DARE TO DREAM 5.0

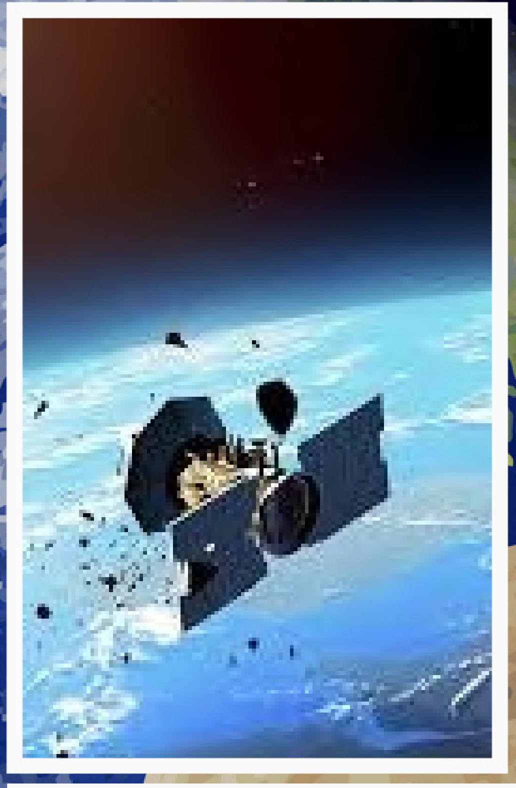
Revolutionary Solution for Space Debris Removal Using Smart Mechanisms

Team Details :

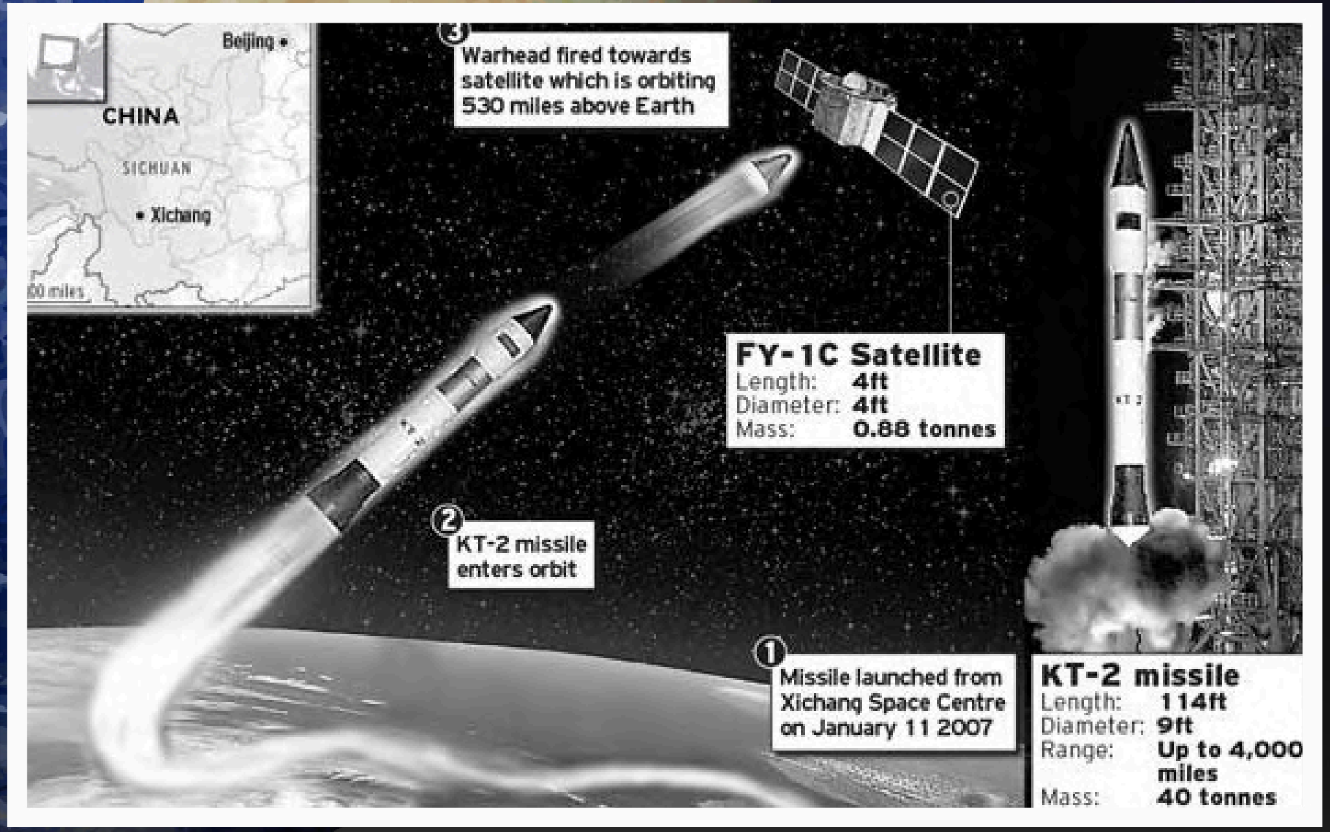
Team leader name: **Dr. Tameshwer Nath**
Problem Statement: **Space Debris Removal (Individual Category)**
Institute Name: **Indian Institute Of Information Technology Bhagalpur**

WHAT IS SPACE DEBRIS?

SPACE DEBRIS, OR SPACE JUNK, REFERS TO DEFUNCT SATELLITES, SPENT ROCKET STAGES, AND FRAGMENTS FROM COLLISIONS ORBITING EARTH, POSING RISKS TO OPERATIONAL SPACECRAFT AND SATELLITES.



PROBLEM FACED DUE TO SPACE DEBRIS?



- **COLLISION RISKS:** IN 2009, A DEFUNCT RUSSIAN SATELLITE COLLIDED WITH AN ACTIVE IRIDIUM SATELLITE, CREATING THOUSANDS OF NEW DEBRIS PIECES. **CHAIN REACTION OF COLLISIONS:** EACH COLLISION GENERATES MORE DEBRIS, EXPONENTIALLY INCREASING THE RISK OF FURTHER COLLISIONS.THIS CHAIN REACTION KNOWN AS THE KESSLER SYN DROME.
- **THREAT TO SPACE MISSIONS:** IN 2007, CHINA’S ANTI-SATELLITE MISSILE TEST DESTROYED A WEATHER SATELLITE, CREATING OVER 3,000 DEBRIS PIECES, SIGNIFICANTLY INCREASING COLLISION RISKS IN LOW EARTH ORBIT.

TYPES OF SPACE DEBRIS

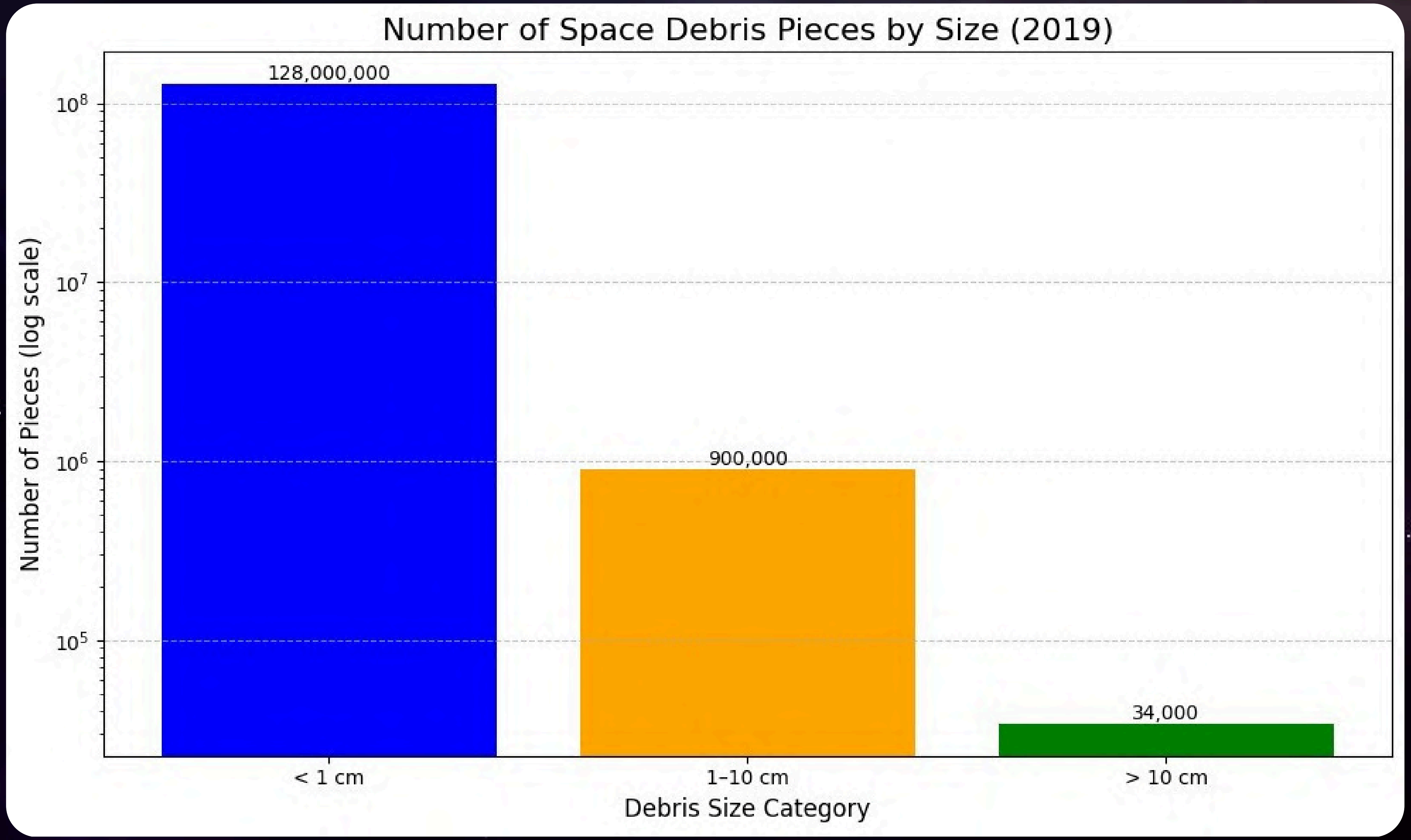
(BASED ON SIZE)

Small Debris
<1 cm

- Examples: Paint flecks, tiny metal fragments, microplastics
- Handling: Burned up during atmospheric re-entry.
- ~900,000 pieces in LEO

Medium Debris
1–10 cm

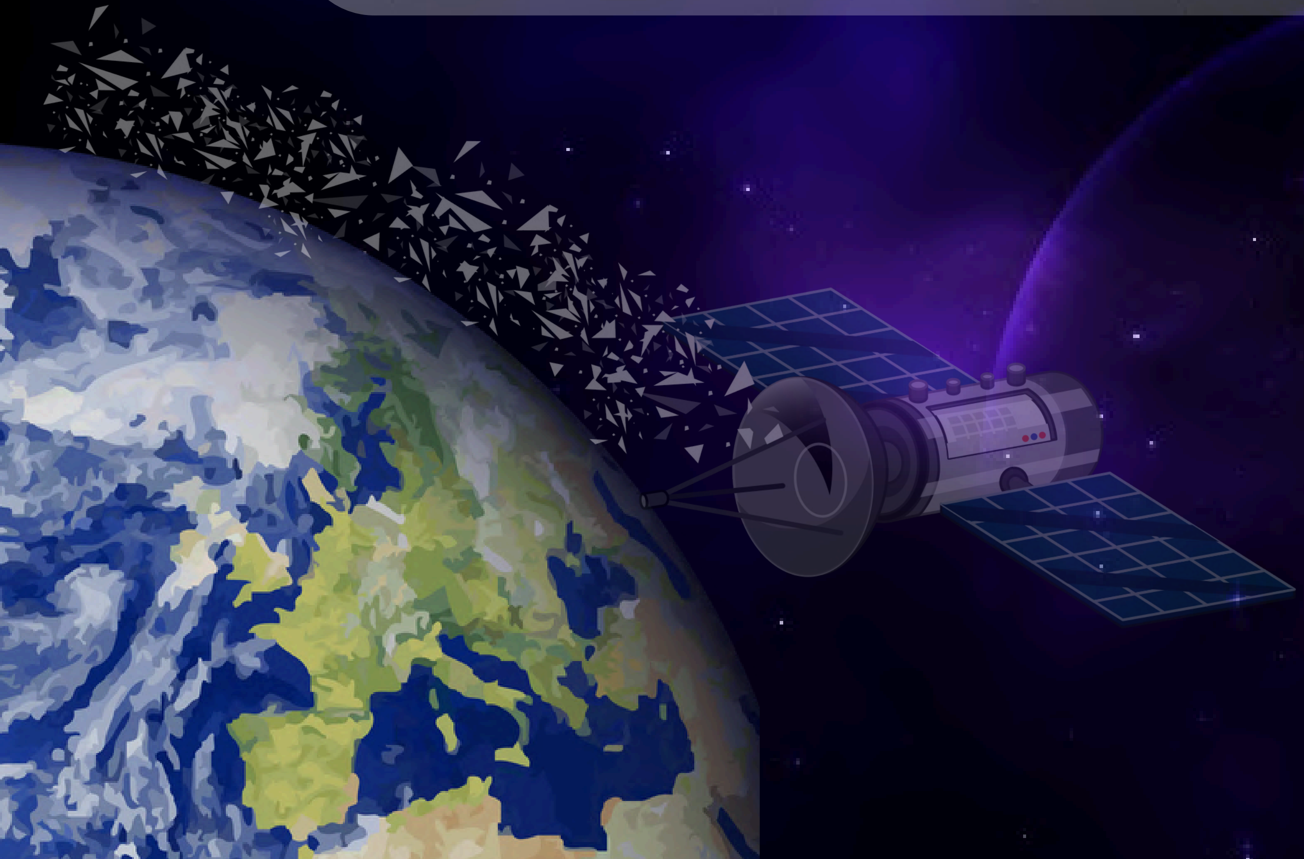
- Examples: Bolts, screws, small satellite parts, shattered rocket fragments
- Handling: Captured with nets and deorbited
- ~34,000 pieces



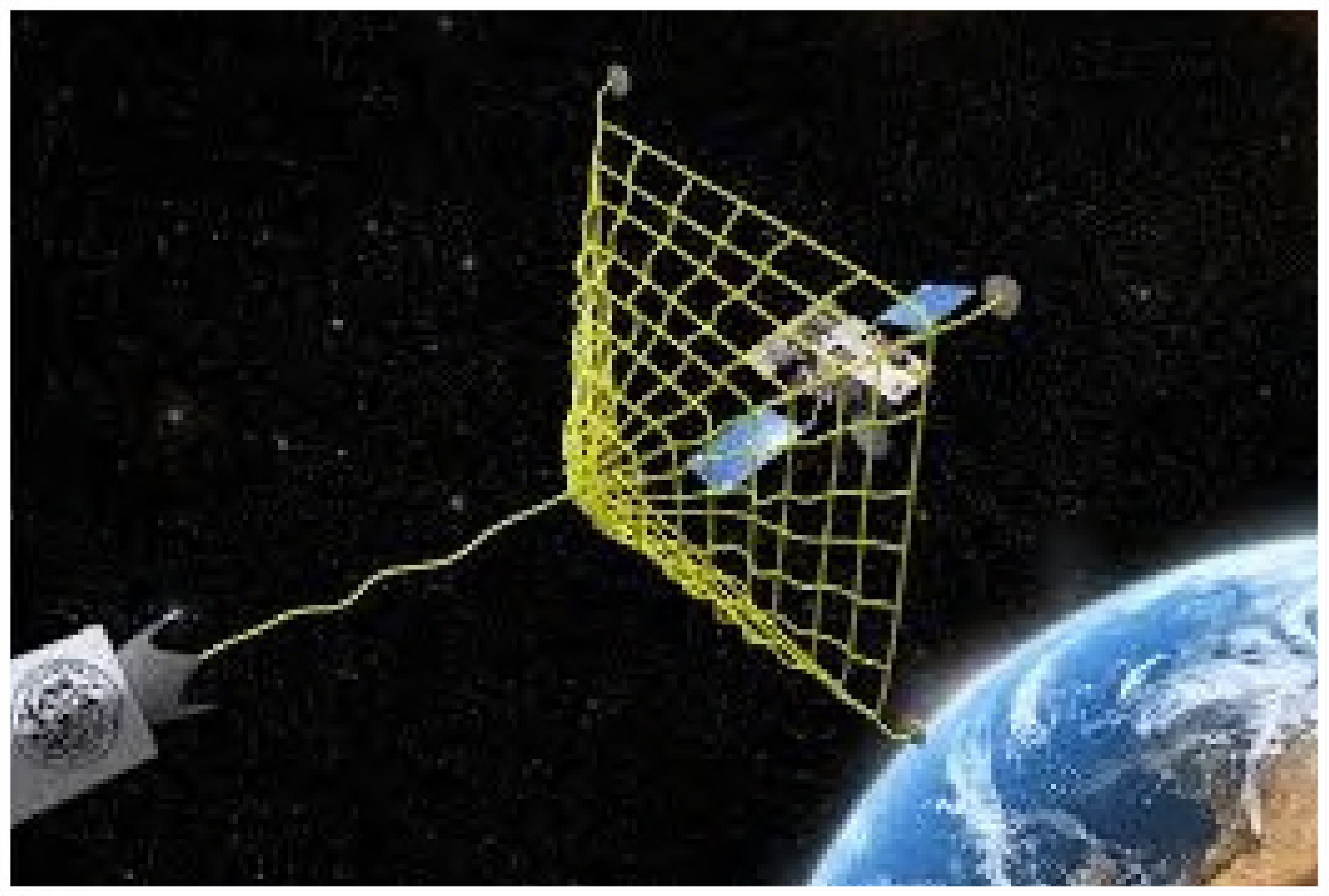
Large Debris
>10 cm

- Examples: Defunct satellite parts, large rocket components, spacecraft fragments
- Handling: Removed with harpoons or lasers for controlled deorbiting
- ~5,500 objects (defunct satellites, spent rocket stages)

SMA-DRIVEN ADAPTIVE ROBOTIC MECHANISMS FOR SPACE DEBRIS REMOVAL



CORE IDEA: **SHAPE MEMORY ALLOY (SMA)** IS AN INTELLIGENT MATERIAL THAT DEFORMS AND REVERTS TO ITS ORIGINAL SHAPE WHEN EXPOSED TO HEAT OR SPECIFIC CONDITIONS. A SHEET METAL ALLOY-BASED **ROBOTIC SYSTEM**, ENHANCED WITH AI, ENABLES ADAPTIVE, ENERGY-EFFICIENT, AND VERSATILE DEBRIS REMOVAL.



ADVANCED FEATURES:

- SMA TECHNOLOGY:
  - LIGHTWEIGHT, COMPACT, AND ENERGY-SAVING ACTUATORS FOR DIVERSE DEBRIS SHAPES AND SIZES.
- AI INTEGRATION:
  - TRAJECTORY PREDICTION FOR PRECISE DEBRIS TARGETING.
  - COLLISION AVOIDANCE USING REAL-TIME PATH OPTIMIZATION.

OVERCOMING LIMITATIONS:

- LASER SYSTEMS: HIGH POWER REQUIREMENTS.
- TETHER SYSTEMS: RISK OF ENTANGLEMENT.
- MAGNETIC CAPTURE: INEFFECTIVE FOR NON-MAGNETIC DEBRIS.

BENEFITS:

- UNIVERSAL APPLICABILITY TO VARIOUS DEBRIS TYPES.
- IMPROVED MISSION SAFETY AND OPERATIONAL EFFICIENCY.
- SUPPORTS SUSTAINABLE AND LONG-TERM SPACE OPERATIONS.

ACTIVE DEBRIS REMOVAL (ADR) & LASER-BASED SYSTEMS

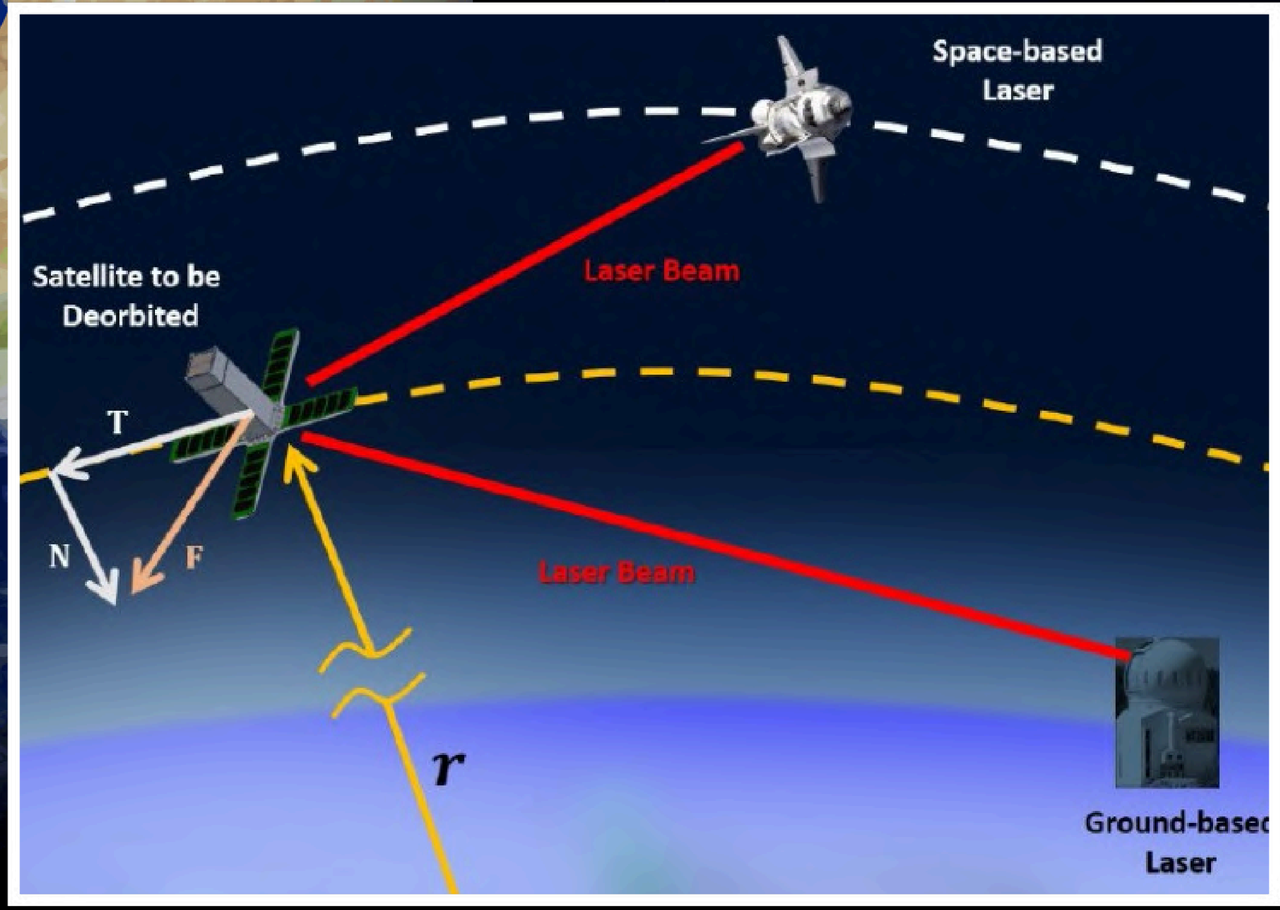
ACTIVE DEBRIS REMOVAL (ADR)

OBJECTIVE: CAPTURE AND REMOVE DEFUNCT SATELLITES AND LARGE DEBRIS FROM ORBIT.
DISADVANTAGE 1: COMPLEXITY OF MECHANISMS

- ROBOTIC ARMS, HARPOONS, AND NETS REQUIRE INTRICATE DESIGNS, MAKING THEM PRONE TO MECHANICAL FAILURES AND REQUIRING EXTENSIVE MAINTENANCE.
- **SMA RESOLUTION:** SMA-DRIVEN ACTUATORS ARE SIMPLER, LIGHTWEIGHT, AND HAVE FEWER MOVING PARTS, REDUCING FAILURE RISKS AND INCREASING RELIABILITY.

DISADVANTAGE 2: LIMITED FLEXIBILITY

- TRADITIONAL ADR TOOLS OFTEN STRUGGLE TO ADAPT TO DEBRIS OF VARYING SHAPES AND SIZES.
- **SMA RESOLUTION:** SMA MATERIALS OFFER ADAPTIVE CAPABILITIES, ENABLING GRIPPERS TO CONFORM TO IRREGULAR DEBRIS SHAPES DYNAMICALLY.



LASER-BASED SYSTEMS

OBJECTIVE: USE LASERS TO ALTER THE ORBIT OF SMALLER DEBRIS PIECES.TYPICAL INTENSITY FOR SPACE DEBRIS REMOVAL: $10^{10} – 10^{12}$ W/CM^2
DISADVANTAGE 1: HIGH ENERGY CONSUMPTION

- LASER ABLATION SYSTEMS REQUIRE SUBSTANTIAL POWER TO GENERATE THE PLASMA JETS NEEDED FOR ALTERING DEBRIS ORBITS.
- **SMA RESOLUTION:** SMA MECHANISMS USE THERMAL ACTIVATION, WHICH REQUIRES SIGNIFICANTLY LESS ENERGY COMPARED TO LASER SYSTEMS.

DISADVANTAGE 2: LIMITED PRECISION FOR LARGE DEBRIS

- LASER SYSTEMS ARE LESS EFFECTIVE FOR LARGE OR IRREGULARLY SHAPED DEBRIS DUE TO TARGETING CHALLENGES.
- **SMA RESOLUTION:** SMA-BASED SYSTEMS CAN PHYSICALLY CAPTURE AND CONTROL LARGE DEBRIS, OFFERING PRECISE HANDLING.

ELECTRODYNAMIC TETHERS AND MAGNETIC & ELECTROSTATIC CAPTURE

ELECTRODYNAMIC TETHERS

OBJECTIVE: GRADUALLY DEORBIT LARGE DEBRIS BY GENERATING DRAG THROUGH. **WORKS BEST IN LOW EARTH ORBIT (LEO), 200–1000 KM.** **DISADVANTAGE 1: SLOW DEORBITING PROCESS**

- TETHERS TAKE A LONG TIME TO LOWER ORBITS, MAKING THEM INEFFICIENT FOR URGENT DEBRIS REMOVAL.
- **SMA RESOLUTION:** SMA MECHANISMS CAN ACTIVELY CAPTURE AND DEORBIT DEBRIS, PROVIDING FASTER AND MORE DIRECT REMOVAL.

DISADVANTAGE 2: SUSCEPTIBILITY TO DAMAGE

- TETHERS ARE VULNERABLE TO COLLISIONS WITH SMALLER DEBRIS, WHICH CAN SEVER THEM AND RENDER THEM INEFFECTIVE.
- **SMA RESOLUTION:** SMA COMPONENTS ARE ROBUST AND CAN WITHSTAND IMPACTS, ENSURING LONGER OPERATIONAL LIFESPANS.

MAGNETIC & ELECTROSTATIC CAPTURE

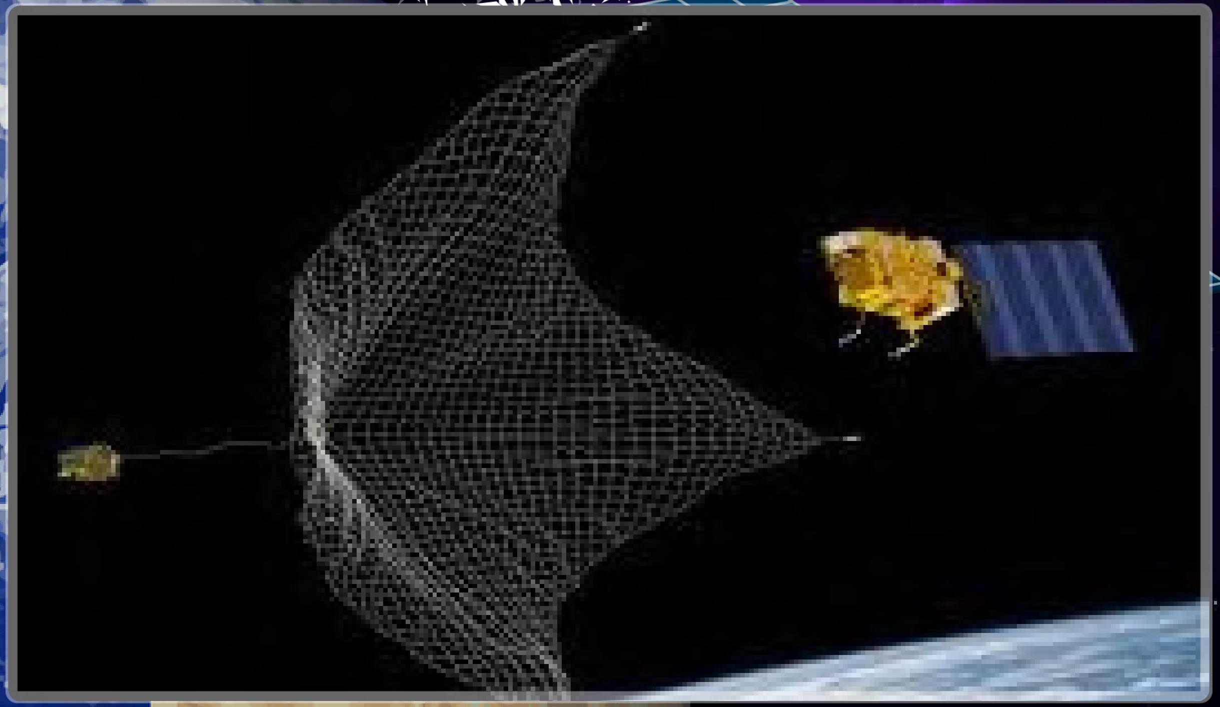
OBJECTIVE: CAPTURE SMALLER, METALLIC DEBRIS FRAGMENTS USING MAGNETIC OR ELECTROSTATIC FORCES.
DISADVANTAGE 1: MATERIAL LIMITATIONS

- THESE TECHNIQUES ARE ONLY EFFECTIVE FOR METALLIC OR CONDUCTIVE DEBRIS, LEAVING NON-METALLIC DEBRIS UNADDRESSED.
- **SMA RESOLUTION:** SMA SYSTEMS CAN MECHANICALLY GRIP AND REMOVE BOTH METALLIC AND NON-METALLIC DEBRIS, ENSURING BROADER APPLICABILITY.

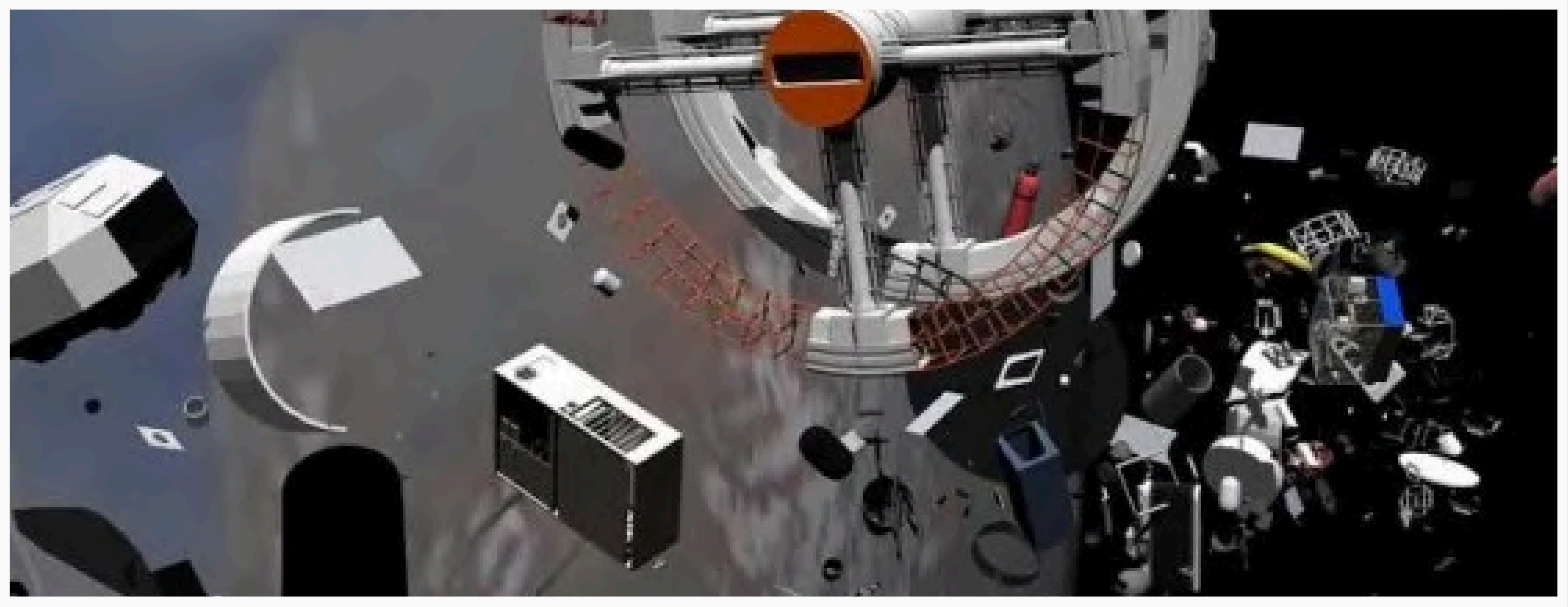
DISADVANTAGE 2: WEAKER FORCE APPLICATION

- MAGNETIC AND ELECTROSTATIC FORCES MAY STRUGGLE WITH HEAVIER OR LARGER DEBRIS DUE TO INSUFFICIENT ATTRACTION FORCES.
- **SMA RESOLUTION:** SMA-BASED ACTUATORS PROVIDE STRONG MECHANICAL FORCES CAPABLE OF HANDLING HEAVIER DEBRIS EFFECTIVELY.

FEATURES OF PROPOSED SOLUTION

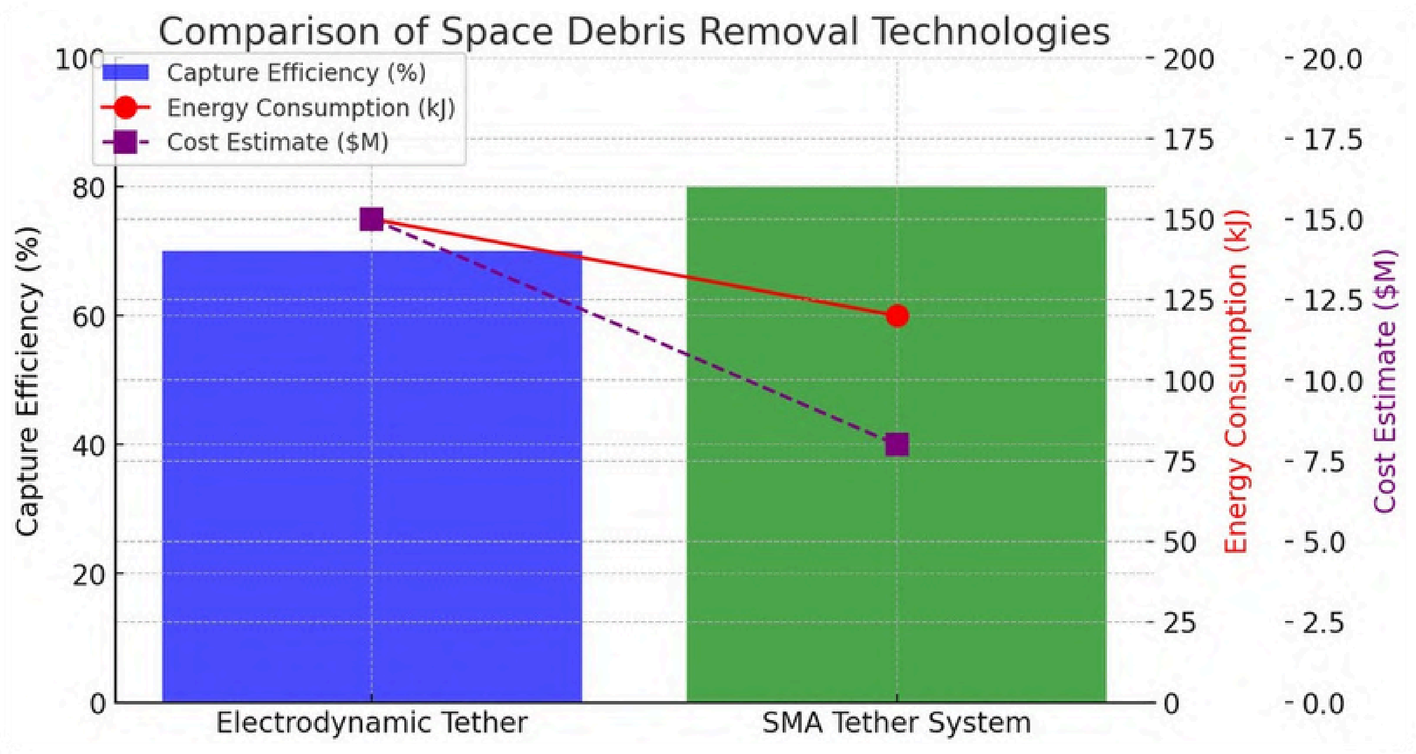


- **PRECISION:** SHAPE MEMORY ALLOY (SMA) COMPONENTS ENABLE **ACCURATE AND EFFICIENT DEBRIS CAPTURE**.
- **SCALABILITY**: MODULAR DESIGN ENSURES **ADAPTABILITY** TO DEBRIS OF **DIFFERENT SIZES.**
- **SUSTAINABILITY**: OPERATES **ENERGY-EFFICIENTLY** AND FEATURES REUSABLE MODULES FOR REDUCED WASTE.
- **COST-EFFECTIVENESS**: DESIGNED FOR SEAMLESS **INTEGRATION WITH EXISTING SPACE MISSIONS**, MINIMIZING EXTRA LAUNCH COSTS.
- **VERSATILE DEBRIS CAPTURE CAPABILITY:**CAN CAPTURE BOTH **ROTATING AND STATIC DEBRIS** USING **ADAPTIVE GRIPPING** TECHNIQUES.WORKS WITH **METALLIC AND NON-METALLIC DEBRIS** USING MECHANICAL GRIPPING + AUXILIARY CAPTURE METHODS.



- **NITINB (NICKEL-TITANIUM-NIOBIUM) SMA INTEGRATION:**
  - HIGHER DAMPING CAPACITY:ABSORBS 20-30% MORE ENERGY, REDUCING VIBRATIONS IN SPACE OPERATIONS.
  - ENHANCED STRENGTH & FLEXIBILITY: EXHIBITS 25% HIGHER TENSILE STRENGTH AND 2X FLEXIBILITY THAN NITIHF, ENSURING ADAPTIVE DEBRIS CAPTURE.
  - CRYOGENIC SUITABILITY: OPERATES EFFICIENTLY AT -200°C TO 250°C, IDEAL FOR LONG-TERM SPACE MISSIONS.

SCIENTIFIC IMPORTANCE OF PROPOSED SOLUTION



- **MITIGATES COLLISION RISKS**: MINIMIZES THE THREAT OF COLLISIONS WITH OPERATIONAL SATELLITES AND SPACE ASSETS, ENSURING MISSION SAFETY AND RELIABILITY.
- **ENHANCES SPACE SUSTAINABILITY**: ALIGNS WITH INTERNATIONAL NORMS TO PROMOTE A SUSTAINABLE AND DEBRIS-FREE SPACE ENVIRONMENT.
- **ADVANCES STRATEGIC COMPETENCE:** STRENGTHENS INDIA'S POSITION IN SPACE TECHNOLOGY LEADERSHIP AND DEBRIS MANAGEMENT INNOVATION.
- **SUPPORTS SCIENTIFIC EXPLORATION:** PROTECTS ORBITAL PATHWAYS CRITICAL FOR FUTURE RESEARCH AND EXPLORATION MISSIONS.
- **ENCOURAGES GLOBAL COLLABORATION:** DEMONSTRATES TECHNOLOGICAL READINESS TO CONTRIBUTE TO GLOBAL EFFORTS IN TACKLING THE SPACE DEBRIS CRISIS.

IMPACT OF OUR SOLUTION FOR INDIA ON THE GLOBAL STAGE

- STRENGTHENS INDIA'S GLOBAL SPACE LEADERSHIP: POSITIONS INDIA AS A PIONEER IN SMA-BASED DEBRIS REMOVAL, ENHANCING ITS REPUTATION IN SPACE SUSTAINABILITY AND INNOVATION.
- BOOSTS COMMERCIAL AND ECONOMIC GROWTH: CREATES NEW OPPORTUNITIES FOR INDIA’S SPACE SECTOR BY ATTRACTING INVESTMENTS AND OFFERING DEBRIS REMOVAL SERVICES GLOBALLY.
- PROTECTS NATIONAL SPACE ASSETS: REDUCES COLLISION RISKS FOR INDIAN SATELLITES, ENSURING UNINTERRUPTED COMMUNICATION, NAVIGATION, AND DEFENSE OPERATIONS.
- FOSTERS INTERNATIONAL COLLABORATION: ENABLES PARTNERSHIPS WITH GLOBAL SPACE AGENCIES, CONTRIBUTING TO COLLECTIVE EFFORTS FOR A CLEANER AND SAFER ORBITAL ENVIRONMENT.
- ALIGNS WITH GLOBAL SUSTAINABILITY GOALS: SUPPORTS UN AND INTERNATIONAL SPACE POLICIES FOR RESPONSIBLE AND SUSTAINABLE SPACE EXPLORATION.

REFRENCES

1. ACTIVE CONTROL OF SPACE STRUCTURES USING SHAPE MEMORY ALLOYS

NATH, T., AKASH, K., CHOUHAN, P., LAD, B. K., & PALANI, I. A. (2016). ACTIVE CONTROL OF SPACE STRUCTURES USING SHAPE MEMORY ALLOYS. 6TH INTERNATIONAL & 27TH ALL INDIA MANUFACTURING TECHNOLOGY, DESIGN AND RESEARCH CONFERENCE (AIMTDR-2016), PUNE, INDIA, DECEMBER 16–18, 2016.P-723, AUGUST 2013).

2. SPACE DEBRIS DISPOSAL: A REVIEW OF FEASIBILITY AND EFFECTIVENESS

GUO, S., LIU, H., ZHANG, R., ARYA, M., & WEDAGE, P. (2023). SPACE DEBRIS DISPOSAL: A REVIEW OF FEASIBILITY AND EFFECTIVENESS. JOURNAL OF STUDENT RESEARCH, VOLUME 12 ISSUE 4.

3. ROBOTIC MANIPULATORS FOR SPACE DEBRIS REMOVAL

AGLIETTI, G. S., TAYLOR, B., & FELLOWES, S. (2020). REMOVEDEBRIS: AN IN-ORBIT DEMONSTRATION OF TECHNOLOGIES FOR THE REMOVAL OF SPACE DEBRIS. THE AERONAUTICAL JOURNAL, 124.

4. LASER-BASED SPACE DEBRIS REMOVAL

PHIPPS, C. R., BAKER, K. L., LIBBY, S. B., ET AL. (2014). A LASER-OPTICAL SYSTEM TO REMOVE LOW EARTH ORBIT SPACE DEBRIS. ACTA ASTRONAUTICA, 9.

5. EUROPEAN SPACE AGENCY (ESA) – SPACE DEBRIS & CLEAN SPACE INITIATIVE

EUROPEAN SPACE AGENCY (ESA). (2023). SPACE DEBRIS MITIGATION AND ACTIVE REMOVAL STRATEGIES. RETRIEVED FROM HTTPS://SDUP.ESOC.ESA.INT/DISCOSWEB/STATISTICS/

6. NASA STUDIES LASER FOR REMOVING SPACE JUNK

EMERGING TECHNOLOGY FROM THE ARXIV. (2011). NASA STUDIES LASER FOR REMOVING SPACE JUNK. RETRIEVED FROM HTTPS://WWW.TECHNOLOGYREVIEW.COM/2011/03/14/196356/NASA-STUDIES-LASER-FOR-REMOVING-SPACE-JUNK/

7. CLEARSPACE – SPACE SUSTAINABILITY & DEBRIS REMOVAL

CLEARSPACE. (2023). SPACE SUSTAINABILITY INNOVATOR CLEARSPACE EXPANDS TO THE UNITED STATES. RETRIEVED FROM HTTPS://CLEARSPACE.TODAY/SPACE-SUSTAINABILITY-INNOVATOR-CLEARSPACE-EXPANDS-TO-THE-UNITED-STATES/

8. HYBRID SAIL FOR SPACE DEBRIS REMOVAL

VISAGIE, L., & THEODOROU, T. (2011). HYBRIDSAIL: A SCALABLE DE-ORBITING SPACECRAFT USING A DEPLOYABLE DRAG SAIL AND ELECTROSTATIC TETHERS. ESA ADVANCED CONCEPTS TEAM. RETRIEVED FROM HTTPS://WWW.SCIENCEDIRECT.COM/SCIENCE/ARTICLE/PII/S1000936114001010