

**Move:** Space- or ground-based lasers nudge debris as necessary




## Responsive Rockets for Nudging Debris

**Move:** Sounding rocket intersects debris' orbit and nudges debris


(Credit ESA)

## Convert Debris into ΔV

**Recycle:** Aluminum in debris is used as propellant to deorbit

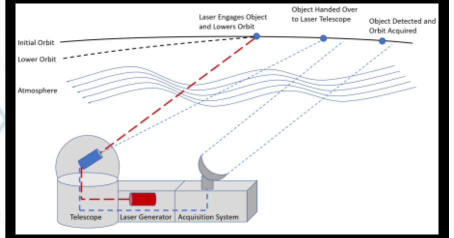
(Credit NASA)

Large Debris

Small Debris

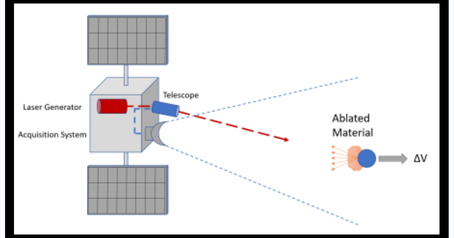
## Ground-Based Laser

**Remove:** Deorbit trackable and nontrackable debris



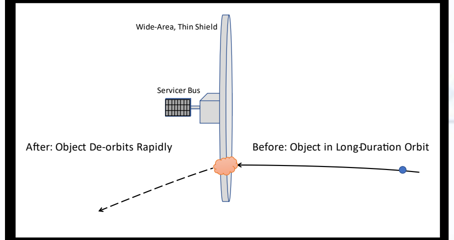

## Space-Based Laser

**Remove:** Deorbit trackable and nontrackable debris



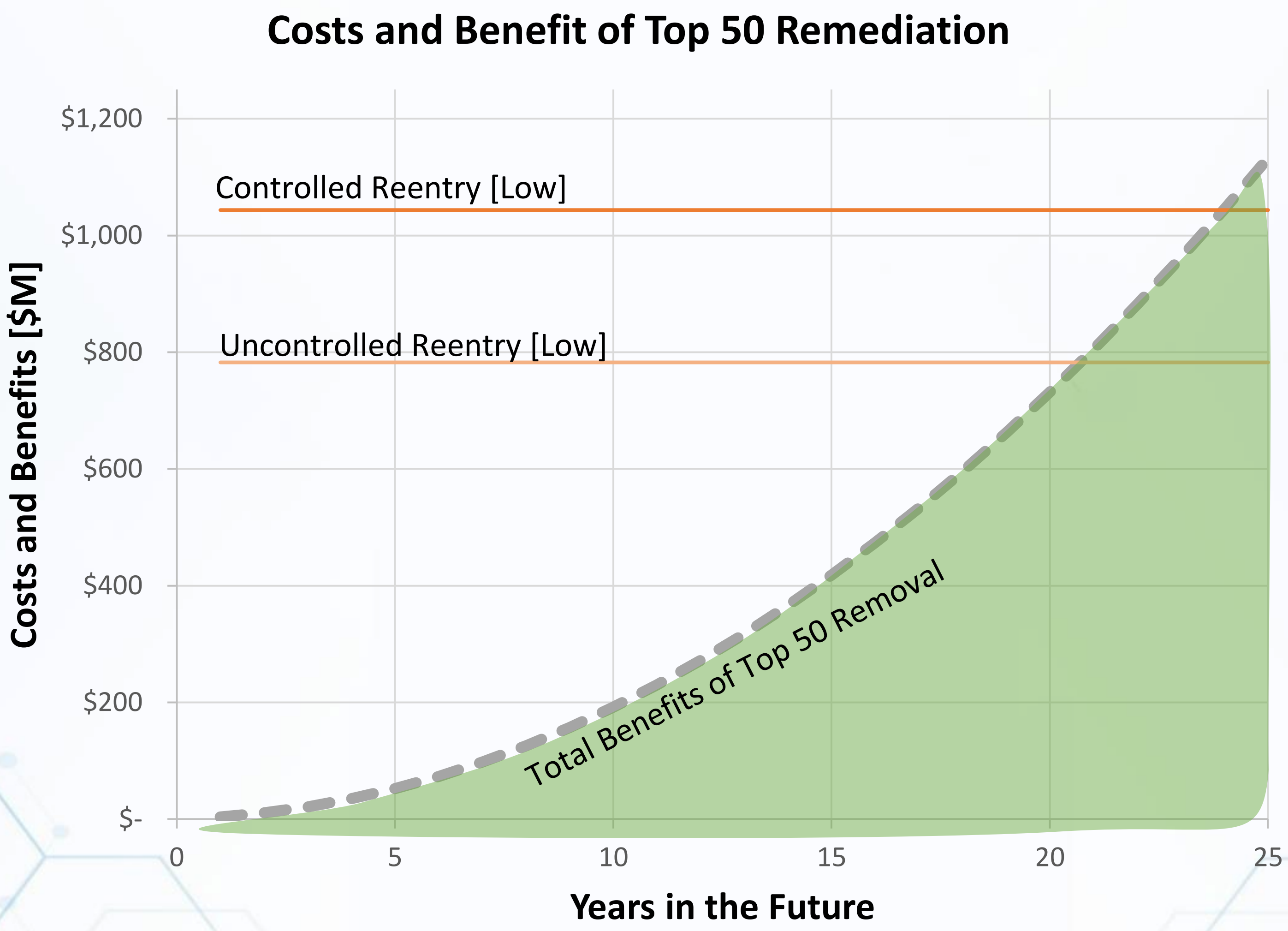

## Physical Sweeper

**Remove:** Capture, slow down, or break up nontrackable debris



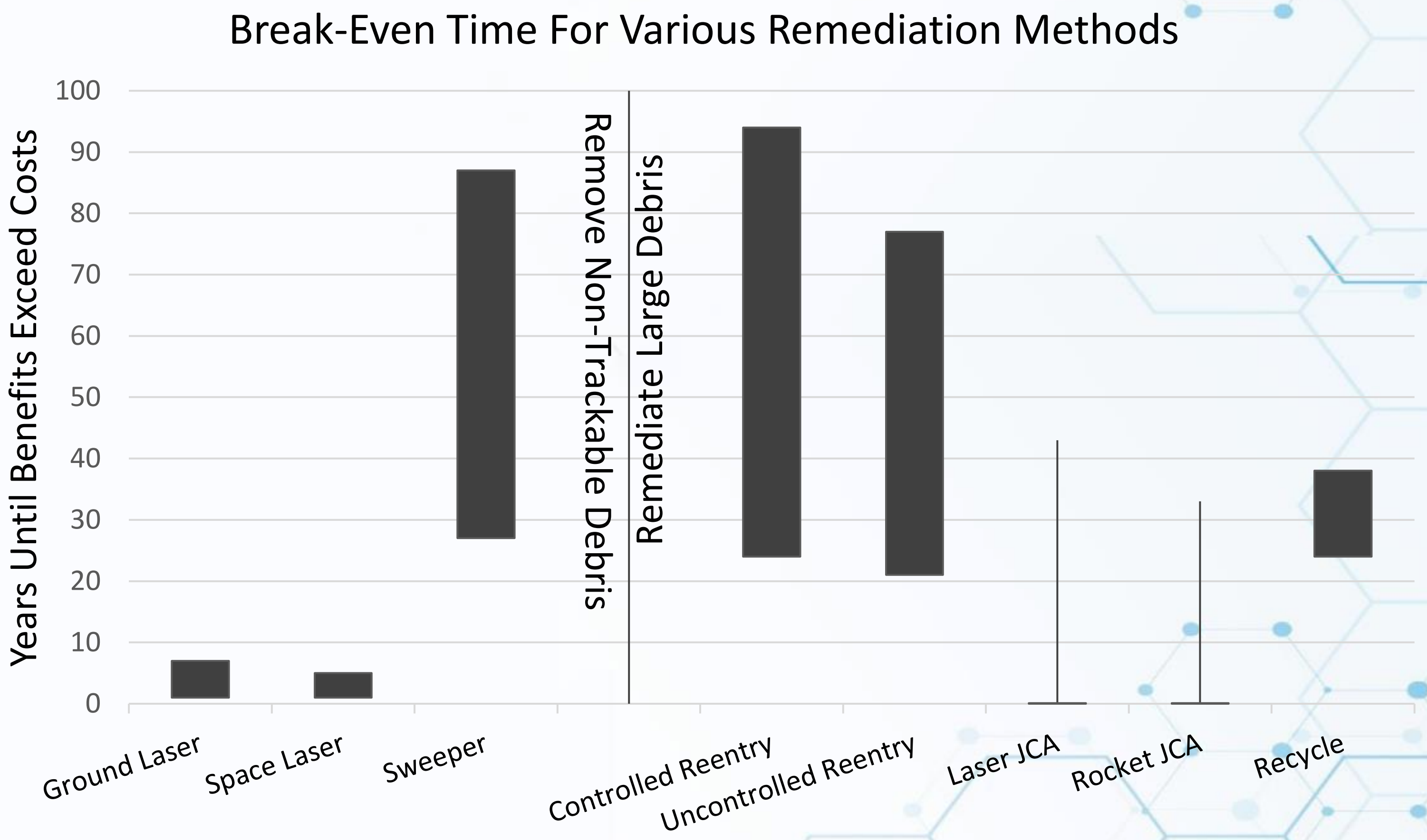
# Break-Even Times (Example)

**Years until benefits of remediation exceed the costs to perform the remediation**



# Findings: Net Benefits are Possible on Operationally Relevant Timescales

- Most effective risk reductions
  - Removal of small debris (1-10cm)
  - Nudging large debris to avoid collisions
- Controlled reentry still relevant
  - Some debris may require it
  - Might payback in 20-30 years
  - Uncontrolled reentry may not be significantly cheaper
- Recycling has pros and cons
- Sweeper is being used outside of its sweet spot of mm-sized debris



# Conclusion

- Most rigorous and wide-reaching analysis in the literature of the negative effects that debris imposes on space operators, measured in dollars
- First to investigate the landscape of remediation methods using a framework for comparing the costs and benefits among them
  - Made many simplifying assumptions, which are detailed in the report
- First to demonstrate that expenditures in remediation methods may achieve net benefits on near-term timescales
  - Most effective methods are removal of 1-10 cm debris and nudging large debris
  - Most of the benefits are future risks reduced, not costs saved
- The space community should focus less on reducing proxies for risk—like total mass or number or debris in space—and focus more on dollars at risk directly

# Next Steps

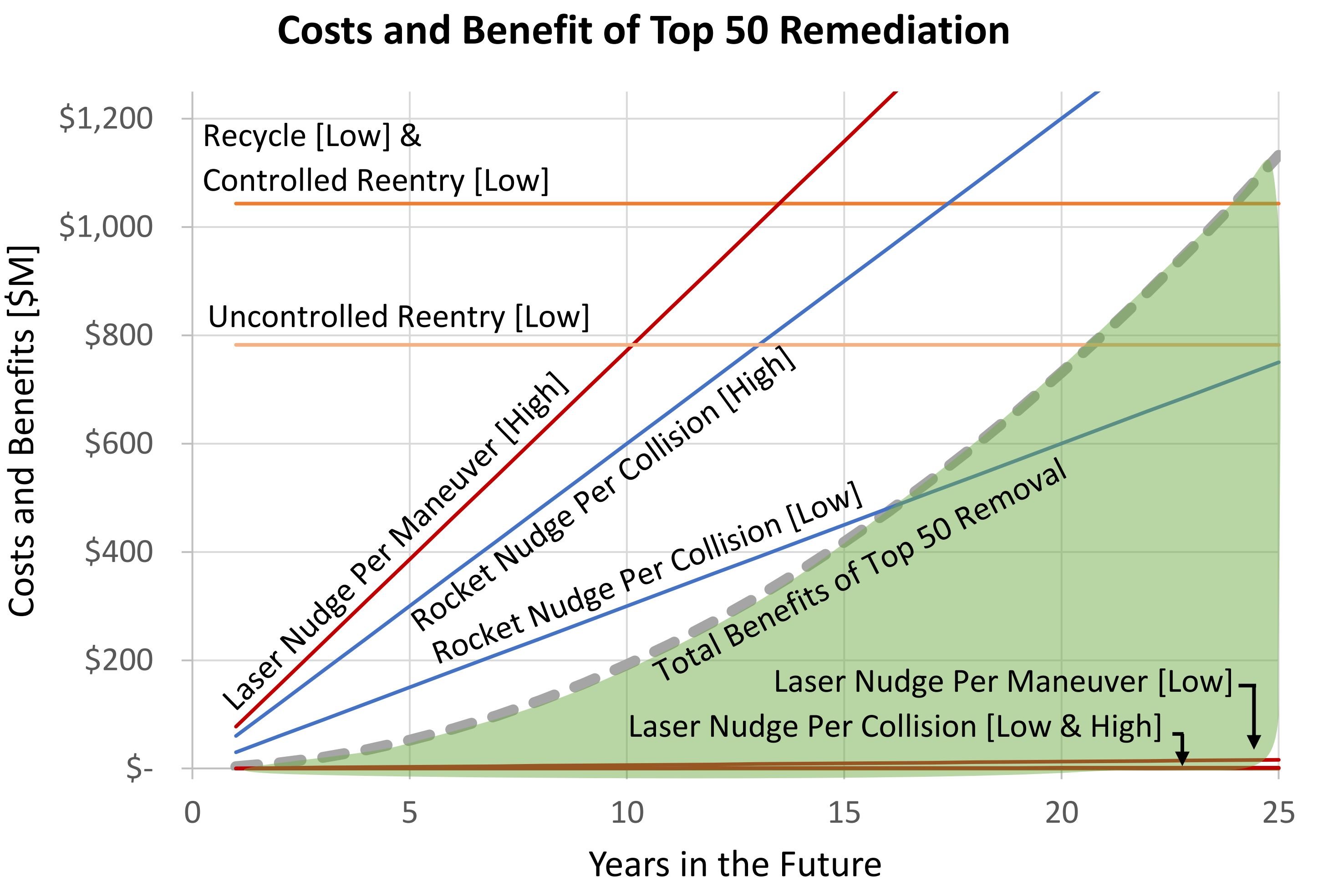
- Feedback on Phase I report and input on Phase II
- Improve the probabilistic risk model
    1. atmospheric decay of orbital debris over time
    2. compounding growth in debris due to collisions
    3. non-circular orbits of spacecraft and debris
    4. scaling the probability of collision with the cross-sectional area of the debris
    5. small debris in the range of 1-10mm
- Reduce cost uncertainties for the most promising debris remediation concepts
- Characterize new developments in mitigation and tracking for use in risk model
- Support a NASA plan for remediation capability and policy development

# Questions?

# Backups

# The Costs and Benefits of Remediating the Top 50 Derelicts

- Costs too high to illustrate
    - Controlled Reentry [High]
    - Uncontrolled Reentry [High]
    - Recycle [High]
- Uncontrolled reentry not much better than Controlled reentry
- Controlled better than some high-cost nudging approaches
- Nudging approaches appear most efficient
    - Could relax the false-positive rate of rocket nudging



# The Costs and Benefits of Removing 100K Small Debris

- Costs too high to illustrate
  - Sweeper [High]
- Sweeper concept costs are highly caveated
  - mm-sized debris not included
  - Mass possibly oversized
  - Very large area but few debris per year
- Other removal methods break even quickly